SDC-92-264

SDC
SOLENOIDAL DETECTOR NOTES

PAC MEETING PRESENTATIONS

SDC REVIEW

May 4-9, 1992

SDC REVIEW - MAY 1992 - PRESENTATIONS

4-May	PLENARY SESSION	Auditorium
8:30	Executive session	
9:00	Overview and Detector Summary	T. Kondo
9:30	Tracking System Summary	A. Seiden
10:00	Calorimeter System Summary	D. Green
10:30	Break	
11:00	Muon System Summary	G. Feldman
11:30	Electronics System Summary	A. Lankford
12:00	Discussion	
12:30	Lunch	
2:00	Physics Performance Summary	K. Einsweiler M. Mangano
3:30	Responsibilities and Funding	G. Trilling
4:00	Discussion	
4:30	Adjourn	

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SDC REVIEW - MAY 1992 - PRESENTATIONS

PARALLEL SESSION A: SUPERCONDUCTING SOLENOID **Directorate**

5-May **Desportes,** Gross, Mulholland, Palmer, Smith

9:00	Introduction, Physics Goals, General Requirements	R. Kephart
9:30	Design of Detector Solenoid	A. Yamamoto
10:30	Break	
11:00	Design of Detector Solenoid, cont.	A. Yamamoto
11:30	Cryogenic System	A. Stefanik
12:00	Discussion	
12:30	Lunch	
1:30	R&D and Prototype	A. Yamamoto R. Kephart
3:00	Cost and Schedule	R. Stanek
3:30	Discussion	
4:00	Adjourn	

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PARALLEL SESSION B: TRACKING **Upstairs**

5-May Olsen, Bowden, Danilov, Dawson, Haller, Karchin, McDonald, Sauli, Witherell

9:00	Requirements and Overview	W. Ford
9:45	Silicon Tracker Summary	A. Seiden
10:15	Break	
10:45	Silicon Mechanical Systems	W. Miller
11:15	Silicon Electronics Systems	H. Spieler
11:45	Silicon Detectors and Radiation Damage	H. Sadrozinski
12:00	Silicon R&D Plan	H. Sadrozinski
12:30	Lunch	
2:00	Straw-tube Tracker Summary	G. Hanson
2:30	Straw-tube Engineering and R&D Plan	H. Ogren
3:15	Straw-tube Electronics	H. H. Williams
3:45	Discussion	
4:00	Adjourn	

6-May

9:00	Gas Microstrip Intermediate Tracker Summary	M. Edwards
9:45	Gas Microstrip Intermediate Tracker R&D Plan	G. Oakham
10:15	Discussion	
10:30	Break	
11:00	Fiber Option Summary	R. Ruchti
11:45	Fiber Option R&D Plan	D. Koltick
12:15	Discussion	
12:30	Adjourn	

SDC REVIEW - MAY 1992 - PRESENTATIONS

PARALLEL SESSION C: CALORIMETRY Auditorium

5-May **Pilcher,** Albrow, Hoffmann, Iwata, Pauss, Sandweiss, Schindler, Takasaki

9:00	Requirements and Summary of Central Calorimeter Design	J. Proudfoot
10:00	Shower Maximum Detector	R. Hubbard
10:30	Break	
11:00	Summary of Radiation Damage Tests	K. Takikawa
11:30	Test Beam Results	J. Freeman R. Rusack
12:15	Discussion	
12:30	Lunch	
2:00	Organization and Prototype Plan	P. Mantsch
2:45	Design Options	R. Kadel J. Freeman
3:45	Discussion	
4:00	Adjourn	

6-May

9:00	Scintillator R & D	G. Foster
9:30	Forward Calorimeter Requirements	M. Barnett
9:55	Forward Calorimeter Requirements, cont'd.	W. Frisken
10:20	Break	
10:50	Liquid Scintillator Option	R. Orr
11:20	High Pressure Gas Option	N. Giokaris
11:50	Electronics Options for Calorimetry	A. Lankford
12:20	Discussion	
12:30	Adjourn	

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PARALLEL SESSION D: MUON SYSTEM **E-311**

5-May **Kamae,** Becker, Bell, Dosselli, Jackson, Marciano

9:00	Requirements and Design Summary	G. Feldman
10:00	Magnet Summary	J. Bensinger
10:30	Break	
11:00	Barrel/Intermediate Chamber Design	H. Lubatti
12:00	Discussion	
12:30	Lunch	
2:00	Forward Chamber Design	Y. Antipov
2:45	Scintillation Counters	R. Thun
3:15	Cerenkov Option	V. Kubarovsky
3:30	Electronics and Trigger	J. Chapman
4:00	Adjourn	

6-May

9:00	Alignment Systems	D. Eartly
9:30	Toroid Engineering	J. Cherwinka
10:00	Assembly and Installation	R. Loveless
10:30	Break	
11:00	R&D and Prototype Plan	J. Bensinger C. Grinnell
12:30	Adjourn	

SDC REVIEW - MAY 1992 - PRESENTATIONS

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PARALLEL SESSION E: ELECTRONICS/DAQ/COMPUTING Strategy Room

5-May	**Zeller**, Breidenbach, Dydak, Haynes, Pordes, Schalk, Sippach	
9:00	Overview and Front-End System Summary	H. H. Williams
9:30	Trigger System Overview and Level 1 Summary	W. Smith
10:10	Level 2 Trigger Summary	P. LeDu
10:30	Break	
11:00	Straw Tube and Muon Front-End Electronics	Y. Arai
11:35	Straw Tube Tracker and Muon Triggers	J. Chapman
12:05	Fiber-Tracker Option Trigger	A. Baumbaugh
12:20	Discussion	
12:30	Lunch	
2:00	Calorimeter Front-End Electronics I	G. Foster
2:25	Calorimeter Front-End Electronics II	M. Levi
2:50	Shower Maximum Detector Front-End Electronics	P. LeDu
3:05	Silicon Tracker Front-End Electronics	H. Spieler
3:30	Gas Microstrip Front-End Electronics/Trig. & Silicon Trig.	R. Nickerson
4:00	Adjourn	
6-May		
9:00	Data Acquisition and On-line Computing Overview	I. Gaines
9:45	Electronics R&D Plan	A. Lankford
10:30	Break	
11:00	Off-line Computing and Software Development	L. Price C. Day
12:30	Adjourn	

SDC REVIEW - MAY 1992 - PRESENTATIONS

PARALLEL SESSION F: INTERACTION HALLS/FACILITIES/INSTALLATION **Directorate**

7-May **Bell,** Desportes, Dydak, Hoffmann, McDonald

2:00	Overview and Schedule	T. Thurston
2:15	Installation Plan	D. Bintinger
3:15	Underground Hall Summary	J. Piles
3:45	Surface Layout Summary	T. Prosapio
4:15	Discussion	
4:30	Break	
5:00	Assembly Building Requirements	T. Winch
5:30	Detector Integration Planning	T. Thurston
6:00	Adjourn	

8-May

9:00	Safety Analysis Status	J. Elias
10:00	Report from Review of Draft CSAR	L. Coulson
10:30	Discussion	
11:00	Adjourn	

SDC REVIEW - MAY 1992 - PRESENTATIONS

PARALLEL SESSION G: PERFORMANCE/TRIGGER/ INTEGRATION/OPERATIONS **Strategy Room**

7-May **Smith** Dawson, Dosselli, Iwata, Pauss, Sauli, Witherell, Zeller

2:00	Trigger System Requirements and Performance	G. Sullivan
2:45	Tracking Simulation Summary	D. Coupal
3:25	Tracking - Integrated Performance and Design Optimization	A. Seiden
4:00	Discussion	
4:30	Break	
5:00	Electron Identification	B. Wicklund
5:40	Discussion	
6:00	Adjourn	

8-May

9:00	Calorimetry - Integrated Performance and Design Optimization	D. Green
9:40	Discussion	
10:00	Muon System - Integrated Performance and Design Optimization	G. Feldman
10:40	Break	
11:10	Discussion and question and answer period	
12:30	Adjourn	

SDC REVIEW - MAY 1992 - PRESENTATIONS

PARALLEL SESSION H: COST AND SCHEDULE — Auditorium

7-May **Breidenbach,** Becker, Bowden, Haller, Hartill, Jackson, Mulholland, Olsen, Pilcher, Schindler

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2:00	Introduction	M. Gilchriese
2:30	Cost/Schedule Procedures	D. Etherton
3:00	Silicon	A. Grillo
3:30	Straw-Tube Tracker	R. Swensrud
4:00	Gas Microstrips	G. Oakham
4:15	Fiber Option	R. Leitch
4:30	Break	
5:00	Central Calorimetry	D. Scherbarth
5:45	Forward Calorimetry	R. Orr
6:00	Adjourn	

8-May

9:00	Muon System	M. Montgomery
9:45	Superconducting Solenoid	R. Stanek
10:15	Break	
10:45	Electronics	A. Lankford H. H. Williams I. Gaines, W. Smith
11:45	On-line Computing	A. Fry
12:00	WBS 7, 8, 9	D. Etherton
12:30	Adjourn	

SDC REVIEW - MAY 1992 - PRESENTATIONS

PARALLEL SESSION I: COLLABORATION/RESOURCES Upstairs

7-May Gross, Albrow, Danilov, Kamae, Karchin, Marciano, Palmer, Sandweiss, Schalk, Takasaki

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2:00	Collaboration Management and Draft Management Plan	T. Kirk
2:45	Status of Responsibilities, Resources and Funding	G. Trilling
3:15	Japan	T. Kondo
3:30	CIS	N. Tyurin
3:45	Italy	G. Bellettini
4:00	Canada	R. Orr
4:15	Break	
4:45	United Kingdom	R. Cashmore
5:00	France	R. Hubbard
5:15	PRC	H. Mao
5:30	Discussion	
6:00	Adjourn	

SDC Review
Plenary Session
May 4, 1992

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PLENARY SESSION

OVERVIEW AND DETECTOR SUMMARY
T. KONDO

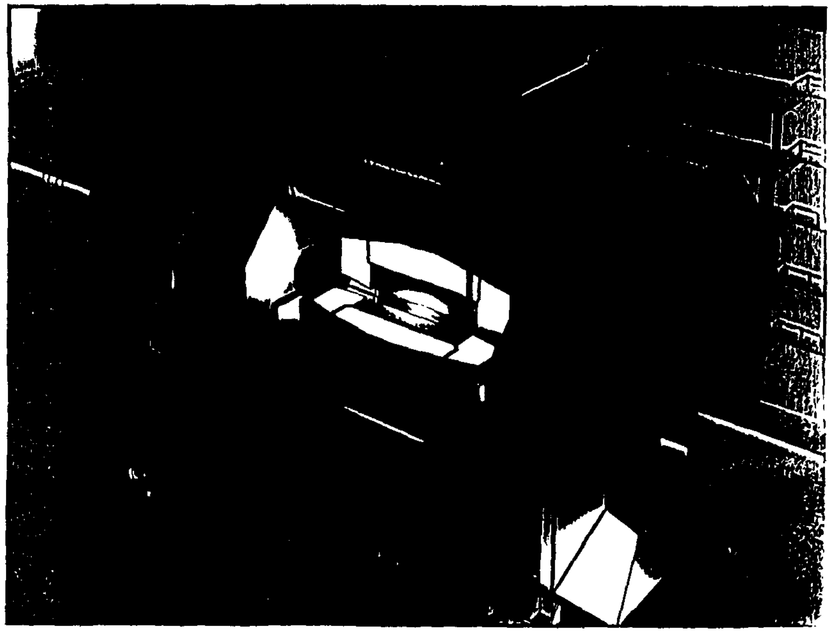
PAC REVIEW

Overview and Detector Summary

Takahiko Kondo (KEK)

May 4, 1992

History and Collaboration
Motivation and Requirements
Technological choices
Detector summary and integration
Principal functions of detector subsystems
Radiation effects on detector components



History

• before 1989	Design activities at LBL, ANL, FNAL, Universities Design activities in Japan and Europe
• 1989 September	Formation of a single collaboration
• 1989 December	1st collaboration meeting Established governance document
• 1990 March	Selection of spokesperson/technical manager
• 1990 May	Submission of Expression of Interest (EoI)
• 1990 November	Submission of Letter of Intent (LoI)
• 1991 January	Approved to proceed to develop a full technical design
• 1992 April	Submission of Technical Design Report (TDR)

SDC Collaboration

country	institutions	collaborators
U.S.A.	53	561
Canada	7	26
Japan	17	101
France	1	21
Italy	3	27
U.K.	4	15
C.I.S.	9	106
PRC	2	35
Israel	1	2
Eastern Europe	4	12
Brazil	1	5
(EoI)	(73)	(500)
(LoI)	(84)	(647)
TDR	102	911

Motivation of SDC detector

- General purpose detector
  for redundant identification of interesting processes
  for new unexpected phenomena
- Balanced combination of tracking, calorimetry and muon system
- Measurement of multiple independent quantities
  e/μ identification
  isolation measurement
  sign of charge and energy measurement of leptons
  isolated photons
  jet energy and direction
  detection of secondary vertices
  charged particle multiplicity
  detection on non-interacting neutrals via p_T balance
- Past experience with collider detectors has demonstrated that a detector with multiple independent measurements is far better that the sum of subsystems
- Successful CDF experience

Requirements on SDC detector

- Challenging experimental environment :

relative to the Tevatron
20-fold increase in energy
~ 1000-fold increase in luminosity

$$\frac{S}{N} \sim \frac{\sigma_{Higgs} \cdot BR}{\sigma_{inel}} \sim \frac{1}{100000000000000}$$

- It requires unprecedented demands on
  - speed-of-response
  - pattern recognition capability
  - excellent momentum resolution
  - segmentation to identify fine structures
- The detector must be sufficiently robust and resistant to radiation for many years of operation

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- Operational potentiality for luminosity increase beyond 10^{33} $cm^{-2}s^{-1}$ and sufficient functionality up to 10^{34} $cm^{-2}s^{-1}$
- Cost / performance optimization
- Upgrade capability

However exceptions that have NO upgrade capabilities are

- central tracking volume
- iron toroid thickness
- calorimeter depth

Their reductions would lead to unacceptable technical and performance risks

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Decision on Tracking Volume (August,1991)

- One of fundamental detector parameters
  Pressure from cost reduction
- Comparison : (radius, half length) = (170 cm, 400cm)
  (150 cm, 300cm)
- Shrinking the tracking volume will
  - substantially reduces the space available for intermediate tracking and makes track triggering difficult in that area
  - increases neutron fluences by ~2 in tracking cavity
  - increases radiation doses in calorimetry near η=3
  - significantly reduces the radial region for straw tracker
  - reduces rapidity range covered by outer barrel tracker
  - degrade momentum resolution by 30%
  - reduce cost by approximately $21M
- Decision was made to keep the tracking radius at 170 cm

BENEFITS OF A SOLENOIDAL DETECTOR

- -The momentum information makes the detector a fine exploratory tool for the study of a wide range of physics at all p_t and at a wide range of luminosities.
- -Determination of electron signs up to at least p_t =1 TeV is provided.
- -Momentum/calorimetry provides effective electron ID. Reconstructed segments in outer layers allow an effective high-p_t electron trigger.
- -Momentum information is necessary to interpret vertex detector measurements.
- -Momentum measurement helps provide in-situ monitoring of calorimetry.
- -Muon momenta can be precisely measured.
- -Jet fragmentation at high p_t can be studied.
- -Charged particle multiplicity for tracks of p_t above a fixed value can be useful for removal of some backgrounds.

Technological choices

- Technology choices have been made through extensive reviews by selection committees based on
  - technical feasibility
  - adequacy of performance
  - survivability
  - acceptable technical risk
  - affordable cost
  - strong interest of SDC members

- R&D programs sponsored by SSCL as well as R&D abroad provided significant influences on the SDC technology choices

- Decision process in most cases:
  1. definition of requirements
  2. preparation of conceptual design reports
  3. oral presentations
  4. recommendations by ad-hoc review committee
  5. review and recommendations by the Technical Board
  6. ratification by the Executive Board

Technological choices (cont.)

- Solenoid magnet styles

type-S (short coil / non-magnetic returns)
type-I (short coil / iron endcap)
type-L (long coil / non-magnetic endplug)
} Sep.1990 → type-(SI)

- Central calorimetry

scintillating tile calorimeter with waveshifting bar readout
scintillating tile calorimeter with waveshifting fiber readout
scintillating fibers embedded in the absorber ("spaghetti")
liquid argon ionization calorimeter
warm liquid ionization calorimeter

⇓ Nov. 1990

tile fiber calorimeter
liquid argon calorimeter

⇓ Sep. 1991

tile fiber calorimeter

Technological choices (cont.)

- Time digitizer for straw chamber

TVC/AMU
TMC
} Sep. 1991 → TMC

- Central outer tracking devices

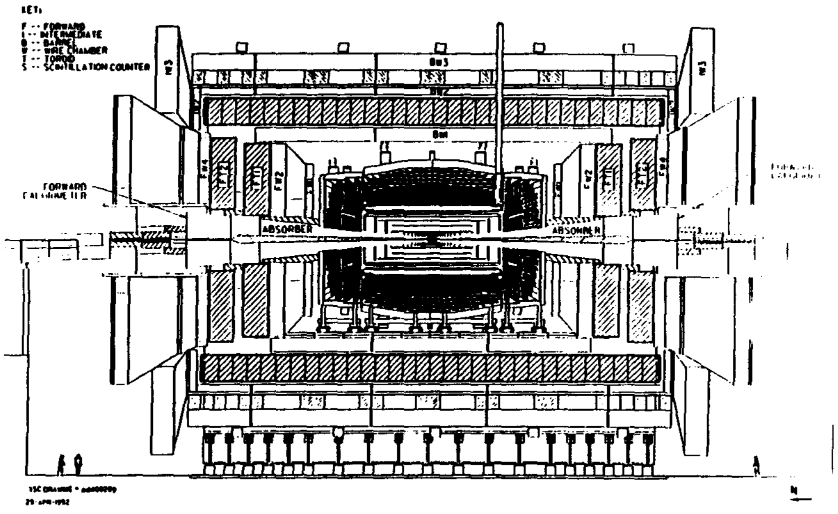
modular straws
hybrid tracker with straws/fibers
scintillating fibers
} Nov.1991 → { straw system / fiber system

- Absorber material of calorimeter

EM/Had : Pb/Pb
EM/Had : Pb/Fe
} Nov. 1991 → Pb/Fe

- Barrel muon chambers

octagonal tube
round tube without field shaping
round tube with field shaping
oval tube with field shaping
jet cell chamber
} Feb. 1992 → round tube with field shaping



SDC DETECTOR SUMMARY

SOLENOID MAGNET (2 Tesla)
Tracking Volume: 3.4 m diameter by 8.6 m long

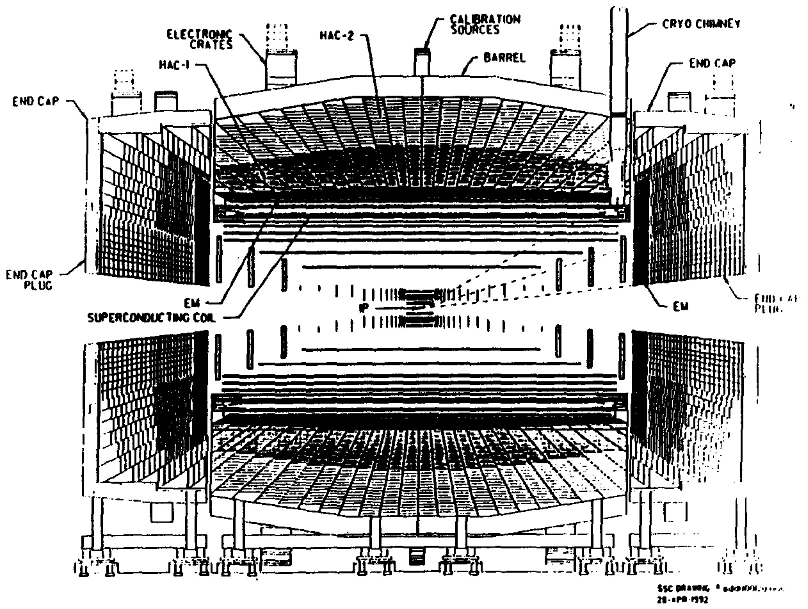
CENTRAL TRACKING AND HIGH RESOLUTION VERTEX DETECTION (COVERING $|\eta| < 2.5$)
Inner Silicon Systems in both Barrel & Intermediate-Angle Region
Outer Straw-Tube or Scintillating-Fiber System in Barrel Region
Outer Gas/Microstrip or Sci-Fiber for Intermediate-Angle Region

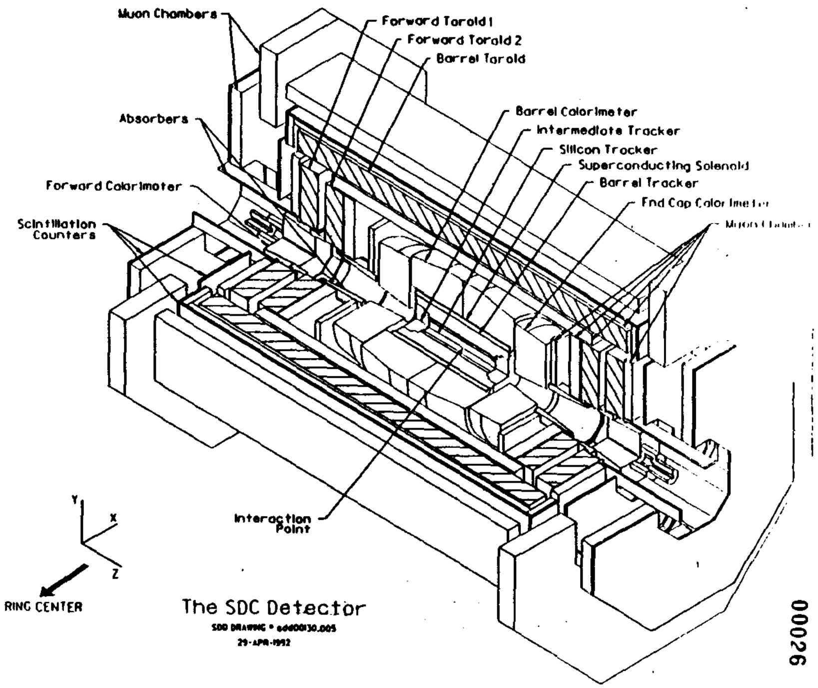
PRECISION HERMETIC CALORIMETRY(COVERING $|\eta| < 3$)
Scintillating Tile with Fiber Readout with Pb (EM), Fe (Had.) Absorber
High Spatial Resolution EM Shower Max Scintillation Detector

FORWARD CALORIMETRY(COVERING $3 < |\eta| < 6$)

MUON SYSTEM WITH IRON MAGNETIC TOROIDS (covering $|\eta| < 2.5$)
Tracking Chambers and Scintillation Counters

ID & PRECISION ENERGY MEASUREMENT OF ELECTRONS/MUONS
Electrons: Central Tracking Plus Calorimetry
Muons : Central Tracking Plus Muon System

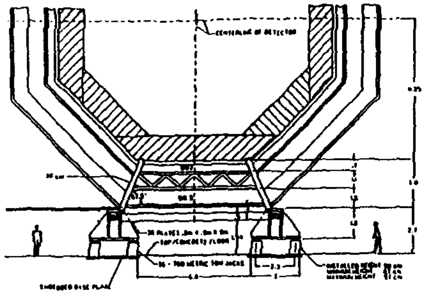


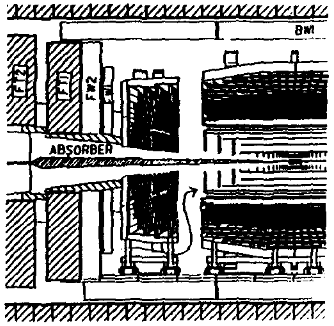


The SDC Detector
SDC DRAWING
29-APR-1992

SDC Detector Integration

- stability of the barrel toroid against floor motion is maintained by the distributed hydraulic jacking system
- access capability to the back of calorimeter
- access to inner trackers by *retracting endcap calorimeter*, FW1 and absorber





Expected Performance of SDC Detector

$\frac{\Delta p_t}{p_t}$ @ 1 TeV	$\eta = 0$	16 %	charged particle	
	$\eta = 2.5$	60 %	charged particle	
$\frac{\Delta p_t}{p_t}$ @ 1 TeV	$\eta = 0$	11 %	muon	
	$\eta = 2.5$	18 %	muon	
$\frac{\Delta E_t}{E_t}$ (EM)	$\lvert\eta\rvert < 3$	$\sim \frac{14\ \%}{\sqrt{E_t}} \oplus 0.01$		
$\frac{\Delta E_t}{E_t}$ (Had)	$\lvert\eta\rvert < 3$	$\sim \frac{60\ \%}{\sqrt{E_t}} \oplus 0.04$		(single π)
$\frac{\Delta E_t}{E_t}$ (Had)	$3 < \lvert\eta\rvert < 5.5$	$\sim \frac{100\ \%}{\sqrt{E}} \oplus 0.08$		

Principal functions of SDC subsystems

Silicon tracker
- pattern recognition inside jets
- b tagging via secondary vertex finding
- track triggering (2nd level)

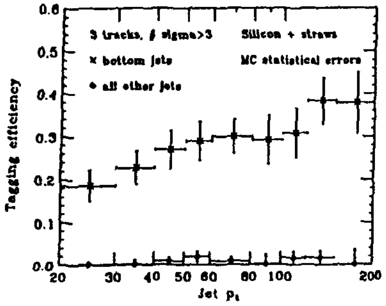


FIG. 4-12. *b* tagging efficiency vs. jet p_t for the combined system using the method described in the text.

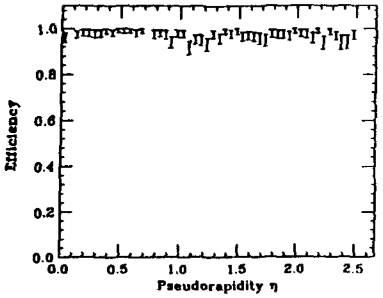


FIG. 4-9. Efficiency of single tracks with $p_t > 1$ GeV/*c* in Higgs events as a function of pseudorapidity.

SDC CAPABILITIES

ELECTRON ID -- (EM calor. energy) / (track momentum), Hadronic/EM response, transverse shape in fine-grain detector at shower maximum

MUON ID -- Traversal of > 14 λ, double measurement of momentum (central tracker, muon toroids)

TAU ID -- Low multiplicity jet, proper kinematics

NEUTRINOS (OR OTHER NON-INTERACTING PARTICLES) Transverse energy unbalance in hermetic calorimeter

QUARKS AND GLUONS -- Jets of hadrons in calorimeter and tracking system

B QUARKS -- Displaced vertices measured in silicon system

PATTERN RECOGNITION IN COMPLEX EVENTS High resolution and excellent two-track separation of silicon tracker

Superconducting Magnet

- Technical challenges : 1. material transparency ~ $1.2X_0$
  2. compressive force (1700 tonf)

in addition to predictable and stable operation
safety against quenches

- Solutions :

$$[A]\ \frac{\text{E(stored energy)}}{\text{M(cold mass)}} = 7.4\ \text{kJoule/kg} \quad (\Delta = 0.4X_0)$$

~ 5 in past

→ development of high strength aluminum stabilized superconductor

→ increase of quench propagation velocity by pure aluminum strips

[B] lighter material for outer vacuum vessel ($\Delta = 0.2X_0$)

→ isogrid (grid-stiffened) shell or brazed aluminum honeycomb panel

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Outer & Intermediate-angle trackers

- accurate momentum measurement
- track triggering (1st and 2nd level)

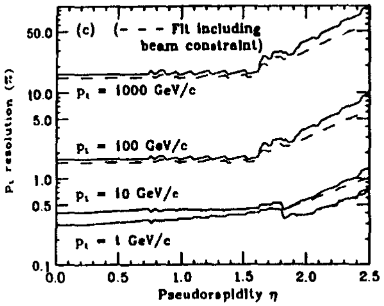


FIG. 4-6. Track parameter errors vs. rapidity for several transverse momentum p_t, c) transverse momentum p_t,

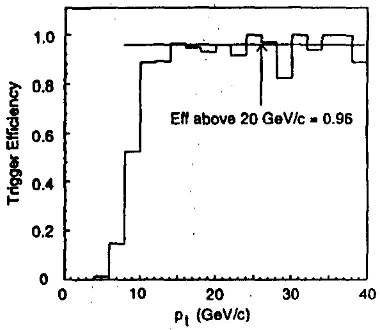
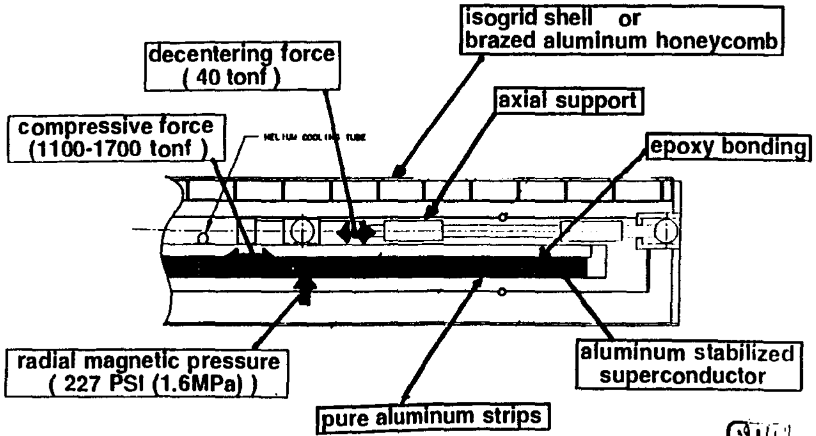


FIG. 4-15. Threshold curve for the two-out-of-three superlayer OTD Level 1 trigger.

Prototype Superconducting Magnet

- started in 1991 and will be completed in 1993
- one quarter length with a full diameter
- joint work by KEK and FNAL



isogrid shell or
brazed aluminum honeycomb

decentering force
(40 tonf)

axial support

compressive force
(1100-1700 tonf)

epoxy bonding

radial magnetic pressure
(227 PSI (1.6MPa))

aluminum stabilized
superconductor

pure aluminum strips

Superconducting Magnet

- provide an axial magnetic field of 2 Tesla
- thin in X_0 and λ_I for calorimeter performance
- long term stability

Table 5-1
General requirements of SDC solenoid.

Magnet envelope		
Cryostat	Inner radius	1.70 m
	Outer radius	2.05 m
	Total half length	4.389 m
Nominal magnetic field		2 T
Transparency	(η=0)	1.2 X_0
		0.25 λ_I
Cool down time		< 14 days
Quench recovery time		< 4 hr

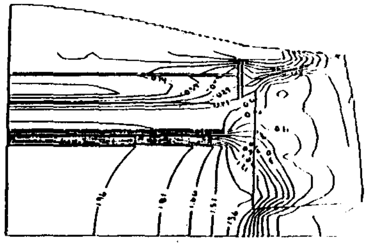


FIG. 5-2. Field contour plot for an axial coil-iron separation of 470 mm. The field is in teslas.

Central calorimeter

- meas. of energy and direction of jet, e, γ, ν
- identification of e,γ,τ,ν
- trigger information on energy, isolation & timing
- correction of EM energy by massless gap
- tagging of μ

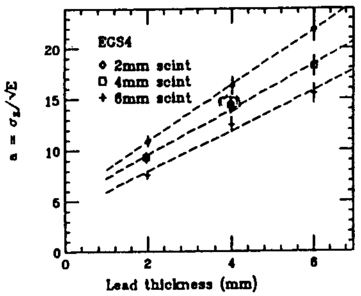


FIG. 6-6. Stochastic resolution term in the EM calorimeter as a function of the thickness of the lead radiator plates.

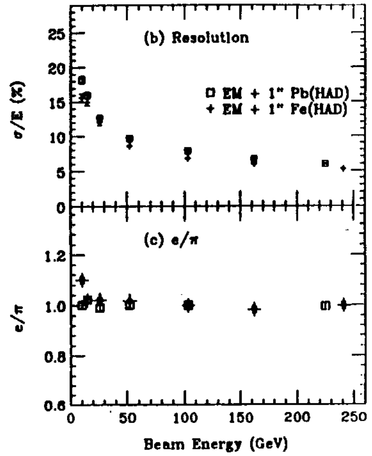
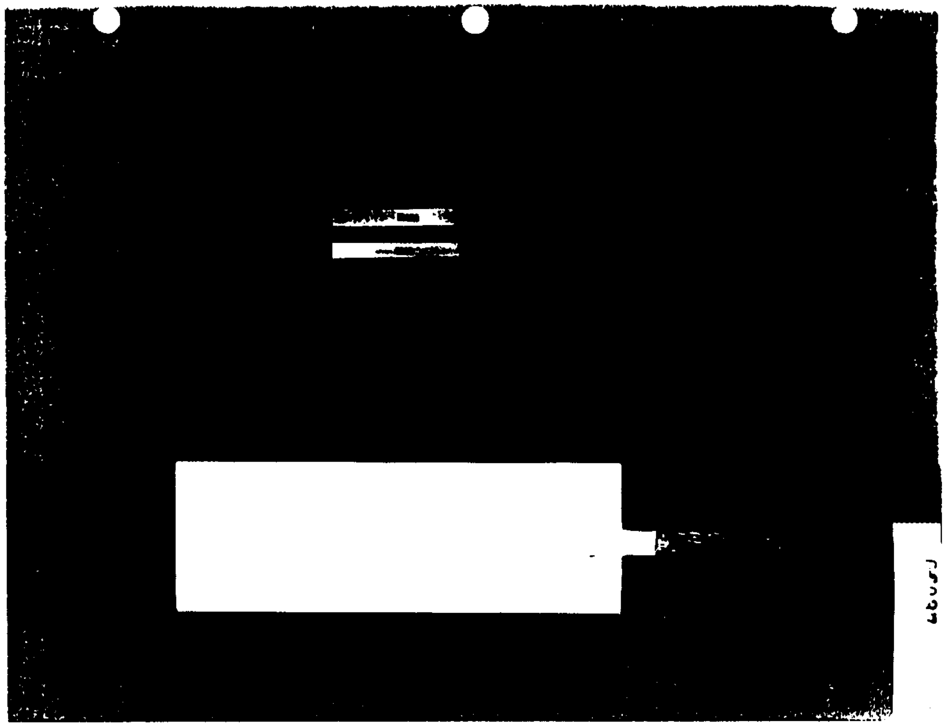


FIG. 6-59. Measured (b) pion resolution and (c) e/π resp. as a function of energy from the hanging file calorimeter



Shower max detector

- measurement of center of gravity of EM shower

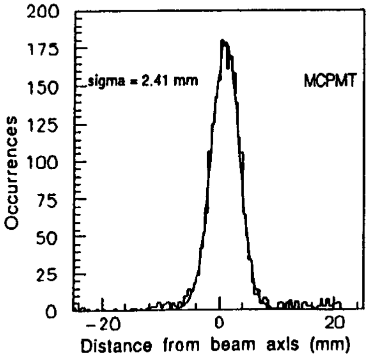


FIG. 6-48. Position resolution for electrons in the SMD collected with the MCPMT readout and 5 mm thick strips.

Forward calorimeter

- measurement of jet energy for missing E_T and WW fusion tagging

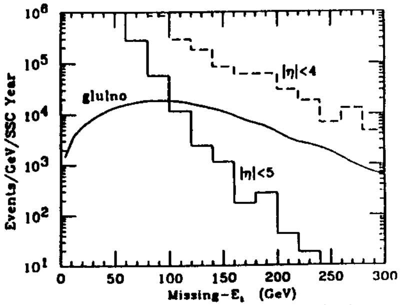
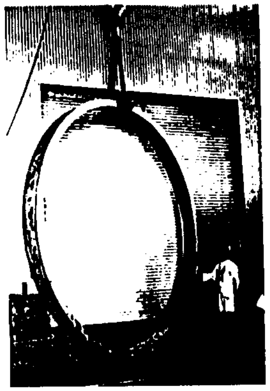
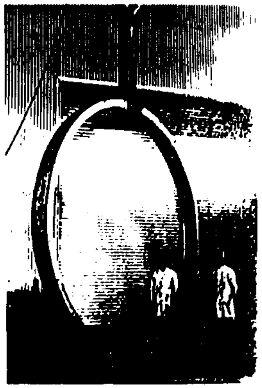


FIG. 3-71. Comparison of the missing-E_t distributions for the background (to light gluino pair production) due to multijet events with energy loss out of the end of the detector, $|\eta| >$ 4 (dashed histogram) or 5 (solid histogram).





Offline computing

- capabilities for production, analysis and simulation
- processing raw data, storage and data access
- network with high data transfer capability
- regional computing centers

Table 10-2
Design parameters for SDC offline computing.

	Requirement
Data recording rate	100 Hz
Raw data event size (maximum)	1 Mbyte
Live time per year	10^7 sec
Raw plus processed event size	2 Mbyte
Expected DST event size	10^5 bytes
Total number of events per year	10^8
Total raw data size per year	10^{16} bytes
Total processed data size per year	10^{15} bytes

Muon system

- muon triggering
- identification of muons
- improve momentum measurement

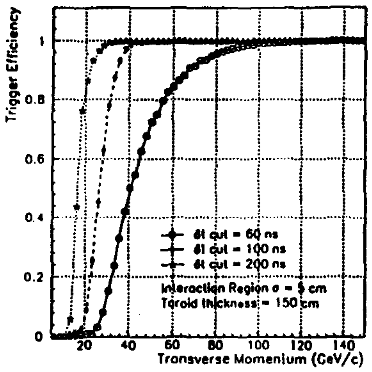


FIG. 7-2. Trigger efficiency versus transverse momentum for three different time difference thresholds.

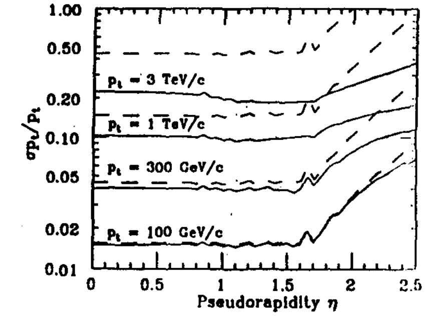


FIG. 7-4. Momentum resolution for muons using combined measurements from the inner tracker and the muon system (solid lines) and from the inner tracker alone (dashed lines).

Radiation Effects on Detector Components

Silicon
- dose rate = 10^{12}~10^{13} particles/year at L_0
- polyethylene liners reduces albedo neutrons much
- detector tests showed lifetime of ~10-100 years

Straw
- no anode damage to 2C/cm (>100 years)
- cathode tested to 0.3C/cm (15-60 years)

Scint fiber
- base material is tested to be radiation tolerant
- radiation test of fibers and waveguides is underway

Gas microstrip
- effect on resistive substrate to be investigated

Tile/fiber calorimetry & Shower max
- dose rate = 2.7-570 krad/year at L_0
- extensive tests showed commercially available scintillators are adequate for barrel calorimeter
- removable EM endcap with two longit. samplings
- removable hadronic endplug at $|\eta|>2$

Forward cal.
- dose rate = 0.1-100 MRad/year at L_0

Front-end electronics
- fast bipolar is intrinsically radiation hard
- radiation-hard CMOS exists and looks promising

Electronics

- Front end: signal processing and buffering
- DAQ: event building, filtering and recording
- Trigger: 10^8 interactions/sec → 50~100 events/sec

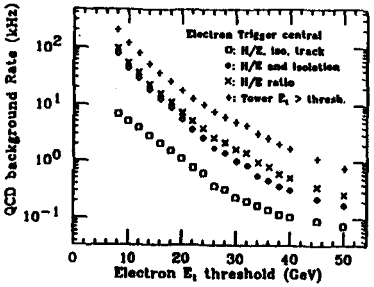


FIG. 8-6. Barrel Calorimeter inclusive electron trigger rate vs. E_t trigger tower sum threshold (crosses), with HAC/EM ratio < 0.04 (x's), isolation as described in the text (diamonds) and matched with track with p_t > 10 GeV/c (squares).

Table 8-3
Combined Level 1 trigger rate for the main electron/photon triggers in the Barrel plus Endcap calorimeters ($|\eta| < 3.0$) versus various combinations of threshold energies. Where e ≡ electron requires 1 tower with HAC/EM< 0.05 and a track with p_t > 10 GeV/c matched in ϕ with the tower, 2e ≡ di-electron requires 2 towers with HAC/EM< 0.1 and a track with p_t > 10 GeV/c, γ ≡ photon requires 1 tower with HAC/EM< 0.05, and 2γ ≡ di-photon requires 2 towers with HAC/EM< 0.05.

Trigger threshold (GeV)				
e	2e	γ	2γ	Rate (kHz) @ 10^{33} cm^{-2}s^{-1}
20	10	30	20	9.8
20	10	40	20	8.1
25	10	40	20	5.0
25	15	40	30	4.7
30	20	45	30	3.8
20	–	–	–	7.0
–	10	–	–	0.3[1]

Physics Performance

Physics Process	Mass Region (GeV)	Physics Signature
Associated Higgs Production		
	80 - 150	$W + H, t\bar{t} + H \to \ell\gamma\gamma$
Direct Higgs Production		
	130 - 180	$H \to ZZ^* \to 4\ell$
	180 - 800	$H \to ZZ \to 4\ell$
	500 - 800	$H \to ZZ \to 2\ell 2\nu$
High Mass Boson Pairs		
Requires integrated luminosity of		$Z\gamma \to \ell^+\ell^-\gamma$
at least 50 fb^{-1} for complete studies	1-2 TeV	$W^+Z \to \ell^+\ell^+\ell^-\nu$
		$W^+W^+ \to \ell^+\ell^+$
Discovery of t Quark		
	$\lesssim$ 1 TeV	$t\bar{t} \to W^+W^- + X \to e^\pm\mu^\mp + X$
Mass Measurement of t Quark		
Sequential Dilepton Mode	$\lesssim$ 500	$t\bar{t}$, one $t \to Wb$; $W \to e\nu$; $b \to \mu + X$ the other $t \to$ 3 Jets
Lepton + Jets + b-tag Mode	$\lesssim$ 500	$t\bar{t}$, one $t \to W + X$; $W \to \ell\nu$ the other $t \to Wb \to b$ + 2 Jets
Non-standard t Decays		
Violation of τ Universality	$M_H \lesssim M_{top} - 15$	$t \to H^\pm b$; $H^\pm \to \tau^\pm\nu$; $\tau^\pm \to \pi^\pm + X$
Peak in 2-Jet Mass Distribution	$M_H \lesssim M_{top} - 25$	$t \to H^\pm b$; $H^\pm \to c\bar{s}$
Gluino and Squark Searches		
Missing-E_t + Jets	300 - 1000	$\tilde{g}\tilde{g} \to E_t^{miss}$ + 3-6 Jets
Like-Sign Dileptons	200 - 2000	$\tilde{g}\tilde{g} \to \ell^\pm\ell^\pm$ + 4 Jets
New Z Searches		
Discovery	$\lesssim$ 4 TeV	$Z' \to \ell^+\ell^-$
Width and Asymmetry	$\lesssim$ 2 TeV	$Z' \to \ell^+\ell^-$
Compositeness		
	$\Lambda \gtrsim$ 25 TeV	Inclusive Single Jet Spectrum

Summary

- SDC is a world wide collaboration with >900 collaborators.

- After 2 years of intense efforts on design and R&D by the SDC, a technical design is proposed with most of relevant parameters fixed and with most of detector technologies selected.

- By requiring excellent capabilities in tracking, calorimetry, muon and electronics system, we believe that the proposed detector embodies maximum redundancy for establishing rare new phenomena in an ocean of backgrounds.

- Given adequate support in participating countries, the SDC is prepared to meet the schedule of collider turn-on for physics late 1999.

PLENARY SESSION

SDC CENTRAL TRACKING
A. SEIDEN

SDC Central Tracking

One of main emphases of SDC is on tracking and its contribution to measurement and identification of leptons and secondary vertices. It is also a key element of the SDC trigger. Because of the very high event rates, density of particles in events and high momenta, the tracking system uses several technologies to meet the detector performance goals in an optimum way.

I will try to first briefly summarize the physics goals which drive the design and then outline the design and rationale for the baseline tracking system.

Some Key Requirements for Tracking System

First set mainly motivated by desire to do Higgs physics. Typicaly involves rare events with multi-leptons. Want to keep as many events as possible.

1) Acceptance, efficiency, and p_t resolution:

   (*a*) $|\eta|$ coverage at least out to $|\eta| = 2.5$ ($H^0 \rightarrow 4$ charged lepton geometrical efficiency $\gtrsim$ 60% for $m_H \geq 200$ GeV/c^2).

   (*b*) Reconstructed (as opposed to parametric) vertex constrained momentum resolution for isolated charged tracks of $\sigma_{p_t}/p_t^2 < 20\%$ TeV/c^{-1} for $|\eta| \leq 1.8$, allowed to rise to $\sigma_{p_t}/p_t^2 \rightarrow 100\%$ TeV/c^{-1} as $|\eta| \rightarrow 2.5$.

   (*c*) Reconstruction efficiency within this acceptance greater than 90% for detecting all four leptons from $H^0 \rightarrow 4$ charged leptons, exclusive of lepton identification and trigger cuts.

   (*d*) Material in the tracking volume, averaged over $|\eta| \leq$ 2.5: $\lesssim 7\%\ X_o$ inside 50 cm, $\lesssim 15\%\ X_o$ for all radii.

---

2) Tracking contribution to trigger:

   (*a*) First level trigger with momentum resolution $\sigma_{p_t}/p_t^2 \sim$ 10 TeV/c^{-1} – implies ~ 10% error for a 10 GeV/c lepton.

   (*b*) First level trigger efficiency $\geq$ 96% per track, with $\leq$ 0.05 false triggers per calorimeter trigger ϕ bin per crossing, over the range $|\eta| \leq 2.5$.

   (*c*) Second-level trigger with momentum resolution $\sigma_{p_t}/p_t^2 =$ 5 TeV/c^{-1}. Gives a 20% error for a 40 GeV/c lepton.

Provides a factor of 10 reduction of first level trigger rate and rejection of most conversion electrons at second level.

Second set of requirements is mainly motivated by desire to do detailed studies of the top quark. Need to identify leptons and do tracking and vertexing for b jets.

3) b tagging efficiency for top studies with 125 $GeV/c^2 \leq M_{top} \leq 250\ GeV/c^2$:

   (*a*) Reconstruction efficiency $\geq$ 80% for tracks of $p_t >$ 5 GeV/c, for b tagging using leptons.

   (*b*) b tagging efficiency $\geq$ 25% using detached vertices. Implies impact parameter resolution $\leq 20\ \mu$m for stiff tracks, $\leq 100\ \mu$m for p_t = 1 GeV/c, and $\geq$ 85% efficiency for finding tracks with $p_t >$ 1 GeV/c within jets of p_t up to 100 GeV/c.

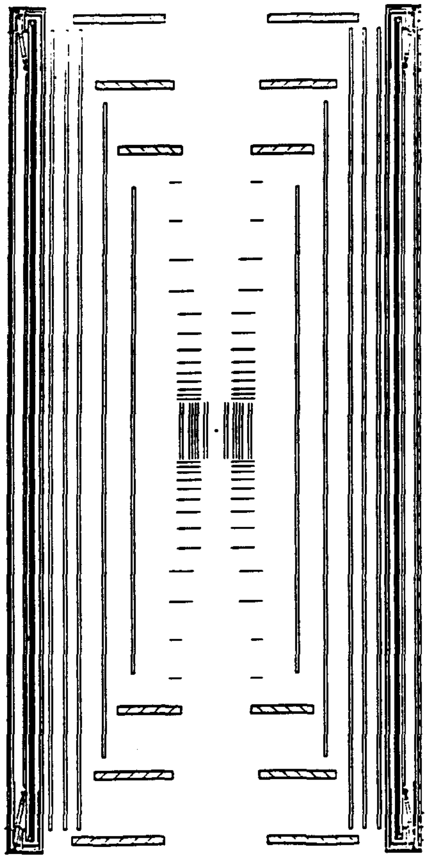
4) Discovery potential—hard to quantify. In general want maximum capabilities from detector. Based on history, highest priority (other than isolated lepton of Higgs case above) would be reconstruction and impact parameter measurement of leptons within jets up to the largest jet p_t possible (at least $\geq$ 500 GeV/c). Desired reconstruction efficiency $\geq$ 50%.

Goals for η acceptance and p_t resolution drive the outer dimensions of detector, resulting in an outer radius = 170 cm and half-length = 430 cm.

Goals for b tagging drive the inner radius, resulting in an inner radius of 9 cm.

Trigger requirements determine the number of layers for the devices participating in the trigger.

Reconstruction efficiency and p_t resolution drive the number of layers overall.



Fiber Tracker Option

The baseline central tracking system has been chosen based on the present status of the various R&D efforts for tracking within the SDC. In the case of the outer tracker, very significant progress has been made in the two major options: tracking based on straw tubes and tracking based on scintillating fibers. The former is less of an extrapolation from existing devices and has, therefore, been selected as the baseline choice.

An outer tracker based on scintillating fibers would also provide a powerful device and have some advantages, particularly in the case of luminosities significantly beyond the SSC design value. This technology is maturing rapidly and the SDC collaboration expects to be able to make a final choice in 1992. I will discuss the fiber option after going over the baseline design.

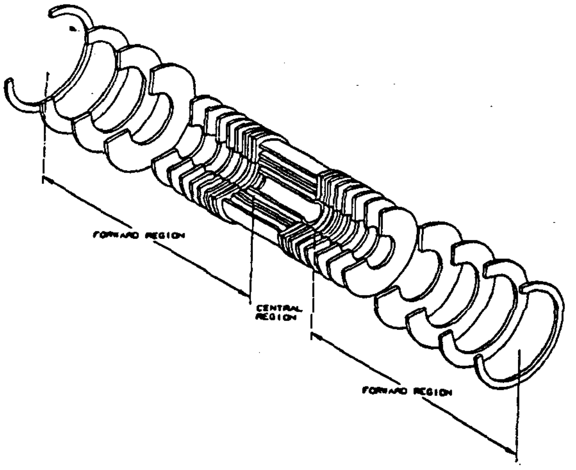
Silicon Tracking System

Covers same η region as muon system: $|\eta| < 2.5$, using barrel detectors in the central region and planar disks at larger rapidities.

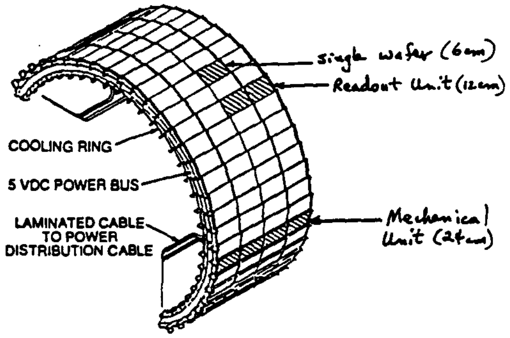
Detectors are double-sided, providing measurements of ϕ on one side and small angle stereo measurements on the other.

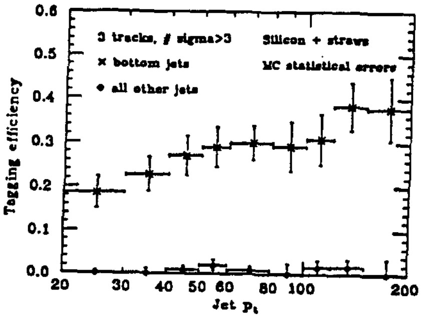
Number of layers chosen to provide excellent track finding efficiency even at several times the design luminosity.

Participates in second level trigger, not first level.



STS detector arrays (pictorial view).





b tagging efficiency vs. jet p_t for the full tracking system.

Barrel Straw Tracking System

Made of 3 axial and 2 stereo superlayers.

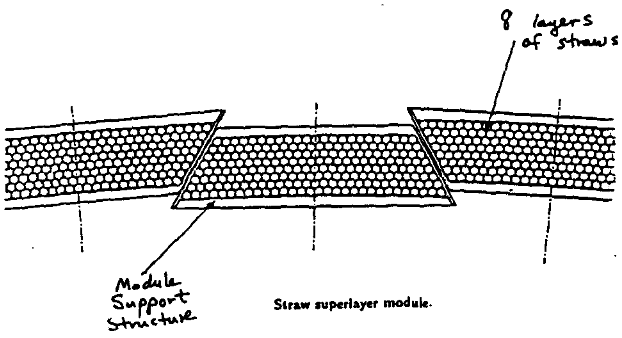
The track reconstruction and trigger use local track segments made from hits in the straws within a superlayer.

The direction of a track segment in an axial layer provides a rough p_t measurement which is used directly in the trigger.

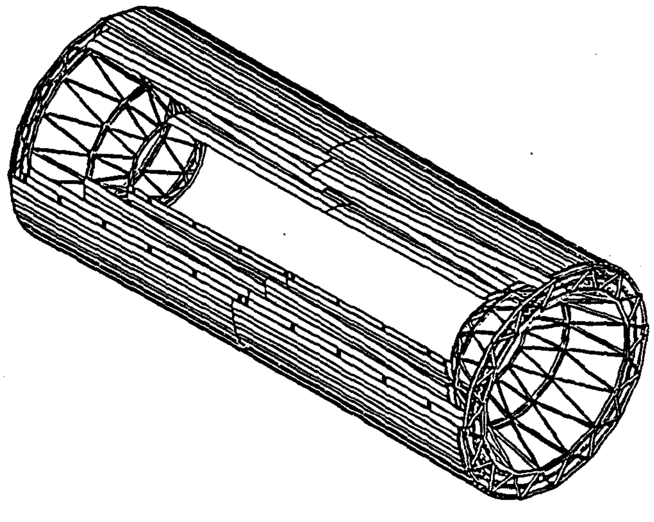
To achieve both excellent background rejection and very high efficiency requires a trigger using two out of three stiff track segments. The straw system has three axial superlayers, the minimum required for the trigger, providing some redundancy and robustness.

Two other superlayers provide z information using small angle stereo. The η coverage is $|\eta| \leq 1.8$.

Trigger Superlayer



Straw superlayer module.



Completely assembled barrel outer tracker

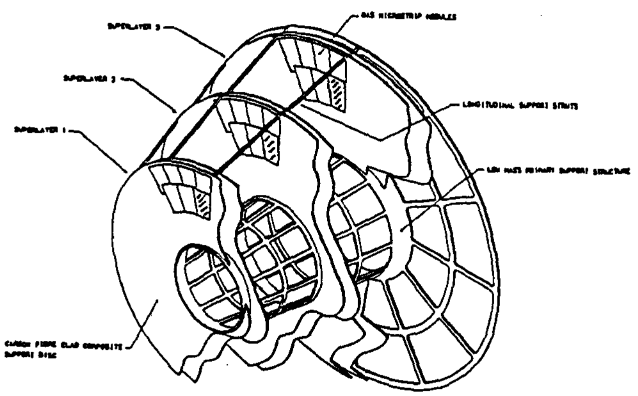
Intermediate Tracking System

Triggering from $|\eta|$ of 1.8 to 2.8 is provided by a system of projective gas microstrip tiles.

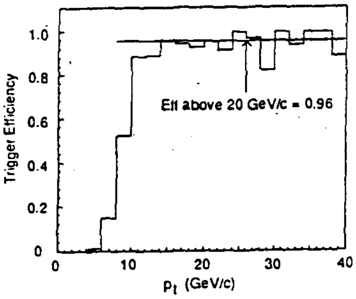
To provide sufficient background rejection and p_t resolution three ϕ measurements, widely spaced along z, are required. To provide very high efficiency each measurement is gotten from an "or" of two closely spaced layers.

To provide radial information each of the three measuring superlayers has two stereo measurements, with positive and negative stereo angles. Thus, each superlayer can provide a separate space point.

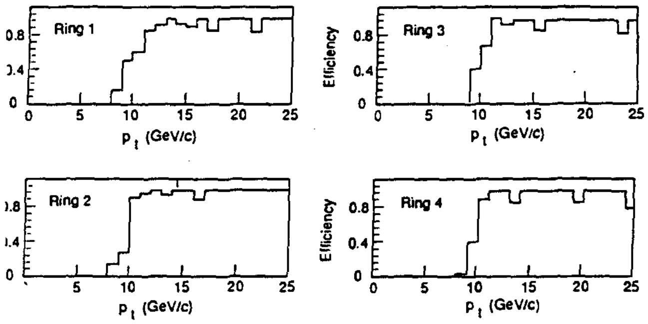
The microstrip detectors are arranged in four annuli which each cover roughly .25 units in η and are separately linked to form a trigger.



First Level Trigger - Design luminosity



Threshold curve for the two-out-of-three superlayer OTD first level trigger.



Trigger threshold curve for the four separate η bins of the ITD trigger.

Silicon System: Made of 6,712 individual wafers and 50,640 readout chips. Area is about 17 m^2 and 6.48 $\times 10^6$ individual strips. Lifetime at design luminosity varies from about 10 years at inner radius to about 100 years at outer radius.

Straw Tube Tracker: 720 modules and 1.37 $\times 10^5$ individual straws. Lifetime at design luminosity is > 15 years.

Intermediate Tracker: About 3,120 gas microstrip tiles and a total of 1.36 $\times 10^6$ individual anodes. Expected to have excellent rate capabilities; requires choice of optimum detector substrate.

Performance numbers including local alignment errors.

Silicon Detector: 17 μm error, each side.
Occupancy typically 10^{-3}.

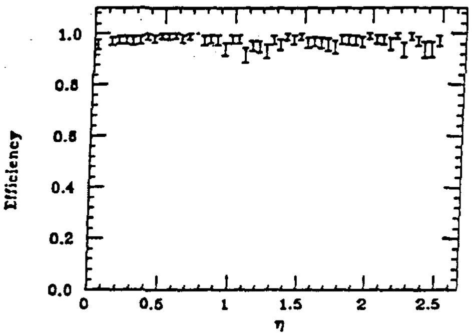
Straw Superlayer: 85 μm error.
Occupancy varies from 9.6% at smallest radius to 2.6% at outside.

Gas Microstrip Detector: 100 μm error.
Occupancy 4×10^{-3}.

The resolution of coordinate measured using stereo is about 1.5 mm for all tracking devices.

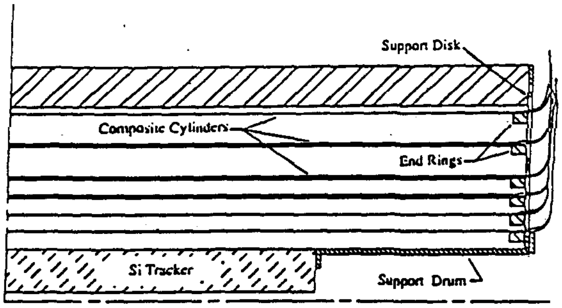
Silicon provides excellent pattern recognition capability, particularly in jets or at very high luminosity. Outer tracker improves momentum resolution by a factor of 10 and polar angle resolution by a factor of 5.

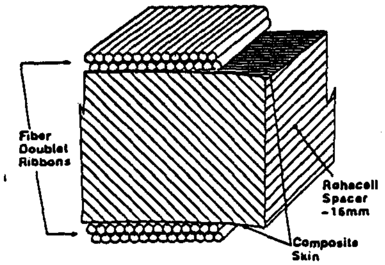
00070



Efficiency of single tracks with $p_t > 1$ GeV/c as a function of pseudorapidity in Higgs events at design luminosity.

00071





00072

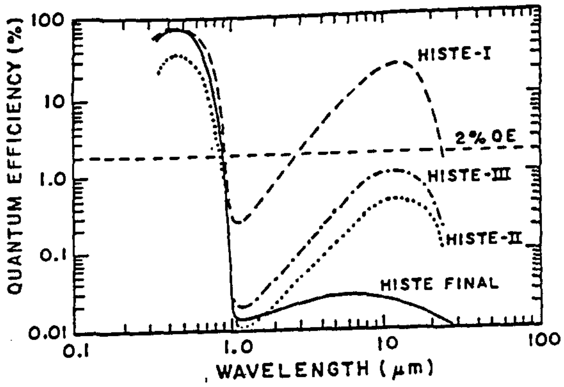
Average occupancies at SSC design luminosity

Superlayer	Radius (cm)	Δη Coverage	Occupancy
B1	60.0	2.3	0.017
B2	76.0	2.3	0.013
B3	92.0	2.3	0.012
B4	108.0	2.1	0.006
B5	136.0	1.9	0.003
B6	165.0	1.7	0.002

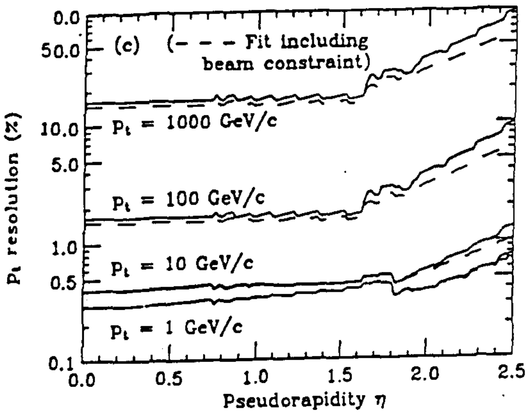
Parameters and Characteristics of the Superlayers of the Scintillating Fiber Tracker

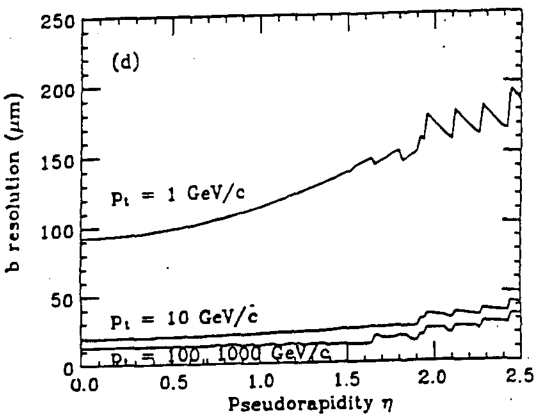
Fiber super-layer	Radial location (cm)	Fiber layers x=axial u=stereo v=stereo	Fiber channels per end	Scifi length for axial fibers (m)	Δη coverage	Wave-guide length (m)	Total fiber length (m)	Expected mean no. of photo-electrons detected for 925 μm diam. (at $\eta = 0$)
B1	60	2x,2x	15.9K	3.00	2.3	6.93	9.93	4.6
B2	76	2x,2x	20.1K	3.65	2.3	6.12	9.77	4.6
B3	92	2x,2x	24.4K					
		2u,2v	24.4K	4.30	2.3	5.31	9.61	4.5
B4	108	2x,2x	28.6K	4.30	2.1	5.15	9.45	4.6
B5	136	2x,2x	36.0K	4.30	1.9	4.87	9.17	4.7
B6	165	2x,2x	43.6K	4.30	1.7	4.58	8.88	4.9
		2u,2v	43.6K					

00073

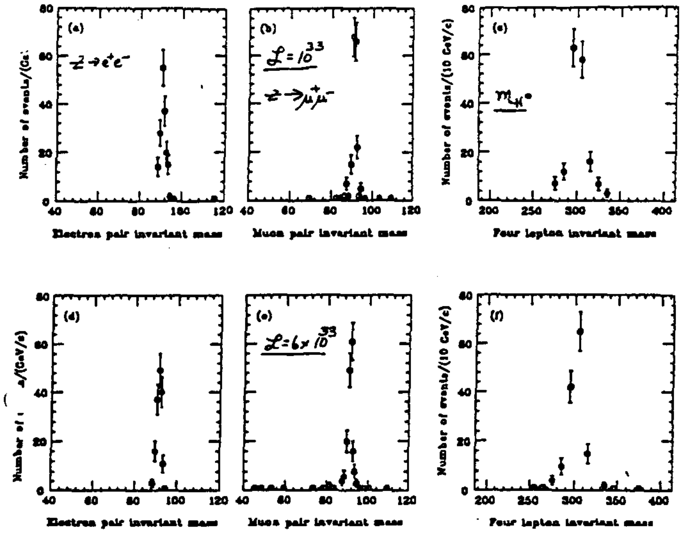


Spectral quantum efficiency for VLPC devices. HISTE-I are DoD restricted devices. HISTE-II and III are unrestricted devices.





300 GeV $H^\circ \to e^+e^-\mu^+\mu^-$



↑ Calorimeter

↑ Central Tracking

Summary of efficiencies and number of fake tracks for $H^0 \to e^+e^-\mu^+\mu^-$ events for various configurations

Luminosity	Fakes per event with $p_t > 5$ GeV/c	Track efficiency $p_t > 10$ GeV/c	Electron E/p efficiency 0.7<E/p<1.4	M_Z cut efficiency e	μ	Higgs reconstruction efficiency
1×10^{33}	0.03 ± 0.01	0.991	0.96 ± 0.01	0.99 ± 0.01	0.99 ± 0.01	0.84 ± 0.04
3×10^{33}	0.04 ± 0.02	0.989	0.96 ± 0.01	1.00 ± 0.01	0.97 ± 0.01	0.83 ± 0.04
6×10^{33}	0.18 ± 0.03	0.972	0.93 ± 0.01	1.00 ± 0.01	0.93 ± 0.02	0.75 ± 0.04

PLENARY SESSION

SDC CALORIMETER SYSTEM

D. GREEN

SDC CALORIMETER SYSTEM
May PAC/SSC

Dan Green

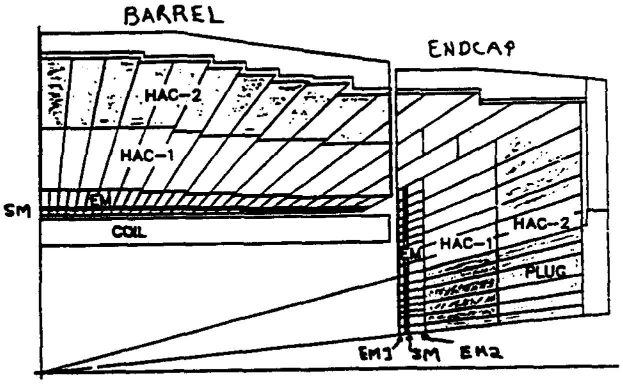
for the

SDC Calorimeter Group

SDC CALORIMETER SYSTEM
REQUIREMENTS

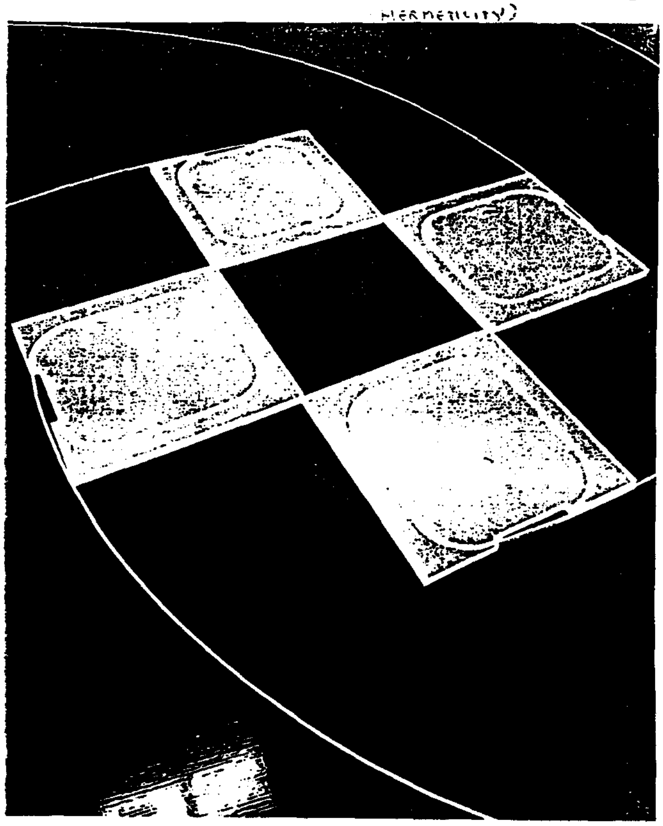
1. Measure the energy, interaction time and direction of quarks (jets), electrons, neutrinos and photons. Provide triggers based on these properties.
2. Provide identification capabilities for electrons (EM/HAD compartments) and photons. Tag muons as noninteracting particles deep in the system. Provide hermetic coverage to allow for neutrino identification. Provide for tau identification with sufficient EM and HAD granularity.
3. Granularity must be sufficient to avoid pileup errors. Depth in EM must be sufficient to preserve precision of the energy measurement. Depth of HAD must be sufficient to contain 10 TeV dijet masses. Transverse scales are set by EM and hadronic shower sizes.
4. Angular coverage must be sufficient to avoid spurious missing Et generation. Precise electron energy measurement must extend over a sufficient angular range to be efficient for 2 gauge boson final states decaying into leptons. $(|\eta| < 6 \ , |\eta| < 3)$

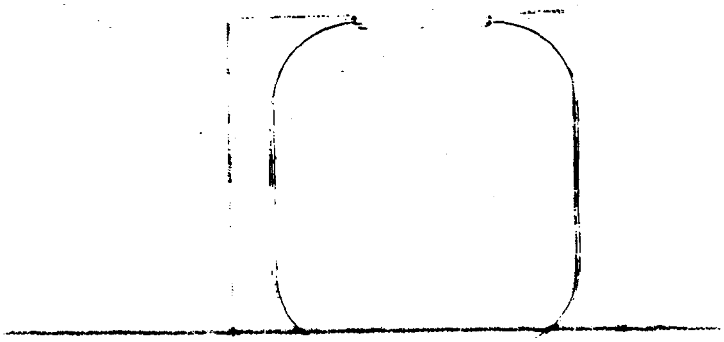
CENTRAL CALORIMETER GEOMETRY



Longitudinal quarter section of the central calorimeter.

[illegible] / FIBER RE HERMETICITY)



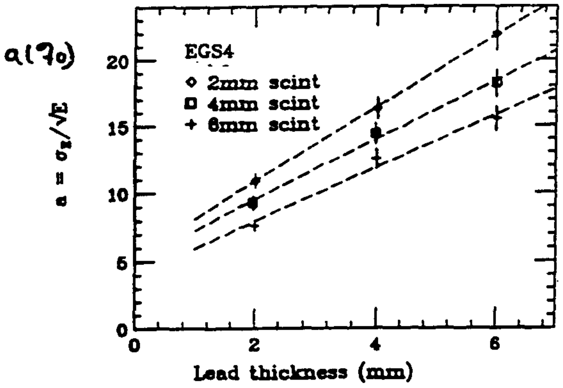


STOCHASTIC COEFFICIENT VS Pb THICKNESS

$$\frac{dE}{E} \equiv \sqrt{(a/E)^2 + b^2}$$

STOCHASTIC

CONSTANT



EM TEST MODULE-Pb CASTING

dE/E , ⊥ SCAN , SM

CONTRIBUTIONS TO THE EM RESOLUTION

- "CONSTANT" TERM -

EM calorimeter constant term budget.

Source of constant term	Contribution
Calibration tower to tower	0.2%
Leakage	0.3%
• Transverse uniformity	0.5%
Tile-to-tile variations incl. thickness variations and longitudinal masking	0.5%
Absorber thickness variations	0.2%
• Radiation damage	0.5%
Total (added in quadrature)	< 1.0%

TILE/FIBER TRANSVERSE UNIFORMITY

"σ" TILE

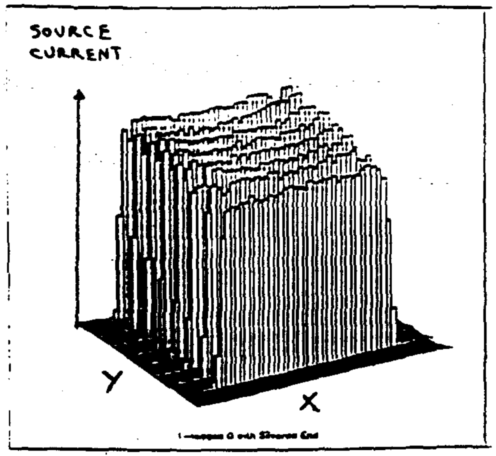
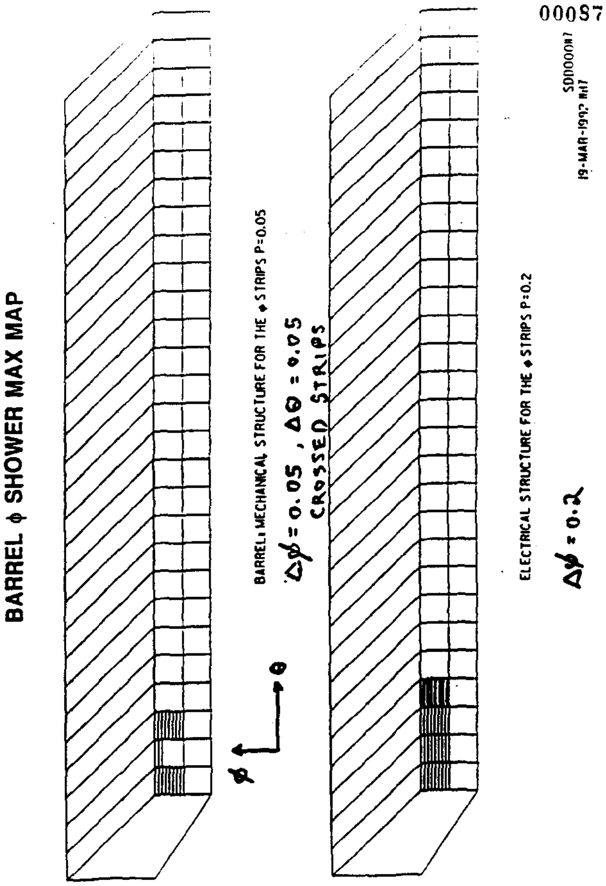


Figure 6.11 Transverse response map for a "Sigma" tile.



$\Delta\phi = 0.05$, $\Delta\Theta = 0.05$
CROSSED STRIPS

$\Delta\phi = 0.2$

DIJET MASS RESOLUTION

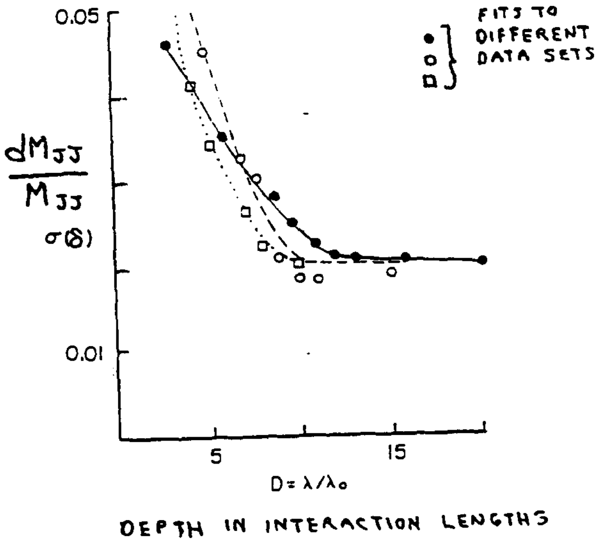
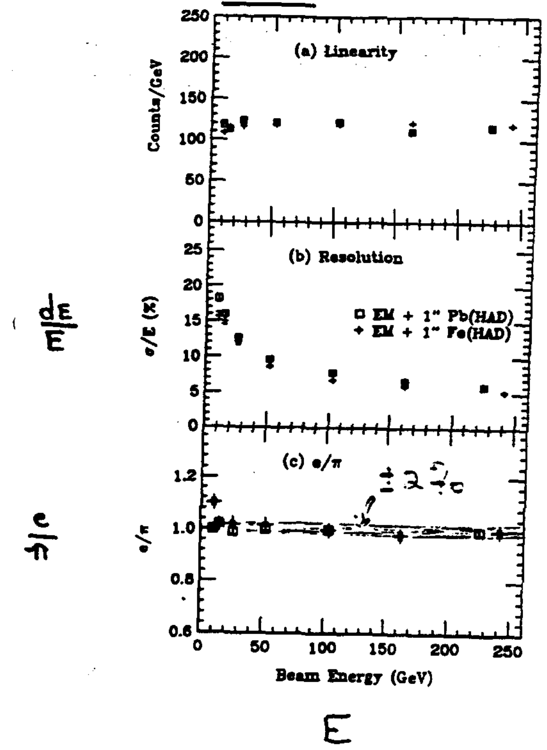


FIGURE 4

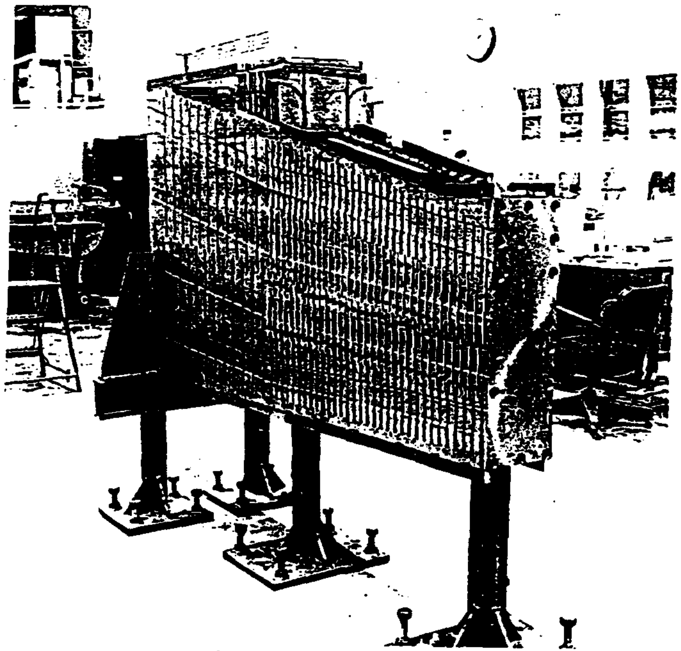
"HANGING FILE" SDC

TEST BEAM DATA

Fe / Pb



RELATIVE EM AND HAD CALIBRATION SET

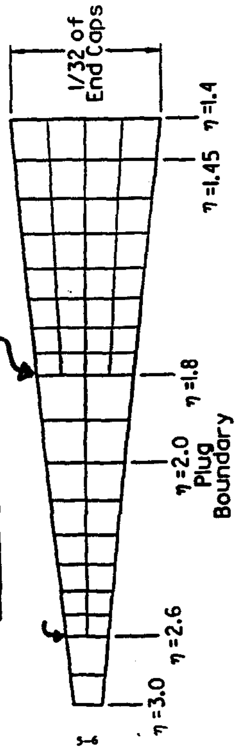


(dE/E)$_c$, ⊥ SCAN

$\Delta\eta = \Delta\phi = 0.05$

UNTIL SEGMENTATION

IS ≈ SHOWER SIZE



END-CAP SEGMENTATION (EM)
ETA - PHI MAP
SSC DWG # SDD000096

RADDAM

INDUCED TRANSVERSE NONUNIFORMITY?

DOSE OF 0.62 MRAD

Ru SOURCE SCAN, X_T

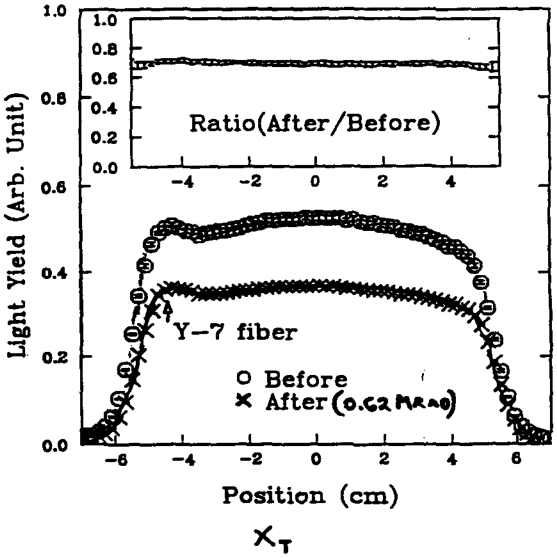


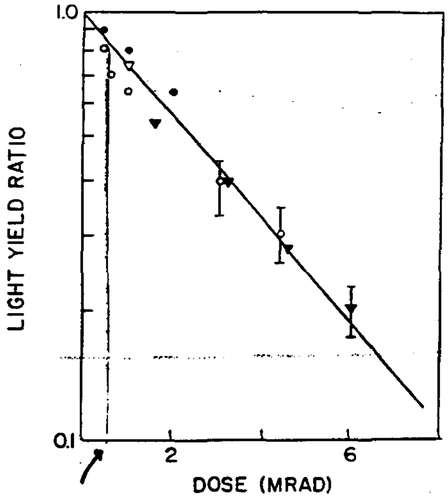
Figure 13: Response map of a tile/fiber assembly measured by scanning with a ^{106}Ru source. This assembly was non-uniformly exposed to ^{60}Co with a dose distribution of 0.62 Mrad at the center and 0.20 Mrad at the edge.

RADDAM

INDUCED LONGITUDINAL NONUNIFORMITY

$D_0 \sim 3.4$ MRAD

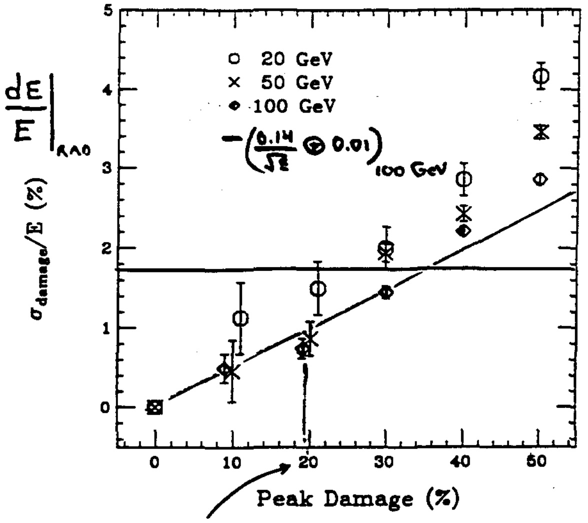
@ SM



100 YEARS
@ $10^{33}/(cm^2 \cdot sec)$
IN BARREL

Figure 7. Summary plot of light yield ratio at shower maximum for Saclay data •, o Tsukuba data, ▼ Beijing data. The line is of the form $1-|d(z)|_{max} = \exp(-D/Do)$.

RADDAM NONUNIFORMITY AND EM RESOLUTION



NO REPAIR
NO LONGITUDINAL SEGMENTATION
100 YR @ $10^{33}/(cm^2 \cdot sec)$
IN BARREL

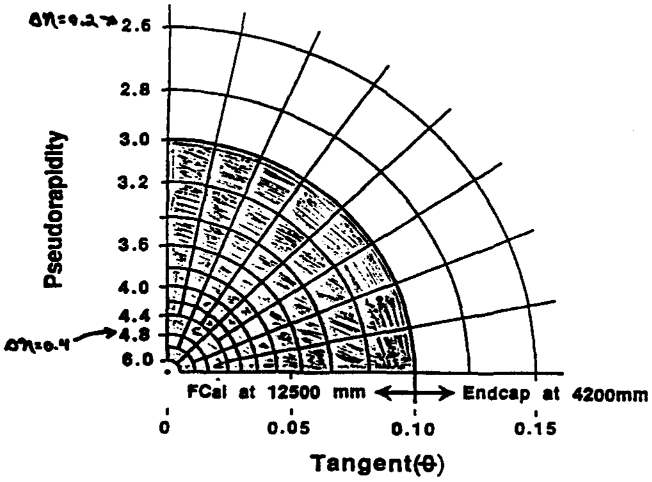
d_{MAX}

Figure 21: Damage-induced error to resolution as a function of the peak damage for energies of 20, 50 and 100 GeV.

ENDCAP: EM1, EM2
REMASK
AND/OR
REPLACE 31
R+D

FCAL SEGMENTATION

LOW P_T ($\sim M_W$) JETS



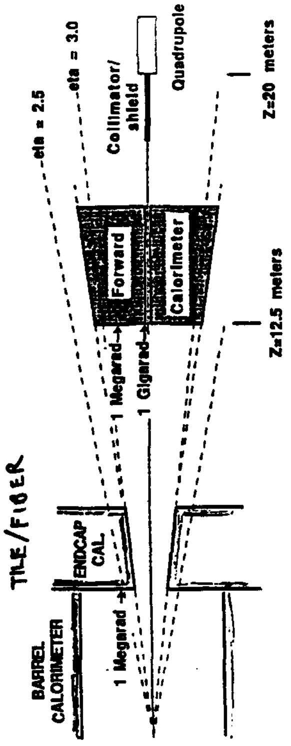
A VIEW FROM THE INTERACTION POINT

A SMOOTH TRANSITION AT 100 MILLIRADIANS

FROM ENDCAP TO FCAL

FCAL GEOMETRY, DOSE

$D \sim 1/\theta^3$



Radiation doses are shown for 10 years at 10**33

1 GIGARAD ⇒ HIGH PRESSURE GAS
OR
LIQUID SCINTILLATOR

SDC CALORIMETER SYSTEM DESCRIPTION

- CENTRAL CALORIMETER Scintillator tile (4 mm) with WLS fiber (1 mm)

Barrel

Massless Gap	Readout first layer in each tower independently. Correct for EM showers initiated in solenoid
EM	Make a precise energy measurement in tower of size 0.05 in eta/phi. Absorber is 4 mm Pb, 21 Xo.
SM	Precise (2 mm) measurement of shower cg. Scale of strip size in eta/phi is 0.05/8< Moliere radius.
HAD	Measure hadronic energy sufficient for jets. Longitudinal segmentation to tag and control leakage. Hermetic to 1% for missing Et. Scale of tower in eta (0.1) is hadronic shower size. Fe, HAD1 (24 mm) + HAD2 (54 mm) = 10 int lengths.

Endcap

Granularity constant until shower size dominates. EM longitudinal segmentation to tag and control radiation damage. Endcap EM and endplug hadron repairable.

- FORWARD CALORIMETER

Coarse segmentation and energy measurement. Tag and measure jets for missing Et and WW fusion.

SDC CALORIMETER SYSTEM SUMMARY

1. SDC Calorimetry is defined by "SDC Calorimeter Conceptual Design Report" and the TDR. Details will appear in the parallel sessions.
2. The calorimetry for SDC has been optimized for the Physics using both Monte Carlo simulations and an extensive program of beam testing. Tests of EM, SM, and HAD test modules were performed at FNAL in 1991.
3. In general, SDC has evolved to emphasize EM resolution, which has precise scales such as Z width/mass rather than HAD resolution where the basic quarks require a less accurate energy measurement due to inherent difficulties in jet definition.
4. Steel absorber and scintillator sampling are chosen on the basis of data. The resulting need for radiation damage studies and extensive calibration systems is being addressed. An existence proof for the barrel has been made. R&D for the endcap is in progress. Replacement plans exist.
5. The next step for the calorimeter group of SDC is to build and test a full size "preproduction prototype" of a barrel wedge. This must be done in 1993 if the SSCL schedule for SDC is to be met.
6. The forward calorimeter options have been reduced to 2 and the geometry has been chosen (backstop), Final technology choice is in progress.

PLENARY SESSION

SDC MUON SYSTEM OVERVIEW

G. FELDMAN

SDC Muon System Overview

G. Feldman
SSC PAC Meeting
May 4, 1992

Plan of the Talk

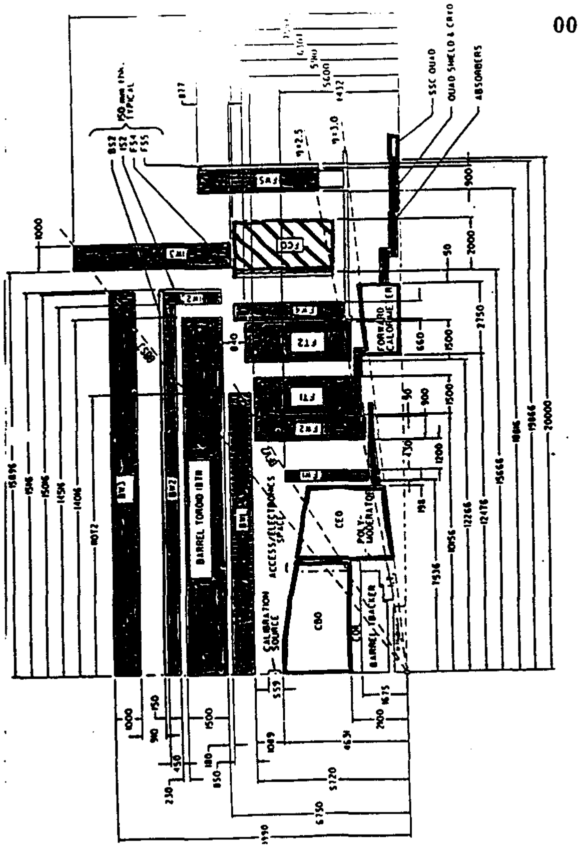
The muon system has three main functions:

- (a) to trigger the detector on a muon over a threshold p_t
- (b) to identify a charged track as a muon
- (c) to improve the precision of the momentum measurement by the central tracker.

Each function places different demands on the muon system, and, in general, each component contributes to more than one function.

The plan of this talk is to first
- (a) introduce the components, and then to
- (b) explain the demands of each function.

In parallel talks tomorrow and Friday, I will attempt to explain why we made various design choices.



Toroids

The toroids are key elements of the muon system. They are essential for providing
- (a) the first level trigger
- (b) a second momentum measurement for muon identification
- (c) improved momentum resolution in the forward direction.

	$\lvert\eta\rvert$ Range	Thickness (m)	Ave. Field (T)	θ Kick (mr)
Central	0-1.4	1.5	1.8	$810/p_t$
Forward	1.4-2.5	3.0	1.8	$1620 \tan\theta/p_t$

The forward θ kick varies between 860 $/p_t$ mr to $268/p_t$ mr as η varies from 1.4 to 2.5.

00105

Scintillation Counters

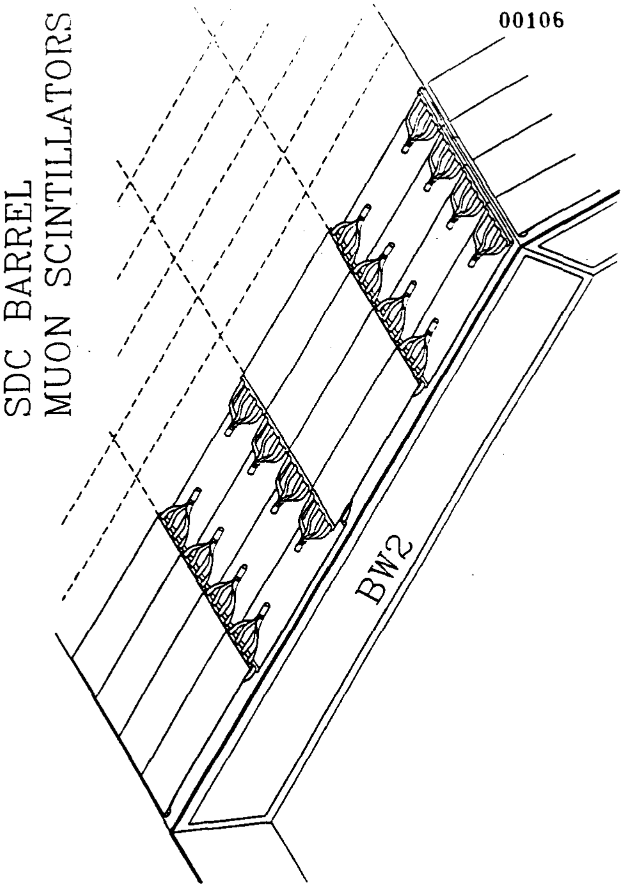
Scintillation counters are used to define the bunch crossing of a muon signal.

The drift chambers will have drift times of up to 1 μs, or 60 bunch crossings. The scintillation counters are needed to localize an event to the 16 ns spacing between bunches.

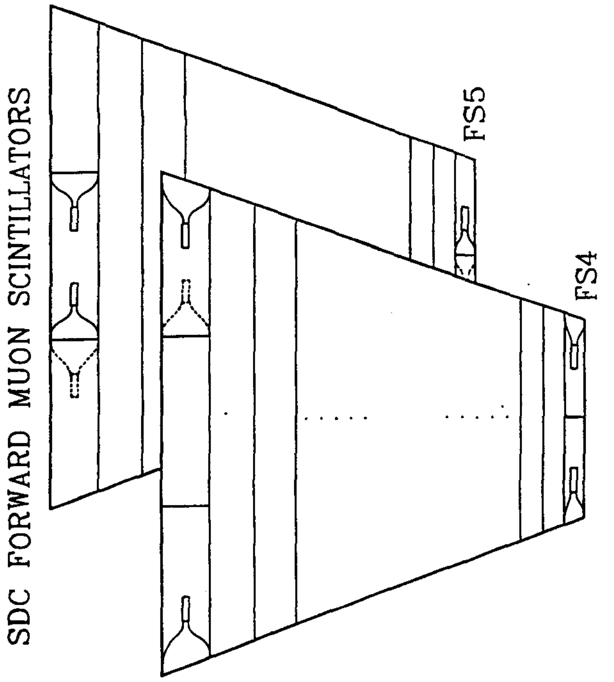
In the central regions, we use one layer of counters, with each counter viewed by two photomultipliers. The counters are about 2 m long and 50 cm wide. They are aligned with the long direction in the θ measuring direction, so that they can be associated with θ chambers at the first level trigger. They also give a π/16 ϕ measurement, which can be used to associate triggers with the calorimeter towers and muon ϕ chambers. 2240 counters.

In the forward regions, where background rates are higher, we use two layers of counters in coincidence, with each counter viewed by one photomultiplier. The coincidence of these counters gives an angle independent p_t threshold. They give either a π/12 or π/8 ϕ measurement, depending on η. 2256 counters.

00106



00107



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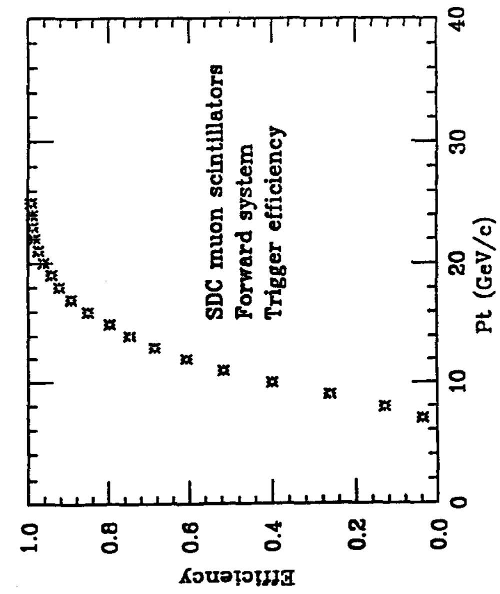
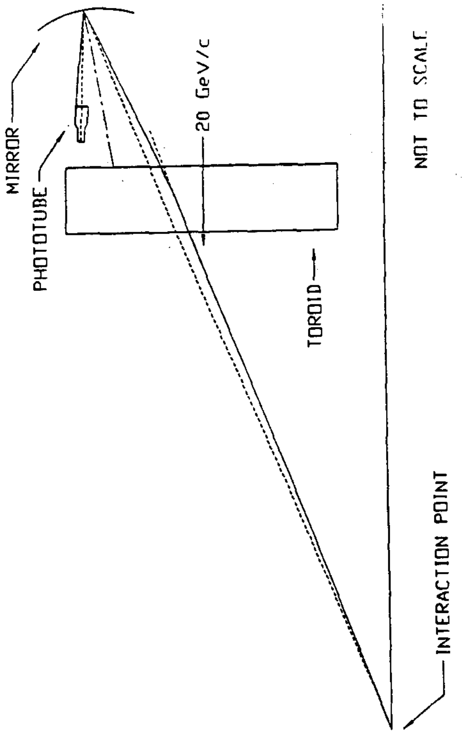
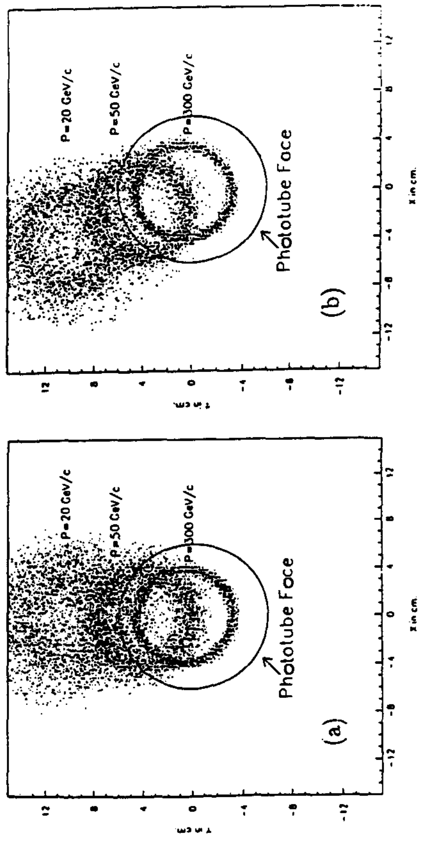


Cerenkov Counters

As a possible future upgrade, and not part of the baseline design, we have included plans for Cerenkov counters in the forward direction to aid in the trigger. These counters are directional and insensitive to low energy backgrounds.





Wire Chambers

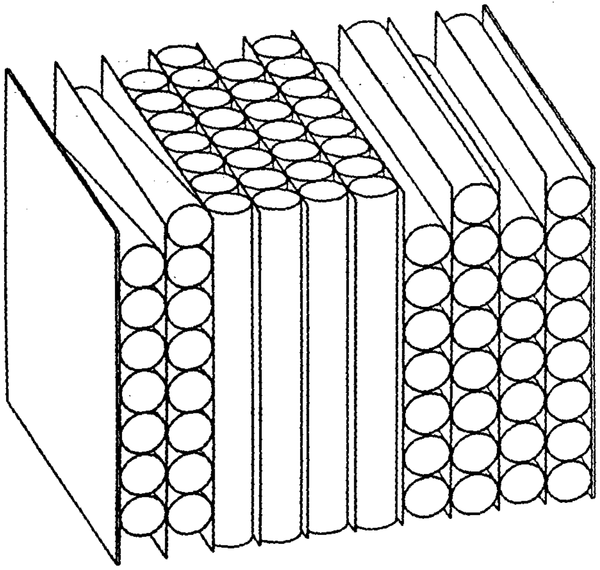
The wire chambers are of a novel design. They are made from long (up to 9 m) cylindrical tubes which are epoxied to thin plates to make a structural unit.

The wires are supported only at their ends, and are indexed by NCN-milled endplates.

The tubes have simple field-shaping electrodes to give relatively uniform drift fields, which are aligned perpendicular to the direction of high p_t tracks by rotating the cylindrical tubes.

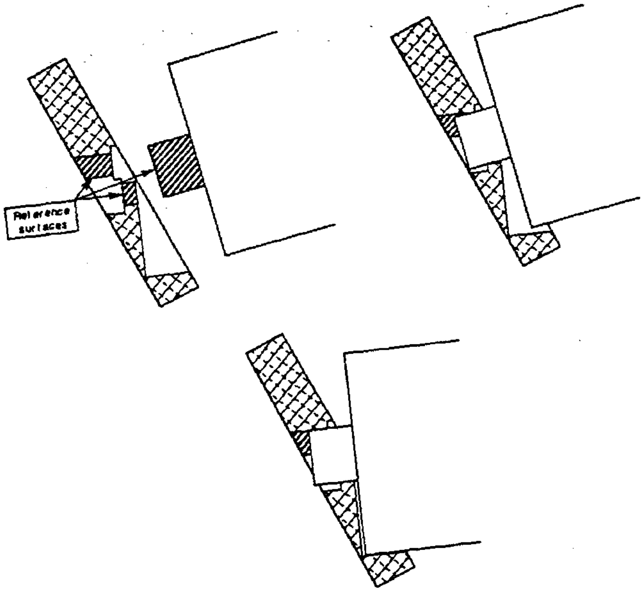
The central tubes are 9.0 cm inner diameter. This is the largest radius which allows a 1 μs drift time for normal gases. The forward tubes are either 4.2 or 5.7 cm inner diameter. The smaller diameters are for reasons of space and occupancy. [Background rates go as the diameter squared for charged particles and the diameter cubed for neutrons.]

00113



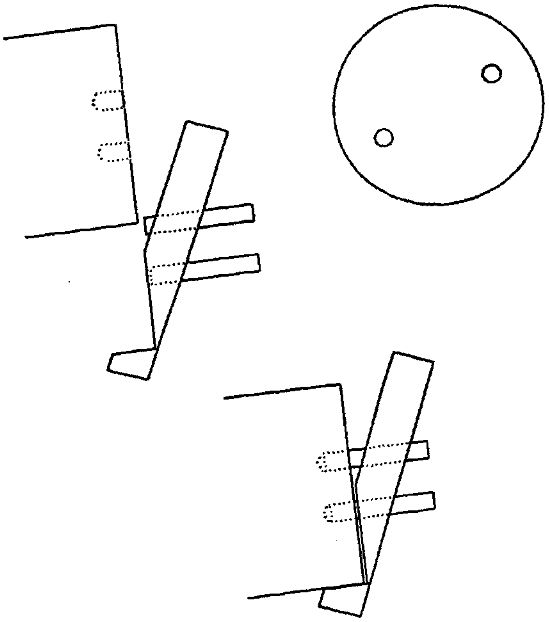
00114

Installing boss end

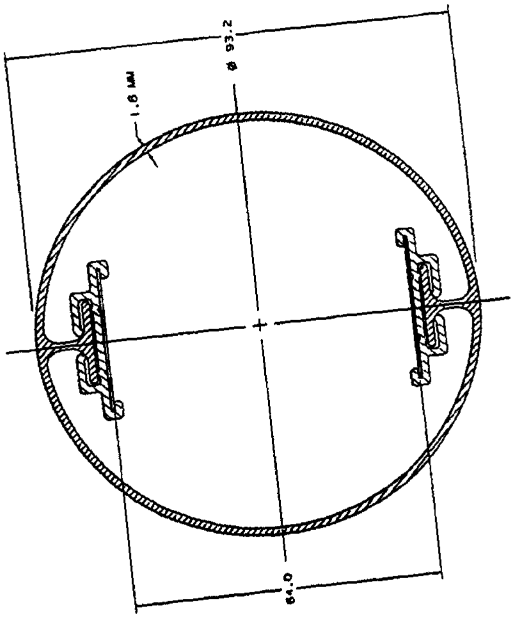


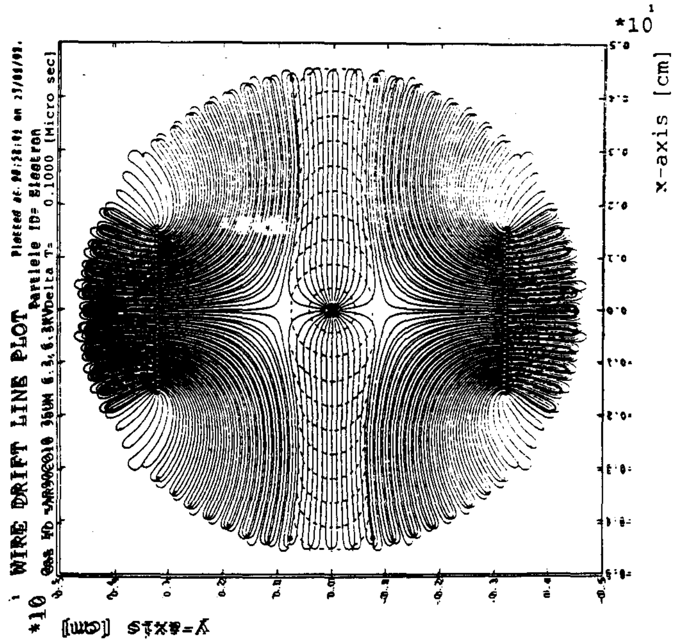
00115

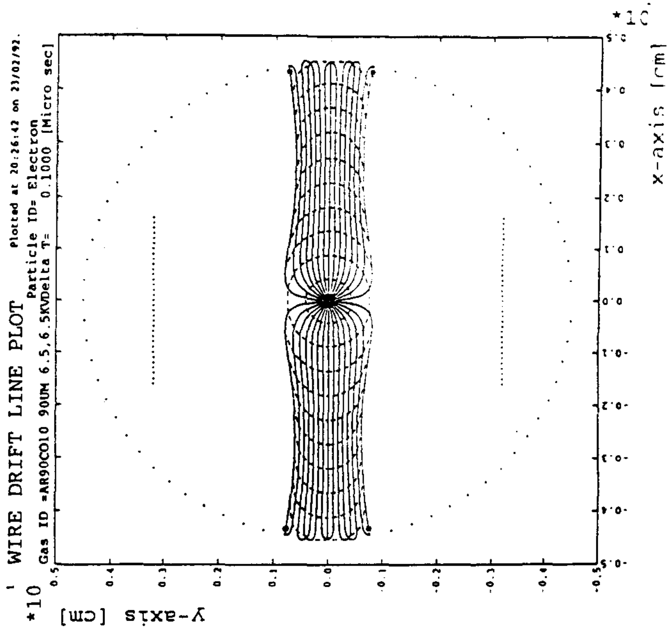
Installing flat end

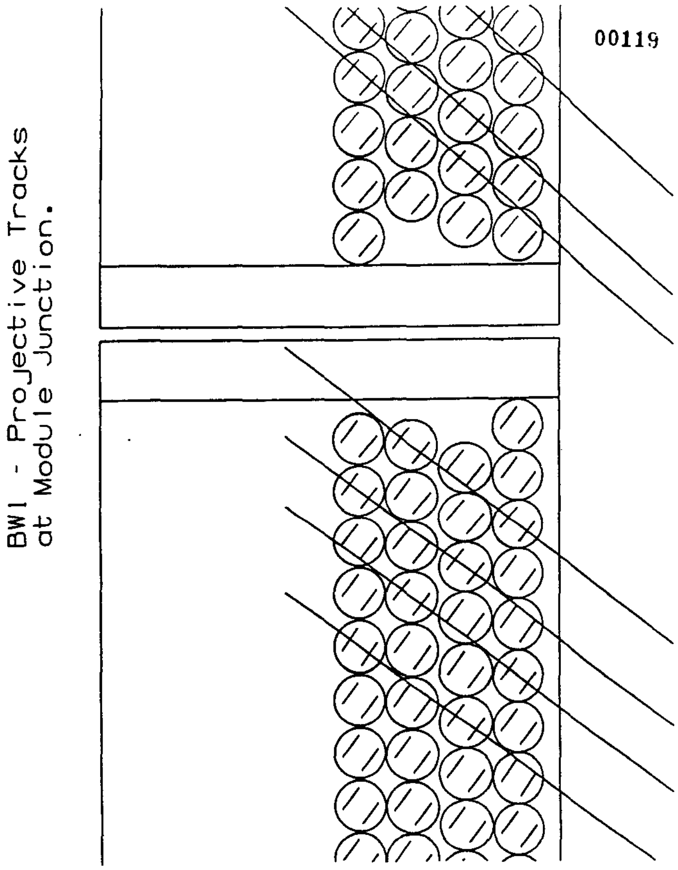


00116









Tubes are positioned to measure θ, ϕ, and stereo in the central regions, and to measure θ and two stereo directions in the forward regions:

Central Chambers

Label	Coor-dinate	Number of Layers	Channels
BW1	θ ϕ	4 4	10674
BW2 IW2	θ	4	9136
BW3 IW3	θ ϕ s	4 4 2	37814
Total		22	57624

Forward Chambers

Label	Coor-dinate	Number of Layers	Channels
FW1	θ	4	4390
FW2	θ	2	11904
	s_1	2	
	θ	2	
	s_2	2	
FW4	θ	4	4310
FW5	θ	2	11636
	s_1	2	
	θ	2	
	s_2	2	
Total		24	32240

In addition, room is being left between the two forward toroids for an additional 4 layers of θ tubes. This upgrade, which is not part of the baseline design, would allow a determination of whether there had been a large-angle muon scatter in one of the toroids, and allow for a correct point-line measurement in the other.

Estimated Occupancies

At $\mathcal{L} = 10^{33}$ cm^{-2} sec^{-1},

Scintillation counters	
Central	$2\ 10^{-6}$
Forward	$2\ 10^{-5}$
Chambers	
Central before torrid	$5\ 10^{-4}$
Central after toroid	$1\ 10^{-4}$
Forward (worst case)	$1\ 10^{-2}$

These relatively low occupancies indicate that the muon system will operate satisfactorily at luminosities an order of magnitude above design.

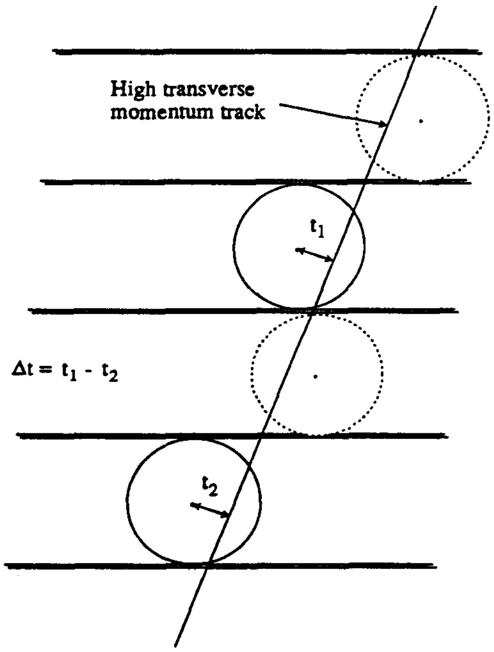
Trigger

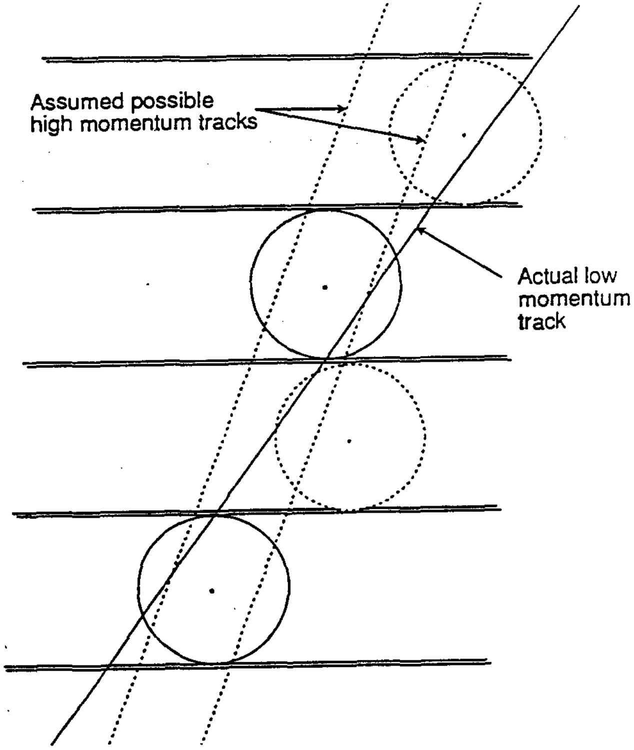
The basic first level trigger is generated by measuring the local bend in θ of a muon candidate outside the toroid. This is done by measuring the time difference in signals from projective wires.

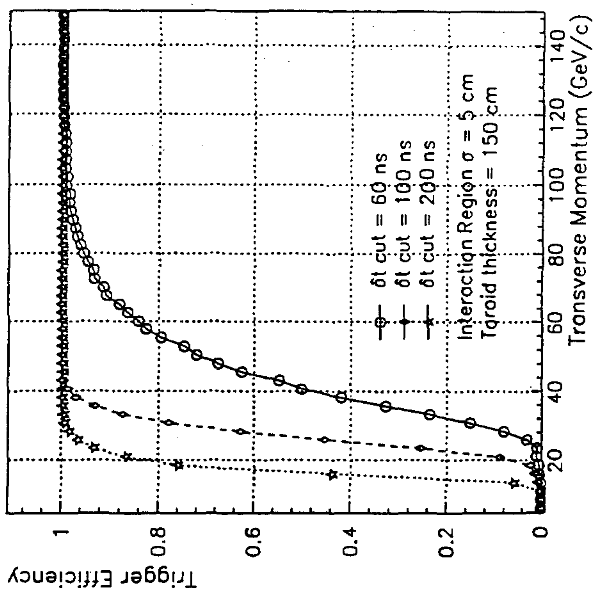
Since a low momentum track can fake a high momentum track by passing on opposite sides of a wire, a coincidence of two measurements is required.

With a 20 GeV/*c* p_t threshold, the first level trigger rate is estimated at about 6 kHz, a number which is somewhat marginal. There is flexibility to enhance the first level trigger if necessary:

- Require a stiff θ stub in BW1. (Reduces triggers from large scatters in the calorimeter.)
- Require a stiff ϕ stub in BW1 or BW3. (Reduces the cosmic ray trigger from ~1kHz to a negligible level.)
- Require isolation in the calorimeter. (Most triggers are from heavy quark decay.)







The second level trigger must refine the p_t measurement to sharpen the threshold. In the central region the primary method is to match a track from the inner tracker to a ϕ measurement in BW1 or BW3 (or IW3).

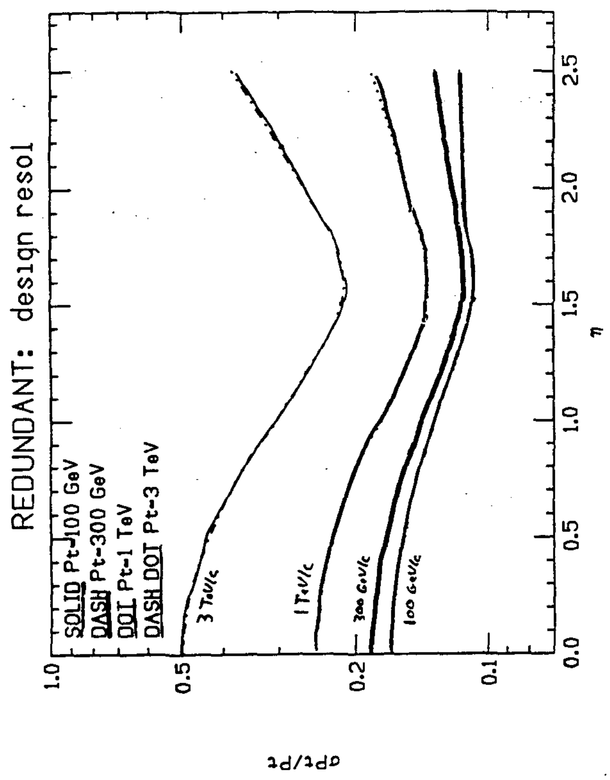
In the forward region, the primary method is a line-line measurement in θ with FW1-FW2 and FW4-FW5.

Muon Identification

The key question for the muon system is whether a track found by the inner tracker is a muon.

A match must be made in θ, ϕ, and momentum. Studies of high-p_t b jets show that both the θ and ϕ matches are required to avoid confusion at the 20 to 30% level.

The match in momentum is necessary to distinguish true muons from the decay products of hadronic showers. This is done by the toroidal measurement.



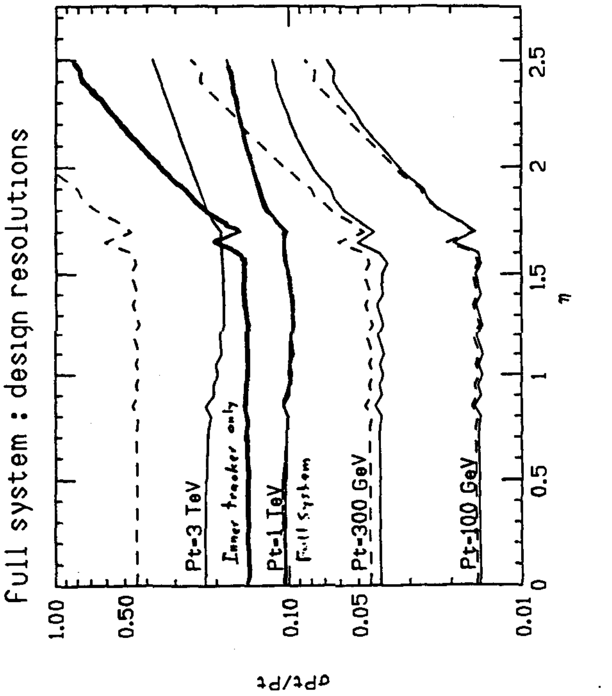
Momentum Measurement

The primary momentum determination comes from the solenoidal measurement with the inner tracker. However, since the effect of the solenoidal field extends out until it is returned in the calorimeter, at very high-p_t, the momentum measurement in the central region is improved by ϕ measurements in the muon system.

The forward toroids contribute to the overall momentum resolution at high η, and become the primary momentum measurement for p_t > 300 GeV/c and $|\eta|$ > 2.2.

For p_t = 1 TeV/c, $\Delta p_t/p_t$ =

$\eta = 0$	0.11
$\eta = 2.5$	0.18



Schedule Highlights

Start Full-scale Prototype Fabrication	Oct 92
Start Central Toroid Procurement	Oct 92
Start Forward Toroid Procurement	Jun 93
Start Counter and Tube Fabrication	Jan 94
Start Supertower Assembly	Dec 94
Complete Central Toroid Fabrication	Apr 96
Start Supertower Installation	Jun 96
Complete Forward Toroid Fabrication	Dec 96
Complete System Ready for Test	Mar 99

PLENARY SESSION

SDC ELECTRONICS SYSTEMS

A. LANKFORD

SDC

ELECTRONICS SYSTEMS

An Overview for the SSCL PAC

A. J. Lankford
for the **Solenoidal Detector Collaboration**
May 4, 1992

SDC ELECTRONICS

Address the challenge of transforming signals from *~10^7 detector channels* for *10^8 interactions/sec* to *50 - 100 events/sec* of record length < *1 MByte* while retaining *all* interesting physics data.

Front-end Electronics:
- perform signal processing of detector signals
- correlate detector signals with particular beam crossings
- buffer data during trigger decisions
- filter data according to Level 1 & Level 2 triggers
- digitize event data
- output event fragments to the Data Acquisition System
- develop primitive information for the Trigger System

Data Acquisition System:
- collect event fragments from Front-end Electronics
- build complete event records from event fragments
- filter events according to Level 3 trigger
- record selected events for offline analysis

Trigger System
- receive trigger primitives from Front-end Electronics
- process trigger data
- select event candidates for further processing
- control Front-ends, Data Acquisition & Trigger

NEW CHALLENGES
for SSC ELECTRONICS SYSTEMS

In addition to the problems of extremely high rates and very large numbers of channels, particular challenges arise from:

Time between crossings < Detector response times
Time between crossings < Time of flight
Time between crossings < Trigger decision time

Requires systems with new features:

- "*deadtime-less*" electronics system with simultaneous analog signal processing and digital readout.
- *pipelined* trigger and data systems.

BASIC ARCHITECTURAL APPROACH
to SDC ELECTRONICS SYSTEMS

Choose a coherent architecture for all detector subsystems.

- must meet the requirements of all subsystems
- optimizes cost, reliability, and ease of debugging

Perform as much signal processing on the detector as practical.

- minimizes bandwidth transmitted from detector
- requires dedicated data paths to trigger
- made practical by extensive use of custom IC's for high channel densities and low cost

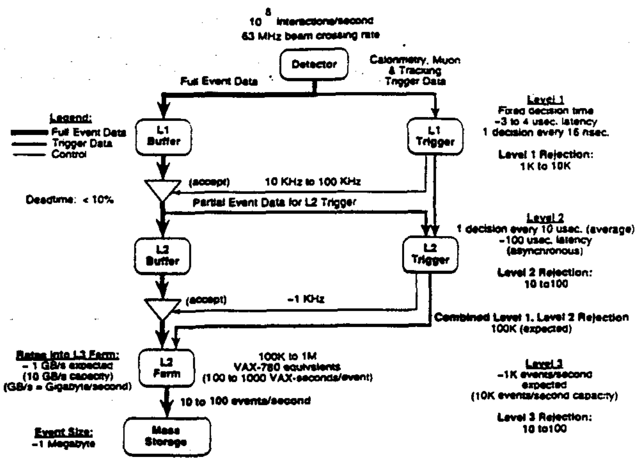
Exploit parallelism throughout architecture.

- avoids bandwidth bottlenecks
- allows capability for upgrade and high luminosity

Implement a *3*-level trigger and readout architecture.

- makes efficient use of bandwidth and processing

DATA FLOW DIAGRAM of 3-LEVEL ARCHITECTURE



PHYSICS and TECHNICAL CHALLENGES to SDC TRIGGER DESIGN

Physics Challenge:

The trigger is the start of the physics event selection process. It must retain interesting physics from the TeVatron range to the highest masses accessible at the SSC.

Technical Challenge:

10^8 interactions/sec -------------> *50 - 100* triggers/sec

10^6 rejection

Architectural Approach:

Multilevel trigger with nearly the same sophistication as offline physics analysis. Exploit simple fast electronics at first levels, high-performance commercial processors at high levels, and transition from simple to more complex processors at intermediate levels.

Design Approach:

- Specify the physics quanta upon which to trigger, and define the criteria by which the quanta are identified.
- Specify the detector data required by the id criteria, and assign the id criteria as algorithms to the trigger levels.
- Design data paths to the trigger levels.
- Design trigger processors at each level.

PHYSICS GOALS of the SDC TRIGGER

- The physics goals of the SDC involve signatures comprised of high-p_t leptons, photons, and jets and of missing E_t. Consequently, the trigger must:

  identify, measure, and count

  $e^{\pm}$, $\mu^{\pm}$, γ, jets, missing E_t.

- The trigger must also acheive thresholds of physics interest within allowable trigger rates.
- The trigger should identify the basic physics quanta by their local signatures in the detector, with minimal use of topological criteria (*e.g.*: isolation) particularly at the earliest levels of the trigger.
- The selection criteria employed by the trigger should be compatible with (and not determine) the identification criteria which will be used for offline analysis.
- The trigger must be measurably efficient.
- Benchmarks for Trigger Performance
  - e's and μ's from inclusive W's and Z's
  - γ's and jets at high-p_t (overlap with lower $\sqrt{s}$)
  - Missing E_t from $H \rightarrow 2l^{\pm}2\nu$ and SUSY

SIGNATURES of SAMP. : PHYSICS PROCESSES

Physics Process	Mass Region (GeV)	Physics Signature
Associated Higgs Production		
	80 - 150	$W+H$, $t\bar{t}+H \rightarrow \ell\gamma\gamma$
Direct Higgs Production		
	130 - 180	$H \rightarrow ZZ^* \rightarrow 4\ell$
	180 - 800	$H \rightarrow ZZ \rightarrow 4\ell$
	500 - 800	$H \rightarrow ZZ \rightarrow 2\ell 2\nu$
High Mass Boson Pairs		
Requires integrated luminosity of		$Z\gamma \rightarrow \ell^+\ell^-\gamma$
at least 50 fb^{-1} for complete studies	1-2 TeV	$W^+Z \rightarrow \ell^+\ell^+\ell^-\nu$
		$W^+W^+ \rightarrow \ell^+\ell^+$
Discovery of t Quark		
	$\lesssim$1 TeV	$t\bar{t} \rightarrow W^+W^- + X \rightarrow e^{\pm}\mu^{\mp} + X$
Mass Measurement of t Quark		
Sequential Dilepton Mode	$\lesssim$ 500	$t\bar{t}$, one $t \rightarrow Wb$; $W \rightarrow e\nu$; $b \rightarrow \mu + X$ the other $t \rightarrow$ 3 Jets
Lepton + Jets + b-tag Mode	$\lesssim$ 500	$t\bar{t}$, one $t \rightarrow W + X$; $W \rightarrow \ell\nu$ the other $t \rightarrow Wb \rightarrow b$ + 2 Jets
Non-standard t Decays		
Violation of τ Universality	$M_H \lesssim M_{top} - 15$	$t \rightarrow H^{\pm}b$; $H^{\pm} \rightarrow \tau^{\pm}\nu$; $\tau^{\pm} \rightarrow \pi^{\pm} + X$
Peak in 2-Jet Mass Distribution	$M_H \lesssim M_{top} - 25$	$t \rightarrow H^{\pm}b$; $H^{\pm} \rightarrow c\bar{s}$
Giuino and Squark Searches		
Missing-E_t + Jets	300 - 1000	$\tilde{g}\tilde{g} \rightarrow E_t^{miss}$ + 3-6 Jets
Like-Sign Dileptons	200 - 2000	$\tilde{g}\tilde{g} \rightarrow \ell^{\pm}\ell^{\pm}$ + 4 Jets
New Z Searches		
Discovery	$\lesssim$ 4 TeV	$Z' \rightarrow \ell^+\ell^-$
Width and Asymmetry	$\lesssim$ 2 TeV	$Z' \rightarrow \ell^+\ell^-$
Compositeness		
	$\Lambda \gtrsim$ 25 TeV	Inclusive Single Jet Spectrum

STRATEGY of TRIGGER LEVELS

Level 1:

Identify Physics Objects

$e^{\pm}$, $\mu^{\pm}$, γ, jets, "υ"

and Combinations of Physics Objects

Level 2:

Refine Identification of Physics Objects

e.g.: Sharper p_t, E_t cuts

Reject conversions

Level 3:

Identify Signatures of Physics Processes

With full event data and capability of full analysis

CHARACTERISTICS of TRIGGER LEVELS

Level 1:

as fast as possible to minimize buffering
decision each 16 ns with < 4 µs latency
=> fully pipelined with much parallelism
rejection in range 10^3 - 10^4
subset of detector signals on separate data paths
hardware processor
fixed decision time

Level 2:

can be iterative or event parallel
prompt, but may use programmable processors
rejection in range 10 - 10^2
still a subset of data on separate data paths
decision time is variable, 10's of µs
event order is preserved

Level 3:

full event and full resolution is available
full power and flexibility of general-purpose CPU's
rejection in range 10 - 10^2

SDC TRIGGER LEVELS AND RATES

	Avg. Time between Decisions	Average Decision Time	Input Rate (Hz)	Expected Rejection	Output Rate (Hz)
Level 1	16 ns	3 µs	10^8	10^3-10^4	10^4-10^5
Level 2	10-100 µs	50 µs	10^4-10^5	10-10^2	~10^3
Level 3	1 ms	0.5 s	~10^3	10-10^2	10-10^2

ELECTRON TRIGGER

Level 1: Identify electromagnetic shower

Calorimeter trigger towers with E_{em}> Thresh
and E_{hac}/E_{em}< Cut

Reject PMT discharge

Shower max hit within calorimeter tower

Demand track associated with shower

Stiff outer tracker segments
pointing in ϕ to trigger tower and shower max hit

Option: Isolation (Surrounding trigger towers below threshold)

Level 2: Reject γ conversions

By demanding hits in inner silicon layers

Reject $\pi^+ - \pi^0$ overlaps

Spatial match of track with shower max in ϕ

Reject π^+ showers

Loose E/P cut

Option: Isolation (Surrounding trigger towers below threshold)

Level 3: Sharpen E_t measurements

Using full calorimeter segmentation and resolution

Advanced pattern recognition for electron id

With calorimeter and shower max profiles

Refine spatial match between tracks and showers

Using shower max profile and finer tracker resolution

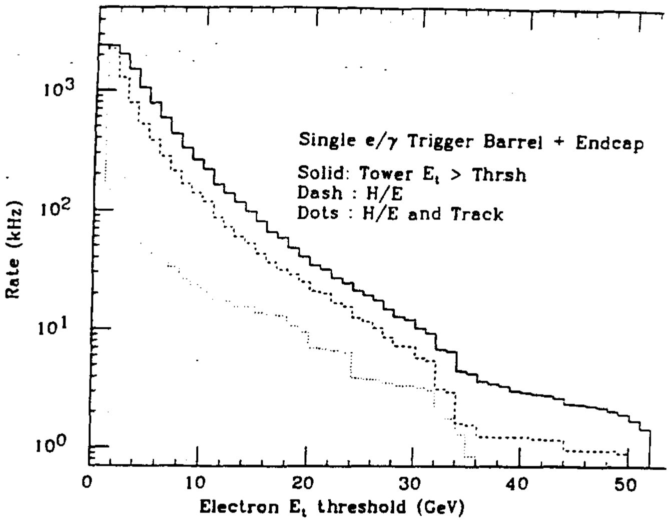
Perform calorimeter energy corrections

For cracks and inert material

Refined rejection of photon conversions

With additional track reconstruction

ELECTRON TRIGGER RATES



MUON TRIGGER

Level 1:

High p_t track segment in outer muon chambers

p_t determined by toroid and θ chambers

Crossing tagged by muon scintillators

Option: Associated stiff outer tracker segment

Option: Isolation (Calorimeter trigger towers below threshold)

Level 2:

Match muon segments to central tracker segments in ϕ and p_t

Improved p_t resolution using momentum in central tracker

Option: Reduce $\sigma(p_t)$ *due to beam spot* (using added θ layer)

Option: Isolation (Calorimeter trigger towers below threshold)

Level 3:

Perform complete 3-D tracking

PHOTON TRIGGER

Level 1:

Identify electromagnetic shower

Calorimeter trigger towers with E_{em}> Thr

and E_{had}/E_{em}< Cut

Reject PMT discharge

Shower max hit within calorimeter tower

Option: Isolation (Surrounding trigger towers below threshold)

Level 2:

Reject π^0 conversions

by examining shower max profile

Option: Isolation (Surrounding trigger towers below threshold)

Level 3:

Sharpen E_t measurements

Using full calorimeter segmentation and resolution

Perform calorimeter energy corrections

For cracks and inert material

Advanced pattern recognition for photon id

With calorimeter and shower max profiles

JET TRIGGER

Level 1:

Localized calorimeter energy above threshold

e.g.: 1.6 x 1.6 overlapping grids of trigger towers

Level 2:

Improved clustering or fixed-cone algorithms

Level 3:

Sharpen E_t measurements

Using full calorimeter segmentation and resolution

Refined jet clustering/cone algorithms

Using full calorimeter segmentation and resolution

Perform calorimeter energy corrections

For cracks and inert material

"NEUTRINO" TRIGGER

Level 1:

Missing E_t > Threshold

determined from calorimeter trigger towers above cut

Level 2:

Refined Missing E_t measurement

by correcting for muons

option: determined by summing over energy clusters

Option: Demand direction not aligned with dead region.

Level 3:

Sharpen Missing E_t measurement

Using full calorimeter segmentation and resolution

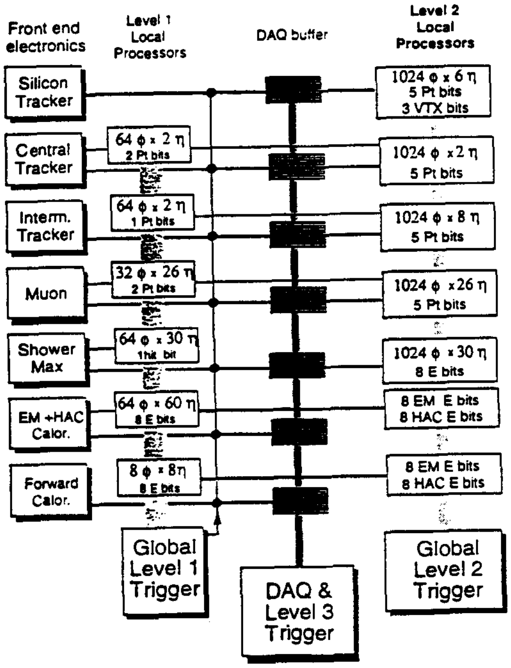
Perform calorimeter energy corrections

For cracks and inert material

Examples of LEVEL 1 TRIGGER RATES

Trigger	Threshold
Electron	20 GeV
Photon	30 GeV
Muon	20 GeV
Jet (1.6 x 1.6 sum)	140 GeV
Missing E_t	80 GeV
2 electrons	10 GeV
2 photons	20 GeV

DATA PATHS to TRIGGER PROCESSORS



STATUS of TRIGGER

Status:

Model 3-level architecture exists.
Model algorithms to trigger on principal physics exist.
Triger data paths have been identified.
Prototypes of many trigger "primitive" IC's exist.

We believe that we know how to select the most interesting physics events. Now we must thoroughly study the effectiveness of our strategy and optimize its implementation. Then we can move on to detailed design and implementation.

What's Next?:

Optimize algorithms and architecture.
Thoroughly evaluate effectiveness of system.
Implement algorithms as trigger logic and processors.

Timescale:

1993	Complete conceptual design
1994-5	Perform detailed design

DESIGN CHALLENGES for SDC FRONT-END ELECTRONICS

Technical Challenge:

Fast, low-power, often *rad-hard, reliable* readout systems with Level 1 and Level 2 *buffering* and with *simultaneous signal processing and data readout,*

Architectural Approach:

Readout based upon high-performance custom integrated circuits for analog signal processing and data storage. High degree of architectural uniformity for all detector systems.

e.g.: 8-chan fast, low-noise, rad-hard bipolar preamp/shaper/discriminator chip for wire chamber readout,
16-chan 63-MHz CMOS transient recorder chip with 4 μsec deep memory for calorimeter readout
128-chan rad-hard CMOS data-driven hit buffer for silicon strip readout

Design Approach:

- Develop critical IC technology and designs.
- Develop conceptual designs of complete systems, including trigger outputs, daq interface, calibration, etc.
- Prototype large systems with full functionality, including operation of analog signal processing in close proximity to simultaneous digital control and readout.
- Complete designs.

DETECTOR-MOUNTED, INTEGRATED FRONT-END SYSTEMS

Why are we developing custom integrated circuits?

Past and Present Motivations:

- improved analog performance
- increased immunity to RF pickup

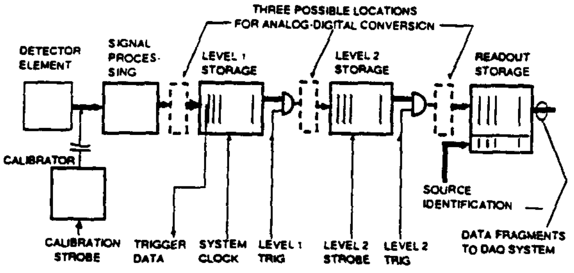
- connection density
- limited cable space

- cost effectiveness
- space efficiency
- reliability

Additional Motivations at SSC:

- reduced power dissipation
- increased functionality
  (*e.g.*: multiple event buffering, trigger solutions)

A "GENERIC" FRONT-END SYSTEM



Functions:

- perform signal processing of detector signals
- correlate detector signals with particular beam crossings
- buffer data during trigger decisions
- filter data according to Level 1 & Level 2 triggers
- digitize event data
- output event fragments to the Data Acquisition System
- develop primitive information for the Trigger System

Implementation is generally a pair of multichannel custom IC's

- Bipolar signal processing IC
- CMOS data storage IC

OVERVIEW of SDC FRONT-END SYSTEMS

Subsystem	Channel Count	Signal Processing		Data Storage		Trigger Data to ...	Comments
Silicon Tracker	6×10^6	Bipolar	ASD	CMOS	Digital Hits	L2	Rad hard Very low power
Straw Tracker	140,000	Bipolar	ASD	CMOS	Digital Time	L1 & L2	Rad hard Low power
Gas Microstrip Tracker	10^6	Bipolar	ASD	CMOS	Digital Hits	L1 & L2	Similar to silicon tracker
Fiber Tracker	473,000	Bipolar	ASD	CMOS	Digital Hits	L1 & L2	
Calorimeter (Option 1) (Option 2)	20,000 20,000	Bipolar Bipolar	Amp/Shape Gated Integ.	CMOS CMOS	Analog Charge Digital Charge	L1 (L2) L1 (L2)	Very large dynamic range
Shower Max	57,000	Bipolar	Amp/Shape	CMOS	as in calorimeter	L1 & L2	Similar to calorimeter
Muon Wires	90,000	Bipolar	ASD	CMOS	Digital Time	L1 & L2	Similar to straw tracker
Muon Counters	7,000	Bipolar	Discrim	CMOS	Digital Time	L1 & L2	Similar to muon wires

ASD = Amplifier/Shaper/Discriminator
Amp/Shape = Amplifier/Shaper
Gated Integ. = Current splitter/Gated integrator/FADC
Discrim = Discriminator

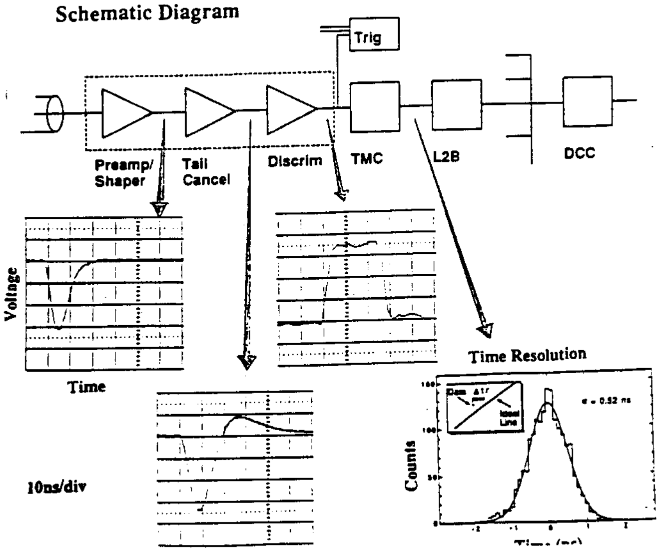
Digital Hits = 1 bit/hit
Digital Time = TMC (Time Memory Cell)
Analog Charge = SCA (Switched Capacitor Array)
Digital Charge = 12 bits/channel

Wire Chamber Readout

Specifications

* **Minimum Detectable Charge**	**≈ 1 fC**
* **Time Resolution**	**< 0.75 ns**
* **Peaking Time**	**5-7 ns**
* **Double Pulse Resolution**	**20 - 30 ns**
* **Power Dissipation**	**< 20 - 25 mW**

Schematic Diagram



STATUS of FRONT-END ELECTRONICS

Status:

Prototypes of nearly all custom IC's exist.
Conceptual designs of all readout systems exist.

The front-end IC's and systems are our long lead-time items. Equipped with prototype IC's and system concepts, we must now demonstrate that our systems will operate with full performance and full functionality and must complete detailed system designs.

What's Next?:

Complete the evaluation of custom IC's
Optimize, design, prototype, and evaluate systems.
Build large test systems for electronics evaluation and for detector prototypes.
Assemble and implement systems.

Timescale:

Major systems in test beams in 1993.
Complete systems as early as 1996 for some subdetectors.

DESIGN CHALLENGES for SDC DATA ACQUISITION

Technical Challenge:

Transport up to *10 GBytes/sec* from F.E.'s to Level 3.
Provide processing power for *Level 3* trigger.
Control data flow in F.E., thru Level 3, to storage.
Monitor operation and performance of detector.
Acheive a *manageable, cost-effective* solution.

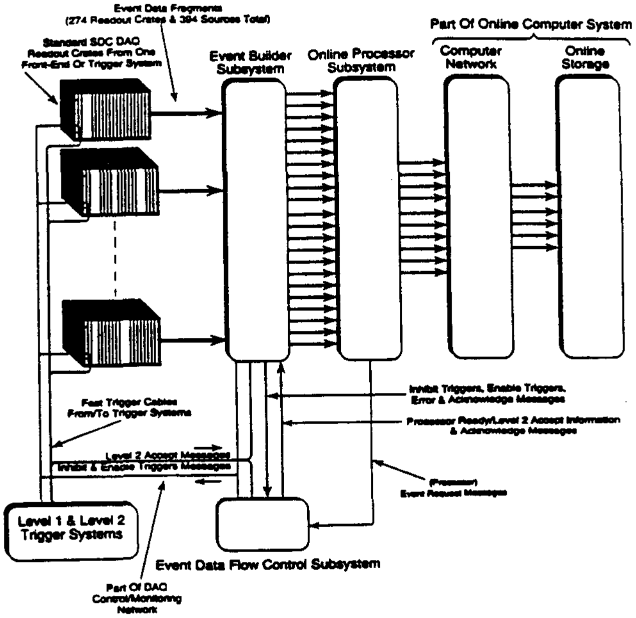
Architectural Approach:

- Extensive use of parallelism.
- Highly buffered data collection from f.e. chips.
- Extensive use of commercial hardware and software from rapidly evolving computer and communications industries.
- Modular, scalable hardware/software architecture.

Design Approach:

- Definition of requirements: functional & performance.
- Conceptual design of scalable architecture.
- Extensive behavioral simulation of architecture.
- Detailed design of system and components.

DATA ACQUISITION BLOCK DIAGRAM



DATA SOURCES to DATA ACQUISITION

System	# Crates & DAQ CPUs	# Data Links
Silicon Tracker	10	10
Gas Microstrip Tracker	10	10
Straw Tracker	8	32
Central Calorimeter including Shower Max	96	192
Forward Calorimeter	2	2
Muon System	64	64
Level 1 Trigger	59	59
Level 2 Trigger	25	25
Total:	**274**	**394**

SDC DATA ACQUISITION REQUIREMENTS

- Performance Requirements
- Partitioning and Stand-alone Operation Requirements
- Control and Monitoring Requirements
- Scalability, Reliability, Maintainability

SDC DAQ Requirements

- **Performance requirements**

- Maximum Level 2 Trigger System input rate:	**100,000 Hz**
- Maximum Level 3 (Online Processer) Subsystem input rate:	**10,000 Hz**
- Number of independent data sources	**420**
- Maximum bandwidth through Event Builder Subsystem (based on 10kHz @ 1 Megabytes per event)	**10 GigaBytes/sec**
- Minimum processing power in online farm	**10**5 MIPS**
- Maximum event size (for a calibration event)	**20 MByte**
- Expected event size (data events); this number needs study	**1 MByte**
- Maximum readout deadtime	**10%**
- Maximum deadtime due to DAQ errors/downtime	**5%**

- **Partitioning and stand-alone operation requirements**

Must be able to operate separate non-interfering DAQ systems for each subsystem during commissioning
Preserve this functionality after detector turn on for debugging and calibration of individual subsystems

- **Other Requirements**

Scalability
Reliability
Maintainability

- **DAQ Control/Monitoring requirements**

Setup (download) entire detector into known condition
Track operation of both DAQ system and detector subsystems
Record conditiions under which data are taken
Allow for calibration data acquisition
Allow for non-event data acquisition
Detect and record error condition
Prioritized alarm system

STATUS of DATA ACQUISITION

Status:
Architectural modelling of components and system.
Definition of requirements and functionality of system and interfaces.
Conceptual design of architecture.

We know what we need to accomplish, we can present a case that the tools exist, and we have a conceptual design of the architecture. Now we must commence designing and implementing the system.

What's Next?:
Architectural model of the complete readout system *(in lieu of a large prototype).*
Crisp definition of the modular pieces of the system.
Design and implementation of full system with all features.

Timescale:
Test beam systems in beams in 1993.
Complete systems as early as 1996 for some subdetectors.

SUMMARY

We have developed a conceptual design of electronics systems which address the challenges of event selection and readout of the SDC Experiment at the SSC.

Its chief features are:

- Three-level architecture
- Extensive use of custom IC's for
    - signal processing
    - data storage

  on the detector.
- Event selection based on:
    - local signatures of physics quanta at early levels,
    - complete physics signatures at final level.
- Data acquisition with
    - common front-end protocols
    - extensive use of:
        - parallelism
        - commercial products.

PLENARY SESSION

PHYSICS PERFORMANCE OF THE SDC DETECTOR

K. EINSWEILER

Physics Performance of the SDC Detector

K. Einsweiler
Lawrence Berkeley Laboratory
Solenoidal Detector Collaboration

1. Introduction
2. Overview of Detector Models
3. Electroweak Symmetry Breaking
   a) Light: $80 < M < 130$ GeV
   b) Intermediate: $130 < M < 180$ GeV
   c) Heavy: $180 < M < 800$ GeV
   d) SUSY Extensions
   e) Strong Symmetry Breaking
4. Heavy Gauge Boson Searches
5. Compositeness Searches

Introduction

- Survey physics relevant to SDC dectector.
- Attempt to isolate most demanding aspects and derive corresponding detector requirements.
- Maintain scepticism about model details—physics understanding may evolve and change.
- Use certain physics processes as archetypes to study general capabilities required of an SSC detector.
- Use simple detector models to capture essentials.
- Start from baseline detector concept and vary parameters to understand impact on physics performance.

Unless otherwise stated, plots are for 1 SSC year of integrated luminosity (10 fb^{-1}).

Physics Topics:

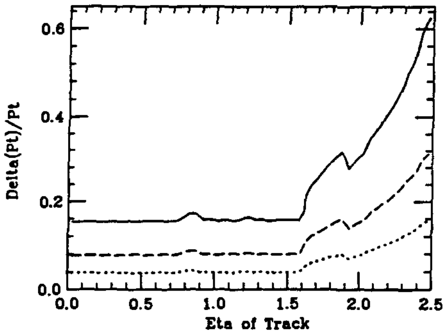
1. Electroweak Symmetry Breaking Studies
2. Top Physics
3. Supersymmetry Searches
4. Heavy Gauge Bosons
5. Compositeness Searches
6. QCD Tests

Overview of Detector

Tracking Models:

- Use parametrized tracking resolution for baseline detector including multiple scattering, detector resolution, and alignment effects.
- When necessary, use results of detailed GEANT simulations including generation of all secondaries in tracking volume. Detector response models generate hits. Actual pattern recognition, reconstruction, and fitting algorithms are used.

Parametrized resolution versus η :



Curves are for constant p_t of 100, 250, 1000 GeV.

Calorimeter Models:

- Use shower parametrizations for EM and HAD shower shapes derived from EGS (EM) and ZEUS data (HAD).
- Use resolution parametrizations for single particles from EGS (EM) and CALOR89 (HAD):

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E_t}} \oplus b \text{ (Barrel) or } \frac{a}{\sqrt{E_l}} \oplus b \text{ (Endcap)}$$

- Use CALOR89 parametrization for π/e response (assuming calibration forces $\pi/e = 1$ at 300 GeV):

$$\pi/e = \alpha - \frac{\beta}{E^{0.15}}$$

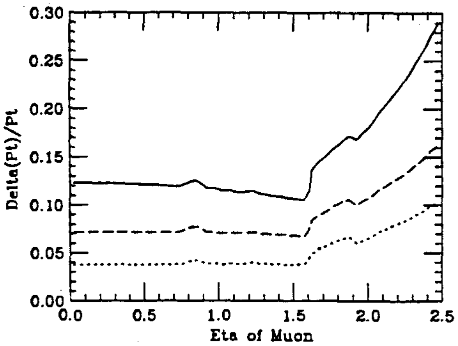
Calorimeter parameters used:

Parameter	Barrel	Endcap	Forward
Coverage	$\lvert\eta\rvert < 1.4$	$1.4 < \lvert\eta\rvert < 3.0$	$3.0 < \lvert\eta\rvert < 6.0$
Radius of front face (m)	2.10		
z position of front face (m)		4.47	12.00
Compartment depth			
EM (+ Coil)	1.1	0.9	
HAD1	4.1	5.1	13.0
HAD2	4.9	6.0	
EM resolution			
a	0.14	0.17	0.50
b	0.01	0.01	0.05
HAD resolution			
a	0.67	0.73	1.00
b	0.06	0.08	0.10
HAD nonlinearity			
α	1.13	1.16	1.16
β	0.31	0.38	0.38

Muon Models:

- Use parametrized tracking resolution for baseline detector including multiple scattering, detector resolution, and alignment effects for combined inner tracking and muon systems.

Parametrized resolution versus η :



Curves are for constant p_t of 100, 250, 1000 GeV.

Lepton and Photon ID:

- Assume global efficiency of 85% for analyses requiring isolated leptons or photons (includes trigger efficiency and all selection criteria).
- Use results from current experiments (CDF) to estimate expected rejections against dominant backgrounds (for $p_t \gtrsim 20$ GeV):
  - * Photon identification: major source of background is a jet fragmenting into a leading neutral meson (π^0, η, K_L^0). CDF rejection (ratio of background in inclusive photon sample to two jet cross section) is $\sim 5 \times 10^{-4}$ with a strict isolation requirement.
  - * Electron identification: major background sources are overlaps of charged track and neutral meson, early showering hadrons, and conversion electrons from photons in jets. CDF rejection (ratio of background in inclusive electron spectrum to two jet cross section) is $\sim 1 \times 10^{-5}$ with a minimal isolation requirement.
  - * Muon identification: major background sources are decay-in-flight (non-prompt muons) and hadronic punch-through. CDF muon system not representative, take UA1 results. Rejection (ratio of background in inclusive muons to two jet cross section) is $\sim 5 \times 10^{-5}$ with no isolation requirement.

Jet Reconstruction:

- Use transverse energy deposition in calorimeter cells.
- Use Seed towers with $E_t > 5$ GeV to define initial jet axis.
- Collect all cells above a threshold of $E_T > 100$ MeV inside a cone of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Iterate the cone axis.
- The vector sum of energy vectors pointing to cells defines the jet momentum; the scalar sum of cell energies defines the jet energy. The resulting jets acquire a mass.
- Studies with ISAJET, using the calorimeter parameters defined previously, lead to a jet energy resolution of:

  $$\frac{\sigma(E)}{E} = \frac{0.61}{\sqrt{E}} \oplus 0.016$$

  The constant term has been reduced by averaging many single particle measurements.

Electroweak Symmetry Breaking

In the Minimal Standard Model, bosons and charged fermions get their masses from interactions with a fundamental scalar field whose vacuum expectation is not zero. One component of this field manifests itself as the Higgs boson.

A general purpose SSC detector must be capable of observing the Standard Model Higgs boson at any allowable mass, either verifying its existence or forcing consideration of alternative scenarios.

Present discussion will cover:

- Standard Model Higgs searches
- Minimal SUSY Higgs searches
- Strongly-coupled Higgs scenarios

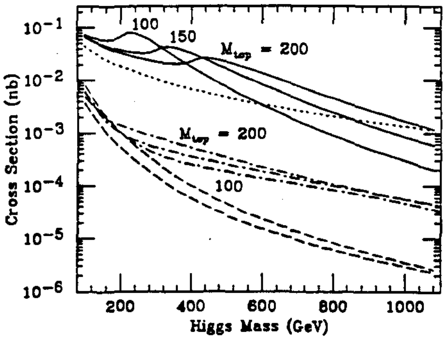
Production of Standard Model Higgs:

The dominant production mechanisms for Standard Model Higgs bosons at the SSC are :

1. Gluon-gluon fusion via heavy quark loop (solid)
2. WW or ZZ boson fusion (dots)
3. Associated production with a $t\bar{t}$ pair (dot-dash)
4. Associated production with a W or Z boson (dash)

Note: Assume a standard value of $M_{\text{top}} = 150$ GeV in all subsequent discussions.

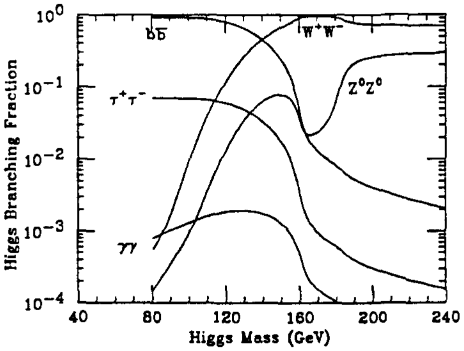
Production cross sections for the Standard Model Higgs at the SSC:



Decays of Standard Model Higgs:

Higgs Mass (GeV)	Higgs Width (GeV)
140	0.01
160	0.1
200	1.4
400	30
800	270

In Low and Intermediate mass region, the Higgs boson is very narrow—mass resolution is critical.



In Heavy region, WW and ZZ decays dominate. $BR(H \to t\bar{t})$ is always less than $\sim 20\%$.

- $H \to \gamma\gamma$ small but significant below 160 GeV.
- $H \to ZZ^*$ or ZZ significant above 140 GeV.
- $H \to WW$ and $H \to \tau\tau$ both interesting but difficult.

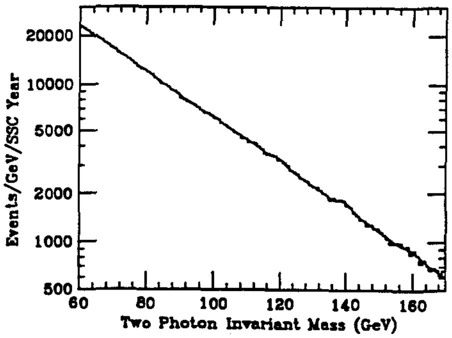
Low Mass Higgs ($80 < M < 130$ GeV)

LEP-II searches are unlikely to extend much beyond 80 GeV, due to statistics and backgrounds from ZZ pair production.

Direct production with $H \to \gamma\gamma$:

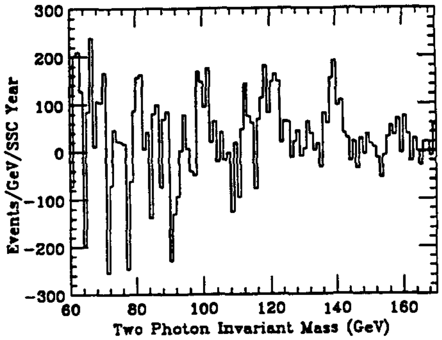
- Large continuum background from QCD production of photon pairs.
- Large background from QCD two jet production.
- Mass resolution requires accurate knowledge of photon directions.

Signals for $M_{\text{Higgs}} = 80$, 100, 120, 140, and 160 GeV:



Only backgrounds from photon pair production are included. The photon direction resolution is assumed to be 1 mrad.

Subtract expected two photon background to study significance of residual signal:



Signal for $M = 140$ GeV has significance of 5σ, ignoring systematic errors arising from background subtraction. There are several hundred events in the peak.

Marginal signal suggests looking for other processes with less background.

Associated production of Higgs with W or t quark gives an additional lepton tag which significantly reduces background.

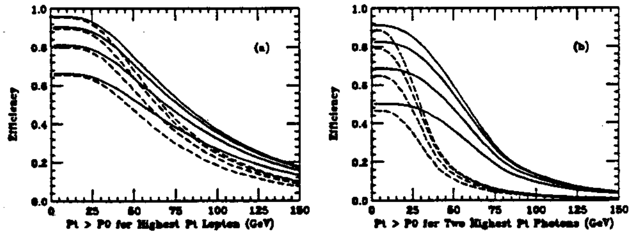
Associated production with $H \rightarrow \gamma\gamma$:

The processes $W+H$, $Z+H$, and $t\bar{t}+H$ all contribute to the $\ell+\gamma\gamma+X$ final state. The dominant source is $t\bar{t}+H$.

Several issues must be addressed, including the effects of the complexity of the final state (especially $t\bar{t}+H$):

- Efficiency for signal events
- Identification of photons and leptons
- Expected mass resolution, including pileup effects
- Expected backgrounds and signal significance

Efficiency for $t\bar{t}+H$ detection versus p_t and η.



Dotted (solid) curves are for $M = 80$ (160) GeV. The four curves are for η coverages of 1.5, 2.0, 2.5, and 3.0.

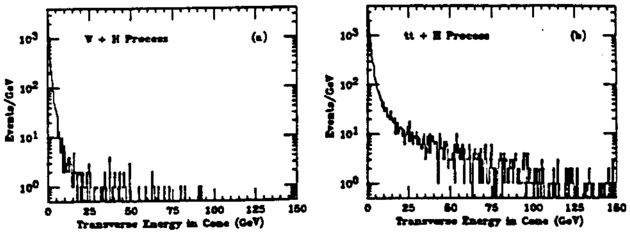
This analysis requires $p_t > 20$ GeV and $|\eta| < 2.5$ for the lepton and both photons.

Two regions are relevant for lepton/photon identification.

- The "identification" region immediately surrounding the lepton is the minimum area required to identify and reconstruct the lepton/photon.
- The "isolation" region is a larger area (typically a radius of $R = 0.3$) used to select events with the correct topology, thereby further reducing backgrounds.

Focus particularly on problems of identifying and measuring electrons and photons in calorimeter (muons are simpler due to lack of confusion outside of the calorimeter).

Distribution of excess E_t in a cone of $R = 0.3$ around photons in associated Higgs production:

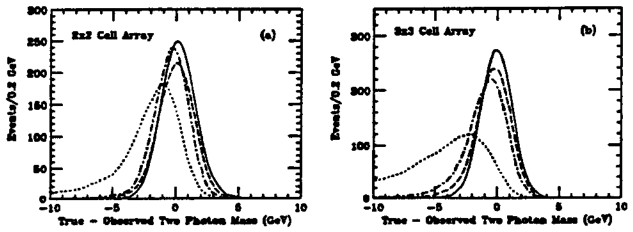


Efficiency for excess $E_t < 10$ GeV requirement on lepton and photons is 93% (73%) for $W+H$ ($t\bar{t}+H$) events.

Effect of pileup on identification and reconstruction:

The energy measurement appears more sensitive than the identification procedure, so study mass resolution in $t\bar{t}+H$ events.

Use 2×2 and 3×3 cell arrays for energy reconstruction (EM and HAD1 segments used to include EM shower leakage).



Different transverse segmentations have been explored, including isolation cuts.

The solid curve is 0.05 EM and HAD segmentation at design luminosity. The 0.05 EM and 0.2 HAD (dashed), and 0.1 (0.2) EM and HAD dot-dashed (dotted) curves are at five times design luminosity.

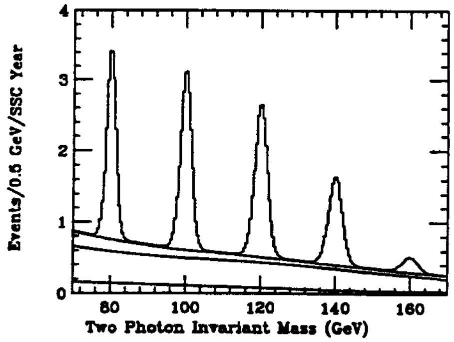
- Mass resolution is a strong function of EM segmentation, and values larger than 0.1 are not acceptable.
- Mass resolution is a weak function of HAD segmentation.

Consider several classes of backgrounds:

- Two photon backgrounds ($W+\gamma\gamma$, $b\bar{b}+\gamma\gamma$, $t\bar{t}+\gamma\gamma$).
- Backgrounds with one real photon and one misidentified jet ($t\bar{t}+\gamma$).
- Backgrounds where both photons arise from misidentified jets.

In the latter two cases, the major source of jets in the events is from the decay of the $t\bar{t}$ system, and hence higher-order QCD corrections are not essential.

Assuming jet rejection of 5×10^{-4}, the only significant sources of background involve two real photons.



Background curves are (in ascending order) $b\bar{b}\gamma\gamma$, $t\bar{t}\gamma\gamma$, and $W\gamma\gamma$. The $t\bar{t}\gamma\gamma$ background increases by a factor 3 if $M_{\text{top}} = 100$ GeV instead of 150 GeV.

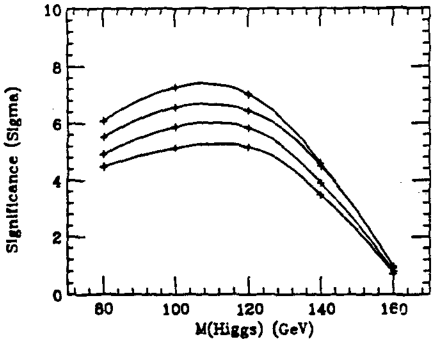
Expected signal typically 15–20 events (including isolation cuts and all efficiencies):

$M_{\rm Higgs}$	$W+H$ events Produced	$W+H$ events Detected	$t\bar{t}+H$ events Produced	$t\bar{t}+H$ events Detected
80	25.0	4.0	49.6	12.2
100	22.0	4.2	48.9	13.7
120	18.4	3.7	45.5	13.7
140	10.2	2.2	28.0	8.8
160	1.6	0.4	5.0	1.6

Signal significance versus calorimeter performance:

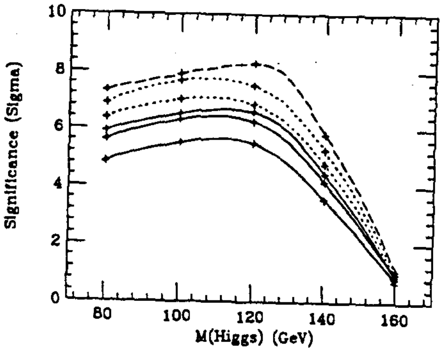
Define the significance $d = \text{Signal}/\sqrt{\text{Background}}$.

The significance d decreases like $\sqrt{\text{Resolution}}$ for fixed integrated luminosity (a factor 2 in resolution is worth a factor 2 in running time).



The curves are for a constant term of 1% and stochastic terms of 7.5%, 10%, 15%, and 20%.

Define a high performance option with stochastic terms of 0.09 and 0.14 in Barrel and Endcap respectively (Baseline has 0.14 and 0.17 stochastic terms in Barrel and Endcap).



The solid curves are the baseline calorimeter with 0.5%, 1%, and 2% constant terms. The dotted curves are a high performance option with constant terms of 0.5% and 1%. The dashed curve is a $0.10/\sqrt{E}$ calorimeter with no constant term.

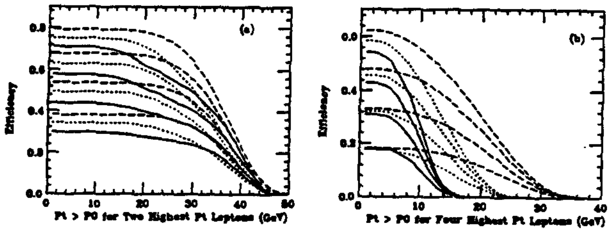
Intermediate Mass Higgs ($130 < M < 180$ GeV)

In this region, the decay $H \rightarrow ZZ^* \rightarrow 4\ell$ provides a distinctive signature.

Several issues must be addressed:

- Efficiency for signal events
- Identification of leptons
- Expected mass resolution, including bremsstrahlung effects
- Expected backgrounds and signal significance

Efficiency for $H \rightarrow ZZ^*$ detection versus p_t and η:

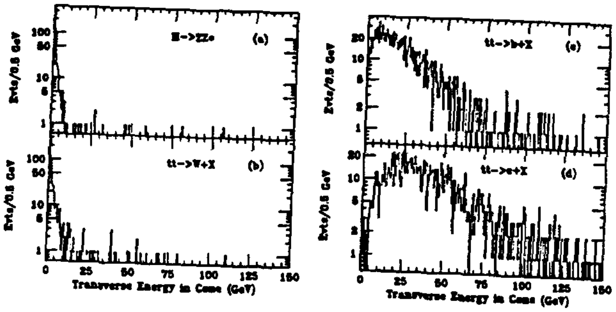


Curves are for $M = 120$ GeV (solid), 140 GeV (dotted), and 160 GeV (dashed). The four curves are for η coverages of 1.5, 2.0, 2.5, and 3.0.

This analysis requires $p_t > 20$ GeV for two leptons and $p_t > 10$ GeV and $|\eta| < 2.5$ for all four leptons.

The decays of $t\bar{t}$ pairs are a major source of multi-lepton backgrounds. Topological isolation requirements are very effective in reducing such backgrounds.

Distribution of excess E_t in a cone of $R = 0.3$ around the leptons for the $H \rightarrow ZZ^*$ signal and the $t\bar{t}$ background.



Leptons from b and lighter quark decays can be strongly suppressed, while retaining high signal efficiency, by requiring that the excess $E_t < 5$ GeV.

This requirement is 94% efficient for signal leptons. For leptons from $t\bar{t}$ events, where the lepton comes from b quark decay, find:

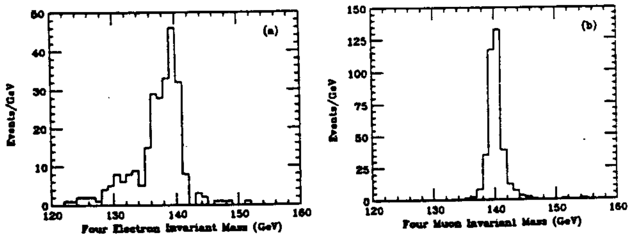
- For $10 < p_t^\ell < 20$ GeV, an efficiency of 0.11
- For $20 < p_t^\ell < 30$ GeV, an efficiency of 0.05
- For $30 < p_t^\ell < 50$ GeV, an efficiency of 0.01

For the low p_t leptons that characterize the $H \rightarrow ZZ^*$ process, the tracking system provides better resolution than the calorimeter (assume $M = 140$ GeV):

- Parametrized resolution for the 4μ final state is 0.8 GeV.
- Calorimetric mass resolution for the $4e$ final state is 1.9 GeV.

The relatively large amount of material present in the tracking volume degrades the tracking resolution for electrons due to bremsstrahlung effects.

Results of a full GEANT simulation of the tracking system resolution for $H \rightarrow ZZ^*$ with $M = 140$ GeV:



For this analysis, we use the calorimeter to reconstruct electrons.

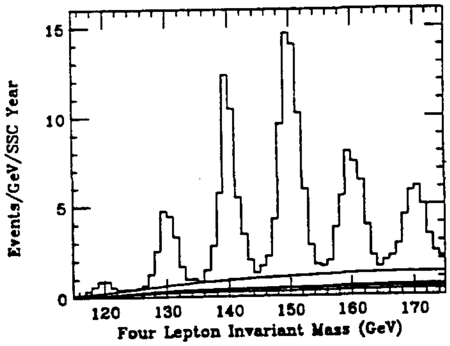
More sophisticated momentum fitting algorithms could reduce the sensitivity to bremsstrahlung.

Several classes of backgrounds have been considered:

- Continuum ZZ production from $q\bar{q}$ and gg initial states. The latter has been approximated by scaling the former by 1.65.
- Production of $Z + b\bar{b}$ and $Z + t\bar{t}$, with the heavy quark pair providing two additional leptons.
- Production of $t\bar{t}$ with subsequent decay into four leptons.

The latter two sources are significantly reduced by the lepton isolation requirement.

Signal for $M_{\text{Higgs}} = 130, 140, 150, 160,$ and 170 GeV.



The curves are for the backgrounds listed above (from lowest to highest).

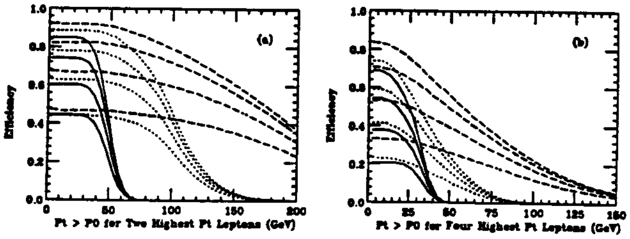
Heavy Higgs (180 < M < 800 GeV)

Consider several possible decay modes:

- Clean but statistically limited modes.
  - * $H \rightarrow ZZ \rightarrow 4\ell$
  - * $H \rightarrow ZZ \rightarrow 2\ell\nu\bar{\nu}$
- Larger branching ratios, accompanied by much larger backgrounds. These modes are discussed to illustrate general capabilities of jet spectroscopy and forward jet tagging.
  - * $H \rightarrow ZZ \rightarrow 2\ell + 2jets$
  - * $H \rightarrow WW \rightarrow \ell\nu + 2jets$

$H \rightarrow ZZ \rightarrow 4\ell$:

Efficiencies for $H \rightarrow ZZ$ detection versus p_t and η:

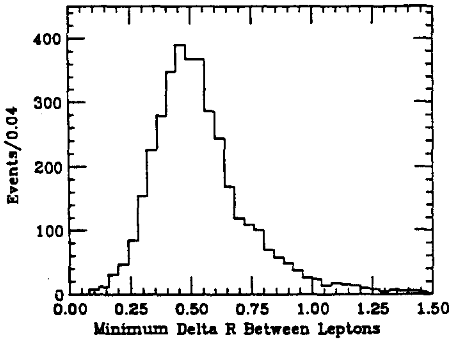


This analysis requires $p_t > 20$ GeV for two leptons and $p_t > 10$ GeV and $|\eta| < 2.5$ for all four leptons.

Background sources are the same as those discussed for the ZZ^* mode, but the second Z mass constraint eliminates all but the ZZ continuum background.

Highly boosted Z's produced in heavy Higgs decay produce leptons which frequently lie close together. This has implications for the EM calorimeter segmentation.

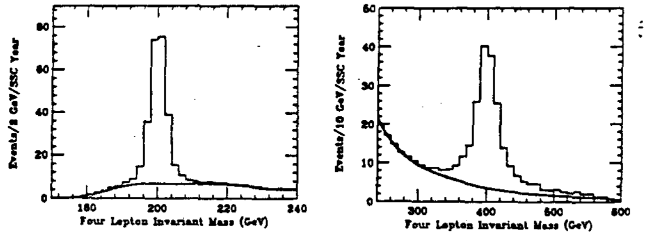
The distance in (η, ϕ) space between pairs of leptons for an 800 GeV Higgs decay:



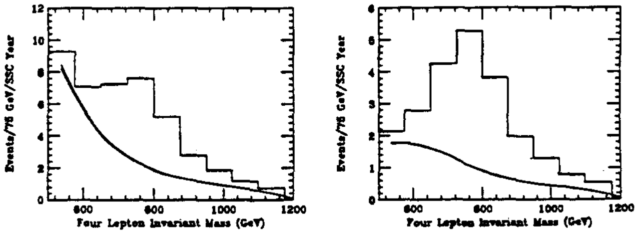
High efficiency for $\Delta R > 0.3$ is required, suggesting that EM calorimeter cells of size 0.1 are not acceptable.

(Two electrons will hit adjacent 2×2 cell arrays.)

Expected signals for $M_{\text{Higgs}} = 200, 400$ GeV:



Expected signals for $M_{\text{Higgs}} = 800$ GeV:



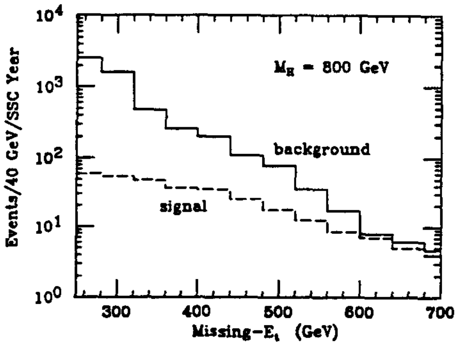
A $p_t(Z) > 200$ GeV requirement reduces the background with little loss of signal. Expect about 14 signal above 6 background in one SSC year.

$\underline{H \rightarrow ZZ \rightarrow 2\ell\nu\bar{\nu}}$:

Branching ratio is factor six larger than 4ℓ decay mode, but two neutrino decay mode more sensitive to background.

The major additional source of background is $Z + jets$, where one of the jets is mis-measured or lost, thereby simulating the presence of neutrinos.

Expected signal from 800 GeV Higgs if calorimeter coverage stops at $\eta = 3$:

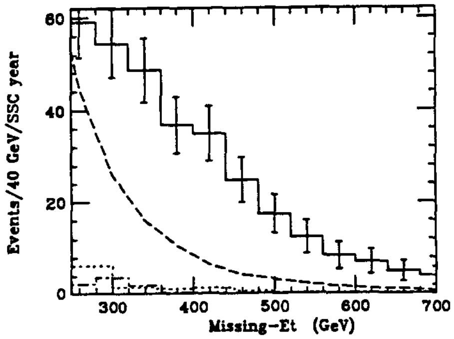


The $Z + jets$ background overwhelms the signal for this η coverage. Studies indicate that a coverage to $\eta = 5$ is appropriate for Higgs searches.

Other sources of background include:

- Continuum production of ZZ pairs.
- Production of $Z + b\bar{b}$ or $Z + t\bar{t}$.

The signal and backgrounds for an 800 GeV Higgs:



The dashed line is the continuum background, the dot-dashed line is $Z + jets$, and the dotted line is $t\bar{t}$. The η coverage for jet detection was taken to be 5.0.

This signal, in combination with that from the 4ℓ final state, would provide strong evidence for an 800 GeV Higgs after one SSC year.

$H \to WW \to \ell\nu + 2jets$:

- Branching ratio roughly 150 times that of 4ℓ decay mode.
- Additional large backgrounds from $W + jets$ and $t\bar{t}$.

Concentrate on two capabilities relevant for high mass symmetry breaking studies :

- $W/Z \to 2\text{-}jet$ reconstruction.
- Reconstruction of forward jets from the WW/ZZ fusion process.

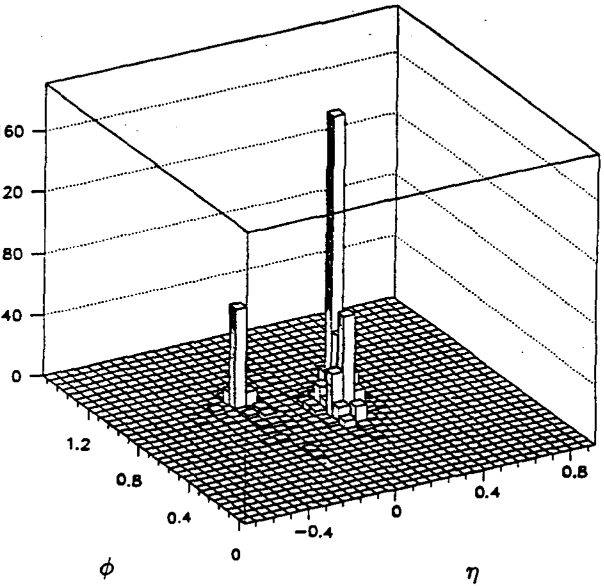
$W/Z \to 2\text{-}jet$ Reconstruction:

Use example of high p_t W/Z produced in decay of 1 TeV Higgs:

The W/Z has $p_t > 250$ GeV, and decays with a mean opening angle of about $\Delta R = 0.5$. The highly boosted jets produced in the decay are much narrower than ordinary jets.

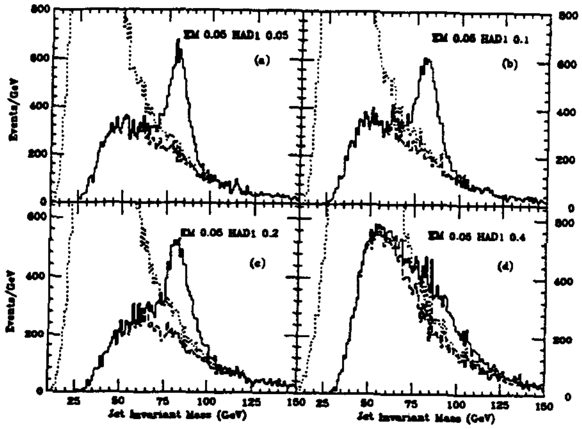
The two decay jets are typically contained in a single jet definition cone of $R = 0.6$. Use small cones of $R = 0.15$ to reconstruct these jets.

A typical event, with $P_t(W) = 713$ GeV, is shown:



Lego plot of E_t in calorimeter.

Study mass resolution as a function of calorimeter segmentation for high p_t W decays:



Dotted curve is $W + jets$ background before cuts (actual background is 30 times larger), dashed is after requiring two narrow jets inside the initial jet cone.

Conclusions:

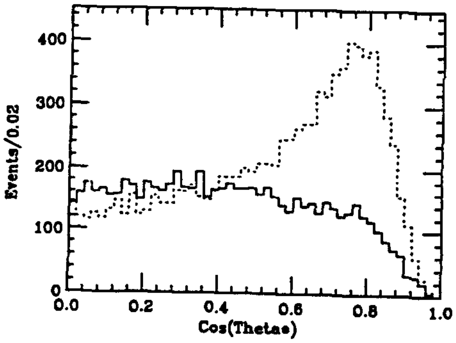
- Little dependence on calorimeter energy resolution.
- Degradation starts for HAD1 segmentation of 0.2.
- Reconstructing two narrow jets inside a standard jet cone is a powerful signature of high p_t W decay.

The energies of the two narrow jets provide a measure of the decay angle:

$$\cos\theta^* \sim \frac{E_1 - E_2}{E_1 + E_2}$$

which is sensitive to the W/Z polarization.

Behavior of $\cos\theta^*$ distribution for signal and background:



- Higgs produces polarized W bosons which decay with $\sin^2\theta^*$ distribution.
- $W + jets$ background produces forward/backward peaked distribution due to soft spectrum of second "jet".

Gives additional handle on signal/background separation.

Forward jet tagging:

The WW/ZZ fusion process for Higgs production becomes dominant at high Higgs masses, and provides a unique kinematic signature that could be used to distinguish it from backgrounds.

Could also allow separation of gg fusion and WW/ZZ fusion mechanisms, thereby measuring the couplings of the Higgs to t quarks and W/Z bosons.

Kinematic signature is a large E jet.

- Single Tag: 1 jet with $p_t > 50$ GeV, $E > 3$ TeV.
- Double Tag: 2 jets with $p_t > 50$ GeV, $E > 1.5$ TeV.

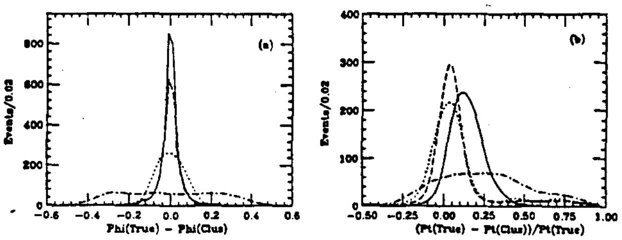
Signal efficiencies:

	Fiducial region	Parton $p_t > 50$ GeV	Jet $p_t > 50$ GeV
Single tag	$2.5 < \lvert\eta\rvert < 6$	0.32	–
	$2.5 < \lvert\eta\rvert < 5$	0.26	0.23
	$2.5 < \lvert\eta\rvert < 4$	0.076	0.068
Double tag	$2.5 < \lvert\eta\rvert < 6$	0.090	–
	$2.5 < \lvert\eta\rvert < 5$	0.072	0.052
	$2.5 < \lvert\eta\rvert < 4$	0.015	0.012

Fiducial coverage out to $\eta = 5$ is required for reasonable acceptance.

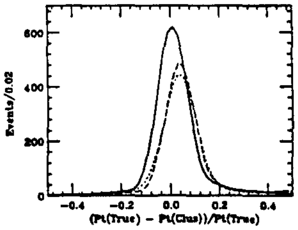
Segmentation and Energy Resolution requirements:

Angular and p_t resolution for jets versus Segmentation:



Solid curve is 0.05, dashed (dotted) is 0.2 (0.4). Dot-dashed is extreme of 0.8. Segmentation in range 0.2–0.4 is acceptable.

p_t resolution for jets versus Energy Resolution:



Solid curve is perfect detector. Dotted (dashed) curves are for $100\%/\sqrt{E} \ominus 10\%$ ($80\%/\sqrt{E} \oplus 5\%$) calorimeter resolution. Energy resolution is not critical.

Summary:

Use a combination of cuts to isolate $H \to WW$:

- $W/Z \to$ 2-*jets* reconstruction
- Veto events with second central jet (defined using $R = 0.6$)
- Require single forward tag jet

These cuts result in the following:

- A signal efficiency of $\sim 10\%$.
- A $W + jets$ rejection of ~ 500.
- A $t\bar{t}$ rejection of $\sim 10^4$.
- Remaining signal to noise ratio of roughly 1:5.

Results are promising and indicate importance of reconstructing $W/Z \to$ 2-*jets* and tagging forward jets in the SDC detector.

Supersymmetric Extensions to the Higgs Sector:

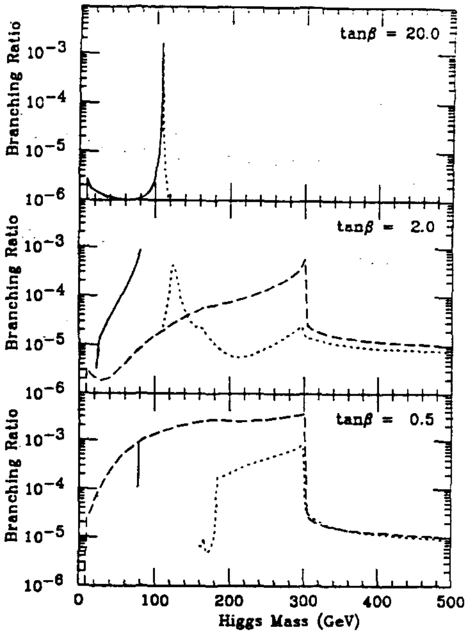
Consider more complex Higgs sector containing two doublets, resulting in five physics Higgs bosons (h^0, H^0, A^0, and $H^{\pm}$).

The minimal supersymmetric extension of the Standard Model is a simple, elegant example of such a model.

- Two free parameters, taken to be M_A and $\tan\beta$ (the ratio of the vacuum expectation values for the two Higgs doublets).
- Large radiative corrections recently calculated, giving the bound $M_{h^0} \lesssim 110$ (140) GeV for $M_{\text{top}} = 150$ (200) GeV. This implies that h^0 may be inaccessible to LEP-II.
- Production cross sections and branching ratios are all modified.

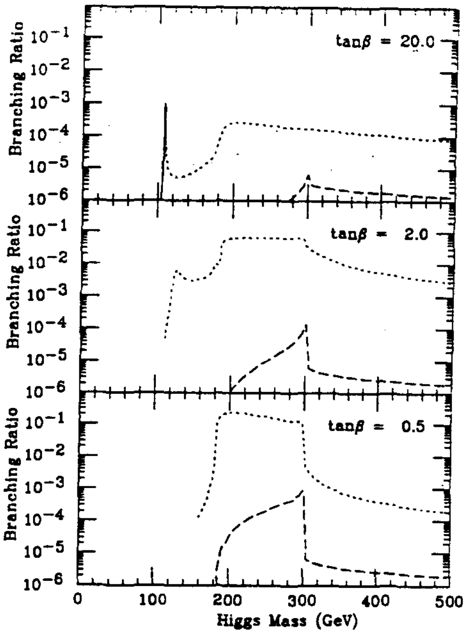
Study implications for Standard Model searches.

Branching ratios for neutral Higgs decays to $\gamma\gamma$: 00204



Solid curve is for h^0, dotted (dashed) are for H^0 (A^0). For large values of M_{h^0}, $h^0 \to \gamma\gamma$ is observable. For small $\tan\beta$, $A^0 \to \gamma\gamma$ should be observable.

Branching ratios for neutral Higgs decays to ZZ: 00205



Solid curve is for h^0, dotted (dashed) are for H^0 (A^0). For large values of $\tan\beta$, $h^0 \to ZZ^*$ observable. For small values of $\tan\beta$, $H^0 \to ZZ$ observable.

Summary (assuming 3–5 years at SSC design luminosity):

- For small M_A, h^0 observable at LEP-II, $t \to H^{\pm}b$ observable at SSC.
- For moderate M_A and small $\tan\beta$, h^0 observable at LEP-II, $H^0 \to ZZ$ and $t \to H^{\pm}b$ observable at SSC.
- For moderate M_A and large $\tan\beta$, none of the Higgs bosons may be observable.
- For large M_A, $h^0 \to \gamma\gamma$ observable at SSC.

These statements are valid for $M_{\text{top}} = 150$ GeV. If the t quark is heavier, the discovery regions are enlarged.

Basic problem is that for large regions of parameter space, Higgs' decay to heavy quarks and are almost unobservable. Searches for $\tau\tau$ decays are promising and may enlarge the regions where minimal SUSY Higgs bosons are observable.

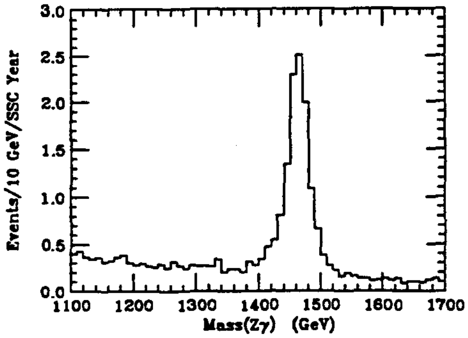
Strongly Coupled Higgs Models: 00207

Two complementary approaches to searching for a strongly coupled Higgs sector exist.

Resonant Channels:

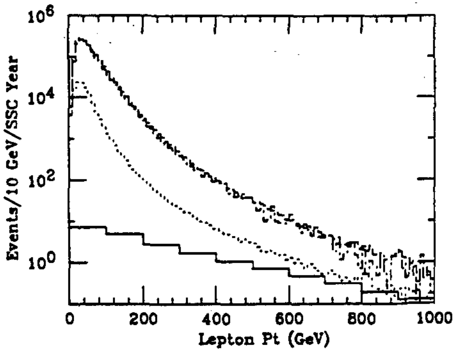
New strong interactions (*e.g.*, Technicolor) may produce resonances in gauge boson pair channels (ZZ, WW, WZ, or $Z\gamma$) in the 1–2 TeV region. These resonances are analogous to the ρ and ω mesons. The signals are distinctive but small $\Rightarrow$ high luminosity is required.

An example of a Techni-ω decaying to $Z\gamma$:



Non-resonant Channels:

A strongly interacting Higgs sector should also enhance non-resonant channels such as W^+W^+. Again, the signals are small.



Signal (assuming strong coupling) given by solid curve.

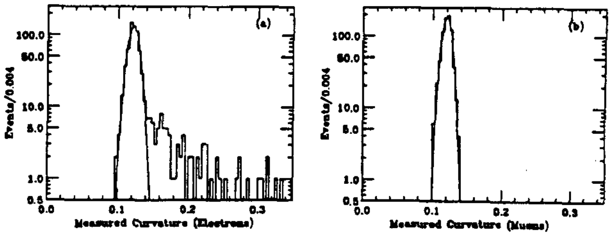
- Lowest order $q\bar{q}$ and gg diagrams for producing transversely polarized backgrounds don't exist.
- Major experimental backgrounds:
  a) Opposite-sign backgrounds: $q\bar{q} \rightarrow W^+W^-$ (dotted) and $gg \rightarrow t\bar{t} \rightarrow W^+W^- + X$ (dashed).
  b) Like-sign backgrounds: $gg \rightarrow t\bar{t} \rightarrow W^+b\bar{b} + X \rightarrow \ell^+\ell^+ + X$ (dot-dashed).

For $p_t^\ell \sim 100$ (500) GeV, need 10^{-5} (10^{-3}) background rejection.

- Charge measurement is critical.
- For $t\bar{t}$ events, some rejection comes from topology cuts (*e.g.*, central jet veto).
- Up to a factor of 10^3 obtainable against non-isolated leptons with $p_t \gtrsim 100$ GeV using isolation cuts.

Study charge measurement in detail, using full GEANT simulation and track reconstruction algorithms.

Fix p_t^ℓ = 500 GeV, and assume a luminosity of $3 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$.



Plot reconstructed curvature, look for tracks with wrong sign. Results indicate mis-measurement $\lesssim 10^{-3}$ for 80% tracking efficiency (a tight χ^2 requirement was made).

Separation will improve for lower p_t values.

Heavy Gauge Bosons

W′ Searches: Discovery up to 5 TeV should be straighforward, there are $\gtrsim$ 10 events for typical $L - R$ Symmetric models for this mass.

Z′ Searches: Concentrate on this to understand how well properties (and therefore the underlying model) can be determined.

- Choose class of Z' which arise in E_6 models (there is one free parameter: $\cos\alpha$).

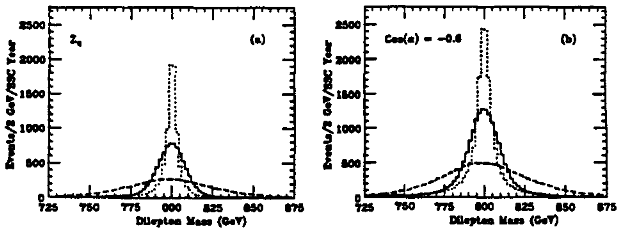
Properties to be measured:

- Mass and Width
- Cross section (determines couplings, but depends on assumptions about branching ratios to exotic channels).
- Angular distributions (determine couplings). In particular, forward/backward asymmetry is a powerful measurement.

Properties of several Z' arising in E_6 models:

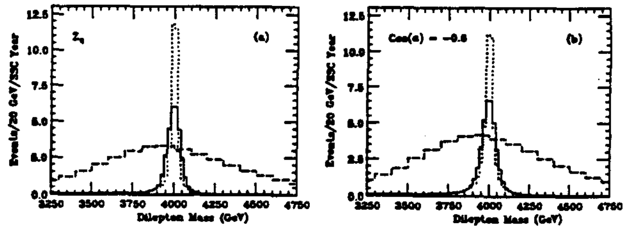
Property	$\cos\alpha = -0.6$	Z_η	Z_ψ	Z_χ	SM Couplings
$\Gamma(M = 800$ GeV)	8.5	5.0	4.2	9.2	21.4
$\Gamma(M = 4000$ GeV)	42.3	25.2	21.0	46.2	106.9
$\sigma(M = 800$ GeV)	2.1	1.2	1.1	2.4	4.3
$\sigma(M = 4000$ GeV)	0.004	0.0032	0.0027	0.0051	0.010

Mass plot for 800 GeV Z':



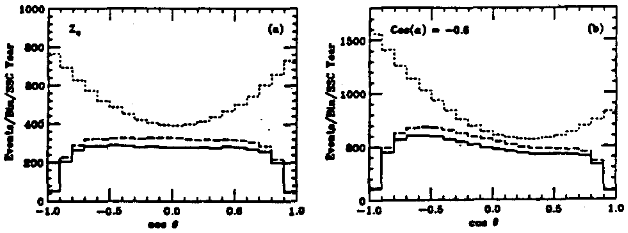
Dotted curve is a perfect detector. Solid (dashed) curve is for $Z' \rightarrow ee$ ($Z' \rightarrow \mu\mu$).

Mass plot for 4 TeV Z':



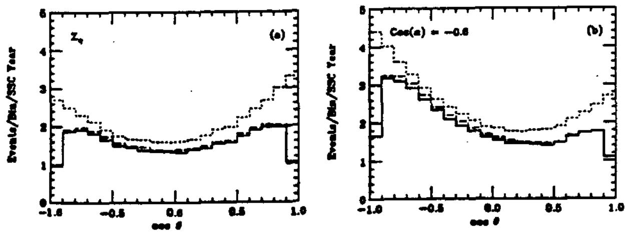
With adequate statistics, it is possible to measure both mass and width over this range using the *ee* final state.

Asymmetry plot for 800 GeV Z' ($P_{long}(Z') > 500$ GeV):



Dotted curve is a perfect detector. Solid (dashed) curve is for $Z' \rightarrow ee$ ($Z' \rightarrow \mu\mu$).

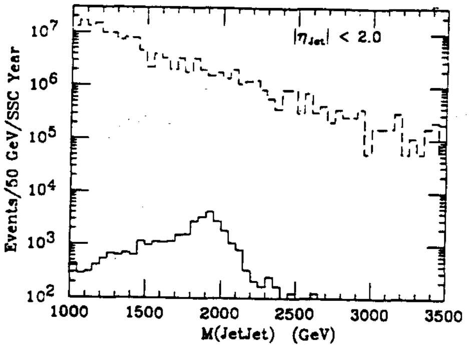
Asymmetry plot for 4 TeV Z' ($P_{long}(Z') > 1000$ GeV):



With adequate statistics, it is possible to measure asymmetry and distinguish two models.

Comments on searching for $Z' \rightarrow$ 2-*jets*:

Study case of Standard Model Z' with mass of 2 TeV.



Signal to noise ratio improves with reduction in η coverage since QCD background is more forward peaked.

Observe signal to noise ratio at peak of roughly ~1:100. This is similar to the UA2 $W/Z \rightarrow$ 2-*jets* analysis at SPS Collider (not impossible, but very difficult).

The Z' mass resolution is a weak function of the calorimeter resolution. The baseline gives a mass resolution of ~ 100 GeV, dramatic changes in calorimeter resolution alter this by less than 20%.

Compositeness Searches

If quarks are made of more fundamental objects, expect 4-fermion interaction of form:

$$\mathcal{L} = -\frac{g^2}{2\Lambda^2}(\overline{u}_L\gamma^\mu u_L + \overline{d}_L\gamma^\mu d_L)(\overline{u}_L\gamma_\mu u_L + \overline{d}_L\gamma_\mu d_L)$$

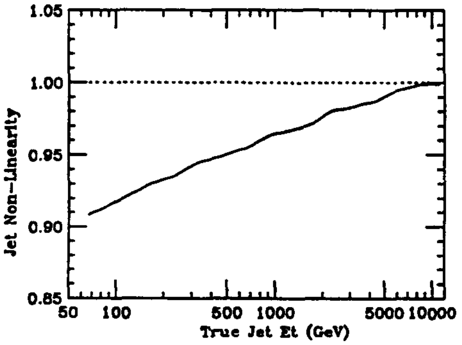
Inclusive jet cross section receives contribution from interference with gluon exchange. $d\sigma/dE_t$ does not fall as steeply with E_t as QCD predicts.

Normalize QCD prediction to data at low E_t ($E_t < 2$ TeV). Look for deviations at large E_t. This technique is sensitive to non-linearities in the jet energy scale.

Previous SDC studies:

- Statistical limit $\Lambda \gtrsim 30$ TeV after 1 SSC year.
- If jet response perfect below 2 TeV, and wrong by 2% at 5 TeV, this limit is reduced to $\Lambda \gtrsim 25$ TeV.

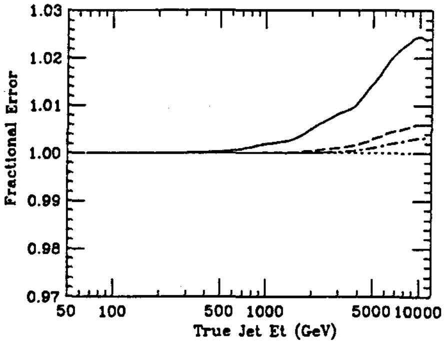
What is the impact of non-linear π/e response on this measurement ?



Plot jet non-linearity due to non-linear single particle response (uses ISAJET two-jet event sample).

Recall SDC calibration scheme normalizes $\pi/e \equiv 1$ at 300 GeV.

The important issue is what is the uncertainty on the non-linearity.



Solid curve assumes perfect knowledge of π/e response up to 100 GeV, and a 5%/TeV extrapolation error above this energy. Dash (dot-dash) assume a 2%/TeV extrapolation error starting from 500 (1000) GeV.

Conclude that if calorimeter is properly calibrated, non-linearities do not significantly degrade capability for compositeness searches.

PLENARY SESSION

PHYSICS PERFORMANCE OF THE SDC DETECTOR II

M. MANGANO

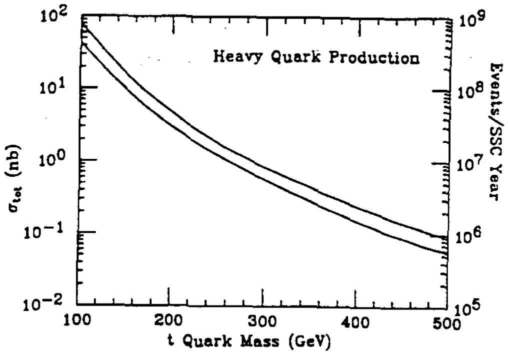
Physics Performance of the SDC Detector II

Michelangelo Mangano
INFN Pisa, ITALY
Solenoidal Detector Collaboration

1. Top Quark Physics
   a) SM Top: detection and mass measurement.
   b) Top → $H^+ + b$.
2. Supersymmetry
   a) $\tilde{g}\tilde{g} \to$ jets + $\not{E}_t$
   b) $\tilde{g}\tilde{g} \to l^{\pm}l^{\pm} + jets$
   c) $\tilde{\chi}\tilde{\chi} \to \geq 3l's$
3. QCD

Top Quark Physics

- Missing piece of the Standard Model
- Huge production cross section:



- Possible window onto beyond-the-SM Physics (*e.g.* $t \to H^+b$)
- Source of Higgs bosons via $pp \to t\bar{t}H$
- Background to rare and exotic phenomena (*e.g.* High energy WW scattering, multilepton final states from WWW or SUSY)

Main Identification Tool in SDC:

semileptonic decay(s) + b-tagging

It will be used to:

- Detect the *top* quark
- Measure its mass m_t
- Study its branching ratios
- Search for $t \to bH^+$ and – if found – measure m_{H^+} and $BR(t \to H^+b)$

Analysis performed using ISAJET $pp \to t\bar{t}$ and detector response as described previously (Einsweiler)

Top Detection and m_t Measurement

Three techniques:

I. Isolated di-leptons:

$$t\bar{t} \to (t \to e\nu b) + (\bar{t} \to \mu\nu\bar{b})$$

II. Isolated lepton + non-isolated muon:

$$t\bar{t} \to (t \to X) + (\bar{t} \to l\nu_l\,\mu\nu_\mu\,\bar{c})$$

III. Lepton plus jets:

$$t\bar{t} \to (t \to e\nu b) + (\bar{t} \to jets)$$

I: Isolated Di-leptons

- Require a pair of isolated e and μ with $p_t^l > 20$ GeV, $|\eta| < 2.5$.
- Background free (at the percent level)
- Yields 10^6 events/yr for $m_t = 150$ GeV
- Comparison with $\sigma_{QCD}^{t\bar{t}}$ and using SM branching ratios results in:

$$\Delta m_t \sim 10 - 15\, GeV$$

Comments:

- After subtraction of Z and Drell-Yan we can compare the $e^{\pm}\mu^{\mp}$ signal with the $l^{\pm}l^{\mp}$ and establish e/μ universality
- The $e^{\pm}\mu^{\mp}$ signal provides a pure sample of b jets on which to tune and debug the b-tagging

---

II: Isolated Lepton + non-isolated Muon

- Comparison with (I) measures the $t \to Wb$ branching ratio.

- Provides a better measurement of m_t: will show case of $m_t = 150$ GeV

Selection cuts:

a) e: $p_t > 40$ GeV and $\sum_{\neq e} E_t < 4$ GeV within $\Delta R < 0.2$

b) μ: $p_t > 20$ GeV and $\sum_{\neq \mu} E_t > 20$ GeV within $\Delta R > 0.4$

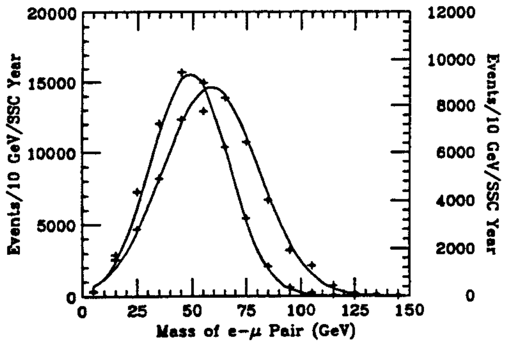
c) $p_t(e\mu) > 100$ GeV

d) $\Delta\phi(e,\mu) < 80^o$, to reduce opposite *charm* background

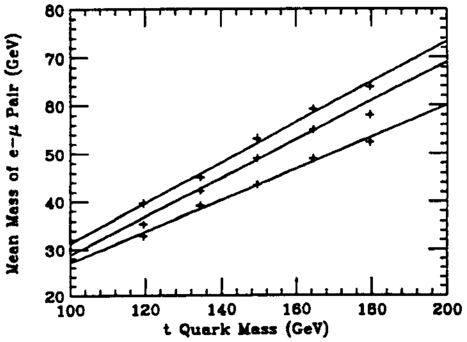
---

m_t measurement:

Fit the $m_{e\mu}$ distribution tuning m_t in the MC. Shown here the case of $m_t = 150$ GeV (leftmost curve, lefthand scale) and $m_t = 180$ GeV:



Check consistency applying different $p_t(e\mu)$ cuts (from the lower to the upper curve: $p_t(e\mu) > 60$, 100 and 140 GeV):



Backgrounds:

WW, $Z \to \tau\tau$: negligible
$Wb\bar{b}$: 0.7 % (3%) for $m_t = 150$ (250) GeV

Statistical Error on m_t:

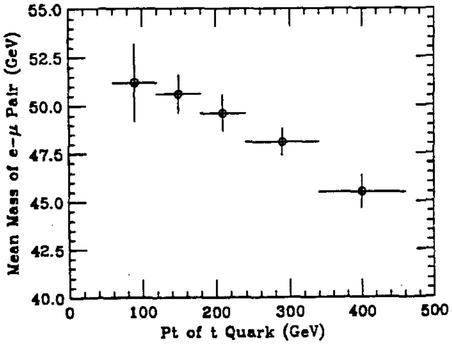
$m_t = 150$ GeV: $\Delta m_t = 0.5$ GeV (70,000 events/yr)
$m_t = 250$ GeV: $\Delta m_t = 0.8$ GeV (17,000 events/yr)

Systematic Errors on m_t:

- $b \to B$ fragmentation function: modeled using Peterson fragmentation, ϵ as measured by *Aleph* varied within $\pm 1\sigma$:

$$\Delta m_t = 1.5\ (3)\ GeV \quad at \quad m_t = 150\ (250)\ GeV$$

- *top* p_t distribution:



Varying initial state Radiation in ISAJET:

$$\Delta m_t = 1.9\ (2.6)\ GeV \quad at \quad m_t = 150\ (250)\ GeV$$

Final Result

$\Delta m_t(m_t = 150\, GeV) = \pm 0.5\ (stat)\ \pm 2.4\ (syst)\ GeV$

$\Delta m_t(m_t = 250\, GeV) = \pm 0.8\ (stat)\ \pm 3.9\ (syst)\ GeV$

III: Lepton + Jets

Will measure the invariant mass of the $t \to 3$ jet system, using large-p_t *top* to reduce combinatorial background.

- Jets: cone size $R = 0.4$, $|\eta| < 2.5$
- Lepton: $p_t > 40$ GeV, $|\eta| < 2.5$, $\sum_{\neq l} E_t < 0.25 p_t^l$ within $\Delta R < 0.4$
- Apply jet-by-jet energy corrections, to account for calorimeter response, out-of-cone corrections

Require:

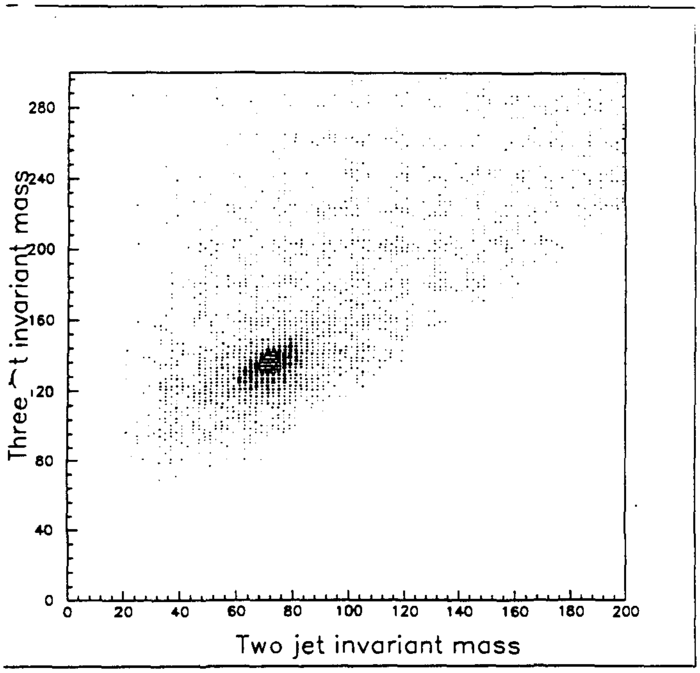
- ≥ 3 jets with $p_t^j > 30$ GeV and $\Delta\phi(j, l) > 90^o$
- A b-tag among these jets ($\to$ force $|\eta_{b\,jet}| < 2$)
- $p_t^{3\,jet} > 200\ (300)$ GeV for $m_t = 150\ (250)$ GeV

Rates:

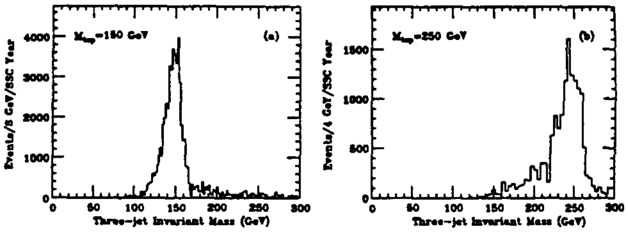
160,000 (40,000) events / year

$\to \Delta m_t(stat) < 100$ MeV

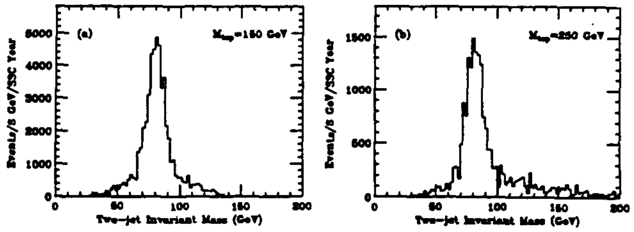
(no jet energy corrections)



Plot $m_{3\,jet}$, requiring $|m_{2\,jet} - m_W| < 15$ GeV:



Plot $m_{2\,jet}$, requiring $|m_{3\,jet} - m_t| < 15\ (25)$ GeV:



Fitting the mass plots with Gaussian distributions gives:

$$\langle m_{2\,jet} \rangle = 80.5 \text{ GeV } (m_W\text{=80 GeV}),\ \sigma = 7.5 \text{ GeV}$$

$$\langle m_{3\,jet} \rangle = 147.9 \ (243.6) \text{ GeV},\ \sigma = 9 \ (14) \text{ GeV}.$$

Fixing the absolute energy calibration using the value of the W mass gives:

$$\Delta m_t < 3\ GeV$$

Charged Higgs Boson

- Present in any extension of the SM with two $SU(2)_L$ Higgs doublets H_1, H_2
- Necessary in Supersymmetry

Will assume the most common implementation:

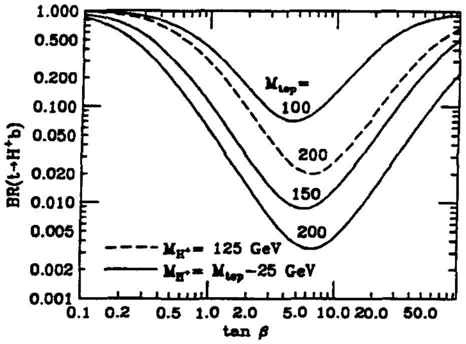
$$\mathcal{L}_m = \lambda_d H_1 Q_L d^c + \lambda_u H_2 Q_L u^c + \lambda_l H_1 L_L e^c$$

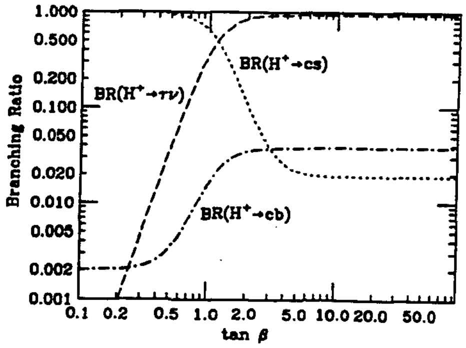
where $Q = (u, d)$, $L = (\nu_l, l)$

Couplings of H^+ are uniquely determined by fermion masses and:

$$\tan\beta \equiv v_2/v_1, \qquad v_i = \langle H_i^0 \rangle$$

If $m_{H^+} < m_t - m_b$ the $BR(t \to H^+ b)$ can be of the order of $BR(t \to Wb)$:





Detection of the H^+

Strategy: Trigger on a SM semileptonic decay of one t and reconstruct the $t \to H^+ b$ decay of the other.

Trigger: Inclusive lepton, $p_t > 40$ GeV, $|\eta| < 2.5$

Require:

- Lepton isolation: $\sum_{\neq l} E_t < 0.25 p_t^l$ within $\Delta R < 0.4$
- b-tag: b-jet with $p_t > 30$ GeV and $|\eta| < 2$

H^+ reconstruction:

I. $H \to \tau \nu_\tau$ (large $\tan\beta$)

II. $H \to c\bar{s} \to 2$ jet (small $\tan\beta$)

I: $H \rightarrow \tau\nu_\tau$

Use the measured $\sigma(t\bar{t} \rightarrow e\mu)$ (from isolated dileptons) to evaluate the expected number of observed $t\bar{t} \rightarrow l\tau$. Check for possible violation of universality.

Use $\tau \rightarrow \pi\nu$ and $\tau \rightarrow K\nu$

- $p_t^\pi > 50$, 100 GeV
- $\sum_{\neq l} E_t < 0.25 p_t^\pi$ within $\Delta R < 0.4$ → jet rejection better than 10^{-3}

τ polarization effects render the τ detection efficiency for the $H \rightarrow \tau\nu$ decay larger than for $W \rightarrow \tau\nu$:

m_t (GeV)	m_{H^+} (GeV)	e_{l-trig}	e_{b-tag}	$e_{\tau\pi}$ $p_t(\pi) > 50$	$e_{\tau\pi}$ $p_t(\pi) > 100$
100	no $H^\pm$	0.35	0.10	0.044	0.0022
100	75	0.34	0.13	0.16	0.020
100	85	0.35	0.087	0.18	0.04
100	95	0.36	0.066	0.27	0.077
150	no $H^\pm$	0.39	0.27	0.065	0.011
150	75	0.38	0.28	0.18	0.043
150	125	0.39	0.22	0.29	0.09
150	140	0.40	0.20	0.32	0.12
200	no $H^\pm$	0.46	0.31	0.091	0.018
200	125	0.46	0.30	0.31	0.11
200	175	0.46	0.26	0.39	0.16

Number of $l\tau$ pairs without H^+ decays:

$$N_{l\tau}^{SM} = 2\, N_{t\bar{t}}\, BR(W \rightarrow l\nu) e_{l-trig} e_{b-trig}$$

$$BR(W \rightarrow \tau\nu) BR(\tau \rightarrow \pi\nu) e_{\tau\pi}^{W}$$

Number of $l\tau$ pairs with H^+ decays:

$$N_{l\tau}^{obs} = (1 - B_H)^2\, N_{l\tau}^{SM} + B_H(1 - B_H) N_{l\tau}^{H}$$

where

$$N_{l\tau}^{H} = 2\, N_{t\bar{t}}\, BR(W \rightarrow l\nu) e_{l-trig} e_{b-trig}$$

$$BR(H \rightarrow \tau\nu) BR(\tau \rightarrow \pi\nu) e_{\tau\pi}^{H}$$

In presence of H^+ decays the number of observed $e\mu$ events would be

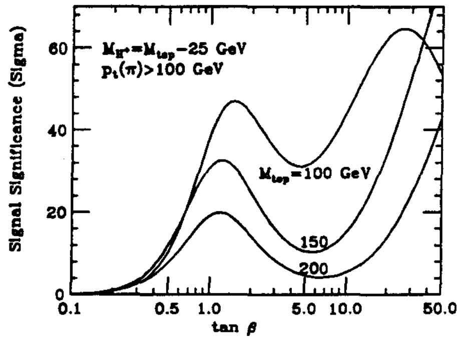
$$N_{e\mu}^{obs} = (1 - B_H)^2\, N_{e\mu}^{SM}$$

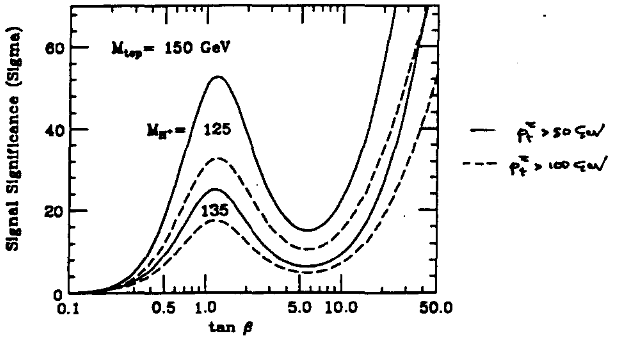
and the universality prediction for $l\tau$:

$$N_{l\tau}^{univ} = (1 - B_H)^2\, N_{l\tau}^{SM}$$

Parametrise the significance of the signal by:

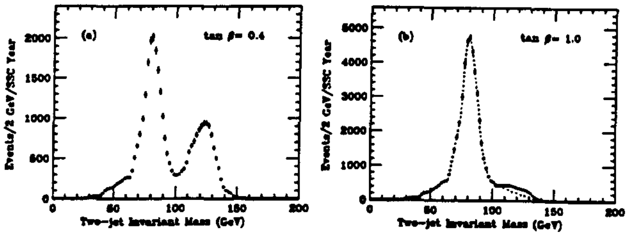
$$N_{SD} = \frac{N_{l\tau}^{obs} - N_{l\tau}^{univ}}{\sqrt{N_{l\tau}^{obs}}}$$





II: $H \rightarrow 2$ jets

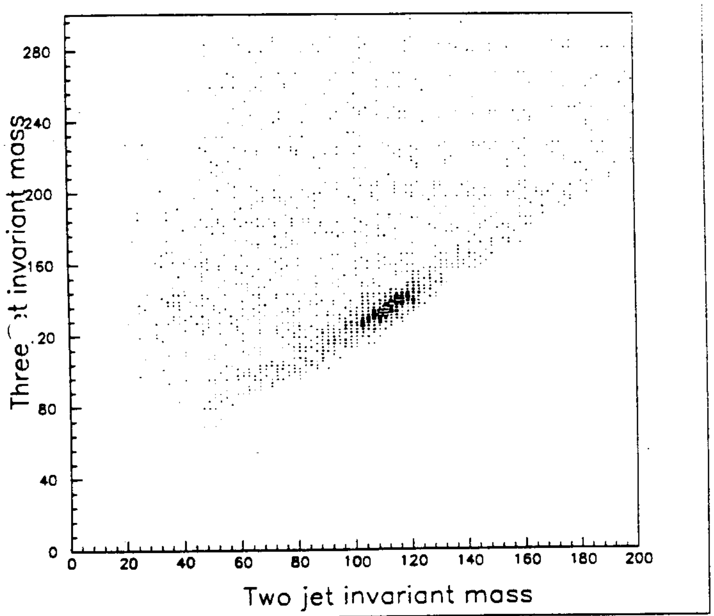
- Study the mass distribution of the two non-b jets recoiling against the lepton (same as previous analysis for $t\bar{t} \rightarrow l + jets$):



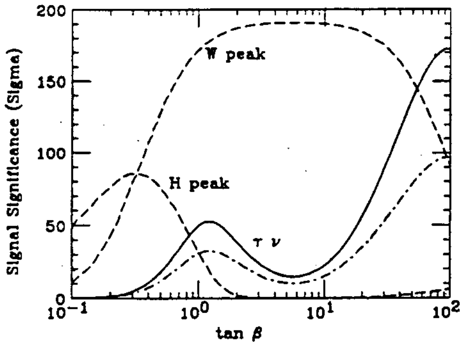
$m_H = 125$ GeV

- Fit the curve with the superposition of the $W + 2$ jet and $H \rightarrow 2$ jet contributions
- Extract $BR(t \rightarrow bH) \times BR(H^+ \rightarrow c\bar{s})$ and m_{H^+}
- Assess the H^+-peak significance by subtracting the combinatorial W-tail background in a 30 GeV region around the H^+-peak and defining:

$$N_{SD} = \frac{N^{peak} - N^{backgd}}{\sqrt{N^{peak}}}$$



Summarv of Charged Higgs Search



- H^+ can be detected for all values of tan$\beta > 0.1$ via the channels:
  $H^+ \to c\bar{s}$ for tan$\beta < 1$
  $H^+ \to \tau\nu_\tau$ for tan$\beta > 0.5$
- m_{H^+} determined to within 10% in the $H^+ \to c\bar{s}$ channel
- Work in progress to determine m_{H^+} in the $H^+ \to \tau\nu_\tau$ channel (use p_t^b spectrum?)

Comments: Use the determination of $BR(t \to Wb)$ from the study of isolated dilepton vs. isolated lepton plus non-isolated muon to overconstrain the system or extract possible evidence for additional *top* decay modes.

Supersymmetry

- Best candidate to solve the mass Hierarchy problem and to connect SM and gravity
- Several possible models, but large set of model independent predictions and features (*e.g.* missing $\not{E}_t$ signatures, $\sigma_{\tilde{g}}(m_{\tilde{g}})$, ...)

Will consider here the Minimal SUSY Model:

Spectrum:

* scalar partners of matter fermions: $\tilde{q}$, $\tilde{l}$
* fermionic partners of gauge and Higgs fields: $\tilde{g}$, $\tilde{w}$, $\tilde{z}$, $\tilde{\gamma}$, $\tilde{h}$. Usually represented by the mass eigenstates indicated as: $\tilde{g}$, $\tilde{\chi}_i^{\pm}$ (i=1,2), $\tilde{\chi}_i^0$ (i=1,..,4)
* additional scalar Higgs fields: $H^{\pm}$, h, A.

Parameters:

* tan$\beta = v_2/v_1$ (defined earlier)
* μ: H mass at the GUT scale
* M: common *gaugino* mass at the GUT scale
* scalar masses

There exists a lightest stable SUSY particle, $\tilde{\chi}_1^0$

Will consider:

- Production of gluino pairs and detection via:
  a) decays to like-sign dileptons and jets:
  $$\tilde{g}\tilde{g} \to l^{\pm}l^{\pm} + (n \geq 4)jets$$
  b) missing $\not{E}_t$ in multi-jet events
- Direct production of weakly interacting gaugino pairs and detection via multileptonic ($n \geq 3$) decays.

$\tilde{g}\tilde{g} \to$ jets + $\not{E}_t$

Consider the more difficult case of a *light* gluino: $m_{\tilde{g}} =$ 300 GeV. Assume also $m_{\tilde{q}} > m_{\tilde{g}}$. Gluino decays are then dominated by the following channels,

$$\tilde{g} \to \tilde{\chi}_1^{\pm} q\bar{q}' \ (BR \sim 60\%)$$
$$\tilde{g} \to \tilde{\chi}_1^{0} q\bar{q} \ (BR \sim 15\%)$$
$$\tilde{g} \to \tilde{\chi}_2^{0} q\bar{q} \ (BR \sim 25\%)$$

followed by the subsequent $\tilde{\chi}$ decays towards the stable state χ_1^0:

$$\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 + X$$
$$\tilde{\chi}_2^{0} \to \tilde{\chi}_1^0 + X$$

where X contains at least a quark or lepton pair.

We will therefore require at least 3 jets with $p_t^j > 70$ GeV, and study the $\not{E}_t$ spectrum.

Backgrounds:

- $(Z \to \nu\nu)$ + jets, $Q\bar{Q} \to \nu$ + jets $(Q = b, t)$
- Jet energy mismeasurement $\to \not{E}_t$
- Jets lost in the forward $\to \not{E}_t$

Jet E_t mismeasurement

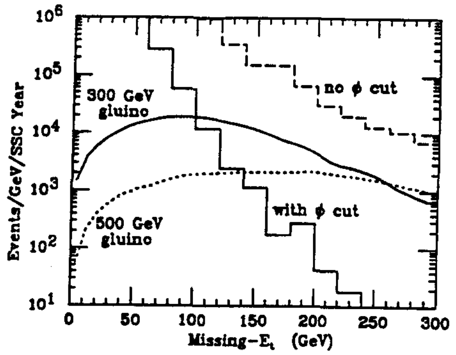
- Dominated by non-gaussian tails (modeled *á la* CDF)
- Dominated by $\not{E}_t$ vector aligned with a large-p_t jet

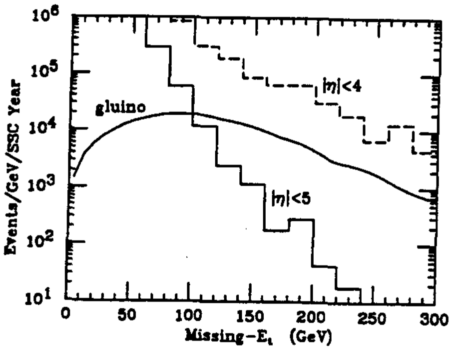
Require:

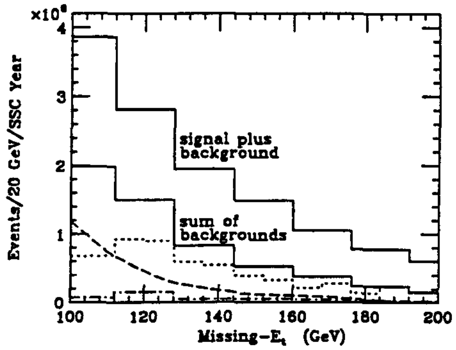
- $\Delta\phi(\not{E}_t \ , jet) > 20^o$

$\not{E}_t$ from forward jets

- Large rate of FWD jets at large p_t(> 100 GeV)
- Vetoing not sufficient: too large signal rejection
- Need segmentation sufficient to impose $\Delta\phi(\not{E}_t \ , jet)$ cut (jet size $= \Delta\eta \times \Delta\phi \sim 0.5 \times 0.5$)
- Constant term in energy resolution: sufficient 10%
- Need coverage down to $|\eta| < 5$







Dot-dashed line: Z+jets. Dashed line: E_t mismeasurement and jets beyond $|\eta| > 5$. Dotted line: $Q\bar{Q}$ final states, with $\not{E}_t$ from neutrinos.

Left with $\sim 10^6$ events/yr with $\not{E}_t$ > 100 GeV. Physical backgrounds can be subtracted

$\tilde{g}\tilde{g} \to l^\pm l^\pm + (n > 4)jets$

Look for the following decay chain for each $\tilde{g}$:

$\tilde{g} \to \tilde{\chi}_1^\pm q\bar{q}'$ ($BR \sim 60\%$)

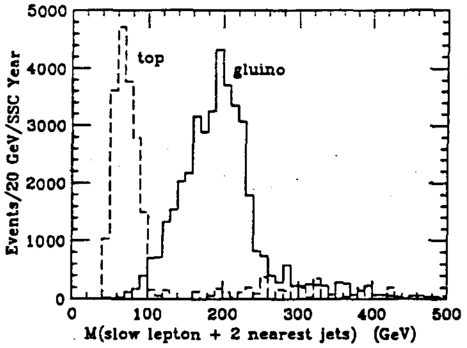
$\tilde{\chi}_1^\pm \to l^\pm \nu \tilde{\chi}_1^0$ ($BR \sim 20\%$)

The total BR is about 2%, half of which corresponds to same-sign lepton pairs. This corresponds to:

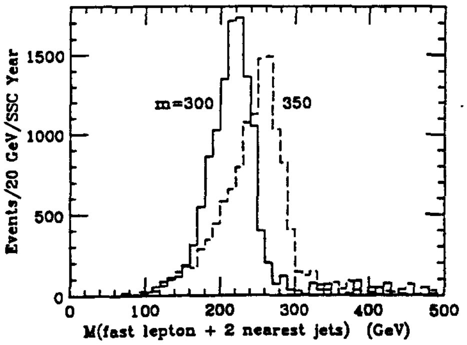
- 2×10^6 events/yr if $m_{\tilde{g}} = 180$ GeV
- 25 events/yr if $m_{\tilde{g}} = 2$ TeV

We will consider here the case $m_{\tilde{g}} = 300$ GeV, and will require:

- ≥ 4 jets with $|\eta| < 3$ and $p_t > 50$ GeV
- $p_t^l > 20$ GeV for both leptons, or $p_t^{l_1} > 40$ GeV and $p_t^{l_2} > 15$ GeV
- $\Delta R_{l\,jet} > 0.5$ (to remove $t\bar{t}$ background)



Dashed line: *top* background without separation cut



Mass resolution ~ 10%

$\tilde{\chi}$ pair production and decay

Independent probe into the couplings of gauge fermions

Study purely leptonic chain decays. Require:

- ≥ 3 leptons with $|\eta| < 2.5$, $p_t^e > 20$ GeV and $p_t^\mu > 15$ GeV
- l isolation: $\sum_{\neq l} E_t < 2$ GeV within $\Delta R < 0.2$
- Absence of jets: $\sum_{\neq l} E_t < 30$ GeV within $|\eta| < 2.5$

Production rates (pb) for multi-leptonic final states

μ (GeV)	M (GeV)	3 l	5 l
−80	100	0.22	7.3×10^{-3}
−80	200	3.4×10^{-2}	7×10^{-4}
−150	100	0.26	2×10^{-4}
−150	200	9.7×10^{-2}	2.1×10^{-3}
top bkgd	$m_{top} = 150$	0.26	$< 10^{-4}$
top bkgd	$m_{top} = 200$	8.2×10^{-3}	$< 10^{-4}$

Mass spectrum (GeV) of the neutralino-chargino sector

μ (GeV)	M (GeV)	χ_1^0	χ_2^0	χ_3^0	χ_4^0	$\chi_1^\pm$	$\chi_2^\pm$
−80	100	51	72	118	141	90	145
−80	200	72	104	108	225	94	224
−150	100	51	108	166	178	111	182
−150	200	96	144	172	225	155	226

SUSY Conclusions

- Gluinos can be discovered and their mass measured in the range $180 < m_{\tilde{g}} < \mathcal{O}(TeV)$ using two independent decay channels
- Weak gauge fermions can be detected in their multi-leptonic decay channel in a large portion of parameter space and for $m_t \geq 150$ GeV
- Supersymmetry will manifest itself in several different phenomena (Higgs properties, *top* decays, $\not{E}_t$, multi-leptons). The coincidence and consistency of the various signals will help selecting the particular model. SDC ability to cover all of these channels will be the key to disentangling the richness of these phenomena into a coherent picture
- More work will be needed to extract additional information from the study of various sources of SUSY signals

QCD and Standard Model Physics

- Several of the predictions for important SSC Physics are affected by theoretical uncertainty (structure functions, behaviour of initial state radiation, higher order corrections, underlying event multiplicity,...). Addressing these issues by performing Standard Model Physics measurements will be one of the initial priorities of SDC.
- The initial lower luminosity running will offer a unique opportunity to determine some of the unknowns involved in the theoretical calculations and to debug critical components of the detector in a rather clean environment.
- Typical measurements will cover:

1. Inclusive- and multi-jet rates and fragmentation properties
2. Heavy Quark production cross-sections and properties
3. Electroweak boson production: γ, $W^{\pm}$ and Z inclusive cross-sections, p_t and η distributions
4. Associated production of EW gauge bosons and (multi-) jet systems
5. Multiple production of gauge bosons

- More work needed to fully explore the SM Physics potential of SDC.

Physics Performance: Conclusions

- SDC is fully committed to engage in a widely scoped study of both Standard Model and beyond the Standard Model Physics.
- A study of Standard Model phenomena during early running will allow SDC to consistently check the reliability of theoretical models used to predict Physics rates and to possibly fix yet poorly known ingredients
- Detection and study of the properties of the most outstanding missing links of the Standard Model – Higgs and Top quark – is guaranteed within the full domain of parameters allowed by the SM.
- SDC has the ability to confirm whether the Higgs and the Top quark behave as predicted by the SM and to possibly detect anomalous properties signalling new Physics.
- SDC is sensitive to several different manifestations of possible new Physics (*e.g.* Supersymmetry, new gauge bosons, compositeness ...) and can constrain the properties of these new phenomena using the *redundancy* of its detection tools.
- The examples discussed represent only a sample of *expected* new Physics. SDC's ability to cover all of the above gives us confidence in SDC's adequacy to look for and detect the ***unexpected***

PLENARY SESSION

RESPONSIBILITIES AND FUNDING
G. TRILLING

SDC ORGANIZATION
The Boards

INSTITUTIONAL BOARD (Chair: election)
One representative/collaborating institution
Governance, admission of new members, conduct of elections publication policy...

EXECUTIVE BOARD (Chair: Spokesperson)
21 elected members from universities and national labs plus Spokesperson, Deputy Spokespersons, Project Manager, Institutional Board Chair all ex-officio.
Provides scientific direction with Spokesperson & Proj. Manager. Appoints Spokesperson & Proj. Manager (in consultation with SSCL Dir.). Reviews major technological recommendations, and approves appointments to Technical Board.

TECHNICAL BOARD (Chair: Project Manager)
Spokesperson, Deputy Spokespersons, Proj. Manager and scientists and engineers in leadership roles in various technical areas of SDC project (subsystem leaders and other experts) appointed by Project Manager, with approval of Spokesperson and Exec. Board.
Reviews and recommends on all major technological and technical issues relevant to the SDC.

PAC REVIEW

George Trilling

May 4, 1992

Management

Detector Cost/Schedule

Responsibilities & Funding

Concluding Remarks

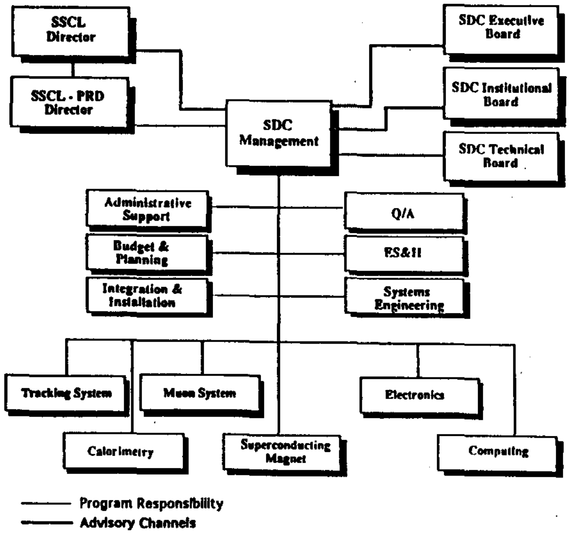
SDC ORGANIZATION
Spokespersons and Project Manager

SPOKESPERSON
Appointed by the Executive Board in consultation with SSCL Director and ratified by Collaboration.
Represents Collaboration in scientific, technical and managerial concerns, speaks on its behalf, chairs the Exec. Board, pursues identification of resources and seeks their commitment.

PROJECT MANAGER & CO-SPOKESPERSON
Appointed jointly by the Exec. Board and the SSCL and ratified by the Collaboration.
Carries responsibility for the design and fabrication of the detector, and for meeting cost, performance, & schedule goals.
Leads SDC Department at SSCL and provides direction for the SDC related scientific program at the SSCL.

DEPUTY SPOKESPERSONS (Japan, Europe, U.S./Canada)
Appointed by Exec. Board in consultation with their constituencies and with Spokesperson.
Provide support and assistance to Spokesperson and PM/Co-Spokesperson in leadership of the SDC.

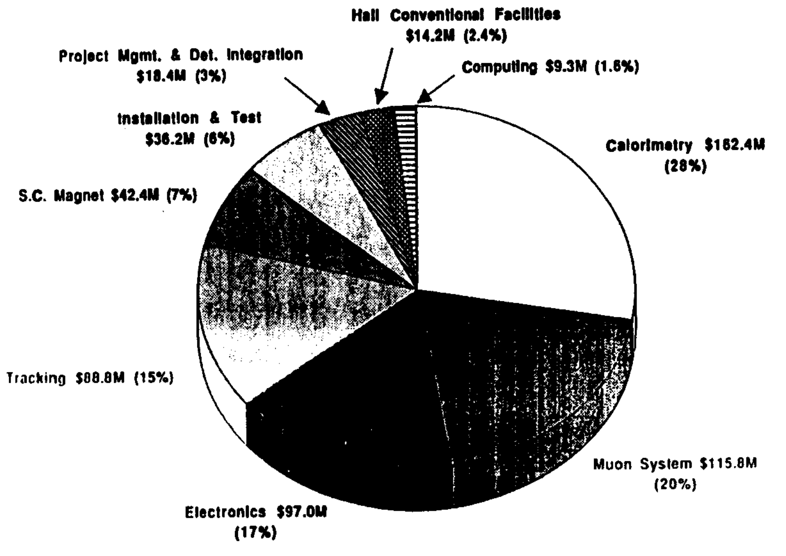
SDC Organization
(Draft SDC Management Plan)



SDC Detector Cost (FY92 $)

	MATL & LAB	EDIA	% EDIA	SUB TOTAL	CONT	% CONT	TOTAL
TRACKING SYSTEMS	55.5	14.1	20%	69.6	19.2	28%	88.8
1.1 SILICON TRACKING SYSTEM	27.8	4.7	15%	32.5	8.7	27%	41.2
1.2 BARREL TRACKER	20.9	5.0	19%	25.8	5.7	22%	31.5
1.3 INTERMEDIATE TRACKER	6.8	4.4	39%	11.3	4.8	43%	16.1
CALORIMETRY	95.3	30.3	24%	125.8	36.6	29%	162.4
2.1 BARREL CALORIMETER	55.2	15.5	22%	70.7	19.9	28%	90.6
2.2 ENDCAP CALORIMETER	32.6	13.0	29%	45.7	13.5	30%	59.2
2.3 FORWARD CALORIMETER	7.6	1.8	19%	9.4	3.2	34%	12.5
MUON SYSTEM	75.0	19.9	21%	94.9	20.9	22%	115.8
3.1 MAGNET SYSTEMS	41.3	9.0	18%	50.3	9.3	19%	59.6
3.2 MUON MEASUREMENT SYSTEM	33.7	10.9	24%	44.6	11.6	26%	56.2
SUPERCONDUCTING MAGNET	29.2	3.1	10%	32.3	10.1	31%	42.4
4.1 SUPERCONDUCTING SOLENOID	23.8	1.8	7%	25.6	8.3	33%	33.9
((CRYOGENIC SYSTEM	5.4	1.3	19%	6.7	1.8	27%	8.5
ELECTRONICS SYSTEMS	[illegible]	30.2	39%	77.3	19.3	26%	97.0
5.1 FRONT-END ELECTRONICS	26.5	9.1	26%	35.7	8.2	23%	43.9
5.2 DATA ACQUISITION SYSTEM	10.4	6.1	37%	16.4	4.0	24%	20.4
5.3 TRIGGER SYSTEMS	9.3	12.5	57%	21.9	7.0	32%	28.8
5.4 ANCILLARY CONTROLS	0.8	2.5	75%	3.3	0.6	18%	3.9
ONLINE COMPUTING	[illegible]	[illegible]	[illegible]	7.5	1.8	24%	9.3
CONVENTIONAL SYSTEMS	[illegible]	[illegible]	[illegible]	11.5	2.7	24%	14.2
INSTALLATION AND TEST	21.0	8.7	29%	29.7	6.5	22%	36.2
8.1 TEST BEAM PROGRAM	4.2	3.1	42%	7.3	1.6	22%	8.9
8.2 SUBSYSTEM INSTALL. AND TEST	16.8	5.6	25%	22.4	4.9	22%	27.3
PROJECT MANAGEMENT	[illegible]	[illegible]	[illegible]	15.9	2.5	16%	18.4
TOTALS	336	128	28%	464	120	26%	584

Summary of SDC Detector U.S. Cost Estimate by Subsystem



SDC MANAGEMENT

(May 4, 1992)

Spokesperson:	G. Trilling (LBL)
Proj. Manager/Co-Spokesp.:	T. Kirk (SSCL)
Deputy Spokespersons:	G. Bellettini (Pisa) D. Green (Fermilab) T. Kondo (KEK)
Act. Proj./Tech. Manager:	M. Gilchriese (LBL/SSCL)
Chair, Inst. Board:	A. Goshaw (Duke)

SDC Executive Board

R. Amendolia (Pisa)
S. Errede (Illinois)
E. Gabathuler (Liverpool)
A. Maki (KEK)
Y. Nagashima (Osaka)
R. Orr (Toronto)
R. Ruchti (Notre Dame)
J. Siegrist (SSCL)
R. Thun (Michigan)
J. Elias (Fermilab)
G. Feldman (Harvard)
K. Kondo (Tsukuba)
S. Mori (Tsukuba)
T. Ohsugi (Hiroshima)
L. Price (ANL)
A. Seiden (U.C.S.C.)
M. Strovink (LBL)
N. Tyurin (Protvino)

Notes: T. Kirk is replacing M. Gilchriese as Project Manager. The Exec. Board will be expanded by 3 members in the next month: 2 from U.S./Canadian universities and one from the former Soviet Union.

SDC Technical Board

(May 4, 1992)

K. Amako (KEK)
G. Bellettini (Pisa)
D. Bintinger (SSCL)
M. Edwards (RAL)
J. Elias (Fermilab)
G. Feldman (Harvard)
W. Frisken (York)
M. Gilchriese (LBL/SSCL)
R. Hubbard (Saclay)
T. Kirk (SSCL)
V. Kubarovsky (Protvino)
A. Maki (KEK)
T. Ohsugi (Hiroshima)
J. Proudfoot (ANL)
J. Siegrist (SSCL)
Y. Takaiwa (KEK)
T. Thurston (SSCL)
Y. Watase (KEK)
A. Yamamoto (KEK)
A. D. Baden (Maryland)
J. Bensinger (Brandeis/SSCL)
M. Campbell (Michigan)
K. Einsweiler (LBL)
D. Etherton (SSCL)
W. Ford (Colorado)
I. Gaines (Fermilab)
D. Green (Fermilab)
R. Kephart (Fermilab)
T. Kondo (KEK)
A. Lankford (U.C.I.)
S. Mori (Tsukuba)
L. Price (ANL)
A. Seiden (U.C.S.C.)
W. Smith (Wisconsin)
R. Thun (Michigan)
G. Trilling (LBL)
H. Williams (Pennsylvania,

Development of Responsibility Matrix For Non-U.S. Collaborators

We have broken up all subsystems into the major elements which contribute to the cost.

On a subsystem by subsystem basis, we have made a preliminary determination of what fractions of these elements will be contributed by our various non-U.S. collaborators.

Corresponding to those fractions, we are determining the cost offsets to estimate the U.S. part of the detector cost.

This process still needs considerable iteration and refinement. However it appears that there exists a plausible match between the interests, aspirations, and technical capabilities of the non-U.S. SDC collaborators and the needs of the detector at the level of about a $200M cost offset. Contributions from the former Soviet republics and the PRC will probably have to involve partial hard currency payments, which are included in the above estimates of net offsets.

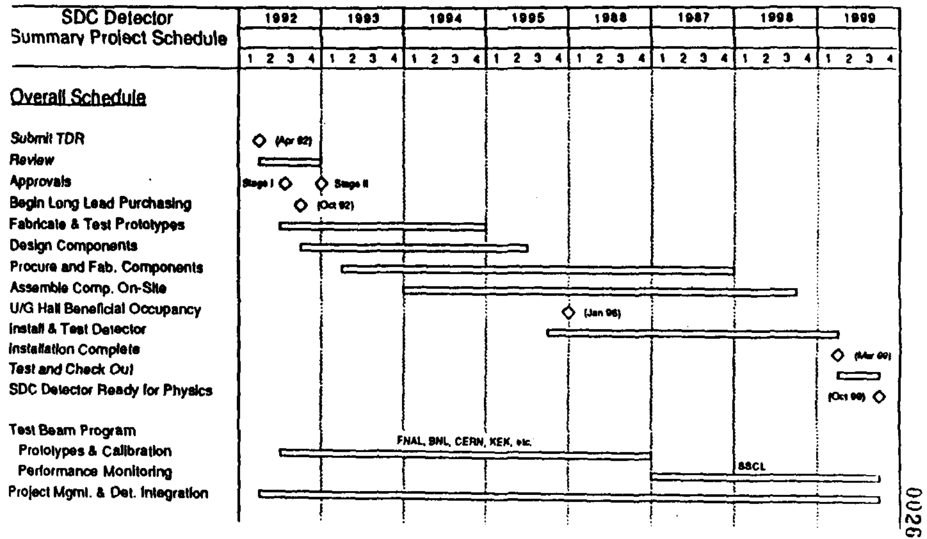
Comments on Responsibility Matrix Definition

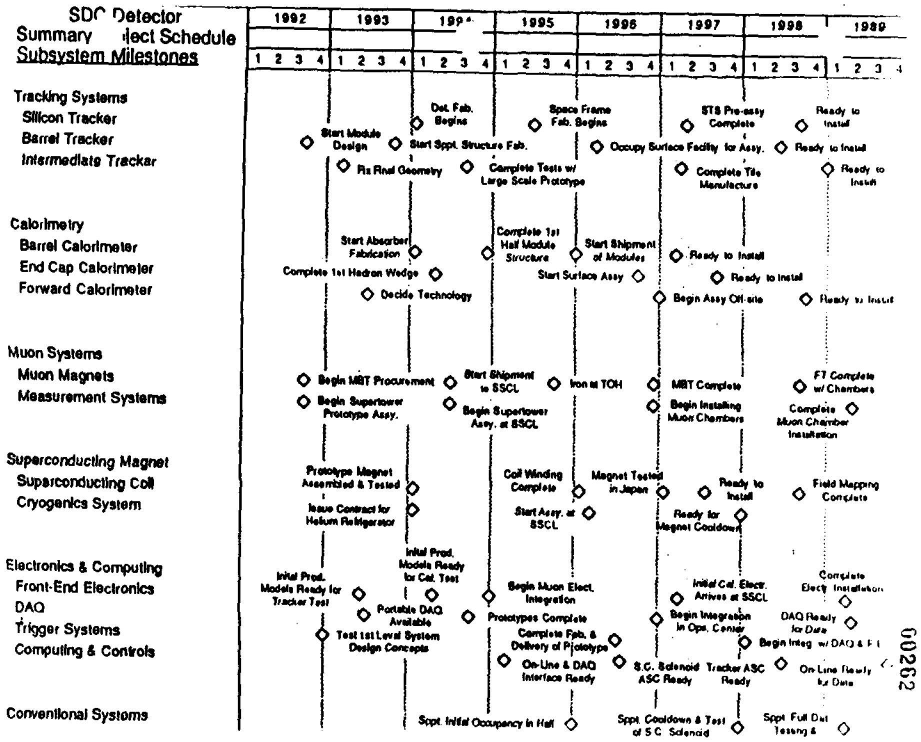
The process is highly iterative. It will require more iterations to make it self-consistent. Furthermore the responsibilities of individual U.S. institutions, as well as those of individual non-U.S. institutions, will have to be defined before the process can be considered close to complete.

The above statement of plausibility is based on the stated interests and capabilities of collaborating physicists. We have no firm assurance from any of the countries of non-U.S. SDC collaborators, except France (Saclay), as to what level of funds, if any, will actually be provided. Real commitments will probably not come until 1993.

It is worth recognizing that the detector cost offsets will be less than the total contributions to the SDC program made by the countries of the collaborators. This is because some of these contributions will have to go into supporting, and equipping the non-U.S. groups for effective participation in SDC detector construction and eventual physics analysis.

This whole process involves many sensitive issues, and requires the greatest of care.





SDC Funding

U.S. Equivalent Costs

	Estimated Cost	U.S.		Non-U.S.	
	M$	%	M$	%	M$
Tracking Systems	**88.8**	**65**	**57.7**	**35**	**31.1**
1.1 Silicon Tracker	41.2	66	27.1	34	14.1
1.2 Straw-Tube Barrel Tracker	31.5	97	30.7	3	0.9
1.3 Gas Microstrip Intermediate Tracker	16.1	0	0.0	100	16.1
Calorimetry	**162.4**	**64**	**104.0**	**36**	**58.4**
2.1 Barrel Calorimeter	90.6	64	57.7	36	32.9
2.2 End Cap Calorimeter	59.2	78	46.3	22	12.9
2.3 Forward Calorimeter	12.5	0	0.0	100	12.5
Muon Systems	**115.8**	**71**	**82.6**	**29**	**33.2**
3.1 Muon Magnets	59.6	58	34.8	42	24.9
3.2 Muon Measurement System	56.2	85	47.8	15	8.4
Superconducting Magnet	**42.4**	**33**	**13.9**	**67**	**28.5**
4.1 Superconducting Solenoid	33.9	16	5.4	84	28.5
4.2 Cryogenic System	8.5	100	8.5	0	0.0
Electronics Systems	**97.0**	**57**	**55.1**	**43**	**42.0**
1 Front-End Electronics	43.9	45	19.9	55	24.0
2 Data Acquisition System	20.4	77	15.7	23	4.7
5.3 Trigger System	28.8	54	15.6	46	13.2
5.4 Control System	3.9	100	3.9	0	0.0
Computing	**9.3**	**90**	**8.4**	**10**	**0.9**
6.1 On-Line Computing	9.3	90	8.4	10	0.9
Conventional Systems	**14.2**	**100**	**14.2**	**0**	**0.0**
7.1 Mechanical Utilities	2.5	100	2.5	0	0.0
7.2 Electrical Utilities	1.7	100	1.7	0	8.0
7.3 Safety Systems	3.6	100	3.6	0	0.0
7.4 Structural Support/Access Equipment	6.4	100	6.4	0	0.0
Installation & Test	**36.2**	**65**	**23.5**	**35**	**12.7**
8.1 Test Beam Program	8.9	65	5.7	35	3.2
8.2 Installation & Test	27.3	65	17.7	35	9.6
Project Management	**18.4**	**100**	**18.4**	**0**	**0.0**
Total $M	584		377		207
Percentages			65%		35%

Note: The breakdown between U.S. and non-U.S. contributions still has great uncertainties.

SDC DETECTOR FUNDING SUMMARY

(All amounts expressed in FY1992 dollars)

Estimated Detector Cost	$584M
Estimated Cost Offset (Non-U.S.)	~ $200M
Net U.S. Cost	~ $384M
Anticipated SSCL Funds ($275M in FY1990$)	$292M
Shortfall	~ $92M

Note: The "~" above reflects the substantial uncertainty in the cost offset from non-U.S. contributions.

How Do We Solve the Shortfall?

BUILD A CHEAPER DETECTOR
Minimizing costs, while maintaining capability, has been a constant theme of the SDC design efforts. It is the strong view of the SDC that further descoping will substantially reduce the detector capabilities. The issues of requirements and scope will be further addressed in the parallel sessions.

LOCATE MORE NON-U.S. COLLABORATORS
Given the existence of HEP programs all over the world which compete for resources, it may be difficult to find more contributions from abroad. Nevertheless we shall continue to seek additional resources both intellectual and financial from outside the U.S.

STAGE THE DETECTOR TO REDUCE PRESENT FUNDING NEEDS
Everyone wants a complete detector by the time that the SSC reaches design luminosity. If one postpones some of the funding until after turnon, detector completion will be many years delayed, hardly consistent with the expectation of top priority for the SSC program. The collaborators want to see important physics within their lifetimes.

GET MORE U.S. FUNDING
(See next transparency)

Potential Further Resources from the U.S.

In its report, the Witherell Subpanel suggests that funding for small SSC experiments might be available in the latter part of the 1990's from the base program on a competitive basis, and recommends not committing the $80M(FY92) presently held in reserve for such experiments until funding for the large detectors is secure.

If the SSCL chooses to follow up on this possibility, and allows assignment of 1/2 of the $80M(FY92) to the SDC detector, the shortfall would be reduced by nearly a factor of 2.
The remaining shortfall of ~$50M would amount to about $6M/year. The SDC would hope to cover this amount through redirection of existing engineering/technical personnel, supported by base program funds, into SDC efforts. This is already happening at a modest level in the collaborating national laboratories.

If the SSCL does not allow consideration of the $80M(FY92) for the large detectors, the shortfall will go from $6M to $10M per year, a figure that we would still hope to cover via base program redirection, but with much greater difficulty.

These figures do not include potential TNRLC support. Present support for SDC work is at ~$2M/year. If continued, this would provide substantial help in completing the funding.

CONCLUDING REMARKS

The SDC has achieved its immediate goal of submitting, on schedule, its Technical Design Report and associated documents, and has demonstrated its ability to work collaboratively in an effective fashion.

The SDC management has been greatly strengthened through the appointment of Tom Kirk as SDC Project Manager and Co-Spokesperson.

The process of responsibility allocation between U.S. and non-U.S. collaborators is well under way (and will be discussed in more detail on May 7). It will require further iteration and refinement; and, of course, the support and approval of the relevant funding agencies.

The allocation of responsibilities within U.S. institutions is beginning. Many of the U.S. efforts will involve close collaboration, even within subsystems, with non-U.S. groups. There is therefore a close linkage with the process of responsibility definition for the non-U.S groups.

FINAL CONCLUSION

The SDC is on schedule in developing its design, setting up its organization, and trying to solve its full funding problem.
It has built up an enormous amount of momentum and excitement among physicists and engineers who have committed large or total fractions of their creative time to the SDC detector project.

It is critical, for the sake of maintaining this momentum and advancing the process for full commitment of non-U.S. contributions, that the SSC Laboratory and the Collaboration work together to move through the approval process as expeditiously as possible. Our expectation is to initiate the construction project by January 1993 to achieve our goal of having a powerful instrument, well matched to the SSC physics opportunities, ready for data taking at the turnon date.

PARALLEL SESSION A:
SUPERCONDUCTING SOLENOID

INTRODUCTION, PHYSICS GOALS, & GENERAL REQUIREMENTS

R. KEPHART

R. Kephart

SDC Solenoid Design Review
May 5, 1992

AGENDA

9:00 - 9:30	Introduction, Physics Goals, General Requirements (R. Kephart)
9:30 - 10:30	Solenoid Design (A. Yamamoto)
10:30 - 11:00	Break
11:00 - 11:30	Solenoid Design (A. Yamamoto)
11:30 - 12:00	Cryogenic system, Helium refrigerator, transfer lines, effect of VLPC (A Stefanik)
12:00 - 1:30	Lunch
1: 30 - 3:00	Prototype coil R&D Conductor, coil winding, cold mass support R&D (A Yamamoto) Outer Vacuum Shell R&D (R. Kephart)
3:00 - 4:00	Cost and Schedule (R. Stanek)
4:00 - ?	Questions / Comments / adjourn (Panel)

Introduction:

The work presented today is the result of the efforts of the SDC Super conducting Magnet Working Group. This a US - Japanese collaborative effort.

SDC Magnet Working Group

Co-leaders: A. Yamamoto (KEK) / R. Kephart (FNAL)

Contributors:

Ron. Fast	FNAL
John Grimson	FNAL
Chuck Grozis	FNAL
Bob Kephart	FNAL
Ang Lee	FNAL
Rich Stanek	FNAL
Andy Stefanik	FNAL
Bob Wands	FNAL
Yosikuni Doi	KEK
Nobuhiro Kimura	KEK
Taka Kondou	KEK
Yasuhiro Makida	KEK
Ken-ichi Tanaka	KEK
Akira Yamamoto	KEK
Hiroshi Yamaoka	KEK

Charles Collins	SSCL
Jim Krebs	SSCL (FNAL)
Bob Richardson	SSCL

Industrial Participants:

Paul Slysh Assoc.	USA
Toshiba	Japan
Sumitomo Light metal	Japan
IHI	Japan
Furakawa Electric	Japan

Physics Goals:

The physics goals of the SDC collaboration require the study the properties of Proton-Proton collisions at the unprecedented center of mass energy of $\sqrt{s}$ = 40 TeV / c and at very high luminosity 10^{33} - 10^{34} $cm^{-2} s^{-1}$.

The SDC collaboration has proposed a general purpose detector designed to explore the Physics of this new energy and luminosity frontier. (Many difficult technical problems to be overcome !)

The detector proposed is optimized to measure quarks and gluons (jets), leptons, photons, and individual hadrons over the largest possible solid angle.

A major feature of this proposed detector is a large superconducting solenoid magnet that provides the magnetic field to momentum analyze charged particles emerging from the collisions.

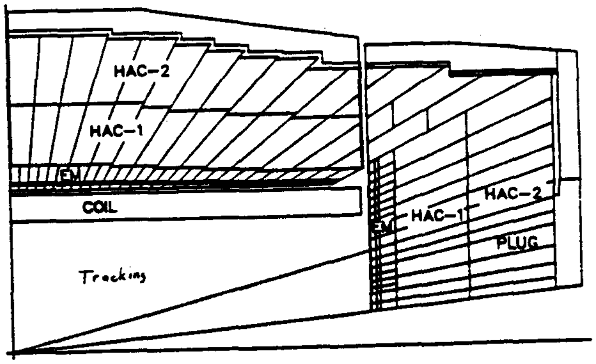
Design considerations:

- The overall geometry of SDC was chosen after extensive Monte Carlo evaluations of the Physics Performance of various detector configurations.

- The SDC central detector design consists of a large scintillating tile calorimeter enclosing the superconducting solenoid. A large central tracking system is immersed in the axial magnetic field provided by the solenoid

- The radiator plates of the hadronic calorimetry are made of iron and provide the solenoids's magnetic flux return.

- Large muon toroids surround the central detector and serve to identify muons and remeasure their momenta.



Longitudinal quarter section of the central calorimeter.

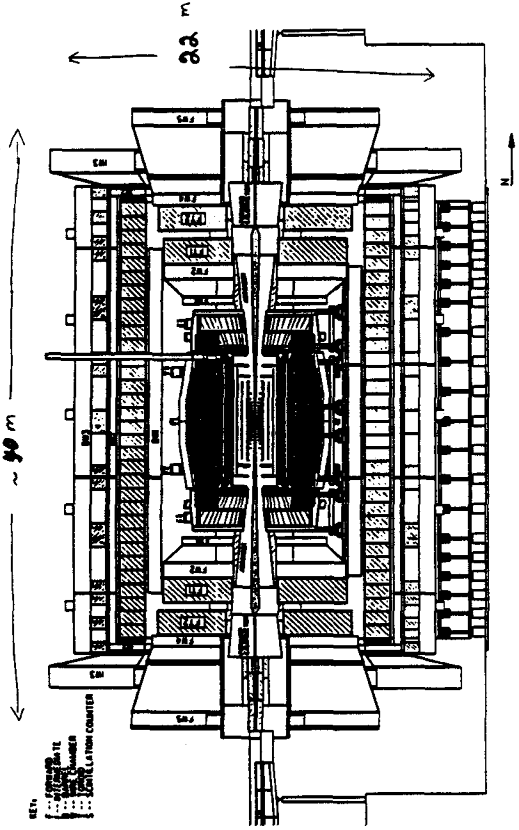


FIG. 2-2. Elevation view of the preliminary baseline detector configuration.

- The SDC coil diameter and central field were specified based upon the required momentum resolution of the SDC central tracking system.

$$\Delta P_T / P_T^2 = 0.15 \text{ (where } P_T \text{ is in TeV / c)}$$

- Radiation damage to the central calorimetry and channel occupancy of the central tracking system at high luminosity were also important considerations. Both argue for a large diameter high field coil.

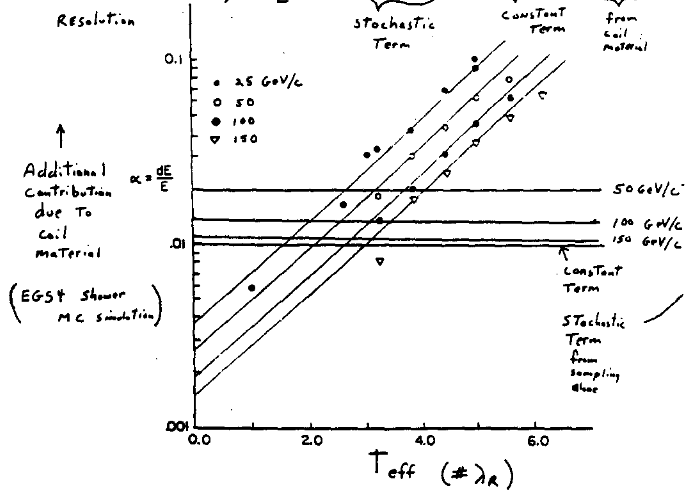
- Since all particles entering the central electromagnetic calorimetry must first pass through the solenoid, the magnet is required to be thin in terms of radiation lengths (λ_R) and interaction lengths (λ_I).

- The desired SDC Electromagnetic calorimeter performance $\sigma(E) / E < 0.14 / \sqrt{E_t} \bullet .01$ requires that the effective thickness of the coil be less than about 3 - 4 λ_R. (fig)

Effect of Coil Material on EM Calorimetry

RESOLUTION

SDC 'Nominal' Resolution $\Rightarrow \frac{\sigma(E)}{E} = \underbrace{0.14/\sqrt{E}}_{\text{Stochastic Term}} \oplus \underbrace{.01}_{\text{Constant Term}} \oplus \underbrace{\alpha(E)}_{\text{from coil material}}$



Conclude: for $t_{eff} \gtrsim 3\lambda_R$ the addition term due To coil material dominates the EM Calorimeter resolution.

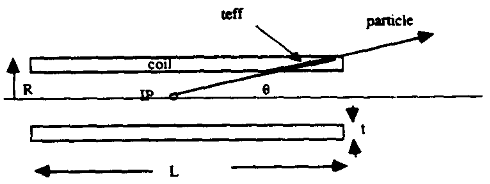
Design considerations (cont.) :

- **For maximum pseudo-rapidity coverage (η)**

η = −ln(tan(θ / 2) of the tracking system it is desirable to have the magnet be as long as possible. However, the effective thickness of the magnet near its ends grows rapidly as the magnet becomes longer.

$t_{eff} = t/\sin(\theta)$ where $\theta = \tan^{-1}(2R / L)$

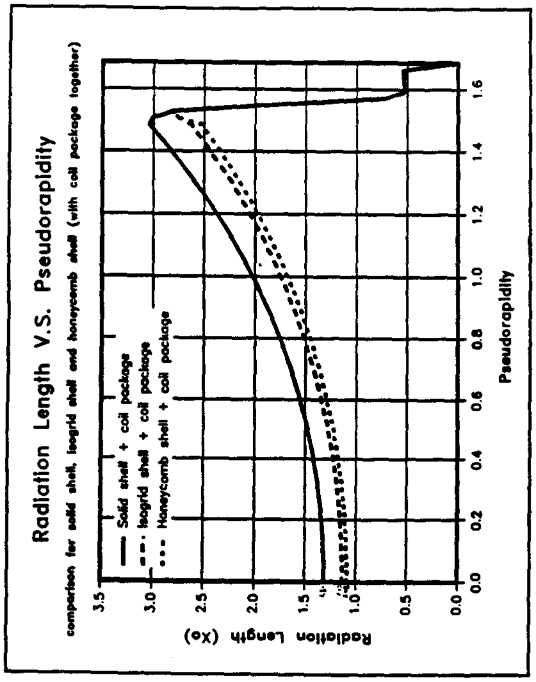
and R = coil radius
L = coil length
t = coil thickness at θ = 90°



this effect limits the maximum practical length of the coil.

- **Finally, overall detector COST issues argue for minimizing the coil Radius and Length.**

The magnet design presented today was a result of an overall optimization that attempted to balance all these considerations to achieve the best overall Physics performance within the SDC overall budget constraints.



SDC Superconducting Solenoid

General Requirements:

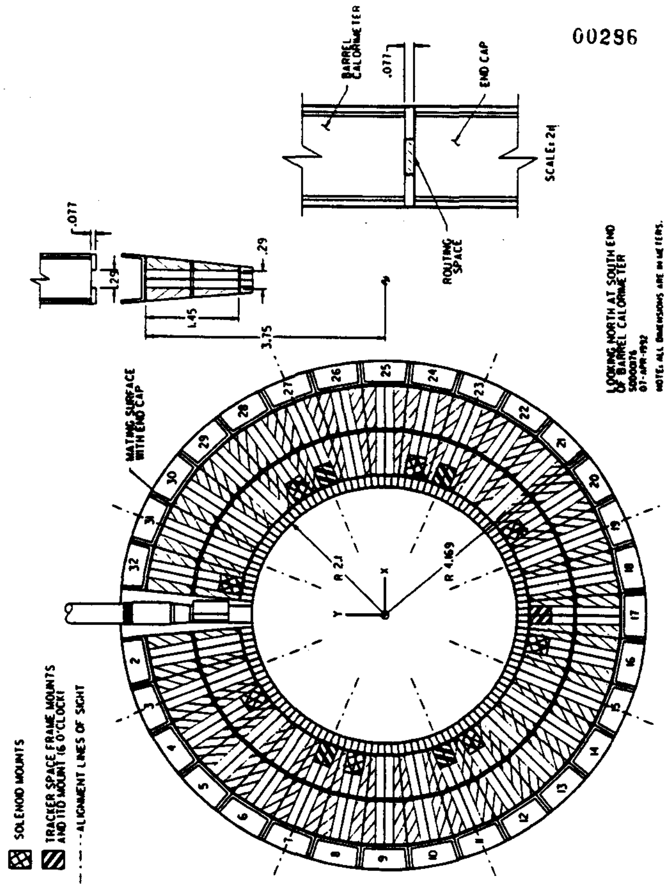
Diameter:	**ID**	**3.4 Meters (useful bore)**
	OD	**4.1 Meters**
Length:		**8.8 Meters**
Central Field:		**2.0 Tesla**
Type		**Al Stabilized / indirectly cooled**
Thickness		**≤ 1.2 λ_R @ 90° incidence**
		≤ 0.25 λ_I

Operational Requirements:

Cooldown time:	**≈ 14 days**
Quench recovery time:	**≈ 4 hours**
Charge time to 2 T:	**≈ 60 minutes**
Slow discharge time const.:	**≈ 500 sec.**

Detector requirements:

Coil mounts:	Coil is attached to steel of SDC Barrel Hadronic Calorimeter
Cryogenic Services:	30 cm diameter verticai penetration for chimney at one end of coil. Chimney extends vertically to control dewar location above muon toroid iron.
Cryogenic plant:	The SDC cryo plant must also provide Helium for tracking VLPC's (visible light photon transducers)



13-2

SDC LOCATION
@ SSCL

Experimental facilities

SDC

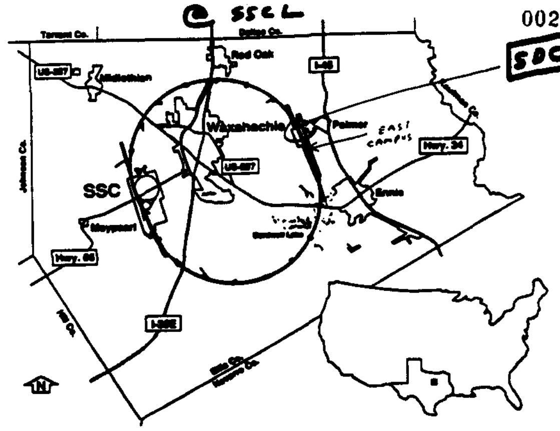


FIG. 13-1. The SSC site.

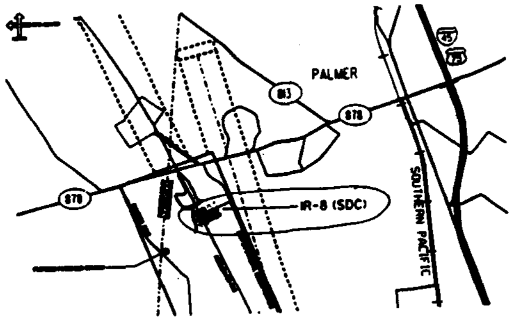


FIG. 13-3. The IR8 site.

Other requirements:

Solenoid location:	Axis of solenoid located 50 m below grade.
Utilities location:	Refrigerator and power supply located at surface level ==> 130 m long cryo lines and bus work.
Access:	SDC will be located in an interlocked radiation area. Access will be very restricted ==> high operational reliability
Radiation dose:	Solenoid must be designed to withstand > 10 years at 10^{34} cm^{-2} s^{-1} luminosity ==> >> 6 megarads without damage.
Construction:	All welded construction (e.g. no O-rings etc.,
Safety codes:	DOE/SSCL requires pressure vessels to be built to ASME / CGA code. Code approved allowable stress levels.

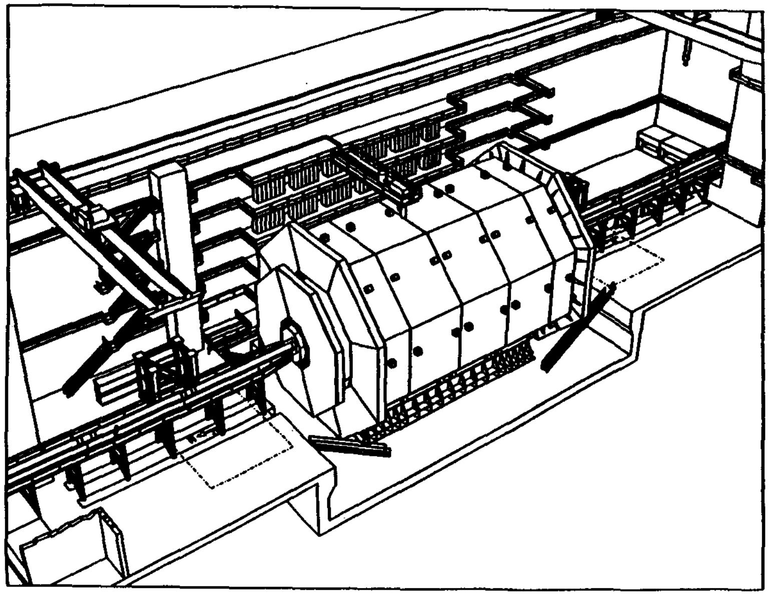


FIG. 13-14. View of the interaction hall showing the completed detector with accelerator components. Month 46 of the installation schedule.

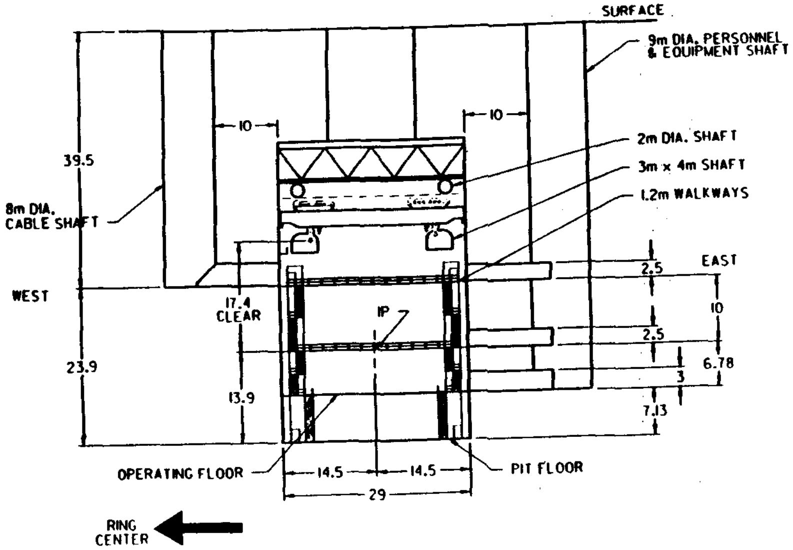


FIG. 12-10. End view of the SDC underground hall.

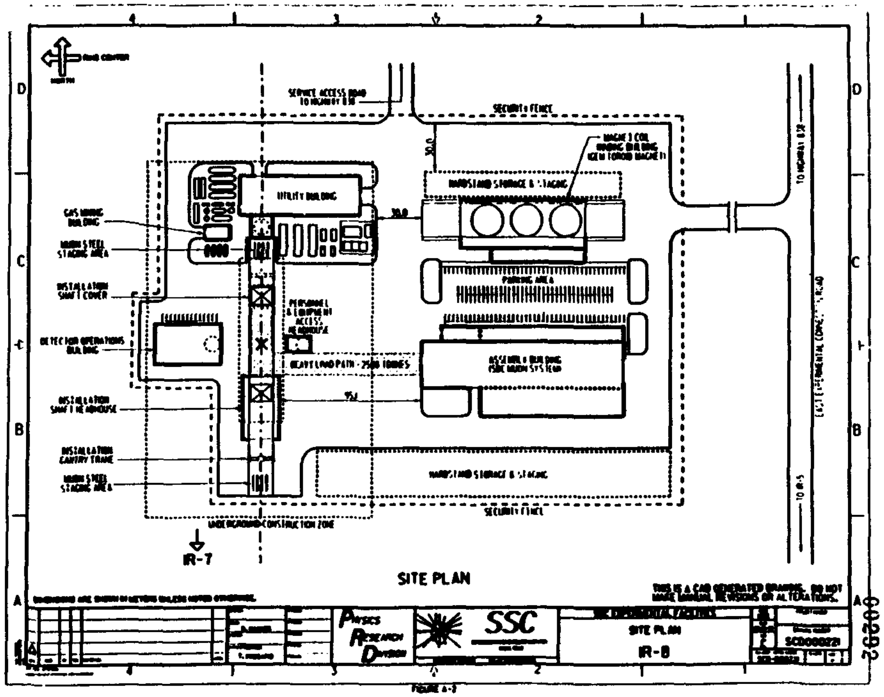


FIGURE A-3

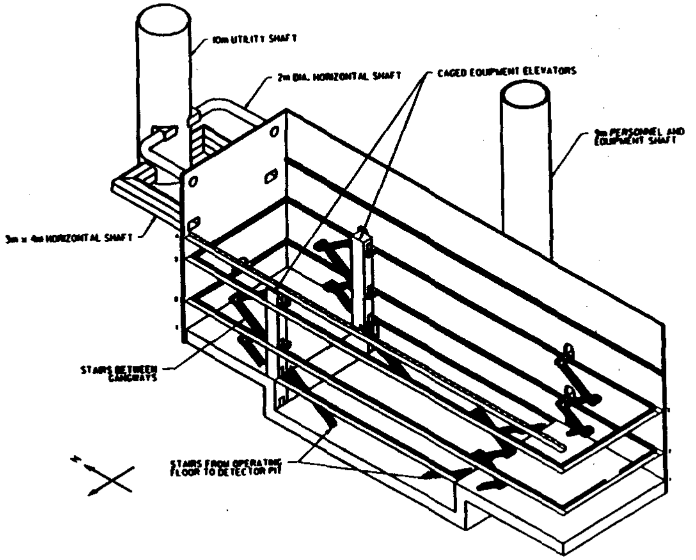


FIG. 12-9. Isometric view of the SDC underground hall showing gangways and access points.

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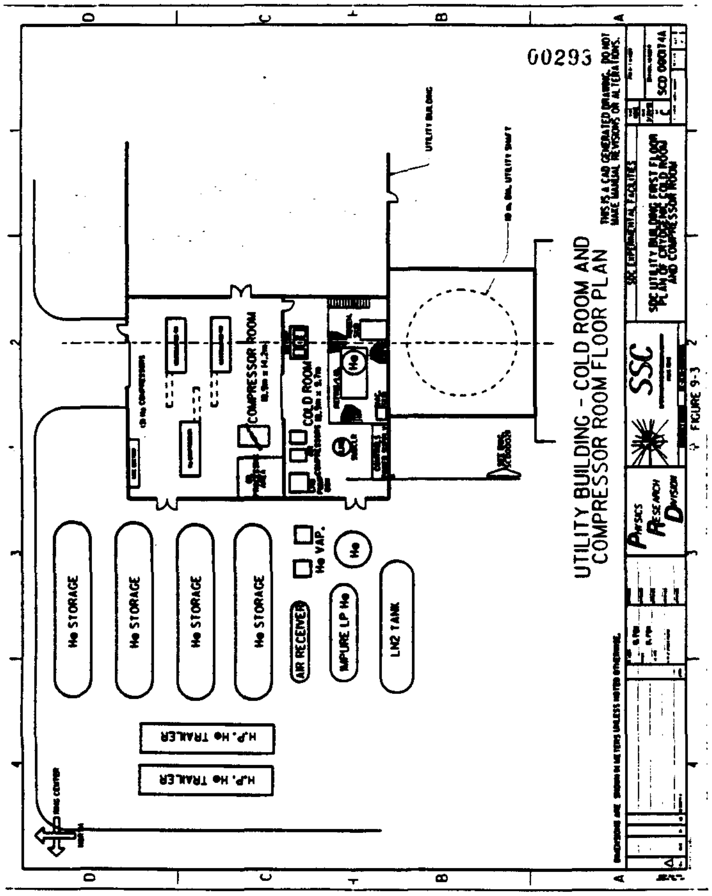

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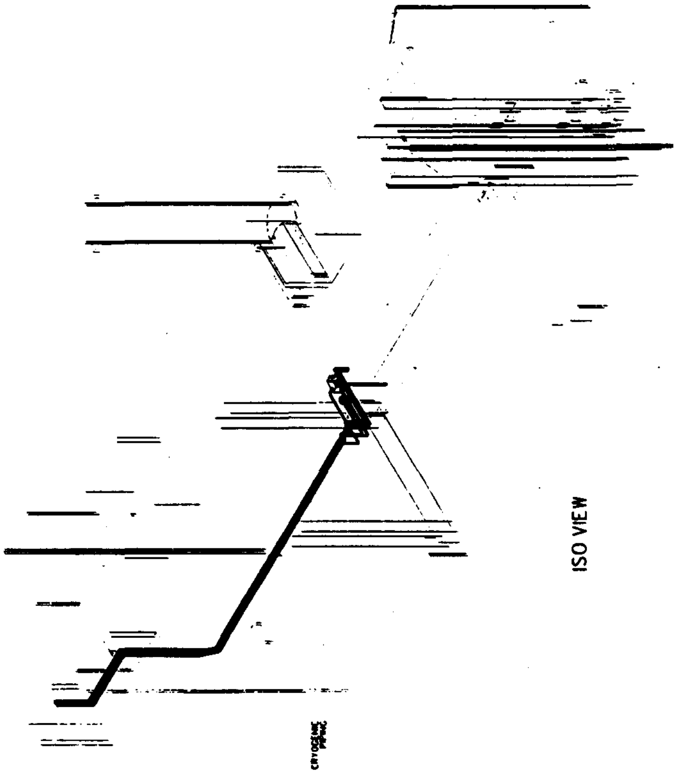

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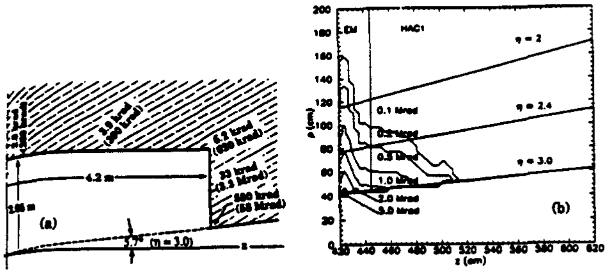

FIG. 6-7. (a) Maximum ionizing dose in the SDC calorimeter for one year of running at design luminosity and (in parentheses) for 10 years at 10 × design luminosity [1]. (b) Equal radiation dose contours for the SDC endcap calorimeter after ten years of running at design luminosity. We have indicated in (b) the separation between the EM and hadronic compartments and overlaid several η boundaries.

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The SDC Magnet Working Group

The approximate division of design effort is as follows:

Conductor development, coil winding, support system , radiation shields, prototype coil (Japan)

Magnetostatic analysis, Cryogenics, He refrigerator, Power Supply/controls ,Utilities, detector integration. (USA)

Quench analysis, stress analysis, outer vacuum shell R&D (shared US-Japan)

Other considerations:

The SDC solenoid will be at the heart of very complicated $580 M detector. Once assembled, access for repairs to the solenoid would require an extended major disassembly of the detector and would be catastrophic to SDC and to the SSCL physics program.

==>

A predictable design, combined with comprehensive R&D, prototype, quality control and testing programs are of paramount importance to insure success.

Conclusion:

The SDC magnet working group believes that it has developed a design that can meet the requirements of SDC and the details of that design are presented in the talks that follow.

DESIGN OF DETECTOR SOLENOID

A. YAMAMOTO

SDC SOLENOID DESIGN

Presented by

Akira Yamamoto

(KEK)

---

* to be presented at SDC Technical Review by SSCL on May 5, 92.

CONTENTS

1. General Design
2. Coil Design
3. Superconductor Design
4. Radiation Shield
5. Cryostat Vacuum Vessel
6. Coil Support
7. Chimney
8. Thermal Design and Cooldown Characteristics
9. Diagnostics and Instrumentation
10. Magnet Assembly and Initial Test

Table 5-1
General requirements of SDC solenoid.

Magnet envelope		
Cryostat	Inner radius	1.70 m
	Outer radius	2.05 m
	Total half length	4.389 m
Nominal magnetic field		2 T
Transparency	(η=0)	1.2 X_0
		0.25 λ_I
Cool down time		< 14 days
Quench recovery time		< 4 hr

1. General Design

Design Bases:

The solenoid with B = 2 T and X = 1.2 Xo

to be used with a calorimeter with either a Feromagnetic iron abosrber or with a non-magnetic absorber.

Technical Concerns:

- Strong Electromagnetic Force initiated by B = 2 T
- Thermal Stress after Quench due to thinness of 1.2 Xo

According to recent technical design decision to take feromagnetic iron abosorber:

Axial Distance b/w Coil and Iron :	47 - 62 cm
Maximum Stress in the Coil:	52 - 54 MPa
Axial Compressive Force:	1100 - 1300 tonnes
Axial Decentering Force:	20 - 15 tonnes/cm

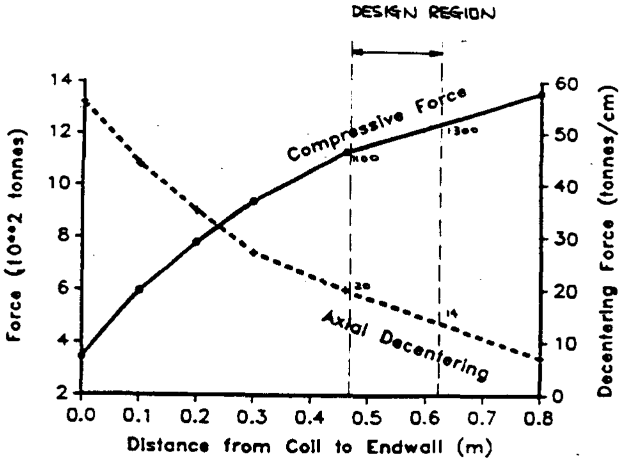


FIG. 5-1. Coil compressive force and axial decentering force as a function of the axial distance between the end of the coil and the iron endcap calorimeter.

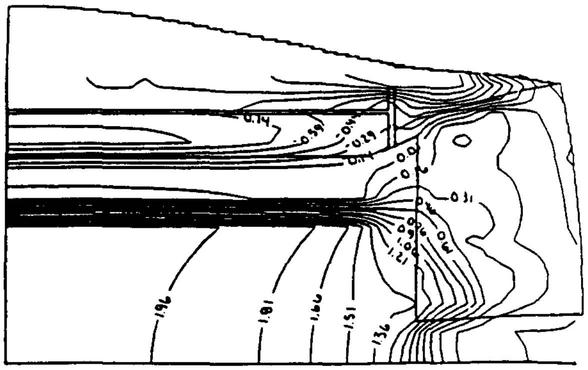


FIG. 5-2. Field contour plot for an axial coil-iron separation of 470 mm. The field is in teslas.

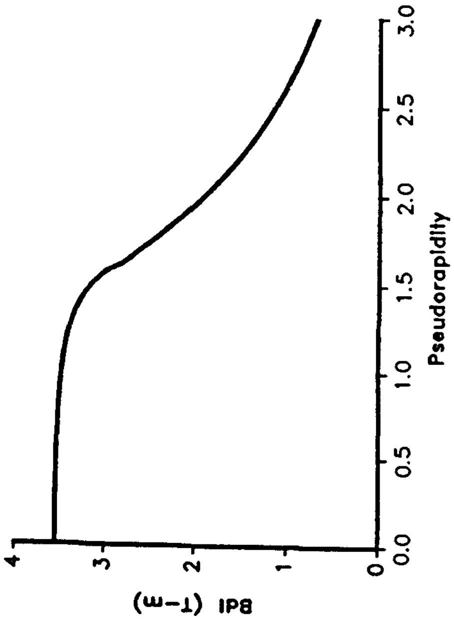
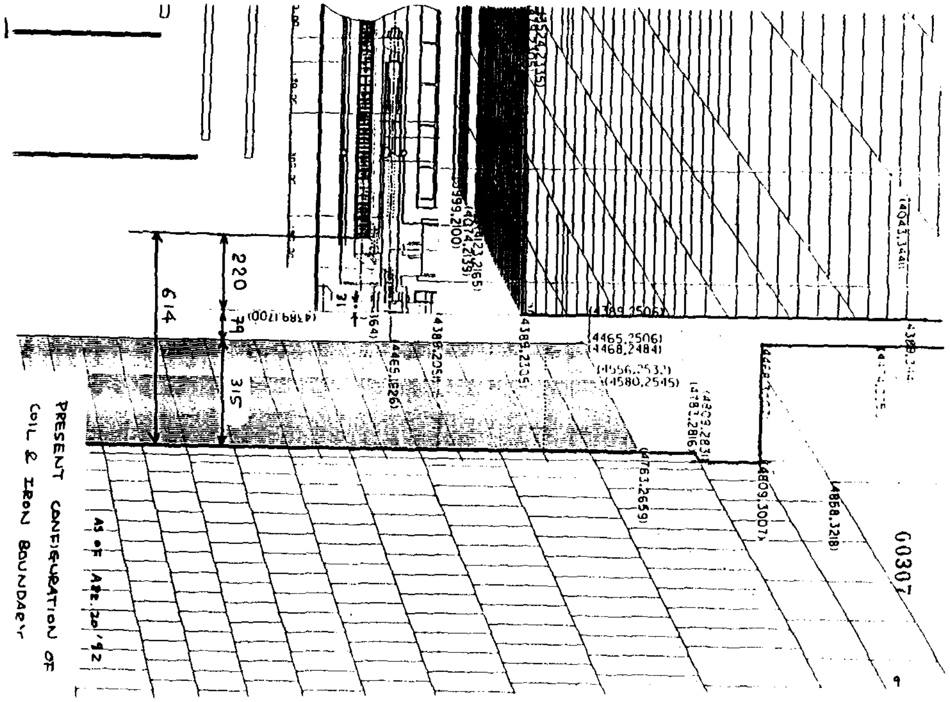


FIG. 5-3. $\int B \times dl$ as a function of pseudorapidity.



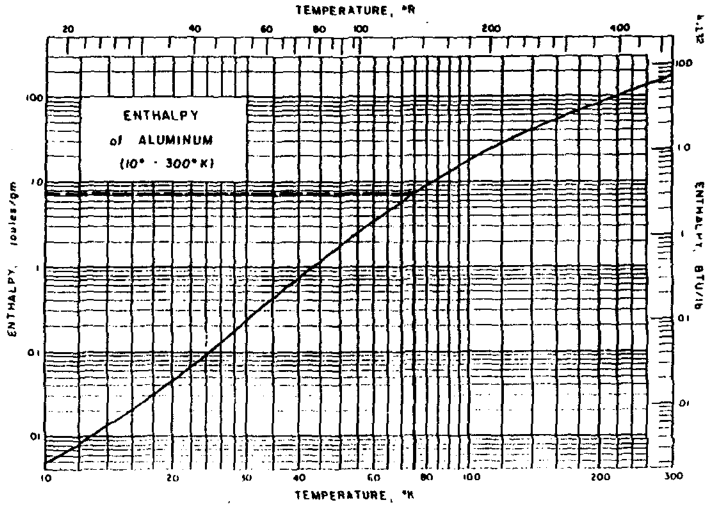
PRESENT CONFIGURATION OF COIL & IRON BOUNDARY

AS OF APR. 20 '92

Design Guide Lines:

- In order to have fully elastic design, the stresses in the coil AND outer-support-cylinder cold mass, the mechanical design will limit the strain in the outer support cylinder to <u>0.1 %.</u>
- To eliminate unacceptable thermal stress in the cold mass following a quench, the maximum hot spot temperature will be limited to <u>100 K.</u>
- To optimize transparency of the magnet (1.2 Xo),

E/M Ratio = H(T2) - H(T1) = 7.5 kJ/kg



ENTHALPY OF AL V.S. TEMPERATURE

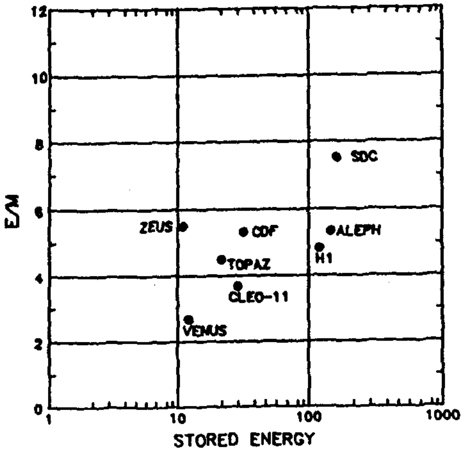
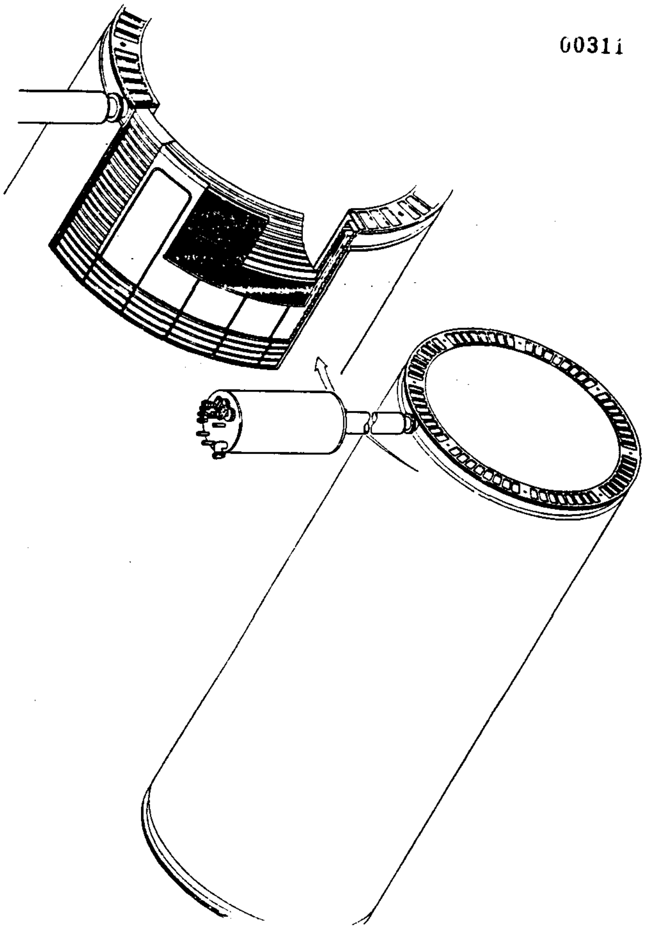


FIG. 5-4. Ratio of stored energy to cold mass for existing thin detector solenoids.



BIRD'S EYE VIEW OF THE SOLENOID

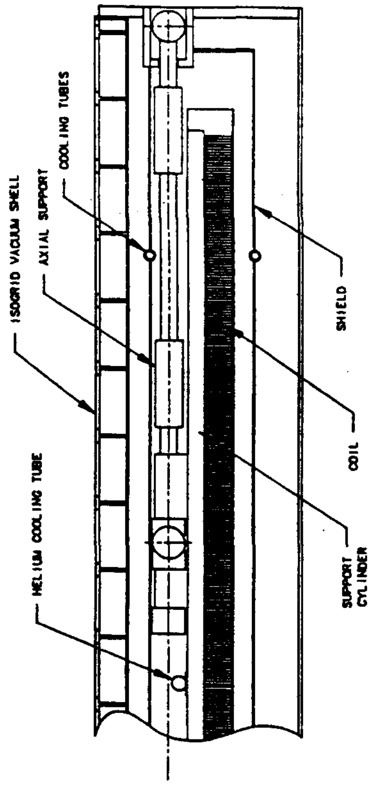


FIG. 5-6. Cross section of the end portion of the detector solenoid[1]

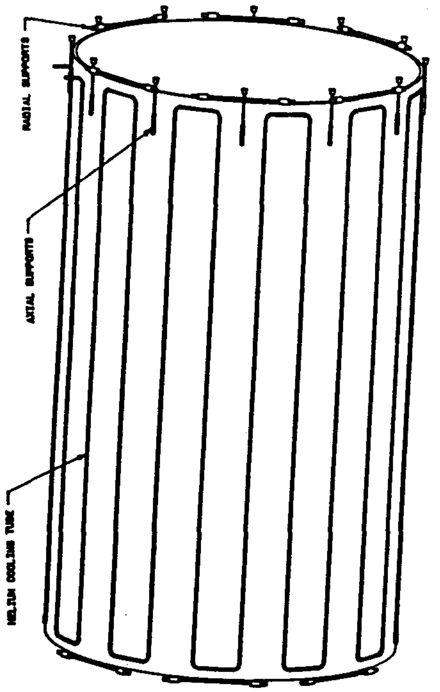


FIG. 5-7. Solenoid cold mass. Radial supports are on both ends, axial supports are on one end only.

Table 5-2
Baseline design parameters of SDC solenoid.

Dimensions:		
Cryostat	**Inner radius**	**1.70 m**
	Outer radius	**2.05 m**
	Half length	**4.389 m**
Coil	**Effective radius**	**1.84 m**
	Half length	**4.12–4.18 m**
Conductor	**Thickness**	**44 mm**
Outer support cylinder	**Thickness**	**31 mm**
Electrical parameters		
Central field		**2.0 T**
Nominal current		**8,000 A**
Inductance		**4.6 H**
Stored energy		**146 MJ**
Stored energy / cold mass		**7.4 kJ/kg**
Typical charging time		**1 hour**
Mechanical parameters		
Effective cold mass		**20 tonnes**
Total weight		**25 tonnes**
Radial magnetic pressure		**1.6 MN/m^2**
Axial compressive force		**11 MN** (13)

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Table 5-5

Design parameters of the SDC superconductor.

Aluminum stabilized superconductor	
Superconductor material	Nb Ti/Cu
Stabilizer	Al (99.999% +200 ppm Zn)
Area ratio (Nb/Ti/Cu/Al)	1/1/29.8
Conductor size	43.8 × 4.37 mm^2
Superconductor strand	
Strand diameter	1.277 mm
Nb Ti filament diameter	20 μm
Number of filaments.	4100
Superconductor cable	
Overall size	6.4 × 2.5 mm^2
Number of cables	10 (2 × 5)
Cabling pitch	50–60 mm
J_c in Nb Ti (at 5 T, 4.2 K)	2500 A/mm^2
Critical current (at 5 T, 4.2 K)	16,000 A
Characteristics of stabilizer	
RRR (Cu)	100
RRR (Al)	500
Yield Strength of Al (at 77 K)	67 MPa
Shear strength b/w Cu / Al	20 MPa
Conductor welding joint	
Joint resistance (at 4.2 K)	$< 10^{-9}\ \Omega$

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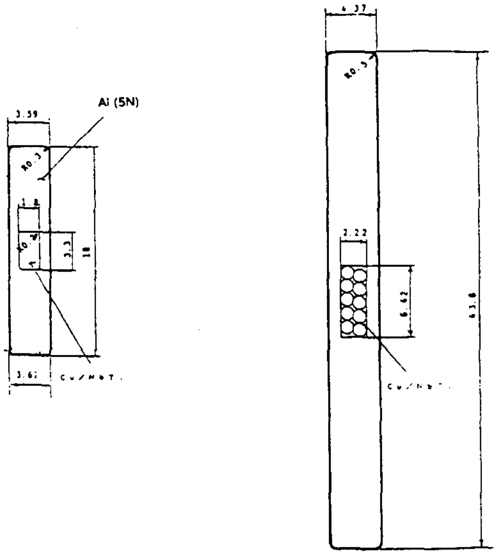

CROSS SECTIONS OF (a)
TOPAZ AND (b) SDC SUPERCONDUCTOR

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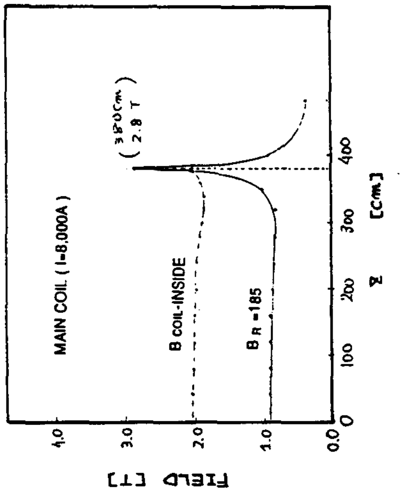

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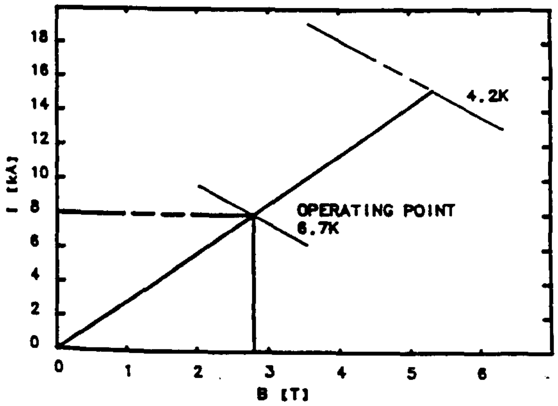


FIG. 5-11. Short-sample characteristics of the SDC conductor and the operating load line.

Table 5-3
Transparency of the solenoid.

Element		Thickness [mm]	X_0	λ_0
Outer vac. wall	(Isogrid)	11	0.138	0.0321
	(Honeycomb)	(7.1)	(0.080)	(0.0180)
Outer rad. shield		2.0	0.022	0.0051
Outer sup. cylinder		31.0	0.348	0.0787
Superconductor				
(Al stab)		39.0	0.438	0.0990
(Nb.Ti/Cu)		2.9	0.181	0.0167
(GFRP)		3.1	0.016	0.0058
(Al Strip)		2.0	0.022	0.0051
Inner rad. shield		2.0	0.022	0.0051
Inner vac. wall		6.0	0.067	0.0152
Super-insulation		2.0	0.007	0.0023
Total	(w/ isogrid)		1.261	0.2651
	(w/ honeycomb)		(1.203)	(0.2510)

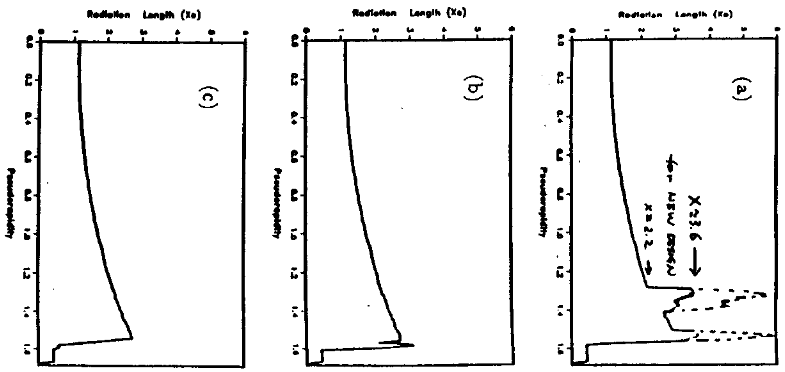


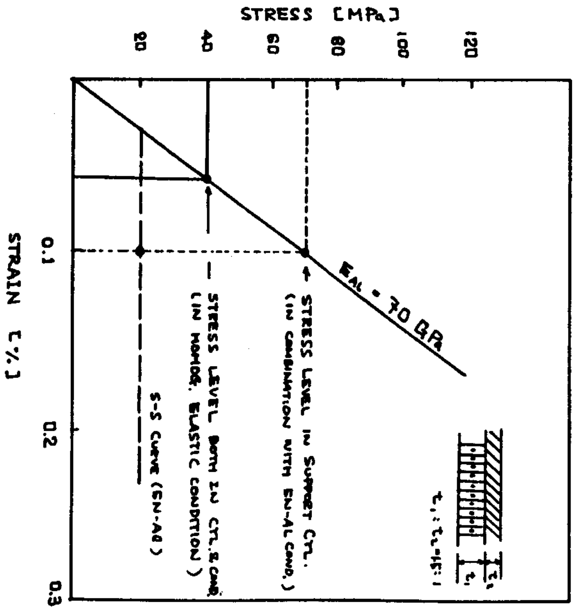
FIG. 5-5. Thickness of solenoid, in radiation lengths, as a function of pseudorapidity. (a) is a path through an axial support and is typical of 6% of the circumference, (b) is through the metallic end fitting of a radial support, 15% of the circumference, and (c) is through the GFRP section of a radial support, 21% of the circumference.

COIL MECHANICAL DESIGN

IMPORTANT ISSUES IN THE SDC MECANICAL DESIGN

1. The combined hoop and axial stress, or stress intensity, in the superconductor during magnet operation in air. This generates a maximum shear stress ($2\tau = s_1 - s_2$) in the pure aluminum, at the axial coil center,
2. The shear stress at the boundary between the coil and the outer support cylinder due to the axial electromagnetic force, which is a maximum at the coil end.

COMPARISON OF RADIAL (HOOP) STRESS
AND STARAIN IN CASES OF SN-AL AND <SN-AL COND.



COIL MECHANICAL DESIGN

$\frac{E}{M} = 7.5 \text{ kJ/kg}$

⇓

$t_{coil} = \frac{E}{2\pi R \cdot l \cdot \rho \, (E/M)} = 0.075 \text{ m}$

⇓

$S_\phi = \frac{R}{t} \times P_R = 39 \text{ MPa}$

$(\because P_R = \frac{B_z^2}{2\mu_0} = 1.6 \text{ MPa})$

$S_z = \frac{-F_z}{2\pi R t} = 15 \text{ MPa}$

$\therefore 2\tau = S_\phi - S_z = 54 \text{ MPa} \quad (\ll 6.7 \text{ MPa})$ Y.S. of Al ST

MAX SHEAR STRESS

(STRESS INTENSITY).

Table 5-4
Mechanical stability of the SDC coil.

Element	Material	Yield stress	Anal. model	FEA
Conductor	Pure Al (3N8)	67 MPa	(54) 52 MPa	52 Mpa
Cylinder	A-5083	169 MPa	(54) 52 MPa	< 52 MPa
Cylindrical bonding	Epoxy	(15 MPa)	< 4 MPa	< 1 MPa

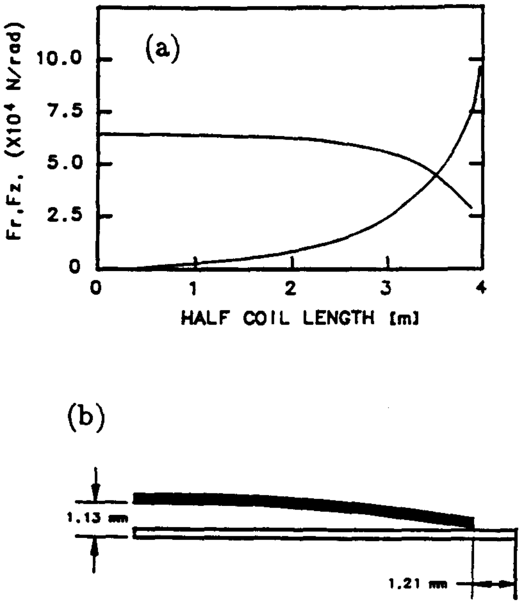


FIG. 5-8. (a) Radial and axial components of the force on the superconducting coil; (b) deformation of the coil under these forces.

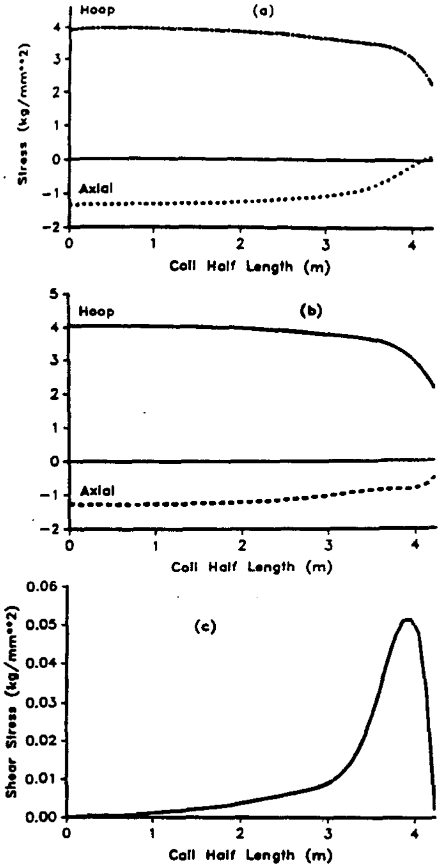


FIG. 5-9. Stresses as a function of axial position (a) on support cylinder, (b) on superconducting coil, and (c) on epoxy joint.

QUENCH PROTECTION

BASIC CONSIDERATION:

- CONDUCTOR STABILITY

  MINIMUM QUENCH ENERGY ..... > 0.1 J

- QUENCH SAFETY

  MAX. TEMP. AFTER QUENCH... 100 K

NEW CONCEPT FOR FAST QUENCH PROPAGATION:

- PURE ALUMINUM QUENCH PROPAGATOR

$$V(phi) = \frac{J \cdot L_0 \theta_s}{\gamma_c (\theta_s - \theta_0)}$$

$$V(z) = (k_z / k_\phi)^{1/2} \cdot v_\phi$$

- AXIAL QUENCH SPEED MAY BE INCREASED INDEPENDENTLY BY USING AXIAL PURE AL STRIP.

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QUENCH BEHAVIOR & THERMAL DESIGN

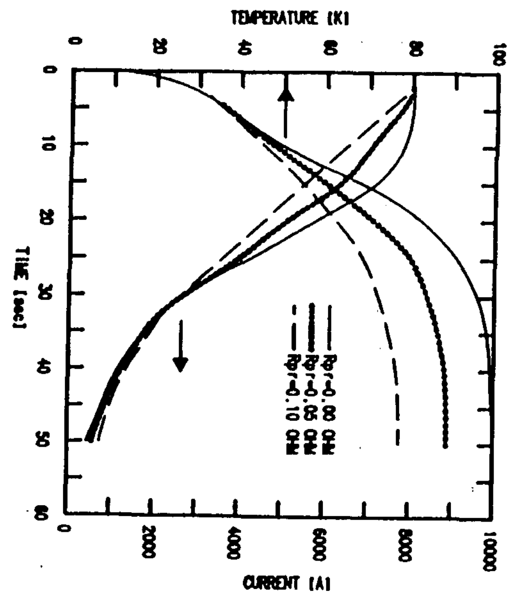

FIG. 5-10. Quench behavior of the SDC solenoid with pure aluminum strips. Quench back in the outer support cylinder is not included in this calculation and the mass of the outer support cylinder is neglected.

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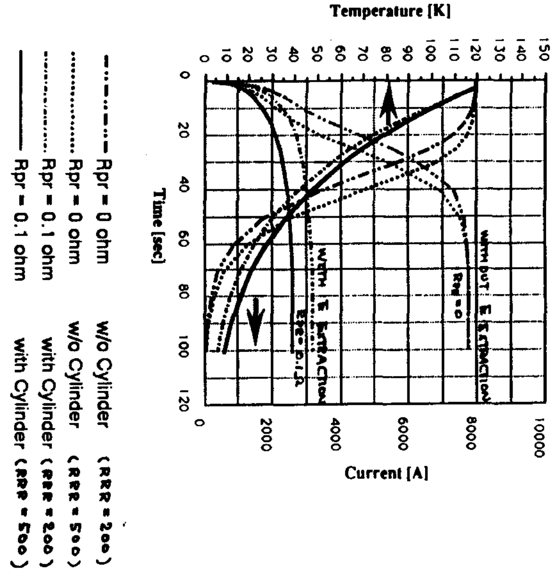

QUENCH BEHAVIOR IN MOST PESIMISTIC AND OPTIMISTIC CASES.

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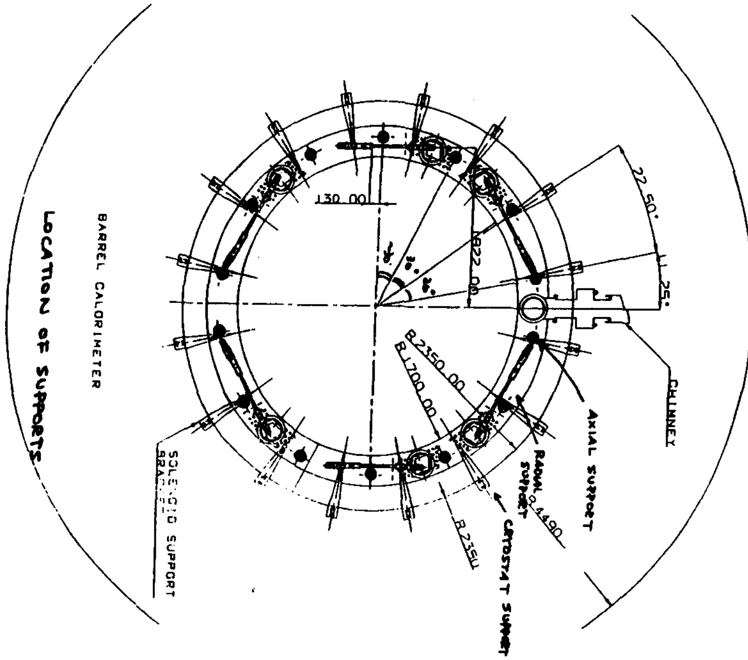
COIL SUPPORT DESIGN



LOCATION OF SUPPORTS

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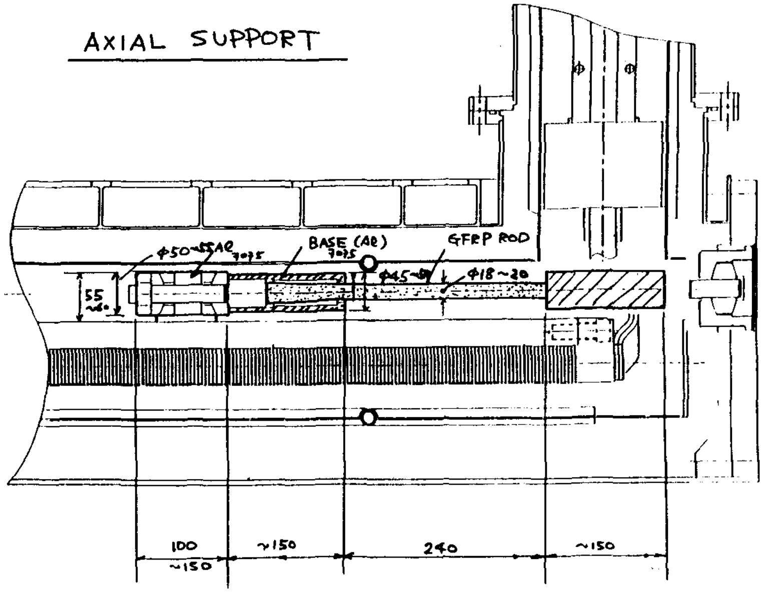
Table 5-8
Design load of the coil support system. (RADIAL SUPPORT)

Function		Upward	Downward	Left/right	F/B-ward
Global force					
Coil weight	(ton)	−20	20		
Applied load	(ton)	40	40	40	40
Design load	(ton)	20	60	40	40
Force constant	(t/mm)	2	2	2	2
Support stiffness	(t/mm)	>10	>10	>10	>10

AXIAL SUPPORT



DESIGN OF AXIAL SUPPORTS OF THE COIL

	TDR	RE-REVISED (APRIL 28)	
MATERIAL FOR SUP.	GFRP	GFRP	
TYPE	SINGLE	SINGLE	
DIA. OF SUPPORT	φ20mm	φ20mm	(18)
EFFECTIVE LENGTH	300mm	300mm	(240)
MATERIAL FOR BASE	Ti-Alloy	Al-Alloy(7075)	
DIA. OF BASE	φ50mm	φ50mm	
LENGTH OF BASE	~150mm	~150mm	
# OF AXIAL SUPPORT	14	14	
TENSILE FORCE/14RDS.	≥300tonnes	≥300tonnes	
BUCKLING FORCE/14RDS.	100tonnes	100tonnes	
THERMAL LOADS/14RDS.	~600mW	~600mW	
BUMP IN TRANSPARENCY	3.7	1.4	
(MAX) at η=1.4	at tR=60mm	(tR=60mm)	

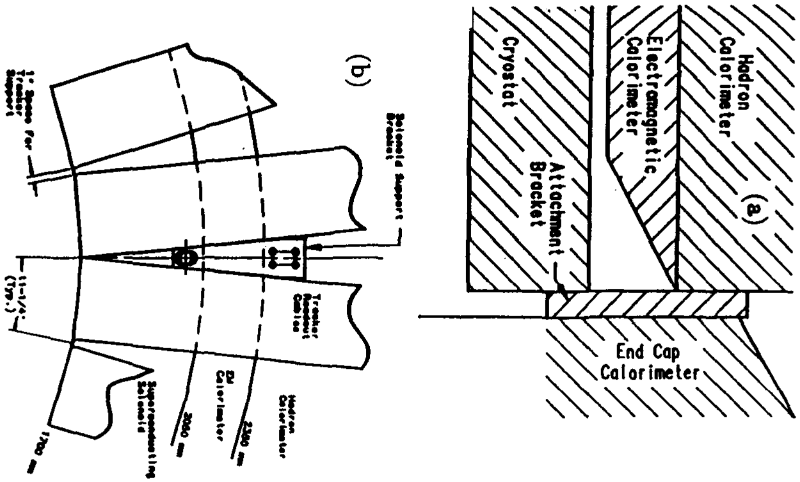
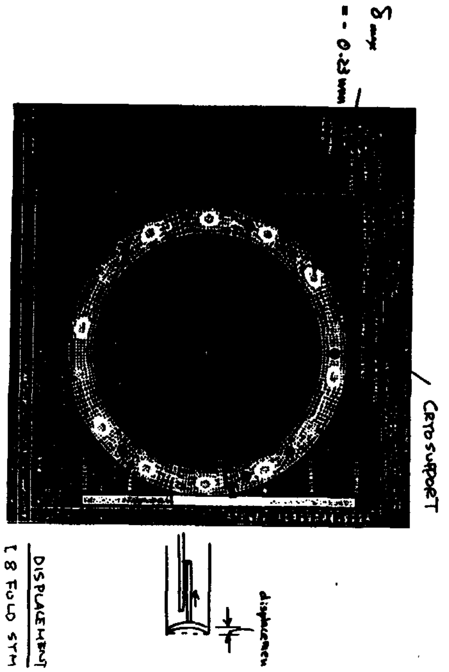
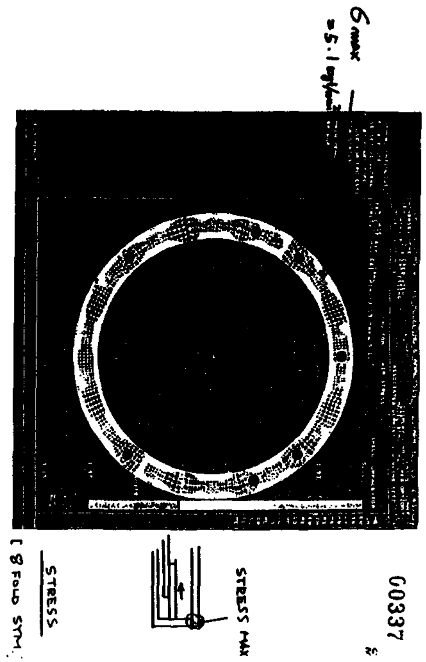


FIG. 5-13. Cryostat attachment to the barrel hadron calorimeter, (a) section view, (b) enlarged end view.





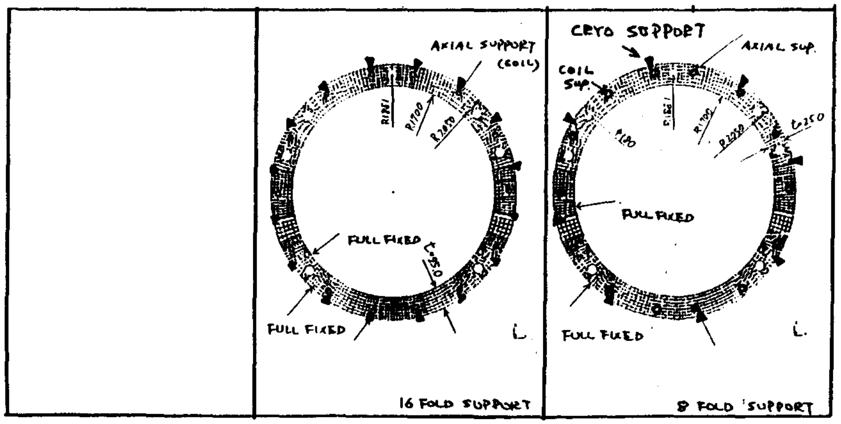
SUPPORT FOR CRYOSTAT &BULKHEAD STRESS ANALYSIS

	16 FOLD SYMMETRY		8 FOLD SYMMETRY	
	MAX STRESS	DISPLACE-MENT	MAX STRESS	DISPLACE-MENT
1 ATM. (-40T)	0.65 kgf/mm2 [6.5 MPa]	0.04 mm	0.78	0.04
1 ATM+Fz(40ton)	3.1	0.16	3.1	0.16
1 ATM-Fz(-40T)	4.4	0.23	5.1	0.23

CRYOSTAT VACUUM WALL DESIGN

Table 5-6
Outer vacuum shell requirements.

Vacuum load	1 atm radial and axial
Design standard	
Radial collapse pressure	> 2 atm
Axial buckling load	> 2 atm
Allowable stress	Based on ASME press. vessel code
Material	Aluminum alloy
Construction	Welded joints



ANALYS MODEL FOR BULKHEAD IN STRESS & DISPLACEMENT DUE TO AXIAL ELECTROMAGNETIC DECENTERING FORCE OF (± 40Tonnes) and 1 ATM LOAD.

CONSIDERATION ON CRYOSTAT VAC. WALL

Table 5-7
Comparison of solid, isogrid, and honeycomb outer vacuum shells.

	Solid	Isogrid	Brz. honeycomb
Aluminum alloy	5083	5083-H32	6951/4045-T6
Total thickness (mm)	27	46	46
Skin thickness (mm)	—	4.0	$3.0 + 3.0$
Skin layers	—	single	double
Node configuration	—	triangle	hexagon
Effective thickness (mm)	27	11	7
Weight reduction ratio	1	1/2.5	1/3.9
Radiation thickness (X_0)	0.303	0.123	0.079
Maximum size of plate (m × m)	2 × 6.4	2.2 × 4.3	1.2 × 4
Units to be welded	8 (= 2 × 4)	12 (= 3 × 4)	21 (= 3 × 7)

THERMAL LOAD AND COOLING CHARACTERISTICS

Table 5-9
An estimate of steady state thermal loads for the SDC solenoid.

Component	300 to 77 K	77 to 4.2 K	300 to 4.2 K
Thermal radiation	300	30	—
Conduction			
Coil support rods ($n = 24$–36)	24	2.5	—
Shield support rods ($n = 12$)	3	—	—
Chimney and service port	36	4.5	—
Current leads (8 kA pair)	—	—	30
Total thermal load	363 W	37 W	30 L/hr

Table 5-10
Cooling design parameters in the initial cool down.

Boundary conditions	
Coil cold mass (aluminium)	20 tons
Radiation shield mass (aluminium)	1 ton
Temperature difference in coil during cool down	<50 K
Coil cooling	
Initial cooling speed	1 K/hr
GHe mass flow required	21 g/s
Initial cooling power	4.4 kW
Initial inlet pressure	0.7 MPa A
Pressure drop in cooling pass (25 mm ϕ × 250 m)	0.2 MPa
Shield cooling	
Initial cooling speed	1 K/hr
GHe mass flow required	1.2 g/s
Initial cooling power	250 W
Initial inlet pressure	0.7 MPa A
Pressure drop in cooling pass (15 mm ϕ × 400 m)	<0.035 MPa

Table 5-11
Cooling design parameters in steady state operation.

Coil		
Typical coil temperature		4.4 K
Quality of two phase helium	Inlet	0.8
	Outlet	0.5
He mass flow required		7 g/s
Pressure drop in cooling pass		small
Current leads mass flow		1–2 g/s
Radiation shield		
Max. shield temperature		< 70 K
Inlet He gas temperature		60 K
Helium gas mass flow required		15 g/s
Heat exchange efficiency		0.5
Pressure drop in cooling pass		small

Table 5-13
Diagnostic instrumentation in the SDC solenoid.

Element	Coil	R/S	Support	V/V	Chimn.
Voltage taps (short pair tap)	13				4
Quench heater	3				
Temperature sensors					
Pt-Co (300 K–4.2 K)	24	24	4	4	6
CGR (high resol. @4.2 K)	17				
Strain gauge (pair of ϕ, z)	12	8	36	16	4
Position sensor (r, ϕ)	8				8
(z)	4				4
Pressure	3				
Total	83	32	40	20	26

Table 5-12
Cooling parameters in excitation and after quench.

Excitation of the coil		
Static heat-in-leakage		37 W
Eddy current loss in support cylinder	(@ 1 mT/s)	88 W
Quality of two phase helium	Inlet	0.8
	Outlet	0.5
He mass flow into cooling pass required		23 g/s
He mass flow into current leads	(2 × 8,000 A)	1 g/s
Quench recovery in coil		
Energy dumped into coil		88 MJ
Recovery time assumed		4 hr
Cooling power required		6.2 kW
Cooling efficiency assumed		0.8
Liquid (two phase) helium flow required		28 g/s (830 L/hr)
Total liquid helium for recovering		3,300 L

Table 5-14
General requirements on the cryogenics for the SDC solenoid.

Typical refrigeration capacity	1,500 W at 4.4 K
Liquid helium transfer rate	750 L/hr (after quench)
Liquid helium storage capacity	5,000–10,000 L
Cold gas helium mass flow at 60 K	12 g/s

5.3.9. Diagnostics and instrumentation

A substantial amount of instrumentation is required to monitor the cooldown and steady-state operation of the magnet and to provide diagnostic data. The monitoring and diagnosis functions include:

- Maintaining the appropriate cool-down rate, allowable temperature distribution, mechanical stress and thermal contraction.
- Monitoring the magnet during excitation and operation by measuring the temperature of the cold mass, thermal shields and support intercepts; the stress in the outer support cylinder and supports; the magnet current and voltage; and the magnetic field.
- Monitoring the magnet during and after a quench to verify the safety of the system. Current, voltage, temperatures, pressures and stresses will be measured as a function of time.

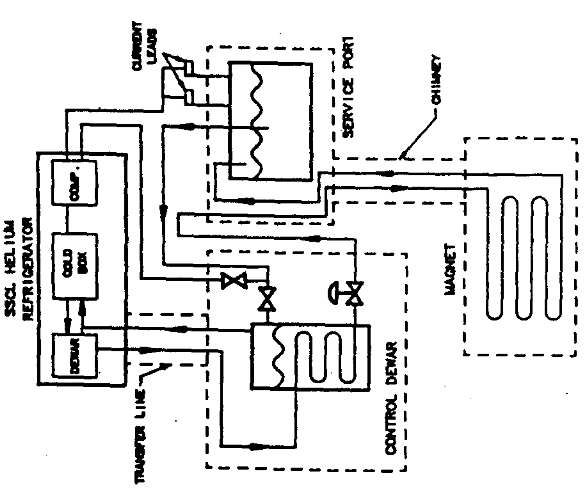


FIG. 5-14. Flow schematic of the cryogenic system for the SDC solenoid.

Table 5-15

General requirements for the SDC electric power system.

Maximum current	10,000 A
Nominal operation current	8,000 A
Regulation	$< \pm 1 \times 10^{-4}$
Inductive voltage (@1 mT/s)	±17 V
Bus-bar voltage drop	10 V
Ramp rate	1–10 A/s
Fast discharge time const.	45 s
Slow discharge time const.	500 s
DC switching time	< 1 s

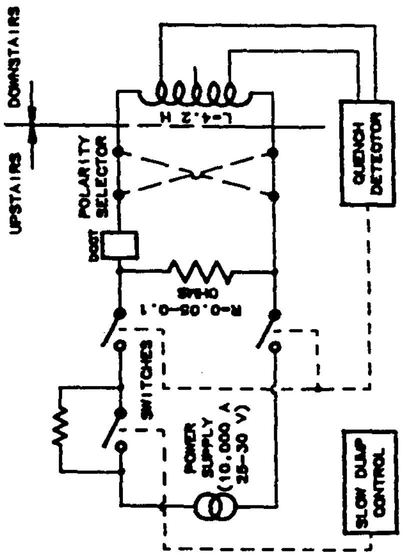


FIG. 5-15. Schematic of DC circuit for SDC solenoid.

Table 5-17

Overall schedule for the prototype solenoid and the production solenoid. The Japanese fiscal year begins April 1 of the year indicated.

JFY1991	Prototype Magnet Development —Superconductor fabrication —Winding machine development —Outer support cylinder fabrication —Isogrid vacuum wall development
JFY1992	—Coil winding —Cryostat element fabrication
JFY1993	—Assembly of the magnet —Cool-down and excitation in air
JFY1994	Production Magnet Fabrication —Superconductor fabrication —Cryostat element fabrication
JFY1995	—Coil winding —Magnet assembly
JFY1996	—Magnet assembly continued —Cool-down and excitation test in air —Transportation to SSCL
JFY1997	—Cool-down and excitation in iron —Field mapping

PARAMETERS IN PHYSICS AND ENGINEERING

Requirements from Physics	Engineering Parameters important
. Magnetic Field	Coil . Mechanical Safety at 2 T
Bc = 2 T	Max. Stress (2 τ) < 60 MPa
Fz = 1300 tonnes	(@ Y.S.$_{0.2\%}$ = 6.7 MPa)
. Tranparency	. Stability in Superconductivity
X = 1.2 Xo (@η = 0)	MQE = 0.27 J
< 3.0 Xo (@η = 1.5)	
λt= 0.25 λt (@ = 0)	. Thermal Safety after QUENCH
	Tmax < 100 K
	Δε < 0.05 %
	Cryostat (Vacuum Wall) . Stability against Buckling
	P_{bkt} > 2 atm

---

3. OVERALL COIL SAFETY PARAMETERS SUCH AS SUPERCONDUCTOR STABILITY, TEMPERATURE RISE AFTER QUENCH, MECHANICAL STRESSES, ETC. ARE SIMILAR TO OTHER SUCCESSFUL SOLENOIDS IN OPERATION.

4. MATERIAL CORRESPONDING TO 0.6 λ_r CAN BE SAVED ; 0.4 λ_r IN THE COIL AND 0.2 λ_r IN THE OUTER VACUUM WALL

5. AN EXTENSIVE R&D PROGRAM IS IN PROGRESS

- PROTOTYPE SOLENOID WITH HIGH E/M RATIO IS BEING BUILT.
- TEST OF AL-STRIP QUENCH PROPAGATORS IN PROTOTYPE COIL
- HIGH STRENGTH AL-STABILIZED CONDUCTOR (Y.S. > 67 MPa)
- TESTS OF COIL WINDING AND BONDING TO OUTER SUPPORT CYLINDER
- TESTS OF HONEYCOMB AND ISO-GRID OUTER VACUUM WALL
- 1/4 LENGTH FULL DIAMETER PROTOTYPE MAGNET TESTED BY 1993

Summary

1. THE SDC SOLENOID DESIGN HAS BEEN OPTIMIZED TO PROVIDE:

B = 2 T
V = 3.8 m dia x 8.8 m
1.2 λ_r (at η = 0)
0.25 λ_t

2. TO MINIMIZE MATERIAL IN THE SOLENOID, THE FOLLOWING TECHNICAL CONCEPTS HAVE BEEN INCLUDED IN THE SOLENOID DESIGN:

- HIGH E/M RATIO OF 7.5 KJ/KG WITH HIGH SPEED QUENCH PROPAGATION USING PURE AL-STRIP QUENCH PROPAGATOR TO SUPPRESS LOCAL TEMPERATURE RISE.
- HIGH STRENGTH PURE ALUMINUM STABILIZER (Y.S.> 65 MPa) HAS BEEN DEVELOPED WITH RRR = 500.
- HONEYCOMB OR ISO-GRID OUTER VACUUM WALL FOR CRYOSTAT

CRYOGENIC SYSTEM

A. STEFANIK

SDC CRYOGENIC SYSTEM

WORK PLAN: EQUIPMENT/SYSTEM SUPPLY

SOLENOID MAGNET, CHIMNEY, SERVICE PORT - KEK

SOLENOID POWER SUPPLY CIRCUIT - FNAL/SSCL

VLPC SYSTEM FOR FIBER TRACKER - TRK GRP

CONTROL DEWAR - FNAL

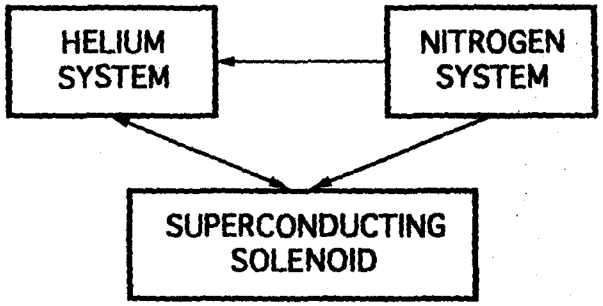
TRANSFER LINES - SSCL

HELIUM REFRIGERATOR/LIQUEFIER - SSCL

NITROGEN SYSTEM - SSCL

CONTROL SYSTEM - SSCL

SDC CRYOGENIC SYSTEM



KEK FNAL SSCL

Presented by A. M. Stefanik - FNAL

SDC CRYOGENIC SYSTEM

DESIGN PHILOSOPHY

1. SAFETY: GOAL IS TO OPERATE IN RISK ZONE 3 ON SSCL RISK ASSESSMENT MATRIX.
2. RELIABILITY: GOAL IS TO MAXIMIZE SYSTEM AVAILABILITY -> SIMPLE YET ROBUST SYSTEM, MTBF DATA, SAFETY ANALYSIS, ACCESS FOR REPAIR, SHORT TERM OPERATION WITH COLDBOX SHUTDOWN.
3. MINIMIZE THE RADIATION AND ABSORPTION LENGTHS OF COMPONENTS IN FRONT OF THE EM CALORIMETER.
4. ENGINEERING ANALYSIS AND TESTING (PREDICTABILITY).

SDC CRYOGENIC SYSTEM

WORK PLAN

1. ESTABLISH DESIGN REQUIREMENTS
2. SUPPLY (DESIGN -> DELIVERY)
3. INSTALLATION
4. COMMISSIONING
5. OPERATION
6. MAINTENANCE

SDC CRYOGENIC SYSTEM

DESIGN PHILOSOPHY

5. ESTABLISH QUALITY ASSURANCE REQUIREMENTS.
6. COMPLIANCE WITH DOE ORDERS, CODES AND STANDARDS.
7. MINIMIZE OPERATING EQUIPMENT IN THE DETECTOR HALL.

Severity of Consequences

	Descriptive Word	Personal Illness/ Injury	Equipment Loss(s)	Test Unit Downtime	Data Compromise	Environmental Effect
1	Catastrophic	Death	>500K	> 4 months	Data never recoverable or primary program objectives lost	Long-Term (5yrs or greater) environmental damage or requiring $500K or more to correct and/or in penalties
2	Critical	Severe injury or severe occupational illness	100K to 500K	2 weeks to 4 months	Repeat of test program	Medium-term (1-5 yrs) environmental damage or requiring $100K-500K to correct and/or in penalties
3	Marginal	Minor injury or minor occupational illness	1K to 100K	1 day to 2 weeks	Repeat of test period	Short-term (less than 1 yr) environmental damage or requiring $1K-100K to correct and/or in penalties
4	Negligible	No injury or illness	< 1 K	< 1day	Repeat data point or data requires minor manipulation or computer rerun	Minor environmental damage that readily can be repaired or requiring less than $1K to correct and/or in penalties

Probability of Mishap

Level	Descriptive Word	Definition
A	Frequent	Likely to occur repeatedly during life cycle of syst.
B	Probable	Likely to occur several times in life cycle of syst.
C	Occasional	Likely to occur sometime in life of system.
D	Remote	Not likely to occur in life cycle of system.
E	Improbable	Prob. of occurrence cannot be distinguished from 0.
F	Impossible	Physically impossible to occur

Risk Zones-

Code		Action
①	High	Imperative to suppress risk to lower level
②	Med	Operation requires written, time-limited waiver endorsed by Mgmt.
③	Low	Operation permissible

Note: PERSONNEL must not be exposed to hazards in Risk Zones 1 and 2

* Adapted from MIL-STD-882B

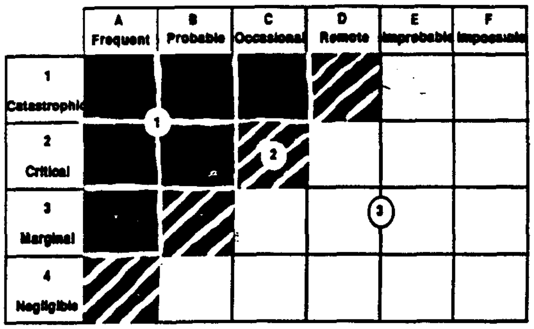
SDC CRYOGENIC SYSTEM

SOLENOID SYSTEM

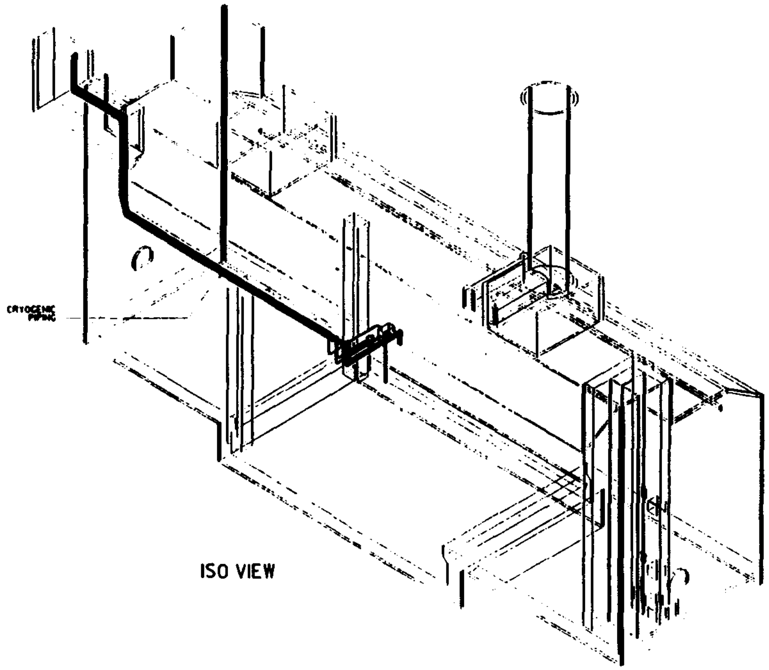
RISK ASSESSMENT AFTER ABATEMENT

1. PERSONNEL AND THE ENVIRONMENT ARE NOT EXPOSED TO HAZARDS IN RISK ZONES 1 AND 2.
2. EQUIPMENT (EQUIPMENT LOSS, TEST UNIT DOWNTIME AND DATA COMPROMISE) ARE NOT EXPOSED TO HAZARDS IN RISK ZONES 1 AND 2 IN MOST CASES.

APPENDIX B. RISK ASSESSMENT MATRIX



	A Frequent	B Probable	C Occasional	D Remote	E Improbable	F Impossible
1 Catastrophic	■	■	■	▨		
2 Critical	■	■	▨ ②			
3 Marginal	■	▨		③		
4 Negligible	▨					



ISO VIEW

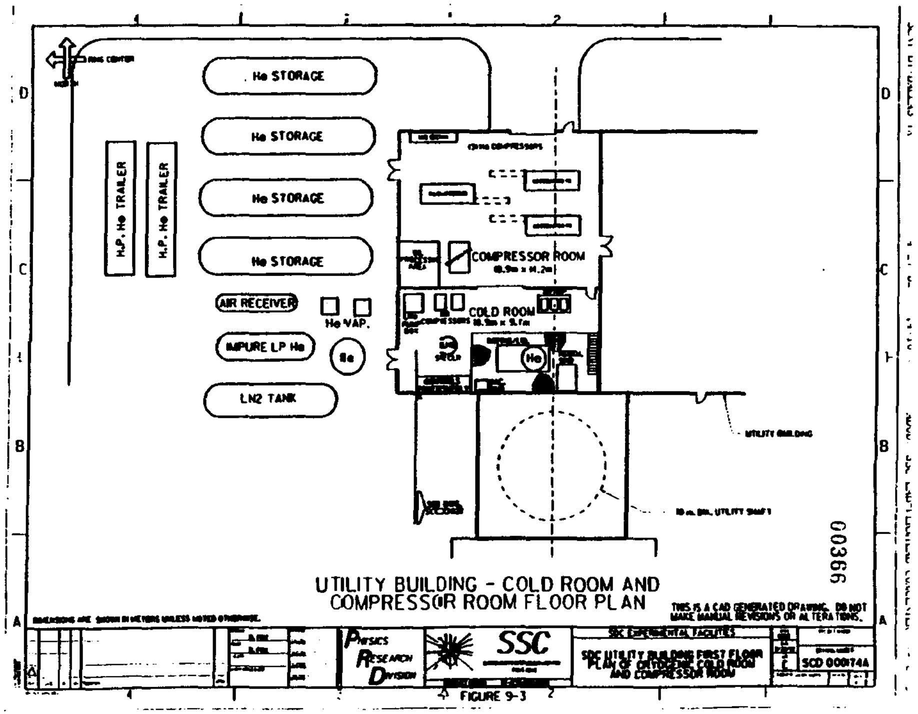
SDC CRYOGENIC SYSTEM

SOLENOID SYSTEM

RISK ASSESSMENT AFTER ABATEMENT

3. EXAMPLES OF EQUIPMENT EXPOSED TO HAZARDS IN RISK ZONES 1 AND 2:

   - LOSS OF THERMAL INSULATION VACUUM, 1-C-1
   - THERMAL SHORT AFTER FINAL ASSEMBLY, 1-D-2
   - ISOGRID OR HONEYCOMB OUTER VACUUM SHELL IS UNACCEPTABLE AFTER IT IS BUILT, 1-D-2. REPLACE WITH NEW ISOGRID OR HONEYCOMB SHELL (1-D-2) OR SOLID PLATE (1-E-3).

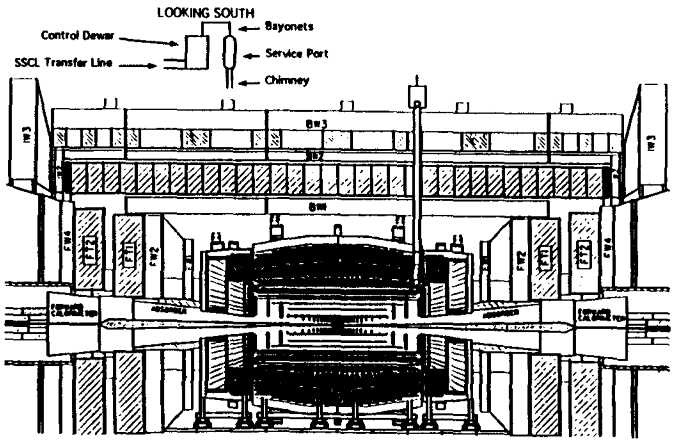


UTILITY BUILDING - COLD ROOM AND COMPRESSOR ROOM FLOOR PLAN

FIGURE 9-3

SDC CRYOGENIC SYSTEM

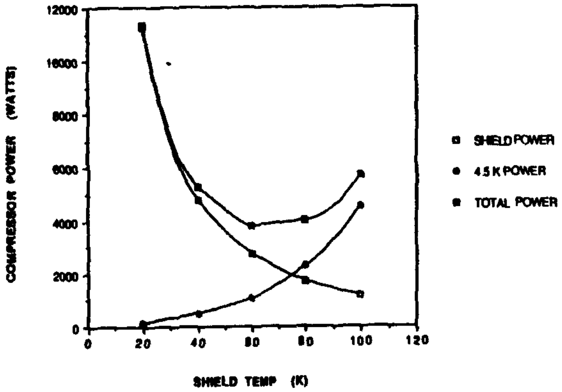
LOCATION OF SOLENOID SYSTEM



SDC CRYOGENIC SYSTEM

COOLING OF SOLENOID THERMAL RADIATION SHIELD

SINGLE SHIELD - CASE 2



SDC CRYOGENIC SYSTEM

COOLING OF COIL/OUTER SUPPORT CYLINDER

THE COIL AND OUTER SUPPORT CYLINDER ARE COOLED WITH FORCED FLOW, TWO-PHASE HELIUM IN A SINGLE PASS COOLING TUBE WHICH IS ATTACHED TO THE OUTER SUPPORT CYLINDER (OSC).

OTHER METHODS CONSIDERED:

1. SINGLE PHASE LIQUID HELIUM - LOWER HEAT TRANSFER COMPARED TO TWO-PHASE HELIUM.

2. THERMOSIPHON - RADIAL SPACE REQUIRED FOR SUPPLY AND RETURN MANIFOLDS

SDC CRYOGENIC SYSTEM

HELIUM COOLING TUBE ON OUTER SUPPORT CYLINDER

1. DESIGN PRESSURE IS BASED ON PRESSURE GENERATED DURING SOLENOID QUENCH - 6.5 MPa -A (945 PSIA) CURRENTLY (250 METER LENGTH, ONE-WAY VENTING).

2. CONSIDER ANSI B31.3 - 302.2.4, "ALLOWANCES FOR PRESSURE AND TEMPERATURE VARIATIONS, METALLIC PIPING", IN SETTING THE DESIGN PRESSURE.

SDC CRYOGENIC SYSTEM

COOLING OF SOLENOID THERMAL RADIATION SHIELD

1. FORCED FLOW, TWO-PHASE NITROGEN

   ADVANTAGES: MAINTAIN SHIELD COOLING DURING SHORT DURATION COLDBOX SHUTDOWNS, AIR SEPARATION PLANT ON THE SITE.

2. HELIUM GAS FROM INTERMEDIATE STAGE IN THE R/L

   ADVANTAGES: SINGLE CRYOGEN SIMPLIFIES THE SYSTEM, REDUCES LIQUID NITROGEN ODH IN THE DETECTOR HALL.

SDC CRYOGENIC SYSTEM

CHIMNEY - CURRENT DESIGN

1. VACUUM VESSEL RELIEVING PRESSURE IS 0.15 PSIG.

   VACUUM VESSEL DESIGN PRESSURE IS 0.6 PSIG.

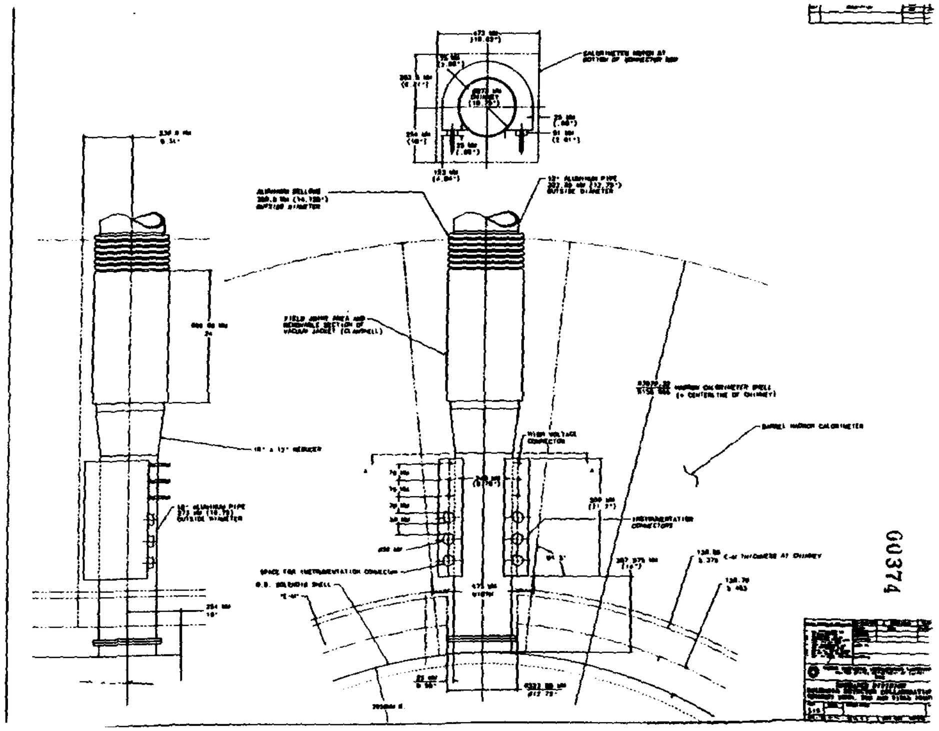
2. VACUUM PUMPING THROUGHPUT IS 2 x10^-3 ATM-CC/SEC AT 2.2 x10^-5 TORR (CDF SOLENOID TRIP POINT).

   CDF LEAK RATE WITH LIQUID HELIUM WAS DETERMINED TO BE ABOUT 1.5 x10^-7 ATM-CC/SEC.

SDC CRYOGENIC SYSTEM

HELIUM COOLING TUBE: MAXIMUM PRESSURE AND HELIUM VENTING RATE DURING A QUENCH

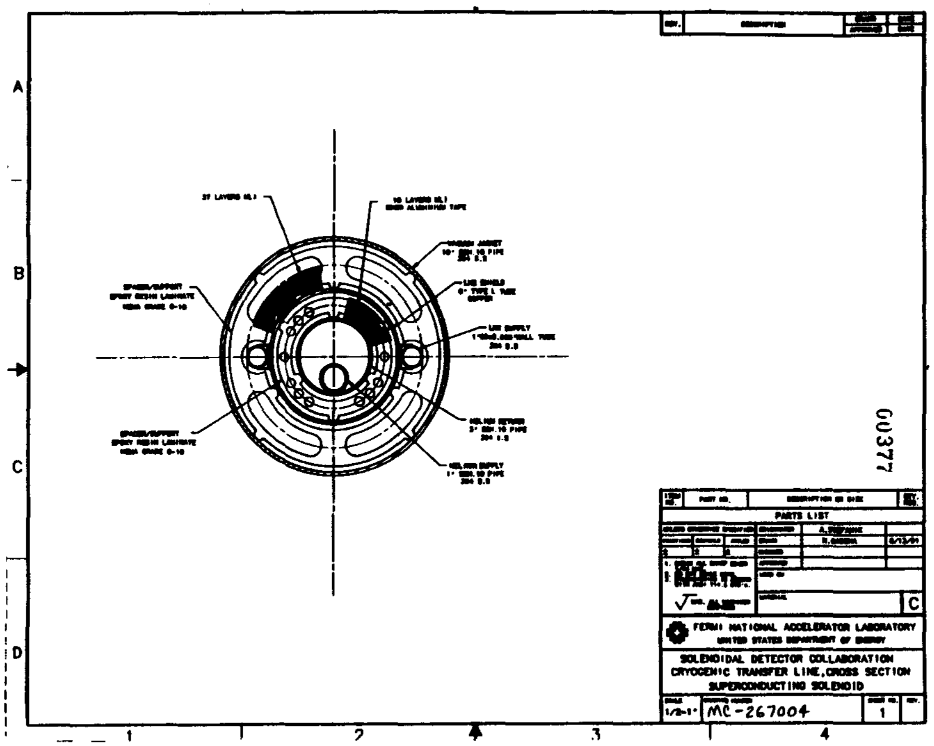
1. CALCULATE SUPPORT CYLINDER HEATING RATE ASSUMING ADIABATIC EDDY CURRENT HEATING (NO QUENCH-BACK).
2. CALCULATE PEAK PRESSURE WITH EQUATION DEVELOPED BY MILLER ET AL (ORNL) USING MAXIMUM HEATING RATE CALCULATED IN #1. CHECK APPLICABILITY.
3. CALCULATE HELIUM VENTING RATE FROM COOLING TUBE DURING EDDY CURRENT HEATING TO SIZE THE RELIEF VALVES.
4. WILL INCLUDE QUENCH-BACK FROM THE OUTER SUPPORT CYLINDER.



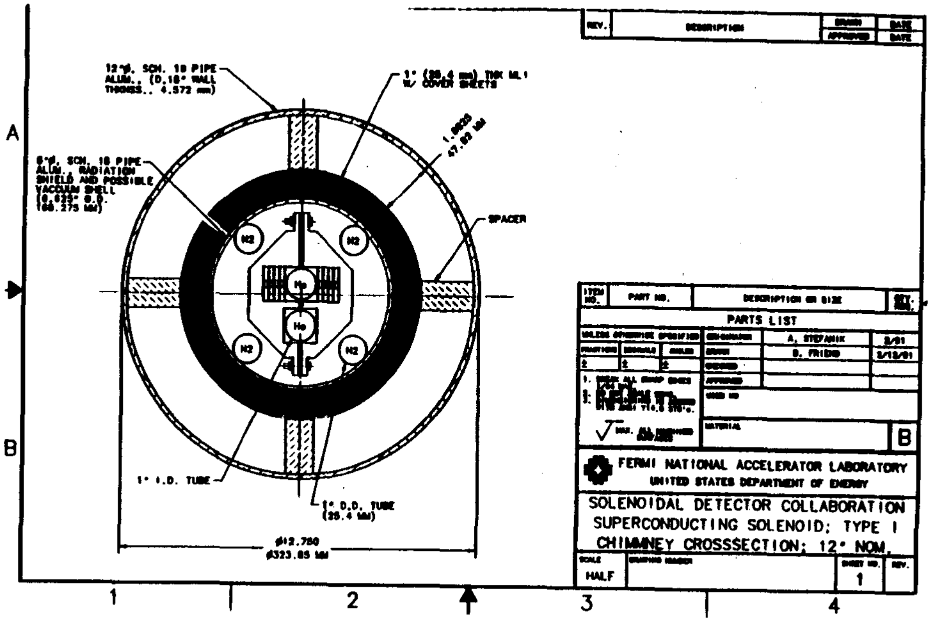
SDC CRYOGENIC SYSTEM

CHIMNEY

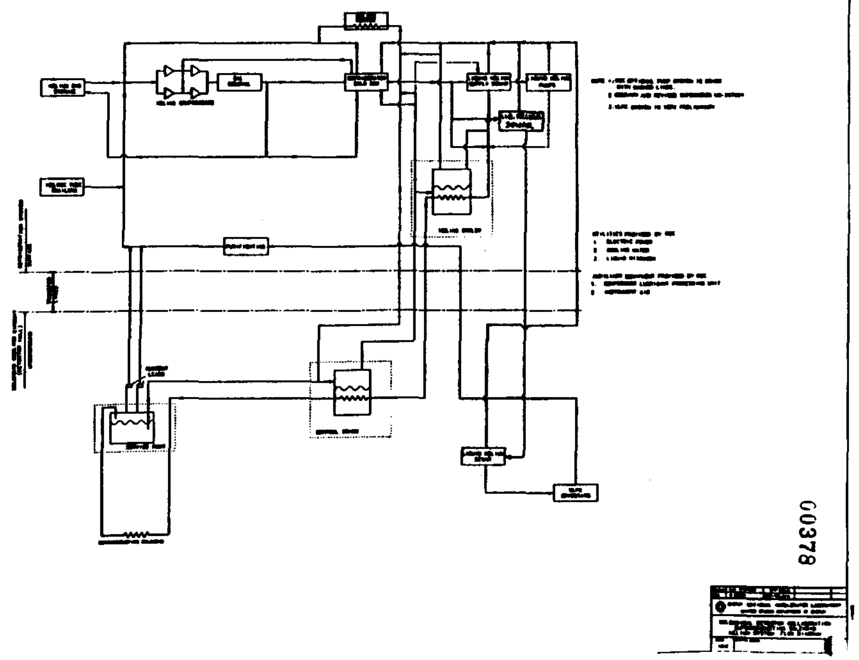
1. PASSAGE FOR CRYOGEN LINES & SUPERCONDUCTING LEADS
2. FLOW CHANNEL FOR PRESSURE RELIEF & VACUUM PUMPING
3. PROVIDE ACCESS TO THE FIELD JOINTS
4. INSTRUMENTATION CONNECTOR BOX
5. ACCOMMODATE DIFFERENTIAL MOVEMENTS
6. SPACE LIMITATIONS



G0377



G0375



G0378

SDC CRYOGENIC SYSTEM

TRANSFER LINES - ALL LINES FOLLOW THE SAME ROUTE

1. 10" CRYOGENIC TRANSFER LINE: LIQUID HELIUM SUPPLY AND RETURN, AND EITHER HELIUM GAS OR LIQUID NITROGEN SUPPLY AND RETURN.
2. CURRENT LEAD FLOW RETURN (ONE LINE FOR EACH LEAD)
3. COOLDOWN
4. NITROGEN GAS SUPPLY
5. PROCESS NITROGEN RETURN
6. WATER COOLED ELECTRICAL BUS
7. VLPC SYSTEM

G0376

SDC CRYOGENIC SYSTEM

MINIMUM 4.35 K COOLING POWER REQUIREMENT FOR THE REFRIGERATOR/LIQUEFIER

1. STEADY STATE: 304 WATTS PLUS 1.2 G/S RETURNING AT 300 K -> 425 WATTS
2. CHARGING: (35 MINUTES) 88 + 425 = 513 WATTS
3. COOLDOWN: (14 DAYS) 700 WATTS
4. QUENCH RECOVERY: (4 HOURS) 2500 WATTS AT 4.5 K

SDC CRYOGENIC SYSTEM

STEADY STATE 4.35 K LIQUID HELIUM REFRIGERATION LOADS

	ESTIMATED
1. SOLENOID SYSTEM	37 WATTS
2. CONTROL DEWAR	13
3. TRANSFER LINE	50
4. 10,000 LITER LHe DEWAR	4
5. VLPC SYSTEM - DISTRIBUTION	200 (BUDGET-?)
TOTAL	304 WATTS

SDC CRYOGENIC SYSTEM

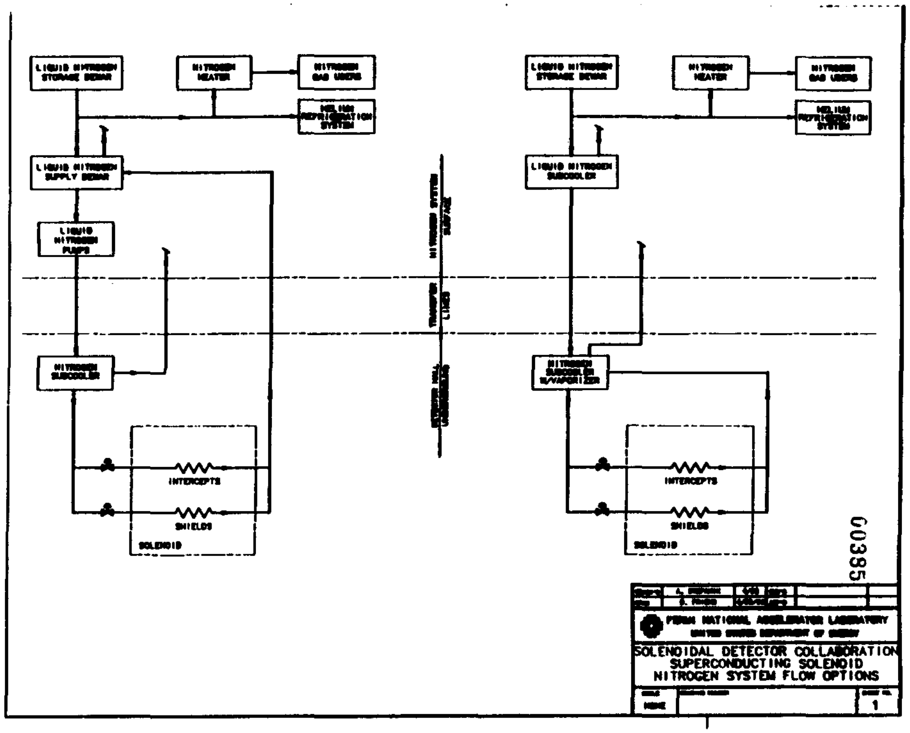
SOLENOID QUENCH RECOVERY

1. 3300 LITERS OF LIQUID HELIUM REQUIRED.
2. 10,000 LITER STORAGE DEWAR - ENOUGH LIQUID IS AVAILABLE TO RECOVER FROM 2 BACK-TO-BACK QUENCHES.
3. COMPRESS AND STORE THE GAS. RELIQUEFY DURING STEADY STATE OPERATION -> 12 HOURS/QUENCH WITH 1500 WATT REFRIGERATOR/LIQUEFIER.
4. A PRESSURE OF 0.31 MPa (45 PSIG) IS NEEDED IN THE LIQUID HELIUM SUPPLY DEWAR AT THE START OF QUENCH RECOVERY TO DELIVER THE REQUIRED FLOW RATE OF 28.5 GRAMS/SEC (3300 LITERS IN 4 HOURS). DEWAR NORMAL OPERATING PRESSURE IS 0.07 MPa (10 PSIG).

SDC CRYOGENIC SYSTEM

STEADY STATE HELIUM LIQUEFACTION LOADS

	ESTIMATED
1. VAPOR COOLED CURRENT LEADS	1 GRAM/SEC
2. VLPC SYSTEM - CASSETTES	0.2
TOTAL	1.2 GRAMS/SEC



G0385

SDC CRYOGENIC SYSTEM

REFRIGERATOR/LIQUEFIER SIZE - CURRENT ESTIMATE

FULL REFRIGERATION CAPACITY OF 1500 WATTS AT 4.35 K IS REQUIRED BASED ON THE STEADY STATE, CHARGING, COOLDOWN AND QUENCH RECOVERY REQUIREMENTS.

G038

SDC CRYOGENIC SYSTEM

STEADY STATE LIQUID NITROGEN SYSTEM LOADS

	ESTIMATED
1. SOLENOID SYSTEM	363+ WATTS
2. CONTROL DEWAR	125
3. TRANSFER LINE	165
4. 75,000 LITER LN2 DEWAR	340
5. PIPING & EQUIPMENT	325
TOTAL	1318+ WATTS

G0386

SDC CRYOGENIC SYSTEM

EFFECT OF TWO-PHASE HELIUM IN THE RETURN LINE FROM THE SOLENOID - 40 METER ELEVATION CHANGE

BOTH CASES ASSUME A FLOW RATE OF 23 G/S AND A RETURN TEMPERATURE TO THE R/L OF 4.35 K.

1. QUALITY = 0.5 AT SOLENOID EXIT -

   OPERATING CONDITIONS AT SOLENOID EXIT:
   0.128 MPa-A, 4.48 K.

2. QUALITY= 0 AT SOLENOID EXIT (WORSE CASE) -

   OPERATING CONDITIONS AT SOLENOID EXIT:
   0.15 MPa-A, 4.68 K.

G0384

SDC CRYOGENIC SYSTEM

HELIUM STORAGE ESTIMATE

1. LIQUID

   10,000 LITER NOMINAL CAPACITY

   2.5 METER DIAMETER BY 5.5 METER OAL

   QUANTITY: 1

2. GAS

   7100 Nm^3

   3.35 METER DIAMETER BY 16.5 METER OAL

   QUANTITY: 4

SDC CRYOGENIC SYSTEM

NITROGEN STORAGE ESTIMATE

1. LIQUID

   75,000 LITER NOMINAL CAPACITY

   3 METER DIAMETER BY 16.5 METER OAL

   QUANTITY: 1

2. GAS

   NONE

00389

R & D AND PROTOTYPE

A. YAMAMOTO

Super conducting Solenoid Magnet

R&D Program

Presented by

A. Yamamoto (KEK) and R. Kephart(FNAL)

Presented at SDC Technical review May 5, 1992.

CONTENTS

- HIGH STRENGTH ALUMINUM STABILIZED SUPERCONDUCTOR (Y.S.> 67 MPa),
- COIL WINDING AND BONDING OUTER SUPPORT CYLINDER,
- PROTOTYPE MAGNET WITH 1/4 LENGTH.
- HIGH E/M RATIO UP TO 15 KJ/KG IN A R&D SOLENOID.
- UNIFORM ENERGY DUMP WITH PURE ALUMINUM STRIP QUENCH PROPAGATOR,
- HONEYCOMB AND ISOGRID VACUUM WALL.

DEVELOPMENT

OF

HIGH STRENGTH AL STABILIZED SUPERCONDUCTOR

- WHY WE NEED IT?:
  - PRESET SUPERCONDUCTORS USED IN CDF, TOPAZ ETC TOO WEAK TO SUSTAIN FORCE AT 2T.
  - FULLY ELASTIC DESIGN DESIRED IN SDC SOLENOID TO MAKE SURE RELIABLE MECHANICAL DESIGN UNDER BOUNDARY CONDITION OF COMPLICATED STRESS: $2\tau = S_\varphi - S_z \simeq 54$ MPa. (39 −(− 15))
- GOAL FOR DEVELOPMENT

$$Y.S.\,(0.2\%) \geq 60\,\text{MPa} \quad (\text{minimum})$$
$$\geq 70\,\text{MPa} \quad (\text{desired})$$

- HOW TO IMPROVE MECH. CHARACTERISTICS
  - ADDITIONAL MATERIAL (100 ~ 200 ppm)
    Si, Zn, Fe, Cu ...
  - MECHANICAL COLD WORK (10 ~ 20%)
    DRAWING, ROLLING ...

