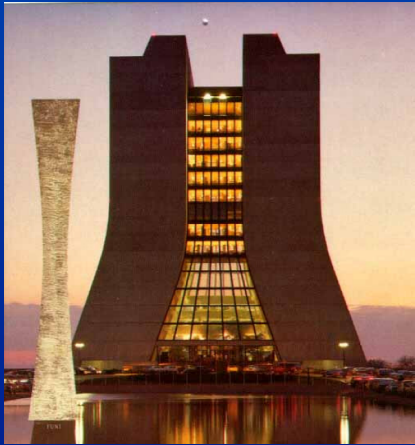# Searches for New Phenomena at the FermilabTevatron

Todd Adams
Florida State University
for the CDF and DØ Collaborations

APS April 2010 Meeting
February 13, 2010

The Tevatron is a Discovery Machine

Proton - Antiproton Collider

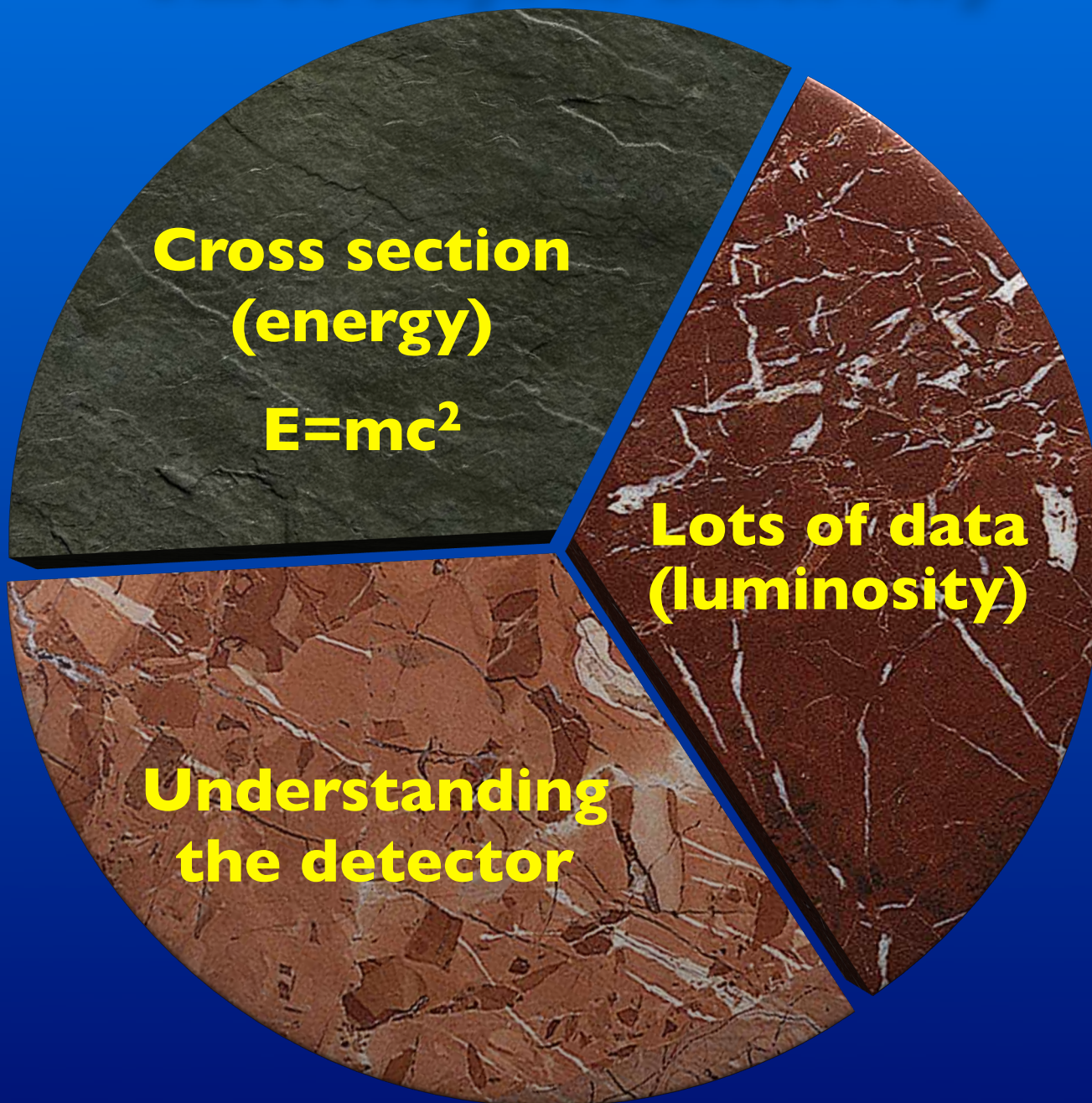### center of mass energy of 1.96 TeV

Tevatron Discoveries:
Top Quark
B_s Oscillations
$\Sigma_b, \Xi_b, \Omega_b$
???

Three Keys to Discovery

Cross section (energy)

$E=mc^2$

Lots of data (luminosity)
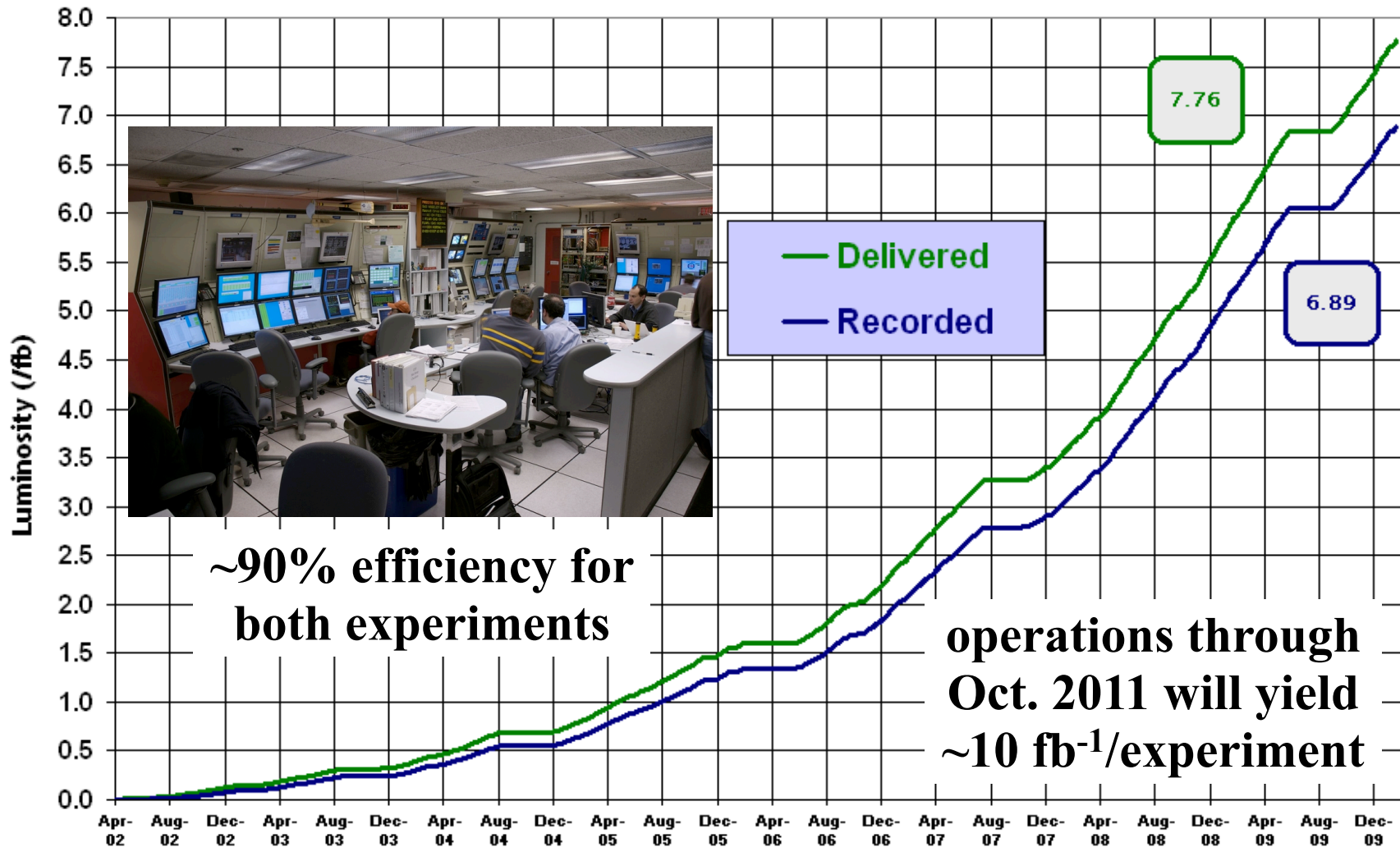
Understanding the detector

- **New phenomena searches (Run II)**
  ▸ **103 publications**
  ▸ **36 additional preliminary results**
  ▸ **not including Higgs**

- **Precision results**
  ▸ **QCD**
  ▸ **electroweak**
  ▸ **top**
  ▸ **b-physics**

Luminosity

Run II Integrated Luminosity

19 April 2002 - 7 February 2010

~90% efficiency for both experiments

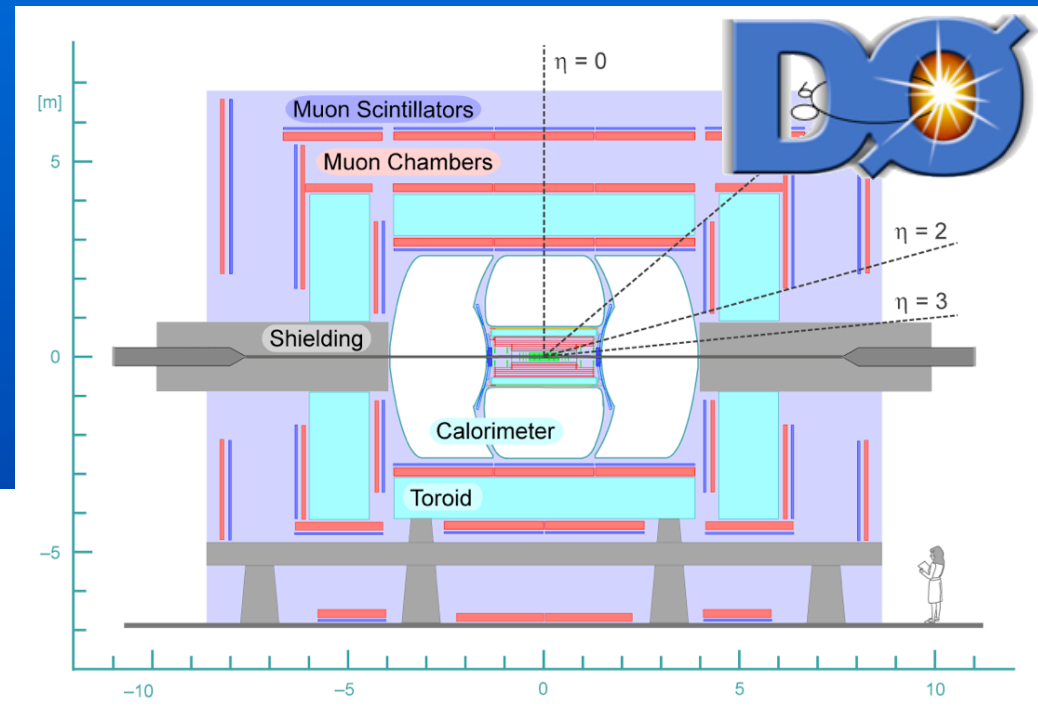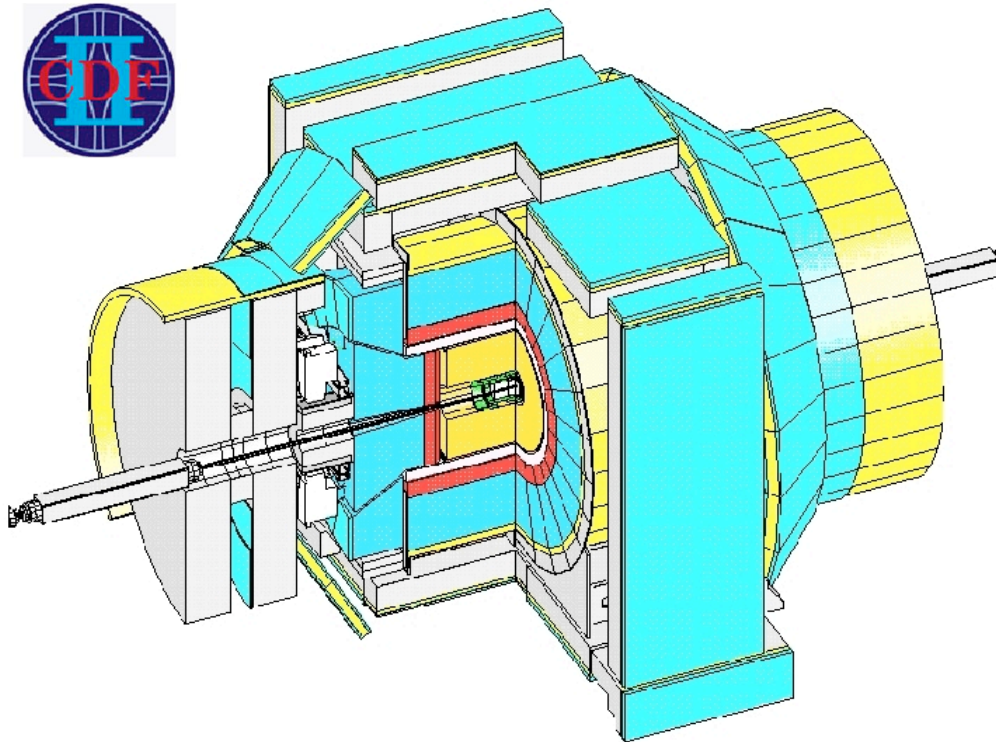**operations through Oct. 2011 will yield ~10 fb^{-1}/experiment**

