A Truth-level Study of GMSB in ATLAS

using $Z(\ell^+\ell^-)+ \not{E}_T$ final state; $\ell = \mu, e$

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August 13, 2009

Preliminaries

- In GMSB, “Messengers” communicate SUSY breaking to super particles
- There are four super particles called neutralinos $(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0)$, labeled in order of increasing mass
- Neutralinos are **Mass** Eigenstates. Each is a mixture of the **Weak** eigenstates: gauginos $(\tilde{W}, \tilde{B})$ and neutral Higgsinos $(\tilde{H}_u^0, \tilde{H}_d^0)$
- “Higgsino-like” Neutralino *means* that the Neutralino has a large component of the Higgsino weak eigenstates
- In any SUSY model, the sparticles cascade decay to the NLSP, which then decays to its standard model partner and the LSP
- In this GMSB “Model Line” the LSP is the gravitino $\tilde{G}$ and the NLSP is $\tilde{\chi}_1^0$

Mass Spectrum Generation

- Generated mass spectrum corresponding to GMSB parameters from Model Line E[1]

Λ	M	N_5	$\tan(\beta)$	μ	C_{grav}
80 TeV	3Λ	2	3	$\frac{3}{4}M_1$=169 GeV	1

- This point in parameter space corresponds to

Paricle	**Mass**
$\tilde{G}$ (LSP)	4.62 eV
$\tilde{\chi}_1^0$ (NLSP)	134.7 GeV
$\tilde{\chi}_4^0$	443.3 GeV
$\tilde{C}_2^{\pm}$	442.9 GeV

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[1] H. Baer *et al.*, Phys. Rev. D **62** (2000)

Event Generation and Preselection

Generation

- Generated 75000 events of the process $pp \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$ based on the SUSY mass spectrum with ATLAS Athena 14.2.25.9
- **Forced** $Z \rightarrow \ell\ell$, $\ell = \mu, e$ decay mode (to save time in event generation)
- For 10 TeV, $\sigma(pp \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0) = 1.88$ pb.

Preselection

- $|\eta(\mu/e)| < 2.5$
- $p_T(\mu/e) > 6$ GeV

Different Production Mechanisms

We separated the SUSY data sample by (1) parent of Z and (2) initial production mechanism. Then we looked at the differences in kinematics.

For the parent of Z, we looked at two channels:
parent is $\tilde{\chi}_1^0$ or
parent is one of $\{\tilde{C}_2^{\pm}, \tilde{\chi}_4^0\}$.

For the initial production, we looked at two channels:
Strong, i.e. first two particles can be $\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$
Weak, i.e. first two particles in chain can be $\tilde{\chi}_i^0\tilde{\chi}_j^0 + \tilde{\chi}_i^0\tilde{C}_j^{\pm} + \tilde{C}_i^{\pm}\tilde{C}_j^{\pm}$

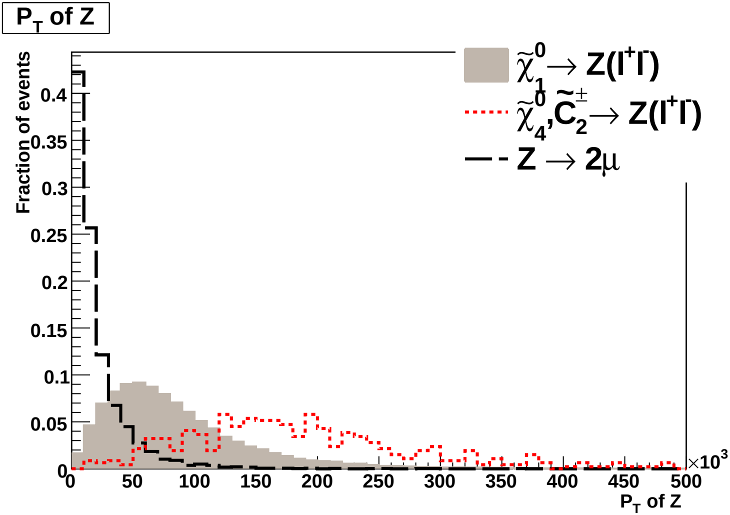
Main background of Standard Model Inclusive Z is plotted alongside signal. All histograms are normalized to 1 for shape comparison.

