Early searches for super particles at the LHC

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arXiv-hep: 11xx.xxxx
arXiv-hep: 1105.2838
http://www.lhcnewphysics.org/

Michael Park, Josh Ruderman, David Shih, Scott Thomas,YZ…

Outline:

- New signature search in early LHC data
  - Multi-lepton +MET
    - Tables classifying all multi-lepton channels
    - Slepton Co-NLSP
    - Stau NLSP
  - Di-photon + MET

New signature search in early LHC data

Jets + Leptons/photons + MET

Separation signals from background

Organize our study by signature, # of leptons/photons

Search first for what you can discover first

- Multi-lepton +MET
- Di-photon + MET

New signature search in early LHC data

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- Multi-lepton +MET
- Di-photon + MET

Tri-lepton search was carried in Tevatron (mSUGRA)

mainly focused on 3-lepton channel

⇒ throw away sensitivity of lower background channels

Collaborating with experimental group

CMS: tri-lepton search ⇒ multi-lepton search

Dominant background:

DY, W/Z production, top production

- Classify all leptonic channels by their charge and flavor information
- Define hierarchy among channels
- Exclusive search to maximize sensitivity in each channel and in combination of all channels

Hierarchy of 4 leptons combinations.

	$\|Q\|$	$N_{\rm DY}$	$N_{\rm OSSF}$
$\ell^\pm\ell^\pm\ell^\pm\ell^\pm$	4	0	0
$\ell^\pm\ell^\pm\ell^\pm\ell'^\pm$	4	0	0
$\ell^\pm\ell^\pm\ell'^\pm\ell'^\pm$	4	0	0
$\ell^\pm\ell^\pm\ell^\pm\ell'^\mp$	2	0	0
$\ell^+\ell^+\ell'^-\ell'^-$	0	0	0
$\ell^\pm\ell^\pm\ell'^+\ell'^-$	2	1	1
$\ell^+\ell^-\ell^\pm\ell'^\pm$	2	1	2
$\ell^+\ell^-\ell^\pm\ell^\pm$	2	1	3
$\ell^+\ell^-\ell^\pm\ell'^\mp$	0	1	2
$\ell^+\ell^-\ell'^+\ell'^-$	0	2	2
$\ell^+\ell^-\ell^+\ell^-$	0	2	4

max DY for one of combinations

sub-classification

sum over all combinations (describing the chance to be from DY)

$l\,l'$ are electron and muon.

Hierarchy of 4 leptons combinations.

	$\|Q\|$	$N_{\rm DY}$	$N_{\rm OSSF}$
$\ell^\pm\ell^\pm\ell^\pm\ell^\pm$	4	0	0
$\ell^\pm\ell^\pm\ell^\pm\ell'^\pm$	4	0	0
$\ell^\pm\ell^\pm\ell'^\pm\ell'^\pm$	4	0	0
$\ell^\pm\ell^\pm\ell^\pm\ell'^\mp$	2	0	0
$\ell^+\ell^+\ell'^-\ell'^-$	0	0	0
$\ell^\pm\ell^\pm\ell'^+\ell'^-$	2	1	1
$\ell^+\ell^-\ell^\pm\ell'^\pm$	2	1	2
$\ell^+\ell^-\ell^\pm\ell^\pm$	2	1	3
$\ell^+\ell^-\ell^\pm\ell'^\mp$	0	1	2
$\ell^+\ell^-\ell'^+\ell'^-$	0	2	2
$\ell^+\ell^-\ell^+\ell^-$	0	2	4

e+e+(μ+μ-)

There is a large possibility that one pair is from DY in BG.

And there is only one way to form DY pair.

(e+e-)e+μ+

e+(e-e+)μ+

There is a large possibility that one pair is from DY in BG.

And there are 2 different ways to form DY pair.

So the 2nd channel has larger BG.

Hierarchy of 4 leptons combinations.

	$\|Q\|$	$N_{\rm DY}$	$N_{\rm OSSF}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minSS}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minOSOF}$
$\ell^\pm\ell^\pm\ell^\pm\ell^\pm$	4	0	0	(2 , 0)	(2 , 0)
$\ell^\pm\ell^\pm\ell^\pm\ell'^\pm$	4	0	0	(2 , 0)	(2 , 0)
$\ell^\pm\ell^\pm\ell'^\pm\ell'^\pm$	4	0	0	(2 , 0)	(2 , 0)
$\ell^\pm\ell^\pm\ell^\pm\ell'^\mp$	2	0	0	(1 , 1)	(1 , 1)
$\ell^+\ell^+\ell'^-\ell'^-$	0	0	0	(0 , 2)	(2 , 0)
$\ell^\pm\ell^\pm\ell'^+\ell'^-$	2	1	1	(1 , 0)	(1 , 0)
$\ell^+\ell^-\ell^\pm\ell'^\pm$	2	1	2	(1 , 0)	(1 , 0)
$\ell^+\ell^-\ell^\pm\ell^\pm$	2	1	3	(1 , 0)	(1 , 0)
$\ell^+\ell^-\ell^\pm\ell'^\mp$	0	1	2	(0 , 1)	(2 , 0)
$\ell^+\ell^-\ell'^+\ell'^-$	0	2	2	(0 , 0)	(0 , 0)
$\ell^+\ell^-\ell^+\ell^-$	0	2	4	(0 , 0)	(0 , 0)

$t\bar{t}$ production

including tau charge

only e/μ

	$\|Q\|$	$N_{\rm DY}$	$N_{\rm OSSF}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minSS}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minOSOF}$
$\ell^\pm \ell^\pm \tau_h^\pm$	3	0	0	(1 , 0)	(1 , 0)
$\ell^\pm \ell'^\pm \tau_h^\pm$	3	0	0	(1 , 0)	(1 , 0)
$\ell^\pm \ell^\pm \tau_h^\mp$	1	0	0	(1 , 0)	(1 , 0)
$\ell^\pm \ell'^\pm \tau_h^\mp$	1	0	0	(1 , 0)	(1 , 0)
$\ell^+ \ell'^- \tau_h^\pm$	1	0	0	(0 , 1)	(0 , 1)
$\ell^+ \ell^- \tau_h^\pm$	1	1	1	(0 , 0)	(0 , 0)

same sign dilepton is more rare than OSOF in BG

Multi-lepton signal is rare in SM

$\Rightarrow$ 4+ leptons+MET, "almost" background free

→ early running

Are there any models providing those signals?

