FERMILAB-SLIDES-10-003-PPD

Nuts and Bolts of the Measurement

R. Tschirhart
for the P996 collaboration

Fermilab
March 12th , 2010

w/ Kovar

P-996 Collaboration Submitted a Proposal to Fermilab November 2009

Proposal:

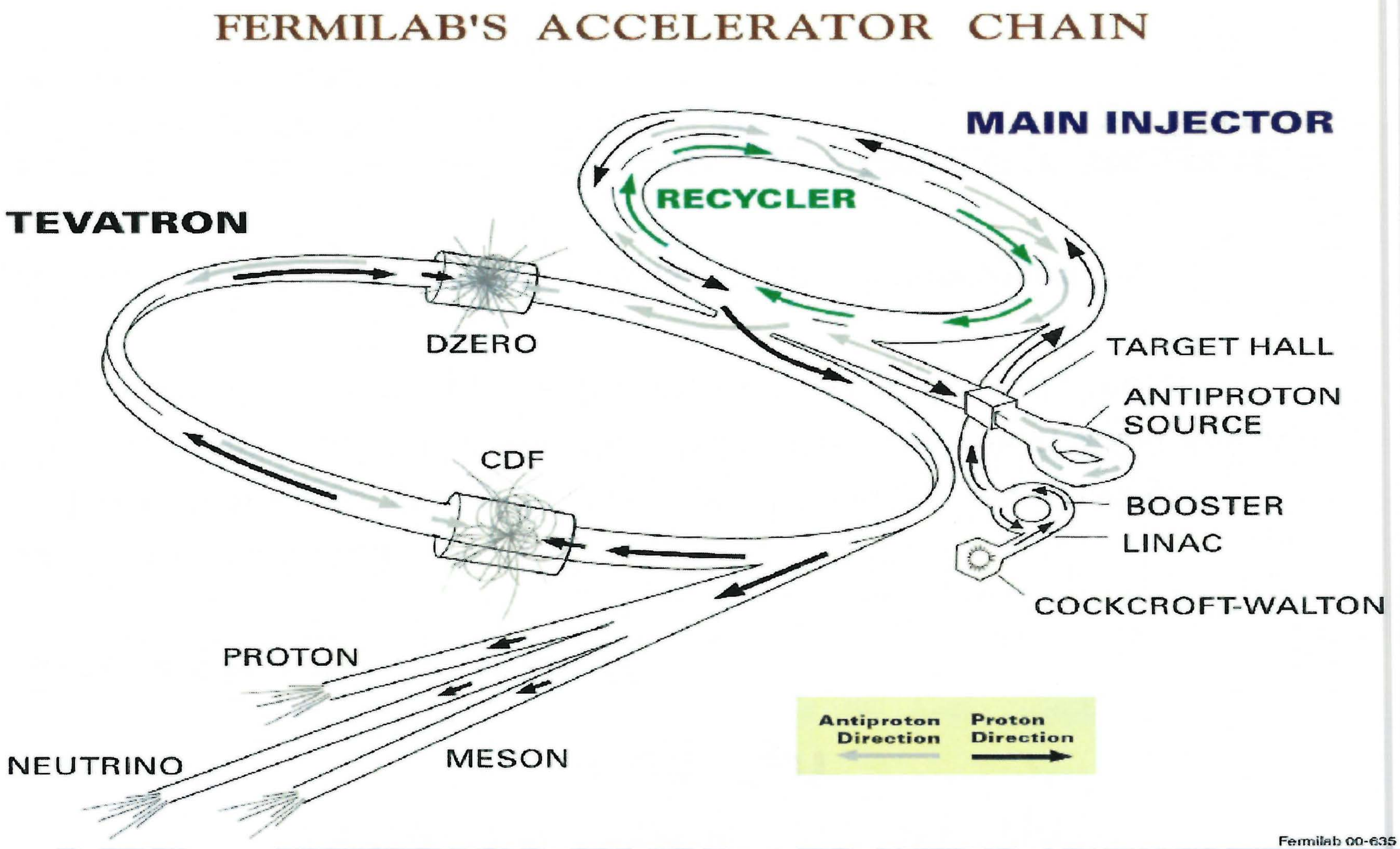
- Arizona State University, USA.
- Brookhaven National Laboratory, USA.
- Fermilab, USA.
- Institute for Nuclear Research - Russia
- Istituto Nazionale di Fisica Nucleare - Pisa, Italy.
- TRIUMF - Vancouver British Columbia, Canada
- University of British Columbia - Vancouver Canada.
- University of Texas at Austin, USA.
- **University of Illinois, Urbana, USA.**
- University of Northern British Columbia - Prince George - Canada.
- Universidad Autonoma de San Luis Potosi - Mexico.
- Tsinghua University, Beijing, China.

- **5 Countries, 12 institutes**
- **3 US universities, growing**
- **2 US National Laboratories**
- **Leadership from all US rare kaon decay experiments from the past 20 years.**

PAC:

"The Experiment [P996] meets the criteria of Stage-I Approval…."

