

Search for SUSY in final states with photons at the Tevatron

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For CDF and DØ Collaborations



Models

✓ Models (many!) SUSY

$$\tilde{\chi}_1^0 \rightarrow \gamma G$$

$$\tilde{\chi}_2^0 \rightarrow \gamma G$$

$\gamma\gamma \cancel{E}_T$, displaced γX , $\gamma\gamma j \cancel{E}_T$, $e\gamma \cancel{E}_T$, $\mu\gamma \cancel{E}_T$, $\gamma b \cancel{E}_T$,
 $\gamma bj \cancel{E}_T$, $\gamma bc \cancel{E}_T$, $\gamma jj \cancel{E}_T$, $\gamma ee \cancel{E}_T$, $\gamma\mu\mu \cancel{E}_T$, $\gamma\gamma ee \cancel{E}_T$,
 $\gamma\gamma\mu\mu \cancel{E}_T$, $\gamma \cancel{E}_T$, $jj\gamma \cancel{E}_T$

Technicolor

$$\omega_T, \rho_T \rightarrow \gamma\pi_T$$

$$\pi_T \rightarrow \gamma\gamma$$

γbb , γjj , γtt , $\gamma\gamma\gamma$, $ee\gamma\gamma$
 $\mu\mu\gamma\gamma$, $\mathbf{ee}\gamma\gamma \cancel{E}_T$, $\mu\mu\gamma\gamma \cancel{E}_T$

Compositeness

$$X^* \rightarrow \gamma X$$

$\mathbf{ee}\gamma$, $\mathbf{ee}\gamma\gamma$, $\mu\mu\gamma$, $\mu\mu\gamma\gamma$, $jj\gamma$, $bb\gamma$, $jj\gamma\gamma$, $bb\gamma\gamma$

Extra Dimensions (RS)

$$G \rightarrow \gamma\gamma$$

$\gamma\gamma$, $\gamma \cancel{E}_T$

Higgs

$$H \rightarrow \gamma\gamma, A \rightarrow \gamma\gamma$$

$\gamma\gamma$, $\mathbf{ee}\gamma$, $\mu\mu\gamma$, $\mathbf{e}\gamma\gamma \cancel{E}_T$, $\mu\gamma\gamma \cancel{E}_T$, $jj\gamma\gamma$, $\gamma\gamma\gamma\gamma$

4th generation

$$b' \rightarrow \gamma b$$

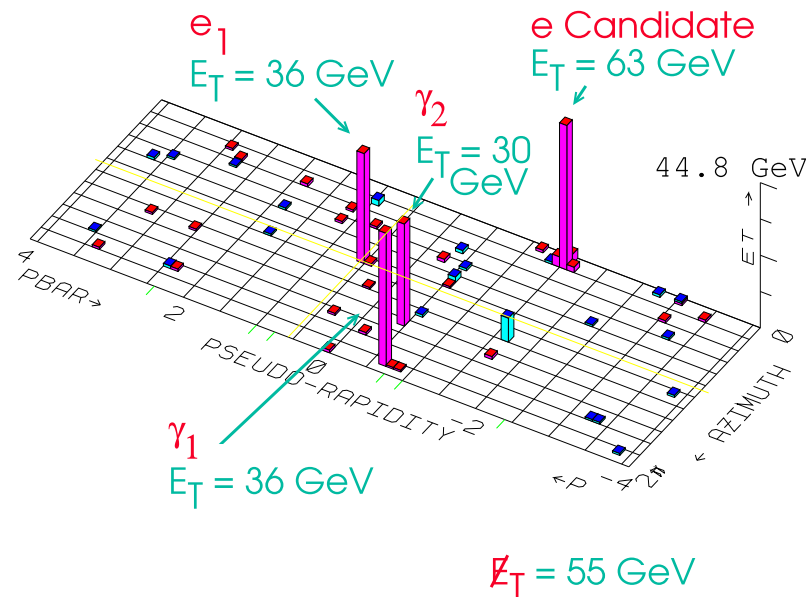
$\gamma\gamma bb$, $ee\gamma bb$, $\mu\mu\gamma bb$, $jj\gamma\gamma bb$

Experiment

✓ Run I Results

- Run I $ee\gamma\gamma\cancel{E}_T$ (10^{-6} expected, 1 observed)

$ee\gamma\gamma\cancel{E}_T$ Candidate Event



✓ Properties of photon

- Coupled to electric charge; massless; stable

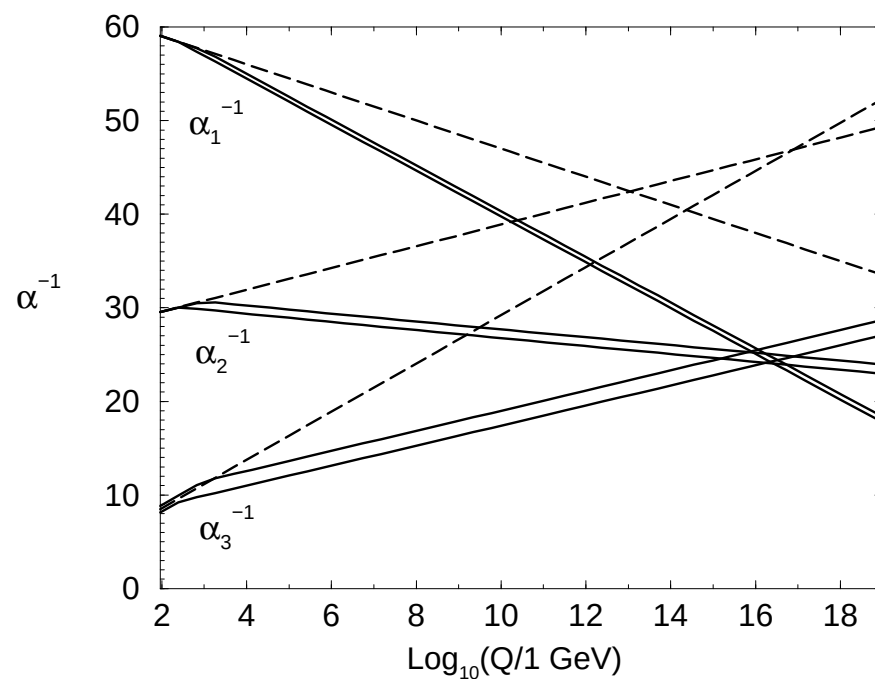
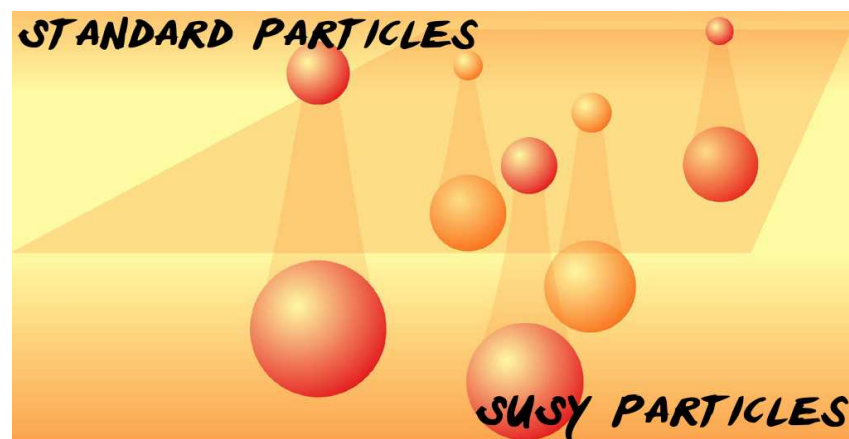
SUSY

