Supersymmetry Searches at the Tevatron

Todd Adams

Florida State University

for the CDF and DØ Collaborations

Hadron Collider Physics Symposium

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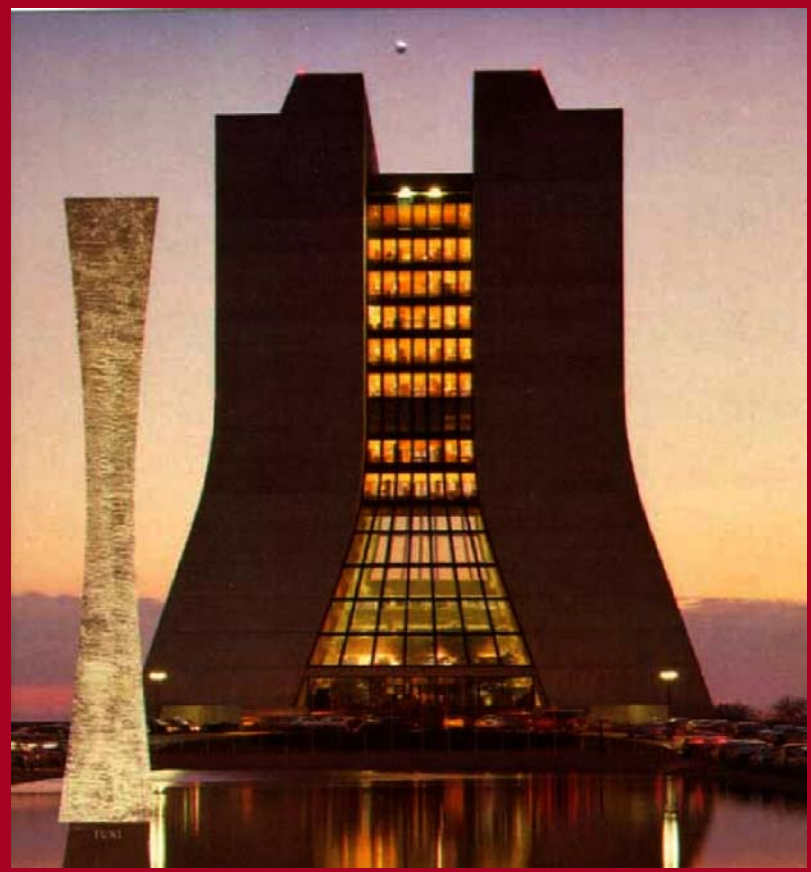
Outline

- SUSY Overview
- "Natural" SUSY
  - squarks and gluinos
    - stop and sbottom
  - charginos and neutralinos
- "Unnatural" SUSY
  - RPV SUSY
  - long-lived SUSY



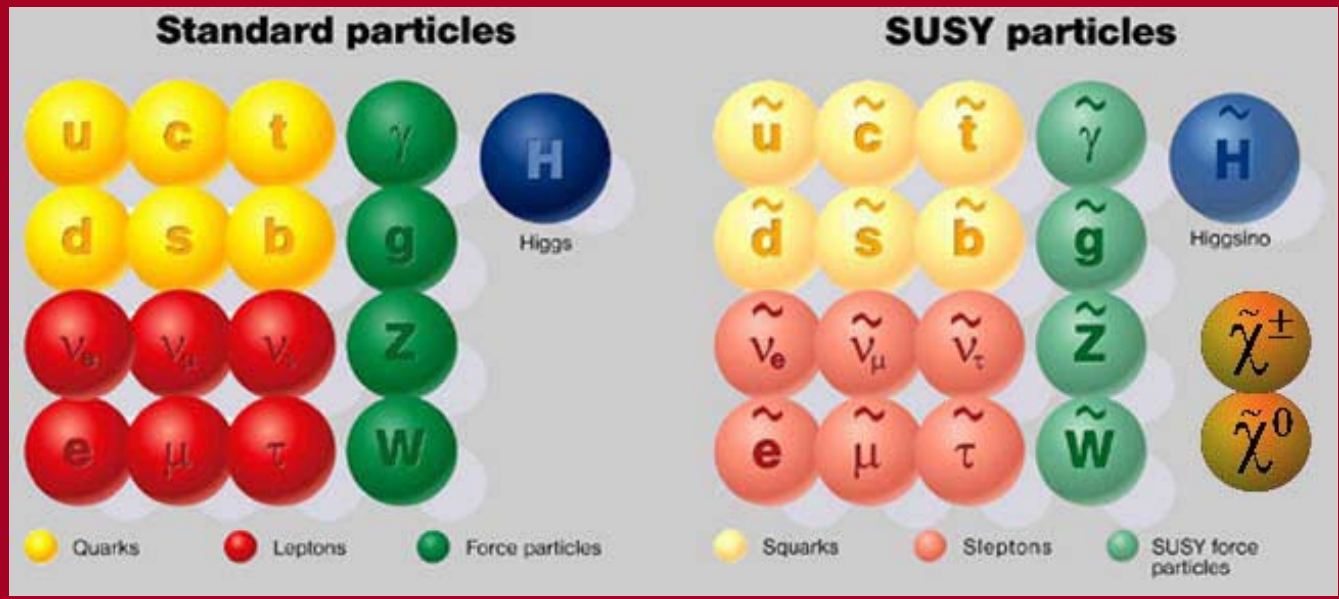
symmetry = beauty

SUSY for Experimenters

Fermions ⇔ Bosons

Broken symmetry ⇒ hidden symmetry

SUSY masses must be large not to be observed so far



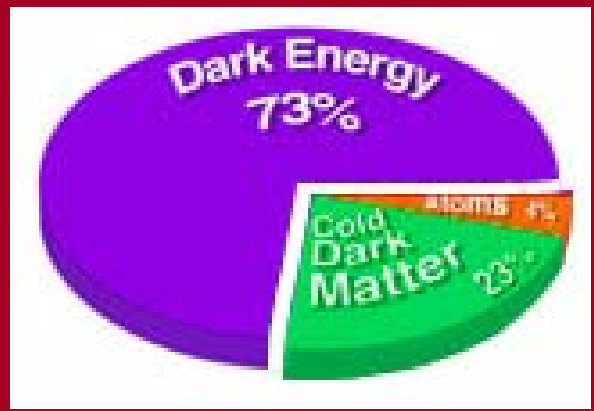
- **Solves many questions about Standard Model**
  - ➢ **Introduces some questions of its own**

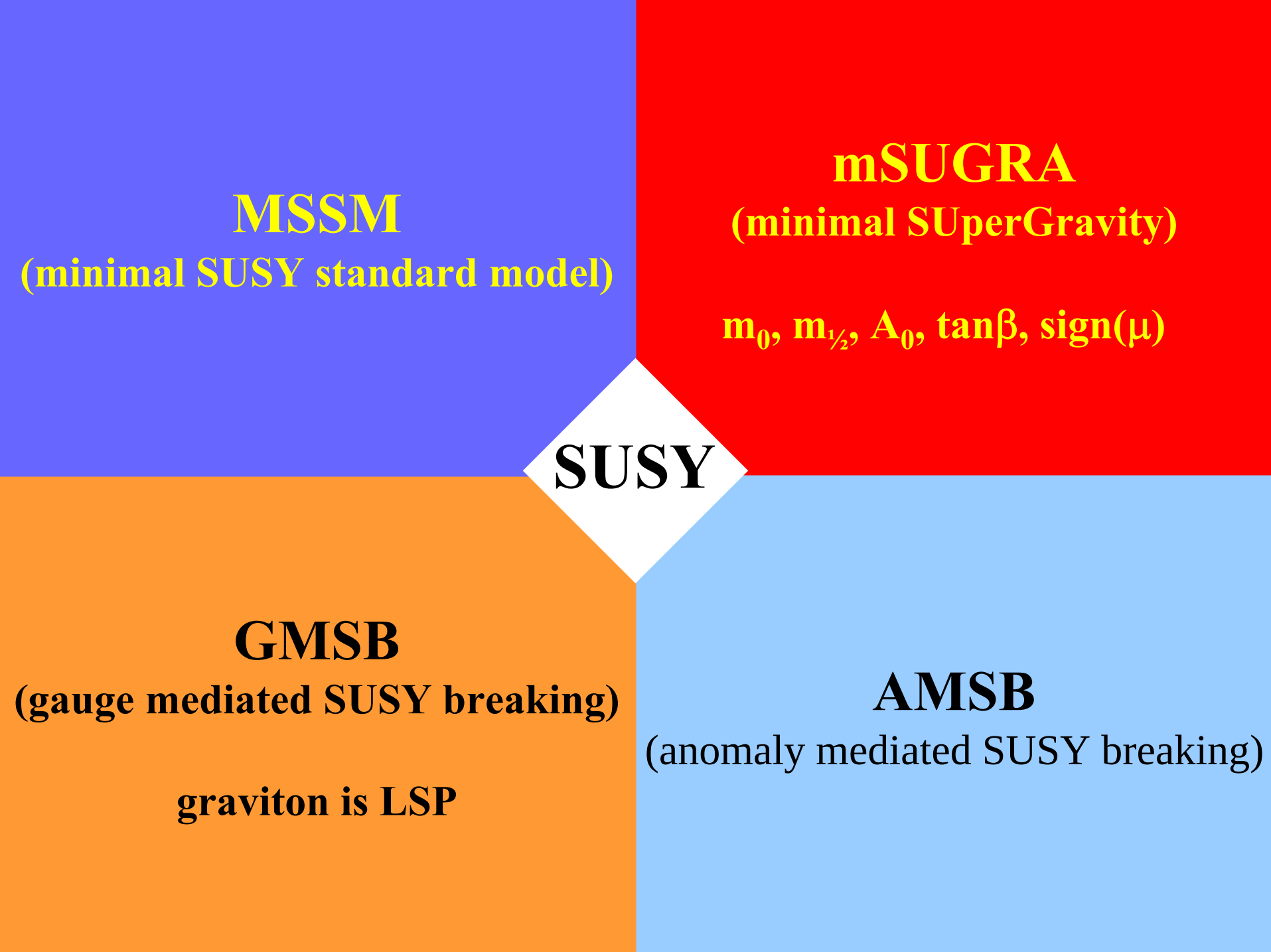
"Natural" SUSY

- **R-parity is conserved**

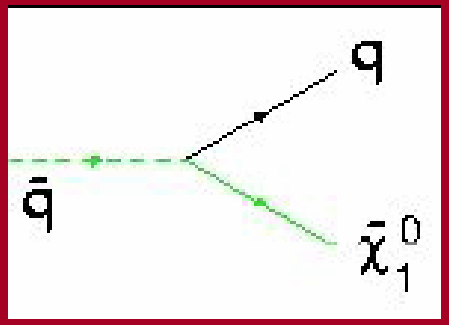
$$R = (-1)^{2j+3B+L}$$

  - **R= +1 normal particles**
  - **R= –1 supersymmetric particles**
- **Lightest supersymmetric particle (LSP) is stable**
  - **all other SUSY particles cascade decay to it and non-SUSY particles**
- **Provides excellent dark matter candidate**
  - **if cosmological constraints are obeyed**

