Simplified Models of Gauge Mediation

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Princeton University

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JTR and David Shih, **1103.6083**

2011 is the year to discover (natural*) low-energy SUSY!

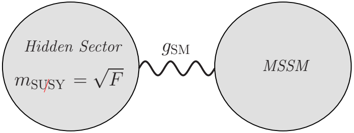
*stay tuned for Natalia Toro's talk.

Road Map

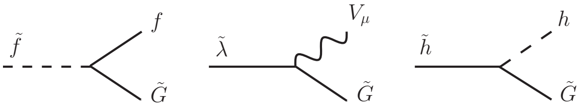
1. Intro to GMSB Collider Signals
2. Simplified Models of Neutralino NLSPs

Gauge Mediation

- SUSY breaking can be communicated to the SM through gauge interactions.



- virtues:
  1. flavor blind
  2. calculable
- the NLSP decays to the gravitino, $m_{\tilde{G}} \sim F/M_p$



Collider pheno determined by identity and lifetime of the NLSP

$$\Gamma_{NLSP} = \frac{m_{NLSP}^5}{16\pi F^2} = (0.1\ \mathrm{mm})^{-1} \times \left(\frac{m_{NLSP}}{100\ \mathrm{GeV}}\right)^5 \left(\frac{100\ \mathrm{TeV}}{\sqrt{F}}\right)^4$$

Spectrum of Gauge Mediation

Minimal Gauge Mediation

- **MGM:** *Dine, Nelson, Nir, Shirman,...*
  1. gaugino unification, $M_1 : M_2 : M_3 \approx 1 : 2 : 6$
  2. sparticle masses roughly fixed by gauge charges

$$m_{\tilde{\lambda}_i} \sim \frac{\alpha_i}{4\pi}\Lambda \qquad\qquad m_{\tilde{f}}^2 \sim \left(\frac{\alpha_i}{4\pi}\right)^2 \Lambda^2$$

  3. bino or right-handed slepton is the NLSP.

Spectrum of Gauge Mediation

Minimal Gauge Mediation vs. General Gauge Mediation:

- **MGM:** *Dine, Nelson, Nir, Shirman,...*
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  3. bino or right-handed slepton is the NLSP.

- **GGM:** *Meade, Seiberg, Shih*
  1. M_1, M_2, M_3 unconstrained
  2. squarks and sleptons satisfy sum rules but are otherwise unconstrained

$$\begin{aligned} \mathrm{Tr}\, Y\, m^2 &= m_Q^2 - 2m_U^2 + m_D^2 - m_L^2 + m_E^2 = 0 \\ \mathrm{Tr}\,(B-L)\, m^2 &= 2m_Q^2 - m_U^2 - m_D^2 - 2m_L^2 + m_E^2 = 0 \end{aligned}$$

  3. any sparticle can be the NLSP

NLSP Zoology

The possible NLSPs and signals in MGM are:

NLSP	Prompt	Displaced
slepton	e,μ,τ	displaced vertices, kinked tracks, CHAMPS, ...
neutralino	γ,Z	non-pointing photons, displaced leptons...

The above signals include $\not\!\!E_{\mathrm{T}}$ carried by the gravitinos.

NLSP Zoology

The possible NLSPs and signals in GGM are:

NLSP	Prompt	Displaced
slepton	e,μ,τ	displaced vertices, kinked tracks, CHAMPS, ...
neutralino/ chargino	γ, Z, W, h	non-pointing photons, displaced leptons...
squark gluino	jets	displaced vertices, R-hadrons
sneutrino	multileptons	

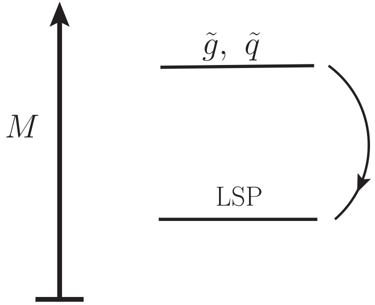
The above signals include $\not\!\!E_{\mathrm{T}}$ carried by the gravitinos.

Simplified Models of Gauge Mediation

In order to tame the large parameter space, we suggest:

- specifying MSSM parameters at the weak scale
- choosing simplified spectra with a small number of particles
- decoupling the rest of spectrum

These are *simplified models* (http://www.lhcnewphysics.org/):



Simplified Models of Gauge Mediation

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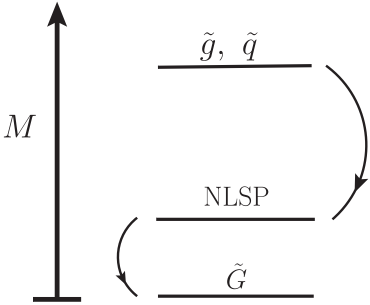


For GMSB, we just add a gravitino.

Neutralino NLSPs

In the MSSM, the bino, winos, and higgsinos mix, giving 4 neutral and 2 charged mass eigenstates,

$$(\tilde{N}_1, \tilde{N}_2, \tilde{N}_3, \tilde{N}_4) \quad \text{and} \quad (\tilde{C}_1, \tilde{C}_2)$$

General neutralino NLSPs have three possible decays,

$$\tilde{N}_1 \to (\gamma, Z, h) + \tilde{G}$$

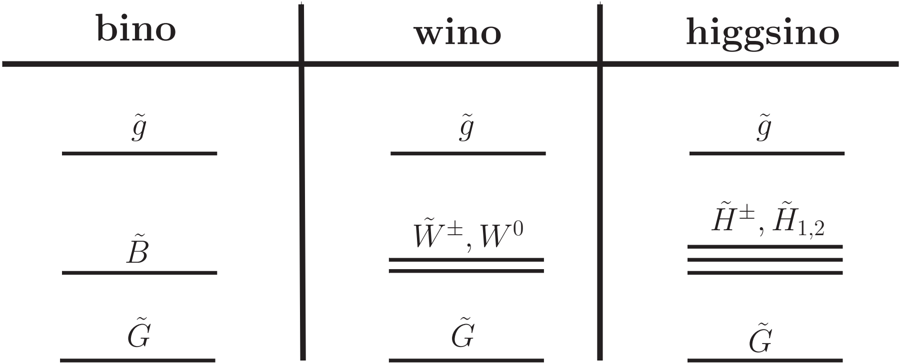
with branching ratios that depend on the neutralino mixing angles.

For simplicity I'm going to specialize to gauge eigenstates,

1. bino NLSP $\quad \tilde{B} \to \gamma, Z + \tilde{G}$
2. wino co-NLSP $\quad \tilde{W}^0 \to \gamma, Z + \tilde{G} \qquad \tilde{W}^\pm \to W^\pm + \tilde{G}$
3. higgsino NLSP $\quad \tilde{H}_1 \to Z, h + \tilde{G}$

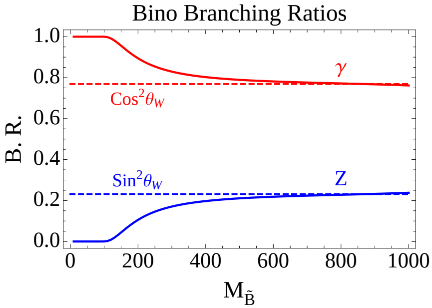
Simplified Models for Neutralino NLSPs

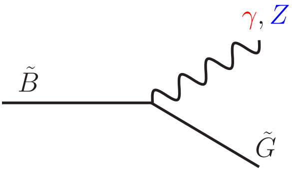
We consider the following three simplified models, which highlight colored production:



bino NLSP

The bino decays to a γ or Z and gravitino,



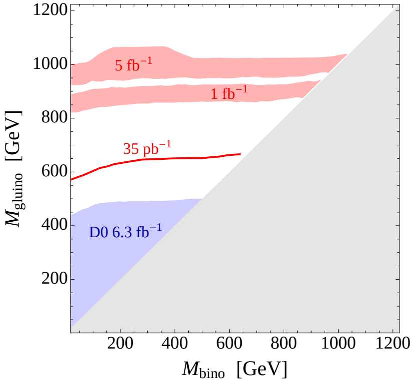


The discovery channel is,

$$\gamma\gamma + \not{E}_T$$

Tevatron Limit and LHC Search

PGS



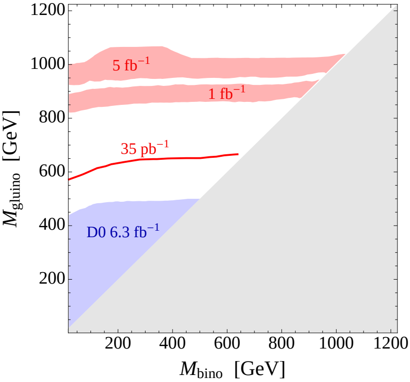
example LHC cuts:

$$p_T^{\gamma_{1,2}} > 50 \text{ GeV}$$

$$\not{E}_{\mathrm{T}} > 100 \text{ GeV}$$

Tevatron Limit and LHC Search

PGS

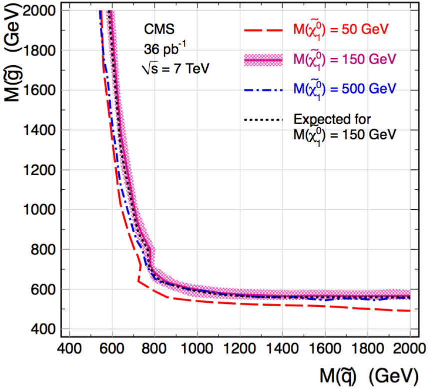


example LHC cuts:

$$p_T^{\gamma_{1,2}} > 50 \text{ GeV}$$

$$\not{E}_T > 100 \text{ GeV}$$

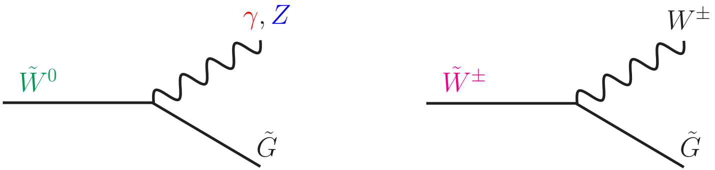
real life (CMS: **1103.0953**)



see Rachel Yohay's talk

wino co-NLSPs

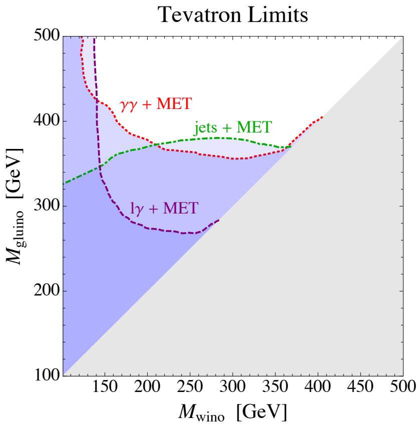
The neutral and charged wino are nearly degenerate, $\Delta m_{\tilde{W}} \sim m_Z^4/\mu^3$, so both prefer to decay directly to the gravitino.



The leading channels are:

- $\gamma\gamma + \not{E}_{\mathrm{T}}$
- $l^\pm\gamma + \not{E}_{\mathrm{T}}$
- $\mathrm{jets} + \not{E}_{\mathrm{T}}$

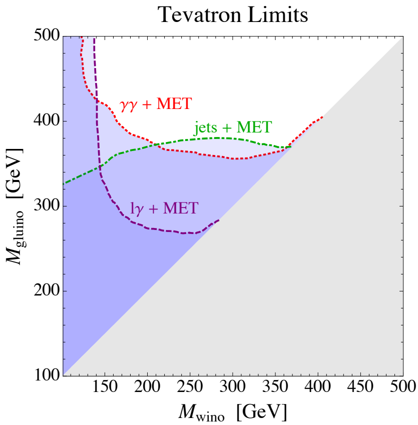
Tevatron Limit and LHC Search

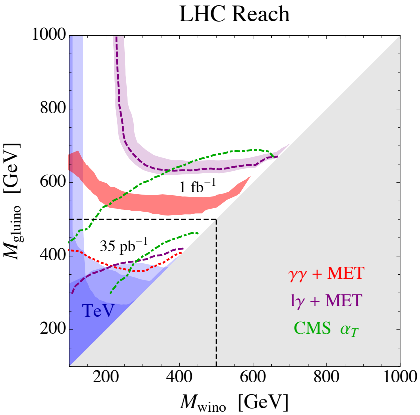


Tevatron searches:

1. $\gamma\gamma + \not{E}_{\rm T}$, $D0$ 6.3 fb^{-1}
2. $l^{\pm}\gamma + \not{E}_{\rm T}$, $D0$ 0.93 fb^{-1}
3. jets $+ \not{E}_{\rm T}$, CDF 2.1 fb^{-1}

Tevatron Limit and LHC Search





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example LHC cuts: $l\gamma$

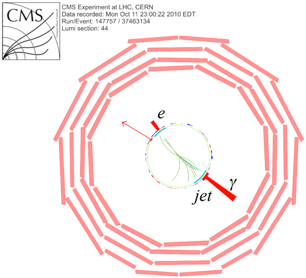
$p_T^l > 25$ GeV $\quad p_T^\gamma > 80$ GeV

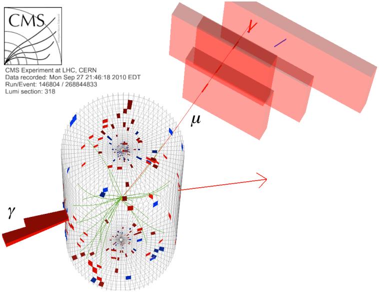
$\not{E}_T > 100$ GeV

$m_T > 100$ GeV

CMS $l + \gamma$ search

CMS is finalizing a search in the $l + \gamma$ channel, motivated by GMSB with wino co-NLSPs.

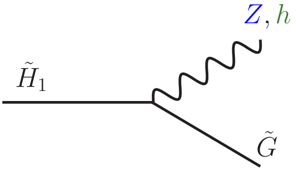




see Rachel Yohay's talk

higgsino NLSP

The lightest neutral Higgsino, $\tilde{H}_1$, decays to a Z or h.



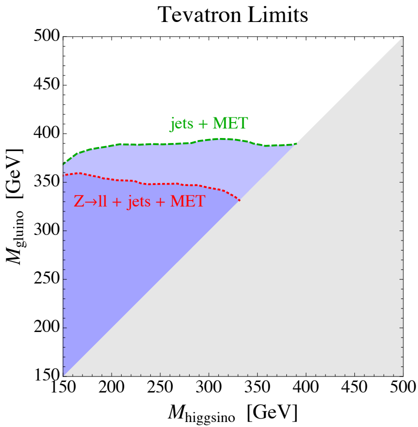
The branching fraction depends on $\tan\beta$ and $\mathrm{sign}(\mu)$.

Here we focus on the Z-rich regime, small $\tan\beta$ and $\mu > 0$

The leading LHC channels are:

- $Z \to l^+ l^- + \not{E}_\mathrm{T}$
- $(Z \to l^+ l^-)^2 + \not{E}_\mathrm{T}$
- $\mathrm{jets} + \not{E}_\mathrm{T}$

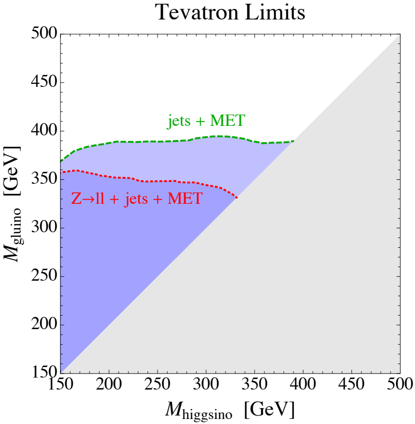
Tevatron Limit and LHC Reach

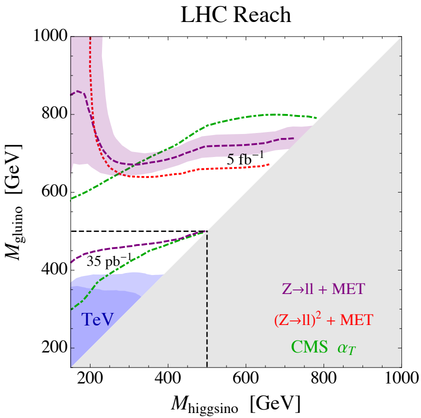


Tevatron searches:

1. $Z \to e^- e^+ + \text{jets} + \not{E}_T$, CDF 2.7 fb^{-1}
2. $\text{jets} + \not{E}_T$, CDF 2.1 fb^{-1}

Tevatron Limit and LHC Reach





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2. $\text{jets} + \not{E}_T$, CDF 2.1 fb^{-1}

example LHC cuts: $Z \to ll + \not{E}_T$

$p_T^l > 20$ GeV $\quad m_{ll} \in (85, 95)$ GeV

$\not{E}_T > 100$ GeV

$H_T > 100$ GeV

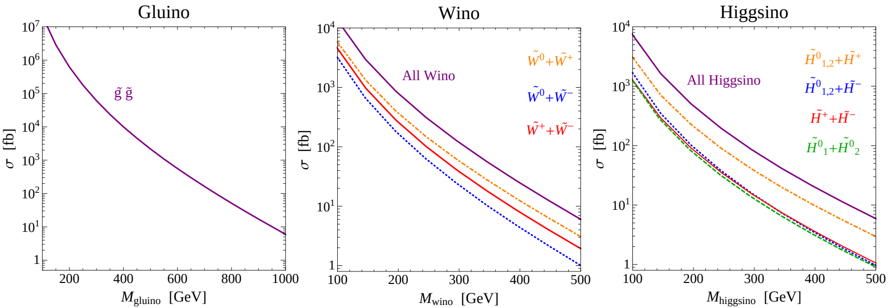
LHC Wishlish to discover Neutralino NLSPs

Let me conclude with a wishlish,

channel	LHC 35/pb	bino	wino	Z-rich higgsino	other higgsino
$\gamma\gamma + \not{E}_T$	✓	•			
$\ell\gamma + \not{E}_T$	✓		•		
jets + $\not{E}_T$	✓		•	•	•
$Z(\ell^+\ell^-) + \text{jets} + \not{E}_T$				•	
$Z(\ell^+\ell^-)Z(\ell'^+\ell'^-) + \not{E}_T$				•	
$Z(\ell^+\ell^-)h(b\bar{b}) + \not{E}_T$					•
$h(b\bar{b})h(b\bar{b}) + \not{E}_T$					•
$\gamma + h(b\bar{b}) + \not{E}_T$					•
$\gamma + \text{jets} + \not{E}_T$		•	•		•
$\ell + \text{jets} + \not{E}_T$	✓		•		

Backup Slides

Cross-Sections



Tevatron:

The strongest limit is by D0 with 6.3 fb $^{-1}$ (**1008.2133**).

$$N_\gamma \geq 2$$
$$p_T^\gamma > 25 \text{ GeV}, |\eta^\gamma| < 1.1$$
$$\not{E}_\mathrm{T} > 75 \text{ GeV}$$

$$N_\mathrm{data}{=}1$$
$$\sigma_\mathrm{back} = 0.3 \text{ fb}$$

Searching for Bino NLSP

Tevatron:

The strongest limit is by D0 with 6.3 fb $^{-1}$ (**1008.2133**).