- Higgs boson mass quantum corrections



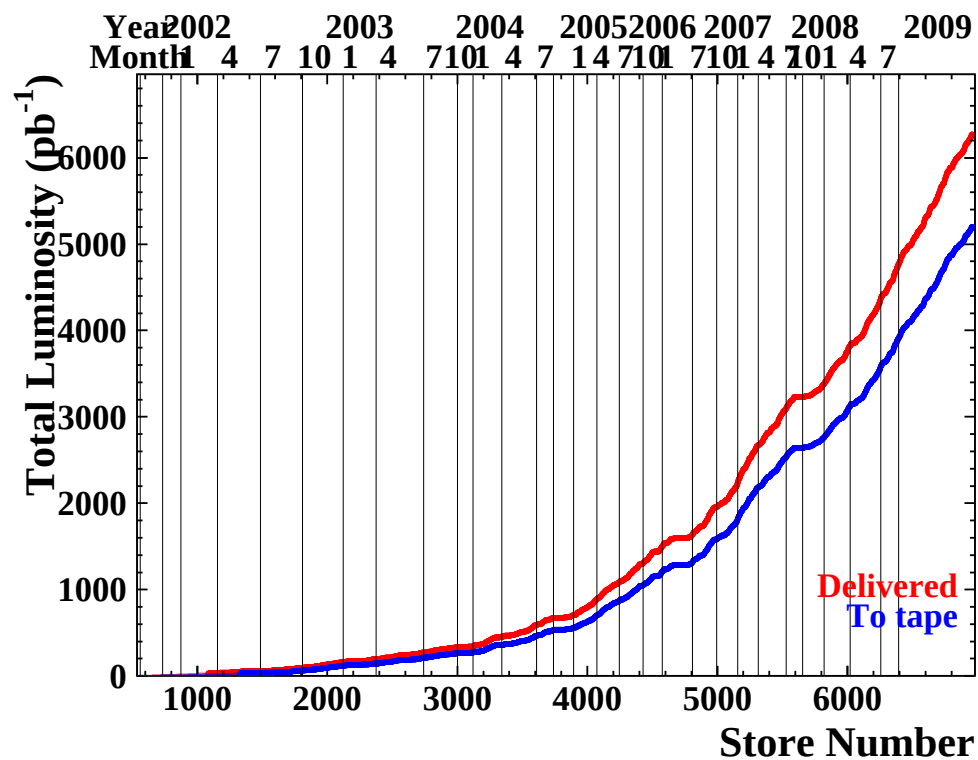
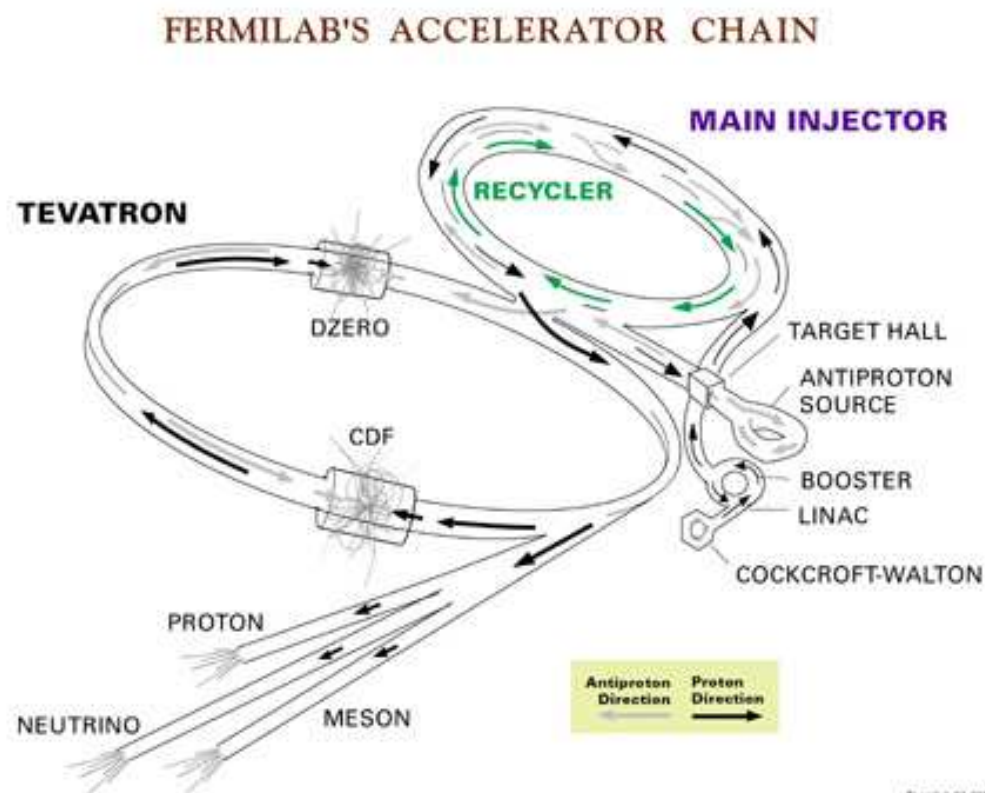
$$\Delta m_H^2 = \frac{1}{8\pi^2}(\lambda_S - |\lambda_f|^2)\Lambda_{UV}^2 + \dots$$

- $Q|\text{Boson}\rangle = |\text{Fermion}\rangle$,
 $Q|\text{Fermion}\rangle = |\text{Boson}\rangle$
- R-Parity: $P_R = (-1)^{3(B-L)+2s}$
 1 for SM, -1 for superpartners
- R-parity is conserved:
 - The SUSY particles produced in pairs
 - Dark Matter candidate
- Supersymmetry is broken
- 32 new particles, 105 new parameters



