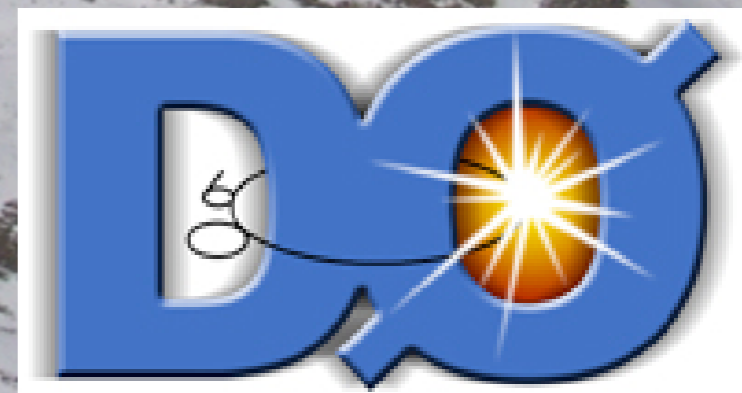


# Tevatron Searches for New Physics with Photons and Jets

Ben Brau

University of Massachusetts, Amherst

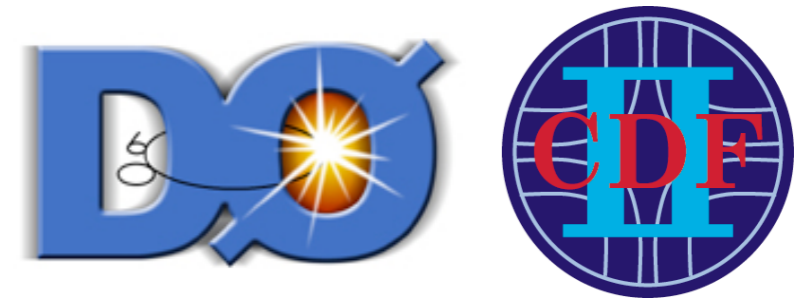
for the CDF and D0 Collaborations





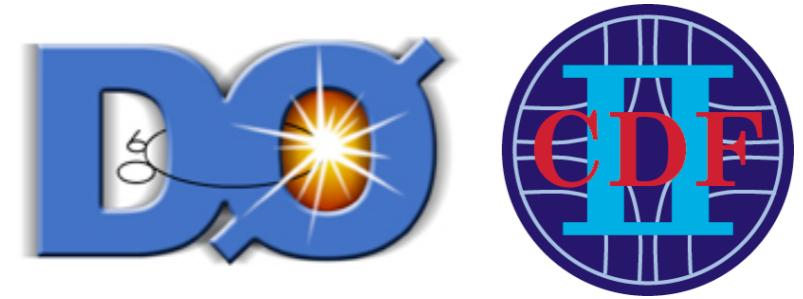
# Introduction

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# Introduction

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- SM is incomplete

# Introduction

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- SM is incomplete
- Dark Matter is a mystery

# Introduction

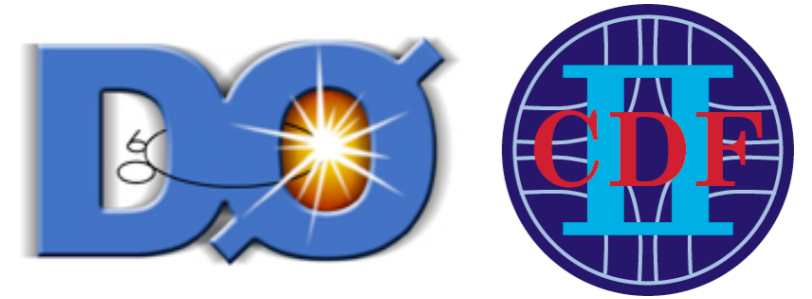
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- SM is incomplete
- Dark Matter is a mystery
- What are we looking for?

# Introduction

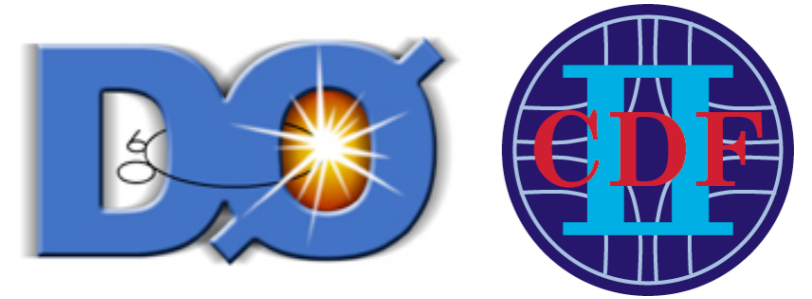
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- SM is incomplete
- Dark Matter is a mystery
- What are we looking for?
  - SUSY?

# Introduction

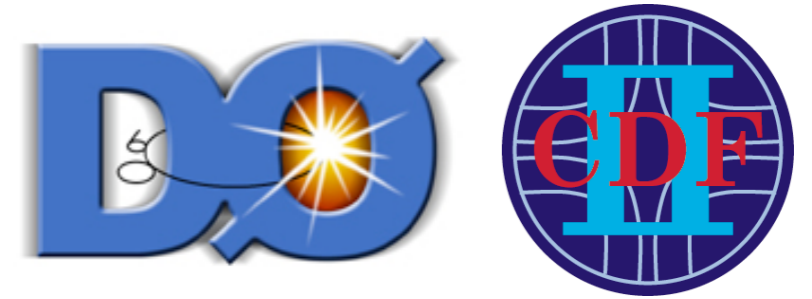
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- SM is incomplete
- Dark Matter is a mystery
- What are we looking for?
  - SUSY?
  - Something else?

# Introduction

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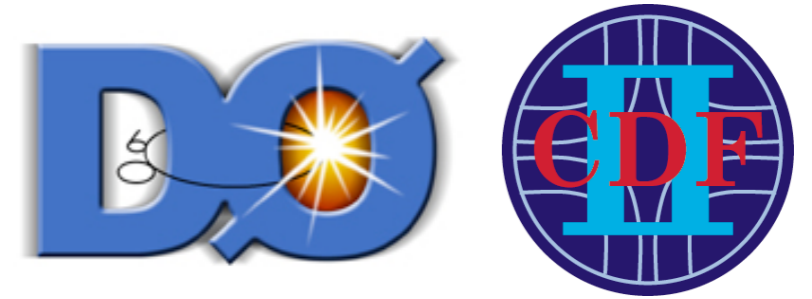


- SM is incomplete
- Dark Matter is a mystery
- What are we looking for?
  - SUSY?
  - Something else?
    - LED, Compositeness, Technicolor, ...



# Introduction

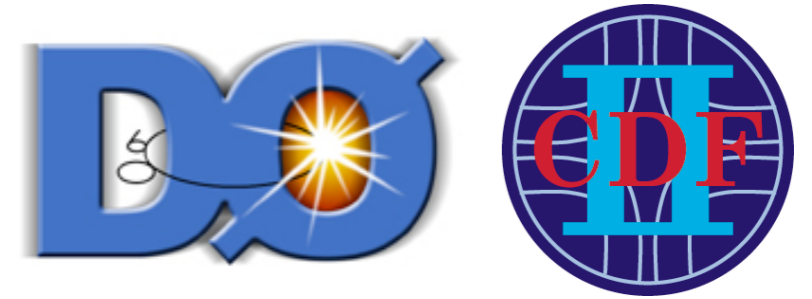
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- SM is incomplete
- Dark Matter is a mystery
- What are we looking for?
  - SUSY?
  - Something else?
    - LED, Compositeness, Technicolor, ...
  - ?

# Introduction

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- SM is incomplete
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# Introduction

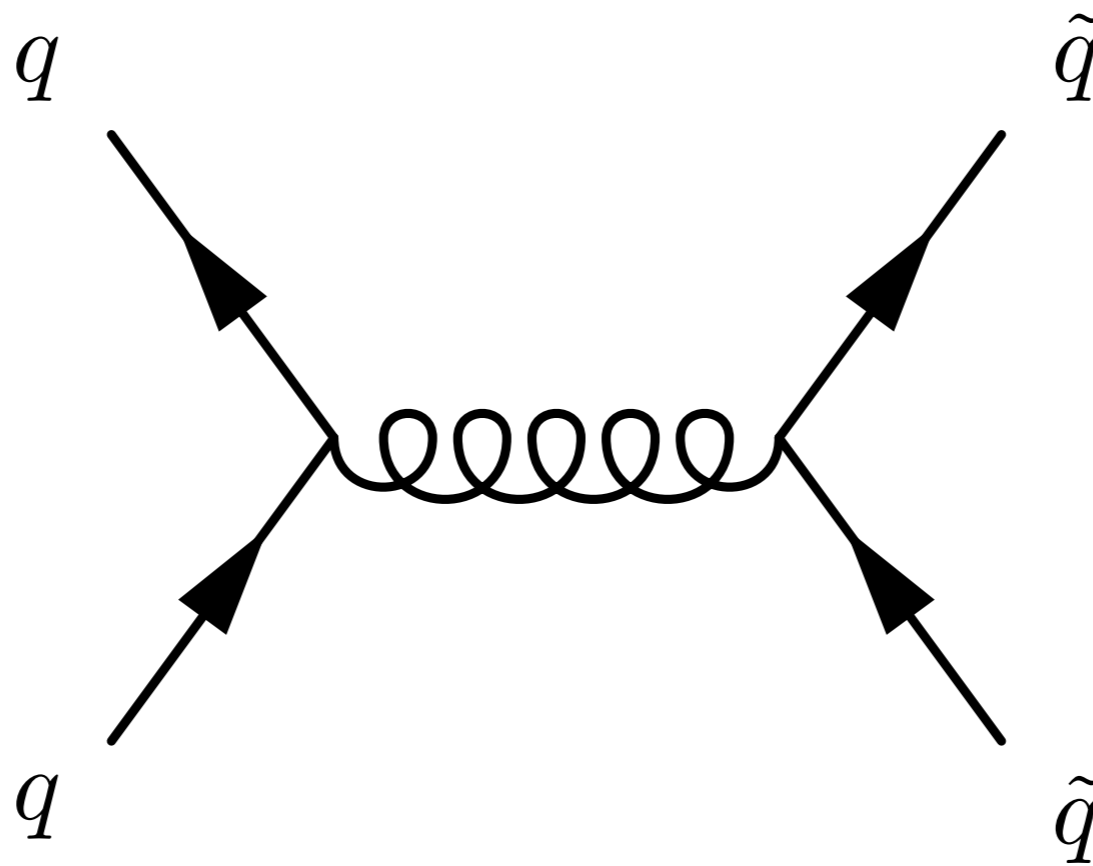
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- SM is incomplete
- Dark Matter is a mystery
- What are we looking for?
  - SUSY?
  - Something else?
    - LED, Compositeness, Technicolor, ...
  - ?
- Brief survey of recent Tevatron results, 2.6 - 4.1 /fb