The Tevatron is a Discovery Machine
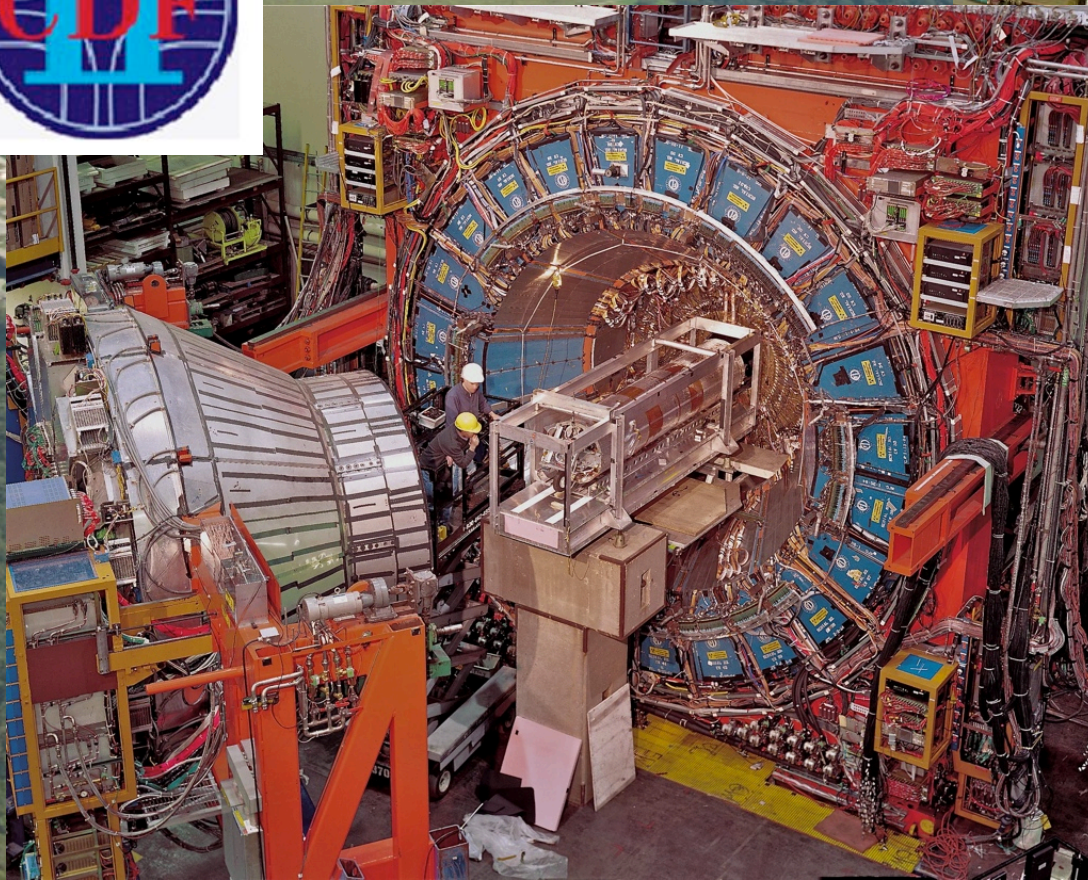
Tevatron Detectors

- **Two multipurpose detectors**

- **~600 scientists per collaboration**

- **electrons**
- **muons**
- **taus**
- **photons**
- **jets**

- **heavy quarks**
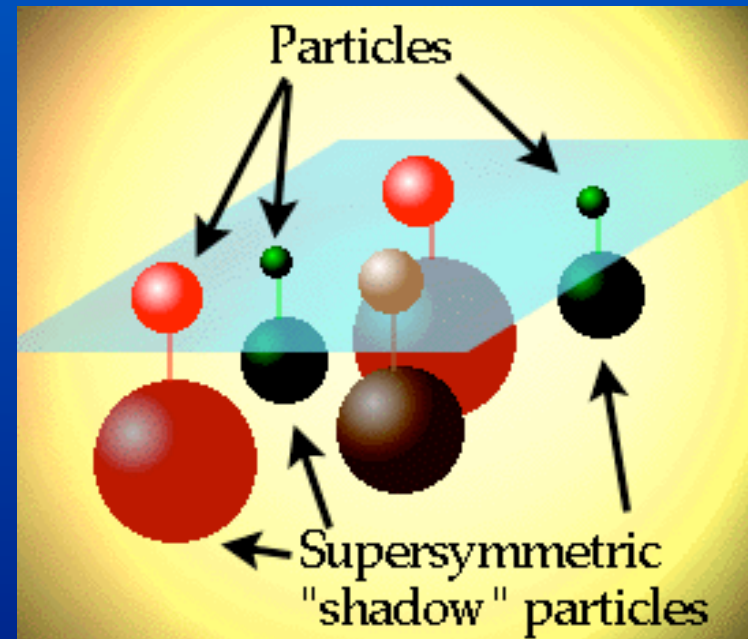- **missing transverse energy**

Looking for signs of new physics using many strategies
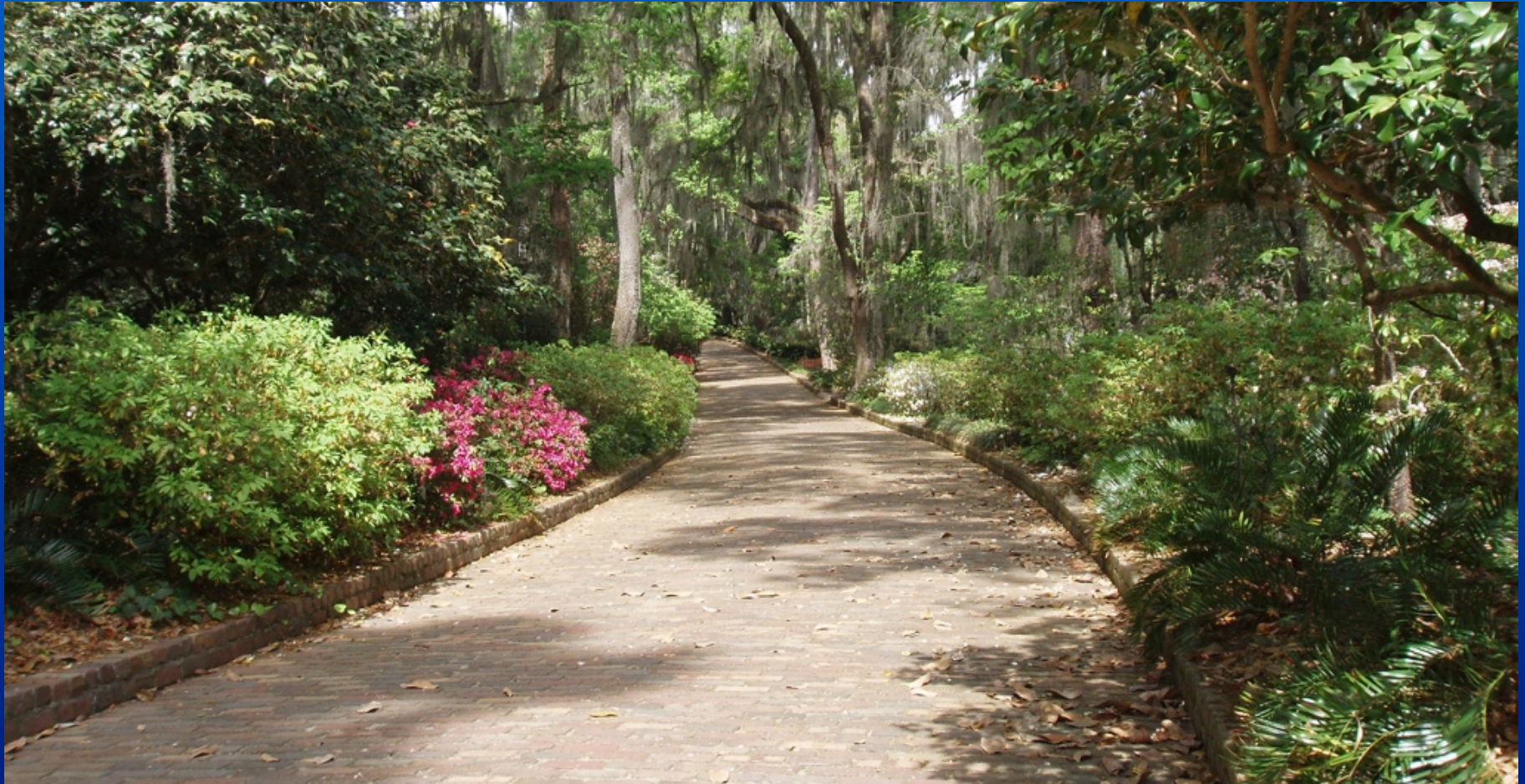
**Starting with model specific searches...**

Supersymmetry

- **(One of) the most popular theories of beyond the standard model physics**

- **New symmetry between fermions and bosons**

- **Broken symmetry $\Rightarrow$ partners have different masses**

- **Many variations:**

  - **mSUGRA, GMSB, SO(10), MSSM**

- **Lightest supersymmetric particle could be stable**

  - **dark matter candidate**
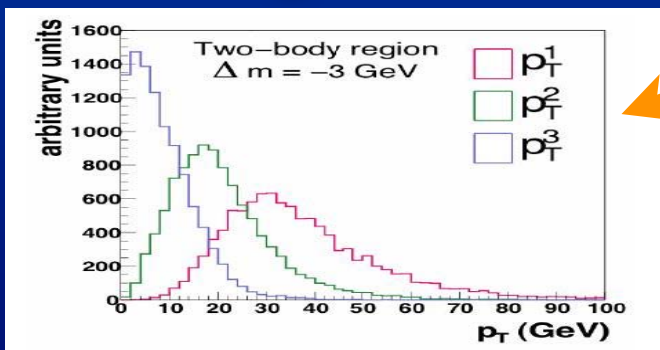
Charginos + Neutralinos
A Model Driven Example
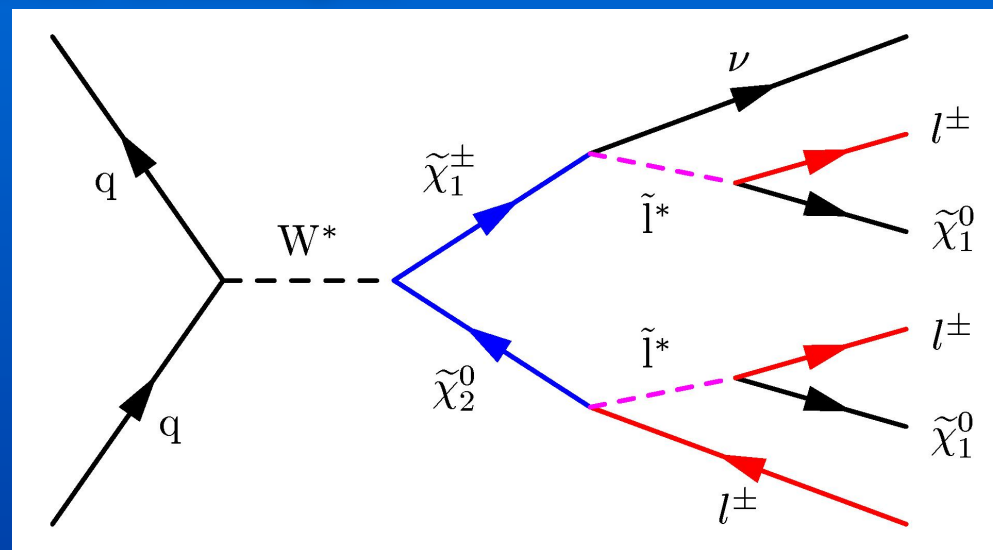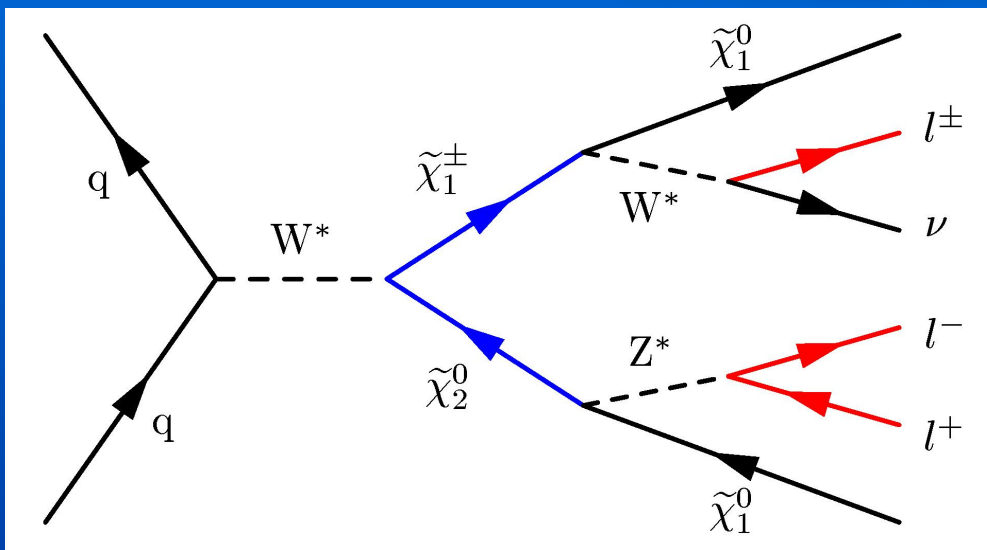
- **"Golden channel"**
  - ▸ **three leptons + missing transverse energy**
  - ▸ **few SM backgrounds**