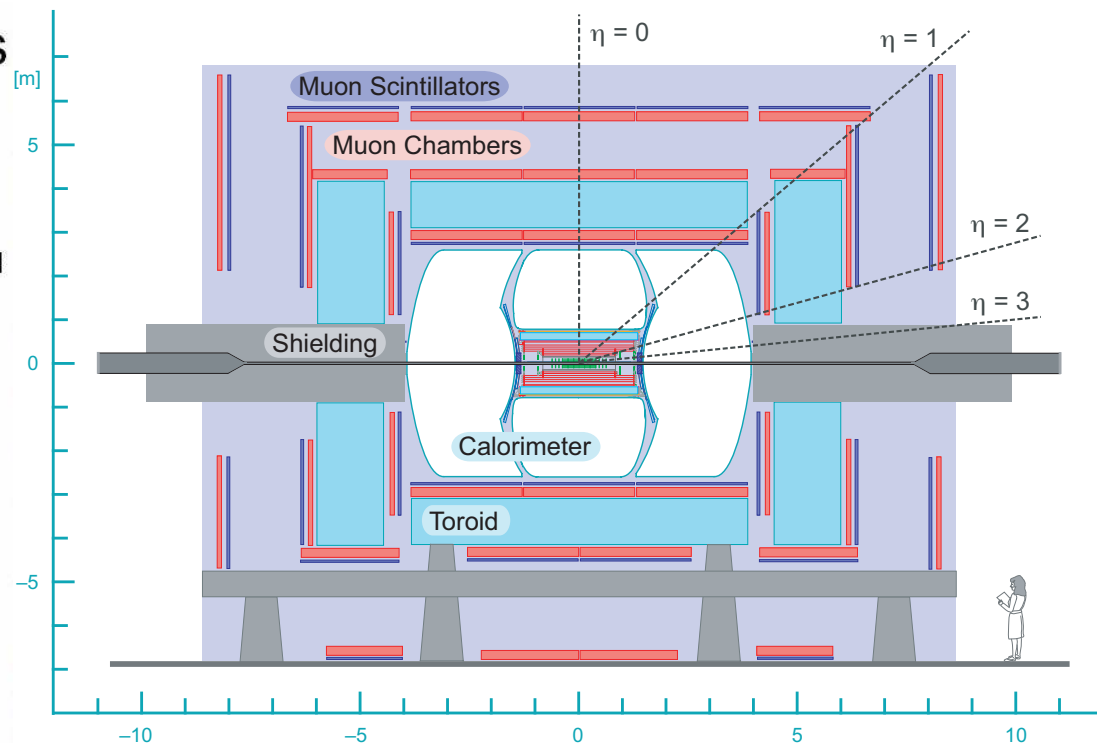
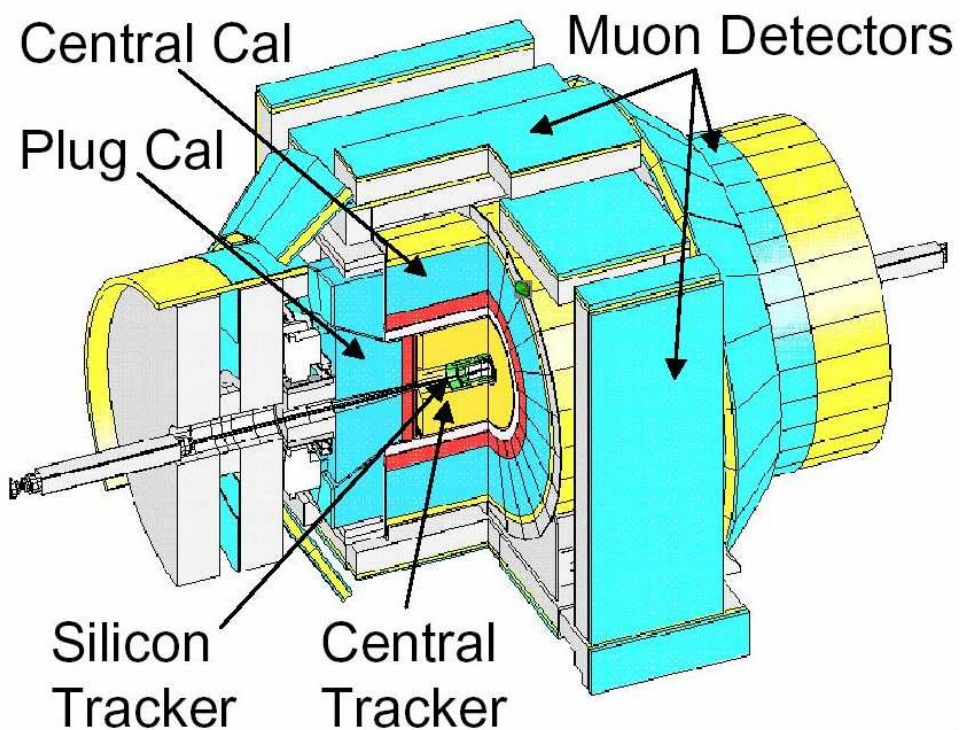
Where: Tevatron

- $p\bar{p}$ Collisions
- $\sqrt{s}=1.96$ TeV
- $\mathcal{L}_{peak} = 3.7 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$



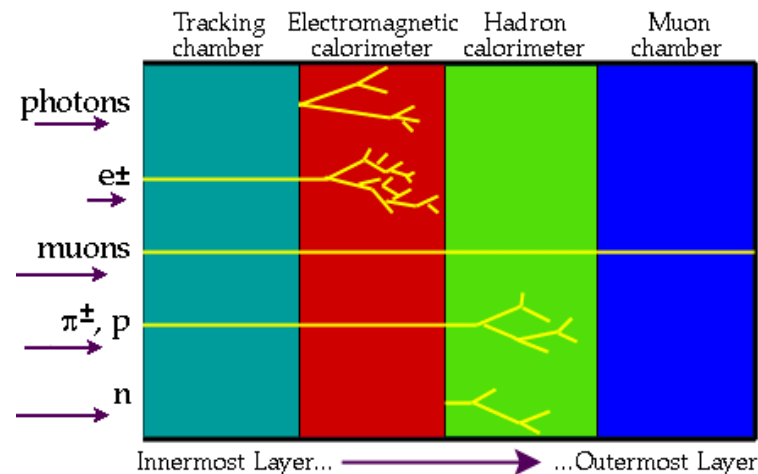
- $\sim 7 \text{ fb}^{-1}$ delivered, $\sim 6 \text{ fb}^{-1}$ on tape
- In this talk: up to 4.1 fb^{-1} results

Where: CDF and $D\bar{O}$

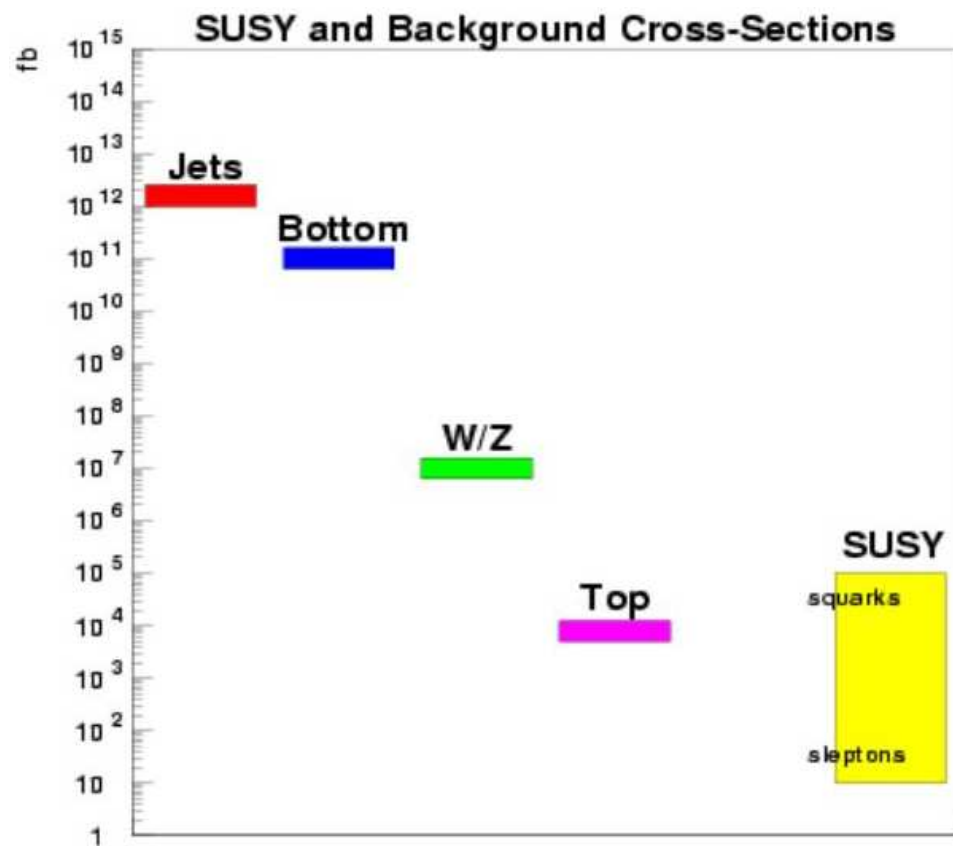


Detectors and identified objects:

- Trackers: e , μ , jets, γ
- Calorimeters: e , μ , jets, E_T , γ
- Muon Detectors: μ , soft μ 's from jets