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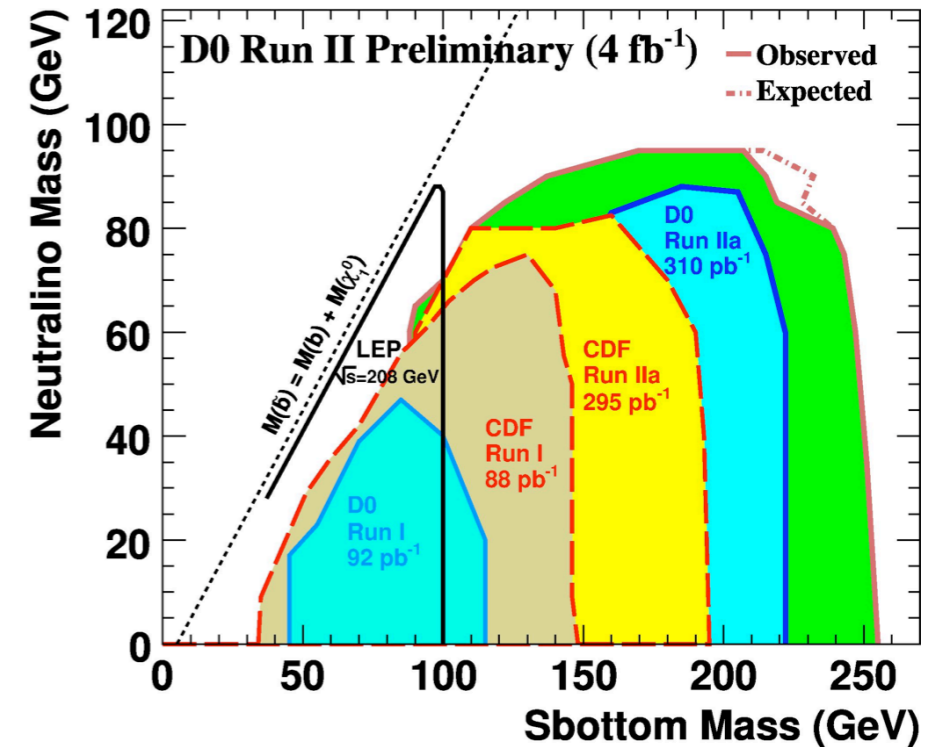
# SUSY: Searches for Squark Production



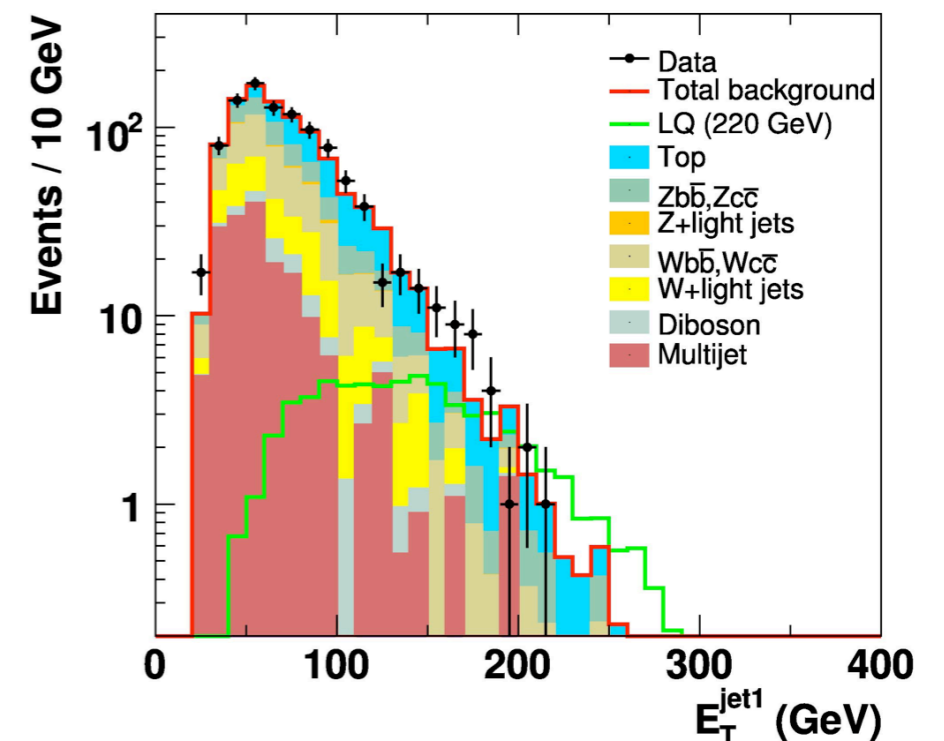


# Sbottom and 3G LQ in $b\bar{b} + \cancel{E}_T$

- Sbottom may be among lightest squarks
  - Assumes SUSY parameter space where only possible decay is  $\tilde{b} \rightarrow b\tilde{\chi}_1^0$
- Look for  $p\bar{p} \rightarrow \tilde{b}_1\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0\bar{b}\tilde{\chi}_1^0$
- W + jets Background normalized to data
- Neural Net b-tagging with variable purity output used on both jets
  - One jet tagged with high purity, one tagged with lower purity
- Use  $\cancel{E}_T$  significance to reject fake  $\cancel{E}_T$
- SUSY exclusion limits set in Neutralino/Sbottom mass plane
- Leptoquark 3rd gen limit:  $M_{LQ} > 252 \text{ GeV}/c^2$



D0 Run II Preliminary (4 fb<sup>-1</sup>)







# Sbottom Pair Production: Jets + $\cancel{E}_T$

- 2 jets, require one Tight SECVTX b-tag
- Backgrounds from mis-tags estimated from data
- Selection criteria optimized in two signal regions in  $\Delta M$ :

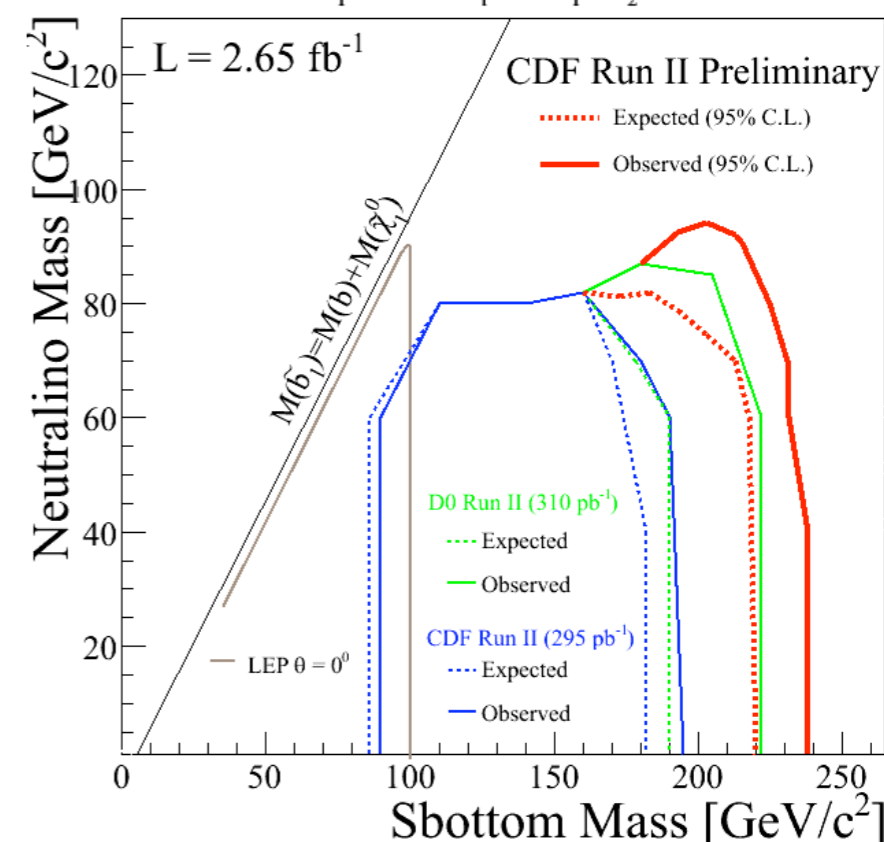
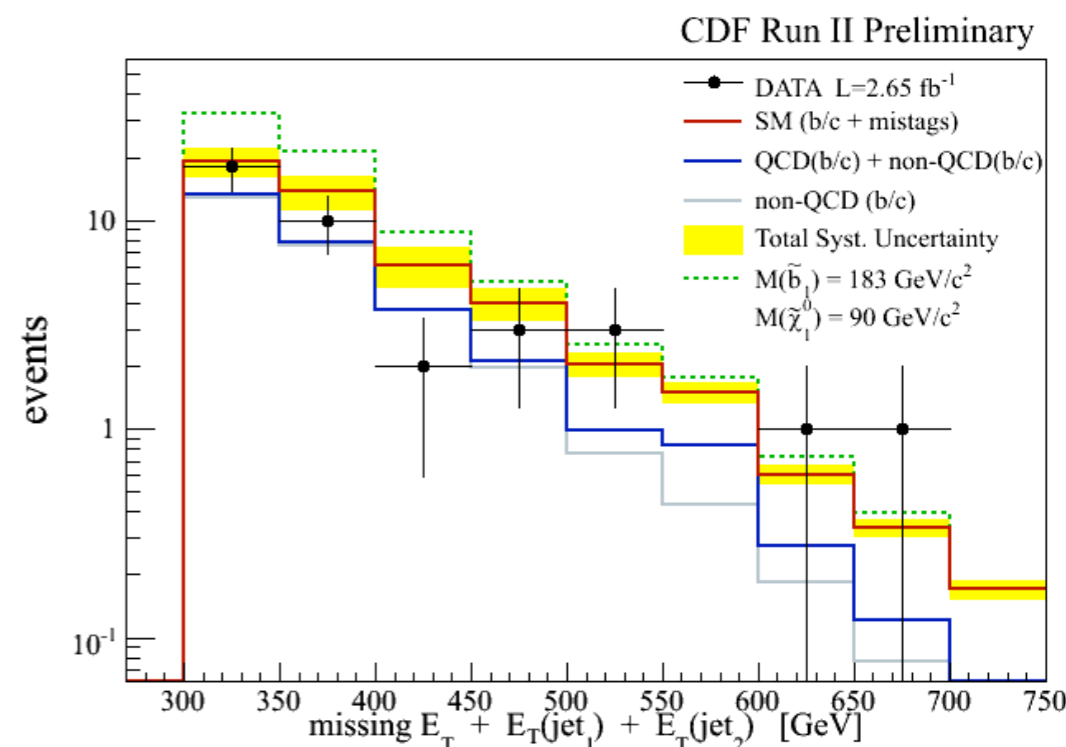
$$\Delta M = M_{\tilde{b}_1} - M_{\tilde{\chi}_1^0}$$

- Require  $\cancel{E}_T$  not aligned with jets:

$$\Delta\phi(\cancel{E}_T, \text{jet}_{1,2}) > 0.4, 0.7$$

Region	SM Prediction	Data
High $\Delta M$	$133.8 \pm 25.2$	139
Low $\Delta M$	$47.6 \pm 8.3$	38