Multi-lepton signal is rare in SM

⇒ 4+ leptons+MET, "almost" background free

→ early running

Are there any models providing those signals?

SUSY is a zoo of signatures!

Neutralino NLSP → γ, Higgs, Z + Goldstino (MET)

Slepton Co-NLSP → Leptons, Tau + Goldstino (MET)

Stau NLSP → Tau + Goldstino (MET)

Squark, Gluino → Jets + Goldstino (MET)

MetaStable Slepton, Stau → Massive - Charged Tracks

MetaStable Gluino, Stop → Charge Exchange Tracks, ...

Metasble Neutralino, Slepton → Displaced γ , Higgs, Z ,
Kink Tracks, ...

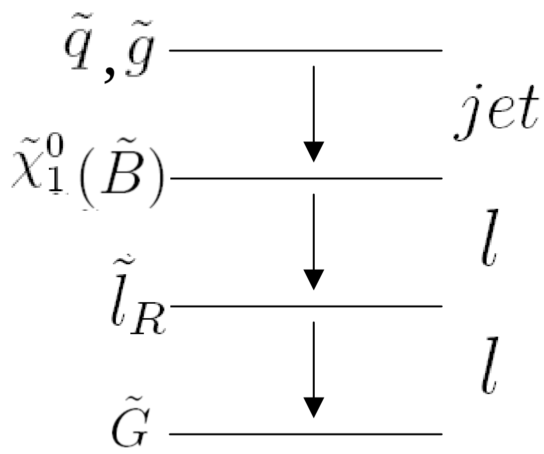
Up to 4-lepton signature:

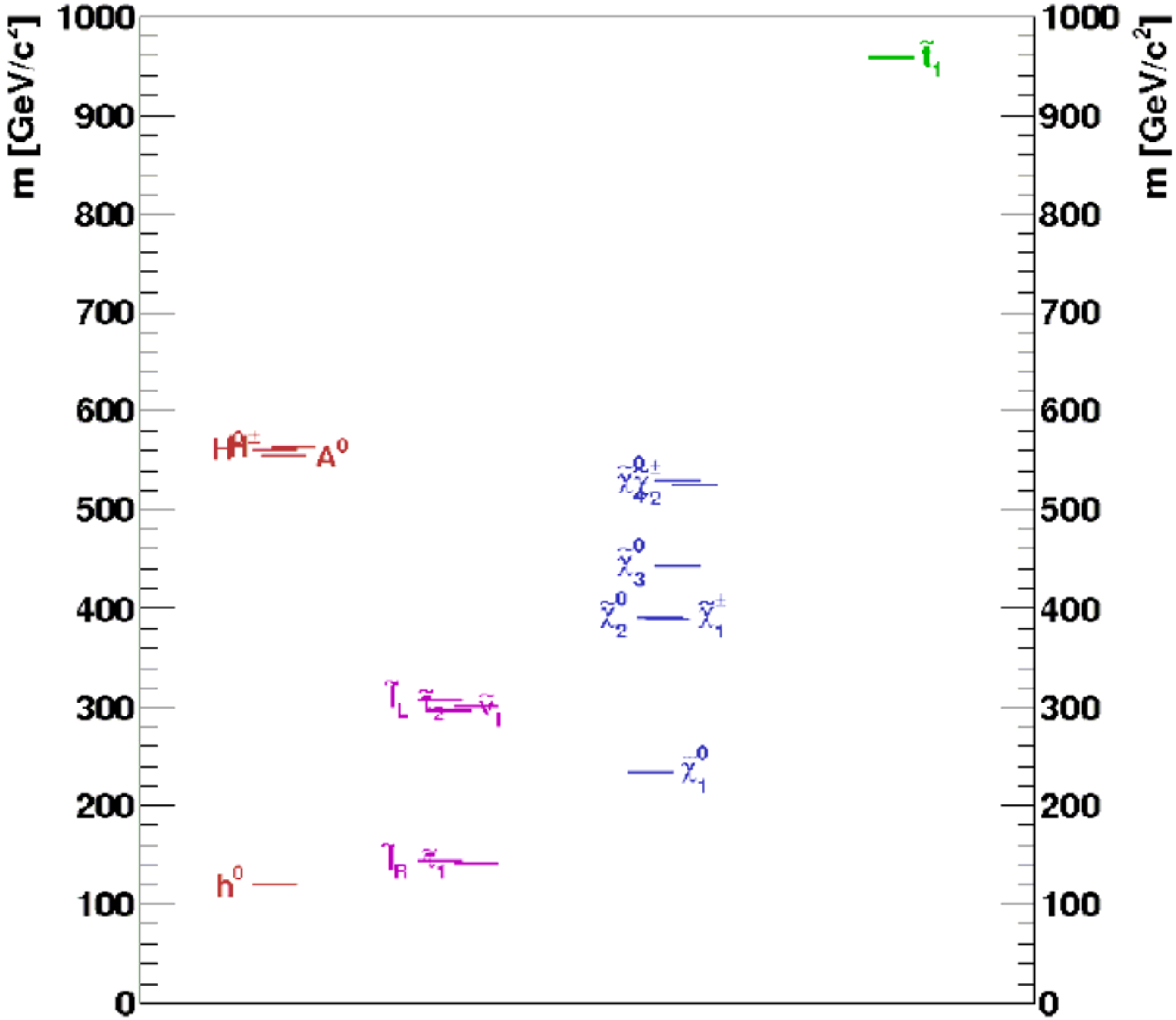
strong pair production at LHC

2× squark/gluino ⇒ slepton(R) ⇒ gravitino

↓ jets+lepton (through Bino) ↓ lepton

$$pp \to \geq 4\,\text{leptons} + X + \not{E}_T$$

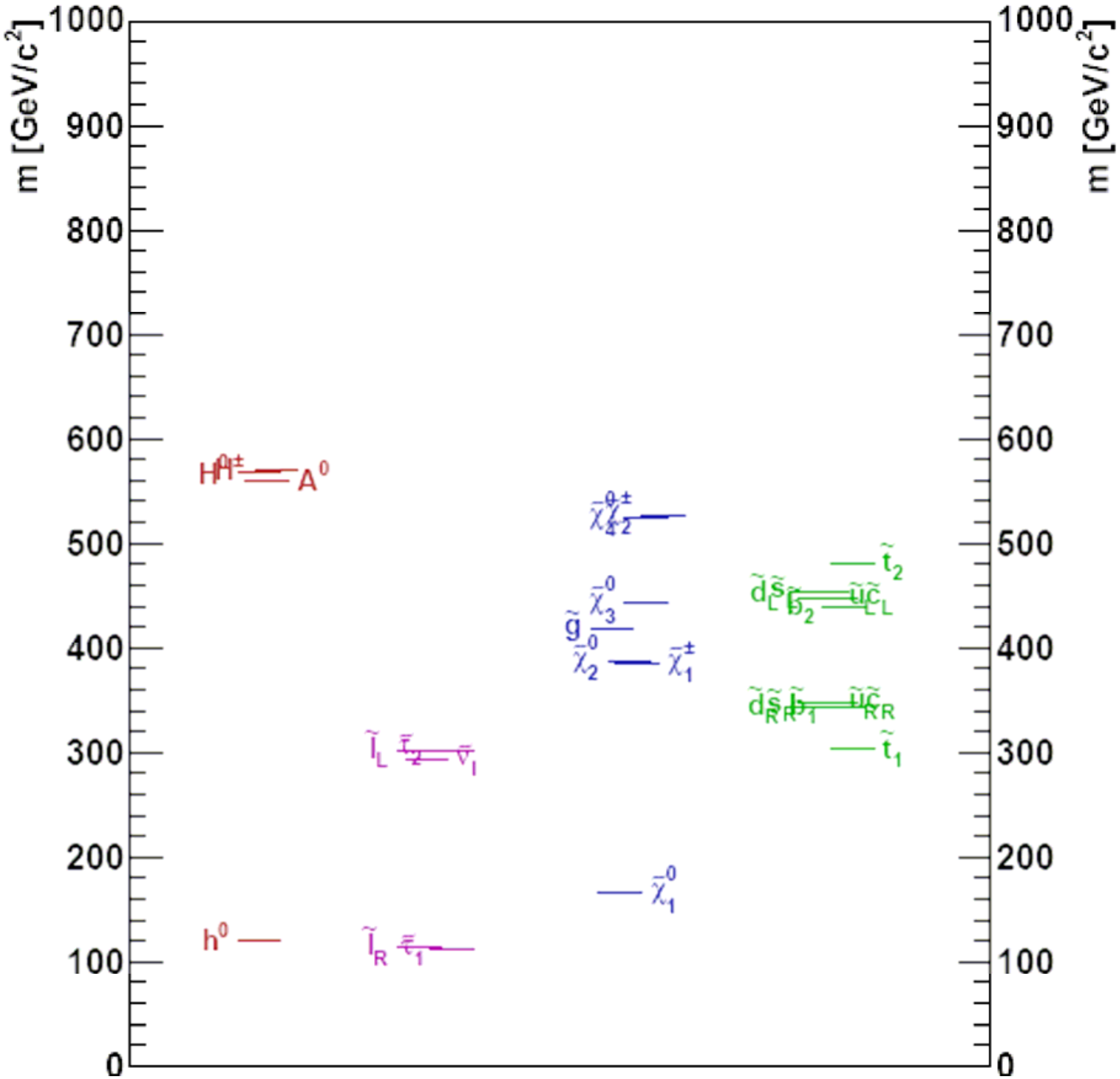




MGM:

$SU(2)_L$ and $SU(3)_C$ messenger fields feel the same strength of SUSY breaking

Gauge ordered stretched spectrum, strong production is suppressed !



GM with Splitting Messengers (GMSM)

Strong and weak messenger fields feel independent sources of SUSY breaking.

Linda Carpenter

Generally gauge ordered but compressed spectrum, strong production is enhanced.

Slepton Co-NLSP VS Stau-NLSP:

Slepton Co-NLSP: ($\tilde{e}$ or $\tilde{\mu}$) - $\tilde{\tau}$ < τ

3-body decay is forbidden.

$$\chi_B^0 \to \tilde{\ell}_i^{\pm}\, \ell_i^{\mp}$$
$$\hookrightarrow \ell_i^{\pm}\, \tilde{G}$$

$$pp \to \ell_i^+ \ell_i^- \; \ell_j^+ \ell_j^- + X + \not{E}_T \qquad i = e, \mu, \tau$$

(low/moderate tanβ)

Stau NLSP: $(\tilde{e}$ or $\tilde{\mu})$ - $\tilde{\tau} > \tau$

3-body decay is open.

soft

charge preserving

$$\chi_B^0 \to \tilde{\ell}_i^{\pm}\, \ell_i^{\mp}$$
$$\hookrightarrow \tilde{\tau}_1^{\pm}\, (\tau^{\mp}\, \ell_i^{\pm})$$
$$\hookrightarrow \tau^{\pm}\, \tilde{G}$$

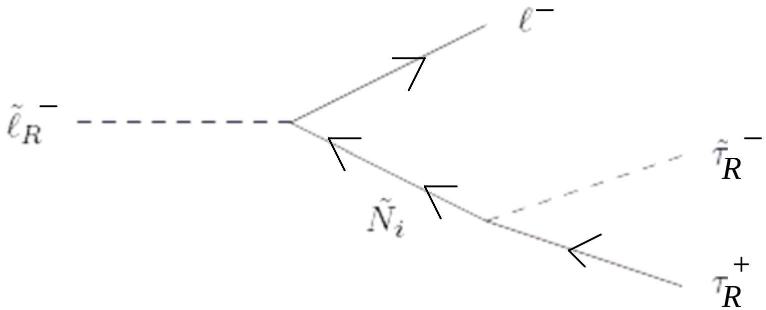
charge changing

$$\chi_B^0 \to \tilde{\ell}_i^{\pm}\, \ell_i^{\mp}$$
$$\hookrightarrow \tilde{\tau}_1^{\mp}\, (\tau^{\pm}\, \ell_i^{\pm})$$
$$\hookrightarrow \tau^{\mp}\, \tilde{G}$$

$$pp \to \ell_i^{\pm}\ell_j^{\mp}\ \tau^{\pm}\tau^{\mp} + X + \not{E}_T$$
$$\ell_i^{\pm}\ell_j^{\pm}\ \tau^{\pm}\tau^{\mp} + X + \not{E}_T$$
$$\ell_i^{\pm}\ell_j^{\mp}\ \tau^{\pm}\tau^{\pm} + X + \not{E}_T$$
$$\ell_i^{\pm}\ell_j^{\pm}\ \tau^{\pm}\tau^{\pm} + X + \not{E}_T$$