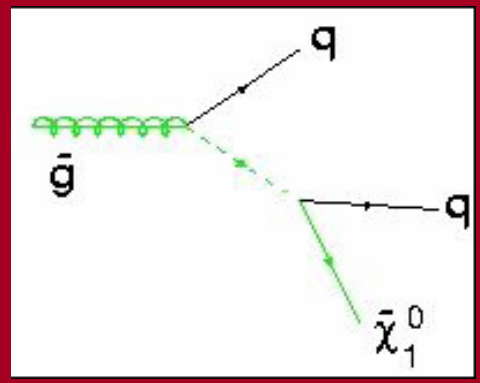



MSSM
(minimal SUSY standard model)
mSUGRA
(minimal SUperGravity)
m_0, $m_{1/2}$, A_0, tanβ, sign(μ)
SUSY
GMSB
(gauge mediated SUSY breaking)
graviton is LSP
AMSB
(anomaly mediated SUSY breaking)

Squarks and Gluinos



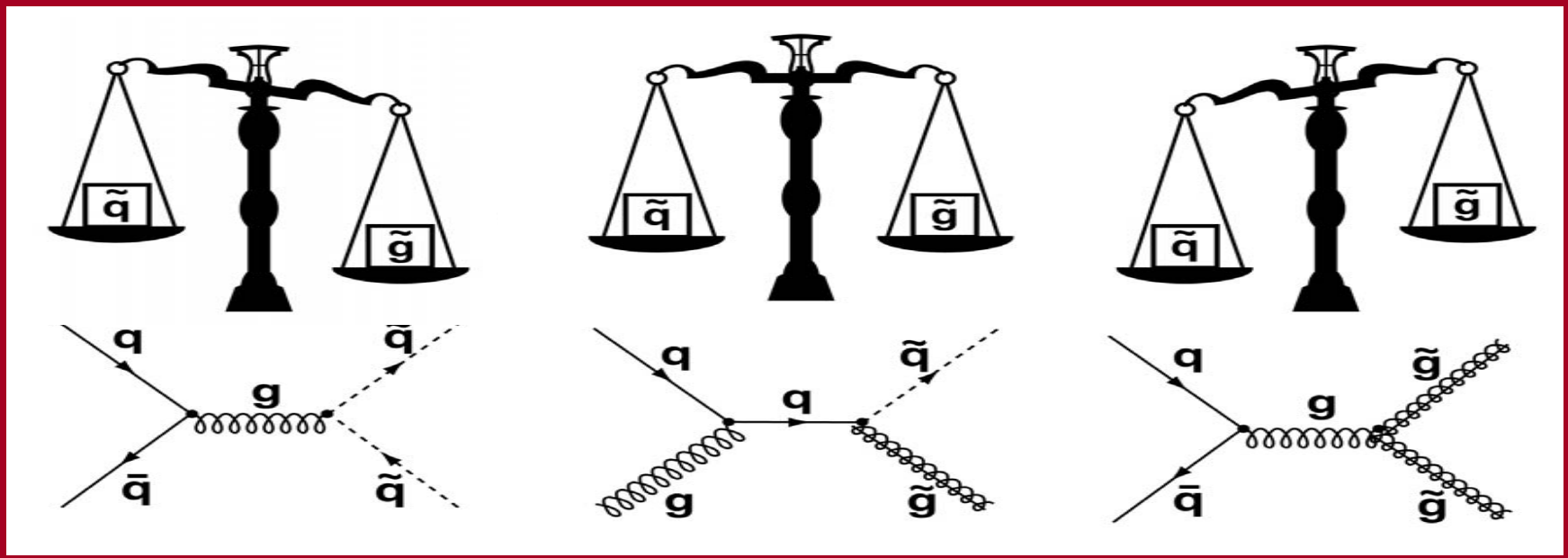
Strong production → large cross section



M(q) « M(g)
2 or more jets

M(q) ≅ M(g)
3 or more jets

M(q) » M(g)
4 or more jets



Squarks and Gluinos

Distinguish from QCD

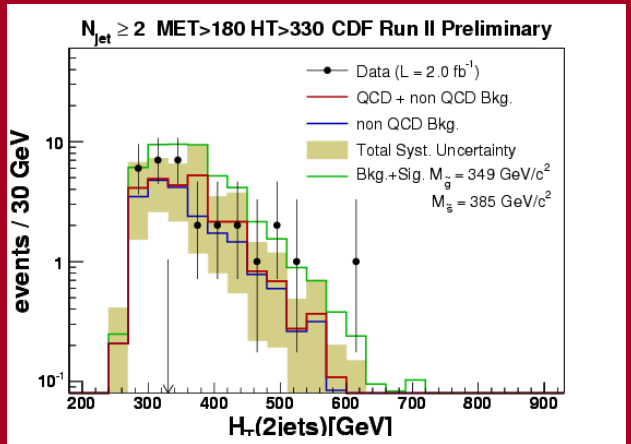
jet p_T

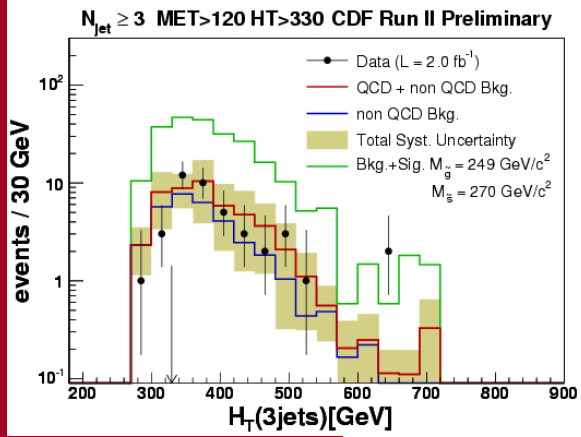
MET

total energy

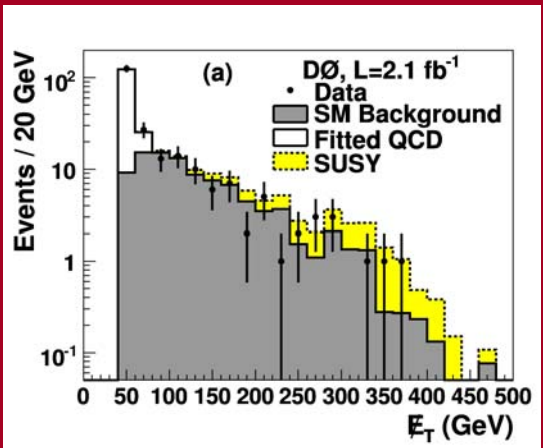
Optimize for multiple SUSY points

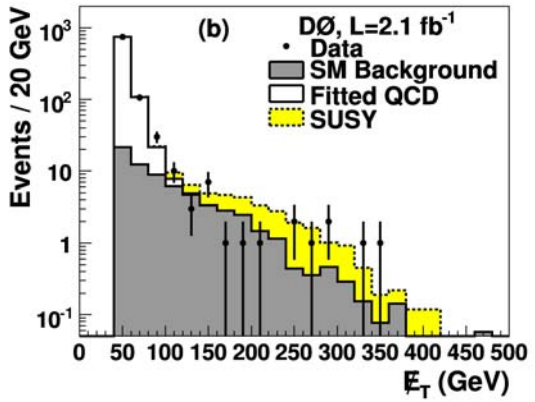