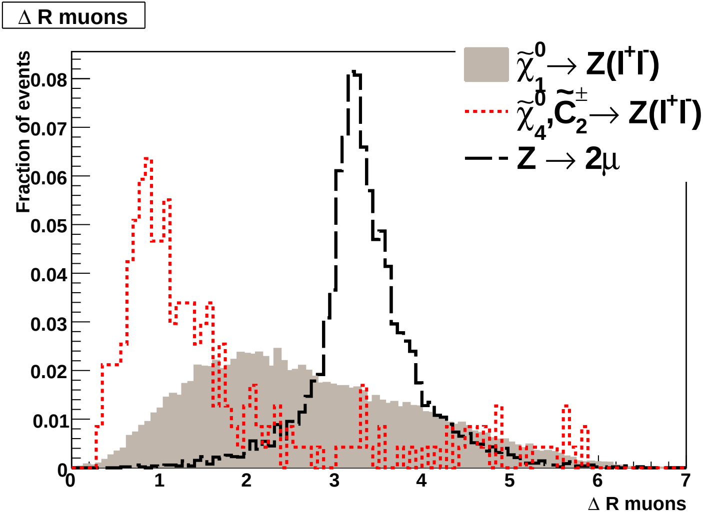
Different Production Mechanisms

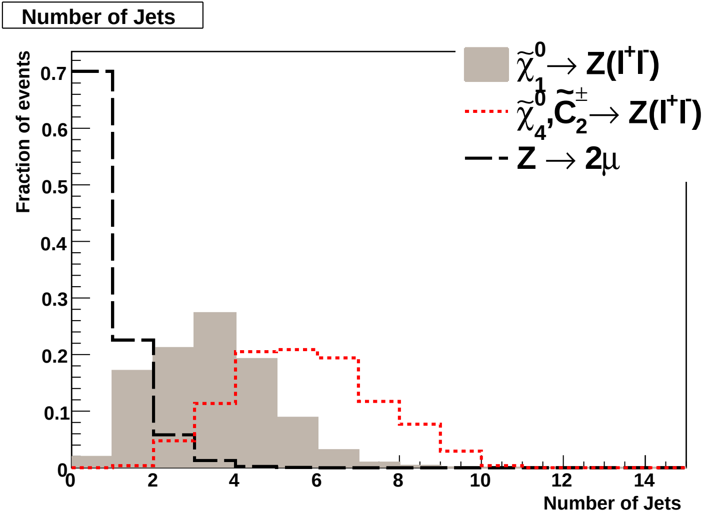
75000 events generated (forced $Z \to \ell\ell$ decay)
40211 events pass preselection

Parent of Z		
Process	Rate	Cross-Section
$\tilde{\chi}_1^0 \to Z(\ell^+\ell^-)\tilde{G}$	39216 52%	66 fb
$\tilde{\chi}_4^0, \tilde{C}_2^\pm \to Z(\ell^+\ell^-)X$	993 1.3%	1.7 fb

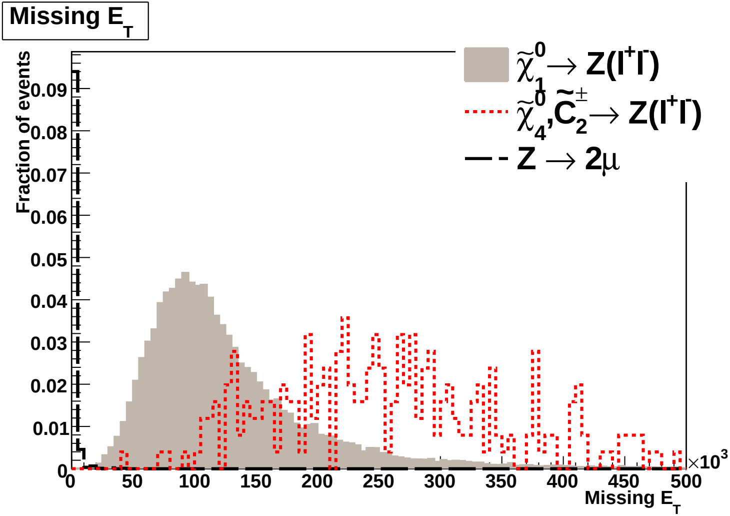
Initial Production in Decay Chain		
Process	Rate	Cross-Section
$q\bar{q} \to \tilde{\chi}_i^0\tilde{\chi}_j^0 + \tilde{\chi}_i^0\tilde{C}_j^\pm + \tilde{C}_i^\pm\tilde{C}_j^\pm$	37651 50%	63 fb
$q\bar{q} \to \tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$	790 1.0%	1.3 fb