DEVELOPMENT OF CONDUCTOR

Table 2. Design parameters of the aluminum-stabilized superconductor for the SDC and TOPAZ detector.

Al-stabilized superconductor			TOPAZ	SDC
Cu/NbTi Insert				
type			monolith	cable
dimension	thickness	mm	1.8	2.2
	width	mm	3.3	6.4
	corner R	mm	0.2	
Cu/NbTi ratio			1	1
filament diameter		μm	50	20
twist pitch		mm	<30	27
RRR of Cu			>120	>100
Al-stabilized superconductor				
dimension	thickness	mm	3.59/3.61	4.42/4.32
	width	mm	18	43.8
	corner R	mm	0.3	0.4
position of Cu/NbTi			central	central
Ic		kA	>7 at 2.4T	>16 at 5T
RRR of Al stabilizer			>1000	500
yield strength of Al		kg/mm2	---	>6 at 77K
(expected)				>6.5
share strength of Al-SC		kg/mm2	>1	>2

Figure 8. Cross-sectional photograghs of full-sized aluminum-stabilized superconductor for the SDC detector by experimental production.

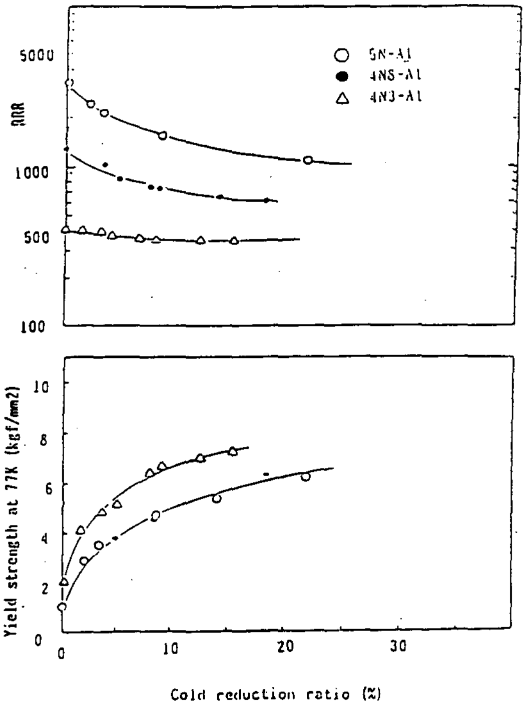


Figure 2. The dependence of yield strength (77K) and RRR about usual high purity aluminum on cold reduction ratio.

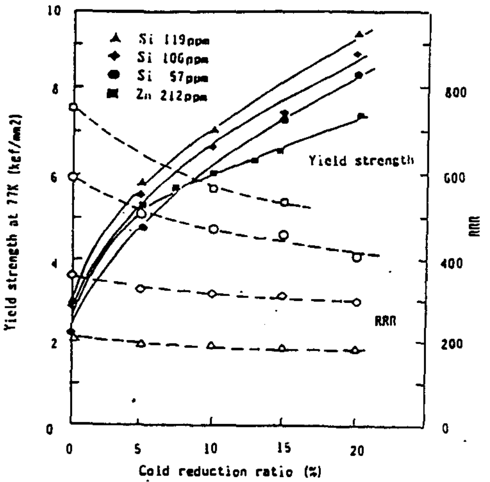


Figure 3. The dependence of the yield strength (77K) and RRR on the cold reduction ratio for Al-Si and Al-Zn.

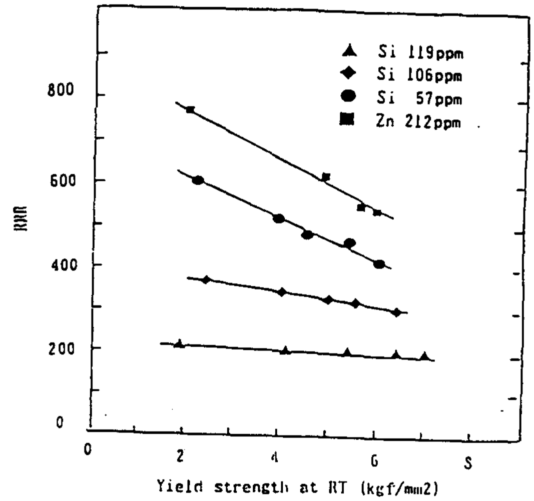


Figure 4. The relationship between the yield strength (RT) and RRR for Al-Si and Al-Zn alloys.

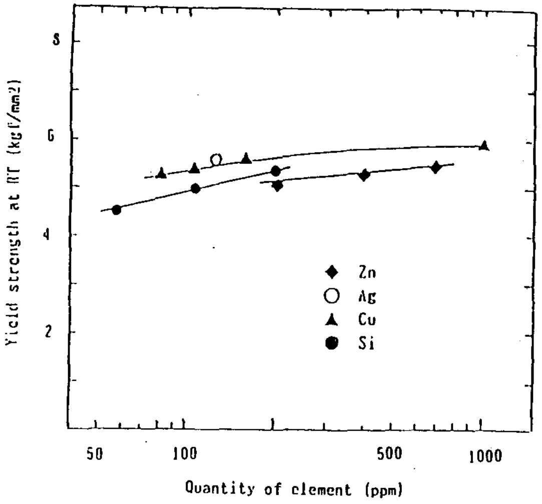


Figure 5. The dependence of the yield strength (RT) on the quantities of added elements after 10% cold-worked.

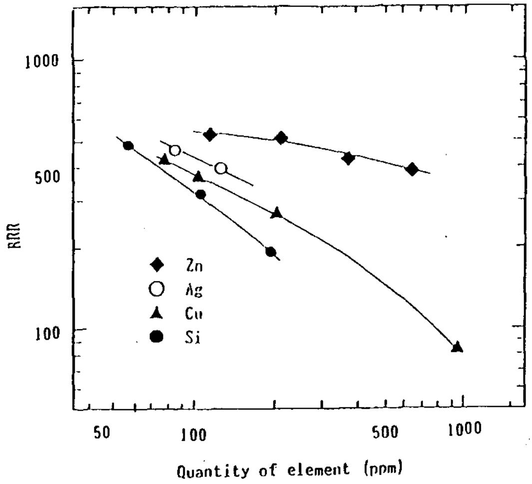
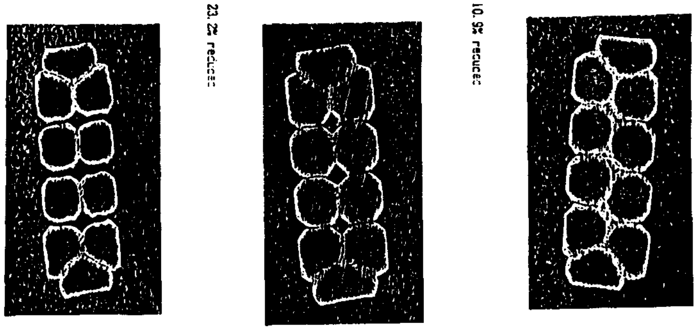


Figure 6. The dependence of RRR on the quantities of added elements after 10% cold-worked.


(1) as extruded

(2) after 10.9% reduced

(3) after 23.2% reduced

Figure 7. Typical cross-sectional photographs of [illegible] sized aluminum-stabilized [illegible] SDC detector [illegible]

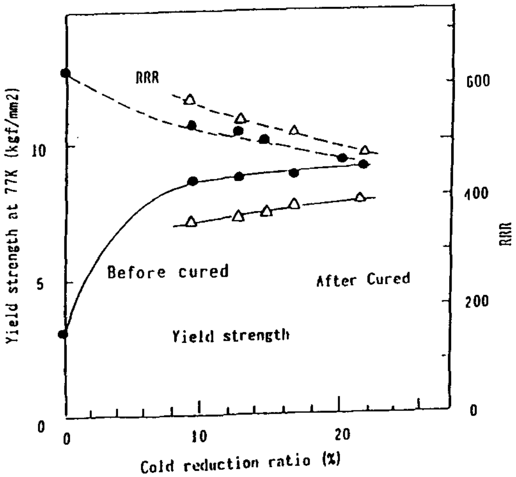


Figure 9. The dependence of the yield strength (77K) and RRR of aluminum matrix on the cold reduction ratio for the full-sized SDC conductor.

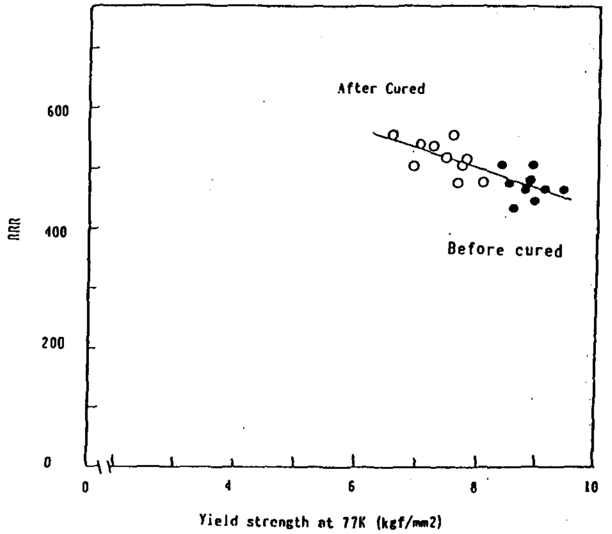
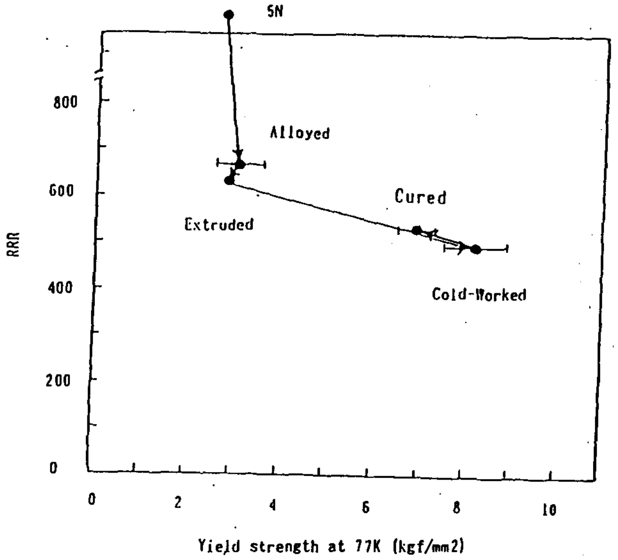


Figure 10. The relationship between the yield strength (77K) and RRR of aluminum matrix on the cold reduction ratio for the full-sized SDC conductor.



Fgure 11. Yield strength (77K) and RRR of aluminum matrix on production stage.

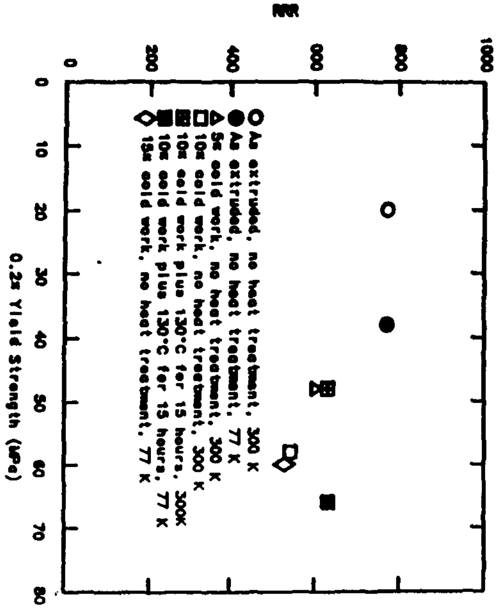
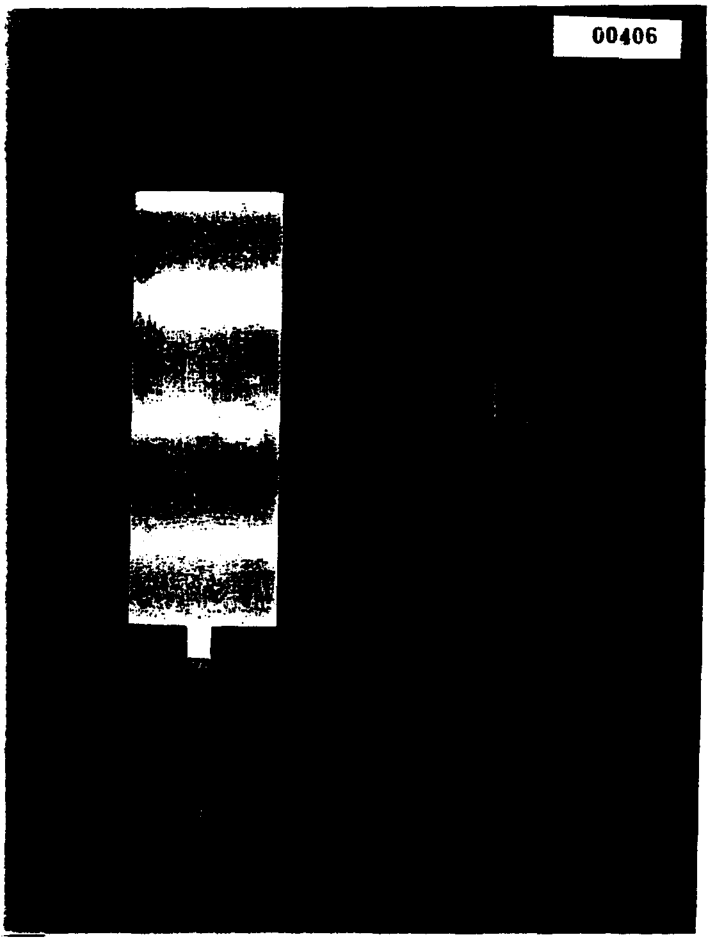


FIG. 5-12. Residual resistivity ratio (RRR) as a function of yield strength in pure aluminum. The operating stress in the conductor is 52 MPa and the minimum acceptable RRR is 500.

Table 3. Mechanical strength and RRR of aluminum matrix on production stages

Step	at RT(kgf/mm2)		at 77K(kgf/mm2)		RRR
	σB	σ0.2	σB	σ0.2	
1.5N (based material)		2.3		~3	2,500
2.Alloyed (200ppmZn)			13.6~15.5	2.6~3.6	680
3.Extruded	5.2	2.3	15.7	2.9	630
4.Cold-worked(12%)	6.6	6.5	15.9~17	7.5~8.9	490
5.Curred	6.3~6.6	5.3~5.6	15.6~16.1	6.5~7.3	530
6.Aged at RT(after 6months)			same as above		

00406



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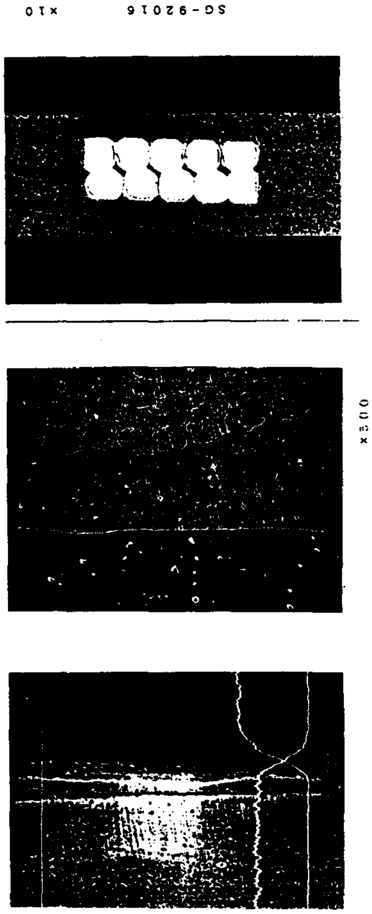
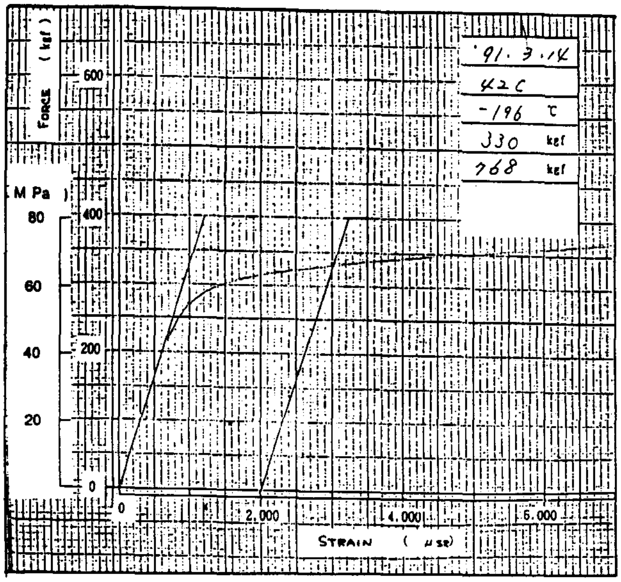


CROSS SECTIONS OF SDC SUPERCONDUCTOR

00408



A STRESS- STRAIN CURVE OF HIGH STRENGTH PURE Al (4N)

00409

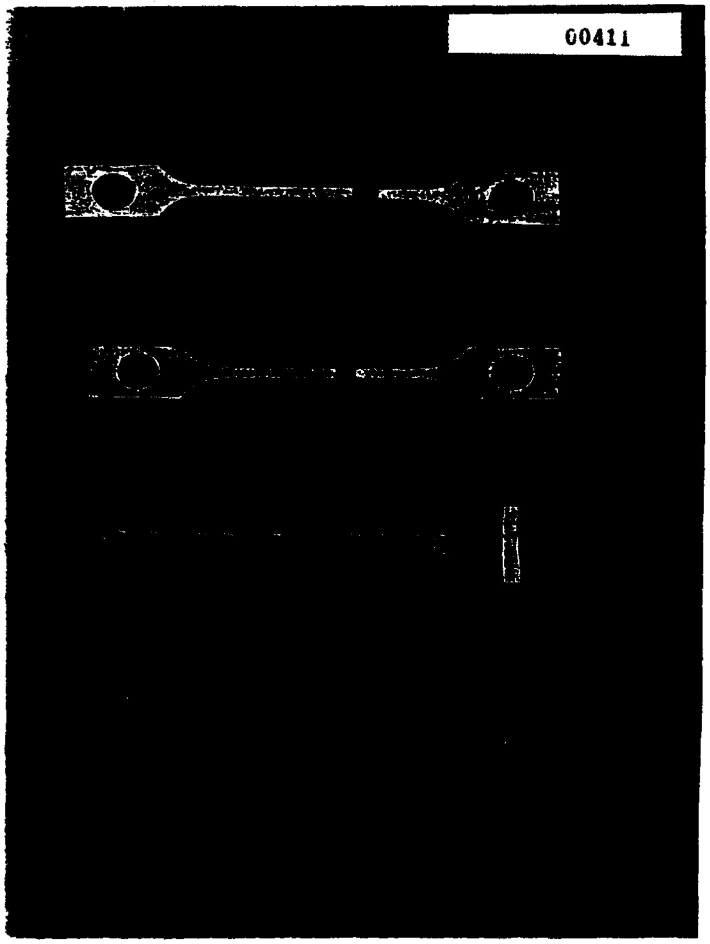
CHARACTERISTICS OF SDC SUPERCONDUCTOR

ITEM	SPEC	before Curing	after Curing
Diamension(mm)			
Strand Dia.	1.277	1.273	
Cable			
thicness	~2.5	2.34	
width	~6.4	6.14	
Conductor			
thickness(L)	(4.42)	4.42	
(S)	(4.32	4.35	
width	43.8	43.8	
corner	≤0.5	0.4	
Al/Cu/NbTi Ratio	27.9/1/1	27.9/0.9/1	
Twist pitch(mm)		27	
IC(A)*1			
at 3.0T		23950	24580 *2
at 4.0 T		19750	20250
at 5.0 T	≥16000	16025	16475
at 6.0 T		12600	13075
at 7.0 T		9225	9500
at 8.0 T		5890	6120
4.2k,10⁻¹¹Ωcm			
RRR	Al Cu	Al Cu	Al Cu
at 0 T	~600,100	497 95	506 97
at 1.0 T		215 79	243 81
at 2.0 T		162 66	198 67
at 3.0 T		140 55	184 56
at 4.0 T		127 47	178 48
at 5.0 T		118 41	176 42

MECHANICAL CHARACTERISTICS OF SDC SUPERCONDUCTOR

00410

ITEM	SPEC	TEST RESULT before Curing			after Curing		
S C Strand		RT	77K	4.2K	RT	77K	4.2K
T.S. [kgf/mm²]		88.9 (88.7) (89.4) (88.6)	121.1 (121.0) (121.1) (121.1)	150.3 (155.7) (144.9)			
Y.S.(0.2%) [kgf/mm²]		40.2 (42.9) (38.6) (39.0)	47.4 (46.7) (45.0) (50.4)	76.9 (76.9) (76.8)			
Elogation [%]		3.0 (3.0) (3.0) (3.0)	1.5 (1.5) (1.5) (1.5)	1.6 (1.6) (1.6)			
Stabilizer		RT	77K	4.2K	RT	77K	4.2K
T.S. [kgf/mm²]		6.3 (6.2) (6.4)	14.7 (14.6) (14.7)	30.4 (30.6) (30.1)	6.0 (6.0) (6.0)	14.5 (14.4) (14.5)	30.2 (30.2) (30.2)
Y.S.(0.2%) [kgf/mm²]	6.0	6.0 (5.8) (6.2)	8.0 (8.0) (7.9)	9.7 (10.0) (9.3)	5.2 (5.4) (4.9)	6.7 (6.6) (6.7)	7.4 (7.0) (7.7)
Elogation [%]		22.4 (23.0) (21.8)	53.9 (55.4) (52.4)	55.0 (55.0)	33.4 (32.8) (34.0)	61.4 (64.2) (58.6)	54.7 (58.6) (52.7)
Overall		RT	77K	4.2K	RT	77K	4.2K
T.S. [kgf/mm²]		11.2 (11.2) (11.2)	17.9 (17.8) (17.9)	( ) ( )	10.7 (10.7) (10.7)	16.8 (16.7) (16.8)	30.2 ( ) ( )
Y.S.(0.2%) [kgf/mm²]		10.3 (10.2) (10.3)	11.2 (11.0) (11.4)	( ) ( )	7.9 (8.0) (7.8)	8.1 (7.7) (8.4)	( ) ( )
Elogation [%]		10.8 (11.0) (10.5)	15.6 (15.3) (15.8)	( ) ( )	11.9 (11.9) (11.9)	16.8 (16.8) (16.7)	( ) ( )
Shearing(Al/Cu)		RT	77K	4.2K	RT	77K	4.2K
[kgf/mm²]	2	3.9 (3.9)	5.8 (5.4)	4.5 (4.5)	3.7 (3.9)	5.7 (6.6)	8.7 (8.7)



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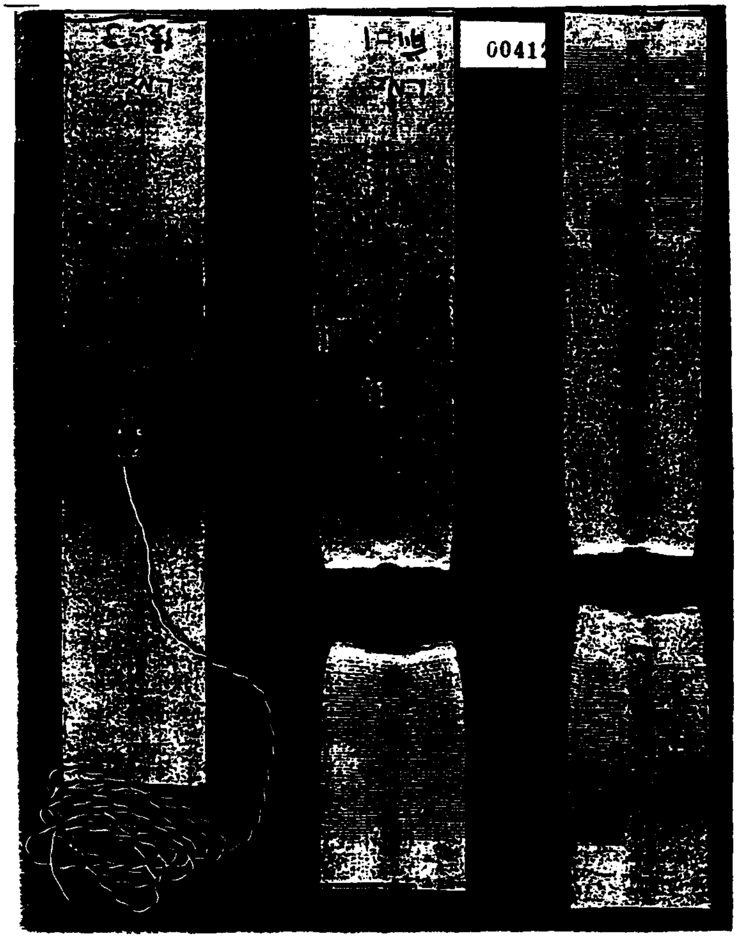

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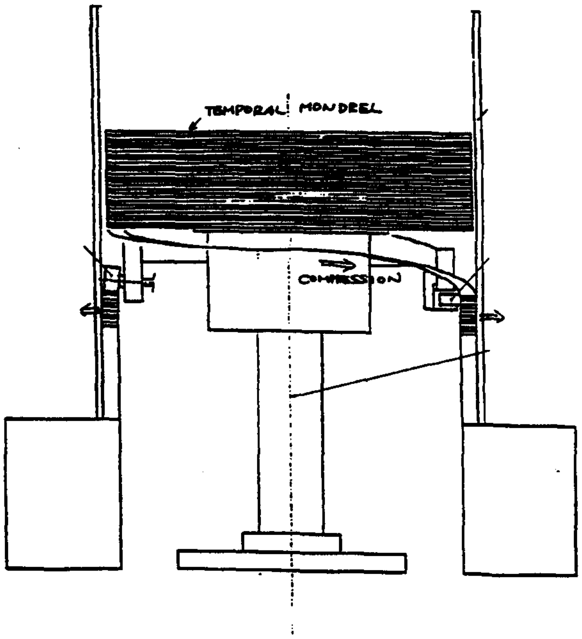
COIL WINDING R&D



COIL WINDING CONCEPT

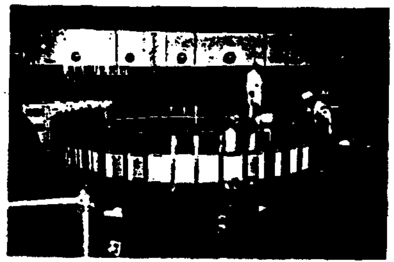
00414 25

END INSULATED SUPPORT CYLINDER

WINDING PREPARATION

WINDING STARTED

00415 26



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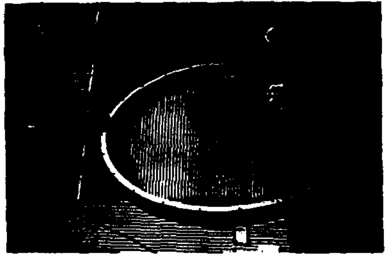
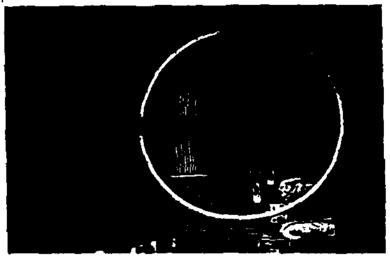
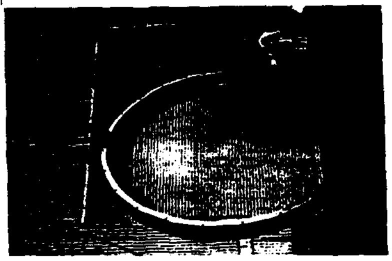
00417 28



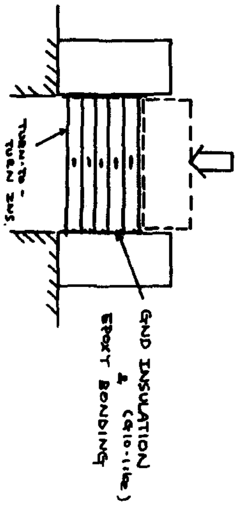




MEASUREMENT OF SHEAR STRENGTH

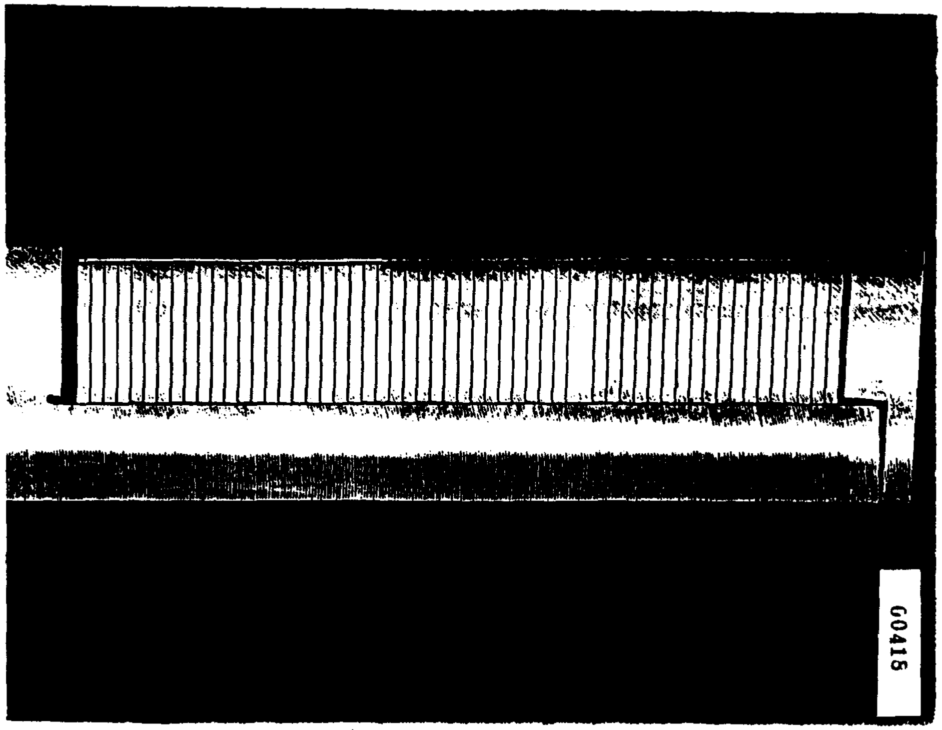
FOR

EPOXY-BONDING B/W COIL AND SUPPORT CYLINDER



TEST RESULT

	RT	77K	4.2K
LOAD EXPECTED			≲0.5 MPa
SHORT SPECIMEN	>15 MPa (n=3)	>15 MPa (n=3)	
SAMPLE CUT FROM FULL DIA WINDING	>5 (n=1)	>5 (n=1)	


00416

PROTOTYPE MAGNET R&D

5.7.1. Prototype coil

The development of a full diameter, one quarter length prototype magnet has been underway since 1991. The purposes of the prototype development are:

- to develop an aluminum stabilised superconductor of high yield strength and RRR;
- to become skilled in the fabrication of a full diameter coil using inner winding techniques;
- to demonstrate that a coil with E/M of about 8 kJ/kg can be quenched safely and without damage or reduced performance; and
- to apply electromagnetic loads to the conductor and outer support cylinder equal to those expected in the detector magnet and to verify the performance under these loads. This can be achieved by operating the prototype to 10-12 kA.

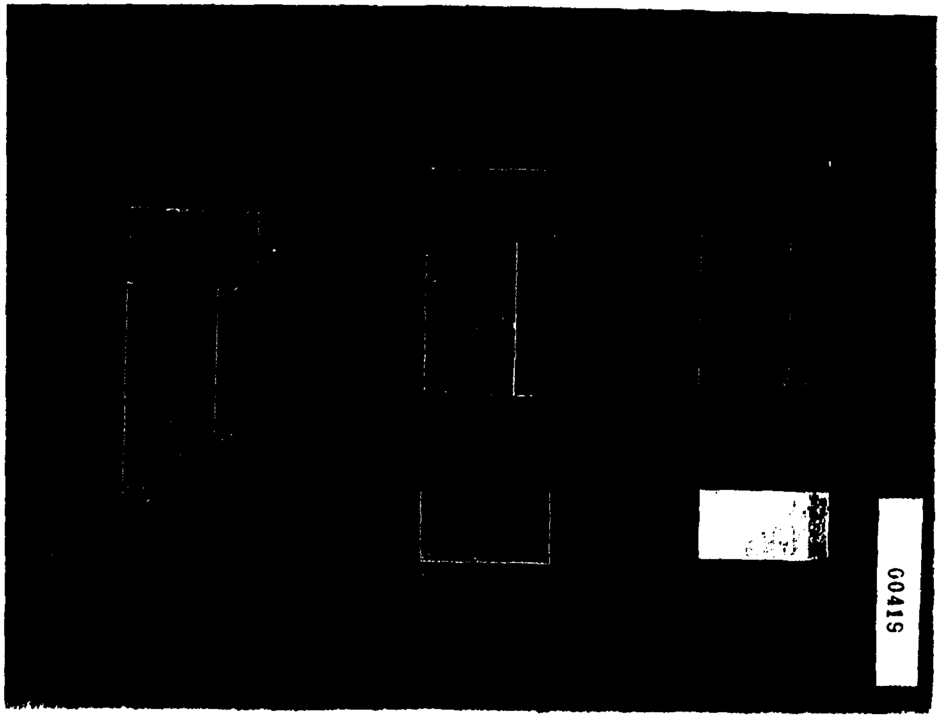

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Table 5-16
Design parameters of the prototype R&D solenoid.

Dimensions		
Cryostat	Inner radius	1.70 m
	Outer radius	2.06 m
	Half length	1.17 m
Coil	Effective radius	1.85 m
	Half length	0.95 m
Conductor	Thickness	44 mm
Outer cylinder	Thickness	33 mm
Transparency	Radiation thickness	1.23 X_0
	Interaction length	0.26 λ_0
Electrical parameters		
Central field		1.54
Nominal current		11,250 A
Inductance		0.68 H
Stored energy		48 MJ
E/M		10 kJ/kg
Mechanical parameters		
Effective cold mass		4.5 tons
Total weight		8 tons
Radial mag. pressure (@z =0)		1.73 MPa
Axial compressive force		16.7 MN
Maximum hoop stress		43 MPa
Maximum axial stress		−19 MPa
Maximum shear stress		62 MPa
Peak field in coil		3.8 T
Load line ratio		70%

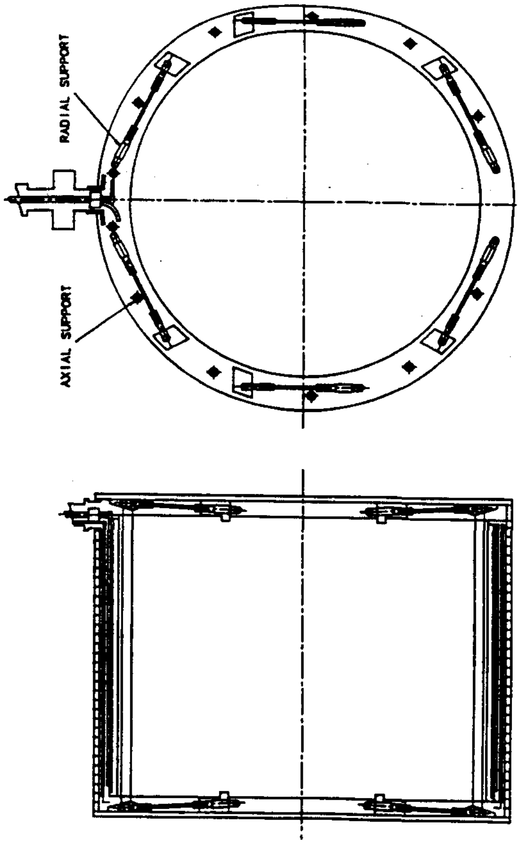
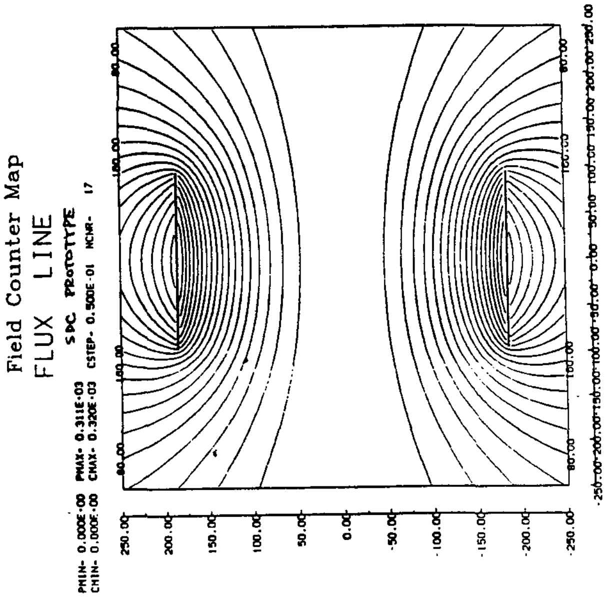
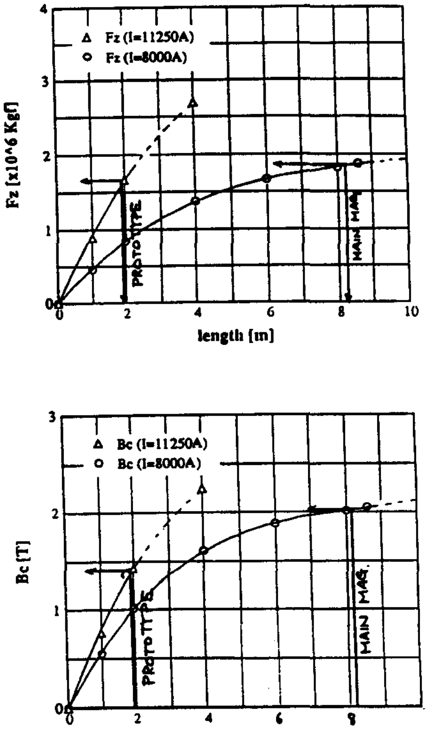


FIG. 5-16. SDC prototype solenoid. Dimensions are given in Table 5-16.





Fz and Bc vs Coil Length

00426

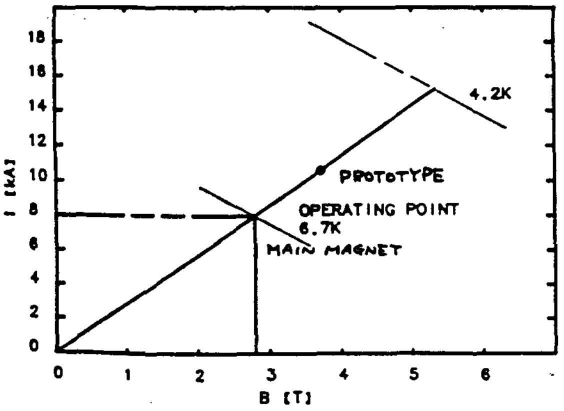
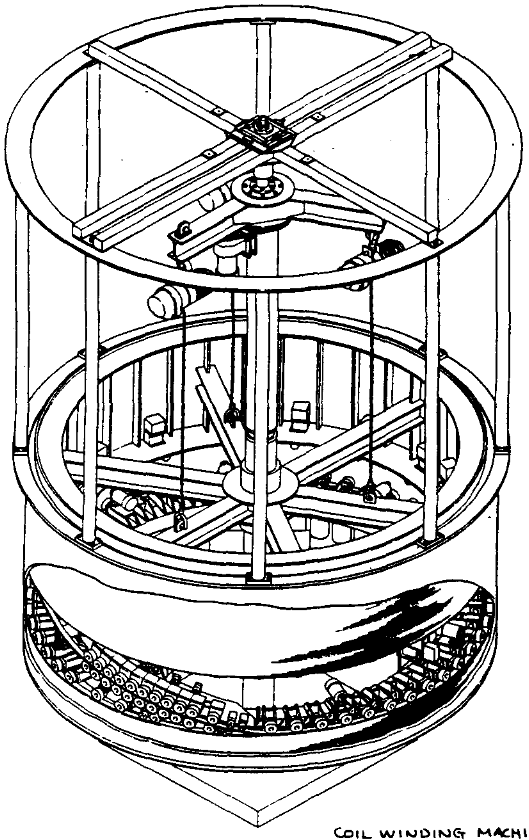


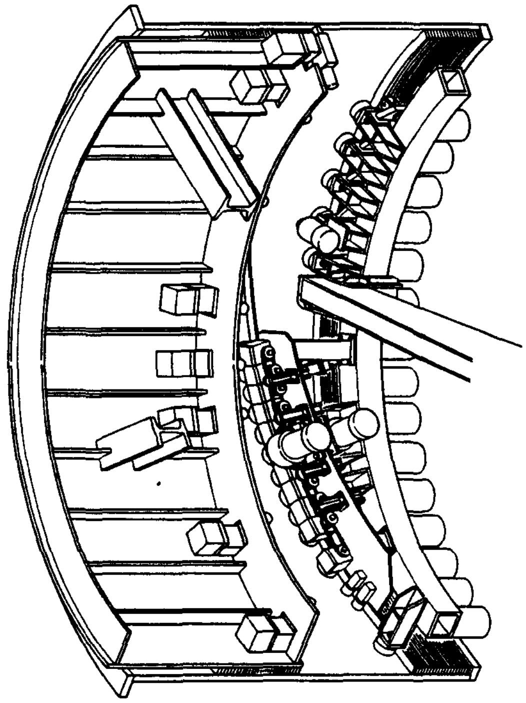
FIG. 5-11. Short-sample characteristics of the SDC conductor and the operating load line.

00427



COIL WINDING MACHINE

00428



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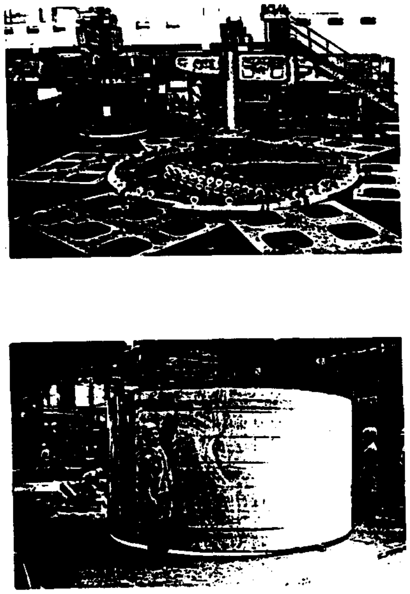
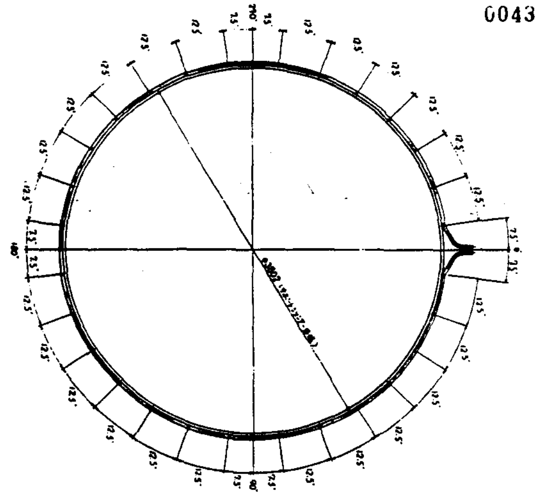
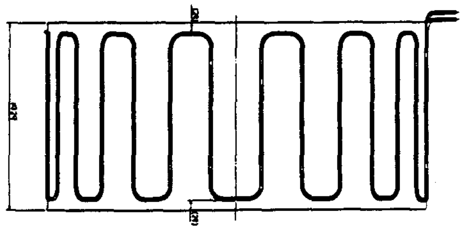
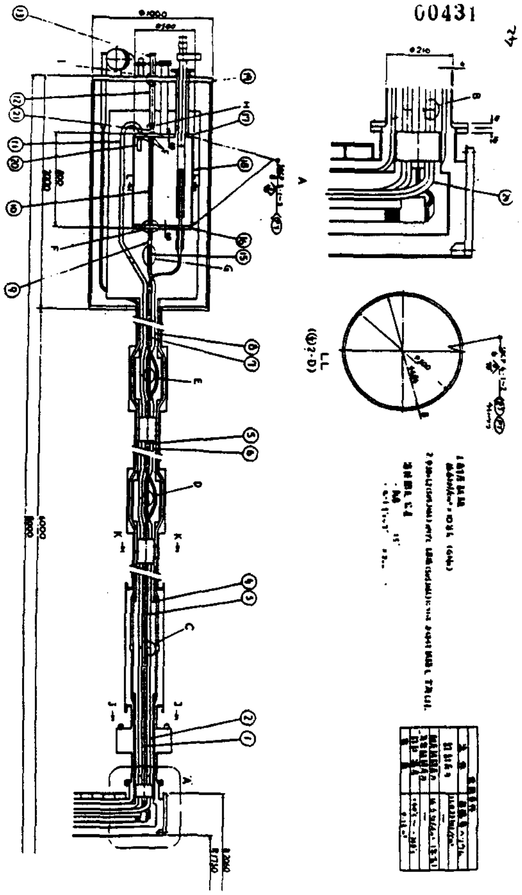


CORE OF WINDING MACHINE & OUTER CYLINDER







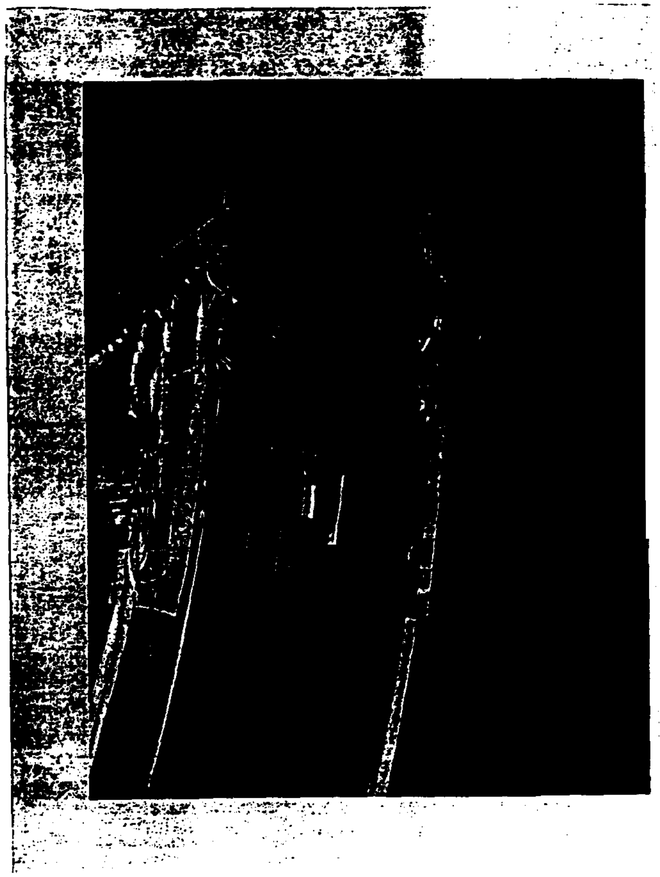
RESEARCH FOR HIGH E/M MAGNET
(ASTROMAG TEST COIL)

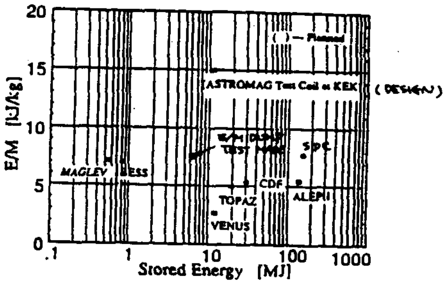
Main parameters of the ASTROMAG test coil

Dimensions	
Coil outer diameter	1.76 m
inner diameter	1.5 m
length	0.19 m
Coil separation (center to center)	2.2 m
Cryostat outer diameter	2.1 m
length	2.6 m
Electric	
Current	800 A
No. of turns	90 × 28
N · I	2.016 MAT
Inductance	32.3 H
Central field	1.5 T
Maximum field in coil	5.6 T
Stored energy	10.3 MJ
Hoop force	140 tonf
Axial repulsive force	27 tonf
Dielectric strength	1000 V turn to turn 2000 V layer to layer
Persistent current switch	
Switching	heater (27 W)
Winding	non-inductive
Current	1000 A
Off resistance	20 Ω
Cooling	indirect cooling
Weight	
Coil mass (1 coil)	330 kg
Cold mass (1 coil) (coil part including support cylinder)	380 kg
Cryostat mass	~1000 kg
Total mass	~2000 kg
Cooling method	indirect cooling

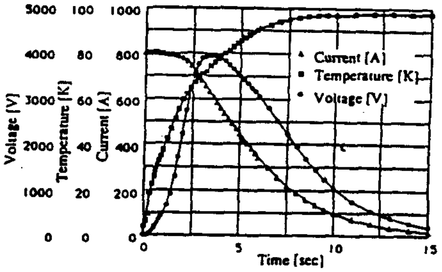
E/M @ 800A 15 kJ/kg

@ 600A 9.5 kJ/kg (TESTED)





E/M in various superconducting magnet.

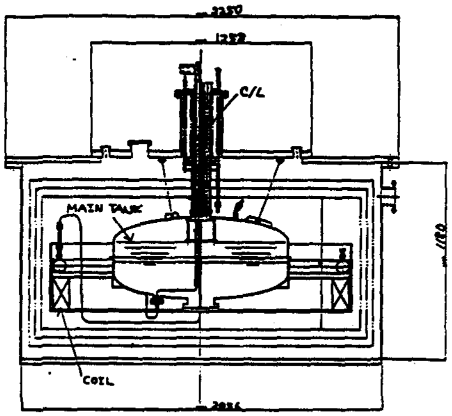


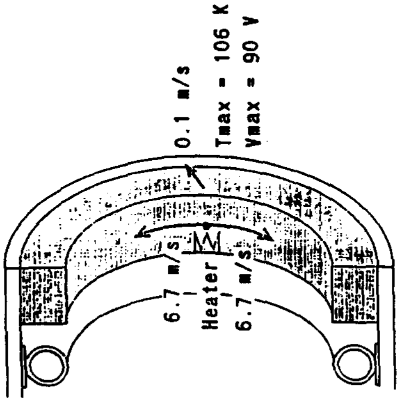
Calculated quench characteristics of the test coil

3. PERFORMANCE TEST RESULT ON EACH COIL

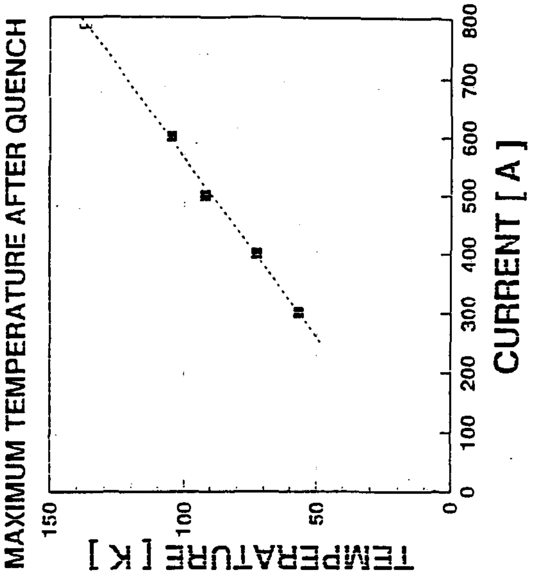
Before coupling the two coils in a horizontal cryostat as shown previously, each of them has been examined on its magnetic performance in a vertical cryostat.

The coil is surrounded by triple stage radiation shields. The LHe is transferred from a main tank to the sub-tank.

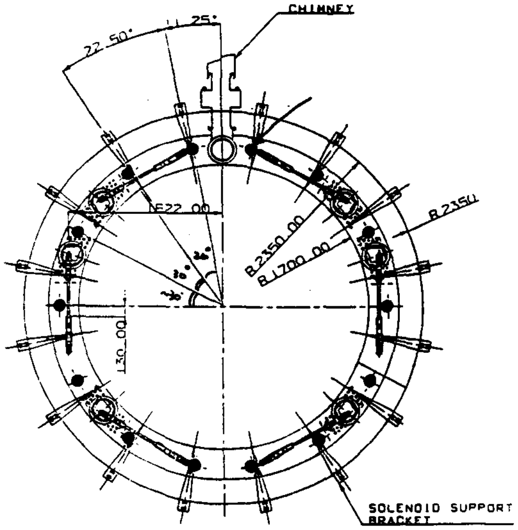




QUENCH CHARACTERISTCS @ 600 A

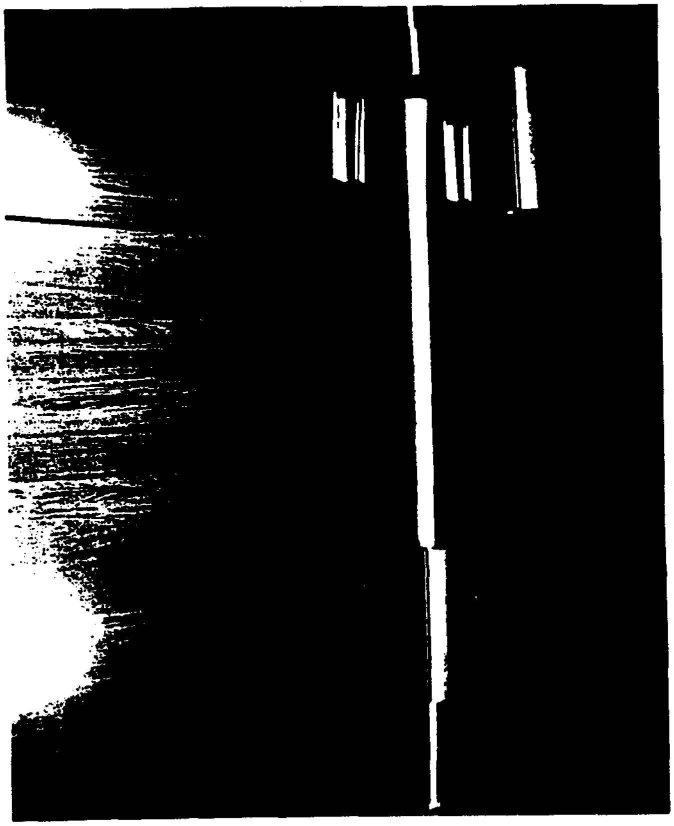


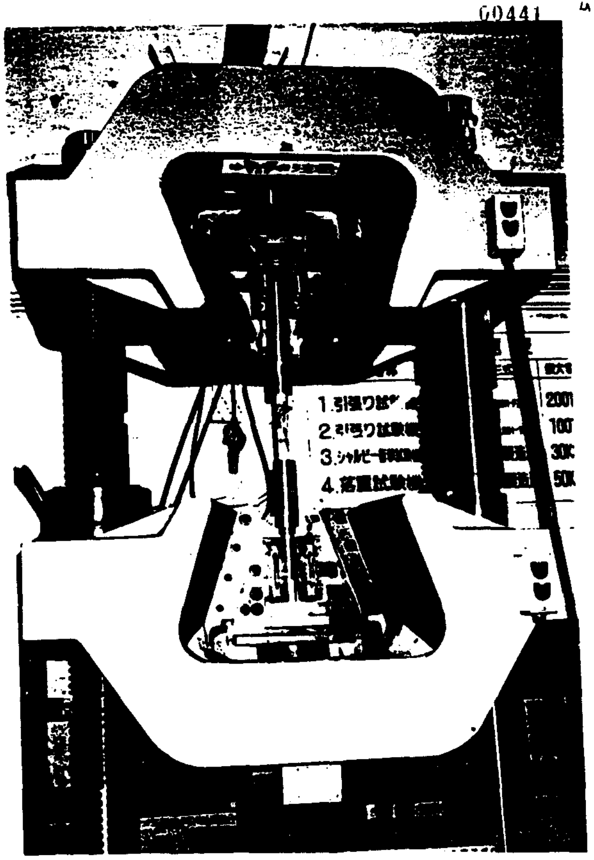
R&D FOR COIL SUPPORT

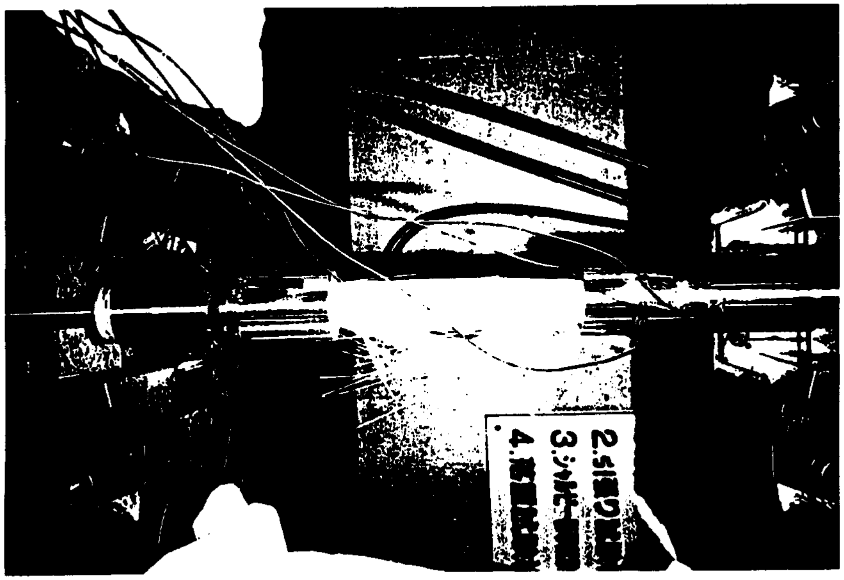


RESULT OF TENSILE TEST

T.S. (77K) = 750 MPa
(RT) = 650 MPa







SUMMARY

FOR

PROGRESS OF THE SDC SOLENOID R&D

1. DEVELOPMENT OF HIGH STRENGTH ALUMINUM STABILIZED SUPERCONDUCTOR HAS BEEN SUCCESSFUL TO REACH Y.S. = 80 MPa WITH RRR = 500.
2. COIL WINDING MACHINE DEVELOPMENT IN PROGRESS,
3. EPOXY BONDING STRENGTH B/W COIL AND CYLINDER HAS BEEN VERIFIED TO BE SUFFICIENTLY STRONG ENOUGH TO SUSTAIN AXIAL MAGNETIC FORCE OF 1300 TONNES
4. ENERGY DUMP TEST INTO A MANGET WITH AN E/M RATIO OF 7.5 KJ/KG HAS BEEN SUCCESFULLY MADE. THE RESULT HAS BEEN CONSISTENT WITH OUR PRESENT DESIGN CONCEPT FOR THE SDC SOLENOID.
5. HONEYCOMB AND ISOGRID R&D IS IN PROGRESS.
6. PROTOTYPE MAGNET DEVELOPMNET IS BEING CARRIED OUT AND TO BE COMPLETED IN JFY1994.

R & D AND PROTOTYPE

R. KEPHART

SDC Solenoid
Outer Vacuum Shell R&D

Purpose:

The SDC solenoid is required to be thin in terms of radiation lengths. If this shell were made with conventional techniques (e.g. Welded shell of solid aluminum) then it would be a major contributor to the overall thickness of the coil in terms of radiation lengths. (.3 λ_r) For this reason the SDC magnet group began a program to develop an improved technique to fabricate this shell.

Outer Vacuum Shell Specifications:

outer radius	2.05 m
total length	8.72 m
High Reliability	metallic - welded
Radiation tolerant	> 6 megarads (10 yrs @ 10^{34} cm^{-2} s^{-1})
Safe - predictable	built to ASME/CGA codes

Plan:

The outer vacuum shell thickness for a solid shell is determined by elastic stability criterion for a cylindrical shell under external pressure.

The SDC magnet group evaluated various fabrication techniques intended to achieve the equivalent stiffness of a solid plate but with much less material.

We chose to pursue R&D on two techniques that we judged most likely to lead to a practical shell that would meet the requirements of SDC:

1) Brazed Aluminum Honeycomb

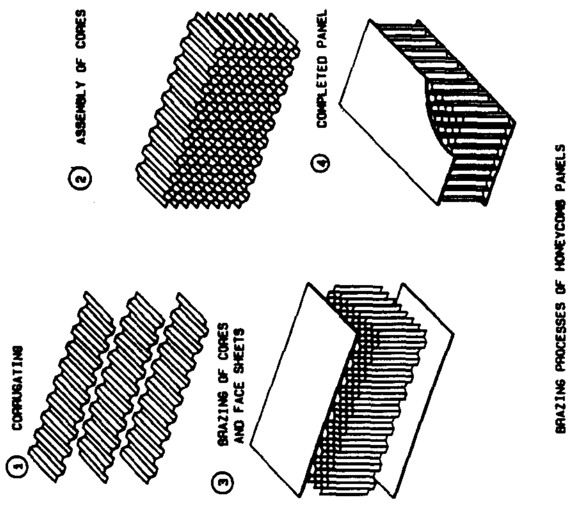
2) Aluminum ISO grid

R&D is in progress at this time on both techniques. I will discuss our progress and plans:

Option 1) Honeycomb

Characteristics of Brazed Aluminum Honeycomb Panels

- Near optimal use of material for high stiffness
- High Thermal Resistance = => Weld able
- High Reliability (no epoxy adhesives)



Honeycomb Vacuum Shell Design Specifications

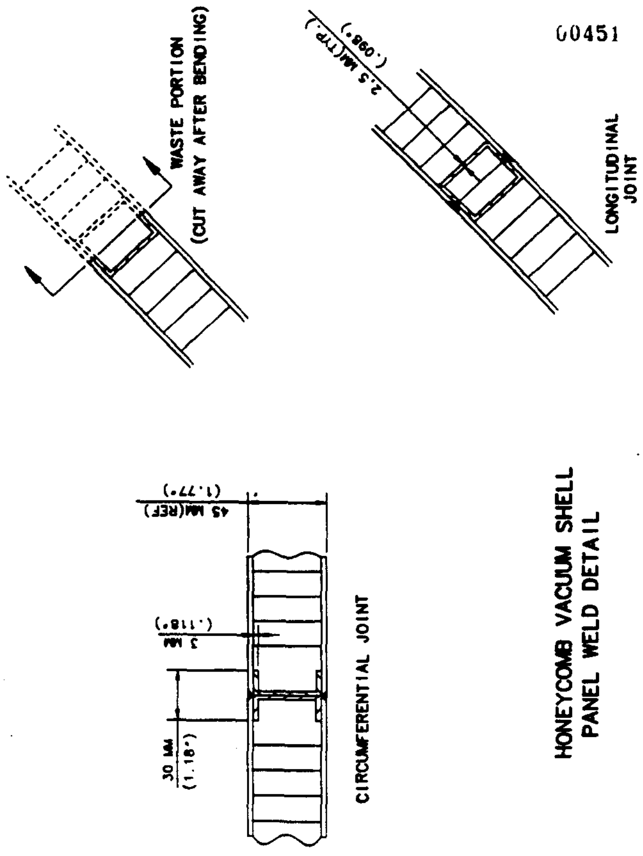
Honeycomb Outer Vacuum Shell

Aluminum alloy	A6951/A4045
Total thickness	45 mm
Skin thickness	3.0 mm + 3.0 mm
Skin layers	double
Node configuration	hexagon
Effective thickness	7.1 mm (Al)
Weight reduction ratio	1/3.83
Radiation thickness	0.08 Xo

Progress with Welding Brazed Honeycomb Panels

- With reinforcement Skin-Skin welding of Honeycomb panels works
- Cores do not melt
- No affect to brazed joints
- Deformation is acceptable (large Stiffness)
- Welded joints are leak tight

Conclusion: Welding seems to have few problems



HONEYCOMB VACUUM SHELL PANEL WELD DETAIL

R&D on Bending Brazed Honeycomb Panels

(Results of 1st Effort 3 Point Panel Bending)

Panel size - 0.9 mx 1.8 m

Panel thickness - 30 mm <---- ***

Facing thickness - 3 mm and 2 mm

*** note t/R is the same at R = (30 mm/45 mm)x2.05m=1.4 m

RESULTS

Radius Formed To:		Thickness:
Plate 1	1.80 m	29.2 mm
Plate 2	1.36 m	29.0 mm <-------***
Plate 3	1.07 m	28.9 mm
Plate 4	0.69 m	28.5 mm

CONCLUSIONS

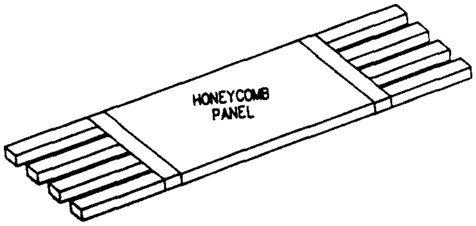
1. Decrease of the panel thickness is due to the buckling of the core material.
2. Large shearing deformation observed at both ends.

R&D on Bending Brazed Honeycomb Panels

(2nd Effort)

3 point panel bending with constraint fixture
(the fixture was expected to prevent shearing deformation)

Panel size was same as the 1st effort

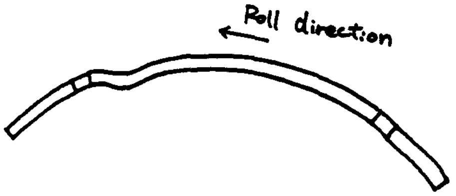


RESULTS

1. A decrease of panel thickness (core material buckling) was found at a relatively large radius.
2. Panel had deformation in the rolling direction and near free edges.

Results

- Decrease of thickness was also found at relatively large radius. (R ≧ 2200mm)
- Panel has deformed like following figure.
  Because of forcing to prevent shearing deformations.



Conclusions of Honeycomb Panel Bending R&D

- At this time collapsing (buckling) of the core material is a problem.
- Shearing deformation has to be controlled.
- 3 point bending will probably not work , more R&D is required to develop an alternative technique.
- The next attempt will be to use 4 point bending.

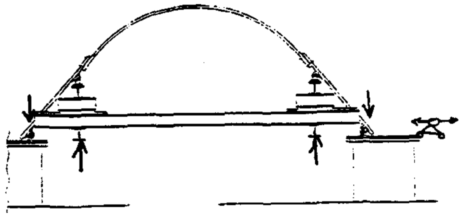
---

	3 POINT BENDING with Bending Roller	4 POINT BENDING
Concept		
Shearing Force Distribution		
Bending Moment Distribution		
Possibility of Cores Collapsed	Expected	None
Possibility of Shearing Deformation	Expected	None
Bending Size	Long	Limited

HONEYCOMB VACUUM STRUCTURE RESEARCH AND DEVELOPMENT

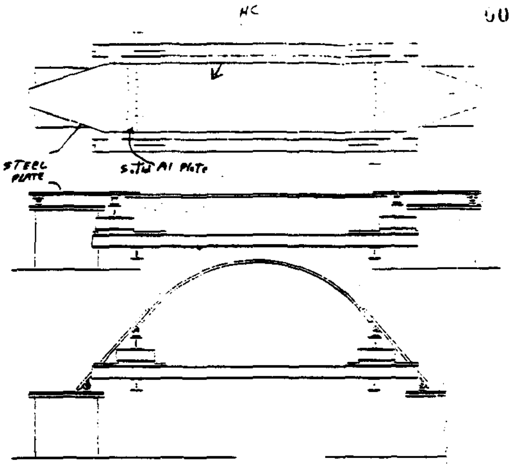
(3RD EFFORT)

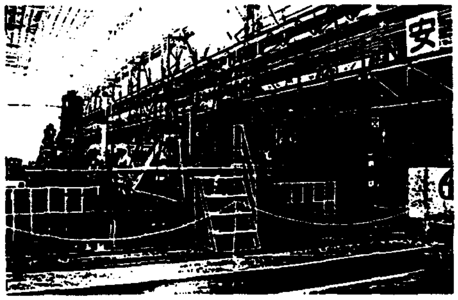
4 POINT PNAEL BENDING WITH CONSTRAINT FIXTURES

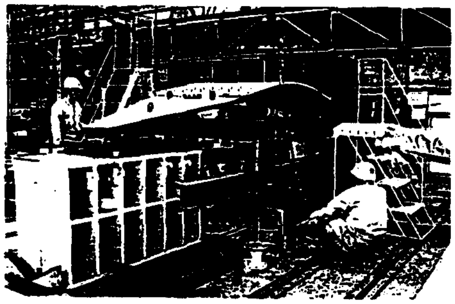


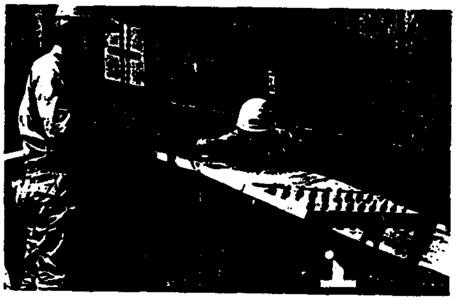
RESULTS

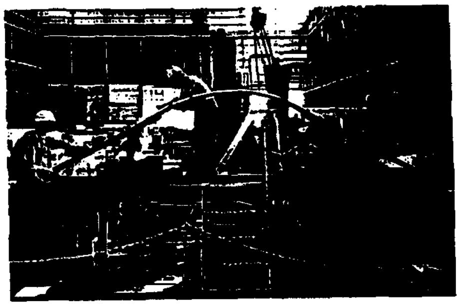
1. BENDING SUCESSFUL DOWN TO R/T RATIO OF 46 WITHOUT BUCKLING,
2. RADIAL SPRING BACK OF 10 % OBSERVED AFTER RELEASING,
3. (SADDLE) ~~HORSE BACK~~ SAGITA OF 15 MM , (IT COULD BE ELIMINATED WITH ANOTHER CONSTRAINT FIXTURE).

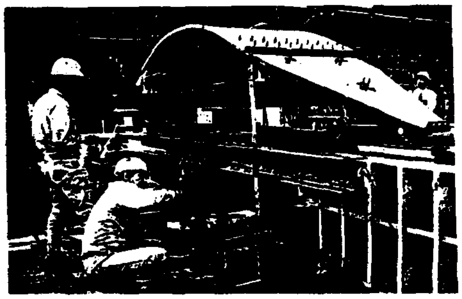












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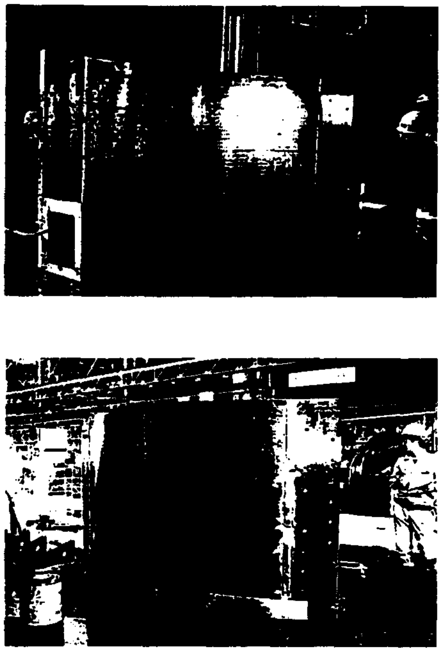

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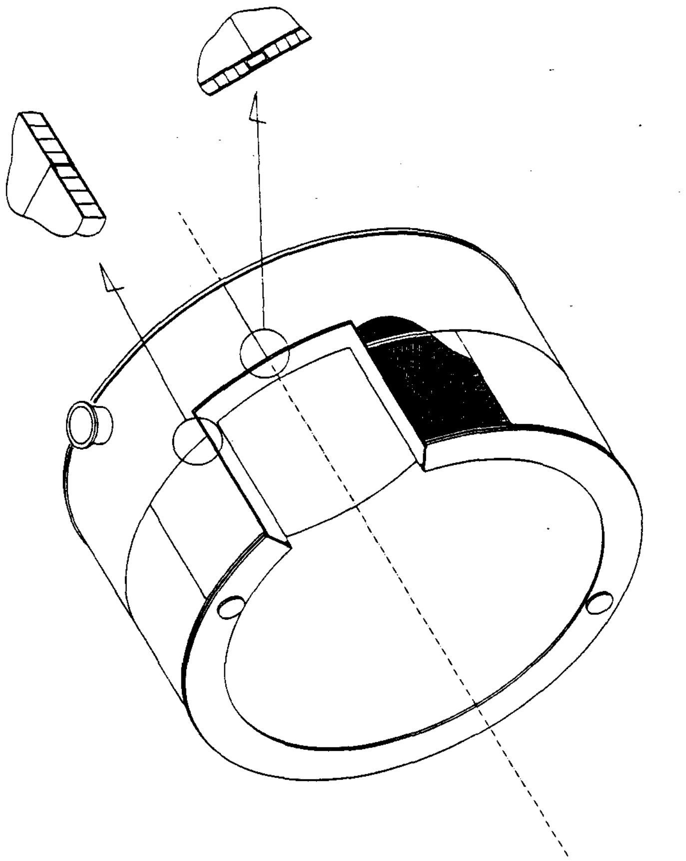

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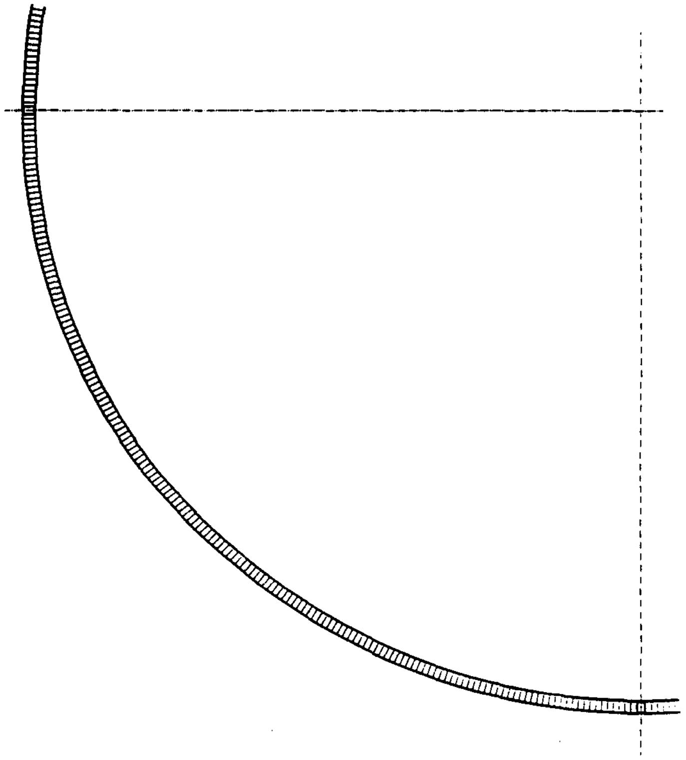

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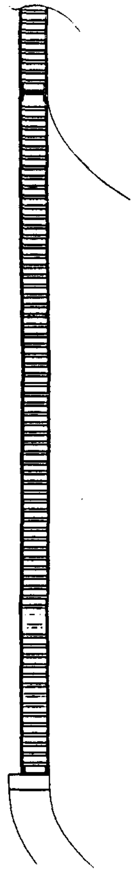
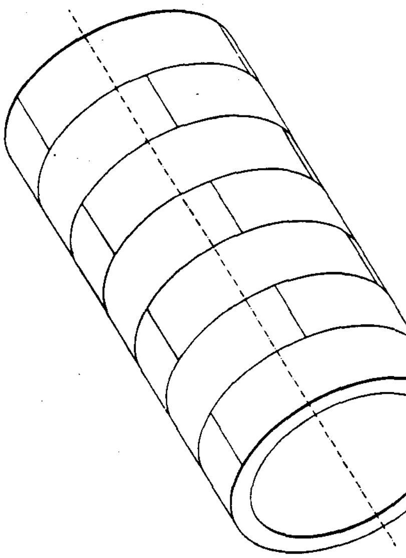




Option 2) ISO grid Shell

Characteristics of Aluminum ISO grid construction

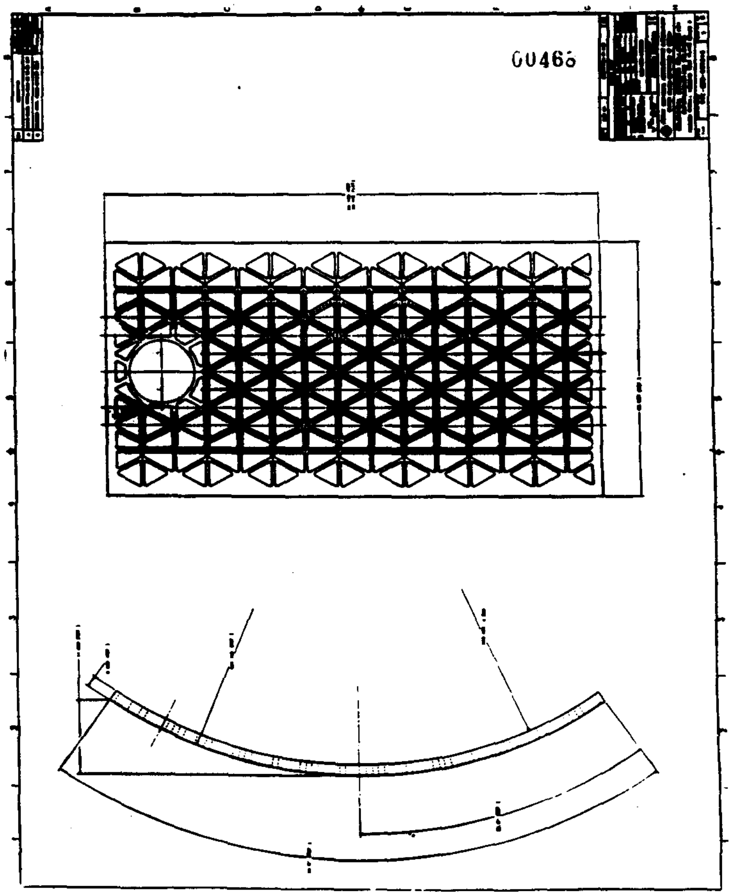
- **A lattice of intersecting ribs forming an array of equilateral triangles.**
- **Isotropic (no directions of instability or weakness)**
- **Efficient use of material for either compression and/or bending**
  - **Lightweight**
  - **Proven analysis techniques**
  - **Can be optimized for wide range of loading intensities**
  - **Readily reinforced for concentrated loads and cutouts**
  - **Regular pattern of nodes provides attach points for other structures**
- **Easily fabricated from solid Al plate with NC machine tools yielding a very reliable material of known costs.**

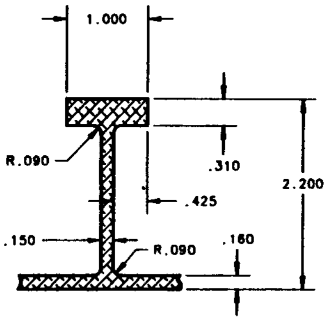
- **Large experience base :**

  In use on major space progrems, extensively investigated by NASA, military, and industry.

  Fermilab has received structural analysis and engineering design assistance from P.S. Associates

  Companies with ISO grid construction experience are available for R&D and for production of final shell. (e.g. machining, welding, bending)





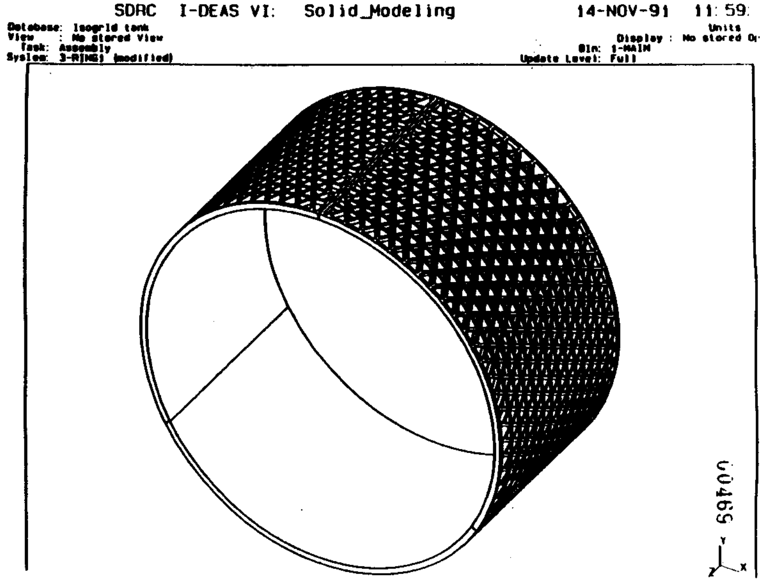
NOTE:

1. NODE SPACING IS 7.092 IN
2. EFFECTIVE THICKNESS IS 0.407 IN.
3. MATERIAL-ALUM. 5083-H321

SUPERCONDUCTING SOLENOID
OUTER VACUUM SHELL
ISOGRID TYPICAL RIB CROSS SECTION

G0471

4/16/92



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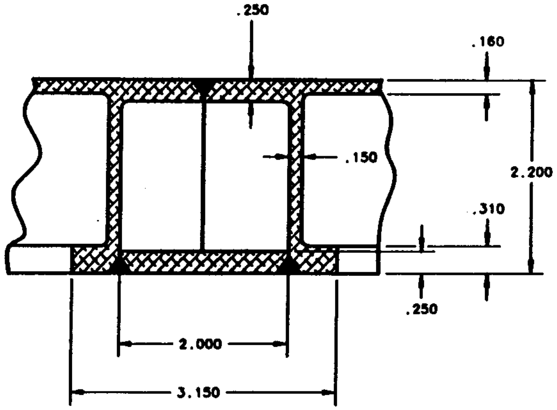
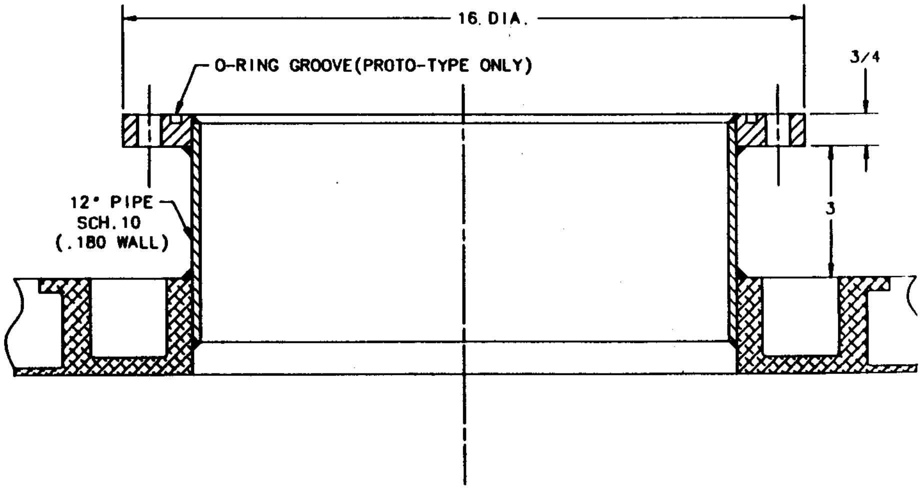


SUPERCONDUCTING SOLENOID
OUTER VACUUM SHELL
ISOGRID PANEL TO PANEL WELD DETAIL

G0472

4/16/92

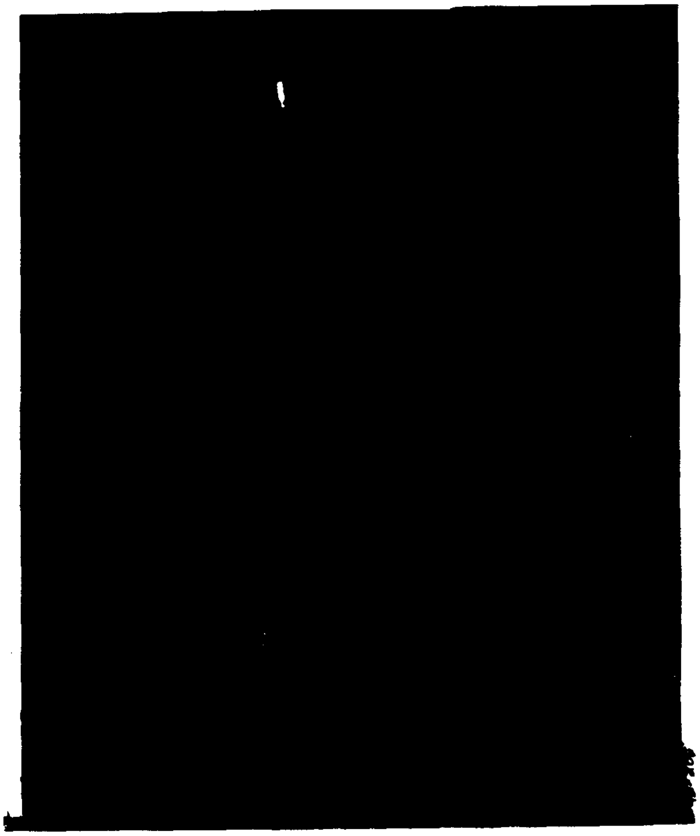


SUPERCONDUCTING SOLENOID
OUTER VACUUM SHELL
ISOGRID(CHIMNEY PENETRATION)

G0470

00473

00474



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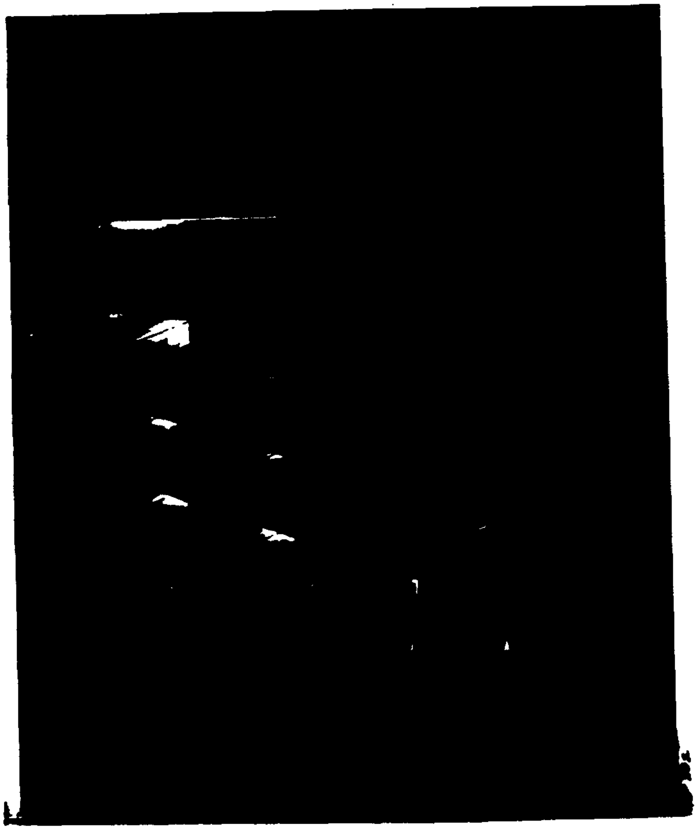

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ISO grid Vacuum Shell Design Specifications

ISO grid Outer Vacuum Shell

Aluminum alloy	5083
Total thickness	46 mm
Skin thickness	4.0 mm
Skin layers	single
Node configuration	triangle
Effective thickness	11 mm (Al)
Weight reduction ratio	1/2.5
Radiation thickness	0.12 Xo

Progress with Welding Aluminum ISO grid Panels

- Weld samples of Panel to Panel joints have been made using 2219-T351 material. (5083 soon)
- No detectable leaks
- Possible to leak check main welded joints before cryostat assembly (probably true with Honeycomb also)
- Deformation at joint is very small (large Stiffness)

Conclusion: Welding ISO grid panels seems also to have few problems

---

R&D on Machining and Bending ISO grid Panels

Machining

Panel size -	0.63 m x 1.1 m (two panels)
Panel thickness -	46 mm
Sin thickness -	4 mm

Bending RESULTS

Radius Formed To:		Thickness:
Plate 1	2.05 m	46 mm
Plate 2	2.05 m	46 mm

CONCLUSIONS

1. No significant problems in brake forming plates if skin is on outside radius. No buckling or web crippling observed.
2. Small deformations observed near edge nodes...understood and easily fixed ===> no problems

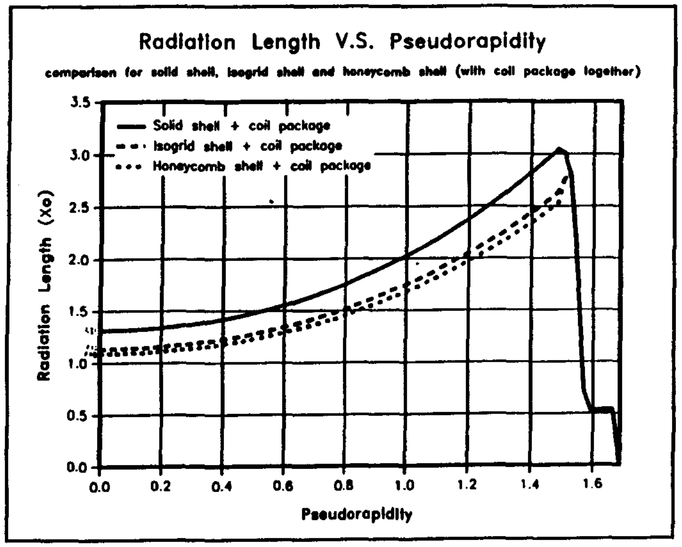
---

Conclusions of ISO grid R&D and Plans

- Technique is likely to be successful but somewhat less efficient than Aluminum honeycomb.
- SDC magnet group decided to fabricate prototype shell using this technique. (3 Al plates 2.5 m x 5 m are on order from Alcoa)
- We will fabricate a large test panel from 5083-H321. This will have exact circumferential and longitudinal weld configurations as Prototype shell. Test panel will be formed to 2.05 m radius.
- More weld joint tests will be done with 5083-H321
- Decision for final shell will depend on outcome of Honeycomb R&D effort.

Expected Performance of SDC Vacuum Shell

(Effective Thickness vs pseudo-rapidity)



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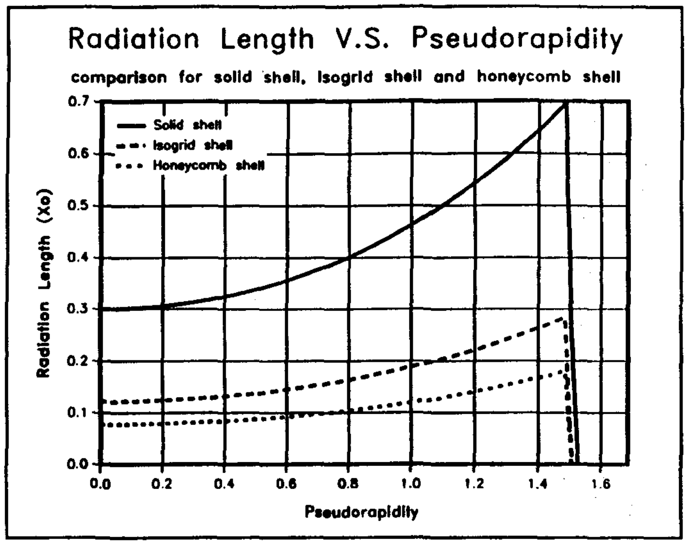

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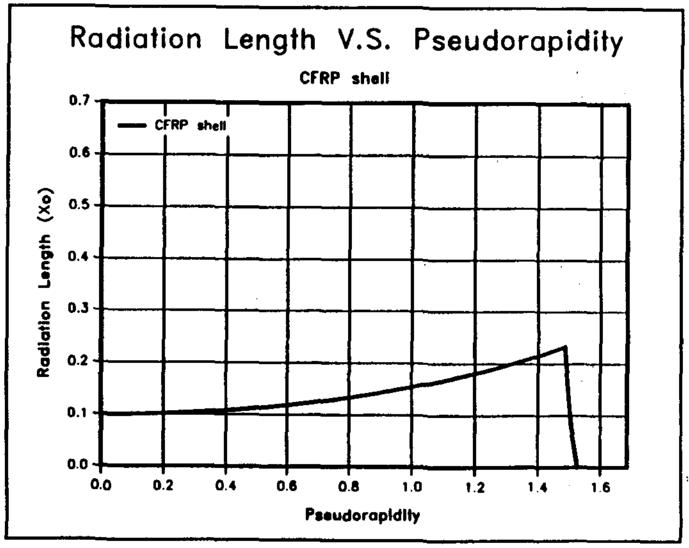

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COST AND SCHEDULE

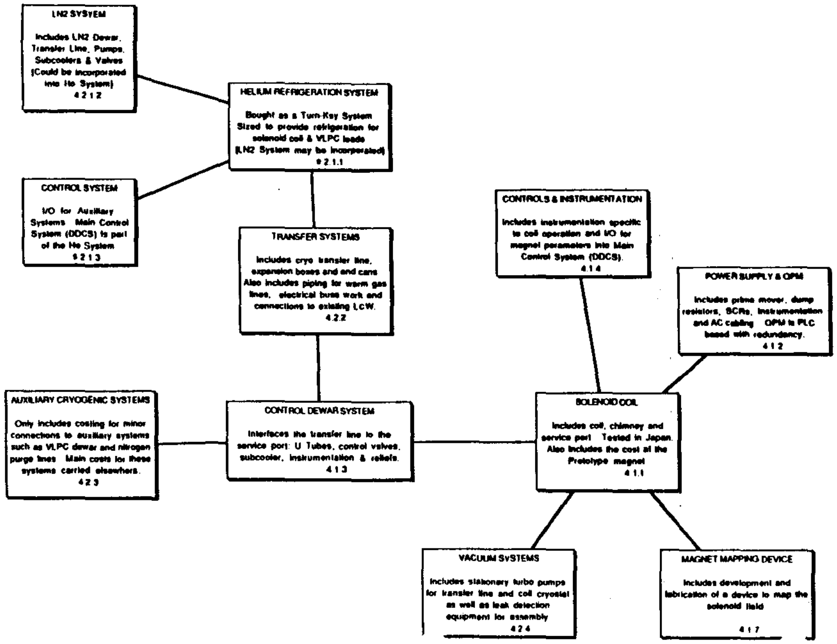
R. STANEK

WBS DICTIONARY ELEMENT 4 2/ LEVEL 5

	A	B	C	D
1	WBS NUMBER	WBS TITLE	QUANTITY	DESCRIPTION
2	4.2	Cryogenic Systems		
3	4.3.1	Refrigeration Systems		
4	4 2 1 1	Helium Refrigerator	1	Includes all costs associated with procuring a refrigeration system (~1 5KW) which is
5				installed and acceptance tested
6				Interfaces with the surface facilities located in the utility building
7	4 2 1 2	Liquid Nitrogen System	1	Includes the liquid nitrogen storage dewar (~20,000 gal.), transfer line and connections
8				to the refrigerator
9				Interfaces to the refrigerator and surface facilities of the utility building
10	4 2 1 3	Control System	1	The DDCS is part of element 4 2.1 1 and so only the costs associated with the LIN
11				system data channels appears here
12				Interfaces with the main control system of the refrigerator and the experiment.
13	4 2 1 4	Assembly & Test	1	Includes costs associated with final assembly and testing of these elements into a
14				complete refrigerator system.
15				Interfaces with surface facilities in the utility building.
16	4 2 1 5	Safety Report	1	A compilation of component lists, operating procedures, hazard and failure mode and
17				effects analysis, etc
18				Interfaces with safety reports generated for the subsystems to form a comprehensive analysis.
19	4 2 1 6	Management & Integration	1	Includes the necessary management and integration for the following. The status of the
20				procured subsystems and fabrication of the liquid nitrogen sybsystem.
21	4.2.2	Transfer Systems		
22	4 2 2 1	Cryogenic Transfer	1	Includes all elements associated with the transfer lines used to connect the refrigerator to the
23		Line System		solenoid. End cans, expansion boxes and straight sections fabricated then assembled @ SSCL.
24				Interfaces with the surface and hall facilities
25	4 2 2 2	Gas Piping Systems	1	Piping systems for warm gas supplies and returns including the lead flows, nitrogen vents
26				and quench header. Connects from the top of the detector to the utility building.
27				Interfaces with the surface and hall layout.
28	4 2 2 3	Electrical Buss System	1	Insulated, water cooled copper pipe which connects the power supply system to the
29				control dewar. Includes all necessary piping supports.
30				Interfaces with the surface and hall layout.
31	4 2 2 4	Water Systems	1	Includes the necessary hook-ups to the ICW & LCW manifolds provided by Mechanical
32				Integration. Costs include piping, valves & instrumentation.
33				Interfaces with the utility building facilities.
34	4 2 2.5	Control Sy stem	1	The DDCS is part of element 4.2.1.1 and so only the costs associated with the Transfer
35				Systems data channels appears here
36				Interfaces with the main control system of the refrigerator and the experiment
37	4 2 2 6	Safety Report	1	A compilation of component lists, operating procedures, hazard and failure mode
38				and effects analysis, etc.
39				Interfaces with safety reports generated for the subsystems to form a comprehensive
40				analysis for the Transfer Systems.

WBS DICTIONARY ELEMENT 4.2/ LEVEL 5

	A	B	C	D
41	4 2 2 7	Management & Integration	1	Includes the necessary management of the seperate transfer subsystems to assure a
42				comprehensive piping package connection from the surface to the hall.
43	4.2.3	Aux. Cryo Support Systems		
44	4 2 3 1	Cryo Equipment for VLPC's	1	At this time, this element contains only the costs associated with providing additional
45				beyonet connections at the end can of the transfer line in the hall.
46				Costs associated with the VLPC cryogenic equipment, ie dewars, cryostats and connection
47				tubes are shown elsewhere
48				Interfaces with the VLPC cryogenic system
49	4 2 3 2	Equipment for Nitrogen Piping	1	At this time, this element contains only the costs associated with additional piping, valves
50				and instrumentation needed to supply nitrogen gas to a gas manifold which is costed
51				under Mechanical Integration.
52				Interfaces with "mechanical integration" manifold to supply gas to a variety of places in the detector
53	4.2.4	Vacuum Systems		
54	4 2.4.1	Solenoid Vacuum System	1	Turbo pump system for evacuation of the cryostat vacuum insulation space.
55				Includes pump cost, piping and valves to assure reliable isolation.
56				Interface with detector and hall layout.
57	4 2.4.2	Transfer Line Vacuum System	1	Turbo pump system for evacuation of the transfer line vacuum insulation space. Includes
58				pump cart, piping and valves to assure reliable isolation.
59				Interfaces with detector and hall layout.
60	4.2.4.3	Auxiliary Vacuum System	1	Includes the additional turbo and rough pump, leak detectors, piping, valves and
61				instrumentation required for operation and maintenance of the cryogenic systems.
62				Interfaces with utility building facilities.
63	4 2.4.4	Vacuum Control System	1	The DDCS is part of element 4.2.1.1 and so only the costs associated with the Vacuum
64				Systems data channels appears here.
65				Interfaces with the main control system of the refrigerator and the experiment.
66	4.2.4 5	Safety Report	1	A compilation of component lists, operating procedures, hazard and failure mode analysis.
67				Interfaces with safety reports generated for the subsystems to form a comprehensive analysis for
68				the vacuum systems.
69	4 2.4.6	Management & Integration	1	Includes the necessary management of the vacuum subsystems to assure the coordination
70				of the seperate specifications so as to end up with a consistent vacuum system.
71	4.2.6	Safety Report	1	Combines all the subsystem reports into a comprehensive safety report dealing with the
72				total cryogenic system. Adds the necessary sections due to subsystem interactions.
73	4.3.8	Assembly & Test	1	Includes all costs associated with combining all of the major subsystems into a cryogenic system
74				capable of operation from a central control point.
75	4.2.7	Management & Integration	1	Includes the necessary management of all subsystems into a cohesive refrigeration system
76				and the costs associated with quality control.



WBS DICTIONARY ELEMENT 4.1/LEVEL 4

	A	B	C	D
1	WBS NUMBER	WBS TITLE	QUANTITY	DESCRIPTION
2	4.1	Superconducting Solenoid		
3	4.1.1	Superconducting Coil	1	Superconducting solenoid coil (dimensions ~3.4m dia. x 8.5m len.)
4				Includes the costs of fabricating SC coil andthe cryostat costs for the vacuum vessel,
5				LIN shield, supports, chimney and service port. Fabricated and tested in Japan.
6				Interfaces with other parts of the detector with respect to mounting and assembly
7	4.1.2	Power Supply System	1	Includes all elements required to power, protect and monitor the coil package
8				consisting of the power supply (2-5KA supplies), quench protection circuitry, dump
9				resistors (fast & slow) and instrumentation.
10				Interfaces with 480 VAC power panels in counting room.
11	4.1.3	Control Dewar System	1	Provides the connection point at the end of the transfer line system to the coil service port
12				and contains a subcooler and a variety of interconnect piping and valves.
13				Sits on top of the detector and interfaces with both the service port (SC Coil) and the
14				dewar for the VLPC system.
15	4.1.4	Controls & Instrumentation	1	Includes temperature, pressure and voltage sensors for the magnet package,
16				an uninteruptable power supply to allow for continuous control operation and
17				associated cabling. The cryogenic control system is part of the overall
18				refrigerator distributed digital control system and so this element only covers
19				the additional costs associated with magnet data channels.
20				Interfaces with the DDCS controls supplied by the refrigerator manufacturer.
21	4.1.5	Safety Report	1	A compilation of component lists, operating procedures, hazard and failure mode
22				and effects analysis, etc.
23				Interfaces with safety reports generated for the subsystems to form a
24				comprehensive analysis.
25	4.1.6	Assembly & Test	1	Includes the coil support system, used to mount to the detector, the necessary
26				specialty fixtures and equipment required for assembly and the test equipment.
27				Interfaces with the rest of the assembly of the detector.
28	4.1.7	Magnetic Field	1	Incorporeres all elements of designing, fabrication, and testing a system
29		Mapping Equipment		to map the solenoids central field. Also includes the necessary field monitor equip.
30				Interfaces only in the final detector assembly steps.
31	4.1.8	Management & Integration	1	Includes all costs associated with managing the design, fabrication and testing of
32				the solenoid system. Travel to Japan is included since interfacing with the initial
33				construction and testing of the solenoid is essential.

SUMMARY STATUS OF COST DATA

4.1.1 Superconducting Coil	Cost/Shedule estimate: -Supplied by Japan
4.1.2 Power Supply System	Cost estimate: -Vendor quote -Engineer estimate
4.1.3 Control Dewar System	Cost estimate: -Based on replacement cost of CDF control dewar.
4.1.4 Controls & Inst.	Cost estimate: -Engineer estimate based on communication with vendor.
4.1.5 Safety Report	Cost/Schedule estimate: -Based on FNAL experience
4.1.6 Assembly & Test	Cost/Schedule estimate: - Engineer estimate
4.1.7 Magnet Map Device	Cost/Schedule estimate: - Engineer estimate based on FNAL experience (Zip Track).
4.1.8 Mgm't & Integration	Cost estimate: - Engineer estimate based on CDF experience.

4.2.1 Refrigeration Systems	Cost/Schedule estimate: -Vendor quote -Engineer estimate
4.2.2 Transfer Systems	Cost/Schedule estimate: -Detailed engineer estimate
4.2.3 Aux. Cryo Systems	Cost/Schedule estimate: -Engineer estimate
4.2.4 Vacuum Systems	Cost estimate: -Vendor quote
4.2.5 Safety Report	Cost/Schedule estimate: -Based on FNAL experience
4.2.6 Assembly & Test	Cost/Schedule estimate: - Engineer estimate
4.2.7 Mgm't & Integration	Cost estimate: - Engineer estimate based on CDF experience.

SDC SOLENOID/CRYOGENIC SYSTEM
COST/SCHEDULE DRIVERS

	DURATION	MILESTONE
PROTOTYPE MAGNET	2.25 YEARS	FEB 94 TEST/JAPAN
SOLENOID COIL	4.25 YEARS	FEB 97 TEST/JAPAN
HELIUM SYSTEM	4.75 YEARS	JUL 97 TEST/SSCL
INSTALLATION & TEST "IN HALL"	0.75 YEARS	JUN 98 MAP MAG

	MAT'L & LAB	EDIA	% EDIA	SUB TOT	CONT	% CONT	TOT
4.0 SC MAGNET	29.2	3.1	10%	32.3	10.1	31%	42.4
4.1 SC SOLENOID	23.8	1.8	7%	25.6	8.3	33%	33.9
4.2 CRYOGENIC SYSTEM	5.4	1.3	19%	6.7	1.8	27%	8.5

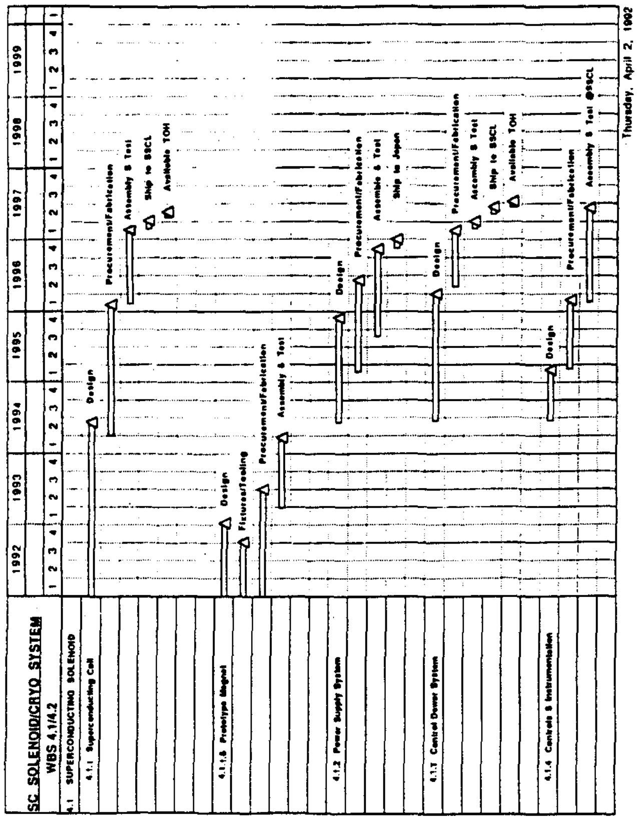
Superconducting Coil as a % of Total 4.1 costs = 75.8%

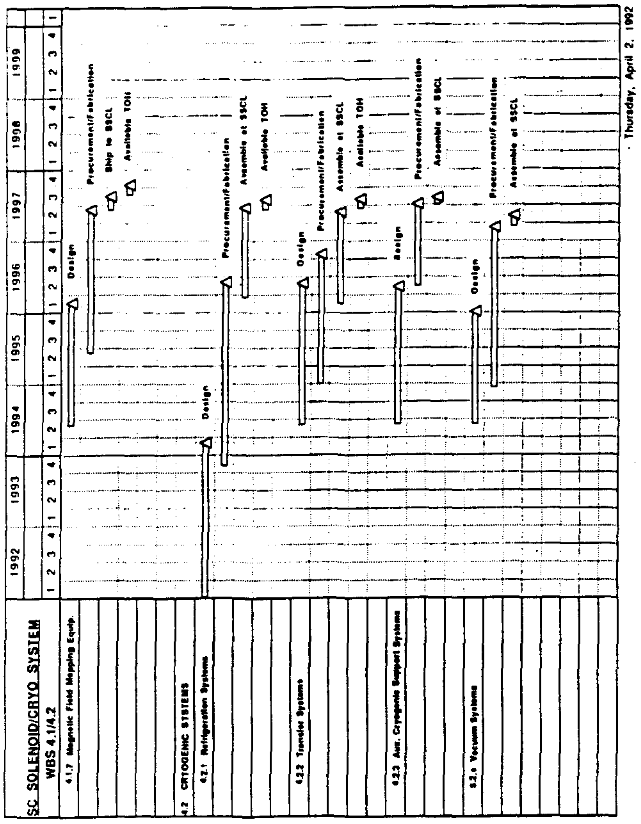
Helium Refrigeration System as a % of Total 4.2 costs = 55.5%

COST NUMBERS SUPPLIED BY TAKA KONDO:

		WBS #	Cont.	Base $
PROTOTYPE SOLENOID	$5.4 M	4.1.1.8	68%	3.27M
Design, management	$.36 M			
Superconductor	$1.1 M			
Coil Winding	$1.2 M			
Cryostat & Cryogenics	$1.0 M			
Power Supply for Test	$.86 M			
Monitors	$.14 M			
Assembly & Inspection	$.29 M			
Excitation Test	$.36 M			
SDC SOLENOID	$26.8 M	4.1.1		
Less Installation Costs = $1.1 M..............	$25.7 M			
Design, Management	$1.4 M	4.1.1.7	38%	1.02M
Supercondutor	$5.7 M	4.1.1.1	24%	4.60M
Coil Winding	$5.6 M	4.1.1.2	28%	4.38M
Cryostat	$5.4 M	4.1.1.3	24%	4.36M
Monitor System	$1.2 M	4.1.1.4	24%	.968M
Assembly & Inspection	$3.6 M	4.1.1.5	32%	2.73M
Excitation Test	$2.1 M	4.1.1.5	32%	1.59M
Transportation	$.71 M	4.1.1.6	16%	.612M
Installation & Test	$1.1 M			

140 yen = $1





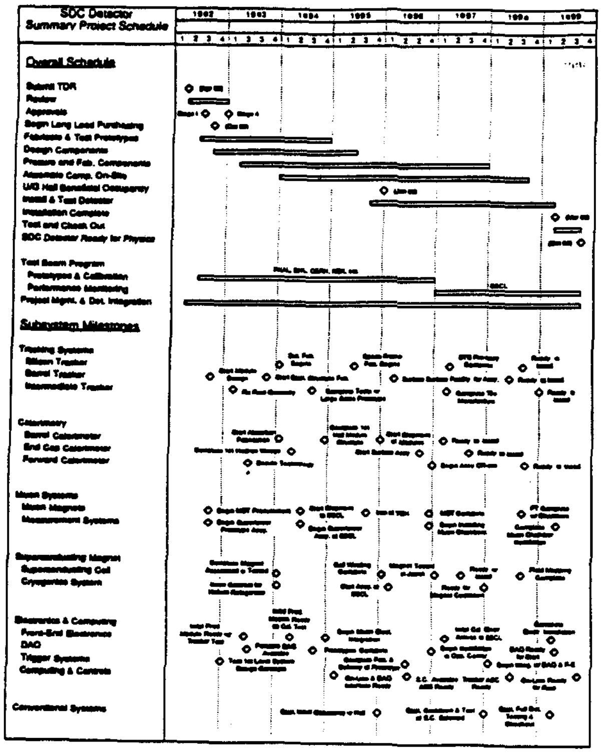


FIG. 15-1. A summary of the schedule for the design, construction and installation of the SDC detector.

REALITY CHECK:

- Compare Manpower Estimate of SDC with CDF Experience

Magnet Support

Classification:	CDF Experience	SDC Estimate
Engineer	7.5 manyears	7.5 manyears
Engineer Assoc.	1.5 manyears	1.5 manyears
Drafting	2.0 manyears	3.0 manyears
Technicians	2.0 manyears	4.1 manyears

Electrical Support

Classification:	CDF Experience	SDC Estimate
Engineer	2.5 manyears	5.0 manyears
Engineer Assoc.	2.5 manyears	1.0 manyears
Drafting	2.5 manyears	2.3 manyears
Technicians	5.0 manyears	7.5 manyears

Refrigerator Support

Classification:	CDF Experience	SDC Estimate
Engineer	6.0 manyears	10.7 manyears
Engineer Assoc.	1.5 manyears	1.5 manyears
Drafting	2.0 manyears	3.7 manyears
Technicians	5.0 manyears	6.8 manyears

TOTAL SUPPORT:

Classification:	CDF Experience	SDC Estimate
Engineer	16.0 manyears	23.2 manyears
Engineer Assoc.	5.50 manyears	4.00 manyears
Drafting	6.50 manyears	9.00 manyears
Technicians	12.0 manyears	18.4 manyears

It appears that the level of manpower estimated for SDC is comparable with that used for CDF in some areas. As expected, the level of manpower is higher in total.

REALITY CHECK II

- Compare Cost Estimate of SDC with LBL paper by R. Byrns
  "Estimating the Cost of Superconducting Magnets and the Refrigerators to Keep Them Cold"

Cost Equations for Solenoid Magnets:

$$C(M\$) = 0.523\,[E(MJ)]^{.662} \qquad = 0.523\,[146]^{.662} \qquad = 14.2\ MS$$

$$C(M\$) = 0.868\,[V(Tm^{3})]^{.577} \qquad = 0.868\,[145]^{.577} \qquad = 15{:}4\ MS$$

SDC Estimates = 20.2 MS Base
5.5 MS Cont

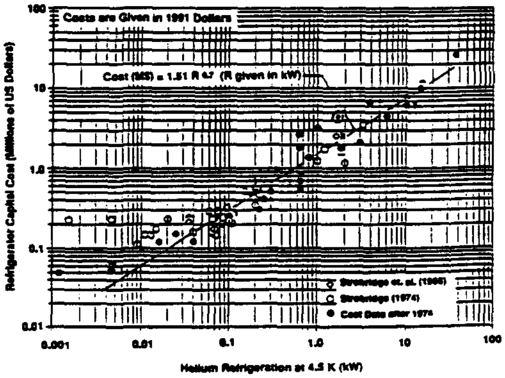
25.7 MS Total

Cost Equations for Helium Refrigeration:

$$C(M\$) = 1.51\,[R(kW)]^{.7} \qquad = 1.51\,[1.5]^{.7} \qquad = 2.0\ MS$$

SDC Estimates = 3.6 MS Base
1.1 MS Cont

4.7 MS Total



SDC Superconducting Solenoid Cost Summary

WBS		Mat'ls. ($k)	Mfg Labor ($k)	EDIA ($k)	Base ($k)	Cont. ($k)	Cont. %	Total w/ Cont. ($k)
[illegible]	Superconducting Coil	21,923	0	0	21,923	7,188	32.8	29,111
[illegible]	Power Supply System	366	303	594	1,263	296	23.4	1,560
[illegible]	Control Dewar System	262	20	173	455	127	27.9	582
[illegible]	Controls & Instrument.	110	140	138	388	124	32.0	512
[illegible]	Safety Report	30	0	120	150	39	26.0	189
[illegible]	Assembly & Test	100	69	189	358	158	44.1	516
[illegible]	Field Mapping Eqpt.	250	184	173	607	243	40.0	850
[illegible]	Mgmt. & Integ.	40	0	384	424	161	38.0	585
[illegible]	Total S.C. Solenoid	23,081	716	1,771	25,568	8,337	32.6	33,906

WBS	Description	Materials (K $)	Manuf. Labor (K $)	Materials + Manuf. Labor (K $)	EDIA (K $)	EDIA (%)	Subtotal (K $)	Contingency (K $)	Contingency (%)	Total (K $)
4.1	Superconducting Solenoid	23,081	716	23,797	1,771	6.9	25,568	8,337	32.6	33,906
4.1.1	Superconducting Coil	21,923	0	21,923	0	.0	21,923	7,188	32.7	29,111
4.1.1.1	Superconducting Wire	4,597	0	4,597	0	.0	4,597	1,103	24.0	5,700
4.1.1.2	Coil Winding Equipment	4,375	0	4,375	0	.0	4,375	1,225	28.0	5,600
4.1.1.3	Cryostat System	4,356	0	4,356	0	.0	4,356	1,045	24.0	5,400
4.1.1.4	Instrumentation System	968	0	968	0	.0	968	232	24.0	1,200
4.1.1.5	Assembly & Test	2,727	0	2,727	0	.0	2,727	873	32.0	3,600
4.1.1.6	Transportation to SSCL	612	0	612	0	.0	612	98	16.0	710
4.1.1.7	Management & Integration	1,015	0	1,015	0	.0	1,015	386	38.0	1,401
4.1.1.8	Prototype Magnet	3,274	0	3,274	0	.0	3,274	2,226	68.0	5,500
4.1.2	Power Supply System	366	303	669	594	46.9	1,264	296	23.4	1,560
4.1.2.1	Prime Mover	122	5	127	38	23.0	165	26	16.0	191
4.1.2.2	Switches & SCRs	31	32	63	61	49.1	124	20	16.0	144
4.1.2.3	Dump Resistors	61	12	73	39	33.9	112	18	16.0	130
4.1.2.4	Quench Protection System	40	28	68	138	66.9	206	66	32.0	272
4.1.2.5	Current Transducers & Instr.	40	15	55	72	56.8	127	41	32.0	168
4.1.2.6	AC Cabling & Breakers	59	56	115	75	39.4	190	30	16.0	220
4.1.2.7	Assembly & Test	12	156	168	172	50.6	340	95	28.0	435
4.1.3	Control Dewar System	262	20	282	173	38.0	455	127	28.0	582
4.1.4	Controls & Instrumentation	110	140	250	138	35.5	388	124	32.0	512
4.1.5	Safety Report	30	0	30	120	80.0	150	39	26.0	189
4.1.6	Assembly & Test	100	69	169	189	52.7	358	158	44.0	516
4.1.7	Magnetic Field Mapping Eqpt.	250	184	434	173	28.5	607	243	40.0	850
4.1.8	Management & Integration	40	0	40	384	90.5	424	161	38.0	585

SDC Cryogenics System Cost Summary

WBS #		Mat'ls. ($k)	Mfg Labor ($k)	EDIA ($k)	Base ($k)	Cont. ($k)	Cont. %	Total w/ Cont. ($k)
2.1	Refrigeration Systems	3,913	28	453	4,394	1,252	28.5	5,646
2.2	Transfer Systems	668	424	418	1,511	332	22.0	1,843
2.3	Auxiliary Cryogenic Sppt.	20	4	43	68	22	32.4	90
2.4	Vacuum Systems	189	42	133	365	92	25.2	457
2.5	Safety Report	2	0	104	106	23	21.7	129
2.6	Assembly & Test	10	82	23	115	41	35.7	156
2.7	Mgmt. & Integration	5	0	126	131	29	22.1	160
	Total Cryogenics Sys.	4,807	580	1,300	6,690	1,792	26.8	8,482

SDC DETECTOR [illegible]

WBS	Description	Materials (K$)	Manuf. Labor (K$)	Materials + Manuf. Labor (K$)	EDIA (K$)	EDIA (%)	Subtotal (K$)	Contingency (K$)	Contingency (%)	Total (K$)
4.2	Cryogenic Systems	4,807	580	5,387	1,300	19.4	6,687	1,782	26.7	8,469
4.2.1	Refrigeration Systems	3,913	28	3,941	453	10.3	4,394	1,252	28.4	5,646
4.2.1.1	Helium Refrigerator	3,487	0	3,487	155	4.2	3,642	1,087	30.0	4,729
4.2.1.2	Liquid Nitrogen System	425	0	425	183	30.1	608	128	21.0	736
4.2.1.3	Control System	10	1	11	14	56.0	25	6	24.0	31
4.2.1.4	Assembly & Test	5	27	32	29	47.5	61	17	28.0	78
4.2.1.5	Safety Report	1	0	1	26	96.3	27	5	18.0	32
4.2.1.6	Management & Integration	5	0	5	46	90.2	51	9	18.0	60
4.2.2	Transfer Systems	668	424	1,092	418	27.6	1,511	332	21.9	1,843
4.2.2.1	Cryogenic Transfer Line	279	244	523	208	28.4	731	150	20.5	881
4.2.2.2	Gas Piping System	270	139	409	83	16.8	492	118	24.0	610
4.2.2.3	Electrical Buss System	90	20	110	27	19.7	137	33	24.0	170
4.2.2.4	Water Systems	6	20	26	19	42.2	45	11	24.0	56
4.2.2.5	Control System	20	1	21	12	35.2	34	8	24.0	42
4.2.2.6	Safety Report	1	0	1	23	95.8	24	4	18.0	28
4.2.2.7	Management & Integration	2	0	2	46	95.9	48	8	18.0	56
4.2.3	Auxiliary Cryogenic Support	20	4	24	43	63.2	68	22	32.0	90
4.2.3.1	Cryogenic Equipment for VLPCs	10	2	12	29	70.7	41	13	32.0	54
4.2.3.2	Equipment for Nitrogen Purging	10	2	12	14	51.9	27	9	32.0	36
4.2.4	Vacuum Systems	189	42	231	133	36.4	365	92	25.3	457
4.2.4.1	Solenoid Vacuum System	32	11	43	35	44.9	78	22	28.0	100
4.2.4.2	Transfer Line Vacuum System	30	10	40	19	32.2	59	17	28.0	76
4.2.4.3	Auxiliary Vacuum System	90	18	108	33	23.5	140	34	24.0	174
4.2.4.4	Vacuum Control System	30	5	35	11	23.9	46	13	28.0	59
4.2.4.5	Safety Report	2	0	2	23	92.0	25	5	18.0	30
4.2.4.6	Management & Integration	5	0	5	12	70.6	17	3	18.0	20
4.2.5	Safety Report	2	0	2	104	98.1	106	23	22.0	129
4.2.6	Assembly & Test	10	82	92	23	20.0	115	41	36.0	156
4.2.7	Management & Integration	5	0	5	126	96.1	131	29	22.0	160

4.1 Solenoid Subsystem Milestones

4.1.1 Superconducting Coil

DATE	MILESTONE DESCRIPTION
May-94	Complete Fixed Design Report/Start Fabrication
Mar-95	Superconductor fabricated
Feb-96	Complete winding of SC Coil
Oct-96	Complete magnet assembly in cryostat
Feb-97	Magnet tested (in air)
Mar-97	Arrives at SSCL
Apr-97	Available TOH

4.1.1.8 Prototype Coil

DATE	MILESTONE DESCRIPTION
Feb-93	Complete winding of SC Coil
Feb-93	Vacuum vessel delivered to Japan
Oct-93	Complete magnet assembly in cryostat
Feb-94	Magnet tested (in air)

4.1.2 Power Supply System

DATE	MILESTONE DESCRIPTION
Nov-95	Complete design of power supply & QPM
May-96	Fabricate power supply/QPM system
Nov-96	Test system
Dec-96	Power supply system delivered to Japan

4.1.3 Control Dewar System

DATE	MILESTONE DESCRIPTION
Mar-96	Complete design of Control Dewar
Feb-97	Complete fabrication of Control Dewar
Mar-97	Test Control Dewar
May-97	Control Dewar arrives at SSCL

4.1.4 Controls and Instrumentation

DATE	MILESTONE DESCRIPTION
Mar-95	Complete design of integrated controls system
Mar-96	Complete fabrication of integrated controls system
May-97	Controls system available at SSCL

4.1.7 Magnetic Field Mapping Equipment

DATE	MILESTONE DESCRIPTION
Mar-96	Complete design of equipment
May-97	Complete fabrication of equipment
Aug-97	Equipment delivered to SSCL
Oct-97	Available TOH

4.2 Cryogenic Systems

4.2.1 Refrigeration Systems

DATE	MILESTONE DESCRIPTION
Feb-94	Issue contract for helium refrigerator
Mar-94	Complete design of integrated cryogenic system
Mar-95	Issue contract for LN_2 dewar
Mar-96	Assembly start at SSCL
Jun-97	Assembly complete at SSCL
Jul-97	Available TOH

4.2.2 Transfer Systems

DATE	MILESTONE DESCRIPTION
May-96	Complete design of integrated transfer systems
Feb-96	Assembly start at SSCL
May-97	Assembly complete at SSCL
Jul-97	Testing complete

4.2.3 Auxiliary Cryogenic Support Systems

DATE	MILESTONE DESCRIPTION
Apr-96	Complete design of cryogenic equipment for VLIC's, nitrogen purge systems
Jun-97	Complete fabrication of systems
Jul-97	Assembly complete at SSCL

4.2.4 Vacuum Systems

DATE	MILESTONE DESCRIPTION
Jan-96	Complete design of vacuum systems
Mar-97	Complete fabrication of vacuum systems
Apr-97	Assembly complete at SSCL

Installation & Test Major Milestones

WBS	MILESTONE DESCRIPTION	DATE
8.2	**Installation and Test**	
	Hall Availability for Support System Installation	Oct-95
	Begin Muon Barrel Installation	Jan-96
	Hall Beneficial Occupancy (Baseline)	Jan-96
	Muon Barrel Toroid Steel at T.O.H.	Feb-96
	Barrel Toroid Steel Complete	Aug-96
	Begin Conventional Systems Installation	Sep-96
	Coil Installation Complete	Dec-96
	Barrel Cal. Toroid Ready at T.O.H.	Apr-97
	Phase I Muon Complete	May-97
	Solenoid & Chimney & Electronics arrives at SSCL	Jul-97
	Ready to Begin Solenoid Installation	Aug-97
	Begin Calorimeter Connect Signal/Power Cool	Oct-97
	End Toroid Steel at T.O.H.	Oct-97
	End Cap Calorimeters at T.O.H.	Nov-97
	Muon Barrel Chambers at T.O.H.	Dec-97
	Solenoid Installation Complete	Dec-97
	Ready to Begin Field Mapping	Mar-98
	Field Mapping Complete	Jun-98
	Ready to Install Tracking System	Jun-98
	Central Trackers Ready for Inst. at T.O.H.	Jun-98
	Si/Pixel Tracker Ready for Installation T.O.H.	Sep-98
	Muon End Chambers at T.O.H.	Sep-98
	Forward Calorimeter at T.O.H.	Oct-98
	Begin Solenoid Installation	Nov-98
	Interm. Tracker Ready for Installation T.O.H.	Jan-99
	Ready to Begin Solenoid Field Mapping	Jan-99
	Ready to Install Electronics for Tracking Systems	Jan-99
	Forward Muon System Ready for Installation	Feb-99
	Tracking System Installation Complete	Mar-99
	Detector Ready to Roll In Forward Muon Toroid Sys.	Mar-99
	Barrel Tracking System Electronics Inst. & Checkout	Mar-99
	End Cap Cals Installed	Apr-99
	Forward Muon System Installed	Apr-99
	Begin Accelerator Work	Apr-99
	Electronics Tracking System Installation Complete	Apr-99
	End Cap Calorimeter Installation Complete	Apr-99
	Begin Electronics Installation & Test	May-99

Accelerator Complete	Jul-99
Detector Turn-on	Oct-99
Conventional Tracking System Installed	Oct-99
End Caps Calorimeter Installed	Oct-99
Hall Conventional Systems Installation Complete	Oct-99

3/27/92

PARALLEL SESSION B:

TRACKING

REQUIREMENTS AND OVERVIEW

W. FORD

W.T. Ford

00508

Tracking System: Requirements and Overview

- Solid Angular Acceptance
- Tracking System Layout and Detector Parameters
- Momentum Resolution Considerations
- Lepton Identification
- Non-Isolated Track Efficiency and Vertex Measurement (*b* tagging and top Physics)
- Trigger
- High Luminosity Considerations

Requirements for Isolated Charged Tracks

- *Acceptance out to* $|\eta| = 2.5$.

  ($H^0 \to \ell^+\ell^-\ell'^+\ell'^-$ geometrical efficiency $\gtrsim 60\%$ per event. for $m_H \geq 200$ GeV/c^2.)

- *Reconstruction efficiency* $\geq 97\%$ *per track* ($p_t \geq 10$ GeV).

  ($\geq 90\%$ per event for $H^0 \to \ell^+\ell^-\ell'^+\ell'^-$.)

- *Momentum resolution:* $\sigma_{p_t}/p_t^2 < 20\%$ (TeV/c)$^{-1}$.

  ($Z^0 \to \mu^+\mu^-$ mass resolution $\lesssim$ the natural width; sign of charge to $p_t \sim$ 1 TeV/c.)

Lepton acceptance ... $p_\perp$, η for $H^0 \to Z^0Z^0 \to 4l$

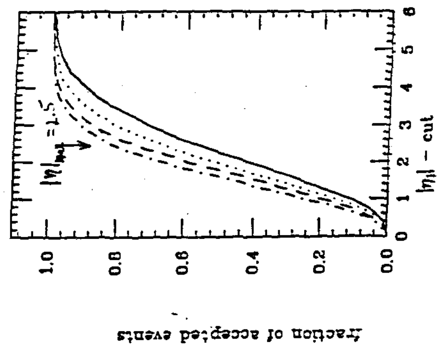


Fig. 1

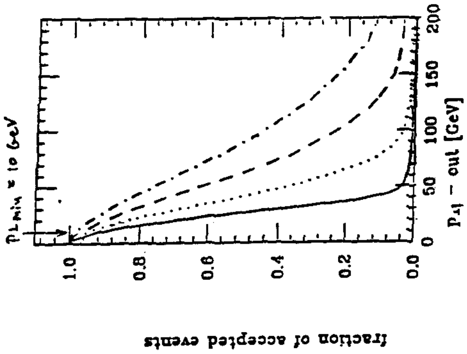
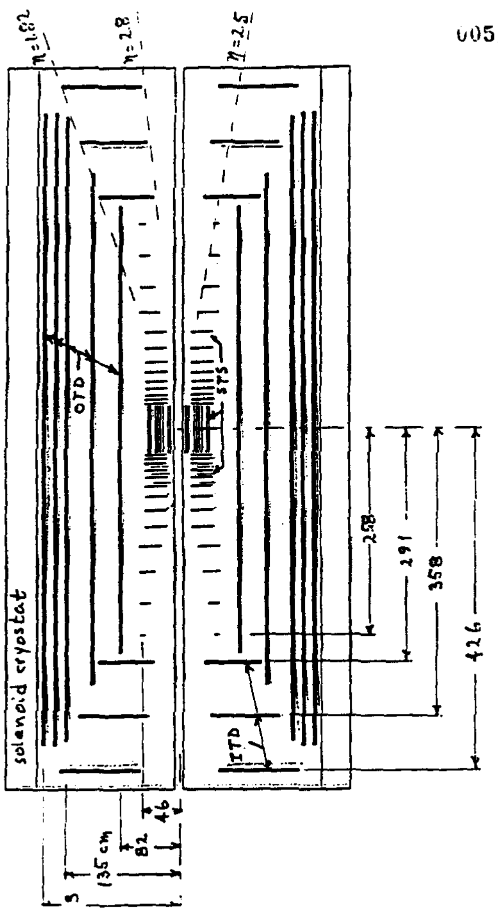


Fig. 2

solid: M_H = 200 GeV, dotted: M_H = 400 GeV
dashed: M_H = 600 GeV, dashed-dotted: M_H = 800 GeV



Tracker Measurement Resolutions

Silicon strip detectors (STS) $0 < |\eta| < 2.5$

- 8 layers, barrel+disks
- double-sided with 10 mrad stereo
- 12 cm long strips 50 μm pitch
- 2-side layer resolution: $\sigma(r\phi) = 12$ μm $\sigma(z \text{ or } r) = 1.2$ mn
- Pixel option for inner layers

Straw tube detectors (OTD) $0 < |\eta| < 1.8$

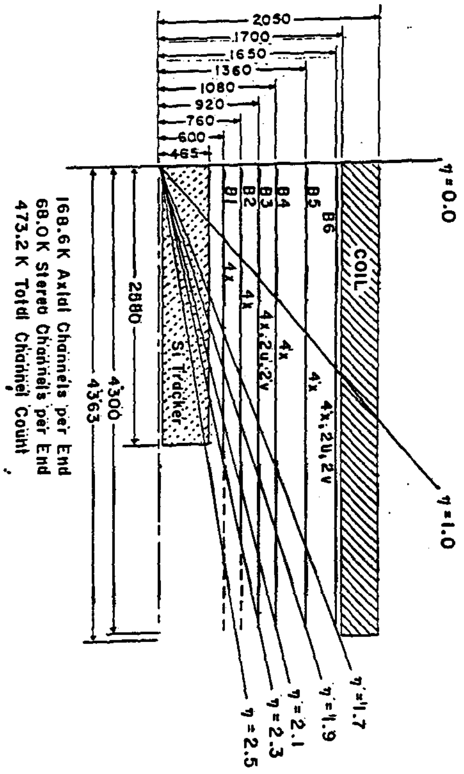
- 5 barrel superlayers in two longitudinal sections
- 6-8 layers/superlayer 4 mm pitch 120 μm/layer
  3 axial/trigger superlayers @8 layers: $\sigma(r\phi) = 83$ μm
- 2 ($\pm 3°$) stereo superlayers @6 layers: $\sigma(r\phi) = 87$ μm
  $\sigma(z) = 1.2$ mm
- local vector direction: $\sigma(\alpha) = 7\text{-}11$ mrad

Gas microstrip detectors (ITD) $1.8 < |\eta| < 2.8$

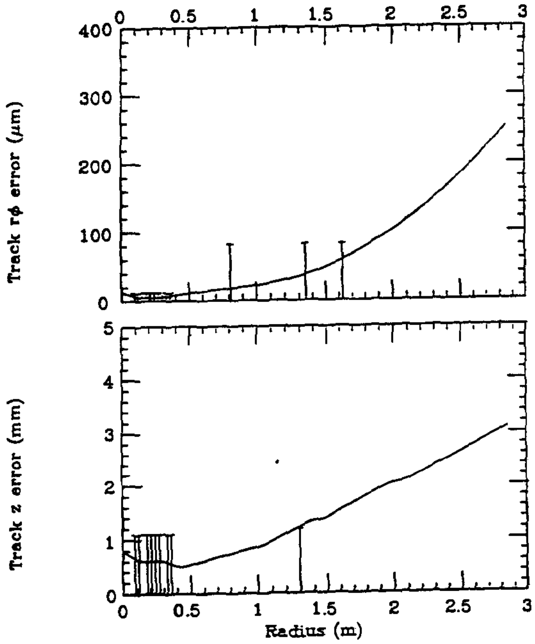
- 3 disk superlayers each end
- mosaic of trapezoidal panels 200-500 μm pitch
- 4 layers/disk: $r\phi$, $+8°$, $-8°$, $r\phi$ $\sim$ 100 μm/layer
- disk resolution: $\sigma(r\phi) = 50$ μm $\sigma(r) = 500$ μm

Scintillating Fiber Option $0 < |\eta| < 2.3$

- 6 barrel superlayers in two longitudinal sections
- 2-4 layer pairs/superlayer 1 mm pitch/2
- 4 axial superlayers @2 layer pairs: $\sigma(r\phi) = 115\ \mu\text{m}$
- 2 axial/stereo superlayers: 2 $r\phi$ pairs, 2 ±6° pairs $\sigma(r\phi) = 90\ \mu\text{m}$ $\sigma(z) = 1$ mm
- local vector direction: $\sigma(\alpha) = 13$ mrad

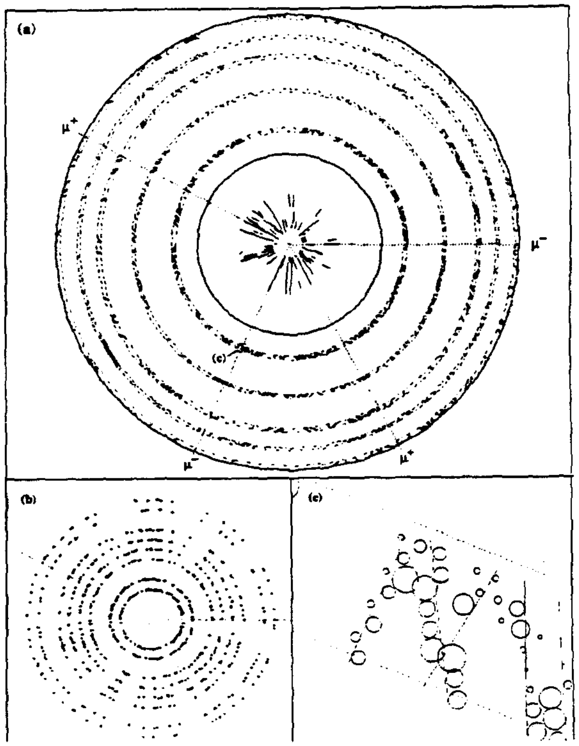


Track Parameter + Envelope Errors (η=0)

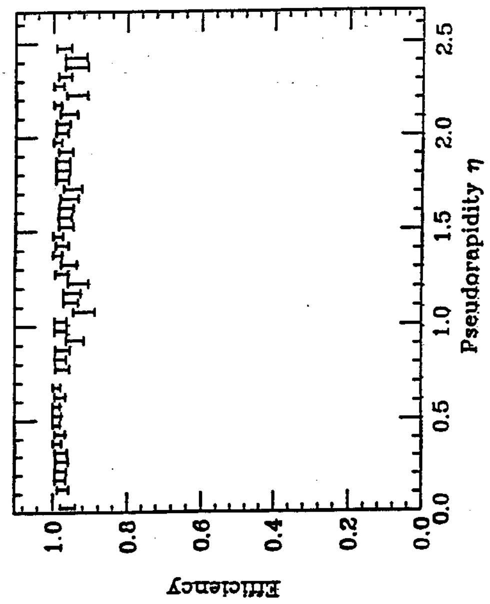


dpt/pt@1TeV= 0.164
db= 13.0 microns
dphi= 0.066 mrad

dcot(theta)= 1.25 mm/m
dz0= 0.77 mm



Reconstruction Efficiency : $P_t > 1$ GeV tracks from $H^0 \to Z^0 Z^0 \to e^+e^-\mu^+\mu^-$



Tracks reconstructed in STS,
Straw segments attached. ($|\eta| < 1.6$): >97% have 4 or 5 straw segments

Some Processes Dependent on $\sigma(p_t)$

Process	Objective	Req'd $\sigma(p_t)/p_t^2$ $(TeV/c)^{-1}$
$H \to ZZ^*,\ Z \to \mu\mu\ (M(H) = 130 - 180\ \mathrm{GeV}/c^2)$	$\sigma[M(\mu\mu)] \sim .42\Gamma_Z \simeq .01M_Z$	0.2
$H \to ZZ,\ Z \to \mu\mu\ (M(H) = 200 - 800\ \mathrm{GeV}/c^2)$	(same)	0.2 – 0.05
$H \to ZZ,\ Z_1 \to \mu\mu,\ Z_2 \to \nu\bar{\nu}$, jet jet	(same)	0.2 – 0.05
$(W,\ Z)$ production, $Z \to \mu\mu$ (e.g., techniresonances)	(same)	0.2 – 0.02
$Z' \to \mu\mu,\ (M(Z') = 200 - 4000\ \mathrm{GeV}/c^2)$	$\sigma[M(\mu\mu)] \sim .01M'_Z$	0.05-0.005
$W^+W^+ \to W^+W^+$	$3 - 4\sigma$ sign det'n @ $p_t = 1$ TeV	< 0.3

Lepton $P_\perp$ spectrum from W, Z, top, γ conversions

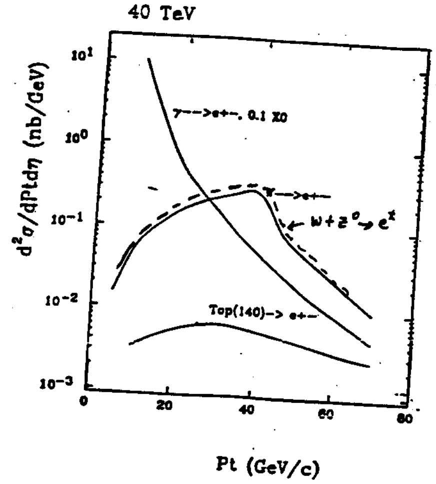
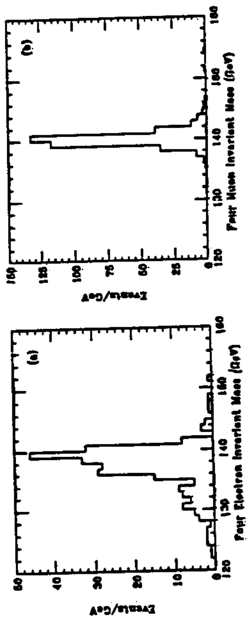
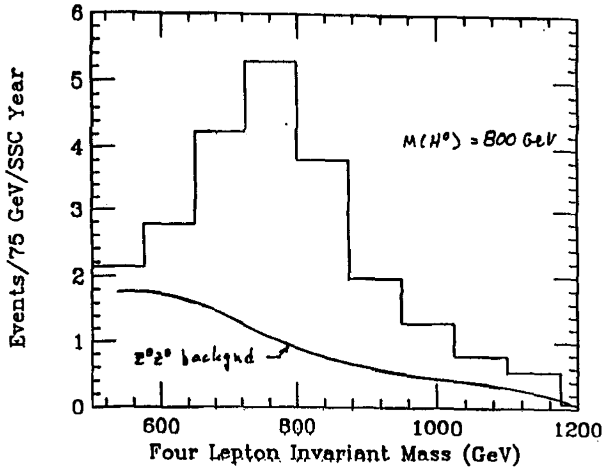


Fig. 5

Higgs mass reconstruction for
$H^0 \to ZZ^* \to 4\ell$
$M(H^0) = 140\ \mathrm{GeV}/c^2$

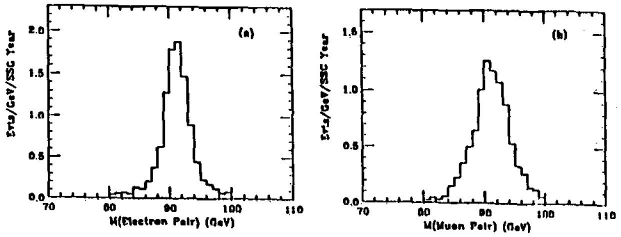




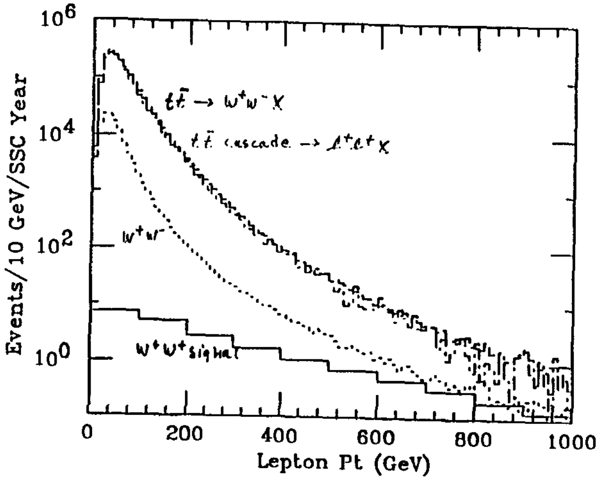
Z^0 Reconstruction for Higgs Decay:

$H^0 \to Z^0 Z^0$
$\hookrightarrow e^+e^-$
$\hookrightarrow \mu^+\mu^-$

$M(H^0) = 800$ GeV/c^2



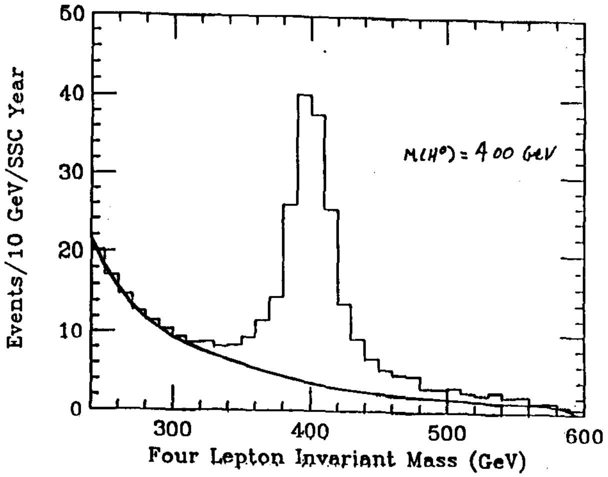
Strong Symmetry Breaking via W^+W^+ Scattering
$W^+ \to \ell^+ \nu$

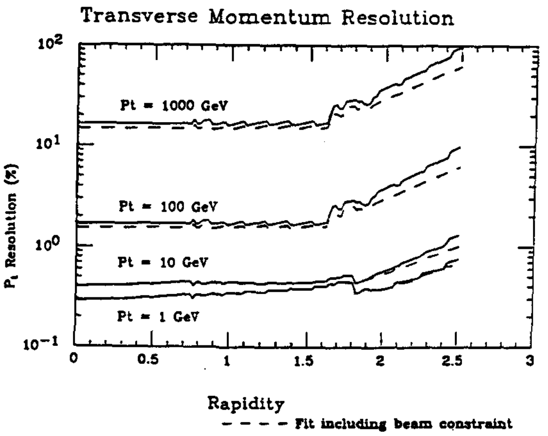


For t decays, gain 10^3 suppression from lepton isolation
10^2 " " veto on "X"

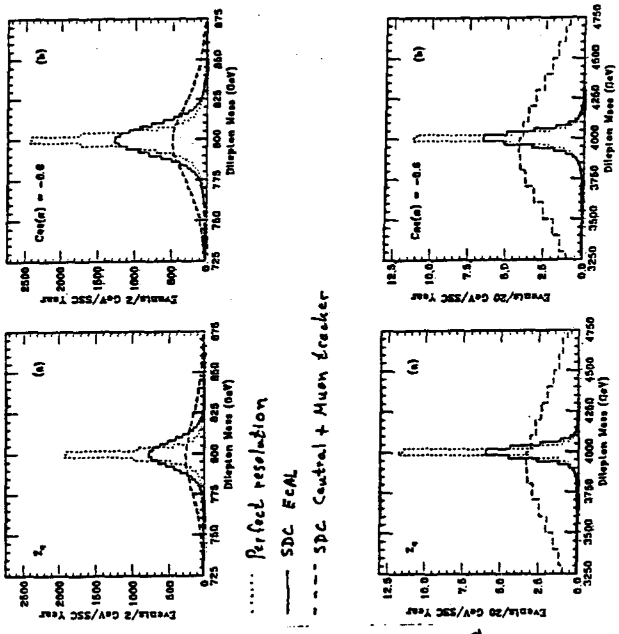
Need 10^{-3} reconstruction wrong sign rejection

$H^0 \to Z^0Z^0 \to 4\ell$





New Heavy $Z' \to \ell^+\ell^-$



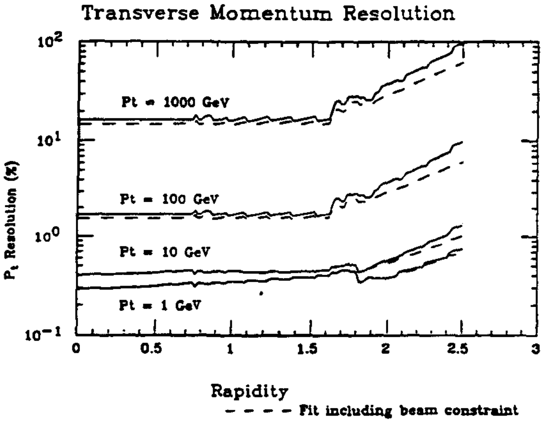
······ Perfect resolation

—— SDC ECAL

– – – SDC Central + Muon tracker

M(Z') ≈ 800 GeV/c²

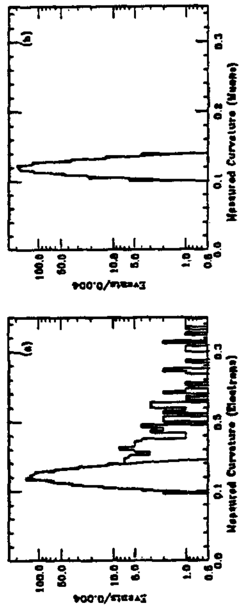
M(Z') = 4000 GeV/c²



Track charge sign measurement

Pt ≈ 500 GeV/c lepton + min. bias background corresponding to $\mathcal{L} \approx 3 \times 10^{33}$ $cm^{-2}s^{-1}$

Reconstructed curvature !



Observe 1 mismeasured sign in 900 events

Electron Identification

Transverse profile in EMCal: confined to 2 × 2 towers ($\Delta\phi = \Delta\eta = .05$)

Longitudinal profile: HAD/EM<cut

Isolation: energy within cone centered on the shower $\sqrt{\Delta\phi^2 + \Delta\eta^2}$ <cut

Geometrical match of track with shower at shower max layer

Track momentum/shower energy match:
$0.7 < E/p < 1.4$

Lepton Identification Requirements

- *No more than 0.15 radiation lengths of material,* $\lesssim .07X_0$ *inside 50 cm.*

  (Match between calorimeter energy and track momentum for electrons.)

- *Position resolution at the calorimeter shower maximum detector* ≤ 5 *mm in* $r\phi$ *(where bremsstrahlung smearing occurs) and* ≤ 2.5 *mm in* z.

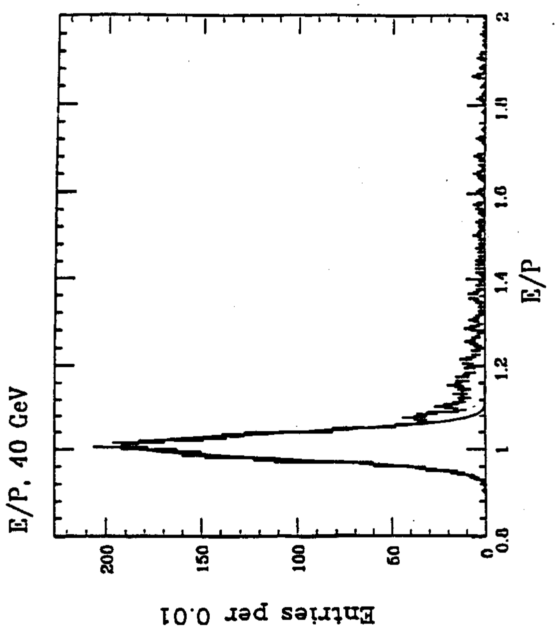
  (Track/shower position match to minimize $\pi^0 \to \gamma$ background for non-isolated electrons.)

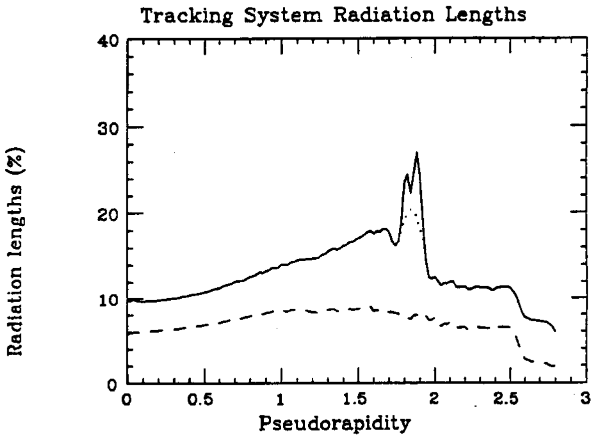
- *Alignment to the muon system of 2 mm in* z.

  (Match trajectory through toroid spectrometer for high momentum, low multiple scattering muons.)

- *Alignment to the muon system of* 100 μm *in* $r\phi$.

  (Measure sagitta in $r\phi$ just inside the solenoid, for high momentum muons.)




Tracking System Radiation Lengths

Average for $0<\eta<2.5$: 13.5%
Silicon alone: 7.4%

Requirements for Non-Isolated Charged Tracks and Vertex Measurement

- *Reconstruction efficiency* ≥ *80% for tracks of* $p_t > 5$ GeV, *with less than 10% fakes, within jets of* p_t *up to* 100 GeV.

  (Leptons from *b* decay.)

- *Impact parameter resolution* ≤ 20 μm *(for stiff tracks,* ≤ 100 μm *for* $p_t = 1$ GeV*), and* ≥ *85% efficiency for finding tracks with* $p_t > 1$ GeV *within jets of* p_t *up to* 100 GeV.

  (Efficient *b* tagging by detached vertices – at least 25%, with ≥ 90% purity.)

- *Resolution for the z component of the vertex of 2 mm*

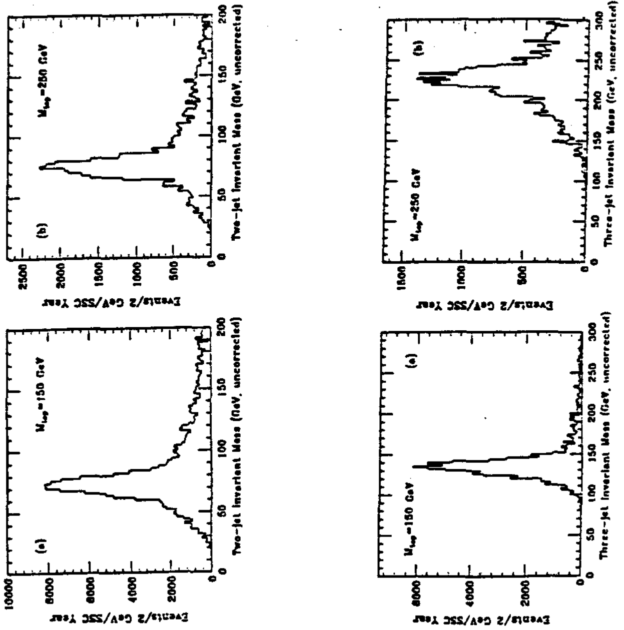
  (Separation of pileup interactions.)

- *Jet charged multiplicity measurement within 15% for jets up to* p_t = 500 GeV

  (QCD studies and background modelling)

$\bar{t} \to W^- \bar{b}$
$\hookrightarrow e^- \bar{\nu}$
$t \to W^+ b$
$\hookrightarrow$ jet jet

Top Reconstruction



3-11-

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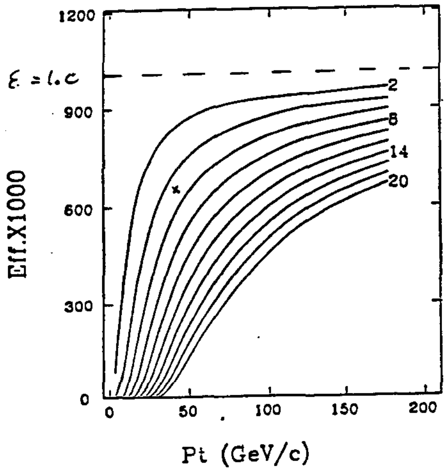
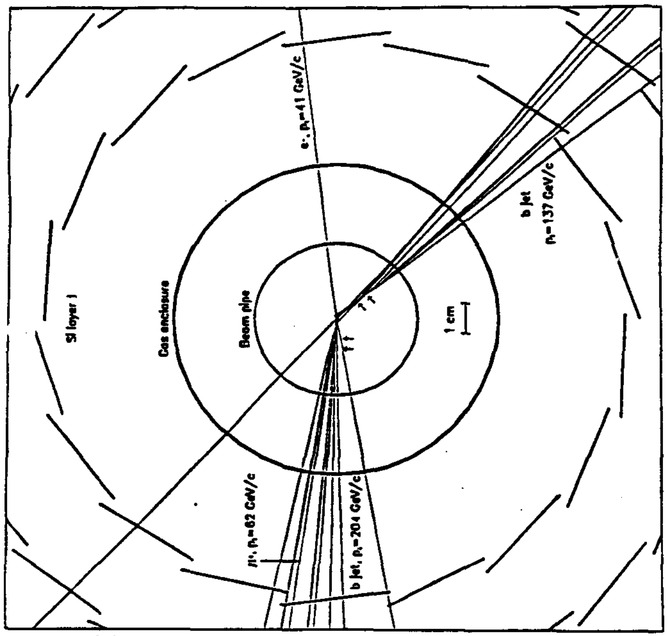
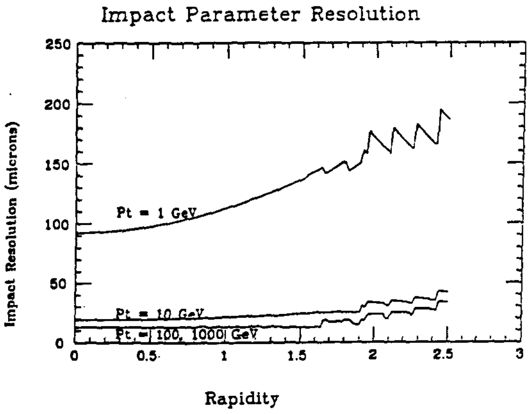
b→e efficiency vs electron $p_\perp$ threshold



Need to detect e's in or near jets with $p_\perp$ down to 5 GeV to get 70% of b→e⁻ decays.
Fig. 9



b tag
via detached
vertex.



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b tagging

Si, no pixels

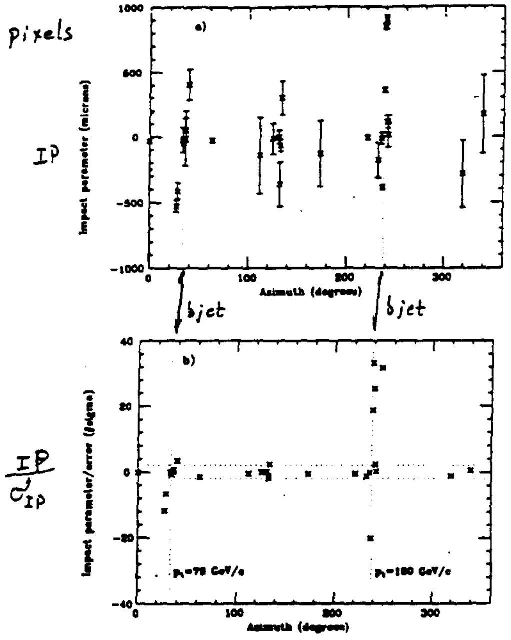
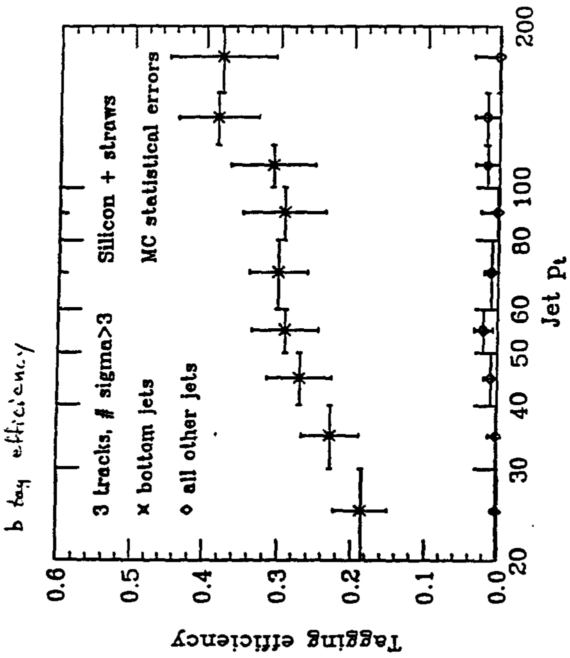


Fig. 24 Charged tracks ($|Y| < 2.5$, $P_\perp > 1$ GeV) in an ISAJET $t\bar{t}$ event with m_{top} = 150 GeV, for the system without a pixel vertex detector. a) Simulated impact parameter and error vs. azimuth ϕ. The two b jets are indicated by dotted lines. b) Number of sigma of impact parameter vs. azimuth ϕ. The horizontal dotted lines show 3 sigma cut.

---

b tag efficiency



Jet multiplicity

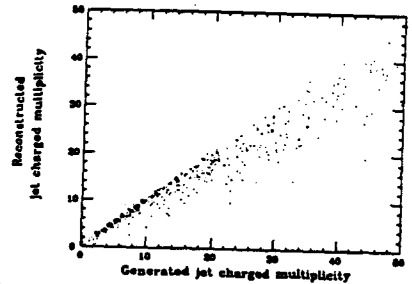
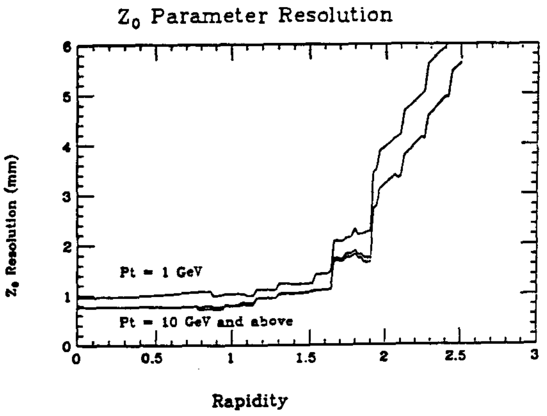


Fig. 23 Reconstructed vs. produced jet multiplicities for 1 TeV ISAJET events.

(e.g., to distinguish (W, Z) from QCD jets;
QCD studies;
background studies)



Triggering Requirements

- *First level trigger efficiency* $\geq$ 96% *per track, with momentum resolution* $\sigma_{p_t}/p_t^2 \leq 10$ (TeV/c)$^{-1}$.

  (Threshold rise over 1 − 2 GeV/c for a 10 GeV lepton, e.g., from $H^0 \to \ell^+\ell^-\ell'^+\ell'^-$.)

- *First level false trigger rate* ≤ 0.05 *per calorimeter trigger* ϕ *bin* $(2\pi/64)$ *per crossing.*

  (Preserve factor 5−10 rate reduction for single electrons.)

- *Second-level trigger with momentum resolution* $\sigma_{p_t}/p_t^2 \leq$ 5 (TeV/c)$^{-1}$.

  (Threshold rise over 8 GeV/c for a 40 GeV/c lepton from $Z \to \ell^+\ell^-$, $W \to \ell\nu$, e.g., for calorimeter calibration.)

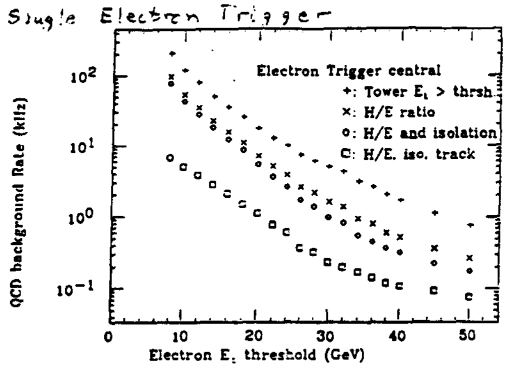


Fig. 10

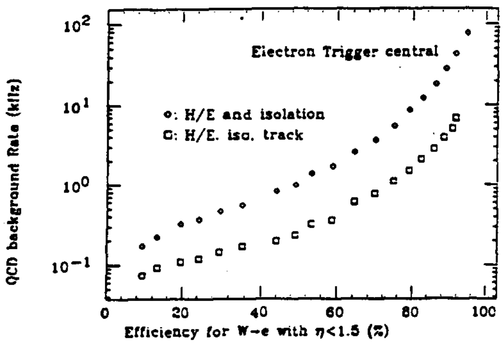
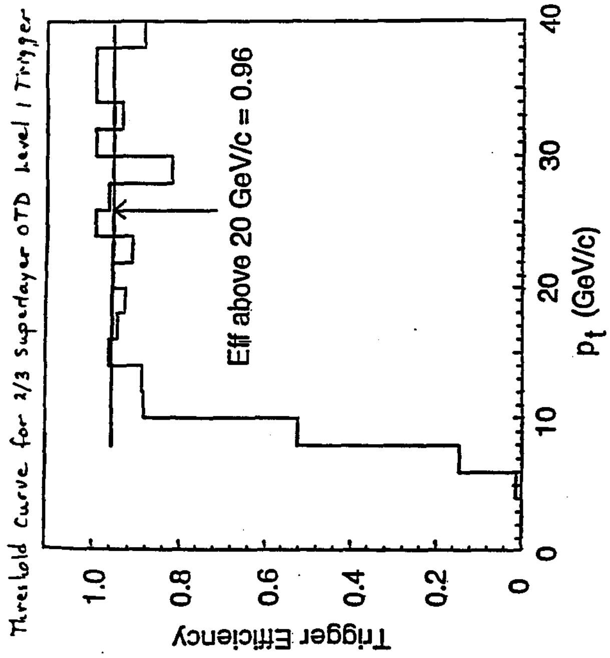


Fig. 11



Requirements for Luminosity Upgrades, Discovery Potential

- *Detection of isolated leptons with efficiency ≥ 90% at 10 × design luminosity*
- *Reconstruction and impact parameter measurement of leptons within jets up to the largest jet p_t possible (at least ≥ 500 GeV, with reconstruction efficiency ≥ 50%).*

  (Discovery potential.)
- *Survivability at standard $\mathcal{L}$ for ≥ 10 years, upgradable to ≥ 10 years at 10× standard $\mathcal{L}$.*

  (Emphasize detection of rare processes, capabilities indicated by experience from initial running.)

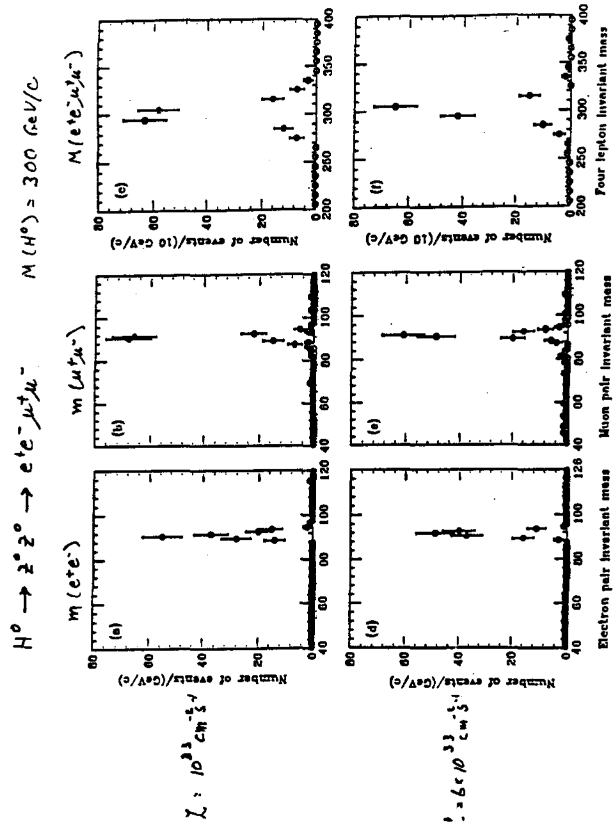


Table 4-6
Summary of efficiencies and number of fake tracks for $H^0 \to e^+e^-\mu^+\mu^-$ events for various configurations.

Luminosity	Fakes per event with p_t>5 GeV/c	Track efficiency p_t>10 GeV/c	Electron E/p efficiency $0.7< E/p <1.4$	M_Z cut efficiency e	μ	Higgs reconstruction efficiency
1 × 10^33	0.03 ± 0.01	0.991	0.96 ± 0.01	0.99 ± 0.01	0.99 ± 0.01	0.84 ± 0.04
3 × 10^33	0.04 ± 0.02	0.989	0.96 ± 0.01	1.00 ± 0.01	0.97 ± 0.01	0.83 ± 0.04
6 × 10^33	0.18 ± 0.03	0.972	0.93 ± 0.01	1.00 ± 0.01	0.93 ± 0.02	0.75 ± 0.04

Parametric Resolutions for the Barrel Tracker (at $\eta = 0$)

Track parameter	σ
$\Delta p_t/p_t$ at 1 TeV/c (20 μm beam constraint)	0.15
$\Delta p_t/p_t$ at 1 TeV/c (no beam constraint)	0.17
$\Delta\phi_0$ (mrad)	0.066
$\Delta \cot\theta$	0.0013
Δb (impact parameter, μm)	13.
Δz_0 (mm)	0.77
Extrapolation error in calorimeter	
$r\phi$ at shower max. (mm)	0.14
z at shower max. (mm)	2.5

Summary

The SDC baseline tracking system is well matched to its requirements for

- Efficient detection of isolated electrons and muons
- Sign of charge determination to 1/1000 at 1 TeV/c
- Match to the calorimeters and muon detectors for lepton identification
- Detection of non-isolated leptons, e.g., from *b* decay
- Detached vertex detection, *b* tagging
- Moderately efficient tracking of charged hadrons in jets
- Stiff track contribution to the trigger
- Survivability and functionality at luminosities at least several times design

00550

SILICON TRACKER SUMMARY

A. SEIDEN

SDC SILICON TRACKING SYSTEM

Innermost part of the Central Tracking Detector whose elements function together to meet the SDC goals for tracking performance.

A. Seiden
May 5, 1992

U.S., Japanese, U.K, Italian, Russian Collaboration

California Institute of Technology
University of California, Davis
University of California, Riverside
University of California, Santa Cruz
University of Hawaii
Johns Hopkins University
University of New Mexico
University of Oklahoma
University of Pittsburgh
Fermi National Accelerator Laboratory
Lawrence Berkeley Laboratory
Los Alamos National Laboratory
Superconducting Supercollider Laboratory
Hiroshima University
Hiroshima Institute of Technology
KEK, National Laboratory for High Energy Physics
Nagoya University
Niigata University
Okayama University
Wakayama Medical College
Universities of Pisa and Sassari, and INFN-Pisa
University of Milan
University di Pavia and INFN-Milano
University of Bristol
University of Oxford
Rutherford Appleton Laboratory
Joint Institute for Nuclear Research, Dubna

Based on work on silicon tracking for:
MARK II, CDF, and ZEUS
and R&D for Pixel Detectors.

Have also collaborated on R&D with several European groups who are not part of SDC.

SILICON TRACKING FOR THE SSC

Why : Excellent precision and two-track separation based on 50 μm pitch.

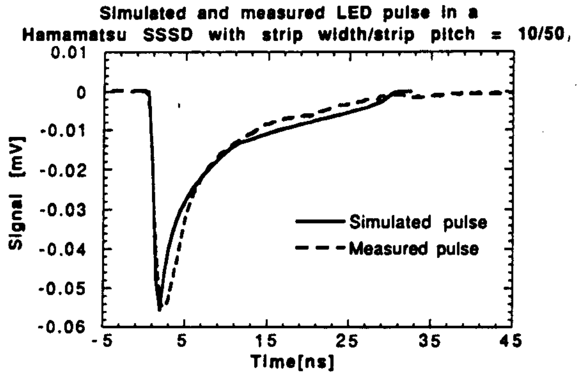
Speed of response, about 20 nsec, is well matched to the SSC collision period.

Excellent performance at high luminosity since occupancy at design luminosity is very low, about 10^{-3}.

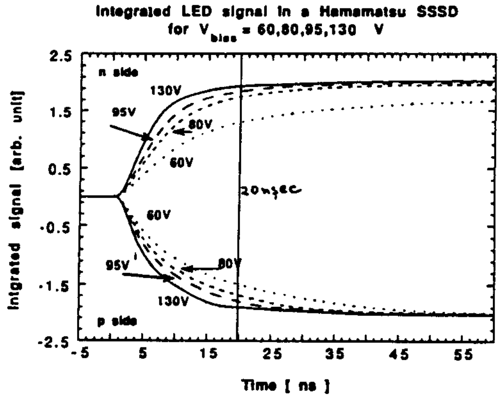
Double-sided measurement gives space-points for pattern recognition after hit association.

One of the few choices with sufficient radiation hardness and segmentation to allow many years of operation at radii smaller than 50 cm.

Essential to meet SDC goals for momentum resolution, large rapidity coverage, vertexing, pattern recognition, and luminosity capability. Will contribute to Higgs search, top studies, and broad-based searches for the unexpected.



Simulated and measured LED pulse in a Hamamatsu SSSD with strip width/strip pitch = 10/50,



Integrated LED signal in a Hamamatsu SSSD for V_{bias} = 60,80,95,130 V

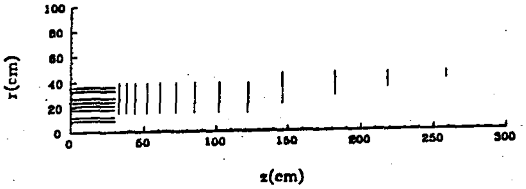


Fig. 1. Silicon tracker design.

Table 2. Dimensions for tracker

Barrel	r	z		
(1)	9 cm	30 cm		
(2)	12 cm	30 cm		
(3)	18 cm	30 cm	6.78 m² for Barrel.	
(4)	21 cm	30 cm		
(5)	24 cm	30 cm		
(6)	27 cm	30 cm		
(7)	33 cm	30 cm		
(8)	36 cm	30 cm		
Disks	r_{in}	r_{out}	z	
(1)	15 cm	39 cm	33 cm	
(2)	15 cm	39 cm	38 cm	
(3)	15 cm	39 cm	44 cm	10.16 m² for Disks (both sides)
(4)	15 cm	39 cm	52 cm	
(5)	15 cm	39 cm	61 cm	
(6)	15 cm	39 cm	72 cm	
(7)	15 cm	39 cm	85 cm	
(8)	15 cm	39 cm	102 cm	
(9)	15 cm	39 cm	122 cm	
(10)	22.5 cm	46.5 cm	146 cm	
(11)	28.5 cm	46.5 cm	182 cm	
(12)	34.5 cm	46.5 cm	218 cm	
(13)	40.5 cm	46.5 cm	258 cm	
		Total Area = 16.94 m²		

Barrel

8 layers
Inner radius = 9 cm
Outer radius = 36 cm
Half length = 30 cm
Number of detectors = 3,600

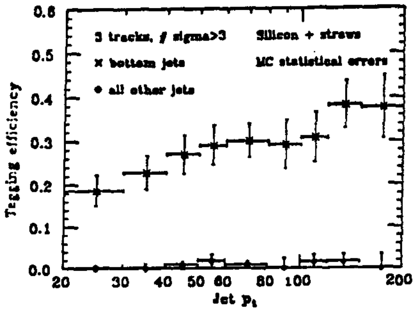
Forward and Backward System

13 disks on each side
On average about 7 layers hit for each track
Inner radius = 15 cm
Outer radius = 46.5 cm
Half length = 258 cm
Number of detectors = 3,112

Full System

Total area = 17 m²
Number of channels = 6.5 million (2 × 50,000 chips)
Power per channel = 1 mW

All detectors are double-sided.
ϕ measurement on one side,
10 mrad small angle stereo on other side.



b tagging efficiency vs. jet p_t for the full tracking system.

P_t Resolution

Straws + silicon from 9 cm - 36 cm	15.9% at 1 TeV.
Straw + 4 silicon layer from 9 cm - 21 cm	28.5% at 1 TeV.

Extrapolation of Tracks from Silicon

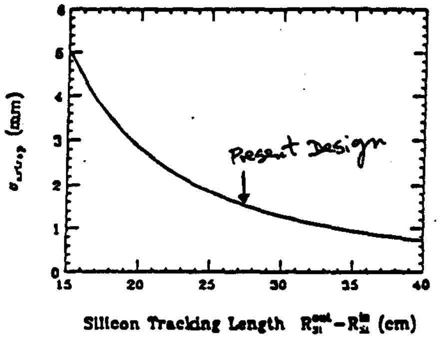


Fig. 6. Position error at 1.6 m radius vs. silicon tracking length.

Impact Parameter Error:

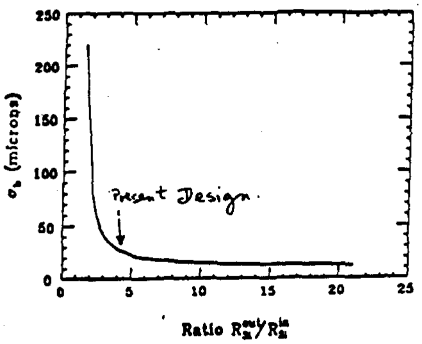
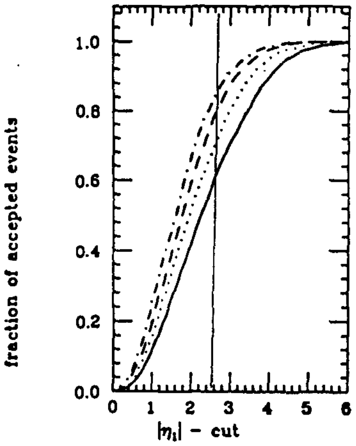


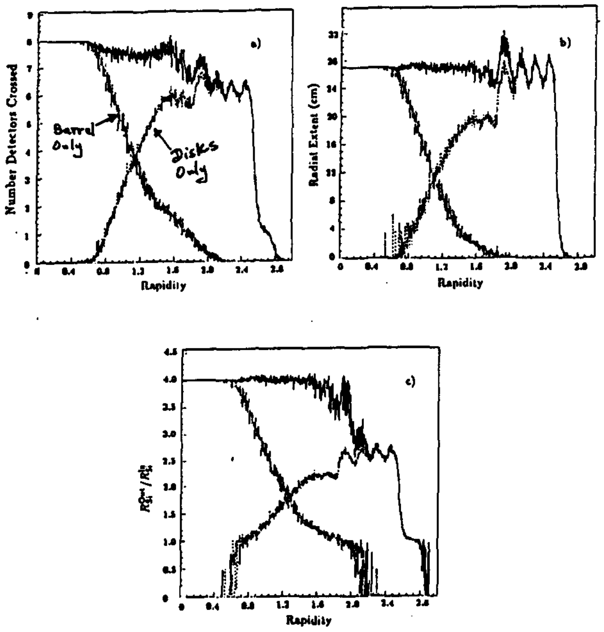
Fig. 4. Impact parameter error vs. detector geometry for high momentum.

Silicon Only.

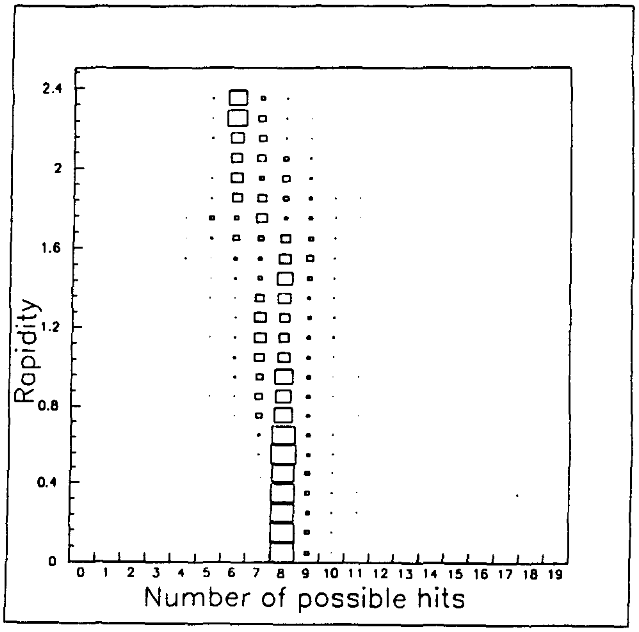
Acceptance for all four leptons from $H^0 \rightarrow Z^0Z^0$ Decay Versus Rapidity Coverage.

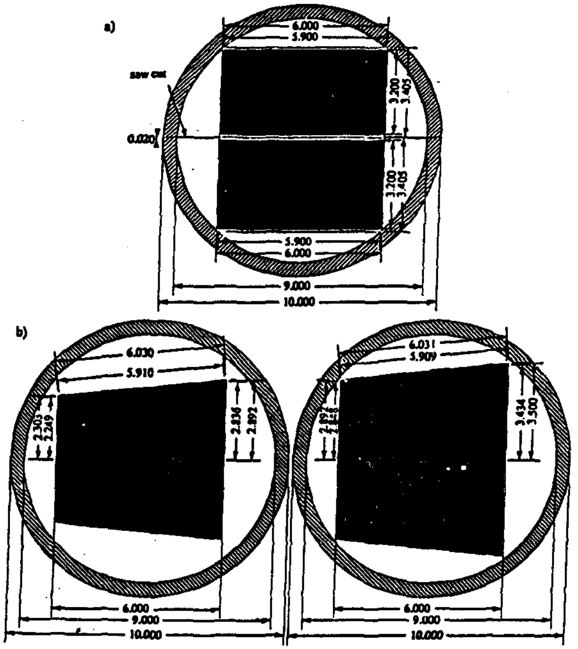


solid: M_H = 200 GeV, dotted: M_H = 400 GeV
dashed: M_H = 600 GeV, dashed-dotted: M_H = 800 GeV



Geometrical Characteristics of Design, Averaged over Beam Spot Size.



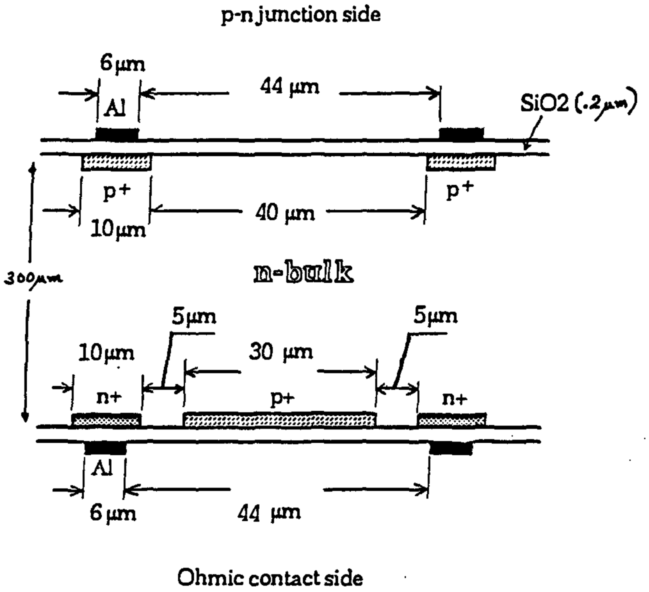


Detector C1 R=22.5 to 28.5 cm,
bonded to detector C2

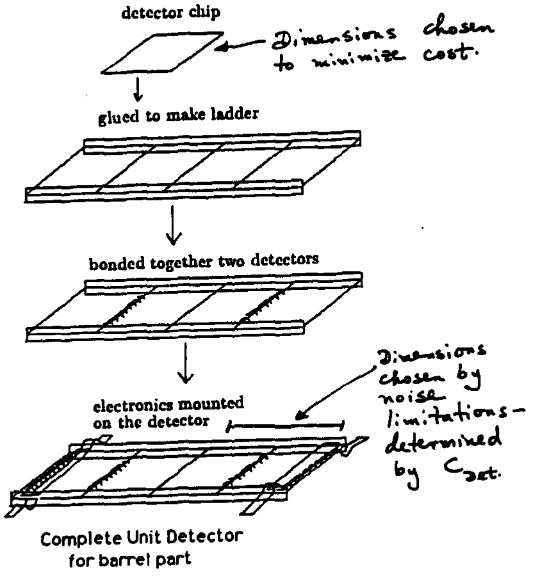
Detector C2 R=28.5 to 32.2 cm,
50 µm pitch at R=32.2cm, 1280 channels

Detector Implants:

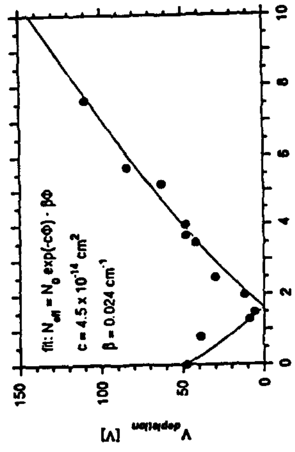
detail structure of both surfaces



Goal: 1.2 pF/cm ≥ C_{Det}
Voltage across each oxide
layer ≥ 75 volts.

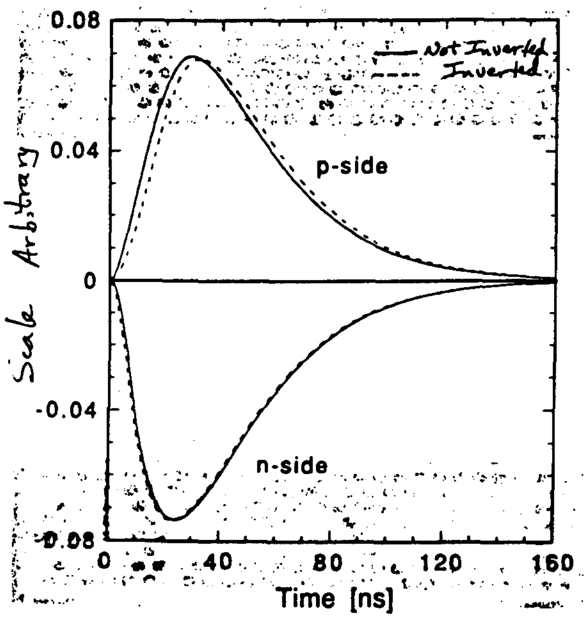


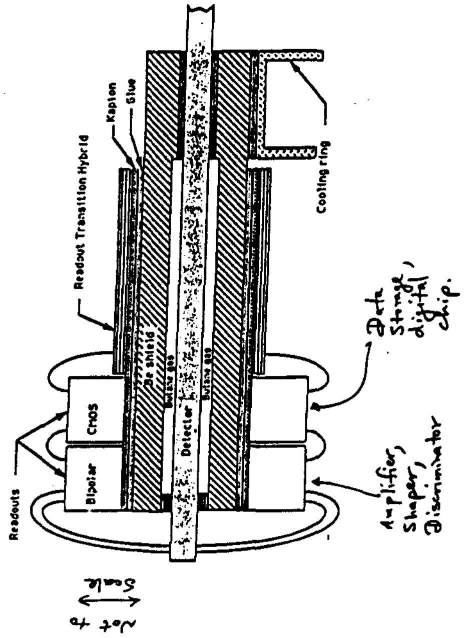
Complete Unit Detector
for barrel part



Voltage = 90 v.
Depletion = 50V

Simulated Detector Signals
CR-RC shaping = 20 nsec





Yearly Fluence Versus Radius

Radius (cm)	Fluence Particles/cm^2	Number of Years to Reach 10^{14}/cm^2
10	11×10^{12}	9
15	5.9×10^{12}	17
20	3.3×10^{12}	30
25	2.2×10^{12}	45
45	0.95×10^{12}	105

↑ Includes factor of 2 safety factor.

We have developed a simulation program to help in the design of the detector and electronics. The program includes:

-- Calculation of electric fields in detector.

-- Landau fluctuations in energy deposit.

-- Drift of electrons and holes, including *B* field effect.

-- Amplifier shaping.

-- Electronic noise.

-- Discrimination.

For the barrel detectors, with:

Threshold = $\frac{1}{4}$ mip.

1500 e^- noise. ← Goal ~ 1200 e⁻

Shaping time = 20 nsec.

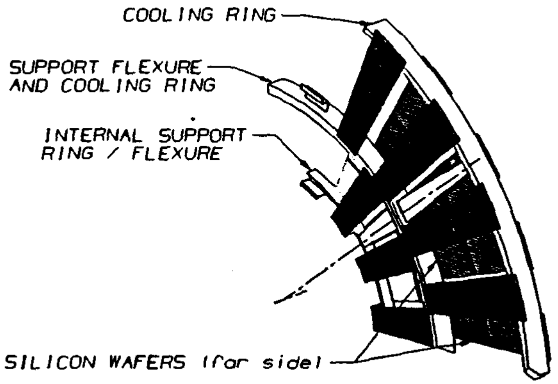
Predict:

	p side	*n* side
Efficiency	.995	.999
Resolution	10 μm	8 μm ← For TDR assumes 17 μm, including alignment

Above numbers are robust against 10–20% changes in parameters chosen above.

SILICON TRACKING SYSTEM

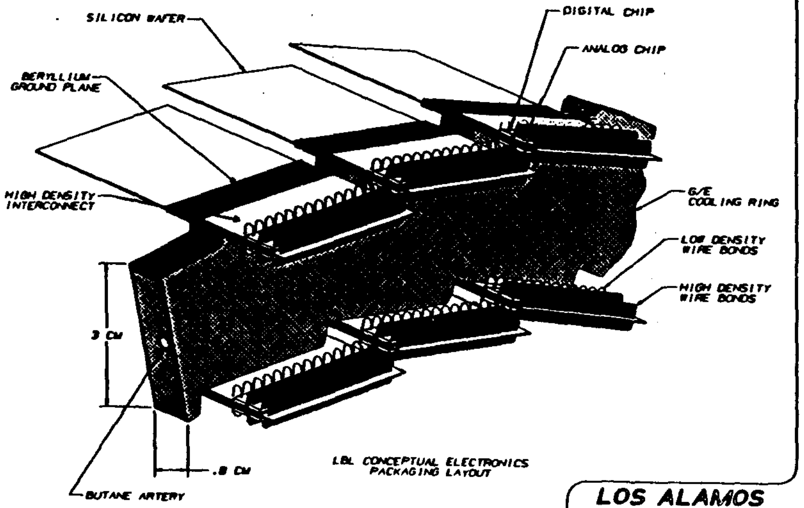
FORWARD REGION PLANAR ARRAY (Typical)



SIL-VG-CJ-1016A

Los Alamos

SILICON TRACKING SYSTEM



LBL CONCEPTUAL ELECTRONICS PACKAGING LAYOUT

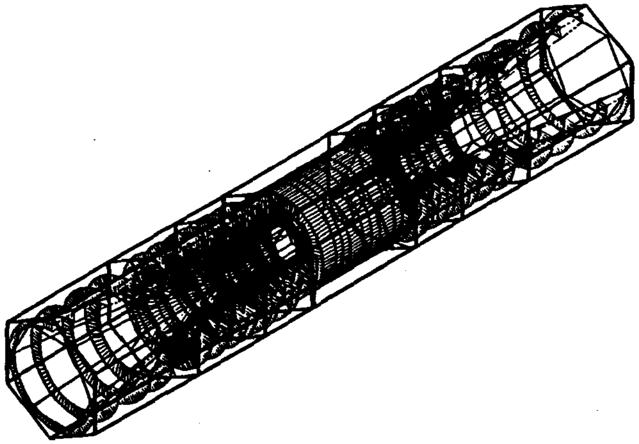
LOS ALAMOS

MEE-12
MECHANICAL AND ELECTRONIC
ENGINEERING DIVISION

FILE: SIL-VG-RLS-1108A.PRT

SILICON TRACKING SYSTEM

SILICON WAFERS AND SPACE FRAME

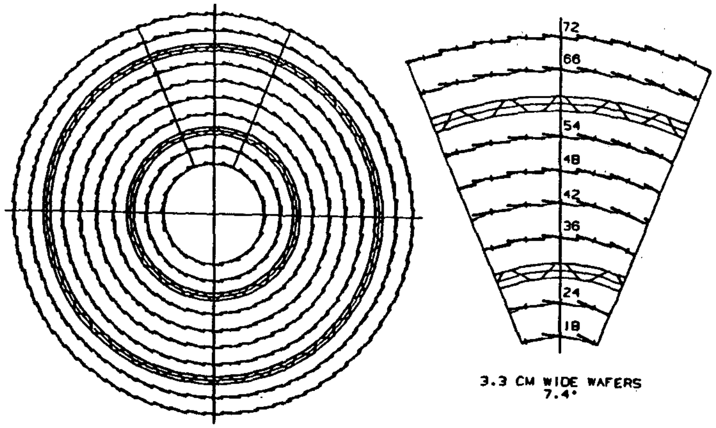


LOS ALAMOS

MEE-12
MECHANICAL AND ELECTRONIC
ENGINEERING DIVISION

SILICON TRACKING SYSTEM

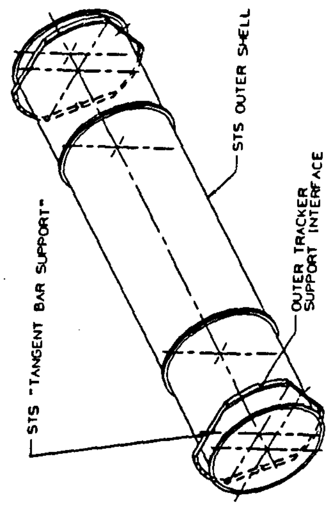
END VIEW CENTRAL REGION



3.3 CM WIDE WAFERS
7.4°

SIL-VG-RR-1018

Los Alamos



RESPONSIBILITIES

Design and Fabrication of Parts:

Detectors	Japanese and Italian Groups
Electronics	LBL, UCSC, RAL
Major Mechanical	LANL
DAQ and Trigger	U.K. and Italian Groups

Module Assembly and Testing:

Central Region	Japan
Forward Disks	U.S. and Italian Groups

Integration and Overall Assembly:

LANL

00577

SILICON MECHANICAL SYSTEMS

W. MILLER

STS Top Level Requirements

Characteristic	Requirement	Approach
Material radiation length	< 3% @ normal incidence	● Low-Z materials, ultralightweight structures, low mass electrical *cables/connectors*
Positional stability	R_ϕ, R, Z-5, 80, 250 μm respectively	● Ultrastable, ultra-stiff support structures and materials ● Kinematic mounting of subsystems ● System isothermality
Electronic cooling	13 kW @ 2 mW/channel heat dissipation	● Evaporative cooling system (phase change @ constant temp) ● Non-corrosive fluid compatibility with electronic circuits and strip detector
Detector sub-cooling	0°C silicon strip detector operation at near 1 atmosphere	● Hydrocarbon evaporative cooling fluid (Butane)
Radiation exposure	10 Mrad, throughout 10 years service life	● Select rad-hard materials
Maintainability	Accessibility and detector replacement	● Maintainable silicon module substructures

---

Silicon Tracking System (STS)

Mechanical Design Review

PAC Meeting
May 4-9, 1992

Superconducting Super
Collider Laboratory

W. Miller
Los Alamos National Laboratory

STS Top Level Requirements

Alignment

- **Maximum local misalignment (resolution of alignment measuring equipment)**

Silicon	5 μm	Circumferential
	250 μm	Z (barrels) or R (disks)
	80 μm	R (barrels) or Z (disks)
Global	10 μrad's	Azimuthal rotation of silicon vs straws or gas microstrips
	15 μm	Common centering silicon vs straw
	40 μm	Common centering silicon vs gas microstrips
	500 μm	Centering of tracker on beam

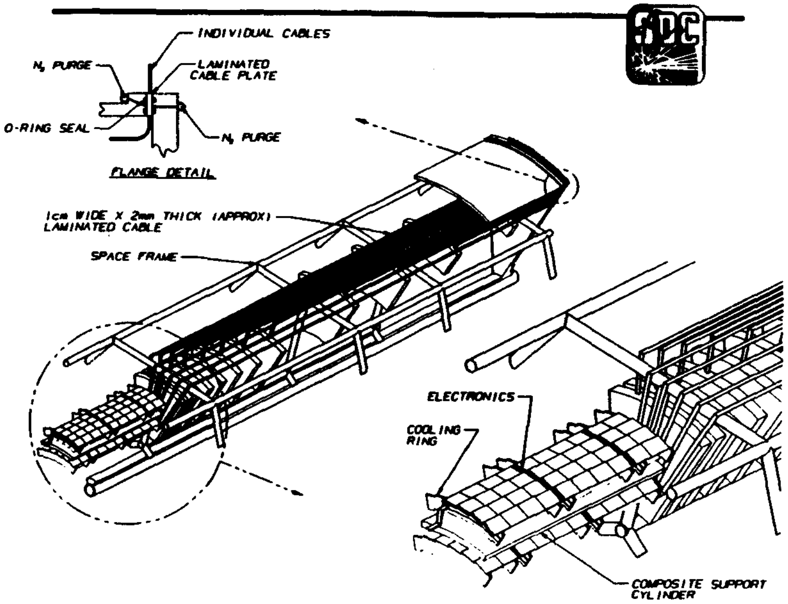
- **Maximum placement error (complete STS)**

Silicon	25 μm	Circumferential
	250 μm	Z (barrels) or R (disks)
	80 μm	R (barrels) or Z (disks)

STS Mechanical Design

Topics

- Design Requirements
- Construction Description
- Material Considerations
- R&D Accomplishments
- Future Work

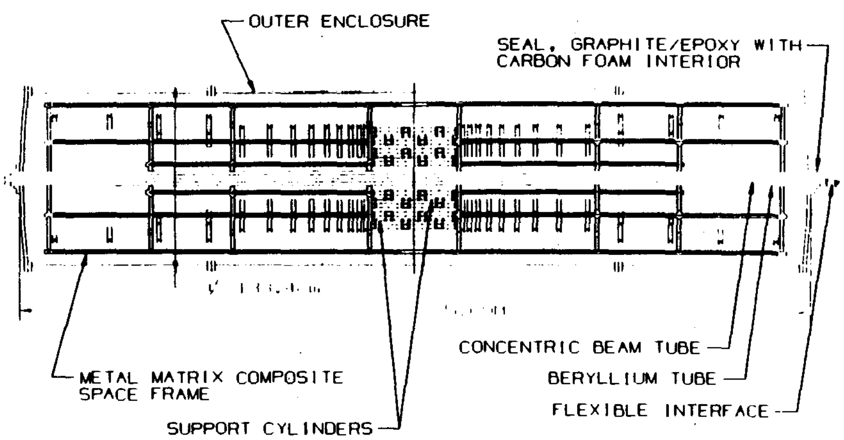


RLS-SIL-SF-SOLID1.PRT

Los Alamos

00584

SILICON TRACKING SYSTEM

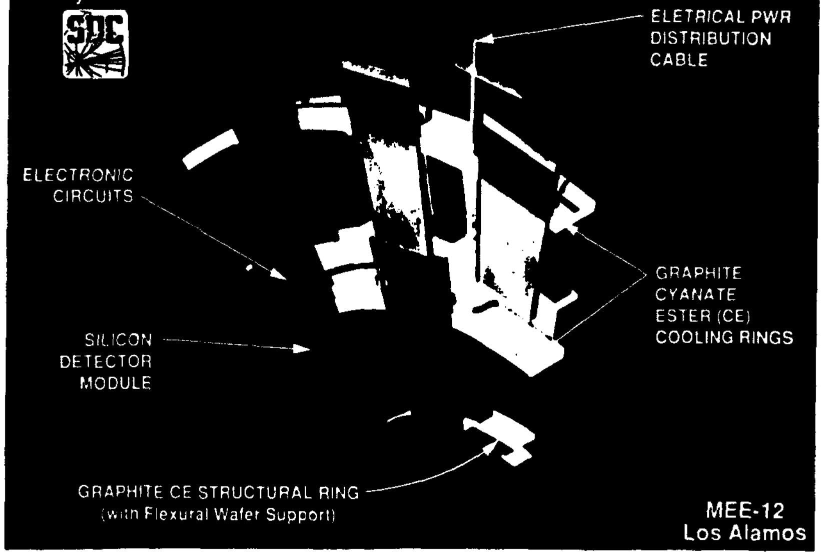


SILVG-005-GEJ
VG SCALE = .045

Los Alamos

FWD REGION (Section)

Silicon Tracking System

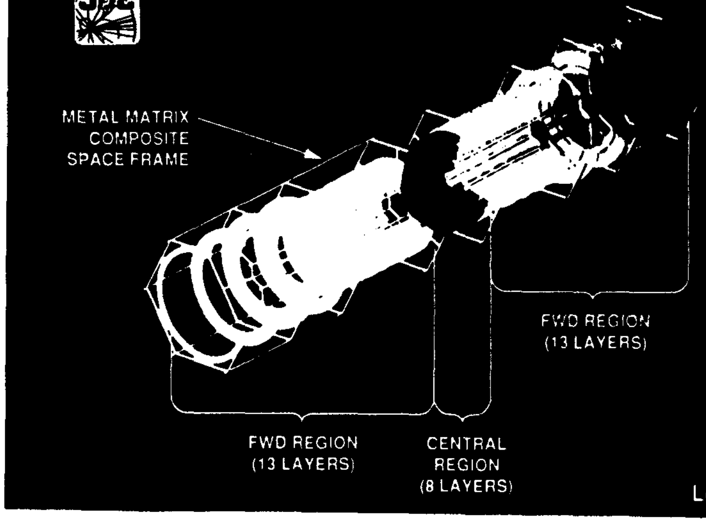


MEE-12
Los Alamos

00585

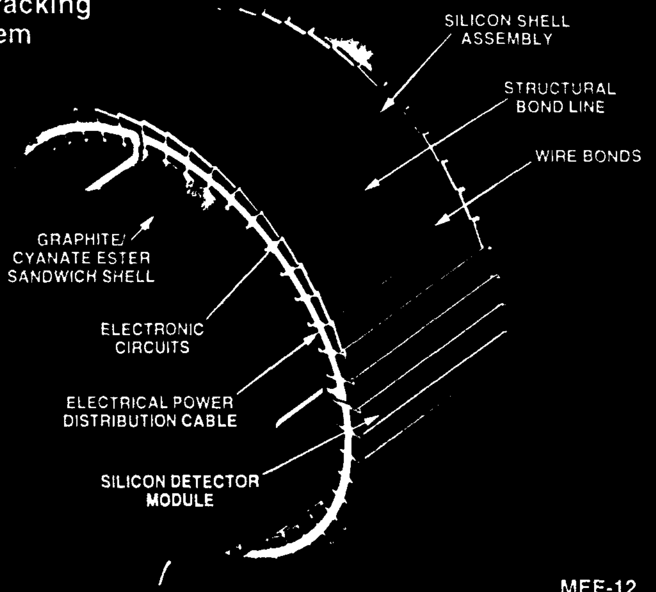
SILICON DETECTOR WITH SPACE FRAME (Cut Away)

Silicon Tracking System



MEE-12
Los Alamos

Silicon Tracking System



MEE-12
Los Alamos

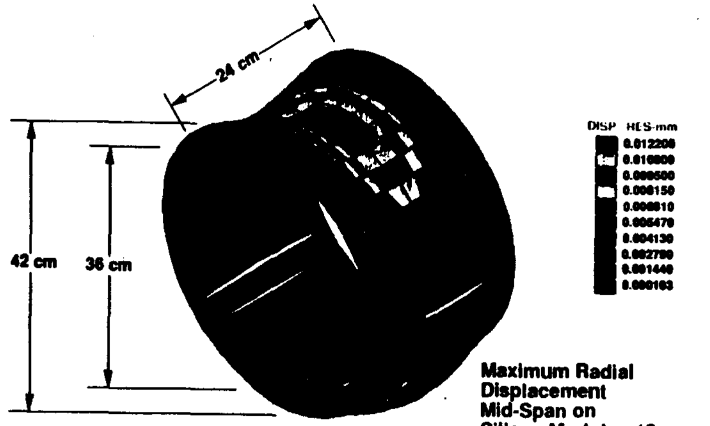
Silicon Detector Description and Quantities

Component	Central Region	Forward Region (total)
Silicon Wafers	3600	3112
Electronics Modules	1800	1632
50 µm Strips	2,304,000	4,177,920
Silicon Layers	8	26
Silicon Subassemblies	12	26
Silicon Detector Modules	1080*	1632

12-cm-long modules total, 1440 of which are structurally joined to form 720, 24-cm-long assemblies

Los Alamos

STS Silicon Shell (Gravity Loading)



Maximum Radial Displacement Mid-Span on Silicon Module - 12 µm

MEE-12/WM-c625

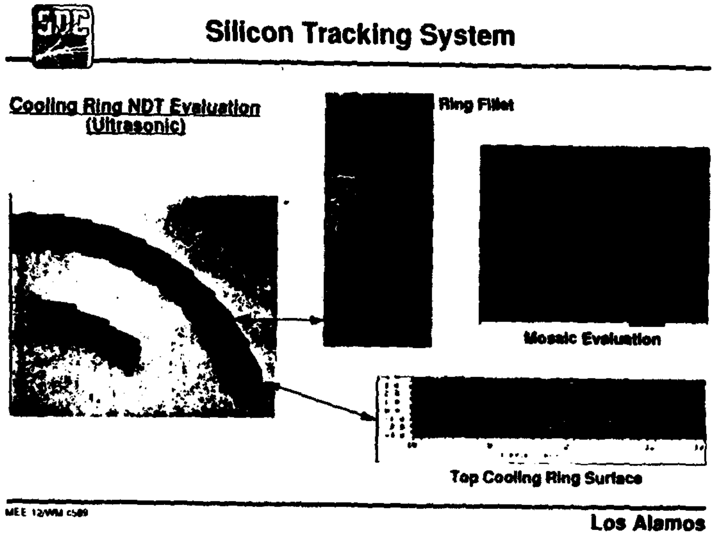
Los Alamos

Silicon Detector Module Specifications

	Central Region	Forward Region
Shape:	Rectangular	Trapezoidal
Active Detector Width:	3.2 cm	~6.4 cm
Number of Channels:	1280 (640 per side)	2560 (1280 per side)
Heat Dissipation:	1 mW per channel*	1 mW per channel*
Module Heat Load:	1.28 W	2.56 W
Thermal Conductive Area: (at cooling surface)	0.8 cm x 3.3 cm	~0.8 cm x 6.5 cm
Module Heat Flux: (at cooling ring surface)	0.5 W/cm^2	0.5 W/cm^2
Operational Temperature: (at silicon detector surface)	0°C	0°C
Cant angle:	7.4°	0°

* Cooling system design point 2mW/channel

Los Alamos



Silicon Tracking System

Cooling Ring NDT Evaluation (Ultrasonic)

Ring Fillet

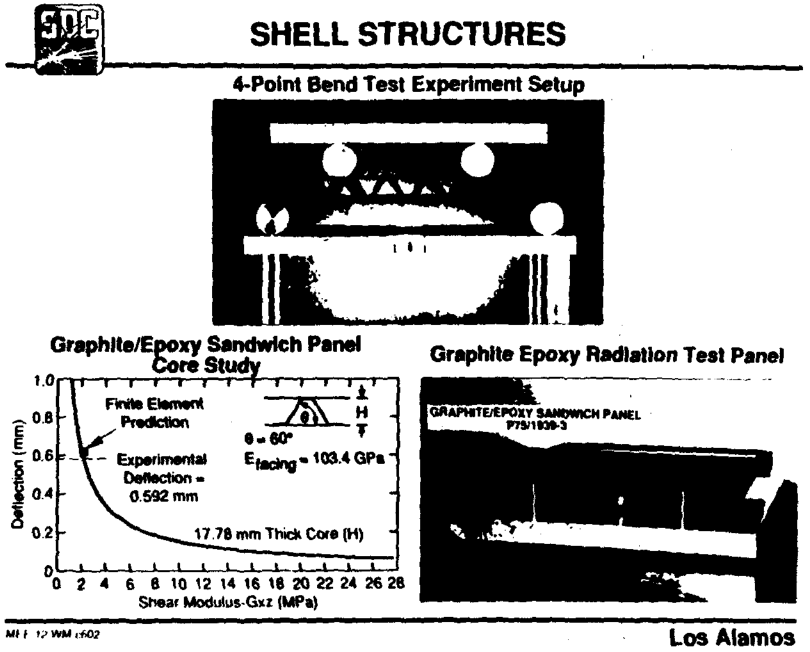
Mosaic Evaluation

Top Cooling Ring Surface

MEE 12/WM c589

Los Alamos

0592



SHELL STRUCTURES

4-Point Bend Test Experiment Setup

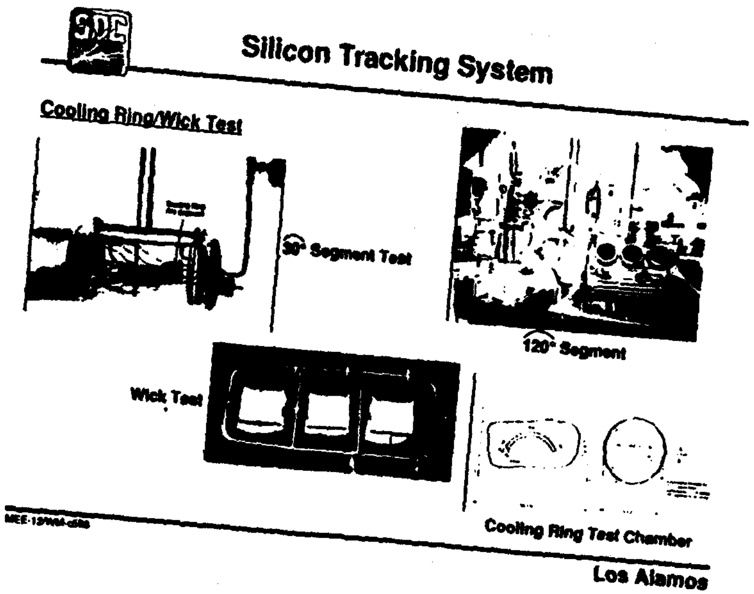
Graphite/Epoxy Sandwich Panel Core Study

Graphite Epoxy Radiation Test Panel

MEE 12 WM c602

Los Alamos

0590



Silicon Tracking System

Cooling Ring/Wick Test

30° Segment Test

120° Segment

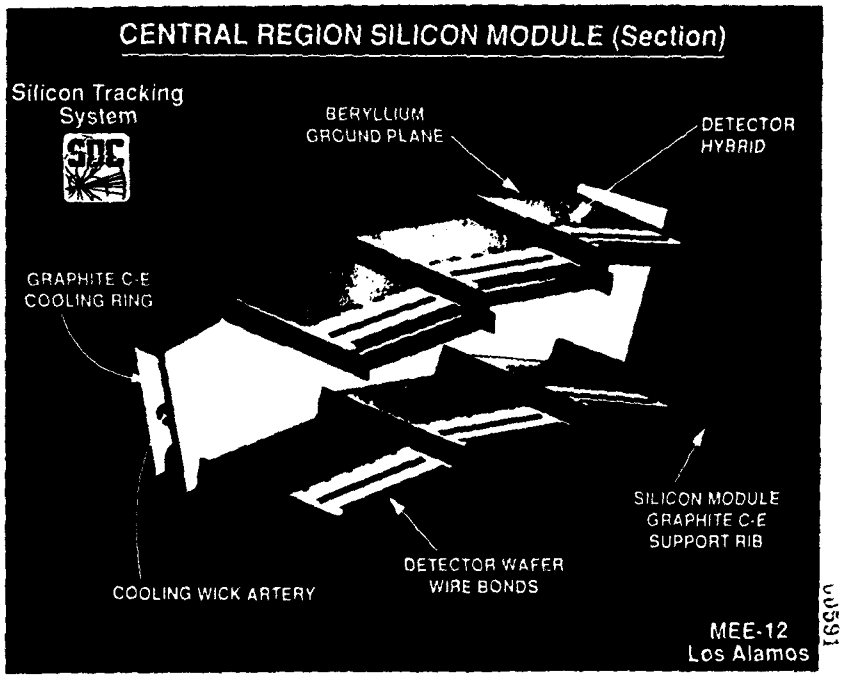
Wick Test

Cooling Ring Test Chamber

MEE-12/WM-c588

Los Alamos

0593



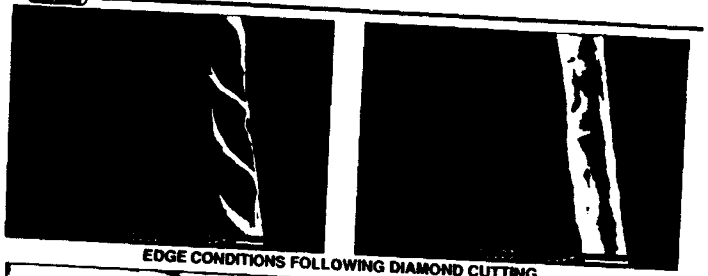
CENTRAL REGION SILICON MODULE (Section)

Silicon Tracking System

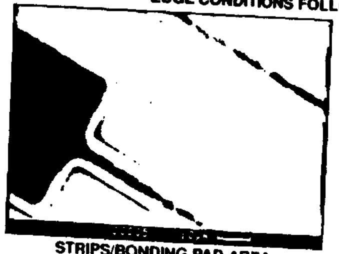
MEE-12
Los Alamos

0591

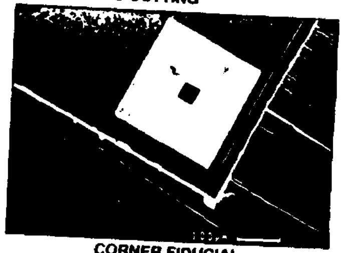
Silicon Tracking System



EDGE CONDITIONS FOLLOWING DIAMOND CUTTING



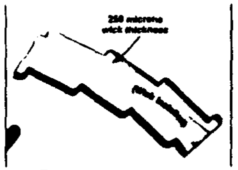
STRIPS/BONDING PAD AREA



CORNER FIDUCIAL

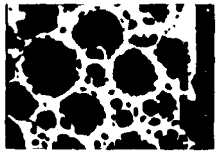
Silicon Tracking System

Wick Development

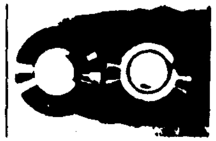


30° Segment Machined Polystyrene Wick

Molded Wick Specimen (~400 *μm thick Polystyrene*)



Wick Structure Photomicrograph



Delrin Mold

STS Materials Summary

Component	Material	Key Criteria
Cooling and Structural Rings	*P75* Chopped Graphite Fiber/Cyanate Ester resin	● *Moldable material for fabricating complex ring geometry* ● Low Coefficient of Thermal Expansion (CTE) ● Low Coefficient of Moisture Expansion (CME) ● Minimize structural distortions from thermal gradients ● Radiation resistant, zero creep structure ● High radiation length (25 cm)
Cooling Ring Wick	Polystyrene	● Moldable material for replicating complex geometry ● Microstructure tailorable (4 μm, pore radius) to achieve optimum wicking behavior ● *High radiation length* ● Radiation resistant
Support Cylinders (central region)	UHM Graphite Fiber/ Cyanate Ester resin 25 *μm prepreg*	● Ultra thin prepreg, less susceptible to fracture ● Sandwich shell *construction with ultra low areal density*, 1.2 kgm/m^2 ● Quasi-isotropic facing sheet construction for maximum stability

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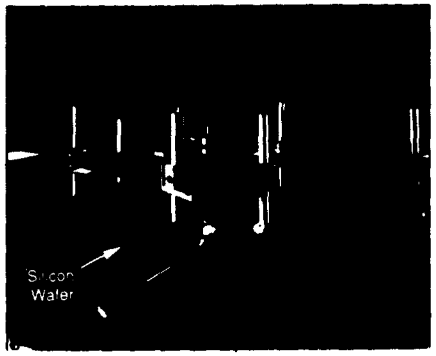
Silicon Tracking System

TV HOLOGRAPHY INSPECTION TECHNIQUE



OPTICAL BEAM PATH

FRINGE PATTERN

KEY STS NEAR TERM GOALS

- Complete mold development process steps for full 360° cooling ring
  - Dimensional quality
  - Material property uniformity
  - High transverse thermal conductivity
- Successful performance demonstration of a fully integrated cooling ring/molded polystyrene wick
  - Artery feed integration
  - Performance boundaries
- Silicon shell (central region) stability demonstration test (0°C)
  - 5 μm stability
- Complete demonstration of assembly/alignment of large silicon shell structures
  - Reasonable construction
  - Maintainable
  - 25 μm placement
- Completion of material compatibility tests in radiation environment
  - Detector
  - Graphite/cyanate ester
  - Electronic chips
- Demonstrations of kinematic mount performance for silicon substructures

---

STS Materials Summary (cont)

Component	Material	Key Criteria
Enclosure	UHM Graphite Fiber/ Cyanate Ester 25 μm prepreg	● Construction same as support cylinders ● Part of STS support concept requires maximum stiffness and stability
Cable	Laminated Beryllium	● Low voltage power transmission for electronics ● Require high radiation length (35 cm) ● Solderable
Space Frame	Metal Matrix Composite (Mg-graphite)	● Maximum stiffness and stability to limit potential distortion from 5 meter truss "metrology" frame ● Stiffness 50% > G/cyanate ester ● Near zero CTE and zero CME ● Zero creep ● Impervious to butane and radiation

---

KEY STS MAJOR MILESTONES

- Conceptual STS design and preliminary structural studies completed
- Materials for all major components have been selected
- Butane evaporative cooling proof-of-principle tests, with machined polystyrene wick completed
- Demonstrated moldability of polystyrene wicks to desired microstructure
- Compression molded ultra-thin (450 μm) high thermal conductivity cooling ring segments (P75/cyanate ester - 30° arc segments)
- Developed mold process steps for graphite/polymeric composite cooling ring
- Demonstrated durability and fabricability of 24 cm long edge-bonded silicon detector module
- Established construction techniques for ultra-light weight (1.2 kg/m^2) graphite/composite sandwich shell
- Demonstrated 5 μm stability of truss core panel after exposure to 1x10^{15} n/cm^2
- Verified butane and composite material compatibility in radiation environment
- Preliminary assessment of strip detector compatibility with butane, adhesives, and graphite composite materials complete
- Developed alignment methods for achieving 25 μm placement accuracy (Rϕ)

00601

SILICON ELECTRONICS SYSTEMS

H. SPIELER

Front-End Electronics and Detector Modules for the SDC Silicon Tracker

Basic Concept

Strip electronics register hit/no-hit
Pixels also record analog information
Beam crossing of hit recorded
Readout after receipt of level 1 trigger

Detector subdivided
- a) at z=0 (±6 cm depending on layer)
- b) in 8 ... 12 sections in φ (barrel + disks) for each radius

Available information
- Layer address (associated with cable)
- Section address (associated with cable)
- chip address
- strip address
- crossing time
- pixels: signal charge

All electronics through data sparsification and local bus drivers in custom ICs on detector.

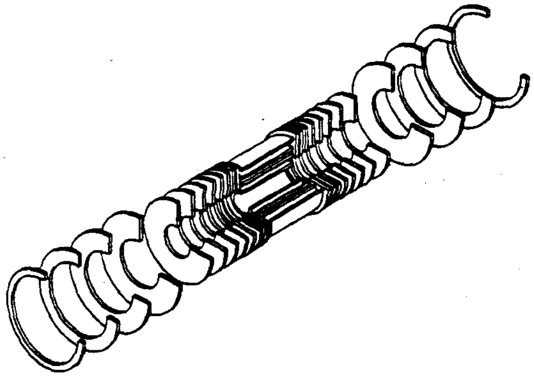


FIG. 4-34. STS detector arrays (pictorial view).

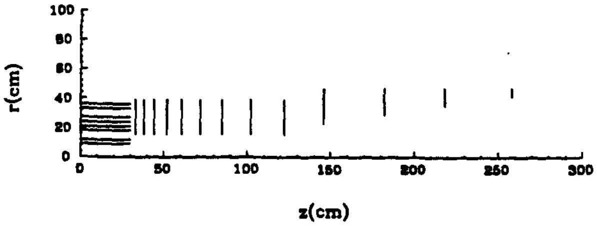


FIG. 4-2. Silicon tracker design.

DETECTOR SIGNAL

WOOD et al.
(OKLAHOMA)

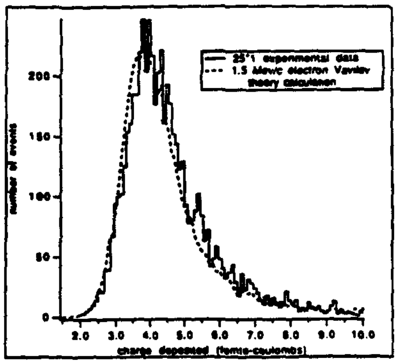


Fig. 14 Comparison of the experimental data from the 25°1 correlation band and a theoretical Vavilov calculation for charge deposited in 300 microns of silicon.

ANZIVINO et al.
(CERN)

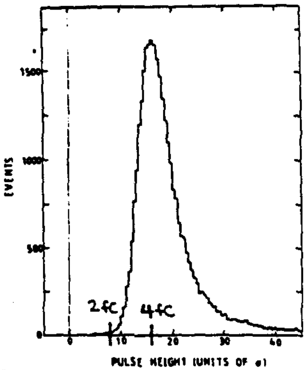


Fig. 5. Pulse height distribution for minimum ionizing particles.

Requirements

Noise	Q_n< 1200 el
Time Resolution	Δt< 16 ns for 1 fC≤Qs≤8 fC
Power Dissipation	P≈ 1 mW/channel for 12 cm strips
Dead Time	~50 ns goal (two successive 4 fC pulses)
Radiation resistance	$\Phi_c+\Phi_n$= 10^{14} cm^{-2} *(limited by type inversion in detector)* Dose > 5 Mrad Demonstrated for both detectors and electronics (analog + digital).

Readout within 10 μs after receipt of level 1 trigger
(also for high-density jets)

Calibration inputs
Externally adjustable thresholds (differential inputs)
Chip disable

Implementation

AC coupled, double-sided detectors
(strip pitch = 50 μm, stereo angle≈10 mrad)

128 channels per chip laid out on <50 μm pitch

BJT Analog chip:	preamplifier shaper timing comparator
CMOS digital chip:	time stamp/data buffering sparse readout differential drivers

Baseline design:
One readout line per section (φ) and layer/ring (r)
Local signal transmission by low-mass Al/Kapton ribbon cables
Intermediate Bus Selector Chips to limit bus loading
Fiber drivers/receivers at outer shell of Si tracker
➡ ~ 160 ... 240 fiber links (300 Mb/s) at each end

Alternatives being investigated:
Low-cost 60 MHz fiber links developed at Oxford
(*e.g.* 1 fiber link per module)
Arrangements that eliminate the Bus Selector Chips
(more cables)

need to balance technology, material, cost

Responsibilities:

1. Front-End Electronics: LBL + UCSC
2. Detector Module Design: LBL
3. Local signal transmission and cabling: LBL
4. Fiber links and external DAQ: Oxford/RAL

Analog IC

Key concepts verified in test circuits designed and tested at UCSC.

Full analog channel that meets SSC requirements designed at LBL and submitted for fabrication.

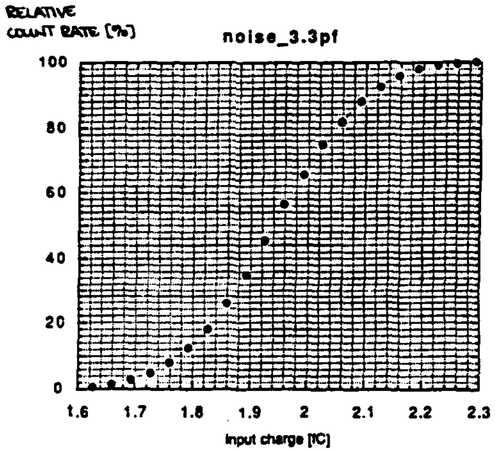
Digital IC

Digital time slice buffer clocked at 10 MHz designed, fabricated in rad-hard CMOS (UTMC), and tested at UCSC

Various buffering schemes simulated at RAL
(test ICs in fabrication)

Selection of final configuration: end 1992

NOISE MEASUREMENT ON SI STRIP FRONT-END FOR ZEUS
TEKTRONIX PROCESS (D. DORFAN + N. SPENCER, UCSC)



➡ $Q_n \approx 800$ el rms

IN GENERAL:

BIPOLAR ICs SHOW GOOD AGREEMENT WITH CALCULATED NOISE LEVELS.

MEASURED NOISE RATES vs. THRESHOLD IN GOOD AGREEMENT WITH THEORY.

Vendor Selection for Analog IC:

Criteria:
1. Adequate speed
2. Radiation resistance
3. Circuit density (Circuit on pitch <45 μm)

3 vendors with suitable processes identified

1. AT&T
2. Tektronix
3. Westinghouse

Some technical issues:

1. AT&T
    - Well characterized (also radiation effects)
    - Currently available process (CBIC-U2) relatively slow with large feature size.
    - High-density process with improved speed to be released in late summer
2. Tektronix
    - Well characterized (also radiation effects)
    - High speed and circuit density
    - Lateral PNP transistors (low current gain after irradiation)
    - Vertical PNPs in preparation
3. Westinghouse
    - Need more data on radiation effects (have obtained test devices)
    - Good speed and circuit density

Expect that all three vendors will have comparable processes (speed, density, radiation resistance) by end of 1992.

Note that for equivalent circuits (same functions for each) the currently available processes differ in power only by ~100 μW.

To allow valid comparison between vendors, specifically to assess

circuit trade-offs
radiation resistance of specific circuit
die size (\$\$\$)
yield (\$\$\$)

we need to fabricate test ICs through all three vendors.

Circuits to be designed to same specifications with same basic circuit, but details tailored to specific process.

Choice for first run: AT&T

Circuit and preliminary layout submitted (LBL)
PO issued (UCSC)
ICs expected in September

At least two different ICs:
1. Individual circuit blocks
2. Complete 64 channel front-end

\+ perhaps
3. Array of preamplifiers

Goal is still to have 128 channels/IC in final design, but we selected 64 ch. for this run to obtain better yield data.

Extensive pre-qualification of multiple vendors is designed to reduce risk in final mass production run.

Silicon Tracker (SSC)
Front-End Bipolar IC (AT&T)

Detector

Strip Length	12	cm
Strip Capacitance (1.2 pF/cm)	14.4	pF
Leakage Current (100 nA/cm, Φ=10^{14} cm^{-2}, T=0 °C)	1.2	µA
Bias Resistor	200	kΩ
Blocking Capacitance	144	pF

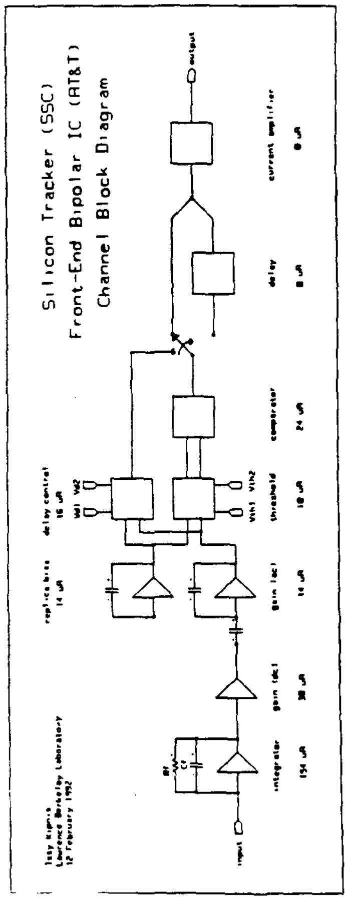
Goals

Equivalent Input Noise Charge	1250	e rms
Differential Comparator Threshold	4σ	
Time Walk [1 fC - 8 fC]	16	nsec
Power Consumption	1	mW
High Impedance Output		

Preliminary Simulation Results (3-channels)

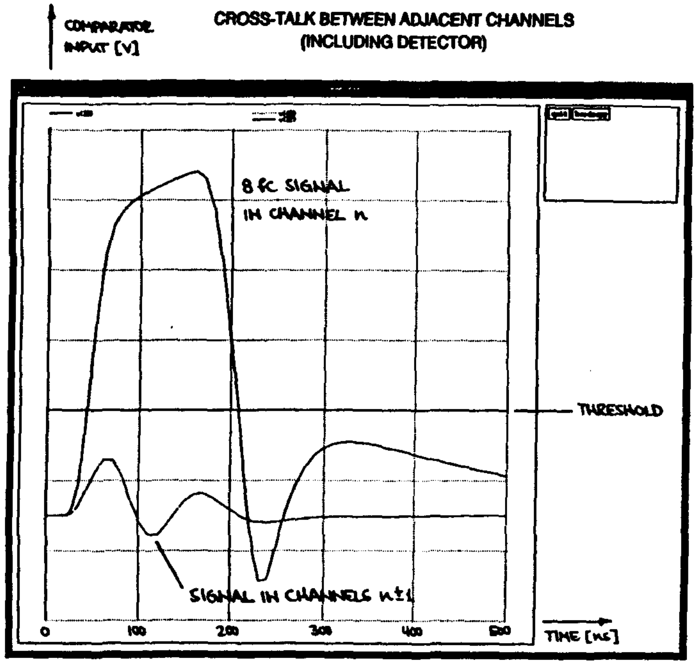
Output Noise Voltage	39	mV rms
Transfer Gain	180	mV/fC
Equivalent Input Noise Charge	1350	e rms
Peak Output Current	400	µA
Comparator Threshold (4σ)	155	mV
Time Walk [1 fC - 8 fC]	12	nsec
Supply Voltage	3.5	V
Power Consumption	950	µW

Issy Kipnis Lawrence Berkeley Laboratory 12 February 1992

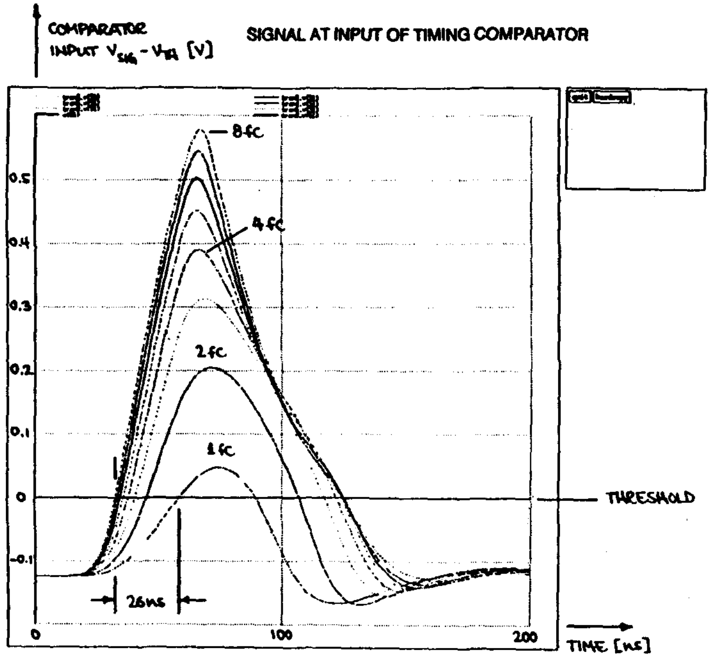


Silicon Tracker (SSC)
Front-End Bipolar IC (AT&T)
Channel Block Diagram

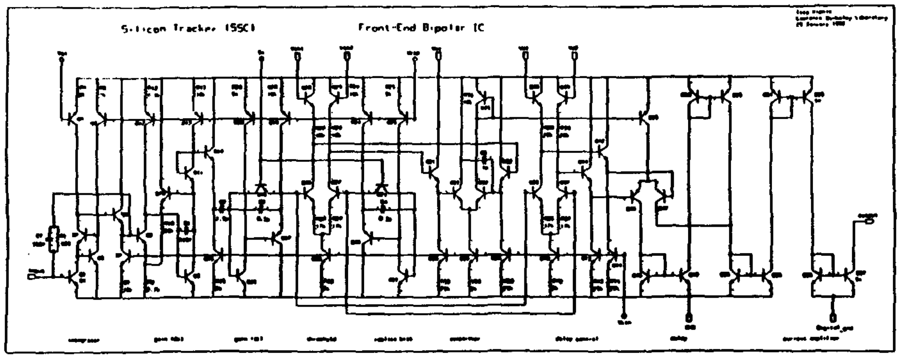
Issy Kipnis
Lawrence Berkeley Laboratory
12 February 1992

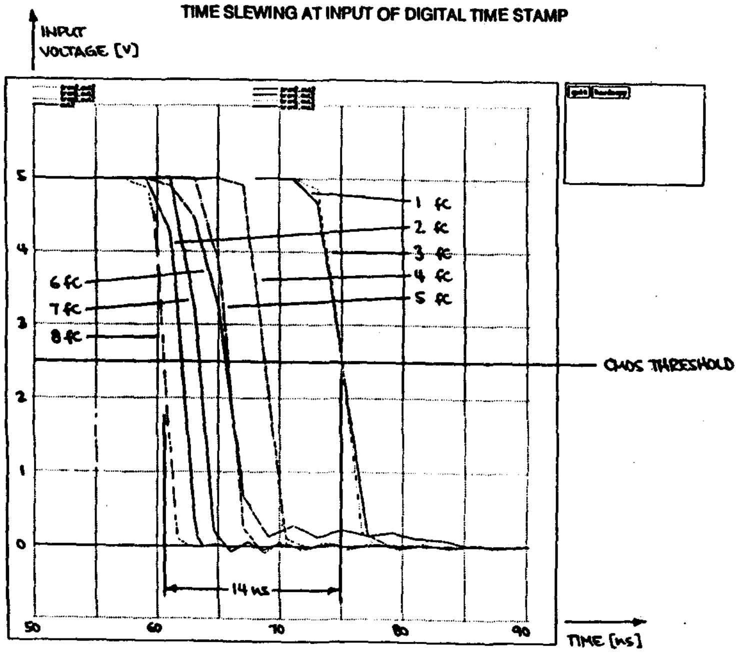


CROSS-TALK BETWEEN ADJACENT CHANNELS (INCLUDING DETECTOR)



SIGNAL AT INPUT OF TIMING COMPARATOR





TIME SLEWING AT INPUT OF DIGITAL TIME STAMP

Silicon Tracker (SSC)
Front-End Bipolar IC (AT&T)

Noise Power Contributions

	$x10^{-6}$ [V^2]	%
Total	1533	100
Q_1	725	47.3
-Ic	-300	-19.6
-Ib	-300	-19.6
-rb	-125	-8.1
Detector Shot Noise	269	17.6
R_f	181	11.8
Q_1 of adjacent channel	93	6.1
Q_1 of adjacent channel	93	6.1
Detector Bias Resistor	58	3.8
R_4	21	1.4
Other (< 1% each)	93	6.1

Notes.

- Adjacent channels contribute ~ 7% to the output noise voltage (increase the equivalent input noise charge by ~ 8%).

-Removing detector noise, Q_1 contributes 84% of the single channel output noise voltage.

Detector Modules

Module:

A detector subassembly that combines detectors, electronics, and cabling to provide a self-contained and completely testable unit.

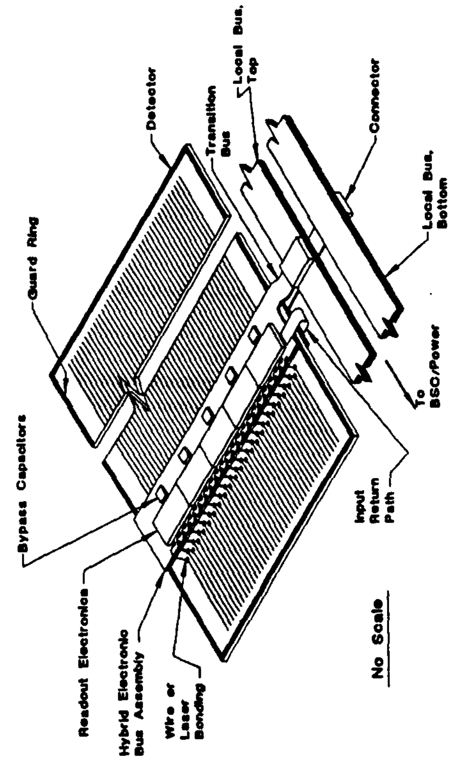
Dedicated power and signal bussing for groups of modules (sections) to minimize global cross-coupling through cables.

Module conceived so that components can be tested at key stages of the assembly process.

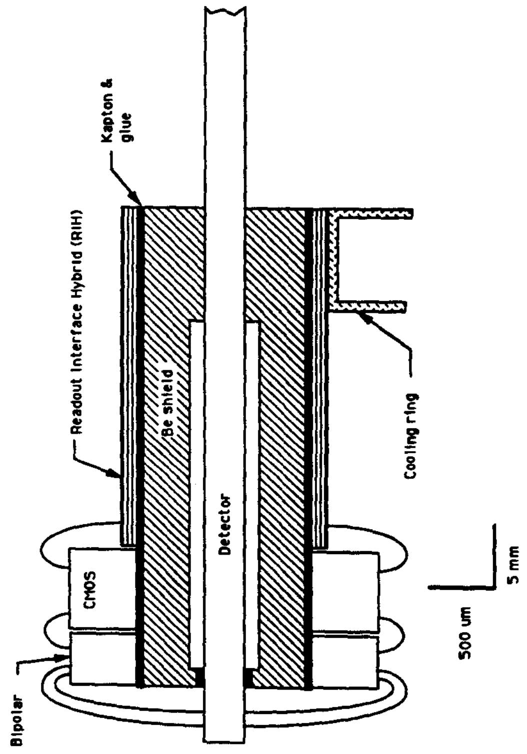
Problems:

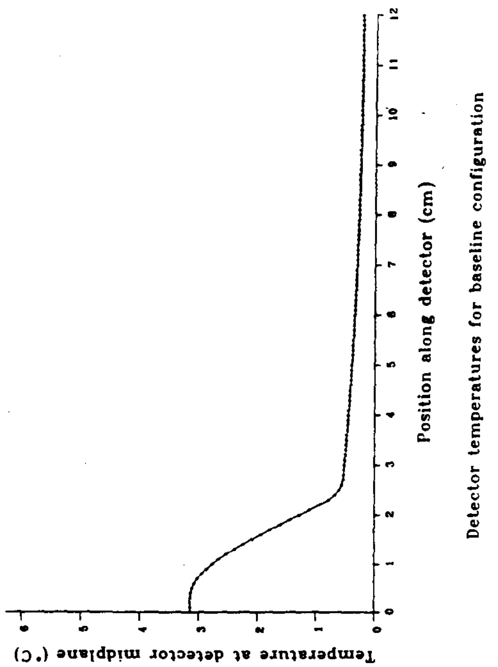
- Cross-talk from electronics to detectors
- Cross-talk from cables to detectors
- Decoupling of electrical supply lines
- Mass bonding (~3·10^7 connections)
- Structural Precision
- Cooling

Schematic of module assembly with cables

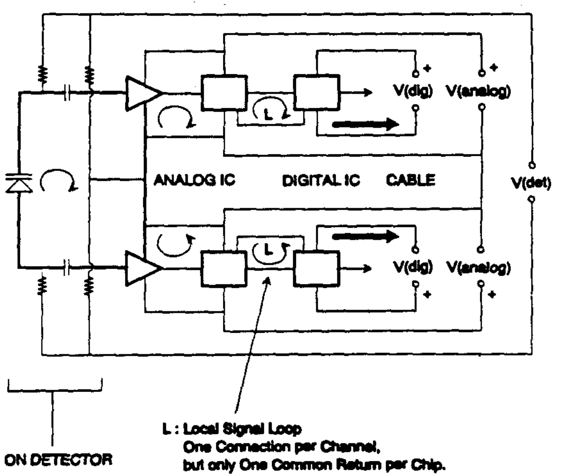


CROSS SECTION OF DETECTOR MODULE
(note difference in x and y scales)





CONNECTION SCHEME FOR DOUBLE-SIDED DETECTORS



L : Local Signal Loop
One Connection per Channel,
but only One Common Return per Chip.
Local Loop has High Impedance
to Digital Power Supply Lines.

HELMUTH SPIELER
01-NOV-91 rev.

Module Connections (Cable Traces)

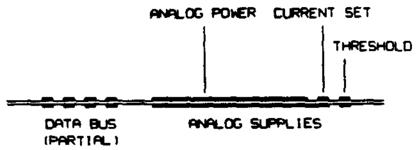
I. DC voltages/currents

1. Detector bias	Positive Bias Negative Bias ground ref.	2 + 1
2. Analog Power V_{CC} = 3.5V Preamplifier Current Set Analog ground		2 + 1
3. Comparator threshold (differential) use analog ground for reference		2
4. Calibration level (differential) (also 2 pulse lines, see below) use analog ground for reference		2
5. Digital Power V_{dd} = 5V Logic + Drivers Digital Ground		2 + 1
	Total DC Lines:	10 + 3

Pulsed Signals (all differential)

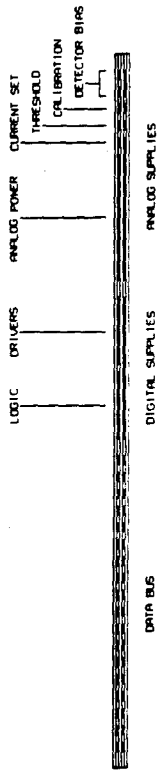
1. Calibration (off + 3 combinations)	2 x 2
2. Master Reset	1 x 2
3. Chip Control (send, receive + 2 other modes)	2 x 2
4. 60 MHz clock	1 x 2
5. I/O Bus	12 x 2
Total Data Lines:	18 x 2

SCHEMATIC CABLE LAYOUT



HELMUTH SPIELER
28-OCT-91

DATA + POWER CABLE



SUBSTRATE + INSULATION: 50 UM KAPTON
CONDUCTORS: ALUMINUM: 25 UM IN LOCAL BUS
50 UM IN SEGMENT BUS

TOTAL WIDTH OF CABLE: 12.9 MM

HELMUTH SPIELER
31-OCT-91

Critical Issues

Unlike existing detectors, signal detection and readout activity are occurring simultaneously.

Note that on-chip sparsification with only hit/no-hit output does not allow signal analysis to reject spurious pickup after readout.

Critical to control cross-talk from
- a) chip to detector
- b) buses to detectors
- c) bus to bus
  (cross-coupling through common impedances)

Front-end circuitry and bussing scheme specifically designed to reduce clock pickup and common mode coupling.

Signal transmission on metal lines fully differential with small line spacing (150 μm lines broadside coupled with 50 μm spacing)

Initial measurements with digital test ICs and cables coupled to detector have yielded promising results.

Goal for 1992:
Assemble detector module with cabling and test at read-out rates typical of SSC operation.

Note that this does not require final electronic system, but only front-end circuitry with the same bandwidth and readout circuitry and drivers capable of the same rate!

00628

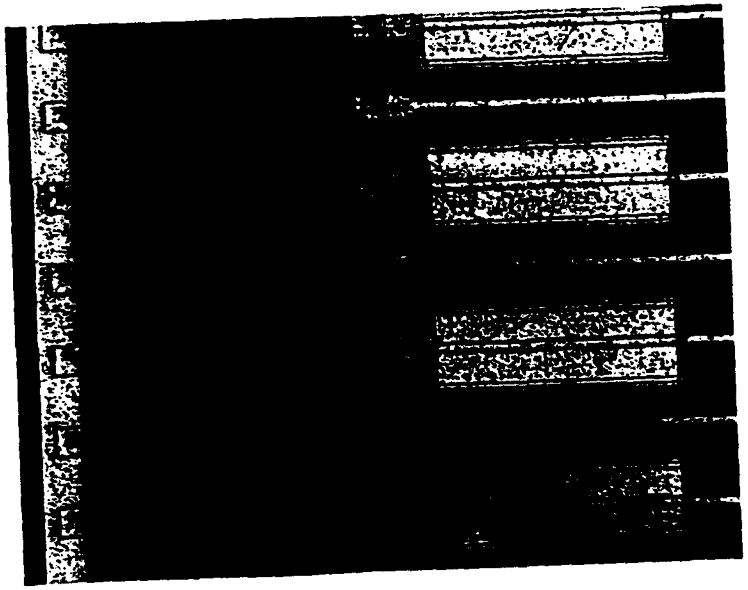
SILICON DETECTORS AND RADIATION DAMAGE

H. SADROZINSKI

Silicon Tracking System Detector R&D Program
(continued)

- Behavior of Silicon bulk under radiation is independent of geometry. Properties can be influenced by details of operation (cooling, adjustment of voltages).

- A large amount of engineering work goes into the surface:
  Careful lay-out of edges and treatment of surfaces
  Careful engineering of the coupling capacitors
  Polysilicon bias resistors on both junction and ohmic side
  P-implants to isolate the n strips on the ohmic side
  Minimize the width of p strips to reduce the parasitic capacitance on the junction side
  Maximize the width of the p-implants to reduce the parasitic capacitance on the ohmic side.



Silicon Strip Detectors
for the SDC Silicon Tracking System

- Detector Development
- Radiation Hardness

Hartmut F.-W. Sadrozinski
U.C. Santa Cruz
SSCL PAC, May 5 1992

STS Detector R&D Program

- Program to develop radiation tolerant double-sided silicon strip detectors for production in 1994.

- SDC Mainstream: Collaboration between Japanese SDC members (T. Ohsugi *et al.*) and Hamamatsu Photonics.

- At the same time, collaboration with European groups who develop detectors at S.I., Micron, VTT, CSEM.

Silicon Tracking System Detector R&D Program
(continued)

- Behavior of Silicon bulk under radiation is independent of geometry. Properties can be influenced by details of operation (cooling, adjustment of voltages).

- A large amount of engineering work goes into the surface:
  - Careful lay-out of edges and treatment of surfaces
  - Careful engineering of the coupling capacitors
  - Polysilicon bias resistors on both junction and ohmic side
  - P-implants to isolate the n strips on the ohmic side
  - Minimize the width of p strips to reduce the parasitic capacitance on the junction side
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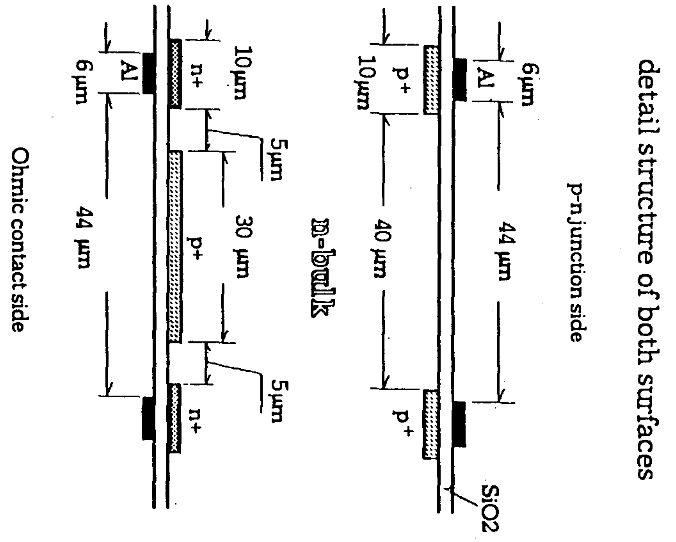
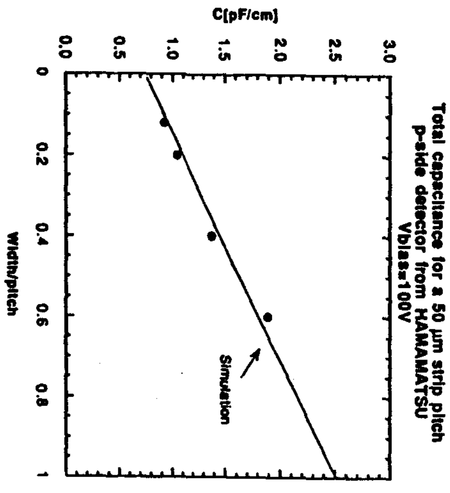
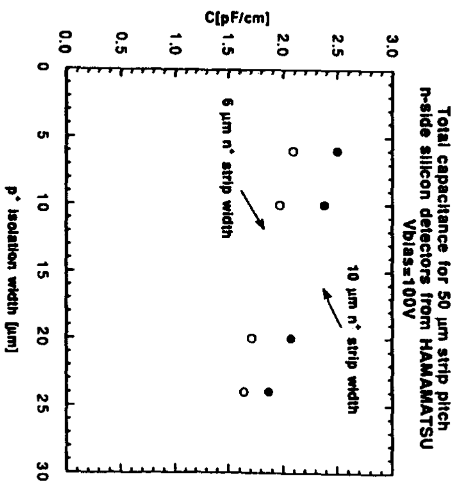






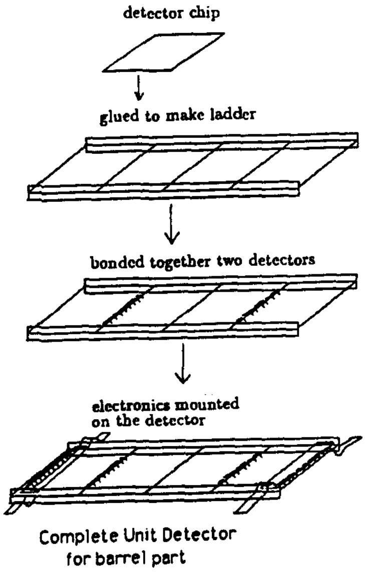
Silicon Tracking System Detector R&D Program

(continued)

- The test detectors work, are radiation hard and give good position resolution.
- At the time of the KEK SDC Collaboration Meeting (late May) Hamamatsu Photonics will deliver the first full-size double-sided detectors built to SDC specification.
- The next step is to produce prototypes of the "wedged" detectors for the forward part of the STS. Issues are the varying pitch and complicated strip patterns.
- A large part of the 1993 program is quality assurance (QA) of the Hamamatsu detectors testing effects of radiation, temperature, butane, operations ("at what voltage do things break?") and confirming the expected position resolution in the beamtest at KEK.

Specifications of Double-sided Silicon Strip Detector (Barrel Part)

1) Substrate
   - Type: n-type
   - Resistivity: 4-8 kΩ·cm
   - Thickness: 300 ± 10 μm
2) Size
   - Overall dimension: 60 mm × 34.1 mm
   - Effective area: 58.8 mm × 32.0 mm
   - Dead area: 600 μm from edge
3) Strip
   - Pitch: 50 μm on both surfaces
   - Strip isolation of ohmic side: p^+ blocking line method
   - Pattern accuracy
     - Position: ±1 μm
     - Size: ±1 μm
     - Relative position of both sides: ≲ 5 μm
4) Bias Resistor
   - Poly-crystalline silicon line on both surfaces
   - Resistance value: 250 ± 50 kΩ
5) Electric properties
   - Initial leakage current: ≲ 1 μA (overall)
≲ 100 nA/channel
   - Bias voltage range: 80 – 150 V
   - Decoupling capacitance of strip
     - Breakdown voltage: ≳ 100 V
     - Capacitance: ≳ 30 pF/cm
   - Readout capacitance: ≲ 1.2 pF/cm (junction side)
≲ 1.4 pF/cm (ohmic side)
6) Fiducial mark for integration
   - (Pattern and position are defined in Fig. 30.)
   - Position accuracy relative to strips: ± 1 μm
7) Dicing
   - Full cutting by diamond saw
   - Cutting zone: ± 30 μm



Detector Module Construction

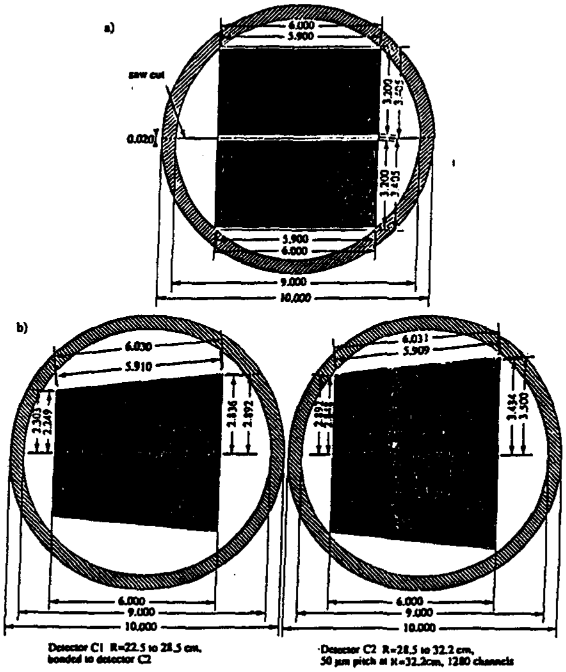


Fig. 20. a) Configuration of two barrel detectors made from one wafer; b) Geometry of largest disk detector as configured on a wafer. Also shown is detector bonded to it.

Radiation Hardness

- Radiation is only one of the environmental concerns we have to consider for the survival of silicon microstrip detectors:

  Radiation (charged particles, neutrons)

  Temperature (0°C)

  Liquids-Gases (coolant)

- We consider mainly radiation due to the p-p interactions, i.e. minimum bias events.

- Our SSCL collaborators are starting to work on other beam related sources of radiation. The present understanding is that the largest potential source is the beam halo, not beam accidents.

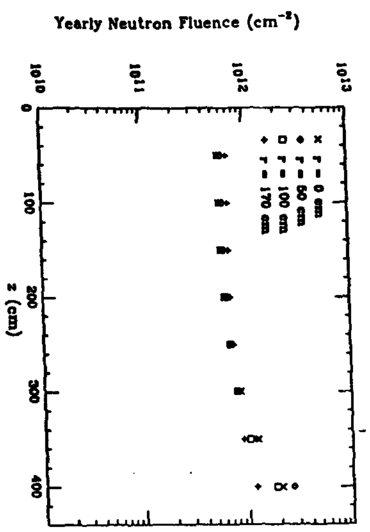
Radiation Hardness

(continued)

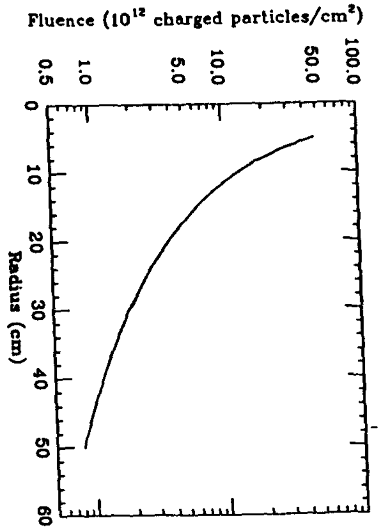
- "Radiation is bad for solid state devices" applies to silicon microstrip detectors as well as to all electronics in the detector (especially inside the tracking volume).

- We understand radiation levels during normal operations.

- For frontend electronics, we have characterized the radiation hardness of the bipolar and CMOS technologies we want to use. The radiation effects are included in the designs. The superior radiation hardness of the bipolar transistors has influenced our choice of a mixed bipolar-CMOS frontend.



Yearly neutron fluences in the SDC tracking volume, at $L = 10^{33}$ ($cm^2\,sec^{-1}$).

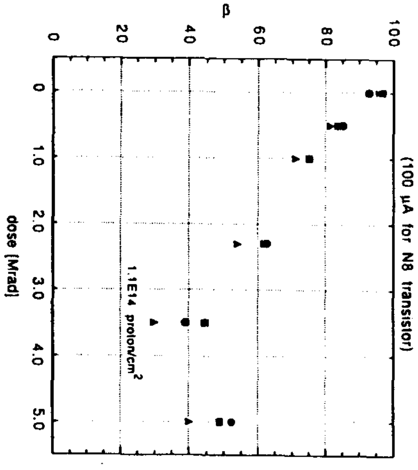


Charged particle fluence vs. radius for one year at Standard Luminosity.

Yearly Fluence Versus Radius

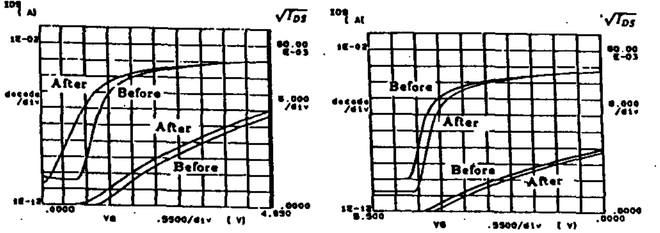
Radius (cm)	Fluence Particles/cm^2	Number of Years to Reach 10^{14}/cm^2
10	11×10^{12}	9
15	5.9×10^{12}	17
20	3.3×10^{12}	30
25	2.2×10^{12}	45
45	0.95×10^{12}	105

CURRENT GAIN β FOR TEKTRONIX SHPi npn' AFTER IRRADIATION WITH ^{60}Co AND 650 MeV PROTONS FOR THE SAME CURRENT DENSITY (100 µA for N8 transistor)



Drain Current vs Gate Voltage for Rad Hard CMOS transistor

Irradiation of 1.2 µm CMOS Chip from UTMC with 3.2 MRad Co^{60}



Threshold Voltage Shift < 200mV for n, p transistors

Radiation Hardness
(continued)

- For silicon microstrip detectors, we understand the radiation induced increase of the leakage current and of the depletion voltage, including temperature dependence and annealing.

- The detector design has features to increase the radiation tolerance:

  Polysilicon resistors as biasing scheme

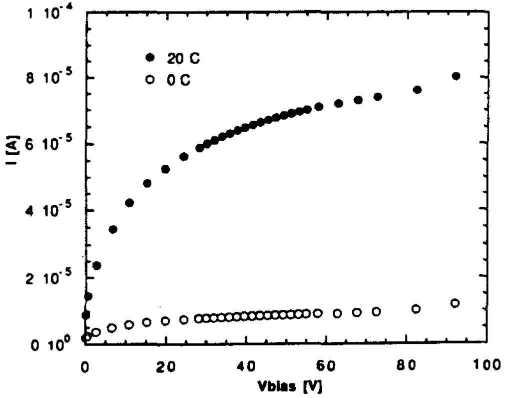
  Reduced value of the biasing resistors

  High breakdown voltage of the coupling capacitor

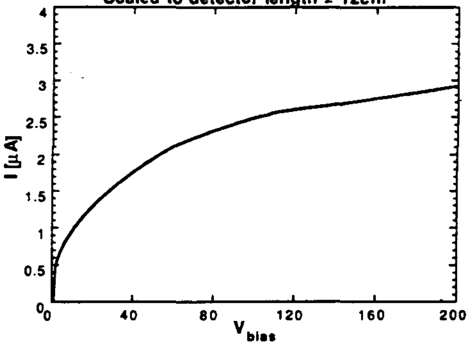
- We will operate the detectors to maximize the radiation tolerance:

  Lowered operating temperature

  Biasing on both sides



Leakage current on a silicon detector at different temperatures



Leakage current per strip after 6.3 10^{13} protons/cm^2, room temperature annealing 1.5 yrs Scaled to detector length = 12cm

G0651

SILICON R & D PLAN

H. SADROZINSKI

SDC Silicon Tracking System (STS)
R&D and Engineering Program

- Critical Requirements
- R&D Work in FY 88-92
- R&D Program in FY 93
- Milestones for FY 93

Hartmut F.-W. Sadrozinski
U.C. Santa Cruz
SSCL PAC, May 5 1992

The R&D Program for the Silicon Tracking System is driven by two considerations:

- Design requirements
  low-power, low-noise, radiation-hard electronics
  radiation tolerant detectors
  low-mass, ultra-stable mechanical structures
  low-mass, vibration-free cooling system
  efficient data transmission, DAQ and triggering systems.
- Schedule
  Date for ToH : July 1998 implies
  a start of electronics and detector production in early 1994.
  Fabrication of mechanical systems start in 1995.

STS R&D FY 1988-91

- Feasibility Studies
  Simulations
  Design Studies
- Investigations of Existing Advanced Technologies
  Radiation Hardness
  of Detectors and Electronics
  Front-end Electronics Development
  (Amp-Comp, Pipeline)
  Cooling Systems
  Finite Element Analyses
  of Large-scale Support Structures

STS R&D WORK IN FY 1992

- Prototypes
  Fast, low power, low noise bi-polar amplifier-comparator chip
  Rad-hard CMOS digital storage chips (clock driven, data driven)
  Double-sided detectors
  Wedged detectors
  Low-mass cables
  Data transmission system (16 fibers × 62 MHz = 1 Gbit/sec)
  Evaporative cooling system
  Crucial mechanical subsystem (Cooling rings, detector modules, 120° segment of shell)

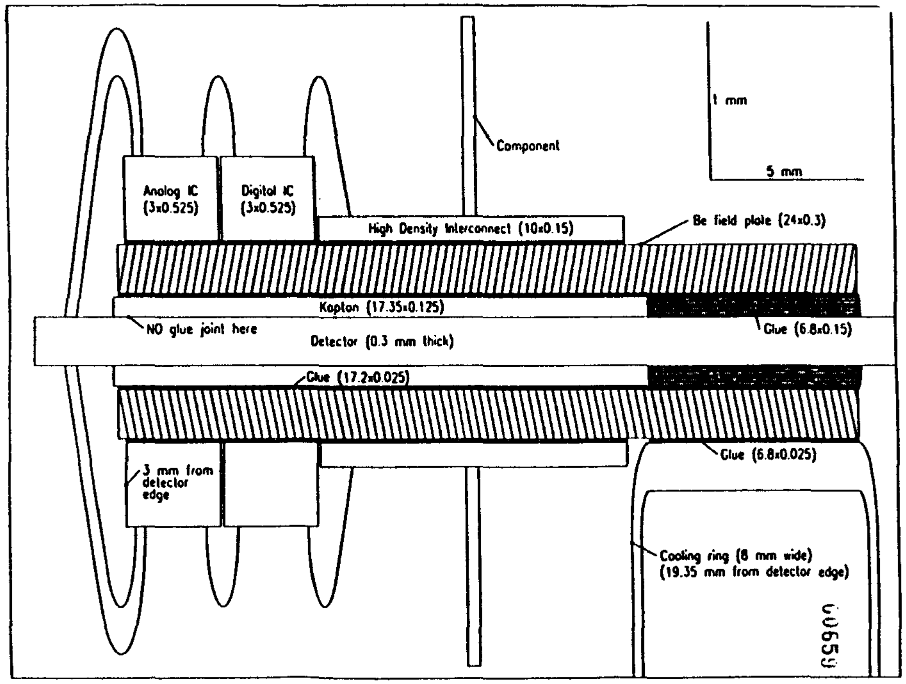
Silicon Tracking System R&D FY 1993

- Final Prototypes

Barrel Detectors	*(Japan, UCSC)*
Forward ('wedged') Detectors	*(Japan, JHU, LBL, UNM, Pitt, UCR, SSCL)*
Bipolar Amp-Comp Chips	*(LBL, UCSC)*
CMOS Digital Data Storage Chips	*(UCSC, U.K., LBL)*
Data Transmission	*(U.K.,UCSC)*
DAQ (Data Receipt)	*(U.K.)*
Cooling Ring	*(LANL)*

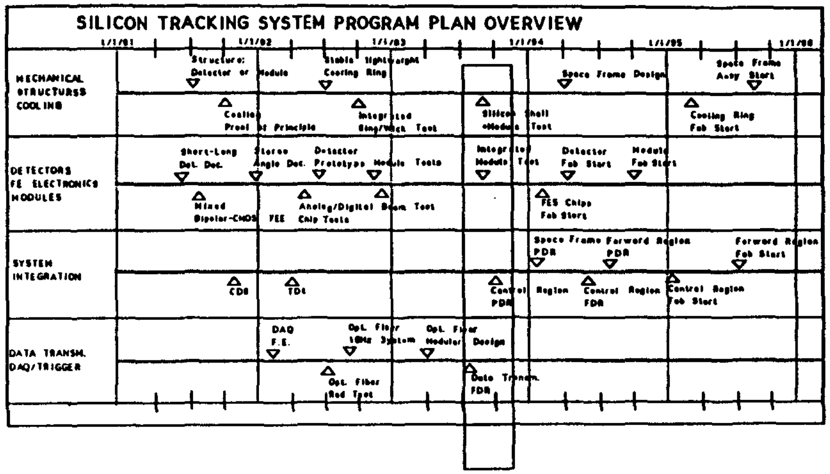
STS R&D FY 1992
(continued)

- Radiation Hardness Studies
  - Detectors
  - Front-end Electronics
  - Optical Fibers and LED's
  - Mechanical Samples
- Initial Integration
  - Module = Detector + FEE Chips + Read Out
  - Investigations of Clock Noise, Pick-up
  - Silicon Shells
- Development of Alignment & Manufacturing Concepts
- Simulations



STS R&D Status at the End of FY 1992:

- We know that detectors and electronics will function through more than 10 years of SSC data taking. We know how they are affected by radiation, lowered temperature and butane coolant.
- We have designs of detectors and electronics which meet the design requirements for efficiency, deadtime and power consumption.
- We will have working prototypes for detectors, amplifier-comparator chips, data storage chips, the data transmission and the data acquisition communicating with the frontend.
- From the chip prototypes from two bipolar foundries (AT&T and Tektronix) and two CMOS foundries (UTMC and Harris) we will be able to extract design parameters for the pre-production prototypes. We can also estimate the yield which is important for costing.
- Mechanical prototypes allow us to predict the properties of larger structures.
- The evaporative cooling concept is mature.
- We will have working modules which integrate detectors, FEE chips and read out into a mechanically stable structure; clock and read out noise is suppressed.
- Assembly and alignment concepts are developed.



CRITICAL TECHNICAL GATE:

- Stability Demonstration
- Silicon Module Performance Test
- Central Region PDR
- Data Transmission FDR

STS R&D FY 1993

(continued)

- <u>QA of Final Vendors</u>

Robustness of Detectors	*(Japan, UCSC, SSCL, JHU, UNM)*
Radiation Hardness	*(Japan, UCSC, SSCL, LANL, UCR, UNM)*
Variations in Chip Parameters	*(UCSC, LBL)*

- <u>Beam Test at KEK</u> *(Japan, UCSC, LBL, UNM, OKU, SSCL)*

Activities/Milestones for FY 93

Mechanical:	
Build Central Region Prototype Cooling Ring	
Central Region Prototype (Stability) Tests	
Central Region PDR	Sep '93
Build Forward Region Prototype Cooling Ring	
Forward Prototype Ready for Test	Sep '93
Internal Electronics/Detectors:	
Build Final Prototype Central Detectors	
Build Final Prototype Forward Detectors	
Build Final Prototype FEE	
Beam Tests at KEK	
Detector FDR	Sep '93
FEE FDR	Nov '93
DAT/DAQ:	
Build Prototype DAT System	
DAT FDR	Jun '93

STRAW-TUBE TRACKER SUMMARY

G. HANSON

Hanson

STRAW-TUBE TRACKER

SUMMARY

G. HANSON

SDC Presentation to PAC

May 5, 1992

MEMBERS OF THE OUTER TRACKING GROUP

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Quantum Research Services

R. L. Swensrud and D. T. Hackworth
Westinghouse Science and Technology Center

SUMMARY OF TRACKING SYSTEM REQUIREMENTS

Tracking system used for almost all physics!

1. $|\eta|$ coverage ≤ 2.5
2. $\sigma_{p_T}/p_T^2 \leq 20\%$ TeV^{-1} for $|\eta| \leq 1.8$, vertex constrained
3. Reconstruction efficiency $\geq 97\%$ for isolated tracks with $p_T \geq 10$ GeV at design luminosity, with ≤ 0.1 false tracks of $p_T \geq 10$ GeV per trigger ($\geq 90\%$ efficiency for $H^0 \rightarrow 4$ charged leptons)
4. Reconstruction efficiency for isolated tracks as above $\geq 90\%$ at 10 × design luminosity
5. Efficiency $\geq 50\%$ for tagging at least one b-jet from $t\bar{t}$ decay
6. Material $\leq 15\%$ X_0, averaged over $|\eta| \leq 2.5$
7. Position resolution at calorimeter shower maximum detector ≤ 5 mm in $r\phi$, ≤ 2.5 mm in z
8. Alignment to muon system to ≤ 100 μm in $r\phi$, ≤ 2 mm in z
9. Jet charged multiplicity measurement to 15%, for jets with $p_T \leq 500$ GeV
10. σ_z of vertex ≤ 2 mm
11. Level 1 trigger with $\sigma_{p_T}/p_T^2 \leq 10$ TeV^{-1} (10% error for 10 GeV particle)
12. Level 1 trigger efficiency $\geq 96\%$ per track, with ≤ 0.05 false triggers per calorimeter ϕ bin per crossing, over $|\eta| \leq 2.5$
13. Level 2 trigger with $\sigma_{p_T}/p_T^2 \leq 5$ TeV^{-1} (20% error for 40 GeV particle)
14. Discovery potential
15. Survivability for ≥ 10 years at design luminosity
16. Natural upgrade path to survivability for ≥ 10 years at 10 × design luminosity

---

RATIONALE FOR TRACKING SYSTEM DESIGN

Five Superlayers

- Superlayers provide local track segments, characterized by azimuthal angle and slope (curvature)

- 3 axial superlayers
  - 8 straws per superlayer
  - Wires parallel to beam
  - Used for high-p_T track segment trigger
  - Allows 2/3 superlayer trigger
  - Provides some redundancy (e.g., electronics for a couple of modules may not be working)

- 2 stereo superlayers
  - 6 straws per superlayer
  - Wires at small angle to beam
  - Give measurement of coordinate along the wire
  - Minimal number: +3°, -3°

- Superlayers divided in half at $z = 0$

Superlayers Composed of Straw Tubes in Modules

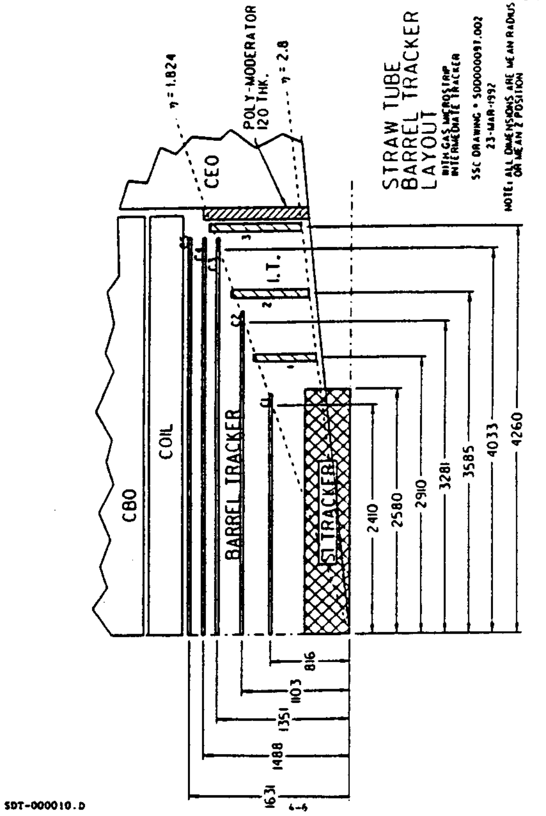
- Each module contains about 200 straws
- Complete drift chamber with own electronics, HV, gas

Modules Supported on Cylinders

- Carbon fiber composite and foam laminate

Cylinders Supported by Space Frame

- Carbon composite



CENTRAL OUTER TRACKING SYSTEM CONFIGURATION

Superlayer	Mean Radius (m)	Modules	Channel Count	Layers/ Superlayer	zmax (m)	Stereo Angle (°)
C1	0.816	92	19.504	8 (trigger)	2.410	0
C2	1.103	124	19.716	6	3.281	+3
C3	1.351	152	32.224	8 (trigger)	4.033	0
C4	1.488	168	26.712	6	4.033	-3
C5	1.631	184	39.008	8 (trigger)	4.033	0

Total number of straws is 137,164.

PARAMETRIC RESOLUTIONS FOR TRACKER AT $\eta = 0$

Track Parameter	Resolution (rms)
σ_{p_T}/p_T at 1 TeV (beam constrained)	0.15
σ_{p_T}/p_T at 1 TeV (no beam constraint)	0.17
σ_{ϕ_0} (mrad)	0.066
$\sigma_{cot\theta}$	0.0013
σ_b(μm)	13
σ_{z_0} (mm)	0.77

Improvements in resolution by outer tracking system over silicon system alone:

Momentum	10
Polar angle	5
Impact parameter	2

Assumes measurement errors of 17 μm for each single-sided silicon measurement and 85 μm for each straw superlayer. These errors include contributions from local alignment errors.

STRAW TUBE DRIFT CHAMBERS

Basic Construction

- Drift cell with central anode wire along axis of metal-coated plastic cathode

Specifics

- 4 mm diameter, copper (0.15 μm) coated Kapton straw
- 38 μm gold-plated tungsten anode wire
- Length up to 4 meters

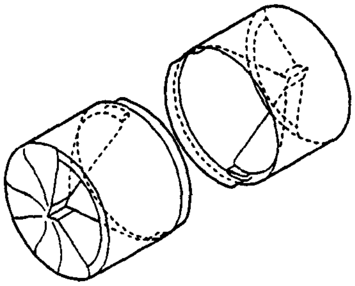
Advantages

- Small cells allow operation in SSC environment
- Only anode wires: no large bulkheads to hold wire tension
- Walls of tube allow supports for long wires, needed for electrostatic stability
- Allow isolation of anode wire

Operating Characteristics

- CF_4 with 20% isobutane
- Low gas gain, ~ 2×10^4, needed to keep current draw and aging effects small (applied voltage ~ 2 kV)
- Drift velocity 105 ± 15 μm/ns
- Maximum drift time 29 ns in 2 Tesla magnetic field
- Spatial resolution ~ 100 μm
- Attenuation length ~ 6.3 m

Double-V Wire Support



Gain Curve

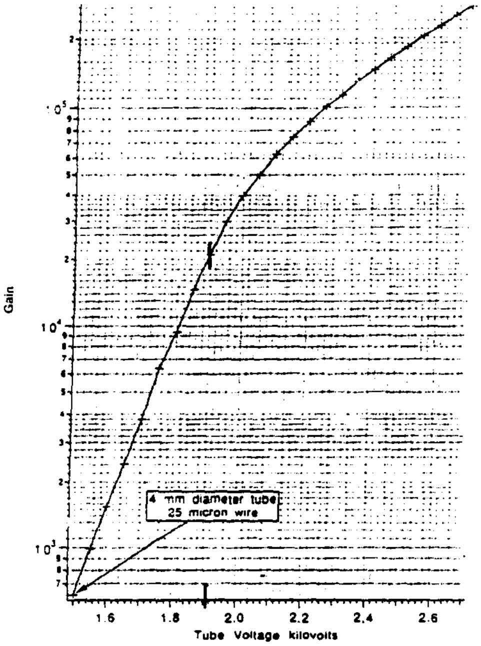
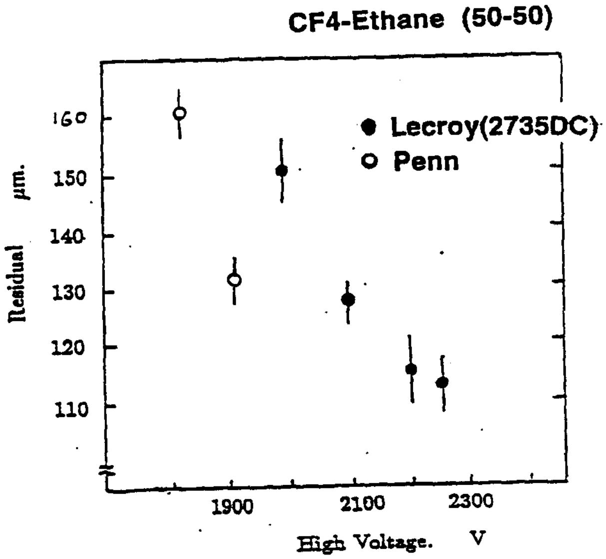


Fig. III.3. The gain curve of a 4 mm straw drift tube with CF_4 -isobutane 80:20 gas. The absolute calibration of the curve is accurate to about 15% but the shape of the curve reflects the true dependence of the gain on voltage.



DUKE
2.7 meter

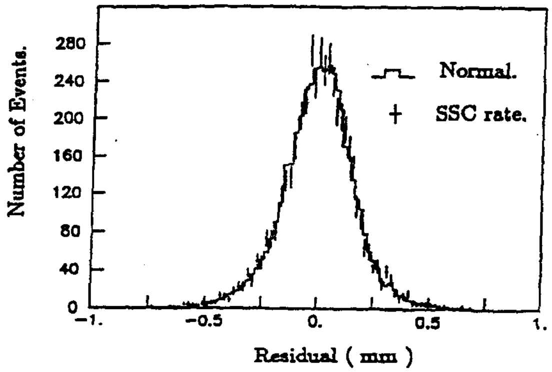
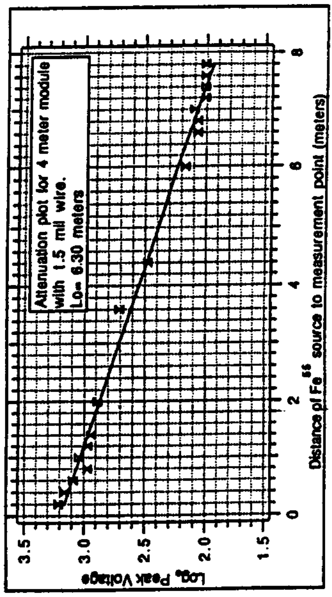


Fig.III. 7. Plot of the residuals of fits to cosmic ray tracks in a module from data taken under two different background conditions. One free of extra background and the other with a background similar to what is expected in an SSC environment.

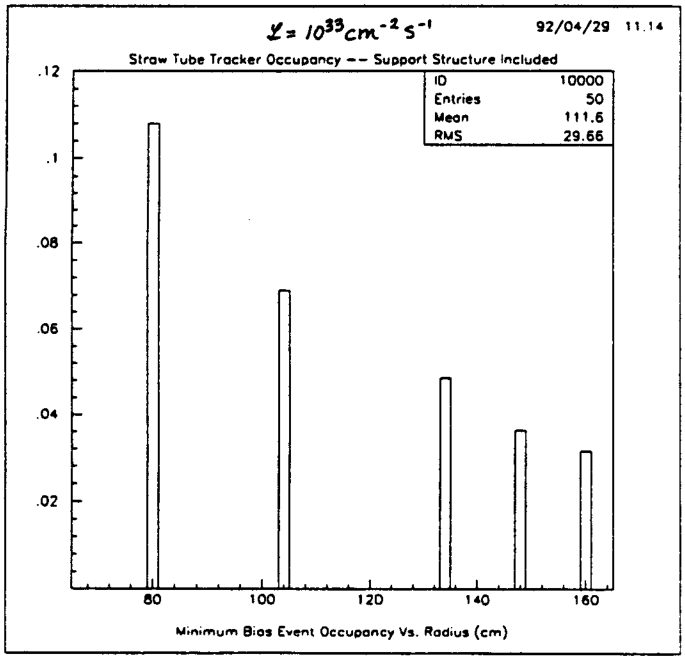


CURRENT DRAW PER STRAW AT DESIGN LUMINOSITY

Includes Neutrons

Superlayer	Radius (m)	Length (m)	Current (Chgd Part) (nA/cm)	Current (Total) (nA/cm)	Integrated Charge in 10 Years (C/cm)
C1	0.816	2.410	1.7	1.9	0.19
C2	1.103	3.281	0.72	0.9	0.09
C3	1.351	4.033	0.39	0.6	0.06
C4	1.488	4.033	0.32	0.5	0.05
C5	1.631	4.033	0.24	0.5	0.05

No anode damage up to 2C/cm
Cathode survivability > 0.3C/cm



RATIONALE FOR MODULES

Description

- A module consists of ~ 200 straw tube drift chambers held in close-packed position in a box of approximately trapezoidal shape

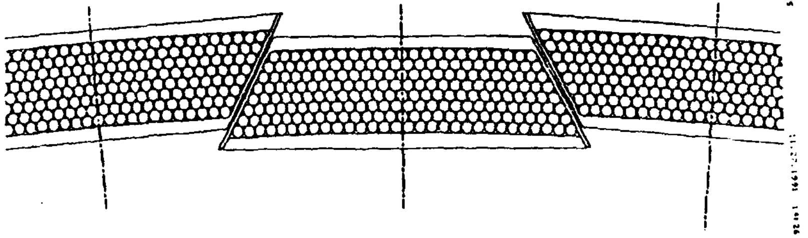
Mechanical Support and Alignment of Straws

- 4-mm diameter 4-meter-long straws need mechanical support
- Walls of module support wire tension (12 kg)
- Endplate of module provides the connections to the wires (high voltage and electronics) and distributes the gas to the straws
- A module is thus a self-contained drift chamber

Practical Aspects

- Modules provide a practical method of assembling over 10^5 straws into a tracking system
- Modules can be mass produced (at several sites)
- Modules can be tested individually before assembly into the complete tracking system
- Modules can be individually transported to a central site (SSCL) for final assembly
- Modules can be replaced if there are problems with part of the tracking system
- Straws are aligned locally along their length in the module

CURVED TRIGGER MODULES

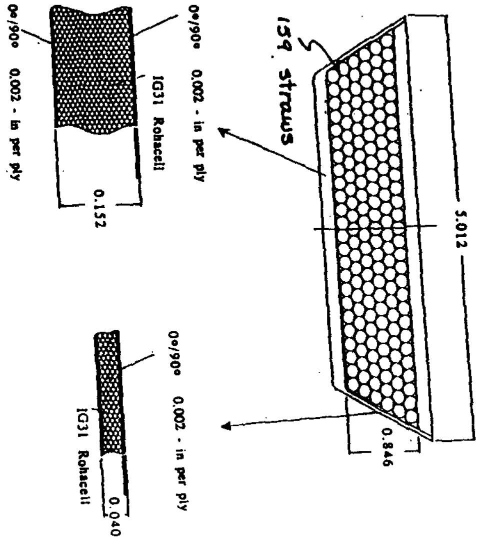


TRIGGER MODULES AS PER CENTRK21 10-16-91
SUPERLAYER 3, INSIDE RADIUS = 133.245 CM
SCALE 1:1

WESTINGHOUSE STC

DM 11-26-91 UU692

Stereo Module



Material
Shell 0.26% X_o
Straws 0.23% X_o 6 straws
0.31% X_o 8 straws

UU690

Positions of Straws in a Module

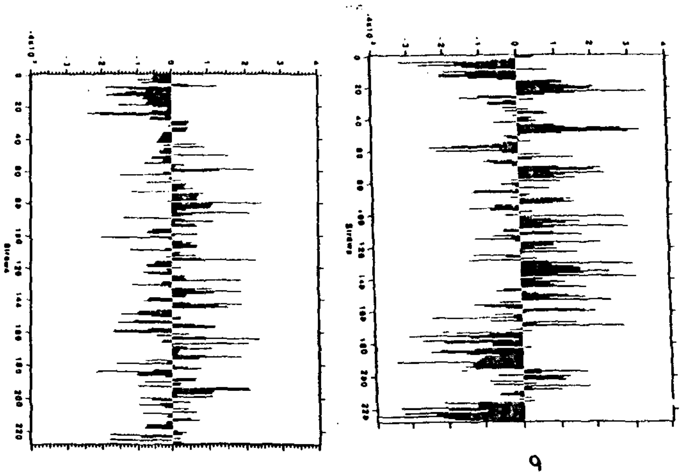


Fig. IV.5. The deviation of the theoretical close packed fit in x position (a) and y position (b) for an 8 layer trapezoid.

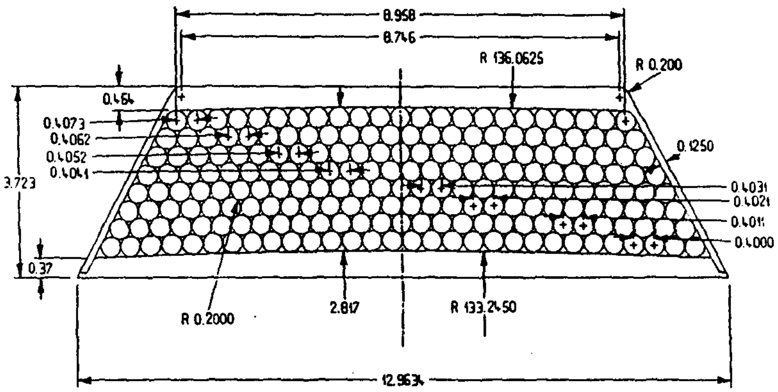
Double V notch measured with optical comparator

UU693

MODULE USED FOR MISSED HITS STUDY - (CMODULE)

Trigger Module

AS PER CENTRK21



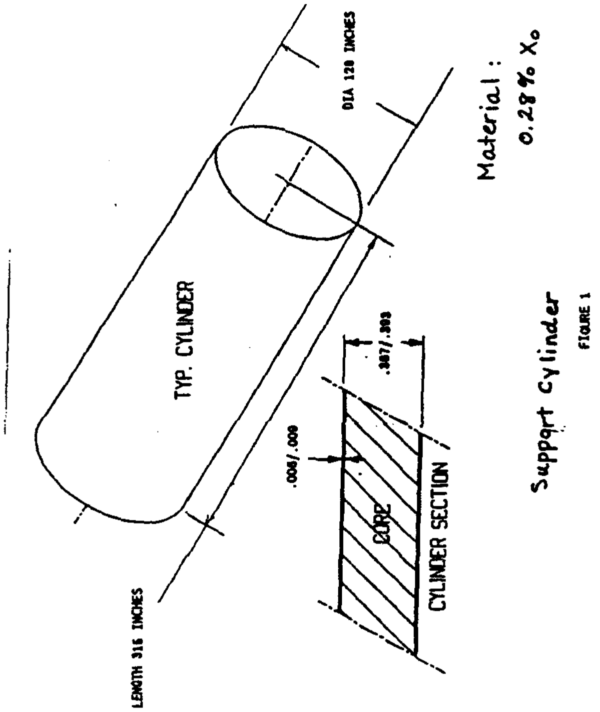
212 straws

ALL DIMENSIONS IN CM
SCALE 1.5:1

WESTINGHOUSE STC

UU691

00684



-11-
CGC10T00 08.01.92
Phase I Material Testing

00685

Stereo Modules on Cylinder

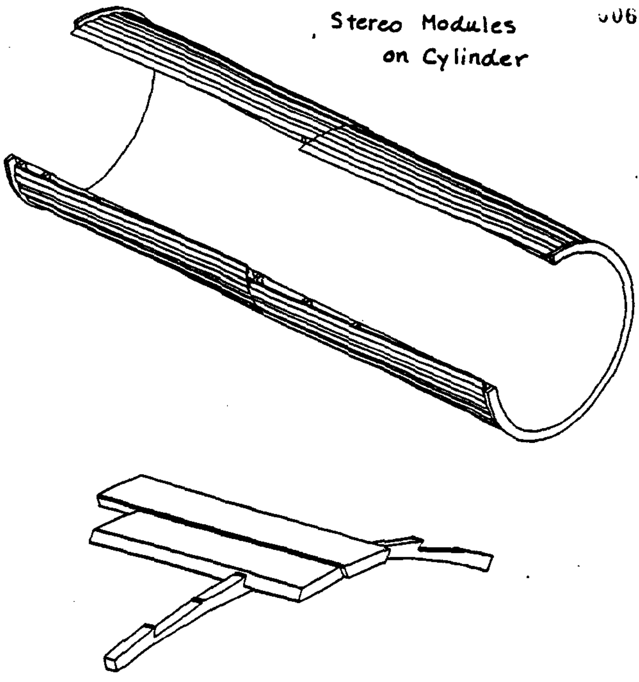


Fig. IV. 12 a) the stereo superlayer as seen in an isometric view. b) Detail of a stereo layer at the midpoint of the cylinder.

00686

Module Attachment

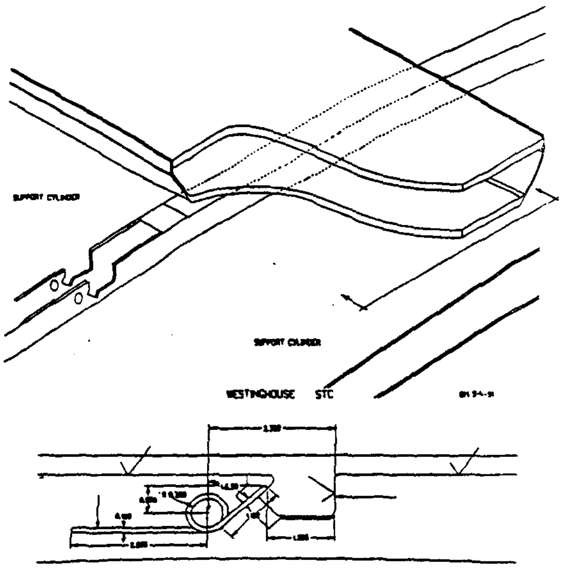
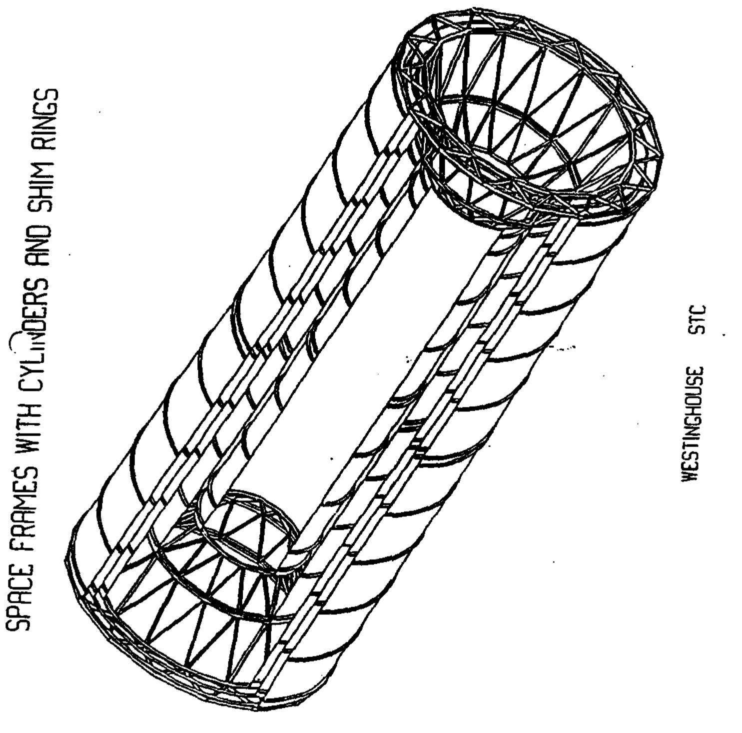
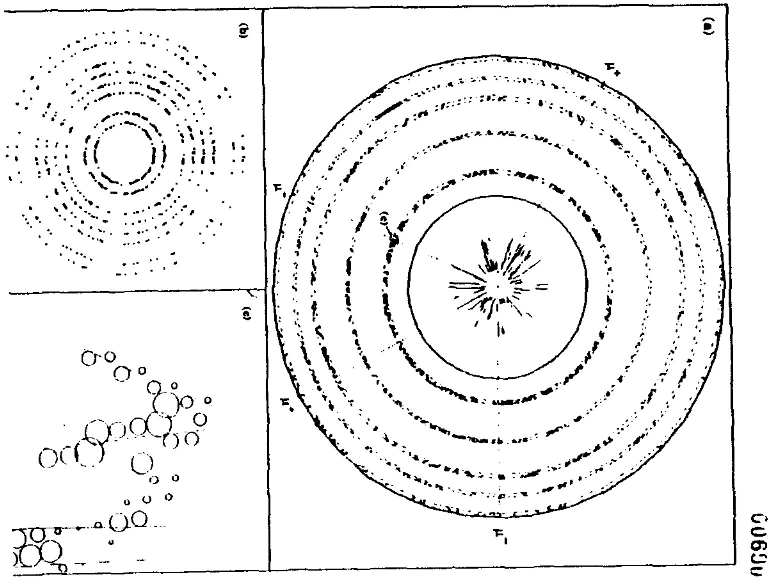


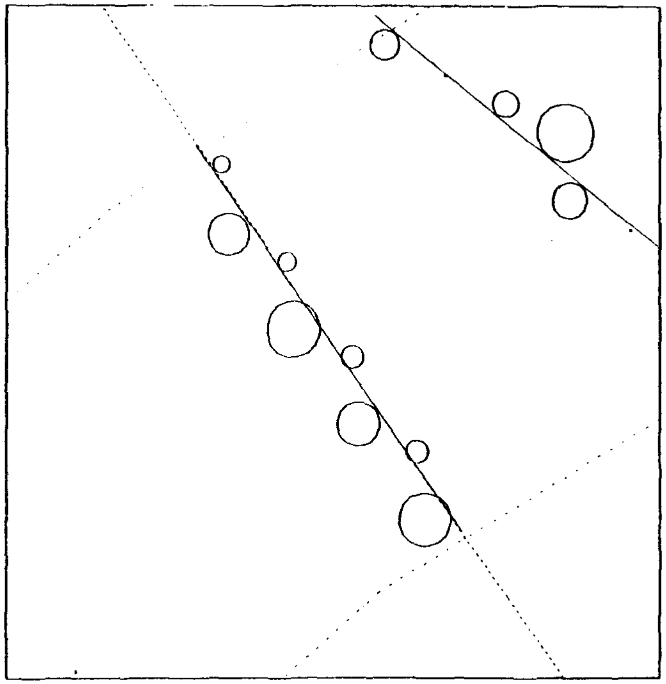
Fig. VI.18. Conceptual design of module and shim ring attachment.

00687



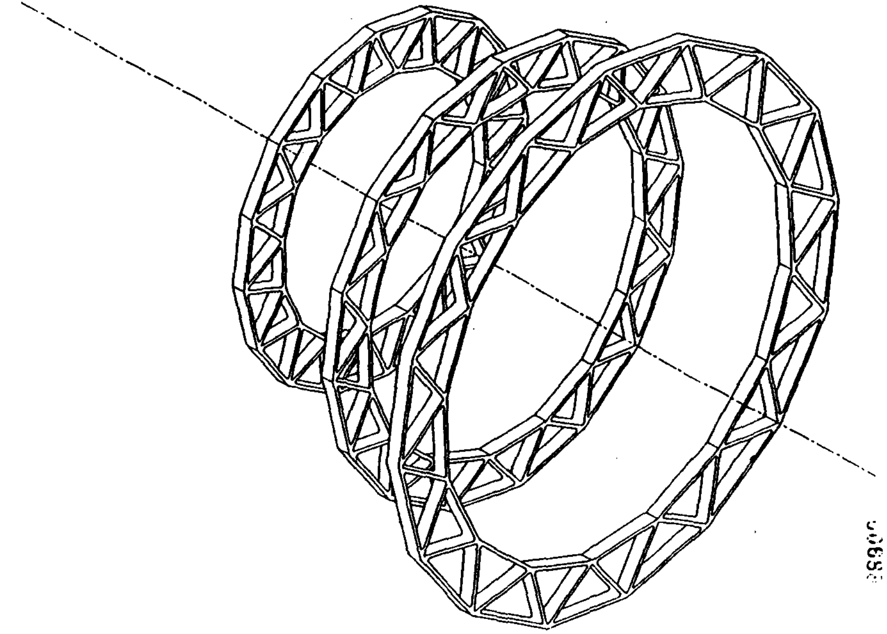


Higgs Event at $\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}

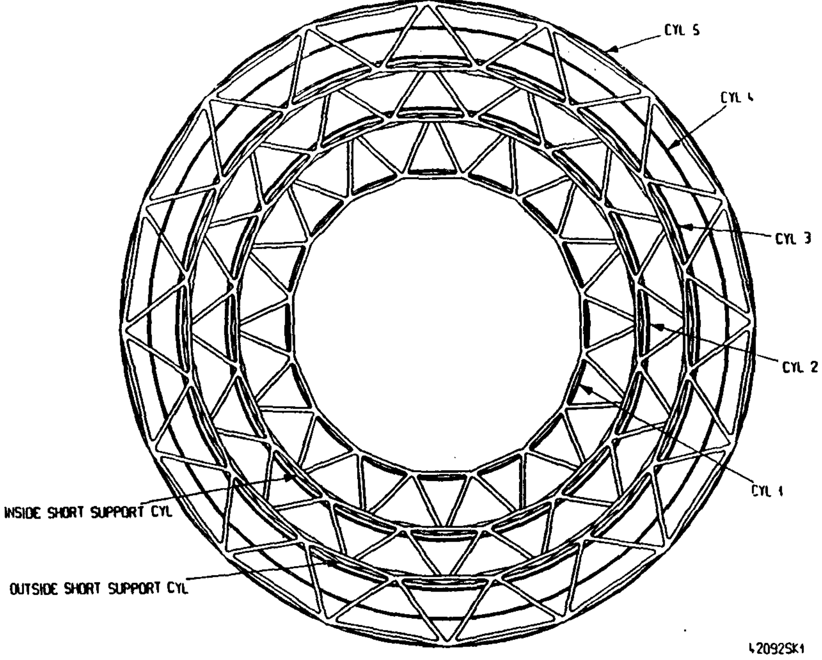


Close-up of Inner Straw Superlayer at 10^{33} cm^{-2} s^{-1}

Space Frame Support Structure

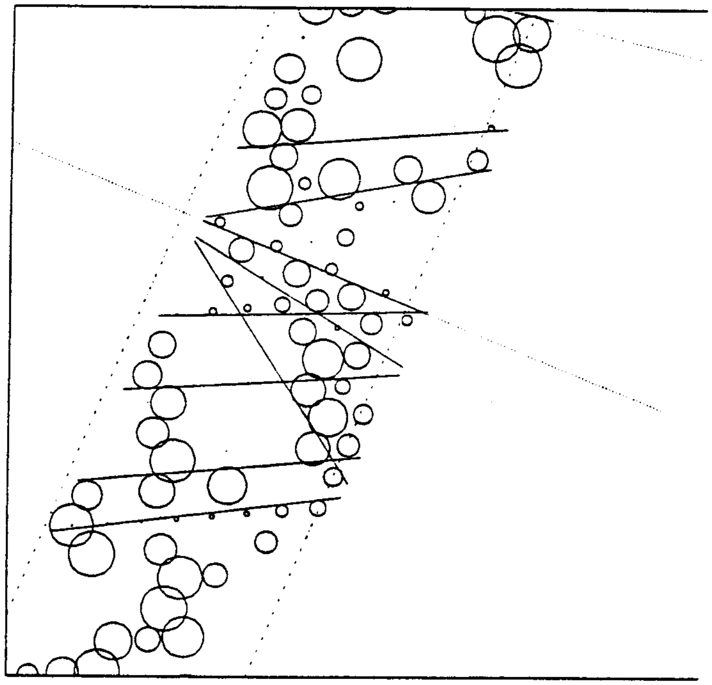


Space Frame End View



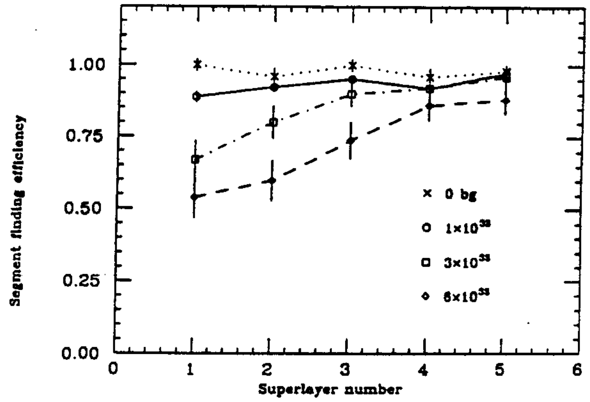
00692

Close-up of Inner Straw Superlayer at $10^{34} cm^{-2} s^{-1}$



00693

Segment Finding Efficiency for Higgs → $4\mu^{\pm}$

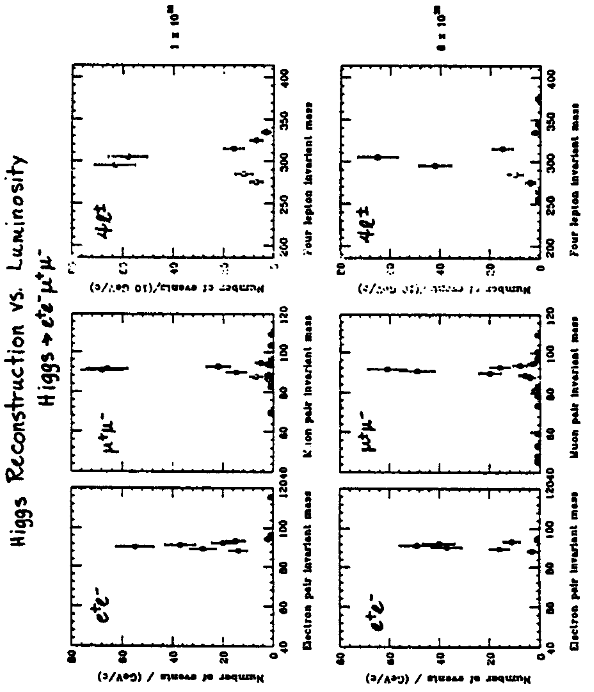


00694

Segment Finding Efficiencies for the Straw Tracker for μ's from Higgs

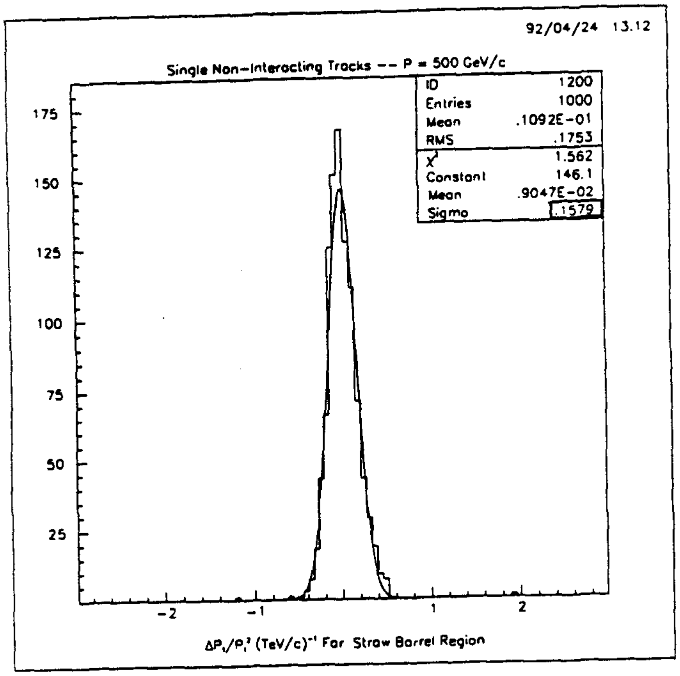
Suplayr No.	ϵ, 1×10^{33}	ϵ, 3×10^{33}	ϵ, 6×10^{33}
1	0.89 ± 0.02	0.67 ± 0.07	0.54 ± 0.07
2	0.92 ± 0.02	0.80 ± 0.06	0.60 ± 0.07
3	0.95 ± 0.01	0.90 ± 0.04	0.74 ± 0.06
4	0.92 ± 0.02	0.92 ± 0.04	0.86 ± 0.05
5	0.97 ± 0.01	0.96 ± 0.03	0.88 ± 0.05

00695

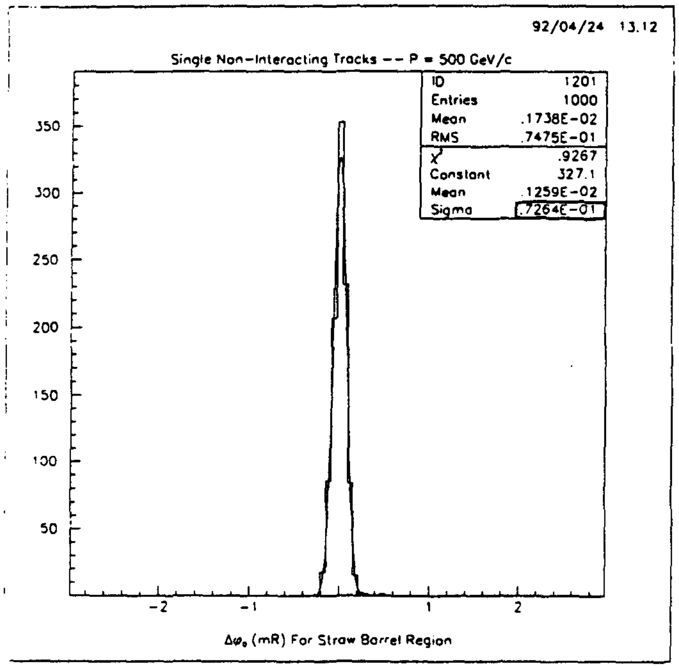

Higgs Reconstruction vs. Luminosity

Higgs → $e^+e^-\mu^+\mu^-$

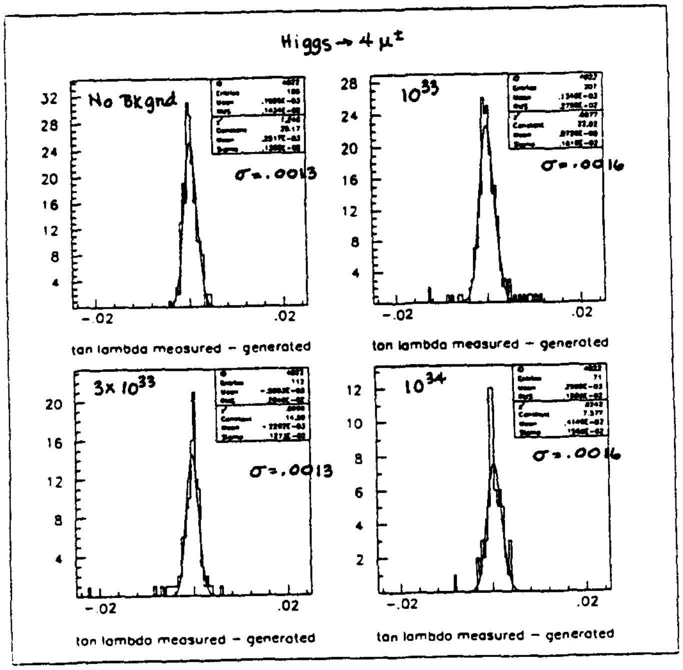
00696



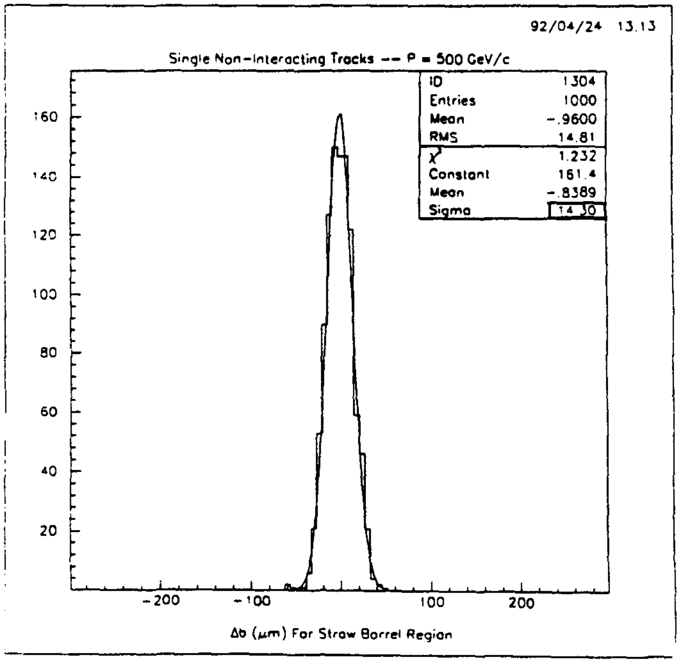
00697



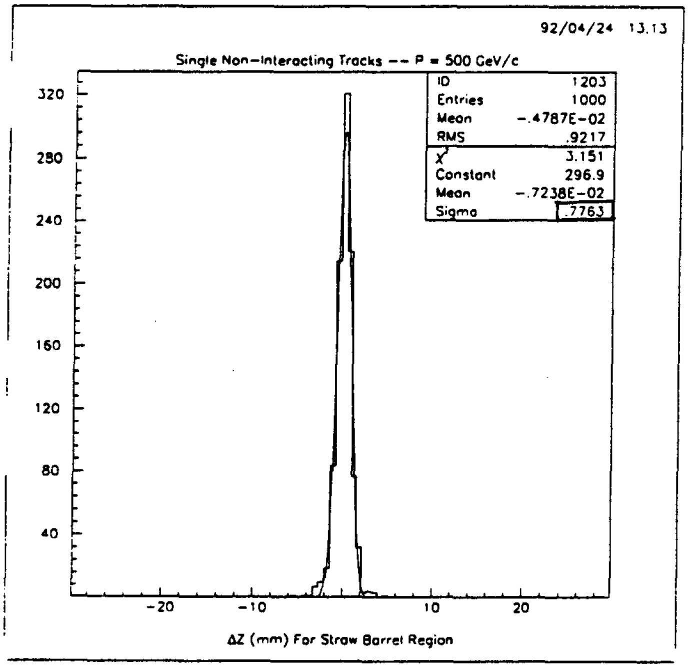
00698



00699

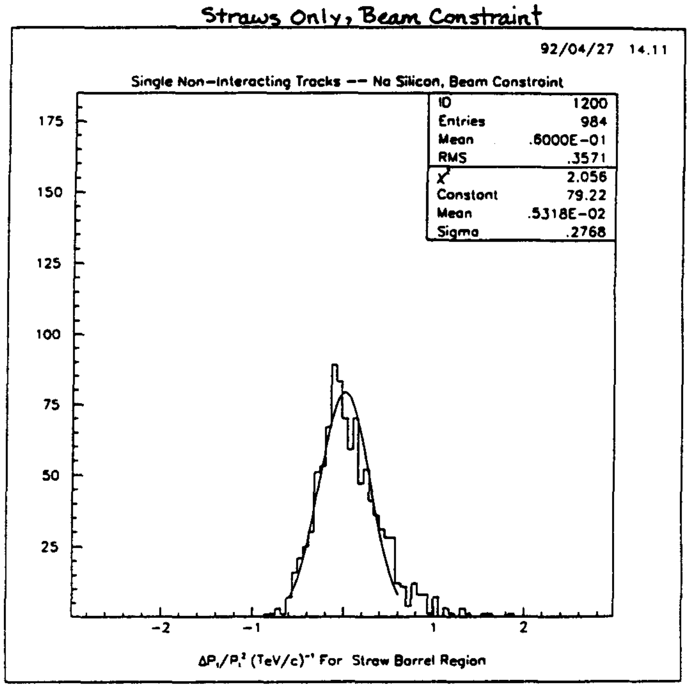


00700



00701

Straws Only, Beam Constraint



00702

Level 1 Trigger
High-p_T Track Segments

One of Eight Patterns

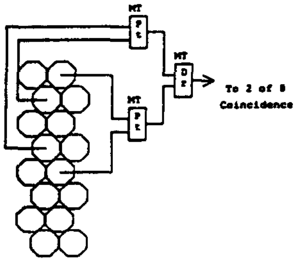


Fig. V.22. A representative mean timer connection for an 8 tube superlayer. The connection shows two mean timers each requiring hits to be consistent with a preset momentum lower limit and output pulses averaged in time to a common radial position. The third mean timer averages these output pulses to arrive at a final pulse whose timing is fixed relative to the particle passage time plus the signal propagation time from its z position to the end of the straws. The pattern shown is one of 8 used in a two-fold coincidence to produce a stiff track trigger.

00703

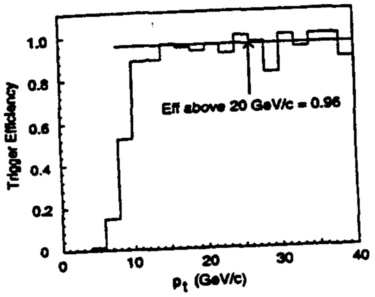
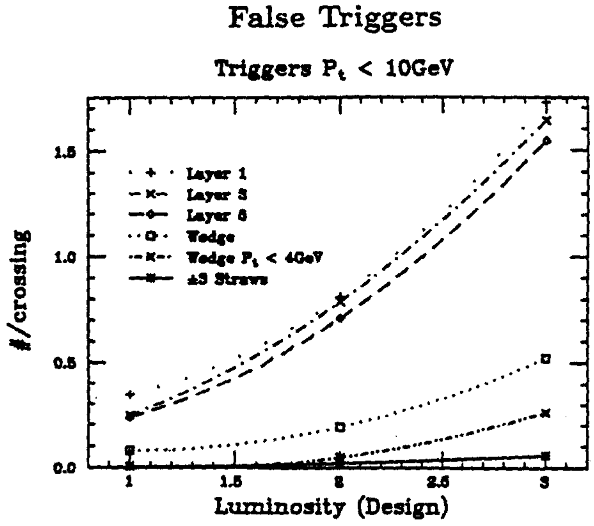


FIG. 4-15. Threshold curve for the two-out-of-three superlayer OTD Level 1 trigger.


False Triggers
Triggers P_t < 10GeV
Layer 1
Layer 3
Layer 5
Wedge
Wedge P_t < 4GeV
±3 Straws
#/crossing
0.0
0.5
1.0
1.5
1
1.5
2
2.5
3
Luminosity (Design)

STRAW-TUBE ENGINEERING AND R & D PLAN

H. OGREN

SDC

R&D and Engineering on the Straw Tracker

Harold Ogren
Indiana University

Presentation to PAC

May 5, 1992

H OGREN

R&D and Engineering on the Straw Tracker

Research and Development on Straw Drift Chambers

- Indiana University
- University of Colorado
- Duke University
- University of Pennsylvania
- University of Michigan
- KEK
- LBL

Engineering

- Westinghouse Science and Technology Center
- Oak Ridge National Laboratory
- Quantum Research Services
- Composites Horizons, Inc.
- Coast Composites
- TRIUMF

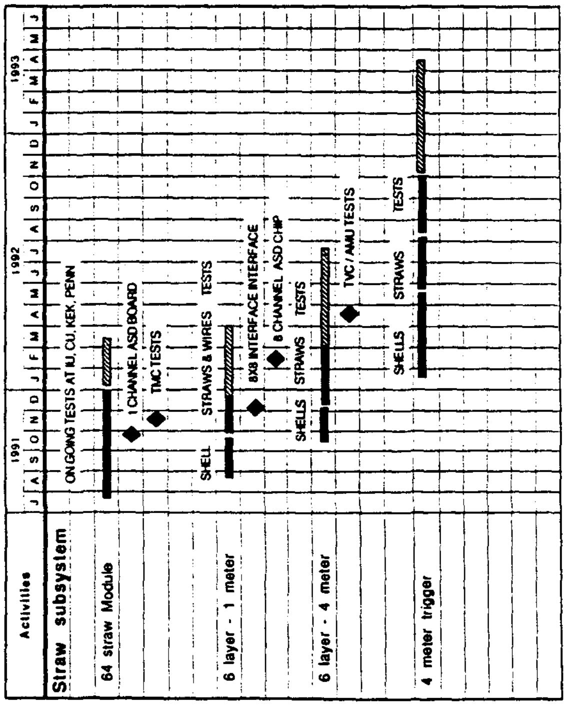
OUTLINE

1) Straw Drift Chamber development
   R&D Plan

2) Spaceframe and Cylinder Support
   R&D Plan

Straw Drift Chamber Development

- R&D on drift and Gas properties
- 64 straw test modules
- 2.7 meter long multistraw array
- 1 meter long full cross section array
- 4 meter long prototype
- future R&D plan



STRAW DRIFT CELL

- prototype work on the straw cells

Indiana, Duke, Colorado, LBL, TRIUMF

(1989-present)

- Gas Studies
  - Lifetime
  - Drift Speed
  - Efficiency of 4 mm cells
  - Wire stability
  - Intrinsic Resolution

STRAW DRIFT CELL

- prototype work on the 4 mm diameter straw cells

Indiana, Duke, Colorado, LBL, TRIUMF

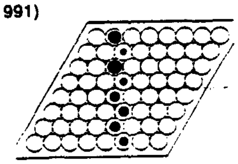
(1989-present)

- Gas Studies
  - Lifetime
  - Drift Speed
  - Efficiency of 4 mm cells
  - Wire stability
  - Intrinsic Resolution

Material Studies on Radiation Resistance.

---

64 straw modules

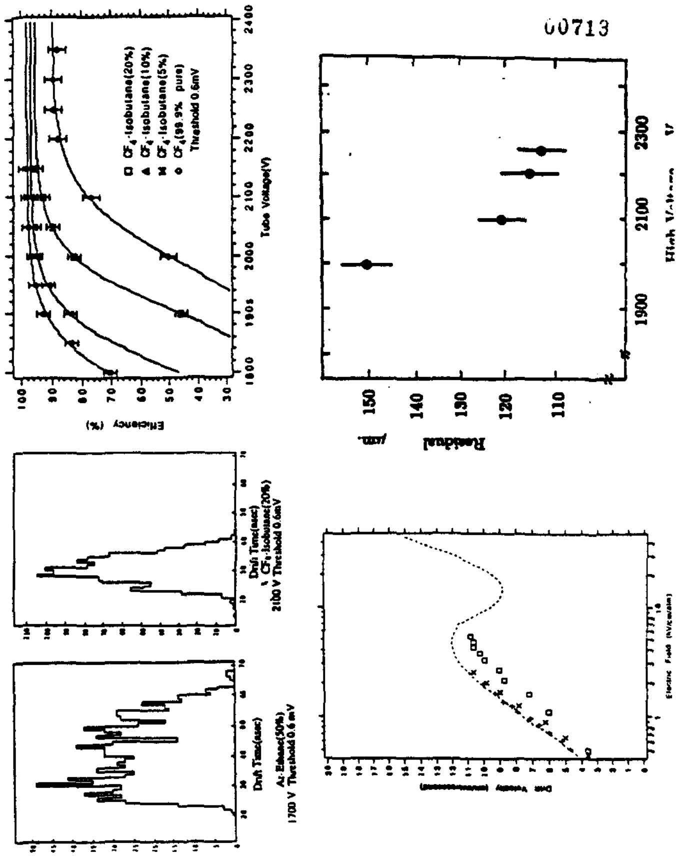


constructed at Indiana (1991)

Delivered to:

Colorado
Michigan
KEK
Pennsylvania

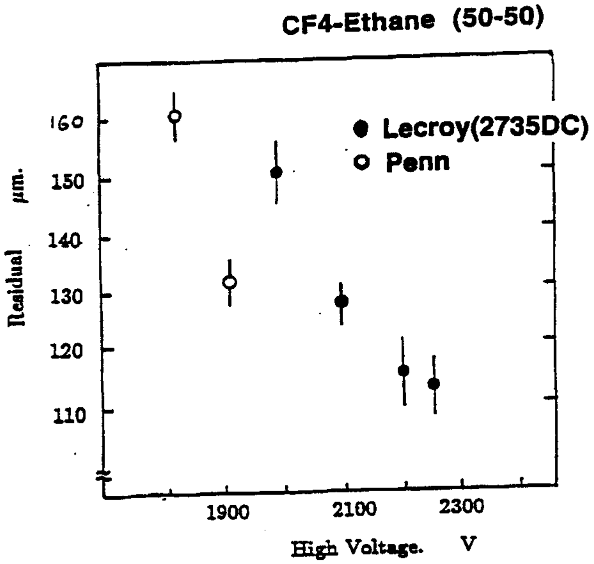
- Carbon composite Shells
  Composite Horizons,Inc
- Endptate Designs
  Liberty Advanced Machining
- Straw Tube production
  Precision Paper Tubes. Inc.
- Electronics for read out
  Penn and Colorado
- wire Supports
  Sabin Industries, RTI Plastics.
- Construction techniques
- Cosmic ray and source tests



Multistraw bundles 2.7 m

Constructed at Duke (1991)

- Straw contruction
  Stone Industrial
- Wire supports
  Machine shop manufacture
- Precision Placement
  Fiber Optic Probe
  Quantum Research Services
- Electronic read out
  Pennsylvania, ORNL, Duke
- Resolution measurements
- High rate tests



DUKE
2.7 meter

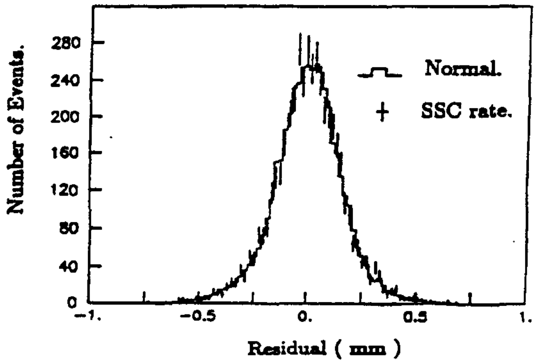
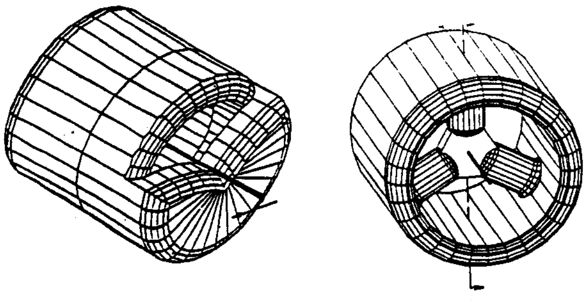


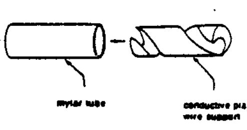
Fig.III. 7. Plot of the residuals of fits to cosmic ray tracks in a module from data taken under two different background conditions. One free of extra background and the other with a background similar to what is expected in an SSC environment.

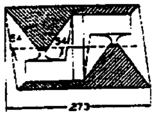
Straw Module Prototypes

1 meter (full cross section) **Indiana (1991)**
4 meter (full prototype) **Indiana, Duke (1992)**

- Full section/length Carbon Composite Shells
  Composite Horizons, Inc
  Coast Composites, Inc
- Four meter long straw production
  Stone Industrial
- Full scale endplates
  Liberty Machining
- Wire supports
  RTI Plastics, Colombine Plastics.
- Assembly Techniques
  EDM Machining, Liberty Machining
  Century Design Inc., Indiana University
- Attenuation
- resolution
- mounting and alignment

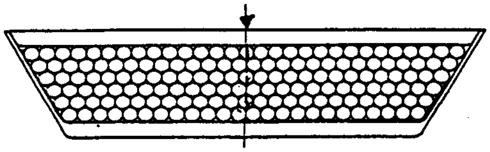


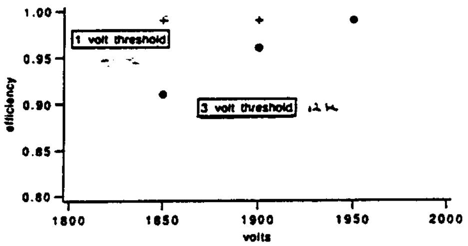




ASSEMBLED WIREHOLDERS (2)
(SNAPPED TOGETHER)

Cosmic Ray Efficiency Measurements

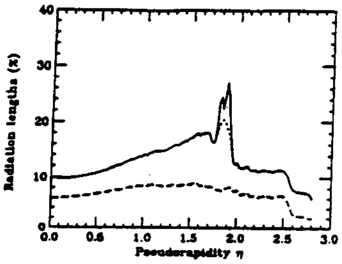




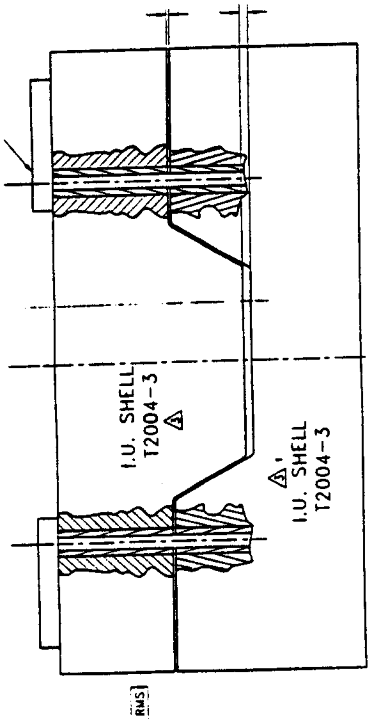
SDC
Program Advisory Committee Meeting
May 5, 1992

Module Construction

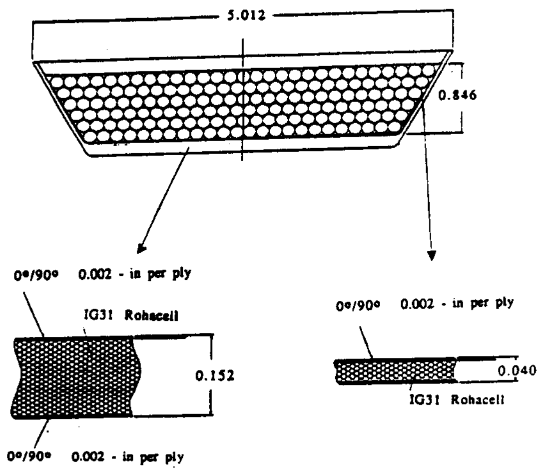
- materials
  Requirements of minimum radiation lengths and high stiffness have driven the design



- superlayer thickness (0.26% shell, 0.23/0.31% straw (0.28% cylinder= 0.77/0.85% total)
- Production of Modules at Composites Horizons, Inc. Covina, California
  Carbon Fiber is M-40 (Toray)
  Lay up is 0-90, two layers, + resin sheet
  Autoclave at about 30 psi, 250 F.
- Mold are solid graphite, matched sets for both the lid and the base. Machining accuracy ±30 μ
  Coast Composites, Irvine, California



SHELL TROUGH TOOL ASSEMBLY

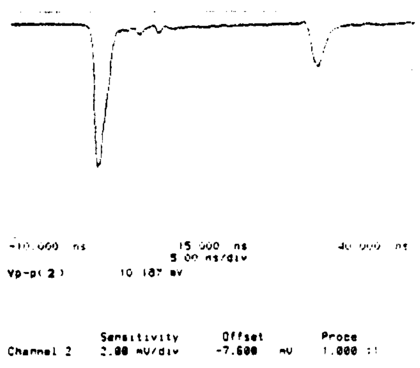


Construction of a module

August 1991-	Contract with Composites Horizons, 1m shell
October, 1991-	Contract for three 4 meter shells CHI
November, 1991	One meter Module complete-IU
December, 1991-	Molds completer- Coast
December, 1991	Shell complete- CHI
February, 1992-	Third shell complete- CHI
April, 1992-	Ist module complete- IU

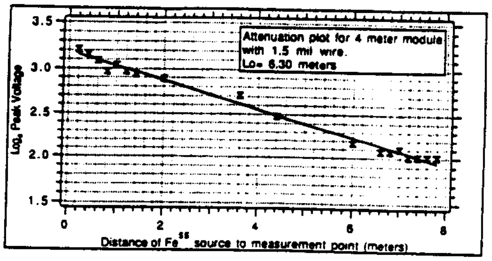
Direct Signal from 4 meter Chamber

- Voltage 2000, CF4-Isobutane (20%)
- Fe 55 Source, near electronics end
- Separation of direct and reflected =7.8 m
- Attenuation lenght= 6.3 meters



Signal Attenuation in a Straw Chamber

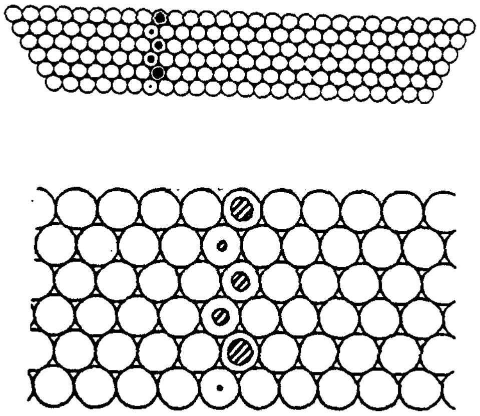
- 4 meter straw
- Copper coated Kapton (150 nm) 90 ohms.
- 37 μ diameter wire, Gold plated tungsten



SDC
Program Advisory Committee Meeting
May 5, 1992

Cosmic ray Test of Four Meter Module

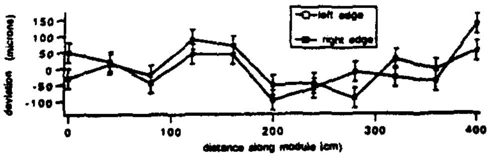
- CF4- Isobutane (20%)
- 2000 V
- Penn Preamplifier



SDC
Program Advisory Committee Meeting
May 5, 1992

Mechanical Measurements on 4 meter Prototype

- Measurements of deviation from straight line for the completed module
- *The* module was unconstrained in "phi".
- Meaurement with an "optical micrometer"



- On the detector the module is constrained by hold down attachments.

Test and calibration of each module

- check gas tightness
- test module with HV
- x ray for wire positon ≤ 15 μ
- cosmic ray tests
- Determine best fit to close packed geometry at each 80 cm point.

SOME R&D MILESTONES

MILESTONE	DATE
Straw R&D	
Develop final wire support design	Sep. 92
Develop resistive terminator	Sep. 92
Develop fabrication technique	Feb. 93
Module R&D	
Complete construction of first 4-meter nontrigger module	Mar. 92
Complete construction of 5 more nontrigger modules	Aug. 92
Complete construction of 4-meter trigger shells (two types)	Sep. 92
Complete construction of 4-meter trigger modules	Nov. 92
Complete construction of 4 more trigger modules, for a total of six	Feb. 93
Detector and Electronics Evaluation	
Develop cross-talk free connection from wires to electronics	Sep. 92
Establish operating condition for modules with prototypes of final electronics (~ 100 μm resolution at $2 - 5 \times 10^4$ gain)	Feb. 93
Aging Studies	
Study materials	Feb. 93
Study wire chamber lifetime (neutrons, etc.)	Feb. 93
Rate studies	Feb. 93

Alignment and stability of Tracking

$\sigma_{superlayer}$ = 80 micons for the track position measurement at each superlayer.

For the modular system we can write:

$$\sigma^2_{superlayer} = (\sigma^2_{intrinsic} + \sigma^2_{wire\ placement})/6 + \sigma^2_{module\ intrinsic} + \sigma^2_{module\ placement}$$

σ intrinsic = 120 microns

σ wire placement = 30 microns

σ module straightness = 40 microns

σ module placement = 50 microns

σ total = 82 microns

Stability more restrictive! << 82 microns!
Correlated errors due to relative rotation, center shift.

Alignment

1) Module Level

Jigs- provide fiducial references

X-Ray verify wire positions

Quality check verify module straightness

2) Cylinder Level

Shim machining- fiducial placement

Ring machining

Ring attachment to Spaceframe

Position verification- Laser and optical

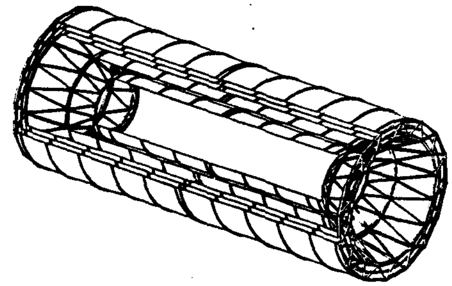
3) Final assembly

Cylinder placement on the spaceframe

Attachment of Modules

Final verification of positions

Design of Tracker Support



Cylinder

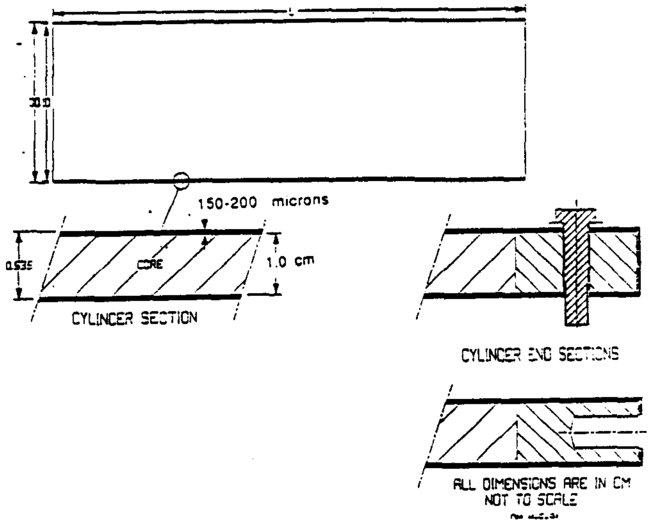
- Design is driven by minimizing radiation length
  maximum stiffness
  load requirements: ·modules, 500 lbs ,max

- Materials studies
  ↔ 9 μ Carbon fiber shell on Rohacel foam
  balanced symmetric layup

- Machining operations on Shim rings.
  Intrinsic to the design of module alignment

Westinghouse Science and Technology Center lead engineering on cylinder and spaceframe.

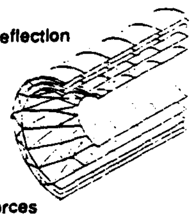
SUPPORT CYLINDER DIMENSIONS



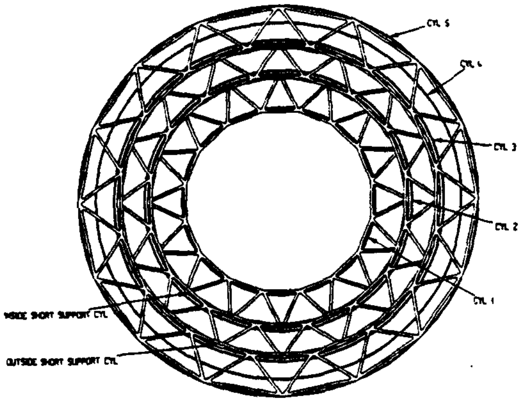
ALL DIMENSIONS ARE IN CM
NOT TO SCALE

Engineering studies of cylinders

- Radiation lengths
- material variations
- Layup variations
- Temperature variations
- humidity effects
- Finite Element analysis - deflection
    - temperature
    - weights
    - out-of-round
- Finite Element Analysis- Forces
    - module hold down forces
    - temerature variations



Design of the spaceframe.



Design driven by requirements of minimum radiation length and maximum stiffness and torsional rigidity.
Carbon Fiber Composite Structure

Engineering Studies on Spaceframe and tracker support

Westinghouse Science and Technology Center

- Materials variations- CTE
- Materials variation- Moisture
- Finite Element analysis - Deflections
    - module weight
    - cabie weight
    - Silicon detector weight
    - differental temperature
- Finite Element analysis- Forces
    - temperature variations
    - Tracker mounting

Case #	Type	Material Properties • Spaceframe	• Cylinders	Deflections Microns Radial	Microns Axial	Forces Lb./In. Radial	Lb./In. Axial
	Gravity						
1	Vertical	5 High-Modulus	5 High-Modulus	98.7	N/A	N/A	+/-2.6
2	Vertical	4 Low-Modulus	4 Low-Modulus	151.8	N/A	N/A	+/-2.6
3	Vertical	10 Mean-Modulus	10 Mean-Modulus	116.5	N/A	N/A	+/-2.6
4	With Silicon	10 Mean-Modulus	10 Mean-Modulus	145.5	N/A	N/A	+/-3.2
	Thermal						
5	Radial	3 High-CTE	8 Low-CTE	-15.2	+14.4	+2.2	0.0
6	Axial	3 High-CTE	6 Low-CTE	-3.2	+41.4	-0.3	-0.5
7	Radial	6 Low-CTE	1 High-CTE	+11.1	+21.4	-1.0	0.0
8	Axial	6 Low-CTE	3 High-CTE	-5.9	-17.5	+0.7	0.0
	Humidity						
9	50%	10 Mean-Modulus	10 Mean-Modulus	+33.5	-81.9	-3.8	+0.9
10	25%	10 Mean-Modulus	10 Mean-Modulus	+16.8	-40.9	-1.9	+0.5

Outer Tracker Assembly Sequence

module assembly

3 locations (Indiana, Colorado, Duke)
testing and calibration
ship to SSCL

Cylinder
Manufacture Cylinder
machine Shim Rings
ship to SSCI

Spaceframe
Manufacture Spaceframes
Machine end structures
ship to SSCI

Assembly at SSCL

Mount cylinders on Spaceframe
Attach modules
Attach electronics
map module positions

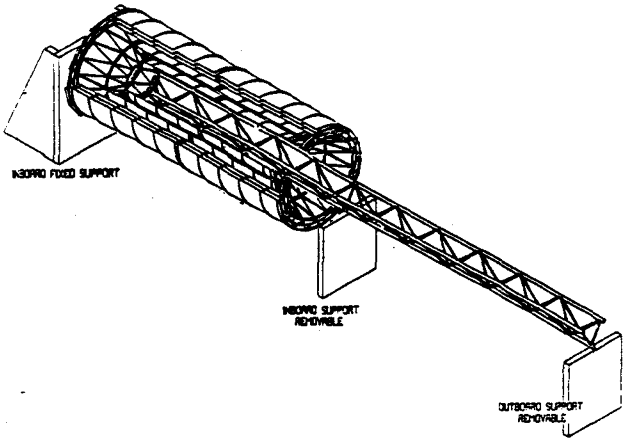


Fig. VI.22. Completed tracking cylinders on assembly fixture.

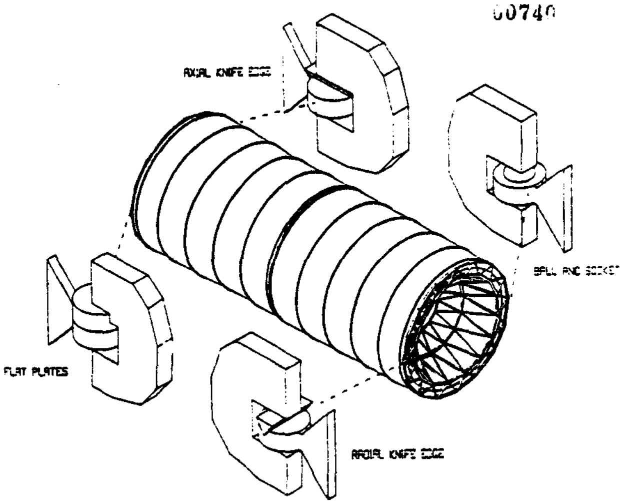


Fig. VI.23. A schematic of the central tracking mounting.

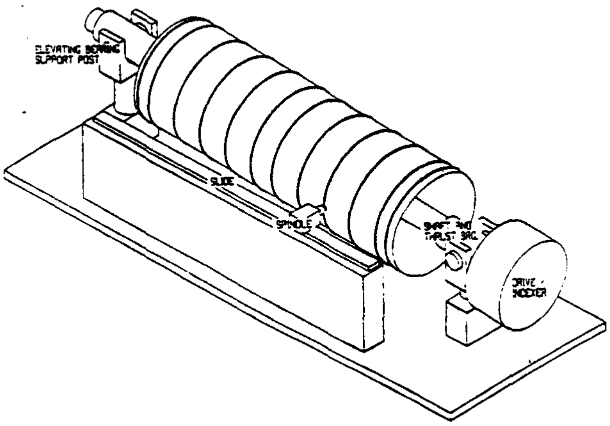


Fig. VI.12. Machining of the shim rings on a completed cylinder.

00742

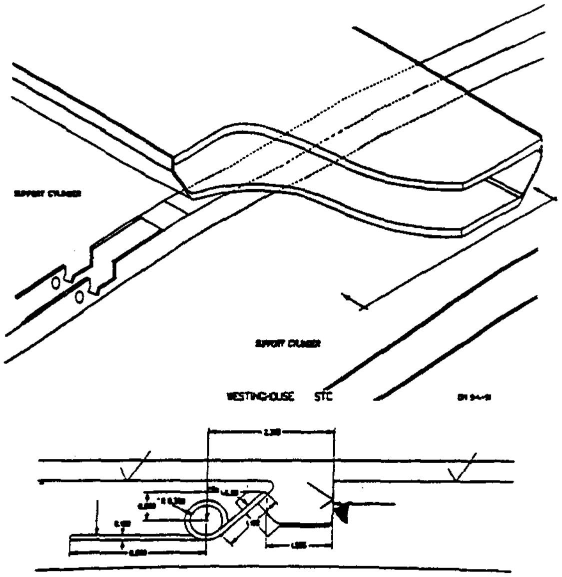


Fig. VI.18. Conceptual design of module and shim ring attachment.

SDC
Program Advisory Committee Meeting
May 5, 1992

0074

Engineering Organization
for Modular Straw Outer Tracker

Engineering on Cylinder and Spaceframe

Westinghouse Science and Technology Center

R. Swensrud
Working group WSTC and ORNL

Engineering on Utilities, facilities

Oak Ridge National Laboratory

D. Davis
Working group ORNL and WSTC

Module Design

Indiana University
Duke University- Alignment
Westinghouse

Electronics Interfacing

Oak Ridge National Laboratory
University of Colorado
Univeristy of Pennsylvania
KEK

00744

Engineering R&D

Develop the spaceframe support design	Sept 92
build and test strut and joint prototypes	Aug 92
Develop cylinder engineering	Sept 92
build and test flat prototype	May 92
build and test small cylinder	Sept 92
Develop layout for trigger and stereo modules	April 92
Develop shim rings	Sept 92
build and test prototype	June 92
Develop module attachment	Sept 92
build and test attachment prototype	July 92
Develop tracker support	Sept 92
design support fixtures	May 92
build and test model	July 92
design silicon mount	July 92
Develop stability test program temp, moisture	July 92
Develop assembly concepts	Sept 92
Develop alignment requirements	Sept 92
Develop alignment techniques	Sept 92
Carry out structural analysis on structure	Sept 92
Design support structure for multilayer beam test	Sept 92
Build multilayer structure	Jan 93
Develop the Outer tracker Utilities	Sept. 92
Design the electronics distribution	July 92
Design the electronics cooling	Aug 92
Design the gas distribution and recovery systems	Sept 92
Design the tracker diagnostic instrumentation	Sept 92
Develop the Outer tracker surface faculties	April 93

Computer Simulation

Determine final configuration of outer tracking system	May 92
Establish performance of combined tracking system	Feb. 93

00745

STRAW-TUBE ELECTRONICS

H.H. WILLIAMS

Electronics for
SDC Straw Tube Tracker

H. H. Williams
University of Pennsylvania

for

SDC Collaboration

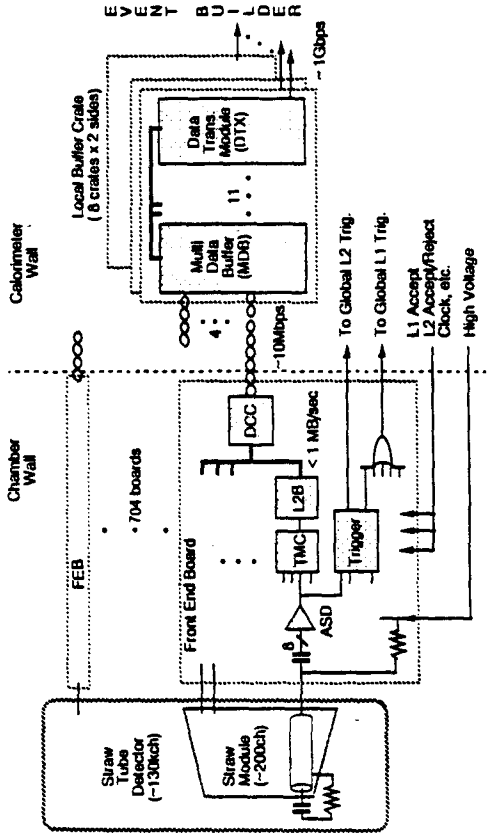
PAC Review
May 5, 1992

Straw Tube Electronics

- Design Requirements
- Straw Modeling
- Amplifier/Shaper/Discriminator
- Time Measurement - TMC
- Radiation Hardness
- Data Collection - DCC
- Mounting & Interface with Chamber

Straw Tube Electronics - Design Requirements

Minimum Detectable Charge	1 fC
Time Resolution	0.75 ns
Double Pulse Resolution	20 - 30 ns
Power Dissipation	25 - 35 mW
Radiation Hard > 1 MRad, > $10^{**}14$ n/cm^2	



Straw Electronics Overview

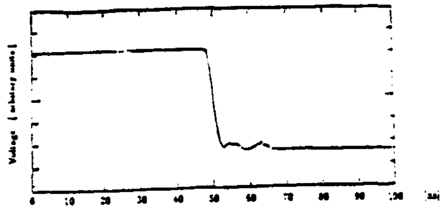


Figure 3: Measurement of step response at output of 1291 mm straw.

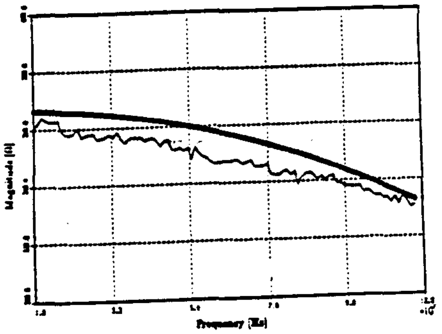
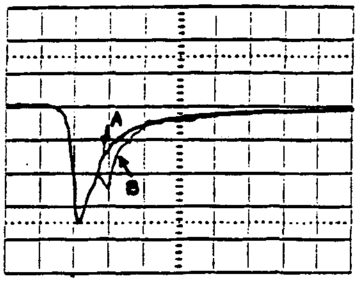


Figure 4: Comparison between measured and simulated (heavy line) input impedance (magnitude) for 429 mm straw with high cathode resistance and 50 μm anode diameter when terminated correctly.

Current Signal from Straw Tube-Effect of Termination

HV 1900V
50 ohm at scope

A: with 300 ohm terminator
B: without terminator



20ns/div
0.5 mV/div

Amplifier/Shaper/Discriminator Design

Preamplifier

* Circuit	Common emitter input cascoded, differential
* Gain	2.5 mV/fC
* Bandwidth	100 MHz
* Input Imp.	115 ohms
* Power	< 4 mW

Shaper/Tail Cancellation

* Circuit	pole-zero cancel (preamp) 3 differential pairs detect. tail cancellation
* Peaking time	6-7 ns
* Double pulse Res.	25ns for 2% to 2%
* DC gain	6
* Power Dissipation	< 4 mW

Amplifier/Shaper/Discrminator (cont)

Discriminator

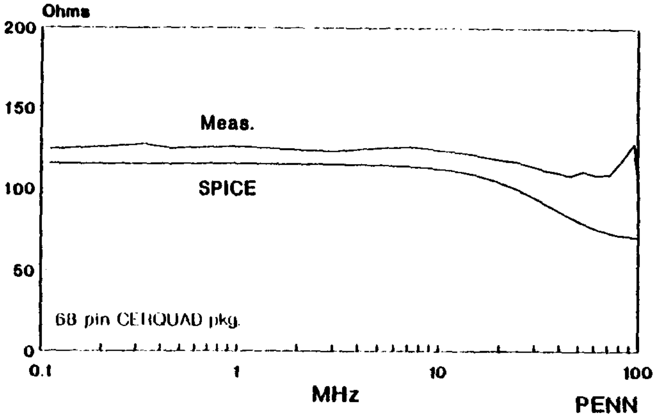
* Circuit	2 stage differential amp, positive feedback, 3 mV hysteresis
* Threshold	20 mV/fC (internal), separate for each channel
* Threshold offset	< 1 mV
* Time Slew	< 1ns /decade of overdrive
* Power	8 mW (excluding drive)
* Output	differential, open collector current programmable

Implementation

* AT&T single channel amp/shaper (exists)

* Tektronix, full ASD (exists)

Measured Input Impedance
ASD-8



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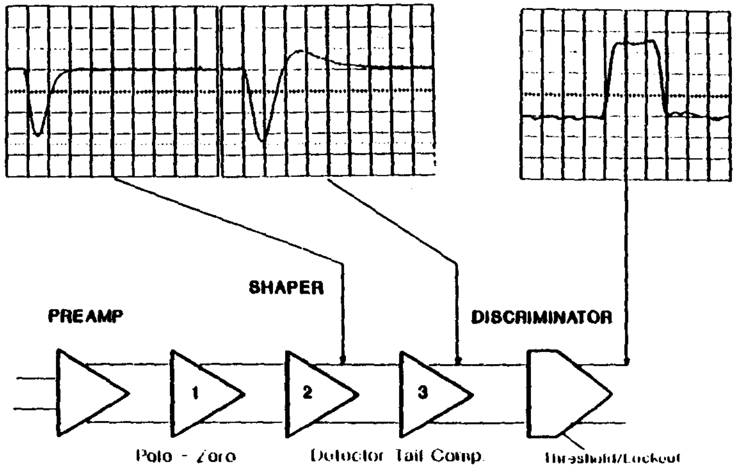
STRAW TUBE ASD



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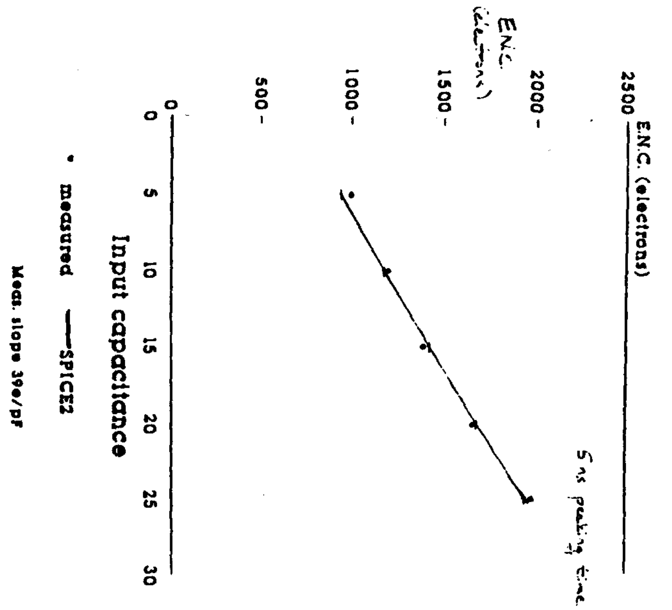
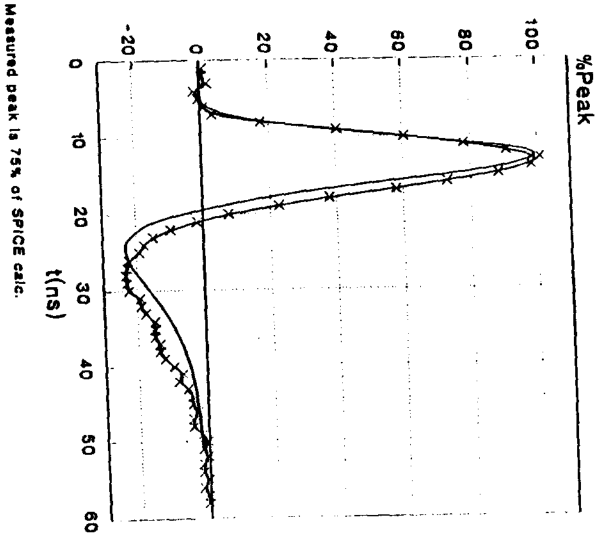
ATT Preamp Noise



00757

ASD-8
Impulse Response at Disc Input
SPICE..vs..Measured



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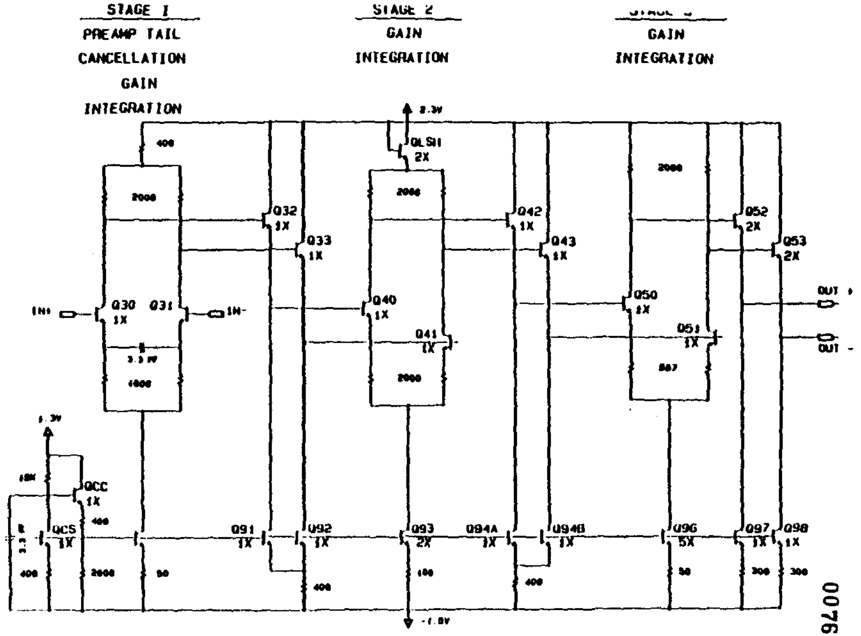

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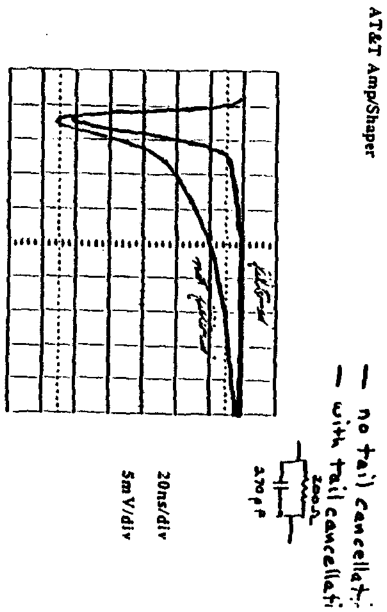
Signal from Straw Tube-
Effect of Tail Cancellation



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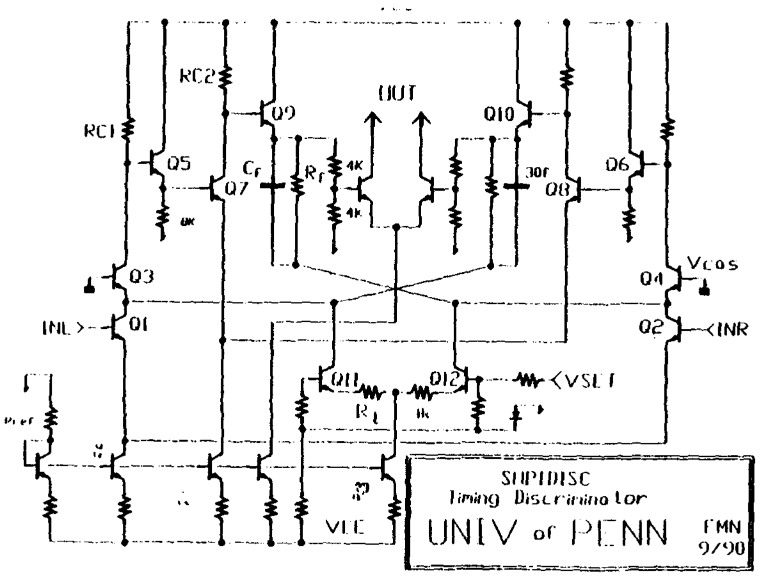

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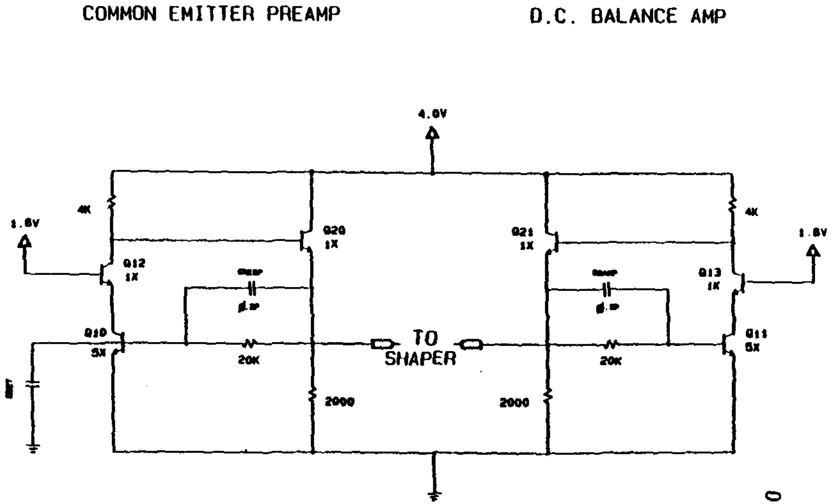

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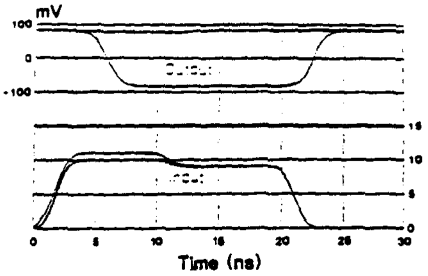
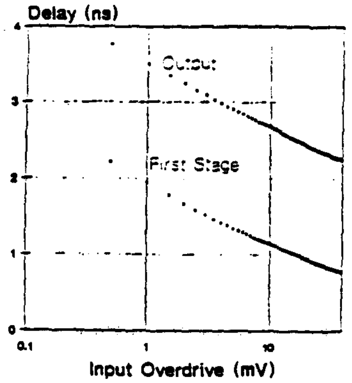
Discriminator Hysteresis
Input and Calculated Output Response



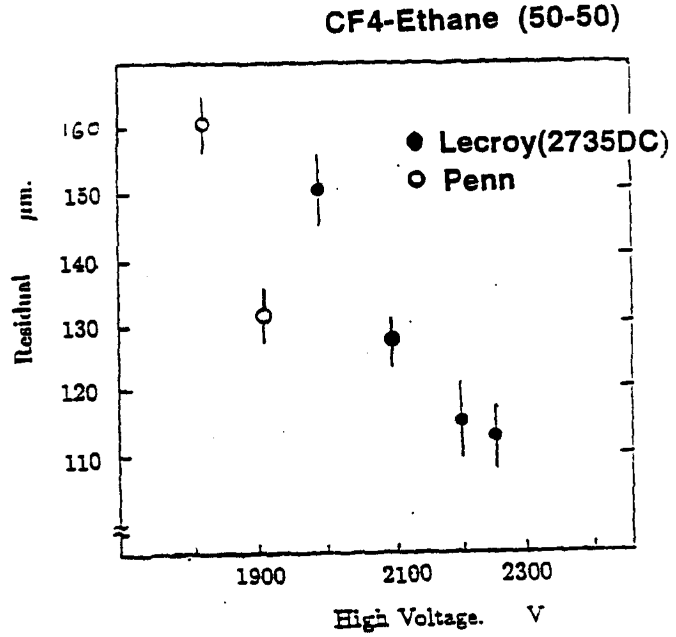
Calculated using Shpi models

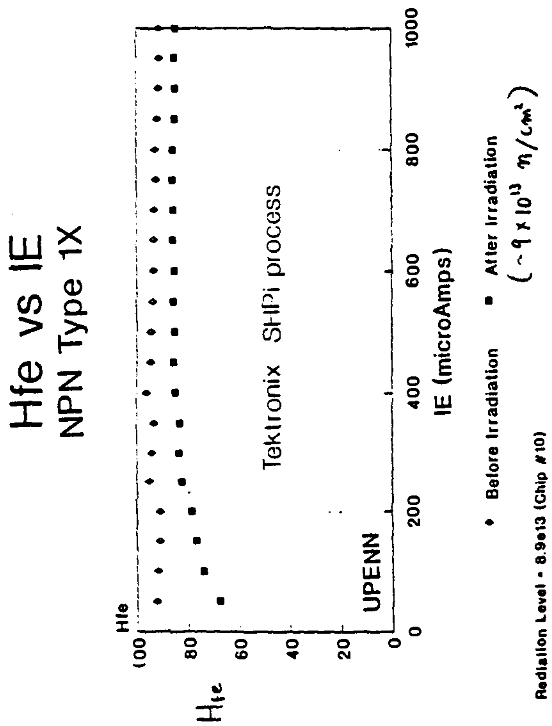
Overdrive ..vs.. Delay
Shpi Process Threshold 10mV



ASD - Summary of Measurements

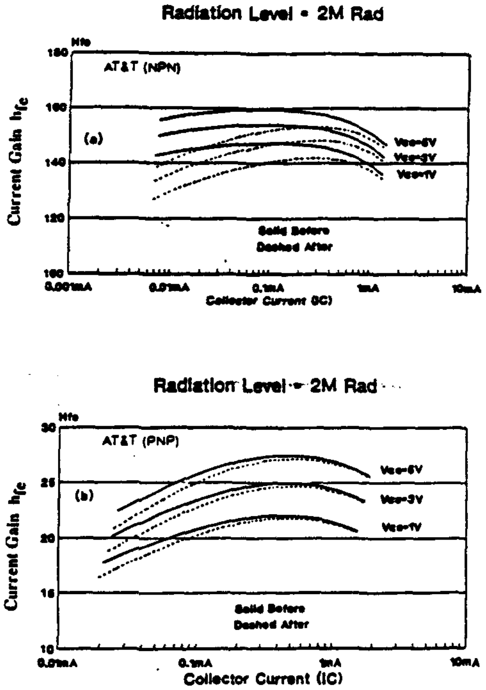
* Gain	75% of expected value, uniform chip to chip, channel to ch. (few %)
* Peaking time	7ns observed, 6 ns expected
* Threshold Var.	< 0.5 fC ch. to ch. < 1 fC chip to chip
* Input impedance	125 +/- 10 ohms meas. 110 ohms expected
* Crosstalk	Noue observed for < 10fC with threshold at 0.5 fC
* Threshold Temp Var.	< 0.2 fC for 40 C
* Time Walk	4.5 ns for 1 - 15 fC (in agreement with SPICE)
* Yield	80% of chips





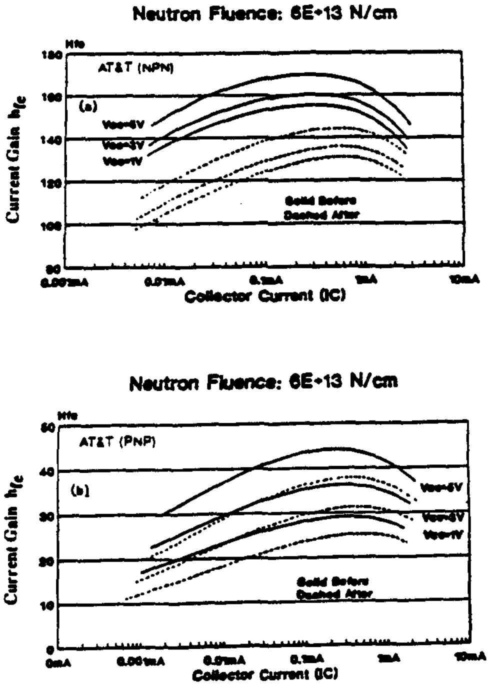
Effect of Co^{60} Radiation on Current Gain

00766

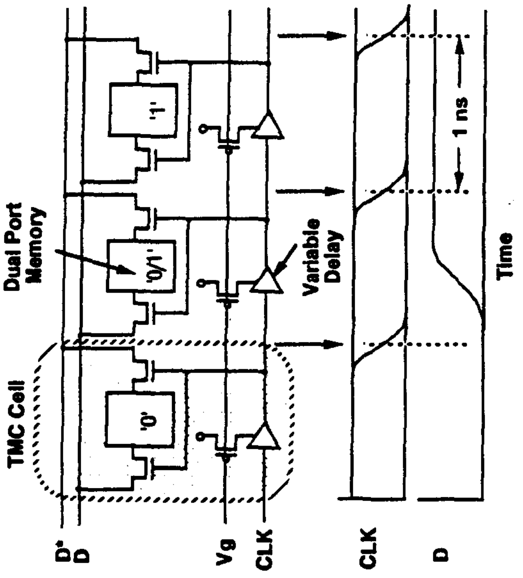


Effect of n Radiation on Current Gain

00767

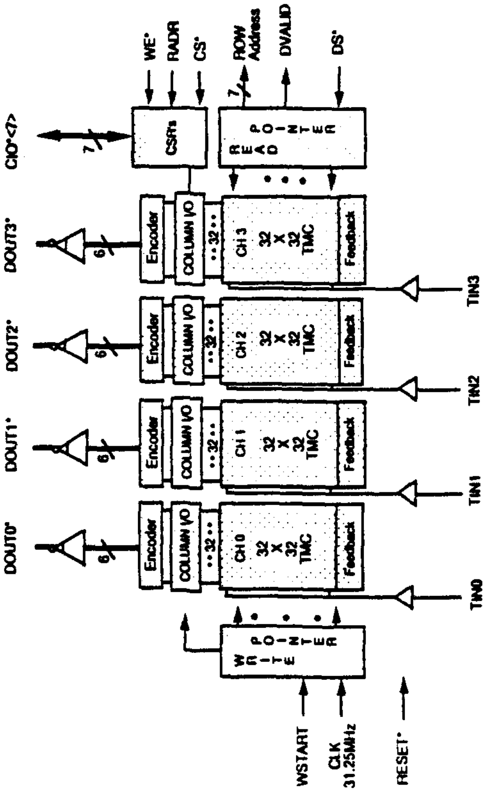


00768

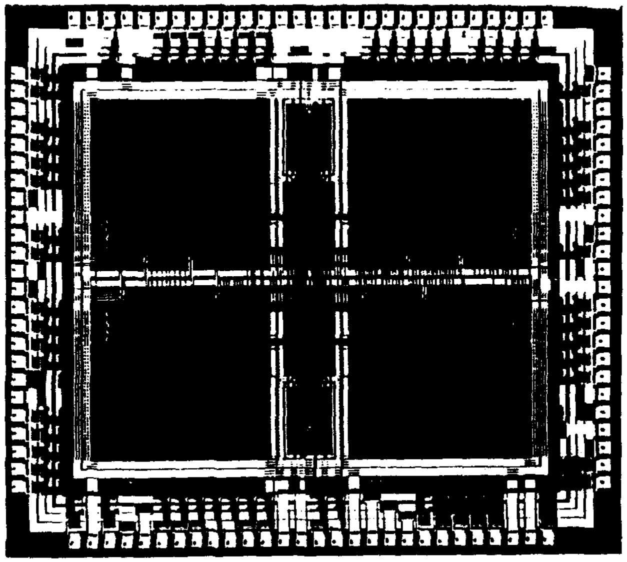


Basic Operation of Time Memory Cell (TMC)

00769



TMC1004 Block Diagram



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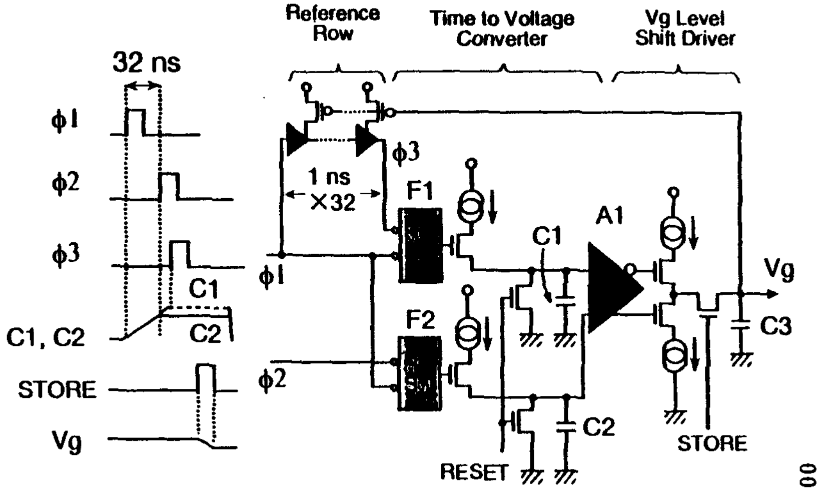
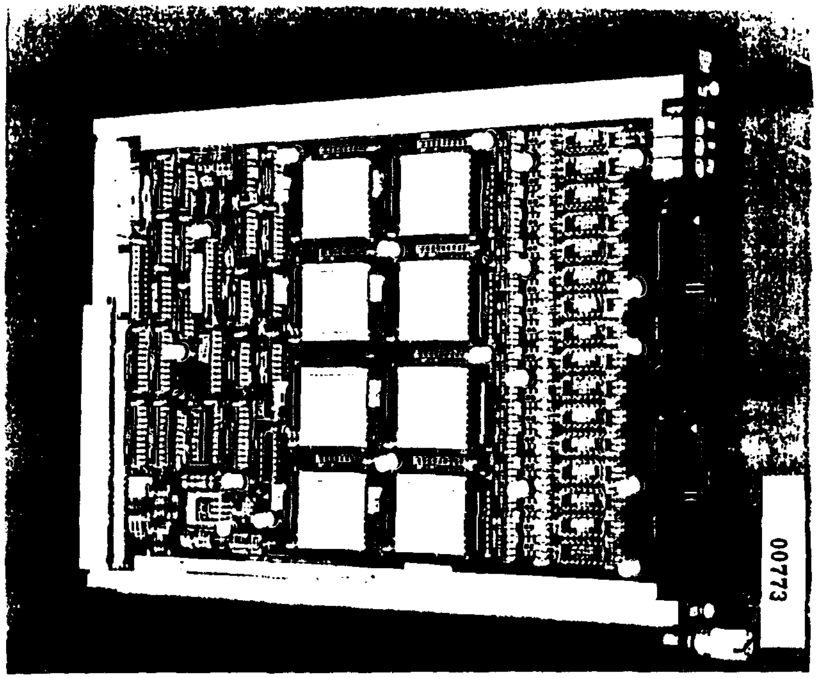
Delay time of a gate is depend on voltage, temp., process

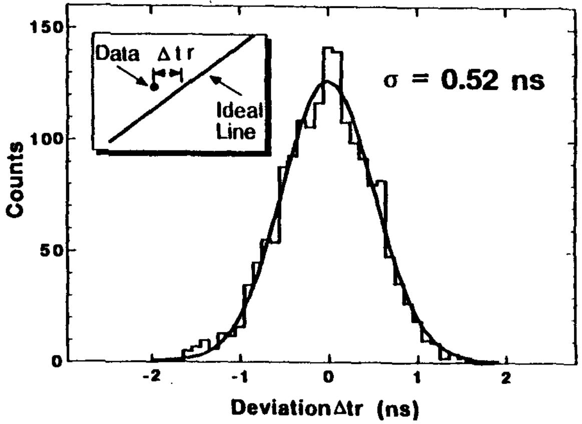
==> Feedback Circuit (Reffer to external clock)



00770



TMC Timing Resolution



00771

Features on Toshiba Rad-Hard Technology

Process

- 1 μm CMOS, Twin-Well Process.
- Radiation Hard up to 1 Mrad(Si).
- Low Temperature Process (< 900 °C).
- Thin Gate Oxide (150 Å), Epitaxial Wafer (5 μm).
- Guard Band Structured MOS FET.