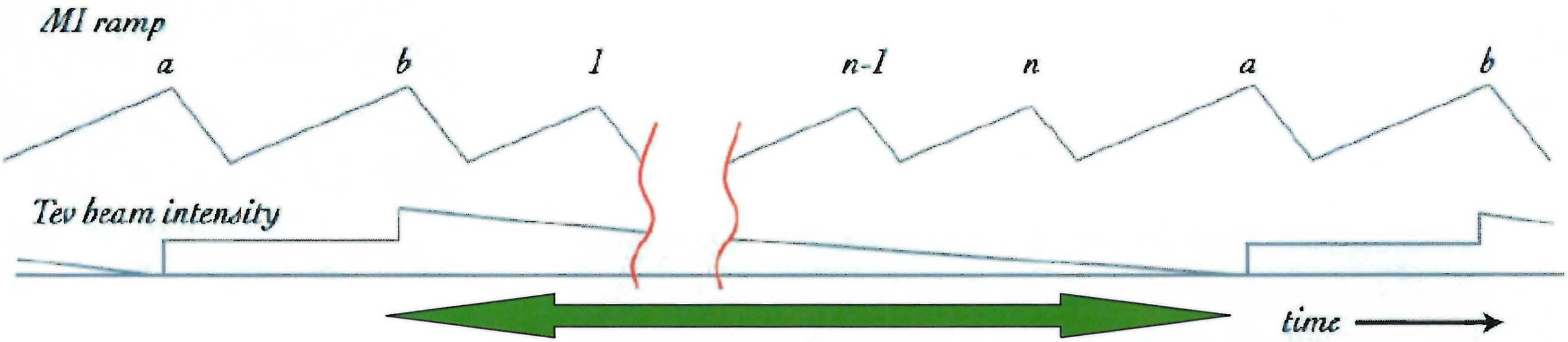
The Tevatron Stretcher Concept



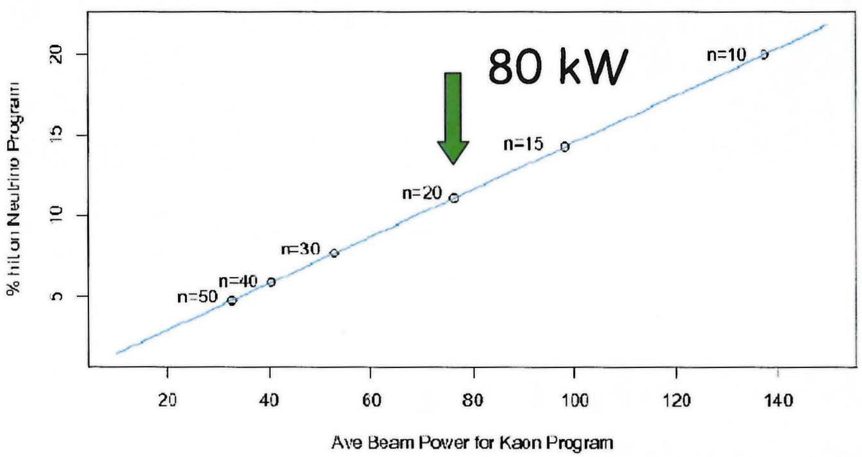
The Tevatron Stretcher Concept

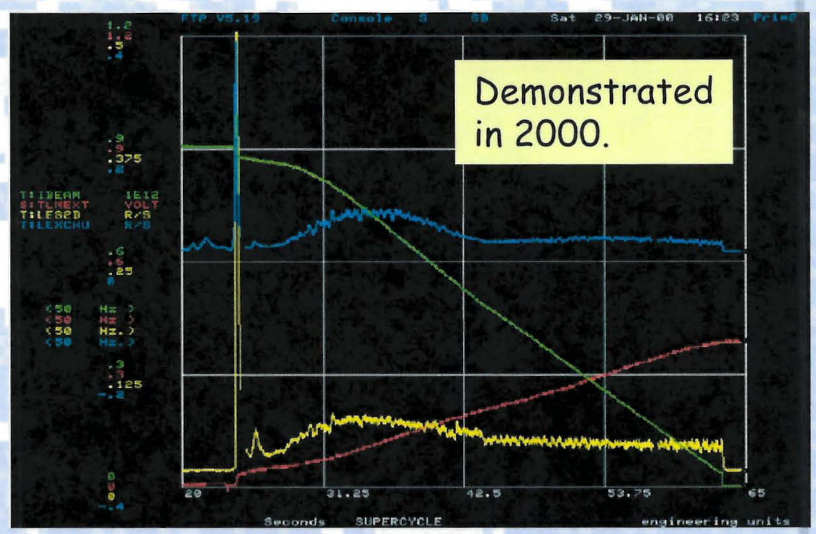
- Can be readily realized after Run-II.
- Good use of a SC machine:
  1) Match Tevatron energy to Main Injector energy. No ramping.
  2) Clean single pulse transfer from MI to the Tevatron at 120-150 GeV.
  3) Slow spill beam out of the Tevatron with very high duty factor.
- 10 % impact on NuMI operations, no impact on 8 GeV program.
- Slow beam extraction is easier at high energy. Beam-charge/Beam-power is x15 better than at 8 GeV for example. Required Slow-Extracted-Beam performance is comparable to 1997 TeV Fixed Target Run.
- Keeping Tevatron "on ice" about ~$6M/year. Tevatron Stretcher power and cryo is $8M/year + staff, estimated total of $15M/year.

Continuous High Power Beam…



26 second spill, 95% duty factor.

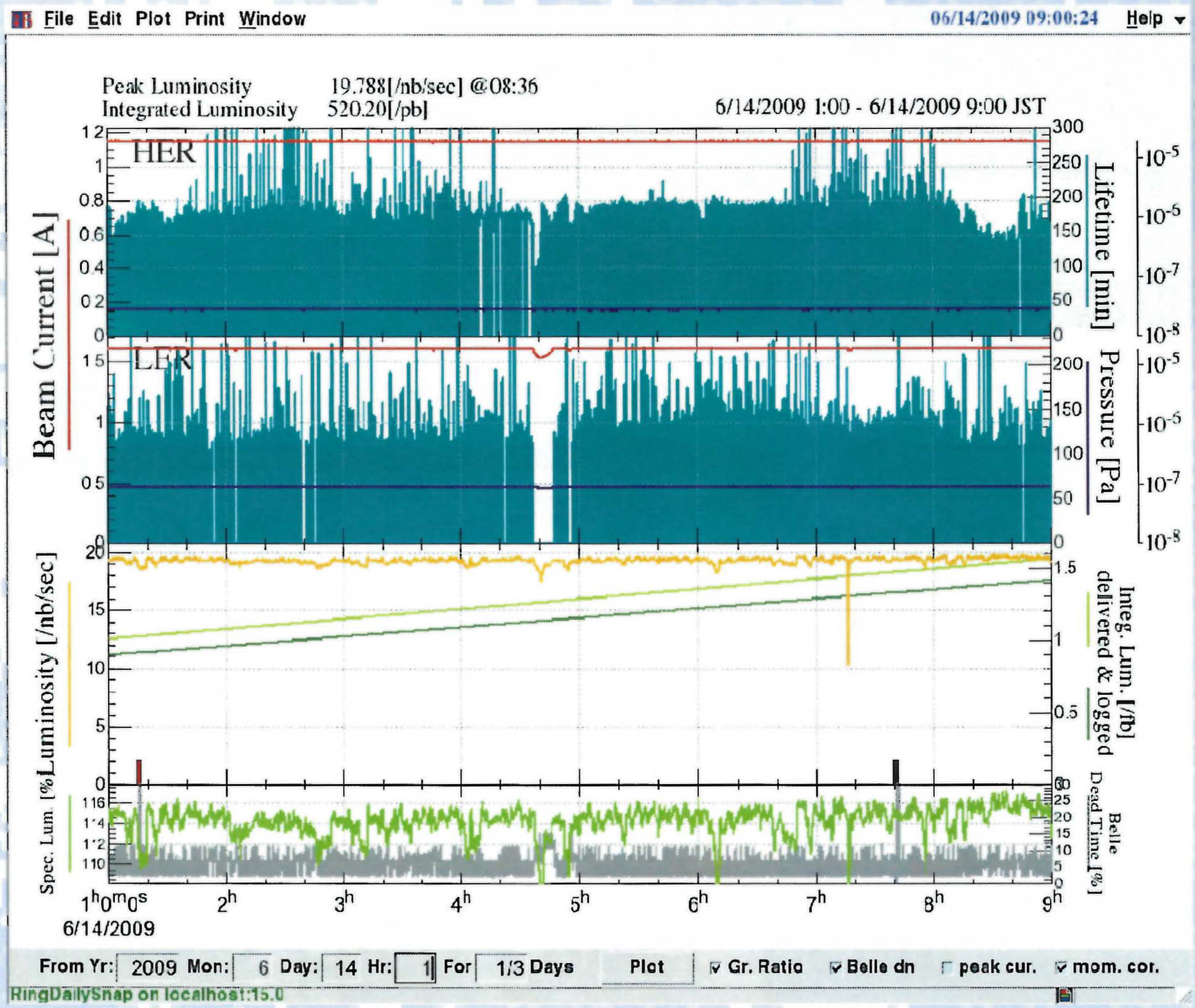




Continuous beam is *the* key to rare-decay facilities

KEK-B factory sets record of 550 pb^{-1} in an 8-hour shift ! (June 2009)

BaBar/PEP-II architects



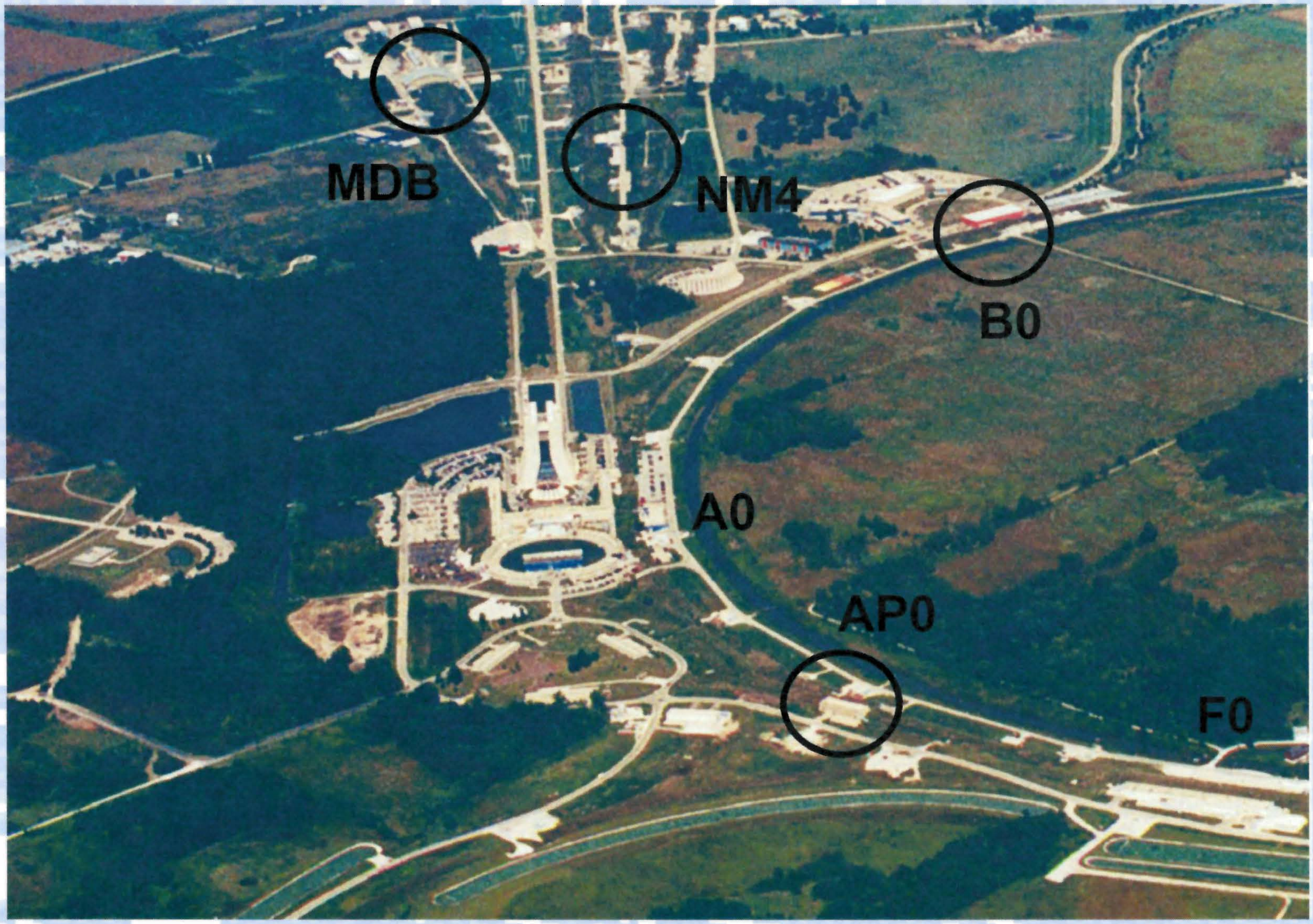
The Stretcher: A World-Leading Machine for the Field...