No data excess observed



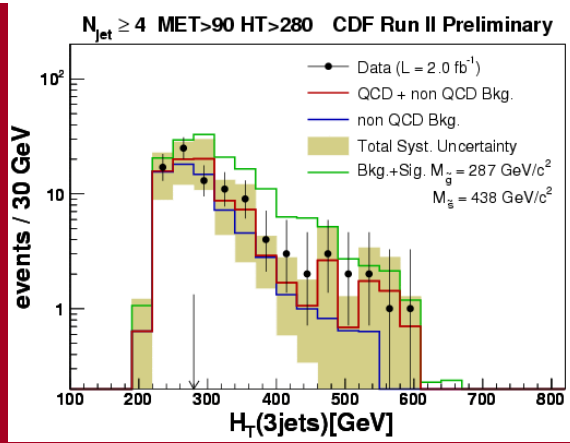


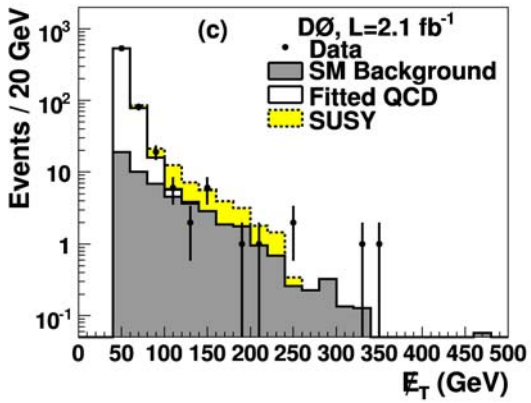
2.0 fb^{-1}





2.1 fb^{-1}

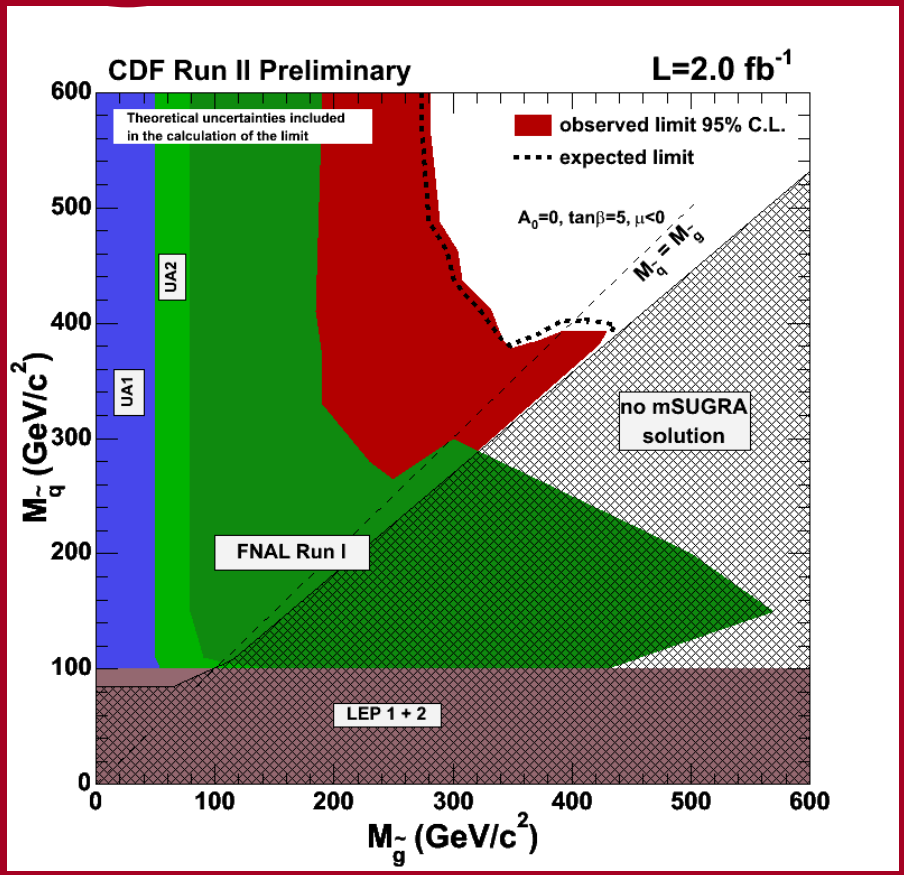


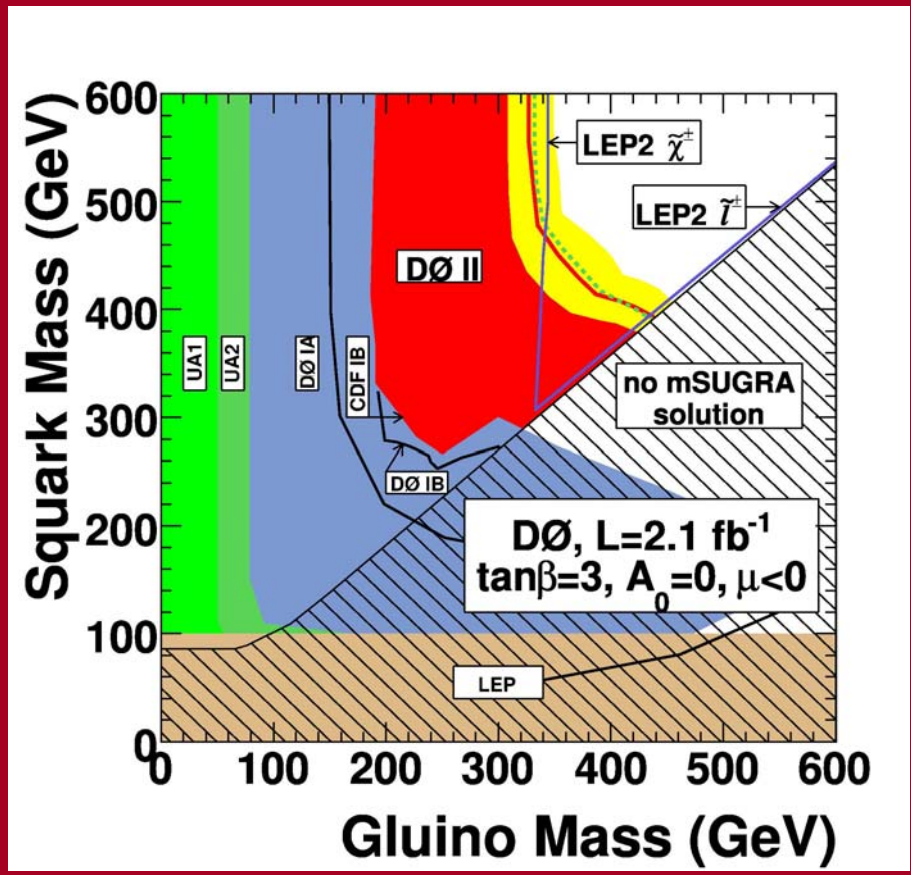


Mass Limits

2.0 fb^{-1}

2.1 fb^{-1}





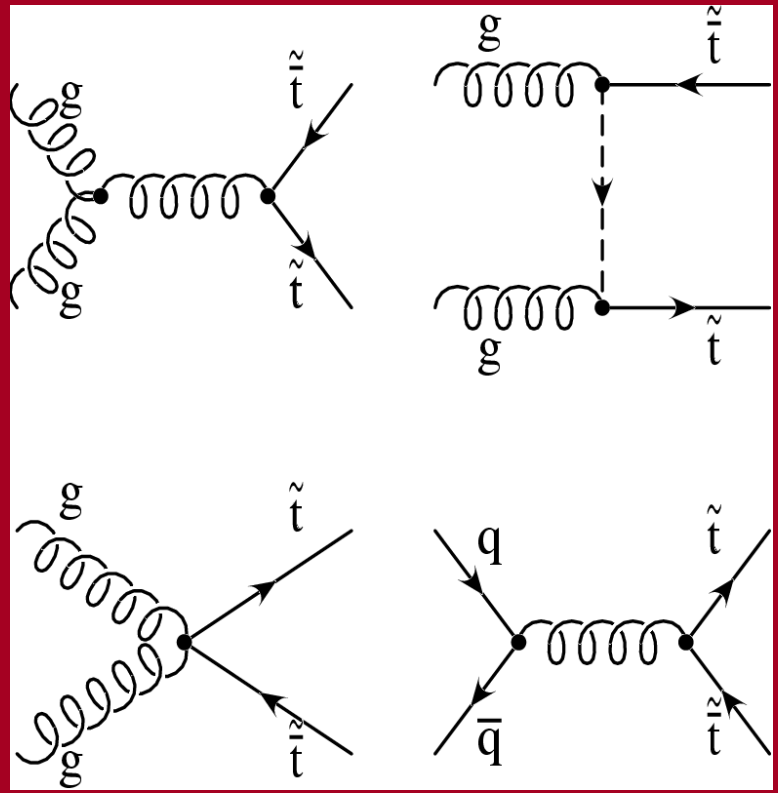
M > 392 GeV [M(q̃)=M(g̃)]
M(g̃) > 280 GeV

M(q̃) > 392 GeV
M(g̃) > 327 GeV
PLB 660, 449 (2008)

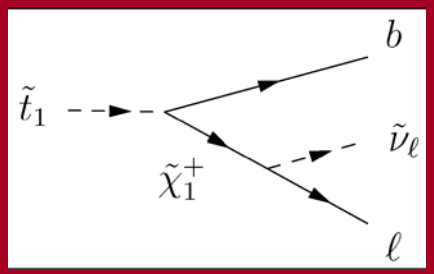
…and sbottom

Stop Searches

- Pair production through strong processes
- Numerous search channels
- Depend on dominant decay mode



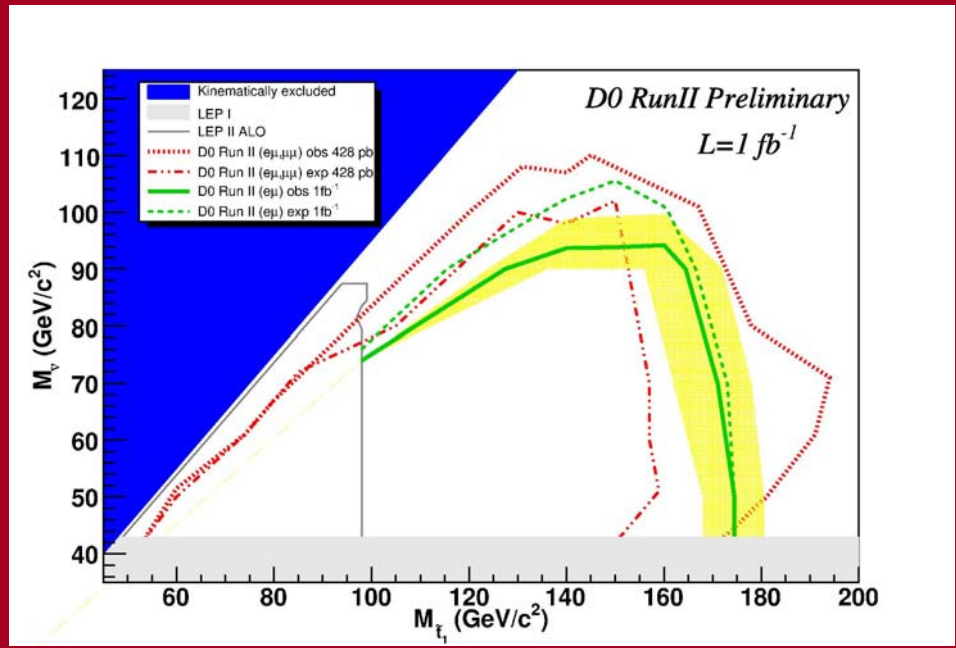
dileptons	heavy flavor+MET	stable, charged particles
ee, eμ, μμ	bb+MET	
+2b+MET	cc+MET	