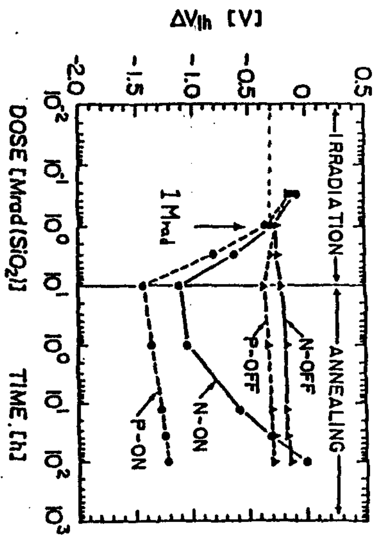
Gate Array

- Sea-of-Gate (≤ 172 k gates. TMC1004 ~ 25 k gates).
- Compatible with Industry TC140G Series.
- Tpd = 0.4 ns.

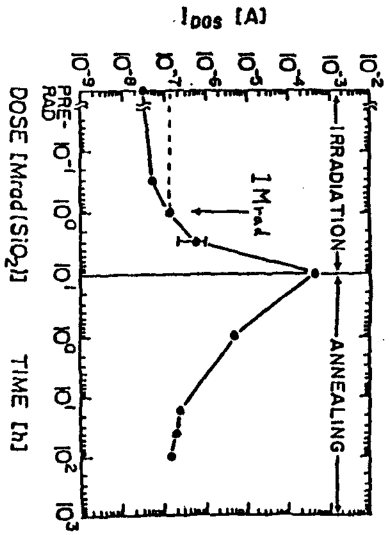
TMC1004 Specifications

• Technology :	0.8 μm CMOS, Single poly, Double Metal
• Channels x Range :	4 channel x 1 μs
• Least Time Count :	1 ns/bit
• Timing Resolution :	σ = 0.52 ns
• Variation of Slope :	< 0.1 % (2.6 - 3.4 V) < 0.1 % (15 - 55 °C)
• Power Consumption:	7 mW/ch (@ 100 kHz L1 Trigger)
• Chip Size :	5.0 mm x 5.6 mm

Threshold Voltage Shift



Standby Current



Radiation Hardness

Frontend electronics of straw experience ~ 100 krad(Si) and 10^{13} neutrons over a 10 year period at 10^{33} luminosity.

⇒ Radiation-Hardness up to 1 Mrad(Si) and 10^{14} neutrons.

- Fast Bipolar : Intrinsically radiation hard for γ and n.
  (AT&T, NTT SST, Tektronix SHPi ...)
- CMOS : Intrinsically radiation hard for neutron.
  Thin gate oxide → Small threshold voltage variation.

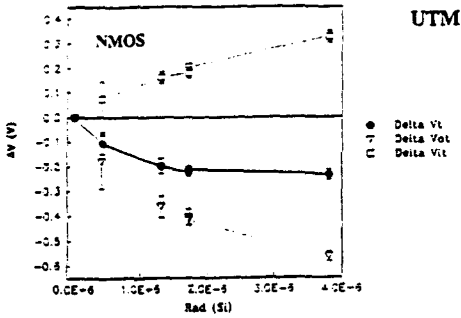
However, thick field oxide cause large leakage current.

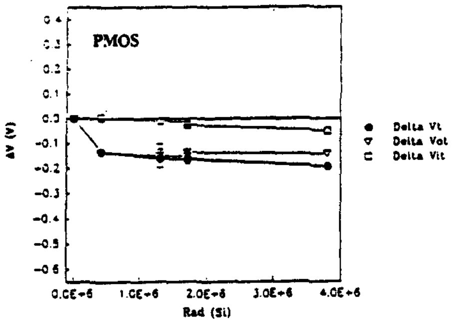
⇒ Need Radiation-hard CMOS process.

- Toshiba 1.0 μm Rad-Hard CMOS Sea-of-Gate.
- (• UTMC 1.2 μm Rad-Hard CMOS.)

Threshold Voltage Shift with Radiation

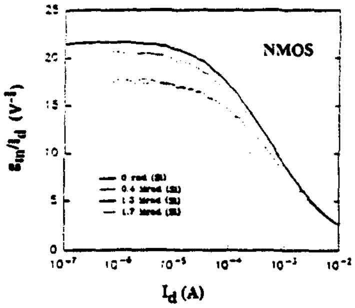
UTMC Process

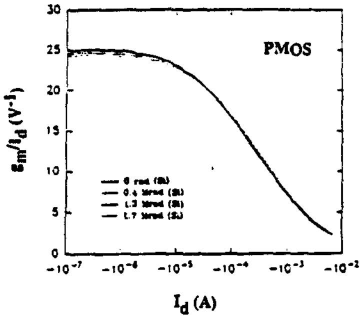




Effect of Radiation on Transconductance

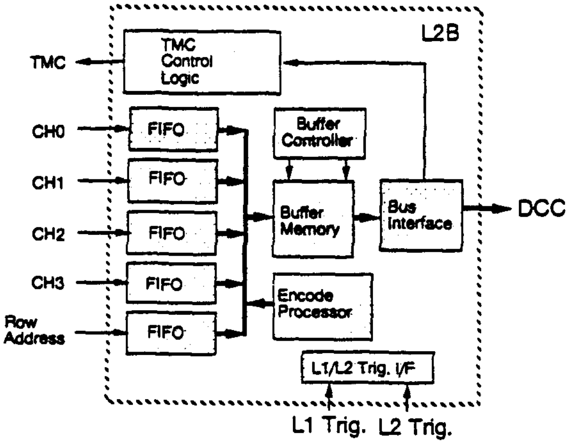
UTMC Process



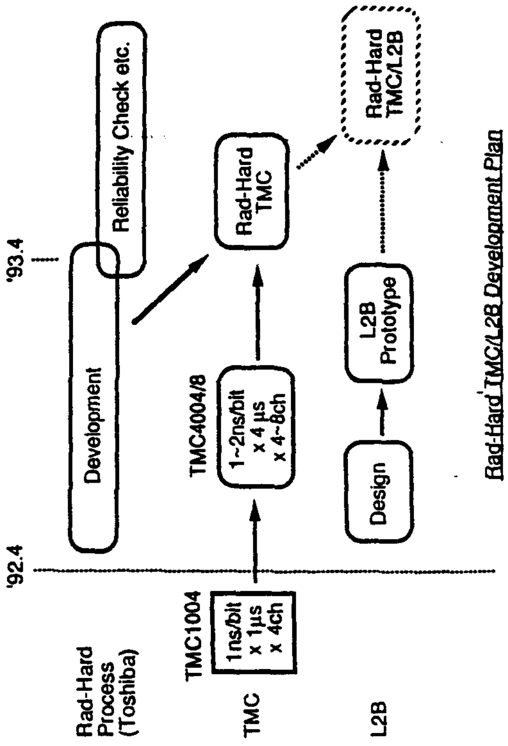


Level 2 Buffer

- Receive TMC output when L1 accept is asserted.
- Encode/Format Input Data.
- Buffer the data for L2 decision time (~ 50 µs).
- Transmit data to DCC.
- Combined with TMC if possible.



Rad-Hard TMC/L2B Development Plan



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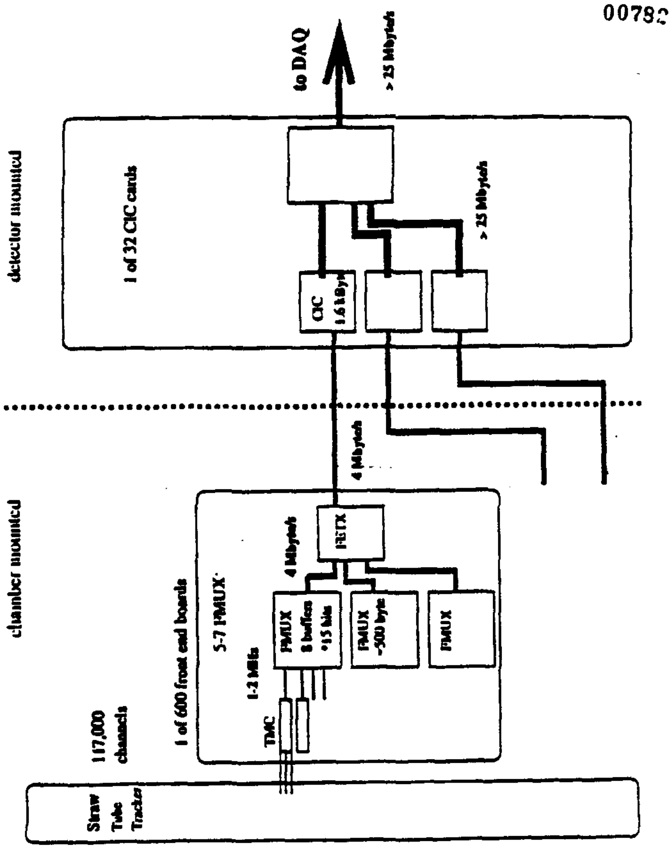

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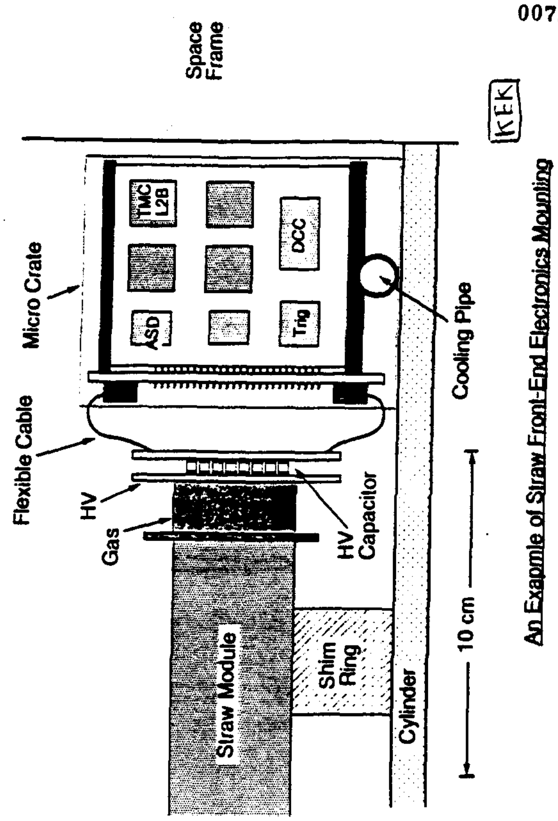
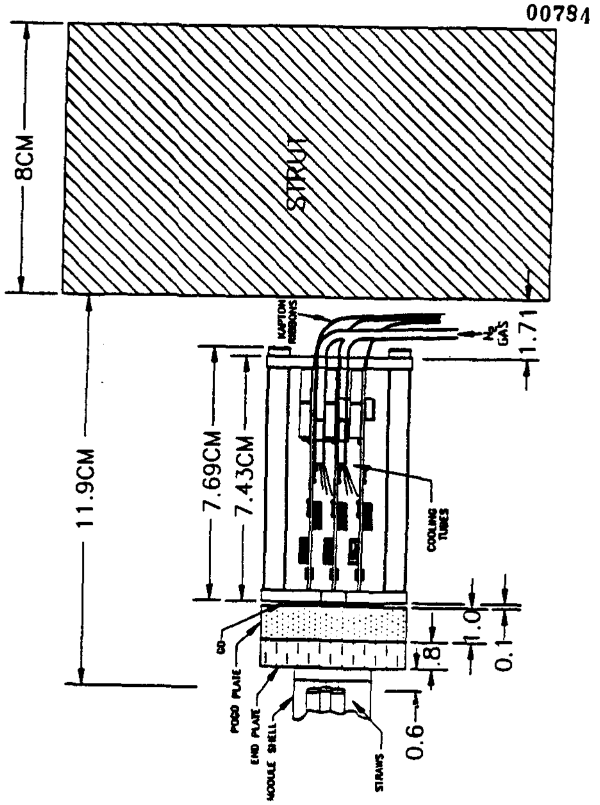


An Exapmle of Straw Front-End Electronics Mounting

00784



Summary

00785

- Understand Straw Signals
- Amp/Shaper/Disc satisfies specifications
- TMC provides full capability for time meas.
- L2B chip under design
- DCC - block schematic & high level simul.
- Radiation Hardness not a problem
- Primary emphasis now on
  - full system test
  - substrate & mounting
  - cooling

GAS MICROSTRIP INTERMEDIATE TRACKER SUMMARY

M. EDWARDS

Edwards

GAS MICROSTRIP
DETECTOR

INTERMEDIATE ANGLE TRACK
DETECTOR

UNIVERSITY OF BRISTOL	(UK)
CARLETON UNIVERSITY	(CA)
CRPP	(CA)
LIVERPOOL UNIVERSITY	(UK)
UNIVERSITE DE MONTREAL	(CA)
OXFORD UNIVERSITY	(UK)
PURDUE UNIVERSITY	(US)
UNIVERSITY OF ROCHESTER	(US)
RUTHERFORD APPLETON LABORATORY	(UK)
TEXAS A&M UNIVERSITY	(US)
TRIUMF	(CA)

11 INSTITUTES

37 PHYSICISTS AND ENGINEERS

PURPOSE OF ITD

REQUIREMENTS OF ITD

BRIEF DESCRIPTION OF GMD

PROPOSED LAYOUT OF ITD

LAYOUT AND REQUIREMENTS

SIMULATION RESULTS

FRONT END ELECTRONICS

MECHANICAL ASSEMBLY

ALIGNMENT

UTILITIES

PURPOSE

EXTEND COVERAGE OF OTD

1) LEVEL 1 TRIGGER ON HIGH P_t

2) MOMENTUM RESOLUTION

3) PATTERN RECOGNITION

4) TRACK PROJECTION INTO CALORIMETER

5) ASSIST MUON SYSTEM

ITD TRACK MEASUREMENT

- FIXED Z LAYERS

  MEASURE $r\phi$ AND $r \rightarrow \phi$ AND r

- IN SOLENOID FIELD

  $\phi = \phi_0 + {}^{eB}/_{2p_z} . z$

  SO MEASURE $^1/_{p_z} = {}^2/_{eB}\, {}^{\Delta\phi}/_{\Delta z}$

  $r = {}^{2p_t}/_{eB} \sin ({}^{eB}/_{2p_z} . z) \sim {}^{p_t}/_{p_z} . z$

  SO MEASURE $^{p_t}/_{p_z} = {}^{\Delta r}/_{\Delta z}$

$\rightarrow \; ^1/_{p_t} = {}^2/_{eB}\, {}^{\Delta\phi}/_{\Delta z} \,/\, {}^{\Delta r}/_{\Delta z}$

cf CTD

$^1/_{p_t} = {}^2/_{eB}\, {}^{\Delta\phi}/_{\Delta r}$

REQUIREMENTS OF ITD

LEVEL 1 TRIGGER WITH SHARP P_t TURN-ON

FOR DISK BASED SYSTEM MUST MEASURE
$d\phi/dz$ ACCURATELY dR/dz LESS ACCURATELY

1) HIGH SEGMENTATION IN ϕ
2) DIVISION OF η INTO BINS.

SIMULATION SHOWS 4 BINS COVERING
$1.8 < \eta < 2.8$ SUFFICIENT.

LOW OCCUPANCY << 10%

3) HIGH GRANULARITY

CHARGED PARTICLES FROM MINIMUM BIAS
EVENTS UP TO 10^4/mm^2/SEC

4) HIGH RATE CAPABILITY

CROSSING TAGGING

5) FAST RESPONSE

AT DESIGN LUMINOSITY - ENVIRONMENT
CHARGED PARTICLES FLUX 10^{12}/cm^2/YEAR
NEUTRON FLUX 4 X 10^{11} 1/cm^2/YEAR

6) RADIATION HARDNESS

MINIMISE MULTIPLE SCATTERING AND
BREMSTRAHLUNG

7) LOW MASS

ALL CHARACTERISTICS ARE AVAILABLE OR
PROMISED BY GAS MICROSTRIP DETECTORS

OTHER TECHNOLOGIES e.g.
RADIAL WIRE DRIFT CHAMBERS
STRAWS IN RADIAL CONFIGURATION
(ETC)

LOOKED AT AND REJECTED
THEY DO NOT SATISFY REQUIREMENTS

GAS MICROSTRIP DETECTORS

BRIEF DESCRIPTION ONLY
MORE DETAIL BY GERALD OAKHAM

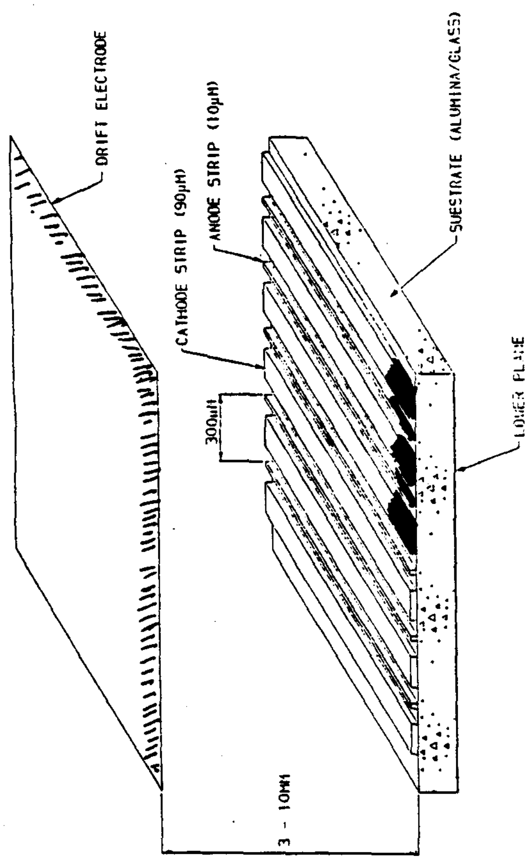
DEVELOPMENT OF MWPC'S USING
HIGH DEFINITION PHOTO-LITHOGRAPHY

"WIRES" PRINTED ONTO SEMI-INSULATING
SUBSTRATE
ALTERNATING ANODE AND CATHODE STRIPS
ANODE TO ANODE PITCH TYPICALLY 300 μm

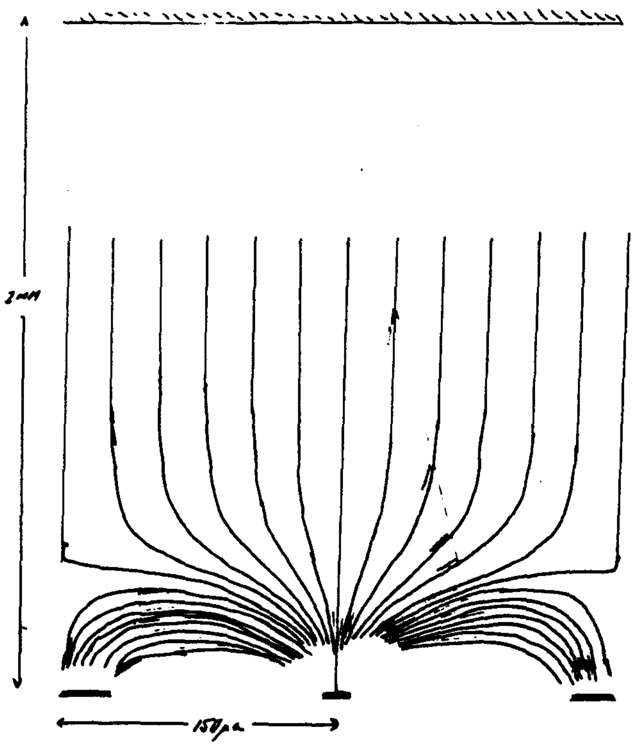
ABOVE SUBSTRATE -GAS VOLUME ≈ 3mm THICK
DRIFT ELECTRODE

REVERSE SIDE OF SUBSTRATE - BACK PLANE
ELECTRODE

IONIZATION IN GAS DRIFTS TO ANODE
GAS MULTIPLICATION $10^3 - 10^4$



TYPICAL DIMENSIONS OF THE MICROSTRIP DETECTOR



ATTRACTIVE FEATURES

1) ELECTRON DRIFT LENGTH SHORT (< 3mm)

2) MAJORITY (90%) POSITIVE IONS TO CATHODE STRIP (~ 100 µm)

3) SUBSTRATE THIN (< 300 µm)

4) NO WIRES → VARIETY OF GEOMETRIES

5) COMPARED TO SILICON
   FEWER PROCESSING STEPS
   BASE MATERIAL CHEAPER
   LARGER SIZE
   → LOWER COST/UNIT AREA

6) SIZE LIMITED BY HIGH DEFINITION PHOTO-LITHOGRAPHY
   BENEFITING FROM DEVELOPMENT OF LARGE AREA FLAT SCREEN DISPLAYS

DETECTOR ELEMENTS ARE "TILES"
ALLOWS NATURAL DIVISION IN R (η)

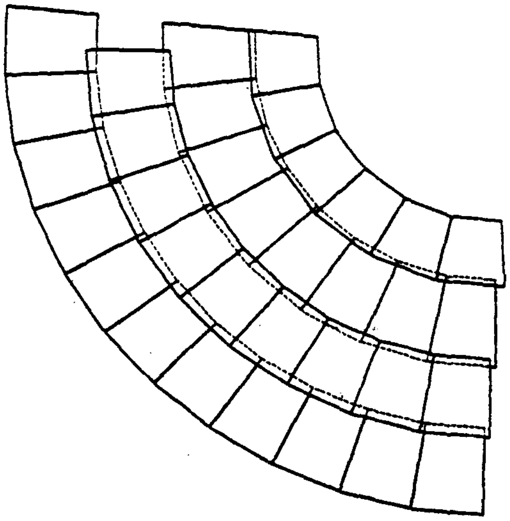
PUT TILES TOGETHER TO MAKE DISKS

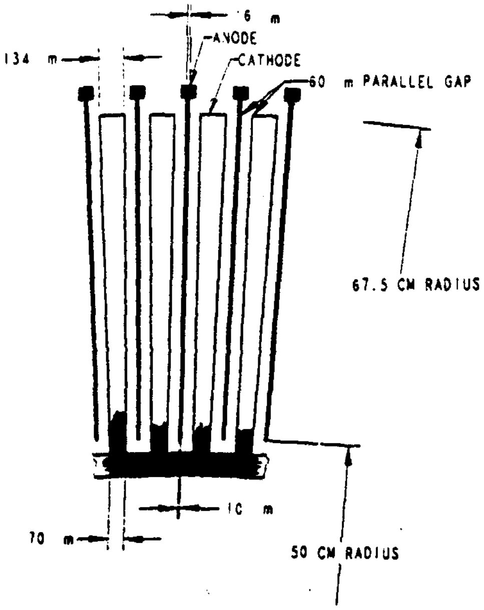
ANODES AND CATHODES ARE PRINTED
∴ CAN BE MADE TRULY RADIAL
DIRECT MEASUREMENT OF ϕ

"KEYSTONE CATHODES"

EASY TO MAKE STEREO LAYERS

PUT ALL TOGETHER ARRIVE AT
PROPOSED LAYOUT





LAYOUT

BOUNDARY WITH OTD
LONG OTD → LITTLE COST INCREASE FOR OTD
COST REDUCTION FOR ITD

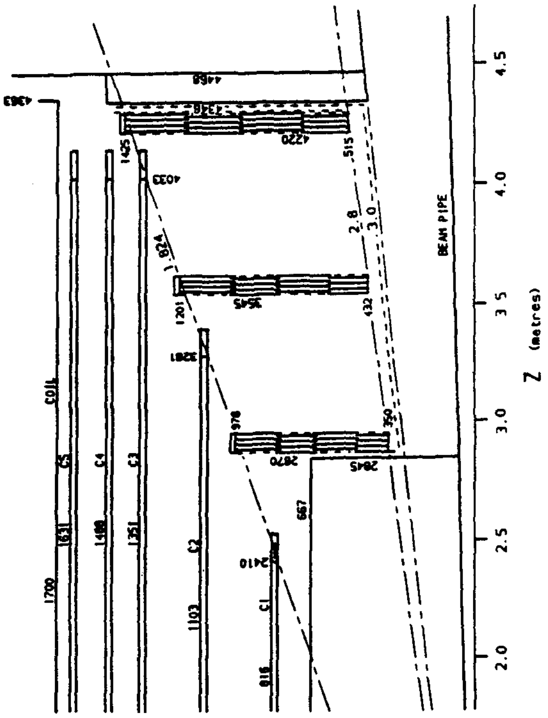
OTD ELECTRONICS OUTSIDE
TRACKING VOLUME

η BOUNDARY SET BY LENGTH OF OTD
SUPERLAYER 3 (TRIGGER)
η = 1.824

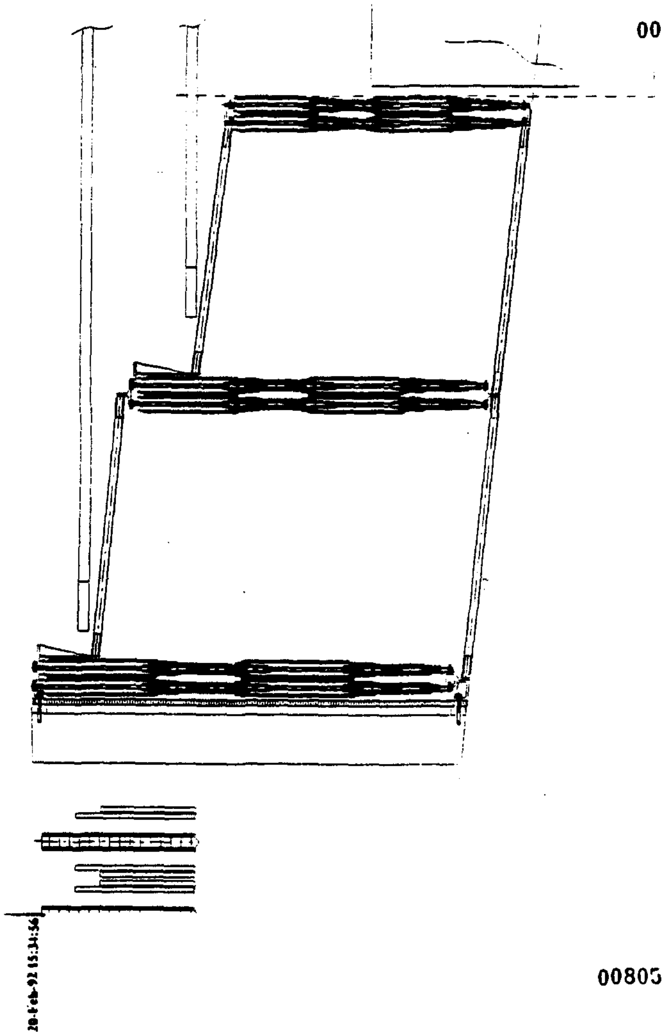
POSSIBLE FOR ITD TO MEET η = 1.824
ONLY IF SUPPORT FOR ITD ON
INNER CIRCUMFERENCE

INNER BOUNDARY OF ITD SET BY
USEFUL COVERAGE OF END CAP CALORIMETER
η = 2.8

Fig 5. Intermediate Tracking Detector

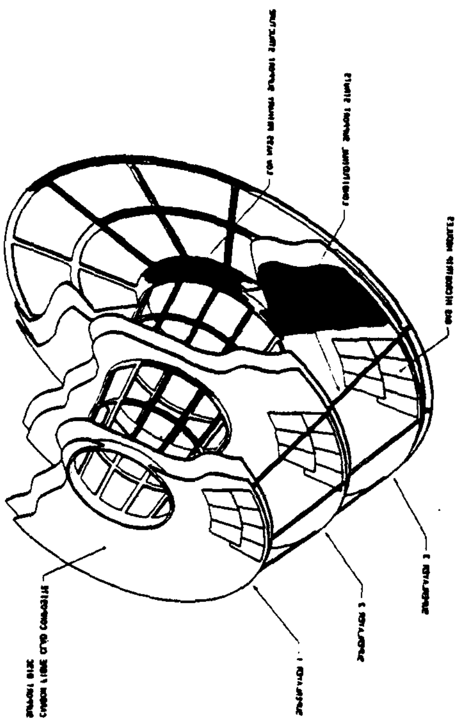


00803



00804

Fig 60. Tile support cone



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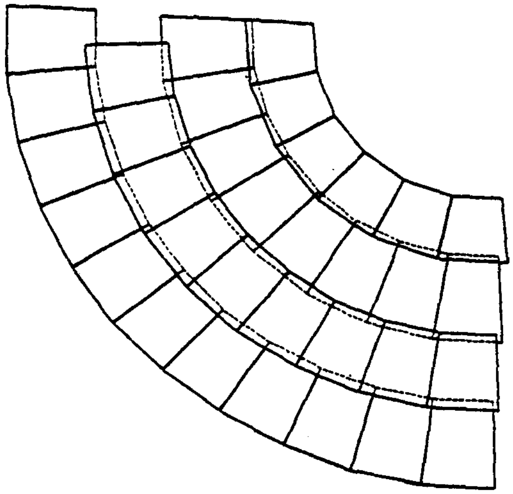


00806

SUPERLAYERS

3 SUPERLAYERS → LEVEL 1 TRIGGER RATES

IF 2 SUPERLAYERS MIN BIAS ACCIDENTAL
RATE = 4/CROSSING
WITH 3 SUPERLAYERS = 1/14 CROSSINGS.

3rd SUPERLAYER USED AS CONFIRMATION

EACH SUPERLAYER 4 "INDEPENDENT" RINGS
WITH COMMON SUPPORT STRUCTURE
RINGS PROJECT TO INTERACTION POINT
RINGS OVERLAP IN η → NO CRACKS

RINGS HAVE SAME NUMBER OF ANODES
IN EACH SUPERLAYER

∴ FULL PROJECTIVITY

LAYERS/SUPERLAYER

REQUIRE TRIGGER TO BE VERY EFFICIENT

EACH LAYER HAS CRACKS IN ϕ
DETECTOR WILL NOT BE 100% EFFICIENT

USE "OR" OF 2 RADIAL LAYERS IN SUPERLAYER

ALL OTHER REQUIREMENTS OF ITD NEED MORE ACCURATE MEASUREMENT OF θ

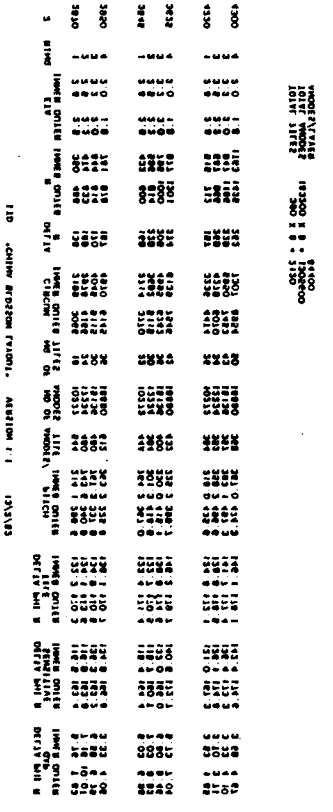
$\therefore$ SMALL ANGLE STEREO LAYERS U AND V

ITD SUMMARY

3 SUPERLAYERS/END
4 LAYERS/SUPERLAYER
$1.824 < \eta < 2.8$

SUPERLAYER	RING	η	TILES	ANODES
	1	2.8-2.5	18	10272
	2	2.5-2.2	24	12224
1	3	2.2-2.0	30	15136
	4	2.0-1.8	36	18880
	1	2.8-2.5	22	10272
	2	2.5-2.2	30	12224
2	3	2.2-2.0	36	15136
	4	2.0-1.8	42	18880
	1	2.8-2.5	26	10272
	2	2.5-2.2	34	12224
3	3	2.2-2.0	42	15136
	4	2.0-1.8	50	18880

TOTAL 3120 TILES
1.3×10^6 ANODES
(3.3×10^5 TRIGGER/END)



ITD *CHINA BLOSSOM LAYOUT* VERSION 1.1 13/2/83

TOTAL TILES 390 X 8 = 3120
TOTAL ANODES 163200 X 8 = 1305600

SIMULATION

SIMULATION IN FULL SDC-SHELL
(VOLUMES HAVE BEEN SORTED)
SINCE BANK STRUCTURES SAME
IT IS EASY TO COMBINE THE STS AND ITD

EXAMPLES:
LEVEL 1 TRIGGER TURN ON

TRACKS FROM H(400 GEV) $\rightarrow Z^0 \; Z^0$
$\hookrightarrow \mu^+\mu^-$
$\hookrightarrow \mu^+\mu^-$

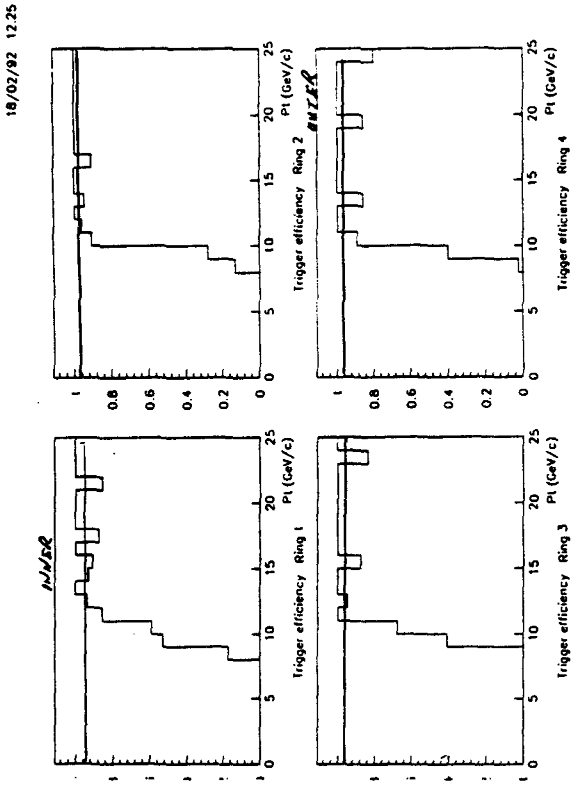
4 μ's R,θ

4 μs R,ϕ

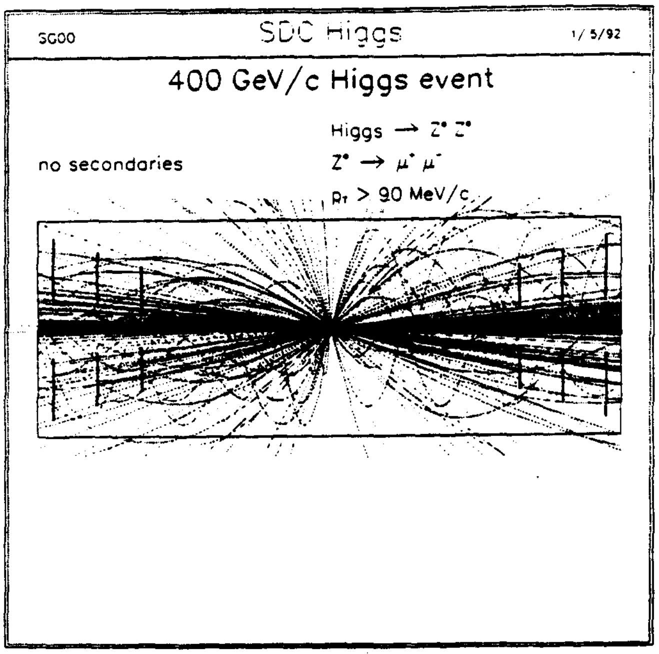
MIN LEPTON P_t V MAX LEPTON $|\eta|$

IMPROVED TRACK PROJECTION INTO CALORIMETER

00811



00812

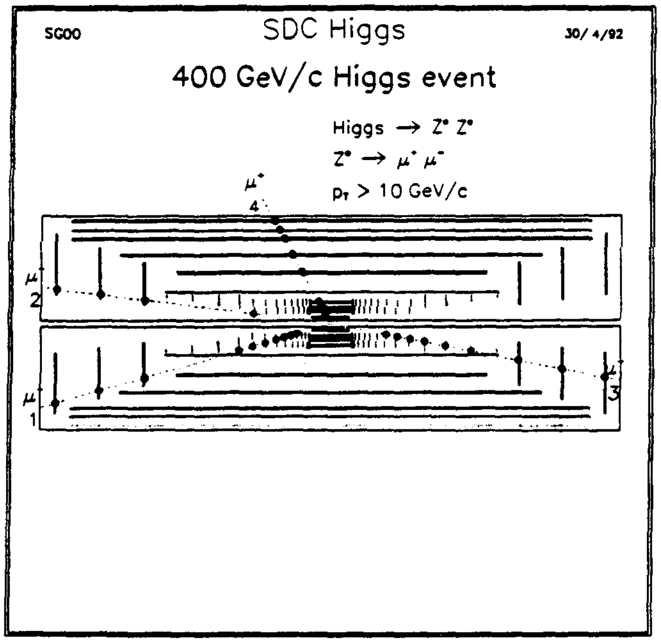

SGOO
SDC Higgs
1/5/92

400 GeV/c Higgs event

no secondaries

Higgs → $Z^\circ Z^\circ$
$Z^\circ \rightarrow \mu^+ \mu^-$
$p_T > 90$ MeV/c

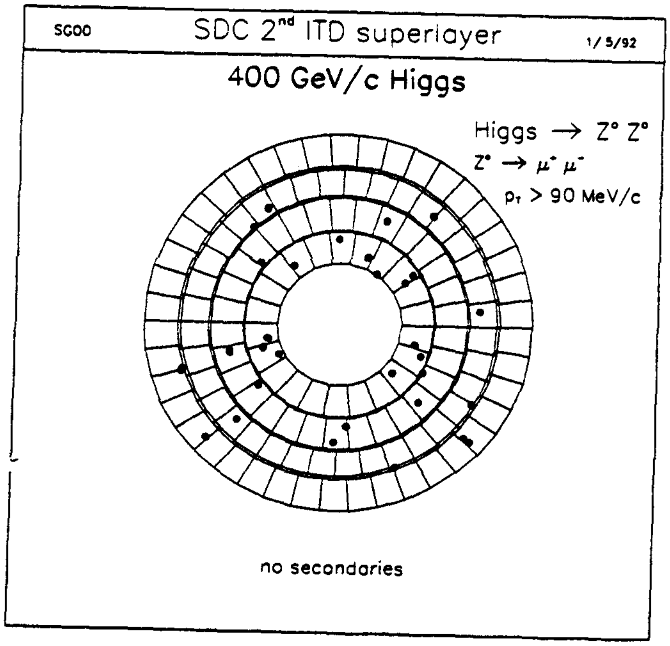
00813


SGOO
SDC Higgs
30/4/92

400 GeV/c Higgs event

Higgs → $Z^\circ Z^\circ$
$Z^\circ \rightarrow \mu^+ \mu^-$
$p_T > 10$ GeV/c

00814


SGOO
SDC 2^{nd} ITD superlayer
1/5/92

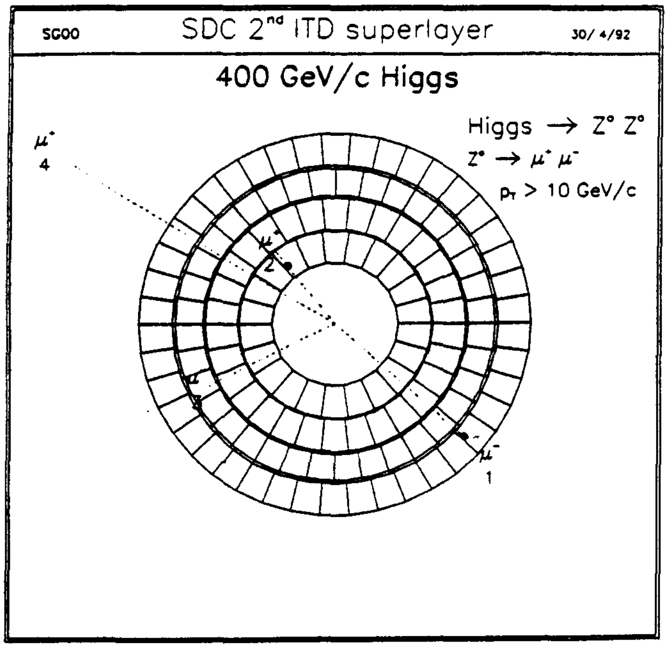
400 GeV/c Higgs

Higgs → $Z^\circ Z^\circ$
$Z^\circ \rightarrow \mu^+ \mu^-$
$p_T > 90$ MeV/c

no secondaries

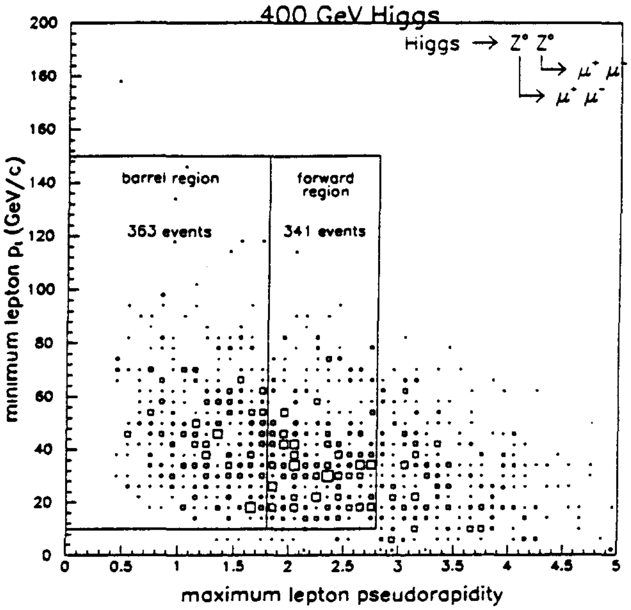
00815

PATTERN RECOGNITION



00816

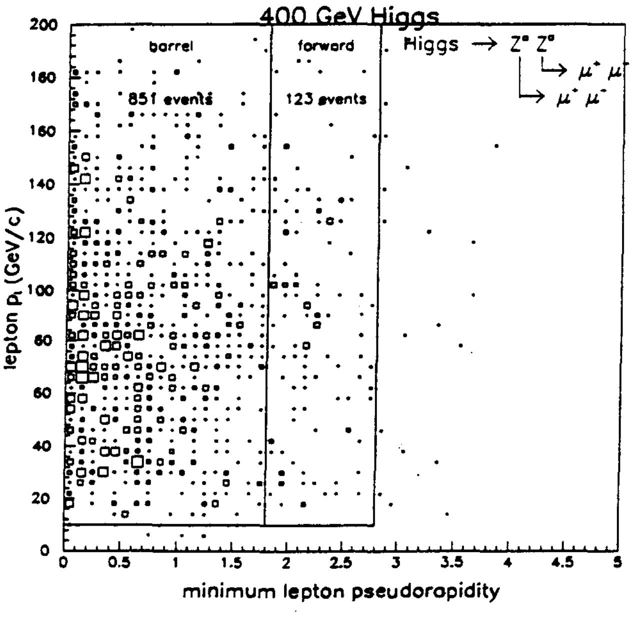
ITD CONTRIBUTION TO TRIGGER
ALL 4 LEPTONS



→ + 100% FROM ITD

00817

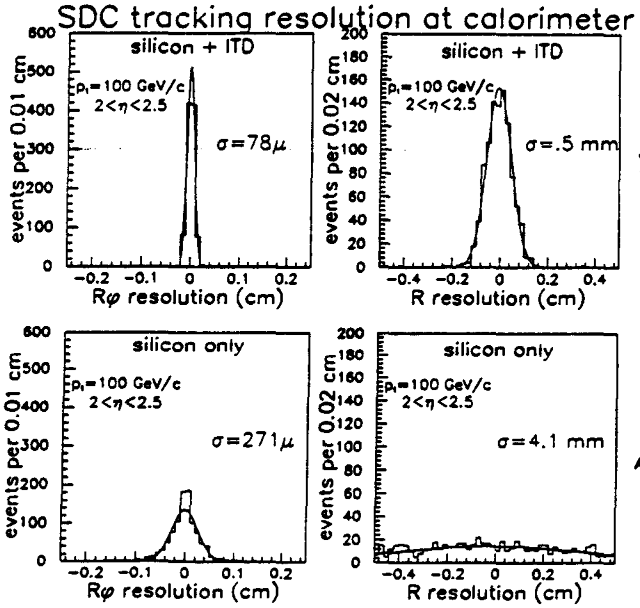
ITD CONTRIBUTION TO TRIGGER
ONLY 1 LEPTON



→ + 15% FROM ITD

00818

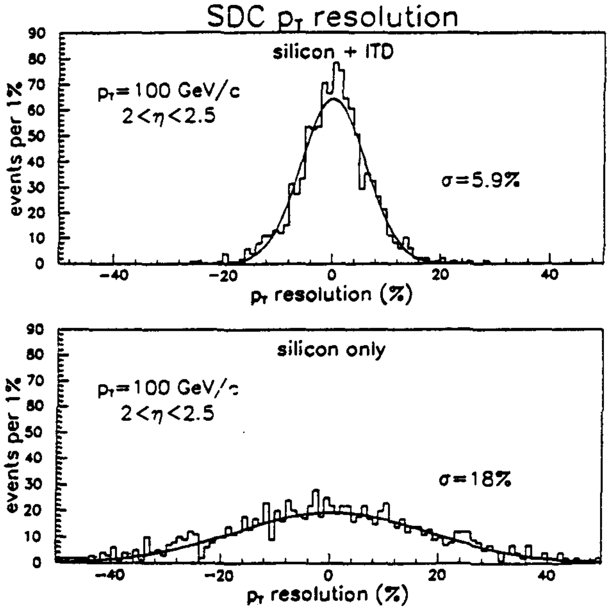
ITD CONTRIBUTION TO TRACK MATCH



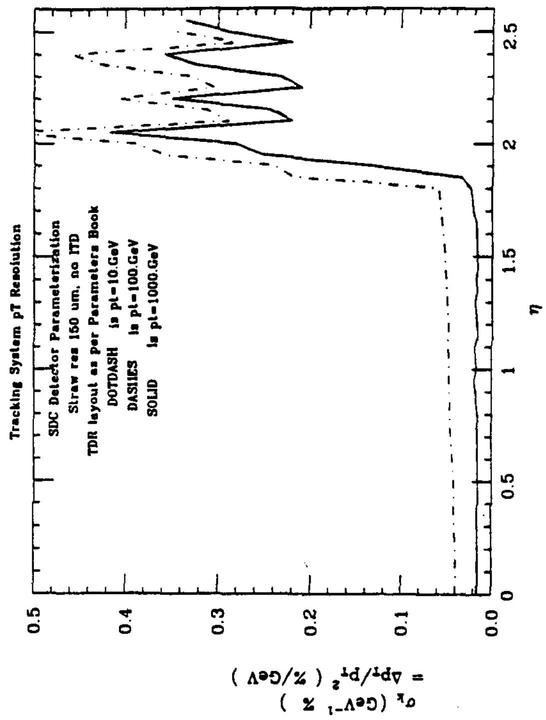
YES

NO

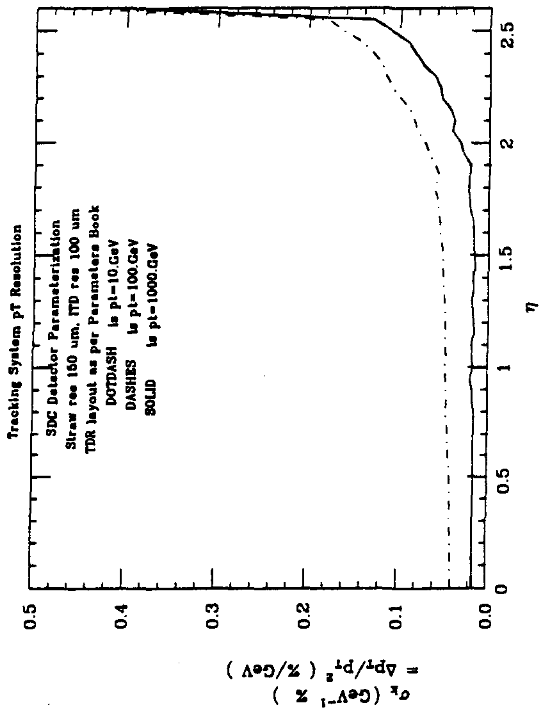
ITD CONTRIBUTION TO $\sigma p_t/p_t$



PARAMETRIC RESOLUTION ($\sigma p_t/p_t^2$) NO ITD



PARAMETRIC RESOLUTION ($\sigma p_t/p_t^2$) WITH ITD



ITD AND P_t RESOLUTION (2 < η < 2.5)

	STS	STS + ITD
$\sigma P_t/P_t$ @ 100 GeV	18%	6%

MAXIMUM P_t FOR CHARGE SIGN DETERMINATION

	# s. d.	STS	STS + ITD
P_t ≤ (GeV)	3	190	550
P_t ≤ (GeV)	2	300	830

ELECTRONICS

PREAMP DESIGN DRIVEN BY LEVEL 1 TRIGGER
REQUIREMENT - SPEED

NOISE	1000 e-
GAIN	60 mV/FC (MAY BE REDUCED)
PEAKING TIME	20 nsec
POWER	< 1mW

DATA TRANSMISSION 63.5 MHz FIBRES
(250 μm DIAMETER - 22,000/END)

LEVEL 2 TRIGGER AND DAQ VERY
SIMILAR TO STS DESIGN

MECHANICAL ASSEMBLY

GMD'S MANUFACTURED AS SELF-CONTAINED
UNITS "TILES"

EACH CONTAINS:

- SUBSTRATE - ANODE/CATHODE STRIPS
  BACK PLANE ELECTRODE

  CATHODE STRIPS IN GROUPS →

  CURRENT LIMITING RESISTOR →
  COMMON H.V. BUS

  ANODE STRIPS WIRE BONDED TO

- FRONT-END ELECTRONICS FROM WHICH

- FIBRE OPTIC CABLES CARRY DATA

- GAS ENCLOSURE

- DRIFT ELECTRODE

- CONNECTORS FOR HIGH AND LOW VOLTAGE
  GAS

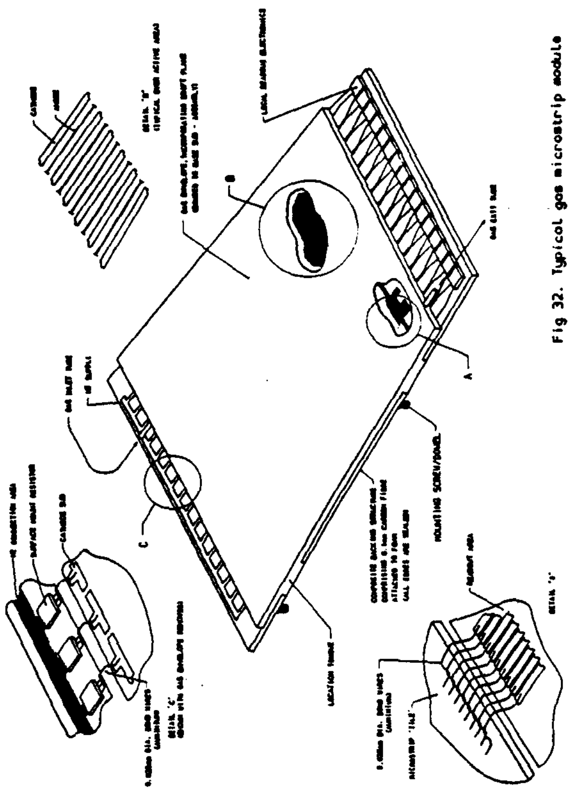


Fig 32. Typical gas microstrip module

AFTER MANUFACTURE BEFORE MOUNTING
STRINGENT TESTS FOR FUNCTIONALITY
RELIABILITY

MOUNTED BOTH SIDES OF SUPPORT DISK

6 SUPPORT DISKS (2/SUPERLAYER)
MOUNTED ON SUPPORT CONE

WHOLE DETECTOR RIGOROUSLY TESTED
BEFORE SHIPPING TO TEXAS

BUILD SCHEDULE ALLOWS TIME FOR THIS
TESTING

MATERIALS USED MAINLY CARBON FIBRE/
CYANATE - ESTER RESIN AND FOAM

BASED ON OTD AND STS STRUCTURES

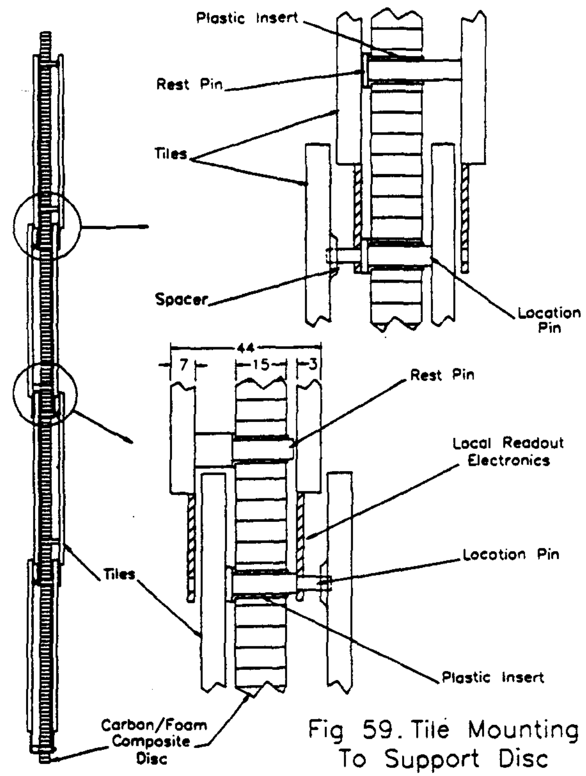


Fig 59. Tile Mounting To Support Disc

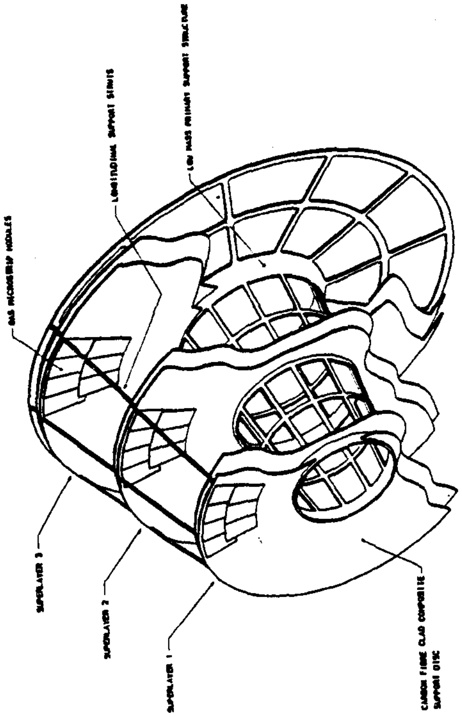


Fig 60. Tile support cone

IN BASELINE DESIGN THE ITD IS MOUNTED FROM END CAP CALORIMETER

LOOKING AT OPTION OF MOUNTING FROM BARREL CALORIMETER

CHOICE WILL BE MADE FOLLOWING DETAILED INVESTIGATION OF:

a) ACCESS TO ALL TRACKING SYSTEMS
b) ALIGNMENT CONSIDERATIONS
c) PASSAGE OF UTILITIES/SERVICES

ALIGNMENT

TRIGGER

PROJECTIVE GEOMETRY :

- INTERNAL PLACEMENT $\Delta r \leq 1$ mm $\Delta(\phi r) \leq 40$ μm
- FIDUCIALS AND DOWELS

RECONSTRUCTION :

- ACCURACY $\Delta r \leq 200$ μm $\Delta(\phi r) \leq 40$ μm
- SURVEY
- POSITION SENSORS
- TRACKS

00831

UTILITIES

- GAS FEED AND RETURN LINES
- HIGH VOLTAGE FEEDS CATHODE STRIPS
  DRIFT ELECTRODE
  BACK PLANE ELECTRODE

- LOW VOLTAGE
- FIBRE OPTIC CABLES
- COOLING FEED AND RETURN LINES
- SUPPLIES TO AND FROM POSITION SENSORS
  LEAK DETECTOR
  TEMPERATURES
  SENSORS
  VOLTAGE SENSORS

ESTIMATE 200 cm^2 CROSS SECTION TOTAL/END
DISTRIBUTED OVER ALL ϕ

00832

ROUTING OF UTILITIES

GAS SUPPLIES/MIXING
COOLING SYSTEM
SENSOR UNITS
ALL OUTSIDE MUON SYSTEM

HIGH AND LOW VOLTAGE SUPPLIES/DISTRIBUTION
FIBRE OPTIC RECEIVERS
BETWEEN CALORIMETER AND MUON

UTILITIES IN NOTCH BETWEEN BARREL
AND END CAP CALORIMETERS

SUPERLAYER 3 TO OUTER CIRCUMFERENCE
SUPERLAYERS 1 AND 2 BEHIND SUPERLAYER 3
ALONG SUPPORT CONE TO INNER CIRCUMFERENCE

00833

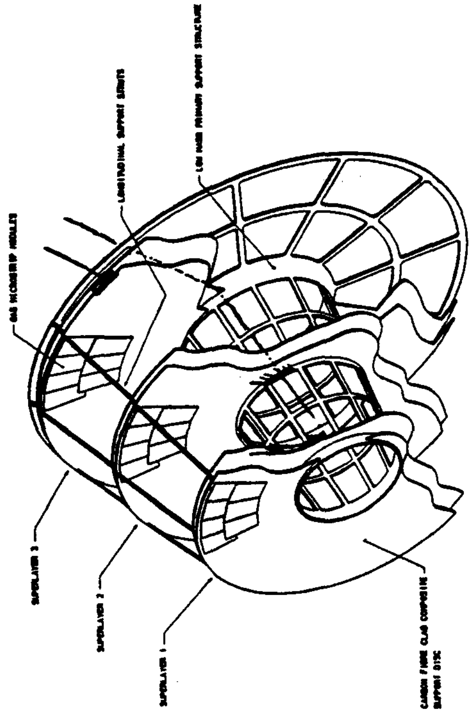


Fig 60. Tile support cone

00834

SUMMARY

GAS MICROSTRIP ITD FOR $1.8 < \eta < 2.8$

- LEVEL 1 TRIGGER WITH PRECISE P_t TURN-ON
  HIGH EFFICIENCY
  LOW FAKE RATE

- IMPROVES MOMENTUM RESOLUTION BY FACTOR 3

- ENABLES TRACK MATCHING TO CALORIMETER TO MEET SPECIFICATION

- OPERATION TO HIGHEST CONCEIVABLE SSC LUMINOSITY

00835

GAS MICROSTRIP INTERMEDIATE TRACKER R&D PLAN

G. OAKHAM

G. Oakham
6/5/92

Intermediate Track Detector
I.T.D.
Gas Microstrip Detectors (G.M.D)

R & D Plan

1) **Introduction**
2) **Status of Current R & D work**
3) **Details of Proposed R & D plan**
4) **Electronics**
5) **R & D plan Summary**

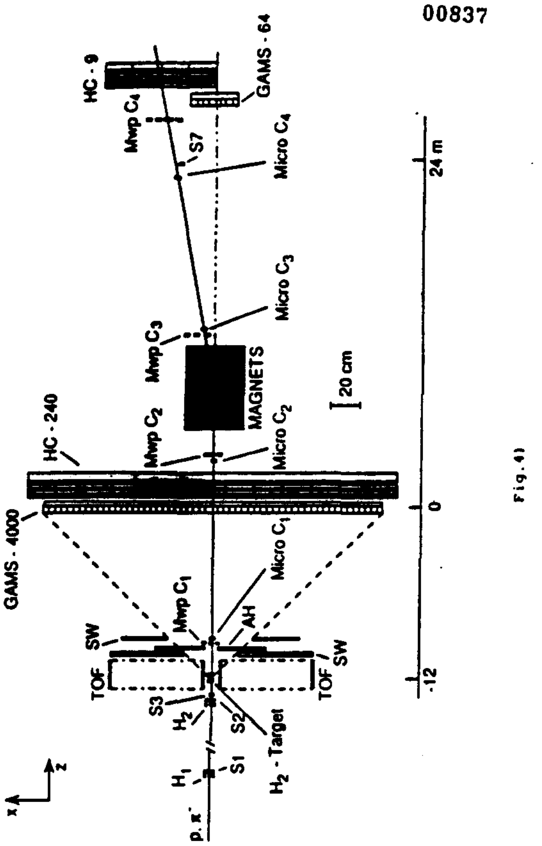


Fig. 41

G.M.D. R&D requirements

Technology has advanced rapidly over the past two years. Further work is required to make a device suitable for tracking systems of multi-TeV Hadron Colliders.

A single device is required that has:-

a) High performance (rate capability)
b) Radiation hardness
c) Good aging behavior
d) Large active areas
e) Low cost/unit area
f) Low mass

G.M.D performance is approaching many of these goals.

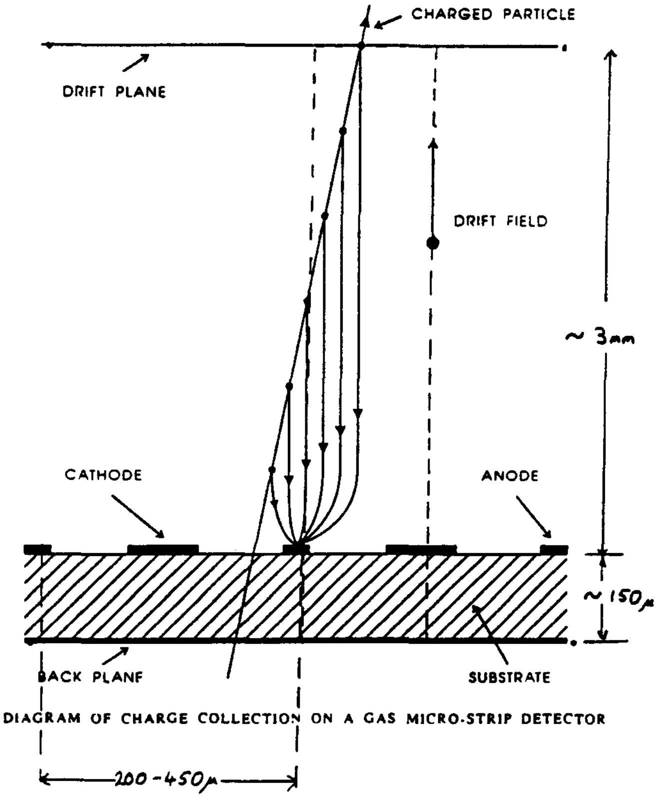


DIAGRAM OF CHARGE COLLECTION ON A GAS MICRO-STRIP DETECTOR

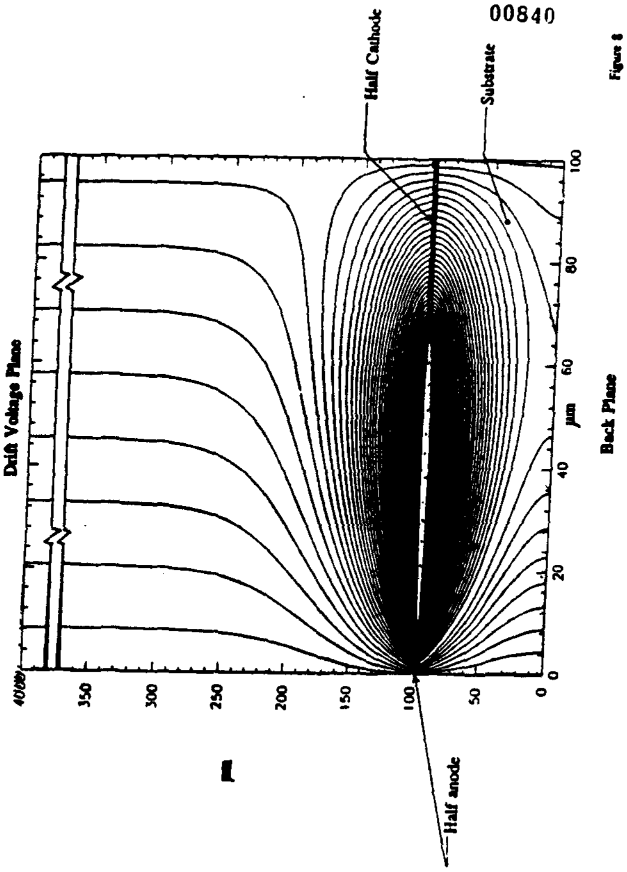


Figure 8

Electrostatic Field in a Gas Miscrostrip Detector

G.M.D. Generic R&D Status

Substrates and Metallization

Substrate properties

a) Surface resistivity - about 10^{13} Ω/square
(about 10^{11} Ω–cm for 100 µ substrate)

As σ increases surface charge builds up

As σ decreases ohmic heating increases

b) Radiation hardness

c) Structural properties

Candidate materials

Glass, Quartz, Silicon, Plastics

G.M.D Generic R&D status cont.

Candidate materials for Substrates

Glass

Tempax; Hoya, Moscow,....
RAL, CERN, Texas A&M, Purdue

- Easy to Metallize (glass 1mm thick)
- Thin glass (150 µ) available
- Ionic or electronic conduction possible
- Cost related to manufacture processing
- Resistivity controlled by addititives in the melt

Quartz

Boron implanted quartz ... NA12 CERN

- Easy to metallize
- Requires surface treatement (Cost)
- Minimum thickness?

Silicon

Si + (SiO2. Amorphous Si...)
U. of Montreal, Liverpool

- Easy to work with
- Requires surface treatment
- Current size limit on wafers

Plastics

Tedlar, ABS/Copolyether, ion implanted polyimides
Carleton, CERN, Texas A&M, Rochester

- Thin sheets available
- Flexible
- Many different resistivities possible
- Metallization can be difficult for some plastics.

G.M.D. Generic R&D status

Notes on Metallization

For generic R&D use small (2-4" dia) process.
Various segmentation of anodes and cathodes
Typical ......

Glass, Quartz, Silicon;
Easy to process. Requires Lab standard similar to that used for chip fabrication.
P.C. board techniques not accurate enough

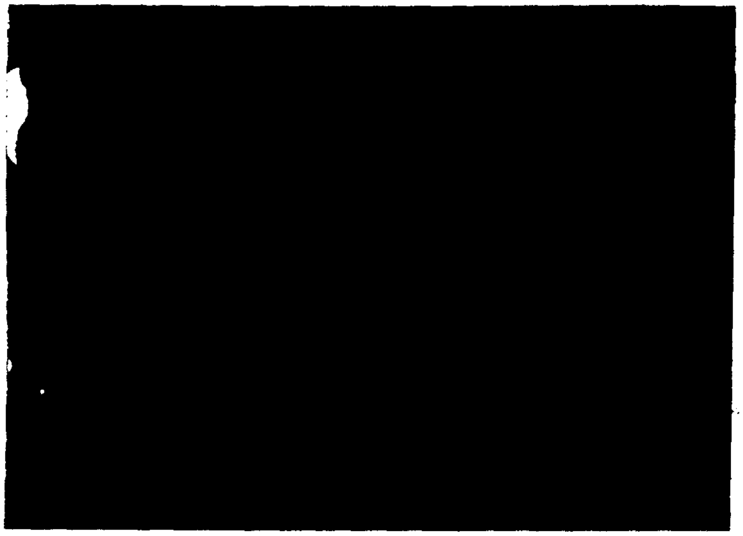
Plastics
A contamination problem for industry.
Often requires separate processing lines
Some problems with adhesion

Metal coatings

Aluminum, Chromium, Tungsten, Gold ...

Some typical results .....

Microstrip pattern for Generic testing



←——————————————————→

3 inches

Carleton/CRPP

G.M.D. Generic R&D status

Testing of Chambers

Generic Chamber

a) Small - less than 10 x 10 cm
b) Straight anodes and cathodes
c) Anodes usually ganged in groups

Lab Tests

1) Tests using Fe^{55} Source
  a) Measure pulse characteristics
  b) Measure Fe^{55} peak and width
  c) Calculate absolute gain of devices

2) Test for instantaneous rate effects.
  (n.b. for ITD rate is about 2×10^4 cts/mm^2/sec)
  Demonstrate principle of operation of the device
  Short (5 minute) burst of X-rays
  No space charge problem at high rate

3) Test for rate effects - medium term - X-rays
  Changes in gain due to the following effects
  a) Surface charge build-up
  b) Ionic movement in substrate

4) Tests for chamber aging
  Changes due to
  a) Aging, deposits on anodes
  b) Aging, erosion of anodes
  c) Changes in substrate material

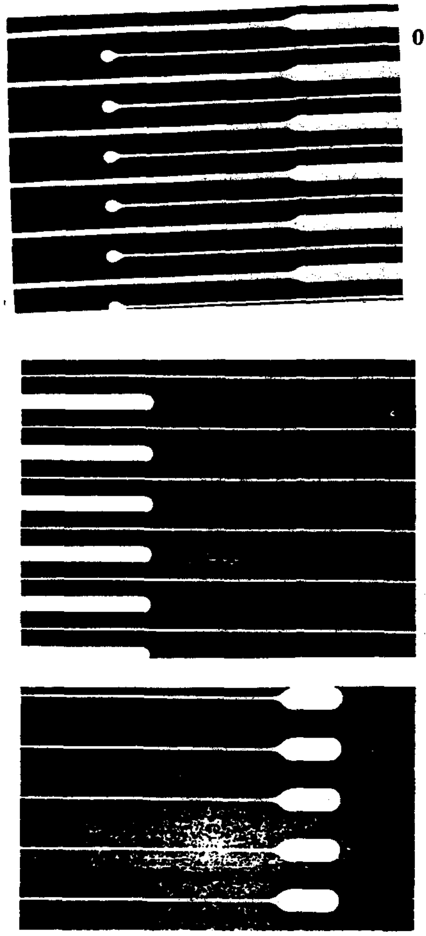
Photomicrograph of GMD

Aluminum on Tedlar - PPM Montreal

←—— 200μ ——→

Photomicrograph of GMD

Aluminum on ABS/Co-polyether - Texas A&M



Photomicrograph of GMD

Aluminium on Tempax glass RAL
(N.B. Individual anode readout)

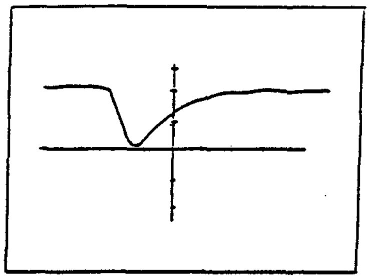
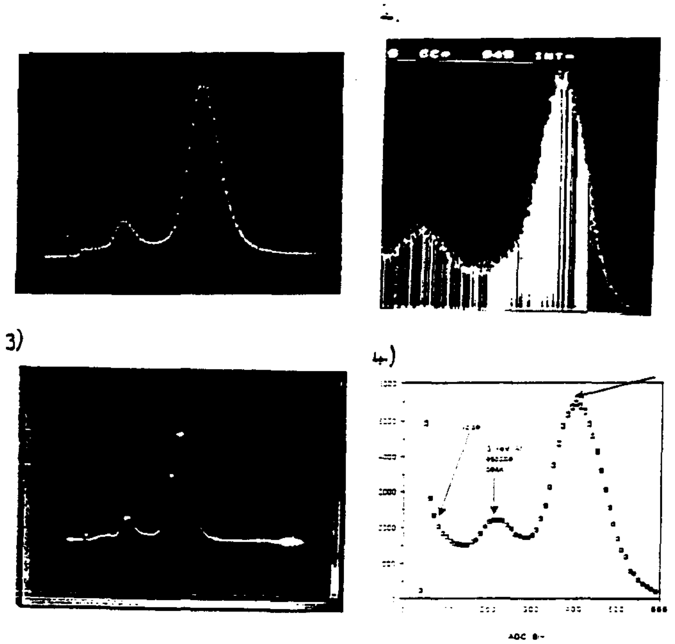


Figure 5

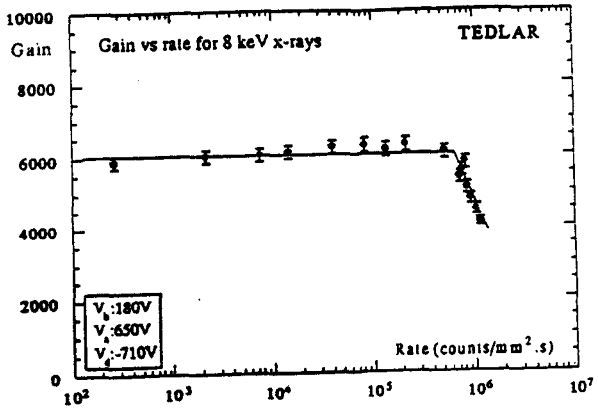
Output of a fast preamplifier connected to anode strips (gain x40) when 6keV X-rays are detected at a gain of ~3000. The horizontal scale is 10ns/cm. The gas is argon + 25% isobutane with Va - Vc = 700V. (The preamplifier rise time is about 5 ns.)

Fe^{55} Spectra from GMD chambers

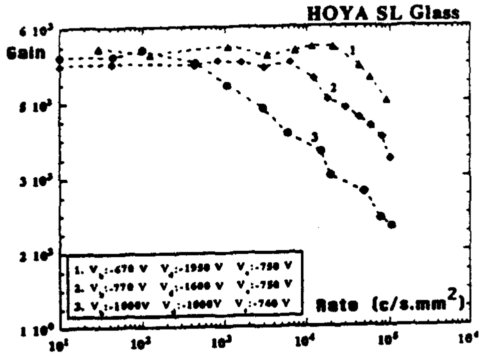
1) **Aluminum on Tedlar - Carleton/CRPP**
2) **Aluminum on ABS/Copolyether - Texas A&M**
3) **Aluminum on Tempax glass - RAL**
4) **Aluminum on Silicon U of Liverpool**



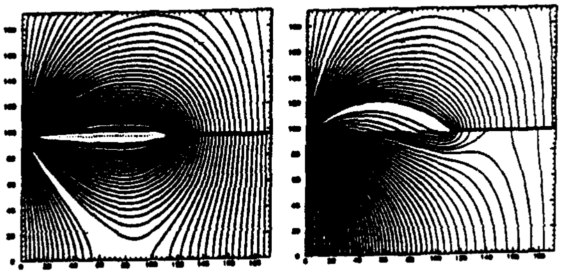
Instantaneous Rate Capability of G.M.Ds
(Bouclier et Al)



Rate capability for different voltage settings

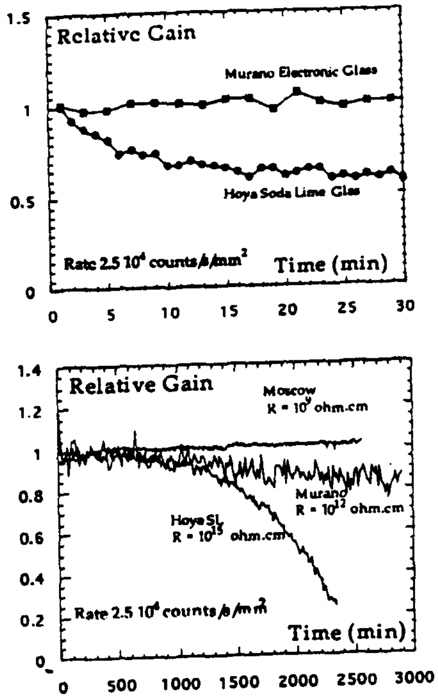


Calculated field lines for different voltage sets



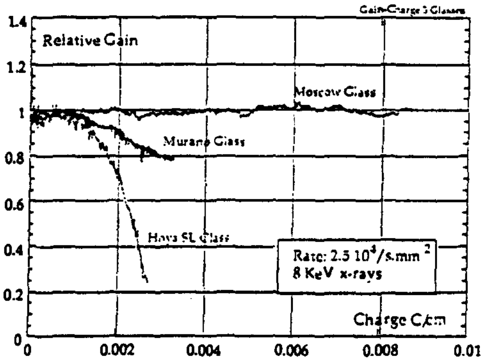
(Bouclier et Al)

Time behaviour of the gain for various glass supports



(Bouclier et Al)

Gain vs detected charge for various glasses:



G.M.D. Generic R&D Work

Other Developments

2-D Readout

Device reported by Bellazini at Vienna Wire Chamber Conference.

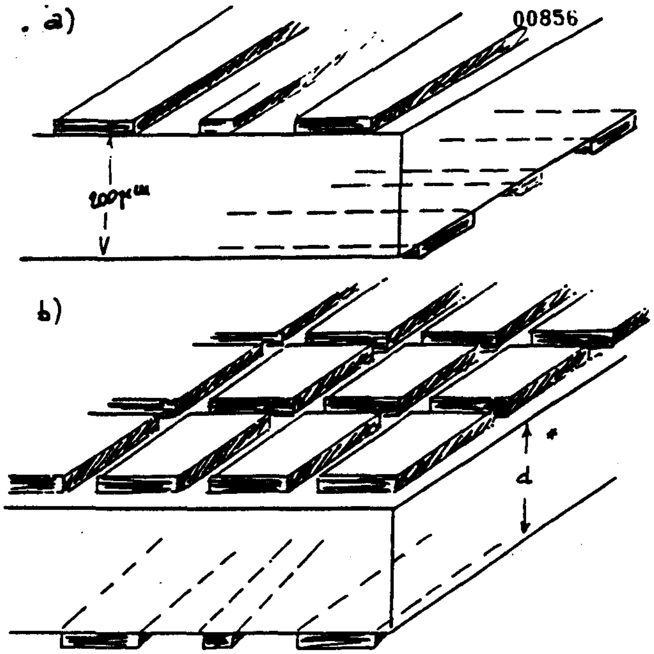
Standard anode/cathode pattern on front
Strips or pad structure on backplane to readout other co-ordinate.

Advantages
2 planes of readout for less material

Disadvantages
Problem of locating electronics in ITD

ODE etching

Very nice results producing pillar/knife-edge structure for use in GMD type device.



New detector structures
a) double side read out
b) pad read out

**) THE CHARGE FRACTION ON THE BACK ELECTRODE*

Photomicrographs of ODE pillar devices
Texas A&M

ITD R &D PLAN

A) Generic Micro-strip R&D plan

- Several substrates have been evaluated for further testing
- Looking for optimal substrates
- Will continue for another year
- Summer 93; decision on substrate and metallization

Evaluation and testing will continue as before

1) Gain : Fe^{55} Sources
2) Rate : 8 KeV X-rays and sources
3) High Intensity tests;
    Rad Hardness ; Aging of whole chamber
        X-ray sources
        Neutron Sources
        Beams

ITD R &D Plan

B) Beam Tests

Why?
- Number of anodes fired/track
- Position resolution
- Time resolution
- 2-track resolution
- Angle effects
- Efficiency

When?

- Late May/June 1992	CERN P.S (Joint test at CERN)
- May/June 1992	ISIS (RAL)
- July 1992	CERN (S.P.S)
- Sept/Oct 1992	CERN (S.P.S)

c) Gas Selection

Need-
- High primary ionization
- High gas gain
- Fast drift velocity
- Aging resistance

Candidates
- Xe/DME
- Xe/DME/CO_2
- DME/CO_2
- CF_4/Iso-butane

ITD Detailed R&D plan

Adaption of G.M.D.s for use in the I.T.D

A) Keystone geometry

To provide radial anodes
Shape cathodes and anodes to provide constant gain

B) Large area detectors 18 x 24 cm size

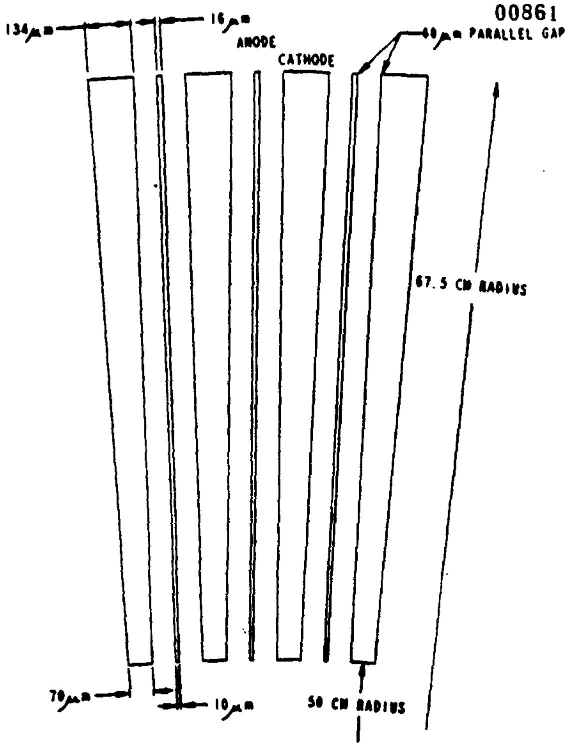
Mainly a question of cost versus yield
- Use large area masks and plates
- Bond smaller plates together

C) Lightweight tiles

- Composite structure for anode and H.V planes
  - i) Independent tile (= 2 support planes)
  - ii) Use structural support disc for one of the tile planes.
- Practical electronic connections and cooling. (Wire bonding, bump bonding)

D) Radiation testing of composite structure

E) Heat dissipation studies



Typical Anode/Cathode keystone geometry

Electronics for G.M.Ds

GMD electronics is being covered in a separate session. Data collection and transmission is similar to that used for the silicon detector. The main difference is the Front-end preamp/shaper/discriminator. Different characteristics are required for GMDs

GMD electronics for tests

Initial testing is being done with commercially available electronics. This includes preamp/shaper/discriminator and ADCs and TDCs

This is O.K for a few channels around 10-20.

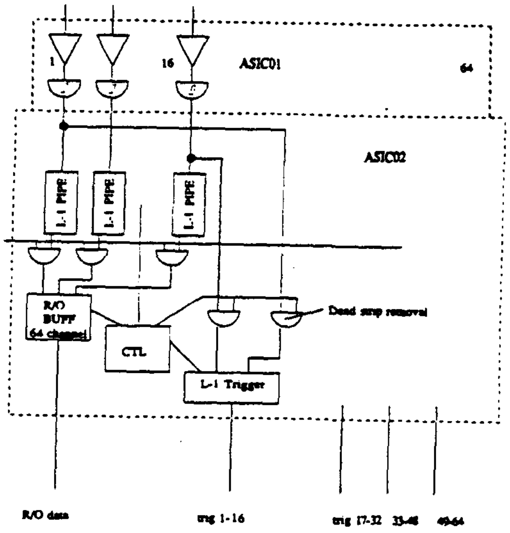
- For beam tests will need readout of individual anodes.
- This could be done using devices such as
  - RAL MX5 and MX6 chip (developed for silicon)
  - New designs for GMDs such as the one developed by the Pisa group.

Electronic development for ITD

Front End
- Amplifier developed by Pisa group
- Pre-amps designed for silicon detectors
- New preamp design at SSCL

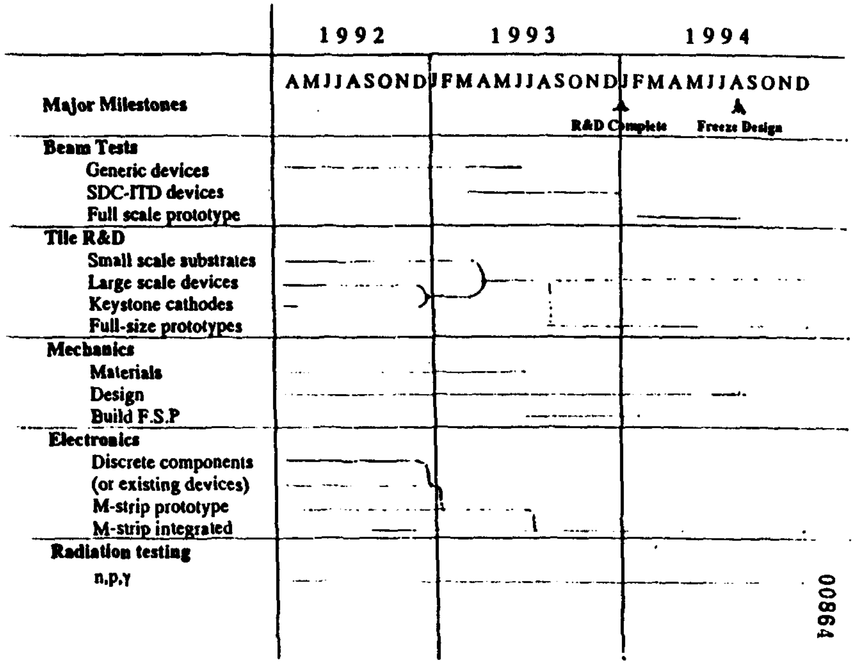
Data collection

Figure 4 ITD Front-end Electronics



Pre-amp/Discriminator **Pipeline and buffers**

Diagram of part of front end electronics for GMDs


1992
1993
1994
AMJJASOND
JFMAMJJASOND
JFMAMJJASOND
Major Milestones
R&D Complete
Freeze Design
Beam Tests
Generic devices
SDC-ITD devices
Full scale prototype
Tile R&D
Small scale substrates
Large scale devices
Keystone cathodes
Full-size prototypes
Mechanics
Materials
Design
Build F.S.P
Electronics
Discrete components
(or existing devices)
M-strip prototype
M-strip integrated
Radiation testing
n,p,γ
00864

FIBER OPTION SUMMARY

R. RUCHTI

SCINTILLATING FIBER OUTER TRACKING DETECTOR

Fiber Tracking Group (FTG)

B.Abbot[k], D.Adams[l], M.Adams[c], E.Anderson[m], T.Armstrong[i], M.Atac[a,b],
A.Baumbaugh[b], B.Baumbaugh[g], P. Besser[n], M.Binkley[b], F.Bird[o], J.Bishop[g],
N.Biswas[g], A.D.Bross[b], C.Buchanan[a], N.Cason[g], R.Chaney[p], D.Chrisman[a], D.Cline[a],
C. Collins[o], M.Corcoran[l], R.Davies[k], J.Elias[b], E.Fenyves[p], D.Finley[b], G.W.Foster[b],
R. Fox[o], H.Goldberg[c], H.Hammack[p], A.Hasan[i], M. Hechler[o], S.Heppelmann[i],
K.Hess[o], J.Jaques[g], J.Kauffman[j], R.Kehoe[g], C.Kelley[e], M. Kelly[g], C.Kennedy[m],
V.Kenney[g], R.Kephart[b], D.Koltick[k], J.Kolonko[a], K.Kondo[q], J.Kubic[a], R.A.Lewis[i],
R.Leitch[h], J.LoSecco[g], B.Lowery[p], J.Marchant[g], R.McCutcheon[m], R.McIlwain[k],
S.Margulies[c], H.Mendez[c], F.Miere[d], H.Mietenen[l], R.Moore[i], R.J.Mountain[g], B.Oh[i],
J.Orgeron[p], H.Paik[d], J.Park[a], J.Passaneau[i], K.Pennington[o], M.Petroff[m], J. Piles[o],
A.Pla-Dalmau[b], C.Rivetta[b], R.Ruchti[g], R.Scalise[i], J.Schmitz[k], W.Shephard[g],
E.Shibata[k], J.Skeens[l], G.A.Smith[i], J.Solomon[c], K.Takikawa[q], C. Talmadge[k],
T.Thurston[o], S.Tkaczyk[b], W.Toothacker[i], Balamurali V[g], D.Vandergriff[h], K.Vasavada[d],
R.Wagner[b],, M.Wayne[g], and J.Whitmore[i]

University of California at Los Angeles[a]
Fermi National Accelerator Laboratory[b]
University of Illinois at Chicago[c]
Indiana University - Purdue University at Indianapolis[d]
Massachusetts College of Pharmacy and Allied Health Sciences[e]
University of Notre Dame[g]
Oak Ridge National Laboratory[h]
Pennsylvania State University[i]
Philadelphia College of Pharmacy and Science[j]
Purdue University[k]
Rice University[l]
Rockwell International, Electro-Optical Center[m]
Rockwell International, Science Center[n]
Superconducting Super Collider Laboratory[o]
University of Texas at Dallas[p]
Tsukuba University[q]

R. RUCHTI
NOTRE DAME
5-6-92

DESIGN STRATEGY

- ALL CYLINDRICAL GEOMETRY $0 \le |\eta| \le 2.5$

  UNIFORMITY OF COVERAGE FOR

  TRACKING
  TRIGGERING
  MECHANICAL SIMPLICITY

  INNER LAYERS FOR TRIGGERING AT LEVEL 1.

  OUTER LAYERS FOR MOMENTUM RESOLUTION

- EXPLOITS: INTRINSICALLY PROMPT RESPONSE OF SCINTILLATOR TO BE SENSITIVE TO INDIVIDUAL BEAM CROSSINGS

  HIGH GRANULARITY/LOW OCCUPANCY TO PROVIDE OPERATION TO 10^{34} LUMINOSITY

DESIGN CONCEPT

- SCINTILLATING FIBERS OF
  - 925 µm DIAMETER
  - PS/PTP/3HF (STANDARD MIX)
  - λ ~ 530 nm
  - (BICRON & KURARAY)
- WAVEGUIDE FIBERS OF
  - 1mm DIAMETER
  - PS ONLY (STANDARD)
  - (BICRON & KURARAY)
- PHOTODETECTORS:
  - VISIBLE LIGHT PHOTON COUNTERS (VLPC)
  - QE ~ 80% AT 565 nm.
  - OPERATE CRYOGENICALLY (6-9 K)
- MECHANICAL:
  - FIBERS FORMED INTO COHERENT RIBBONS
  - RIBBONS PLACED ON STABLE-BASE CYLINDERS OF CARBON FILAMENT/ ROHACELL STRUCTURE
  - SYSTEM IS HELD AND SUPPORTED FROM END RINGS
  - CRYOSTATS FOR VLPCs ARE PLACED OUTSIDE OF THE CALORIMETRY
- TRIGGER/DAQ:
  - OUTPUT IS DIGITAL
  - LEVEL I TRIGGERING IMPOSED IN ASIC TECHNOLOGY

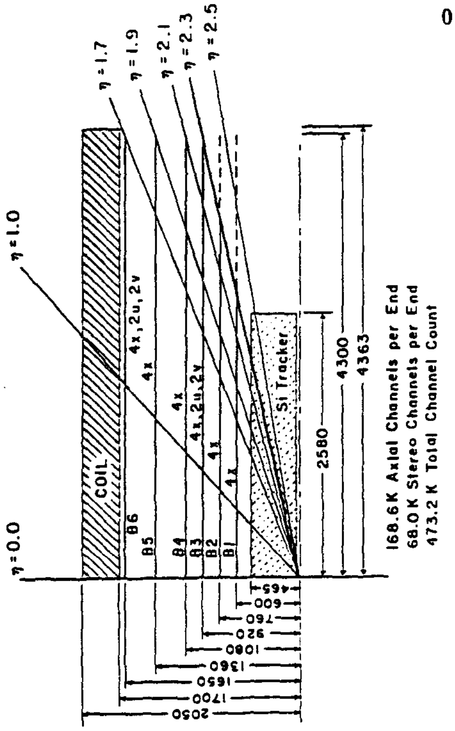


Table 4-21
Parameters and characteristics of the superlayers of the scintillating fiber tracker.

Radial location (cm)	Fiber layers x=axial u=stereo v=stereo	Fiber channels per end	Scifi length for axial fibers (m)	$\Delta\eta$ coverage	Wave-guide length (m)	Total fiber length (m)	Expected mean no. of photo-electrons detected for 925 μm diam. (at $\eta = 0$)
60	2x, 2x	15.9K	3.00	2.3	6.93	9.93	4.6
76	2x, 2x	20.1K	3.65	2.3	6.12	9.77	4.6
92	2x, 2x	24.4K					
	2u, 2v	24.4K	4.30	2.3	5.31	9.61	4.5
108	2x, 2x	28.6K	4.30	2.1	5.15	9.45	4.6
136	2x, 2x	36.0K	4.30	1.9	4.67	9.17	4.7
165	2x, 2x	43.6K	4.30	1.7	4.56	8.86	4.9
	2u, 2v	43.6K					

TOTAL 473.2K

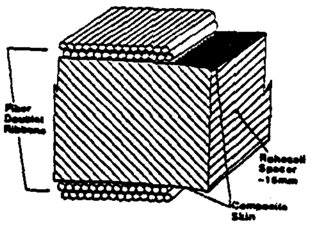
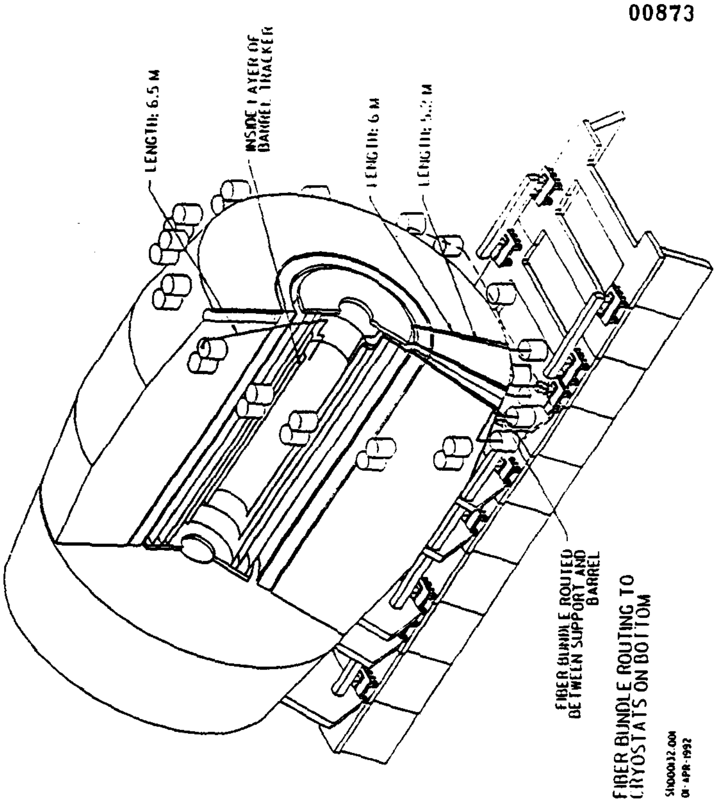


FIG. 4-58. Schematic of a superlayer having axial fiber doublet ribbons mounted on the inner and outer surfaces of a support cylinder.

Table 4-23
Average occupancies at SSC design luminosity.

Superlayer	Radius (cm)	$\Delta\eta$ coverage	Occupancy
B1	60.0	2.3	0.017
B2	76.0	2.3	0.013
B3	92.0	2.3	0.012
B4	108.0	2.1	0.006
B5	136.0	1.9	0.003
B6	165.0	1.7	0.002



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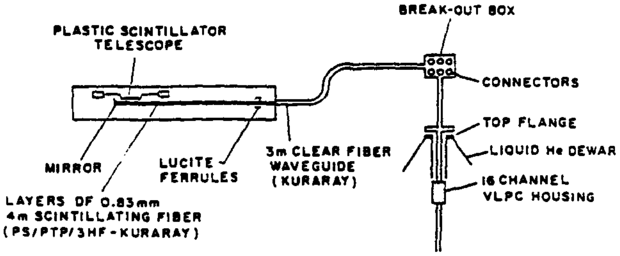

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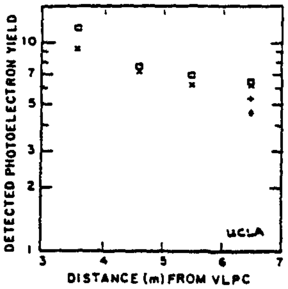


DISTANCE = 3m CLEAR WAVEGUIDE
SPLICED TO A SCINTILLATING
FIBER

DIAMETER 830μm

PS/PTP/3HF (KURARAY)

□ x } MIRRORED END

+ ◇ } UNMIRRORED END

00876

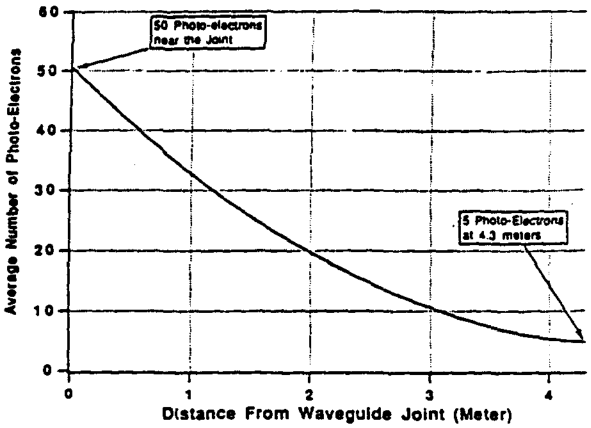


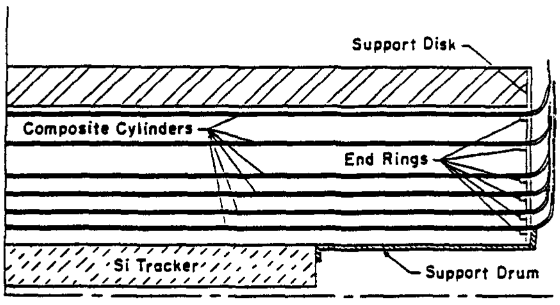
Figure 5.3.3-1 Mean detected photoelectron yield as a function of position along a scintillating fiber in layer B3 of the tracker

00877

FOR A FIBER DOUBLET 925μm DIAMETER
[illegible] FIBER

⟨N p.e.⟩	EFFICIENCY	σ
1.6	0.87	170μm
2.4	0.95	
3.2	0.98	130μm
4.0	0.99	
4.8	0.995	115μm

00878



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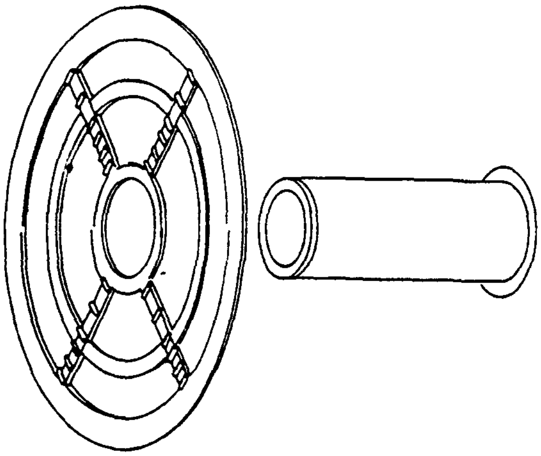
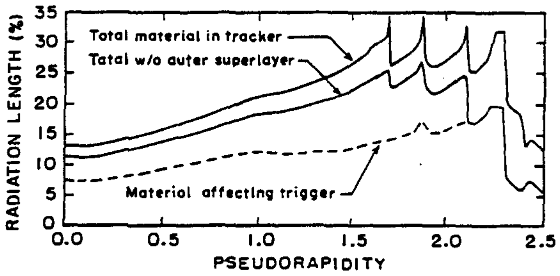


Figure 4.2-2 a.) the simple thin panel forms the backbone of the tracking system. b) The nose which connects to the silicon tystem to the outer tracking system.

00880



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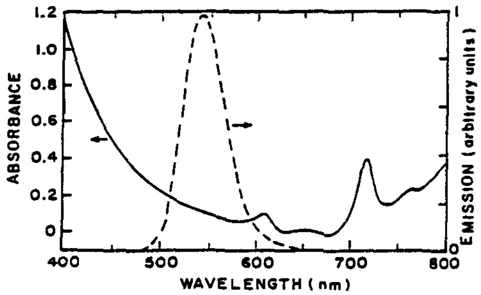


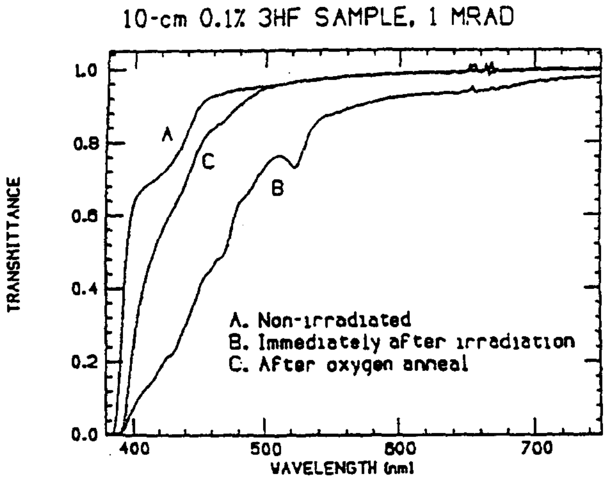


Figure 5.2-1 Transmission in polystyrene/PTP/3HF scintillator as a function of wavelength. Before and after irradiation by ^{60}Co to 1 MRad, and after annealing.

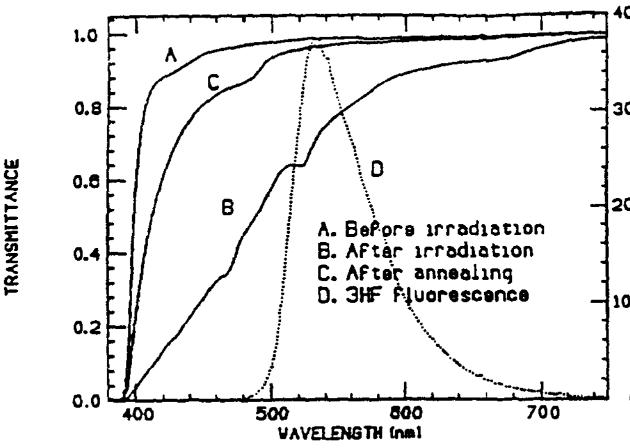


Figure 5.2-2 Transmission in polystyrene/PTP/3HF scintillator as a function of wavelength. Before and after irradiation by ^{60}Co to 10 MRad, and after annealing.

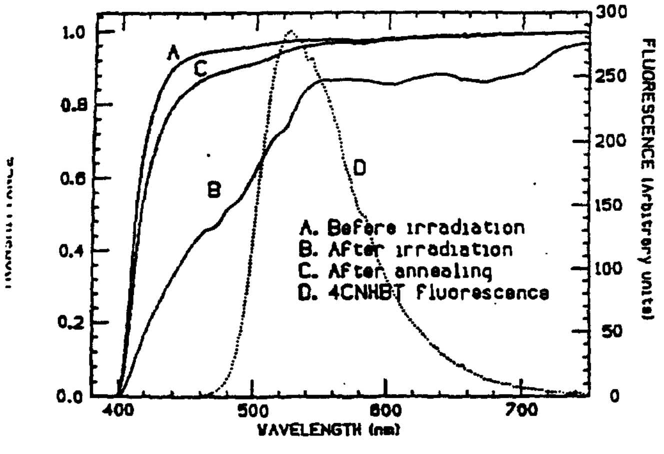
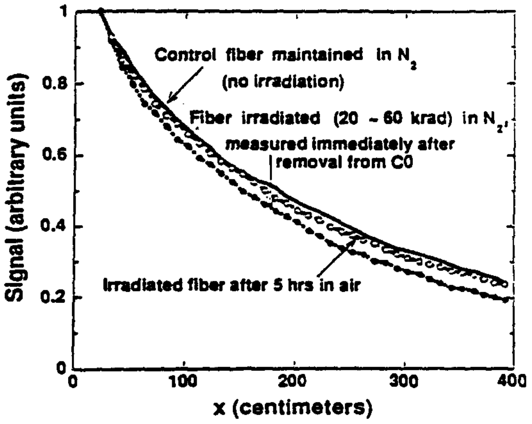
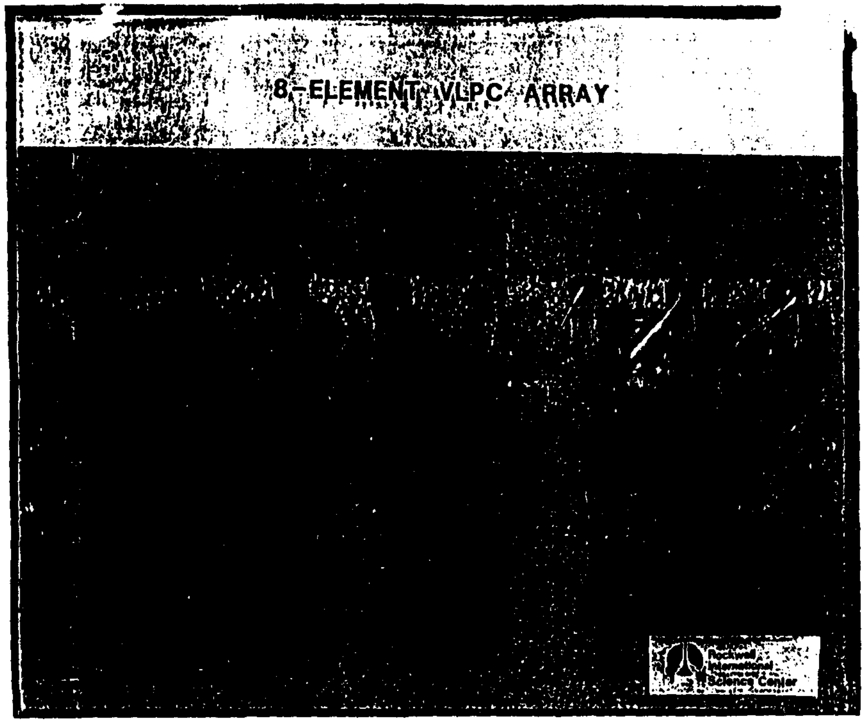


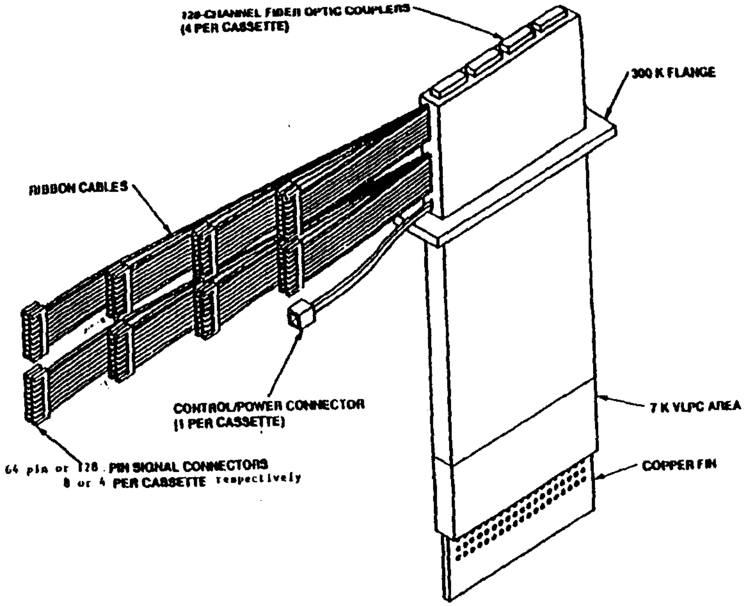
Figure 5.2-3 Transmission in polystyrene/PTP/4CNHBT scintillator as a function of wavelength. Before and after irradiation by ^{60}Co to 10 MRad, and after annealing.

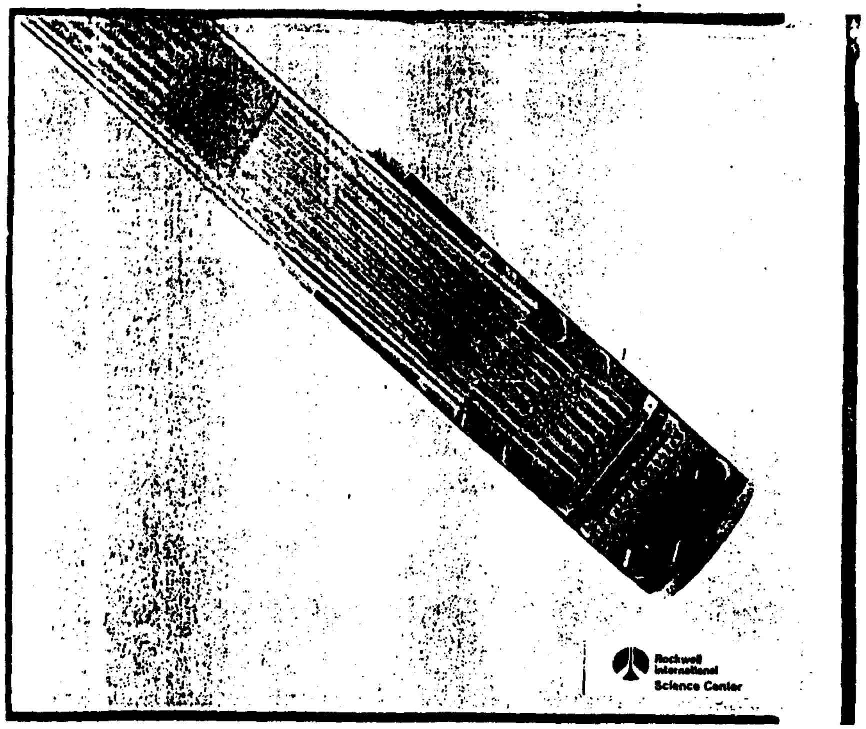
RESULTS (pT+3HF)



Transmission curves
(normalized to unity at x = 22 cm)

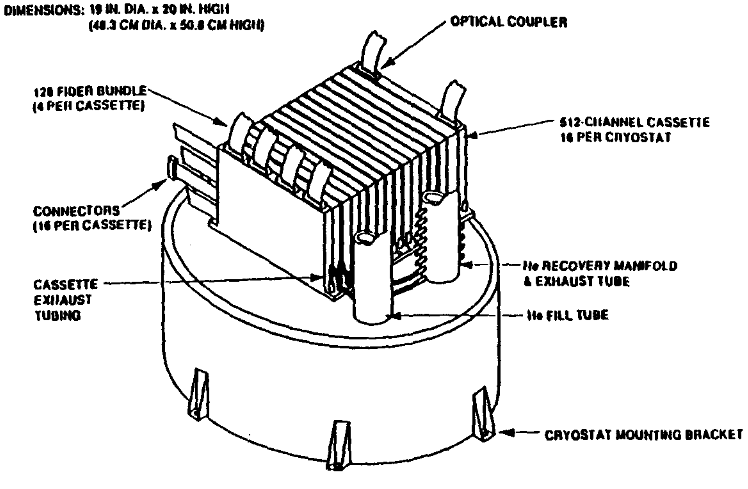






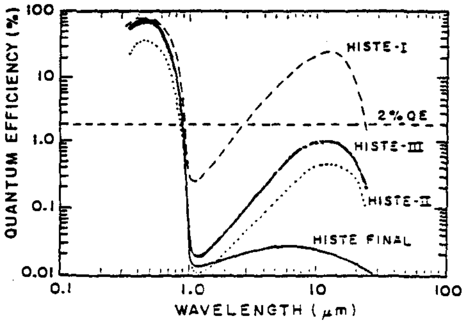
8192 CHANNEL CRYOSTAT
BASELINE DESIGN

DIMENSIONS: 19 IN. DIA. x 20 IN. HIGH
(48.3 CM DIA. x 50.8 CM HIGH)



Rockwell International

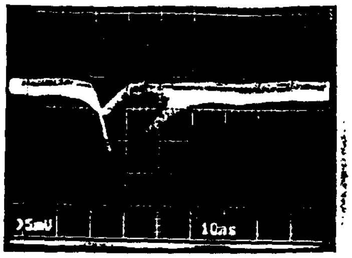
00890



00891

Table 4-24
Geometric and operating characteristics of visible light photon counters.

Parameter	Achieved	Goal
Active area	575 × 575 μm²	1 mm diameter
Array configuration	1 × 8	1 × 10
Contact resistance	1000 Ω	<100 Ω
Pulse rise time	< 5 ns	< 5 ns
Average gain	20,000	30,000
Gain dispersion	< 30%	< 30%
Effective QE at 565 nm	85%	70–90%
Infrared QE at 15	< 0.5%	< 2%
Dead time	None (continuous)	None (continuous)
After pulses	< 0.01%	< 0.01%
Dark pulse rate	10 kHz	5 kHz
Saturation pulse rate	25 MHz	25 MHz
Average current	< 200 nA	< 200 nA
Average power	1.4 μW/channel	1.6 μW/channel
Breakdown voltage	7.5 V	> 8.5 V
Operating bias voltage	6–8 V	6–8 V
Neutron damage level	> 10^{12} n/cm²	> 10^{12}n/cm²
Operating temperature	6–8 K	6–8 K



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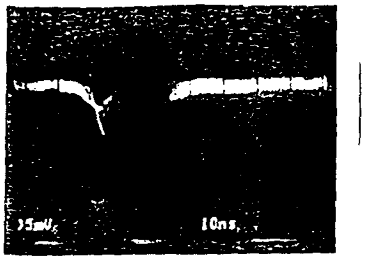
Tests with HISTE-II VLPCs
Using VTX amplifiers
Bias Voltage : 7.8 vollts
Temperature: 9.5 K
Looking at thermal electron pulses

1/2/1992



00893

Figure 2.2-14 Typical signal from the HISTE-II/VTX system operating in the test beam at Fermilab, indicating a clear single-photoelectron line above noise and a pulse rise of less than 5ns. As displayed, the signal has received additional amplification in an LRS 612 preamplifier as was the case prior to data recording in the LRS2880 ADC system.

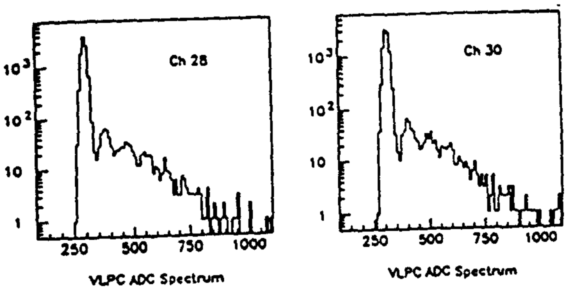
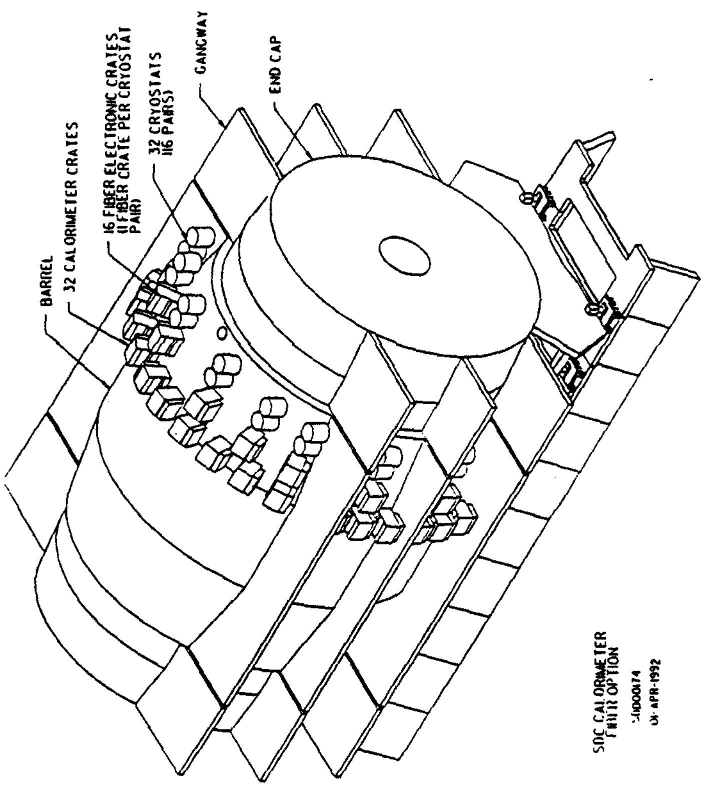


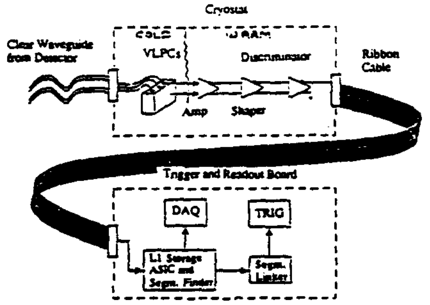
Figure 2.2-15 A typical pulse height spectrum observed in the fiber/HISTE-II/VTX system recorded during the beam tests at Fermilab and exhibiting characteristic photopeaks.

00894



SDC CALORIMETER
FIBER OPTION
JH000174
04-APR-1992

00895



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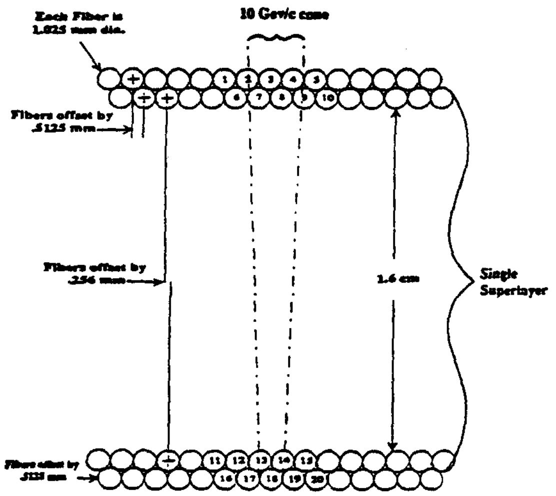
Track Segment Finding Algorithm



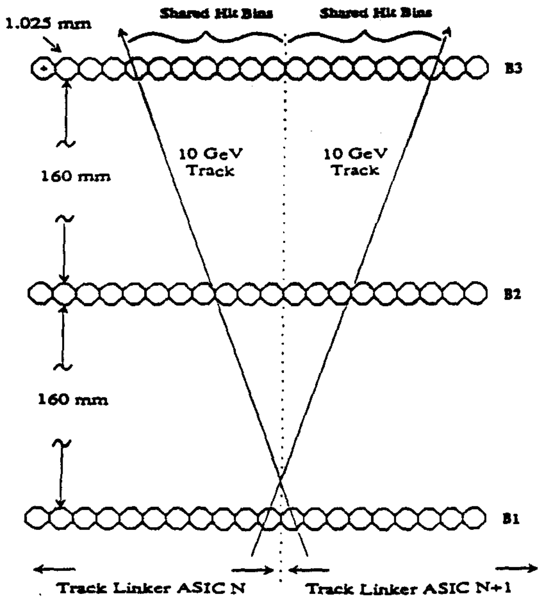
Acceptance cones for 10 GeV tracks
in single fiber bins

KLK
01/22/92

00897

Triplet Superlayers for Trigger

Single Fiber Diameter Hit Locations



KLK
01/22/92

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4–90

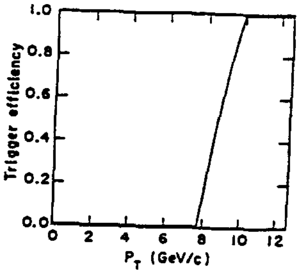

FIG. 4-64. Trigger efficiency as a function of p_t for the scintillating fiber tracking trigger using superlayers B1, B2, and B3.

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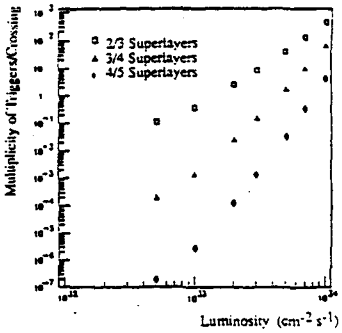
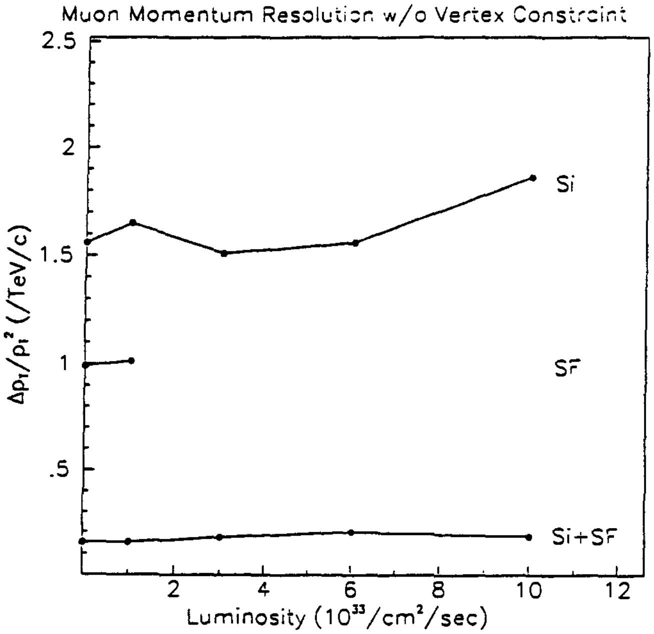


00900



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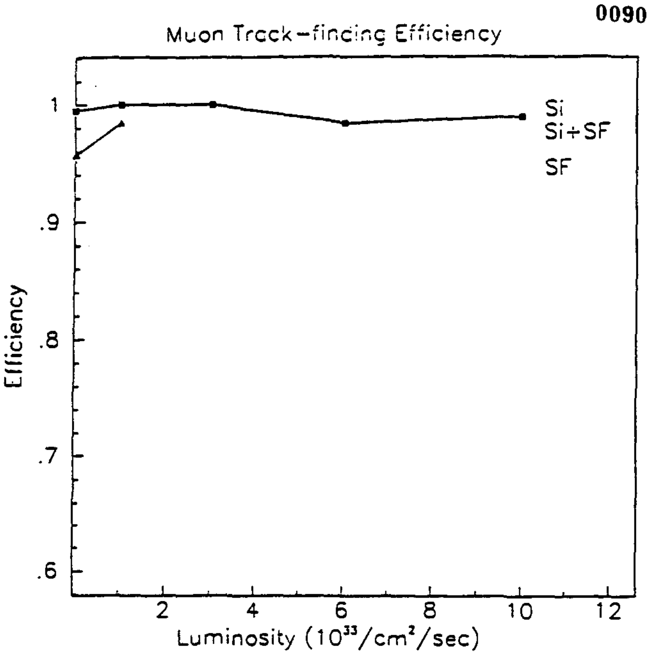
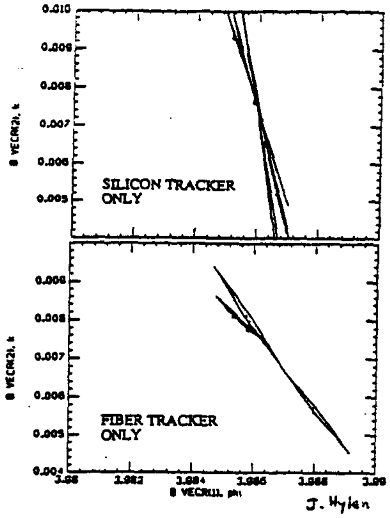
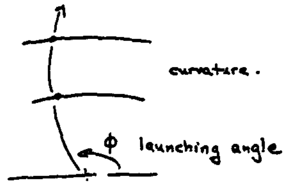




J. Hylen



SUMMARY: SCINTILLATING FIBER OUTER TRACKER

1. INTRINSICALLY PROMPT RESPONSE
2. LOW OCCUPANCY
3. |η| < 2.5 COVERAGE WITH CYLINDRICAL GEOMETRY
    - NO CRACKS
    - MECHANICAL SIMPLICITY
    - LOWER COST
4. READOUT & ELECTRONICS OUTSIDE TRACKING VOLUME
    - ACCESS EASE
    - NO POWER DISSIPATION IN TRACKING VOLUME.
5. DIGITAL OUTPUT
6. LEVEL 1 TRIGGERING

CHALLENGES

1. CRYOGENIC COOLING FOR PHOTODETECTORS
2. SCINTILLATOR PERFORMANCE
    - RADIATION
    - ENVIRONMENT
3. RIBBON & CYLINDER FABRICATION
    - PLACEMENT
    - STABILITY
    - MONITORING

00904

FIBER OPTION R & D PLAN

D. KOLTICK

Scintillating Fiber Tracker

Future R & D

D. Koltick May 6, 1992 SSCL

I. Status of VLPCs
   - HISTE III
   - Review of Project
   - Prototype Cassette

II. BNL Beam Test
   - Fibers
   - Superlayers
   - Trigger
   - System Photo-electron yield

III. Mechanical
   - Flat Panels
   - Small Cylinders
   - Fiber Ribbon Production
   - Superlayer Production

IV. Status of Scintillating Fibers
   - -3HF Baseline
   - New Improved Dyes

V. Beam Test/Rad Damage Studies
   - T-851 and beyond
   - Environmental Effects
   - Future Beam Tests

VLPC Visible Light Photon Counter

A solid-state photomultiplier

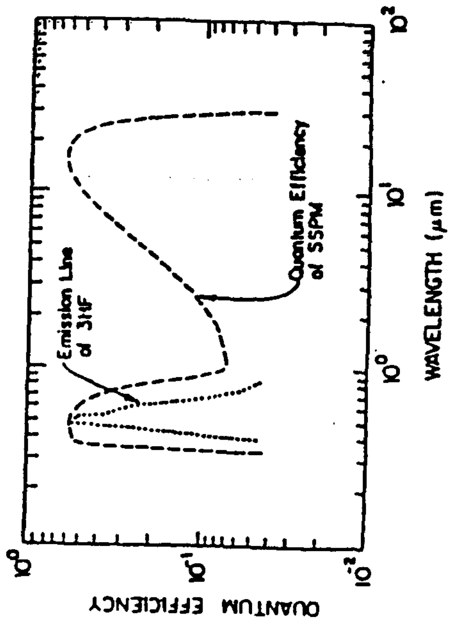
gain $\gtrsim 10^4$

Q. E. $\gtrsim$70%

(devices have achieved 85%)

Risetime < 8 η sec.

Cryogenic Operation ~7° k



Science Center
Rockwell International Corporation
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803-3105

Rockwell International

031-3C16

March 24, 1992

Prof. M. Atac
Department of Physics
University of California - Los Angeles
Los Angeles, California 90024

Dear Muzaffer:

The purpose of this letter is to update you on the status of lot HISTE -III Visible Light Photon Counters (VLPCs).

VLPCs exhibiting very good performance have been obtained from lot HISTE-III. Wafer fabrication of this lot of devices was completed recently on the HISTE (High-Rate Scintillating Fiber Tracking Experiment) contract from UCLA.

The lot included three groups of wafers with different variations of material parameters; all three groups yielded operating VLPCs. Detailed evaluation of the best performing group has been carried out using dies of an 8-element line array from each of the three wafers in that group. Results to date are very positive and are summarized below.

Quantum efficiency in the visible and infrared spectral regions was measured on these devices and concurrently on a Solid State Photomultiplier (SSPM) fabricated earlier in lot HMC for checkout of a HISTE mask set. Table I summarizes the device quantum efficiencies estimated from these data. The estimated accuracy of these measurements is +5% to -15%.

TABLE I

	Quantum Efficiency* (%)	
Wavelength (um)	HMC Device	HISTE-III Device
Visible - 0.55	85	80
Infrared -1.0 to 2.0	1	< 0.12
3.2	3	< 0.25
15	38	< 1.3
20	30	< 0.5

* These devices do not have the anti-reflection coating optimized for the visible spectrum.

It is clear that these HISTE-III devices combine high quantum efficiency in the visible spectrum with negligible quantum efficiency in the infrared. It should also be noted that these HISTE-III devices demonstrate a substantial performance improvement over the HISTE-II devices released for beam tests in December 1991 which had a visible spectrum quantum efficiency approaching 40%. The HISTE-III devices are Visible Light Photon Counters that could be made available for beam tests and other evaluations without the restrictions associated with SSPMs.

The dark count rate and biasing current of these HISTE-III devices are higher (factor of 2 to 4) than that of the best HMC devices. These can be reduced, if necessary, by tailoring the material parameters. Gain and gain dispersion have been observed qualitatively to be excellent, equivalent to or better than lot HMC devices. Quantitative data needs to be gathered.

HISTE-III VLPCs operate over a fairly wide temperature range (6 to 8.5K) with bias between 8.0 and 8.6V. Optimum performance is obtained at a temperature between 6.5 and 7K and at a bias of 8.2V, which is very comfortably below the breakdown voltage of 9.0 to 10.0V.

We plan to take data on additional devices. From past experience on impurity band conduction devices, we do not expect the variations from device to device on a wafer to be significant.

The VLPC refinement effort proposed for FY'92 funding will address adjustments between the various device performance characteristics (quantum efficiency, dark count, latchup, etc.) and material/process parameters (doping concentrations, layer thicknesses, AR coating) to provide optimization of the device performance and stability range for SSC requirements.

ROCKWELL INTERNATIONAL CORPORATION
SCIENCE CENTER - ANAHEIM

Paul Besser

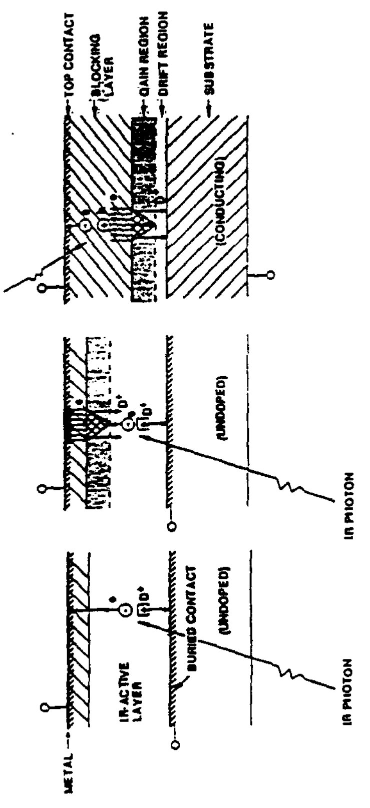
P. J. Besser
Manager
Silicon Programs

PJB:bc

IMPURITY BAND CONDUCTION DETECTORS

M.ATAC

DEVICE STRUCTURES



Rockwell International

Level 1

The production and operation of 8-channel arrays of VLPCs with accurate dimensions and uniform operating conditions within each element of the array. This step has been accomplished. See Figure 1.

Level 2

The production and operation of working sub-assemblies consisting of 4 arrays (32 channels) with high density packing and uniform operating characteristics for each of the VLPC channels. This step has been accomplished. See Figure 2.

Level 3

The production of integrated sub-assemblies into a high density 128-channel unit which can serve as a sub-module for a fully integrated cassette. A design now exists and is shown in Figure 3.

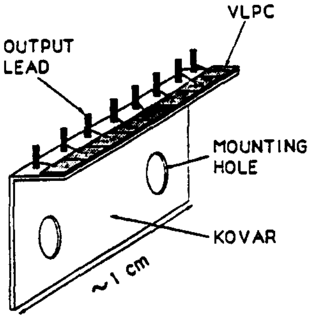
Level 4

The production and operation of a fully integrated 512-channel cassette containing sensitive high speed pre-amplifiers and low voltage digital line drivers. This cryogenics module will accept the light output from a group of scintillating fibers and output a digital signal to both a fast trigger system and a simple latch for storage to be read by the data acquisition system. A preliminary design of the cassette now exists and is shown in Figure 4.

Level 5

The production and operation of a 16 cassette system (~8,000 channels) as is shown in Figure 5. This is the highest level of integration that is necessary for the SSC. This is the element that will be replicated to form the operating system.

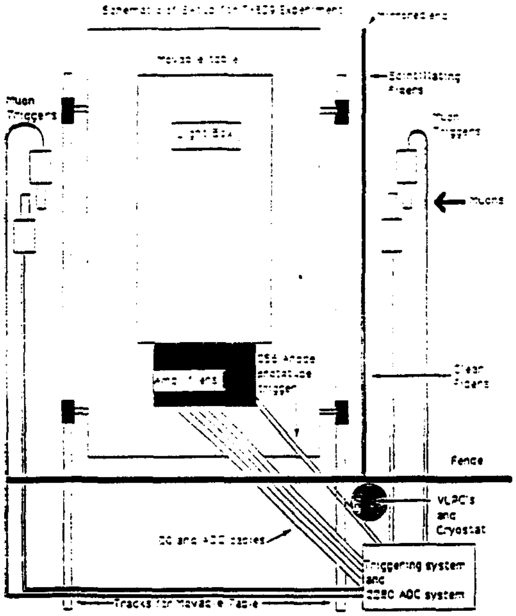
00913



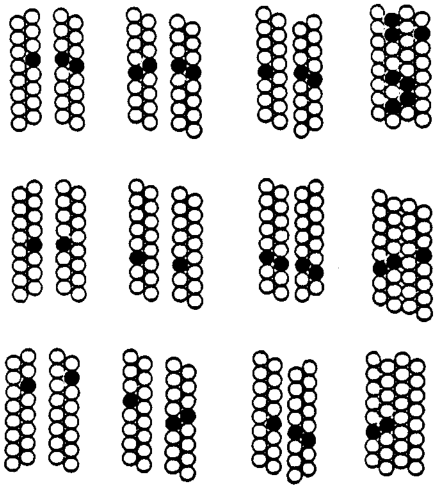
Eight Channel VLPC Mount

Fig. 1 An 8 channel VLPC array, wire bounded and placed unto a Kovar Mount. New mounts will be made of Invar. The new pixels will be 1 mm in diameter, round to eliminate cross coupling. These have been successfully operated.

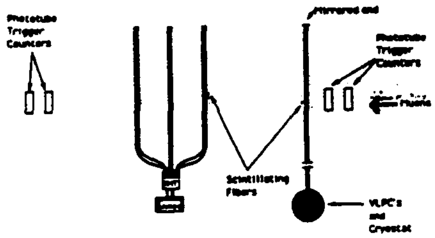
00914



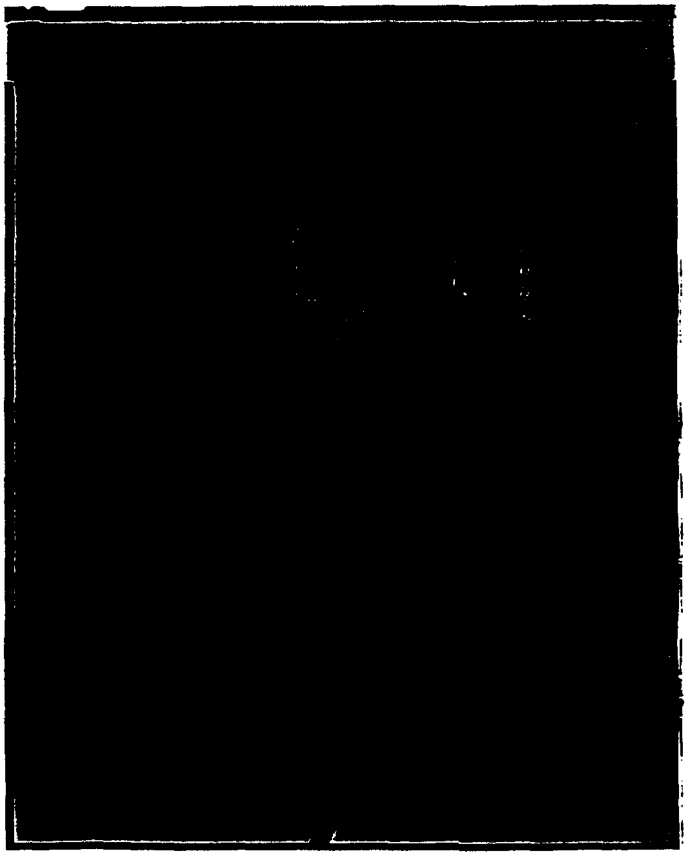
00915

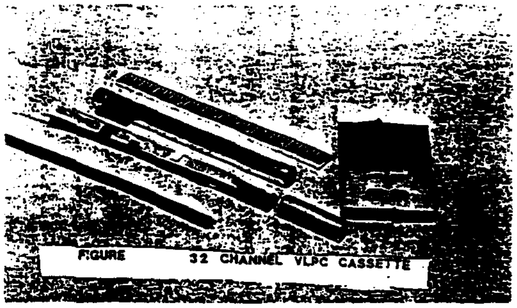


Schematic of T-839 Experiment



00916





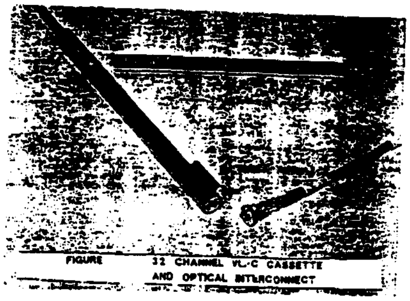


Fig. 2 A 32 channel VLPC cassette. Successful operation of this device has been carried out in Fermilab Beam Test T-839. The present cassette works using the "boiling cryostat" technique.

128 CHANNEL VLPC MODULE

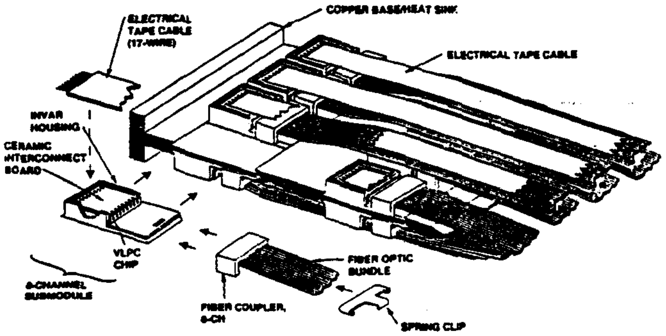


Fig. 3 Present preliminary design of a 128 channel VLPC module. There are many aspects of this design that need detailed analysis and critical review before prototype production can proceed.

512 CHANNEL CASSETTE

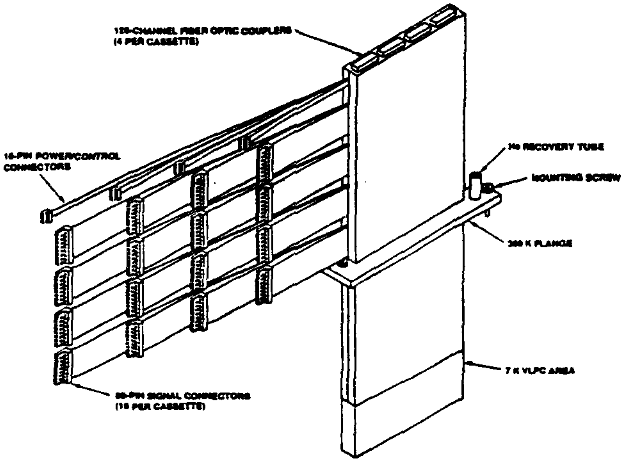


Fig. 4 Conceptual design of a 512 channel VLPC cassette. The funding request is aimed at building two of these cassettes and operating them by the end of 1992 or early 1993.

8192 CHANNEL CRYOSTAT BASELINE DESIGN

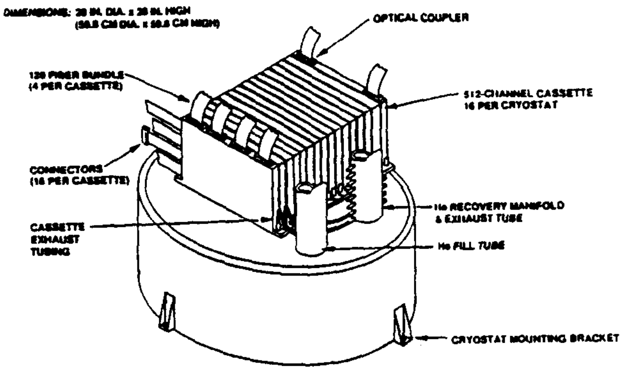
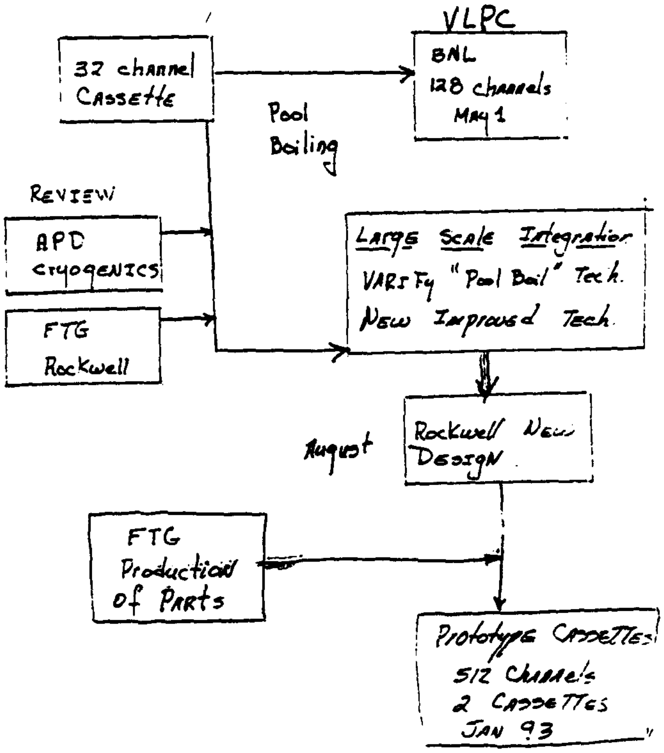


Fig. 5 Conceptual design of a 16 cassette cryostat. The funding request proposes only to build a cryostat capable of holding two cassettes. This will be adequate for verifying the design.

VLPC - Cryogenics

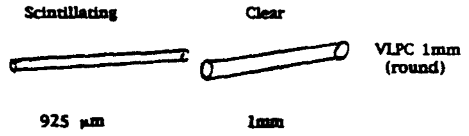


VLPC - Development

HISTE - III	**Excellent**
November 1	**HIST - III**

Anti-Reflective coating S13N4

New Mask Set 1mm



Characterize one lot of HIST IV Range of Materials

November 1, 1992 (start)

Final VLPC Design Optimization of SSC.

Contact Resistance

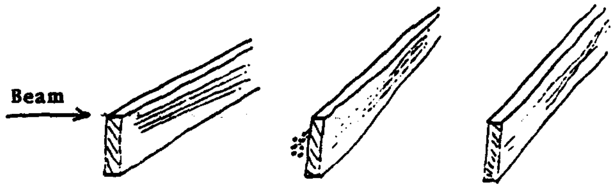
Latch-up Suppression

Fully Optimized Q. E.

July 1993 (start)

Production of 10,000 channel lot of VLPCs

BEAM TEST AT BNL



Ribbons accurately placed on flat 4.3 m x 1.6 cm boards

Readout with HISTE III VLPC

Custom made cryostat (design by Rockwell)

- **128 VLPC channels (min)**
- **3 double sided superlayers**
- **830 µm 3 HF fibers (1000 ppm) (Bicron order has been placed)**
- **2 x 10 doublet ribbons**

Goals of the BNL Beam Test

Start May 1992

Operation of 128 channel system

Produce accurate ribbons

- Bicron
- Kuraray
- FTG

Light yield from 4.3 meter fiber with SDC length waveguides

Measure resolution
  checks fiber placement

Stability of system for 1 month run

Self Trigger (3 superlayer trigger)

Accurate Ribbon Fabrication

SSC Quality Ribbons

$< 25\ \mu m$ $\left\{ \begin{array}{l} \text{center to center misplacement} \\ \text{100 x 2 doublet ribbons} \end{array} \right.$

Attempt 512 x 2 doublet ribbons

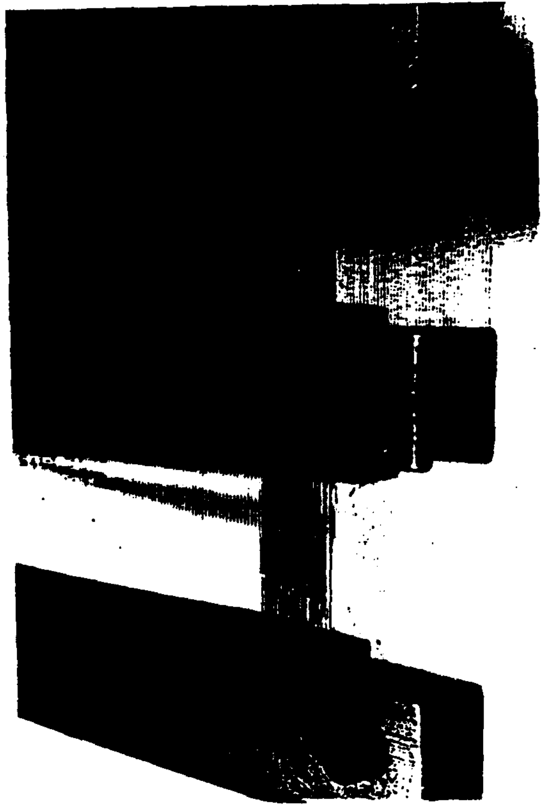
4.5 m ribbons with 10 cm free ends

Ribbon fab at Bicron with FTG participation

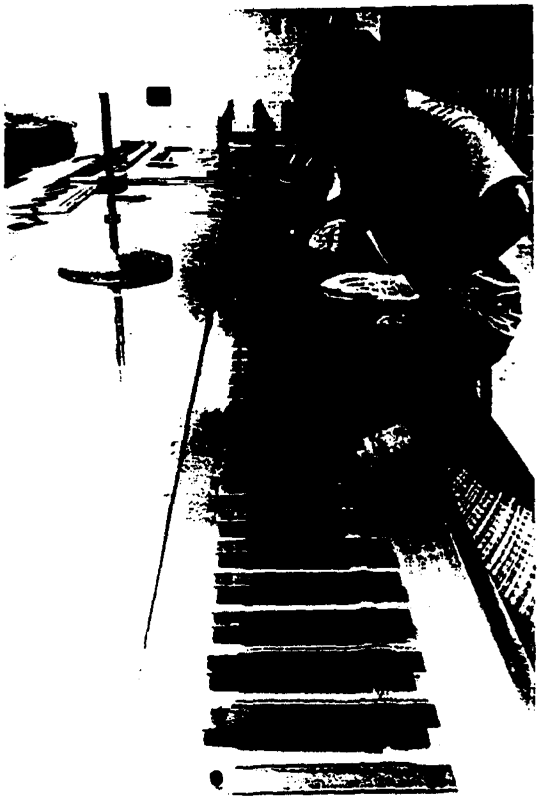
- check environment
- quality of product
- material for ribbons
- refinement to process

Kuraray Ribbons

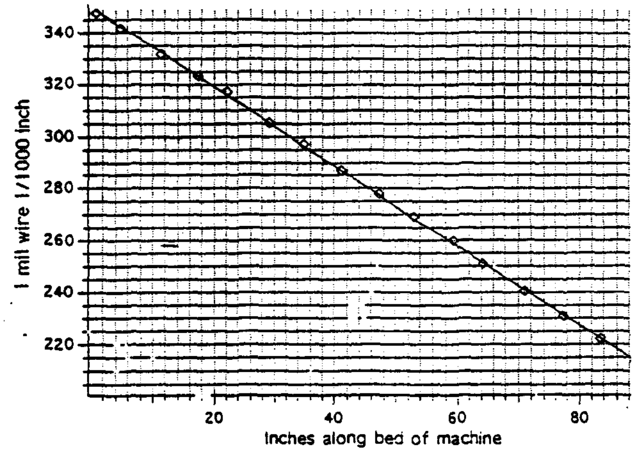
00929



00930



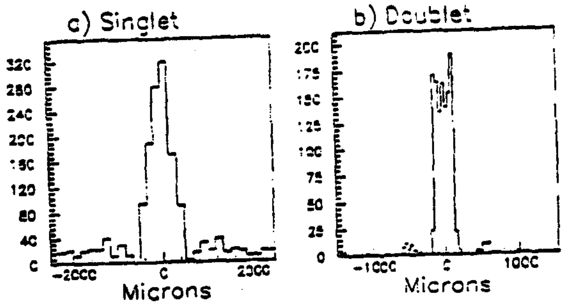
00931



σ ≤ 12μm Error consistant with measuring Error.

Ribbon
Making Jig.

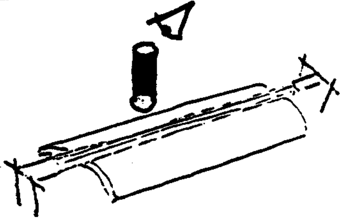
00932



Resolution measured in test beam experiment T-831.
A) A single layer ribbon
B) A double layer ribbon.

00933

Accurate placement of ribbons on curved surface

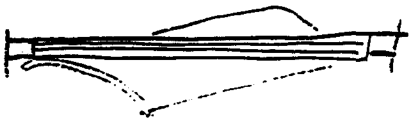


Development of placement technique

Check of placement of fibers on curved surface

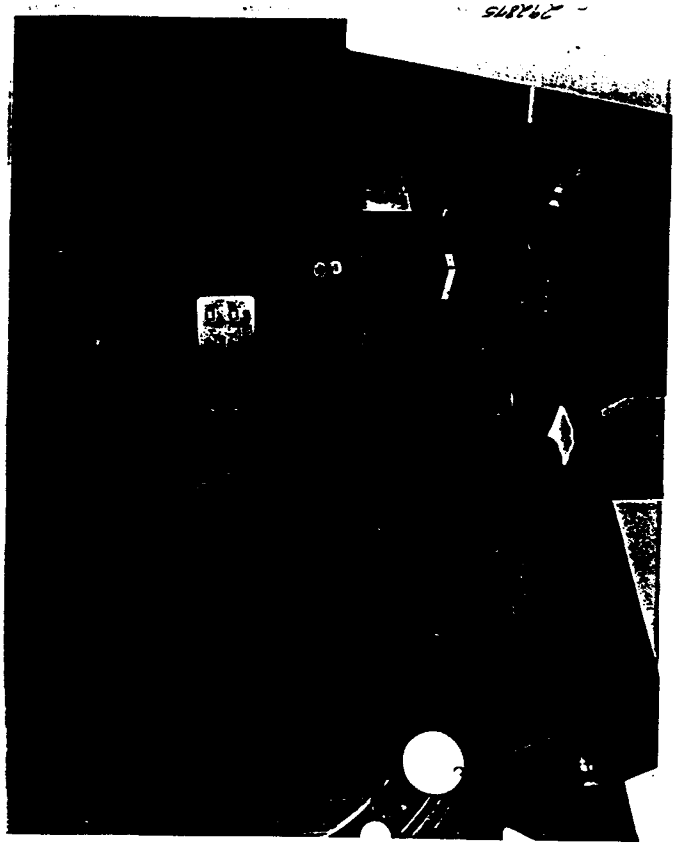
Placement of fibers on curved surface

ATTempt

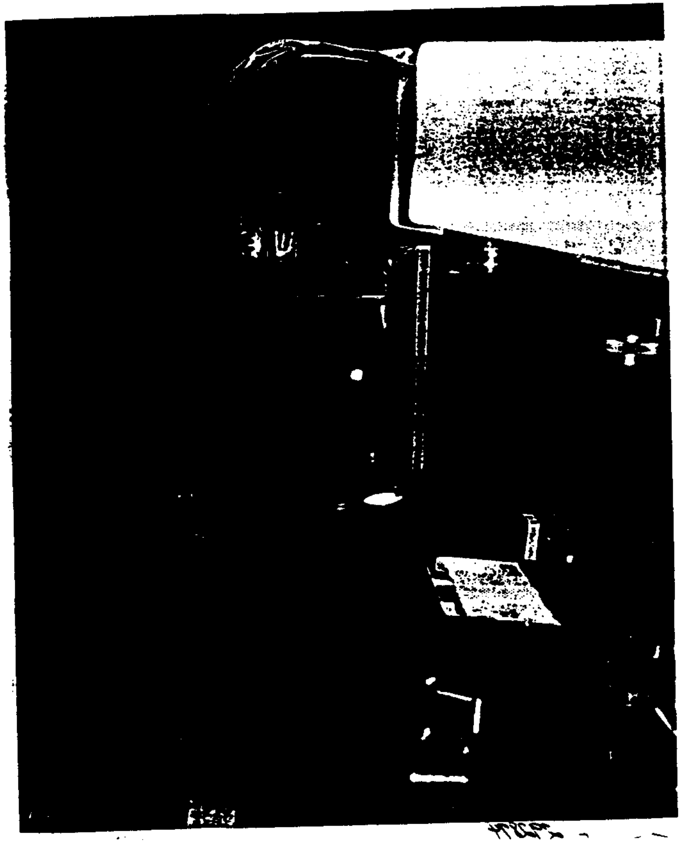


Stereo placement of ribbons

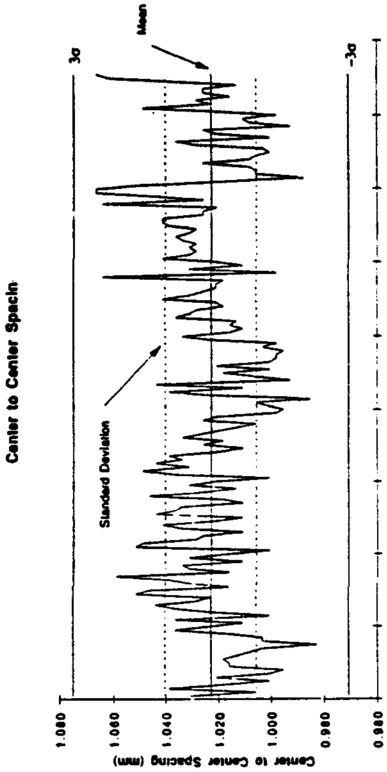
00934

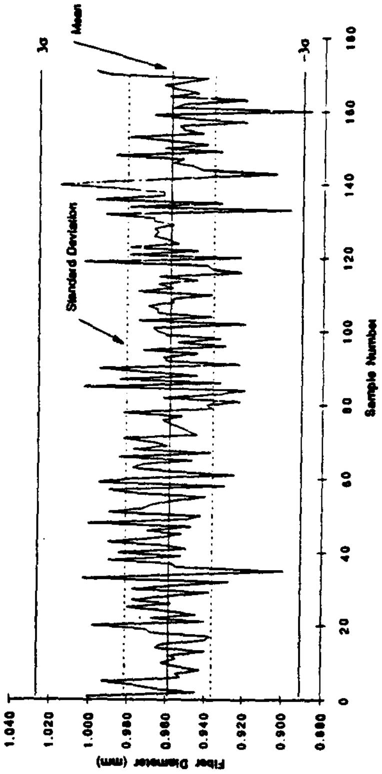


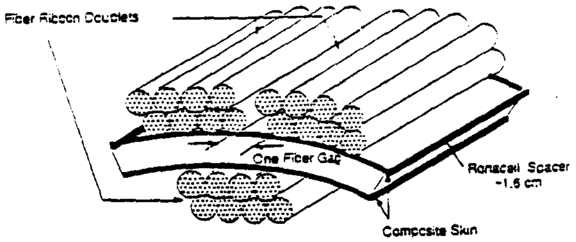
00935



00936



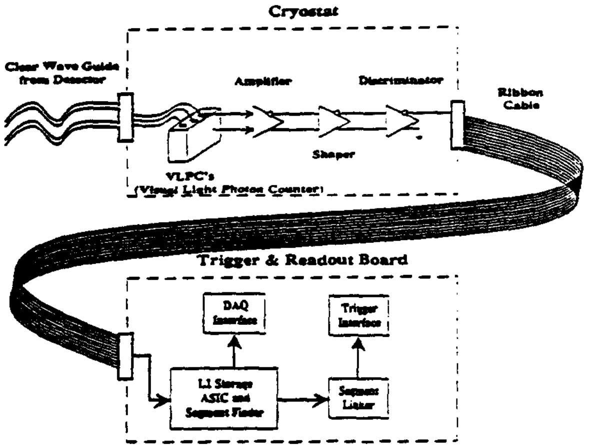


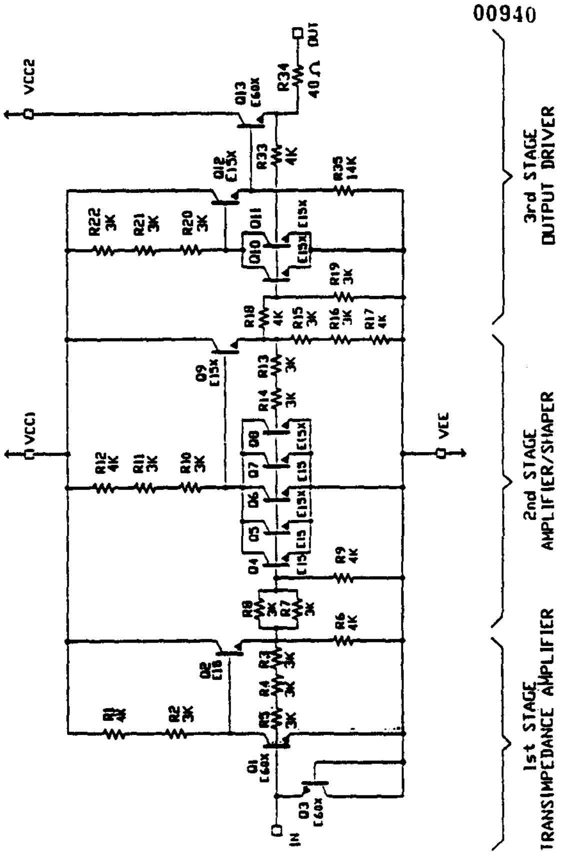


Cosposite Cylinders

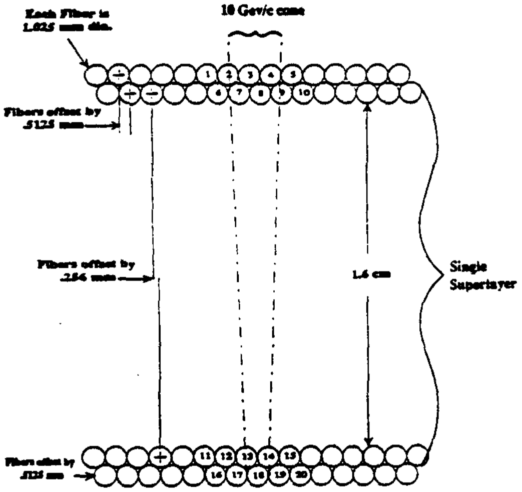
- Carbon Fiber Epoxy Skins ~ .6 mils
  Thick
- First Flat 'plane' boards
  4.3 m x 15 cm x 1.6 cm
  (In hand for BNL)
- 2 prototype Cylinders
  Now In production
  at HERcules (Finish July)
- TesT stand at FNL
  (Cosmic Ray)
- STudies
  - Accuracy
  - Moisture test
  - Radiation
  - Temp
  - Surface

Scintillating Fiber Front End Electronics





Track Segment Finding Algorithm



Acceptance cones for 10 GeV tracks in single fiber bins

KLK
01/22/92

FLUORESCENT DYE DEVELOPMENT

STANDARD MATERIAL

PS/PTP/3HF (KURARAY/BICRON) ~530 nm FIBER

	FTG0 -	MOPOM/K27	~ 500 nm	FIBER
	FTG 1 -	DBTem-POPOP/K27		
	FTG2 -	BC447	~ 540 nm	FIBER
	FTG3 -	KAUFFMAN - A	~ 525 nm	
	FTG4 -	KAUFFMAN - B	~ 525 nm	
•	FTG5 -	BCF99-42	~ 530 nm	FIBER
•	FTG6 -	KELLEY - A	~ 530 nm	DRAWING FIBER
•	FTG7 -	KELLEY - B	~ 530 nm	PREFORMS
	FTG 8 -	KELLEY - C KAUFFMAN	PROPOSED FOR DELIVERY SUMMER 92	

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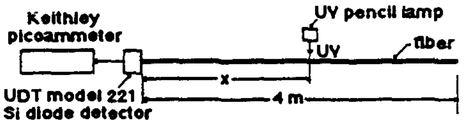
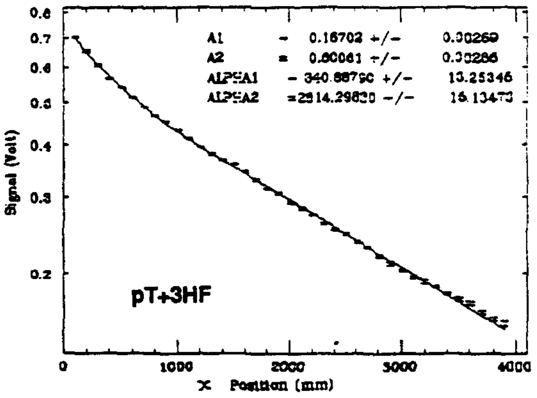
2. Attenuation lengths

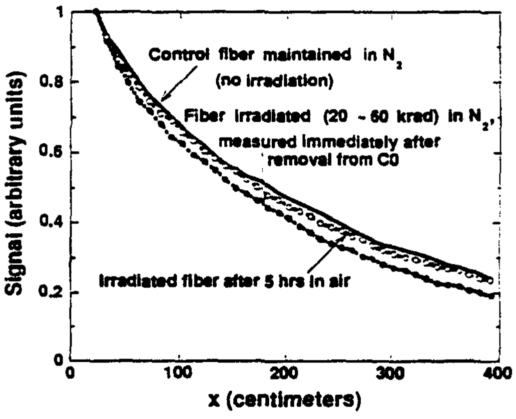
Measured by excitation with ultraviolet.





Typical transmission measurement for a fiber. The smooth curve is a fit using the sum of two exponentials.

RESULTS (pT+3HF)



**Transmission curves
(normalized to unity at x = 22 cm)**

TEST CONDITIONS
for clear and scintillating waveguides

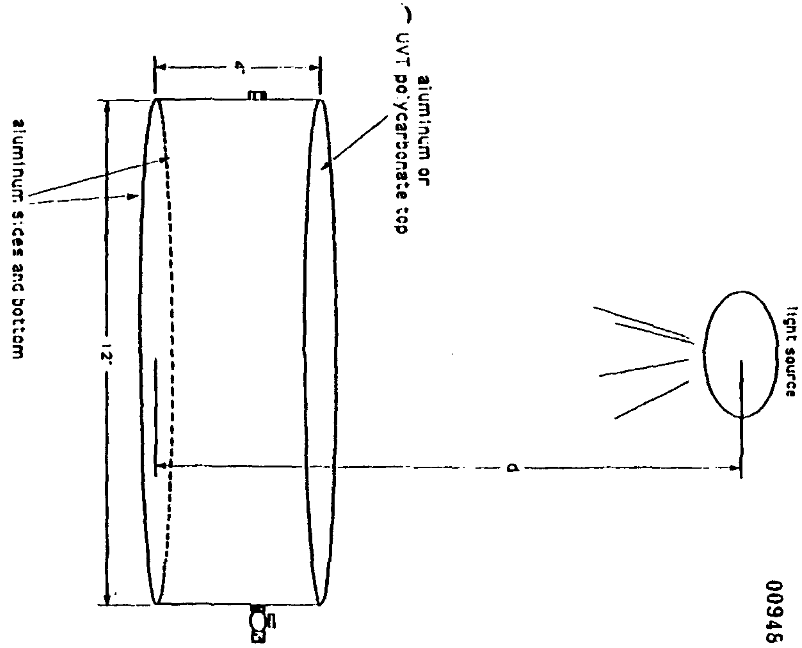
	light sources				
environment	dark	cool white fluorescent	multi-vapor high-intensity discharge	incandescent	type OC photographic safelight
dry nitrogen	Al and UVT	UVT	UVT	UVT	UVT
dry air	Al	UVT	UVT	UVT	UVT
humid air	Al	UVT	UVT	UVT	UVT
distilled water	Al				
isopropyl alcohol exposure	Al				
body oils (hands)	Al				
epoxy	Al				

Al = aluminum lid
UVT = ultraviolet transmitting polycarbonate lid
(Polycast SUVT-3)

Long term test of environment and lighting on scintillating and clear waveguide fibers

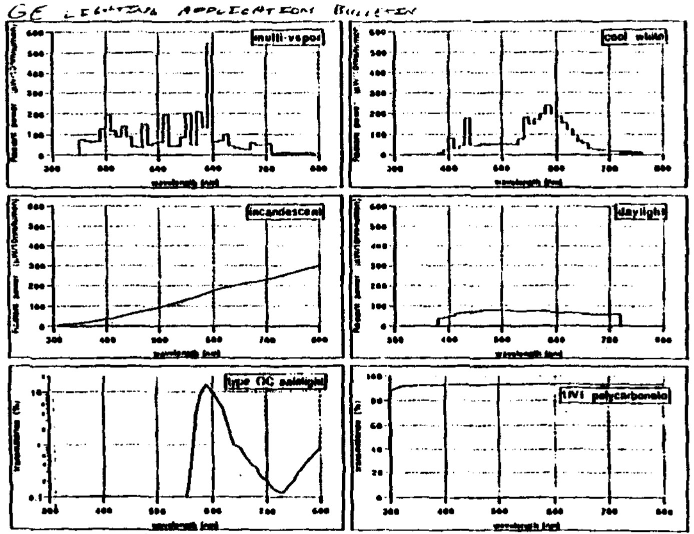
C. John Schmitz
Purdue University

4 March, 1992



) SOURCES:

GE LIGHTING APPLICATION BULLETIN



HANDBOOK OF KODAK PHOTOGRAPHIC FILTERS

POLYCAST INFORMATION

Goals of the Fiber Tracking Group in 1992

Beam Test of 3 superlayer prototypes at BNL

Accurate Ribbon Fabrication at Bicron and Kuraray

Accurate verfication of SDC quality ribbons

Accurate placement of ribbons on cured surface

Refinements to VLPC
(improve Q.E., contact Ω, latch up . . .)

Brassboard (512 channels)

Warm Amp development

PARALLEL SESSION C:

CALORIMETRY

00951

REQUIREMENTS AND SUMMARY OF CENTRAL CALORIMETER DESIGN

J. PROUDFOOT

SDC Central Calorimeter Design

Requirements and Summary

J. Proudfoot
May 5, 1992

- Function
  - *Measurement of electrons, photons, jets & missing energy*
- Mechanical Design Overview
  - *Hadron: Stacked Fe Plate*
  - *Electromagnetic: Cast Pb Sheet*
- Optical System Overview
  - *Scintillating Tile with Wavelength-shifting Fiber*
- Performance Issues
  - *Hadron Calorimeter*
  - *Electromagnetic Calorimeter*

Table 0-1
Performance requirements on the SDC calorimeter.

Parameter	Requirement	Basis
η max for $e^\pm$ ID	2.5	$H \to 4e, 2e2\mu$
EM efficiency loss in $\lvert\eta\rvert < 2.5$	$< 5\%$	electron ID
η max for jets	5	SUSY searches
Gaps in full jet coverage, $\lvert\eta\rvert < 5$	$\leq 1\%$	Missing-E_t
EM energy resolution,		$H \to \gamma\gamma, Z' \to ee$
stochastic term	$\leq 15\%/\sqrt{E_t}$	
constant term	$\leq 1\%$	
EM transverse segmentation	0.05	$H \to 4e, H \to \gamma\gamma$
Hadronic energy resolution,		dijet mass resolution
stochastic term	$\leq 70\%/\sqrt{E_t}$	
constant term (single $\pi^\pm$)	$\leq 6\%$	
Hadronic transverse segmentation	0.10	dijet mass resolution
EM residual nonlinearity	$\leq 1\%, E_t > 10$ GeV	$ee,\gamma\gamma$ mass resolution
Jet residual nonlinearity	$\leq 1\%$/TeV, $E_t > 2$ TeV	compositeness search
Dynamic range (EM and HAC)	20 MeV-4 TeV	e ID, compositeness
EM depth	22/25 X_0	$ee,\gamma\gamma$ mass resolution
Calorimeter depth ($\eta = 0$)	$\geq 10\ \lambda$	dijet mass resolution

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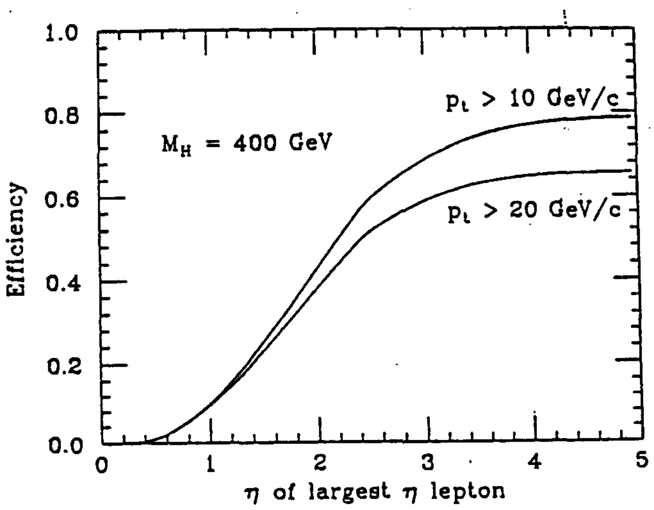
Acceptance for Higgs → 4 leptons



$H \to Z\ Z$

$\hookrightarrow e^+e^-\ \hookrightarrow e^+e^-$

Mechanical Design

{Baseline}

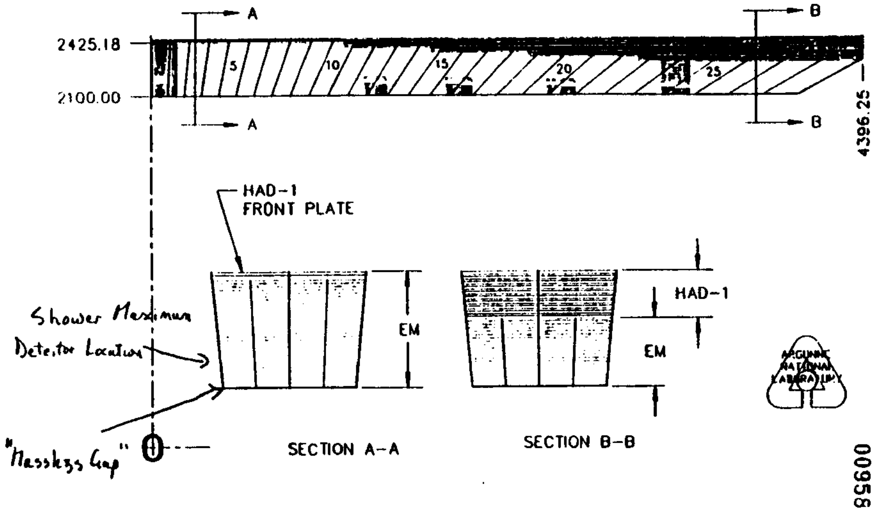
Wedges, granularity 1/32 of 2π
Stacked Fe Plates
Cast Pb Sheet

Table 6-4
Central calorimeter parameters.

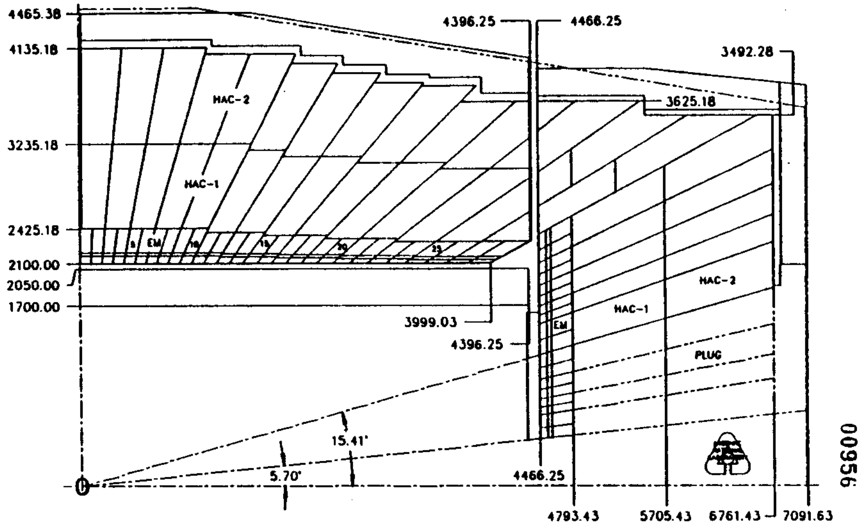
	Barrel			Endcap			
	EM	HAC1	HAC2	EM1	EM2	HAC1	HAC2
Longitudinal readouts	1(2)*	1	1	1	1	1	1
Lateral segmentation	0.05	0.1	0.1	≥ 0.05	≥ 0.05	≥ 0.1	≥ 0.1
Absorber layers	29	28	15	6	17	20	11
Absorber material	lead	iron	iron	lead	lead	iron	iron
Absorber thickness (mm)	4.0	23.95	53.90	6.0	6.0	42.	90.
Scint. thickness (mm)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Cell thickness (mm)	10.0	30.0	60.0	12.0	12.0	48.0	96.0
Depth (not including coil)	21 X_0			6.9 X_0	18.3 X_0		
	0.85 λ	4.14 λ	4.91 λ	0.3 λ	0.8 λ	5.04 λ	5.99 λ

* Possible upgrade.

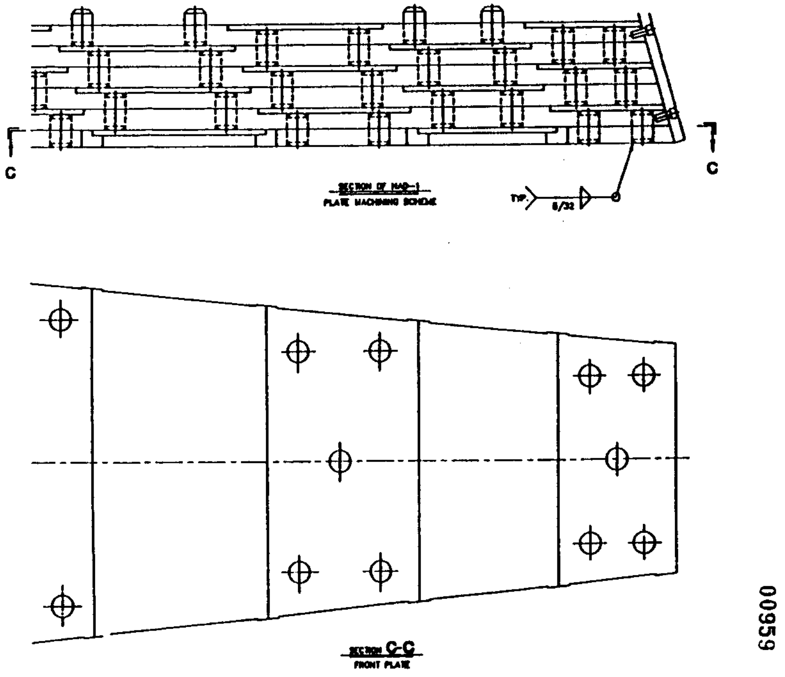
Barrel EM Calorimeter
(Quadrant Cross Section)

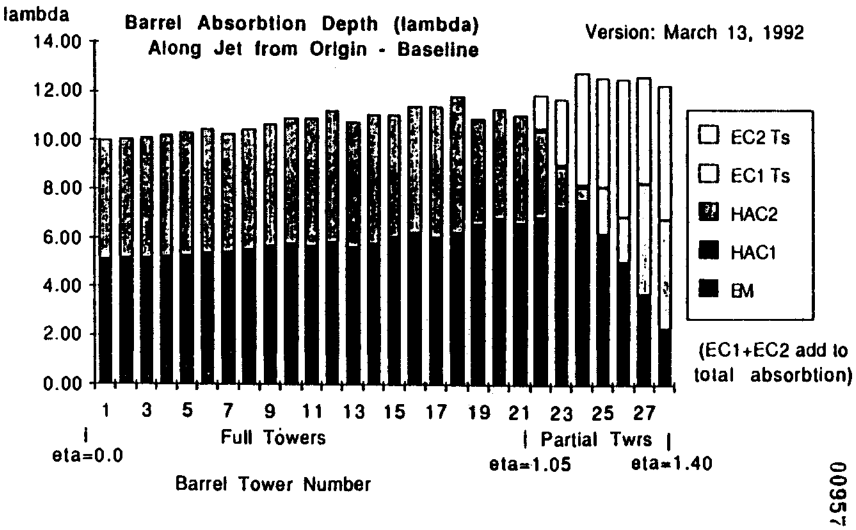


Tile/Fiber Projective Calorimeter
(Quadrant Cross Section)



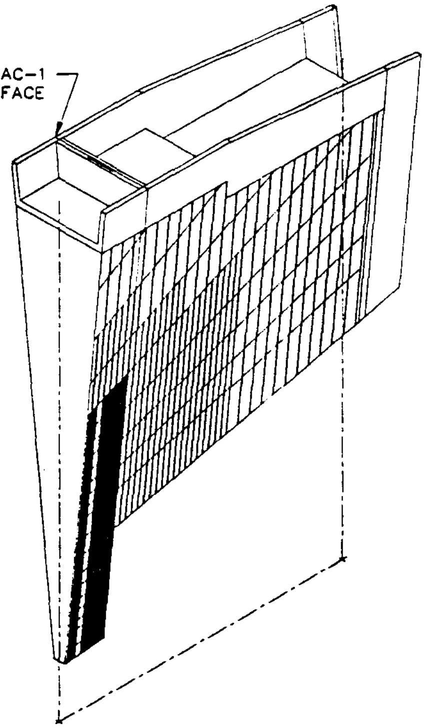
Hadron Calorimeter Fabrication Concept





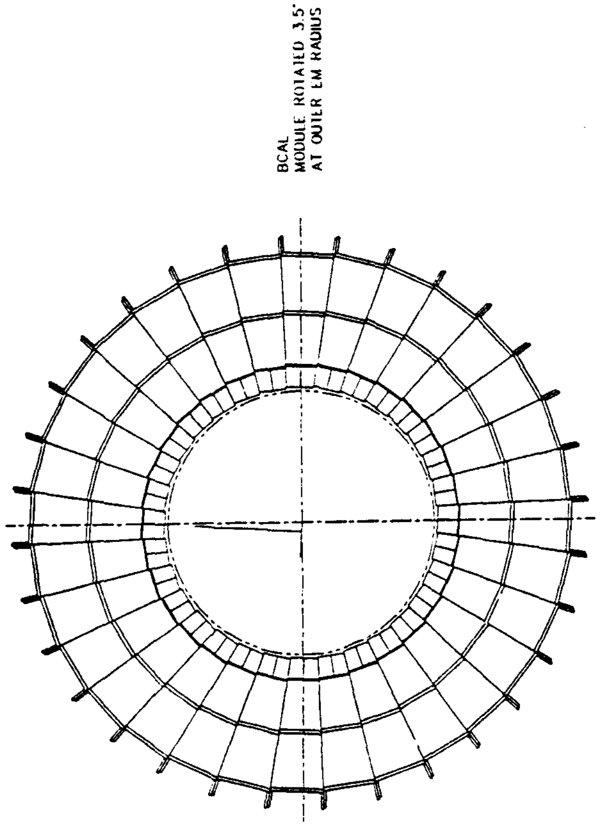
00960

Endcap Wedge Module

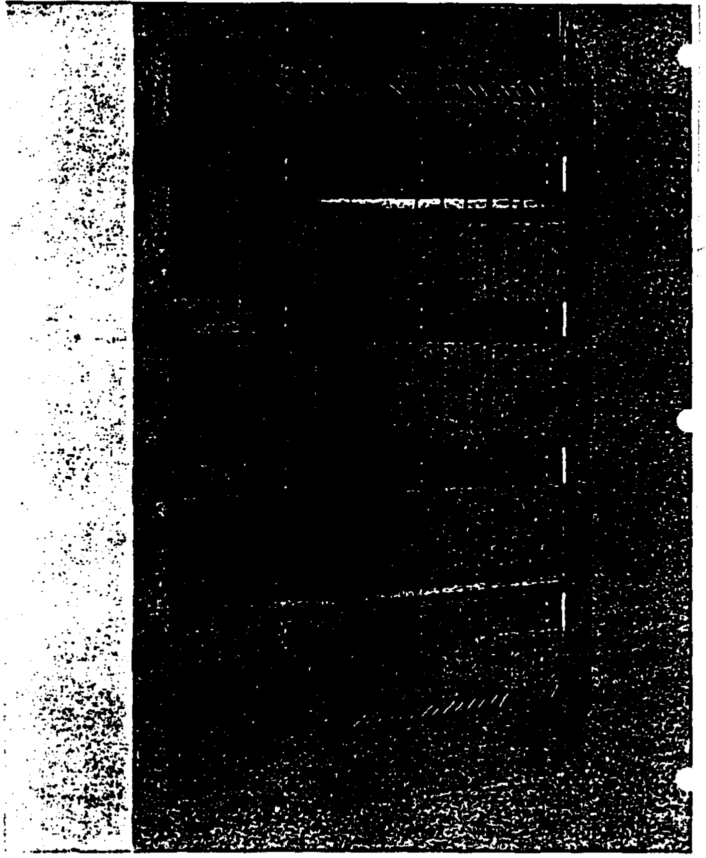


00961

Module - Interaction Point : φ Rotation



00962



00963

Optical System Design Overview

Scintillating Tile

\+

Embedded Wavelength Shifting Fiber

\+

Tile Reflective Mask / Wrapping

\+

{Tile Edge Preparation}

\+

Plastic Optical Fiber

\+

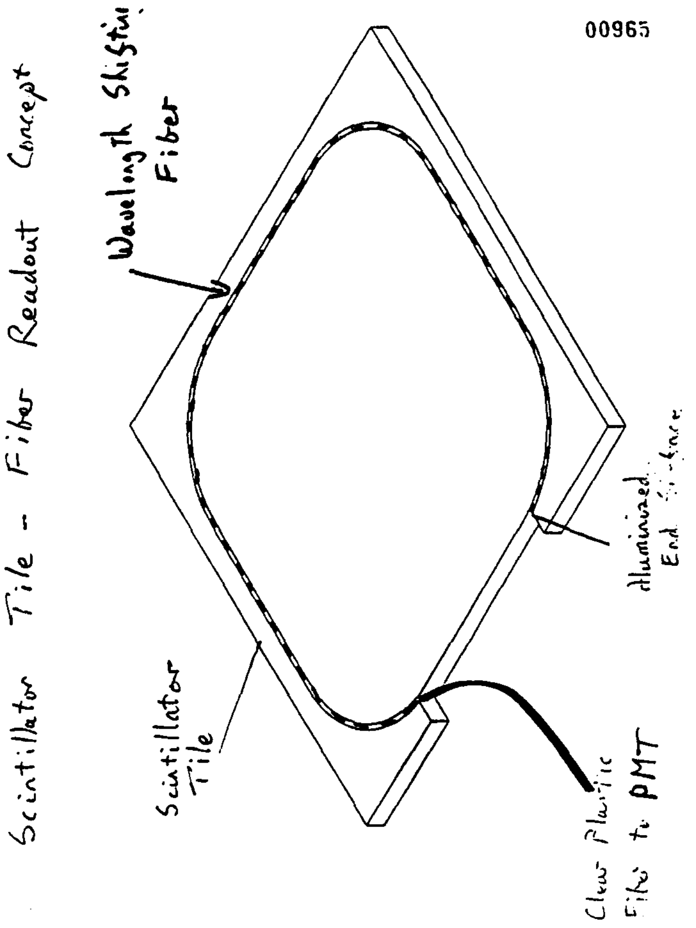
Neutral Density Mask

\+

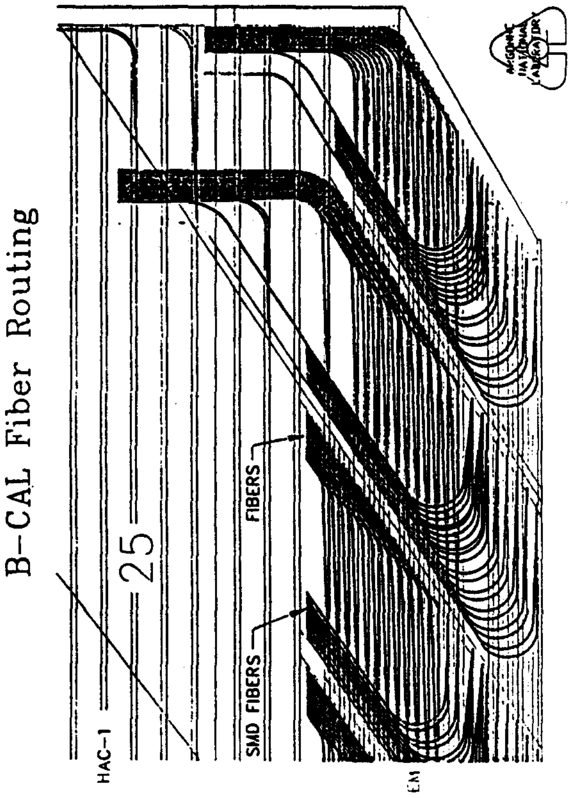
Photomultiplier

\+

{Calibration System}



Scintillator Tile - Fiber Readout Concept



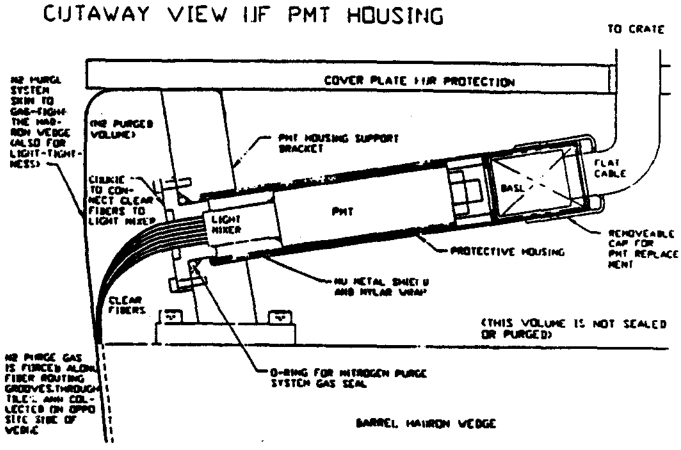
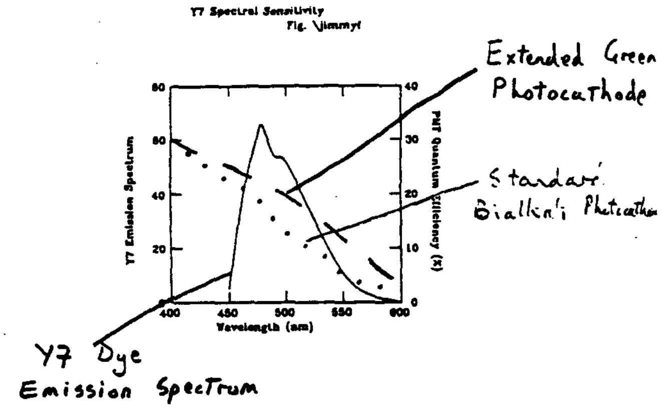
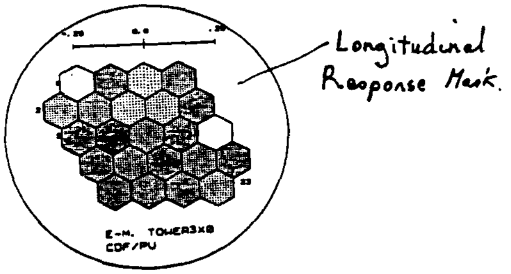


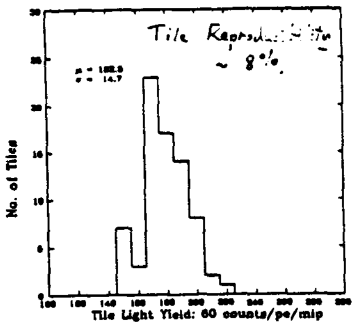
Figure 7.2 Design for a Photomultiplier Tube Mount showing cover plate, N2 purge, μ metal shield, cookie, mixer, and base.

Y7 Spectral Sensitivity
Fig. \jimmy\



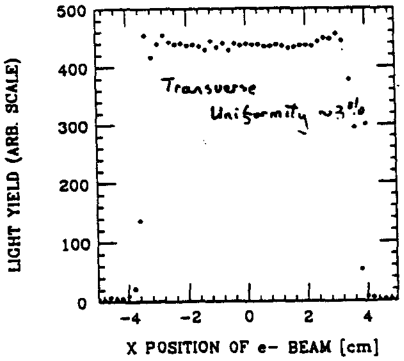


EM Test Module No. 1: Light Yield



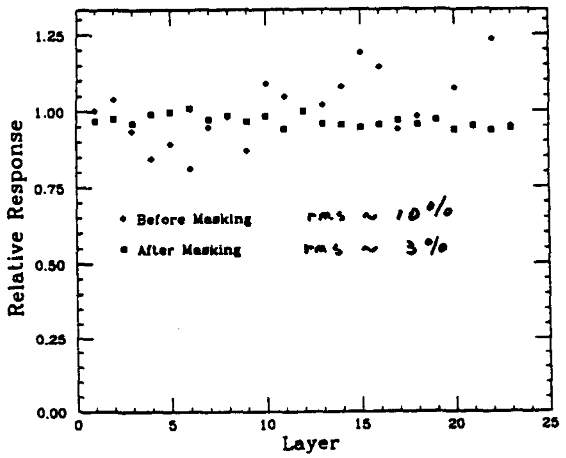
Scintillator tile light yield at center as measured by collimated Ruthinium source

UNIFORMITY OF σ TILE LIGHT YIELD



Longitudinal Mask – Typical Performance

EM Tower, Relative Response by Layer



Hadron Calorimeter

Performance Issues

Energy Resolution
{ stochastic term, constant term}

e/pi Response
{ linearity, constant term}

Transverse Segmentation
{ Isolation, Jet Mass determination}

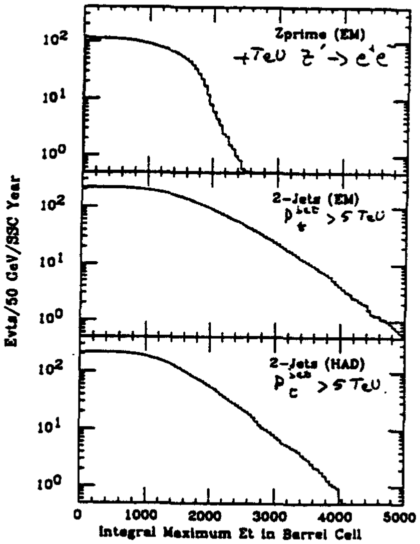
Longitudinal Segmentation
{leakage correction}

Hermiticity
{energy loss}

00972

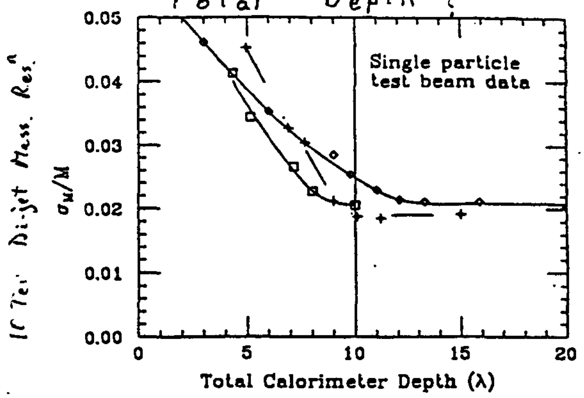
Figure calreqfiga. calorimeter chapter

Events with $E_T > E_T$(test)

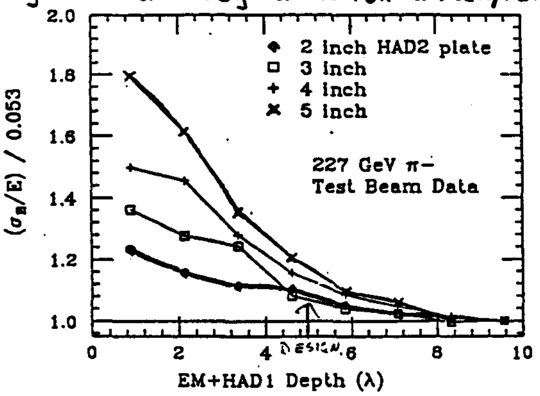


00973

Total Depth ?



Longitudinal Segmentation & Sampling



00974

-20-

Hadronic Shower Profile: 100 GeV π.

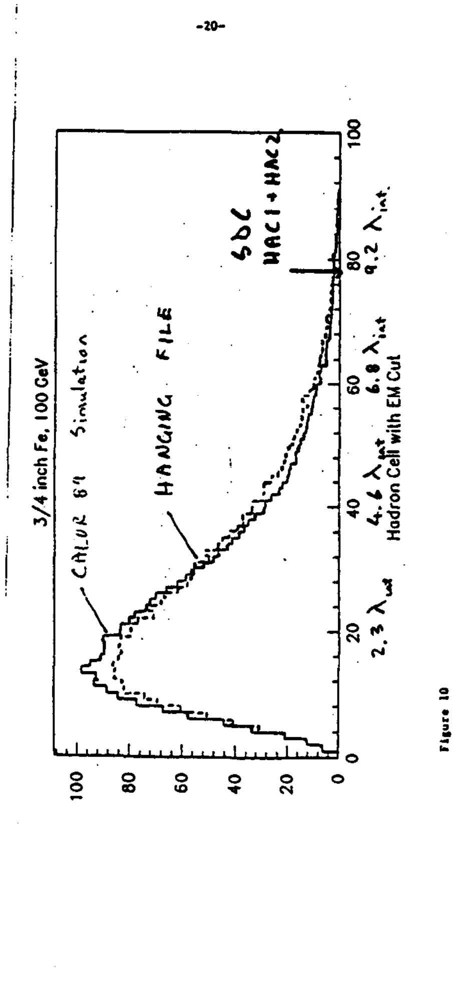
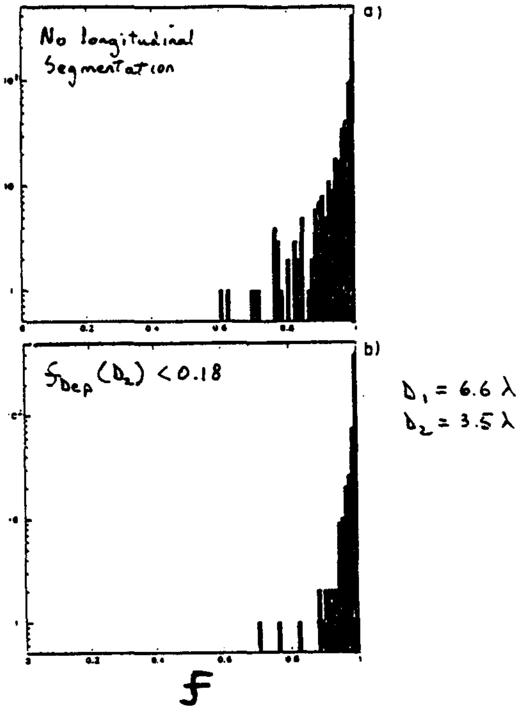


Figure 10

00975

Containment Fraction for 450 GeV Beam



16. The distribution, for 1000 events, of the containment fraction f for 450 GeV incident beam.

a. D = 10.1 calorimeter, no longitudinal segmentation.

b. D = 10.1 calorimeter with D1 = 6.6 and D2 = 3.5 longitudinal segmentation. The fractional beam energy, Δ, in the back, D2, segment must be < 0.18.

Linearity & Constant Term

Studied using CALOR89 hadron shower simulation code, the "Hanging File" beamtest and ISAJET.

Model A: *Fe Hadron Calorimeter , close to the version described in the TDR.*

Model B: *Pb Hadron Calorimeter with a similar sampling plate thickness to the Fe design.*

Table 6-8
Jet response (barrel), $a/\sqrt{E} \oplus b$, from a CALOR89 simulation.

Case	τ	nonlinearity* 0.1 TeV	at 1 TeV	at 10 TeV	$a\sqrt{\text{GeV}}$	b
Model A	16 ns	0.918 ± 0.002	0.962	0.998	0.633 ± 0.002	0.019
Model A	96 ns	0.922	0.964	0.998	0.56	0.016
Model B	16 ns	0.967	0.982	0.998	0.52	0.014
Model B	96 ns	0.997	1.00	1.00	0.44	0.010

* Nonlinearity defined as E_t(measured)/E_t(true).

Linearity : Pb vs Fe ?

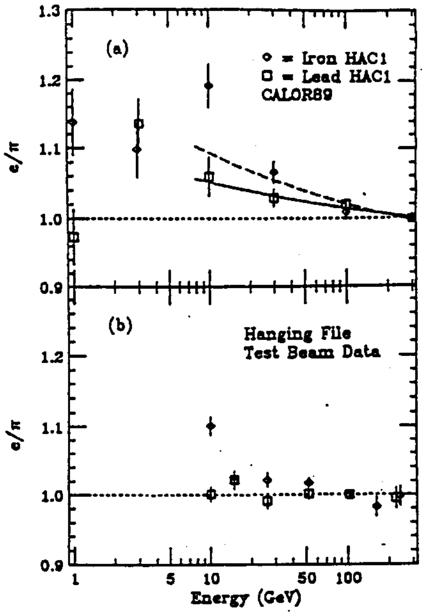


FIG. 6-11. (a) e/π vs energy as predicted by CALOR89 for 16 ns integration time for iron HAC1 (solid) and lead HAC1 (dashed). (b) e/π measured by the hanging file calorimeter (96 ns integration).

Hadron Calorimeter Transverse Segmentation.

Di-jet Mass : $H \to WW \to \ell\nu + 2$ jets.

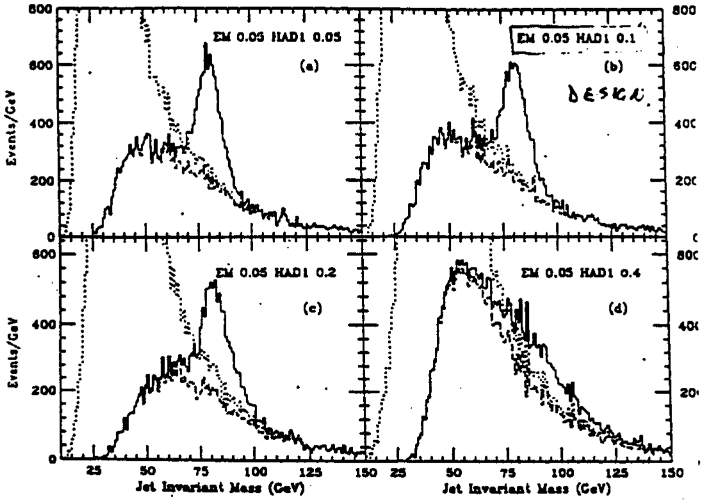


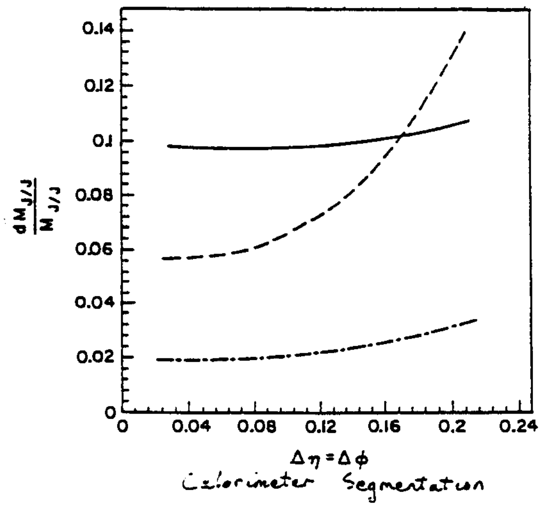
FIG. 3-30. The invariant mass distribution for the highest p_t jet in $H \to WW \to \ell\nu + 2$ jets ev

(a) with an EM segmentation of 0.05 and a HAD1 segmentation of 0.05
(b) with an EM segmentation of 0.05 and a HAD1 segmentation of 0.1
(c) with an EM segmentation of 0.05 and a HAD1 segmentation of 0.2
(d) with an EM segmentation of 0.05 and a HAD1 segmentation of 0.4

Mass Resolution

$Z^0 \to$ jet jet

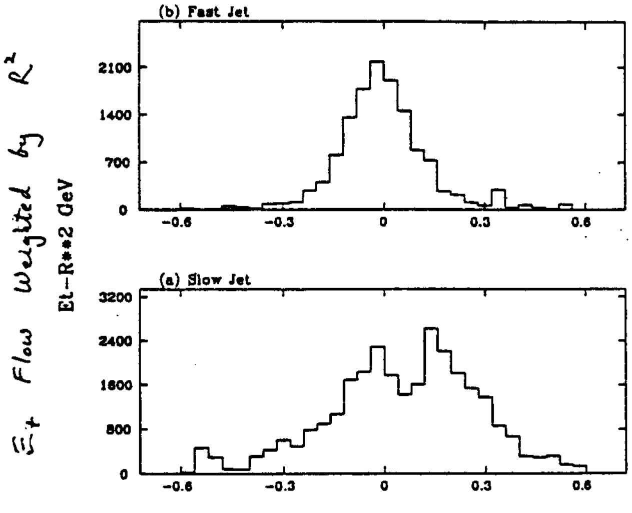
with $P_t^Z = 0.55$ TeV.



$Z^0 \rightarrow$ Jet-Jet.

$p_t^Z > 500$ GeV/c

Parameterised Shower Response



Projection on Parallel Axis.

Figure (5)

Z^0 Mass Resolution wrt Cell Size

Cell Size	Z Mass Res. (GeV)
0.2	13.3
0.1	4.6
0.05	2.6
0.025	1.6

Electromagnetic Calorimeter

Performance Issues

Resolution *{Pb/Scintillator Thickness, Light Yield}*

Uniformity *{Tolerances}*

Hermiticity *{Tolerances, good fiducial volume}*

Speed *{Noise, Pileup}*

Massless Gap Readout *{Correction for Dead Material}*

- Shower Maximum Detector Integration *{e ID}*

Calibration *{Precision}*

- Radiation Induced Degradation *{Precision, Uniformity}*
- Material in Tracking Volume *{e ID efficiency}*
- B Field Effects on Scintillator Response *{Gain Uniformity}*

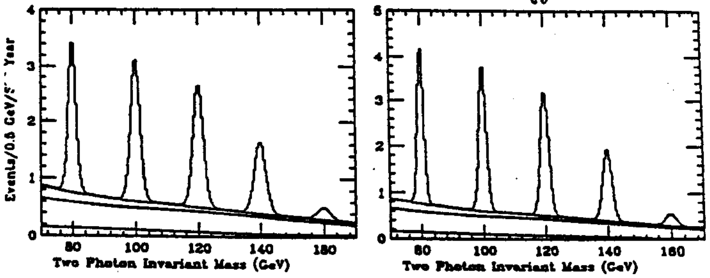
$H \rightarrow \gamma\gamma$.

Table 3-3

Two photon invariant mass resolutions in GeV for events from the $t\bar{t}+H$ process. The entries in the table are the sigma of a Gaussian fit to the signal (in GeV). The simulation was done at the particle level using parametrized resolutions, where "Base" refers to the terms given in Table 3-1. The final columns summarize the resolution expected for the high performance option defined in Section 3.1.1.

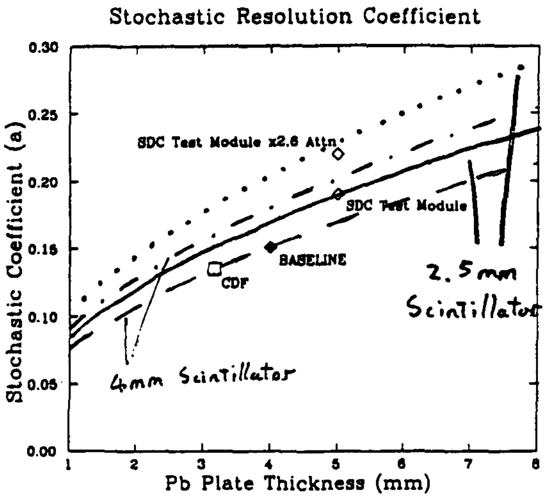
M_{Higgs}	a = Base b = 0%	a = Base b = Base	a = Base b = 2%	$10\%/\sqrt{E}$	a = 9%/14% b = 0.5%	a = 9%/14% b = Base
80	1.08	1.23	1.56	0.67	0.80	0.93
100	1.24	1.44	1.89	0.78	0.93	1.11
120	1.39	1.65	2.19	0.87	1.05	1.28
140	1.52	1.81	2.51	0.96	1.16	1.44
160	1.64	2.00	2.81	1.03	1.25	1.61

Associated Production $gg \rightarrow t\bar{t}H$.



M_{Higgs}	Signal events Baseline resolution	Background events Baseline resolution	Signal events High performance	Background events High performance
60	15.6	7.7	15.8	6.2
100	17.2	7.5	17.5	6.2
	16.9	7.3	17.2	6.3
140	10.7	6.6	10.6	4.9
160	1.9	5.6	1.9	4.3

Lead/Scintillator Thicknesses?

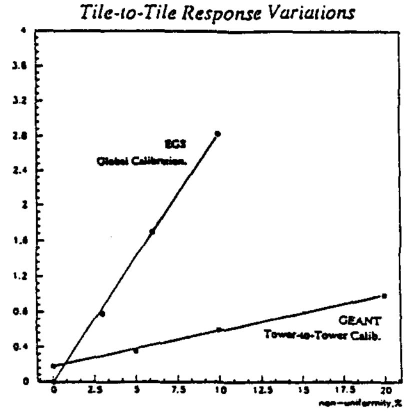


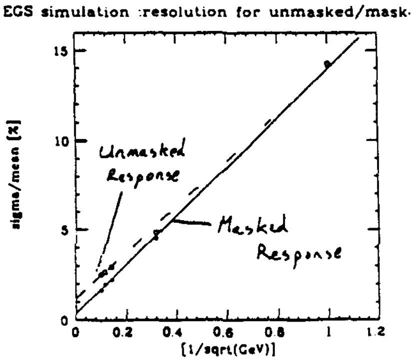
Uniformity

$$\left[\frac{\sigma_E}{E}\right]^2 = \left[\frac{a}{E^{1/2}}\right]^2 + b^2$$

Table 6-5
EM calorimeter constant term budget.

Source of constant term	Contribution
Calibration tower to tower	0.2%
Leakage	0.3%
Transverse uniformity	0.5%
Tile-to-tile variations incl. thickness variations and longitudinal masking	0.5%
Absorber thickness variations	0.2%
Radiation damage	0.5%
Total (added in quadrature)	< 1.0%



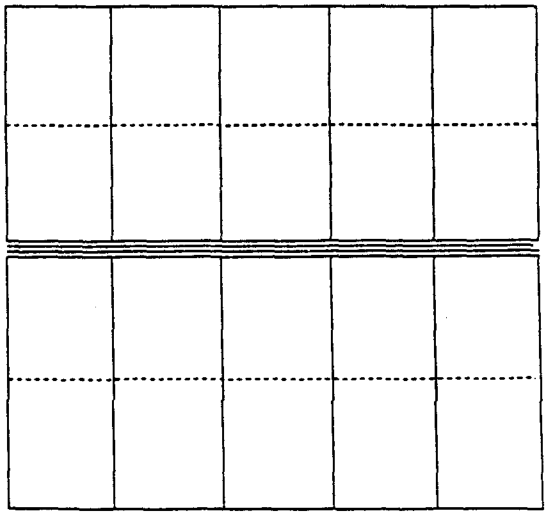


Hermiticity
(cracks)

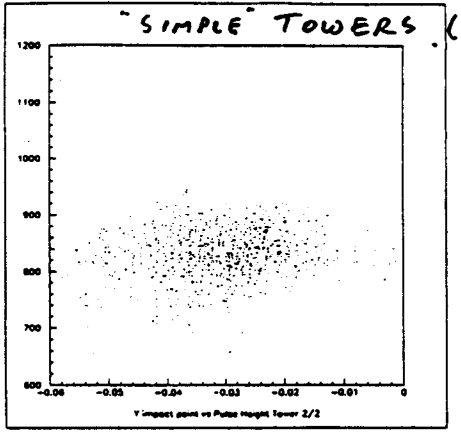
Air Gap Between Towers

Air Gap + Stainless Steel Bulkhead Between Towers

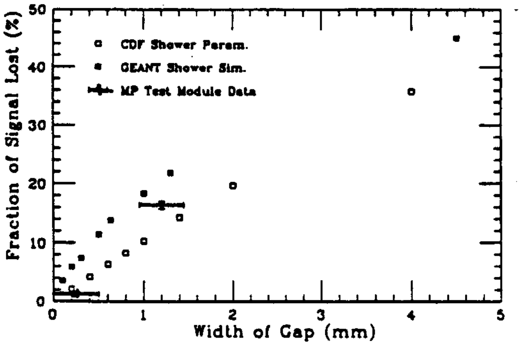
Air Gaps + Skins Between Towers (Diff. Modules)



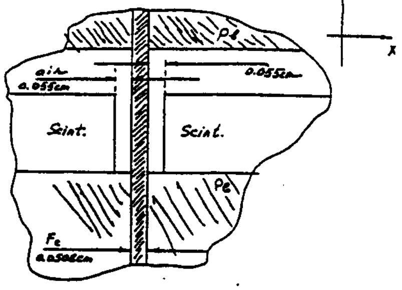
CRACK SCAN ACROSS "SIMPLE" TOWERS (Air gap only)



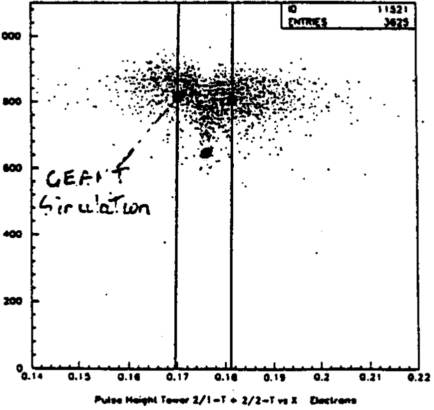
Loss of Signal in Crack Between Towers



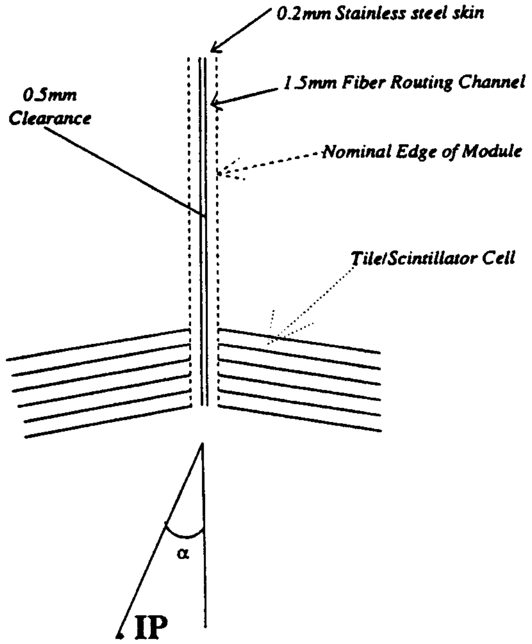
Bulkhead area



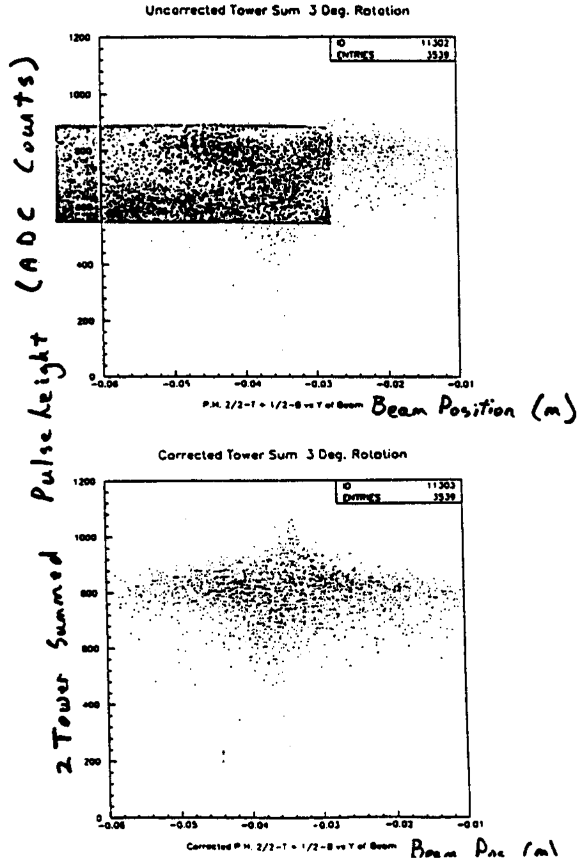
Scan Across Towers Separated by 0.5mm Stainless Steel Bulkhead



InterModule Gap

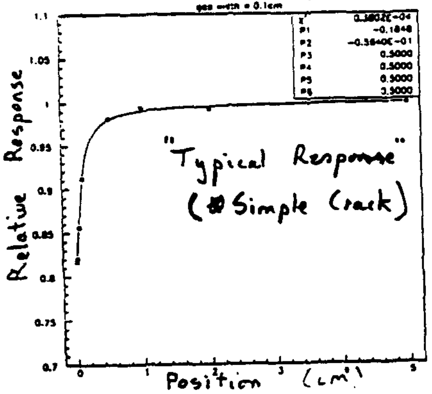


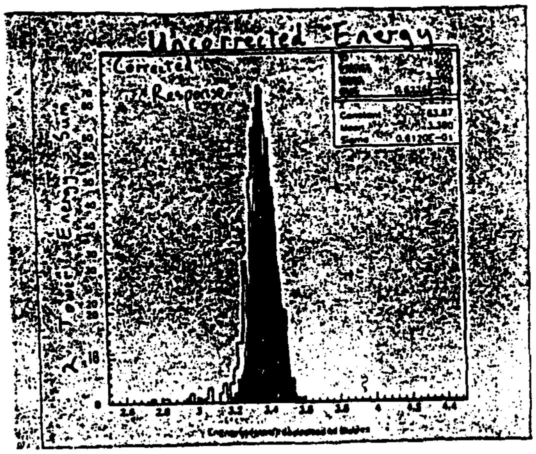
Inter-Module φ Crack Scan



00992

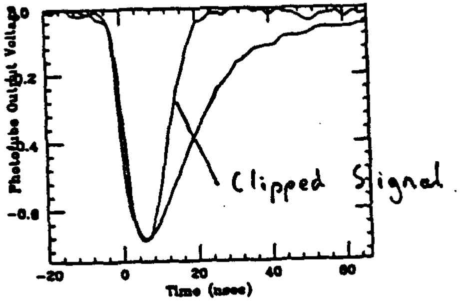
GEANT Simulation: Energy Correction from Parameterisation





00993

Speed
(noise, pileup)

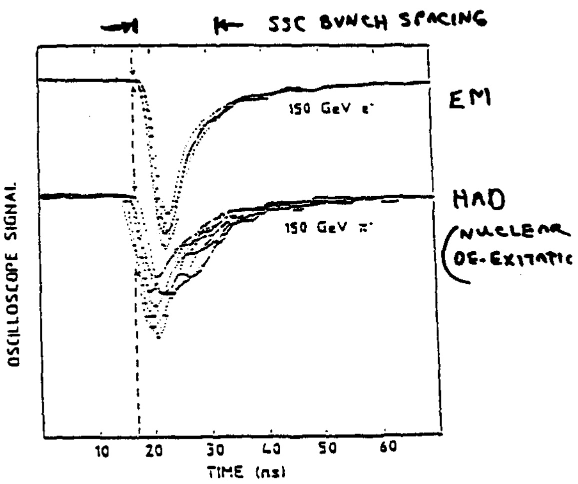


τ_{decay} (K27) ~ 8 nsec. (Optimist) - 10 nsec (Pessimist)

→ Bicron "G2" Even Faster ~ 3 nsec.
(Being Evaluated.)

00994

SPACAL CALORIMETRY
SCINTILLATOR BASED

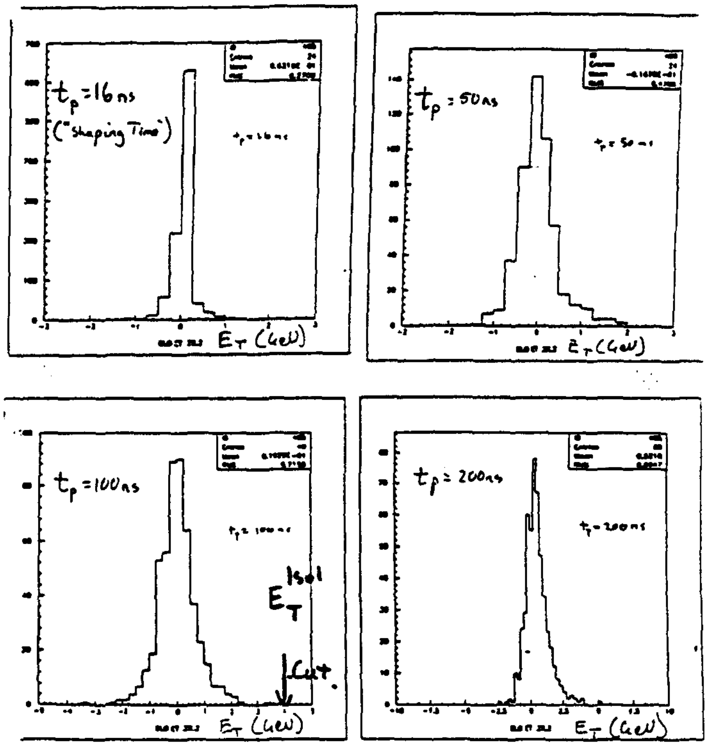


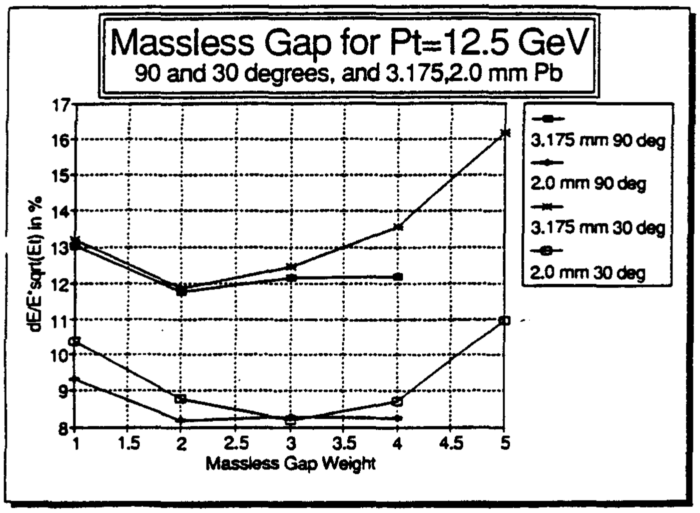
c.f. K27 τ_{decay} ~ 10 ns
G2 τ_{decay} ~ 3 ns.

00995

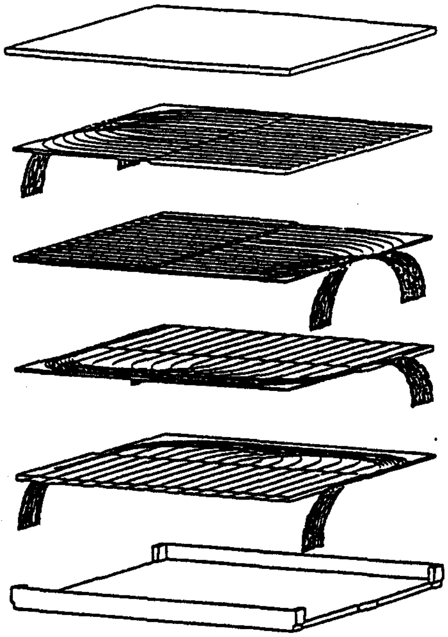
Min Bias Pileup @ Design $\mathcal{L}$.

FIG 3
E_T in .2×.2 cells

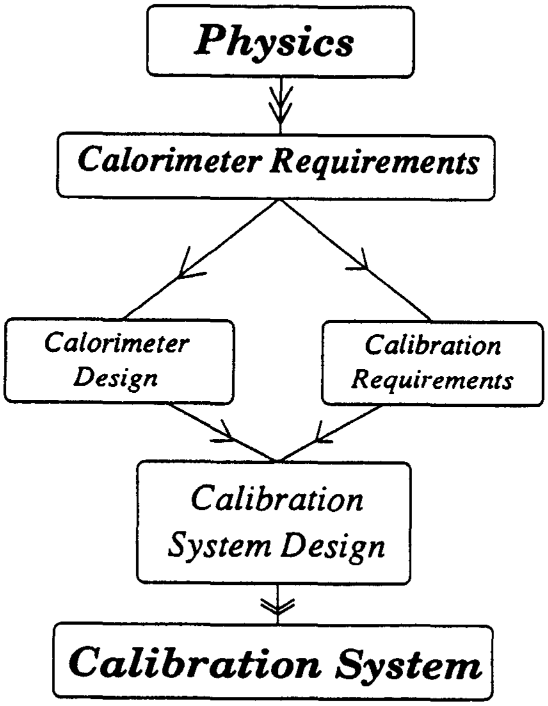




Shower Maximum Detector Integration



Calibration



Physics

Calorimeter Requirements

Calorimeter Design

Calibration Requirements

Calibration System Design

Calibration System

SDC Calorimeter Calibration Requirements

Energy Scale

Tower-to-Tower Variations

Spatial Non-uniformity

Temporal Stability

Timing

Radiation Damage

Linearity & Dynamic Range

Timing Resolution

CALIBRATION SOURCE TUBES

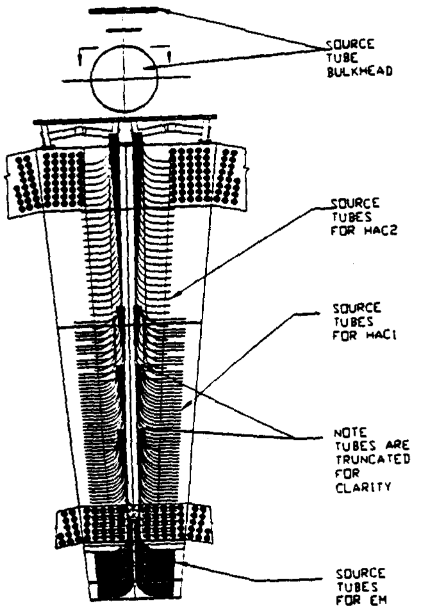


Figure 9.2 Layout of the source tubes for a single barrel wedge. Two basic tyubes fan out to the 2 towers of the wedge. Each tile in the wedge is scanned transversely.

Typical Longitudinal Source Scan.
("Raddam" Module)

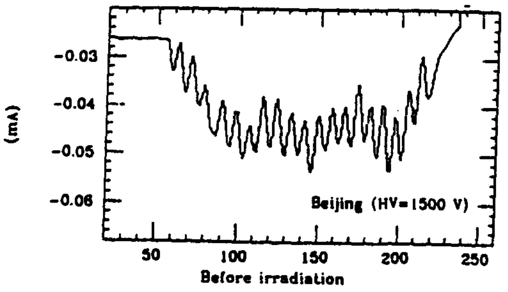
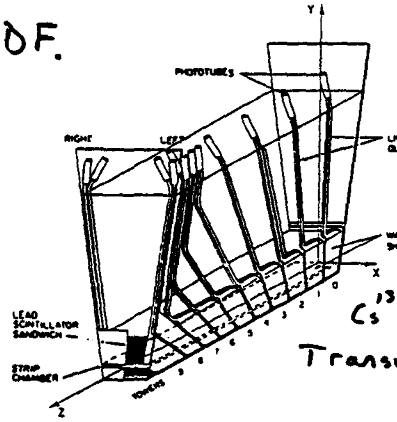


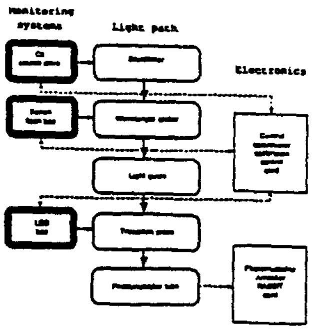
Figure9.1 A plot of PMT current as a function of longitudinal source position. The background dark current is evident, as are the peaks from all 20 tiles. The test module nonuniformity has not been removed by longitudinal masking.

CDF.



Cs^{137}. Tube
Transverse to Tile

1. Schematic of a wedge module of the CDF central calorimeter showing the coordinate system as measured by the strip chamber for test beam energy and mapping measurements. The 45° end plate is in the + z direction; the "left" of the module was defined as being in the + x direction.



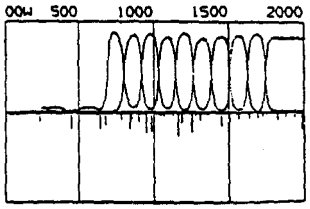
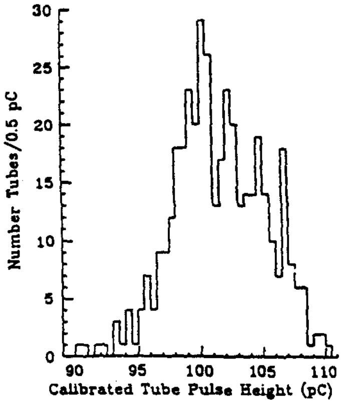


Fig. 4. Typical output of the real-time source monitoring program showing some of photomultiplier current readouts a a ^{137}Cs source travels at a constant rate through a wedge module.

CDF. e^- Beam Response

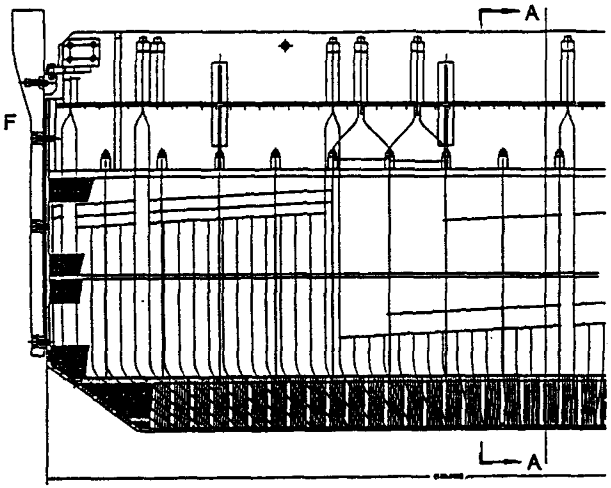
Tube HV
Set using
Cs^{137} Current

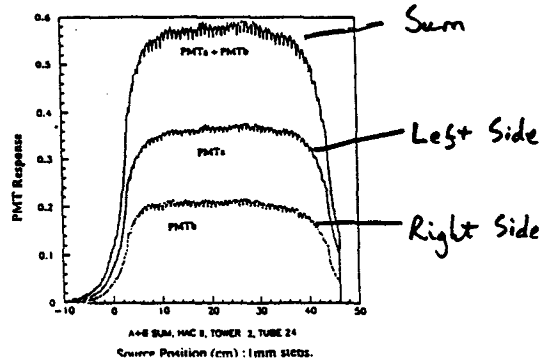


- Mean pulse height for 50 GeV electrons using ^{137}Cs system was 102.0pC. Standard deviation was 3.5% of mean.
- If one averages pulse heights by tube location it removes errors from original determination of target currents. The standard deviation is then 2.5% for Cobalt and 2.9% for Cesium.
- Above implies target currents calculated to accuracy of 1.3% for Cobalt and 1.9% for Cesium.

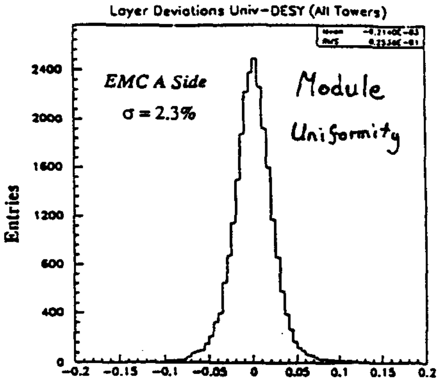
Contribution from non-tracking of source and electron response is estimated to be 2.3-2.4%.

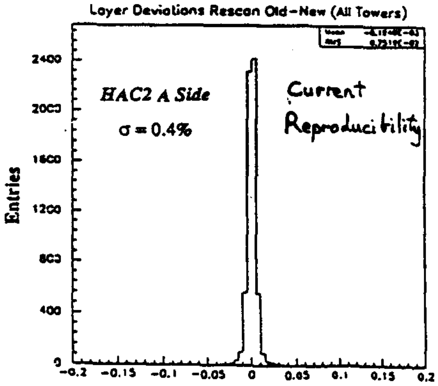
ZEUS. - longitudinal Source Tubes

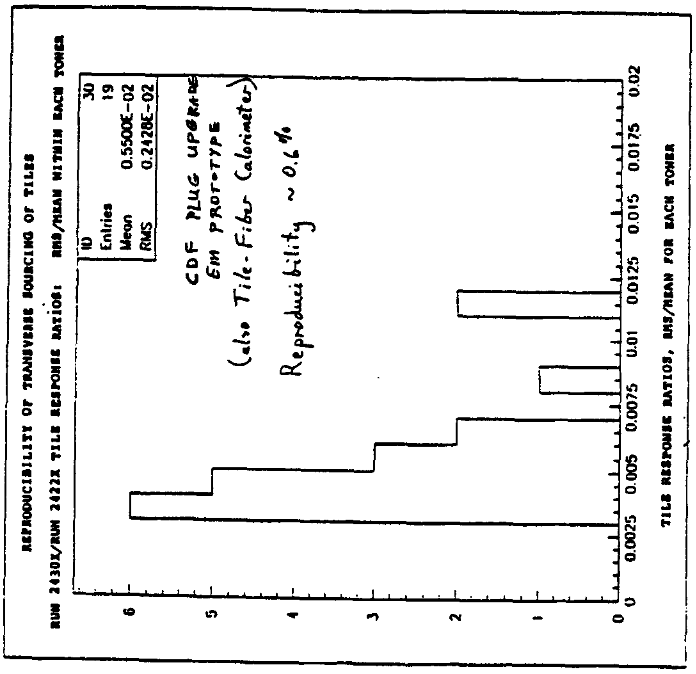




ZEUS : Source Current used for QA.







in situ Calibration

Electrons (Photons)

$W \rightarrow e\ \nu$

$Z \rightarrow e\ e$

Absolute calibration to 0.2% for all towers in the region η *< 2.5. {CDF with 1500 W's achieved an absolute calibration of 0.24% and a relative calibration of 1.7% over 480 towers.}*

Hadrons

Absolute calibration is obtained at moderate energies from E/P for isolated tracks.

Jets

Absolute and relative response as a function of jet Et can be done at the 3% level using a variety of physics processes: dijet balancing; high Pt W and Z production and $\gamma -$ *jet Et balancing.*

Radiation Damage

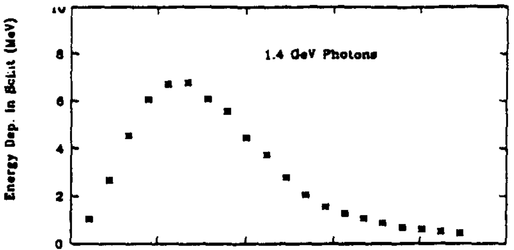
Apply Triage Philosophy

1) Use conventional techniques to improve present day scintillators and wavelength shifters :
additive, fluors, processing.

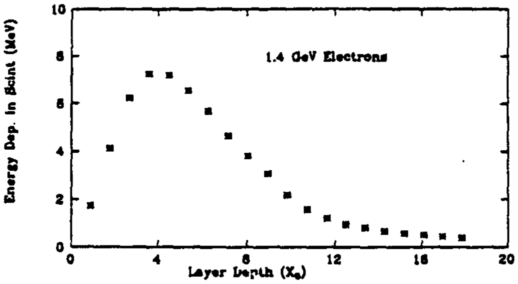
2) Accomodate radiation damage effects within the design of the mechanical and optical systems :
Incorporate refurbishment as a basic concept in the calorimeter design in those areas susceptible to significant radiation induced degradation. Develop techniques and requirements for dynamical correction of response to recover performance.

3) Continue R&D on innovative approaches to resolving the "Raddam Problem":
revolutionary polymers, silica fibers

Damage Mainly from low energy π°/γ.
Characteristic Energy Deposition



Energy deposited in scintillator as a function of depth for 1.4 GeV incident photons



Energy deposited in scintillator as a function of depth for 1.4 GeV incident electrons

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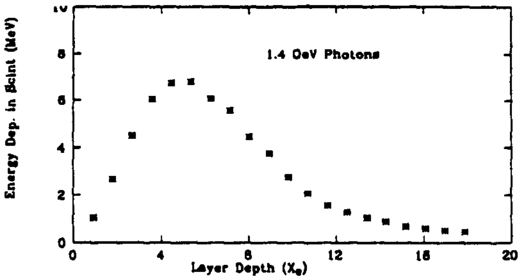
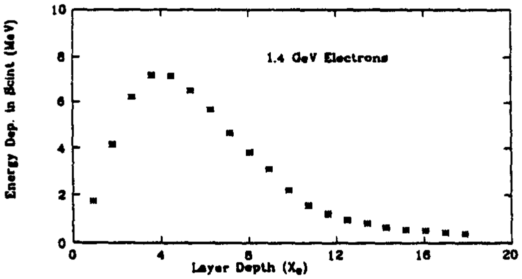


Energy deposited in scintillator as a function of depth for 1.4 GeV incident photons



Energy deposited in scintillator as a function of depth for 1.4 GeV incident electrons

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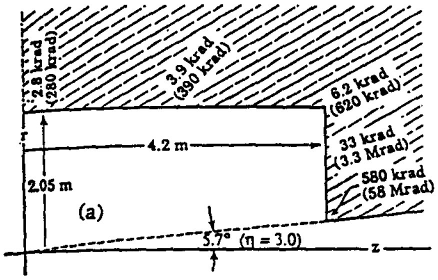
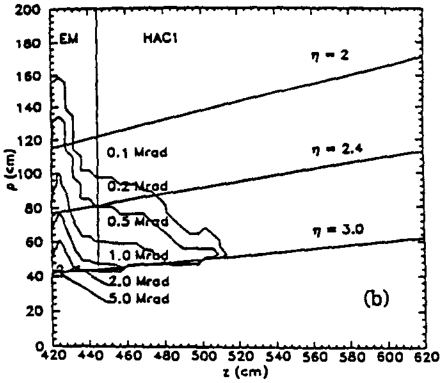
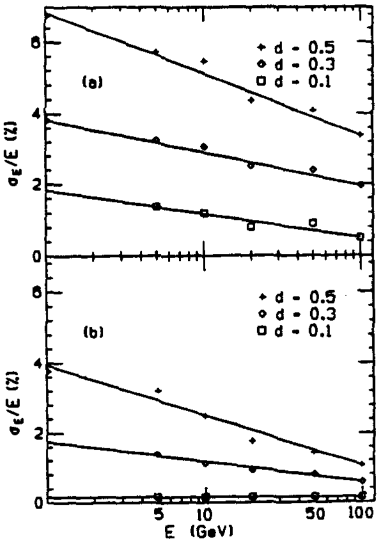
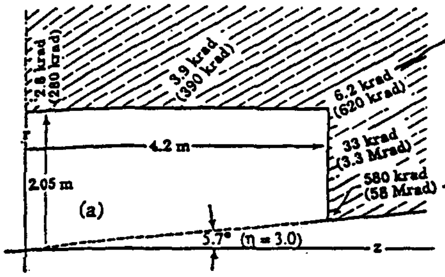




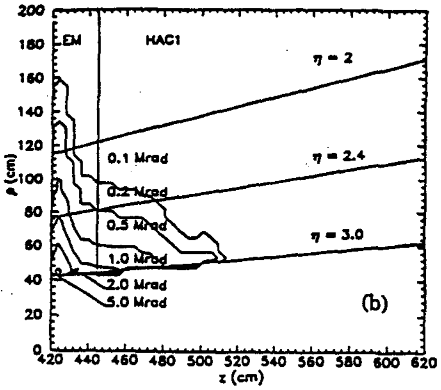
absradf topdraw
Fig. \absradf, section \hearty





1 yr. DESIGN $\mathcal{L}$ $10^{33}\ cm^{-2}s^{-1}$

10yr @ 10x Design $\mathcal{L}$

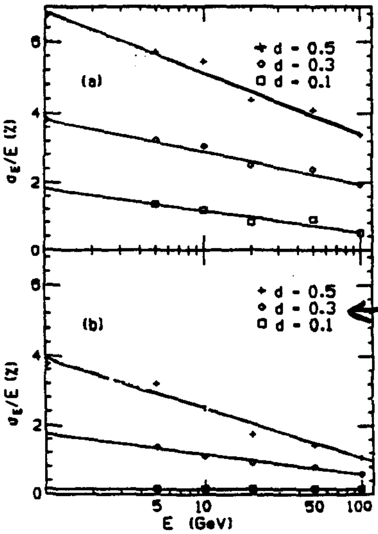


SDC
Tile + Fiber

absradf topdraw
Fig. \absradf, section \hearty

ONE DEPTH READOUT

CORRECTED USING TWO DEPTH READOUTS



≥0.6%

Summary

$$\frac{\sigma_E}{E} = a/\sqrt{E} + b$$

- → Acceptance
- → Uniformity
- → Stability

} Constant Term

Leakage	0.3%	(EGS)
Transverse Unif.	0.5%	(EGS)
Tile-to-Tile	0.5%	(EGS)
Absorber Thickness	0.2%	(EGS)
Calibration	0.2%	(in situ)
Radiation Damage.	0.5%	(EGS)
Total (added in quadrature)	< 1.0%	

01016

SHOWER MAXIMUM DETECTOR

R. HUBBARD

SHOWER MAXIMUM DETECTOR

Dick Hubbard
Saclay

Institutions :

Northeastern, Rockefeller, Saclay, Tel Aviv,
UCLA, Yale + Italy, Japan

Responsabilities :

Mechanics :	France + Japan
Photodetectors :	U.S. + Italy
Electronics :	France + Italy

Outline of talk :

- Electron / Gamma Identification
- Shower Max Requirements
- Shower Max and Massless Gap Detectors
- Photodetectors
- Test Results
- Shower Max Detector in Trigger

---

e / γ DETECTORS

PS Preshower Detector — Scint. Fibers
between coil &EMC
$\Delta\eta \times \Delta\Phi = 1.4 \times 0.05 / 160$ + stereo
Rejected in favor of Shower Max.

MG **Massless Gap** — **Tile / Fiber**
First EMC tile
$\Delta\eta \times \Delta\Phi = 0.05 \times 0.05$

EMC **Electromagnetic Calorimeter** — **Pb / Scint**
$\Delta\eta \times \Delta\Phi = 0.05 \times 0.05$

SMD **Shower Maximum Detector** — **Tile / Fiber**
within EMC
η strips : $\Delta\eta \times \Delta\Phi = 0.05/8 \times 0.20$
Φ strips : $\Delta\eta \times \Delta\Phi = 0.20 \times 0.05/8$

HAC **Hadronic Calorimeter** — **Fe / Scint**
$\Delta\eta \times \Delta\Phi = 0.10 \times 0.10$

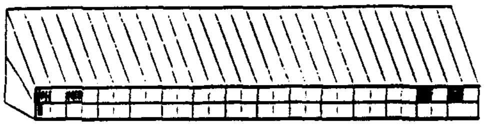
---

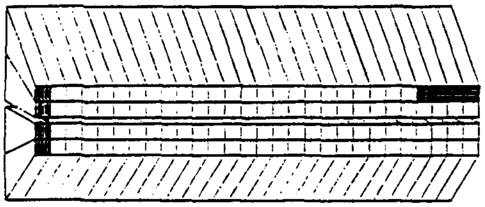
e / γ IDENTIFICATION

e Identification	**Background**	**Detectors**
EM / HAD	$\pi^{\pm}$	EMC + HAC
Isolation	jets	EMC + HAC
E = p	$\pi^{\pm}\ \pi^{0}$	Trk + EMC
Track-Shower match	$\pi^{\pm}\ \pi^{0}$	Trk + SM
Shower Shape	$\pi^{\pm}$	SM
Shower Depth	$\pi^{\pm}$	MG
Vertex Position	$\gamma \rightarrow e^{+}e^{-}$	Silicon Trk

γ Identification	**Background**	**Detectors**
EM / HAD	jets	EMC + HAC
Isolation	jets	EMC + HAC
Shower Shape	π^{0}, $\pi^{0}\ \pi^{0}$	SM
Statistical Separation	π^{0}	MG

SHOWER MAXIMUM GRANULARITY IN BARREL





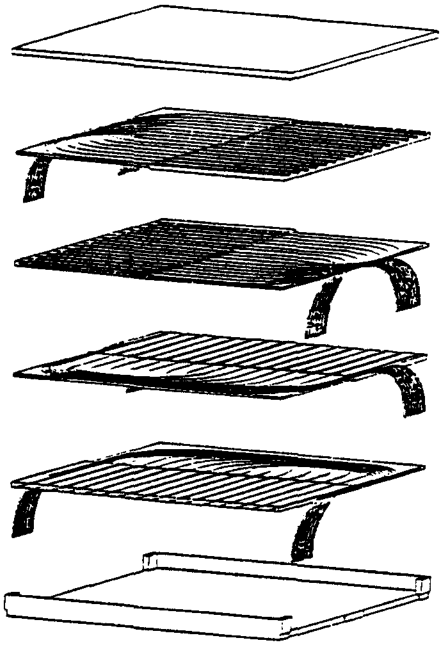
Gang 4 physical SM strips ⇒ 1 electronic channel

Occupation @ $L = 10^{33}$: ≈ 0.3 %

Upgrade path : Gang 2 strips ⇒ 1 channel

0.05 / 8 x 0.10	Electronic channels	0.10 x 0.05 / 8

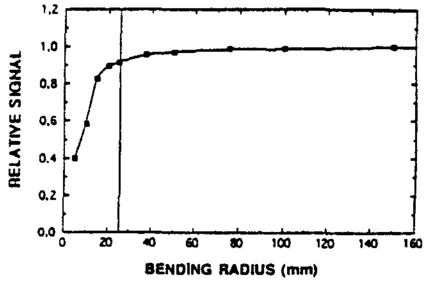
FIBER ROUTING



64 strips per 4-tower slot

TRANSMISSION vs BENDING RADIUS

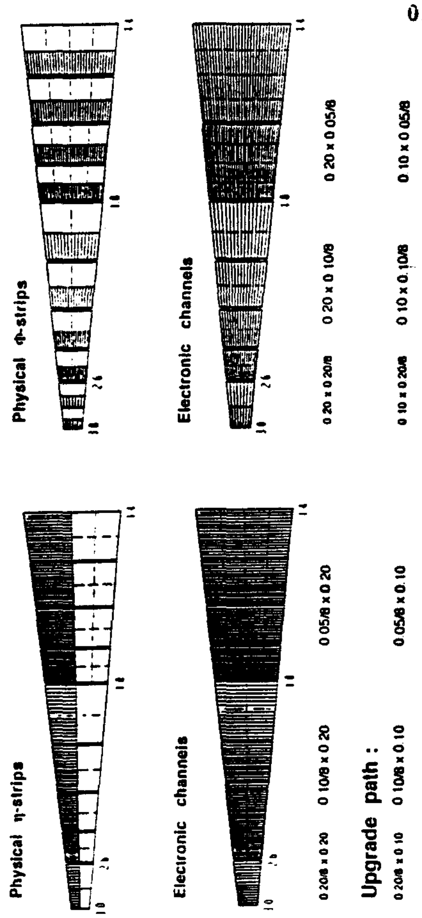
Clear polystyrene fiber
Diameter 1 mm, length 2 m
Light signal after 360° turn



Conclusion : Minimum radius ≈ 1 inch

Fiber routing is difficult !
Easier with 0.7 mm fibers.

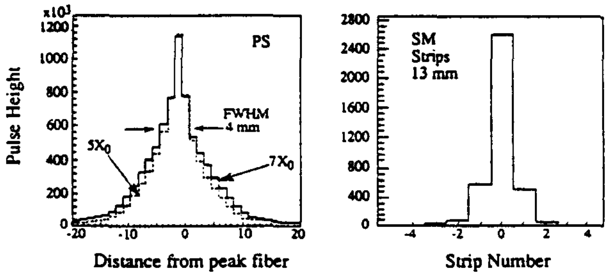
SHOWER MAXIMUM SEGMENTATION IN ENDCAPS



π^0 / γ REJECTION

Moliere Radius : Pb / Scint ≈ 3 cm
Strip Width : 0.05 / 8 ≈ 1.3 cm

Use narrow core for improved π^0 rejection ?



π^0 rejection factor for 80 % electron efficiency :

E_{π^0}	$\varepsilon_\gamma / \varepsilon_{\pi^0}$ (0.05/8)	$\varepsilon_\gamma / \varepsilon_{\pi^0}$ (0.05/16)
25 GeV	6.7	8.9
50 GeV	1.5	2.6
75 GeV	1.3	1.5

Trade-off : Readout fibers x 2
⇒ π^0 background x 2/3.

RADIATION DAMAGE

Co^{60} irradiation of SM strips + WLS fiber

1.3 Mrad —> 40% loss

SM Detector at shower maximum for E = 10 GeV

Barrel SM Detector @ 7 X_o @ eta = ~~0~~ 1.4

25% loss in 100 SSC years

Endcap SM Detector @ 7 X_o @ eta = 3

Quartz fiber readout

50% loss in 4 SSC years

Move to 10 X_o (shower max for 10 GeV)

50% loss in 7 SSC years

Retreat to eta = 2.6 ?

50% loss in 20 SSC years

Factor 4 loss probably O.K. at eta = 3

PHOTODETECTORS

Shower Max and Massless Gap Detectors

Baseline

Philips 64-channel PMT
Used in Fermilab beam test
QE = 12% @ 520 nm; crosstalk 5-10%

MCPMT Development

Philips 64- and 96-channel PMT's
Hamamatsu 256-channel PMT
Green-enhanced photocathodes QE = 16%

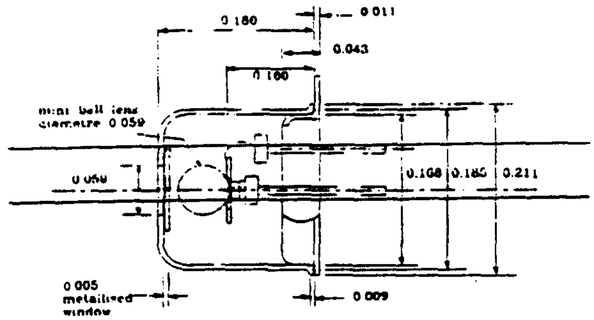
Avalanche Photodiodes

EG&G APD with ball lens in beam test
QE = 60% @ 520 nm; no crosstalk
Arrays @ EG&G, Hughes, Advanced Photonix

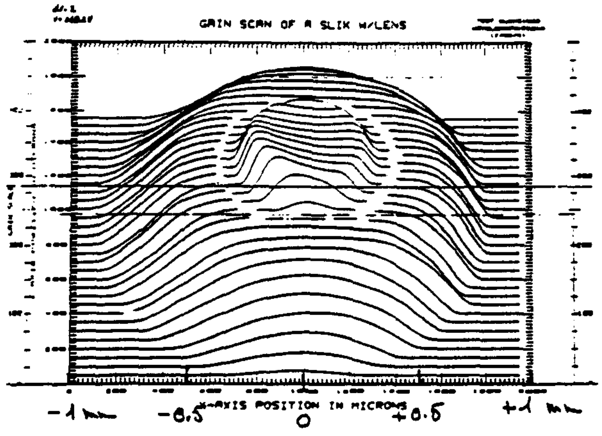
APD-PMT

APD array in proximity-focussed image tube
Gain 5 x 10^5 and large dynamic range
64-channel prototypes for 1993 prototype
GaAs photocathode with QE = 34% @ 540 nm
Hughes Aircraft and Litton Electron Devices

APD with Ball Lens from EG&G



Gain Scan with and without Ball Lens



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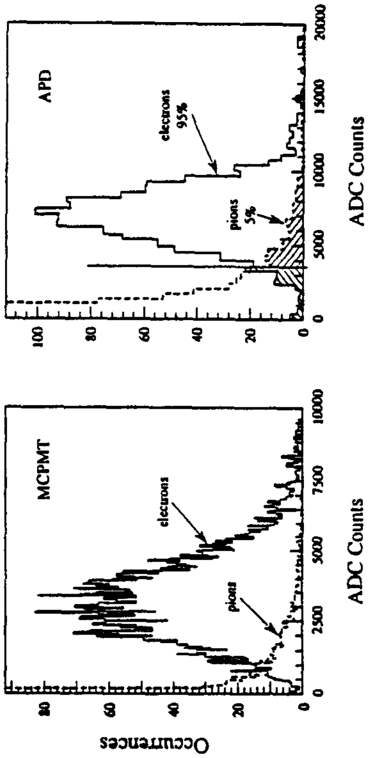
e / π SEPARATION @ 35 GEV

Fermilab Beam Test 1991



SHOWER MAX DYNAMIC RANGE

01029

What can we get with 12 bits ?

Goal : EM shower position $\sigma \leq \Delta / 5$
$10 \text{ GeV} < E_T < 1 \text{ TeV}$

<u>Dynamic Range</u> :

Energy 10 GeV - 1 TeV	33	@ 6 X_0
High tail @ 1 TeV	x 1.5	
Low tail @ 10 GeV	x 2	
Center of gravity	x 10	
Pedestal separation	x 4	minimal !
MCPMT gain variation	x 1	adjusted
Dynamic range	4000 ⇒ 12 bits	

<u>η dependance</u>

x 2	barrel
x 5	ends

⇒ Limit η range covered by one MCPMT
Adjust overall gain (MCPMT anode voltage)

SHOWER MAX DETECTOR IN TRIGGER

01030

<u>Level 1</u> : Decision time 4 μs
1 bit per 16 SM Φ strips
Protection against noisy EMC PMT's

<u>Level 2</u> : Decision time 50 μs
8 bits per SM Φ strip
Track - shower match in Φ (1024 bins)
Shower shape in Φ

<u>Level 3</u> : Decision time 100 MIPS-sec
12 bits per SM η- and Φ-strip
Track - shower match in η, Φ ($\sigma \approx 2$ mm)
Shower shape in η, Φ
Mini - isolation cuts
Bremstrahlung cluster at same η, different Φ
Massless gap
$\pi^{\pm}$ rejection
π^0 / γ statistical separation

SUMMARY

01031

<u>Massless Gap</u>

EM energy correction
$\pi^{\pm}$ rejection
π^0 / γ statistical separation

10368 channels ⇒ 192 MCPMT's

<u>Shower Max</u>

Track-shower match
Shower shape
Trigger Level 1, 2, 3

159 744 physical SM strips
47 104 electronic channels ⇒ 768 MCPMT's
<u>Upgrade</u> to match trigger segmentation
94 208 channels ⇒ 1472 MCPMT's

01032

SUMMARY OF RADIATION DAMAGE TESTS

K. TAKIKAWA

May 5,1992 SSCL
K. Takikawa

SUMMARY OF RADIATION DAMAGE TESTS

Scintillating tile/fiber calorimeters are used for the central region of the SDC detector. The radiation field in the SDC is orders of magnitude higher than in existing collider experiments and radiation damage to the plastic tiles and fibers is potentially a serious problem.

Extensive studies have been performed on radiation damage of tile/fiber calorimeters. They are divided into two categories: radioactive source tests of individual calorimeter components and electron beam tests of complete instrumented calorimeter modules.

List of Contents

1. Radiation Field in the SDC calorimeter
2. Source Tests
3. Beam Tests
4. Monte-Carlo Simulation on Radiation-Induced Degradation of the Calorimeter Performance
5. Conclusions

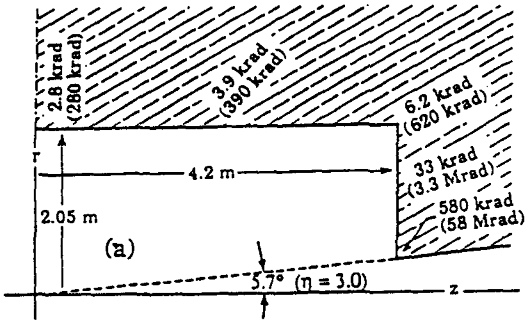
1. Radiation Field in the SDC Calorimeter

The radiation field in the SDC calorimeter is due to neutral and charged pions abundantly produced in 20 TeV on 20 TeV p-p collisions. The average transverse momentum of these minimum-bias particles is $<p_T> = 0.6$ GeV/c.

About a third of the particles from the primary collision are π^0's, so as many photons as hadrons strike the calorimeter. The resulting EM showers produce an ionizing dose which peaks more sharply and therefore more intensely than does the dose from a hadronic cascade.

At any given η, the maximum radiation dose is four times higher in the EM compartment than in the hadron compartment.

Maximum ionizing dose in the SDC calorimeter for one year of running at the design luminosity of 10^{33} $cm^{-2}sec^{-1}$ and (in parentheses) for 10 years at 10 x design luminosity.



Dose at cascade maxima = $A / r^2 \sin^{2+\alpha} \theta$

	$A/(1\ m)^2$	α	$<p_T>$
Photons	124 Gy yr^{-1}	0.93	0.3 GeV/c
Hadrons	29 Gy yr^{-1}	0.89	0.6 GeV/c

2. Source Tests

A number of radiation damage tests were performed using ^{60}Co γ-sources and low-energy (3 MeV) electron beam as a radiation source.

^{60}Co source tests were performed on tiles, fibers, glues, paints, and tile/fiber assemblies at:

Fermilab
Louisiana State University [2.1]
University of Michigan
INFN Padova
Saclay [2.2]
University of Tsukuba [2.3]

Emission spectra, light yield and transmission of tiles and fibers, and light yield of tile/fiber assemblies were studied as a function of radiation dose.

Tests of the different fibers, tiles, splice joints, and machine speeds for groove cutting were carried out at Florida State University using a 3 MeV electron beam.

[2.1] A.R. Fazely et al., "Radiation Damage Studies for the SDC Electromagnetic Calorimeter", SDC-92-172 (January, 1992).

[2.2] P. Bonamy et al., "Radiation Damage in Scintillating Plates and Fibers", SDC-91-11 (March,1991).

[2.3] K. Hara et al., "Radiation Hardness Study of Scintillating Tile/Fibers", SDC-92-186 (March,1992).

These source tests are simpler and quicker to perform than beam tests of calorimeters and are suitable to choose the best available materials and to study radiation-induced degradation of tile/fiber response in detail. As will be shown later, the ^{60}Co source test results on light yield of tile/fiber assemblies agree with the beam test results.

Out of the many results obtained at various institutions, let me show, as an example, the results from the Tsukuba group.

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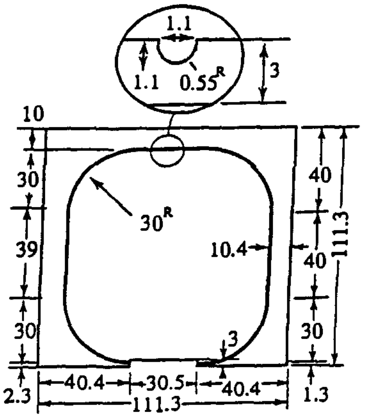
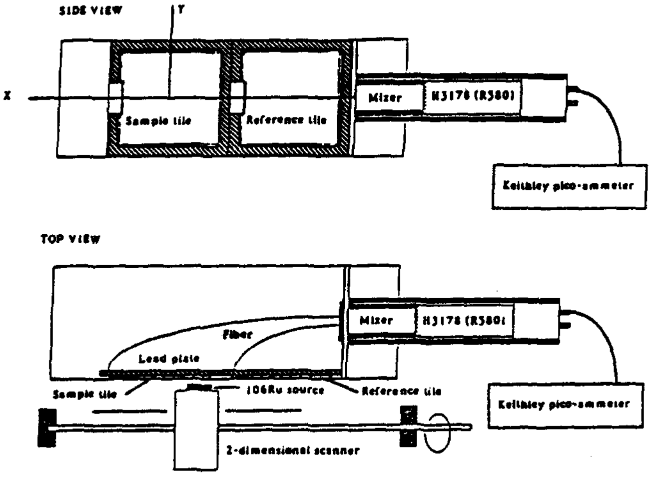
^{60}Co Source Tests at Tsukuba

Schematic diagram of the sample tile/fiber (unit in mm)



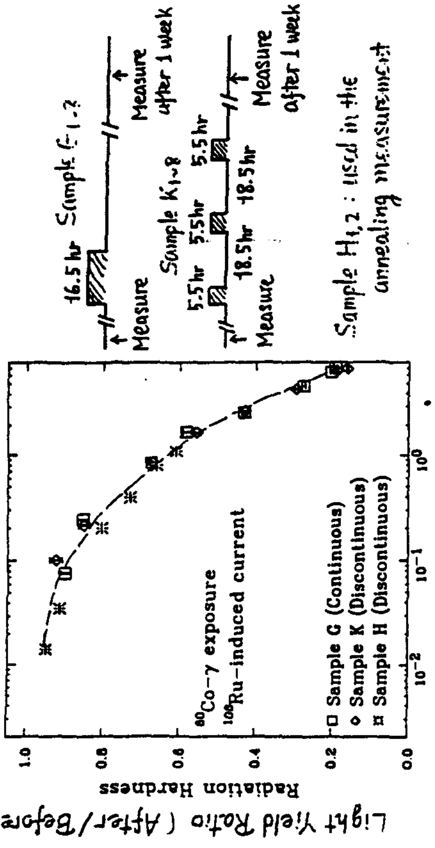
The tile size (11 cm x 11 cm) is typical of the barrel EM tiles.
Tile edge polished
WLS fiber 1 mmϕ
Tile/fiber assembly wrapped in white paper
The design and fabrication essentially the same as used in the Tsukuba beam tests.

The light yields of tile/fiber assemblies were measured by a ^{106}Ru source scanner. Ru beam spot ~ 5 mmϕ.



Radiation Hardness of a tile/fiber was evaluated by
Light Yield (After) / Light Yield (Before) = 1 − Damage
where the Light Yield was evaluated by
Ru-induced current from Sample / That from Reference
at the center of the tile (average over ± 10 mm, i.e., 11 points).

Co-induced damage SCSN81/Y7

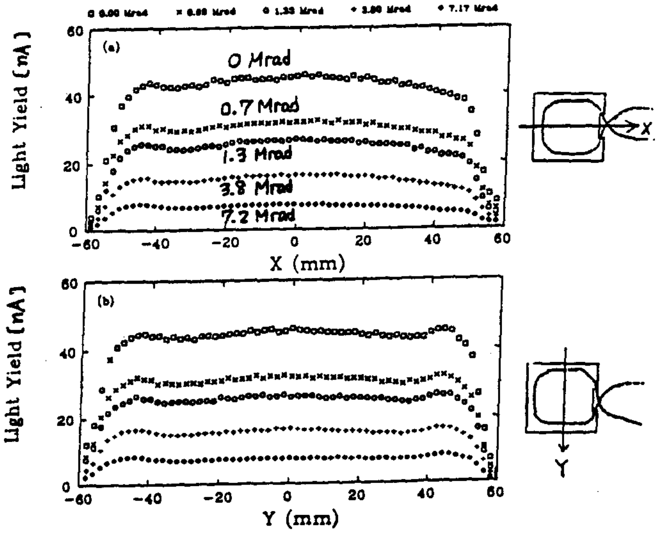


No difference observed between the continuos & discontinuous irradiations

Response Uniformity Mapping

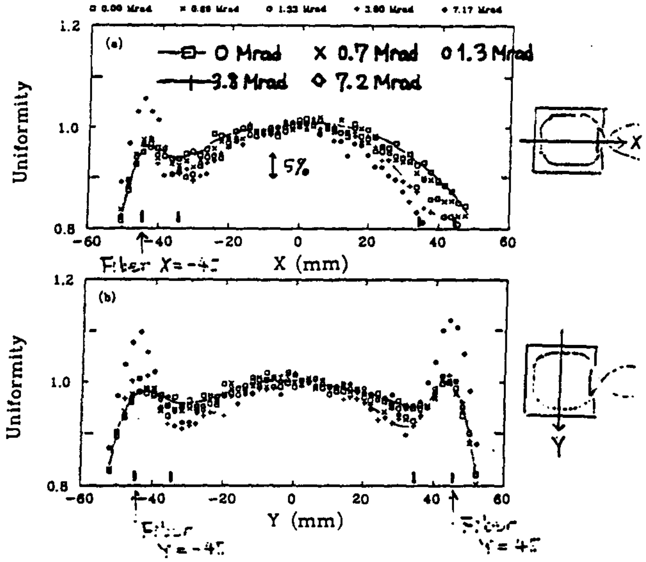
^{60}Co exposures of SCSN81/Y7 up to 7.2 Mrad

^{106}Ru induced current



Normalized Response Map

The light yield at each point was normalised by the light yield at the tile center.



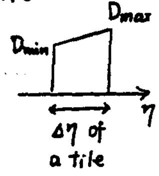
Degradation of response uniformity is small up to ~ 1 Mrad, and ≤ 5% at 3.8 Mrad.

Effects of Dose Imbalance on Response Uniformity

$$\text{Dose} = \frac{A}{r^2 \sin^{2+\alpha}\theta} \qquad \alpha \sim 1$$

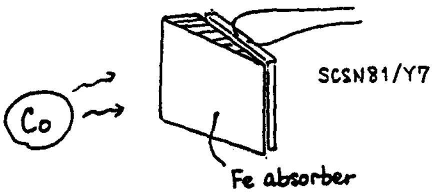
Expected dose imbalance $\Delta D/D$ in a tile

η	$\Delta\eta$	$\Delta D/D$
0 - 1.4	0.05	0 - 12%
1.4 - 1.8	0.05	13 %
1.8 - 2.6	0.1	25%
2.6 - 3.0	0.2	44%

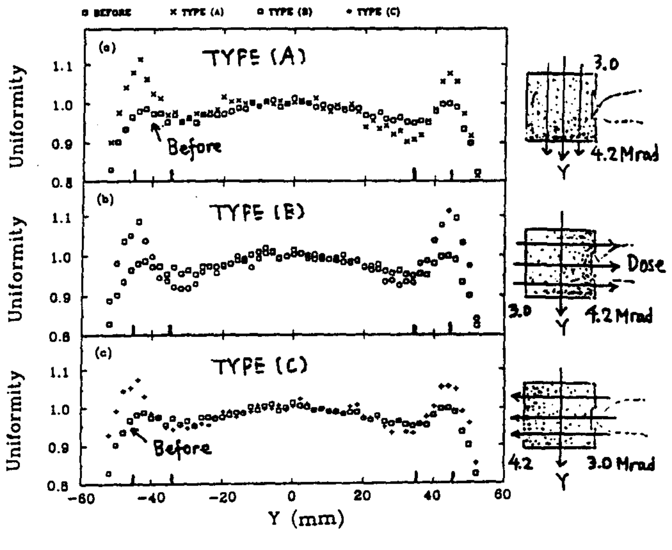


$$\frac{\Delta D}{D} \simeq \frac{D_{max} - D_{min}}{D_{max}}$$

^{60}Co Source Tests of Non-uniform Irradiation



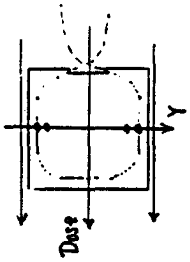
Response uniformity before (□) and after irradiation of 4.2 Mrad at maximum, with 25% dose imbalance

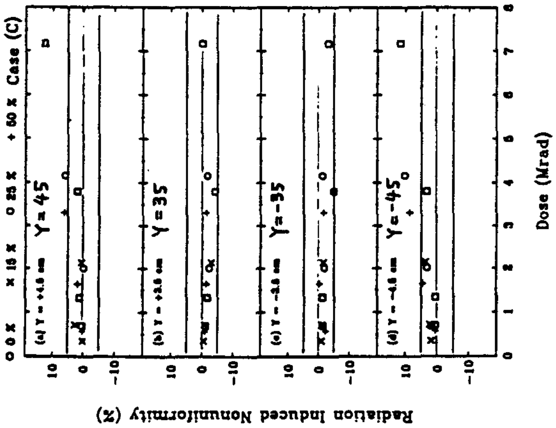


Response uniformity does not depend strongly on how the tile/fiber is placed w.r.t. the direction of dose imbalance.

Uniformity degradation at Y = ±35, ±45 mm as a function of maximum dose

SCSN81/Y7





□ 0% × 15% ○ 25% + 50%

- Radiation induced non-uniformity does not depend strongly on the dose imbalance between 0-50% up to 3~4 Mrad.
- It is ≲ 2% up to ~1 Mrad, ≲ 5% at 3~4 Mrad.

---

3. Beam Tests

In order to investigate systematic effects of radiation damage on the performance of tile/fiber calorimeters, electromagnetic test modules were built and exposed to electron beams at Beijing, KEK, and Orsay, with energies ranging from 1 to 2.5 GeV.

The beam test at Beijing [3.1] is a joint effort of IHEP Beijing, Fermilab, Florida State, and Purdue; the KEK beam test [3.2] was performed by a collaboration of Tsukuba and KEK, and the Orsay beam test [3.3] by the Saclay group.

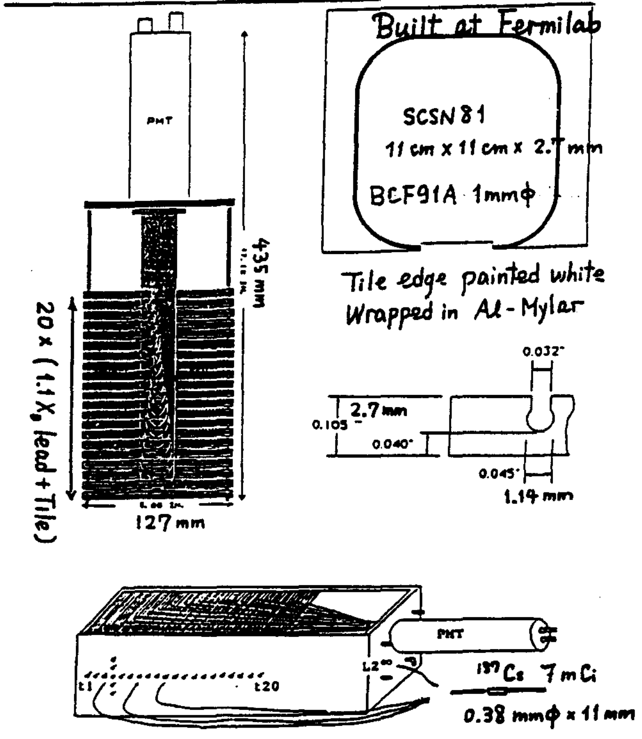
The radiation damage was measured by scanning the tiles with a ^{137}Cs source driver system in the Beijing and Saclay experiments. In the KEK experiment the measurement was performed in a test beam of 0.5–3 GeV/c electrons and also by a ^{106}Ru source scan.

[3.1] L. Hu et al., "Radiation Damage of Tile/Fiber Scintillator Modules for the SDC Calorimeter", SDC-91-119.

[3.2] S. Funaki et al., "Beam Test on Radiation Hardness of a Scintillating Tile/Fiber Calorimeter", SDC-91-85.

[3.3] P. Bonamy et al., "Radiation Damage in Tile/Fiber Calorimeter Modules", SDC-91-125.

Test modules used in the Beijing and Saclay tests

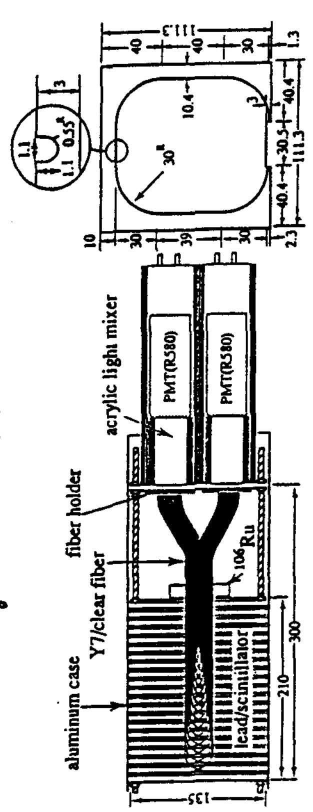


Tile edge painted white
Wrapped in Al-Mylar

- A moving fine wire carrying a Cs source provides longitudinal and transverse scans of the tiles.

Test module used in the KEK test

Basic design : Same as Fermilab module



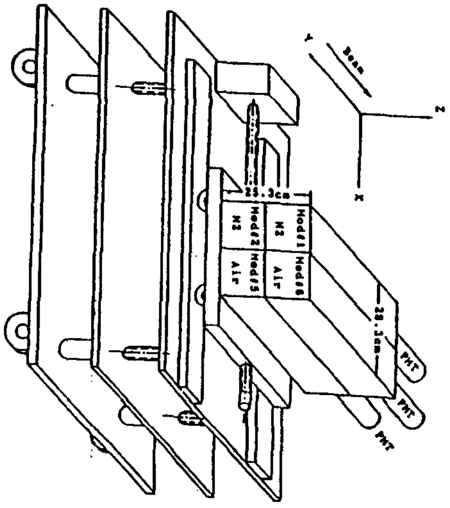
21 layers

SCSN81 11cm x 11cm x 3mm
Y7 1mmφ
Lead plate 13cm x 13cm x 6.35mm

- Tile edge polished
- Tile wrapped in white paper
- Y7 spliced to a clear fiber
- Ru source to monitor PMT gain

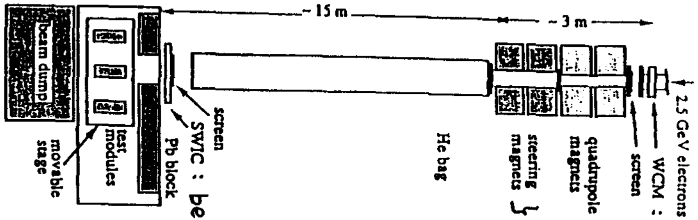
Moveable table and test module arrangement

Beijing



A similar setup was employed at Orsay.

Setup at KEK 2.5 GeV Linac



WCM : intensity monitor

steering magnets } beam steering

Beam pulse $\simeq 2\,ns$

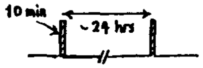
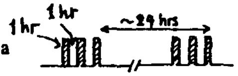
$\sim 2 \times 10^9$ electrons/pulse

$f = \frac{25}{4}, \frac{25}{10}, \frac{25}{25}$ Hz

SWIC : beam profile monitor

$\sigma \simeq 4-5$ cm

Doses and Dose Rates in Beijing, Saclay, Tsukuba beam tests

	Typical irradiation cycle	Dose Rate [krad/h]	<Dose Rate> [krad/h]	Dose [Mrad]
Beijing		100	20	6
Saclay		120 - 2400	0.7 - 12	0.25 - 2
Tsukuba		16 - 140	2 - 10	0.3 - 5

The Dose Rate is an instantaneous rate during a period the module was exposed to the beam. The <Dose Rate> is an average rate given by a total dose divided by the elapsed time.

At the design luminosity, SSC average dose rate is ~ 1 rad/h at end of barrel
~ 70 rad/h at η = 3.0

Our radiation damage tests are an accelerated test.

Measured PMT current by a Longitudinal tube scan

SACLAY

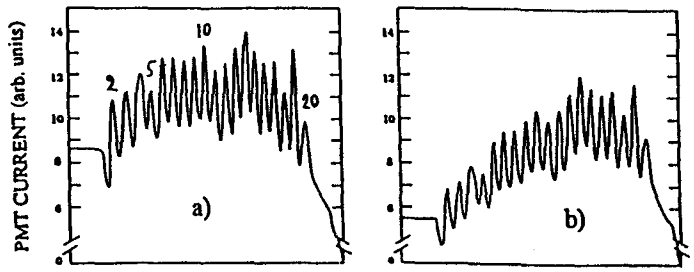


Figure 5: Measured PMT current induced by a ^{137}Cs source moving along a lontitudinal tube in the module before (a) and after (b) irradiation. The first tile seen by the beam is on the left. The vertical scale is arbitrary.

Damage profile from longitudinal tube scans

BEIJING

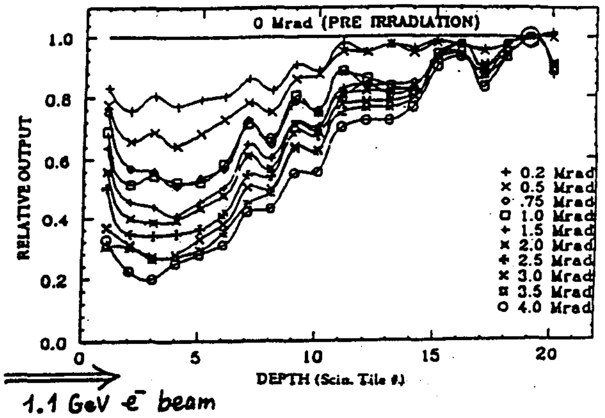
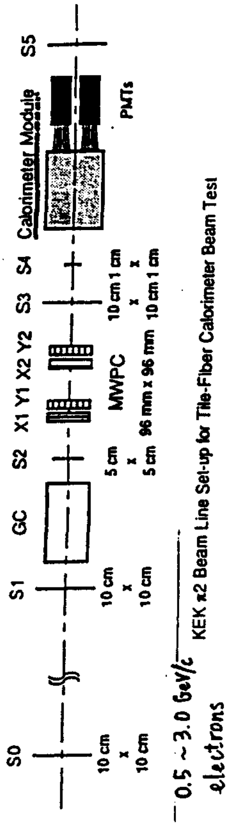
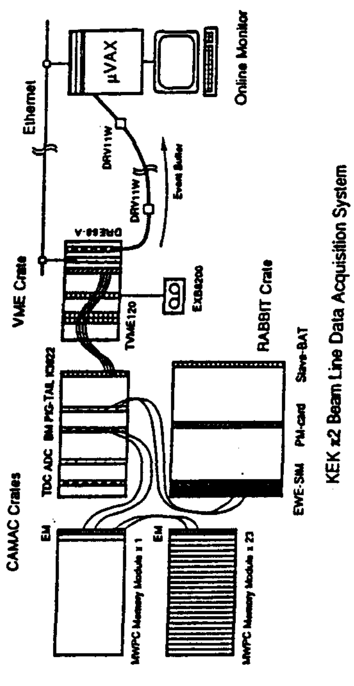


FIG. 6-34. Damage profile from source tube scans immediately after irradiation. The data are normalized to no damage at depth $t = 19$.

Setup at KEK PS π2 test beam

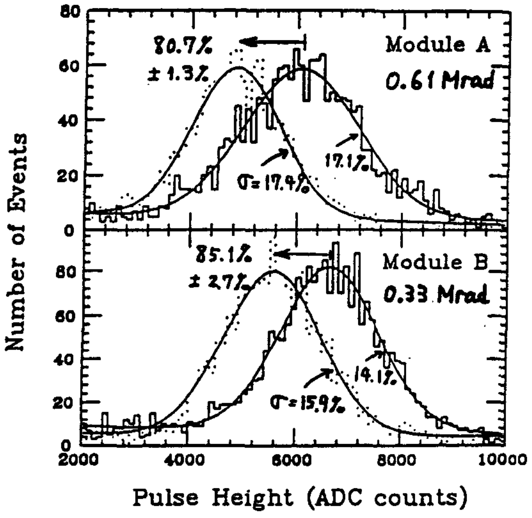


KEK π2 Beam Line Set-up for Tile-Fiber Calorimeter Beam Test



KEK π2 Beam Line Data Acquisition System

Pulse height distribution for 2 GeV electrons

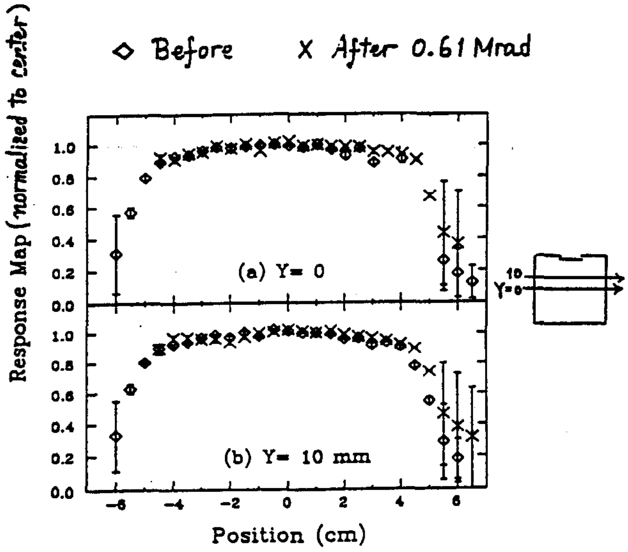


Shift of pulse height peak:

19.3 ± 1.3% after 0.61 Mrad at shower max.
14.9 ± 2.7% after 0.33 Mrad

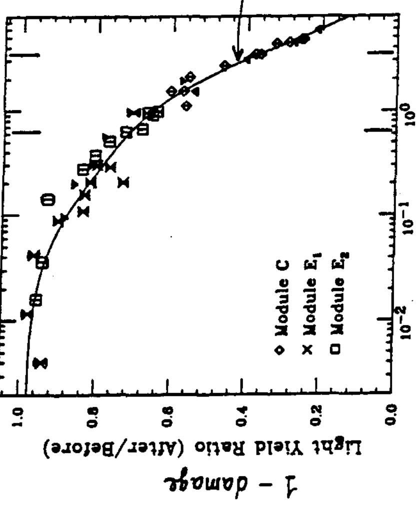
↑ stat. & sys.

Response uniformity measured with 2 GeV electrons



Uniformity is not degraded.

Damage vs Dose by 2.5 GeV Electron Shower



Tsukuba modules C, E_1, E_2 were dismantled after irradiation and radiation damage of individual tile/fibers were measured by a Ru source scan.

$0.82\, e^{-0.23D} + 0.16\, e^{-7.4D}$

▲ Beijing

▼ Saclay

0.62 Mrad

① Results from 3 labs are consistent.

0.62 Mrad	28% damage
3.3 Mrad	62% damage

② Beam test results and Co source test results agree well.

---

4. Monte Carlo Simulation

Neutral pions with an average p_T of 0.6 GeV/c, abundantly produced in 20 TeV on 20 TeV p-p collisions, are the main contributors to the radiation field in the SDC calorimeter. Photons from these π^0's produce radiation damage localized in depth.

This localized damage profile causes non-linearities of energy response and degradation of energy resolution for high energy electrons. Gradual shift of the EM shower maximum with incident electron energy causes a fractional energy shift $\Delta E/E$ to depend on energy. Fluctuation of the EM shower development, mostly due to a fluctuation in the shower starting point, results in a fluctuation of the measured energy.

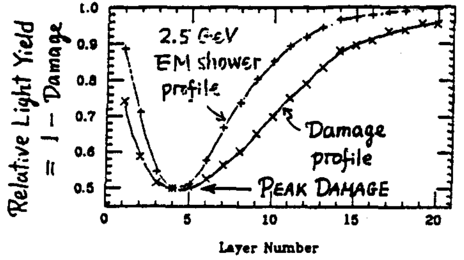
Green et al. [4.1, 4.2] performed the EGS simulation of these effects, and pointed out the usefulness of two EM longitudinal compartments (see TDR FIG. 6-8).

The damage profile was assumed to be given by the average shower profile of 1 GeV, 10 GeV electrons.

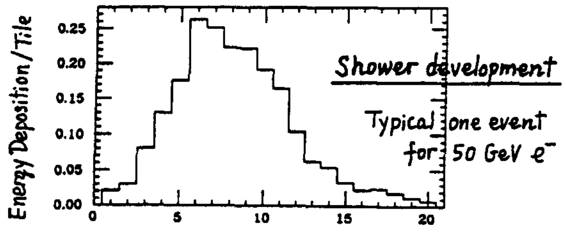
[4.1] D. Green, A. Para and J. Hauptman, "Radiation Damage, Calibration and Depth Segmentation in Calorimeters", Fermilab Note 565 (1991).

[4.2] J. Hauptman, "EM "Constant" Term due to Radiation Damage in Scintillator" (1991).

Damage profile for Peak damage = 0.5

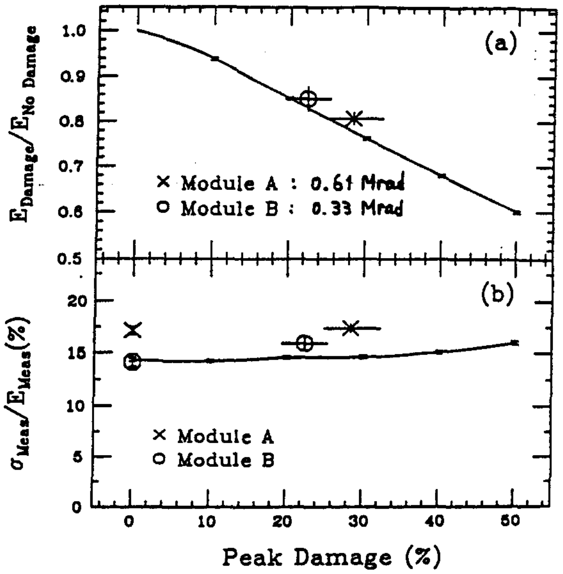


Shower development



Using the measured curve of damage vs dose, the Tsukuba group performed the MC simulation for the damage-causing electron energies of 1, 2.5, and 10 GeV [3.2]. The results are essentially the same as in Ref. [4.1, 4.2]. The contributions from radiation damage are mainly determined by the magnitude of the peak damage and does not depend strongly on the detailed shape of the damage profile.

Simulation for 2 GeV electrons compared with experiment

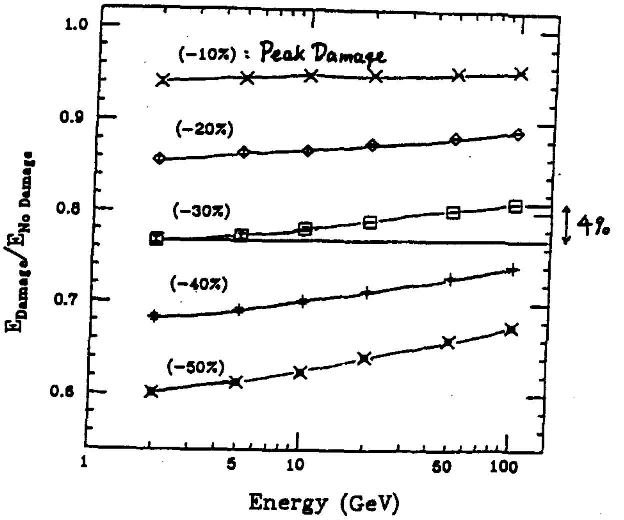


The simulation reproduces the measured energy response and energy resolution.

Figure 15: (a) Reduction of the energy response and (b) the energy resolution as a function of the peak damage. The solid lines are the simulation for 2-GeV electrons. The measured values for Modules A and B are shown by crosses and circles.

Simulation of Damage-induced Non-linearity

2.5 GeV electron induced damage



Non-linearity should be corrected for by using in situ source calibration and electrons from W/Z decays.

Figure 16: Reduction of the energy response as a function of the electron energy simulated for peak damages of 10% to 50%.

Resolution as a function of Peak Damage

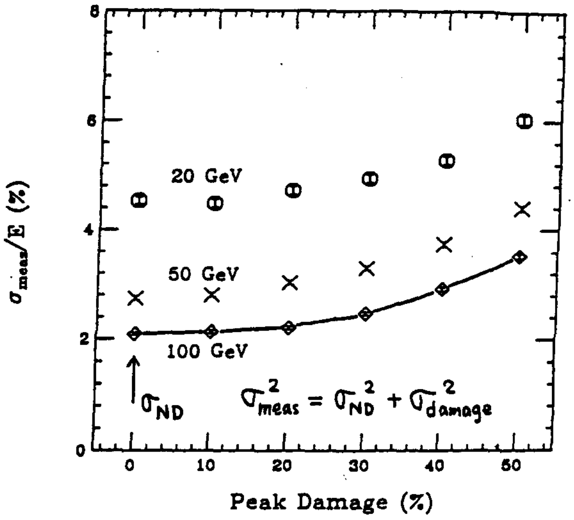
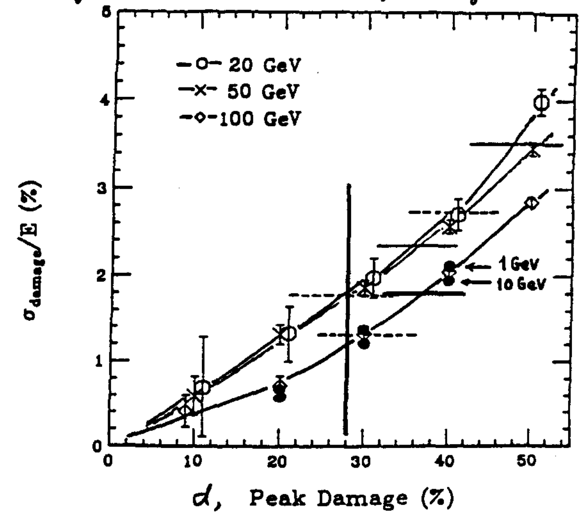


Figure 18: Resolution as a function of the peak damage for energies of 20, 50 and 100 GeV.

Damage-induced error to energy resolution

$\sigma_{damage}^2 = \sigma_{meas}^2 - \sigma_{ND}^2$ Damage-causing electron = 2.5GeV



From damage-dose curve, $d = 28\%$ for 0.62 Mrad.

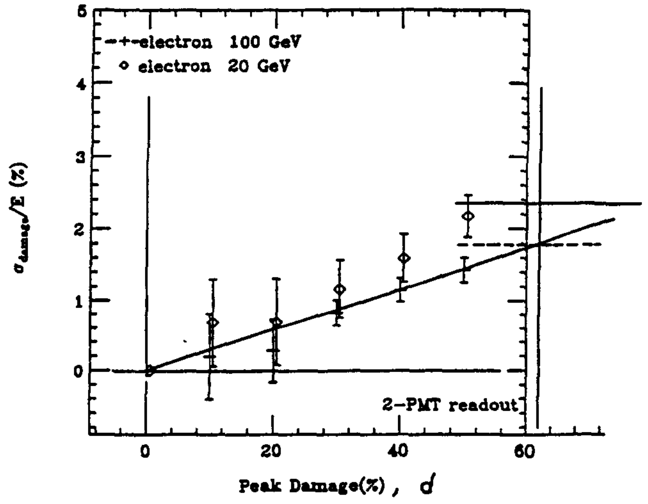
For 10 years at 10 X design luminosity.

$$\left[\frac{\sigma_{damage}}{E}\right]_{BARREL} < \frac{15\%}{\sqrt{E}} \oplus 1\% \quad (\text{— - —})$$

$$\lesssim \frac{12\%}{\sqrt{E}} \oplus 0.5\% \quad (\text{- - - -})$$

Damage-induced error to energy resolution

Endcap with 2 PMT readout   After correction



For 10 years at 10 x design luminosity. Endcap at $\eta = 2$ is exposed up to 3.3 Mrad. ⇒ $d = 62\%$

$$\left[\frac{\sigma_{damage}}{E}\right]_{1.4<\eta<2.0} < \frac{15\% \times \sqrt{2}}{\sqrt{E}} \oplus 1\% \quad (\text{—})$$

$$\lesssim \frac{12\% \times \sqrt{2}}{\sqrt{E}} \oplus 0.5\% \quad (\text{---})$$

5. Conclusions

Extensive studies of radiation damage of scintillating tile/fiber calorimeters have been performed by the many collaborators of the SDC calorimeter group. From these studies we conclude:

(1) The barrel calorimeter made of existing plastics will survive for 10 years of running at 10 x design luminosity (0.62 Mrad).

Degradation of energy resolution and of transverse uniformity is small enough to be acceptable.

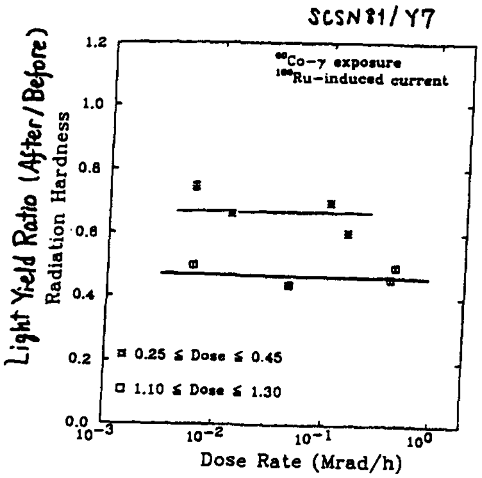
(2) With existing plastics, the endcap at $\eta = 2.0$ will barely survive for 10 years of running at 10 x design luminosity (3.3 Mrad).

Degradation of energy resolution is reduced to an acceptable level by employing 2 EM longitudinal segmentation.

Degradation of transverse uniformity seems to limit lifetime dose to ~ 3 Mrad at present.

Development of tiles and fibers that are more resistant to radiation is desirable for the endcap calorimeter.

Dose Rate Dependence



No significant effect is observed in the range $6 \le \dot{D}_{inst} \le 360$ krad/h.

SSC at 10^{33} $cm^{-2}s^{-1}$ $\dot{D}_{inst} = 0.2$ krad/h at $\eta=3.0$

TEST BEAM RESULTS

J. FREEMAN

(J.Freeman)

Test Beam Results

4 different calorimeters

1) CDF plug upgrade calorimeter
(technology)

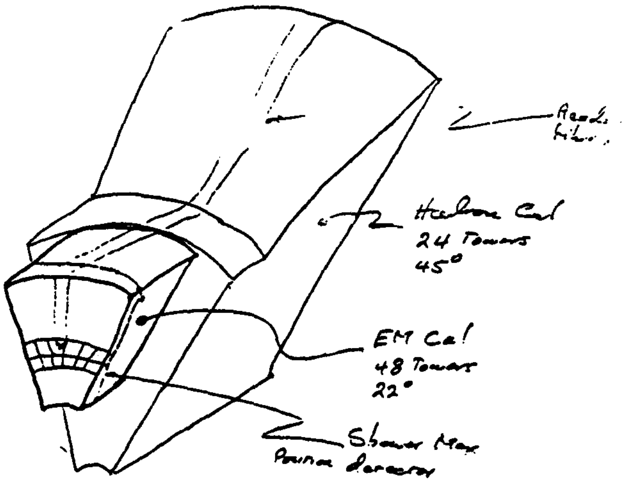
2) "Sigma" calorimeter
(fiber pattern, uniformity, light yield)

3) SDC cast lead prototype
(performance)

4) Hanging File Calorimeter
(Fe vs Pb, linearity, HAD2)

CDF prototype

- fiber splicing
- transverse uniformity (masking)
- longitudinal masking

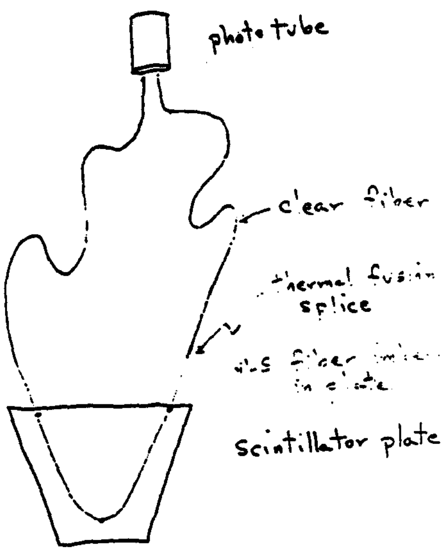


EM: 23 layers 4.8mm Pb
23 layers 4mm BC408
48 Projective Towers

Had: 23 layers 5cm Fe
23 layers 6mm SCSN81
24 Projective Towers

---

optics



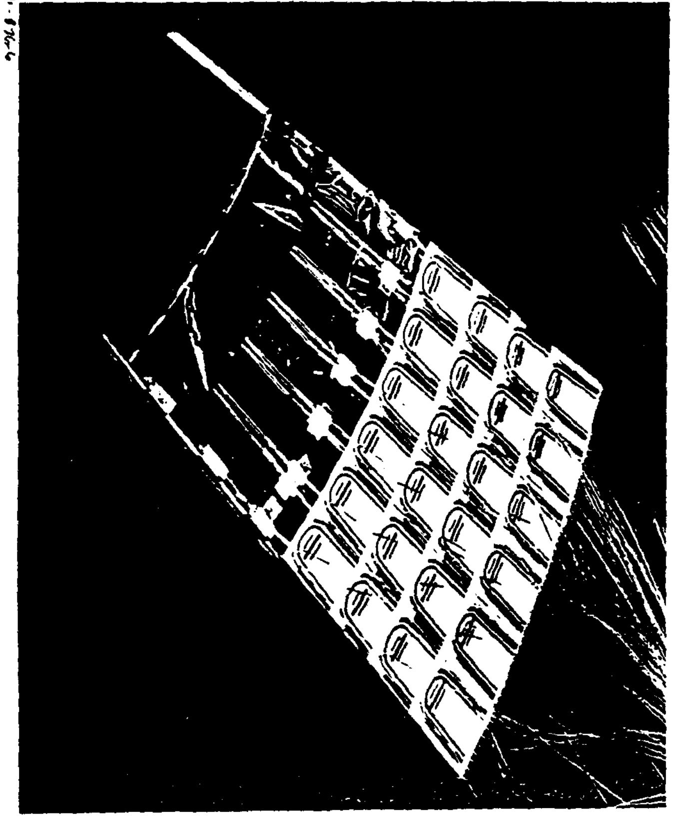
Scintillator : 4mm BC 408, EM
6mm SC SN 81, Had

WLS fiber : BC-91, 1mm

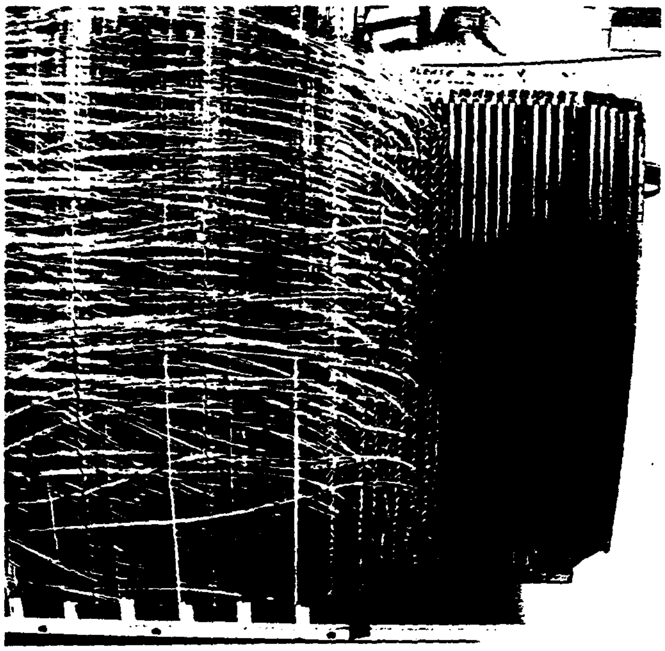
clear fiber : Kurari polystyrene, 1mm
typical length = 155 inches

01072

91-876-6



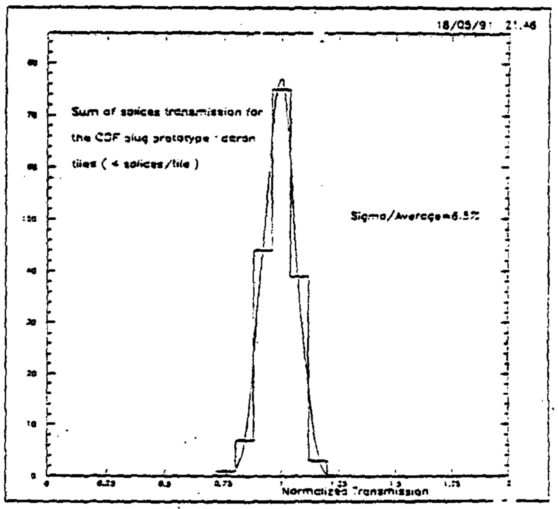
01073



91-929-6

01074

01075

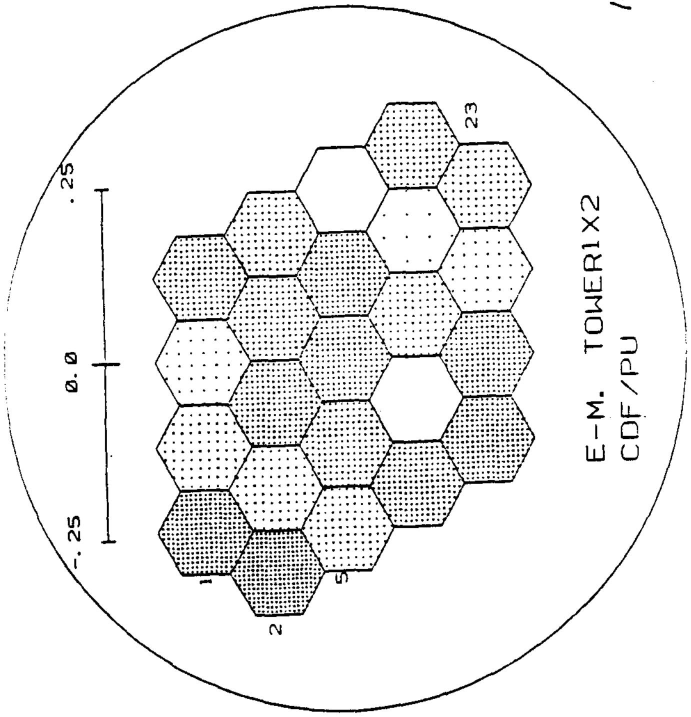


Splice green- clear

$\sigma \sim 6.5\%$

01076

10/14/91



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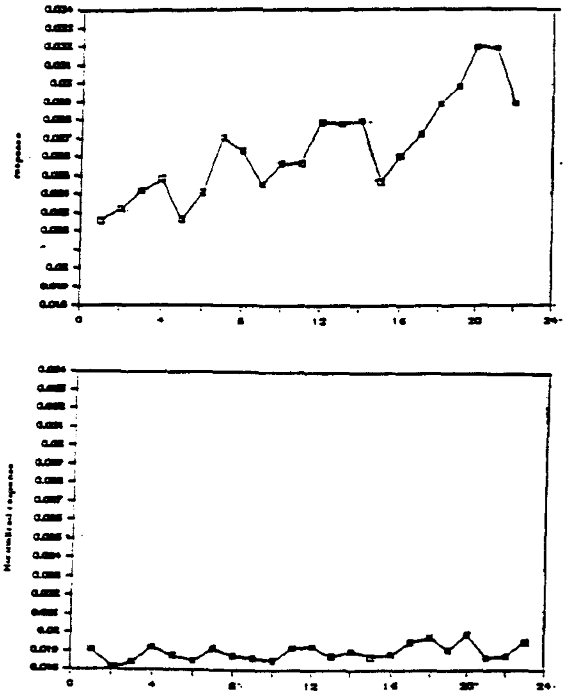


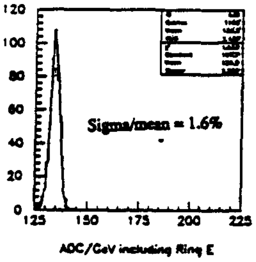
Figure 6.17 a) The longitudinal response of tiles in a tower. The hortisontal scale is tile number ranging from 1 (front) to 23 (back). The vertical scale is relative light yield. The RMS variation is 11.5%.

b) The same tower as in (a), after longitudinal masking. The RMS variation is now 2.6%.

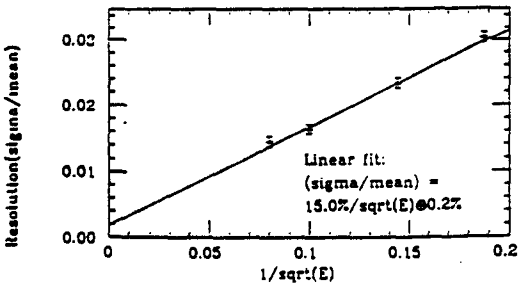
01078

RESOLUTION AND LINEARITY EM

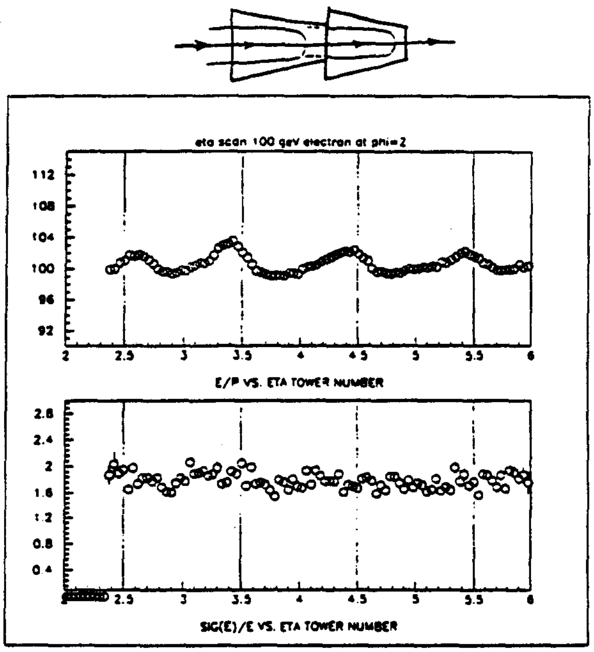
400 pe / Gev
4.3 pe / mip / tile



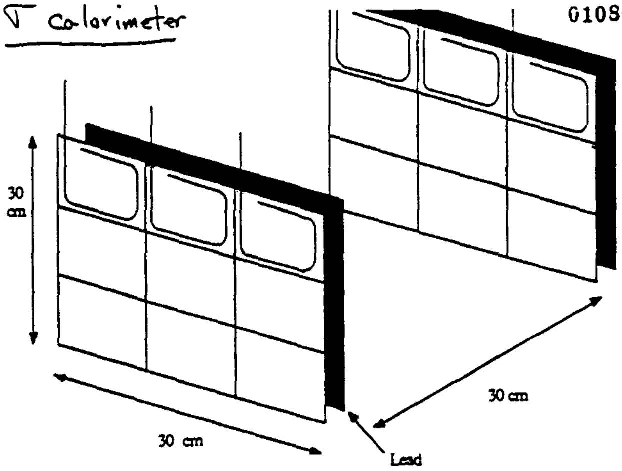
Distribution for 100 Gev
Electron beam



01079



√ Calorimeter



R&D Issues:

- Study of reflectivity properties of aluminazed fibers
- Light transmission / yield of WLS fibers of different diamaters
- Tiles light yield
- Uniformity Response of Tiles
- New Shower Maximum Detector Ideas

SIGMA CALORIMETER

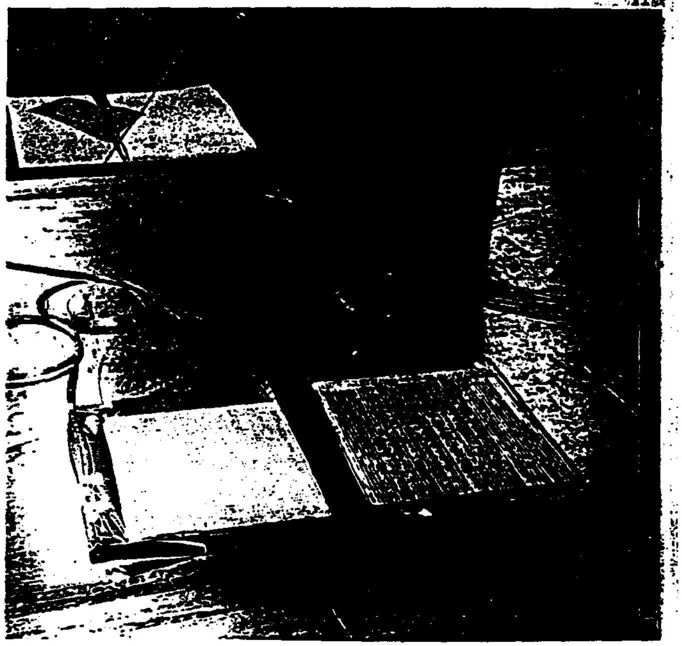
	EM
# Towers	9
Absorber	6.5 mm Pb
Depth	25 Layers
Scintillator	SCSN-[illegible] 38
Thickness	4 mm
Fiber	1.3 meters of 0.75 mm BCF91-A (light attenuated by 50 %)
Fiber positioning in the groove	Spot Glued

No splice

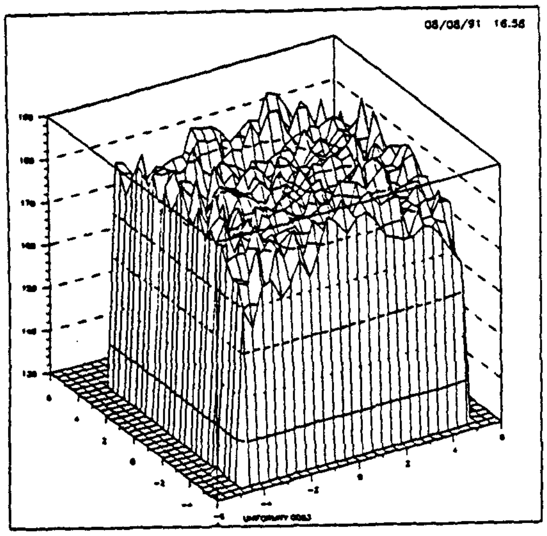
Muon Peak + ADC calibration + PMT absolute Gain determination gives 2.5 pe / mip / tile

Argonne measurement 2.8 pe / mip / tile

(with Bialkali photo cathode.
green sensitive pmt, 580-17, gives
~ 4 pe/mip/plate)

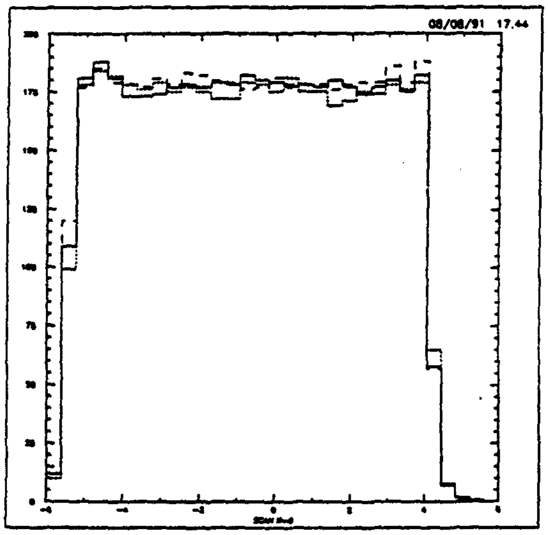


01084

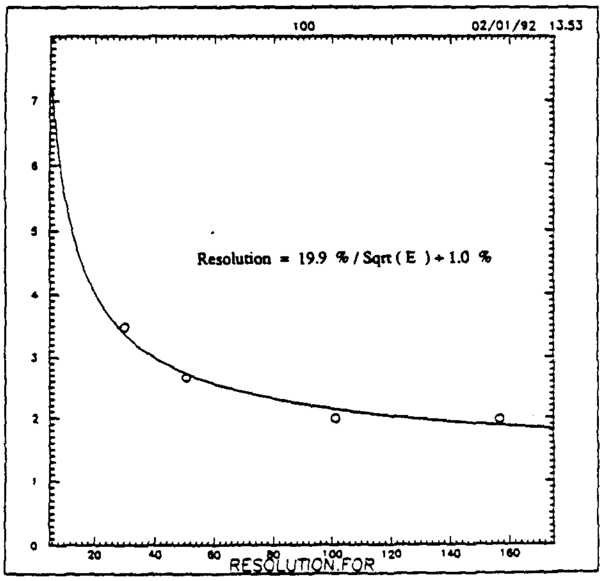


01085

$\mu = 178 \pm 4.4$

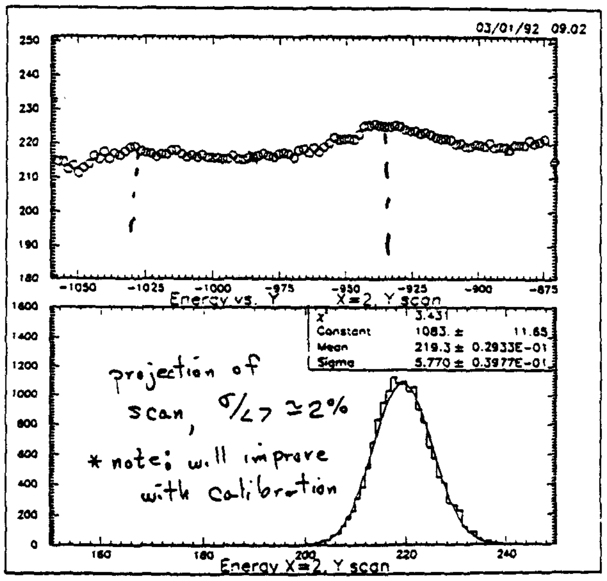


01086



01087

Sigma Cal. transverse uniformity



projection of scan, $\sigma/\langle\rangle \simeq 2\%$

* note: will improve with calibration

→ working on Calibration

SDC Cast Lead Prototype

- manufacturing feasibility
- transverse uniformity
- inter-wedge cracks, bulk-heads

Results from Casting Two (2) Barrel EM Test Beam Prototypes

Frame Fabrication:

- Distortion due to welding.
- Requirement for frame straightening
- Resulting dimensional error

Casting # 1

- Underpour resulting in porosity
- Failure of the holddown allowing spacers to float
- Requirement for machining
- Spacer tolerances
- Spacer machining

Casting # 2

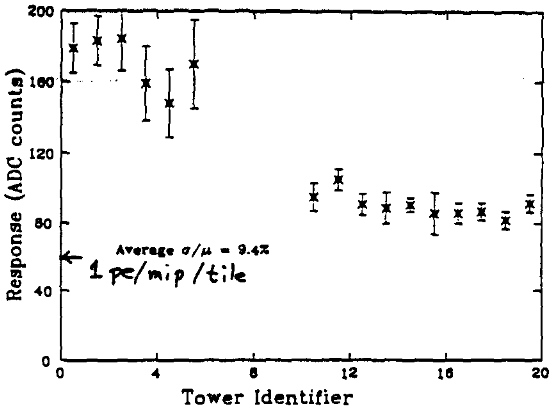
- Increased depth of mold
- Improved holddowns
- Eliminated strap threaded inserts
- Better dimensional control on Frame # 2
- Reduced welding to intermittent weld on rear plate
- Redesigned frontplate to bulkhead connection

Conclusions:

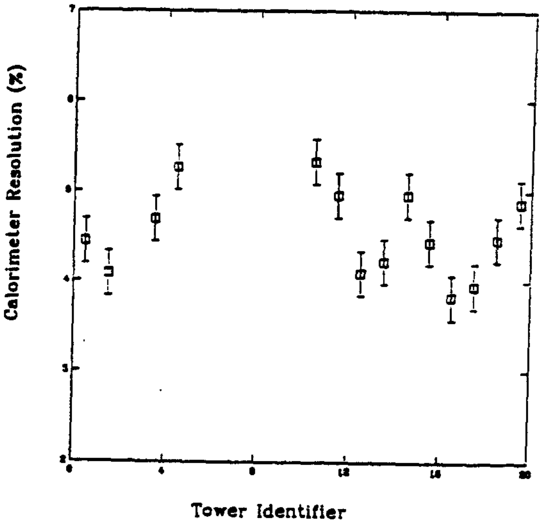
- Successful casting that can be expanded for full size module
- Will study lead to structure connections
- Will probably use alloyed lead to improve loading acceptance of absorber plates
- Implications of reduced absorber thickness

longitudinal uniformity of cast pb towers (rad. source)

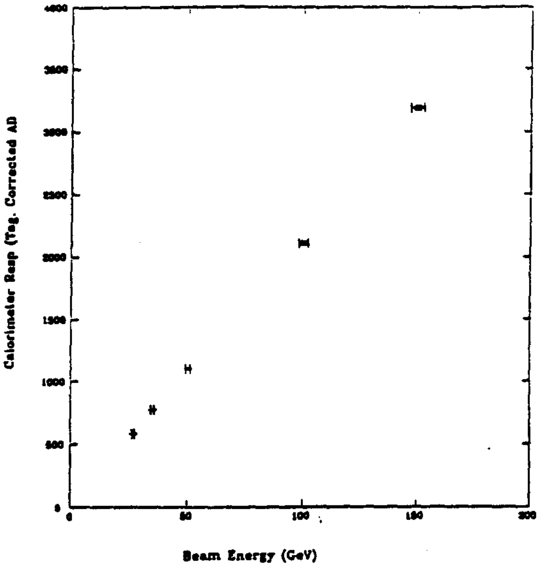
SDC EM Test Calorimeter
Tower Response



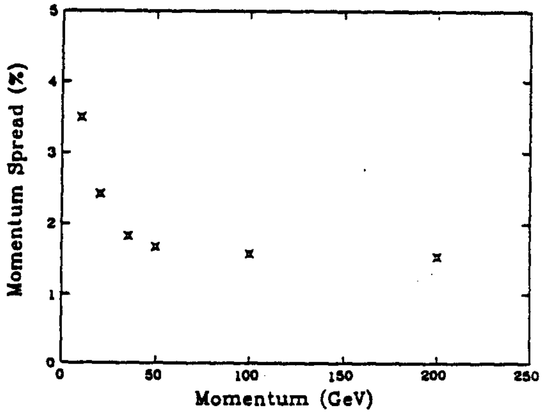
Average response over all tiles in a tower from Ruthinium source measurements. The error bar represents the rms spread in the measurements



SDC EM Test Module
35 GeV Electron Beam Calibration
(preliminary)



EM Test Module Energy Scan (preliminary)



Monte Carlo Momentum Spread of MP Beam

Monte Carlo calculation of multiple scattering limit on the momentum determination from material in the beam tagging system.

BEAM TEST OF RECONFIGURABLE-STACK CALORIMETER

A. Byon-Wagner. G. W. Foster, J. Freeman,
D .Green, R. Tokarek. Y. Zhou , A. Beretvas
Fermi National Accelerator Laboratory

V. Hagopian
Florida State University

D. E. Groom , R. Kadel , R Donahue
Lawrence Berkeley Laboratory

R. Gustafson. M. Shappirio , C. Leggett
University of Michigan

J. Huston
Michigan State University

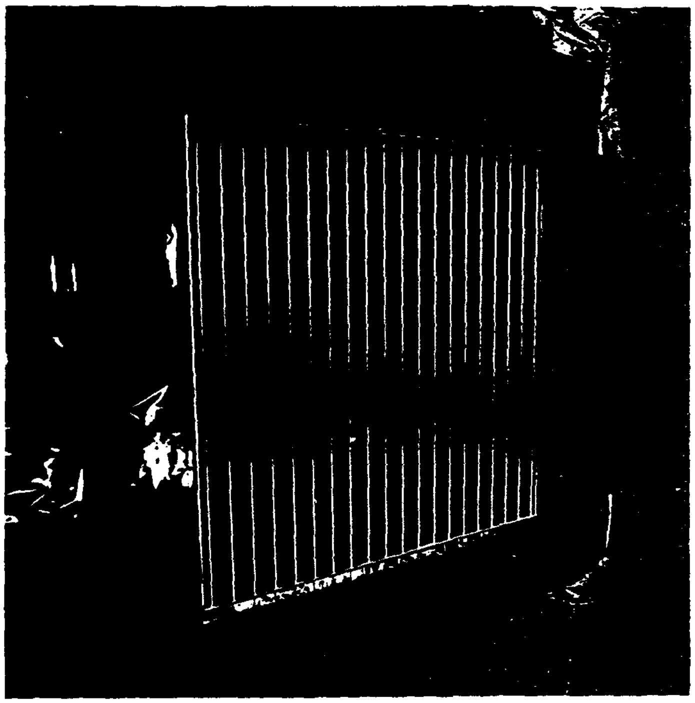
I. Cremaldi. D. Summers , B. Moore
University of Mississippi

V. E. Barnes , A. Laasanen
Purdue University

P. de Barbaro. H. Budd, A. Bodek, W. Sakamoto
University of Rochester

C. Zhao
University of Wisconsin

01096



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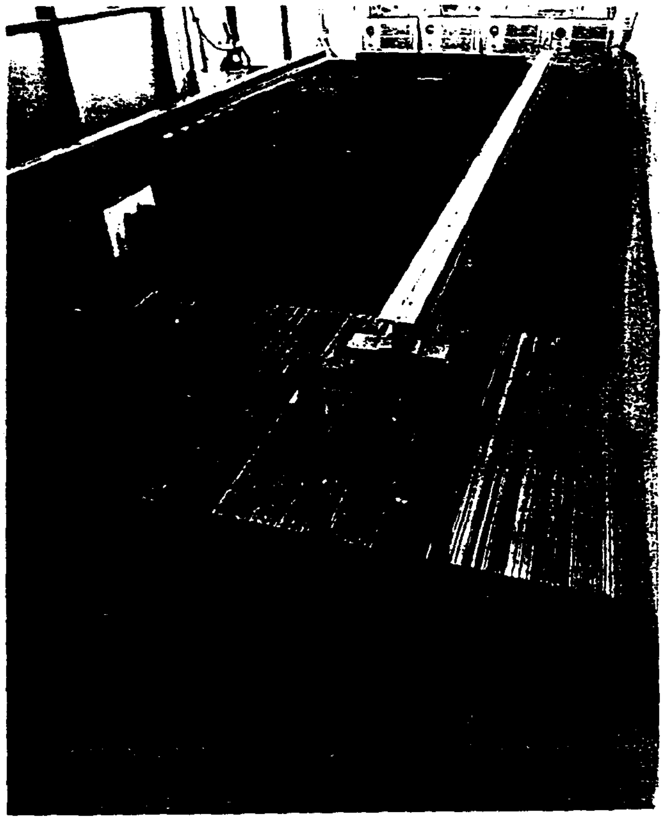
01097



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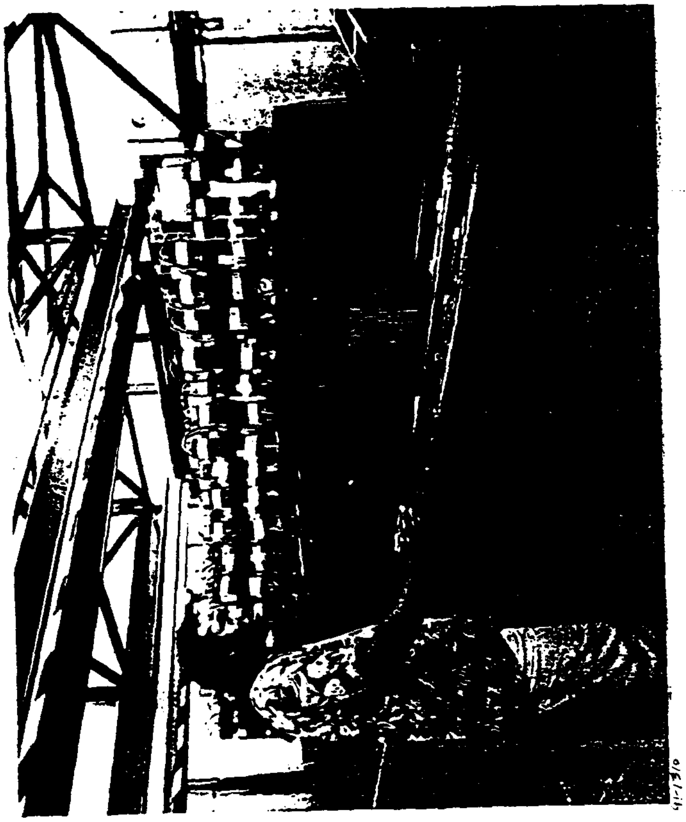
01098



91-1510

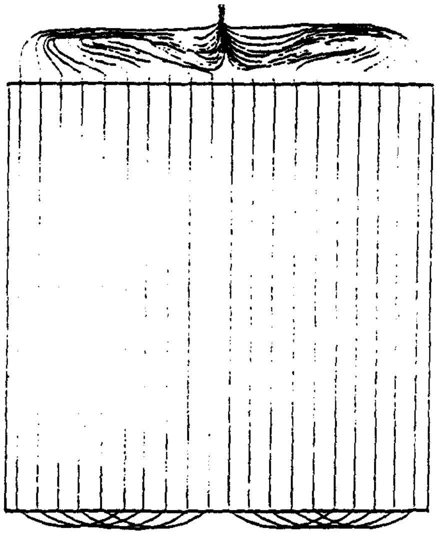
91-533-3

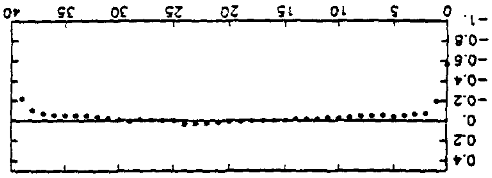
01099

1m x 1m x 3mm SCSN-81

20 lines of 1mm fiber, 2" spacing

air joint

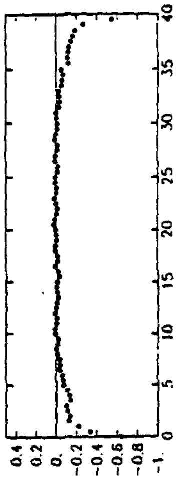




> 95% shower containment in middle 60 x 60 cm

we have uniform response (σ < 2%)

absolute light yield ≳ 1.5 PE/mip



Data taken (40 configurations)

- EM1 = (1" Pb + Scin)*52
  EM1 = (1" Fe + Scin)*55
  EM1 = (7/8" Pb + Scin)*20 + (1"Fe + Scin)*35
  EM1 = (1"Fe + 1/8"Al + Scin + 1/8"Al)*55
  EM1 = (1"Fe + 1/8"Al + Scin + 1/8"Al)*21 + (1"Fe + Scin)*34

} SDC HAD

EM2 = (2"Fe + 1*Scin)*35
EM2 = (2"Fe + 2*Scin)*27 +(1"Fe + Scin)*1
EM2 = (2"Fe + 2*Scin +1/8"Al)*27 + (1"Fe + Scin)*1
EM2 = (1/4"Pb + 2"Fe + 1*Scin)*35
EM2 = (1/4"Pb + 2"Fe + 1/8"Al + 1*Scin)*35
EM2 = (2"Fe + 1/8"Al + 1*Scin)*35

} CDF plug upgrade

- (3/4" Pb + Scin) * 92
- (3/4" Pb + 1/16" Al + Scin + 1/16" Al) * 50 + (3/4" Pb + Scin) * 42
- (1/8" Pb + 1/8" Al + 3/8" Pb + Scin) * 50 + (3/4" Pb + Scin)*42
  (3/8" Pb + 1/8" Al + 3/8" Pb +1/16" Al + Scin + 1/16" Al) * 50
  + (3/4" Pb + Scin)*42
  (3/4" Pb + 1/8" Al + Scin + 1/8" Al) * 62 + (3/4" Pb + Scin) * 30
  (3/8" Pb + 1/4" Al + 3/8" Pb + Scin) * 50 + (3/4" Pb + Scin)*42
- (3/8" Pb + Scin) * 40 + (3/8" Pb + 1/8" plastic + 3/8" Pb + Scin)*50
- ((1/8" Pb + 1/8" plas)*2 + 1/8" Pb + Scin)*40 + ((1/8" Pb + 1/8" plas)*5 + 1/8" Pb + Scin)*24 + (3/8" Pb + 1/8" plas + 3/8" Pb + Scin)*27

(1" Fe + Scin)*69
(1" Fe + 1/8" Al + Scin + 1/8" Al)*69
(1/2" Fe + 1/4" Al + 1/2" Fe + Scin)*68
(1/2" Fe + 1/8" Al +1/2" Fe + 1/16" Al + Scin + 1/16" Al)*50 +
(1/2" Fe + 1/8" Al +1/2" Fe + 1/8" Al + Scin)*18

Sampling fraction
material ratio &
cladding

- (3/4" Fe + Scin) * 90
- (3/4" Fe + 1/16" Al + Scin + 1/16" Al) * 50 + (3/4" Fe + Scin) * 40
- (3/8" Fe + 1/8" Al + 3/8" Fe + Scin) * 50 + (3/4" Fe + Scin)*40
- (3/8" Fe + Scin) * 40 + (3/8" Fe + 1/8" plastic + 3/8" Fe + Scin)*50
- ((1/8" Fe + 1/8" plas)*2 + 1/8" Fe + Scin)*40 + ((1/8" Fe + 1/8" plas)*5 + 1/8" Fe + Scin)*31 + (3/8" Fe + 1/8" plas + 3/8" Fe + Scin)*19

(1" Fe + Scin + 1/8" Pb) * 50 + (1" Fe + Scin) * 19
(1" Fe + 1/16" Al + Scin + 1/16" Al + 1/8" Pb) * 50 + (1" Fe + Scin) * 19
(1" Fe + 1/8" Pb + 1/16" Al + Scin + 1/16" Al) * 49 + (1" Fe + Scin) * 19
(1" Fe + 1/8" Pb + Scin) * 49 + (1" Fe + Scin) * 19

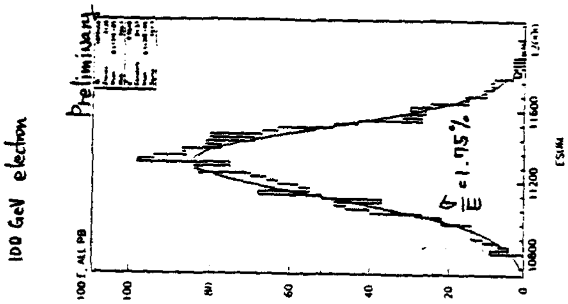
(1/4" Pb + Scin)*21 + (1" Fe + Scin)*69
(1/8" Pb + plastic + 1/8" Pb + Scin)*21 + (1" Fe + Scin)*69
(1/8" Pb + 2*plastic + 1/8" Pb + plastic + Scin)*21 + (1" Fe + Scin)*69
(1/4" Pb + 3/16" air + Scin + 3/16" air)*21 + (1" Fe + 3/16" air + Scin + 3/16" air)*19 + (1"Fe + Scin)*50

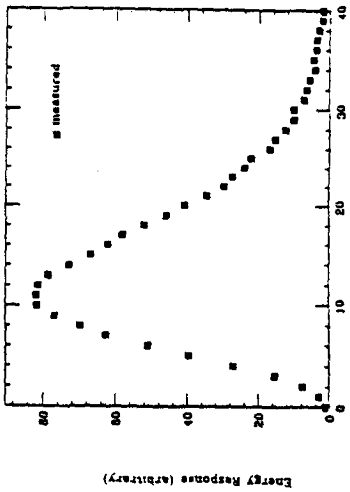
[redacted]

} EM PLASTIC FRACTIO:

- (1" Fe + Scin) * 72 with 100 nsec gate width
- (1" Fe + Scin) * 72 with 200 nsec gate width
- (1" Fe + Scin) * 72 with 80 nsec gate width
- (1" Fe + Scin) * 72 with 50 nsec gate width

} integration time





EM = (1/8" Pb + 3mm Scin) × 40

at 100 GeV, $\left(\frac{\sigma}{E}\right)_{mea} = 1.75\%$

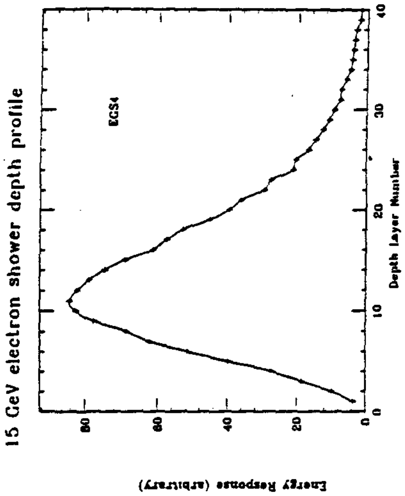
$\left(\frac{\sigma}{E}\right)_{expected}$

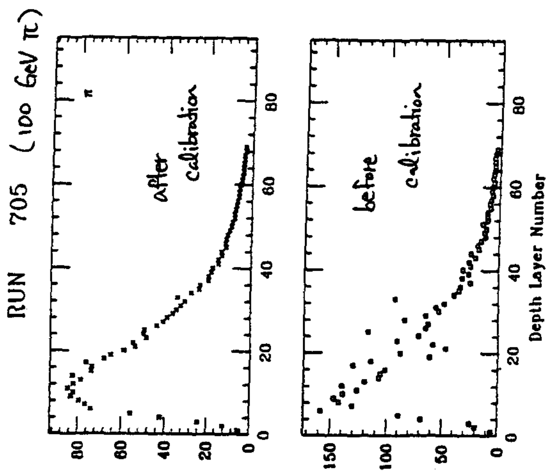
$= 1.2 \oplus$ photo. stat. $\oplus$ beam $\overset{\shortparallel}{0.5}$

120 counts/GeV
1.3 pe/MIP
1.5 counts/MIP

$\Rightarrow$ 104 pe/GeV ∫∫ 10%

$\therefore \left(\frac{\sigma}{E}\right)_{expected}$
$= 1.2 \oplus \frac{10}{\sqrt{100}} \oplus 0.5$
$= 1.64\%$





(1" Fe + Scin) * 69

- CDHS (2.5 cm Fe + 0.5 cm Scin) 60 × 60 cm²
- HFC (1" Fe + 0.3 cm Scin) 100 × 100 cm²

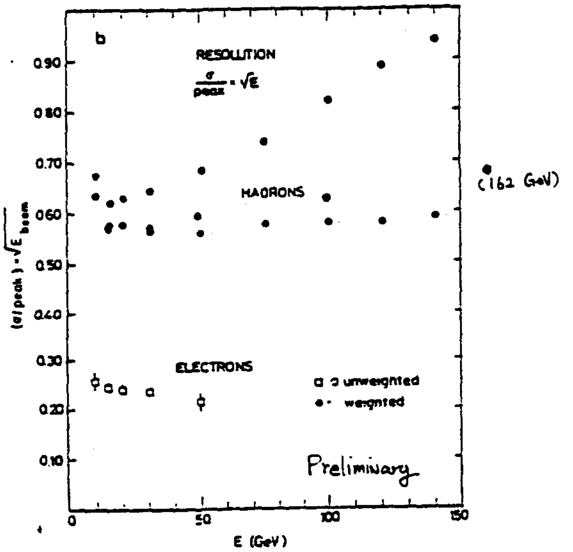


Fig. 4. a) Calorimeter response to hadrons and electrons in terms of numbers of equivalent particles (nep) per incident energy (GeV) against the energy of the incident particle. E_{beam} in GeV. b) The width of the energy distributions. $(\sigma/\text{peak})\sqrt{E_{beam}}$ against incident energy, E_{beam} in GeV.

The energy deposited in a calorimeter due to dE/dx is

material	dE/dx	density	thickness(cm)	Total (MeV)
Pb 1/8in	1.13	11.35	.318	4.08
Pb 7/8in			2.22	28.55
Pb 1 in			2.54	32.64
Fe 1 in	1.48	7.87	2.54	29.58
Scintillater	1.95	1.032	.3	.604
Al 1/8in	1.62	2.70	.318	1.39

Total Energy/ Energy in scintillater

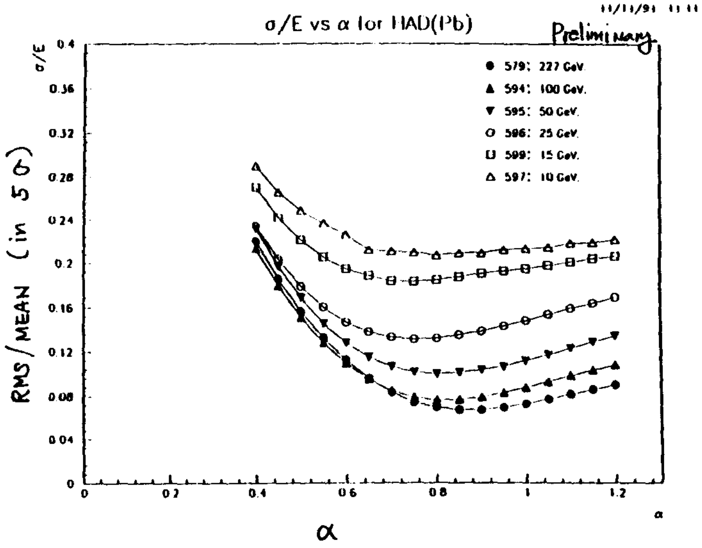
1/8" lead = (.604 + 4.08)/.604 = 7.75
1" lead = (.604 +32.84)/.604 = 55.04
7/8" lead = (.604 +28.55)/.604 = 48.27
1" iron = (.604 +29.58)/.604 = 49.97
1"Fe+1/8"Al+Scin+1/8"Al = (.604+1.39+29.58+1.39)/.604 = 54.58
1/8"Pb+1/8"Al+Scin+1/8"Al = 12.36

If we normalize to 1/8" lead EM = 1,
HAD(1" lead) = 7.10
HAD(7/8" lead) = 6.23
HAD(1" iron) = 6.46
HAD(1"Fe+1/8"Al+Scin+1/8"Al) = 7.04
HAD(1/8"Pb+1/8"Al+Scin+1/8"Al) = 1.59

$\Big\}\ W(\frac{dE}{dx})$

↑ correction factor for sampling thickness

$$E = \Sigma\, ADC(EM) + \left(\Sigma\, ADC(HAD) * \textcircled{x}\ W\left(\frac{dE}{dx}\right)\right)$$

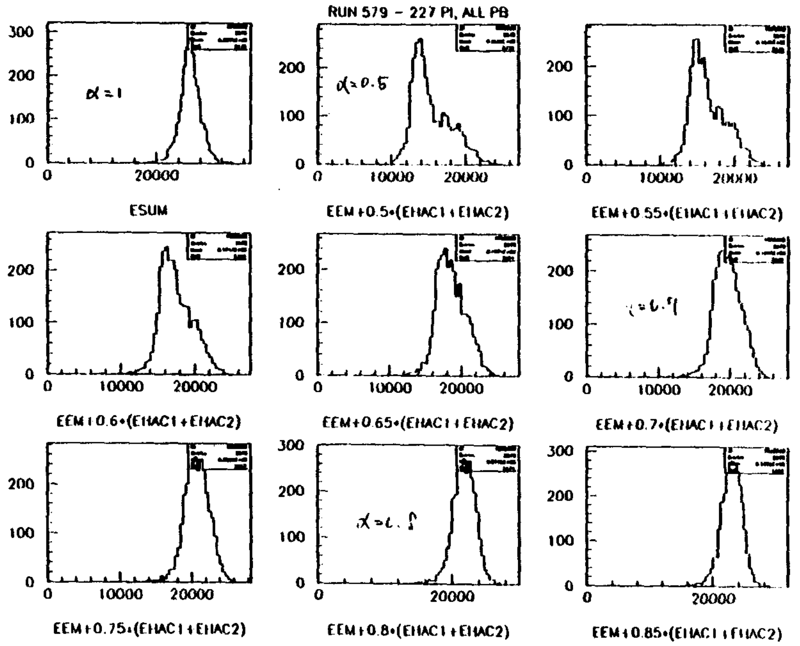


$E = E(EM) + \alpha . W_{Pb} \cdot E(HAD)$

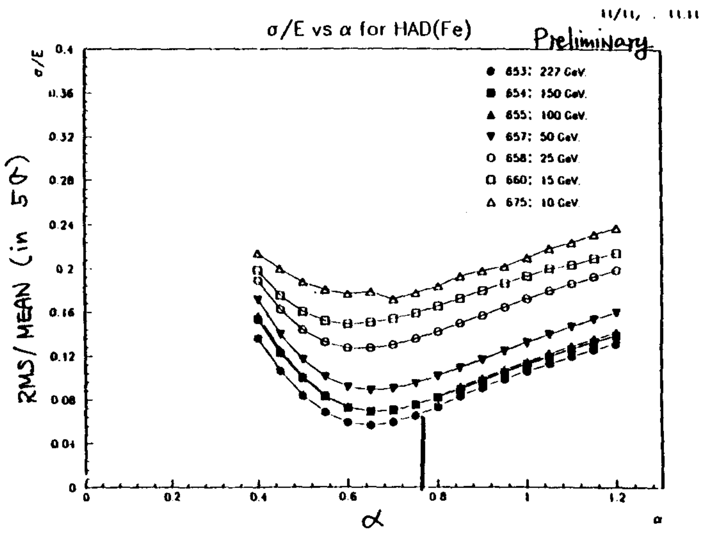
$W_{Pb} = 7.1$

G110

$W(\frac{dE}{dx})_{Pb} = 7.1$



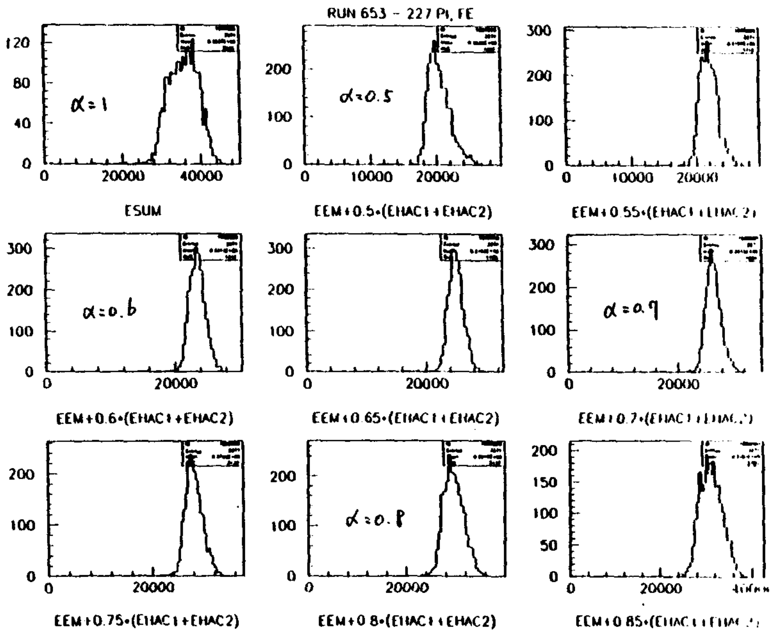
G105



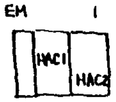
G111

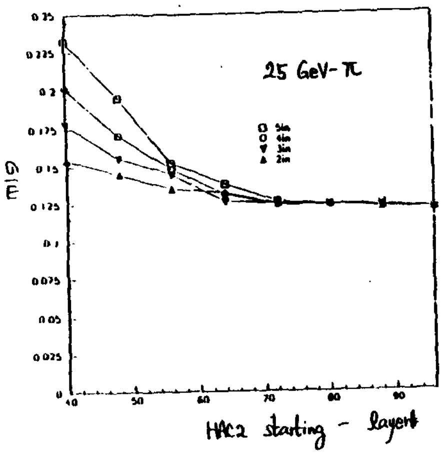
$W_{Fe} = 6.46$

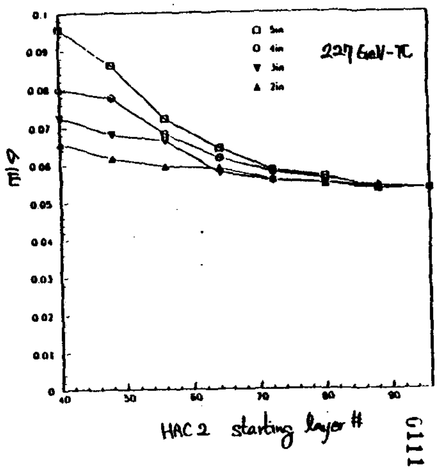
$W(\frac{dE}{dx})_{Fe} = 6.46$



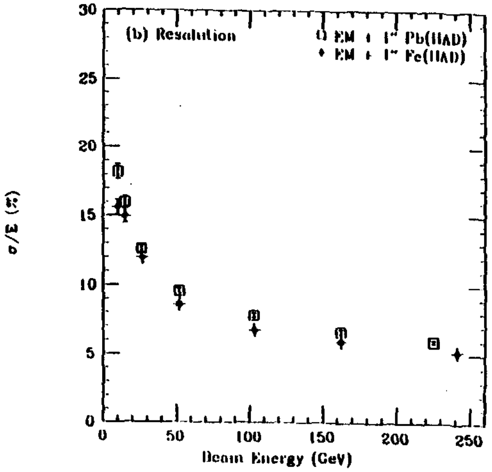
G109





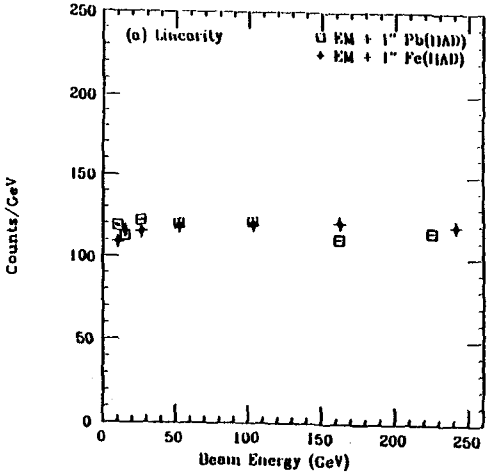


G1111



Configuration	w	σ/E (%)
EM + 1"Pb(HAD)	0.92	57/√E ⊕ 5.0
EM+ 1"Fe(HAD)	0.72	52/√E ⊕ 4.5

G1112



G1113

01115

TEST BEAM RESULTS

R. RUSACK

R. Rusack
May 5th 1992

TEST BEAM RESULTS ON THE SHOWER MAXIMUM AND MASSLESS GAP IN THE SDC CALORIMETER

DESCRIPTION OF FNAL/T841 TEST BEAM
- Preshower/Massless Gap
- Shower Maximum

PRESHOWER/MASSLESS GAP RESULTS
- Shower Width/Profiles
- Using PS to correct EM resolution

SHOWER MAXIMUM RESULTS
- Shower Width Profiles
- Track-Centroid Resolution

PI/E SEPARATION RESULTS
- PS, SM, EM, Had rejection factors
- Combined rejection factors

CONCLUSIONS

CONTRIBUTORS

Northeastern University: M. Hulbert, I.Leedom, S. Reucroft, D. Ruuska, T. Yasuda.

Rockefeller University: A. Bhatti, K. Goulianos, P. Melese, R. Rusack.

CEN Saclay : P. Bonamy, G. Comby, J. Ernwein, P. Le Du, J. R. Hubbard.

SSC Laboratory: H. Fenker, K. Morgan, T. Regan

South Carolina University: A. Weng, J. Wilson.

Yale: P. Cushman, S. R. Hou.

TEST SETUP

Test Beam:

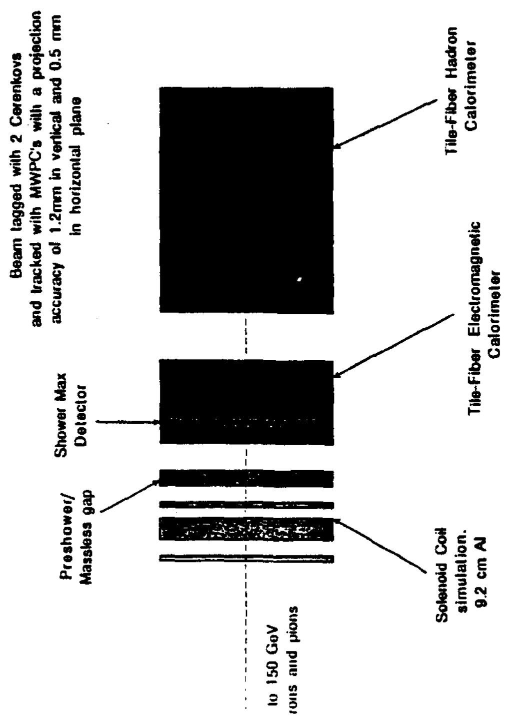
Electrons and pions in the energy range of 15 to 150 GeV.
Particle type tagged with two Cerenkov counters.
Muon contamination ~15% of the beam.
Large beam spot size: 5cm * 5cm.
Position of the incident particle determined with 4 MWPC's resolution 1.2mm in vertical axis and 0.5 mm in the horizontal.
Massless gap and shower maximum data were taken simultaneously with the electromagetic and hadron calerimeters.

Preshower/Massless Gap Detector

Fiber detector with 6 double layers of1mm fibers read out at both ends. At one end with an image intensifier/CCD system capable of measuring both position and pulse-height information for all 1200 fibers. At the other end the fibers were readout with MCPMT's, APD's and the photo-tubes. Served as instrument to measure in detail the shape of the shower as well as the energy deposited at different depths.