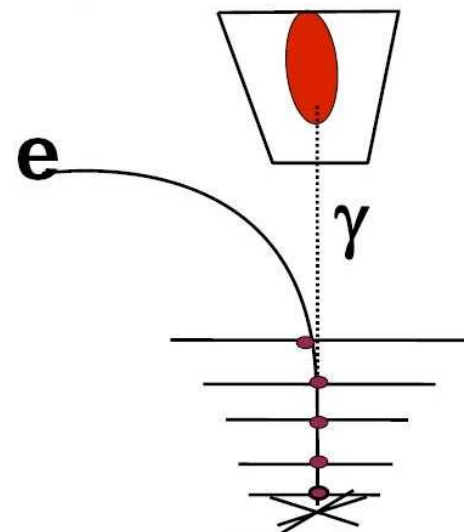
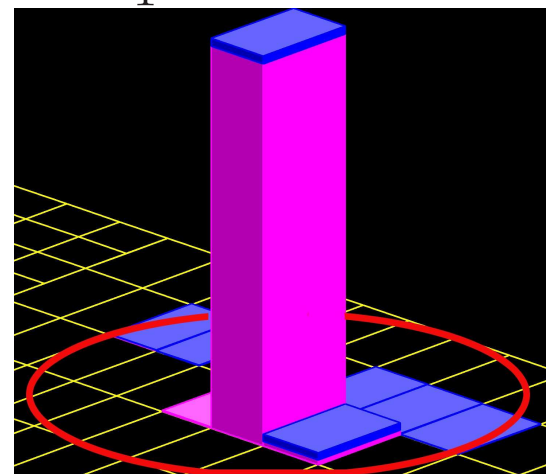
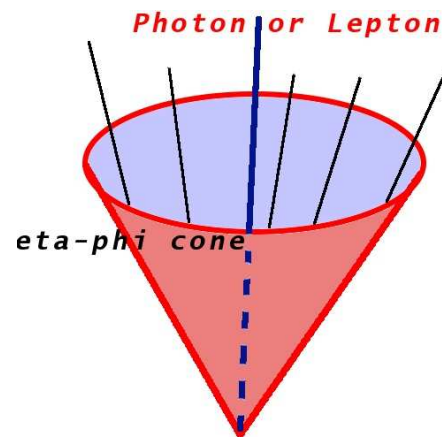


Physics



Tracking Iso: $\sum p_T^{track}$ in $\eta - \phi$

Calorimeter Iso: $\sum E_T^{tower}$ in $\eta - \phi$



Data-driven backgrounds are crucial

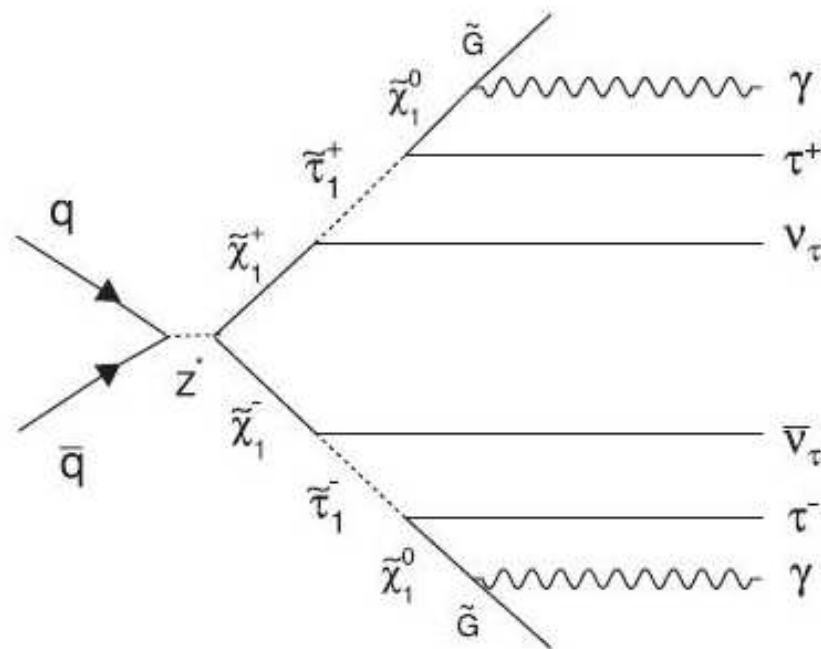
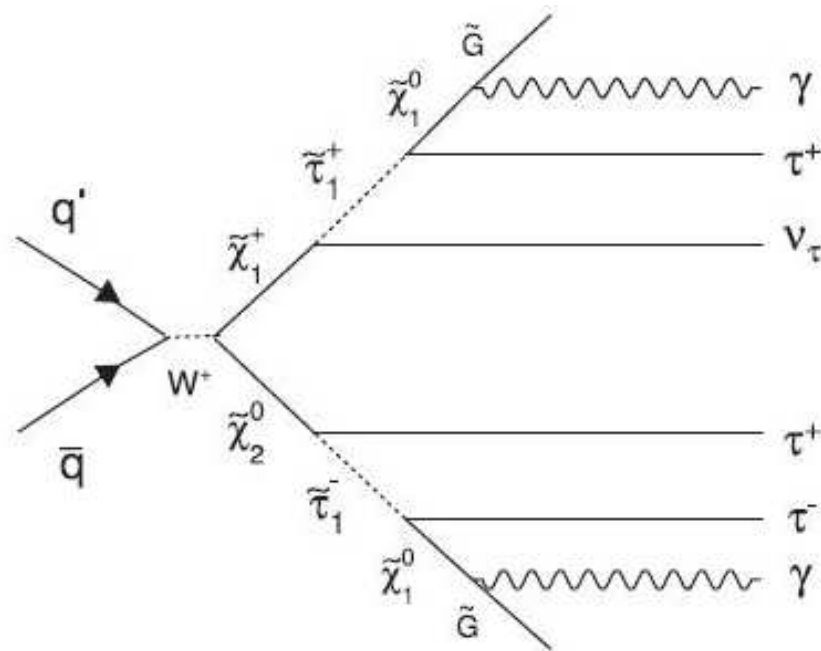
- Electrons / Jets misID as photons
- Jets misID as leptons
- Fake $\cancel{E}_T$ (mismeasured jet, lost μ)