Stop in eμ+2b+MET

1 fb^{-1}

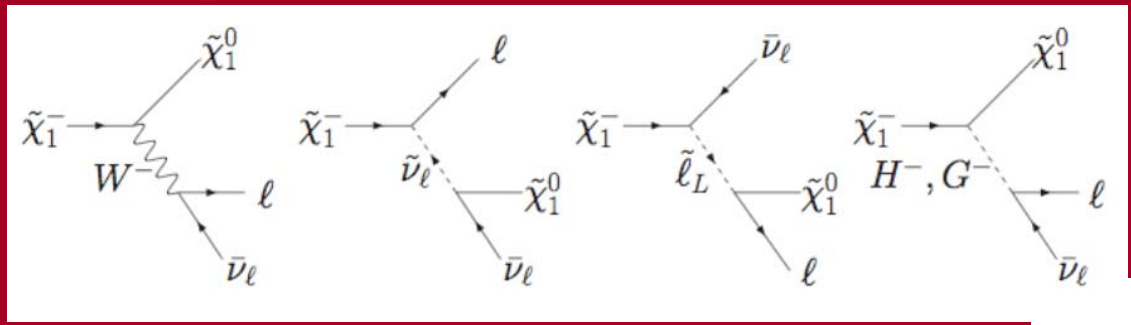
- decay mode stop → bℓν̃
- sneutrino is LSP
- use eμ channel
  - highest dilepton branching fraction
  - low backgrounds



Σp_T (jets) (GeV)	$p_T(\mu) + p_T(e) + MET$ (GeV)					
	0-70		70-120		>120	
	Data	Bkgd	Data	Bkgd	Data	Bkgd
0-15	1	0.3±0.3	15	13±2	12	19±2
15-60	1	0±0	6	4.2±0.9	11	8±1
60-120	0	0±0	1	1.6±0.6	8	9±1
>120	0	0.0±0.0	0	0.9±0.4	6	7±1

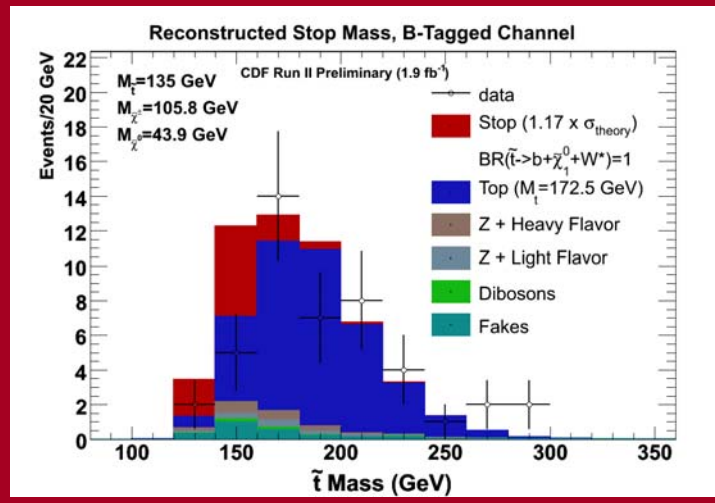
1.9 fb^{-1} Stop → b$\ell\tilde{\chi}_1^0$

- stop mass = 135-155 GeV
  - several chargino/neutralino mass points

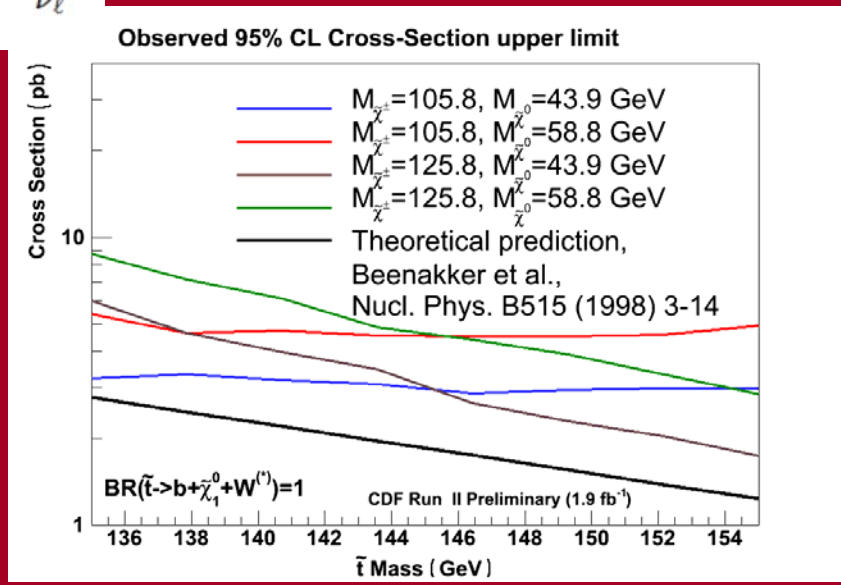


	Background	Data
ee	10.62±1.49	10
μμ	9.46±1.27	11
eμ	22.46±2.88	24
l l	42.53±5.56	45

no evidence of stop signal



neutralino is LSP



Stop and Sbottom in cc(bb)+MET

0.3 fb^{-1}

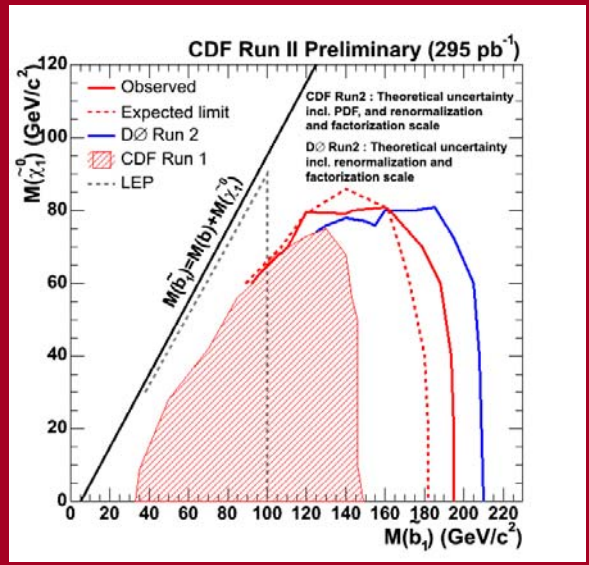
- **Pair production of stop or sbottom**

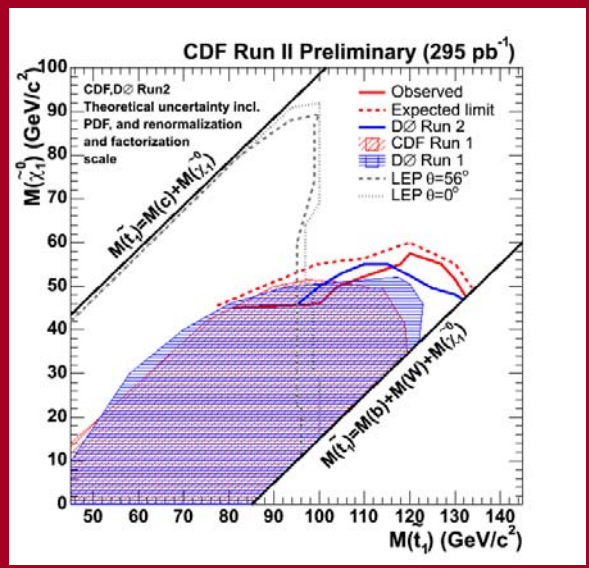
  stop → c + $\tilde{\chi}_1^0$ sbottom → b + $\tilde{\chi}_1^0$

- **Signature**
  - two energetic jets + MET
  - one heavy flavor tagged jet
- **Optimize selection for each channel in three mass regions**

stop	<100	100-120	>120
bkgd	137±6.2±14.6	94.9±5.0±9.9	42.7±2.6±4.6
data	151	108	43
sbottom	<140	140-180	>180
bkgd	55.0±4.2±5.9	17.8±1.7±1.6	4.7±2.1±0.5
data	60	18	3

PRD 76, 072010 (2007)