- **Challenging**
  - ▸ **small cross section times branching fraction**
  - ▸ **often at least one low p_T lepton**
    - – **depends on masses**
  - ▸ **many final states to consider**
    - – **eee, $ee\mu$, $ee\tau$, $\mu\mu\mu$, $\mu\mu e$, $\mu\mu\tau$, $\mu\tau\tau$, $e\mu\tau$, $\tau\tau\tau$, $\tau\tau e$**

mSUGRA Limits

- **CDF search**
  - ‣ **trilepton and dilepton + track**
  - ‣ **eee, eeµ, eµµ, µµµ, ee$l$, eµl, µµl**

- **DØ search**
  - ‣ **dilepton + track and muon + tau**
  - ‣ **ee$l$, eµl, µµl, µττ, µτl**
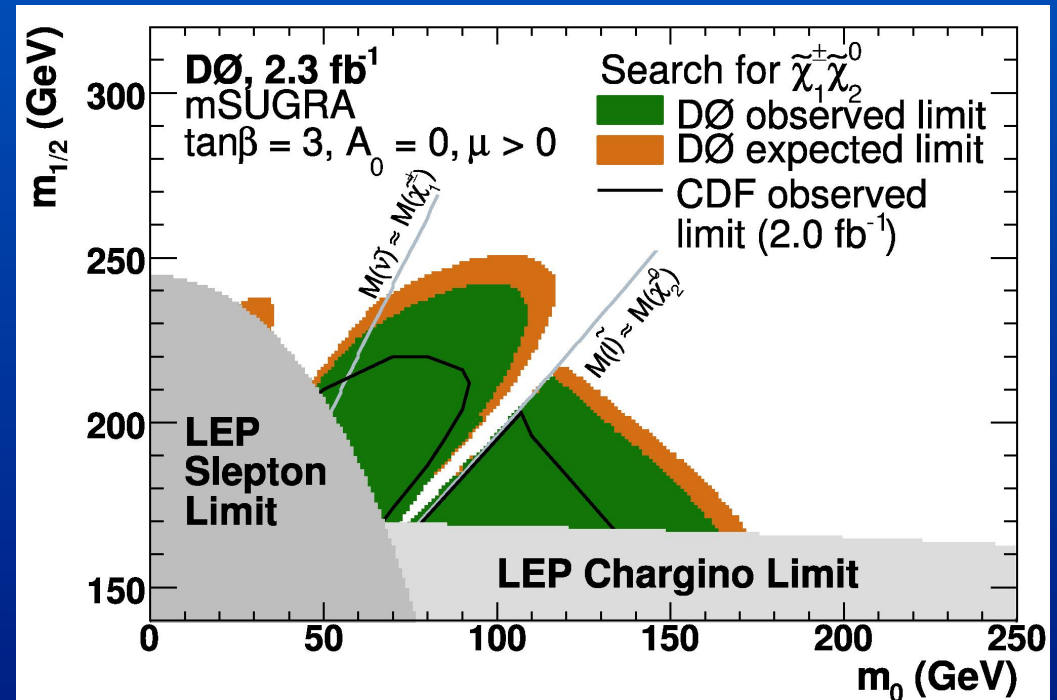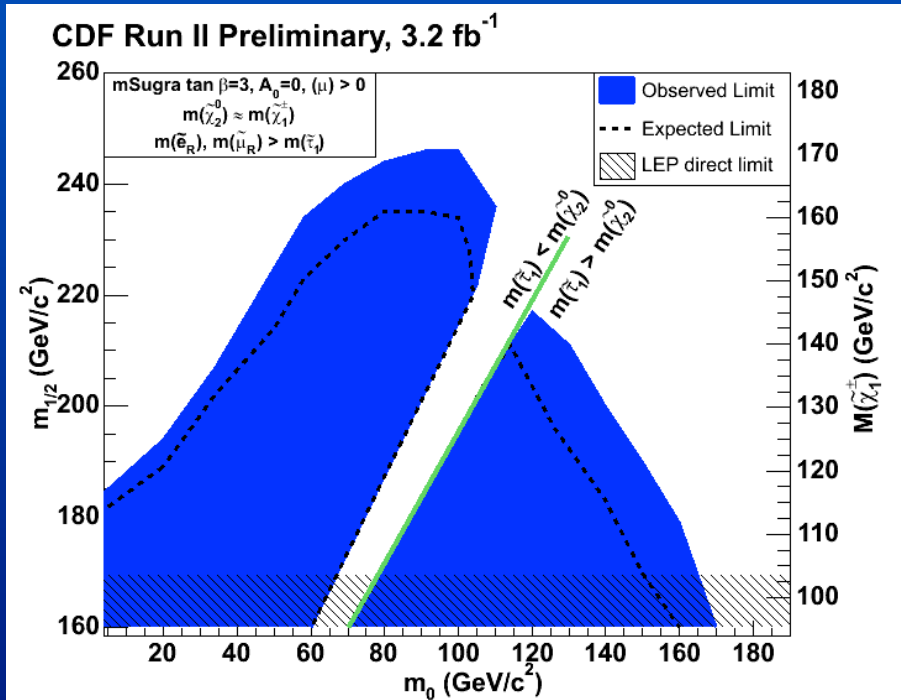
PLB 680, 34 (2009)

W'
Physics driven, not model specific

- **Many possible searches**
  - **W'→eν**
    - **CDF, 0.2 fb⁻¹, PRD (2007)**
    - **D0, 1 fb⁻¹, PRL (2008)**
  - **W'→tb**
    - **D0, 0.23 fb⁻¹, PLB (2006)**
    - **D0, 0.9 fb⁻¹, PRL (2008)**
    - **CDF, 1.9 fb⁻¹, PRL (2009)**
  - **W'→WZ**
    - **CDF, *e*νjj, 2.9 fb⁻¹, preliminary**
    - **DØ, *lll'*ν, 4.1 fb⁻¹**
      PRL 104, 061801 (2010)
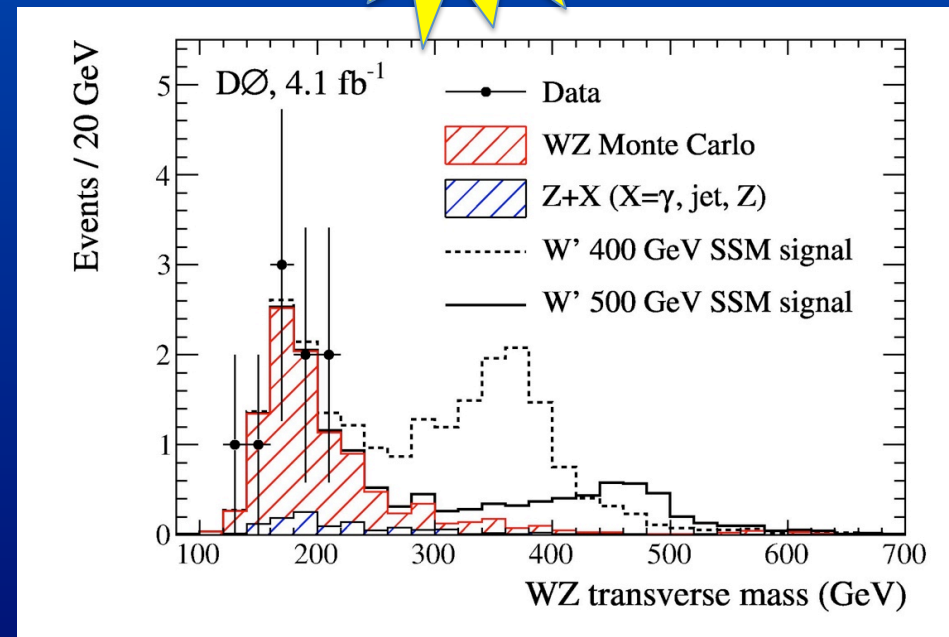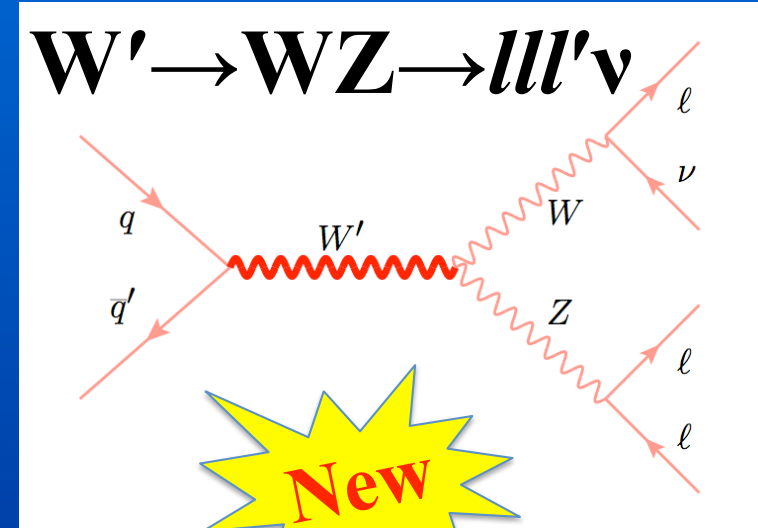
$$W'{\rightarrow}WZ{\rightarrow}lll'\nu$$

W'→WZ→*lll'*v Results
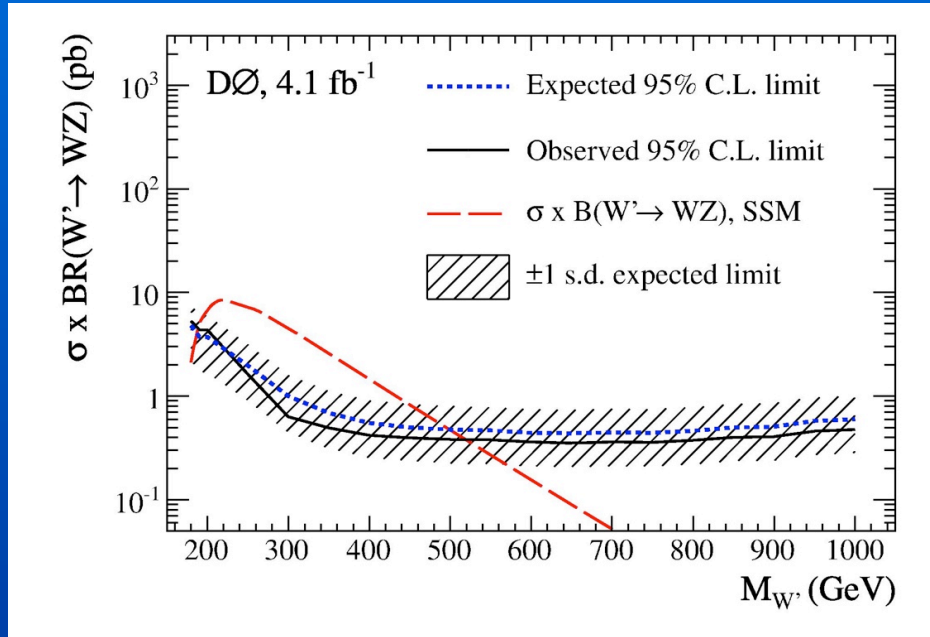
- **Related to diboson cross section measurement and Higgs searches**