$$N_\gamma \geq 2$$
$$p_T^\gamma > 25 \text{ GeV}, \; |\eta^\gamma| < 1.1$$
$$\not{E}_\mathrm{T} > 75 \text{ GeV}$$

$$N_\mathrm{data}=1$$
$$\sigma_\mathrm{back} = 0.3 \text{ fb}$$

LHC:

We will use the example LHC cuts:

$$N_\gamma \geq 2$$
$$p_T^\gamma > 50 \text{ GeV}, \; |\eta^\gamma| < 1.5$$
$$\not{E}_\mathrm{T} > 100 \text{ GeV}$$

The background is dominated by QCD, which is hard to simulate.

Instead I'll consider the range $\sigma_\mathrm{back} = 1 - 10$ fb.

Searching for Wino co-NLSP

Tevatron:

1. $\gamma\gamma$ from above
2. *D*0 jets + $\not\!\!E_{\rm T}$, 2.1 fb^{-1}

   2,3,4 jet channels requiring $\not\!\!E_{\rm T} > 100, 175, 225$ GeV
3. CDF *l* $+ \gamma$ search, 0.93 fb^{-1}

   increase $\not\!\!E_{\rm T}$ cut from 25 to 50 GeV

Searching for Wino co-NLSP

Tevatron:

1. $\gamma\gamma$ from above
2. $D0$ jets + $\not{E}_T$, 2.1 fb^{-1}

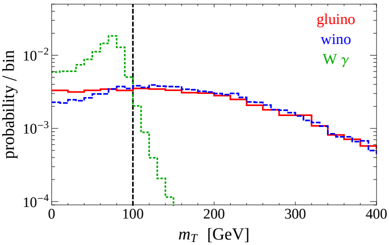
   2,3,4 jet channels requiring $\not{E}_T > 100, 175, 225$ GeV
3. CDF $l + \gamma$ search, 0.93 fb^{-1}

   increase $\not{E}_T$ cut from 25 to 50 GeV

LHC:

1. $\gamma\gamma$ from above
2. $l + \gamma + \not{E}_T$

$p_T^l > 25$ GeV and $p_T^\gamma > 80$ GeV
$\not{E}_T > 100$ GeV
$m_T > 100$ GeV



3. CMS α_T search, 35 pb^{-1}

Tevatron:

1. CDF search with 3 fb^{-1} for $(Z \to e^+e^-) + (W \to jj) + \not{E}_{\mathrm{T}}$,
2. $D0$ jets + $\not{E}_{\mathrm{T}}$, 2.1 fb^{-1}

Searching for Higgsino NLSP

Tevatron:

1. CDF search with 3 fb^{-1} for $(Z \to e^+e^-) + (W \to jj) + \not{E}_{\mathrm{T}}$,
2. $D0$ jets $+ \not{E}_{\mathrm{T}}$, 2.1 fb^{-1}

LHC:

- $Z \to l^+l^- + \not{E}_{\mathrm{T}}$

$p_T^{l_i} > 20$ GeV
$m_{ll} \in (85, 95)$ GeV
$H_T > 100$ GeV
$\not{E}_{\mathrm{T}} > 100$ GeV

- $(Z \to l^+l^-)^2 + \not{E}_{\mathrm{T}}$
- CMS α_T

Search Backgrounds (after cuts)

- $\gamma\gamma + \not{E}_{\mathrm{T}}$

  guess: $\sigma_{\mathrm{back}} \sim 1 - 10$ fb

- $l^{\pm}\gamma + \not{E}_{\mathrm{T}}$

  We used Madgraph to simulate the $l\gamma$ backgrounds: $W\gamma$, $t\bar{t}\gamma$, $t\bar{t}$ (+ fake $e \to \gamma$).

  Their sum is about $\sigma \sim 1.4$ fb.

- $Z \to l^{+}l^{-} + \not{E}_{\mathrm{T}}$

  We estimate the biggest backgrounds to be:

  $t\bar{t}$, $\sigma \sim 20$ fb

  dibosons, $\sigma \sim 7$ fb.