Physics

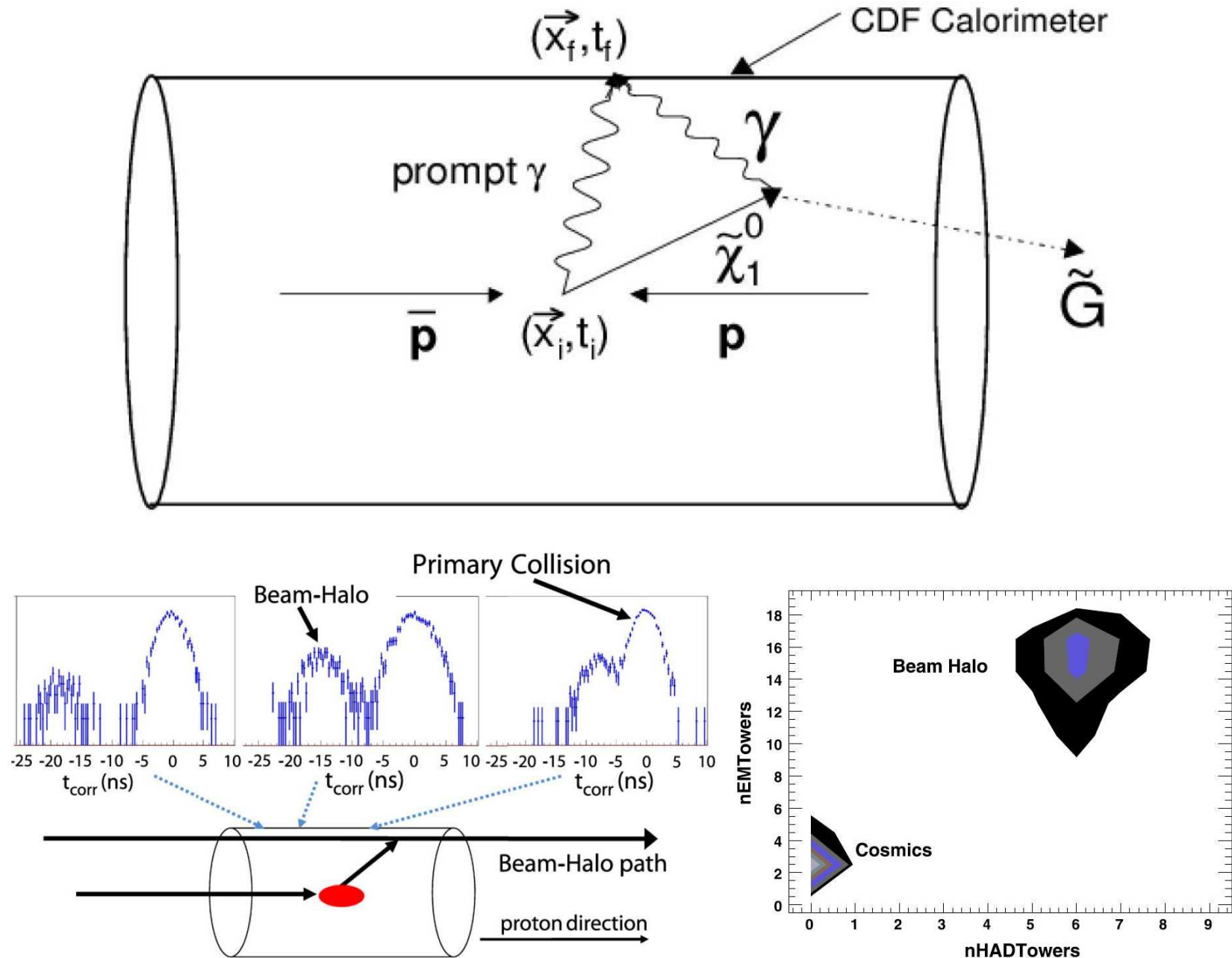
- **GMSB in $\gamma\gamma\cancel{E}_T$**
 - ✓ $D\bar{D}$ Collaboration, Phys. Lett. B 659 , 856 (2008)
 - ✓ CDF Collaboration, to be submitted to the PRL
- **GMSB in $\gamma j\cancel{E}_T$**
 - ✓ CDF collaboration, PRD 78, 0321015 (2008), PRL 99, 121801 (2007)
- **Search for dark photons**
 - ✓ $D\bar{D}$ Collaboration, arXiv:0905.1478 (FERMILAB-PUB-09-229-E)
- **Non-SUSY Photon Searches at the Tevatron**
 - ✓ talk by Enrique Palencia tomorrow morning (July 17, 2009)

Gauge Mediated SUSY Breaking

- LSP Gravitino G
- NLSP Neutralino $\tilde{\chi}_1^0$
- $\tilde{\chi}_1^0 \rightarrow \gamma G$
- Cosmological Constraints $\Rightarrow$
 - $M(G) \sim 1 - 1.5 \text{ GeV}$
 - $\tau(\tilde{\chi}_1^0)$ not defined
- Final States
 - $\gamma j \cancel{E}_T$ ($2 \text{ ns} < \tau_{\tilde{\chi}_1^0} < 10 \text{ ns}$)
 - $\gamma\gamma \cancel{E}_T$ ($\tau_{\tilde{\chi}_1^0} < 2 \text{ ns}$)



CDF EM Timing System



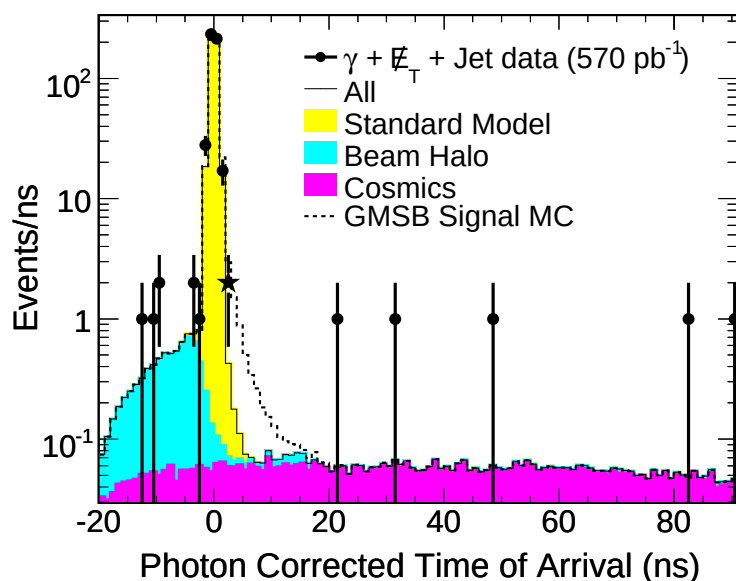
Delayed Photons ($\gamma \cancel{E}_T + \text{jets}$)

Model

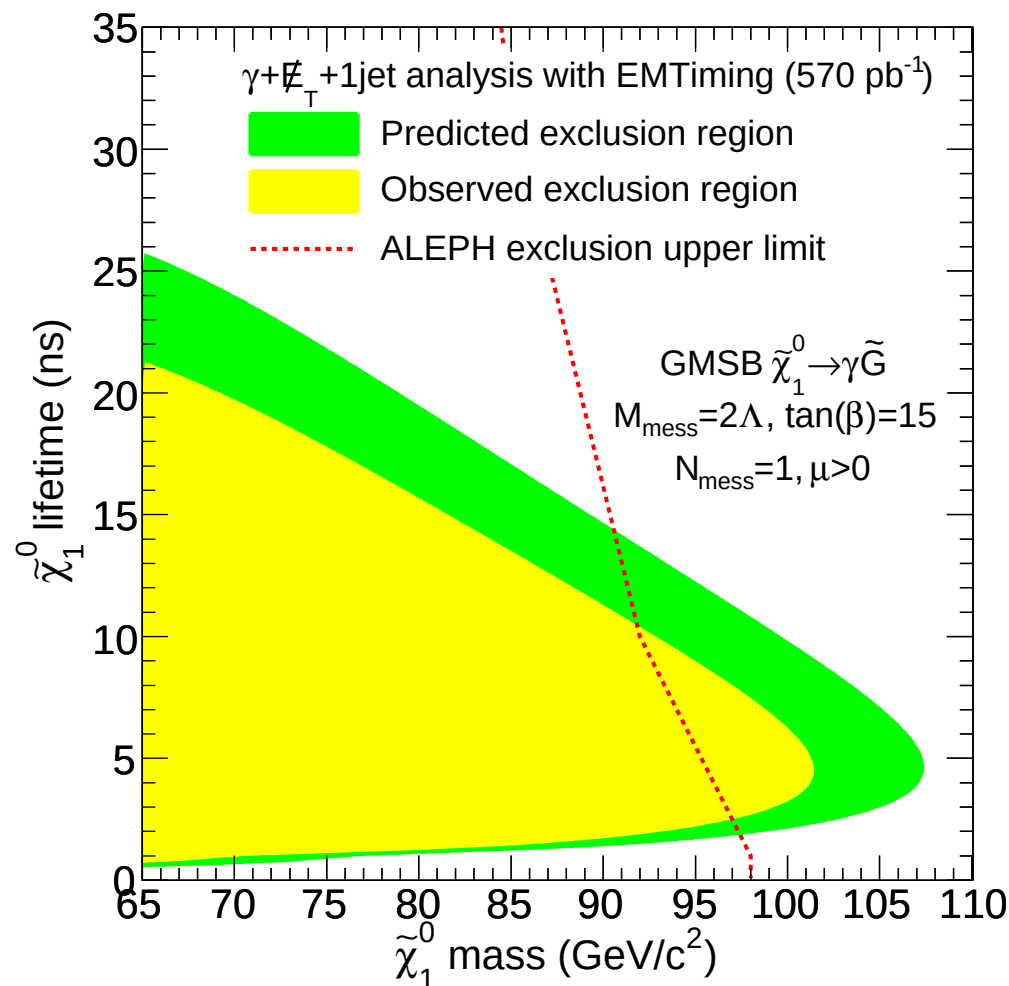
- GMSB decays of $\tilde{\chi}_1^0 \rightarrow \gamma G$
($2 \text{ ns} < \tau_{\tilde{\chi}_1^0} < 10 \text{ ns}$)

Technique

- EM Timing ($\sigma = 0.6 \text{ ns}$)



- Arrival time of photons in 2-10 ns
- 2 observed, 1.3 ± 0.7 expected
- 0.71 Standard Model,
0.46 Cosmics, 0.07 Beam Halo



CDF PRD 78, 0321015 (2008)

CDF PRL 99, 121801 (2007)

GMSB in $\gamma\gamma \cancel{E}_T$

Model

- **GMSB decays of $\tilde{\chi}_1^0 \rightarrow \gamma G$**
($\tau_{\tilde{\chi}_1^0} < 2 \text{ ns}$)

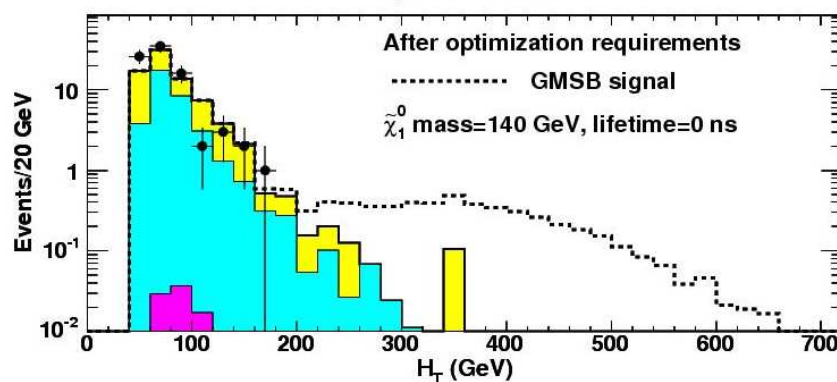
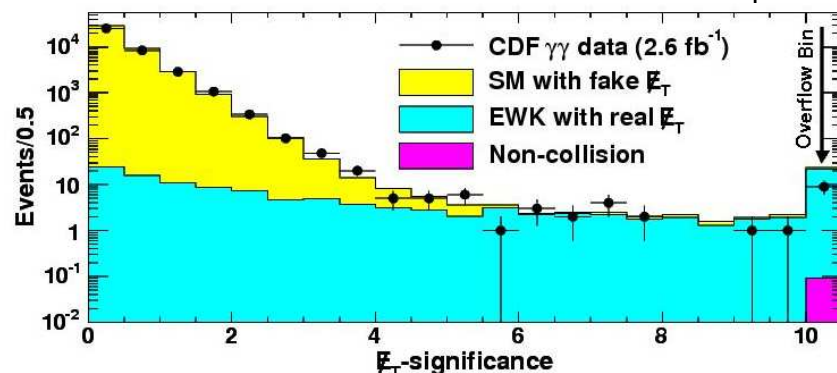
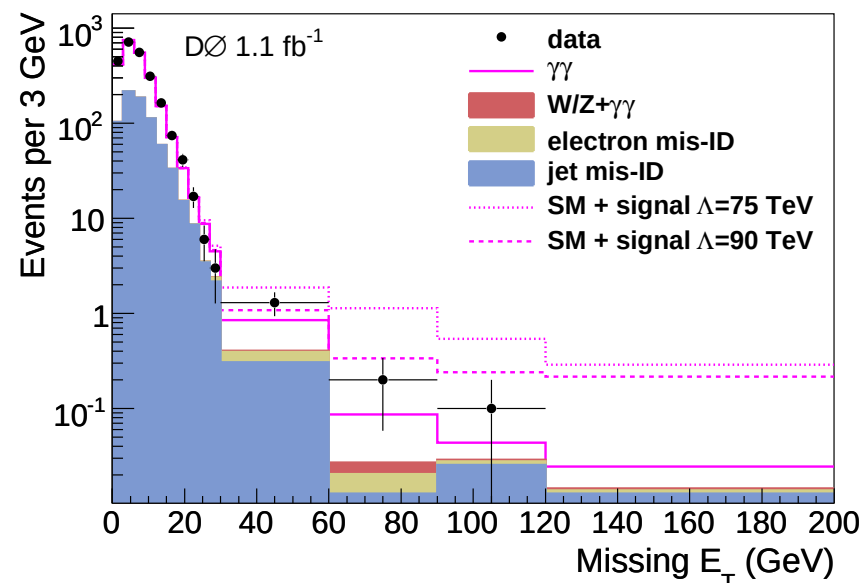
Selection

- Large $\cancel{E}_T$ ($D\phi$) or $\cancel{E}_T - Sig$ (CDF)
- Large H_T (CDF)

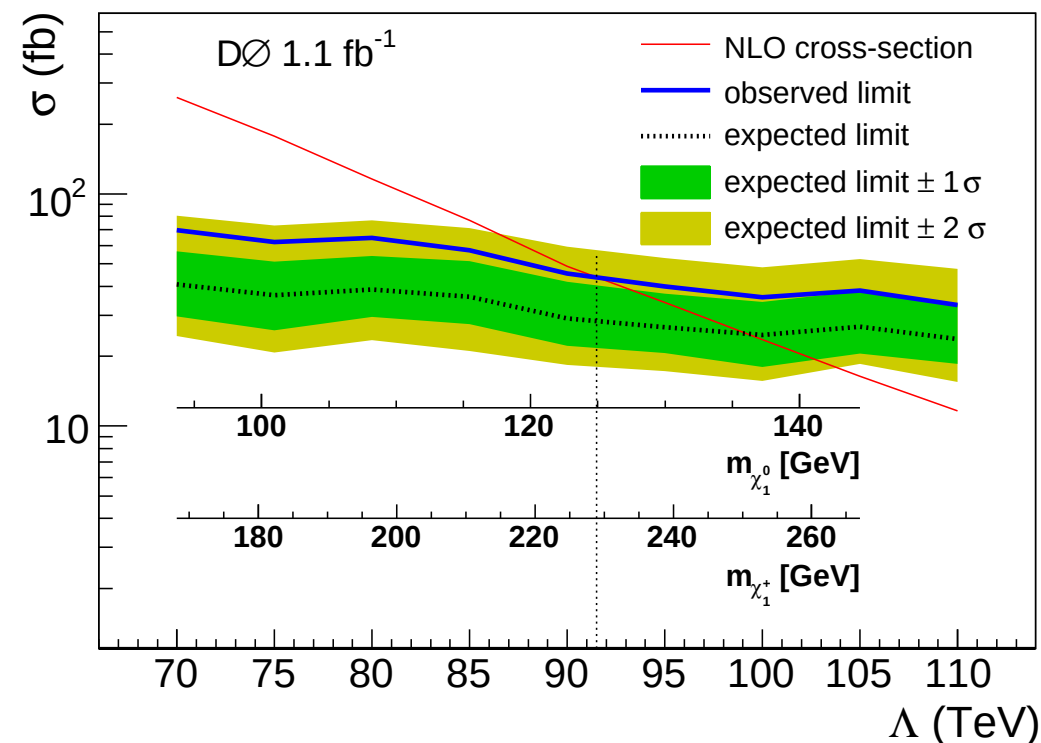
Technique

- **EM Pointing** ($D\phi$)
- **EM Timing** (CDF)
- **Met Model** (CDF)
- $e \rightarrow \gamma$ with real $\cancel{E}_T$: from $e\gamma$ events
- **QCD with fake γ / fake $\cancel{E}_T$**
 - CDF: fake $\cancel{E}_T$
 - $D\phi$: fake γ