- Low  $\Delta M$ :  $E_{T, \text{jet1}} > 80$  GeV ;  $E_{T, \text{jet2}} > 25$  GeV ; MET > 60 GeV ; no cut on (MET+HT);
- High  $\Delta M$ :  $E_{T, \text{jet1}} > 90$  GeV ;  $E_{T, \text{jet2}} > 40$  GeV ; MET > 80 GeV ; (MET+HT) > 300 GeV;

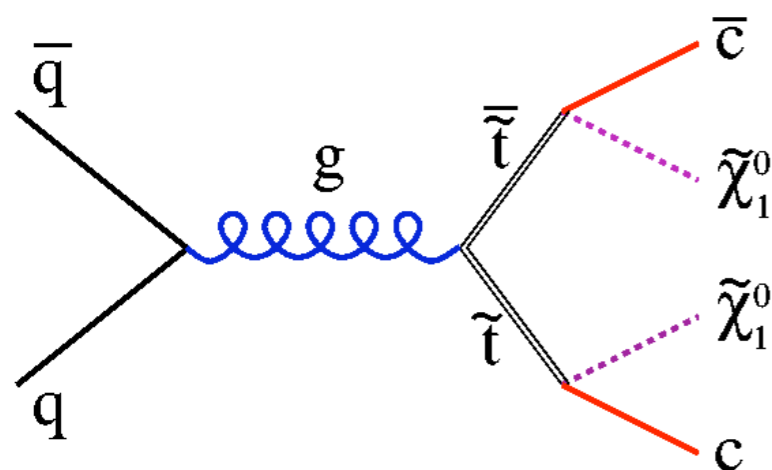




# Stop decaying to Charm + Neutralino

- Stop may be lightest squark
- Signature: c-jets + MET
- Neural-Network Heavy Flavor multijet rejection
- Require one jet have secondary vertex tag
- 2-d Neural-Network Charm flavor separator

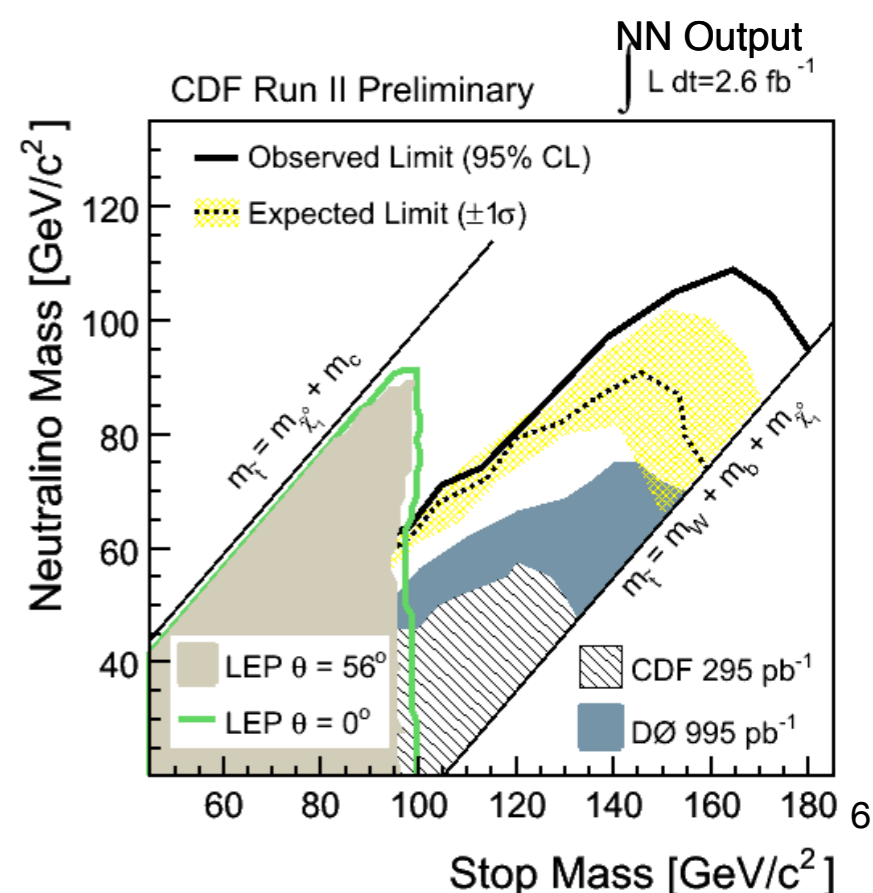
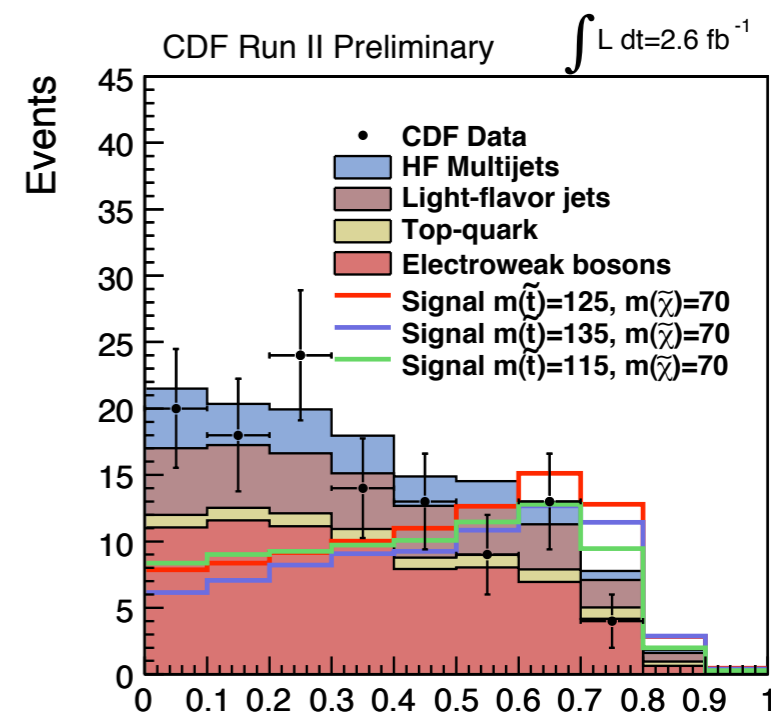
- Optimized for  $m_{\tilde{t}} = 125 \text{ GeV}/c^2, m_{\tilde{\chi}_1^0} = 70 \text{ GeV}/c^2$



CDF Run II Preliminary 2.6 fb<sup>-1</sup>

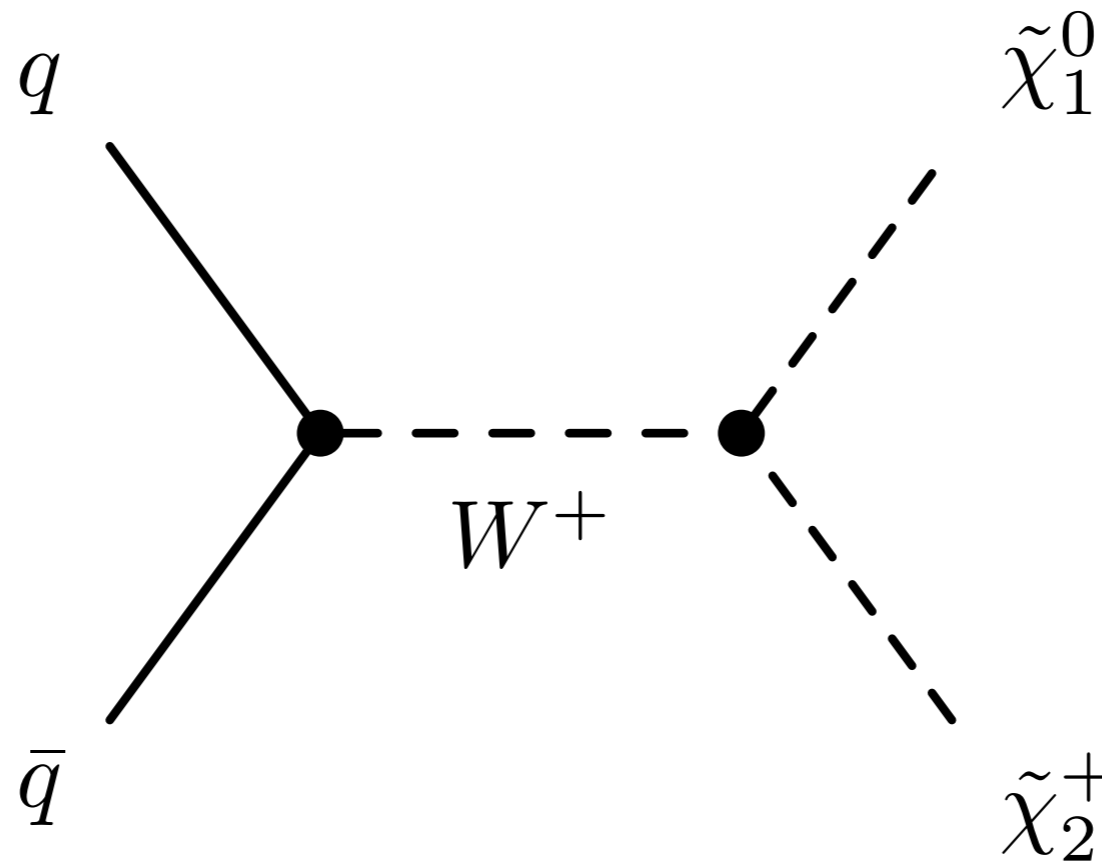
	Final Region
W/Z + jets production	60.9 ± 26.6
Diboson production	10.7 ± 1.9
Top pair production	4.6 ± 1.3
Single top production	3.2 ± 0.8
HF QCD Multijets	20.4 ± 15.2
Light-flavour contamination	32.2 ± 12.7
<b>Total expected</b>	<b>132.0 ± 24.4</b>
<b>Observed</b>	<b>115</b>
Signal $m(\tilde{t})=125, m(\tilde{\chi}_1^0)=70$	90.2 ± 23.9
Signal $m(\tilde{t})=135, m(\tilde{\chi}_1^0)=70$	78.0 ± 20.7
Signal $m(\tilde{t})=115, m(\tilde{\chi}_1^0)=70$	82.4 ± 21.8

Rencontres de Moriond EW 2010



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# SUSY: Searches for Gaugino Production