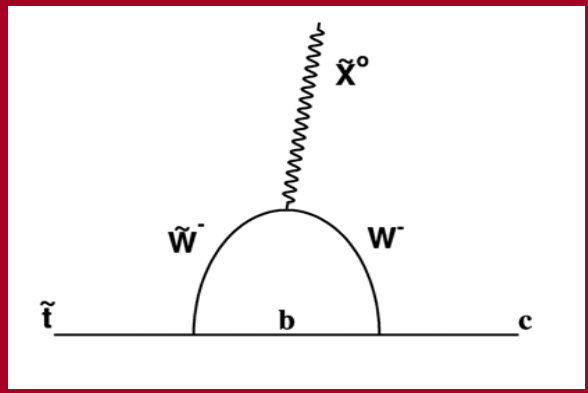




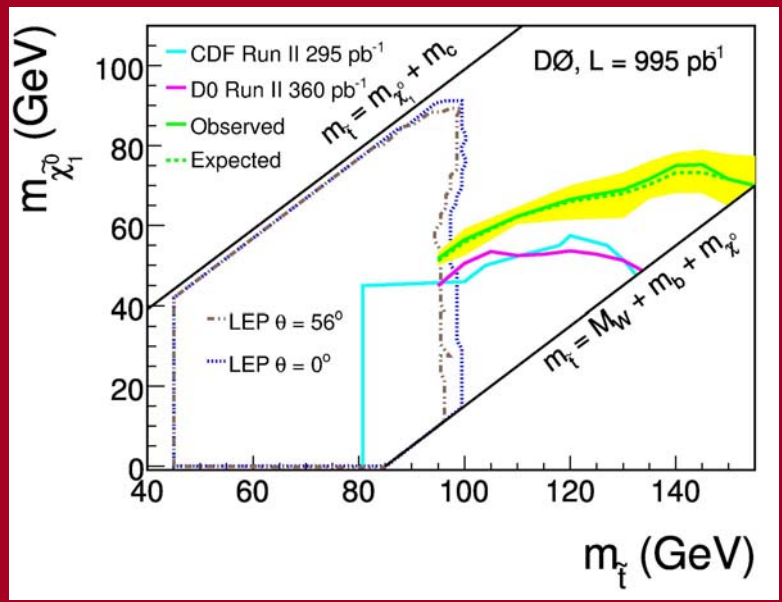
Stop in cc+MET

1 fb^{-1}

- decay mode stop→c+$\tilde{\chi}_1^0$
  - $m_{\tilde{t}} < m_b + m_{\tilde{\chi}_1^+}$
  - $m_{\tilde{t}} < m_W + m_b + m_{\tilde{\chi}_1^0}$
- search for acoplanar charm jets



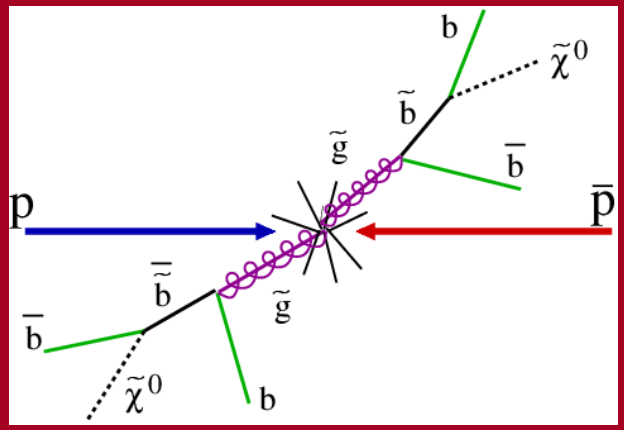
stop mass	background	data
95-130 GeV	$85.3 \pm 1.8\ ^{+12.8}_{-13.0}$	83
135-145 GeV	$59.0 \pm 1.6\ ^{+8.5}_{-8.8}$	57
150-160 GeV	$66.6 \pm 1.1\ ^{+9.6}_{-10.0}$	66



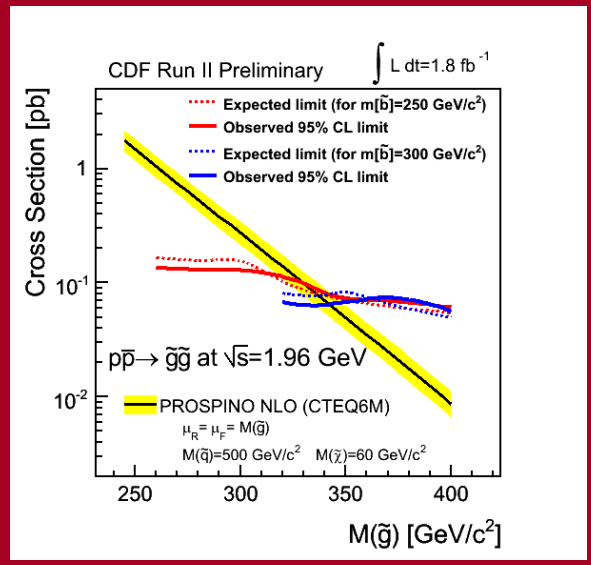
arXiv:0803.2263

Sbottom in Gluino Production

1.8 fb^{-1}

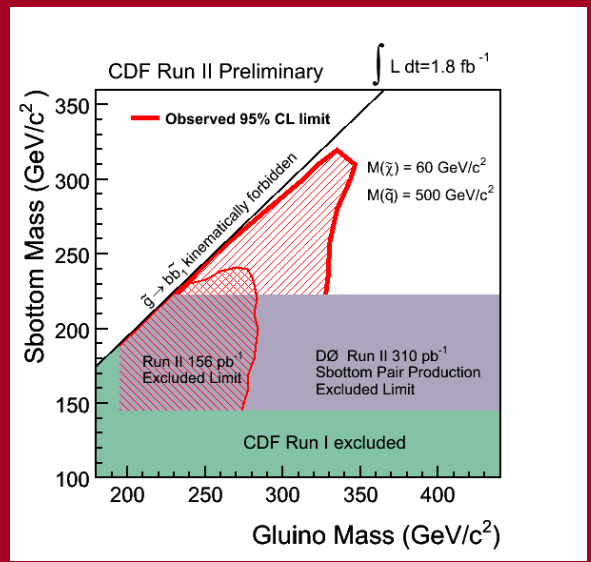


- Pair production of gluinos
- Gluino decays to sbottom+bottom
- Sbottom decays to bottom+neutralino



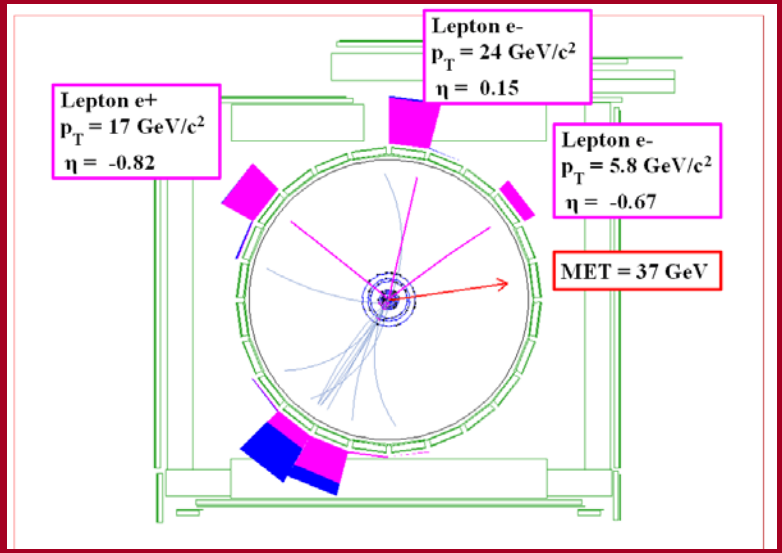
- Search for events with multiple jets (at least one b-tagged) and MET
- Two regions of $\Delta m = M(\tilde{g}) - M(\tilde{b})$

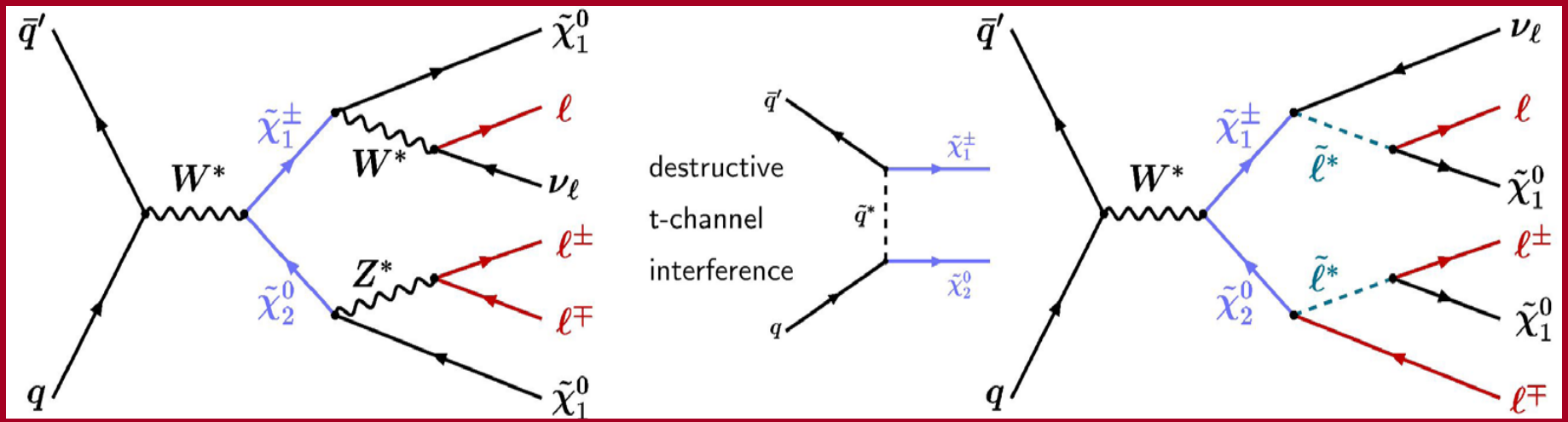
	Large Δm	Small Δm
Background	22.7 ± 4.6	22.0 ± 3.6
Data	25	19



Associated Production of Charginos and Neutralinos

- **Excellent SUSY signature ("golden channel")**
  - ➢ **three leptons in final state**
    - **trileptons**
  - ➢ **very small backgrounds**