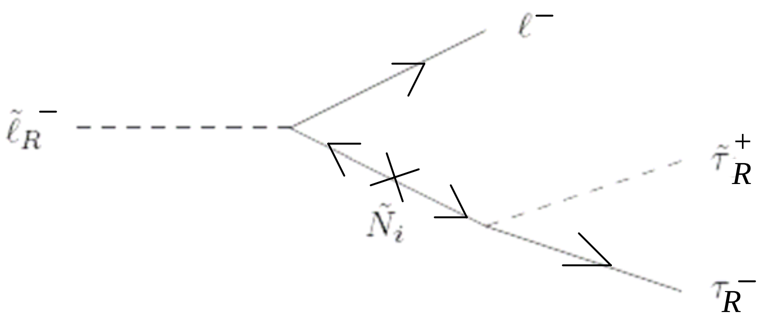
$$i, j = e, \mu$$

(moderate/high tanβ)



$$\tilde{l}_R^- \rightarrow l_R^- \tau_R^+ \tilde{\tau}_R^-$$

chirality preserving



$$\tilde{l}_R^- \rightarrow l_R^- \tau_R^- \tilde{\tau}_R^+$$

chirality violating

Ambrosanio, Kribs and Martin

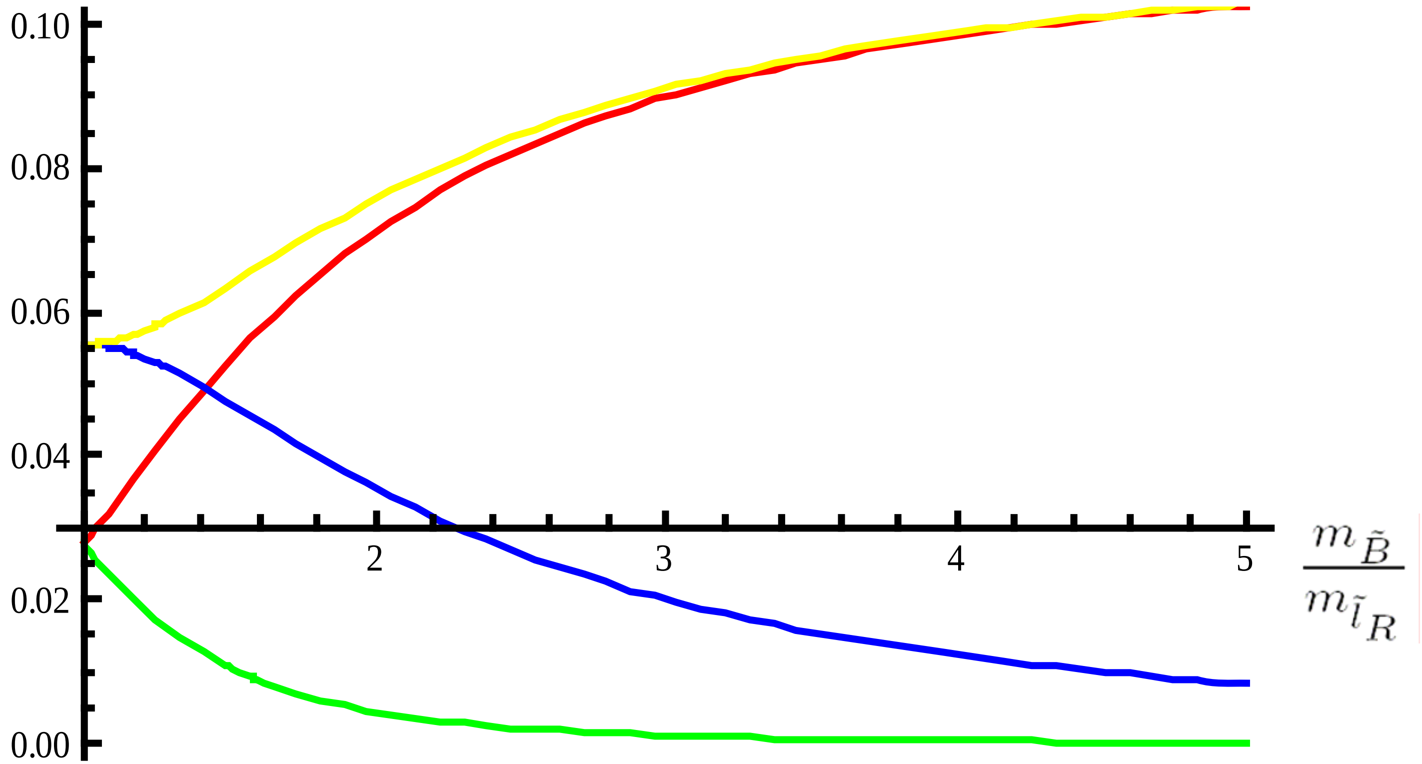
Treating leptons and tau as massless particles, one gets

$$\frac{\Gamma(\tilde{l}_R^- \rightarrow l_R^- \tau_R^+ \tilde{\tau}_R^-)}{\Gamma(\tilde{l}_R^- \rightarrow l_R^- \tau_R^- \tilde{\tau}_R^+)} \sim \frac{M_{\tilde{l}_R}^2}{M_{\tilde{B}}^2}$$