P$_T$ of Z
Fraction of events
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
50
100
150
200
250
300
350
400
450
500
×10^3
P$_T$ of Z
$\tilde{\chi}_1^0 \rightarrow Z(l^+l^-)$
$\tilde{\chi}_4^0, \tilde{C}_2^\pm \rightarrow Z(l^+l^-)$
$Z \rightarrow 2\mu$


Δ R muons
Fraction of events
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0
1
2
3
4
5
6
7
Δ R muons
$\tilde{\chi}_1^0 \rightarrow Z(l^+l^-)$
$\tilde{\chi}_4^0, \tilde{C}_2^{\pm} \rightarrow Z(l^+l^-)$
$Z \rightarrow 2\mu$



$E_T(jet) > 20$ GeV for N_j variable

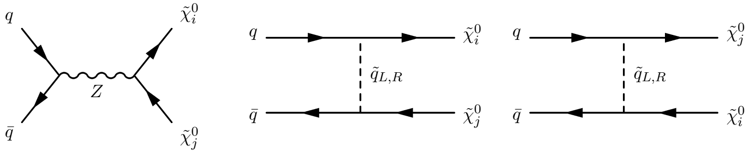

Missing E_T
Fraction of events
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
$\tilde{\chi}_1^0 \to Z(l^+l^-)$
$\tilde{\chi}_4^0, \tilde{C}_2^\pm \to Z(l^+l^-)$
$Z \to 2\mu$
0
50
100
150
200
250
300
350
400
450
500
$\times 10^3$
Missing E_T

Different Production Mechanisms

- Due to the greater momentum transfer for more massive parents $\{\tilde{C}_2^{\pm}, \tilde{\chi}_4^0\}$, these events are easier to discriminate from SM inclusive Z background.
- However, the rate for events with more massive parent is much smaller than for NLSP.
- Variables with very clean separation include Number of Jets, ΣE_T of Jets, Missing E_T, and ΔR between muons.

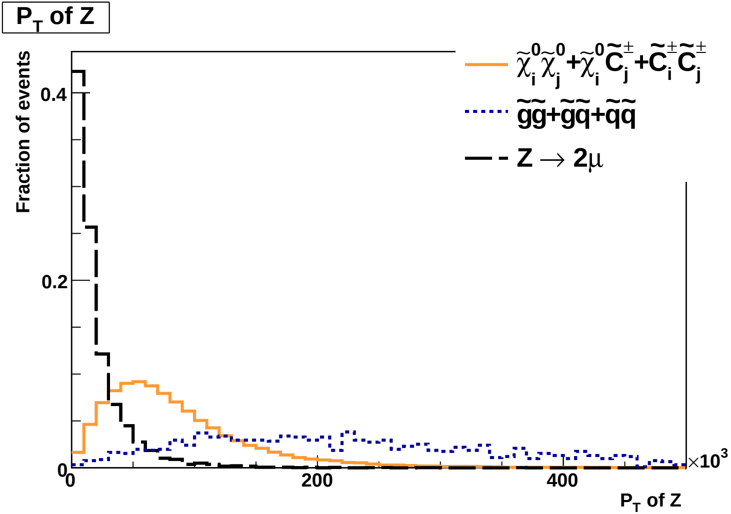
Different Production Mechanisms

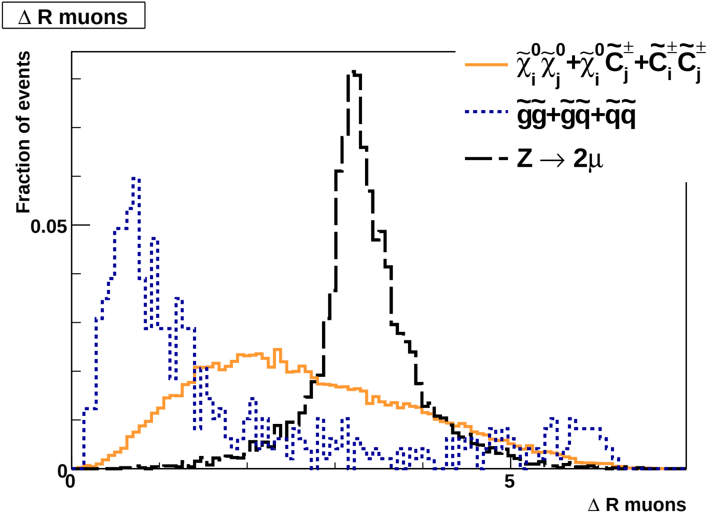
Next we separated the signal between
Strong production ($\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$) and
Weak production ($\tilde{\chi}_i^0\tilde{\chi}_j^0 + \tilde{\chi}_i^0\tilde{C}_j^\pm + \tilde{C}_i^\pm\tilde{C}_j^\pm$).