Slow-Spill proton facility	Beam Energy	Beam Power (average)	Duty Factor	Hours/year K^+ decays/year
BNL AGS (E949)	22 GeV	40 kW	50%	1000 2×10^{12}
CERN SPS (NA62)	450 GeV	13 kW	30%	1400 5×10^{12}
JPARC MR	30 GeV	1 kW Plan: 50 kW Goal: +100 kW	20-30%	2000
FNAL Tevatron (97,99 FT runs)	800 GeV	65kW	30-50%	5000
FNAL Stretcher (P996)	**150 GeV**	Plan: **+80kW**	**95%**	**5000 60×10^{12}**
Project-X	3 GeV	Goal: 1000kW	95%	5000 $\sim 600 \times 10^{12}$

The Stretcher: Re-purposing Modern and Well Maintained Accelerator Infrastructure

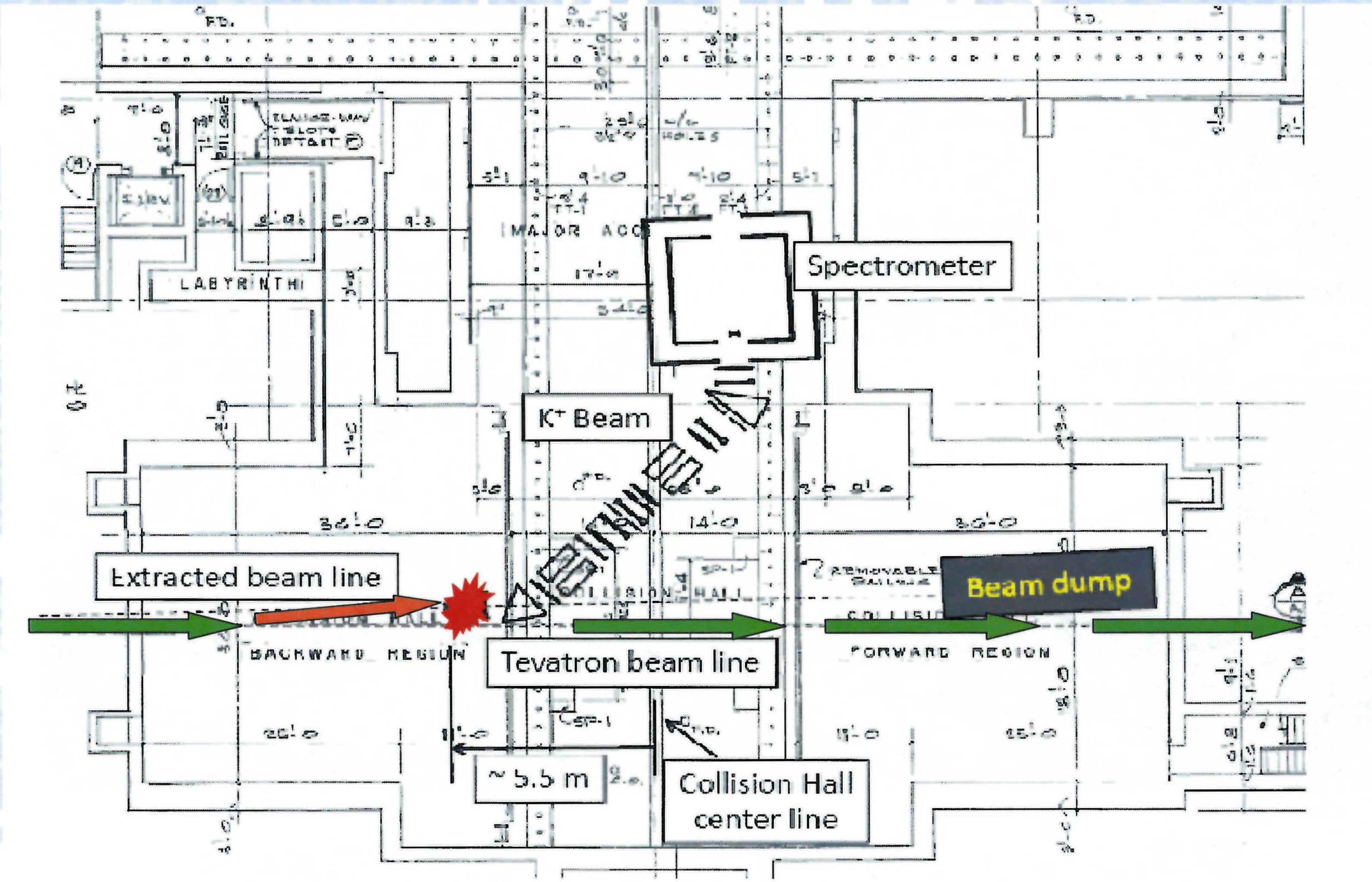
The Stretcher: Re-purposing Modern and Well Maintained Accelerator Infrastructure

P996 Experiment Site Options

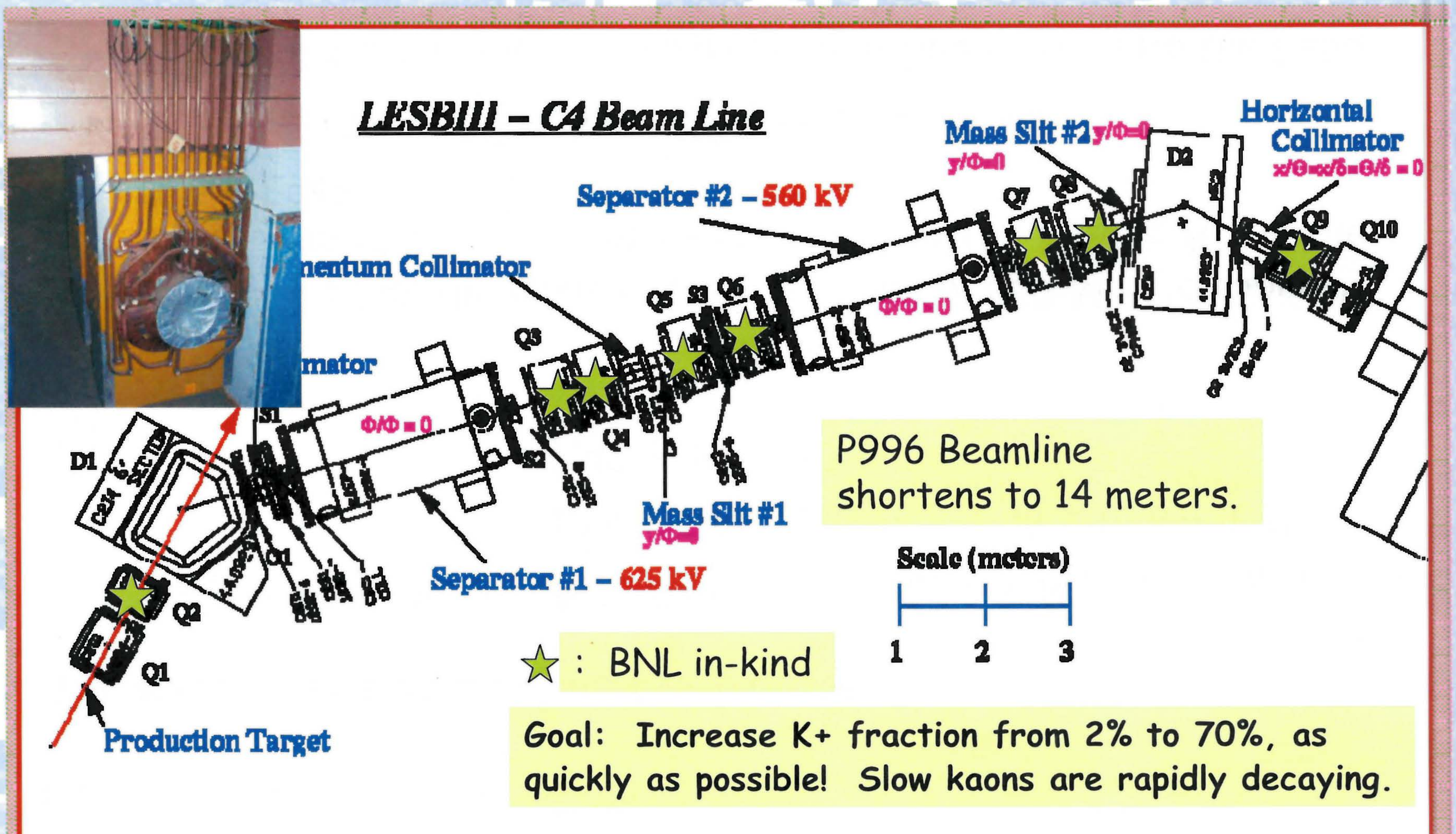


P996 Experiment Site Options

Beamline and Detector at CDF hall (B0)



K+ Beamline: Focus a low energy separated charged beam on a stopping target. Measure kaon decays at Rest!