$D\phi$ Phys. Lett. B 659 , 856 (2008)
CDF, to be submitted to the PRL



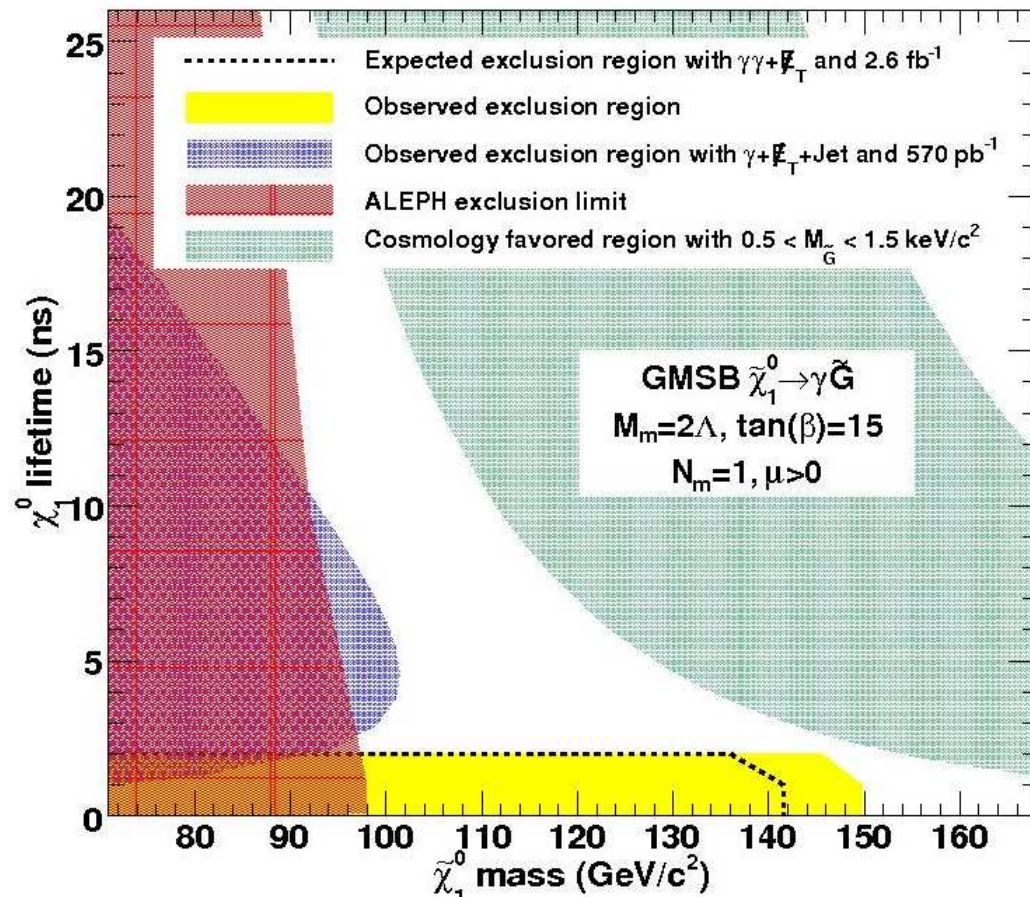
GMSB in $\gamma\gamma\cancel{E}_T$



DØ Phys. Lett. B 659 , 856 (2008)

$$M_{\tilde{\chi}_1^0} > 125 \text{ GeV}$$

$$M_{\tilde{\chi}_1^\pm} > 229 \text{ GeV}$$



CDF, to be submitted to the PRL

$$M_{\tilde{\chi}_1^0} > 149 \text{ GeV} \ (\tau_{\tilde{\chi}_1^\pm} = 0 \text{ ns})$$

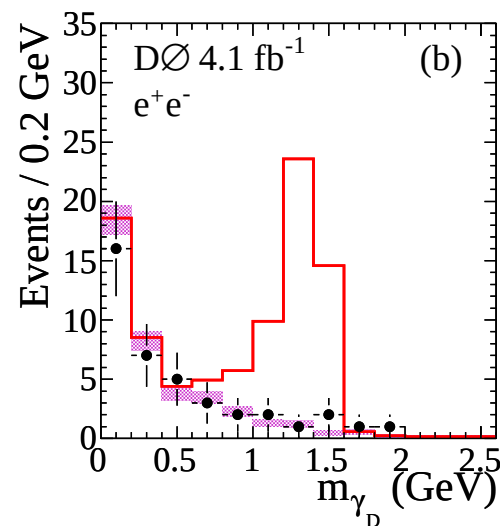
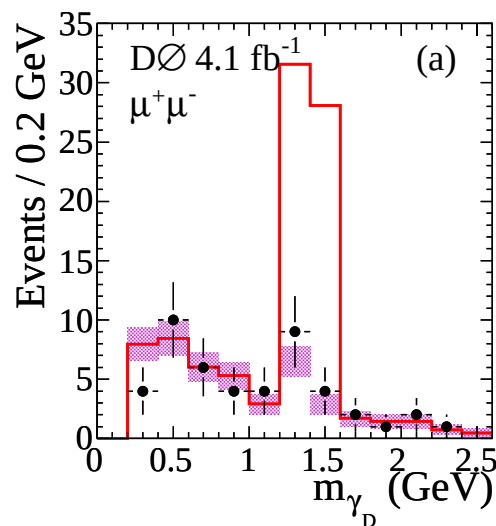
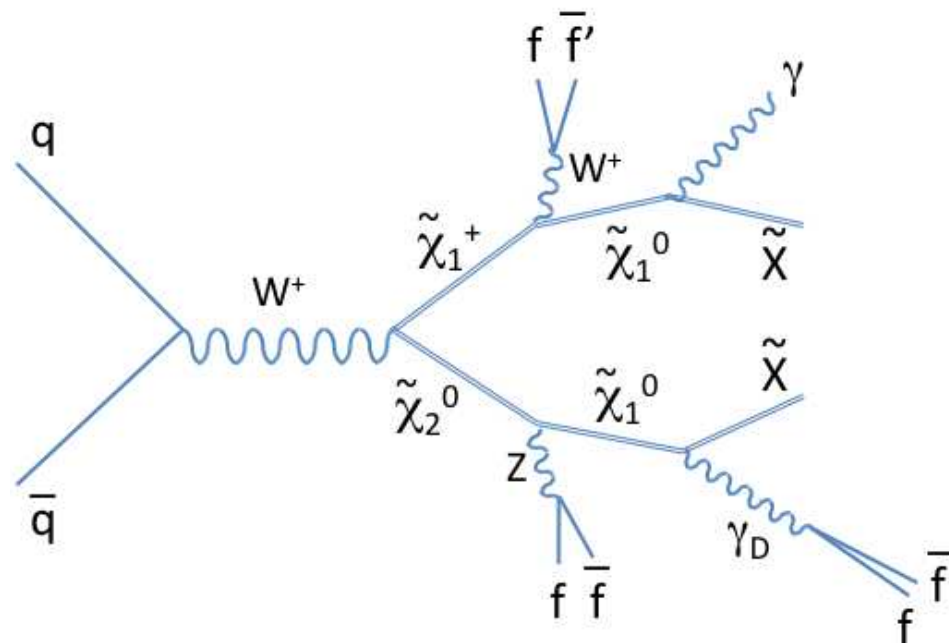
Search for dark photons

Model

- “Hidden Valley” models
- Cosmology: excess of high- E e^+
- dark photons: light gauge bosons
- $\ell\ell\gamma$ ($\ell\ell$ are spatially close)

Selection/Technique

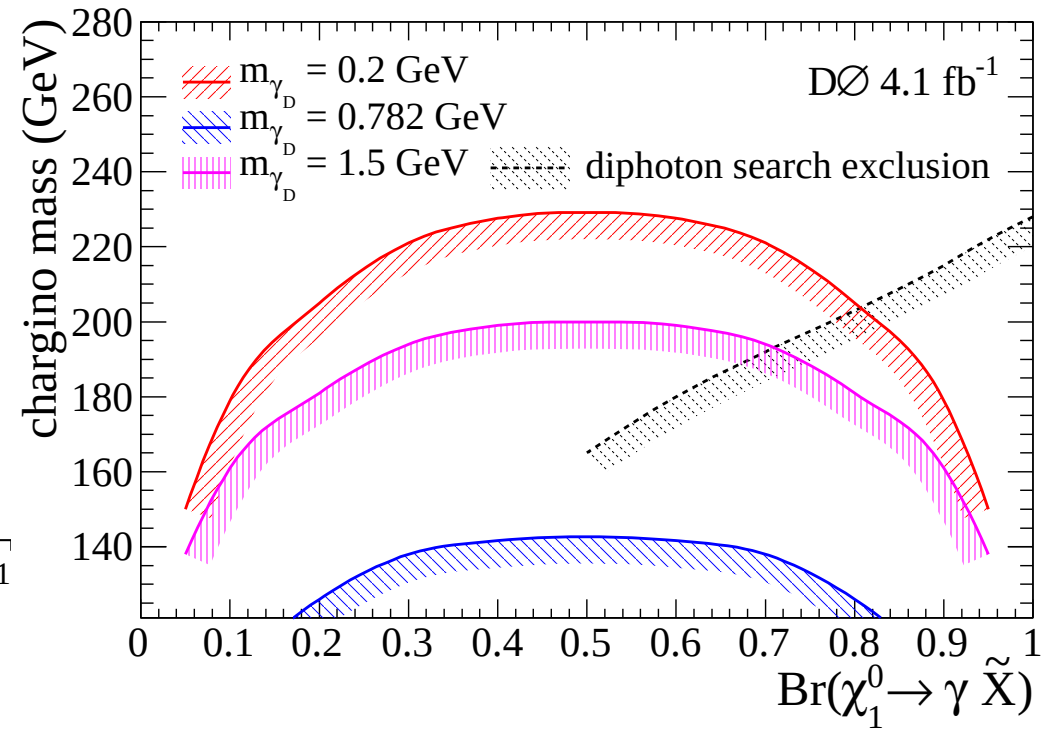
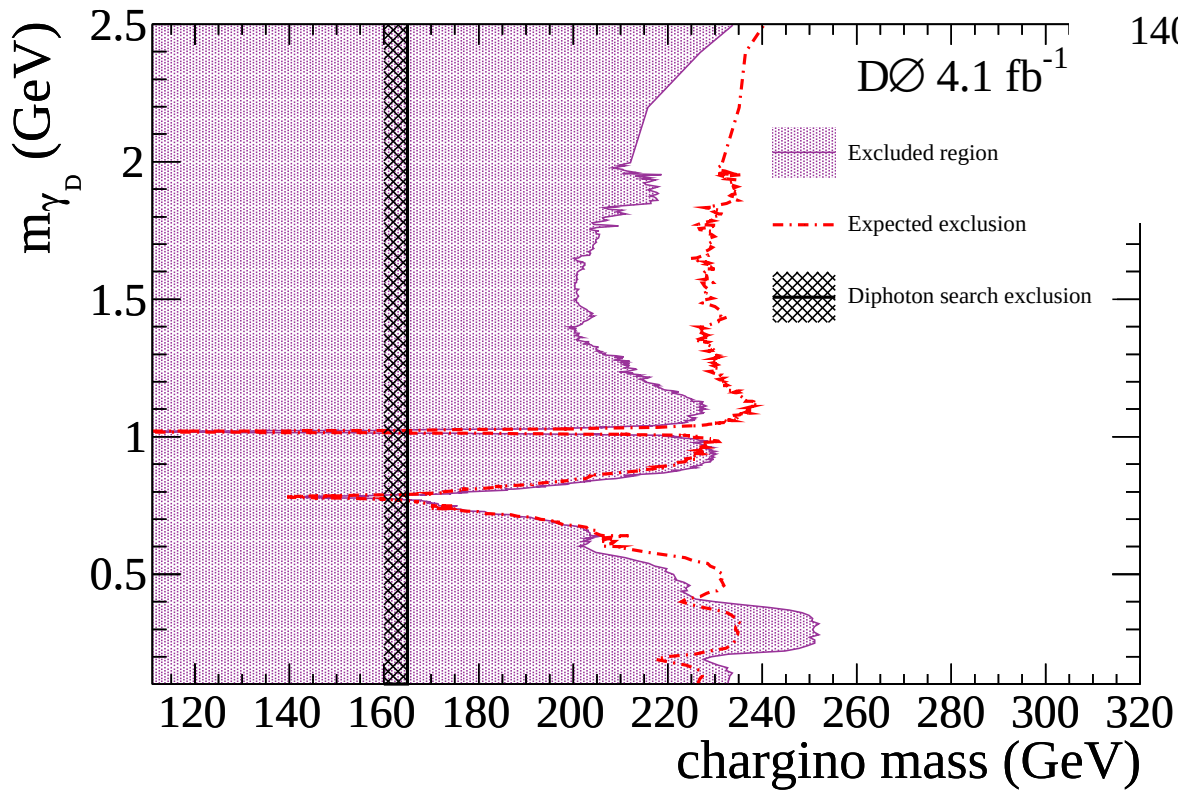
- $E_T^\gamma > 30 \text{ GeV}$, $E_T > 20 \text{ GeV}$,
- two tracks $\Delta R < 0.2$ from the same vertex
- $p_T^1 > 10 \text{ GeV}$, $p_T^2 > 5 \text{ GeV}$,
- isolation requirement
- EM cluster (ee) or reconstructed muon ($\mu\mu$)



D0 arXiv:0905.1478

Search for dark photons

$D\bar{O}$ arXiv:0905.1478



Summary

- Supersymmetry is not discovered... yet
- Tevatron, CDF, $D\emptyset$ are running very well
- New techniques, new ideas
- Data sample is getting bigger
 - Expect at least 10 fb^{-1} of data to analyze
 - Can look at the rarer signatures
 - Keep digging and pushing limits
- CDF Exotics:
<http://www-cdf.fnal.gov/physics/exotic/exotic.html>
- $D\emptyset$ Exotics:
<http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm>
- “Non-SUSY Photon Searches at the Tevatron”
talk by Enrique Palencia tomorrow morning
(July 17, 2009)