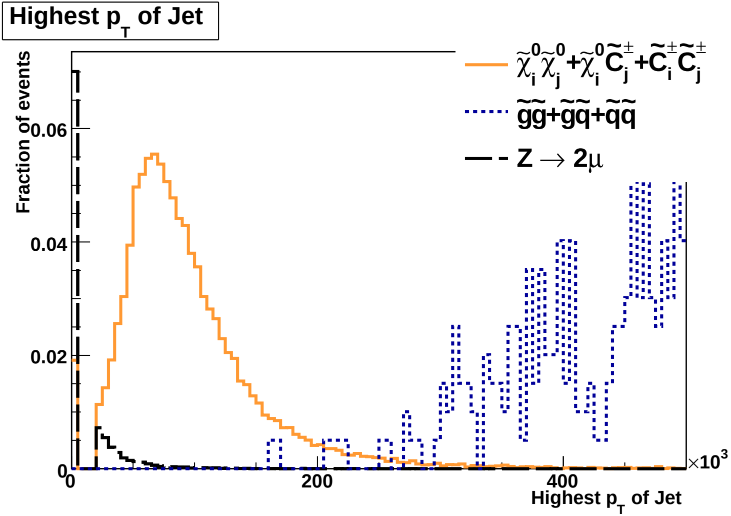


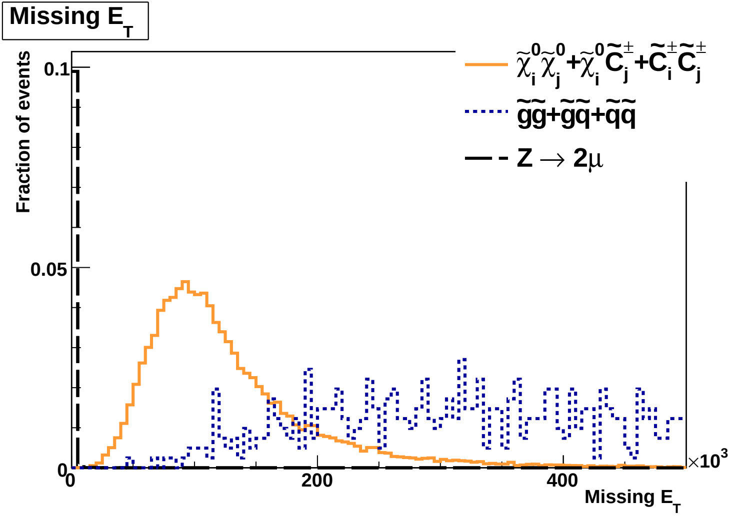
Example of Neutralino-Neutralino production in GMSB

Likewise, SM Inclusive Z is plotted alongside signal.


P_T of Z
Fraction of events
0.4
0.2
0
0
200
400
$\times 10^3$
P_T of Z
$\tilde{\chi}_i^0\tilde{\chi}_j^0+\tilde{\chi}_i^0\tilde{C}_j^\pm+\tilde{C}_i^\pm\tilde{C}_j^\pm$
$\tilde{g}\tilde{g}+\tilde{g}\tilde{q}+\tilde{q}\tilde{q}$
$Z \rightarrow 2\mu$


Δ R muons
Fraction of events
0.05
0
0
5
Δ R muons
$\tilde{\chi}_i^0\tilde{\chi}_j^0+\tilde{\chi}_i^0\tilde{C}_j^\pm+\tilde{C}_i^\pm\tilde{C}_j^\pm$
$\tilde{g}\tilde{g}+\tilde{g}\tilde{q}+\tilde{q}\tilde{q}$
$Z \to 2\mu$


Highest p_T of Jet
$\tilde{\chi}_i^0\tilde{\chi}_j^0+\tilde{\chi}_i^0\tilde{C}_j^\pm+\tilde{C}_i^\pm\tilde{C}_j^\pm$
$\tilde{g}\tilde{g}+\tilde{g}\tilde{q}+\tilde{q}\tilde{q}$
$Z \rightarrow 2\mu$
Fraction of events
0.06
0.04
0.02
0
0
200
400
$\times10^3$
Highest p_T of Jet