# SUSY GMSB: Gaugino Production in $\gamma\gamma + \cancel{E}_T$

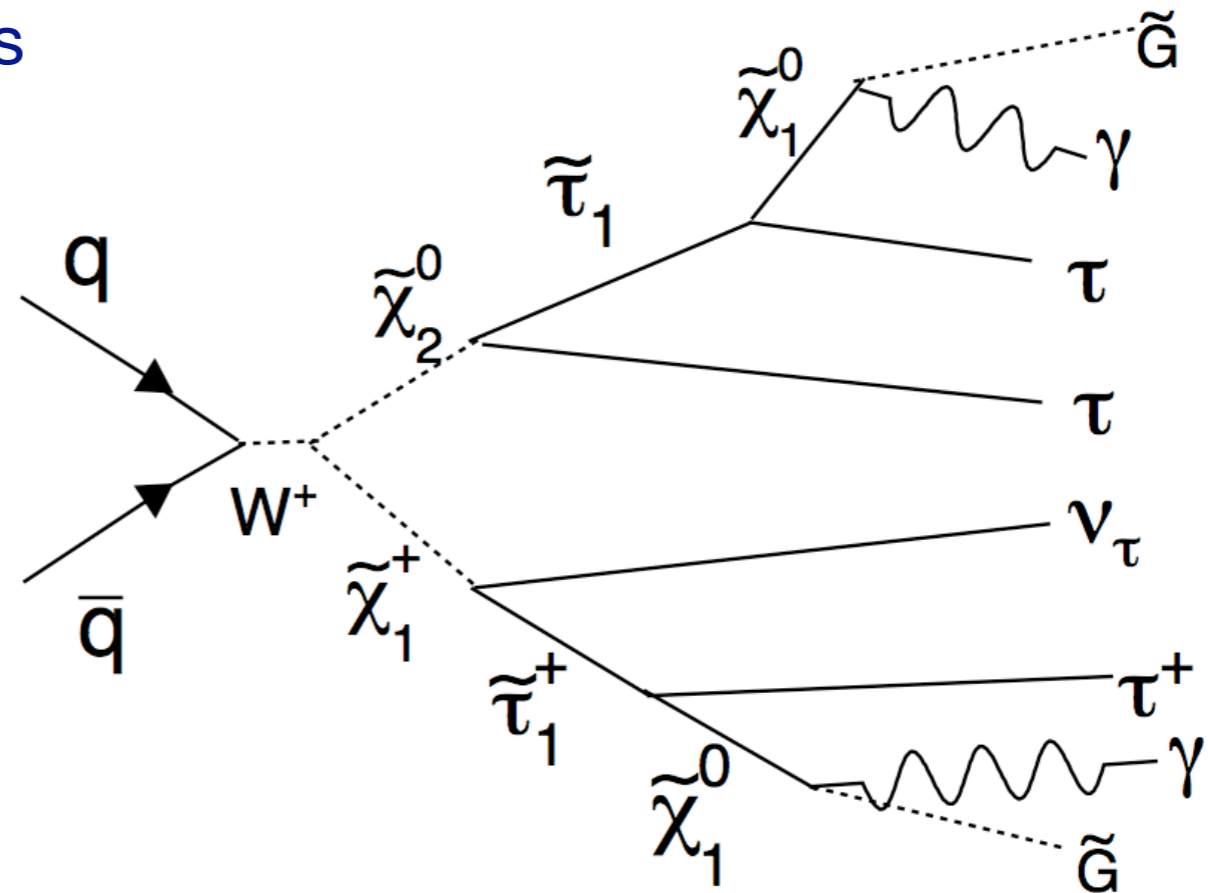


- In Gauge-Mediated Symmetry-Breaking models (GMSB), Gravitino is LSP

- Signature:  $\gamma\gamma + \cancel{E}_T + X$

- Backgrounds:

- QCD - fake  $\cancel{E}_T$
- EWK - real  $\cancel{E}_T$
- Non-Collision -  $\cancel{E}_T$  doesn't make sense
- Can we understand  $\cancel{E}_T$  better?



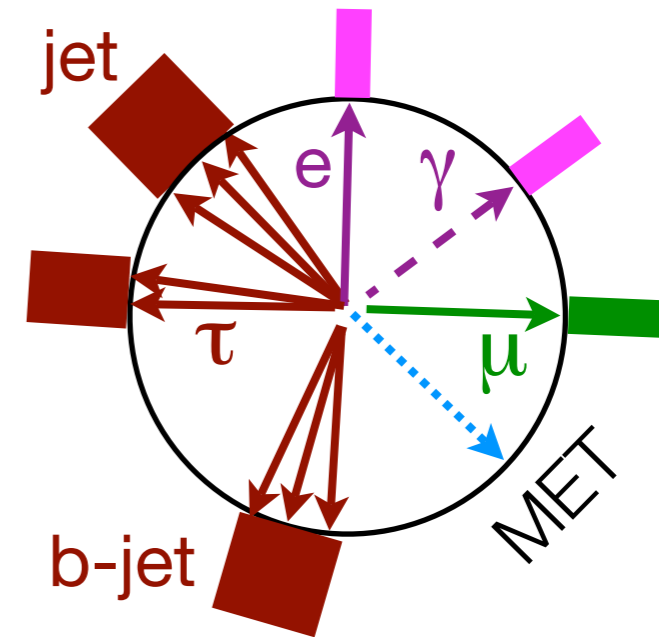
# Can we improve on $\cancel{E}_T$ ?



- $\cancel{E}_T$  is computed from everything else in the event.

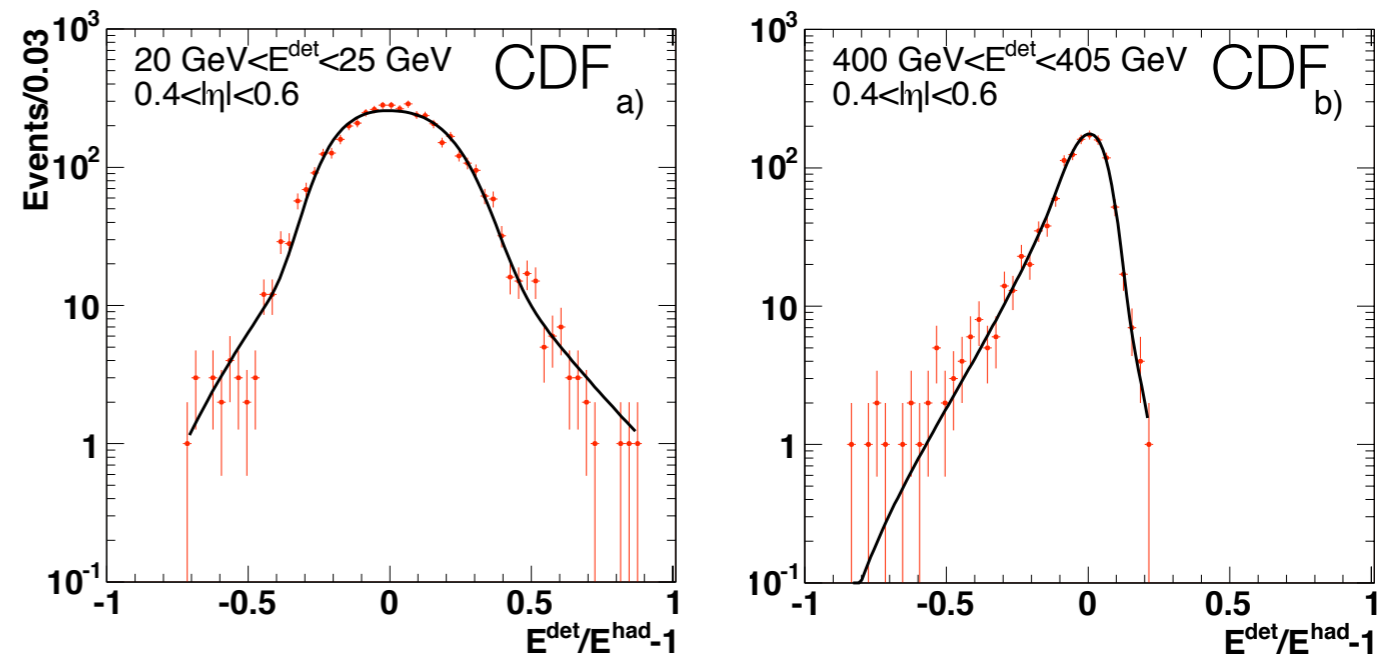
$$\cancel{E}_T = \left| - \sum_i E_T^i \vec{n}_i \right|$$

- “least common denominator”: most poorly measured parts of each event dominate uncertainty on  $\cancel{E}_T$



- $\cancel{E}_T$  Significance

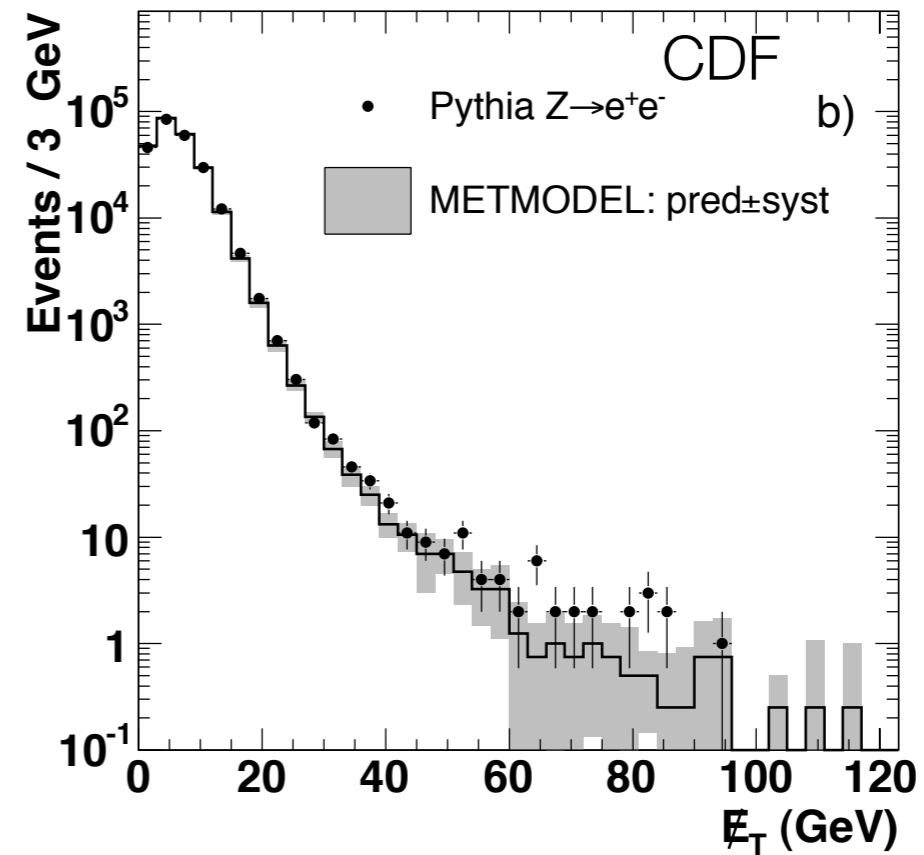
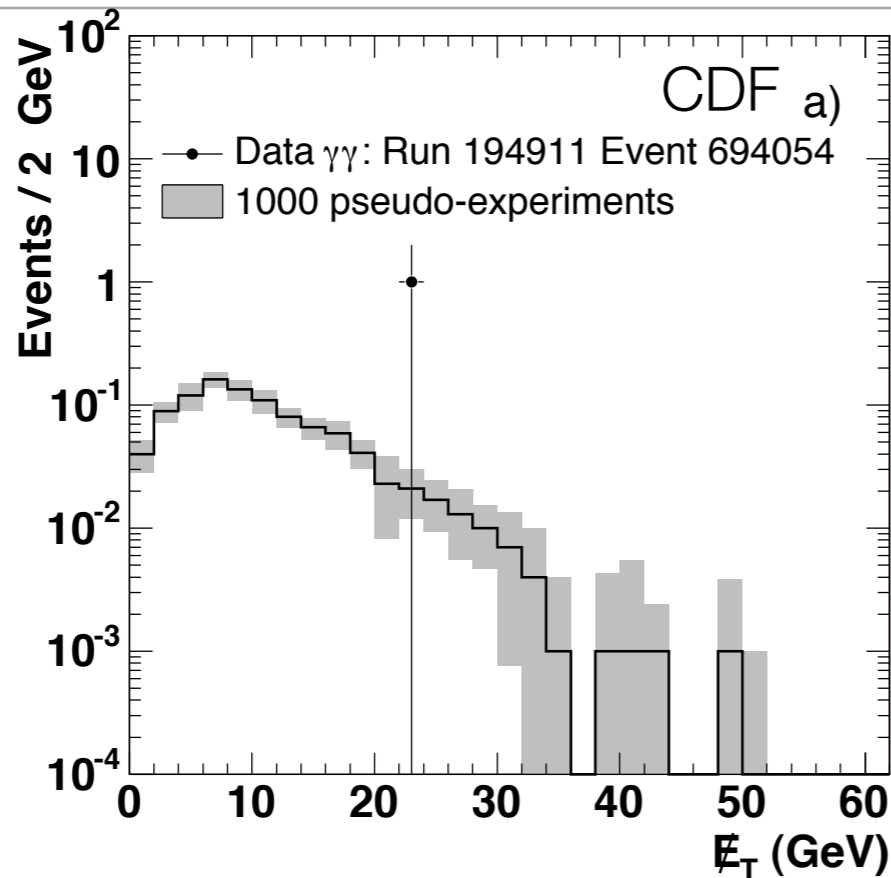
- Finely-segmented model of  $\cancel{E}_T$  Resolution, *event by event*
- Used to predict event-by-event probability of mismeasured  $\cancel{E}_T$
- Allows quantitative rejection of poorly-measured events