- **technicolor interpretation**
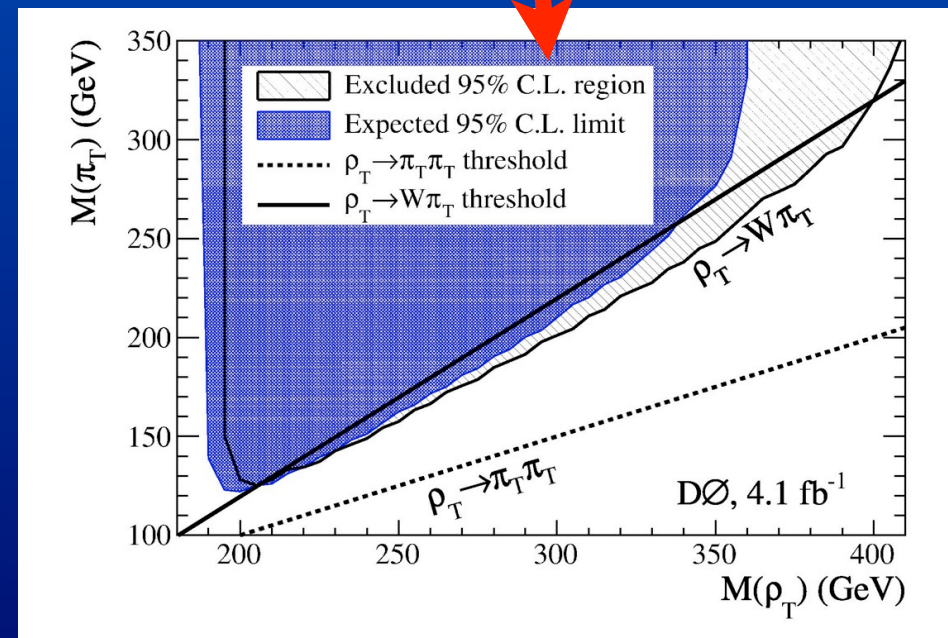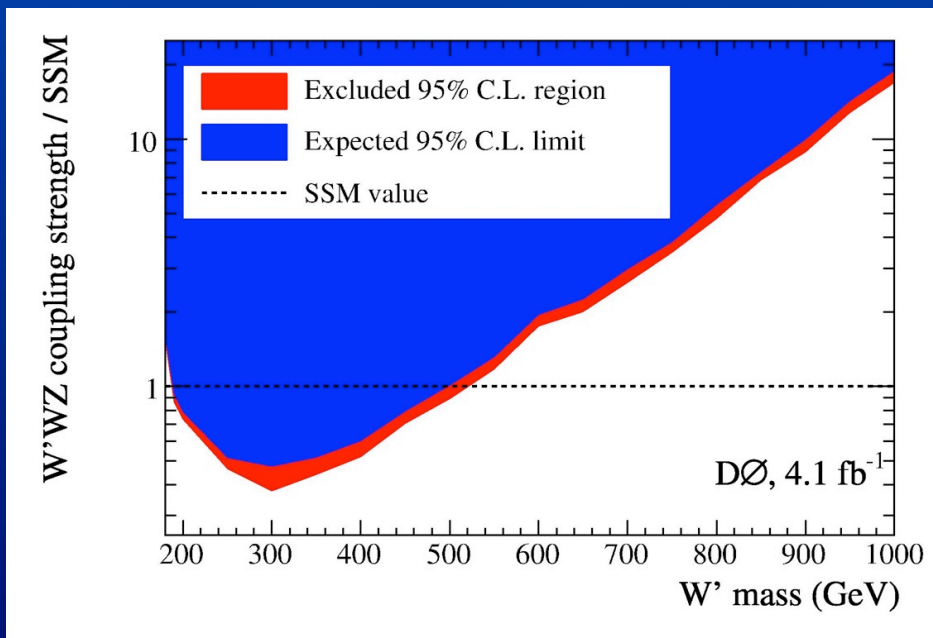
Diphoton + X
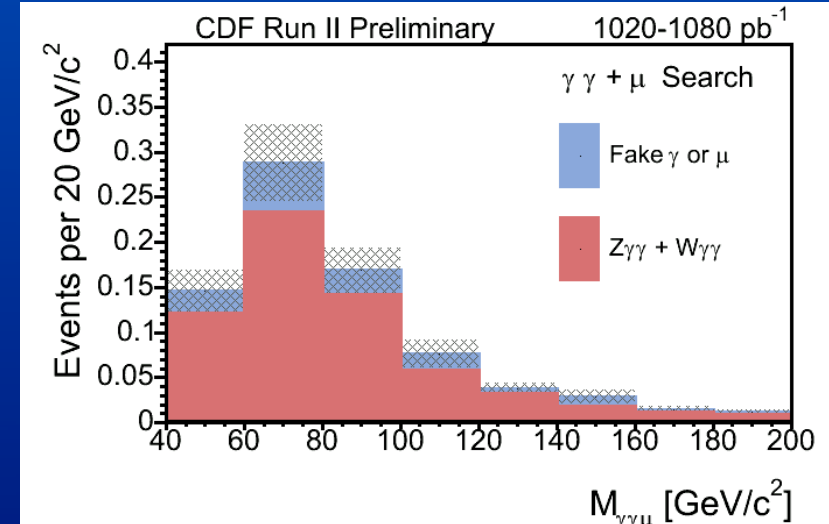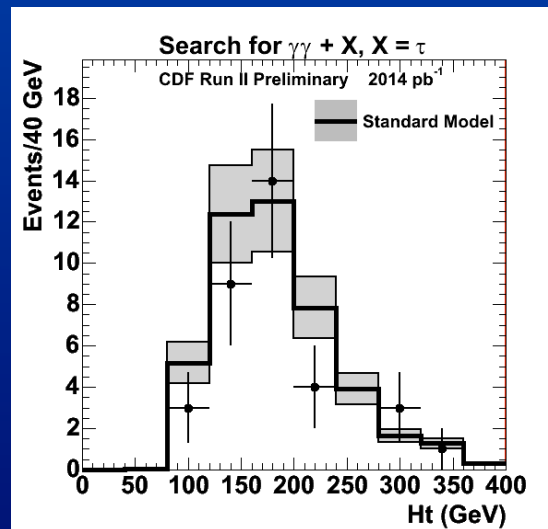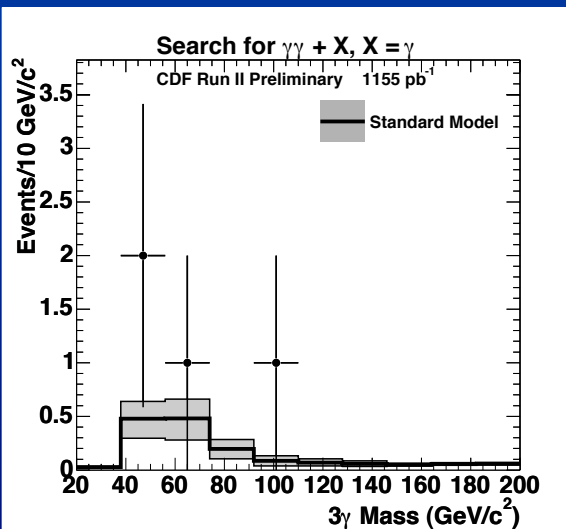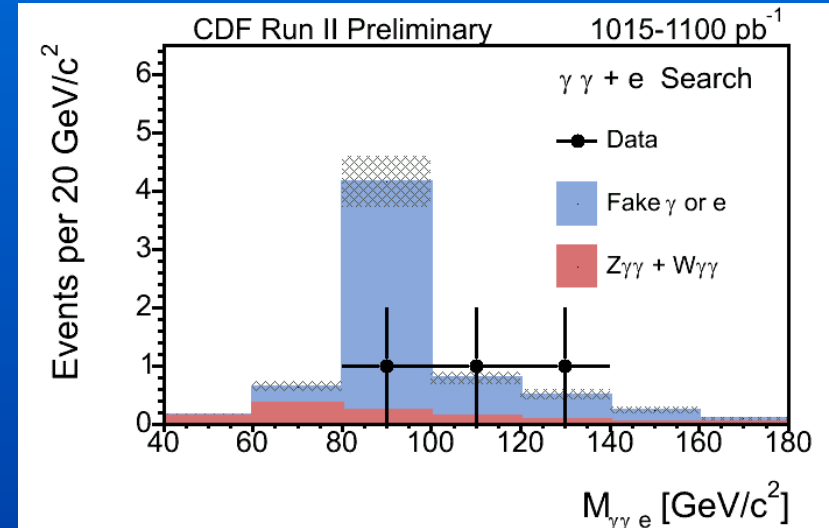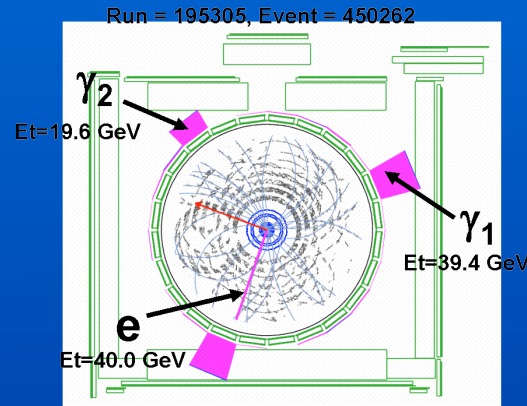## A Topology Based Search

- **Diphoton + X**
  - ▸ X = electron
  - ▸ X = muon
  - ▸ X = tau
  - ▸ X = photon
  - ▸ X = missing E_T

- **Common photon criteria**

arXiv:0910.5170

Diphoton + MET in GMSB
Turning a Topological Search into a Model Search

- **Optimize for MET selection**

- **Apply to GMSB**

New

Expected exclusion region with $\gamma\gamma + \not{E}_T$ and 2.6 fb^{-1}
Observed exclusion region
Observed exclusion region with $\gamma + \not{E}_T$ +Jet and 570 pb^{-1}
ALEPH exclusion region
Cosmology favored region with 0.5 < $M_{\tilde{G}}$ < 1.5 keV/c^2

GMSB $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$
$M_m = 2\Lambda$, tan(β)=15
$N_m = 1$, $\mu > 0$
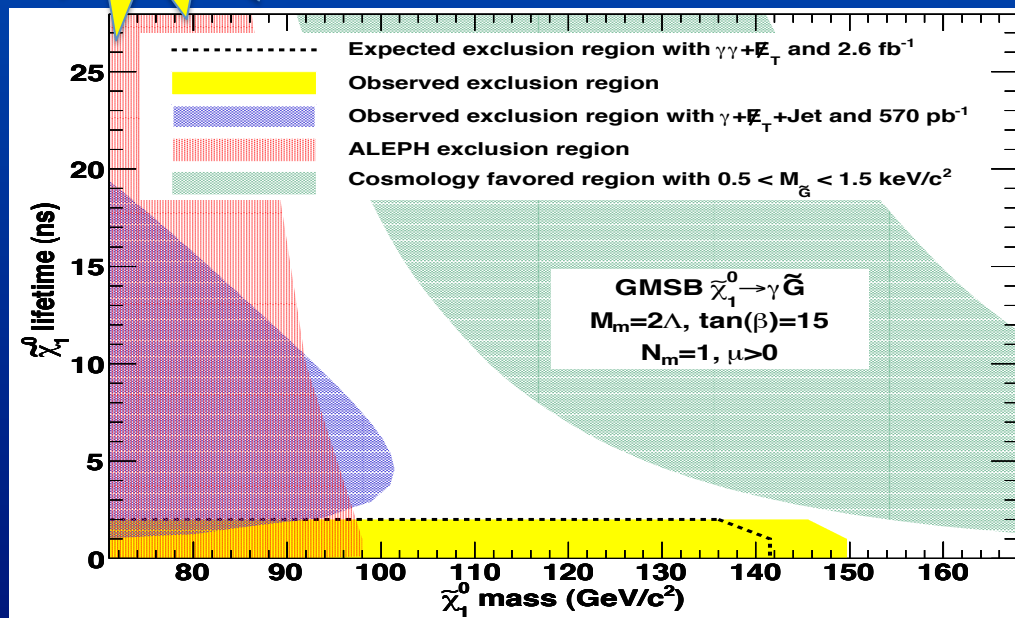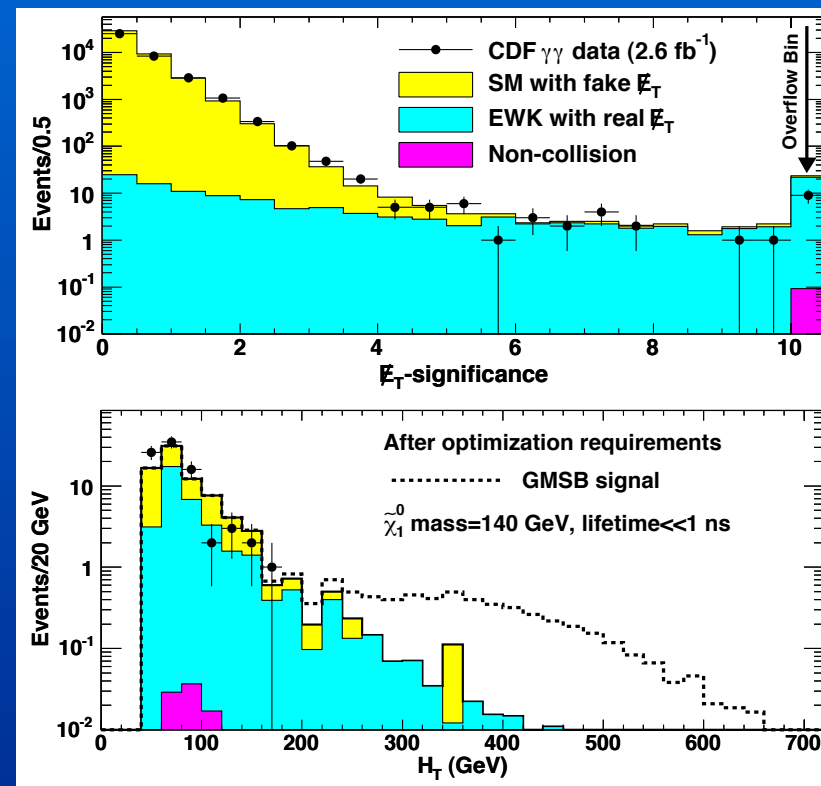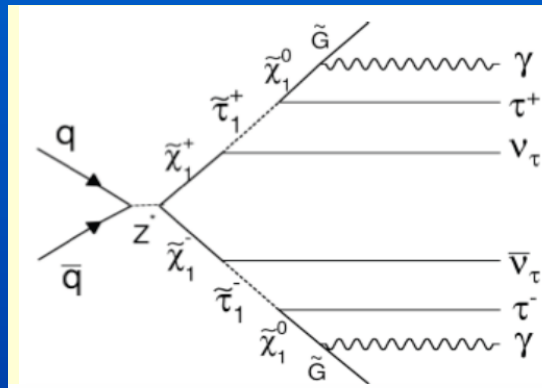
PRL 104, 011801 (2010)