Missing E_T
Fraction of events
0.1
0.05
0
0
200
400
$\times 10^3$
Missing E_T
$\tilde{\chi}_i^0 \tilde{\chi}_j^0 + \tilde{\chi}_i^0 \tilde{C}_j^\pm + \tilde{C}_i^\pm \tilde{C}_j^\pm$
$\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$
$Z \rightarrow 2\mu$

Conclusions

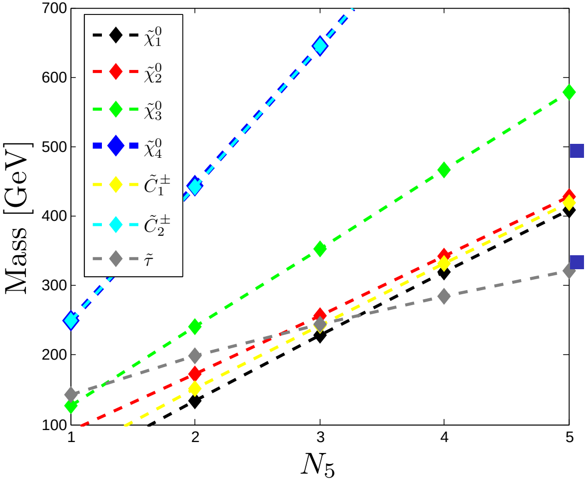
- Although strong production has a much smaller cross-section than weak production (1 fb vs 60 fb), it is easier to distinguish from background.
- Variables with very clean separation include Number of Jets, ΣE_T of Jets, Missing E_T, and ΔR between muons.

Expanding Parameter Space

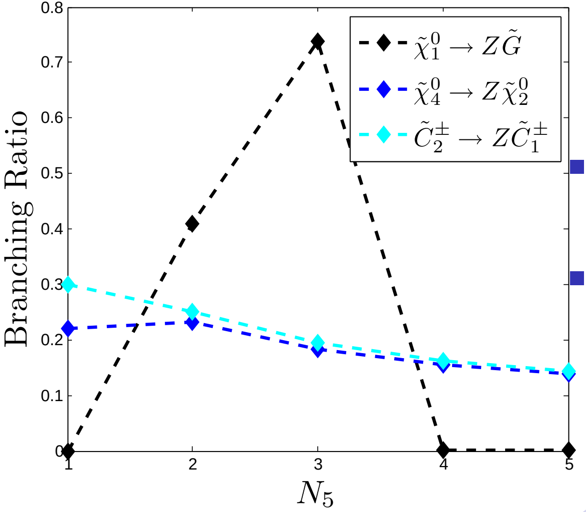
- We chose one point in parameter space along this "Model Line"

Λ	M	N_5	$\tan(\beta)$	μ	C_{grav}
80 TeV	3Λ	2	3	$\frac{3}{4}M_1$=169 GeV	1

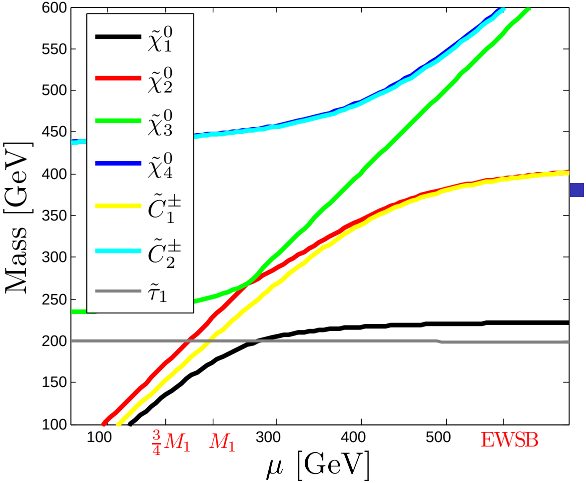
- M_1 is the gaugino mass and it depends on the other parameters
- In this model line, Λ = 80 TeV balances a high branching ratio $\mathrm{Br}(\tilde{\chi}_1^0 \rightarrow \tilde{G}Z)$ and a high neutralino production cross section - so it is fixed
- We varied Number of Messengers N_5, μ, and $\tan(\beta)$
- Since the kinematics depend heavily on the masses and branching ratios of NLSP among other particles, we plot these.



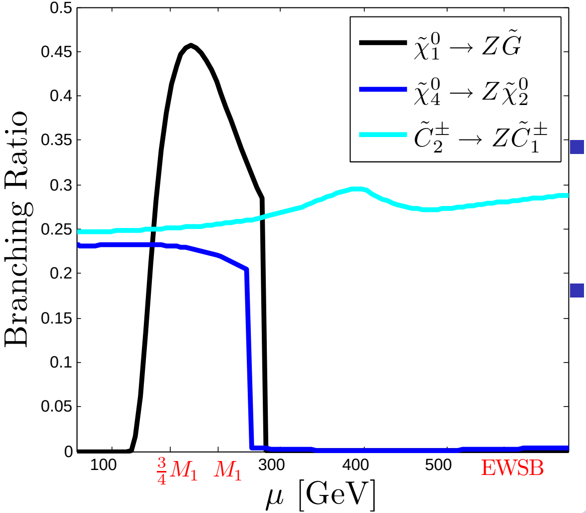
- For $N_5 = 1$, the mass of the $\tilde{\chi}_1^0$ is too small to decay to Z
- For $N_5 > 4$, the $\tilde{\tau}_1$ becomes the NLSP



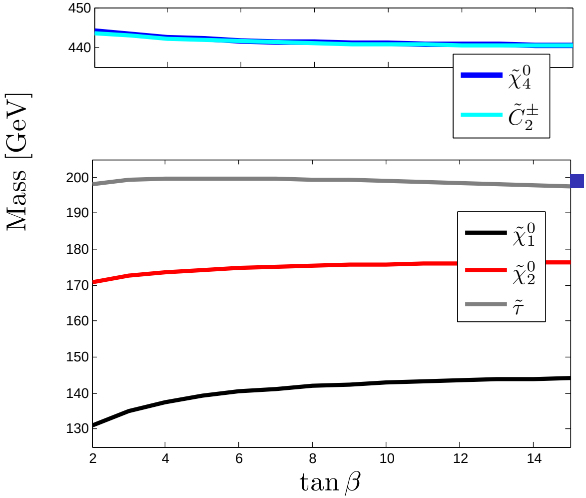
- For $N_5 = 1$, the mass of the $\tilde{\chi}_1^0$ is too small to decay to Z
- For $N_5 > 4$, the $\tilde{\tau}_1$ becomes the NLSP



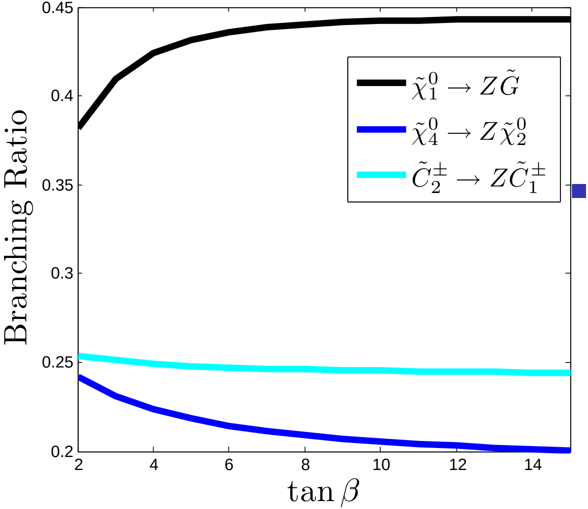
- As μ becomes greater than ~ 300 GeV, the $\tilde{\tau}_1$ becomes the NLSP



- μ has the power to make the $\tilde{\chi}_1^0$ Higgsino-like or Bino-like
- As μ becomes larger, $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ dominates



- Relatively little change in masses of sparticles over this range of tan(β)



- Branching ratio of NLSP to *Z* actually improves as tan(β) increases

Conclusions

- Only $N_5 = 2, 3$ is relevant for this study (NLSP to Z branching ratio zero otherwise)
- Masses of relevant sparticles increase linearly with N_5, thus reconstruction would have to change for $N_5 = 3$
- Branching ratios to Z and sparticle masses vary little from $\tan(\beta) = 2$ to 15.

Acknowledgements

Dr. Natalia Panikashvilli

Professor Homer Neal

Professor Jean Krisch

Professor Myron Campbell

Jeremy Herr

Fellow REU Students

Backup