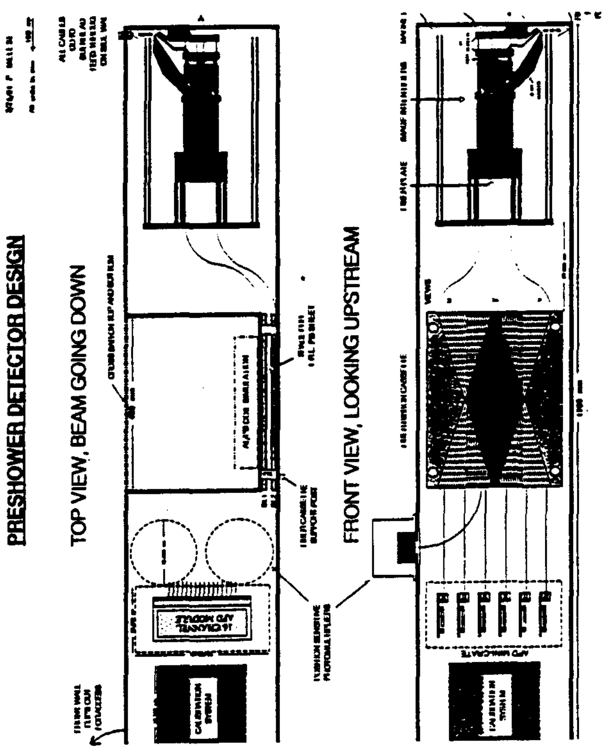
Shower Maximum Detector.

Eight strips of plastic scintillator per calorimeter tower raedout with WLS fibers which were coupled to clear fibers by a 64 channel connector to either 2 Philips 64 channel MCPMT's or to 96 APD's.
Total number of strips readout in these tests was 128.
Strip dimensions were 12.5 wide , 100 long and 2.5, 4.0 and 5 thick.
Two different construction techniques were tested.
Individually painted and wrapped with aluminized mylar and a single 4.0 mm thick calorimeter tile cut with 3mm deep grooves to isolete different strips.



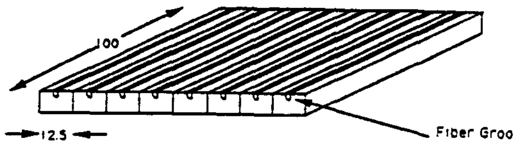
Schematic of the detector elements in the Fermilab Test beam T841.

01120



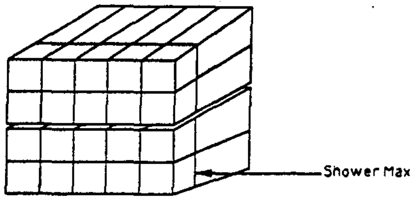
01121

Details of the Shower Maximum Detector used in FNAL Beam Tests.



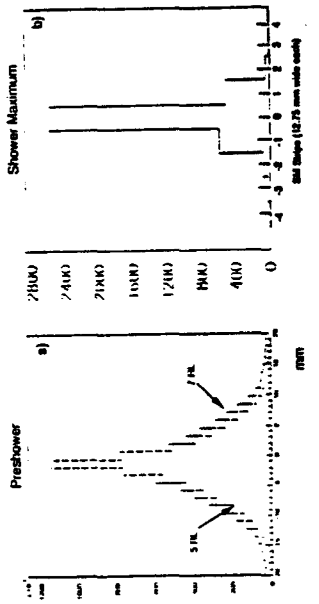
Array of 8 shower max tiles used in one calorimeter tower.

Construction of shower max detector tiles. Aluminized mylar was placed between the tiles



Cast Lead Calorimeter showing location of the shower maximum detector at 6 RL

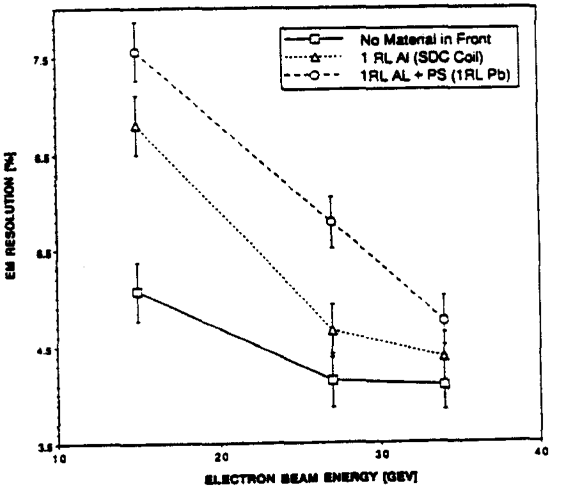
01122



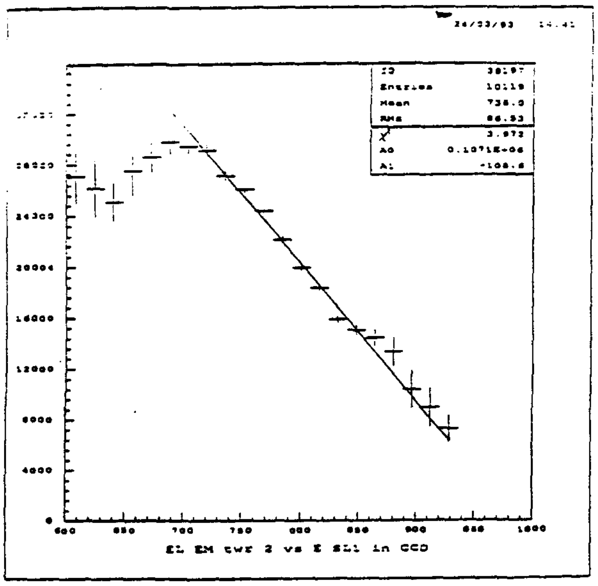
Shower profiles for 35 GeV electrons measured with the preshower and the shower maximum detectors

01123

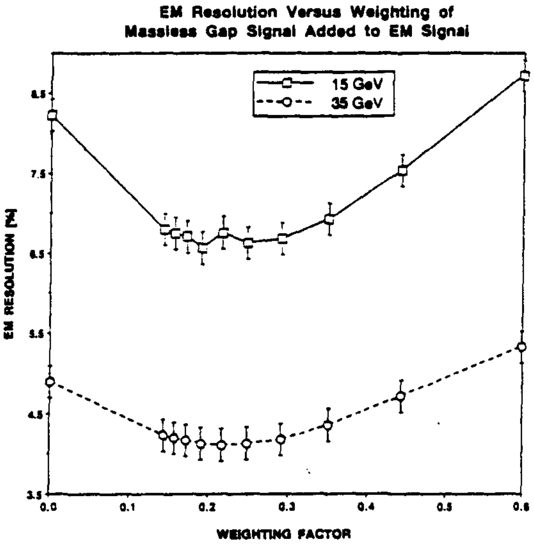
EM Resolution Versus Beam Energy
Effect Of Material (1-2RL AL,Pb) In Front Of Calorimeter



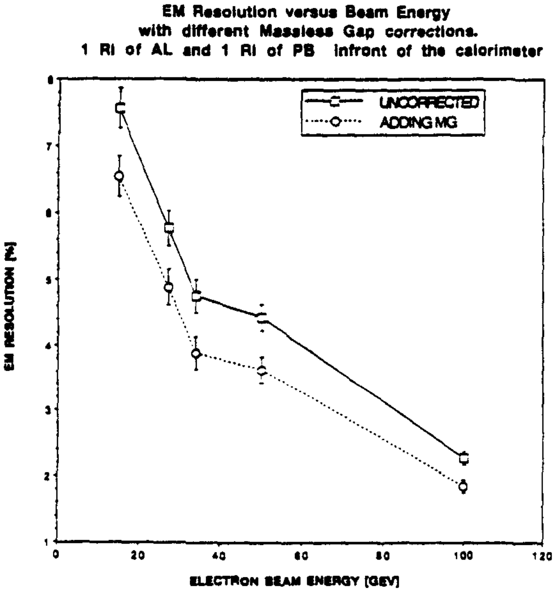
01124



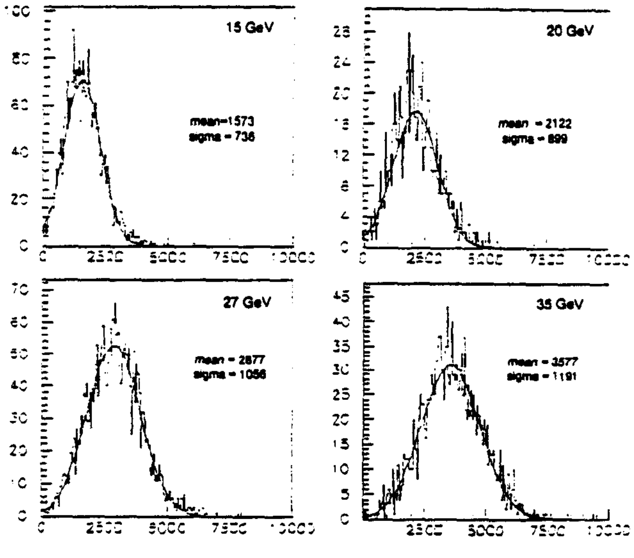
01125


EM Resolution Versus Weighting of Massless Gap Signal Added to EM Signal

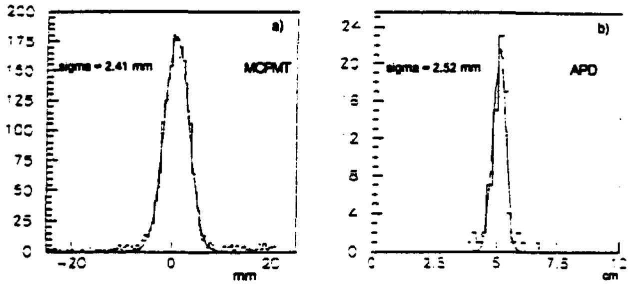
01126


EM Resolution versus Beam Energy with different Massless Gap corrections. 1 Rl of AL and 1 Rl of PB infront of the calorimeter

01127

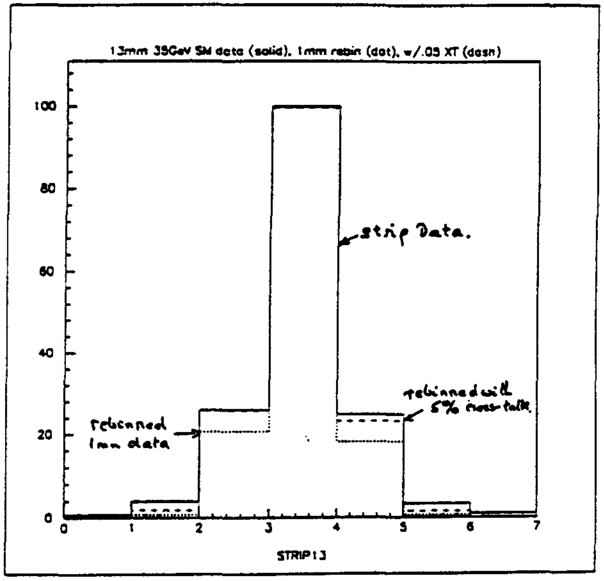


Energy Deposited by electrons in the shower maximum detector versus beam energy.

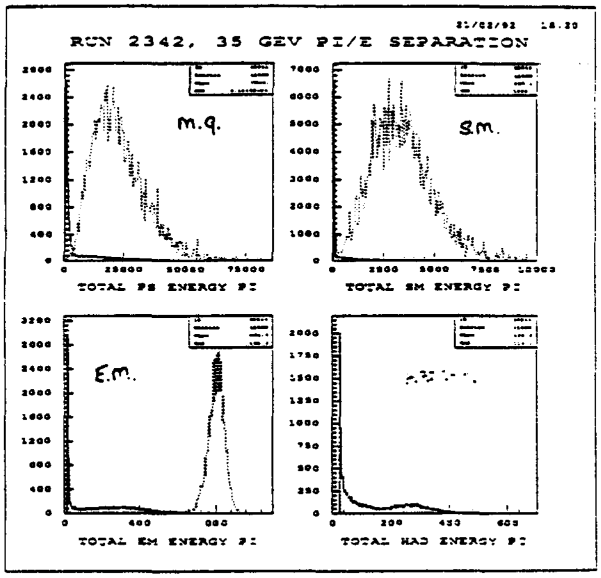


Shower Maximum Position Resolution.
at 35 GeV. Measured with MCPMT and
APD readout.

Shower Maximum Beam Profile measured with 1.25cm strips and rebinned data measured with 1mm fibers.

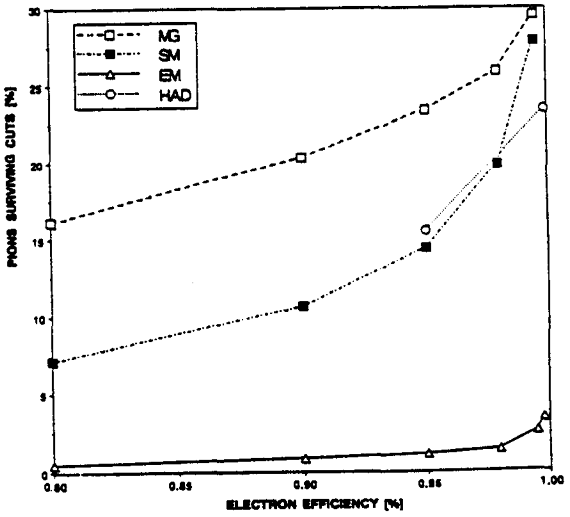


π/e response at 35 GeV.

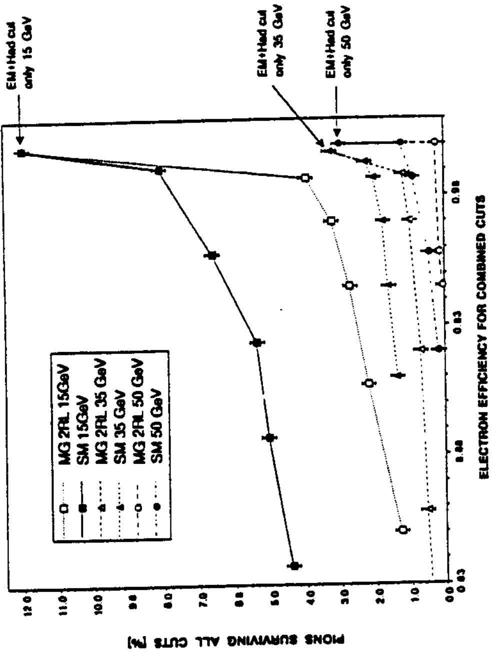


35 GeV

Pions Remaining After Cuts on the Massless Gap, Shower-Max, the EM and Hadronic Calorimeter. Cuts applied Seperately.



Pions Remaining Versus Electron Efficiency Cutting on EM and Hadron Calorimeters, Adding Massless Gap or SM Cuts for 15, 35, and 50 GeV.



CONCLUSIONS

We have evaluated in a test beam at Fermilab the performance of our strip SM detector and the massless gap. This was done in conjunction with the prototype tile fiber EM and hadron calorimeters

We have measured the position resolution of the shower max detector to be 2.5mm.

We have shown that the shower shape does not change significantly between 5 and 7 radiation lengths.

The degradation to the EM resolution caused by the magnet coil is improved when the weighted signal from the massless gap is added to the EM signal.

We have measured the combined EM, Hadron, Masless Gap and Shower Maximum signals and shown how they provide a powerful method to separate electrons from charged pions.

01134

ORGANIZATION AND PROTOTYPE PLAN

P. MANTSCH

Sanda Birmingham
214/708 6360

SDC CALORIMETER

ORGANIZATION AND PROTOTYPE PLAN

OR

GETTING IT BUILT!

Tasks

Resources

Project Management

Construction Plan

Prototype

Tasks

Fabricate EM Radiators

- Lead casting with tile pockets

Fabricate Hadron Absorbers

- Stacked steel plates with tile pockets

Cut Tiles / Attach Readout Fibers

Assemble Wedge Modules

Build Support

Assemble Barrel (and Endcap)

Resources

Industry

- Lead radiator
- Steel absorber
- Scintillating tiles
- Optics

Laboratories

- Engineering design
- Major component assembly
- Final assembly (SSCL)

Universities

- Subassemblies
- Fabrication QC
- Calibration
- Beam testing

Engineering Resources
(5/6/92)

Argonne Nat'l Lab

Hill
Guarino
Nasiatka

+ 1.5 designers

Fermilab

Bartroszek
Banas
Hahn
Da Silva
Lee
Larson
Carson
Richardson
+ 2 openings

+ 5 designers

LBL

Pope
Thur

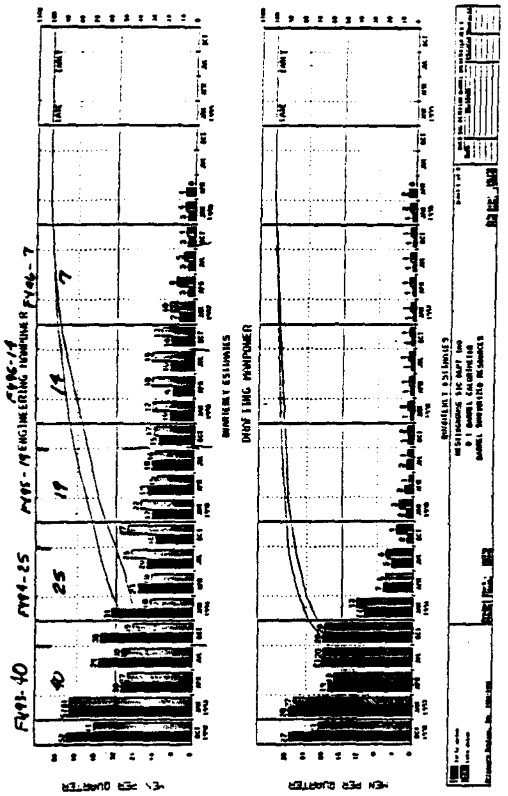
+ 2 designers

Universities

2 - 4

Non US

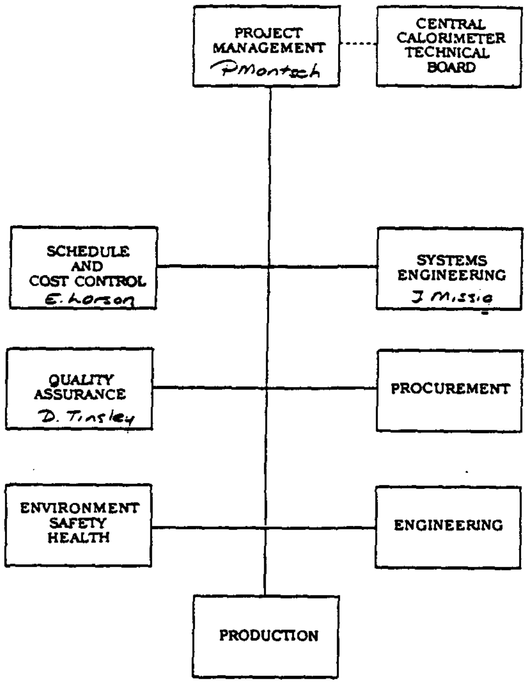
6



5/1/92 PMM

Project Management

DRAFT



Project Management Responsibilities DRAFT

Project Manager

- Manage all aspects of the design fabrication. procurement. cost and schedule.
- Oversee the preparation and maintenance of the project WBS.
- Oversee the establishment and maintenance of the Cost Schedule Control System.
- Coordinate all reporting of the cost. schedule. and technical status to SDC project management.
- Ensure effective interface between the Calorimeter effort and the SDC project.
- Recommend membership for the Calorimeter Technical Board.
- Serve as secretary to the Calorimeter Technical Board.
- Implement all applicable ES&H and Quality Assurance proceedures and requirements.
- Coordinate allocation of manpower.
- Prepare and track project budget.
- Prepare budget reports.
- Chair Configuration Control Board.

Schedule and Cost

- Establish and maintain project schedule and cost control.
- Coordinate procurement priorities to assure schedule.
- Track project costs.
- Maintain project cost projections.
- Chair critical parts meetings.

Systems Engineering

- Establish and maintain calorimeter system technical requirements and specifications.
- Establish and maintain calorimeter system configuration control.
- Serve as secretary to the configuration control board.
- Establish and maintain material requirements and standards.
- Chair material review board.
- Establish document control system.
- Maintain interface control within the calorimeter and with SDC.
- Assure effective system integration.
- Organize technical reviews.

Quality Assurance

- Develope and maintain Quality Assurance Program.
- Manage the Quality Assurance organization.
- Assist Project Engineering in the development of the traveler.
- Review travelers and shop proceedures.
- Train management and shop workers in the quality control program.
- Maintain instrumentation calibration and associated documentation.
- Maintain QA document control.
- Assure quality of procured parts and assemblies.
- Audit Quality Assurance program

ES&H

- Assist project manager in developing ES&H program.
- Assist the Project Manager in carrying out the ES&H program.
- Perform ES&H inspections and audits as required.
- Train management and employees in ES&H requirements and proceedures.

Procurement

- Oversee the procurement of materials and services.
- Oversee incoming inspection of parts.
- Assist Project Manager in negotiating and tracking contracts.

Engineering

- Responsible for product engineering and design.
- Develop Quality Control traveler and manufacturing proceedures.

Production Management

- Manage the component assembly.
- Ensure the ES&H in the workplace.
- Implement product Quality Assurance Program.

Construction Plan

R & D

- **Tiles**
- **Absorber assembly methods**
- **Small scale prototypes** 10 TOWER CASTING SLIDE / TEST WEDGE

Barrel Final Design (Endcap follows by 6 months)

Barrel Wedge Preproduction Prototype

Procurement

Component Assembly

Final Assembly

- **Barrel - Mar 1997**
- **Endcap - Sept 1997**

SDC CENTRAL CALORIMETER

COST SUMMARY BY WBS

WBS ELEMENT	COSTS (K$)			
	BARREL	END CAP	END PLUG	TOTAL
COMPONENTS	53621	30637	5752	90010
ASSY	7430	5021	932	13383
SUPPORT	4054	3243	331	7628
TOOLING	10655	2570	845	14070
FACILITIES	5553	622	369	6544
SURFACE ASSY	2399	2219	141	4759
MANAGEMENT	3408	3142	1360	7910
R&D/PROTOTYPE	3512	1512	503	5527
TOTAL	90632	48966	10233	149831

Westinghouse
Science & Technology Center

SDC CENTRAL CALORIMETER

ALTERNATE COST SUMMARY

COMPONENT OR ACTIVITY	COSTS (K$)			
	BARREL	END CAP	END PLUG	TOTAL
SCINTILLATORS	24797	8466	2049	35312
MODULE STRUCTURE (W/O CALIBRATION GROOVES)	31667	16875	3072	51614
PMT'S	6420	4635	432	11487
MODULE ASSY. AND MISC MODULE COMPONENTS	8219	5782	1466	15467
SUPPORT SYSTEM	4054	3243	331	7628
SURFACE ASSY	3910	2284	284	6478
MANAGEMENT	3408	3142	1360	7910
R&D/PROTOTYPE	3512	1512	503	5527
CALIBRATION	4644	3031	737	8412
TOTAL	90631	48970	10234	149835

Viewgraph 7
GWS
4 30 92

Westinghouse
Science & Technology Center

Preproduction Wedge Prototype

Objectives:

- **Promote design choices**
- **Focus design effort**
- **Establish collaborative infrastructure**
- **Verify mechanical design**
- **Develop manufacturing and assembly methods**
- **Refine cost and schedule**
- **Verify performance**

P.Manusch April 30, 1992

Prototype Configuration

Full (1/32) Wedge plus

Partial Wedge (for hadron containment)

Instrumentation:

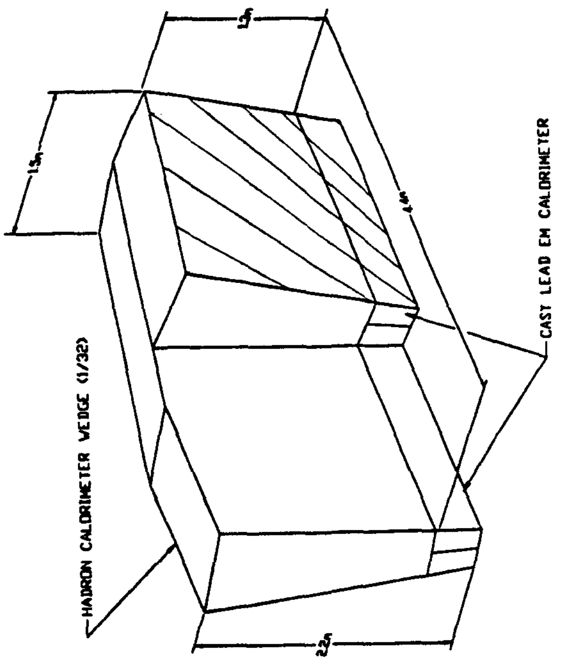
EM	8 x 4 towers	(.05 x .05)
Hadron	4 x 4 towers	(0.1 x 0.1)

960 EM tiles (32 channels)

688 Had tiles (16 channels)

P.Manusch April 30, 1992

PREPRODUCTION PROTOTYPE WEDGE



Prototype Milestones

Refine radiator/absorber designs (May- July)

Mockup barrel calorimeter wedge (May-July)

- **Fiber routing studies**
- **PMT and crate mounting**

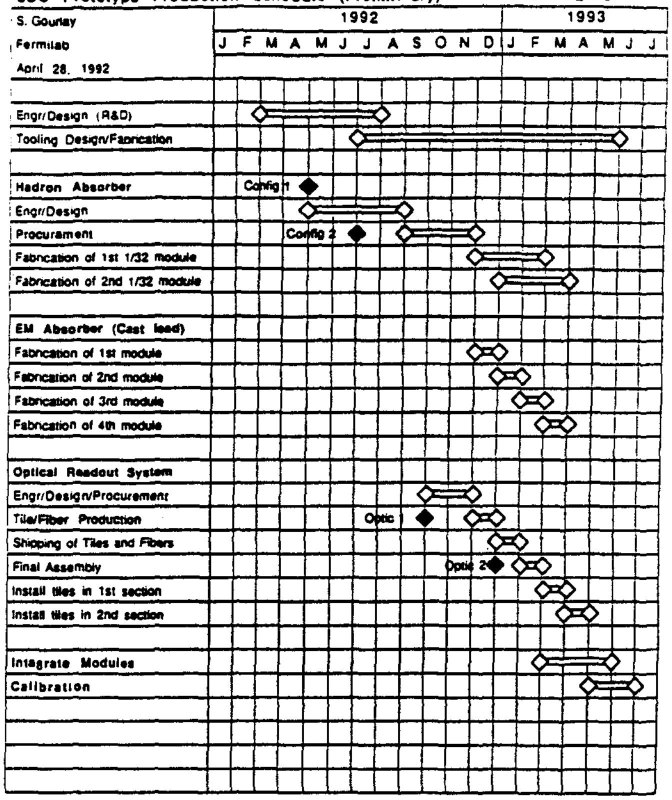
Freeze prototype design (July 1)

Begin final assembly (May 1993)

Finish final assembly (July 1993)

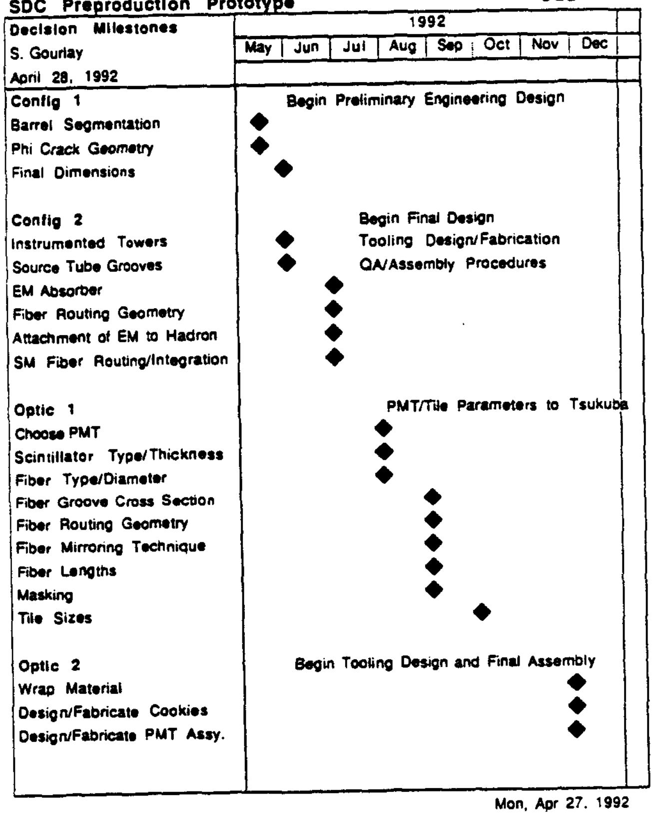
P.Mantsch April 30, 1992

SDC Prototype Production Schedule (Preliminary)



Mon, Apr 27, 1992

SDC Preproduction Prototype



Mon, Apr 27, 1992

Prototype Responsibilities

(Tentative)

EM Radiator

- *Design/Fab - Argonne/Westinghouse*

Had Absorber

- *Design - Fermilab*
- *Fab - PRC*

Tiles/Optics - Japan, PRC

Component Assembly - Argonne/ Fermilab

Calibration - SSCL, UTA, Argonne, Purdue

Test Fixture -

Summary

Calorimeter design converging

Design concepts being tested

Organization and management coming together

Task assignments being made

Prototype wedge being built to exercise organization and verify design

01156

DESIGN OPTIONS

R. KADEL

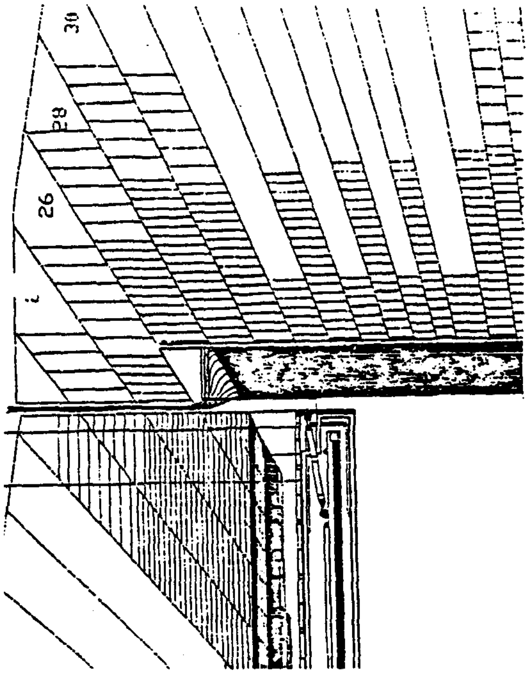
Kadel

Monolithic Electromagnetic Endcap Calorimeter

R. W. Kadel
April 25, 1992

Requirements

- **Coverage:** $1.4 \leq \eta \leq 3.0$
- **Resolution:** $\sigma / E(l) = 18\% / \sqrt{E(l)} \oplus 1\%$ (6mm Pb absorber)
- **Depth** 25 Xo
- **Longitudinal Segmentation:** EM1 and EM2 7 Xo + 18 Xo
- **Transverse Segmentation:** $\delta\eta \times \delta\phi \geq 0.05 \times 0.05$
- **Non-Linearity :** < 1% after correction
- **Dynamic Range:** 20 MeV < E(t) < 5 TeV
- **"Massless gap" behind end of coil**
- **Position Detector ("Shower Max") at 7 Xo**



Monolithic Electromagnetic Endcap Issues and Benefits

- **Radiation Dose varies from:**

50 krad –> 5 Mrad

over fiducial area in 10 years of running
at design luminosity.

Choose Radiation Resistant Construction
Convey signals in Silica fibers
Replaceable core

- **Gravitational load always in plane of Pb. Endcap EM is of modest weight and size:**

30 Tonne, 5 m diameter.

Easier to handle mechanical forces and
and creep as compared to barrel.
Optimal design for barrel may not be
best for the endcap.

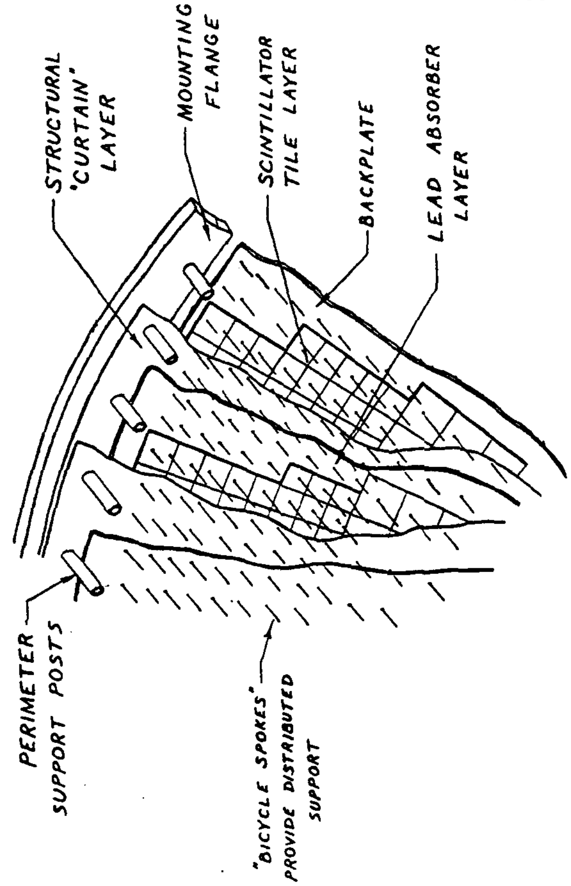
- **Minimize cracks**

We have proposed a low mass, diffuse
mechanical support with the EMEC built
as single piece.

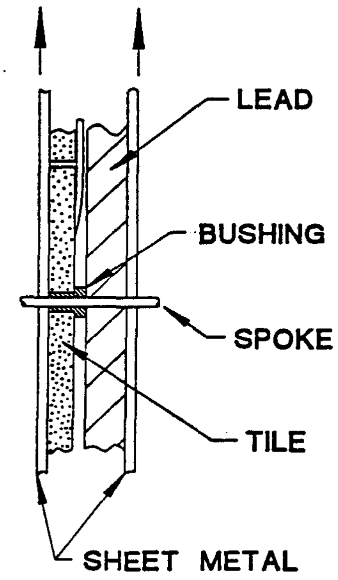
No ϕ cracks between modules

No η bulkheads

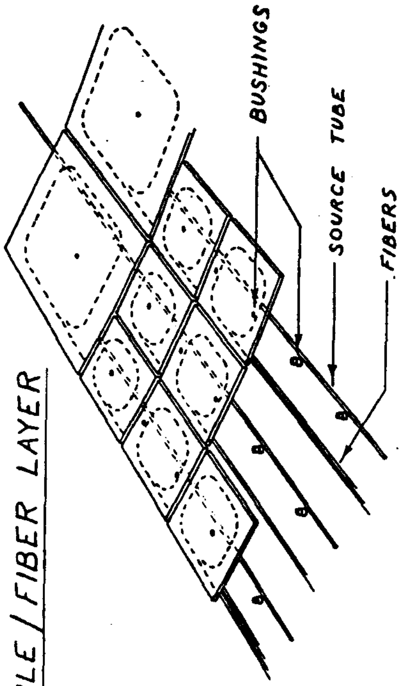
In this design (non-projective)
supports occupy less
than 0.1% of the fiducial area.



BASIC STRUCTURE



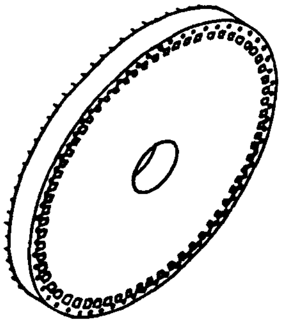
ASSEMBLY OF A TILE/FIBER LAYER



Monolithic Electromagnetic Endcap

Mechanical Considerations

- All Pb radiator plates have same hole pattern (except boundary).
- Design independent of Pb or scintillator thickness.
- All support "curtains" have same design.
- 396 tile shapes
  (= 18 η towers x 22 layers deep)
  Same as TDR. No new tile shapes.
  Design consistant with "megatiles", if desired .
- Mechanical support hidden behind Barrel EM calorimeter
- No ϕ cracks between modules.
- No η bulkheads between towers.



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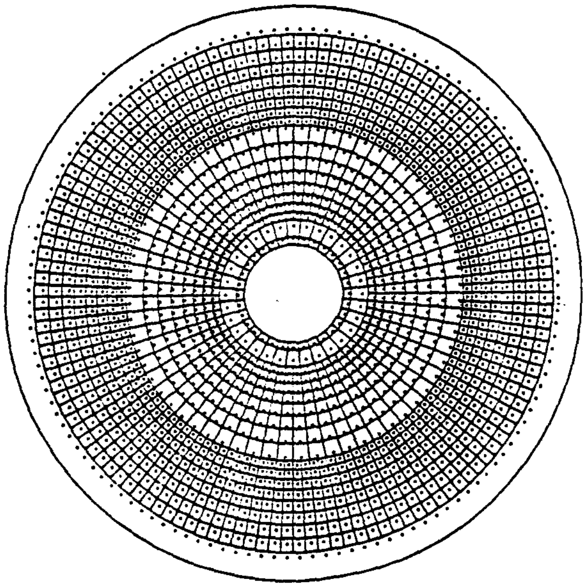

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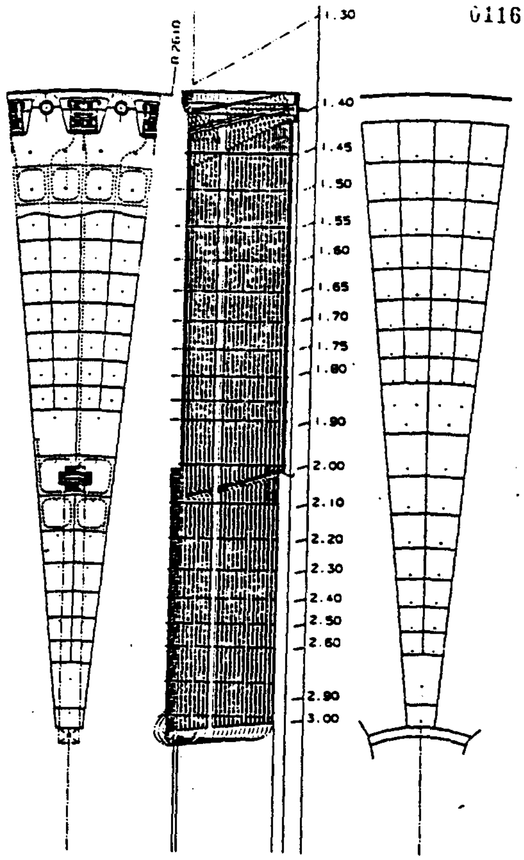

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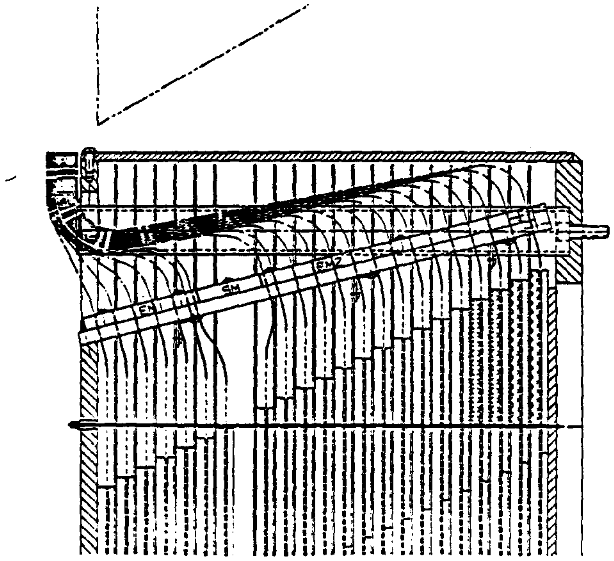

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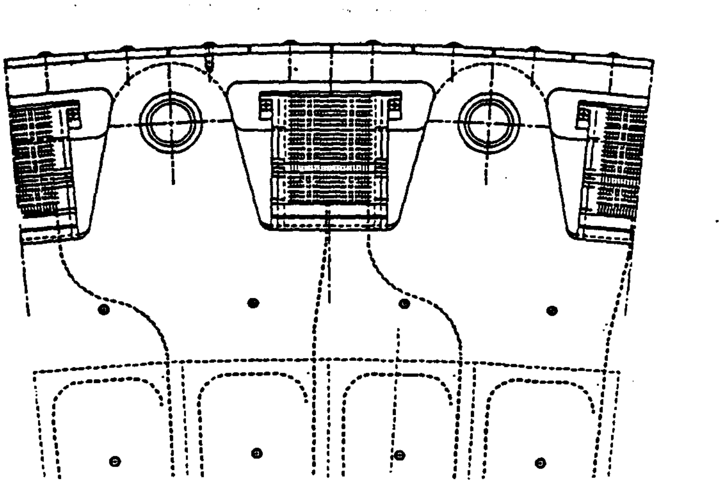
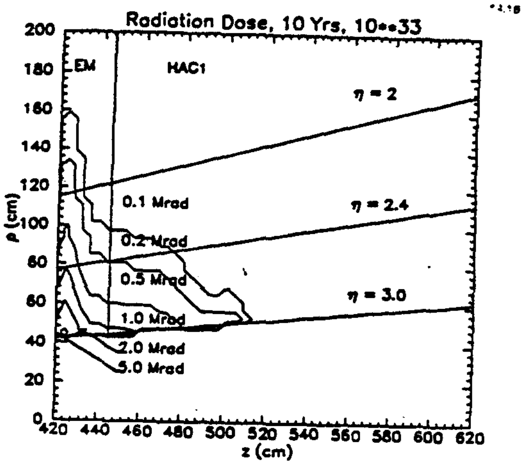
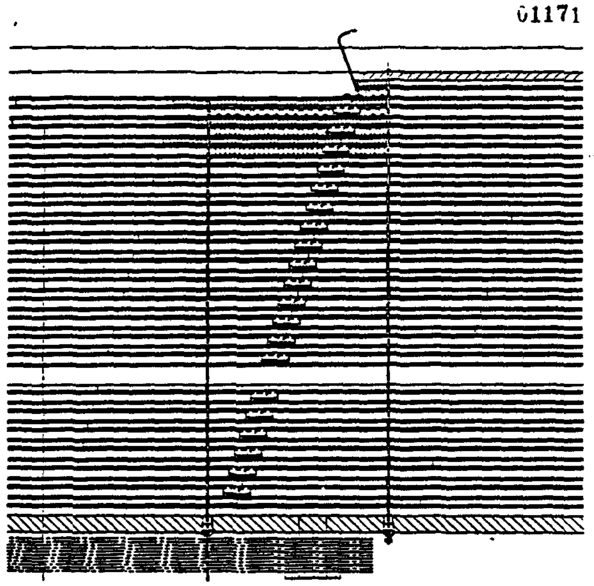
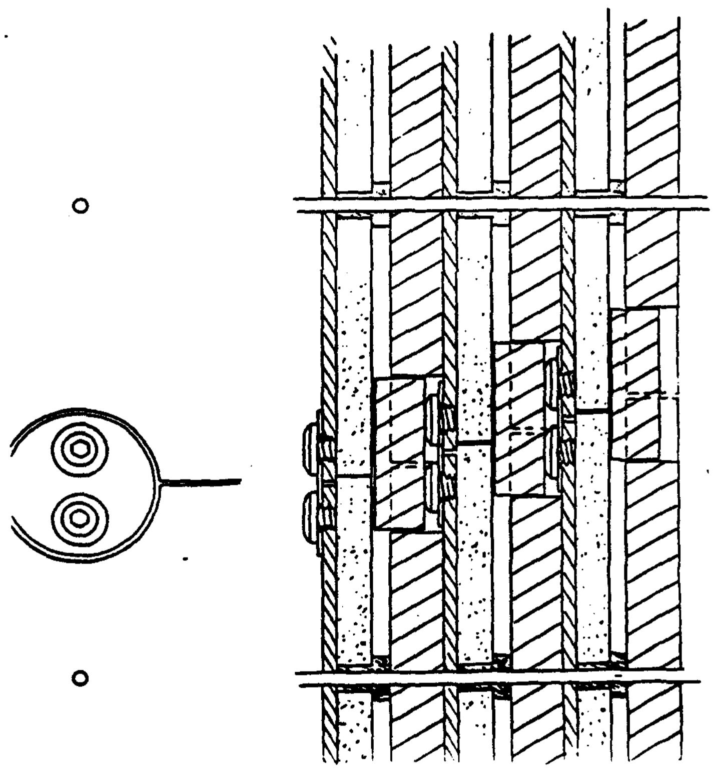


Replaceable Core

- Only innermost 1meter of EMEC has radiation dose greater than 1 Mrad in 10 years of running at design luminosity.
- No need to replace 80% of EMEC at outer diameter.
- Design replaceable core so that outer 80% of calorimeter is left largely undisturbed.







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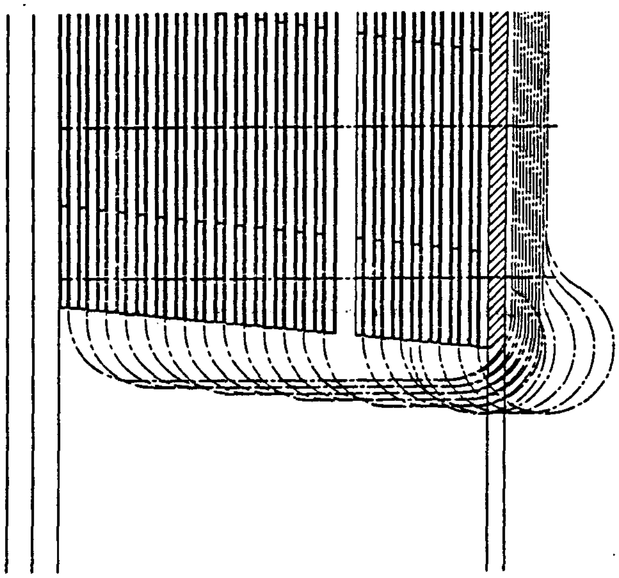


01174

Calorimeter Test Module

Constuction

16 Towers
EM1 7Xo
EM2 15Xo

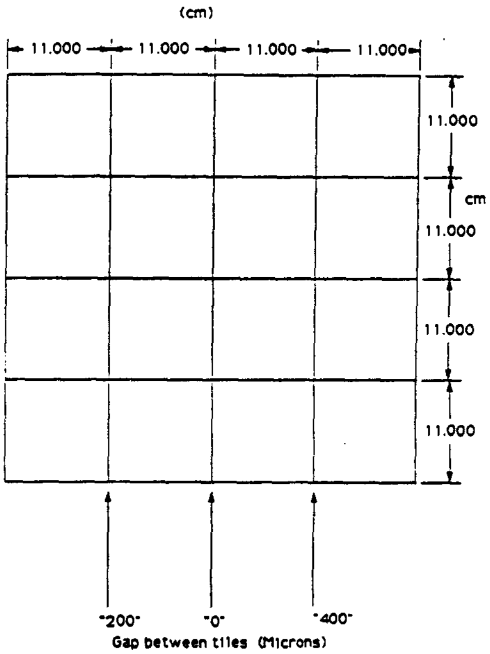
32 PMT's
R580-17
ext. Green

6.35 mm Pb

4mm SCSN81

Fiber

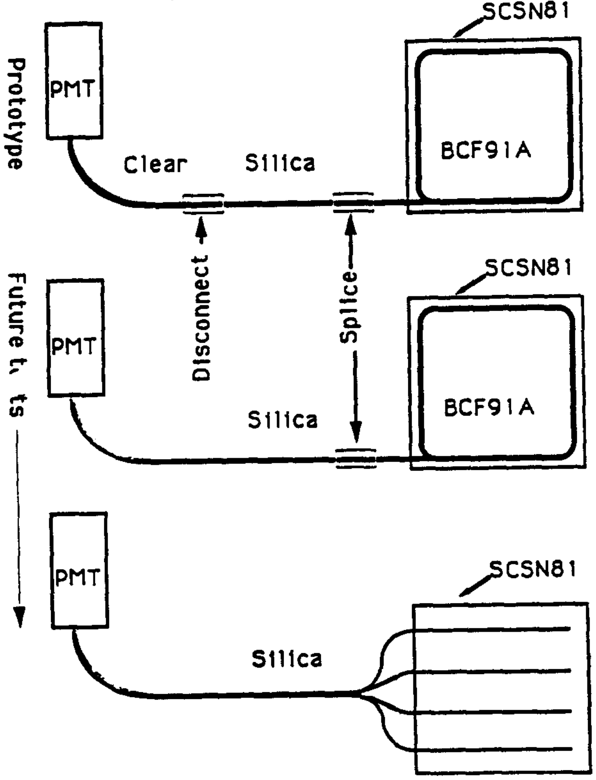
BCF91A
(WLS)
(0.4m)
↓
3M UMT -1.0
(silica)
(1.0m)
↓
BCF98
(clear)
(1.3m)



R. W. Kadel
Dec 16, 1991
REV APRIL 23, 1992

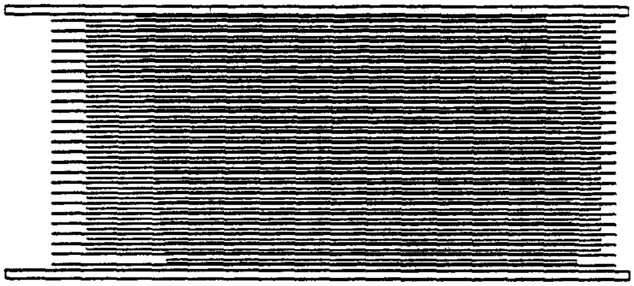
01175

OPTICAL SYSTEM



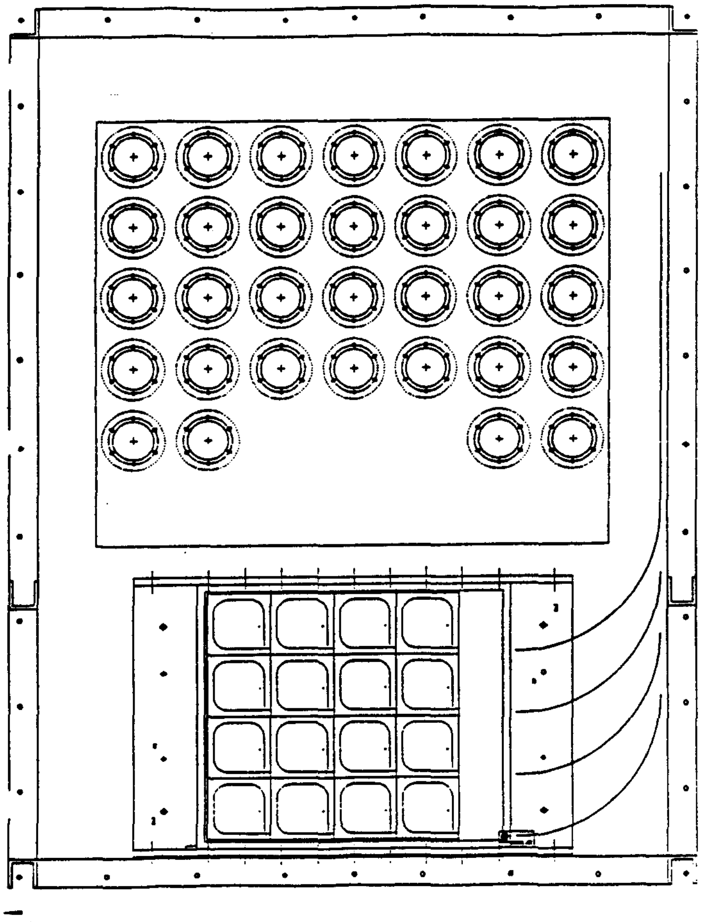
01176

Calorimeter Test Module (side view)



- Towers projective in one dimension
- Axial spokes
- Angle of towers representative of $\eta = 2.0$
- 3mm diameter hole for spokes (0.1% of area)

01177



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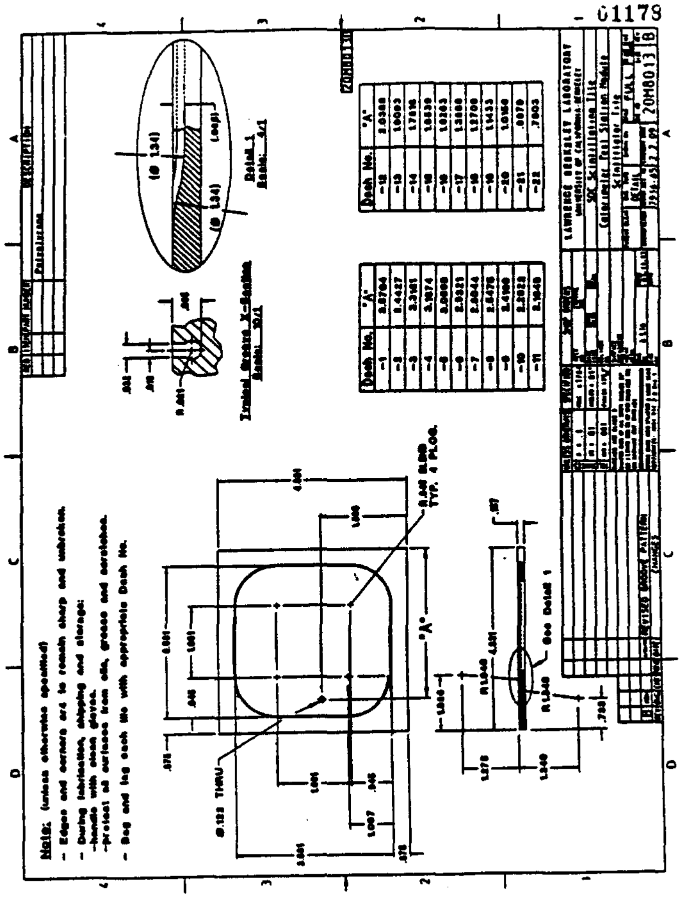

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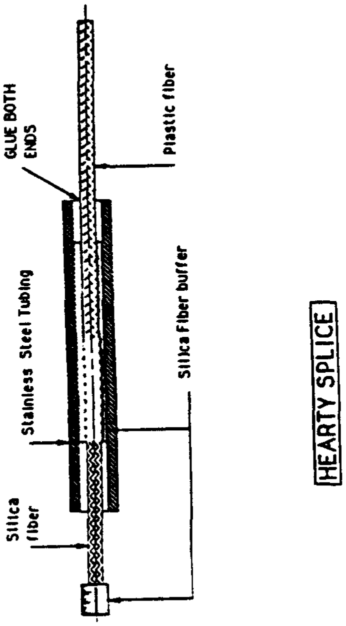

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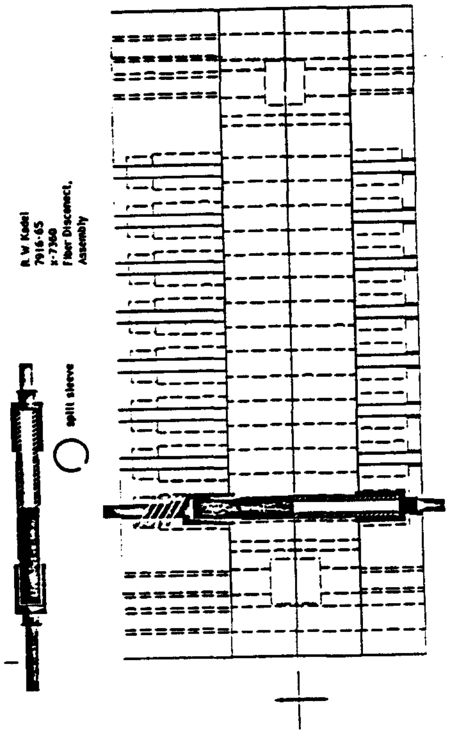


Summary

Simple design which meets requirements

- Low Mass, diffuse support
- All supports non-projective
- Replaceable core $2.0 \leq \eta \leq 3.0$
- No ϕ cracks between modules
- No η bulkheads between towers

Test Beam Module

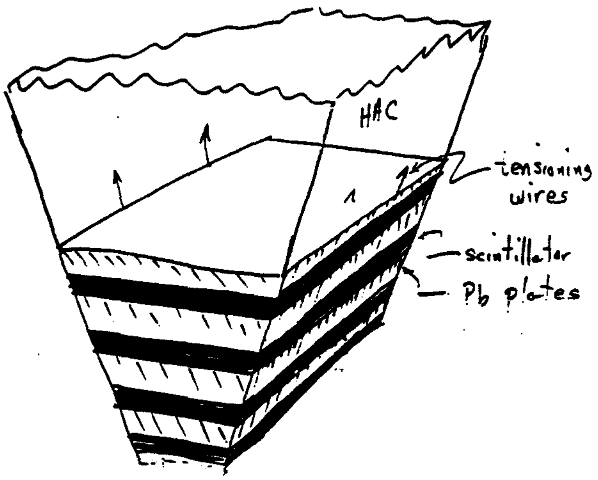
- Study support system
- Splices between dissimilar fiber materials
- Incorporates source calibration
- Provision for "longitudinal" masking
- Ready for test at BNL in June 1992.

DESIGN OPTIONS

J. FREEMAN

Freeman

Alternate EM Barrel Design

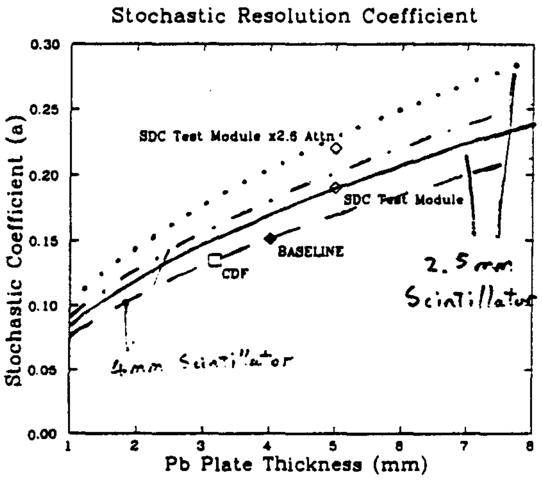


⇒ compressed stack EM calorimeter
(like CDF barrel EM) wire tensioning.

Compressed Stack EM features

- allows use of "mega-tiles"
  - → ~ 50X reduction in number of tiles, reduced handling cost;
  - → reduced inter-tile cracks because of no tolerance build-up
  - → longer shower max strips for reduced channel count or improved performance
- allows possibility of thin Pb plates, improved EM resolution.

Lead/Scintillator Thicknesses?



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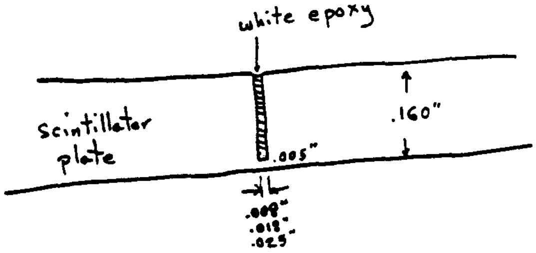
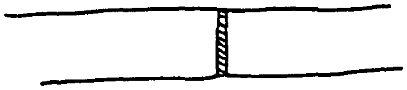
mega-tile



or



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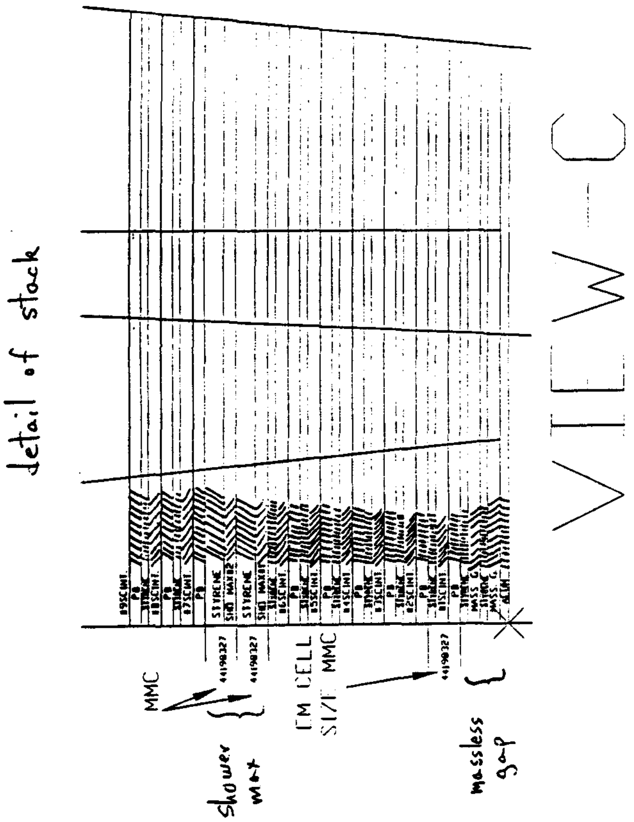
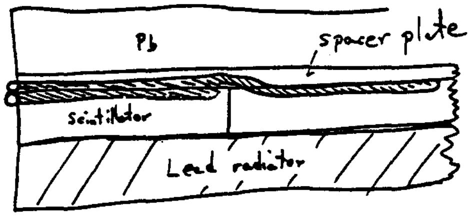


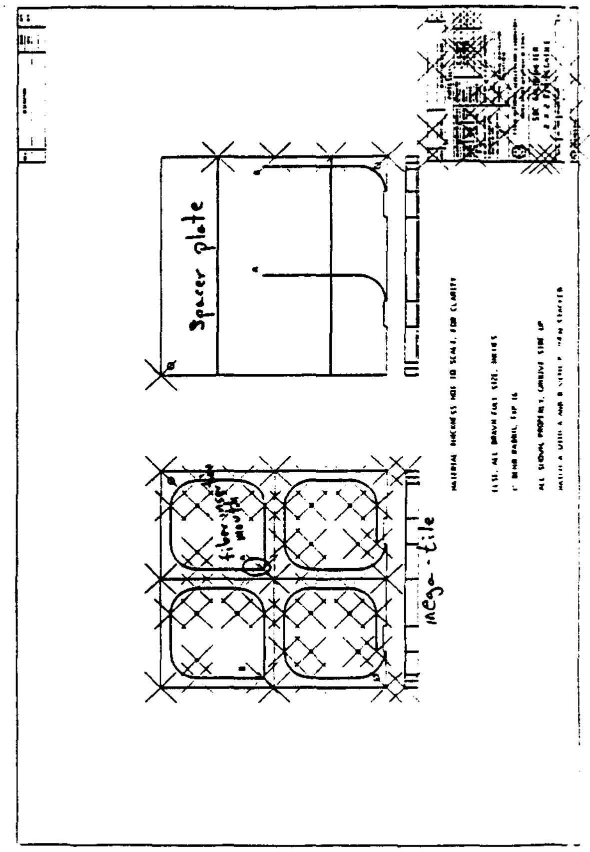
61188

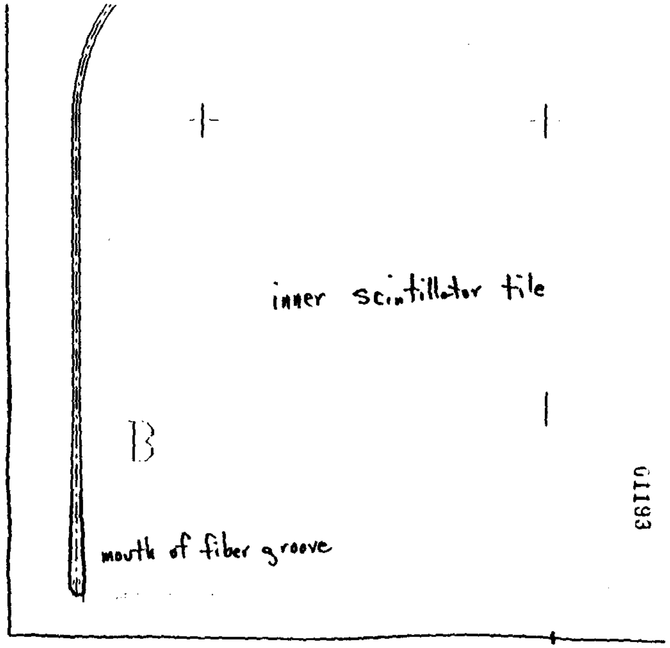
61189



scheme for inserting fibers into inner tiles after assembly.

61190





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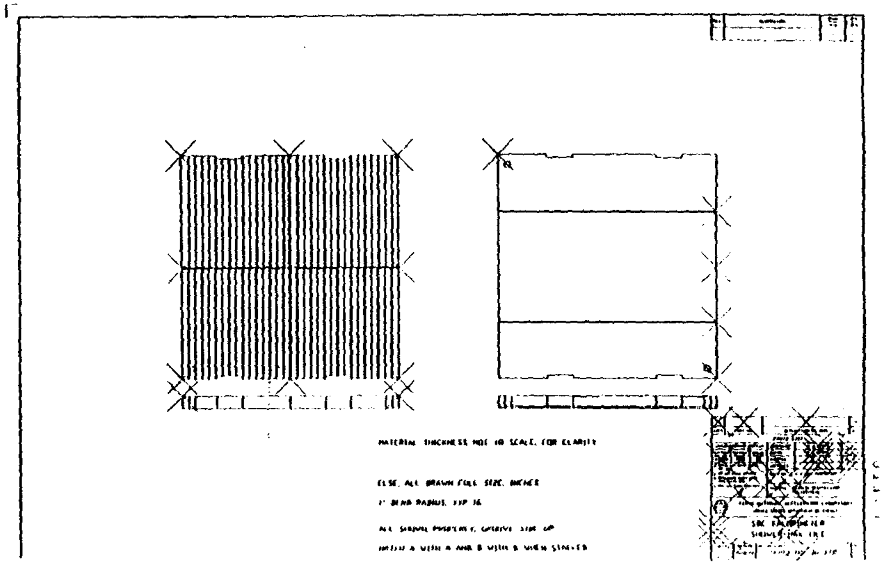

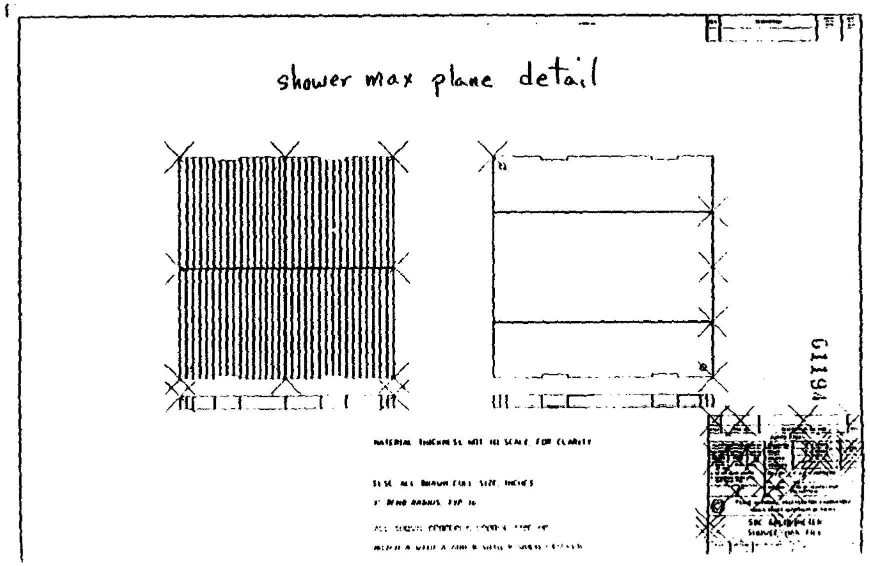

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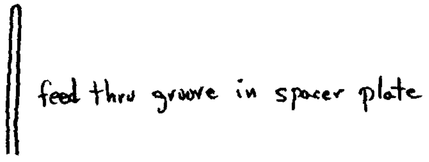


61192

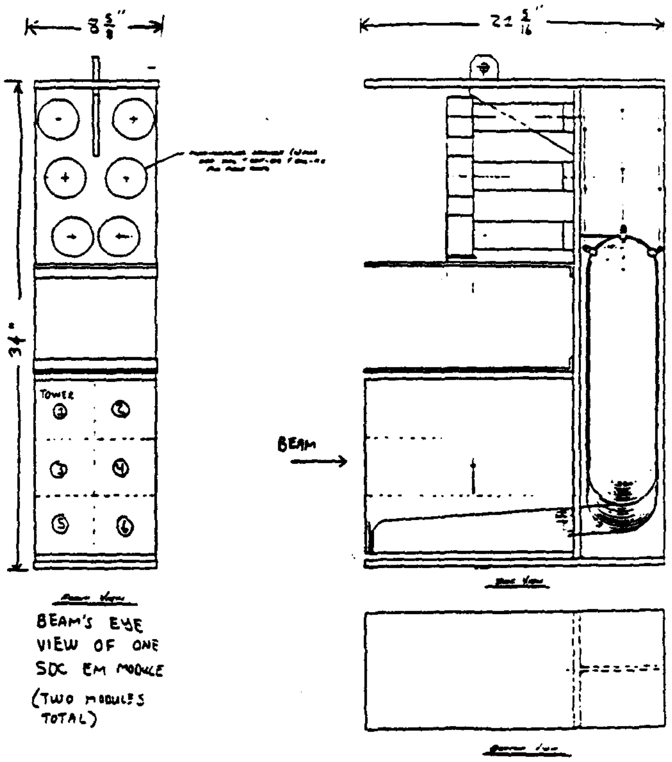
01195

Prototyping Schedule

- calorimeter in test beam at BNL
  May 21
  2 modules 2×3 towers, realistic cracks
  2mm pb, 4mm scint. (120 mega-tiles)
  ~ 9%/$\sqrt{E}$ target resolution
  measure uniformity, light yield
- full length mechanical prototype in mid-June
  study assembly strategy, fiber routing
- engineering, costing studies

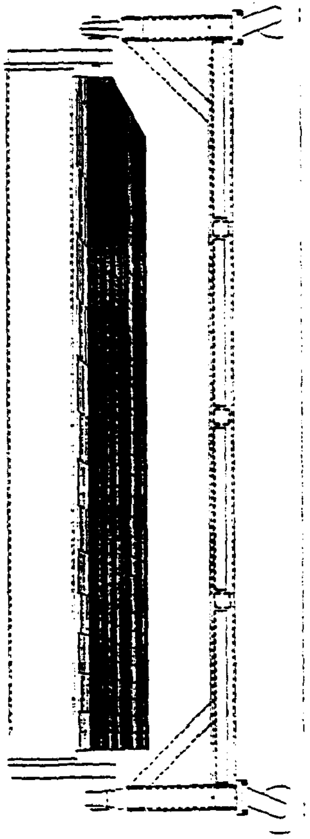
01196

SDC BARREL EM PROTOTYPE MODULE (FNAL)



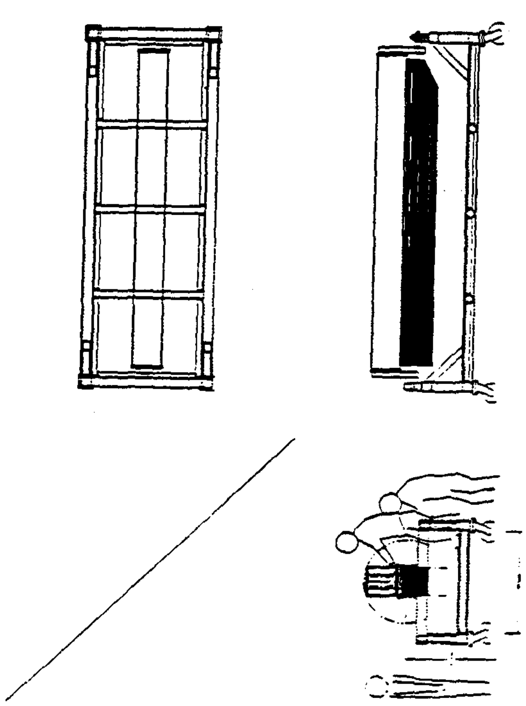
BEAM'S EYE VIEW OF ONE SDC EM MODULE (TWO MODULES TOTAL)

01197



full scale prototype

01198



01199

SCINTILLATOR R & D

G. FOSTER

[illegible]

SDC Calorimeter Rad-Hard Scintillator R&D

SCINTILLATOR TILES

Requirements Under Radiation

- Maintain Adequate Light Yield
- Maintain Adequate Uniformity
- Maintain Mechanical Integrity

The Direct Radiation-Induced Drop in the Scintillation Light Yield Is Small

- <~ 20% for a 50-MRad Dose (for most fluors)
- Major Effects are Due to Light Attenuation in Base Plastic

01202

GW Foster 5/5/92

SDC Calorimeter Rad-Hard Scintillator R&D

Radiation Hardness and the SDC Calorimeter

The SDC Calorimeter is Specified to Survive "100 years" at Design Luminosity.

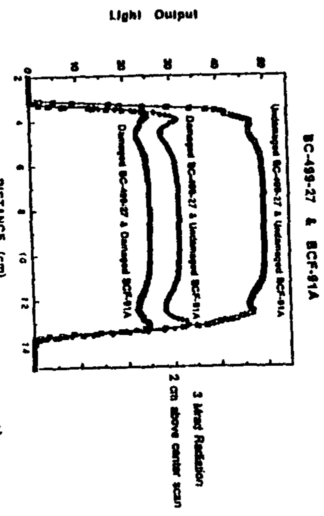
- Realistically, 10 years at 10^{33}, then 10 years at 10^{34}.
- Standard scintillators and fibers are adequate for the Barrel, which sees a lifetime dose of < 0.6 MRad.

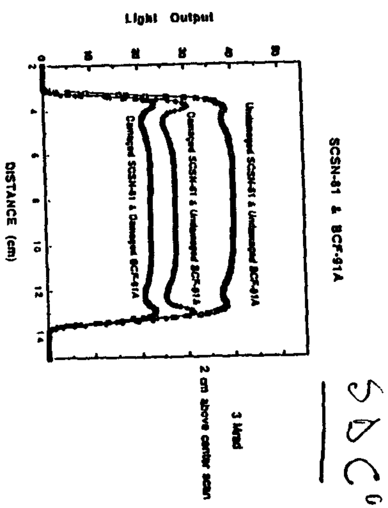
The Baseline Design allows for periodic replacement of the scintillator assemblies in the Endcap EM, which see lifetime doses of up to 60 MRad.

If Economically Justified, it would be Tremendously Convenient if Rad-hard Materials could be found which avoid this Periodic Replacement.

01200

GW Foster 5/5/92





30 KeV x-ray scans across Tile-Fiber
Damaged data after recovery

U. Haygpian
SDC
01203

SDC Calorimeter Rad-Hard Scintillator R&D

PROPERTIES OF TILE/FIBER CALORIMETRY

Separated Function of Optical Components:

- Scintillator Plate
- Waveshifting Fiber
- Clear Readout Fiber

Each Component Sees Different Stress from Radiation Damage at Different Regions of Eta.

Separation of Function allows each component to be optimized to handle Radiation Damage.

01201

GW Foster 5/5/92

SDC Calorimeter Rad-Hard Scintillator R&D

Strategies to Prevent light Drop from Scintillator Tiles (cont'd)

3.Keep The Plastic From Turning Brown

- Understand the Chemical Pathways... recent progress
- Obstruct them, or React Away the Radiolysis Products

4. Switch to a New Plastic Base Material

- Many Aromatic Polymers commercially available.
- Most of these will Scintillate.
- Light Yield and Optical Quality are Negotiable for the small region of high radiation damage.

GW Foster 5/5/92

SDC Calorimeter Rad-Hard Scintillator R&D

LIGHT YIELD & PHOTOSTATISTICS

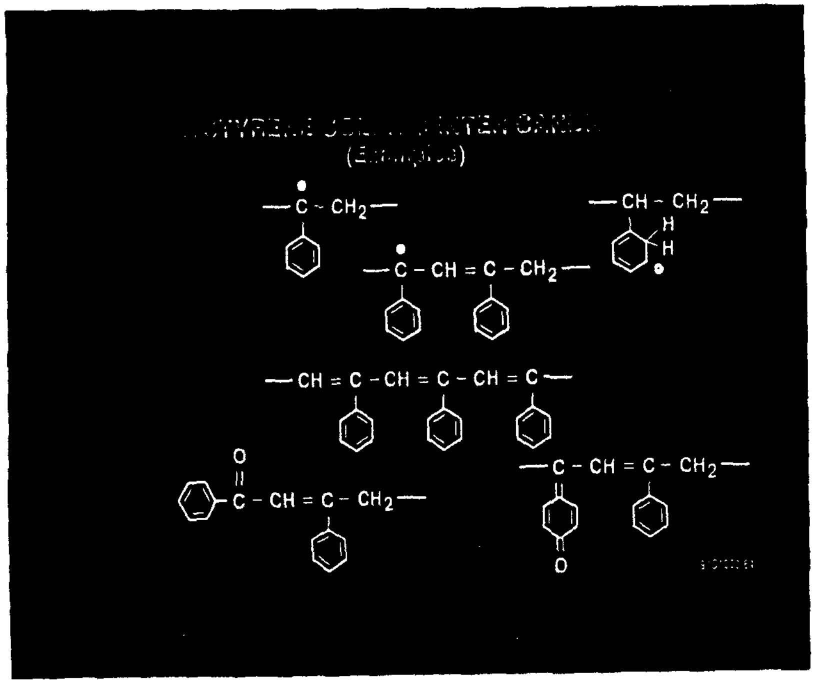
SDC Baseline Design Maintains E_T Resolution

- ~400 PE/GeV In Barrel..................Safety Factor ~4
- ~4000 PE/Gev E_T at Eta=3...........Safety Factor ~40

Photostatistics Will Not Limit E_T Resolution In Region of Highest Radiation Damage

- Optical Masking at PMT will ensure Uniformity in Depth
- Rad-Damage Limit will come from Transverse Uniformity

GW Foster 5/5/92



SDC Calorimeter Rad-Hard Scintillator R&D

Strategies to Prevent light Drop from Scintillator Tiles

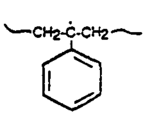
1.Reduce Optical Pathlengths

- 10cm in the Barrel
- 1-2cm (if necessary) near Eta = 3

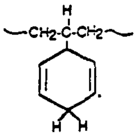
2. Change Optical Wavelengths to Region of less Absorbtion

- Green Plate/Yellow Fiber
- Requires Fast, Efficient new Fluors & PMT

GW Foster 5/5/92



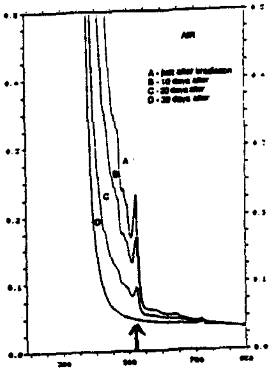
Benzyl Radical



Cyclohexadienyl Radical

Absorption Bands.
(nm)

Benzyl	Cyclohexadienyl.
258	308
293	314
304	512
316	554
422	
436	
452	



... Thousands of Anti RADS (Radical Scavengers) Commercially available...

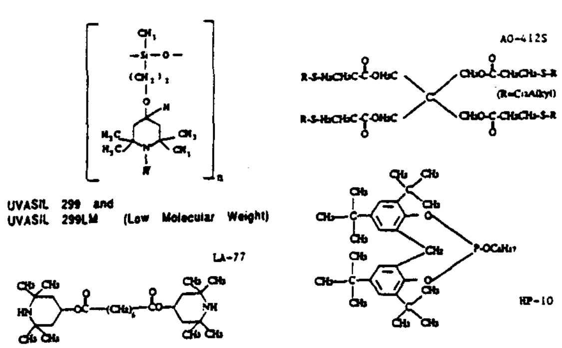


Fig. 9. Chemical structure of antirads

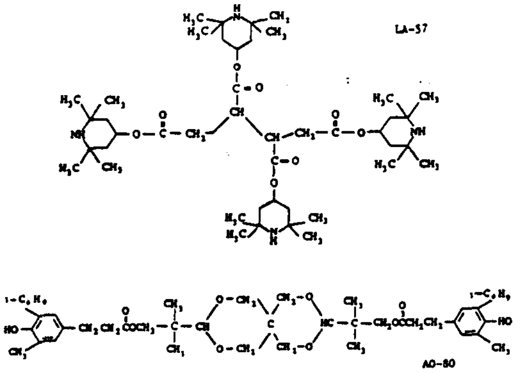


Fig. 10. Chemical structure of antirads

Some Success With Additives

SUMMARY AND CONCLUSIONS

Figure 31 summarizes the data for several of the most promising systems. D18UV is the sample discussed in the abstract. All samples (except the BC408 control from Bicron) are 70 pbw of Dow polystyrene, 30 pbw of DC705, 2 pbw para-terphenyl, .2 pbw of secondary shifter, and .5 pbw of antirad when present. It has been demonstrated that DC705 oil is effective in increasing the anneal rate of polystyrene scintillators. It has also been shown to be effective in activating antirad agents. Is theorized that major reason for the improvements is the increased mobility of reactive species. The DC705 used alone increases the permanent radiation damage, but that is negated by the antirads. Useful plates of scintillator have been made and are being tested with shifter fibers before and after radiation. Good scintillators have been made from polymers and it has been proven that they can be injection molded. A scintillator that decreases it's light output by only 4% after 10 megarads has been made.

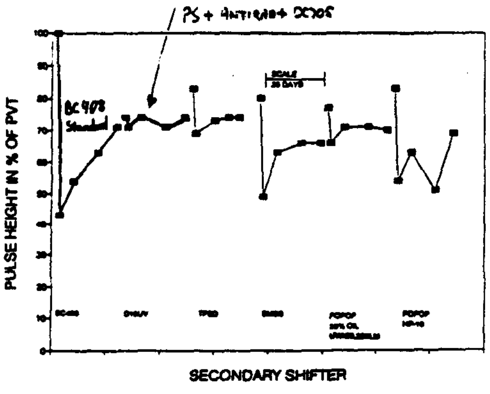


Fig. 31. Anneal rates for "best" samples 3-12-92
(30% oil except as noted)

Plates w/various Anti-RADS being tested @BICRON, [illegible] etc...

/ MANY NEW PLASTICS INVESTIGATED

-Polyalphamethylstyrene
Polyarylate
Polyarylsulfone
Polycarbonate
epoxy
-Polyethyleneglycoldiallylcarbonate (CR-39)
Polyethylenemethacrylicacid
Polyethylenevinylacetate
Polyethyleneterephthalate
Polymethylmethacrylate
Polyphenylsulfone
- Polystyrene
Polystyreneacrylonitrile
Polystyrenemethacrylate
Polysulfone
- Polyvinyltoluene
Celluloseacetateproprionate
- Polyetherimid
Fluorinatedethylenepropylene
Polystyreneacrylicacid
Polymethylpentene
Polyvinylbutaral
Polyvinylidenefluoride
Polyvinylpyrolidone
- POLYISOBUTYL METACRYLATE

Fig. 27. Plastics investigated

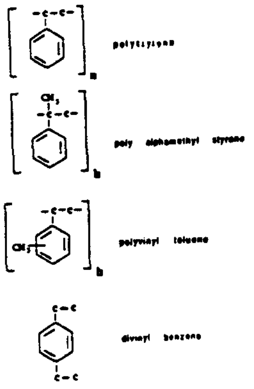
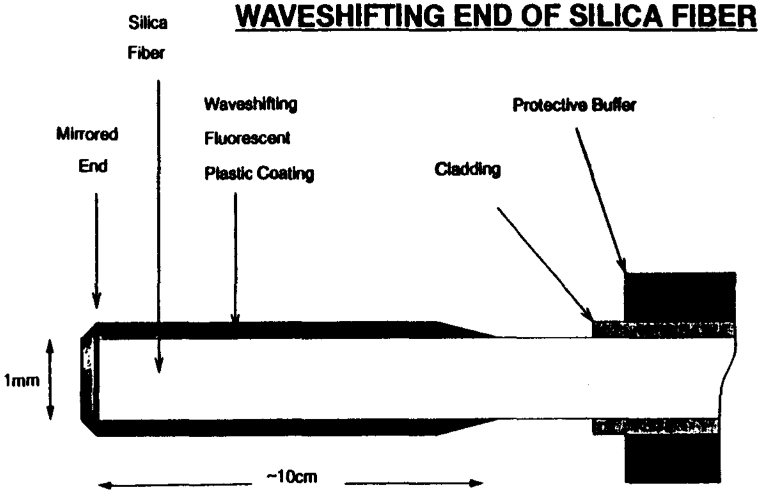


Fig. 28. Chemical structure of styrenes

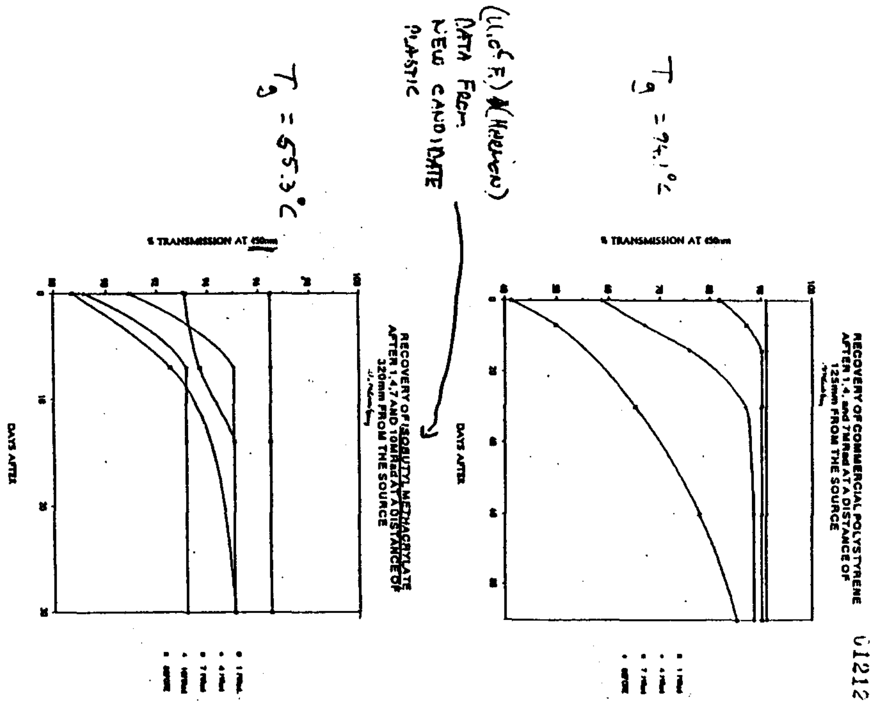
SDC Calorimeter Rad-Hard Scintillator R&D

WAVESHIFTING END OF SILICA FIBER



01214

GW Foster 5/5/92



RECOVERY OF COMMERCIAL POLYSTYRENE AFTER 1, 4, and 7 MRad AT A DISTANCE OF 125mm FROM THE SOURCE

RECOVERY OF ISOBUTYL METHACRYLATE AFTER 1,4,7 AND 10MRad AT A DISTANCE OF 320mm FROM THE SOURCE

01212

SDC Calorimeter Rad-Hard Scintillator R&D

FAST GREEN WAVESHIFTERS

PULSEWIDTH OF EM CALORIMETER

IS LIMITED BY FALL TIME OF WLS FLUOR

- Back to Baseline in 3 Crossings (no shaping)
- Back to Baseline in 2 Crossings (Clipline Shaping)
- Tests indicate we can achieve 6-8ns FWHM with fast dye

Evaluation & Test of Faster, Green Shifter Fluors

- Candidates from NE Technology, Bicron, & laser dyes
- Dye must have Established Track Record of Stability by '94

01215

GW Foster 5/5/92

SDC Calorimeter Rad-Hard Scintillator R&D

WAVESHIFTER READOUT

SHORT OPTICAL PATH

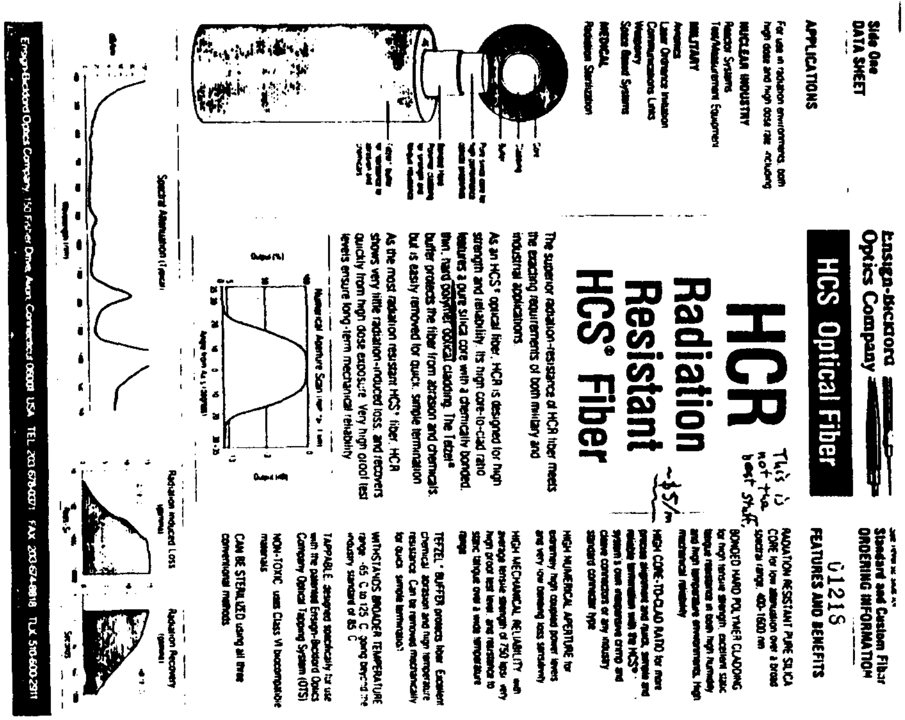
- ~30cm in Barrel EM
- ~10cm (if necessary) in End Plug
- High-quality Optical Fiber *Not Required*

Does Not Have To Scintillate

- Non-Aromatic Vinyl Polymers & Siloxanes OK
- Does not have to carry Primary & Secondary Shifter Fluors
- Fluorescent Coating on Silica Fiber Candidate at High Eta

01213

GW Foster 5/5/92



Side One
DATA SHEET

Ensign-Bickford
Optics Company

HCS Optical Fiber

HCR Radiation Resistant HCS® Fiber

This is not the best stuff.
~$5/m

The superior radiation-resistance of HCR fiber meets the exacting requirements of both military and industrial applications.

As an HCS® optical fiber, HCR is designed for high strength and reliability. Its high core-to-clad ratio features a pure silica core with a chemically bonded, thin, hard polymer optical cladding. The Tefzel® buffer protects the fiber from abrasion and chemicals, but is easily removed for quick, simple termination.

As the most radiation resistant HCS® fiber, HCR shows very little radiation-induced loss, and recovers quickly from high dose exposure. Very high proof test levels ensure long-term mechanical reliability.

APPLICATIONS

For use in radiation environments, both high dose and high dose rate, including:

NUCLEAR INDUSTRY
Reactor Systems
Test/Measurement Equipment

MILITARY
Avionics
Laser Ordnance Initiation
Communications Links
Weaponry
Space Based Systems

MEDICAL
Radiation Sterilization

Standard and Custom Fiber
ORDERING INFORMATION

01218

FEATURES AND BENEFITS

RADIATION RESISTANT PURE SILICA CORE for low attenuation over a broad spectral range, 400-1600 nm

BONDED HARD POLYMER CLADDING for high tensile strength, excellent static fatigue resistance in both high humidity and high temperature environments. High mechanical reliability

HIGH CORE-TO-CLAD RATIO for more precise alignment and quick, simple and reliable termination with the HCS® system's own inexpensive crimp and cleave connectors or any industry standard connector type

HIGH NUMERICAL APERTURE for extremely high coupled power levels and very low bending loss sensitivity

HIGH MECHANICAL RELIABILITY, with average tensile strength of 750 kpsi, very high proof test level, and resistance to static fatigue over a wide temperature range

TEFZEL® BUFFER protects fiber. Excellent chemical, abrasion and high temperature resistance. Can be removed mechanically for quick, simple termination

WITHSTANDS BROADER TEMPERATURE range: -65 C to 125 C, going beyond the industry standard of 85 C

TAPPABLE: designed specifically for use with the patented Ensign-Bickford Optics Company Optical Tapping System (OTS)

NON-TOXIC: uses Class VI biocompatible materials

CAN BE STERILIZED using all three conventional methods

Ensign-Bickford Optics Company, 150 Fisher Drive, Avon, Connecticut 06001 USA TEL 203 678-0371 FAX 203 674-8818 TLX 510-600-2311

SDC Calorimeter Rad-Hard Scintillator R&D

RADIATION HARDNESS OF CLEAR READOUT FIBER

Longest Optical Path

- 2m in Barrel Tower, 30cm in radiation field
- 3-5m in Endwall, 0.1m-2.0m in radiation field

Large Variation in Total Dose Along Fiber

- 0.1 MRad-Meters worst case 100-yr dose in barrel
- 27 MRad-Meters integrated dose for readout fiber from Eta=3.0 in "pizza-pie" geometry at EM shower-max

Aging of Readout Fibers *Can* be Corrected at PMT

01216

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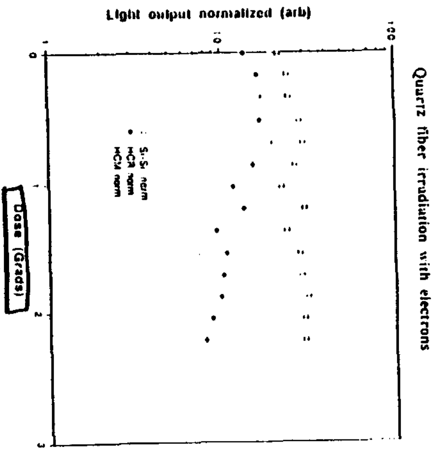

= 10^9 RADS

01219

SDC Calorimeter Rad-Hard Scintillator R&D

RADIATION HARDNESS OF CLEAR READOUT FIBER (cont'd)

PS core/PMMA clad Fiber OK in Barrel

- Useable to total doses of ~1MRad-meter
- Useful for majority of channels in Endcap

Silica Fiber Probably Necessary Near Eta=3

- Useable to total doses of GigaRad
- Total Cost for using Silica on *Entire* ECEM ~~$300k

In between, maybe room for new candidates...

- e.g. polyisobutylmethacrylate (modified acrylic) cored fiber

01217

GW Foster 5/5/92

SUMMARY

01220

J. Proudfoot

May 13 1992

— RADDAM '92 —

INTERNATIONAL CONFERENCE ON RADIATION-TOLERANT SCINTILLATORS AND DETECTORS

Florida State University
Tallahassee, Florida
April 28 to May 2nd. 1992

Conference Organizers:

Roger Clough
Sandia National Laboratories
Organization 1811
Albuquerque,NM
USA 87185
Ph:(505)844-3492
FAX:(505)844-9624

Kurtis F. Johnson
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E-mail:
FSUHEP::RADDAM92

Peter Sonderegger
CERN
CH-1211,Geneva
Switzerland
Ph:(22)767-4670
FAX:(22)782-4897
E-mail:
RADDAM92@CERNVM

This symposium is intended to bring together major research workers involved in the development of advanced, radiation resistant scintillators or particle physics detectors. Presentations of research results will be made in the areas listed below, and discussion sessions will be scheduled on key issues which remain to be resolved. Since an important concern is communication between radiation chemists and detector designers, tutorial sessions will be organized for both physicists and chemists.

The proceedings of this conference will be published as a special issue of the journal: Radiation Physics and Chemistry.

- Materials Requirements for Scintillator-based Detectors
- Radiation Damage Mechanisms in Polymeric Scintillators
- Strategies for Developing More Radiation Tolerant Systems
- Predictive Aging Tests for Scintillator Lifetimes
- Survey of Radiation Resistance of Optical Properties in Different Polymers
- Nature and Structure of Radiation-induced Color Centers
- The Role of Oxygen
- Kinetics and Mechanisms of Color Center Annealing
- Radiation Effects on Scintillator Dyes; Synthesis of Advanced Dyes
- Radiation Damage to Other Organic Materials Crucial to Scintillation Detectors (Adhesives, Coatings, etc.)
- Operating Experience and Long-term Radiation Results
- Other Advances in Scintillator Properties (Speed. Efficiency)

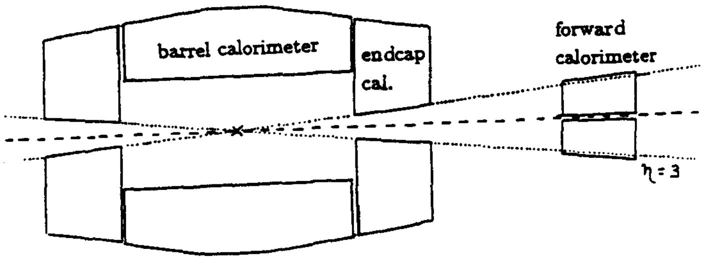
FORWARD CALORIMETER REQUIREMENTS

M. BARNETT

Michael Barnett
May 6, 1992

Physics Requirements for the Forward Calorimeter

The Forward Calorimeter



Physics Priorities at the SSC

- Understanding Electroweak Symmetry Breaking
- Testing the Standard Model
- Are Quarks and Leptons Composite?
- Exotic Particles and Phenomena

Forward Calorimeter May Play Critical Role in Finding:

Higgs Bosons

Supersymmetry

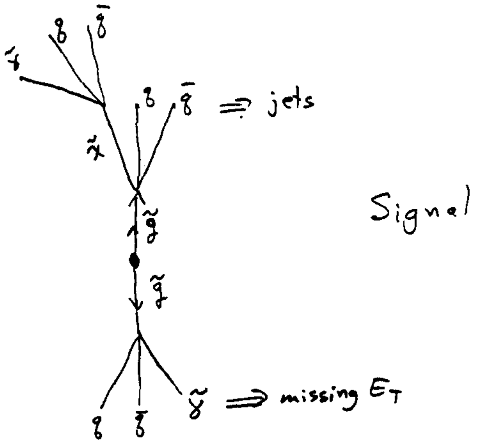
Expanded Gauge Sector

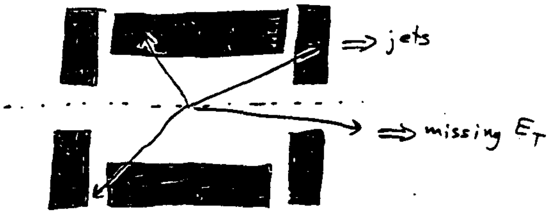
Strongly Interacting $W_L W_L$

Properties of Top Quark

Extra Generations

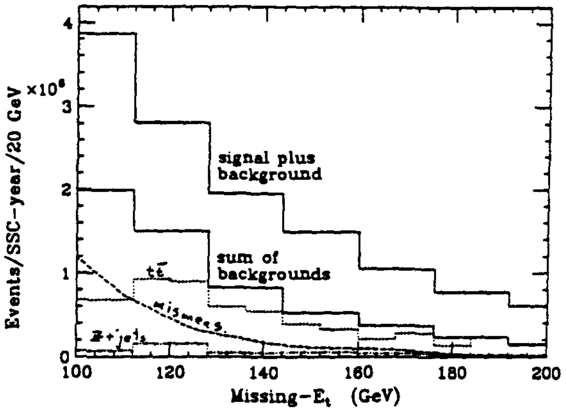
Gluino





Detector Background

With Forward Calorimeter.

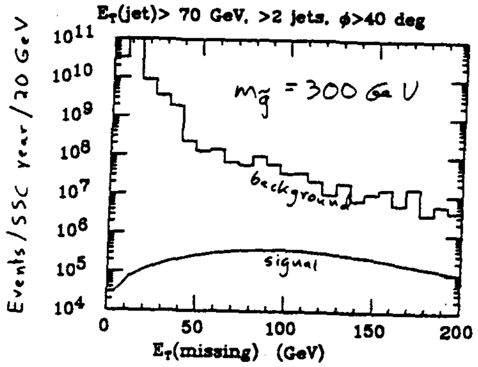


Signal: $pp \to \tilde{g}\tilde{g}X$ $m(\tilde{g}) = 300$ GeV

Detector background: multi-jet QCD events with mismeesurement

---

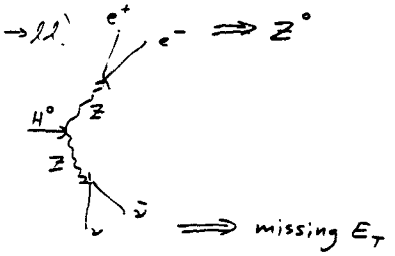
No Forward Calorimeter



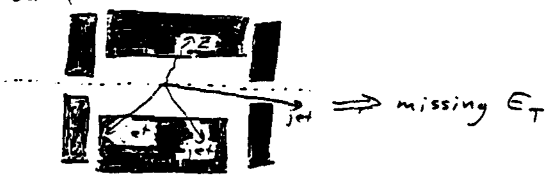
Heavy Higgs

$\nu(Z \to \nu\bar{\nu}) = 6\ 3(Z \to \ell\ell)$

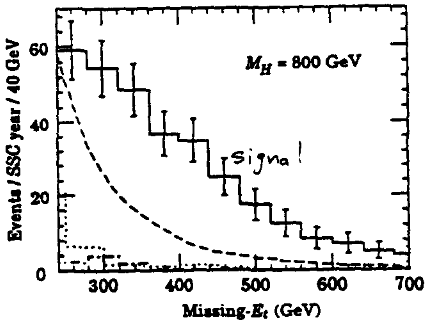
Signal



Background



With Forward Calorimeter



No Forward Calorimeter

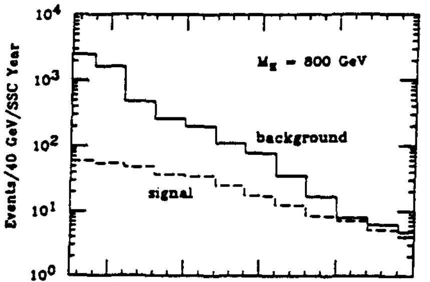
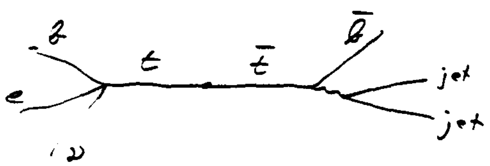


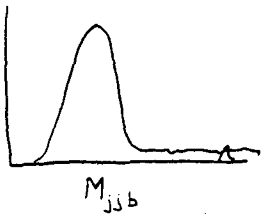
FIG. 3-27. The comparison of the missing-E_t for the signal $H^0 \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$ and the background from $Z + jets$ events in which one or more jets at $|\eta| > 3$ is lost out the end of the detector. This summarizes the effect of leaving out the forward calorimeter in SDC, which leads to substantial increases in backgrounds to processes with missing-E_t. A Higgs mass of 800 GeV has been assumed.

4th Generation Top Quark

m_t = 150 GeV ← background

$m_{t'}$ = 400 GeV ← signal



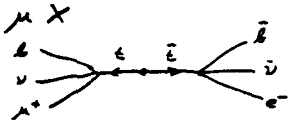


E_T^{miss} cut can enhance t' by 10-20

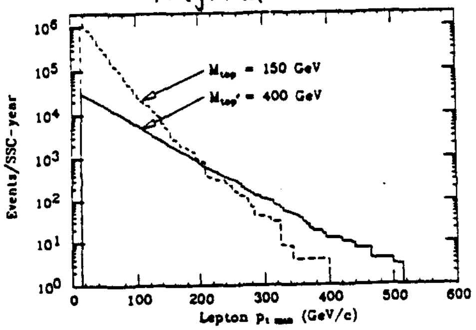
What if there is a 4th generation top quark t' ?

Integrated (E-Mu) Signal for TOP

$pp \to t\bar{t} \to e\mu X$

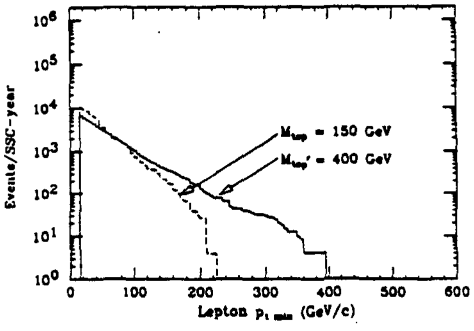


integrated



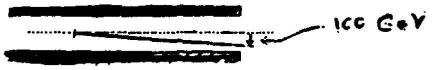
Integrated (E-Mu) Signal for TOP (MissEt>200)

E_t(missing) > 200 GeV



Detector Backgrounds to Gluino Production

- Mismeasurement of multi-jet (QCD) events due to poor resolution, cracks, non-gaussian tails.
- Multi-TeV jet escaping the beam hole in multi-jet events.



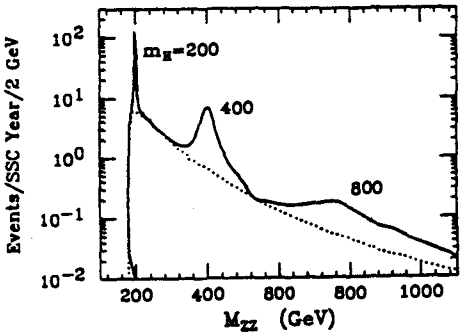
Both can yield $E_T(missing) > 100$ GeV.

Both types of mismeasurement are quite rare.

But rate for multi-jet QCD events is extremely high.

- New techniques were developed that allow the generation of extremely rare mismeasurement events.

Higgs to ZZ to 4 leptons



Notice increasing width
and decreasing rate.

Increase Statistics

Use $H^\circ \to Z^\circ Z^\circ$

$\qquad\qquad \hookrightarrow \ell^+\ell^-$

$\qquad\qquad \hookrightarrow \nu\bar{\nu}$

Rate $(\ell^+\ell^-\nu\bar{\nu}) = 6$ Rate $(\ell^+\ell^-\ell^+\ell^-)$

Signature is

$Z \to \ell^+\ell^-$ and Missing E_t

Backgrounds are

- $t\bar{t}$ with $t\bar{t} \to \ell^+\nu b\ \ell\bar{\nu}\bar{b}$
  - $\nu\bar{\nu} \Rightarrow$ missing E_t
  - $\ell^+\ell^-$ can have $m(\ell^+\ell^-) \simeq m(Z)$
- $Zt\bar{t}$ with $Z \to \ell^+\ell^-$, $t \to b\ell\nu$
- Continuum $Z^\circ Z^\circ$ production with $Z \to \ell^+\ell^-$, $Z \to \nu\bar{\nu}$
- Z + jets with $Z \to \ell^+\ell^-$ and mismeasure jets E_t yielding missing E_t.

$H^\circ \to ZZ \to \ell^+\ell^-\ell^+\ell^-$

$H^\circ \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$ $\boxed{\times \frac{1}{6}}$

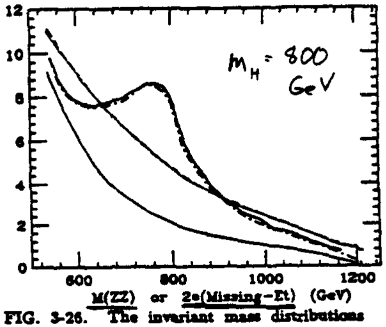


FIG. 3-26. The invariant mass distributions for $H \to 4\ell$ and twice the missing-E_t for the process $H \to 2\ell 2\nu$ are compared. The signal for the latter has been reduced by a factor of six so that the area of the signals is approximately the same. The intention of the figure is simply to show the shape of the signal distribution. The dot-dashed curve is for the 4ℓ final state; the dashed curve is for the $2\ell 2\nu$ final state. A Higgs mass of 800 GeV has been assumed.

Higgs Boson and Jet Tagging

Branching Fractions for Heavy Higgs

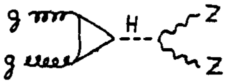
$$B(H \to ZZ \to \ell^+\ell^-\ell^+\ell^-) \approx 0.14\%$$

$$B(H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}) \approx 0.8\%$$

$$B(H \to W^+W^- \to \ell^+\nu\ell^-\nu) \approx 3\%$$

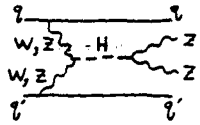
$$B(H \to W^+W^- \to \ell^+\nu jj) \approx 20\%$$

gg Fusion



dominant for lower m_H

WW/ZZ Fusion



forward jet tagging

If *H* discovered by other means, then (in principle) can establish couplings to *W/Z* bosons and *t* quarks by measuring *WW/ZZ* fusion with jet tagging and comparing with observed total σ.

⟹ Info on SM Higgs vs. other.

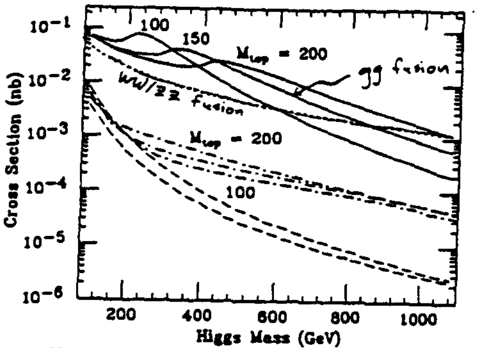


FIG. 3-3. The cross section for the production of a Higgs boson in *pp* collisions at $\sqrt{s} = 40$ TeV as a function of the Higgs boson mass for several different production mechanisms: *gg* fusion (solid), *WW/ZZ* fusion (dotted), $t\bar{t} + H$ production (dot-dashed), $W + H$ production (upper dashed), and $Z + H$ production (lower dashed). When the cross section depends on the *t*-quark mass, several curves have been included for different values of M_{top}.

Jet Tagging

Acceptances for signals & backgrounds

(How unique is signal?)

Table 3-9

A summary of the acceptance for requiring one- or two-tag jets for the signal and background processes of interest. No requirements on the event configuration in the central region have been made. The single tag case required one jet with $E > 3.0$ TeV, whereas the double tag case required two jets at opposite η with $E > 1.5$ TeV. The jets were reconstructed using cones with $R = 0.6$ in a forward calorimeter with cells of size $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ and were required to have $p_t > 50$ GeV and $2.5 < |\eta| < 5.0$.

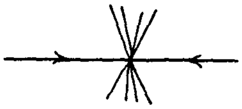
	WW/ZZ fusion	*gg* fusion	*W + jets* background	$t\bar{t}$ background
Single tag	0.23	0.082	0.11	0.035
Double tag	0.052	0.007	0.005	0.002

Background and gg fusion can have forward jets from initial-state radiation.

Herwig with Shower Parameterization.

Is Jet Size $\Delta\eta = 0.5$ in Forward Region ?

- When $\theta \approx 90°$, $\Delta\theta \approx 30°$.

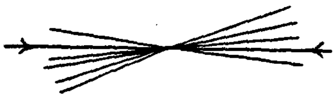


$E_T(\text{jet}) = 100$ GeV

$x_1 = x_2 =$ small

- When $\theta \approx 2°$ ($\eta = 4$), $p_L = 3$ TeV.

  If $x_1 = x_2$, $\Delta\theta \approx 30°$ again.



but $\hat{s} = x_1 x_2 s$

$= 6$ TeV,

so $x_1 = x_2 =$ large,

so σ is suppressed.

- Instead choose boosted frame:

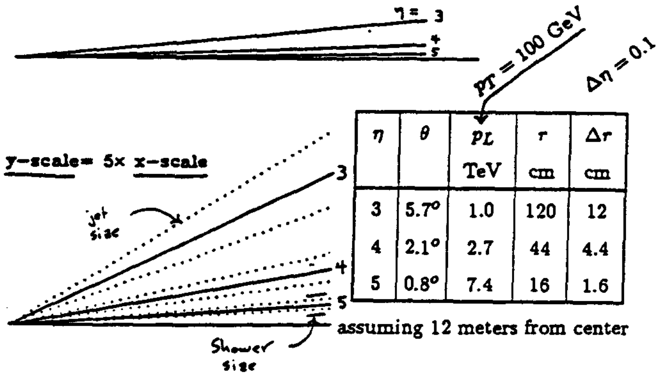
  $(x_1 = \text{small}, x_2 = \text{large})$

  Then in c.o.m. $p = 100$ GeV.

  Not suppressed.

Produces jets with fixed $\Delta\eta$ but not fixed $\Delta\theta$.

Geometry of Forward Calorimeter



η	θ	p_L TeV	r cm	Δr cm
3	5.7°	1.0	120	12
4	2.1°	2.7	44	4.4
5	0.8°	7.4	16	1.6

assuming 12 meters from center

Want to Measure E_T

$$E_T = E \sin\theta \approx E\theta$$

Error on E_T, $\frac{\Delta E_T}{E_T}$, is $\frac{\Delta\theta}{\theta} \oplus \frac{\Delta E}{E}$ where $\frac{\Delta\theta}{\theta} \approx \Delta\eta$.

So $\Delta\eta = 0.2$ corresponds to $\frac{\Delta\theta}{\theta} \approx 20\%$,

and $\frac{\Delta E}{E} < 10\%$ won't help $\frac{\Delta E_T}{E_T}$.

Why choose a light gluino (300 GeV) as the test case ?

1. It yields little $E_T^{missing}$, so is difficult.
2. It has the biggest possible background: ordinary QCD multi-jet events.

- Signal–
  $\geq$ 3 jets with $E_T > 70$ GeV
  $E_T^{missing} > 100$ GeV.
- Detector Background–
  $\geq$ 3 jets with one or more jets badly mismeasured.

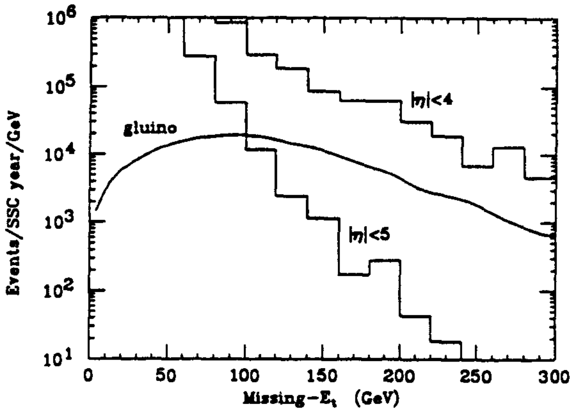
Difficult to generate rare mismeasurement.
Better statistics with parton Monte Carlos.
Where compared with fragmenting Monte Carlos results are similar.

(Tagging results from Herwig).

What η coverage is required by E_T^{miss} ?

$m(\tilde{g}) = 300$ GeV   3 jets with $E_T > 70$ GeV

$\phi(\text{jet}) - \phi(E_T^{miss}) > 40°$



Fiducial region must reach $|\eta| = 5$

Acceptances for tagging in forward region

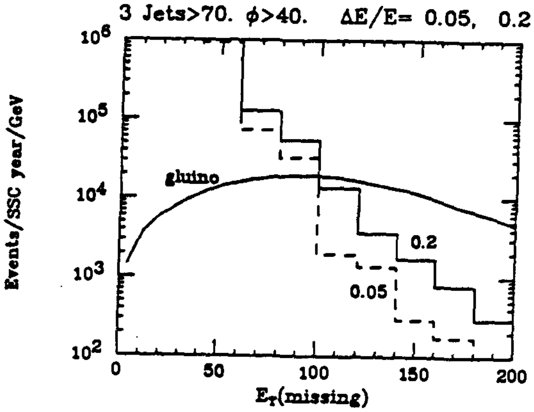
Table 3-8

A summary of the acceptance for requiring one or two tag partons or jets in the forward region. The single tag case requires one parton or jet with $E > 3.0$ TeV, whereas the double tag case requires two partons or jets at opposite η with $E > 1.5$ TeV. The jets were reconstructed using cones with $R = 0.6$ in a forward calorimeter with cells of size $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$. The missing entries correspond to cases where the jets lie beyond the fiducial calorimeter coverage.

	Fiducial region	Parton $p_t > 25$ GeV	Parton $p_t > 50$ GeV	Jet $p_t > 25$ GeV	Jet $p_t > 50$ GeV
Single tag	$2.5 < \lvert\eta\rvert < 6$	0.40	0.32	–	–
	$2.5 < \lvert\eta\rvert < 5$	0.27	0.26	0.23	0.23
	$2.5 < \lvert\eta\rvert < 4$	0.076	0.076	0.068	0.068
ouble tag	$2.5 < \lvert\eta\rvert < 6$	0.16	0.090	–	–
	$2.5 < \lvert\eta\rvert < 5$	0.10	0.072	0.078	0.052
	$2.5 < \lvert\eta\rvert < 4$	0.015	0.015	0.012	0.012

WW/ZZ fusion (signal)

What Resolution is required in Forward Calorimeter ?

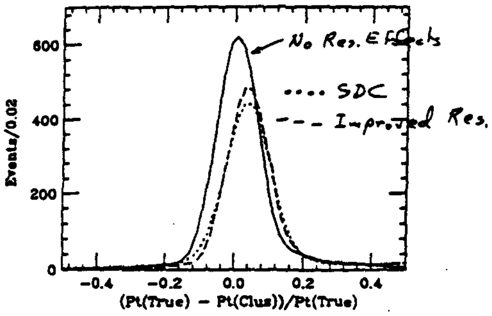


$$\frac{\sigma}{E} = \frac{0.8}{\sqrt{E}} \oplus 0.05 \text{ or } 0.2$$

---

p_t Resolution for final segmentation

Jet Tagging



Solid - No E Res. Effects

Dotted - SDC Baseline

Dashed - EM $0.3/\sqrt{E} \oplus 0.02$ (Better)

Had $0.8/\sqrt{E} \oplus 0.05$

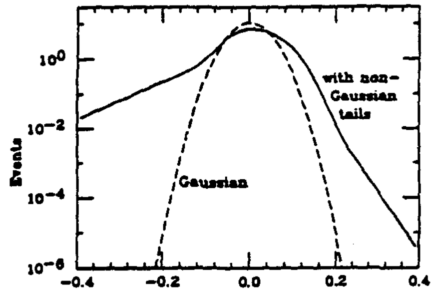


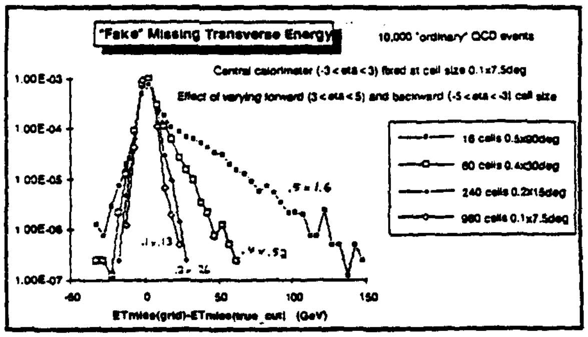
FIG. 3-69. The comparison of a Gaussian jet energy resolution function (dashed curve) with a resolution (solid curve) in which nonGaussian tails have been included. E_{in} is the energy of the jet before mismeasurement (fixed at 500 GeV for this figure), while E_{out} represents the measured energy. It is expected that the SDC detector will have significantly smaller tails than those shown here.

R. D. Field ISAJ_C30.XLC Revised 11/1/91

Rick Field - ISAJET

Segmentation

$\phi > 40°$



Note limited E_T range

Page 1

Jet Tagging

Resolution vs. Segmentation

Segm. = 0.05, 0.2, 0.4, 0.8

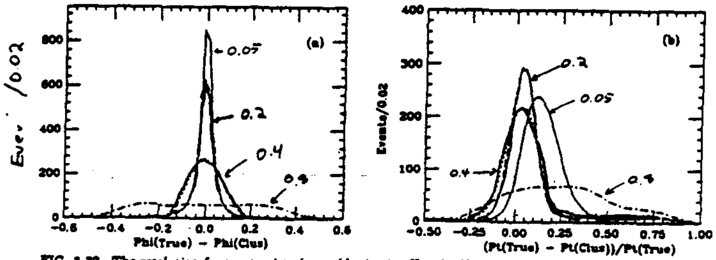
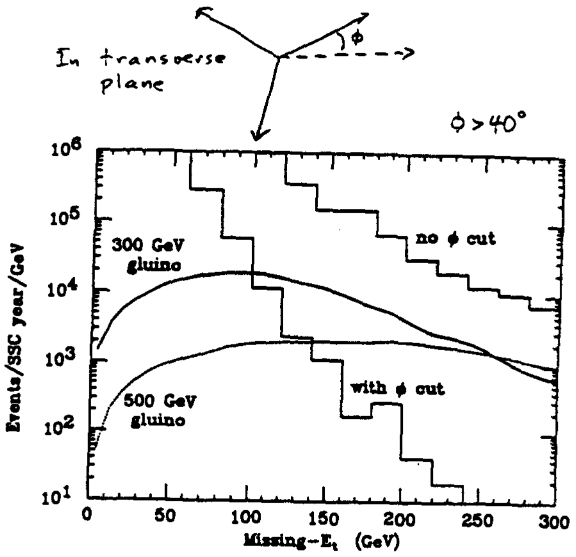
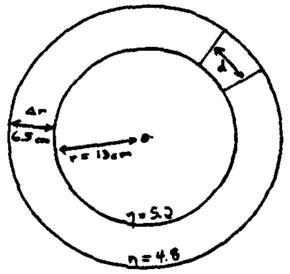


FIG. 3-32. The resolution for two tag jet observables in the $H \to WW \to \ell\nu + 2$ *jets* analysis as a function of the forward calorimeter segmentation. The solid curve is for a segmentation of 0.05 in both EM and HAD1. The dashed (dotted) are for 0.2 (0.4). The dot-dashed curve is for the extreme case of 0.8 (a) The ϕ resolution, defined to be ϕ(true) − ϕ(observed). (b) The p_t resolution, in percent, defined to be $(p_t(\text{true}) - p_t(\text{observed}))/p_t(\text{true})$.

cell threshold

$\Phi \equiv \phi(\text{missing } E_T) - \phi(\text{nearest jet})$





$d = r\Delta\phi$

$\Delta r = r\Delta\eta$

Suppose that the forward calorimeter goes from $\eta = 3$ to 6.8 and starts at 12 meters from interaction point.

The following are the <u>coarsest</u> possible cell sizes for which tagging and missing E_T physics remains possible.

Measuring missing E_T does not require fine segmentation; however, segmentation is essential to find jets in order to make cuts that reduce backgrounds below signal.

η of cell	$\Delta\eta$	Δ(radius)	radius × $\Delta\phi$	for $\Delta\phi$
3.0 – 3.2	0.2	22 cm	21 cm	0.20 = 11 degrees
⋮ 3.6 – 3.8	0.2	12 cm	12 cm	0.20 = 11 degrees
⋮ 4.2 – 4.4	0.2	6.5 cm	6.4 cm	0.20 = 11 degrees
4.4 – 4.8	0.4	9.7 cm	9.5 cm	0.39 = 22 degrees
4.8 – 5.2	0.4	6.5 cm	6.4 cm	0.39 = 22 degrees
5.2 – 6.0	0.8	7.3 cm	7.0 cm	0.79 = 45 degrees

Physics Requirements Conclusions for Foward Calorimeter

	$\tilde{g}$ Missing E_T	Higgs Tagging
η coverage	$\lvert\eta\rvert < 5$ (fiducial)	$\lvert\eta\rvert < 5$
resolution	$\frac{100\%}{\sqrt{E}} \oplus 10\%$	$\frac{100\%}{\sqrt{E}} \oplus 10\%$
segmentation	0.2 - 0.4	0.2 - 0.4

FORWARD CALORIMETER REQUIREMENTS

W. FRISKEN

5/2/92 TALK #3

Frisken@SSCL. 5/4/92

SDC FORWARD CALORIMETRY

Presented by Bill Frisken, LBL/York U.
SSCL, May 6/92

OUTLINE:

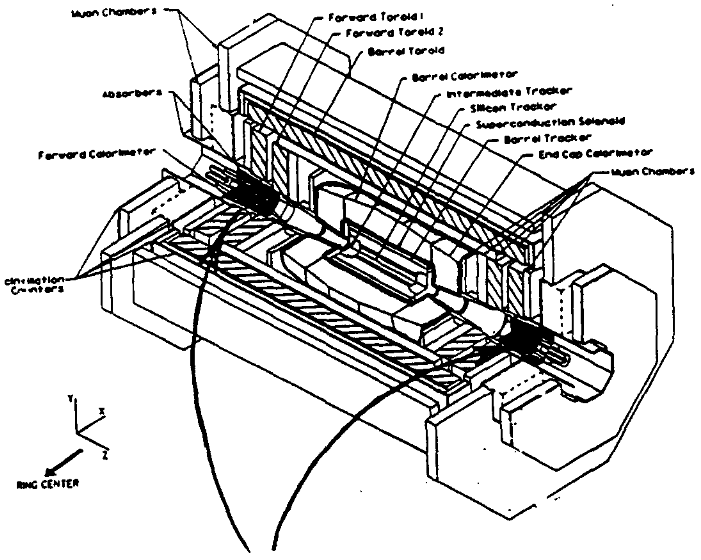
1. THE FCal ENVIRONMENT

2. FCal PERFORMANCE REQUIREMENTS

3. CHOICE OF SAMPLING TECHNOLOGY

BILL FRISKEN / MAY 6, 92

FORWARD CALORIMETERS



2 FCals

As FAR FROM I.R. AS POSSIBLE.

- HADRONIC SHOWER SIZE VS JET SIZE
  - PHYSICS RESOLUTION
  - TOWER OCCUPANCY
- RADIATION DAMAGE (AND ACTIVATION) of FCal ELEMENTS
- FRONT FACE ALBEDO → TRACKER OCCUPANCY

Frisken@SSCL. 5/4/92

1. THE FCal ENVIRONMENT

- Luminosity, event rate

  $L=10^{33}$ m^2/sec

  $R=10^8$ min bias events per second

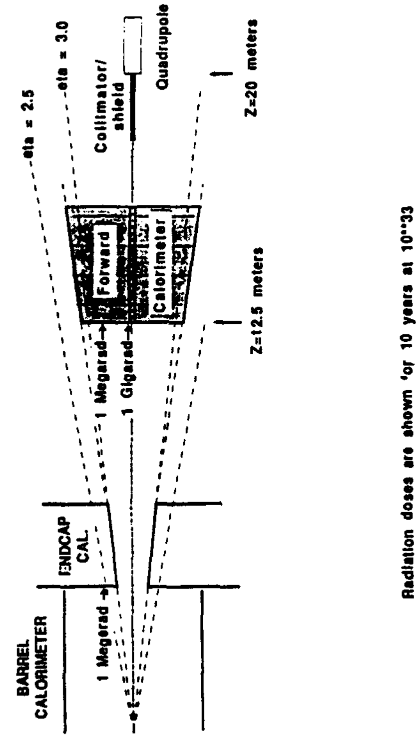
- 10 year radiation exposure for FCal components near shower max ---> GigaRad regime

- Radioactivation of SDC and SSC components

  e.g. Run 30 days at 10^{33}, cool down 1 day

  Surface dose near shower max at eta = 5.0 is 80 mrem/hr

- Integration (of FCal, and mech/logistical support):
  - FMuon system
  - SDC vacuum pipe (and auxiliary pumps)
  - IR Quads and collimator/shield (hottest spot in town)

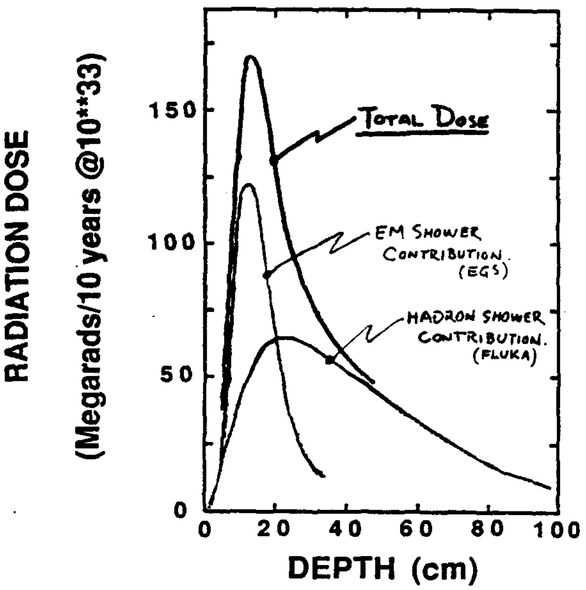


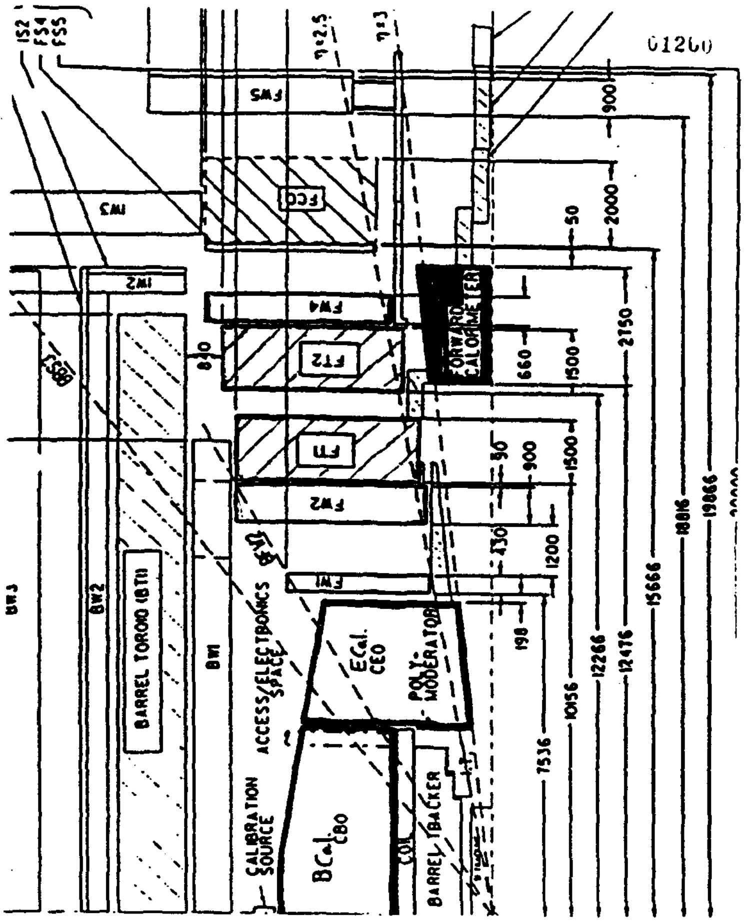
Radiation doses are shown for 10 years at 10**33

<E>= 44 GeV

DAMAGE PROFILES at eta = 5.0
(Calorimeter at 12.5 meters)

Solid Iron





Frisken@SSCL, 5/4/92

Frisken@SSCL, 5/4/92

2. FCal PERFORMANCE REQUIREMENTS

- Some Physics drivers:
  - + Missing Et

    H--->ZZ, where one Z--->2 neutrinos

    T' decays, SUSY partner decays

    plus 10 billion multijet QCD events per year, in which one jet might fake missing Et. (find all jets near the missing Et vector)
  - + Forward Jet Tagging (in massive Higgs by WW and ZZ fusion)

- Trigger expectations of FCal
  - -Smooth transition of lateral seg. from Endcap
  - -Pulse shape: identification of bunch crossing.

- Radiation Resistance. Design must provide:
  - + Survival of performance. Rad hard and/or recycling sampling medium.
  - + Disposal strategy for recycled sampling medium.

FCal PERFORMANCE REQUIREMENTS (continued)

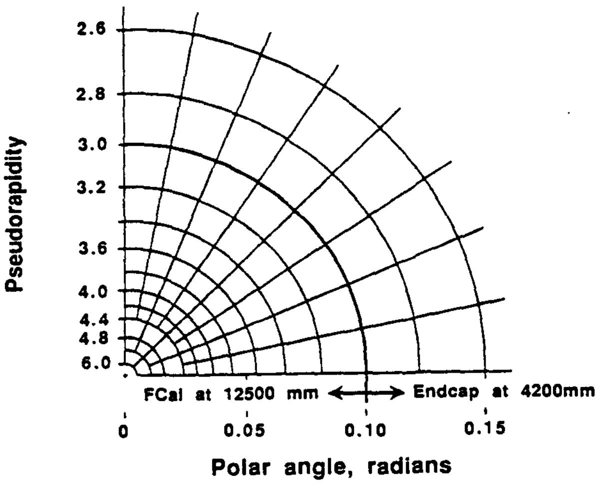
- Rate/Speed/Pileup
  - + dN/deta = constant, but in FCal
    - -lateral segmentation is coarser by factor of 4 to 16
    - -even worse if FCal is too close to I.R.
  - + Pile up noise: Signal collection should take as few bunch crossing times (16 nanoseconds) as possible.
  - + Bunch crossing i.d.: rise time, < 5 nanoseconds
  - + Rate dependence: keep changes of charge collection efficiency (gain) and/or time (pileup noise) due to space charge buildup in ionization detectors < 10%.

FCal PERFORMANCE REQUIREMENTS (continued)

- Eta coverage:
  - + Jet axis in the range 3.0 < eta < 5.0
  - + Detector range 2.8 < eta < 6.0

- Eta/phi segmentation
  - +Three segmentation drivers:
    - -jet recognition:
      - missing Et phi-cut strategy
      - tag jets (heavy Higgs via WW/ZZ fusion).
    - -tower occupancy: pileup noise
    - -trigger--->smooth transition to ECal segments.
  - +This means deta*dphi=0.2*0.2 at eta=3.0,
    relaxing to 0.4*0.4 at eta=5.0

    (dphi = 0.2 means 2π/32)



A VIEW FROM THE INTERACTION POINT

A SMOOTH TRANSITION AT 100 MILLIRADIANS

FROM ENDCAP TO FCAL

- Energy resolution
  - + High Et jets have very high energy. Missing Et measurement is insensitive to stochastic term
  - + Quadrature sum of contributions to constant term to be kept below 10%.

This means good maintenance of tower to tower and segment to segment intercalibration in the face of the severe FCal radiation environment.

- Hermeticity and containment (to avoid non gaussian tails).
  - + Depth: 12-14 lambda, with a HAC2 segment.
  - + The 10% limit on the constant term may require an electromagnetic compartment (but with hadronic lateral segmentation).

FCal Task Force set up by SDC Tech Board Nov. 90.

- Tasks
  - +stimulate discussion and work
  - +encourage proponents of various technologies
  - +reduce options before end of February 1992.
- 1991: many meetings and 2 major workshops investigating
  - +2 distinct geometries
    - -backstop
    - -inverse cone
  - +3 different sampling technologies
    - -warm liquid ionization
    - -high pressure argon gas ionization
    - -liquid scintillator
- December 1991, requested SDC Technical Board to help with the review process.
- January 1992, Tech Board appoints ad hoc committee (Strovink, chair) from Task force and outside members.

Charge: "Pick 1 geometry and at most 2 technologies."

01267
Frisken@SSCL. 5/4/92

FCal review committee @ SSCL Jan 24-5, 1992

1. Geometry choice:

- performance seen as similar. Glitch in sim. response at eta=3.0 transition to backstop not compelling.
- Backstop geometry chosen as likely to be easier to build, and easier to calibrate.

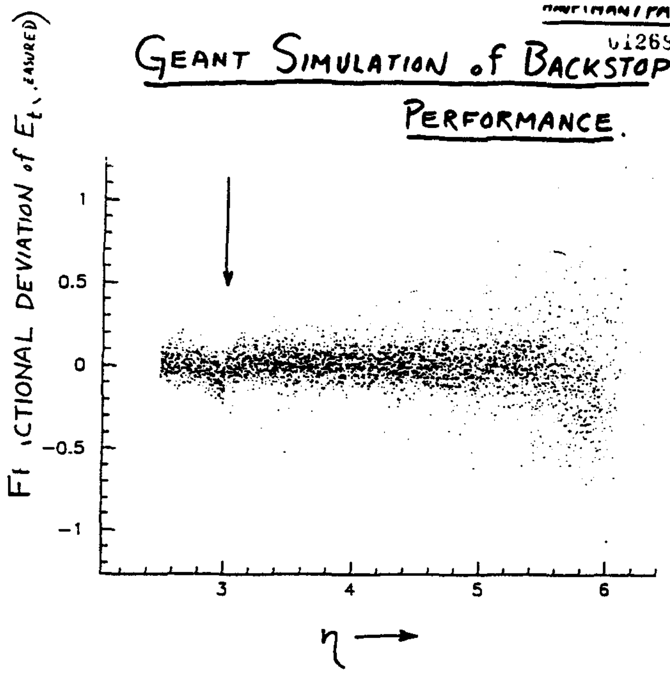
2. Technology choice:

- Sought to minimize total risk to SDC by choosing technologies with orthogonal risks from:
  - +radiation damage, and space charge effects
  - +not yet proven principle
  - +difficulty and cost of implementation.
- Chose to support continued R/D in
  - +high pressure gas ionization
  - +liquid scintillator

HARRIMAN/FARAG

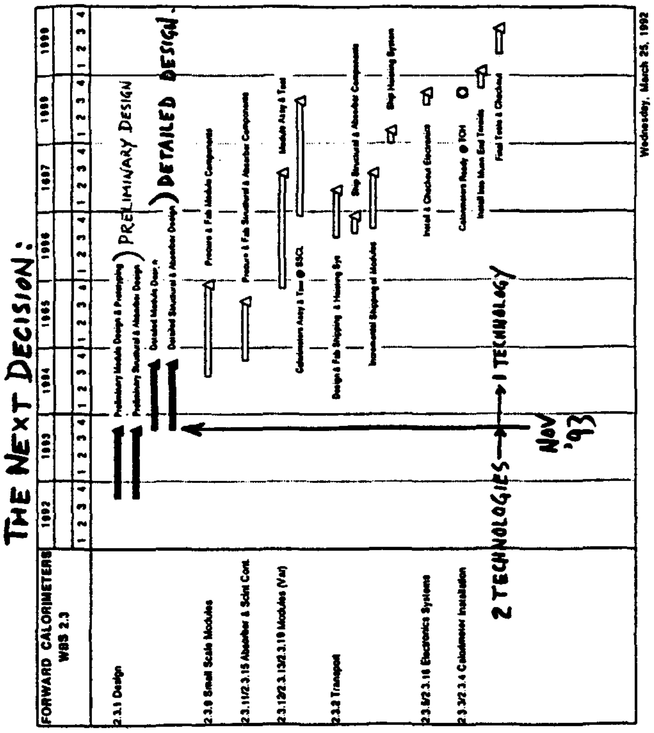
01265

GEANT SIMULATION of BACKSTOP PERFORMANCE.



01269

THE NEXT DECISION:



01270

FCal REQUIREMENTS

Radiation Survival	Recycling/replacement/disposal strategy for Gigarad lifetime doses.
Rate/speed/pileup	
•risetime	< 5 nanoseconds
•distance to I.P.	> 12.5 meters
•signal length	< 50 nanoseconds
•Space charge effects	< 10%
Acceptance in η	
•for jets	$3.0 < \eta < 5.0$
•for single particles	$2.8 < \eta < 6.0$
Lateral segmentation	
•At $\eta = 3.0$	$d\eta \times d\phi = 0.2 \times 2\pi/32$
•At $\eta = 5.0$	$d\eta \times d\phi = 0.4 \times 2\pi/16$
Energy Resolution	< 10% at 1 TeV. (beware tails)

LIQUID SCINTILLATOR OPTION

R. ORR

9 : RR

LIQUID SCINTILLATOR OPTION FOR SDC FORWARD CALORIMETER

BOB ORR – MAY 1992

OUTLINE

- ADVANTAGES OF LIQUID SCINT.
- RADIATION HARDNESS ISSUES
- MOTIVATION FOR LIQUID FILLED TUBES
- ATTENUATION LENGTH REQUIREMENTS
  - LIQUID
  - GLASS
- MEASUREMENTS OF ATTENUATION LENGTHS
- FUTURE TEST BEAM WORK
- MECHANICAL DESIGN ISSUES

ADVANTAGES OF LIQUID SCINTILLATOR IN GLASS TUBES

– IDEAL CALORIMETER WOULD HAVE UNIFORM TECHNOLOGY COVERING ALL η

- SCINTILLATOR IS FAST
  - ONE WOULD EXPECT TO DO BETTER THAN 15ms
    - NO SECONDARY WAVE SHIFT
  - GOOD MATCH TO REST OF CALORIMETER SYSTEM
- CAN BE MADE VERY RADIATION HARD
  - LIQUIDS ARE INTRINSICALLY MORE RADIATION HARD THAN SOLIDS
    - EG ISOPROPYL BIPHENYL
  - CAN ARRANGE FOR CONTINUOUS REPLACEMENT OF LIQUID
  - ATTENUATION LENGTH OF GLASS TUBES CAN BE QUITE SHORT.

ISSUES IN ACHIEVING RAD HARD

- DAMAGE TO SOLVENT
  - ATTENUATION LENGTH
  - OUTGASSING.
  - DEPOSITS ON TUBE WALLS
- DAMAGE TO FLUORS
  - LIGHT OUTPUT
- DAMAGE TO TUBE WALLS
  - EFFECTIVE ATTENUATION LENGTH.

MOTIVATION FOR LIQUID IN TUBES

- FOR ANY SOLID OPTICAL CALORIMETER

$$\text{LIGHT} \rightarrow \underset{\sim 2m}{\text{TRANSPARENT SOLID}} \rightarrow \text{PHOTO DETECTOR}$$

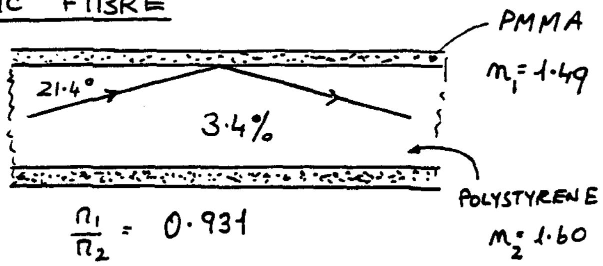
- FOR LIQUID IN TUBE
  - FOR EACH INTERNAL BOUNCE PENETRATE $\sim \lambda$
  - ~ 1 BOUNCE FOR EACH DIAM. d
  - FRACTIONAL DISTANCE IN SOLID OVER TRANSPORT DISTANCE

$$\sim \frac{\lambda}{d} \sim \frac{500\,mm}{1\,mm} \sim 10^{-3}$$

  - λ_{ATT} OF TUBE WALL 10^{-3} OF REQUIREMENT IN "SOLID" CALOR.

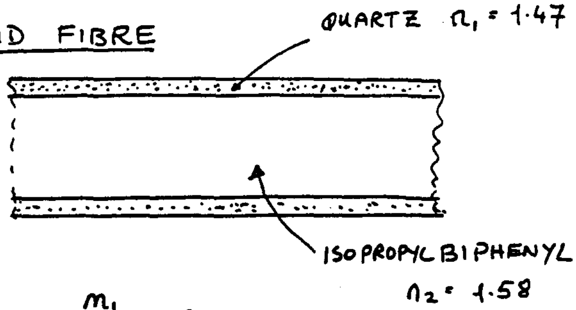
→ ABILITY TO CHANGE LIQUID MAKES DEVICE EXTREMELY RADIATION HARD.

PLASTIC FIBRE



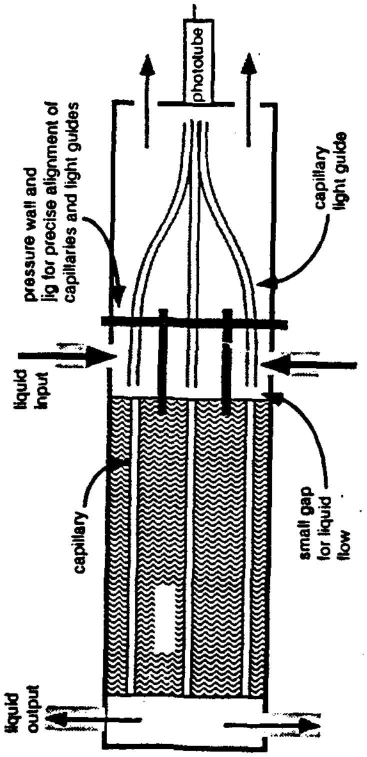
$\frac{n_1}{n_2} = 0.931$

LIQUID FIBRE



$\frac{n_1}{n_2} = 0.930$

CARTOON OF CONCEPT.



Tuesday, October 22, 1991
Conceptual Design - Mark I

WHAT λ_{ATT} IS NEEDED IN GLASS TUBES?

- AS BEFORE ASSUME THAT NUMBER OF INTERNAL REFLECTIONS IS:-

$$\frac{\text{TUBE LENGTH}}{\text{TUBE DIAMETER}} = \frac{L}{d}$$

- ON EACH REFLECTION, LIGHT PENETRATES ONE WAVELENGTH IN GLASS

PATH LENGTH IN GLASS $= \lambda \cdot \frac{L}{d}$

- FOR 400 CM ; 3mm TUBES AT 500nm

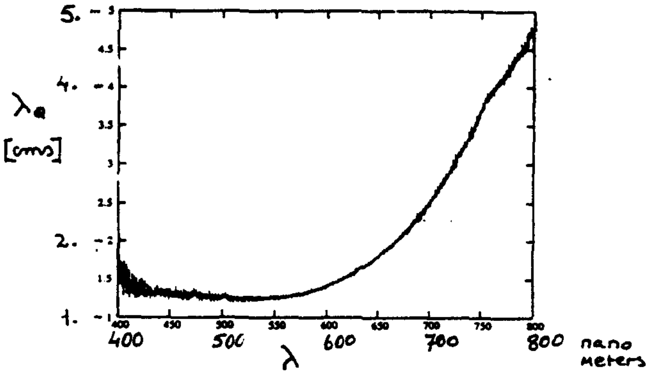
PATH ≈ 1mm

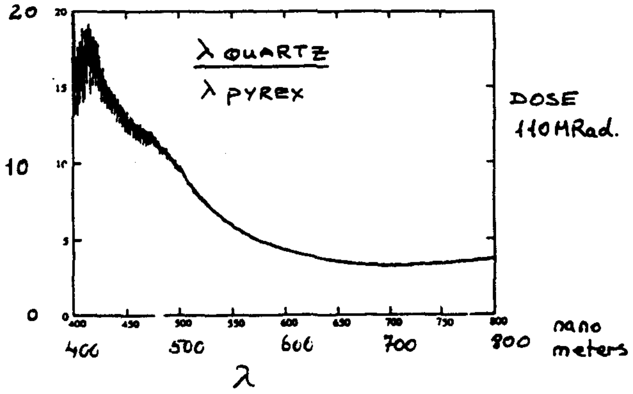
- AT 500nm AFTER 110 MRad

$\lambda_{QUARTZ} = 1.3$ cms

$\lambda_{PYREX} = 0.16$ cms

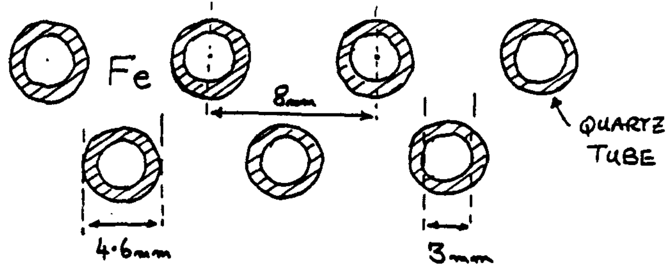
ATTENUATION LENGTH OF QUARTZ
DOSE = 110 MRad.





NECESSARY LATERAL MODULARITY

TEST MODULE UNDER CONSTRUCTION { SEE LATER



- QUARTZ TUBES IN STEEL MATRIX
- Fe : SCINTILLATOR BY VOLUME 5·6 : 1
- SAMPLING FRACTION (MIP) 3%

→ FROM CDHS PLATE CALORIMETER (3·3% SF)

$$\boxed{\left[\frac{\sigma(E)}{E}\right]_{STOCH} \approx 75\% \sqrt{\frac{3\cdot3}{3\cdot0}} \approx \frac{80\%}{\sqrt{E}}}$$

NECESSARY LATERAL MODULARITY

- TEST MODULE STRUCTURE, ESTIMATE

$$\left[\frac{\sigma(E)}{E}\right]_{STOCH} \approx \frac{80\%}{\sqrt{E}}$$

- SCALING BY $\frac{1}{\sqrt{SF}}$ ← SAMPLING FRACTION IN MIPS

  - INTERNAL TUBE DIAM 5mm
  - WALL THICKNESS 0·5mm
  - TUBE - TUBE SPACING 13mm

→ SAMPLING FRACTION (MIP) = 2·3%

ESTIMATE

$$\left[\frac{\sigma(E)}{E}\right]_{STOCH} \approx \frac{90\%}{\sqrt{E}}$$

INFLUENCE OF λ_{ATT} ON CONSTANT TERM

- FLUCTUATIONS IN LONGITUDINAL SHOWER DEVELOPMENT

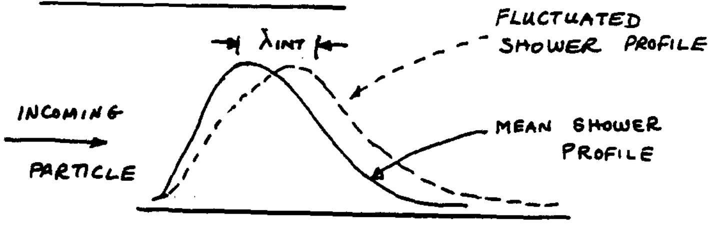
↓

SYSTEMATIC SHIFTS IN OBSERVED LIGHT AT END OF CAPILLARY

→ A SHORT ATTENUATION LENGTH IN THE CAPILLARIES WILL CERTAINLY INDUCE A CONSTANT TERM IN THE HADRONIC ENERGY RESOLUTION

? WHAT DOES "SHORT" MEAN IN QUANTITATIVE TERMS ?

A SIMPLE MODEL



- FIRST CONSIDER A SINGLE HADRON
- TAKE INTERACTION LENGTH AS MEASURE OF LONGITUDINAL FLUCTUATION

$$\frac{\delta(LIGHT)}{LIGHT} = \pm \left(e^{\frac{-\lambda_{INT}}{\lambda_{ATT}}} - 1\right)$$

- TAKE THIS NUMERICALLY EQUAL TO INDUCED CONSTANT TERM.

SINGLE HADRONS INCIDENT OF FCAL STRUCTURE

01284

- ASSUME AN FCAL STRUCTURE

ϕ_{TUBE}	3 mm	Fe
ϕ_{HOLE}	4.5 mm	QUARTZ
SPACING	8 mm	LIQ. SCI.

Fe : SCINT = 5.6 : 1 BY VOLUME

$\langle\rho\rangle$ = 6.05 grm cm^{-3}

λ_{INT} = 19.3 cm.

λ_{ATT} cm IN TUBES	INDUCED CONSTANT TERM %
200	± 9.2
250	± 7.4
275	± 6.8
310	± 6.0
360	± 5.2

FOR SINGLE HADRONS

CONSTANT	10 %	NEEDS	200cms
TERM	5 %	λ_{ATT}	360 cms

WHAT ABOUT JETS ?

λ_{ATT} INDUCED CONSTANT TERM FOR JETS

0128

- FORWARD CAL. MEASURES JETS, NOT SINGLE HADRONS
- INTUITIVELY ONE KNOWS THAT LONGITUDINAL FLUCTUATIONS IN JET-INDUCED SHOWERS WILL BE LESS IMPORTANT,
- FOR SINGLE HADRONS

$$\frac{\delta(\text{LIGHT})}{\text{LIGHT}} = \pm\left(e^{-\frac{\lambda_{INT}}{\lambda_{ATT}}} - 1\right)$$

- MODEL EFFECT OF n-PARTICLE JET

$$\frac{\delta(\text{LIGHT})}{\text{LIGHT}} = \pm\left(e^{-\frac{\lambda_{INT}}{\lambda_{ATT}\sqrt{N}}} - 1\right)$$

λ_{ATT} INDUCED CONSTANT TERM 10 PARTICLE JETS

01286

SAME FCAL STRUCTURE

λ_{ATT} cm IN TUBES	INDUCED CONSTANT TERM %
100	± 6.1
200	± 3.1
250	± 2.5
275	± 2.3
310	± 2.0
360	± 1.7

BLUE IPB 515mm BROWN TUBE

- AN INDUCED CONSTANT TERM OF 10% IS "TRIVIAL"

- ALREADY OBSERVED λ_{ATT} CORRESPONDS TO INDUCED CONSTANT TERM ~ 2% IN 3mm ϕ_T STRUCTURE

DOES SIMPLE MODEL AGREE WITH DATA ?

01287

- SPACAL STRUCTURE

ϕ_{FIBRE} = 1mm

Pb : Fibre = 4 : 1

AS ESSENTIALLY SAME λ_{INT} AS THE FCAL STRUCTURE WE CONSIDER

- MEASURE CONSTANT TERM = 1.2 %
- IN OUR SIMPLE MODEL PUT

λ_{INT} = 21 cms

λ_{ATT} = 600 cms

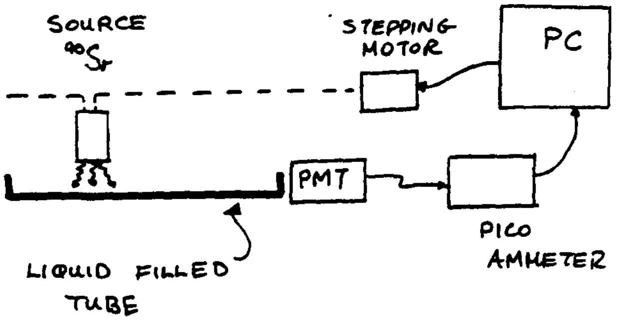
PREDICT CONSTANT TERM INDUCED BY λ_{ATT} = 1.1%

WE CONCLUDE THAT λ_{ATT} IS NOT REALLY AN ISSUE.

λATT TEST SETUP

J. T. WHITE
TEXAS A&M

01288



HORIZONTAL + VERTICAL ALIGNMENT
≤ 0.005"

λATT MEASUREMENTS

TEXAS
A&M

01289

- FOUR LIQUID SCINTILLATORS

BICRON	BC599-12 BC599-13	~450nm
NATIONAL DIAGNOSTIC	ND XII 135-1 ND XII 135-2	

→ NOTE THESE ARE BLUE

BICRON – ISO PROPYL BIPHENYL

N.D. – PSEUDOCUMENE

→ AT PRESENT MEASURING

NE 209E

→ GREEN IPB (495mm)

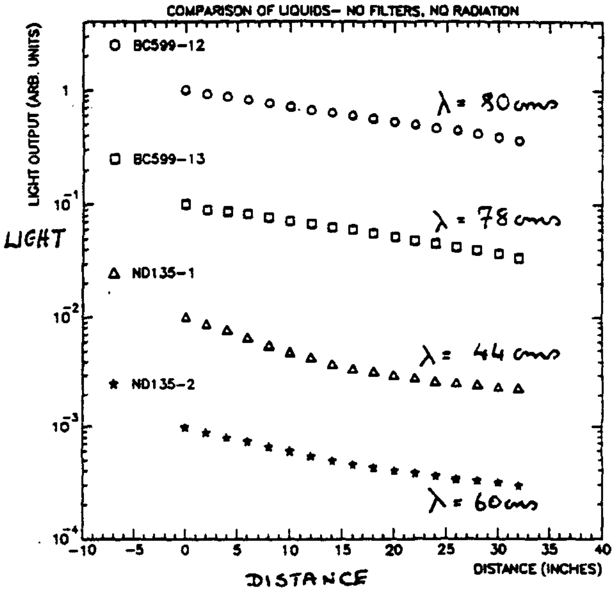
01290

MEASUREMENTS

- FRESH LIQUIDS / FRESH TUBES
- FRESH LIQUIDS / TUBES IRRADIATED EMPTY
- FRESH LIQUIDS / TUBES IRRADIATED FULL
- IRRADIATED LIQUIDS IN IRRADIATED TUBES
- DOSE ~ 100 MRAD. γ's

01291

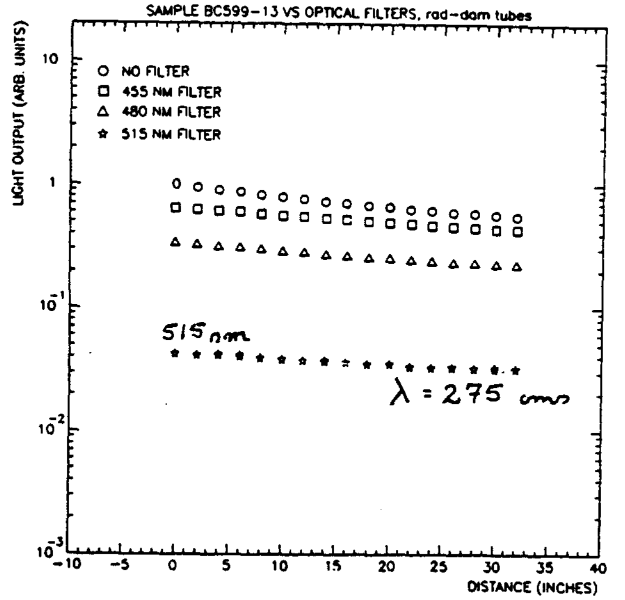
UNIRRADIATED LIQUIDS & TUBES
– NO OPTICAL FILTER



FRESH LIQUID

01292

RADIATION DAMAGED TUBE



FITTING SECOND HALF OF DATA

λ = 361 cms

01293

ATTENUATION LENGTH SUMMARY

BICRON BC599-13

BLUE
ISOPROPYL -
BIPHENYL

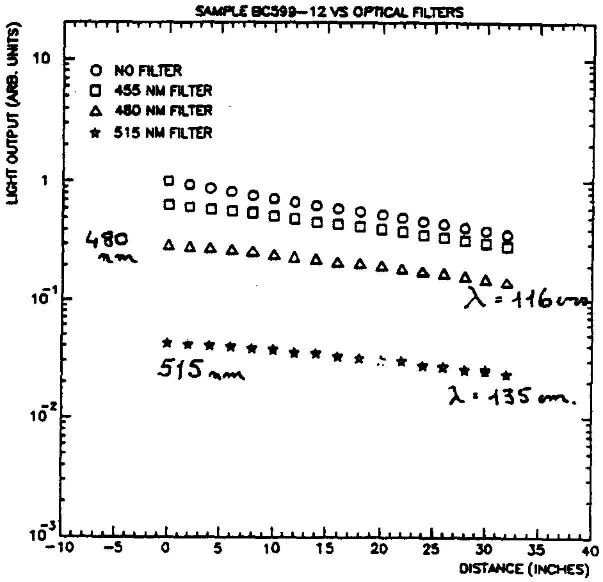
	FIT RANGE		
FILTER	ALL	1st 17"	LAST 17"
NONE	135	116	170
455	202	192	221
480	196	171	239
515	275	235	361

ATTENUATION LENGTH IN CMS.

→ INVESTIGATING GREEN IPB

EFFECT OF OPTICAL FILTER

01294

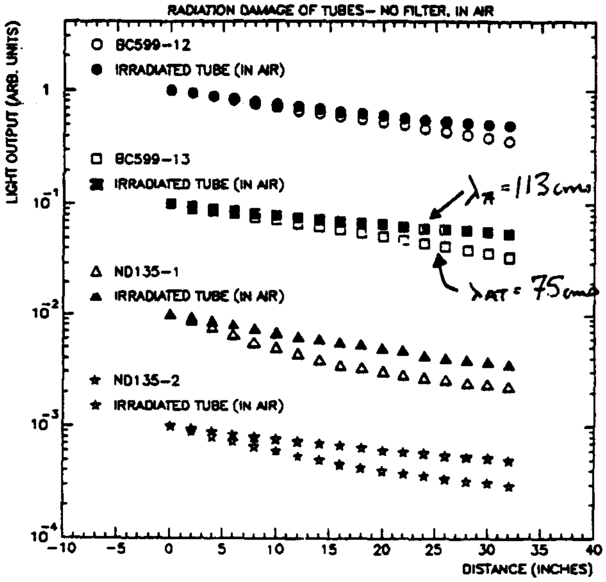


01295

FRESH LIQUID - IRRADIATED TUBE

□ NON-IRRADIATED

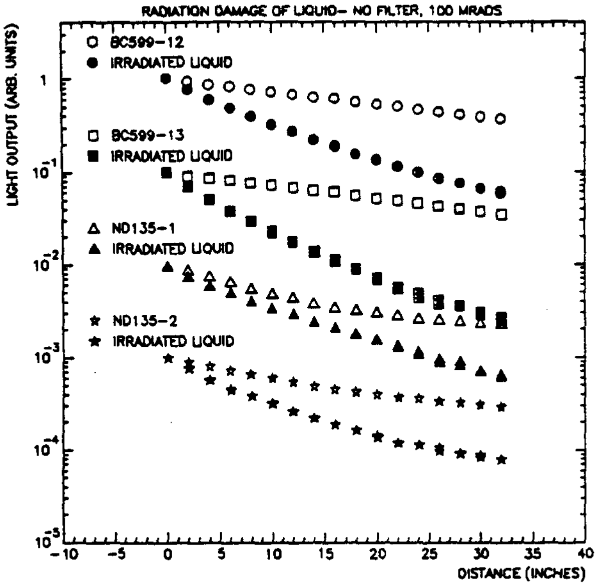
▨ IRRADIATED



AFTER IRRADIATION, TUBES HAVE LONGER λ_{ATT}

RADIATION DAMAGE OF LIQUID

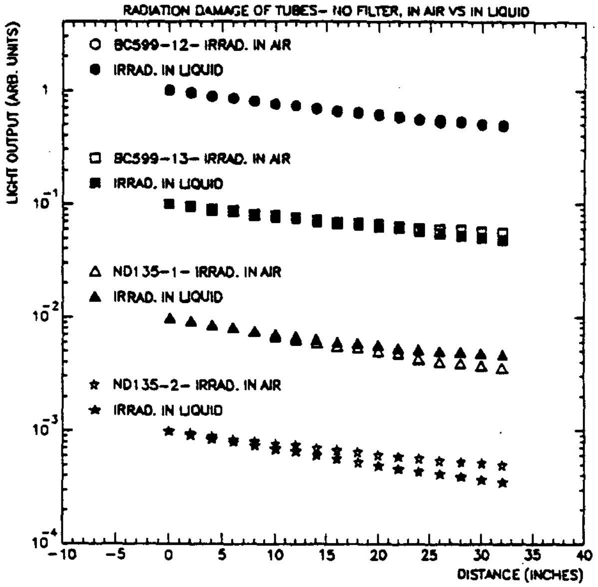
100 Mrads



BC599-13 $\frac{\lambda(\text{FRESH})}{\lambda(\text{IRRAD})} = \frac{78}{17}$ cms

$= 4.5$

NO EVIDENCE FOR DEPOSITS ON TUBE WALLS DURING IRRADIATION



COMPARISON OF TUBES

IRRADIATED • EMPTY } FRESH
• FULL } LIQUID

CONCLUSIONS:

- λ_{ATT} OF IRRADIATED QUARTZ OK
- λ_{ATT} OF LIQUID FILLED TUBES IS 200 – 300 cms WITH BLUE FLUOR (INVESTIGATING GREEN)
- DEPOSITS ON TUBE WALLS DURING IRRADIATION NOT AN ISSUE AT 100 MRad.

SMALL TEST MODULE UNDER CONSTRUCTION

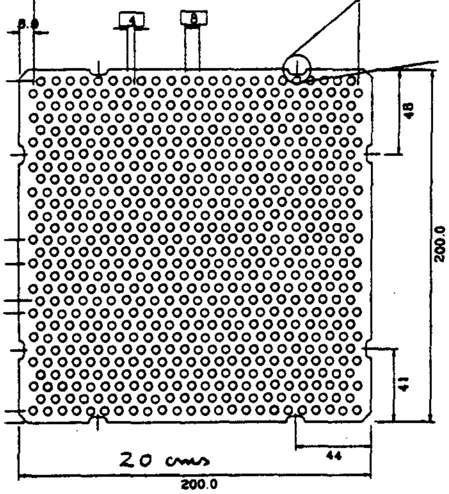
– TEST THIS SUMMER AS PRECURSOR TO "HADRONIC" MODULE

- VERIFY THAT IT ACTUALLY WORKS AS A CALORIMETER
- STUDY LIGHT COLLECTION METHODS

"EM SIZED" TEST MODULE

01300

EXPECT $\frac{\sigma}{E} \sim \frac{35\%}{\sqrt{E}}$ ELECTRONS



54.5 cms LONG

ϕTUBE 3 mm

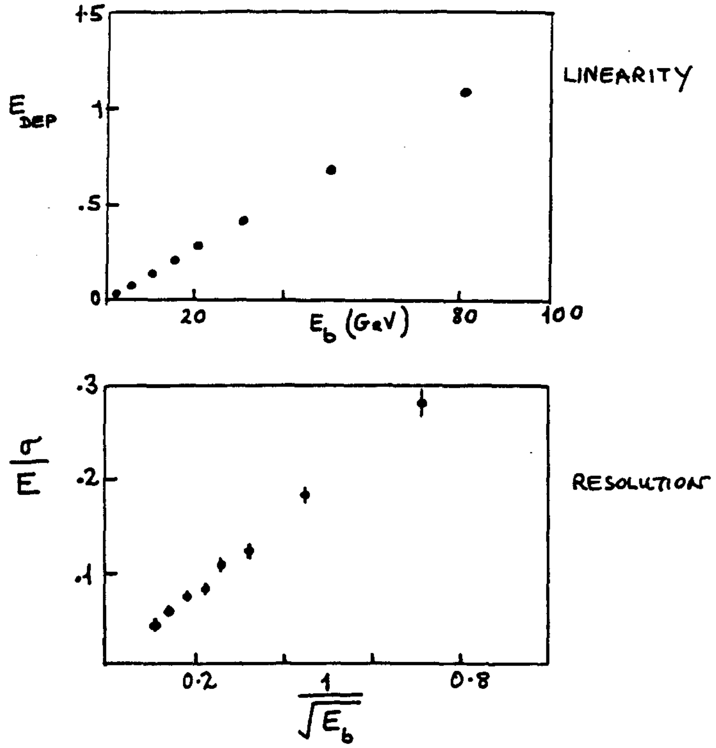
SPACING 8 mm

SAMPLING FRACTION (MIP) 3%

MONTE CARLO OF TEST MODULE

01301

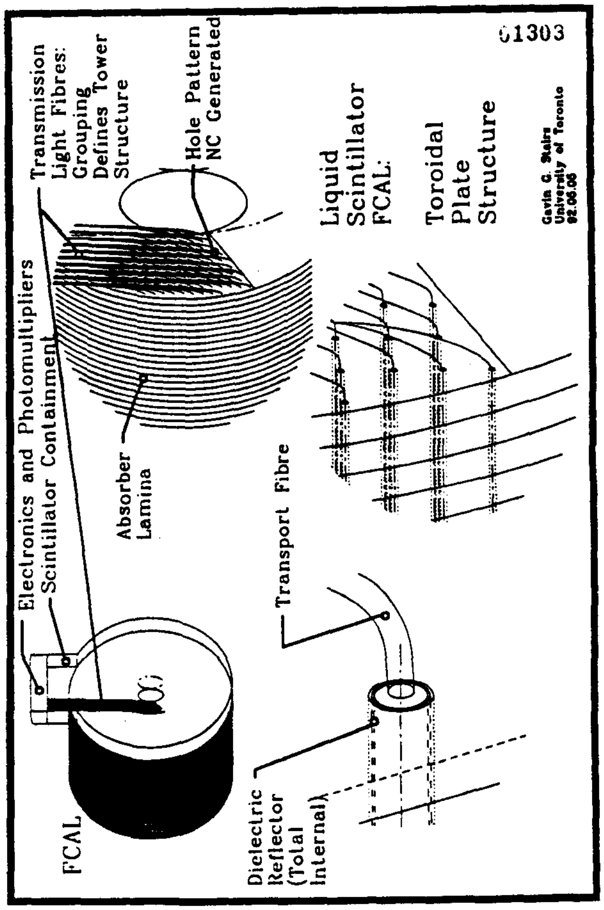
ELECTRONS

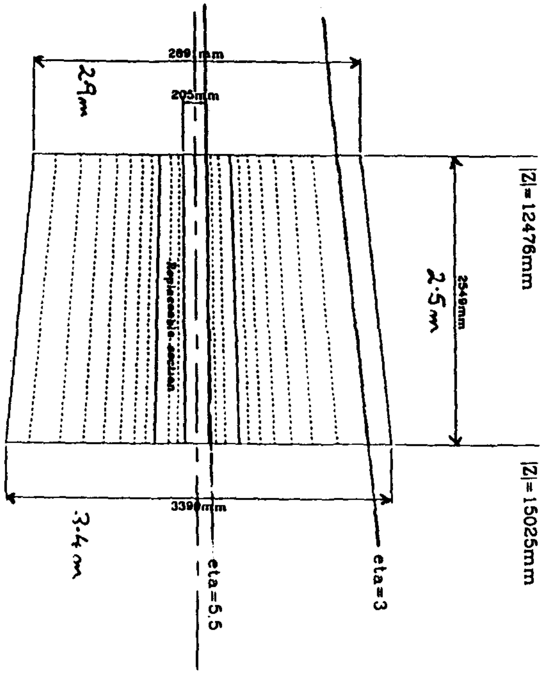


MECHANICAL DESIGN ISSUES

01302

- MECHANICAL ARRANGEMENT
  eg TOWERING:- PARAXIAL
  PROJECTIVE
- MANUFACTURE OF ABSORBER PLATES
  - FINE BLANKING
  - PUNCHING
- LIGHT COLLECTION INTERCONNECT
- PLUMBING FOR SCINTILLATOR FLOW
- REPLACEMENT OF LARGE M
- SAFETY



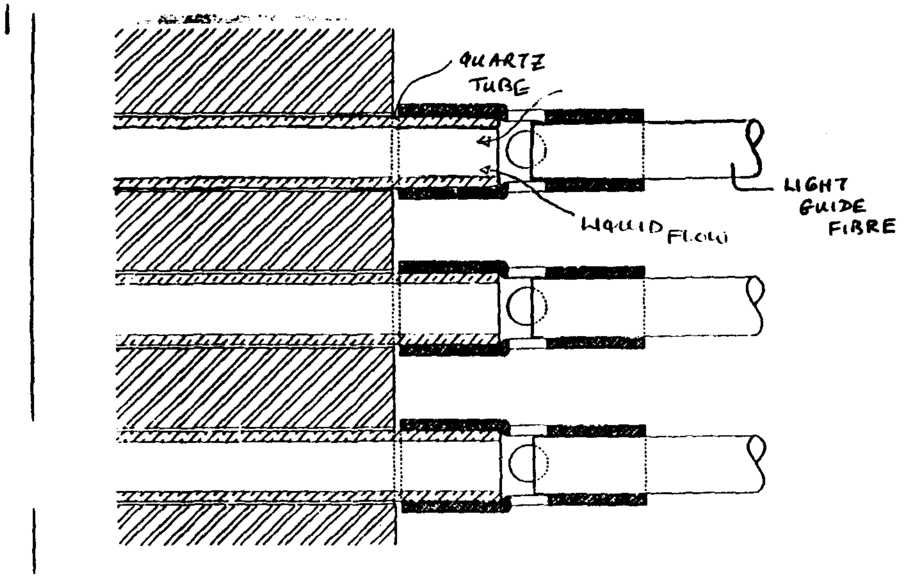


PROTECTIVE TOWERING

Liquid Scintillator Backstop FCal for SDC
Showing Projective Tower Formation

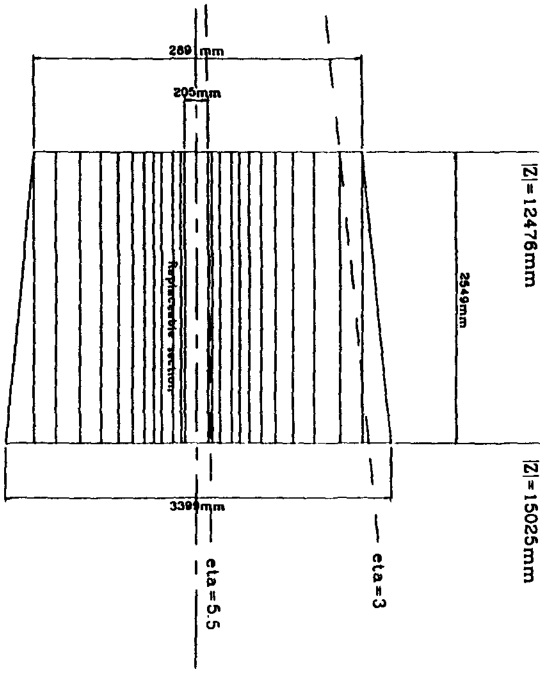
12 Lambda, 1 Lambda lateral containment, 3<eta<5.5+, 12476mm<|Z|<15025mm

61306



Transition from 3mm ID 4.2mm OD Quartz Tubes to a Light Guide Fibre

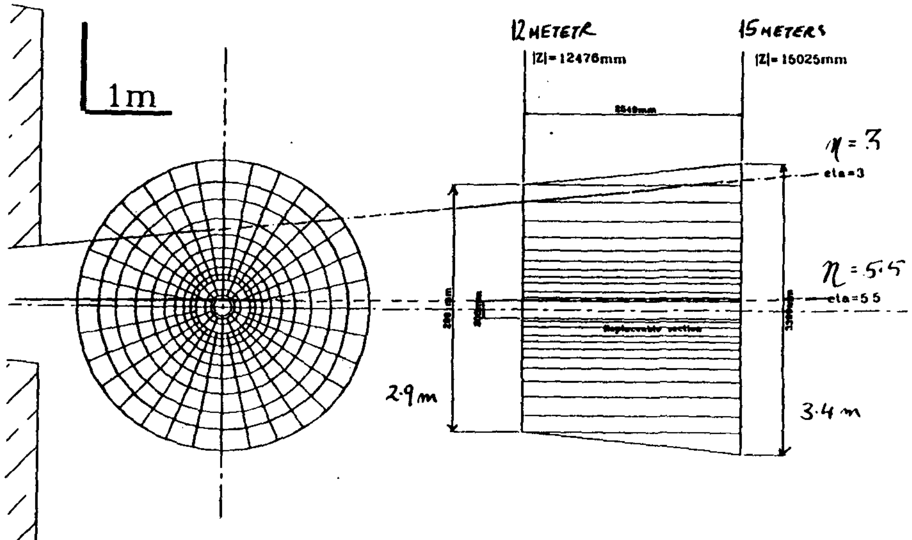
61304



Liquid Scintillator Backstop FCal for SDC
Showing Paraxial Tower Formation

12 Lambda, 1 Lambda lateral containment, 3<eta<5.5+, 12476mm<|Z|<15025mm

61307

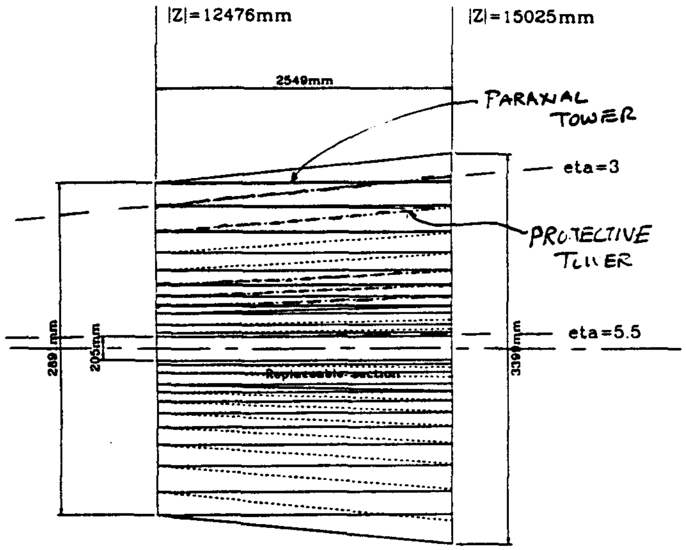


Liquid Scintillator Nonprojective (Paraxial) Backstop FCal for SDC

12 Lambda, 1 Lambda lateral containment, 3<eta<5.5+, 12476mm<|Z|<15025mm

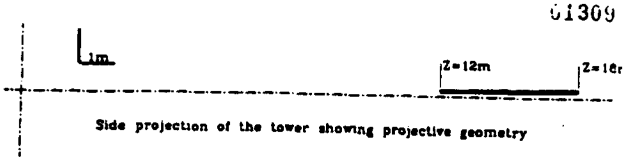
12 λ_{INT} ; 1 λ_{INT} LATERAL CONTAINMENT

61305

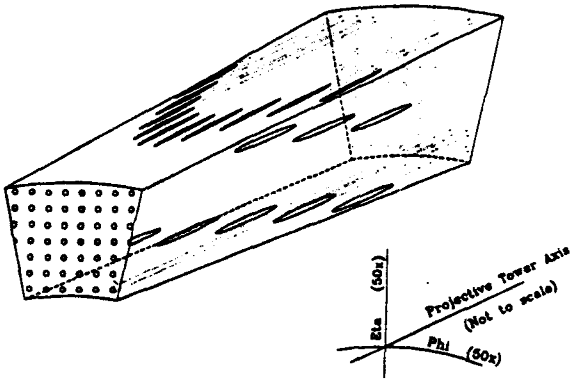


Liquid Scintillator Backstop FCal for SDC
Comparing Projective to Paraxial Tower Formation

12 Lambda, 1 Lambda lateral containment, 3<eta<3.5+, 12476mm<|Z|<15025mm

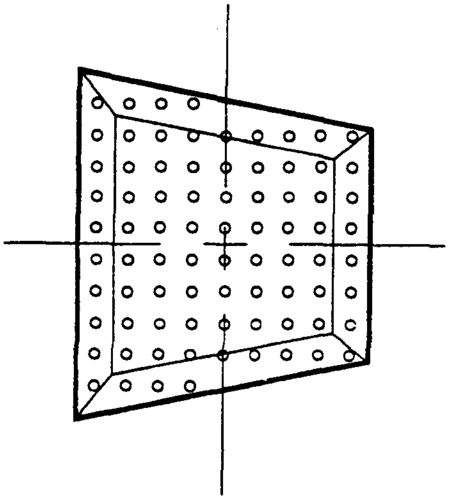


Side projection of the tower showing projective geometry



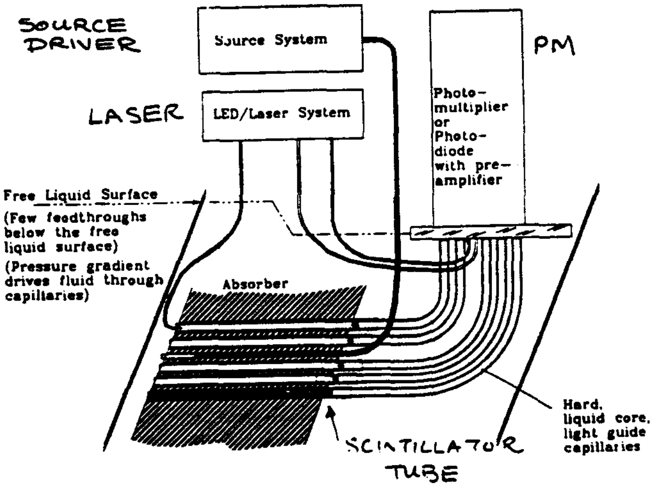
Oblique Phantom Sketch of a Tower at 4.8<eta<5.2

Showing capillary tubes which exit at the sides of the absorber block



Axial Projection of a Tower at 4.8<eta<5.2

Rectilinear pattern, straight capillary tubes



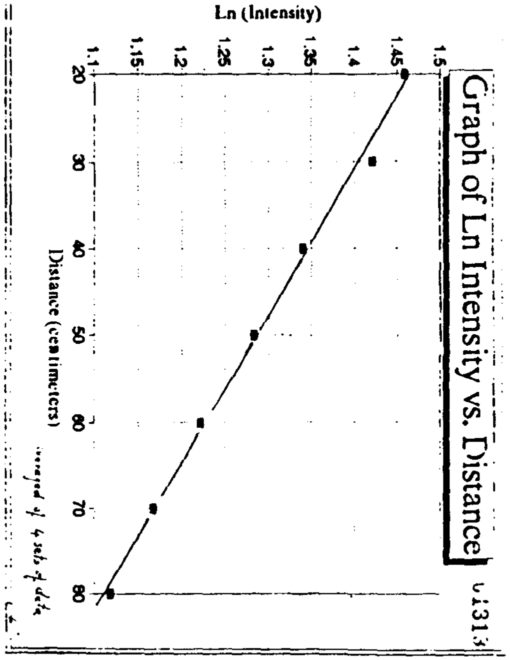
Liquid Scintillator SDC FCAL --
Light Path and Calibration Schematic

MONITORING CONCEPT

Curtis G. Stairs U of Toronto Physics
IPP Canada SDC 91.12.04

5TH MAY 1992

WBS NUMBE	WBS OR ACTIVITY DESCRIPT	WBSBASE (K	CONTING(K	WBS TOTAL(K
2.3.	FCal	1302	5	1307
2.3.1	Design Documents	656	71	727
2.3.2	Transport	600	48	648
2.3.3	FCal North	0	0	0
2.3.4	FCal South	0	0	0
2.3.5	FCal Monitor and Slow Control	120	5	125
2.3.6	Small Scale Modules	355	61	416
				0
Ephemera				0
2.3.11	Absorber	2400	422	2822
2.3.12	Capillaries	320	67	387
2.3.13	Scintillator Subsystems	1300	374	1674
2.3.14	Light Transport Subsystems	80	42	122
2.3.15	Scintillator Containment	350	116	466
2.3.16	Electronics	1560	376	1936
		9043	1587	10630



CLEAR, FRESH ISOPROPYL BIPHENYL

505 ± 10 nm

λ_{ATT} = 176 cm.

01314

HIGH PRESSURE GAS OPTION

N. GIOKARIS

MAY 6, 1992

HIGH PRESSURE GAS OPTION FOR THE FORWARD SDC CALORIMETER

Nikos Giokaris
The Rockefeller Univ.

Rockefeller
Dubna
Fermilab
Rochester
Wisconsin
Michigan (Ann Arbor)
Ability Engineering Technology, Inc.

TALK OUTLINE

I. RESULTS FROM TESTS WITH A HIGH PRESSURE TEST VESSEL

II. RESULTS FROM A BEAM TEST OF A PARALLEL PLATE PROTOTYPE EM CALORIMETER

III. RESULTS FROM RADIATION DAMAGE STUDIES ON HIGH PRESSURE GASSES

IV. DESIGN OF A HIGH PRESSURE GAS IONIZATION TUBE CALORIMETER FOR FCAL

V. 1992 R&D

VI. CONCLUSIONS

II, III AND IV : AVAILABLE AS PAPERS TO BECOME SDC NOTES
I & OTHERS : AVAILABLE AS SUPPORTING DOCUMENTATION

HIGH PRESSURE GAS CALORIMETRY

DEFINITION

USE AS SAMPLING MEDIUM HIGH PRESSURE GAS (~ 100 ATM)
DENSITY OF 100 ATM ARGON = 0.178 gr/cm^3 = 1/8 DENSITY OF LIQUID ARGON

MOTIVATION

UNITY GAIN

VERY RADIATION HARD

VERY FAST

GOOD ENERGY RESOLUTION

VERY EASY TO RECYCLE GAS (IF YOU EVER NEED)

NO TEXAS TOWERS PROBLEM (ENERGY SAMPLING FRACTION IS ~ 1%)

NO GLOW MODE PROBLEM (NO CHARGE AMPLIFICATION ON THE ANODE)

NO SPACE CHARGE PROBLEM

NO CRYOSTAT

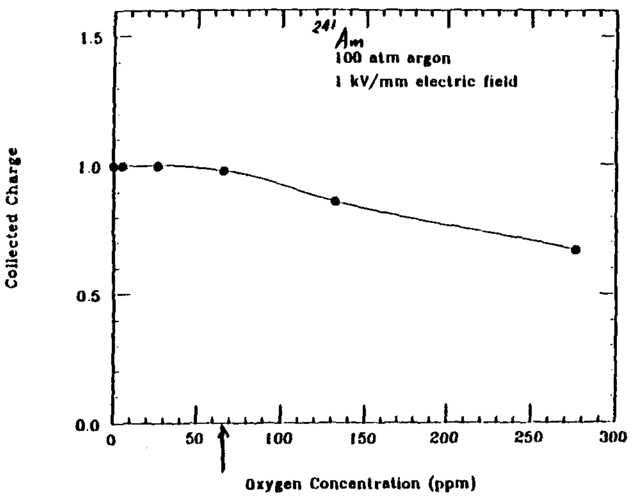
NO IMPURITIES PROBLEM (ppb AT TMP)

NO GAS CHEMISTRY

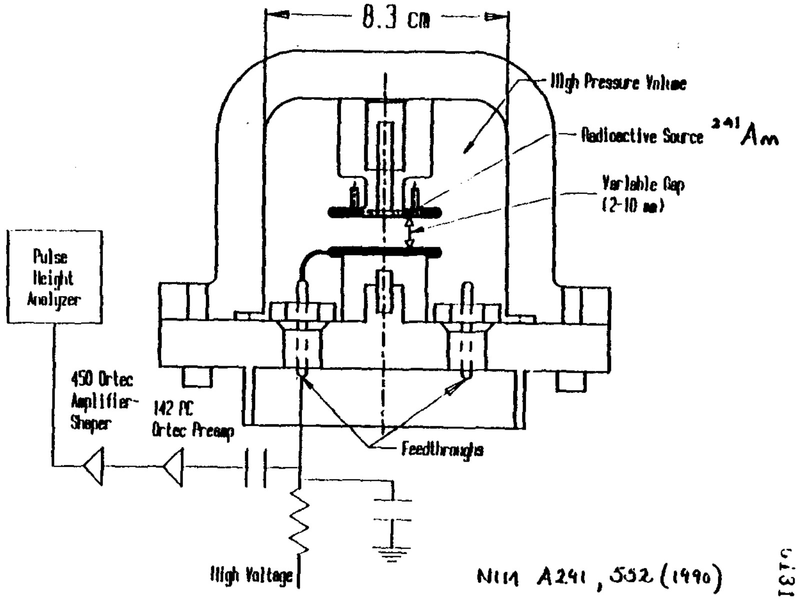
AND VERY COST EFFECTIVE

I. RESULTS FROM TESTS WITH A HIGH PRESSURE TEST VESSEL

- TESTS PERFOMED IN 1988-89

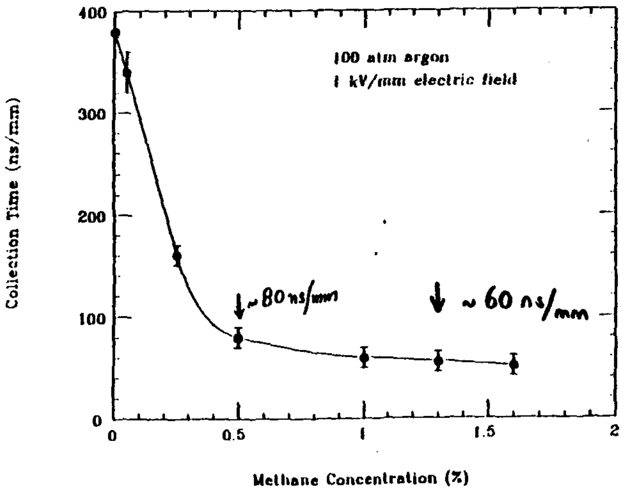


61321



NIM A241, 552 (1990)

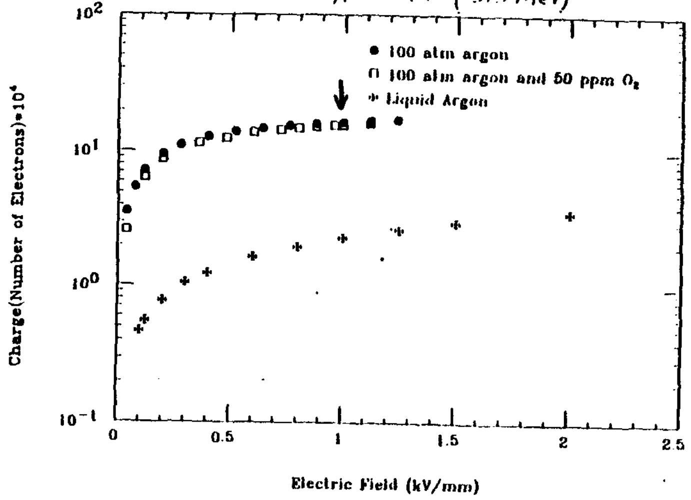
61318



FOR LqAr & TMP
$v^{-1} = 250$ nsec/mm
at: $E = 1$ kV/mm

61322

^{241}Am α's (5.5 MeV)



61320

CONCLUSIONS FROM TEST VESSEL

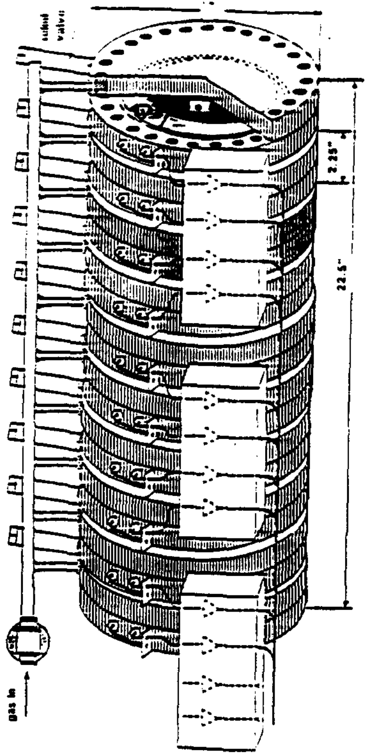
OXYGEN HAS NO EFFECT ON THE SIGNAL FOR CONCENTRATIONS UP TO ~70 ppm

FOR 99% Ar + 1% CH_4 AT 100 ATM : (DRIFT VELOCITY)$^{-1}$ = 60 nsec/mm

II. Prototype Parallel Plate Electromagnetic High Pressure Gas Calorimeter

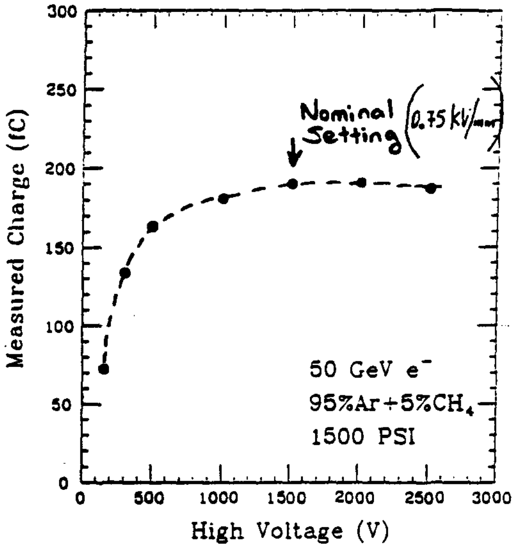
[1991 ÷ Support by TNRLC]

10 High Pressure Vessel

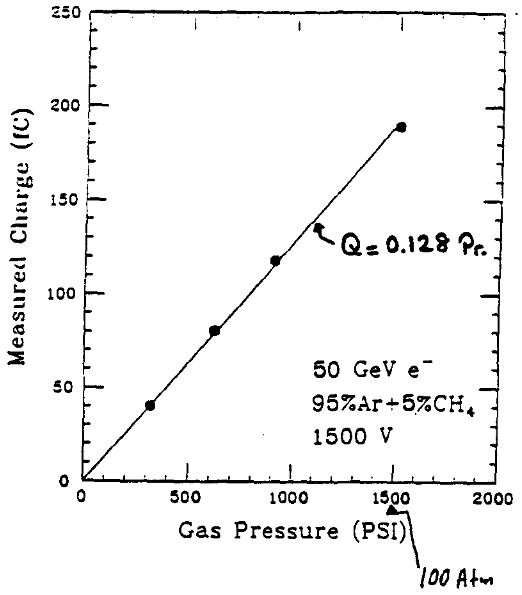


RESULTS FROM ~~A~~ THE BEAM TEST OF ~~A~~ THE PARALLEL PLATE PROTOTYPE EM CALORIMETER

01327



01328



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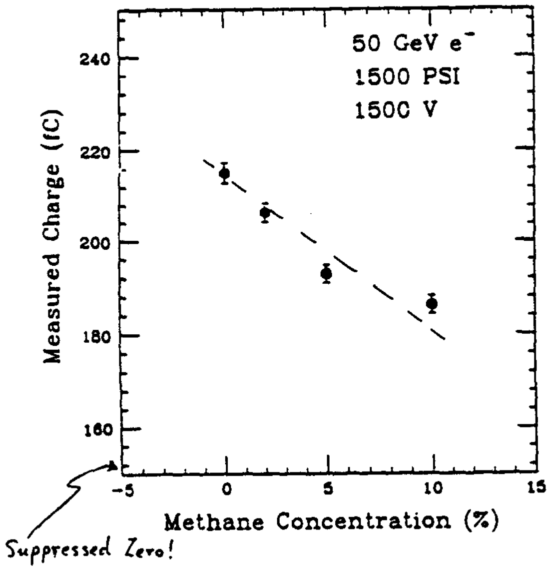
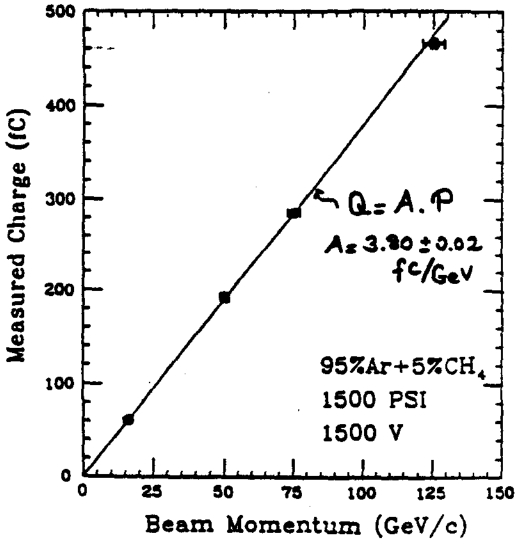


01330



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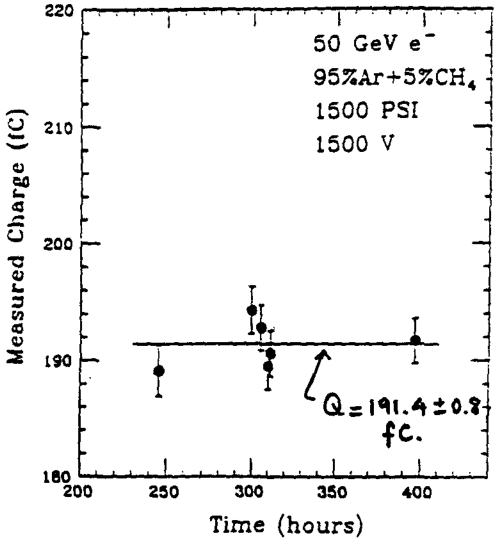

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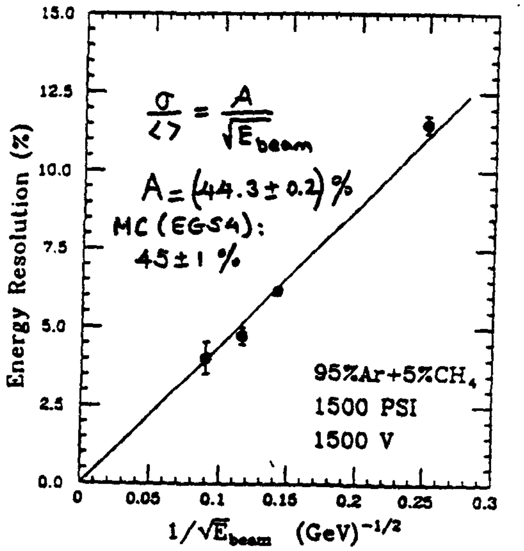
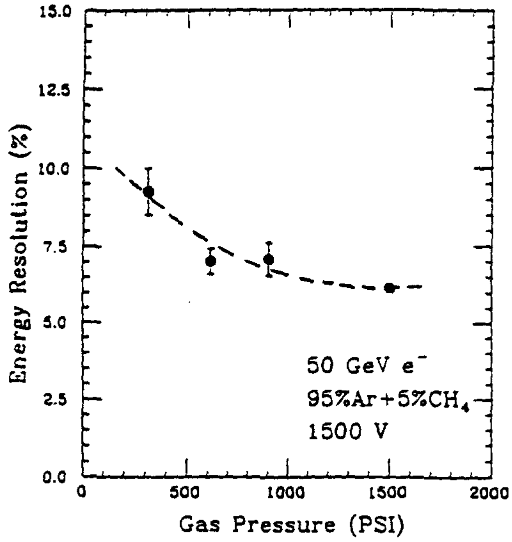
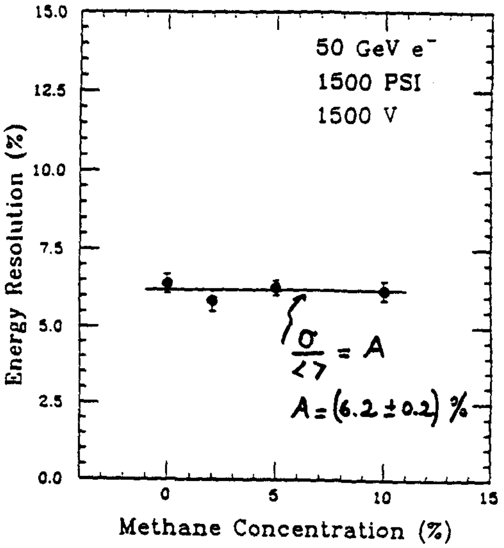
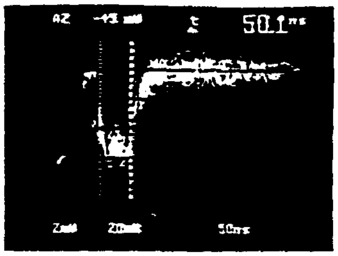


01333



01334





95% Ar + 5% CH4 at 100 Atm

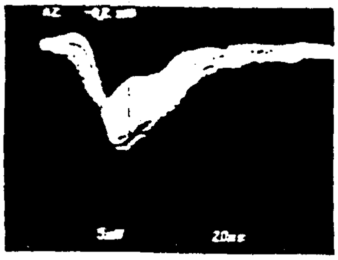
E = 1.25 kV/mm

Am241 alpha source

Shuvalov preamplifier

(a)

2mm gas gap



95% Ar + 5% CH4 at 100 Atm

E = 0.75 kV/mm

50 GeV electrons

Velkov preamplifier

(b)

~50 nsec base widt'
(~35 nsec for scintillator present)

CONCLUSIONS

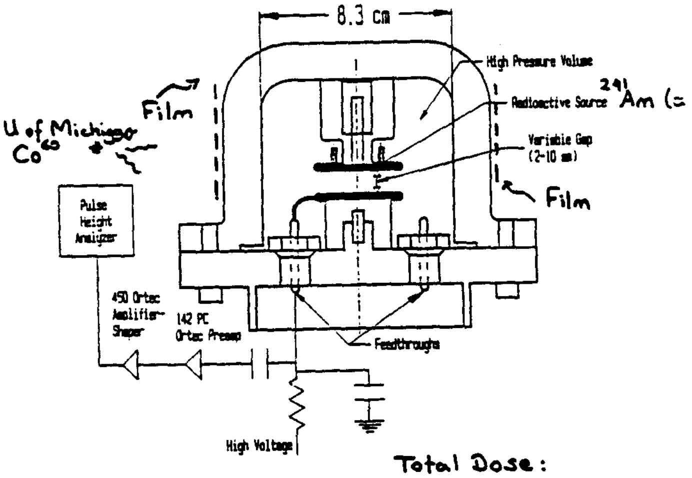
PARALLEL PLATE PROTOTYPE EM TEST

(GAS MIXTURE: 95% Ar + 5% CH_4)

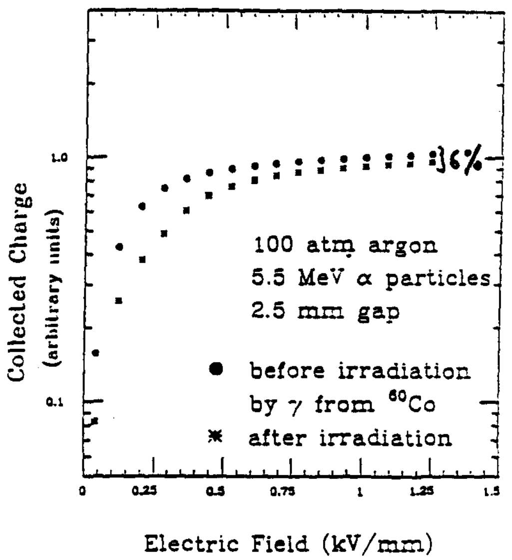
1. SIGNAL SATURATES FOR AN ELECTRIC FIELD E = 0.75kV/m
2. SIGNAL VERSUS PRESSURE IS LINEAR IN THE TESTED RANGE 20—100 atm
3. SIGNAL VERSUS ENERGY IS LINEAR IN THE TESTED RANGE 20—125 GeV
4. ENERGY RESOLUTION AGREES WITH EGS4 MONTE CARLO PREDICTION
5. MEASURED ELECTRON DRIFT VELOCITY ≈ 20 nsec/mm
6. FAST PREAMPLIFIER OUTPUT SIGNAL: RISE TIME IS LESS THAN 15 ns, BASE WIDTH IS ABOUT 50 ns
7. CHARGE COLLECTED IS 3.8 ± 0.4 fC/GeV, OR 85% OF THE EXPECTED CHARGE IF $\epsilon/\mu = 0.92$

PROTOTYPE EM PROVED TO BE VERY EASY TO OPERATE.

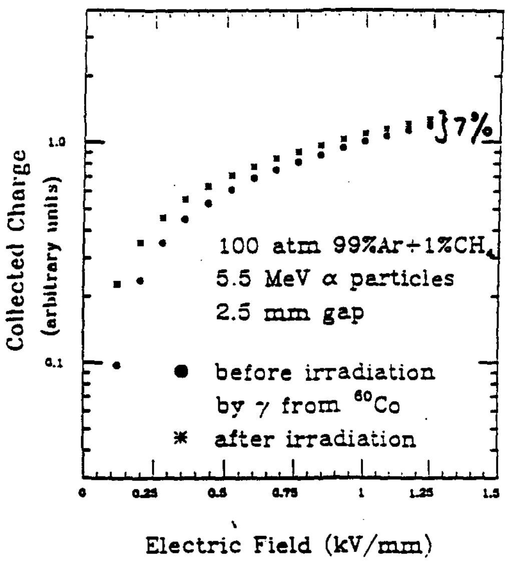
III. RADIATION DAMAGE TESTS



Total Dose:
~16 Mrad (Ion Chamber
~50 Mrad (Film)



Faster Signal



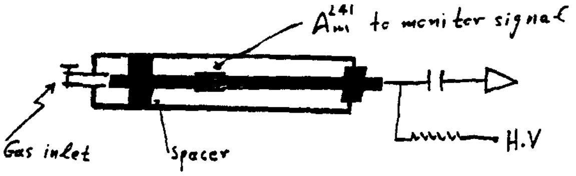
No change in signal speed

Conclusions From Radiation Damage Tests:

- **Pure Argon (Ar) gas and 99% Ar + 1% CH_4 gas mixture at 100 Atm were exposed to 16 Mrad (maybe as high as 50 Mrad) of ^{60}Co gammas,**
- **No significant pulse height (from alpha source) reduction observed,**
- **No need to renew the gas for at least one year of SSC operation at nominal luminosity.**

Next Radiation Damage Tests:

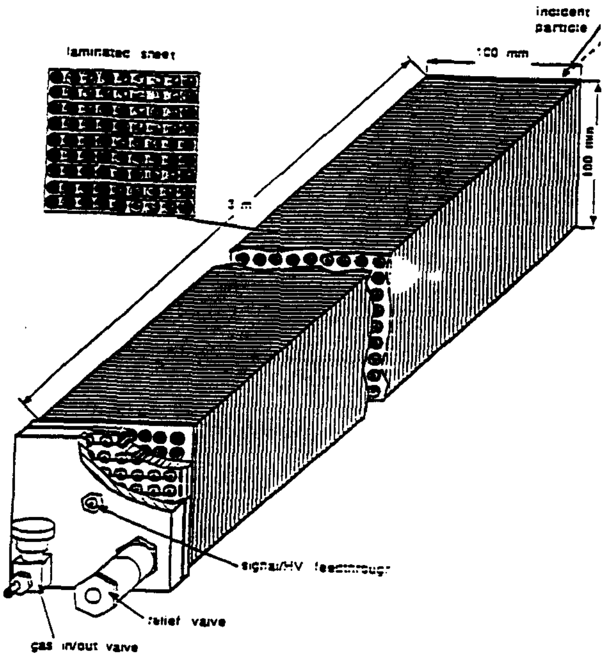
Expose 95% Ar + 5% CH_4 and 90% Ar + 10% CH_4 to ≈ 1000 Mrad of ^{60}Co gammas and neutrons with anode [redacted] connected to high voltage.

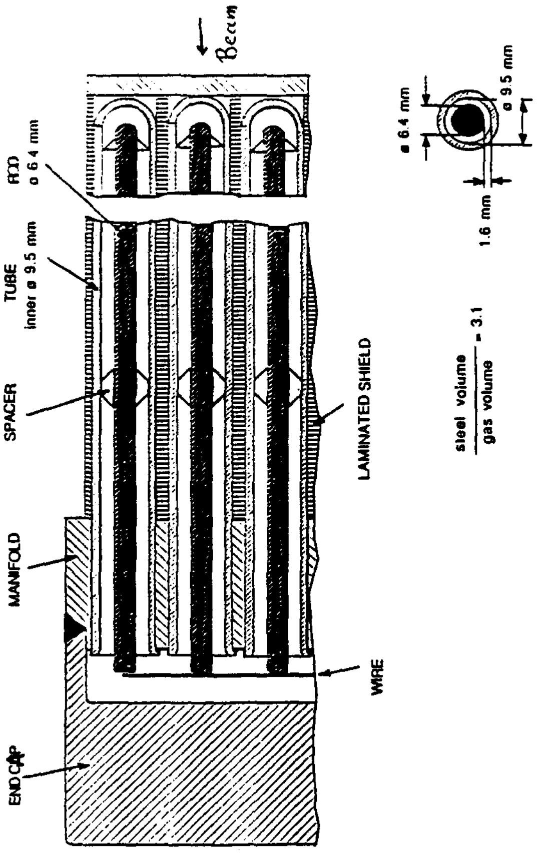


TUBE & ROD WITH A_m^{241} SOURCE
ARE UNDER CONSTRUCTION

IV. HIGH PRESSURE GAS TUBE CALORIMETER

01343

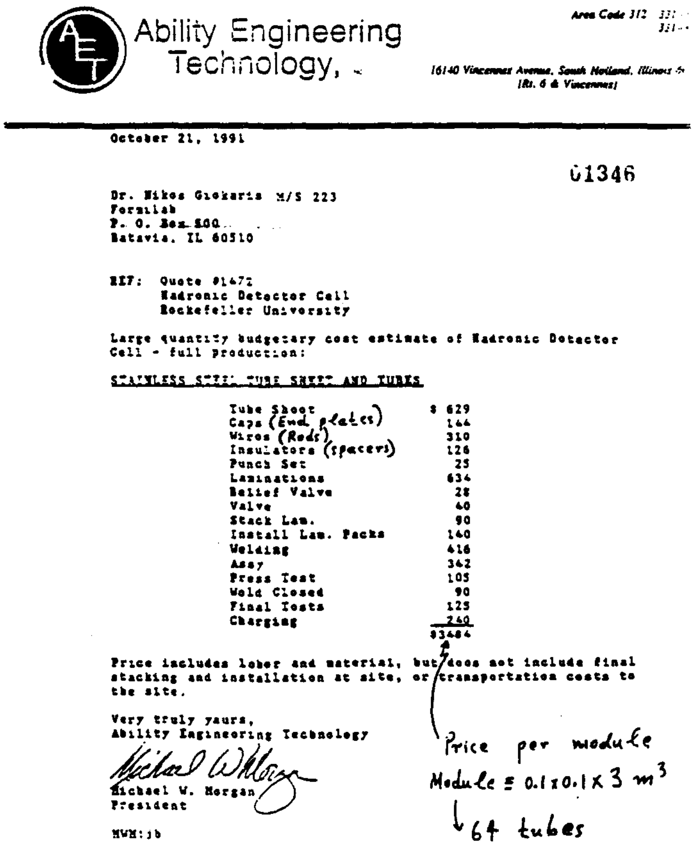




01344

01345

- END PLATE WELDING TESTED HYDRAULICALLY
- WELDING FAILED AT 9,600 PSI
- OPERATING PRESSURE ~ 1,500 PSI
- A $0.1 \times 0.1 \times 0.6\ m^3$ PROTOTYPE MODULE HAS BEEN CONSTRUCTED



Ability Engineering Technology,

Area Code 312 331
331

16140 Vincennes Avenue, South Holland, Illinois
(Rt. 6 & Vincennes)

October 21, 1991

01346

Dr. Nikos Giokaris M/S 223
Fermilab
P. O. Box 500
Batavia, IL 60510

REF: Quote #1472
Hadronic Detector Cell
Rockefeller University

Large quantity budgetary cost estimate of Hadronic Detector Cell - full production:

STAINLESS STEEL TUBE SHEET AND TUBES

Tube Sheet	$ 629
Caps (End plates)	144
Wires (Rods)	310
Insulators (spacers)	126
Punch Set	25
Laminations	634
Relief Valve	28
Valve	40
Stack Lam.	90
Install Lam. Packs	140
Welding	416
Assy	342
Press Test	105
Weld Closed	90
Final Tests	125
Charging	240
	$3484

Price includes labor and material, but does not include final stacking and installation at site, or transportation costs to the site.

Very truly yours,
Ability Engineering Technology

Michael W. Morgan
Michael W. Morgan
President

MWM:jb

Price per module
Module = $0.1 \times 0.1 \times 3\ m^3$
↳ 64 tubes

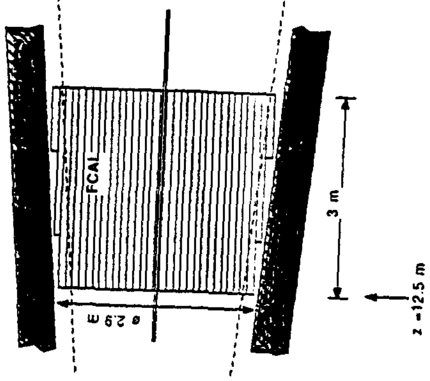
01347

~800 modules per side

1600 modules total

$3,500/module

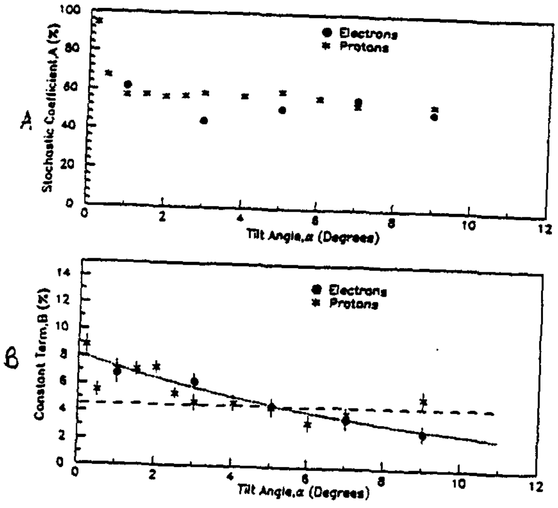
Total price $5.6M



GEANT MONTE CARLO

01348

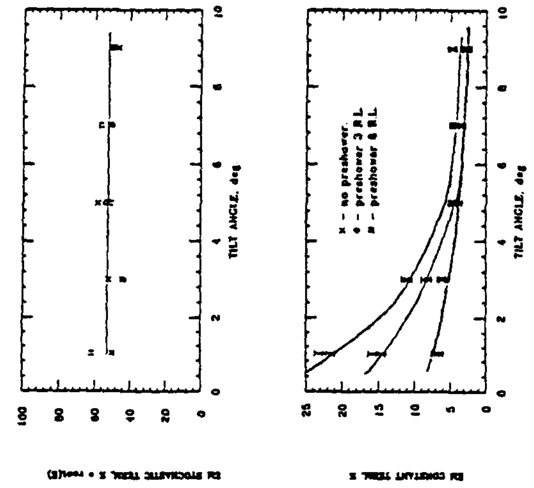
$$\frac{\sigma}{E} = \frac{A}{\sqrt{E}} \oplus B$$



With 6 Radiation Lengths of Preshower

01349

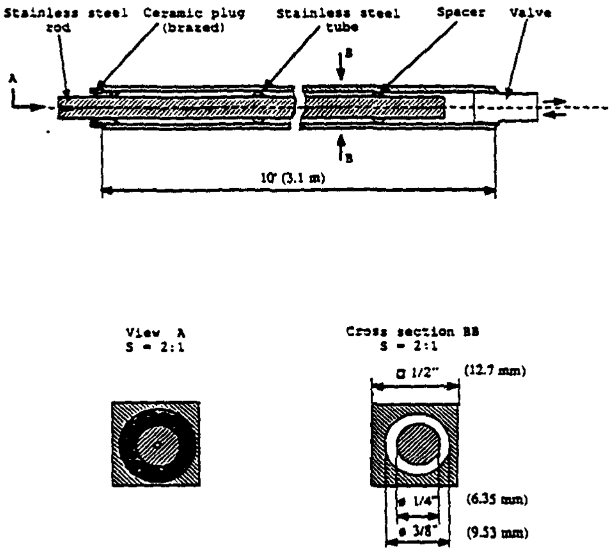
GEANT MONTE CARLO



ANOTHER APPROACH UNDER CONSIDERATION:

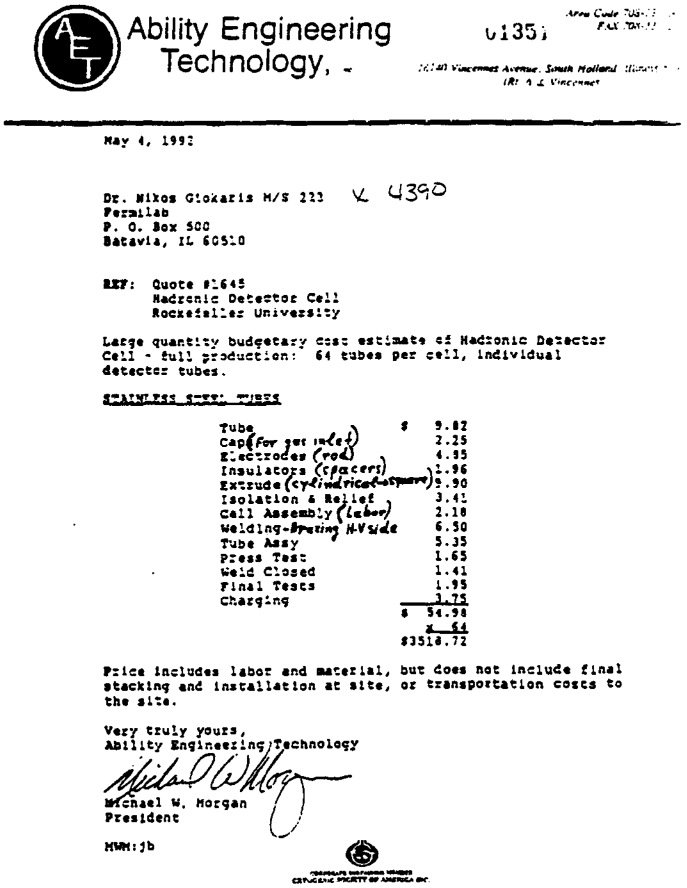
MAKE EACH TUBE ITS OWN PRESSURE VESSEL

01350



gas gap = 1/16" = 1.6 mm

- WELD TOGETHER 64 TUBES TO MAKE ONE $0.1 \times 0.1 \times 3\ m^3$ MODULE
- PRICE/MODULE ≃ $3,500 {see next page}



Ability Engineering Technology, Inc.
Area Code 708-[illegible]
FAX 708-[illegible]
[illegible] Vincennes Avenue, South Holland, Illinois [illegible]
(Rt. [illegible] & Vincennes)

May 4, 1992

Dr. Nikos Giokaris M/S 223 X 4390
Fermilab
P. O. Box 500
Batavia, IL 60510

REF: Quote #1645
Hadronic Detector Cell
Rockefeller University

Large quantity budgetary cost estimate of Hadronic Detector Cell - full production: 64 tubes per cell, individual detector tubes.

STAINLESS STEEL TUBES

Tube	$ 9.82
Cap (for gas inlet)	2.25
Electrodes (rod)	4.35
Insulators (spacers)	1.96
Extrude (cylindrical ~~square~~)	9.90
Isolation & Relief	3.41
Cell Assembly (labor)	2.18
Welding-Brazing H-V side	6.50
Tube Assy	5.35
Press Test	1.65
Weld Closed	1.41
Final Tests	1.95
Charging	1.75
	$ 54.98
	x 64
	$3518.72

Price includes labor and material, but does not include final stacking and installation at site, or transportation costs to the site.

Very truly yours,
Ability Engineering Technology

Michael W. Morgan
Michael W. Morgan
President

MWM:jb

CORPORATE SUSTAINING MEMBER
CRYOGENIC SOCIETY OF AMERICA INC.

V. 1992 R&D EFFORT

- DESIGN AND BUILD NECESSARY ELECTRONICS
- BUILD AND BEAM-TEST HADRONIC TUBE PROTOTYPE $\equiv 0.4 \times 0.4 \times 3 m^3$ (i.e 16 MODULES)
- DEVELOP DETAILED SDC FCAL ENGINEERING DESIGN

VI. CONCLUSIONS

- HAVE SHOWN THAT HIGH PRESSURE GAS CALORIMETRY WORKS
- A HADRONIC HP TUBE CALORIMETER WILL BE:

  RAD - HARD
  FAST (~ 35 nsec)
  SAFE
  VERY COST EFFECTIVE (~ \$140k/m^3)

G1354

ELECTRONICS OPTIONS FOR CALORIMETRY

A. LANKFORD

TALK #6

ELECTRONICS

for SDC CALORIMETRY

An Overview for the SSCL PAC

A. J. Lankford
for the **Solenoidal Detector Collaboration**
May 6, 1992

OUTLINE

TRIGGER

FRONT-END ELECTRONICS

- READOUT WITH ANALOG MEMORIES
- DIGITAL PMT READOUT
- SHOWER MAX READOUT

SUMMARY

TRIGGER

for SDC CALORIMETER

ROLE of the CALORIMETER

The calorimeter provides the most effective way to accomplish fast, efficient reduction of event rate by selecting interesting high-p_t events and identifying jets, electrons, photons, and missing energy.

Tasks:
- Identify local energy deposition
  - *e.g.:* EM showers, jets
- Calculate global energy-related quantities
  - *e.g.:* missing E_t, ΣE_t

Electrons:
- Identify EM shower
- Longitudinal and transverse shower profiles
- Spatial and E/p match to charged track
- Isolation

Photons:
- Like electrons, but without track

Jets:
- Deposition of energy in a cone

"Neutrinos":
- Measurement of missing E_t vector

TRIGGER DATA

Calorimeter at Levels 1 & 2:
Define trigger towers:
$\Delta\eta\times\Delta\phi = 0.1\times0.1$
sum energy in tower
perform separate EM and HAD sums
digitize every beam crossing
12-bit range (8-bit non-linear response ok)
output 16 bits per crossing on 1 Gbps fiber

Shower Max at Level 1:
Define $\Delta\eta\times\Delta\phi = 0.2\times0.1$ regions:
1 bit per region indicating hit above threshold
output 16 regions per crossing on 1 Gbps fiber

Shower Max at Level 2:
Use individual shower max strips:
either hit strip or pulse height information

TRIGGER PROCESSORS

Calorimeter at Level 1:
- Search trigger towers for EM showers.
- Sum E_t in overlapping $\Delta\eta\times\Delta\phi = 1.6\times1.6$ regions.
- Continue to sum E_t and to calculate missing E_t .
- Also check isolation by searching cone for energy.

Calorimeter at Level 2:
- Use same data as at Level 1 to recompute E_t for:
  electrons, jets, missing E_t, and isolation
  using clustering or fixed-cone algorithms.
- Apply loose E/p cut to electron candidates.

Shower Max at Level 1:
- Associate hit SMD region with trigger tower.

Shower Max at Level 2:
- Associate ϕ-position of shower in SMD with projected position from central tracker.
- Loose shower profile cut possible for e's, γ's.

CALORIMETRY

FRONT-END ELECTRONICS

GENERAL REQUIREMENTS

- Measure pulse heights with high dynamic range
- Sample at bunch crossing frequency
- Capability to read out multiple samples per event or to combine (w/ weights) samples nearby in time
- Analog signal processing simultaneous with output of digital data in "deadtimeless" operation
- Uniform, cost-effective solution for:
  - calorimeter towers
    - barrel
    - end caps
    - forward
  - shower maximum detectors

  despite differences in:
  - photodetectors and ionization amplitudes
  - dynamic range requirements
  - trigger requirements

• Central:	~13,500	EM channels	(~20,700 post-upgrade)
	~6300	HAC channels	
	~3200	trigger towers (each with EM & HAC)	
• Forward:	~1100	channels	
• SMD:	~57,500	channels	(~104,500 post-upgrade)

DYNAMIC RANGE REQUIREMENTS
for CENTRAL CALORIMETER

- Minimum detectable signal: **20 MeV E_t**

  set for:
  - detection of 100 MeV transverse leakage of e^{+-}'s
  - detection of 250 MeV minimum ionizing deposit

- Full-scale signal: **4 TeV E_t**

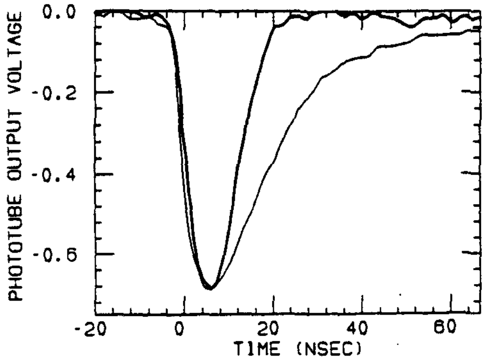
  set for:
  - extremely rare saturation
    for processes with > 100 events/SSC year
    (*e.g.*: dijets w/ $m_{jj} > 20$ TeV deposit $E_t > 4$ TeV
    in EM compartment in 3 events/year)

=> Dynamic Range = **2×10^5** (~18 bits)

- Trigger dynamic range:
  4×10^3 (12 bits)
  nonlinear 8-bit digitization is sufficient.

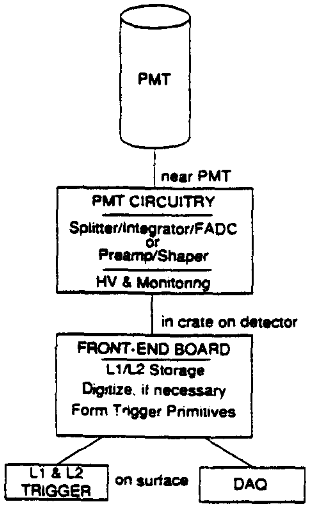
SIGNAL CHARACTERISTICS
for CENTRAL CALORIMETER

- > 250 photoelectrons per incident GeV
- signal shape dependent on fluors in scintillator and wavelength shifter (*e.g.*: signal from EM prototype)



- PMT requirements:
  match maximum linear pulsed current (~1 nC) to
  maximum energy deposition (4 TeV ~ 10^6 p.e.'s)
  => PMT gain ~ few x 10^3
  => 6 to 7 stages

PHYSICAL LAYOUT
for CENTRAL, FORWARD, & SMD


PMT
near PMT
PMT CIRCUITRY
Splitter/Integrator/FADC
or
Preamp/Shaper
HV & Monitoring
in crate on detector
FRONT-END BOARD
L1/L2 Storage
Digitize, if necessary
Form Trigger Primitives
L1 & L2 TRIGGER
on surface
DAQ

- Signal processing mounted on PMT base or nearby.
- Front-end boards in crates on calorimeter.
- Trigger tower energy sums on front-end boards.
- Trigger and readout data transmitted by fiber optics.
- Partitionable into stand-alone systems.

ARCHITECTURAL APPROACHES

In order to address the design challenge of readout with large dynamic range at high sampling frequency, we are currently pursuing two different architectural approaches.

- Digital Phototube Readout

  digitizes at beam crossing frequency
  with "floating-point" flash encoder

- Readout with Analog Memories

  stores analog signal in a switched capacitor array
  (SCA) until digitzation after a Level 2 trigger

The two approaches share many basic similarities. In particular, they both interface to the calorimeter and to the trigger and data acquisition systems in similar ways. Each approach offers its attractions and disadvantages, and both are now nearing demonstration that they can deliver the requisite dynamic range in a full system implementation.

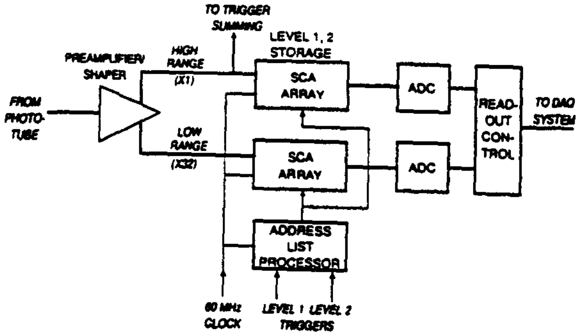
CALORIMETER READOUT

with

ANALOG MEMORIES

ARCHITECTURE

Provide 18-bit dynamic range with two 13-bit scales.



- Preamplifier/Shaper
    - located near PMT
    - 2 x 10^5 dynamic range preamp (AT&T bipolar)
    - delay-line shaping
    - dual range output
- SCA Card with dual ranges per channel
    - level 1, 2 analog storage
    - digitization after trigger accept
    - address control
    - output to trigger and data acquisition

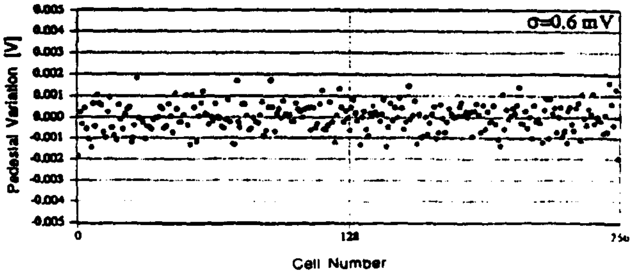
DYNAMIC RANGE

Dynamic range can be limited by cell-to-cell variations.

- Acheived results on pedestal variation:
    - On bench:
      0.6 mV RMS in 10 V differential swing
      => single scale dynamic range = 14 bits
    - On VME-card w/ simultaneous read/write operation
      1.1 mV RMS in 10 V differential swing
      => single scale dynamic range = 13 bits
- Measured cell-to-cell capacitance variation:
  0.07 % RMS
- Measured cell-to-cell crosstalk << 1%

=> 18-bit dynamic range w/ dual 13-bit scales

=> Same pedestal and gain correction applies to all samples on each scale.

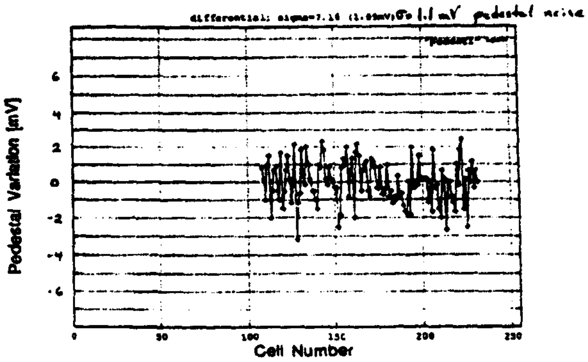


SCA Pedestal Variation

Readout on VME CARD

⇒ **Single shot variation**

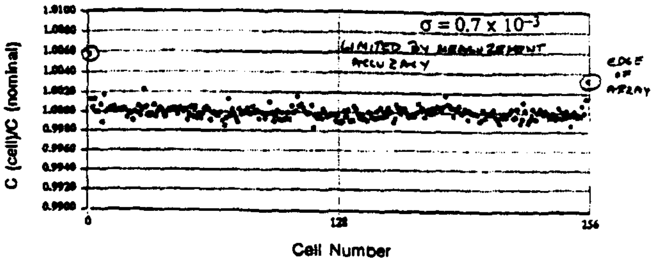
⇒ **Differential inputs w/ 10 volt effective input swing.**



⇒ 13.2 bit dynamic range (1:9000) achieved w/ SCA mounted on VME card in simultaneous R/W operation

CALORIMETER READOUT WITH ANALOG MEMORIES

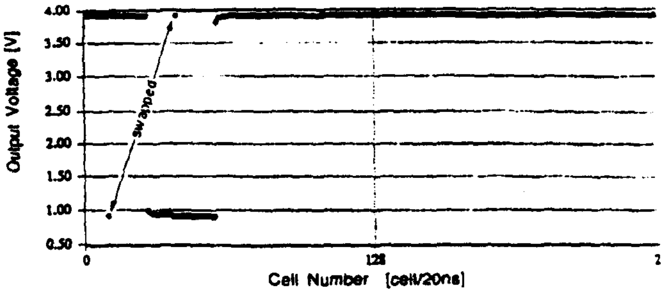
Capacitor Variation



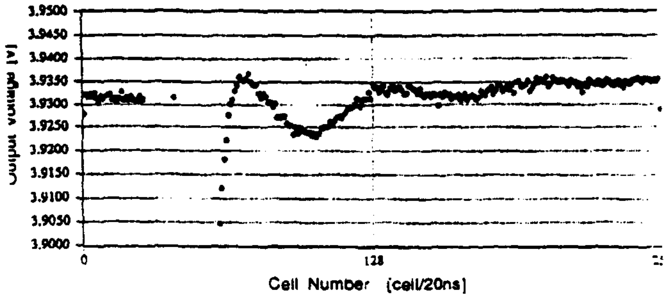
CALORIMETER READOUT WITH ANALOG MEMORIES

Crosstalk Measurements

Swap Single Cell Order:



Expanded Vertical Scale:



CALORIMETER READOUT WITH ANALOG MEMORIES

STATUS

1) SCA chip
   - 16 channels, 256 samples each.
   - maximum sample rate 90 MHz.
   - existing version meets performance requirements.
   - next version for beam test in design.

2) Dynamic range maintained in system tests
   - SCA tested on VME-card with simultaneous R/W.
   - SCA tested w/ Wisconsin preamp and w/ cable.

3) ADC chip
   - 16-channel, 12-bit (1.2µm CMOS).
   - 10 µs simultaneous conversion of all channels.

4) Address List Processor chip (ALP)
   - in test.

5) VME card for prototype calorimeter tests in design.

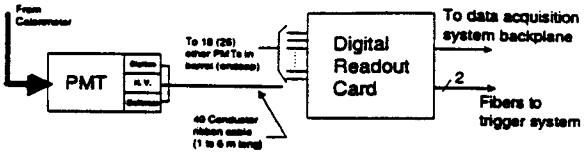
DIGITAL PMT READOUT

of CALORIMETER

DIGITAL PMT READOUT OF CALORIMETER

ARCHITECTURE

Provide 20-bit dynamic range with twelve 8-bit scales.
Digitize at beam crossing rate.
Provide trigger with full-resolution digitizations.

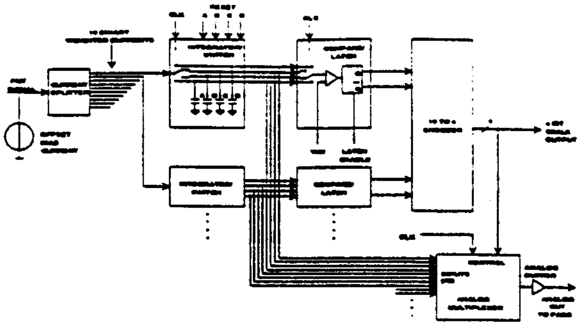


- PMT Base
  - flash digitization
  - "floating point" output (12 digital bits, 20-bit range)
  - Cockcroft-Walton voltage multiplier HV
- Digital Readout Card
  - calibration lookup table
  - level 1, 2 digital storage
  - output to trigger and data acquisition

DIGITAL PMT READOUT OF CALORIMETER

DYNAMIC RANGE

Large dynamic range is restricted to 1st element.



- Gated Integrator Digitizer ASIC
  - Current Splitter
    - splits PMT current into 12 binary ranges
  - Gated Integrator/Switch
    - integrates current from each range onto storage capacitor (in set of four)
  - Comparator/Latch & Encoder
    - select range of interest
  - Analog Multiplexer
    - switches capacitor of interest to FADC

Integrator, mux, and FADC are 8-bit dynamic range.

DIGITAL PMT READOUT OF CALORIMETER

STATUS

1) Digitizer ASIC
   - prototype BiCMOS circuit
     w/ splitter, gated integrator, analog mux, output buffer, and reset switches.
   - noise < 0.6 fc (6 MeV).
   - splitter accuracy < 0.7%.
   - linearity and temperature stability good.
   - future versions with complete set of integrators and range-select circuitry this summer.

2) Digital Pipelined Storage ASIC
   - prototype (2 μm CMOS) of "serial-in/random-out" tested w/ write at 56 MHz and read at 46 MHz.
   - future versions in 1.2 μm CMOS.

3) Floating-Point Adder ASIC
   - prototype (1.2 μm CMOS) synchronous pipelined adder at 100 MHz.
   - future versions with 8:1 adder tree.

4) System Tests
   - measurements of crosstalk at analog input from digital signals of 60 MHz FADC.
     less than 1/2 count in 20-bit range
     - discrete circuits to study:
       generation & response to 60 MHz digital signals.
       coherent noise in sums of PMT's.

READOUT for

SHOWER MAX DETECTOR

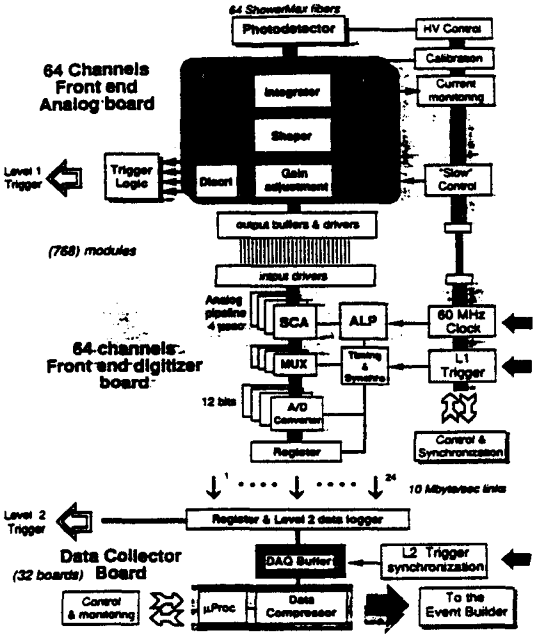
REQUIREMENTS

- Large channel count
  - 47,104 SMD channels (94,208 after upgrade)
  - 10,368 Massless Gap channels
- 12-bit dynamic range
- Least count of 1 p.e. (1/2 mip)
- Gain adjustment for photodetector gain variations
- Data to level 1 & level 2 triggers

ARCHITECTURE

- Photodetectors
  - Multichannel PMT's (MCPMT's) w/ 64 channels adopted as "baseline"
  - Additional R&D:
    - Avalanche photodiodes (APD's)
    - Hybrid APD-MCPMT's
    - Visible Light Photon Counters (VLPC's)
- Analog Signal Processors
  - Charge-sensitive preamplifier
  - Shaper
  - Gain adjustment (to match photodetectors)
  - Discriminator (with output to level 1 trigger)
- Front-end Digitizer Board
  - Analog signal storage (SCA)
  - 12-bit ADC
  - Details depend on how many bits per SMD channel are required for level 2 trigger,
    - *e.g.*: 1 bit available from Analog Signal Processor
      12 bits requires full digitization.
- Data Collection Board
  - Dependent upon requirements of level 2 trigger.
    - *e.g.*: 12 bits to L2 => buffer shared by L2 and DAQ.
      1 bit to L2 => same board as calorimeter towers.

BLOCK DIAGRAM



SUMMARY

SUMMARY

Trigger:

- Calorimeter plays a crucial role in the trigger, particularly at early trigger levels.
- Its data can be delivered and processed simply, but bandwidth is large.

Calorimeter Tower Readout:

- Challenge arises from:
  - Large dynamic range (2 x 10^5)
  - Simultaneous writing and reading of data
  - System and development costs.
- Two promising approaches are being pursued:
  - Readout with analog memories
    - proof-of-principle nearly complete.
  - Digital PMT readout
    - promising, potentially more robust.

Shower Maximum Readout:

- Large channel count system.
- Bandwidth requirements less (4 x 10^3)
- Challenges arise from:
  - Photodetector development
  - Potentially would like full resolution to L2.

PARALLEL SESSION D:

MUON SYSTEM

REQUIREMENTS AND DESIGN SUMMARY

G. FELDMAN

SDC Muon System

Requirements and Design Summary

(Design Choices)

G. Feldman
SSC PAC Meeting
May 5, 1992

Welcome to the Muon System Parallel Sessions

Before we begin, I want to point out that quantitatively, if not qualitatively, the muon system is most of the SDC.

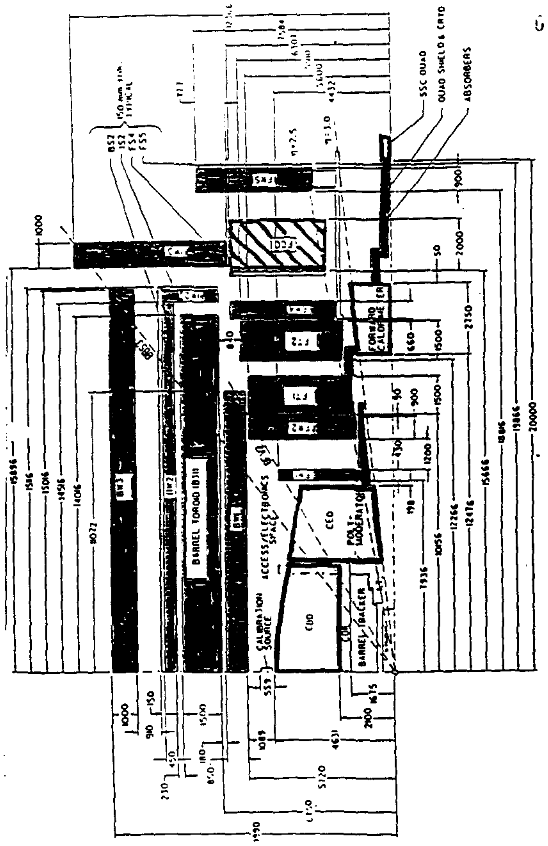
- It is 90% of the volume.
- And 80% of the weight.
- But only 20% of the cost.

Design Choices

The main purpose of this talk is to explain why we made the various design choices. This issues to be discussed are

- Toroid thickness
- Number of layers
- ϕ layer placement
- Chamber separation

I will first briefly review the components and functions of the muon system from yesterday's overview.



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Components

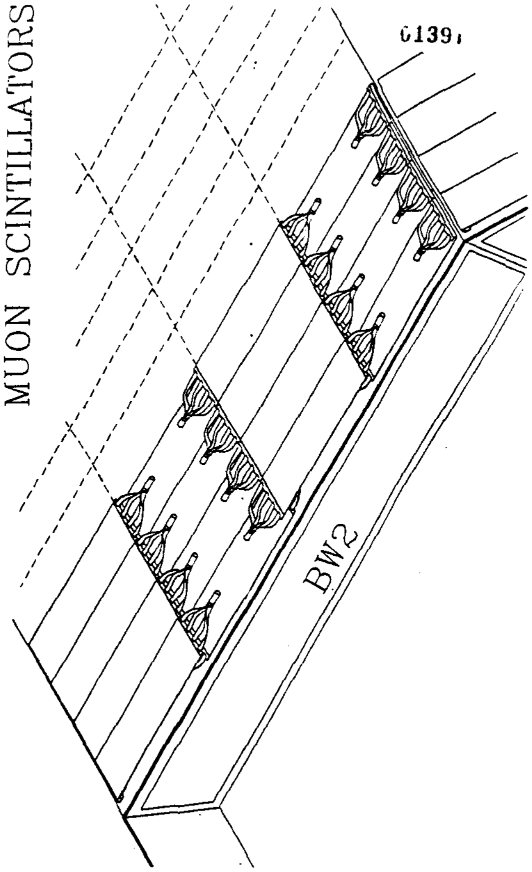
Toroids
- Central: 1.5 m thick magnetized iron.
- Forward: 3.0 m thick magnetized iron.

Scintillators
- Central: 1 layer, each counter viewed by 2 photomultipliers
- Forward: 2 layers, each counter viewed by 1 photomultiplier

Chambers
- Round field-shaped tubes expoxied to thin sheets to make a rigid structure.
- Central: 9.0 cm inner diameter, 22 layers.
- Forward: 4.2 and 5.7 cm inner diameter, 24 layers.

01391

SDC BARREL
MUON SCINTILLATORS



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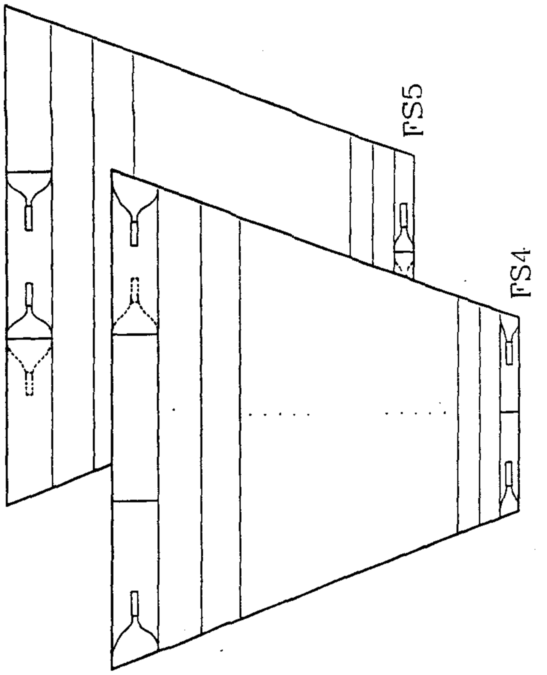
SDC FORWARD MUON SCINTILLATORS



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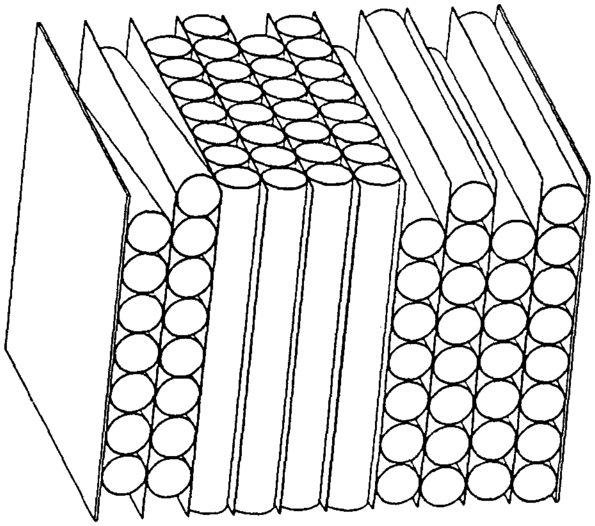
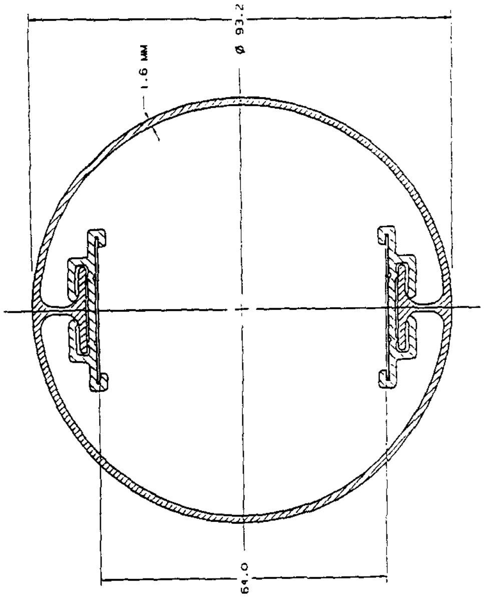
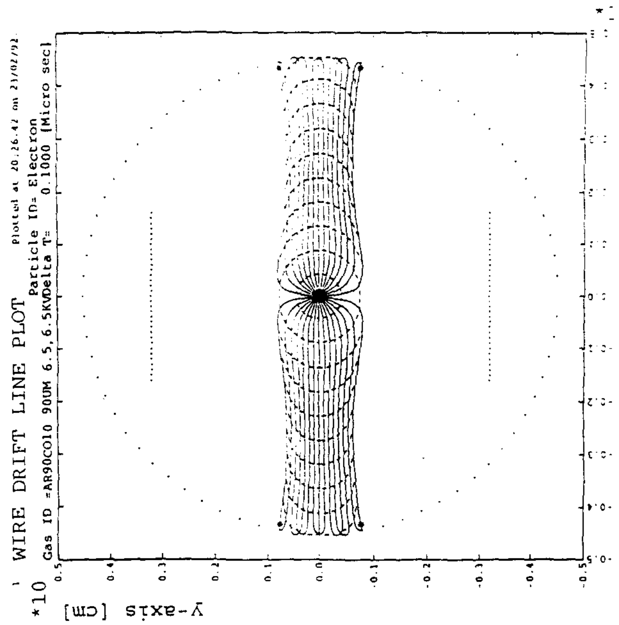






Functions of the Muon System

- To trigger the detector on a muon over a threshold. p_t.
- To identify a charged track as a muon.
- To improve the precision of the momentum measurement by the central tracker.

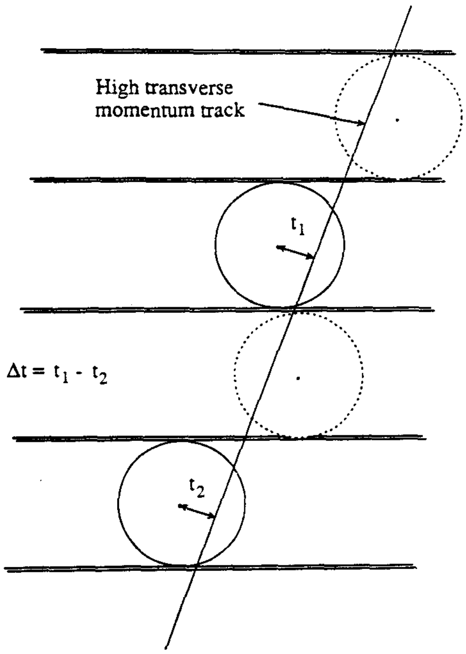
Trigger

The basic first level trigger is generated by measuring the local bend in θ of a muon candidate outside the toroid. This is done by measuring the time difference in signals from projective wires.

Since a low momentum track can fake a high momentum track by passing on opposite sides of a wire, a coincidence of two measurements is required.

With a 20 GeV/c p_t threshold, the first level trigger rate is estimated at about 6 kHz, a number which is somewhat marginal. There is flexibility to enhance the first level trigger if necessary:

- Require a stiff θ stub in BW1. (Reduces triggers from large scatters in the calorimeter.)
- Require a stiff ϕ stub in BW1 or BW3. (Reduces the cosmic ray trigger from ~1kHz to a negligible level.)
- Require isolation in the calorimeter. (Most triggers are from heavy quark decay.)



The second level trigger must refine the p_t measurement to sharpen the threshold. In the central region the primary method is to match a track from the inner tracker to a ϕ measurement in BW1 or BW3 (or IW3).

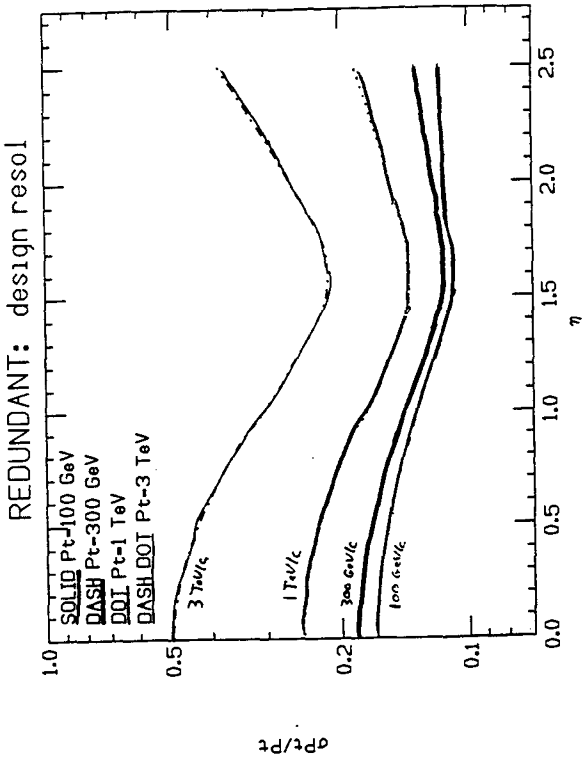
In the forward region, the primary method is a line-line measurement in θ with FW1-FW2 and FW4-FW5.

Muon Identification

The key question for the muon system is whether a track found by the inner tracker is a muon.

A match must be made in θ, ϕ, and momentum. Studies of high-p_t b jets show that both the θ and ϕ matches are required to avoid confusion at the 20 to 30% level.

The match in momentum is necessary to distinguish true muons from the decay products of hadronic showers. This is done by the toroidal measurement.



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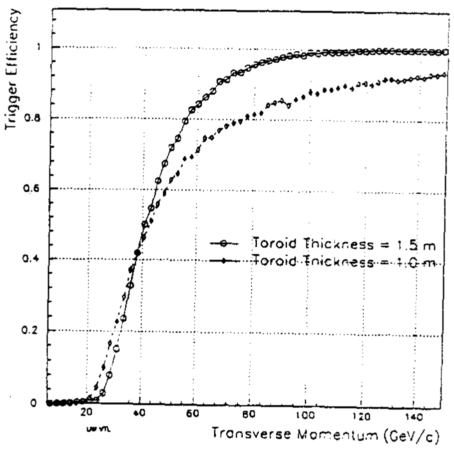

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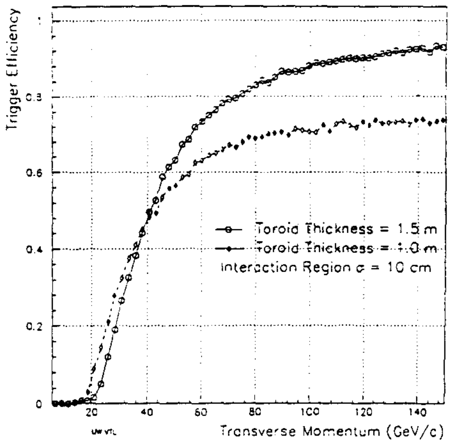


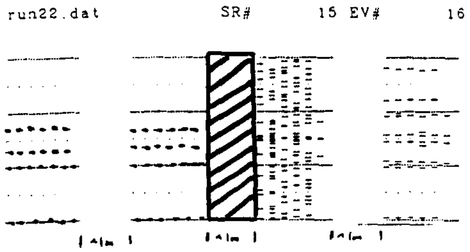
Number of Layers:

We have designed the system with the absolute minimum number of layers for a robust system.

It must be remembered that 20 to 30% of the time, high energy muons exiting material are accompanied by electromagnetic debris. This debris tends to be at wide angles to the muon, and should not be a major problem for chambers with good two-track separation. However, some of the time, a measurement will be corrupted by the wrong particle creating the signal. Thus, our design does not depend on a single superlayer for a critical measurement.

Each superlayer contains 4 layers: 2 pairs of half-cell offset projective wires. The projective wires are needed for the level 1 and 2 triggers and the half-cell offset is needed for efficiency.

T816 Test Beam



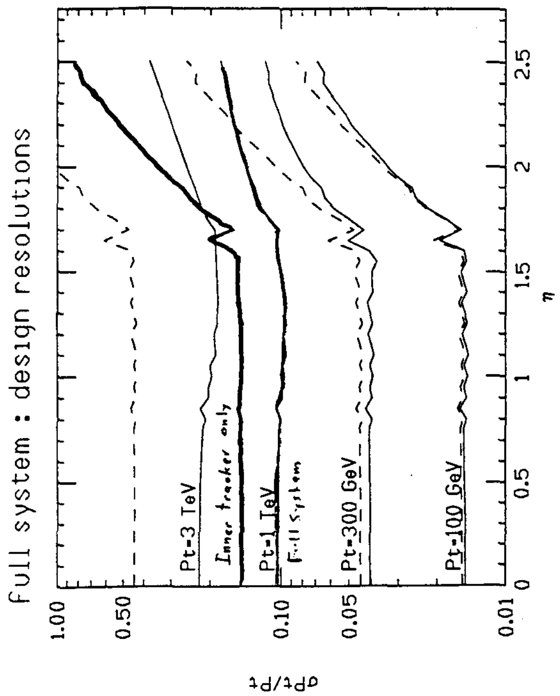
Momentum Measurement

The primary momentum determination comes from the solenoidal measurement with the inner tracker. However, since the effect of the solenoidal field extends out until it is returned in the calorimeter, at very high-p_t, the momentum measurement in the central region is improved by ϕ measurements in the muon system.

The forward toroids contribute to the overall momentum resolution at high η, and become the primary momentum measurement for $p_t > 300$ GeV/c and $|\eta| > 2.2$.

For $p_t = 1$ TeV/c, $\Delta p_t/p_t =$

$\eta = 0$	0.11
$\eta = 2.5$	0.18



Toroid Thickness:

Central Toroid:

The thickness of the central toroid is 1.5 m. We considered 1.0 m for some time and rejected it as too risky.

Having a thinner toroid would clearly reduce the resolution of the toroidal momentum measurement. However, the more important issue was the first level trigger rate. The rate is dominated by low-p_t muons which scatter to appear to be higher-p_t muons. Lowering the thickness from 1.5 m to 1.0 m would change the bend to scatter ratio from 3.9 to 2.8, sharply increasing an already marginal rate (~6 kHz).

Further, we would become quite sensitive to any increase in the longitudinal bunch length.

The forward toroids have a total thickness of 3 m. The issue here is momentum resolution. For $p_t > 300$ GeV/c and $|\eta| > 2.2$, most of the momentum resolution comes from the toroidal measurement. Having 3 m of iron allows a multiple scattering limited resolution of 11%, only about a factor of two worse than in the central region.

Contributions to the time difference of the first level trigger:

η	θ (deg)	Bend	Scattering	IP	Chamber Res.
0.0	90	$810/p_t$	$210/p_t$	5.9	1.8
1.0	45	$810/p_t$	$160/p_t$	2.5	1.2
2.0	15	$450/p_t$	$70/p_t$	0.9	1.7

"Bend" varies as the thickness,
"Scattering" varies as the square root of the thickness, and
"IP" and "Chamber Res." are independent of the thickness.

Central Region ϕ Layers:

There are two superlayers, one before the toroid and one after. These layers are critical for the second level trigger, track matching to the inner tracker, and high-precision momentum measurements of high-p_t muons.

The superlayer before the toroid has less error from multiple scattering; the superlayer after the toroid has a less hostile environment.

Central Region Stereo Layers:

Two single layers are a clear minimum.

Forward Region Chambers:

The same arguments generally apply. There are two main differences:

(a) There is a better and more independent momentum measurement. There is one additional θ superlayer, FW1, to provide a line-line measurement.

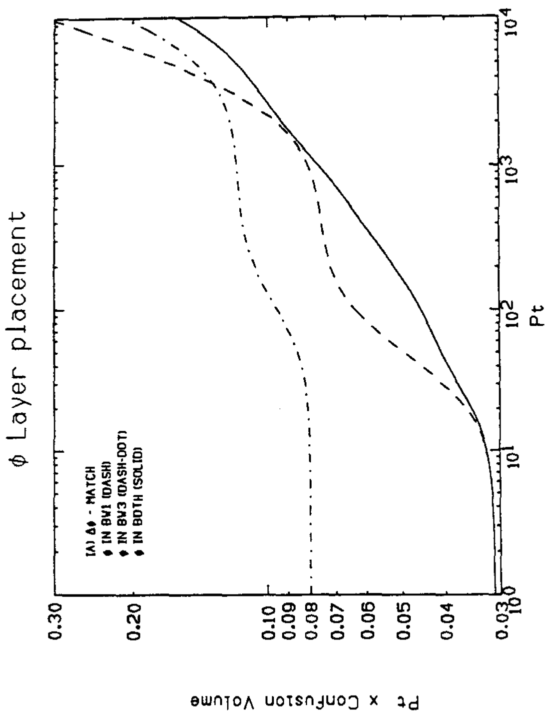
(b) Small angle stereo is used instead of ϕ. (ϕ measurements are difficult in the forward direction and link moderate and high η.)

ϕ Chamber Placement:

One of the ϕ superlayers is placed before the toroid. This is strongly preferred for track-matching, because of the lower multiple scattering error.

BW2-BW3 and FW4-FW5 Separation:

These values were set near knees in the respective resolution curves.



Tubes are positioned to measure θ, φ, and stereo in the central regions, and to measure θ and two stereo directions in the forward regions:

Central Chambers

Label	Coor-dinate	Number of Layers	Channels
BW1	θ φ	4 4	10674
BW2 IW2	θ	4	9136
BW3 IW3	θ φ s	4 4 2	37814
Total		22	57624

Forward Chambers

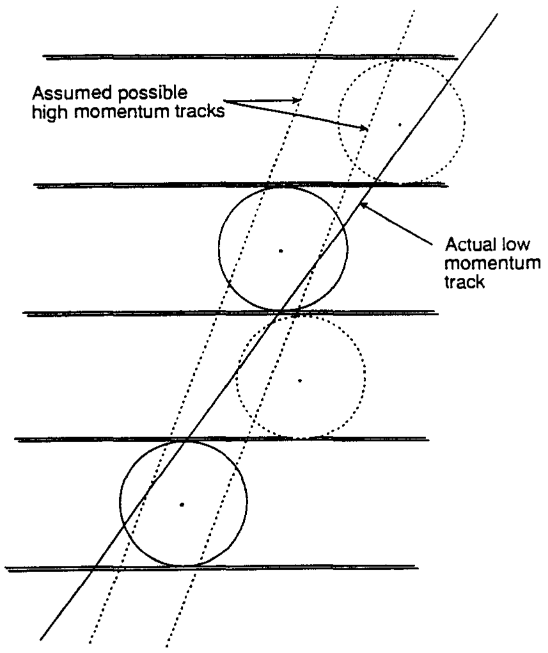
Label	Coor-dinate	Number of Layers	Channels
FW1	θ	4	4390
FW2	θ s_1 θ s_2	2 2 2 2	11904
FW4	θ	4	4310
FW5	θ s_1 θ s_2	2 2 2 2	11636
Total		24	32240

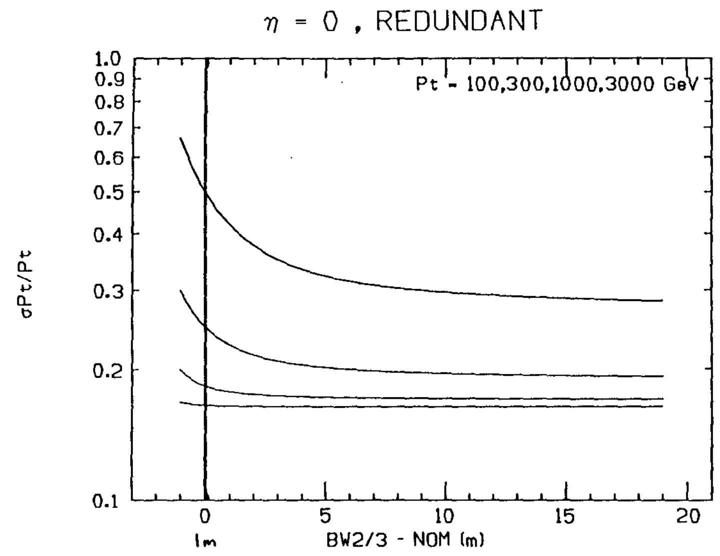
In addition, room is being left between the two forward toroids for an additional 4 layers of θ tubes. This upgrade, which is not part of the baseline design, would allow a determination of whether there had been a large-angle muon scatter in one of the toroids, and allow for a correct point-line measurement in the other.

Central Region θ Layers:

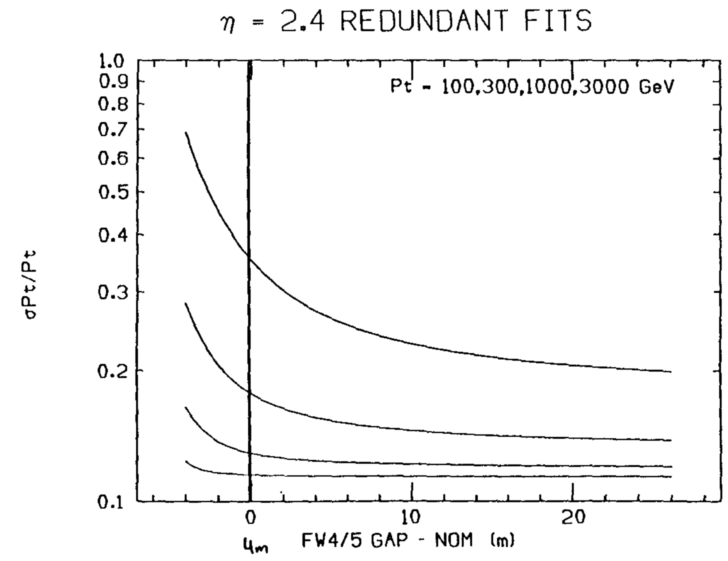
There are two superlayers after the toroid and one before. The two after the toroid are used for the first level trigger. Both are needed for high efficiency since a coincidence of two pairs of projective wires are needed to suppress low-p_t fakes.

The superlayer before the toroid is used for the toroidal momentum measurement, may be used in an augmented first or second level trigger, and is useful for track-matching. It has no redundancy, but its functions are not as critical as others. For example, the input vector for the toroidal momentum measurement can be taken from the inner tracker, with a larger error due to multiple scattering in the calorimeter.





η = 0 , REDUNDANT



η = 2.4 REDUNDANT FITS

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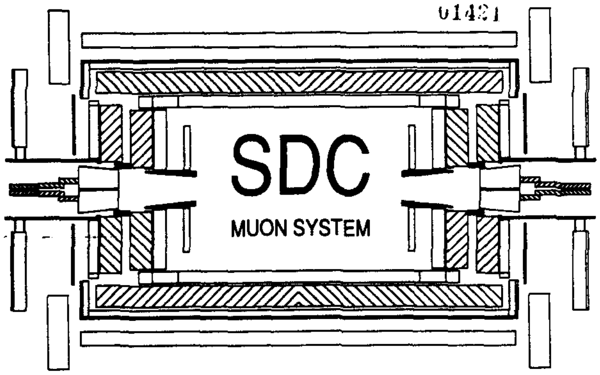
MAGNET SUMMARY

J. BENSINGER



Muon Toroid Magnet
PAC Review

Jim Bensinger
May 5, 1992

History

- 3 Designs
  - Thin Plate Design
  - Large Plate Design
  - ✓ Large Block Design
- Reviews
  - SSC Laboratory - Martin Marietta Astronautics
  - Collaboration - Review Panel
- Contacts with Russian Steel Mills
  - 2 Trip to Izhora Steel Mill
  - Two Trips by Izhora Engineers to the SSC
- Conceptual Designs
  - Barrel Toroid
  - Support Structure
  - Safety Analysis - CSAR

Magnet Specifications

1) 1.8 Tesla field measured at $\Phi = 0°$ and $\Theta = 90°$.

$$\int_{\text{Inner Face}}^{\text{Outer Face}} \vec{B} \times \vec{dl} = [1.8\,\mathrm{T}] \times [1.5\,\mathrm{m}]$$

2) Dimensions.

Parameter	Value	Unit
SI	13,500	mm
SO	16,500	mm
T	1,500	mm
L	28,032	mm
M	16,406,674	Kgm
W	18,134	Ton (short)

3) Magnet envelope.

Centered on the nominal IP
Axis is along the nominal beam line
Inner IP-to-flat (SI/2) - 15 mm
Outer IP-to-flat (SO/2) + 15 mm
Length IP-to-end (L/2) + 15 mm

4) The axis of the toroid will be along the beam line.

5) Any ray from the Interaction Point through the steel must experience 98% of the nominal steel dimension along that path. No gap may be greater than 3 mm.

6) Any laminates of the steel must be parallel to the flux lines.

Magnet Specifications (cont.)

7) Toroid motion: The toroid should be within 3 mm of its nominal position everywhere. Adjustments on the base of the toroid will accommodate floor motion or removal and reinstallation of the intermediate toroids and the central calorimeter. Periodic adjustment of the base structure of the toroid to bring it within 3 mm of nominal will be made.

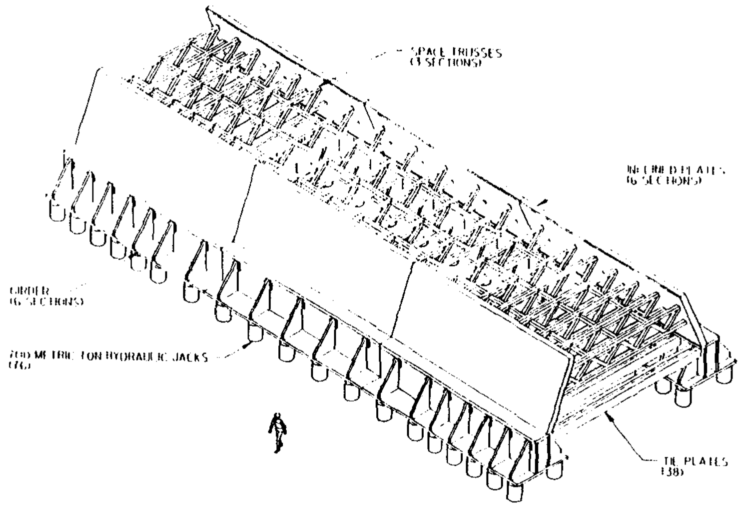
8) Movement of the magnet when the field is turned on will be less that 1.5 mm for any point on the magnet.

9) Pre-assembly of every vertical section will be done at the manufacturing site. Bolting, not welding, will be the preferred assembly method in the hall for major pieces of the toroid.

10) The field will be calculated by measuring the permeability of individual pieces as manufactured and then the final field will be calculated from this data. Verification will be done by having nonmagnetic plates with probe holes in the toroid, transverse to the field lines.

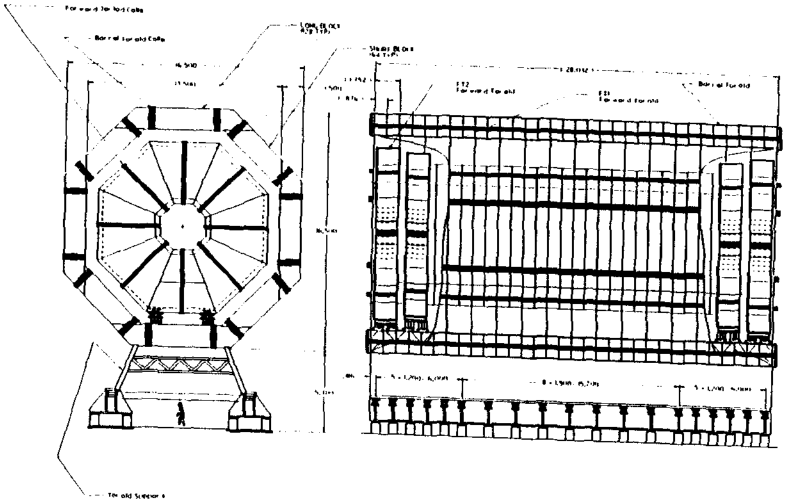
11) It is not intended that the muon toroid will have to be disassembled in the hall and no specific provisions will be made for that eventuality.

12) The toroid will behave as a single mechanical unit under the influence of floor motion or other perturbations. There will be no discontinuous motion of separate parts of the toroid.



SDC Support Installation

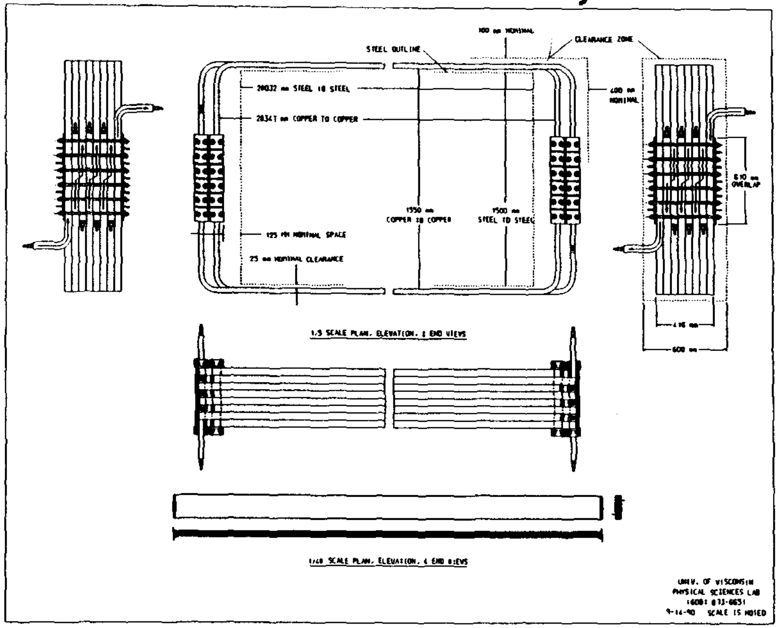
U1427



SDC MUON MAGNET ASSEMBLY

U1423

Muon Barrel Toroid Coil Layout



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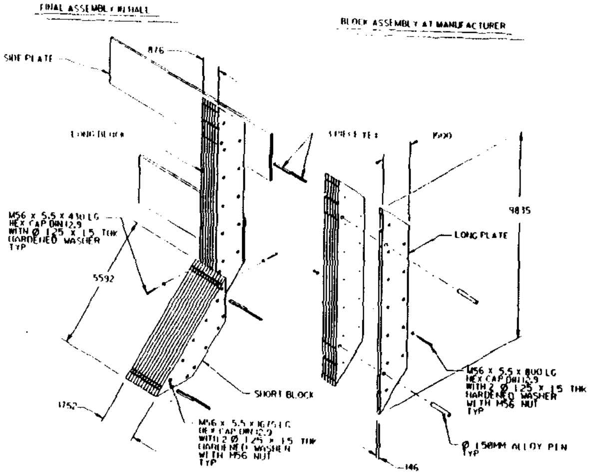

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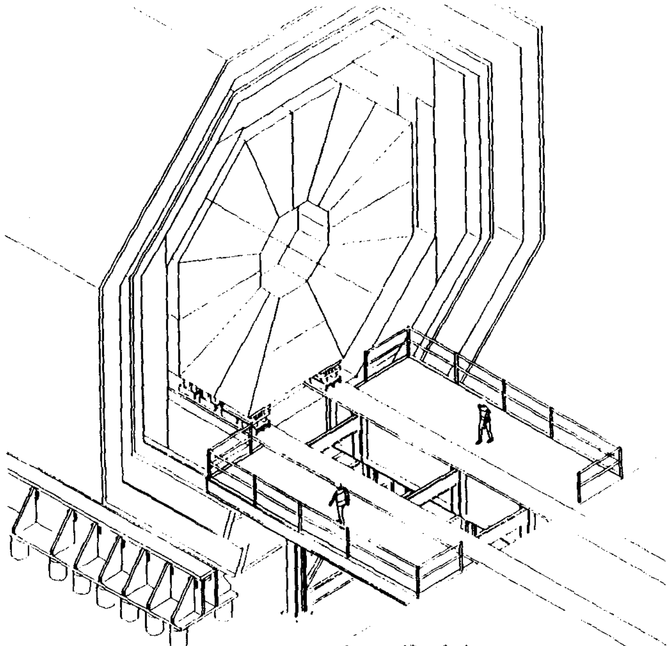

Transfer Bridge

01431

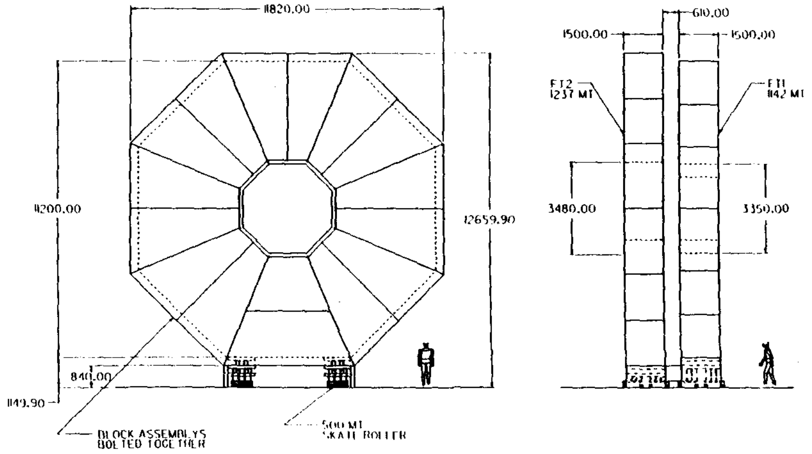

FIG. 7-58 Forward toroid assembly.

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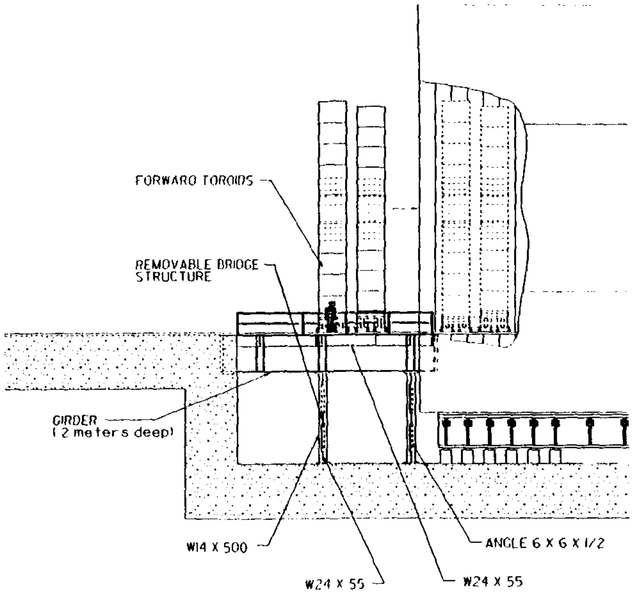

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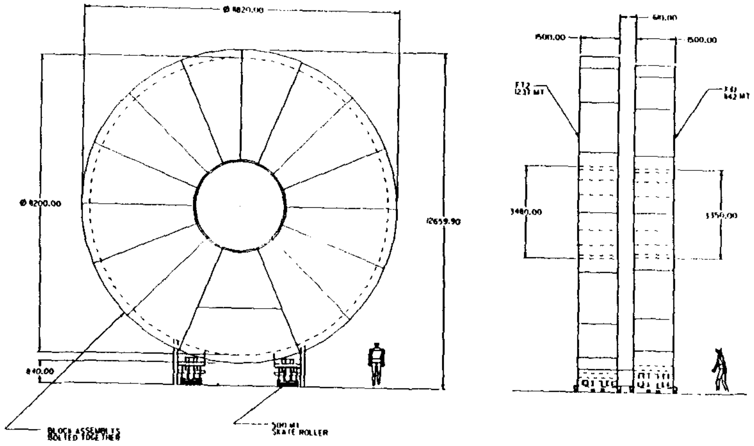


Forward Toroid Design Concept

01430

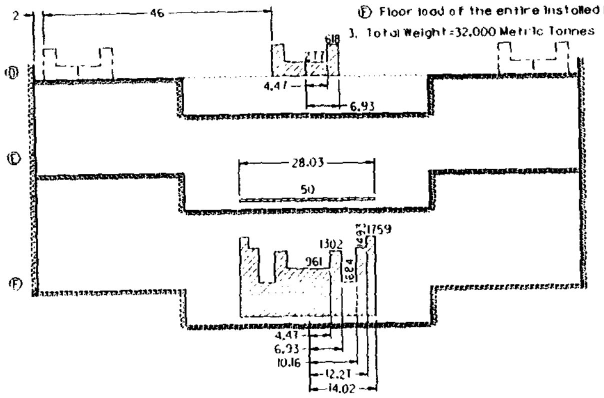
2. (CONT.)

(D) Moving Calorimeter, tracker. Superconducting solenoid, and part of the absorber.

(E) Support and Jack weight.

(F) Floor load of the entire installed Detector.

3. Total Weight=32,000 Metric Tonnes



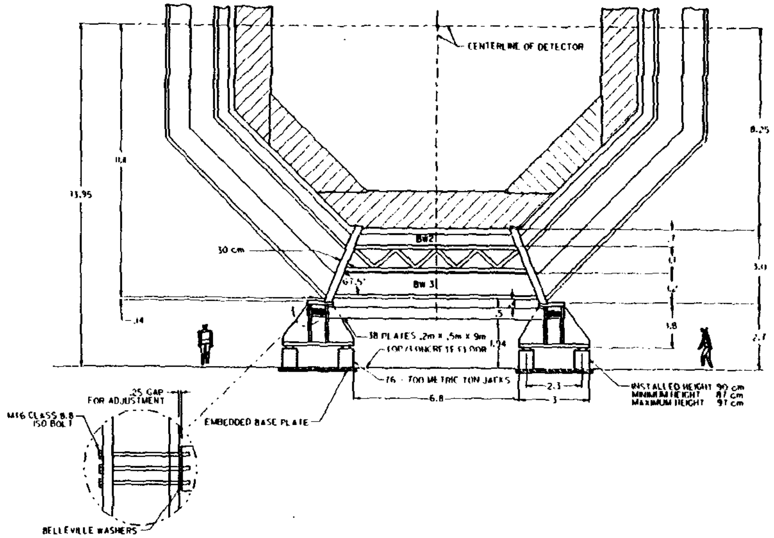
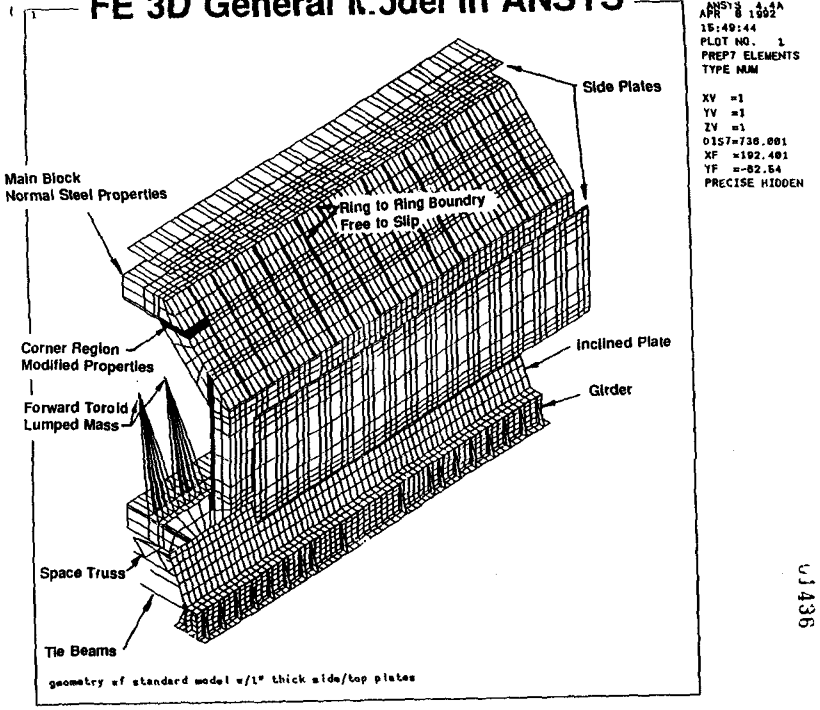


FIG. 7-57 Barrel toroid support assembly.

FE 3D General Model in ANSYS



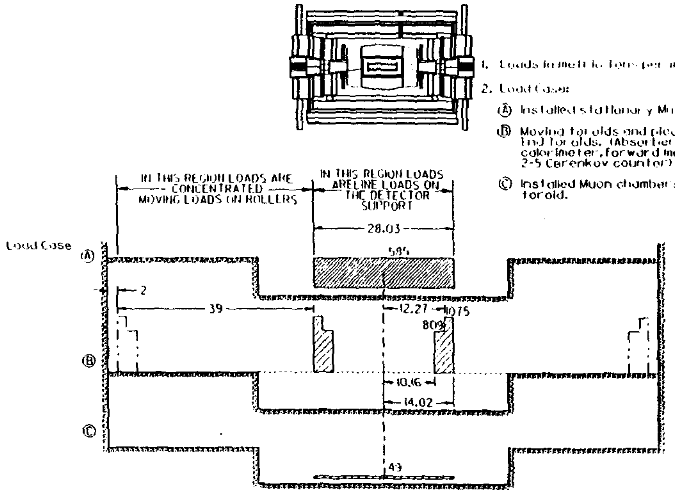
1. Loads in metric tons per meter.

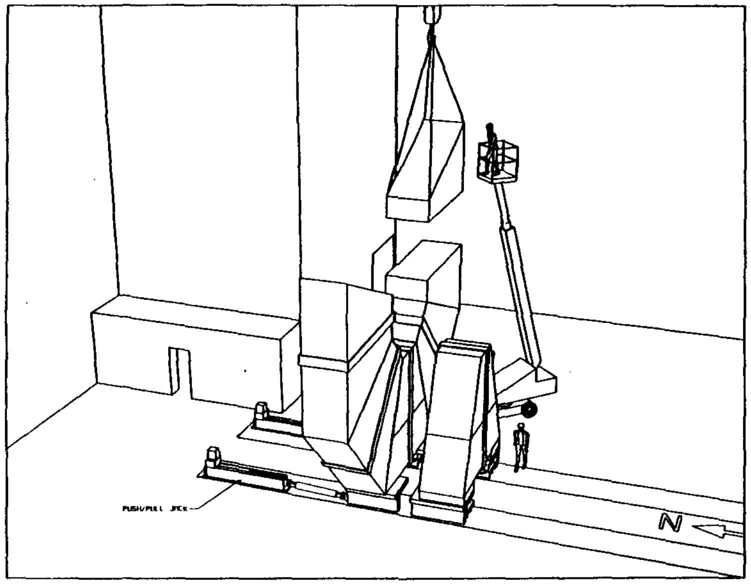
2. Load Case:

(A) Installed stationary Muon Barrel toroid.

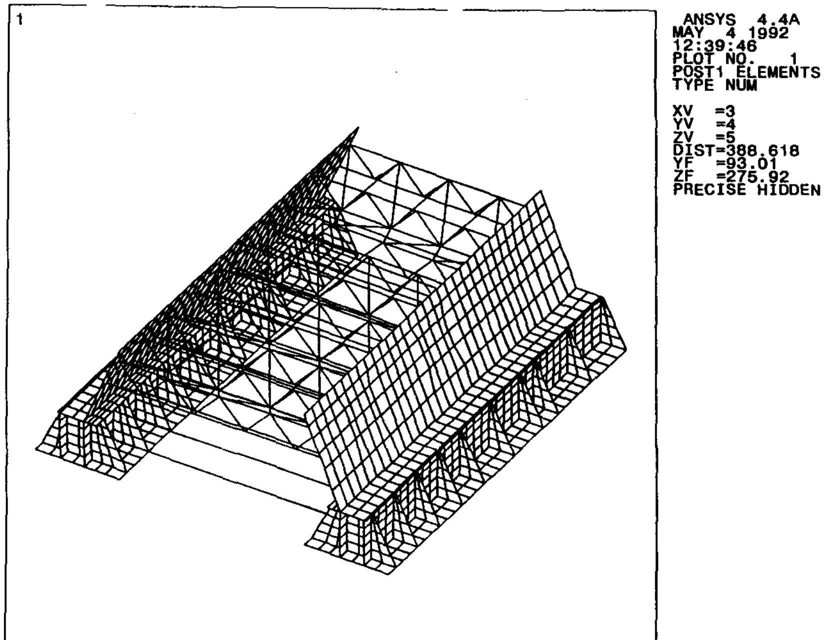
(B) Moving toroids and pieces attached to End toroids. (Absorber, foward colorimeter, forward muon chambers 2-5 Cerenkov counter)

(C) Installed Muon chambers on the barrel toroid.

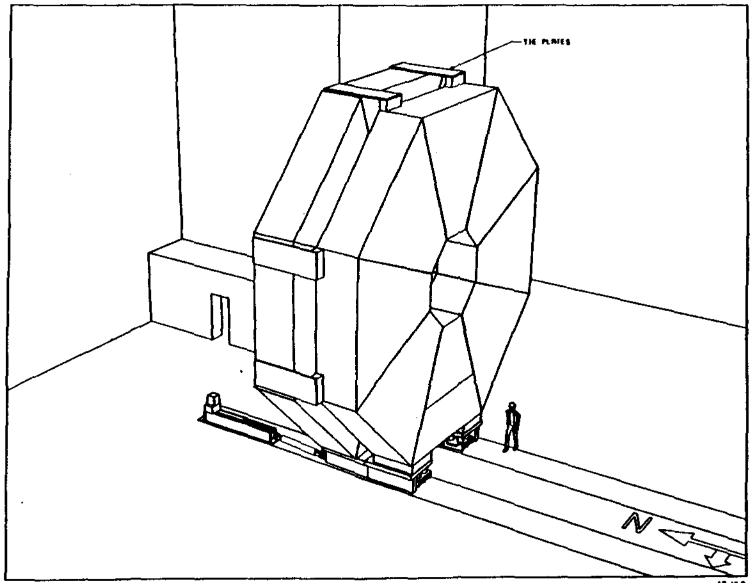




SDC DETECTOR - FORWARD TOROID CONSTRUCTION
FIGURE 2



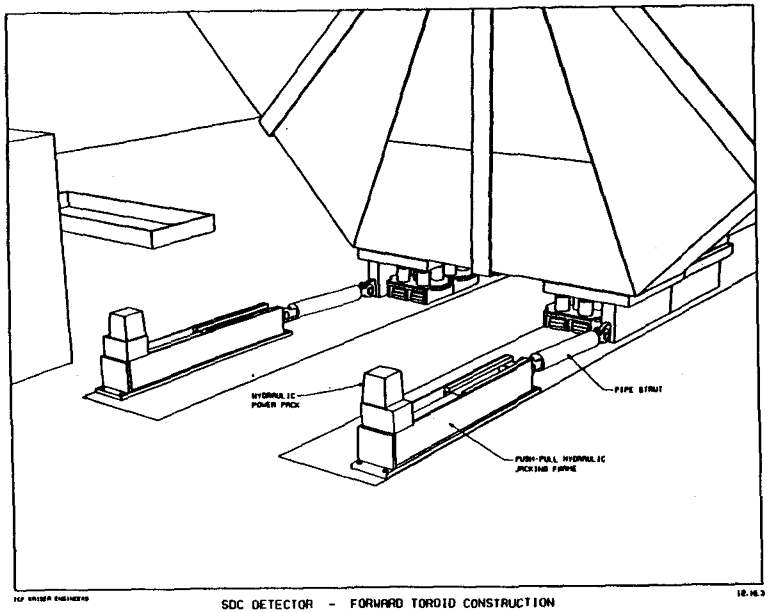
SDC Detector Muon Toroid Support Platform (TDR Geometry)



SDC DETECTOR - FORWARD TOROID CONSTRUCTION
FIGURE 3

Muon Barrel Toroid
Load Cases Under Study

1. MBT gravity Load
2. Calorimeter Load (before and after adjustment)
3. Forward System Load (before and after adjustment)
4. 6% Load at C.G. in X and Z
5. 800 tonne Load in Z for Calorimeter Installation
6. Magnetic Field
7. Failure of a Hydraulic Circuit
8. Tolerance in XY Plane
9. Tolerance in YZ Plane
10. Dynamic During Assembly



SDC DETECTOR - FORWARD TOROID CONSTRUCTION
FIGURE 4

MUON MAGNET JACKING

Estimated Costs

HYDRAULIC JACKS:

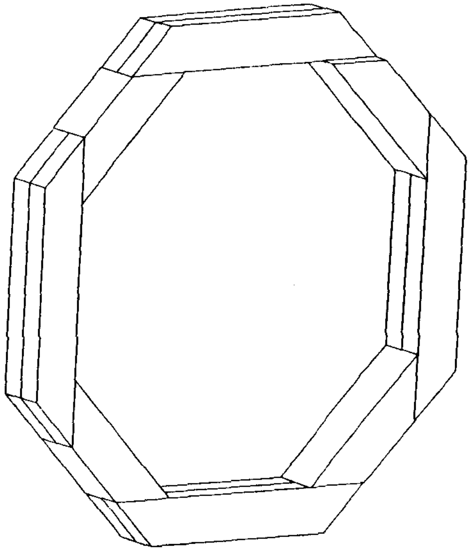
COMPANY	REP.	CAPACITY (m. tonnes)	STROKE (in.)	HYDR. PRESS. (psi)	PRICE $ / jack
Templeton, Kenly & Co.	Norm Martinson	700	6	5,000.00	25,000.00
REXROTH/Womack Machine Supply	Parveen Gupta Glen Chambers	700	6	5,000.00	40,000.00 (Preliminary, to be re-eval.)

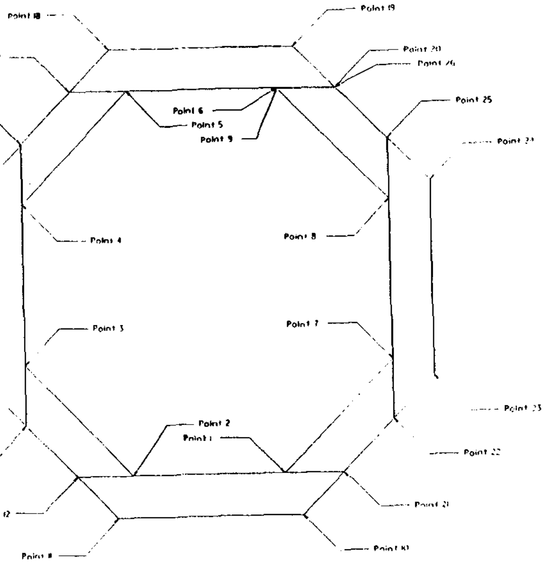
MECHANICAL JACKS:

COMPANY		REP.	CAPACITY (m. tonnes)	STROKE (in.)	POWER SOURCE	PRICE $ / jack
AIR - LOC Products	(Wedge Jacks)	Benny J. Sgaggero	< 500	< 2	Electric/Hydr.	NO BID
Joyce/Nicholson	(Wedge Jacks)	James A. Whitehouse	1000	2	Hydraulic	59,728+Contr.
UNISORB Mach.Inst.S.	(Wedge Jacks)	Wayne H. Whittaker	900	1	Hydraulic	60,000+Contr.

Vadim Kopytoff, PhD
4/30/92

Gap exagerated for clarity





Case with the largest difference
[illegible] mm

	Coodinates of points (mm)		nominal		diff	
1	0.00	0.00	0.00	0.00	0.00	0.00
2	-5592.40	0.00	-5591.88	0.00	-0.52	0.00
3	-9547.57	3953.68	-9545.94	3954.06	-1.63	-0.38
4	-9549.15	9546.08	-9545.94	9545.94	-3.21	0.14
5	-5597.30	13501.66	-5591.88	13500.00	5.42	1.66
6	-5.90	[illegible]	0.00	13500.00	5.90	4.82
7	3955.17	3953.68	3954.06	3954.06	1.11	-0.38
8	3956.75	9545.08	3954.16	9545.94	2.59	-0.86
9	4.90	13500.66	0.00	13500.00	4.90	0.66
10	621.32	-1500.00	621.32	-1500.00	0.00	0.00
11	-6213.72	[illegible]	-6213.20	[illegible]	-0.52	0.00
12	-7713.72	-0.20	-7713.20	0.00	0.52	-0.20
13	-9547.17	1832.36	-9545.94	1832.74	-1.23	-0.38
14	-11047.39	3331.93	-11045.94	3332.74	-1.45	-0.80
15	-11049.33	10866.97	-11045.94	10867.26	-3.38	-0.29
16	-9549.95	11667.40	-9545.94	11667.26	-4.01	0.14
17	-7718.62	13500.26	-7713.20	13500.00	-5.42	0.26
18	-6219.47	15001.31	-6213.20	15000.00	-6.26	[illegible]
19	[illegible]	15005.17	621.32	15000.00	-6.75	5.17
20	[illegible]	13505.82	2121.32	13500.00	-5.90	5.82
21	2121.32	-0.20	2121.32	0.00	0.00	-0.20
22	3954.77	1832.36	3954.06	1832.74	0.71	-0.38
23	[illegible]	3331.93	5454.06	3332.74	0.94	-0.80
24	[illegible]	[illegible]	5454.06	[illegible]	3.87	-1.29
25	3957.55	11666.40	3954.06	[illegible]	3.49	-1.86
26	[illegible]	13499.66	2121.32	13500.00	4.90	-0.34

Bolt Tensioning Techniques

Superbolt
- Advantages
  - Easy to install
- Disadvantages
  - expensive

Supernut
- Advantages
  - Easy to install
  - Uses stud instead of bolt
- Disadvantages
  - expensive (may be less expensive than Subperbolt)

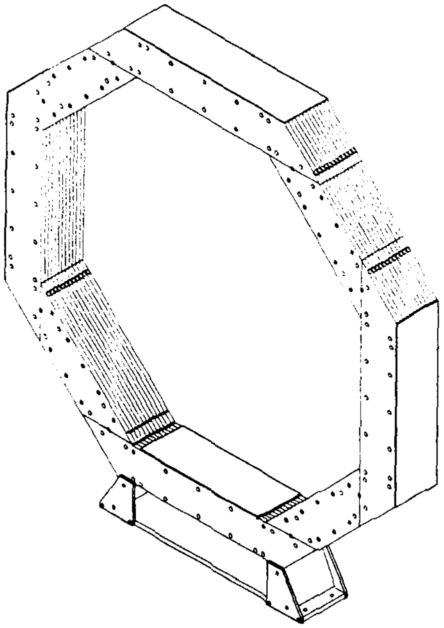
Hydraulic Wrench
- Advantages
  - No need for special nuts or bolts
- Disadvantages
  - Probably too heavy for one person to handle

Torque Multiplier
- Advantages
  - No need for special nuts or bolts
- Disadvantages
  - Probably too heavy for one person to handle
  - Need power source

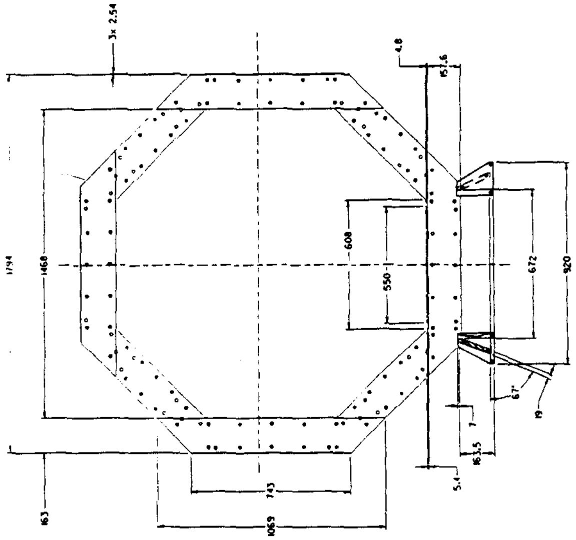
Stud Tensioner
- Advantages
  - More direct reading of stud tension
  - Can use more than one at a time
  - Less work wasted on friction
- Disadvantages
  - Loss of tension when tensioner removed unknown

Interfaces

- Support / Floor
- Magnet / Chamber
- Coils
- Muon Utilities
- Calorimeter Tracks
- Forward Toroid Tracks
- Bridge
- Alignment System
- Cryo Stack
- Internal Utility Support Lattice
- Personnel Access
- Ventilation
- Cable way
- Safety Systems
- Scaffold (for Toroid Erection)



MBT TEST MODEL RING ASSEMBLY AND SUPPORT



MBT TEST MODEL RING ASSEMBLY AND SUPPORT

1.0 Purpose of Test Model

The purpose of the test model for the muon barrel toroid is to discover any problem associated with the design, fabrication, and assembly of the scale model. Through the fabrication, assembly and testing of the scale model, we may have enough test date to verify the FE analysis results of the model and better understand the full toroid through the behavior of the scale model. The experience from the scale model should bring about some design improvements and the awareness of the potential problems on fabrication and assembly for the full toroid that require workable solutions prior to completing the the final design.

In addition, a magnetic test on the scale model will be performed to measure the magnetic flux distribution in the magnet steel. The magnetic properties of the steel may be better understood from the test results and the computer model for the magnetic field analysis may be verified.

The anticipated questions for the scale model as well as the full toroid are summarized below.

1. The out-of-plane bending during the installation of the vertical ring may impose additional load to the toroid. If the vertical ring needs to be adjusted to eliminate this out-of-plane deflection, can the corner joint be strong enough to withstand the bending? What will the upper limit of this bending for the current design to withstand?

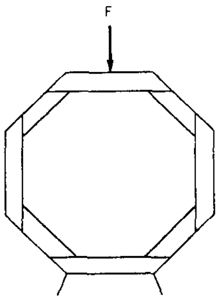
2. The fabrication of the long and short plates may not be as flat as we like them to be. If these thin plates are bolted together to form long and short blocks, can the middle plates be flattened during the assembly of blocks? Is there an optimal thickness for fabricating the plate in terms of flatness?

3. Can the straight pins, taper pins or square keys on the long and short blocks be installed as designed without much technical difficulties? Is there an optimal method to fit the pins and keys to the blocks?

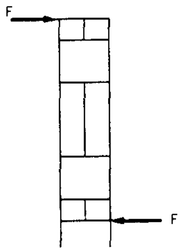
4. Under different failure modes, which will be the limiting on the structural integrity for the blocks? for the ring? for the bolts? What is the maximum deflection for the ring in all directions?

5. What effect will the impact load between blocks have on the bolts during assembly of the ring ?

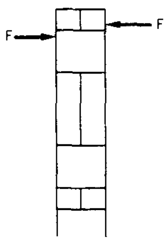
6. What effect do different materials have on the magnetic field distribution in the toroid? How much impact can be predicted on the magnetic flux distribution in the toroid due to bolts, pins, notches or air gaps.



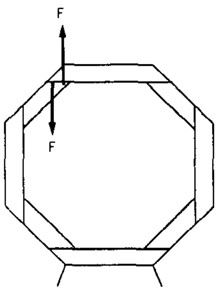
Case 1 - Vertical Loading for X-Y Plane Deflection



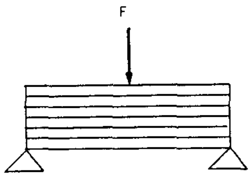
Case 2 - Longitudinal Loading for Y-Z Plane Deflection



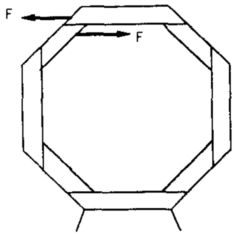
Case 3 - Longitudinal Loading for Y-Z Plane Deflection



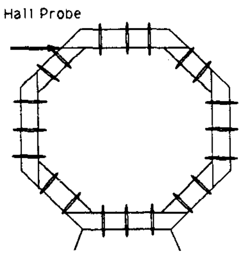
Case 4 - Vertical Loading for Corner Misalignment



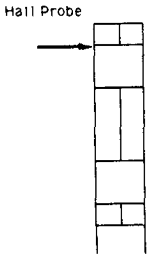
Case 5 - Vertical Loading for Laminated Plate Stiffness



Case 6 - Horizontal Loading for Corner Misalignment



Case 7 - Magnetic Test for X-Y Magnetic Flux Distribution



Case 8 - Magnetic Test for Y-Z Magnetic Flux Distribution

STRAINSERT

Standard Internally Gaged 12-POINT CAP SCREWS†

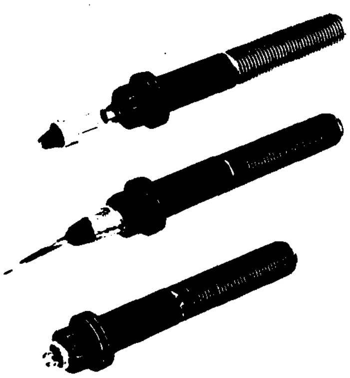
(STEEL ALLOY) (SDH SERIES)

To Measure
accurate preload,
service load and overload
of bolted assemblies

For Maximum
uniformity, efficiency
and reliability
in bolted assemblies

For Effective
research, testing
and manufacture
of bolted assemblies

† Ferry Cap
Counter-Bor Screws
interchangeable
with 1960
Series Socket
Head Cap Screw



01453

BULLETIN #363-C

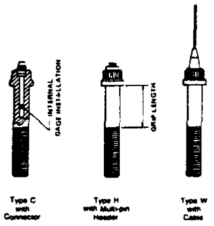
Strainsert fasteners utilize an exclusive internal gaging method* to indicate bolt tension due to preload and subsequent service loads with strain gage accuracy. They are the first fasteners to provide a means for accurate, independent inspection of an assembled bolt for preload, thereby enhancing the structural integrity and reliability of both the bolt and the assembly.

The gaging process consists of the installation of foil type strain gages bonded in a small hole drilled along the longitudinal neutral axis of the bolt. This method compares favorably in accuracy and stability with the best external gage installations, but it is vastly superior to external installations in mechanical and environmental ruggedness and miniaturization since the internal strain gage installation is self-protecting.

Neither the gage nor the drilled hole reduce the allowable bolt load in a Strainsert fastener. The gage installation will withstand and accurately indicate the full allowable load of the highest strength bolts available. Hole depth is confined to the grip length of the bolt, and the hole diameter is controlled so that the bolt cross-section through the threads is smaller than the section through the shank with the gage hole.

Standard 12-point cap screws are available in three types, based on provisions for lead wires:

LEAD WIRE TERMINATIONS



Type C: with screw type miniature connector, requiring mating cable assembly

Type H: with multi-pin header, for soldered lead wire connections

Type W: same as Type H, with 10-ft. factory-installed cable.

Over 130 different Strainsert 12-Point Cap Screws are stocked, ready for gaging. Delivery is two weeks or less, f.o.b. West Conshohocken, Pennsylvania. For specific sizes available, ask for the Price and Stock List on Internally Gaged 12-Point Cap Screws. For a more complete description of internal gage installations in bolts and studs ask for Strainsert Bulletin #361-7.

*U.S. Patent #2,873,341

01454

6.2 Schedule & Milestones

• Scoping Document approved	5/11/92
• Material Procurement Start	5/11/92
• One long Block Complete	5/26/92
• One Short Block Complete	6/1/92
• Ring Support Complete	6/15/92
• All Blocks Complete	6/22/92
• Assembly Frame Complete	6/29/92
• Ring Assembly Complete	7/13/92
• Model Test Complete	8/10/92

01455

CWT

SSC Laboratory

Physics Research

PACK NO. 1

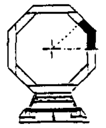
SDC MUON BARREL TOROID

- DESIGN SCHEDULE
- DESIGN MILESTONES
- DESIGN TASK STATUS

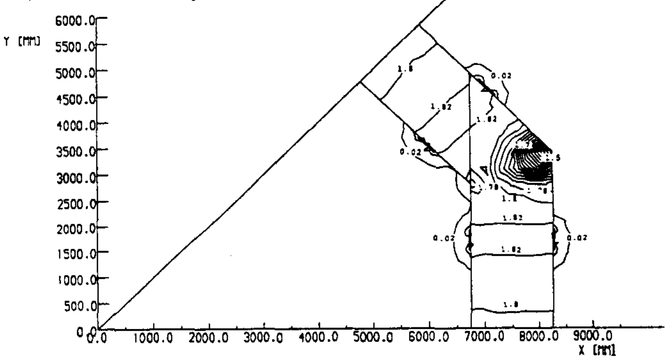
5/4/92

TVG

01456



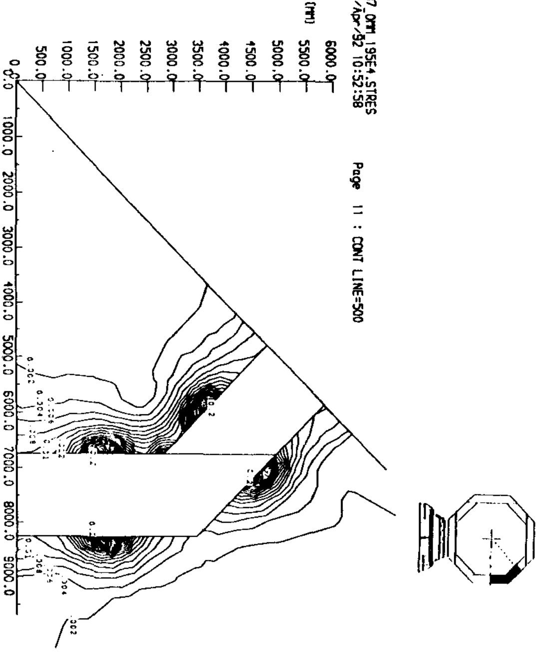
A87_OMM 195E4.STRES
24/Apr/92 13:53:31 Page 9 : CONT COMP=BMOO LINE=90



ELEM=LINE STMM=XY SOLN=AT SCALE=1.0 FIEL=MAGN
Static Solution Mesh 1056 Elements 11 Regions

VF/PE2D.8

Total current = 28392 A
Steel - A-87 (Russia)



Muon System Major Milestones

WBS	MILESTONE DESCRIPTION	DATE
3.1.1	**Magnet Barrel Toroid System**	
	MBT System Procurement Contract Award	Oct-92
	MBT Final Design Review(FDR)	Dec-92
	MBT Support System Procurement Contract Award	Jan-93
	Complete MBT Coils Prototype	Oct-93
	Start MBT Coils Fabrication	Nov-93
	Complete MBT Iron Ring Test	Dec-93
	Start MBT Iron Shipment to SSCL	Jul-94
	Complete MBT Support System Fabrication	Jun-95
	Complete MBT Iron Fabrication	Oct-95
	MBT Support System Available T.O.H.	Oct-95
	Complete MBT Coil Fabrication	Dec-95
	Initial Coils Available T.O.H.	Jan-96
	Final MBT Available T.O.H.	Apr-96
	Final Coils Available T.O.H.	Aug-96
3.1.2	**Forward Toroid System**	
	Forward Toroid System's PDR	Mar-93
	Start Forward Toroid Procurement/Fabrication	Jun-93
	Forward Toroid System FDR	Sep-93
	Start Forward Toroid Coils Shipment To SSCL	May-95
	Complete Forward Toroid Coils Pre-assembly/Test	Jun-96
	Forward Toroid System Available T.O.H.	Dec-96

01459

BARREL/INTERMEDIATE CHAMBER DESIGN

H. LUBATTI

SDC CENTRAL MUON SYSTEM

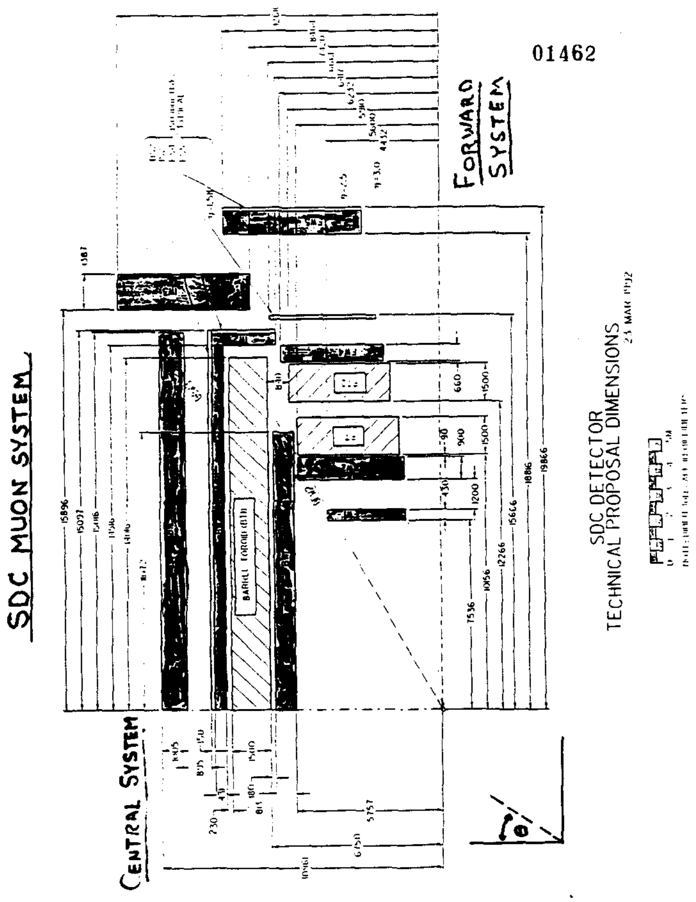
PAC PRESENTATION

H. LUBATTI

MAY 5, 1992

CENTRAL MUON SYSTEM

- TRACKING BEFORE AND AFTER CENTRAL TOROID
  - THETA MEASURES MOMENTUM
  - PHI CONNECTS TO CENTRAL TRACKER
- TRACKING ELEMENTS
  - ROUND Al DRIFT CELLS WITH FIELD SHAPING
  - ASSEMBLED INTO MODULES WHICH ATTACH TO BARREL TOROID.



ORGANIZATION

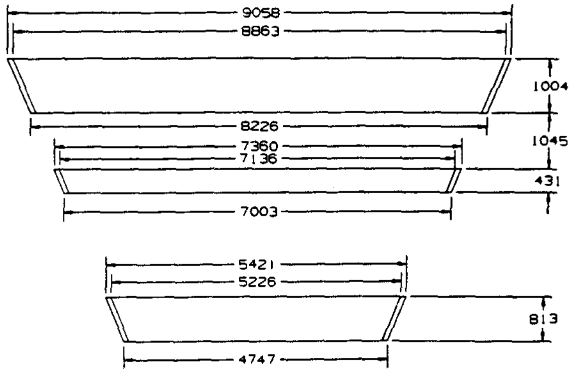
- GEOMETRY
- MODULE CONSTRUCTION
- DRIFT CELL DESIGN
- PROTOTYPE

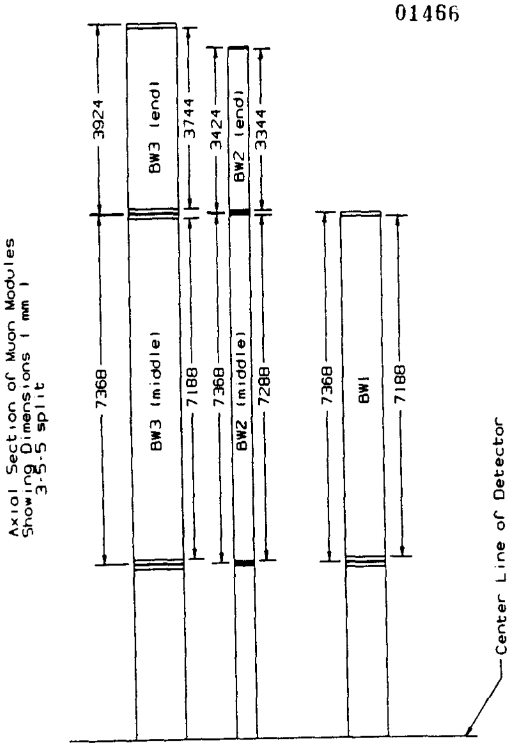
GEOMETRY

- OVERALL MODULE LAYOUT
- TUBE LAYOUT WITHIN MODULE
- PROJECTIVE GEOMETRY
- SPARSE TUBE LAYOUT
- MUON TRACK COVERAGE

PAC PRESENTATION
MAY 5, 1992
HJL

Cross Section of Modules
Showing Dimensions
94 mm tubes, 3-5-5 split



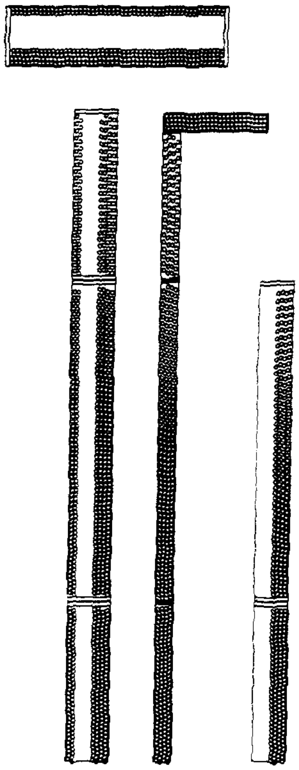

Axial Section of Muon Modules
Showing Dimensions (mm)
3-5-5 split

TDR Layer Configuration and Channel Count

Modules	Layer	Channels
BW1	4θ, 4φ	10674
BW2	4θ	7536
BW3	4θ, 4φ, 2s	26166
IW2	4θ	1600
IW3	4θ, 4φ, 2s	11648
Total		57624

- The order of θ, φ and stereo layers can be changed
- The optimal ordering of the θ, φ and stereo layers is under study
- The design can easily accomodate any ordering

01468



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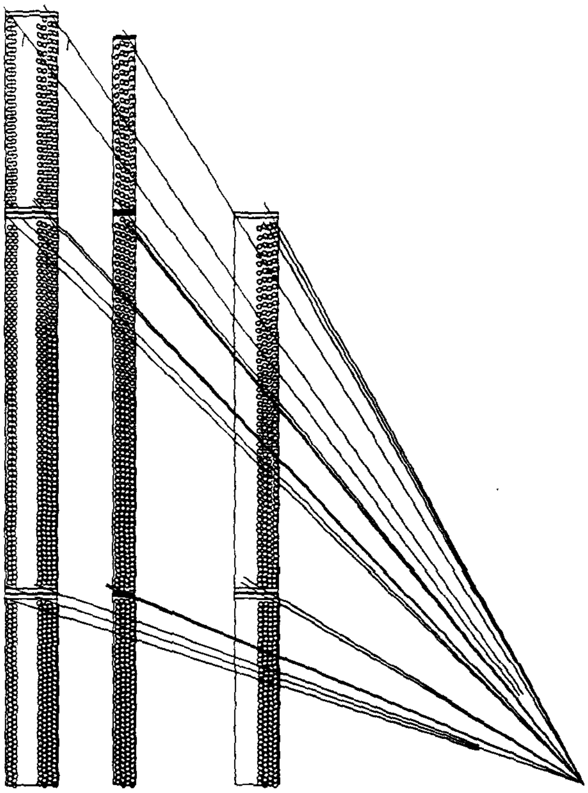
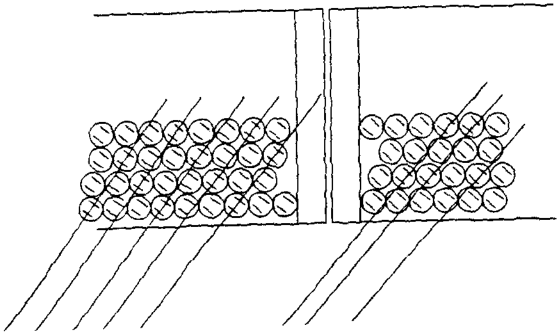


01470

BW1 - Projective Tracks
at Module Junction.



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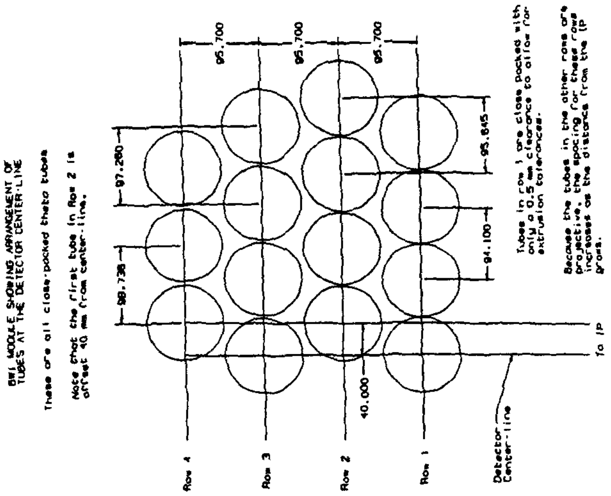


BWI MODULE SHOWING ARRANGEMENT OF
TUBES AT THE DETECTOR CENTER-LINE

These are all close-packed theta tubes

Note that the first tube in Row 2 is
offset 40 mm from center-line.

Tubes in row 1 are close packed with
only a 0.5 mm clearance to allow for
extrusion tolerances.

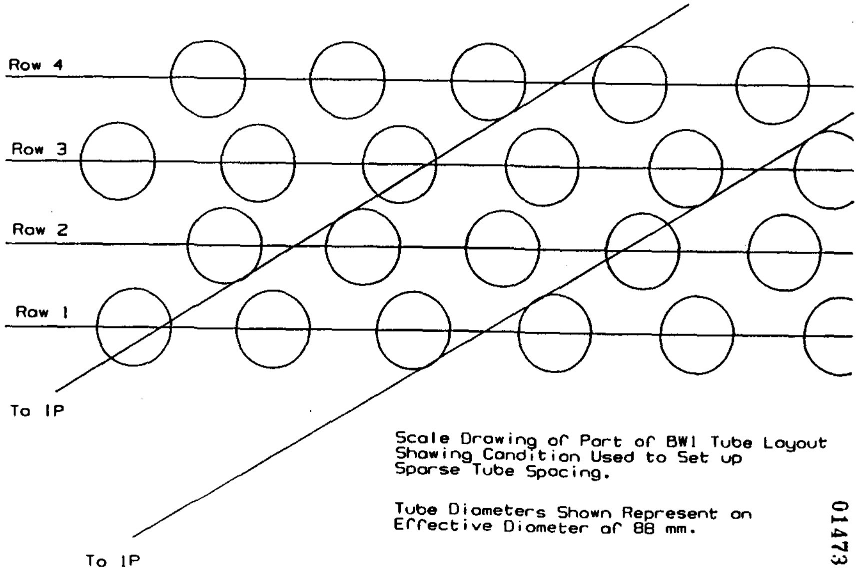
Because the tubes in the other rows are
projective, the spacing for these rows
increases as the distance from the IP
grows.

Sparse Tube Layout

- BW1 - Non-Deflected Tracks
  - Geometric Condition
  - Geometry of Algorithm
- BW2/BW3 - Deflected Tracks
  - Assume 0.08 radian Deflection
  - Geometric Condition
  - Geometry of Algorithm
- Initial Tube Location
  - At Detector Centerline
  - At Inter-module Cracks

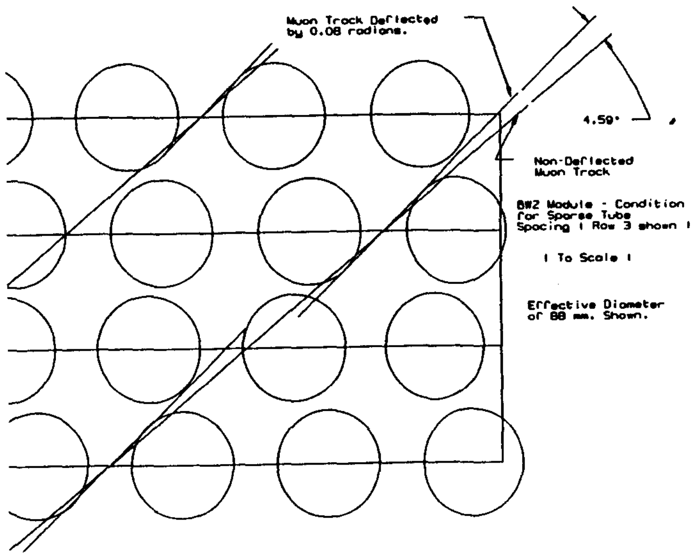
Note that Muon Tracks are Tangent to Adjacent Tubes in Row 3 and in Row 4.

They are not Tangent to the Tubes in Row1 and Row 2.



Scale Drawing of Part of BW1 Tube Layout Showing Condition Used to Set up Sparse Tube Spacing.

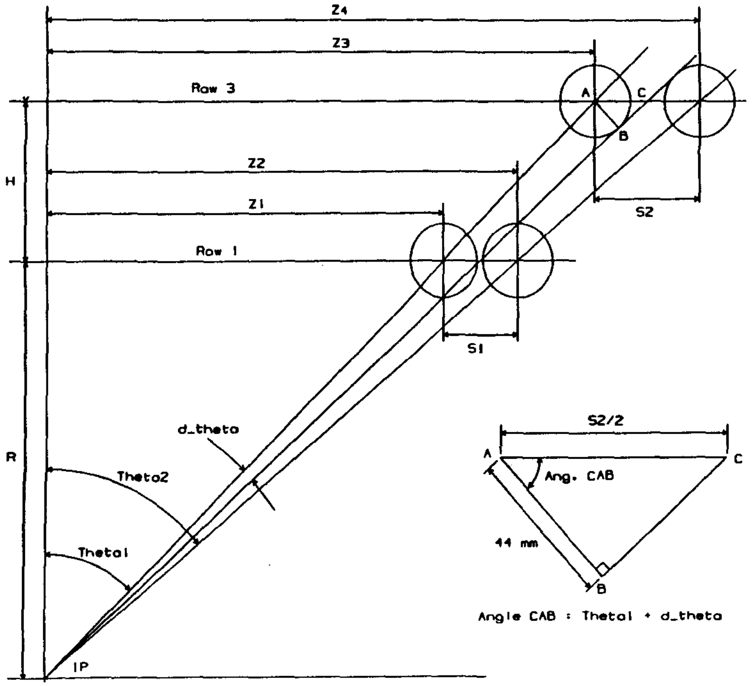
Tube Diameters Shown Represent an Effective Diameter of 88 mm.



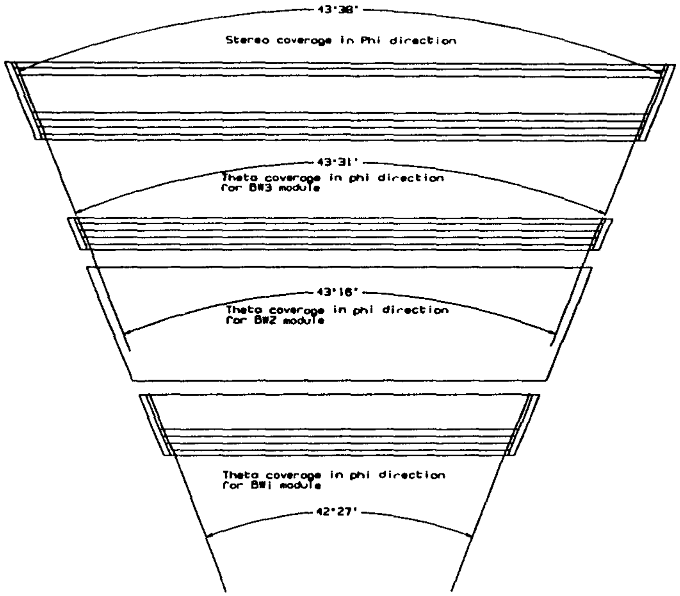
BW2 Module - Condition for Sparse Tube Spacing (Row 3 shown)

(To Scale)

Effective Diameter of 88 mm. Shown.



Angle CAB = Theta1 + d_theta



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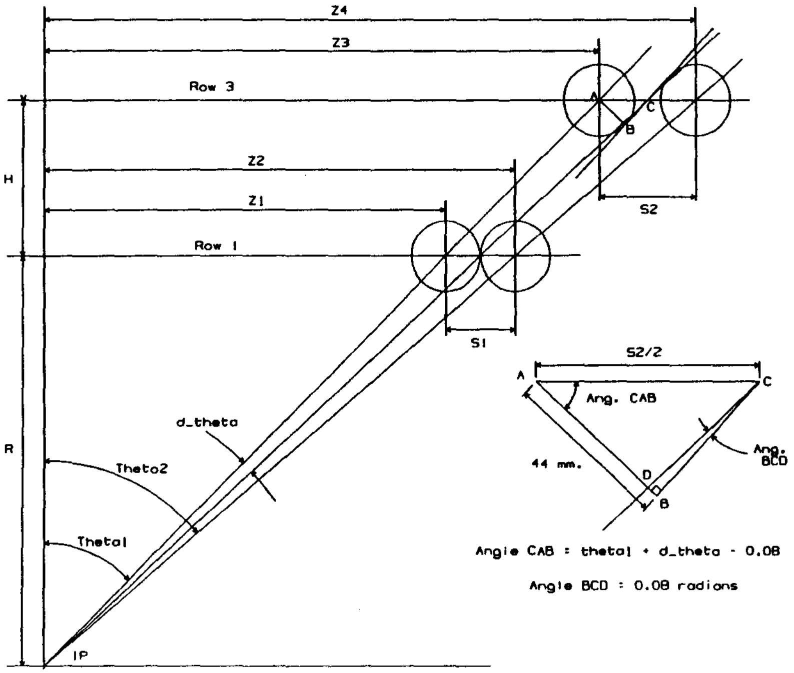

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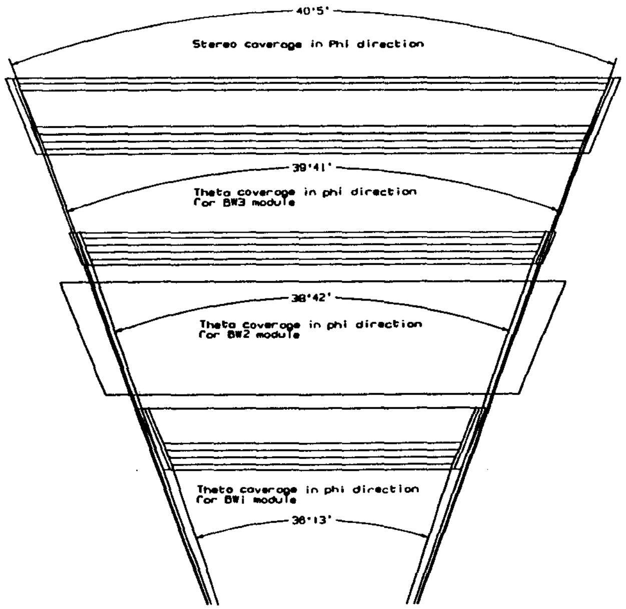

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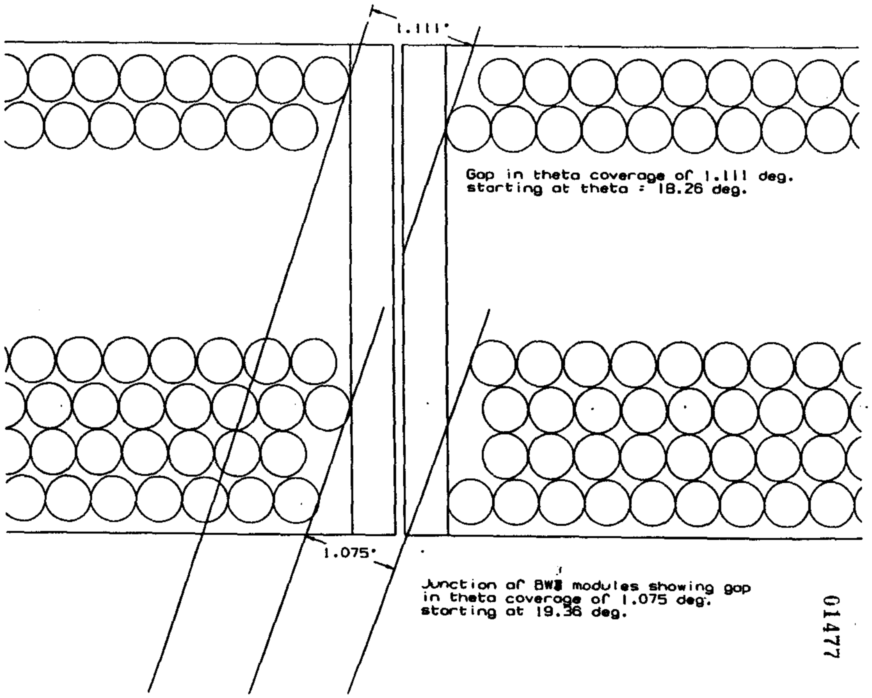

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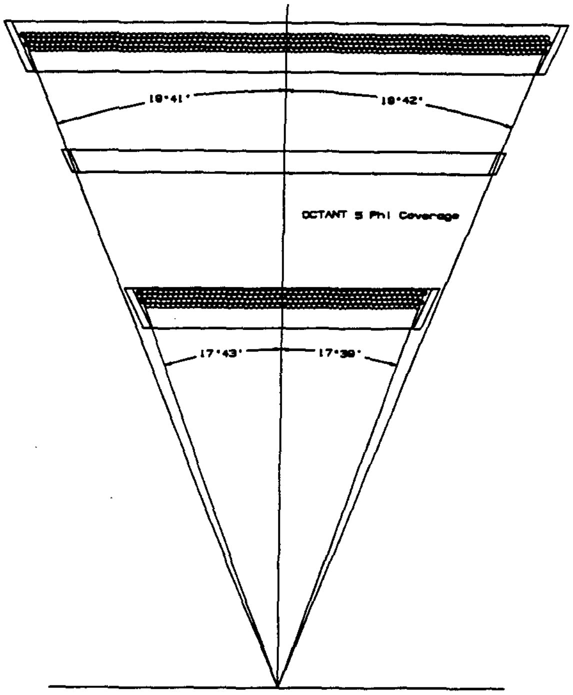


Theta and Stereo Tube Coverage for Barrel Muon System

- θ - Direction

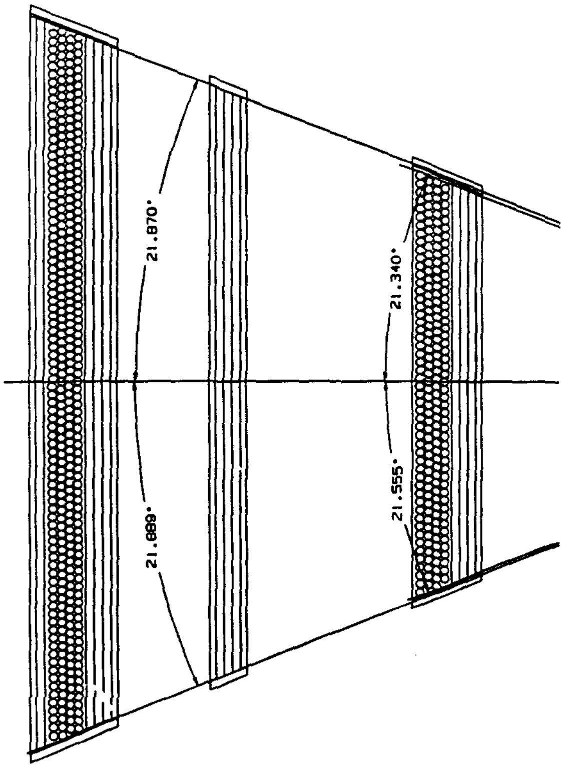
BW1	0 to 61.88° with gap of 0.78°	98.7%
BW2	0 to 59.20° with gap of 0.23°	99.6%
BW3	0 to 55.96° with gap of 1.08°	98.1%
Stereo	0 to 53.97° with gaps of 1.46°	97.3%

- ϕ - Direction

BW1	333.37°	92.6%
BW2	341.85°	94.9%
BW3	342.85°	95.2%
Stereo	345.52°	96.0%

- Solid Angle Coverage

BW1	91.4%
BW2	94.5%
BW3	93.4%
Stereo	93.4%



Phi Track Coverage
94 mm tubes, 3-5-5 split

Phi Tube Coverage for Barrel Muon System

- θ - Direction

BW1	0 to 61.16° with gap of 1.67°	97.3%
BW3	0 to 54.52° with gap of 1.80°	96.7%

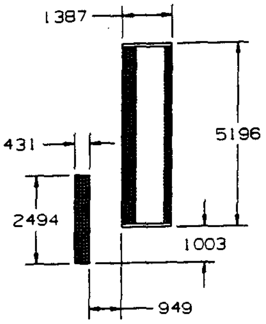
- ϕ - Direction

BW1	336.53°	93.5%
BW3	346.28°	96.2%

- Solid Angle Coverage

BW1	91.0%
BW3	93.0%

01484



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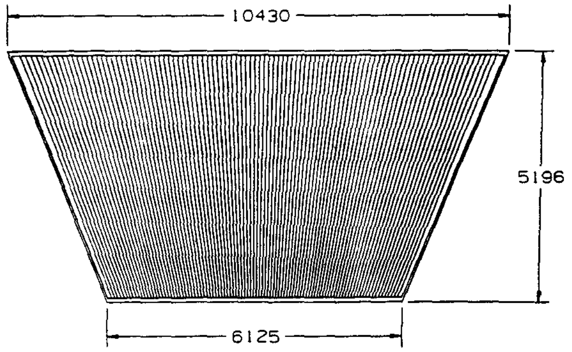

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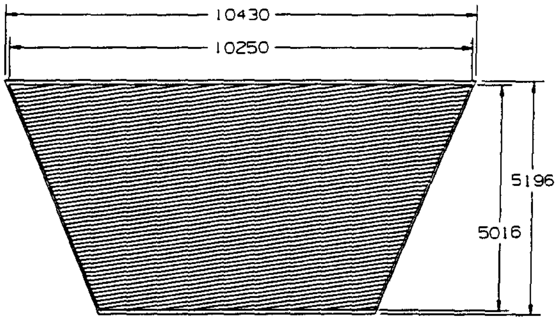

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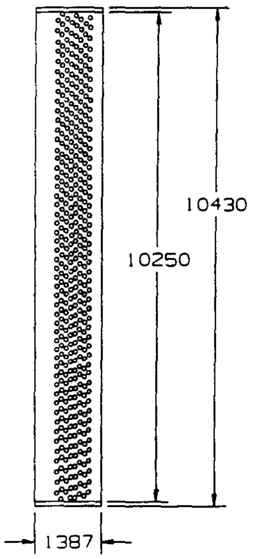
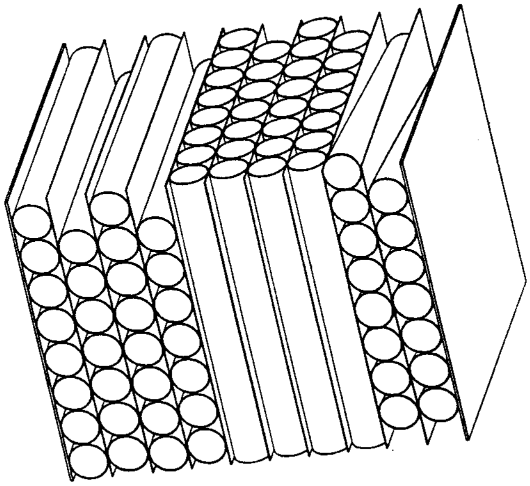
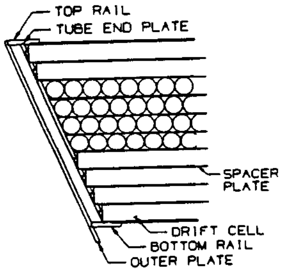


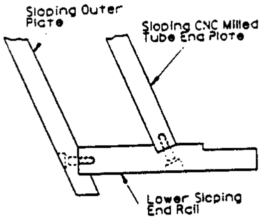
MODULE CONSTRUCTION

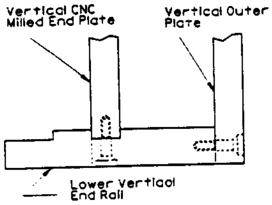
- USES DRIFT TUBES AS STRUCTURAL ELEMENTS
- INTERLEAVED PLATES TO TRANSMIT SHEAR
- STRONG, STIFF PERIPHERAL STRUCTURE
- WIRE ENDS LOCATED BY PRECISION END PLATES
- BW2/BW3 MODULES ASSEMBLED AS 1 UNIT
- THREE POINT KINEMATIC SUPPORT

PAC PRESENTATION
MAY 5, 1992
HJL









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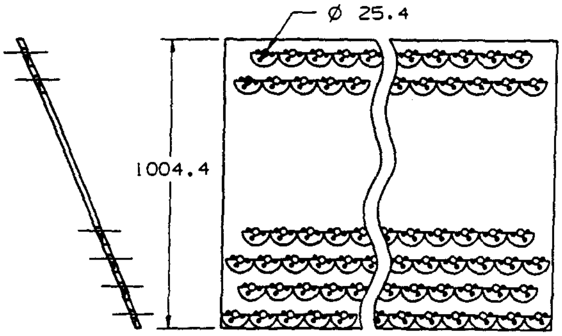

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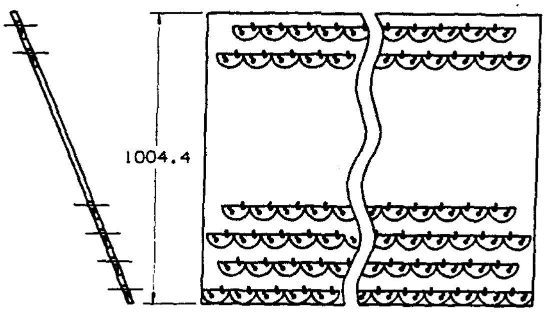
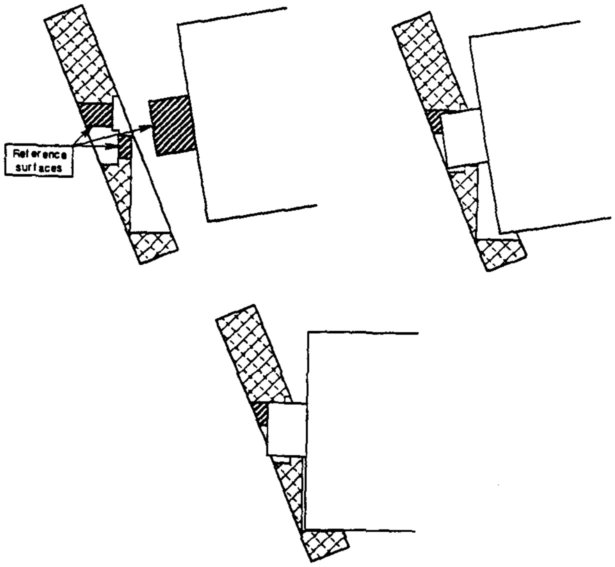


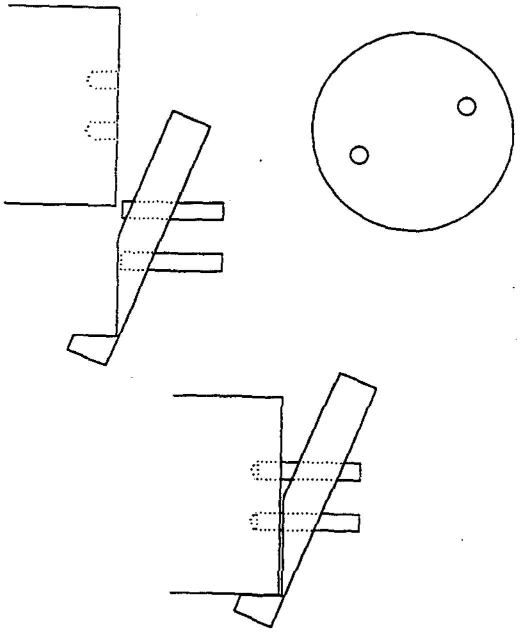
01494

Installing boss end



01495

Installing flat end



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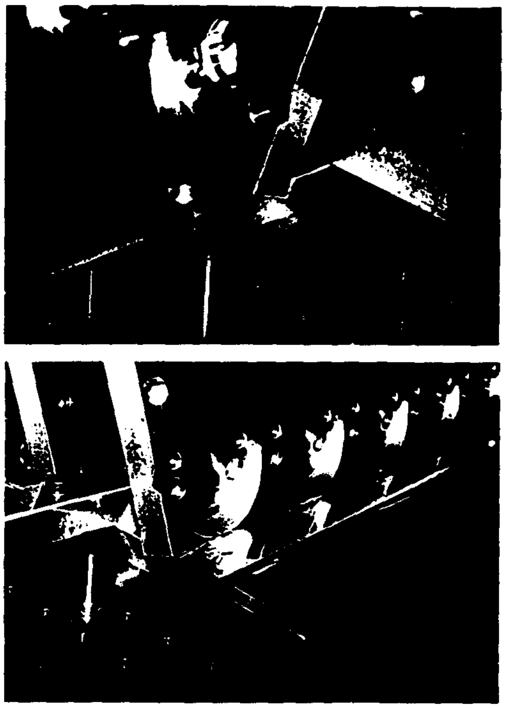
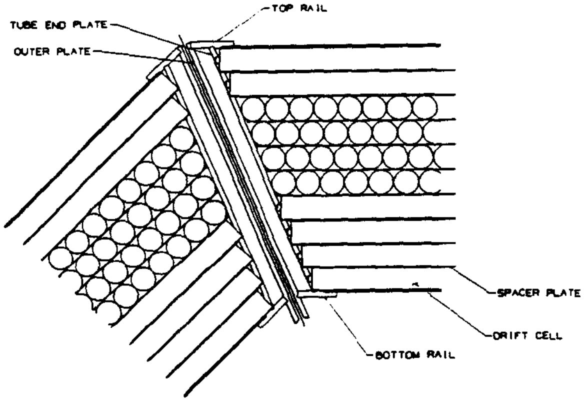


01497

01498

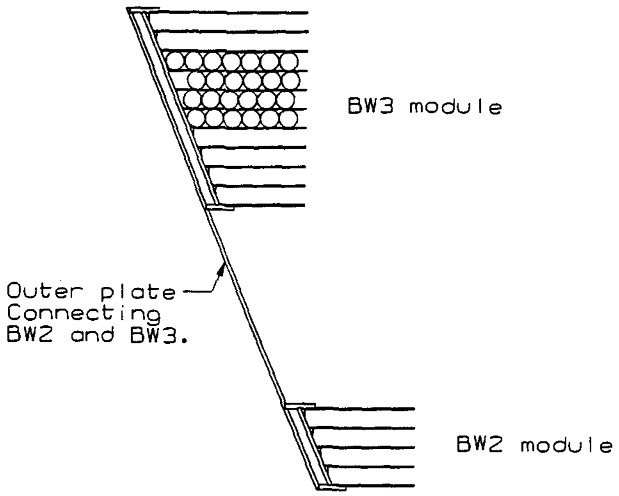


01499

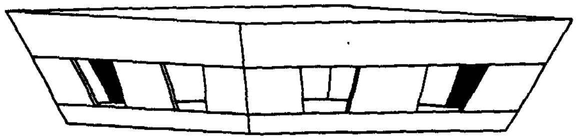
OUTER PLATES

- Outer plates form a box-like peripheral structure
- Enclose gas and electrical connections
- Provide strong structure for mounting points
- Tie BW2 and BW3 modules together
- BW2/BW3 assembly also on three-point, true kinematic supports

01500



01501



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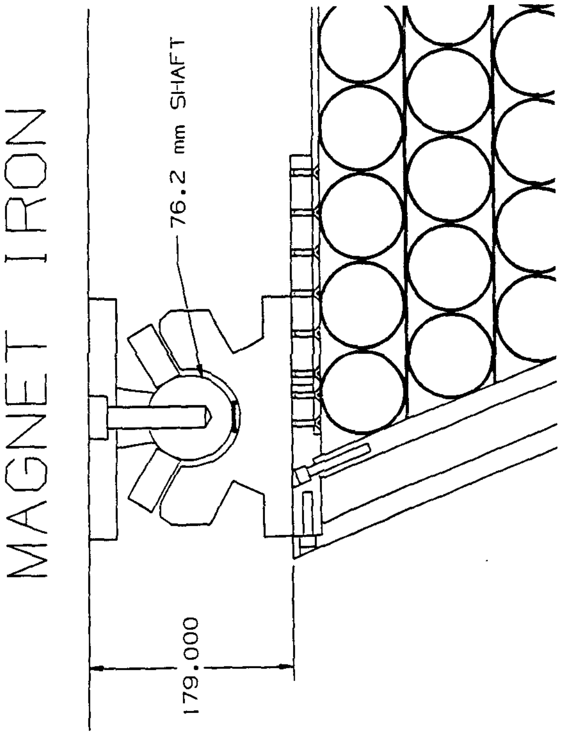

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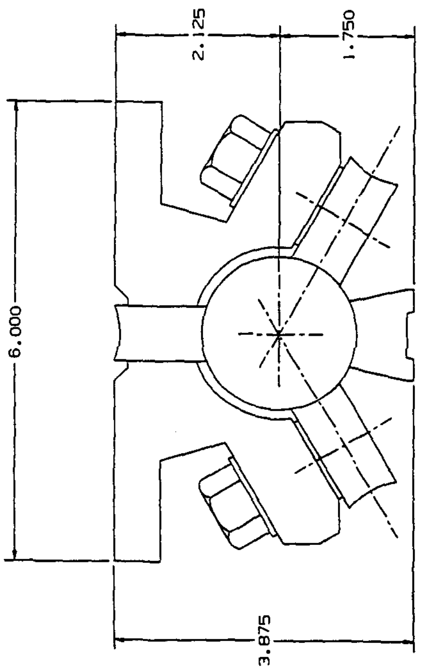


01504

MODULE WEIGHTS

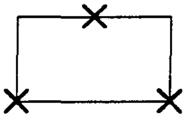
BW1 (middle module)	9290 kg.
BW2/3 (middle assembly)	30600 kg.

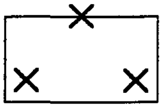
Barrel Muon Module Deflections
Gravity Loading

01505

- All data is for 3-point, kinematic support of modules
- Longest modules have greatest deflection
- Top octant (Octant 1) has greatest deflection

BW1	Corner support locations	0.75 mm
BW1	Optimum support locations	0.64 mm
BW2/3	Corner support locations	0.98 mm


Supports at Corners


Optimum Support Locations

Corner supports work best for BW2/3 because of the very rigid peripheral structure

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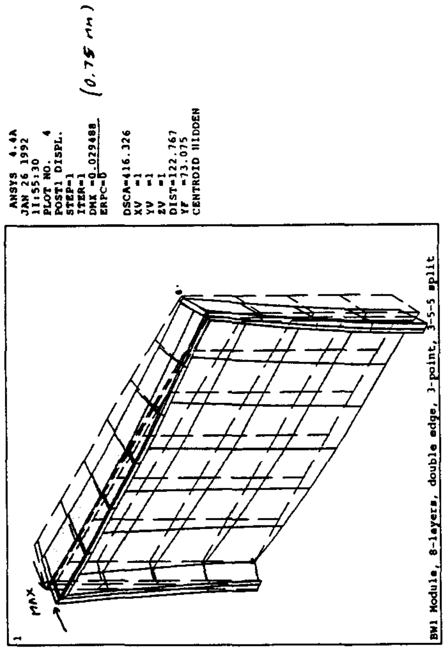
01506



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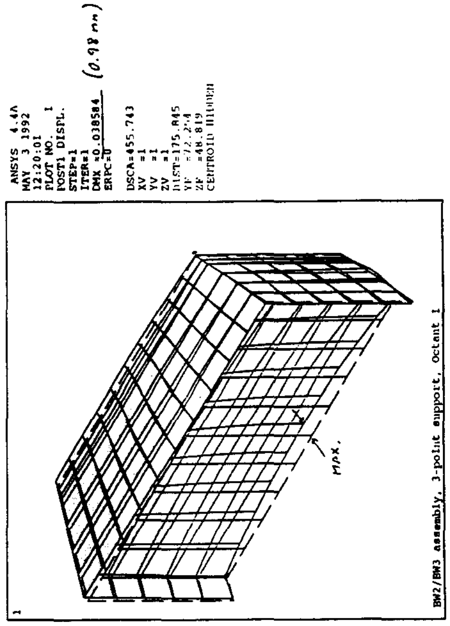


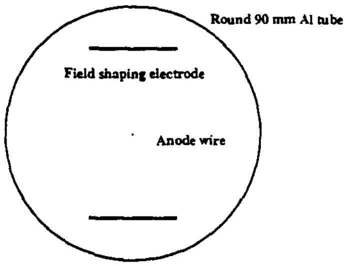
SUMMARY

- TUBES ASSEMBLED INTO LARGE MODULES CONTAINING Θ, Φ AND STEREO LAYERS
- WIRE END POSITIONING ESTABLISHED BY FOUR LARGE, CNC MILLED END PLATES.
- FIELD SHAPING ELECTRODES ORIENTATION ALSO ESTABLISHED BY THESE PLATES.
- STRUCTURE OF BOX TIED TOGETHER BY TOP AND BOTTOM PLATES.
- ALL MATERIAL ALUMINUM.
- ALL ELEMENTS EPOXY BONDED TO FORM A SINGLE, MONOLITHIC STRUCTURE.
- ALL ELEMENTS, INCLUDING TUBES, CONTRIBUTE TO RIGIDITY AND STRENGTH.
- THREE-POINT, TRUE KINEMATIC SUPPORT.