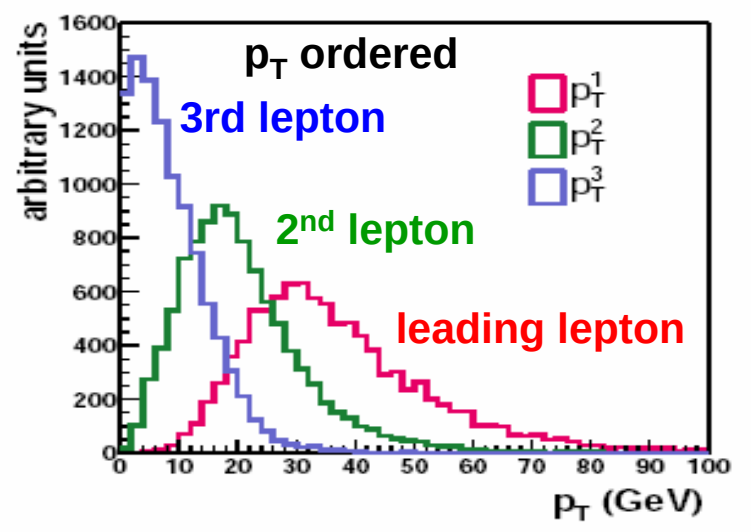




2.0 fb^{-1}

Trilepton Analyses

0.9-1.7 fb^{-1}



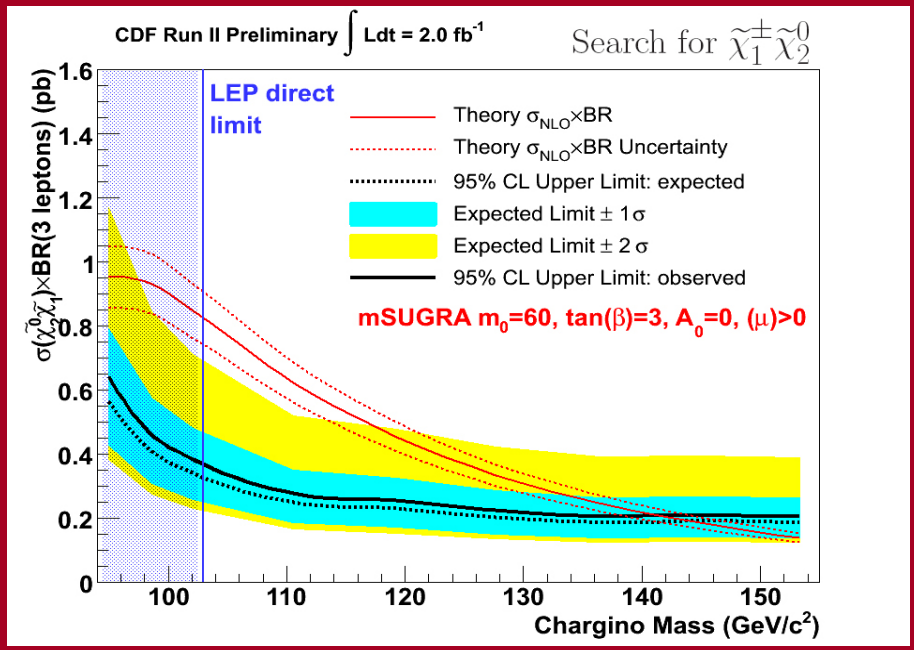
- Three search techniques
  - 3 identified leptons (l=e or μ)
  - 2 leptons + isolated track
  - two same sign leptons
- Allows for some additional acceptance
  - taus and low pT leptons

CDF	Background	Data
3 tight	0.49±0.04±0.08	1
2 tight, 1 loose	0.25±0.03±0.03	0
1 tight, 2 loose	0.14±0.02±0.02	0
Total trilepton	0.88±0.05±0.13	1
2 tight, 1 track	3.22±0.48±0.53	4
1 tight, 1 loose, 1 trk	2.28±0.47±0.42	2
Total dilepton+track	5.5±0.7±0.9	6

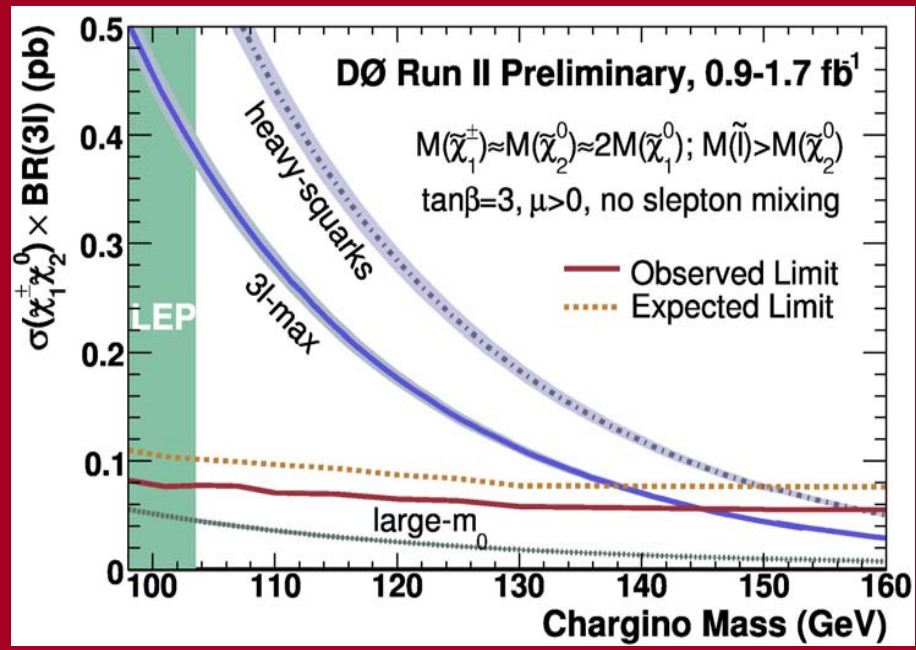
DØ	Background	Data
ee*l*	1.8±0.8	0
μμ*l*	0.3+1.3-0.3	2
eμ*l*	0.9±0.4	0
$\mu^+\mu^+$	1.1±0.4	1
l = lepton or track		

Chargino/Neutralino Limits

2.0 fb^{-1}



0.9-1.7 fb^{-1}



$M(\tilde{\chi}_1^{\pm}) > 140$ GeV

mSUGRA

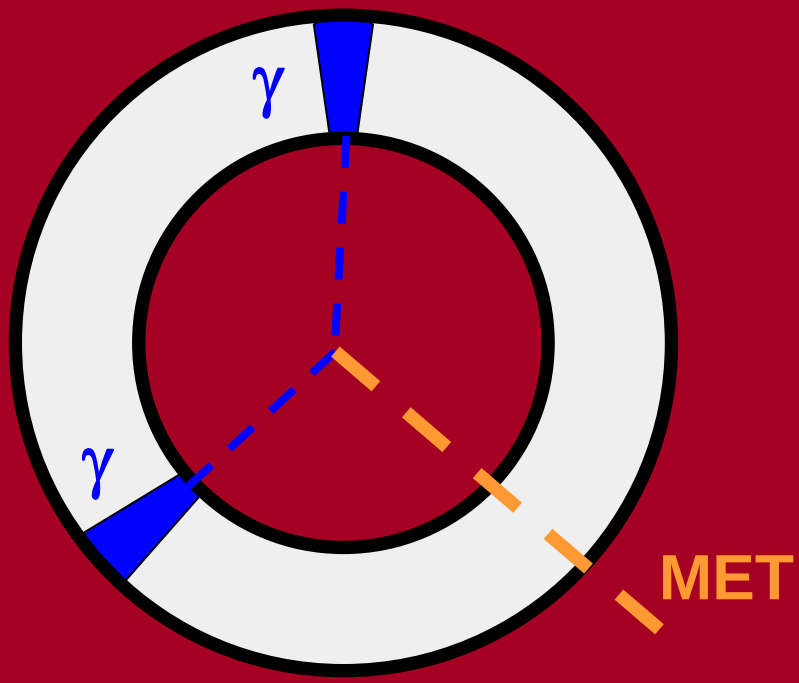
$M(\tilde{\chi}_1^{\pm}) > 145$ GeV

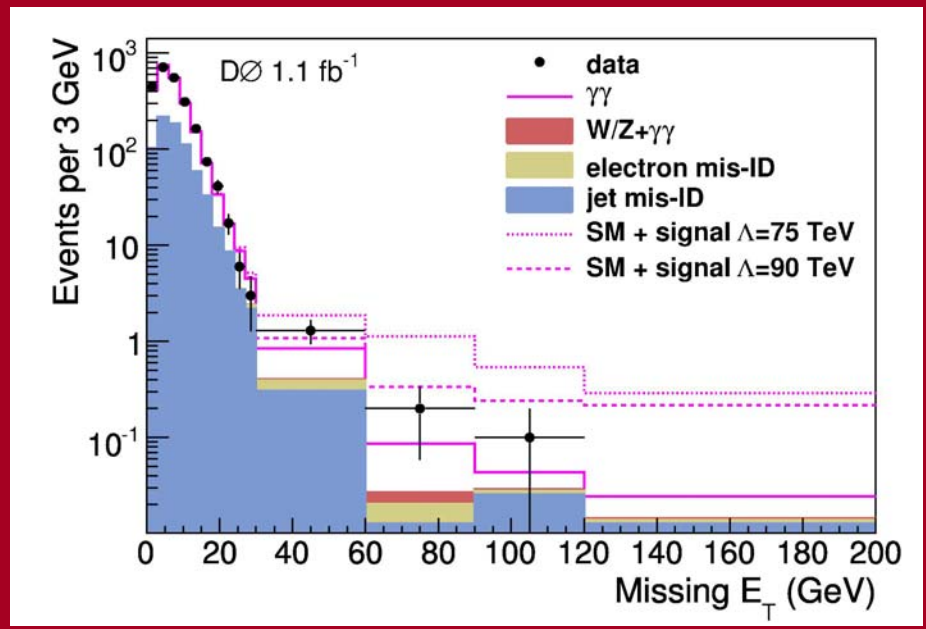
mSUGRA, no slepton mixing

GMSB in Di-photons

1.1 fb^{-1}

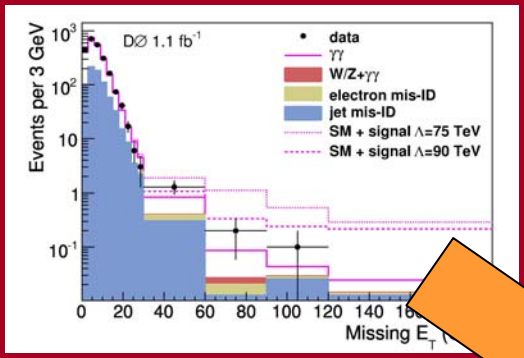
- LSP: gravitino NLSP: neutralino
- $p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 + X \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 + Y \rightarrow \gamma\tilde{G}\gamma\tilde{G} + Y$
- signature: two photons and MET