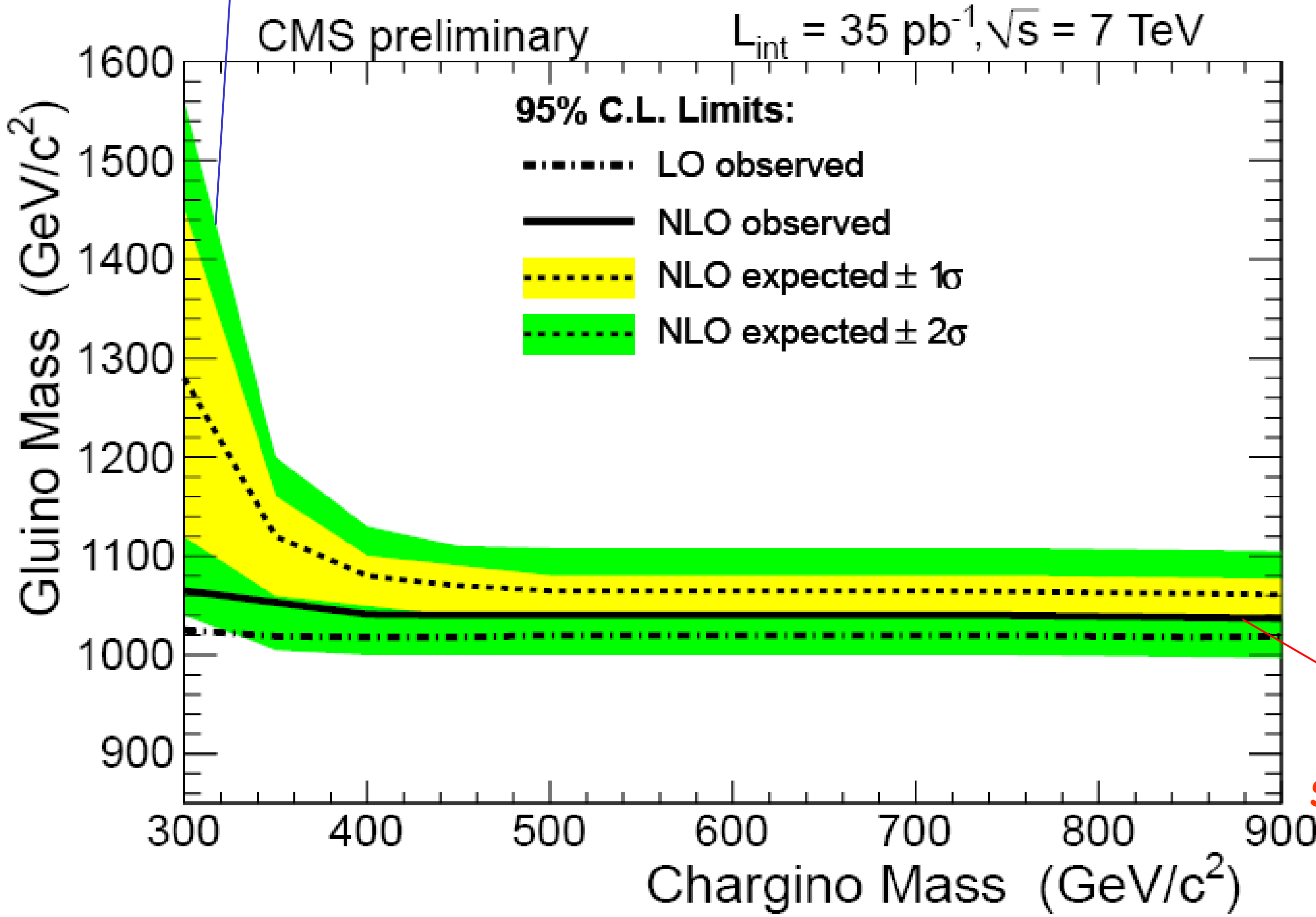
	$\|Q\|$	N_{DY}	$\mathcal{N}_{\mathrm{OSSF}}$	$(N_{\mathrm{SS}}, N_{\mathrm{OSOF}})_{\mathrm{minSS}}$	$(N_{\mathrm{SS}}, N_{\mathrm{OSOF}})_{\mathrm{minOSOF}}$	Cascade
$\ell^\pm \ell^\pm \tau_h^\pm \tau_h^\pm$	4	0	0	(1 , 0)	(1 , 0)	$\frac{R^2}{9(R+1)^2}$
$\ell^\pm \ell'^\pm \tau_h^\pm \tau_h^\pm$	4	0	0	(1 , 0)	(1 , 0)	$\frac{R^2}{9(R+1)^2}$
$\ell^\pm \ell^\pm \tau_h^+ \tau_h^-$	2	0	0	(1 , 0)	(1 , 0)	$\frac{2R}{9(R+1)^2}$
$\ell^\pm \ell'^\pm \tau_h^+ \tau_h^-$	2	0	0	(1 , 0)	(1 , 0)	$\frac{2R}{9(R+1)^2}$
$\ell^\pm \ell^\pm \tau_h^\mp \tau_h^\mp$	0	0	0	(1 , 0)	(1 , 0)	$\frac{1}{9(R+1)^2}$
$\ell^\pm \ell'^\pm \tau_h^\mp \tau_h^\mp$	0	0	0	(1 , 0)	(1 , 0)	$\frac{1}{9(R+1)^2}$
$\ell^+ \ell'^- \tau_h^\pm \tau_h^\pm$	2	0	0	(0 , 1)	(0 , 1)	$\frac{2R}{9(R+1)^2}$
$\ell^+ \ell'^- \tau_h^+ \tau_h^-$	0	0	0	(0 , 1)	(0 , 1)	$\frac{R^2+1}{9(R+1)^2}$
$\ell^+ \ell^- \tau_h^\pm \tau_h^\pm$	2	1	1	(0 , 0)	(0 , 0)	$\frac{2R}{9(R+1)^2}$
$\ell^+ \ell^- \tau_h^+ \tau_h^-$	0	1	1	(0 , 0)	(0 , 0)	$\frac{R^2+1}{9(R+1)^2} + \frac{4}{9}$

$$R = \frac{m_{\tilde{B}}^2}{m_{\tilde{l}_R}^2}$$

Branching ratio and label curves



weak productions dominate



hep-ex:1106.0933

strong productions dominate

simulating our parameter space by PGS
adopting CMS definition of tau
our plot is similar to experimental results

Summary on multi-lepton search:

- We break up the leptonic search channels in an exclusive way to maximize the sensitivity.
- Define hierarchies among channels according to the BG from SM.
- Introduce some SUSY benchmarks to study the multi-lepton signatures. (Compressed spectrum)
- Different detector signatures in

  Slepton Co-NLSP VS Stau NLSP
- Detector simulation in parameter space and put reach limits for early LHC data.

New signature search in early LHC data

Jets + Leptons/photons + MET

Separation signals from background

Organize our study by signature, # of leptons/photons

Search first for what you can discover first

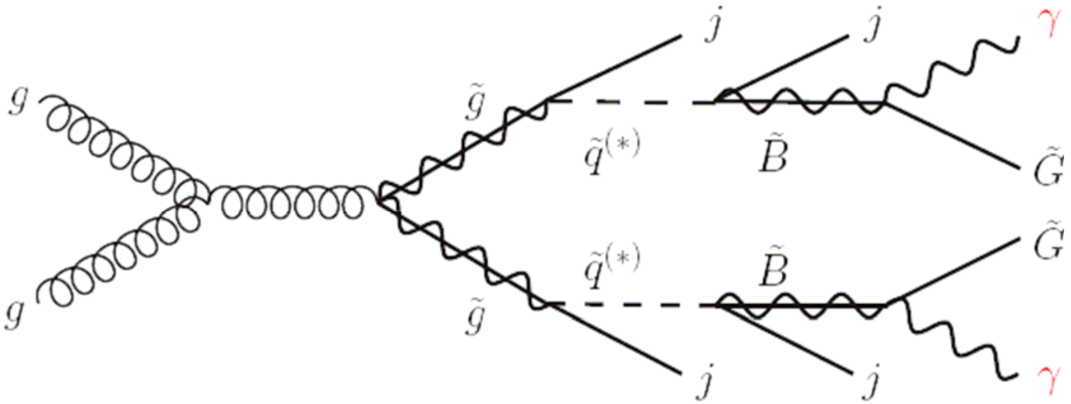
- Multi-lepton +MET
- Di-photon + MET

Di-photon search in early LHC:

Bino-like Neutralino ⇒ NLSP

Leading decay mode: photon + gravitino

Sub-dominate decay mode: Z + gravitino



$$pp \to \gamma\gamma + X + \not{E}_T$$

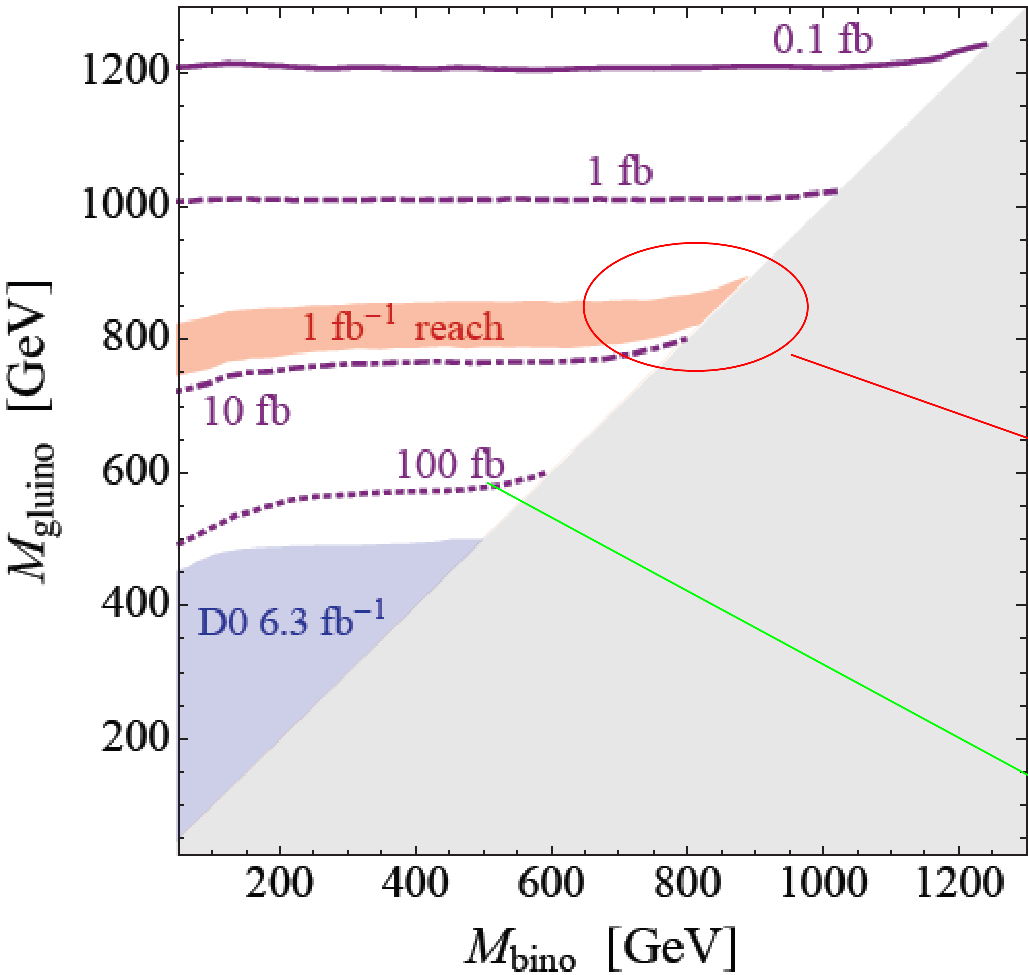
CDF and D0 carried out the di-photon search

no clear evidence for non-standard model signal

Propose simple model-independent parameter space

Optimize search/estimate reach/set limits.