TUBE

- Each tube is an independent, fully functional drift cell
- Round Aluminum Tube
- Field Shaping
- Identical Except for Length
- Orientation and Wire Placement Fixed by End Caps
- No Wire Supports
- Tube plus End Cap Forms Complete Electrostatic and Environmental Shield with Electronic Components Inside
- Saturated, Non-Flammable Gas
- Simple Field-Shaping Electrode

DRIFT TUBE



- FUNCTION OF DRIFT TUBE

  COORDINATE MEASUREMENTS
  250 micron RESOLUTION
  5 mm TWO TRACK SEPARATION

  BOTH REQUIRE FIELD SHAPING

- FIELD SHAPING

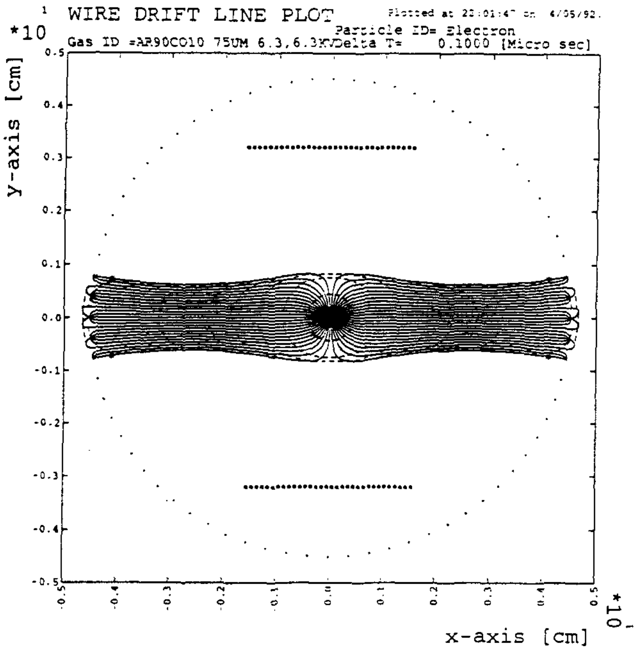
  FIELD IS SUM OF ANODE MONOPOLE
  FIELD AND FIELD SHAPING ELECTRODES
  QUADRUPOLE FIELD

PAC PRESENTATION
MAY 5, 1992
HJL

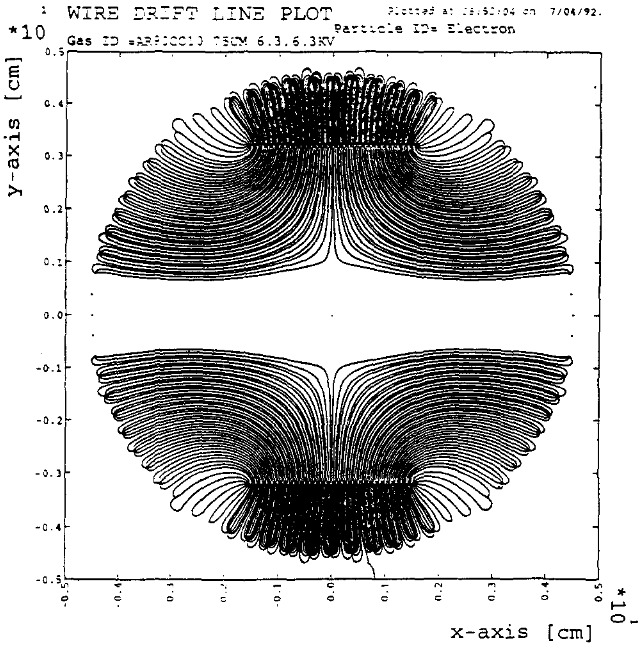
DRIFT CELL PARAMETERS

Inside radius	45 mm
Wall thickness	1.8 mm
Wire material	Gold plated tungsten
Anode wire diameter	75 or 90 μm
Wire tension	700 or 1,000 g
Electrode width	32 mm
Electrode separation	64 mm
Gas mixture	Ar-CO_2 90:10
Voltage at anode	6.3 or 6.7 kV
Voltage at electrodes	6.3 or 6.7 kV
Gas gain	$\sim 10^5$
Position resolution	250 μm
Double track separation	5 mm

01512



01513

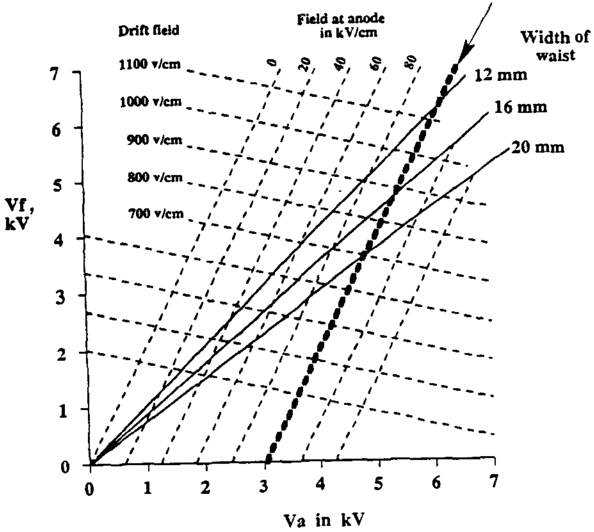


01514

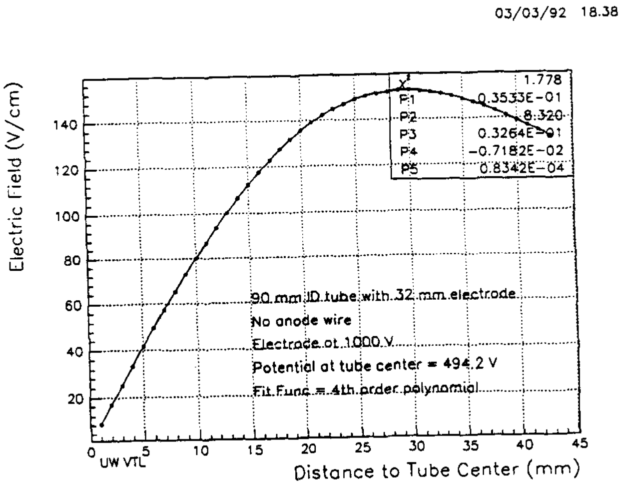
Fields in 90 mm drift tube

Anode wire diameter : 90 microns

Field shaping electrodes
width : 32 mm
spacing : 64 mm



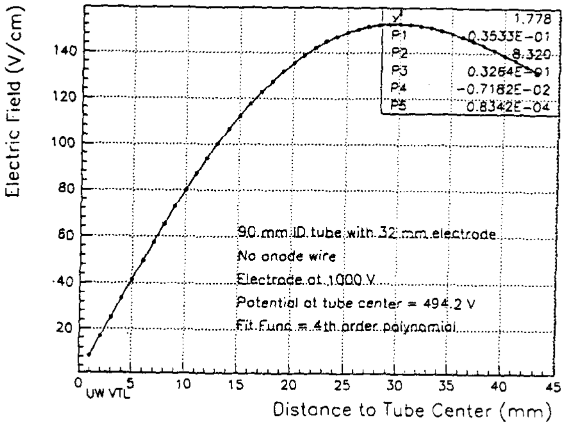
01515



90 mm ID tube with 32 mm electrode
No anode wire
Electrode at 1000 V
Potential at tube center = 494.2 V
Fit Func = 4th order polynomial

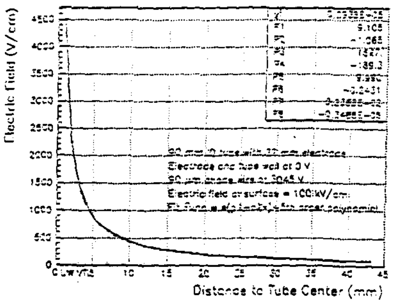
01516

03/03/92 18.38

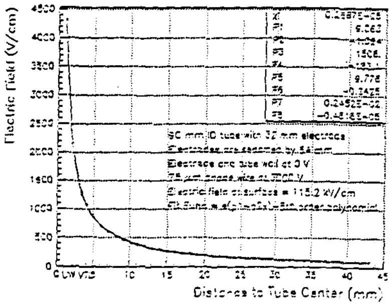


01517

03/03/92 18.27

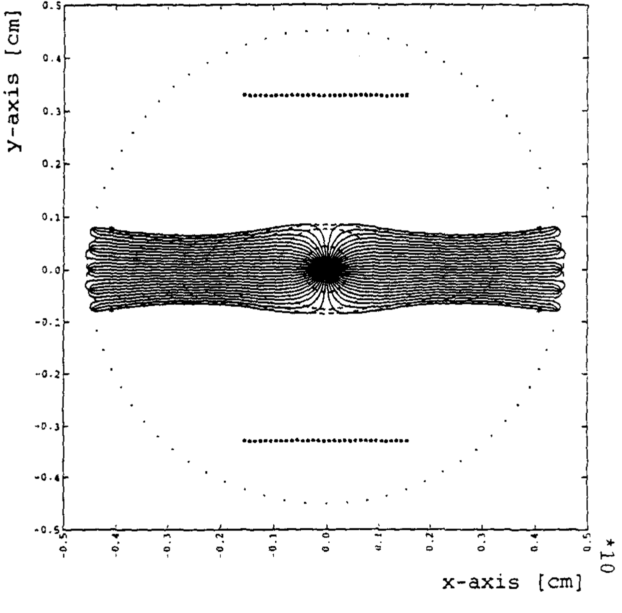


05/03/92 11.24



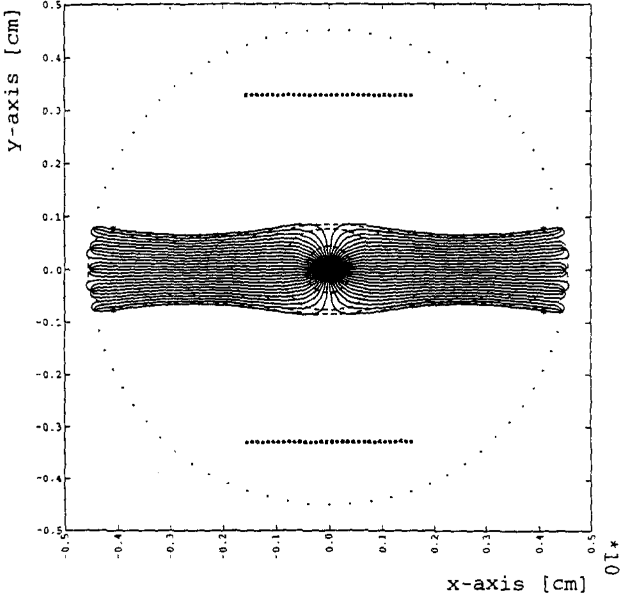
01518

1 WIRE DRIFT LINE PLOT Plotted at 16:17:39 on 4/05/92.
Particle ID= Electron
Gas ID =AR90C010 75UM 6.3,6.3KVDelta T= 0.1000 [Micro sec]

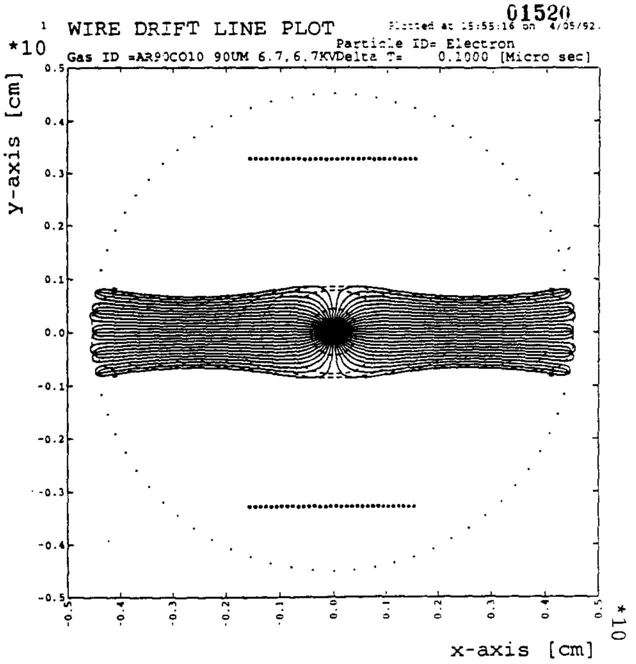


01519

1 WIRE DRIFT LINE PLOT Plotted at 16:17:39 on 4/05/92.
Particle ID= Electron
Gas ID =AR90C010 75UM 6.3,6.3KVDelta T= 0.1000 [Micro sec]



01520



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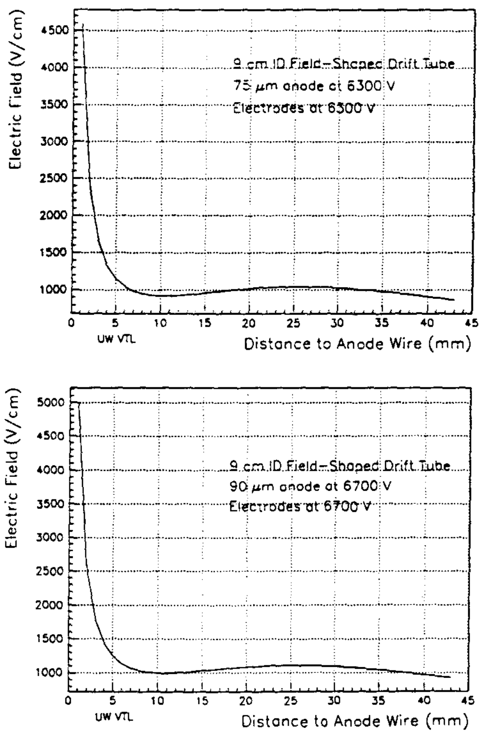

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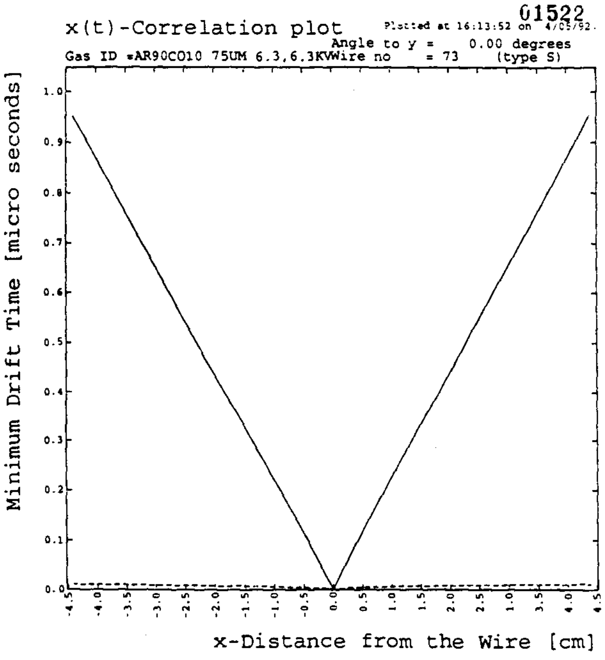

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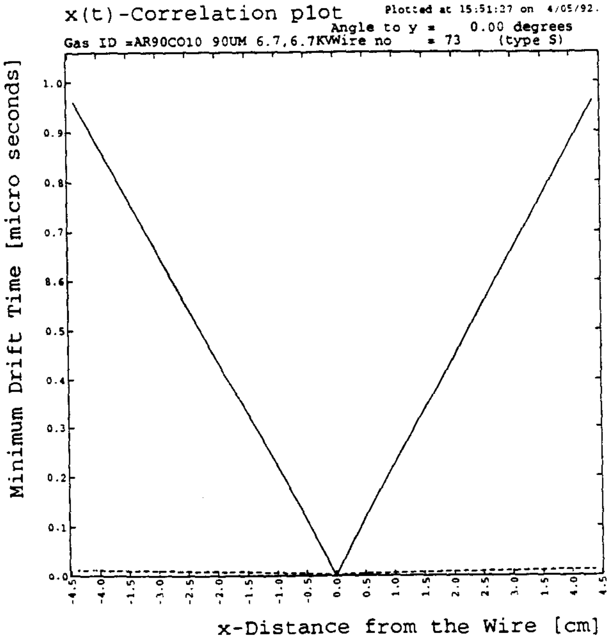

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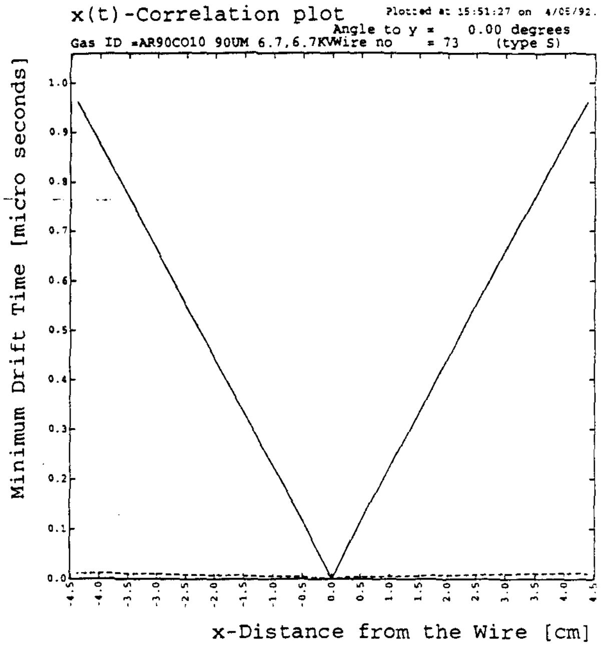


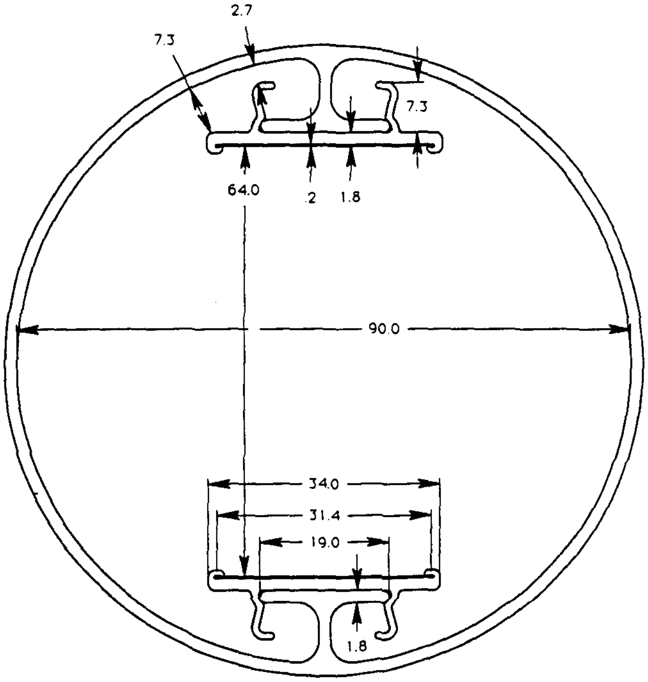
01525

FIELD SHAPING ELECTRODES

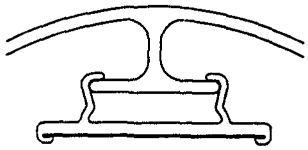
- Noryl/Al co-extrusions
- Have snap-on design

Prototype had slide-on electrodes.
Snap-on will save assembly time.

01526



01527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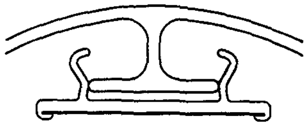
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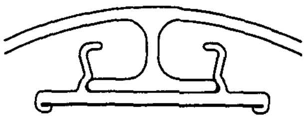
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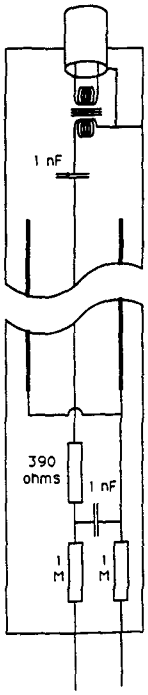


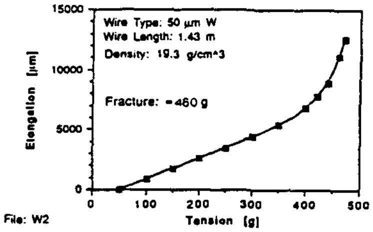


Figure 8 a

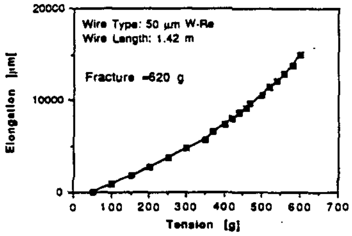


Figure 8 b

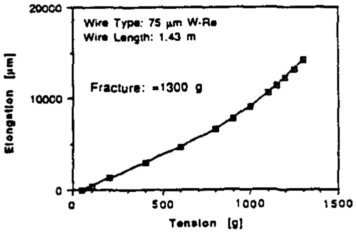


Figure 8 c

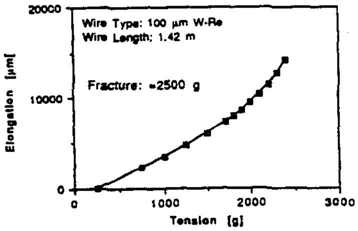


Figure 8 d

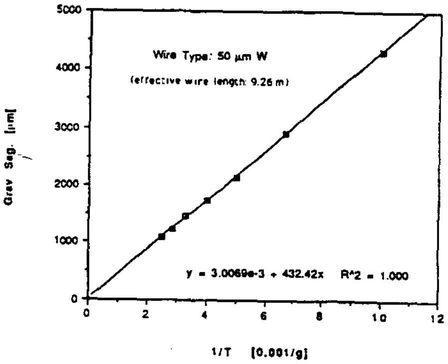


Figure 10 a

END CAP DESIGN

GENERAL CONCEPT:

- WIRE POSITION CONTROLED BY PRECISION CNC MACHINING OF END CAPS AND PRECISION MACHINED FEEDTHROUGH
- PLACEMENT OF ALL ELECTRICAL COMPONENTS IN A REMOVABLE PLUG
- INSURE LONG TERM HIGH VOLTAGE STABILITY BY POTTING ELECTRONICS AND USING ROBUST HIGH VOLTAGE CONNECTIONS
- METALLIC SHELL SURROUNDS ALL ELECTRICAL COMPONENTS TO INCREASE ELECTRICAL SHIELDING. ALL METALLIC PARTS ARE GROUNDED TO EACH OTHER USING SOLID MECHANICAL FASTENING TECHNIQUES
- AUTOMATE ASSEMBLY PROCESS WHEREVER POSSIBLE TO REDUCE COSTS

HIGH VOLTAGE CONNECTIONS

- SPRINGS ARE BOLTED TO THERMALLY INSERTED HIGH VOLTAGE PINS
- HIGH VOLTAGE CONTACT SPRINGS ARE NOT EXPOSED TO INSIDE OF DRIFT CELL
- ALL HIGH VOLTAGE CONNECTIONS ARE SURROUNDED BY GOOD DIELECTRIC

NORYL;	VOLUME RESISTIVITY	1015 OHM CM
	DIELECTRIC STRENGTH	630 V/MIL

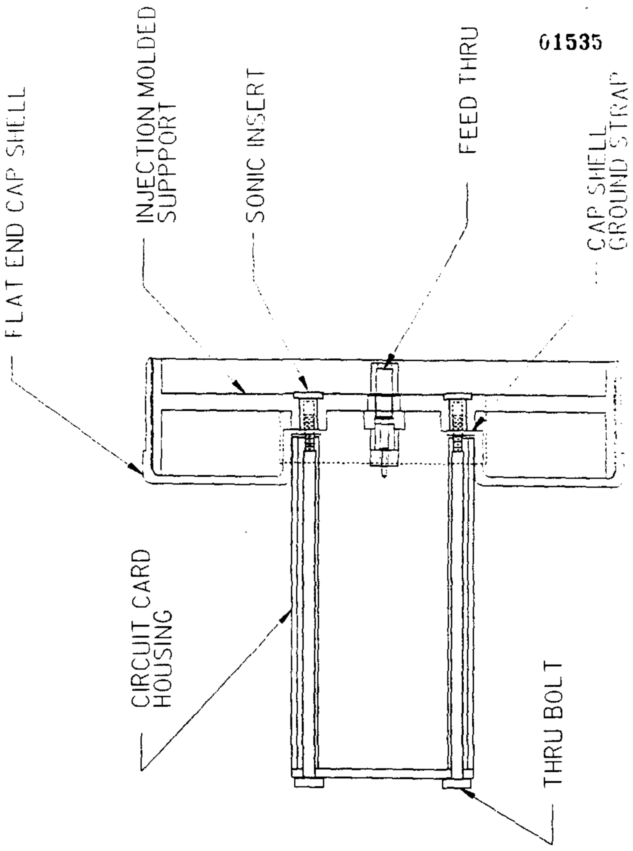
- ELECTRICAL PLUG IS POTTED FOR LONG TERM HIGH VOLTAGE STABILITY

EMI SHIELDING

- ALL ELECTRONICS ARE ENCLOSED IN ALUMINUM ENCLOSURES WITH ROBUST GROUND CONNECTIONS AND OVERLAPING METAL JOINTS
- CENTER TAP OF OUTPUT TRANSFORMER IS GROUNDED TO TUBE. THIS SHOULD BLOCK THE COMMON MODE SIGNAL COMING IN ON THE OUTPUT TWISTED PAIR. (THESE COMMON MODE SIGNALS CAN COUPLE TO THE PRIMARY OF THE OUTPUT TRANSFORMER AND RETURN AS DIFFERENTIAL SIGNALS.)

MECHANICAL FEATURES

- WIRE POSITION CONTROLED BY PRECISION CNC MACHINING OF END CAPS AND PRECISION MACHINED FEEDTHROUGH
- ELECTRICAL CONTACTS AND GAS FITTING ARE THERMALLY INSERTED INTO NORYL
- ELECTRICAL PLUG IS BOLTED TO ENDCAP



END CAP PRODUCTION

- DESIGN INCORPORATES LOW COST MASS PRODUCTION TECHNIQUES SUCH AS INJECTION MOLDING, METAL FORMING AND EXTRUDING
- WE ARE CURRENTLY WORKING WITH UTA'S AUTOMATION AND ROBOTICS RESEARCH INSTITUTE TO AUTOMATE THE ASSEMBLY OF THE END CAPS

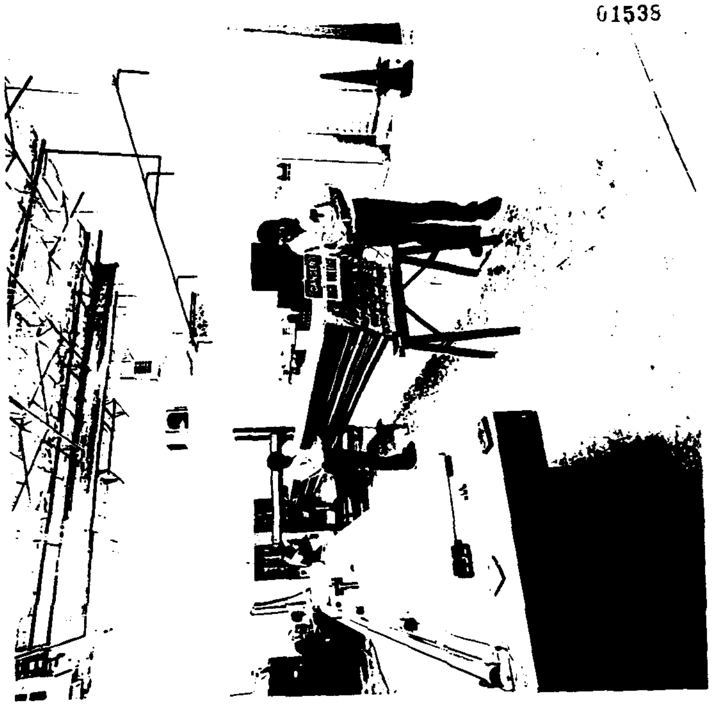
PROTOTYPE MODULE

NINE METER MODULE WITH FOUR LAYERS OF Θ-TUBES FABRICATED IN SDC MUON LAB

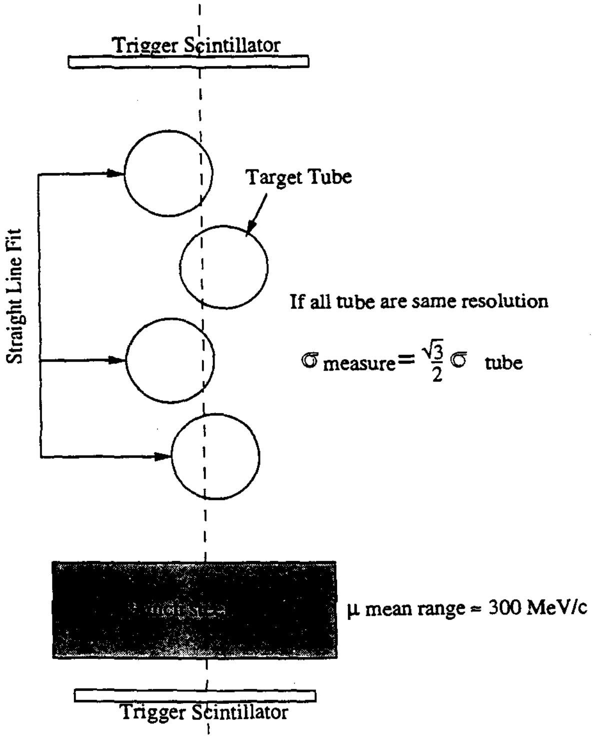
- Drift cell 75 mm
- Anode wire 50 μm

TAKING COSMIC RAY DATA

COME AND SEE IT !!!



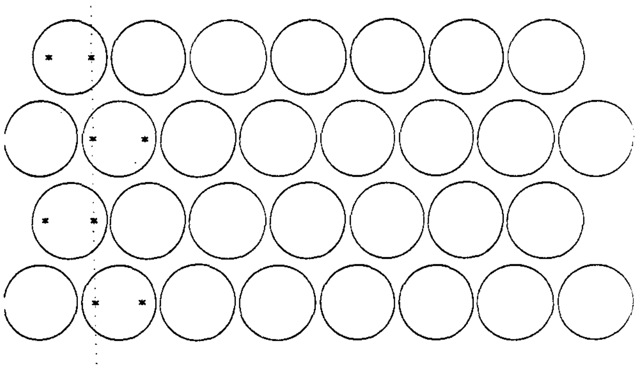
SDC Muon Chamber Prototype
Cosmic Ray Test



01540

Cosmic Ray Test

Event Number 13
Y = -.56E+02* X +0.28E+04



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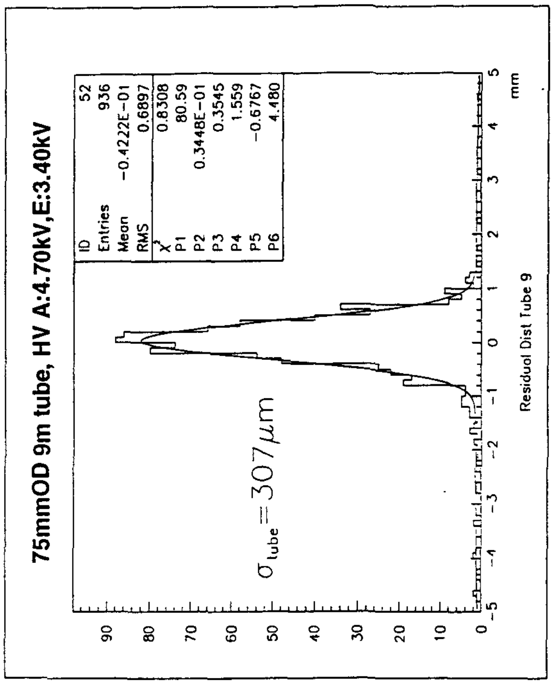
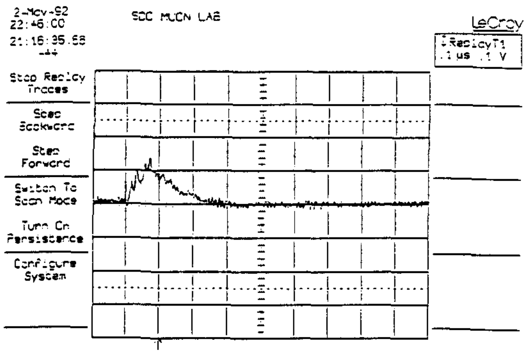
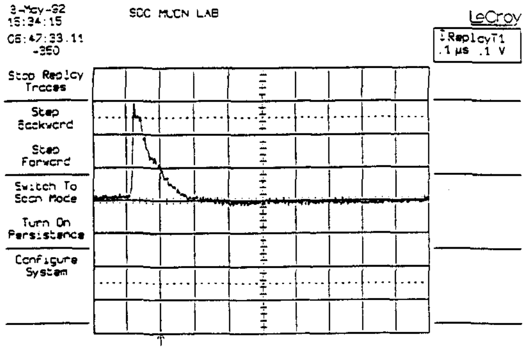


Short Tube Cosmic Ray Events
Preamp output : near wire

01542





01543

FORWARD CHAMBER DESIGN

Y. ANTIPOV

FORWARD DETECTOR
MUON TRACKING SYSTEM

University of Maryland,
USA

Institute for High Energy Physics
(IHEP,Protvino)
Russia

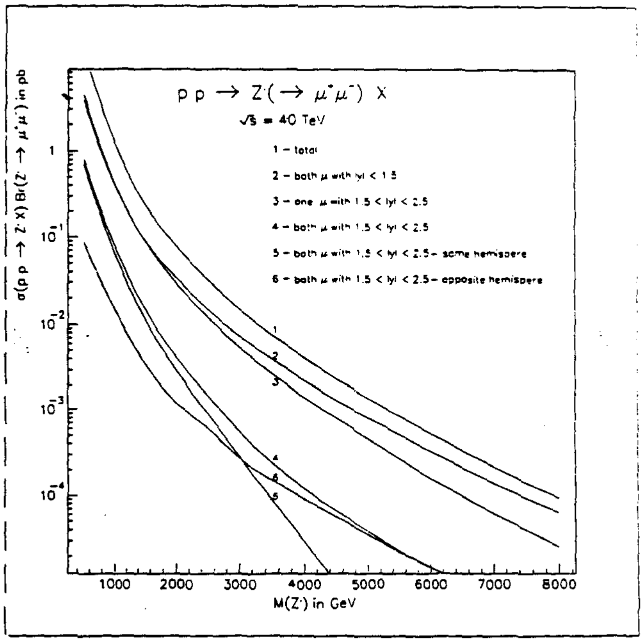
(presented by Yu.Antipov)

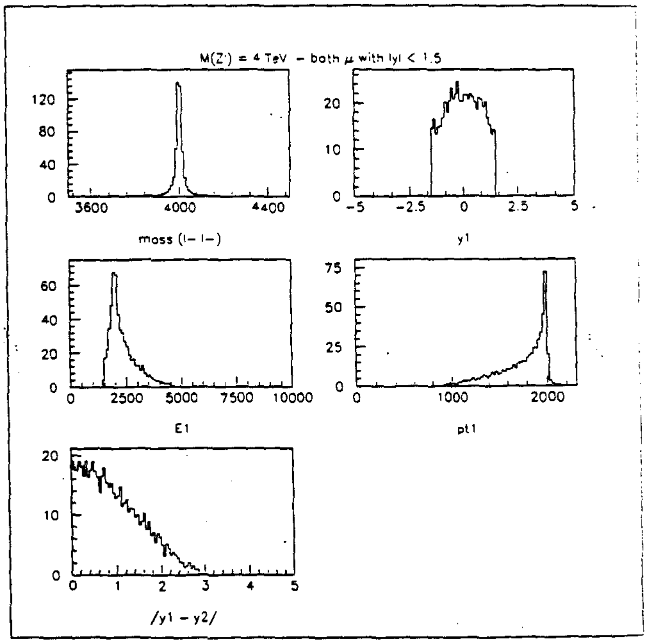
Special considerations.

Detecting, measuring, and triggering on muons is more difficult in forward direction than in the central region.

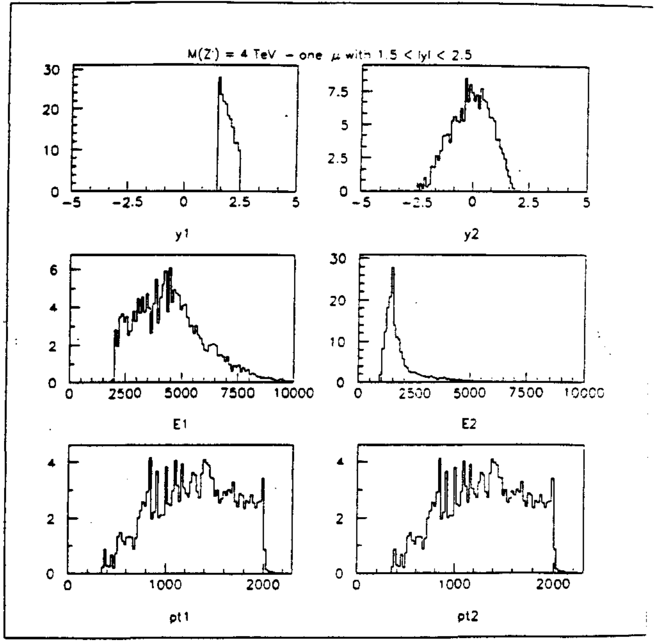
These muons tend to have higher momenta and often accompanied by low-energy electromagnetic debris (electrons and photons) and may confuse the trigger; such effects are under study.

To unravel the effect of knock-on electrons, the muon detector must have good multiple track resolution.

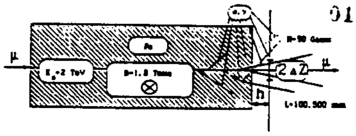


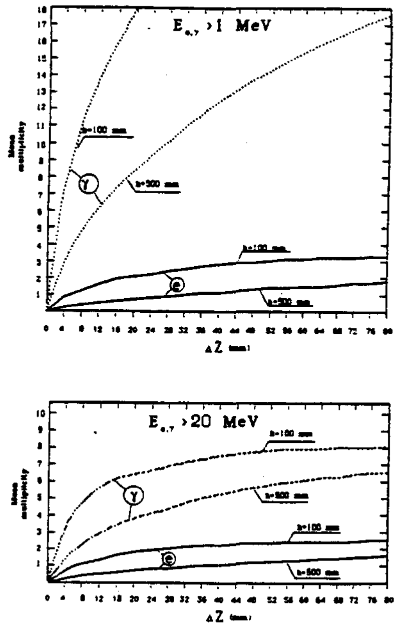


01543E

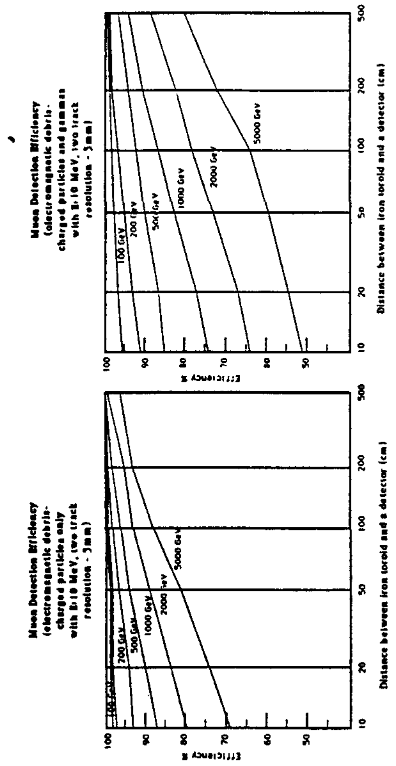


01543F





01543G



Low-energy neutron background.

01543H

Without shielding, the neutron rate in the forward region is estimated to lead to
2-3% occupancies in the drift tubes.

An iron/polyethylene absorber around the entire beam pipe region protects the forward muon system from the major impact of such neutrons, but no reliable estimates yet exists of the effectiveness of such an absorber for neutrons below 10 MeV.

01543I

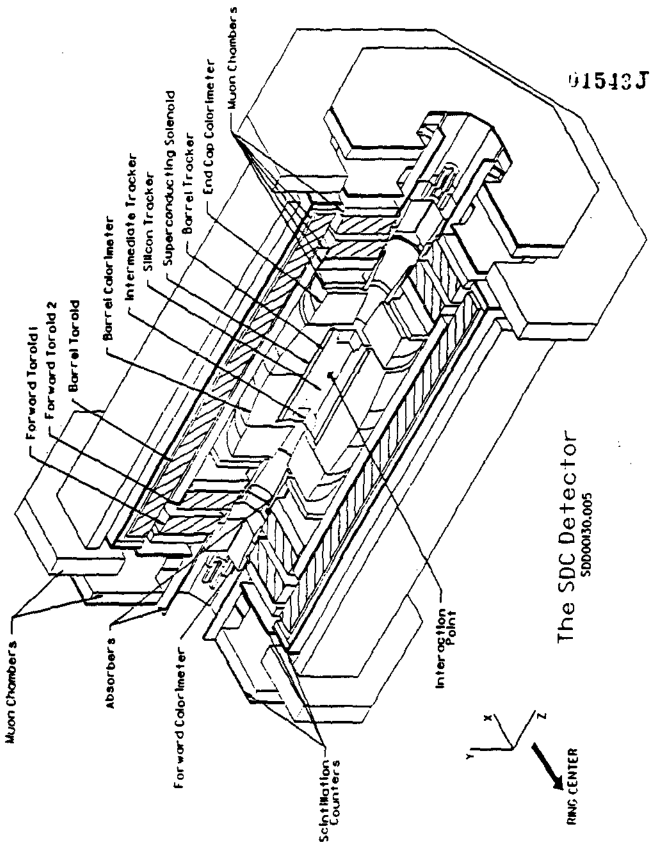
To design a good tracking detector for a detection 5000 GeV muons we should:

1. minimize tracking detector thickness (radiation length) up to the limit;
2. use detection technique with good two-track resolution;
3. move the most important detector planes as far from the iron toroid as possible.

To design a detector that will survive in high neutron background conditions we should:

1. minimize tracking detector thickness (radiation length) up to the limit;
2. decrease the hydrogen contamination in the detector;
3. make a detector as fast as possible.

01543J



Special constraints

01543K

Access and servicing requirements place special constraints on the forward muon system.

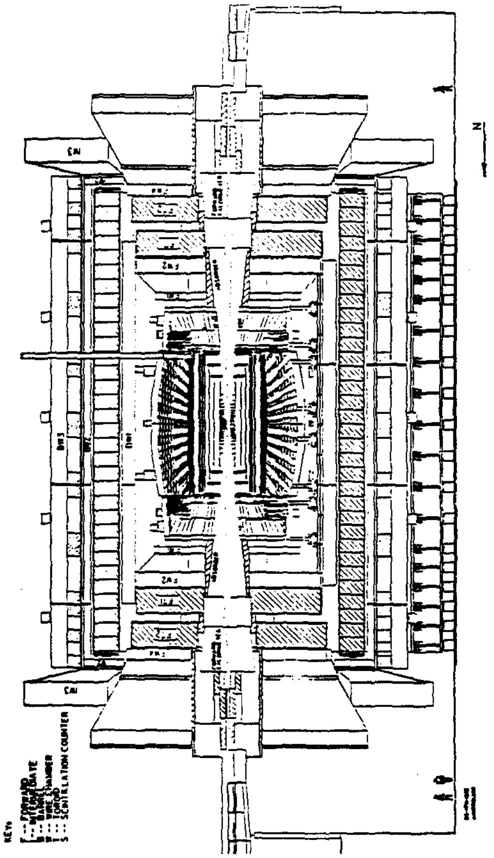
The major items that must be considered are:

1. Access to the chamber readout and trigger electronics and H.V. and gas distribution during short machine shutdowns requires that all these major distribution points be locates at the periphery of the detector.

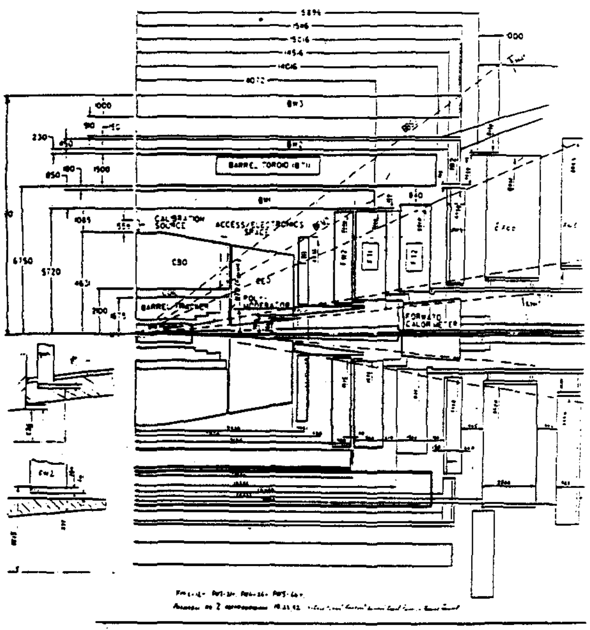
2.Access to the endcap calorimeter and inner tracker requires that FW1 be retracted toward FW2 by 1.2 m.

3.Access is required to local electronics for FW1-FW5, Cerenkov, FS4, FS5, support structure must be designed with this in mind.

01543L



01543M



01543N

Muon Measurement System (continued)
(WBS 3.2)

Forward chambers	FW1	FW2	FW3 *	FW4	FW5
Z position (mm)	7536	9166	(11746)	13856	18816
Thickness (mm)	430	900	(430)	660	900
Inner radius (mm)	1345	1415	(1841)	2190	3010
Outer radius (mm)	4432	5600	(5910)	6232	8464 |
Orientation of layers	4 theta	4 theta 4 stereo	(4 theta)	4 theta	4 theta 4 stereo
Number of channels (Both Ends)	4390	11904	(5788)	4310	11636 |
Number of Supermodules (Both Ends)	2	2	(2)	2	2 |
Outer Tube Diameter (mm)	45	45	45	60	60 |

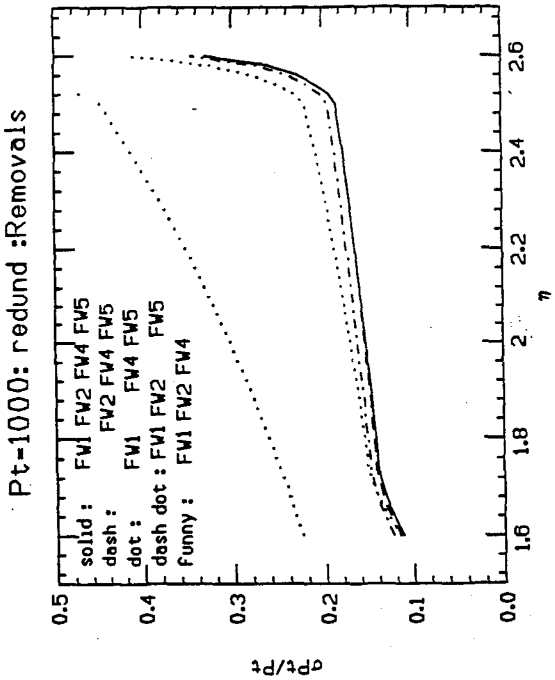
* Note: FW3 is an upgrade option under study.
Source: University of Maryland, Forward Detector Muon Sytem Report, 1/22/92

Updated: 24 Mar 92

Total tube number - 32240

All super layers measure 4 theta coordinates, but superlayers FW2 and FW5 also measure four stereo coordinates, i.e. two stereo (+7.5 °) and two stereo (-7.5°)

01543O



01543P

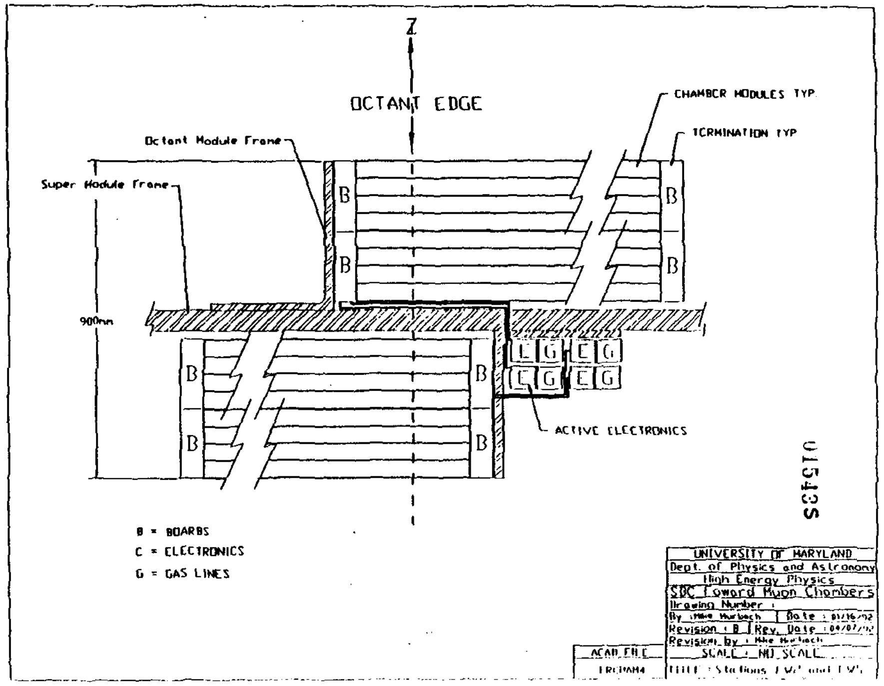
The octant modules are to be mounted onto a support frame, overlapped octant by octant.

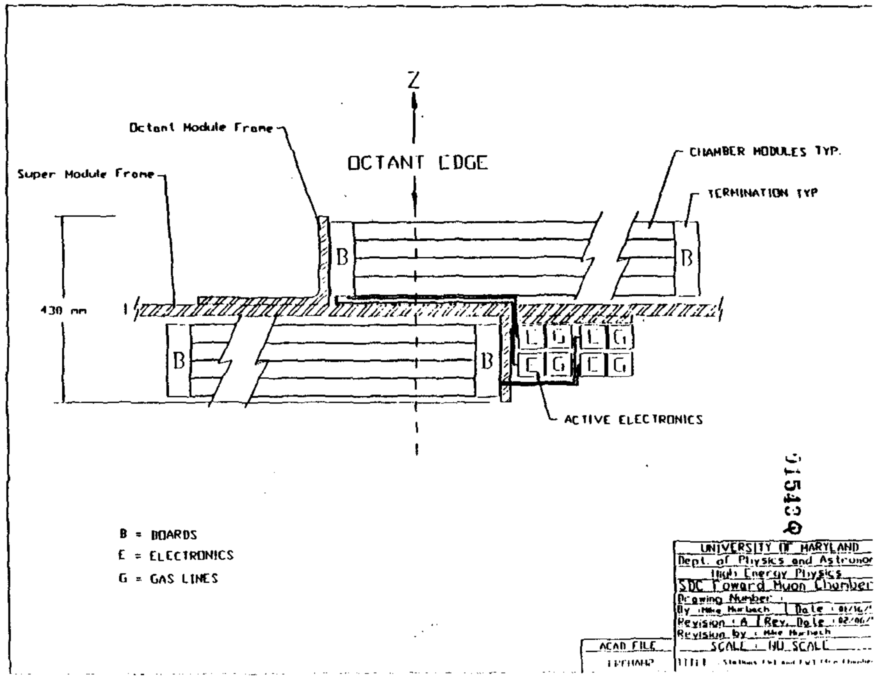
The octagonal support frame is made of extruded aluminum radial spokes and an inner and outer mounting rings to tie all the spokes together.

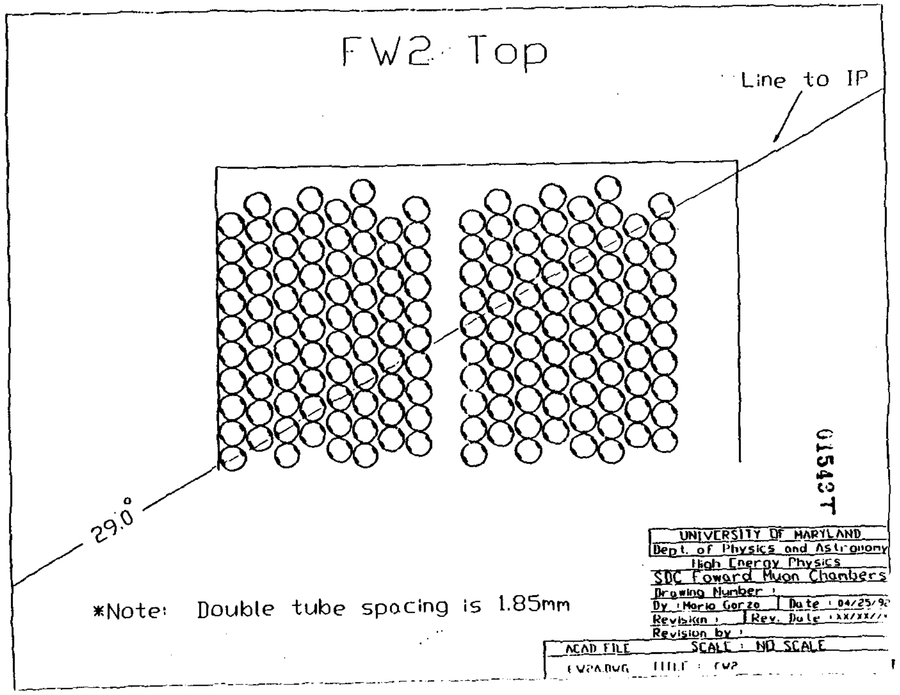
The extra depth in z provided by the octant modules overlap contributes to the structural strength of the module.

The gas, power and H.V. distribution boxes are located in the niches of this structure.

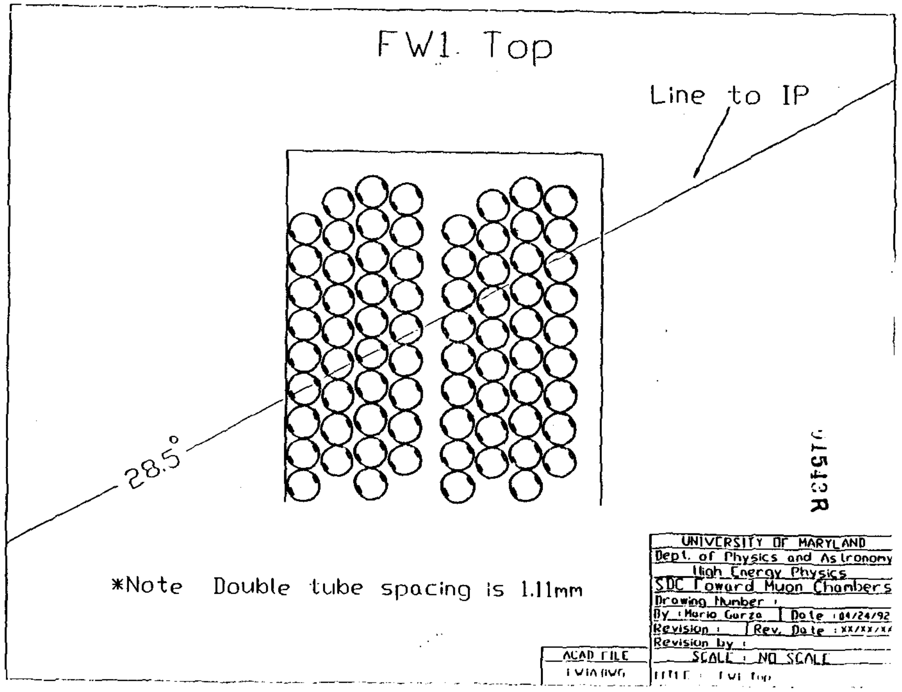
It has a weight less than 35 tons for the largest supermodule.



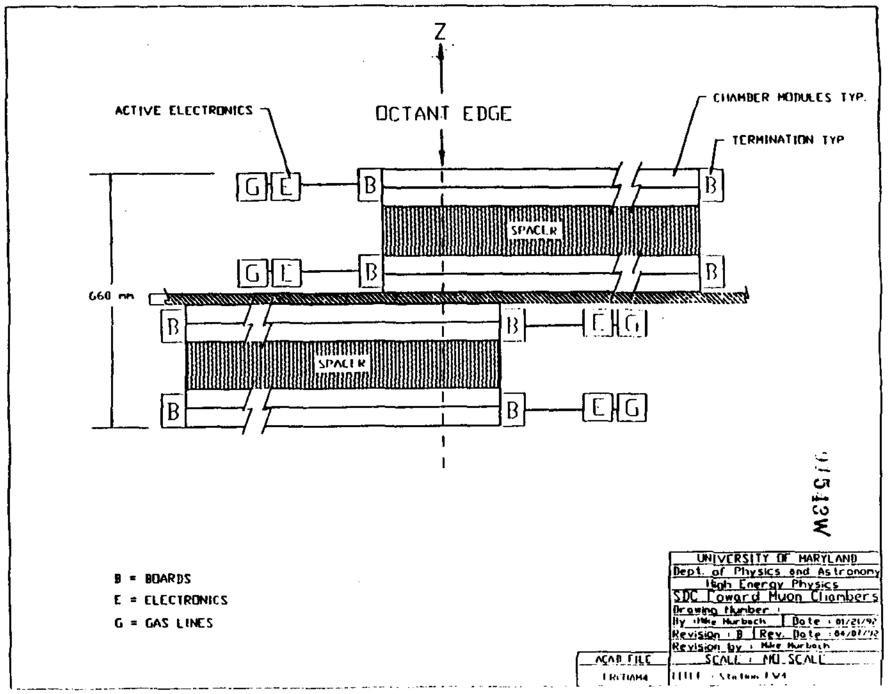




*Note: Double tube spacing is 1.85mm

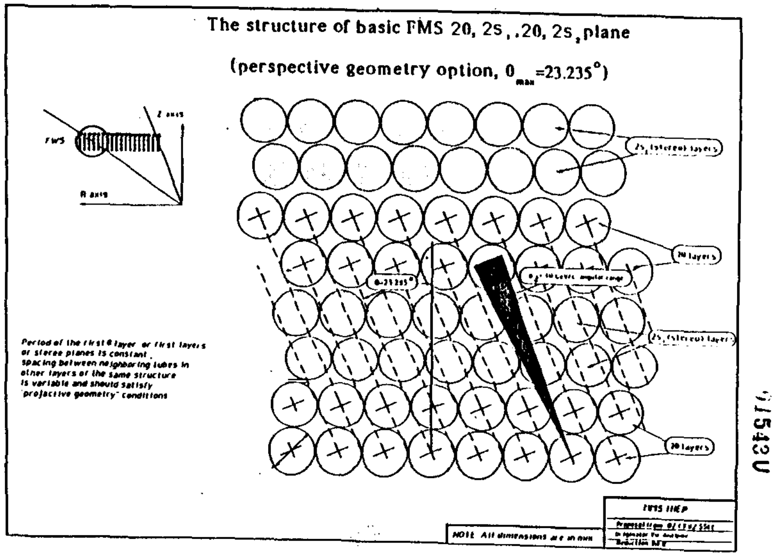


*Note Double tube spacing is 1.11mm

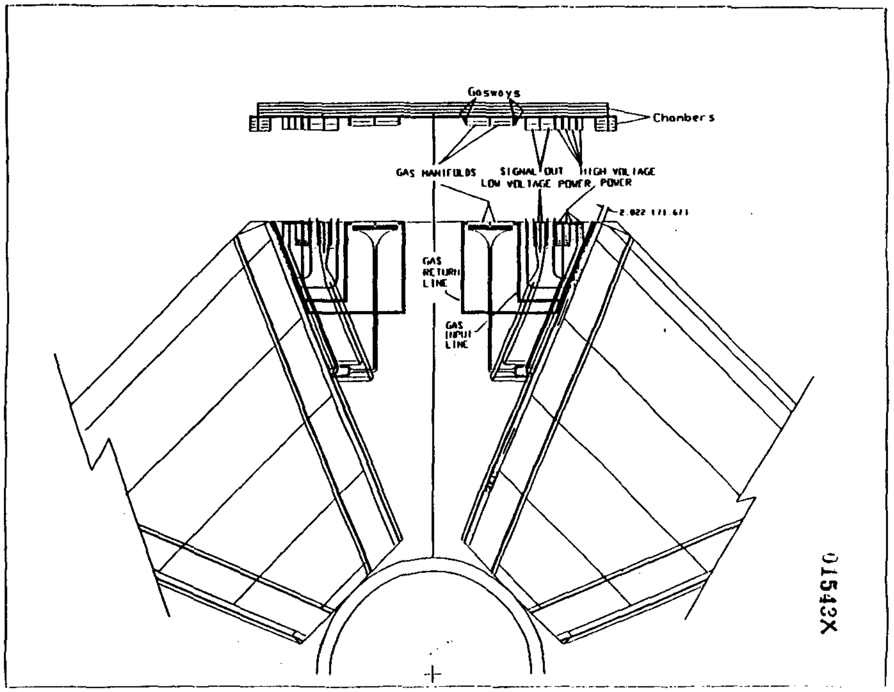


The structure of basic FMS 20, 2s , .20, 2s plane

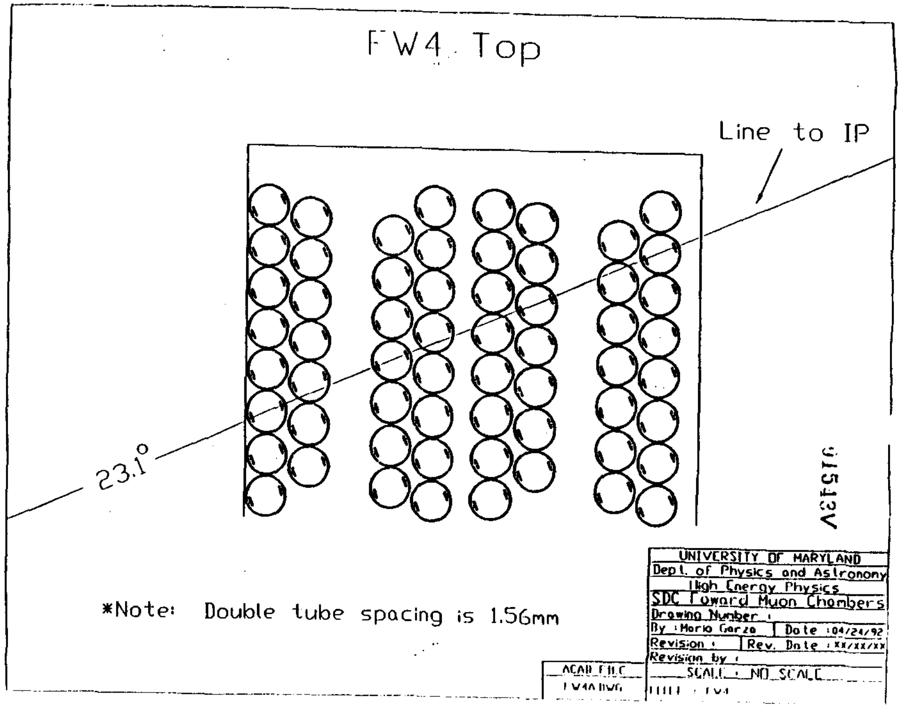
(perspective geometry option, 0_{max}=23.235°)



Period of the first θ layer or first layers of stereo planes is constant.
Spacing between neighboring tubes in other layers of the same structure is variable and should satisfy "projective geometry" conditions

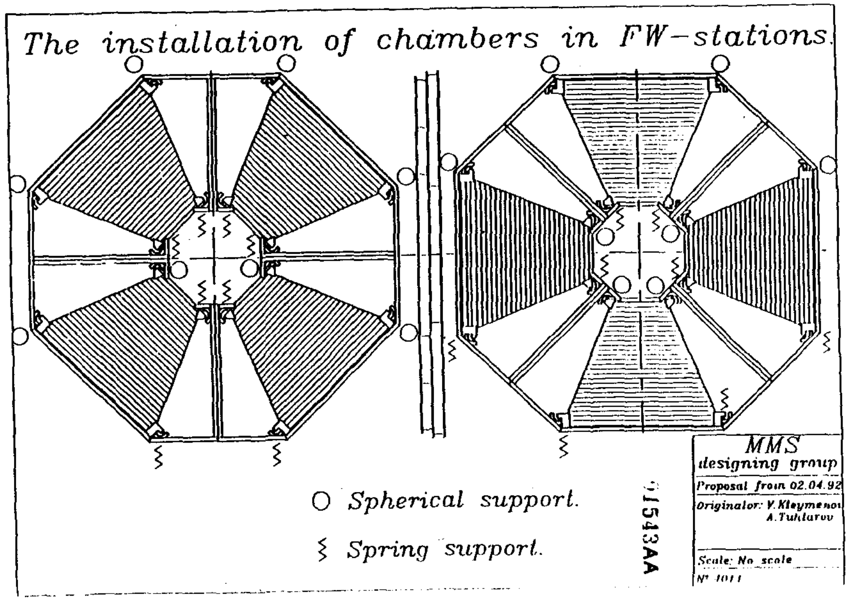


FW4 Top

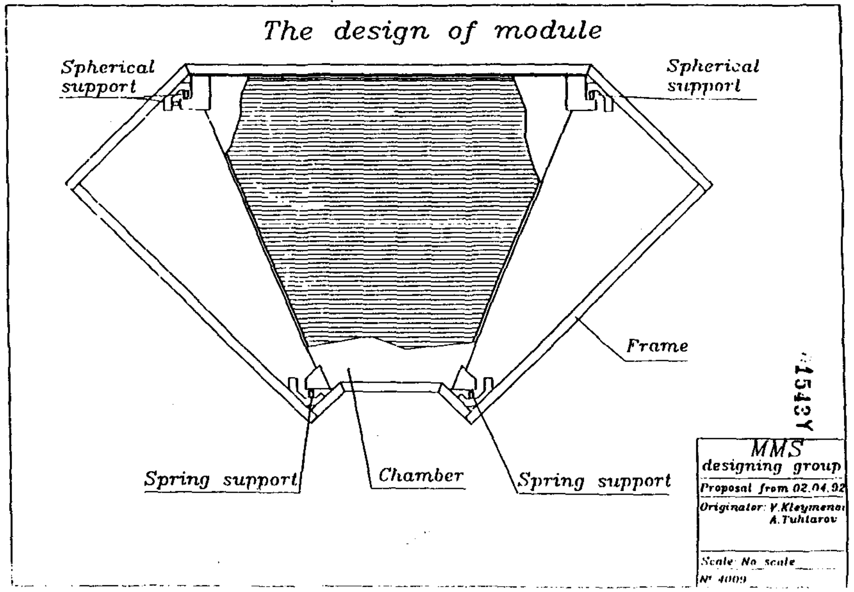


*Note: Double tube spacing is 1.56mm

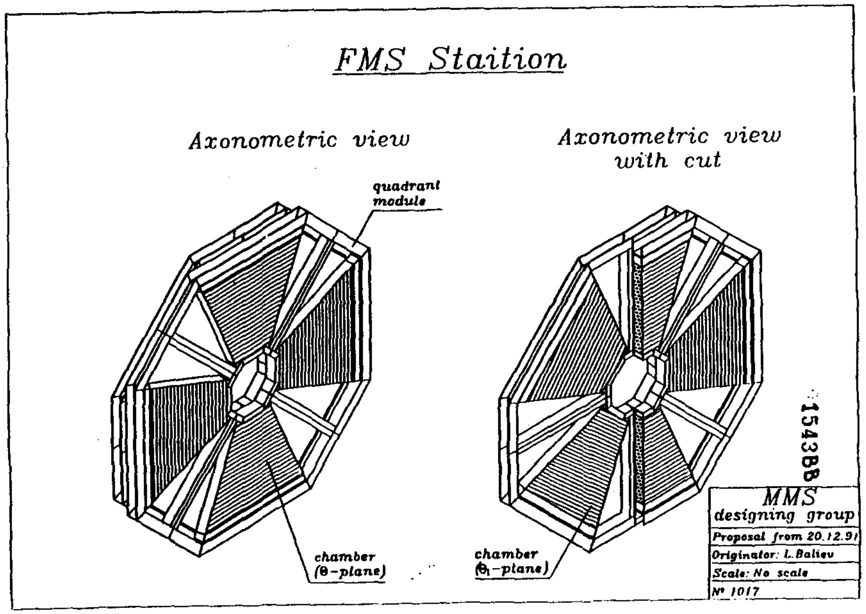
The installation of chambers in FW-stations.



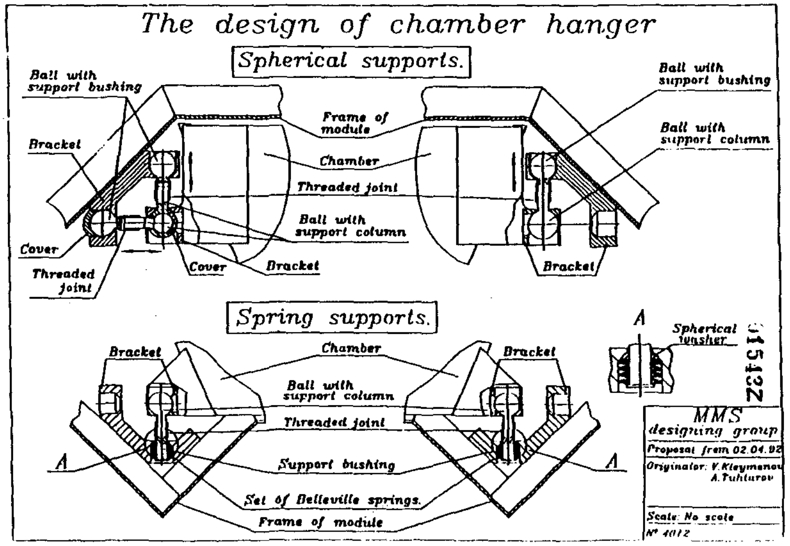
The design of module



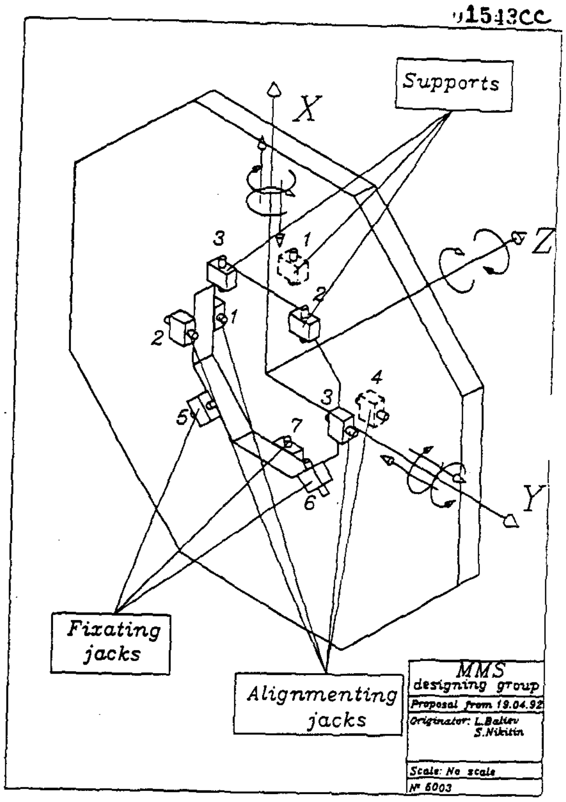
FMS Staition



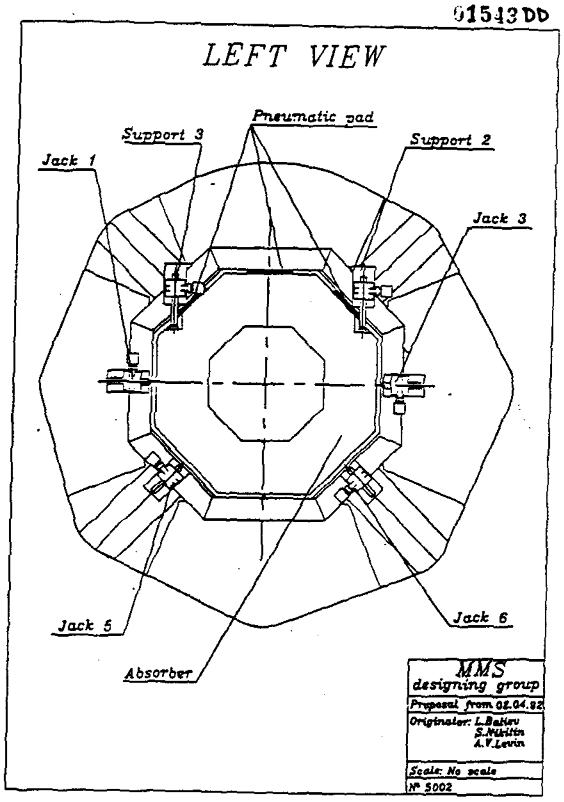
The design of chamber hanger



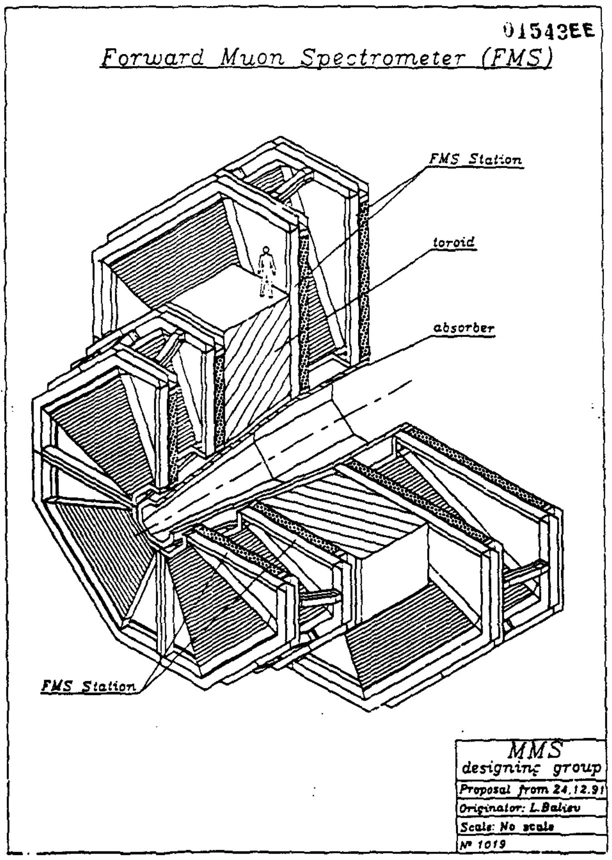
01543CC



01543DD



01543EE



01543FF

Forward Muon System Drift Tubes

The forward muon system drift tubes are round tubes with field-shaping electrodes.

The baseline design is a smaller diameter version of the central tubes, namely 42 inside diameter for FW1,FW2 and 57 inside diameter for FW4 and FW5, but alternative candidates also exists.

All such drift tubes will be tested in a high-energy particle beam during the next six months, and their characteristics compared to the baseline design.

The drift tube must have a single-track resolution better than 250 μm and two-track separation better than 5 mm.

IHEP April 92
Test Beam Run

01543GG

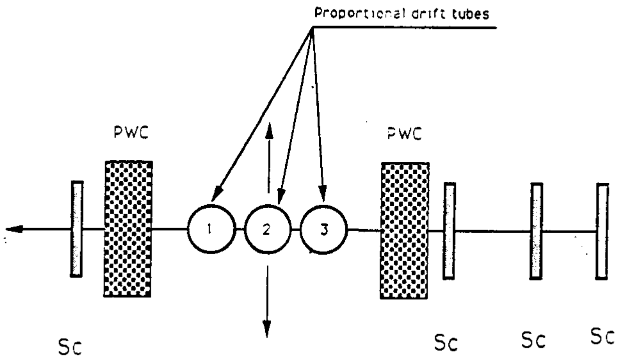
The tasks of this run:

1. **to study proportional drift tubes (SSCL-Washington design) with various gas mixtures;**
2. **to study spatial resolution for some gas mixtures;**
3. **to study two track separation;**
4. **test thin wall drift tube with wires field-shaping electrodes.**

IHEP April 92
Test Beam Run

01543HH

Test Beam Layout

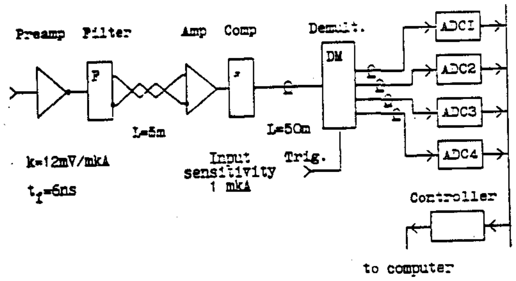


Momenta of beam particles - 40 GeV/c
PWC- Proportional wire chamber,
PWC spatial resolution σ =0.3mm .
Sc - scintillation counters.
Drift tube #2 could be shifted perpendicular to the beam to study two-track resolution. In this studies sense wire outputs of tubes #2 and #3 were connected.

IHEP April 92
Test Beam Run

01543II

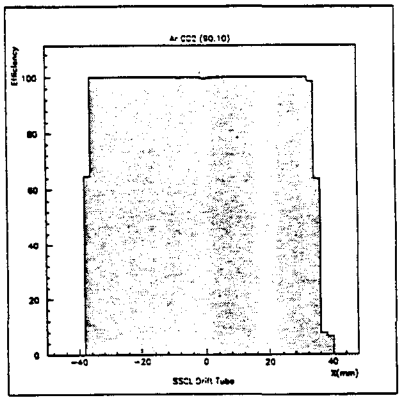
One channel measuring circuit



01543JJ

IHEP April 92
Test Beam Run Results
(preliminary)

Coordinate-Efficiency Dependence

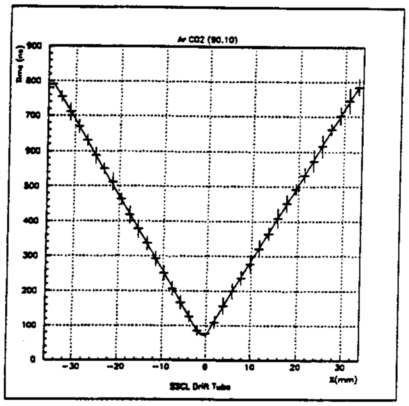


- H.V. on field shaping electrodes - 3.5 kV
- H.V. on anode wire - 4.5kV

IHEP April 92
Test Beam Run Results
(preliminary)

1543KK

Time-Coordinate Correlation



- H.V. on field shaping electrodes - 3.5 kV
  H.V. on anode wire - 4.5kV

* Points represents the average value of time distributions in each Δx bin.

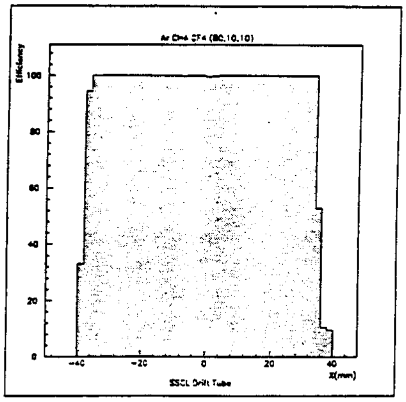
** Error bars represents the σ of time distributions in each Δx bin, but not the σ of average values.

4/30/92 YA

IHEP April 92
Test Beam Run Results
(preliminary)

1543LL

Coordinate-Efficiency Dependence

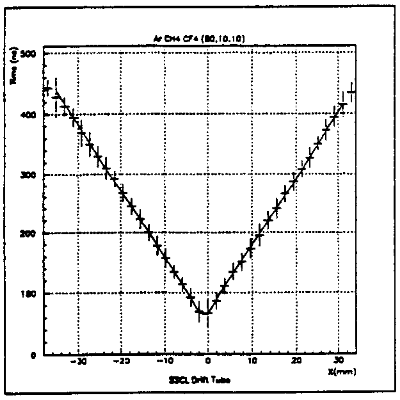


- H.V. on field shaping electrodes - 4.0 kV
  H.V. on anode wire - 5.0 kV

IHEP April 92
Test Beam Run Results
(preliminary)

1543MM

Time-Coordinate Correlation



- H.V. on field shaping electrodes - 4.0 kV
  H.V. on anode wire - 5.0 kV

* Points represents the average value of time distributions in each Δx bin.

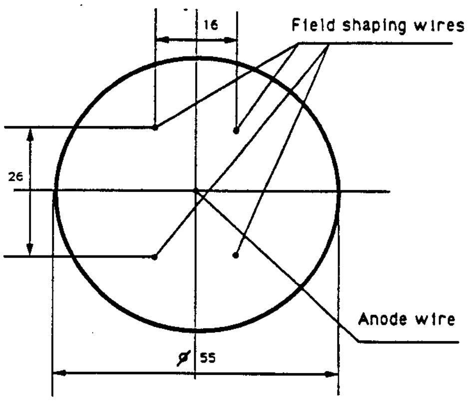
** Error bars represents the σ of time distributions in each Δx bin, but not the σ of average values.

4/30/92 YA

IHEP April 92
Test Beam Run

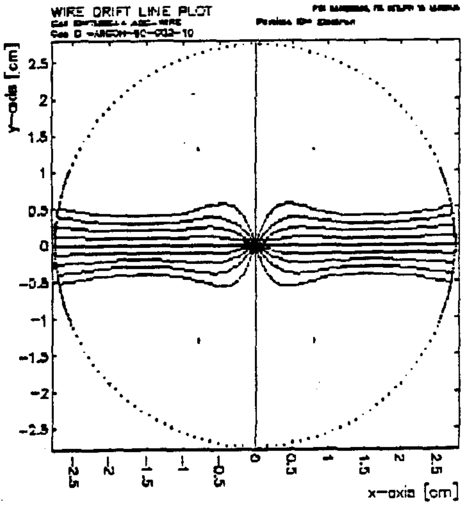
1543NN

Cross-section of drift tube with 4 additional field-correcting wires



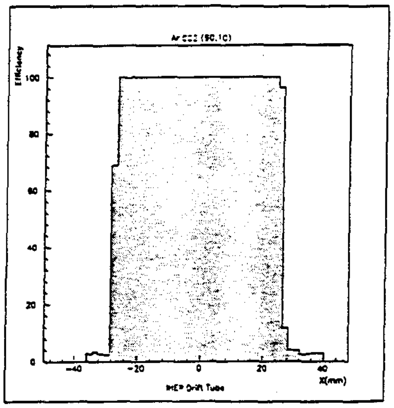
Anode wire - 0.05 mm
Field-correcting wires - 0.2 mm

5/1/92 YA



IHEP April 92
Test Beam Run Results
(preliminary)

Coordinate-Efficiency Dependence

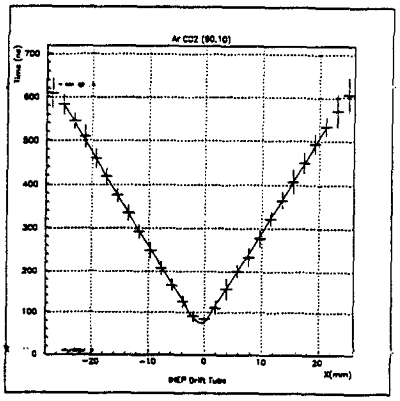


- H.V. on field shaping electrodes - 4.0 kV
- H.V. on anode wire - 3.8kV

5/1/92 YA

IHEP April 92
Test Beam Run Results
(preliminary)

Time-Coordinate Correlation

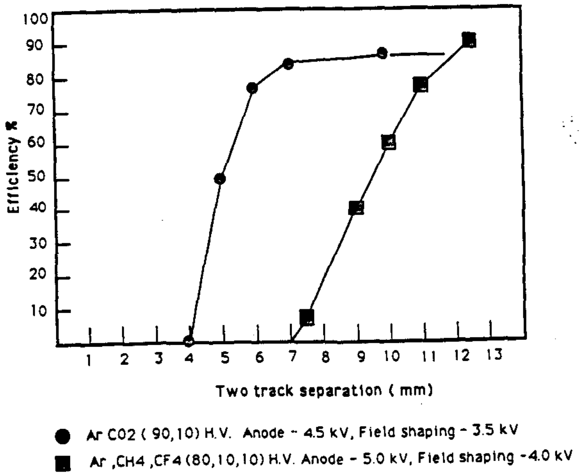


- H.V. on field shaping electrodes - 4.0 kV
H.V. on anode wire - 3.8kV
* Points represents the average value of time distributions in each Δx bin.
** Error bars represents the σ of time distributions in each Δx bin, but not the σ of average values.

4/30/92 YA

IHEP April 92
Test Beam Run Results
(preliminary)

Second Track Detection Efficiency



● Ar CO2 (90,10) H.V. Anode - 4.5 kV, Field shaping - 3.5 kV
■ Ar ,CH4 ,CF4 (80,10,10) H.V. Anode - 5.0 kV, Field shaping -4.0 kV

5/1/92 YA

IHEP April 92
Test Beam Run

Preliminary Results Summary

1. For SSCL-Washington drift tubes gas mixtures such as:
    Ar CO_2 (90%,10%)
    [V^{-1} = 21 ns/mm]
    and
    Ar CH_4 CF_4 (80%,10%,10%)
    [V^{-1} = 11 ns/mm]
give stable operational conditions.

2. Spatial resolution for a single drift tube are:
<200 μm for Ar CO_2 (90%,10%)
<250 μm for Ar CH_4 CF_4(80%,10%,10%)

3.Two track separation are about:
5mm for Ar CO_2 (90%,10%) ;
10 mm for Ar CH_4 CF_4(80%,10%,10%)
and can be improved by proper pulse shaping.

4. Characteristics of the tubes with wires field-shaping and SSCL-Washington design are close.

Conclusions

1. Detection a very high energy muon in forward direction is a challenge.

2. Proposed forward muon system is adequate for the task.

3. Further test beams studies of proportional drift tubes with field shaping at BNL and at IHEP can be very useful.

4. Substantial amount of design work should be done at US and Russia.

5. Qualification of people and the resources University of Maryland and IHEP group are sufficient to fulfil a job.

01544

SCINTILLATION COUNTERS

R. THUN

SDC MUON SCINTILLATORS

R. Thun...5 May 92

1. **Function, Requirements, Rates**
2. **Baseline Configuration**
3. **Who Is Doing What**
4. **R&D**
5. **Barrel Counter Prototype**
6. **Barrel Mounting Scheme**
7. **Forward System**
8. **Possible Upgrades**
9. **What Needs To Be Done**

Function

1. Identify beam crossing associated with muon
2. Provide position information for trigger

Requirements

1. Time resolution: significantly better than 16 nsec
2. Efficiency: greater than 99%
3. Integrated with rest of trigger system

Rates in Barrel and Intermediate System

(Standard luminosity; -1.5< η <1.5)

1. Muons from pion and kaon decay............42 kHz
2. Muons from charm and bottom decay.....45 kHz
3. Cosmic-ray muons....................................20 kHz
4. Punch-thru, neutrons..........................<100 kHz

Total rate per counter <100 Hz

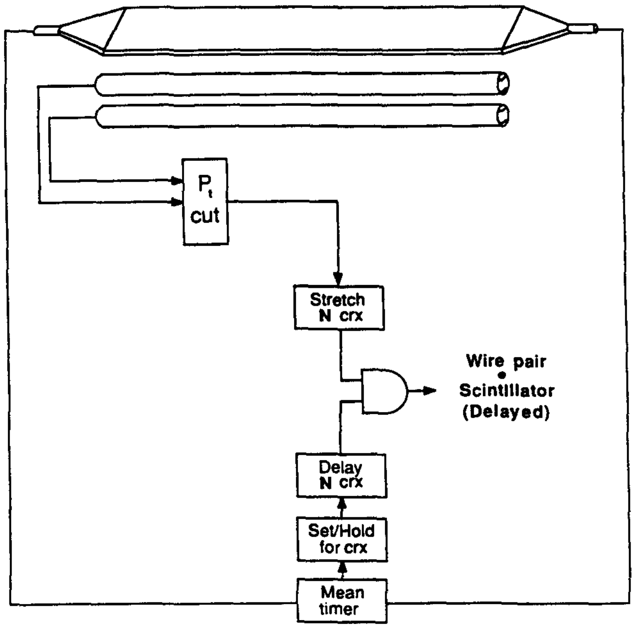
Rates in Forward System

(Standard luminosity; 1.5< $|\eta|$ <2.5)

1. Muons from pion and kaon decay.............400 kHz
2. Muons from charm and bottom decay.......100 kHz
3. Neutrons..........................perhaps at level of MHz

Total rate per counter (est).....0.1-10 kHz

Simplified Muon Trigger



Baseline Configuration

Barrel and Intermediate Region

1. Single layer of counters, BS2 and IS2
2. Each counter approx. 1.0 x 50 x 185 cm
3. Two phototubes per counter; one at each end
4. Both signals in coincidence thru mean-timer
5. Time resolution <1.0 nsec
6. Number of photoelectrons >20 everywhere
7. Number of counters = 1920 (BS2) + 320 (IS2)

Forward Region

1. Two layers of counters, FS4 and FS5
2. Counter widths vary from 7 to 23 cm
3. One phototube per counter
4. Two layers in coincidence thru mean-timer
5. Time resolution (est) 1.0 nsec
6. Number of photoelectrons >20 everywhere
7. Number of counters = 1120 (FS4) + 1136 (FS5)

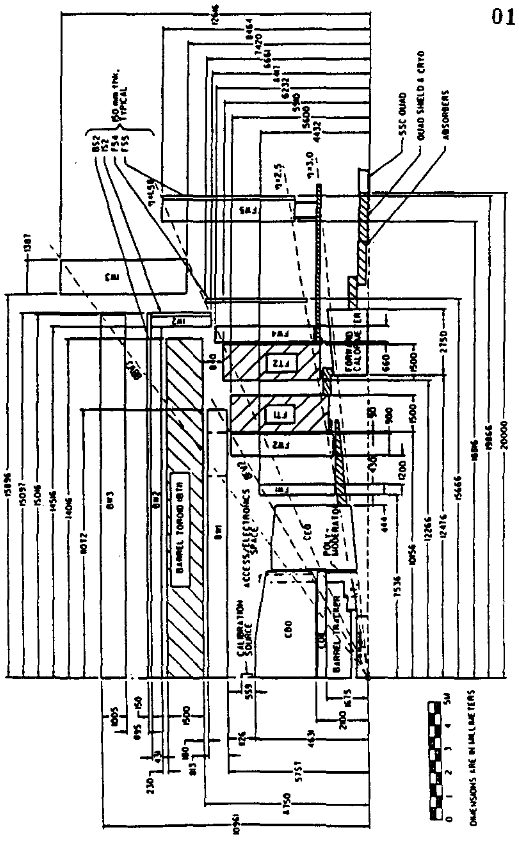
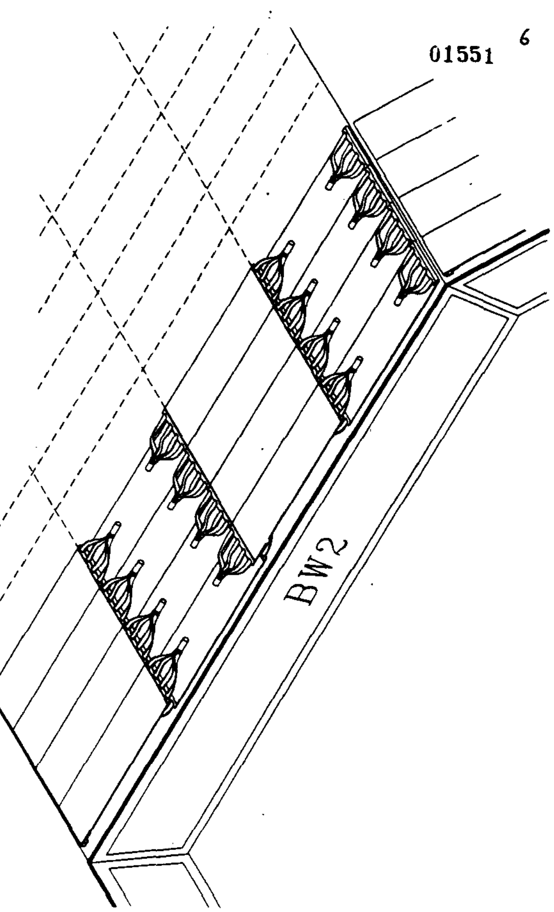
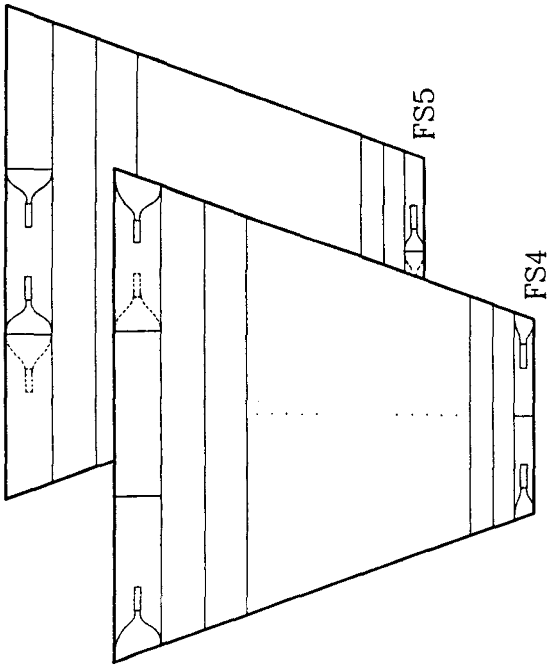


FIG. 2-7. Layout of the muon system.

SDC BARREL MUON SCINTILLATORS



SDC FORWARD MUON SCINTILLATORS



Who Is Doing What

University of Michigan

Counter R&D, design, testing:

E. Dodd, S. Hong, R. Thun, C. Weaverdyck

M. Marcin (now at U. of Texas)

Electronics and trigger:

J. Chapman, K. Hashim, J. Mann, C. Murphy

Various contributions:

K. De, R. Gustafson, M. Longo, L. Oesch, G. Tarle

University of Arizona

Neutron measurements, design of PMT bases:

K. Johns

IHEP (Serpukhov)

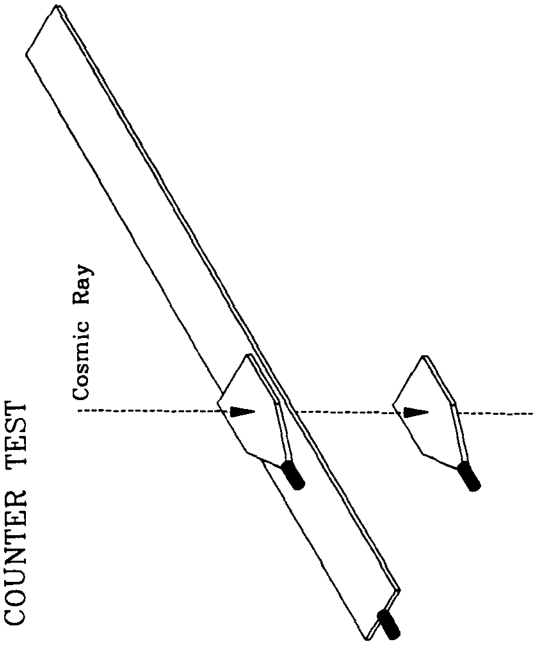
Counter and phototube R&D:

V. Rykalin and collaborators

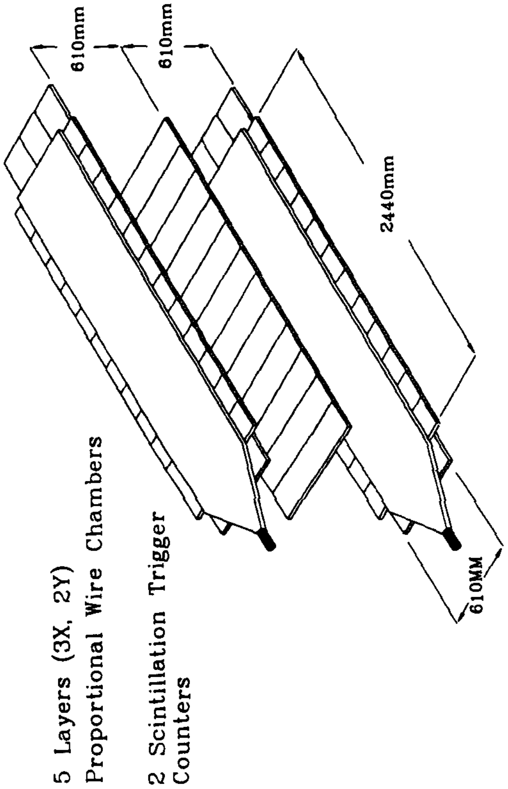
Muon Counter R&D

1. **Scintillator Properties**
2. **Light Guides**
3. **Optical Coupling**
4. **Mean-Timer**
5. **Base Design**
6. **Photomultipliers**
7. **Calibration System**
8. **Mechanical Integration**

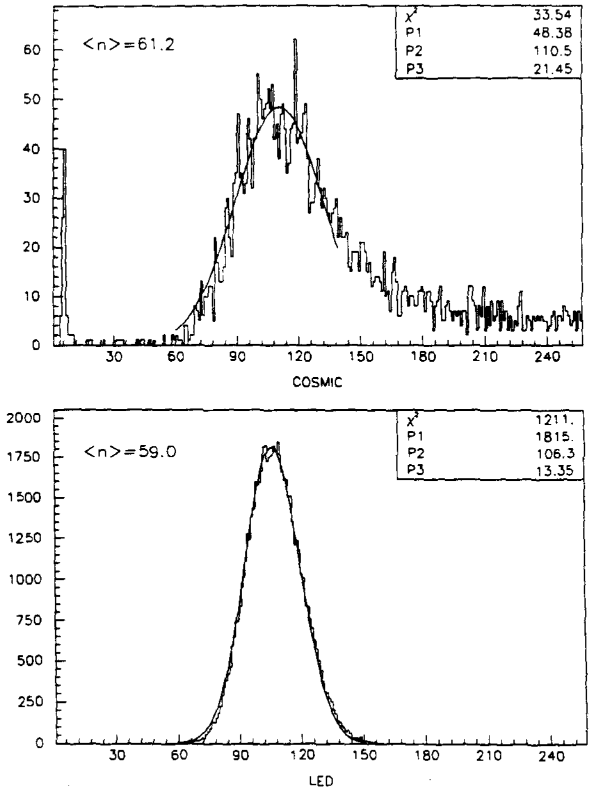
COUNTER TEST



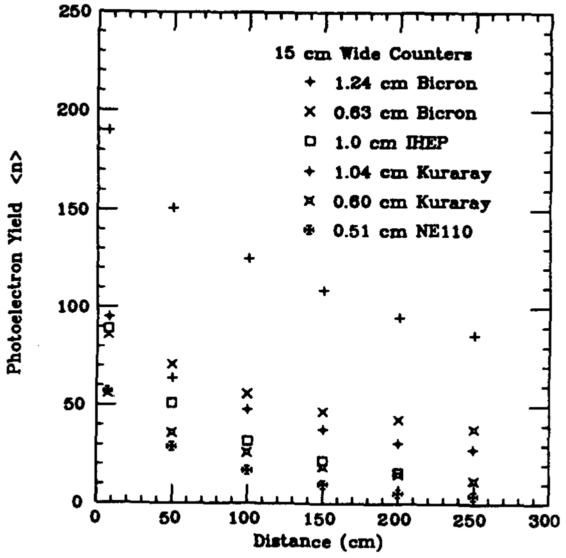
Cosmic Ray Test Stand

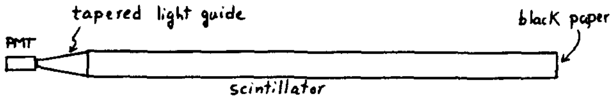


Kuraray SCSN-81 (17cm from light guide)

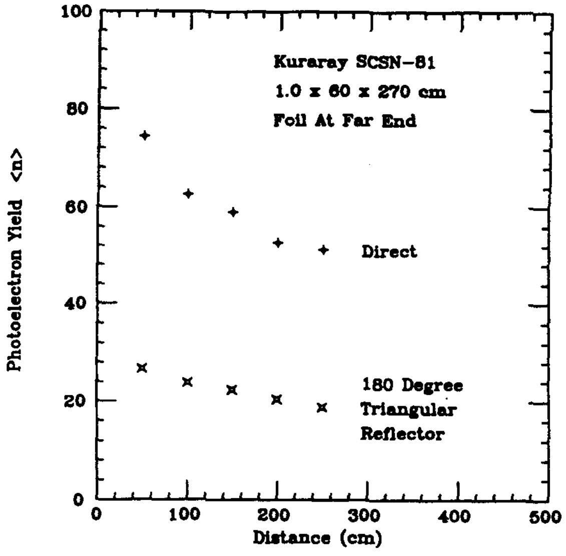


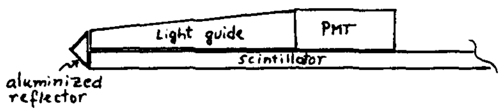
Scintillator Light Yields



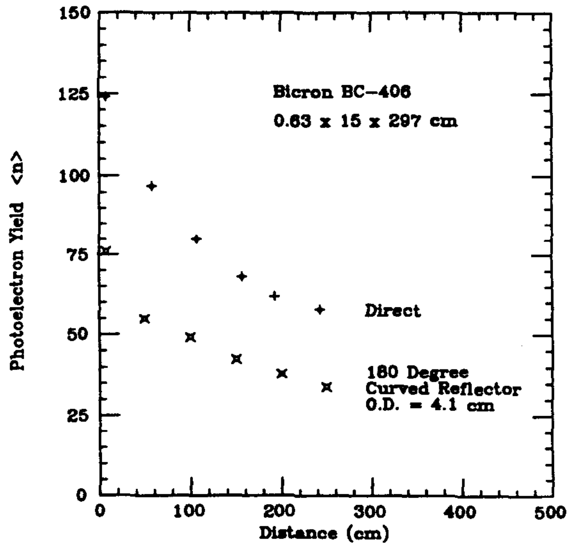


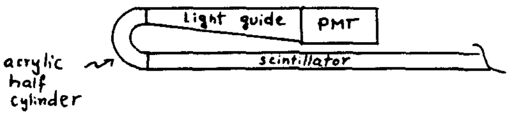
Test of Simple Reflector



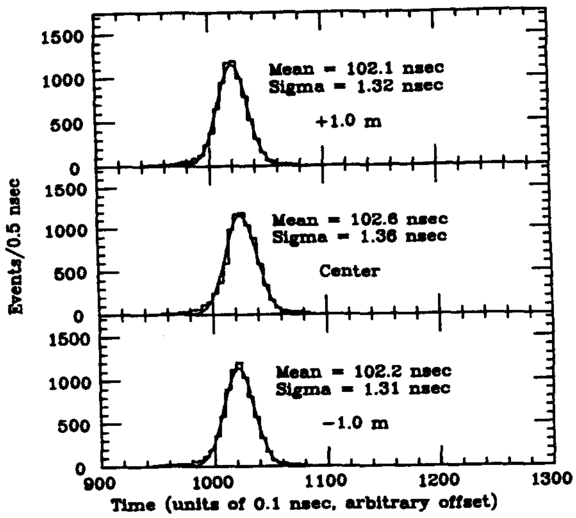


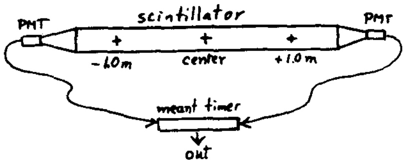
Test of Compact, Curved Reflector





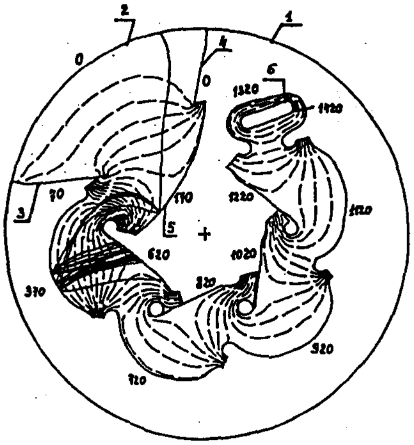
Mean-Timer Measurements



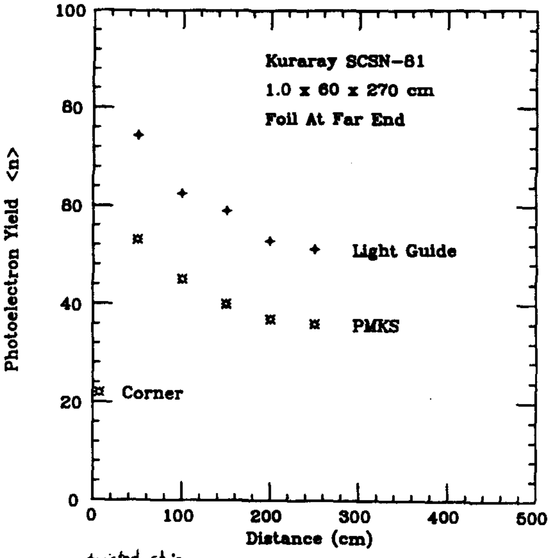


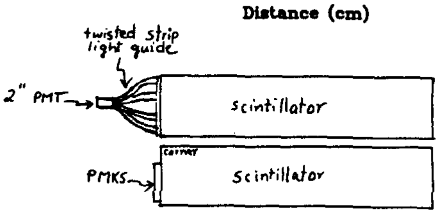
IHEP Design "PMKS"

16 cm long photocathode



Cross section view of one - dimentional coordinate - sensitive PM with discrete dynodes. 1- PM tube, 2- photocathode, 3,4- side electrodes, 5- first dynode, 6- anode. The digits near both electrodes and dynodes are the voltages applied. The equipotential lines of electric field are shown by dashed lines. Calculated photoelectron trajectory and the first cascades of multiplying are shown by solid lines.





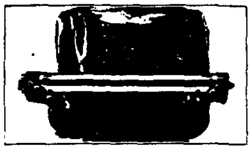
HAMAMATSU

TENTATIVE DATA
Feb. 1989

PHOTOMULTIPLIER TUBE

R2605-01

CYLINDRICAL SIDE-ON PHOTOMULTIPLIER TUBE
2 INCH DIAMETER, 20 INCH LENGTH, BIALKALI PHOTOCATHODE



GENERAL

- Spectral Response··········300 to 650nm
- Wavelength of Maximum Response···420nm
- Photocathode
  - Material·····················Bialkali
  - Minimum Useful Size······21mm× 370mm
- Window Material·····Borosilicate glass
- Dynode
  - Structure······Box-and-grid and mesh
  - Number of Stages···················12
- Base···················JEDEC No.B14-38
- Socket··············E678-14A(Optional)

MAXIMUM RATINGS (Absolute Maximum Values)

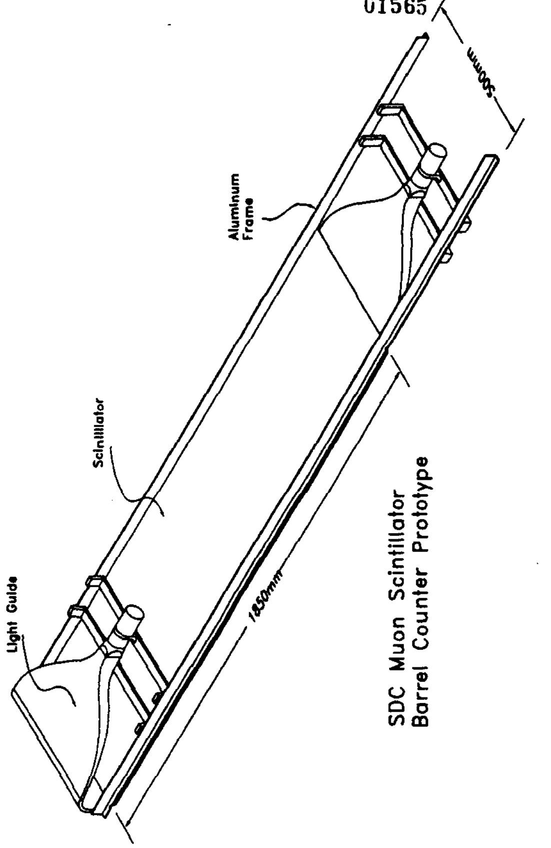
- Supply Voltage
  - Between Anode and Cathode·····························1500Vdc
- Average Anode Current··································0.1mA
- Ambient Temperature··································-80 to +50°C

CHARACTERISTICS(at 25°C)	Min.	Typ.	Max.	Units
Cathode Sensitivity				
Luminous(2856K)························	-	8D	-	μA/lm
Radiant at 420nm························	-	72	-	mA/W
Blue(CS No.5-58 filter)················	-	9.D	-	μA/lm-b
Anode Sensitivity				
Luminous(2856K)························	-	50	-	A/lm
Radiant at 420nm························	-	4.5× 10⁴	-	A/W
Current Amplification ··················	-	6.3× 1D⁵	-	
Anode Oark Current				
(after 30 minute storage in darkness)···	-	5D	-	nA
Time Response				
Anode Pulse Rise Time··················	-	6.4	-	ns
Electron Transit Time··················	-	35	-	ns

VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

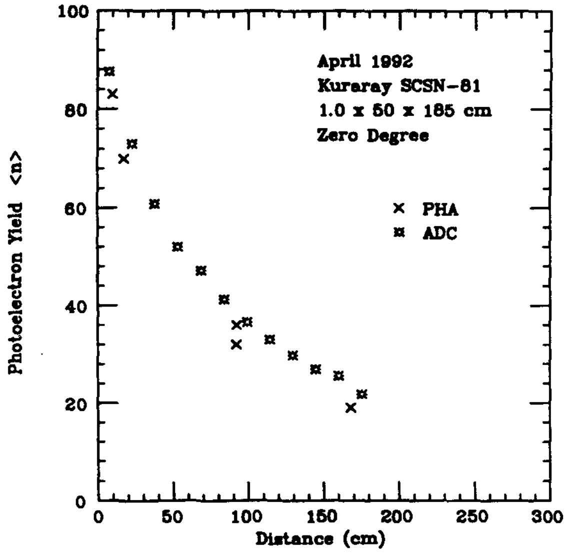
Electrode:	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	P.
Ratio:	2	2	1	1	1	1	1	1	1	1	1	1	1	

Supply Voltage:1250Vdc K:Cathode Dy:Dynode P:Anode



SDC Muon Scintillator
Barrel Counter Prototype

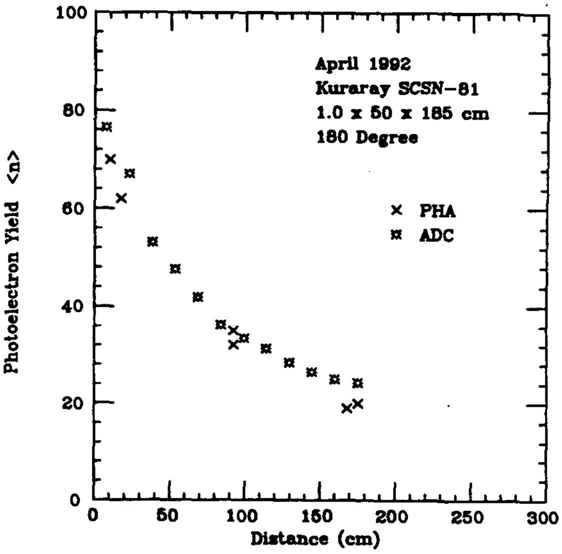
01566 21



SDC Barrel Prototype Counter

Straight Light Guide

01567 22

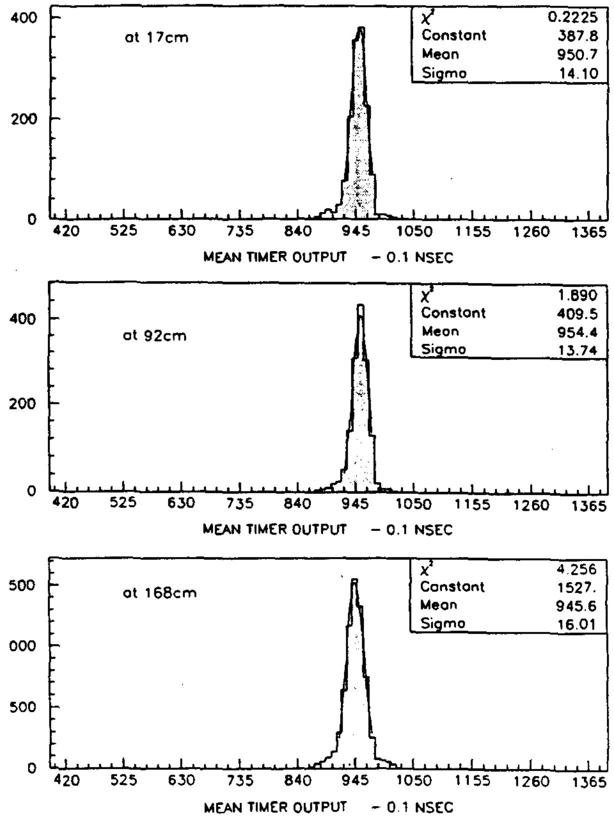


SDC Barrel Prototype Counter

Curved Light Guide

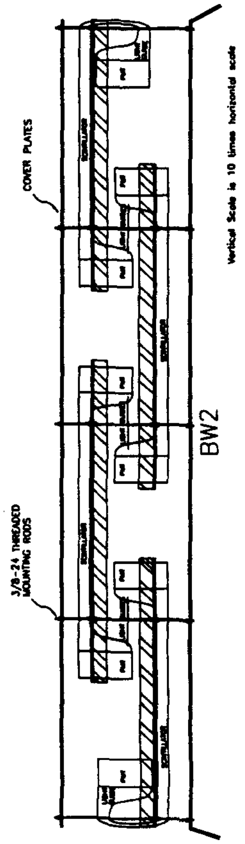
SDC Muon Scintillator
Barrel Counter Prototype

01568 23

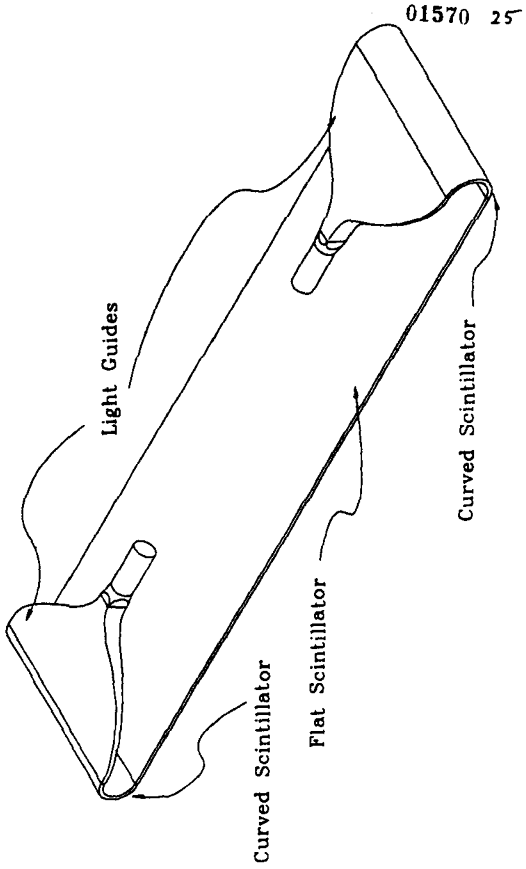


01569 24

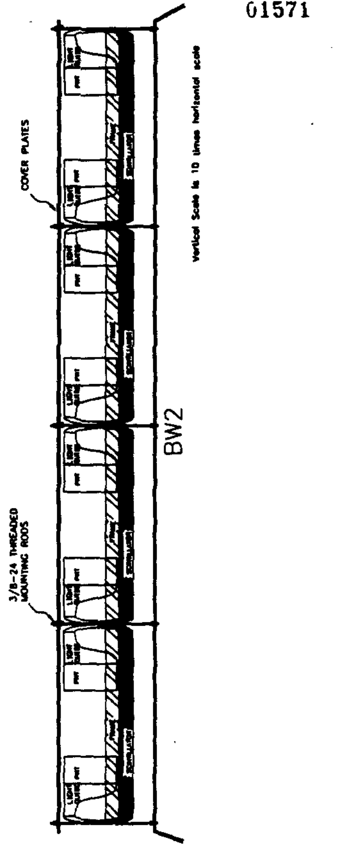
SDC Muon Scintillator Mounting Scheme



Alternate Counter Layout

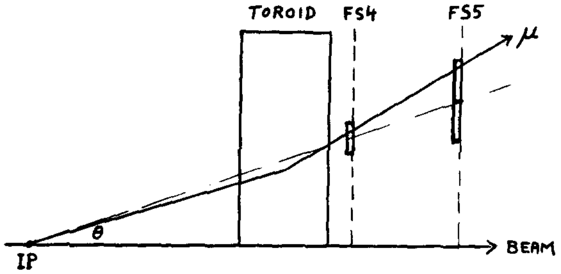


Alternate Scintillator Layout



Forward System

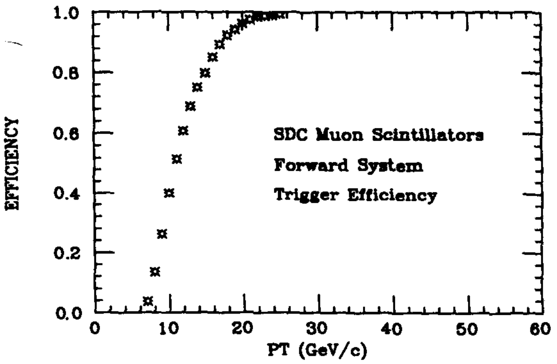
Two Layers Define Trigger Roads:



Constant Pt response requires:

Counter Width = Const$\cdot(\sin\theta)^{1.35}$

Will approximate varying width with a few discrete steps



Possible Upgrades

Forward Region

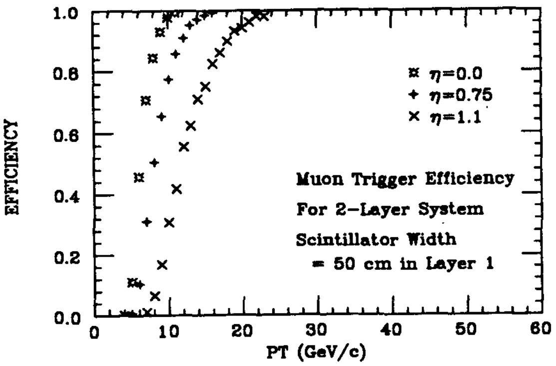
Cerenkov Counters (discussed elsewhere):

highly directional; insensitive to neutrons

Barrel and Intermediate Region

Addition of Second Layer; BS3 and IS3:

would allow fast Pt threshold;
less sensitive to neutrons, local backgrounds



What Needs To Be Done

1. **Refine barrel counter design**
2. **Fix barrel counter dimensions**
3. **Integrate mounting scheme**
4. **Design means of access**
5. **Fix FS4 and FS5 geometry**
6. **Develop photomultiplier base**
7. **Cost/performance study of PMTs**
8. **Develop calibration scheme**
9. **Construct full-scale prototype modules**

01577

CERENKOV OPTION

V. KUBAROVSKY

5.May.92
SSCL

The Cerenkov Counter for the Forward Muon System of SDC

Presented by V. Kubarovsky

Institute for High Energy Physics, Protvino
Russia

High luminosity of SSC

High collision rates

High flux of particles in the Forward Muon System

The particles rates in the forward system are expected to be approximately one order of magnitude higher than in the barrel.

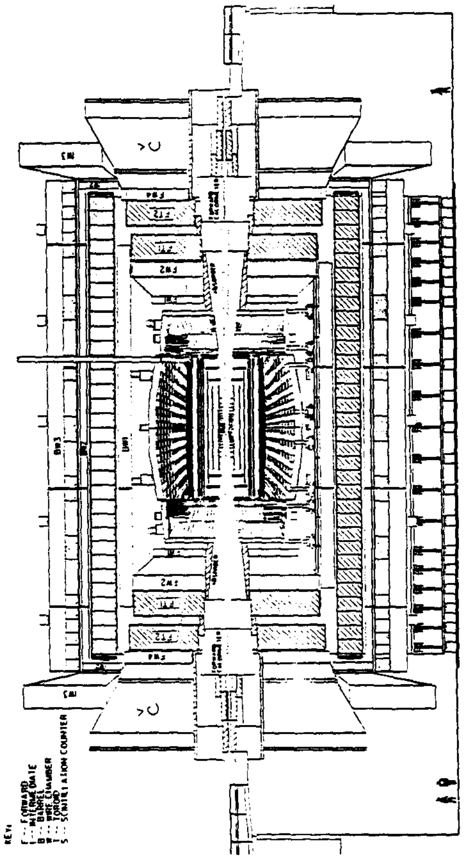
Very roughly our expectation are:

(a) Muons from pion and kaon decay	200 kHz
(b) Muons from charm and bottom decay	100 kHz
(c) Detected low energy neutrons	*uncertain but potentially high*

The overall rate is hardly to estimate at this time.

Low energy neutrons come from the interaction of the secondary particles in the construction elements such as beam-pipe, calorimeters and collimators.

It may be difficult to operate an efficient trigger system with only the use of standard scintillator counters, particularly at luminosity above the design value. For this reason, we are proposing, as an upgrade option, the incorporation of multi-cell nitrogen gas Cerenkov counters into the forward trigger.



Design Parameters of the Gas Cerenkov Counter

Parameter	Value
Gas medium	N_2
Gas pressure	1 atm.
Index of refraction	1.000309
Width of counter	2.00 m
Width of Cerenkov media	1.85 m
Number of photoelectrons	17.5
Number of cells per counter	200
Focal length of each mirror	1.40 m
Cerenkov ring radius at PMT	37 mm
Momentum threshold for muons	4.25 GeV
Momentum threshold for electrons	20 MeV

The Cerenkov counter has the obvious advantages for the background rejection.

1. The Cerenkov counter is very fast. It is easy to achieve the time resolution better than 1 ns.

2. The Cerenkov counter is two-fold device. It is possible to reject the particles in Θ and ϕ simultaneously. Scintillator and drift chambers are one dimensional devices.

3. The Cerenkov counter is completely insensitive to the neutrons and the low momentum particles expected as a main background.

Momentum threshold for muons = 4.25 GeV/c,
for electrons and positrons = 20 MeV/c).

98% of the background particles in the Cerenkov box have gamma < threshold value !

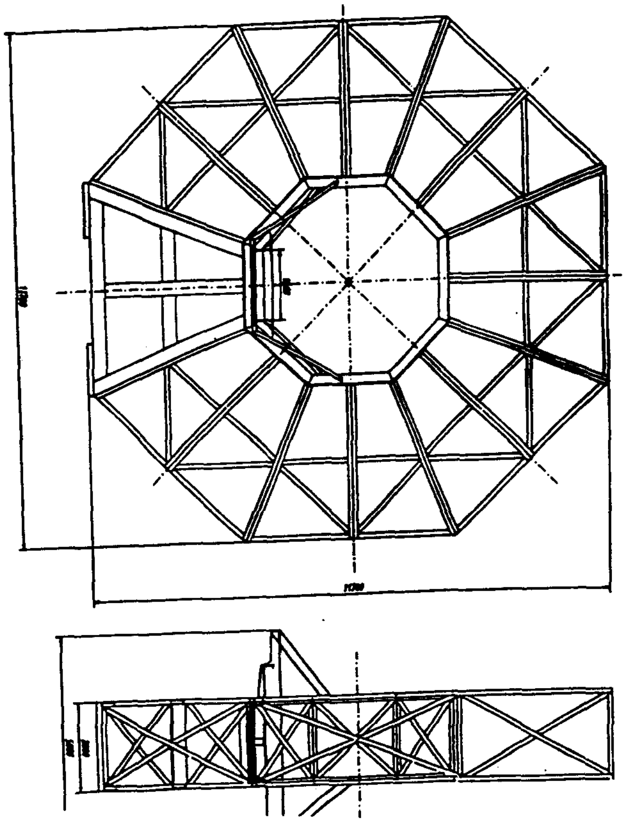
$$\frac{\text{Background rate of the Cerenkov counter}}{\text{Background rate of the scintillator hodoscope}} << 1$$

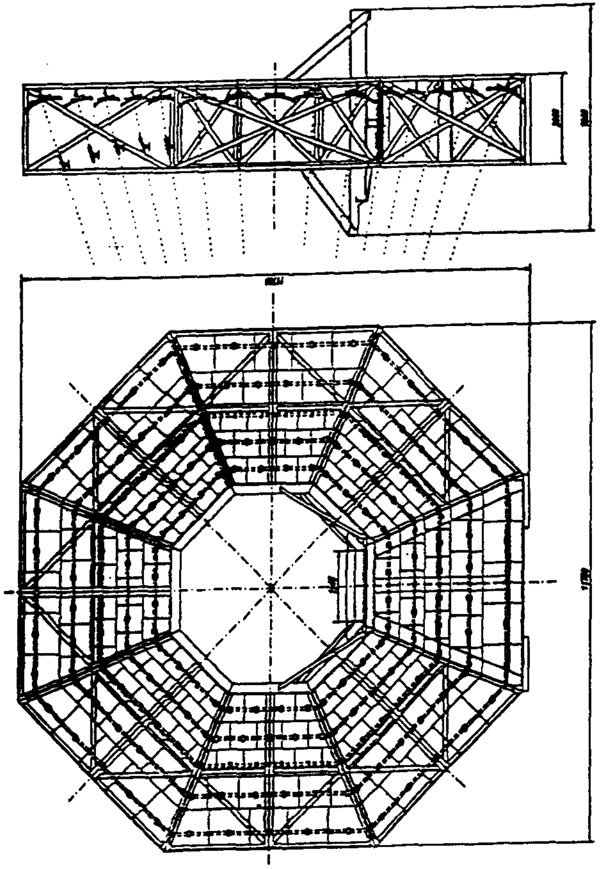
Mechanical Structure

The counter in each end is divided into octants located radially and perpendicular to the beam line Fig. 2-3 shows a frontal schematic view of the support structure, mirror structure and the location of the photomultipliers. Each photodetector observes one mirror.

There will be approximately:

25 cells in one octant,
200 cells in each counter
400 cells in the whole system.





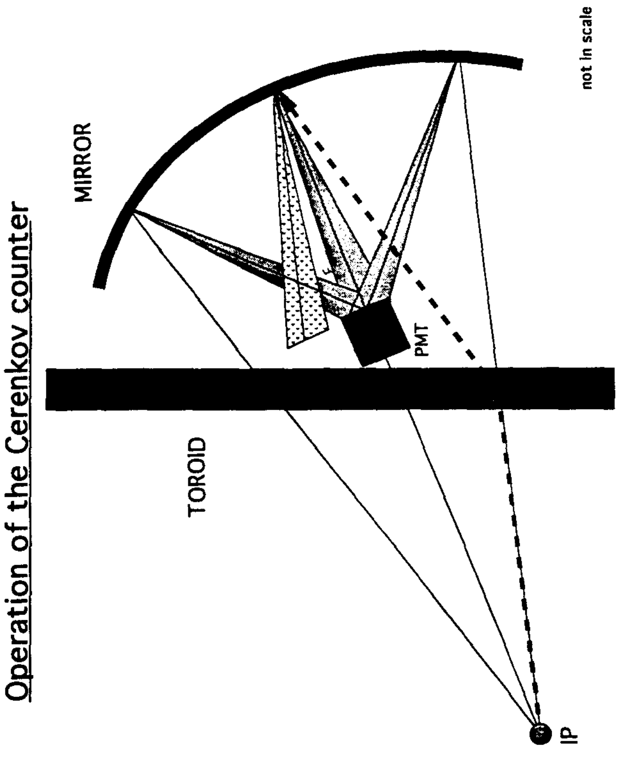
Operation of the Cerenkov Counter

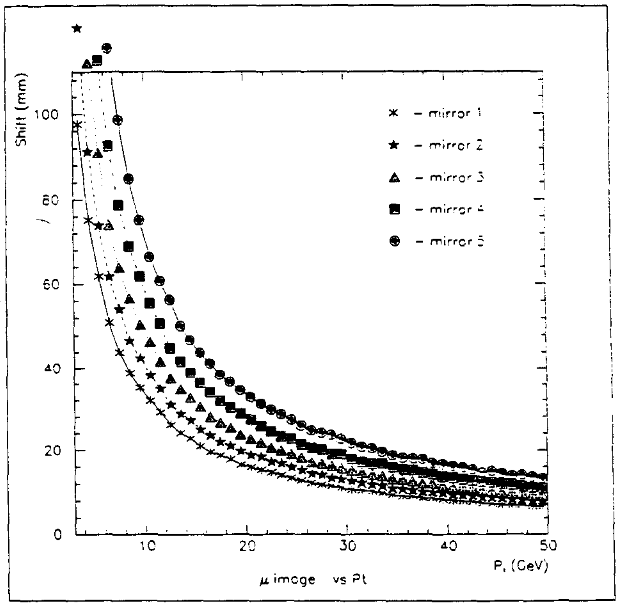
The photodetector is placed near the image of the interaction point (IP). High energy muons have low deflection angle in the iron toroid. The center of the Cerenkov ring lies in the image of IP.

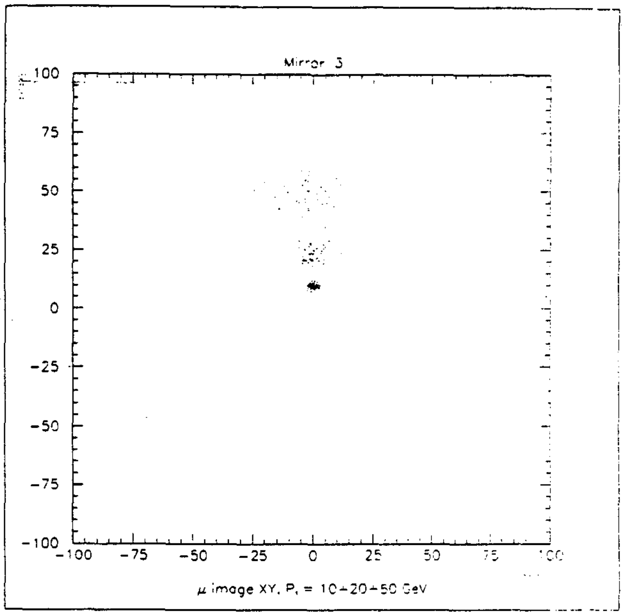
As a muon is bent by the magnetic field in the forward toroids, the Cerenkov ring moves in the PMT's plane in proportion to the momentum. The Cerenkov photons from low energy muons go away from the photomultiplier face.

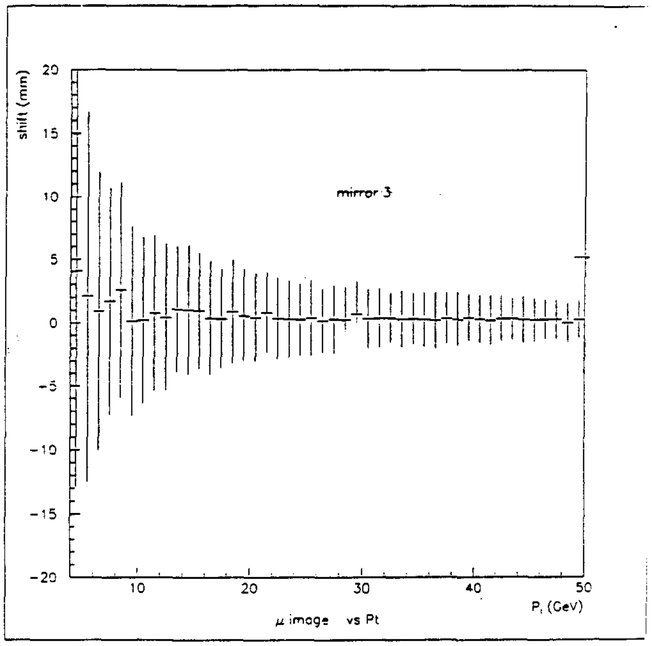
The effect of multiple scattering is minimal compared to the toroid bending power. The multiple scattering is about 1/7 of the bend angle and this ratio is independent of momentum.

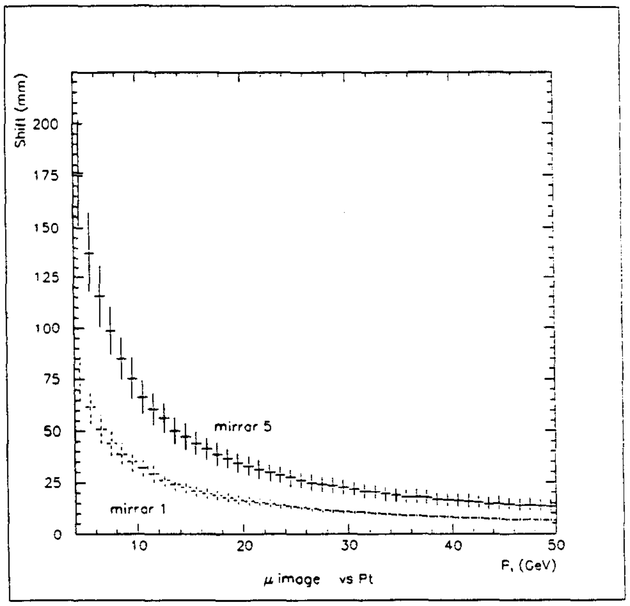
The effect of multiple scattering is clearly seen in the increasing spread of light rings for low energy muons. The scatter in the 300 GeV ring is due to mainly to spherical aberrations.











Optimization of the geometry of the Cerenkov counter.

There are some free parameters to be optimized.

The distance between the mirror and photodetector.

The focal length of the mirror.

The size of the mirror.

The geometry of the photodetector.

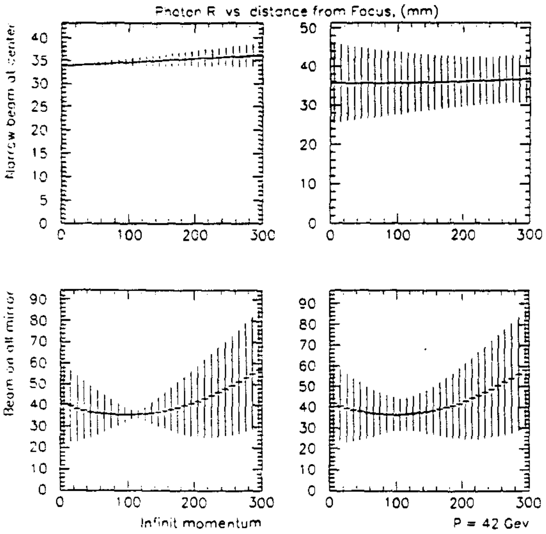
The distance between the mirror and photodetector.

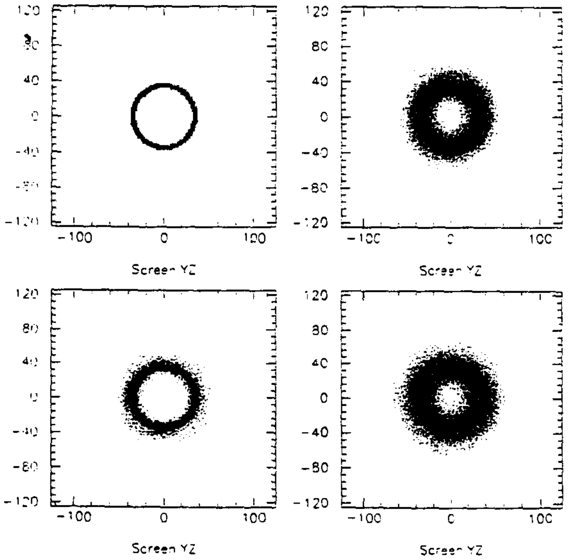
If the particle hits the mirror in its center the best position of the PM is the focal plane.

But in the case when the source of the particles is a point and beam is spread over all the mirror the best position of PM lies near the image of IP in the mirror.

In this case the Cerenkov rings have no additional shift with respect to the rings from "central" particles.

14/01/92 07.58





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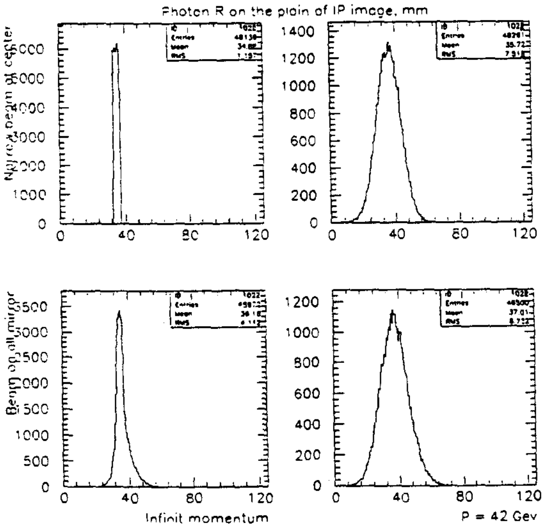


The Focal Length of the Mirror

In the first approximation we have a 'scaling' of the image in the plane of PM with respect to the mirror's focal length. By this reason the rejection power of the Cerenkov counter is independent on the focal length.

It is better to place PM as far from the mirror as possible (if the size of the photodetector is big enough).
In this case the effect of the shadow of PM is minimal.

Mirror	1	2	3	4	5
η	2.41	2.25	2.09	1.92	1.77
Θ (mrad)	178	209	245	287	334
Size (mm)	480	570	768	810	974

The size of the mirror varies from 480 mm near the beam to 974 mm at outer row

The background is significantly greater at small radii. The increase of the density of PMT's near the beam line leads to approximately equal background rate per one PMT.

The geometry of the photodetector.

The rejection power of the detector may be improved by using two PM's per channel with rather small diameter (2"). The coincidence of PM's is required.

Advantages of such construction:

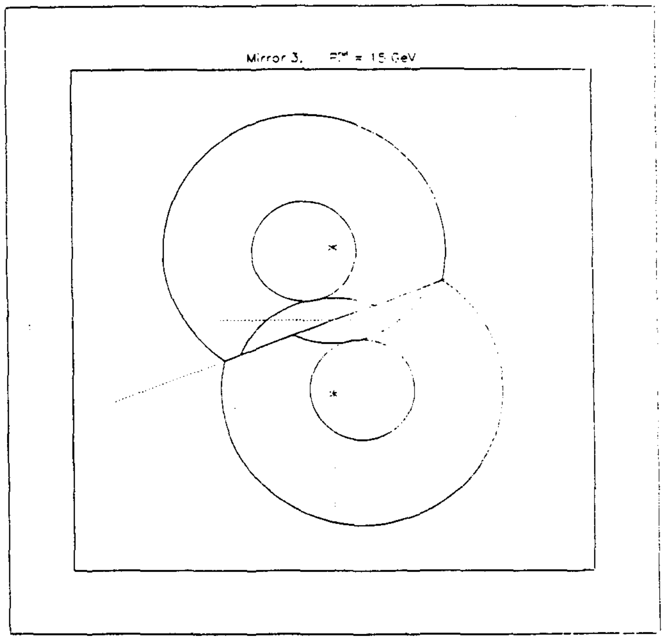
1. Coincidence between these PM's powerfully kills the influence of the noise of PM to the trigger rate.

2. Coincidence excludes false triggers when the background particle pass through the photocathode windows of PM's.

3. The smaller tubes have better quantum efficiency than big one and can be easily shielded from the magnetic field.

4. Price of 2" tube is about 4 times less than 5" one.

5. The special form of the photodetector gives the possibility to receive a "tunable" trigger with sharp Pt cut.



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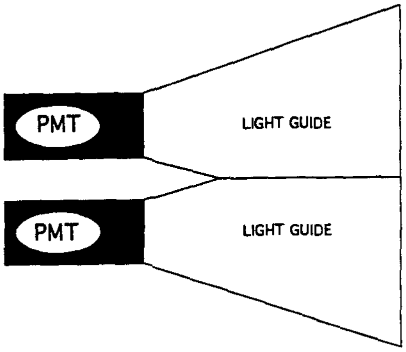
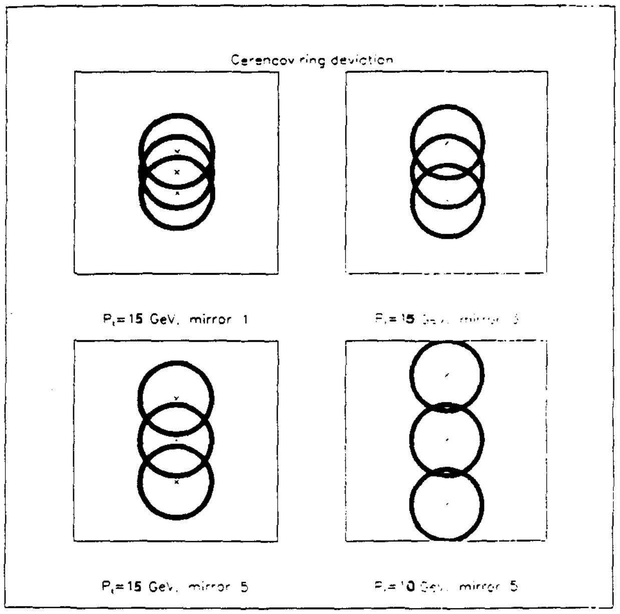
Photodetector for the Cerenkov Counter



not in scale

01603



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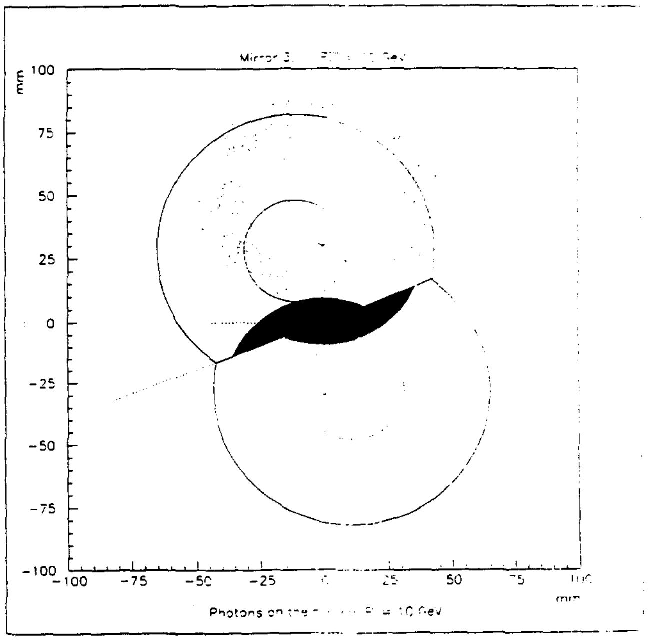

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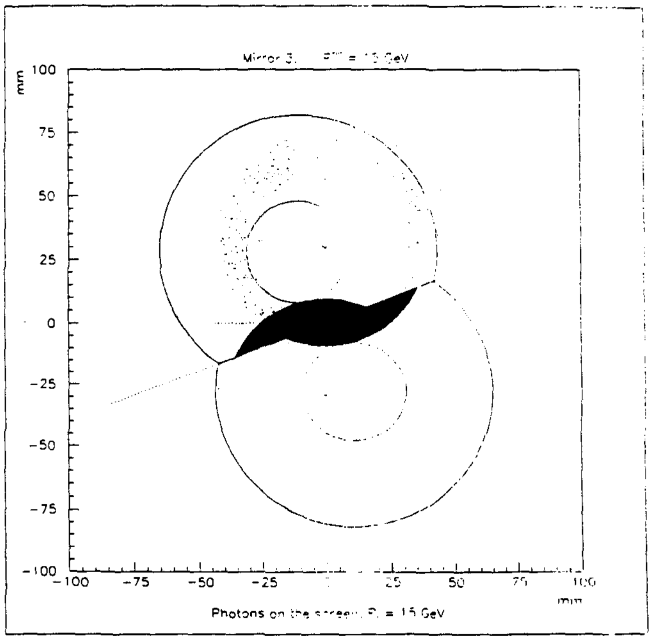

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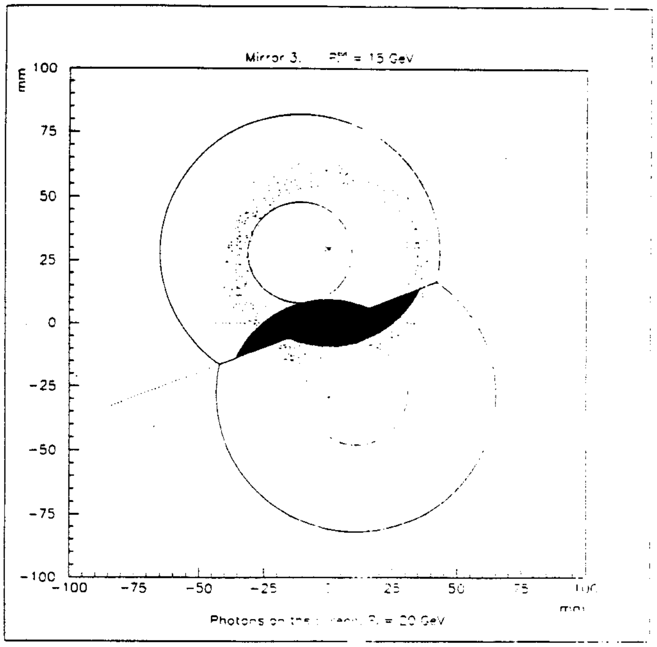

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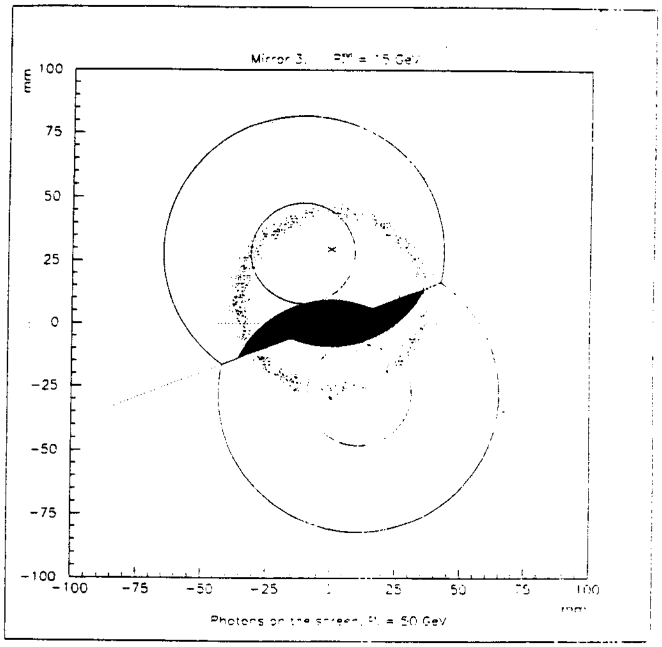

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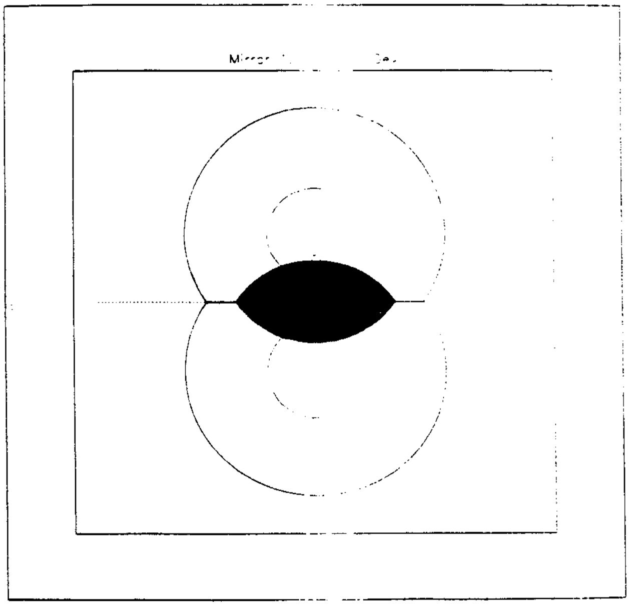

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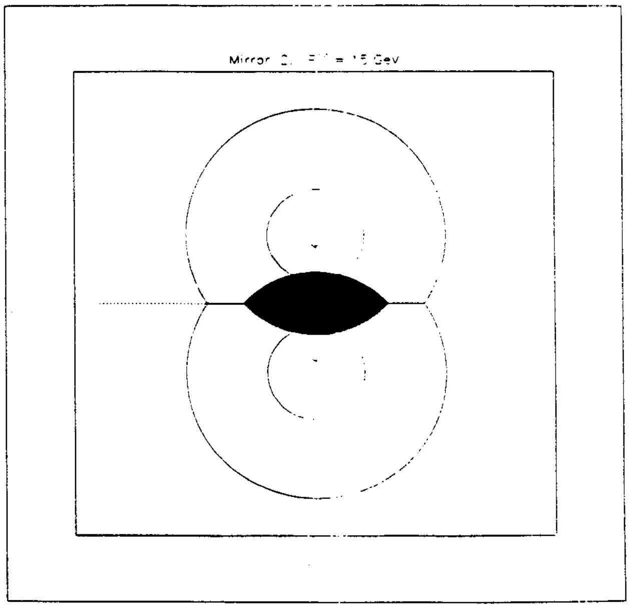

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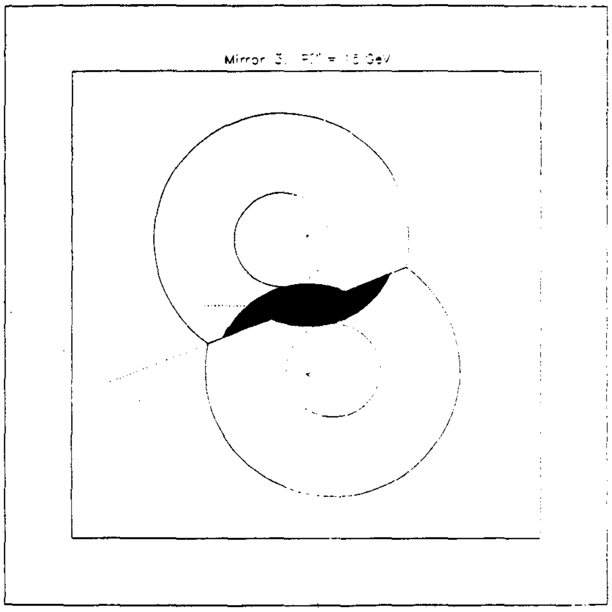

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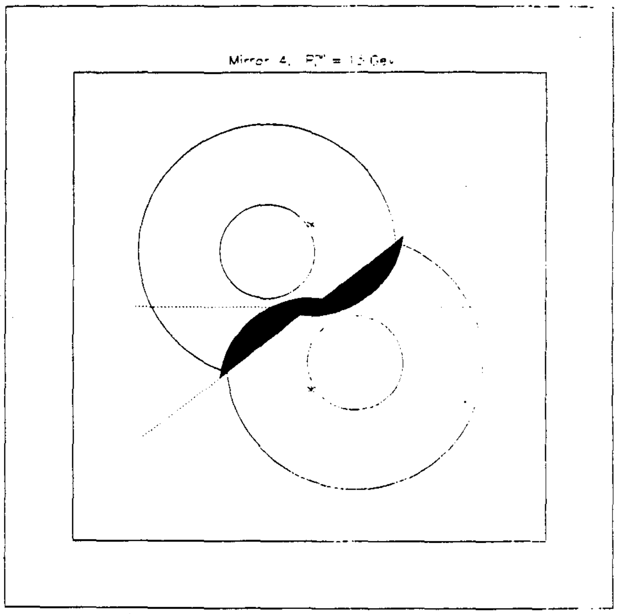

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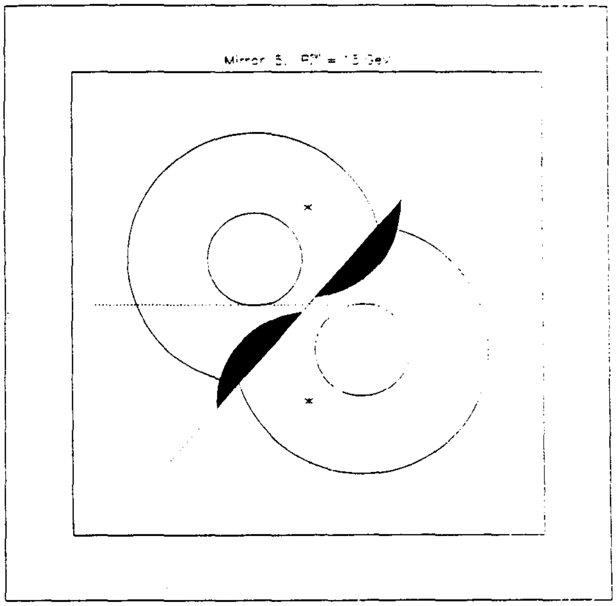

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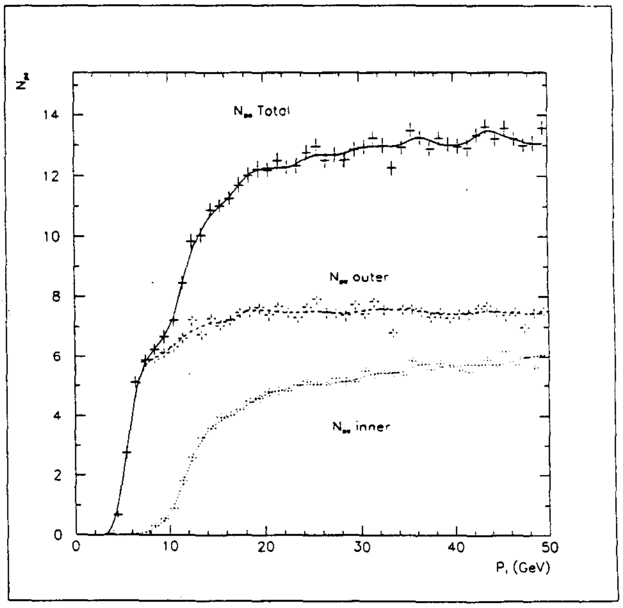
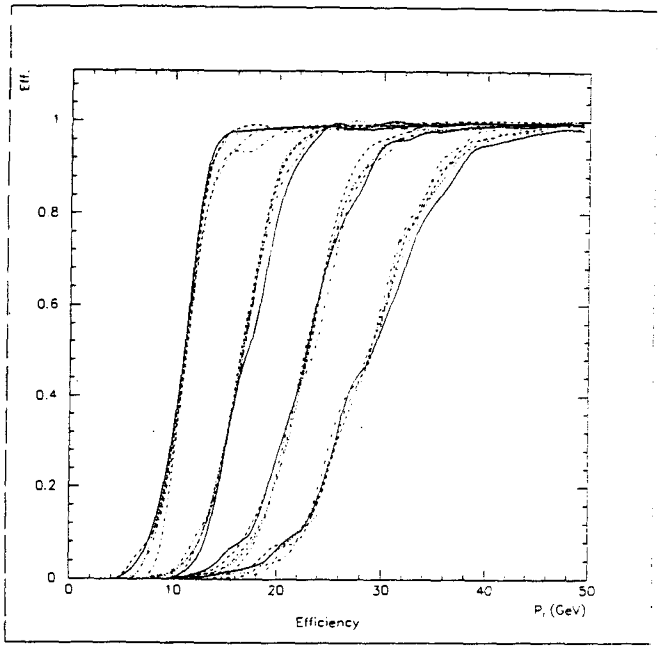
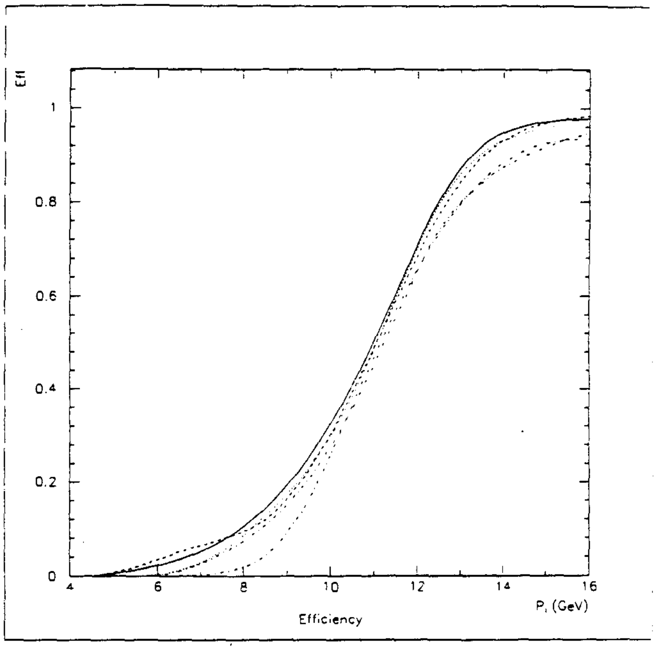






Test Beam Results

FNAL:

Cerenkov cell unit was installed in muon beam laboratory behind experiment E-665.

5" Burle 8854 PMT with WLS coating was used.

10.2+/-1 photoelectrons per meter were received. It corresponds to the constant of Cerenkov counter N_0=177

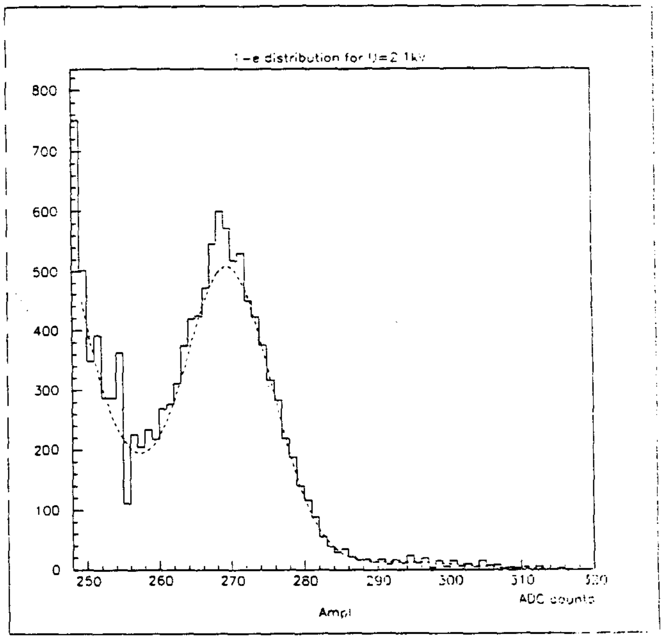
$$(N_{Ph.el.}=N_0 L(cm)\ Sin^2\Theta_C)$$

IHEP, Protvino:

The prototype of the Cerenkov counter was installed in the 70 GeV proton beam.

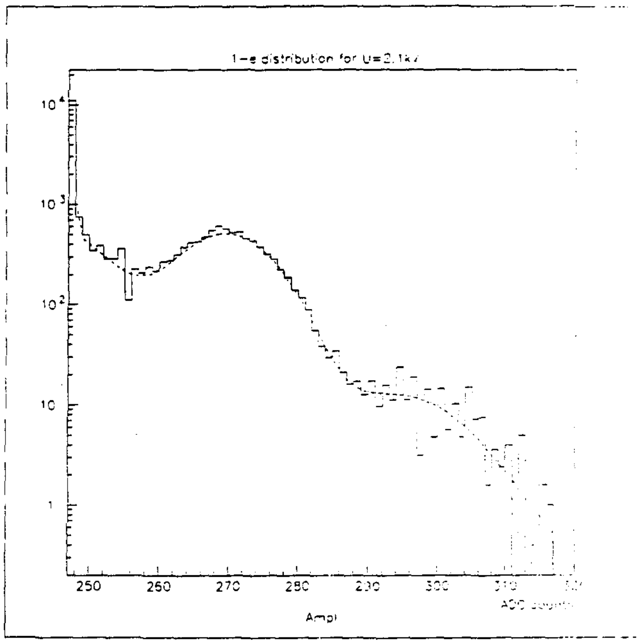
12 cm Russian PMT "CASCADE" without coating was used in the test.

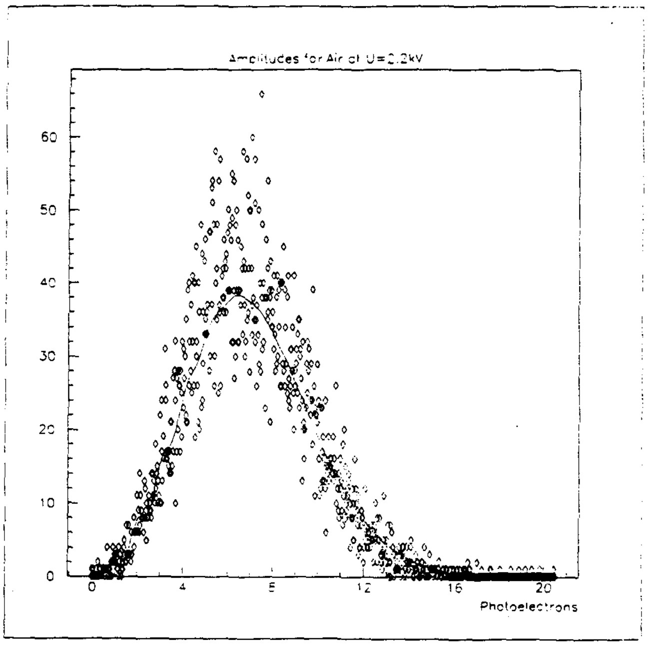
N_0=120 was received. This result is in reasonable agreement with FNAL results. We are continuing R&D to improve the quality of PMT "CASCADE".



ELECTRONICS AND TRIGGER

J. CHAPMAN





Conclusion

Cerenkov Counter:

1. Very fast.
   Trigger timing about 1 ns.
   Easily resolve beam crossing.
   Can be used for Drift Chambers timing.

2. Totally insensitive to low momentum charged particles.
   Insensitive to neutrons.

3. Technology is radiation hard and well understood.

4. Trigger rates predictable.

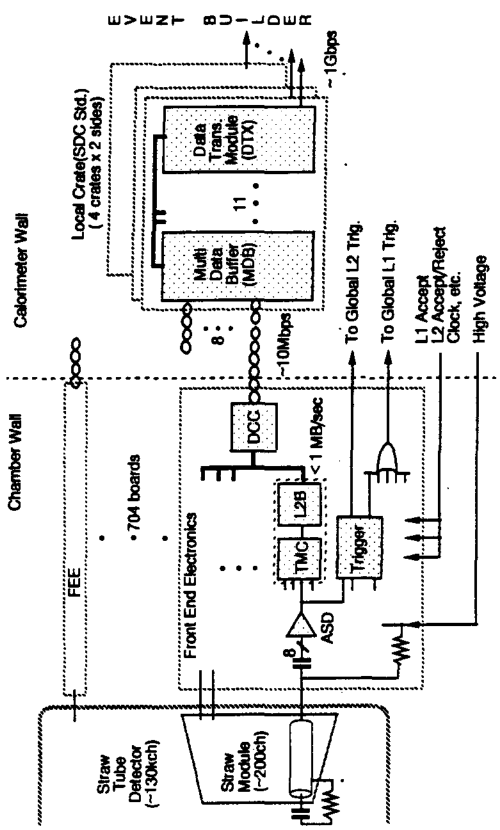
5. Can be done adjustable trigger for muons with high Pt in the wide range.

6. Rather inexpensive.
   The cost of the Cerenkov counter = 0.5 % of SDC

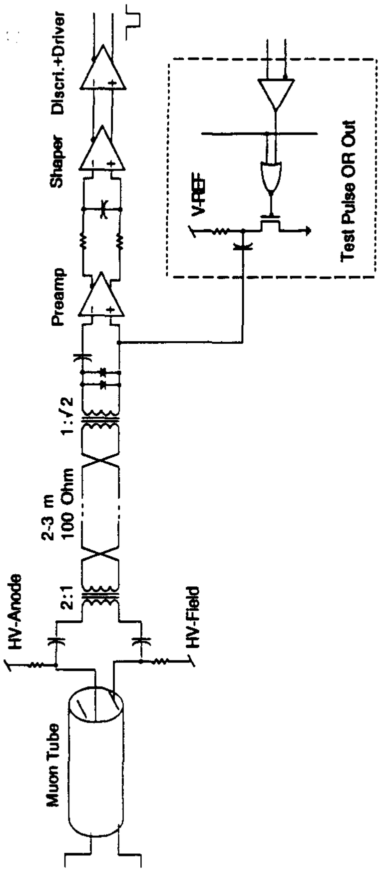
SDC Muon Front-end and Trigger

J. Chapman
University of Michigan
5 May 92

for the SDC Collaboration Review



Straw Electronics Overview



Muon Front-end Electronics (J. Oliver, Harvard)

Amplifier/Shaper/Discriminator Design

Preamplifier

* **Circuit**	**Common emitter input cascoded, differential**
* **Gain**	**2.5 mV/fC**
* **Bandwidth**	**100 MHz**
* **Input Imp.**	**115 ohms**
* **Power**	**< 4 mW**

Shaper/Tail Cancellation

* **Circuit**	**pole-zero cancel (preamp) 3 differential pairs detect. tail cancellation**
* **Peaking time**	**6-7 ns**
* **Double pulse Res.**	**25ns for 2% to 2%**
* **DC gain**	**6**
* **Power Dissipation**	**< 4 mW**

Amplifier/Shaper/Discrminator (cont)

Discriminator

* **Circuit**	**2 stage differential amp, positive feedback, 3 mV hysteresis**
* **Threshold**	**20 mV/fC (internal), separate for each channel**
* **Threshold offset**	**< 1 mV**
* **Time Slew**	**< 1ns /decade of overdrive**
* **Power**	**8 mW (excluding drive)**
* **Output**	**differential, open collector current programmable**

Implementation

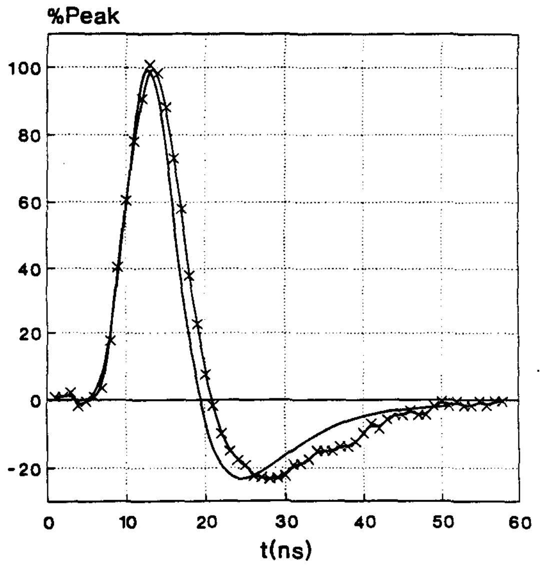
- **AT&T single channel amp/shaper (exists)**
- **Tektronix, full ASD (exists)**

ASD - Summary of Measurements

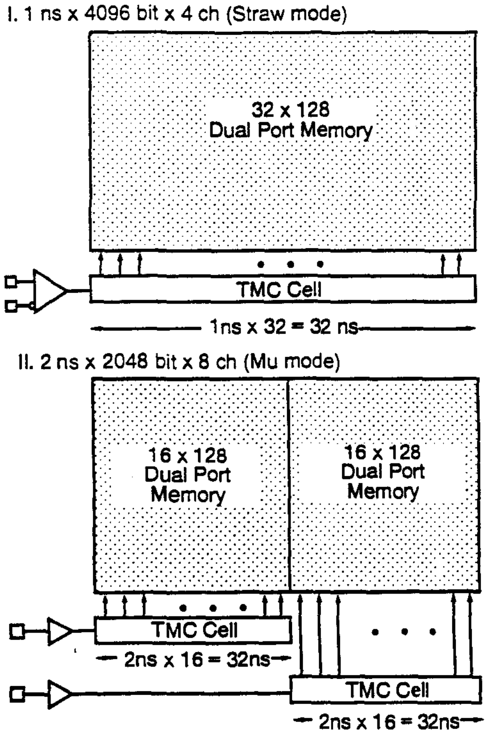
* **Gain**	**75% of expected value, uniform chip to chip, channel to ch. (few %)**
* **Peaking time**	**7ns observed, 6 ns expected**
* **Threshold Var.**	**< 0.5 fC ch. to ch. < 1 fC chip to chip**
* **Input impedance**	**125 +/- 10 ohms meas. 110 ohms expected**
* **Crosstalk**	**None observed for < 10fC with threshold at 0.5 fC**
* **Threshold Temp Var.**	**< 0.2 fC for 40 C**
* **Time Walk**	**4.5 ns for 1 - 15 fC (in agreement with SPICE)**
* **Yield**	**80% of chips**

ASD-8

Impulse Response at Disc Input
SPICE..vs..Measured



Measured peak is 75% of SPICE calc.



TMC4004/8 Memory Block

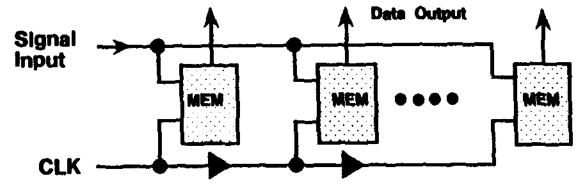
Time Memory Cell (TMC)

- To Reduce Power Consumption
  - Use CMOS LSI (Power = C x V^2 x F)

fine process
< 1 μm

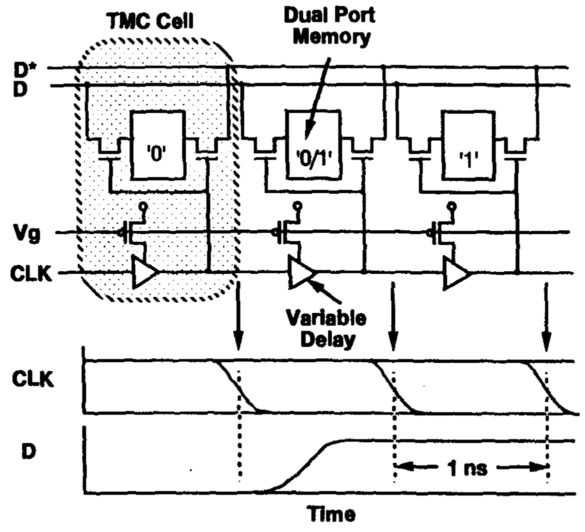
lower voltage
≤ 3 V

low frequency,
reduce active circuit
⇒ Memory & Delay

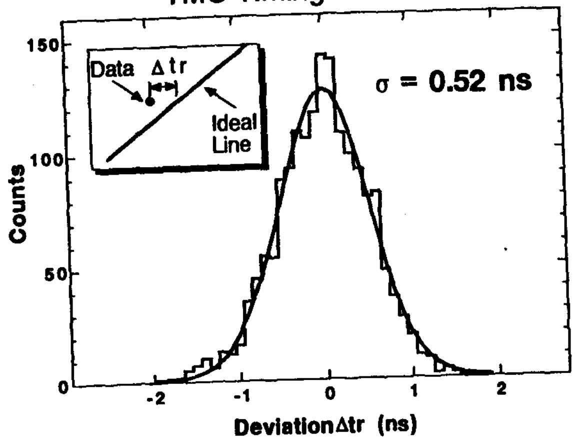


⇨ **Time-to-Digital Converter + Buffer Memory**

Basic Operation of Time Memory Cell (TMC)



TMC Timing Resolution



Muon Detector Trigger

Requirements

Design - Scintillators + Projective Wires

- Scintillators - timing to crossing
- Wires - Programable P_t thresholds

Simulation studies

Circuit development

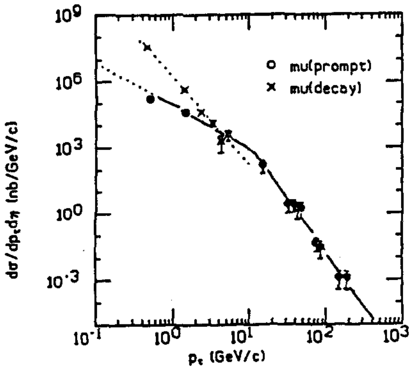
- Scintillator circuit
- Wire circuit

Test results

Future tasks

- Supertower prototype
- Full simulation of detector/trigger
- Integrated storage,trigger,DAQ

Muon P_t Distribution



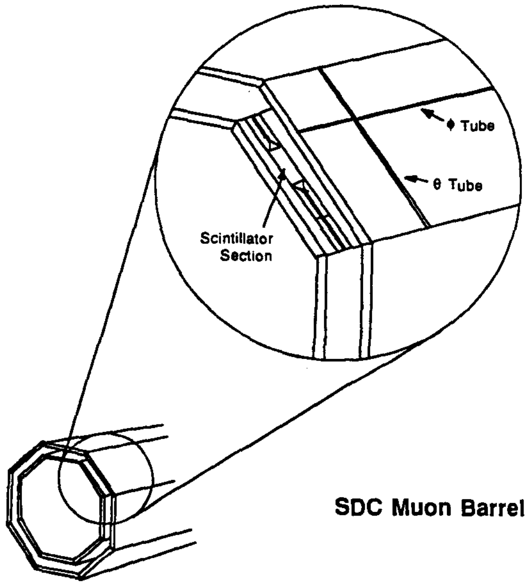
Muon Rates

Rates in Barrel and Intermediate System
(Standard luminosity; -1.5< η <1.5)

Muons from pion and kaon decay	42 kHz
Muons from charm and bottom decay	45 kHz
Cosmic-ray muons	20kHz
Punch-thru, neutrons	<100 kHz
Total rate per scintillator	<100 Hz
Total rate above 20GeV	6 kHz

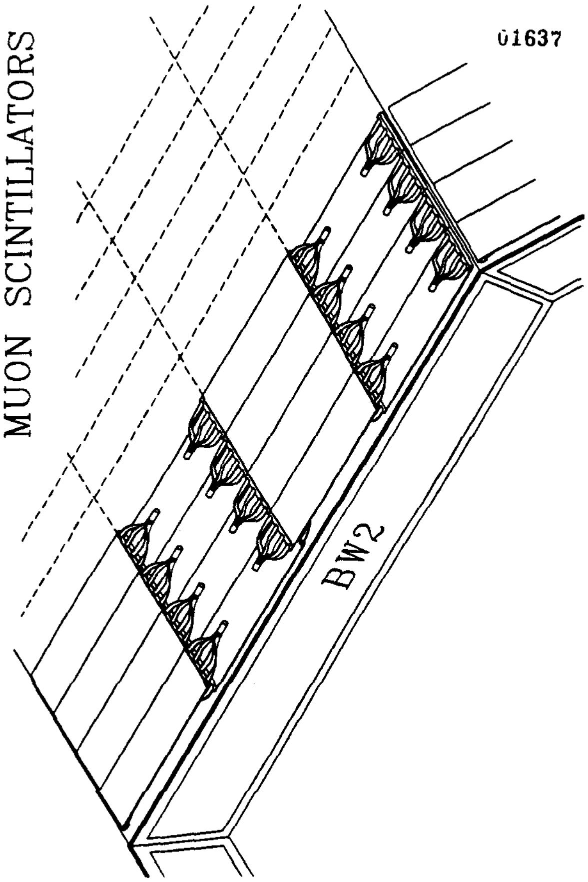
Rates in Forward System
(Standard luminosity; 1.5< $|\eta|$ <2.5)

Muons from pion and kaon decay	400 kHz
Muons from charm and bottom decay	100 kHz
Neutrons	≈MHz
Total rate per scintillator (est)	1-10 kHz



SDC Muon Barrel

SDC BARREL
MUON SCINTILLATORS



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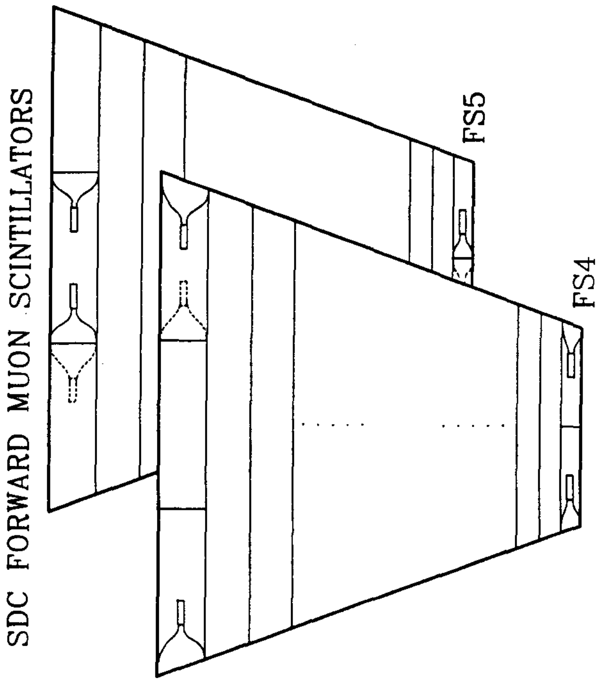

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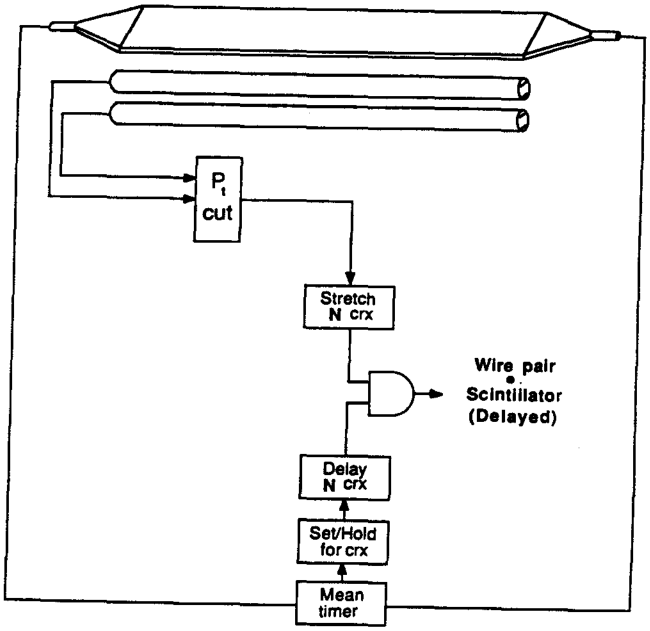
Simplified Muon Trigger



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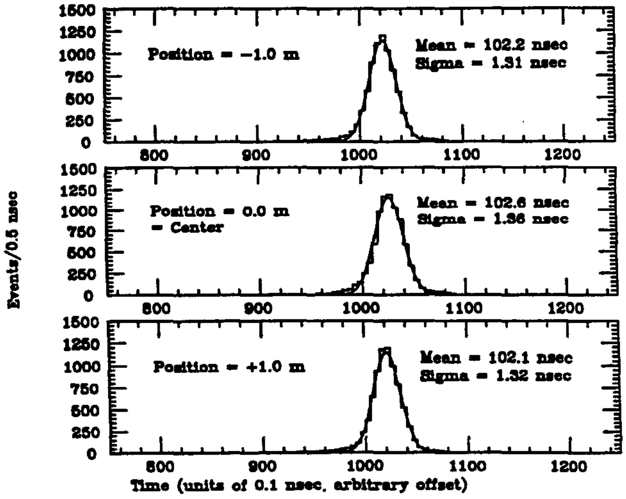
Crossing Determination



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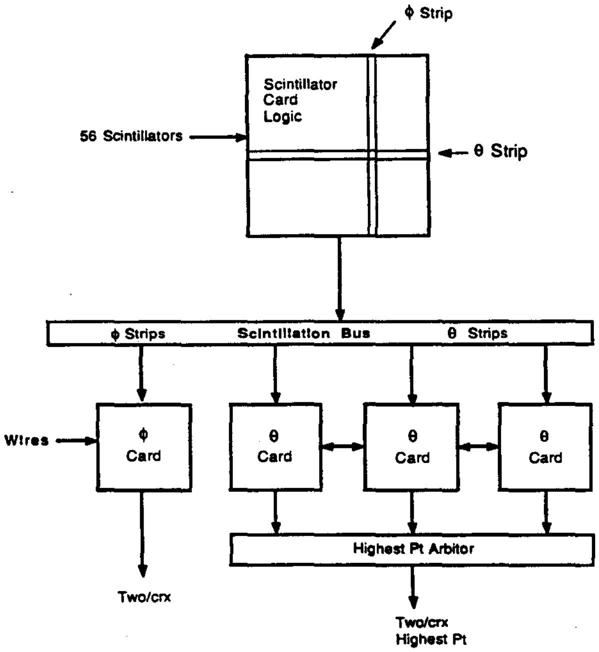

Muon Level 1 Trigger

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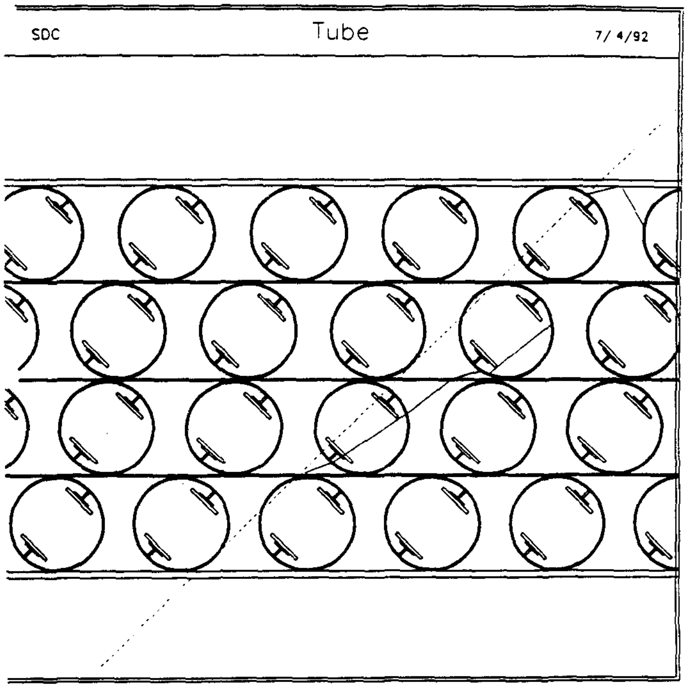

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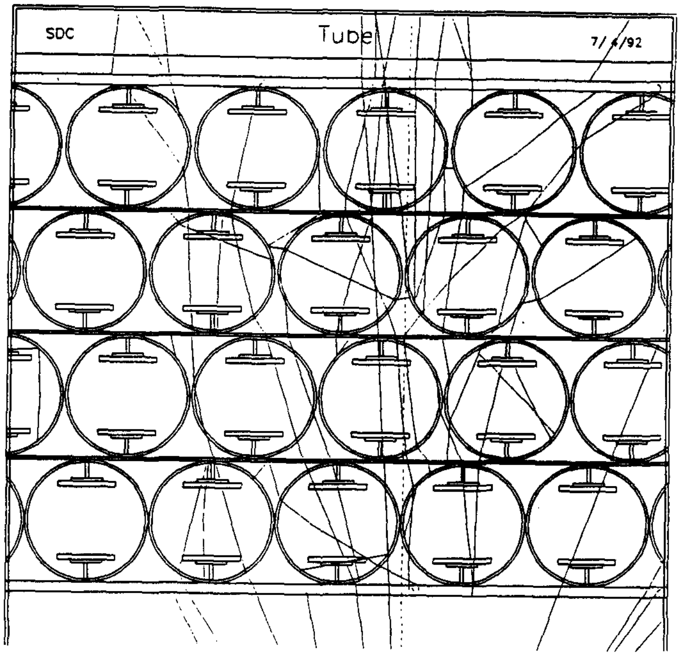

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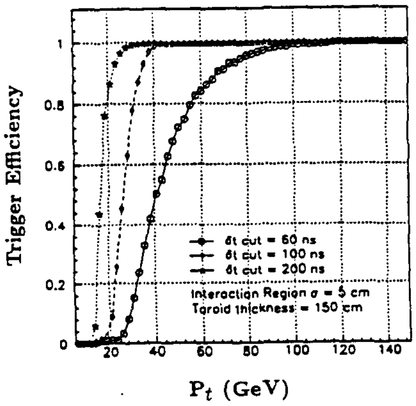
Central Muon Trigger

Example P_t Thresholds



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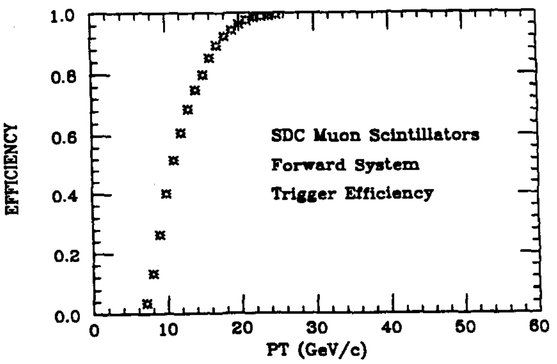


SDC μ Trigger

Data Items

- 3 P_t thresholds
- 14θ 16ϕ scintillator strips
- θ wire pairs ($\approx$300 max)
- ϕ wire pairs ($\approx$150 max)
- Scintillator patches (224 max)

Data Sizes

- 2-bits P_t ← Level 1
- 4-bits θ scintillator
- 4-bits ϕ scintillator
- 8-bits ϕ wire pair
- 9-bits θ wire pair
- 8-bit scintillator patch address ← Level 2

SDC Straw and Muon Triggers

J. Chapman
University of Michigan
5 May 92

for the SDC Collaboration Review

Straw Tracker Trigger

Requirements
- Electron ID
- Muon P_t resolution

Design features

Options

Simulation studies

Circuit development

Test results

Future tasks
- Packaging - storage,trigger,DAQ
- Radiation hard implementation
- Integrated testing - noise

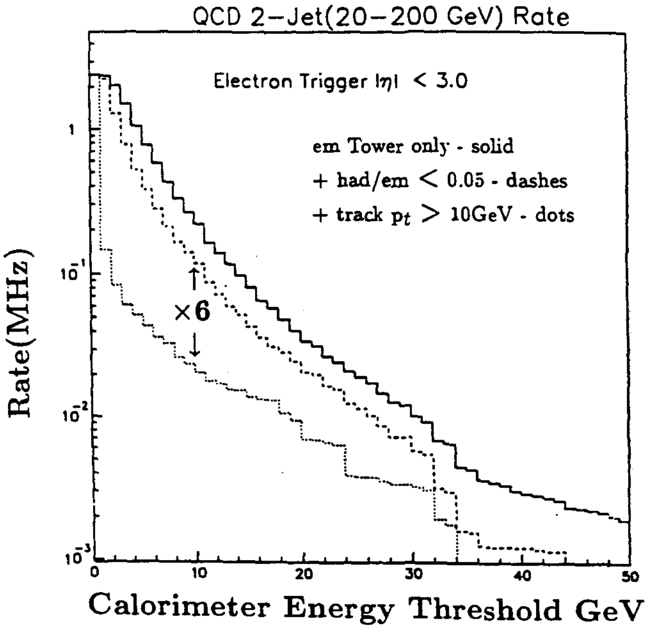
Requirements

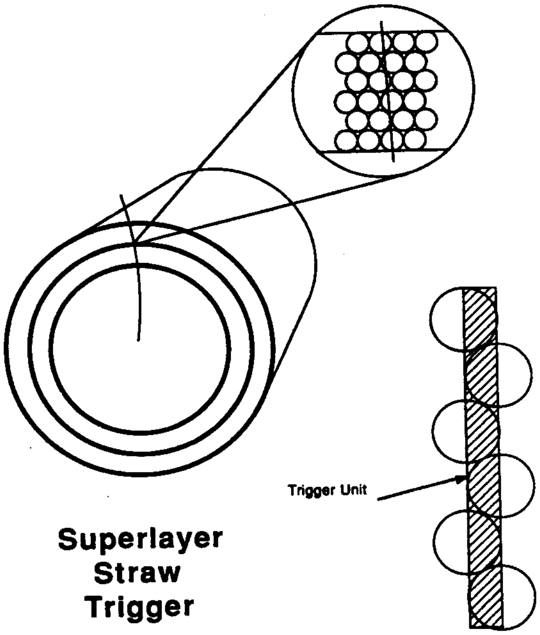
Requirement	Motivation
Identify "stiff" track	High P_t physics
Determine crossing	Assemble event
Match with calorimeter/showermax	Electron ID
Match with muon	Improve P_t
Associate with silicon	Reject conversions

Basic Plan has all of the above.

Options:
- **Early vrs Late in the Level 1 ↔ Level 2 tradeoff**
- **Precision/granularity**

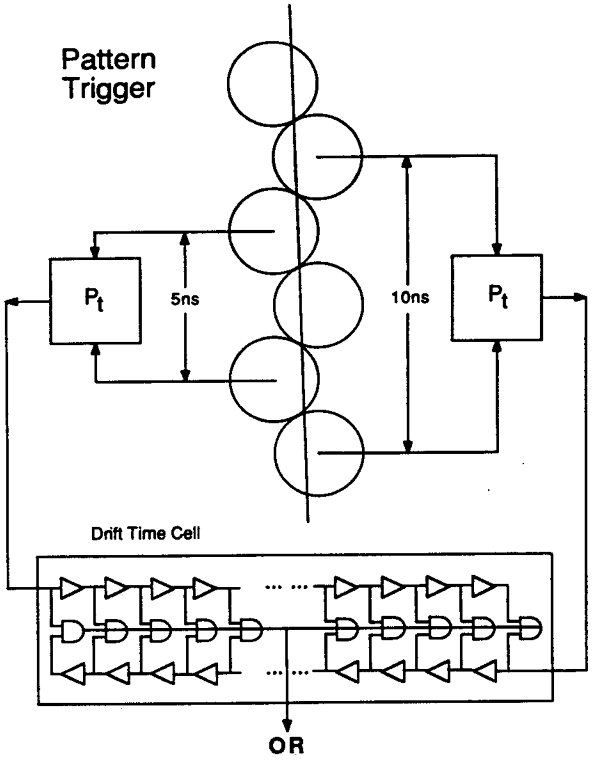
Background Rejection





Superlayer Straw Trigger

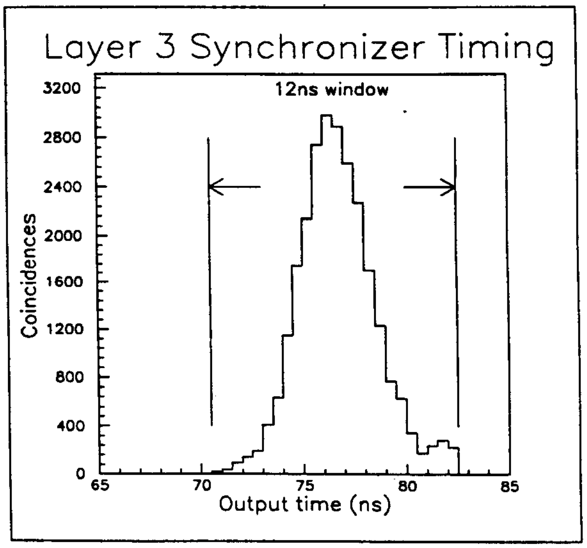
Pattern Trigger



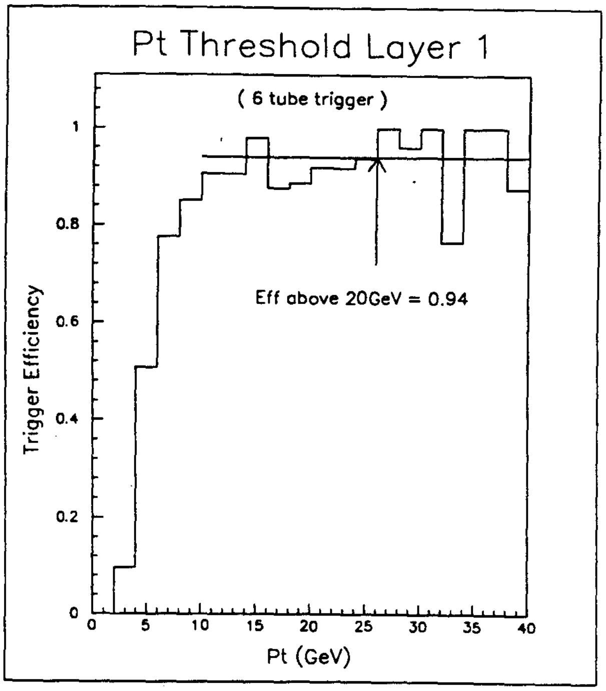
Straw Trigger Simulation

- Simulation work: (SDCSIM)
  - 450 H → WW events
  - 450 e and μ alone
  - 450 e and μ with min-bias
  - 450 min-bias at 1, 2, 3 × 10^{33}
- Trigger Options: (2 of 3 coincidence)
  - 64 overlapping wedges
  - ±3 straws (10GeV)
- Summary:
  - Efficient trigger with low "false" rate
  - CMOS ASIC implementation

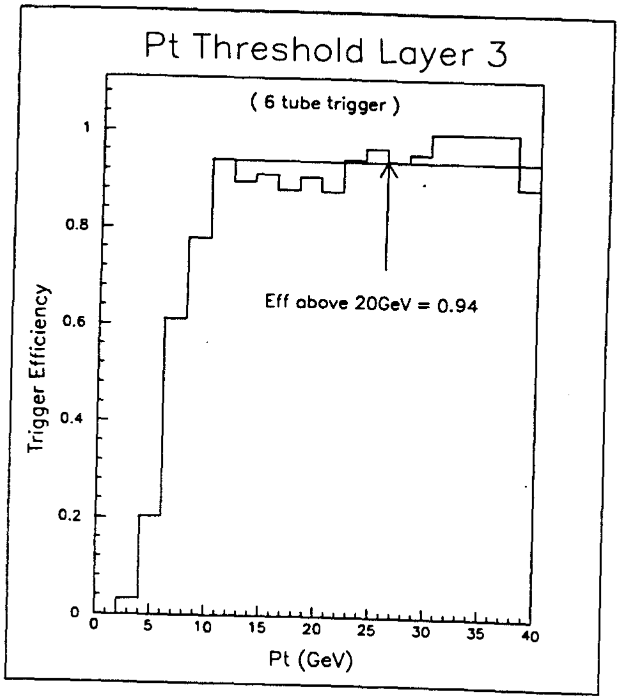
Crossing Determination



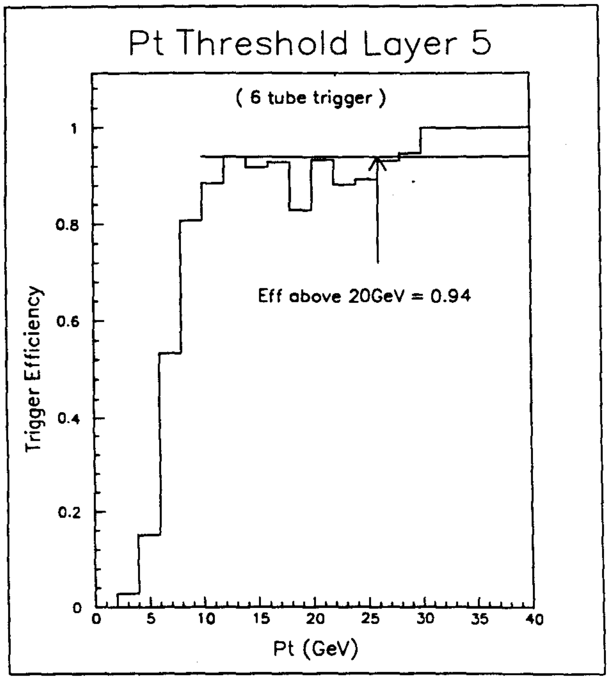
Single Layer Trigger 01655



Single Layer Trigger 01656



Single Layer Trigger 01657



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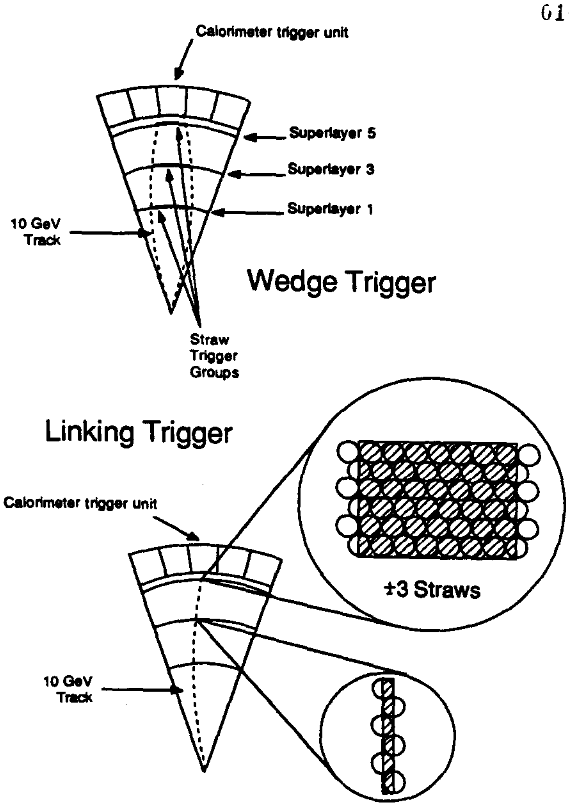

Wedge Trigger Option

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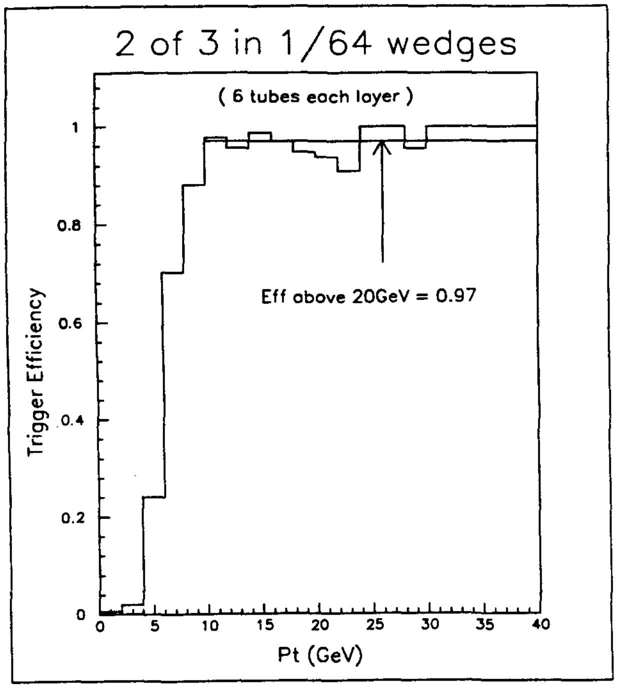

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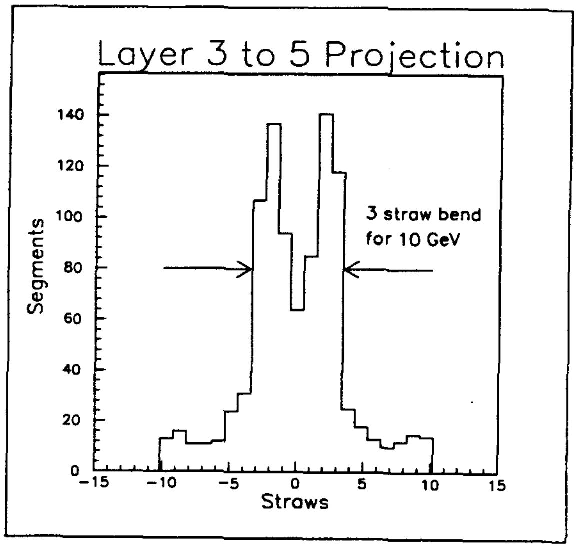

Interlayer Linking Option

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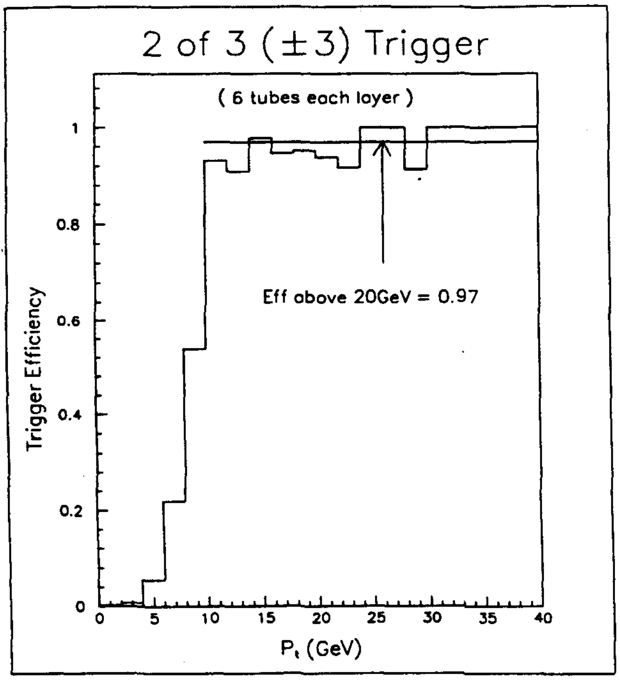

2 × Design Luminosity

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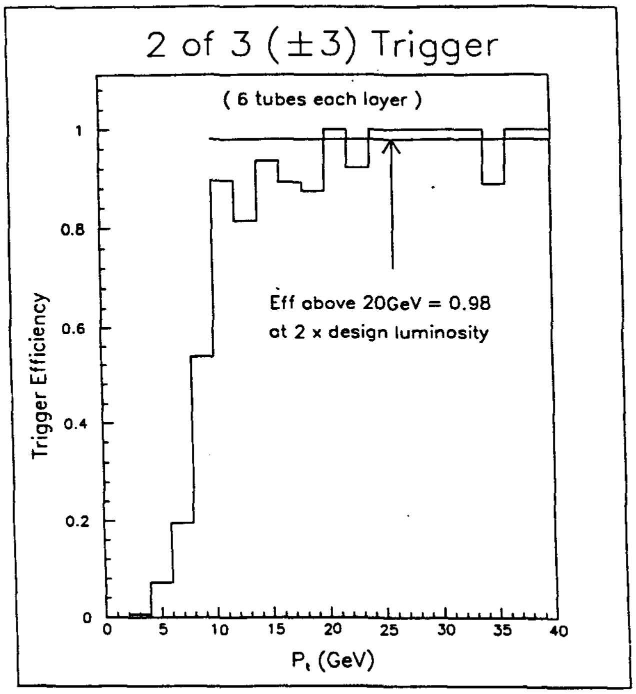
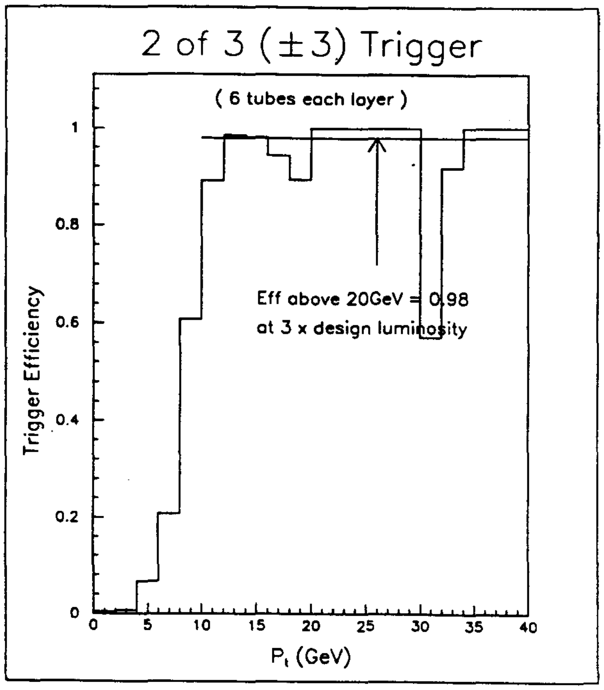
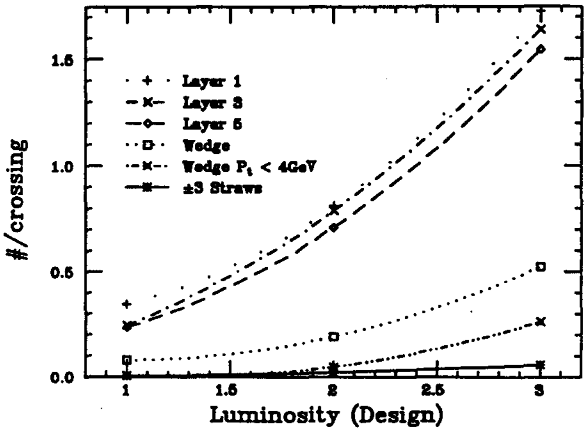


3 × Design Luminosity



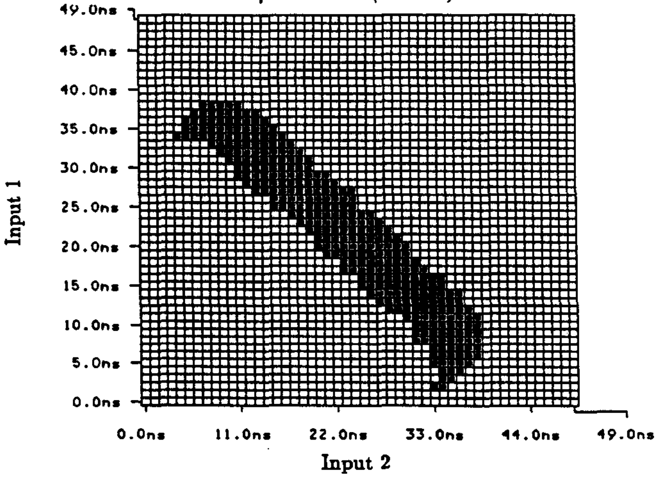
False Triggers

Triggers P_t < 10GeV



Digital Mean Timer Test

1.2μm CMOS (MOSIS)



Note : Dots indicate presence of output at fixed time. Circuit test was done with a Tektronix LV511.

SDC Central Tracker Trigger

Performance Summary

- Level 1
  - Single Layer $P_t > 6$ GeV
    False rate ≈ 1/5csx at 10^{33}
  - 2 of 3 superlayers ± 3 straws $P_t > 10$GeV
    False rate 1/225csx from minimum bias $P_t < 10$GeV
  - 2 of 3 superlayers, wedge ORs
    False rate 1/12csx mostly 5GeV < P_t < 10GeV
- Level 2
  - "stiff" track "hits"
    500μm - 2000μm bins

Data Summary

- Level 1
  - 2 of 3 (±3 straws) 3-bits P_t/track
  - 2 of 3 wedge ORs (calorimeter wedges) 1-bit/wedge
- Level 2
  - Layer/module/trigger unit "hit" address

Muon Detector Trigger

Requirements

Design - Scintillators + Projective Wires
- Scintillators - timing to crossing
- Wires - Programable P_t thresholds

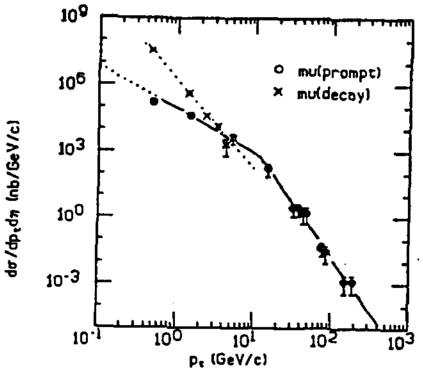
Simulation studies

Circuit development
- Scintillator circuit
- Wire circuit

Test results

Future tasks
- Supertower prototype
- Full simulation of detector/trigger
- Integrated storage,trigger,DAQ

Muon P_t Distribution



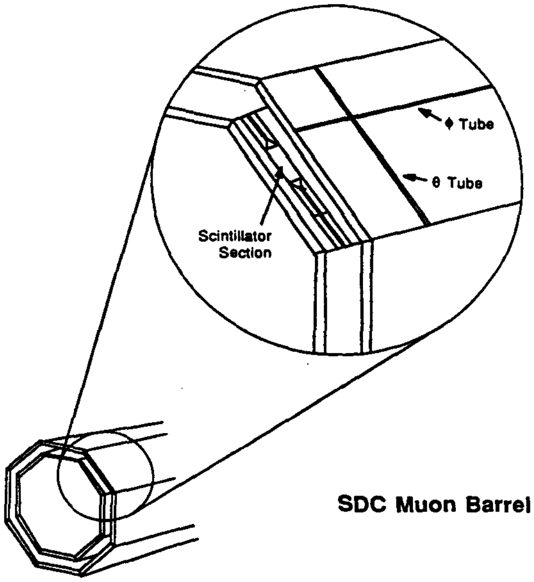
Muon Rates

Rates in Barrel and Intermediate System
(Standard luminosity; -1.5< η <1.5)

Muons from pion and kaon decay	42 kHz
Muons from charm and bottom decay	45 kHz
Cosmic-ray muons	20kHz
Punch-thru, neutrons	<100 kHz
Total rate per scintillator	<100 Hz
Total rate above 20GeV	6 kHz

Rates in Forward System
(Standard luminosity; 1.5< $|\eta|$ <2.5)

Muons from pion and kaon decay	400 kHz
Muons from charm and bottom decay	100 kHz
Neutrons	≈MHz
Total rate per scintillator (est)	1-10 kHz



SDC Muon Barrel

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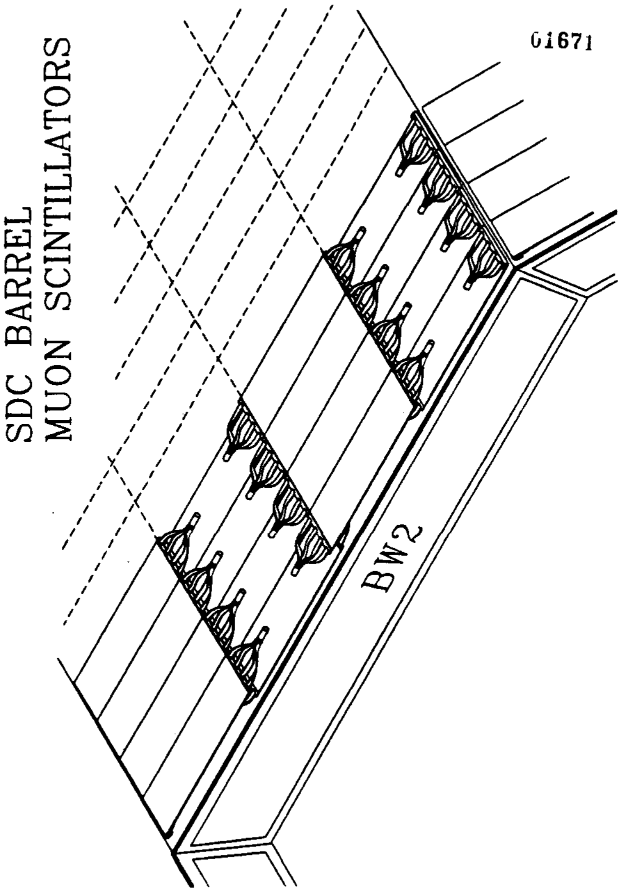

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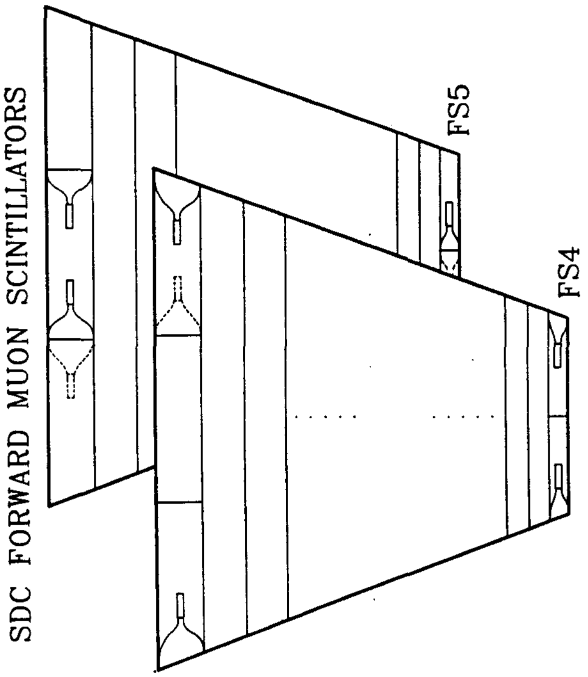

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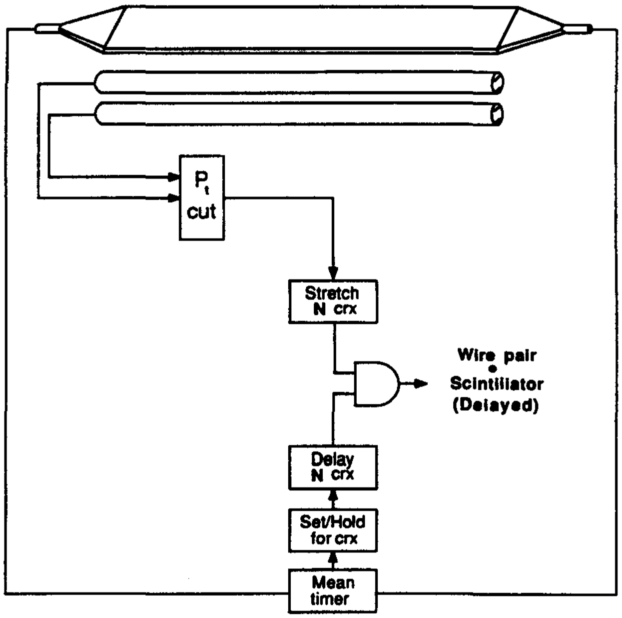
Simplified Muon Trigger



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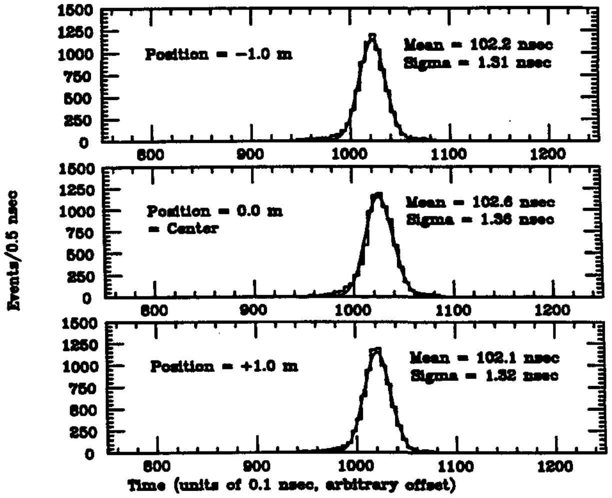
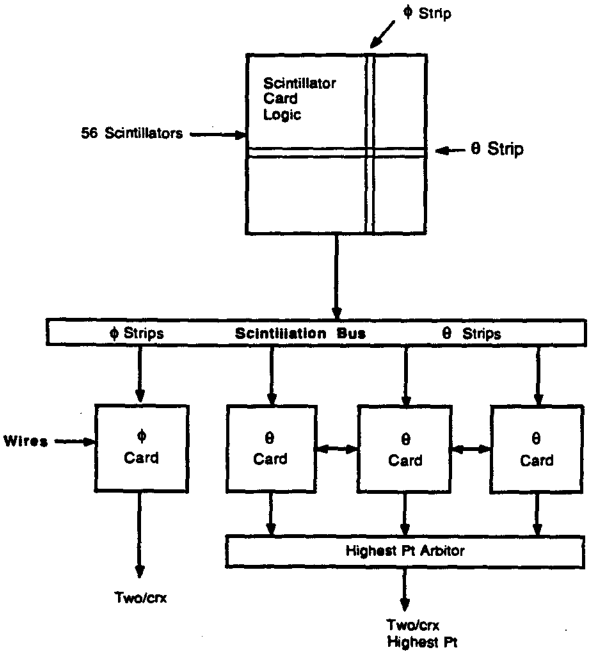
Crossing Determination

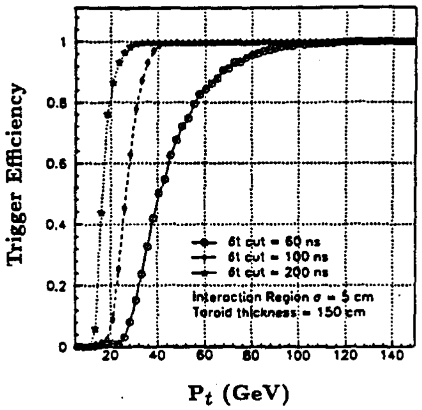


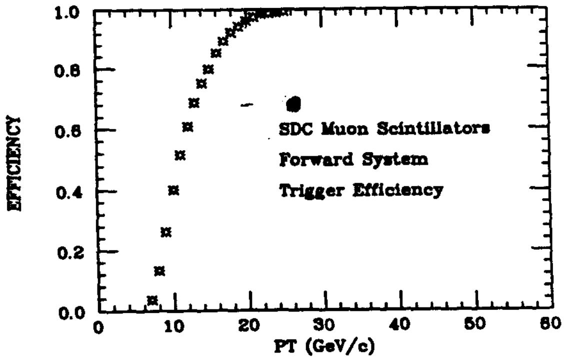


Muon Level 1 Trigger

Central Muon Trigger

Example P_t Thresholds





SDC μ Trigger

Data Items

- 3 P_t thresholds
- 14θ 16ϕ scintillator strips
- θ wire pairs ($\approx$300 max)
- ϕ wire pairs ($\approx$150 max)
- Scintillator patches (224 max)

Data Sizes

- 2-bits P_t ← Level 1
- 4-bits θ scintillator
- 4-bits ϕ scintillator
- 8-bits ϕ wire pair
- 9-bits θ wire pair
- 8-bit scintillator patch address ← Level 2

0167

ALIGNMENT SYSTEMS

D. EARTLY

May 06,1992

SDC Muon Alignment-Position Monitoring Requirements

(1) Barrel Level I local Theta trigger

alignment-few mm (position)	knowledge < wire resolution 150μm 250μm

(2) Barrel stand alone momentum trigger-Level II

alignment < 2mm	knowledge < wire resolution

$\Delta P_t < \sigma Pt$ $P_t < 100$ Gev/c (RΘ)

(3) Barrel Phi trigger-Level II

alignment < 3mm	knowledge < wire resolution

$\Delta P_t < \sigma Pt$ $P_t < 200$ Gev/c (RΦ)

(4) Muon matching to CTD tracks

$\Delta\chi 2 < 1$ at 2 Tev/c	knowledge < wire resolution

position knowledge < 250 μm

(5) Forward trigger

alignment < 3mm	knowledge < wire resolution 150μm 250μm

The detector will be maintained to the Beamline coordinate system (BCS) to < 3 mm

---

SDC Muon Alignment Position Monitoring System Description

A. Supermodule knowledge tolerances

(1) Tube to bulkhead fiducial relationship- BARREL
CNC holes 12μm, wire to endcap centering 40μm, endcap to bulkhead 12μm, position sensor locating pins to 25μm, 50μm electronic drift resolution
70μm supermodule Tolerance

(2) Tube to Octant frame fiducial relationship-FORWARD
Wire-end feedthroughs 40μm, feedthroughs-endcaps 40μm, CNC holes in frame 20μm, mounting fixture compensating for tube sag, position sensor locating pins to 25μm, 50μm electronic drift resolution
78μm superlayer Tolerance

(3) Measure fiducial-sensor locating pin relationships in Supermodule assemblies- install Optical staight line monitoring, corner proximity sensor assemblies which have been calibrated in a test fixture, and temperature sensors
50μm measurement Tolerance

(4) Surface facility survey of (BW3+BW2) box assembly and BW1 supermodule in all orientations on a magnet mockup

Survey of (IW2+IW3) assembly in all orientations on the surface using magnet mountings transfer fixture-reference and calibration of IW2-IW3, IW3-BW3, IW2-BW2, IW2-FW4 relative position sensors

(5) Survey of Forward supermodule rings in the Vertical plane before and after system assembly and reference relative position sensors which have been calibrated in a test fixture

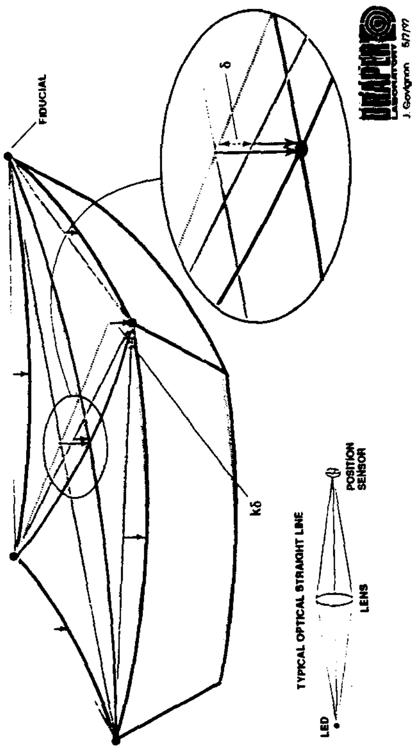
50μm measurement Tolerance

Accumulated tolerance-100μm, alignment system tolerance-100μm

---

"LOCAL ALIGNMENT" to Monitor Module Deformations

- Through local alignment, the wire ends positions are related to the fiducial marks at module's corners (tied to global alignment)
- Straight line monitors measure low order structural mode shape
- Low order mode shape ascertained by analysis & prototype
- Mode shape is determined by:
  - Fabrication errors
  - Thermal & gravity loadings
  - Mounting conditions (# of support points & location)
- Length determined by Fabrication tolerance & temperature sensing



B. <u>Magnet Shape and Support Base monitoring (Reference Stability)</u>

(1) Liquid level systems on the magnet and on the base sections-monitor the elevation (to references) and shape of the magnet and base to control distortions due to floor motion, calorimeter and Forward system installation (50μm LTResolution)

(2) Precision inclinometer distribution on barrel iron to interpret shape changes- verified by survey measurements throughout detector assembly (25μrad LTResolution)

Global Alignment and relative position monitoring

We present a position monitoring scheme based on R&D long term stability test results. It is a distributed, redundant sensor system to determine the relative position of fiducial marks. Further R&D will determine the final systems to be used.

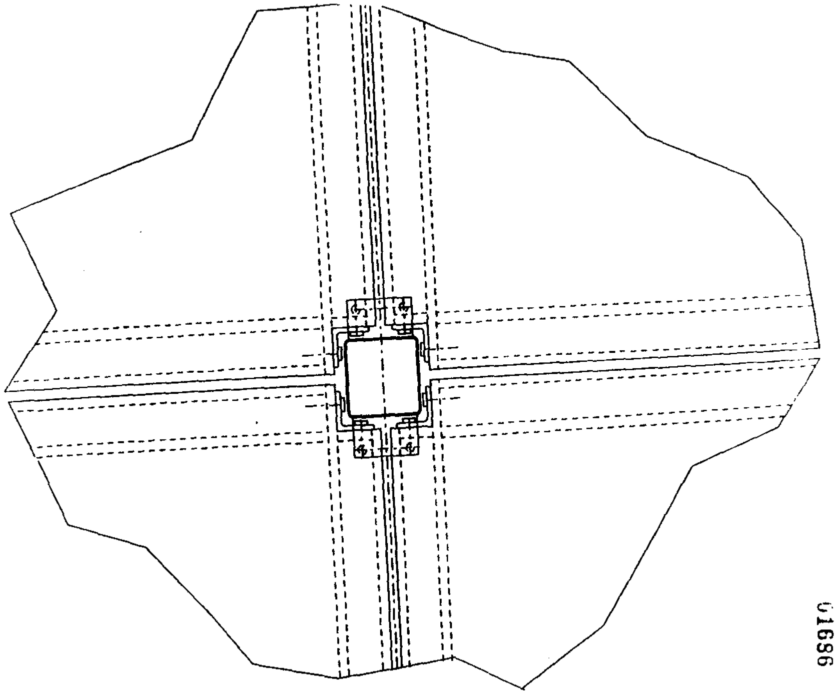
(1) Position muon detectors using a Detector Coordinate system established from the surface Geodetic network and maintained by a three dimensional matrix of survey points and references

(2) Barrel octant support rails, IW support pin references, FWn supports positioned to 500μm, magnet and supermodule temperature distributions will be monitored

(3) FW1 supermodules will articulate on precision rails and relocate on precision stops/supports relative to FW2

(4) Muon supermodule relative position monitoring via distance sensing to fenceposts at the corners of adjacent supermodules -transverse and radial sensing by each layer **TRANS**

Fenceposts include internal optical shape monitoring (OSLMs), inclinometers, temperature sensors, and end survey references. They are calibrated in orientation in a surface calibration fixture The open posts are originally surveyed in the DCS



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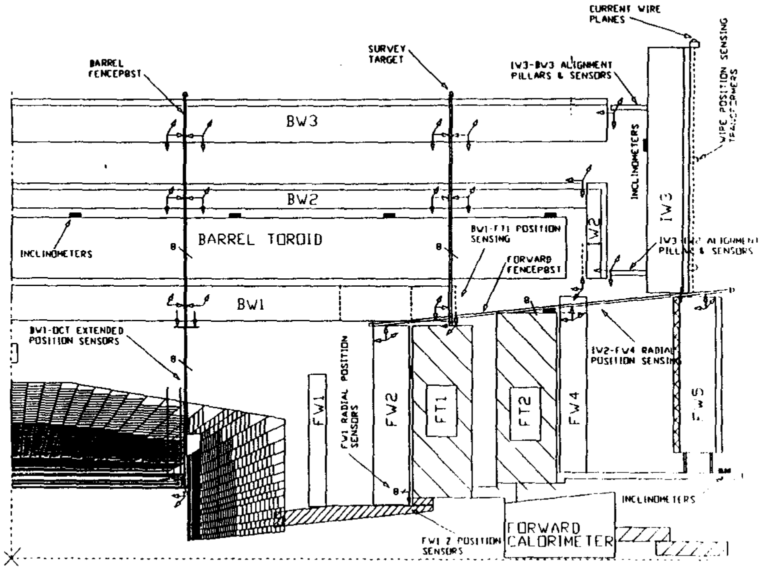
SCHEMATIC-POSITION MONITORING



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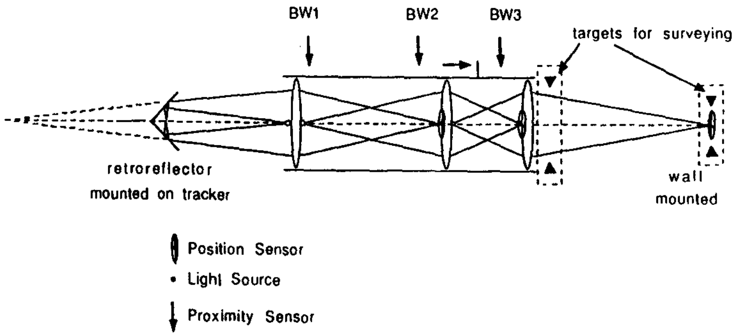

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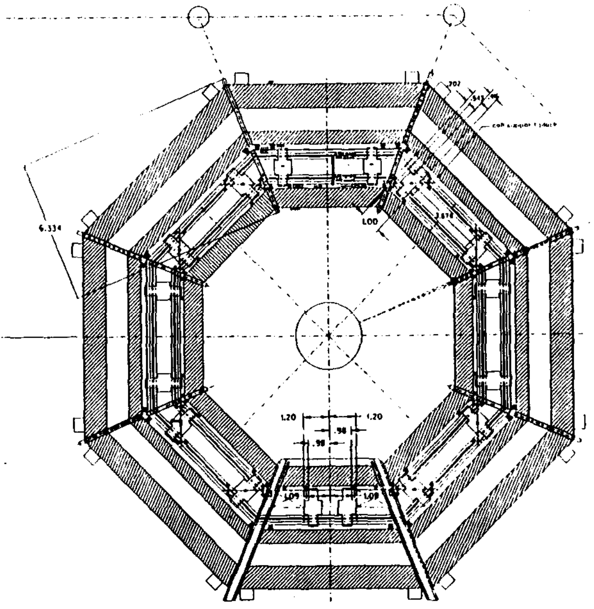


U1685

Forward fenceposts or OSLMs at the outer octant boundaries of the FW1-FW5 superlayers with linking to the Barrel system and survey of FW5

With no on demand precision global survey system, physical interpretation of the position monitoring system would be achieved through a computer model of the detector where the fiducial positions are established with thermally corrected sensor data.

With an on demand range only global survey system (ROS), external optical extensions of the posts can be independently measured in the DCS and correlated to inclinometer or relative optical axis measurement between posts and radial position measurements to a horizontal reference optical line TRANS

Relative position measurement of the two ends of the Central tracking system and the Muon system via optical extensions of the central two rings of fenceposts and retroreflectors on the tracking system (IP)-link to all of detector and accelerator by ROS-- BCS link by measurement of precision Beam Position Monitors on the Forward muon systems

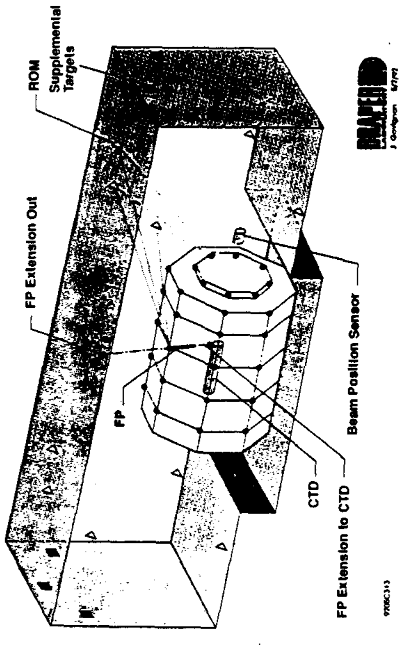
(5) Barrel regional linking by relative position monitoring of IW2-IW3, IW2 -BW2, IW3-BW3 in all octants-ROS outer IW3 surface position measurements, or OSLMs, or WireSLMs

(6) Forward linking by distance and relative transverse position monitoring between BW1-FW2, BW1-FT1, IW2-FW4, IW3-FW5, and possible direct linking of barrel and forward fenceposts,-ROS outer FW5 surface position measurements to determine Forward system positions

---

Option for GLOBAL ALIGNMENT

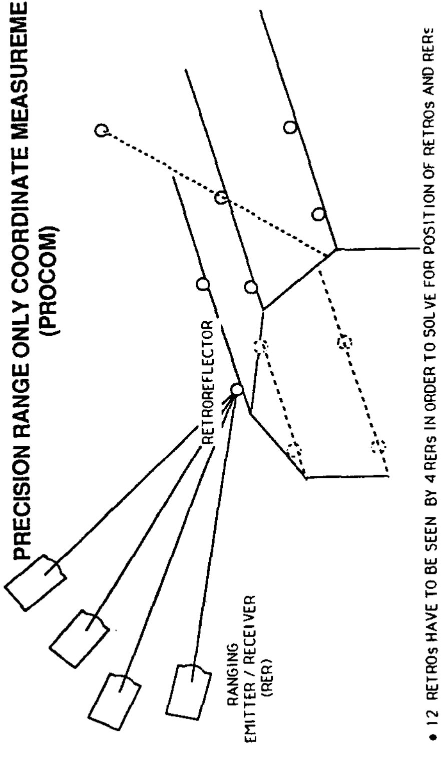
- To provide external closure of the network of optical straight lines and relate it to the survey network & beam line
- Based on a system of automated distance-only-measuring devices using laser diode ranging, organized in clusters providing self alignment capability



MUON DETECTOR ALIGNMENT CONCEPT

SSC LABORATORY

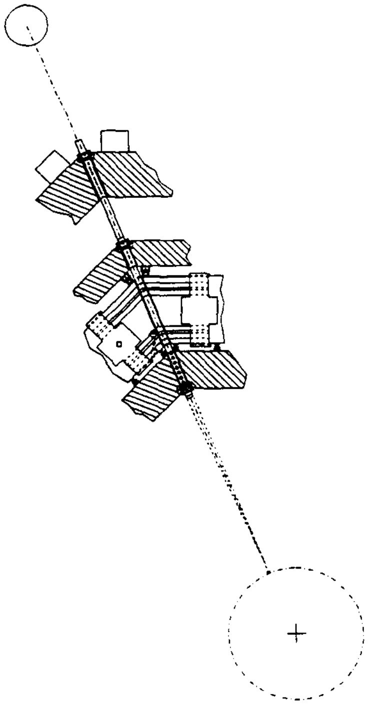
PRECISION RANGE ONLY COORDINATE MEASUREMENT (PROCOM)

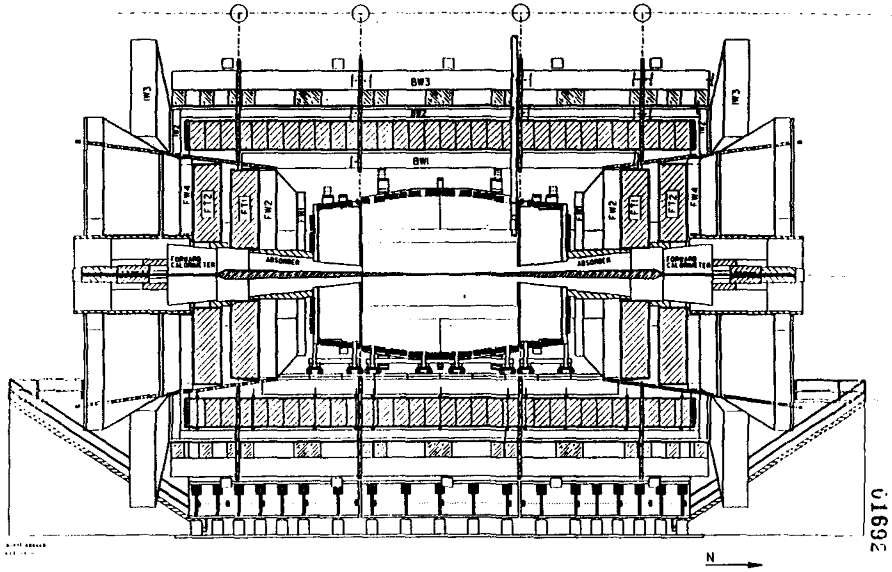


- 12 RETROs HAVE TO BE SEEN BY 4 RERs IN ORDER TO SOLVE FOR POSITION OF RETROS AND RERs
- MORE RETROs MAY BE SEEN BY ONLY 3 RERs
- 3 RETROs SEEN BY 2 CLUSTERS OF RERs ALLOW FOR THE STITCHING OF THE POSITION INFORMATION
- PRELIMINARY ESTIMATE OF 24 RERs SURROUNDING THE DETECTOR FOR COMPLETE COVERAGE

J. GOVIGNON

DRAPER LABORATORY





D. Devices which have been studied in our R&D program

(1) Liquid level systems- FNAL D0 detector, B0 low beta quads

(2) Precision inclinometers

(3) Optical straight line monitors TRANS

(4) Linear analog output inductive proximity sensors

(5) Analog output capacitive proximity sensors

(6) Short range Laser distance measuring systems

(7) Ultrasonic ranging

E. Development plans

(1) Optimize the detector configuration for position linking

(2) Prototype mechanical fencepost-thermal motion (shape) studies

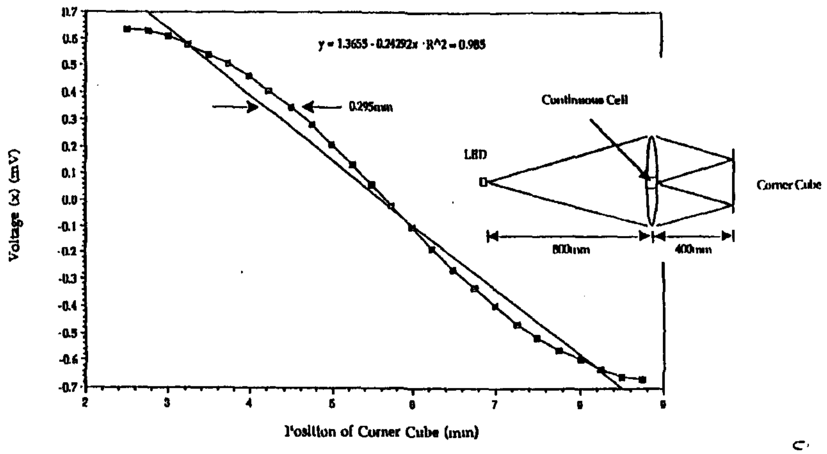
(3) Prototype internal optics system for fenceposts and determine LT Resolution and stability

(4) Continued studies of OSLMs and laser distance devices for BW, IW-FT-FW linking

(5) Measure sensitivity, stability, and system resolution in supertower tests

(6) Prototype Range only measurement system

Voltage as a Function of Corner Cube Translation In the X Direction for 90° Orientation of Cell



MUON DETECTOR
ALIGNMENT CONCEPT

DISTANCE-ONLY-MEASUREMENT for GLOBAL ALIGNMENT

- Targets are located on Surface of Detector, Extensions of Fenceposts, Walls and Beam Sensor

- A Distance measurement provides 1 equation relating the unknown coordinates (3) of Ranging Head's pivot point to the coordinates (3) of target's optical center.

- A cluster of M Ranging Heads successively measuring distances to N targets provides M x N equations with 3 M + 3 N unknowns

- Self calibration requires M ≥ 4 and 3 M + 3 N ≤ M x N

- For example M = 4 ==> N ≥ 12 and M = 5 ==> N ≥ 8

- Once Coordinates of Ranging Heads are known (using N targets), other less accessible targets can be measured with M = 3 only

- Laser Radar Technology with Laser Diodes adapted to SDC problem with advantages from:
  - Discrete number of cooperative targets
  - Stable geometry during measurement time (complete time of few minutes)
  - Possibility of relatively long (~ seconds) integration time for each distance
  - Temperature monitoring

  ==> Expected Accuracy of ~ 100 µm

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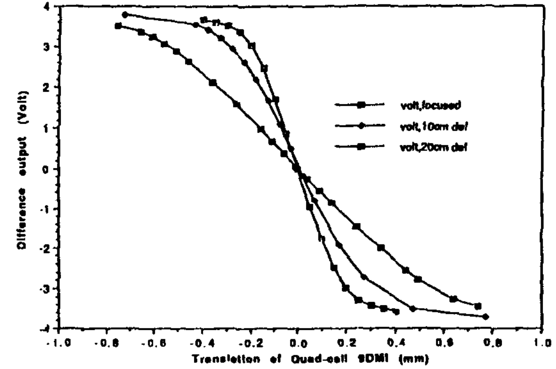
MUON DETECTOR LOCAL ALIGNMENT:

STRAIGHT LINE MONITOR



Linear range can be extended by defocusing:

LED 1102, Ambiant Light On, Optical Bench Set-up: l=2m, mag 2+1

Other Options:

- Continuous Lateral Detector
- Larger Light Source (or Optical Fiber)
- Square light source (Mask)
- Detector Array (CCD)

J. GOVIGNON

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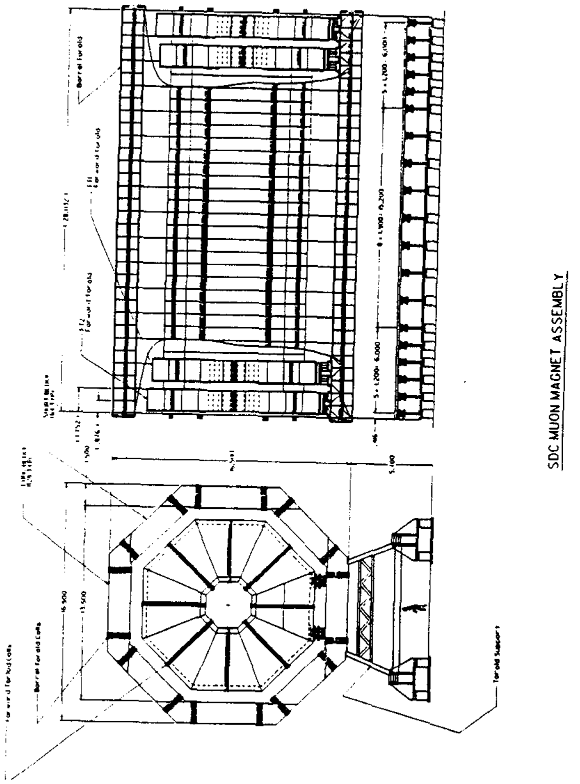
TOROID ENGINEERING

J. CHERWINKA

SDC Muon Magnet System Design

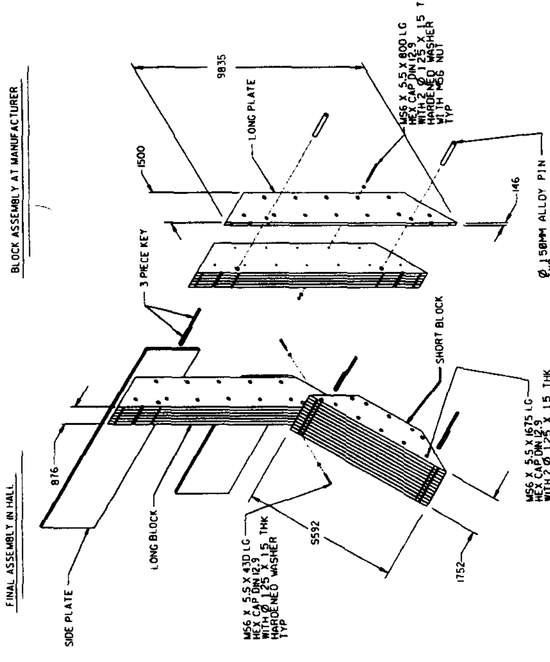
I.Functions of the Muon Magnet System
- A.Provide a Magnetic Field to bend Muons
- B.Absorb Lower Energy Particles
- C.Structural Support for the Experiment

II.Components
- A.Muon Barrel Toroid Steel (MBT)
- B.Barrel Support
- C.Barrel Coils
- D.Muon Forward Toroid Steel (FT's)
- E.Forward Coils



SDC MUON MAGNET ASSEMBLY

III.Muon Barrel Toroid Steel and Barrel Support
- A.Design Philosophy
  - 1.Minimize Work and Uncertainties in Assembly
    - a.Large piece size but less than 90 tonne for transportation
    - b.Machined mating surfaces
    - c.Mounting holes and surfaces in blocks before assembly
  - 2.Minimize Welding
  - 3.Minimize Gaps and Holes in the Magnetic Path
    - a.High strength bolts
    - b.Gaps kept in compression
    - c.Small tolerances
  - 4.Minimize Movement and Stress in Assembled Magnet
    - a.Adjustable support base
    - b.Small tolerances
    - c.Z connection
- B.MBT Long and Short Bolted Block Concept
  - 1.Long Blocks (128 long blocks 86.0 metric ton)
    - a.Plates (6 per block 146mm thick)
    - b.Flattening bolts and nuts (14 per block M56)
    - c.Alignment and shear pins (4 per block 150mm diam)
  - 2.Short Blocks (64 short blocks 84.4 metric ton)
    - a.Plates (12 per block 146mm thick)
    - b.Flattening bolts and nuts (8 per block M56)
    - c.Alignment and shear pins (4 per block 150mm diam)
  - 3.Corner Bolts (3072 corner bolts M56)
  - 4.Shear Keys (100mm x 100mm cross section)
  - 5.Side Plates (top outside, vertical sides outside, bottom inside)
    - a.25 to 50 mm thick
    - b.Staggered seams
    - c.Attached with plug welds (25mm diam)
- C.Barrel Support Inclined Plate Concept
  - 1.Inclined Plates (3 pieces for each side 300mm thick)
  - 2.Space Truss (weldment of 150mm square tube)
  - 3.Girder Assembly (3 pieces for each side)
  - 4.Tie Beams (200mm by 500mm cross section)
  - 5.Hydraulic Jacks (76 cylinders with 700 metric ton capacity)
  - 6.Load Pad



MUON BARREL BLOCK ASSEMBLY

J.J.C/L.J.C./G.M.G
4-23-92

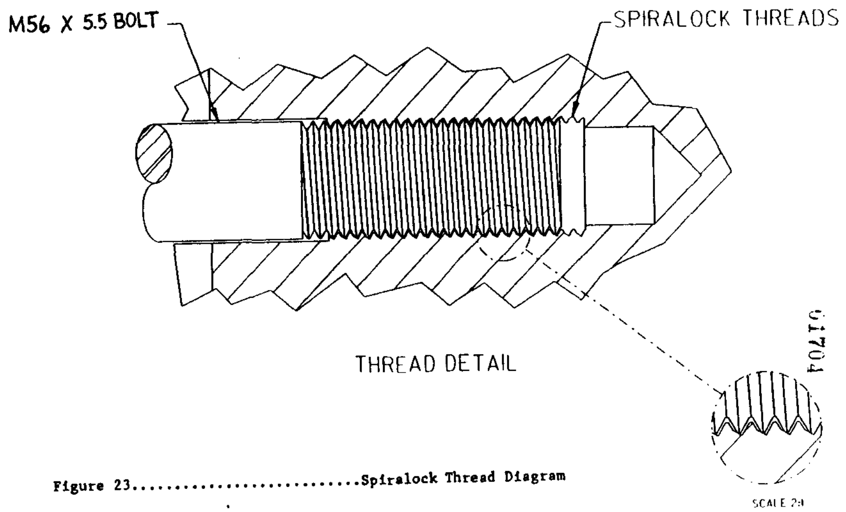
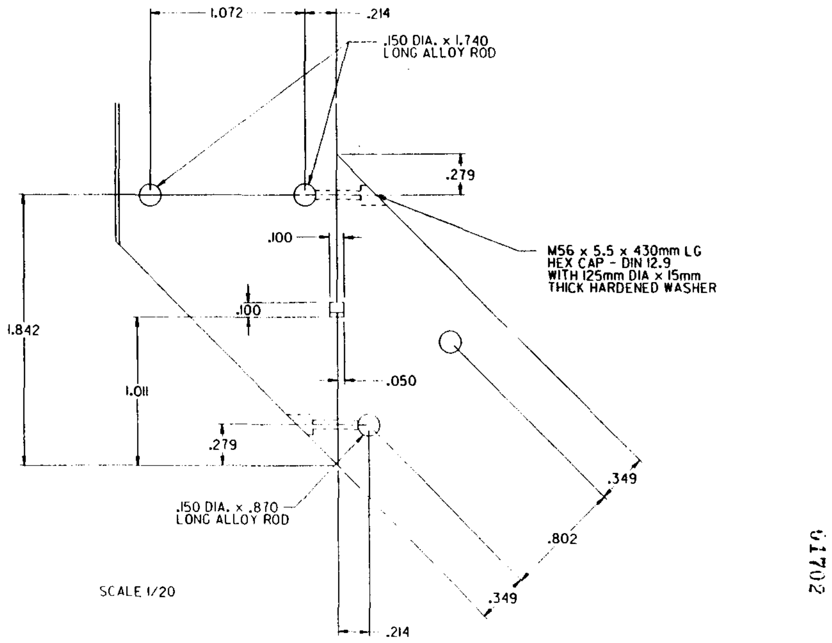
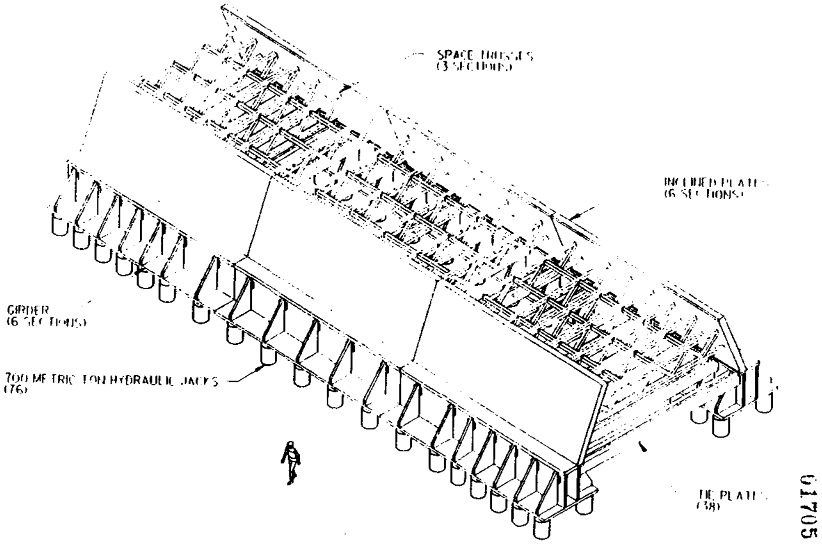
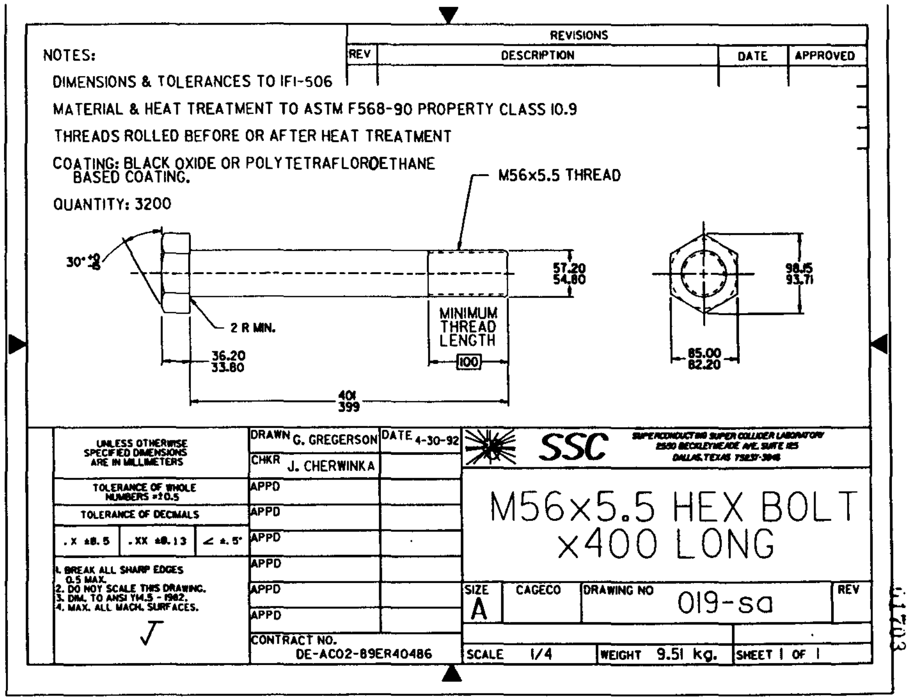


Figure 23.........................Spiralock Thread Diagram





SDC Support Installation



NOTES:

DIMENSIONS & TOLERANCES TO IFI-506

MATERIAL & HEAT TREATMENT TO ASTM F568-90 PROPERTY CLASS 10.9

THREADS ROLLED BEFORE OR AFTER HEAT TREATMENT

COATING: BLACK OXIDE OR POLYTETRAFLOROETHANE BASED COATING.

QUANTITY: 3200

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS

TOLERANCE OF WHOLE NUMBERS ±0.5

TOLERANCE OF DECIMALS

.X ±0.5 | .XX ±0.13 | ∠ ±.5°

1. BREAK ALL SHARP EDGES 0.5 MAX.
2. DO NOY SCALE THIS DRAWING.
3. DIM. TO ANSI Y14.5 - 1982.
4. MAX. ALL MACH. SURFACES.

DRAWN G. GREGERSON
DATE 4-30-92
CHKR J. CHERWINKA
APPD
APPD
APPD
APPD
APPD
APPD
CONTRACT NO. DE-AC02-89ER40486

SSC
SUPERCONDUCTING SUPER COLLIDER LABORATORY
2550 BECKLEYMEADE AVE. SUITE 125
DALLAS, TEXAS 75237-3946

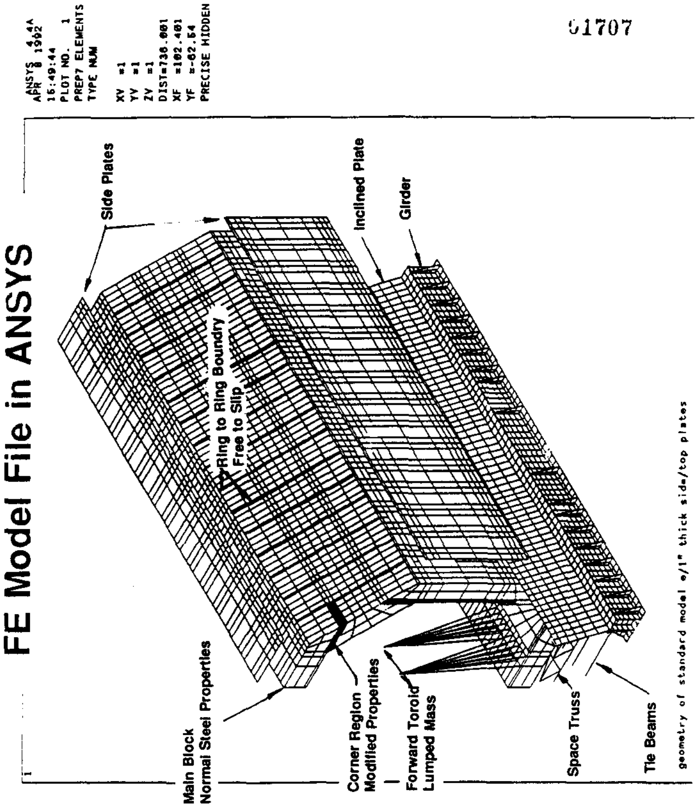
M56x5.5 HEX BOLT
x400 LONG

SIZE A
CAGECO
DRAWING NO 019-sa
REV
SCALE 1/4
WEIGHT 9.51 kg.
SHEET 1 OF 1

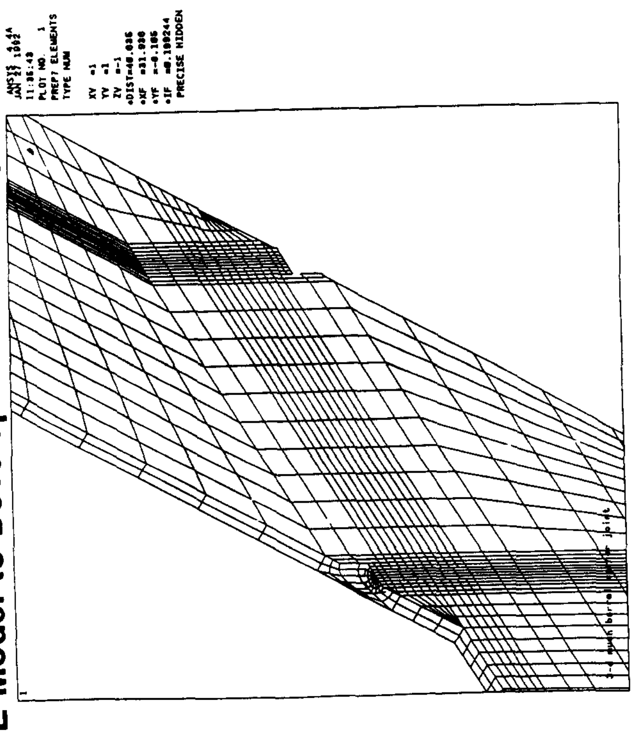
D.Barrel System Analysis

- **1.Mechanical**
  - **a.Full System 3D FE model**
    - **(1)Linear elastic model including floor, support, and steel**
    - **(2)Modified material properties simulate joints**
      - **(a)Block shear modulus (detailed block and ring models)**
      - **(b)Corner joint elastic modulus (detailed corner model)**
    - **(3)Load cases**
    - **(4)Stress**
    - **(5)Deflection**
  - **b.Block details**
    - **(1)Plate flattening**
    - **(2)Pin Size (150mm diameter)**
  - **c.Corner details**
    - **(1)Corner Bolt Sizing**
    - **(2)Shear Key Sizing**
  - **d.Side plate details**
    - **(1)Plate thickness**
    - **(2)Plug weld size and number**
  - **e.Tolerance requirements**
  - **f.Support**
    - **(1)Stability**
    - **(2)Stress**
    - **(3)Deflection**
- **2.Magnetic Analysis**
  - **a.Field Map of the Iron**
  - **b.Sensitivity to Coil Position**
  - **c.Coil Current**
  - **d.Sensitivity to holes in the Iron**
  - **e.Deflection Due to Gaps and Magnetostriction**
  - **f.Forces**
  - **g.Fringe Field**
  - **h.Accuracy of Field Measurement in Gap Plate**
  - **i.Sensitivity to Permeability Variation**

FE Model File in ANSYS

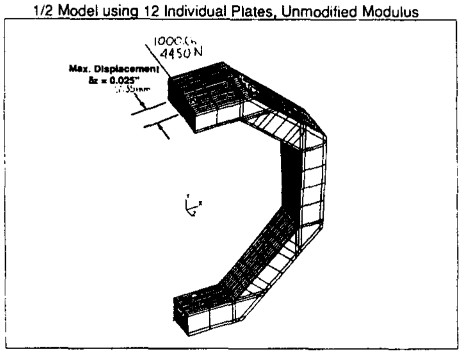


FE Model to Develop Modified Properties



DISPLACEMENT FOR 1000 LBS LOAD IN Z-AXIS

1/2 Model using 12 Individual Plates, Unmodified Modulus

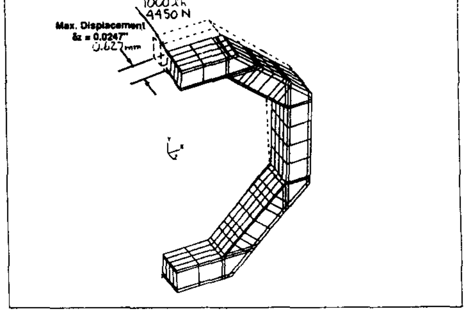


Ex = Ey = Ez = 30^06 psi
μxy = μyz = μxz = 0.29
Ex = Ey = Ez = 4^06 psi (Corner Bolts Area)

Gxy = Gyz = Gxz = 11.6^06 psi

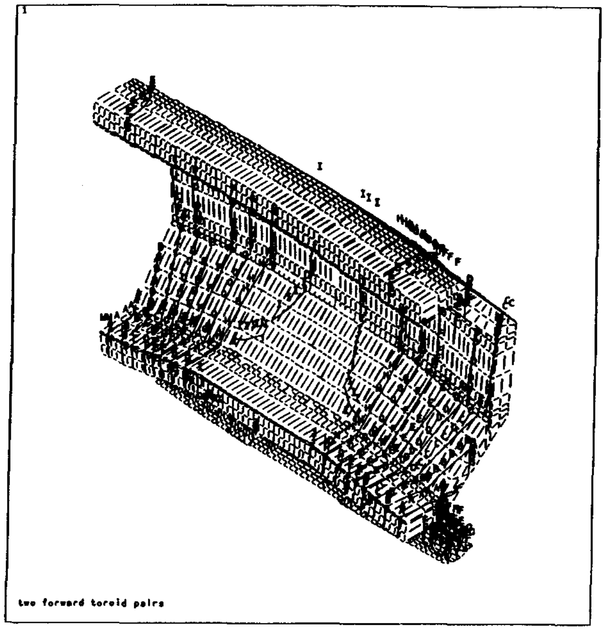
DISPLACEMENT FOR 1000 LBS LOAD IN Z-AXIS

1/2 Model using Solid Elements, Modified Modulus Gxz = 1/50 (steel)



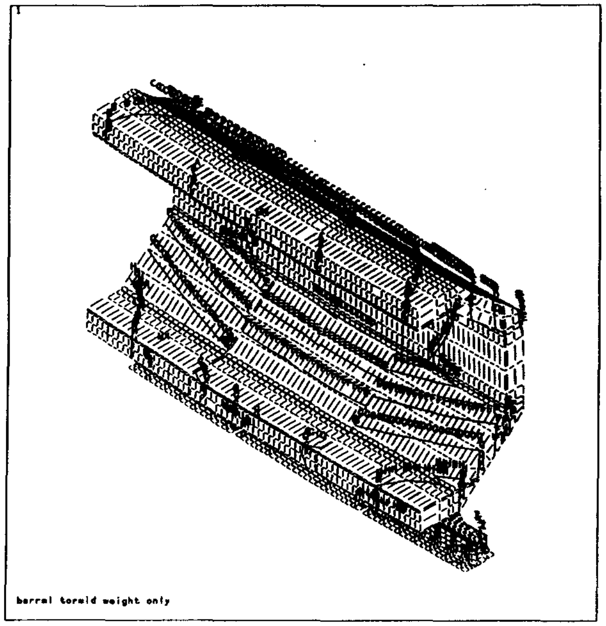
Ex = Ey = Ez = 30^06 psi
μxy = μyz = μxz = 0.29
Ex = Ey = Ez = 4^06 psi (Corner Bolts Area)

Gxy = Gyz = 11.6^06 psi
Gxz = 11.6^06 / 50 = 2.32^05 (Modified)



2.12mm

two forward toroid pairs



7.2
6.2
5.5
4.7
4.0
3.3
2.6
1.9
1.2

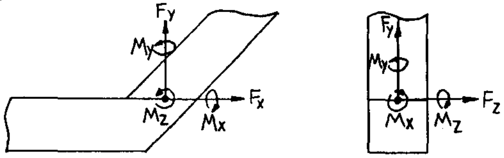
in mm

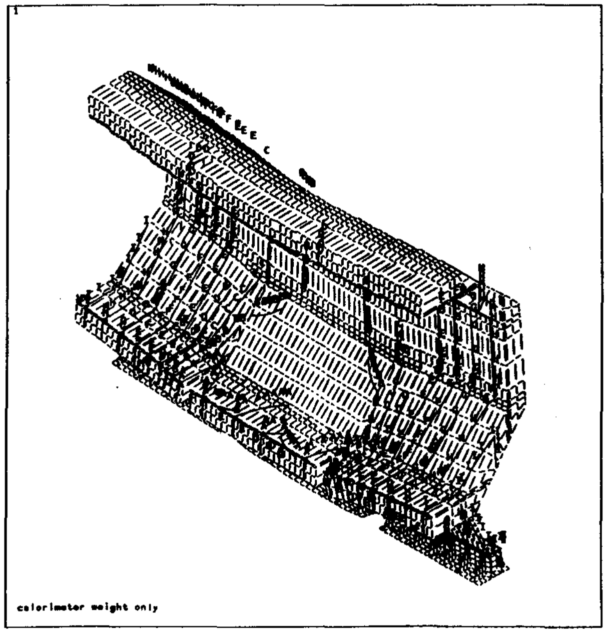
Ring Deflection
B-H = 4.3mm
A-G = 4.6mm

Dishing
SMN-B = 1.1mm

barrel toroid weight only

SDC - MBT Loads and Moments in the Corner Joints						
All values are *per ring joint* (1.752 m in Z)						
Load Case Description	Maximum Loads and Moment from 3D FE Model (Bob Wands)					
	Fx - along line	Fy - along line	Fz - along line	Mx - about axis	My - about axis	Mz - about axis
	// to joint &	perp. to joint &	// to joint &	// to joint &	perp. to joint	// to beam
	perp. to beam	perp. to beam	// to beam	perp. to beam		
	N	N	N	Nm	Nm	Nm
Barrel Weight Alone	3,631,702	4,529,061	289	3,052	989	5,614,043
Calorimeter Weight Alone	257,952	257,952	54,722	271,436	197,192	417,098
Forward Toroid Weight Alone	508,073	508,073	53,076	208,154	210,979	944,827
Barrel, Forward, and Calorimeter Weight	3,856,820	4,751,510	98,678	339,803	407,832	5,836,661
10mm Bow in the Floor Alone	2,445,159	2,445,159	340,169	1,048,452	956,015	2,814,932
10mm Bow with Weight	5,049,592	5,943,837	371,445	1,133,431	1,167,332	7,040,154
0.06g Z Accel. (// to beam) Alone	404,635	404,635	310,183	714,525	859,283	418,906
0.06g Z Accel. with Weight						
0.06g Z Accel. with Weight and Bow	5,343,224	6,237,469	650,441	1,367,349	1,787,725	7,333,965
0.06g X Accel. (perp. to beam) Alone						
0.06g X Accel. with Weight						
0.06g X Accel. with Weight and Bow						
XY Tolerance Correction Alone						
YZ Tolerance Correction Alone						
XY & YZ Tolerance and Weight						
Hydraulic Circuit Failure						
Magnetic						
Static Assembly						
Dynamic Assembly						

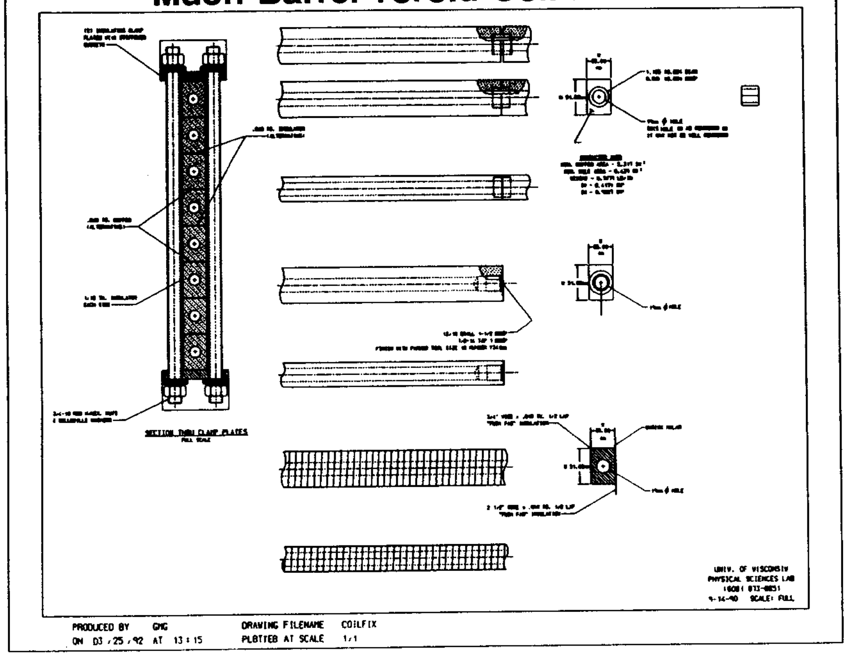




1.13mm

calorimeter weight only

Muon Barrel Toroid Coil Details



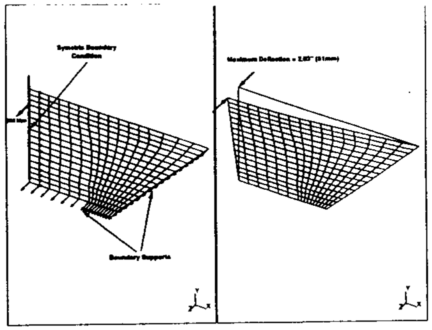


Figure 8.8 Half Shert Plate Model for 147 mm thick Deformed over the entire span 220"

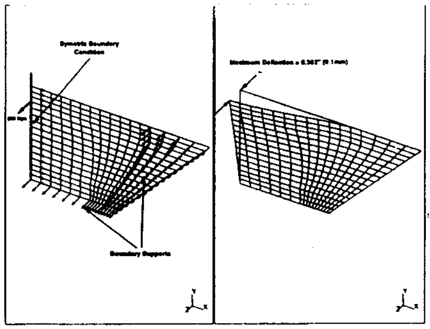
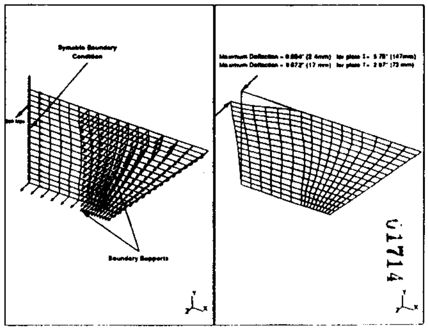


Figure 9.8 Half Shert Plate Model for 147 mm thick Deformed over Four Belt Span 146.8"

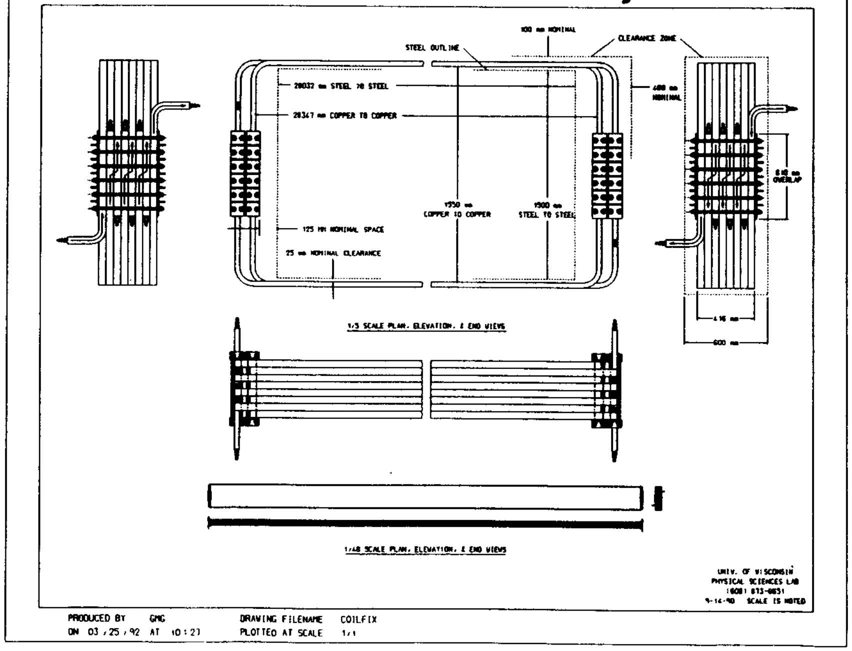


Summary af the FEM Results:

The results for the analysis on 147 mm plates are shown in Figures 7.0 through 9.0 and tabulated as follows:

Plate Deformed Shape	No. of Waves per 12 feet Length	span ft	Maximum Deflection
One wave over the entire span	1/2	18.3'	2.030"
One wave between 4 bolts	1	12.2'	0.362"
One wave between 2 bolts	2	6.12'	0.094"
One wave between 2 bolts (73 mm Pl)	2	6.12'	0.672"

Muon Barrel Toroid Coil Layout



01717

ASSEMBLY AND INSTALLATION

R. LOVELESS

Richard
Loveless

01715

MUON MEASUREMENT SYSTEM

	channels (9m long tube)	modules ~ 8x8 m²
Barrel		
BW1 (4 theta, 4 phi layers):	10674	24
BW2 (4 theta layers):	7536	40
BW3 (4 theta, 4 phi, 2 stereo layers):	26166	40
Intermediate		
IW2 (4 theta layers):	1600	16
IW3 (4 theta, 4 phi, 2 stereo layers):	11648	16
Forward		
FW1 (4 theta layers):	4390	16
FW2 (4 theta, 4 phi layers):	11904	16
FW4 (4 theta layers):	4310	16
FW5 (4 theta, 4 phi layers):	11636	16
total	90000	200

Muon Measurement Overview

01713

year	activity
'91-'93	Design tubes, chambers, supports, utilities
'93-'94	Build prototype tower and evaluate
'95-'97	Produce and test 90,000 tubes (mostly 9m long)
'96-'98	Assemble into modules, towers, supertowers chamber resolution: 250 microns (barrel & inter.) 150 microns (forward)
'96-'98	Install on-chamber utilities (gas, HV, readout, etc.)
'96-'98	Mount scintillator counters
'96-'98	Measure wire locations in position on alignment stand
'97-'99	Install modules and towers in SDC detector

nb. We must build a company to produce 25M$ worth of highly technical equipment in 4 years, then go out of business.

MUON PRODUCTION FACILITIES

01720

Extrusion production (Aluminum companies)

- produce extrusions
- bore ends to correct length and label pieces (test leak T structure)
- clean tubes and treat surface (alodyning?)
- quality checking
- package and ship to tube factory

Tube factory (5-6 located at universities, labs, etc.)

- receive and test parts (endcaps, extrusions, electrodes, etc.)
- install electrode inside tube extrusion
- string wire and install endcaps
- tension wire and crimp
- test each tube: wire tension
  electrical properties
  vacuum leak test
  burn-in period to identify infant mortality
- package and ship to assembly facility

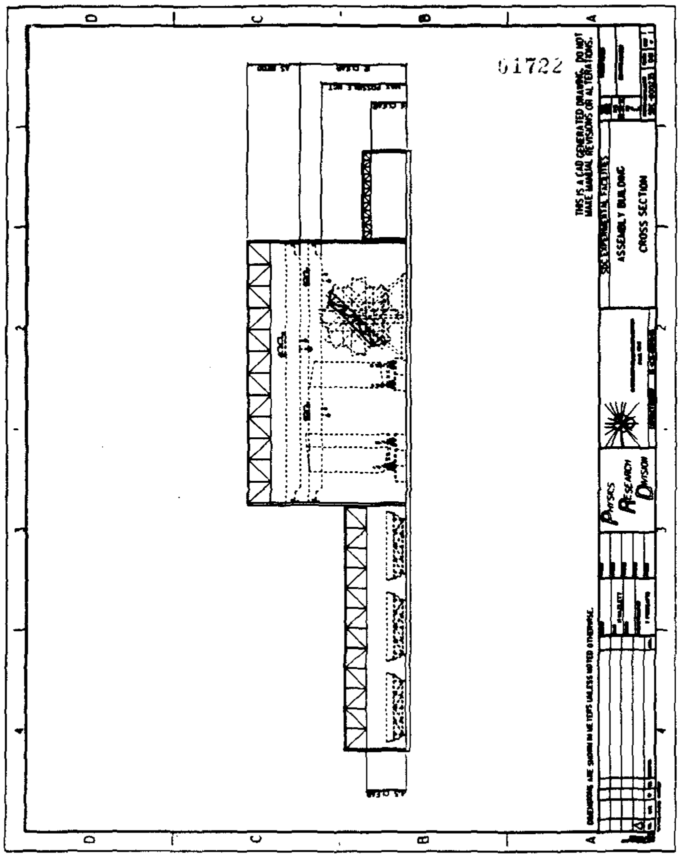
Muon assembly building ([illegible])

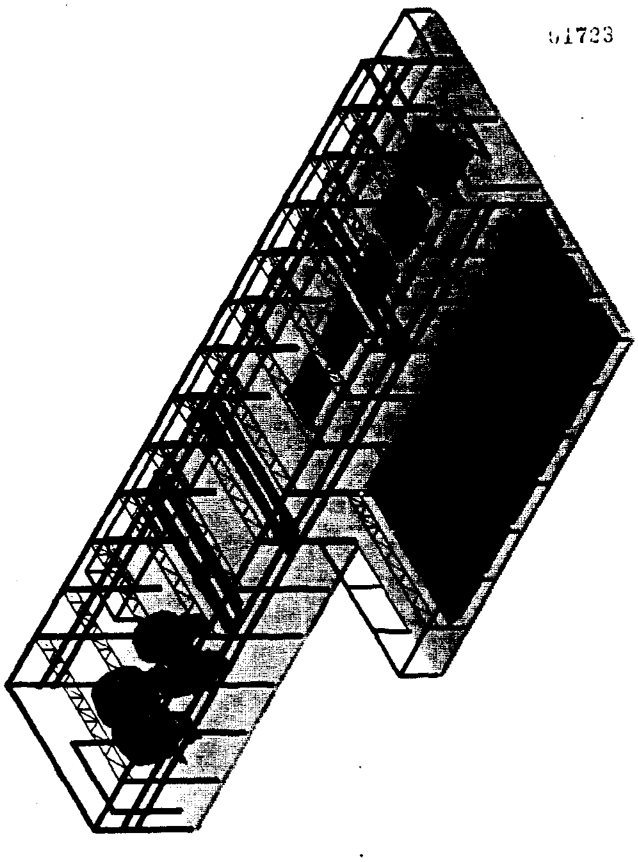
01721

- receive, store, and test tubes for barrel and forward modules
- receive IW2 and IW3 modules for intermediate towers
- receive and store frames and supports (barrel, inter. and forward)
- assemble tubes into modules:

  (Typical modules are 8 x 9 m sq. and are too large to be shipped)

  build and align endplate frames
  clean and surface prep each tube
  insert tubes into endplates and pin in place
  glue tubes and spacers
  add interstitial plates between layers
  add cover plates when all tubes installed
- mount modules into towers: BW2-BW3 (barrel)
  IW2-IW3 (intermediate)
  forward supermodules
- mount barrel/intermediate towers on alignment stand in
  correct orientation, measure alignment parameters, and
  calibrate fiducials (test installation techniques)
- store modules/towers for installation (test during storage)





building parameters:

3000 meter square area under crane

1 50-ton, 2 20-ton cranes (hook 12m high)

50 and 20 ton cranes run on different rails (can pass)

1300 m sq. storage area (no crane)

store modules/towers on rails

BW1 modules could hang from ceiling (or atop other modules

4 large assembly areas (12 m sq.)

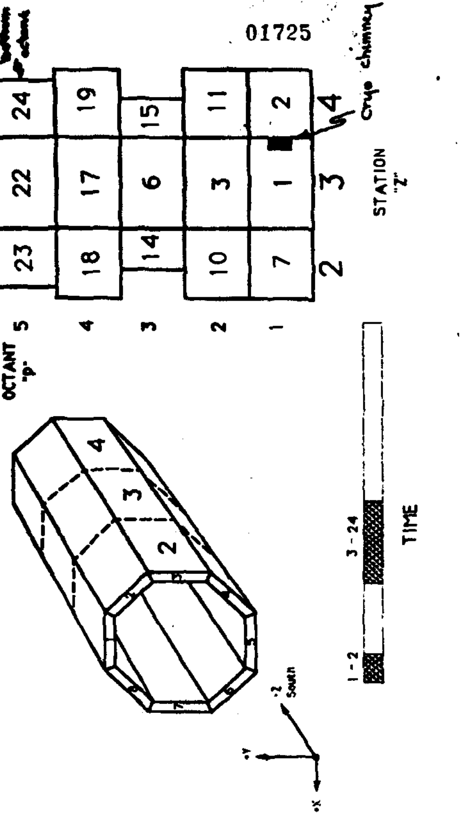
Additional assembly areas

Since Muon Assembly Building is too small for the complete system some assembly must be done in remote facilities.

- assemble IW2 and IW3 modules (small enough to be shipped to SSCL)
- assemble smaller forward modules

Tentative Installation Sequence

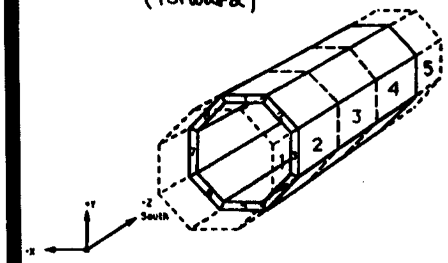
MBW1.Z.P
(inner barrel)



Tentative Installation Sequence

MFW.S.Z.P

(forward)



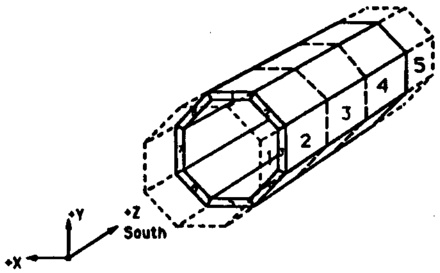
OCTANT "P" \ SUPER MODULE "S"	5	4	2	1	1	2	4	5
8	26	18	10	2	34	42	50	58
7	28	20	12	4	36	44	52	60
6	30	22	14	6	38	46	54	62
5	32	24	16	8	40	48	56	64
4	31	23	15	7	39	47	55	63
3	29	21	13	5	37	45	53	61
2	27	19	11	3	35	43	51	59
1	25	17	9	1	33	41	49	57
STATION "Z"	1	2	3	4	5	6	7	8

01728

Tentative Installation Sequence

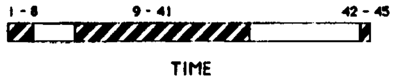
MBW2/3.Z.P

(outer barrel)

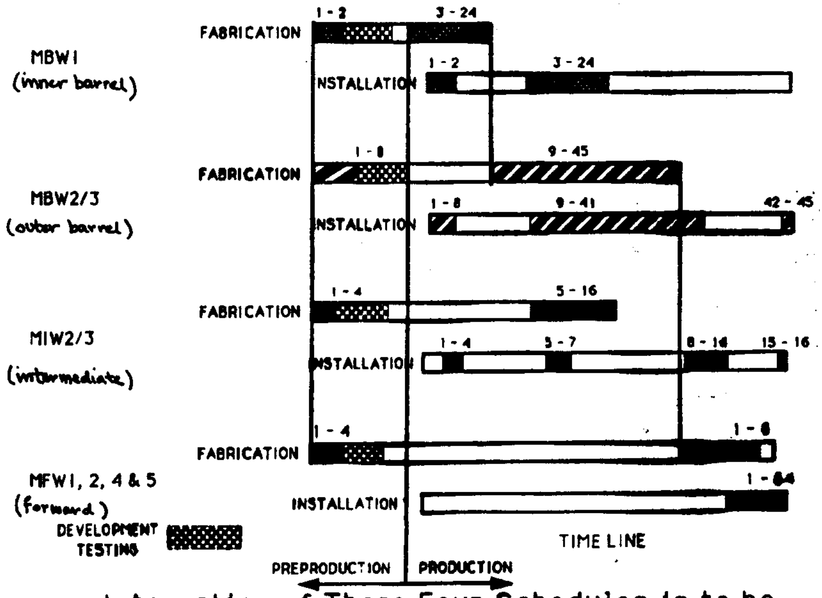


X = BLOCKED

	OCTANT "P"						
X	8	9	14	21	25	28	
	7	30	23	18	16	12	
	6	39	37	35	33	31	X
	5	42 43	2 4	1 5	3 6	44 45	
	4	40	38	36	34	32	X
	3	11	17	20	27	29	
X	2	10	15	22	24	26	
	1	19	13	7	8	41	
	STATION "Z"	1	2	3	4	5	



01726



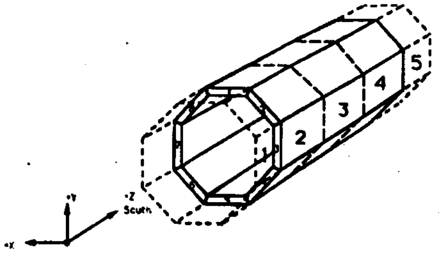
01729

Integration of These Four Schedules is to be Performed

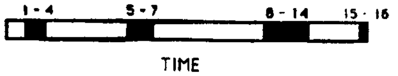
Tentative Installation Sequence

MIW2/3.Z.P

(intermediate)



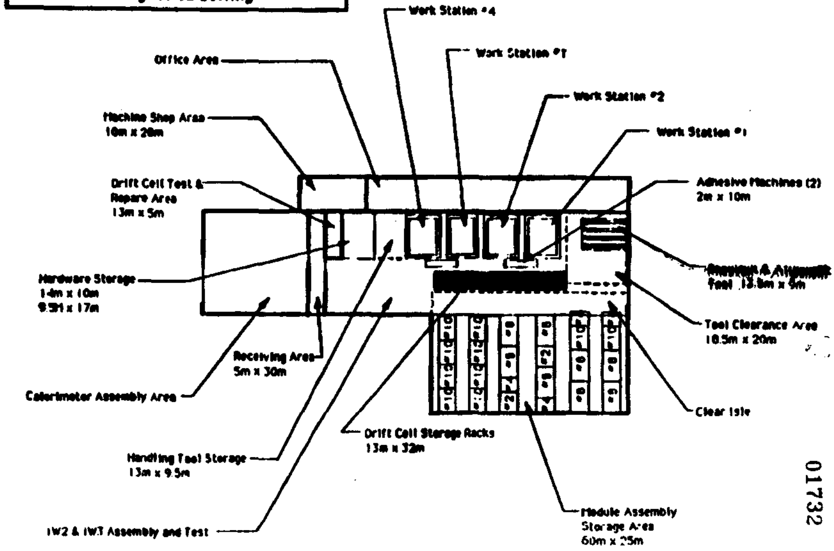
OCTANT "P"	1	5
8	1	9
7	11	6
6	13	3
5	15	16
4	12	4
3	5	10
2	2	8
1	7	14
STATION "Z"	1	5



01727

SDC ASSEMBLY FACILITY

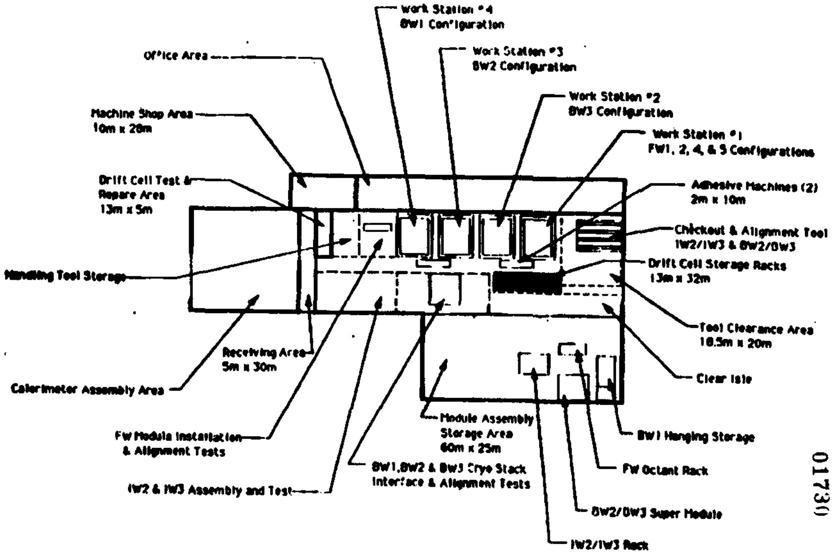
Facility Usage, Barrel Muon Production BW1 Modules Shown Hanging From the Storage Area Ceiling



01732

SDC ASSEMBLY FACILITY

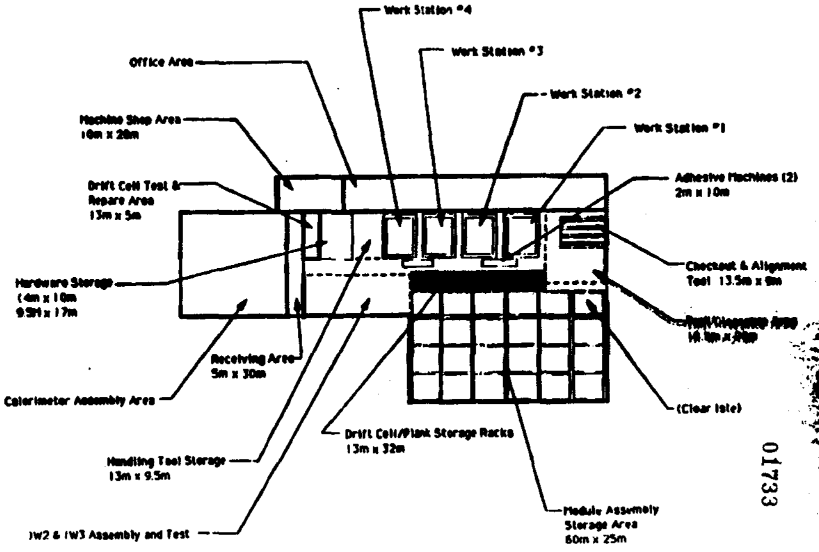
Facility Usage, Muon System, Preproduction Phase



01730

SDC ASSEMBLY FACILITY

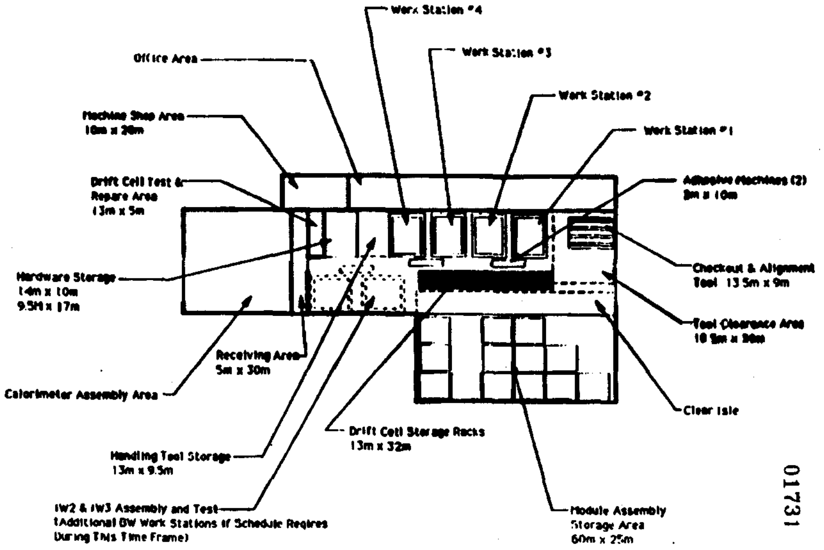
Facility Usage, Barrel Muon Production at 80% Complete



01733

SDC ASSEMBLY FACILITY

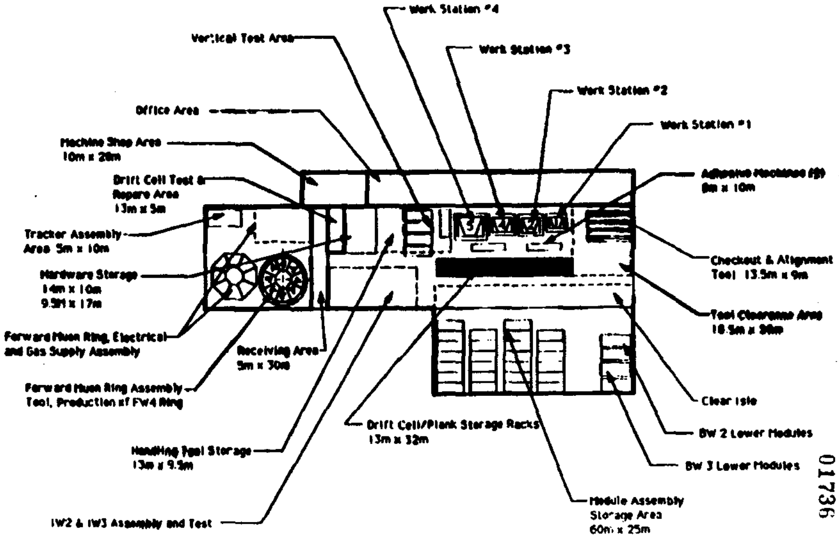
Facility Usage, Barrel Muon Production at 40% Complete



01731

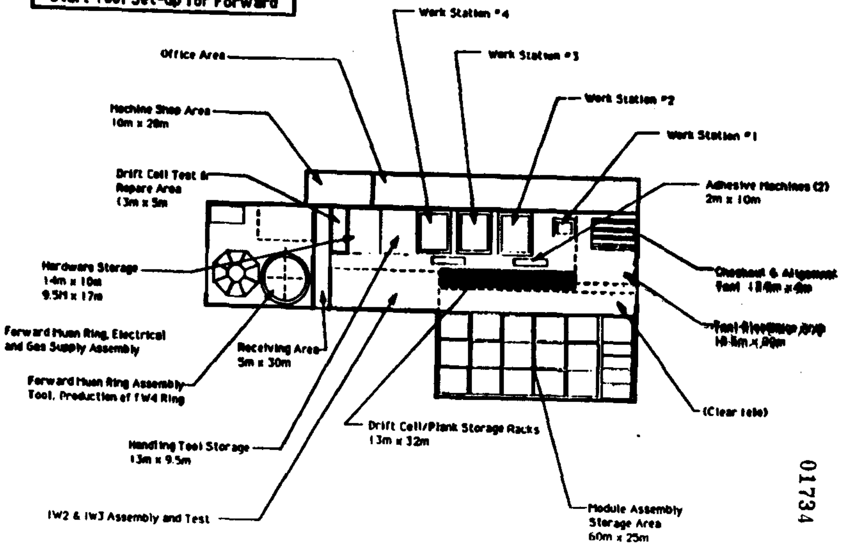
SDC ASSEMBLY FACILITY

Facility Usage, Forward Muon Production at 70% Complete



SDC ASSEMBLY FACILITY

Facility Usage, Barrel Muon Production at 95% Complete, Start Tool Set-up for Forward

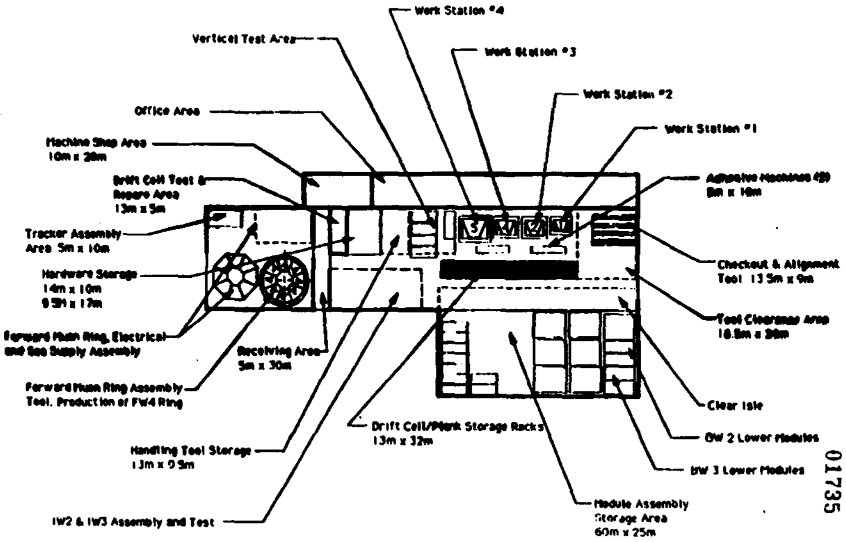


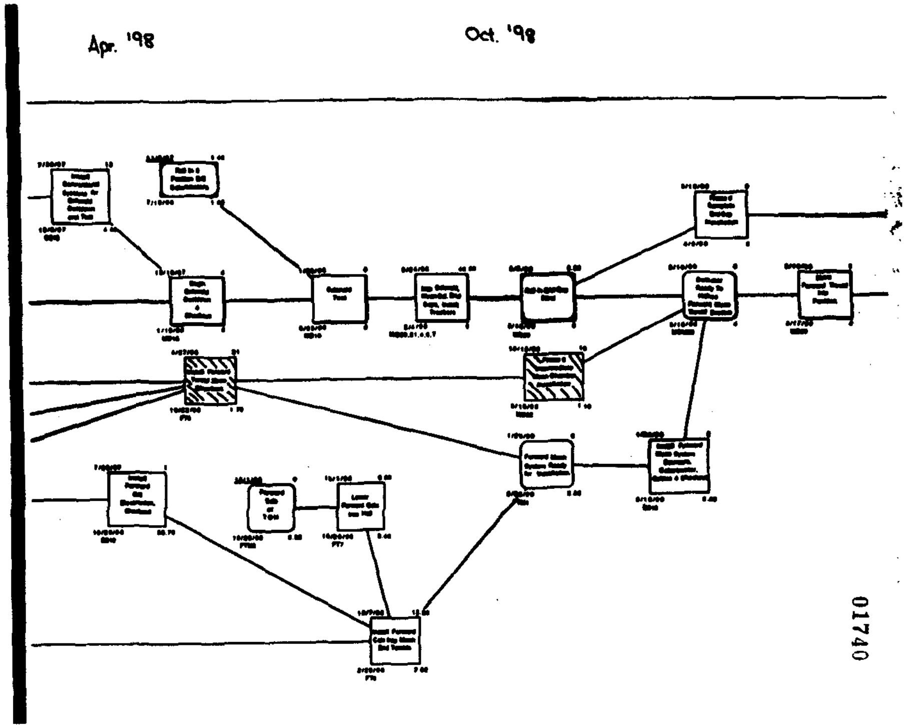
MUON SYSTEM INSTALLATION

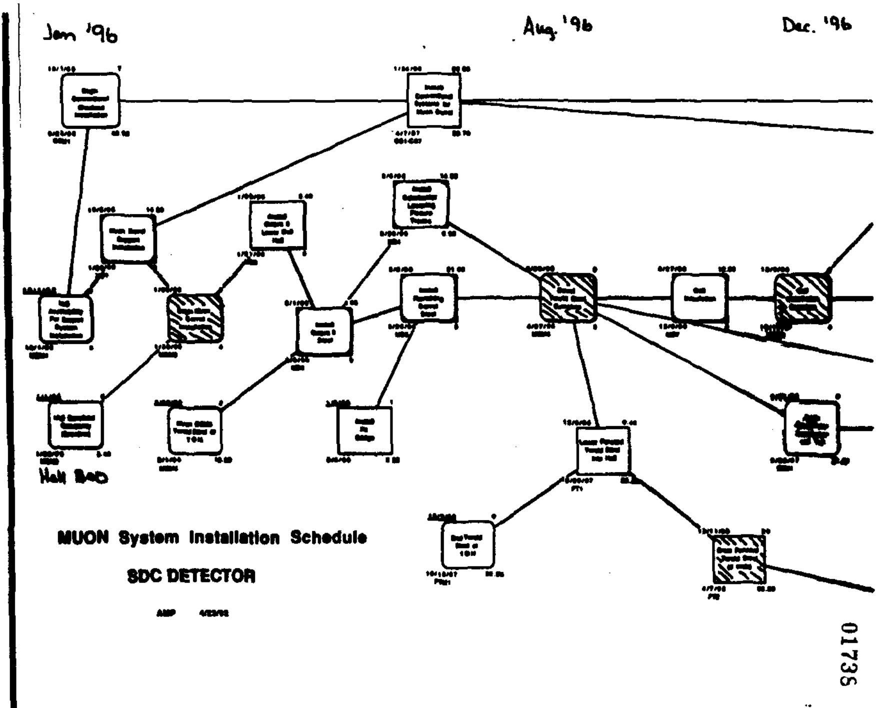
- barrel steel
  - supports and girders
  - inclined planes and space truss
  - octant 5 long blocks (and lower coil)
  - short blocks (lower 45 degree)
  - vertical, upper 45 degree, and top blocks (one ring at a time)
- coils
- intermediate towers (2 or 3 before cable ducts)
- lower rails, cables, water cooling, gas plumbing
- roll some barrel modules into position
- pause for calorimeter installation
- roll most of the remaining barrel modules/towers into position
- insert remaining intermediate towers (except octant 5)
- roll forward systems (toroids, FW1, FW2, FW4?) into position
- remove bridges
- install remaining BW2/BW3 modules and IW2-IW3 towers
- install FW5 octants (too large to fit on the bridge)

SDC ASSEMBLY FACILITY

Facility Usage, Forward Muon Production at 20% Complete



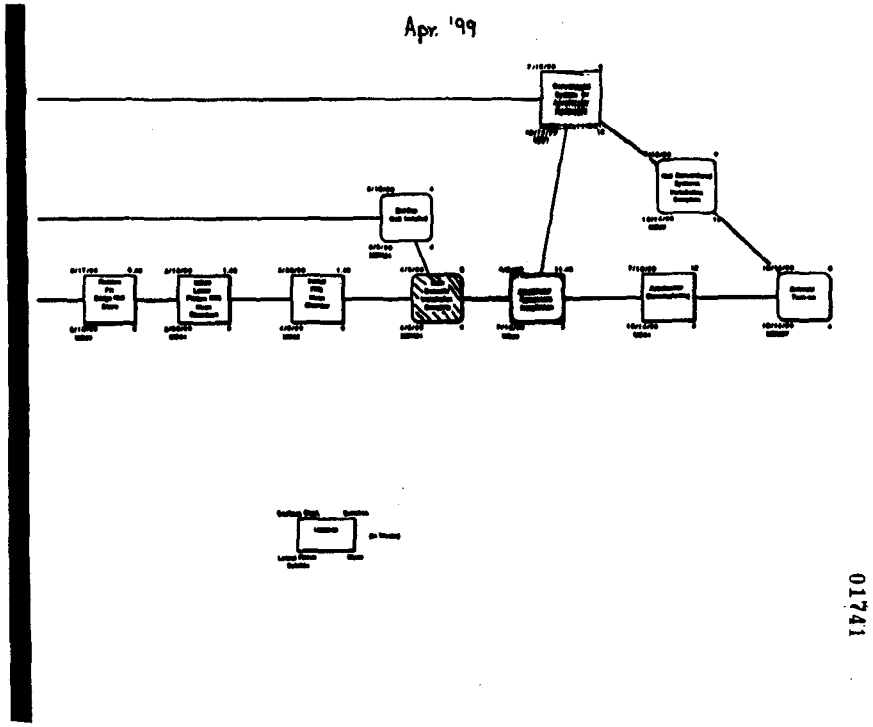


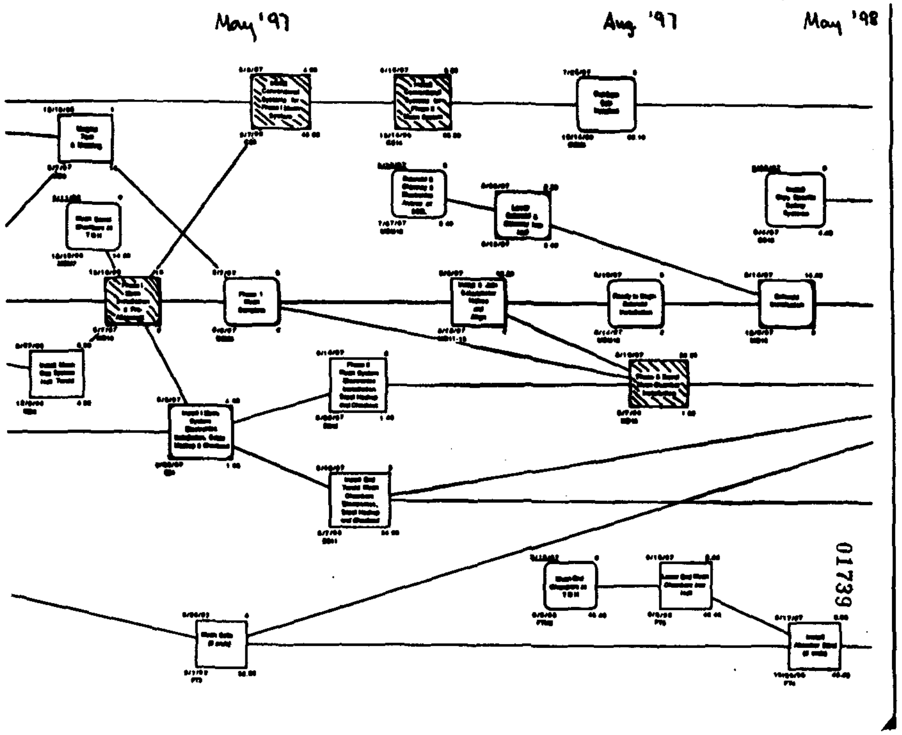


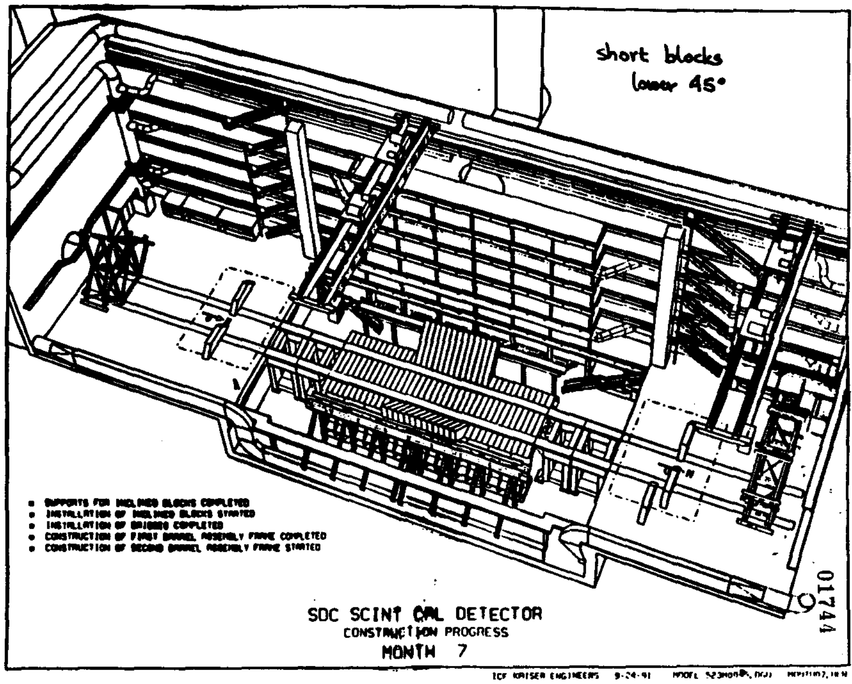
MUON System Installation Schedule

SDC DETECTOR

AMP [illegible]







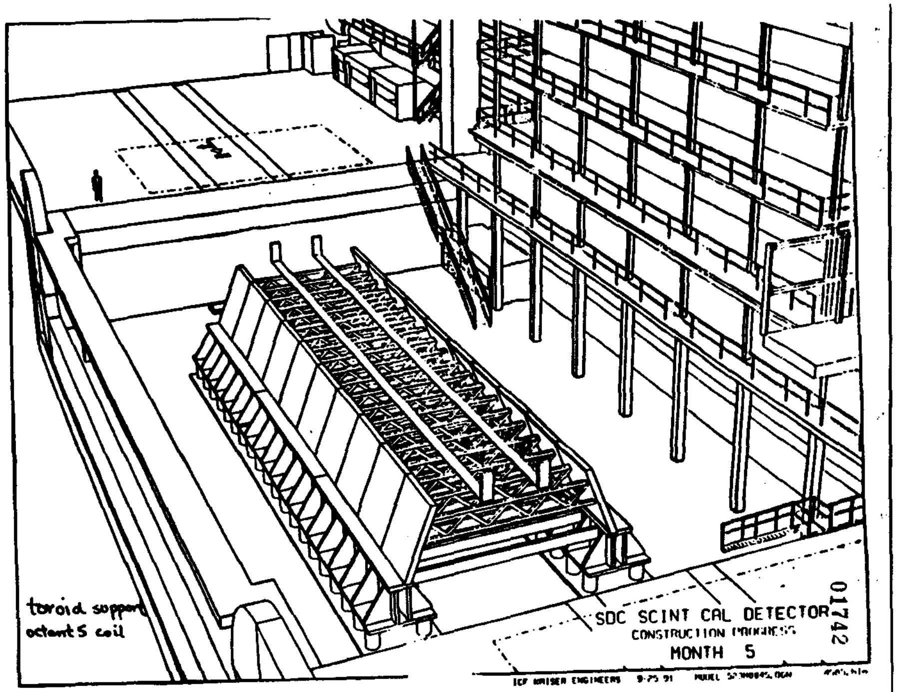
short blocks
lower 45°

- SUPPORTS FOR INCLINED BLOCKS COMPLETED
- INSTALLATION OF INCLINED BLOCKS STARTED
- INSTALLATION OF BRIDGES COMPLETED
- CONSTRUCTION OF FIRST BARREL ASSEMBLY FRAME COMPLETED
- CONSTRUCTION OF SECOND BARREL ASSEMBLY FRAME STARTED

SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 7

01744

ICF KAISER ENGINEERS 9-24-91 MODEL [illegible] [illegible]

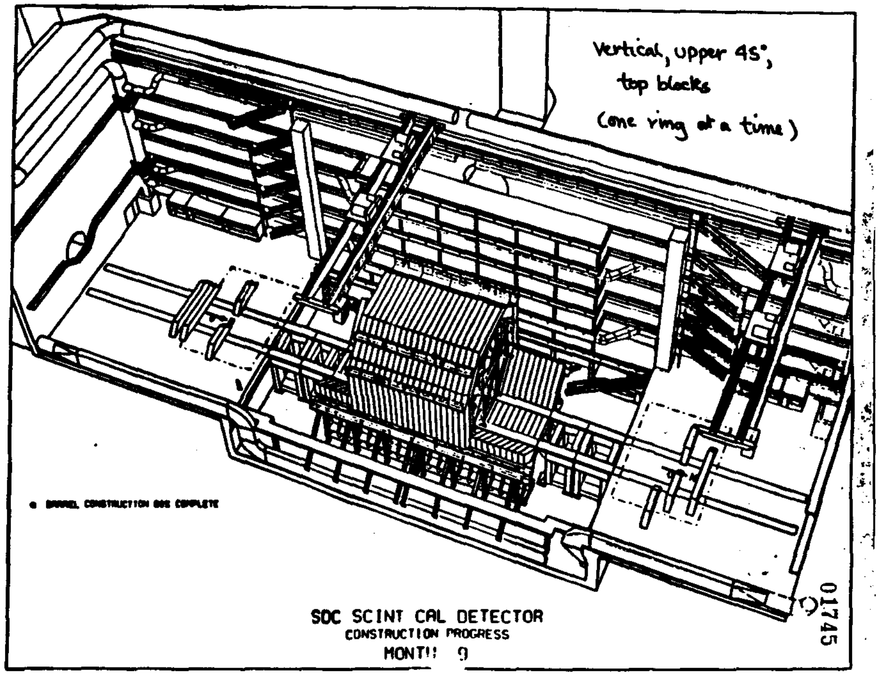


toroid support
octant 5 coil

SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 5

01742

ICF KAISER ENGINEERS 9-25-91 MODEL [illegible] [illegible]



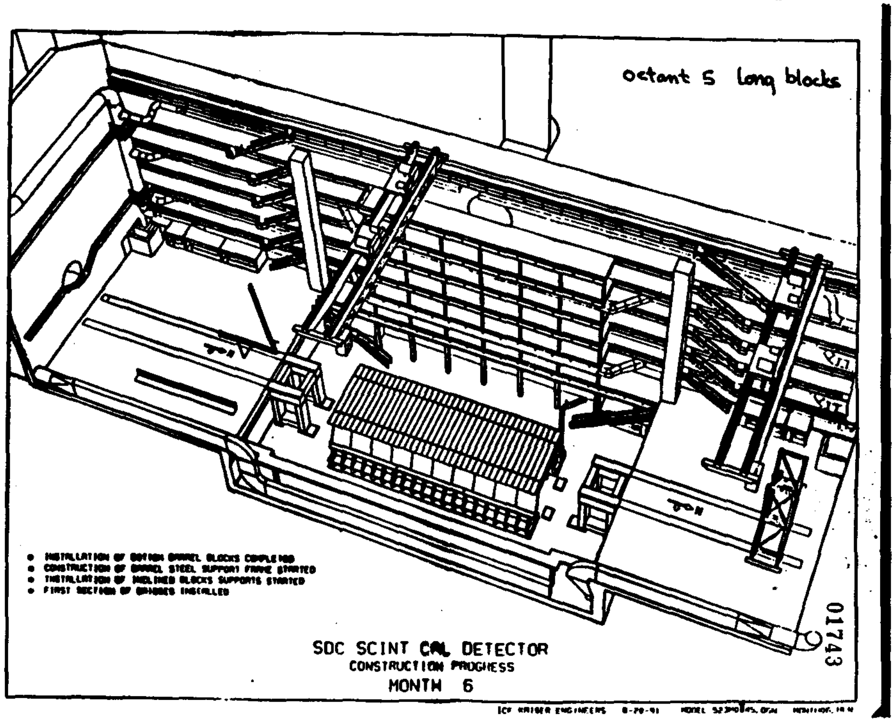
Vertical, upper 45°,
top blocks
(one ring at a time)

- BARREL CONSTRUCTION [illegible] COMPLETE

SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 9

01745

ICF KAISER ENGINEERS 9-24-91 MODEL [illegible] [illegible]



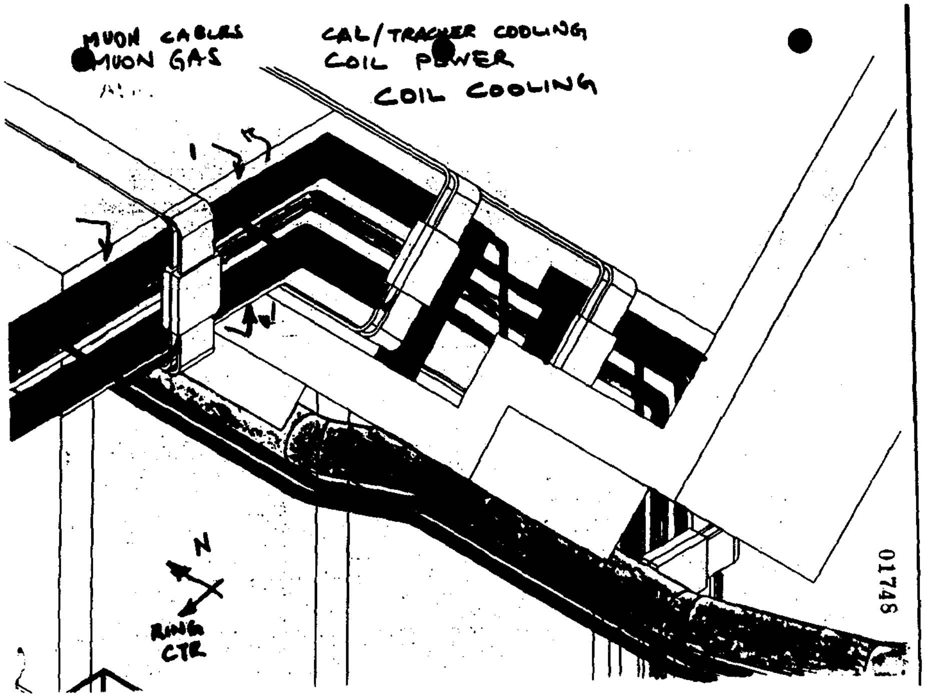
octant 5 long blocks

- INSTALLATION OF BOTTOM BARREL BLOCKS COMPLETED
- CONSTRUCTION OF BARREL STEEL SUPPORT FRAME STARTED
- INSTALLATION OF INCLINED BLOCKS SUPPORTS STARTED
- FIRST SECTION OF BRIDGES INSTALLED

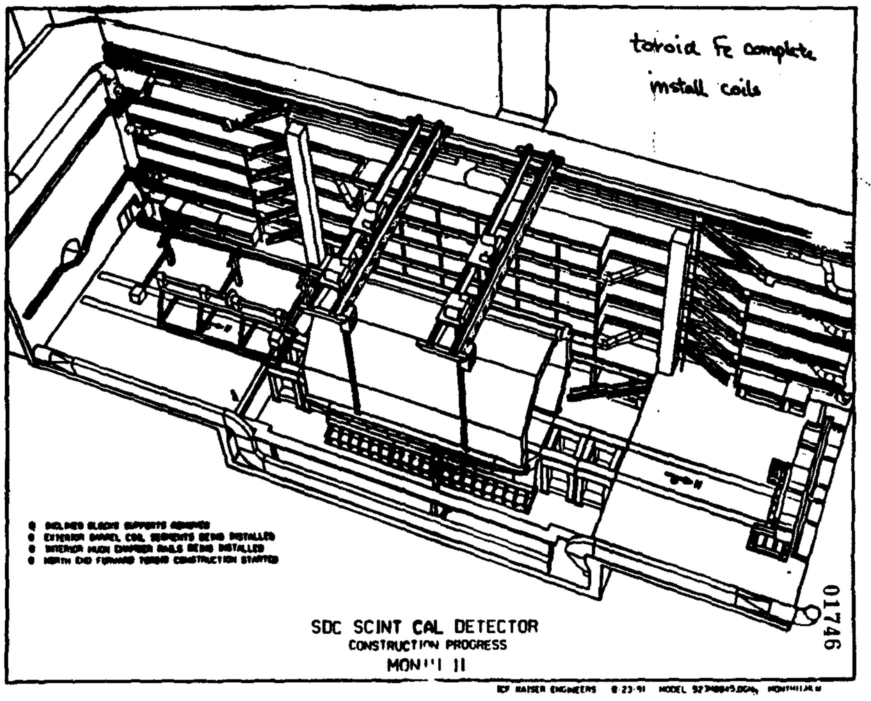
SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 6

01743

ICF KAISER ENGINEERS [illegible] MODEL [illegible] [illegible]



01748

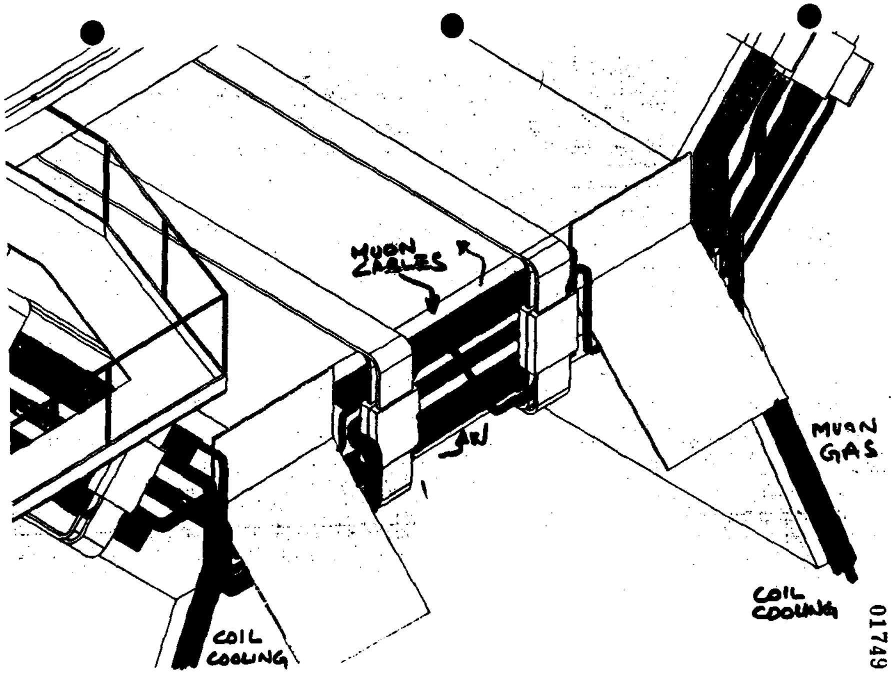


- INCLINED BLOCKS SUPPORTS REMOVED
- EXTERIOR BARREL COIL SEGMENTS BEING INSTALLED
- INTERIOR MUON CHAMBER RAILS BEING INSTALLED
- NORTH END FORWARD TOROID CONSTRUCTION STARTED

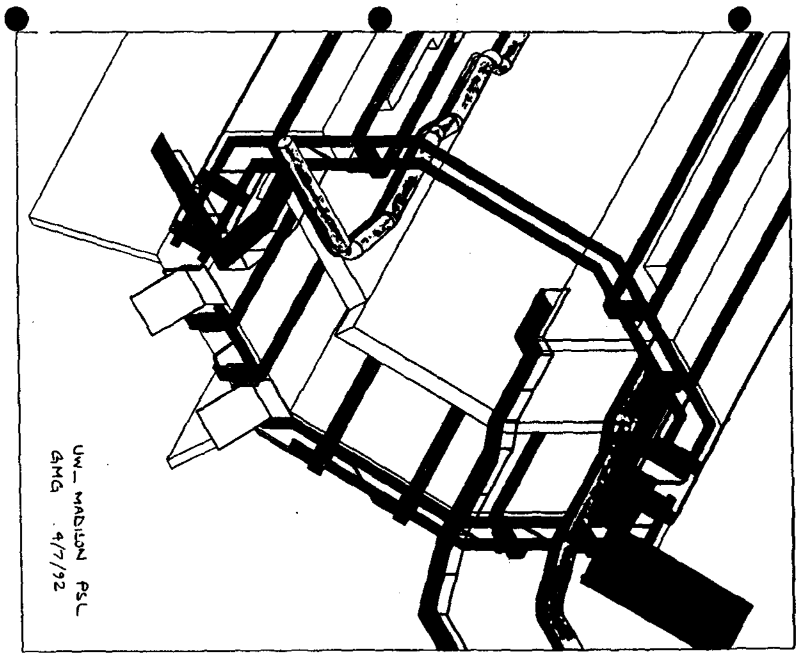
SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 11

ICF KAISER ENGINEERS 8-23-91 MODEL [illegible]

01746

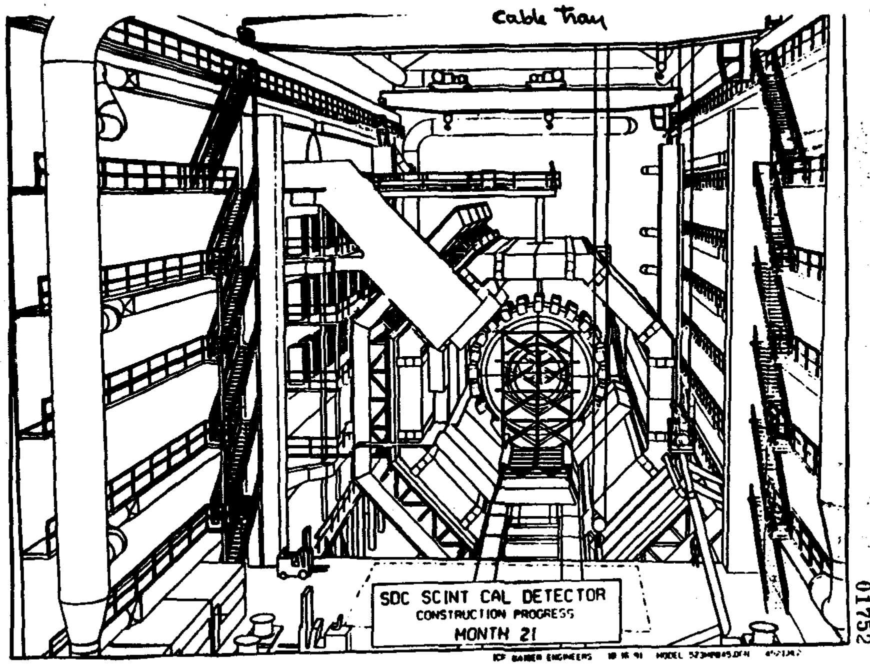


01749

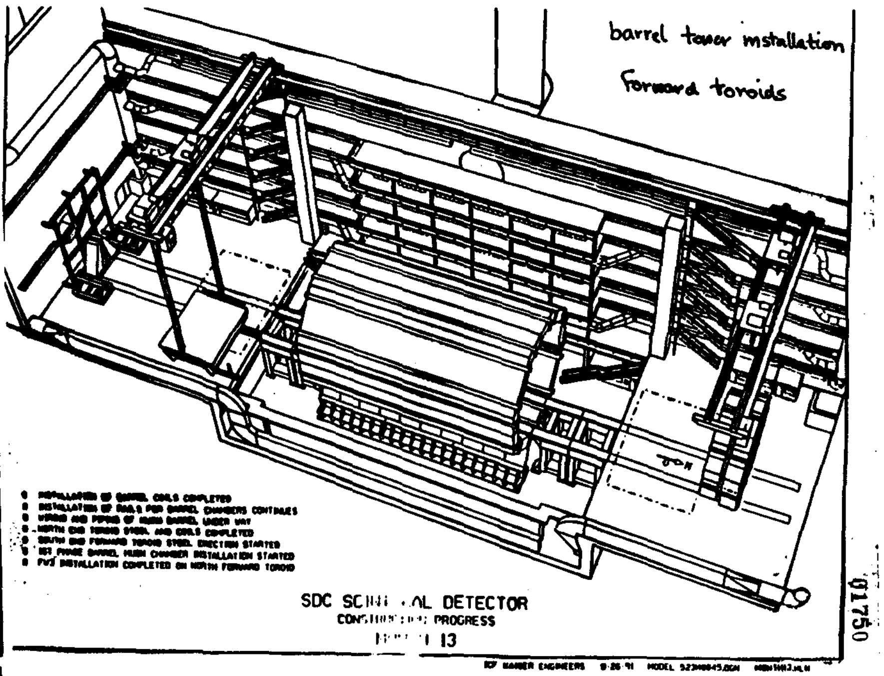


UW-MADISON PSL
GMG 4/7/92

01747



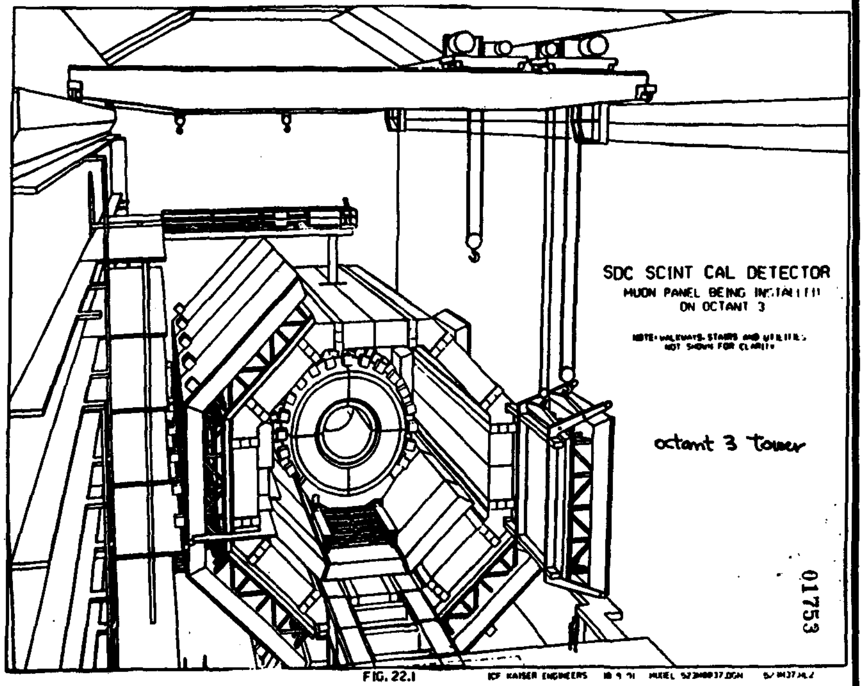
cable tray



barrel tower installation

Forward toroids

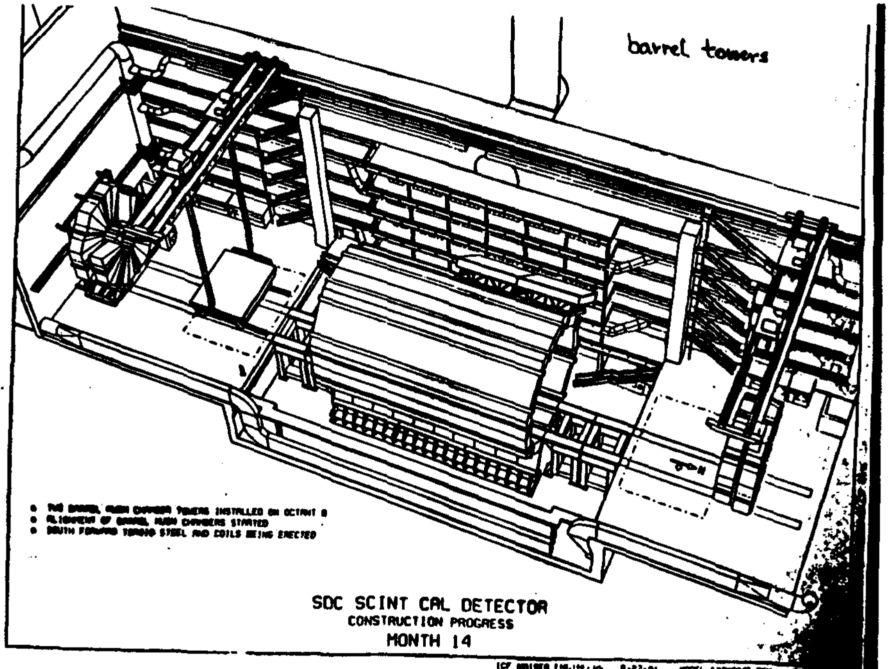
- INSTALLATION OF BARREL COILS COMPLETED
- INSTALLATION OF RAILS FOR BARREL CHAMBERS CONTINUES
- WIRING AND PIPING OF MUON BARREL UNDER WAY
- NORTH END TOROID STEEL AND COILS COMPLETED
- SOUTH END FORWARD TOROID STEEL ERECTION STARTED
- 1ST PHASE BARREL MUON CHAMBER INSTALLATION STARTED
- FVT INSTALLATION COMPLETED ON NORTH FORWARD TOROID



NOTE: WALKWAYS, STAIRS AND UTILITIES NOT SHOWN FOR CLARITY

octant 3 tower

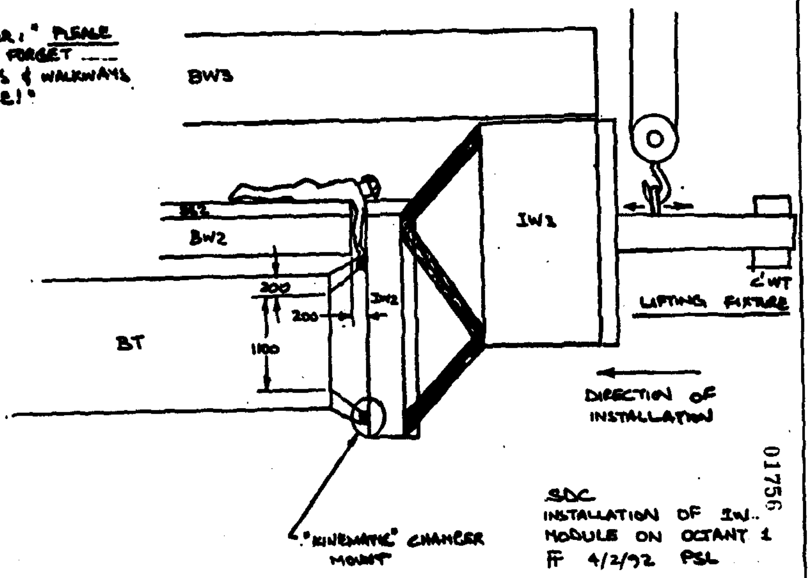
FIG. 22.1



barrel towers

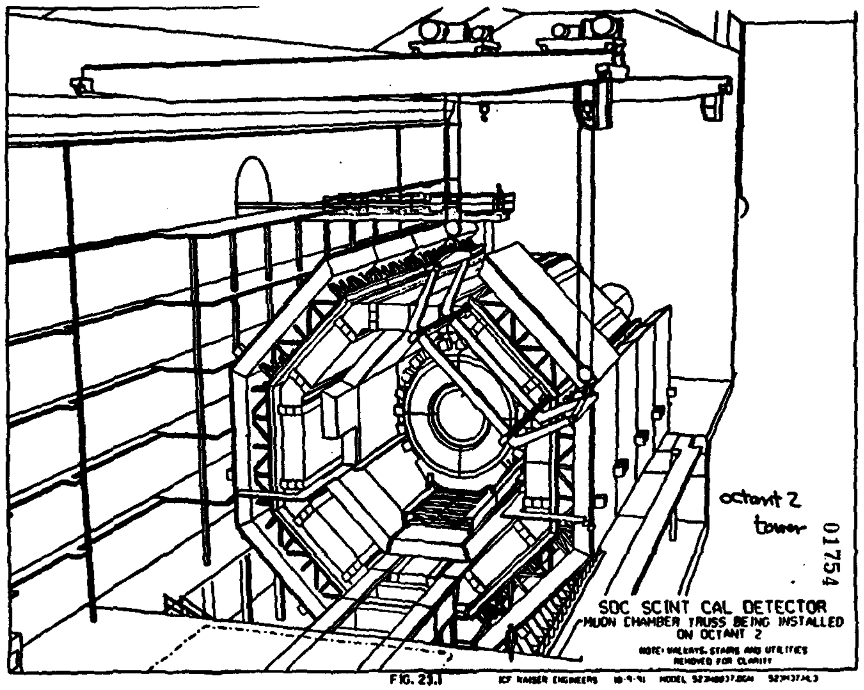
- TWO BARREL MUON CHAMBER TOWERS INSTALLED ON OCTANT 8
- ALIGNMENT OF BARREL MUON CHAMBERS STARTED
- SOUTH FORWARD TOROID STEEL AND COILS BEING ERECTED

INSTALLER: "PLEASE DON'T FORGET ---- LADDERS & WALKWAYS FOR ME!"



SDC
INSTALLATION OF IW MODULE ON OCTANT 1
FF 4/2/92 PSL

01756

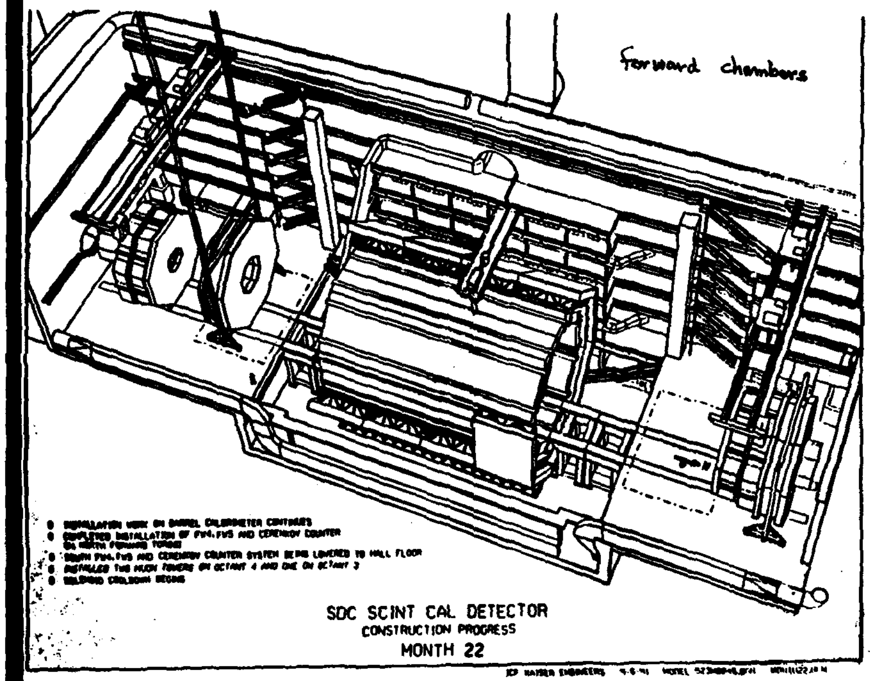


SDC SCINT CAL DETECTOR
MUON CHAMBER TRUSS BEING INSTALLED ON OCTANT 2

NOTE: WALKWAYS, STAIRS AND UTILITIES REMOVED FOR CLARITY

FIG. 23.1 ICF KAISER ENGINEERS 10-9-91 MODEL [illegible]

01754

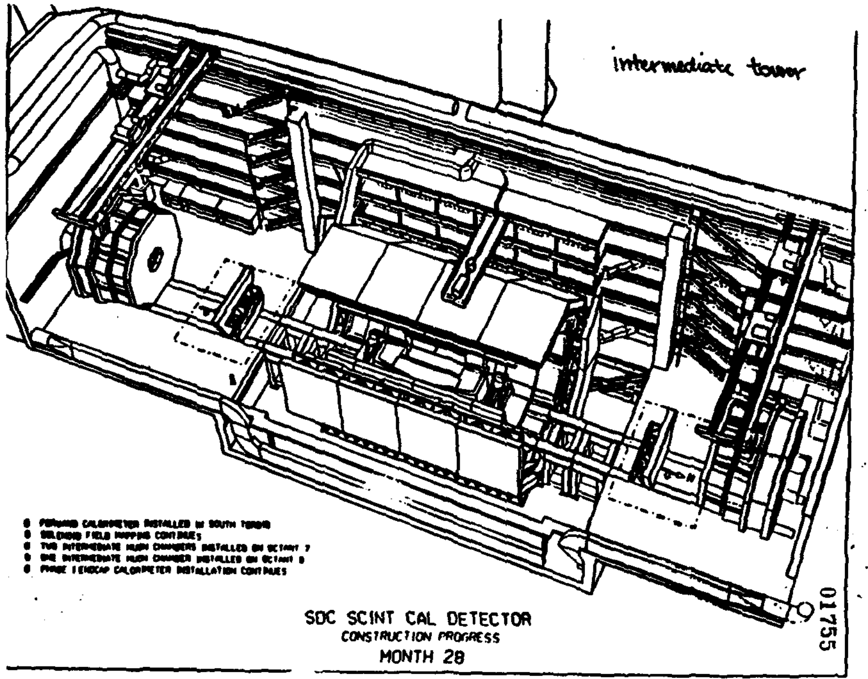


- INSTALLATION WORK ON BARREL CALORIMETER CONTINUES
- COMPLETED INSTALLATION OF FW4, FW5 AND CERENKOV COUNTER ON NORTH FORWARD TOROID
- SOUTH FW4, FW5 AND CERENKOV COUNTER SYSTEM BEING LOWERED TO HALL FLOOR
- INSTALLED TWO MUON TOWERS ON OCTANT 4 AND ONE ON OCTANT 3
- SOLENOID COOLDOWN BEGINS

SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 22

ICF KAISER ENGINEERS 9-6-91 MODEL [illegible]

01757

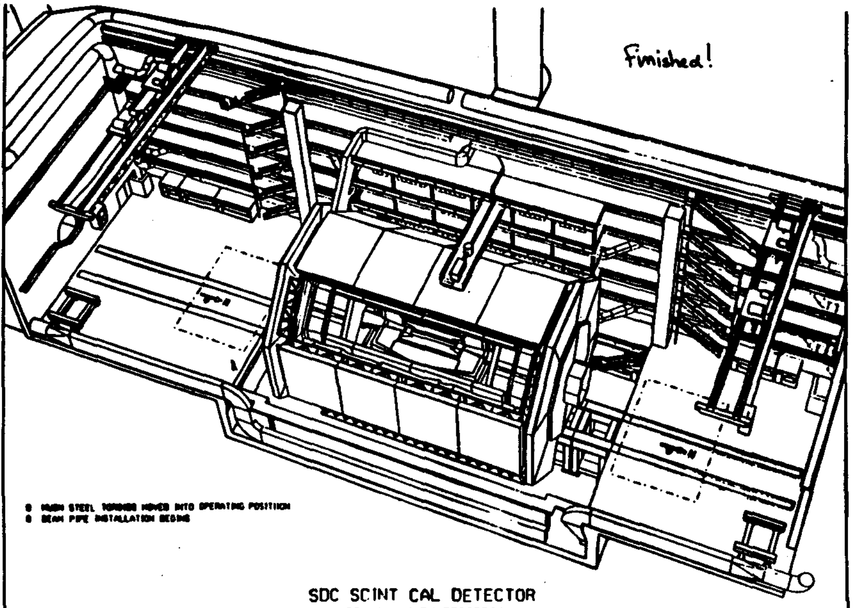


- FORWARD CALORIMETER INSTALLED IN SOUTH TOROID
- SOLENOID FIELD MAPPING CONTINUES
- TWO INTERMEDIATE MUON CHAMBERS INSTALLED ON OCTANT 7
- ONE INTERMEDIATE MUON CHAMBER INSTALLED ON OCTANT 8
- PHASE I ENDCAP CALORIMETER INSTALLATION CONTINUES

SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 28

ICF KAISER ENGINEERS 9-17-91 MODEL [illegible]

01755



Finished!

- MUON STEEL TOROIDS MOVED INTO OPERATING POSITION
- BEAM PIPE INSTALLATION BEGINS

SDC SCINT CAL DETECTOR

CONSTRUCTION PROGRESS

MONTH 37

ICF KAISER ENGINEERS 10-13-91 MODEL 523MR045.DGN MONTH37.JAN

R & D AND PROTOTYPE PLAN

C. GRINNELL

R&D, Engineering
and
Prototype Plan

Charles Grinnell

SDC Muon Measurement System
Chief (3.2) Engineer

May 6, 1992
SSCL

Research and Development
Detecting Element

- Extensive R&D with prototypes for the detecting *element(and geometry) completed on 4 options:*
  - Jet cell
  - Oval tube
  - Octagonal tube
  - Round tube
- Decision to proceed with 'Round tube' option with field shaping for Barrel and Intermediate regions
- Forward system requirements from radiation and rates dictate further R&D (BNL and IHEP tests)

C. Grinnell 05/06/92

MUON DETECTOR ALIGNMENT

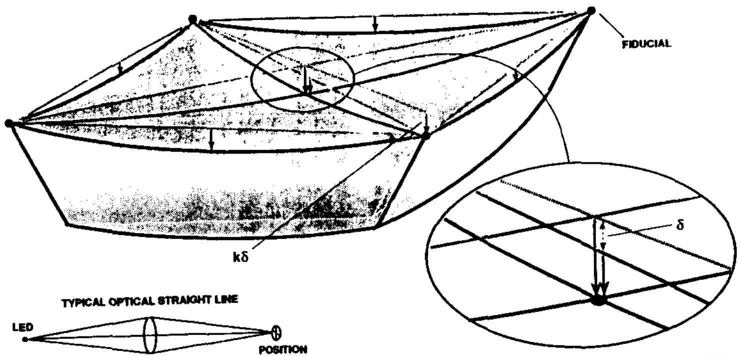
Subsystem R&D Plans

- Fencepost : concatenation implementation ==> accuracy, range, temperature, drift, aging, radiation effects, calibration
- Other types of Straight-Line multipoint sensing
- Proximity Sensor Types:
  Attachment to fencepost, accuracy, range, temperature,...
- Ranging Subsystem:
  - Ranging Electronic technique and implementation: time- of-flight, AM modulation, FM modulation
  - Optical Head mechanization
  - Targets
  - Calibration procedures
- Other Subsystems: Angle transfer, Inclinometer, Liquid Level

J. GOVIGNON
5/4/92

'LOCAL ALIGNMENT' to Monitor Module Deformations

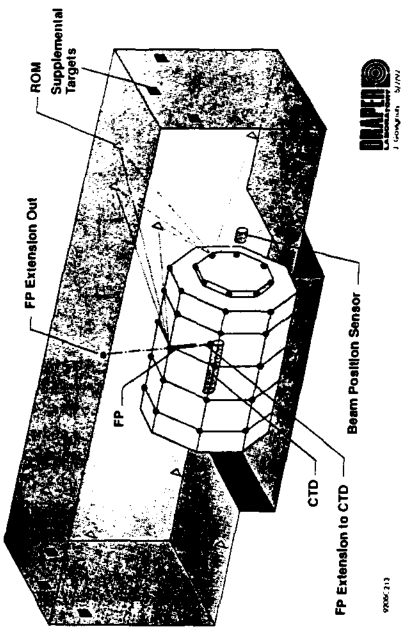
- Through local alignment, the wire ends positions are related to the fiducial marks at module's corners
- Straight line monitors measure low order structural mode shape
- Low order mode shape ascertained by analysis & prototype
- Mode shape is determined by:
  - Fabrication errors
  - Thermal & gravity loadings
  - Mounting Conditions (# of support points & location)
- Length determined by Fabrication tolerance & temperatute sensing



J. Govignon 5/2/92

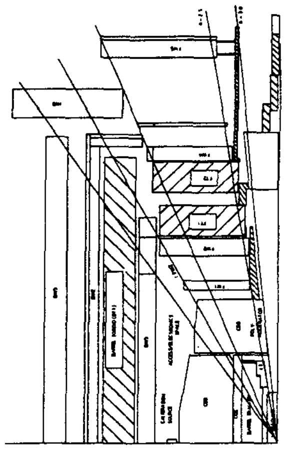
Option for GLOBAL ALIGNMENT

- To provide external closure of the network of optical straight lines and relate it to the survey network & beam line
- Based on a system of automated distance-only-measuring devices using laser diode ranging, organized in clusters providing self alignment capability



Development

- With the sensing element of the detector determined, the configuration can be optimized and fixed
- This is done in 2 parts: Configuration studies / Engineering design studies



C. Grinnell 05/06/92

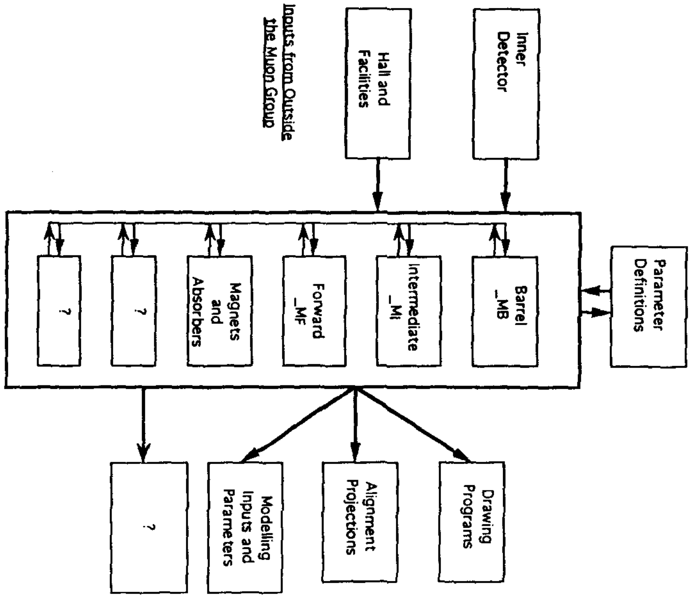
Muon Measurement System
Configuration Issues*

* Items which could change the conceptual design of any part of the subsystem and/or require changes in other subsystems.

Configuration Issues Outline

Responsibilities	μ	S	I	TB
Superlayers				
• Tube spacer specifications and analysis	x			
• Creep tests on wires and superlayers	x			
Detailed Layouts				
• Stereo validation and optimum location	x	x		x
• Phi and theta optimized in all layers	x	x		x
• Scintillators	x	x		x
Alignment				
• Location and dimensions of access to CTD	x		x	x
• Validate link of B/I/F and all to CTD	x			
• Projective lines of sight requirement	x		x	
• System tolerance allocation	x	x		
[• SDC overall support, adjustment and control plan]			x	
[• Exact layouts for magnet wormhole locations (6/92)]			x	
System Cracks				
• Phi solutions for barrel	x	x		x
• Theta at B/I/F interfaces	x	x		
• Matching cracks and function with CTD	x		x	
• General philosophy: minimize dead or soft zones	x	x		x
• Support base angled or vertical	x		x	
• B/I overlap	x		x	
Service and Access Ways				
• Consistent with supermodule layout	x		x	
• Consistent with installation and schedule	x		x	
• Minimize all	x		x	x
Cryo Chimney				
• Dimensions and location	x		x	x
• Performance in region - behind calorimeter gap - behind muon system gap - true gap at toroid including flux variations	x	x		
Forward System				
• Inclusion in facilities and resource requirements	x		x	
• Inner detector access	x		x	
• Support and assembly sequence	x		x	
• FCAL and beam pipe support	x		x	
• Absorber specifications and support	x	x	x	

SDC MUON SYSTEM ENGINEERING DATABASE OVERVIEW



Inputs from Outside the Muon Group

Inner Detector

Hall and Facilities

Parameter Definitions

Barrel _MB

Intermediate _Mi

Forward _MF

Magnets and Absorbers

?

?

Drawing Programs

Alignment Projections

Modelling Inputs and Parameters

?

Development

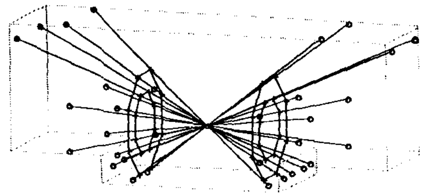
Configuration Studies Tool

- Parametrically driven numeric description of the detector under development
- Provides fast turn-around assessments of changes to the configuration with output of:
  - Geometric coverage
  - Channel counts
  - Model for simulation
- Other planned uses:
  - Configuration Management
  - Parameter drawing packages
  - Alignment studies

C. Grinnell 05/06/92

Example Output

Projections of the IW3 alignment lines onto the cavern walls for survey monument definition.



G. Holden
5/4/92

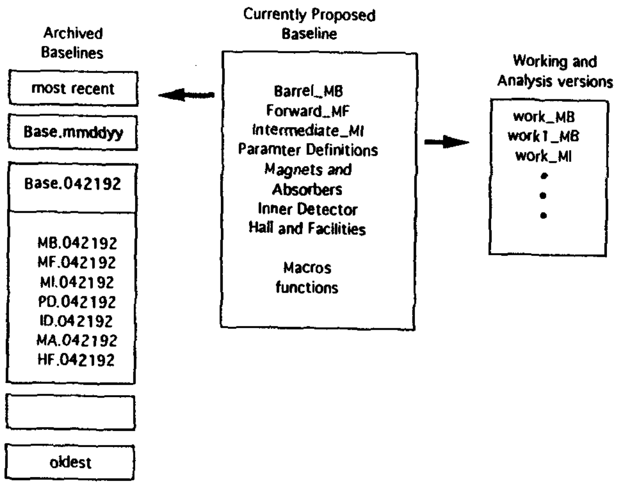
SDC Muon Measurement System Engineering Parameters Database

G. Holden
5/4/92

Engineering Organization

- The people
- The schedule
- The tasks

Baseline Archiving Configuration



Engineering Organization
Engineering groups Involved

- **University of Washington**
  - Barrel system design
- **University of Maryland**
  - Forward system design
- **FNAL**
  - Alignment
  - Facilities and services
- **University of Texas @ Arlington**
  - Production
  - Robotics
- **Martin Marrietta**
  - Resource allocation model
  - Overall system design
- **University of Wisconsin**
  - Intermediate system design
  - Facilities and services
- **IHEP**
  - Forward system design
- ***Draper Laboratory***
  - Alignment
  - System engineering
  - Forward system?
- **SSCL**
  - Schedules
  - *Integration*
  - Facilities
  - Prototype
- **PSL (Wisconsin)**
  - Intermediate sysiem design
- ***Harvard University***
  - Tube design
- **University of Michigan**
  - Scintillator system

Transition
from
R&D to Design

- Some real R&D remains on topics like alignment, electronics, scintillators, gas, etc.
- Configuration issues must be resolved soon
- The focus is now shifting to:
  1. scoping out the detailed design effort
  2. adding configuration specific details to the schedules
  3. organizing the engineering and other resource requirements

Engineering Organization
Continuing Schedule Development

Design
Construction
Installation

- Installation schedule updating for changes in underground hall and detector configuration
- Construction phase details by MM developed from
  1. detailed(≈500 task) Open Plan
  2. continuation of Resource Allocation Model
- Design task details under study(next topic)

NOTE that the nature of this detector and the assembly facilities requires integration of the muon system construction and installation schedules with overall SDC schedules from the outset.

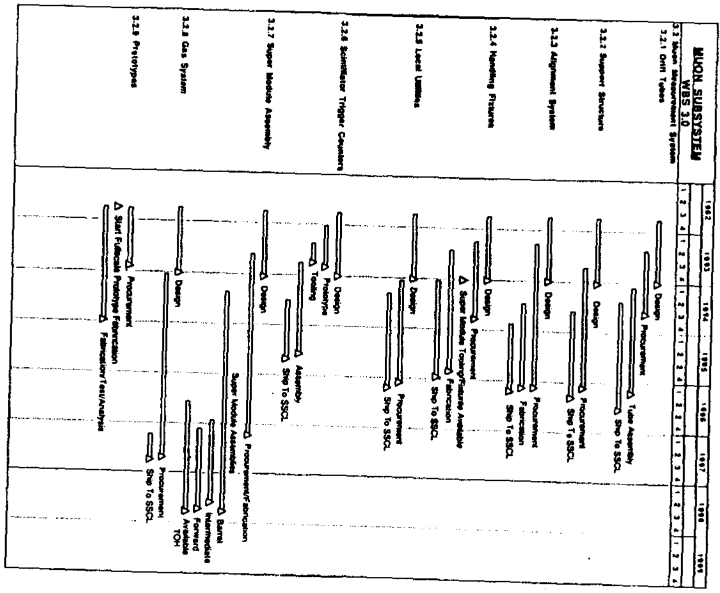
Engineering Organization
Baseline Schedules

- SDC Project Cost/Schedule Summary Book
  April 1, 1992 baseline
- Compilation of:
  1. installation studies by Kaiser/LBL
  2. assembly and fabrication studies by MM (RAM)
  3. development/design estimates by muon group

Engineering Organization
Installation Schedule

- Overall responsibility for SDC installation planning:
  Dave Etherton and Tom Winch
- A dedicated muon scheduling person, Matt Piazza, has recently joined the SSCL staff
- Inputs to the installation schedule come from review by the muon group and assessment by the RAM model

---

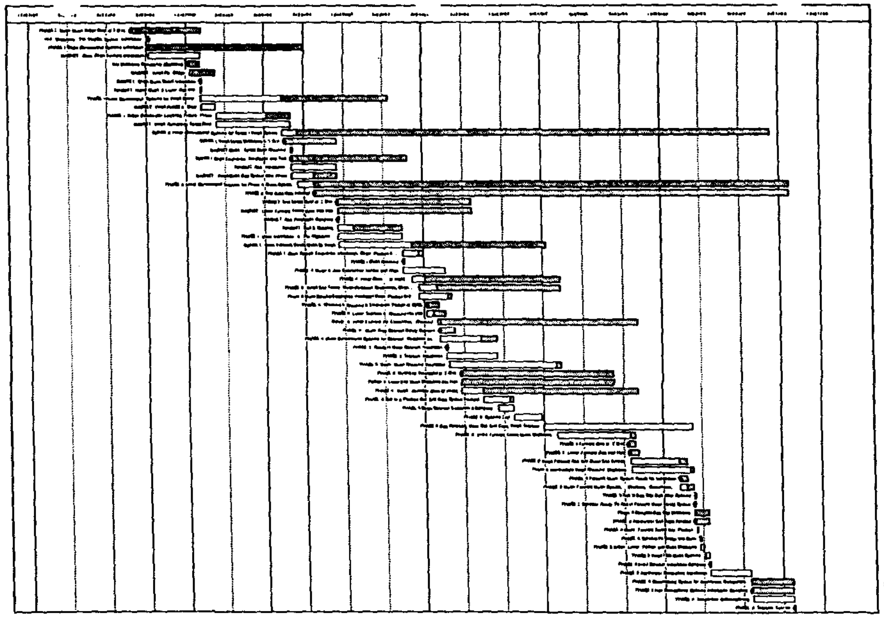


Resource Allocation Simulation

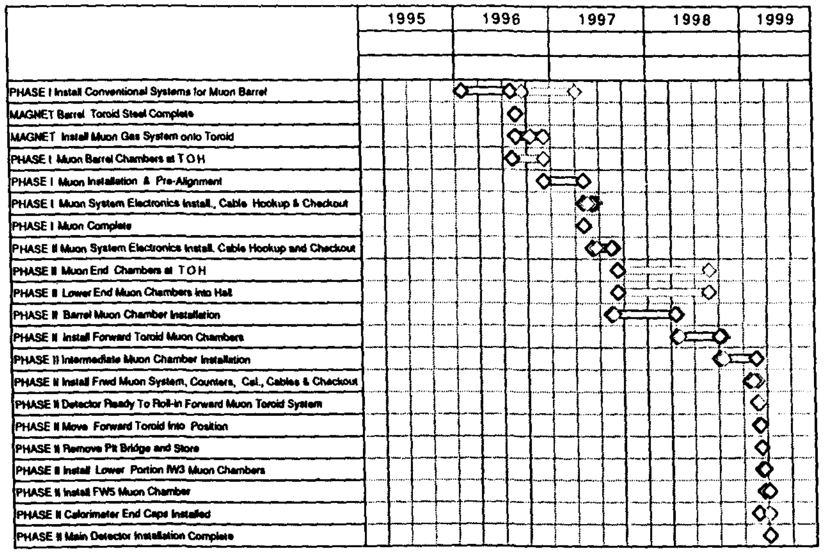
A Systematic Process Using Flexible Computer Tools for Efficiently Allocating and Scheduling Program Resources (Equipment, Facilities, Personnel) to Achieve Program Objectives.

Characteristics

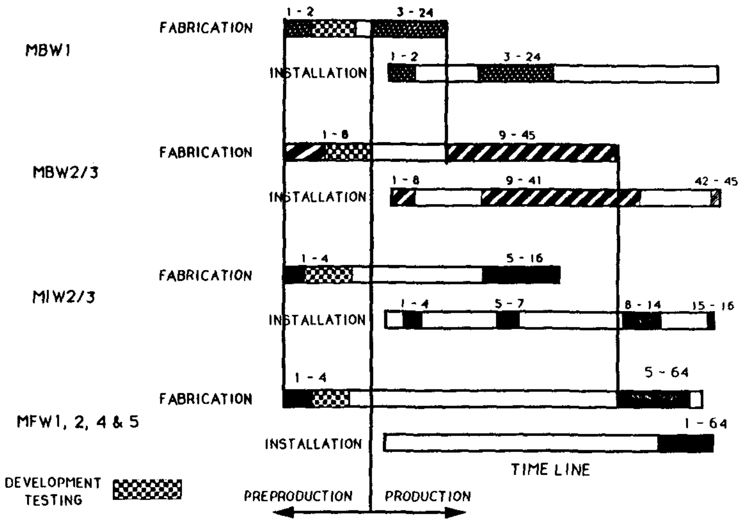
- Monte Carlo Simulation Using a Discrete Event Simulator
- Simulates Variable Time Periods
- Simulates Scheduled and Unscheduled (e.g. Removal and Replacement of Failed Resources) Events
- Addresses the Availability of Major Resources (Equipment, Facilities, and Personnel)
- Fortran Language



CONDENSED MUON MEASUREMENT SYSTEM INSTALLATION



Tuesday, April 28, 1992



Integration of These Four Schedules is to be Performed

Program Inputs/Outputs

- **Input Requirements**
  - Resources
  - Starting Flow Path
  - Starting Time Spans
- **Output Displays**
  - Data Reported by Graphs and Histograms
  - Schedules and Schedule Delays
  - Failures (Type, Location, Downtime, Uptime, and Wait Time)
  - Resource Utilization Quantities and Hours
  - Identification of Problem Areas
  - Other Mathematically Definable Results

MARTIN MARIETTA

Engineering Organization

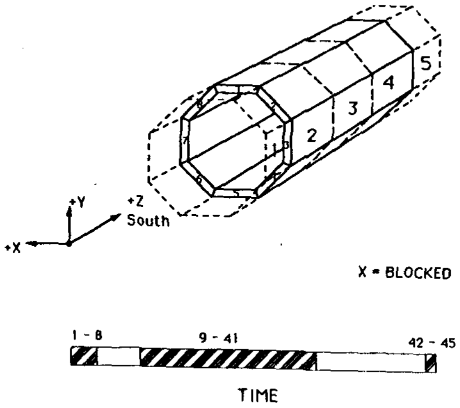
Construction Schedule

- **Detailed Open Plan schedule has been built from inputs by the muon design groups**
- **Schedule includes detailed tasks which now must be properly linked with network logic**
- **RAM development uses all tools, stations, facilities, etc.**
- **Output is facilities usage layouts for discrete time 'slices'**

C. Grinnell 05/06/92

Tentative Installation Sequence

MBW2/3.Z.P



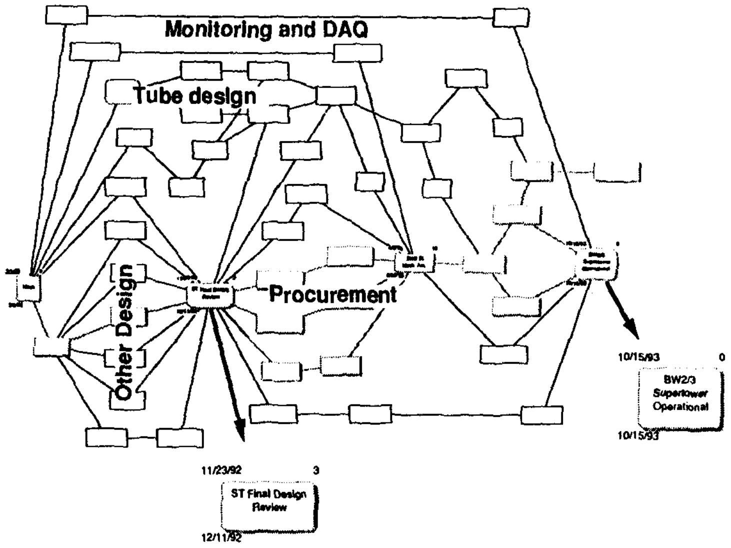
OCTANT "P"

X	8	9	14	21	25	28	
	7	30	23	18	16	12	
	6	39	37	35	33	31	X
	5	42 43	2 4	1 5	3 6	44 45	
	4	40	38	36	34	32	X
	3	11	17	20	27	29	
X	2	10	15	22	24	26	
	1	19	13	7	8	41	
		1	2	3	4	5	

STATION "Z"

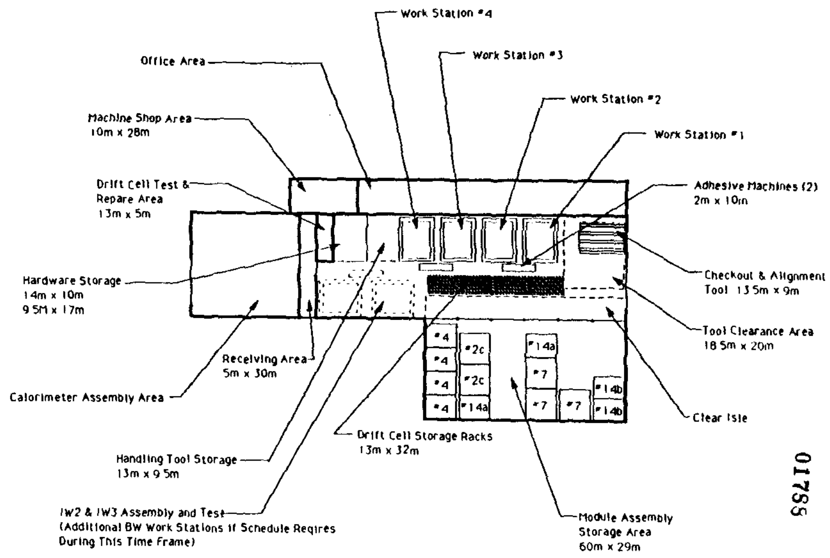
X = BLOCKED

Barrel Supertower Project Schedule



SDC ASSEMBLY FACILITY

Facility Usage, Barrel Muon Production at 40% Complete



Engineering Organization
Task Development

- A 'Task Organization' is being developed with different levels of detail serving different functions
- The structure used is consistent with the organization of the muon group and the eventual division of hardware responsibilities
- The WBS and the Task Organization must be consistent and compatible
- Level 2 and 3 of the task outline are currently being developed - initial inputs from groups last week

---

Engineering Organization
Design phase schedule

- Detailed work begun last month
- Focus is on barrel 'Supertower 1'
- May only be done in parallel with the detailed definition of design tasks (next topic)

Organization II - Level 1

Barrel System Design		Institute	Contact
	Tube Design		
	Function/Test (QA/QC)		
	Supermodule Design		
	Supertower Design		
	Services (onboard)		
Intermediate System Design			
	Tube Design (see barrel)		
	Function/Test (QA/QC)		
	Supermodule Design		
	Supertower Design		
	Services (onboard)		
Forward System Design			
	Tube Design (see barrel)		
	Function/Test (QA/QC)		
	Supermodule Design		
	Supertower Design		
	Services (onboard)		
Alignment System Design			
	System Design		
	Superlayer Devices		
	Supermodule Devices		
	Toroid Support Base Devices		
	Toroid Devices		
	Global System Devices		
	System Model Development		
Trigger Counters Design			
	System Design		
	Barrel Scintillator		
	Intermediate Scintillator		
	Forward Scintillator		
Services			
	Gas Delivery		
	High Voltage		
	Cooling Water		

Organization II - Level 1

Support System Design				
	Large Fixtures/Tooling			
	Forward Region			
	Attachments and Actuation			
Coordination				
	System Design			
	System Engineering			
	Safety			
	Integration			
	Management			

Organization.3

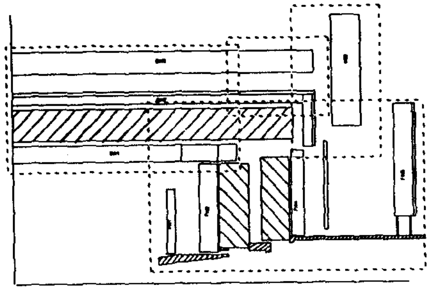
Barrel System Design			Institute	Contact	P	PD	S	M	E	A	D	C&S	MP total
	Tube Design				0	0	0	0	0	0	14.25	0	14.25
		Extrusion									2		2
		Field Shaper									2		2
		Endcaps									4		4
		Spacers									0.25		0.25
		Mechanical Assembly									2		2
		Fixtures/Tooling									4		4
	Function/Test (QA/QC)				0	0	10	0	0	0	2	0	12
		Development					10						10
		Fixtures/Tooling									2		2
	Supermodule Design				0	0	12	36	0	24	30	0	102
		Suppon Frame						12			24		36
		Mechanical Assembly					12						12
		Analysis								24			24
		Alignment Referencing						12					12
		Fixtures/Tooling						12			6		18
	Supertower Design				0	0	0	24	0	24	15	0	63
		Support Frame						6			12		18
		Mechanical Assembly						6					6
		Analysis								24			24
		Alignment Referencing						6					6
		Fixtures/Tooling						6			3		9
	Services *(onboard)*				0	0	0	0	0	0	4	0	4
		Gas Delivery									2		2
		Cabling									2		2
Manpower Subtotals:					0	0	22	60	0	48	65.25	0	195.25

Supertower 1 - Manpower Estimates

Coordination			Institute	Contact	P	PD	S	M	E	A	D	C&S	MP total
	System Design												12
		Configuration Development					6				6		0
		Performance Review											
	Systems Engineering												4
		Configuration Management					4						2
		Interface Control					2						0
		Documention Control											0
		QA/OC											
	Safety												
	Integration												4
		Assembly					2				2		3
		Installation					2				1		3
		Facilities					2				1		4
		Services					2				2		
		Access					1				1		
	Management												
		Management											
		Contracts											
		Procurement											
		Cost											
		Schedule											
		Review											
		Documentation											
					0	0	21	0	0	0	13	0	32
Manpower Subtotals:													
					0	0	58.5	63.5	2	50.5	97.25	0	269.75
Manpower Totals:													= 22.5 my

Barrel Supertower 1

- Barrel region should be first task
- Intermediate region should be second task
- The end modules on the Barrel could be special tests with whole barrel modules
- It is not clear what to 'prototype' in the Forward region

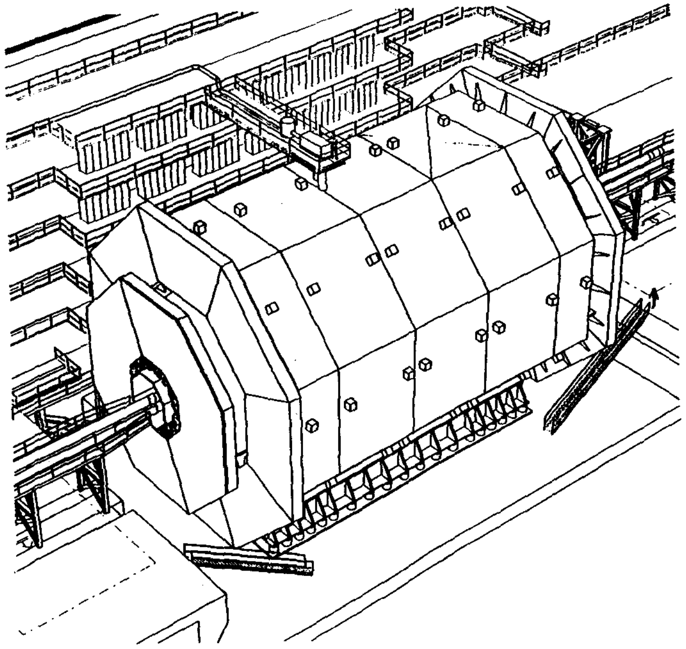


Engineering Organization
Task Development

- When task details to level 3 have been done and compiled with manpower estimates they may then be linked to a schedule to determine the resource requirements
- With this information the muon group may then decide the distribution of these resources for the best solution of how to get the job done

↓

'task - schedule - location' match



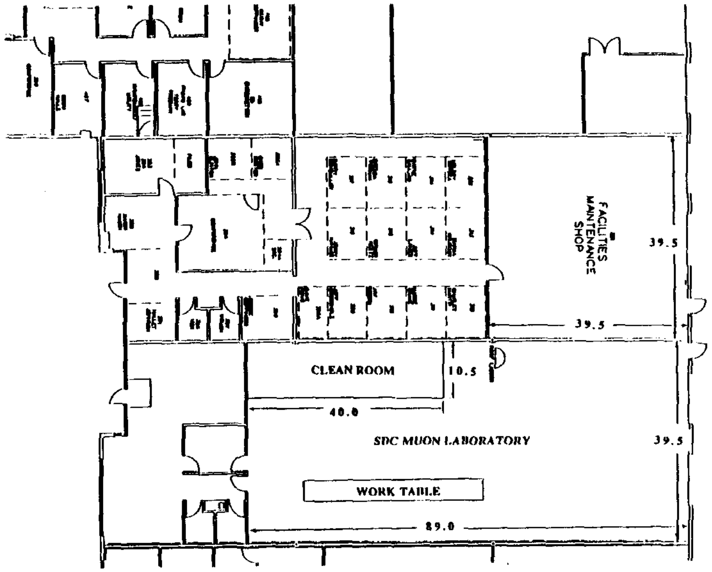
Prototype Plans
Definition

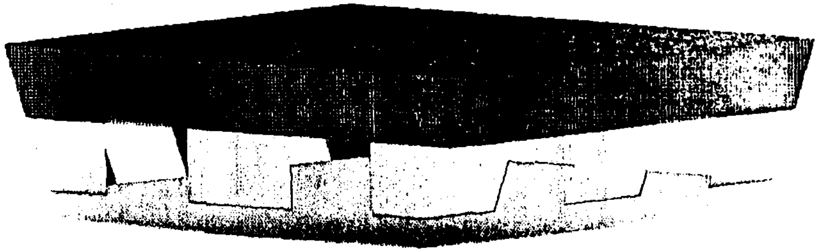
- Many component prototypes now being designed or under construction - focus here on integrated detector module
- Intent is to verify all principles and concepts before committing to serial production:

(02/24/92 engineering meeting)

- assembly techniques	- DAQ
- installation techniques	- MRP (man. rec. pl.)
- mechanics	- QA/QC
- alignment	- suppliers
- chamber function	- test procedures
- trigger	- services
- safety	- +..........