- **CDF (2.6 fb^{-1})**
  - $m(\tilde{\chi}_1^0) > 149$ GeV (95% CL)
- **DØ (1.1 fb^{-1})**
  - $m(\tilde{\chi}_1^0) > 125$ GeV (95% CL)

Charged Massive Stable Particles (CHAMPs)
A Unique Signature

- **Many models allow for long-lived, charged, massive particles**
  - muon-like
  - R-hadrons
- **Signature**
  - deeply penetrating
  - slow moving
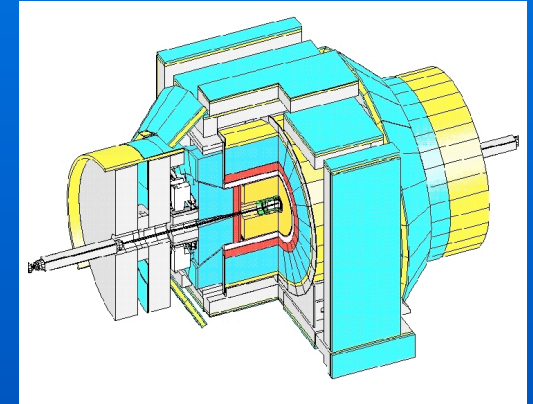 - heavily ionizing

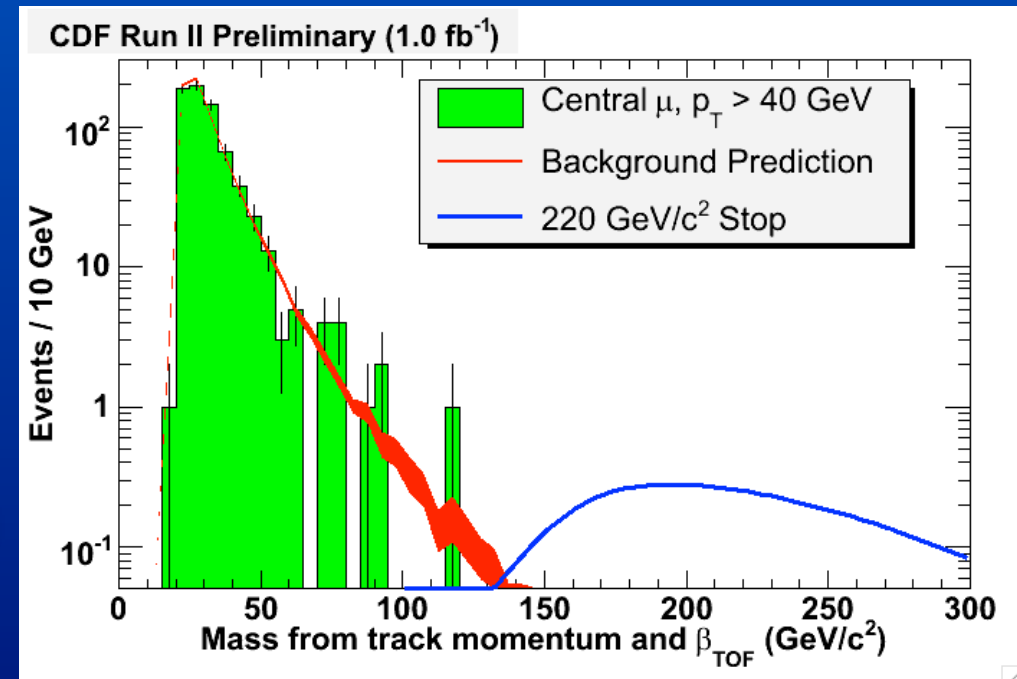- **CDF: stop R-hadron**
- **DØ: stau muon-like**
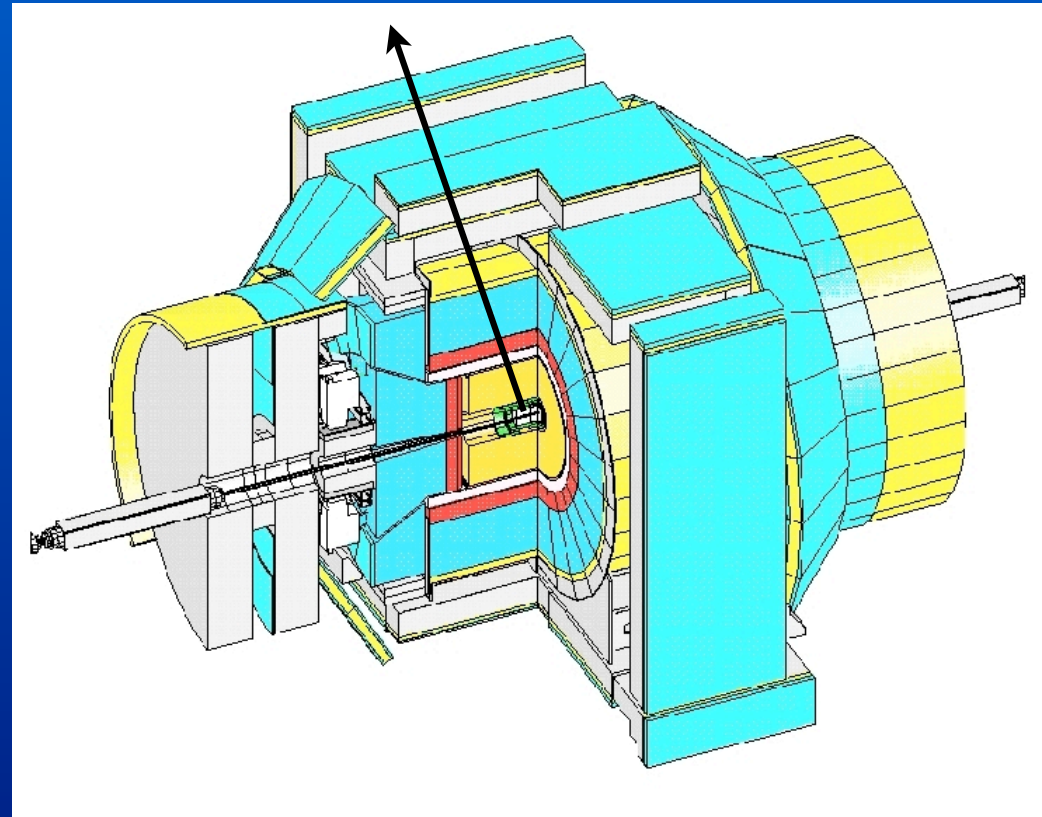
Finding CHAMPs

- **Preselect events with muons $p_T > 20$ GeV**

- **Determine velocity of particle**
  - ▸ **time of flight (TOF) detector outside tracking volume**
  - ▸ **determine distance travelled**

- **Determine mass**
  - ▸ **velocity**
  - ▸ **momentum**

- **Two regions**
  - ▸ **signal: $p_T > 40$ GeV**
  - ▸ **control: $20 < p_T < 40$ GeV**

- **Apply $\beta < 0.9$**

CDF Run II Preliminary (1.0 fb^{-1})

Central μ, $p_T > 40$ GeV
Background Prediction
220 GeV/c^2 Stop

Events / 10 GeV

Mass from track momentum and β_{TOF} (GeV/c^2)
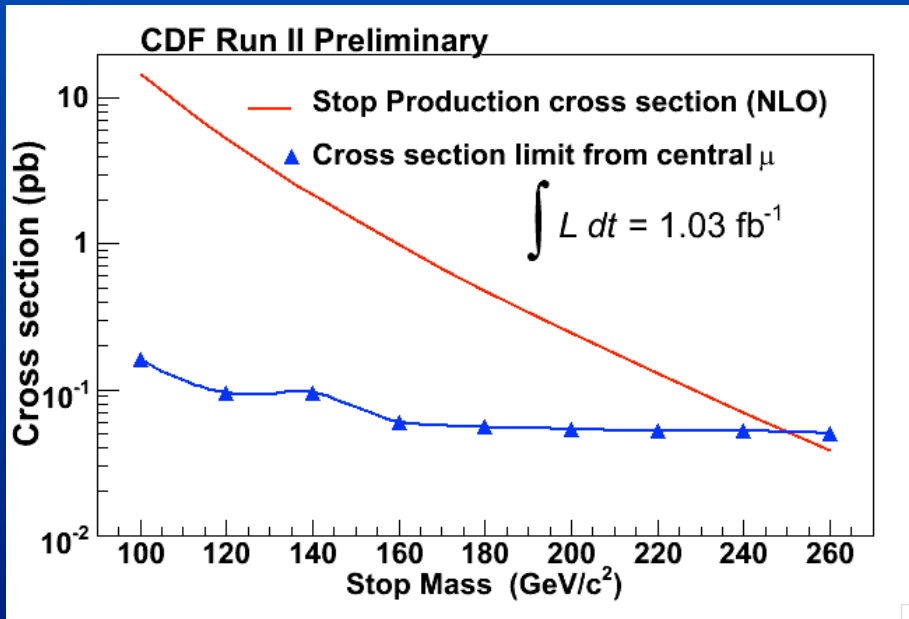
CHAMP Results
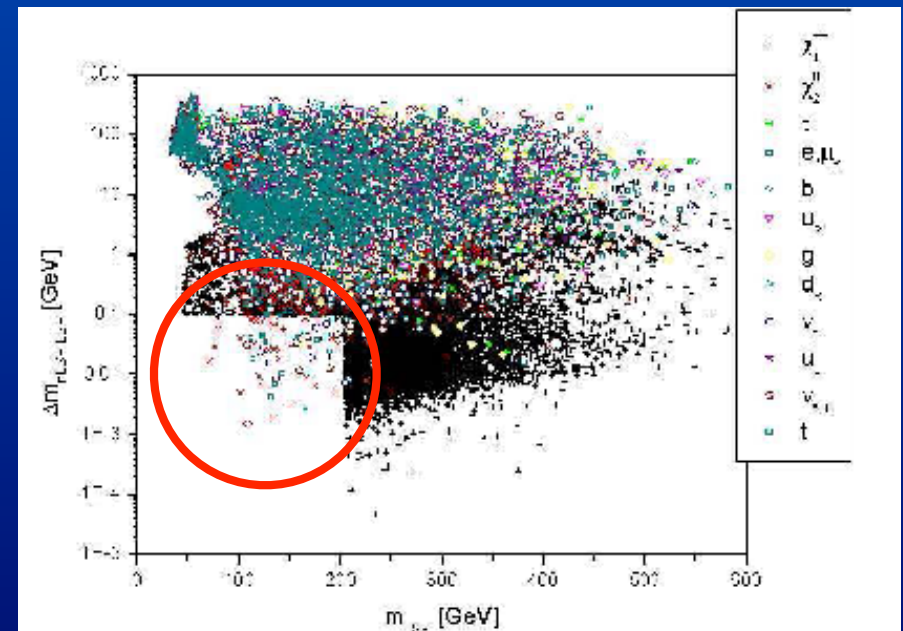
- **CDF limits**