Gluino mass VS Bino mass



strong production

Purple contour is the Xsec at 7 TeV after imposing cuts

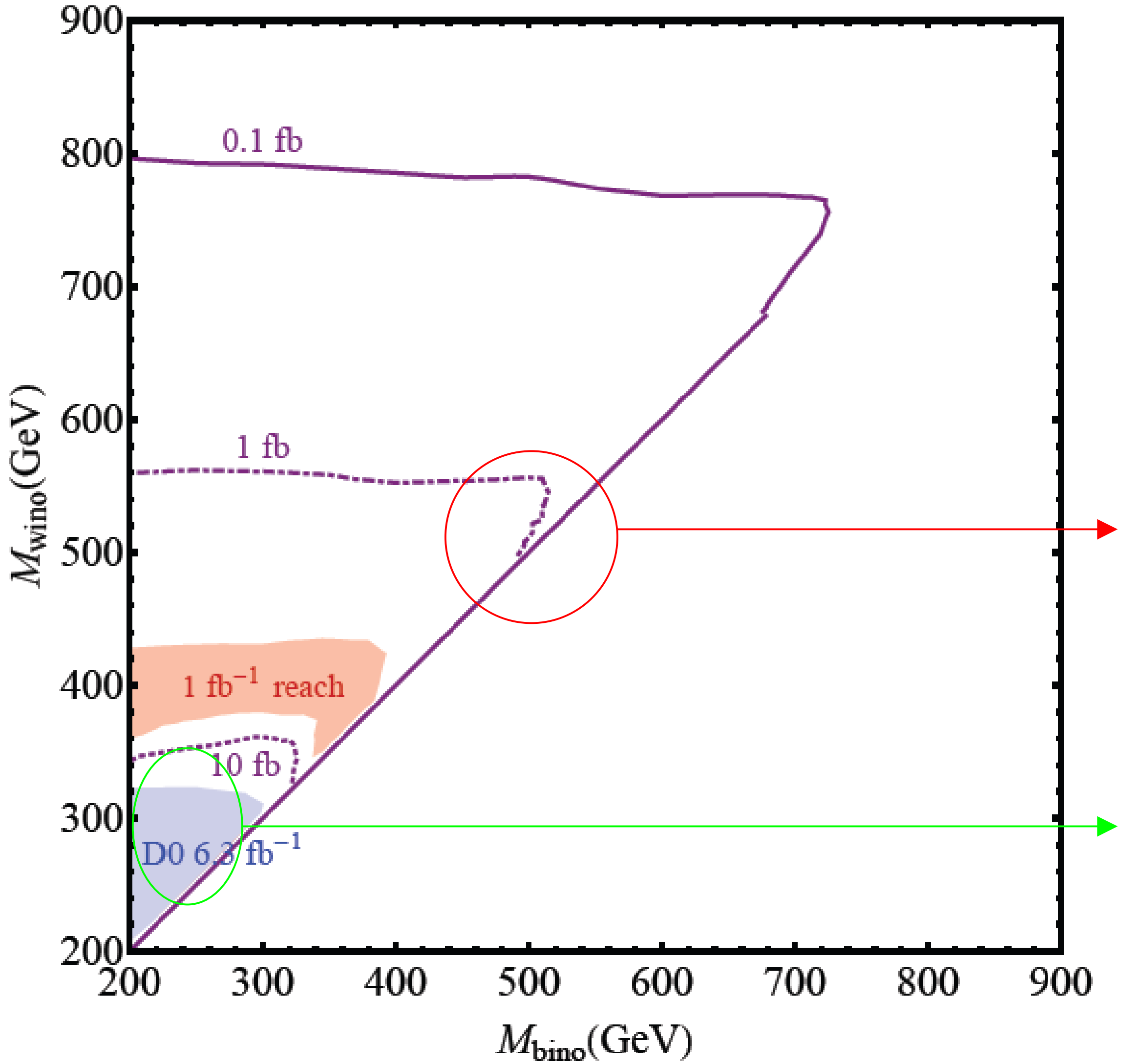
Background is estimated around

1fb ~ 10 fb

3.5 events for 100 fb null result
BG < O(1) event,
100 fb
⇒95% exclusion limits.

The LHC has been beyond Tevatron reach for strong production.

Wino mass VS Bino mass



weak production

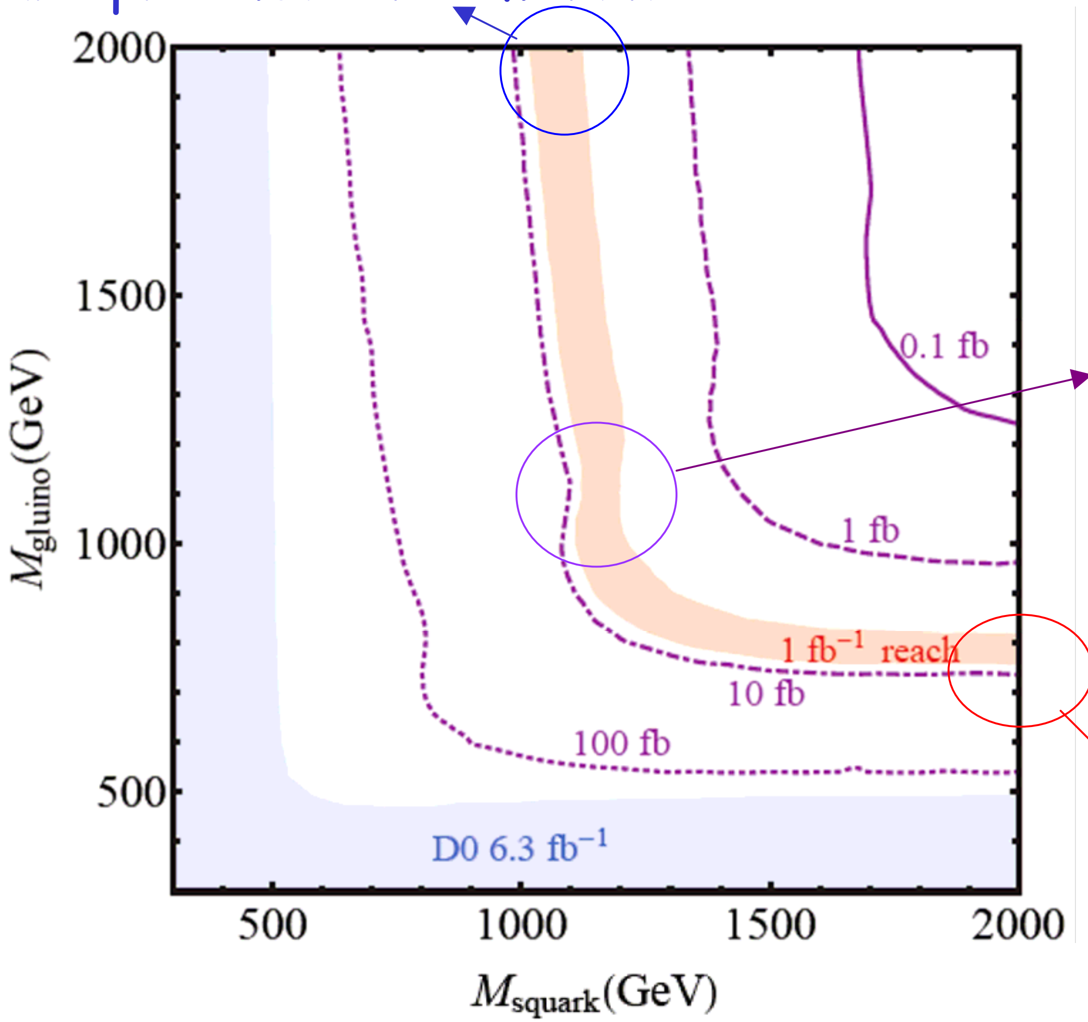
Wino and bino are too degenerate, wino decays directly to gravitino

For 35 pb^{-1}, Tevatron still gives most strict bound on weak production

Summary:

- Multi-lepton + MET search
  - Exclusive search to maximize the sensitivity.
  - SUSY benchmarks (Slepton Co-NLSP VS Stau NLSP)
  - Reach limits for early LHC data.
- Di-photon + MET search
  - SUSY benchmark (Bino-like neutralino as NLSP)
  - Reach limits for early LHC data.