Jet energy resolution from Pythia, di-jet and Z+jet data



# $\cancel{E}_T$ Significance



- Use detailed model of resolution to predict the  $\cancel{E}_T$  from mis-measurement event-by-event
- Generate pseudo-experiments for every event to build envelope of possible  $\cancel{E}_T$  from mis-measurements
- Assign per-event-probability that  $\cancel{E}_T$  is from mis-measurement of event.

# CDF Gaugino Pair Production:



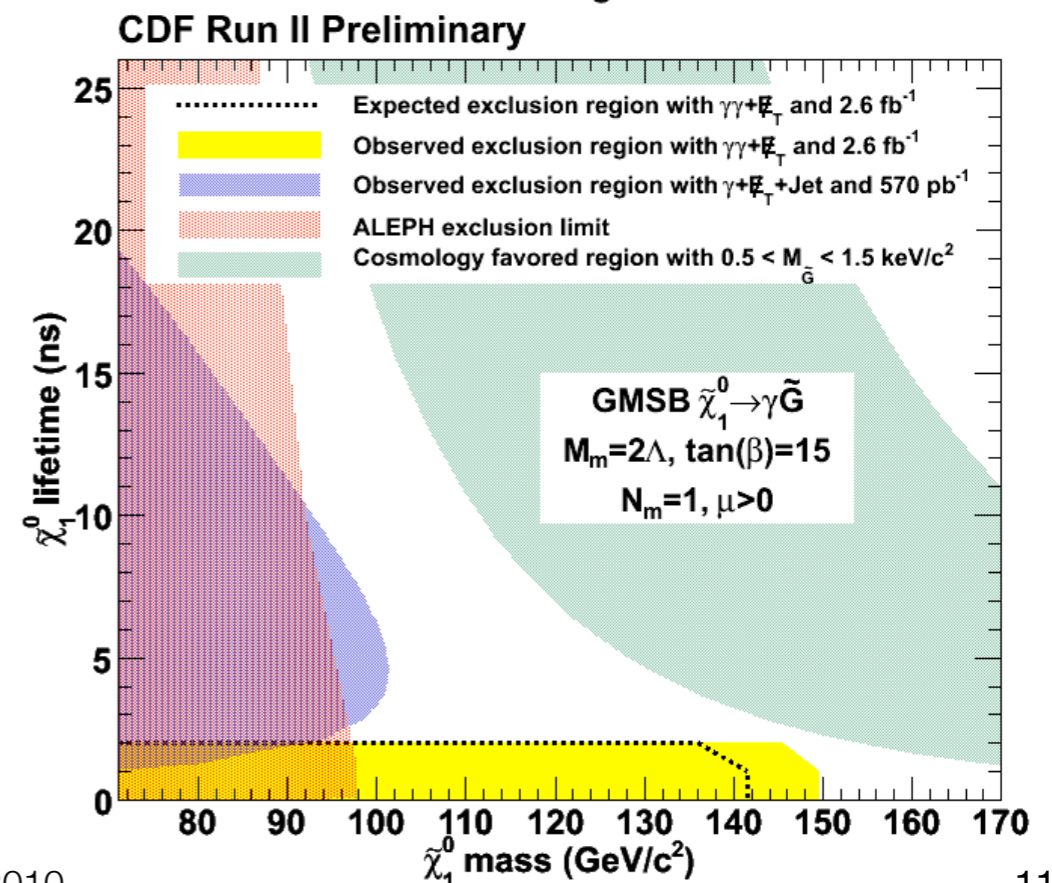
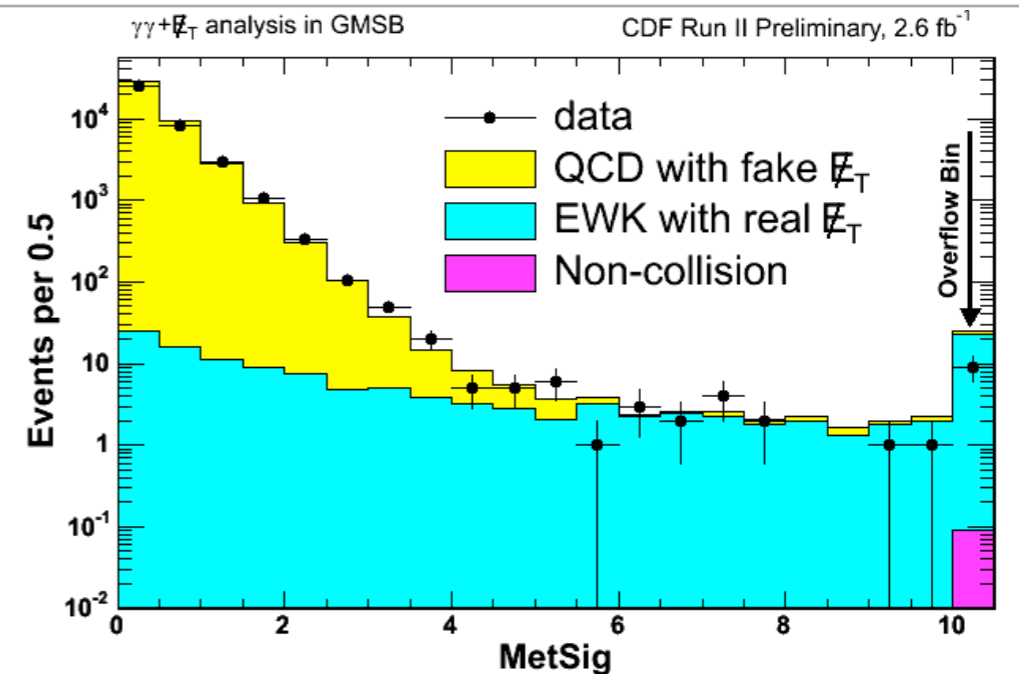
$$\gamma\gamma + \cancel{E}_T$$

- Photon timing and  $\cancel{E}_T$  significance improve background rejection
- Selection optimized in  $\tau_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_1^0}$  space for lifetimes  $< 2$  ns
- Require  $\cancel{E}_T$  significance  $> 3$ ,  $H_T > 200$  GeV, and  $\Delta\phi(\gamma_1, \gamma_2) < \pi - 0.35$  rad

Background Source	Prediction
Electroweak (mainly $Z\gamma\gamma$ )	$0.9 \pm 0.4$
Other SM with fake MET	$0.5 \pm 0.2$
Non-Collision	$0.001 \pm 0.008$
Total	$1.4 \pm 0.4$
Data	0

- **Limit:**  $m_{\tilde{\chi}_1^0} > 149$  GeV/ $c^2$  for  $\tau(\tilde{\chi}_1^0) < 1$  ns

Phys. Rev. Lett. **104**, 011801 (2010)