GMSB in Di-photons

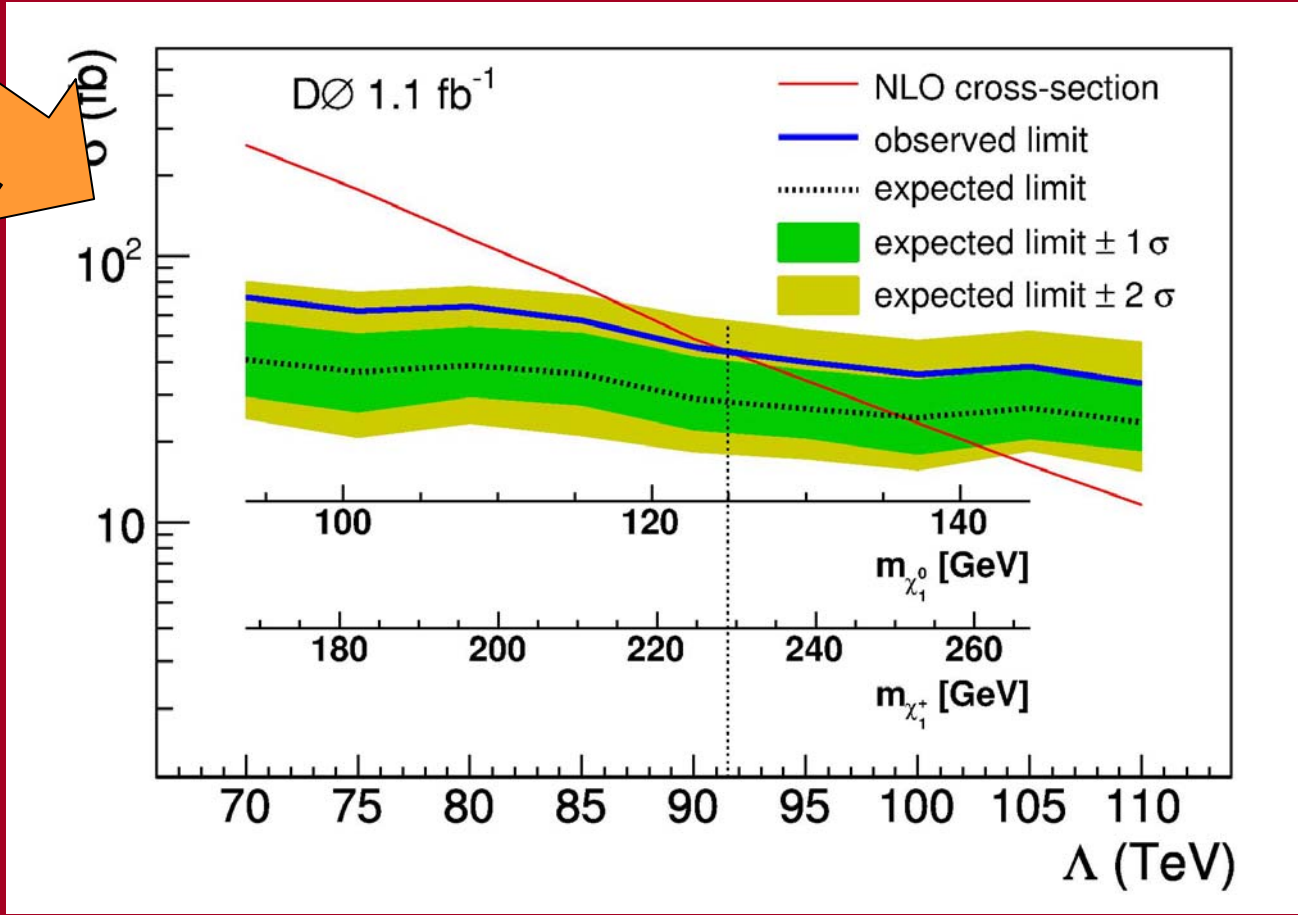
1.1 fb^{-1}



M($\tilde{\chi}_1^0$) > 125 GeV
M($\tilde{\chi}_1^\pm$) > 229 GeV
1.1 fb^{-1}

Previous CDF and DØ combination:
M($\tilde{\chi}_1^0$) > 114 GeV
M($\tilde{\chi}_1^\pm$) > 209 GeV

CDF has analyzed this channel in 2 fb^{-1} and is working on a GMSB interpretation



PLB 659, 856 (2008)

“Unnatural” SUSY

No dark matter candidate
or
addition to basic SUSY

"Unnatural" SUSY

- **RPV SUSY**

$$W = W_{MSSM} + W_{RPV}$$

$$W_{RPV} = \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

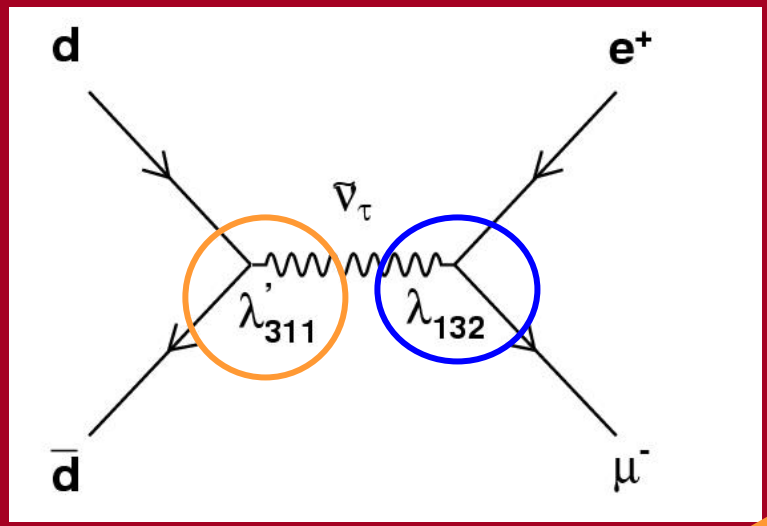
ΔL=1: Lepton number violation
Gauge symmetry: $\lambda_{ijk} = -\lambda_{ijk}$
→9 λ couplings

ΔL=1: Lepton number violation
27 λ′ couplings

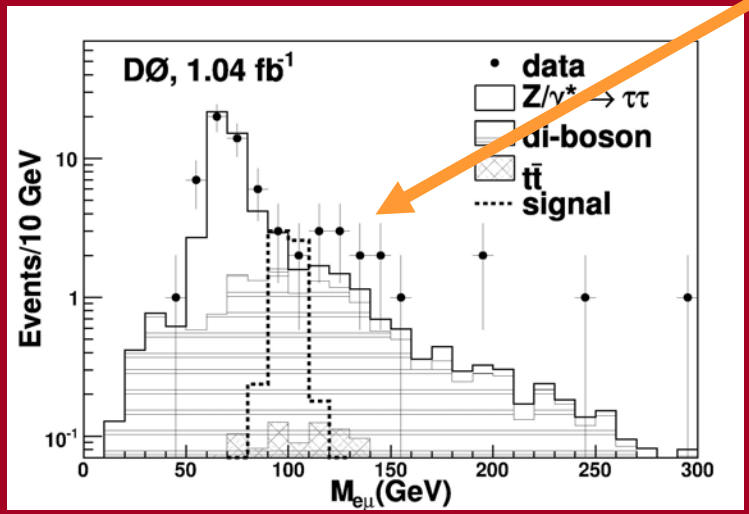
  - **can create small BR or long lifetimes**
- **Long-lived particles**
  - **suppressed decays (couplings or mass splittings)**
- **Different signature → may miss → dedicated searches**

RPV Sneutrinos

1 fb^{-1}



- single sneutrino production
- RPV for production and decay
  - different couplings λ'_{311} and λ_{132}
- search for eμ resonance