  ‣ **single, weakly interacting σ < 10 fb**

  ‣ **stop mass > 249 GeV**

PRL 103, 021802 (2009)

- **CHAMPs results broad reaching**

  ‣ **C.F. Berger, J.S Gainer, J.L. Hewett, T.G. Rizzo JHEP 0902:023 (2009).**
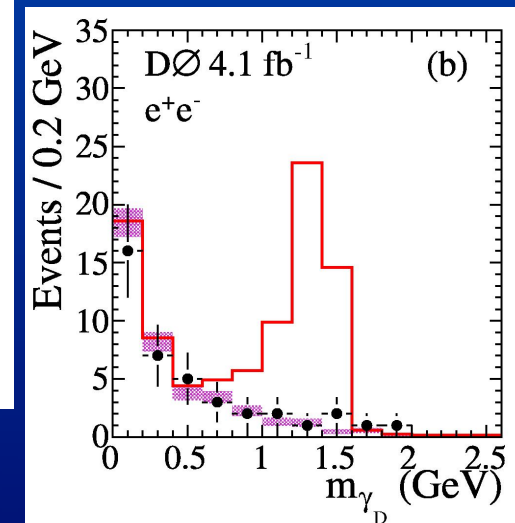
  ‣ **limits on SUSY from DØ CHAMP search**

Dark Photons
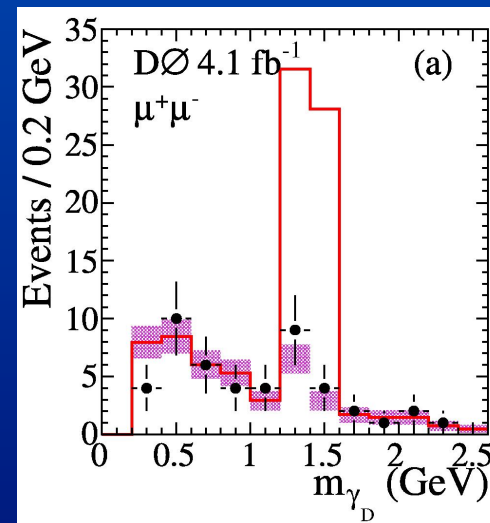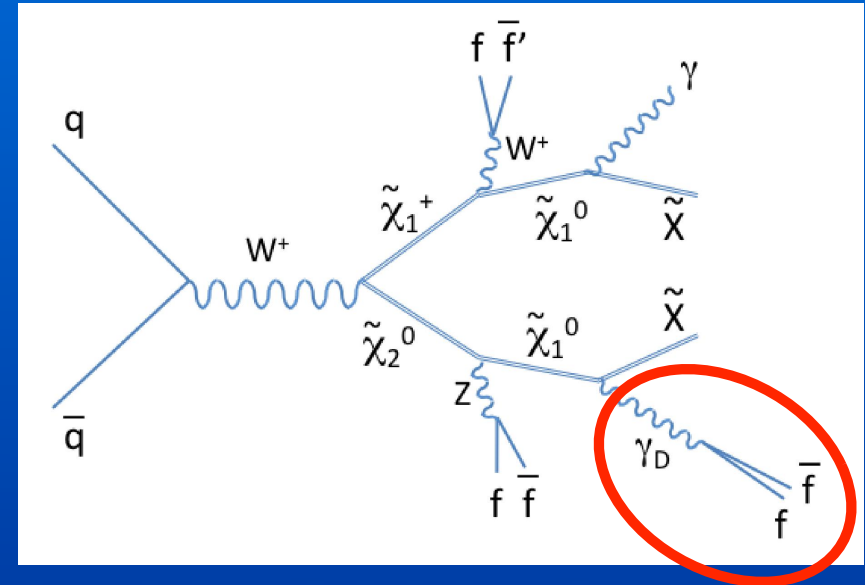## Expanding our Discovery Potential

- **Idea inspired by recent astrophysics results**

    ▸ **PAMELA, ATIC, EGRET, FERMI-LAT, HESS**

- **Supersymmetry with a hidden sector (dark sector)**

    ▸ **lightest dark sector particle can be dark photon**

    ▸ **can be light**

- **Unique signature**

    ▸ **two fermions with small opening angle**

- **No signal in e^+e^- or $\mu^+\mu^-$**

Lots of Data

e+e

e+μ

e+μ+2b+2ν

e+2μ+3ν

μ+j+ν

μ+μ

e+j

e+μ+j

e+2τ+2b+3ν

2e+3j

3e+3ν+j

2μ+2τ+j

2μ+2b

e+τ+2j

e+2τ+ν+j

μ+τ+2b

2μ+2j+2ν

τ+τ

2e+τ+2ν+2j

e+2j+ν

2τ+2b

2τ+2j+ν

2b+4j

e+μ+τ+3ν

γ+e+ν

γ+μ+ν+2j

γ+τ+ν

4j+ν

2b+2ν

γ+2e+ν

2b+2j

γ+c+ν

γ+γ

γ+b+2j

j+ν

γ+ν

2γ+2j

2γ+2μ+3j

j+j

Model Independent Searches

- **CDF and DØ both have searches designed to look at "all" the data**

Divide the data based on objects in event

Run II Data

| 2e+2j | μ+2j+MET | γ+2e+2j | μ+e+4j | τ+b+MET | μ+2τ |

| 2e+2j | μ+2j+MET | γ+2e+2j | μ+e+4j | τ+b+MET | μ+2τ |

Run II Simulation

Compare data to predictions. Look for deviations.
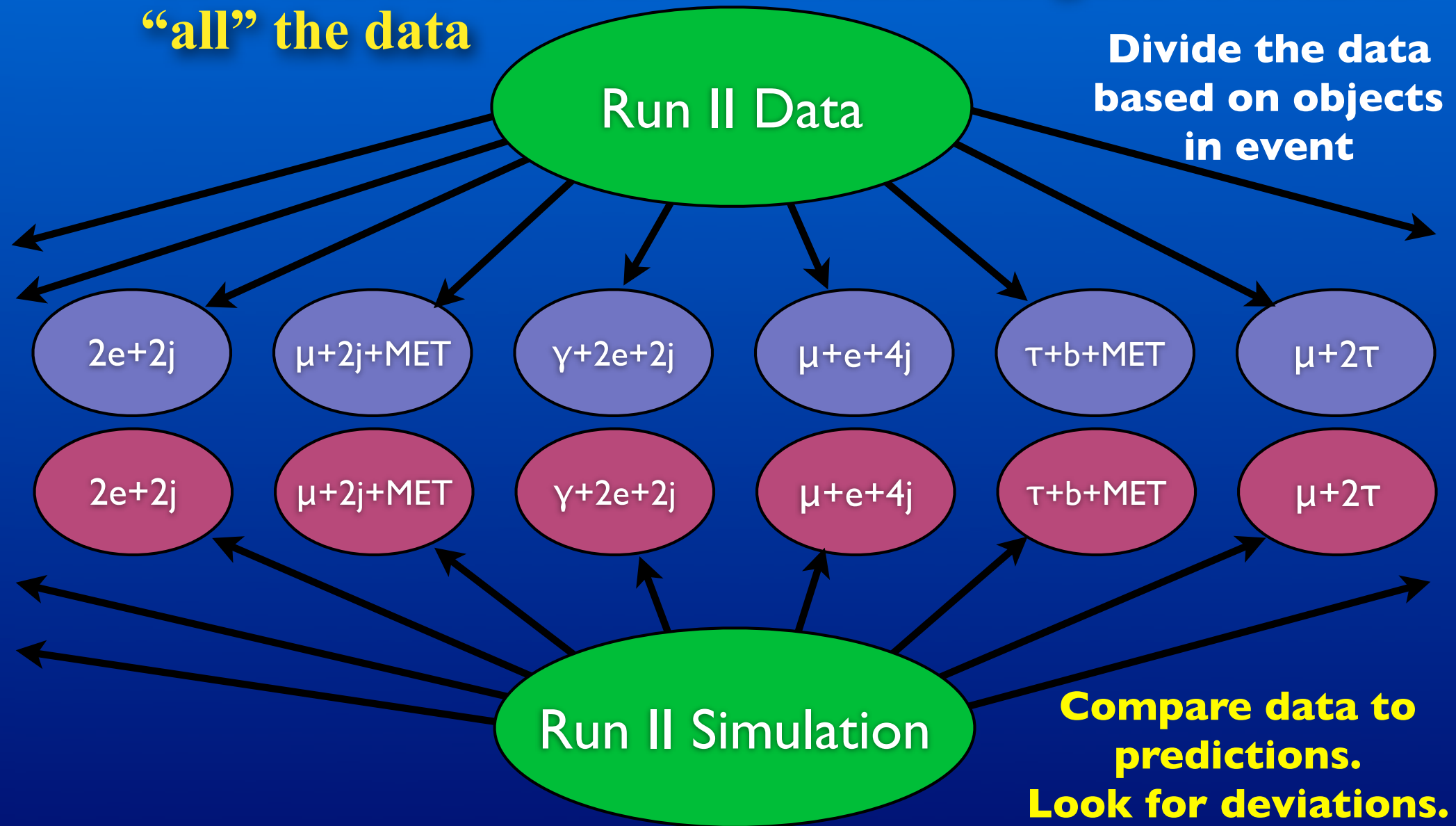
Selected Vista Distributions

- **Investigate**
  - **normalization**
  - **shape**
  - **high p$_T$ tails**
  - **bump hunt**

CDF Run II Preliminary (2.0 fb^{-1})

Final State	Data	Background	σ	σ_t
$be^{\pm}\not{p}$	690	817.7 ± 9.2	-4.3	-2.7
$\gamma\tau^{\pm}$	1371	1217.6 ± 13.3	$+4.0$	$+2.2$
$\mu^{\pm}\tau^{\pm}$	63	35.2 ± 2.8	$+3.7$	$+1.7$
$b2j\not{p}$ high-Σp_T	255	327.2 ± 8.9	-3.7	-1.7
$2j\tau^{\pm}$ low-Σp_T	574	670.3 ± 8.6	-3.6	-1.5
$3j\tau^{\pm}$ low-Σp_T	148	199.8 ± 5.2	-3.5	-1.4
$e^{\pm}\not{p}\tau^{\pm}$	36	17.2 ± 1.7	$+3.5$	$+1.4$
$2j\tau^{\pm}\tau^{\mp}$	33	62.1 ± 4.3	-3.5	-1.3
$e^{\pm}j$	741710	764832 ± 6447.2	-3.5	-1.3
$j2\tau^{\pm}$	105	150.8 ± 6.3	-3.4	-1.2
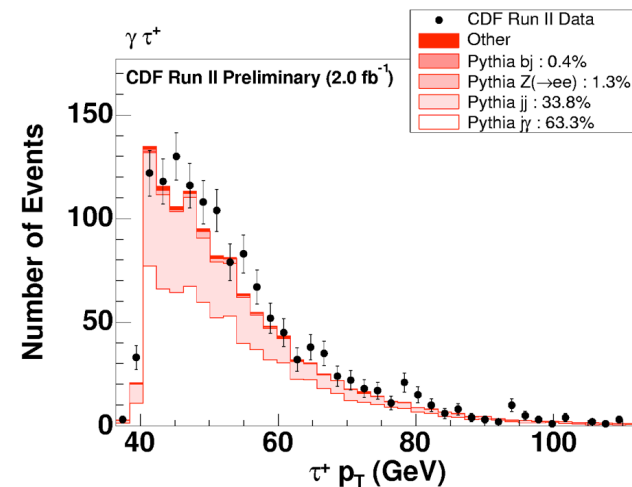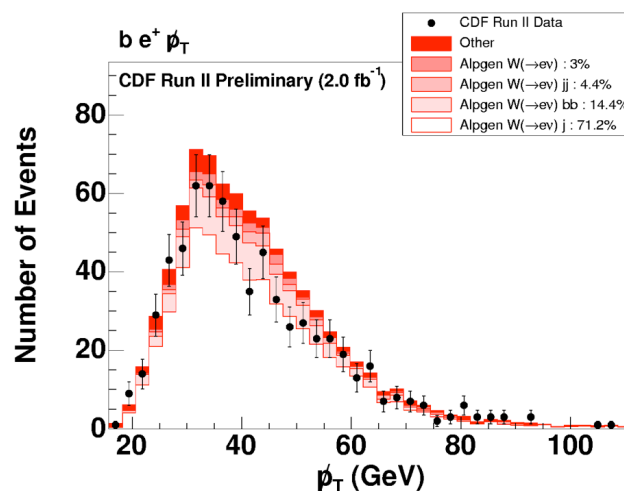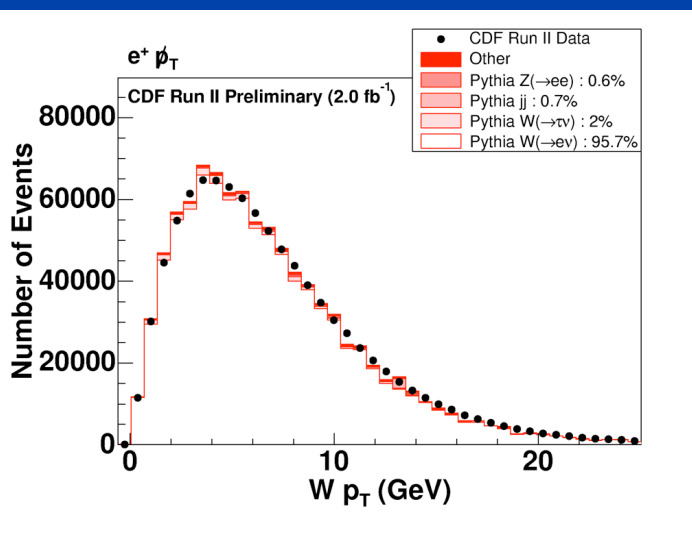
PRD 79, 011101 (2009)

Look for excesses in high p_T tails
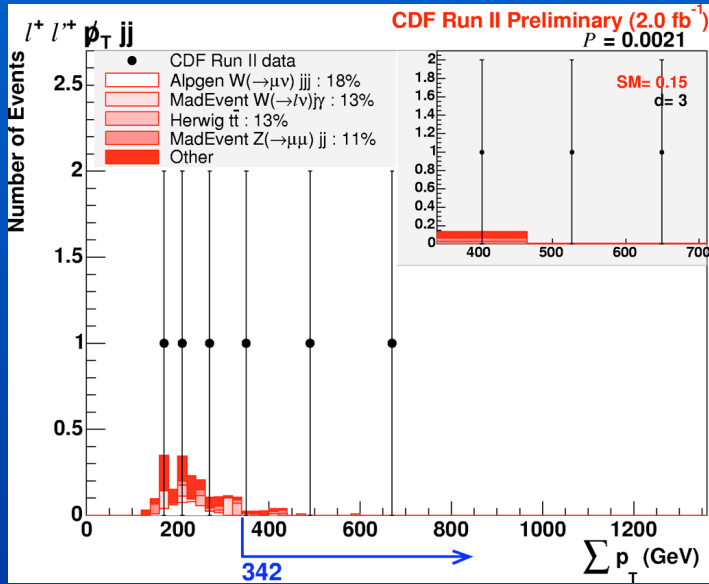
CDF Run II (2 fb^{-1})	
Final State	$\mathcal{P}$
$l^+l'^+$	0.00055
$l^+l'^+$jj+MET	0.0021
$l^+l'^+$+MET	0.0042
$l^+l^-l'^+$+MET	0.0047
$l^+\tau^+$+MET	0.0065
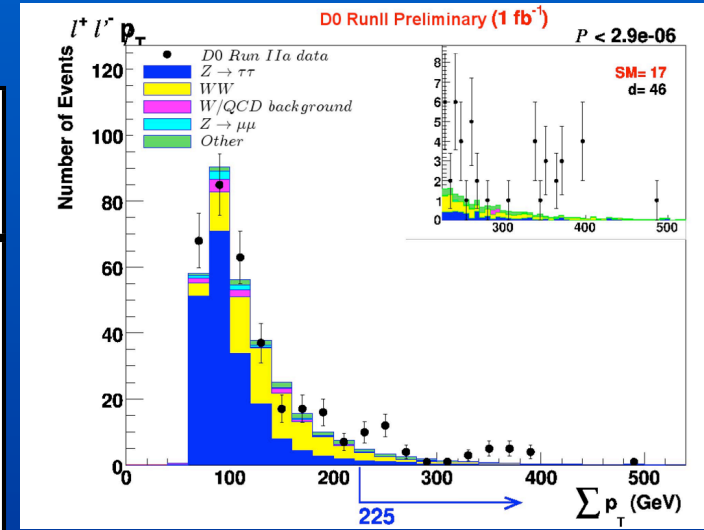
DØ Run II Preliminary (1 fb^{-1})	
Final State	$\mathcal{P}$
$l^+l'^-$+MET	0.00018
l+MET	0.049
$l^+l'^-$	0.17
$l^+\tau^-$ + MET	0.31
$l^+\tau^-$	0.33
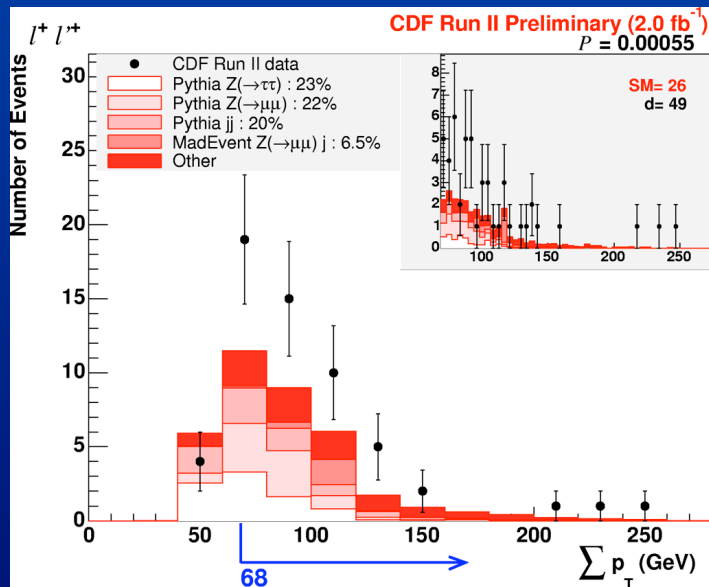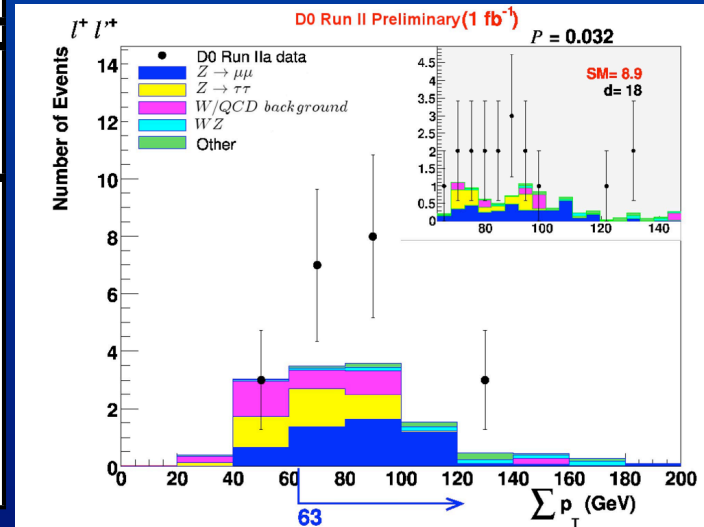
PRD 79, 011101 (2009)
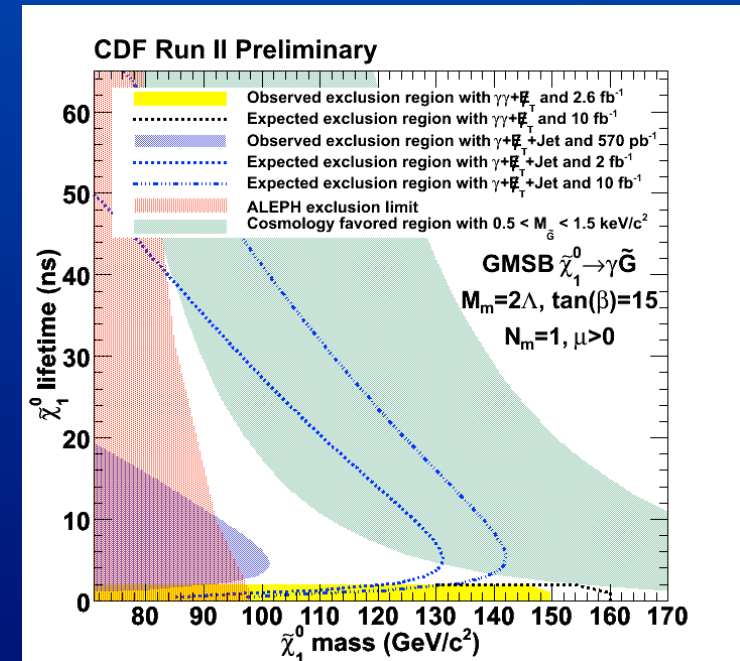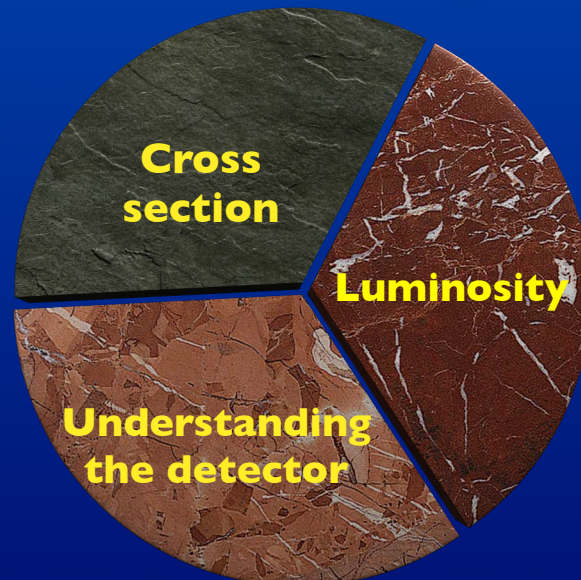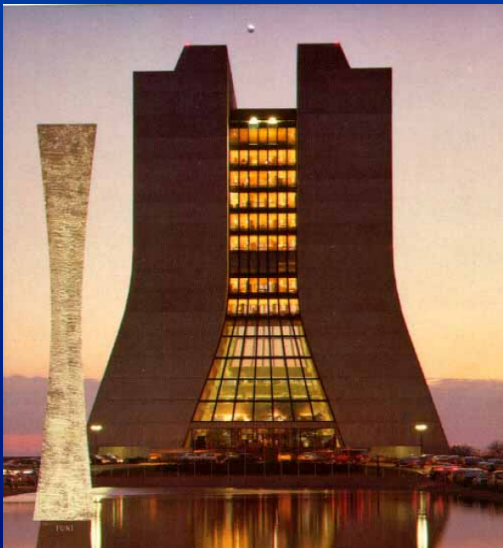
More Details Available

- **See the parallel sessions - LOTS of Tevatron talks**

- **Tuesday - New Phenomena**
  - **X12.00003 : Search for Fermiophobic Higgs in the 4-gamma + X Final State**
    - **Atsunari Hamaguchi, Osaka City University**
  - **X12.00005 : A Search for Randall-Sundrum Gravitons in the Dielectron and Diphoton Channels with 5.4 fb^{-1} of Data**
    - **Ning Zhou, Columbia University**
  - **Y12.00001 : Search for trilepton chargino-neutralino signal at CDF**
    - **Marcelo Vogel, University of New Mexico**
  - **Y12.00003 : Search for Hadronic Resonances in Multijet Final States**
    - **Tim Lou, Rutgers University**
  - **Y12.00007 : A Search for Charged Massive Long-Lived Particles at the Fermilab Tevatron**
    - **Sungwoong Cho, Korea University**
  - **Y12.00009 : Search for High-Mass Resonance in the Vector Boson + Jets Channel with 5.4 fb^{-1} of Data**
   - **Seth Caughron, Columbia University**

Summary

- I've shown you <1/10th of the ~140 new phenomena searches from the Tevatron Run II

  ▸ many ways to search

- More results and work in progress will be shown in parallel and plenary talks this week

- The Tevatron has the pieces in place to continue to explore new phase space for discovery