- Discussions continue within muon group on the eventual 'resting place' of the prototype





Enough is Enough

- R&D on system components is proceeding
- Engineering organization including detailed tasks and schedules is being prepared for the May 24-29 KEK meeting
- Prototype or 'Barrel Supertower 1' plans continue for start at end 92 and completion of the BW2/3 mechanical assembly by end 93

Barrel Supertower 1

- Developing detailed design tasking
- Developing detailed schedules
- Dominant parameters to be ratified and fixed by the muon group at the coming KEK meeting
    - mechanical envelope
    - layer ordering
- Space is being arranged for in SSC Muon Lab Building 3 - Suite 200
- Alignment and monitoring system are being defined

PARALLEL SESSION E:

ELECTRONICS/DAQ/COMPUTING

OVERVIEW AND FRONT-END SYSTEM SUMMARY

H. H. WILLIAMS

Electronics for the SDC Detector

H. H. Williams

for the

SDC Collaboration

Outline

- **Overview of Electronics System**
  - Philosophy
  - Structure
  - Common Features (minimize complexity)
- **Examples & Status of Some Front End Systems**
  - Emphasis on Integrated Circuits
  - Comparison of systems
  - Status of protoypes & performance
- **Radiation Hardness of Electronics**
  - It's not a problem
- **Overview of Data Acquisition System**
  - Overall structure
  - Common features
  - Some simulations

Comments:

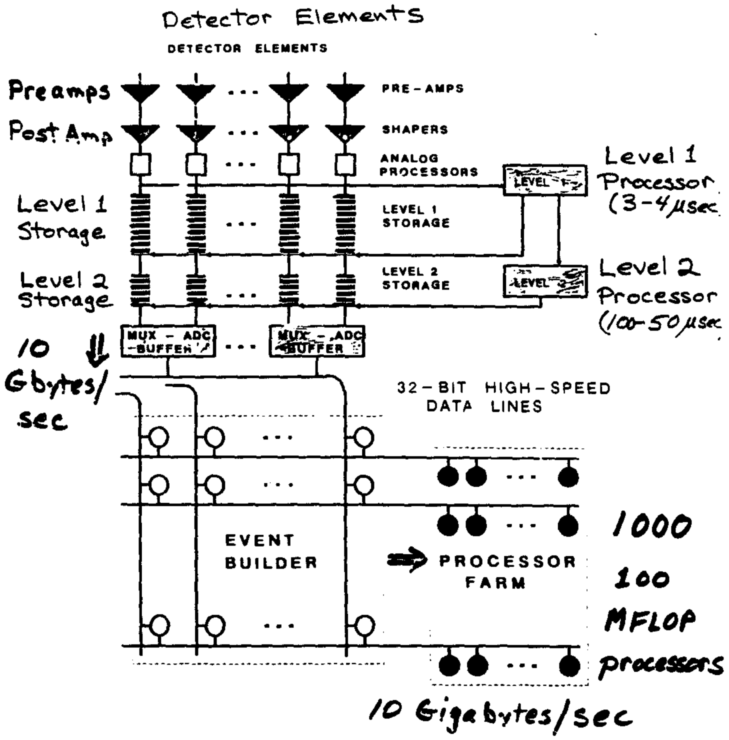
Emphasis on Front End Electronics
Two trigger talks follow
DAQ tomorrow

Philosophy

- **Front End Circuits**
  - Optimal performance
  - Minimal power, cost
  - High Reliability
  - High Degree of Confidence in System
- **Trigger**
  - Tag Bunch Crossing for each system
  - Three levels for max. rejection, flexibility, minimal load on DAQ
- **DAQ**
  - Move data to L3 Trigger, Storage media
  - High efficiency, reliability
  - Flexible
  - Simplicity

Extensive use of custom integrated circuits

Emphasize common features, simplicity



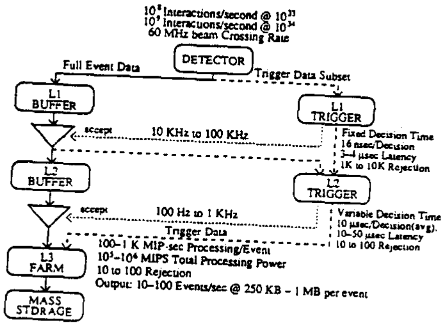


FIG. 8-3. Trigger and Data Acquisition data flow.

OVERVIEW of SDC FRONT-END SYSTEMS

Subsystem	Channel Count	Signal Processing		Data Storage		Trigger Data to ...	Comments
Silicon Tracker	$6x10^6$	Bipolar	ASD	CMOS	Digital Hits	L2	Rad hard Very low power
Straw Tracker	140,000	Bipolar	ASD	CMOS	Digital Time	L1 & L2	Rad hard Low power
Gas Microstrip Tracker	$1.3x10^6$	Bipolar	ASD	CMOS	Digital Hits	L1 & L2	Similar to silicon tracker
Fiber Tracker	473,000	Bipolar	ASD	CMOS	Digital Hits	L1 & L2	
Calorimeter							
(Option 1)	20,000	Bipolar	Amp/Shape	CMOS	Analog Charge	L1 (L2)	Very large
(Option 2)	20,000	Bipolar	Gated Integ.	CMOS	Digital Charge	L1 (L2)	dynamic range
Shower Max	57,000	Bipolar	Amp/Shape	CMOS	as in calorimeter	L1 & L2	Similar to calorimeter
Muon Wires	90,000	Bipolar	ASD	CMOS	Digital Time	L1 & L2	Similar to straw tracker
Muon Counters	7,000	Bipolar	Discrim	CMOS	Digital Time	L1 & L2	Similar to muon wires

ASD = Amplifier/Shaper/Discriminator
Amp/Shape = *Amplifier/Shaper*
Gated Integ. = Current splitter/Gated integrator/FADC
Discrim = *Discriminator*

Digital Hits = 1 bit/hit
Digital Time = TMC (Time Memory Cell)
Analog Charge = SCA (Switched Capacitor Array
Digital Charge = 12 bits/channel

Common Elements of Electronics

Design & Implementation

- Common signals/protocols for Front End Circuits
- Common DAQ protocols for all systems
- Standard Crate, DAQ interface card, Clock & Trigger interface card
- New standard for low level differential signals?

Development

- Exchange of information on detailed designs
- Shared processing runs (bipolar, rad hard CMOS)
- Exchange of subcircuits, layout, etc.
- Common design/layout tools

Protocols for Front End & DAQ

Signals for Front End Circuits

- 60 MHz Clock
- Level 1 Accept (option Level 1 Reject)
- Level 2 Accept/Reject
- Fast Synch Pulse
- Test Pulse
- Slow Control

Protocols for Front End Circuits (Examples)

- Min. spacing between L1 Accept of 4-5 crossings
- L2 Accept/Rejects ordered in time
- Min spacing between L2 Accept/Reject: 1-2 μsec
- Level 1 Trigger # locally generated
- Treatment of Two Level 1 Accepts within resolving time of detector
- Error Handling

Overview of Bipolar Preamp/Shaper IC's

System	Minimum Detectable Charge	Peaking Time (ns)	Time Resol (ns)	Double Pulse Resolution	Power Dissipation (mW)
Silicon	≈ 1 fC	25 - 30	5-15	60 - 100	1 - 2
Gas Micr	≈ 1 fC	25 - 30	5-15	60 - 100	3 - 8
Straw	1 - 2 fC	5 - 7	0.75	20 - 30	10 - 15
Muon	2 - 3 fC	8 - 15	1 - 2	60 - 100	20 - 30
Fiber Tr	1 - 2 fC	5 - 8	5-15	16 - 32	10 - 15
Calorim					
SCA	≈ 1 fC	8 - 10	16	≈ 32	≈ 100
FQDC	≈ 1 fC	8 - 10	16	≈ 32	100-200
Shower	≈ 1 fC	8 - 10	16	≈ 32	≈ 100

Overview of CMOS Storage IC's

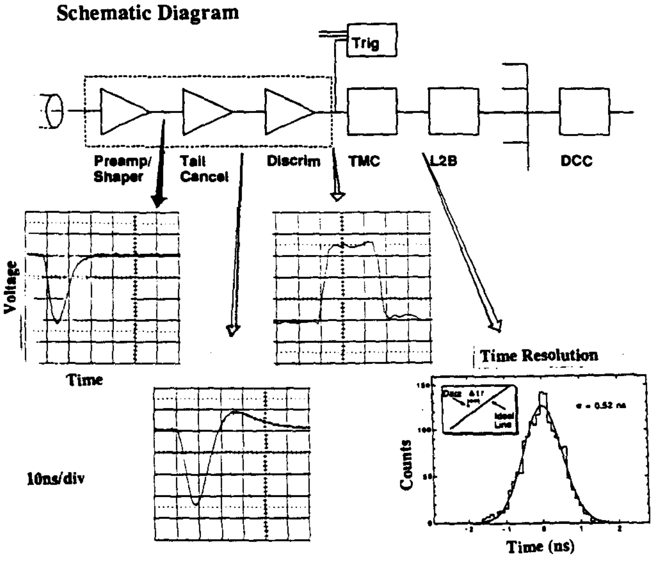
System	Function	L1 Storage (technique)	Level 2 Storage
Silicon	Digital Hits	Time Stamp, Data-driven, CAM	off-chip
Gas Mic	Digital Hits	Time Stamp, Data-driven, CAM	off-chip
Straw	Dig Time	Memory, Synch (TMC)	Distinct
Muon	Dig Time	Memory, Synch (TMC)	Distinct
Fiber	Digital Hits	Memory, Synch, FIFO	Distinct
Calorim			
SCA	Analog	Analog Mem, Synch (SCA)	"Virtual"
FQDC	Digital	Memory, Synch, FIFO	Distinct
Shower	as in calorimeter		
Muon Counter	Dig Time	Memory, Synch, TMC	Distinct

Wire Chamber Readout

Specifications

* Minimum Detectable Charge	≈ 1 fC
* Time Resolution	< 0.75 ns
* Peaking Time	5-7 ns
* Double Pulse Resolution	20 - 30 ns
* Power Dissipation	< 20 - 25 mW

Schematic Diagram

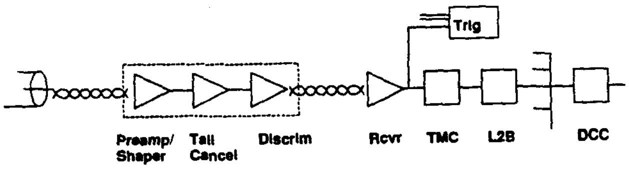


Muon Chamber Readout

Specifications

* Minimum Detectable Charge	2-3 fC
* Time Resolution	1-2 ns
* Peaking Time	10 - 15 ns
* Double Pulse Resolution	60 - 100 ns
* Power Dissipation	100-200 mW

Schematic Diagram



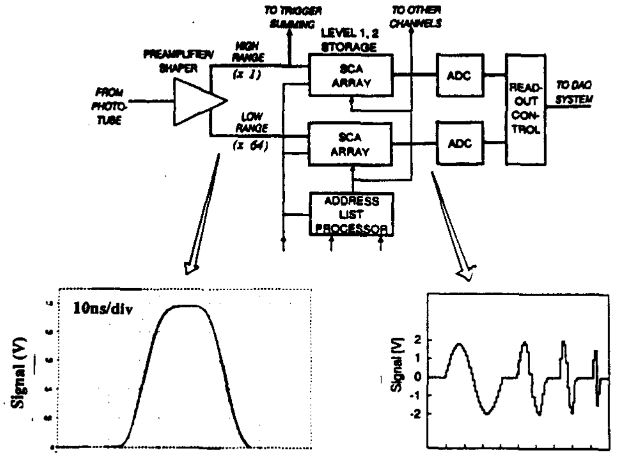
Calorimeter Readout

01818

Specifications

- **Minimum Detectable Charge** ≈ 1 fC
- **Dynamic Range** $2 * 10^5$
- **Peaking Time** 8 - 10 ns
- **Power Dissipation** ≈ 0.5 W

Schematic



Simulations of $2x10^5$ AT&T Bipolar Preamplifier

Output: 90 MHz Sampling

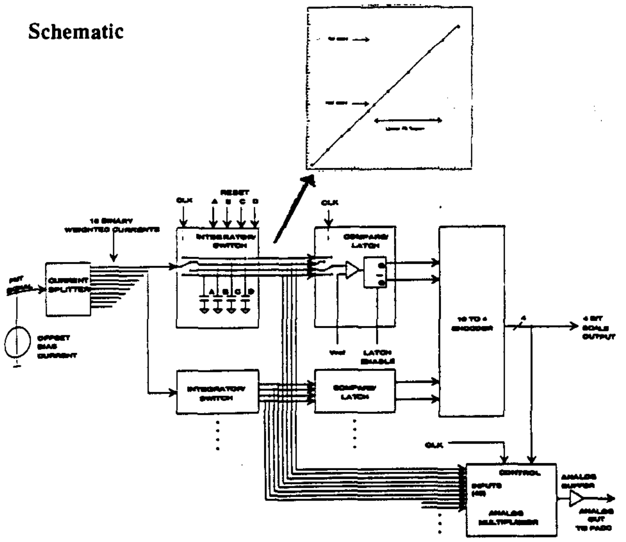
Calorimeter Readout - Flash QDC

01819

Specifications

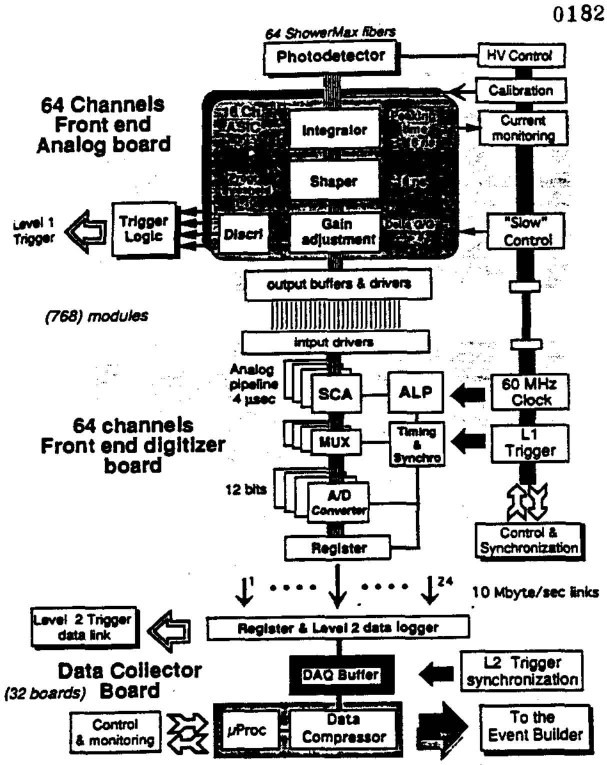
- **Minimum Detectable Charge** ≈ 1fC
- **Dynamic Range** 18-20 bits
- **Rise Time** 5 - 8 ns
- **Accuracy** 8-9 bits

Schematic



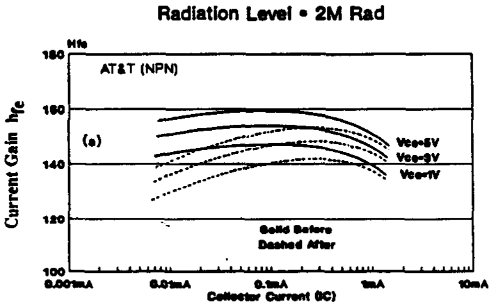
Shower Maximum Detector Readout

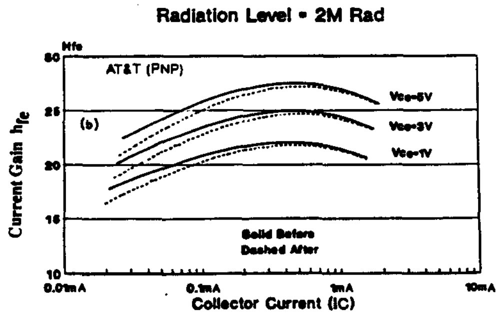
01820



Effect of Co^{60} Radiation on Current Gain

01821





Radiation Hardness

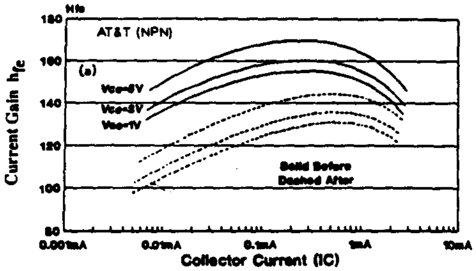
- * **Bipolar technologies good to 5 MRads**
  - **Noise, gain, risetime, current gain**
- * **CMOS good to 2 - 5 Mrads**
  - **Noise, gain, leakage**

The electronics is probably more radiation hard than any of the detectors

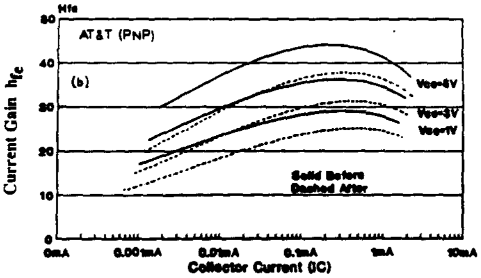
---

Effect of n Radiation on Current Gain

Neutron Fluence: 6E+13 N/cm



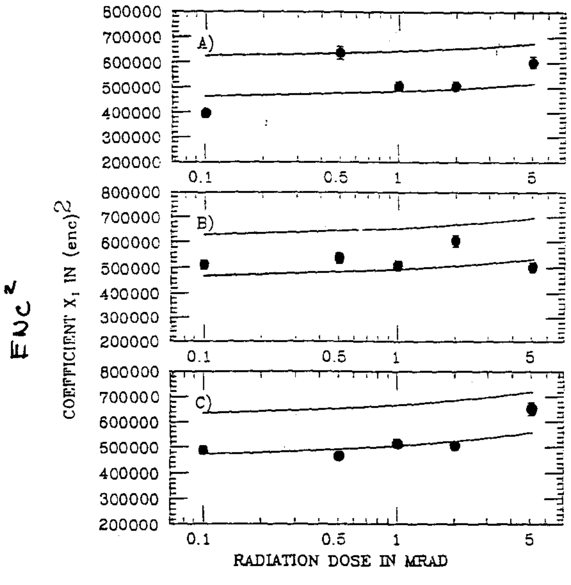
Neutron Fluence: 6E+13 N/cm

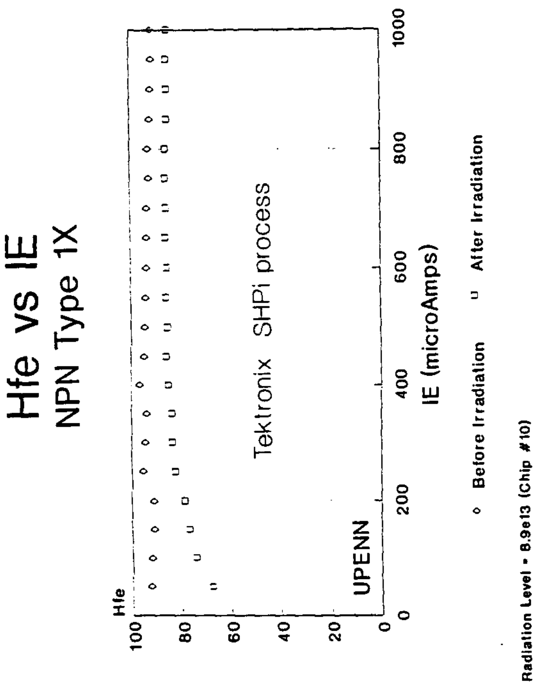


Noise as function of Radiation

Bipolar ATT SST process

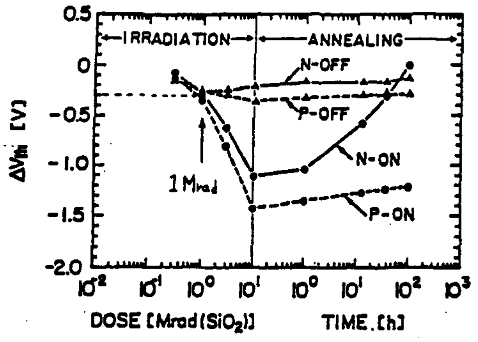
Ikeda, KEK



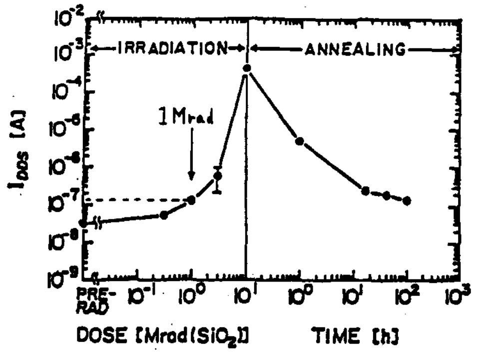


Toshiba 1um Rad-Hard CMOS

Threshold Voltage Shift

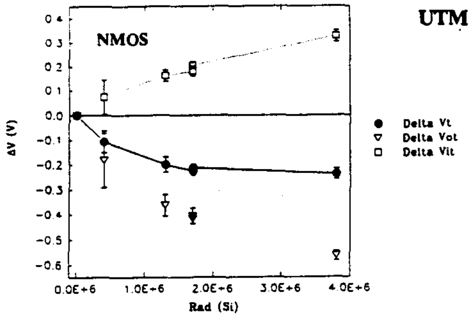


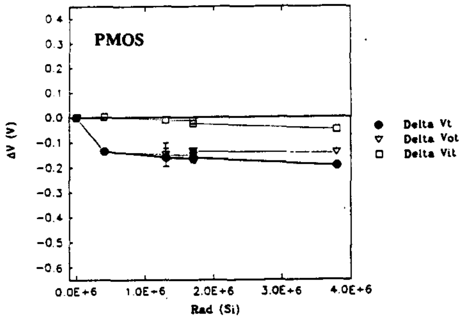
Standby Current



Threshold Voltage Shift with Radiation

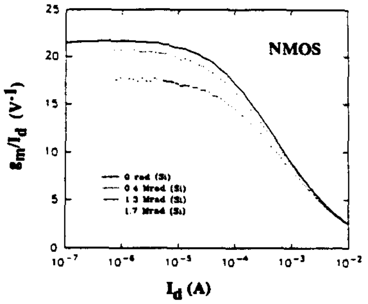
UTMC Process

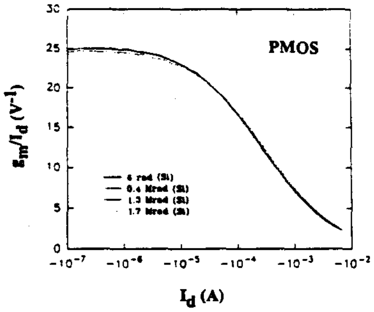




Effect of Radiation on Transconductance

UTMC Process

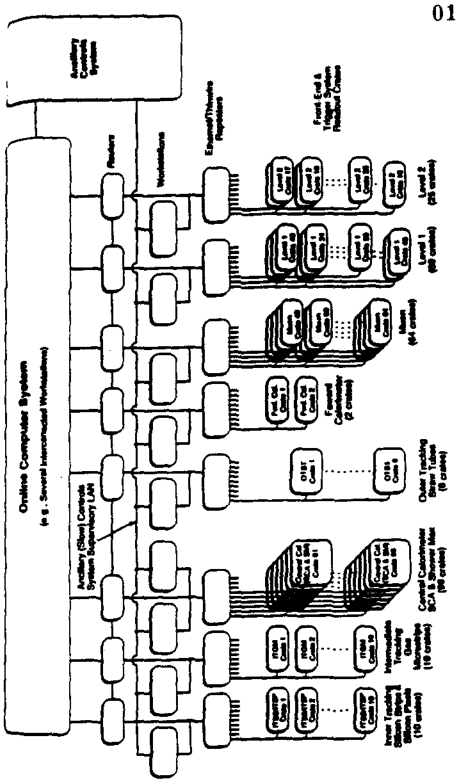




Data Acquistion System

- **Overall Structure**
- **Some Simulations**

01830



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DATA SOURCES to DATA ACQUISITION

System	# Crates & DAQ CPUs	# Data Links
Silicon Tracker	10	10
Gas Microstrip Tracker	10	10
Straw Tracker	8	32
Central Calorimeter including Shower Max	96	192
Forward Calorimeter	2	2
Muon System	64	64
Level 1 Trigger	59	59
Level 2 Trigger	25	25
Total:	274	394

01832

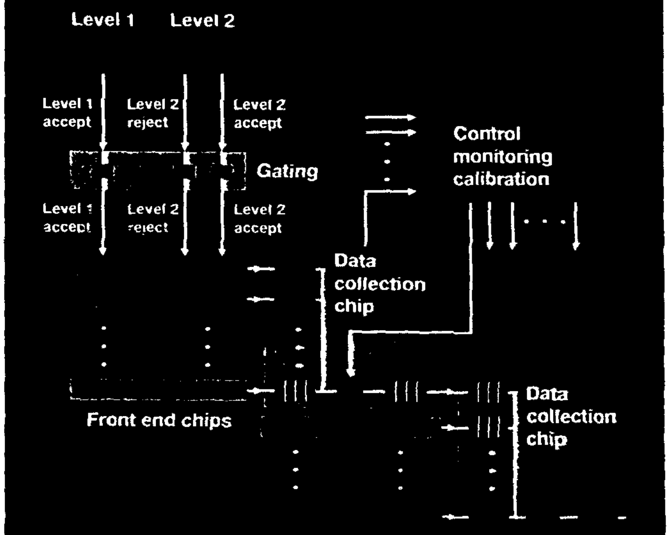
DAQ Protocols for Front End System

- **Digitized Data**
- **Data Stored unitl L2 Accept**
- **Complete Event Data for each L2 Accept**
- **Bunch Crossing or Trigger # ID**
- **Ordered by Time and Channel #**
- **Common Format for All Detector Systems**
- **Standardized Set of Control Signals**
- **Locally Resolve Ambiguities when Two Triggers within Detector Resolving Time**

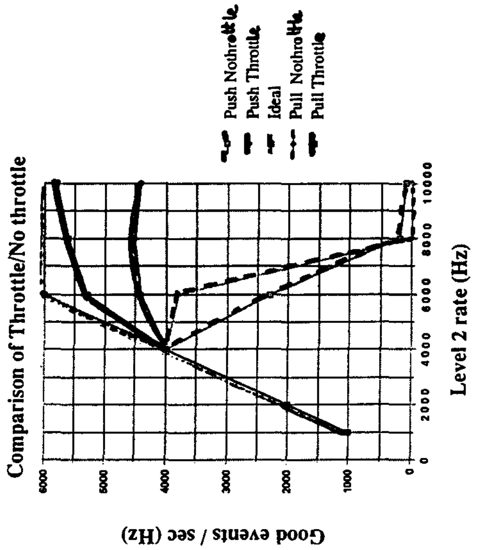
SSCL

01833

Data Collection Network



SSCL



27

Summary

Front End Electronics

- **Performance in hand for all systems**
- **Integrated Circuit develop. well advanced**
- **Proceed to full system tests within 1 year**
- **Few major decisions remaining**
  (review of calorimeter readout in June)

Trigger

- **Conceptual Design looks good**
- **Proceed to more detailed conceptual designs**

DAQ

- **Overall topology (at crate level) specified**
- **Proceed to detailed simulations**
- **Refine topology**

Overall we are quite confident our goals will be met

0183

TRIGGER SYSTEM OVERVIEW AND LEVEL 1 SUMMARY

W. SMITH

Smith

SDC TRIGGER SYSTEM

Wesley Smith
University of Wisconsin

on behalf of the SDC Collaboration

SDC Review -- May 5, 1992

SDC TRIGGER SYSTEM

Requirements:

Input Rate: 10^8 Interactions per second
(average 1.6 interactions per
16 nsec bunch crossing)

Output Rate: 50 - 100 Hz can be written to tape

Physics Rate: 50 Hz of Top, W's, Z's
(Little Spare Bandwidth)

☞ 10^6 Rejection needed

SDC TRIGGER PRINCIPLES

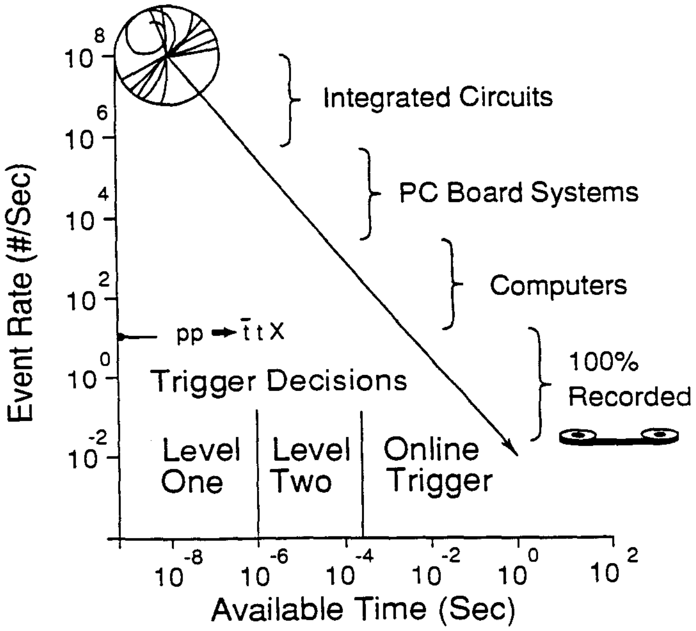
Philosophy:

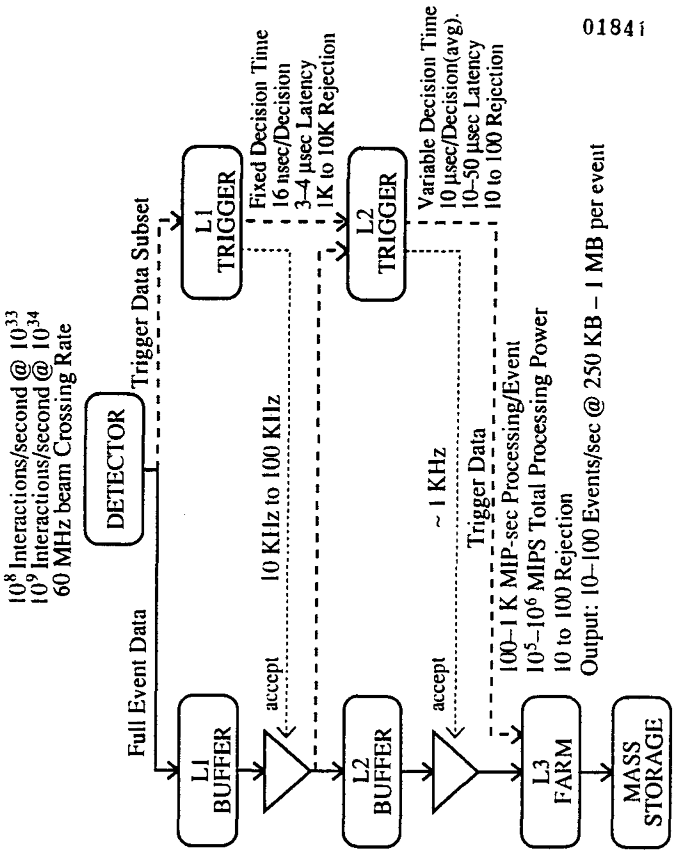
- Local:
  - Signatures of e's, γ's, μ's, jets in $\eta \times \phi$ regions
  - (ex: ν's)
- Measurably Efficient:
  - Overlapping Programmable Triggers
  - Prescaled Lower Thresholds
  - Prescaled Triggers w/ less conditions
- Efficient Use of DAQ Bandwidth:
  - Efficient Lepton and Jet Identification
  - Consistency with Offline Cuts

Benchmarks for Trigger Performance:

- e's, μ's from inclusive W's, Z's:
  - 50% efficiency (cut on lepton P_T)
- Jets, γ's at high P_T:
  - 1-2 decade overlap with lower $\sqrt{s}$ data
- Missing E_T:
  - Good efficiency for channels such as:
    - $H \rightarrow 2\ell 2\nu$
    - SUSY particles
- Low P_T multileptons:
  - B Physics

SSC TRIGGERING: EVENT RATES & TECHNOLOGIES





SDC TRIGGER LEVELS

Level 1:

Identify Physics Objects:

- Electrons
- Photons
- Muons
- Taus
- Jets
- Neutrinos
- *Combinations of Above*

Level 2:

Refine Identification of Physics Objects:

- Sharper P_T Cuts
- Electrons From Conversions
- Muons from Decay/Punchthrough
- Refine Energy Sums/Clusters
- Displaced Vertices

Level 3:

Full Physics Analysis/Decisions:

- Specialized Algorithms
- Heirarchy of Decisions
- DST-type cuts on Physics

Level 1 system segmentation and trigger information.

Subsystem	Total channels	L1 segmentation	L1 data
Barrel Track	$64\phi \times 2\eta$	0.1ϕ	2 p_t bits
Int. Track	$64\phi \times 2$ ends	0.1ϕ	1 p_t bit
Barrel Cal.	$64\phi \times 28\eta$	$0.1\,\phi \times 0.1\eta$	8 bits EM & HAC Energy
Endcap Cal.	$64\phi \times 14\eta \times 2$ ends	$0.1\phi \times 0.1\eta^{\dagger}$	8 bits EM & HAC Energy
Forward Cal.	$8\phi \times 4\eta \times 2$ ends	$0.8\phi \times 0.8\eta$	8 bits EM & HAC Energy
Shower Max.	$64\phi \times 30\eta$	$0.1\phi \times 0.2\eta$	Hit Flags
Barrel Muon	$32\phi \times 10\eta$	$0.2\phi \times 0.2\eta$	2 p_t bits × 2 tracks
Int. & Fwd. Muon	$32\phi \times 8\eta \times 2$ ends	$0.2\phi \times 0.2\eta$	2 p_t bits × 2 tracks

† For $|\eta| > 2.2$, the η and ϕ trigger tower dimensions switch to 0.2 and then to 0.4.

LEVEL 1

Electrons & Photons:

Find (.1 x .1) Cal Towers with E_{em} > Thr

Require E_{hac}/E_{em} < .04 - .10

Option: Pattern of surrounding quiet towers (isolation)

γ's: Match w/Shower Max in .2η x .2ϕ

e's: Find Outer Track Segments w/P_T > 10 GeV/c

Match Track Segments w/Shower Max in ϕ in 1/64

Assign Δη = 0.2 from Shower Max to Track

Match Track w/Cal on Δη=0.2, Δϕ=0.2

Muons:

Muon Tracks from Scint + θ-layers w/P_T > 10 GeV/c

*Option:*Find Central Tracker Sgmts w/P_T > 10 GeV/c

Match w/Muon ϕ-layer Track Sgmts in 1/64

Use Momentum cut on Central Tracker P_T cut

(Use Scint to associate ϕ and θ tracks)

Match Track w/Quiet Cal on Δη=0.2, Δϕ=0.2

Jets:

1.6 x 1.6 grids of overlapping towers > E_{thr}

Neutrinos:

Sum Missing E_T over .1 x .1 Towers > E_{thr}

Level 2 trigger information beyond that from Level 1.

Subsystem	Total channels	L2 segmentation	L2 data
Silicon Track	1024 $\phi \times 6\ \eta$	0.00626 $\phi \times 0.4\ \eta$	5 p_t bits 3 vertex bits
Barrel Track	1024 $\phi \times 2$ ends	0.00625 ϕ	5 p_t bits
Int. Track	1024 $\phi \times 4\ \eta \times 2$ ends	0.00625 $\phi \times 0.25\ \eta$	5 p_t bits
Shower Max	1024 $\phi^{\dagger} \times 15\ \eta \times 2$ ends	0.00625 $\phi^{\dagger} \times 0.2\ \eta$	8 bits energy
Barrel Muon	1024 $\phi \times 10\ \eta$	0.00625 $\phi \times 0.2\ \eta$	5 p_t bits for 2 tracks
Int. & Fwd. Muon	1024 $\phi \times 8\ \eta \times 2$ ends	0.00625 $\phi \times 0.2\ \eta$	5 p_t bits for 2 tracks

† For $|\eta| > 2.2$, the ϕ trigger tower dimensions switch to 0.0125 and then to 0.025.

LEVEL 2*

Electrons:
Use Si Track to Tag (Kill) Conversions
Use Si Track to impose P_T vs. E cut

Muons:
Use Si Track to Kill/Tag Punchthrough/Decay
Compare Si Track P_T vs. Muon P_T
Additional Muon θ-layer reduces beam spot $\sigma(P_T)$

Jets:
Measure Energy in cone
Find Stiff Tracks in Jet
Search for Unisolated Electrons near/in Jet
(stiff track + Tower w/low H/E)
Use Si Track to find displaced vertices

Neutrinos
Add Muon Energy into $\not{E}_T$ sum
Sum Jet (cone) Energies
Topology: location of $\not{E}_T$ vector (hole)
Search for lower energy leptons

**Level 2 Trigger in subsequent talk*

Level 3 Initial Pass Algorithms

- Recalculate various E_t measurements using the full calorimeter resolution to sharpen thresholds
- Use advanced pattern recognition in the calorimeter and shower maximum detector for electron identification
- Make a precise position match between electron track segments and the shower maximum detector profile
- Perform jet clustering and refine jet triggers
- Include calorimeter information in muon selection
- Include forward calorimeter information in E_t sums

Level 3 Detailed Algorithms

- Perform complete 3-D tracking in the muon system
- Match track segments in all tracking layers for stiff tracks
- Incorporate various calorimeter energy corrections, including corrections for dead material. gaps between barrel/endcap calorimeters. and gaps between calorimeter modules

---

Level 3 Final Pass Algorithms

- Advanced pattern recognition algorithms in tracking system to find photon conversions. secondary vertices. and topology signatures (*e.g.*, τ's)
- 3-D track finding to locate vertex position. correlate tracks from a single interaction. and reduce ambiguities in tracking
- Track fitting to help solve pattern recognition ambiguities and eliminate fake tracks
- Full offline reconstruction of the event

LEVEL 1 TRIGGER STUDIES: CALORIMETER

Rate:

Level 1 Rate Target = 30 KHz
15 KHz each for Cal. and Muon Triggers

Calorimeter:

Total rate is sum of:
- single e's
- single γ's
- pairs: ee, eγ, γγ
- jets
- $\not E_T$

☞ Target Rate of 3 KHz for single object triggers

Procedure:

Background Rates:
QCD 2-jet events: 20 - 400 GeV P_T
mixed with minimum bias events
run through hardware simulation
Find threshold for e, γ, jet, $\not E_T$ ⇒ 3 KHz
Examine threshold vs. trigger conditions
Examine efficiency vs. E_T

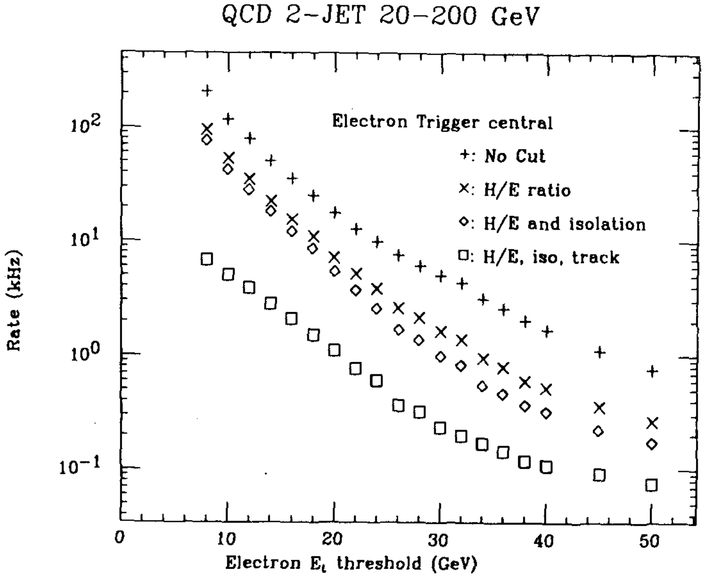


Figure 7

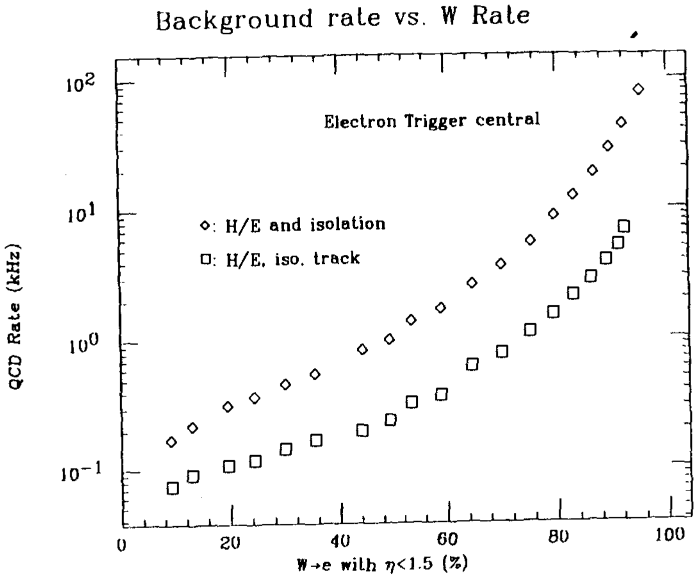


Figure 8

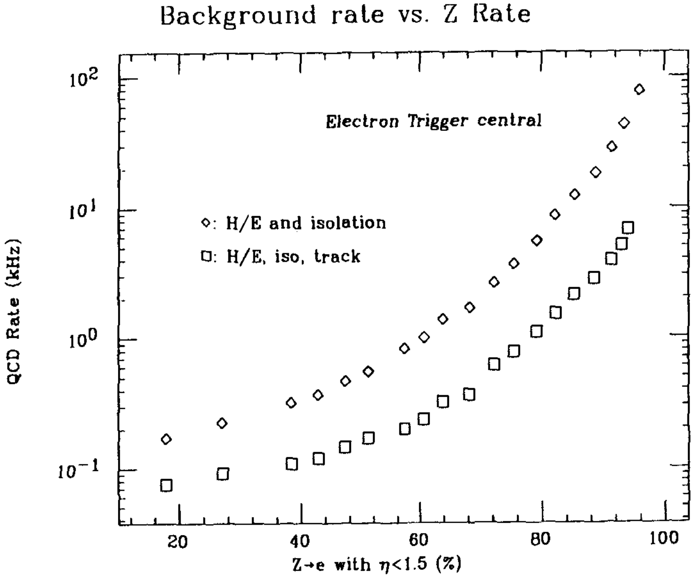


Figure 9

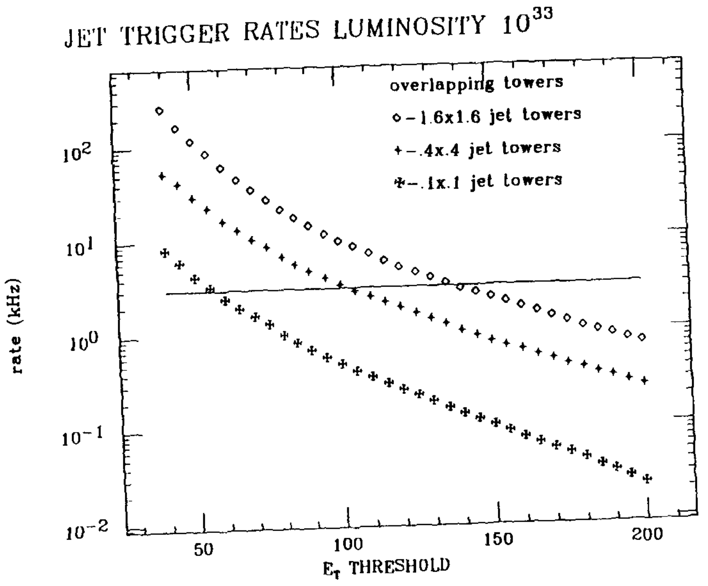


Figure 1

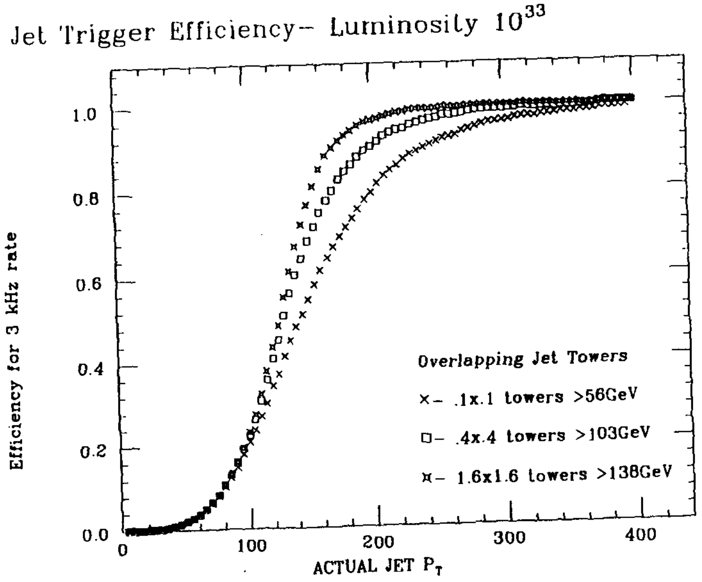


Figure 3

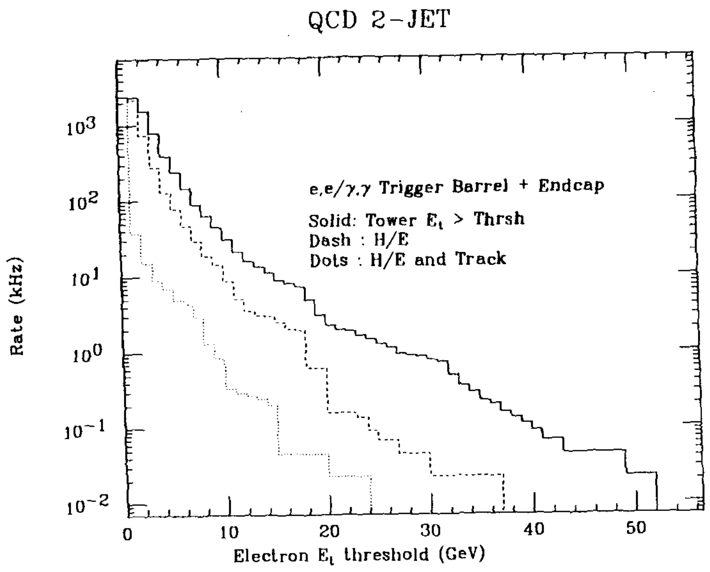


Figure 11

Combined Level 1 trigger rate for the main electron/photon triggers in the Barrel plus Endcap calorimeters ($|\eta| < 3.0$) versus various combinations of threshold energies. Where e $\equiv$ electron requires 1 tower with HAC/EM< 0.05 and a track with $p_t > 10$ GeV/c matched in ϕ with the tower, 2e $\equiv$ di-electron requires 2 towers with HAC/EM< 0.1 and a track with $p_t > 10$ GeV/c, $\gamma \equiv$ photon requires 1 tower with HAC/EM< 0.05, and $2\gamma \equiv$ di-photon requires 2 towers with HAC/EM< 0.05.

Trigger threshold (GeV)				
e	$2e$	γ	2γ	Rate (kHz) @ 10^{33} cm^{-2}s^{-1}
20	10	30	20	9.8
20	10	40	20	8.1
25	10	40	20	5.0
25	15	40	30	4.7
30	20	45	30	3.8
20	–	–	–	7.0
–	10	–	–	0.3

Type of jet trigger	3 kHz at 10^{33}	10 kHz at 10^{34}
.1 × .1	287	387
.4 × .4 non-overlapping	243^3	336^2
1.6 × 1.6 non-overlapping	211	281^3
.4 × .4 overlapping	229	313^2
1.6 × 1.6 overlapping	190	253^3
1.6 × 1.6 overlap/8-bit scale	205	268^3
all have low energy cutoff at .1 GeV except as noted		
^{2} – low energy cutoff at .2 GeV		
^{3} – low energy cutoff at .5 GeV		

Jet p_T at which 95% efficiency is achieved (GeV)

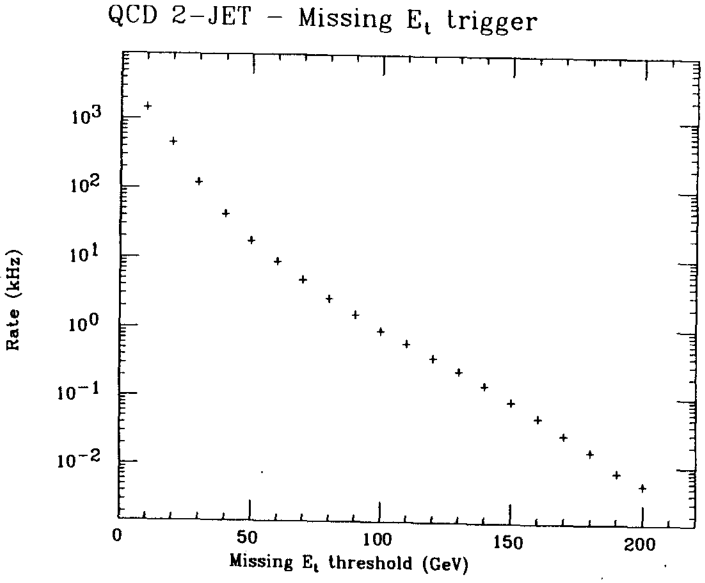


Figure 12

LEVEL 1 TRIGGER STUDIES: MUONS

Rate:

For Muon System, total rate is sum of:

single μ's

pairs: μμ,μe,μγ

energy: μ & jet, μ & $\not{E}_T$

☞ Target Rate of 5 KHz for single muon triggers

Procedure:

Determine Prompt and Decay Rates

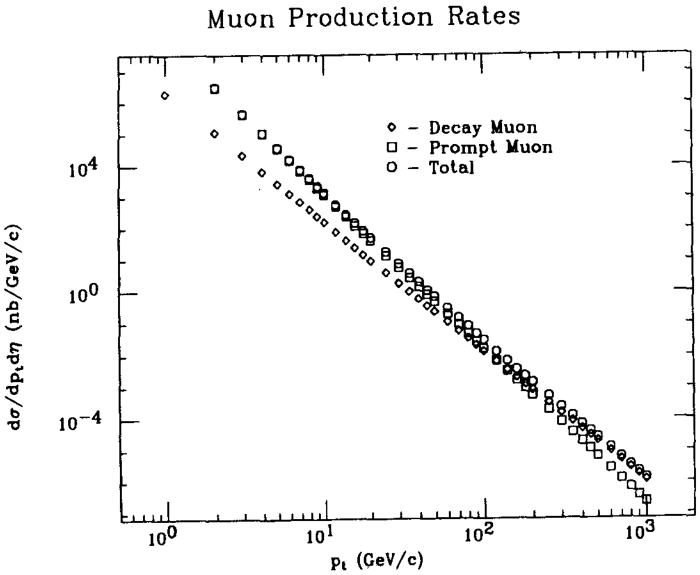
Simulate Muon Trigger Circuit (δT → P_T cut)*

Determine Threshold Response of Muon Trigger

Fold These together to calculate Trigger Rate

---

* *more on muon triggers in subsequent talk*



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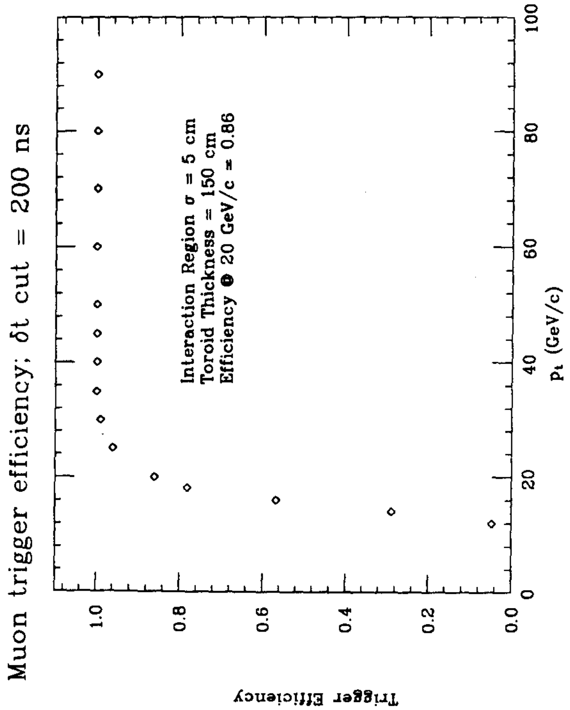

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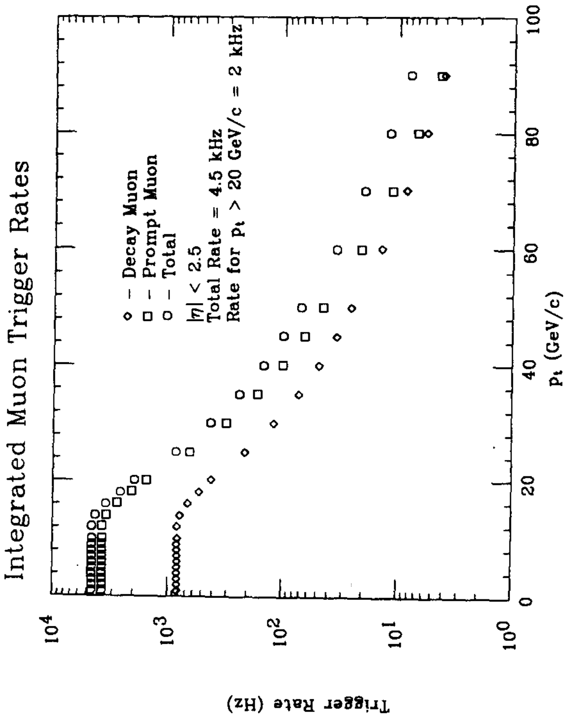

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Representative level 1 trigger E_t thresholds.

Trigger	Threshold
Electron	20 GeV
Photon	30 GeV
Two electrons	10 GeV
Two photons	20 GeV
Missing E_t	80 GeV
Single Tower Hadron (.1 × .1)	60 GeV
Jet (1.6 × 1.6 sum)	140 GeV
Muon	20 GeV

01864

LEVEL 1 BASELINE DESIGN

- 1 Gbit/s optical fibers carry trigger primtives from detector electronics to crates in electronics house on surface.
- Design assigns logic blocks to boards in crates, implemented using standard technology (i.e. 100K ECL, HCMOS) with ASIC's only where necessary.
- Design maximizes flexibility and programmability through use of digital logic built around memory lookup tables and programmable gate arrays.
- Boards and crates designed for power, circuit space, I/O connections (std. density), fiber optic interfaces, backplane traffic, timing, and DAQ and trigger clock/control interfaces.
- Design minimizes hardware on detector: reduce detector cooling, power, space; maximize access; decouple trigger and detector geometry.
- Fiber optic and twisted pair cable plant have been designed to reduce the inaccessible single point failure risk to 1-2% and to minimize interconnects between crates.
- The system carries sufficient information for diagnostics, efficiency studies, and understanding of trigger behavior.

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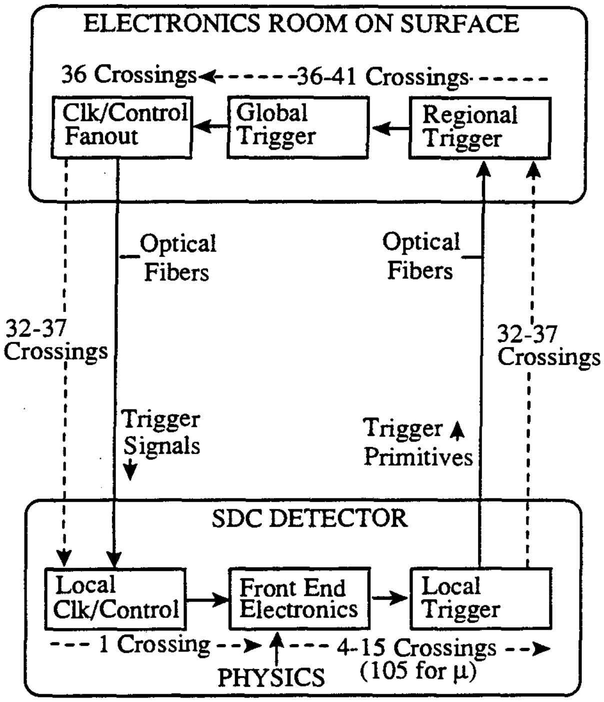
LEVEL 1 TRIGGER PHYSICAL LAYOUT



→Total Level 1 Pipeline Length
≤ 250-256 Crossings = 4 μsec

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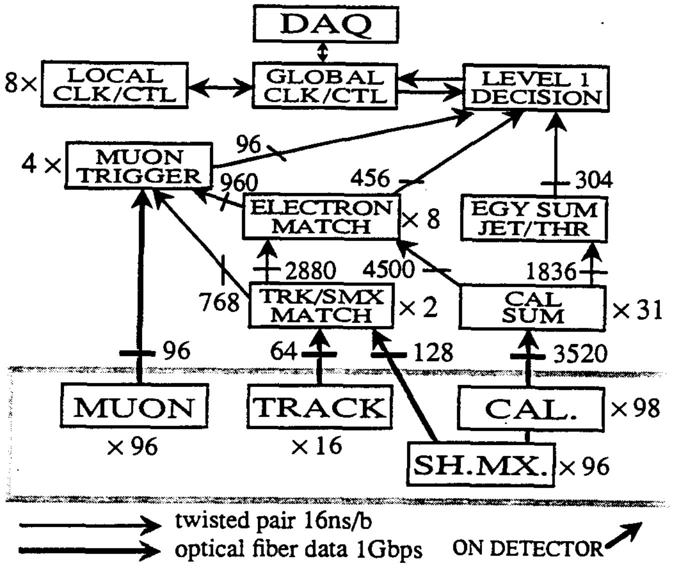

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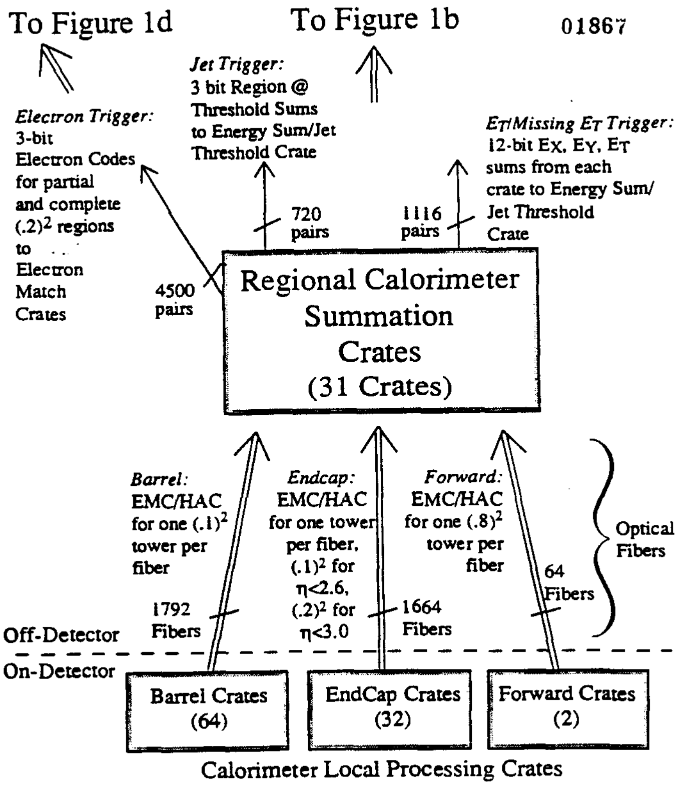

Figure 1a

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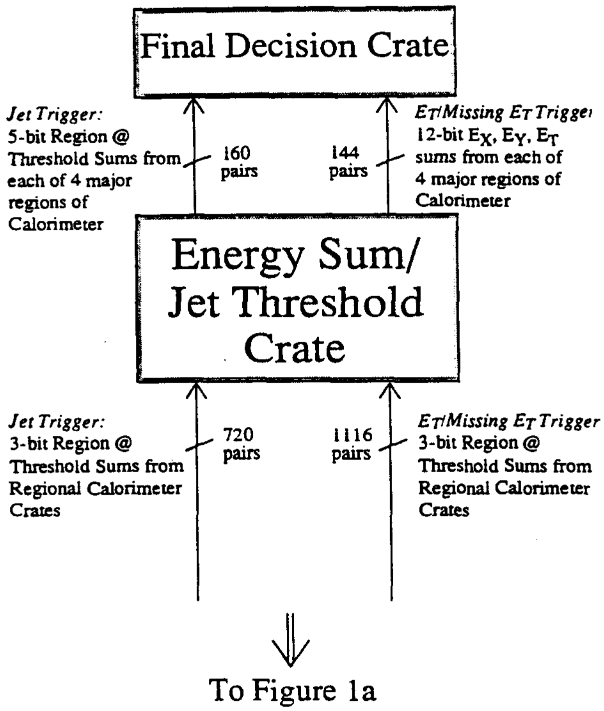

Figure 1b

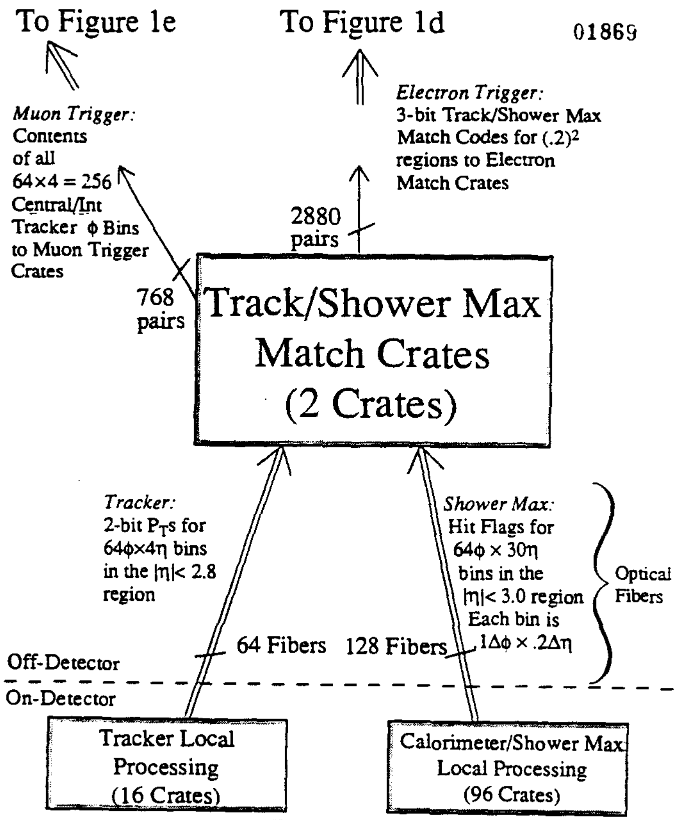

Figure 1c

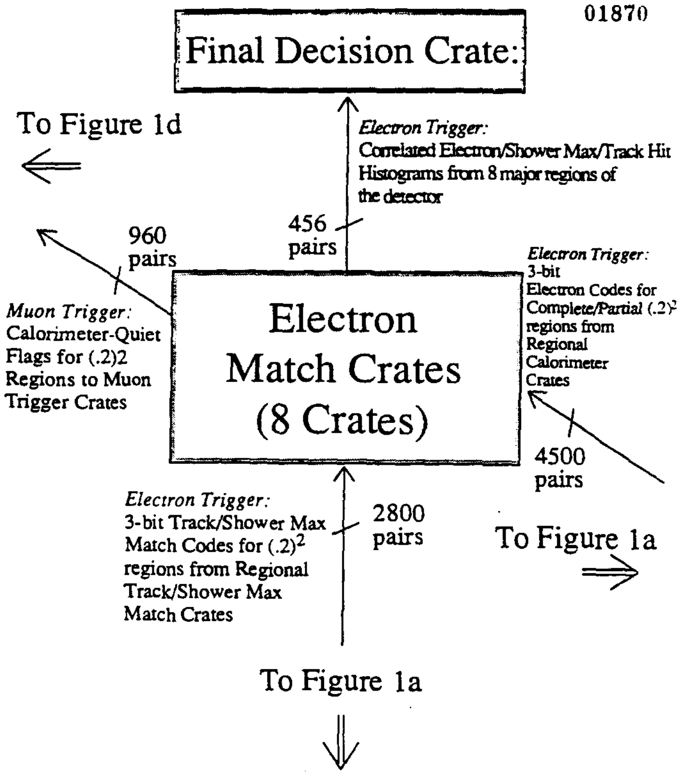

Figure 1d

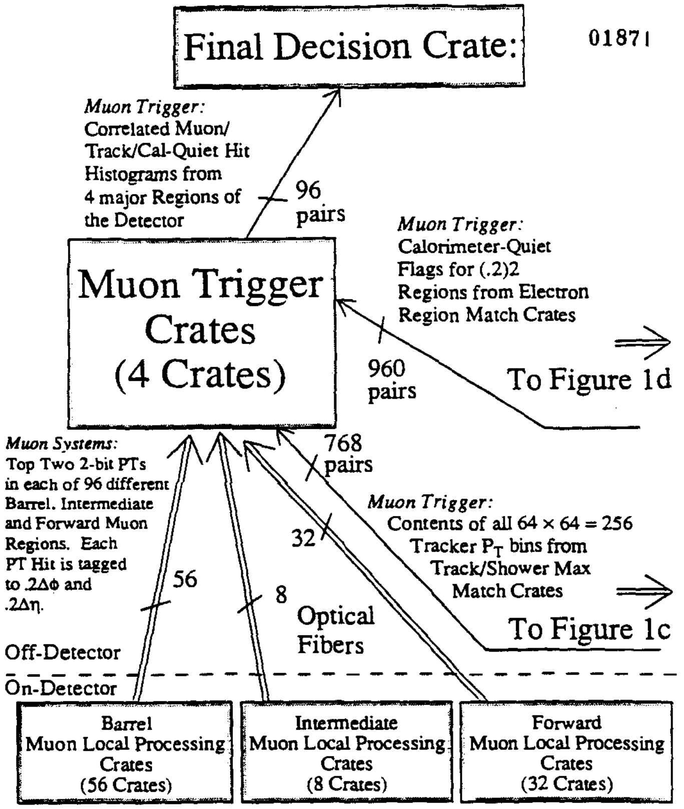

Figure 1e

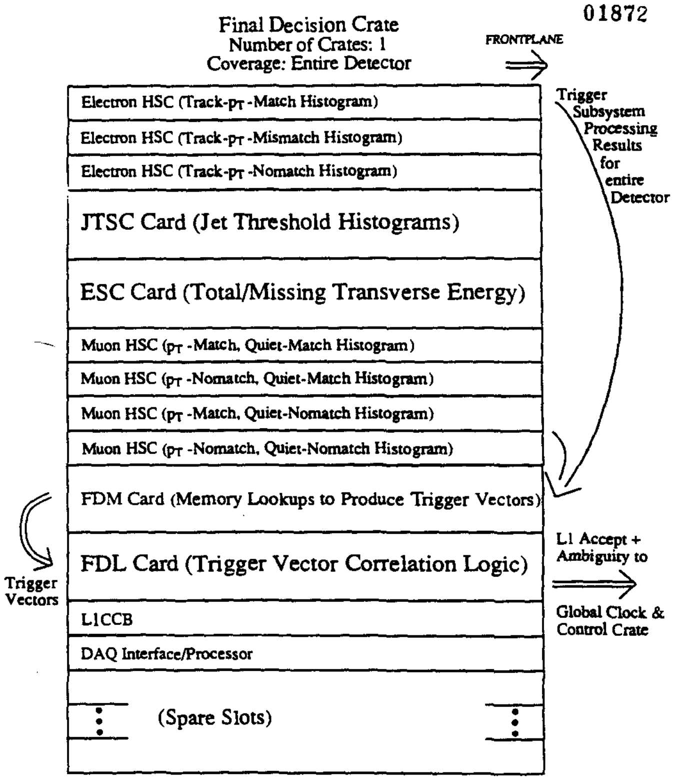

Figure 16

TRIGGER CLOCK & CONTROL

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Clock:

Trigger System sends out a 60 MHz clock to all Front End Electronics, Trigger and DAQ Subsystems

Control:

Trigger System sends out:
- Level 1 Accept/Reject
- Level 2 Accept/Reject
- Reset, Synch, Test, Empty Crossing, etc.
- Readout Type bits
- Phase Information

Status:

Subsystems send back:
- Busy, Error
- Phase Information

Hardware:

Signals are transmitted on optical fibers:
- One each for Clock, Control Status

Interface with Subsystem Crate:
- Level 1 Clock & Control Board (L1CCB)

Fanout Module:
- Level 1 Clock & Control Fanout (L1CCF)

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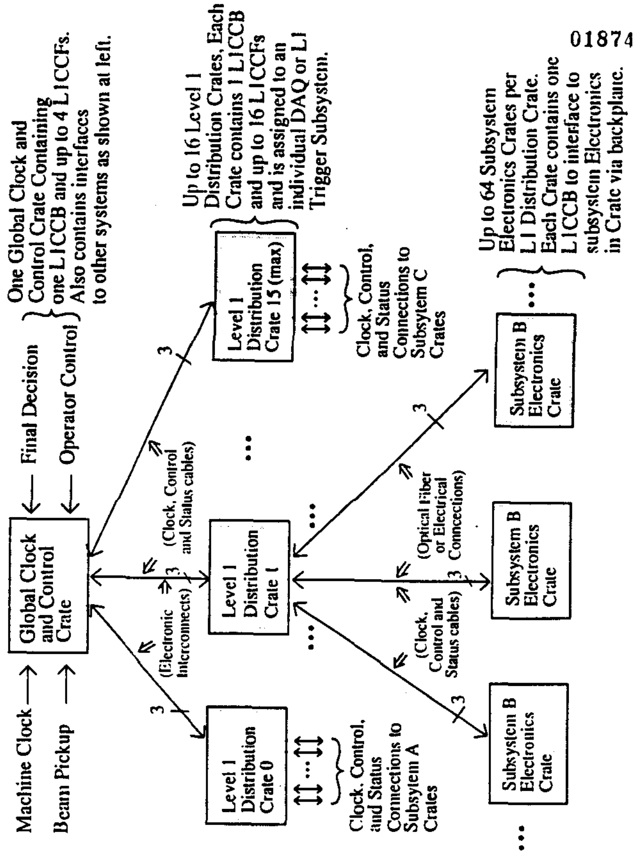

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Trigger Schedule Milestones.

Major Milestone	Scheduled Date
Start Final L1 Design	January 1993
Test System Available	May 1993
Complete L1 Design Specs.	December 1993
Final L1 Design Review	January 1995
Complete Design of Level 1	June 1995
Start Final L2 Design	January 1994
Complete L2 Design Specs.	December 1994
Final L2 Design Review	July 1995
Complete Design of Level 2	December 1995
Deliver L1 & L2 Prototypes	June 1996
Initial Delivery of Trigger Interfaces	June 1996
Delivery of Trigger System Begins	January 1997
Begin Integration & Test w/partial systems	June 1997
Begin Integration & Test w/final systems	January 1998
Commission Trigger System	October 1999

LEVEL 2 TRIGGER SUMMARY

P. LEDU

The SDC Level 2 Trigger

A global view of the level 2 trigger

Summary

PAC meeting

May 92

P. Le Dû

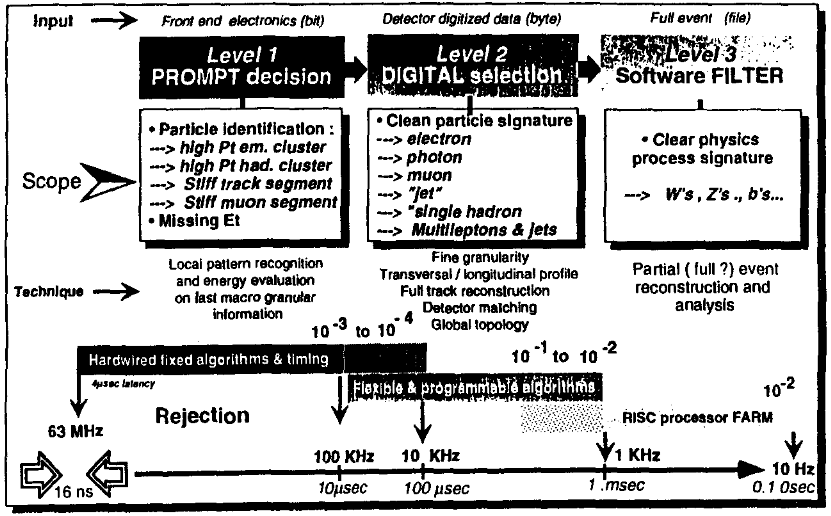
Saclay & LBL

The SDC Level 2 DIGITAL trigger

Menu

Event selection scheme
Overview
Level 2 tasks
Strategy
Philosophy
Conceptual design
Technical constraints
Implementation
Data flow diagram
Techniques & tools
Algorithms
Conclusions

Event selection scheme



Input ---> *Front end electronics (bit)* | *Detector digitized data (byte)* | *Full event (file)*

Level 1 PROMPT decision → **Level 2 DIGITAL selection** → **Level 3 Software FILTER**

Scope

- Particle identification :
  - ---> ***high Pt em. cluster***
  - ---> ***high Pt had. cluster***
  - ---> ***Stiff track segment***
  - ---> ***Stiff muon segment***
- Missing Et

- Clean particle signature
  - ---> ***electron***
  - ---> ***photon***
  - ---> ***muon***
  - ---> ***"jet"***
  - ---> ***"single hadron***
  - ---> ***Multileptons & jets***

- Clear physics process signature
  - ---> ***W's , Z's ., b's...***

Technique --->

Local pattern recognition and energy evaluation on last macro granular information

Fine granularity
Transversal / longitudinal profile
Full track reconstruction
Detector matching
Global topology

Partial (full ?) event reconstruction and analysis

10^{-3} to 10^{-4}

10^{-1} to 10^{-2}

10^{-2}

Hardwired fixed algorithms & timing

4µsec latency

Flexible & programmable algorithms

RISC processor FARM

Rejection

63 MHz

16 ns

100 KHz *10µsec*

10 KHz *100 µsec*

1 KHz *1 .msec*

10 Hz *0.1 0sec*

Overview

- **Refine & complement the Level 1 trigger cuts**
  - add new detectors ---> Silicon tracker .
  - information not available at the level 1 ---> Muon , ShowerMax ..
- **Clean signature of :**
  - high Pt inclusive particles
  - simple subprocess (dileptons ....)
  - multiple signatures
- **Rejection factor ---> 10 to 100**
  - **Estimated Level 1 rate @ L= 10**33 => 30 KHz**
    - 50 % ---> Calorimetry
    - 50 % ---> Muons
- **Average 10 µsec between 2 decisions**
  - Accept / reject < 10µsec
  - select & flag , prescale ---> up to 50 µsec latency
- **Flexible & programmable algorithms**
- **Strongly connected the L1 T & DAQ**
  - synchronization
  - L2 buffer
  - data extraction

Philosophy

Basic ideas & guidelines

.... from many past experiences.

- **MODULAR & FLEXIBLE**

--- > *scalable as the Physics, machine luminiosity & techniques evolve*

- **COHERENT**

---> *realistic compromise between Physics guess, technology complexity & cost...*

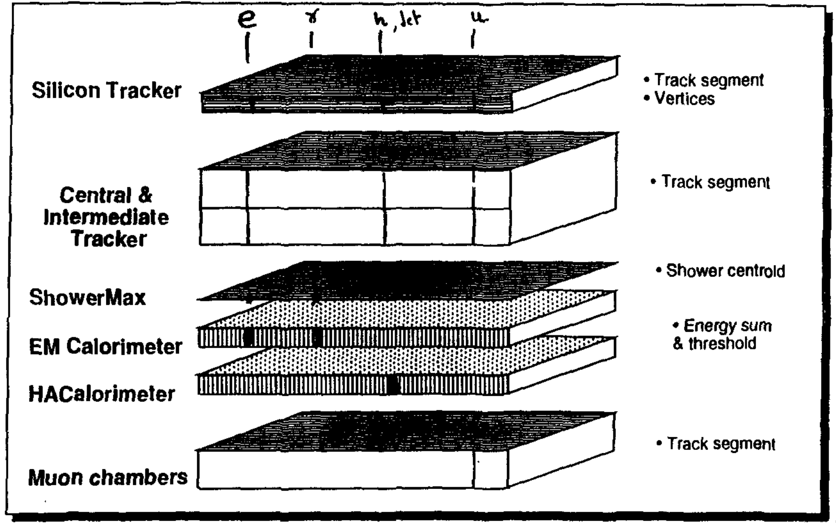
---> *"Simple" : easy to integrate, commission, debug, test & control*

Level 2 tasks

• Muon	• **Refine selection** ----> Track- Muon segment match (Phi, Pt)
• Electron	• **Refine selection** ---> Track-Shower Match (Phi , E=P, isolation) • **Tag (kill) photon conversion** ---> Si tracker
• Photon	• **Refine selection** ---> Shower profile , low H/E, isolation
• Jet	• **Identify** ---> measure energy in cone
• Hadron	• **Identify isolated high Pt track** ---> track,$\overline{\text{SMD}}$,low E/H,E=P
• Heavy flavor	• **Displaced secondary vertices** ---> Si tracker + VTX track
• Neutrino	• **Refine missing energy** ---> add muon energy into $\not{E}$t sum ...
• Di-leptons di- Jets...	• **Search for lower energy lepton** ---> combination of e, μ, jets, stiff tracks, nu, displaced VTX.....
• Others .	• **Redundancy with the level 1** ---> more sophisticated algorithms • **Rejection of unexpected backgrounds & noises** • **Fast on line checks & diagnostics** ---> *trigger efficiencies*

Conceptual design

Combine with redundancy the different detector layers with the finest granularity



Strategy

A 3 steps procedure

- **Adopt a PHILOSOPHY**

---> *using input parameters from :*
Physics simulation & Detectors

- **Define an ARCHITECTURE**

---> *Identify functional blocks & their connections*
(independantly of any techniques)

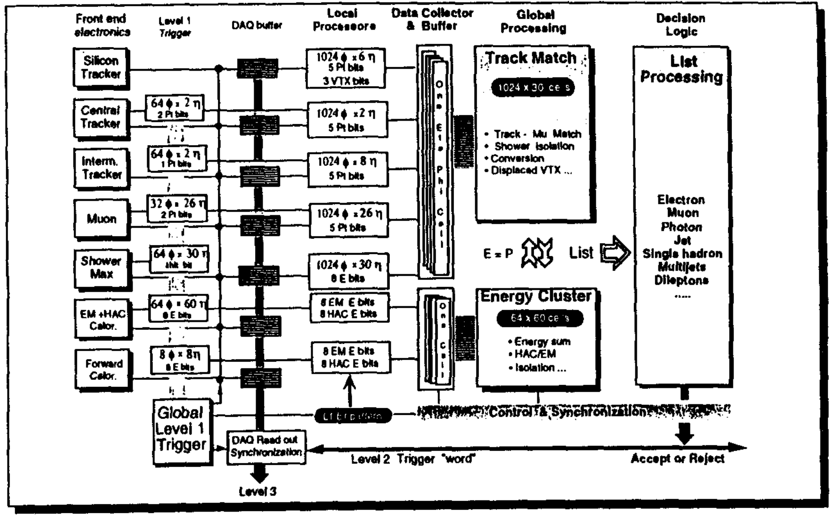
- **Select tools to build & evaluates PROTOTYPES**

---> *using "the BEST of" modern techniques able to be realistically extrapolated for the future.*

Goal ➢

Be sure that all input signals will be available in time.
---> Front end electronics design
---> Detector segmentation

Data Flow



Technical constraints

How to extract & combine signals ?

Mechanical design of detectors :

---> compatible segmentation

- Tracking ,Muon, ShowerMax => 1024 Phi x 30 Eta
- EMC & HAC Calorimetry => 64 Phi x 60 Eta

Basic granularity ➡ **1024 x 60 cells**

Electronics & Read out chain:

---> front end data collection chip (16, 32 , 64 ... packaging)
---> topology (where ? on detector, on surface ?)
---> data extraction (DAQ buffer , special data path ...)
---> cabling (trhroughput , connectors ...)

Techniques & Tools

Local Processors ⇨
- **Dedicated processors**
  ---> histogrammers....
- **Associative memories**
- **Memory Look Up table...**

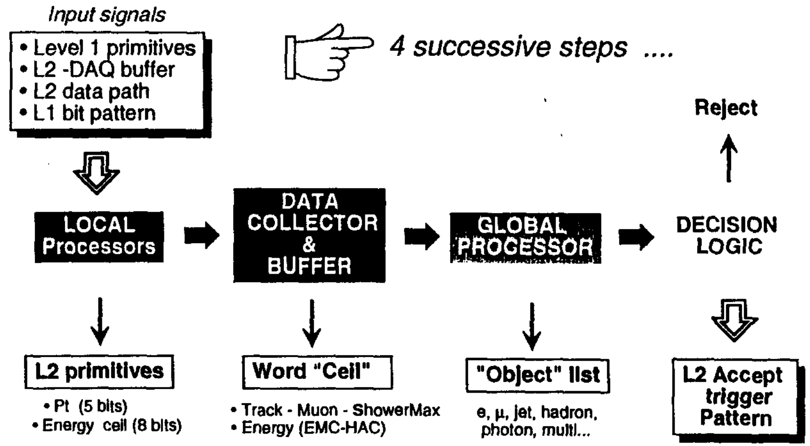
Data Collector & Buffer ⇨
- **FIFO registers**
- **Fast Dual Port Memory**

Global Processor ⇨
- **High level of parallelism & connection**
  ---> commercial "vector processors"
- Massively Parallel SIMD machines
- Neural Network
- Transputer ...

Final Decision ⇨
- **"Scalar" processors**
  ---> 100 MHz DSP , RISC....

Communication ⇄
- **Point to point links**
  need 100 Mbytes/sec --> HIPPI
  ===> *Optical fibres*

Implementation



Input signals

- Level 1 primitives
- L2 -DAQ buffer
- L2 data path
- L1 bit pattern

4 successive steps ....

LOCAL Processors ➡ **DATA COLLECTOR & BUFFER** ➡ **GLOBAL PROCESSOR** ➡ **DECISION LOGIC**

Reject

L2 primitives
- Pt (5 bits)
- Energy cell (8 bits)

Word "Cell"
- Track - Muon - ShowerMax
- Energy (EMC-HAC)

"Object" list
e, μ, jet, hadron, photon, multi...

L2 Accept trigger Pattern

Level 2 Conclusions

- **ARCHITECTURE**

  ---> Identify 4 functional modular blocks , their connections and clean interfaces (indcpendantly of any techniques)

- **SEGMENTATION**

  ---> Basic granularity of 1024 Phi x 60 Eta as been defined with their consequences on Detectors, Front end electronics & Cabling.

- **ALGORITHMS**

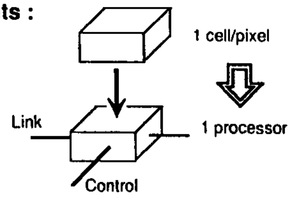
  ---> List of tasks & elementary steps to be simulated with modern processing techniques . (and optimized)

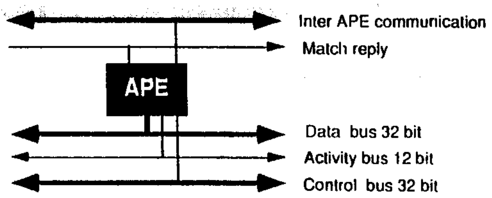
---

one example : The ASP

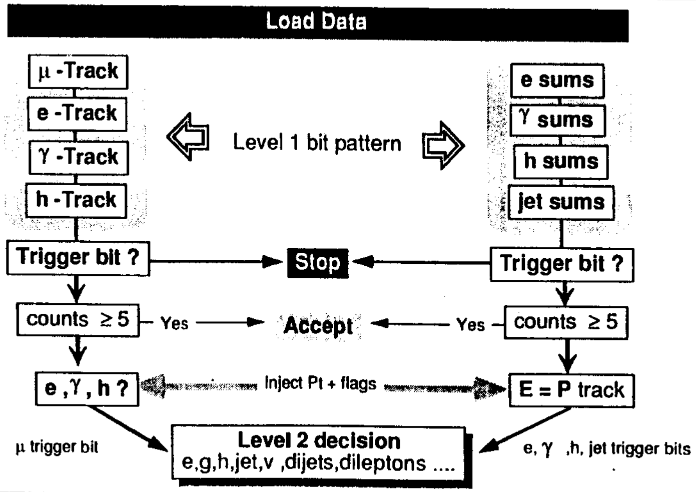
Architecture --> Massively Parallel SIMD machine

- **String of associative processing elements :**
  APE (2µm CMOS 64 APE chip, 25 MHz)
  ---> 64 bit associative memory cell
  ---> 70 bit comparator
  ---> 1 bit processor
  ---> 10 bit activity and flag
  ---> communication capabilities
- **Programmable structure**
- **Scalable**





Algorithms flow chart



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STRAW TUBE AND MUON FRONT-END ELECTRONICS

Y. ARAI

ARAI

Straw & Muon Front End Electronics

SDC TDR Review @ SSCL
1992.5.5 Y. Arai (KEK)

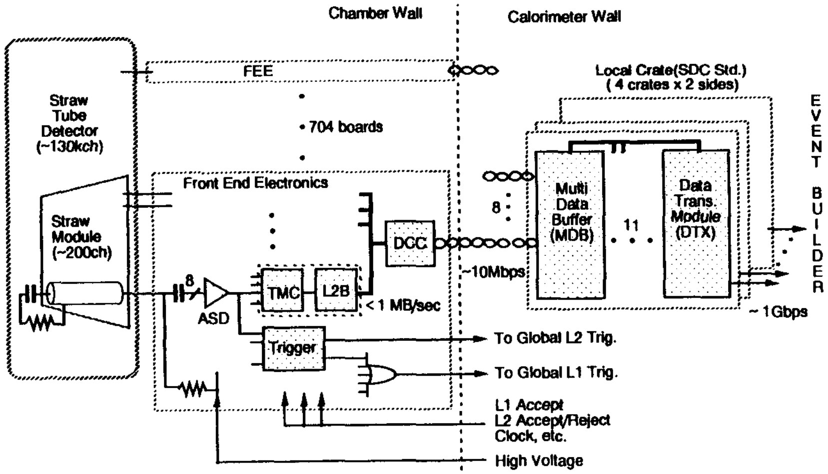
I. Straw Electronics
  1. Design Requirements and Overview
  2. Analog Signal Processing : ASD chip
  3. Drift Time Measurement : TMC, L2B chips
  4. Radiation Hardness

II. Muon Electronics
  1. Design Requirements and Overview : (Difference from straw electronics)
  2. Development Status

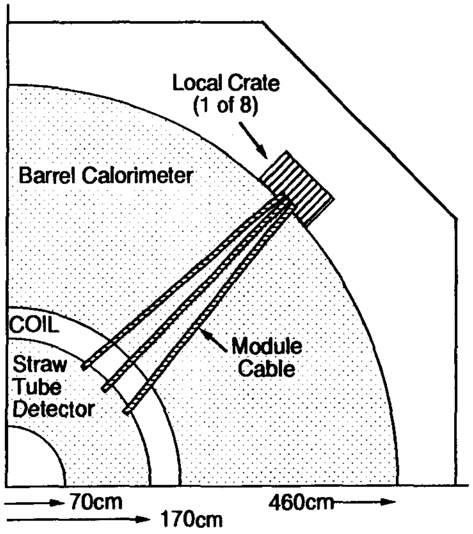
III. Summary

Design Requirements

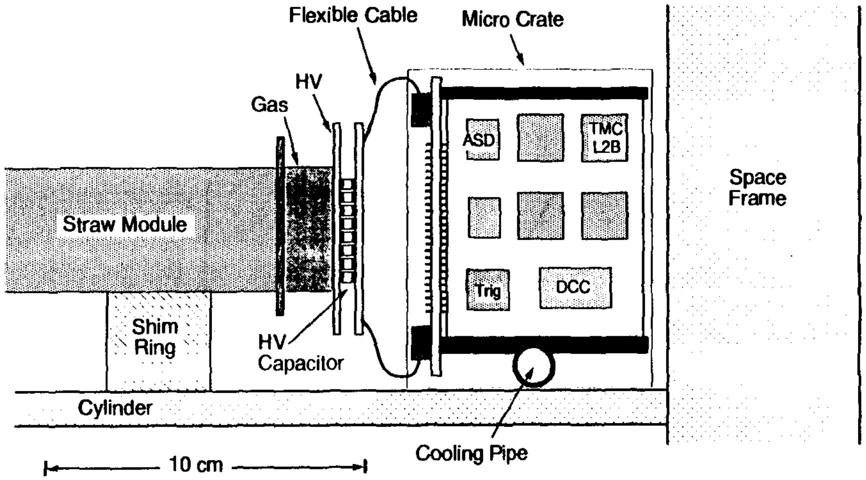
- Large number of channels (130 k ch) @ r = 0.7 ~ 1.7 m
  Small Crack → Install Electronics (Amp~L2B) at the detector.
- Gas Gain ~ a few x 10^4 → Low Noise Electronics.
- Straw σx ~ 100 μm → < 0.75 ns time accuracy.
- High Rate → 20-30 ns double pulse resolution.
- 16 ns Bunch Cross → Deadtime-less readout.
  (L1 Buffer ~ 3μsec, L2 Buffer ~ 50μsec)
- Radiation Hard : ~ 1 Mrad and > 10^{14} n/cm^2.



Straw Electronics Overview



Module cable and Local crate physical placement.



An Exapmle of Straw Front-End Electronics Mounting

KEK

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Power Consumption

- ASD : 18 mW/ch
- TMC : 8 mW/ch
- L2B : 2 mW/ch
- DCC, Trig.,etc. : 2 mW/ch

Total 30 mW/ch → 6 W/Board → 2 kW/End

Cooling

Heat Transfer : $P_{(W)} = \Delta T_{(°C)} \bullet V_{(cm^3/sec)} \bullet C_{P(J/g/°C)} \bullet \gamma_{(g/cm^3)}$

(Ex. $\Delta T = 5$ °C)

- Air : $V = 300$ ℓ/sec ⇒ 30 m/sec @100 cm^2 duct
- Water : $V = 100$ cc/sec ⇒ 10 cm/sec @10 cm^2 duct

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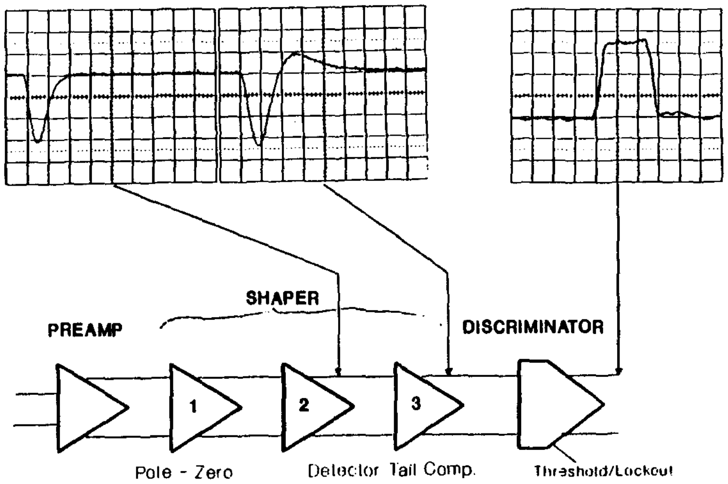
STRAW TUBE ASD



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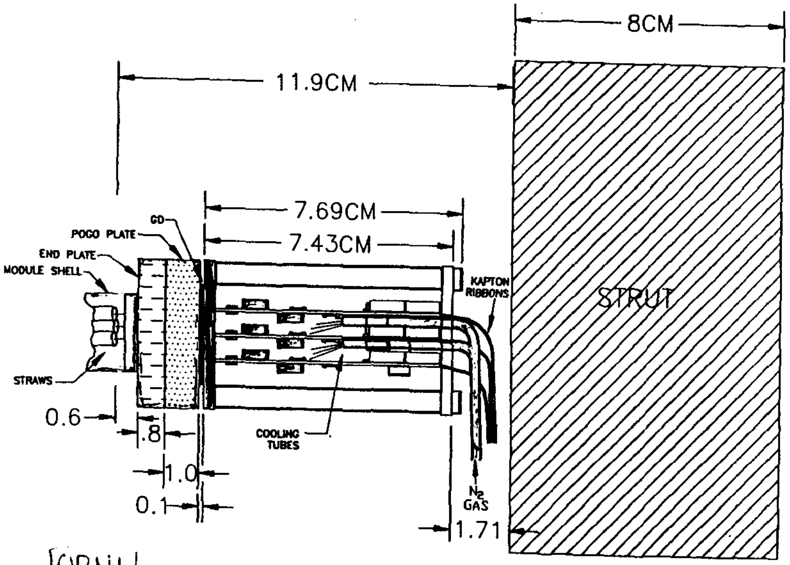


ORNL

01895

Amplifier/Shaper/Discriminator Design

Preamplifier

* Circuit	Common emitter input cascoded, differential
* Gain	2.5 mV/fC
* Bandwidth	100 MHz
* Input Imp.	115 ohms
* Power	< 4 mW

Shaper/Tail Cancellation

* Circuit	pole-zero cancel (preamp) 3 differential pairs detect. tail cancellation
* Peaking time	6-7 ns
* Double pulse Res.	25ns for 2% to 2%
* DC gain	6
* Power Dissipation	< 4 mW

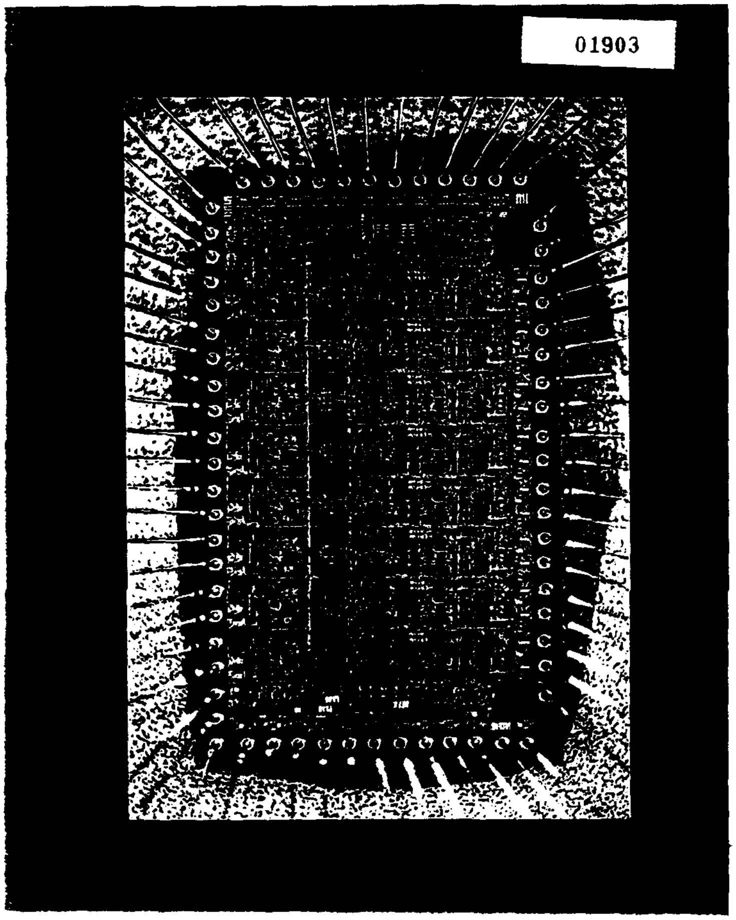
Amplifier/Shaper/Discrminator (cont)

Discriminator

* Circuit	2 stage differential amp, positive feedback, 3 mV hysteresis
* Threshold	20 mV/fC (internal), separate for each channel
* Threshold offset	< 1 mV
* Time Slew	< 1ns /decade of overdrive
* Power	8 mW (excluding drive)
* Output	differential, open collector current programmable

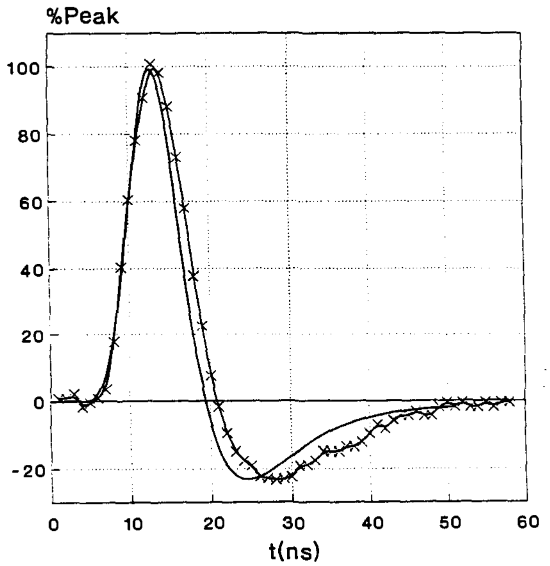
Implementation

- * AT&T single channel amp/shaper (exists)
- * Tektronix, full ASD (exists)



ASD-8

Impulse Response at Disc Input
SPICE..vs..Measured



Measured peak is 75% of SPICE calc.

ASD - Summary of Measurements

* Gain	75% of expected value, uniform chip to chip, channel to ch. (few %)
* Peaking time	7ns observed, 6 ns expected
* Threshold Var.	< 0.5 fC ch. to ch. < 1 fC chip to chip
* Input impedance	125 +/- 10 ohms meas. 110 ohms expected
* Crosstalk	None observed for < 10fC with threshold at 0.5 fC
* Threshold Temp Var.	< 0.2 fC for 40 C
* Time Walk	4.5 ns for 1 - 15 fC (in agreement with SPICE)
* Yield	80% of chips

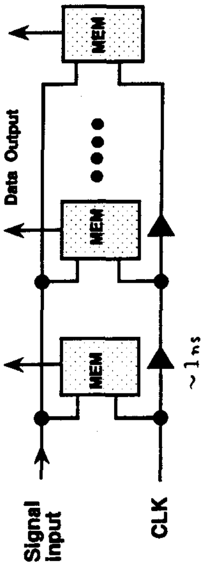
Time Memory Cell (TMC)

- To Reduce Power Consumption
  - Use CMOS LSI (Power = C x V^2 x F)

fine process
< 1 μm

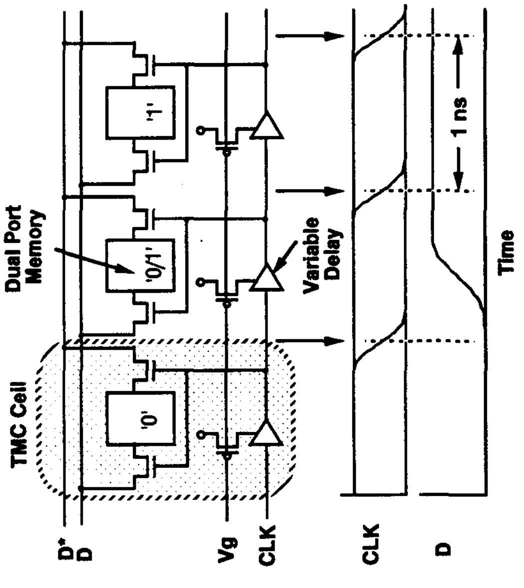
lower voltage
≤ 3 V

low frequency,
reduce active circuit
⇒ Memory & Delay

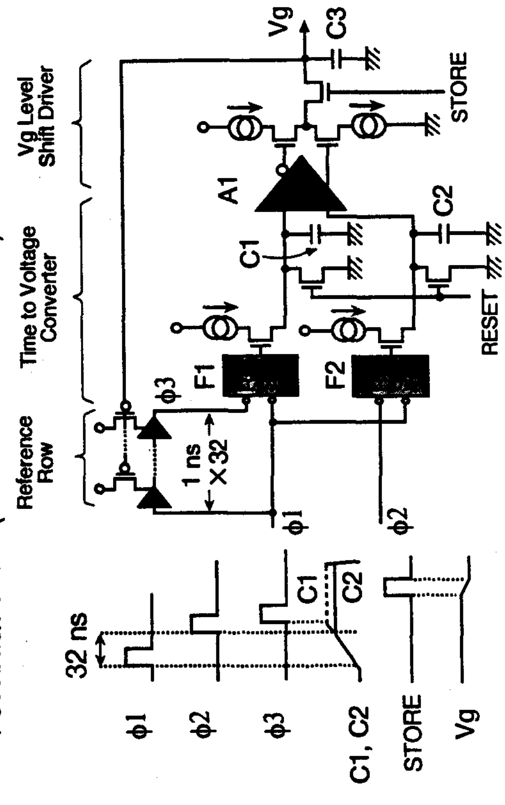


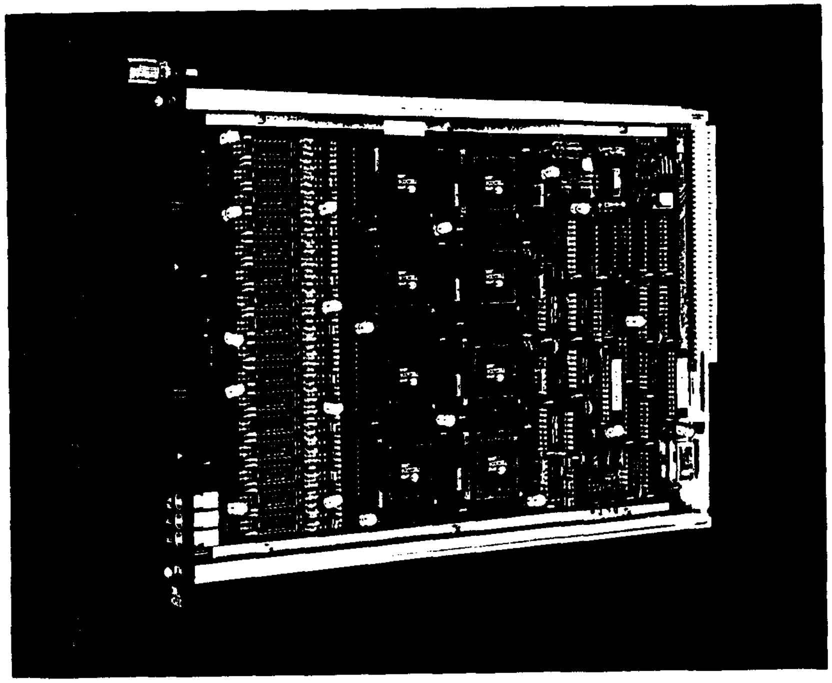
⇨ Time-to-Digital Converter + Buffer Memory

Basic Operation of Time Memory Cell (TMC)

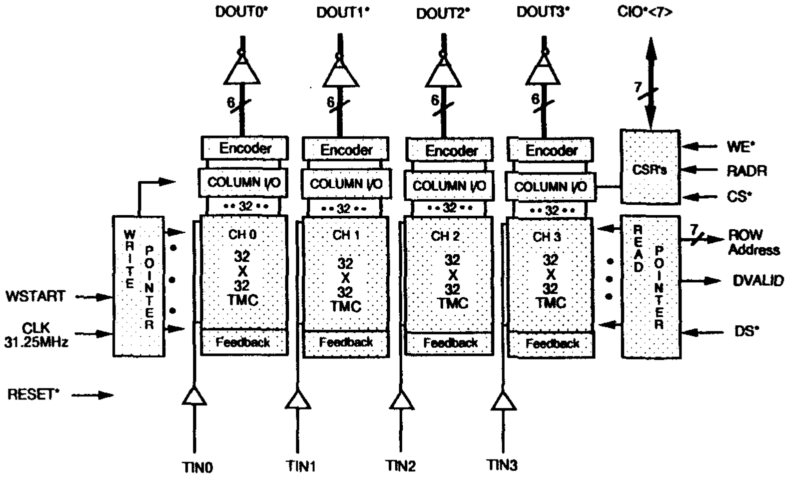


Delay time of a gate is depend on voltage, temp., process
==> Feedback Circuit (Reffer to external clock)



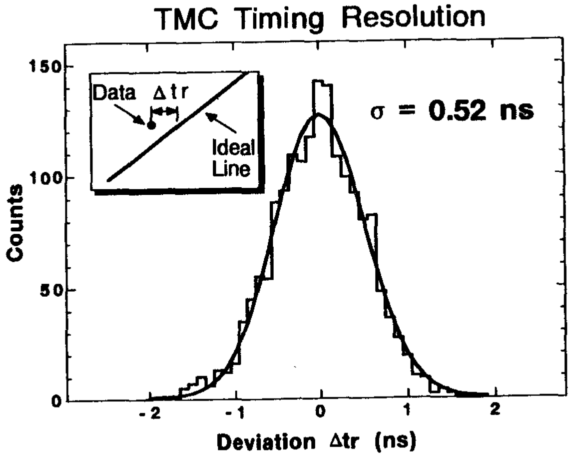


01911



TMC1004 Block Diagram

01909



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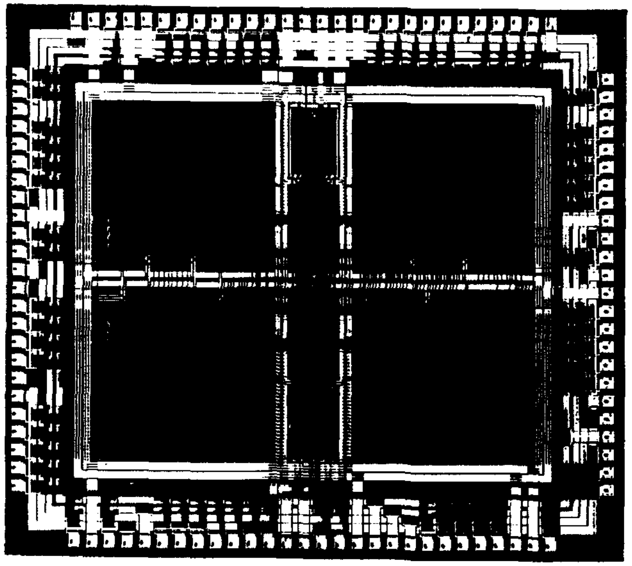


01910

Radiation Hardness

Frontend electronics of straw experience ~ 100 krad(Si) and 10^{13} neutrons over a 10 year period at 10^{33} luminosity.

⇒ Radiation-Hardness up to 1 Mrad(Si) and 10^{14} neutrons.

- Fast Bipolar : Intrinsically radiation hard for γ and n.
  (AT&T, NTT SST, Tektronix SHPi ...)
- CMOS : Intrinsically radiation hard for neutron.
  Thin gate oxide → Small threshold voltage variation.

However, thick field oxide cause large leakage current.

⇒ Need Radiation-hard CMOS process.

- Toshiba 1.0 μm Rad-Hard CMOS Sea-of-Gate.

(• UTMC 1.2 μm Rad-Hard CMOS.)

TMC1004 Specifications

• Technology :	0.8 μm CMOS, Single poly, Double Metal
• Channels x Range :	4 channel x 1 μs
• Least Time Count :	1 ns/bit
• Timing Resolution :	$\sigma = 0.52$ ns
• Variation of Slope :	< 0.1 % (2.6 - 3.4 V) < 0.1 % (15 - 55 °C)
• Power Consumption:	7 mW/ch (@ 100 kHz L1 Trigger)
• Chip Size :	5.0 mm x 5.6 mm

Features on Toshiba Rad-Hard Technology

Process

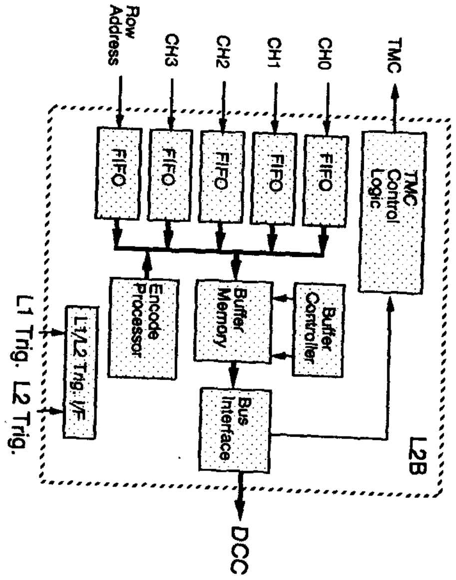
- 1 μm CMOS, Twin-Well Process.
- Radiation Hard up to 1 Mrad(Si).
- Low Temperature Process (< 900 °C).
- Thin Gate Oxide (150 Å), Epitaxial Wafer (5 μm).
- Guard Band Structured MOS FET.

Gate Array

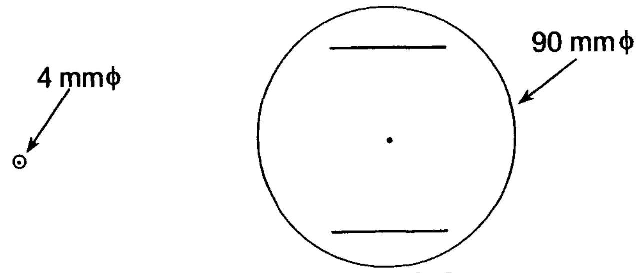
- Sea-of-Gate (≤ 172 k gates. TMC1004 ~ 25 k gates).
- Compatible with Industry TC140G Series.
- Tpd = 0.4 ns.

Level 2 Buffer

- Receive TMC output when L1 accept is asserted.
- Encode/Format Input Data.
- Buffer the data for L2 decision time (~ 50 μs).
- Transmit data to DCC.
- Combined with TMC if possible.

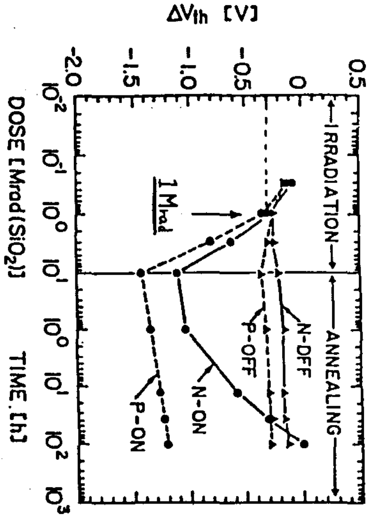


Difference between Straw and Muon

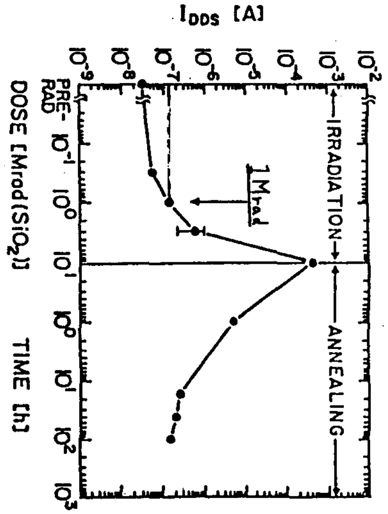


Straw Tube	Muon Tube
Drift Time = 30 ns	Drift Time = 800 ns
Gas Gain ~ a few x 10^4	Gas Gain ~ 10^5
Electronics: • Detector Mount • Rad-Hard • Low Power • High Density	Electronics: • Distributed • Non Rad-Hard • No Severe Limit on Power • Low Density

Toshiba 1μm Rad-Hard CMOS

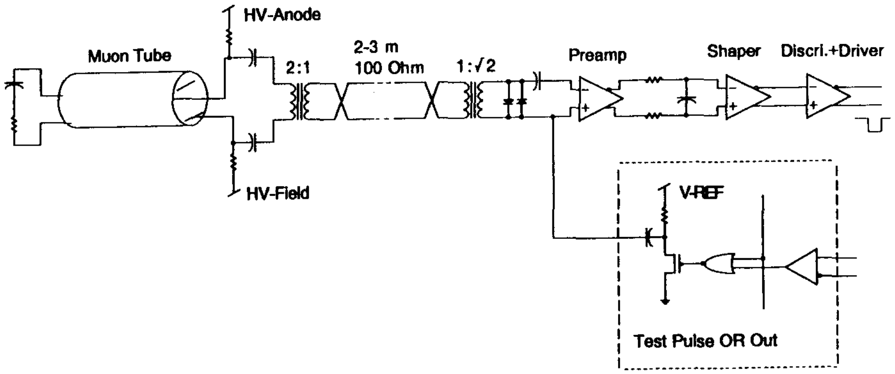


Threshold Voltage Shift

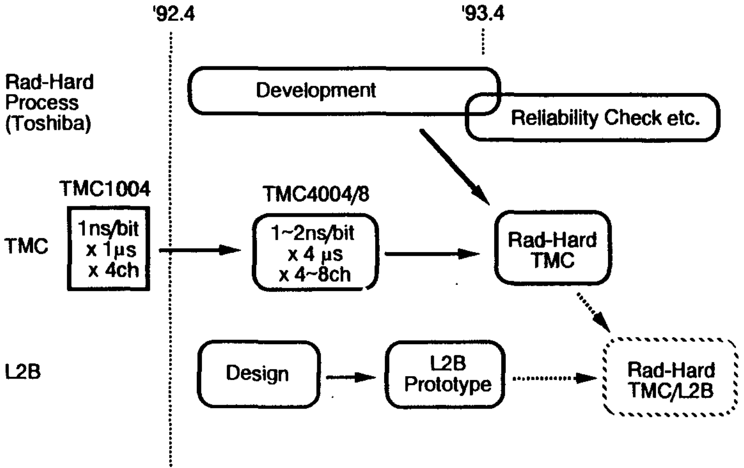


Standby Current

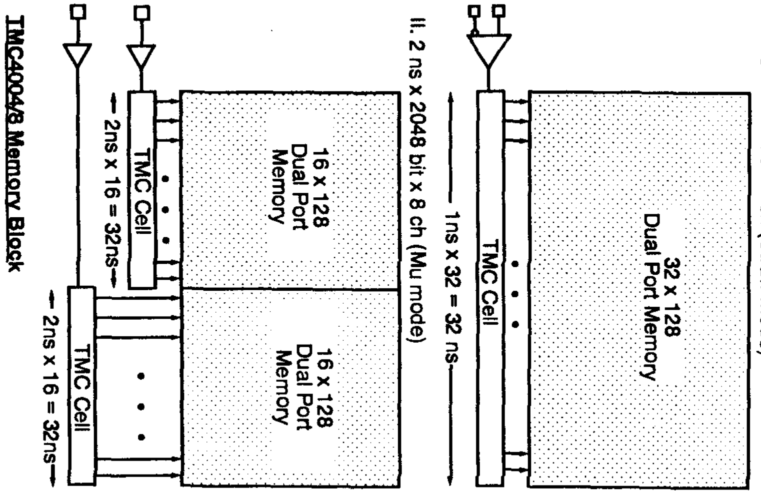
(4)



Muon Front-end Electronics (J. Oliver, Harvard)



Rad-Hard TMC/L2B Development Plan



TMC4004/8 Memory Block

Summary

- Overall designs for the straw/muon electronics are presented.
- Prototype 8ch-ASD chip was fabricated and showed good performance.
- TMC chip is suitable device in SSC environment for straw/muon.
- Bipolar ASD chip has enough radiation hardness.
- Rad-Hard CMOS process is available from Toshiba.
- Packaging and cooling problems are not trivial, but we think they are manageable.

STRAW TUBE TRACKER AND MUON TRIGGERS

J. CHAPMAN

CHAPMAN

SDC Straw and Muon Triggers

J. Chapman
University of Michigan
5 May 92

for the SDC Collaboration Review

Straw Tracker Trigger

Requirements
- Electron ID
- Muon P_t resolution

Design features

Options

Simulation studies

Circuit development

Test results

Future tasks
- Packaging - storage,trigger,DAQ
- Radiation hard implementation
- Integrated testing - noise

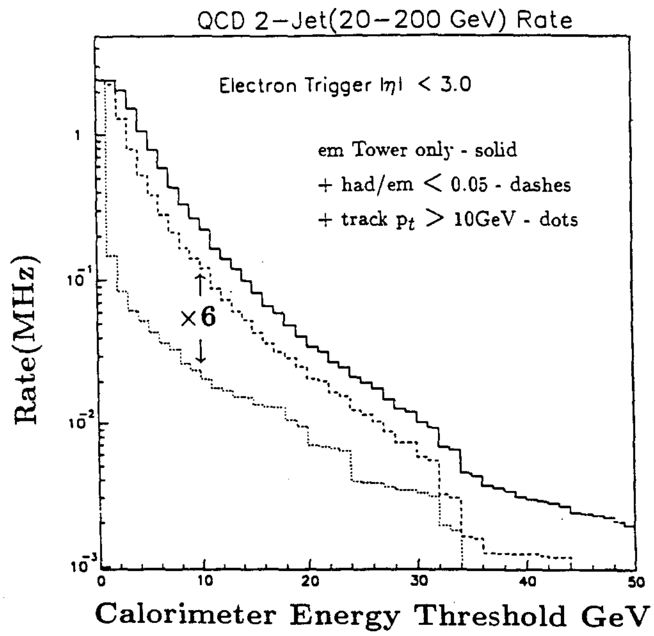
Requirements

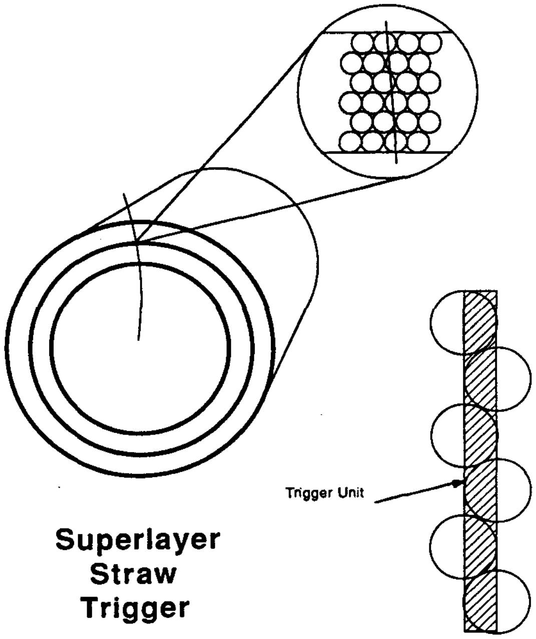
Requirement	**Motivation**
Identify "stiff" track	High P_t physics
Determine crossing	Assemble event
Match with calorimeter/showermax	Electron ID
Match with muon	Improve P_t
Associate with silicon	Reject conversions

Basic Plan has all of the above.

Options:
- **Early** vrs **Late** in the **Level 1** ↔ **Level 2** tradeoff
- Precision/granularity

Background Rejection

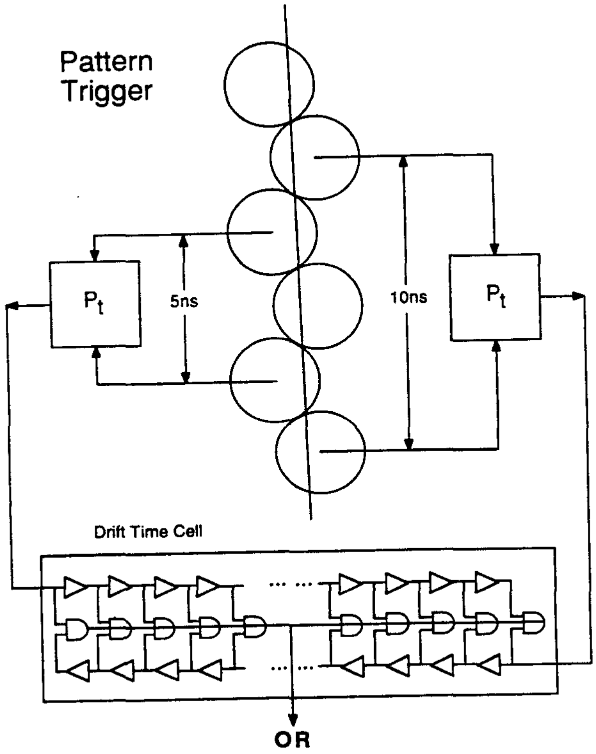




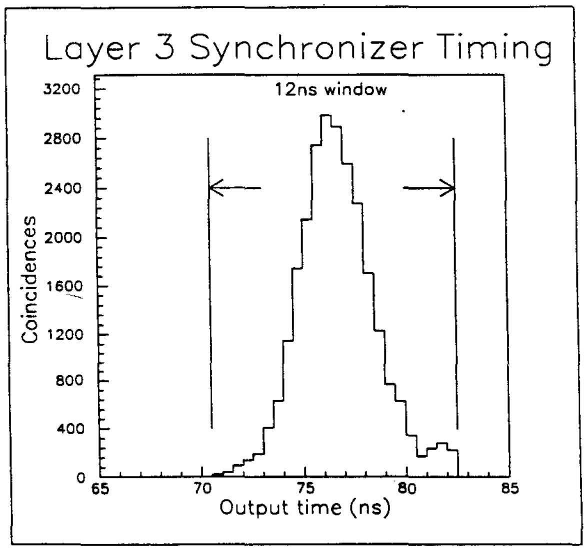
Superlayer Straw Trigger

Straw Trigger Simulation

- Simulation work: (SDCSIM)
  - 450 H → WW events
  - 450 e and μ alone
  - 450 e and μ with min-bias
  - 450 min-bias at 1, 2, 3 × 10^{33}
- Trigger Options: (2 of 3 coincidence)
  - 64 overlapping wedges
  - ±3 straws (10GeV)
- Summary:
  - Efficient trigger with low "false" rate
  - CMOS ASIC implementation

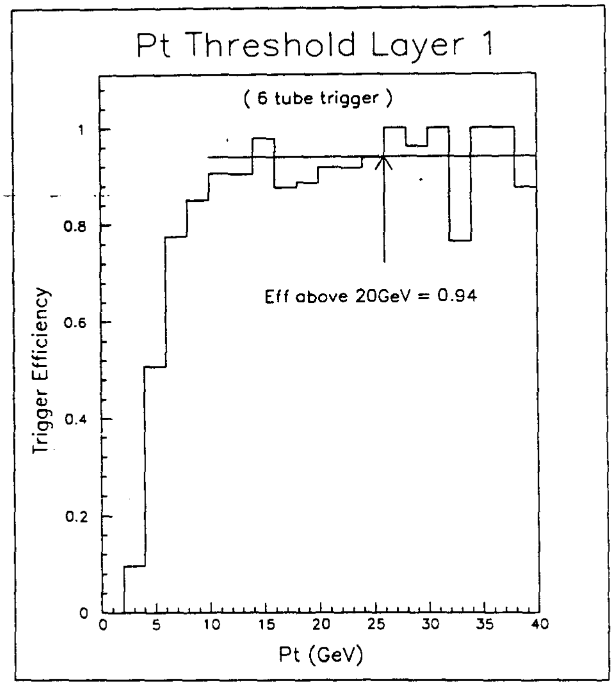


Crossing Determination



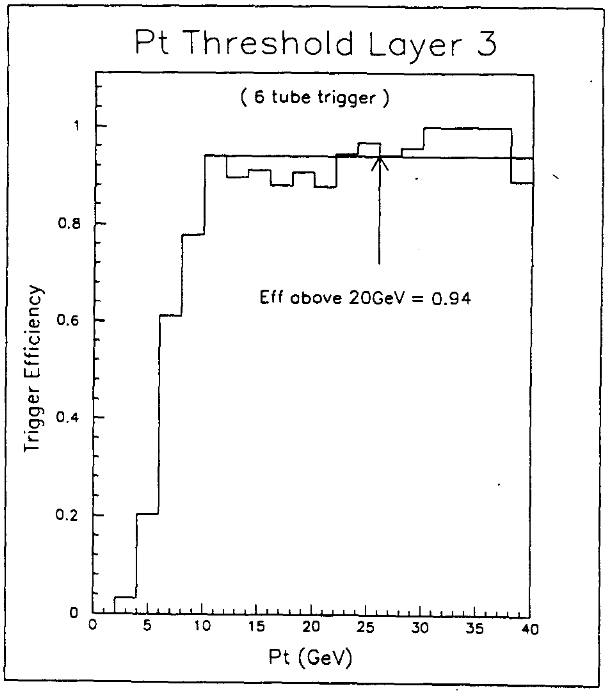
Single Layer Trigger

01932



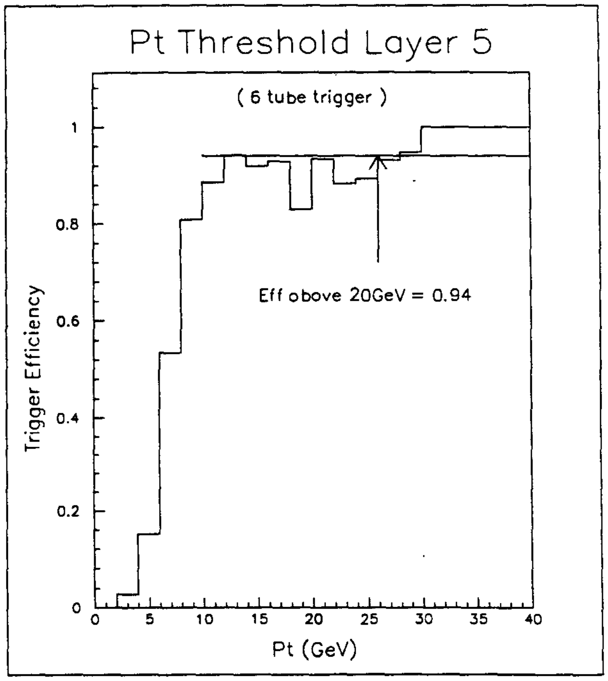
Single Layer Trigger

01933



Single Layer Trigger

01934



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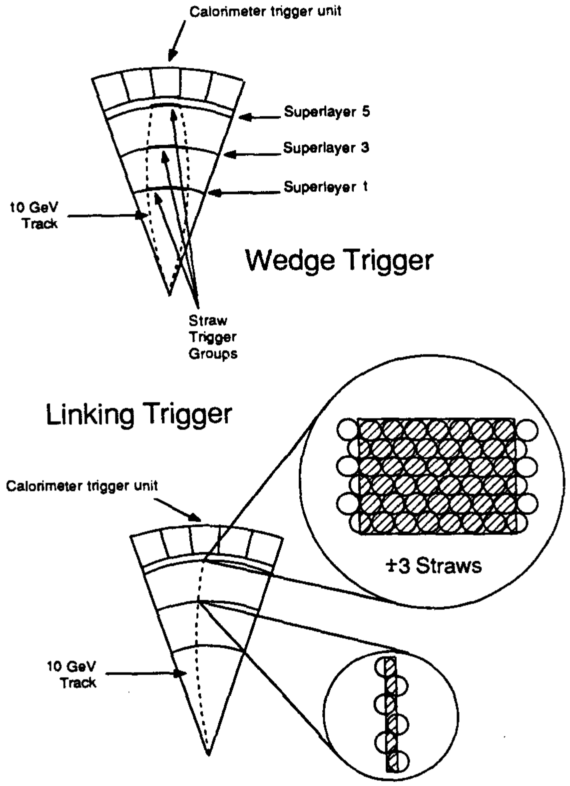
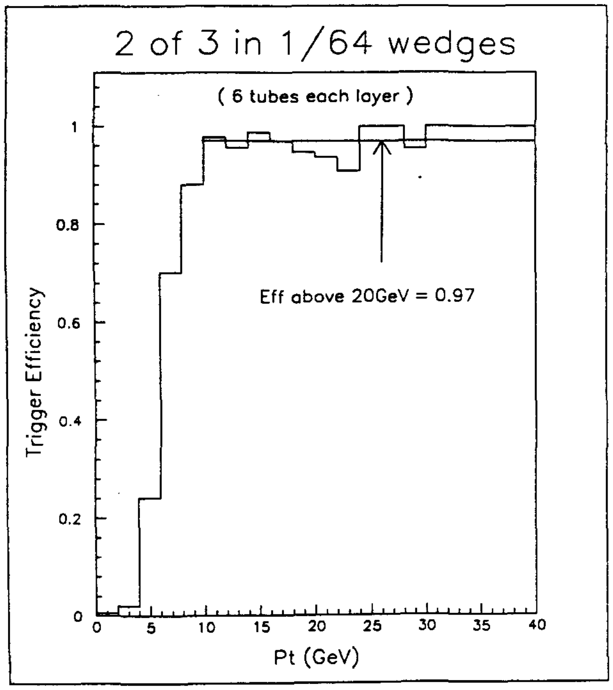


Wedge Trigger Option

01936



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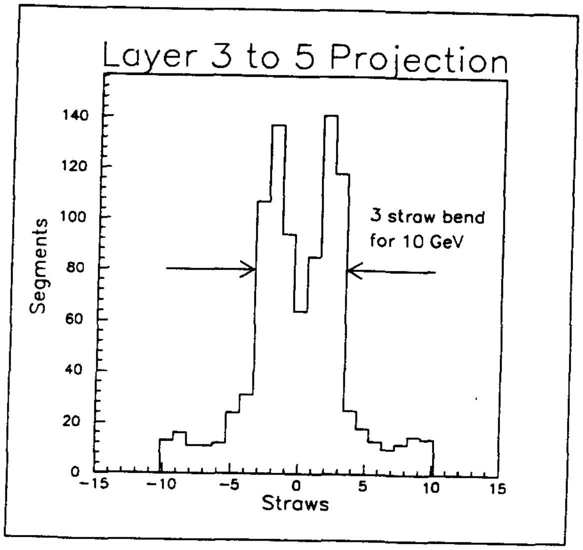
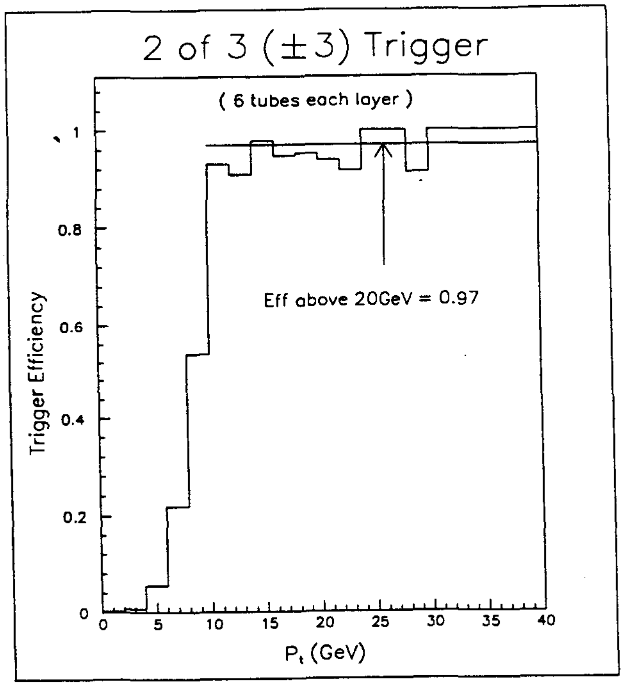


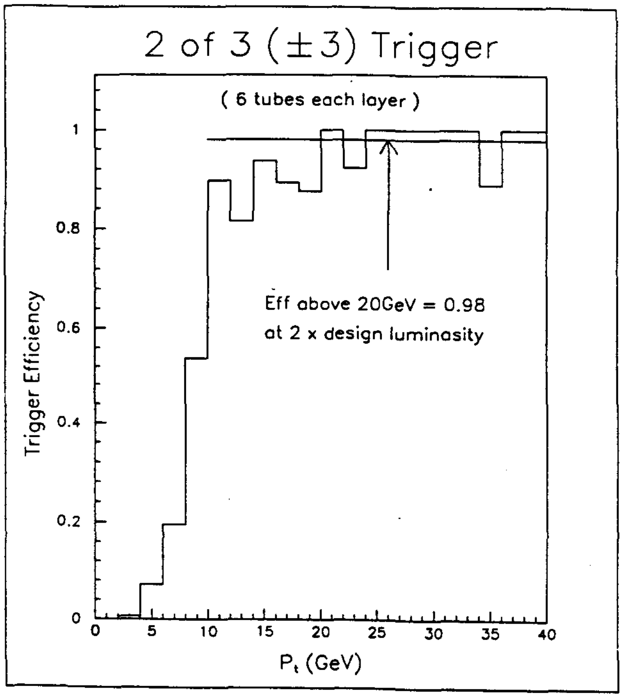
Interlayer Linking Option

01938

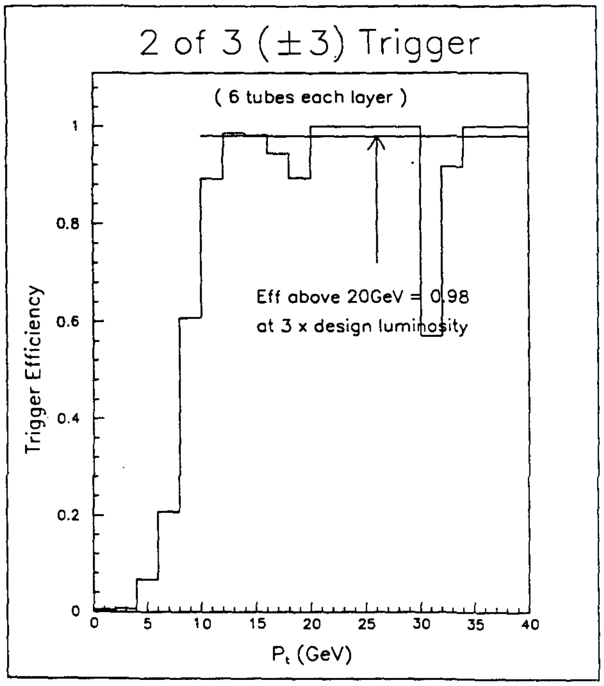


2 × Design Luminosity

01939

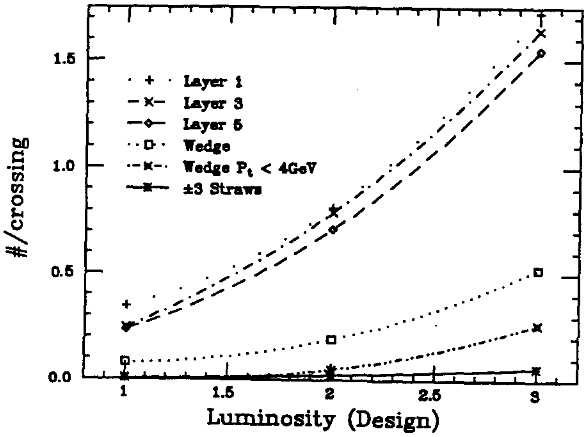


3 × Design Luminosity



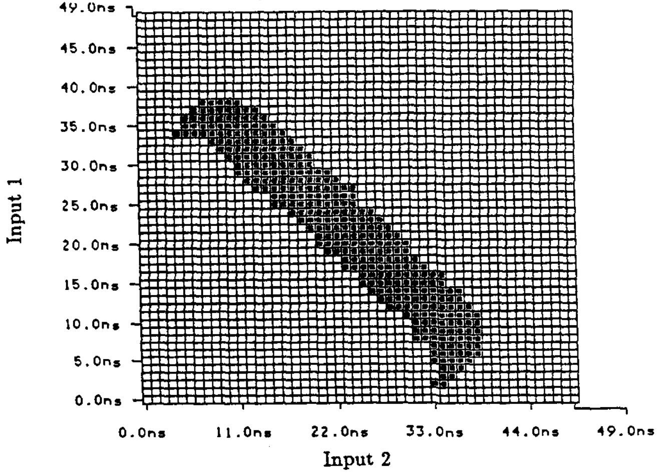
False Triggers

Triggers P_t < 10GeV



Digital Mean Timer Test

1.2μm CMOS (MOSIS)



Note : Dots indicate presence of output at fixed time. Circuit test was done with a Tektronix LV511.

SDC Central Tracker Trigger

Performance Summary

- Level 1
  - Single Layer $P_t > 6$ GeV
    False rate ≈ 1/5csx at 10^{33}
  - 2 of 3 superlayers ± 3 straws $P_t >$ 10GeV
    False rate 1/225csx from minimum bias $P_t <$ 10GeV
  - 2 of 3 superlayers, wedge ORs
    False rate 1/12csx mostly 5GeV < P_t < 10GeV
- Level 2
  - "stiff" track "hits"
    500μm - 2000μm bins

Data Summary

- Level 1
  - 2 of 3 (±3 straws) 3-bits P_t/track
  - 2 of 3 wedge ORs (calorimeter wedges) 1-bit/wedge
- Level 2
  - Layer/module/trigger unit "hit" address

Muon Detector Trigger

Requirements

Design - Scintillators + Projective Wires
- Scintillators - timing to crossing
- Wires - Programable P_t thresholds

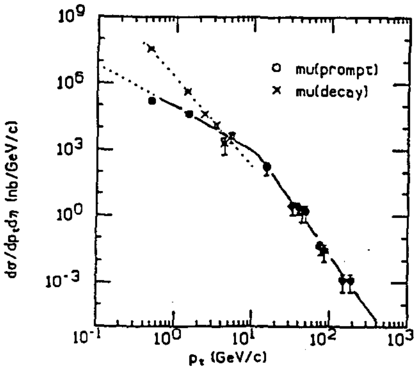
Simulation studies

Circuit development
- Scintillator circuit
- Wire circuit

Test results

Future tasks
- Supertower prototype
- Full simulation of detector/trigger
- Integrated storage,trigger,DAQ

Muon P_t Distribution



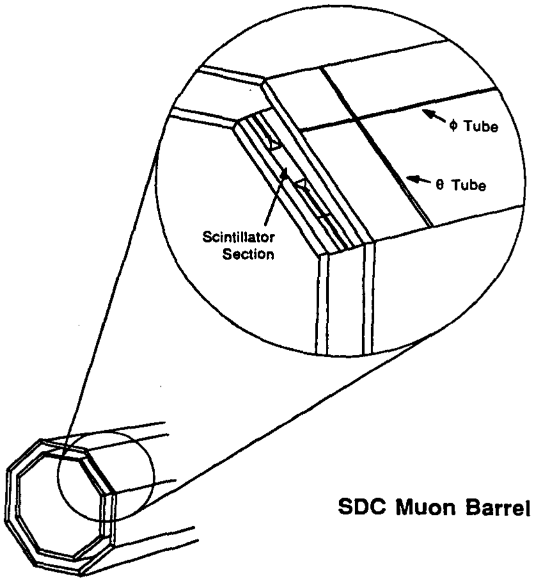
Muon Rates

Rates in Barrel and Intermediate System
(Standard luminosity; -1.5< η <1.5)

Muons from pion and kaon decay	42 kHz
Muons from charm and bottom decay	45 kHz
Cosmic-ray muons	20kHz
Punch-thru, neutrons	<100 kHz
Total rate per scintillator	<100 Hz
Total rate above 20GeV	6 kHz

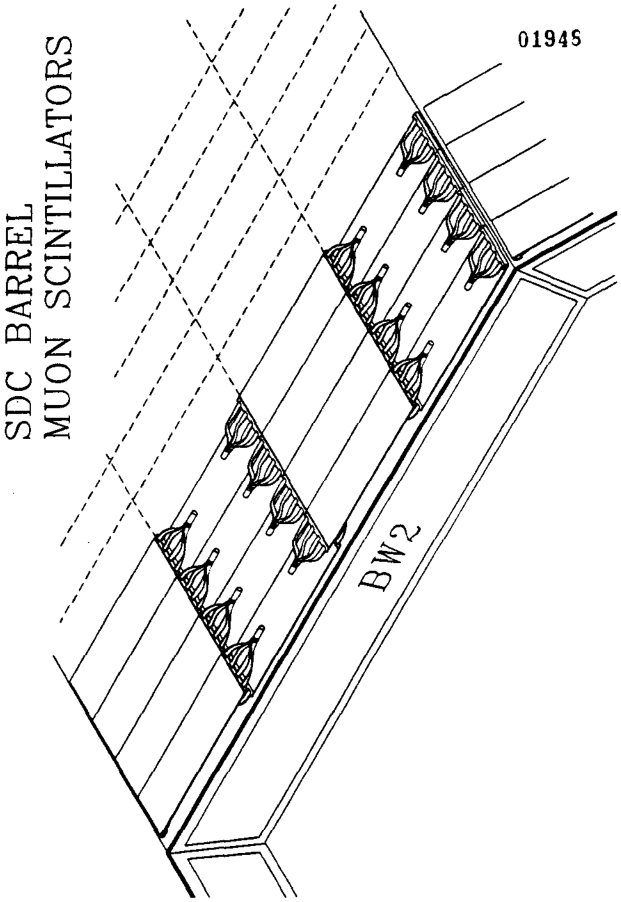
Rates in Forward System
(Standard luminosity; 1.5< $|\eta|$ <2.5)

Muons from pion and kaon decay	400 kHz
Muons from charm and bottom decay	100 kHz
Neutrons	≈MHz
Total rate per scintillator (est)	1-10 kHz

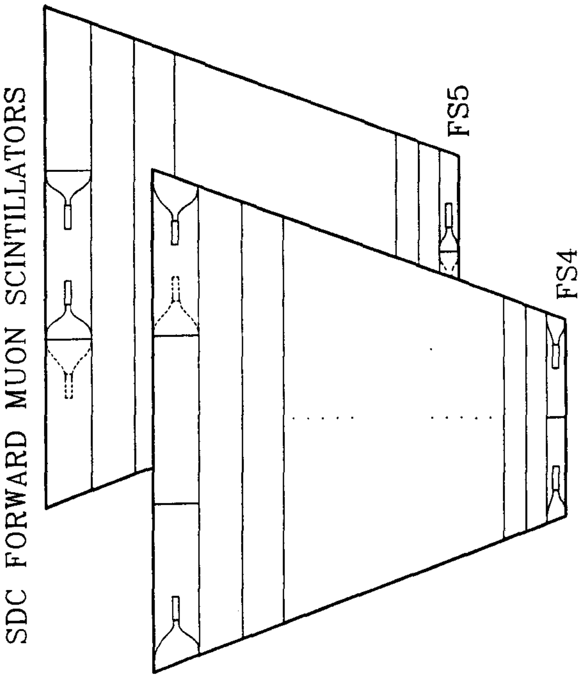


SDC Muon Barrel

01948

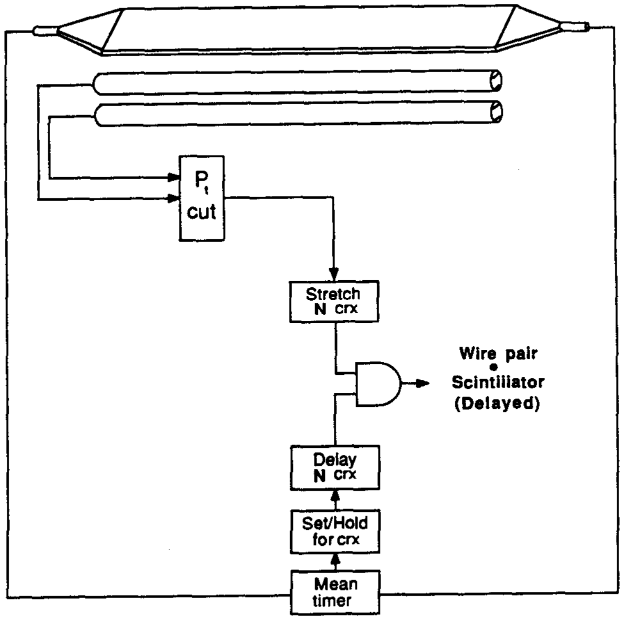


01949



01950

Simplified Muon Trigger



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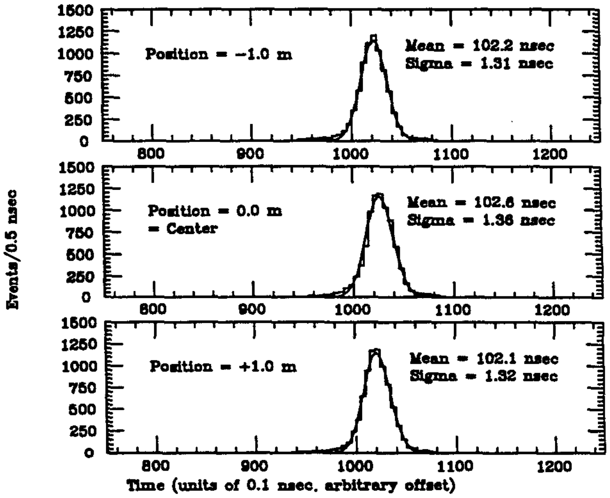
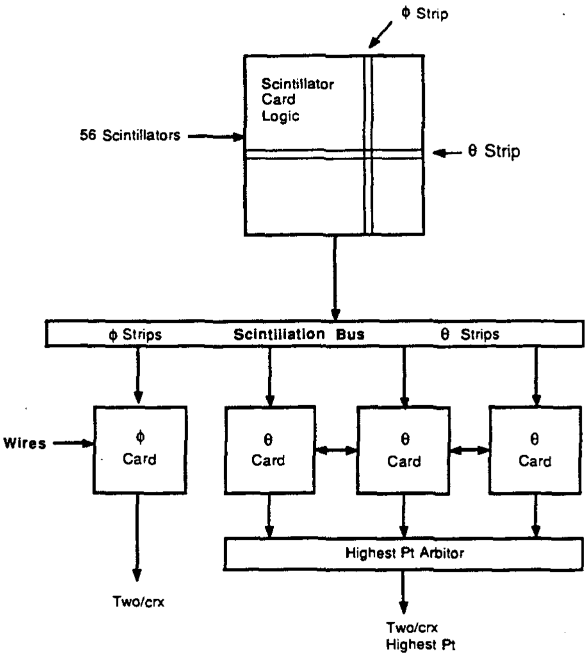
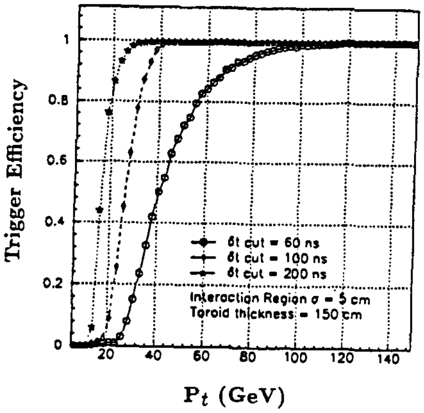
Crossing Determination

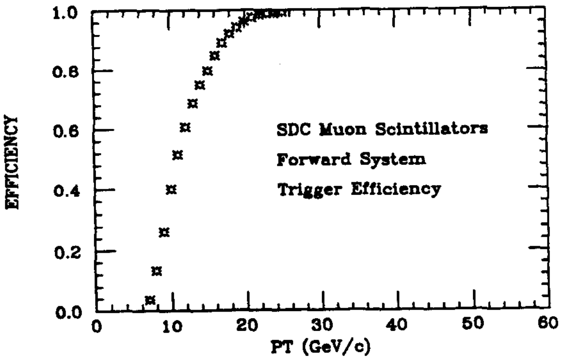




Muon Level 1 Trigger

Central Muon Trigger
Example P_t Thresholds





SDC μ Trigger

Data Items

- 3 P_t thresholds
- 14θ 16ϕ scintillator strips
- θ wire pairs (≈300 max)
- ϕ wire pairs (≈150 max)
- Scintillator patches (224 max)

Data Sizes

- 2-bits P_t ← Level 1
- 4-bits θ scintillator
- 4-bits ϕ scintillator
- 8-bits ϕ wire pair
- 9-bits θ wire pair
- 8-bit scintillator patch address ← Level 2

01956

FIBER-TRACKER OPTION TRIGGER

A. BAUMBAUGH

SDC Review. May 4-10, 1992 at SSCL.
Front-end Electronics and Trigger for Scintillating Fiber Central Tracker

Alan E. Baumbaugh
Fermilab

Outline:

1) Overview of detector layout and superlayer structures

2) Front-end electronics overview

3) Requirements

4) VLPC (Visual Light Photon Counter) cryostats and cassettes

5) ASDs (Amplifier Shaper Discriminators)

6) Trigger Methodology and Layer Structure

7) First level ASIC (Application Specific Integrated Circuit) Storage and Track Segment finding

8) Track Segment Linking (Track finding)

9) Readout Board

10) Readout Crate

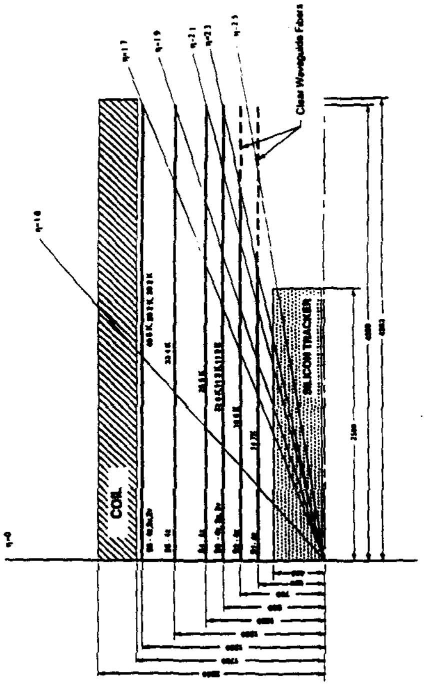
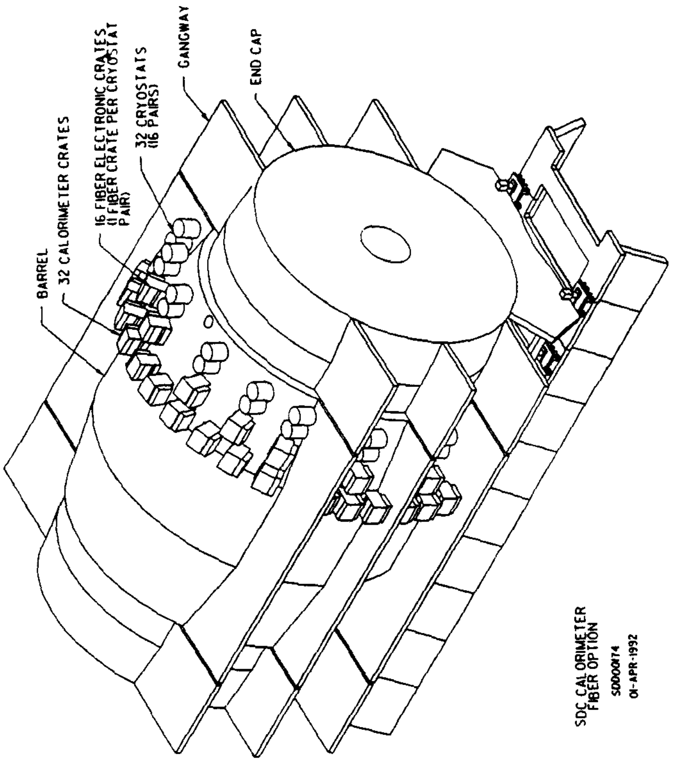
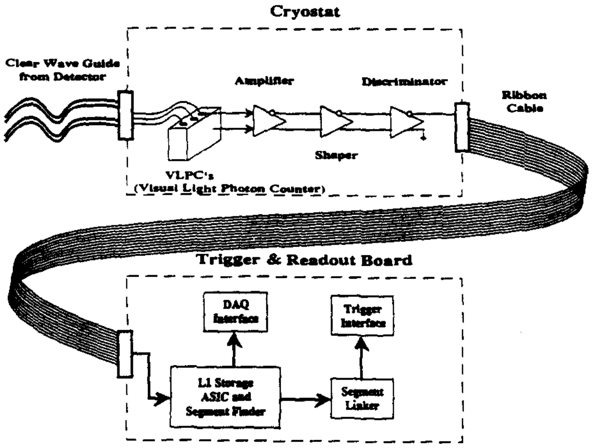


Figure 3.1-1. Schematic of the central tracker exhibiting the fiber superlayers.



Scintillating Fiber Front End Electronics



Requirements for Front-end electronics for Scintillating Fiber central tracker

System must provide:

1) Monitoring and support for VLPC (Visual Light Photon Counter) Cassettes. (Temperature, Voltage, etc.)

2) Receivers for digital outputs from VLPC Cassettes.

3) Local storage for SDC Level 1 trigger delay and SDC Level 2 trigger delay.

4) Track finding and reporting to the SDC level 1 and level 2 trigger system with position resolution of at least 1 part in 1024 to match Shower Max Detector and 3-4 bits of Pt information.

5) Receiver interface for SDC trigger signals (L1 accept, L2 accept and reject, Reset, and clocks.)

6) Readout interface to standard SDC DAQ readout controller. (Maximum readout rate is 20 MB/sec/crate with no data compression at all.)

7) Ease of maintenance and diagnostics.

8) Must "fit" standard readout crate power and cooling requirements as well as fit standard crate dimensions.

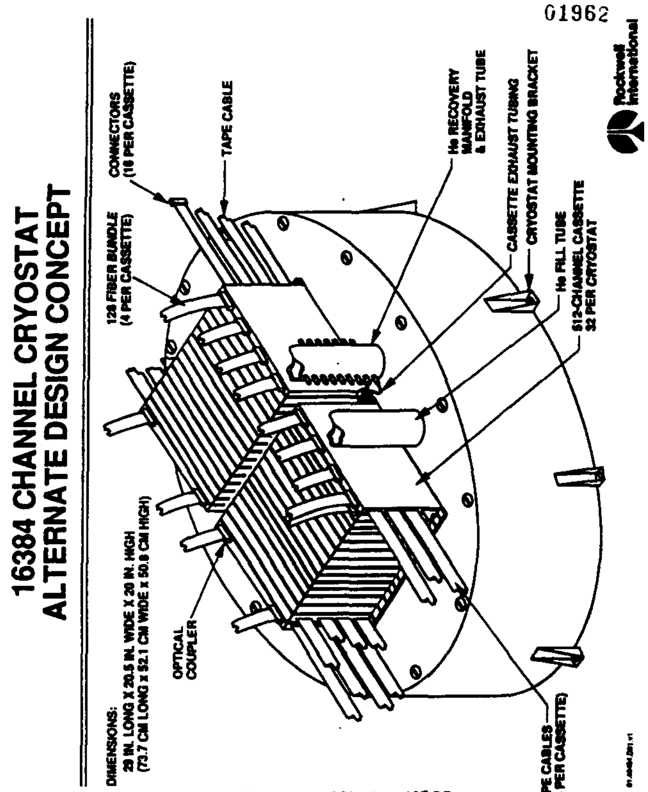


Figure 7.3.1-2. 16,384 channel VLPC cryostat.

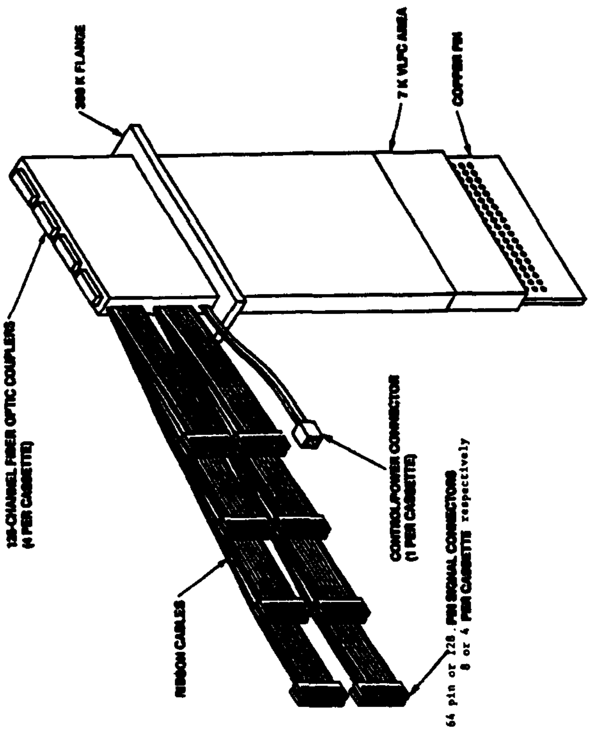


Figure 7.3.1-3. 512 channel VLPC cassette.

Figure 7.3.1-3. 512 channel VLPC cassette.

Cryostat ASD Performance Characteristics:

Single Photon Counting Efficiency > 60%

Background counting rate < 5kHz

Cross talk < 2% for from 1 to 30 photons input

Time skewing < 5 ns for from 1 to 30 photons input

Output :

Single ended 53 Ohms to ground

Pulse width 14ns

Bit rate 62.5 Mbs

Note:

Work is in progress on the final ASD which will reside inside the VLPC cryostat, but at the room temperature end, and on the definitions of the logic levels to be transmitted. The final decisions must wait for the determination of where the readout crates reside in relation to the cryostats as this determines the cable length and driver characteristics.

Performance

Preamplifier type: Single ended common emitter, three stage inverting

Channels/chip: 6 (independently powered sections of 4 and 2 channels)

Power supply: 4V

Inputs: One signal and one ground per channel

Quiescent input voltage: 0.7V

Input impedance: 130 *ohms*

Outputs: One per channel, single ended. External pulldown to negative voltage required.

Quiescent output voltage: 1.0V

Output impedance: 43 ohms

Impulse gain: 1.0 mv/fc (with a capacitively coupled 43 ohm load)

Impulse risetime (10-90%): 5 ns

Impulse falltime (90-10%): 16 ns

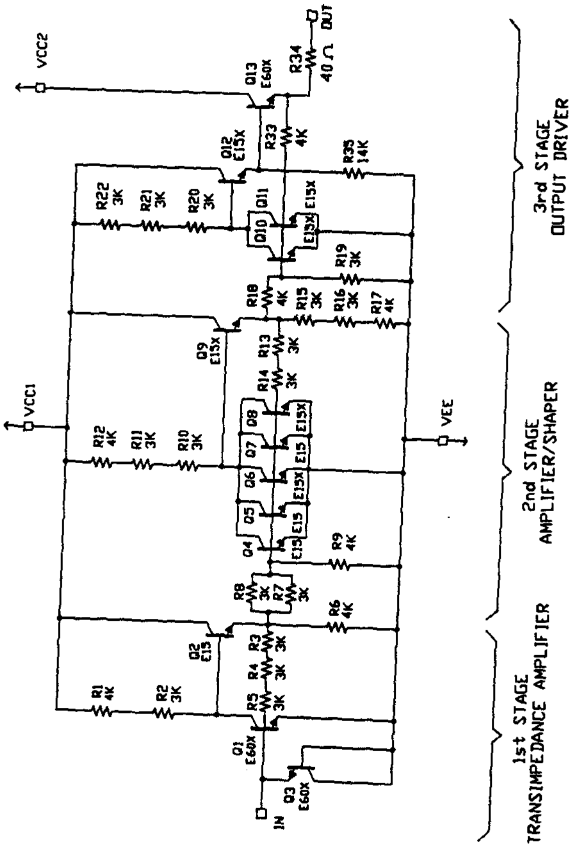
Dynamic range: -400 fc to +20 fc inputs, linear to within 3% at the maximum output (1 ma output pulldown current)

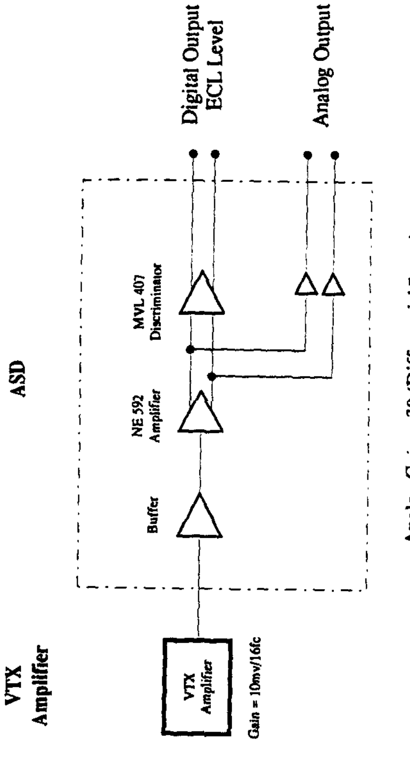
Power dissipation: 10 mw/channel (1 ma output pulldown current)

Input noise: 860 electrons + 47 e/pf (100 MHz bandwidth)

Crosstalk: <0.5% between any two channels

(All measurements were very close to simulation results.)





Analog Gain = 30 (Differential/Input)

128 Channels; 8 X 16 VTX Amplifiers 3 ASD Boards (48 each one)

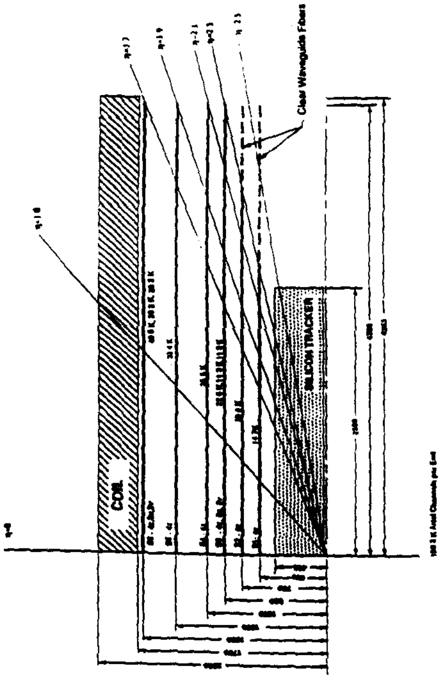
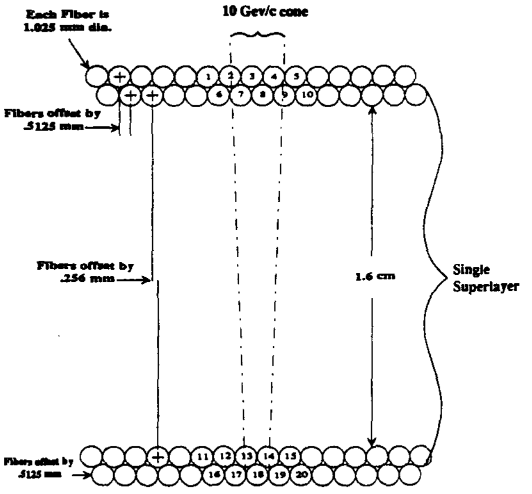


Figure 3.1-1. Schematic of the central tracker exhibiting the fiber superlayers.

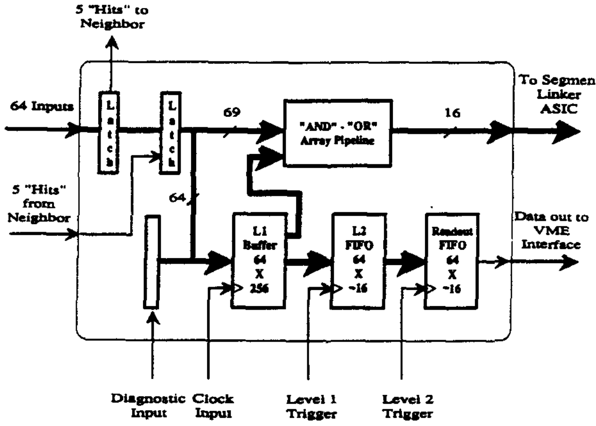
Track Segment Finding Algorithm



Acceptance cones for 10 GeV tracks
in single fiber bins

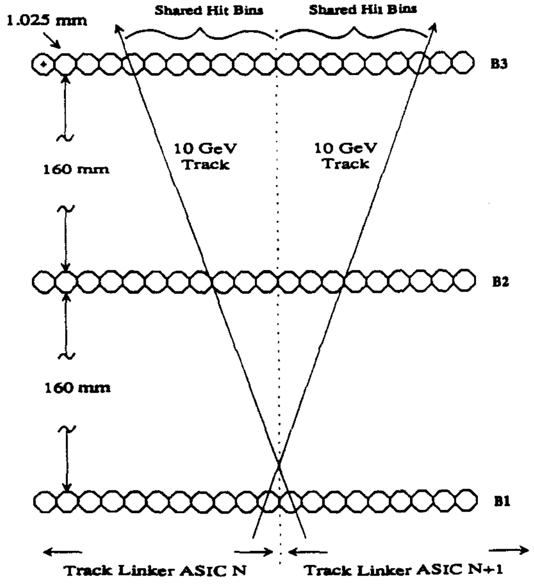
KLK
01/22/92

Fiber Tracker L1 and L2 storage and Segment Finder ASIC



Triplet Superlayers for Trigger

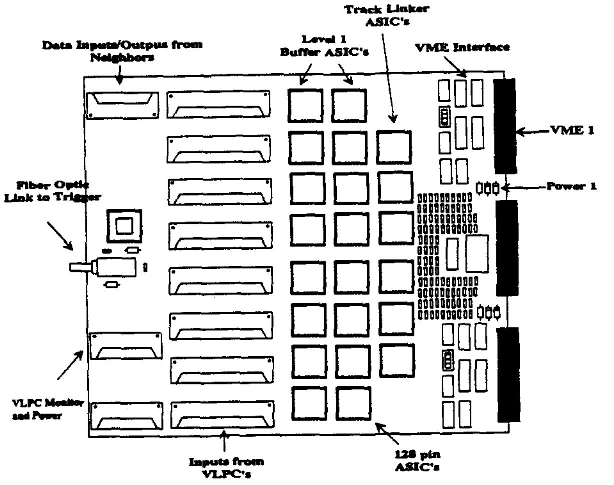
Single Fiber Diameter Hit Locations



KLK
01/22/92

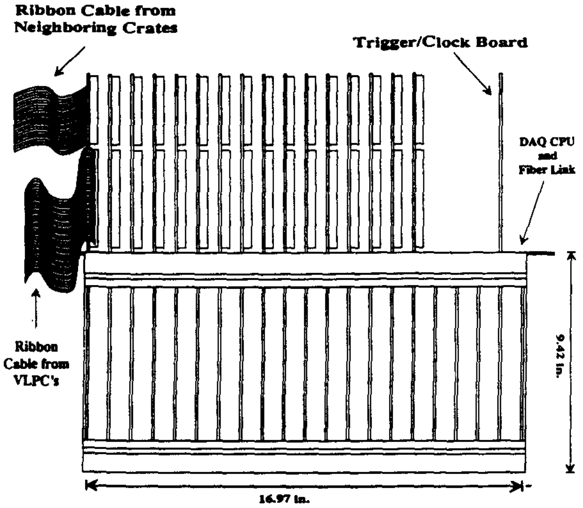
SDC Fiber Tracker Reciever Board

9U X 400 mm (14.437" X 15.750") Printed Circuit Board



SDC Fiber Tracking Crate

Bottom View



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CALORIMETER FRONT-END ELECTRONICS I

G. FOSTER

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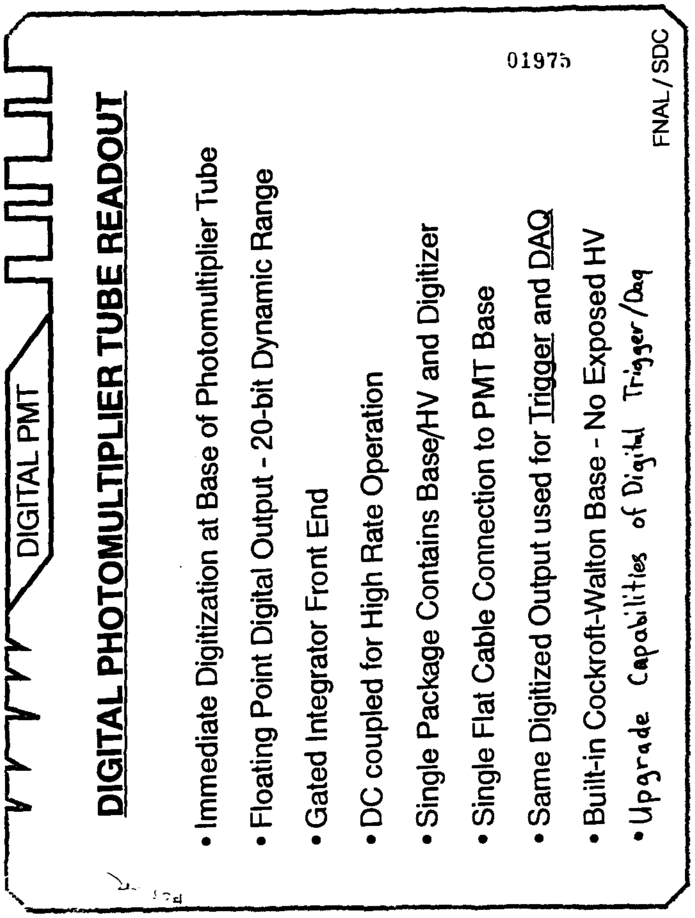

DIGITAL PHOTOMULTIPLIER TUBE READOUT

- Immediate Digitization at Base of Photomultiplier Tube
- Floating Point Digital Output - 20-bit Dynamic Range
- Gated Integrator Front End
- DC coupled for High Rate Operation
- Single Package Contains Base/HV and Digitizer
- Single Flat Cable Connection to PMT Base
- Same Digitized Output used for Trigger and DAQ
- Built-in Cockroft-Walton Base - No Exposed HV
- Upgrade Capabilities of Digital Trigger/Daq

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BASELINE IMPLEMENTATION OF THE DIGITAL PHOTOTUBE READOUT SYSTEM FOR THE SDC CALORIMETER

September 3, 1991

Al Baumbaugh, G. William Foster, Sten Hansen, Jim Hoff,
Mark Larwill, Catherine Newman-Holmes,
Claudio Rivetta, Raymond Yarema, Tom Zimmerman

Fermi National Accelerator Laboratory

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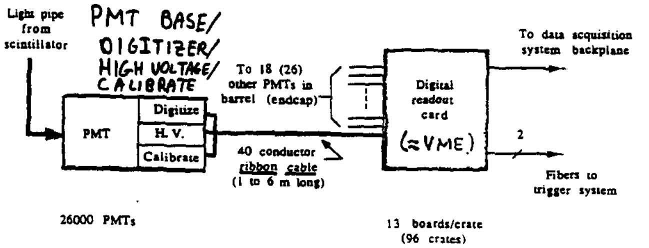
Digital Phototube Readout - Block Diagram



→ Two Components ⇒ Small engineering $

→ Flexible Mechanics ⇒ Simple mounting on Calor.

→ Single Flat Cable To Each PMT
⇒ no ground loops, etc.

ALL ANALOG PROCESSING TAKES PLACE IN THE INTERIOR OF A LITTLE METAL CAN!

Fig. 8.3.3.1 - DIGITAL PMT READOUT SYSTEM BLOCK DIAGRAM. There are two components in the system. The first component is the PMT Base/Digitizer assembly which contains the Phototube HV, Digitization, Current Monitoring and Calibration circuitry. These are connected via flat cables to the second component, a card which contains the digital ASICs which perform DAQ, Trigger, and calibration/monitoring functions. In the baseline trigger design [3] this card accepts flat cables from 8 towers of calorimetry and transmits energy sums for two "trigger towers" onto optical fibers to the trigger.

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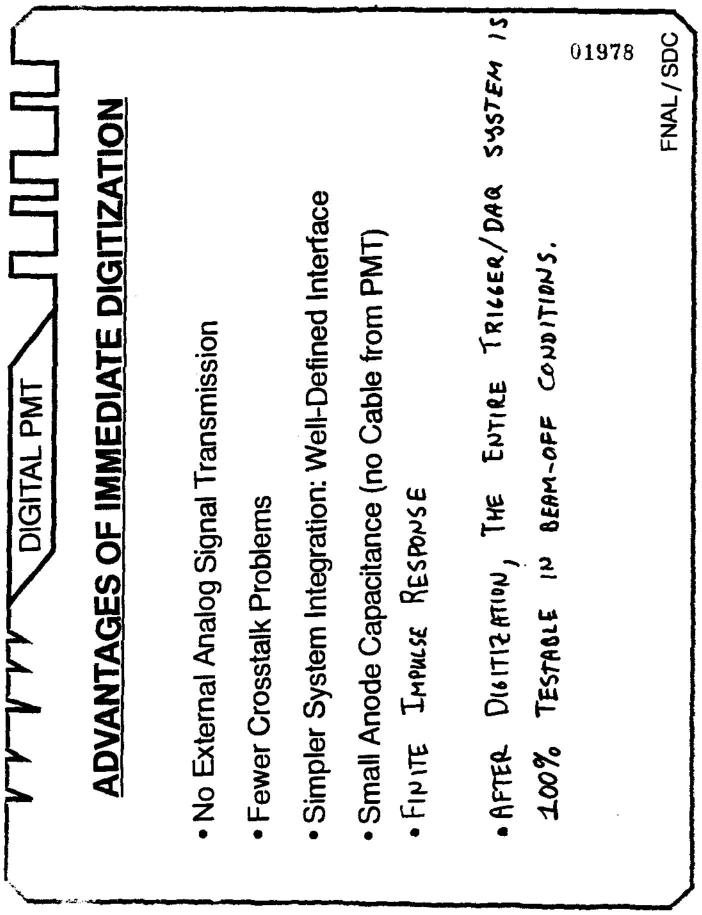
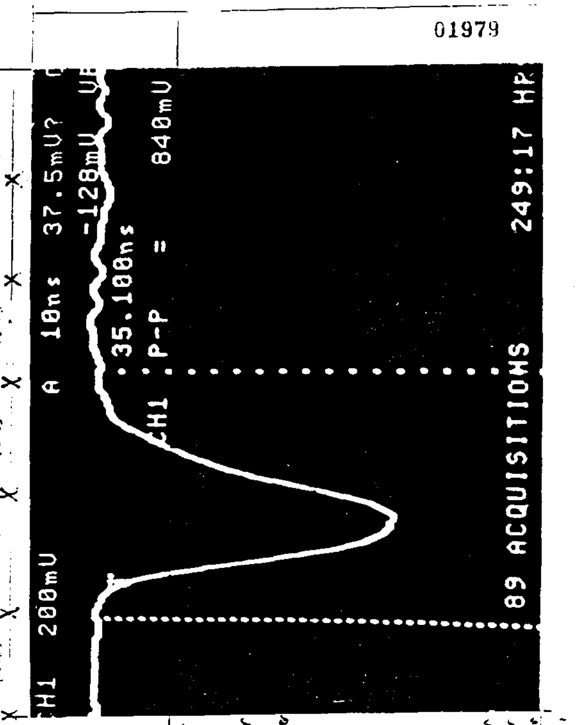


ADVANTAGES OF IMMEDIATE DIGITIZATION

- No External Analog Signal Transmission
- Fewer Crosstalk Problems
- Simpler System Integration: Well-Defined Interface
- Small Anode Capacitance (no Cable from PMT)
- Finite Impulse Response
- After Digitization, the Entire Trigger/DAQ System is 100% Testable in Beam-off Conditions.

HERE'S THE EVIDENCE



100 GeV e^-

EM Tile/Fiber Test Calorimeter

5ns, 50Ω/3 clipline

Substituting [illegible] Fluor with faster fluor should get factor two in speed.

. . . BUT THEY ARE NOT COMING AT US ALL AT ONCE. . . .

RF STRUCTURE OF SSC COLLIDER

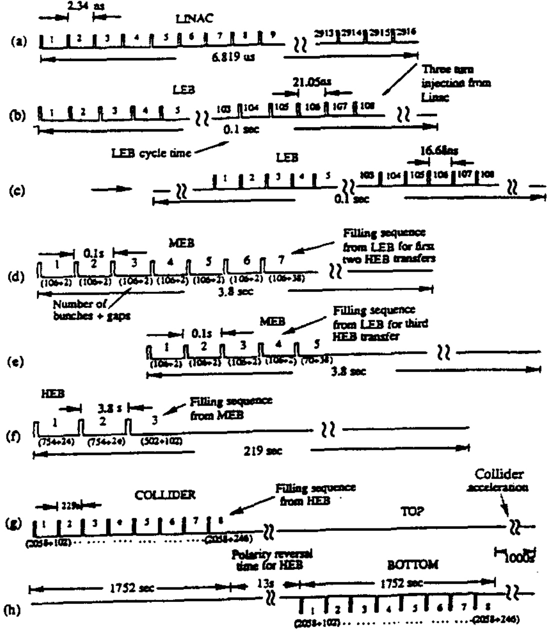


Figure 4.: Filling sequence for collider operation with timing information.

INJECTION GAPS, ABORT GAPS, PARTLY FILLED BUCKETS

⊕ ENORMOUS STOCHASTIC FLUCTUATIONS IN HIT RATE/CHANNEL

HIGH RATES ⇒ DC COUPLING ⇒ CLASSICAL GATED INTEGRATOR WITH FULL CAPACITOR RESET

Table 1: Digital Readout Specifications for Calorimeter and Shower-Max

	Digital Calorimetry Readout	Digital Shower-Max
Channel Count	~26,000	~47,000
Channels/Module	1 (single PMT Assy)	64 (Multi-anode PMT)
Location of Digitizer	PMT base	PMT Base
Location of L1/L2 Storage	Readout Crate (on Detector)	PMT Base
Dynamic Range	20 bits	13 bits
Least Count	10 MeV (1fC)	40 Mev (4 fC)
Full Scale	10 TeV (1nC)	160 GeV (160pc)
Accuracy	σ < 0.2% of Reading, (or 1 Least Count)	σ < 1.5% of Reading, (or 1 Least Count)
Crosstalk	$< 10^{-6}$	$< 10^{-2}$
Peak PMT Current	100ma	10ma
Signal Rise Time	~5-8ns (3-5 ?)	~5-8ns
Gate Timing Adjustment	+/- 0.5ns Programmable Individually Per Tube	+/- 0.5ns Programmable Individually Per Strip
Power/channel	~1W	~100mW
Flash ADC	Commercial 8-10 bit	5-bit; internal to ASIC
Output to L1 Trigger	12-bit Floating Point digital flat cable	Single Bit/Channel digital flat cable
Output Format to DAQ	12-bit parallel Digital Floating Point (8+1)bit mantissa, 4 bit exponent.	Serial Data Digital Floating Point (5+1)bit mantissa, 4 bit exponent.
High Voltage Supply	Cockroft-Walton on Base	Cockroft-Walton on Base
Current Monitor	1/PMT (on Base)	1/PMT (on Base)

DIGITIZATION ACCURACY VS. ENERGY

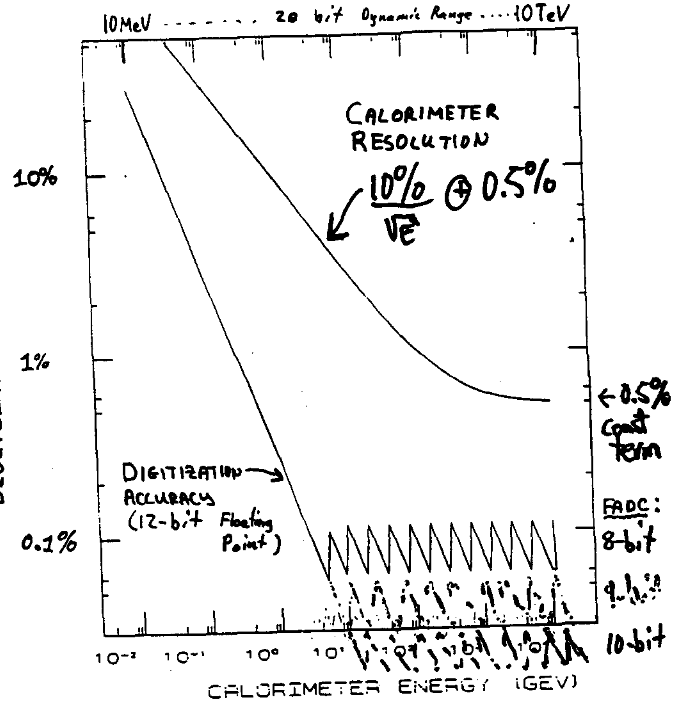


Fig.3.4 DIGITIZATION ERROR and ENERGY RESOLUTION OF CALORIMETER as a function of energy. The bottom curve gives the digitization σ (= *least count*)/$\sqrt{12}$) for the floating-point output of the digitizer. Except at the low end of the scale. a signal is digitized to a least-count accuracy which varies between 1/256 and 1/512 of itself. Also shown is a (rather optimistic) calorimeter energy resolution of 10%/$\sqrt{E}$.⊕0.5%.

PMT BASE/DIGITIZER CIRCUIT DIAGRAM 01983

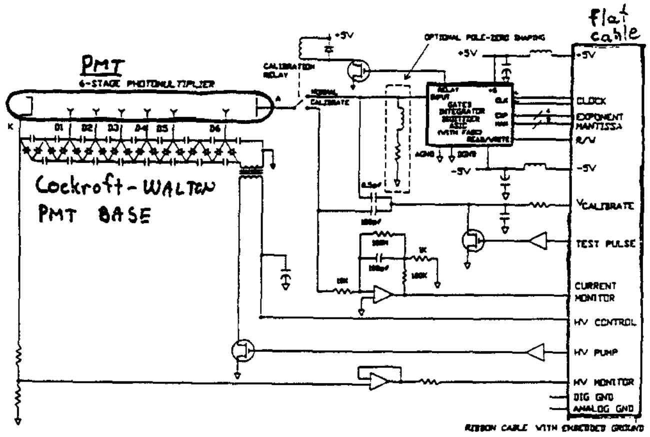


Fig. 8.3.3.2 - PMT BASE/DIGITIZER MODULE circuit diagram. It contains the Phototube, Cockroft-Walton "charge pnmp" HV supply, current monitor, charge injection circuit, and PMT digitizer ASIC. This diagram assumes the FADC has been integrated into the digitizer ASIC. In out initial design a commercial 8-bit FADC will be used.

CIRCUIT-PER-CHANNEL ON DIGITAL READOUT CARD 01984

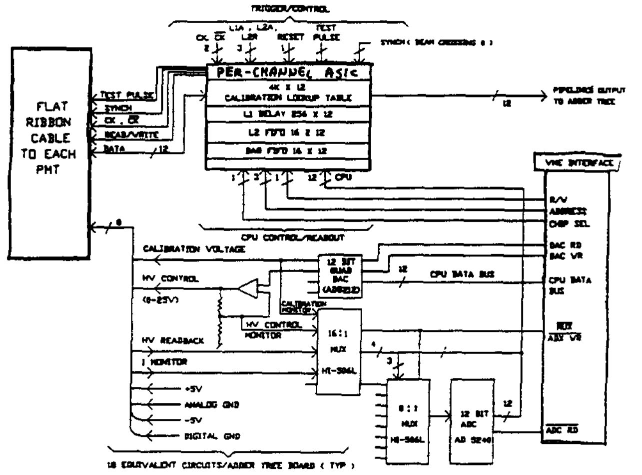


Fig. 8.3.3.4 - CIRCUIT-PER-CHANNEL ON READOUT BOARD for Digital PMT System. A single flat cahle carries clock, data, and control signals to each PMT. The L1/L2/Calibration ASIC on the Readout Board recieves the digitized data from a channel, then passes it through a pipelined calibration RAM. The calihrated data is pipelined out to the trigger energy sum adders, and is also stored locally for ~256 crossings in the L1 delay memory. Upon reciept of a L1 accept, the output of the L1 delay is loaded into the Level2 FIFO, where it is stored pending a level 2 decision. The output of the L2 fifo is either discarded, or loaded into a DAQ FIFO for suhsequent readout by the local processor in each crate. This ASIC also provides programmahle timing for the ADC gate and test pulses. Also shown are the circuits for providing DC power and HV monitor/control voltages, which are constructed using standard DACs, multiplexors, and ADCs.

PHOTOTUBE DIGITIZER ASIC BLOCK DIAGRAM

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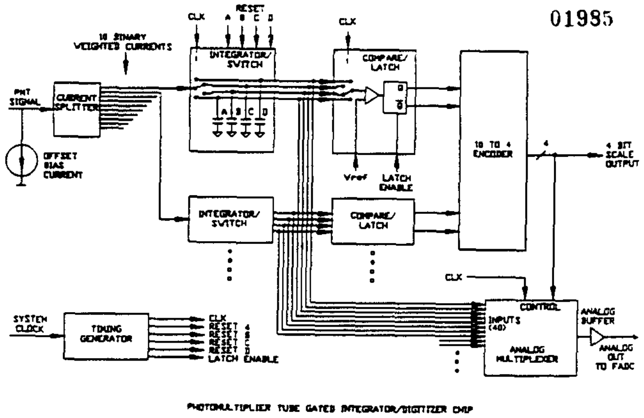

1. RESET CAPACITOR (16ns)
2. INTEGRATE PMT CHARGE (16ns)
3. DETERMINE RANGE/SCALE (16ns)
4. OUTPUT TO FADC (16ns)

4-phase
16ns
Round Robin

Fig 8.3.3.5 - PMT DIGITIZER BLOCK DIAGRAM. Main circuit elements are: (i) Current Splitter, which splits the Phototnbe current into ~10 binary weighted scales; (ii) Integrator/Switch, which integrates the charge from each scale on one of four capacitors in a pipelined "round-robin" manner: (iii) Comparator/Latch, which determines if the capacitor contans an "interesting" voltage (between 1/2 and full scalc), (iv) Encoder, which uses the comparator outputs to generate the 4-bit scale code ("mantissa"), and (v) Analog Multiplexor/Buffer, which selects the "interesting" capacitor voltage and outputs it the FADC on each cycle.

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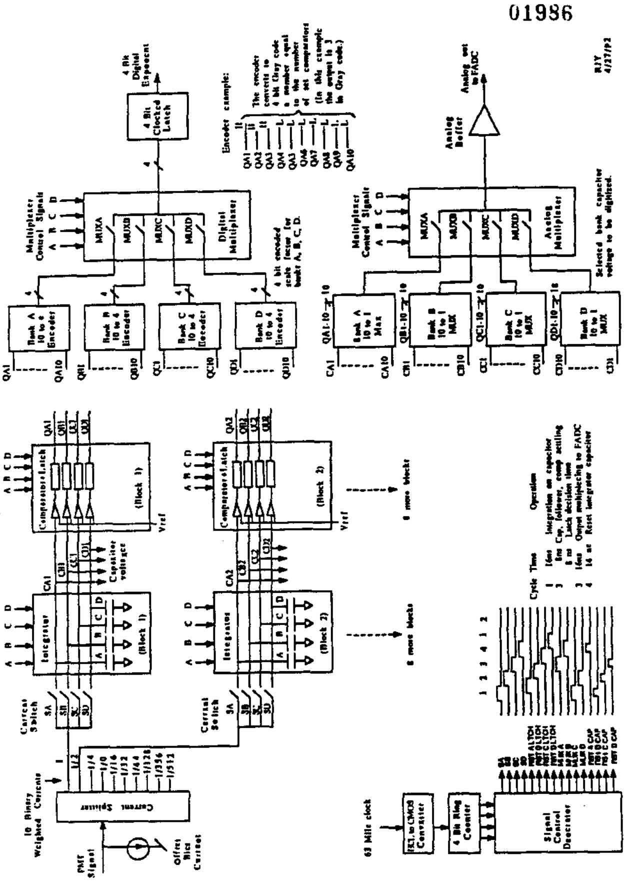
... more detailed PMT digitizer block diagram ...



Detailed strategy for testing splitter/integrator chip, including milestones for ASIC development.

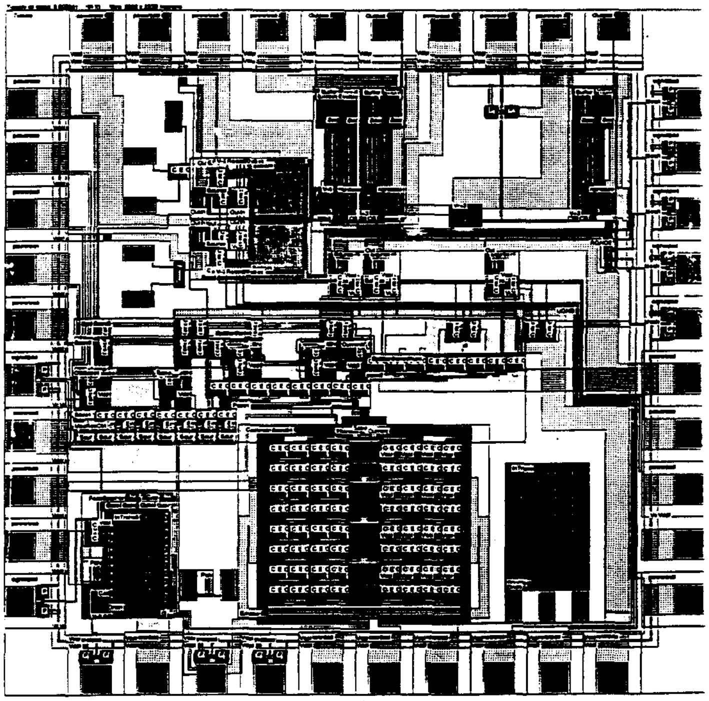
Version 1 - October '91 → testing complete, Writeup Jan 14

- Splitter Design (10 Output)
  - rise time OK
  - stability OK
  - DC Accuracy OK
  - Noise OK
  - Dynamic Range OK
  - Temp Drift OK
  - Run-Run reproduc. OK
- Gated Integrator (2-way) Works
- Integrator Reset Works
- Analog Output Mux Works
- Analog Output Buffer Works

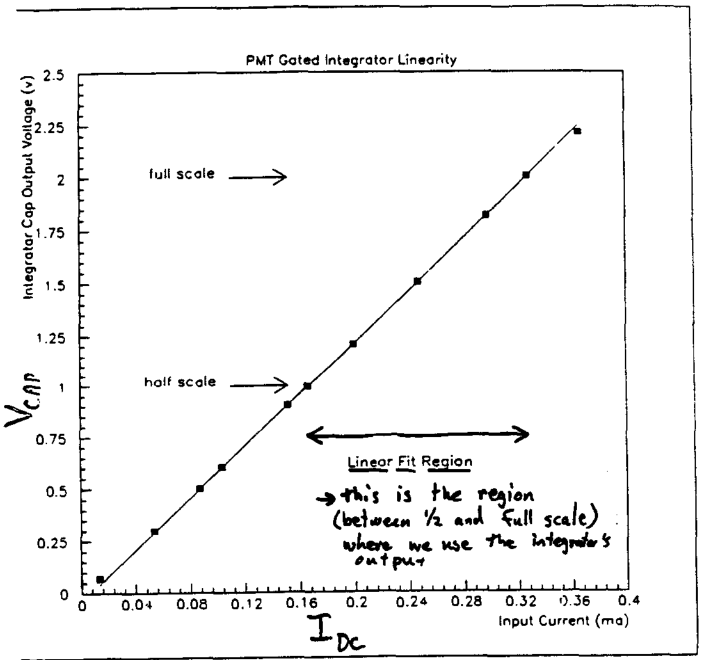
Version 1a Feb '92 → testing complete, Mar 31 writeup

- More Sensitive Integrator Measure Noise floor <2000 e? } ≤ 1mV on 1 pf all scales
- Measure Linearity of Integrator → coming up
- Test of current amp to extend low range of splitter -->20 bits } WORKS FINE

VERSION 1a GATED Integrator / Current Splitter test chip.



LINEARITY MEASUREMENTS OF VERSION 1a ASIC

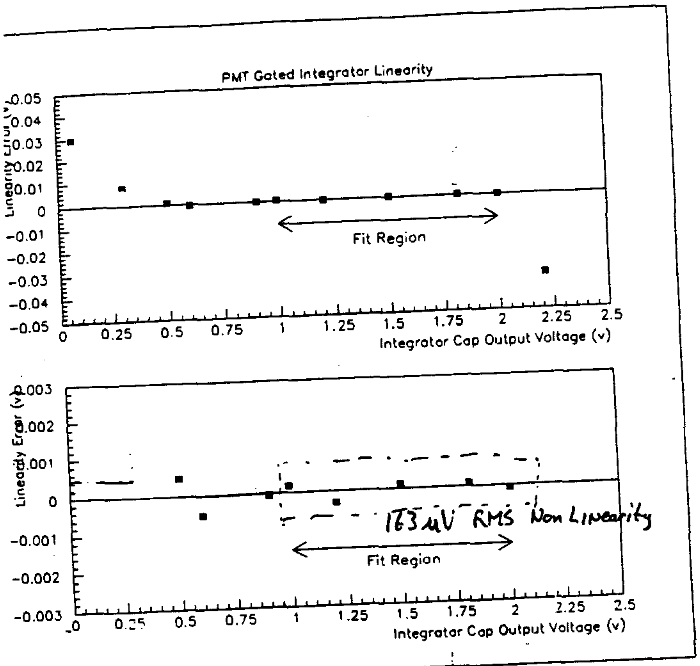


→ this is the region (between ½ and full scale) where we use the integrator's output

TEST PROCEDURE:

1) INJECT DC CURRENT
2) 16ns gate time
3) Repetitive Clocking Waveform, Cap Reset
4) PLOT FINAL CAPACITOR VOLTAGE vs. DC INPUT CURRENT

GATED INTEGRATOR NON LINEARITY (cont'd)



$$\text{NON LINEARITY} = \frac{163\,\mu\text{v RMS}}{2\text{V full scale}} = \underline{82\ \text{PPM}}$$

...good enough to justify a 16-bit FADC.

Table 3: Digital PMT Readout: Gated Integrator/Digitizer Performance Summary

	Specification	Measurement
Least Count (~noise level)	10 MeV (1 fc) = 0.1μA x 10ns current pulse from PMT	< 0.6 fc pedestal RMS for gate times <50ns on 1st version of Current Splitter/Gated Integrator Test Chip
Full Scale	= 10 TeV (1 nC) = 100ma x 10ns pulse = 10^6 least counts (20 bits)	Current Splitter measured linear for pulses up to 100ma
Accuracy	1-2% before calibration	Current Splitting Accuracy Measured < 0.7% on multiple ranges up to 100ma
Rise Time	~5-8ns (faster than scint rise time)	<4ns over entire dynamic range 0→100ma
Time Slewing vs. Pulseheight	<< 16ns PMT Gate Width	~1ns difference in splitter propagation delay for pulses of ~0 → 100ma
Gated Integrator		Functional
Capacitor Reset		Functional
Output Multiplexor and Buffer		Functional
Settling Time of Analog Output	<16ns to accuracy required by FADC	9ns settling to ~8 bit accuracy
Temperature Stability	<0.25% over 10 degrees CC operating temperature range	<0.5% change in Current Splitter Accuracy for 30 degrees C change.
Immunity to Run-to-Run Process Variation	< 1% before calibration	Current Splitting Absolute Accuracy Measured < 0.7% for test chips from two sepatate ORBIT runs
System Noise	$\sigma \leq 1$ least count $6{,}000e^-$ RMS	$\sigma \sim 5000e^-$ (0.8fC) mesured on 60 MHz test board including FADC noise, discrete amplifier noise, digital noise from clock & line drivers. etc.

Version 2   April '92 → Back From Fab Testing Starting New ~5/5/92

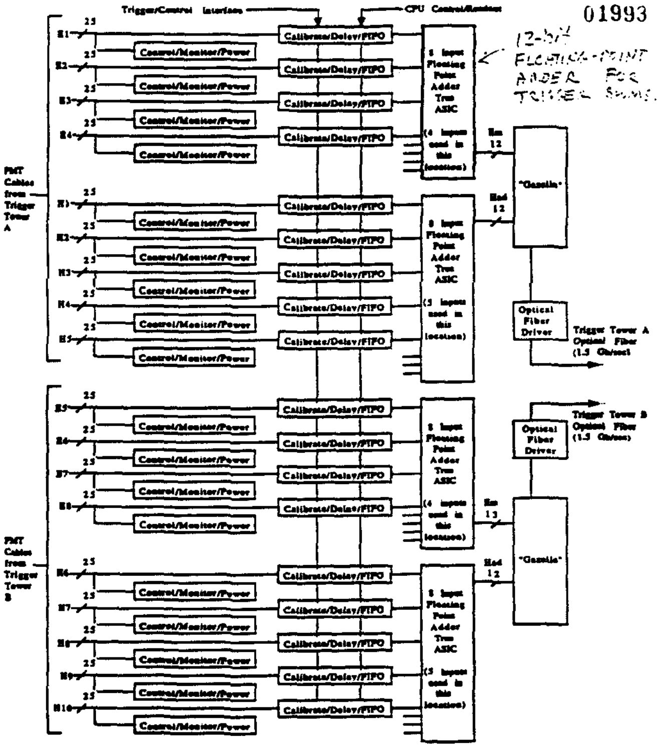
- Design complete
- layout ~3/4 complete
- 4 stage timing/control logic
- Takes data synchronously with FADC
- Low-Level Differential Clock
- No Auto-ranging logic: can switch low-->hi scales via changing jumpers
- This version should be usable for 1st pass PMT digitizer.

Version 3   ~July '92

- Automatic Ranging → Submitted ~10 APRIL 92 back ~20 may
- "Final Splitter" for ~20-bit dynamic range.
- This version should be fully functional for PMT Dig Assy.

VERSION X - FADC TEST CHIP
- BASED ON COMPARATOR DESIGN FOR V3.
- 5-bit, 30mw FADC for shower max
- 10-bit, 2-stage pipelined, 80mw FADC for calorimeter readout.

DIGITAL READOUT BOARD ... QUITE BORING, ACTUALLY...



12-bit FLOATING-POINT ADDER FOR TRIGGER SUMS.

Fig. 8.3.3.3 - DIGITAL PMT READOUT BOARD BLOCK DIAGRAM. (Barrel Calorimeter Version). Each board has connects to eight calorimeter towers (18 Phototubes). HV Control, Monitor, Power, Calibration and DAQ functions are performed on a per-channel basis identically for all PM tubes. Trigger signals from 4 towers of calorimetry are summed into EM and HAC sums for two trigger towers. Trigger sums are formed digitally using the floating-point adder described in Section 12. and transmitted to the trigger by optical

2. FLOATING POINT ADDER FOR TRIGGER SUM OUTPUTS.

Two versions have been produced in 1.2u CMOS.

1st version (Sept 91) was fully functional in fall-through mode at 66MHz.

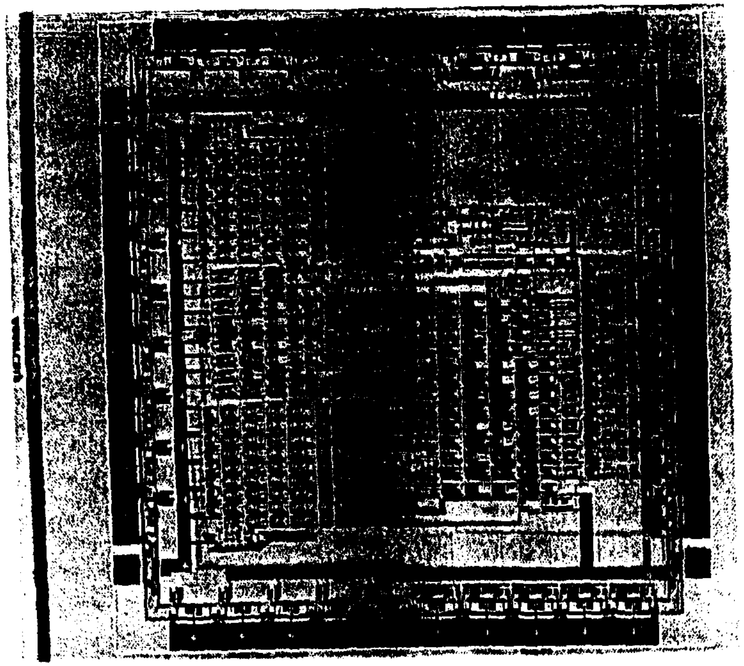
2nd version (Jan '92) contained:
- improvements in the clocking structure,
- logic changes due to a redefinition of our floating-point format,

--> Functions in synchronous pipelined mode at ~100MHz.

Design is essentially complete.

Seven copies of this subcircuit will be laid out and fabricated on a single die to form the 8:1 adder tree required for Trigger Tower Energy sums in the Baseline Trigger design.

Should have a working VME test board by this fall.



01995

DIGITAL PMT

SUMMARY

- SUCCESSFUL TEST CHIPS FOR KEY ANALOG COMPONENTS:
  - current splitter
  - gated integrator
- CIRCUITS UNDER FABRICATION FOR REST OF DIGITIZATION ASIC
  - AUTO-RANGING
  - OUTPUT MULTIPLEXING
- SHOULD HAVE FULLY FUNCTIONAL PROTOTYPE BY END OF SUMMER
  - 18+ bits dynamic range
  - Commercial FADC
- INCORPORATION OF FADC ON CHIP PROCEEDING
- VME BOARDS, etc. READY FOR SYSTEM TEST
- LOTS OF NEW COLLABORATORS

01996

FNAL / SDC

CALORIMETER FRONT-END ELECTRONICS II

M. LEVI

Front-End Electronics for SDC Calorimetry Based on Analog Memories

1) Introduction
2) Conceptual Design
3) Status of R&D and Performance Results
    a) Phototube Preamplifier & Shaper
    b) Switched Capacitor Array
    c) Performance with VME Card
    d) Multi-channel ADC
    e) Address List Processor
    f) Trigger Interface
4) Conclusions

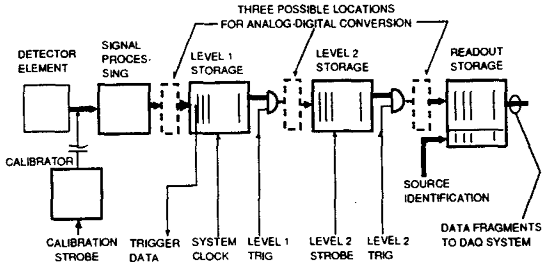
Data Management

- Three Trigger Levels
- 4 μsec Level 1 Latency
- On Detector Storage
- Data Acquisition After Level 2 Accept

Shower Max Detector May Require Digitization After Level 1 Accept.

Calorimeter Requires Digitization After Level 2 Accept.

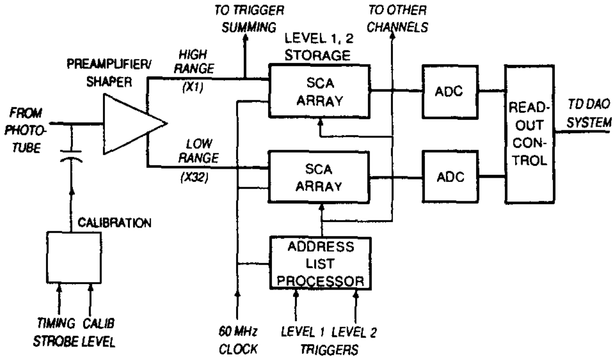
⇒ Versatile System Concept



Conceptual Design

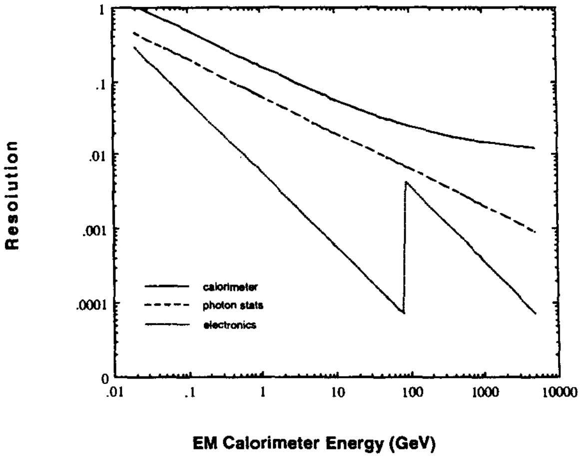
Requirements:
1) Excellent Signal Fidelity
2) High Speed -- 60 Mhz & Zero Deadtime
3) 18 Bit Dynamic Range with << 1% Accuracy & Linearity
4) Hold Data Pending 4 μsec Trigger Decision
5) Digitize Data After Trigger Decision
6) Stable Calibration
7) 100 KHz Level 1 Accept Rate
8) 10 KHz Level 2 Accept Rate

Features:
1) Passive Front-End Preamps and Range Splitters
2) High Speed Dual Ported Analog Memory
3) Large Dynamic Range -- 18 bits Constructed from Dual Range of 12+ bits each
4) 256 Storage Locations
5) On Chip ADC
6) Only Two Calibration Constants
7) No limit on Level 1 Accept Rate
8) Standard Design Used in Other Expts. (ZEUS, NA-34, EOS)
9) Integrated Design with Shower Max. Compatible with APD's or PMT's

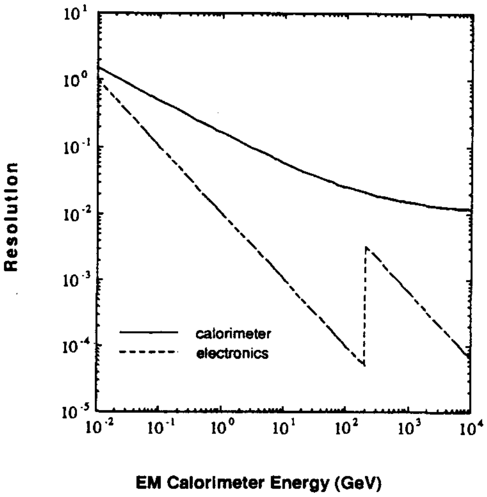


Dynamic Range

- Two 12-bit ranges (1:4096)
- Dual range extends dynamic range to $2x10^5$
- Least count is 20 MeV
- Greatest count is 4 TeV
- Fractional Accuracy is always < 1%



Theoretical Dynamic Range



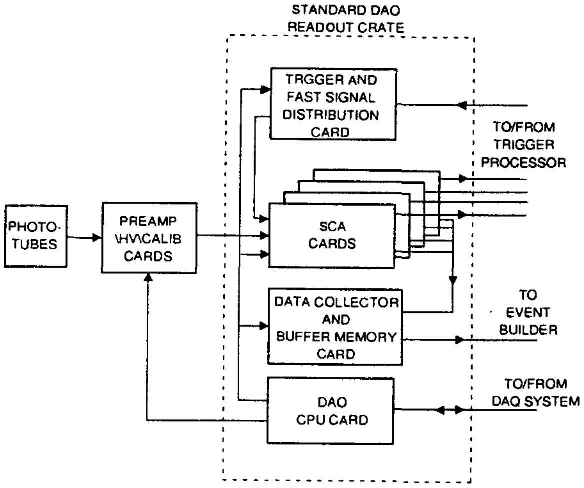
Block Diagram

96 Front-End Crates (32 on each Barrel End & 16 on each Endcap)

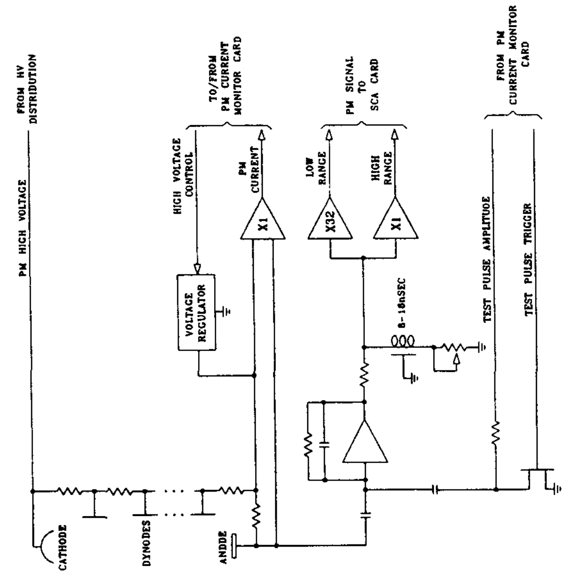
20352 Channels upgradable to 26968

96 PMT's per SCA Card

3 Cards per Crate (w/ room for Shower Max, Trigger, DAQ, & Power)

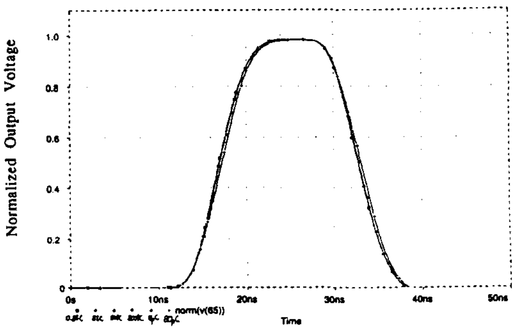


PHOTOMULTIPLIER AND PREAMPLIFIER CARD

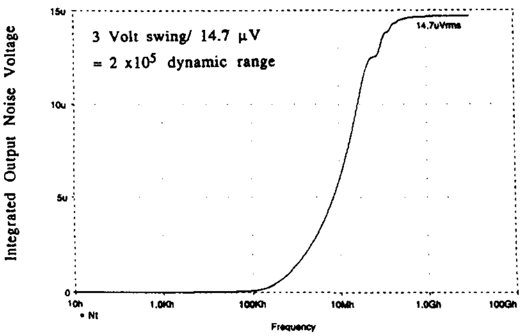


Simulations of $2x10^5$ AT&T Bipolar Preamplifier

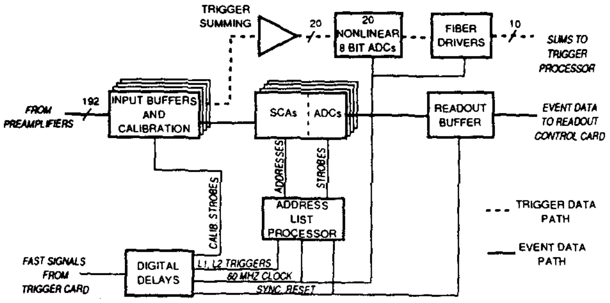
PREAMP WITH AT&T TRANSISTORS



PREAMP WITH AT&T TRANSISTORS



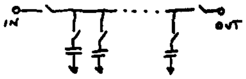
SCA Front-End Card



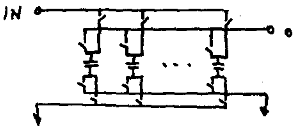
SWITCHED CAPACITOR ARRAY PRIMER

TRACK - HOLD :

ARRAY :

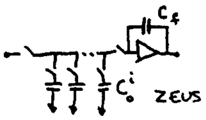


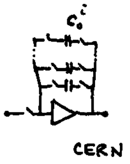
DUAL PORTED ARRAY:



THERE IS A LARGE BUS PARASITIC IN ALL DESIGNS, SO ONE NEEDS A FEEDBACK ELEMENT TO AMPLIFY SIGNAL

CIRCUIT TOPOLOGIES :

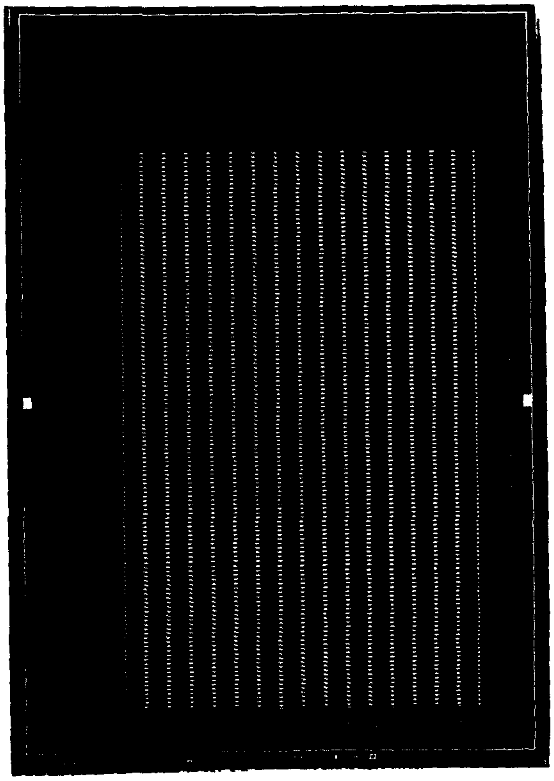


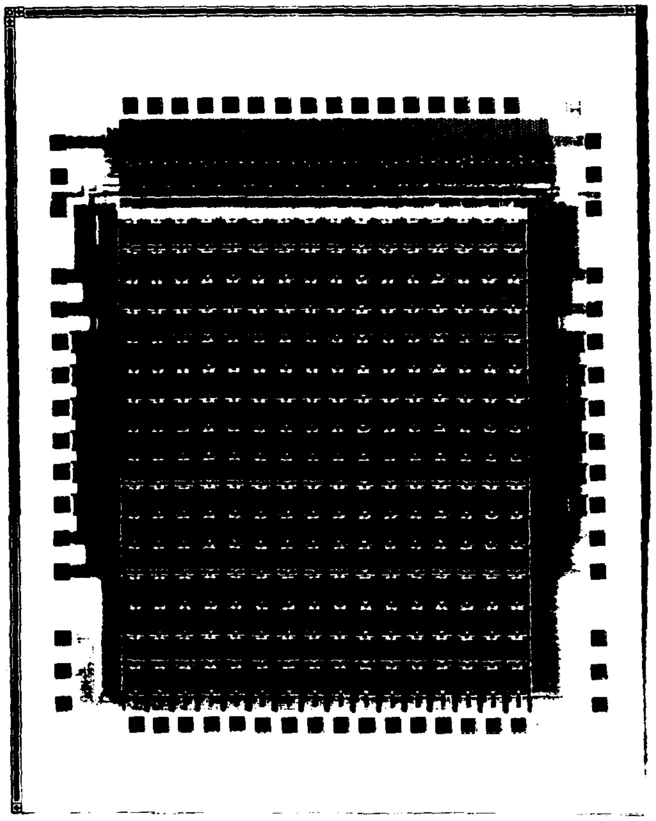


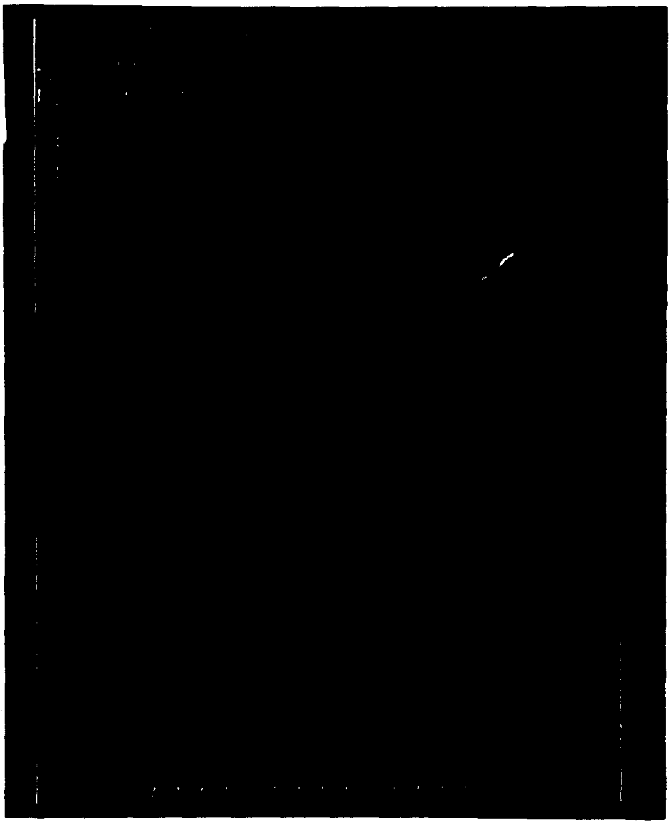
$V_{OUT} = \frac{C_o^i}{C_f} \cdot V_{IN}$ (VOLTAGE SAMPLER)

$V_{OUT} = \frac{G_{IN}}{C_c^i}$ (CHARGE SAMPLER)

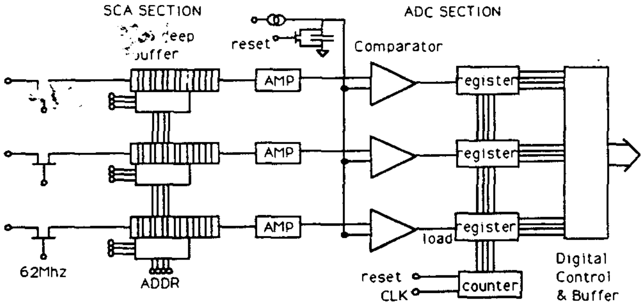
$V_{OUT} = V_{IN}$ (VOLTAGE SAMPLER)



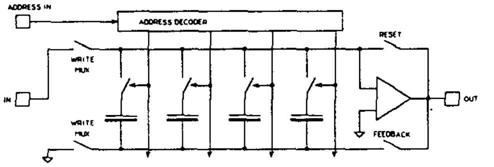




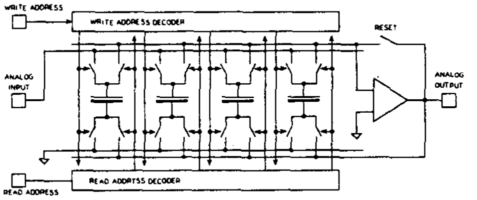
A 256 Element 16 Channel Switched Capacitor Array With a 12-bit Single Slope ADC



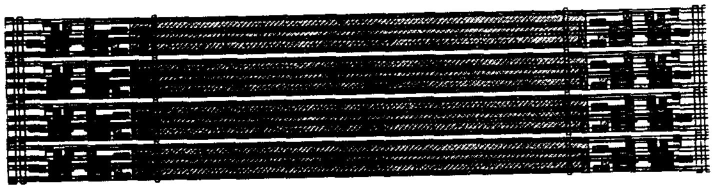
Basic Cell of Switched Capacitor Array:

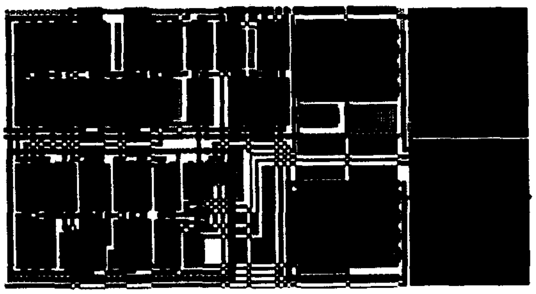


Basic Cell with Simultaneous Read/Write Capability:

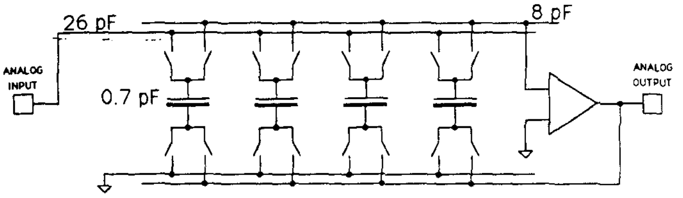


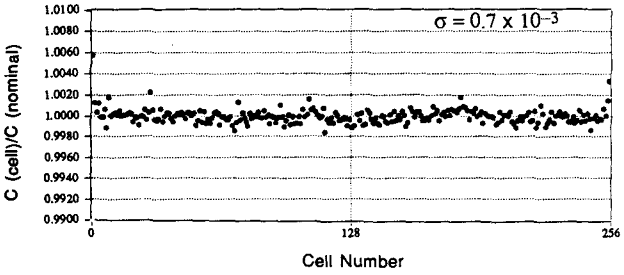
Storage Cell





Capacitor Variation

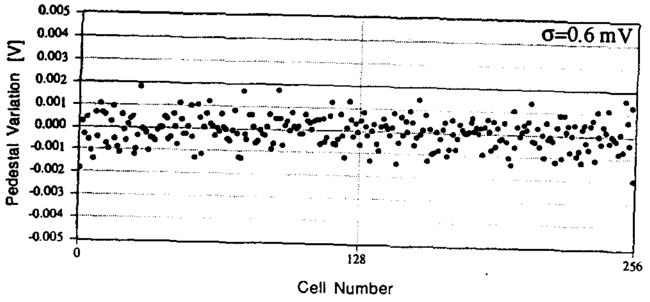




SCA Pedestal Variation

⇒ Single shot variation

⇒ Differential inputs with 10 volt effective input swing.



⇒ Pedestal variation must be ≤ 1.2 mV rms in a 5V range to achieve 12-bit dynamic range (1:4096).

SCA Chip Parameters:

SCA Parameters	Achieved Performance
No. channels/chip	16
No. of elements/channel	256
Power/channel	10 mW
Non-linearity	±0.1% (±0.5% of value)
Pedestal variation	0.6 mV rms (diffrntl)
Charging time constant	1.5 ns
Channel dynamic range	16600 (differential)
Maximum sample rate	90 MHz
Maximum readout rate	500 KHz
Crosstalk(spatial, temporal)	< 1 mV
Input voltage range	0.0-5.0 Volts
Capacitor droop rate	0.1 mV/msec
Output settling time	1.2 µsec (to 0.02%)

Current Status:

Work continuing on improving dynamic range
Learning how to reduce effects of digital noise
Improving performance of op amp and op amp noise

Design Work in Progress:

New single phase clock address decoder
Low level digital inputs
ADC being integrated with SCA

ADC

Counter

12-bit pipelined gray code counter.
Counts on every edge of 200 MHz clock (400 MHz effective rate).

Analog Ramp

5V ramp in 10 µsec.
Excellent linearity due to improved error amplifier

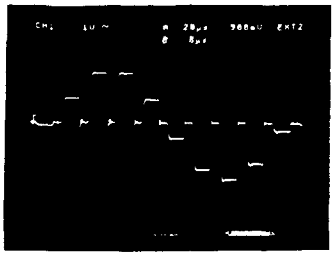
Comparator

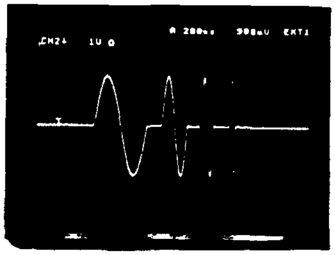
5 stage linear amplifier with hysteresis
sensitivity ≤ 1 mV

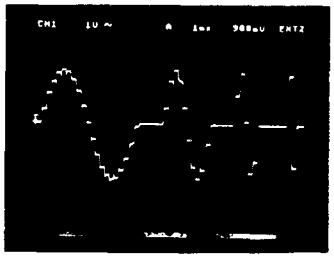
Operation

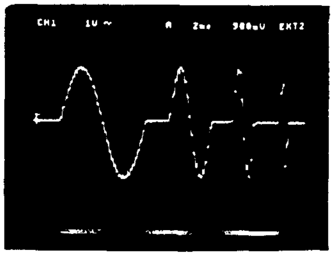
12 bit conversion with 100 kHz throughput.
10 mW/channel

Integrated circuit successfully combines high speed CMOS f_{clk} = 62 MHz with analog signals smaller than 1 mV



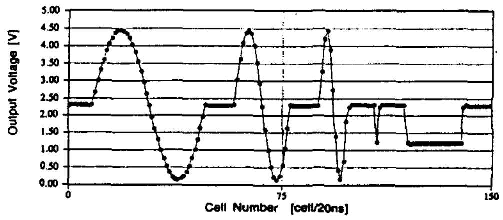




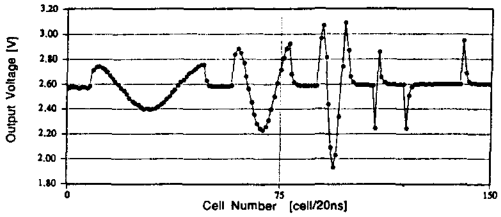


Current Mode Operation

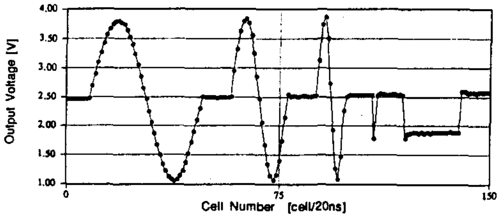
Normal Voltage Sampling Mode:



Capacitively Coupled Voltage Sampling:

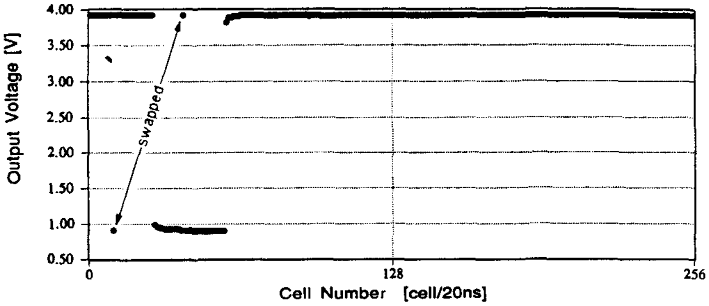


Current Sampling Mode:

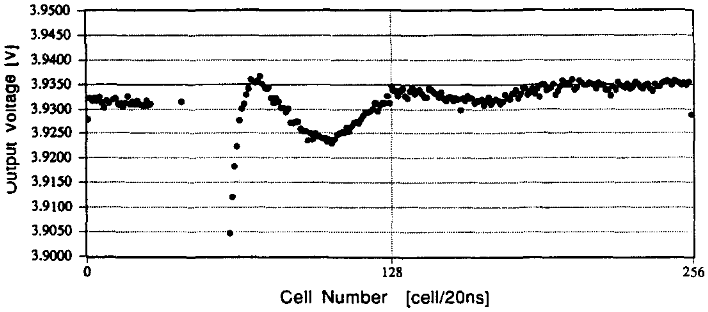


Crosstalk Measurements

Swap Single Cell Order:

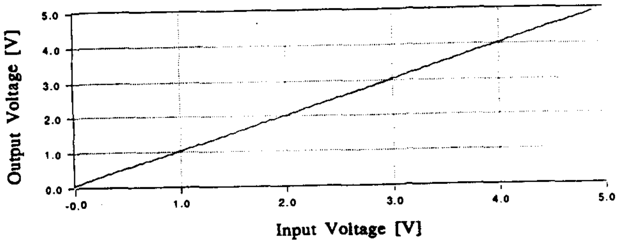


Expanded Vertical Scale:

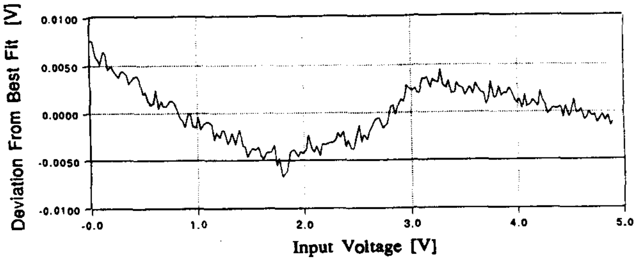


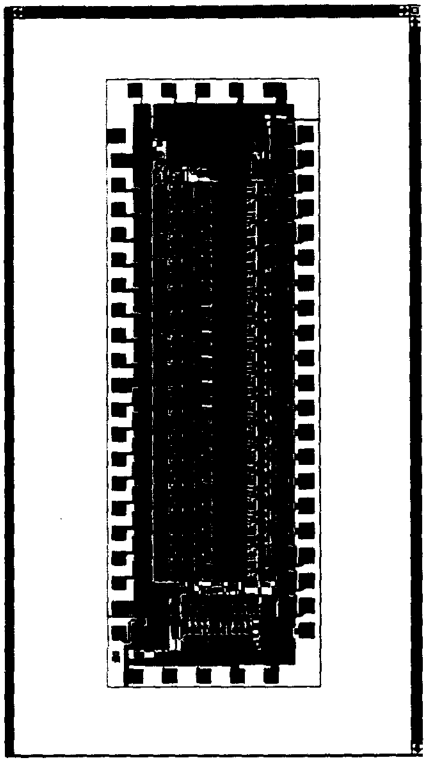
SCA Linearity

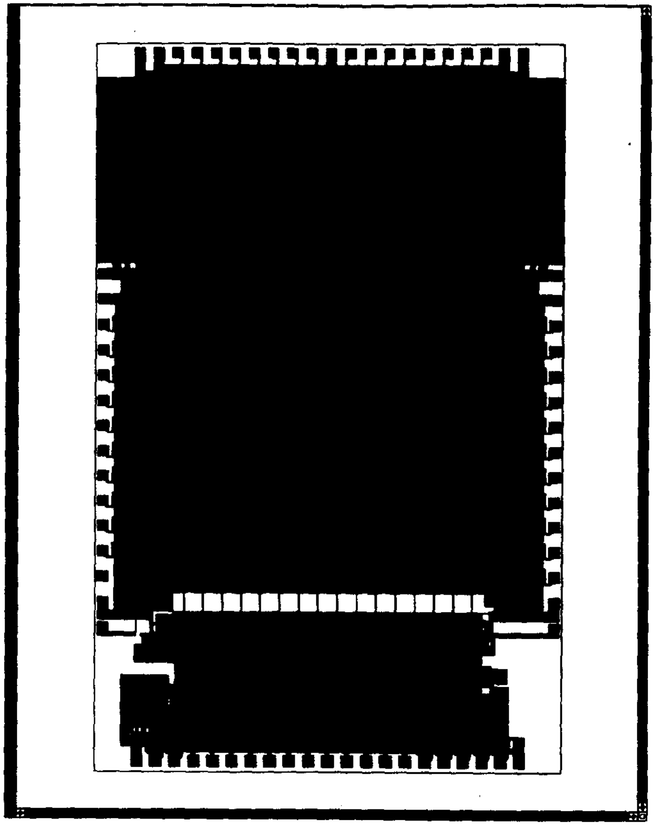
Output vs. Input

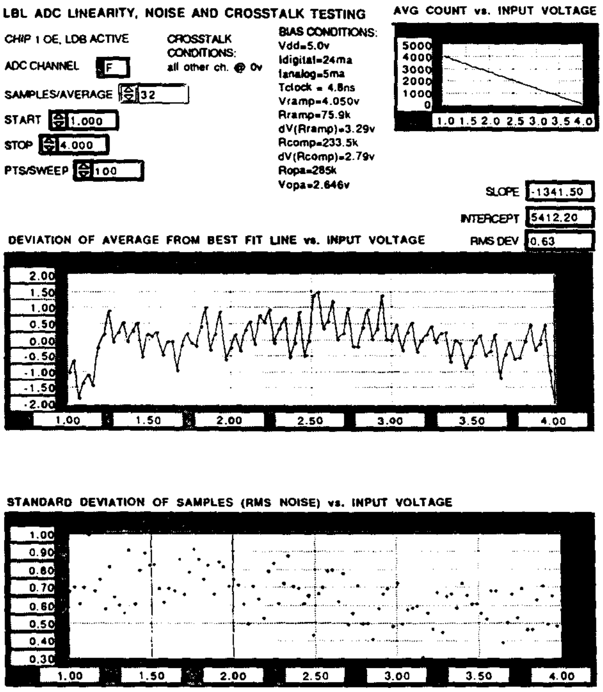


Deviation From Best Fit









LBL ADC LINEARITY, NOISE AND CROSSTALK TESTING

CHIP 1 OE, LDB ACTIVE

ADC CHANNEL: F

SAMPLES/AVERAGE: 32

START: 1.000

STOP: 4.000

PTS/SWEEP: 100

CROSSTALK CONDITIONS:
all other ch. @ 0v

BIAS CONDITIONS:
Vdd=5.0v
Idigital=24ma
Ianalog=5ma
Tclock = 4.8ns
Vramp=4.050v
Rramp=75.9k
dV(Rramp)=3.29v
Rcomp=233.5k
dV(Rcomp)=2.79v
Ropa=285k
Vopa=2.646v

SLOPE: -1341.50

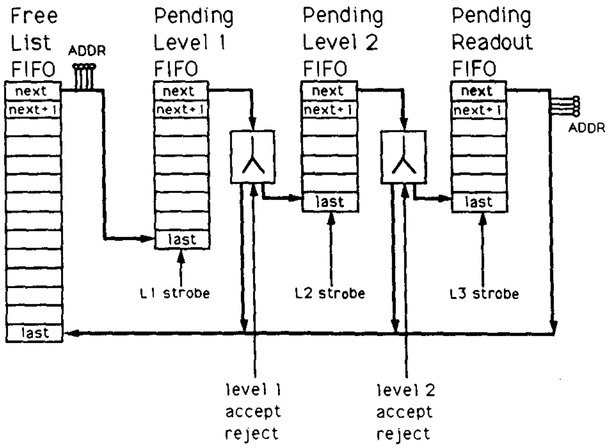
INTERCEPT: 5412.20

RMS DEV: 0.63

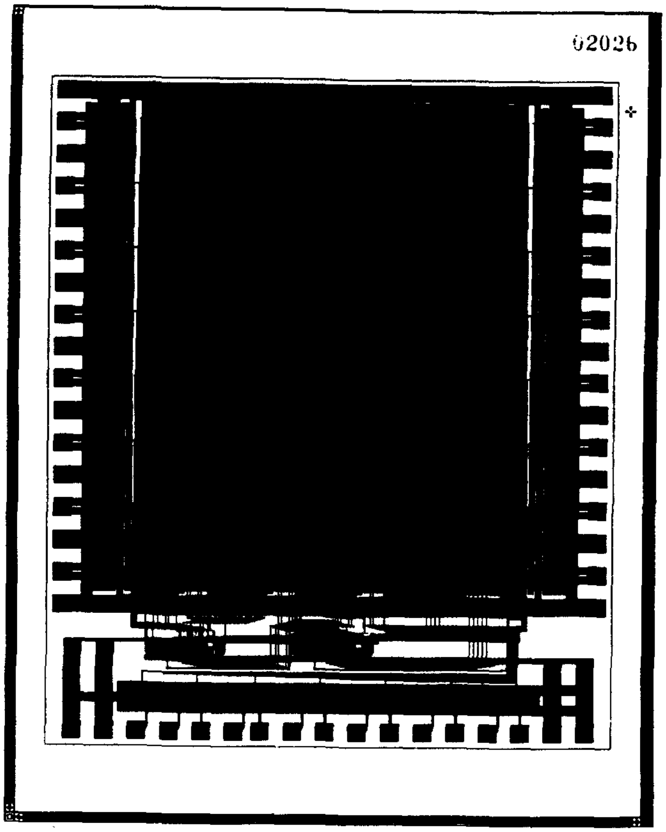
Address List Processor

Address Generation & Pointer Manipulation:

1) Generates input storage locations for the SCA at 60 MHz.
2) Maintains a list of saved data until trigger decision is complete.
3) Propagates the list of pointers through the multi-tiered trigger decision chain.
4) Generates addresses for SCA readout.
5) Consists of four high-speed First-In First-Out memories.



02026



Trigger Interface

02027

Each calorimeter tower of 0.1x0.1 connected to trigger through a 1 Gbit/s fiber.

Up to 10 calorimeter readout channels summed, converted to logarithmic scale, digitized to 8 bits, and then transmitted along each fiber optic cable.

Electromagnetic and Hadronic information digitized separately, so two words (bytes) of information from each tower are transmitted on fiber during one beam crossing.

Event number transmitted as part of framing information every 1024 beam crossings. This maintains synchronicity across all trigger inputs.

Design assumes that costs for this type of signal transmission will be reasonable by '96/'97.

Presently possible to purchase a four port (two full duplex) 0.25 Gbit/s per port for $400 (i.e. $100/port). Or a two port 1.0 Gbit/s link for $1200.

We have constructed a suitable single port 1.25 Gbit/s link for $380. We expect that this price will drop dramatically as standards are adopted and competition reduces parts costs.

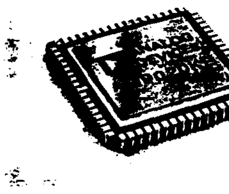
ANALOG DEVICES

10-Bit, 60 MSPS A/D Converter

02028

FEATURES
Monolithic 10-Bit/60 MSPS Converter
TTL Outputs
Bipolar (±1.75 V) Analog Input
56 dB SNR @ 2.3 MHz Input
Low (45 pF) Input Capacitance

APPLICATIONS
Digital Oscilloscopes
Medical Imaging
Professional Video
Radar Warning/Guidance Systems
Infrared Systems

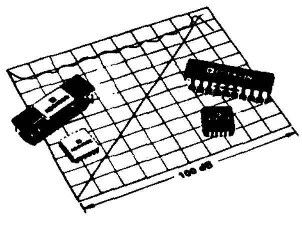


ANALOG DEVICES

DC Coupled Demodulating 120MHz Logarithmic Amplifier

FEATURES
Complete, Fully Calibrated Monolithic System
Five Stages, Each Having 10dB Gain, 350MHz BW
Direct Coupled Fully Differential Signal Path
Logarithmic Slope, Intercept and ac Response are
 Stable Over Full Military Temperature Range
Dual Polarity Current Outputs Scaled 1mA/Decade
Voltage Slope Options (1V/Decade, 100mV/dB, etc.)
Low Power Operation (Typically 220mW at ±5V)
Low Cost Plastic Packages Also Available

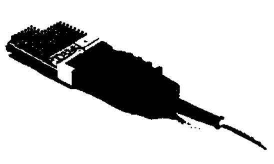
APPLICATIONS
Radar, Sonar, Ultrasonic and Audio Systems
Precision Instrumentation from dc to 120MHz
Power Measurement with Absolute Calibration
Wide Range High Accuracy Signal Compression
Alternative to Discrete and Hybrid IF Strips
Replaces Several Discrete Log Amp ICs



IBM Data Module 1062

Fiber Channel Standard Gigabit Performance

02029



Features
- 1.0625 Gb/s fiber optic transceiver
- Integrated serializer/deserializer
- ANSI Fibre Channel Standard compatible
- Worldwide Class 1 laser safety
- 1300 nm laser
- 2 km link capability

Description

The IBM DM1062 is a high speed fiber optic transceiver module for data communication applications. It is intended that production level modules will be fully compatible with the ANSI *Fibre Channel Standard* at the 100 Mbyte/s throughput rate.

The DM1062 transmits and receives serial optical data at the rate of 1.0625 Gb/s. The primary optical components are a 1300nm InGaAsP laser diode and an InGaAs PIN photodetector. Data transmission is over the user's 9/125um single mode fiber optic cable

Electrical

The electrical data paths into the user's system consist of two 20 bit interfaces, one for transmit data and the other for receive data. The data is encoded in the user's system using the 8B/10B coding scheme. The transmit and receive interfaces operate asynchronously from each other. Electrical interface signal levels ara CMOS compatible (3.6V). Data transfer over the electrical interfaces is at a 53.125 Mb/s rate. Data serialization/deserialization as well as clock generation and recovery are all performed within the DM1062 module. A 53 125 Mhz reference clock is required to be supplied by the user's system.

Packaging

The DM1062 is a pin in hole pin grid array module package. It has a cast aluminum housing and a plastic connector insert. Supply voltage requirements are +3.6V and +5.0V Power dissipation is 3.6W typical and 5.0W maximum. The operating temperature range is 10 degrees C to 60 degrees C. Module dimensions are 12.0 mm (0.47 in) high, 42.0 mm (1.65 in) wide, and 91.2 mm (3.59 in) long with the ESCON connector insert.

Laser Safety

The DM1062 will be Class 1 laser safety certifiable prior to delivery of any prototype hardware. The DM1062 supports a data link transmission distance of up to 2 km based on an 8 dB minimum loss budget. Receiver sensitivity is −20 dBm at a BER of 10exp(−12).

Availability

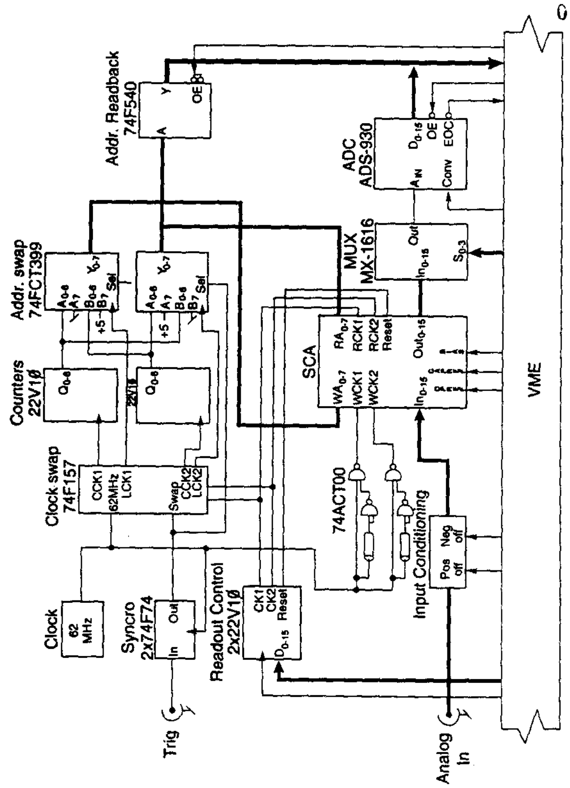
Early prototype modules will accommodate only the single mode ESCON connector. Later prototypes and production level modules will accommodate the ANSI Fibre Channel Standard SC Duplex connector.

Prototypes available 2H92.

Disclaimer

Contact Information

For further information on this product, please call International Business Machines, Opto-Electronics Enterprise, 1701 North Street, Endicott NY 13760 Telephone number (607) 755-9935 Fax (607) 755-1239

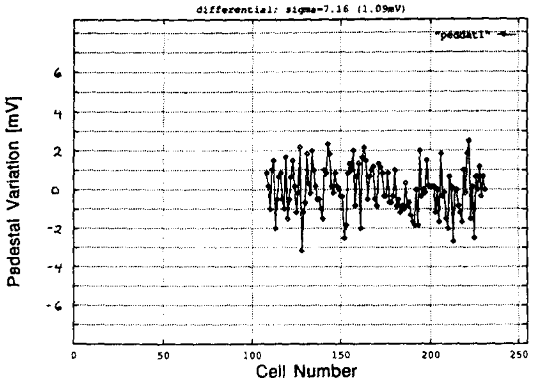


SCA Pedestal Variation

Readout on VME CARD

⇒ Single shot variation

⇒ Differential inputs w/ 10 volt effective input swing.

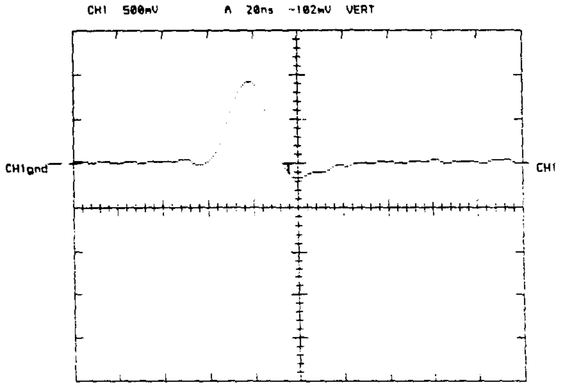


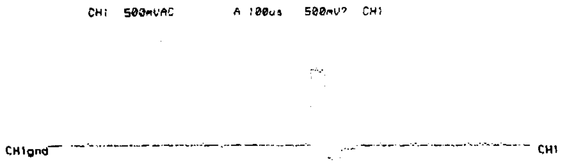
⇒ 13.2 bit dynamic range (1:9000) achieved w/ SCA mounted on VME card in simultaneous R/W operation.

Observed PMT Signals

⇒ R580 PMT w/ scintillator hodoscope

⇒ Ru^{106} source





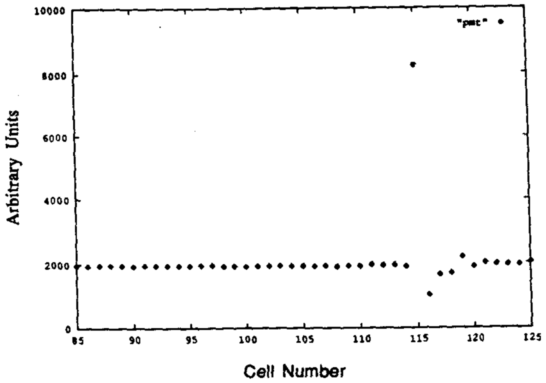
Observed PMT Signals

Readout on VME SCA Card

⇒ R580 PMT w/ scintillator hodoscope

⇒ simultaneous R/W operation w/ trigger

⇒ Ru^{106} source



Test Beam VME Card

2 Front-End Crates, one for calorimeter, one for shower max

Approximately 128 calorimeter & 256 shower max channels

32 channels per 6U VME card

SCA's readout through commercial 14-bit 6.3 µsec ADC

Cards provide full simultaneous read/write capability

Supports high speed block transfer readout

Permits event acquisition rates in excess of 1 KHz

Full waveform transient recording

Expect 13 bit - 14 bit performance per energy scale

Expect 2 x 10^5 to 1 x 10^6 dynamic range

Card is presently in design

Conclusions

1) Results from Switched Capacitor Array measured on bench top
- < 0.5% non-linearity.
- Low spatial and temporal crosstalk (< 1 mV).
- Operates in current mode or voltage mode.
- 0.6 mV pedestal noise (single shot differential)
- 14 bit dynamic range in bench measurements (1:16600)
- implies 20 bit effective dynamic range w/ dual range system
- Uses cheap 1.2 micron CMOS process

2) VME Card with SCA fabricated.
- 1.1 mV pedestal noise (single shot)
- 13 bit dynamic range in bench measurements (1:9000)
- Operated with PMT dual range preamplifier and R580
- 2.5 x 10^5 effective dynamic range with dual range
- Ru^{106} source signals recorded

3) Bipolar PMT preamplifier designed for SCA based system
- Uses high performance AT&T bipolar process

4) 16 channel 12-bit ADC fabricated in 1.2 µm CMOS.
- Achieves < 10 µsec simultaneous conversion on 16 channels

5) L1/L2/Readout Architecture chip (ALP) in test

6) Test Beam VME card in Design

02036

SHOWER MAXIMUM DETECTOR FRONT-END ELECTRONICS

P. LEDU

Requirements

- Provide pulse height information with 12 bit dynamic range and a least count of one photoelectron (half MIP)
- Distinguish between event every 16 ns
- Supply a single bit per 16 channels to the Level 1 trigger every 16 ns
- Store analog pulse height during the 3 - 4 µsec Level 1 latency
- Provide information to the level 2 trigger
- Read out selected event to the DAQ at up to 10**4 Hz

The SDC ShowerMax Electronics

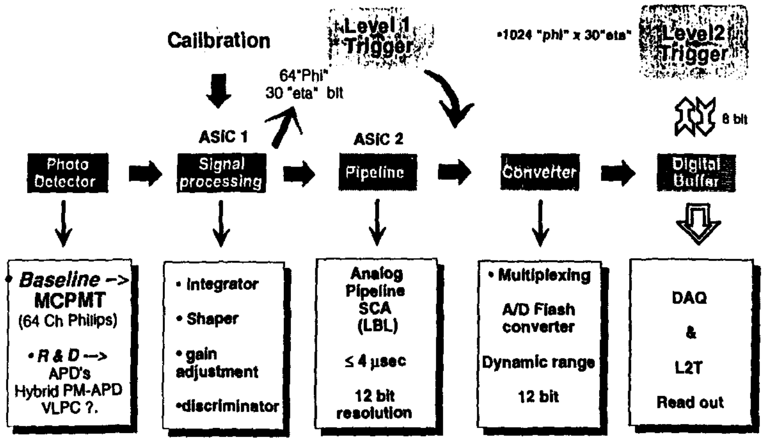
An Introduction ....

P. Le Dû

PAC
May 92

Front end read out components

today status
(baseline design)



Calibration

Level 1 Trigger

64"Phi"
30 "eta" bit

•1024 "phi" x 30"eta"

Level2 Trigger

8 bit

Photo Detector → ASIC 1 Signal processing → ASIC 2 Pipeline → Converter → Digital Buffer

- Baseline --> MCPMT (64 Ch Philips)
  - R & D --> APD's Hybrid PM-APD VLPC ?.
- Integrator
  - Shaper
  - gain adjustment
  - discriminator

Analog Pipeline SCA (LBL)
≤ 4 µsec
12 bit resolution

- Multiplexing

A/D Flash converter
Dynamic range
12 bit

DAQ
&
L2T
Read out

Constraints

- **Large number of channels** → 47104

  ----> (94,208 after upgrade)
  ----> plus 10368 Massless gap.

⇨ **"cheap" and compact electronics**
array of devices (photodetectors .....)
analog pipeline scheme ---> SCA
multiplexed read out electronics

- **Gain correction**

  - Photodetector array
  - Radation dammage

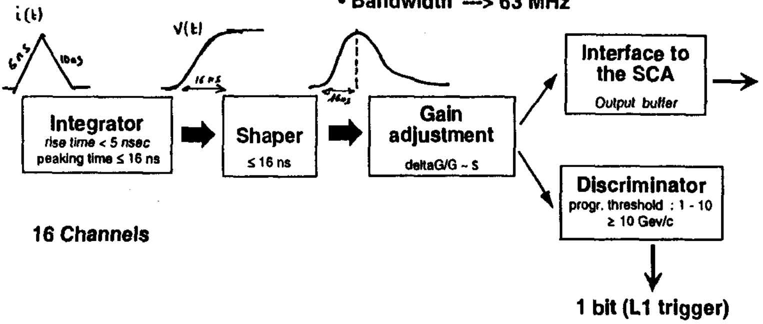
⇨ **"Dedicated "front end ASIC**

Signal Processing ASIC

Input Parameters ⇨
- "specific to the Showermax"
- independant of the type of photodetector
- current sensitivity 15 FmCb to 60 PcCb

----> dynamic range = 4000 .
- Maximum occupancy = 5 %

---> recovery time ~ 1 µsec
- Bandwidth ---> 63 MHz



Integrator
rise time < 5 nsec
peaking time ≤ 16 ns

Shaper
≤ 16 ns

Gain adjustment
deltaG/G ~ 5

Interface to the SCA
Output buffer

Discriminator
progr. threshold : 1 - 10
≥ 10 Gev/c

1 bit (L1 trigger)

16 Channels

02043

Photodetectors

	Multianode PMT	APD	Hybrid APD	VLPC	Ideal
• Gain	≥ 10 ** 5	10** 2 to 10**3	≥ 10**5	10**4	≥ 10**5
• Quantum Efficiency @ 550nm	10 to 12 %	40 to 80%	10 to 12%	80%	100%
• Dynamic range	≤ 10**3	10**4	≥ 10**4	10**3 ?	≥ 10**4
• Noise	≤ 15 Mev	30 Mev	?	≤ 5 Mev	5 Mev
• Crosstalk	10%	0	?	0	0
• Linearity	(OK)	OK	?	OK	_
• Temperature stabilitization	No	Stable	Stable	7 degres K	No
• *Magnetic stray field*	500 Gauss max ?	OK	OK	. OK . . .	_
• Status	Established	Tested for SMD	Design Proto	Prototype	_
• Availability in 92	OK	OK	No	OK	_
• *Technical complexity*	None	Preamp	?	Cryostat	None
• Cost per channel	20 to 25 $?	40 ?	?	≤ 30 $	≤ 20 $
• Supplyer	Philips Hamamatsu	EGG-RCA API *Hugues*	Litton	Rockwell	

02041

Read out organization

Try to optimize between
- *physical granularity*
- *electronics packaging*
- *trigger segmentation*
- *DAQ test , integration & monitoring*

• Front End ➤ **64 Channels elementary read out block** ➡ *768 units*

----> 768 MCPMT (64 Ch)
----> 768 Front end "planchers"
....or 384 front end boards (128 Ch)

• Data Collection ➤

5 x 64 Ch.	7 x 64 Ch.	7 x 64 Ch.	5 x 64 Ch.
5	7	7	5
end cap	wedge	wedge	end cap

---> 24 groups of 64 Ch.

"Data Collector" Board
One per "phi" sector

⇨
- 32 "phi"x 30 longitudinal strips
- 1 x 736 transversal strips

➡ *32 units*

---> 32 Data Collection Boards & 32 control & monitoring µProc.

• Data Read out ➤ **"Data Source Node"**
20 slots crate

Autonomous "local"
----> read out
----> control
----> synchronization ....

➡ *4 units*

02044

Photodetectors summary

MCPMT ➤ **Established technology , but presently not good enough in**
- dynamic range
- crosstalk
- gain uniformity
- price

----> *new development*

APD ➤ **Successfully tested for SMD , but crucial questions are :**
- *long term stability of many channels*
- cheap low noise amplification
- engineering

----> *new development underway*

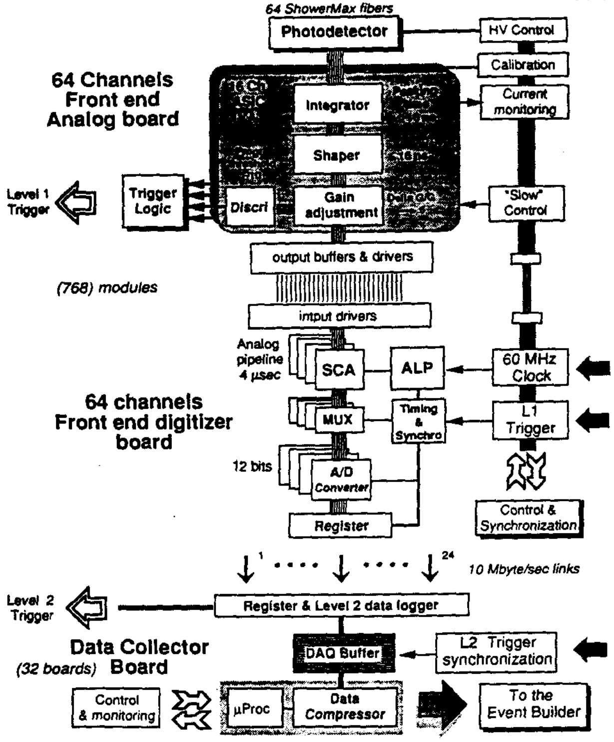
PM-APD ➤ **Promising technology :**

----> *still in design stage*

VLPC ➤ **State of the art , but important issues :**
- dynamic range
- engineering (distributed cryogenics ...)
- preampli integration

----> *application in SMD needs to be tested*

02042


64 ShowerMax fibers
Photodetector
HV Control
Calibration
64 Channels Front end Analog board
Integrator
Current monitoring
Shaper
Level 1 Trigger
Trigger Logic
Discri
Gain adjustment
"Slow" Control
output buffers & drivers
(768) modules
intput drivers
Analog pipeline 4 μsec
SCA
ALP
60 MHz Clock
64 channels Front end digitizer board
MUX
Timing & Synchro
L1 Trigger
12 bits
A/D Converter
Control & Synchronization
Register
1
24
10 Mbyte/sec links
Level 2 Trigger
Register & Level 2 data logger
Data Collector Board
(32 boards)
DAQ Buffer
L2 Trigger synchronization
Control & monitoring
μProc
Data Compressor
To the Event Builder

02046

SILICON TRACKER FRONT-END ELECTRONICS

H. SPIELER

Front-End Electronics and Detector Modules for the SDC Silicon Tracker

Basic Concept

Strip electronics register hit/no-hit
Pixels also record analog information
Beam crossing of hit recorded
Readout after receipt of level 1 trigger

Detector subdivided
  a) at z≈0 (±6 cm depending on layer)
  b) in 8 ... 12 sections in φ (barrel + disks) for each radius

Available information
  Layer address (associated with cable)
  Section address (associated with cable)
  chip address
  strip address
  crossing time
  pixels: signal charge

All electronics through data sparsification and local bus drivers in custom ICs on detector.

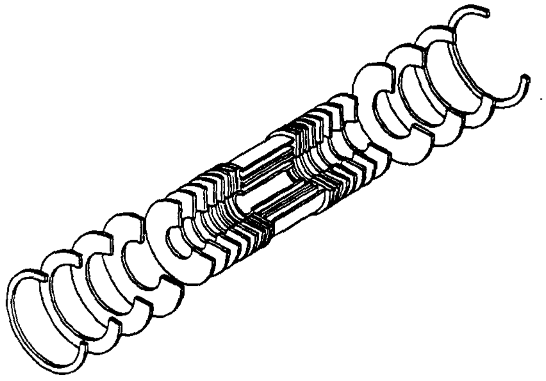


FIG. 4-34. STS detector arrays (pictorial view).

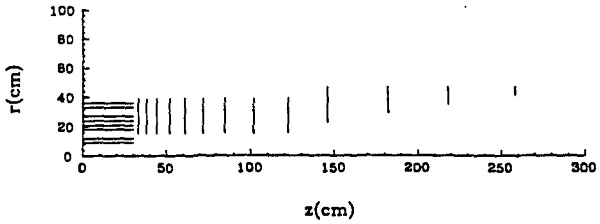


FIG. 4-2. Silicon tracker design.

Requirements

Noise	$Q_n <$ 1200 el
Time Resolution	$\Delta t <$ 16 ns for 1 fC $\leq Qs \leq$ 8 fC
Power Dissipation	$P \approx$ 1 mW/channel for 12 cm strips
Dead Time	~50 ns goal (two successive 4 fC pulses)
Radiation resistance	$\Phi_c + \Phi_n = 10^{14}$ cm^{-2} (limited by type inversion in detector) Dose > 5 Mrad Demonstrated for both detectors and electronics (analog + digital).

Readout within 10 μs after receipt of level 1 trigger
  (also for high-density jets)

Calibration inputs
Externally adjustable thresholds (differential inputs)
Chip disable

Implementation

AC coupled, double-sided detectors
  (strip pitch ≈ 50 μm, stereo angle ≈ 10 mrad)

128 channels per chip laid out on <50 μm pitch

BJT Analog chip:	preamplifier shaper timing comparator
CMOS digital chip:	time stamp/data buffering sparse readout differential drivers

Baseline design:
One readout line per section (φ) and layer/ring (r)
Local signal transmission by low-mass Al/Kapton ribbon cables
Intermediate Bus Selector Chips to limit bus loading
Fiber drivers/receivers at outer shell of Si tracker
  ⇒ ~ 160 ... 240 fiber links (300 Mb/s) at each end

Alternatives being investigated:
  Low-cost 60 MHz fiber links developed at Oxford
    (*e.g.* 1 fiber link per module)
  Arrangements that eliminate the Bus Selector Chips
    (more cables)

need to balance technology, material, cost

Responsibilities:

1. Front-End Electronics: LBL + UCSC
2. Detector Module Design: LBL
3. Local signal transmission and cabling: LBL
4. Fiber links and external DAQ: Oxford/RAL

Analog IC

Key concepts verified in test circuits designed and tested at UCSC.

Full analog channel that meets SSC requirements designed at LBL and submitted for fabrication.

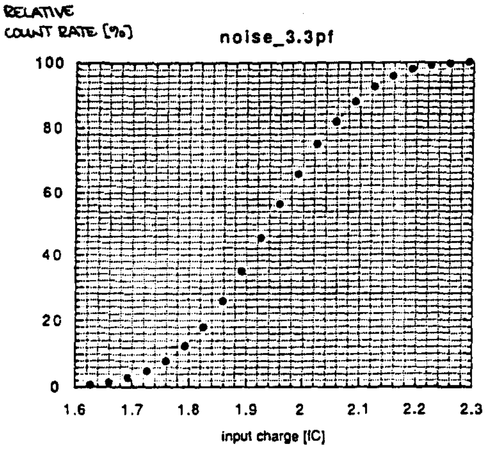
Digital IC

Digital time slice buffer clocked at 10 MHz designed, fabricated in rad-hard CMOS (UTMC), and tested at UCSC

Various buffering schemes simulated at RAL
(test ICs in fabrication)

Selection of final configuration: end 1992

NOISE MEASUREMENT ON Si STRIP FRONT-END FOR ZEUS
TEKTRONIX PROCESS (D. DORFAN + N. SPENCER, UCSC)



⇒ Qn≈800 el rms

IN GENERAL:

BIPOLAR ICs SHOW GOOD AGREEMENT WITH CALCULATED NOISE LEVELS.

MEASURED NOISE RATES vs. THRESHOLD IN GOOD AGREEMENT WITH THEORY.

Vendor Selection for Analog IC:

Criteria:
1. Adequate speed
2. Radiation resistance
3. Circuit density (Circuit on pitch <45 μm)

3 vendors with suitable processes identified

1. AT&T
2. Tektronix
3. Westinghouse

Some technical issues:

1. AT&T
    - Well characterized (also radiation effects)
    - Currently available process (CBIC-U2)
        relatively slow with large feature size.
    - High-density process with improved speed
        to be released in late summer
2. Tektronix
    - Well characterized (also radiation effects)
    - High speed and circuit density
    - Lateral PNP transistors
        (low current gain after irradiation)
    - Vertical PNPs in preparation
3. Westinghouse
    - Need more data on radiation effects
        (have obtained test devices)
    - Good speed and circuit density

Expect that all three vendors will have comparable processes (speed, density, radiation resistance) by end of 1992.

Note that for equivalent circuits (same functions for each) the currently available processes differ in power only by ~100 μW.

To allow valid comparison between vendors, specifically to assess

- circuit trade-offs
- radiation resistance of specific circuit
- die size (\$\$\$)
- yield (\$\$\$)

we need to fabricate test ICs through all three vendors.

Circuits to be designed to same specifications with same basic circuit, but details tailored to specific process.

Choice for first run: AT&T

Circuit and preliminary layout submitted (LBL)
PO issued (UCSC)
ICs expected in September

At least two different ICs:
1. Individual circuit blocks
2. Complete 64 channel front-end

\+ perhaps
3. Array of preamplifiers

Goal is still to have 128 channels/IC in final design, but we selected 64 ch. for this run to obtain better yield data.

Extensive pre-qualification of multiple vendors is designed to reduce risk in final mass production run.

Silicon Tracker (SSC)
Front-End Bipolar IC (AT&T)

Detector

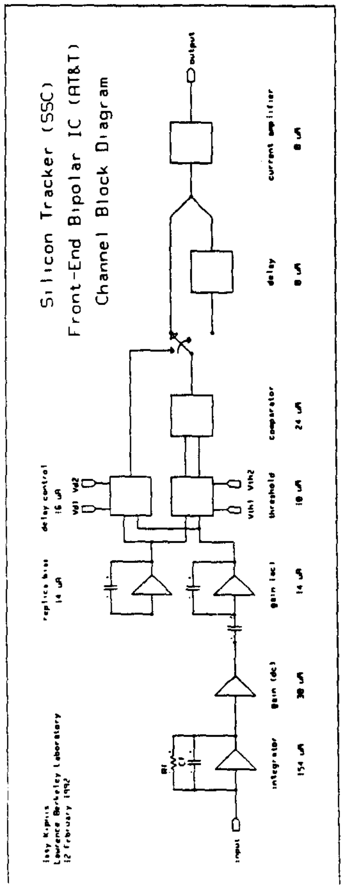
Strip Length	12	cm
Strip Capacitance (1.2 pF/cm)	14.4	pF
Leakage Current (100 nA/cm, $\Phi=10^{14}$ cm^{-2}, T=0 °C)	1.2	µA
Bias Resistor	200	kΩ
Blocking Capacitance	144	pF

Goals

Equivalent Input Noise Charge	1250	e rms
Differential Comparator Threshold	4σ	
Time Walk [1 fC - 8 fC]	16	nsec
Power Consumption	1	mW
High Impedance Output		

Preliminary Simulation Results (3-channels)

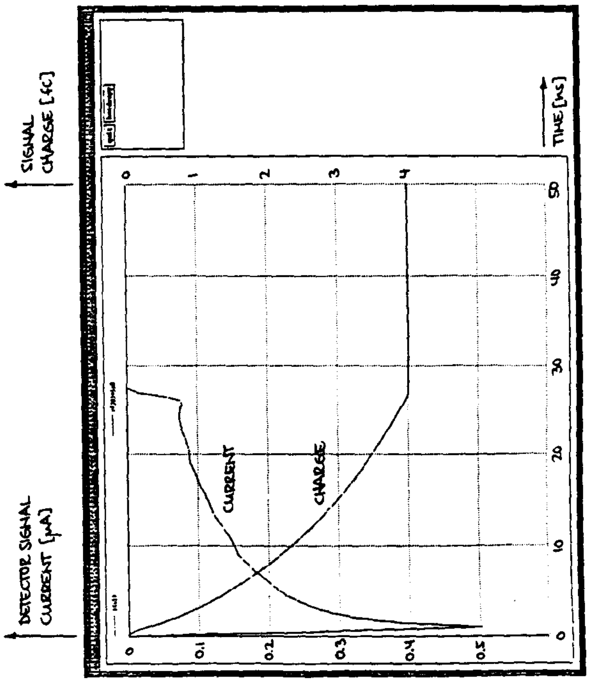
Output Noise Voltage	39	mV rms
Transfer Gain	180	mV/fC
Equivalent Input Noise Charge	1350	e rms
Peak Output Current	400	µA
Comparator Threshold (4σ)	155	mV
Time Walk [1 fC - 8 fC]	12	nsec
Supply Voltage	3.5	V
Power Consumption	950	µW

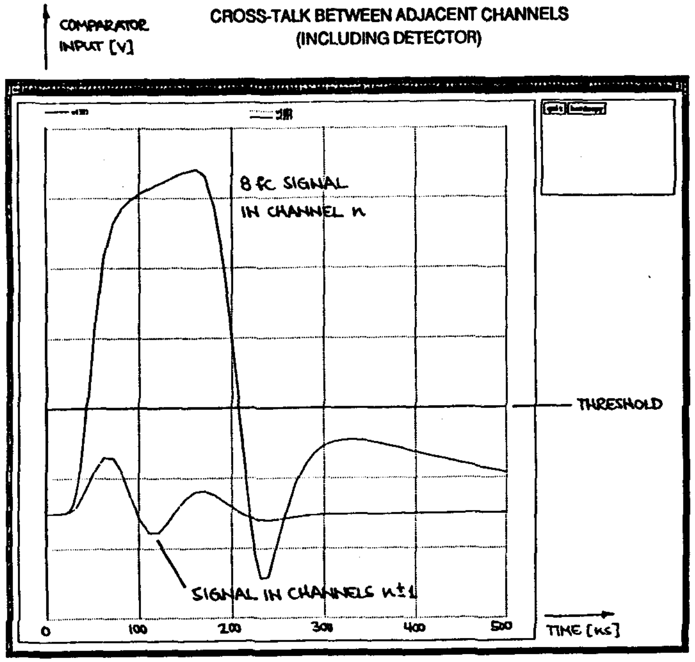


Silicon Tracker (SSC)
Front-End Bipolar IC (AT&T)
Channel Block Diagram

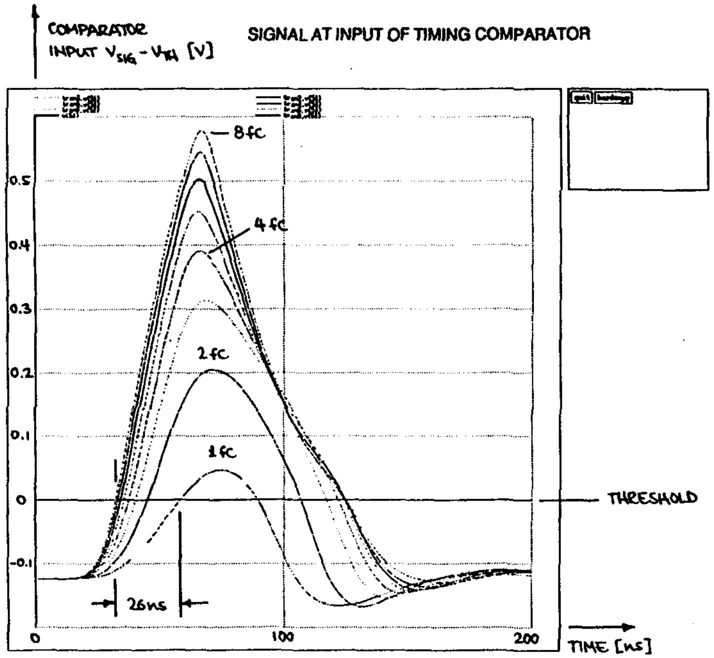
Issy Kipnis
Lawrence Berkeley Laboratory
12 February 1992

DETECTOR SIGNAL USED FOR ELECTRONICS SIMULATIONS
(V_{DET} = 90 V, V_{DEPL} = 60 V)
MEASUREMENT ON p-SIDE (= WORST CASE)

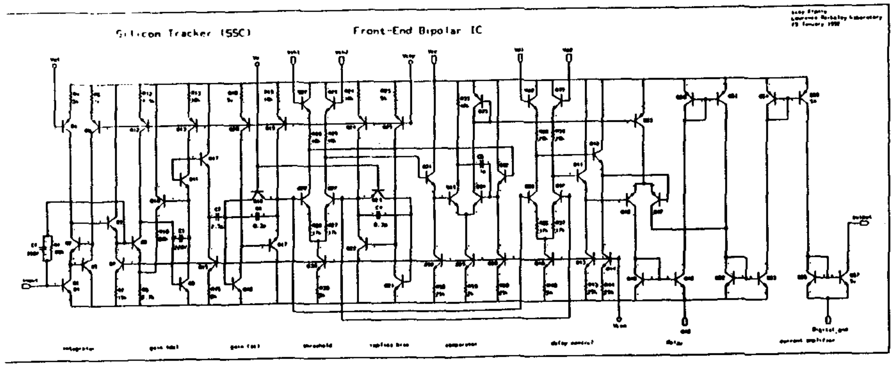




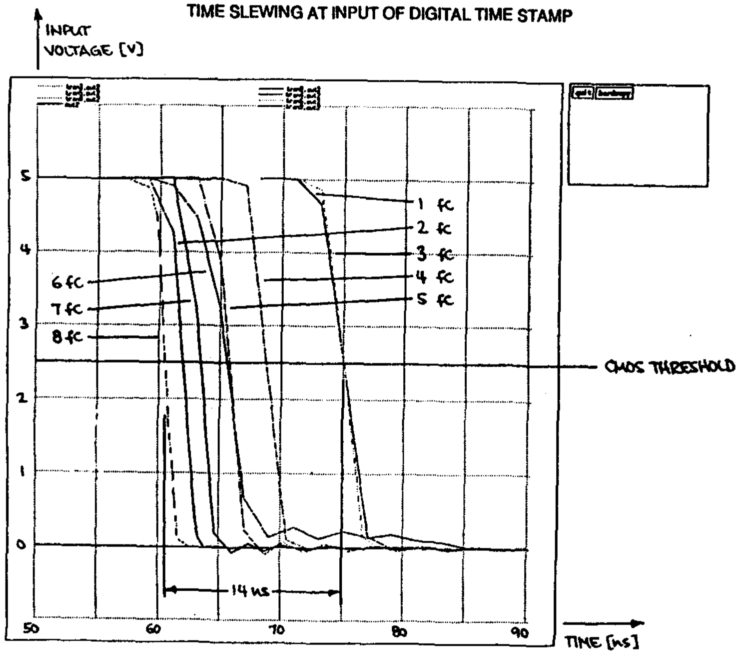
G2061



G2059



G2062



G2060

Silicon Tracker (SSC)
Front-End Bipolar IC (AT&T)

Noise Power Contributions

	$x10^{-6}$ [V^2]	%
Total	1533	100
Q_1	725	47.3
-Ic	-300	-19.6
-Ib	-300	-19.6
-rb	-125	-8.1
Detector Shot Noise	269	17.6
R_f	181	11.8
Q_1 of adjacent channel	93	6.1
Q_1 of adjacent channel	93	6.1
Detector Bias Resistor	58	3.8
R_4	21	1.4
Other (< 1% each)	93	6.1

Notes.

- Adjacent channels contribute ~ 7% to the output noise voltage (increase the equivalent input noise charge by ~ 8%).

-Removing detector noise, Q_1 contributes 84% of the single channel output noise voltage.

Detector Modules

Module:

A detector subassembly that combines detectors, electronics, and cabling to provide a self-contained and completely testable unit.

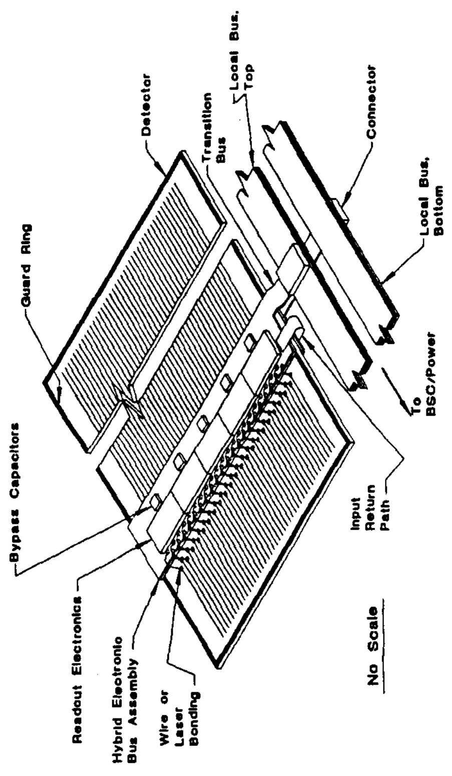
Dedicated power and signal bussing for groups of modules (sections) to minimize global cross-coupling through cables.

Module conceived so that components can be tested at key stages of the assembly process.

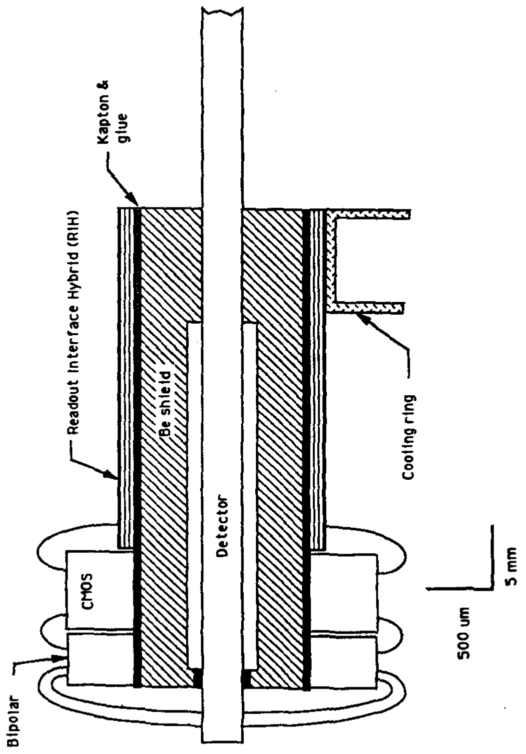
Problems:

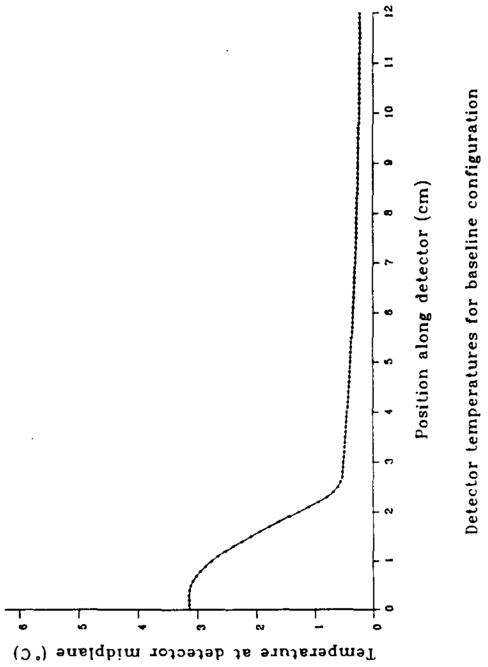
Cross-talk from electronics to detectors
Cross-talk from cables to detectors
Decoupling of electrical supply lines
Mass bonding (~3·10^7 connections)
Structural Precision
Cooling

Schematic of module assembly with cables

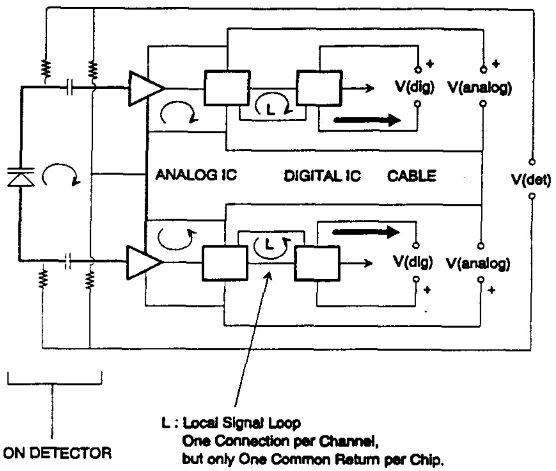


CROSS SECTION OF DETECTOR MODULE
(note difference in x and y scales)





CONNECTION SCHEME FOR DOUBLE-SIDED DETECTORS.



L : Local Signal Loop
One Connection per Channel,
but only One Common Return per Chip.
Local Loop has High Impedance
to Digital Power Supply Lines.

HELMUTH SPIELER
01-NOV-91 rev.

Module Connections (Cable Traces)

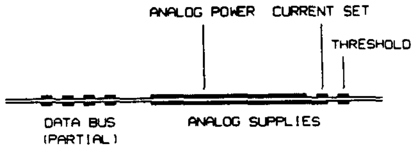
I. DC voltages/currents

1. Detector bias	Positive Bias Negative Bias ground ref.	2 + 1
2. Analog Power V_{CC} = 3.5V Preamplifier Current Set Analog ground		2 + 1
3. Comparator threshold (differential) use analog ground for reference		2
4. Calibration level (differential) (also 2 pulse lines, see below) use analog ground for reference		2
5. Digital Power V_{dd} = 5V Logic + Drivers Digital Ground		2 + 1
	Total DC Lines:	10 + 3

Pulsed Signals (all differential)

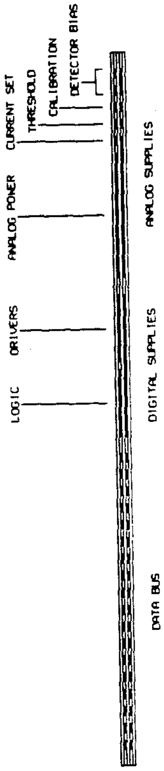
1. Calibration (off + 3 combinations)	2 x 2
2. Master Reset	1 x 2
3. Chip Control (send, receive + 2 other modes)	2 x 2
4. 60 MHz clock	1 x 2
5. I/O Bus	12 x 2
Total Data Lines:	18 x 2

SCHEMATIC CABLE LAYOUT



HELMUTH SPIELER
28-OCT-91

DATA + POWER CABLE



SUBSTRATE + INSULATION: 50 UM KAPTON
CONDUCTORS: ALUMINUM: 25 UM IN LOCAL BUS
50 UM IN SEGMENT BUS

TOTAL WIDTH OF CABLE: 12.9 MM

HELMUTH SPIELER
31-OCT-91

Critical Issues

Unlike existing detectors, signal detection and readout activity are occurring simultaneously.

Note that on-chip sparsification with only hit/no-hit output does not allow signal analysis to reject spurious pickup after readout.

Critical to control cross-talk from
a) chip to detector
b) buses to detectors
c) bus to bus
(cross-coupling through common impedances)

Front-end circuitry and bussing scheme specifically designed to reduce clock pickup and common mode coupling.

Signal transmission on metal lines fully differential with small line spacing (150 μm lines broadside coupled with 50 μm spacing)

Initial measurements with digital test ICs and cables coupled to detector have yielded promising results.

Goal for 1992:
Assemble detector module with cabling and test at read-out rates typical of SSC operation.

Note that this does not require final electronic system, but only front-end circuitry with the same bandwidth and readout circuitry and drivers capable of the same rate!

02073

GAS MICROSTRIP FRONT-END ELECTRONICS/TRIG. & SILICON TRIG.

R. NICKERSON

Gas Microstrip Electronics and Trigger
Silicon Trigger

(ITD electronics.. differences from silicon)

ITD Front-end Electronics

Fibre Optic Read-out

Off-detector Electronics

Level-2 Trigger

Gas Microstrip Electronics

	Silicon	GMD
# channels	6 M	2M
pitch	50um	300um
<signal> in 16ns	25k e	80k e
Max power/channel	1mW	5mW
<power density>@max	30mW/cm	7mW/cm
mean occupancy	0.2%	0.1%
detector capacitance	18pF	6pF

Large number of digital R/O channels
-> same read-out architecture

Similar signal sizes and speed requirements
-> similar front-end amplifiers

Primary Differences

Pitch
lower density electronics desireable

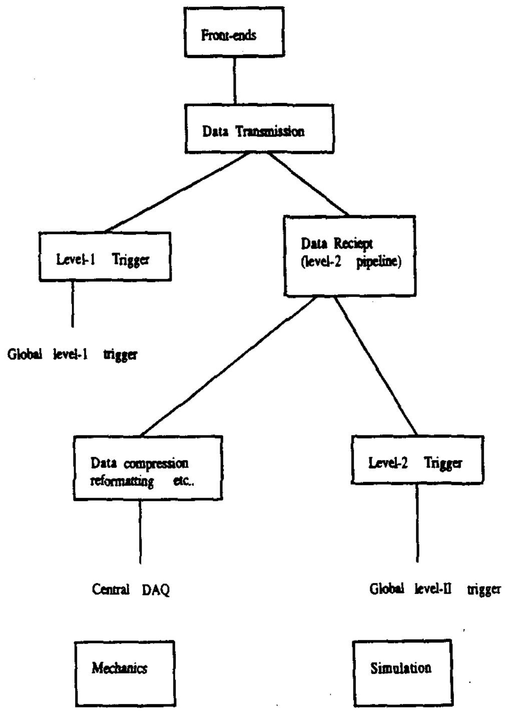
HV
approximately x10 higher voltages

L1 Trigger
additional elements in digital R/O chip

Longer Signals
edge sensitive digital design

Higher Data Rates
(L-1 trig) more fibre optic channels

Electronics Chain



Front-ends

Data Transmission

Level-1 Trigger

Data Reciept
(level-2 pipeline)

Global level-1 trigger

Data compression
reformatting etc..

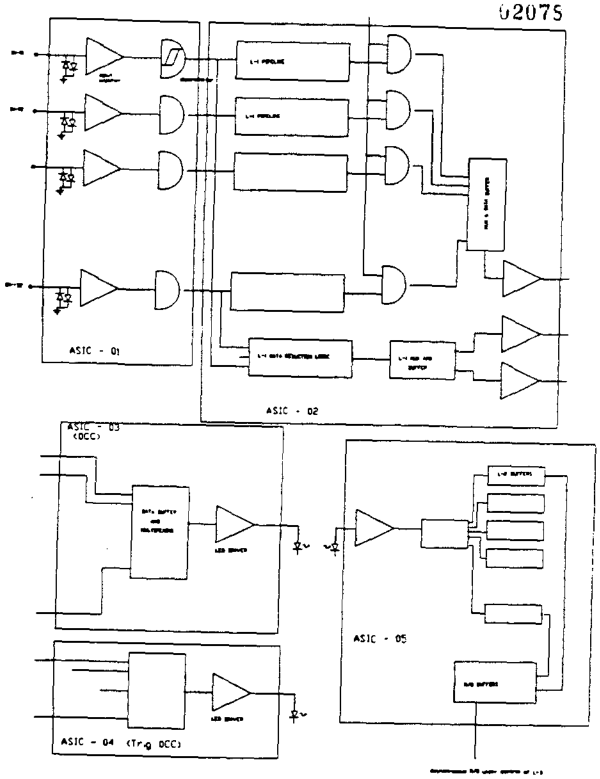
Level-2 Trigger

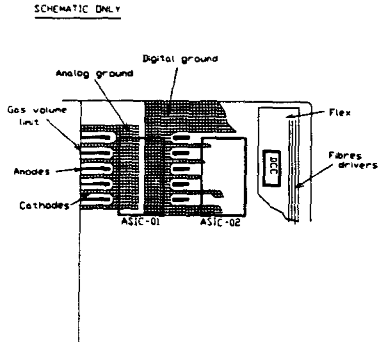
Central DAQ

Global level-II trigger

Mechanics

Simulation





Layout of stereo modules

The tracker design incorporates six-layer stereo modules in two of the outer superlayers. Each one is positioned at about a 3° angle with respect to the cylinder axis. The separation of the adjacent modules thus changes as a function of the distance from the center of the cylinder. These modules are also positioned at two different average radial distances, so that there is complete coverage for all tracks in the overlap region of adjacent modules. The position of the modules in this stereo configuration has been worked out in detail and is shown in Fig. 4-30.

4.4.4. ITD design and module

As discussed in the introduction, the ITD is segmented into bites of approximately 0.25 units in η and made of annuli composed of gas microstrip tiles. The dimensions are listed in Table 4-4. Including overlap, tiles of length up to 270 mm are required, which falls within the manufacturing limits that we confidently expect. The tile widths are chosen not to exceed the manufacturing limitation, which is an active width of 180 mm, and to be identical within each annulus thus minimising manufacturing costs. A typical gas microstrip tile structure is shown in Fig. 4-31.

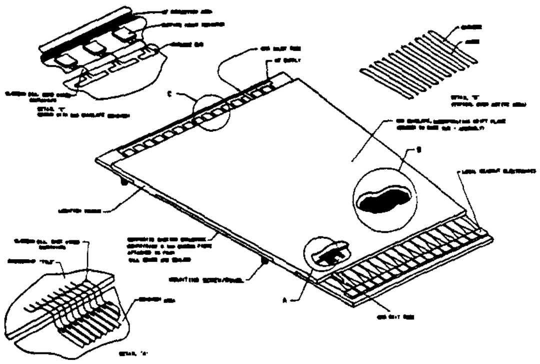


FIG. 4-31. Typical gas microstrip module structure.

The microstrip tiles (GMDs) consist of a microstrip substrate and a plane of drift electrodes separated by a small gap of about 3 mm. Both the substrate and the drift plane will require support to enhance their rigidity. The edges of the tile are sealed to create a gas volume, gas connections being provided to allow gas to be circulated through the drift volume. The anode and cathode lines are laid out radially on the substrate. HV connections to the cathode lines are made at one edge of the tile, the signal connections to

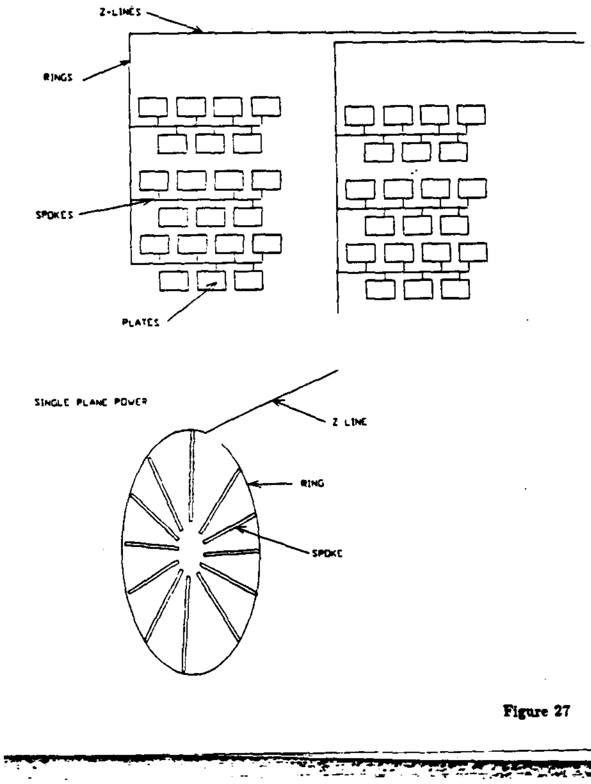


Figure 27

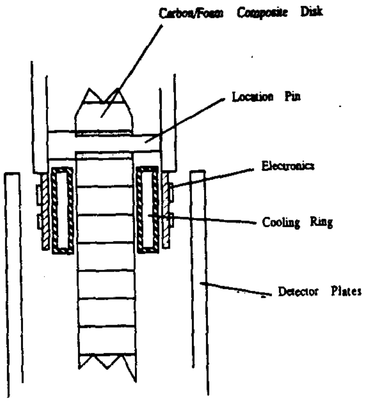


Figure 2 Data Format

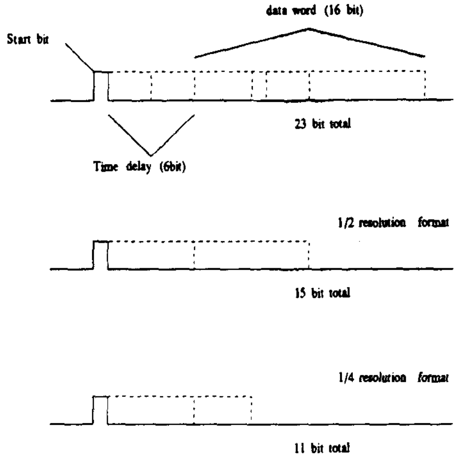
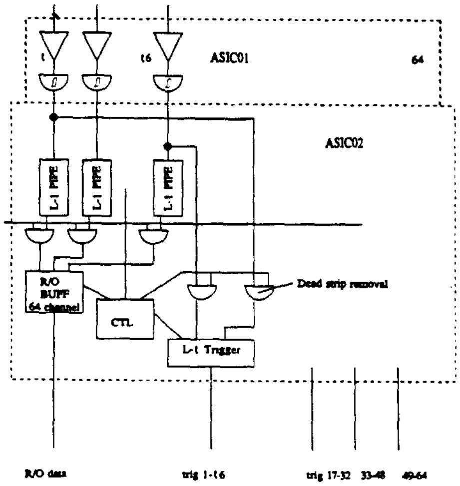
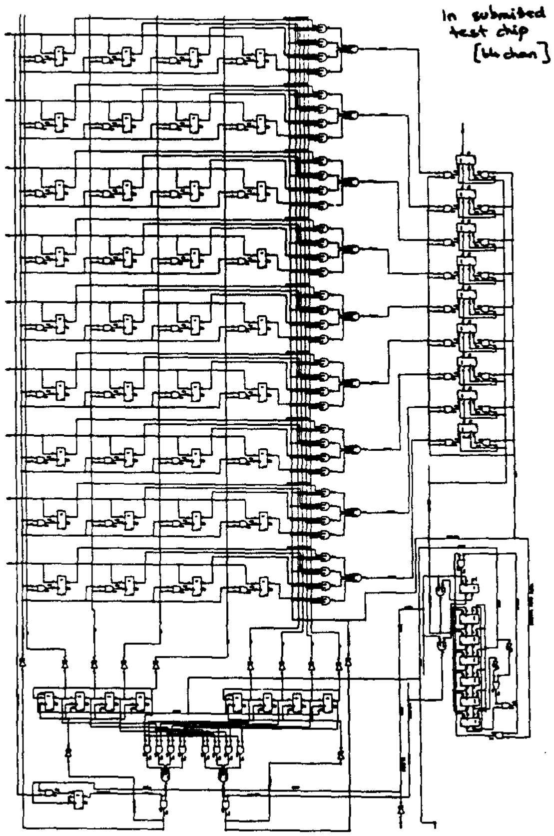


Figure 3 ITD Front-end Electronics

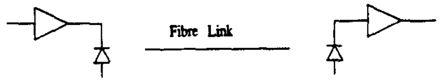


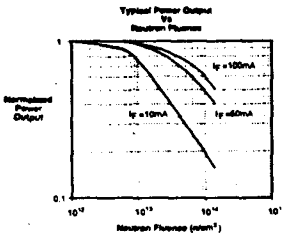
In submitted
test chip
[16 chan]

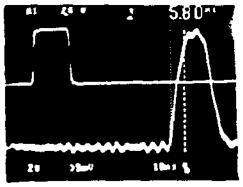


Low Speed, Low Link Cost, Fibre Optics [62.5MHz(66MHz)]

- Simple fibre optic transmission scheme
- based on LEDs, PIN diodes, 50/125 fibre
- and use many links to achieve bandwidth

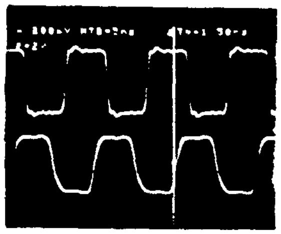






16ns drive pulse
with received signal
showing 5.8ns (10–90%) risetime

- Estimated Cost 11 pounds / link
- in quantities of 100,000



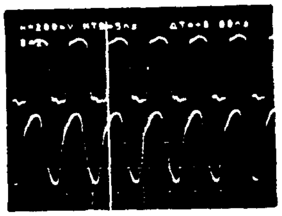
Top trace = system clock 62.5 MHz

Bottom trace = Received clock

via Honeywell HMP2103 LED, 50 metres 50/125 fibre,

Honeywell HFD3038 PIN plus preamp,

and LeCroy MVL407 comparator



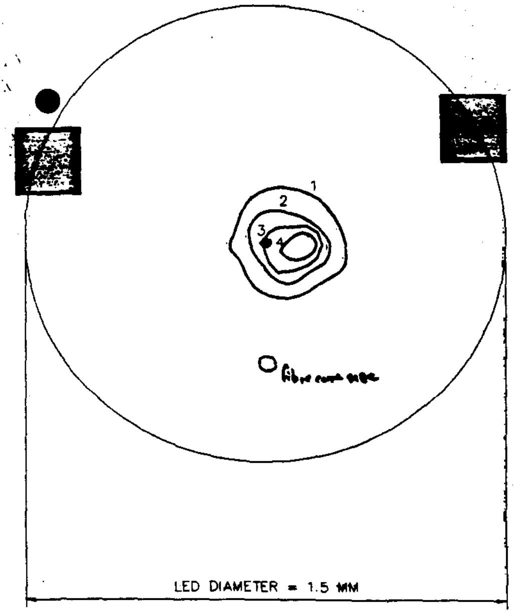
Top trace = system clock 125 MHz

Bottom trace = Received clock

via Honeywell HMP2103 LED, 50 metres 50/125 fibre,

Honeywell HFD3038 PIN plus preamp,

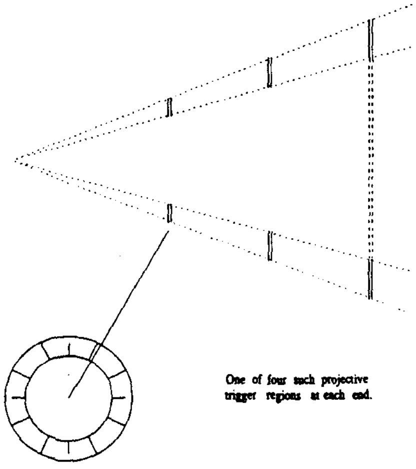
and LeCroy MVL407 comparator



[illegible]ve power levels over LED su[illegible]

Flat window LED – Rad hard

Figure 1 ITD Trigger Geometry



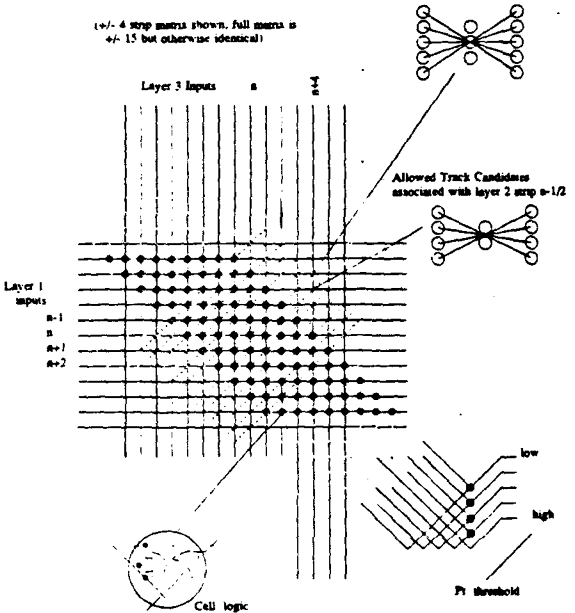
One of four such projective trigger regions at each end.

TRACK DEFINED BY 2 HITS

→ "TRACK CANDIDATES"

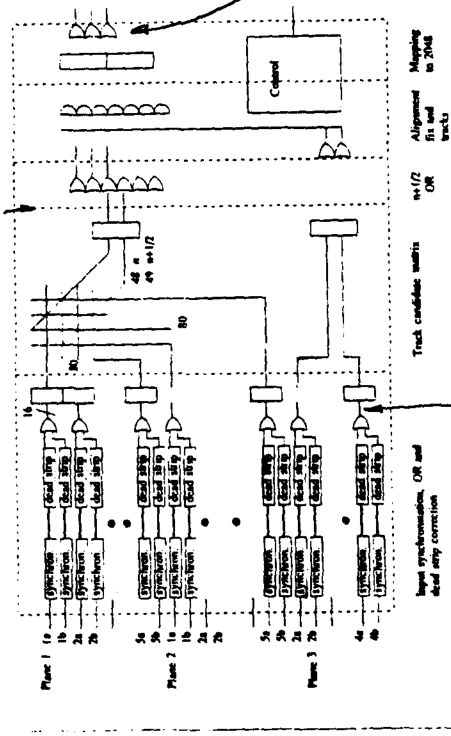
FIGURE 7

Track Candidate Matrix



nb sequential OR not required
→ fewer multi-input may be required to achieve prop-delay

Figure 9 Chip Organisation



software controlled map to 2048 φ regs

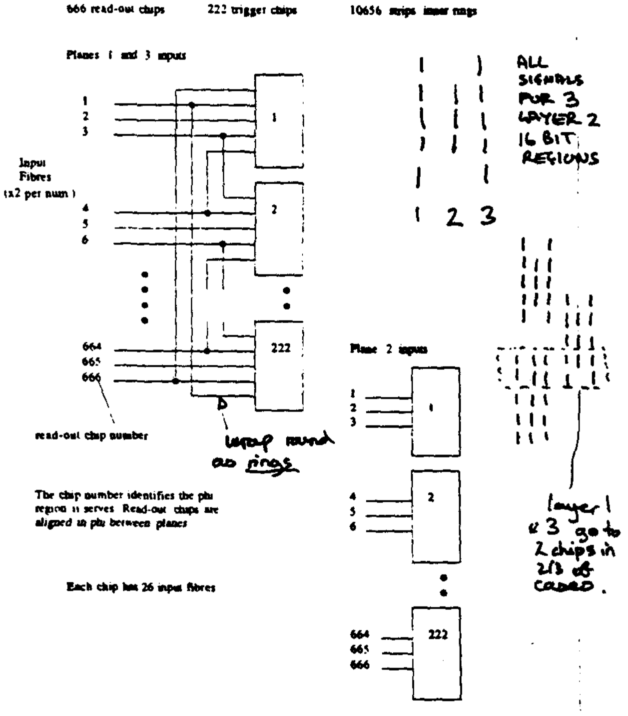
layer 2 rotation only + OR + 2.(TRK CAND)

n-1/2 — in between layer 2
n —— exact layer 2
n+1/2

"BLOW" step not shown
[1/2, 1/4 → full resolution under software control]

WITH AGGRESSIVE FULL CUSTOM DESIGN
ALL SIGNAL FOR 2×16 LAYER 2 REGIONS
SHOULD BE POSSIBLE IN < 1cm×1cm CHIP

Figure 10 Highest Eta trigger region Chip interconnection



The chip number identifies the phi region it serves. Read-out chips are aligned in phi between planes

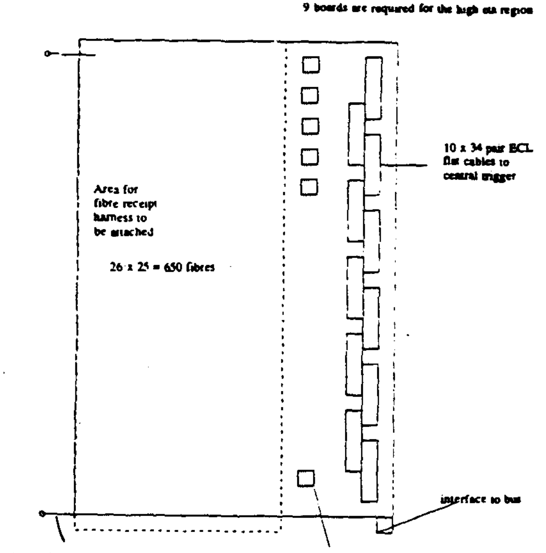
Each chip has 26 input fibres

wrap round as rings

ALL SIGNALS FOR 3 LAYER 2 16 BIT REGIONS

layer 1 & 3 go to 2 chips in 2/3 of CASES.

Figure 11 Board Layout



[ditto at top] + [TRIG OUTPUTS x 2]

65 identical boards required for whole system

EXT DAQ

Figure 1 Global Silicon External DAQ

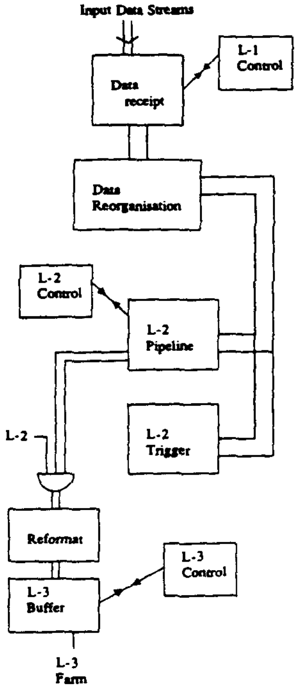


Figure 2 Data Format

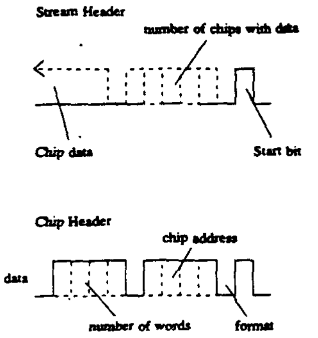


Figure 4 Synchronization

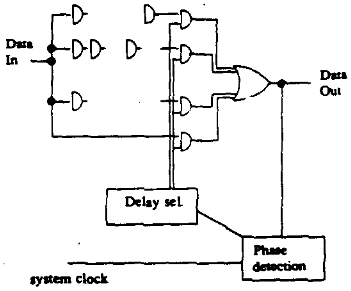
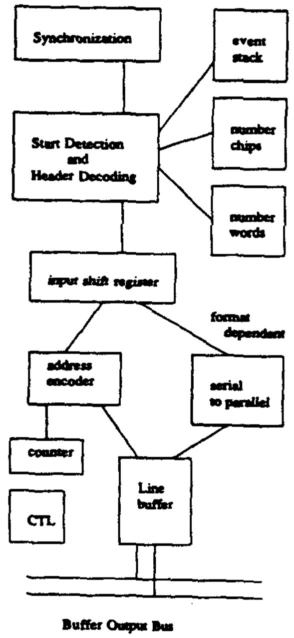


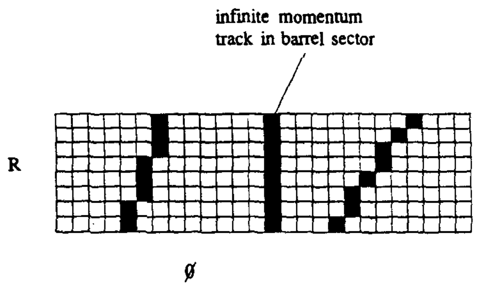
Figure 3 Data Receipt

(One channel in ASIC shown)



IDENTIFIED INDIVIDUAL	TASK
	ITR AMP
	FE PIPE(S)
N.K.	L-1 REDUC.
N.M. CB	F/O
RW	DATA REC.
RW, RBN	DATA FORM
SB	EXT SYS
	L-2 PIPE
RBN	L-1 TRIG EXT
	L-2 TRIG EXT

Figure 2.3



02098

Figure 2.4

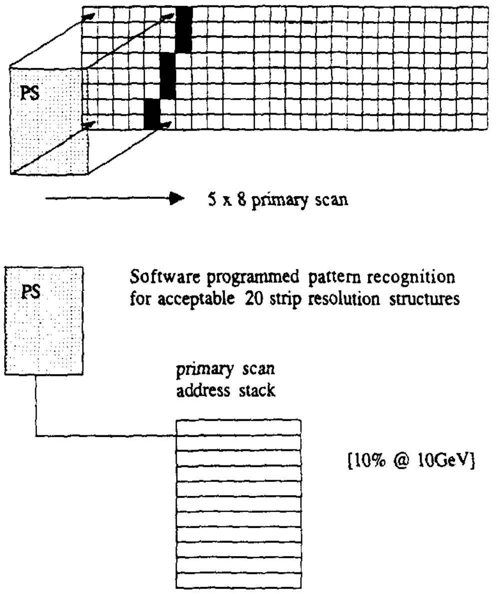


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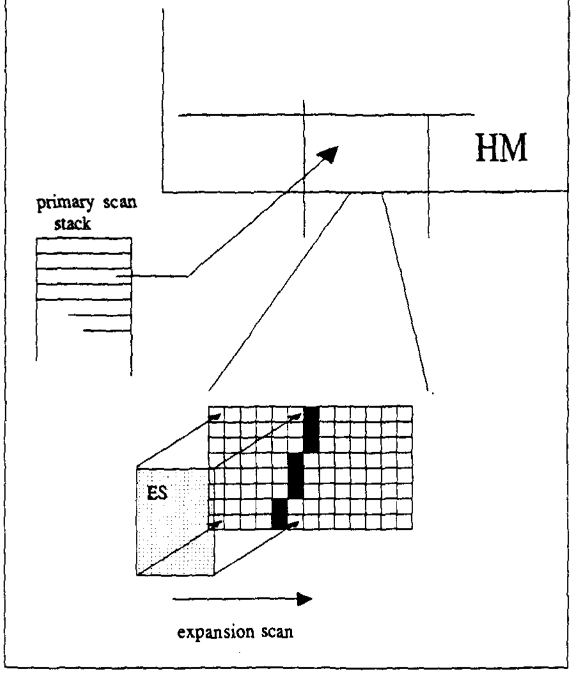
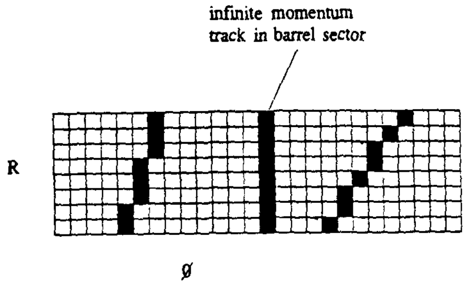
Figure 2.5



02100

Figure 2.3



02101

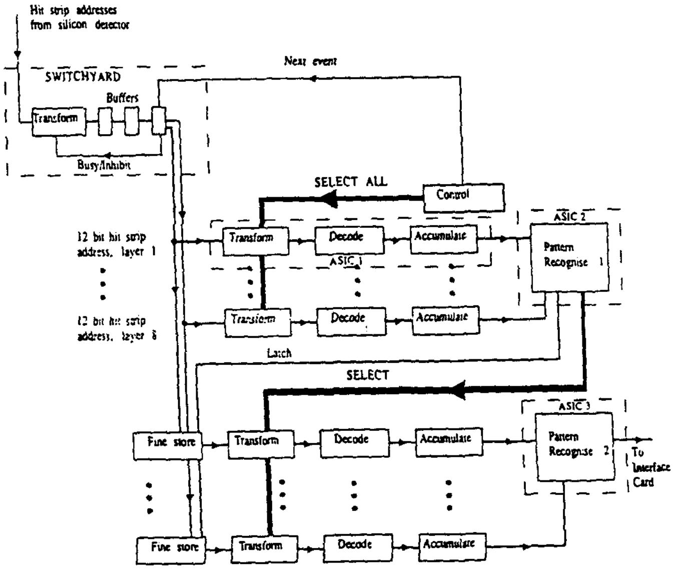


Figure 6: Block diagram showing the main elements of the second level trigger. The switchyard module shown at the top left directs the hit strip data to the appropriate processor cards. The remainder of the figure shows the processing on one half of a PRC module. The areas enclosed in dashed lines and labelled ASIC1, 2 and 3 indicate the parts of the logic which could profitably be manufactured as ASICs.

02102

DATA ACQUISITION AND ON-LINE COMPUTING OVERVIEW

I. GAINES

SDC Data Acquisition & On-Line Computing

Irwin Gaines
May 6, 1992

SDC Data Acquisition System Design and Scope

(outline of what is in technical proposal)

- Design Philosophy
- Requirements
- Functional Overview
- Boundaries with other Subsystems
- Components
- Simulations
- Cost and Schedule

SDC DAQ Design Philosophy

- Standardization
- Commercial Components
- Modularity/Scaleability
- Separate data and control paths (Simplicity)

SDC DAQ Requirements

- Performance requirements
- Partitioning and stand-alone operation requirements
- Other Requirements
- DAQ Control/Monitoring requirements

SDC DAQ
Requirements

- Performance requirements

- Maximum Level 2 Trigger System input rate:	100,000 Hz
- Maximum Level 3 Trigger input rate:	10,000 Hz
- Number of independent data sources	400
- Maximum bandwidth through Event Builder Subsystem (based on 10kHz @ 1 Megabytes per event)	10 GB/sec
- Minimum processing power in online farm	10**5 MIPS
- Maximum event size (for a calibration event)	20 MByte
- Expected event size (data events)	1 MByte
- Maximum readout deadtime	10%
- Maximum deadtime due to DAQ errors/downtime	5%

SDC DAQ
Requirements

- Partitioning and stand-alone operation requirements

Must be able to operate separate non-interfering DAQ systems
for each subsystem during commissioning
Preserve this functionality after detector turn on for debugging
and calibration of individual subsystems

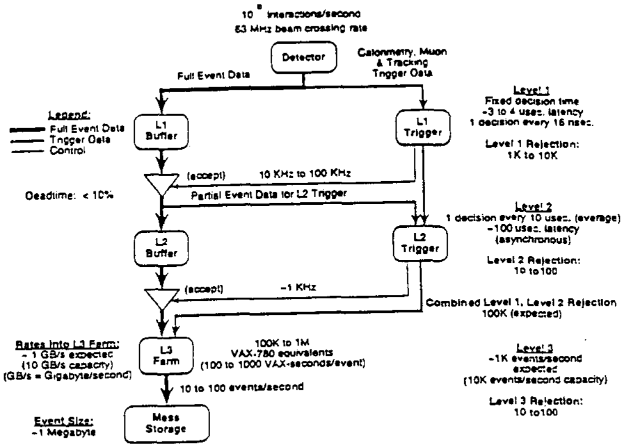
- Other Requirements

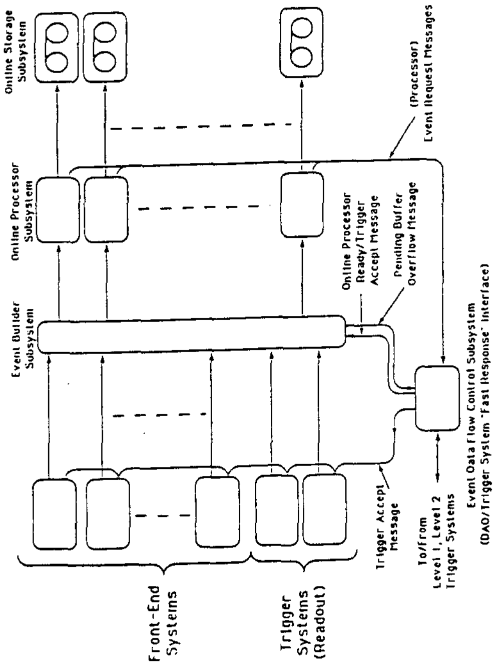
Scalability
Reliability
Maintainability

- DAQ Control/Monitoring requirements

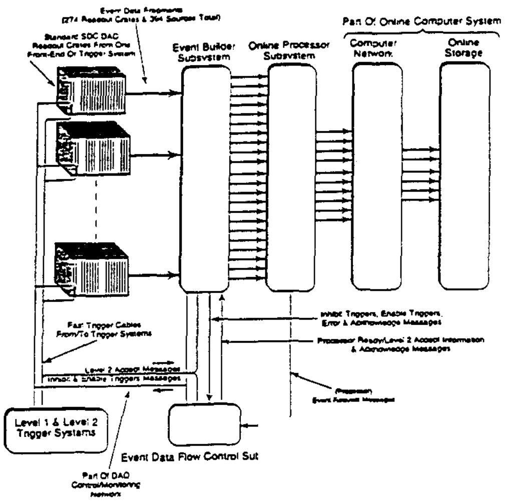
Setup (download) entire detector into known condition
Track operation of both DAQ system and detector subsystems
Record conditiions under which data are taken
Allow for calibration data acquisition
Allow for non-event data acquisition
Detect and record error condition
Prioritized alarm system

SDC DAQ
Functional Overview





Simplified Block Diagram
Of Costed Data Acquisition System Architecture



SDC DAQ
Boundaries with other Subsystems

- Front-End and Trigger
- Ancillary Control System
- On-line Processor Farm (Level 3 Trigger)
- On-line Computing
- Off-line Computing

SDC DAQ
Boundaries with other Subsystems

- Front-End and Trigger

  Standard Front-end readout crate: Crate designed by DAQ, used by front-end cards (with augmented specila purpose backplane if required); Trigger/gating card built by trigger group, generated high speed control signals; DAQ readout processor built by DAQ group.

- Ancillary Control System

  Uses common network (see figure). DAQ group writes applications programs to provide control/monitoring functionality using low level subroutines provided by ancillary control group. Control programs can be run from control computers, online computers, subsystem workstations, or DAQ processors.

- On-line Processor Subsystem (Level 3)

  DAQ group builds/buys level 3 hardware, input and output networks, software to manage farm (downloading, debugging, delivering events, monitoring and controling performance). Trigger and offline groups provide actual physics code running at level 3.
  ****Level 3 processors must support the full offline environment, including operating system calls and data base references.*****

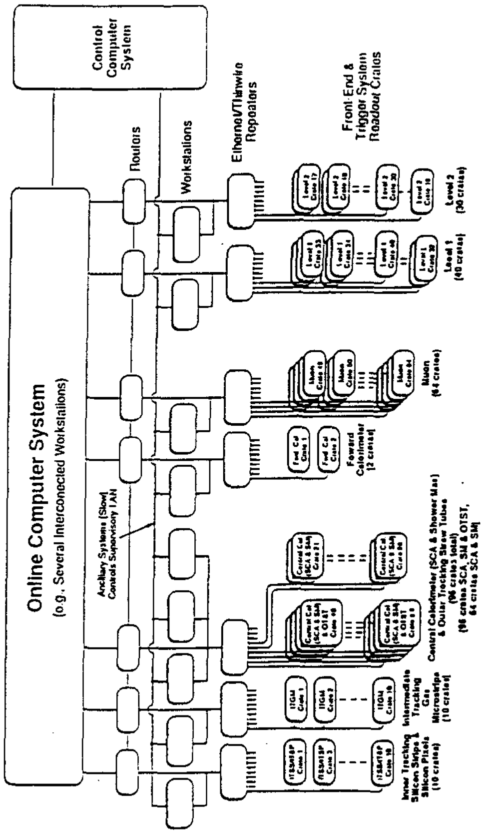
SDC DAQ
Boundaries with other Subsystems

- On-line Computing

  HW: boundary is at interface between level 3 processors and online storage subsystem. This network will be jointly designed by DAQ and online.
  SW: DAQ and online will use common tools, mostly chosen by online but some (eg real time operating system) by DAQ. DAQ will use online supplied tools in preparing application programs; both DAQ and online will supply tools and templates for subsystem physicists to prepare applications.

- Off-line Computing

  Online storage subsystem and network link for express line analysis both belong to online.



SDC DAQ
Components

- Standard readout crates
- DAQ readout processors
- Event Builder Subsystem
- Online Processor (level 3 trigger farm) Subsystem
- Event Data Flow Control Subsystem
- DAQ Control/Monitoring System
- Rack Protection

SDC DAQ
Components

- Standard readout crates: 274 crates
- DAQ readout processors: 274 processor modules
- Event Builder Subsystem: 1 system, 394 inputs, 100 outputs, 10GB/sec aggregate bandwidth
- Online Processor (level 3 trigger farm) Subsystem: 1 system, 10**5 Mips total processing power
- Event Data Flow Control Subsystem: 394 links
- DAQ Control/Monitoring System: 290 links

DAQ Components

Front-End/Trigger System	# Crates	# Sources	Crate Type	Location
Inner Tracking Silicon Strips & Inner Tracking Silicon Pixels	10	10	SDC DAQ Std.	Counting Room
Outer Tracking Straw Tubes	8	32	SDC DAQ Std.	On Detector
Intermediate Gas Microstrip Tracker	10	10	SDC DAQ Std.	Counting Room
Central Calorimeter (SCAs) & Central Calorimeter Shower Max	96	192	SDC DAQ Std.	On Detector
Central Calorimeter (Flash ADCs)*	96	96 (+96 for shower max)	Special	On Detector
Forward Calorimeter	2	2	SDC DAQ Std.	Counting Room
Muon (Wires)	48	48	SDC DAQ Std.	On Detector
Muon (Counters)	16	16	SDC DAQ Std.	On Detector
Level 1 Trigger (<= 1 KB/crate)	59	59	SDC DAQ Std.	Counting Room
Level 2 Trigger (<= 1 KB/crate)	25	25	SDC DAQ Std.	Counting Room
	===	===		
Totals:	274	394		

* Central Calorimeter (Flash ADCs) not counted in totals

Option:replaces outer straw & gas microstrip Outer Tracking Scintillating Fiber & Intermediate Tracking Scintillating Fiber	14	14	Special	On Detector

Table 1
Crates With DAQ CPUs & Front-End/Trigger System Event Data Sources

---

SDC Data Acquisition System Component Quantities

Ken Treptow, Fermilab
January 28, 1992
Revised April 3, 1992

1.0 Components

The following tables show what data aquisition components are contained in each Front-End System, Trigger System and Data Acquisition Subsystem.

Front-End System, Trigger System or Data Acquisition Subsystem	DAQ C/M Network Routers	DAQ C/M Network Repeaters	DAQ C/M Links	DAQ Crate & Cooling Units	DAQ Crate Fan Units
WBS Number	5.2.4.4.4.1	5.2.4.5.4.1	5.2.4.6.4.1	5.2.5.4.4	5.2.5.5.4
Inner Tracking Silicon Strips & Silicon Pixels			10	10	10
Intermediate Tracking Gas Microstrips			10	10	10
Central Calorimeter (SCAs), & Shower Max			96	96	96
Outer Tracking Straw Tubes			8	8	8
Forward Calorimeter			2	2	2
Muon			64	64	64
Level 1 Trigger			59	59	59
Level 2 Trigger			25	25	25
Event Builder			5	5	5
Online Processor Subsystem					
Event Data Flow Control			2	1	1
DAQ C/M Network	7	7	34		
DAQ Remote C/M Network					
Design for general use					
Commissioning Components	1	1	12	8	8
Totals	8	8	327	288	288

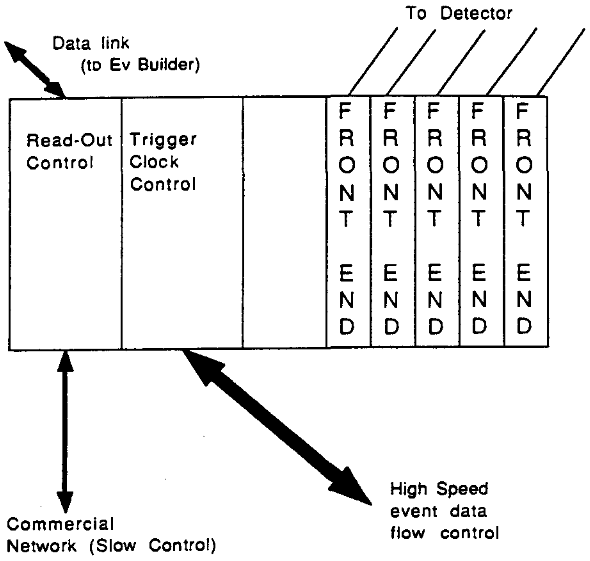
Sub System	DAQ Heat Exchangers	DAQ CPU Modules	DAQ C/M Slave Interface	Event Data Readout Port Interface	Crate Adapter/ Interface Modules
WBS Number	5.2.5.6.4	5.2.6.4.5	5.2.6.5.4	5.2.6.6.3	5.2.6.7.5
Inner Tracking Silicon Strips & Silicon Pixels	10	10			10
Intermediate Tracking Gas Microstrips	10	10			10
Central Calorimeter (SCAs), & Shower Max	96	96			96
Outer Tracking Straw Tubes	8	8			8
Forward Calorimeter	2	2			2
Muon	64	64			64
Level 1 Trigger	59	59			59
Level 2 Trigger	25	25			25
Event Builder	5	5			5
Online Processor Subsystem					
Event Data Flow Control	1	1			1
DAQ C/M Network					
DAQ Remote C/M Network					
Design for general use			1	1	
Commissioning Components	8	8			8
Totals	288	288	1	1	288

Sub System	Event Data Links	Remote C/M Links	Remote C/M Link Repeaters	Data Balancing/ Input Queueing Logic	Switching Network
WBS Number	5.2.6.8.4	5.2.6.10.5	5.2.6.11.5	5.2.10.5.5	5.2.8.5.3.1
Inner Tracking Silicon Strips & Silicon Pixels	10				
Intermediate Tracking Gas Microstrips	10				
Central Calorimeter (SCAs), & Shower Max	192				
Outer Tracking Straw Tubes	32				
Forward Calorimeter	2				
Muon	64				
Level 1 Trigger	59				
Level 2 Trigger	25				
Event Builder				1	1
Online Processor Subsystem					
Event Data Flow Control					
DAQ C/M Network					
DAQ Remote C/M Network		128	32		
Design for general use					
Commissioning Components	16	8	2		
Totals	410	136	34	1	1

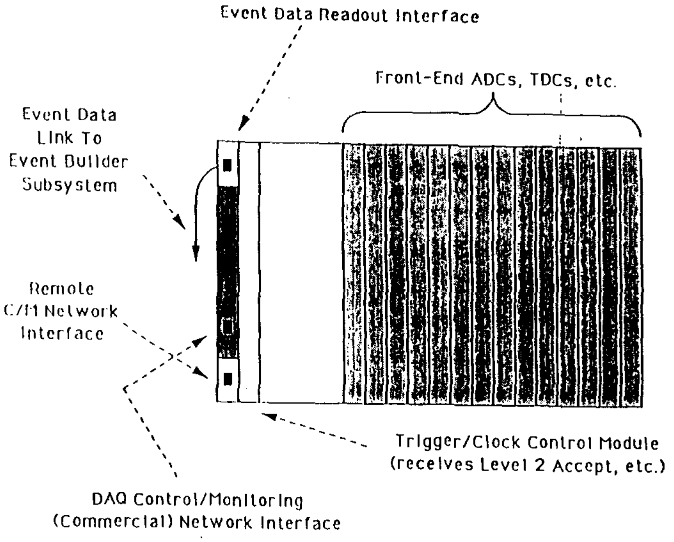
Sub System	EBS/OPS Event Data Links	Data Flow Control Unit	Data Flow Control Links to Event Builder	Processor Array	Event Request Links
WBS Number	5.2.8.6.4.1	5.2.9.4.5	5.2.9.5.4	5.2.11.4.5.1	5.2.11.5.4.1
Inner Tracking Silicon Strips & Silicon Pixels					
Intermediate Tracking Gas Microstrips					
Central Calorimeter (SCAs), & Shower Max					
Outer Tracking Straw Tubes					
Forward Calorimeter					
Muon					
Level 1 Trigger					
Level 2 Trigger					
Event Builder	32				
Online Processor Subsystem				1	7
Event Data Flow Control		1	1		
DAQ C/M Network					
DAQ Remote C/M Network					
Design for general use					
Commissioning Components	4	1	1		2
Totals	36	2	2	1	9

Sub System	Online Processor to Online Storage Data Links	Electronics Rack Protection Chassis	Electronics Rack With Protection & Cooling Hardware
WBS Number	5.2.11.6.4.1	5.2.15.4.4	5.2.15.5.4
Inner Tracking Silicon Strips & Silicon Pixels			
Intermediate Tracking Gas Microstrips			
Central Calorimeter (SCAs), & Shower Max			
Outer Tracking Straw Tubes			
Forward Calorimeter			
Muon			
Level 1 Trigger			
Level 2 Trigger			
Event Builder		2	2
Online Processor Subsystem	3		
Event Data Flow Control			
DAQ C/M Network			
DAQ Remote C/M Network			
Design for general use			
Commissioning Components	2	1	1
Totals	5	3	3

Standard DAQ Crate

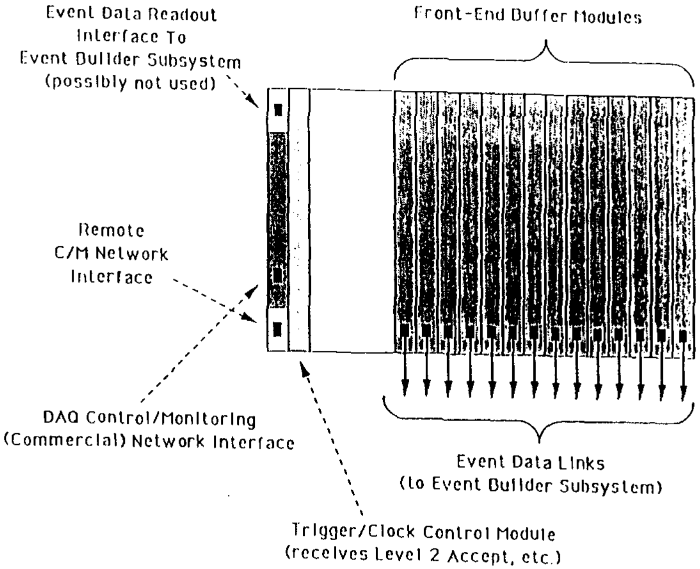


Standard Commercial crate and backplane
(augmented with SDC specific signals)



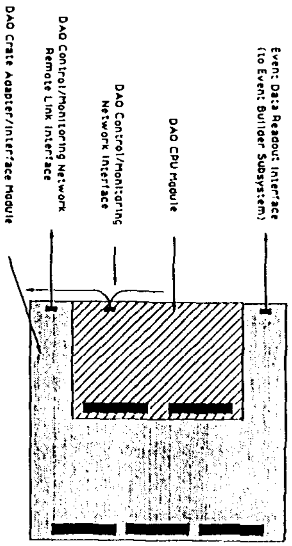
SDC Standard DAQ Crate
(with commercial crate & backplane (& no Buffer Modules))

92127



SDC Standard DAQ Crate
(with commercial crate & backplane (& Buffer Modules))

92128



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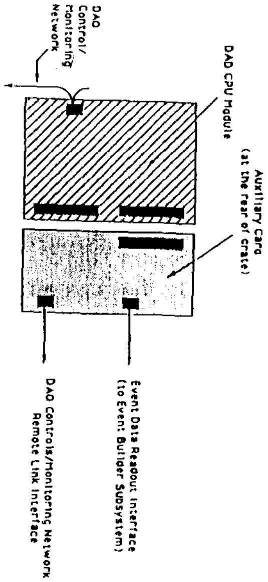

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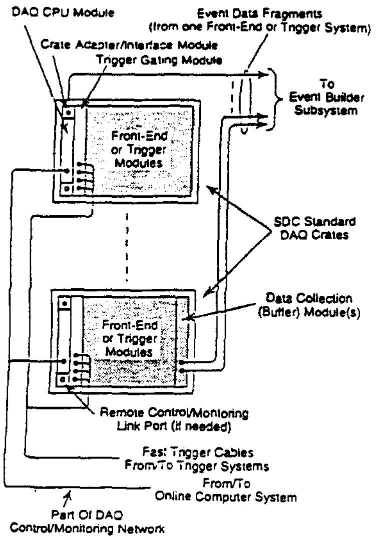

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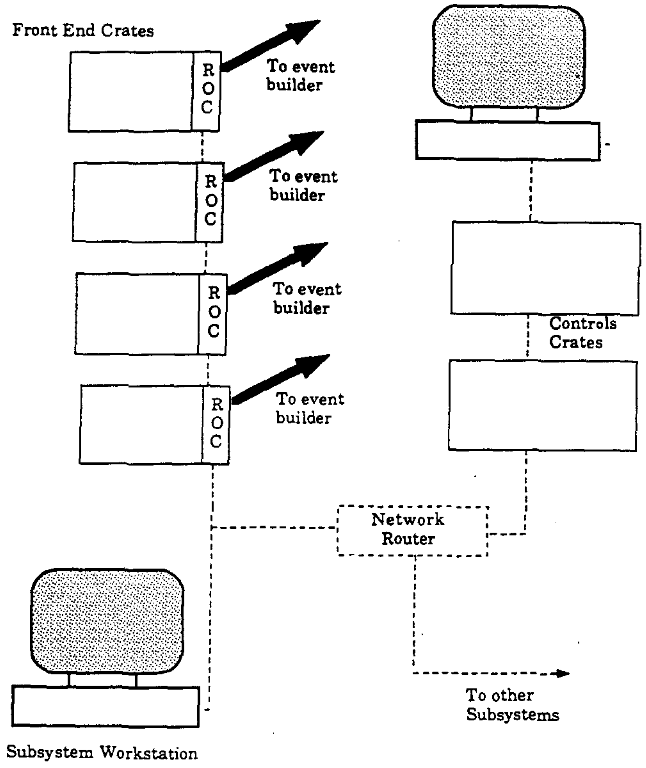
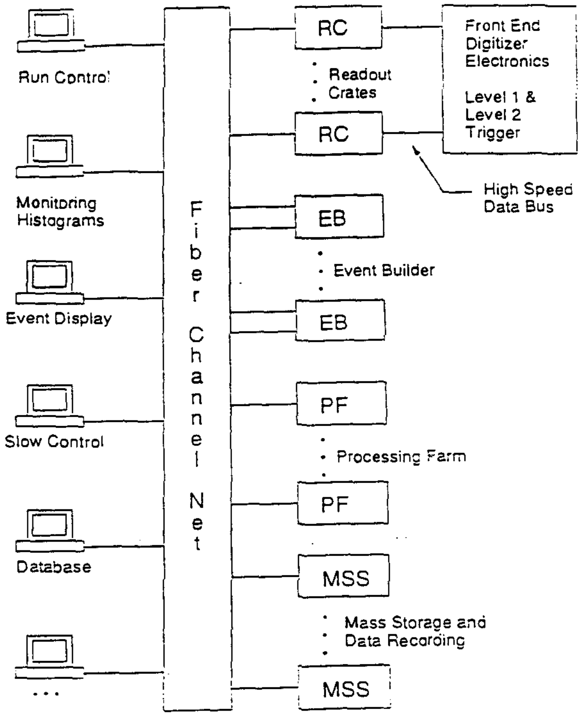
DAQ for each Subsystem



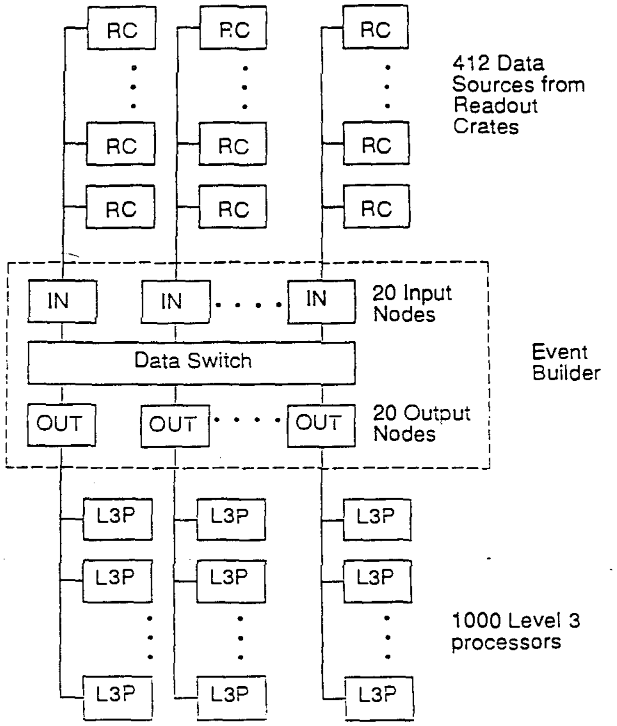
Fiber Channel Based DAQ

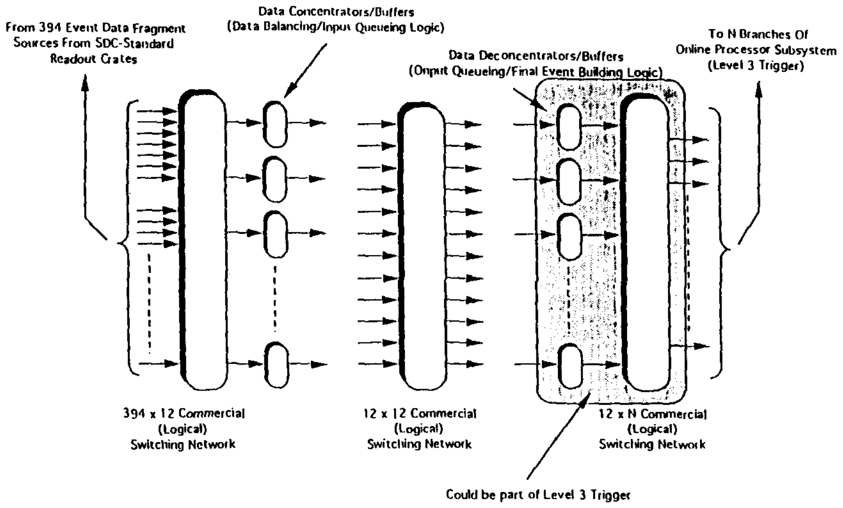
62133



SDC Data Switch Architecture

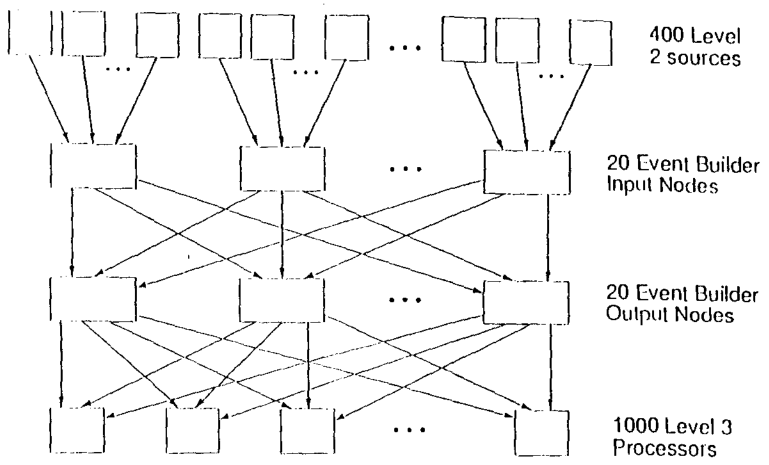
62134

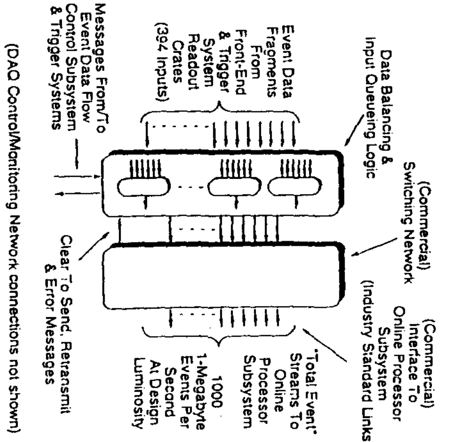


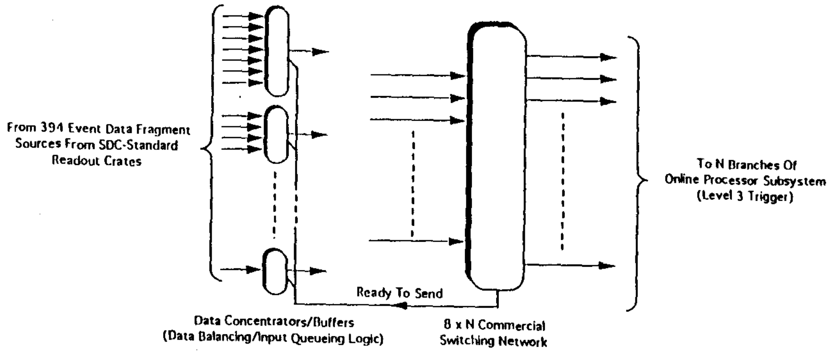


0.5 Gigabyte/second Event Builder Subsystem
(Commercial Switching Network/Asynchronous Mode)

DAQ Data Flow



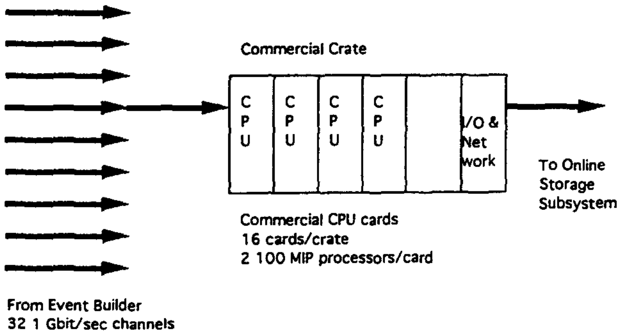




0.5 Gigabyte/second Event Builder Subsystem
(Commercial Switching Network/Synchronous Mode)

(Connections to Event Data Flow Control Subsystem & DAQ Control/Monitoring Network not shown)

Online Processor Subsystem
(Level 3)



Commercial Crate

C P U | C P U | C P U | C P U | I/O & Net work

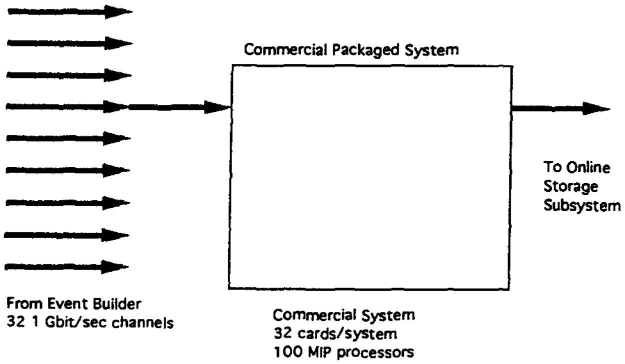
To Online Storage Subsystem

Commercial CPU cards
16 cards/crate
2 100 MIP processors/card

From Event Builder
32 1 Gbit/sec channels

Option 1: We do system integration
1000 100 MIP processors in 32 crates

Online Processor Subsystem
(Level 3)



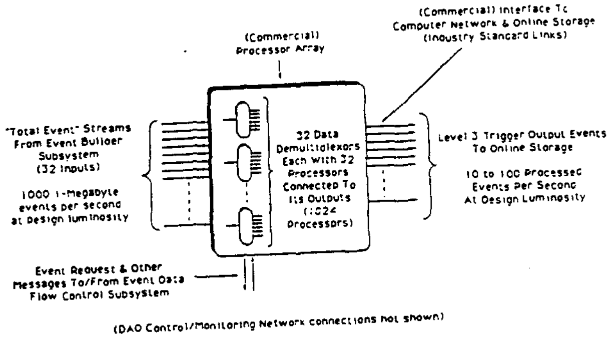
Commercial Packaged System

To Online Storage Subsystem

From Event Builder
32 1 Gbit/sec channels

Commercial System
32 cards/system
100 MIP processors

Option 2: Vendor does system integration
1000 100 MIP processors in 32 boxes



(Commercial) Processor Array

(Commercial) Interface To Computer Network & Online Storage (Industry Standard Links)

"Total Event" Streams From Event Builder Subsystem (32 Inputs)

1000 1-Megabyte events per second at Design luminosity

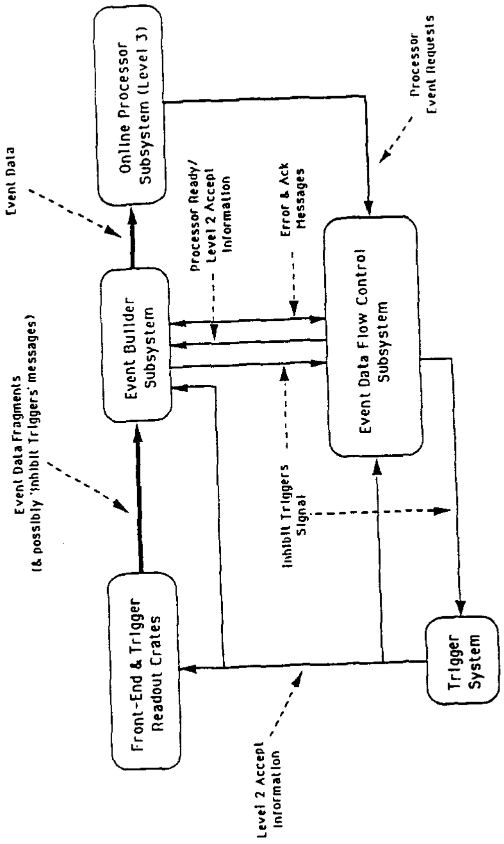
32 Data Demultiplexors Each With 32 Processors Connected To Its Outputs (1024 Processors)

Level 3 Trigger Output Events To Online Storage

10 to 100 Processed Events Per Second At Design Luminosity

Event Request & Other Messages To/From Event Data Flow Control Subsystem

(DAQ Control/Monitoring Network connections not shown)



Online Processor Subsystem (Level 3)

Event Data

Processor Event Requests

Processor Ready/ Level 2 Accept Information

Error & Ack Messages

Event Builder Subsystem

Event Data Flow Control Subsystem

Event Data Fragments (& possibly 'Inhibit Triggers' messages)

Inhibit Triggers Signal

Front-End & Trigger Readout Crates

Trigger System

Level 2 Accept Information

SDC Data Acquisition System
Event Data Flow & Control Block Diagram

SDC DAQ SOFTWARE

- Runtime User Interface
  - Run Control
  - Control of online processor subsystem
  - Histogramming
  - Event Displays
  - Calibration Database
  - Consumer Processes
- Control, monitoring and downloading interface
  - Software supporting memories and intelligent processors
    - Downloading
    - I/O (file system) services
    - Terminal connections for debugging
    - Network connections
  - Software suppoting "non-event" data acquisition
    - Detector parameter monitoring and logging
    - Calibration DAQ
    - Data Base Access
  - Software for recording unusual occurrences
    - Supervising remote control/monitoring links
    - Online diagnostics
    - Error monitoring and recording
    - Alarms and limits
  - Software for control of adjustable devices

SDC DAQ Simulations

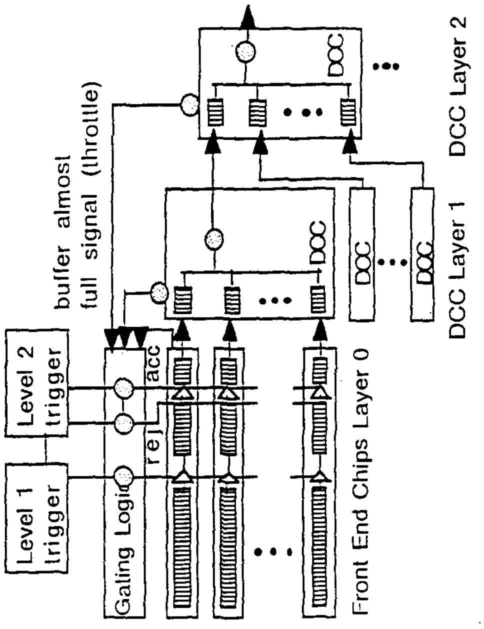
SSCL

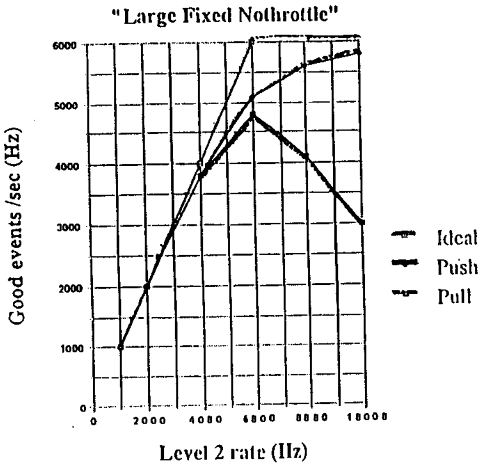
DAQSIM Introduction

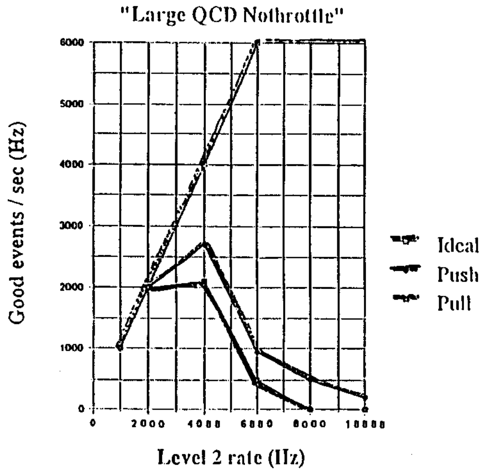
- At the SSC we have developed a tool for studying the behavior of Data Acquistion Systems
- Based on the MODSIM II object-oriented programming language
- Allows designers to evaluate alternative DAQ architectures in terms of deadtime, throughput and buffer usage, etc.
- Specify dynamically the number of chips, buffer sizes, processing time, bandwidth of links, for various interconnection topologies
- Graphical User Interface, Various types of input data

SSCL

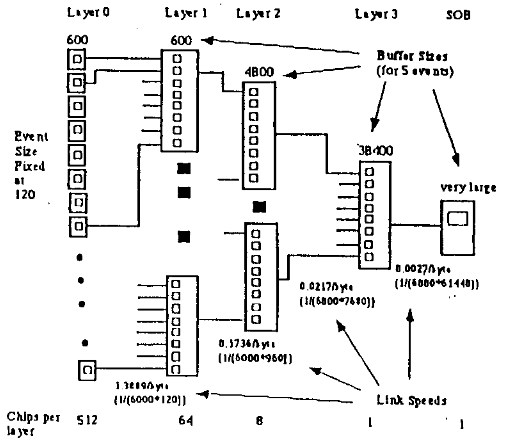
DAQ System



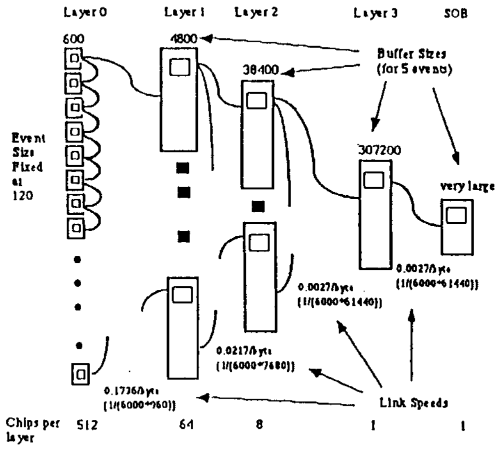




LARGE PUSH DCC NETWORK



LARGE PULL DCC NETWORK



Results - Interesting Observations

SSCL

- Good balancing of the data load over the data collection channels is essential.
- Data collection schemes that use throttling to limit buffer overflows, show a much more graceful degradation at high rates than systems that handle high rates by discarding part of the data.
- There is little difference in performance between 2 and 3 layers of DCC's
- Pull is somewhat better than push in throttled systems with non-fixed data sizes
- Under normal running conditions the Imagecheck protocol does not perform significantly better than the simpler SpaceCheck protocol.
- The buffer sizes in the deeper layers of the system are larger than required for smooth running.
- Performing 'zero suppression' in the first data collection layer rather than in the front-ends has little impact on throughput, provided that sufficient bandwidth is available for data transport to layer 1.

Future Studies

SSCL

Using DAQSIM for Proposed "Real" Detectors

Research into Architectures which Incorporate Redundancy

Refining some of the models

Provide Animation

Integrate Expert System and Fault Insertion Utility

SDC DAQ
Cost and Schedule

SDC DAQ Milestones

Completion of DAQ requirements	Nov, 91
Completion of DAQ system design, incl. technical choices	1993
Completion of DAQ component design	1994
Portable DAQ for use in test beams/labs	1994
Prototypes of all DAQ components	1995
Delivery of partial DAQ systems for subsystems	Jan, 97
Muon subsystem	?
Calorimeter subsystem	?
Tracking subsystem	?
Installation of complete DAQ system	Jan, 99
Certification of full, working DAQ system	July, 99

SDC On-Line Computing Design and Scope

- Requirements
- Event Flow
- Control Flow
- Cost/Schedule

SDC On-Line Requirements

- Acquiring and Recording Data
- Insuring Data Integrity
- Physics processing

SDC On-Line Requirements

- Acquiring and Recording Data

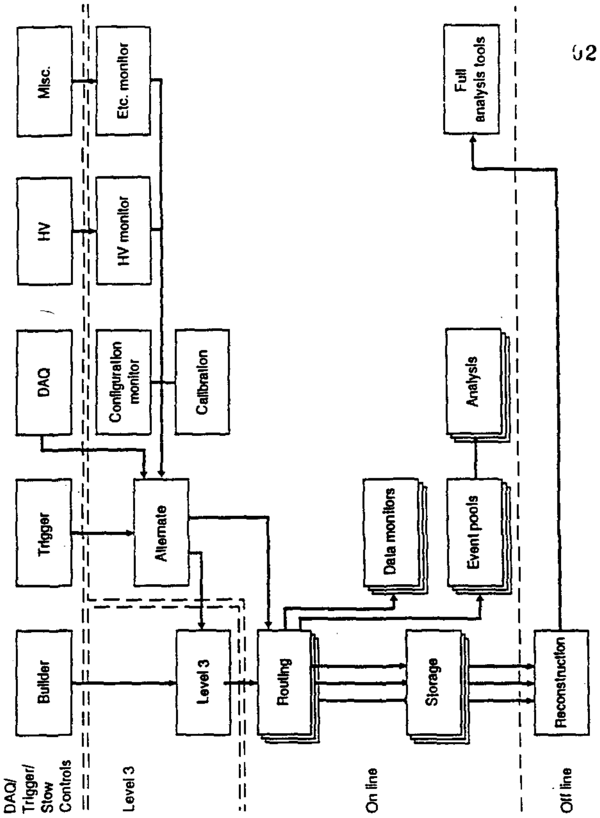
  Operability and reliability
  Data logging: 100 MB/sec, 20 streams + 1MB/sec express line
  Run control

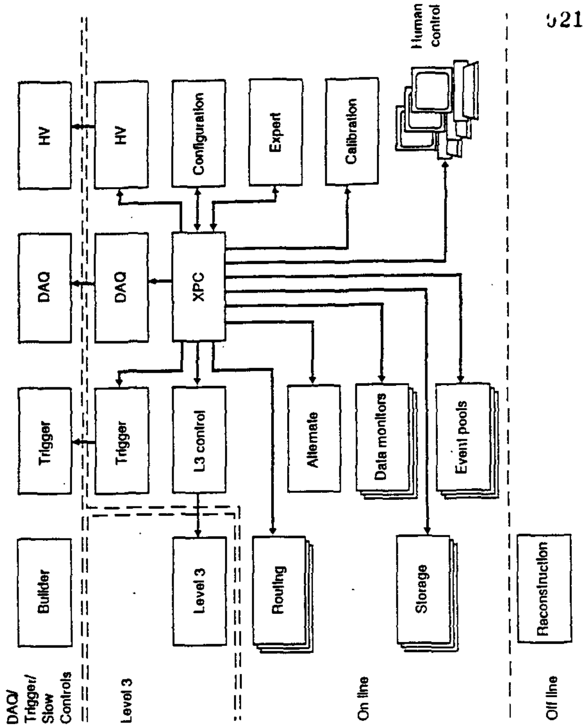
- Insuring Data Integrity

  Data monitoring
  Parameter and configuration management
  Calibration services
  Error detection and alarms
  Diagnostic services
  Database/history services

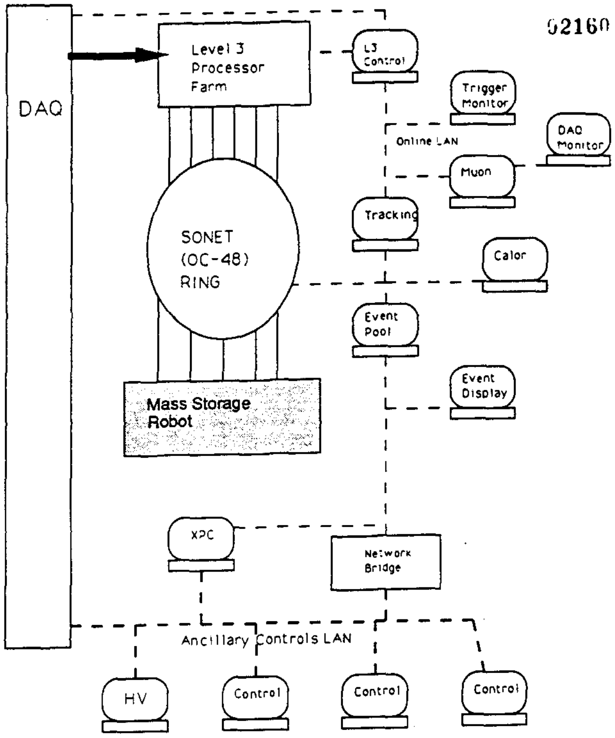
- Physics processing

  Event displays
  Interactive histograms
  Event pools for analysis
  Dynamic full offline analysis framework





92159



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92161

DAQ & ONLINE SUMMARY

- System requirements are understood
- Baseline architecture is understood, will not require bleeding edge technologies
- Design is consistent with goals of standardization, modularity, use of commercial components
- Schedule requires specific technology choices (bus for standard crate, real-time OS) to be made in next 12-18 months

02162

ELECTRONICS R & D PLAN

A. LANKFORD

ELECTRONICS R&D

An Overview for the SSCL PAC

A. J. Lankford
for the **Solenoidal Detector Collaboration**
May 6, 1992

PRESENT ORGANIZATION
of SDC Electronics R&D

Electronics, Data Acquisition, and Trigger Technical Steering Committee

SDC Electronics Integration Group

SDC Electronics Cost/Schedule Group

Electronics, Data Acquisition, and Trigger Technical Steering Committee

Charge:

Prepare Technical Design Report
Direct R&D program leading to TDR.