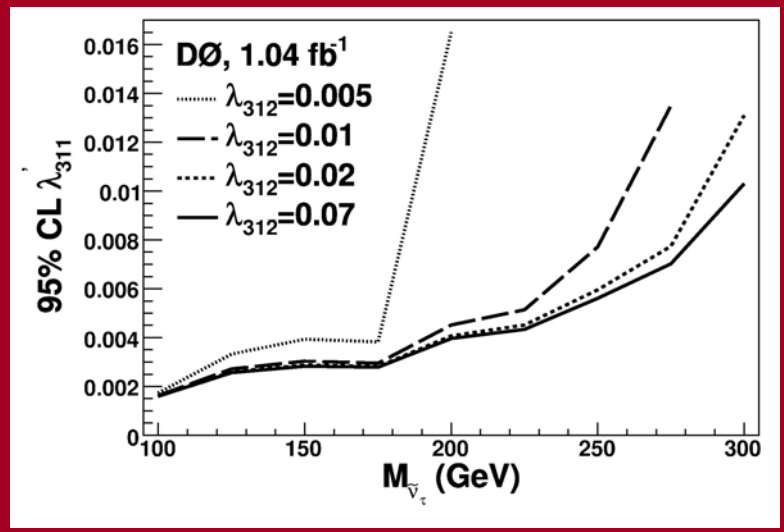


Data

68

Bkgd

59.2 ± 5.3



arXiv:0711.3207

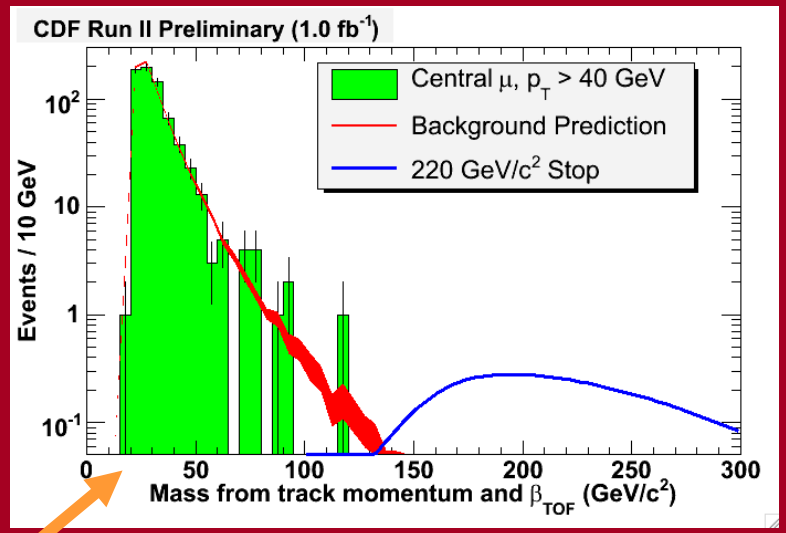
1 fb^{-1}

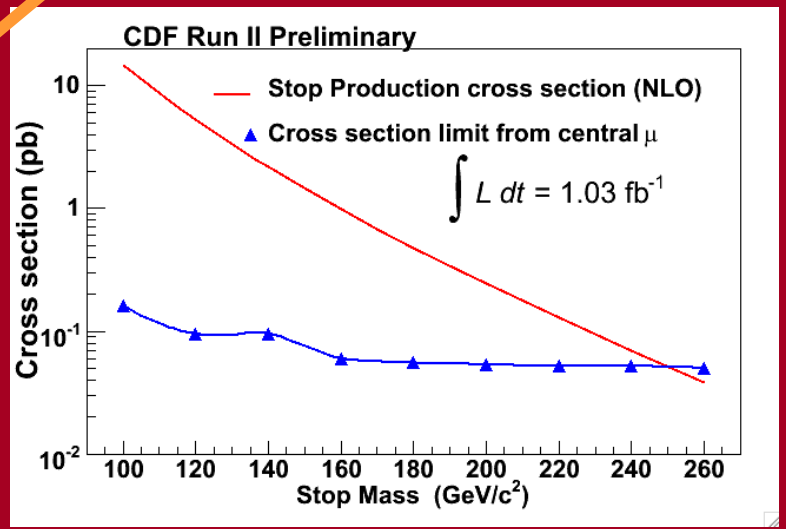
Long-lived Stop

- SUSY
  - long-lived stop – escapes detector before decay
- CHAMPS – charged, massive, stable particles
- Signature: slow-moving, muon-like particle
  - measure mass

time of flight → velocity + momentum → mass

- No standard model background
  - use data to estimate background in signal region
- m(stop) > 250 GeV

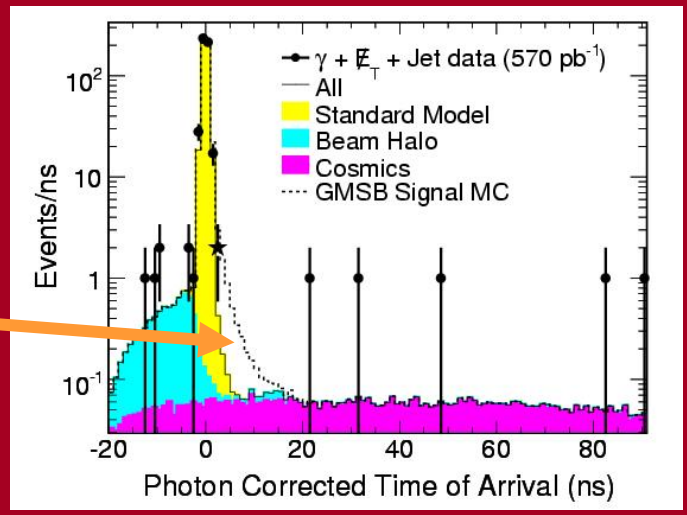


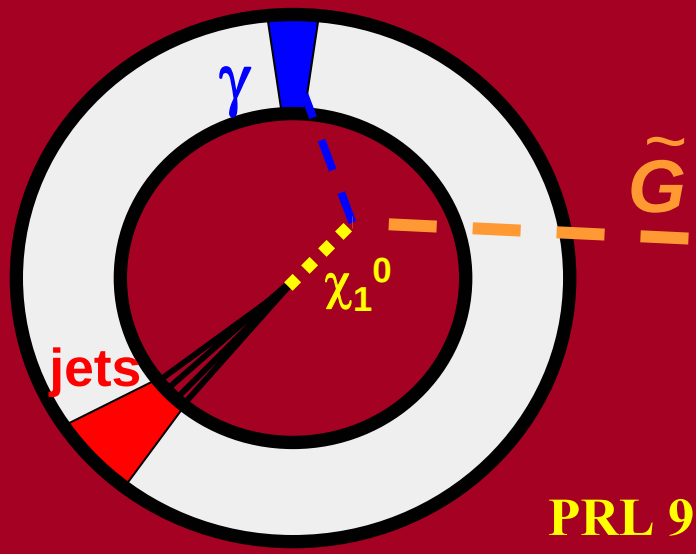


Long-lived Neutralinos

0.6 fb^{-1}

- **GMSB SUSY**
  - $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ (same as diphoton)
  - $\tilde{\chi}_1^0$ is long-lived
  - if heavy → slow moving
- **Search for γ+jets+MET events**
- **Measure arrival time of photon**
  - optimize for τ = 5 ns



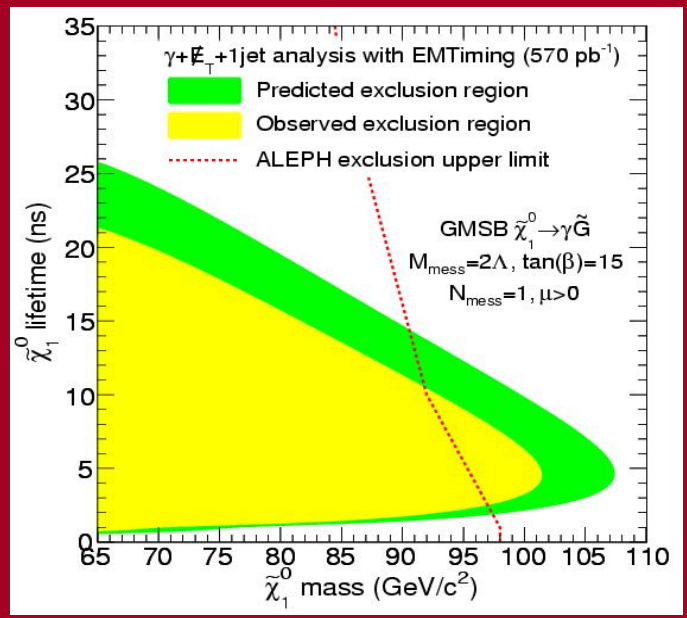


Data

2

Bkgnd

1.25 ± 0.66



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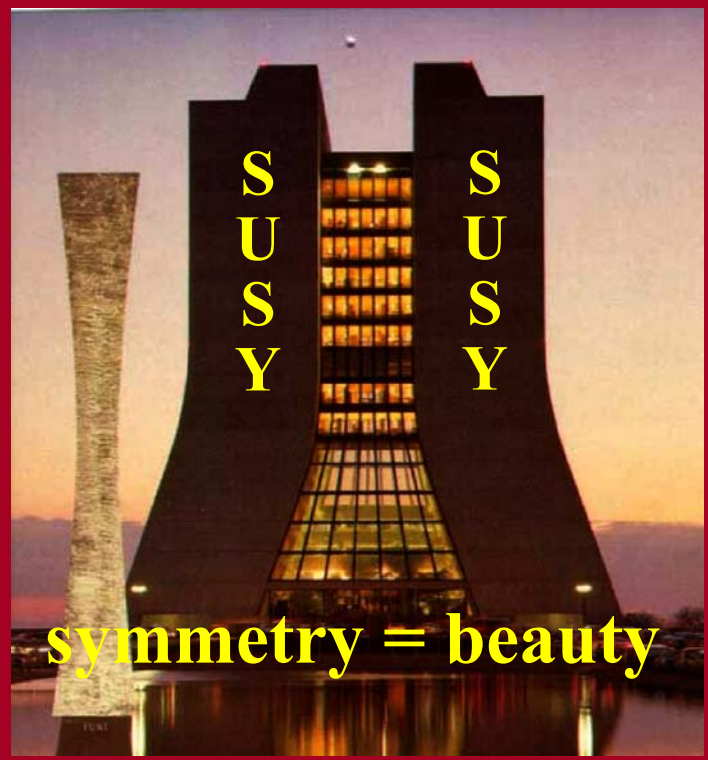
Other SUSY Searches

- Numerous BSM Higgs searches
- B_s and B_d into $\mu\mu$
- Squarks in jets+tau+MET
- Stop in b+tau
- Stopped gluinos
- Long-lived neutralinos decaying to dimuons
- 2^{nd} generation slepton resonances
- RPV SUSY in trileptons
- Long-lived charginos and staus

And earlier versions of many analyses presented here

Conclusions

- We have extended the excluded SUSY space to new limits
- More data available/coming
- Well-understood detectors



- New possibilities still under exploration

http://www-cdf.fnal.gov/physics/exotic/exotic.html

http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm