Latest New Phenomena Results from DØ

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For the DØ Collaboration

New Phenomena with DØ

- **Supersymmetry:**
  - **Squarks/Gluinos**
  - **Charginos/Neutrallinos**
- **Leptoquarks** (1,2,3 generation)
- **Large Extra Dimensions**
- **Long-lived Particles**

Results from $1-3\ \mathrm{fb}^{-1}$ of data

Supersymmetry

- Most studied extension of the Standard Model to solve some of its shortcomings
- New (s)particles, differing from their SM partners by spin 1/2

Quark	q	*Squark*	$\tilde{q}_R, \tilde{q}_L$	
Lepton	l	*Slepton*	$\tilde{l}_R, \tilde{l}_L$	
Neutrino	ν	*Sneutrino*	$\tilde{\nu}$	
Photon	γ	*Photino*	$\tilde{\gamma}$	**4 Neutralinos**
W-,Z-Boson	$W^{\pm}, Z$	*Wino, Zino*	$\tilde{W}^{\pm}, \tilde{Z}$	$\tilde{\chi}^0$
Higgs	$H^{\pm}, H^0$	*Higgsino*	$\tilde{H}_1^0\ \tilde{H}_2^+$	**2x 2 Charginos**
	h, A		$\tilde{H}_1^-\ \tilde{H}_2^0$	$\tilde{\chi}^{\pm}$
Gluon	g	*Gluino*	$\tilde{g}$	

R-parity:

$$R_p = \begin{cases} +1, & \text{for SM} \\ -1, & \text{for SUSY} \end{cases}$$

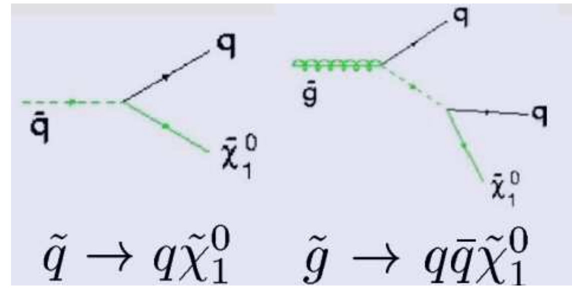
MSSM: R-parity conservation - LSP is stable, s-partners are created in pairs

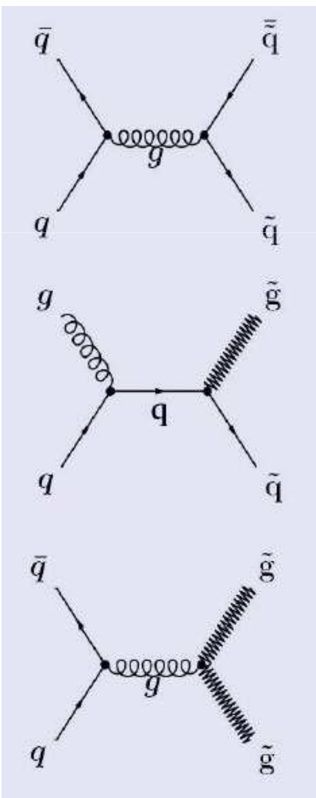
- SUSY must be broken: mSUGRA, GMSB etc.

- mSUGRA parameters: $m_0, m_{1/2}, A_0, \tan\beta, \text{sign}\mu$

Supersymmetry: squarks and gluinos

- MSSM (mSUGRA)
- R-parity conserved (LSP stable)
- $\geq 2\text{jets} + \text{MET}$





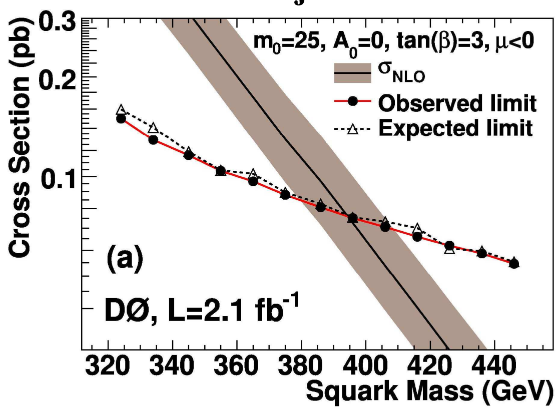
Low m_0 , $m(\tilde{q}) < m(\tilde{g})$ **(at least 2 jets)** “di-jet”

Medium m_0 ,$m(\tilde{q}) \approx m(\tilde{g})$ **(at least 3 jets)** “3-jet”

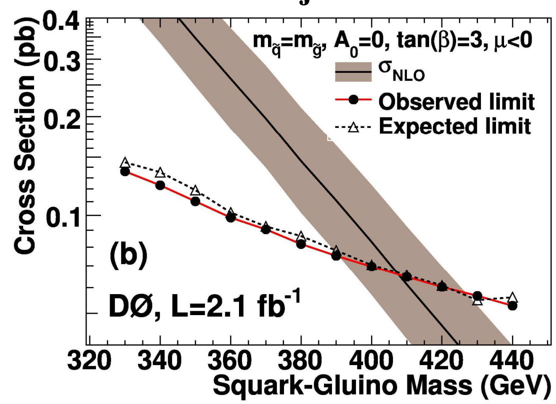
High m_0 , $m(\tilde{q}) > m(\tilde{g})$ **(at least 4 jets)** “gluino”

Squarks and gluinos: results

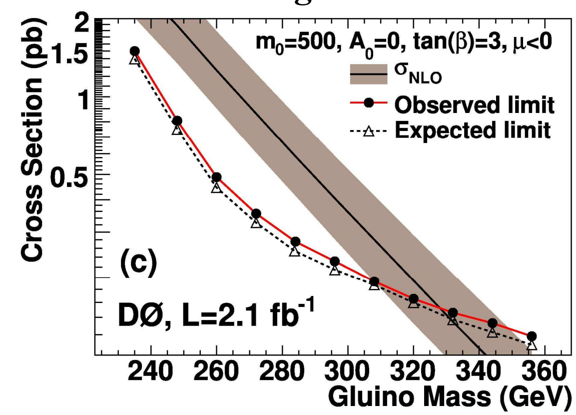
"di-jet"



"3 jet"



"gluino"



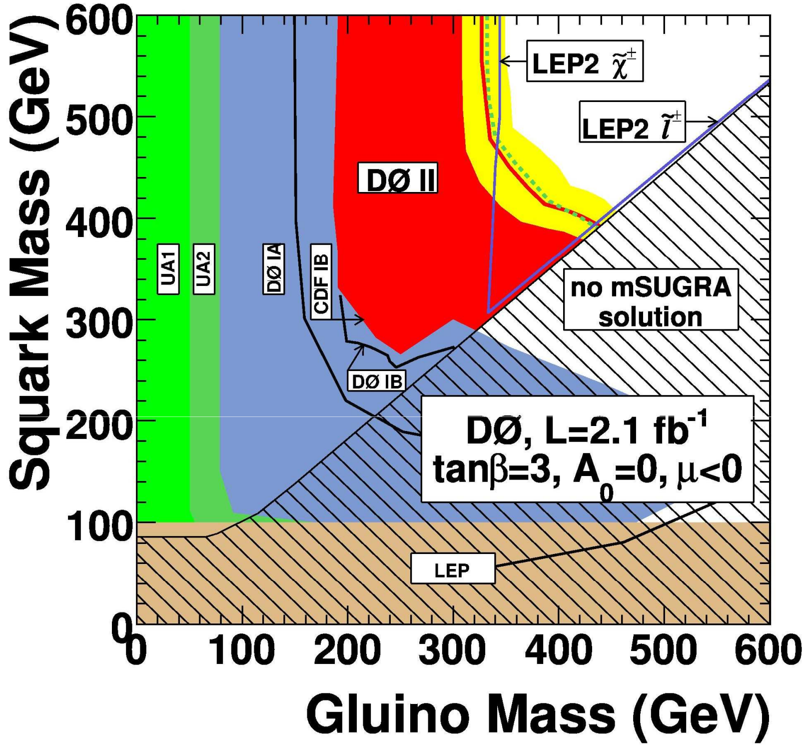
Using minimal cross-section

$m(\tilde{q})>379$ GeV

$m(\tilde{g})>308$ GeV

Corresponding previous limits (D0, 310 pb^{-1}) are improved by 54 and 67 GeV

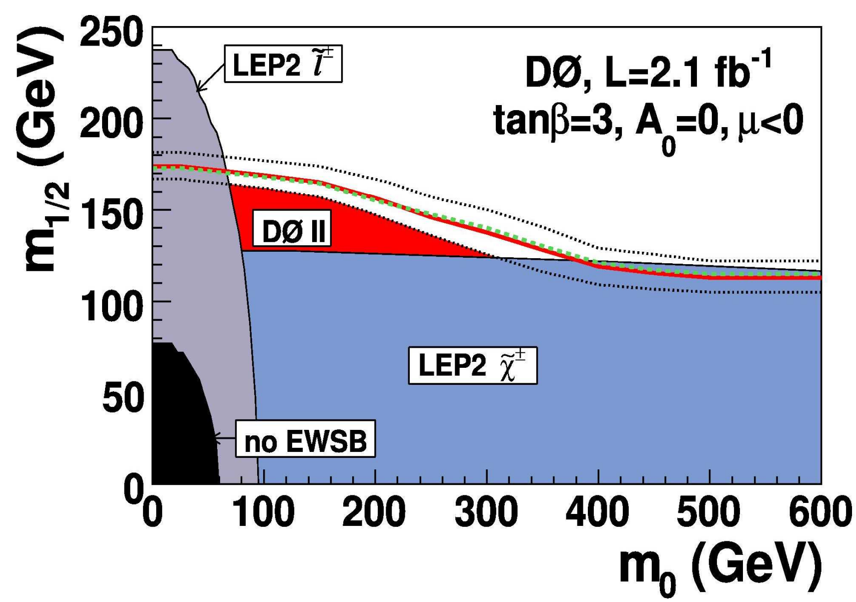
Squarks and gluinos: results



CDF ($2.0\,\text{fb}^{-1}$, $\tan\beta = 5$):

$m(\tilde{q}) > 392\,\text{GeV}$

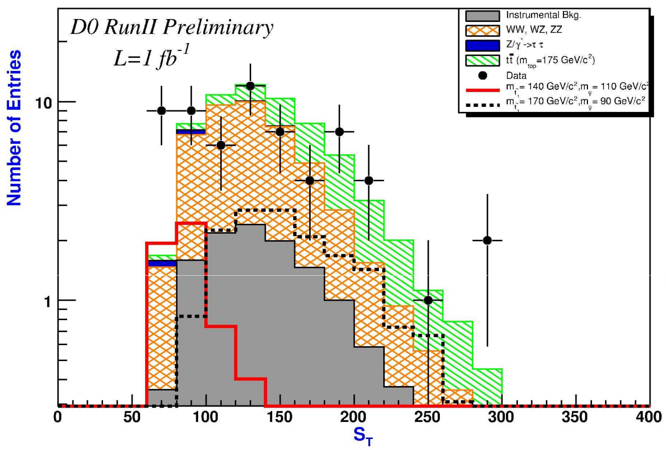
$m(\tilde{g}) > 280\,\text{GeV}$

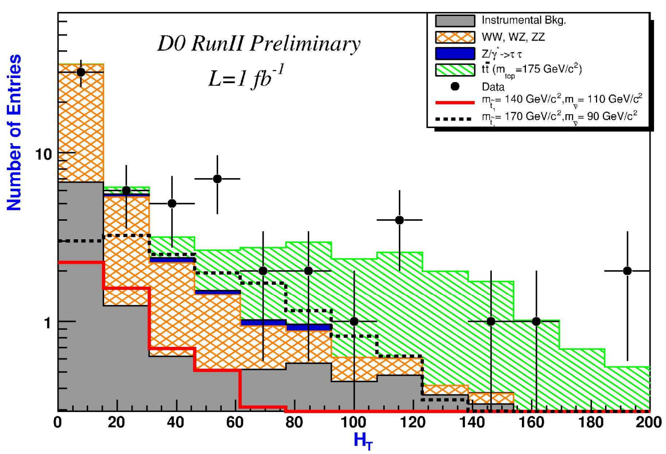


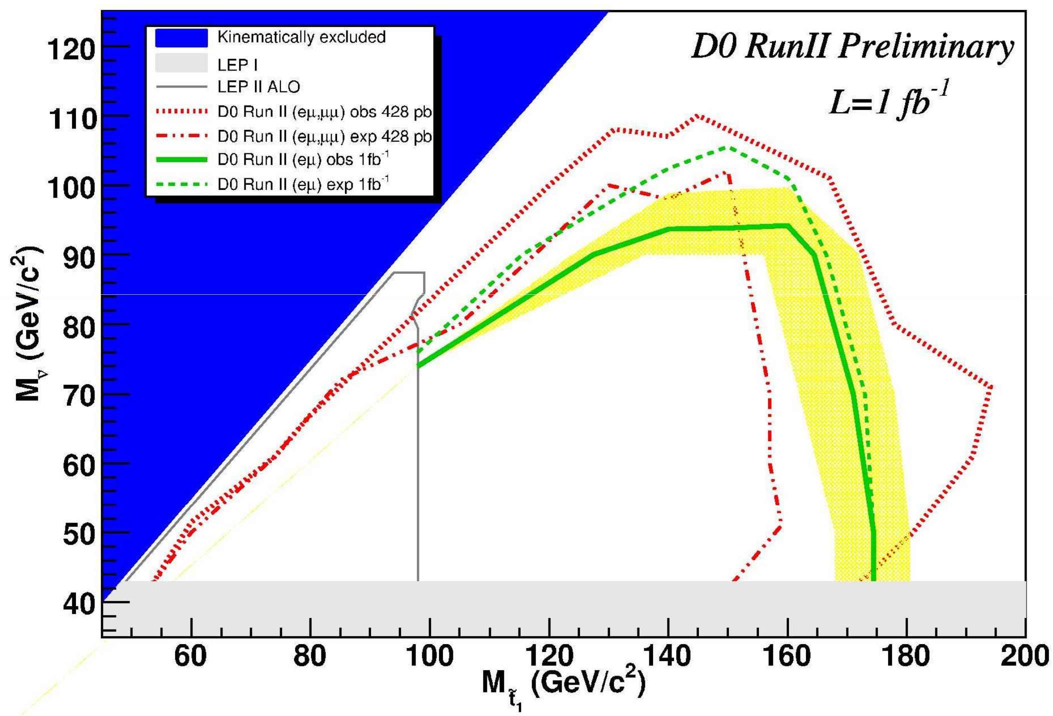
Yellow band: variations due to PDF uncertainties and renormalization/factorization scale variations

Search for pair production of the supersymmetric partner of the top quark

$$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow b\bar{b}e\mu\tilde{\nu}\bar{\tilde{\nu}}, \quad \tilde{\nu}\text{-LSP}$$



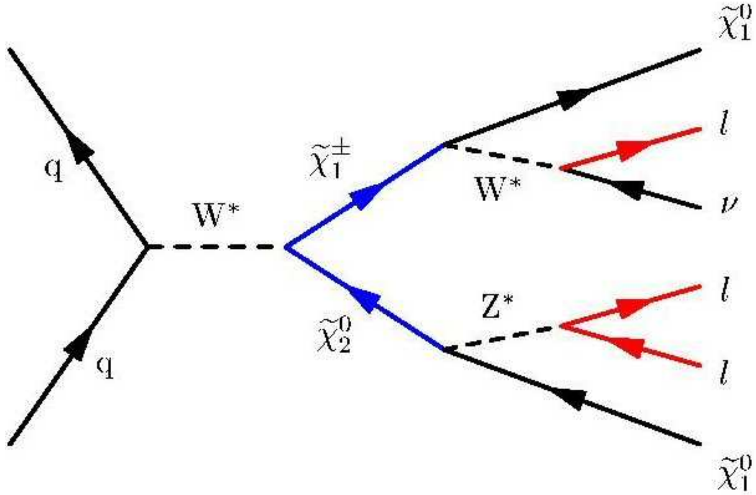


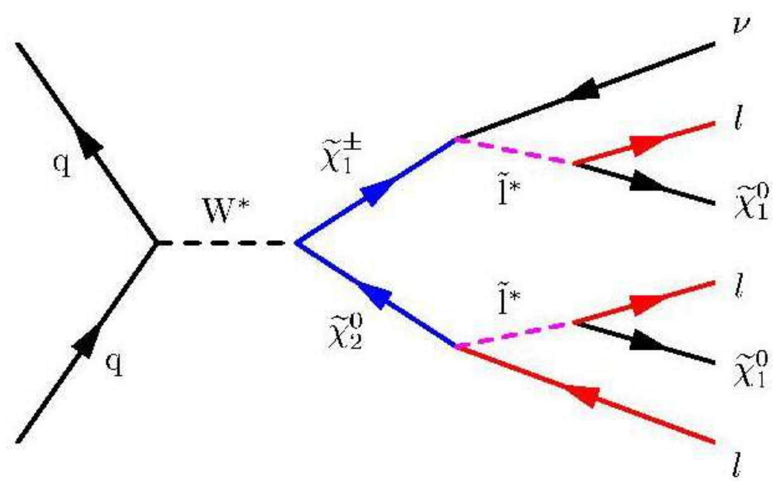


$m(\tilde{t}) > 175\,\text{GeV}$

for large $(m_{\tilde{t}} - m_{\tilde{\nu}})$

Charginos and Neutrallinos: 3*l* - state

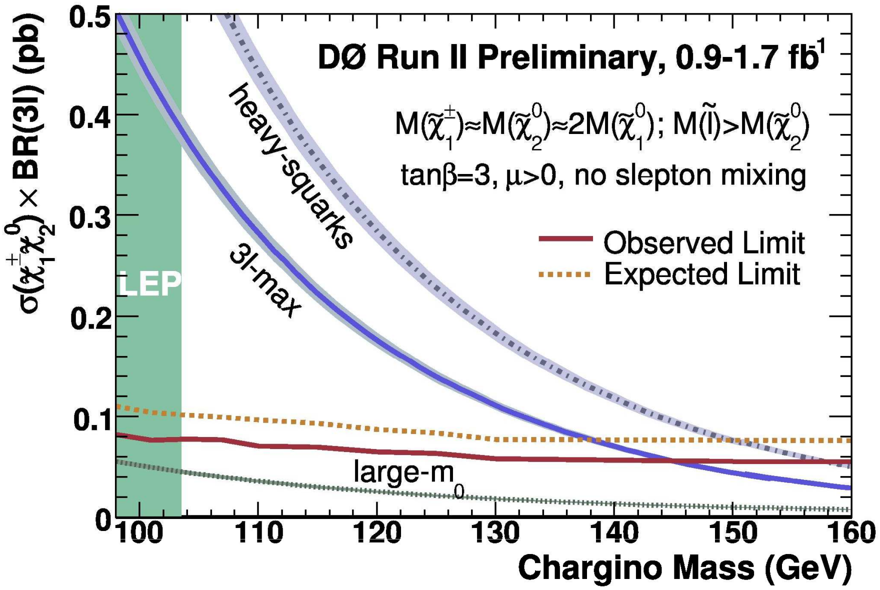




- **Gaugino pair production via EW interactions**
  - Small cross-sections (0.1 – 0.5 pb)
- **R-parity conservation: LSP stable**
- **LSP escapes detection: large MET**
- **SUSY signature:**
  - Two electrons or muons
  - Third lepton
  - Large MET

Small cross-sections but very clean signatures

Trilepton results



“Heavy squarks”: maximal production cross-section

“3l-max”: mSUGRA with light sleptons, large BR(3l)

“large-m0”: W/Z exchange dominates, small BR(3l)

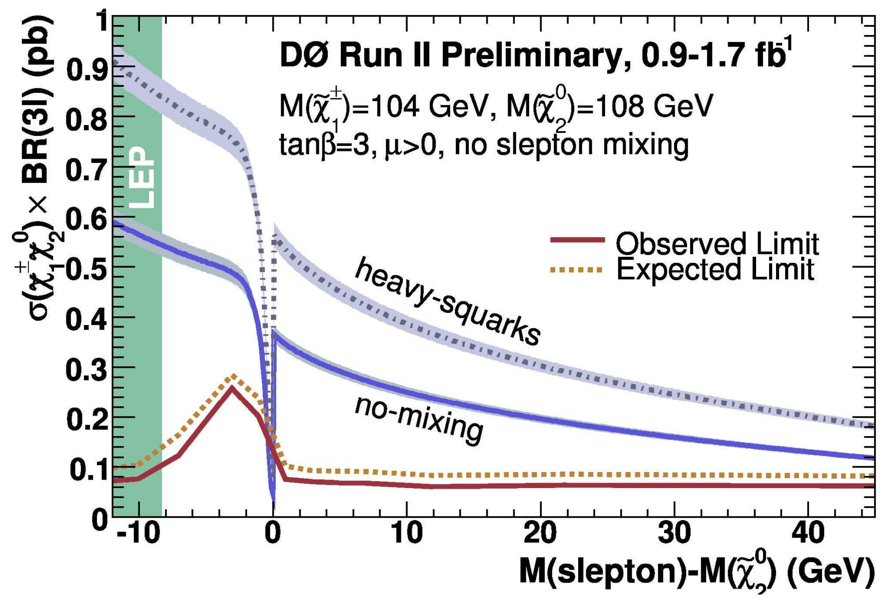
$$m_{\tilde{\chi}^{\pm}} > 145\,\text{GeV}$$

in “3l-max” scenario

CDF (2.0 fb^{-1}):

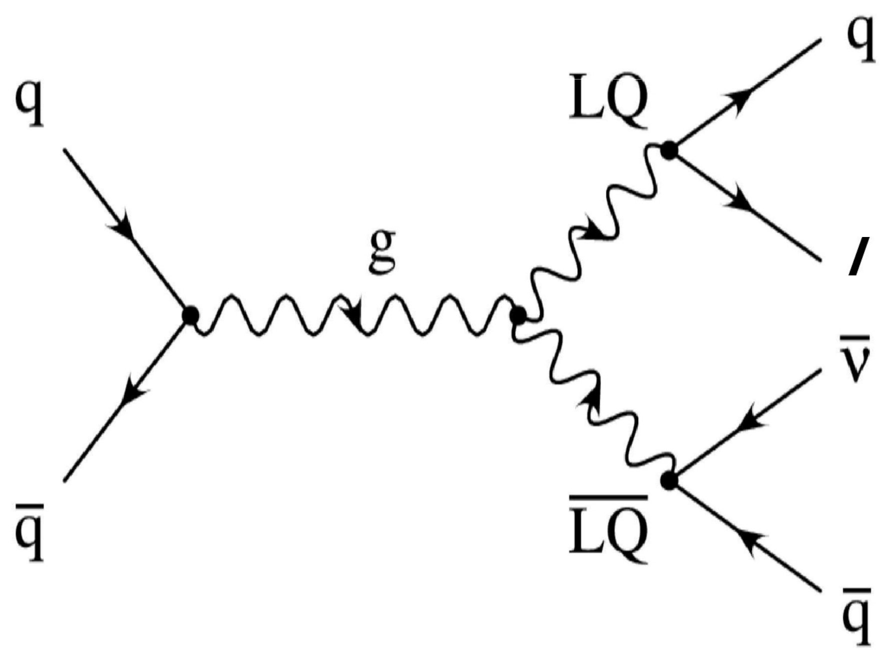
$$m_{\tilde{\chi}^{\pm}} > 145\,\text{GeV},\ (m_0 = 60\,\text{GeV})$$

$$m_{\tilde{\chi}^{\pm}} > 127\,\text{GeV},\ (m_0 = 100\,\text{GeV})$$



Leptoquarks

- Leptoquark – boson with third-integer charge, carrying lepton and quark quantum numbers (GUT, Technicolor, Compositeness)
- Three generation, each coupled to one fermion generation only
- Pair production: no dependence from LQ coupling to *l* and *q*



$$\beta = BR(LQ \to lq)$$

$$BR(LQ \to \nu q) = 1 - \beta$$

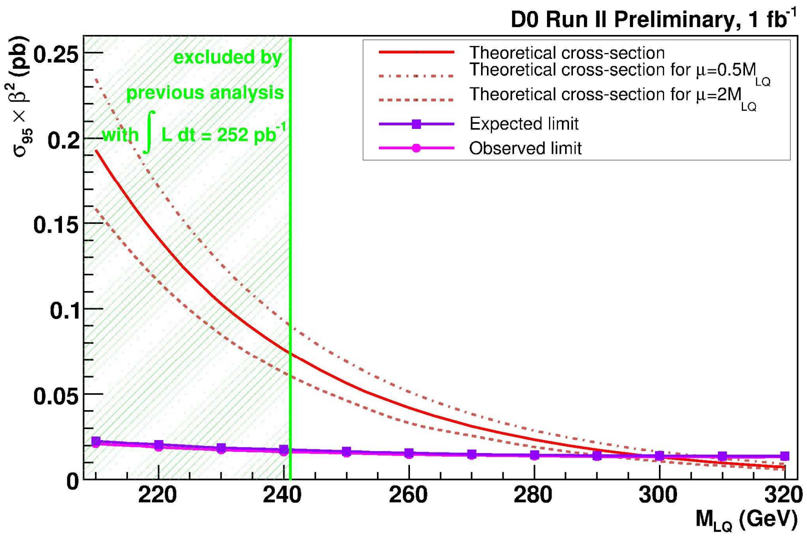
Leptoquarks: First Generation

- $p\bar{p} \rightarrow LQ_1 \overline{LQ_1} \rightarrow eeqq, \quad \beta=1$
- Scalar and vector leptoquarks
- Vector leptoquarks: VM-type ($T_3 = -1/2, \quad Q_{em} = 1/3, \quad \lambda = e$)
- Cross section depends on the LQ mass and "anomalous couplings" $\{k_G, \lambda_G\}$
- $\{k_G = 1, \lambda_G = 0\}$ (Minimal Coupling, MC),

  $\{k_G = 0, \lambda_G = 0\}$ (Yang-Mills Coupling, YM),

  $\{k_G = -1, \lambda_G = -1\}$ (Minus Minus Coupling, MM)

Leptoquarks: First Generation



Scalar:

M_{LQ}>292 GeV

(1.02 fb^{-1})

Previous result: ~240 GeV

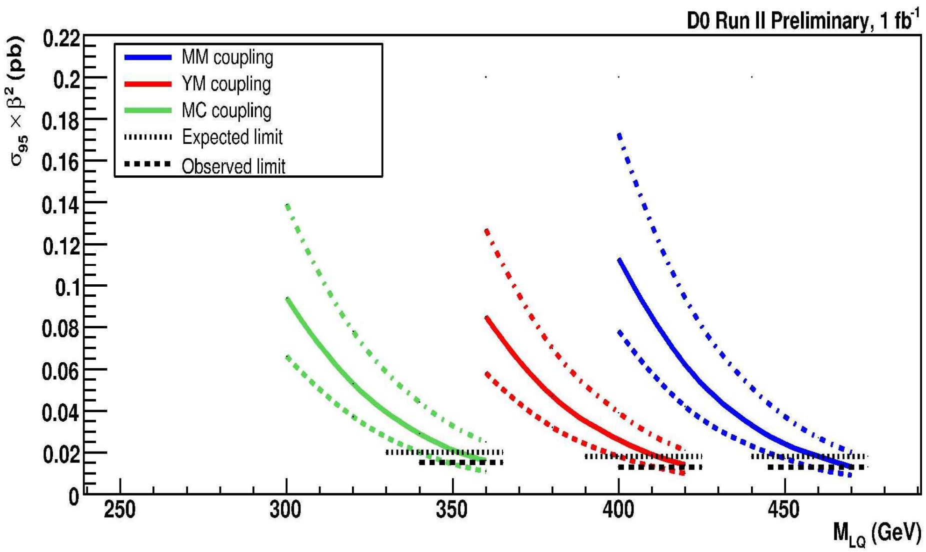
(~250 pb^{-1})

Vector:

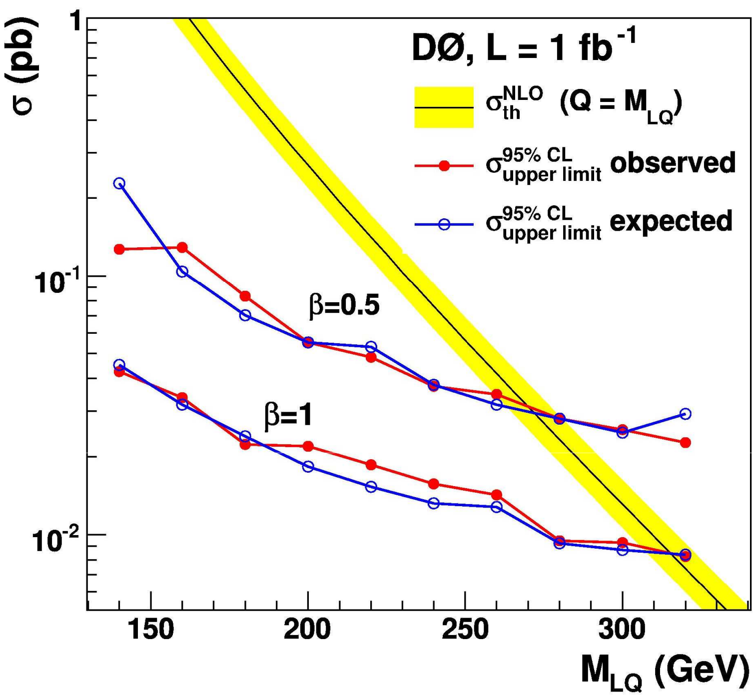
M_{LQ}>350 GeV (MC)

M_{LQ}>410 GeV (YM)

M_{LQ}>458 GeV (MM)



Leptoquarks: Second Generation



- Scalar leptoquarks
- $p\bar{p} \to LQ_2 LQ_2 \to \mu\mu qq$
  $p\bar{p} \to LQ_2 LQ_2 \to \mu\nu qq$
- BR($\mu\mu$qq)=β^2, max at β=1
  BR($\mu\nu$qq)=2β(1-β), max at β=0.5

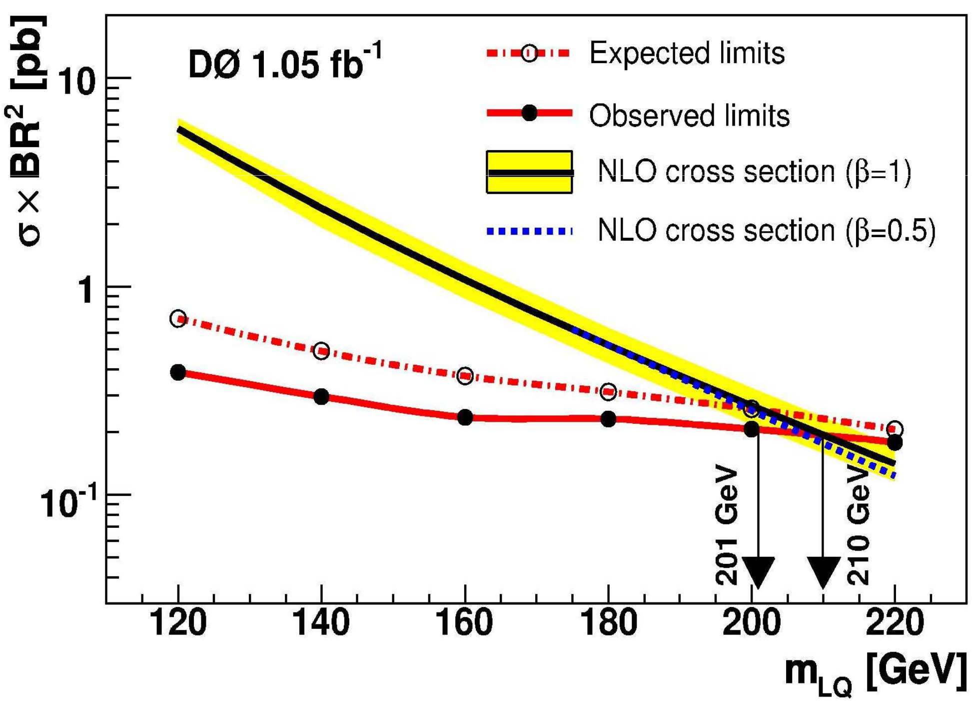
M(LQ) > 270 GeV (β=0.5)
M(LQ) > 316 GeV (β=1)

CDF Run II ($198\,pb^{-1}$)
M(LQ)>208 GeV (μμ,μν,νν)

Exceed the corresponding previous bounds by 65 GeV
(D0, $290\,pb^{-1}$)

Leptoquarks: third generation ($\tau b\,\tau b$ state)

$$p\bar{p} \to LQ_3 LQ_3 \to \tau b \tau b,\ \tau_1 \to \mu \nu_\mu \nu_\tau,\ \tau_2 \to hadrons$$



Best previous limit for this channel is 99 GeV

M(LQ) > 210 GeV (β=1)

($1.05\ \mathrm{fb}^{-1}$)

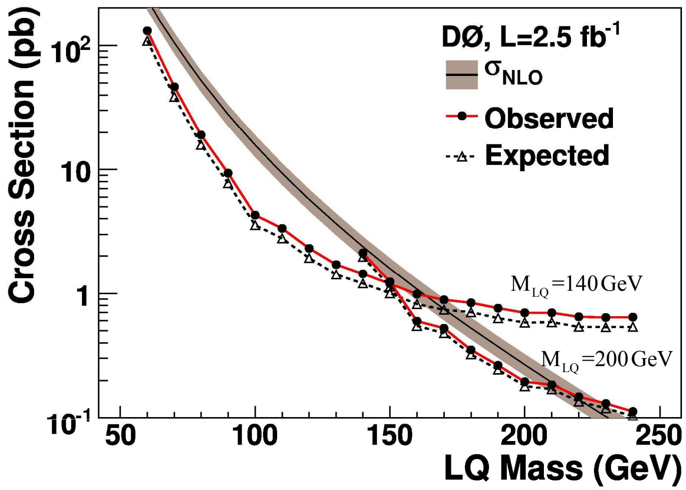
CDF (VLQ_3, $322\ \mathrm{pb}^{-1}$):

M(LQ) > 235 GeV (β=1)

Search for scalar Leptoquarks and T-odd quarks in the acoplanar jet topology

- Topology: two acoplanar jets and large missing $\not{E}_T$
- Leptoquarks: $p\bar{p} \rightarrow LQ\,\overline{LQ} \rightarrow \nu\nu qq,\ \beta=0$. Most stringent limit: $M_{LQ} > 136\ \mathrm{GeV}$ (D0, 310 pb^{-1})
- Little Higgs Model with T-parity (LHT): T-odd quarks $\tilde{Q} \rightarrow q\tilde{A}_H$
  $\tilde{A}_H$ - Lightest T-odd Particle (LTP), stable and weakly interacting.
  $p\bar{p} \rightarrow \tilde{Q}\tilde{Q} \rightarrow qq\tilde{A}_H\tilde{A}_H$ - same topology as for the leptoquarks.
- Most stringent limit: $M_{\tilde{Q}} > 100\ \mathrm{GeV}$ (LEP)
- 2.5 fb^{-1} of Run II data

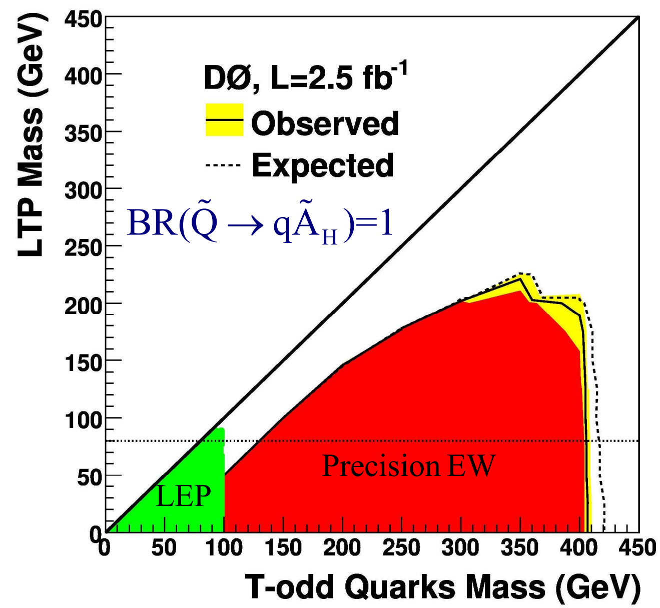
Search for scalar Leptoquarks and T-odd quarks in the acoplanar jet topology



M_{LQ}>205 GeV (β=0)

$M_{\tilde{Q}}$>404 GeV

for high $M_{\tilde{Q}}$-$M_{\tilde{A}_H}$ mass difference



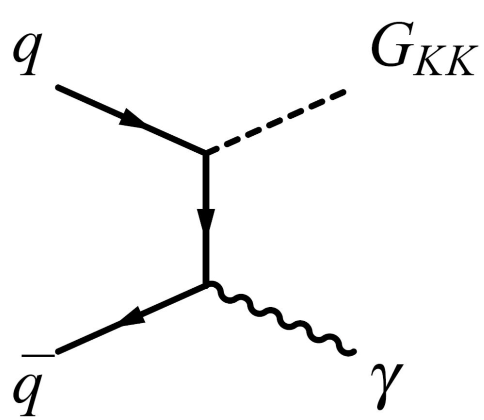
Large Extra Dimensions

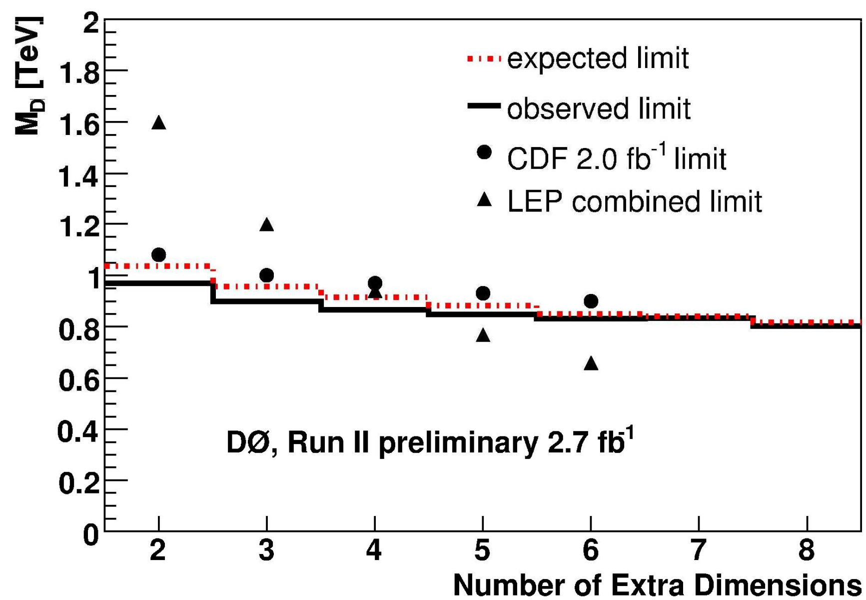
- Large Extra Dimensions to solve hierarchy problem:

$$M_{PL}^2 = 8\pi M_D^{n+2} R^n$$

- Kaluza-Klein Graviton (G_{KK}) – massive, stable, noninteracting

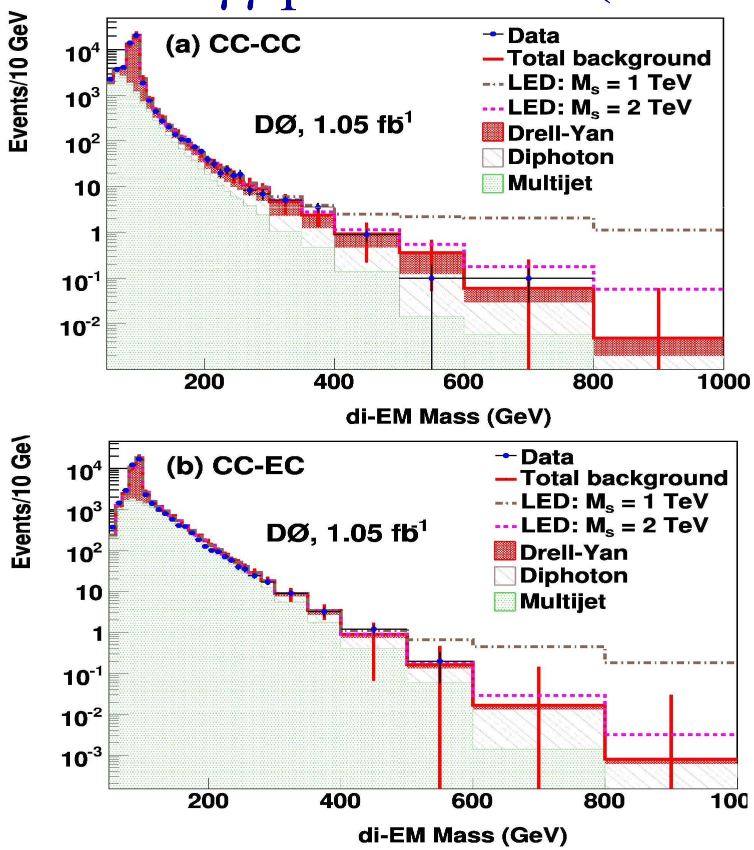
- $p\bar{p} \to \gamma G_{KK}$ - single photon + missing $\not\!\!E_T$ (2.7 fb^{-1})

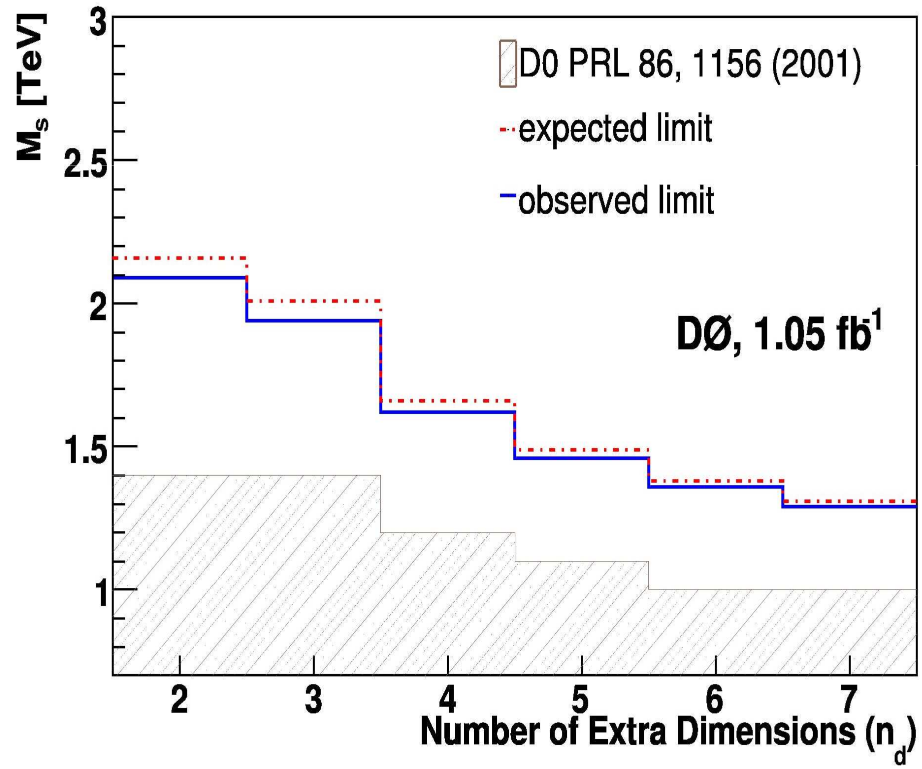




Large Extra Dimensions

- Existence of LED can be probed by searching for the effect of G_{KK} on fermion or boson pair production
- Effect on cross-section depends from M_s (M_s and M_D are of the same order of magnitude)
- ee and γγ production (1.05 fb^{-1})

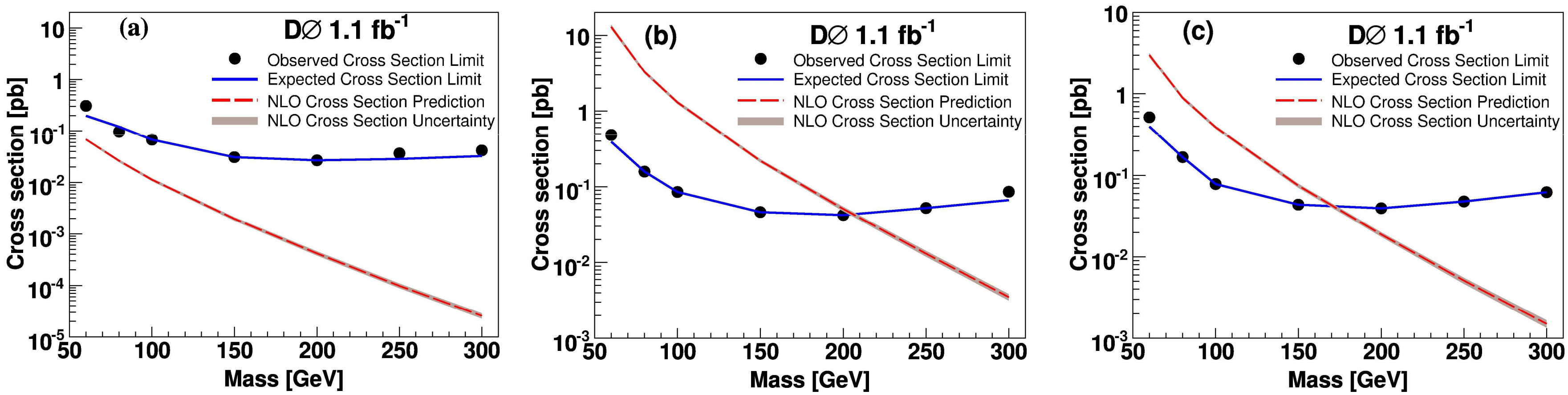




Long-lived particles

- Several SUSY scenarios: long-lived $\tilde{\tau}$ or $\tilde{\chi}^{\pm}$
- LLP pair production: detecting in outermost DZero muon system and has relatively large time of flight

$\tilde{\tau}$ Gaugino-like $\tilde{\chi}^{\pm}$ Higgsino-like $\tilde{\chi}^{\pm}$



M_{LLP}>206 GeV (Gaugino-like $\tilde{\chi}^{\pm}$), M_{LLP}>171 GeV (Higgsino-like $\tilde{\chi}^{\pm}$)

LEP limit for stable charginos: 104 GeV

Conclusion

- Many searches for beyond Standard Model effects are progressing at the Tevatron, you can find all results on the WWW
  DØ NP page: **http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm**
  CDF "Exotic" page: **http://www-cdf.fnal.gov/physics/exotic/exotic.html**
- Standard Model works pretty well and no significant deviations so far have been observed at DØ and CDF for now…
- All search analyses are benefiting from more data and we expect with $9-10\ \text{fb}^{-1}$ in Run II to increase data set by a factor of ~5 – 10
- Discoveries might come – stay tuned!

Backup slides

Squarks and gluinos: results

	Data	SM exp.	Signal
di-jet	11	$11.1 \pm 1.2^{+2.9}_{-2.3}$	$10.4 \pm 0.6^{+1.8}_{-1.8}$
3-jet	9	$10.7 \pm 0.9^{+3.1}_{-2.1}$	$12.0 \pm 0.7^{+2.5}_{-2.3}$
gluino	20	$17.1 \pm 1.1^{+5.5}_{-3.3}$	$17.0 \pm 1.2^{+3.3}_{-2.9}$

mSUGRA parameters

$$\tan\beta = 3, A_0 = 0, \mu < 0$$

$$m_0 = 25\,\text{GeV}, m_{1/2} = 175\,\text{GeV} \quad (\text{"di-jet"})$$

$$m_{\tilde{q}} = m_{\tilde{g}} = 400\,\text{GeV} \quad (\text{"3-jet"})$$

$$m_0 = 500\,\text{GeV}, m_{1/2} = 110\,\text{GeV} \quad (\text{"gluino"})$$

Charginos and Neutrallinos: 3*l* - state

$ee + l$ (588 pb^{-1} Run IIb)

Cut	Data	SM expected	mSUGRA
Preselection	64877	65393 ± 104	9
Anti-Z	5577	6566 ± 36	5.3
Third Track	182	208 ± 7	2.9
MET	1	1.5 ±0.4	1.9
MET x pT(3)	0	1.0 ±0.3	1.4

$$\tan\beta = 3, A_0 = 0, \mu > 0$$
$$m_{\tilde{\chi}^{\pm}} = 125\,\mathrm{GeV}$$
$$m_{\tilde{\chi}_2^0} = 127\,\mathrm{GeV}$$
$$m_{\tilde{\chi}_1^0} = 69\,\mathrm{GeV}$$
$$m_0 = 98\,\mathrm{GeV}, m_{1/2} = 192\,\mathrm{GeV}, m_{\tilde{l}} = 129\,\mathrm{GeV}$$

Perspective