Cross section

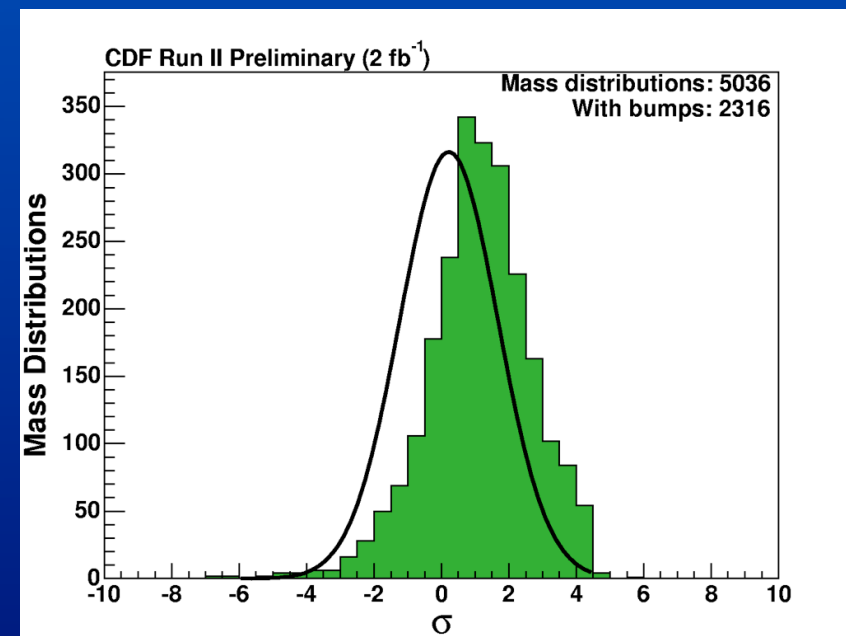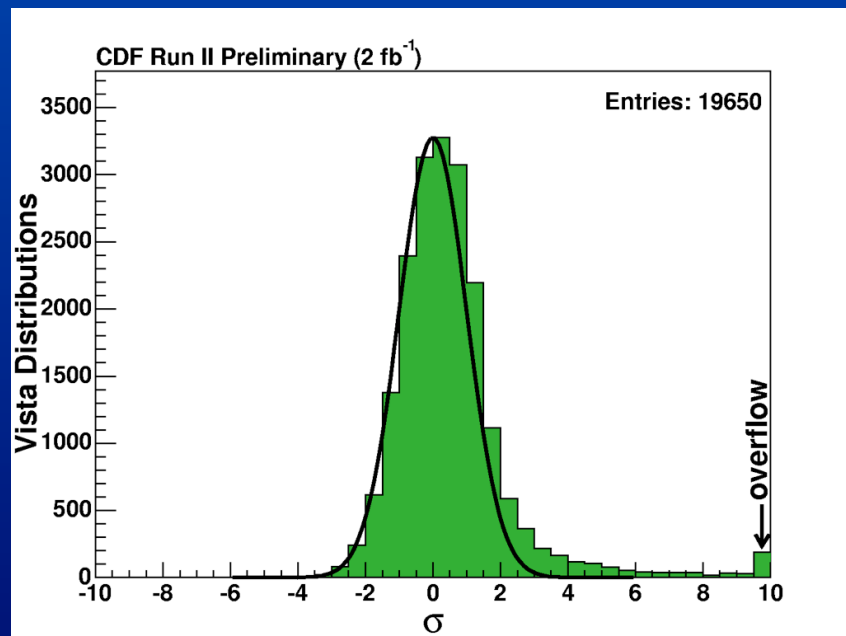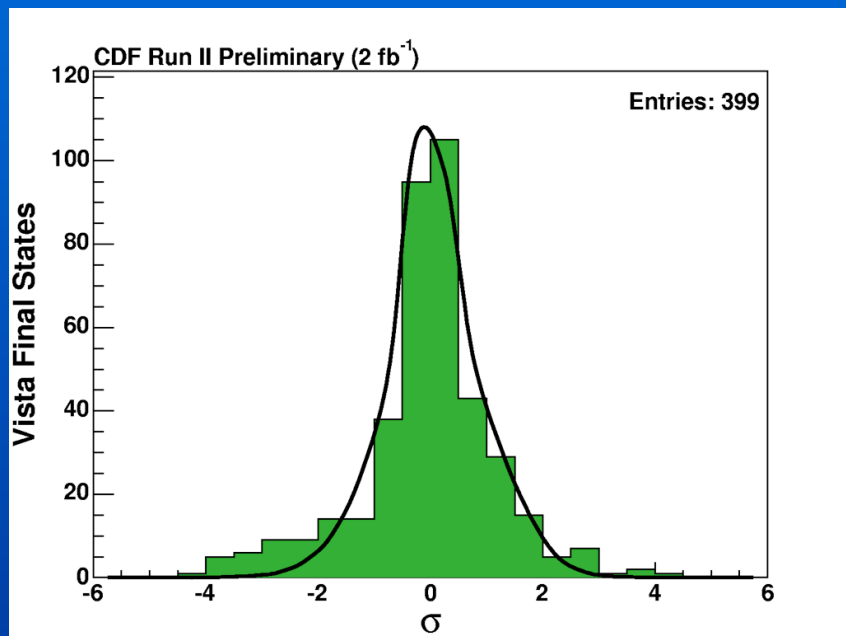Luminosity

Understanding the detector

CDF Run II Preliminary

Observed exclusion region with $\gamma\gamma + \not{E}_T$ and 2.6 fb^{-1}
Expected exclusion region with $\gamma\gamma + \not{E}_T$ and 10 fb^{-1}
Observed exclusion region with $\gamma + \not{E}_T$ + Jet and 570 pb^{-1}
Expected exclusion region with $\gamma + \not{E}_T$ + Jet and 2 fb^{-1}
Expected exclusion region with $\gamma + \not{E}_T$ + Jet and 10 fb^{-1}
ALEPH exclusion limit
Cosmology favored region with $0.5 < M_{\tilde{G}} < 1.5$ keV/c^2

GMSB $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$
$M_m = 2\Lambda$, $\tan(\beta) = 15$
$N_m = 1$, $\mu > 0$

$\tilde{\chi}_1^0$ lifetime (ns)

$\tilde{\chi}_1^0$ mass (GeV/c^2)

Dark Photon Results

- **Limits depend on**
  - **chargino mass**
  - **dark photon mass**
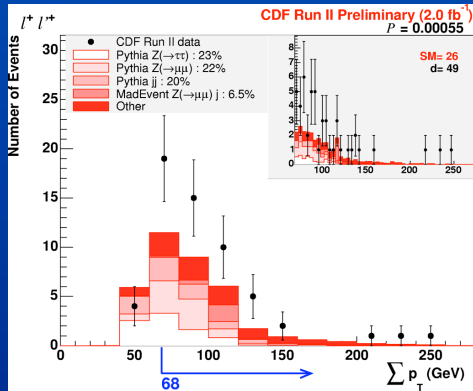 - **neutralino branching ratio**
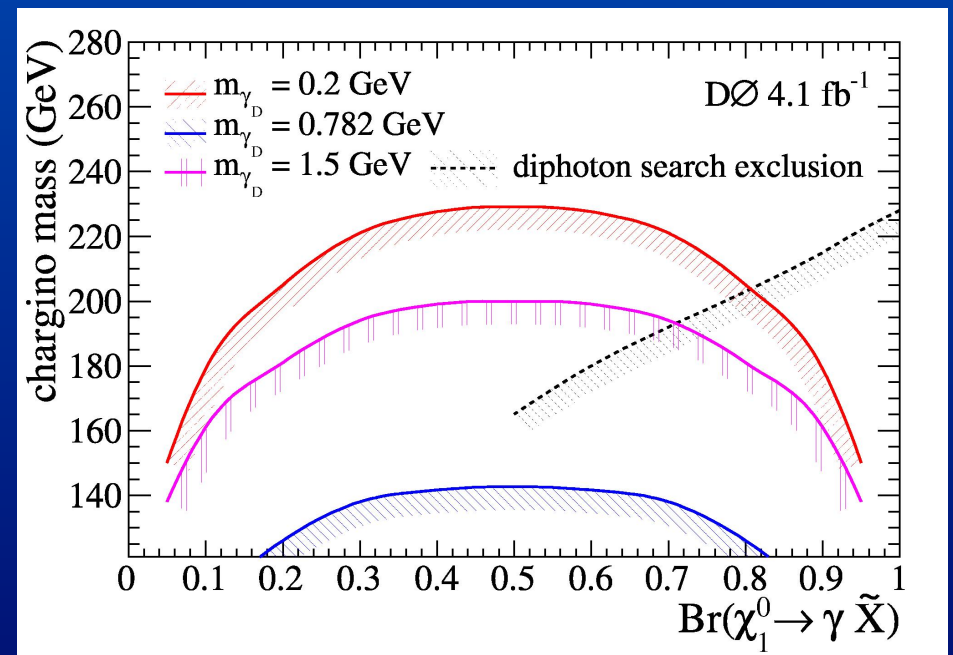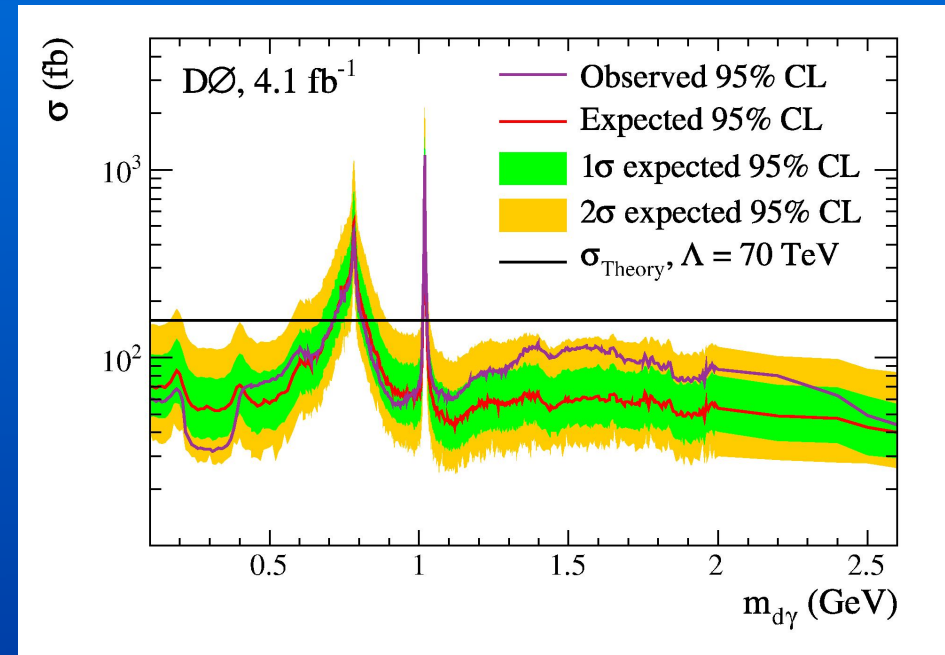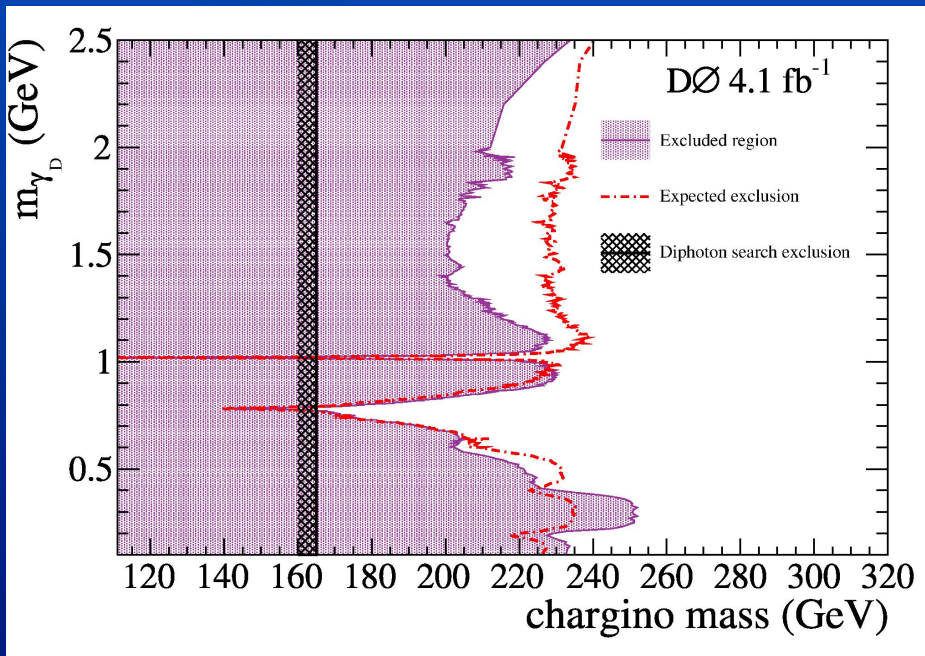
Vista Results

- **Three measures**
  - ▸ **normalization**
  - ▸ **shape**
  - ▸ **bump hunting**

Selected Sleuth Distributions

Look for excesses in high p_T tails

Model Independent Searches

- CDF and D0 both have searches designed to look at "all" the data

Run II Data

Divide the data based on objects in events

2e+2j	μ+2j+MET	γ+2e+2j	μ+e+4j	τ+b+MET	μ+2τ
2e+2j	μ+2j+MET	γ+2e+2j	μ+e+4j	τ+b+MET	μ+2τ

**Compare data to predictions.
Look for deviations.**

e+e

e+μ

e+μ+2b+2ν

e+2μ+3ν

μ+j+ν

μ+μ

e+j

e+μ+j

e+2τ+2b+3ν

2e+3j

3e+3ν+j

2μ+2τ+j

2μ+2b

e+τ+2j

τ+τ

μ+τ+2b

2μ+2j+2ν

2e+τ+2ν+2j

2τ+2b

2b+4j

e+2j+ν

e+μ+τ+3ν

2τ+2j+ν

2b+2ν

γ+e+ν

γ+μ+ν+2j

γ+τ+ν

4j+ν

2b+2j

γ+γ

γγeμμττν

γγeμμττν

γ+b+2j

j+ν

γ+ν

2γ+2j

γγeμμττν

j+j