# Gaugino Production

## Dark Photons - SUSY Hidden Valley

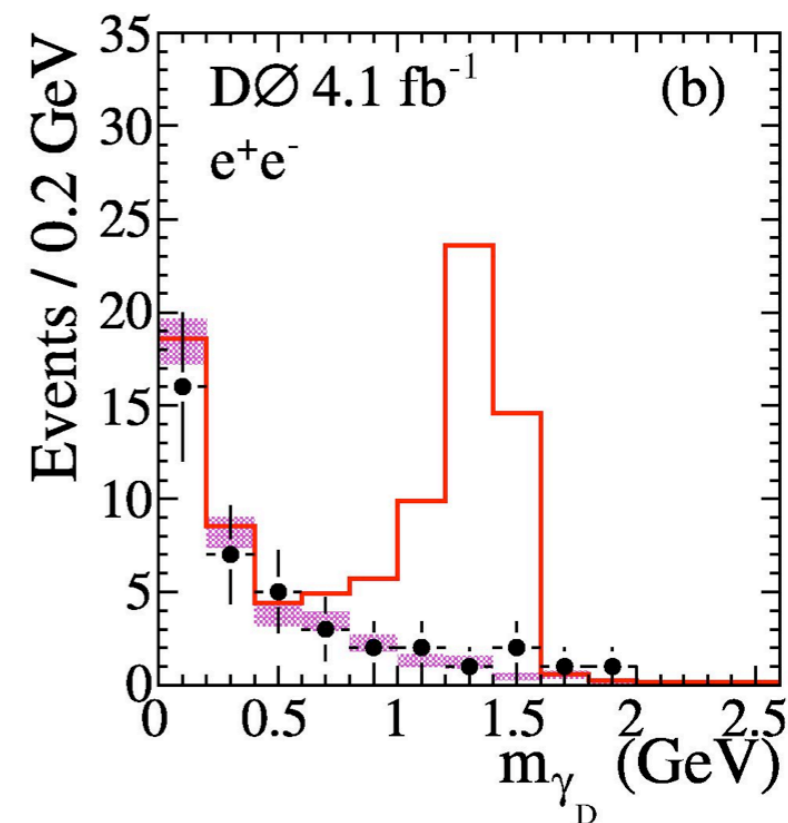
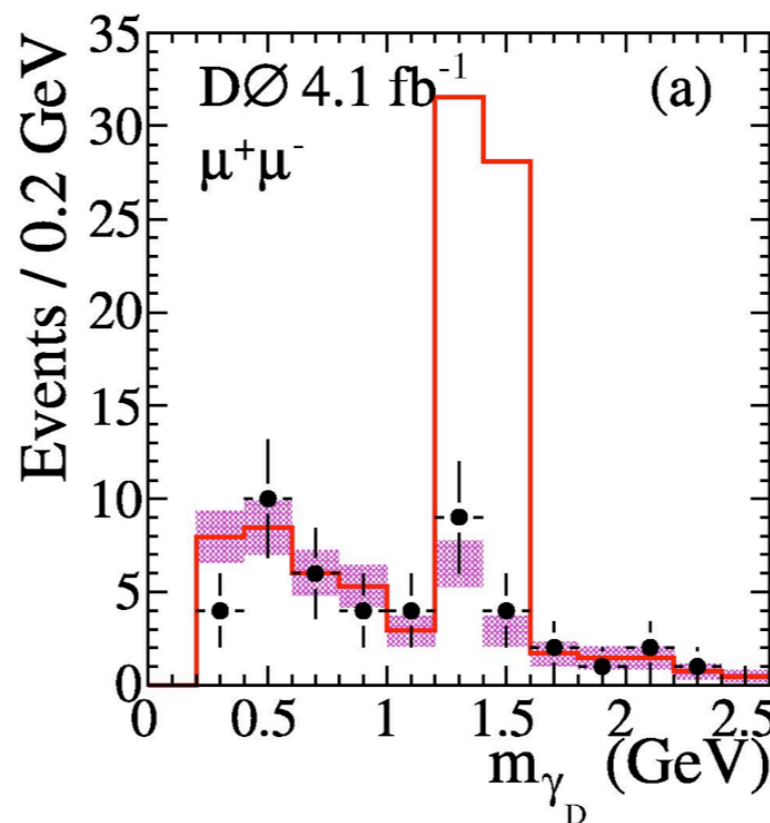
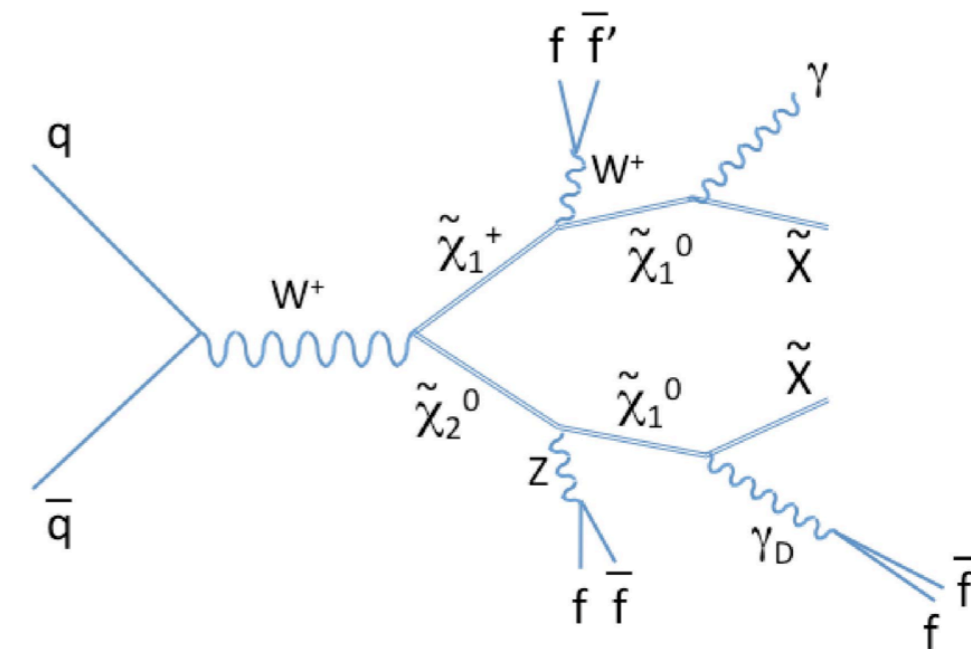


- Subset of Hidden Valley models with SUSY recently proposed to explain excess of high-energy cosmic positrons (Pamela and Fermi/LAT) Nature 458, 607 (2009), Nature 456, 362 (2008)

- Explanation: Dark Matter annihilation to dark photons
- Decays to pairs of  $e, \mu$  depending on mass

- Gaugino decays to  $\gamma_D$
- Search for  $\gamma + ll + \cancel{E}_T$
- Single photon trigger
- Main BG: QCD + conversions
- Signal discriminant is dark photon mass

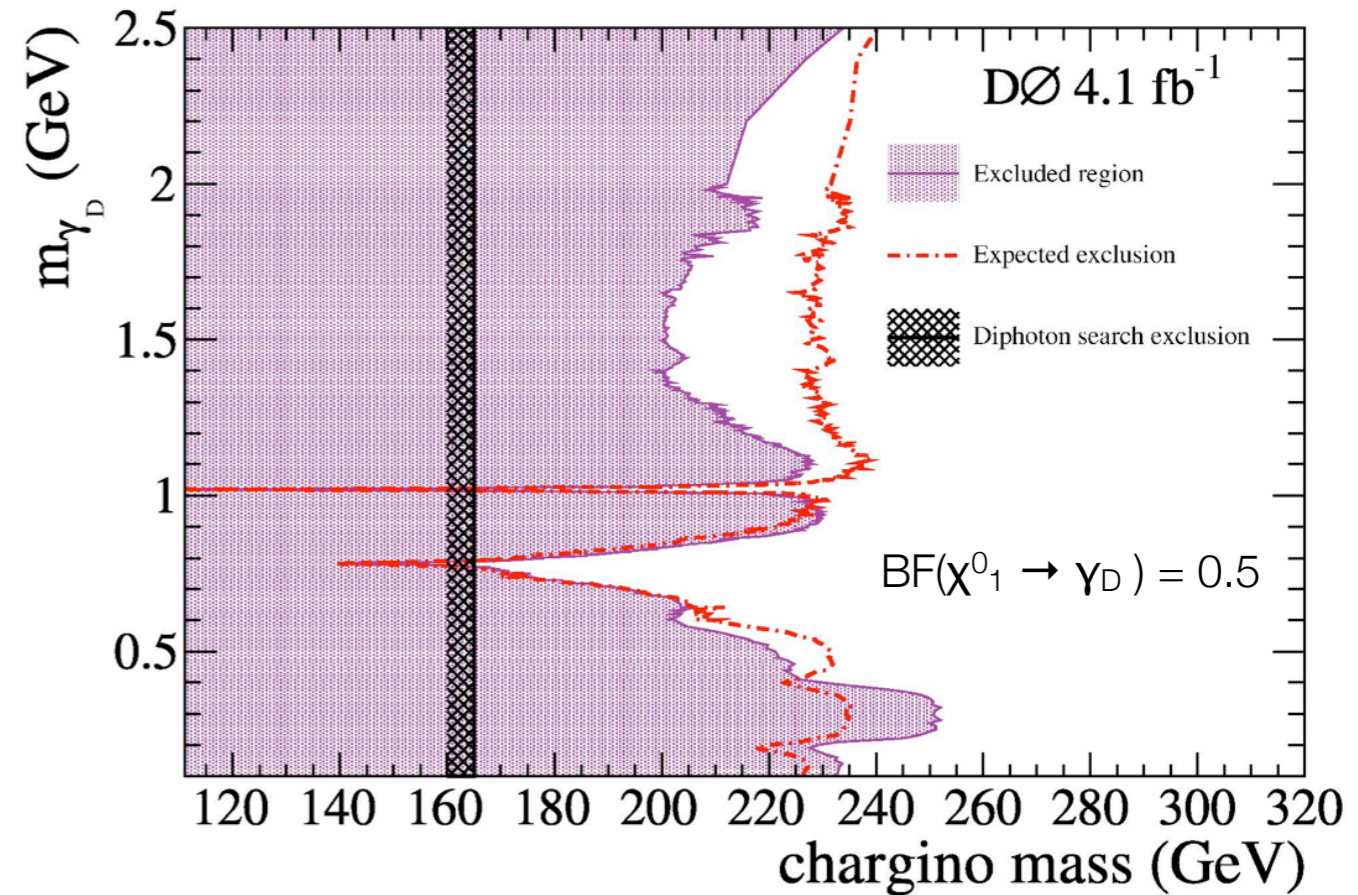
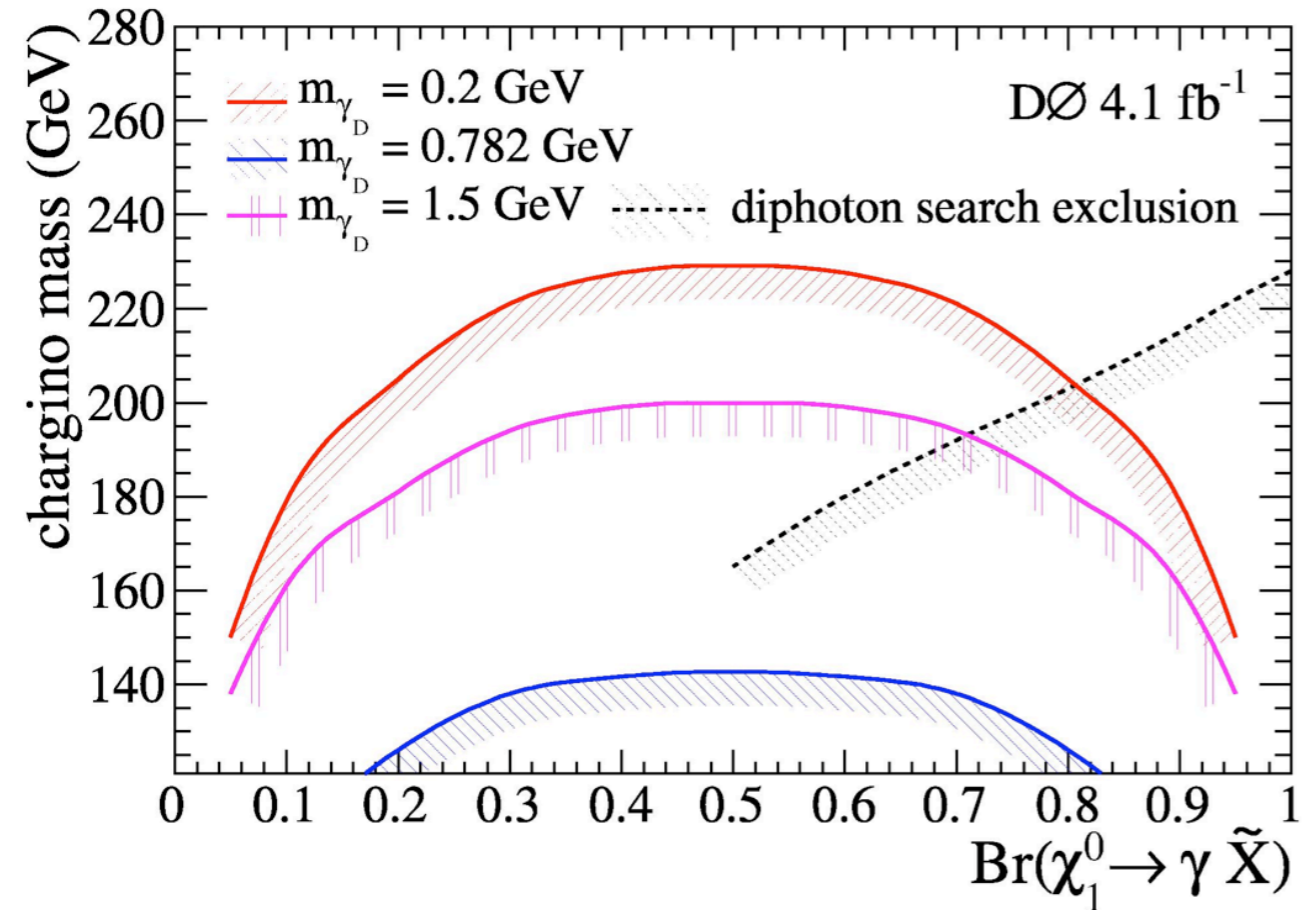
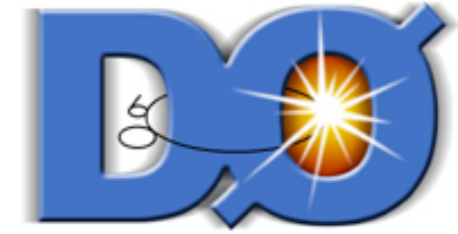
Phys. Rev. Lett. **103**, 081802 (2009)