P996 Beamline shortens to 14 meters.

★ : BNL in-kind

Goal: Increase K+ fraction from 2% to 70%, as quickly as possible! Slow kaons are rapidly decaying.

Rate of Incident Kaons

The expected rate of kaons incident on P996:

$$
\begin{aligned}
N_K(\mathrm{P996})/\mathrm{spill} &= N_K(\mathrm{E949})/\mathrm{spill} \times R_{\mathrm{surv}} \times R_{\mathrm{proton}} \times R_{K/p} \\
&= 12.8 \times 10^6 \times 1.1048 \times 1.48 \times (6.8 \pm 1.7) \\
&= (142 \pm 36) \times 10^6.
\end{aligned}
$$

- $R_{\mathrm{surv}} = 1.1048$, the relative rate of survival of 550 MeV/c kaons in the 13.74m P996 K^+ beamline compared to 710 MeV/c K^+ in the 19.6m E949 beamline,
- $R_{\mathrm{proton}} = (96 \times 10^{12})/(65 \times 10^{12})$ protons per spill,
- $R_{K/p} = 6.8 \pm 1.7$, the relative production rate of K^+ into the P996 and E949 kaon beamline acceptance as determined from MARS-LAQSGM simulation.

Rate of Stopped Kaons

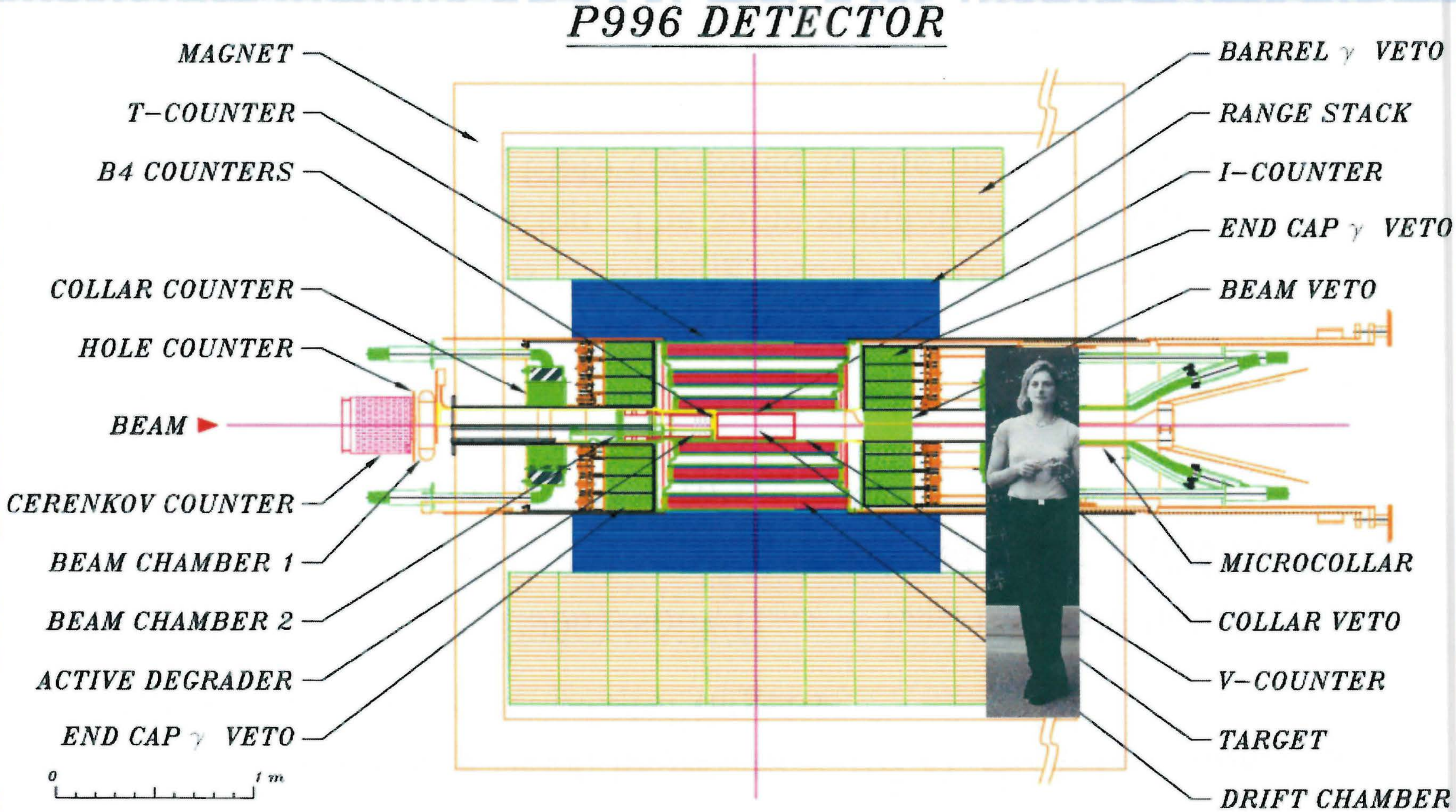
For one year of running (5000 hours=18×10^6 s), the total number of stopped kaons in the experimental target is

$$\begin{aligned} N_{\mathrm{Kstop}}/\mathrm{year} &= N_K(\mathrm{P996})/\mathrm{spill}/(t_{spill} + t_{inter}) \times 5000 \text{ hours} \times f_{\mathrm{stop}} \\ &= (142 \pm 36) \times 10^6/27.33\mathrm{s} \times 18 \times 10^6 \times (0.60 \pm 0.13) \\ &= (5.6 \pm 1.9) \times 10^{13}. \end{aligned}$$

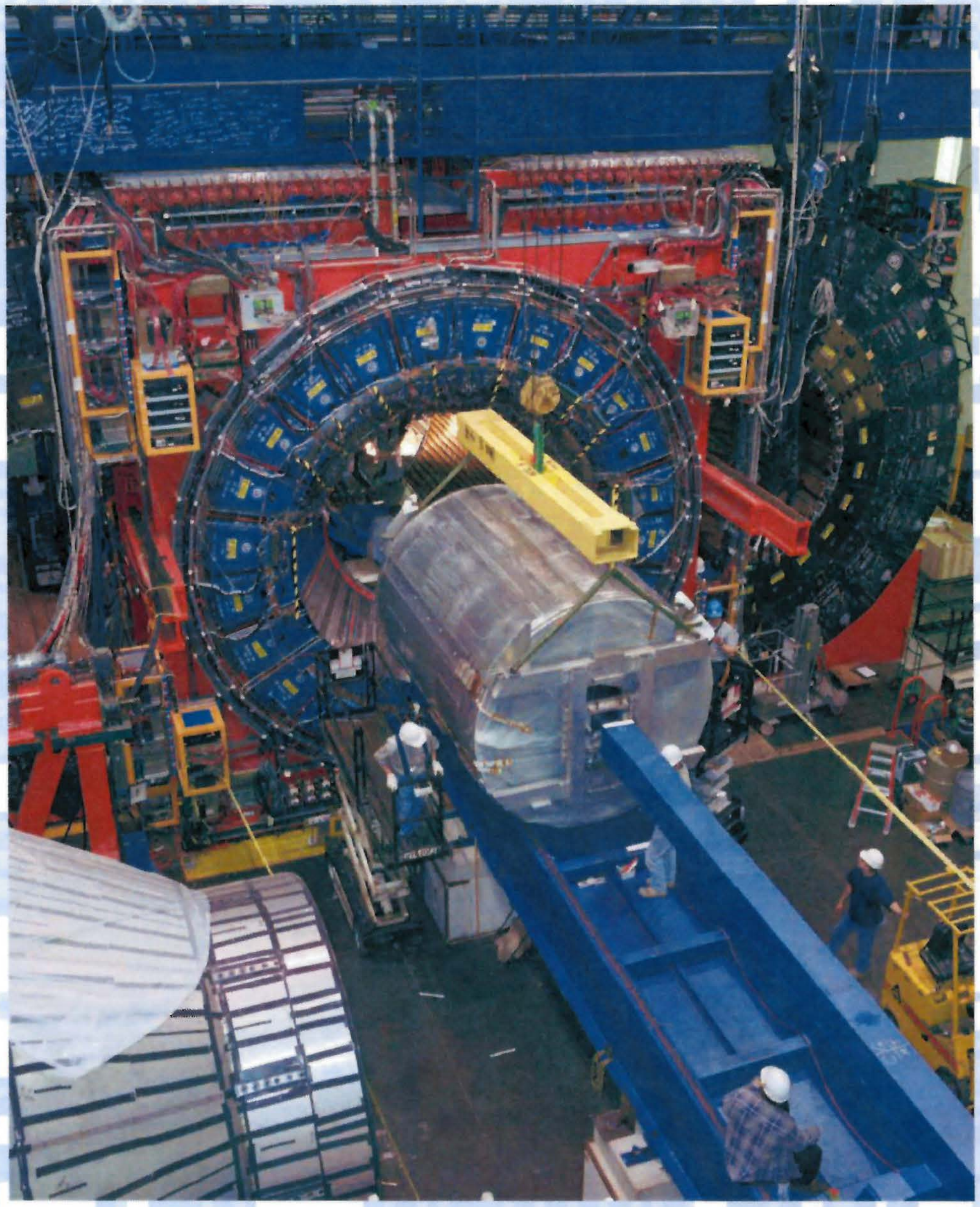
- $t_{spill} = 25.67$s spill,
- $t_{inter} = 1.67$s interspill with the stretcher,
- $f_{\mathrm{stop}} = 0.60 \pm 0.13$, K^+ stopping fraction estimated with FLUKA-based simulation. The same simulation estimated a 27% stopping fraction for E949 compared to the measured 21% stopping fraction.

	E949	P996	
Instantaneous Rate (K^+, π^+)	8.4	7.6	MHz

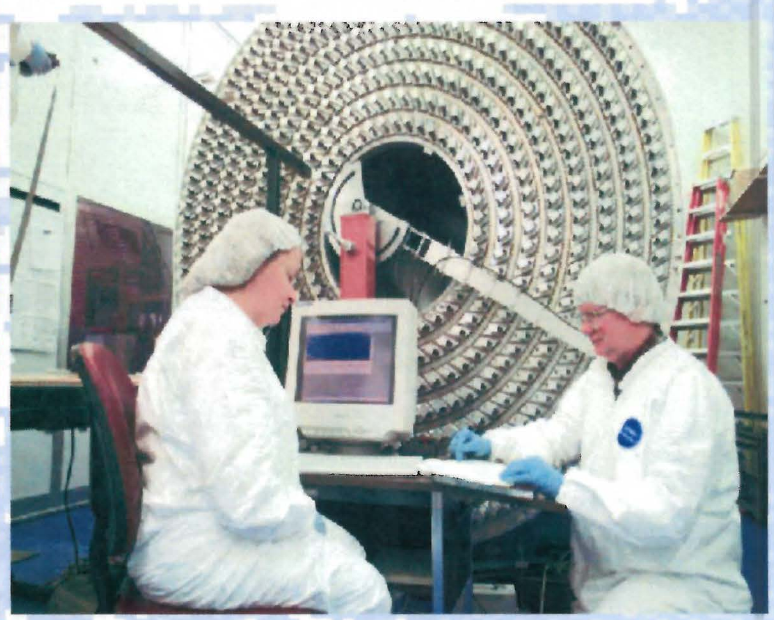
The detector that watches 8-million kaon decays per second



Lisa Randall with an experiment that discovers evidence for extra dimensions…



The P996 new detector payload replaces the CDF tracker volume.



The Range Stack measures the π^+ decay chain, energy, range: Ripe for upgrade

Detector Acceptance

P996 detector improvements will enable increases in signal acceptance.
Expected increases are based largely on E949/E787 data and measurements.

Component	Acceptance factor
$\pi \to \mu \to e$	2.24 ± 0.07
Deadtimeless DAQ	1.35
Larger solid angle	1.38
1.25-T B field	1.12 ± 0.05
Range stack segmentation	1.12 ± 0.06
Photon veto	$1.65^{+0.39}_{-0.18}$
Improved target	1.06 ± 0.06
Macro-efficiency	1.11 ± 0.07
Delayed coincidence	1.11 ± 0.05
Product (R_{acc})	$11.28^{+3.25}_{-2.22}$

Additional acceptance gains expected from trigger improvements are not yet quantified.

$K^+ \to \pi^+ \nu\bar{\nu}$ Events per Year

The number of signal events per 5000-hour year is

$$
\begin{aligned}
N_{K^+\to\pi^+\nu\bar{\nu}} &= \mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) \times N_{\mathrm{Kstop}} \times A_{\mathrm{E949}} \times R_{\mathrm{acc}} \\
&= (0.85 \pm 0.07) \times 10^{-10} \times (5.6 \pm 1.9) \times 10^{13} \\
&\quad \times (3.59 \pm 0.36) \times 10^{-3} \times (11.3^{+3.3}_{-2.3}) \\
&= 194^{+89}_{-79}
\end{aligned}
$$

where

- $\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (0.85 \pm 0.07) \times 10^{-10}$
- $A_{\mathrm{E949}} = (2.22 \pm 0.17) \times 10^{-3} + (1.37 \pm 0.14) \times 10^{-3}$
  $=$ PNN1 + PNN2 acceptance
- $R_{\mathrm{acc}} = (11.3^{+3.3}_{-2.3})$, the product of acceptance factors gained over E949.

Summary of Improvement Factors

Ratio P996/E949	
$11.3^{+3.3}_{-2.3}$	Detector acceptance
6.3 ± 2.1	Stopped kaons per hour
5.3	Hours per year

Stopped kaon yield $\equiv R_{\mathrm{prot}} \times R_{K/p} \times R_{\mathrm{surv}} \times R_{\mathrm{stop}}/R_{\mathrm{spill}}$
where

- R_{proton} is the ratio of protons per spill,
- $R_{K/p}$ is the relative production rate of K^+ into the P996 and E949 kaon beamline acceptance.
- R_{surv} is the relative K^+ survival rate in the kaon beamline,
- R_{stop} is the relative K^+ stopping fractions, and
- R_{spill} is the relative spill length.

Comparable K^+, π^+ instantaneous rate in E949 (8.4 MHz) and P996 (7.6 MHz).

Table 10.2: Estimated project cost. All costs in FY10 $k.

WBS element		Description	Total Cost	60% conting.	Total w/cont.	
1.0		**TPC**	**$33M**	**$20M**	**$53M**	★
1.1		**Accelerator and Beams**	**7,500**	**4,500**	**12,000**	
	1.1.1	Tevatron Modifications	940	560	1,500	
	1.1.2	Extraction and Lines	1,250	750	2,000	
	1.1.3	Target and Dump	940	560	1,500	
	1.1.4	Kaon Beam	4,370	2630	7,000	★
1.2		**Detector**	**22,390**	**13,430**	**35,820**	
	1.2.1	Spectrometer Magnet	500	300	800	
	1.2.2	Beam and Target	600	360	960	
	1.2.3	Drift Chamber	1,900	1,140	3,040	★
	1.2.4	Range Stack	2,500	1,500	4,000	★
	1.2.5	Photon Veto	3,000	1,800	4,800	
	1.2.6	Electronics	4,000	2,400	6,400	★
	1.2.7	Trigger and DAQ	2,000	1,200	3,200	★
	1.2.8	Software and Computing	2,000	1,200	3,200	★
	1.2.9	Installation and Integration	5,890	3,530	9,420	
1.3		**Project Management**	**2,740**	**1,640**	**4,380**	
1.4		**OPC**	**700**	**420**	**1,120**	
	1.4.1	R&D	300	180	480	
	1.4.2	Comissioning	400	240	640	

From P996 Proposal

Proposed Schedule..

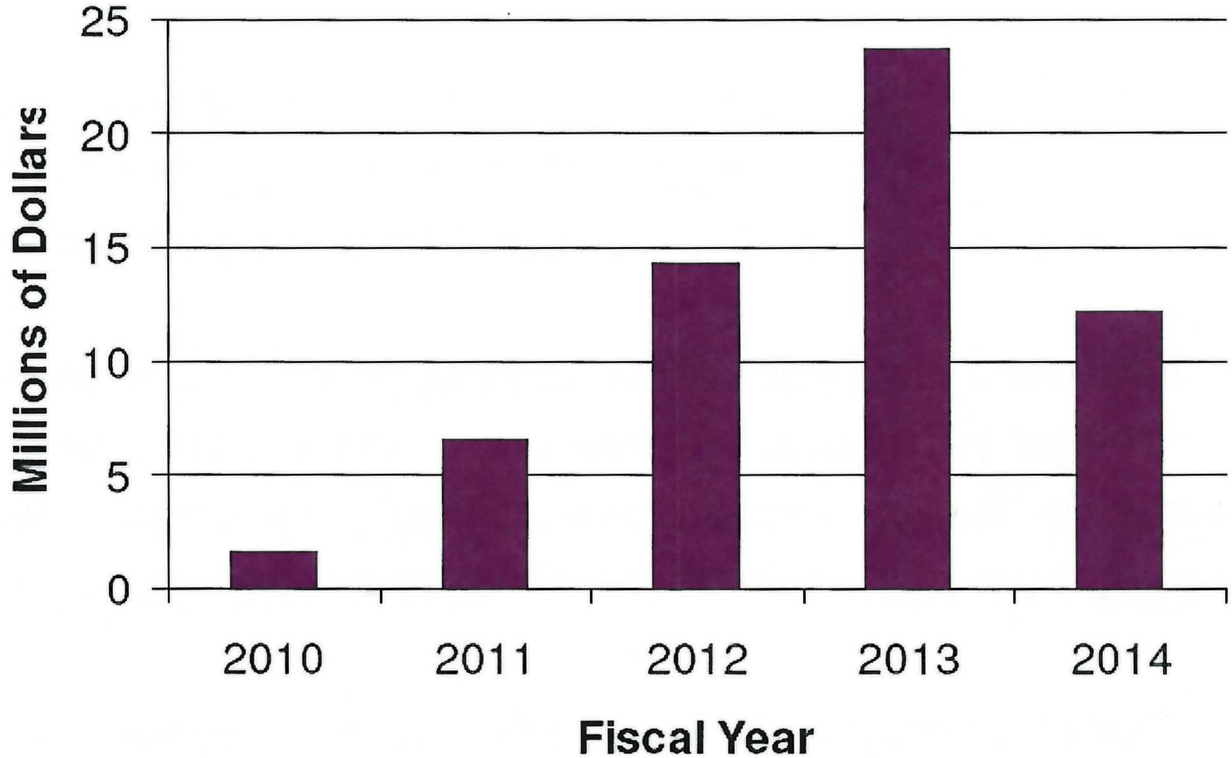


Figure 11.1: A funding profile that assumes our estimated TPC of $58M in then-year dollars. While based on general considerations rather than detailed plans, a funding profile close to this will be necessary to meet our proposed schedule.

From P996 Proposal

Progress on Reducing the Experiment TPC

- Direct savings on CDF decommissioning and infrastructure:

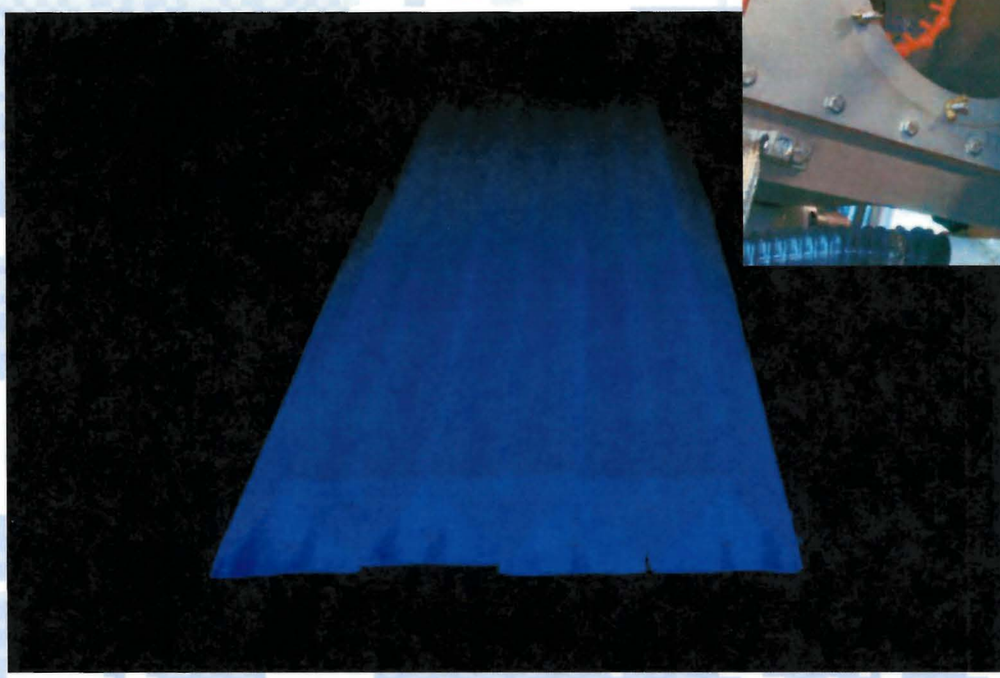
- Save $6-9M in CDF decommissioning (retaining central detector and coil)
- Save $2-3M on electronics (Racks, power, crates, cooling, monitoring, etc)
- Save $0.4M on Drift Chamber front-end electronics (ASDQ)
- Save $0.5M on power and cooling for trigger and DAQ computing.

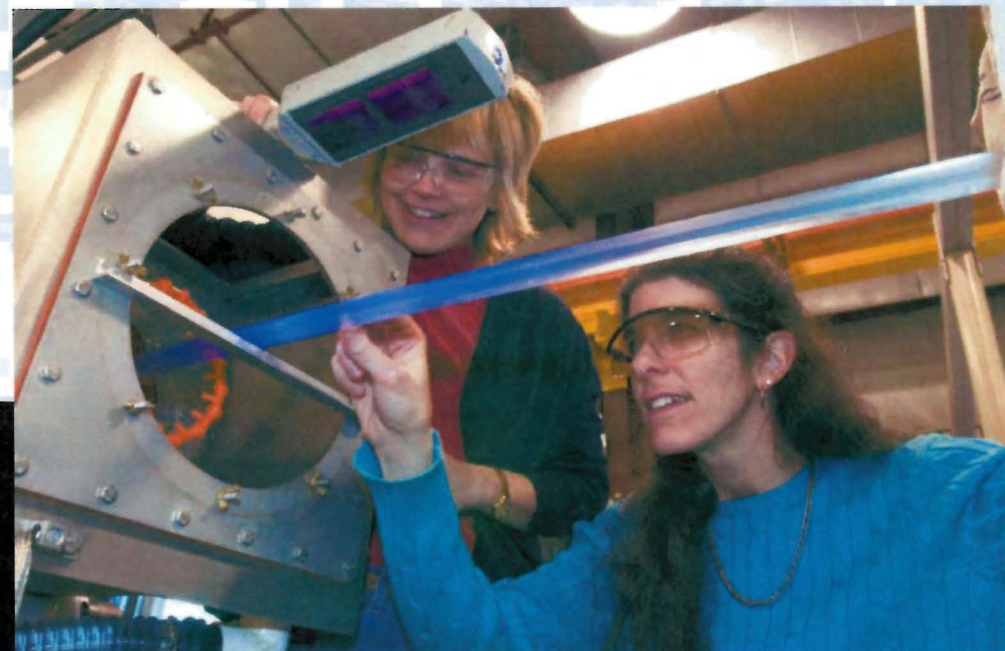
- CDF re-use reduces TPC estimate by: $9-13M
- BNL in-kind reduces TPC estimate by: $3M
- S&C off project reduces TPC by: $3.2M

- TPC after CDF reductions, BNL in-kind, and removing S&C:

  $53M - $(15-18)M = $(35-38)M

Extruded Scintillator technologies can lower costs...



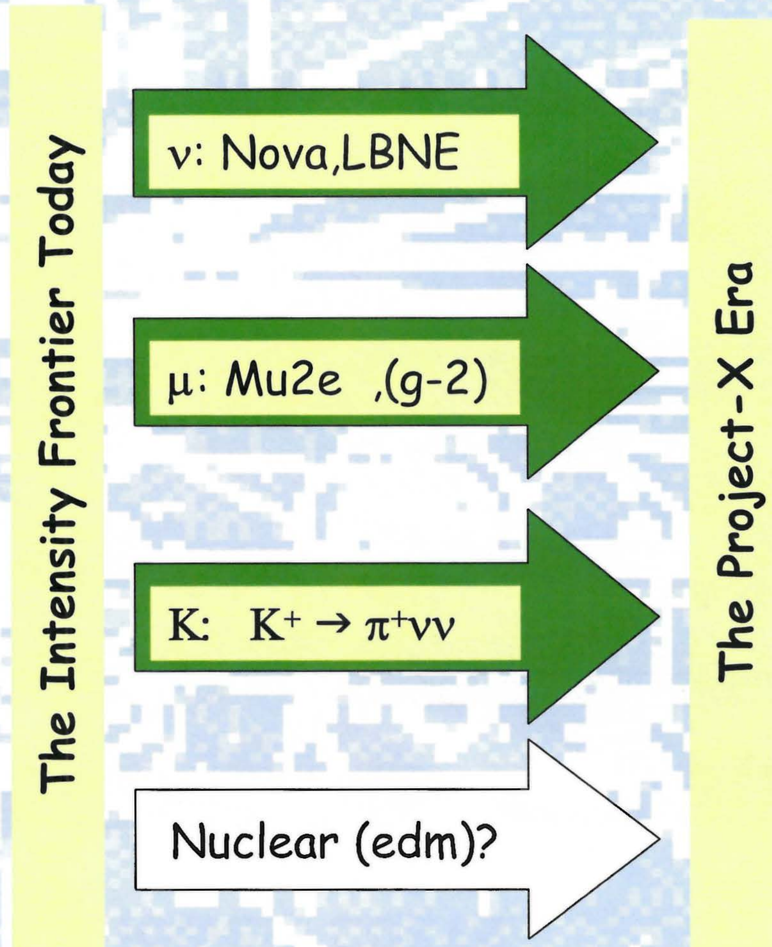


Minerva Scintillator

Relationship of P996 to Project-X

- Physics from P996 will energize the flavor physics community this decade.
- The P996 detector can be driven with Project-X beam in Stage-II.
- Project-X era experiments are challenging:

  The P996 experiment and community will be well positioned to exploit the revolutionary beam power of Project-X.



A Vision for Rare Processes in the Project-X era...

- Mu2e and P996 are the first stage of the Project-X ultra-rare decay research program.

- These experiments will *accelerate* progress on the Project-X research program much like Run-II has now positioned the US to exploit the potential of the LHC.

- The 2009 Project-X task force effort* identified many (20+) world class experiments driven by the CW linac which would complement the long-baseline neutrino physics research program.

*http://www.fnal.gov/pub/projectx/pdfs/ICD2_Research_Program_Task_Force_v6.pdf

What P996 Needs from OHEP to Advance

- A Path toward Critical Decision Zero for P996 this spring.

- Support for operating the Tevatron after Run-II as a Stretcher machine.

- Support for the US university community to engage in this endeavor.

Resources required from Fermilab in 2010 to make progress:

- Effort to validate CDF/B0 as the detector site. Requires Beamline physicists, engineering-physicists, a small amount of of FESS.
- Effort for beamline and target design for detailed costing.
- Computing professional support for setting up simulation infrastructure.
- Chemist, engineering-physicist, technician support for low cost extruded scintillator studies. Work in the context of a Field Work Proposal to OHEP.

Direct Opportunities for OHEP to Support P996 in the Near Term

- Supplemental support for collaborating DOE HEP universities labs to develop conceptual designs for detector sub-systems. Many good opportunities here.

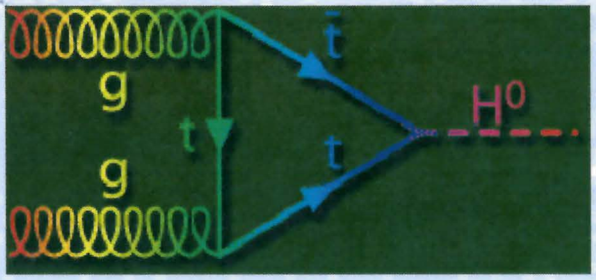
  ($200K-300K scope)

- Support for BNL to recover, refurbish and ship beamline quadrapoles and power supplies to Fermilab.

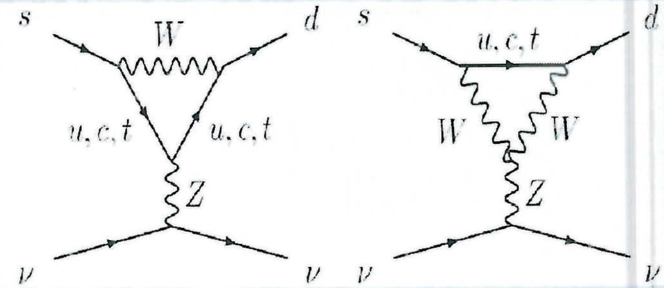
  ($200K, possibly as part of AGS D&D)

- Consider Field Work Proposal support for developing extruded scintillator to the required P996 performance.

  (estimate FWP scope of $200K)



Summary



- Fermilab Proposal P996 can deliver on the long sought after goal of precisely measuring $K^+ \rightarrow \pi^+ \nu \bar{\nu}$. This goal can be achieved with modest resources.

- P996 is a "kaon experiment" in the same way that CMS and ATLAS are "proton experiments". We are using familiar hadrons as tools to explore and study the Terascale.

- P996 is a timely opportunity which accelerates progress toward Project-X and the future discoveries there.

Spares

High duty-factor proton beams: Why is this important??

- Experiments that reconstruct an "event" to a particular time from sub-detector elements are intrinsically vulnerable to making mistakes at high instantaneous intensity (I). The probability of making a mistake is proportional to $I^2 \times \delta t$, where δt is the event resolving time.

- Searching for rare processes requires high intensity.

- Controlling backgrounds means minimizing the instantaneous rate and maximizing the time resolution performance of the experiment.

- This is a common problem for Run-II, LHC, Mu2e, High-School class reunions, etc.

Slow Extracted Beam: The Standard Tool to Drive Ultra Rare Decay Experiments

- Techniques developed in the late 1960's to "slow spill" beam from a synchrotron.
- Technique operates at the edge of stability---Betatron oscillations are induced which interact with material in the beam (wire septum) to eject particles from the storage ring beam phase space.
- Technique limited by septum heating & damage, beam losses, and space charge induced instabilities. Works better at higher energies where the beam-power/charge ratio is more favorable.
- Performance milestones:

  Tevatron 800 GeV FT: 64 kW of SEB in 1997.
  BNL AGS 24 GeV beam, 50-70 kW of SEB.

- JPARC Goal: 300 kW of SEB someday, a few kW within reach now.

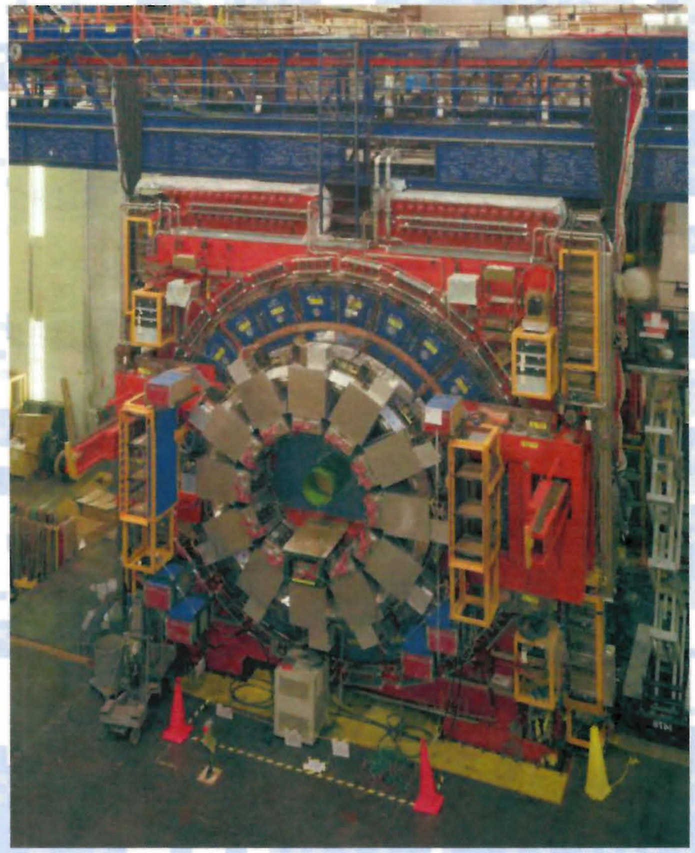
Sensitivity of Kaon Physics Today

- CERN NA62: 100×10^{-12} measurement sensitivity of $K^+ \to e^+\nu$
- Fermilab KTeV: 20×10^{-12} measurement sensitivity of $K_L \to \mu\mu ee$
- Fermilab KTeV: 20×10^{-12} search sensitivity for $K_L \to \pi\mu e$, $\pi\pi\mu e$
- BNL E949: 20×10^{-12} measurement sensitivity of $K^+ \to \pi^+\nu\bar{\nu}$
- BNL E871: 1×10^{-12} measurement sensitivity of $K_L \to e^+e^-$
- BNL E871: 1×10^{-12} search sensitivity for $K_L \to \mu e$

Probing new physics above a 10 TeV scale with 20-50 kW of protons.

Next goal: ***1000-event*** $\pi\nu\nu$ **experiments...10^{-14} sensitivty.**

CDF detector, then and now...



Summary of Options
Tev at Liquid Nitrogen Temp.

Dollar Amounts are in thousands of 2008 dollars, and are direct costs only						
		COST/FTE w/OH		$175		
	M&S	M&S w/OH	Person-years	SWF	TOTAL COST w/OH	
One Time Costs (incurred in first year only)						
Leak Check	$0	$0	6.3	$1,094	$1,094	
Miscellaneous Mechanical	$257	$298	3.2	$568	$866	Primarily Mech Techs
Contingency	$257	$298	9.5	$1,662	$1,960	
Per year costs (incurred in all years, including the first)						
CHL Operations	$638	$740	0.5	$88	$827	M&S is power: 1300 kW at $0.056/kW
Helium	$922	$1,069			$1,069	25000 scf/day @ $10.10/100 scf
Nitrogen	$1,764	$2,046			$2,046	60 Mscf/month @ $0.245/100 scf
Miscellaneous Mechanical	$213	$247	3.2	$568	$815	
Contingency	$884	$1,026	3.7	$655	$1,681	
Year one costs	$4,934	$5,724	26.5	$4,634	$10,358	
Out year annualcos	$4,420	$5,128	7.5	$1,310	$6,438	

Paul C. Czarapata: DOE S&T Review, June 30 - July 2, 2009

Tevatron Cryogenic System Operating Costs

J. C. Theilacker

5/1/2008

	Maintain Tevatron at 300K	Cool Down Tevatron at 80K	Cool Down Tevatron at 4.5K	CNR On 900 GeV Operation	CNR Off 900 GeV Operation	CNR On 980 GeV Operation	CNR Off 980 GeV Operation
Electric							
satellite	0.0 MW	1.0 MW	9.0 MW	7.0 MW	7.0 MW	7.3 MW	7.3 MW
CHL	0.3 MW	0.3 MW	3.0 MW	3.0 MW	3.0 MW	4.3 MW	4.3 MW
CNR	0.0 MW	0.0 MW	0.0 MW	2.5 MW	0.0 MW	2.5 MW	0.0 MW
Total	0.3 MW	1.3 MW	12.0 MW	12.5 MW	10.0 MW	14.1 MW	11.6 MW
demand	$0.00 /MW	$0.00 /MW	$0.00 /MW	$0.00 /MW	$0.00 /MW	$0.00 /MW	$0.00 /MW
demand cost	$0 /month	$0 /month	$0 /month	$0 /month	$0 /month	$0 /month	$0 /month
rate	$56.00 /MW-hr	$56.00 /MW-hr	$56.00 /MW-hr	$56.00 /MW-hr	$56.00 /MW-hr	$56.00 /MW-hr	$56.00 /MW-hr
rate cost	$12,264 /month	$53,144 /month	$490,560 /month	$511,000 /month	$408,800 /month	$576,408 /month	$474,208 /month
subtotal	$12,264 /month	$53,144 /month	$490,560 /month	$511,000 /month	$408,800 /month	$576,408 /month	$474,208 /month
Helium							
usage	0 scf/day	25,000 scf/day	25,000 scf/day	25,000 scf/day	25,000 scf/day	25,000 scf/day	25,000 scf/day
rate	$10.10 /100 scf	$10.10 /100 scf	$10.10 /100 scf	$10.10 /100 scf	$10.10 /100 scf	$10.10 /100 scf	$10.10 /100 scf
subtotal	$0 /month	$76,802 /month	$76,802 /month	$76,802 /month	$76,802 /month	$76,802 /month	$76,802 /month
Nitrogen	purging						
usage	1.5 Mscf/month	60 Mscf/month	90 Mscf/month	20 Mscf/month	80 Mscf/month	41 Mscf/month	101 Mscf/month
rate	$0.245 /100 scf	$0.245 /100 scf	$0.245 /100 scf	$0.245 /100 scf	$0.245 /100 scf	$0.245 /100 scf	$0.245 /100 scf
subtotal	$3,675 /month	$147,000 /month	$220,500 /month	$49,000 /month	$196,000 /month	$101,537 /month	$248,537 /month
One-Time Costs		leak check	helium charge				
		75 mm	60,000 liters				
		$75,000 /year	$10.10 /100 scf				
		$468,750	$164,719				
		4.5 m shutdown					
Total Rate	$15,939 /month	$276,946 /month	$787,862 /month	$636,802 /month	$681,602 /month	$754,747 /month	$799,547 /month
One-Time Cost		$468,750	$164,719				
	40880						
	56						
	71.68						
	75.6						

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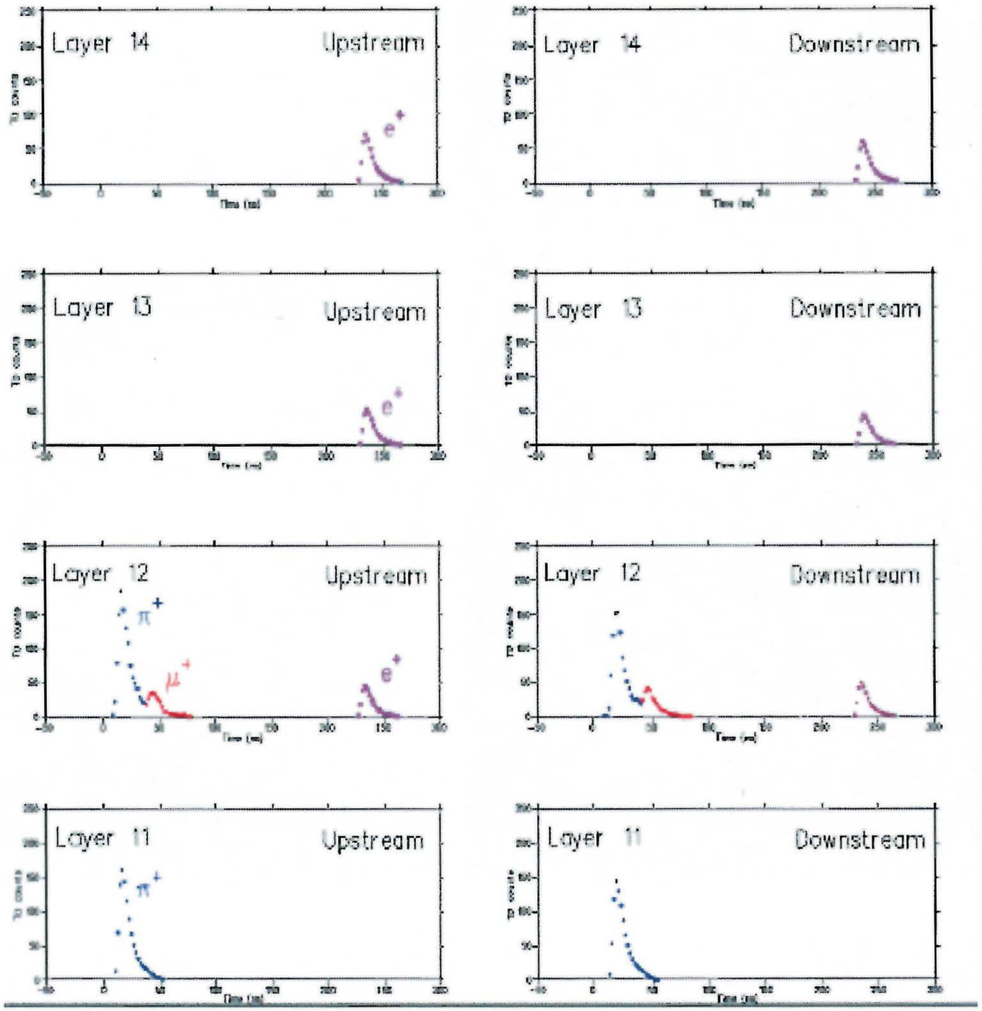
$\pi \rightarrow \mu \rightarrow e$ detection in E949



Development required for more precise extrusion and compact photon readout...