squark production dominant



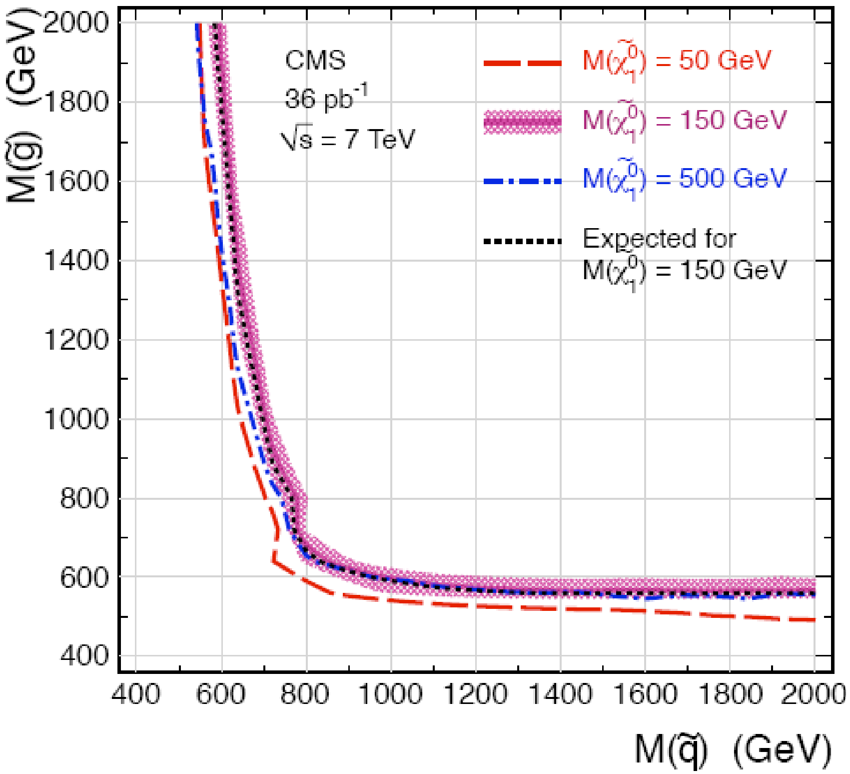
gluino decay has more jets than squark decay

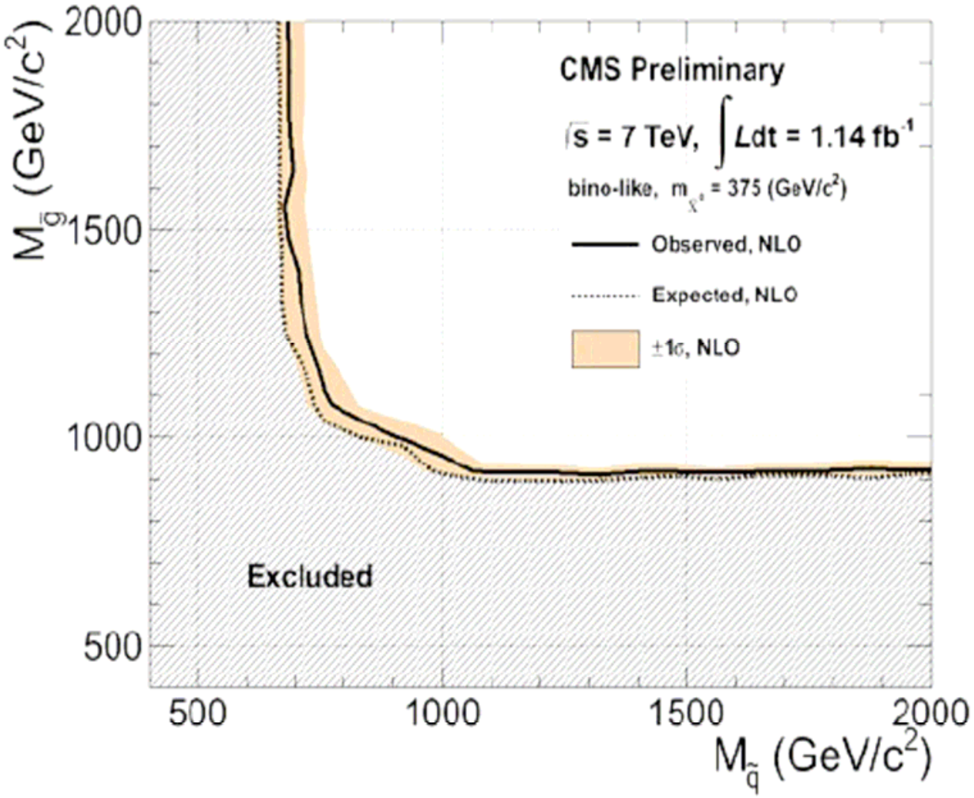
gluino production dominant

$$p\bar{p}, pp \to \tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{\bar{q}}, \tilde{q}\tilde{\bar{q}}, (\tilde{q}\tilde{\chi}^0_B, \tilde{\bar{q}}\tilde{\chi}^0_B, \tilde{\chi}^0_B\tilde{\chi}^0_B)$$

sub-dominant through t-channel

CMS result:





arXiv: 1103.0953

Rachel Yohay

	After Lepton ID Requirements					Inclusive Selection		
	Z+jets	$t\bar{t}$	VV+jets	ΣSM	Data	ΣSM	Data	ML01
Channel	three-lepton channels							
OS($\ell\ell$) e	1.7	0.1	1.2	4.4 ± 1.5	6	0.1 ± 0.1	0	121
OS($\ell\ell$) μ	2.8	0.2	1.7	4.7 ± 0.5	6	0.1 ± 0.1	0	124
OS($\ell\ell$) T	122	0.5	0.7	123 ± 16	127	0.4 ± 0.1	0	80
$\ell\ell' T$	0.7	0.5	0.2	1.7 ± 0.7	3	0.4 ± 0.2	2	18.6
SS($\ell\ell$) ℓ'	0.13	0.1	0.0	0.2 ± 0.1	0	0.2 ± 0.1	0	2.8
SS($\ell\ell$) T	0.25	0.0	0.1	0.7 ± 0.4	3	0.1 ± 0.1	0	9.0
ℓTT	47	0.3	0.1	48 ± 9	30	0.4 ± 0.1	0	8.0
$\Sigma\ \ell\ell(\ell/T)$	127	1.4	3.8	135 ± 16	145	1.3 ± 0.2	2	356
Channel	four-lepton channels							
$\ell\ell\ell\ell$	0	0	0.2	0.2 ± 0.1	2	0	0	164
$\ell\ell\ell T$	0	0	0.1	0.1 ± 0.1	0	0	0	62
$\ell\ell TT$	0	0	0	0.0 ± 0.1	0	0	0	21
$\Sigma\ \ell\ell(\ell/T)(\ell/T)$	0	0	0.3	0.3 ± 0.1	2	0	0	247