Reports to SDC Technical/Project Manager and Technical Board.

This group has:

- organized all collaboration and working group meetings for approximately two years.
- guided development efforts and organized full coverage of subsystems, and fostered systems engineering.
- organized preparation of conceptual design reports for each front-end electronics subsystem and for trigger and data acquisition.
- organized a major design review of front-end subsystems (Sept. 91) and reviewed or discussed all conceptual designs.
- prepared R&D plans and allocated R&D funds for FY91 and FY92.

Electronics, Data Acquisition, and Trigger Technical Steering Committee

Membership:

Co-chairpersons and members of SDC Technical Board:

Myron Campbell	Michigan
Irwin Gaines	FNAL
Andy Lankford	UCI
Wesley Smith	Wisconsin
Yoshiyuki Watase	KEK
Brig Williams	Penn

Other members:

Bill Foster	FNAL
Henry Frisch	Chicago
Hiro Ikeda	KEK
Mike Levi	LBL
Richard Partridge	Brown
Luciano Ristori	Pisa
Yoshihide Sakai	KEK

Working Groups:	Leaders:
Front-Ends	Williams, Lankford, Ikeda
Data Acquisition	Gaines, Partridge, Watase
Trigger	Smith, Campbell, Sakai

SDC Electronics Integration Group

This group is constituted of a physicist, or a physicist and an engineer, for each subsystem. It has considered such issues as requirements for:

- Power
- Cooling
- Cabling
- Space

and location and layout of electronics. It interacts with the mechanical integration group and the chief engineer.

SDC Electronics Integration Group

Lead Physicist for Integration:	Andy Lankford
chief (indispensible assistant):	Chris Bebek
Lead Engineer for Integration:	Tom Moore
assistants:	Gene Oberst, Andy DuBois, Ken Hess
Front-end Electronics:	
Silicon	
On detector	Spieler
Off detector	Nickerson
Straws	Williams / Van Berg
Fibers	Baumbaugh
Gas Microstrips	Nickerson
Calorimeter	
Digital Readout	Foster / Yarema
Analog Memory	Levi / Jared
Shower Max	LeDu
Muon	
Wires	Oliver / Chapman / Hess
Counters	Thun / Chapman / Hess
Data Acquisition:	Gaines / Barsotti
Ancillary Controls:	Moore
Online:	Fry
Trigger System:	Smith
Calorimeter	Smith / Lackey
Shower Max	LeDu
Straws, Muons	Chapman
Fibers	Baumbaugh
Silicon, GMD	Nickerson
Global L1	Smith / Lackey
Global L1	LeDu

SDC Electronics Cost/Schedule Group

This group has prepared electronics elements of SDC Cost/Schedule Book.

Lead Physicist for Cost & Schedule:		Andy Lankford
Lead Engineer for Integration:		Tom Moore
assistant:		Gene Oberst
Front-end Electronics:	Coordinator:	Oberst
Straws		Van Berg
Fibers		Baumbaugh
Muons		Hess
Calorimeter		
Digital Readout		Yarema
Analog Memory		Jared
DAQ, Trigger, Controls:	Coordinator:	Moore
Data Acquisition:		Barsotti
Ancillary Controls:		Moore
Trigger		Smith

SUMMARY OF FRONT-END ELECTRONICS

The Challenge: Fast, low-power, often rad-hard, reliable systems with Level 1 and Level 2 buffering and simultaneous signal processing and data readout,
for silicon, scintillating fiber, straw, and gas microstrip trackers, scintillating tile/fiber and forwardcalorimeters, shower max detector, and muon counters and chambers.

The Solution: Readout based upon high-performance custom integrated circuits for analog signal processing and data storage. High degree of architectural uniformity for all detector systems.
e.g.: 8-chan fast, low-noise, rad-hard bipolar preamp/shaper/discriminator chip for wire chamber readout,
16-chan 63-MHz CMOS transient recorder chip with 4 μsec deep memory for calorimeter readout
128-chan rad-hard CMOS data-driven hit buffer for silicon strip readout

The Status: Prototypes of nearly all custom IC's exist.
Conceptual designs of all readout systems exist.

The front-end IC's and systems are our long lead-time items. Equipped with prototype IC's and system concepts, we must now demonstrate that our systems will operate with full performance and full functionality and must complete detailed system designs.

What's Next? Complete the evaluation of custom IC's.
Optimize, design, prototype, and evaluate systems.
Build large test systems for electronics evaluation and detector prototypes.
Assemble and implement systems with full control, calibration, monitoring, readout, and software.

Timescale: Major systems in test beams in 1993.
Complete systems as early as 1996 for some subdetectors.

FRONT-END ELECTRONICS R&D

SCHEDULE CONSTRAINTS

Integration of electronics with detectors:

6/94	11/95	Silicon Tracker
1/95	9/98	Muon System
5/96	8/98	Calorimeter & Shower Max
7/96	8/98	Gas Microstrip Tracker
11/96	6/98	Straw or Fiber Tracker

MAJOR DESIGN MILESTONES

Silicon Tracker:

12/92	Selection of digital storage chip
2/94	Complete design / Begin production

Gas Microstrip Tracker:

1/96	Complete design / Begin production

Straw Tracker:

1/93	Preliminary design review
3/95	Complete design / Begin production

Calorimeter & Shower Max Detector:

6/92	Select readout technology
3/93	Preliminary design review
6/93	Calorimeter prototype beam test
8/94	Complete design / Begin production

Muon System:

11/92	Preliminary design review
6/94	Complete design / Begin production (Regional)
12/94	Complete design / Begin production (Wires)
10/95	Complete design / Begin production (Counters)

FRONT-END ELECTRONICS R&D

Recent R&D Focus:

The recent focus of front-end electronics R&D has been:

- Continued development of the critical signal processing and data storage IC's for each detector subsystem.
- Development of conceptual designs of complete readout systems for each detector subsystem.
- Development of a consistent overall architecture.
- Shared developments and techniques.

Recent R&D Activities:

Development of IC's for signal processing and storage.
Tests of IC's on detectors and on boards.
Support of detector tests.
Conceptual design of readout systems.
Preliminary development of data collection.
Estimates of power, space, cooling, and cabling needs.

R&D Priorities:

- Complete proof-of-principle of critical IC's.
- System tests.
- Evolution of Conceptual Designs.
- Engineering across subsystems.
- Support of detector prototype tests and beam tests.

Front-End R&D Priorities (cont'd)

Complete proof-of-principle of critical IC's:

  - Complete proof-of-principle of signal processing and data storage IC's (see individual subsystems below).

- **System tests:**
  - Demonstrate performance of signal processing in the noisy environment of simultaneous readout, and subsequently of systems of many channels.

- **Evolution of Conceptual Designs:**
  - Continue optimization of system implementations.
  - Complete process of incorporating full functionality into conceptual designs.
    e.g.: calibration,
    initialization,
    monitoring,
    preprocessing.
  - Adapt to SDC standards.

Front-End R&D Priorities (cont'd)

- **Engineering across Subsystems:**
  - Complete development of protocols and interfaces between front-ends and trigger and between front-ends and daq,
    e.g.: front-end control signals,
    minimum spacing between "accept"s.
  - Initiate development of support IC's,
    e.g.: programmable delays,
    low-level differential drivers,
    clock drivers,
    data collection.

- **Support of detector prototype tests and beam tests:**
  - For example,
    tests of modules of straws,
    muon supertower test,
    beam test of prototype calorimeter.

STRAW FRONT-END R&D

Overview:

Preamp, shaper, discriminator, data buffering, formation of trigger primities, and data collection circuits are all mounted on chamber endplate. Packaging of this electronics is challenging, and these circuits are in a high-radiation environment.

R&D Priorities:

- Preamp/shaper/discriminator:
  Complete tests of 8-channel ASD in Tektronics.
  Fabrication of AT&T version.
- Data storage and readout:
  Extend TMC pipeline.
  Convert TMC to rad-hard process.
  Complete conceptual design of L2B.
  Complete conceptual design of DCC.
- System:
  System tests of digital/analog crosstalk.
  Study packaging for mounting on chamber.
  Study cooling.
  Refine system conceptual design.
    - Support chamber tests with ASD's.

MUON FRONT-END R&D

Overview:

Chamber-mounted and base-mounted electronics provide amplified and discriminated signals to nearby crates which buffer and collect data for readout and which form trigger primitives. Design will use ASD's and storage IC's developed for straw readout. The organization of the system is strongly influenced by the trigger requirement of combining information from counters and multiple chamber planes at Level 1.

R&D Priorities:

- Preamp/shaper/discriminator:
  Evaluate straw ASD's.
  Design ASD with required output drive or design CMOS cable driver.
- System:
  Refine system conceptual design.
- Support muon supertower tests.

CALORIMETER (SCA) R&D

including Shower Max Detector

Overview:

Towers:

Preamp/shapers with dual range outputs are mounted near PMT's. SCA cards in crates contain analog storage pending L1/L2 decisions, trigger tower sums, and interface to data acquisition.

Shower Max:

Analog signal processors are mounted near photodetectors. SCA cards in crates contain analog storage pending L1 decision and perhaps pending L2 decisions. If more than 1 bit per hit strip is required by Level 2, then digitization will be performed after Level 1.

R&D Priorities:

- Select calorimeter readout technology.
- Determine Level 2 requirements upon Shower Max.
- Preamp/shapers:
  Fabricate, test, and refine bipolar design for towers.
  Design analog signal processor for shower max.
- Data storage and readout:
  Complete unified design for towers and shower max.
- System:
  System tests of digital/analog crosstalk.
  Refine system conceptual design.
- Support prototype calorimeter tests.

SUMMARY OF TRIGGER

The Challenge: Reduce 10^8 interactions/sec to a manageable number of the most interesting physics events.
Implement this reduction in a discriminating, efficient, and flexible manner.
Define upgradable data paths and processors.

The Solution: Identify and parameterize physics quanta:
$e, \mu, \gamma, jet,$ missing E_T
at early trigger levels. Combine quanta and select at highest level.
Exploit simple fast electronics at first levels, high-performance commercial processors at high levels, and transition from simple to more complex processors at intermediate levels.

The Status: Model three level architecture exists.
Model algorithms to trigger on principal physics exist.
Trigger data paths have been identified.
Prototypes of some trigger primitive IC's exist.

We believe that we know how to select the most interesting physics. Now we must thoroughly study the effectiveness of our strategy and optimize its implementation. Then we can move on to detailed design and implementation.

What's Next? Optimization of algorithms within overall architecture,
i.e.: complete design of architecture.
Thorough evaluation of effectiveness of system.
Implementation of algorithms,
i.e.: design of trigger primitives logic and processors.

Timescale: 1993 Complete conceptual design
1994-5 Perform detailed design

SCHEDULE CONSTRAINTS

1993	Prototype Clock & Control modules needed for tests of front-end systems and for beam tests.
1996	Start of commissioning of Trigger with DAQ.
1997	Serial integration of detector subsystems begins.
1999	Trigger system installation complete.

MAJOR DESIGN MILESTONES

Level 1:

1/93	Start final L1 design.
12/93	Complete L1 design specification.
6/95	Complete L1 design.
6/96	L1 prototypes.

Level 2:

1/94	Start final L2 design.
12/94	Complete L2 design specification.
12/95	Complete L2 design.
6/96	L2 prototypes.

Level 3:

97-99	Coding of L3 algorithms.
99	Installation of L3 processors.

TRIGGER SYSTEM R&D

Recent R&D Focus:

The recent focus of SDC trigger R&D has been a "baseline" 3-level conceptual design which provides a credible solution to the problems of "deadtimeless" event selection at SSC rates. The conceptual design identifies the data which must be extracted from the front-end electronics for each level, as well as a hardware implementation of the event selection criteria.

Recent R&D Activities:

Requirements definition:
  physics,
  times and rates,
  clock and control.
Determination of level 1 latency ("pipeline" length).
Physics simulation.
Conceptual design of architecture.
Definition of:
  inputs from subsystems to each level,
  data paths,
  control paths.
Conceptual design of trigger processors, for L1 & L2.
Development of prototypes of critical components,
  e.g.: clock & control distribution,
  calorimeter adder trees
  straw tracker segment finder
  fiber tracker segment finder
  fiber tracker segment linker
  muon system mean timers

R&D Priorities:

- Evolution of Conceptual Design
- Long Lead-time Components
- Beam Test Related Items
- Detailed Specification of System Components.

Trigger R&D Priorities (cont'd)

- **Evolution of Conceptual Design:**
  - Exhaustive physics simulation of event selection criteria and algorithms.
  - Evolution of Conceptual Design of Architecture
    - Optimize partitioning of event selection criteria among trigger levels.
      - Optimize deployment of algorithms between L1 & L2.
      - Study residual backgrounds at L2, and study strategies for reduction.
      - Optimize deployment of algorithms between L2 & L3.
    - Complete definition of data paths,
      - front-ends to L1,
      - front-ends & trigger to L2.
  - Evolution of Conceptual Designs of Major Trigger Subsystems
    e.g.: intermediate tracker L1 trigger
    silicon tracker L2 trigger,
    global L2 trigger,
    timing system.
  - Definition of interfaces, (allow upgrades).
  - Track technology advances,
    e.g.: fiberoptic data transmission,
    signal and image processors.

Trigger R&D Priorities (cont'd)

- **Long Lead-time Design Items:**
  - Define protocols and interface to front-ends, to allow completion of front-end design.
  - Circuits to form trigger primitives.
- **Beam Test Related Items:**
  - Prototype clock & control module.
- **Begin Detailed Specification of System Components:**
  - Starting w/ definition of modularity & interfaces.

CALORIMETER TRIGGER R&D

Overview:

The calorimeter trigger is based on digital data from trigger towers at 60 MHz. Energies are summed and electrons are identified by patterns of energy deposition, The method of sums within trigger towers, and subsequent sums of trigger towers, depend on particular approach adopted for calorimeter readout (analog memory or digital). Prototype adder IC's have been designed. One type has been tested. A conceptual design of electron pattern logic has been completed.

R&D Priorities:

- Analog trigger tower sum (analog memory readout).
- Develop design for digital adder tree,
  12-bit (analog memory readout)
  "floating-point" (digital readout)
- Develop design for electron pattern & isolation logic.
- Develop electron sorter logic,
  to identify most energetic electrons.
- Develop strategy to put all energy into a single trigger time bucket.
- Investigate techniques for clustering energy and adding energy in fixed cones for Level 2.

SHOWER MAX TRIGGER R&D

Overview:

At Level 1, hits in SMD strips in front of a trigger tower are "OR"ed in order to reject PMT discharges. The "OR" is performed on the analog signal processing card. At Level 2, one or more bits per strip is needed in order to determine shower position (to match to a stiff track) and to examine shower profile. More than one bit per strip will require extraction of pulse height after Level 1.

R&D Priorities:

- Determine the number of bits needed per strip at L2.
- Develop scheme to extract needed bits from f.e.
- Develop strategy and circuit to transform response to energy in a single time sample for trigger.
- Investigate techniques for measuring shower profile.

FIBER TRACKER TRIGGER R&D

Overview:

Stiff track segments are found in superlayers by combinatorial logic. Track segments are also linked using combinatorial logic. Digital ASIC's provide trigger functionality. Prototype segment finder and linker has been constructed in discretes for use in beam test.

R&D Priorities:

- Emulation of trigger in test beam.
- Completion of conceptual design of ASIC's,
  including determination of gate count.
- Study of interconnections for segment linking.

STRAW TRACKER TRIGGER R&D

Overview:

A stiff track segment finder ("synchronizer") is constructed from digital delay chains configured as mean timers. Maximum drift time and momentum cuts are programmable. The circuit's capability has been extensively simulated. Segments can be linked to form tracks. A prototype one-channel synchronizer is undergoing detailed tests.

R&D Priorities:

- Multichannel version of synchronizer.
- Prototype tests with arrays of straws.
- Develop L1 buffer to store segments for L2.

MUON TRIGGER R&D

Overview:

Stiff muon track segments are identified at Level 1 by scintillator and chamber hits using mean timers and coincidences. Combining counters and multiple chamber layers determines organization of muon front-end electronics. At Level 1, p_t is determined from segments within the muon system. At Level 2, p_t is determined by the central tracker or by line-to-line fitting in forward muon system. Prototype mean timer IC's have been tested. A conceptual design of the logic for combining detectors and coordinates exists.

R&D Priorities:

- Test logic of segment finding and time tagging on muon supertower.
- Study association of muon and tracker tracks for L2.
- Study forward muon trigger at L2.
- Refine conceptual design of logic.

ITD TRIGGER R&D

Overview:

The radial layers of the ITD are arranged in a projective geometry in phi. This allows pattern recognition in z-phi space. Straight lines are found at Level 1 and corrected for dip angle. Simulations show the algorithm to be efficient and relatively immune to background. At Level 2, the ITD trigger is identical to that of the silicon tracker.

R&D Priorities:

- Study robustness vs. occupancy of transmission scheme.
- Seek cost-effective way to reduce amount of data transferred off detector.
- Further study of efficiency and rejection.

SILICON TRACKER TRIGGER R&D

Overview:

The axial layers in the barrel and the radial layers in the forward direction of the silicon tracker are used in a two-stage process which identifies tracks by matching patterns of hits to programmed masks, first in coarse roads, then with the full resolution of the silicon tracker. The technique exploits the azimuthal symmetry of the tracker. Outer track segments may be included in the same processor.

R&D Priorities:

- Study the robustness of the first stage of pattern matching in coarse roads.
- Develop technique for pattern matching with full granularity.
- Study effectiveness and efficiency of rejecting conversions.
- Explore possibility of incorporating outer tracker.

SUMMARY OF DATA ACQUISITION

The Challenge: Transport up to *10 GBytes/sec* from F.E.'s to Level 3.
Provide processing power for Level 3 trigger.
Control data flow in F.E.. thru Level 3, to storage.
Monitor operation and performance of detector.
Acheive a manageable, cost-effective solution.

The Solution: Extensive use of parallelism.
System integration of f.e. readout and control protocols.
Highly buffered data collection from f.e. chips.
Data transport on fiber optics.
Parallel event building w/ commercial switching network.
Extensive use of commercial hardware and software from rapidly evolving computer and communications industries.
Modular, scalable hardware/software architecture.

The Status: Architectural modelling of components and system.
Definition of requirements and functionality of system and of interfaces.
Conceptual design of architecture.

We know what we need to accomplish, we can present a case that the tools exist, and we have a conceptual design of the architecture. Now we must commence designing and implementing the system.

What's Next? Architectural model of the complete readout system (*in lieu of a large prototype*).
Crisp definition of the modular pieces of system.
Design and implementation of full system w/ all features.

Timescale:

Test beam system	Mid 93
Technology choices	Oct 93
Component designs	Oct 94

SCHEDULE CONSTRAINTS

1993	Stand-alone data acquisition needed for tests of front-end systems and for beam tests.
1997	Serial integration of detector subsystems begins.
1999	Data acquisition installation complete.

Expensive commercial components should be purchased as late as possible to take advantage of falling costs.

MAJOR DESIGN MILESTONES

6/93	Stand-alone systems for test beams.
10/93	Complete design specification, including technical choices.
12/94	Completion of component design.
3/96	Prototypes of all components.

DAQ SYSTEM R&D

Recent R&D Focus:

The recent focus of data acquisition R&D has been a "baseline" conceptual design which provides a credible solution to the problems of high bandwidth and "deadtimeless" operation. The architecture allows scaling performance to very high levels. It also allows advantageous use of future progress in communications and computing technology.

Recent R&D Activities:

Requirements definition.
Conceptual design.
Architectural modelling.
Development of front-end protocols.
Preliminary development of data collection.
Prototype barrel-shifter event builder complete.

R&D Priorities:

- Evolution of Conceptual Design
- Long Lead-time Design Items
- Beam Test Related Items
- Detailed Specification of System Components.

DAQ R&D Priorities (cont'd)

- **Evolution of Conceptual Design:**
  - Optimize baseline.
  - Comprehensive architectural model of system, including detailed inclusion of subsystems, and simulation of control mechanisms. Model *in lieu of* system prototype.
  - Initiate systems engineering,
    e.g.: common protocols and control for front-end systems,
    issues of large system design, reliability & redundancy.
  - Investigate technology choices,
    e.g.: standard daq crate,
    event builder,
    control/monitoring network.
  - Track technology advances,
    e.g.: fiberoptic data transmission,
    switching networks.

DAQ R&D Priorities (cont'd)

- **Long Lead-time Design Items:**
  - Define protocols and interface to front-ends, to allow completion of front-end design. Initiate design of data collection circuits.
  - Some components of event builder, such as input queuing network.
- **Beam Test Related Items:**
  - Standalone daq systems.
  - Software for standalone daq systems.
- **Begin Detailed Specification of System Components:**
  - Involves:
    technology tracking
    definition of modularity and interfaces.

02195

OFF-LINE COMPUTING AND SOFTWARE DEVELOPMENT

L. PRICE

Price

SDC OFFLINE COMPUTING

PAC Review of SDC

L. E. Price
May 6, 1992

SDC OFFLINE COMPUTING FUNCTIONS

Production Reconstruction

Event Filtering and analysis

Simulation

Communication

Software Development

Calibration

CONTRIBUTORS TO SDC COMPUTING PLANNING

SDC collaboration members

SSCL Physics Research Computing Group

IBM Federal Systems Company (Houston)

Semi-independent R&D projects

EVENT SIZE AND PROCESSING

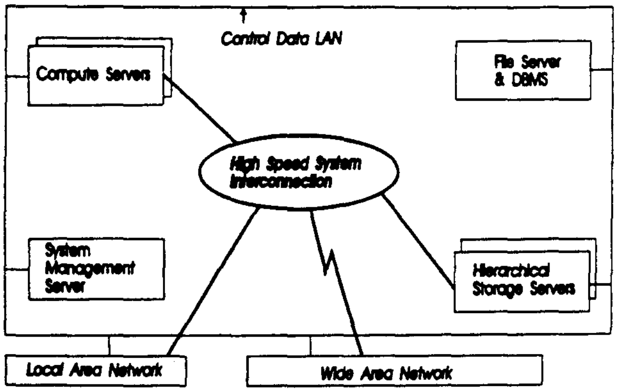
Assumptions

Trigger Rate	100 Hz
Event Size	1 MB
Processing for reconstruction	1000 SSCUPS sec/event
DST Event Size	100 KB
Processing for analysis/histo.	10 SSCUPS sec/event

Hardware Requirements

Data recording rate	100 MB/sec
Annual storage	2 PB
Production processing	10^5 SSCUPS
Master DST at SSCL	100 TB
Working DST	10M events, 1-10 TB
Analysis Processing (distrib.)	10^5 SSCUPS total 3 TB fast storage 30 TB med. sp. stor.

02200



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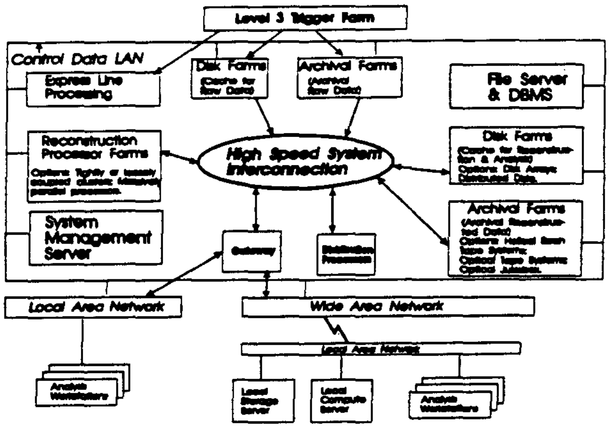

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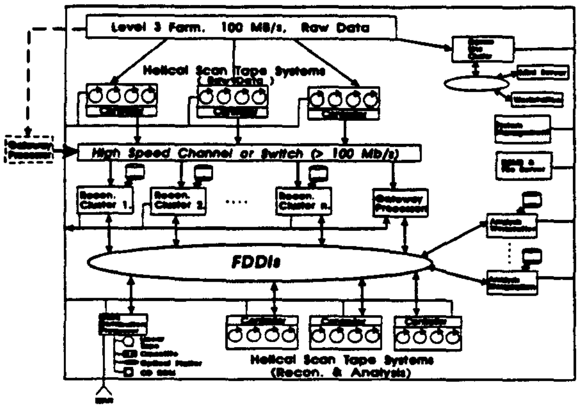


02203

Production System Example

Data Reconstruction Ranch

Compute servers (20 x 200 SSCUPS)	25
Cabinet, bus, power supply	1
CPU Boards (4 CPUs w. 512 MB/ board)	5
Disk (5 GB)	4
Network interface	2
Basic software	
Control/management workstations	5
Tape drives	5
Raw data tape library	
Data servers	3
Recorders	3
Tape robot	1
Control/management workstation	1
Internal network	

Analysis Tape Library

Recorders	20
Tape robot	1
Control/management workstations	5
Internal Network	
Data Servers to analysis system	20

Simulation Facility

Compute servers	25
Disk Arrays	1.6 TB
Control/management workstation	1
Tape drive	1
Internal network	

Express-line cluster

Software Requirements

"Open" operating system: UNIX/POSIX

Portability

Modularity

Graphical User Interface

- Analysis "without programming" largely

Programming languages

- Fortran 90 (including Fortran 77)
- C++ (including C)

Kernal system with basic system provided by computing group

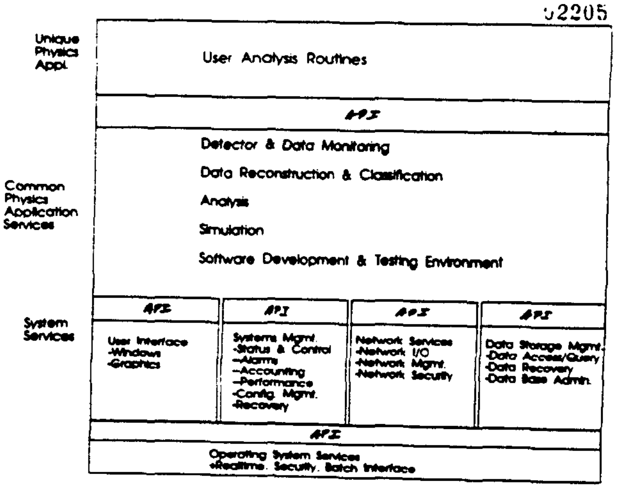
Detector-oriented software provided by subsystem groups

Hierarchy of engineering and documentation standards

Review and certification process for all production code

Database organization of data

- Metadata: keys and index files widely accessible
- Hierarchical storage
- Ability to read selected portions of event



Unique Physics Appl.

User Analysis Routines

API

Common Physics Application Services

Detector & Data Monitoring

Data Reconstruction & Classification

Analysis

Simulation

Software Development & Testing Environment

System Services

API	API	API	API
User Interface -Windows -Graphics	Systems Mgmt. -Status & Control --Alarms --Accounting --Performance -Config. Mgmt. -Recovery	Network Services -Network I/O -Network Mgmt. -Network Security	Data Storage Mgmt. -Data Access/Query -Data Recovery -Data Base Admin.

API

Operating System Services
-Realtime, Security, Batch Interface

ANALYSIS SYSTEM

Regional Centers

About 10
- 5 in US
SSCL
KEK
Pisa
.
.
.

Each system

- > 10^4 SSCUPS Processing
- 300 GB fast storage
- 3 TB medium speed storage
- Filter 1000 events/sec

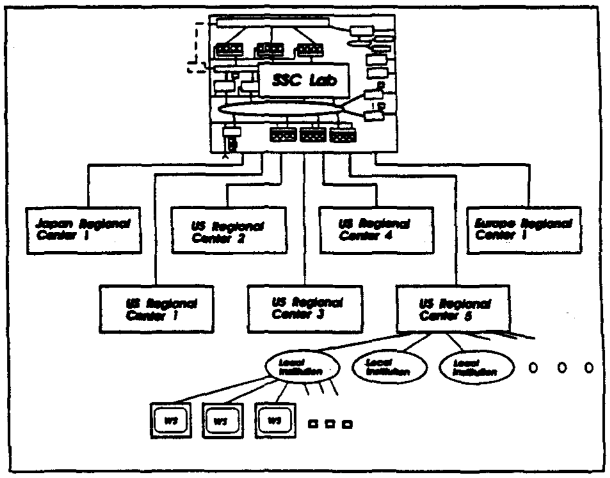
Local Institutions

1 Midrange workstation per physicist doing analysis
(or equivalent X-terminal + departmental computer)

> 100 SSCUPS + 10 GB disk each user

Histogram > 100 events/sec

Use regional center or SSCL for larger jobs



02208

VERIFICATION OF HARDWARE DESIGN

Simulation with RESQME

02209

COMMUNICATIONS REQUIREMENTS

Data Networks

From online system to offline	1 Gb/s
Around SSCL ring (to production system?)	"
To analysis systems at SSCL and regional centers	"

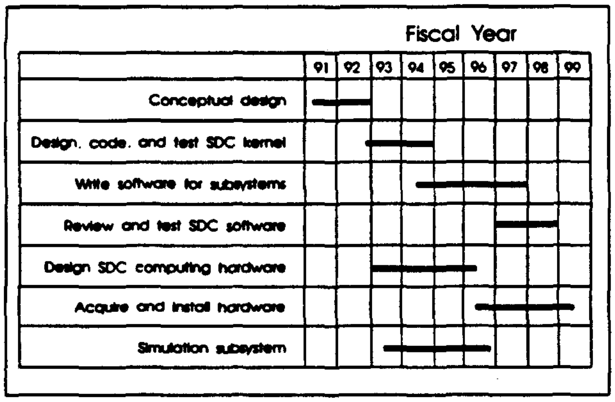
Video

Conference rooms

Workstations

OFFLINE COMPUTING SCHEDULE

02210



SDC COMPUTING SCHEDULE & MILESTONES

02211

Milestone	Hardware	Date
Fix baseline design		1/92
Baseline cost estimate		3/92
Final design		1/96
Acquire production system	1%	1/97
	10%	1/98
	100%	3/99
Acquire analysis system	10%	1/98
	100%	9/99

Milestone	Software	Date
Identify software development systems	Kernel	10/92
	Detector Code	10/03
Core system:		
Requirements analysis		6/92
Functional specification		10/92
Complete design		10/93
Complete coding Release 1		10/94
Complete testing Release 1		10/95
Physics/Detector systems:		
Requirements analysis		5/94
Functional specification		10/94
Complete design		10/95
Complete coding Release 1		10/97
Complete testing Release 1		10/98
Simulation:		
Requirements analysis		9/92
Functional specification		1/93
Complete design	Rel.1	1/94
	Rel.2	10/95
Complete coding	Rel.1	1/95
	Rel.2	10/96
Complete testing	Rel.1	1/96
	Rel.2	10/97

Hardware Costs at SSCL

02212

Table 10-7
SDC computing costs.

Cost Element	FY92 M$
Production storage system:	
Tertiary storage system	3.70
Communications link to online	0.25
Production computing farm (10^5 SSCUPS)	6.00
Production disk system(s)	1.50
Software	2.00
Data distribution system	1.00
Express line system	1.00
Simulation system (10^5 SSCUPS)	6.00
Local analysis system	2.20
External Networking	0.25
Total	23.90

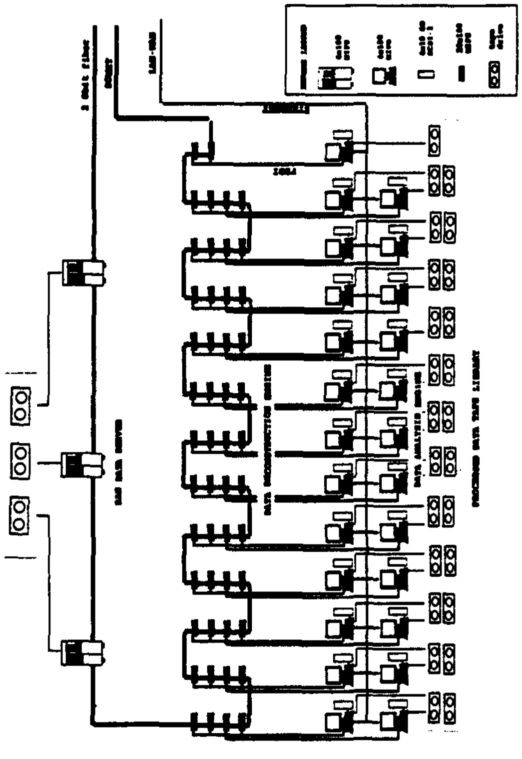
Scaling assumptions:
Cost of cpu ÷ 1.4 /year
Cost of storage ÷ 1.2 /year

Effort at SSCL 02213

Table 10-8
SSCL manpower required for SDC computing.

Task	FTE-yr.
SDC Computing Support group 4(1992) - 10(1999)	25
Hardware	
Requirement analysis	3
System design	6
System modeling	2
Procurement	2
Installation	5
Testing	5
Software	
Core system (production and analysis)	
Requirements analysis	5
Design	10
Coding	5
Testing	5
Reviews	2
Documentation	3
Physics/Detector Systems	20
(additional 80 FTE-yr provided by the SDC)	
Simulation software	10
(additional 40 FTE-yr provided by the SDC)	
	118

02214



CONCEPTUAL DESIGN - SDC OFF LINE COMPUTING

02215

SDC OFF-LINE COST ESTIMATE

	A	B	C	D	E	F
1	WBS NUM	WBS OR ACTIVITY DESCRIPTION	UNIT	QTY	COST EA($K)	TOTAL ($K)
2						
3	10.0	OFF-LINE COMPUTING				19181
4						
5	10.1	Reconstruction Ranch	1E05 SSCUPS			6120
6	10.2	Analysis Tape Library	25 DRIVES, 1 PB ROBOT			5795
7	10.3	Analysis Facility	1E04 SSCUPS			1326
8	10.4	Simulation Facility	1E04 SSCUPS			1326
9	10.5	Express Line Cluster				232
10	10.6	Raw Data Tape Library	3 DRIVES			3505
11	10.7	Control LAN				352
12	10.8	System Management	(Included in each system)			0
13	10.9	DBMS and Server	(HW Included in analysis)			100
14	10.10	Data Distribution Center				425

Page 1LRC D

92216

Planned Computing Organization

Computing Manager

At SSC Laboratory

Area Coordinators

- Core software
- Detector software
- Networking and Communications
- Production system
- Analysis server system
- Simulation system
- Regional centers

Detector software coordinators

- Tracking
- Calorimetry
- Muon

92217

Committees

- Computing Technical Committee
  - Plan SDC computing system
  - Assess progress
  - Advise manager
- Software Committee
  - Core software coordinator
  - Tracking software coordinator
  - Calorimeter software coordinator
  - Muon software coordinator
- Production Software Review Board
  - Certifies software for use in production reconstruction
- Computing review committee
  - High level review by experts inside and outside of SDC

Physics Research Computing Group

92218

R&D Needed for SDC Computing

Data Storage and Access

- HPCCI Project: ANL, UIC, UMd, LBL, SSCL
- IBM IRAD

Software Engineering, CASE

- SSCL PRD computing group starting studies

Modular Software Architectures

Human Interfaces

- Active work needed to take advantage of industry developments
- Graphical interfaces
- Visualization
- Voice input

OFF-LINE COMPUTING AND SOFTWARE DEVELOPMENT

C. DAY

Off-line Software Development

SDC PAC Review
May, 1992

Christopher T. Day
LBL ICSD/STA

Overview

- Very large effort
  - Unprecedented quantity of data
  - CDF has 1 Meg lines of code; more expected for SDC
- Multiple components from varied sources
  - Operating system, compilers, etc.
  - Core system
    - Process distribution and communication
    - User interface
    - Data access/data repository
    - Processing control
    - Standard HEP software as appropriate
    - Professionally written for the most part

Overview {cont.}

- Multiple components {cont.}
  - Subsystem Reconstruction
    - Built on Core services
    - Written by physicists familiar with subsystems
  - Individual physicists analysis
    - Built on Core services and contributed code
    - Written by physicists for personal use
  - Simulation
    - Built on Core services
    - Written by physicists familiar with subsystems
  - Level 3 trigger
    - Built on specialized Core services
    - Not off-line, but specialized versions of contributed code

---

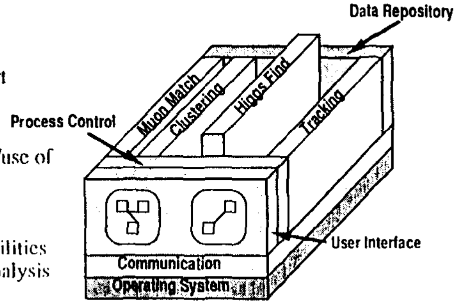
New Approaches

- Data modeling
  - Working with extended relational and object oriented styles
- Data access and storage
  - Moving from Zebra to database techniques
- Use of standards for portability
  - Posix, X windows, Motif, DCE, *etc.*
- Software engineering
  - Commercial, tool based systems
  - Rigor matched to use of software
- Languages
  - FORTRAN 90 for backward compatibility
  - C++/C for object-oriented and service level programming

Work in progress

- Core software task force
- Data modeling task force
- Software development task force
- HPCCI database computing project
- Analysis environment development
- Simulation software

Software Architecture



- Frameworks
  - Fixed support services
  - Simplifies construction/use of modules
- Modules
  - Reusable facilities to support analysis
- All components replaceable

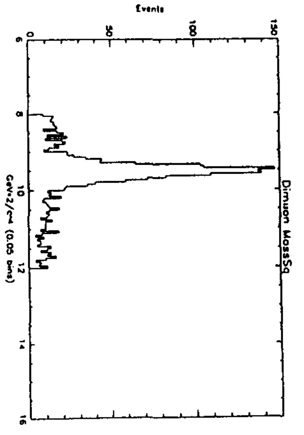
Database Computing Project

- Collaborative effort by LBL, ANL, UIC and U. Maryland
- 5 year project
- Funded by DOE's HPCCI program & SSCL
  - $1M+ for FY92
- Proof of principle systems already
  - Relational database system
  - Object-oriented database systems
- Major focuses
  - Scale > 4 orders of magnitude
  - Develop physicist usable interfaces

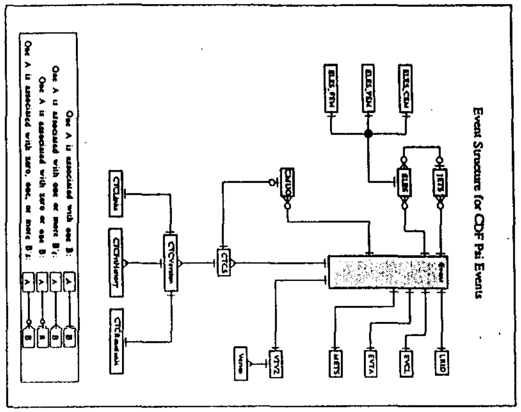
Schedule

- Conceptual design due end FY92
- Code design, code and test FY92 through FY94
- Start subsystem code 3Q FY94, test and review FY97 through FY98
- Simulation subsystem 3Q FY93 through FY96

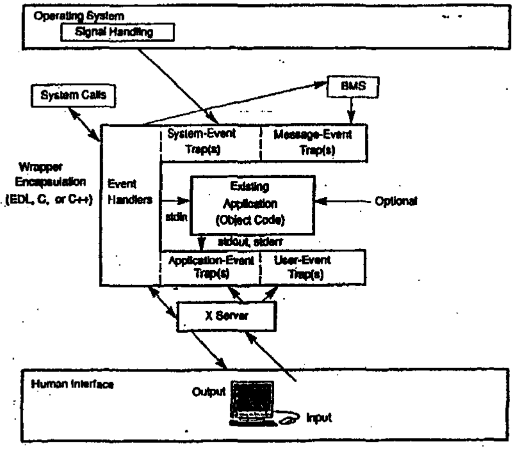
Ψ Plot



Ψ Data Structure



Message Based Communication



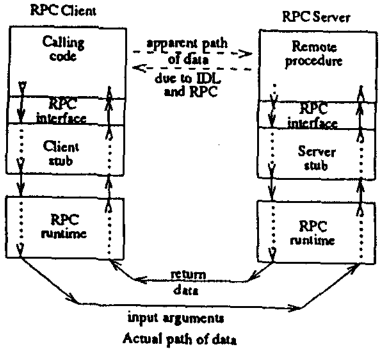
"Horizontal" Event Storage

- All data for a single event is *not* stored together
- One database for each type of component bank—all bank instances for all events in that database
- Database never opened if its banks are not needed in filter
- Rarely used data migrates to backing store even if other parts of the event are frequently used

Advantages

- Collaboration
  - Stable, robust system
    - Production
    - Level 3
  - Reuse of code and minimization of maintenance
- Everyday user
  - Concentrate on analysis of interest
  - Override standard modules when desired
  - Multiple modes
    - Interactive
    - Batch
  - Most complexity hidden in framework
- Allows transparent parallelism

Remote Procedure Call Communication



Simulation Software

- *Current system to remain in use for 2-3 years*
- Replacement system to be integrated with SDC Core software
- Reuse existing code as much as possible
- Replacement system to be developed in parallel to Core software and feedback requirements to it

---

Processing Control

- Understands overall flow of analysis process
- Different processing control for different processes
  - Production process
    - Multiple streams
    - Batch mode
    - High reliability
  - Level 3 process
    - Stripped down for efficiency
  - General user analysis process
    - High flexibility
    - Interactive or batch
    - Investigating dataflow models for parallelism

Example Process Production

- Certification
  - Submitted code must have:
    - Requirements Spec., Design Doc., User's Guide
    - Test suite
    - Read by at least one other person
- Integration/build
  - Automated dependency and build tools
  - Configuration control
  - Final configuration approved at collaboration level
- Testing
  - Automated regression testing on all test suites
  - Problems referred to developer, not fixed by production team
  - Problem resolution tracked by tools

Software Development Process

- Industry developed, tool-based methodology
- Probably object-oriented design and analysis methodology
- Not forced on everyday users, but contributed code must be incorporated
- Maximum use of tools to check methodology adherence
- Automated tools for configuration control and regression tests
- Potential to gather management info for schedules, cost, etc.

Example Process Level 3

- Initial build similar to Production process
- Swat team approach to on-line changes
  - Expedited process, short circuit some approval boards
  - Scope of changes determined before changes made
  - Leave audit trail of all changes
- Swat team supported by
  - On call experts in particular areas
  - Good documentation
  - Analysis tools
  - Test suites

Software Migration

- Important filters and intermediate analyses start as everyday code
- Need to migrate from everyday to production/on-line
- Fit to framework →
  - All frameworks have same interface to communications systems and data repositories
- Fit to methodology →
  - Everyday code is free of methodology conformance while everyday, but conformance *required* for acceptance

Example Process
Everyday User

- Central group provides
  - SDC Application Developer's Toolkit
  - SDC Application Developer's Style Guide
  - Problem support on Core software
  - Safeguards against runaway user code
- User free of development methodology
- User fully responsible for
  - Testing
  - Maintenance
  - Code control
  - Documentation
- Code for common use must be certified

Summary

- Very large effort
- Phased approach
  - Core services first
  - Subsystem code to fit into Core framework
  - Distributed software development
  - Let the methodology fit the code
- Flexible architecture
- Selected use of modern software technologies
- Some R&D left
  - Data access and storage
  - Point and click physics analysis interface

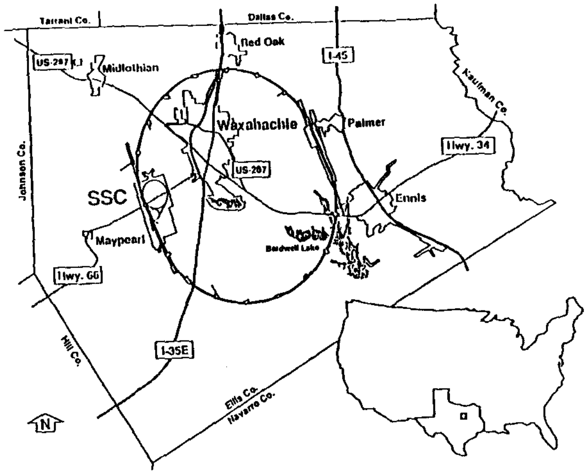
PARALLEL SESSION F:

INTERACTION HALLS/ FACILITIES/INSTALLATION

OVERVIEW AND SCHEDULE

T. THURSTON

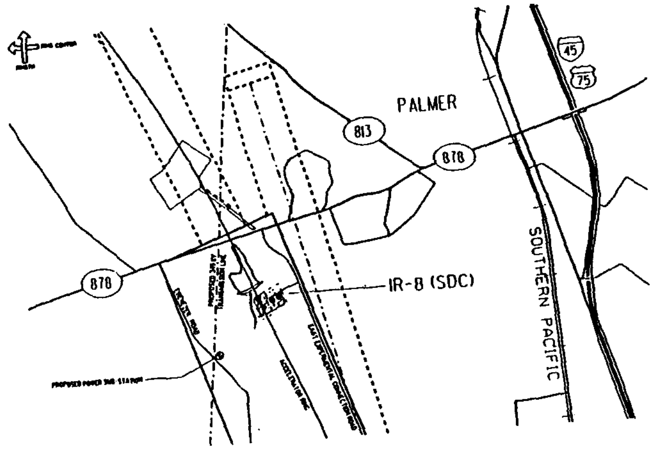
Assembly/Installation Facilities



OVERVIEW

Tim Thurston

Assembly/Installation Facilities



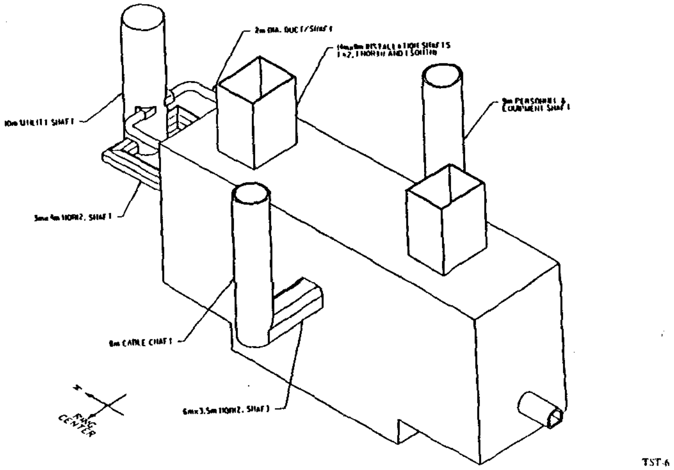
Overview:

Interaction Halls

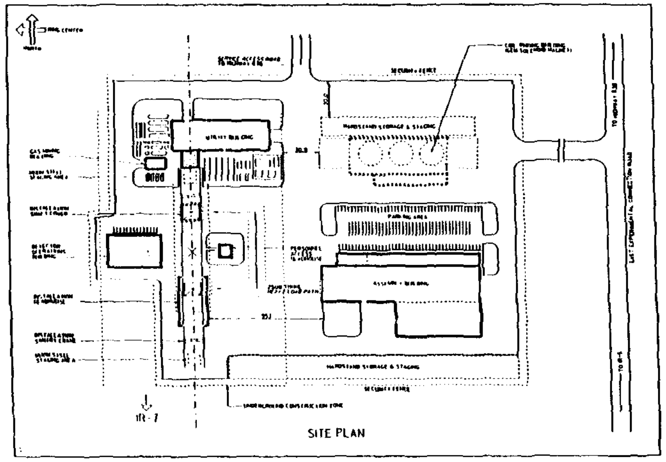
Facilities &

Installation

U/G Hall Isometric



Surface Facilities Layout



Assembly Plan

- Component Level Assembly - Most Provided At Design Institution - Small Assemblies Or Components Shipped To IR-8 Site
- Subsystem Assembly - Sub-Assembles & Components Stagged & Assembled Into Subsystems At IR-8 Assembly Facilities (Surface)
- Final Assembly (Installation) - Subsystems Final Assembly At IR-8 Interaction Hall

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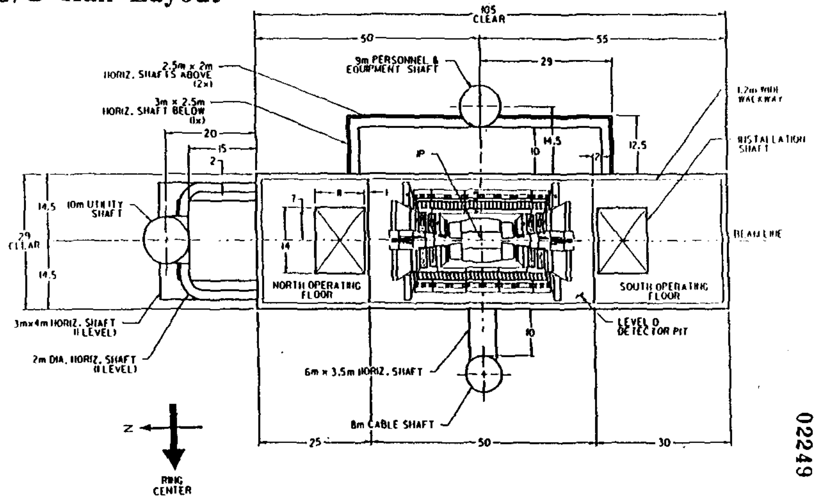
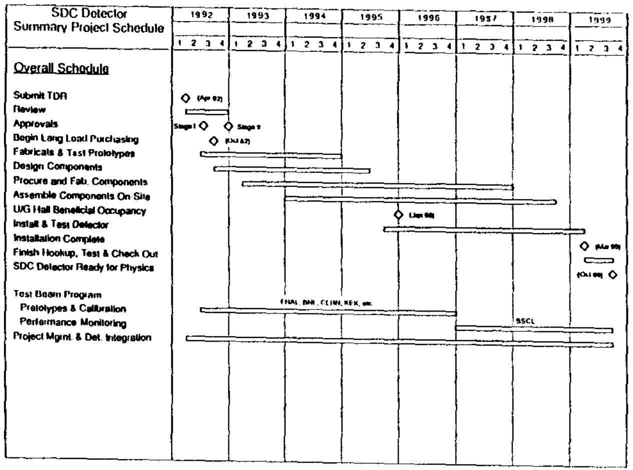
U/G Hall Layout



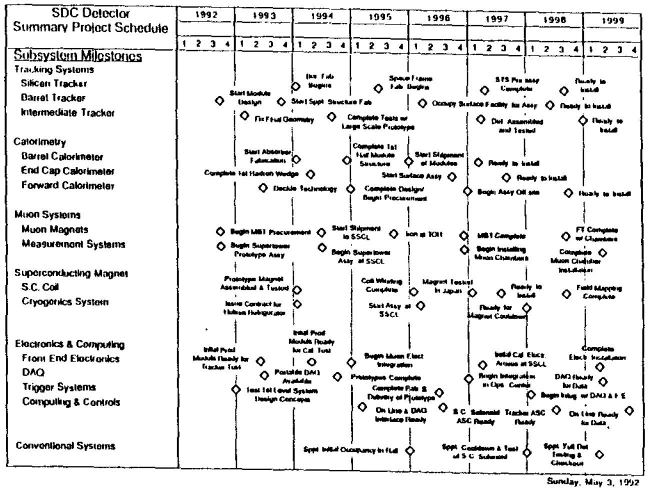
Facility Occupancy Requirements

Building	SDC Date	"Baseline" Date	Months Delayed
Assembly Building			
Hi-bay Assembly Area (BOD)	Jan-94	Aug-94	7
Storage Area (BOD)	Jul-94	Aug-94	7
Office/Shop Area (BOD)	Jul-94	Aug-94	7
Experimental Hall			
Experimental Hall (JOD)	Oct-95	Jan-96	3
Experimental Hall (BOD)	Jul-96	Aug-96	1
Installation Facilities			
Headhouse	Jan-96	Oct-96	9
Gantry Crane	Oct-95	Oct-95	-
Shaft Cover	Jan-96	Jan-96	-
Utility Building (BOD)	Jul-96	Jul-96	-
Personnel & Equipment Access Building (BOD)	Jul-96	Jul-96	-
Detector Operations Building (BOD)	Jan-97	Jan-97	-
Gas Mixing Building (BOD)	Mar-97	Mar-97	-

Project Schedule

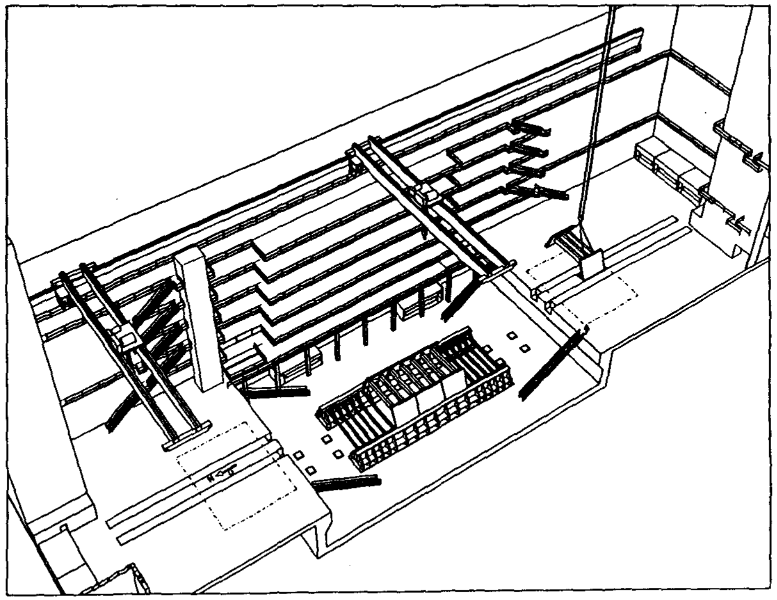


Project Milestones



INSTALLATION PLAN

D. BINTINGER



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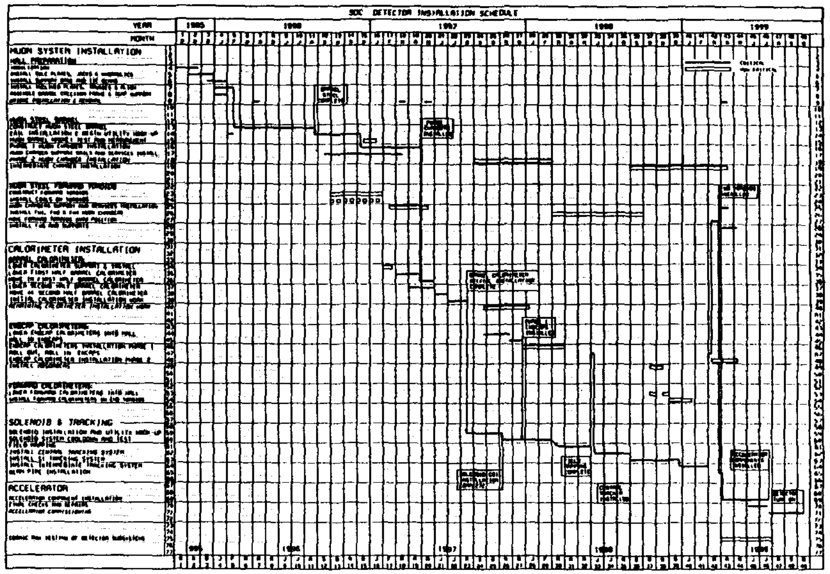

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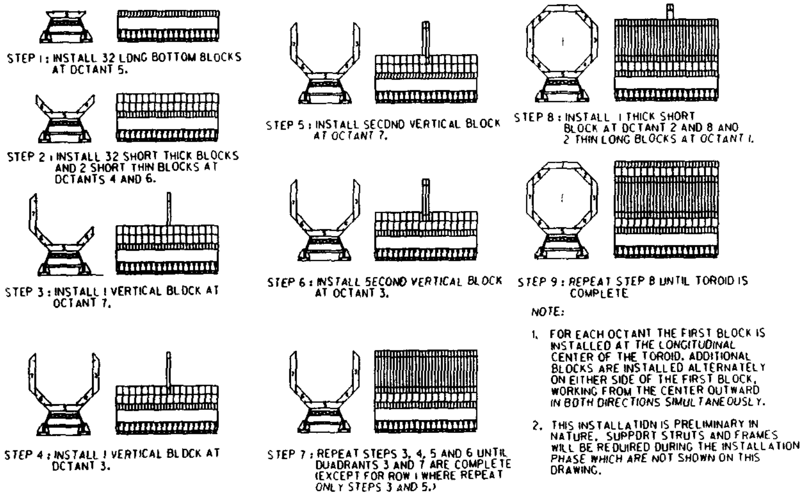


STEP 1 : INSTALL 32 LONG BOTTOM BLOCKS AT OCTANT 5.

STEP 2 : INSTALL 32 SHORT THICK BLOCKS AND 2 SHORT THIN BLOCKS AT OCTANTS 4 AND 6.

STEP 3 : INSTALL 1 VERTICAL BLOCK AT OCTANT 7.

STEP 4 : INSTALL 1 VERTICAL BLOCK AT OCTANT 3.

STEP 5 : INSTALL SECOND VERTICAL BLOCK AT OCTANT 7.

STEP 6 : INSTALL SECOND VERTICAL BLOCK AT OCTANT 3.

STEP 7 : REPEAT STEPS 3, 4, 5 AND 6 UNTIL QUADRANTS 3 AND 7 ARE COMPLETE (EXCEPT FOR ROW 1 WHERE REPEAT ONLY STEPS 3 AND 5.)

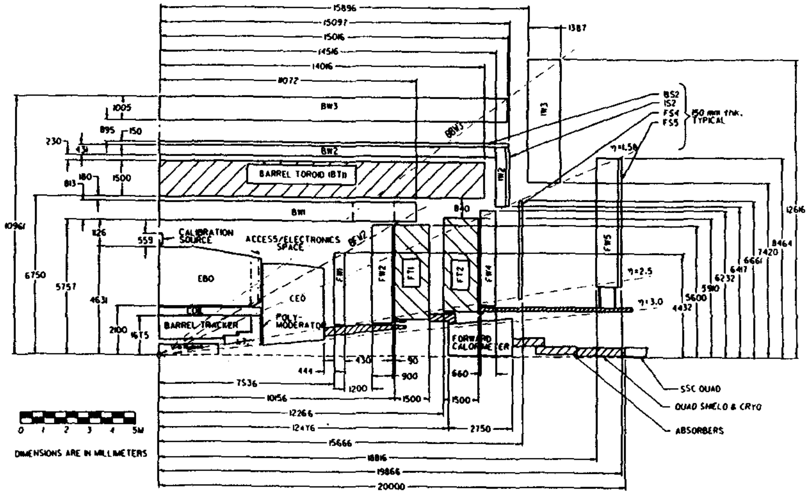
STEP 8 : INSTALL 1 THICK SHORT BLOCK AT OCTANT 2 AND 8 AND 2 THIN LONG BLOCKS AT OCTANT 1.

STEP 9 : REPEAT STEP 8 UNTIL TOROID IS COMPLETE

NOTE:

1. FOR EACH OCTANT THE FIRST BLOCK IS INSTALLED AT THE LONGITUDINAL CENTER OF THE TOROID. ADDITIONAL BLOCKS ARE INSTALLED ALTERNATELY ON EITHER SIDE OF THE FIRST BLOCK, WORKING FROM THE CENTER OUTWARD IN BOTH DIRECTIONS SIMULTANEOUSLY.
2. THIS INSTALLATION IS PRELIMINARY IN NATURE. SUPPORT STRUTS AND FRAMES WILL BE REQUIRED DURING THE INSTALLATION PHASE WHICH ARE NOT SHOWN ON THIS DRAWING.

02259



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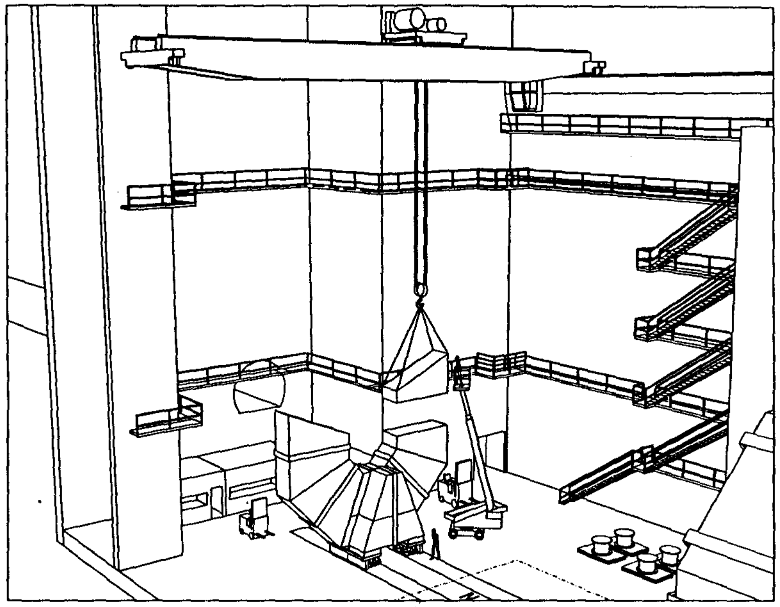

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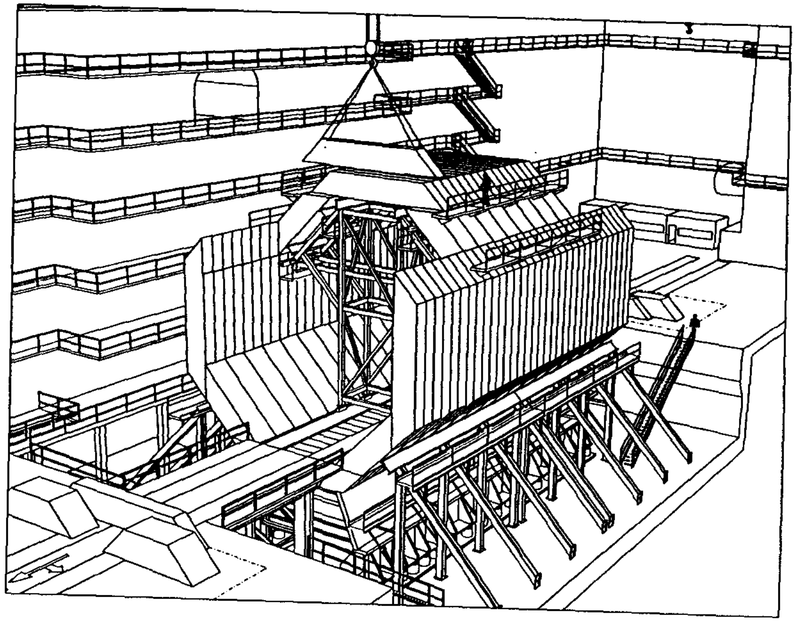

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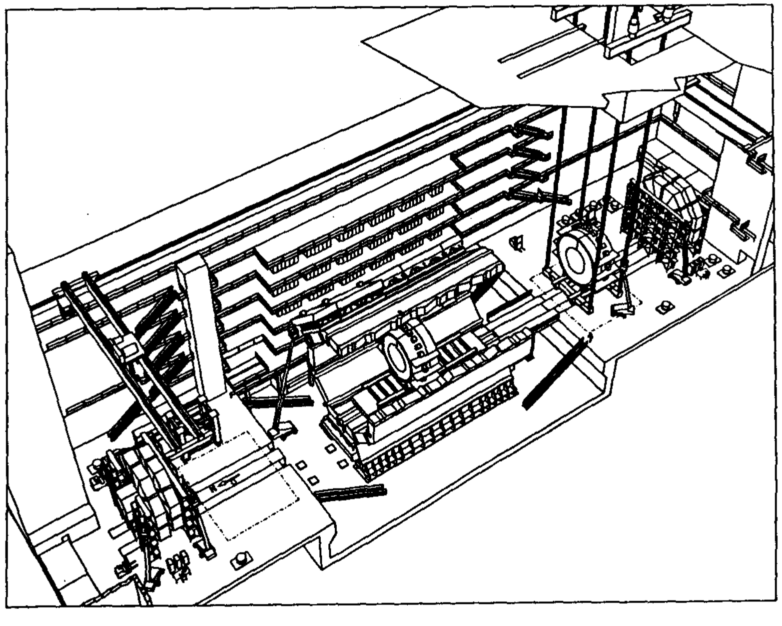

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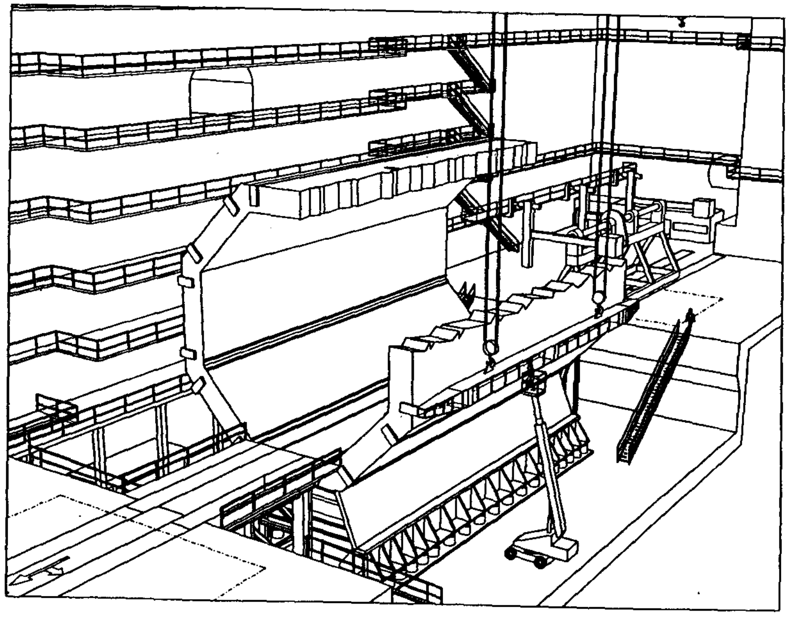

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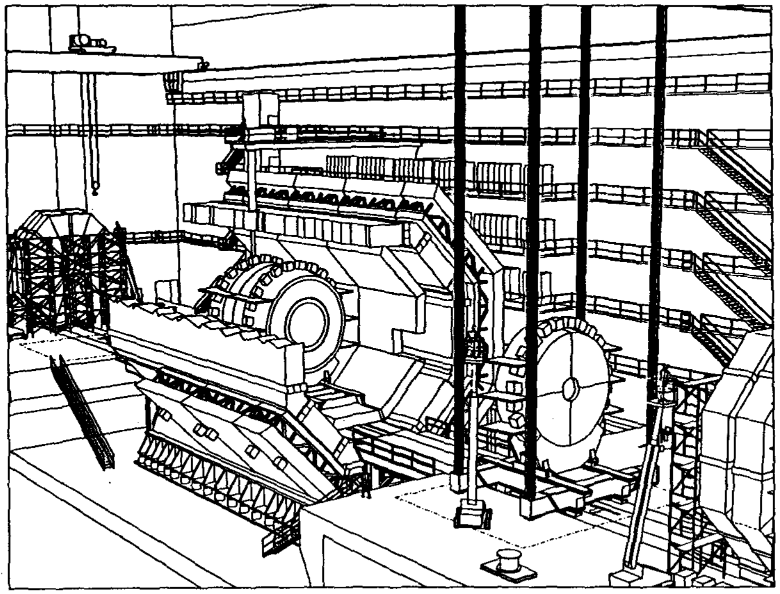
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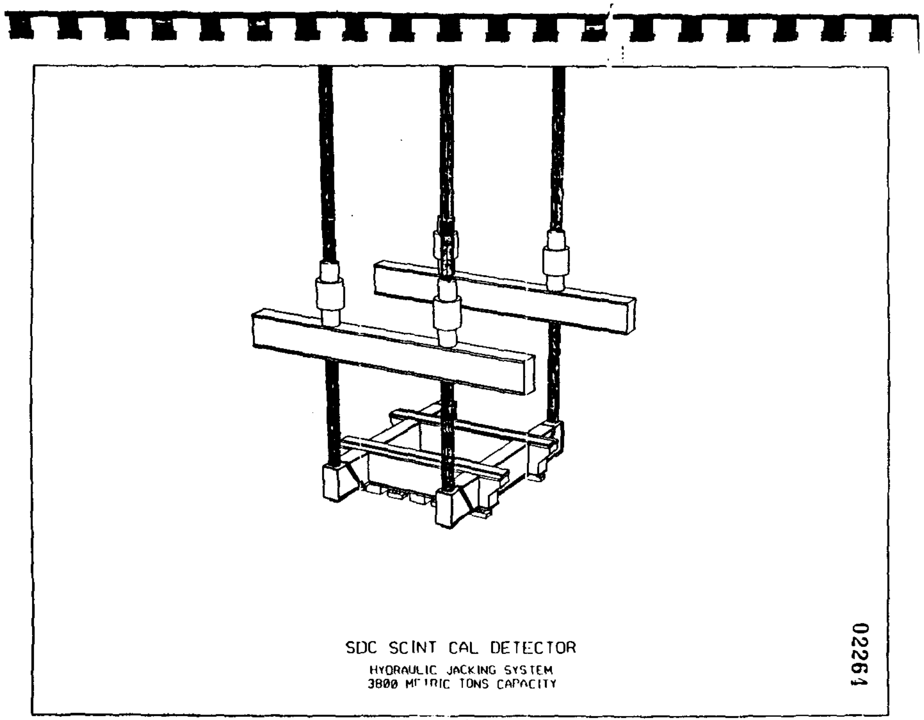
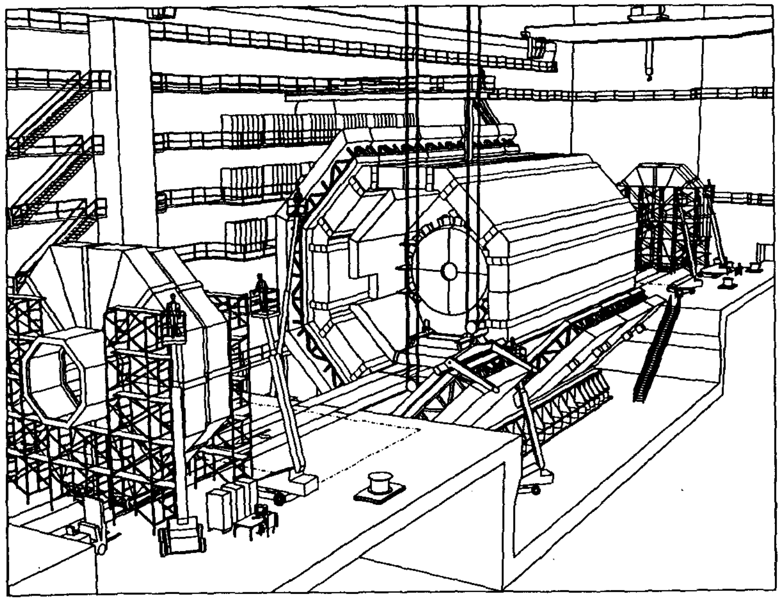

SDC SCINT CAL DETECTOR
HYDRAULIC JACKING SYSTEM
3800 METRIC TONS CAPACITY
02264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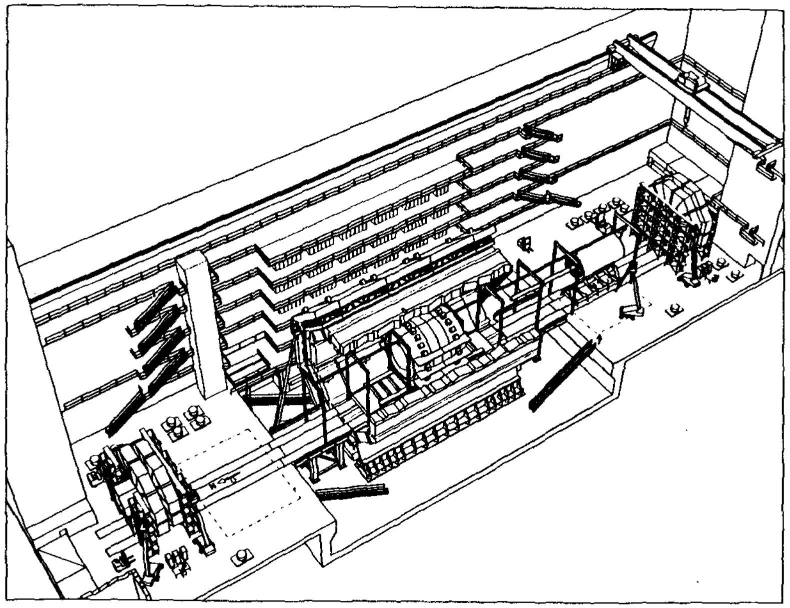
02265

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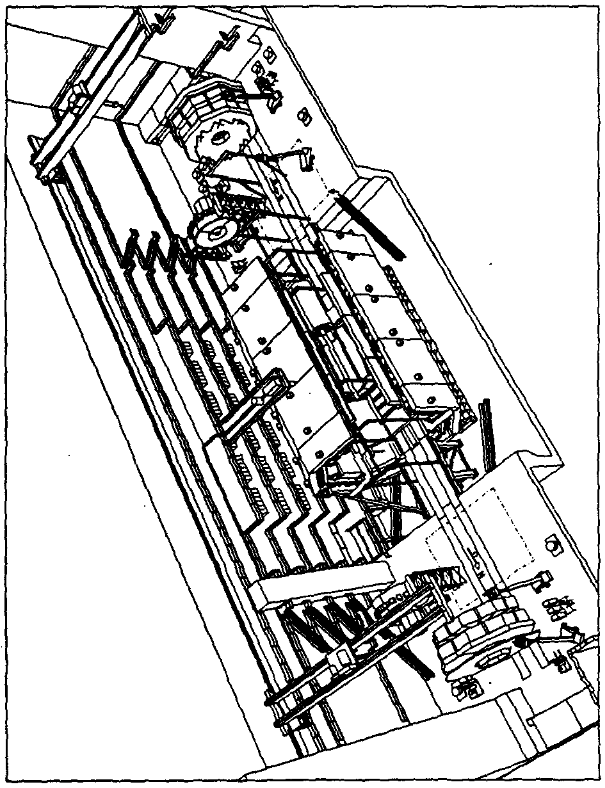

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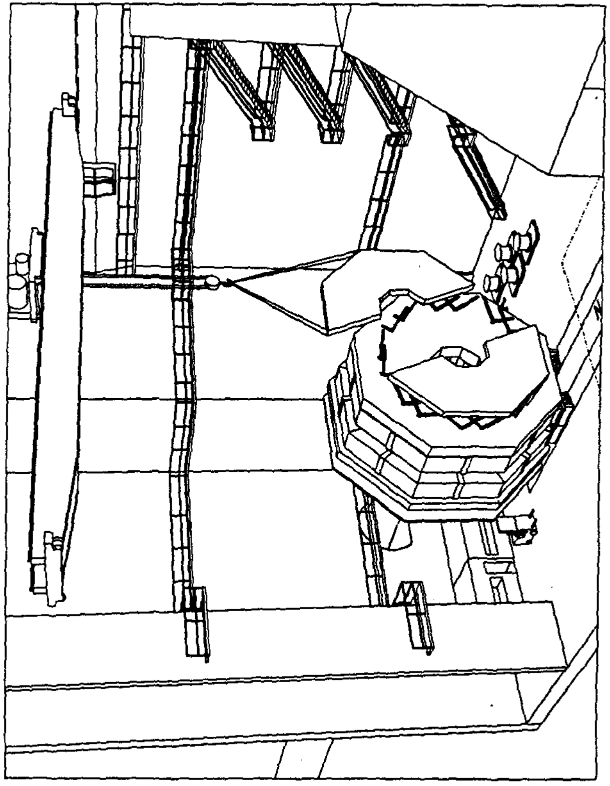

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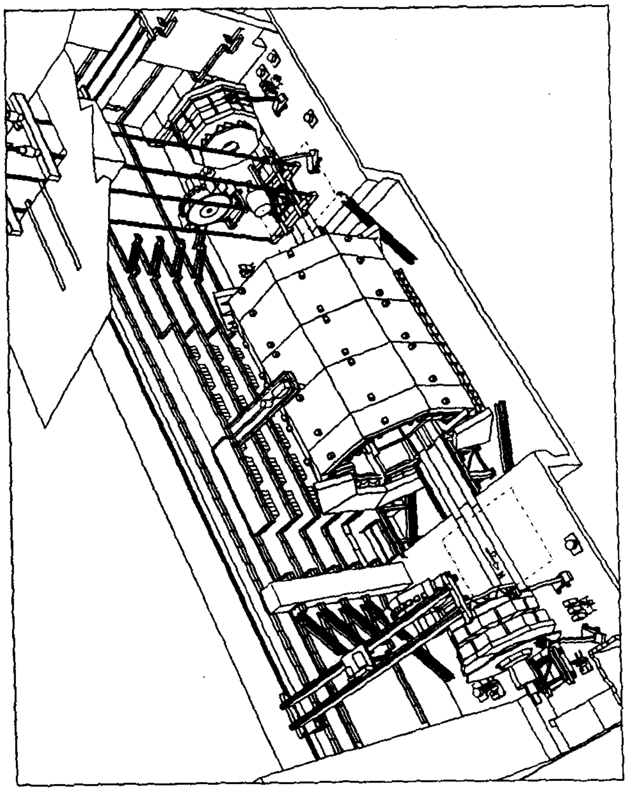

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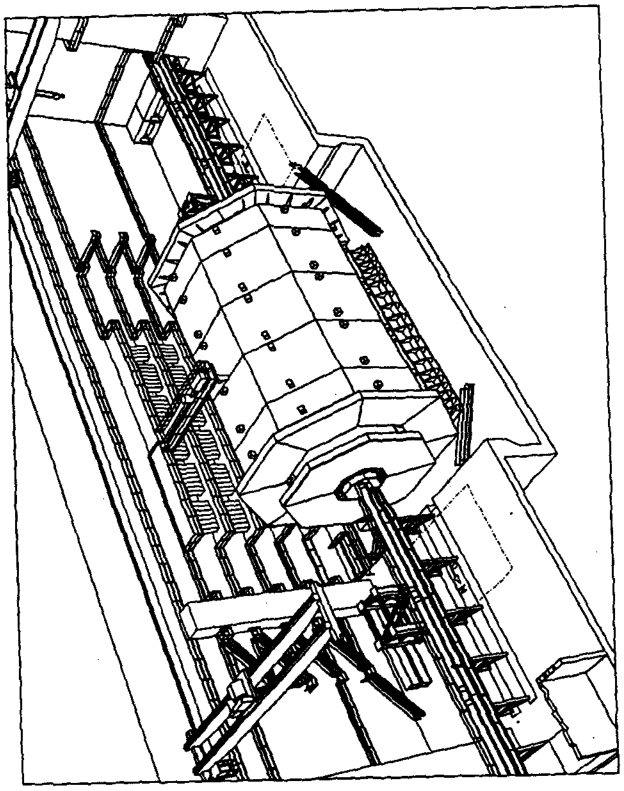
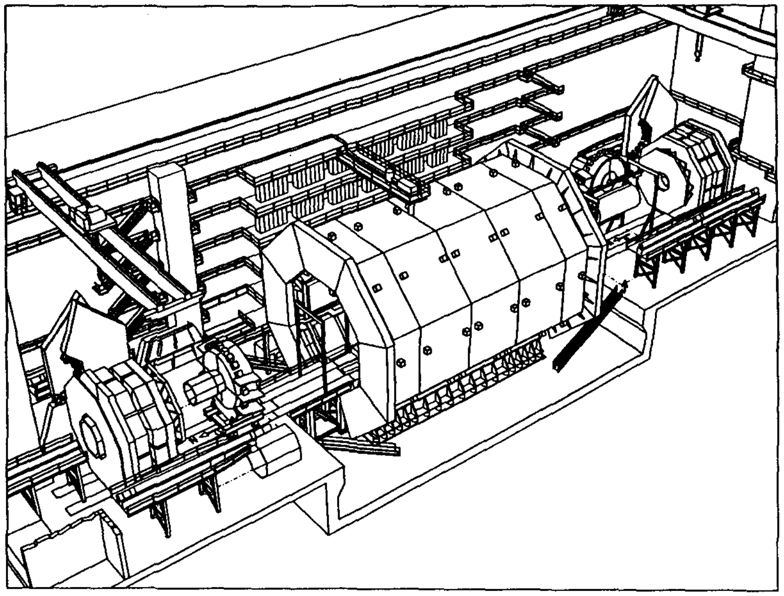
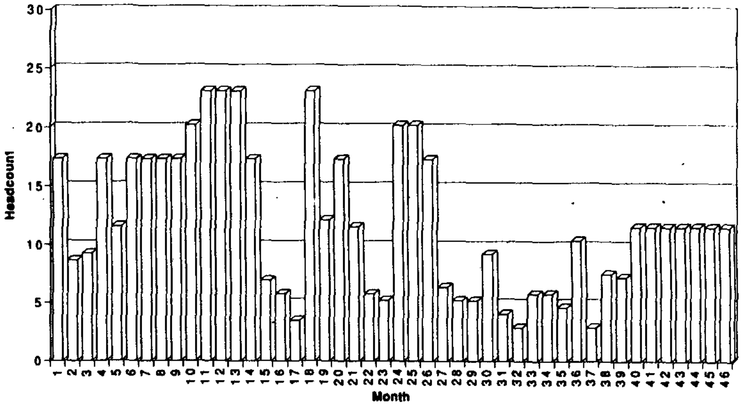




Kaiser Preliminary Construction Plan

Installation Headcount

(assumes 173 Hours/Month and 1 Shift/Day - construction labor only)



10/23/91 - DLE

UNDERGROUND HALL SUMMARY

J. PILES

Underground Hall

Jon Files

SDC Major Underground Hall Requirements:

1. Clear area for assembly and installation of detector: (Original width of 31 m was reduced to help meet the cost constraints)
   - 29 meters wide by 105 meters long
2. North and South operating floors level with I.D. of Iron Toroid.
   - South Floor 29 meters wide by 30 meters long
   - North Floor 29 meters wide by 25 meters long
3. Detector Pit
   - 29 meters wide by 50 meters long.
4. Egress through cable shaft.
   - Egress from the operations center to the underground hall.
5. Two assembly shafts for installation of detector:
   - 14 meters by 11 meters.
6. Experimental Hall Cranes
   - two separate 100 tonne/20 tonne overhead bridge cranes.

IR8 Underground Hall Cost Estimate:
- Current estimated cost of underground hall meeting requirements listed is: $34,400,000

Definitions JOD and BOD:

JOD (Joint Occupancy Date)

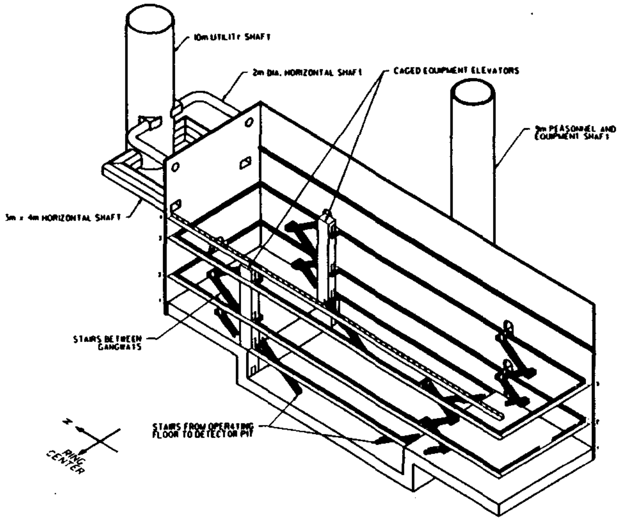
a. Underground Hall concrete floor finished.
b. Base plates and tracks fully integrated into floor.
c. Full use of one assembly shaft with surface cover.
d. Overhead bridge cranes installed, tested and operational.
e. Accessibility to power.
f. Survey references established.
g. Personnel Access to the Underground Hall.

BOD (Beneficial Occupancy Date)

Turnover of Underground Hall from AE/CM to SDC.

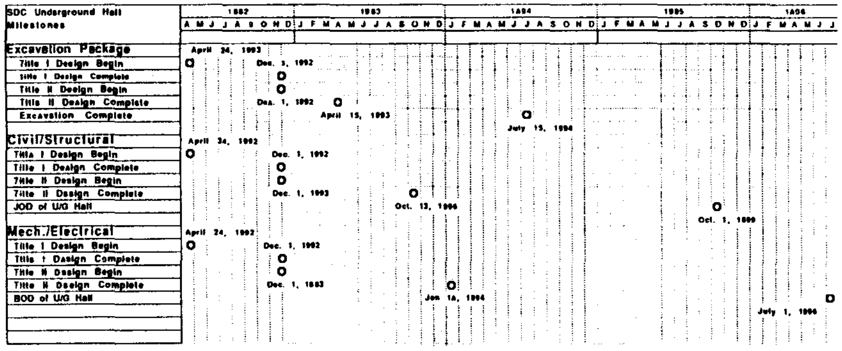
a. Full use of second assembly shaft.
b. All conventional services installed and checked out.
    1. HVAC
    2. Power
    3. Cooling
c. All walkways and platforms installed.
d. Fully functional interior elevators
e. All shafts completed and fully equiped. (ie stairways, elevators, utilities)
f. Fire protection system installed and tested.

SDC Underground Hall



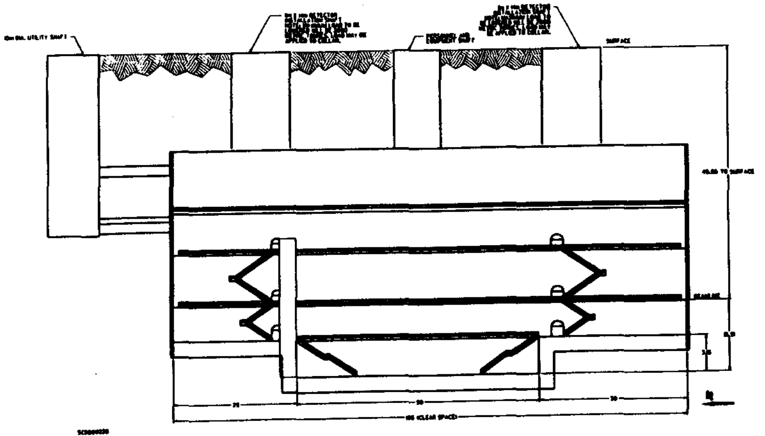
5/7/92

SDC Underground Hall



5/7/92

SDC Underground Hall



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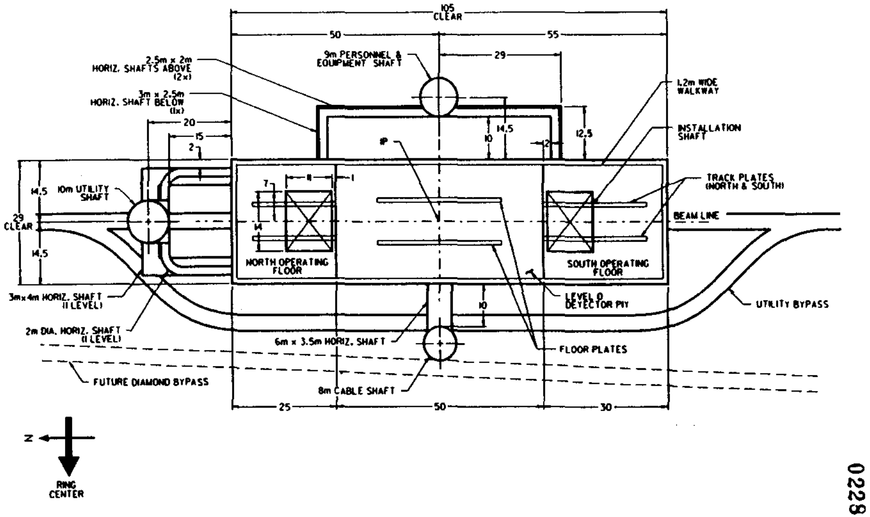
SDC Underground Hall



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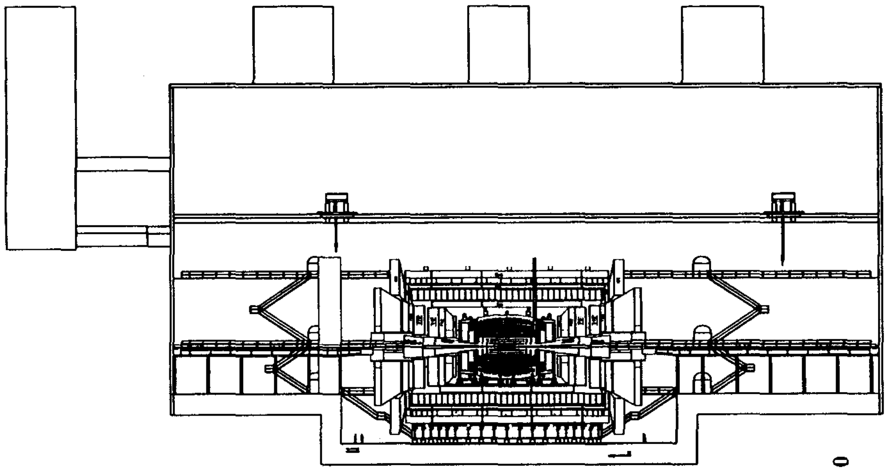

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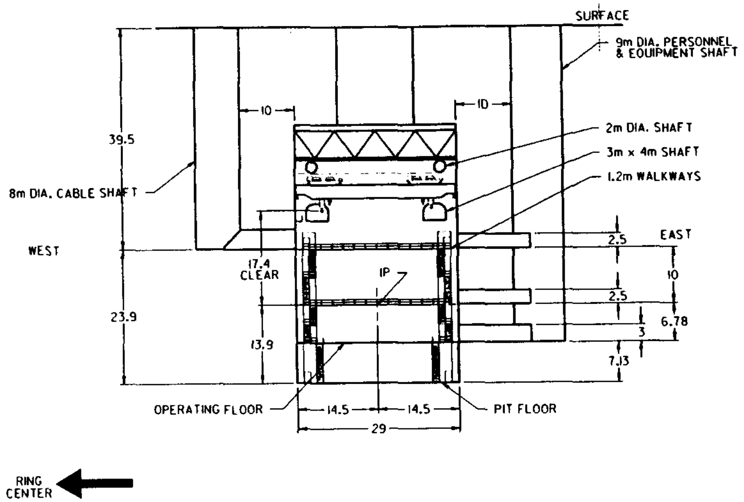

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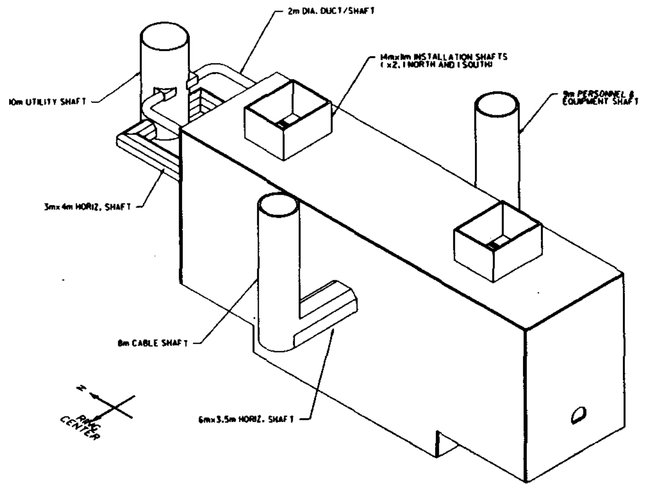
SCD-000226
07-MAY-1992

SDC Underground Hall

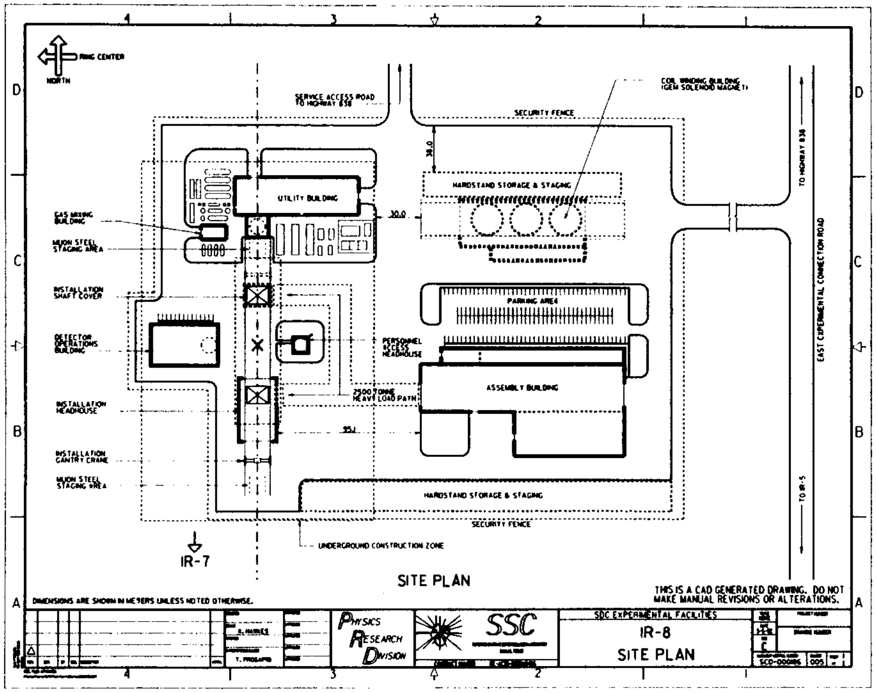


5/7/92

02286

SURFACE LAYOUT SUMMARY

T. PROSAPIO



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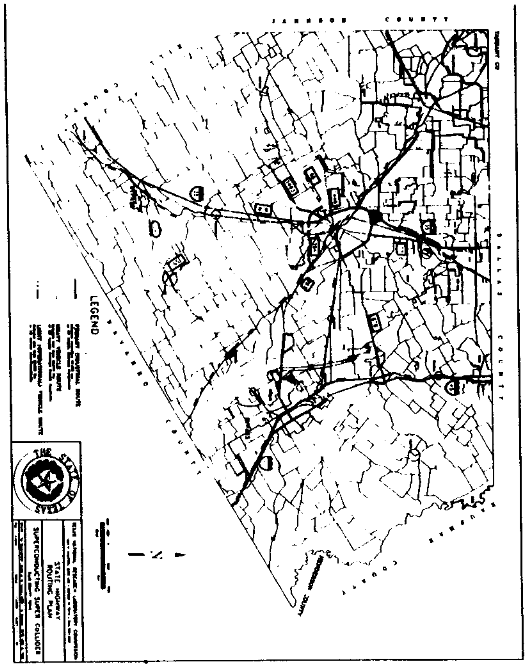

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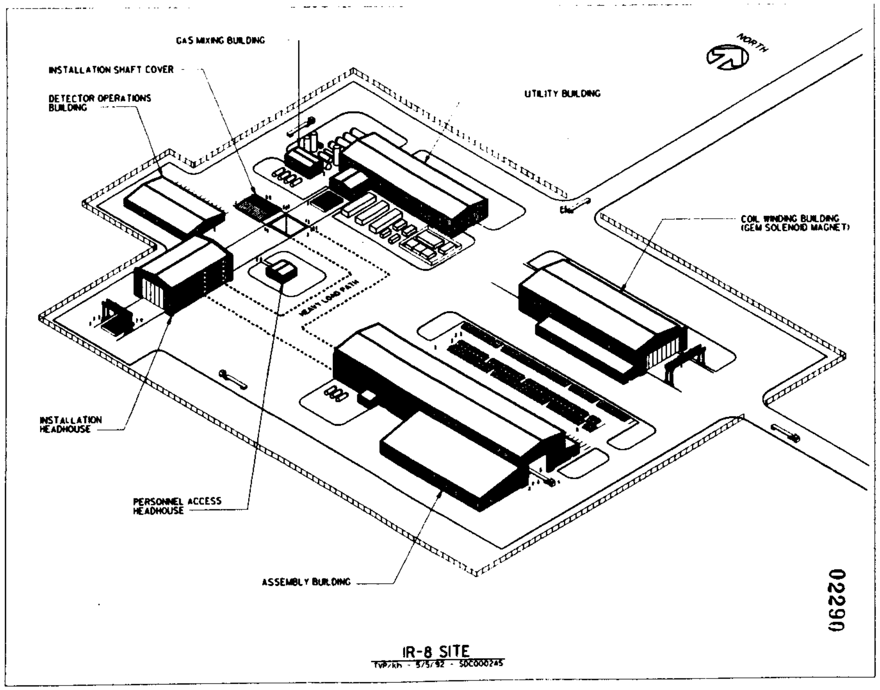
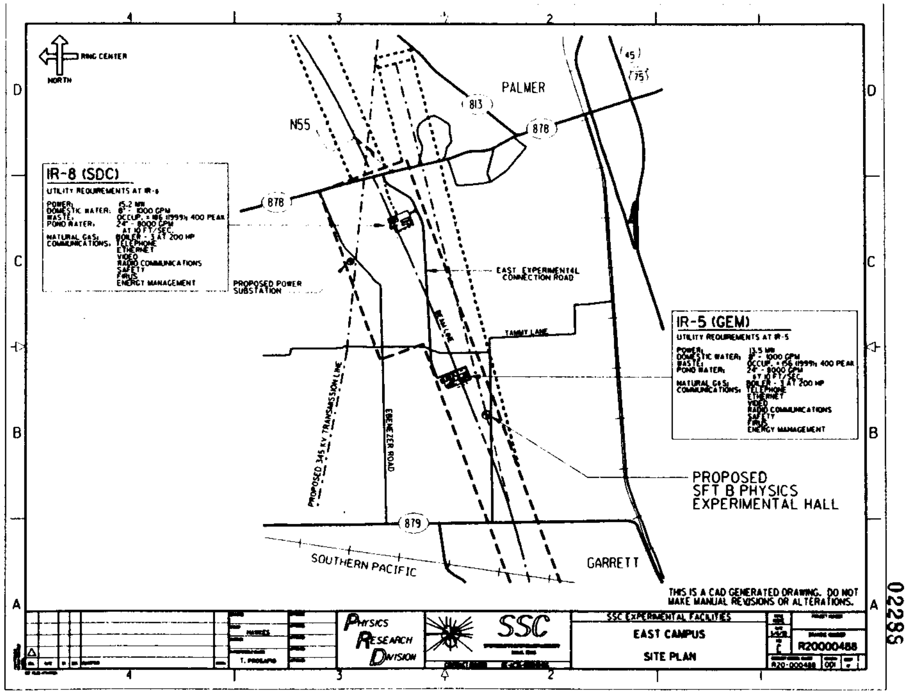
T Prosapio



IR-8 SITE
TVP/kh - 5/5/92 - SDC000245

02290



IR-8 (SDC)

UTILITY REQUIREMENTS AT IR-8

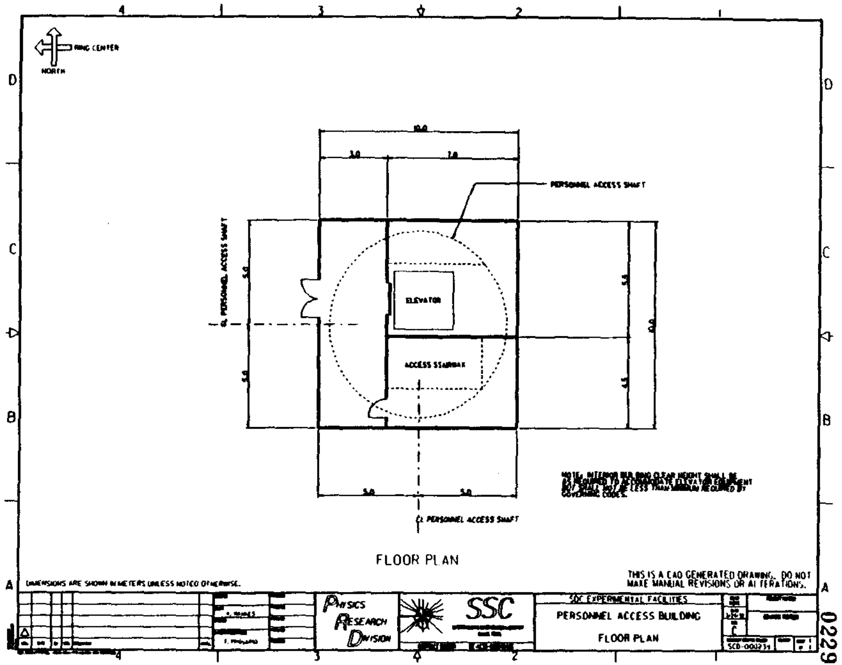
POWER:	15.2 MW
DOMESTIC WATER:	8" - 1000 GPM
WASTE:	OCCUP. = 106 (1999); 400 PEAK
POND WATER:	24" - 8000 GPM AT 10 FT/SEC.
NATURAL GAS:	BOILER - 3 AT 200 HP
COMMUNICATIONS:	TELEPHONE ETHERNET VIDEO RADIO COMMUNICATIONS SAFETY FIRUS ENERGY MANAGEMENT

IR-5 (GEM)

UTILITY REQUIREMENTS AT IR-5

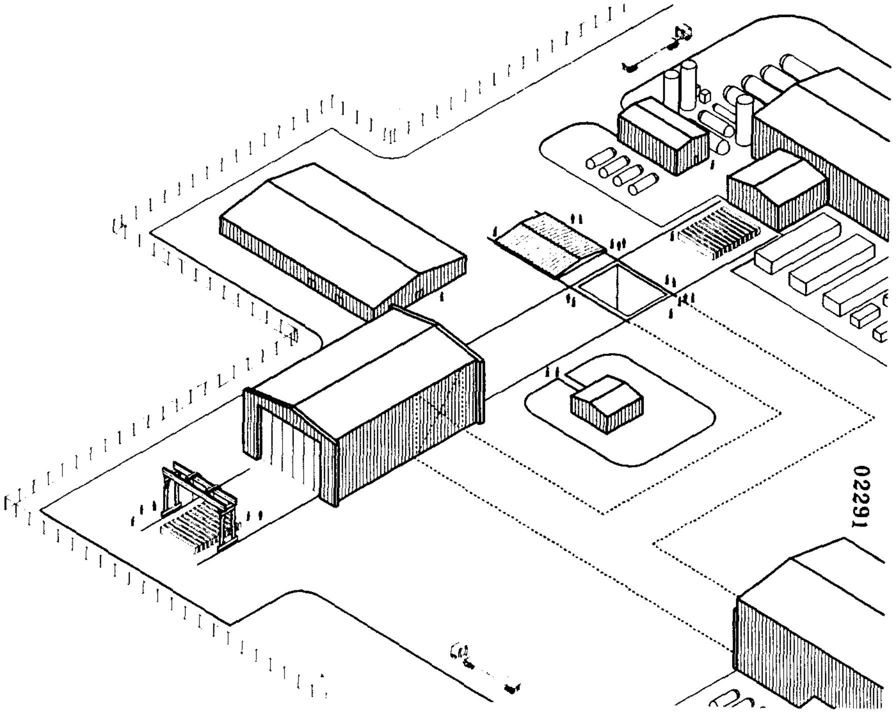
POWER:	13.5 MW
DOMESTIC WATER:	8" - 1000 GPM
WASTE:	OCCUP. = 156 (1999); 400 PEAK
POND WATER:	24" - 8000 GPM AT 10 FT/SEC.
NATURAL GAS:	BOILER - 3 AT 200 HP
COMMUNICATIONS:	TELEPHONE ETHERNET VIDEO RADIO COMMUNICATIONS SAFETY FIRUS ENERGY MANAGEMENT

02285



02293

FIGURE 10-1



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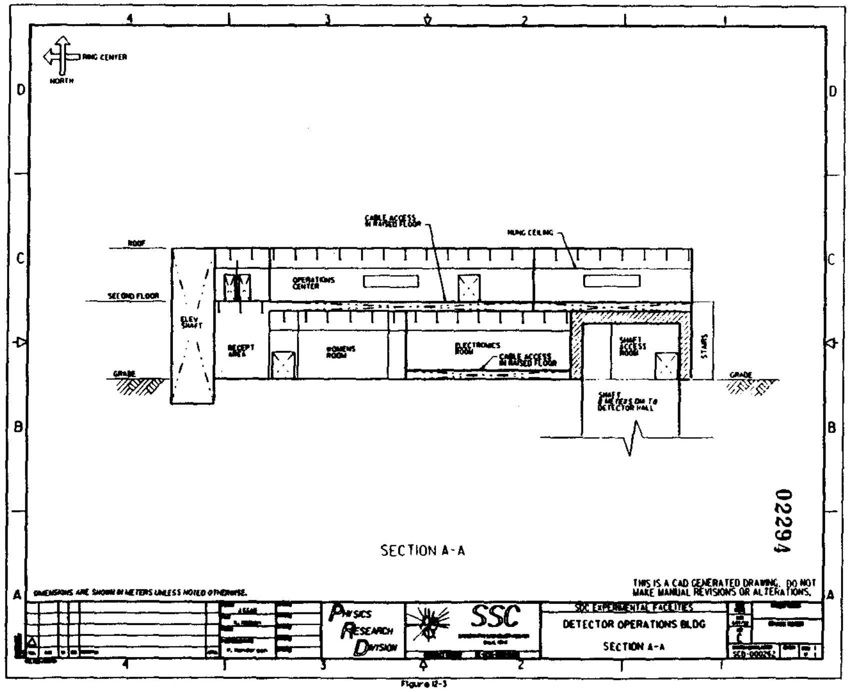
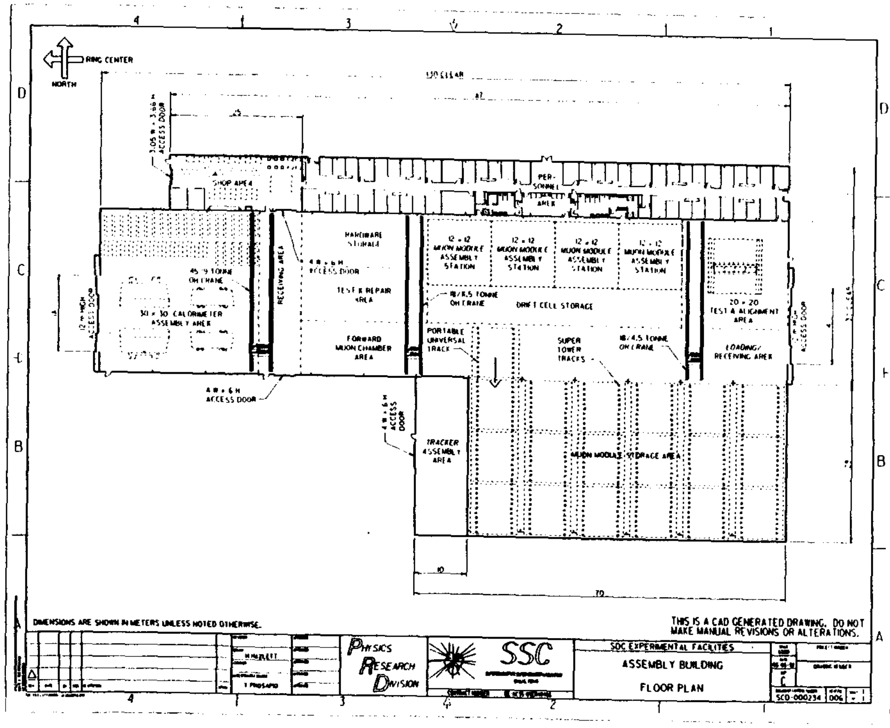


02294

Figure 12-3



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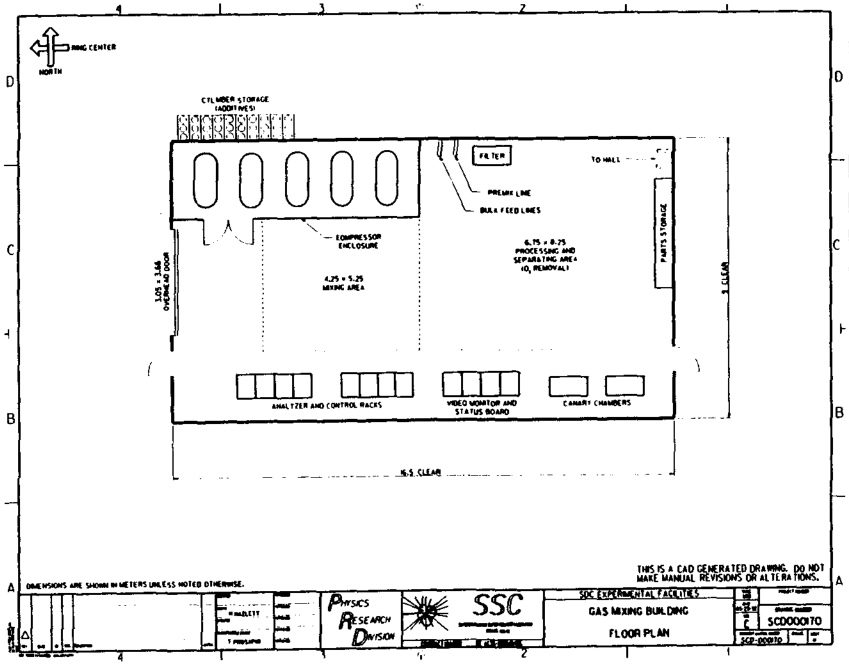


FIGURE 13-2

02297

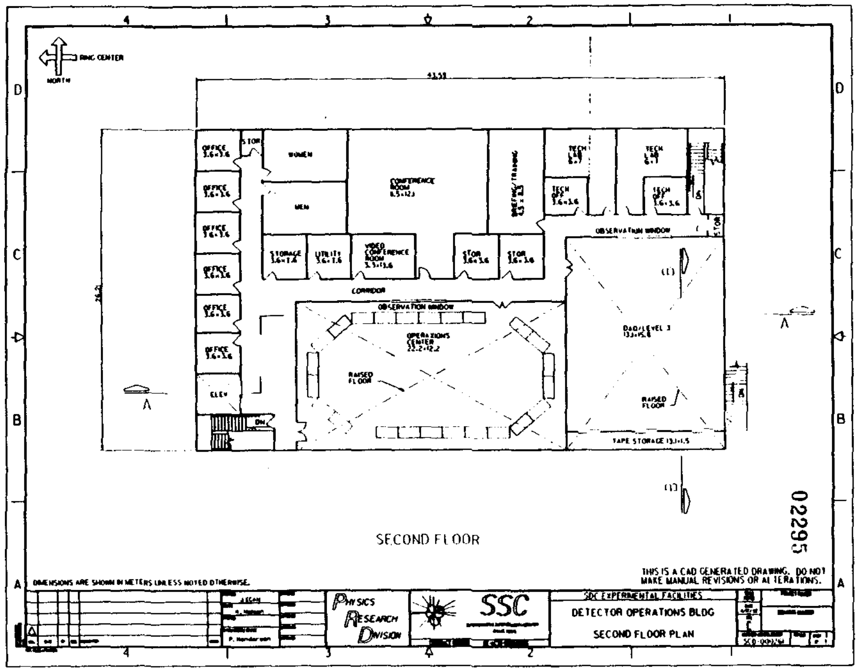


Figure 12-2

02295

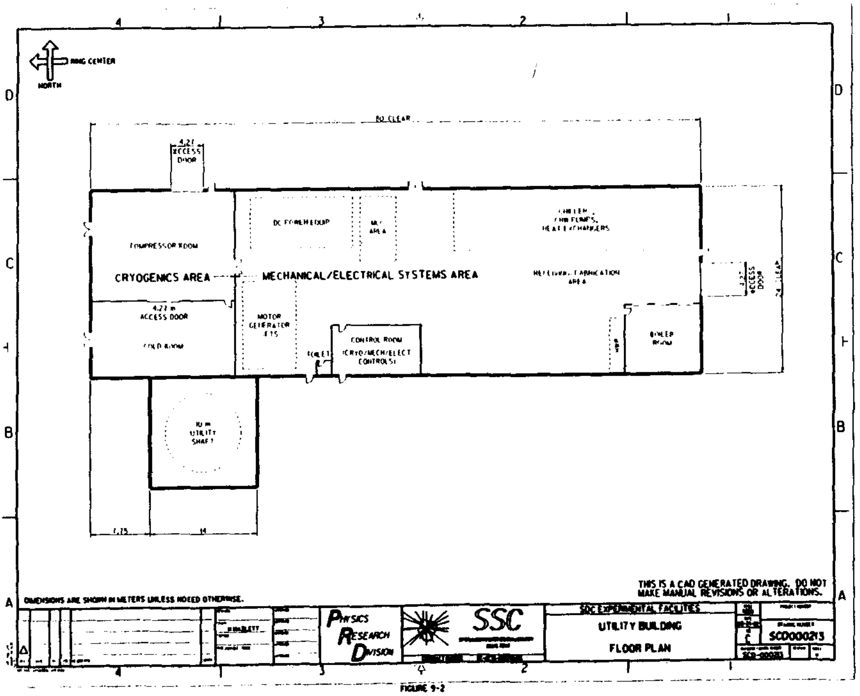


FIGURE 9-2

02296

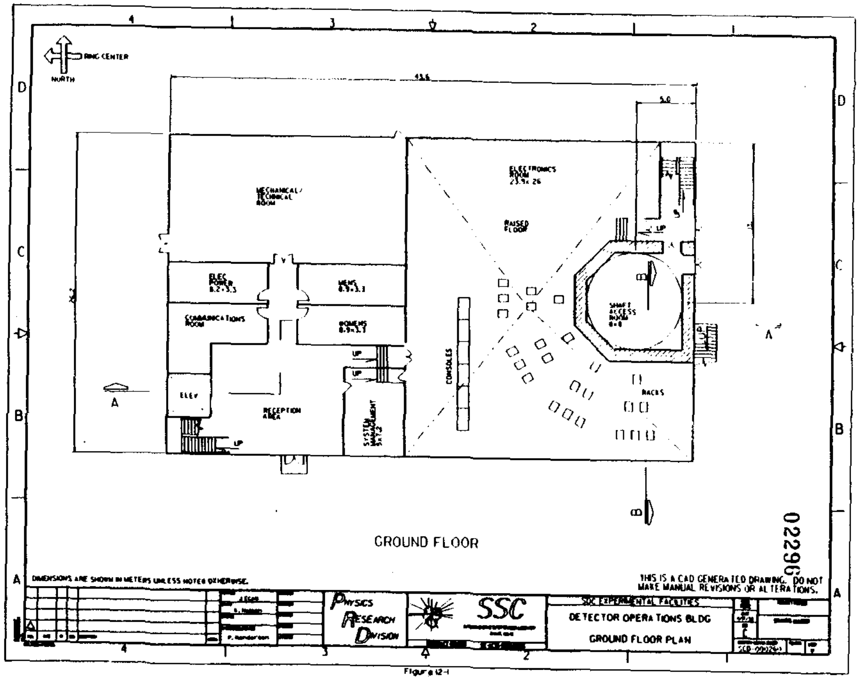


Figure 12-1

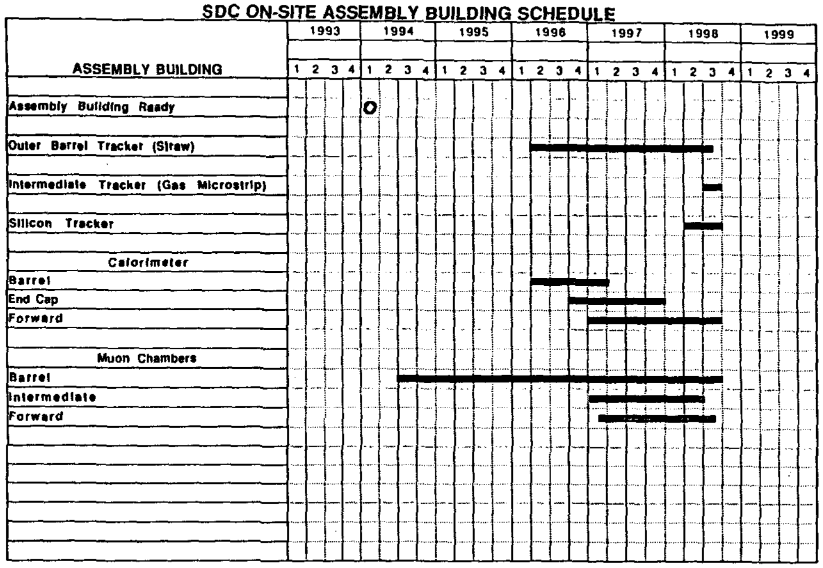
02296

02299

ASSEMBLY BUILDING REQUIREMENTS

T. WINCH

SDC ON-SITE ASSEMBLY BUILDING SCHEDULE



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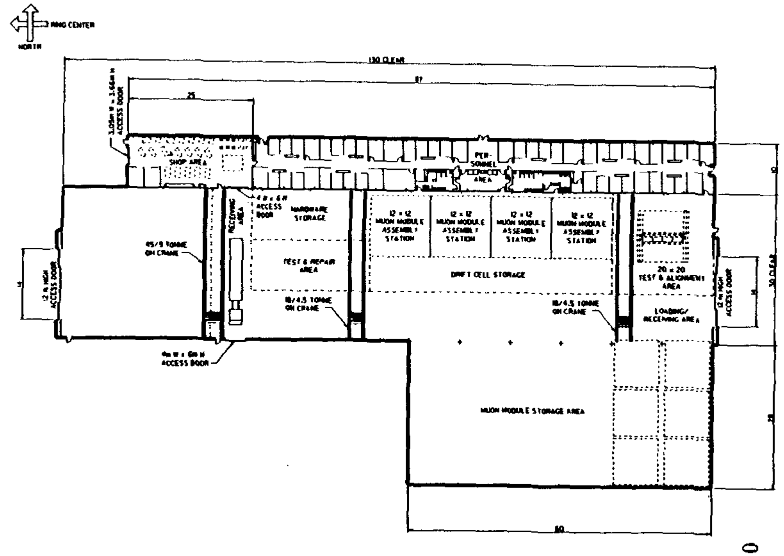
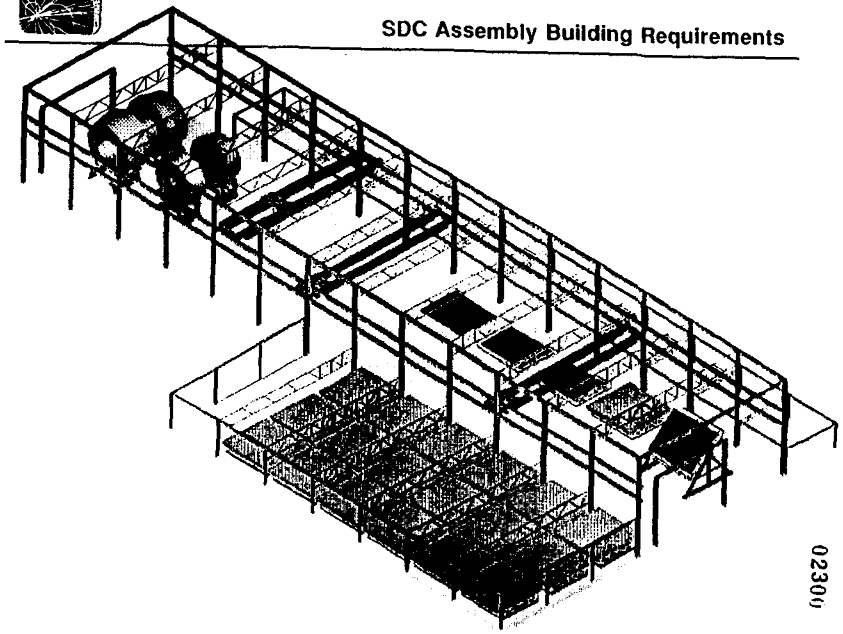


MID - 1995

02303

SDC Assembly Building Requirements



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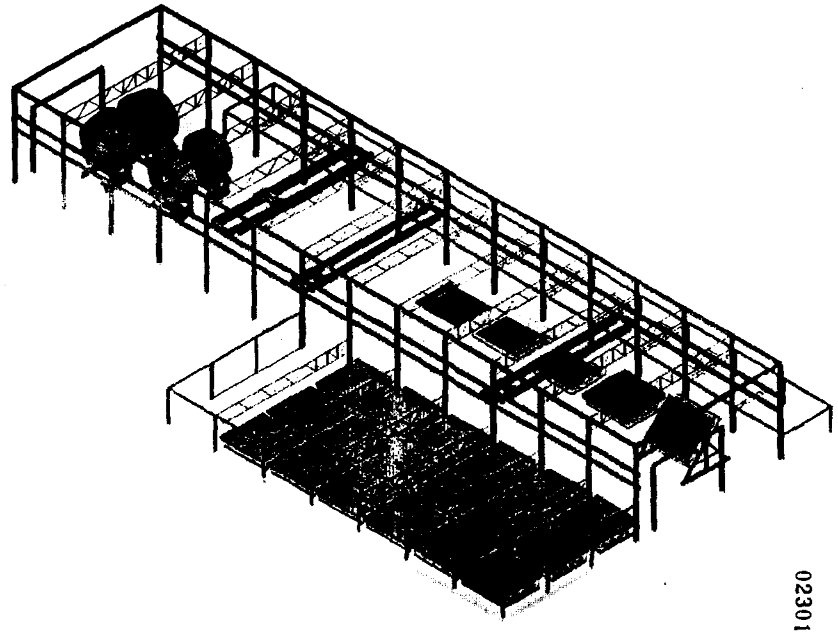
T Winch



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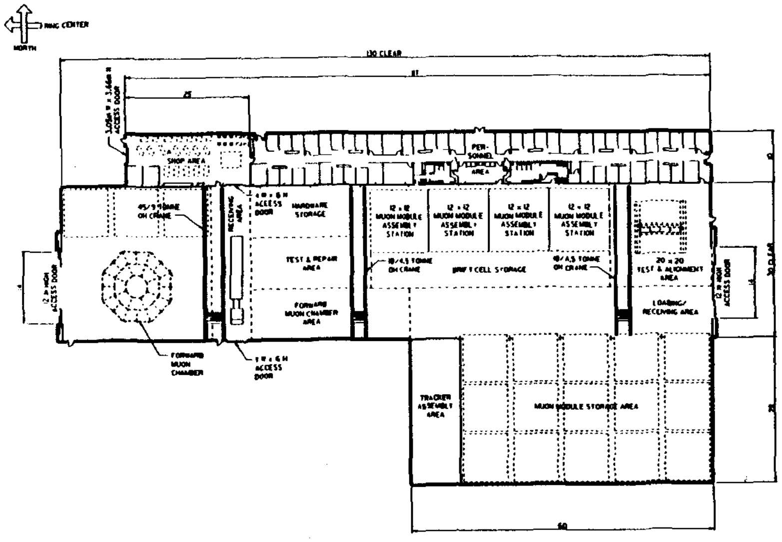
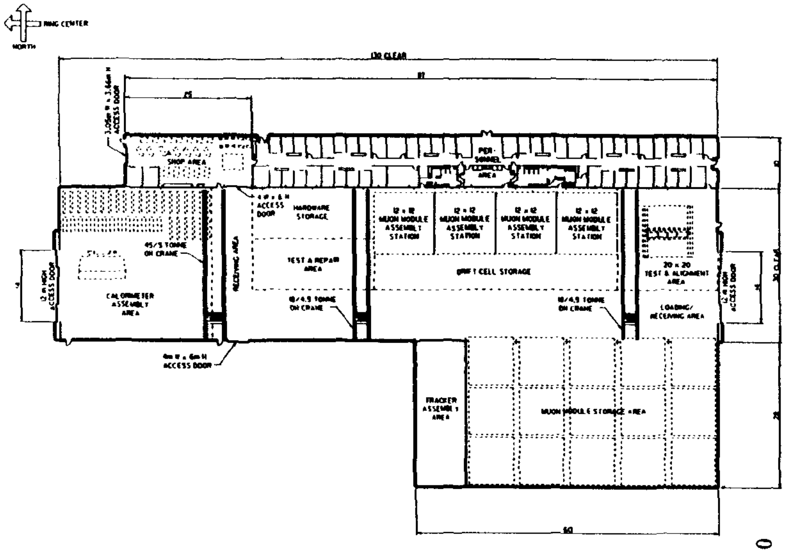


MID - 1998



MID - 1996

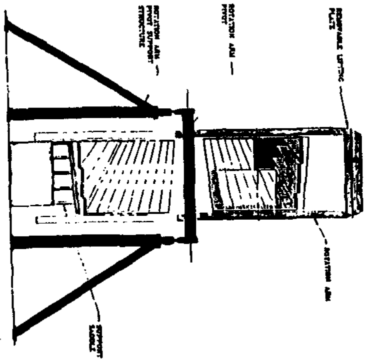
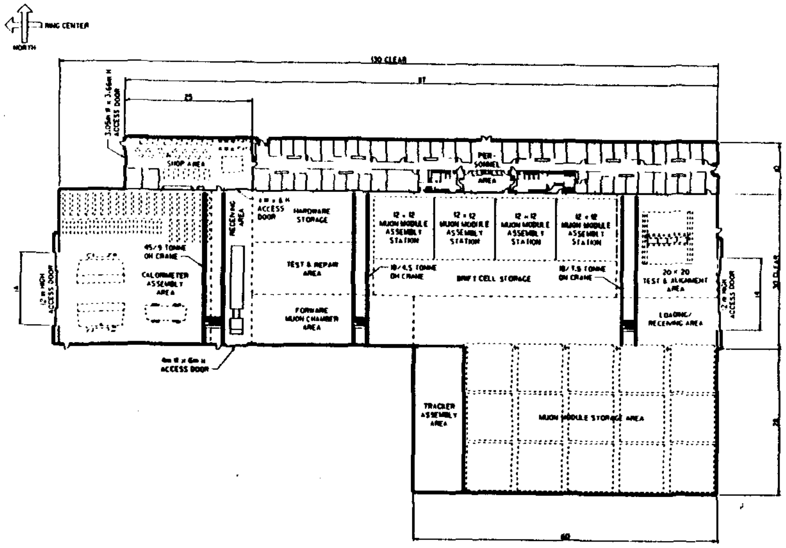


Figure 4.34 Endcap HAC assembly support structure



MID - 1997

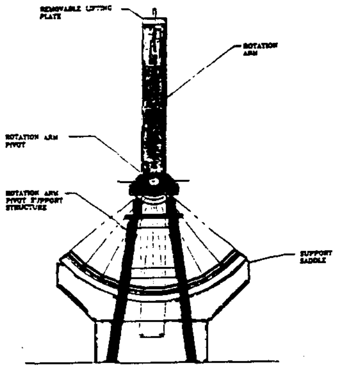


Figure 4.33 Endcap HAC assembly support pivot and installation sequence.

DRAWING OF BRACKETS ATTACHING BARREL WEDGES TO EACH OTHER

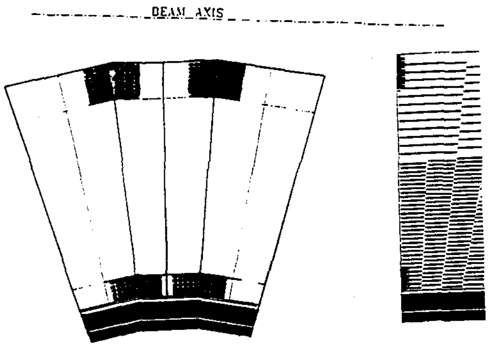


Figure 3.5(a) - Three views of barrel calorimeter module, showing brackets used to attach wedges together during stacking.

Figure 3.5(b) - Details of 90-degree support brackets used to attach wedges together during stacking.

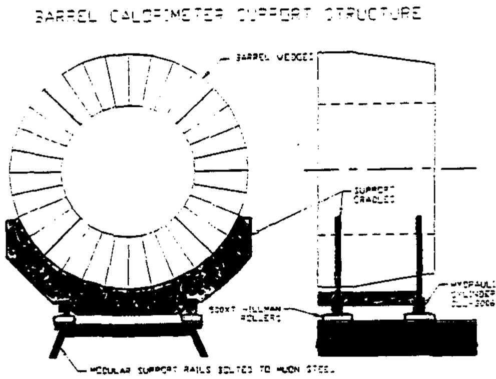


Figure 3.15(a) - Barrel calorimeter support structure. In the iron design, only two cradles and Hillman rollers are required.

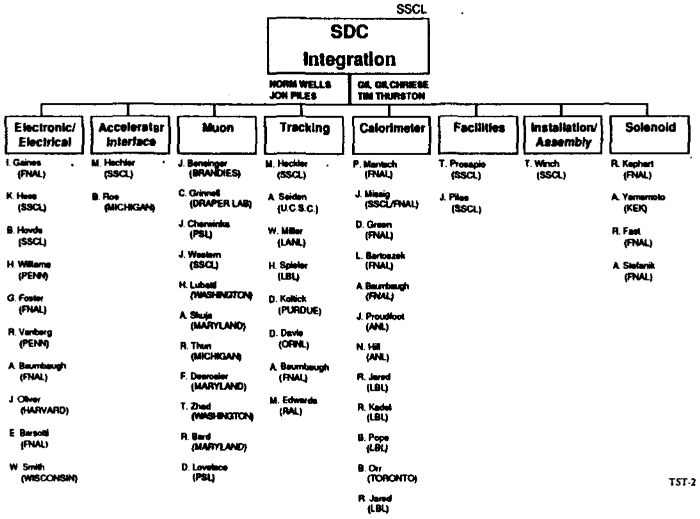
DETECTOR INTEGRATION PLANNING

T. THURSTON

02313

Detector Integration Planning

Integration Working Group



SSCL

SDC Integration

NORM WELLS
JON PILES — GIL GILCHRIESE
TIM THURSTON

Electronic/ Electrical	Accelerater Interface	Muon	Tracking	Calorimeter	Facilities	Installation/ Assembly	Solenoid
I. Gaines (FNAL)	M. Hechler (SSCL)	J. Beninger (BRANDIES)	M. Heckler (SSCL)	P. Mantsch (FNAL)	T. Prosapio (SSCL)	T. Winch (SSCL)	R. Kephart (FNAL)
K. Hess (SSCL)	B. Roe (MICHIGAN)	C. Grinnell (DRAPER LAB)	A. Seiden (U.C.S.C.)	J. Mieaig (SSCL/FNAL)	J. Piles (SSCL)		A. Yamamoto (KEK)
B. Hovde (SSCL)		J. Cherwinka (PSL)	W. Miller (LANL)	D. Green (FNAL)			R. Fast (FNAL)
H. Williams (PENN)		J. Western (SSCL)	H. Spieler (LBL)	L. Bartoszek (FNAL)			A. Stefanik (FNAL)
G. Foster (FNAL)		H. Lubatti (WASHINGTON)	D. Koltick (PURDUE)	A. Baumbaugh (FNAL)			
R. Vanberg (PENN)		A. Skuja (MARYLAND)	D. Davis (ORNL)	J. Proudfoot (ANL)			
A. Baumbaugh (FNAL)		R. Thun (MICHIGAN)	A. Baumbaugh (FNAL)	N. Hill (ANL)			
J. Oliver (HARVARD)		F. Desrosier (MARYLAND)	M. Edwards (RAL)	R. Jared (LBL)			
E. Barsotti (FNAL)		T. Zhao (WASHINGTON)		R. Kadel (LBL)			
W. Smith (WISCONSIN)		R. Bard (MARYLAND)		B. Pope (LBL)			
		D. Lovelace (PSL)		B. Orr (TORONTO)			
				R. Jared (LBL)			

02315

Detector Integration Planning

Parameters Book

- Component Weights
- Component Sizes
- Component Geometries
- Channel Counts
- Technology
- Subsystem Layouts
- Electrical Layouts
- Facility Layouts

Thurston

02312

Detector Integration Planning

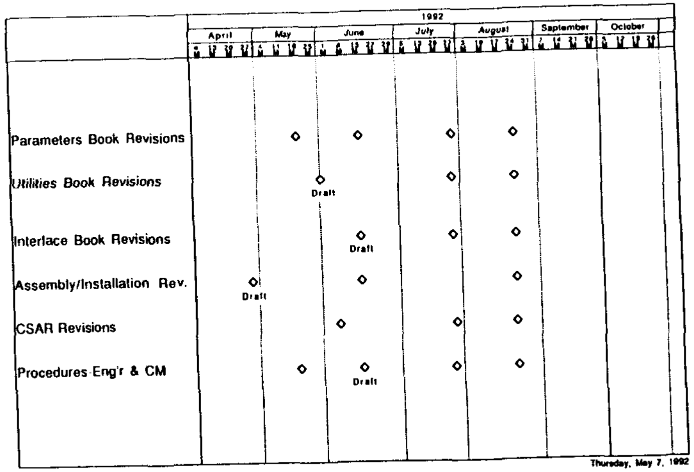
Detector Integration Plan

- Hierarchical Integration:
  Detector (SSCL)
  Sub-systems (SSCL & Design Institution)
  Sub-assembly (Design Institution)
  Components (Design Institution/Vender)
- Integration Working groups
- Configuration Control Documents
  - Parameters Book
  - Utilities Book
  - Interface Book
  - Facilities Users Requirements
  - Assembly/Installation Book

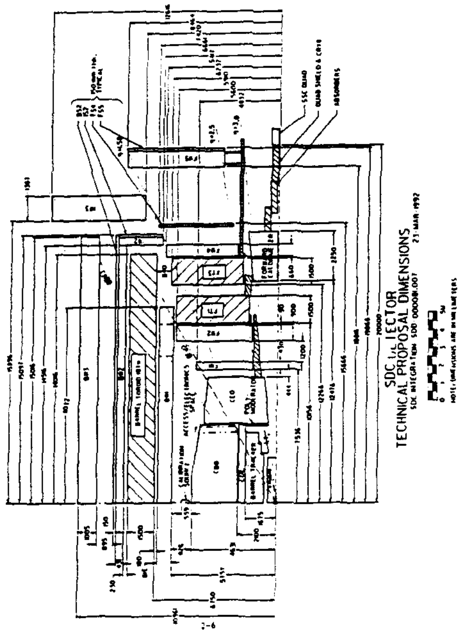
02314

Detector Integration Planning

Integration Document Schedules



Parameters Book - Detector Dimensions



Parameters Book - Silicon Tracker

Silicon Tracker
(WBS 1.1)

Cylinders:

Layer	Type	R(cm)	L/2 (cm)	A(cm**2)	Nstrip/end
1	strip[1]	9	30	1700	57.6k
2	strip[1]	12	30	2260	76.8k
3	strip	18	30	3390	115.2k
4	strip	21	30	3960	134.4k
5	strip	24	30	4520	153.6k
6	strip	27	30	5090	172.8k
7	strip	33	30	6220	211.2k
8	strip	36	30	6790	230.4k
				Total	1,152,000

Area: 6.78 m^2 for Cylinders

Disks

Layer	Type	R1(cm)	R2(cm)	Z(cm)	A(cm**2)	Ns/end
1	strip	15	39	33	4070	163.84k
2	strip	15	39	38	4070	163.84k
3	strip	15	39	44	4070	163.84k
4	strip	15	39	52	4070	163.84k
5	strip	15	39	61	4070	163.84k
6	strip	15	39	72	4070	163.84k
7	strip	15	39	85	4070	163.84k
8	strip	15	39	10	4070	163.84k
9	strip	15	39	12	4070	163.84k
10	strip	22.5	46.5	14	5200	194.56k
11	strip	28.5	46.5	182	4241	194.56k
12	strip	34.5	46.5	218	3050	112.64k
13	strip	40.5	46.5	258	1640	112.64k
					Total	2,088,960

Area: 10.16 m^2 for Disks

Weight: 160kg

Primary source: Silicon Tracking Conceptual Design Report, Nov., 1991. Technical Board Meeting 2/2/92

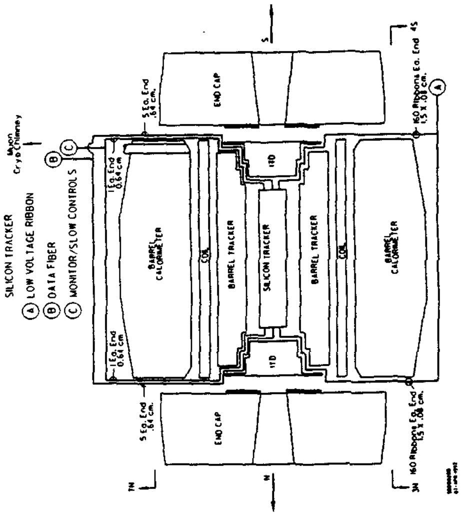
Source: 27 Feb 92 Collaboration Meeting and 26 Feb 92 TDR Draft

Updated: 24 Mar 92

Cable & Utilities Book

- System Schematics
- Cable Routing Diagrams
- Cable Costs and Track
- Connector Definition
- Cable Tray/Bundle Layouts

Utilities Book - Signals and Services Diagrams



02326

SAFETY ANALYSIS STATUS

J. ELIAS

Safety Overview and CSAR Methodology

- Environment Safety and Health Program Overview
- Analysis Methodology
- CSAR Results

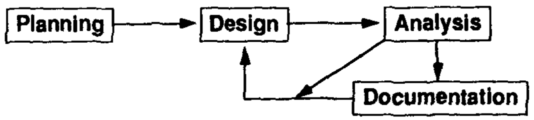
Safety Analysis Status
Program Advisory Committee Meeting

May 8, 1992

John Elias

ES&H Program Overview

- Department of Energy Orders are the root requirements



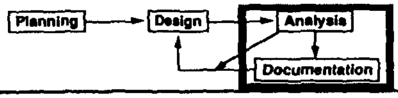
- SDC ES&H Implementation Plan
- System Safety Design Engineering, Design for Maintenance Human Factors Engineering
- Safety Analysis and Review System

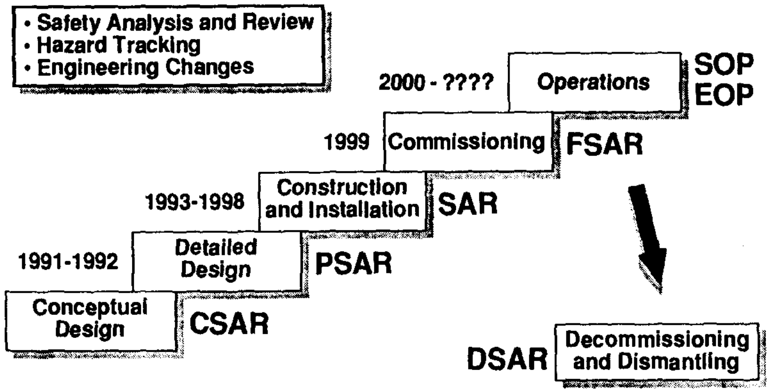
Solenoidal Detector Collaboration

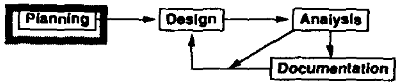
Safety Analysis Status

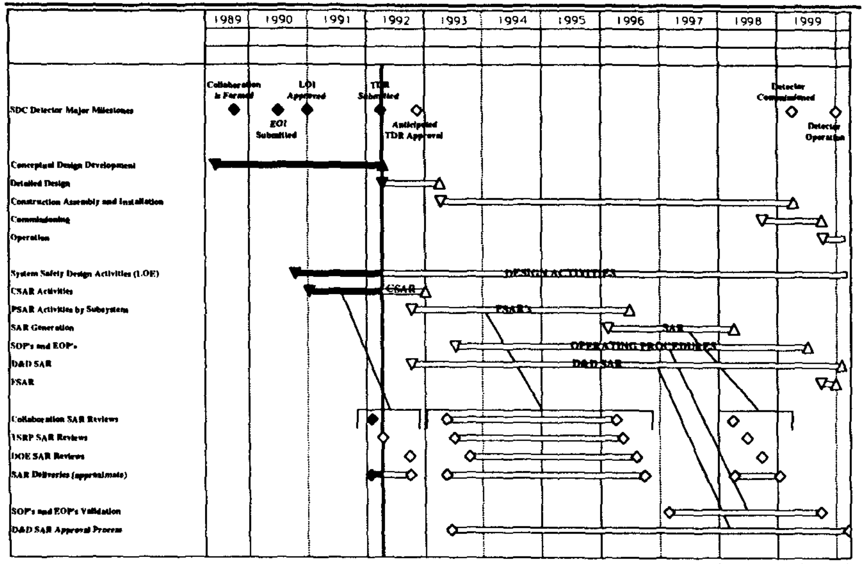
Program Advisory Committee Meeting

May 8 1992







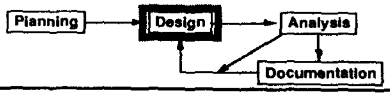


Monday, April 20, 1992

Initial Analysis and Documentation . . . CSAR

Conceptual Safety Analysis Report

- Qualitative analysis based on TDR conceptual design
- Scope includes all major detector subsystems in some detail
  - Beam Pipe
  - Tracking Systems
  - Superconducting Solenoid
  - Calorimetry
  - Muon Systems
  - Structures
  - Electronics
  - Access Spaces
- Support systems to a lesser level of detail
  - Integrated safety systems
  - Fire protection
  - Utilities



- System Safety
  - Personnel and Equipment Safety
  - *Required Design Criteria*
  - Required Performance Criteria
  - Electrical, Mechanical, ADP
  - Fire Protection
- Industrial and Construction Safety
- *Design for Maintainability*
  - Personnel Access
  - Confined Spaces
  - Mechanical Design of High Maintenance Items
- Human Engineering
  - Man/Computer Interface Design
  - Detector PASS System
  - Integrated Safety Systems Design
  - Ergonomics

Severity of Consequences

	PERSONNEL EFFECTS	EQUIPMENT LOSS	EQUIPMENT DOWNTIME	DATA COMPROMISE	ENVIRONMENTAL EFFECTS
CATASTROPHIC	DEATH	>500K	> 4 MONTHS	UNRECOVERABLE DATA LOSS OR PRIMARY PROGRAM OBJECTIVES LOST	5 YEAR+ TERM DAMAGE >500K CORRECTION OR PENALTIES
CRITICAL	SEVERE INJURY	100K TO 500K	2 WEEKS TO 4 MONTHS	REPEAT OF CONSIDERABLE AMOUNT OF RESEARCH	1 TO 5 YEAR TERM DAMAGE 100K TO 500K CORRECTION OR PENALTIES
MARGINAL	MINOR INJURY	1K TO 100K	1 DAY TO 2 WEEKS	REPEAT OF SOME RESEARCH	< 1YEAR TERM DAMAGE 1K TO 100K CORRECTION OR PENALTIES
NEGLIGIBLE	NO INJURY	< 1K	< 1 DAY	NON DATA LOSS	MINOR TO NO ENVIRONMENTAL DAMAGE, LESS THE 1K$

SDC Safety Working Group

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Jeffery Cherwinka (University of Wisconson)	Muon Toroids
Mike Hechler (SSCL)	Beam Tube
Gavin Stairs (*University of Toronto*)	Forward Calorimetry

Probability of Occurrence

FREQUENT	LIKELY TO OCCUR REPEATEDLY DURING THE LIFE CYCLE OF THE DETECTOR
PROBABLE	LIKELY TO OCCUR SEVERAL TIMES IN THE LIFE CYCLE OF THE DETECTOR
OCCASIONAL	LIKLY TO OCCUR SOMETIME IN THE LIFE CYCLE OF THE DETECTOR
REMOTE	NOT LIKELY TO OCCUR IN THE LIFE CYCLE OF THE DETECTOR
IMPROBABLE	POSSIBILITY OF OCCURANCE CONNOT BE DISTINGUISHED FROM 0
IMPOSSIBLE	PHYSICALLY IMPOSSIBLE TO OCCUR

Analysis Methodology

- Hazard list developed based upon technology and design in TDR
- Each item in list identified geographically
- Each item analyzed in terms of

  1. probability of occurrence
  2. severity of consequences

- Results of above rated against a "<u>Occurrence vs Criticality</u>" risk matrix
- Mitigation hierarchy based upon accepted government and industry approaches

Risk Matrix Summary Results

Risk Assessment Summary

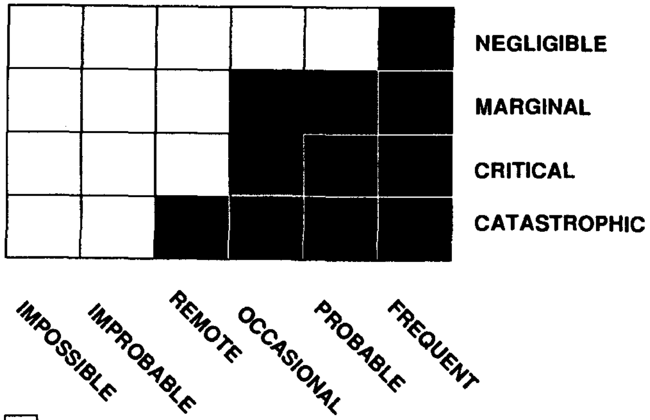
BEFORE ABATEMENT

	impossible	improbable	remote	occasional	probable	frequent
catastrophic		1	18	7	5	29
critical				20	3	
marginal		1		1	4	1
negligible						1

AFTER ABATEMENT

	impossible	improbable	remote	occasional	probable	frequent
catastrophic		60				
critical		3	20			
marginal		2	1	4		
negligible		1				

Probability vs Severity Matrix

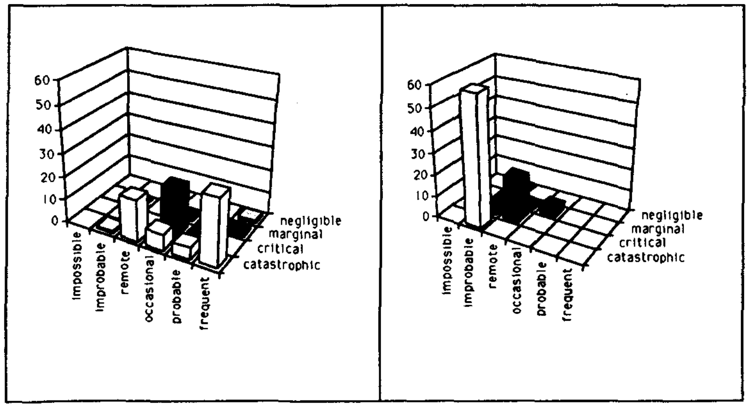


☐ OPERATION PERMISSIBLE

■ OPERATION REQUIRES WRITTEN, TIME LIMITED WAIVER BY MGMT

■ REQUIRES MITIGATION TO A LOWER LEVEL

Risk Matrix Summary Results



Before Mitigation **After Mitigation**

Mitigation Hierarchy and Examples

1. **Design or redesign for Minimum Risk**
   - redesign of muon chamber electrodes to meet performance goals using non-flammable gas
2. **Incorporate Safety Mechanisms**
   - overtemp and overcurrent crate protection
   - overpressure relief devices
3. **Provide Adequate Warning Mechanisms**
   - ODH monitoring
   - Incipient fire detection (VESDA)
4. **Use of Safety Oriented Procedures and Training**
   - confined space training
   - beam tube maintenance procedures

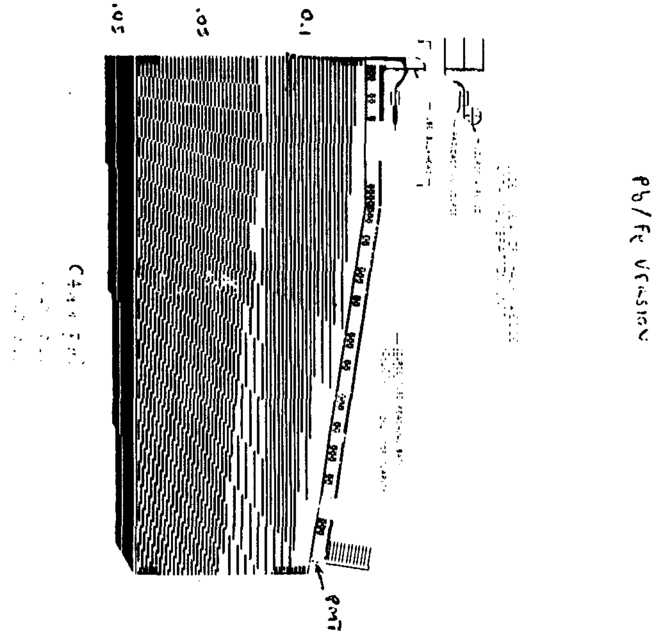
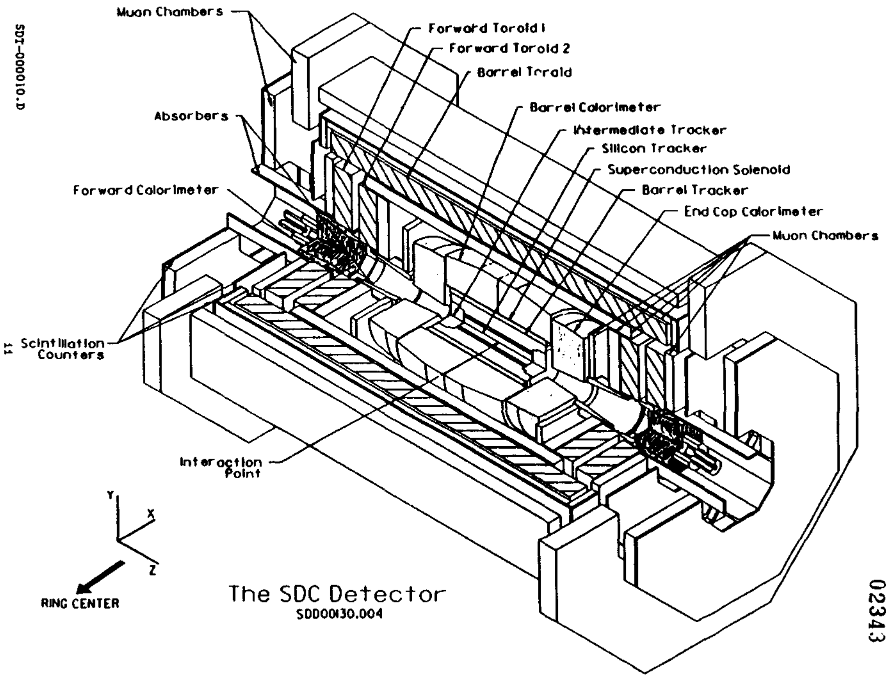


Figure 3.1(d) · Side views of a typical barrel calorimeter wedge, showing pattern of staggered slots in the iron calorimeter, PMTs, and source drives.

02345



The SDC Detector

SDD00130.004

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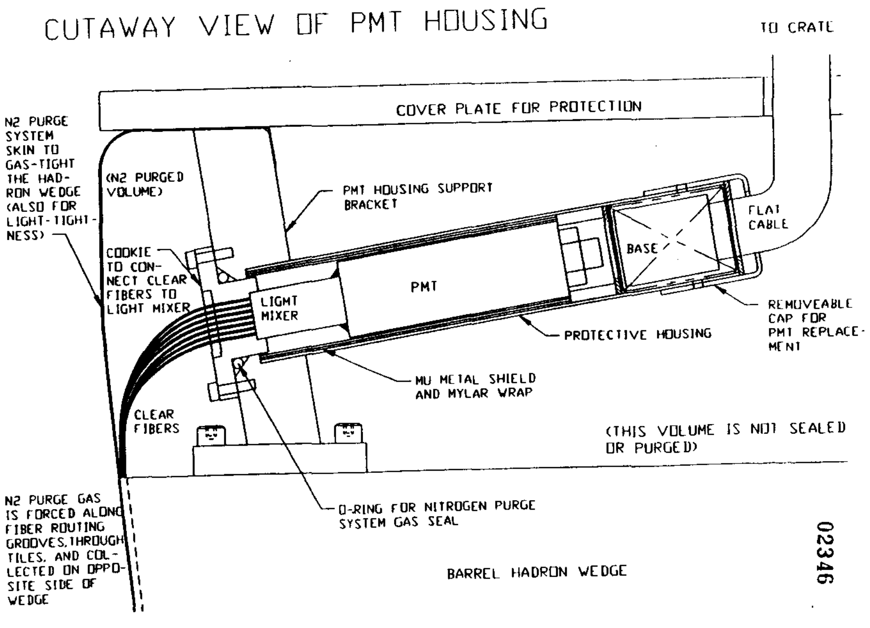

CUTAWAY VIEW OF PMT HOUSING

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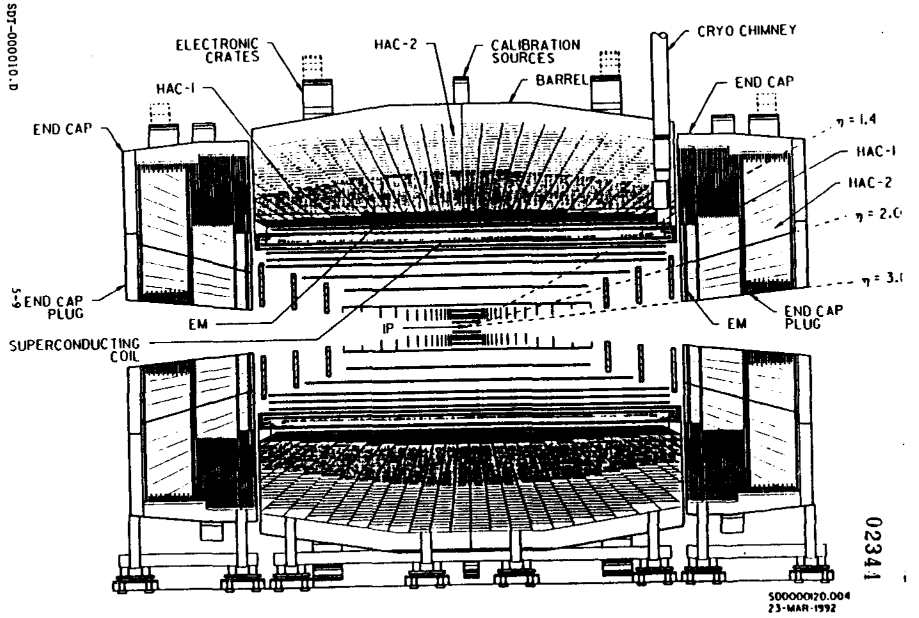

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Central Calorimetry

Fire Hazard Issues

Analysis 1-D mitigated to 1-E

Catastrophic-Remote ----> Catastrophic-Improbable

adding fire/loss control ----> Marginal - Improbable could be a possible future outcome

Basic Numbers

Scintillator weight	60 tonnes
Metal weight	3700 tonnes
Ratio	1 part in 60

Encapsulation

The light-tight requirement was combined with the stack compression requirement and answered with the choice of 10 mil stainless steel clading plus tensioning bands.

Analysis

There is good thermal contact between the "skin" of a wedge unit and the enclosed absorber metal stack.

The combustible scintillator is not accessible in the early stages of a fire incident, where accessible requires either

- a breach or mechanical failure of the container, or
- preheating the entire stack to the scintillator melting point

---

Central Calorimetry

Materials Hazards

Lead 3-E no mitigation needed

Marginal - Improbable

The individual wedge modules arrive on-site fully assembled with their light-tight metal containers in place. Lead exposure could occur through a handling mishap coupled with some as yet unidentified mechanism for dispersal/contamination.

Radioactive Sources 2-C mitigated to 2-D

Critical - Occasional ----> Critical - Remote

The 192 calibration sources mounted on the calorimeter are remotely movable via wires inserted inside capillary tubes traversing the complete set of scintillator tiles. Ingestion or respiration of these source materials will be precluded by design of the system, and the risk of induced damage exposure will be mitigated by periodic surveys.

Radioactivation 1-C mitigated to 1-E

Catatrosphic - Occasional ----> Catatrosphic - Improbable

Over time, the metal at shower maximum, a few inches into the lead part of the stack, will become activated leading to a radiation exposure hazard in the immediate vicinity of the conical hole near the beam pipe. Mitigation involves the design of appropriate portable shielding structures to be installed during times of access.

Central Calorimeter

Magnetic Forces Hazard

Issue

A large amount of magnetic flux passes through the end cap calorimeters from the tracking volume to the barrel calorimeter which results in hundreds of tons of compressive force on the end caps.

If the solenoid were to be energized with an end cap partially removed, the resultant mechanical instability could lead to loadings exceeding the design criteria with the potential for structural failure.

Mitigations

All mitigation measures involve inhibition of the solenoid power supply, by mechanical, lockout, and electronic means. The final choices have not yet been made pending detailed failure mode and effects analyses and magnetic calculations of the forces involved.

- **Operational readiness lockout**
  Final authorization to operate dependent on operational readiness signoff subsequent to a physical inspection of the end caps.
- **End cap access lockout**
  Authorization to withdraw one or more end caps is dependent on lockout of the power supply
- **Proximetry sensors**
  Power supply permit interlock chain would include sensors registering the proper end cap positioning
- **Fastener sensors**
  Power supply permit interlock chain would include sensors integral to the mechanism which atttaches the end caps to the barrel

---

Forward Calorimetry

Hazard: Radioactivation

Design: Long thin tubes penetrate the metal absorber stack to sample the showers

Option 1. Tubes pressurized with Ar(g) at about 100bar, readout via electrode (wire) down the tube axis

- no mixed waste
- can be made as code stamped modules

Option 2. Tubes filled with flowing liquid scintillator, readout via wave-shifting fiber down the tube axis

- replace liquid scintillator before reaching mixed waste thershold
- no penetrations into vessel below liquid level

Environment Safety & Health

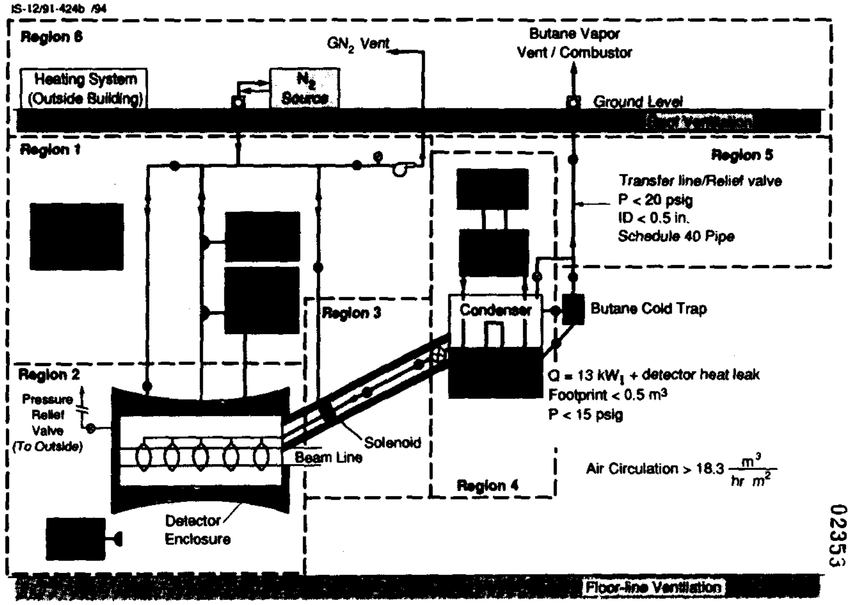


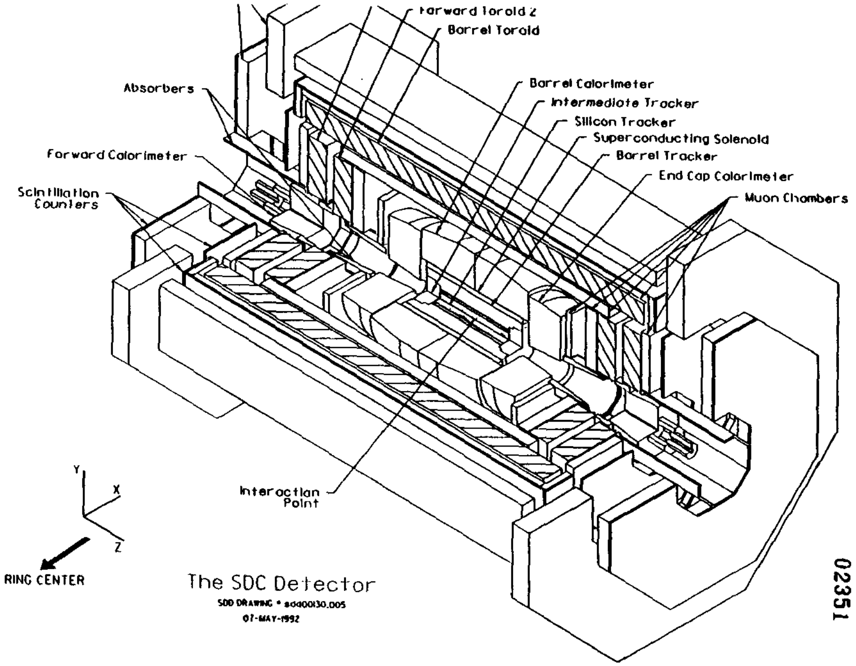
Figure 7.2-3 SDC Butane Cooling Safety Features

HAZARD ABATEMENT HIGHLIGHTS

Inerting Strategies

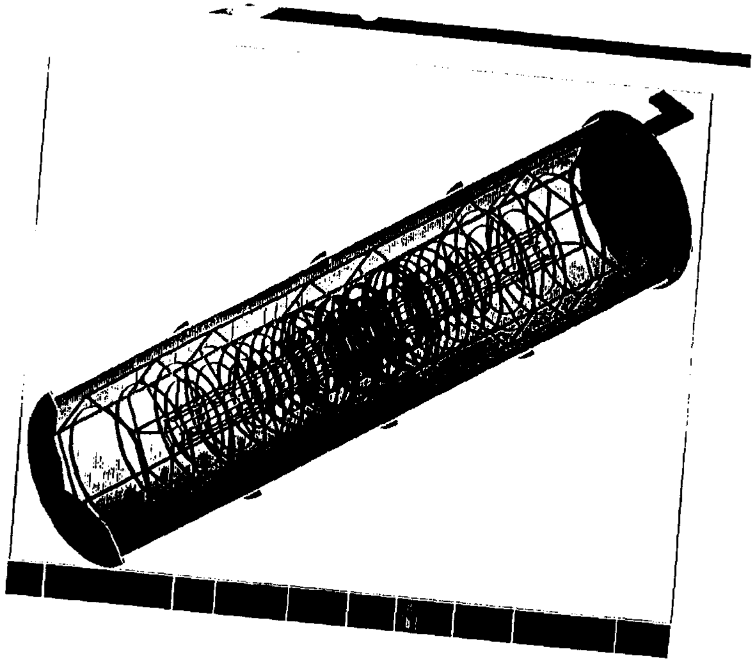
- The total butane inventory within the detector enclosure, condenser, and feed lines shall be minimized.
- All seals and joints and structures containing working fluid shall be designed for no leakage and shall be double enclosed, the outer enclosure filled with flowing nitrogen gas.
- A slightly positive pressure shall be maintained between the detector enclosure and the inerting volume.
- Eight Circulation Changes/Hour in Detector Array
- Nitrogen Flow Outside Enclosure to Eliminate Oxygen Near Detector
- Nitrogen Feed Line into Detector for Fire Suppression
- Adequate circulation shall be maintained in the detector hall to prevent accumulation of vapor above 0.2 of the LEL in the event of any credible breach.

Los Alamos



The SDC Detector

SDC DRAWING • sdd00130.005
07-MAY-1992



HAZARD ABATEMENT HIGHLIGHTS

Miscellaneous Strategies

- Ethylene Glycol Heat Exchanger Located at Butane Condenser Level
- Condenser Charged with Butane from Inside the Detector Hall

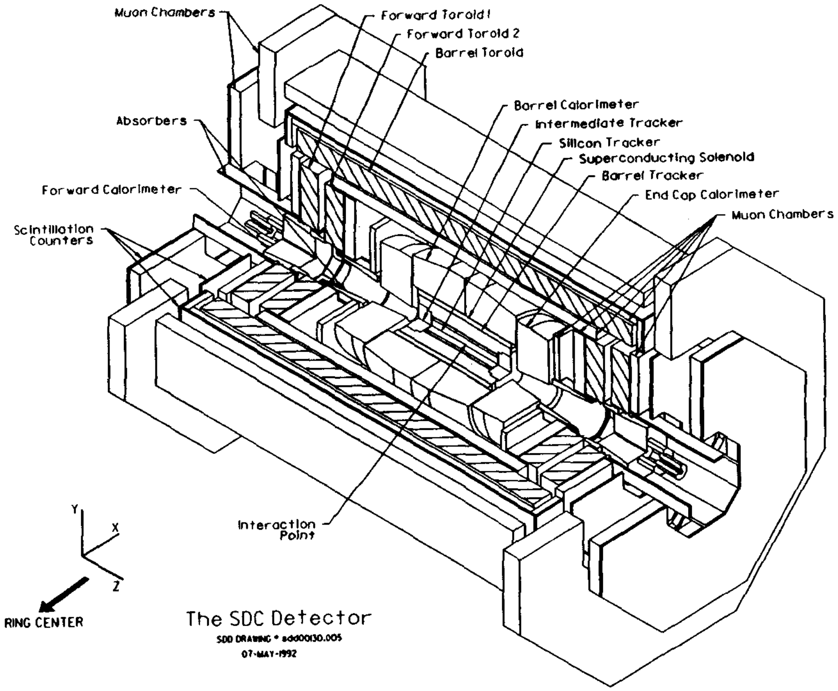
Los Alamos

HAZARD ABATEMENT HIGHLIGHTS

Redundancy and Control Strategies

- Redundant liquid feed lines will run between the condenser and the detector enclosure.
- Redundant vapor return lines will run between the detector enclosure and the condenser.
- Redundant pressure relief valves will be place inside the enclosure to prevent over or
- Interlocks will be placed between the condenser refrigeration system and the detector power supply
- Flow activated interlocks on liquid supply lines are used to cut power in the event of a loss of cooling accident.
- A pressure activated interlock will be placed between the liquid return line solenoid and the detector power supply
- Passive "fail safe" shutdown mechanism

Los Alamos



The SDC Detector

SDD DRAWING # sdd00130.005

07-MAY-1992

HAZARD ABATEMENT HIGHLIGHTS

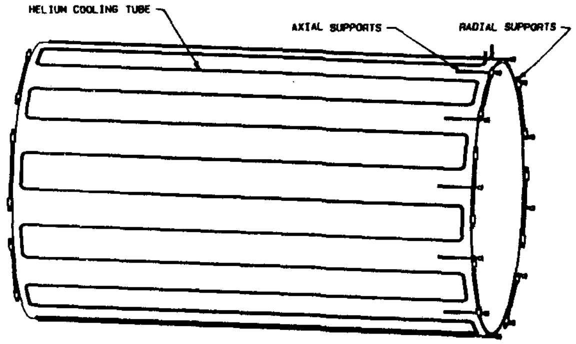
Hazard Detection Strategies

- Hydrocarbon sensors shall be installed at appropriate locations throughout the system to monitor for butane leaks within the detector hall.
- IR Hydrocarbon Sensors are used in place of catalytic hydrocarbon sensors
- A three-tiered alarm system triggered at 10 and 25 percent of LEL with automatic shutdown well before 100 percent of LEL
- Oxygen sensors shall be installed at appropriate locations to monitor oxygen levels. Oxygen detection sensors are located in annular seal nitrogen supply line, in the detector array, and in the inerting volume.

Los Alamos

SDC SOLENOID SYSTEM

OUTER SUPPORT CYLINDER



SDC SOLENOID SYSTEM

MAJOR COMPONENTS

1. SUPERCONDUCTING SOLENOID
2. CHIMNEY
3. SERVICE PORT
4. CONTROL DEWAR

SDC SOLENOID SYSTEM

MAJOR PARTICULAR HAZARDS AND ABATEMENT STRATEGIES

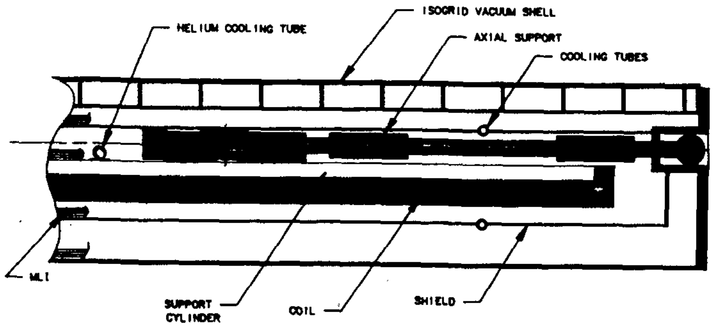
1. NEW DESIGN CONCEPTS AND ADVANCES IN TECHNOLOGY:

   ABATEMENT:

   - ENGINEERING ANALYSIS
   - TESTING COMPONENTS
   - QUALITY CONTROL
   - PROVING DESIGN CONCEPTS BY BUILDING, OPERATING AND TESTING THE PROTOTYPE SOLENOID

SDC SOLENOID SYSTEM

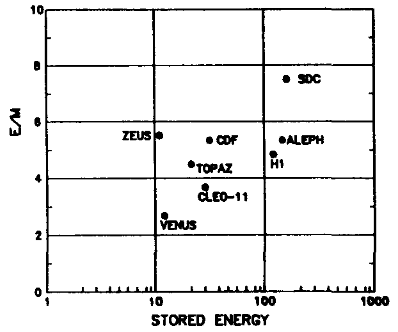
CROSS SECTION AT END OF SUPERCONDUCTING SOLENOID



SDC SOLENOID SYSTEM

MAJOR PARTICULAR HAZARDS AND ABATEMENT STRATEGIES

2. RATIO OF STORED ENERGY TO COLD MASS, E/M RATIO



SDC SOLENOID SYSTEM

MAJOR PARTICULAR HAZARDS AND ABATEMENT STRATEGIES

2. RATIO OF STORED ENERGY TO COLD MASS, E/M RATIO:

ABATEMENT:

- DESIGN FOR THE SOLENOID TEMPERATURES GENERATED BY OPEN CIRCUIT QUENCHES
- DESIGN FOR THE ELECTROMAGNETIC AND STATIC LOADS
- PROVE THE DESIGN IN THE PROTOTYPE SOLENOID

SDC SOLENOID SYSTEM

MAJOR PARTICULAR HAZARDS AND ABATEMENT STRATEGIES

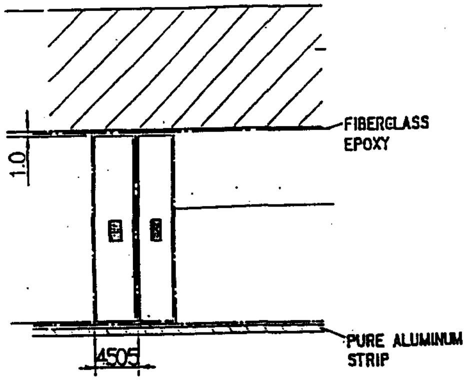
3. QUENCH - ABRUPT TRANSITION FROM SUPERCONDUCTING TO NORMAL, RESISTIVE STATE

ABATEMENT:

- DESIGN FOR FAST QUENCH PROPAGATION VELOCITY TO DISTRIBUTE THE RELEASED ENERGY OVER THE ENTIRE COIL
- POSSIBLE USE OF QUENCH PROPAGATION STRIPS
- PROVIDE RELIEF VALVES ON THE HELIUM COOLING TUBE CIRCUIT

SDC SOLENOID SYSTEM

QUENCH PROPAGATION STRIP



Muon Chambers

Very large chamber system
Layers of tubes would cover 12 acres

Flammable/toxic gas hazard

The drift tubes have been engineered to meet performance specifications using nontoxic-nonflammable gas

Central and intermediate	Argon/CO(2)	90%/10%
Forward	Argon/Ethane	90%/10%

Oxygen deficiency hazard

- ODH sensing and warning system throughout the detector
- Overpressure reliefs vented outside
- Flow restrictors
- Monitor supply, return, and makeup gas flows
- Monitor oxygen content of return gas

Environment Safety & Health

02369

SDC SOLENOID SYSTEM

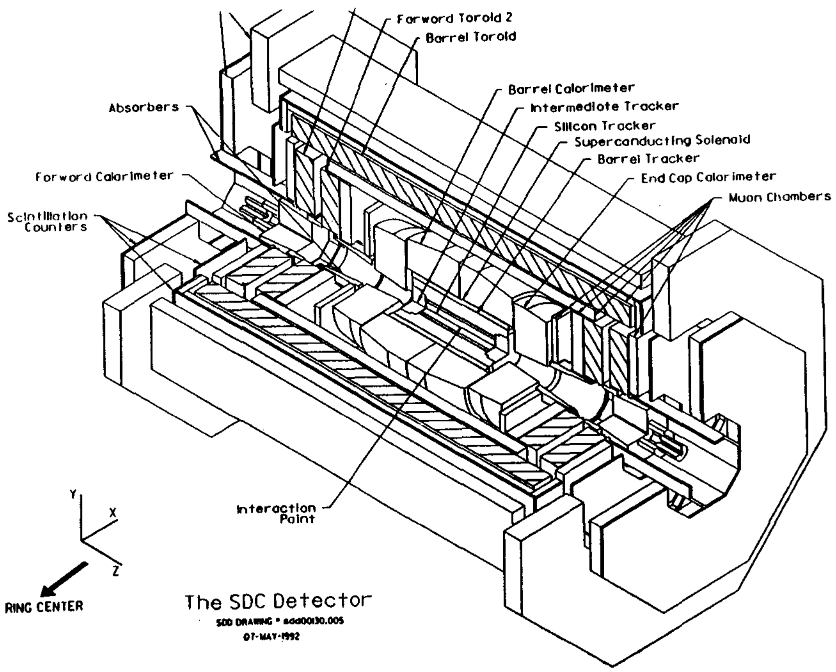
MAJOR PARTICULAR HAZARDS AND ABATEMENT STRATEGIES

4. OVERSIZED POWER SUPPLY (EXCESSIVE CURRENT):

ABATEMENT:

- DO NOT OVERSIZE
- CONTROL SYSTEM MONITOR AND TAKE CORRECTIVE ACTION (LIMIT CURRENT OUTPUT/SHUTDOWN)
- DESIGN THE SOLENOID FOR AN OPEN CIRCUIT QUENCH USING THE MAXIMUM POSSIBLE STORED ENERGY

02367



The SDC Detector
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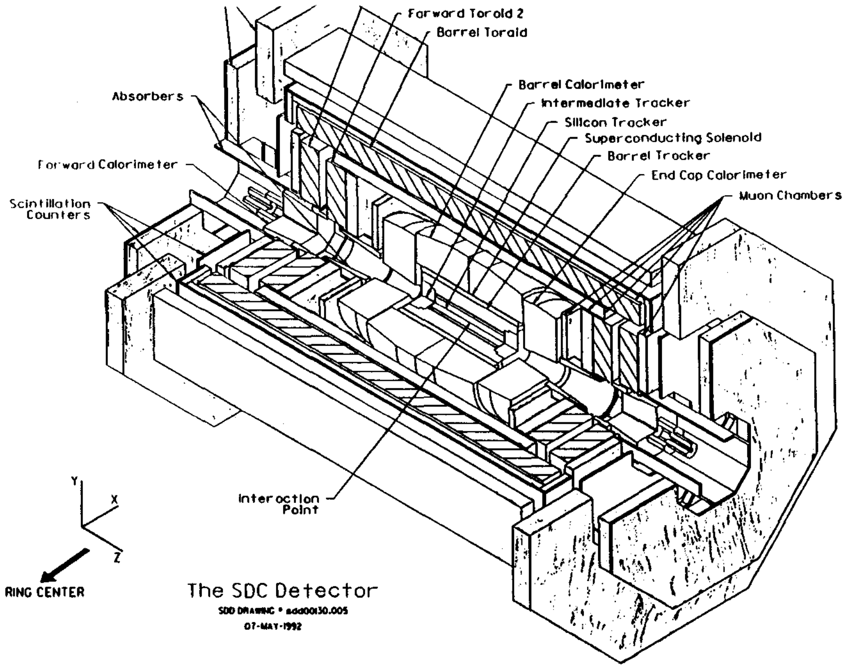

The SDC Detector
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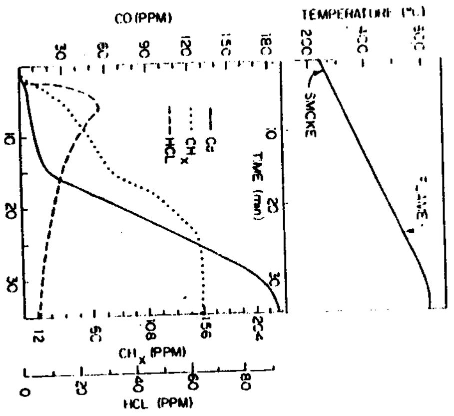
Fire Detection

Incipient Detection is a Solved Problem

VESDA	sample-draw aspiration system measures obscuration optically 1000 times more sensitive than spot detectors
CDF PPM	fuel specific evolved gas signature measures CO, CH(x), and HCL in ppm units more sensitive than VESDA

Incipient detection is planned for all interior spaces within the SDC detector and the overhead space immediately above it.

Multi-tiered alarming is planned to take maximal advantage of the early warning provided by incipient detection.



Structures

Design, engineer, and fabricate in compliance with the guidance listed in applicable codes and DoE orders for allowable stresses and safety factors

eg: AWS D1.1 Structural Welding Guide
DoE 6340.1A General Design Criteria

Design criteria are not limited to static situations - allowance must also be made for deflections and stresses from:

- movement of very heavy objects
- probable failures, eg one jack in a multijack support
- floor settling
- seismic requirements

Safety Review	addresses adequacy of design criteria
Peer Review	addresses accuracy of design calculations

Fire Protection

Work on development of a comprehensive and integrated fire protection plan for the SDC detector and its associated facilities is just beginning.

Fire Protection Workshop

Participants:	SDC, PRD, other DoE labs, AT&T, Sandia, and Factory Mutual Experts on fire protection for high-tech facilities
Purpose:	Evaluate the unusual hazards of the SDC detector
Risk Analysis:	very low intrinsic probability potentially catastrophic consequences

The approaches being taken with regard to
detection
control
prevention
mitigation
follow the concepts developed during the workshop.

Prevention

Primary ignition source is electronics and electrical equipment

Mitigation:
- Overcurrent Protection Policy
- Rack Protection System
- Crate Protection System
- NEC/OSHA Compliance

Other Measures:
- Tracking Volume Inertion
- Flammable Gas Safety System
- Housekeeping Policy
- Welding, Burning, Brazing Permit Policy
- Process Monitoring
- Containerized Plastic Scintillator

Multitiered Alarms

Purpose: distinguish between small problems and hazardous conditions
allow for early intervention to keep small problems small

3-Level Example:

- **Level 1** Off-normal condition
  alarm is sent to local operations center for diagnosis
  condition logged into trouble database, slow controls
- **Level 2** Pre-Alarm
  alarm sent as above and to relevant operations service center plus site emergency center (advisory)
  condition logged into trouble and alarm databases
  investigative response is mandatory
- **Level 3** Fire Alarm
  klaxons sound, gas & power shutdowns triggered, ...

Mitigation

Measures and Actions to Abate the Severity of an Incident

Halogen-free environment - materials control issue

Power shutdowns, both manual and automatic

Smoke ejection

Pre-alarms and trained on-site personnel

CCTV surveillance system

Control

GOAL provide for a broad range of suppression equipment to allow a staged response appropriate to the scale of an incident

emphasize local application and localized application zones to minimize the induced damage of the fire control method

PROBLEM
- halon is no longer available
- lack of people-safe alternatives
- lethal suppression systems would require lockout and tagout during personnel access periods
- effectiveness of incipient detection diminished by delay waiting for access control system to validate complete evacuation

Confined Space Issues

- Detector maintenance access spaces meet the classic requirements for confined space
  - ready escape
  - possibility of hazardous atmospheric conditions
  - Oxygen > 19.5 %
  - Flammables > than 10% LEL
  - tight working environment with
  - mechanical and electrical hazards present

Detector Maintenance Access Spaces

- Calorimeter Access Space
- Muon Access Space
- Tracking Access Space
- Detector Pit Area

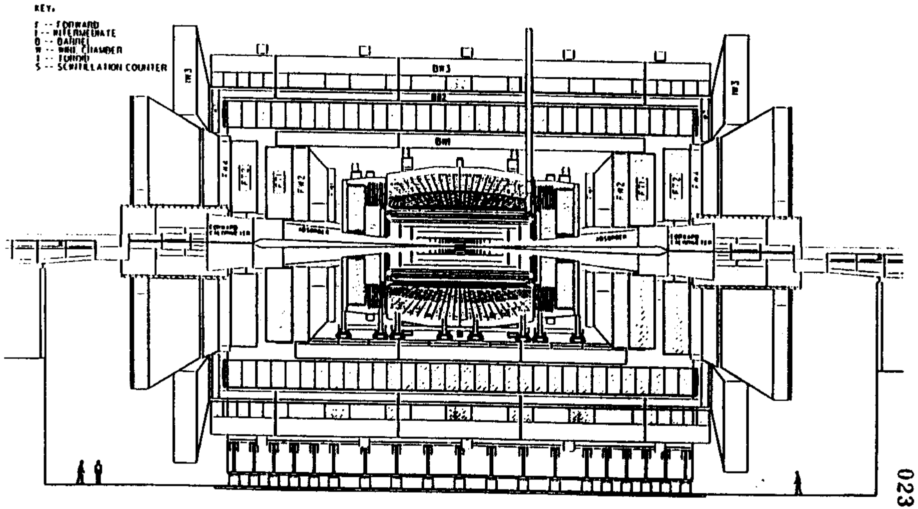
Confined Space Issues

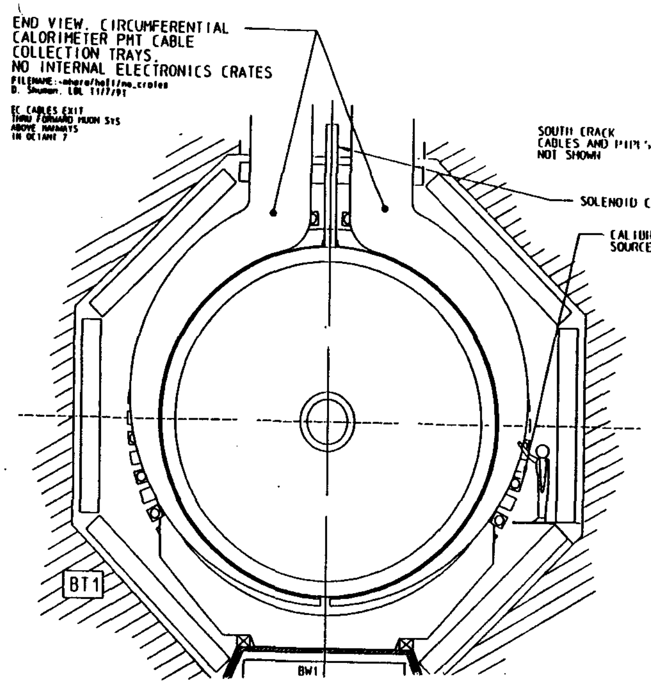
- Safety Systems Design and Integration

Confined Space Requirements

- Formal confined space survey
- Formal confined space classification
- Written procedures
- Training
- Atmospheric monitoring and testing
- Permit system (personnel access and control)
- Attendants and 2 man-rule
- Lockout/Tagout procedures
- HVAC procedures
- PPE

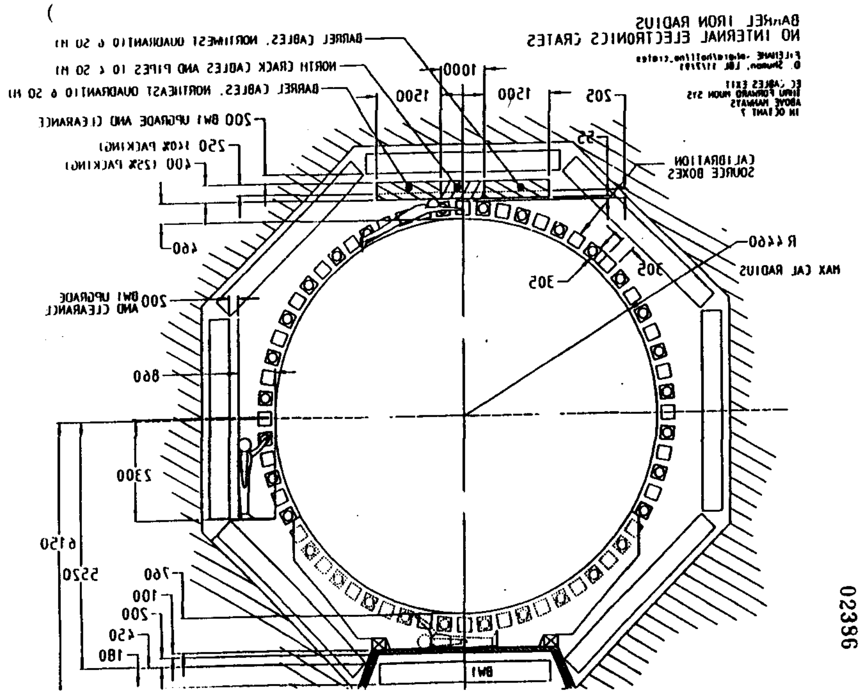
Detector Maintenance Access Spaces





Preliminary Evaluation Results

- **Based upon preliminary evaluation, engineering controls and initial estimates of hazard potential . . .**
  - Calorimeter access is "Permit required" during normal ops
  - Calorimeter access is "Permit required" during the 1.2 pullback
  - Calorimeter access is "Nonpermit" during major pullback
  - Muon access is "Permit required" during normal ops
  - Muon access is "Permit required" during the 1.2 pullback
  - Muon access is "Nonpermit" during major pullback
  - Tracking access is "Permit required" during normal ops
  - Tracking access is "Permit required" during the 1.2 pullback
  - Tracking access is "Nonpermit" during major pullback
  - Pit area access is "Nonpermit"



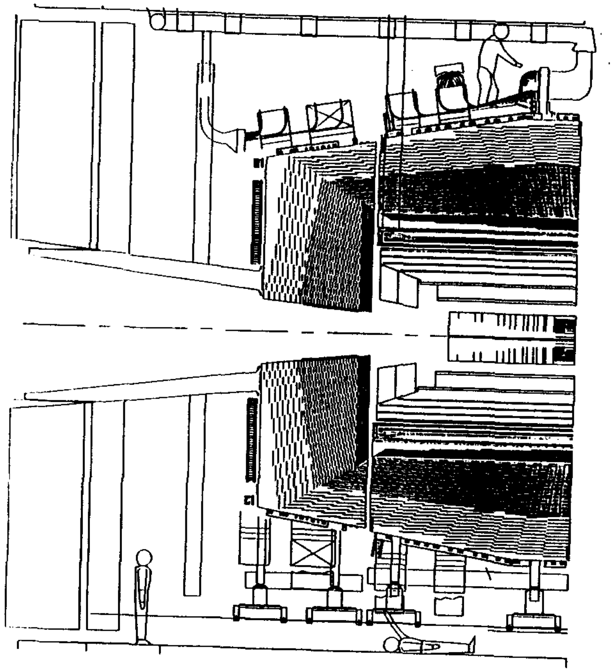
Calorimeter Maintenance Access Space

Safety Systems Design and Performance Criteria

- All systems integrated to provide a comprehensive situation awareness, alarm, and response structure
- Minimal cognitive interpretation required for assessment
- User-Friendly man/computer interface design
- Minimal workload under non-normal situations
- Based upon a 3 level alarm scheme

1. Engineering Out of Tolerance condition
2. Pre-alarm Condition ... immediate response
3. Emergency Condition w/ associated activities

- In <u>some</u> cases two 1's make a 2
- In <u>all</u> cases two 2's make a 3
- Corroboration and Persistence



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Fire Protection

- Integrated with Hall and Laboratory systems
- Will utilize both incipient and traditional detection
- Three level alarm scheme
- Comprehensive coverage based upon fuel loadings and ignition sources as a result of detailed fire hazard analysis
- High Reliability - Low Maintenance

Integrated Safety Systems

- Fire Protection System (Detection & Control/Suppression)
- Personnel Access and Control (ie. PASS)
- Detector Systems Monitoring
- Utilities Monitoring
- Atmospheric Management System
- Control - Display Integration

Detector Utilities Monitoring

- Gas and liquid flow rates at interfaces and sources
- Power draw

Personnel Access

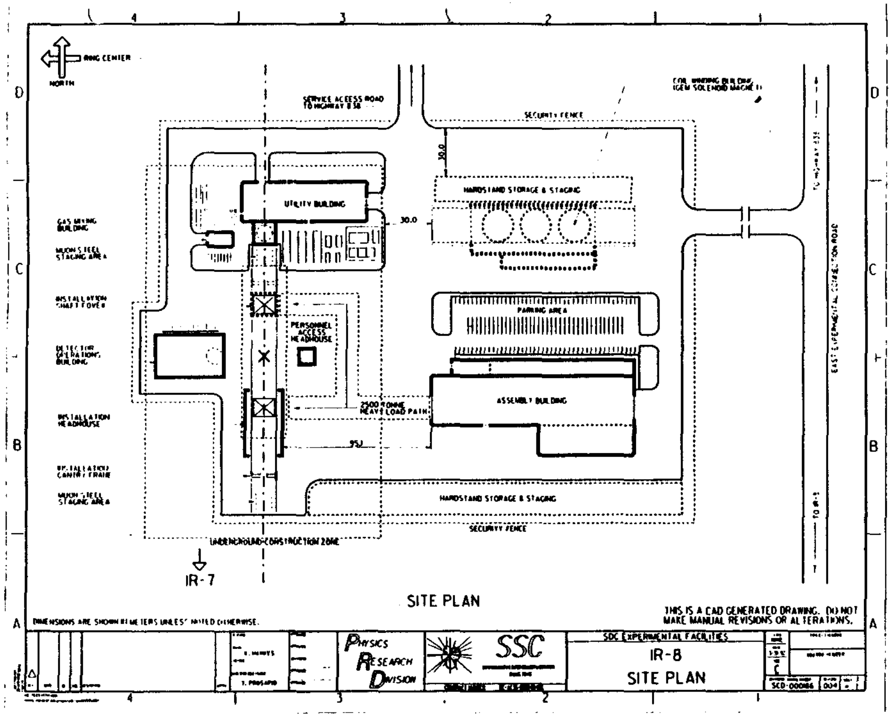
- Designed to be complimentary with Lab PASS
- Facilitates confined space safety features
- To be implemented for both Hall and Detector interior
- Redundant, high reliability design

Atmospheric Management System (AMS)

- Monitors detector interior and pit area
- Integrated with Hall AMS
- Integrated with appropriate alarm systems
- Monitors for both O_2 concentration and experimental gases

Detector Systems Monitoring

- Monitors utilities and performance of detector systems
- Gas and liquid parameters inside the detector
- Electronics overtemp and overcurrent
- Makeup rates of selected detector utilities
- Radiation dosage data



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The approaches being taken with regard to
- **detection**
- **control**
- **prevention**
- **mitigation**

follow the concepts developed during the workshop.

UTILITIES

WATER COOLING SYSTEM

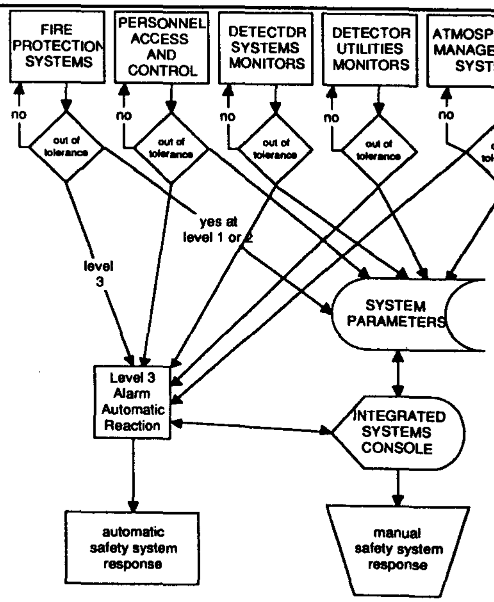
HEATING VENTILATION AIR CONDITIONING

GAS SYSTEM

ELECTRICAL

CRYOGENICS

Detector Safety Systems



Gas System

A gas mixing facility will supply the detector systems with experimental gases at required pressure, flow rate, temperature, purity and gas constituent rations.

SYSTEMS	GAS
Barrel & Intermediate chambers	Gaseous Argon Carbon Dioxide 90%/10%
Forward Muon chambers	Argon/Ethane 90%/10%
Forward Calorimeters	High Pressure Argon
Barrel Tracker Straw tube option	CF4 and Isobutane 30%/20% N2 inerting N2 cooling
Silicon Tracker	Gaseous Nitrogen

Water Cooling Systems

Cooling pond/tower water is used as the primary cooling medium for all cooling requirements. The majority of the heat rejected to the cooling water system will be transferred to the atmosphere by means of evaporative cooling. These systems are:

Cooling pond/tower water (CPW)
Low conductivity water (LCW)
Chilled Water (CHW)

Electrical System

Electrical power will be supplied by three circuits from the East Main Substation feeding the Detector operations building, Utility building and the balance of the surface building.

Power Summary

Location	Est. Load KVA	Service Voltage	Remarks
SURFACE:			
Conventional	2054	480Y, 208Y	
Technical	269	408Y, 208Y	4260 VAC for cryo
UNDERGROUND:			
Conventional	2024	480Y, 208Y	
Technical	9772	480Y, 208Y	
EMERGENCY	970	480Y, 208Y	
TOTAL	15099		

HVAC

Two systems make up the HVAC for the detector:

1. Detector hall ventilation system mixes 25% outside air with 75% return air before conditioning. During emergency, units can double their airflow and use 100% outside air.

   Provides air occupancy
   Dilutes any escaping gases
   Provides a heat sink for heat not removed by water system

2. Detector ventilation system provides 100% conditioned air for the interior of the detector.

   During operation the system removes escaping gases
   Provides fresh air for occupancy during maintenance
   Provides a heat sink for heat not removed by water system

Liquid Nitrogen System

Supports cooling of the thermal shields in the magnet system, helium refrigerator/liquefier and the transfer lines

Supplied from a storage dewar adjacent to me Utility building

A liquid nitrogen subcooler and three liquid nitrogen pumps are housed with the helium cold box module in the Utility building

The gaseous nitrogen piping is routed along with the liquid helium and liquid nitrogen transfer lines.

Source of the gaseous nitrogen.

Cryogenics

Two systems make the cryogenics:

Helium refrigerator/liquefier

Liquid Nitrogen

Hazards and Mitigations

HAZARDS	MITIGATIONS
Oxygen Deficiency	ODH monitoring, HVAC purge
Flammable Gas Leaks	Flammable gas detection monitoring Code compliance
Support Equipment Fire	Fire alarm, detection and suppression
Personnel Identification	Pass installed in the hall
Electrical	Code compliance Training, certification program
Cryogenic leak	ODH monitoring, HVAC purge process monitoring
Overpressurization	Rupture disks and over pressure relief valves systems

---

Helium Refrigerator/Liquefier

Supports the superconducting magnet and the Visible Photon Counters (VLPCs)

Refrigeration and liquefaction capacity of approximately 12oo watts and liquid flow rate of 90 gm/s

System is housed in the Utility building and consists of compressors, oil remover and purification systems, coolers and support equipment

Interface point between the refrigerator/liquefier and the detector cryogenics is at the input of the control dewar located on the top of the detector.

REPORT FROM REVIEW OF DRAFT CSAR

L. COULSON

Primary Hazard Categories

- **Life Safety**
  - **Confined Spaces**

    Barrel Calorimeter Electronics
    Muon System between BS2 and BW3
  - **Underground Enclosure**

5/7/92

L. Coulson

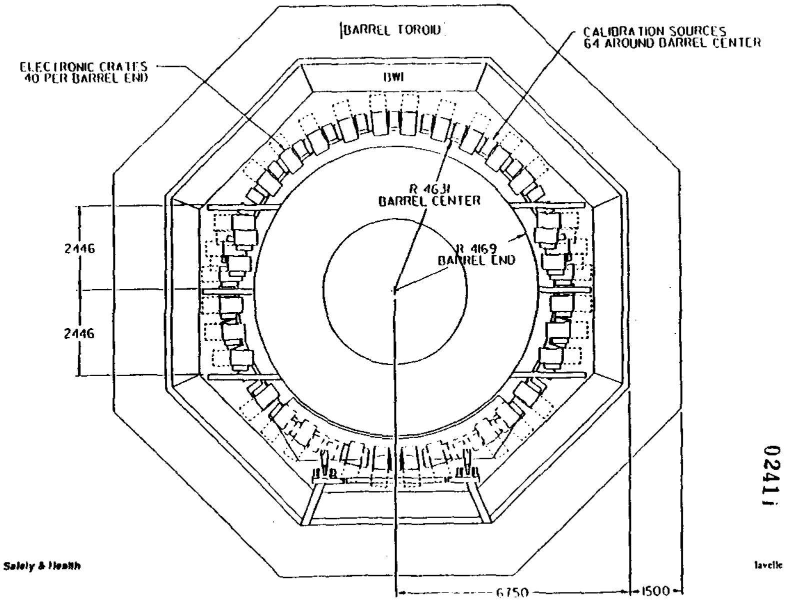
Charge to Panel

Evaluate the SDC Conceptual Design, the technology choices, and the facilities required of the Laboratory infrastructure and address the following questions.

- **What are the principal hazards of the detector and associated infrastructure during the operation and maintenance.**
- **Have the hazards been correctly identified and assessed?**
- **Can the hazards be reduced, eliminated or adequately controlled, and what is the resultant level of risk?**

5/7/92

Detector Maintenance Access Spaces



Environment Safety & Health

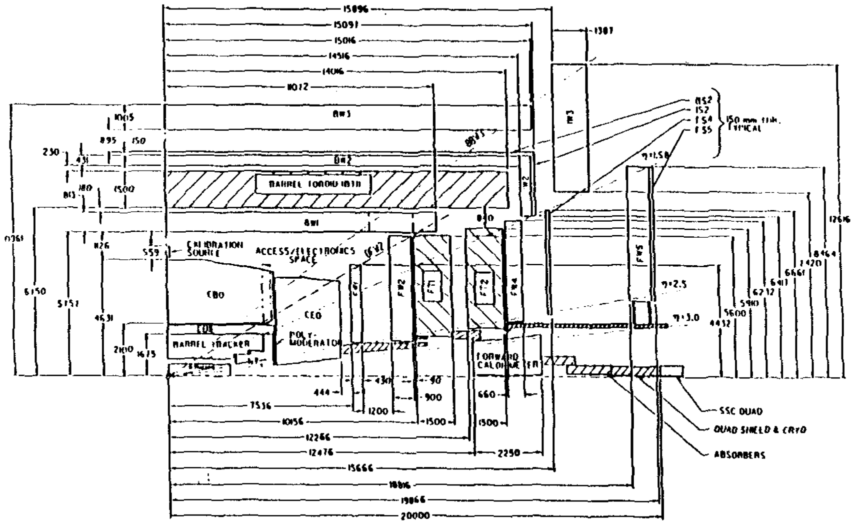
lavelle

Panel Membership

Robert Bell	**SLAC**
Jeff Bull	**SSC**
Larry Coulson (Chairperson)	**SSC**
David Hawkins	**SSC**
Barry Hendrix	**SSC**
Lewis Kelller	**SLAC**
Robert Macek	**LAMPF**
Edward Verminski	**SSC**

- Radiation
    - Induced Residual Levels
    - Accidental Beam Losses
- Environmental Releases
- Emergency Detection/Response

Detector Maintenance Access Spaces



- Mechanical Integrity
- Electrical Hazards
    - Low Voltage/High Current
    - High Voltage
- Oxygen Deficiency/Cryogenic Liquids

- Fire
    - Large Combustible Load

      Cables and Scintillator
    - Many Ignition Sources
    - Butane

SDC Conceptual Safety Analysis Report
Review Panel Summary

The Panel was impressed with the depth of analysis, systematic approach, and level of detail which is contained in the draft CSAR. No show stoppers were detected which the Panel believes would prevent the experiment from being constructed as currently being planned.

The Panel concludes that the SDC has a system and organization in place which will identify hazards, assess the magnitude of the hazards, and assess the impact of proposed mitigation measures. The Panel found no hazards which had not been already identified by the SDC safety analysis process. Because there are still numerous technical choices to be made in the detector components and the SDC is still in the process of identifying and assessing mitigation measures, the Panel did not feel it appropriate to attempt to determine the resultant level of risk.

However, it appears the Panel, that sufficient mitigation techniques have been identified and can be applied to the final design to lower the resultant risk to acceptable levels.

The Panel also concludes that there are serious environment, safety, and health (ES&H) problems to be solved. It is, therefore, important that the SCC continue to utilize the best possible resources in dealing with these ES&H issues.

02418

PARALLEL SESSION G:

PERFORMANCE/TRIGGER/ INTEGRATION/OPERATIONS

TRIGGER SYSTEM REQUIREMENTS AND PERFORMANCE

G. SULLIVAN

Sullivan

SDC Trigger System Requirements
and Performance

Greg Sullivan
University of Chicago

SDC Review
Session on Trigger, Physics and
Integrated Performance
May 7, 1992

SDC Trigger System Requirements

"Hardware"

Input Rate:	Beam crossing every 16 nSec 10^8 interactions per second at $\mathcal{L} = 10^{33}$ First level trigger at 60 MHz
Output Rate:	50- 100 Hz written to "Tape"

$\Longrightarrow 10^6$ **rejection**

"Physics"

Higgs/SUSY:
leptons - $P_T > 40 GeV$
dileptons - $P_T > 20 GeV$
diphotons - $P_T > 20 GeV$
missing $E_T > 100 GeV$

Bread & Butter:

(push the thresholds down)	$P_T > 20GeV$?
$t\bar{t}$	(1-90 Hz)
$W \rightarrow e\nu$	(10 Hz)
$W \rightarrow \mu\nu$	(10 Hz)
$Z \rightarrow ee$, $Z \rightarrow \mu\mu$	

Physics rate $\sim$ 20-100 Hz

Physics rate $\approx$ Tape rate $\Longrightarrow 10^6$ rejection and high signal/background

---

SDC Trigger Structure

- **Physics Rate $\approx$ Tape Rate**
  Final trigger level must use offline style cuts.
  RISC processor farm with many MIPS.
  Need a reasonable rate into processor farm($\sim kHz$).
- **16 nSec between crossings**
  First level trigger operates at 60 MHz.
  Algorithms at 60 MHz are expensive.
  Fixed and small latency ($\sim 4\mu S$).
  Can't reduce rate to $\sim 1kHz$ in first level

$\Longrightarrow$ **3 Level Trigger Scheme:**
Algorithms at level 1 (60MHz) are difficult and expensive.
Reduce rate with simple "hardwired" algorithms at Level 1.
Level 2 operates at 10-100 kHZ $\rightarrow$ reduced speeds allow processors (more economical)
Level 2 uses programmable algorithms to reduce rate to a few kHz

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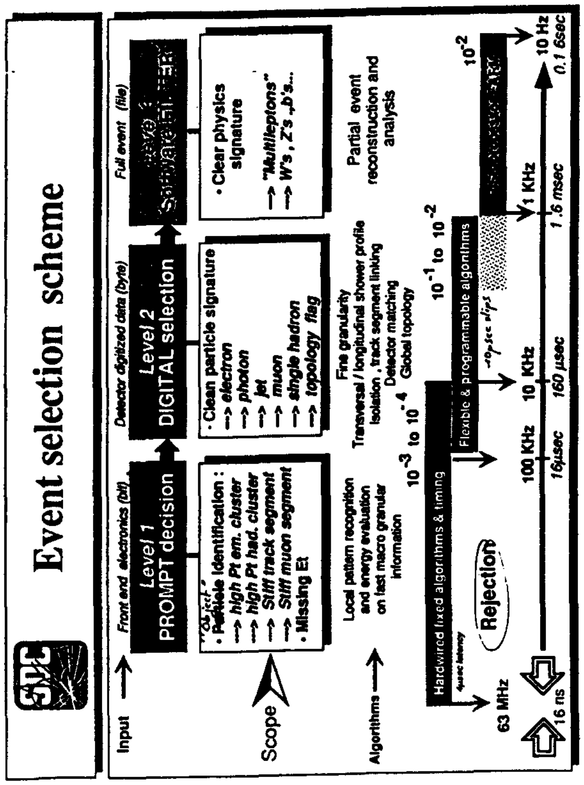


3/3/92

SDC level 2 trigger - Patrick Le Du

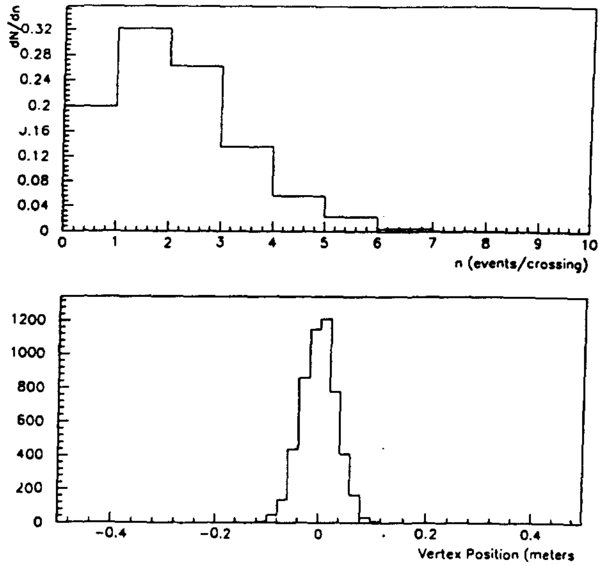
Trigger Rate Simulation

Isajet plus fast detector simulation. Uses parameterizations of detector response.

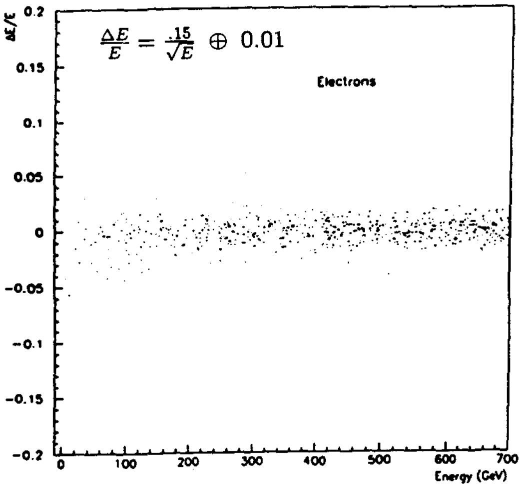
Includes:

- Multiple interactions
- Vertex position smearing
- Calorimeter response shaping function
- π and K Deacys
- Photon conversions
- Tracking resolution and efficiency from full simulations of tracking trigger
- Calorimeter longitudinal & lateral shower fluctuations
- Electron Bremsstrahlung
- Shower maximum detector parameterized from full simulation

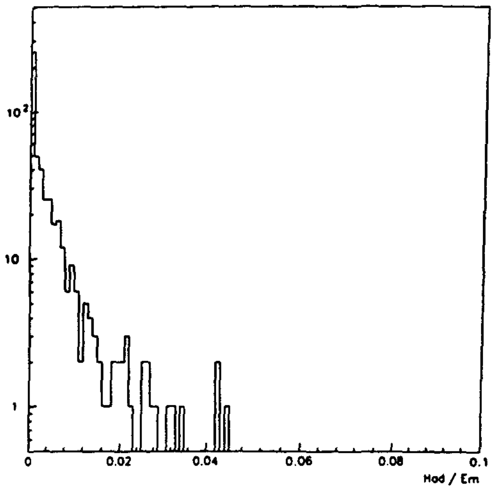
Interactions per crossing $< n >= 1.6$ and vertex position smearing



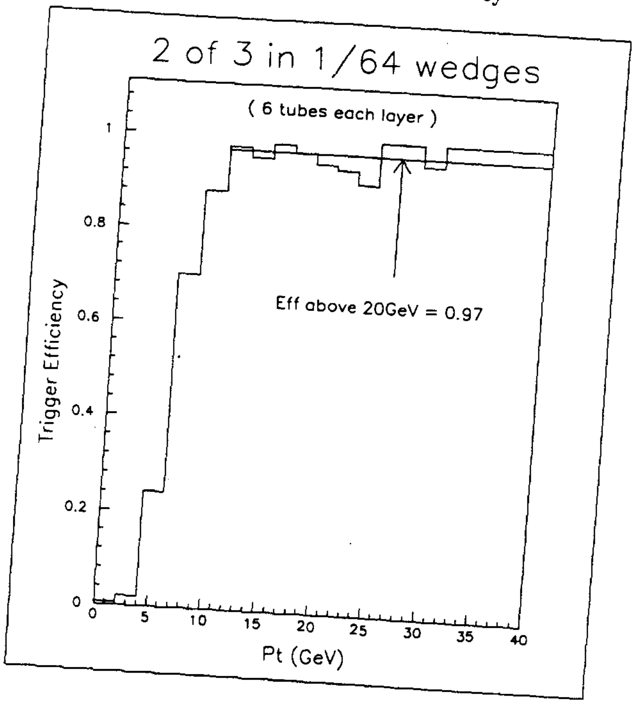
EM Resolution



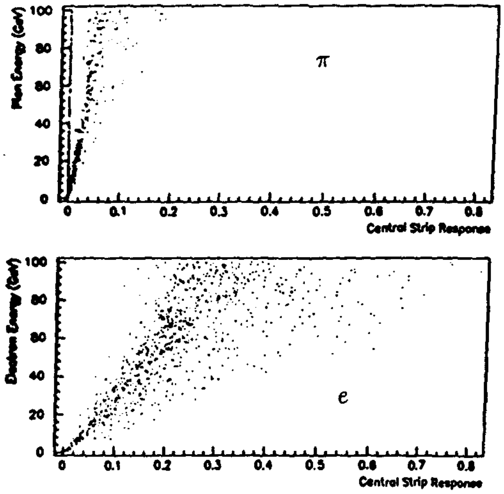
Had/Em ratio for Electrons for $.1 \times .1$ towers



Straw Tube L1 Trigger Efficiency



Shower Max Response vs. Energy for Pions and Electrons



SDC Level 1 Trigger

Electrons and Photons:
(.1 x .1) calorimeter towers with E_T > Threshold
E_{had}/E_{em} <.04 - 0.1
Shower max above threshold in .2η x .2ϕ segmentation

electrons: Track Segment with $P_T > 10.0GeV$
Track segment matched in ϕ to tower.

Muons:
Muon "hits" from Scint + Θ chambers with P_T > threshold

Option: "link" with track segments from tracker in 1/64 bins in ϕ cutting on track P_T

Jets and Hadrons:

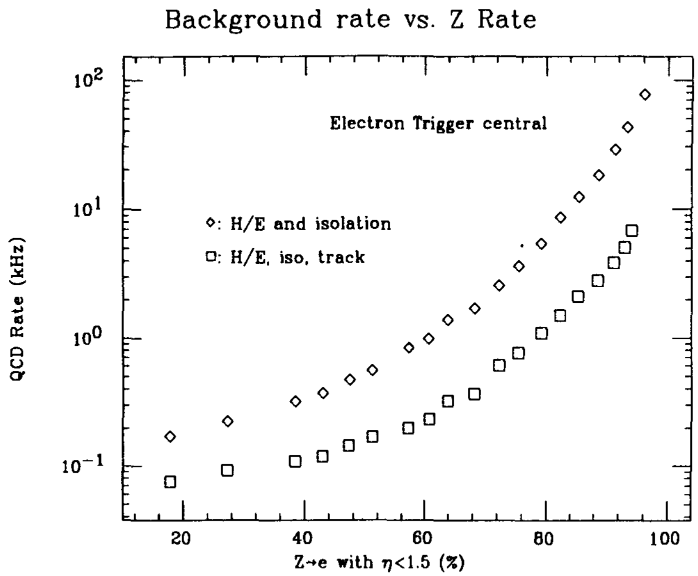
Calorimeter energy sums and single tower energy > threshold
hadrons: E_{had}/E_{em} > thresh
Shower max below em threshold

Neutrinos:
Missing E_T for sums of .1 x .1 towers > E_{thr}

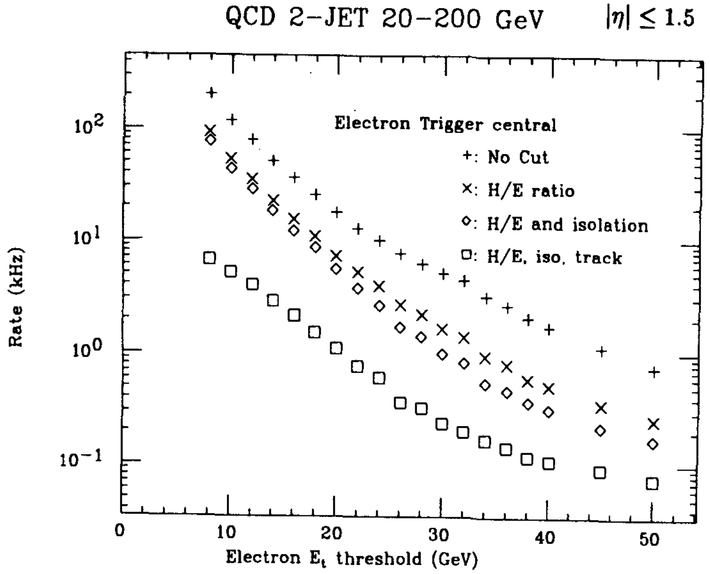
⟹ Level 1 tigger rate ≈ 30 kHz

SDC Level 1
Trigger Rtaes

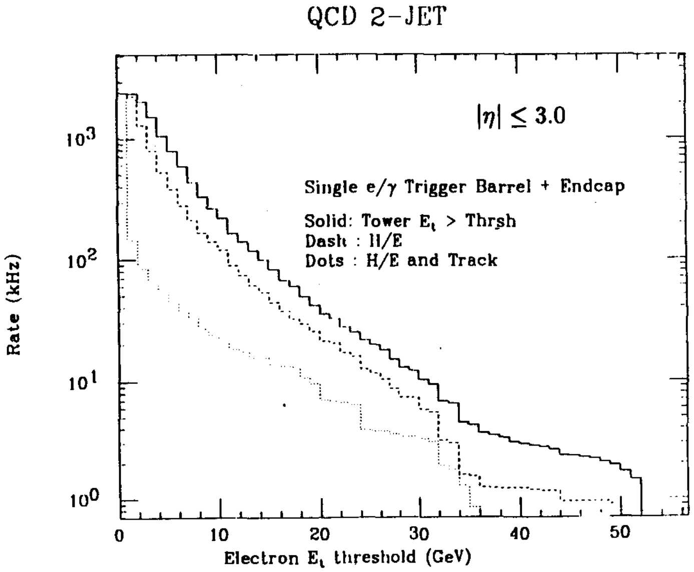
Background Rates from QCD 2-jet events
with 20 GeV < Pt < 200 GeV
mixed with minimum bias events



02434



02432



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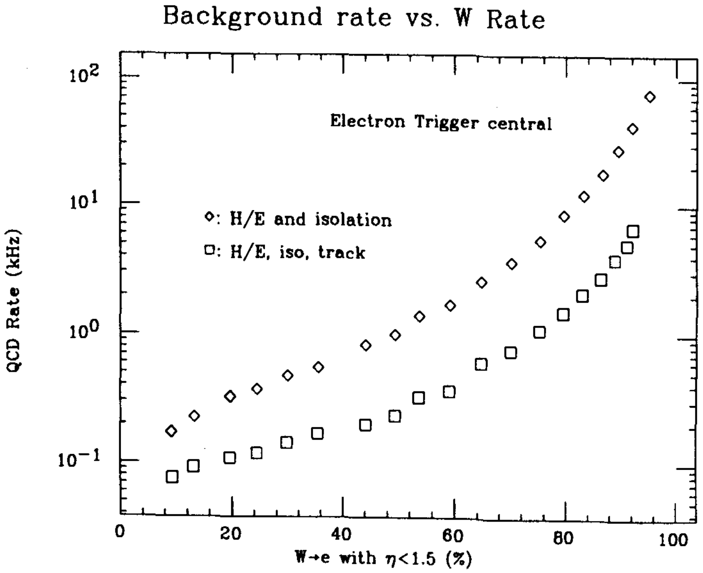

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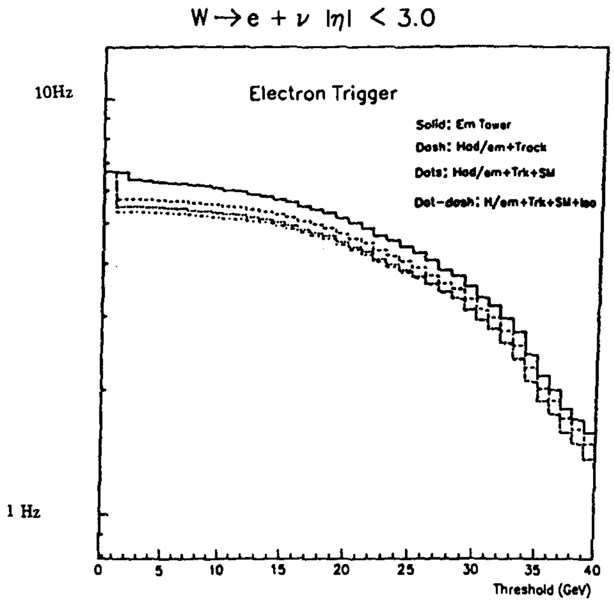

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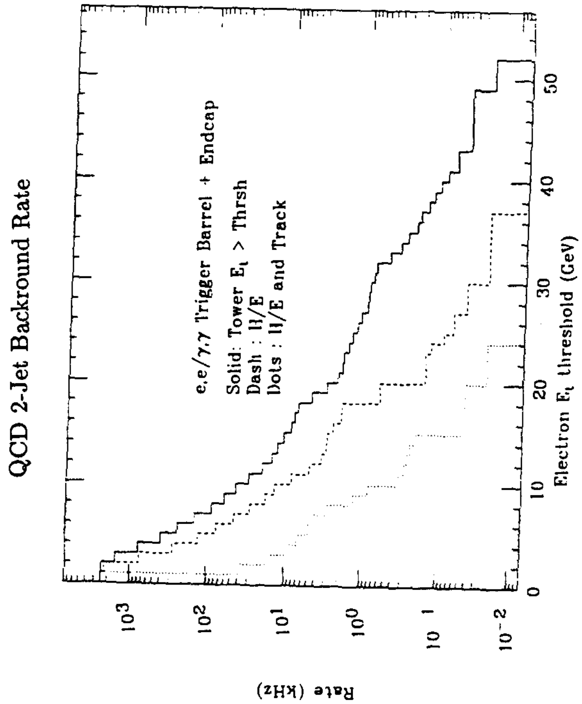


02438

<u>Combined EM Trigger Rates</u>

e = electron ; Had/Em < 0.05 ,
Track Pt > 10 GeV matched
in ϕ with tower

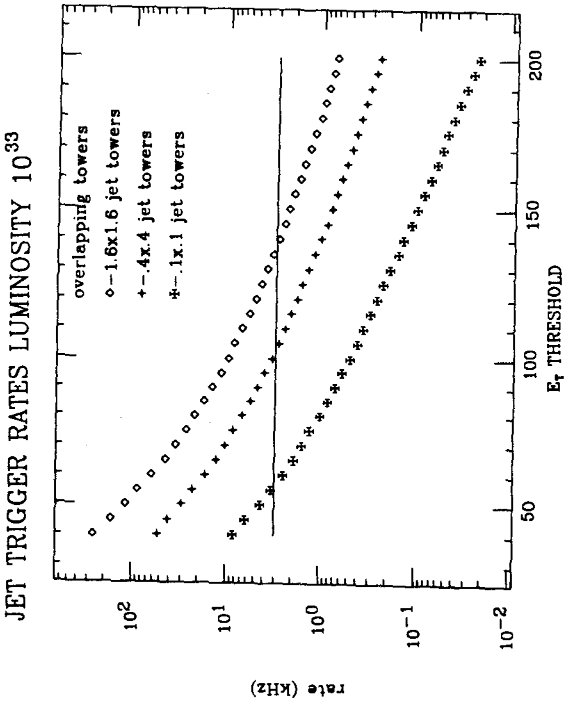
2e = dielectron ; Had/Em < 0.1 ,
Track Pt > 10 GeV

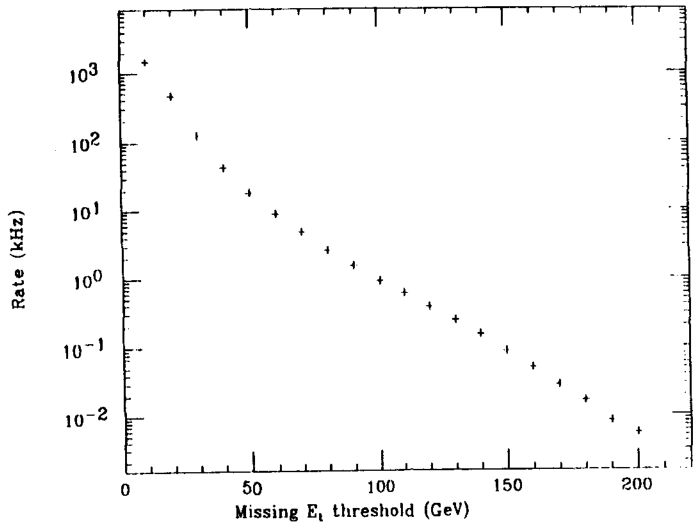
γ = photon; Had/Em < 0.05

2γ = diphoton; Had/Em < 0.05

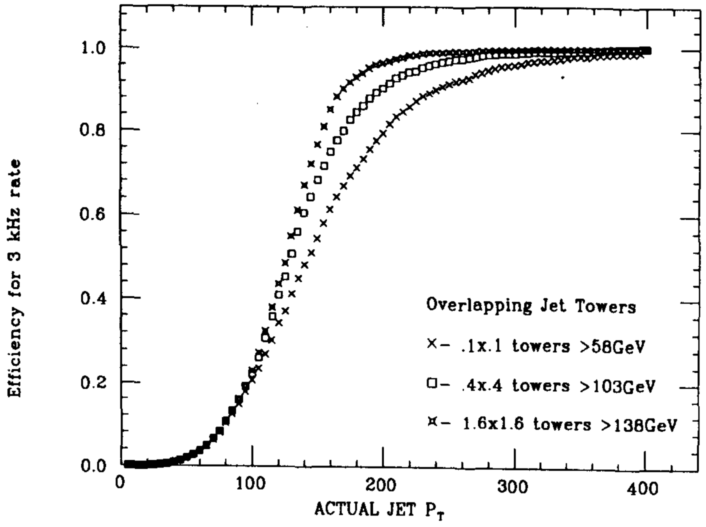
Trigger Threshold (GeV)				Rate (kHz)
e	2e	γ	2γ	@$10^{33}cm^{-2}S^{-1}$
20	10	30	20	9.8
20	10	40	20	8.1
25	10	40	20	5.0
25	15	40	30	4.7
30	20	45	30	3.8
20	-	-	-	7.0
-	10	-	-	0.3

02439



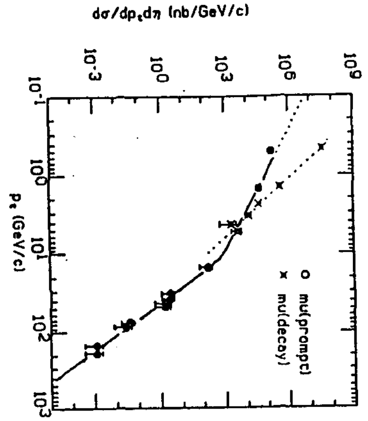

QCD 2-JET - Missing E_t trigger

02442


Jet Trigger Efficiency– Luminosity 10^{33}

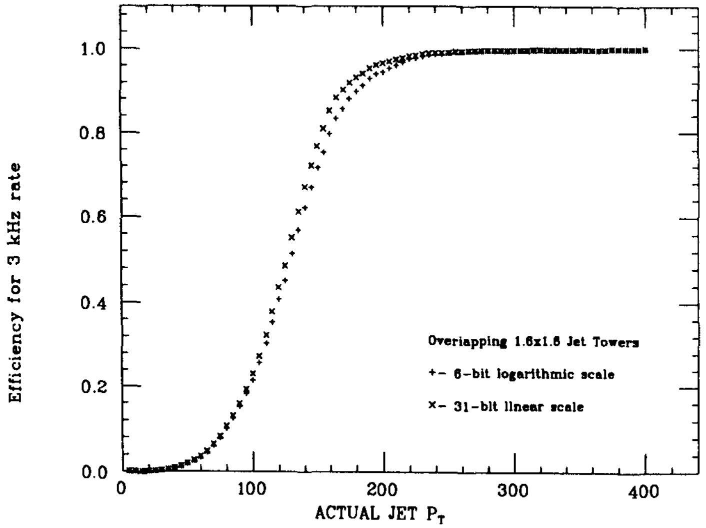
02440

Muon Rates



$P_T > 20.0\,GeV \implies \sim 6\,kHz$

02443

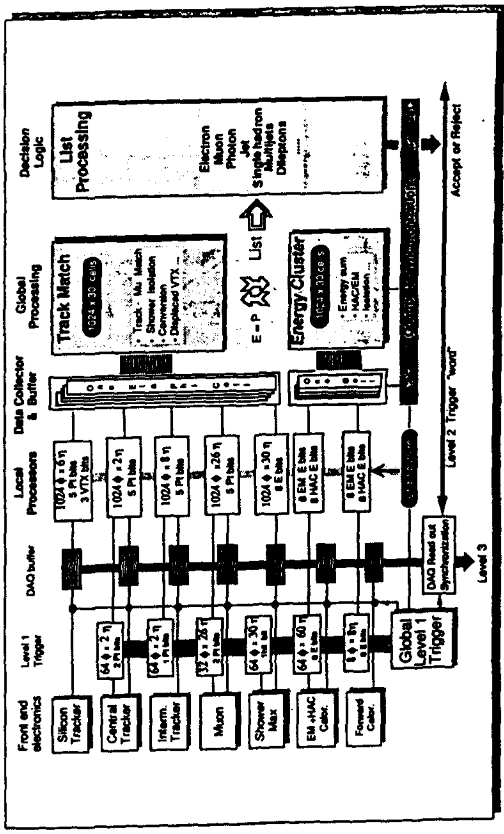

Jet Trigger Efficiency– Luminosity 10^{33}

02441

Level 1 Trigger Thresholds

Trigger	Threshold (GeV)
electron	20
dielectron	10
photon	30
diphoton	20
1 twr. hadron	50
Jet (1.6 x 1.6)	140
muon	20
dimuon	<20
e-mu	10-20
missing E_T	80

Data Flow (TDR)



3/25/92

SDC level 2 trigger -

SDC Level 2 Trigger

Electrons and Photons:
cluster E_T > Threshold
E_{had}/E_{em} <.04 - 0.1
Isolation where necessary

electrons: silicon tracker tags conversions
Track matched in ϕ to shower max in 1/1024
to reduce $\pi^+ - \gamma$ overlap
sharpened track P_T

Muons:
Match muon system to Silicon and outer tracker
sharpen P_T threshold.
Isolation using calorimeter

Jets and Hadrons:

Cluster energy sums and single tower energy > threshold
hadrons: E_{had}/E_{em} > thresh
Shower max below em threshold
track isolation

Neutrinos:
Missing E_T for sums of .1 x .1 towers > E_{thr}
Correct for Muons
missing E_T from sum of jet energies

Displaced vertex trigger:
Displaced vertex from Silicon tracker

$\Longrightarrow$ **Level 2 tigger rate $\approx$ 1-3 kHz**

Preliminary
SDC Level 2
Trigger Rtaes

$|\eta| < 3.0$

1 mb = 1 MHz @ 10^{33}

Background Rates from QCD 2-jet events
with 20 GeV < Pt < 200 GeV
mixed with minimum bias events

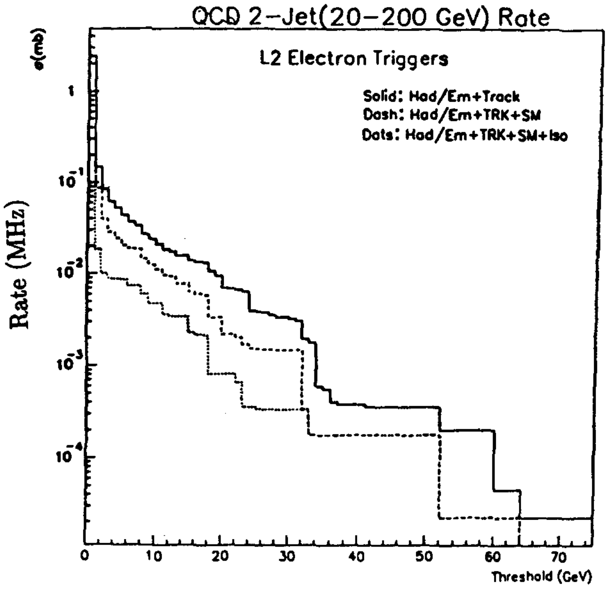
NOTE:

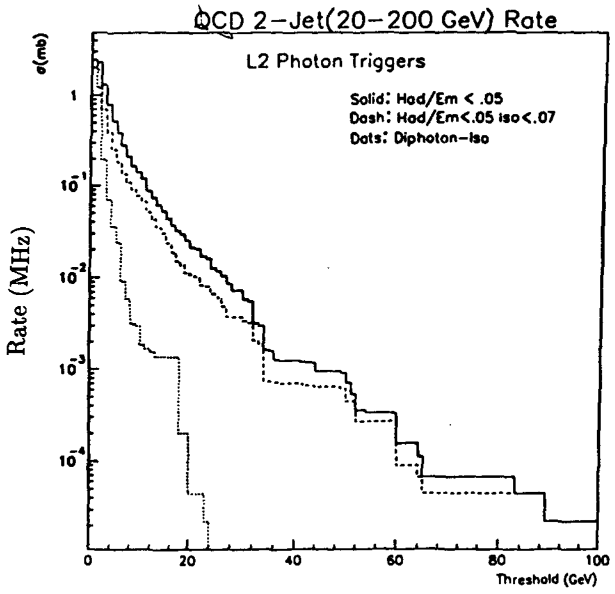
No Level 2 clustering Done - single towers only

No Conversions removed - The level 1 rate is dominated by charged pion-neutral pion overlap and conversion electrons in approx. equal proportions.

- Track ≡ Track with $P_T > 10GeV$ matched in ϕ with tower
- SM ≡ Shower-Max strip over threshold mathed to 1/1024 in ϕ with track and $\Delta\eta = .2$ with tower
- ISO ≡ 8 surrounding Had towers/Energy < 0.07

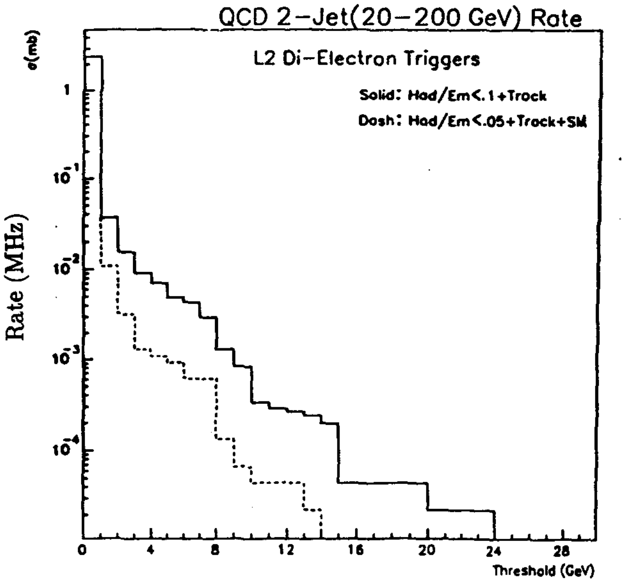
Conversions not Removed





Rate for 2 towers over threshold
(Conversions not Removed)

- Track ≡ Track with $P_T > 10GeV$ matched in ϕ with tower
- SM ≡ Shower-Max strip over threshold mathed to 1/t024 in ϕ with track and $\Delta\eta = .2$ with tower



Summary of Performance

"Hardware"

Input Rate: Beam crossing every 16 nSec
10^8 interactions per second at $\mathcal{L} = 10^{33}$
First level trigger at 60 MHz

Trigger Rate: 50- 100 Hz written to "Tape"
Level 1 ⟹ 30 kHz
Level 2 ⟹ 1-3 kHz
Level 3 ⟹ 20-100 Hz "Physics" rate
offline style cuts.

"Physics"

L1 Thresholds: leptons - $P_T > 20GeV$
dielectrons - $P_T > 10GeV$
photons - $P_T > 30GeV$
diphotons - $P_T > 20GeV$
Jets - $P_T > 150GeV$
missing $E_T > 80GeV$

L2 Thresholds(?): leptons - $P_T \geq 20GeV$
dielectrons - $P_T > 10GeV$
photons - $P_T \geq 35GeV$
diphotons - $P_T > 20GeV$
Jets - prescaled
missing $E_T \geq 100GeV$ (?)

The trigger can achieve 10^6 rejection while maintaining sufficiently low thresholds.

02452

TRACKING SIMULATION SUMMARY

D. COUPAL

COUPAL

Summary of Tracking Simulation Results

Presented by: David Coupal

Work done by:	D. Adams	B. Hubbard
	F. Bird	W. Lockman
	D. Coupal	F. Luehring
	P. Estabrooks	K. O'Shaughnessy
	W. Ford	...

- → SDC Tracking System Design
- → Resolution
- → Occupancy
- → Tracking Algorithms
- → Higgs
- → Jets
- → b-jet Tagging
- → Conclusions

Purpose

The purpose in these simulations is to verify that:

a) we get sufficient single-track efficiency and reconstructed mass efficiencies as to not significantly impact the acceptance for the physics processes open to SDC, and,

b) we maintain resolution close to the TDR parametric values,

with a realistic model of the environment and detector response.

NOTE:

This is a difficult business.

Many results are from not fully-optimized tracking algorithms.

Ongoing improvements in track reconstruction algorithms will improve performance

Adding more reality (dead channels, noise hits, misalignments) will worsen performance.

Physics Motivation

Physics Process	Signature	Demand on Tracking System
Associated Higgs Production	$W+H, t\bar{t}+H \to l\gamma\gamma$	$\lvert\eta\rvert < 2.5$ Efficiency > 97% Low fake trigger rate $\sigma_{pt} / p_t^2 \sim 20\%$
Direct Higgs Production	$H \to ZZ^* \to 4$ leptons $H \to ZZ \to 4$ leptons $H \to ZZ \to 2\upsilon + 2$ leptons	
High Mass Boson Pairs	$H \to l^+l^-\gamma$ $W^+Z \to l^+l^+l^-\gamma$ $W^+W^+ \to l^+l^+$	$\lvert\eta\rvert < 2.5$ $\sigma_{pt} / p_t^2 \sim 20\%$
Discovery of t Quark	$t\bar{t} \to W^+W^- + X \to e\mu + X$	Efficiency > 85% in jets b jet tagging > 25%
t Quark Mass Measurement	$t \to e\upsilon b$; $\bar{t} \to 3$ Jets $\quad \hookrightarrow \mu + X$ $t \to l\upsilon X$; $\bar{t} \to b +$ jets	

Physics Motivation (cont.)

Physics Process	Signature	Demand on Tracking System
New Z Searches	$Z' \to l^+l^-$	$\lvert\eta\rvert < 2.5$ $\sigma_{pt} / p_t^2 \leq 20\%$
QCD Jet Fragmentation	Jets	Efficiency > 85% in jets with p_t (jet) < 500 GeV/c Low fake rate

Environment

HOSTILE!!

Average of 1.6 interactions / crossing, each interaction producing ~ 20 tracks with $P_t > 400$ MeV/c and $|\eta| < 2.5$

Beam crossings every 16 nsec

⇒ contributions from previous and later crossings due to:
1) time window spanning several crossings
2) loopers

Add to this:

- → Trigger event (e.g. Higgs, another 70 tracks)
- → Neutrons
- → Luminosity $> 10^{33}$

Reconstruct tracks in this mess with:

{16 hits in silicon} + {36 hits in outer straws} per track at η=0
or {32 hits in outer fiber}

> Compare to Mark II at SLC: <n> = 22, 16 msec between beam crossings
> 3 Silicon + 38 VDC + 72 CDC hits per track
> (2-3 person-years to develop optimized track finding and fitting code)

⇒ Not a Large Safety Margin in SDC

Monte Carlo Simulation

Physics Event (typically):

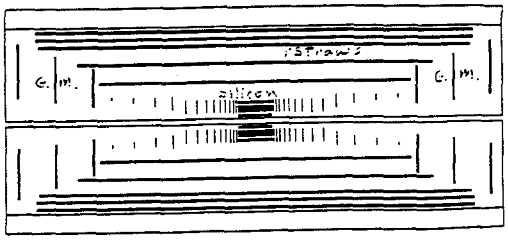
Signal:	ISAJET Beam spot simulated (5μm×5μm×5cm)
Background:	PYTHIA minimum bias Beam spot (-4,+2) beam crossings ⟨n⟩ = 1.6 events/crossing at 10^{33}

Detectors:

- → GEANT used to track particles through a fairly complete model of detector elements (active and inert).
- → Digitizations are generated, including detector time windows and dead-time, and reconstruction algorithms work off of these data.
- → Some studies done with pre-TDR designs that may differ slightly from final design.
- → GEANT simulation is slow: full simulation of just tracking detector at $L = 10^{34}$ is
  > 1 hour / event on 25 MIP machine

Detector Configuration

Silicon + Straws + Gas Microstrip



Status in Simulation:

Silicon and Straws:
Detailed model of detector response and averaged material thicknesses. Straw segment-finding and silicon-based track reconstruction working and being optimized.

Gas Microstrips:
Detailed model of detector recently installed. Also recently added to track reconstruction.

Detector Configuration

Silicon + Fibers

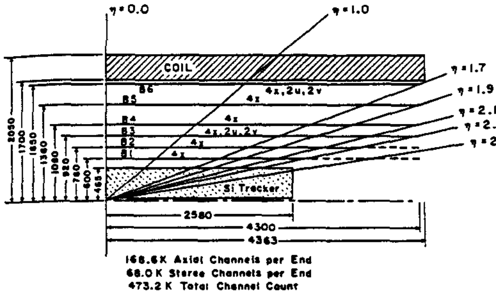


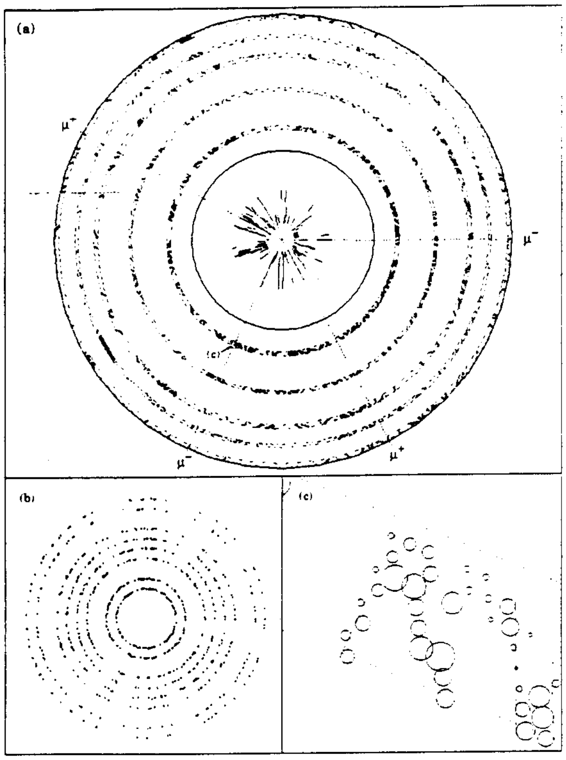
FIG. 4-57. Schematic of the central tracker exhibiting the fiber superlayers.

Status in Simulation:

Fibers:
Detailed model of detector response and averaged material thicknesses. Road-search track-finding algorithm working, some initial results. Optimization in progress

$H \to ZZ \to 4\mu$, Straw option, 10^{33}

02461

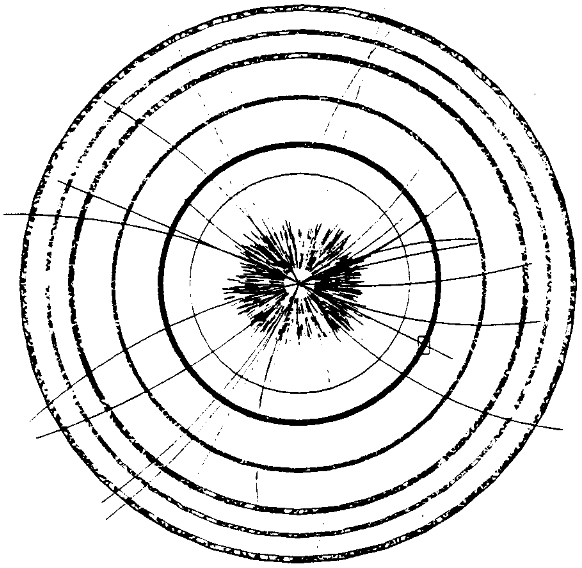


PAC Review
Review of Tracking Simulation Results
May 7, 1992
David Coupal

Higgs Event at 10^{34}

02462

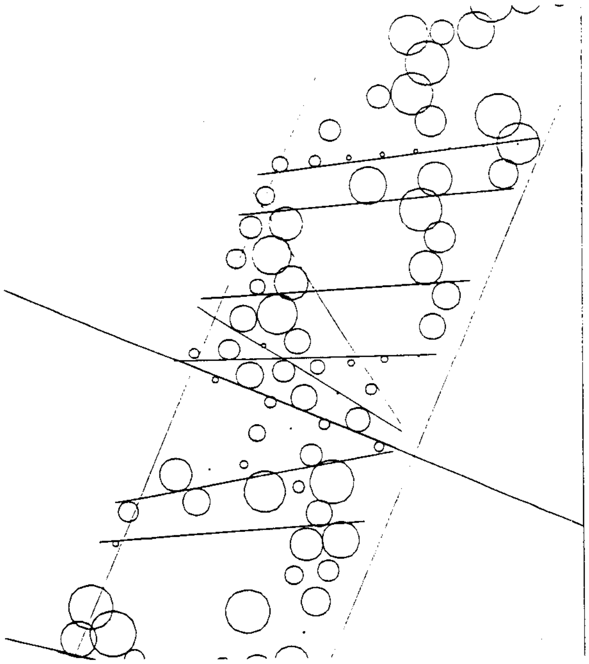
Higgs → $Z^\circ Z^\circ \to 4\ \mu$, Silicon + Straw, Luminosity = 10^{34}



PAC Review
Review of Tracking Simulation Results
May 7, 1992
David Coupal

Higgs Event at 10^{34}: Muon in Straw Layer 1

02463



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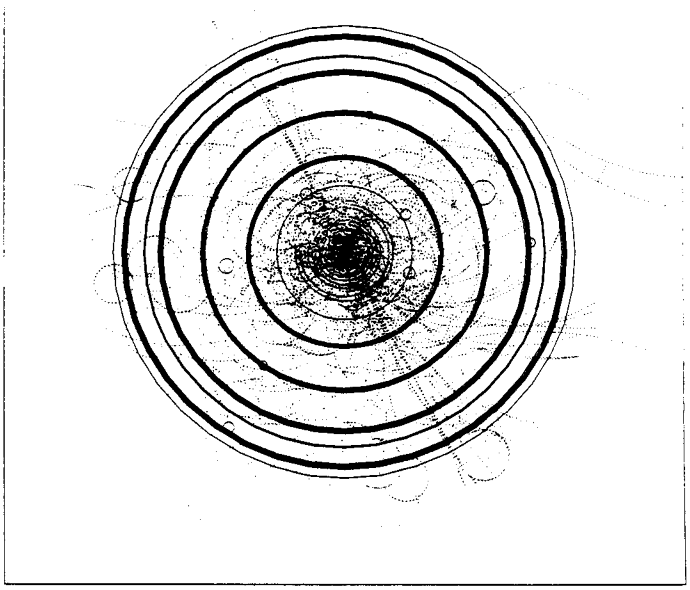
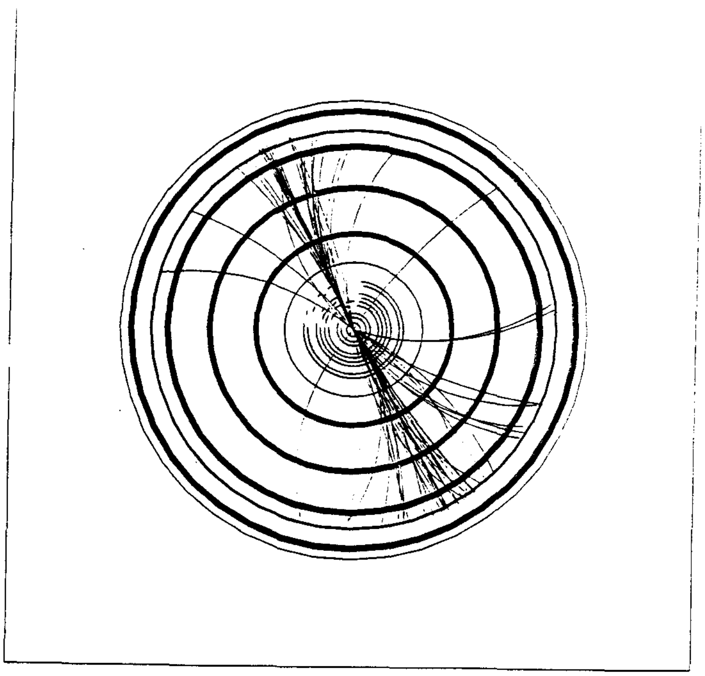
300 GeV Jets, Straw Option, 10^{33}

MC tracks 02464

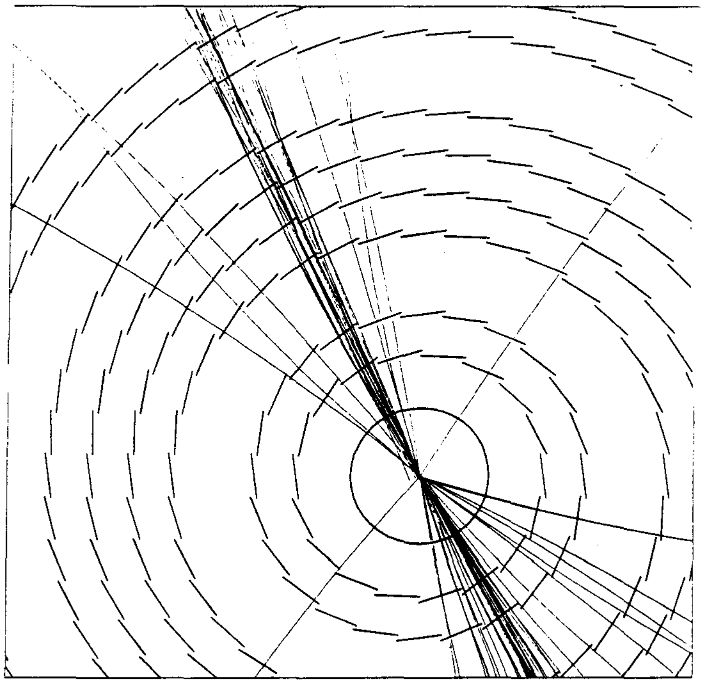


02465

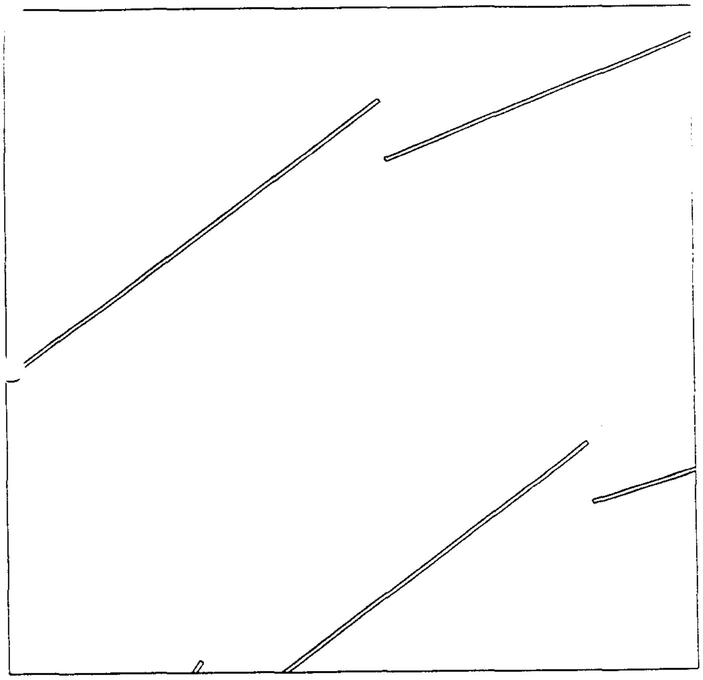
Reconstructed



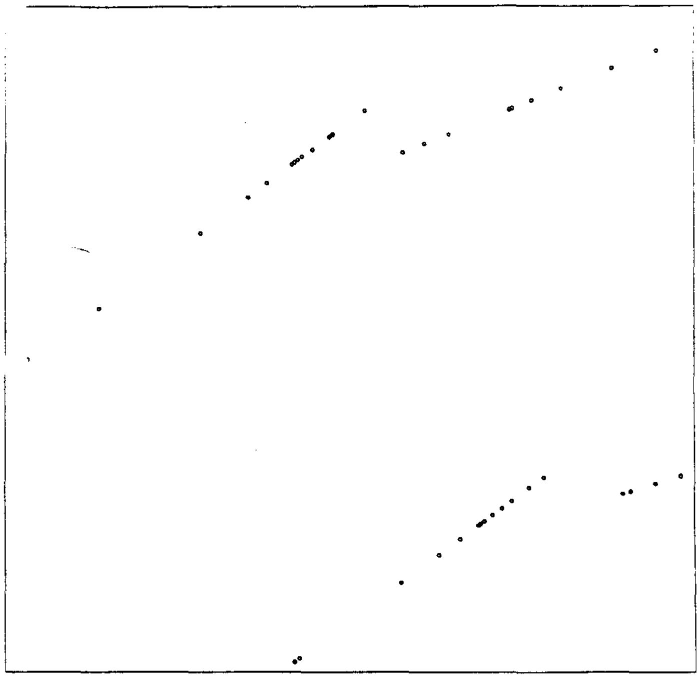
02466



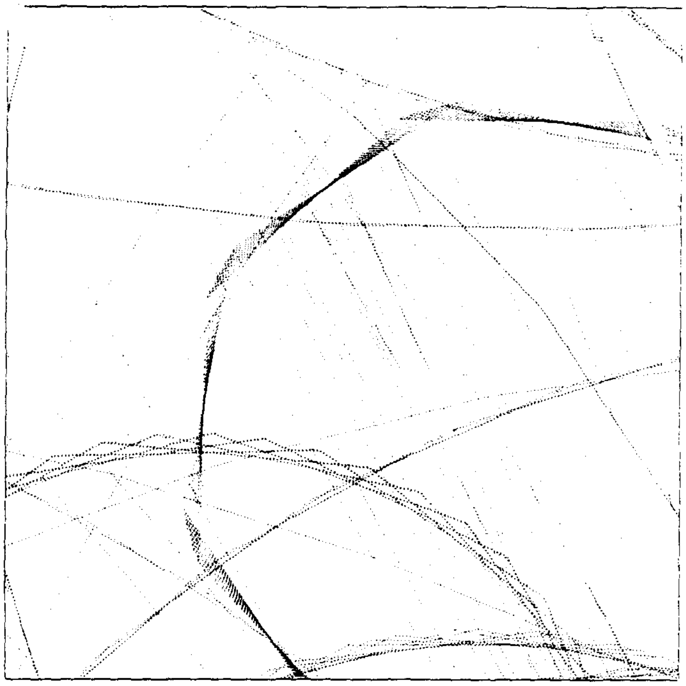
02467



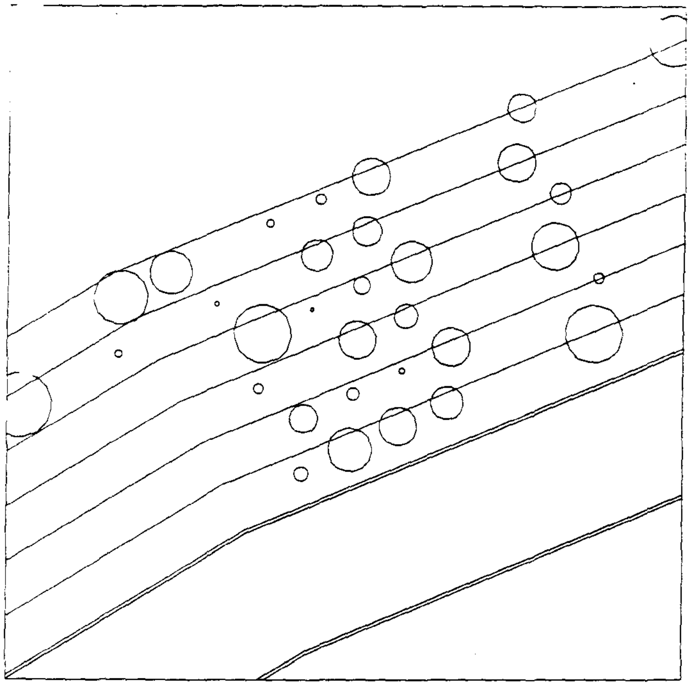
02468



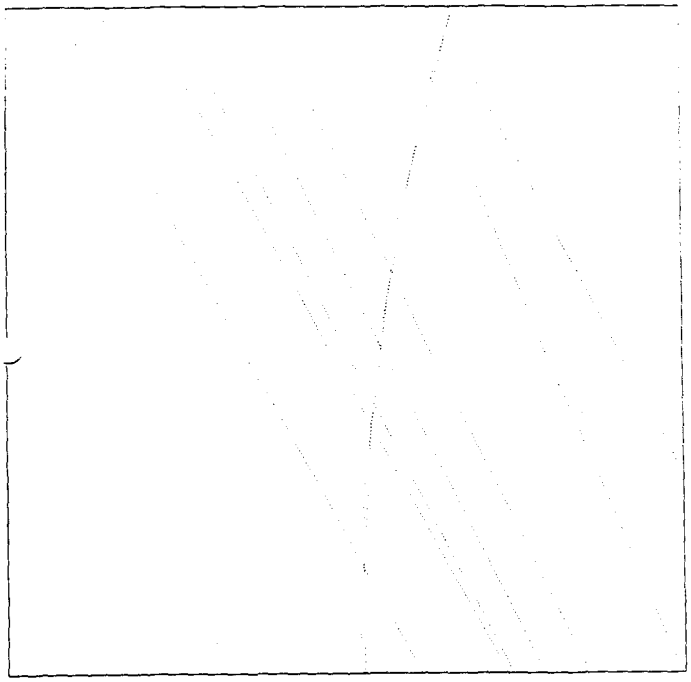
MC Tracks 02469



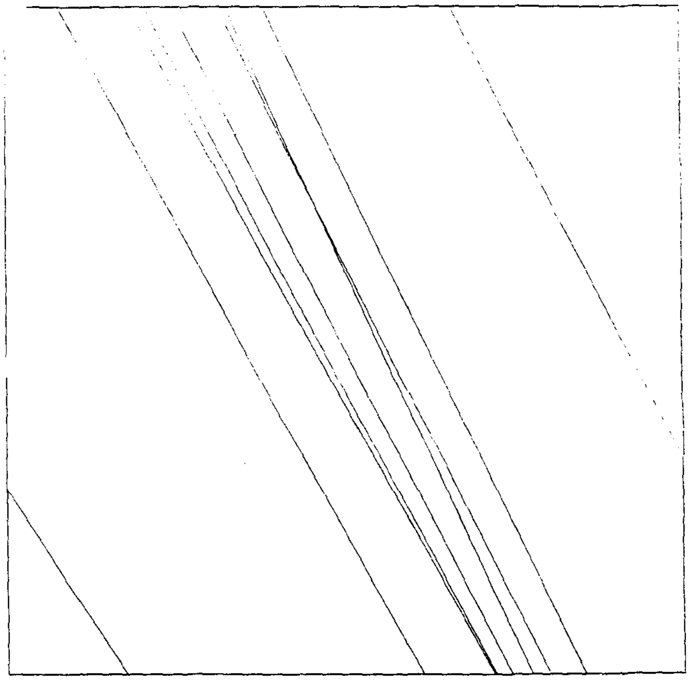
02470



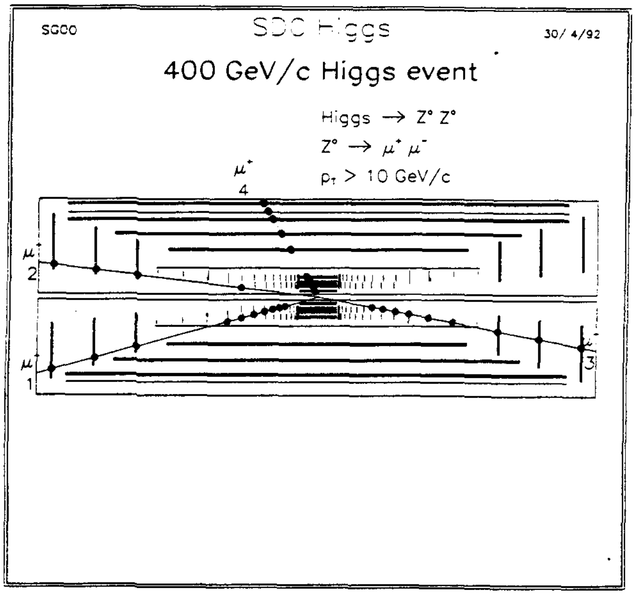
MC tracks 02471



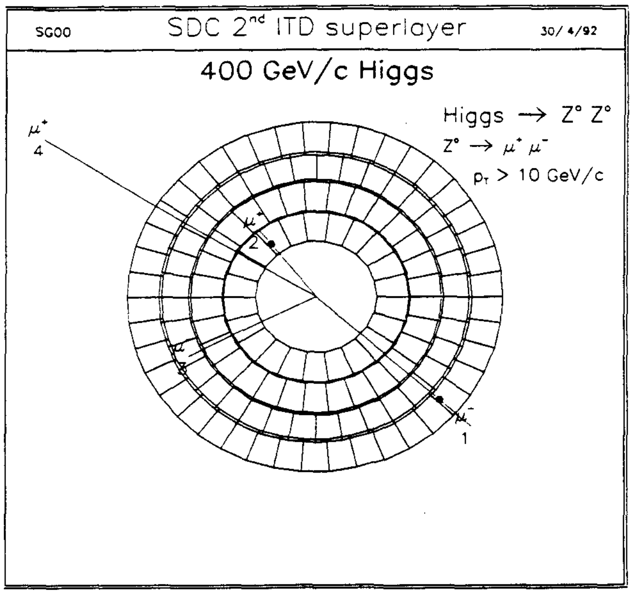
02472



Higgs to 4 Muons in ITD



Higgs to 4 Muons in ITD



Resolutions

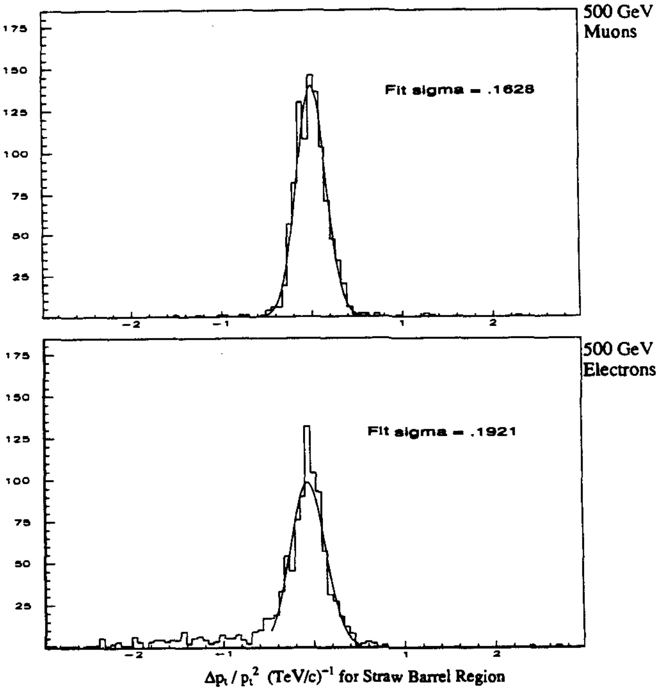
Summary of parameters affecting resolution

	Silicon (Barrel)	Straw	Fiber	Gas Microstrip
# of layers	16	36	32	12
# of superlayers	8	5	6	3
resolution/superlayer(μm)	12	85	90	100
stereo angle	10 mrad	3°	6°	8°
σ_{pt} / p_t^2 (TeV/c)$^{-1}$ at $\eta = 0$	2.0	1.0	1.0	—

(σ_{pt} / p_t^2 = .16 (TeV/c)$^{-1}$ for combined system)

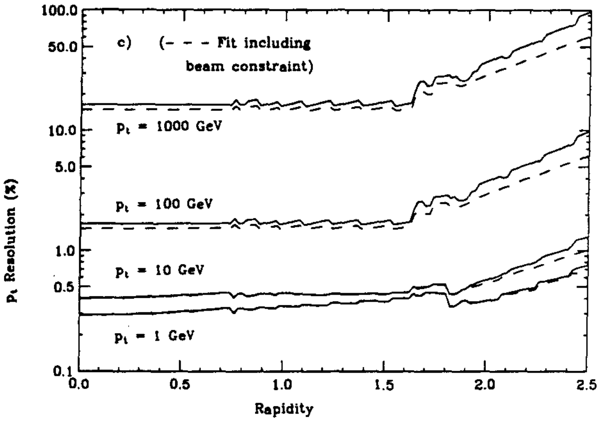
Resolutions

Silicon + Straws



Parametrized Resolutions

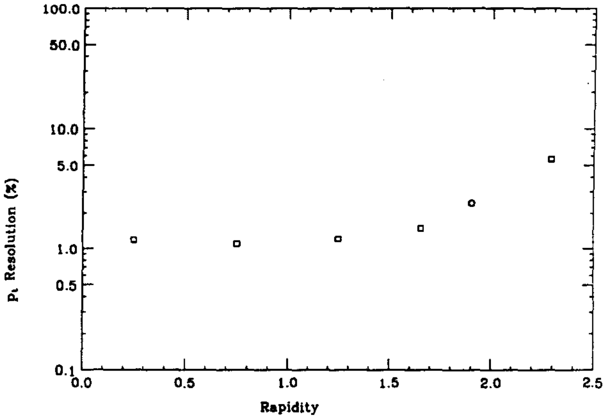
Silicon + Straws



Parametrized Resolutions

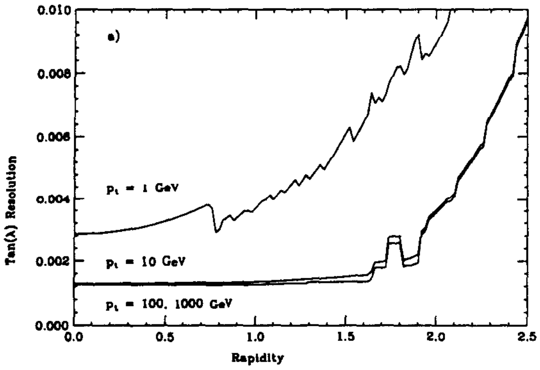
Silicon + Straws

Measured resolutions for single 100-GeV muons



Parametrized Resolutions

Silicon + Straws

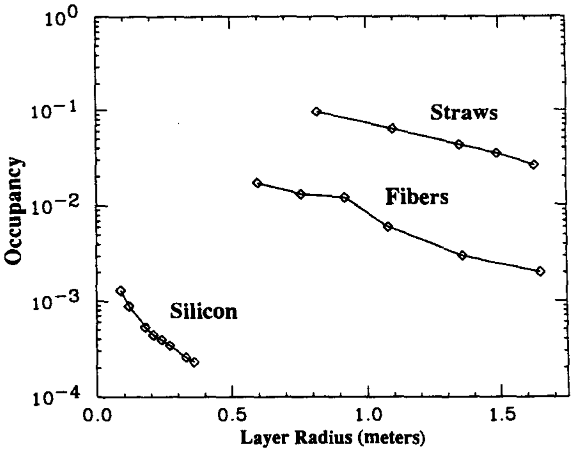


Occupancy

Occupancy has several contributions:

Trigger event
1.6 events/crossing of minimum bias
secondaries
looping tracks from previous beam crossings
detector time windows that span several crossings

Occupancy vs layer radius including all the above effects except the trigger event. (Adding a Higgs to 4 lepton event increases occupancy by × 2 - 2.5) :



Track Reconstruction Algorithms

Several algorithms are in use:

- "Segment-clustering" -

  1) hits in silicon are paired to form segments (local track vectors)
  2) segments are clustered in curvature-phi space to form tracks
  3) least-squares fit done to silicon track
  4) silicon track projected to outer tracker to pick up straw segments or fiber coordinates, refitting each time one is added to track

- "Road-following" -

  1) pairs of hits are used to start a track at some radius.
  2) candidate track is projected outward and/or inward to pick up additional hits
  3) least-squares fit each time a hit is added

- "Binning" -

  1) detector divided up into overlapping curvature, phi and tanλ bins
  2) bins subdivided until small number of segment combinations in bin
  3) Fit all combinations for best single-track fit

Track Reconstruction Algorithms (cont.)

The low occupancy and high resolution of silicon tracker make it a powerful pattern recognition tool.

Critical to the integrated performance of the entire tracker, no matter what algorithm is used, is the error on a silicon track projected to the outer tracker.

At η=0, the error on a track found in the silicon, projected to the first straw or fiber layer is

σ_{proj}^{Si} (r = .7 m) < 100 μm.

Well-matched to superlayer resolutions of the outer tracker.

Projecting to larger radii, it gets quickly worse:

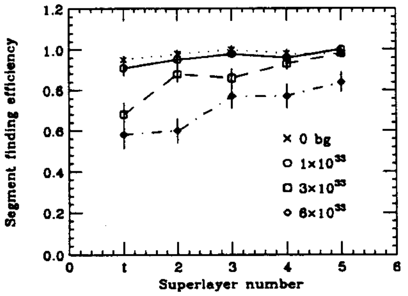
σ_{proj}^{Si} (r = 1.6m) ~ 2 mm

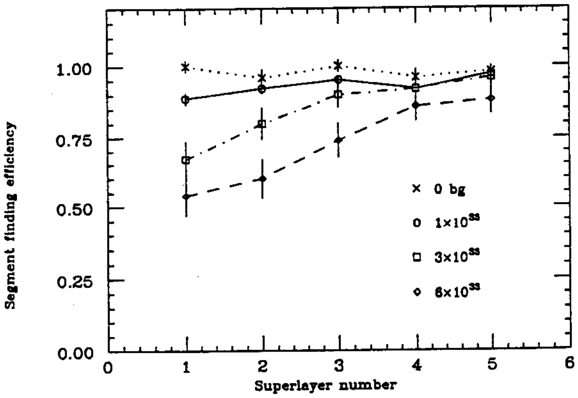
Segment-finding efficiency

Segment Finding in Straw Outer Tracker

Method: Brute force search starting with pairs of hits in extreme layers of superlayer and projecting inward. Segments locally straight within a superlayer.

Performance:
Pt > 2 GeV/c
H → 4μ





Higgs

Requirements:

→ Efficiency ∝ (single-lepton efficiency)^4

⇒ efficiency ≥ 97% for high p_t isolated tracks.
over full acceptance ($|\eta|<2.5$)

→ Z^0 mass reconstruction

⇒ $\Delta p_t \ / \ p_t^2 \le 20\% \ (\mathrm{TeV/c})^{-1}$

+ massive H^0, massive gauge bosons, W^+W^+ may require that SDC maintain above performance at luminosities beyond 10^{33}.

Study of Higgs → 4 Leptons

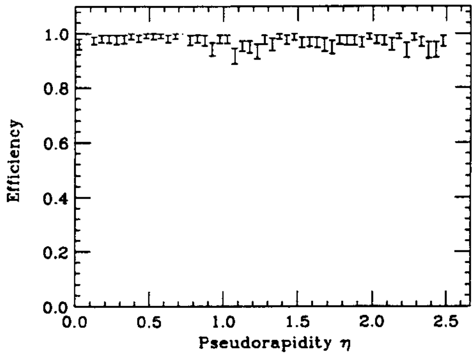
$H^\circ \to Z^\circ Z^\circ$
$\quad \hookrightarrow e^+ e^-$
$\quad \hookrightarrow \mu^+ \mu^-$

H° mass = 300 GeV

Luminosity = $10^{33} \to \sim 10^{34}$

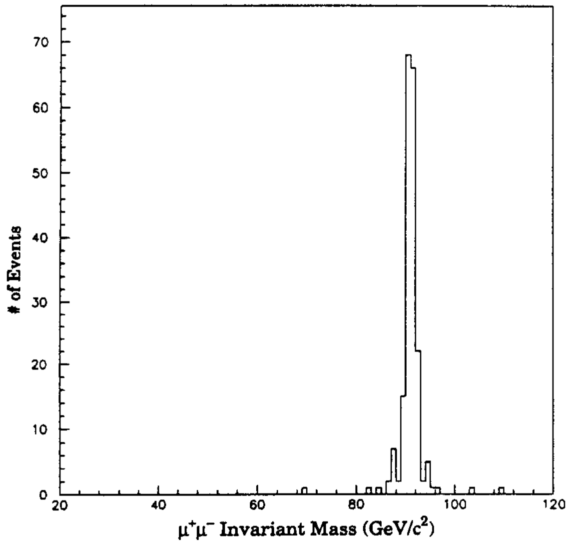
Most results shown here use straw outer tracker option. Some results on lepton efficiencies and resolutions for fiber option.

Overall efficiency at 10^{33} vs η for tracks with $p_t > 1.0$ GeV/c (si+straw):



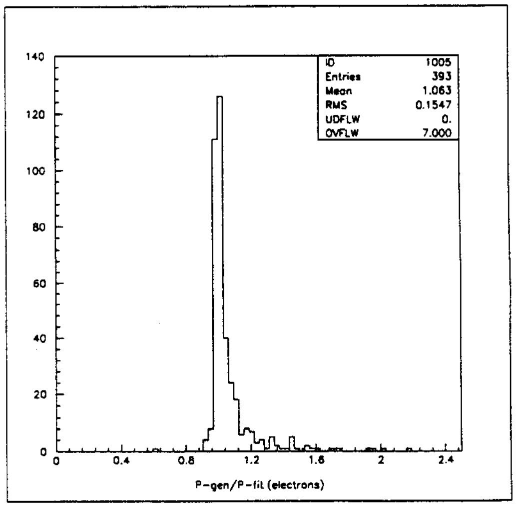
Higgs → 4 Leptons (cont.)

$\mu^+\mu^-$ invariant mass for $H^\circ \to Z^\circ Z^\circ \to e^+e^-\mu^+\mu^-$ events:



Higgs → 4 Leptons (cont.)

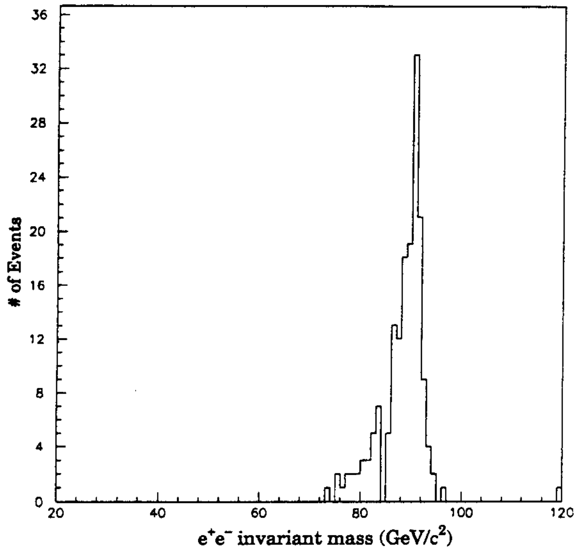
Electron identification requires E/p cut:



Set the cut at $.7 < E/p < 1.4$

Higgs → 4 Leptons (cont.)

e^+e^- invariant mass for $H^\circ \to Z^\circ Z^\circ \to e^+e^-\mu^+\mu^-$ events:



For the reconstruction of the Higgs mass use calorimeter energy for electrons

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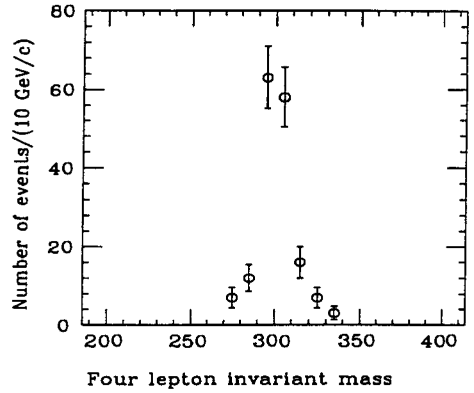
Higgs → 4 Leptons (cont.)

Reconstructed Higgs mass for $H^\circ \to Z^\circ Z^\circ \to e^+e^-\mu^+\mu^-$ events:



Final Efficiencies:

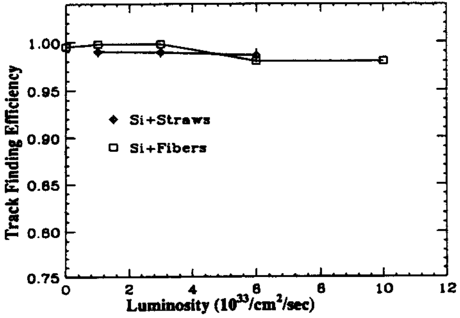
Luminosity	Track efficiency pt>10GeV/c	Electron E/p efficiency .7<E/p<1.4	M_Z cut efficiency e	μ	Higgs reconstruction efficiency
1.0×10^{33}	.991	.96 ± .01	.99 ± .01	.99 ± .01	.84± .04

Exclusive of E/p cut overall eff = $(.991)^4 \cdot .99 \cdot .99$ = .94

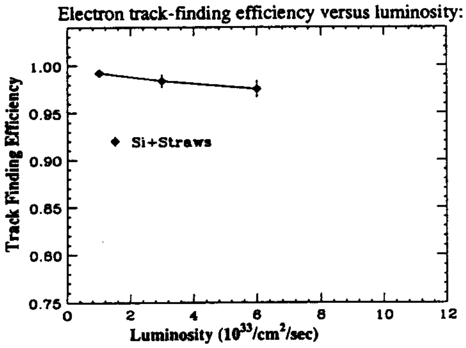
(Goal: .90)

Higgs → 4 Leptons: High Luminosity

Muon track-finding efficiency versus luminosity:



Electron track-finding efficiency versus luminosity:



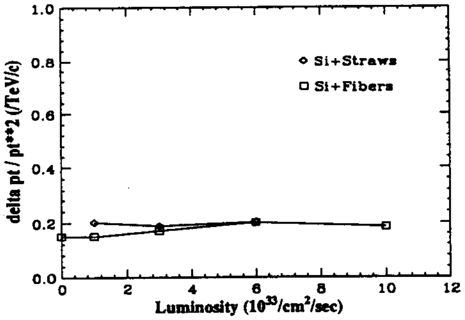
Higgs → 4 Leptons: High Luminosity

Resolution remains good out to limits of study:

6.0×10^{33} Silicon + Straws

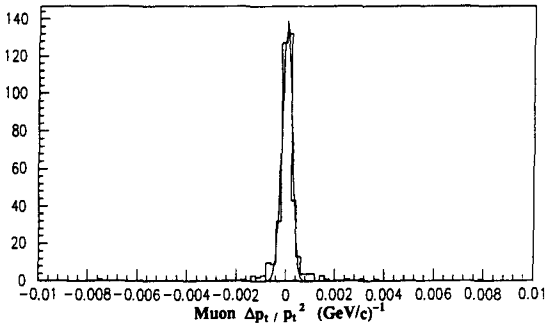
1.0×10^{34} Silicon + Fibers

Muon pt resolution versus luminosity:

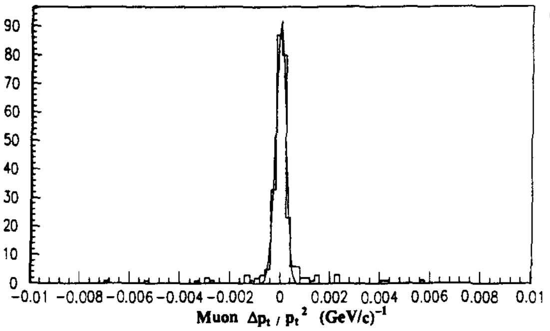


Higgs → 4 Leptons: High Luminosity

Some loss in the tail: Silicon + Straws:



1.0×10^{33}



6.0×10^{33}

Higgs → 4 Leptons: Higher Luminosities

Final Efficiencies (Silicon + Straws):

Luminosity	Track efficiency pt>10GeV/c	Electron E/p efficiency .7<E/p<1.4	M_Z cut efficiency e	μ	Higgs reconstruction efficiency
1.0×10^{33}	.991	.96 ± .01	.99 ± .01	.99 ± .01	.84± .04
3.0×10^{33}	.989	.96 ± .01	1.00 ± .01	.97 ± .01	.83± .04
6.0×10^{33}	.972	.93 ± .01	1.00 ± .01	.93 ± .02	.75± .04

Luminosity	Fake rate
1.0×10^{33}	.03 ± .01
3.0×10^{33}	.04 ± .02
6.0×10^{33}	.18 ± .03

$W^+ W^+$

Requirements:

$W^+ W^+$ signal has large background from $W^+ W^-$ where one lepton sign is mismeasured.

To reduce this background requires:

charge mismeasurement probability < 10^{-5} at p_t (lepton) < 100 GeV/c

< 10^{-3} at p_t (lepton) ≅ 500 GeV/c

Study:

Ran 1000 500-GeV/c electrons and muons on background of 3×10^{33}

One muon track out of 1000 had wrong sign.

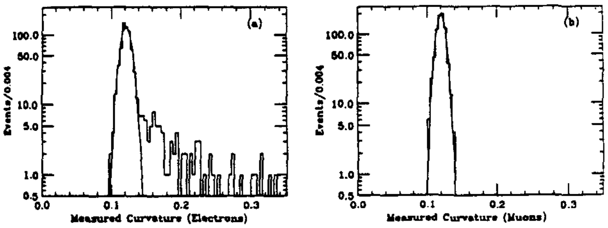


FIG. 3-39. The curvature distribution for a sample of events consisting of lepton tracks with $p_t = 500$ GeV superimposed on a minimum bias background corresponding to a luminosity of $3 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. The curves represent Gaussian fits to the data, and demonstrate the absence of any non-Gaussian tails towards small values of the curvature (the relevant aspect for charge mis-measurement studies). (a) The distribution for $p_t = 500$ GeV electrons. (b) The distribution for $p_t = 500$ GeV muons.

Track-finding in Jets

Requirements:

b-quark jet tagging and reconstructing leptons from b decay ⇒

Track reconstruction efficiency in jets > 85 %

for jet $P_t < \sim 100$ GeV/c

Jet fragmentation measurements to 15% up to 500 GeV/c ⇒

Efficiency in jets > 80-85% for jet $P_t < \sim 500$ GeV/c

Study:

Used ISAJET 2-jet samples with $P_t^{\min}$ = 50, 100, 200, 500

Jets found using clustering algorithm with a fixed cone size of

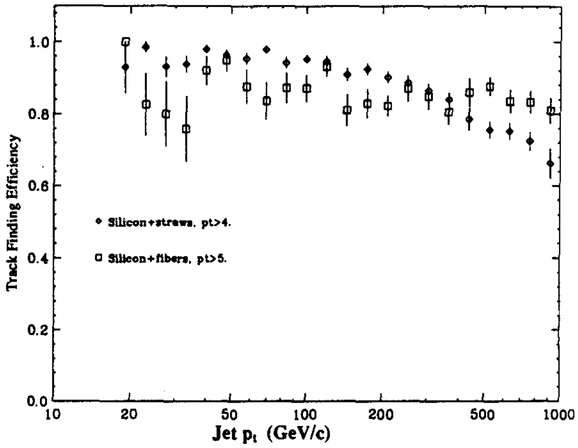
$$R = \sqrt{(\Delta\varphi)^2 + (\Delta\eta)^2} = .5$$

Track-Finding Efficiency in Jets

For Silicon + Straws: $p_t > 4.$ GeV/c
$|\eta| < 1.5$

For Silicon + Fibers: $p_t > 4.$ GeV/c
$|\eta| < 0.7$

Preliminary! Algorithms not yet tuned for dense environment of jet cores.



Design requirements

b-jet tagging

jet fragmentation

"Discovery potential"

---

b-Jet Tagging

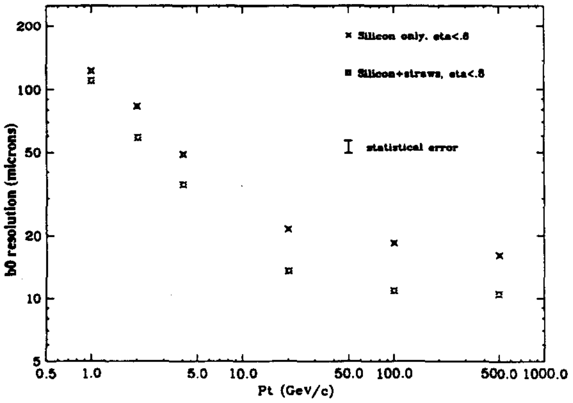
Requirements:

In $t\,\bar{t}$ studies, b-jet tagging significantly reduces the background from non $t\,\bar{t}$ and the combinatorics in reconstructing the top quark mass.

The SDC goal is a tagging efficiency of 25%.

One needs an impact parameter resolution small compared to typical impact parameters of the decay products of the B meson (100-200 μm).

For Silicon + Straw system:



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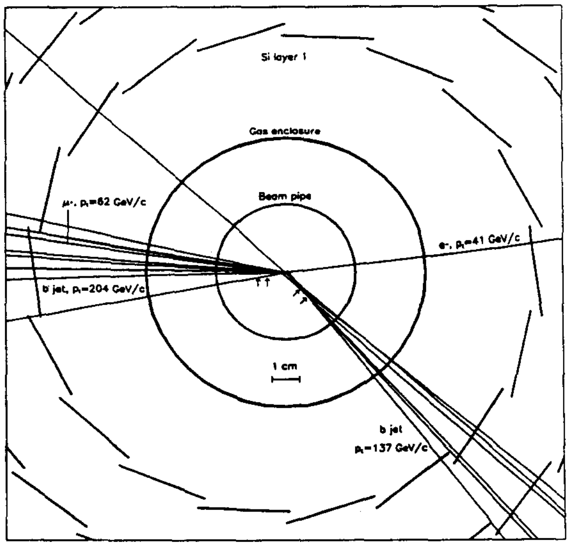
b-Jets in $t\,\bar{t}$ Event

$t\,\bar{t} \rightarrow e\mu\nu\nu b\,\bar{b}$ with $m_{top} = 150$ GeV/c^2.
Arrows indicate true decay vertices of b and c mesons within b jets.



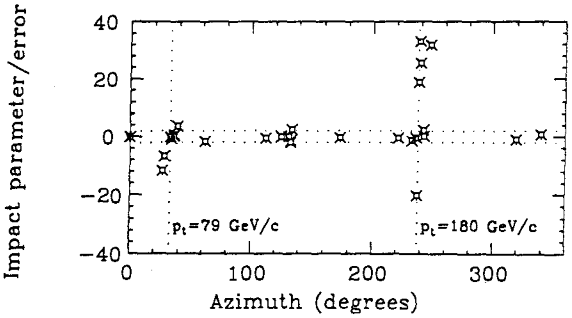
b-Jet Tagging

b-jet tagging algorithm:

Demand 3 or more tracks in a jet have:

(Measured impact parameter) / (predicted error) > 3.

Example for $t\ \bar{t}$ event with $m_{top} = 150\ \mathrm{GeV/c^2}$:



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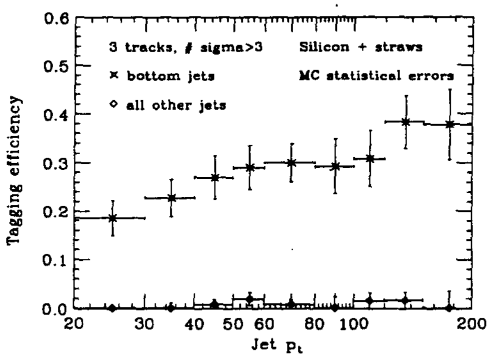
b-Jet Tagging

b-jet tagging efficiency vs b-jet p_t and background from non-b jets.



Conclusions

Moderately detailed simulations of the SDC central tracking design show it to be:

- Very efficient for high p_t isolated tracks and reasonably efficient for non-isolated tracks
- Adequate resolution for most of the physics goals of SDC
- Robustness to luminosities of 6×10^{33} for Silicon + Straws and 10^{34} for Silicon + Fibers

minimal goals for a detector with an emphasis on tracking.

Future:

Work continues on track reconstruction algorithms. Some improvement in performance expected.

Work also continues on adding more reality (dead channels, misalignment, noise). Worsened performance guaranteed.

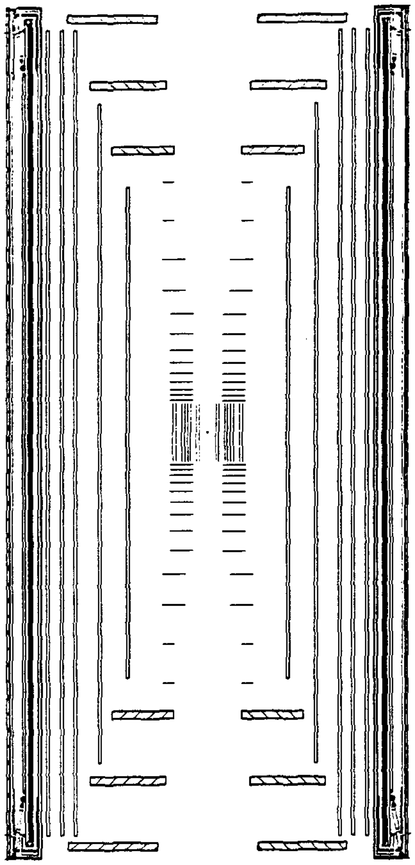
025

TRACKING-INTEGRATED PERFORMANCE AND DESIGN OPTIMIZATION

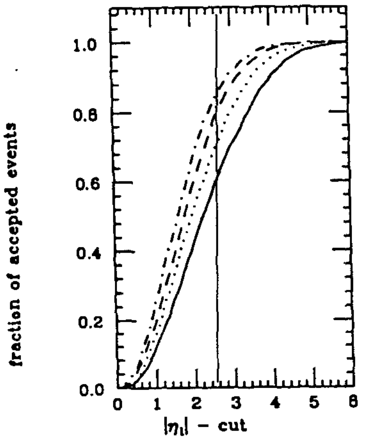
A. SEIDEN

CENTRAL TRACKING PERFORMANCE AND DETECTOR LAYOUT

A. Seiden
May 1992



Acceptance for all four leptons from $H^0 \to Z^0Z^0$ Decay Versus Rapidity Coverage.



solid: M_H = 200 GeV, dotted: M_H = 400 GeV
dashed: M_H = 600 GeV, dashed-dotted: M_H = 800 GeV

Characterize Tracking By:

$$\frac{\sigma_{P_t}}{P_t} = \sqrt{(.008)^2 + (\alpha P_t)^2} \; , \; P_t \text{ in TeV.}$$

SDC

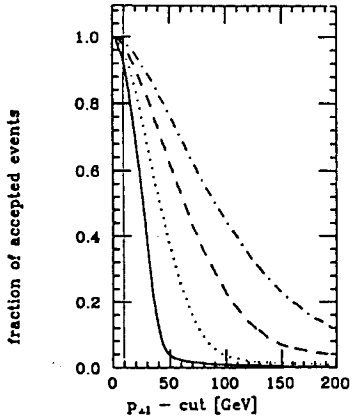
M_H (GeV)	α 0.05	0.1	0.2	0.3	0.5	Natural Width (GeV)
	Resolution FWHM(Z):					
200	1.3	1.9	2.7	3.7	4.8	2.5
400	1.4	2.1	3.1	4.1	5.7	2.5
600	1.7	2.7	4.7	6.2	7.6	2.5
800	2.1	3.9	5.3	6.7	9.2	2.5
	Resolution FWHM(H)					
200	2.2	3.3	4.8	6.6	9.3	1.4
400	5.1	8.7	14.0	18.0	31.0	30.0
600	10.3	19.0	34.0	51.0	73.0	107.0
800	17.0	26.0	39.0	57.0	83.0	255.0

Matched to Γ_Z

Narrow H^0

For Supersymmetry, mode useful for $M_{H^0} < 2M_t$, then narrow H^0.

Higgs Acceptance for Various Lepton P_t cuts.



solid: M_H = 200 GeV, dotted: M_H = 400 GeV
dashed: M_H = 600 GeV, dashed-dotted: M_H = 800 GeV

Issues I will cover for baseline design:

(1) Momentum Resolution

(2) Pattern Recognition and Vertexing

(3) Triggering

The ability to measure characteristics of complicated high P_t events: multiplicity; presence of leptons within jets; vertexing in general, add to the discovery potential of SDC, but are hard to quantify.

Momentum Resolution

SDC has chosen to do accurate momentum measurement for muons in the central tracking volume for $|\eta| \lesssim 1.8$.

This is a cost effective choice (allows thin muon toroids) which also has the benefit of avoiding tails from muon radiation in the calorimeter and allows sign of charge measurements for electrons to very high momenta, over 1 TeV.

Momentum Resolution

SDC has chosen to do accurate momentum measurement for muons in the central tracking volume for $|\eta| \lesssim 1.8$.

This is a cost effective choice (allows thin muon toroids) which also has the benefit of avoiding tails from muon radiation in the calorimeter and allows sign of charge measurements for electrons to very high momenta, over 1 TeV.

Resolution depends on the radial lever arm. Thus, for fixed transverse momentum resolution in the central tracker, at large dip angles the detector half length would have to be:

$$z = r \tan \lambda$$

For $\eta = 2.5$, $\tan \lambda \simeq 6$, would imply a $z = 10$ m for r = 1.7 m. This is impractically long (and would lead to an unacceptably thick coil, in radiation lengths, preceding the calorimeter). Thus, at very large rapidities the muon toroid system has been chosen to provide the better measurement at very high transverse momentum.

The central tracking does still provide a vertex constrained σ_{P_t}/P_t =3% at P_t = 50 GeV and $\eta = 2.5$. Thus, for leptons from low P_t Z° decays (for example, from a modest mass Higgs) it still provides a reasonably good measurement.

P_t = 50 GeV is typical for calorimeter calibration. Provides a resolution varies from 1% at $\eta = 0$ to 3% at $\eta = 2.5$.

A disadvantage of the SDC design is that tracking elements have to survive the full flux of particles coming from interactions. Thus, it requires a careful design from the point of view of occupancy and radiation damage which we have done.

From the point of view of momentum resolution alone, an error of 20% at 1 TeV would require:

2.2 m straw tracking length <u>or</u>
.8 m silicon tracking length.

SDC system of silicon + straws requires 1.4 m.

Including the distance to the first measuring layer and allowing for a contribution from global misalignment we arrive at the SDC 1.7 m tracking volume.

Allows most of straws to sit at $r > 1$ m where occupancy is fairly small.

Silicon in central region covers a radius of 9 cm to 36 cm which satisfies momentum resolution, pattern recognition, and vertexing goals. For large η, the silicon goes out to a radius of 46.5 cm to partly compensate for the smaller lever arm for the full tracking system.

Gas microstrips for $|\eta| > 1.8$ complete the coverage for triggering and provide the tracking measurements for radii > 46.5 cm.

For the SDC design both the silicon and straws contribute together to provide the momentum resolution which is dominated by the position and direction of the silicon portion of the track combined with the outermost straw measurements.

Resolution ~ (outer radius)$^{-2}$. Outer system improves resolution by factor of 10 over silicon alone at $\eta = 0$.

Example of dependence on silicon at $\eta = 0$, for P_t = 1 TeV, σ_{P_t}/P_t is:

	σ_{P_t}/P_t
Baseline system, 8 silicon layers $r_{(\text{inner})} = 9$ cm, $r_{(\text{outer})} = 36$ cm + straws	15.9%
4 silicon layers $r_{(\text{inner})} = 9$ cm, $r_{(\text{outer})} = 21$ cm + straws	28.5%

In the SDC design the silicon provides extremely good pattern recognition, particularly in high P_t jets or at very high luminosity. To achieve the full resolution of the system we want to use the measurements from all tracking devices together.

Guarantee good matching if silicon track projected out has an error $\lesssim$ size of an outer tracker measuring element.

Extrapolation of Tracks from Silicon

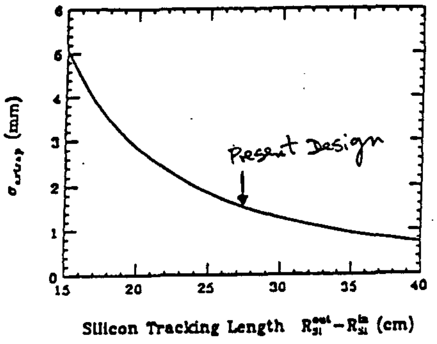


Fig. 6. Position error at 1.6 m radius vs. silicon tracking length.

Impact Parameter Error!

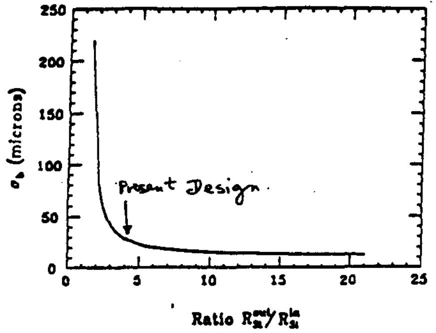
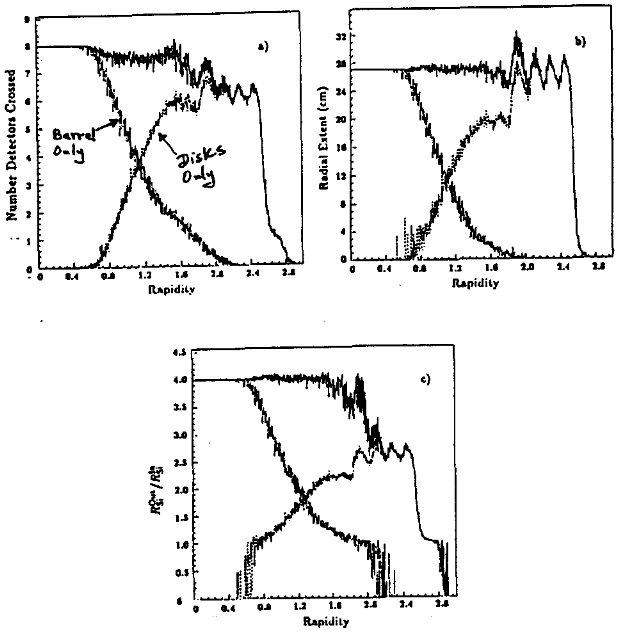


Fig. 4. Impact parameter error vs. detector geometry for high momentum.

Silicon Only.

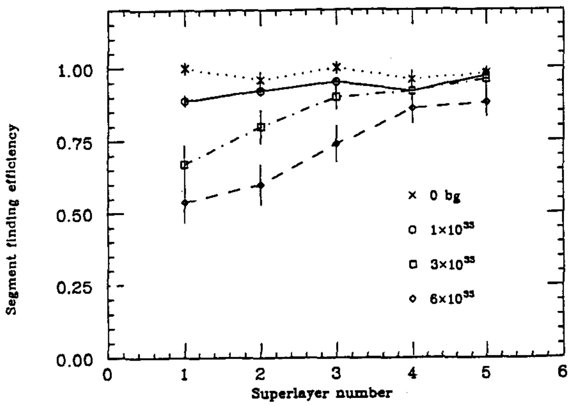


Geometrical Characteristics of Design, Averaged over Beam Spot Size.

Straw system has 3 axial plus 2 stereo layers. Three axial layers is the minimum needed for 2 out of 3 trigger allowing robustness and good rejection of fakes.

System will allow significant independent track finding which will be useful for understanding efficiencies and alignment.

Provides track segments which simplify pattern recognition and are the basis for the trigger.



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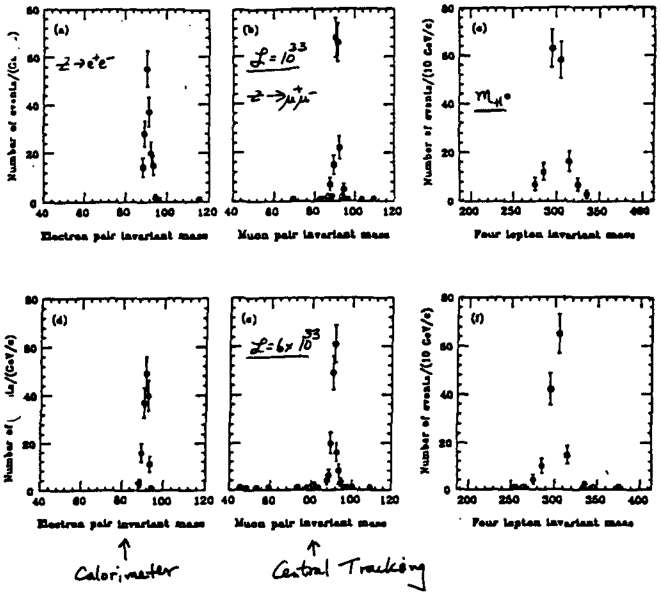
300 GeV $H^\circ \to e^+e^-\mu^+\mu^-$



Summary of efficiencies and number of fake tracks for $H^0 \to e^+e^-\mu^+\mu^-$ events for various configurations

Luminosity	Fakes per event with $p_t > 5$ GeV/c	Track efficiency $p_t > 10$ GeV/c	Electron E/p efficiency 0.7<E/p<1.4	M_Z cut efficiency e	M_Z cut efficiency μ	Higgs reconstruction efficiency
1×10^{33}	0.03 ± 0.01	0.991	0.96 ± 0.01	0.99 ± 0.01	0.99 ± 0.01	0.84 ± 0.04
$\times 10^{33}$	0.04 ± 0.02	0.989	0.96 ± 0.01	1.00 ± 0.01	0.97 ± 0.01	0.83 ± 0.04
6×10^{33}	0.18 ± 0.03	0.972	0.93 ± 0.01	1.00 ± 0.01	0.93 ± 0.02	0.75 ± 0.04

Tracking Length for Gas Microstrips

Determined by trigger requirements. Again requires three superlayers for high efficiency and small fake rate. Basis for trigger is measurement of curvature via local deviation of track from a ray emanating from origin. Thus, in barrel measure $d\phi/dr$, in forward system $d\phi/dz$.

Errors on curvature (K) scale as:

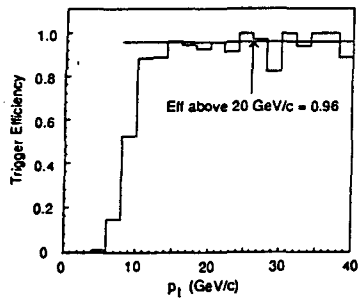
$$\delta K_{\text{barrel}} \propto \frac{1}{r_{\text{barrel}}} \left[\frac{\sigma_{\text{position}}}{\Delta r}\right]$$

$$\delta K_{\text{forward}} \propto \frac{1}{r_{\text{forward}}} \tan(\lambda) \left[\frac{\sigma_{\text{position}}}{\Delta z}\right] ,$$

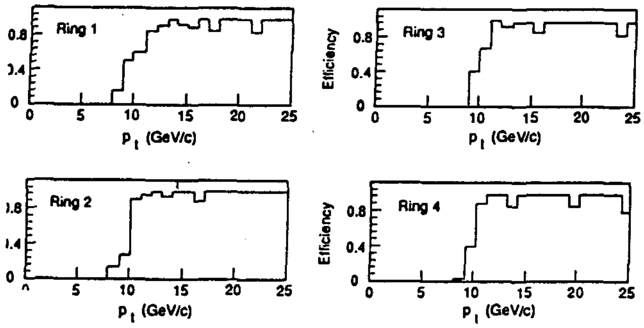
where Δr = barrel radial tracking length to measure K and Δz = length along z to measure K for the gas microstrips.

Since $\frac{r_{\text{forward}}}{r_{\text{barrel}}} \sim 3$ and $\tan(\lambda)$ can be larger than 6, Δz has to be $\sim 20 \times \Delta r$. Requires significant length along z. More careful calculation gives a tracking length for the gas microstrips of about 1.3 m.

First Level Trigger - Design Luminosity

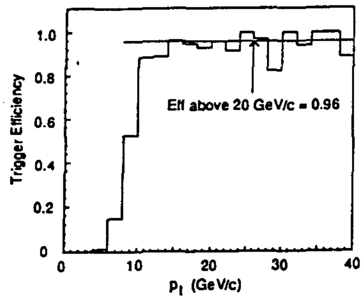


Threshold curve for the two-out-of-three superlayer OTD first level trigger.

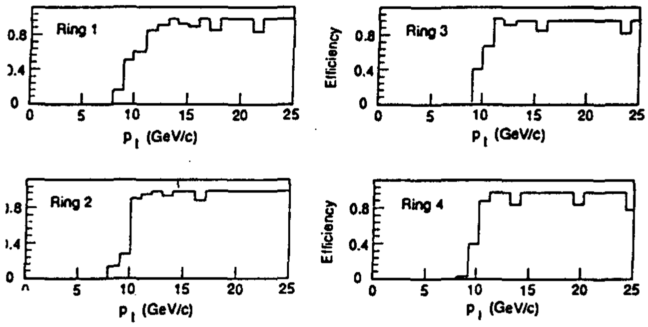


Trigger threshold curve for the four separate η bins of the ITD trigger.

First Level Trigger - Design Luminosity



Threshold curve for the two-out-of-three superlayer OTD first level trigger.



Trigger threshold curve for the four separate η bins of the ITD trigger.

02527

ELECTRON IDENTIFICATION

B. WICKLUND

A. B. Wicklund
May 7, 1992

Electron Identification

- See: TDR, MP Testbeam, CDF
- Physics "Benchmarks":

Isolated	–	W, Z, Top, H → $\gamma\gamma$
Nonisolated	–	t → b (→ e)
Other	–	$\gamma_{QCD} \to e^+e^-$

- Systems:

E/p	(Tracking, Calorimetry)
HAC/P	(Hadron Leakage)
"Massless Gap"	(Preshower at ~ 1.2 Xo)
SMD	(Shower Max Energy, Profile)

- Electron ID
  - * $\pi^\pm \pi^\circ$ overlaps
  - * Electron-Hadron Separation
  - * Conversions
- γ/π° Separation
- Effect of Materials (Inner Detector, Coil)
- Calibrations

	Barrel		Endcap
	CDF	SDC	SDC
Pb (cm)	.32	.4 (.2)	.6
Fe (cm)	2.5	2.4	4.2
Rm (cm)	3.5	3.4 (5.4)	2.7
λEM/cm	.030	.030 (.021)	
λHAC/cm	.040	.049	.052
Depth (Presh.)	1.1 Xo	1.2 - 2.4 Xo	
Depth (SM)	6 Xo	6.2 Xo	
R (SM)	184 cm	210 cm	
ΔX (SM)	1.5 cm	1.2 cm	
$\Delta(\pi^\circ \to \gamma\gamma)$	1.0 cm	1.2 cm	
Depth (HAC)	19 Xo	22 Xo	25 Xo

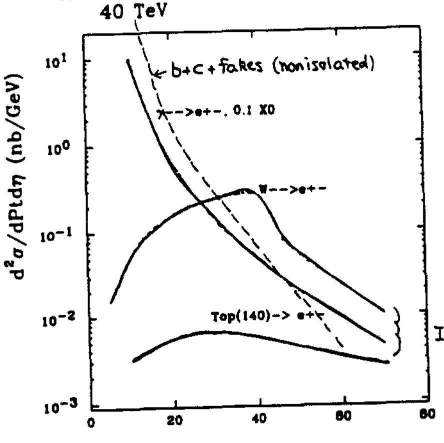
Central calorimeter parameters.

	Barrel			Endcap			
	EM	HAC1	HAC2	EM1	EM2	HAC1	HAC2
Longitudinal readouts	1(2)*	1	1	1	1	1	1
Lateral segmentation	0.05	0.1	0.1	≥ 0.05	≥ 0.05	≥ 0.1	≥ 0.1
Absorber layers	29	28	15	6	17	20	11
Absorber material	lead	iron	iron	lead	lead	iron	iron
Absorber thickness (mm)	4.0	23.95	53.90	6.0	6.0	42.	90.
Scint. thickness (mm)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Cell thickness (mm)	10.0	30.0	60.0	12.0	12.0	48.0	96.0
Depth (not including coil)	21 X_0			6.9 X_0	18.3 X_0		
	0.85 λ	4.14 λ	4.91 λ	0.3 λ	0.8 λ	5.04 λ	5.99 λ

* Possible upgrade.

Inclusive single electron rates at SDC

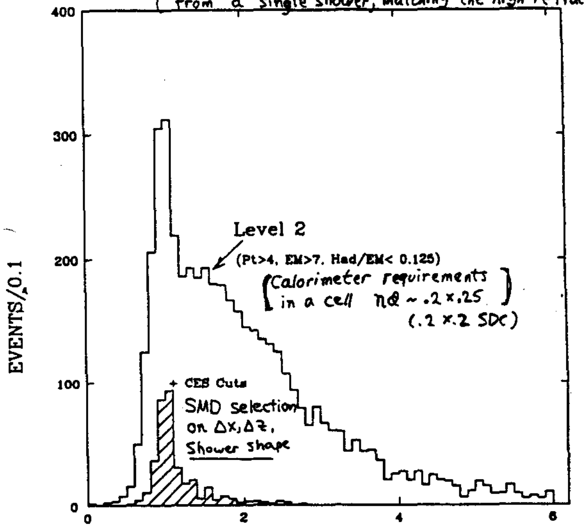
- $W, Z \to e^\pm$
- top → $(W \to e^\pm)$
- γ_{QCD} → Conversion in 0.1 Xo



Pt (GeV/c)

$\sigma(P_t > 30, \eta < 2.5) \sim 50$ nb (isolated $e^\pm$) "PHYSICS"
~3000 nb (L2, HAD/EM + TRACK P_t)
~1000 nb (L2 " + SMD MATCH)

CDF: Separation of electrons from "$\pi^\pm$-γ" Overlaps"
(In effect, SMD guarantees that EM energy comes from a single shower, matching the high P_t track.)



E/P

Figure (1)

Lateral Shower Size Hierarchy

02532

- Require EMC/HAC

· Jet (R<.7) . . .	±140 cm	
· HAC leakage from $h^\pm$	± 25 cm	(HAD/EM)
· EMC Shower energy (e,γ)	± 3.5 cm	(E/P)

- Further require SMD

· e/γ Shower position + Shape	± 0.4 cm	{ Q-Jet rejection H→γγ open. angle
· $\pi^0 \to \gamma\gamma$ Separation @ 50 GeV	1.2 cm	{ γ/π⁰ Separation

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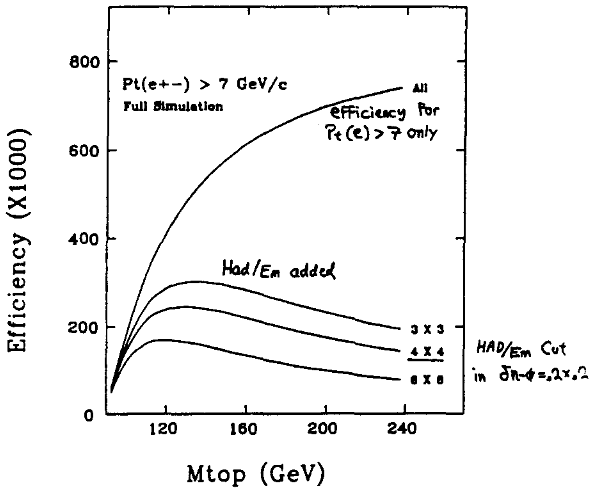
02533

$t \to b(\to e^\pm)$ Tagging efficiency

- ×2 for b⊕$\bar{b}$ not included
- ×11% for b→e not included



- Assume $t\bar{t}$ trigger does not look for b→e, only $t \to W b \to e \nu b$

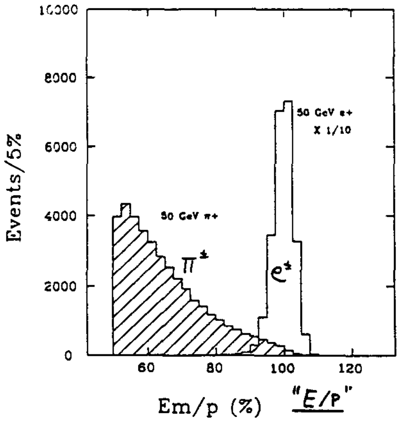
⇒ HAD/Em isolation cuts are inefficient for b→e

⇒ Local electron ID (SMD) is crucial

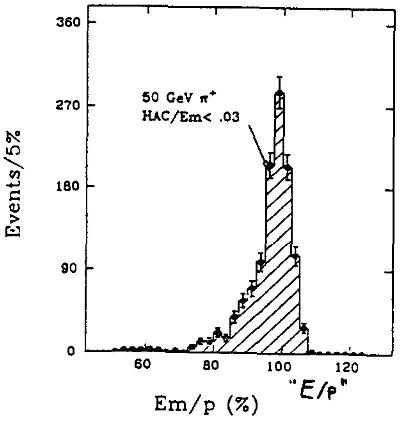
⇒ HAC1 Segmentation (.1×.1) is fine enough

02534

CDF Testbeam @ 50 GeV



- All $\pi^\pm, e^\pm$



- $\pi^\pm$ after tight $\frac{Had}{EM}$ cut.

⇒ E/P, Had/Em are strongly correlated (energy is conserved in Calorimeter!)

Use of Shower Max Detector

02535

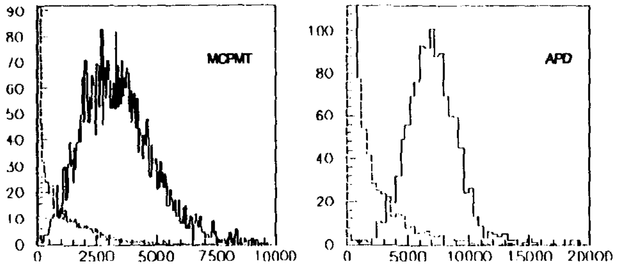
(1) Total pulse-height near projected track
(Separates e - π, σ ~ 30%)

(2) Shower Shape (normalized to total P.H.)

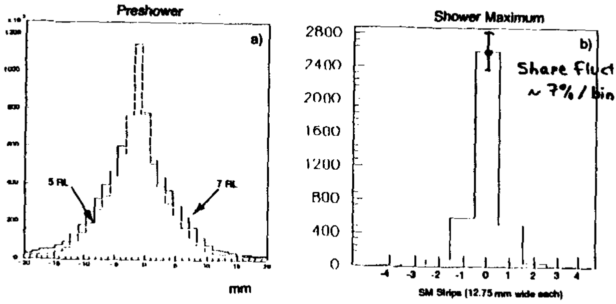
- Separates e±, π±, π°/γ
- SMD bins ~ 12 mm
  * Shower size, exp (-x/5 mm)
  * Fitted resolution, σ(x) ~ 1-2 mm
  * $\pi^\circ \to \gamma\gamma$ separation, Δx, z ~ 8 mm at 50 GeV
- "Surgical" fit to testbeam shower shape takes advantage of smallness of fluctuations (~ 5% per bin) ⇒ x, z, χ^2 (x, z)

(3) Provides ID local to track,
(Ideal for non-isolated b → e)

(4) Also use SMD to eliminate other γs in the "electron" cell ($\pi^\pm\ \pi^\circ$ overlap)

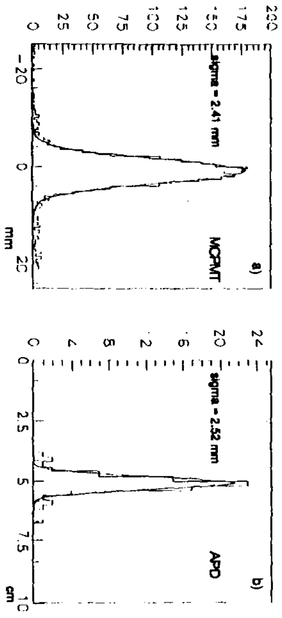


e/pi Response in Shower Maximum at 35 GeV
with signal measured with MCPMT or APD's



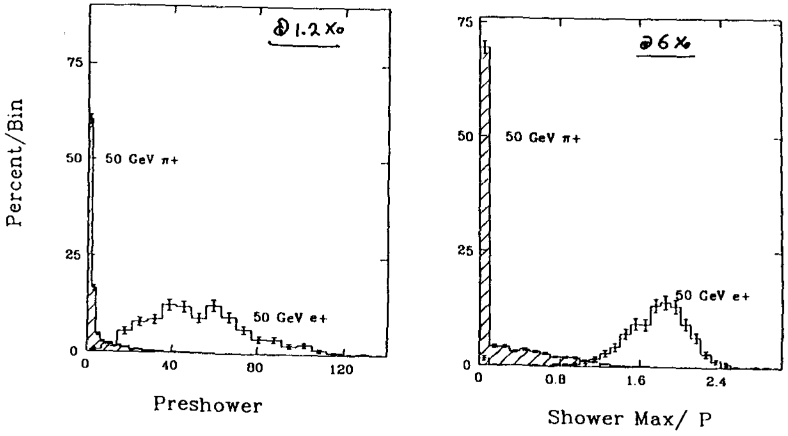
Share fluctuations
~ 7%/bin at 50 GeV

Shower profiles for 35 GeV electrons
measured with the preshower
and the shower maximum detectors



Shower Maximum Position Resolution
at 35 GeV. Measured with MCPMT and
APD readout.

Position matching from SMD Shower Shape

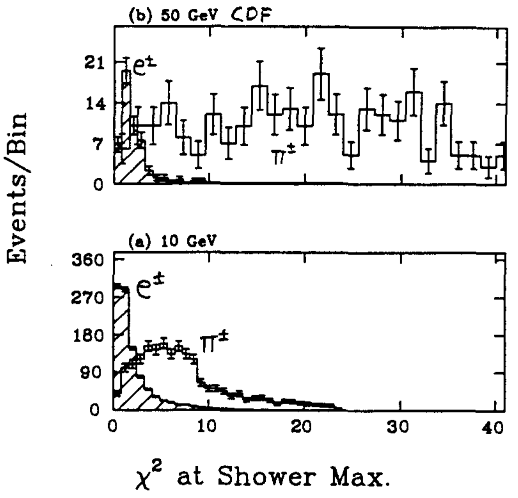


∂ 1.2 X0

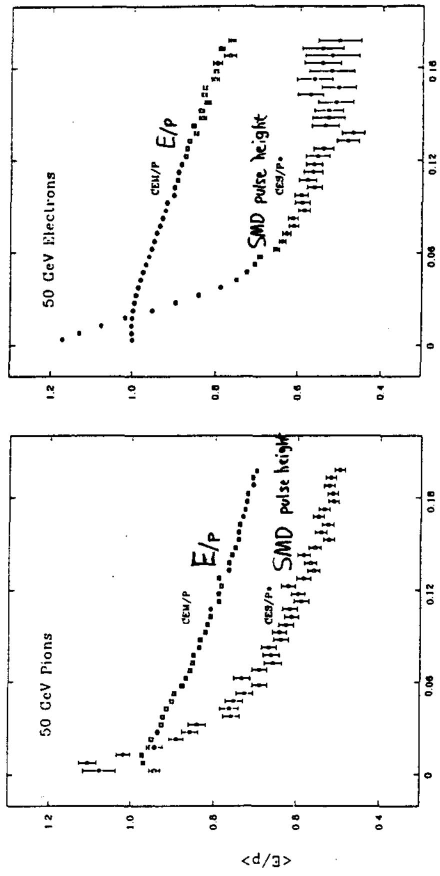
∂ 6 X0

•π/e separation via pulse height in Preshower and SMD (CDF)

- π/e Separation via Shower shape in SMD
  (Improves with energy, Shape Fluctuations ~ $1/\sqrt{E}$)



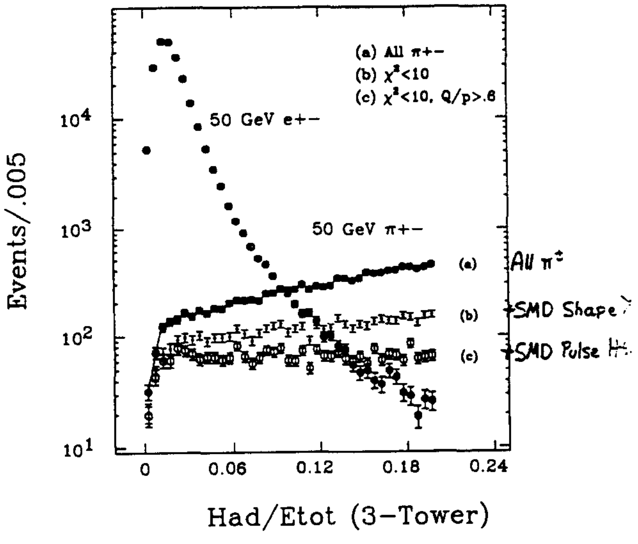
CDF



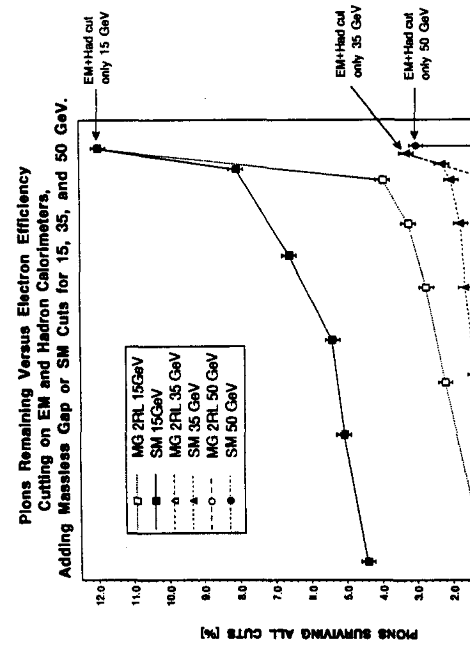
- SMD (6X₀) is strongly correlated with Had/Em (due to fluctuations in longitudinal development)

CDF Testbeam

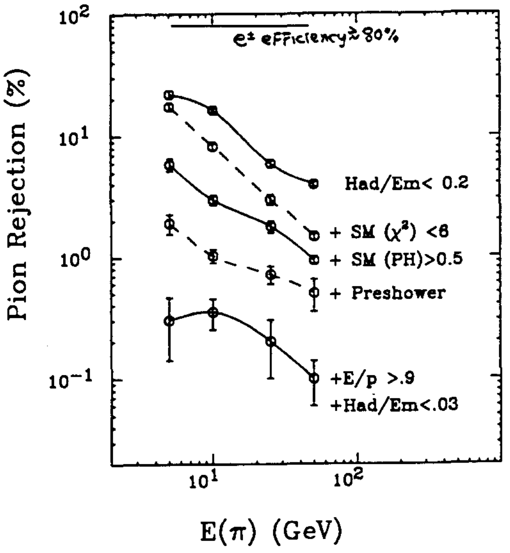
Equal samples of π, e (233,000 e)



⇒ SMD improves π/e by ~X3 in electron signal region (Had/Em<.04)
- Without introducing structure!
- Extra handle for flagging fake $h^\pm$ control sample.



CDF Testbeam



⇒ Although SMD, Preshower responses are correlated for early showering pions,

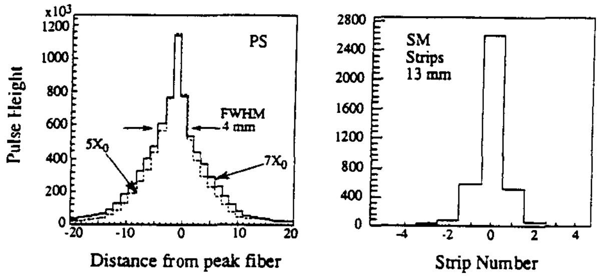
- each response gives X 2-3 incremental rejection

π° / γ REJECTION

Moliere Radius : Pb / Scint ≈ 3 cm

Strip Width : 0.05 / 8 ≈ 1.3 cm

Use narrow core for improved π^0 rejection ?

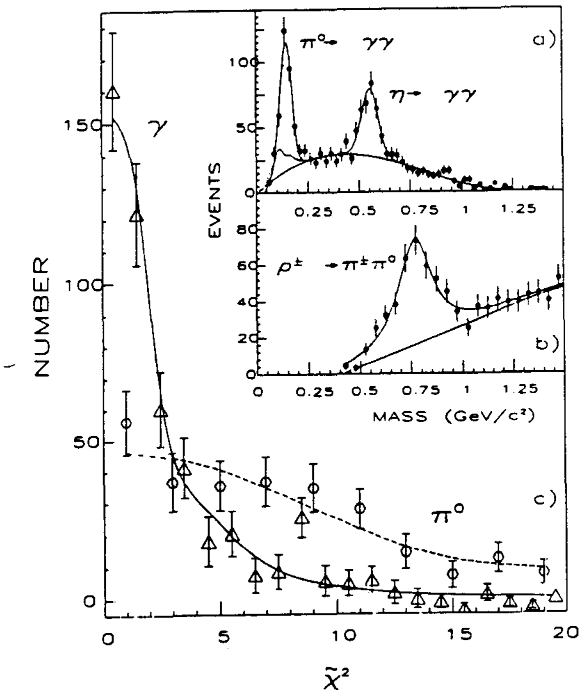


π^0 rejection factor for 80 % electron efficiency :

E_{π^0}	$\varepsilon_\gamma / \varepsilon_{\pi^0}$ (0.05/8)	$\varepsilon_\gamma / \varepsilon_{\pi^0}$ (0.05/16)
25 GeV	6.7	8.9
50 GeV	1.5	2.6
75 GeV	1.3	1.5

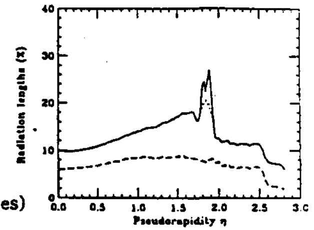
Trade-off : Readout fibers x 2

⇒ π^0 background x 2/3.



Materials Issues

(1) Tracking System



- 0.14 Xo (external)
  + 0.025 Xo (W → eν internal)
  (0.05 + 0.025 Xo, CDF)
- γ → e+e- conversions (see rates)
- e brehmsstrahlung
  - E/P losses (trigger, offline)
  - E/P calibrations
  - Shower-Track position matching

Utilize STD (only 0.06 Xo)

For "p" in E/p ⇒ ~95% efficiency for E/p <1.4 (SDC simul.)
~94% " " (CDF, .05 Xo)
~≥90% " " ⊕ ΔrΦ Match (SDC, Simul

(2) Coil

- 1.2 - 2.4 Xo
- "Massless Gap" corrections using first EMC tile

Effects of brehms in Inner Detector on ΔX (=SMD - track) (CDF)

02548

- due to magnetic separation of { electron ("p") / brehm-γ ("E-p")
- Scales up at SDC due to B-Field (2 kg/1.4 kg)

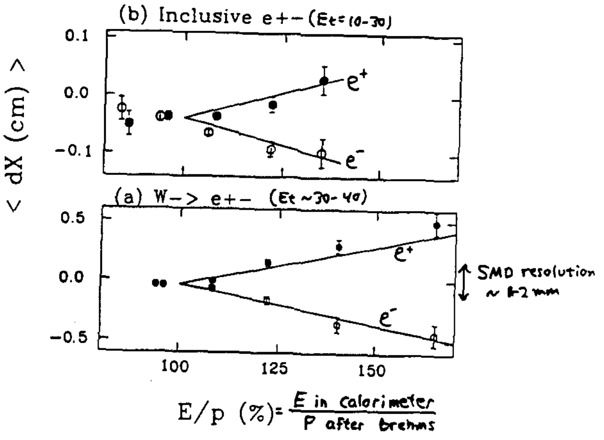


Figure 6

"Massless Gap"

02549

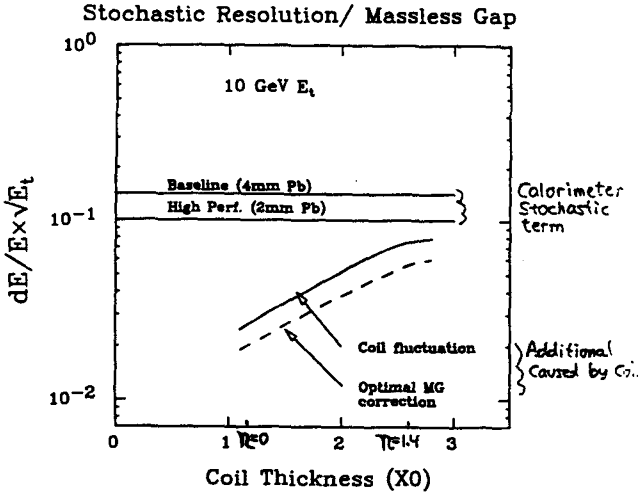
$$\frac{\sigma_E}{E} = \frac{\sigma_{E_t}}{E_t} = \frac{a}{\sqrt{E_t}} \oplus \frac{b(t,E)}{\sqrt{E}}$$

"a" = Pb Sampling + Photostatistics (~ 1/sin θ)

"b" = Coil Loss Fluctuations $\left(\sim e^{t/t_0}\right)$

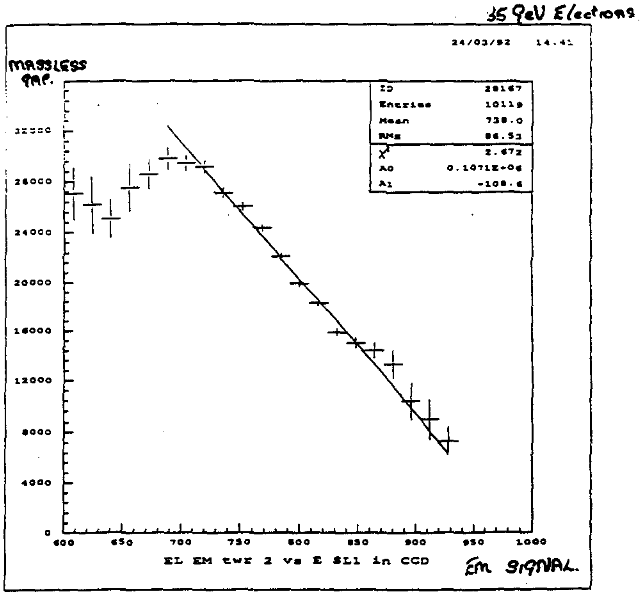
- Use preshower pulse height correlation to estimate coil loss
- "Undercorrect" (weighting), otherwise dE/E dominated by preshower fluctuations
- $\frac{\sigma_E}{E} = \frac{1}{\sqrt{E_t}} \bullet \left\{ a \oplus b(t,E)(\sin\theta)^{1/2} \right\}$

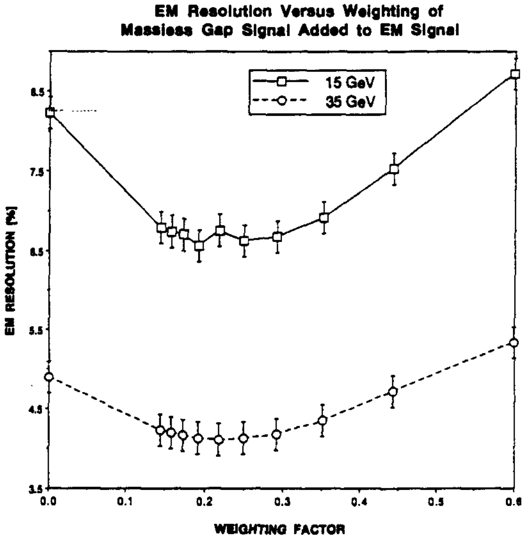
02550



Correlation between massless gap and e.m. calorimeter.

02551




EM Resolution Versus Weighting of
Massless Gap Signal Added to EM Signal
15 GeV
35 GeV
EM RESOLUTION [%]
8.5
7.5
6.5
5.5
4.5
3.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
WEIGHTING FACTOR

CALORIMETRY-INTEGRATED PERFORMANCE AND DESIGN OPTIMIZATION

D. GREEN

SDC CALORIMETRY: BARREL (90.6), ENDCAP (59.2) FORWARD (12.5)

SDC Barrel Calorimeter Cost Summary

02554

WBS #		Mat'ls. ($k)	Mfg Labor ($k)	EDIA ($k)	Base ($k)	Cont. ($k)	Cont. %	Total w/ Cont. ($k)
2.1.1	Module Components	27,191	10,862	4,489	42,542	11,079	26.0	53,62
2.1.2	Module Assembly	380	3,730	1,531	5,641	1,789	31.7	7,43
2.1.3	Support Structure	1,509	603	1,102	3,214	840	26.1	4,05
2.1.4	Tooling	3,641	1,724	2,484	7,849	2,806	35.7	10,65
2.1.6	Facilities	410	2,036	1,763	4,210	1,344	31.9	5,55
2.1.7	Surface Assembly	0	1,352	458	1,809	590	32.6	2,39
2.1.8	Program Management	310	0	2,628	2,938	470	16.0	3,40
2.1.9	R&D/Prototypes	901	599	1,030	2,530	982	38.8	3,51
	Total Barrel Calorimeter	34,342	20,905	15,485	70,733	19,899	28.1	90,631

	Cost Summary by Major System Components	Total w/ Cont. ($k)
	Scintillators → "MEGATILE" ?	● 24,981
	Module Structure (W/O Calibration Grooves) CAST, STACKED Pb ? Fe LAMINATIONS ?	● 31,563
	Photo-Multiplier Tubes (PMT's)	6,384
	Module Assembly and Misc. Support System Components	8,181
	Support System	4,042
	Surface Assembly	1,582
	Management	3,431
	R&D/Prototypes	3,512
	Erection Tooling for Surface Assembly and Hall Installation	2,319
	Calibration	4,637
	Total Barrel Calorimeter	90.631

02555

STAGE/PHASE ELECTRONICS?

SDC Front-End Electronics Cost Summary

* FEWER CHANNELS THAN DØ

WBS & Subsystem	Scaling Parameters (Channels)	Total Cost ($K)	Cost Formute
5.1.2 Straw Tracker	137,164	$12,711	$6.1M + $48/Ch.
5.1.3.1 Calorimeter (SCA)	* 20,352	$9,315 ●	$3.8M + $271/Ch.
5.1.3.2 Shower Max (SCA) + MG	57,472	$5,961 ●	$2.6M + $59/Ch.
5.1.4.1 Muon Wire Chamber	89,864	$3,486	$1.4M + $23/Ch.
5.1.4.2 Muon Scintillator Counter	6,736	$1,236	$0.3M + $139/Ch.
5.1.4.4 Regional Electronics	96,600	$10,021	$4.4M + $58/Ch.
5.1.4.5/6 Sys. Integ. & P.M.		$1,153	$1.2M
5.1 Front-End Subtotal*	311,588	$43,883	$19.8M + $77/Ch.

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in situ Calibration

02556

- **Electrons (Photons)**

$W \rightarrow e\ \nu$ 10 Hz

$Z \rightarrow e\ e$ 1 Hz

@ DESIGN ℒ

Absolute calibration to 0.2% for all towers in the regioi η < 2.5. {CDF with 1500 W's achieved an absolute calibration of 0.24% and a relative calibration of 1.7% over 480 towers.}

- **Hadrons**

Absolute calibration is obtained at moderate energies from E/P for isolated tracks. – LOW P_T

- **Jets**

Absolute and relative response as a function of jet Et can be done at the 3% level using a variety of physics processes: dijet balancing; high Pt W and Z productio and γ– jet Et balancing. – JJ JZ JW Jγ

C_S^{137} SOURCE TUBE CALIBRATIONS 02557

± 0.6% STABILITY, ABSOLUTE 2-3% SCALE SET

R+D ON SOURCE LOCATION CONTROL AND PMT SPACE CHARGE CORRECTIONS

02558

OPTICS AND RANDOM FLUCTUATIONS WITH λ << R_M (~ 3CM) ARE BENIGN

⟹ E.G. ⊥ NONUNIFORMITY FINE STRUCTURE NEAR FIBER (TAKIKAWA TALK)

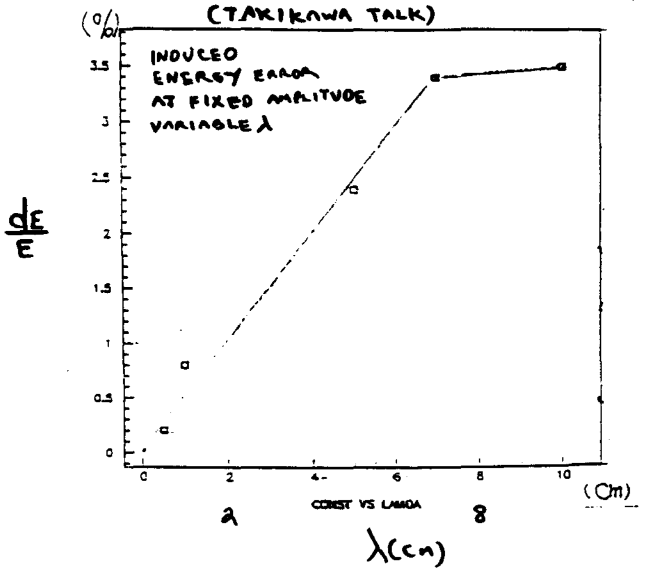


Figure 6.4 Constant term in energy resolution vs wavelength for a sinusoidally varying transverse response. Note that short wavelength variations do not generate degraded resolution.

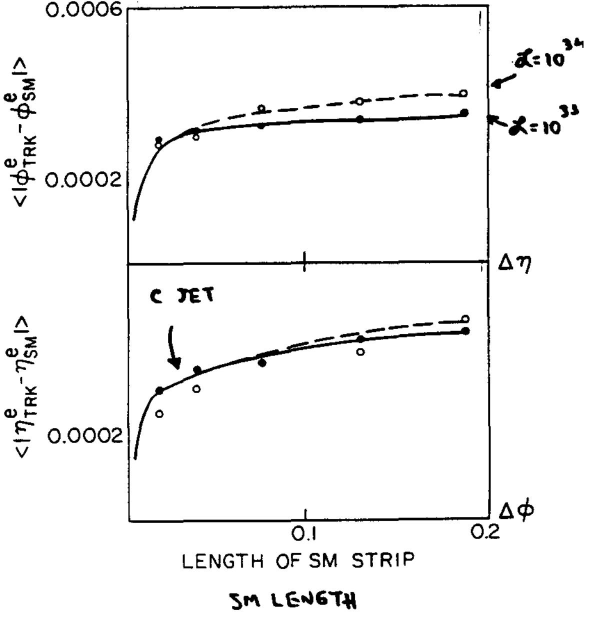
- FOR |η|<2 - 100 YEARS AT DESIGN $\mathcal{L}$ IS OK
  FOR |η|>2 - ^{16}REPAIR SCENARIOS (SMALL VOLUME)

02559

$t \to Wb$
$\hookrightarrow e\nu$

CG VS STRIP SIZE

E.G. LIMITED BY FLUCTUATIONS IN EM ⊥ SHOWER DEVELOPMENT



π^0 / γ REJECTION

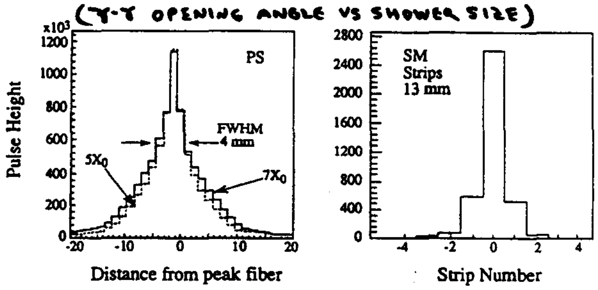
02560

SM STRIP WIDTH

Moliere Radius : Pb / Scint ≈ 3 cm

Strip Width : 0.05 / 8 ≈ 1.3 cm

Use narrow core for improved π^0 rejection ?
(γ-γ OPENING ANGLE VS SHOWER SIZE)



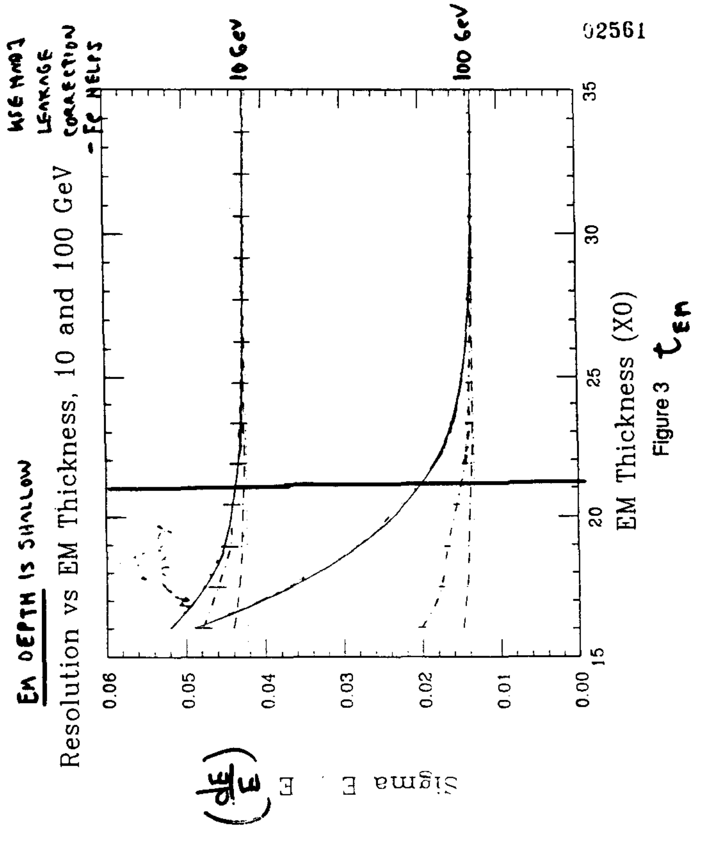
π^0 rejection factor for 80 % electron efficiency :

E_{π^0}	$\epsilon_\gamma / \epsilon_{\pi^0}$ (0.05/8)	$\epsilon_\gamma / \epsilon_{\pi^0}$ (0.05/16)
25 GeV	6.7	8.9
50 GeV	1.5	2.6
75 GeV	1.3	1.5

Trade-off : Readout fibers x 2
⇒ π^0 background x 2/3.

+ H → γγ
θ_γ

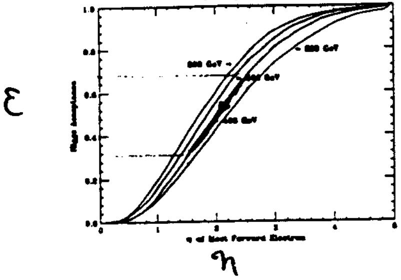
02561



02562

H → ZZ → 4e

CCAL ANGULAR COVERAGE



LOSE 1 UNIT OF ACCEPTANCE
⇒ ε ~ 0.7
↓
ε ~ 0.3

Figure 1: Acceptance of Higgs particles (M_H = 200, 400, 600 and 800 GeV) in the decay mode $H \to ZZ \to 4e$ where all four electrons have η less than η_{max}.

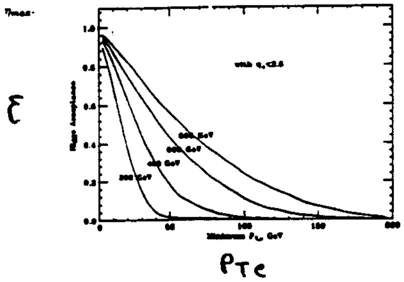


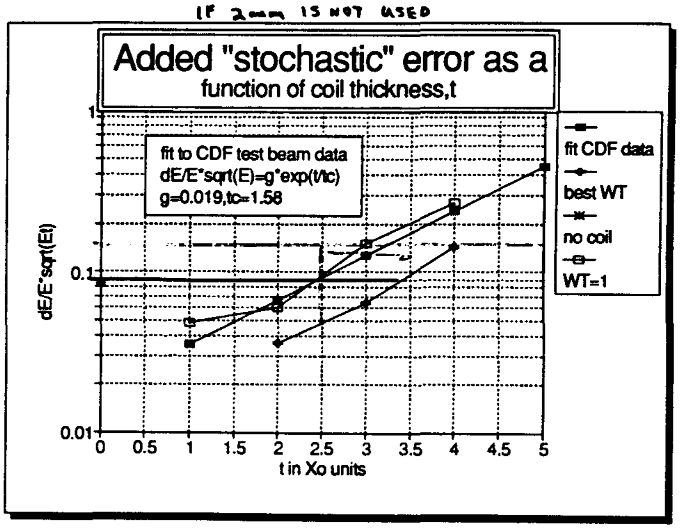
Figure 2: Higgs acceptance vs. mimimum $P_{T,elec}$ (for M_H =200, 400, 600 and 800 GeV). Assumes η = 2.5 cut on electrons.

20

02563

SOLENOID MATERIAL

SOC HAS A SMALL MARGIN OF SAFETY - EVENT AT Θ = 30° IF 2mm IS NOT USED

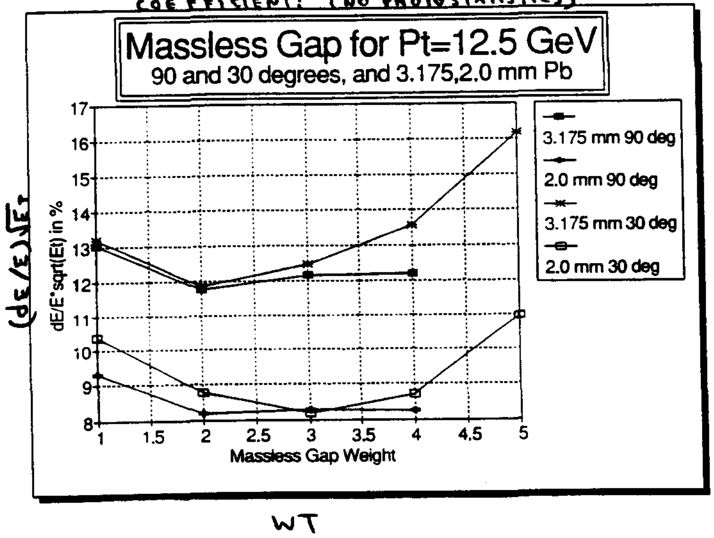


CONVERSELY - SOC IS NOT PREVENTED FROM DOING EM CALORIMETRY WITH ≲ 10% STOCHASTIC COEFFICIENT BY THE SOLENOID

02564

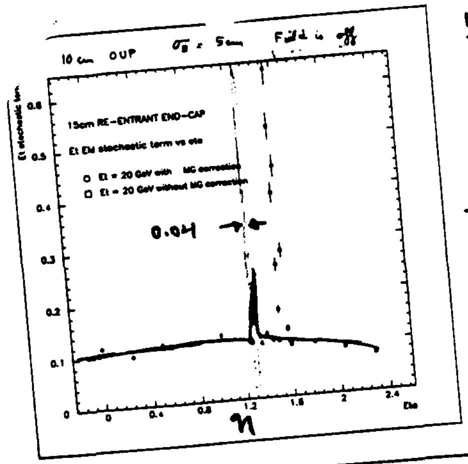
SOLENOID AND MASSLESS GAP

SOC IS NOT PREVENTED FROM DOING EM CALORIMETRY WITH < 10% STOCHASTIC COEFFICIENT! (NO PHOTOSTATISTICS)

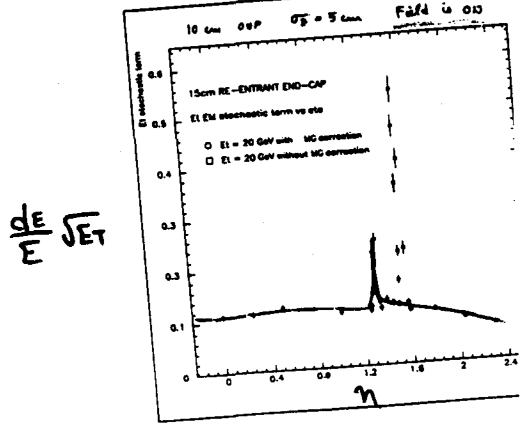


HERMITICITY - V

02565

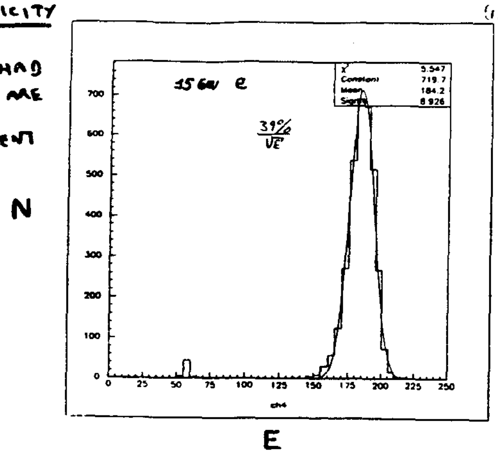


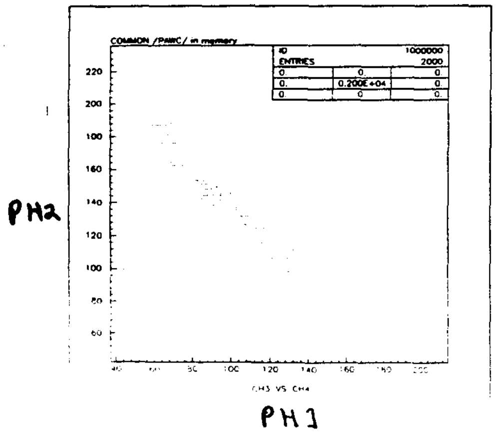
THE SOLENOID LOSSES CAUSE A FIDUCIAL VOLUME LOSS FOR PRECISION e BUT DO NOT CAUSE A CATASTROPHIC $\not{E}_T$ LOSS



HERMITICITY

EM AND HAD CRACKS ARE NOT CONGRUENT



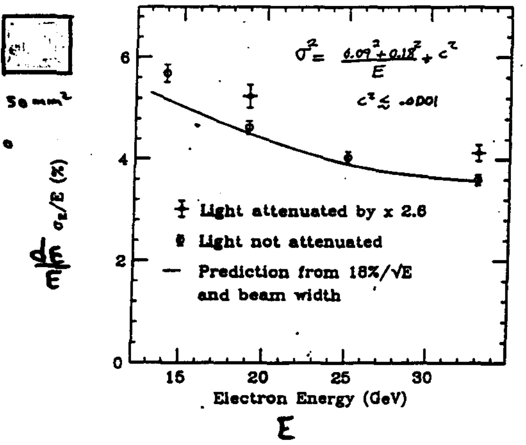


HERMITICITY

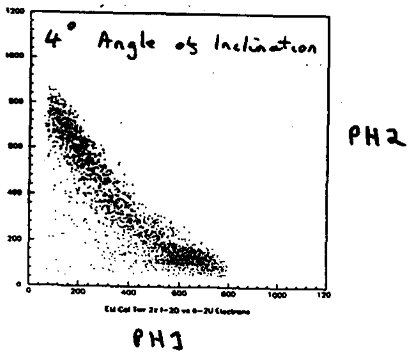
FIBER ~ 50 mm² BUNDLE

⇒ < 1%

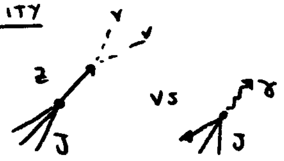
Tile/Fiber EMC Resolution

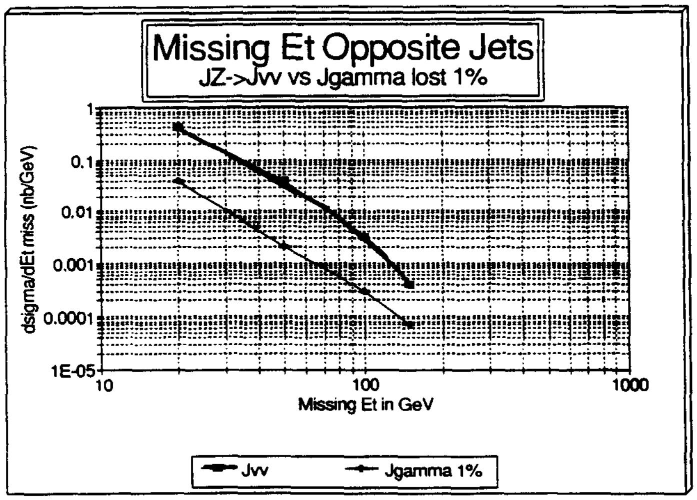


EM CONSTRUCTION IS HERMETIC



HERMITICITY





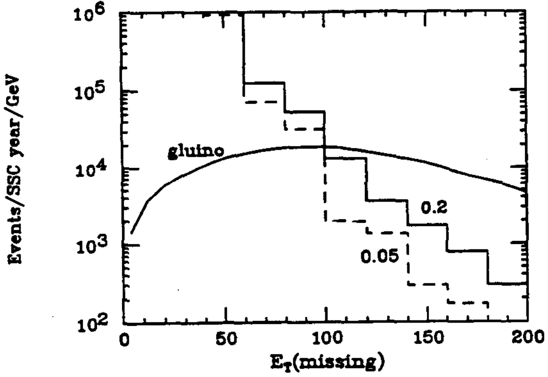
⇒ WITH 1% HERMITICITY REAL PHYSICS $\not{E}_T$ DOMINATES LEAKAGE AND/OR LOSSES

FCAL: RESOLUTION

What Resolution is required in Forward Calorimeter?

$$\frac{dE}{E} = 100\%/\sqrt{E} \oplus 10\%$$

3 Jets>70. φ>40. ΔE/E= 0.05, 0.2



$$\frac{\sigma}{E} = \frac{0.9}{\sqrt{E}} \oplus 0.05 \text{ or } 0.2$$

MEASURE LARGE E, LOW P_T W JETS

⇒ SEGMENTATION $\Delta\eta = \Delta\phi \geq 0.2$

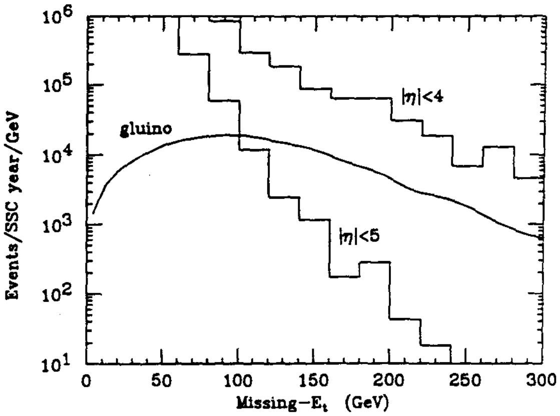
FCAL: COVERAGE

02570

What η coverage is required by E_T^{miss} ?

$m(\tilde{g}) = 300$ GeV   3 jets with $E_T > 70$ GeV

$\phi(jet) - \phi(E_T^{miss}) > 40°$ } NO JET LEAKAGE



Fiducial region must reach $|\eta| = 5$.