# Gaugino Production

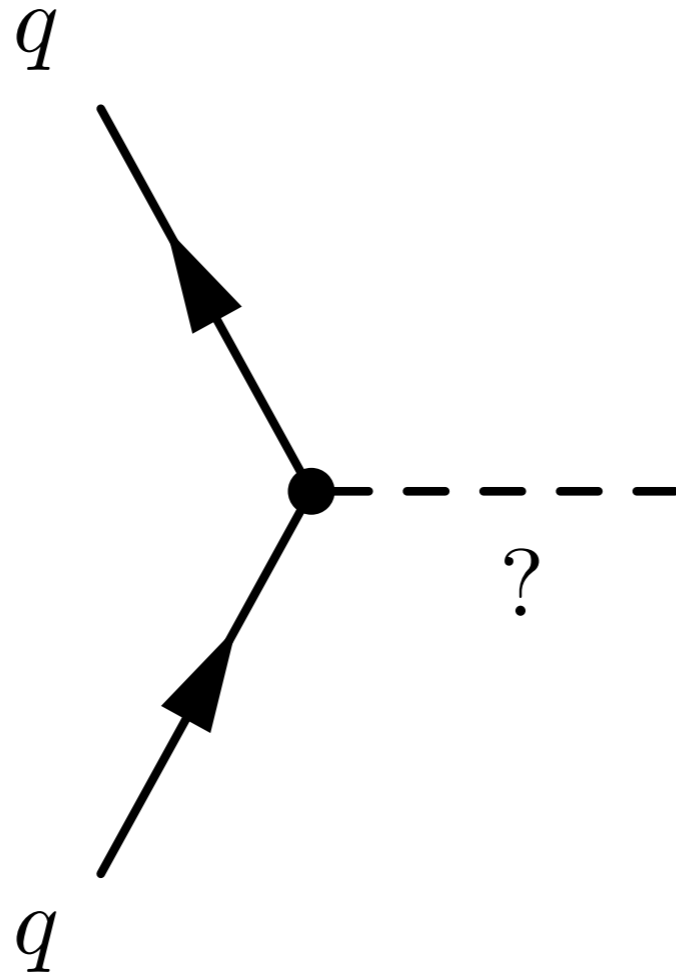
## Dark Photons - SUSY Hidden Valley



- No excess observed - set limits

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# Who ordered that? Other possibilities...

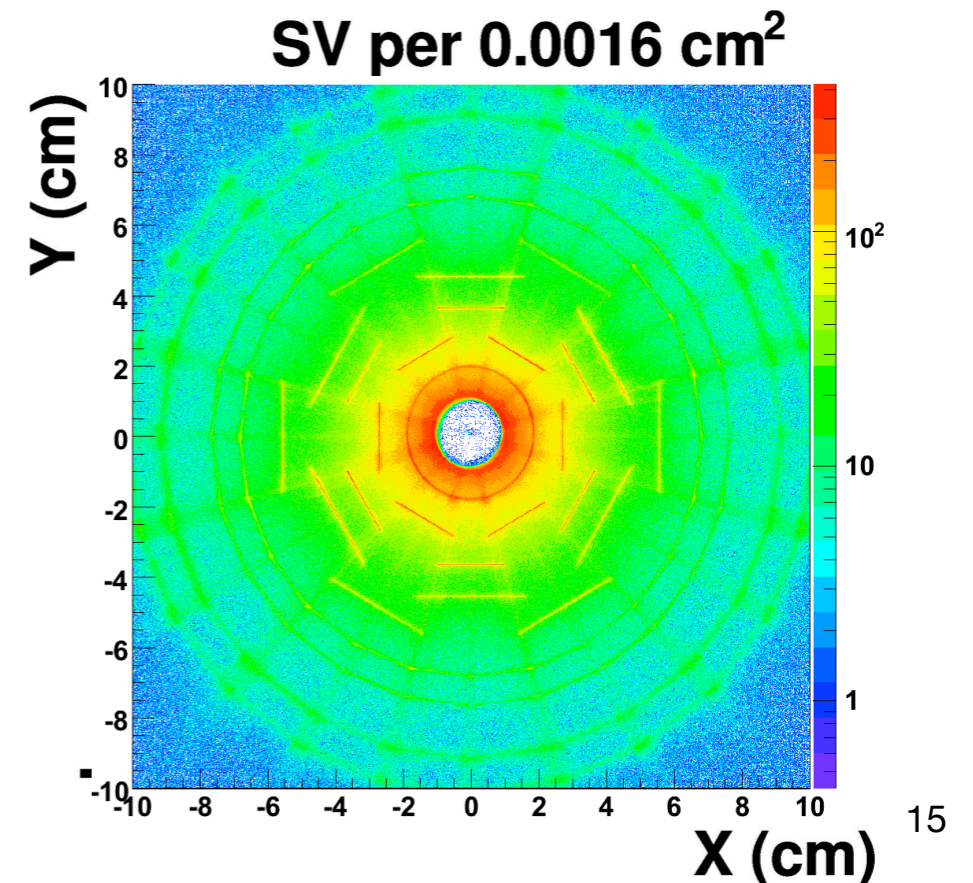
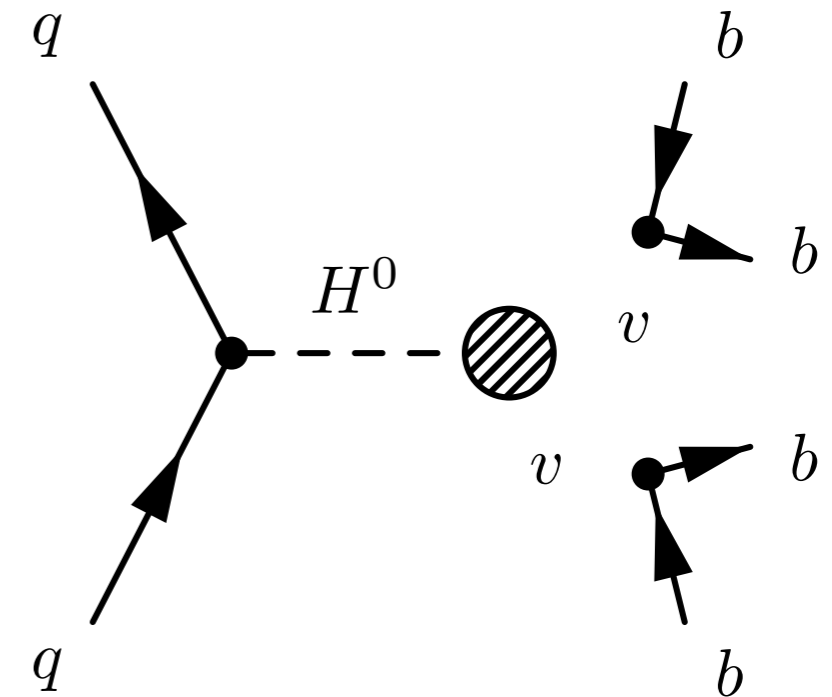






# Hidden Valley: Neutral LLP in $b\bar{b}$

- If Hidden Valley Higgs mixes with SM Higgs, SM Higgs can decay to pairs of hidden sector v-hadrons
- v-hadrons preferentially couple to heavy SM particles (helicity suppression) and could themselves be long-lived
  - decay to  $b\bar{b}$
- Signature: highly-displaced secondary vertices (SV)
- Trigger on muons
- Require at least 2 separated 4-track SVs with  $L_{xy} > 1.6$  cm

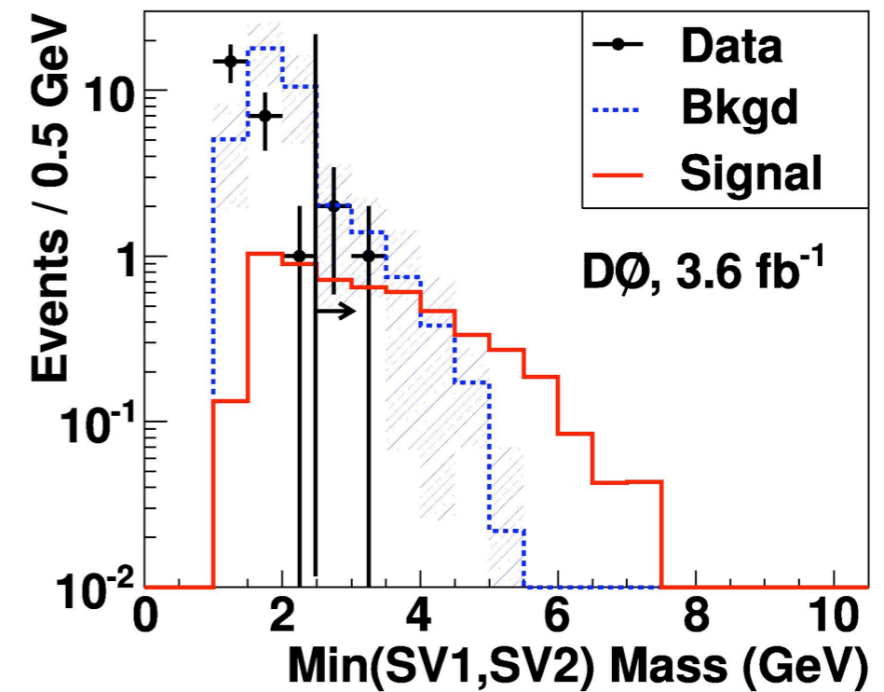
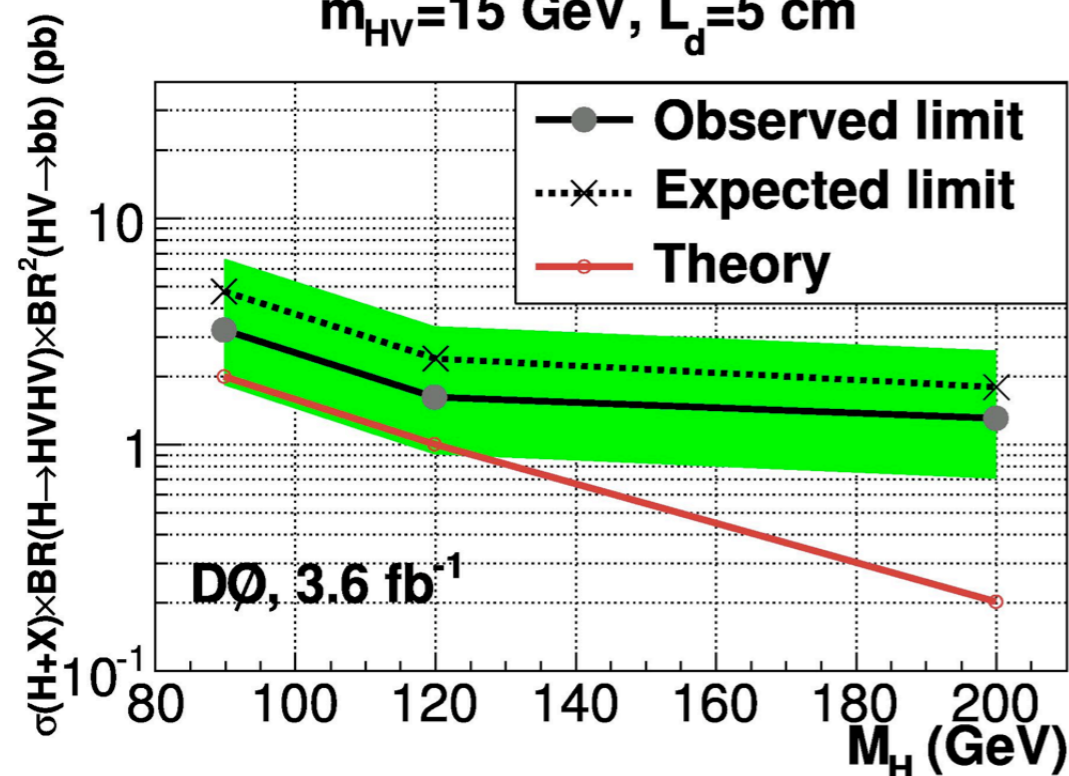




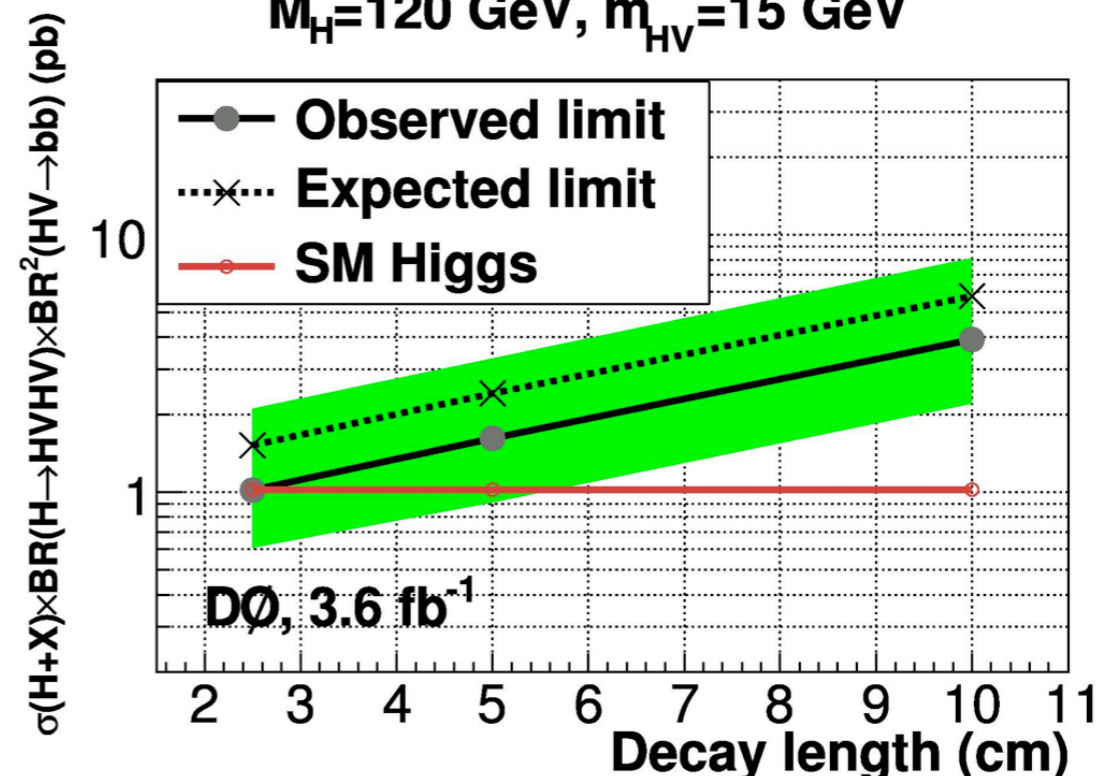
# Hidden Valley: Neutral LLP in $b\bar{b}$

- SV mass, collinearity used to select signal region
  - Set limits on SM Higgs production!\*
- \* assuming Higgs always decays to dark sector v-hadrons, which always decay to  $b\bar{b}$ , using Higgs cross section from Phys. Lett. B 674, 291 (2009)

Phys. Rev. Lett. **103**, 071801 (2009)  
 $m_{HV}=15$  GeV,  $L_d=5$  cm



$M_H=120$  GeV,  $m_{HV}=15$  GeV



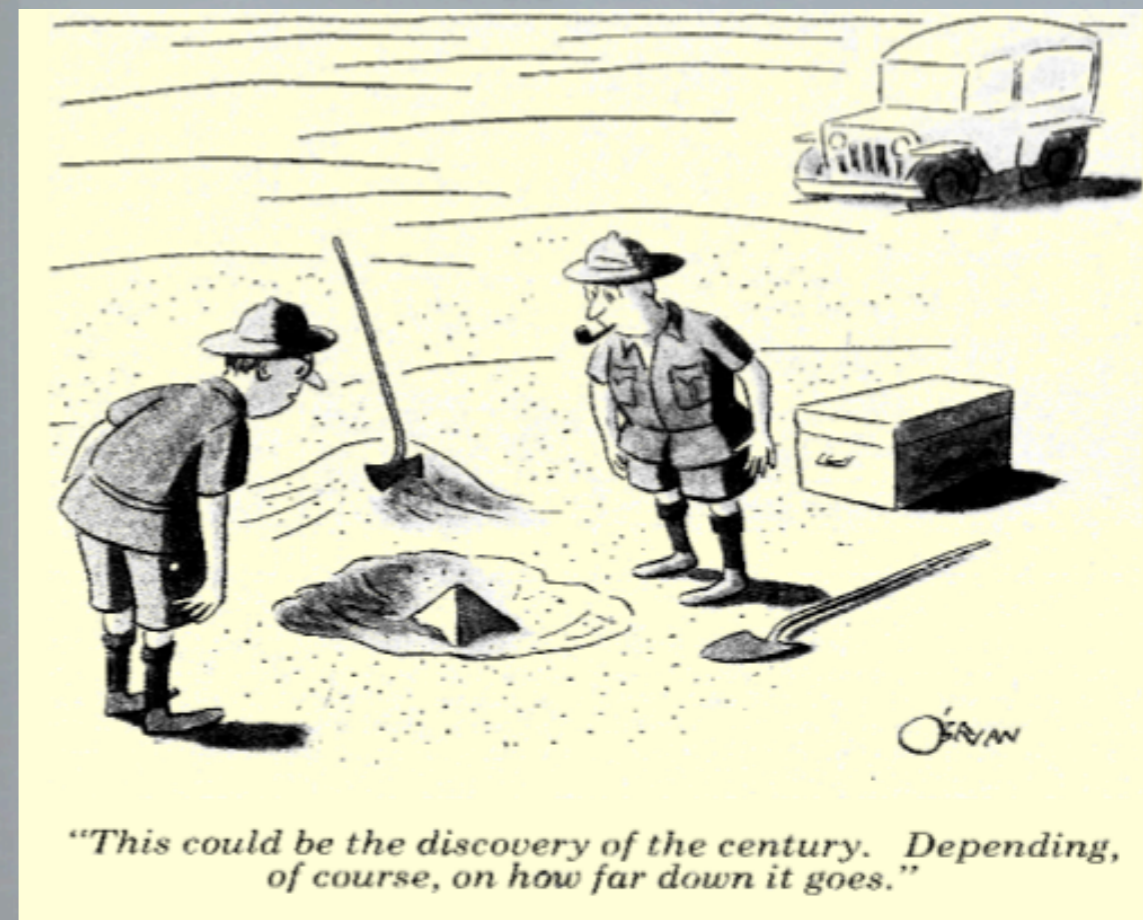


# Outlook

- The excellent Tevatron performance has enabled this rich program of BSM searches.
- D0 and CDF continue to search our ever-growing datasets for new phenomena

The most exciting phrase to hear in science, the one that heralds new discoveries, is not “Eureka!” but “That’s funny ...”

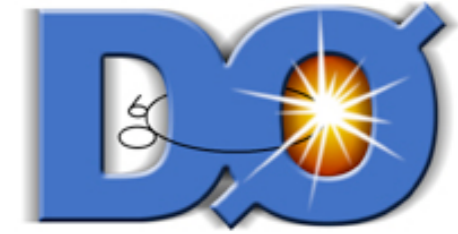
- Isaac Asimov



# Backup

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# Search for Squark production in Jets +Tau+MET



- Stau lightest slepton, lighter than chargino
- Require >2 jets, MET, hadronic tau
- Sensitive to 'tau corridor'