$|\eta| < 6$

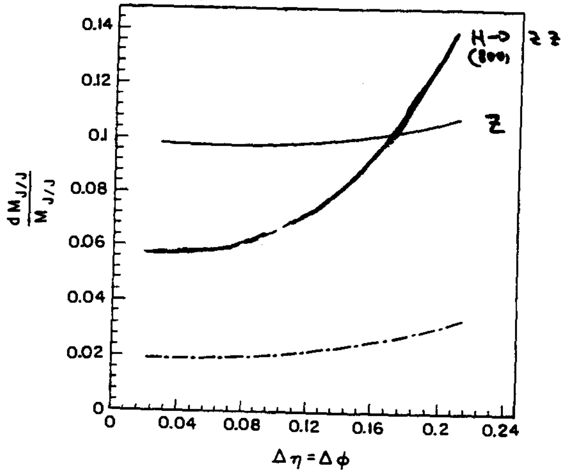
FOR FCAL COVERAGE

($|\eta| < 5$ FIDUCIAL)

02571

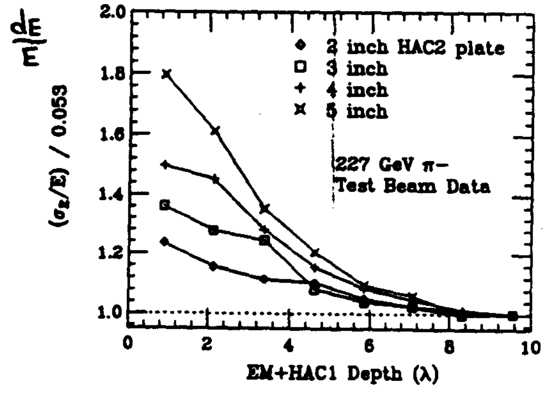
Z → JJ , M_{JJ} VS SEGMENTATION

MUST BE PREPARED TO
LOOK AT ZZ SCATTERING
UP TO TeV SCALE TO
INSURE "NO LOSE" SCENARIO



02572

SAMPLING OPTIMIZATION



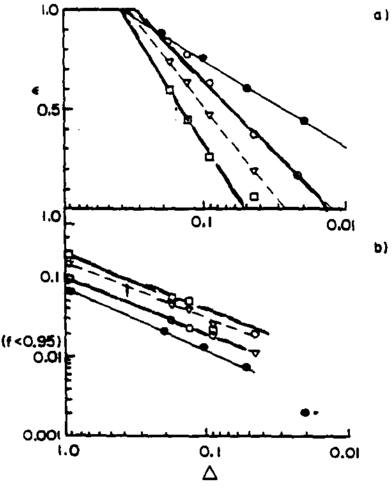
TOTAL = 10 λ

2", 3", 4", 5" HAD2 SAMPLING

DEPTH; CONTAINMENT AND EFFICIENCY

02573

FLUCTUATIONS



17. In this Figure lines are drawn to guide the eye. Solid lines refer to 100 GeV data while dashed lines refer to 450 GeV data. The meaning of the symbols is that:

• = 100 GeV, D = 10.1, D1 = 6.6, D2 = 3.5
● = 450 GeV, D = 10.1, D1 = 6.6, D2 = 3.5
∇ = 450 GeV, D = 9.4, D1 = 5.9, D2 = 3.5
■ = 450 GeV, D = 8.7, D1 = 5.2, D2 = 3.5

a. Efficiency of event acceptance as a function of Δ, the fractional beam energy cut in the back segment.

b. Fraction of events, F, with containment fraction, f, < 95% as a function of Δ.

HADRON CALORIMETER

HAS BEEN MATCHED TO JET DEFINITION ACCURACY

$$\text{QUARKS}\quad \begin{bmatrix} u \\ d \end{bmatrix} \begin{bmatrix} c \\ s \end{bmatrix} \begin{bmatrix} t \\ b \end{bmatrix},\ Q=\begin{bmatrix} 2/3 \\ -1/3 \end{bmatrix}$$

$$\text{LEPTONS}\quad \begin{bmatrix} e \\ \nu_e \end{bmatrix} \begin{bmatrix} \mu \\ \nu_\mu \end{bmatrix} \begin{bmatrix} \tau \\ \nu_\tau \end{bmatrix},\ Q=\begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

GAUGE BOSONS	STRONG	g_s	GLUONS	g
	EM	e	PHOTONS	γ✱
	WEAK	g_w	W^+ W^-	Z

Figure A.1: Standard Model for matter and energy. Constituents are doublets of quarks and leptons in three generations. Forces are transmitted by gauge bosons with dimensionless couplings.

— = JETS ("POOR" CALORIMETRY MATCHED TO JETS)

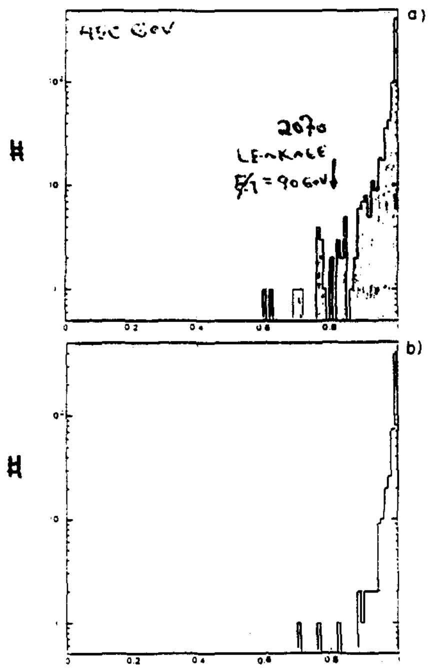
$\leq 70\%/\sqrt{E_T}$

$\oplus$

$\leq 6\%$

✱ LEAVES ONLY e, γ AS PRECISION OBJ...

DEPTH FOR $M_{JJ} = 10$ TeV, $P_{TJ} \sim 5$ TeV, $\langle Z_1 \rangle \sim 0.2 \Rightarrow \&_1 \sim 1$ TeV



USING LONGITUDINAL SEGMENTATION

f = E_ABSORBED / E

16. The distribution, for 1000 events, of the containment fraction f for 450 GeV incident beam.

a. D = 10.1 calorimeter, no longitudinal segmentation.

b. D = 10.1 calorimeter with D1 = 6.6 and D2 = 3.5 longitudinal segmentation. The fractional beam energy, Δ, in the back, D2, segment must be < 0.18

35

DIJET MASS RESOLUTION

DOMINATED BY FLUCTUATIONS OUT OF CONE (J) AND INTO CONE (MINBIAS)

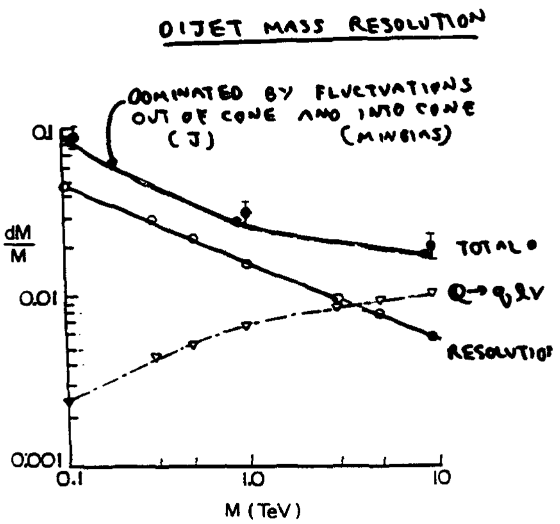


FIGURE 12

Table 6-1
Performance requirements on the SDC calorimeter.

Parameter	Requirement	Basis
η max for $e^\pm$ ID	● 2.5	$H \to 4e, 2e2\mu$
EM efficiency loss in $\lvert\eta\rvert < 2.5$	< 5%	electron ID
η max for jets	● 5	SUSY searches
gaps in full jet coverage, $\lvert\eta\rvert < 5$	● ≤ 1%	Missing-E_t
EM energy resolution,		$H \to \gamma\gamma, Z' \to ee$
stochastic term	● $\leq 15\%/\sqrt{E_t}$	
constant term	● ≤ 1%	
EM transverse segmentation	● 0.05	$H \to 4e, H \to \gamma\gamma$
Hadronic energy resolution.		dijet mass resolution
stochastic term	● $\leq 70\%/\sqrt{E_t}$	
constant term (single $\pi^\pm$)	≤ 6%	
Hadronic transverse segmentation	● 0.10	dijet mass resolution
EM residual nonlinearity	≤ 1%, $E_t > 10$ GeV	$ee, \gamma\gamma$ mass resolution
Jet residual nonlinearity	≤ 1%/TeV. $E_t > 2$ TeV	compositeness search
Dynamic range (EM and HAC)	20 MeV–4 TeV	e ID. compositeness
EM depth	● 22/25 X_0	$ee, \gamma\gamma$ mass resolution
Calorimeter depth ($\eta = 0$)	● ≥ 10 λ	dijet mass resolution

Table 6-2
Performance requirements on the shower maximum detector.

Parameter	Requirement
Strip width	< 1.5 cm ●
Resolution $r - \phi$ and z	< 3 mm
Resolution on relative energy (strip-strip)	< 10%
Strip length ($\Delta\eta$ or $\Delta\phi$)	≤ 0.2 ●
Cross talk	≤ 0.5% after correction

Table 6-3
Performance requirements on the forward calorimeter.

Parameter	Requirement
Energy resolution	● < 10% at 1 TeV
Transverse segmentation, $\eta = 3$	0.2
$\eta = 5$	0.4
Time resolution	$\sigma_t < 5$ ns. $E_t > 50$ GeV
Noise	$\sigma_{E_t} < 30$ GeV
η coverage, jet axis	● $3 \leq \lvert\eta\rvert \leq 5$
(physical)	● $2.8 \leq \lvert\eta\rvert \leq 6$

02578

MUON SYSTEM-INTEGRATED PERFORMANCE AND DESIGN OPTIMIZATION

G. FELDMAN

SDC Muon System

Integrated Performance
and
Design Optimization

(Design Choices)

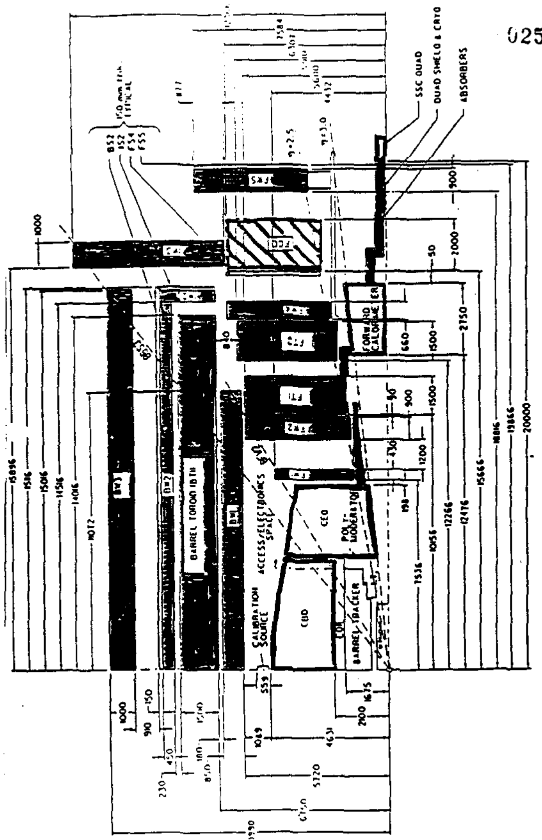
G. Feldman
SSC PAC Meeting
May 8, 1992

Design Choices

Since I was asked to be brief, I will only discuss why we made two sets of design choices:

- Toroid thickness
- Number of layers

These choices drive the cost of the muon system.



Toroid Thickness:

Central Toroid:

The thickness of the central toroid is 1.5 m. We considered 1.0 m for some time and rejected it as too risky.

Having a thinner toroid would clearly reduce the resolution of the toroidal momentum measurement. However, the more important issue was the first level trigger rate. The rate is dominated by low-p_t muons which scatter to appear to be higher-p_t muons. Lowering the thickness from 1.5 m to 1.0 m would change the bend to scatter ratio from 3.9 to 2.8, sharply increasing an already marginal rate (~6 kHz).

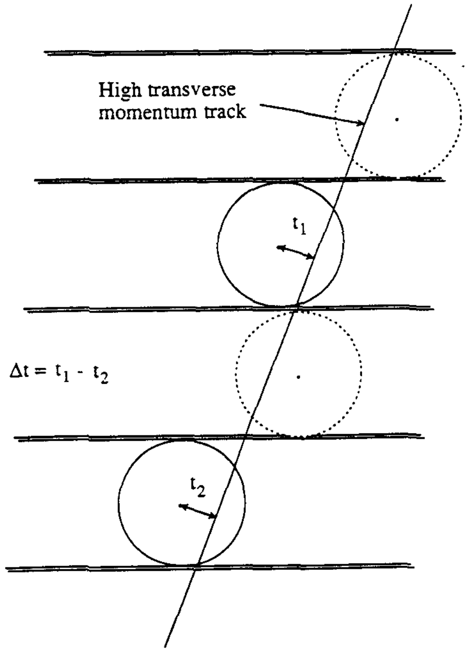
Further, we would become quite sensitive to any increase in the longitudinal bunch length.

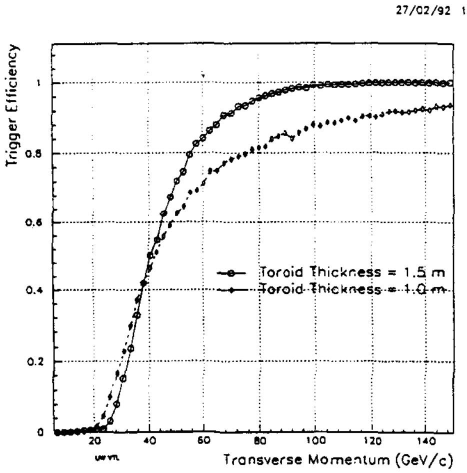
The forward toroids have a total thickness of 3 m. The issue here is momentum resolution. For $p_t > 300$ GeV/c and $|\eta| > 2.2$, most of the momentum resolution comes from the toroidal measurement. Having 3 m of iron allows a multiple scattering limited resolution of 11%, only about a factor of two worse than in the central region.

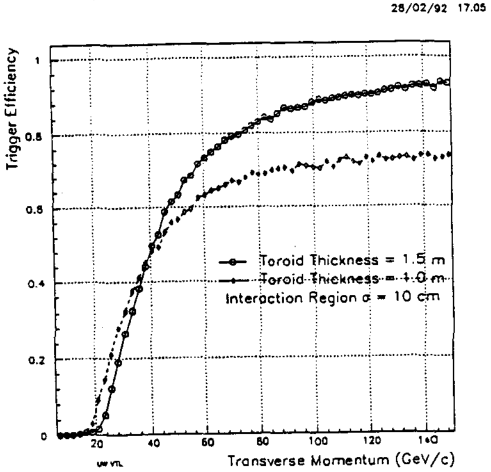
Contributions to the time difference of the first level trigger:

η	θ (deg)	Bend	Scattering	IP	Chamber Res.
0.0	90	$810/p_t$	$210/p_t$	5.9	1.8
1.0	45	$810/p_t$	$160/p_t$	2.5	1.2
2.0	15	$450/p_t$	$70/p_t$	0.9	1.7

"Bend" varies as the thickness,
"Scattering" varies as the square root of the thickness, and
"IP" and "Chamber Res." are independent of the thickness.







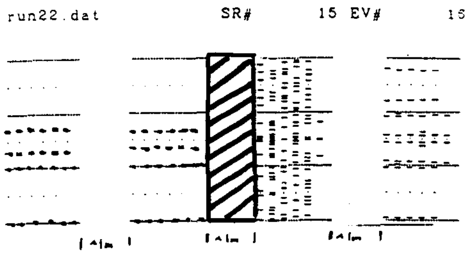
Number of Layers:

We have designed the system with the absolute minimum number of layers for a robust system.

It must be remembered that 20 to 30% of the time, high energy muons exiting material are accompanied by electromagnetic debris. This debris tends to be at wide angles to the muon, and should not be a major problem for chambers with good two-track separation. However, some of the time, a measurement will be corrupted by the wrong particle creating the signal. Thus, our design does not depend on a single superlayer for a critical measurement.

Each superlayer contains 4 layers: 2 pairs of half-cell offset projective wires. The projective wires are needed for the level 1 and 2 triggers and the half-cell offset is needed for efficiency.

T816 Test Beam



Tubes are positioned to measure θ, ϕ, and stereo in the central regions, and to measure θ and two stereo directions in the forward regions:

Central Chambers

Label	Coor-dinate	Number of Layers	Channels
BW1	θ ϕ	4 4	10674
BW2 IW2	θ	4	9136
BW3 IW3	θ ϕ s	4 4 2	37814
Total		22	57624

Forward Chambers

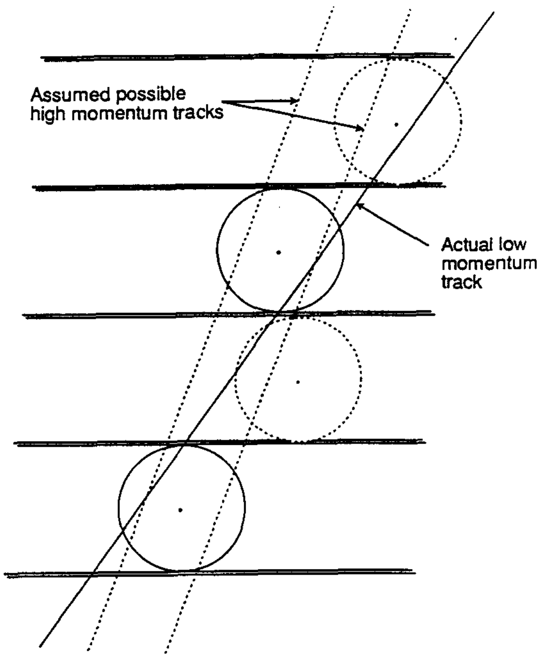
Label	Coor-dinate	Number of Layers	Channels
FW1	θ	4	4390
FW2	θ s_1 θ s_2	2 2 2 2	11904
FW4	θ	4	4310
FW5	θ s_1 θ s_2	2 2 2 2	11636
Total		24	32240

In addition, room is being left between the two forward toroids for an additional 4 layers of θ tubes. This upgrade, which is not part of the baseline design, would allow a determination of whether there had been a large-angle muon scatter in one of the toroids, and allow for a correct point-line measurement in the other.

Central Region θ Layers:

There are two superlayers after the toroid and one before. The two after the toroid are used for the first level trigger. Both are needed for high efficiency since a coincidence of two pairs of projective wires are needed to suppress low-p_t fakes.

The superlayer before the toroid is used for the toroidal momentum measurement, may be used in an augmented first or second level trigger, and is useful for track-matching. It has no redundancy, but its functions are not as critical as others. For example, the input vector for the toroidal momentum measurement can be taken from the inner tracker, with a larger error due to multiple scattering in the calorimeter.



Central Region ϕ Layers:

There are two superlayers, one before the toroid and one after. These layers are critical for the second level trigger, track matching to the inner tracker, and high-precision momentum measurements of high-p_t muons.

The superlayer before the toroid has less error from multiple scattering; the superlayer after the toroid has a less hostile environment.

Central Region Stereo Layers:

Two single layers are a clear minimum.

Forward Region Chambers:

The same arguments generally apply. There are two main differences:

(a) There is a better and more independent momentum measurement. There is one additional θ superlayer, FW1, to provide a line-line measurement.

(b) Small angle stereo is used instead of ϕ. (ϕ measurements are difficult in the forward direction and link moderate and high η.)

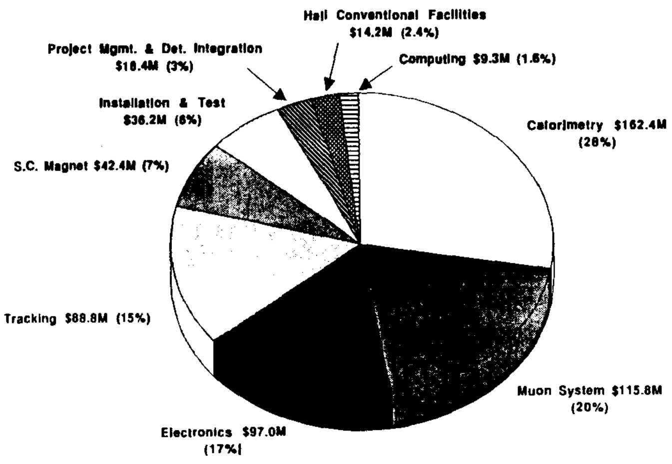
02595

PARALLEL SESSION H:
COST AND SCHEDULE

INTRODUCTION

M. GILCHRIESE

Summary of SDC Detector U.S. Cost Estimate by Subsystem



Total FY92 U.S. Cost Equivalent = $584M

Solenoidal Detector Collaboration

Cost and Schedule

Introduction and Summary

M. G. D. Gilchriese

May 7, 1992

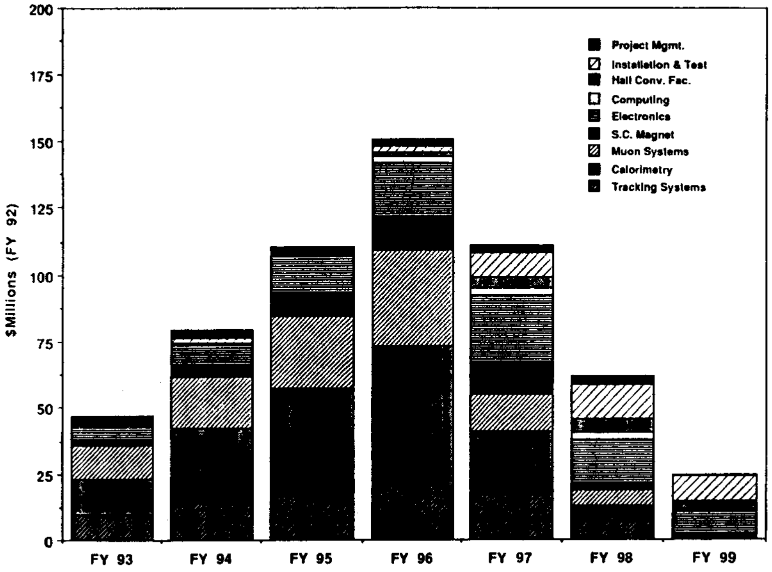
Cost History

- Previous estimates escalated to FY92
- Same accounting as present detailed estimate
- See graph

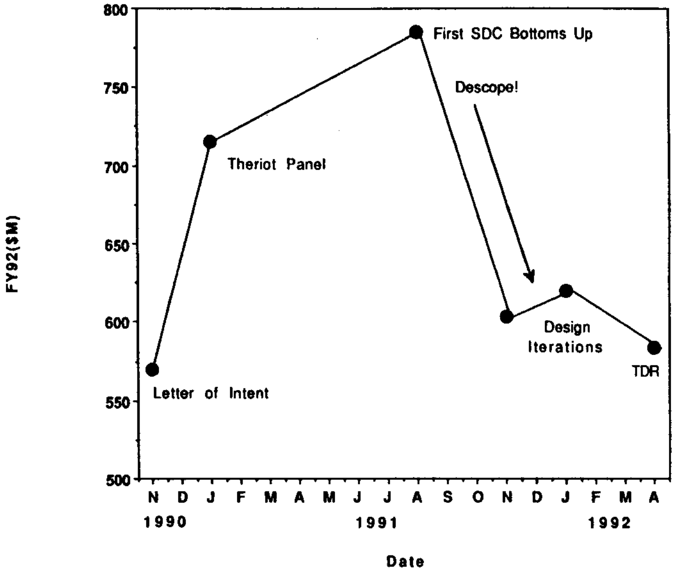
Cost Summary

- Detailed "bottoms-up" estimate for all systems
- Based on Parameters Book Rev. D
- All costs (including R&D and prototypes) from U.S. FY93 - FY99.
- No physicists salaries
- U.S. estimating practices (to the best of our ability)
- Does not take account of existing infrastructure - calculate cost offsets later
- Non - U.S. contributions (cost offsets) will not be discussed here - presented in separate session
- Cost information documented at three levels of detail
  1) Cost and schedule summary
  2) Cost detail - rollup
  3) Cost backup

SDC Detector Funding Profile
U.S. Cost Estimate



SDC Cost History



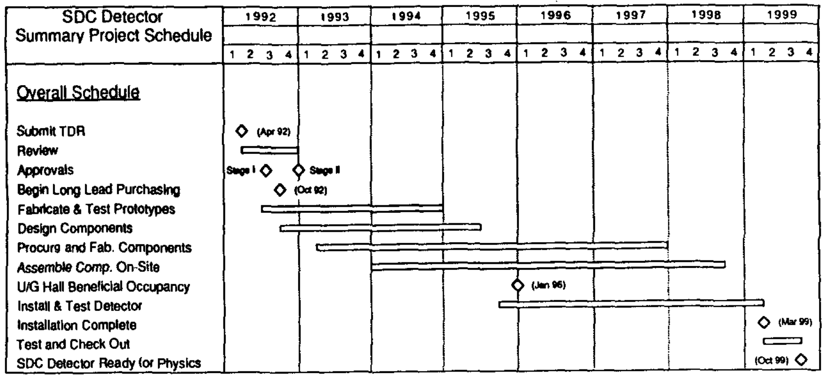
Funding Profile(FY93- FY99) and Previous Funding

- Integrated schedule does not yet exist => preliminary funding profile only
- Construction funding profile - U.S. equivalent - see Fig.
- Funding - from SSCL "detector pot"

FY91(post LoI approval in Jan. '91)	$2.4M
FY92(present)	$16.4M
FY93(request - start construction)	$35-40M

- In addition there is funding this year (FY92) from non - U.S. sources (≈ $3 - 5M), State of Texas (≈ $~~2~~ equivalent) and other SSCL and DHEP sources (≈$3M) 3

	LoI	TDR
Silicon	$28\ m^2$ ----------->	$17m^2$
Straws	8 ----------------->	5 superlayers
	188,000 ---------->	137,164 channels
Intermediate	straws ---------->	gas microstrip detectors
Central calor.	41,000 ----------->	20,352 tower channels
	25,000 ----------->	47,104 shower max. channels
	Pb ---------------->	Fe hadronic absorber
Forward calor.	7000 ------------->	1056 channels
Muon system	108,400 --------->	89,864 wire channels
	7,800 ------------>	4496 scintillation counters
	28 ---------------->	22 layers - central region
	26 ---------------->	24 layers - forward region
	4m --------------->	3m forward toroid thickness
Trigger	----decrease scope---->	
DAQ	-----stage part of Level 3--->	



02607

Schedule Summary

- Fully integrated schedules under development - first pass complete by Sept. 1 in time for DOE review
- Summary schedule - see Figs.
- What's on or close to the critical path?
  - Barrel toroid and its support
  - Central calorimeter
  - Underground hall
- See summary book for more details

02605

IR8 (SDC) Facility Occupancy Dates

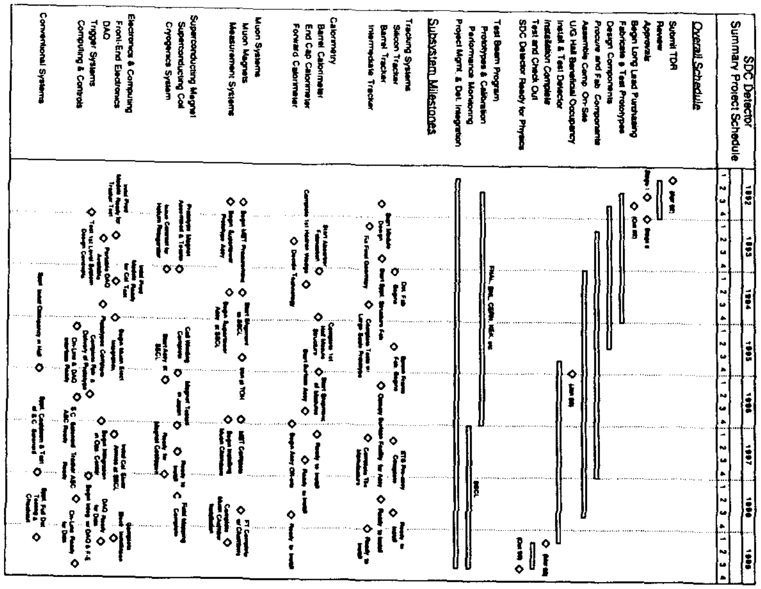
Building	SDC Date	"Baseline" Date	Months Delayed	Detector Assembly or Installation / Activity Affected
Assembly Building				
Hi-bay Assembly Area	Jan-94	Aug-94	7	Start-up of on-site Muon Supertower assembly
Storage Area	Jul-94	Aug-94	1	Storage of Muon Chambers
Office/Shop Area	Jul-94	Aug-94	1	Offices for SDC personnel
Storage & Staging Area	Oct-95	not specified	-	Staging of Muon Barrel Toroid Steel & Support components
Installation Gantry Crane	Oct-95	Oct-95	-	Lowering of Barrel Toroid Support components
Experimental Hall				
Experimental Hall (JOD)	Oct-95	Jan-96	3	Installation of Barrel Toroid Support
Experimental Hall (MJOD)	Jan-96	Jan-96	-	Installation of Barrel Toroid
Experimental Hall (BOD)	Jul-96	Aug-96	1	Continuation of Detector installation & Forward Toroid erection
Installation Headhouse	Jan-96	Oct-96	9	Covered lowering of Barrel Toroid steel
Installation Shaft Cover	Jan-96	Jan-96	-	Lowering of Barrel Toroid steel, rain protection of installation shaft
Utility Building	Jul-96	Jul-96	-	Installation of Utilities, connection of U/G systems to surface
Personnel & Equipment Access Building	Jul-96	Jul-96	-	Ingress into Underground Hall for detector installation
Detector Operations Bldg.	Jan-97	Jan-97	-	Installation and hook-up of Detector Electronics systems
Gas Mixing *Building*	Mar-97	Mar-97	-	Installation of gas systems and connection to U/G systems

Notes:

1. CCD Experimental Hall schedule is divided into three construction packages, Excavation, Hall Construction, and Mechanical/Electrical. Excavation finish is 15-July-94, Hall Construction finish is 12-January-96, and Mechanical/Electrical finish is 15-August-96.
2. JOD for Experimental Hall (Joint Occupancy Date) requires access through (1) installation shaft, and activation of crane capacity.
3. MJOD for Experimental Hall (Mechanical/Electrical Joint Occupancy Date) requires access through (2) installation shafts and substantial clear floor area.

4/29/92

02608



02606

Future Plans

- Level of detail needed for project of this magnitude greater than previous HEP experiments!
- Cost machinery in place and can track detector design changes
- Need to integrate schedules
- Detailed funding profiles and identify major procurements
- Survive DOE review in September!
- Establish baseline cost

02610

COST/SCHEDULE PROCEDURES

D. ETHERTON

SDC

U.S. Cost Estimate

&

Preliminary Project Schedule

Cost/Schedule Procedures

DOE Guidelines for Costing :

- The cost estimating process should include the following tasks:
  1) Define and plan the estimating tasks.
  2) Select the estimating structure for preparing cost data.
  3) Collect, evaluate and apply the necessary cost and cost related data.
  4) Apply the proper estimating methods.
  5) Document the estimate in enough detail, so that it can be reviewed, evaluated, and used in the decision-making process.
- Uncertainties, limiting assumptions, and constraints identified by the estimator must be understandable.
- The most frequently used methods of estimating are as follows:
  - Bottom-up technique
  - Specific Analogy technique
  - Parametric technique
  - Cost Review and Update technique
  - Trend Analysis technique
  - Expert Opinion technique

Cost/Schedule Procedures

SSCL PMP Guidelines for Costing :

- Cost estimates will be made in compliance with DOE Order 5700.2C and will be coordinated with and approved by the PMO and DOE.
- Main points of DOE 5700.2C are:
  - establish and document the basis for the estimate
  - show basis for estimating quantities of materials not yet detailed on drawings, and for wage rates, productivity factors, and installation man-hours, etc.
  - perform a contingency analysis on the project estimates.
  - estimate in constant-year dollars in the year the estimate is performed, escalation will be addressed by spreading the constant-year cost over the project funding schedule and applying appropriate escalation indices.

PRD Guidelines for LOI Costing :

- Guidelines exist for Detector LOI costing. These encompass EDIA definition, labor rates for on-site activities, proposed method for contingency analysis, and escalation guidelines and indices.

Cost/Schedule Procedures

SDC Approach for Costing/Scheduling :

- Procedure for cost estimating and scheduling is in SDT-000009.
- Main points are:

  Organizational
  - establishes Work Breakdown Structure to manage costing/scheduling efforts and to track detector through conceptual design.
  - establishes organization and management of costing/scheduling process.
  - provides guidelines and mechanisms for submittal, roll-up, and documentation.

  Procedural
  - estimates to be in base year FY92 dollars, including labor and material.
  - costs to be included from October 1992 until project completion.
  - costs not to be included are support provided by existing HEP funding of physicists at collaboration institutions.
  - labor rates identified for each institution.
  - contingency analysis performed at lowest level.
  - establishes scheduling approach tied to costing at lowest feasible level.
  - calls for common milestones, sets-forth calendars, establishes mechanisms for schedule summarization and integration.

Cost/Schedule Procedures

Research & Development (>$34M) :

- R&D including prototypes and development models beyond October 1992 were to be included in the cost estimates.
- Most (if not all) of engineering effort for prototypes addressed as EDIA and not included in $34M.
- R&D costs identified within WBS by subsystem are:

Trackers	>$2M
Calorimeters	6M
Muon System	1M
S.C Magnet	6M
Electronics& Computing	>19M
Total	>$34M

- This adds to R&D from prior years and FY92 with the total for SDC related R&D to be around $60M.

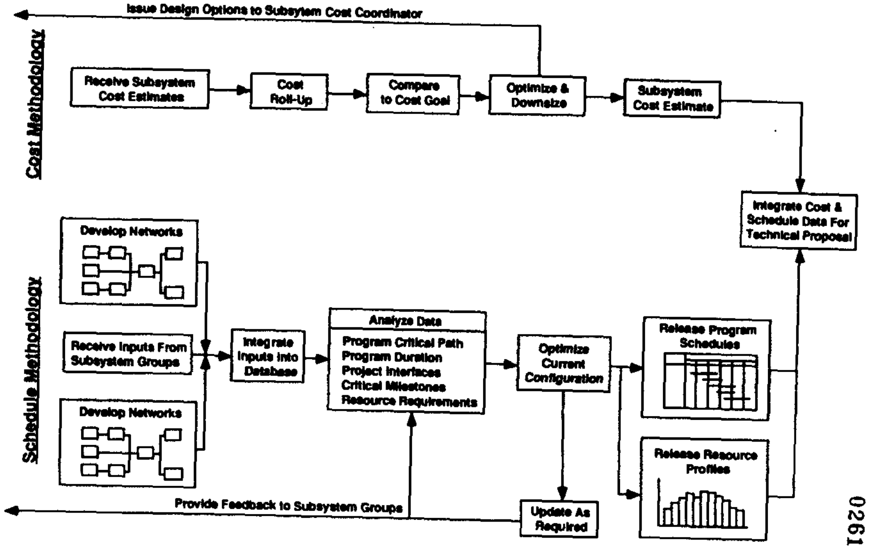
Cost/Schedule Procedures

Labor and Labor Rates :

- Labor, including Manufacturing labor and Engineering, Design, Inspection and Acceptance (EDIA) labor is divided into labor categories associated with relative pay-scale at institution or work location:

Manufacturing	EDIA
Engineer - EN.M	Engineer - EN
Engineer Associate - EA.M	Engineer Associate - EA
Drafter - DR.M	Drafter - DR
Administrative - AD.M	Administrative - AD
Technician - TE.M	Technician - TE
Laborer - LA.M	Laborer - LA

- All labor was identified including manufacturing support and direct administrative support. Indirect efforts were reflected in the burdened labor rates.
- Labor rates were developed for each institution that was designated as a work center. This includes individual national labs, university groupings, SSCL, and industry.



Cost Methodology

Issue Design Options to Subsytem Cost Coordinator

Receive Subsystem Cost Estimates

Cost Roll-Up

Compare to Cost Goal

Optimize & Downsize

Subsystem Cost Estimate

Integrate Cost & Schedule Data For Technical Proposal

Schedule Methodology

Develop Networks

Receive Inputs From Subsystem Groups

Develop Networks

Integrate Inputs into Database

Analyze Data

Program Critical Path
Program Duration
Project Interfaces
Critical Milestones
Resource Requirements

Optimize Current Configuration

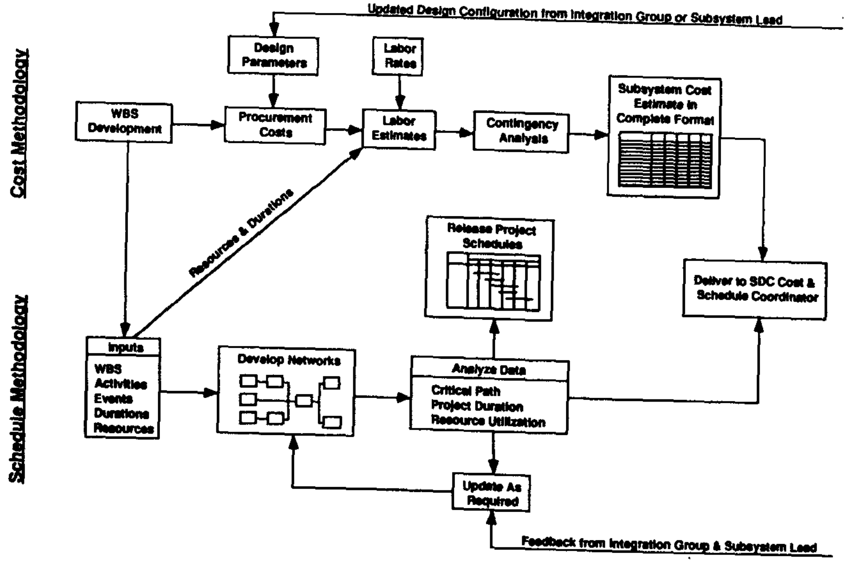
Release Program Schedules

Release Resource Profiles

Update As Required

Provide Feedback to Subsystem Groups

SDC PLANNING GROUP COST & SCHEDULE RESPONSIBILITIES



Cost Methodology

Updated Design Configuration from Integration Group or Subsystem Lead

Design Parameters

Labor Rates

WBS Development

Procurement Costs

Labor Estimates

Contingency Analysis

Subsystem Cost Estimate in Complete Format

Resources & Durations

Schedule Methodology

Release Project Schedules

Deliver to SDC Cost & Schedule Coordinator

Inputs

WBS
Activities
Events
Durations
Resources

Develop Networks

Analyze Data

Critical Path
Project Duration
Resource Utilization

Update As Required

Feedback from Integration Group & Subsystem Lead

SUBSYSTEM GROUP COST & SCHEDULE RESPONSIBILITIES

Cost/Schedule Procedures

EDIA ($124M = 175 person-years) :

Engineering & Design

1. Design *Engineering*
   - design documentation
   - drawing development
   - design maintenance and support
   - labs
   - facility requirements and design
2. Design Analysis
   - stress
   - thermal
   - physics
   - other analysis
3. Design Support
   - materials engineering
   - CAD engineering support
   - checking & release
   - change control
4. Test Engineering
   - test requirements
   - test plans & procedures
   - test operations
5. Systems Engineering
   - subsystem integration and support
6. Logistics Engineering
   - training
   - technical publications
   - spares management
7. Engineering Administration
8. Pack and Ship
9. Tool Engineering
   - tool design
   - tool manufacturing
   - tool procurement
   - tool maintenance plans
   - test equipment design
   - calibration
10. Manufacturing Engineering
    - preplanning, *producibility*
    - process plans
    - operations management
    - Industrial Engineering
    - numerical control planning
    - tool control
    - automated systems
11. Quality Engineering
12. Safety
13. Planning
14. Contracts
15. Procurement
16. Finance
17. Publication Services
18. Personnel
19. Program Managers

21. Factory Receiving & Inspection
22. Fab./Assy/Installation Inspection
23. Factory Quality Control Support
24. Local & Offsite Procure. Inspection
25. QA Pack & Ship
26. Quality Management and Supervision

Cost/Schedule Procedures

Manufacturing Labor ($100M = 177 person-years) :

- Includes:
  - efforts for fabrication, assembly, and installation.
  - covers all efforts including tooling, production support, factory test, as well as "touch" labor.
  - also includes fabrication supervision, facility modifications, material handling, and packing/shipping.
- Addressed at lowest level to guide design development (design-to-cost) and because design flexibility (early stage) reduces ability to develop bid packages for vendor quotes of large assemblies.
- Obtain, document, and incorporate vendor estimates to the greatest extent possible. Especially for high volume repetitive work where industry knowledge is greater than laboratory experience.

Cost/Schedule Procedures

Contingency ($120M) :

TECHNICAL, COST, & SCHEDULE RISK FACTORS

Risk Factor	Technical	Cost	Schedule
1	Existing Design and Off the Shelf H/W	Off the shelf or catalog item	Not used
2	Minor Modifications to an Existing Design	Vendor quote from established drawings	No schedule impact on any other item
3	Extensive Modifications to an Existing Design	Vendor quote with some design sketches	Not used
4	New Design, Nothing Exotic	In-house estimate based on previous similar experience	Delays completion of non-critical path subsystem item
6	New Design, Different from established designs Existing Technology	In-house estimate for item with minimal experience but related to existing capabilities	Not used
8	New Design, Req's, some R&D but does not advance the State-of-the-Art	In-house estimate for item with minimal experience and minimal in-house capability	Delays completion of critical subsystem item
10	New Design dev. of new tech. which advance state-of-the-art	Top-down estimate from analogous programs	Not used
15	New design, way beyond the current State-of-the-Art	Engineering judgement	Not used

TECHNICAL, COST & SCHEDULE WEIGHTING FACTORS

	Condition	Risk %
Technical	Design OR Manufacturing	2%
	Design AND Manufacturing	4%
Cost	Material Cost OR Labor Rate	1%
	Material Cost AND Labor Rate	2%
Schedule	Same for all	1%

Cost/Schedule Procedures

Materials ($242M) :

- Includes:
  - raw material for fabrication.
  - procurement of components, subassemblies and tooling from outside sources.
  - detector hardware, equipment, fixturing, tooling, utilities, test equipment, assembly equipment, computer hardware/software, and procurement processing.
- Three categories for cost visibility and future acquisition planning:
  1) Expense - single procurements <$5k
  2) Minor - single procurements >$5 and <$50k
  3) Major - single procurements >$50k
- Obtain, document, and incorporate vendor estimates to the greatest extent possible.
- Vendor estimates obtained prior to FY92 were escalated by 6.31% and 3.66% for FY90 and FY91 respectively.

TDR Review - Cost and Schedule

Cost Summary

SDC Integrated Project Schedule :

- Integrate installation schedule, facility milestones, and subsystem summary schedules in OPEN PLAN.
- Establish programmatic constraints for Design Reviews, Production Readiness Reviews, Safety Reviews, etc.
- Tie subsystem schedules together via subsystem-subsystem interfaces, i.e. calorimeter electronics available for calorimeter module test, etc.
- Use integrated level 4 schedules as communication tool with subsystem groups including funds negotiation, project status and control, international contribution tracking (schedule commitments), and subsystem activity reporting.
- Committed to having an integrated project schedule by Sept. 1, 1992.

TDR Review - Cost and Schedule

Cost/Schedule Procedures

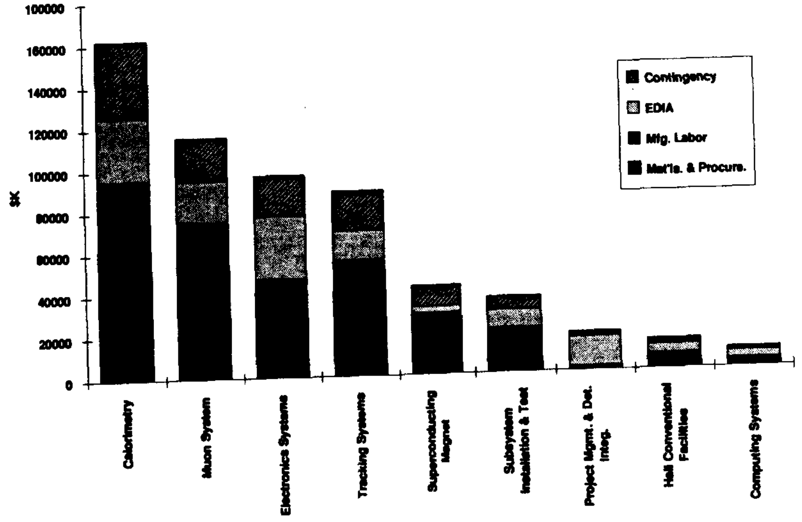
Cast of Players :

- Principal contact people

WBS	Description	Name	Inst.
1.1	Silicon Detector	R. Stone, A. Grillo	LBL, UCSC
1.2	Barrel Tracker (Straws)	R. Swensrud	Westinghouse
1.2	Barrel Tracker (Fiber)	R. Leitch	ORNL
1.3	Intermediate Tracker (G-M)	G. Oakham	FNAL, CRPP
2.1	Central Calorimeter	D. Scherbarth, P. Mantsch	WSTC, FNAL
2.2	End Cap Calorimeter	D. Scherbarth, P. Mantsch	WSTC, FNAL
2.3	Forward Calorimeter (Liq. Scint.)	G. Stairs	U of Toronto
3	Muon Systems	M. Montgomery (B. Vinnedge)	Martin Marietta
4	S.C. Magnet	R. Stanek	FNAL
5.1	Electronics	G. Oberst, et. al	LLNL
5.2	DAQ	E. Barsotti, E. Gaines	FNAL
5.3	Trigger	W. Smith	Wisconsin
5.4	Ancillary Systems Controls	T. Moore	LLNL
6.1	On-Line Computing	A. Fry	SSCL
7.1	Mechanical Utilities	M. Hechi	SSCL
7.2	Electrical Utilities	W. Kampmeier	SSCL
7.3	Safety Systems	B. Lavelle	SSCL
7.4	Struct. Supt. & Access	B. Barney	LBL
8.1	Test Beam Program	J. Siegrist	SSCL
8.2	Subsystem Installation/Test	D. Etherton	SSCL
9	Project Management	D. Etherton	SSCL

- with assistance from many others ...

SDC U.S Cost Summary
Level 3 WBS Elements showing Cost Categories



TDR Review - Cost and Schedule

Cost Summary

Where We've Been :

- Have 2892 element cost estimate database to continue design-to-cost process, to follow/understand design evolution of subsystems, and to track cost offsets of foreign participation.
- Can do parametric studies based on minor modifications of detector parameters, i.e. length, radius, channel counts, weights.
- Have established initial contact with vendors and industrial groups.
- Have developed summary schedules and milestones to be used as initial guidance.

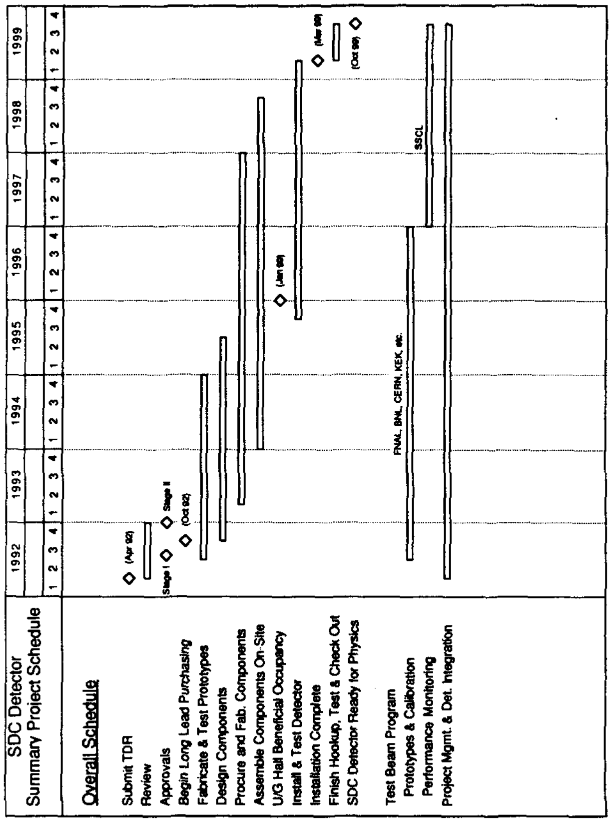
Where We are Headed :

- Get ready for DOE review...
- Develop international funding plan...
- Develop integrated project schedule for SDC ...

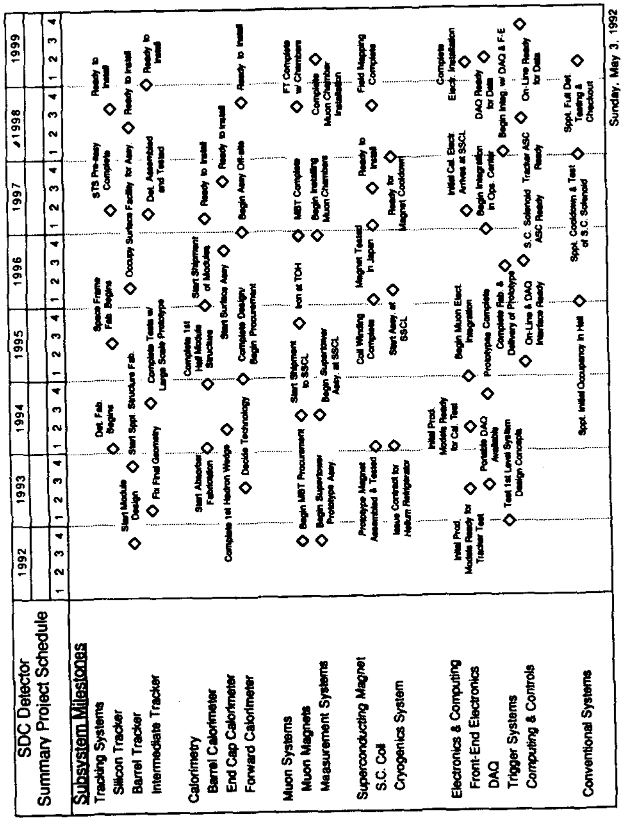
SDC U.S. COST ESTIMATE SUMMARY

Detector cost in equivalent U.S. FY92 $M

	MAT'L & LABOR	EDIA	% EDIA	SUB TOTAL	CONT	% CONT	TOTAL
1 Tracking Systems	[illegible]	14.1	[illegible]	[illegible]	19.2	[illegible]	88.8
1.1 Silicon Tracking System	27.8	4.7	15%	32.5	8.7	27%	41.2
1.2 Barrel Tracker	20.9	5.0	19%	25.8	5.7	22%	31.5
1.3 Intermediate Tracker	6.8	4.4	39%	11.3	4.8	43%	16.1
2 Calorimetry	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27%	152.4
2.1 Barrel Calorimeter	55.2	15.5	22%	70.7	19.9	28%	90.6
2.2 End Cap Calorimeter	32.9	13.0	29%	45.7	13.5	30%	59.2
2.3 Forward Calorimeter	7.9	1.8	19%	9.4	3.2	34%	12.5
3 Muon Systems	75.0	[illegible]	[illegible]	[illegible]	20.9	22%	115.8
3.1 Magnet Systems	41.3	9.0	18%	50.3	9.3	18%	59.6
3.2 Muon Measurement System	33.7	10.9	24%	44.9	11.6	26%	56.2
4 Superconducting Magnet	29.2	3.1	10%	32.3	10.1	31%	42.4
4.1 S.C. Solenoid	23.8	1.8	7%	25.6	8.3	33%	33.9
4.2 Solenoid Cryogenic System	5.4	1.3	19%	6.7	1.8	27%	8.5
5 Electronics Systems	[illegible]	[illegible]	[illegible]	77.3	[illegible]	[illegible]	97.0
5.1 Front-End Electronics	26.5	9.1	26%	35.7	8.2	23%	43.9
5.2 Data Acquisition System	10.4	8.1	37%	16.5	4.0	24%	20.4
5.3 Trigger Systems	15.0	6.6	31%	21.9	7.0	32%	28.8
5.4 Slow Controls	0.8	2.5	75%	3.3	0.6	18%	3.9
6 Computing	[illegible]	[illegible]	[illegible]	[illegible]	1.6	[illegible]	9.3
7 Conventional Systems	7.0	4.4	[illegible]	11.5	2.7	24%	14.2
8 Installation & Test	21.0	8.7	29%	29.7	6.5	22%	36.2
8.1 Test Beam Program	4.2	3.1	42%	7.3	1.6	22%	8.9
8.2 Subsystem Installation & Test	18.8	5.6	25%	22.4	4.9	22%	27.3
9 Project Management	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16%	18.4
TOTALS	342	123	26%	464	120	26%	584



Sunday, May 3, 1992



Sunday, May 3, 1992

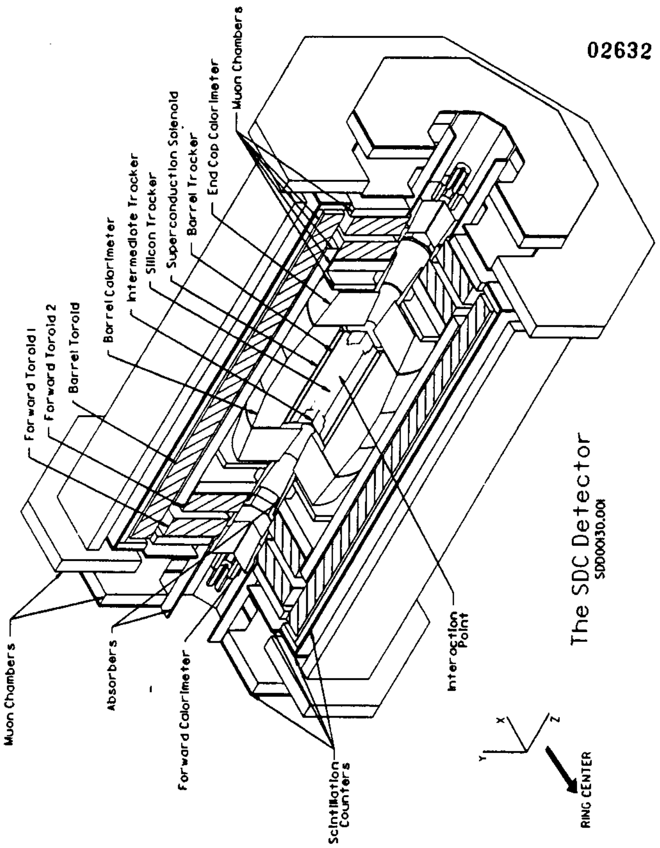
02630

SILICON

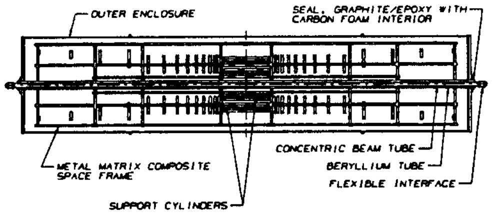
A. GRILLO

Silicon Tracker
Cost & Schedule Review

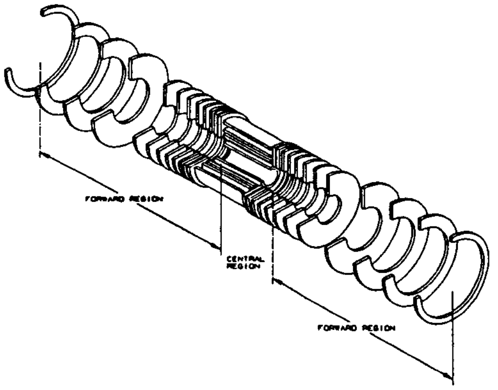
Alex Grillo
UC Santa Cruz
SSCL PAC Review
7-May-1992



The SDC Detector
SD00030.001



STS layout (side view)



STS detector arrays (pictorial view)

Estimating Process

Principal Authors:

LANL:
William Miller
T. Thompson
C. Grastataro
R. Reid

LBL:
Roger Stone
Helmuth Spieler
Bob Barney

Project has been broken down to WBS level 5 elements

There are over 600 activities included in the project design

A cost and time estimate has been made for each activity

- Engineering estimates
- Vendor quotes
- Based upon engineering drawings & specifications

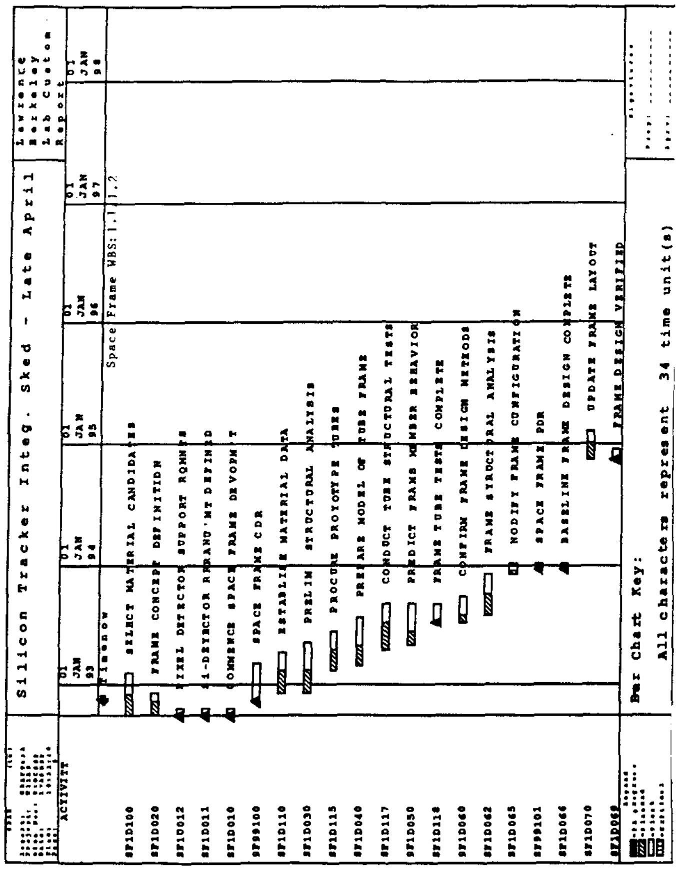
Examples of Estimating Process

(Taken from STS Cost/Data Book)

W.B.S. number:	1.1.1.2.1
W.B.S. name:	Tubes, Space Frame
Estimate source:	Vendor estimate Engineering judgment Historical reference
Definition:	A collection of graphite/aluminum tubes sharing a common diameter and wall thickness but varying in over all length. Component of the space frame. All conditions apply regarding the space frame assembly. Reference drawing 89Y279132-J1.
Basis:	Labor type identified in detailed W.B.S. format under labor categories. Prototype effort included for testing. Manufacturing effort based on vendor estimate.

W.B.S. number:	1.1.2.1.2
W.B.S. name:	Front-end electronics (FEE)
Estimate Type:	Vendor quote
Definition:	The front-end electronics include the bipolar preamp and the CMOS digital circuits. Included are the necessary storage buffers. These components are connected to 1.2.1.1 DET, at the input side and 1.1.2.1.3 RIH at the output side. They will be attached by adhesive to 1.1.2.1.4 Other module components as shown by Figure 1.1.2-2. Some funds for prototypes are included. The number of readouts required is on EXCEL worksheet "1.1.2.1 Mod assy Worksheet".
Basis:	A quote was received from UTMC for rad-hard, 100-channel CMOS readouts in 100 k lots. Personnel from UCSC estimated the equivalent size for the 128-channel chip and determined the estimated costs. A quote was received from Tektronix for the bipolar chip.

EXAMPLE DF DETAILED MECHANICAL SCHEDULE



Risk Reduction

We believe that we have significantly reduced the risk of construction and the uncertainty of the cost & schedule estimates by the R & D effort already expended.

Detailed analysis of mechanical design

Fabrication of prototype components

30° and 120° arc segments
Edge-bonded detector modules
Material studies

For Example:
Construction of prototype edge-bonded detector modules (full 24 cm long) has demonstrated structural integrity of this key STS building block.

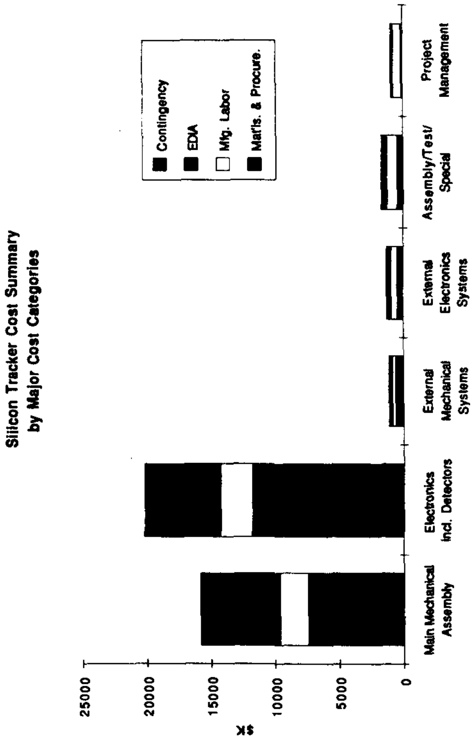
Simulations of detector and electronics designs

Fabrication of prototype devices

Double sided detectors
Bipolar analog circuits
CMOS digital circuits

For Example:
Tektronix prototype has allowed verification of both functionality and production issues: chip size, yield, and verification that we don't need laser trimming.

Over $5 Million have been spent in the last 4 years on design and prototyping for the Silicon Tracker to insure that the construction plan can be met. This includes work in the U.S., Japan and the U.K.



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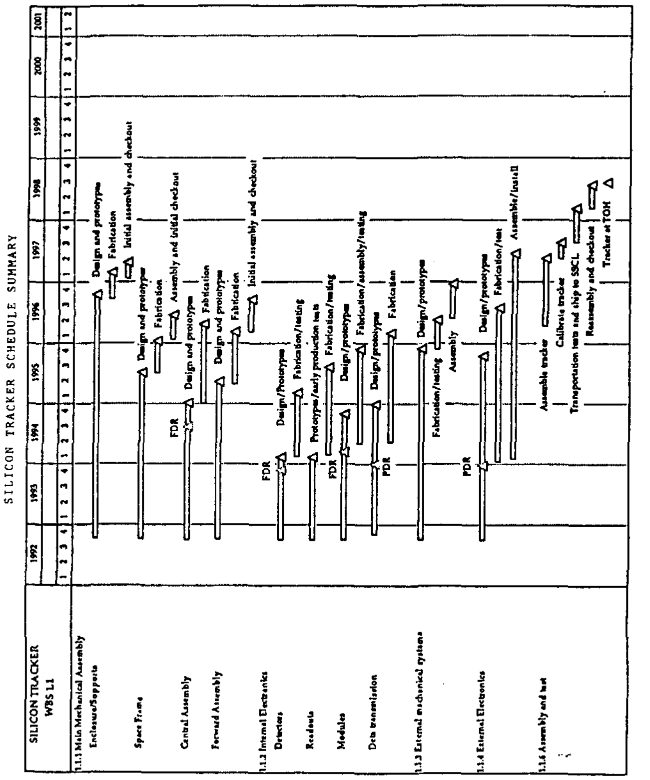
Major Cost Drivers

Item	Unit Cost, k	Unit	Number	Total, k
Barrel detector	$0.750	each	3600	$2,700
Frwd detector	$1.500	each	3112	$4,668
Barrel readout	$0.053	each	18000	$954
Frwd readout	$0.053	each	32640	$1,730
Optical trans/rec	$0.500	set	1236	$618
FEE Design/test Labor	$3,008	effort	1	$3,008
Enclosure/supports	$881.0	each	1	$881
Space frame/mounts	$501.0	each	1	$501
Disc cooling ring	$11.3	each	48	$542
Heat rejection sys	$516.0	each	1	$516
Trker assy/test	$879.0	each	1	$879
Mech Int/exp	$2,254.3	effort	1	$2,254
In-situ alignment	$511.3	sys	1	$511
Program Management	$848	effort	1	$848

Silicon Tracker Totals

Base Cost:	$32,472 K
Contingency:	26.9%
Total Cost:	$41,204 K

02640



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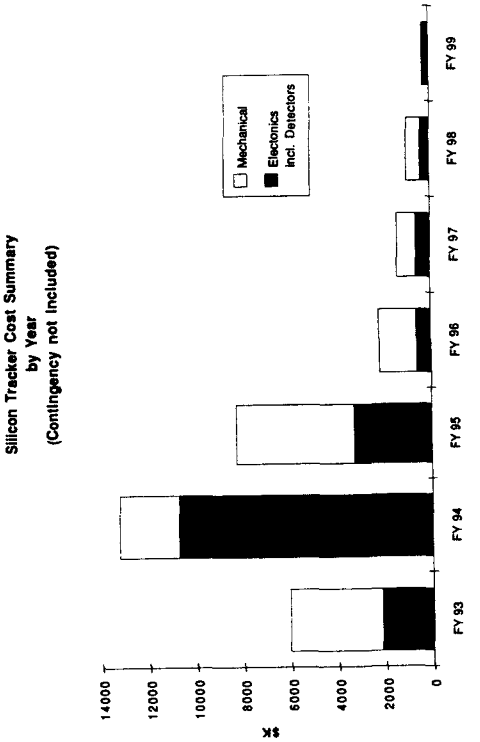

02642

STRAW-TUBE TRACKER

R. SWENSRUD

SDC MODULAR STRAW OUTER TRACKER

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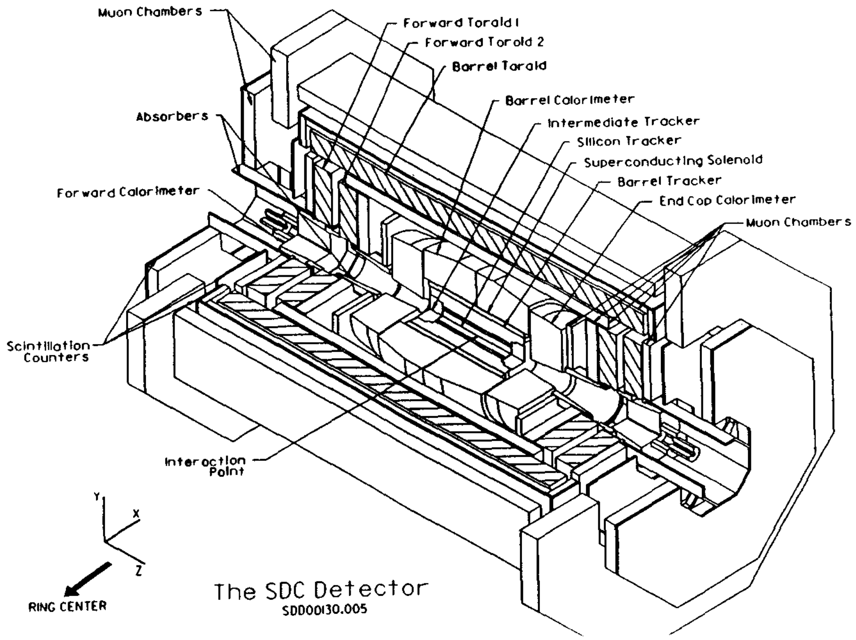
SDC OUTER STRAW TRACKER
FOR THE SSCL

PAC COST & SCHEDULE REVIEW
AT SSCL
MAY 07 1992

WESTINGHOUSE ELECTRIC CORPORATION
(W)STC
PITTSBURGH, PA

R.L.SWENSRUD (ROGER)



The SDC Detector

SDD00130.005

SDC MODULAR STRAW OUTER TRACKER

INTRODUCTION

This set of viewgraphs presents a short summary of the cost and schedule for the modular straw outer tracker for the SDC detector for the SSCL.

SDC MODULAR STRAW OUTER TRACKER

2. WBS FOR THE OUTER TRACKER

This WBS Major Element Summary is taken from the Complete WBS (316 line to level 9) used for Cost and Schedule work.

HIGH LEVEL ELEMENTS:

1.2	Central Tracker
1.2.1	Modules
1.2.2	Support Structure
1.2.3	Cylinder into Superlayer Assembly
1.2.4	Modules into Support Structure
1.2.5	Equipment, Tooling, & Fixtures
1.2.6	Final Surface Facility Assembly
1.2.7	Final Surface Facility Testing
1.2.8	"Reserved" Tracker Transportation
1.2.9	Drift Gas System
1.2.10	Facilities
1.2.11	Program Management
1.2.12	R & D Effort

Viewgraph 5
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SDC MODULAR STRAW OUTER TRACKER

1. OUTER TRACKER OVERVIEW

THE MAIN COMPONENTS ARE:

1) The Detector Elements
   - o Five Superlayers of 720 Straw Containing Modules
   - o Modules 292 Stereo @ 159 Straws Each & 428 Trigger @ 212 Each or 137,164 Total
2) The Support System
   - o Two Spaceframes
   - o Five support Cylinders
3) Methodology
   - o Modular Shell Aligns the Straws.
   - o Support Structure Aligns the Modules

Viewgraph 4
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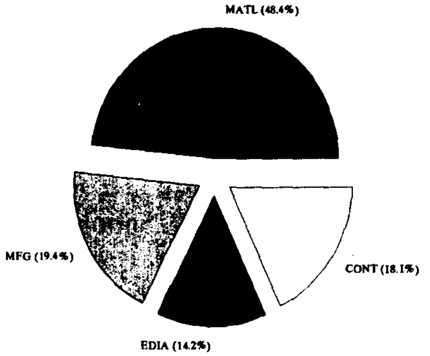
SDC OUTER TRACKER

COST CONTENT PERCENTAGE BREAKDOWN



BASE COST + CONTINGENCY IS $31.5 MILLION

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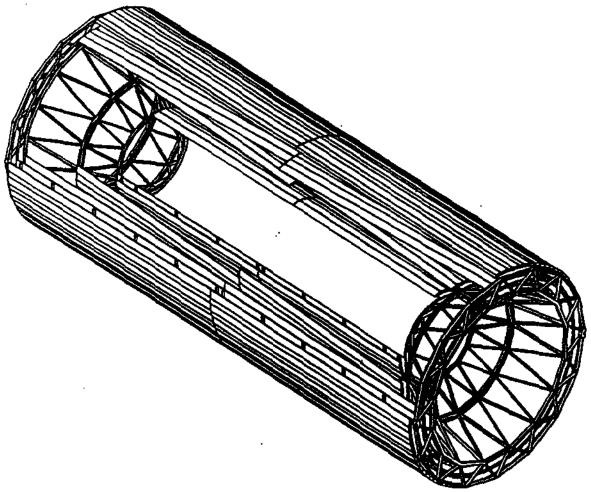
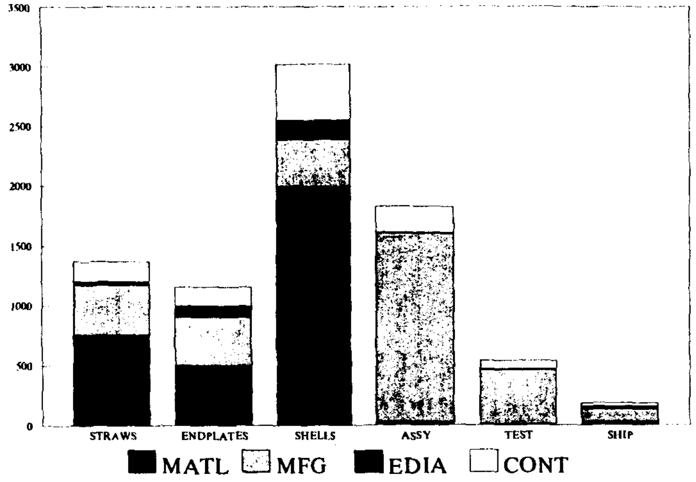


Figure 1.2 — Outer tracking detector.

SDC OUTER TRACKER (K$)

WBS 1.2.1.1 TRIGGER & WBS 1.2.1.2 STEREO MODULES



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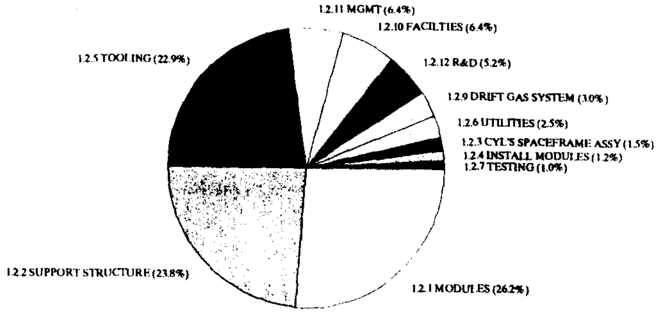
SDC OUTER TRACKER

COST CONTENT PERCENT WBS 1.2.1 THRU 1.2.12



BASE COST + CONTINGENCY IS $31.5 MILLION

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SDC MODULAR STRAW OUTER TRACKER

2.3a WBS 1.2.1.1 & 2 MODULES

COST DRIVERS

STRAWS ASSEMBLIES:	**QUOTES**	
	Wire	**$58K**
	Wire Supports	**$274K**
	Metalized Wrapper	**$343K**
	Winding	**$69K**
	Bal (Estimates & Travel)	**$8K**
MODULE SHELLS:	**QUOTES**	
	Trigger Shells	**$1,113K**
	Stereo Shells	**$759K**
	Bal (Estimates & Travel)	**$117K**

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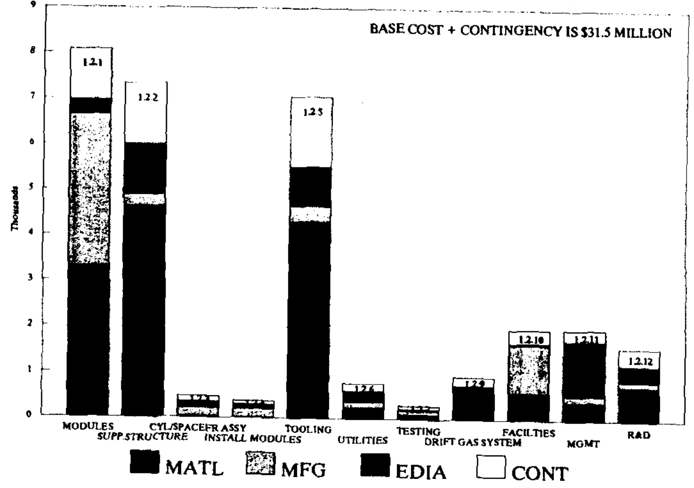
SDC OUTER TRACKER (K$)

COST CONTENT BY WBS 1.2.1 THRU 1.2.12



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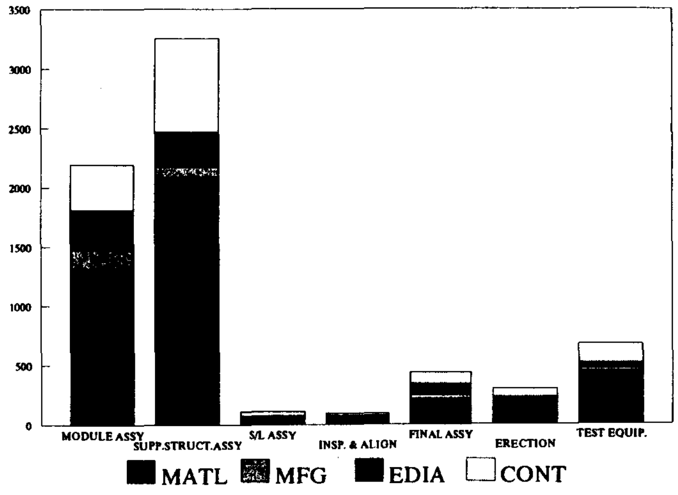
SDC OUTER TRACKER (K$)

WBS 1.2.5 TOOLING



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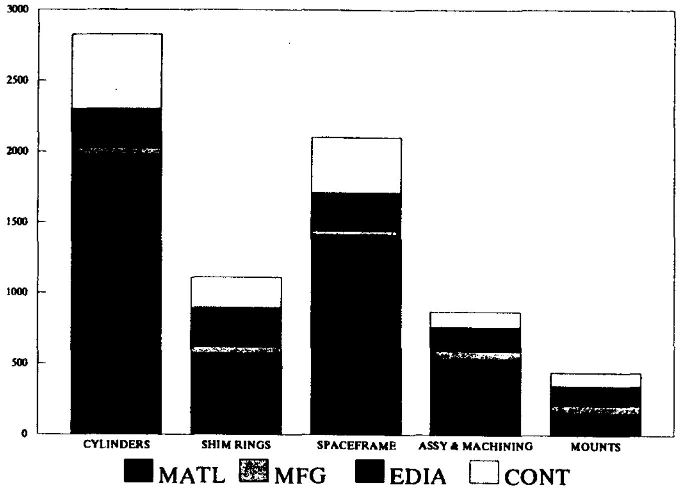
SDC OUTER TRACKER (K$)

WBS 1.2.2 SUPPORT STRUCTURE



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SDC MODULAR STRAW OUTER TRACKER

2.3c WBS 1.2.5 TOOLING

COST DRIVERS

SHELL MOLDS:	QUOTED		
		1 Stereo	$58K
		4 Trigger	$346K
MANDRELS:	QUOTED		
		5 Steel Mandrels	$1,208K
		Shipping	$39K
	Bal (Estimates & Travel)		$5K
MACHINE STATION:	ENGINEERING ESTIMATE		
		1 Machine 3 Axes	$630K
	Bal (Estimate & Travel)		$8K
BALANCE:	ENGINEERING ESTIMATES		$2,001K

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SDC MODULAR STRAW OUTER TRACKER

2.3b WBS 1.2.2 SUPPORT STRUCTURE

COST DRIVERS

CYLINDERS:	QUOTES		
		5 Cylinders	$1,890K
		Shipping	$65K
	Bal (Estimates & Travel)		$16K
SHIM RINGS:	QUOTES		
		5 Sets Shim Rings	$550K
	Bal (Estimates & Travel)		$16K
SPACEFRAMES:	QUOTED		
		2 Spaceframes	$1,385K
		Shipping	$7K
	Bal (Estimates & Travel)		$14K

Viewgraph 7
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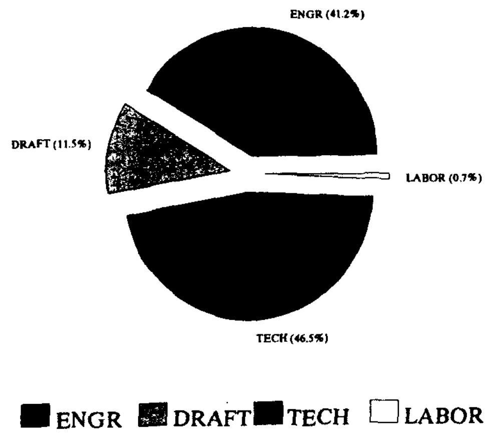
SDC OUTER TRACKER

MANPOWER PERCENT BREAKDOWN

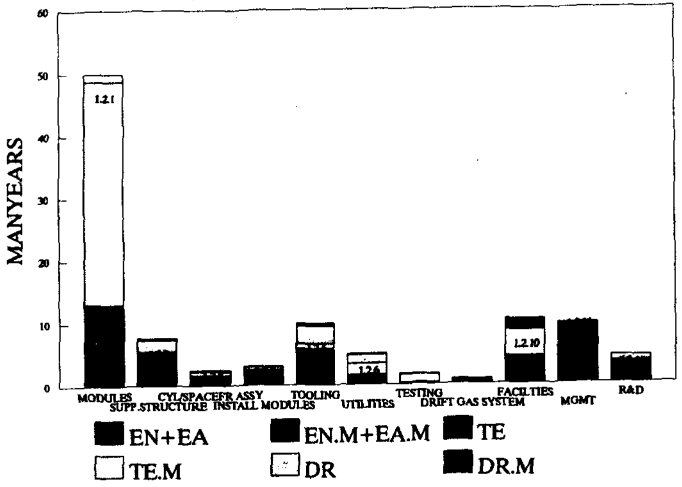


Westinghouse Electric Corporation – STC

VG NO.7

SDC OUTER TRACKER

MANPOWER BY WBS 1.2.1 THRU 1.2.12



Westinghouse Electric Corporation – STC

VG NO.9

SDC MODULAR STRAW OUTER TRACKER

2.3d WBS 1.2.12 R & D EFFORT

COST DRIVERS - MATERIALS ONLY

CYLINDER PROTOTYPE:	$ 108K
MODULE PROTOTYPE:	$ 208K
MODULE INTERFACE PROTOTYPE:	$ 88K
SUPPORT SPACEFRAME PROTOTYPE:	$ 88K
SUPPORT PROTOTYPE:	$ 51K
BEAM TEST PROTOTYPE SECTOR:	$ 193K
TOTAL	$ 736K

Viewgraph 9
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SDC MODULAR STRAW OUTER TRACKER

3. SUMMARY OF MANPOWER NEEDS - MANYEARS

EDIA:		MANUFACTURING;	
Engineer	21.38	Engineer	8.24
Engineer Associate	2.18	Engineer Associate	11.65
Drafting	9.34	Drafting	2.82
Technician	4.26	Technician	44.76
Labor	0.00	Labor	0.76
Subtotal	37.16	Subtotal	68.23
Total	105.4 MANYEARS		

Note: Labor Rates Used are University, Laboratory, and Industrial.

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SDC MODULAR STRAW OUTER TRACKER

3.2 MANPOWER NEEDS BY ELEMENT 1.2.1 THRU 1.2.12

COST DRIVERS

- **MANAGEMENT WBS 1.2.11**
  - **Project Engineer - EN.**
    - 1670 MD's at 6.2 Year Project Duration is One Man Full Time.
  - **Safety and Quality Engineering**
    - 344 MD's at 6.2 Year Project Duration is One Man One Fifth Time.
- **FACILITIES WBS 1.2.10 MODULE AND SUPPORT STRUCTURE**
  - **Facility Supervision - EN.M**
    - 1000 MD's at 3.5 Yrs at 2 Facilities Averages 143 MD per Year or Half Time.
  - **Project Assistant - TE.M**
    - 1000 Mandays Also is Half Time
  - **Drafting - DR.M**
    - 400 MD's at 3.5 Yrs at 2 Facilities Averages 57 MD per Year or One Fifth Time.

SDC MODULAR STRAW OUTER TRACKER

3.2 MANPOWER NEEDS BY ELEMENT 1.2.1 THRU 1.2.12

COST DRIVERS

- **MODULES WBS 1.2.1**
  - **Assembly Technician - TE.M**
    - 8560 Mandays at 720 Modules is 11.9 Mandays per Module
  - **Assembly Testing and Supervision - EN.M+EA.M**
    - 2655 Mandays at 720 Modules is 3.7 Mandays per Module
  - **Balance - EN .M+EA.M**
    - 463 Mandays EN and 308 Mandays DR

SDC MODULAR STRAW OUTER TRACKER

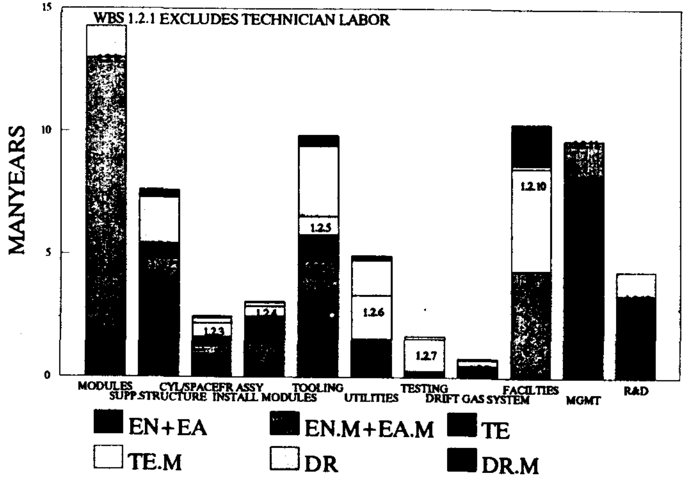
4. SCHEDULE SUMMARY FOR THE OUTER TRACKER

The WBS Schedule and Milestone Summary Presented is developed from the Complete WBS (316 line to level 9) Schedule used to Design, Procure, and Assemble the Outer Tracker.

Task	Summary Durations: Years
Design & Procure Components	3.5
Assemble and Test at SSCL	2.1
Install and Test	0.6
Total	6.2

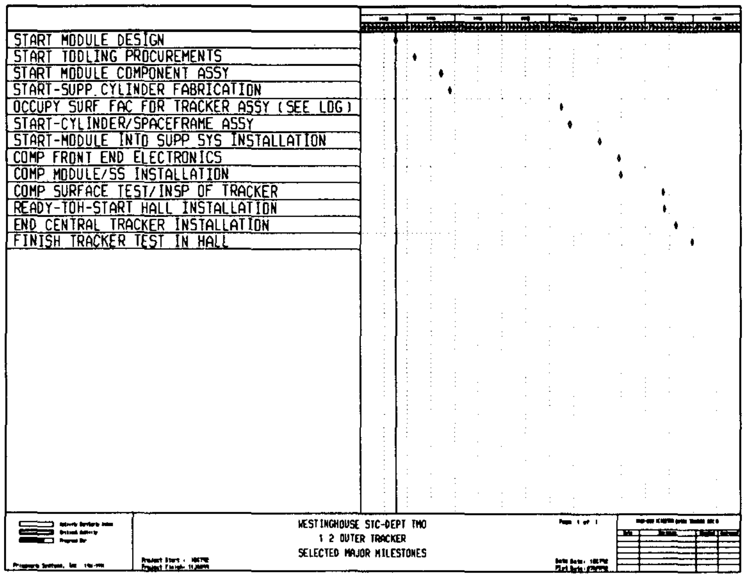
SDC OUTER TRACKER

MANPOWER BY WBS 1.2.1 THRU 1.2.12



* 1.2.1 EXCLUDES TECHNICIAN TIME

SDC OUTER TRACKER



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GAS MICROSTRIPS

G. OAKHAM

G. Oakham
7th May 1992

Intermediate Track Detector
Cost Estimate

What is being costed:-

a) Location of ITD in the SDC Detector

b) Basic detector element of ITD; a microstrip tile

c) Engineering sketch of support structure

Costing Method

Detector will be built in Canada and the U.K. *but* for the SDC cost estimate we have used:-

a) Standard methods based on SSCL costing procedure

b) U.S labour rates

c) SSCL methods for estimating contingency

The costing is based on an Engineering estimate of the components of the system.

ITD Cost Summary table

Category	Cost k$	Cont. k$	Cost+cont k$
Microstrip chamber modules	5345	2837	8182
Front End electronics	714	301	1015
Mechanical Engineering	2625	980	3605
Detector Design	750	210	960
Miscellaneous	1840	490	2330
TOTAL COST	**11274**	**4917**	**16092**

ITD COST DRIVERS

"Base" Cost ; Design, support etc	$6631k
Layer Mechanical cost $25k per layer 24 Layers	$ 600k
Microstrip tile cost $2.84k per tile 3120 tiles	$ 8861k
Total	**$16092k**

G.M.D Tile Cost summary

Category	Cost k$	Contingency k$
Fixed Costs; Infrastructure, Jigs and Fixtures, Masks	453	182
Developement of technique for tile assembly	90	36
Costs of detector tile production (Includes assembly and testing)	918	323
Costs of detector tiles:-		
Microstrip plates 3300 @$600	1980	1550
Frame & backing 3200 @$300	960	384
HV supply board 3200 @$75	240	80
Preamp/FE board 3200 @$150	480	192
Wire bonding 3200 @$70	224	90
(Total unit cost per tile = $1195)		
Total cost of microstrip modules	5345	2837

TOTAL **Cost + Contingency = $ 8182k**

I.T.D. Milestones

Jun 93	Fix Final Geometry
Dec 93	Complete R&D of Detector Tiles
Jun 94	Freeze Detector Design
Aug 94	Freeze Tile Design
Dec 94	Complete Tests with Large Scale Prototype
Mar 97	Complete Tile Manufacture
Dec 97	Detector Complete
Aug 98	Detector Assembled and Tested
Sep 98	Transport to SSCL
Feb 99	Complete Installation

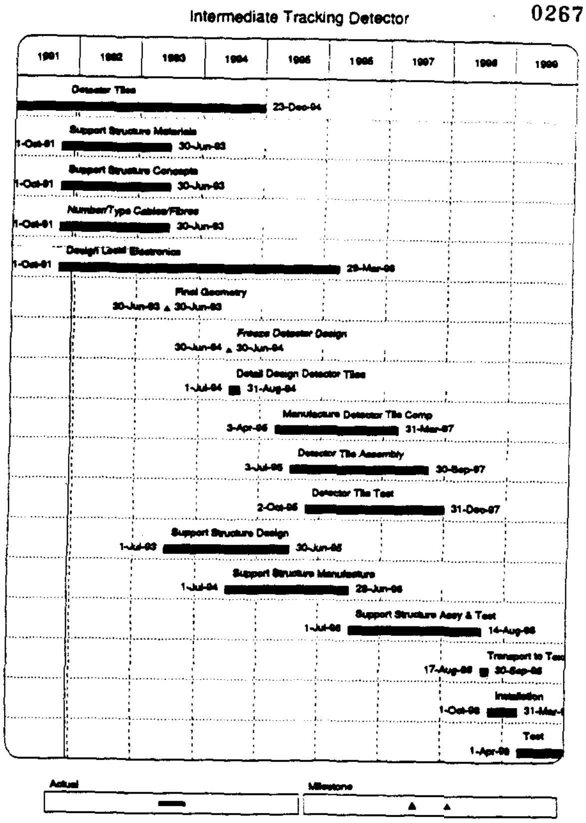


Figure 34

	A	B	C	D	E	F	G	H	I
1	WBS NUMBER	WBS DESCRIPTION	TECHRSK	COSTRSK	SKEDRSK	TECHWT	COSTWT	SKEDWT	COMPOSITE RI
2	1.3	INTERMEDIATE ANGLE TRACKER (MICROSTRIPS)							
3	1.3.1	Gas Microstrip Detector Tiles							
4	1.3.1.1	Detector Tile Design	10	6	8	2	2	1	40
5	1.3.1.2	Masks	6	6	4	4	2	1	40
6	1.3.1.3	Microstrip Plate	10	15	8	4	2	1	78
7	1.3.1.4	Frame and Backing	6	10	8	2	2	1	40
8	1.3.1.5	HV Supply Board	4	8	8	2	2	1	32
9	1.3.1.6	Preamp/FE board	6	10	8	2	2	1	40
10	1.3.1.7	Wire Bonds	6	10	8	2	2	1	40
11	1.3.1.8	Prototype Assemblyt Jigs for Dev	6	10	8	2	2	1	40
12	1.3.1.9	Tile Assembly Jigs and Fixtures	6	10	8	2	2	1	40
13	1.3.1.10	Infrastructure for Assembly	6	10	8	2	2	1	40
14	1.3.1.11	Inspection of components	8	15	8	2	1	1	39
15	1.3.1.12	Tile Assembly	4	10	4	2	2	1	32
16	1.3.1.13	Tile Testing	6	15	8	2	1	1	35
17	1.3.2	Front End Electronics							
18	1.3.2.1	Prototype 1 (Component Development	8	8	8	2	2	1	40
19	1.3.2.2	Preamp/disc/shaper	6	8	8	4	2	1	48
20	1.3.2.3	Encoder Digital Pipeline	6	6	8	4	2	1	44
21	1.3.2.4	Data Transmission Components	6	6	8	2	2	1	32
22	1.3.3	Mechanical Engineering - Support Structure							
23	1.3.3.1	CAD Equipment (all applications)	1	15	8	2	1	1	25
24	1.3.3.2	Conceptual Design	10	15	8	2	1	1	43
25	1.3.3.3	Material Development	8	15	8	2	1	1	39
26	1.3.3.4	Detetector Design	3	15	8	2	1	1	29
27	1.3.3.5	Development of Support Structure	6	4	8	4	2	1	40
28	1.3.3.6	Development Hardware	6	4	8	4	2	1	40
29	1.3.3.7	Tile Mounting Jigs & Fixtures	6	4	8	4	2	1	40
30	1.3.3.8	Structural Layers	3	15	4	2	1	1	25
31	1.3.3.9	Structural Cones	6	4	8	4	2	1	40
32	1.3.3.10	Mounting Supports	6	4	8	4	2	1	40
33	1.3.3.11	Alignment Equipment	6	4	8	4	2	1	40
34	1.3.4	Cables	3	15	4	2	1	1	25
35	1.3.5	Gas Systems	4	15	4	2	2	1	42
36	1.3.6	Cooling Systems	4	15	4	2	2	1	42
37	1.3.7	Assembly							
38	1.3.7.1	Assemble Tiles on Layers	6	10	8	2	2	1	40
39	1.3.7.2	Assemble layers and Cones	6	10	8	2	2	1	40
40	1.3.7.3	Trial Assembly	10	10	8	2	1	1	38
41	1.3.7.4	Transportation and Packing	1	15	8	2	1	1	25
42	1.3.8	Final Installation	10	15	8	2	1	1	43
43	1.3.9	System Integration and Test	8	15	8	2	1	1	39
44	1.3.10	Project Management	1	10	8	2	1	1	20
45	1.3.11	Manufacture Control	1	15	8	2	1	1	25
46	1.3.12	Travel	1	6	8	2	1	1	16

	A	B	U	V	W	X	Y	Z
1	WBS NUMBER	WBS OR ACTIVITY DESCRIPTION	WBS MH	WBS MAT [illegible]	[illegible] (K$	CONTING %	CONTINGENCY [illegible]	TOTAL(K
3	1.3	INTERMEDIATE ANGLE TRACKER (MICROSTRIPS)						
4	1.3.1	Gas Microstrip Detector Tiles						
5	1.3.1.1	Detector Tile Design	165	0	55	40	22	77
6	1.3.1.2	Masks	0	83	83	40	33	116
7	1.3.1.3	Microstrip Plate	1790	1452	1980	78	1544	3525
8	1.3.1.4	Frame and Backing	1840	454	960	40	384	1343
9	1.3.1.5	HV Supply Board	640	54	240	32	77	316
10	1.3.1.6	Preamp/FE board	1020	192	480	40	192	672
11	1.3.1.7	Wire Bonds	724	32	224	40	90	313
12	1.3.1.8	Prototype Assemblyt Jigs for Dev	198	40	90	40	36	126
13	1.3.1.9	Tile Assembly Jigs and Fixtures	430	40	170	40	68	238
14	1.3.1.10	Infrastructure for Assembly	0	200	200	40	80	280
15	1.3.1.11	Inspection of components	420	0	128	39	50	178
16	1.3.1.12	Tile Assembly	1288	63	450	32	144	593
17	1.3.1.13	Tile Testing	896	5	285	35	100	385
18	1.3.2	Front End Electronics						
19	1.3.2.1	Prototype 1 (Component Developmer	410	36	170	40	68	239
20	1.3.2.2	Preamp/disc/shaper	410	90	224	48	107	331
21	1.3.2.3	Encoder Digital Pipeline	360	77	196	44	86	282
22	1.3.2.4	Data Transmission Components	165	64	124	32	40	163
23	1.3.3	Mechanical Engineering - Support Structure						
24	1.3.3.1	CAD Equipment (all applications)	0	200	200	25	50	250
25	1.3.3.2	Conceptual Design	300	4	110	43	47	158
26	1.3.3.3	Material Development	300	4	110	39	43	153
27	1.3.3.4	Detetector Design	1540	0	550	29	160	710
28	1.3.3.5	Development of Support Structure	448	19	150	52	78	228
29	1.3.3.6	Development Hardware	20	143	150	40	60	211
30	1.3.3.7	Tile Mounting Jigs & Fixtures	890	92	350	40	140	490
31	1.3.3.8	Structural Layers	1000	141	480	25	120	600
32	1.3.3.9	Structural Cones	860	238	500	40	200	700
33	1.3.3.10	Mounting Supports	500	46	200	40	80	280
34	1.3.3.11	Alignment Equipment	200	131	200	40	80	280
35	1.3.4	Cables	478	68	200	25	50	250
36	1.3.5	Gas Systems	220	10	70	42	30	100
37	1.3.6	Cooling Systems	232	15	70	42	30	100
38	1.3.7	Assembly						
39	1.3.7.1	Assemble Tiles on Layers	880	10	252	40	101	353
40	1.3.7.2	Assemble layers and Cones	430	4	123	40	49	172
41	1.3.7.3	Trial Assembly	1120	31	300	38	114	413
42	1.3.7.4	Transportation and Packing	60	6	20	25	5	25
43	1.3.8	Final Installation	280	29	84	43	36	120
44	1.3.9	System Integration and Test	80	7	36	39	14	50
45	1.3.10	Project Management	1120	62	550	20	110	660
46	1.3.11	Manufacture Control	448	25	220	25	55	275
47	1.3.12	Travel	0	290	290	16	46	336
48								
49	TOTALS		22074	4457	11274	0.43	4818	16092

Table 1
Intermediate-angle Track Detector Cost Summary

Category	Cost k$	Cont. k$	Cost+Cont. k$
Micro-strip chamber modules	5345	2837	8182
Front End electronics	714	301	1015
Mechanical Engineering	2625	980	3605
Detector design	750	210	960
Miscellaneous	1840	490	2330
TOTAL COST	11274	4917	16092

Table 2
Intermediate-angle Track Detector Cost Summary
Gas Microstrip Detector Tiles

Category	Cost k$	Contingency k$
Fixed costs:		
Masks including secondary, 36 at $2300	83	32
Jigs and fixtures needed for assembly	170	70
Infrastructure for assembly (Clean rooms, microscopes)	200	80
Development of technique for tile assembly:		
Hardware	40	16
Labour = 0.7 year (tech)	50	20
Costs of Detector tile production:		
Design of detector tile 0.5 year (engr)	55	23
Inspection of components 1.7 years (tech)	128	50
Assembly of tiles 6 yrs (tech)	450	150
Testing of tiles 3.8 (tech)	285	100
Baseline design 3120 tiles - max 10" x 8"		
Microstrip plate, 3300 at $600 (Includes substrate, metal coating, etching, and inspection to verify the lithography)	1980	1550
Frame and backing, 3200 at $300 (Backing plate, gas tight frame, drift plane)	960	384
HV supply board, 3200 at $75	240	80
Preamp/FE board, 3200 at $150	480	192
Wire bonding, 3200 at $70	224	90
Total unit cost per tile = $1195		
TOTAL cost of micro-strip chamber modules	5345	2837

Table 3
Intermediate-angle Track Detector Cost Summary
Front End Electronics

Category	Cost k$	Contingency k$
Fixed costs:		
Component development costs	170	70
Local electronics development		
Component costs:		
Preamp/disc/shaper		
Encoder/digital pipeline		
Data transmission		
total component costs	544	231
TOTAL FE electronics	714	301

Table 4
Intermediate-angle Track Detector Cost Summary
Detector Design

Category	Cost k$	Contingency k$
5 years engineering time	550	160
Infrastructure, CAD equipment	200	50
TOTAL Detector Design	750	210

Table 5
Intermediate-angle Track Detector Cost Summary
Mechanical Engineering

Category	Cost k$	Contingency k$
Conceptual design and material development:		
2 years (engineer)	220	90
Final detector hardware:		
Structural layers 24 at 20k	480	120
Structural cones 2 at 250k	500	200
Mounting supports	200	80
Alignment	200	80
Jigs/fixtures and handling for mounting tiles into layers	350	140
Development hardware	150	60
Manpower:		
Development of support structure (2 years-tech)	150	60
Assembly - putting tiles on layers, assemble layers and cones, labour for alignment (5 years-tech)	375	150
TOTAL Mech Engineering	2625	980

Table 6
Intermediate-angle Track Detector Cost Summary
Labour, Travel, and Miscellaneous Costs:

Category	Cost k$	Contingency k$
Manufacturing control, 2 years (engr)	220	55
Project management, 5 years (engr)	550	110
Travel* for engineering coordination:		
UK/Canada, 16 trips/yr × 5 yrs × $2K = $160K		
Manufacturer/supplier visits –		
Structure 20 trips × $0.8K = $16K		
Tiles 40 trips × $0.8K = $32K		
SDC coord, 6 trips/yr × 5 yrs × $1.5K = $45K		
Installation prep, 6 trips × $2K = $12K		
Installation, 6 trips × $4K = $24K		
Total Travel	290	50
Trial Assembly:		
Hardware	30	10
Labour (9 months to 3 years) (mix of skills)	270	100
Final installation and test:		
Hardware	30	10
Transport and packing	20	5
Labour (3 months to 1 year) (mix of skills)	90	40
Physical Plant:		
Cables	200	50
Gas pipes	70	30
Cooling	70	30
TOTAL labour, travel, and miscellaneous	1840	490

* Since the ITD group plans to assemble the detector outside of the U.S. then ship it to the SSC Laboratory for installation, travel is listed explicitly.

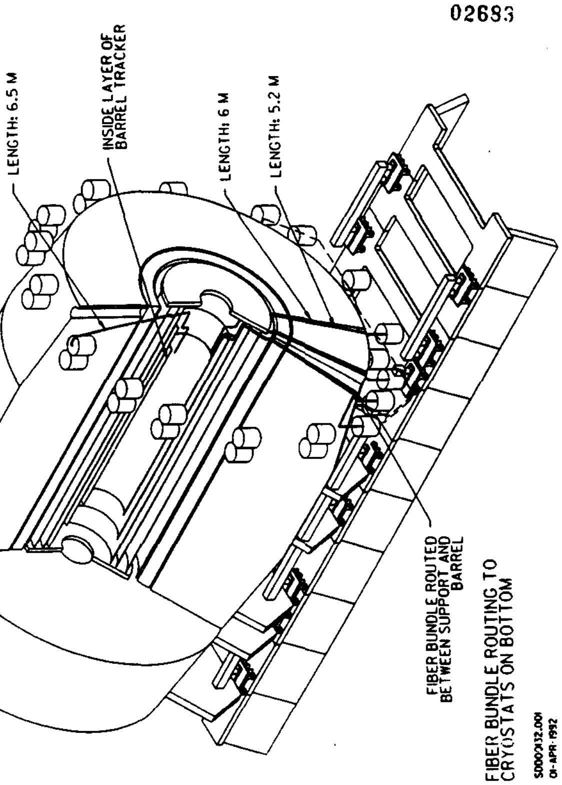
FIBER OPTION

D. DAVIS

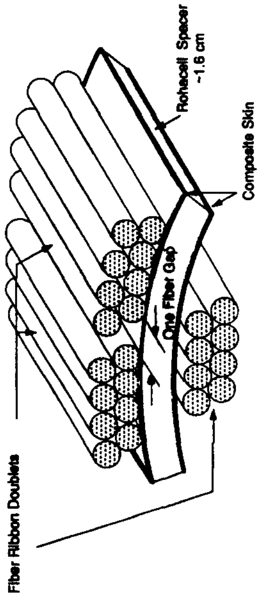
SCINTILLATING FIBER TRACKER

COST AND SCHEDULE OVERVIEW

Dale M. Davis
Oak Ridge National Laboratory



SCINTILLATING FIBERS



SCINTILLATING FIBER TRACKER

COST SUMMARY

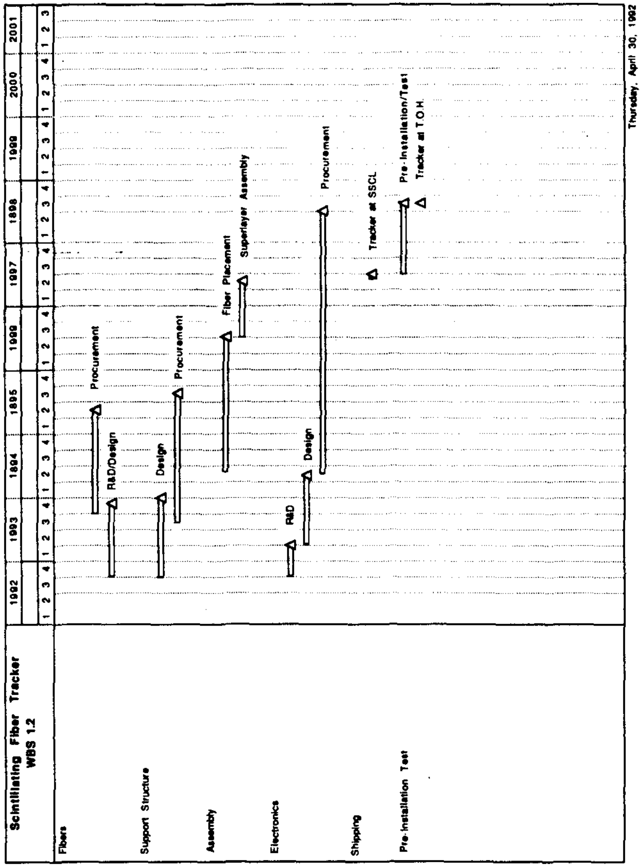
Support Structure	5.6 M
Fibers/Ribbons	6.6 M
Electronics	12.2 M
Assembly/Test/Shipping	4.0 M
Project management	3.0 M
Contingency	9.5 M

	40.9 M

SCINTILLATING FIBER TRACKER

COST DRIVERS

Tooling	
Fibers/Ribbons	2.4 M
Support Structure	2.5 M
Assembly	.4 M
Electronics	12.2 M
Fiber	4.2 M



SCINTILLATING FIBER TRACKER

SCHEDULE DRIVERS

Ribbon Fabrication

Cylinder Fabrication

Superlayer Fabrication and Assembly

SCINTILLATING FIBER TRACKER

KEY MILESTONES

Begin Cylinder Production	July '93
Begin Fiber Production	Sept. '93
Complete Assembly	May '97
Tracker at SSCL	June '97
Tracker at Top of Hole	August '98

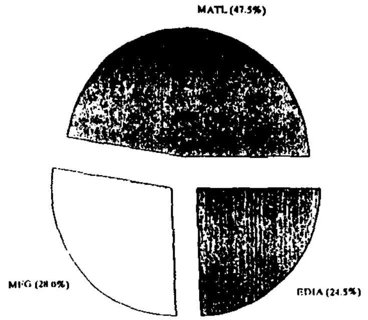
02690

CENTRAL CALORIMETRY

D. SCHERBARTH

SDC CENTRAL CALORIMETER

BASE COST PERCENTAGE BREAKDOWN



CONTINGENCY IS 29 % OF BASE COST

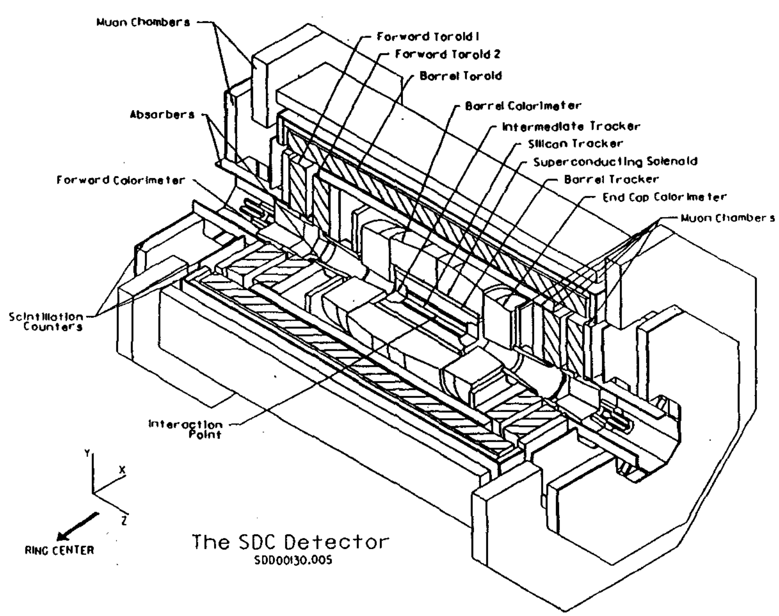
BASE COST IS $116 MILLION

BASE COST + CONTINGENCY IS $150 MILLION

▨ MATL ☐ MFG ■ EDIA

Westinghouse – STC VG NO.3

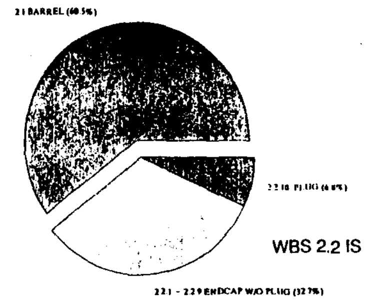
0269C



0269A

SDC CENTRAL CALORIMETER

COST CONTENT BY MAJOR COMPONENT



WBS 2.2 IS 39.5 %

TOTAL COST IS $150 MILLION

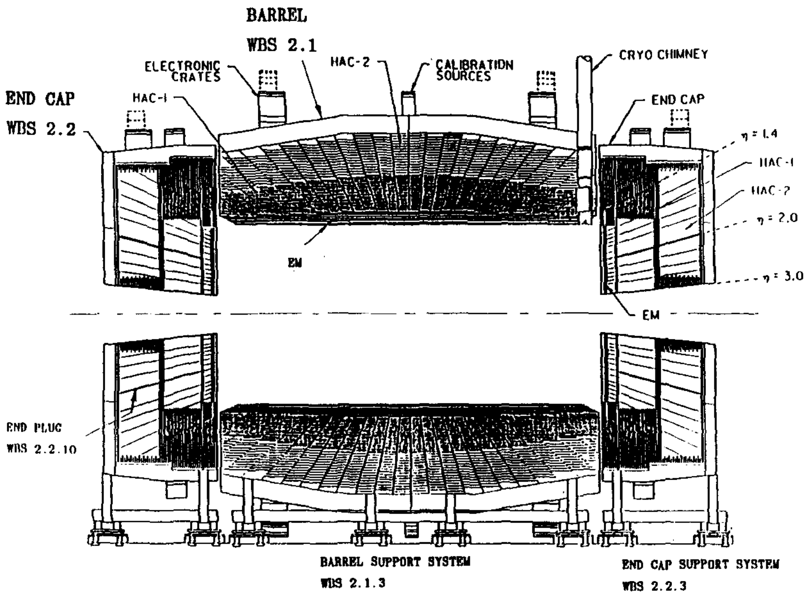
■ BARREL ▨ ENDCAP W/O PLUG

■ PLUG

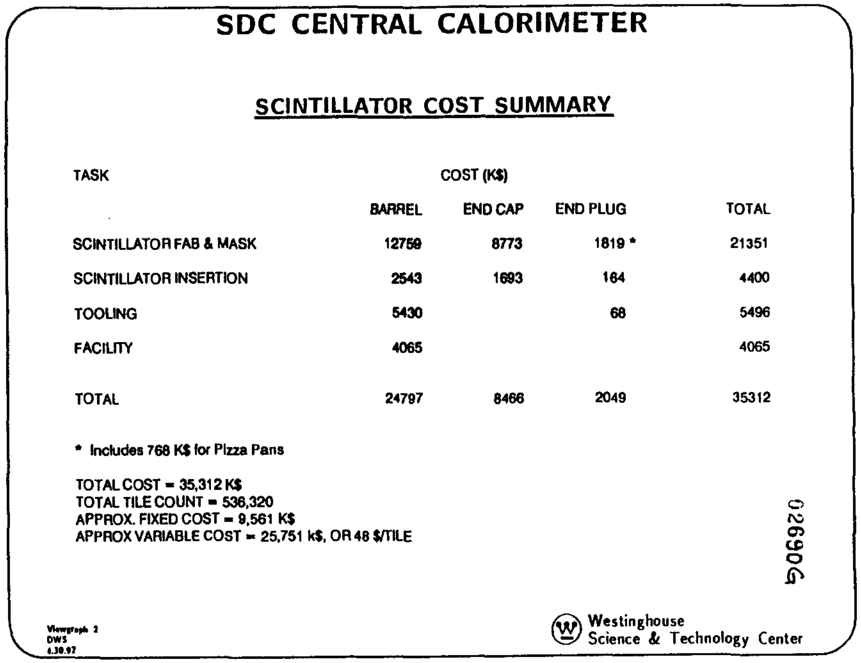
Westinghouse – STC VG NO.1

0269D

CENTRAL CALORIMETER - MAJOR COMPONENTS



0269B



SDC CENTRAL CALORIMETER

SCINTILLATOR COST SUMMARY

TASK	COST (K$)			
	BARREL	END CAP	END PLUG	TOTAL
SCINTILLATOR FAB & MASK	12759	8773	1819 *	21351
SCINTILLATOR INSERTION	2543	1693	164	4400
TOOLING	5430		68	5496
FACILITY	4065			4065
TOTAL	24797	8466	2049	35312

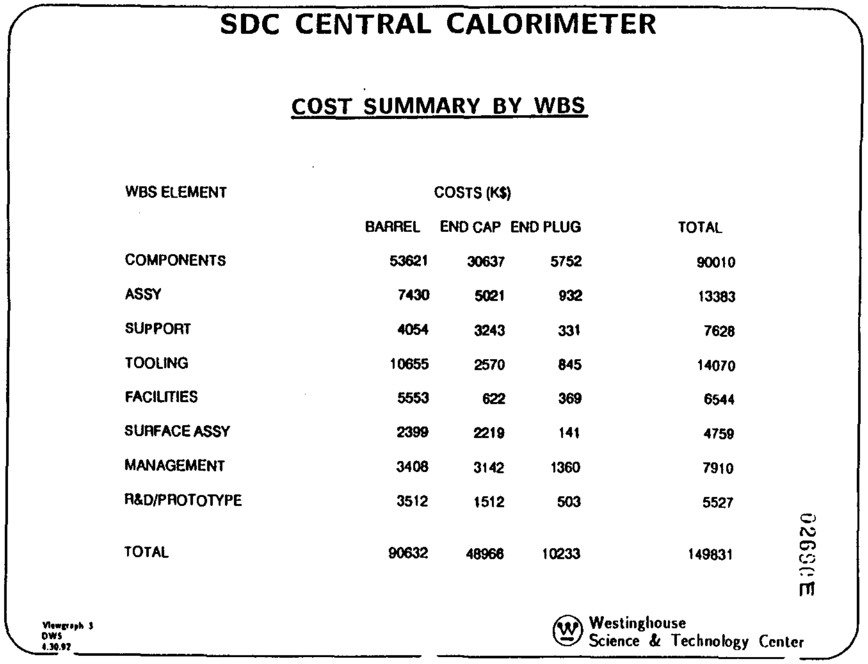
* Includes 768 K$ for Pizza Pans

TOTAL COST = 35,312 K$
TOTAL TILE COUNT = 536,320
APPROX. FIXED COST = 9,561 K$
APPROX VARIABLE COST = 25,751 k$, OR 48 $/TILE

02690G

Viewgraph 2
DWS
4.30.92

Westinghouse
Science & Technology Center



SDC CENTRAL CALORIMETER

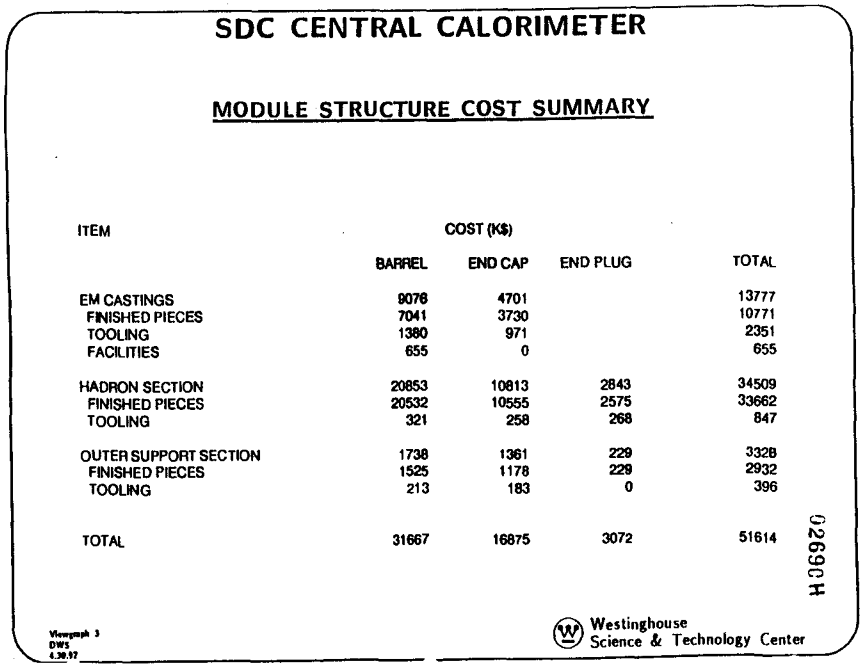
COST SUMMARY BY WBS

WBS ELEMENT	COSTS (K$)			
	BARREL	END CAP	END PLUG	TOTAL
COMPONENTS	53621	30637	5752	90010
ASSY	7430	5021	932	13383
SUPPORT	4054	3243	331	7628
TOOLING	10655	2570	845	14070
FACILITIES	5553	622	369	6544
SURFACE ASSY	2399	2219	141	4759
MANAGEMENT	3408	3142	1360	7910
R&D/PROTOTYPE	3512	1512	503	5527
TOTAL	90632	48966	10233	149831

02690E

Viewgraph 3
DWS
4.30.92

Westinghouse
Science & Technology Center



SDC CENTRAL CALORIMETER

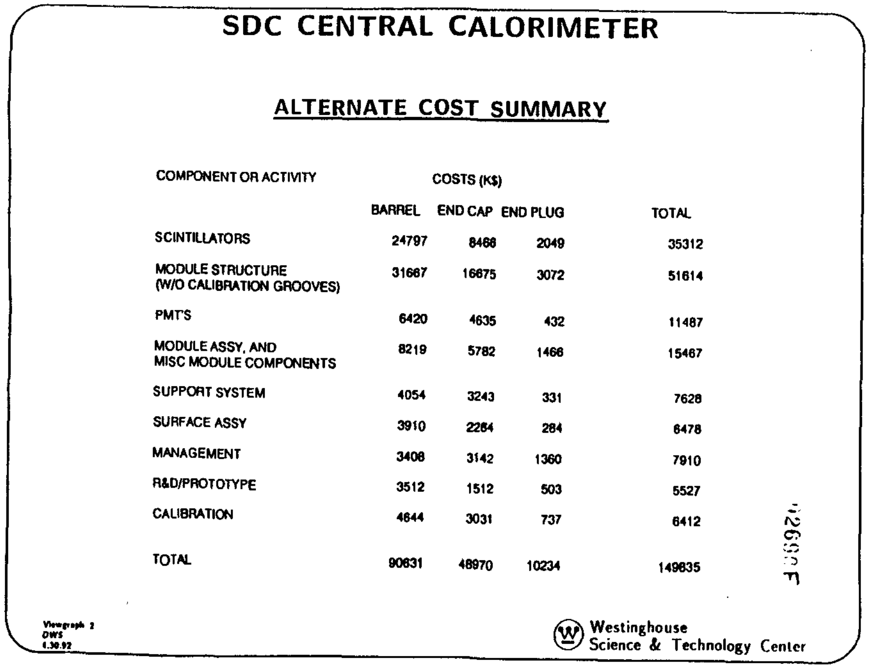
MODULE STRUCTURE COST SUMMARY

ITEM	COST (K$)			
	BARREL	END CAP	END PLUG	TOTAL
EM CASTINGS	9076	4701		13777
FINISHED PIECES	7041	3730		10771
TOOLING	1380	971		2351
FACILITIES	655	0		655
HADRON SECTION	20853	10813	2843	34509
FINISHED PIECES	20532	10555	2575	33662
TOOLING	321	258	268	847
OUTER SUPPORT SECTION	1738	1361	229	3328
FINISHED PIECES	1525	1178	229	2932
TOOLING	213	183	0	396
TOTAL	31667	16875	3072	51614

02690H

Viewgraph 3
DWS
4.30.92

Westinghouse
Science & Technology Center



SDC CENTRAL CALORIMETER

ALTERNATE COST SUMMARY

COMPONENT OR ACTIVITY	COSTS (K$)			
	BARREL	END CAP	END PLUG	TOTAL
SCINTILLATORS	24797	8466	2049	35312
MODULE STRUCTURE (W/O CALIBRATION GROOVES)	31667	16675	3072	51614
PMT'S	6420	4635	432	11487
MODULE ASSY, AND MISC MODULE COMPONENTS	8219	5782	1466	15467
SUPPORT SYSTEM	4054	3243	331	7628
SURFACE ASSY	3910	2284	284	6478
MANAGEMENT	3408	3142	1360	7910
R&D/PROTOTYPE	3512	1512	503	5527
CALIBRATION	4644	3031	737	6412
TOTAL	90631	48970	10234	149835

02690F

Viewgraph 2
DWS
4.30.92

Westinghouse
Science & Technology Center

SDC CENTRAL CALORIMETER

CALIBRATION COST SUMMARY

Component or Activity	Cost (K$)	Quantity	Unit Cost ($)
Tubes	1,568	36,352	43
Hadron Grooves	2,136	18,688	114
Permanent Source Drives	942	36	26,000
Portable Source Drives & Support Electronics	254	3	85,000
Test	3,512		
Total Cost	8,412		

0269CK

Viewgraph 7
DWS
4.30.92

Westinghouse
Science & Technology Center

SDC CENTRAL CALORIMETER

HADRON STEEL COST SUMMARY

Component	Cost (K$)	Quantity (Tonnes)	Unit Cost ($/Lb)	Basis of Estimate
Barrel Steel	20,532	1,938	4.81	Quotes
End Cap Steel	10,555	1,000	4.79	Scaled from Barrel Quotes
End Plug Steel	2,575	194	6.03	Scaled from Barrel Quotes
Total	33,662	3,132	4.87	

Costs include raw material, fabrication, assembly, EDIA, contingency. Costs do not include tooling and source tube grooves.

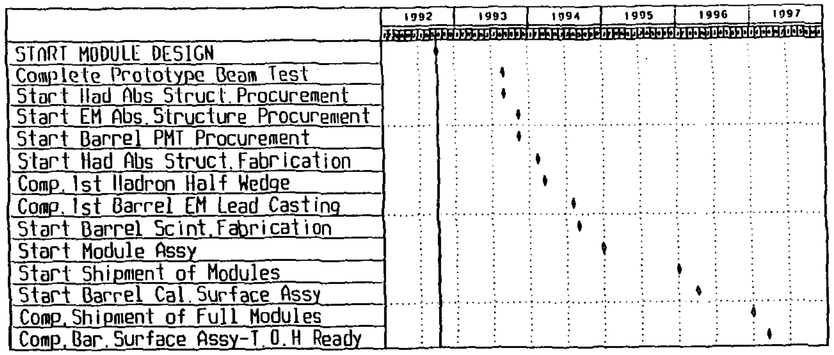
0269CH

Viewgraph 5
DWS
4.30.92

Westinghouse
Science & Technology Center

SDC CENTRAL CALORIMETER

BARREL CALORIMETER SCHEDULE HIGHLIGHTS



0269CL

Viewgraph 3
DWS
4.30.92

Westinghouse
Science & Technology Center

SDC CENTRAL CALORIMETER

PMT COST SUMMARY

Component or Activity	Cost (K$)	Quantity	Unit Cost ($)
*Single Channel PMT for EM, HAD1, HAD2	4,725	20,352	232
*64-Channel PMT for Shower Max, Massless Gap	5,418	960	5,644
PMT Drift Monitoring System	1,145	21,312	54
Tooling	199		
Total	11,487		

*Includes PMT, magnetic shields, fasteners, assembly, test, EDIA, and contingency. Does not include bases.

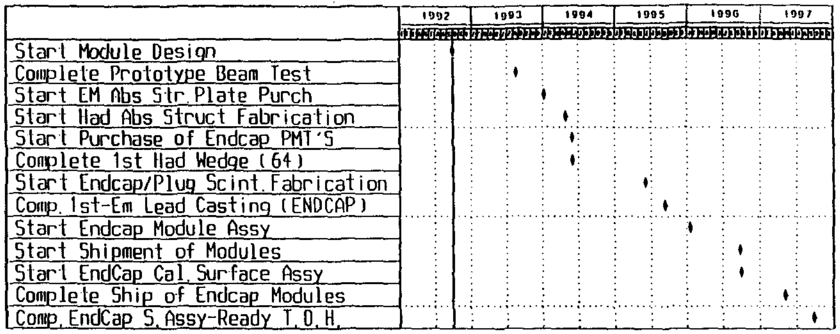
0269CJ

Viewgraph 6
DWS
4.30.92

Westinghouse
Science & Technology Center

SDC CENTRAL CALORIMETER

END CAP CALORIMETER SCHEDULE HIGHLIGHTS



Start Module Design
Complete Prototype Beam Test
Start EM Abs Str.Plate Purch
Start Had Abs Struct Fabrication
Start Purchase of Endcap PMT'S
Complete 1st Had Wedge (64)
Start Endcap/Plug Scint.Fabrication
Comp. 1st-Em Lead Casting (ENDCAP)
Start Endcap Module Assy
Start Shipment of Modules
Start EndCap Cal.Surface Assy
Complete Ship of Endcap Modules
Comp.EndCap S.Assy-Ready T.O.H.

02690M

Viewgraph 4
DWS
4.30.92

Westinghouse
Science & Technology Center

02691

FORWARD CALORIMETRY

G. STAIRS

WBS and Costing for the Liquid Scintillator FCal

SDC FCal Group, IPP Canada

presented by
Gavin Stairs, University of Toronto
Project Engineer

SSCL, May 7, 1992

LIQUID SCINTILLATOR FCal
WBS & COSTING

- STATUS SUMMARY - WBS & COSTING
- RAPID OVERVIEW OF DESIGN
- PRESENTATION OF WBS MATRIX & SUMMARY
- SOME COST CALCULATIONS
  - Quartz tubes
  - Absorber plates
  - Scintillator
  - Electronics
  - Transport
- MECHANICAL MODULE QUOTES FOR HIGH PRESSURE GAS OPTION
- DISCUSSION

Note on bias:

1. Historical – Original numbers developed with conical geometry model.
2. Method – Original numbers were conservative estimates for early funding budgets.
3. In view of 1 & 2 above, base costs ~~stated~~ herein are probably overstated, while risks and weights with respect to general model ad parameter changes are probably understated.

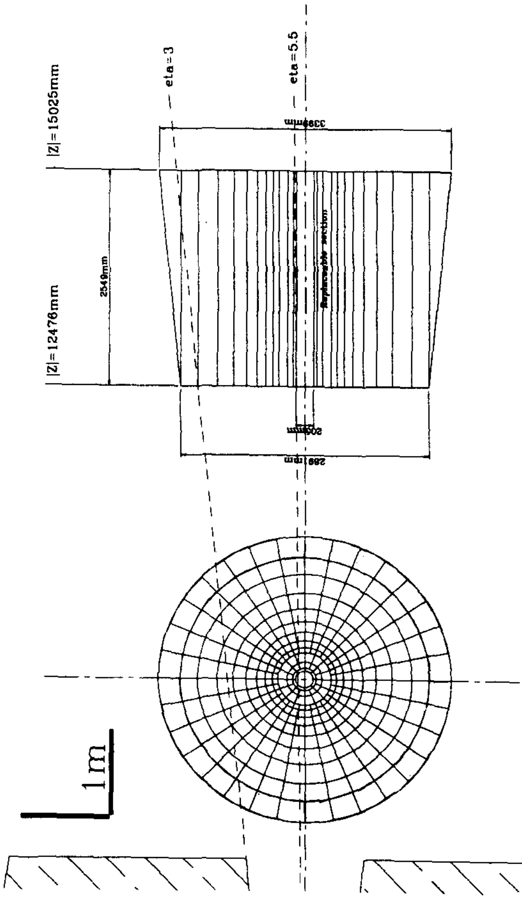
G. Stairs, U of Toronto
SSCL May 7, 1992

LIQUID SCINTILLATOR FCal
WBS & COSTING STATUS

- TECHNOLOGY, GEOMETRY, etc. NOT YET FIXED
  Many fundamental decision not yet firm:
  - projective vs paraxial.
  - scintillator solvent and fluor system
  - light transport system & PMTs.
  - repurification or replacement strategy for scintillator.

  ⋮
- CANDIDATES AVAILABLE for ABSORBER PLATE & CAPILLARY & SCINTILLATOR SYSTEMS, HOWEVER NEGOTIATIONS FOR FULL SCALE PURCHASE OR MANUFACTURE AT VERY PRELIMINARY STAGE (E.G., ESTIMATES; NO QUOTES).
- PROTOTYPES UNDER CONSTRUCTION / TEST AT SMALL SCALE (IE., E-M MODULES). MEDIUM SCALE PROTOTYPE NEXT STEP (IE., HADRONIC MODULE).
- COST MATRIX REFLECTS THIS PRELIMINARY STAGE: IE., SKELETON, WITH FEW DETAILS.
- LINE ITEM DESCRIPTIONS AND TIME DEVELOPMENT NOT YET AVAILABLE.

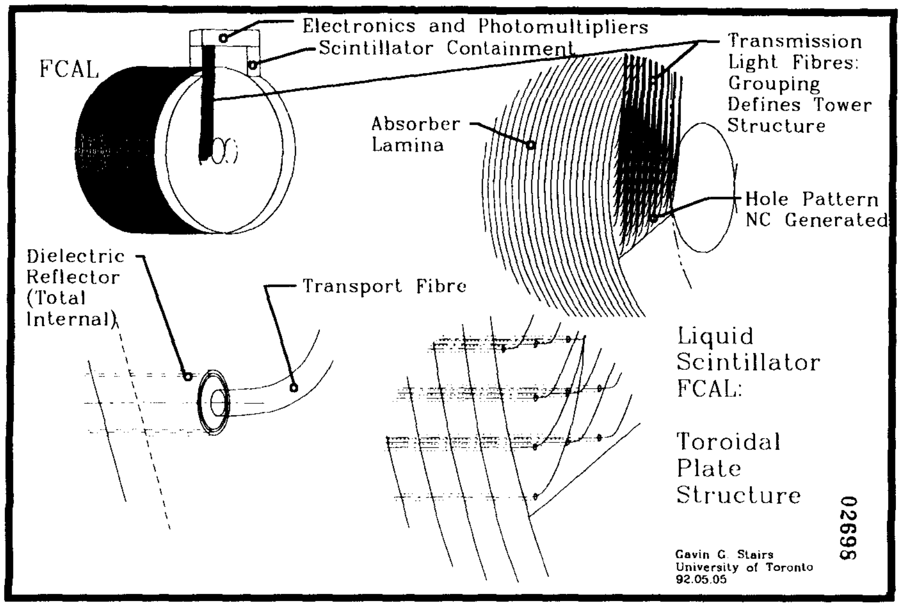
G. STAIRS, U of Tor
SSCL MAY 7, 199



Liquid Scintillator Nonprojective (Paraxial) Backstop FCal for SDC

12 Lambda, 1 Lambda lateral containment, 3<eta<5.5+, 12476mm<|Z|<15025mm

Gavin G. Stairs U of Toronto 92.05.04

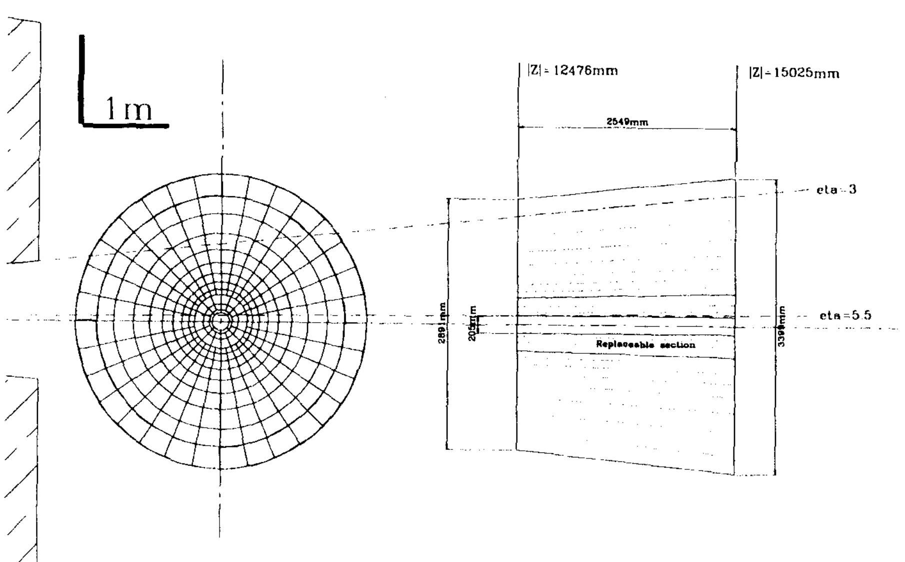


Liquid Scintillator FCAL:

Toroidal Plate Structure

Gavin G. Stairs
University of Toronto
92.05.05

02698



Liquid Scintillator Projective Backstop FCal for SDC

12 Lambda, 1 Lambda lateral containment, 3<eta<5.5+, 12476mm<|Z|<15025mm

Gavin G. Stairs U of Toronto 92 05 04

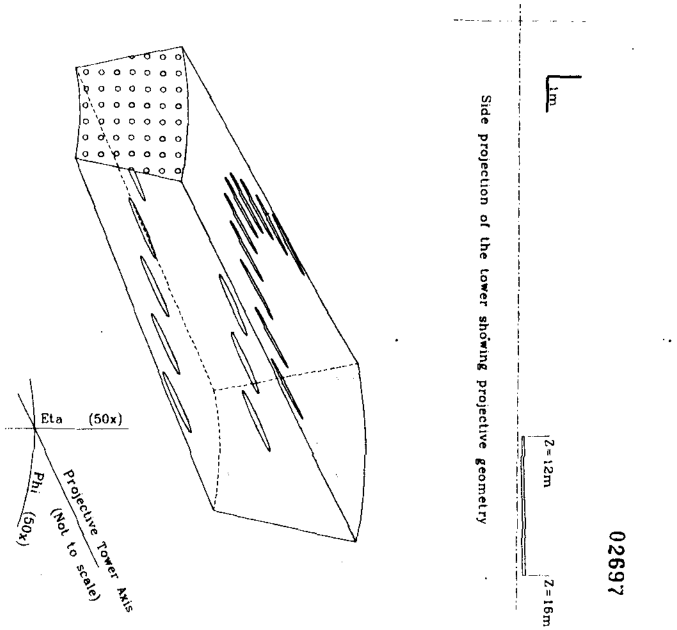
02696

WBS NUMBE	WBS OR ACTIVITY DESCRIPT	WBSBASE (K	CONTING(K	WBS TOTAL(K
2.3.	FCal	1302	5	1307
2.3.1	Design Documents	656	71	727
2.3.2	Transport	600	48	648
2.3.3	FCal North	0	0	0
2.3.4	FCal South	0	0	0
2.3.5	FCal Monitor and Slow Control	120	5	125
2.3.6	Small Scale Modules	355	61	416
				0
Ephemera				0
2.3.11	Absorber	2400	422	2822
2.3.12	Capillaries	320	67	387
2.3.13	Scintillator Subsystems	1300	374	1674
2.3.14	Light Transport Subsystems	80	42	122
2.3.15	Scintillator Containment	350	116	466
2.3.16	Electronics	1560	376	1936
		9043	1587	10630

02699

Oblique Phantom Sketch of a Tower at 4.8<eta<5.2

Showing capillary tubes which exit at the sides of the absorber block

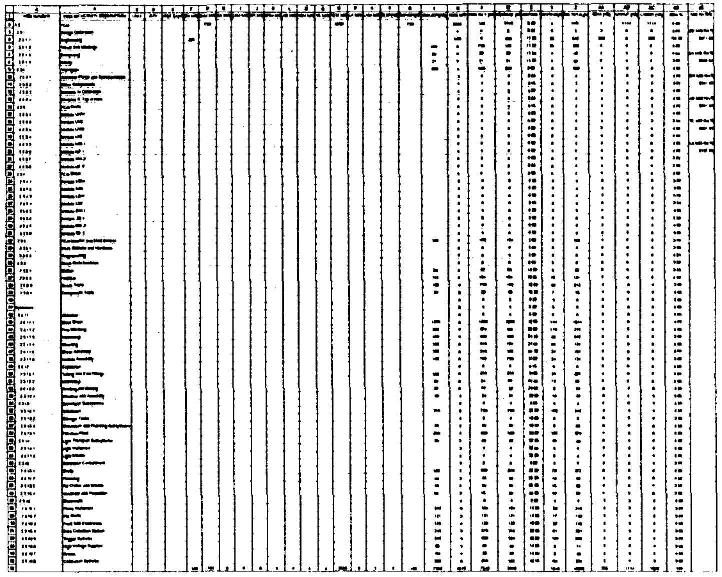


Side projection of the tower showing projective geometry

02697

WBS23_03.XLS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
40																	
41	Ephemera																
42	2.3.11	Absorber															
43	2.3.11.1	Steel Sheet															
44	2.3.11.2	Fine Blanking															
45	2.3.11.3	Machining															
46	2.3.11.4	Cleaning															
47	2.3.11.5	Sheet Assembly															
48	2.3.11.6	Module Assembly															
49	2.3.12	Capillaries															
50	2.3.12.1	Tubing and End Fittings															
51	2.3.12.2	Machining															
52	2.3.12.3	Grading and Sorting															
53	2.3.12.4	Insertion and Assembly															
54	2.3.13	Scintillator Subsystems															
55	2.3.13.1	Scintillator															
56	2.3.13.2	Storage Tanks															
57	2.3.13.3	Circulation and Plumbing Subsystems															
58	2.3.13.4	Filtration Plant															
59	2.3.14	Light Transport Subsystems															
60	2.3.14.1	Light Collectors															
61	2.3.14.2	Light Guides															
62	2.3.15	Scintillator Containment															
63	2.3.15.1	Shells															
64	2.3.15.2	Plumbing															
65	2.3.15.3	PM Crates and Shields															
66	2.3.15.4	Assembly and Inspection															
67	2.3.16	Electronics															
68	2.3.16.1	Photo Multipliers															
69	2.3.16.2	PM Bases															
70	2.3.16.3	Front End Electronics															
71	2.3.16.4	Data Collection System															
72	2.3.16.5	Trigger System															
73	2.3.16.6	High Voltage Supplies															
74	2.3.16.7	Crates															
75	2.3.16.8	Calibration Systems															
76						820	709	0	0	0	0	0	0	0	2969	0	0



WBS23_03.XLS

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1	$EXP(K$)	$MINOR(K$)	$MAJOR(K$)	WBS M/D	WBS MAT (K$)	WBSBASE (K$)	CONTING %	CONTING(K$)	WBS TOTAL(K	EDIA (K$)	MANUF (K$)	LABOR (K$)	EDIA %	MD/ RATES
3		186		3696	186	1302	0.00	5	1307	0	1114	1114	0.00	
4				0	0	0	0.00	5	5	0	0	0	0.00	ED M/D RATE
5				820	0	386	11.00	42	429	386	0	386	100.00	$471.00
6			210	0	210	210	11.00	23	233	0	0	0	0.00	
7			39	0	39	39	11.00	4	43	0	0	0	0.00	EA M/D RATE
8			21	0	21	21	11.00	2	23	0	0	0	0.00	$353.00
9			600	0	600	600	0.00	0	600	0	0	0	0.00	
10				0	0	0	8.00	0	0	0	0	0	0.00	DR M/D RATE
11				0	0	0	8.00	0	0	0	0	0	0.00	$341.00
12				0	0	0	6.00	0	0	0	0	0	0.00	
13				0	0	0	8.00	0	0	0	0	0	0.00	AD M/D RATE
14				0	0	0	0.00	0	0	0	0	0	0.00	$321.00
15				0	0	0	0.00	0	0	0	0	0	0.00	
16				0	0	0	0.00	0	0	0	0	0	0.00	TE M/D RATE
17				0	0	0	8.00	0	0	0	0	0	0.00	$261.00
18				0	0	0	0.00	0	0	0	0	0	0.00	
19				0	0	0	0.00	0	0	0	0	0	6.00	LA M/D RATE
20				0	0	0	0.00	0	0	0	0	0	0.00	$157.00
21				0	0	0	0.00	0	0	0	0	0	0.00	
22				0	0	0	0.00	0	0	0	0	0	0.00	
23				0	0	0	0.00	0	0	0	0	0	0.00	
24				0	0	0	0.00	0	0	0	0	0	0.00	
25				0	0	0	0.00	0	0	0	0	0	0.00	
26				0	0	0	0.00	0	0	0	0	0	0.00	
27				0	0	0	8.00	0	0	0	0	0	6.00	
28				0	0	0	0.00	0	0	0	0	0	0.00	
29				0	0	0	0.00	0	0	0	0	0	0.00	
30				0	0	0	0.00	0	0	0	0	0	0.00	
31				0	0	0	0.00	0	0	0	0	0	0.00	
32			120	0	120	126	5.00	6	126	0	0	0	0.00	
33				0	0	0	5.00	0	0	0	0	0	0.00	
34				0	0	0	5.00	0	0	0	0	0	0.00	
35				0	0	0	0.00	0	0	0	0	0	0.00	
36			33	0	33	33	14.00	5	38	0	0	0	0.00	
37			104	0	104	104	15.00	17	121	0	0	0	0.00	
38			180	0	180	180	18.00	32	212	0	0	0	0.00	
39			39	0	39	39	18.00	7	46	0	0	0	0.00	

WBS23_03.XLS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	WBS NUMBER	WBS OR ACTIVITY DESCRIPTION	UNIT	QTY	COST EA(K$	EN M/D	ENM M/D	EA M/D	EAM M/D	DR M/D	DRM M/D	AD M/D	ADM M/D	TE M/D	TEM M/D	LA M/D	LAM M/D
3	2.3.	FCal					709								2969		
4	2.3.1	Design Documents															
5	2.3.1.1	Engineering				820											
6	2.3.1.2	Travel and Meetings															
7	2.3.1.3	Computing															
8	2.3.1.4	Safety															
9	2.3.2	Transport															
10	2.3.2.1	Absorber Plates and Subassemblies															
11	2.3.2.2	Other Components															
12	2.3.2.3	Modules to Calibration															
13	2.3.2.4	Modules to Top of Hole															
14	2.3.3	FCal North															
15	2.3.3.1	Module UNW															
16	2.3.3.2	Module UNE															
17	2.3.3.3	Module LNW															
18	2.3.3.4	Module LNE															
19	2.3.3.5	Module NW-1															
20	2.3.3.6	Module NE-1															
21	2.3.3.7	Module NW-2															
22	2.3.3.8	Module NE-2															
23	2.3.4	FCal South															
24	2.3.4.1	Module USW															
25	2.3.4.2	Module USE															
26	2.3.4.3	Module LSW															
27	2.3.4.4	Module LSE															
28	2.3.3.5	Module SW-1															
29	2.3.3.6	Module SE-1															
30	2.3.3.7	Module SW-2															
31	2.3.3.8	Module SE-2															
32	2.3.5	FCal Monitor and Slow Control															
33	2.3.5.1	Work Stations and Hardware															
34	2.3.5.2	Programming															
35	2.3.6	Small Scale Modules															
36	2.3.6.1	EMCal															
37	2.3.6.2	HADCal															
38	2.3.6.3	Beam Tests															
39	2.3.6.4	Component Tests															

02704

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
40				0	0	0	0.00	0	0	0	0	0	0.00	
41				0	0	0	0.00	0	0	0	0	0	0.00	
42				0	0	0	0.00	0	0	0	0	0	0.00	
43			1200	0	1200	1200	12.00	144	1344	0	0	0	0.00	
44			500	0	500	500	22.00	110	610	0	0	0	0.00	
45			400	0	400	400	24.00	96	496	0	0	0	0.00	
46			100	0	100	100	24.00	24	124	0	0	0	0.00	
47			100	0	100	100	24.00	24	124	0	0	0	0.00	
48			100	0	100	100	24.00	24	124	0	0	0	0.00	
49				0	0	0	0.00	0	0	0	0	0	0.00	
50			220	0	220	220	18.00	40	260	0	0	0	0.00	
51			50	0	50	50	24.00	12	62	0	0	0	0.00	
52			20	0	20	20	24.00	5	25	0	0	0	0.00	
53			30	0	30	30	32.00	10	40	0	0	0	0.00	
54				0	0	0	0.00	0	0	0	0	0	0.00	
55			750	0	750	750	26.00	195	945	0	0	0	0.00	
56				0	0	0	18.00	0	0	0	0	0	0.00	
57			50	0	50	50	18.00	9	59	0	0	0	0.00	
58			500	0	500	500	34.00	170	670	0	0	0	0.00	
59			80	0	80	80	52.00	42	122	0	0	0	0.00	
60				0	0	0	52.00	0	0	0	0	0	0.00	
61				0	0	0	52.00	0	0	0	0	0	0.00	
62				0	0	0	0.00	0	0	0	0	0	0.00	
63			200	0	200	200	36.00	72	272	0	0	0	0.00	
64			50	0	50	50	36.00	18	68	0	0	0	0.00	
65			50	0	50	50	32.00	18	68	0	0	0	0.00	
66			50	0	50	50	20.00	10	60	0	0	0	0.00	
67				0	0	0	0.00	0	0	0	0	0	0.00	
68			184	0	184	184	14.00	26	210	0	0	0	0.00	
69			121	0	121	121	14.00	17	138	0	0	0	0.00	
70			123	0	123	123	18.00	22	145	0	0	0	0.00	
71			310	0	310	310	26.00	81	391	0	0	0	0.00	
72			500	0	500	500	26.00	130	630	0	0	0	0.00	
73			62	0	62	62	14.00	9	71	0	0	0	0.00	
74			60	0	60	60	14.00	8	68	0	0	0	0.00	
75			200	0	200	200	42.00	84	284	0	0	0	0.00	
76	0	198	7355	4518	7543	9043		1545	10586	388	1114	1500	100	

Quartz Tubing Parameters and Costs

02705

Assume a 12 nuclear interaction length backstop at 12476mm |Z|, with 5mm ID tubes on 13mm centres in a hexagonal array.

At the cost of last purchase of tubing (from John Scientific, Toronto, Canada):

Total cost = US $2.35 Million

At cost of ballpark estimate from GTE, Ipswich, NH:

Total cost = US $0.268 Million

Absorber Parameters and Costs

02706

Assume a 12 nuclear interaction length backstop at 12476mm |Z|, with 5mm ID tubes on 13mm centres in a hexagonal array, and mild steel absorber.

Total steel mass for both ends: 310 metric tons (Mg)

Canadian Fine Blanking Ltd. estimate based on 4.6mm diameter holes (for 3mm inside diameter tubing), plates 2mm thick with 100 holes per plate, standard cleaning and deburring:

US $0.30 per piece
136 g per piece
2.28 million pieces
US $0.684 million

Rough scaled estimate for 7.4mm diameter holes (for 5mm inside diameter tubing). plates 3.2mm thick with 50 holes:

US $0.40 per piece
184 g per piece
1.69 million pieces
US $0.674 million

I.e.: For a given sampling fraction, the cost is independant of hole size.

Surface finishing, thickness sizing, cleaning, square corners, etc. are additional costs.

Scintillator Parameters and Costs

02707

Assume a 12 nuclear interaction length backstop at 12476mm |Z|, with 5mm ID tubes on 13mm centres in a hexagonal array, and mild steel absorber.

Volume of scintillator inside absorber:	6514 litres
Volume of scintillator outside absorber:	1486 litres
Total Volume of scintillator (one fill):	**8000 litres**

Most recent purchase cost of IBP Scintillator, quantity 15 litres:
US $35 / litre

Cost of one fill of IBP Scintillator: **US $ 0.28 Million**

LIQUID SCINTILLATOR FCal

ELECTRONICS Parameters

Geometry:

Number of capillary tubes (both ends): 123,544
Area of exit face of tubes: 19.6 mm²/tube
2.43 m²/total
1.21 m²/end
Effective area of a 2" tube: ~ 1250 mm²

NUMBER OF TUBES TO COVER THE EXIT AREA: ~ 1000/end.
~ 2000 total.

NUMBER OF PROJECTIVE TOWERS: 296/end
592 total

NO OPTIMAL MAPPING OF TUBES → TOWERS YET
EDGE EFFECTS — 2000 → 3000 tubes
OR ACCEPT LIGHT LOSS 3000 → ~ 600 tubes.

MAJOR DECISIONS YET TO BE MADE.

IF 3000 channels of electronics, COST EST = $520/CHANNEL ALL INCLUSIVE.

ESTIMATE IS CLOSE TO UPPER BOUND

G. Stairs, U of Toronto
SSCL May 7, 1992

LIQUID SCINTILLATOR FCAL

WBS & COSTING — TRANSPORT

MAJOR AMOUNT FOR TRANSPORT OF FINISHED MODULES
- TO TEST & CALIBRATION SITE
- TO TOP OF HOLE.

EACH QUARTER MODULE ~ 38 METRIC TONS.
~ 2.8 M × 1.8 m × 2.0 m

TRANSPORT MODES AVAILABLE
- SHIP, BARGE
- RAIL
- SPECIAL FLOAT FOR ROAD TRANSPORT
  OVERSIZE, OVERWEIGHT, ESCORT, etc.

EIGHT LARGE MODULES TO SHIP, ONE OR TWO TRIPS.
ESTIMATE ALLOWANCE $30,000 - per TRIP

CONSERVATIVE — PROBABLE OVER ESTIMATE

OVERSEAS SHIPMENT OF ZEUS MODULES FROM TORONTO (MARKHAM) TO HAMBURG, ~12 TONS OVERHEIGHT STANDARD CONTAINER ~ $10,000 / SHIPMENT.

Gavin Stairs, U of Toronto
SSCL May 7, 1992

AET
Ability Engineering
Technology,

Area Code 708-331-0025
FAX 708-331-5090

16140 Vincennes Avenue, South Holland, Illinois 60473
(Rt. 6 & Vincennes)

May 4, 1992

Dr. Nikos Giokaris M/S 223 X 4390
Fermilab
P. O. Box 500
Batavia, IL 60510

REF: Quote #1645
Hadronic Detector Cell
Rockefeller University

Large quantity budgetary cost estimate of Hadronic Detector Cell - full production: 64 tubes per cell, individual detector tubes.

[redacted] STEEL TUBES

Tube	$ 9.82
Caps	2.25
Electrodes	4.85
Insulators	1.96
Extrude	9.90
Isolation & Relief	3.41
Cell Assembly	2.18
Welding	6.50
Tube Assy	5.35
Press Test	1.65
Weld Closed	1.41
Final Tests	1.95
Charging	3.75
	$ 54.98
	x 64
	$3518.72

→ $5.5 M TOTAL

Price includes labor and material, but does not include final stacking and installation at site, or transportation costs to the site.

Very truly yours,
Ability Engineering Technology

Michael W. Morgan
Michael W. Morgan
President

MWM:jb

AET
Ability Engineering
Technology,

Area Code 312 331-0025
331-0036

16140 Vincennes Avenue, South Holland, Illinois 60473
(Rt. 6 & Vincennes)

October 21, 1991

Dr. Nikos Giokaris M/S 223
Fermilab
P. O. Box 500
Batavia, IL 60510

REF: Quote #1472
Hadronic Detector Cell
Rockefeller University

Large quantity budgetary cost estimate of Hadronic Detector Cell - full production:

[redacted] STEEL TUBE SHEET AND TUBES

Tube Sheet	$ 629
Caps	144
Wires	310
Insulators	126
Punch Set	25
Laminations	634
Relief Valve	28
Valve	40
Stack Lam.	90
Install Lam. Packs	140
Welding	416
Assy	342
Press Test	105
Weld Closed	90
Final Tests	125
Charging	240
	$3484

Price includes labor and material, but does not include final stacking and installation at site, or transportation costs to the site.

Very truly yours,
Ability Engineering Technology

Michael W. Morgan
Michael W. Morgan
President

MWM:jb

SDC TRIGGER COST AND SCHEDULE

Wesley Smith
University of Wisconsin

on behalf of the SDC Collaboration

SDC Review -- May 8, 1992

SDC TRIGGER COST ASSUMPTIONS - I

1. **Cost Per Electronics Board ($):**

Parts	1,200.
Board	400.
Assembly	400.
Total	2,000.

2. **Crate Costs Each ($):**

Hardware*	2,500.
Power Supplies	2,500.
Processor	5,000.
Total	10,000.

(*more if custom backplane)

SDC TRIGGER COST ASSUMPTIONS - II

3. **Engineering Time Per Electronics Board:**

"Easy" Design	1.0 MY
"Average" Design	2.0 MY
"Hard" Design	3.0 MY

4. **Engineering Time Per ASIC Design:**

"Easy" Design	1.0 MY
"Average" Design	2.0 MY
"Hard" Design	3.0 MY

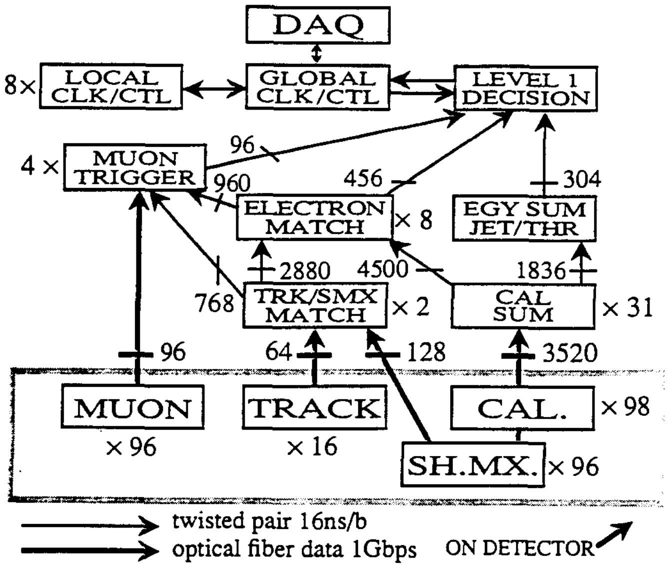
5. **Each MY of Engineering Time uses:**

Technician	1.0 MY
Travel	5.0 K$
Computing (incl. CAD)	5.0 K$
Supplies	2.5 K$

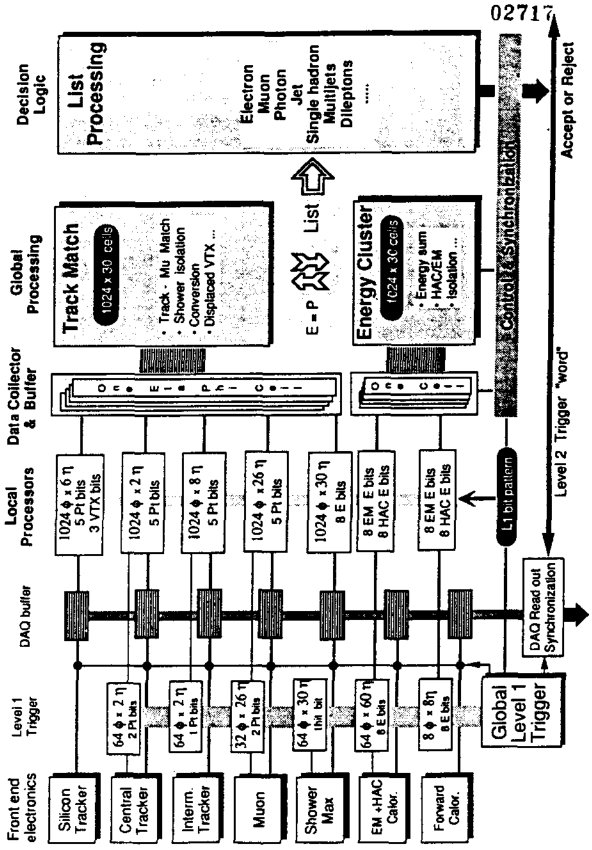
LEVEL 1 BASELINE DESIGN

- 1 Gbit/s optical fibers carry trigger primtives from detector electronics to crates in electronics house on surface.
- Design assigns logic blocks to boards in crates, implemented using standard technology (i.e. 100K ECL, HCMOS) with ASIC's only where necessary.
- Design maximizes flexibility and programmability through use of digital logic built around memory lookup tables and programmable gate arrays.
- Boards and crates designed for power, circuit space, I/O connections (std. density), fiber optic interfaces, backplane traffic, timing, and DAQ and trigger clock/control interfaces.
- Design minimizes hardware on detector: reduce detector cooling, power, space; maximize access; decouple trigger and detector geometry.
- Fiber optic and twisted pair cable plant have been designed to reduce the inaccessible single point failure risk to 1-2% and to minimize interconnects between crates.
- The system carries sufficient information for diagnostics, efficiency studies, and understanding of trigger behavior.

02716



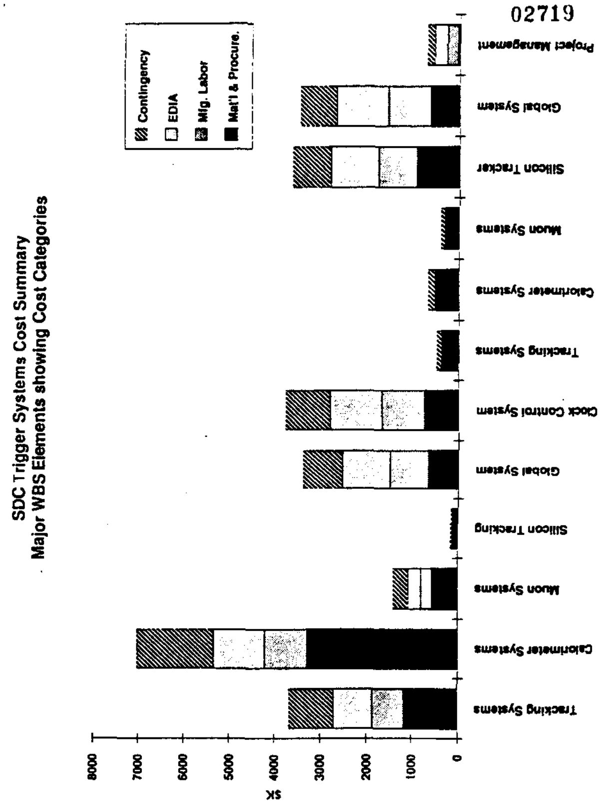
02717



SDC TRIGGER COSTS 02718

Item	Cost (K$)	Conting (K$)	Total (K$)
Level 1:	14,589	4,855	19,444
Track	2,706	966	3,672
Calorimeter	5,342	1,691	7,033
Muon	1,076	343	1,419
Silicon	128	37	165
Global	2,536	848	3,384
Level 2:	6,772	1,949	8,671
Track	378	110	488
Calorimeter	522	151	673
Muon	306	89	395
Silicon	2,822	818	3,640
Global	2,694	781	3,475
Proj. Manag.	552	160	712
Total	21,863	6,965	28,828

02719



Trigger Schedule Milestones.

Major Milestone	Scheduled Date
Start Final L1 Design	January 1993
Test System Available	May 1993
Complete L1 Design Specs.	December 1993
Final L1 Design Review	January 1995
Complete Design of Level 1	June 1995
Start Final L2 Design	January 1994
Complete L2 Design Specs.	December 1994
Final L2 Design Review	July 1995
Complete Design of Level 2	December 1995
Deliver L1 & L2 Prototypes	June 1996
Initial Delivery of Trigger Interfaces	June 1996
Delivery of Trigger System Begins	January 1997
Begin Integration & Test w/partial systems	June 1997
Begin Integration & Test w/final systems	January 1998
Commission Trigger System	October 1999

02721

MUON SYSTEM

M. MONTGOMERY

SDC TDR Cost Review

SDC Muon System Costs and Schedules

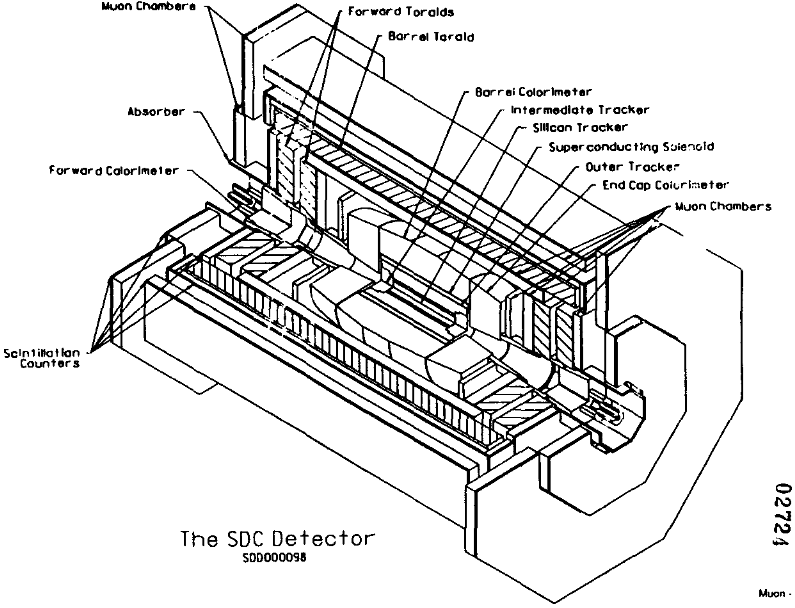
Michael Montgomery
8 May 1992

MARTIN MARIETTA
Science Systems

Agenda

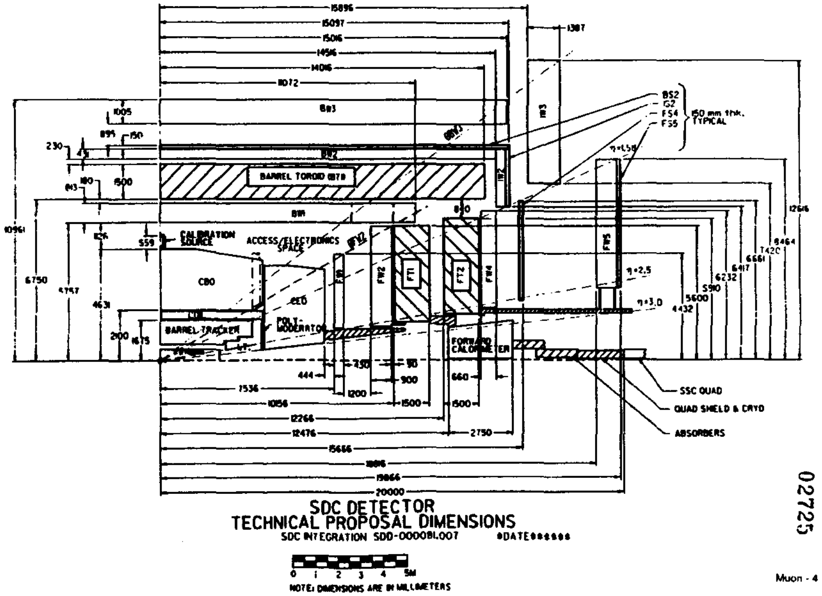
- Configuration
- Key Design Parameters
- Cost Ground Rules and Assumptions
- Muon System Cost Model
- Labor Categories and Rates
- Muon System Cost Evolution
- Review of Costs
- Schedules and Milestones
- Cost/Schedule Book

SDC Detector



The SDC Detector
SDD000098

Layout of SDC Muon System



SDC DETECTOR
TECHNICAL PROPOSAL DIMENSIONS
SDC INTEGRATION SDD-00008L007 *DATE******

0 1 2 3 4 5M
NOTE: DIMENSIONS ARE IN MILLIMETERS

Key Estimating Parameters

Magnet System

- Weight (MT)
- Number of Plates
- Number of Blocks
- Number of Fasteners
- Number of Coils
- Number of Jacks/Load Cells
- Toroid thickness (mm)
- Plate/Coil/Support Dimensions

Measurement System

- Number of Channels
- Number of Layers
- Number of Supermodules
- Scintillator Area
- Number of Counters
- Drift Tube Dimensions
- Drift Cell Orientation
- Chamber Locations

Cost Ground Rules and Assumptions

- 1992 Dollars
- Estimates Reflect Current Maturity of the Design
- Explanations of Costing Methods Included in WBS Dictionary
- Estimates Follow SDC Costing and Scheduling Procedures
- Nine Different Labor Categories Used
- Costs Reported as EDIA, Procurement, Mfg Labor, and Contingency
- Procurement Includes Raw Material, Vendor Delivered Components, and Expenses (Travel and Consumables)
- University and National Laboratory Labor Rates Applied
- Costs Reported to Lowest Level in WBS (~425 Elements)
- "SDC Muon System Costs and Schedules (Supporting Documentation for Techinical Proposal)" Document Should Be Referenced For Detailed Cost Backup and Estimating Methodology

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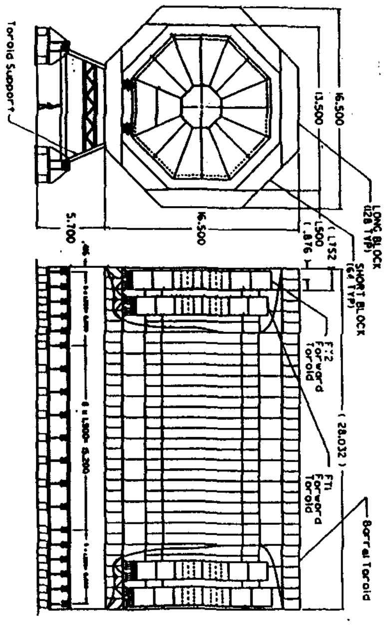


FIG. 7-54. Muon barrel and forward toroid assembly.

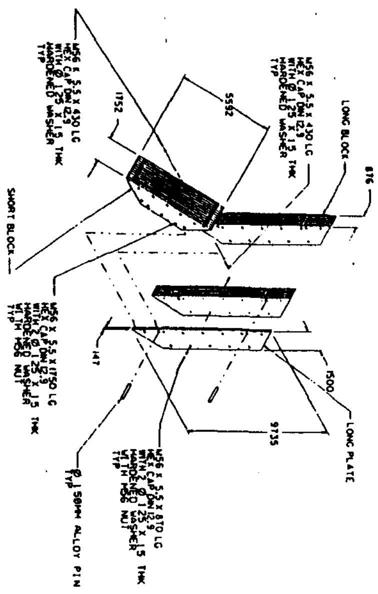


FIG. 7-55. Barrel toroid block assembly.

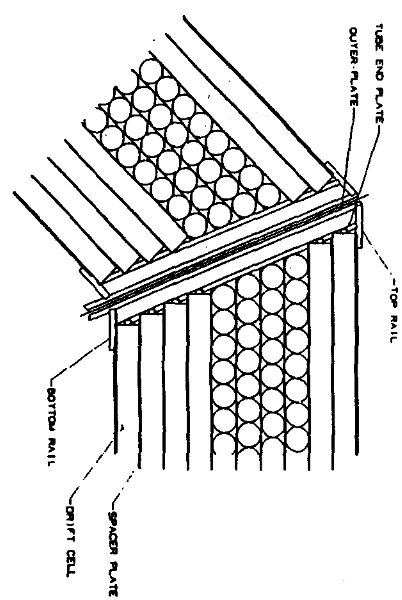


FIG. 7-25. Cross sectional view of the corners of two adjacent BW3 modules containing θ, φ, and stereo layers.

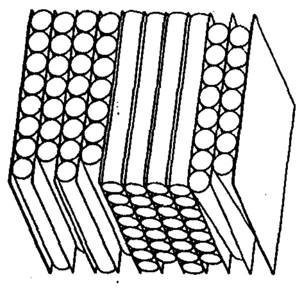


FIG. 7-34. Internal structure of a typical module.

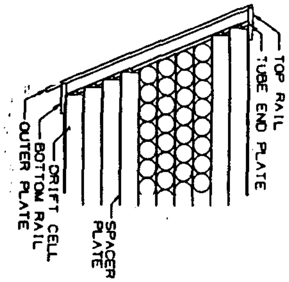
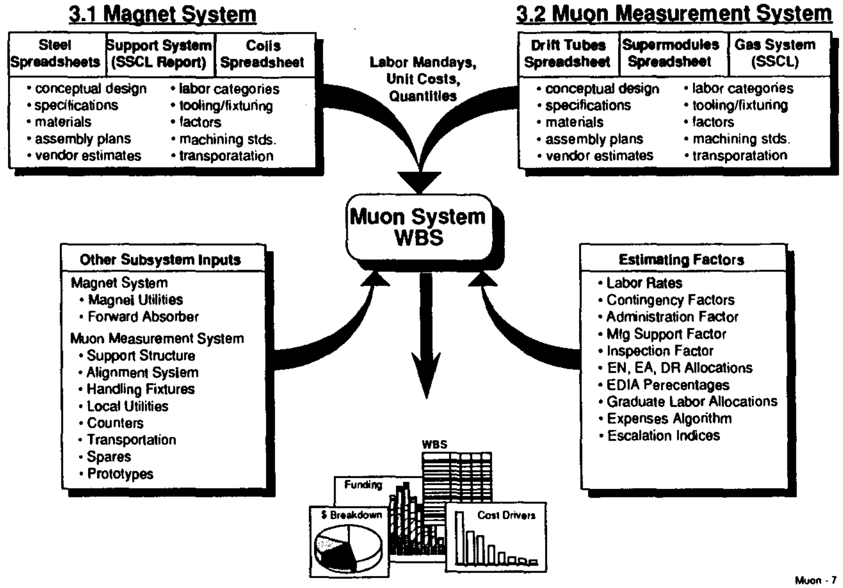


FIG. 7-35. Cross section of module edge structure.

Muon System Cost Model Flow Diagram



3.1 Magnet System

Steel Spreadsheets	Support System (SSCL Report)	Coils Spreadsheet

- conceptual design
- specifications
- materials
- assembly plans
- vendor estimates
- labor categories
- tooling/fixturing
- factors
- machining stds.
- transporatation

Labor Mandays, Unit Costs, Quantities

3.2 Muon Measurement System

Drift Tubes Spreadsheet	Supermodules Spreadsheet	Gas System (SSCL)

- conceptual design
- specifications
- materials
- assembly plans
- vendor estimates
- labor categories
- tooling/fixturing
- factors
- machining stds.
- transporatation

Muon System WBS

Other Subsystem Inputs

Magnet System
- Magnet Utilities
- Forward Absorber

Muon Measurement System
- Support Structure
- Alignment System
- Handling Fixtures
- Local Utilities
- Counters
- Transportation
- Spares
- Prototypes

Estimating Factors

- Labor Rates
- Contingency Factors
- Administration Factor
- Mfg Support Factor
- Inspection Factor
- EN, EA, DR Allocations
- EDIA Perecentages
- Graduate Labor Allocations
- Expenses Algorithm
- Escalation Indices

Labor Categories and Estimating Methodology

Labor Category	Estimating Methodology
EN (Engineering)	Bottoms-Up Estimates and Factors
EA (Engineering Associate)	30% of EN mandays allocated as EA
DR (Draftsman)	10% of EN mandays allocated as DR
TE (Inspection)	Factored at 15% of TEM
AD (Engr. Administration)	12% of EN, EA, DR and TE
ENM (Mfg Support)	30% of TEM and LAM
TEM (Technician)	Bottoms-Up Estimates
LAM (Graduate Student)	67% of TEM for drift tubes/scintillators allocated as LAM
ADM (Administration, Mfg.)	8% of ENM, TEM and LAM

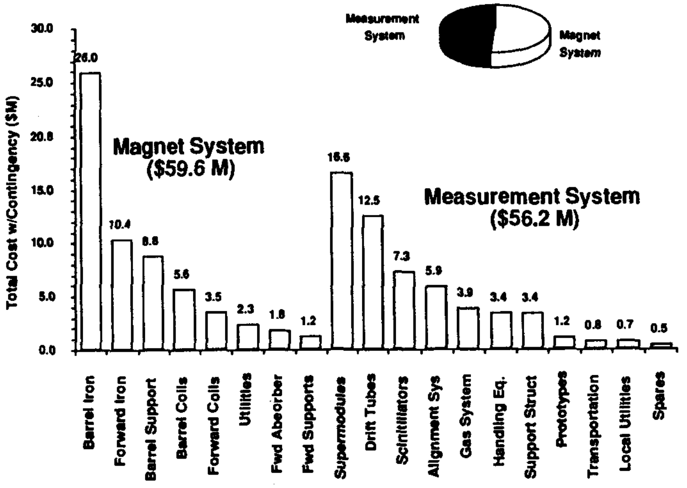
Assignment of Labor Rates by WBS Element

WBS #	WBS Description	EDIA	Mfg Labor
3.1.1.1 & 3.1.2.1	Barrel & Forward Steel	SSCL	SSCL
3.1.1.2 & 3.1.2.2	Barrel & Forward Coils	PSL	PSL
3.1.1.3 & 3.1.2.3	Barrel & Forward Supports	SSCL	SSCL
3.1.3	Utilities	SSCL	SSCL
3.1.4	Forward Absorber	SSCL	SSCL
3.2.1	Tracking Chambers	Avg. Univ.	Avg. Univ.
3.2.2	Support Structure	SSCL	SSCL
3.2.3	Alignment System	SSCL	SSCL
3.2.4	Handling Fixtures	SSCL	SSCL
3.2.5	Local Utilities	SSCL	SSCL
3.2.6	Scintillators	Avg. Univ.	Avg. Univ.
3.2.7	Supermodule Assembly	SSCL	SSCL
3.2.8	Gas System	SSCL	SSCL
3.2.9	Transportation	SSCL	SSCL
3.2.10	Spares	Avg. Univ.	Avg. Univ.
3.2.11	Prototype	SSCL	SSCL

Labor Rates ($/Manday)

Institution	EN	EA/ENM	DR/DRM	TE/TEM	AD/ADM	LA/LAM
Average University	397	268	238	248	201	106
National Labs	392	306	300	325	220	200
SSCL	421	302	248	250	197	160

Muon System Tall Poles



Muon System: $115.8 M

Muon System Cost Evolution

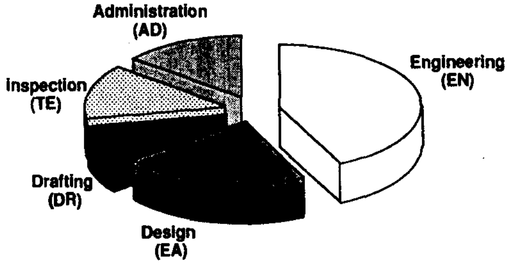
1. SDC LOI Review Panel (5/91)	$150 M
2. Muon System Downsize (12/91)	$123 M

- Reduce Forward Toroid Thickness 1 Meter
- Reduce Barrel Toroid Length 2 Meters
- Reduce BW1 Chamber Layers From 10 to 4
- Reduce Barrel and Forward Toroid Radius 0.5 Meter
- Develop Muon System Cost Model and Parametrics

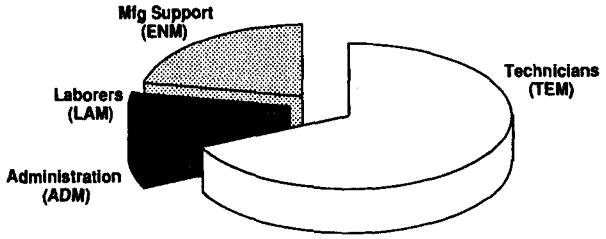
3. Prototype Experience and Bottoms-Up Estimates (3/92)	$116 M

- Toroid Conceptual Design Report & Specifications
- Drift Tube Prototypes and Round Tube Selection
- Further Maturity of Designs and Estimates
- Cerenkov Counters, FW3 Chambers, Additional Scintillator Layers Now Options

Muon System Labor Breakdown

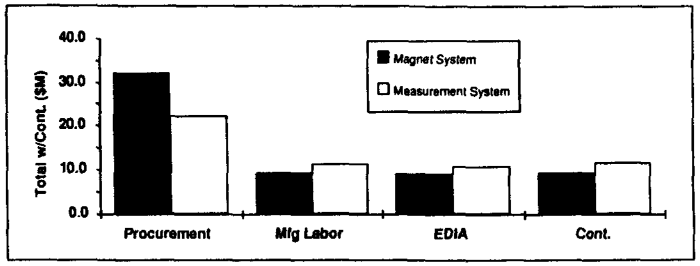


EDIA: $19.9 M

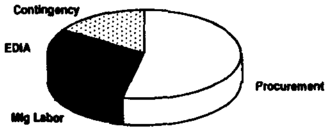


Manufacturing Labor: $20.7 M

Muon System Project Costs

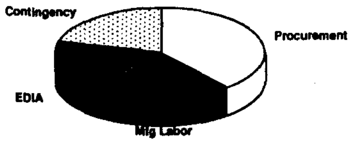


Magnet System



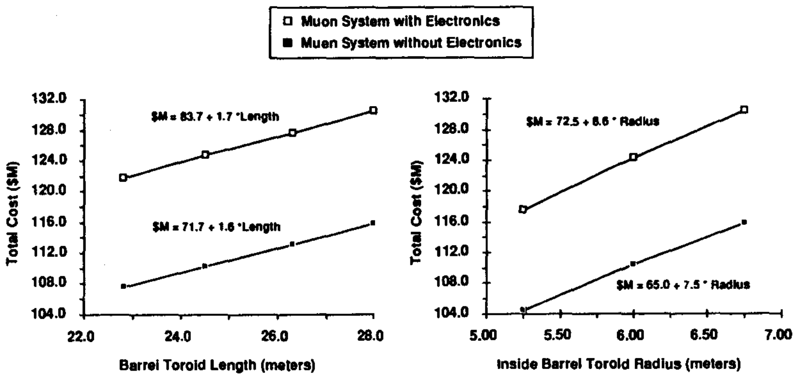
	$ M
Procurement	32.0
Mfg Labor	9.3
EDIA	9.0
Contingency	9.3
TOTAL	59.6

Measurement System



	$ M
Procurement	22.2
Mfg Labor	11.5
EDIA	10.9
Contingency	11.6
TOTAL	56.2

Muon System Cost Parametrics

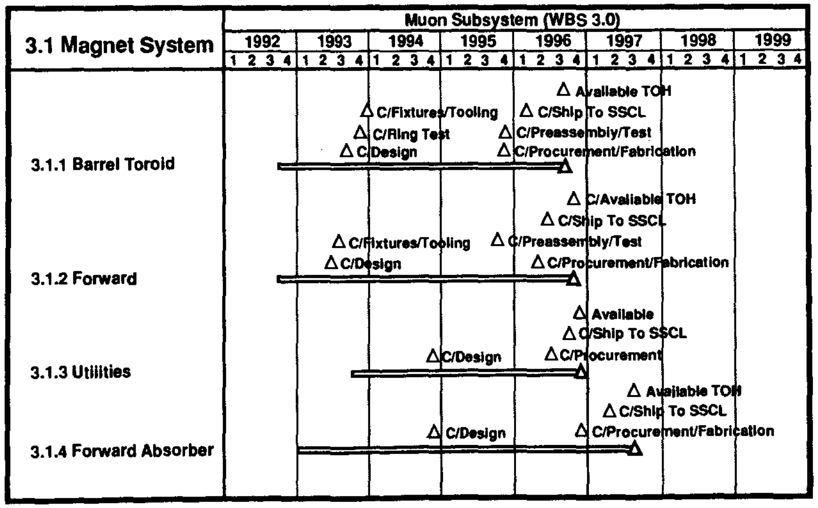


Muon System Costs May Be Reduced By $1.6M ($1.7M with Electronics) per Meter of Reduction In Barrel Toroid Length and $7.5M ($8.6M with Electronics) per Meter of Reduction of the Inside Barrel Toroid Radius

Muon System Level 3 Cost Summary

WBS #	WBS Description	Procurement ($M)	Mfg Labor ($M)	EDIA ($M)	Base ($M)	Cont. ($M)	Total w/ Cont. ($M)
3.1	Magnet System						
3.1.1	Barrel Toroid	22.2	6.5	5.8	34.5	5.8	40.4
3.1.2	Forward Toroids	7.4	2.5	2.7	12.6	2.5	15.2
3.1.3	Utilities	1.3	0.2	0.3	1.8	0.5	2.3
3.1.4	Forward Absorber	1.1	0.2	0.1	1.3	0.4	1.8
	Total Magnet System	32.0	9.3	9.0	50.3	9.3	59.6
3.2	Muon Measurement System						
3.2.1	Drift Tubes	6.0	1.1	4.0	11.1	1.4	12.5
3.2.2	Support Structure	1.7	0.4	0.5	2.6	0.8	3.4
3.2.3	Alignment System	2.0	1.6	0.8	4.4	1.5	5.9
3.2.4	Handling Fixtures	2.0	0.3	0.3	2.5	0.9	3.4
3.2.5	Local Utilities	0.3	0.1	0.1	0.6	0.2	0.7
3.2.6	Trigger Counters	4.5	0.5	0.5	5.5	1.8	7.3
3.2.7	Supermodules	3.1	6.4	3.3	12.7	3.8	16.6
3.2.8	Gas System	1.7	0.6	1.0	3.2	0.7	3.9
3.2.9	Transportation	0.4	0.2	0.1	0.7	0.1	0.8
3.2.10	Spares	0.2	0.1	0.0	0.4	0.1	0.5
3.2.11	Prototypes	0.2	0.2	0.4	0.9	0.3	1.2
	Total Measurement System	22.2	11.5	10.9	44.6	11.6	56.2
3	Total Muon System	54.2	20.7	19.9	94.9	20.9	115.8

Muon System Schedule



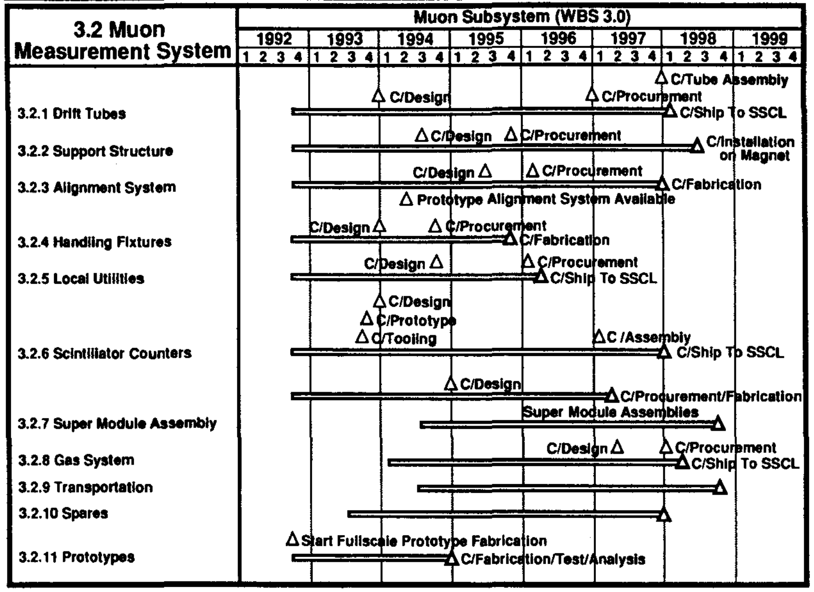
Muon System Costs by Detector Region

WBS Description	Procurement ($M)	Mfg Labor ($M)	EDIA ($M)	Base ($M)	Cont. ($M)	Total w/ Cont. ($M)
Barrel						
BT	23.2	6.6	6.1	35.9	6.2	42.0
BW1	2.3	1.4	1.4	5.1	1.2	6.4
BW2	1.8	1.0	1.0	3.8	0.9	4.7
BW3	6.3	3.5	3.4	13.2	3.2	16.5
BS2	3.1	0.3	0.3	3.8	1.2	4.9
Total Barrel	36.7	12.9	12.2	61.8	12.7	74.5
Intermediate						
IW2	0.3	0.2	0.2	0.7	0.2	0.9
IW3	2.5	1.6	1.3	5.4	1.4	6.8
IS2	0.5	0.1	0.1	0.6	0.2	0.9
Total Intermediate	3.3	1.8	1.5	6.7	1.8	8.5
Forward						
FT1	3.7	1.3	1.4	6.4	1.3	7.7
FT2	4.0	1.3	1.5	6.7	1.4	8.1
FW1	0.4	0.4	0.4	1.3	0.3	1.6
FW2	1.3	1.2	1.2	3.7	1.0	4.6
FW3	0.0	0.0	0.0	0.0	0.0	0.0
FW4	0.7	0.4	0.4	1.5	0.4	1.9
FW5	2.1	1.2	1.2	4.4	1.1	5.5
FS4	0.4	0.1	0.0	0.5	0.2	0.7
FS5	0.4	0.1	0.0	0.5	0.2	0.8
CC	0.0	0.0	0.0	0.0	0.0	0.0
Absorber	1.1	0.2	0.1	1.3	0.4	1.8
Total Forward	14.2	6.0	6.2	26.4	6.4	32.7
Total Muon System	54.2	20.7	19.9	94.9	20.9	115.8

Magnet System Estimating Basis

- Barrel Steel Estimated Bottoms-Up From Conceptual Design Report
- Coils Estimated From Preliminary Concept & Other Projects Ongoing
- Forward Steel Estimated From Preliminary Designs & Barrel Estimate
- Utilities Based On Vendor Estimates & Historical Costs
- Support Systems Estimated Bottoms-Up From SSCL Conceptual Design Report
- Forward Absorber Estimated From $/lb Based On Barrel Steel

Muon System Schedule (continued)



Measurement System Estimating Basis

- Drift Tube Estimates Based On Vendor Deliveries and Prototype Experience
- Trigger Counters and Alignment System Estimates Based On Vendor Estimates & Physicists Judgement
- Supermodules, Support Structure, Handling Fixtures and Transportation Estimated From Manufacturing Engineering Analysis And Production Simulations Utilizing The Resource Allocation Model (RAM)
- Gas System Estimated Bottoms-Up By SSCL
- Prototypes and Spares Factored From Manufacturing Costs

Overview of Muon System Cost/Schedule Book

- Introduction
  - Report Content
  - Cost Model
  - Muon System Configuration and Parameters
- Cost Ground Rules and Assumptions
- Review of Costs (Viewgraphs w/Facing Page Text)
- WBS Dictionary (Definitions, Parameters, Cost Methodology by WBS)
- Muon System Cost Evolution
- Potential Upgrades
- Schedules
- Appendices
  - Costs by WBS Element (425 items)
  - Contingency Analysis
  - Engineering Estimates
  - Subsystem Detailed Cost Estimates
  - Detailed Schedules, Logic Flows, and Resource Listings

02746

SUPERCONDUCTING SOLENOID

R. STANEK

SDC SOLENOID SYSTEM

Table 5-2
Baseline design parameters of SDC solenoid.

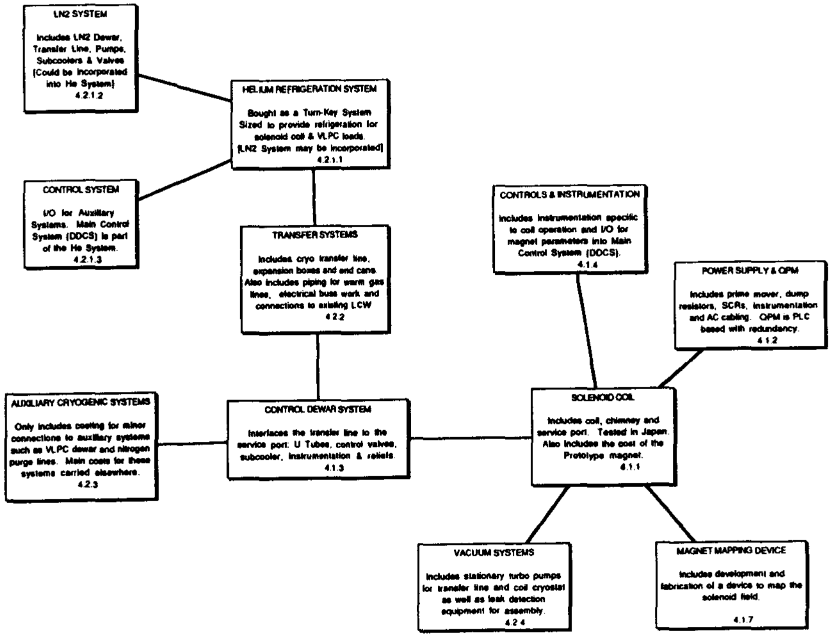
Dimensions:		
Cryostat	**Inner radius**	**1.70 m**
	Outer radius	**2.05 m**
	Half length	**4.389 m**
Coil	**Effective radius**	**1.84 m**
	Half length	**4.12–4.18 m**
Conductor	**Thickness**	**44 mm**
Outer support cylinder	**Thickness**	**31 mm**
Electrical parameters		
Central field		**2.0 T**
Nominal current		**8,000 A**
Inductance		**4.6 H**
Stored energy		**146 MJ**
Stored energy / cold mass		**7.4 kJ/kg**
Typical charging time		**1 hour**
Mechanical parameters		
Effective cold mass		**20 tonnes**
Total weight		**25 tonnes**
Radial magnetic pressure		**1.6 MN/m²**
Axial compressive force		**11 MN**

SDC Cost / Schedule Overview
Superconducting Solenoid & Cryogenics
WBS 4.1 and 4.2

Rich Stanek

Fermilab

May 8, 1992



LN2 SYSTEM

Includes LN2 Dewar, Transfer Line, Pumps, Subcoolers & Valves (Could be incorporated into He System)
4.2.1.2

HELIUM REFRIGERATION SYSTEM

Bought as a Turn-Key System Sized to provide refrigeration for solenoid coil & VLPC loads. [LN2 System may be incorporated]
4.2.1.1

CONTROL SYSTEM

I/O for Auxiliary Systems. Main Control System (DDCS) is part of the He System.
4.2.1.3

TRANSFER SYSTEMS

Includes cryo transfer line, expansion boxes and end cans. Also includes piping for warm gas lines, electrical buss work and connections to existing LCW
4.2.2

CONTROLS & INSTRUMENTATION

Includes instrumentation specific to coil operation and I/O for magnet parameters into Main Control System (DDCS).
4.1.4

POWER SUPPLY & QPM

Includes prime mover, dump resistors, SCRs, instrumentation and AC cabling. QPM is PLC based with redundancy.
4.1.2

AUXILIARY CRYOGENIC SYSTEMS

Only includes costing for minor connections to auxiliary systems such as VLPC dewar and nitrogen purge lines. Main costs for these systems carried elsewhere.
4.2.3

CONTROL DEWAR SYSTEM

Interfaces the transfer line to the service port: U Tubes, control valves, subcooler, instrumentation & reliefs.
4.1.3

SOLENOID COIL

Includes coil, chimney and service port. Tested in Japan. Also includes the cost of the Prototype magnet.
4.1.1

VACUUM SYSTEMS

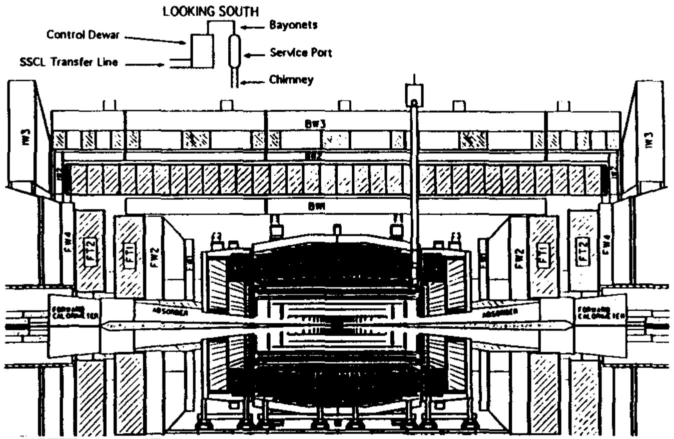
Includes stationary turbo pumps for transfer line and coil cryostat as well as leak detection equipment for assembly.
4.2.4

MAGNET MAPPING DEVICE

Includes development and fabrication of a device to map the solenoid field.
4.1.7

SDC SOLENOID SYSTEM

LOCATION OF COMPONENTS



SUMMARY STATUS OF COST DATA

4.1.1 Superconducting Coil	Cost/Shedule estimate: -Supplied by Japan
4.1.2 Power Supply System	Cost estimate: -Vendor quote -Engineer estimate
4.1.3 Control Dewar System	Cost estimate: -Based on replacement cost of CDF control dewar.
4.1.4 Controls & Inst.	Cost estimate: -Engineer estimate based on communication with vendor.
4.1.5 Safety Report	Cost/Schedule estimate: -Based on FNAL experience
4.1.6 Assembly & Test	Cost/Schedule estimate: - Engineer estimate
4.1.7 Magnet Map Device	Cost/Schedule estimate: - Engineer estimate based on FNAL experience (Zip Track).
4.1.8 Mgm't & Integration	Cost estimate: - Engineer estimate based on CDF experience.

4.2.1 Refrigeration Systems	Cost/Schedule estimate: -Vendor quote -Engineer estimate
4.2.2 Transfer Systems	Cost/Schedule estimate: -Detailed engineer estimate
4.2.3 Aux. Cryo Systems	Cost/Schedule estimate: -Engineer estimate
4.2.4 Vacuum Systems	Cost estimate: -Vendor quote
4.2.5 Safety Report	Cost/Schedule estimate: -Based on FNAL experience
4.2.6 Assembly & Test	Cost/Schedule estimate: - Engineer estimate
4.2.7 Mgm't & Integration	Cost estimate: - Engineer estimate based on CDF experience.

SDC SOLENOID/CRYOGENIC SYSTEM COST/SCHEDULE DRIVERS

	DURATION	MILESTONE
PROTOTYPE MAGNET	2.25 YEARS	FEB 94 TEST/JAPAN
SOLENOID COIL	4.25 YEARS	FEB 97 TEST/JAPAN
HELIUM SYSTEM	4.75 YEARS	JUL 97 TEST/SSCL
INSTALLATION & TEST "IN HALL"	0.75 YEARS	JUN 98 MAP MAG

	MAT'L & LAB	EDIA	% EDIA	SUB TOT	CONT	% CONT	TOT
4.0 SC MAGNET	29.2	3.1	10%	32.3	10.1	31%	42.4
4.1 SC SOLENOID	23.8	1.8	7%	25.6	8.3	33%	33.9
4.2 CRYOGENIC SYSTEM	5.4	1.3	19%	6.7	1.8	27%	8.5

Superconducting Coil as a % of Total 4.1 costs = 75.8%

Helium Refrigeration System as a % of Total 4.2 costs = 55.5%

COST NUMBERS SUPPLIED BY TAKA KONDO:

		WBS #	Cont.	Base $
PROTOTYPE SOLENOID	$5.4 M	4.1.1.8	68%	3.27M
Design, management	$.36 M			
Superconductor	$1.1 M			
Coil Winding	$1.2 M			
Cryostat & Cryogenics	$1.0 M			
Power Supply for Test	$.86 M			
Monitors	$.14 M			
Assembly & Inspection	$.29 M			
Excitation Test	$.36 M			
SDC SOLENOID	$26.8 M	4.1.1		
Less Installation Costs = $1.1 M...............	$25.7 M			
Design, Management	$1.4 M	4.1.1.7	38%	1.02M
Superconductor	$5.7 M	4.1.1.1	24%	4.60M
Coil Winding	$5.6 M	4.1.1.2	28%	4.38M
Cryostat	$5.4 M	4.1.1.3	24%	4.36M
Monitor System	$1.2 M	4.1.1.4	24%	.968M
Assembly & Inspection	$3.6 M	4.1.1.5	32%	2.73M
Excitation Test	$2.1 M	4.1.1.5	32%	1.59M
Transportation	$.71 M	4.1.1.6	16%	.612M
Installation & Test	$1.1 M			

140 yen = $1

Table 5-17

Overall schedule for the prototype solenoid and the production solenoid. The Japanese fiscal year begins April 1 of the year indicated.

JFY1991	Prototype Magnet Development —Superconductor fabrication —Winding machine development —Outer support cylinder fabrication —Isogrid vacuum wall development
JFY1992	—Coil winding —Cryostat element fabrication
JFY1993	—Assembly of the magnet —Cool-down and excitation in air
JFY1994	Production Magnet Fabrication —Superconductor fabrication —Cryostat element fabrication
JFY1995	—Coil winding —Magnet assembly
JFY1996	—Magnet assembly continued —Cool-down and excitation test in air —Transportation to SSCL
JFY1997	—Cool-down and excitation in iron —Field mapping

REALITY CHECK:

- Compare Manpower Estimate of SDC with CDF Experience

Magnet Support

Classification:	CDF Experience	SDC Estimate
Engineer	7.5 manyears	7.5 manyears
Engineer Assoc.	1.5 manyears	1.5 manyears
Drafting	2.0 manyears	3.0 manyears
Technicians	2.0 manyears	4.1 manyears

Electrical Support

Classification:	CDF Experience	SDC Estimate
Engineer	2.5 manyears	5.0 manyears
Engineer Assoc.	2.5 manyears	1.0 manyears
Drafting	2.5 manyears	2.3 manyears
Technicians	5.0 manyears	7.5 manyears

Refrigerator Support

Classification:	CDF Experience	SDC Estimate
Engineer	6.0 manyears	10.7 manyears
Engineer Assoc.	1.5 manyears	1.5 manyears
Drafting	2.0 manyears	3.7 manyears
Technicians	5.0 manyears	6.8 manyears

TOTAL SUPPORT:

Classification:	CDF Experience	SDC Estimate
Engineer	16.0 manyears } 21.5	23.2 manyears } 27.2
Engineer Assoc.	5.50 manyears	4.00 manyears
Drafting	6.50 manyears	9.00 manyears
Technicians	12.0 manyears	18.4 manyears
	40	54.6 my

It appears that the level of manpower estimated for SDC is comparable with that used for CDF in some areas. As expected, the level of manpower is higher in total.

REALITY CHECK II

- Compare Cost Estimate of SDC with LBL paper by R. Byms
  "Estimating the Cost of Superconducting Magnets and the Refrigerators to Keep Them Cold"

Cost Equations for Solenoid Magnets:

$$C(M\$) = 0.523\,[E(MJ)]^{.662} \qquad = 0.523\,[146]^{.662} \qquad = 14.2\ M\$$$

$$C(M\$) = 0.868\,[V(Tm^{3})]^{.577} \qquad = 0.868\,[145]^{.577} \qquad = 15.4\ M\$$$

SDC Estimates = 20.2 M$ Base
5.5 M$ Cont

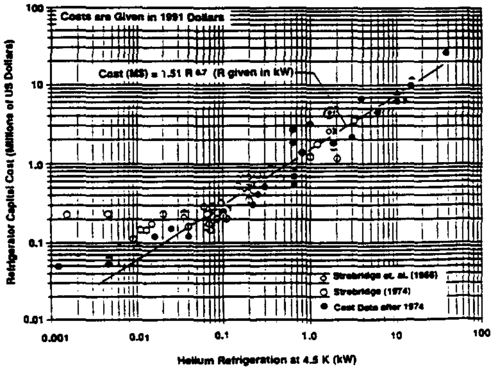
25.7 M$ Total

Cost Equations for Helium Refrigeration:

$$C(M\$) = 1.51\,[R(kW)]^{.7} \qquad = 1.51\,[1.5]^{.7} \qquad = 2.0\ M\$$$

SDC Estimates = 3.6 M$ Base
1.1 M$ Cont

4.7 M$ Total



SDC REALITY CHECK III

COMPARE THE SCALED UP HISTORICAL COSTS OF CDF TO SDC ESTIMATES:

CDF magnet in 1983-84 dollars cost $4M (600M yen) [Parameters=30MJ and 1.5T]

Scaled for inflation = $5.3M (4%, 7 years)

Scaled for stored energy = $15.1M (using formula: $[146/30]^{.662}$)

- This compares favorably with the costs generated by LBL cost equations.

CDF refrigerator in 1983-84 dollars cost $1M [Parameters=.6KW, FNAL labor]

Scaled for inflation = $1.5M (6%, 7 years)

Scaled for refrigeration = $2.9M (using formula: $[1.5/.6]^{.7}$)

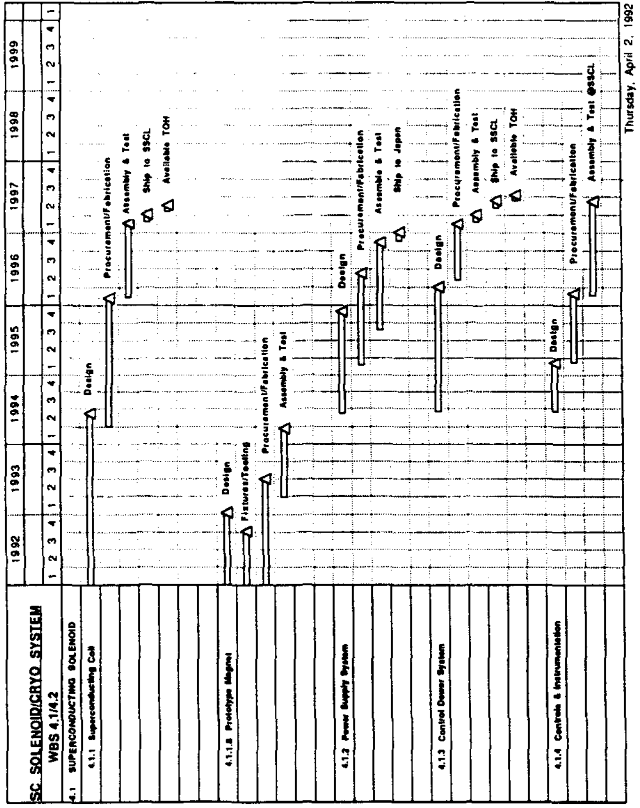
- This is more than the costs generated by the LBL cost equation but less than the quote from the vendor (which is expected).

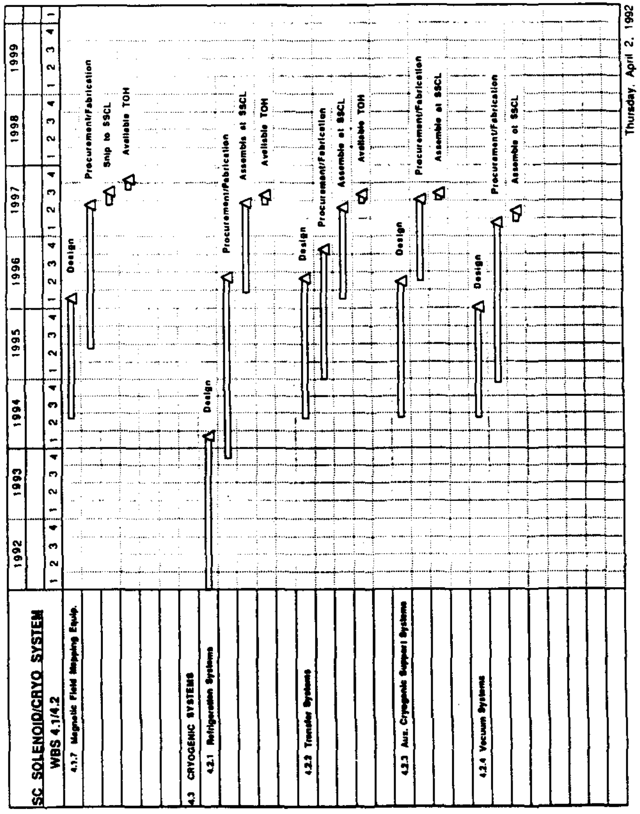
SDC Superconducting Solenoid Cost Summary

WBS		Mat'ls. ($k)	Mfg Labor ($k)	EDIA ($k)	Base ($k)	Cont. ($k)	Cont. %	Total w/ Cont. ($k)
[illegible]	Superconducting Coil	21,923	0	0	21,923	7,188	32.8	29,111
[illegible]	Power Supply System	366	303	594	1,263	296	23.4	1,560
[illegible]	Control Dewar System	262	20	173	455	127	27.9	582
[illegible]	Controls & Instrument.	110	140	138	388	124	32.0	512
[illegible]	Safety Report	30	0	120	150	39	26.0	189
[illegible]	Assembly & Test	100	69	189	358	158	44.1	516
[illegible]	Field Mapping Eqpt.	250	184	173	607	243	40.0	850
[illegible]	Mgmt. & Integ.	40	0	384	424	161	38.0	585
	Total S.C. Solenoid	23,081	716	1,771	25,568	8,337	32.6	33,906

SDC Cryogenics System Cost Summary

WBS #		Mat'ls. ($k)	Mfg Labor ($k)	EDIA ($k)	Base ($k)	Cont. ($k)	Cont. %	Total w/ Cont. ($k)
[illegible]	Refrigeration Systems	3,913	28	453	4,394	1,252	28.5	5,646
[illegible]	Transfer Systems	668	424	418	1,511	332	22.0	1,843
[illegible]	Auxilliary Cryogenic Sppt.	20	4	43	68	22	32.4	90
[illegible]	Vacuum Systems	189	42	133	365	92	25.2	457
[illegible]	Safety Report	2	0	104	106	23	21.7	129
[illegible]	Assembly & Test	10	82	23	115	41	35.7	156
[illegible]	Mgmt. & Integration	5	0	126	131	29	22.1	160
	Total Cryogenics Sys.	4,807	580	1,300	6,690	1,792	26.8	8,482





02763

ELECTRONICS

H. H. WILLIAMS

Cost & Schedule
for
Front End Electronics

H. H. Williams
University of Pennsylvania

for

SDC Collaboration

Comments on Costing Procedure

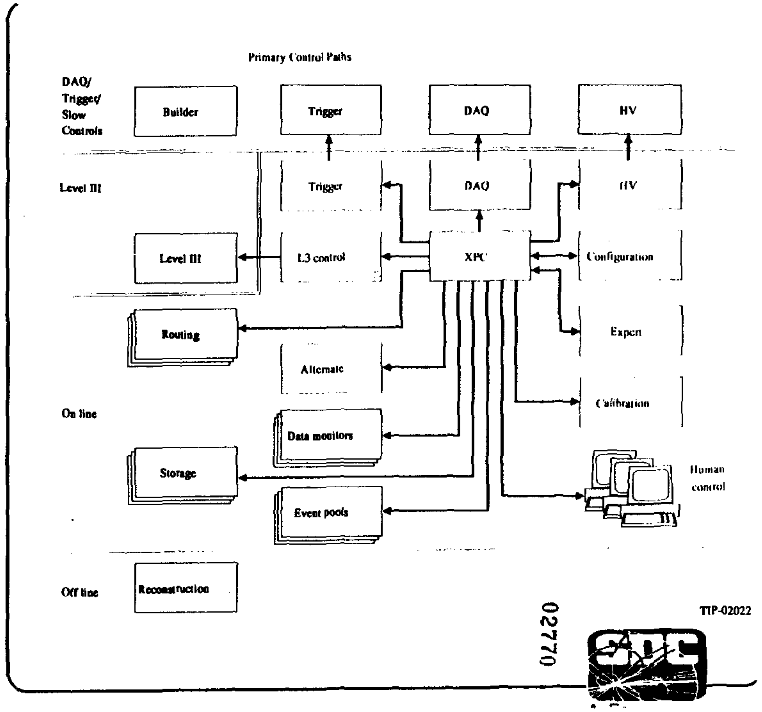
- WBS for most systems to Level 7
- Lowest level typically PC boards, custom IC's, special commercial IC's, connector, cable, etc.
- Most items based on recent experience or written/phone quotes from manufacturers
- Costing of all systems reviewed in joint session for consistency
- Engineering estimates typically 3/4 - 2 years for PC boards, IC's (depending on complex)
- Engineering estimates included for tracking production
- Estimates assume much of IC design largely completed by Oct 1992

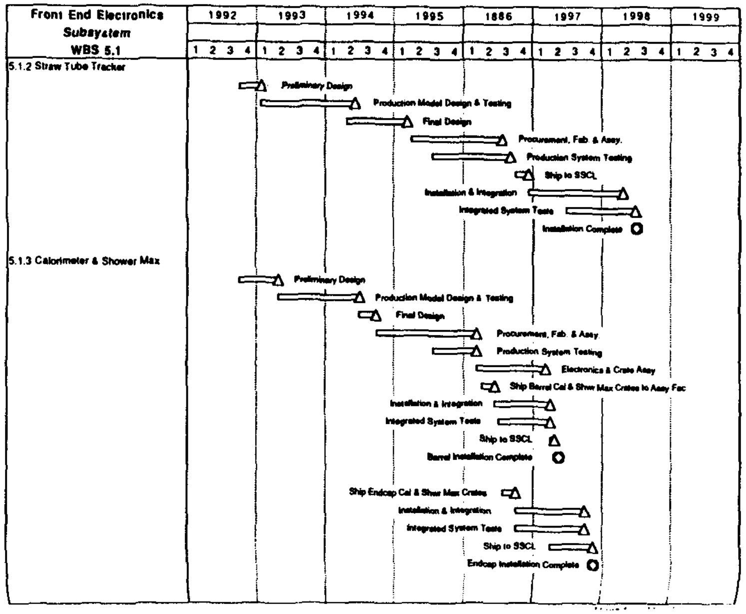
SDC Front-End Electronics Cost Summary

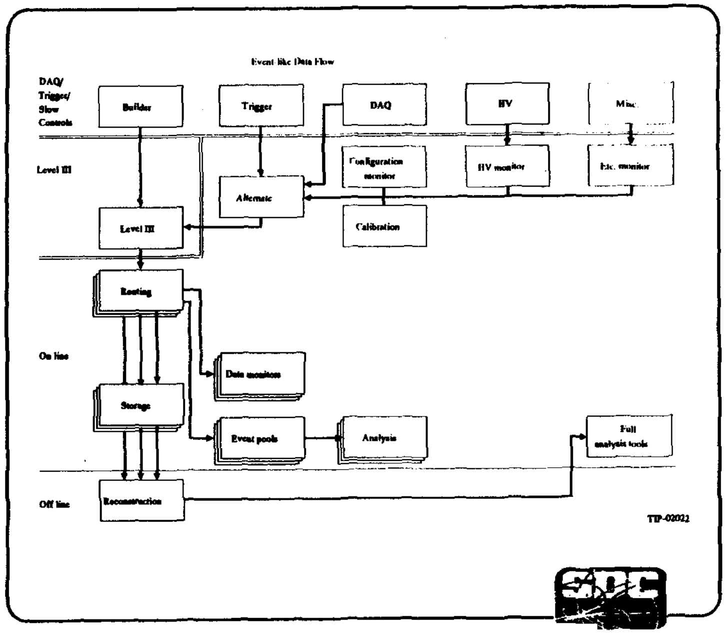
WBS & Subsystem	Scaling Parameters (Channels)	Total Cost ($K)	Cost Formula
5.1.2 Straw Tracker	137,164	$12,711	$6.1M + $48/Ch.
5.1.3.1 Calorimeter (SCA)	20,352	$9,315	$3.8M + $271/Ch.
5.1.3.2 Shower Max (SCA)	57,472	$5,961	$2.6M + $59/Ch.
5.1.4.1 Muon Wire Chamber	89,864	$3,486	$1.4M + $23/Ch.
5.1.4.2 Muon Scintillator Counter	6,736	$1,236	$0.3M + $139/Ch.
5.1.4.4 Regional Electronics	96,600	$10,021	$4.4M + $58/Ch.
5.1.4.5/6 Sys. Integ. & P.M.		$1,153	$1.2M
5.1 Front-End Subtotal*	311,588	$43,883	$19.8M + $77/Ch.

Some Interesting Comparisons

	Eng. Manpower (mandays)
Straw Readout	2654
Calorimeter	3066
Shower Max	1801
Muon	5250
Total	12771
DAQ	9500
Trigger	19000







Summary

- We believe cost estimate is reasonable
- It is necessary to more very fast to achieve it

02772

Online Cost & Schedule Summary (92.05.08)

50 man-years of effort

- o evaluation and selection of commercial tools
- o detailed high level design and review
- o development and testing of proto-type software
- o documentation
- o close cooperation with off-line, daq, trigger, detector sub groups.
- o support/consultation with various subgroups
- o frequent incremental builds of the system

A. Fry

02773

Online Cost & Schedule Summary (92.05.08)

Procurement

- o 50% of cost is hardware procurement and software licensing, assume some site licensing of well used products.
- o use "off the shelf" workstations, typically about 100 Mips: 4GB disk, about $25K each. Used in the online system and for development and debugging by the daq/detector groups.
- o some workstations will have higher performance some will act as fileservers, typically $50K each
- o mass storage tape drives $350K

A. Fry

02774

Online Cost & Schedule Summary (93.05.08)

Major Milestones:

Data Structures etc.	July 93
Preliminary proto-types	Jan 94
SSCL testbeam	Jan 97
Level III routing & data logging	Oct 97
Muon system readout	Oct 97
Cosmic Ray tests	Mar 99

A. Fry

02775

Online Cost & Schedule Summary (93.05.08)

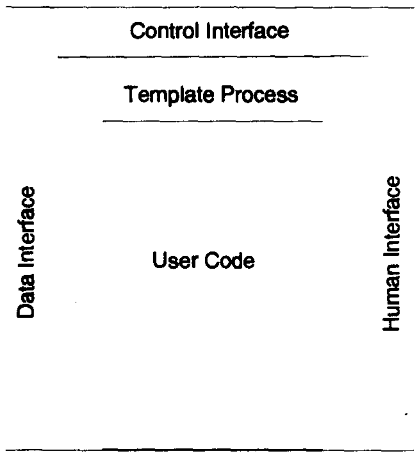
Variables

- o Extent of overlap with:
  - testbeam program
  - integration costs
  - offline software
- o Extent to which it is appropriate to adapt and reuse existing software
- o time spent coordinating with and supporting software efforts of other groups
- o degree to which commercial software is appropriate
- o trade-off of quality vs man years
- o contingency ~~about~~ ≤ 30%

A. Fry

Online Cost & Schedule Summary (92.05.08)

Encapsulation of User Code



Control Interface

Template Process

Data Interface

User Code

Human Interface

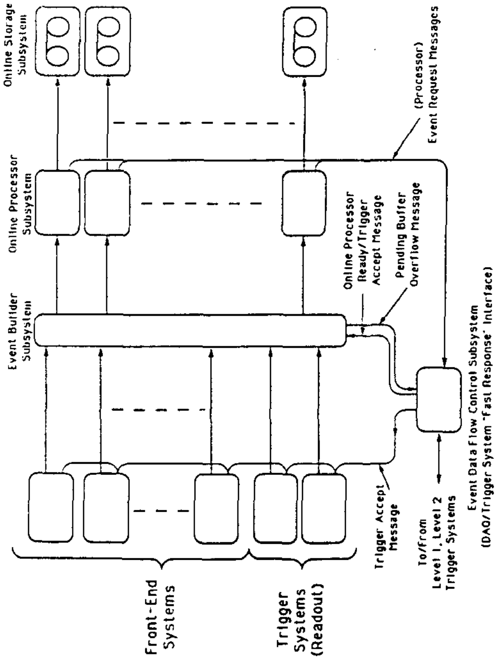
A. Fry

02777

ELECTRONICS

I. GAINES

SDC DAQ
Cost and Schedule



Simplified Block Diagram
Of Costed Data Acquisition System Architecture

SDC DAQ Milestones

Completion of DAQ requirements	Nov, 91
Completion of DAQ system design, incl. technical choices	1993
Completion of DAQ component design	1994
Portable DAQ for use in test beams/labs	199~~4~~3
Prototypes of all DAQ components	1995
Delivery of partial DAQ systems for subsystems	Jan, 97
Muon subsystem	?
Calorimeter subsystem	?
Tracking subsystem	?
Installation of complete DAQ system	Jan, 99
Certification of full, working DAQ system	July, 99

5/6/92

WBS #	WBS Item	Total Cost (Materials)	Total Cost (Manpower)	Cont %	Total Cost
5.2	DATA ACQUISITION SYSTEM	$7,397K	$9,093K		$20,471K
5.2.1	Project Management	$241K	$1,057K	38.74	$1,801K
5.2.2	System Design Document	$0K	$124K	21.74	$151K
5.2.3	Data Acquisition System Development Infrastructure	$718K	$58K	9.46	$850K
5.2.4	Data Acquisition System Control/Monitoring (C/M) Network	$107K	$399K	16.00	$587K
5.2.5	SDC Standard Data Acquisition System Interface Single Crate & Cooling Unit	$210K	$307K	13.78	$588K
5.2.6	SDC Standard DAQ Event Data Readout & C/M Network Interface Components	$2,096K	$1,711K	24.39	$4,736K
5.2.7	System Integration Tests Of Prototype C/M Network, Crate Units & Event Data Readout		$94K	28.00	$120K
5.2.8	Event Builder Subsystem	$991K	$874K	34.70	$2,513K
5.2.9	Event Data Flow Control Subsystem	$44K	$540K	29.44	$756K
5.2.10	System Integration Tests Of The Event Builder & Event Data Flow Control Subsystems		$67K	40.00	$94K
5.2.11	Online Processor Subsystem	$2,835K	$513K	17.35	$3,930K
5.2.12	System Integration Tests Of The Event Builder & Online Processor Subsystem Interface		$64K	46.00	$93K
5.2.13	DAQ Online Computing Interface	$50K	$2,723K	24.28	$3,446K
5.2.14	System Integration Tests Of Event Data Readout Through The Entire DAQ System		$88K	28.00	$113K
5.2.15	Electronics Rack Protection, Powering & Cooling (ERPPC) Subsystem	$105K	$430K	18.62	$635K
5.2.16	Data Acquisition System Design Reviews		$43K	38.00	$60K

5/6/92

WBS #	WBS Item	Total Cost (Materials)	Total Cost (Manpower)	Cont %	Total Cost
	Infrastructure (materials)	$1,038K			
	Design Documents (materials)	$0K			
	Travel (materials)	$165K			
	Prototype (materials)	$514K			
	Pre-production (materials)	$490K			
	Production (materials)	$5,154K			
	Project Management (materials {miscellaneous only})	$36K			
	Hardware And/Or Software Maintenance (materials)	$0K			
	Infrastructure (manpower)	$125K			
	Design Documents (manpower)	$2,097K			
	Prototype (manpower)	$2,162K			
	Pre-Production (manpower)	$306K			
	Production (manpower)	$2,539K			
	Design Reviews (manpower)	$519K			
	Project Management (manpower {effort only})	$1,057K			
	Prototype & Pre-Production Integration & Testing (manpower)	$288K			
	Total Cost (materials)	$7,397K			
	Total Cost (materials + contingency)	$8,908K			
	Total Cost (manpower)	$9,093K			
	Total Cost (manpower + contingency)	$11,563K			
	Total Cost (excluding contingency)	$16,490K			
	Total Cost (including contingency)	$20,471K			

5/6/92

WBS #	WBS Item	Total Cost (Materials)	Total Cost (Manpower)	Cont %	Total Cost
5.2	DATA ACQUISITION SYSTEM (fixed costs)				
5.2.1	Project Management	$241K	$1,057K	38.89	$1,855K
5.2.2	System Design Document	$0K	$124K	21.74	$145K
5.2.3	Data Acquisition System Development Infrastructure	$718K	$58K	9.46	$847K
5.2.5	SDC Standard Data Acquisition System Interface Single Crate & Cooling Unit	$210K	$307K	15.80	$562K
5.2.7	System Integration Tests Of Prototype C/M Network, Crate Units & Event Data Readout		$94K	28.00	$111K
5.2.8	Event Builder Subsystem	$991K	$874K	34.71	$2,445K
5.2.10	System Integration Tests Of The Event Builder & Event Data Flow Control Subsystems		$67K	40.00	$07K
5.2.11	Online Processor Subsystem	$2,835K	$513K	17.31	$3,902K
5.2.12	System Integration Tests Of The Event Builder & Online Processor Subsystem Interface		$64K	46.00	$87K
5.2.13	DAQ Online Computing Interface	$50K	$2,723K	24.27	$3,372K
5.2.14	System Integration Tests Of Event Data Readout Through The Entire DAQ System		$88K	28.00	$106K
5.2.16	Data Acquisition System Design Reviews		$43K	38.00	$57K
	Total Fixed Costs	$5,045K	$6,012K	22.77	$13,576K
5.2	DATA ACQUISITION SYSTEM (variable costs)				
5.2.4	Data Acquisition System Control/Monitoring (C/M) Network	$107K	$399K	16.00	$563K
5.2.6	SDC Standard DAQ Event Data Readout & C/M Network Interface Components	$2,096K	$1,711K	24.31	$4,609K
5.2.9	Event Data Flow Control Subsystem	$44K	$540K	29.37	$717K
5.2.15	Electronics Rack Protection, Powering & Cooling (ERPPC) Subsystem	$105K	$430K	18.58	$603K
	Total Variable Costs	$2,352K	$3,080K	19.51	$6,492K
Allocations of variable costs to subsystems					
	Silicon Tracker	$85K	$106K		$229K
	Straw Tracker	$71K	$118K		$227K
	Intermediate Tracker	$85K	$106K		$229K
	Barrel/Endcap Calorimeter	$550K	$725K		$1,524K
	Shower Max	$280K	$428K		$849K
	Forward Calorimeter	$17K	$21K		$46K
	Barrel/Intermediate Muon	$273K	$341K		$733K
	Forward Muon	$273K	$341K		$733K
	Trigger System	$717K	$894K		$1,923K

SDC DAQ Cost Drivers (Material)

WBS #	WBS Item	Prototype Quantity	Unit Cost	Pre-Prod Quantity	Unit Cost	Production Quantity	Unit Cost	Total Cost (Materials)
5.2	**DATA ACQUISITION SYSTEM**							$7,397K
5.2.1	**Project Management**							$241K
5.2.1.1	Special Infrastructure (Computer Equipment & Supplies)	2	$20.00K					$40K
5.2.1.3	Travel	110	$1.50K					$165K
5.2.1.4	Miscellaneous	72	$0.50K					$36K
5.2.3	**Data Acquisition System Development Infrastructure**							$718K
5.2.3.2.1	CASE Workstations Hardware & Software	3	$70.00K					$210K
5.2.3.3.1	CAE Workstations Hardware & Software	3	$100.00K					$300K
5.2.3.4	PC-Like Workstations & Software	3	$18.00K					$54K
5.2.3.5.1	Networking Equipment Hardware & Software	2	$15.00K					$30K
5.2.3.6.1	Hardcopy & Archival Equipment Hardware & Software	2	$15.00K					$30K
5.2.3.7.1	Logic State Analyzers	2	$35.00K					$70K
5.2.3.7.2	Oscilloscopes	2	$12.00K					$24K
5.2.4	**Data Acquisition System Control/Monitoring (C/M) Network**							$107K
5.2.4.3	Special Infrastructure	1	$30.00K					$30K
5.2.4.4.3.1	DAQ System Control/Monitoring Network Routers Hardware & Software	2	$4.00K			8	$4.00K	$40K
5.2.4.5.3.1	Data Acquisition System Control/Monitoring Network Repeaters Hardware	2	$2.00K			8	$2.00K	$20K
5.2.4.6.3.1	Data Acquisition System Control/Monitoring Network Links Hardware	10	$0.10K			327	$0.05K	$17K
5.2.5	**SDC Standard Data Acquisition System Interface Single Crate & Cooling Unit**							$210K
5.2.5.3	Special Infrastructure	1	$20.00K					$20K
5.2.5.4.3	Prototype Crate & Cooling Units	26	$6.50K					$169K
5.2.5.5.3	Prototype Crate Fan Unit	26	$0.55K					$14K
5.2.5.6.3	Prototype Heat Exchanger	26	$0.25K					$7K
5.2.6	**SDC Standard DAQ Event Data Readout & C/M Network Interface Components**							$2,096K
5.2.6.3	Special Infrastructure	1	$60.00K					$60K
5.2.6.4.3.1	DAQ CPU Modules Hardware & Software	4	$7.00K	26	$6.00K	288	$5.00K	$1,624K
5.2.6.5.3	Event Data Readout & Control/Monitoring Network Bus Slave Interface	1	$2.00K			1	$0.40K	$2K
5.2.6.6.3	Event Data Readout Port Interface	1	$2.00K			1	$0.60K	$3K
5.2.6.7.3	Crate Adapter/Interface Modules	4	$3.00K	26	$0.80K	288	$0.70K	$234K
5.2.6.8.3	Event Data Links	4	$0.60K			610	$0.30K	$125K
5.2.6.9.3	Event Data Link Transmitter/Receiver Test Modules	2	$3.00K			6	$1.20K	$13K
5.2.6.10.3	Data Acquisition Remote Control/Monitoring Link	1	$0.20K	8	$0.20K	136	$0.10K	$15K
5.2.6.11.3	Data Acquisition System Remote Control/Monitoring Link Repeater	1	$2.40K	2	$1.20K	34	$0.40K	$11K
5.2.8	**Event Builder Subsystem**							$991K
5.2.8.3	Special Infrastructure	1	$40.00K					$40K
5.2.8.4.3	Data Balancing/Input Queueing Logic	1	$40.00K	1	$30.00K	1	$256.00K	$326K
5.2.8.5.3.1	Switching Network Hardware & Software	1	$100.00K			1	$512.00K	$612K
5.2.8.6.3.1	EBS To OPS Event Data Links Hardware	4	$0.60K			36	$0.30K	$13K
5.2.9	**Event Data Flow Control Subsystem**							$44K
5.2.9.3	Special Infrastructure	1	$20.00K					$20K
5.2.9.4.3	Event Data Flow Control Unit	1	$6.00K	1	$4.50K	2	$3.50K	$18K
5.2.9.5.3	Event Data Flow Control Links To/From Event Builder Subsystem	2	$3.00K			2	$0.30K	$7K

SDC DAQ Cost Drivers (Material)

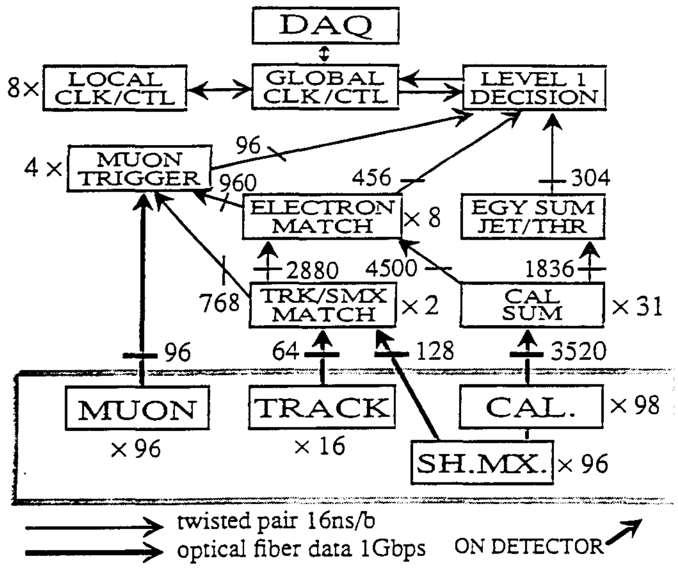
WBS #	WBS Item	Prototype Quantity	Unit Cost	Pre-Prod Quantity	Unit Cost	Production Quantity	Unit Cost	Total Cost (Materials)
5.2.11	**Online Processor Subsystem**							$2,835K
5.2.11.3	Special Infrastructure	1	$40.00K					$40K
5.2.11.4.3	Processor Array Hardware & Software	1	$40.00K	1	$275.00K	1	$2,475.00K	$2,790K
5.2.11.5.3	Event Request Links Hardware	4	$0.20K			9	$0.20K	$3K
5.2.11.6.3	OPS To OSS Event Data Link Hardware	2	$0.60K			5	$0.30K	$3K
5.2.13	**DAQ Online Computing Interface**							$50K
5.2.13.3	Special Infrastructure	1	$50.00K					$50K
5.2.15	**Electronics Rack Protection, Powering & Cooling (ERPPC) Subsystem**							$105K
5.2.15.3	Special Infrastructure	1	$20.00K					$20K
5.2.15.4.3	Electronics Rack Protection Chassis	4	$5.00K			3	$3.00K	$29K
5.2.15.5.3	Rack With Rack Protection, Powering & Cooling Hardware	4	$10.00K			3	$5.20K	$56K

0278

ELECTRONICS

W. SMITH

278CE



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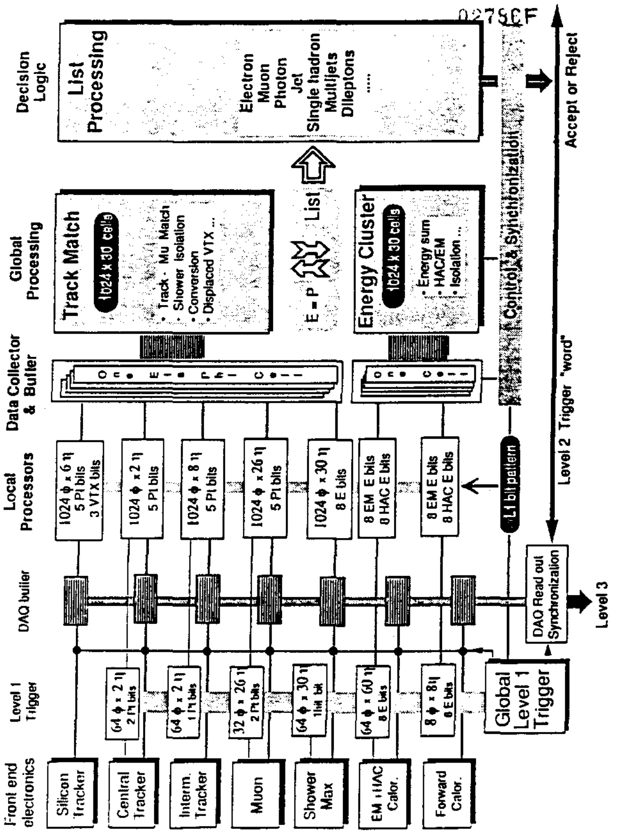
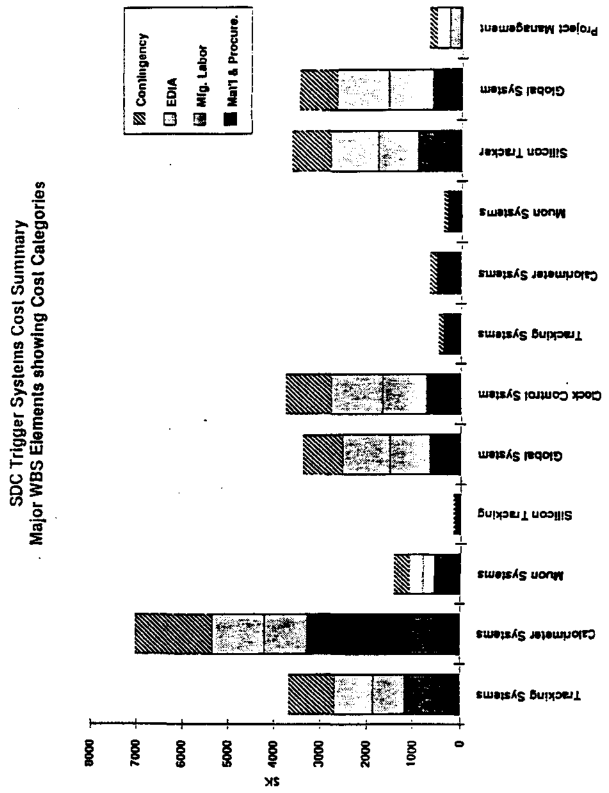


0278CG

SDC TRIGGER COSTS

Item	Cost (K$)	Conting (K$)	Total (K$)
Level 1:	14,589	4,855	19,444
Track	2,706	966	3,672
Calorimeter	5,342	1,691	7,033
Muon	1,076	343	1,419
Silicon	128	37	165
Global	2,536	848	3,384
Level 2:	6,772	1,949	8,671
Track	378	110	488
Calorimeter	522	151	673
Muon	306	89	395
Silicon	2,822	818	3,640
Global	2,694	781	3,475
Proj. Manag.	552	160	712
Total	21,863	6,965	28,828

0278CH


SDC Trigger Systems Cost Summary
Major WBS Elements showing Cost Categories

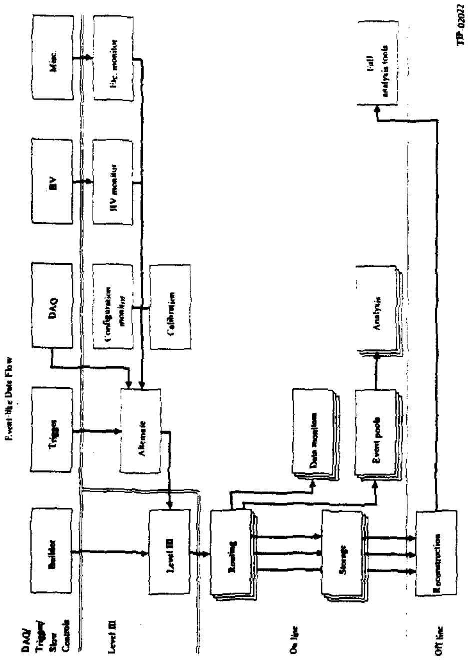
Trigger Schedule Milestones.

Major Milestone	Scheduled Date
Start Final L1 Design	January 1993
Test System Available	May 1993
Complete L1 Design Specs.	December 1993
Final L1 Design Review	January 1995
Complete Design of Level 1	June 1995
Start Final L2 Design	January 1994
Complete L2 Design Specs.	December 1994
Final L2 Design Review	July 1995
Complete Design of Level 2	December 1995
Deliver L1 & L2 Prototypes	June 1996
Initial Delivery of Trigger Interfaces	June 1996
Delivery of Trigger System Begins	January 1997
Begin Integration & Test w/partial systems	June 1997
Begin Integration & Test w/final systems	January 1998
Commission Trigger System	October 1999

ON-LINE COMPUTING

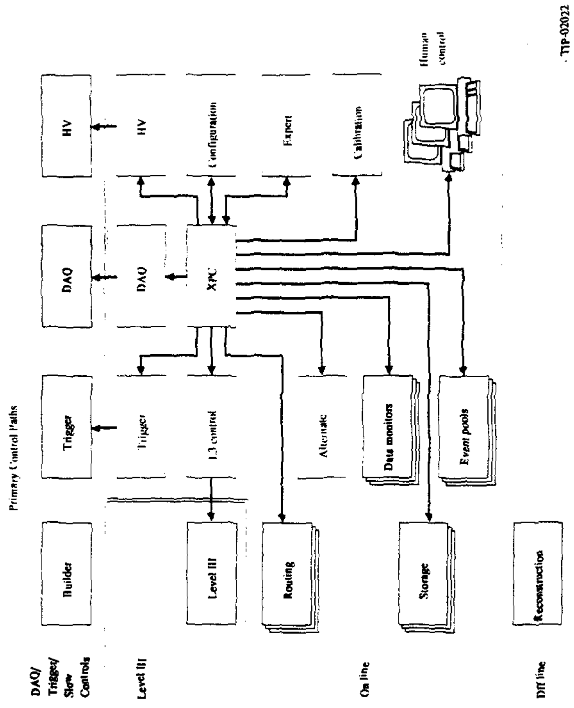
A. FRY

02788



A. Fry

02789



02790

Online Cost & Schedule Summary (92.05.08)

50 man-years of effort

- o evaluation and selection of commercial tools
- o detailed high level design and review
- o development and testing of proto-type software
- o documentation
- o close cooperation with off-line, daq, trigger, detector sub groups.
- o support/consultation with various subgroups
- o frequent incremental builds of the system

A. Fry

02791

Online Cost & Schedule Summary (92.05.08)

Encapsulation of User Code

Control Interface

Template Process

Data Interface

User Code

Human Interface

A. Fry

Online Cost & Schedule Summary (92.05.08)

Procurement

- o 50% of cost is hardware procurement and software licensing, assume some site licensing of well used products.
- o use "off the shelf" workstations, typically about 100 Mips: 4GB disk, about $25K each. Used in the online system and for development and debugging by the daq/detector groups.
- o some workstations will have higher performance some will act as fileservers, typically $50K each
- o mass storage tape drives $350K

A. Fry

Online Cost & Schedule Summary (93.05.08)

Major Milestones:

Data Structures etc.	July 93
Preliminary proto-types	Jan 94
SSCL testbeam	Jan 97
Level III routing & data logging	Oct 97
Muon system readout	Oct 97
Cosmic Ray tests	Mar 99

A. Fry

Online Cost & Schedule Summary (93.05.08)

Variables

- o Extent of overlap with:
  - testbeam program
  - integration costs
  - offline software
- o Extent to which it is appropriate to adapt and reuse existing software
- o time spent coordinating with and supporting software efforts of other groups
- o degree to which commercial software is appropriate
- o trade-off of quality vs man years
- o contingency ~~about~~ ≤ 30%

A. Fry

02795

WBS 7, 8, 9

D. ETHERTON

Conventional Systems
WBS 7

- **WBS Totals:**

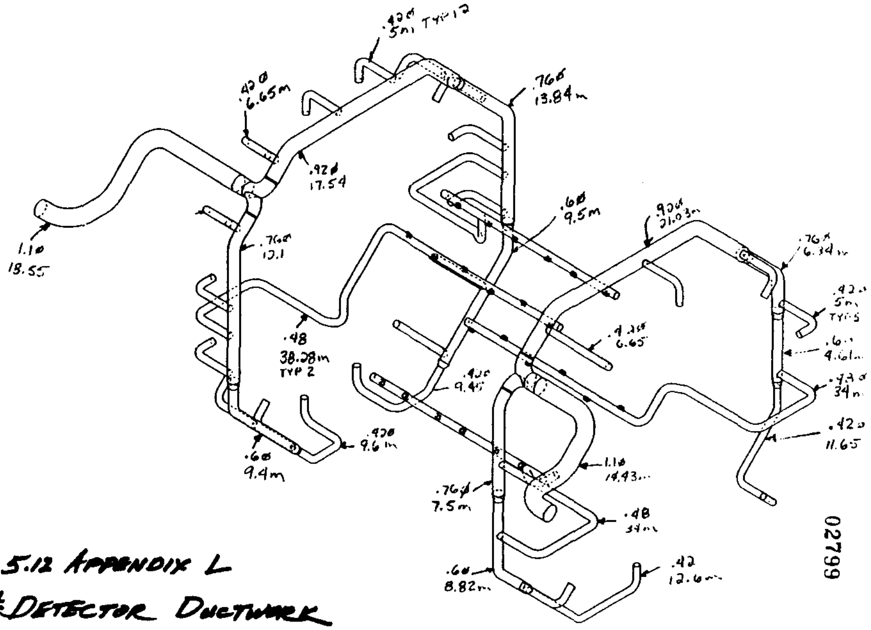
$11.5M	Base
2.7M	Contingency
$14.2M	Total

- **7.1 Conventional Mechanical Utilities = $2.5M**
  - 7.1.1 Deionizing Station
  - 7.1.2 HTLCW System
  - 7.1.3 LTLCW System
  - 7.1.5 MCHW System
  - 7.1.6 Detector Duct Work
  - 7.1.7 Venting Systems
- **7.2 Electrical Utilities = $1.7M**
  - 7.2.1 400 Hz Power
  - 7.2.2 Cable Trays
  - 7.2.3 60 Hz Distribution Power
  - 7.2.4 Grounding System
  - 7.2.5 IR Region Comm.
  - 7.2.6 Conv. Const. Interface

SDC

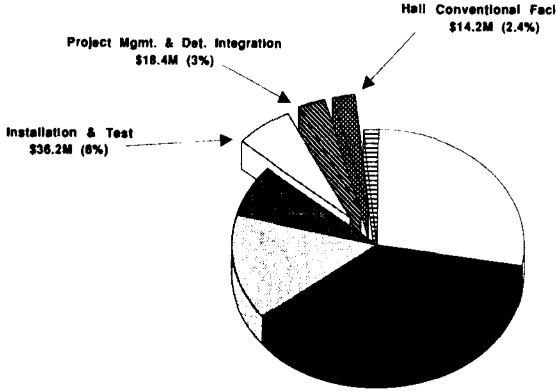
U.S. Cost Estimate

WBS Elements 7, 8, & 9

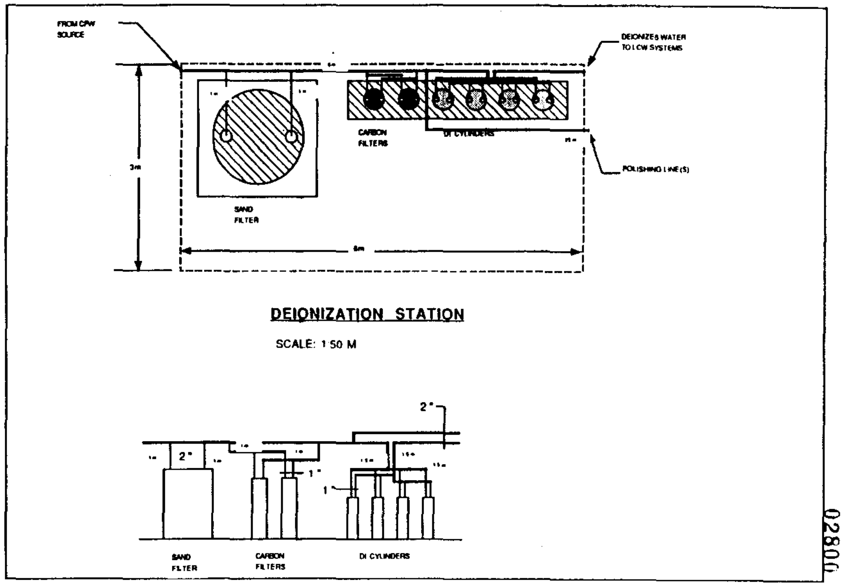


5.12 Appendix L
#4: Detector Ductwork

Summary of SDC Detector U.S. Cost Estimate by Subsystem



Total FY92 U.S. Cost Equivalent = $584M



5.12 Appendix L #1. Deionization Station

WBS DICTIONARY
BASIS OF ESTIMATE

WBS # 7.1.1

WBS NAME DI Station Sch 10 SS

ESTIMATE SOURCE/TYPE 1, 2, 4

1. VENDOR
2. BOTTOMS-UP
3. ANALOGY
4. ENGINEERING JUDGMENT
5. MANUFACTURING ANALYSIS/IE STANDARDS
6. HISTORICAL
7. PARAMETRICS/FACTORS

DEFINITION The deionization station consists of the filters and deionization tanks with standard carbon steel piping for the raw water and stainless steel type 316L schedule 10 for the deionized water. This serves as the make-up water system and polishing system for the HTLCW and LTLCW.

BASIS Pipe sizes and lengths are based on the conceptual design and drawings presented in the SEFUR. A sketch of the piping layout at the equipment is used for the material take-off with 10% of the piping allowed for fittings. Equipment and valving are actual take-off quantities. Cost of controls is based on an estimated number of control points and an average cost per point, using engineering judgment.

An escalation factor of 10% is used on all vendor supplied quotes to get 1992 material costs.

The pipe manifolds are assumed to be SSCL shop fabricated with manhours based on either the 1991 MEANS or an estimating textbook. The same is true for the installation of equipment and valving. All procured materials and equipment are temporarily stored at SSCL and shipped from the same place to the site.

The Installation assumes materials and/or equipmant cost approximately equal to 1% of total subsystem cost, and Testing at about 1/2%.

The engineering portion is based on 4 drawings at 24 mandays each, equally divided into preliminary and final designs with resources EN, EA, and DR proportioned as 25%,25% and 50%, raspectivaly.

5.11 Appendix K - #1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	WBS NUMBER	WBS OR ACTIVITY DESCRIPTION	UNIT	QTY	COST EA($)	EN M/D	ENM M/D	EA M/D	EAM M/D	DR M/D	DRM M/D	AD M/D	ADM M/D	TE M/D	TEM M/D	LA M/D
2	4/2/92															
3	7.1.1	DI Station Sch10 SS														
4	7 1 1 1	Engineering Documents	SS	1		24		24		48						
5	7 1 1 1 1	Prelim design				9		9		18						
6	7 1 1 1 2	Prelim review				3		3		6						
7	7 1 1 1 3	Final design				8		9		18						
8	7 1 1 1 4	Final review				3		3		8						
9	7 1 1 2	Header Subassembly	SS	1	3	16		1				15		3		3
10	7 1 1 2 1	Procure subassy matls				15						15				
11	7 1 1 2 2	Fab header subassy				1		1						3		3
12	7 1 1 2 3	2" manifold	LF	80	10											
13	7 1 1 2 4	1" branch lines	LF	40	6											
14	7 1 1 2 5	3/4" ball valves	Ea	12	32											
15	7 1 1 2 6	1/4" needle valves	Ea	4	63											
16	7 1 1 2 7	pressure gages with valves	Ea	4	143											
17	7 1 1 2 8	1" drain valves	Ea	2	42											
18	7 1 1 2 9	1" relief valve	Ea	1	210											
19	7 1 1 3	Deinization Station	SS	1	60	43		7				34		22		28
20	7 1 1 3 1	Major procura LLIM				30						38				
21	7 1 1 3 2	2- 25 gpm sand filters, 2-carbon filters	Ea	1	20000											
22	7 1 1 3 3	1 micron canister filter	Ea	2	2000											
23	7 1 1 3 4	2" ball valves	Ea	4	107											
24	7 1 1 3 5	2" strainers	Ea	3	1050											
25	7 1 1 3 6	2" check valves	Ea	2	429											
26	7 1 1 3 7	conductivity probes	Ea	2	2000											
27	7 1 1 3 8	2" pressure regulating vlalves	Ea	2	1980											
28	7 1 1 3 9	2" electronic flow meter	Ea	1	1800											
29	7 1 1 3 10	2" 3-way valve	Ea	1	4000											
30	7 1 1 3 11	2" polishing lines	LF	30	10											
31	7 1 1 3 12	2" main lines	LF	70	10											
32	7 1 1 3 13	Controls	Ea	14	700											
33	7 1 1 3 14	Hangers, Etc	Ea	70	100											
34	7 1 1 3 15	Preship review				4		4				4				
35	7 1 1 3 16	Ship to site				2										8
36	7 1 1 3 17	Install equipment				1		1						3		3
37	7 1 1 3 18	Install headers, piping				1		1						10		10
38	7 1 1 3 19	Install controls				1		1						3		3
39	7 1 1 3 21	Interface with CPW system				2								4		4
40	7 1 1 3 22	Component testing												2		
41	7.1.2	HTLCW Sys Sch16 SS														
42	7 1 2 1	Engineering Documents	SS	1		37		37		34				1		
43	7 1 2 1 1	Prelim design				14		14		28						
44	7 1 2 1 2	Prelim review				5		5		10						
45	7 1 2 1 3	Final design				14		14		28						
46	7 1 2 1 4	Final review				4		4		8				1		
47	7 1 2 2	Header Subassembly	SS	1	32	19		4				15		30		30
48	7 1 2 2 1	Procure subassy matls				15						15				
49	7 1 2 2 2	Fab header assy				4		4						30		30
50	7 1 2 2 3	6" butterfly	Ea	2	416											
51	7 1 2 2 4	4" butterfly	Ea	12	290											
52	7 1 2 2 5	4" strainer	Ea	3	2000											
53	7 1 2 2 6	4" check valves	Ea	3	1200											
54	7 1 2 2 7	3/8" vent valves	Ea	12	63											
55	7 1 2 2 8	pressure gauges	Ea	14	143											
56	7 1 2 2 9	thermometer wells	Ea	14	22											
57	7 1 2 2 10	4" control valves	Ea	3	3000											

5.9 Appendix I Cost Estimate Rollup Input

	A	B	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
1	WBS NUMBER	WBS OR ACTIVITY DESCRIPTION	SEMP	MINOR	MAJOR	WBS	WBS MAT	WBSBASE	CONTING	CONTING	WBS TOTAL	EDIA	MANUF	LABOR	EDIA
2	4/2/92		(K$)	(K$)	(K$)	M/D	(K$)	(K$)	%	(K$)	(K$)	(K$)	(K$)	(K$)	%
3	7 1 1	DI Station Sch10 SS													
4	7 1 1 1	Engineering Documents				96	0	29	10	3	32	29	0	29	100.00
5	7 1 1 2	Header Subassembly	3			36	3	14	10	1	16	11	0	11	78.91
6	7 1 1 3	Deinization Station			60	134	60	97	10	10	107	37	0	37	38.06
7	7 1 2	HTLCW Sys Sch 10 SS													
8	7 1 2 1	Engineering Documents				149	0	45	19	9	54	45	0	45	100.00
9	7 1 2 2	Header Subassembly		32		96	32	56	19	11	67	24	0	24	43.32
10	7 1 2 3	HTLCW Equipment and Piping			160	260	160	230	19	44	273	70	0	70	30.37
11	7 1 3	LTLCW Sys Sch10 SS(Abvgnd)				0	0	0		0	0	0	0	0	0.00
12	7 1 3 1	Engineering Documents				182	0	58	19	11	70	59	0	59	100.00
13	7 1 3 2	Header Subassembly		31		90	31	54	19	10	64	23	0	23	42.30
14	7 1 3 3	Aboveground LTLCW System			176	243	176	237	19	45	282	61	0	61	25.81
15	7 1 4	LTLCW Sys SS Sch 40 (unagnd)				0	0	0		0	0	0	0	0	0.00
16	7 1 4 1	Engineering Documents				240	0	73	19	14	87	73	0	73	100.00
17	7 1 4 2	Hall Equipment and Piping			134	96	134	162	19	31	192	26	0	28	17.13
18	7 1 4 3	Detector Equipment and Piping			131	126	131	166	19	32	200	37	0	37	21.91
19	7 1 5	FKLCW System													
20	7 1 5 1	Engineering Documents				240	0	73	23	17	90	73	0	73	100.00
21	7 1 5 2	Header Subassembly		2		55	7	18	23	4	22	11	0	11	81.12
22	7 1 5 3	FKLW Equipment and Piping			444	130	444	482	23	111	593	38	0	38	7.92
23	7 1 6	Detector Ductwork				0	0	0		0	0	0	0	0	0.00
24	7 1 6 1	Engineering Documents				192	0	59	32	19	77	59	0	59	100.00
25	7 1 6 2	Ductwork and Accessories			86	72	86	109	32	35	143	23	0	23	20.80
26	7 1 7	Venting Systems				0	0	0		0	0	0	0	0	0.00
27	7 1 7 1	Engineering Documents				96	0	29	46	13	43	29	0	29	100.00
28	7 1 7 2	Vent Equipment and Materials		19		67	19	38	46	18	56	19	0	19	50.48
29	TOTALS		3	89	1191	2634	1263	2032	0.21	436	2469	740	0	740	36.07
30															
31															
32															
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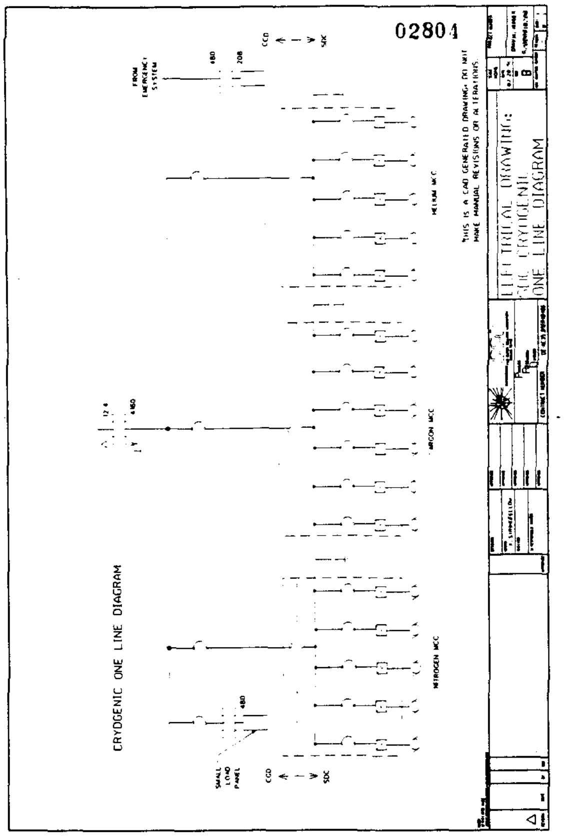
54															

5.1 Appendix A Cost/EDIA Summary WBS 7.1

02804



02805

Technical Board Review

Conventional Systems (cont.)

- 7.3 Safety Systems = $3.6M
  - 7.3.1 Oxygen Mngt. System
  - 7.3.2 Flammable Gas Mngt. System
  - 7.3.3 Personnel Access Safety System
  - 7.3.4 Emergency Centers
- 7.4 Structural Support and Access = $6.4M
  - 7.4.1 Structural Support for Detector
  - 7.4.2 Detector Access Systems
  - 7.4.3 Mechanical Shops
  - 7.4.4 Electrical/Electronic Shops
  - 7.4.5 Storage Facilities

DLE-3

5/3/92

WORK BREAKDOWN STRUCTURE

02806

WBS: 7.3
WBS Name: SYSTEM SAFETY INTEGRATED SYSTEM

Definition: The system safety integrated system includes all pertinent safety systems associated with the detector. This includes oxygen management systems for both personnel safety and material conditioning, flammable gas management for personnel and equipment protection, personnel access safety systems, and emergency centers. The interfaces of these elements are with the detector and laboratory safety control systems. This section contains engineering and material/labor costs.

7.3.1
WBS Name: OXYGEN MANAGEMENT SYSTEM

Definition: The oxygen management systam provides oxygen monitoring and enunciation through out the detector. The interfaces of this element are with the detector ventilation system and the detector control center. This section contains engineering and material/labor costs.

WBS: 7.3.2
WBS Name: FLAMMABLE GAS MANAGEMENT

Definition: The flammable gas management systems consists of monitoring, enunciation, and detection of flammable gasses of the detector. The interfaces of this element are with the mechanical gas mixing systems, the detector subsystems and the detector control center. This section contains engineering and material/labor costs.

WBS: 7.3.3
WBS Name: PERSONNEL ACCESS SAFETY SYSTEM

Definition: The personnel access safety system consists of the detector and pit access. It provides personnel access control, monitoring and procedures for construction repairing and operation the detector. The interfaces of this elements are with the hall infrastructure, and the control centers. This section contains engineering and material/labor costs.

WBS: 7.3.4
WBS Name: EMERGENCY CENTERS

Definition: The emergency centers consists of save zones and emergency equipment in the detector and detector pit. The interfaces of this element are with the hall infrastructure. This section contains material/labor costs.

02807

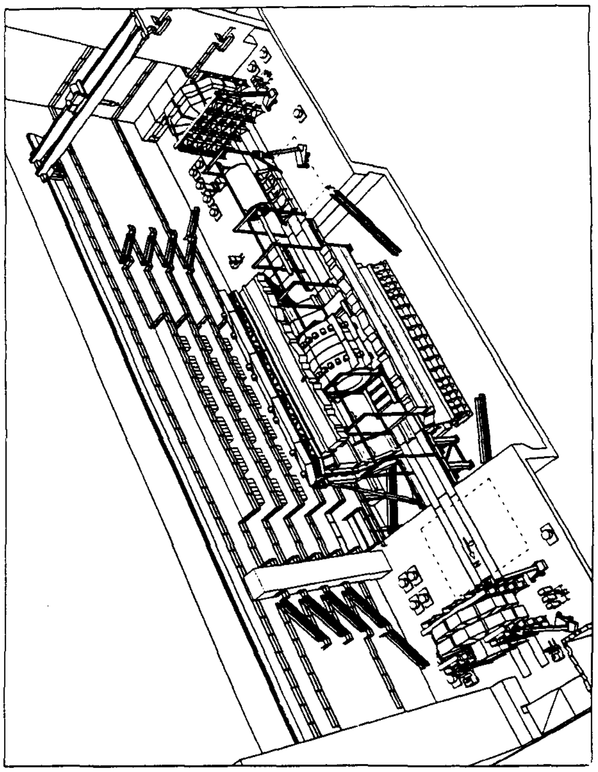


FIG. 13-8. View of interaction hall showing the superconducting solenoid being installed. Approximately month 24 of the installation schedule.

BY: FSS

5/1/92

SDC TEST BEAM PROGRAM

SUBSYSTEM BEAM TESTS

WBS 8.1.3

		BASE K$	CONTINGENCY 20%	TOTAL K$
8.1.3.1	FERMILAB	1,447	289	1,736
8.1.3.2	BNL	981	196	1,177
8.1.3.3	CERN	0	0	0
8.1.3.4	SSCL	1,989	398	2,387
	TOTAL FOR WBS 8.1.3	4,417	883	5,300

Prepared by Cost Estimating Group.

Rev 2

Technical Board Review

Test Beam Program
WBS 8.1

- WBS estimate is:

$7.3M	Base
1.6M	Contingency
$8.9M	Total

- 8.1.1 Fixtures & Facilities = $1.7M
- 8.1.2 Test Beam DAQ = $1.9M
- 8.1.3 Subsystem Beam Tests = $5.3M
- Estimate method was to identify possibilities for off- and on-site beam tests and supply facility modifications, test cadre, data acquisition and processing systems, and test operations expense money.

5/3/92

DLE-4

BY: FSS

5/1/92

SDC TEST BEAM PROGRAM

DAQ SYSTEM

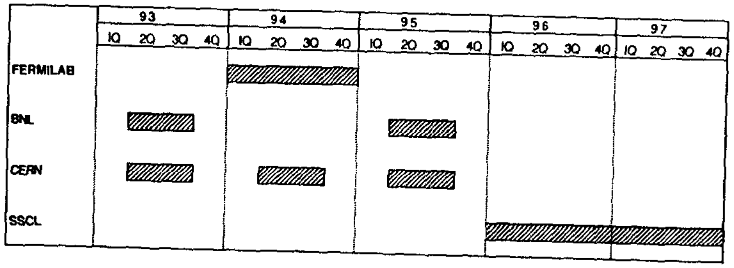
WBS 8.1.2

		BASE K$	CONTINGENCY 28%	TOTAL K$
8.1.2.1	TEST BEAM DAQ (PREVIOUS ESTIMATE BY ALAN FRY DATED 8/27/91, EXCLUDED TEST BEAM SUPPORT & PROJECT MANAGEMENT).	1,500	420	1,920
	TOTAL FOR WBS 8.1.2	1,508	420	1,920

Prepared by Cost Estimating Group.

Rev 2

SDC TEST BEAM PROGRAM
BEAM TIME AVAILABILITY



FSS

5/1/92

TEST BEAM PROGRAM

5/1/92

		JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	TOTAL	TOTAL
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	MD	K$
8.1.3	SUBSYSTEM BEAM TESTS																																																	11382	4377.8
8.1.3.1	FERMILAB	0	0	0	0	0	0	0	0	0	5	5	5	13	13	13	13	13	13	13	13	13	13	13	13	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3696	1466.4
8.1.3.1.1	SET UP																																																		
	ENGINEER										2	2	2																																					126	50.4
	ENGR-ASSOC.										2	2	2																																					126	45.4
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN																																																	0	0.0
	LABORER										1	1	1																																					63	11.1
	TOTAL LABOR										5	5	5																																					315	106.8
	MAJOR CONTRACTS $K																																																		
	TRAVEL										0	0	0																																						0.0
	FACILITIES										10	10	10																																						30.0
	TRANSPORT										10																																								10.0
8.1.3.1.2	RUN TIME																																																		
	ENGINEER													4	4	4	4	4	4	4	4	4	4	4	4																									1008	403.2
	ENGR-ASSOC.																																																	0	0.0
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN													6	6	6	6	6	6	6	6	6	6	6	6																									1512	435.5
	LABORER													3	3	3	3	3	3	3	3	3	3	3	3																									756	133.1
	TOTAL LABOR													13	13	13	13	13	13	13	13	13	13	13	13																									3276	971.7
	MAJOR CONTRACTS $K																																																		
	TRAVEL													0	0	0	0	0	0	0	0	0	0	0	0																										0.0
	CONSUMABLES													22	22	22	22	22	22	22	22	22	22	22	22																										260.0
8.1.3.1.3	TEAR DOWN																																																		
	ENGINEER																									1																								21	8.4
	ENGR-ASSOC.																																																	0	0.0
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN																									2																								42	12.1
	LABORER																									2																								42	7.4
	TOTAL LABOR																									5																								105	27.9
	MAJOR CONTRACTS $K																																																		
	TRAVEL																									0																									0.0
	TRANSPORT																									0																									0.0

BY: FSS

5/1/92

SDC TEST BEAM PROGRAM

FIXTURING

WBS 8.1.1

		BASE K$	CONTINGENCY 20%	TOTAL K$
8.1.1.1	CALIBRATION MANIPULATOR (FROM PREVIOUS ESTIMATE PREPARED BY DENNIS COX DATED 11/4/91)	1,133	227	1,360
8.1.1.2	CALIBRATION TEST STANDS	100	20	120
8.1.1.3	LIFTING FIXTURES	150	30	180
	TOTAL FOR WBS 8.1.1	1,383	277	1,660

Prepared by Cost Estimating Group.

TEST BEAM PROGRAM

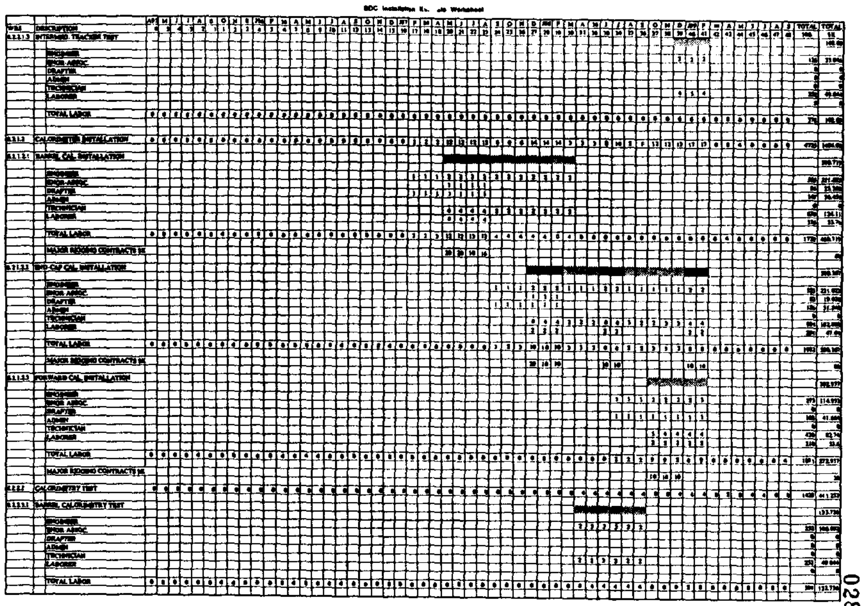
5/1/92

		JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O			TOTAL	TOTAL
		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82			MD	K$
8.1.3.4	SSCL	0	0	0	0	0	0	0	0	0	5	5	5	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	5	0	0	0	0	0	0	0	0	0			5964	1966.8
8.1.3.4.1	SET UP																																																		
	ENGINEER										2	2	2																																					126	63.0
	ENGR-ASSOC.										2	2	2																																					126	38.1
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN																																																	0	0.0
	LABORER										1	1	1																																					63	10.1
	TOTAL LABOR										5	5	5																																					315	101.2
	MAJOR CONTRACTS $K																																																		
	TRAVEL										0	0	0																																						0.0
	FACILITIES										10	10	10																																						30.0
	TRANSPORT										10																																								10.0
8.1.3.4.2	RUN TIME																																																		
	ENGINEER													2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2													1008	424.4
	ENGR-ASSOC.																																																	0	0.0
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN													6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6													3024	756.0
	LABORER													3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3													1512	241.9
	TOTAL LABOR													11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11													5544	1422.3
	MAJOR CONTRACTS $K																																																		
	TRAVEL													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0														0.0
	CONSUMABLES													16	16	16	16	16	16	16	16	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17														400.0
8.1.3.4.3	TEAR DOWN																																																		
	ENGINEER																																					1												21	8.8
	ENGR-ASSOC.																																																	0	0.0
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN																																					2												42	[illegible]
	LABORER																																					2												42	[illegible]
	TOTAL LABOR																																					5												105	[illegible]
	MAJOR CONTRACTS $K																																																		
	TRAVEL																																					8													8.0
	TRANSPORT																																																		0.0

TEST BEAM PROGRAM

5/1/92

		JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	JAN	F	M	A	M	J	J	A	S	O	N	D	TOTAL	TOTAL
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	MD	K$
8.1.3.2	BNL	4	4	4	4	4	4	4	4	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1722	981.9
8.1.3.2.1	SET UP																																																		
	ENGINEER	1	1	1																						1	1	1																						126	63.0
	ENGR-ASSOC.	2	2	2																						2	2	2																						252	76.1
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN																																																	0	0.0
	LABORER	1	1	1																						1	1	1																						126	20.2
	TOTAL LABOR	4	4	4																						4	4	4																						504	140.3
	MAJOR CONTRACTS $K																																																		
	TRAVEL	16	16	16																						16	16	16																							96.0
	FACILITIES	10	10	10																						10	10	10																							60.0
	TRANSPORT	10																								10																									20.0
8.1.3.2.2	RUN TIME																																																		
	ENGINEER				1	1	1	1	1	1																			1	1	1	1	1	1																252	108.1
	ENGR-ASSOC.																																																	0	0.0
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN				2	2	2	2	2	2																			2	2	2	2	2	2																504	126.0
	LABORER				1	1	1	1	1	1																			1	1	1	1	1	1																252	40.3
	TOTAL LABOR				4	4	4	4	4	4																			4	4	4	4	4	4																1008	272.4
	MAJOR CONTRACTS $K																																																		
	TRAVEL				16	16	16	16	16	16																			16	16	16	16	16	16																	192.0
	CONSUMABLES				7	7	7	7	2	7																			7	7	7	7	2	2																	80.0
8.1.3.2.5	TEAR DOWN																																																		
	ENGINEER										1																								1															42	17.7
	ENGR-ASSOC.																																																	0	0.0
	DRAFTER																																																	0	0.0
	ADMIN																																																	0	0.0
	TECHNICIAN										2																								2															84	21.0
	LABORER										2																								2															84	13.4
	TOTAL LABOR										5																								5															210	52.1
	MAJOR CONTRACTS $K																																																		
	TRAVEL										20																								20																40.0
	TRANSPORT										10																								10																20.0



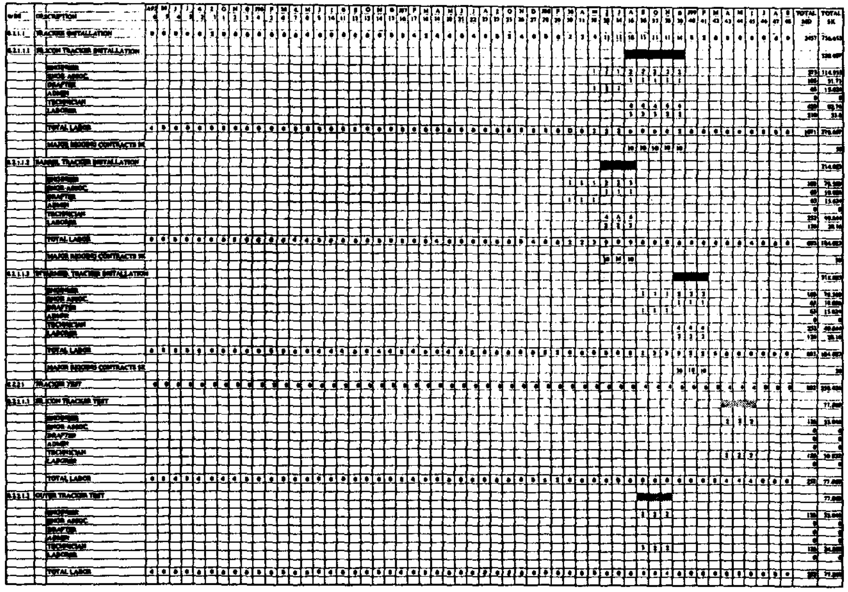
Technical Board Review

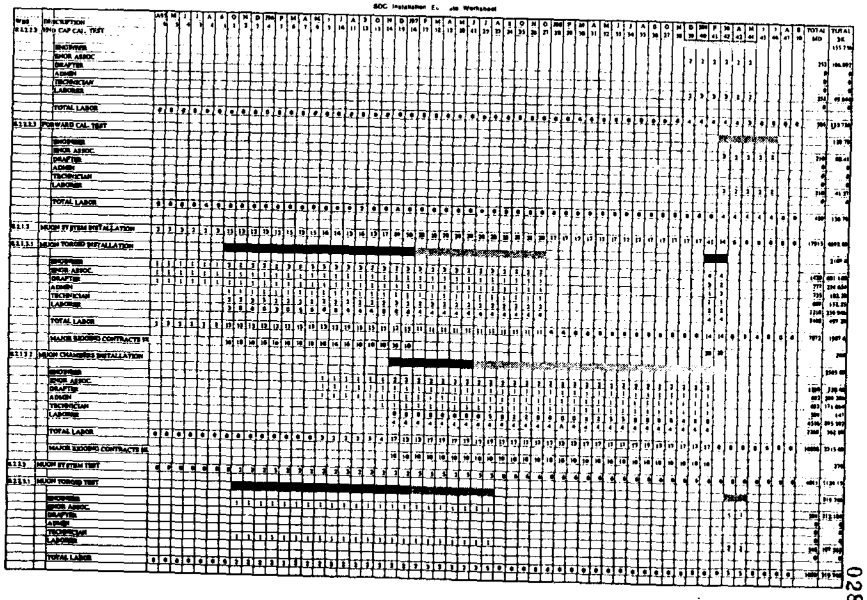
Subsystem Installation & Test
WBS 8.2

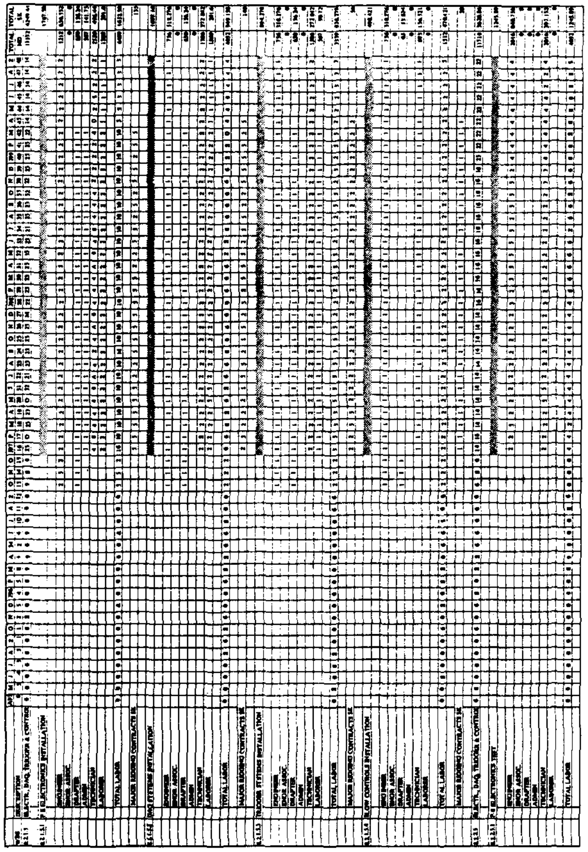
- WBS estimate is:

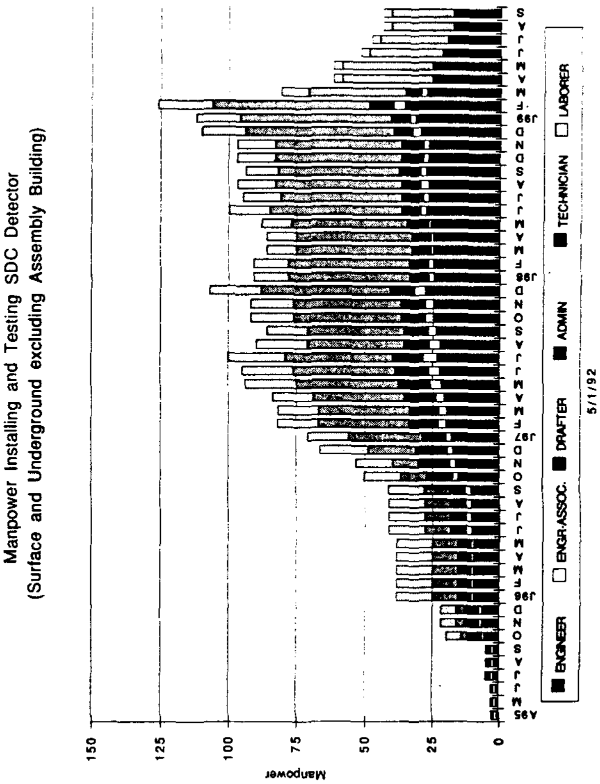
$22.4M	Base
4.9M	Contingency
$27.3M	Total

- Takes system components from "Top of Hole" and assembles, installs, integrates, and tests.
- Finishes with commissioning of detector - Ready to receive beam in October 1999.
- Strategy is to identify common facility tasks like crane operators, some riggers, tool crib personnel, clean-up crews, etc. and have those provided by SSCL under Facility Operations.
- Estimating method uses preliminary schedule and forecasts labor, material, and rigging contracts to install and test each subsystem









Installation & Test Major Milestones

8.2 Installation & Test Major Milestones

Hall Availability for Support System Installation	Oct-95
Begin Conventional Systems Installation	Oct-95
Muon Barrel Toroid Steel at T.O.H.	Oct-95
Begin Muon Barrel Installation	Jan-96
Hall Beneficial Occupancy (Baseline)	Jan-96
Barrel Toroid Steel Complete	Aug-96
Begin Electronics Installation & Test	Aug-96
Muon Barrel Chambers at T.O.H.	Aug-96
Coil Installation Complete	Dec-96
End Toroid Steel at T.O.H.	Dec-96
Barrel Cal. Toroid Ready at T.O.H.	Jan-97
Phase I Muon Complete	May-97
Begin Calorimeter Connect Signal/Power Cool	Jun-97
Solenoid & Chimney & Electronics arrives at SSCL	Jun-97
Begin Solenoid Electronics Installation	Aug-97
Ready to Begin Solenoid Installation	Aug-97
Muon End Chambers at T.O.H.	Sep-97
End Cap Calorimeters at T.O.H.	Nov-97
Solenoid Installation Complete	Dec-97
Barrel Tracking System Electronics Inst. & Checkout	Feb-98
Ready to Begin Solenoid Electronics Field Mapping	Feb-98
Ready to Install Electronics for Tracking Systems	Feb-98
Ready to Begin Field Mapping	Mar-98
Central Trackers Ready for Inst. at T.O.H.	May-98
Field Mapping Complete	Jun-98
Ready to Install Tracking System	Jun-98
Si/Pixel Tracker Ready for Installation T.O.H.	Jul-98
Forward Calorimeter at T.O.H.	Oct-98
Interm. Tracker Ready for Installation T.O.H.	Nov-98
Forward Muon System Ready for Installation	Feb-99
Conv. Systems End Caps Calorimeter Installed	Mar-99
Conventional Tracking System Installed	Mar-99
Detector Ready to Roll In Forward Muon Toroid Sys.	Mar-99
Electronics Tracking System Installation Complete	Mar-99
End Cap Calorimeter Installation Complete	Mar-99
End Cap Cals Installed	Mar-99
Tracking System Installation Complete	Mar-99
Begin Accelerator Work	Apr-99
Main Detector Installation Complete	Apr-99
Accelerator Complete	Jul-99
Hall Conventional Systems Installation Complete	Jul-99
Detector Turn-on	Oct-99

Project Management
WBS 9

- WBS estimate is:

$15.9M	Base
2.5M	Contingency
$18.4M	Total (3.2% of total project cost)

- Defined as overall SDC project management at SSCL supporting total project planning, tracking, administration, coordination, and integration.
- Includes: SDC project manager, chief engineer & staff.
  Project planning, tracking, and reporting
  Document control and distribution
  Detector integration
  ES&H, QA
- ~27 FTE's x 7 Years = 192 FTE's = $18.4M
- Is augmented by Subsystem project management at lower levels of WBS elements 1 - 6 (about $22M to add to $18M = $40M or 7% of total cost)

02825

PARALLEL SESSION I:
COLLABORATION/RESOURCES

COLLABORATION MANAGEMENT AND DRAFT MANAGEMENT PLAN

T. KIRK

SDC Review

Parallel Session Presentations

May 7, 1992

Parallel Session I

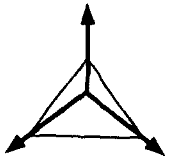
Collaboration / Resources

Thomas B. W. Kirk
SDC Project Manager

The Project Manager's

Dilemma . . .

TECHNICAL PERFORMANCE
better!



cheaper!
COST
PERFORMANCE

faster!
SCHEDULE
PERFORMANCE

Once the basic mission has been identified, its execution becomes a continuous struggle to stay within the sponsor's ***triangle of acceptability.***

Basic SDC Project Goals and Tools for their Realization

GOAL	TOOL
The detector must meet its physics performance specs.	Physicist oversight, insight and reviews
The detector elements must work (technical performance)	Engineering reviews, CM and Q/A Programs
The detector must be ready on time (schedule performance)	Management role, i.e. planning, tracking and resource allocation
The costs cannot exceed the funding provided (cost performance)	Value engineering, early procurement, and vigilant production oversight; vigorous sponsor solicitation

---

Strategy for Detector Work

- Offsite Design & Production to Max Extent
  - — U.S. Sources
  - — Non-U.S. Sources
- SSCL - Based Integration & Installation
  - — Installation at SSCL is intrinsic
  - — Integration has three key areas of application
    - - detector subsystems
    - - machine/detector interface
    - - conventional facilities interface
- Beam Tests / R & D Activity
  - — FNAL in early years
  - — CERN/BNL/KEK/BEPC for special studies
  - — SSCL after 1996
- Management and Tracking
  - — SSCL - based for high level aspects
  - — Offsite - based for subsystem level aspects
  - — Coordination/liaison personnel as needed
- ESH Aspects
  - — Installed elements must meet SSCL standards
  - — Offsite activity must meet local standards

SDC Management

- Management is organized by major subsystems (WBS) with staff support functions.
- Subsystem managers are geographically dispersed
- Major technical decisions are made by SDC Technical Board
- Reporting is through PRD for SDC Project and through SDC Executive Committee for Collaboration issues
- Tracking, reporting, integration and change control are centered at SSCL
- Details of management tropical areas and methods in SDC Project Management Plan (Draft due to D&E, September 1991)

SOLENOIDAL DETECTOR COLLABORATION
DRAFT PROJECT MANAGEMENT PLAN
APRIL 1, 1992

Submitted by

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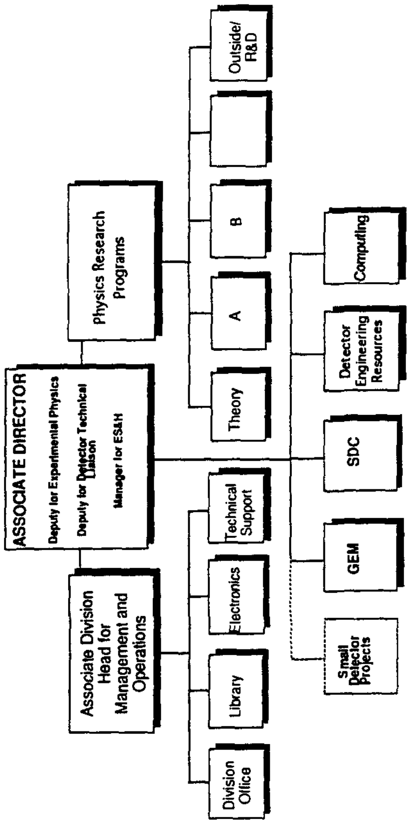
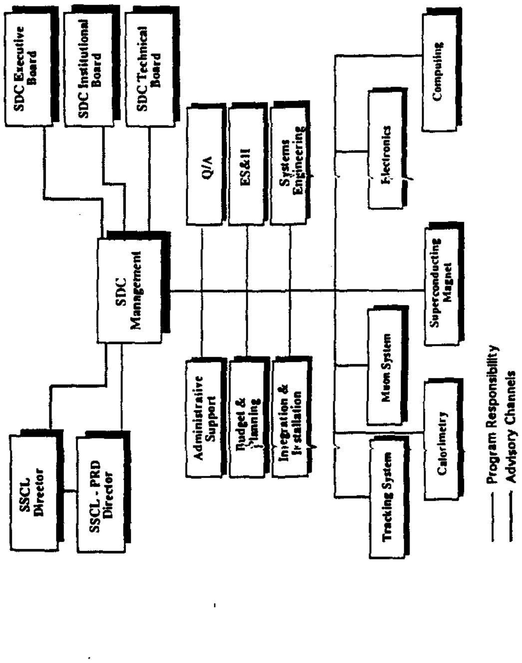
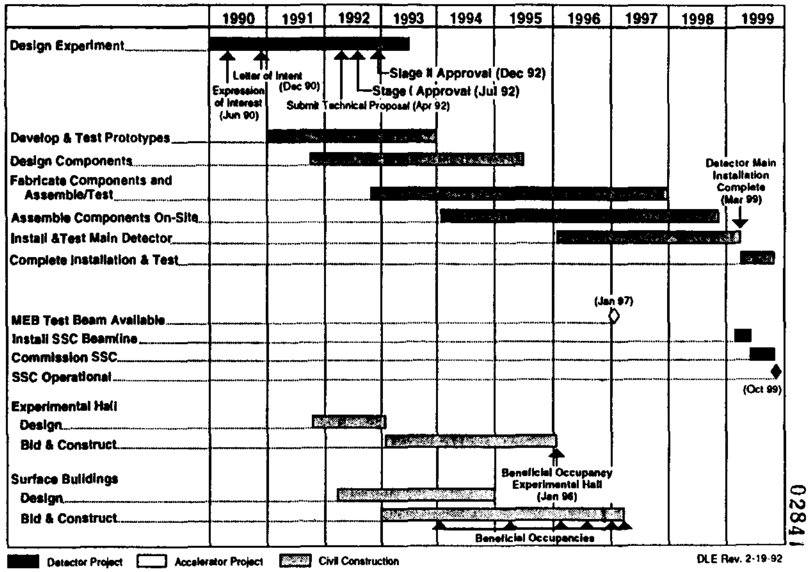
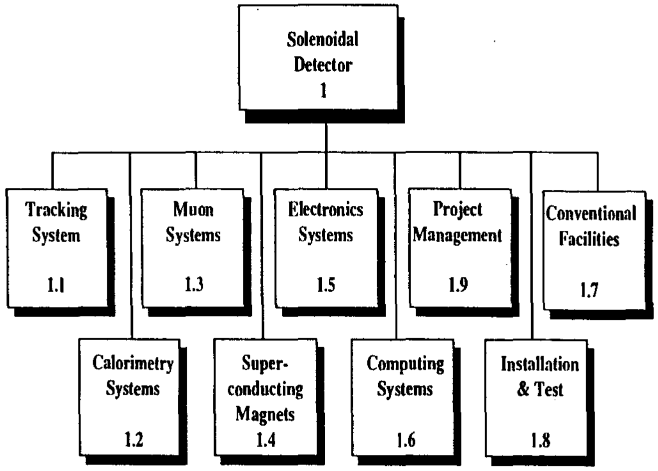
Physics Research Division Organization



SDC Organization
(Draft SDC Management Plan)







Solenoidal Detector
1

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- Calorimetry Systems 1.2
- Muon Systems 1.3
- Super-conducting Magnets 1.4
- Electronics Systems 1.5
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Measurement and Reporting Overview

An integrated cost/schedule/technical Performance Measurement System (PMS) will be utilized on the SDC Project, in order to support SDC project management and reporting. Based on the SDC WBS, and the baselines established following establishment of the approved SDC Technical Design, the SDC will establish monthly performance measurement reporting. For SDC activity performed at non-US institutions, or involving in-kind contributions, special procedures will be implemented to track schedule and technical progress. In most cases those special approaches will be spelled out in individual institutional agreements established by SDC management.

Detector Cost Considerations

- **The cost estimation and tracking will follow methodology described in the SDC Project Management Plan (PMP)**
- **Resources to meet the approved cost elements will be provided through multiple U.S. and non-U.S. resources**
  - **— multiple accounting methods for foreign contributions**
  - **— resulting cost tracking will be evaluated using SSCL methodology (U.S. protocols)**
- **Reporting on project evolution will follow the prescriptions identified in the SDC PMP**
- **Oversight and review of the cost performance will be carried out as prescribed in SDC PMP**

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STATUS OF RESPONSIBILITIES, RESOURCES AND FUNDING

G. TRILLING

Solenoidal Detector Collaboration

International Funding Plan

INTRODUCTION

The Solenoidal Detector Collaboration (SDC) is proposing to design and build a large, general purpose detector to pursue a broad range of physics goals at the Superconducting Super Collider (SSC). The SDC is comprised of approximately 100 institutions from throughout the world. The distribution and number of the institutions is summarized in Table 1. About 900 physicists and engineers are presently involved in the design of the SDC detector. The design, construction and eventually operation of the SDC detector will be the responsibility of the participating institutions and their respective staffs. Funds for the design and construction of the detector will be provided by the countries involved through the laboratories and universities who are members of the SDC. This document summarizes the present understanding of the division of responsibilities among the various countries within the SDC for design and construction of the detector subsystems and also provides a brief overview of the funding situation within each country. Negotiations as to the divisions of responsibilities between collaborating groups are further advanced in some subsystems than in others, and, in such cases, are reflected in specific percentage divisions of effort. In most cases, the divisions are still under discussion, and no specific percentages are given.

Table 1
Collaboration Institutional Membership

Brazil	1 institution
Canada	7 institutions
China	2 institutions
Commonwealth of Independent States	9 institutions
Eastern Europe	4 institutions
France	1 institution
Israel	1 institution
Italy	3 Institutions
Japan	17 institutions
United Kingdom	4 institutions
U.S.A.	53 institutions

COST SUMMARY

The cost of the SDC detector has been estimated in detail by using standard U.S. estimating practices and the detailed costs are summarized elsewhere.(1) To a large extent the contributions to the design and fabrication of the detector components from outside the United States will be in the form of in-kind contributions totally funded by the countries involved. In the case of the member states of the Commonwealth of independent States (CIS) and the Peoples Republic of China (PRC), hard currency compensatory payments from the United States or other SDC collaborating countries may have to be provided to defray the costs of local industry and the subsistence costs of collaborators from those countries in connection with their SDC-related visits to the SSCL or other institutions. These compensatory payments will not exceed 50% of the estimated U.S. costs for the items being provided.

Taking account of the in-kind contributions, and, where relevant, the compensatory payments, we obtain the subsystem by subsystem apportionment of detector costs shown in Table 2. The totals given in Table 2 for the non-U.S. contributions represent the U.S. EQUIVALENT COST OFFSETS, and do NOT represent the totals of funds actually being requested in the various countries. Accounting practices in each country are different; and, in many cases, most labor costs associated with design and fabrication are separated out from the funding requests, unlike U.S. practice.

The numbers given in Table 2 are very preliminary and represent the present status of the division of responsibilities among the countries involved in the SDC. As the design of the detector evolves, the national responsibilities will become more precisely defined. In the sections below, we describe in general terms the responsibilities of the various countries in each subsystem. A summary of the general funding situation in each country is also provided. This document provides a framework for more detailed agreements to be worked out between these countries and the Department of Energy and/or the SSC Laboratory.

Table 2

SDC Funding

U.S. Equivalent Costs

	Estimated Cost	U.S.		Non-U.S.	
	M$	%	M$	%	M$
1 Tracking Systems	**88.8**	**65**	**57.7**	**35**	**31.1**
1.1 Silicon Tracker	41.2	66	27.1	34	14.1
1.2 Straw-Tube Barrel Tracker	31.5	97	30.7	3	0.9
1.3 Gas Microstrip Intermediate Tracker	16.1	0	0.0	100	18.1
2 Calorimetry	**162.4**	**64**	**104.0**	**36**	**58.4**
2.1 Barrel Calorimeter	90.6	64	57.7	36	32.9
2.2 End Cap Calorimeter	59.2	78	46.3	22	12.9
2.3 Forward Calorimeter	12.5	0	0.0	100	12.5
3 Muon Systems	**115.8**	**71**	**82.6**	**29**	**33.2**
3.1 Muon Magnets	59.6	58	34.8	42	24.9
3.2 Muon Measurement System	56.2	85	47.8	15	8.4
4 Superconducting Magnet	**42.4**	**33**	**13.9**	**67**	**28.5**
4.1 Superconducting Solenoid	33.9	16	5.4	84	28.5
4.2 Cryogenic System	8.5	100	8.5	0	0.0
5 Electronics Systems	**97.0**	**57**	**55.1**	**43**	**42.0**
5.1 Front-End Electronics	43.9	45	19.9	55	24.0
5.2 Data Acquisition System	20.4	77	15.7	23	4.7
5.3 Trigger System	28.8	54	15.6	46	13.2
5.4 Control System	3.9	100	3.9	0	0.0
6 Computing	**9.3**	**90**	**8.4**	**10**	**0.9**
6.1 On-Line Computing	8.3	90	8.4	10	0.9
7 Conventional Systems	**14.2**	**100**	**14.2**	**0**	**0.0**
7.1 Mechanical Utilities	2.5	100	2.5	0	0.0
7.2 Electrical Utilities	1.7	100	1.7	0	0.0
7.3 Safety Systems	3.6	100	3.6	0	0.0
7.4 Structural Support/Access Equipment	6.4	100	6.4	0	0.0
8 Installation & Test	**36.2**	**65**	**23.5**	**35**	**12.7**
8.1 Test Beam Program	8.9	65	5.7	35	3.2
8.2 Installation & Test	27.3	65	17.7	35	9.6
9 Project Management	**18.4**	**100**	**18.4**	**0**	**0.0**
Total $M	584		377		207
Percentages			65%		35%

TRACKING

Silicon Tracker

The construction of the silicon subsystem will involve a large international collaboration with the following general interests:

a. High precision vertexing - Italian and U.S. groups.
b. Integration and testing of barrel detector - Japanese groups.
c. Integration and testing of forward disk detectors - U.S. groups in collaboration with Italian groups.
d. Mechanical integration of full system - U.S. groups.
e. Development of DAQ and Trigger for silicon (mentioned for completeness, but discussed in DAQ and Trigger budgets) - Collaboration of Italian and U.K. groups.

Despite the large geographical spread of activities, we plan to have a unified design. Items will be procured in the most cost-effective manner and then distributed to the groups focusing on specific parts of the full silicon detector (e.g., barrel and disk regions).

Given this approach we foresee the following contributions from non-U.S. groups:

1. The vertex-oriented inner detectors (5% of total)-Italy

2. The remaining detectors (95% of total)-Japan

3. The assembly of modules, and the bonding and testing for the barrel (35% of total module assembly costs) - Japan

4. Mechanical support structures for barrel (10% of total mechanical costs) - Japan

5. The assembly of modules into structure (35% of assembly costs) - Japan

6. The assembly of modules, bonding and testing for forward disks (20% of total module assembly costs) - Italy

7. Purchase of front-end electronics (25% of total front-end electronics costs) - Italy

8. Purchase of power supplies (100% of total) - Italy

In addition, should the collaboration proceed with the addition of pixel detectors (initially or as an upgrade) the Italian groups will contribute 50% of the pixel costs. The remaining systems, including the remaining front-end electronics, will be responsibilities of U.S. groups.

Barrel Tracker

We are considering two alternative options for the barrel tracker: a straw tube tracker or a scintillating-fiber tracker. The design and fabrication of either option for the barrel tracker is almost completely a U.S. responsibility. In the case of the straw tracker, Japan will contribute effort for the mechanical mounting of the electronics, since Japan will have the major responsibility for the electronics (see front-end electronics section). In the case of the scintillating fiber tracker, Japan and Italy could contribute the full fiber ribbons, and discussions are under way. All other aspects of both options would be a U.S. responsibility.

Gas Microstrip Intermediate Tracker

Groups from Canada and the United Kingdom will request, at an appropriate time, their respective funding authorities to make available the necessary resources to build and install the detector, its support structure, front end electronics, utilities, trigger and DAQ systems. There is general agreement among the groups that the funding will be split approximately 50/50 between Canada and the U.K.

SUPERCONDUCTING SOLENOID

A prototype of the superconducting magnet is presently under construction in Japan as a collaborative effort between Japan (90%) and the U.S. (10%). The U.S. is responsible for the prototype vacuum vessel. The final magnet will be produced exclusively in Japan and the Japanese group will be responsible for transportation to the U.S. The responsibilities for installation, the cryogenics system, the power supply systems and the field-mapping systems are under discussion between the U.S. and Japanese groups.

CALORIMETRY

Central Calorimetry

Significant contributions to central calorimetry are expected from France, Italy, Japan, the PRC, and possibly the Russian Federation. Contributions to the mechanical structure of Pb and Fe absorber plates are being discussed with institutions in both the PRC and Russia. The scintillator tiles must be cut, polished, and grooved. Wavelength shifting fibers (WLS) are then installed within the grooves and spliced to clear fibers which run to the photo multiplier tubes (PMT) which are located on the rear of the calorimeter. The fabrication and testing of the tile/fiber assemblies will be the responsibility of Italy, Japan and the PRC. Italy and Japan will share PMT procurement and testing. The shower maximum detector (SMD) strip/fiber assembly will be solely the responsibility of France, while the SMD transducer procurement, test, and screening will be the joint responsibility of Italy and the U.S.

The assembly of the optical system into the absorber structure will be done by the U.S. institutions. The assembly of the PMT into the calorimeter tower structure will similarly be done in the U.S. The signal/HV bases will be built and tested jointly by Italy, Japan, and the U.S. The somewhat different SMD bases will be built and tested by Italy and the U.S. The calibration system is integral to the optical assembly and quality control. Therefore, it will be done entirely in the U.S., where final assembly into the absorber structure takes place. The high voltage power supplies for the PMT will be jointly purchased by Italy, Japan, and the U.S. Possible cost sharing among countries for the design and construction of the support structure has not yet been negotiated.

Forward Calorimetry

It is expected that the Canadian SDC group will request funding from Canada to cover the Forward Calorimeter as a complete subsystem. The subsystem will consist of the detector itself, power supplies, front-end electronics, calibration and monitoring systems, trigger electronics, and the data acquisition and control system. While the installation will be mostly performed by SSCL personnel, the Canadian group will help to provide manpower for installation.

MUON SYSTEM

The muon system will be designed and fabricated by a collaboration of U.S., Japanese, and CIS groups. A contribution by Italy is also being discussed. The U.S. and CIS groups will collaborate on the design and fabrication of the muon toroids and magnetizing coils. The U.S. and Japanese groups will work together on the barrel and intermediate chamber systems and the U.S. and CIS on the forward muon chambers. Production of the scintillation counters will be the responsibility of the CIS, the U.S. and possibly Italy.

Iron Toroids

The viability of construction of all the iron toroids in the CIS is presently under study, including the determination of compensatory payments. Design of the barrel toroid will be done primarily in the U.S. with some contribution from CIS groups. Design of the forward toroids would be split between the U.S. and CIS. CIS would contribute materials for the construction of the coils for the barrel toroid, but design and fabrication would take place in the U.S. Coils for the forward toroids would be designed and fabricated in the CIS. Power supplies will be provided by the U.S. The U.S. would design the support structures for the toroids. Potential cost sharing on the fabrication of these support structures is yet to be negotiated.

Chambers

The U.S. and Japan will collaborate on the production of the muon chambers for the barrel and intermediate regions. The U.S. and CIS will share the responsibility for the forward chambers, with most of the chamber fabrication occurring in the CIS.

Responsibility for all assembly and alignment will be primarily borne by the U.S., since this must be done at the SSC site.

Scintillation and Cerenkov Counters

The CIS, Italy and the U.S. shall have the major responsibility for fabrication of scintillation counters, with compensatory payments shared between the U.S. and Italy. The U.S. will share responsibility for design and production, and have final responsibility for assembly on site. The major responsibility for the Cerenkov option will be in the CIS, which will be responsible for phototubes, mirrors and support structure fabrication. Design work will be divided between the U.S. and the CIS.

FRONT-END ELECTRONICS

Barrel Straw Tracker

Japan will design and produce the straw tube front-end electronics in collaboration with the U.S. Primary responsibility for manufacture of chamber-mounted front-end boards will be Japanese. U.S. R&D on radiation-hard amplifier-shaper-discriminator and data-collection chip (DCC) IC's will continue. Primary responsibility for the mechanical interface of front-end boards to the chamber will be U.S., as will primary responsibility for the nearby, on-detector interface cards. It is estimated that, in these efforts, Japan would carry most of the straw tube front-end electronics cost, with the U.S. carrying the rest.

Fiber Tracker

The U.S. will carry full responsibility for front-end electronics.

Central Calorimetry

The U.S. will carry full responsibility for the tower front-end electronics.

France will adapt the design of the front-end electronics of the calorimeter towers for the relevant photodetectors, dynamic range, and trigger interface required for the shower maximum detector (SMD) strips. The design will use the current splitter/integrator or switched capacitor array (SCA) ASIC's developed for the calorimeter towers. France and Italy will share in the production of the readout boards for the SMD.

Forward Calorimetry

Canada will adapt the design of the front-end electronics of the calorimeter towers for the appropriate active media and segmentation in the forward calorimeters. Canada will fabricate all front-end electronics boards and crates, including purchase of ASIC's common with the central calorimeter.

Muon System

Japan and the U.S. will collaborate on the design of front-end electronics and the mechanical interface of electronics to chambers. The design envisages use of the same amplifier-shaper-discriminator (ASD), time memory cell (TMC), and Level 2 buffer (L2B) ASIC's as designed for the straw tracker. Japan will fabricate the front-end electronics boards, including purchase of ASIC's for the barrel and intermediate chambers. The U.S. will purchase the ASIC's for the forward chambers, and the U.S. and CIS will share the fabrication of the front-end electronics for the forward chambers. The U.S. and Italy will design, and the U.S., Italy, and CIS will provide the PMT bases and preamplifiers for muon scintillators in all angular regions. The Level 1 and Level 2 storage and trigger interface for the scintillators is included on the same front-end boards as for the chambers. It is expected that the Japanese effort will amount to a major part of the muon front-end electronics cost; and that, including compensatory payments, the remainder will be split between the U.S. and CIS.

DATA ACQUISITION SYSTEMS

Silicon Tracker

Italy (50%) and the U.K. (50%) will collaborate on the design and fabrication of all off-detector readout electronics and software specific to the silicon tracker, including Level 2 buffers, crates, DAQ CPU's, links to the event builder, and trigger control modules. Much of this electronics is integral with the silicon tracker Level 2 trigger electronics, which is shared by Italy and the U.K. in the same proportion.

Barrel Tracker

The U.S. will carry full responsibility for the straw tube and fiber tracker DAQ systems.

Gas Microstrip Intermediate Tracker

Canada (50%) and the U.K. (50%) will collaborate in adapting the design of silicon tracker off-detector electronics to the gas microstrip intermediate tracker and on the fabrication of all off-detector readout electronics and software specific to the gas microstrip intermediate tracker, including Level 2 buffers, crates, DAQ CPU's, links to the event builder, and trigger control modules. Much of this electronics is integral with the gas microstrip Level 2 trigger electronics, which is shared by Canada and the U.K. in the same proportion.

Forward Calorimeter

Canada will design and fabricate all data acquisition electronics and software specific to forward calorimeter, including crates, CPU's, links, and trigger control modules.

Muon System

Japan and the U.S. will collaborate on the design and fabrication of all data acquisition electronics and software specific to the muon system, including crates, CPU's, links, and trigger control modules.

Development, crates, etc.

The U.S., Japan, Canada, and France will collaborate on the design of the portion of the data acquisition system which is not specific to particular subsystems and which lies upstream of the event builder, its input queuing logic, and the Level 3 farm. Canada will contribute to the design of data collection from front-end chips. France will design and fabricate dedicated modules necessary for hierarchical control and data access of subsystems (eg: subsystem crates or local data nodes). Japan and the U.S. will collaborate on specification and design of fiber optic data links, and Japan will provide the links. The U.S. will design and provide other components which are common to all subsystems.

Event Builder or Equivalent

Japan and the U.S. will collaborate on the design and fabrication of the event builder or its equivalent, including the input queuing and data balancing logic, data links to the Level 3 farm, and the control and monitoring network

Level 3 Farm

Japan will provide 30% of the processors in the Level 3 farm, the rest being provided by the U.S.

TRIGGER

Silicon Tracker

Italy (50%) and the U.K. (50%) will collaborate on design and fabrication of the Level 2 silicon tracker trigger. Much of this electronics is integral with the silicon tracker data acquisition electronics, which is shared by Italy and the U.K. in the same proportion.

Barrel Tracker

The U.S. will carry full responsibility for the barrel tracker trigger systems, with either straw tube or fiber options.

Gas Microstrip Intermediate Tracker

Canada (50%) and the U.K. (50%) will collaborate on design and fabrication of the Level 1 and Level 2 gas microstrip intermediate tracker triggers. Much of this electronics is integral with the gas microstrip intermediate tracker data acquisition electronics, which is shared by Canada and the U.K. in the same proportion.

Calorimetry

The U.S. will design and fabricate the Level 1 and Level 2 central calorimeter trigger systems. Canada will adapt the design of the Level 1 and Level 2 calorimeter trigger electronics to the forward calorimeters and will fabricate the trigger electronics specific to the forward calorimeters. France will design and fabricate the Level 1 and Level 2 calorimeter shower-max trigger systems.

Muon System

Japan and the U.S. will collaborate on the design and fabrication of the Level 1 and Level 2 muon system triggers. While Japan will focus on the barrel and intermediate muon systems, and the U.S. on the forward muon system, it is envisaged that the designs of the trigger systems for all these regions will be very similar.

Global Level 1 and 2

The U.S., France and Italy will carry responsibility for the Global Level 1 trigger, clock/control system, and Global Level 2 trigger.

CONTROL SYSTEM

The U.S. will carry full responsibility for the control system for electronics systems.

ON-LINE COMPUTATION

Japan will carry responsibility for 30% of the high speed magnetic storage devices. The U.S. will have responsibility for the remainder of the storage devices as well as all other aspects of the hardware and software for the on-line system.

INSTALLATION

Our estimate for installation and in-place testing of detector systems includes all costs associated with installation and test of subsystems in the underground hall and installation of data acquisition and trigger electronics and on-line computing in the surface operations center. Hence, the cost of engineering and technical labor during this period is covered under the installation cost. The engineering and technical staff in each country that will be responsible for design and fabrication of a particular component will also, in general, be responsible for its installation and test, aided by SSCL resident staff. The cost of these staffs is included in the installation estimate. As a result, we are expecting the U.S. to bear about 65% of the installation, the remainder being distributed among other countries in rough proportion to their overall contributions.

TEST BEAM PROGRAM

The bulk of test beam work will be done in the U.S. and primarily supported by the U.S., although all the countries will help support test beam work relevant to the systems which they are contributing. Testing of radiation damage to calorimeter modules will also be conducted in France, Japan and the PRC. Muon chamber beam tests will also occur in the CIS and Japan, gas microstrip tests in Europe, and silicon module tests in Japan.

CONVENTIONAL FACILITIES

Responsibility for mechanical and electrical technical systems to connect the detector to air-conditioning, power, water, etc. will be borne by the U.S. Safety systems and other conventional facilities (shops, scaffolding, etc.) will also be U.S. responsibilities. Possible cost sharing with non-U.S. collaborators is under discussion.

PROJECT MANAGEMENT

The SDC overall Project Management will be located at the SSCL and will be a U.S. responsibility.

RESPONSIBILITIES AND FUNDING STATUS FOR SDC COUNTRIES

CANADA

The responsibilities of the Canadian groups within SDC will include the following:

1. Full responsibility for the forward calorimeters, including mechanical, electronics, trigger, DAQ and calibration functions.
2. Shared responsibility with the U.K. for the full Gas-Microstrip intermediate Tracker, including mechanical, electronics, trigger, DAQ, and calibration functions.
3. Participation in design and development of the general DAQ system.
4. Participation in installation and test beam efforts relevant to the forward calorimetry and the gas-microstrip tracking detectors.

FUNDING STATUS

In 1992/1993, for the first time, the Canadian groups have been awarded sufficient funds to pursue a reasonable R&D program. We expect that this "operating" level of funding will continue, and increase in-line with the developing situation.

The earliest date for substantial construction funds is April 1993, which would entail the submission of a proposal in Summer of 1992. Such a funding request would be for a "Major Installation Grant". In the past (eg. ZEUS) such funds have been awarded for the construction of a designed and developed system. Given the schedule for both the Intermediate Tracker and the Forward Calorimeter, this may be a somewhat optimistic schedule. If "Major installation" money is not requested by Summer 1992, the earliest date that these funds could be awarded would be April 1994. In view of this date, we are investigating less conventional avenues of funding, which do not have such a strict annual rhythm.

The final level of funding may depend on the level of Canadian enthusiasm for such alternative projects as LHC. There is a small Canadian involvement in LHC developments, but, at present, the level of activity on SDC is much higher.

PEOPLES REPUBLIC OF CHINA

The PRC groups' involvement in the SDC detector will include the following:

1. Testing of radiation damage characteristics of scintillators with the BEPC linac.
2. Calorimeter WLS fiber cutting, end polishing, silvering, splicing to clear fibers, and testing of the resulting assemblies, for a fraction of all tile-fiber assemblies.
3. Barrel calorimeter steel absorber fabrication and assembly by Chinese industry are under negotiation.

FUNDING STATUS

The PRC groups intend to apply to their funding authorities for resources relevant to items 1 and 2, and to the support of industrial liaison relevant to item 3. Preliminary industrial contacts for the steel fabrication have been made by IHEP Beijing, and the provision of the absorber approved at the level of the Academia Sinica. The U.S. will have to provide compensatory payment for the steel absorber at a level not to exceed 50% of the estimated U.S. cost.

CONFEDERATION OF INDEPENDENT STATES

Negotiations in progress are aimed toward establishing the following areas of potential responsibility for SDC groups from the former Soviet Union:

1. Participation in the design of barrel and forward toroids.
2. Fabrication of the barrel and forward toroids.
3. Provision of copper for the coils in the barrel toroid.
4. Design and fabrication of the coils for the forward toroid.
5. Design and fabrication of the absorbers in the forward muon systems.
6. Participation in the design of forward muon chambers, scintillation counters for all parts of the muon system, and the Cerenkov counters (if that option is adopted).
7. Fabrication of major part of the forward muon chambers, scintillation counters, and Cerenkov Counters (if Cerenkov option is adopted).
8. Fabrication of part of the front-end electronics for forward muon chambers and scintillation counters, as well as part of PMT bases, with electronic components supplied from the U.S. and elsewhere.
9. Fabrication of the absorber plates and structures for the central calorimeter.
10. Participation in the test beam *program*.

FUNDING STATUS

Most of the above efforts are centered in collaborating institutions in the Russian Federation with the exception of item 3 in which collaborators in Uzbekhistan may also be involved. Interlaboratory agreements between SSCL and both JINR (Dubna) and IHEP (Protvino) have already been signed. They provide the general framework for collaboration on the detectors. It is expected that all scientific and technical manpower provided by the CIS collaborating institutions to carry on the responsibilities listed above will be supported through the budgets of those institutions. Compensatory payments will apply to contributions from CIS industry and in support of SDC-related subsistence/travel costs, and will in no case exceed 50% of U.S. costs for the same items.

FRANCE

FRENCH RESPONSIBILITIES

The responsibilities of the French group within the SDC include the following:

1. Full responsibility for *mechanical construction* of the *Shower Maximum Detector* (SMD), including provision of all tile/fiber assemblies.
2. Production of part of SMD front-end electronics.
3. Participation in design and production of the trigger including the SMD and Global Level 2 triggers.
4. Installation of SMD, and test beam effort relevant to the SMD.

FUNDING STATUS

It is expected that the costs incurred for the SDC tasks can be covered from the Saclay budget. The allocation in capital funds expected to be available from 1991 to 1998 totals 20MF (about $3.6M), and the allocation in engineering/technician manpower is 130 man-years. Any excess cost for the above items will have to be covered *elsewhere* in the Collaboration.

ITALY

The responsibilities of the Italian SDC groups will include:

1. For the silicon tracking system:
   a) Procurement, assembly, bonding and testing of the two innermost cylindrical barrel layers of strip detectors and participation in their integration into the barrel detector.
   b) Development of alternative pixel version of a), in collaboration with U.S. groups and fabrication of the two innermost barral layers as pixel devices if this option is implemented.
   c) Sharing the assembly of modules, bonding, and integration of forward disks.
   d) Purchase and running-in of all low-voltage power supplies and a fraction of silicon front-end electronics.
2. For the central calorimetry:
   a) Sharing in the design, fabrication and testing of tile-fiber assemblies and in the procurement, testing, installation, and checkout of PMT and bases for calorimetry towers.
   b) Sharing in the procurement, testing, installation, and checkout of sensors and bases for the shower-maximum detector (SMD).
   c) Sharing the purchase and checkout of PMT HV power supplies.
3. For the muon scintillation counters (this contribution is still under discussion):
   a) Sharing in the design, fabrication, and procurement of scintillation counters and in their mechanical assembly.
   b) Sharing in the purchase, checkout and running-in of phototubes and bases as well as HV power supplies.
4. For the *front-end* electronics, trigger and DAQ:
   a) Sharing in the design, checkout and running-in of SMD front-end electronics.
   b) Sharing in the design, procurement, fabrication, checkout, and running-in of silicon tracker Level 2 trigger, as well as off-detector readout electronics and software specific to silicon tracker.
   c) Sharing in the design, fabrication, checkout and running-in of Global Level 1 and Level 2 trigger.
5. Participation in test-beam and installation efforts with emphasis on systems for which Italy carries responsibilities.
6. For the outer tracking system, if scintillating-fiber technology is adopted:
   a) Providing one superlayer (~20%) of the fiber ribbons.

FUNDING STATUS

The funding for the Italian contributions outlined above (with the exception of item 6) have been discussed in the appropriate Italian Committee in a first meeting in March 1992, with the goal of inserting this effort for the SDC detector as part of the INFN research activities in the Quinquennial Plan for the years 1994 - 1998. At this time (April 1992), the Quinquennial Plan, as drafted in the above meeting, includes the SDC project with a support level for hardware and detector components of about 10% of the overall INFN construction effort at LHC and SSC, which is estimated at $100M.

JAPAN

The Japanese SDC group intends to contribute approximately 20% of the total cost of the SDC detector including the development, production, testing and installation of the detector components as described below. This proposal assumes that the Japanese Government approves nearly the full amount of the requested collaboration funding for the collider itself and for the experiments. The proposed contributions include the following items:

1. The assembly and checkout of the barrel section of the silicon tracker, and its shipment to the SSCL for final integration. The detailed responsibilities are as follows:
   a) Development and production of the double-sided strip sensors for both the barrel section and for the forward disk section. The sensors for the disk section are to be delivered to the disk silicon group after basic performance tests show that specifications are met. Development and design of the sensors of the disk section is the responsibility of the disk silicon group, and the Japanese group will help them to work with the manufacturer.
   b) The U.S. silicon group is to develop and provide the front-end electronics system including cabling system for the barrel section to the Japanese group. The electronics system must be tested to meet specifications before shipment.
   c) The Japanese group has responsibility for the assembly and testing of the detector units for the barrel section except for these units that are the responsibility of the Italian group.
   d The Japanese group is responsible for the integration of the detector units into the support structure and testing them for the barrel section. Japan will purchase the necessary components. The Japanese group expects that the Italian group will provide tested detector units for the inner two layers, which are integrated into the barrel section in Japan.
   e) The shipping of the assembled barrel section of the detector to LANL or SSCL and its integration into the space frame are Japanese responsibilities.

2. For the Superconducting Solenoid:
   a) Fabrication and testing of R&D prototype coil including responsibility for:
      - Superconductor,
      - Coil fabrication,
      - Radiation shield, coil support and chimney,
      - Magnet Assembly,
      - Test including the equipment required in the test and the power supply
      - Data taking system, cryogenics etc.
   b) The fabrication of the main solenoid including responsibility for:
      - Superconductor,
      - Coil fabrication,
      - Cryostat fabrication,
      - Magnet assembly,
      - Test in air including the equipment required in the test,
      - Transportation of the magnet to the U.S.
   c) The organization of an independent R&D program at KEK to make an effort to develop brazed honeycomb vacuum vessel.

3. For the central calorimeter:
   a) Provision of most of the scintillating tiles, fibers and PMT for the towers.
   b) Procurement of a fraction of the photomultiplier-tube bases and power supplies for photomultiplier tubes.

4. For the barrel and Intermediate Muon Chambers:
   a) The design and construction of a fraction of the wire-strung tubes.

5. For the front-end electronics:
   a) In the straw-tube readout the Japanese group will take responsibility:
      i) Design and fabrication of the front-end readout units that are attached to the straw chambers.
      ii) Design and fabrication of TMC chips and Level 2 trigger buffer. The responsibility for design and fabrication of other parts (preamp/shaper/discriminator, DCC, Level 1 trigger, HV distribution, calibration circuits etc) will be shared with U.S. collaborators.
      iii) The assembly, test, and shipment of front-end readout boards.
      iv) Radiation-hard CMOS technology will be available in a Japanese company in 2-3 years. We will pursue this possibility to accomplish the rad-hard TMC and Level 2 buffer.
   b) in the muon chamber read-out, the Japanese group will be responsible for the front-end electronics of the barrel and intermediate muon detectors, which includes preamp/shaper/discriminator (ASD), TMC, second-level buffer, data collection system, and Level 1/Level 2 trigger systems. The Japanese group is primarily interested in taking responsibility for ASD, TMC, Level 2 buffer and Level 2 trigger. Design and fabrication of other parts will be shared with other collaborators. Critical components for the forward muon readout system will be provided.

6. For data acquisition:
   a) The design and production of fraction of the data transfer system.
   b) The design and production of part of the event builder or equivalent with ECL switches.
   c) The development and production of a fraction of the level -3 farm system.

7. For the Trigger System, the development and production of local trigger units for the Muon Detector.

8. For the On-line Computing systems, the development of part of the hardware.

9. For the Off-line Computing systems:
   a) The support of the SDC regional computer center in Japan.
   b) The support funding of the SDC detector remote control center in KEK.

10. Participation in the installation of the silicon detector, central calorimeter, solenoid, and electronics-trigger of the barrel muon detector.

11. Participation in the test beam program for the silicon detector, central calorimeter, and barrel muon detector.

FUNDING STATUS

The contributions of Japan to the SSC project including the collider have been discussed between the U.S. and the Japanese governments. When President Bush visited Japan in January 1992, the possibility of Japanese collaboration on the SSC project was one of the major topics discussed by the President and Japanese Prime Minister Miyazawa. The two governments agreed that a working group would be formed soon to establish the mechanism by which Japan should play a role in international collaboration in the SSC project.

In Japan the collaborations on the SSC collider and on the SSC detectors are regarded as being a single package. This is in order to minimize possible funding conflicts between the SSC contribution, future domestic accelerator projects, and currently ongoing international collaboration experiments, by handling the SSC project as a "special case". Therefore the details

of the detector collaboration, including funding, will be settled only after an agreement on SSC collider collaboration is reached. The earliest fiscal year for serious involvement by the Japanese government, if Japan agrees to participate, begins in April 1993.

The Japanese collaboration in the SDC, known as the JSD, is organized by about 100 physicists. Various decisions concerning physics research as well as organizational activities have been made through JSD collaboration meetings, workshops, or JSD executive board meetings. The group has submitted a very informal budget proposal, for the Japanese contribution to the SDC, to the Ministry of Education, the Japanese HEP funding agency, through KEK. How the Ministry of Education treats this proposal depends strongly upon the outcome of the U.S.-Japan Working group for the SSC.

During JFY1991 (beginning April 1, 1991) a total of about 400MY (about $2.8M) was allocated to detector R&D for hadron colliders from the U.S. Japan High Energy Physics Collaboration Program. A budget proposal for JFY1992 has been submitted. There seems to be no indication of a budget increase in JFY 1992.

UNITED KINGDOM

Contributions of the U.K. groups to the SDC include the following items:

1. Shared responsibilities with Canadian groups for the gas microstrip intermediate tracker (ITD), including front-end electronics and power supplies, trigger system and data acquisition systems.

2. Major participation in data acquisition and trigger system for silicon strip tracker.

3. Installation of the above systems.

4. Test beam program relevant to the above systems.

FUNDING STATUS

The UK groups of the SDC intend to apply to their funding authority for the resources required to make the above contributions.

The future funding of particle physics in the U.K. is currently under consideration. Until these decisions are made, and funding levels for possible LHC experiments are known, it is inappropriate for the U.K. groups collaborating in the SDC to apply for capital and manpower expenditure commitments. We believe, at this time, that an appropriate time to make these formal applications will be in mid to late 1993. In the meantime we are confident that we will receive sufficient funding to enable us to continue the R&D necessary to meet the schedule. Current estimates (U.K. accounting methods) of the intended U.K. contribution to the above systems are 5.22M pounds sterling plus 71 man-years of non-physicist effort.

UNITED STATES

In the previous pages, the responsibilities associated with the various countries whose groups are non-U.S. members of the SDC have been summarized. Not all countries represented in the SDC are included, but because of the limited capabilities or resources of the groups in these other nations, it seems unlikely that large additional contributions can be expected (although some resources and intellectual inputs are certainly expected). This means that practically all the responsibilities not covered in the previous summaries will be carried by U.S. institutions.

The sum of $585M(FY92) has been allocated by the SSC Laboratory to the two large detectors SDC and GEM from the SSC Total Project Cost. It is expected that at least half of that amount, namely $293M(FY92), will be allocated to the SDC.

OVERALL SDC DETECTOR COST AND RESOURCE SITUATION

Table 2 summarizes our present understanding of the capabilities and interests of the physicists from countries represented in the SDC to design, procure, fabricate, and install detector components. Although the table is based on a plausible set of responsibilities for the SDC non-U.S. collaborators, final and detailed commitments from the relevant funding agencies will, in almost all cases, not be made until early to late 1993. The actual level of support from outside the U.S. that will actually be committed is therefore quite uncertain at this time.

Given this situation, we can only provide an estimate rather than a precise measure of non-U.S. contributions to the SDC detector. We consider it plausible to assume a match between the interests and capabilities of the non-U.S. members of the collaboration, the resources that they can command, and the needs of the detector at the level of about a $200M(FY92) cost offset from the total estimated cost. It should be emphasized that each country has its own accounting practices, and that the above figure is based on the U.S. accounting equivalent corresponding to the in-kind contributions described earlier. Given the overall detector cost estimate of about $584M(FY92), the above expected U.S. SSCL contribution and estimated non-U.S. cost offset, additional funding at the level of about $90M(FY92) is needed to complete the SDC detector.

It is important to note from Table 2 that non-U.S. involvement permeates almost the whole detector. The inevitable consequence of this fact is that removal of the $90M shortfall through scope reduction would, on any reasonable scenario, entail substantial simultaneous reduction of the non-U.S. contribution. There is simply no way to make large reductions in the U.S. part *without impacting* in a major way the non-U.S. parts. The consequence is that a reduction of the needed U.S. input by something close to $90M(FY92), accompanied inevitably by very substantial non-U.S. reductions, would require a dramatic change in the detector concept. We are therefore led to examine credible ways to fund the above shortfall.

It seems unlikely that substantial non-U.S. funding beyond the $200M(FY92) indicated above will be forthcoming, although we will continue to seek such funding and to add new non-U.S. groups. It is also not prudent at this time to assume that additional funding will be available from more favorable distribution of the $585M(FY92) for large detectors, or from the use of SSC Project contingency. However, we note that the Report of the 1992 HEPAP Subpanel on the U.S. Program of High Energy Physics (April 1992), in the section labelled *Other Recommendations and Comments*, states that resources for modest-size SSC experiments "should be made available in the latter part of the 1990's from the base High Energy Physics Program, on a competitive basis..", and recommends not committing the $80M(FY92) now held in reserve by the SSCL for smaller experiments "until the funding for the large detectors is *secure*". If the SSCL were to follow up on that suggestion and assign half of the $80M(FY92) to each of the large detectors, nearly half of the above shortfall would disappear. The remaining funding needed would amount to about $6M/year, which one might plausibly obtain from the resources potentially available to the collaboration in the U.S. If the SSCL does not make the $80M(FY92) available to the large detectors, the full shortfall would have to be obtained from the other U.S. collaboration resources. The required yearly amount of $10M would be much more difficult to obtain.

At the present time, there are about 400 U.S. experimental particle physicists in the SDC, and this number is expected to grow somewhat by the end of the decade. Thus we estimate that the SDC will represent at least 30% of the U.S. experimental HEP community during the remainder of this decade. Furthermore, in terms of actual FTE (Full-Time-Equivalent), we estimate that the SDC effort, averaged over the next eight years will represent about 225 FTE, or about 20% of the full U.S. experimental HEP community. As this large community devotes more and more time to the SDC detector, it seems reasonable to expect that the internal resources available to the universities and laboratories within the SDC will increasingly be allocated to the SDC. These universities and laboratories are supported primarily by the Division of High Energy Physics (DHEP) of the DOE. If the universities and laboratories continue to receive such support from DHEP, we believe that it is realistic to obtain most of the additional needed support ($6M/year under the conditions discussed above) from redirection of effort at the more than 50 U.S. institutions involved in the SDC, assuming continued support by DHEP of the redirected technical resources. These resources include engineers, technicians, shops and other facilities that will be used to design and build the SDC detector components. As stated above, if the SSCL does not allocate the $80M(FY92), presently reserved for smaller experiments, to the large detectors, it may still be possible to fund most of the shorfall through the above means, but it will be much more difficult to do so.

Finally, the State of Texas has pledged about $100M for research and development and improvements to university infrastructure. The SDC universities have already benefitted from this support at the level of a few millions of dollars from the $20M that has already been allocated by the State of Texas. We would expect this to continue, at least during the design and R&D phase of the SDC project.

In summary, we intend to proceed to develop a detailed funding plan for the U.S. as well as for the non-U.S. members of the collaboration. The U.S. funding plan must include contributions from the existing infrastructure within collaborating universities and laboratories in the United States. Without this support, the U.S. members of the SDC will simply not be able to fulfill the responsibilities which they want to carry within the Collaboration, and participate as they expect in the fabrication of their detector.

REFERENCES

1. SDC — Project Cost and Schedule Summary, SDT-000021, April 1, 1992.

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JAPAN

T. KONDO

KONDO

Status on SSC Collaboration

- January, 1992
  President Bush and Prime Minister Miyazawa had agreed in setting up a joint working group of Japanese and US Governments in order to establish the mechanism by which Japan should play a role in international collaboration in the SSC project.
- April 9-10, 1992
  1st JWG in Tokyo
  - set up two sub working groups on
    cost estimate
    physics/scientific goals
  - outline of the JWG plan
    interim report by July 1992
    final report by December 1992
- April 20-23, 1992
  visit to SSCL by Japanese team on accelerator
- May 11-13, 1992
  sub-working group meeting for physics/scientific goals at SSCL

Activities toward SSC Experiments in Japan

- 1987-1989
  - 9 workshops on high-energy hadron collider physics and experiments
  - Detector R&Ds under US-Japan HE Collaboration
- Sep. 1989
  two ideas on solenoid detector for SSC
- Nov. 1989
  formation of JSD group by ~ 110 physicists & engineers(
  JSD = Japan Solenoidal Detector
  representative of JSD group : Y. Nagashima (Osaka U)
- April 1990 : Workshop on Solenoidal Detectors for SSC
  May 1991 : SDC Collaboration meeting at KEK
  May 1992 : SDC Collaboration meeting at KEK
  4 JSD workshops
- Detector R&D and design activities have been supported by the US-Japan collaboration on High Energy Physics

JFY1990	~ 150 Myen (~ $ 1.1M)
JFY1991	~ 380 Myen (~ $ 2.8M)
JFY1992	~ 380 Myen (~ $ 2.8M) ?

as well as by the KEK Physics Department

Comments

- In Japan, the collaborations on the SSC collider and on the SSC detectors are regarded as being a single package.
- In order to avoid possible funding interference, the Japan Science Council recommended to Prime Minister in Nov. 1991 that the SSC funding should be handled "separately".
- KEK director Sugawara has stated for every possible occasions that domestic future plans of high energy physics such as asymmetric B-factory and/or JLC projects must be proceeded before the large scale international collaboration such as SSC come in.

SDC responsibility-1

item	representative	institutes
silicon	T. Ohsugi	Tohoku Gakuin , Niigata, KEK, Nagoya , Osaka, Wakayama Med. Coll., Okayama, Hiroshima, Saga
straw readout	T. Ohska	KEK, Tokyo Metropolitan U., Tokyo U of A&T
solenoid	A. Yamamoto	KEK
central calorimetry	K. Takikawa	Tsukuba, KEK
muon	S. Mori	Tsukuba, KEK, Ibaraki Coll of Tech, INS, Osaka City U.
DAQ	Y. Watase	KEK, Tokyo Inst. of Tech,
computing	K. Amako	Tohoku, KEK, Tsukuba, Tokyo Metropolitan, Fukui, Kyoto, Naruto, Hiroshima Inst. of Tech

SDC responsibility -2

Silicon Tracker
- R&D and production of double-sided strip sensors for both barrel and forward disk sections
- assembly and testing of the detector of barrel section (except for inner 2 layers)
- integration, testing and shipping of the barrel section

Straw-tube readout electronics
- front-end readout units, TMC, 2nd level buffer
- assembly, testing and shipment of the front-end boards

Superconducting Solenoid
- fabrication and testing of R&D prototype coil
- fabrication, testing and transportation of the magnet

Central Calorimeter
- most of the scintillating tiles, fibers and PMT
- fraction of PMT-bases and power supplies

SDC responsibility -3

Muon chambers
- fraction of the wire-strung tubes
- front-end readout electronics and trigger system for the barrel/intermediate muon detectors
- critical components for forward muon readout system

Data acquisition
- design and production of fraction of DAQ system
- part of event builder
- development and production of a fraction of level-3 farm

Computing system
- software and hardware development for simulation, data-taking and analysis
- regional computer center in Japan
- remote control center in KEK

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CIS

N. TYURIN

Responsibilities (proposed)

1. Participation in the design of barrel and forward toroids.
2. Fabrication of the barrel and forward toroids.
3. Provision of copper for the coils in the barrel toroid.
4. Design and fabrication of the coils for the forward toroid.
5. Design and fabrication of the absorbers in the forward muon system.
6. Participation in the design of forward muon chambers, scintillation counters for all parts the muon system, and the Cerenkov counters.
7. Fabrication of major part of the forward muon chambers, scintillation counters, and Cerenkov counters.
8. Fabrication of part of the front-end electronics for forward muon chambers and scintillation counters, as well as part of PMT bases with electronic components supplied from the U.S. and elsewhere.
9. Fabrication of the ahsorber plates and supporting structures for the central calorimeter.
10. Participation in the test beam program (at 70 GeV accelerator).

The Status of Management, Resources and Funding at CIS

N.Tyurin

Institute For High Energy Physics, Protvino

Russia

Resources required to follow the proposed responsibilities

1. Personnel. Principally agreed. Composition will depend on responsibilities approved by the collaboration.
2. Workshops and assembling area. Decision has been taken. Construction work is required.
3. Assistance of the central workshops at IHEP and JINR, general engineering.
4. Beam time. Will be provided at U-70 accelerator in accodance with requirements.

Participants (CIS)

- Russian Federation:	IHEP, Protvino JINR, Dubna ITEP, Moscow
- Georgia:	Tbilisi State University (IHEP)
- Belorussia:	Gomel State University Academy of Sciences
- Armenia:	Institute of Physics, Erevan
- Uzbekistan:	INP, PTI, Tashkent

Initial Management Structures

Yu.Antipov	(drift tube chambers)
V.Kochetkov	(iron toroids)
V.Kubarovsky	(Cerenkov counters, coordination, link with SDC)
V.Rykalin	(scintillator counters)
N.Tyurin	

- regular overvews,
- priorities, distribution of funding for R&D,
- resources allocation
- personnel policy

Funding

Already available sources of funding are:

- basic budgets of the Institutions,
- the State program "High energy Physics"

The proposed contribution can not be totally funded by Russia. It is expected that compensatory payments will be used to obtain detector systems, in general, at a cost of less than 50% of the estimated US cost.

J.Budagov	(calorimetry)
V.Snyatkov	(toroid, design)

MANAGEMENT

Coordination between IHEP, JINR, ITEP on construction of the barrel and forward toroids:

V.Kochetkov	- IHEP
V.Snyatkov	- JINR
O.Pogorelko	- ITEP

- trace design in home institutions
- create joint policy in respect to industry

Report is expected on May 20,21 in Dubna:
- choice of industrial firm
- discussion of design issues
- proposal on future design work and supervision

1. Interlaboratory agreements between SSCL and IHEP (Protvino) and JINR (Dubna) have already been signed.

2. General agreement between DOE and Ministry of Atomic Energy (Russian Federation) is under preparation.

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1. Raw material and components to produce sc. counters for prototype.
2. PMT's for prototype (standard).
3. R&D contract for drift tubes (preparation for industrial production, prototype samples).
4. Raw material and R&D contract to develop technology of PMT's (with long photocathodes) production.
5. Machinery for large scale production of sc. counters.
6. Construction work to create the area (workshop) to fabricate scintillator.
7. Conceptual design work on FMS and its parts.

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ITALY

G. BELLETTINI

Bellettini

TO APPEAR IN THE SDC TECHNICAL PROPOSAL

PISA	Salvator Roberto Amendolia	Professore associato
	Franco Bedeschi	Primo ricercatore INFN
	Giorgio Bellettini	Professore ordinario
	Valeria Bolognesi	Borsista
	Marina Cobal	Borsista
	Hans Grassmann (Visitor)	Ricercatore INFN
	Sandra Leone	Borsista
	Michelangelo Mangano	Ricercatore INFN
	Aldo Menzione	Primo ricercatore INFN
	Giovanni Pauletta (visitor)	Professore associato
	Hans Wenzel	Borsista
	Francesco Zetti	Prof. Scuola Media Sup.
MILANO	Giovanni Cesura	Dottorando
	Piero Inzani	Tecnologo X Liv.
	Pierfrancesco Manfredi	Professore ordinario
	Dario Menasce	Primo Ricercatore INFN
	Luigi Moroni	Primo Ricercatore INFN
	Daniele Pedrini	Ricercatore INFN
	Valerio Re	Ricercatore Universita`
	Silvano Sala	Primo Ricercatore INFN
	Francesco Svelto	Dottorando
PAVIA	Gianluigi Boca	Ricercatore Universitario
	Mario Cambiaghi	Professore Associato
	Gianluca Introzzi	Ricercatore Universitario
	Giuseppe Liguori	Tecnico Laureato
	Sergio Ratti	Professore Ordinario
	Paola Torre	Ricercatore Universitario

February 18, 1992

ZERO-LEVEL GUESS OF SDC FUNDING BY ITALY

SUMMARY OF ITALIAN CONTRIBUTIONS

SILICONS	3.2 M$	(1.0 for Pixels R/D)
FIBERS	0.4 M$	(cancelled if straws are adopted)
CALORIMETRY	9.9 M$	
BARREL COUNTERS	2.2 M$	
FORWARD COUNTERS	0.6 M$	
FORWARD CHAMBERS	2.4 M$	
FRONT-END	1.5 M$	
TRIGGER	2.8 M$	
DAQ	0.1 M$	
TEST BEAM	0.5 M$	
INSTALLATION	1.5 M$	
TOTAL	25.1 M$	

Giorgio Bellettini
SSCL, May 7, 1992

SDC FUNDING STATUS BY INFN

- CALENDAR YEAR 1991	≈ 20 K$	for R/D
- CALENDAR YEAR 1992	≈ 70 K$	for "PSDC"
- LIKELY REQUEST FOR 1993	≈ 200 K$	group operation
plus	≈ 500 K$	detector prototypes

- CALENDAR YEARS 1994-1998
(NEXT INFN QUINQUENNIAL PLAN)
FORECAST OF " COMMITTEE No 1" (particle physics experiments at accelerators)
≈ 10 M$ CAPITAL EQUIPMENT for SDC detector construction

- CALENDAR YEAR 1999
NEW FUNDS EXPECTED FROM NEW PLAN

HISTORY OF FORECAST FOR 1994-1998

PREMISE

Overall INFN budget expected:

1994 ≈ 1993 + inflation + very few % 1 s ≅ 250 M$

Following years: allow for ≅ 5% inflation.

Since traditionally "Committee No 1" spends ≈ 20 % of budget

⇓

TOTAL FOR "COMMITTEE 1" IN QUINQUENNIUM: ≈ 280 M$

WHAT HAPPENED RECENTLY:

Committee 1 meeting of March 20, 1992

a) ESTIMATED COST OF CONTINUED ACTIVITY OF ALL SCIENTIFIC AND TECHNICAL STAFF, AND HOME INFRASTRUCTURES

b) SHARED REMAINDER AMONG

- ON-GOING EXPERIMENTS (LEP, HERA, CDF, etc.)
- INVESTMENTS ON NEW DETECTORS (DAΦNE, LHC, SSC)

CONCLUSION:

AVAILABLE FOR HADRON COLLIDER DETECTORS
~ 100 M$ IN QUINQUENNIUM

NEXT:

ESTIMATE SDC/LHC ~ 1/10 BASED ON PRESENT NUMBER OF PEOPLE WHICH LEAVES

⇓

~ 10 M$ FOR SDC CONSTRUCTION

NOTE:

REQUEST PRESENTED BY SDC ITALIANS WAS
~ 25 M$ FOR (OVERALL) SDC CAPITAL EQUIPMENT
COMMITTEE FELT THAT WE SHOULD LIVE WITH LESS, BECAUSE:

MOTIVATION →→→→→→→→→→ IMPACT

- No people presently involved in muon chambers	→ cancel contribution
- Few people presently involved in calorimetry	→ reduce contribution
- Few people presently involved in muon counters	→ reduce contribution

---

WE CAN LIVE WITH IT.
REMEMBER:

INFN CRITERIA WHEN FUNDING EXPERIMENTS

a) apply filter to select significant experiments
b) put money where people go

NOTE:

In the past, condition b) was better satisfied than condition a).

FORECAST FOR SDC

- Condition b) will be enforced strictly (LHC competition)
- Depending on people work, **REAL** CONTRIBUTION TO CAPITAL EQUIPMENT can be more than 10 M$.

EXTREME EXAMPLE: CDF

- In 1980, conditional approval for a total contribution to detector construction not to exceed 1.2 M$.
- 1980→1992 integral budget (for capital equipment parts only) ≈ 7 M$
- Acknowledged italian contribution (US accounting standards) ~ 13 M$ ("COST OFFSET")

WHY CDF IS AN EXTREME EXAMPLE ?
BECAUSE ALL CONDITIONS CHANGED IN FAVOUR OF CDF:

a) At the start, the italian group was very small. Now it comprises ~ 50 people.

b) At the start, the CERN collider program was shadowing that of Fermilab. Now the Tevatron Collider has monopoly of the field.

c) The prestige of the Fermilab accelerators was poor. Now is much better.

d) CERN was expected to discover everything. Now we have the best chance for the Top.

IN CONCLUSION, FOR THE FUTURE:

a) Let us shoot for a stronger italian group.

b) How will LHC proceed ?

c) Let us build SSC in time and within specifications.

d) Let us make clear to everybody that our program is second to no one in scientific quality.

02893

CANADA

R. ORR

CANADIAN PARTICIPATION IN SDC

→ FUNDING ISSUES

BOB ORR - MAY 1992

- CANADIAN GROUP, PROJECTS
- PREVIOUS FUNDING OF MAJOR HEP PROJECTS
- OVERALL CANADIAN FUNDING
- PLANNING PROCESS
- FUNDING METHODOLOGIES
- TIME SCALE.

PRESENT CANADIAN GROUP

→ 21 GRANT ELIGIBLE INVESTIGATORS. THESE ARE INDIVIDUALS, SUCH AS TENURED FACULTY & LAB SCIENTISTS, WHO CAN APPLY FOR GOVERNMENT FUNDING

- EXPECT ROUGHLY SAME NUMBER OF POST-DOCS & ENGINEERS, AS PROJECT ACTIVITY LEVEL INCREASES.
- SIX UNIVERSITY GROUPS
TWO LAB GROUPS
- PEOPLE DRAWN MAINLY FROM ZEUS & OPAL.
- PRESENT R & D FUNDING (FROM APRIL 1992) ≈ US $\$400^{00}$K PER YEAR

DESIRED GROWTH PROFILE

	92/3	94	'95	'96	'97	'98	'99
FTE	7	14	20	25	30	30	30
OPS $M	0·4	0·83	1·24	2·0	2·5	2·5	2·7
CAPITAL $M	–	1·7	5.0	8·3	8·3	6·6	3·3

FTE = FULL TIME EQUIVALENT GRANT ELIGIBLE.

→ ASSUMES ALL PRESENT FTE FULLY COMMITTED BY 1995.

→ REQUIRES INCREASE IN ACTUAL PEOPLE.

→ FUNDING PROFILE HAS NO OFFICIAL STATUS WHATSOEVER.

PROJECTS

- INTERMEDIATE TRACKER BASED ON GAS MICROSTRIPS ~ 50%
- FORWARD CALORIMETER SYSTEM ~ 100%
- WE HAVE UNDERTAKEN TO APPLY INITIALLY FOR ~$\$24 \times 10^6$

FUNDING REQUEST IN CANADIAN CONTEXT

- IN THE PERIOD 1985 - 1992 (US$)

OPAL CAPITAL	$1.2 M
OPAL OPERATING	$8.84 M
ZEUS CAPITAL	$8.0 M
ZEUS OPERATING	$5.1 M
ARGUS	$3.0 M
HERA MACHINE	$3.5 M
	~ $30 M

- TOTAL SUBATOMIC PHYSICS IN SAME PERIOD $122M EXCL TRIUMF
- PRESENT ANNUAL FUNDING OF SUBATOMIC PHYSICS $16.2 M EXCL TRIUMF

CANADIAN PLANNING PROCESS

LONG RANGE PLANNING COMMITTE - 1990 LOOKED AT THREE SCENARIOS

1) $150M p.a — KAON $98M pa
SSC+LHC $30M pa
⋮

2) $75M pa — SSC/LHC $30M pa
TRIUMF $25M pa
⋮

3) $40M pa — ?

➡ AT PRESENT WE ESSENTIALLY HAVE SCENARIO 2) — FOR WHICH THE RECOMMENDATION WAS SSC/LHC TO HAVE HIGHEST PRIORITY.

➡ NEW PLANNING COMMITTEE IS REVIEWING THE SITUATION.

FUNDING METHODOLOGIES

- PROJECTING OPERATING GRANTS

  OPAL US$2.1 M p.a.

  → SDC is NOT ANOMALOUS

- EQUIPMENT GRANTS

  ~ $100K → FOR COMPUTERS & WHAT NOT

- MAJOR INSTALLATION GRANTS

  ZEUS $8M

  ↑ THIS IS ONLY EXISTING AVENUE FOR RAISING CAPITAL.

  → TO PUT ~ $$25 \times 10^6$ INTO SDC IS NOT COMPLETELY ANOMALOUS

  → BUT WILL REQUIRE A POLICY DECISION

FUNDING CYCLES & TIMESCALES

- OPERATING GRANTS

  REQUEST SEPT 199m

  → MONEY (?) APRL 199(m+1)

- MIG CYCLE SIMILAR

  TO RECEIVE CAPITAL FUNDS IN 1993 WE HAVE TO MAKE FIRST

  MAJOR INSTALLATION GRANT REQUEST ~ SEPT 1992

02902

UNITED KINGDOM

R. CASHMORE

RJC 1
7/5/92

UK Participation in SDC

Groups:

Bristol

Liverpool

Oxford

RAL

Activities

- ITD - construction
  - FE electronics
- UK|Canada - L1 trigger
- (US) - L2 trigger
  - DAQ
- Silicon - L2 trigger
- UK/Italy - DAQ

} common project

RJC 2
7/5/92

Estimated Resources Required

Materials £6.2M

Manpower 71 Manyears

≡ $ 15M

RJC 3
7/5/92

Method of Support in UK

① Baseline Support to Universities
↳ Mainly manpower
(Approx constant)

② Construction Funds
"Extra" manpower through RAL
+
"Expert" (Has been decreasing over last ~7 years)

Historical Distribution

~ 65% - 70% → CERN expts

~ 30% → elsewhere
(DESY, US)

⇒ Hope for similar distribution in

RJC 4
7/5/92

Current Levels of Support

- Operation of LEP, HERA + others
  Some R&D for future

Not sufficient for major pp construction Program

Future Levels of Support

- Major request
  ↳ Increase of ~£50M/10 years

➡ Clearly tied to LHC at CERN

➡ Any SSC request coupled to LHC situation

How do we proceed in the UK?

1. Continued R&D

ITD ~ 4.5 My/year }
Si ~ 3.5 My/year } + modest £

⇒ Prepare major well argued and well founded proposal
(for specific items)

2. Timing of Proposal

~ Mid 1993 - Late 1993

3. Size of Request

$15M - base prog contribution
($5M - 6M)

⇒ $10M.

02908

FRANCE

R. HUBBARD

FRANCE IN LHC / SSC

02908

CNRS = National Scientific Research Commission

HEP in IN²P³ **Head : Detraz**

Many Universities and Laboratories

Policy : LHC only

L3 :	Annecy, Villeurbanne
CMS :	Annecy, Lyon, Ecole Polytechnique
EAGLE :	Annecy, Clermont-Ferrand, Grenoble, Marseille, LAL Orsay, Paris VI

CEA = Atomic Energy Commission

HEP is at Saclay

Division Head : Aymar (DSM)

Department Head : Turlay (DAPNIA)

Policy : 1 expt. @ LHC + 1 expt. @ SSC

Investments : LHC / SSC ≈ 4 / 1

Physicists : LHC / SSC ≈ 30 / 15

LHC :	**ASCOT**	Saclay on 3 Eol's.
	CMS	Choose 1 LoI
	EAGLE	in June 1992
SSC :	**SDC**	March 1990

Dick Hubbard

02910

SACLAY RESPONSABILITIES IN SDC

e / γ Identification

SHOWER MAXIMUM DETECTOR

Northeastern, Rockefeller, Saclay, Tel Aviv, UCLA
+ Italy, Japan

Mechanics, Optics & Raddam :	**Saclay**
Photodetectors :	**U.S. Groups**
Front-end electronics :	**Saclay**

Japan : Scintillator & fibers

Italy : Participation in electronics

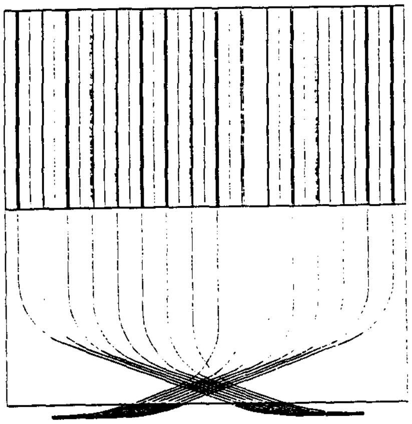
GLOBAL LEVEL 2 TRIGGER

Saclay responsability

Italian participation

02911

SHOWER MAXIMUM DETECTOR



η strips

0.05/8 x 0.05

Φ strips

0.05 x 0.05/8

159 744 physical SM strips

Gang 4 fibers ⇒ 1 electronic channel

47 104 channels ⇒ 768 MCPMT's

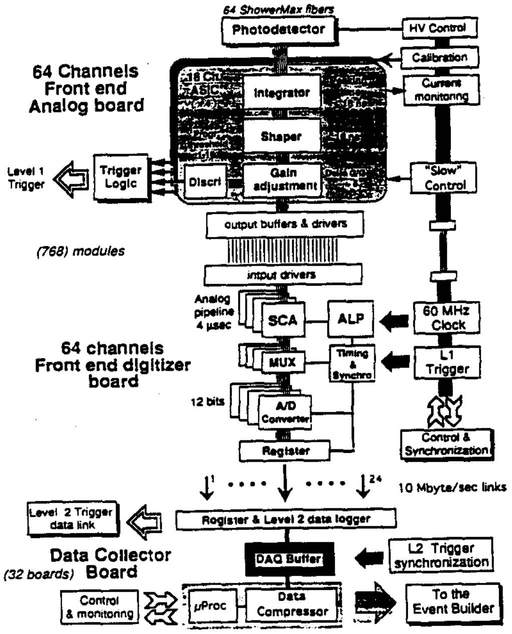
Upgrade x 2 to match trigger segmentation

Massless Gap readout

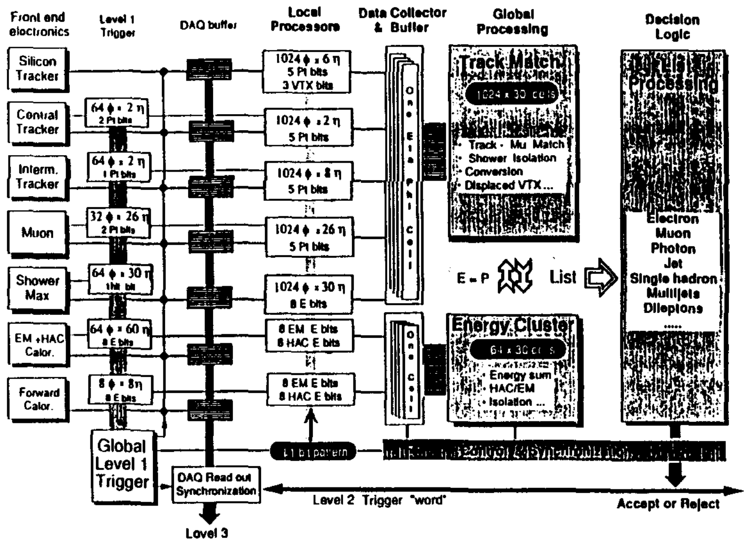
10 368 channels ⇒ 192 MCPMT's

02912

SHOWER MAXIMUM FRONT-END ELECTRONICS



DATA FLOW IN LEVEL 2 TRIGGER



02913

FRENCH RESOURCES

FRENCH RESPONSABILITIES	Percent	Material	Labor	Total	US equiv.
1. Shower Maximum Detector	100%	11.0 MF	75 MY	45.7 MF	8.1 M$
2. SMD Front-end Electronics	40%	2.0 MF	20 MY	11.2 MF	2.0 M$
3. SMD Trigger	7%	0.3 MF	5 MY	2.6 MF	0.5 M$
4. Global Level 2 Trigger	75%	6.0 MF	18 MY	14.3 MF	2.5 M$
5. Installation	3%	0.4 MF	10 MY	5.0 MF	0.9 M$
6. Test Beam	2%	0.3 MF	2 MY	1.2 MF	0.2 M$
		20.0 MF	130 MY	80.0 MF	14.2 M$

02914

SDC R&D @ SACLAY

02915

Preshower Design

Shower Maximum Design

Physics Simulation

PS / SM beam test

Shower Max chosen in August 1991

Optical properties of SM strips

Optical disconnects

Radiation Damage Studies for EMC & SM

Co^{60} & 1 GeV e^- beam @ Orsay

APD characteristics / supply for beam test

MCPMT characteristics / supply for beam test

Front-end electronics for Shower Maximum

Adapt LBL Switched Capacitor Array

Level 2 Trigger

Architecture

Algorithms

String Processor Prototypes

PRC

H. MAO

FOR SDC MAY REVIEW MEETING

H. Mao

Institute of High Energy Physics
Beijing, China

May 4–9, 1992
at Dallas, USA

1 · INTRODUCTION

2 · RADIATION DAMAGE

3 · FIBER

4 · STEEL ABSORBER

5 · CONCLUDING REMARKS

FOR SDC MAY REVIEW MEETING

1. INTRODUCTION

The SDC is a truly international collaboration comprised of approximately 100 institutions from more than 11 countries.

As a member of the SDC, IHEP / China is very happy to make our contribution to the design and construction of the SDC detector.

Presently,the proposed responsibilities for the IHEP of PRC are mainly concerned with the calorimeter,and are as follows;

(1)Barrel Calorimeter steel absorber fabrication and assembly 100%

(2)Calorimeter Wave Length Shifting (WLS)fiber cutting, end polishing, silvering,splicing to clear fibers, and QA/QC testing of the resulting assembly. 20%

(3) Testing of radiation damage characteristics of scintillators using the BEPC electron linac. 30%

2. RADIATION DAMAGE (RADDAM) TEST

"ITEM 3, TESTING OF RADIATION DAMAGE CHARACTERISTICS OF SCINTILLATORS USING THE BES ELECTRON LINAC 30%"

Any detector operating in the SSC facility will encounter a considerable amount of radiation. The worst case occurs in the calorimeters where all the particle energy is deposited. Within the calorimeters, the worst location is at electromagnetic (EM) shower maximum.

Because the calorimeter will play a very important role in the physics program of SDC, and because it is the single most costly subsystem, it is absolutely crucial to decide whether or not the tile / fiber scintillator calorimeter will survive at the SSC.

This technology has been chosen by SDC with the proviso that it must be established that plastic scintillators will withstand a radiation dose corresponding to a luminosity of

$$10^{34}/cm^2 \cdot sec$$

for 10 years of operation.

From the radiation damage test data taken by the physicists of the IHEP/ China, the tile / fiber technology has been proven to fully preserve the functionality of the SDC barrel calorimeter.

The work done at IHEP made a substantial contribution to the SDC calorimetry R & D effort.

The collaboration item will continue.

a) RADDAM TEST SCHEDULE

Oct.1990 – 1993, ~ 3 Years

7 module's tests have been completed.

MODULE	TILE	FIBER	PMT	GROOVE	GAS
FIRST ROUND					
MOD #1	SCSN81	BCF 91	XP-2020	U	N_2
MOD #2	SCSN81	BCF 91	OR	U	N_2–AIR
MOD #5	SCSN81	BCF 91	56 AVP	U	AIR
MOD #8	SCSN81	BCF 81		U	AIR
SECOND ROUND					
MOD #1	SCSN81	BCF91A	XP-2081B	U	AIR
MOD #2	SCSN81	+CLEAR	extended green	U	AIR
MOD #3	SCSN81+Y7 (Green)	ORANGE +CLEAR		U	AIR

The RADDAM test of various scintillator tiles, fibers and PMTs WILL BE CONTINUED UNTIL 1993.

b) TEST BEAM

BEPC LINAC 1.1–1.3 Gev electron beam

The radiation at the SSC in P-P collisions is due to the abundantly produced neutral and charged pions. Most of the effects of radiation damage on the calorimeter performance are due to the production of electromagnetic showers in the calorimeter itself, through the two gamma decay of pions. These photons will have energies typically in the few GeV range. This condition allows us to use an electron beam with beam energy of about 1 GeV as an optimum radiation source for the study of radiation damage in multi-TeV SSC operational environment.

c) ORGANIZATION

At IHEP / China, there are about 15 physicists and engineers involved in

the RADDAM test and organized into a group. Their first job is the RADDAM test.

In addition, FNAL, FSU and Pudue Univ. contribute to the joint experiment with IHEP/China.

d) FUNDING

Some of equipment was provided by the U.S., such as the moveable table and source driver.

Most of equipment was supplied by IHEP/ China.

IHEP/China will support all of the test funding except for the tested samples, scintillator tiles, fibers and PMTs will be provided by FNAL.

THIS COLLABORATION ITEM (No.3), HAS BEEN AND WILL BE COMPLETED IN A VERY TIMELY FASHION.

3. FIBERS

"ITEM No.2, CALORIMETER WAVE LENGTH SHIFTING(WLS) FIBER CUTTING, END POLISHING, ALUMINIZING (or SILVERING), SPLICING TO CLEAR FIBERS, AND TESTING OF THE RESULTING ASSEMBLY - 20% "

According to the present design, there are 365,440 fibers in total in the calorimeter.

This collaboration will require a lot of human resources. Since most of the work in this item are rather delicate, the formation of a team at IHEP, consisting of technicians and highly skilled workers under the supervision of physicists, will be very important and necessary.

a) HUMAN RESOURCES

IHEP/PRC will organize a special group to be responsible for the collaboration item.This group will consist of several physicists and enough trained technicians and highly skilled workers.

In IHEP, there are many experienced scientists, engineers and technicians who have previosly worked on the BES subdetectors, such as TOF(Scintillator, Laser calibration system via fibers), Drift Chamber (Stringing about 20,000 wires in Main Drift Chamber), Calorimeter, Muon tubes and so on.

WE ARE CONFIDENT THAT IHEP WILL BE ABLE TO ORGANIZE A VERY GOOD GROUP TO TAKE RESPONSIBILITY FOR THE FIBER ITEM.

---

b) FUNDING

Usually, funding comes from 3 sources in China.

One is IHEP research funding, which comes from the China government.

The salary of all manpower and operating equipment for research will be paid by this funding.

Second, funding may come from the companies associated with the institute, which develop products for sale.

Unfortunately, IHEP does not have many products which can be sold.

Third, there is National Natural Science Fundation of China for research and development of science and advanced technology. Collaboration items 2 and 3, the scientific contribution for SDC, can get support from this kind of funding because these 2 items belong to the R &D of the advanced technology and science.

---

c) EQUIPMENT AND TRAINING OF LABOUR

IHEP will provide the standard and normal equipment.

Some special equipment, such as the fiber finisher, fiber splicer and Evaporation system, will be provided by FNAL or loaned by FNAL.

IHEP will send one or two physicists to FNAL for training and learning how to operate and repair this special equipment.

As you know,the demanding tasks for the fiber work means that the quality of the labour is the crucial factor for the fiber task. So

WE BELIEVE THAT IHEP/CHINA IS A SUITABLE CANDIDATE TO COMPLETE THE FIBER (20%) WORK SUCCESSFULLY.

---

4. STEEL ABSORBER

" FIRST COLLABORATION ITEM IS BARREL CALORIMETER STEEL ABSORBER FABRICATION 100%"

The steel absorber of the barrel calorimeter consists of two half barrels. Each half barrel is currently designed to be assembled from 64 wedge shaped pieces.

One wedge,out of a total of 128 wedges, is about 1.7 meters in width, 4.2 meters in length, 0.4 meters in thickness and 15 English tons in weight. Each wedge is composed of many different steel plates.

The plates have many slots and grooves machined into them to create gaps for scintillator tiles, optical fibers, and radioactive source tubes. There are about 60,000 slots for the barrel tiles and 10,000 grooves for the source tubes.

There is about 2000 tons of steel in the barrel alone.

Because of the large size of the wedges, even individual pieces inside them weigh up to 1000 pounds. Fully assemble wedges must also have machining done on their outer surfaces.The most important feature of the finishing wedge shape is that it have the correct wedge angle and correct thickness so the capability of a large machine shop is clearly necessary.

The plates inside the wedges are currently thought to be fastened together by plug welding, so welding capability is also necessary in the fabricating shop.

Each steel plate has to conform to a complete set of manufacturing tolerances defining both the size and the form to guarantee the accuracy of the assembled wedge.

The current schedule calls for all wedges to be built in a two year period, from 1994 to 1996.

The status is briefly described as follows,

a) The physicists and engineers of IHEP are studing the blue prints and the structures of the steel absorber.

The directors of IHEP had a special meeting to discuss the SDC collaboration. The collaboration contract will be sighed between U.S.side and IHEP. The IHEP will deal with everything with chinese industrial factory.

The leaders have chosen several senior engineers and physicists to work on the absorber. All of them have experience with the successful BES detector. These engineers and physicists will be in charge of the absorber fabrication and will be directly responsible to the SDC calorimeter project manager. They must solve technical problems, monitor,ensure and check on the quality of every fabrication step. Some of them will live and work at the factory during the fabrication period.

b) The presidents of Academia Sinica will make every effort to help IHEP complete the RADDAM and Fiber items (2 & 3), and they will make sure that the industries involved in item #1 will perform satisfactorily.

c) IHEP/China have made preliminary contacts with industries in China with which IHEP has dealt in the past for BES. The leaders and scientists of IHEP /China think that the XinHe shipyard is a qualified candidate.

The shipyard fablicated the magnet for BES and that industry has a lot of experience with steel plate fablication for huge ships. The XinHe shipyard is in TiaJin,the 3rd largest city in China, and has a port. It will be very convenient to ship the huge and heavy absorber from China to U.S.A. using the port facilities.

d) The XinHe shipyard already has organized a special group, which consists of director, deputy director, chief engineer,mechanical engineer and etc. of the factory.

Under their leadership there are 6 group technology, quality control,equipment improvement, test and check and so on, to be in charge of the fablication of the absorber.

The engineers of the factory are studing the blue prints and the key manufacturing technology. They have made a preliminary cost estimate on the basis of "no gain, no loss".

The engineers of the factory will make a wood prototype of a wedge, to explore the fabrication process. Of course, it will be very helpful for the joint discussions when the 2 American engineers visit the shipyard in May.

The factory hopes that the steel materials will be supplied or bought from U.S.A. if it is not expensive. It will ensure the quality of the steel.

The highest leader of the general ship company, the former deputy minister of the National Economic Plan Commission of China asked and supported the XinHe shipyard to do best.

e) 2 American Engineers will visit the IHEP and the Shipyard in May, and will discuss the technology with the engineers and physicists of IHEP and the Shipyard in detail.

f) IHEP/China will arrange that the engineers participate in the joint further design of the absorber if it is necessary and helpful.

5. CONCLUDING REMARKS

IHEP/China has participated in and succesefully completed several international collaboration items, for example,

About 4000 channel proportional tubes of FNAL(E636),were made in IHEP. The tubes worked very well in FNAL (E745 and E782), from 1984 to 1991.

Another experiment,which IHEP/ China has been involved in, is the ALEPH collaboration at LEP, CERN. In total, more than 25000 8-fold tubes, ranging from 4 m to 7 m long were completed in IHEP and shipped to CERN on time.

On other hand, All members of the shipyard attach importance to the collaboration item. They have promised to put and always to keep the item as their first priority, and to ensure that the task will be finished on time.

Finally, the leaders, from IHEP directors, Academia Sinica leaders to the top leaders are very aware of the SDC collaboration. It is important in China.

WE, IHEP/CHINA BELIEVE THAT WE WILL MAKE OUR CONTRIBUTION TO THE CALORIMETER OF SDC.

WE ARE ALSO WILLING TO ACCEPT MORE TASKS IF SDC DESIRES.

Thank You.