Discovery Potential for Slepton LSPs in R-Parity Violating SUSY

Sebastian Grab

Santa Cruz Institute for Particle Physics
University of California, Santa Cruz

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Alexander von Humboldt
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in collaboration with
K. Desch, *H. Dreiner*, *S. Fleischmann*
and *T. Stefaniak*

Outline

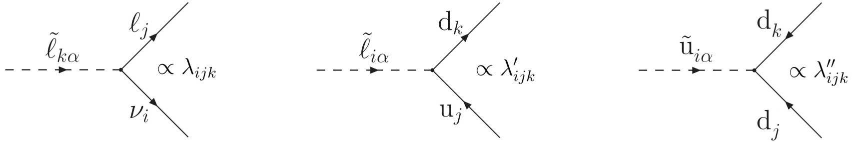
1. Introduction
   - R-Parity Violation
   - LSP Candidates
2. Stau LSPs at the LHC
   - Multi Lepton Final States
   - Discovery Potential with Early LHC Data
3. Summary and Outlook

MSSM with R-parity violation (RPV)

General superpotential of the MSSM superfields:

$$W_{R_p} = (\mathbf{Y}_E)_{ij} L_i H_d \bar{E}_j + (\mathbf{Y}_D)_{ij} Q_i H_d \bar{D}_j + (\mathbf{Y}_U)_{ij} Q_i H_u \bar{U}_j + \mu H_d H_u \,,$$

$$W_{\not R_p} = \underbrace{\frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k}_{\Delta L \neq 0} + \underbrace{\frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{\Delta B \neq 0} + \underbrace{\kappa_i L_i H_u}_{\Delta L \neq 0} .$$



The lepton/baryon number violating terms lead to proton decay.
It is sufficient to suppress $\Delta L \neq 0$ or $\Delta B \neq 0$ terms to keep proton stable.
[Dreiner, Luhn, Thormeier, Phys.Rev.D73:075007,2006]

Effects of RPV

What will change if R-parity is violated?

- Sparticles can be produced singly, possible on resonance.
- Neutrino masses can be generated.
- The RGEs get additional contributions.
- The lightest supersymmetric particle (LSP) is not stable anymore.
  $\Rightarrow$ The LSP is no dark matter (DM) candidate.
  $\Rightarrow$ The LSP can be charged.

LSP candidates

$$\tilde{\chi}_1^0,\ \tilde{\chi}_1^\pm,\ \tilde{\ell}^\pm_{L/Rj},\ \tilde{\tau}_1,\ \tilde{\nu}_i,\ \tilde{q}_{L/Rj},\ \tilde{b}_1,\ \tilde{t}_1,\ \tilde{g}$$

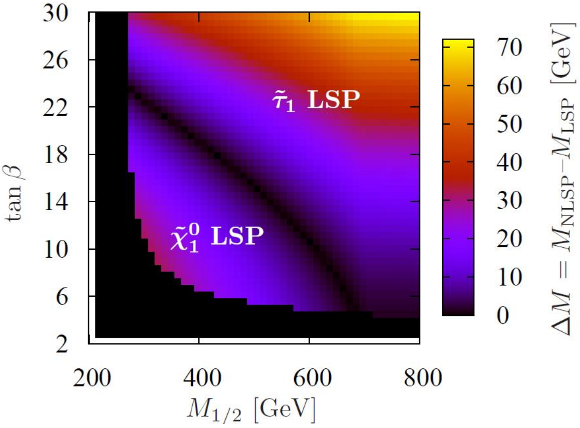
Potential other DM RPV candidates:

- Axino [Chun, Kim, Phys.Rev.D60:095006,1999]
- LUP in the UMSSM [Lee, Phys.Lett.B663:255,2008]

$\tilde{\chi}_1^0$ LSP versus $\tilde{\tau}_1$ LSP

Assume mSUGRA framework [Allanach, Dedes, Dreiner, Phys.Rev.D69:115002,2004].

$$\lambda \lesssim \mathcal{O}(10^{-2}),\ M_0 = 100\text{ GeV},\ A_0 = -100\text{ GeV},\ \mu > 0.$$



$\Rightarrow$ $\tilde{\tau}_1$ LSP as well motivated as $\tilde{\chi}_1^0$ LSP.

What is the $\tilde{\tau}_1$ LSP discovery potential
with early LHC data?

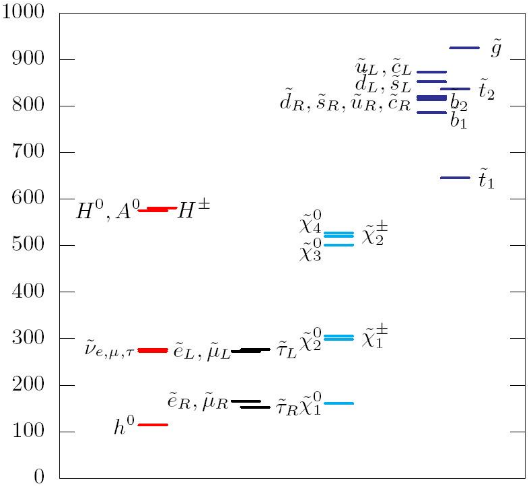
[Desch, Dreiner, Fleischmann, SG, arXiv:1006.xxxx [hep-ph]]

Benchmark scenario BC1

BC1

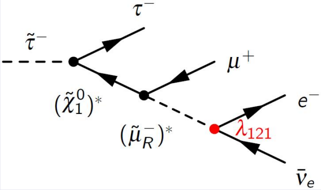
- $M_0 = A_0 = 0$
- $\lambda_{121} = 0.032$
- $\tan\beta = 13$
- $M_{1/2} = 400$ GeV
- $\text{sgn}(\mu) = +1.$

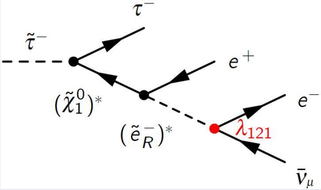
[Allanach et. al., Phys.Rev.D75:035002,2007]



LHC Phenomenology of BC1

4-body decay of $\tilde{\tau}_1$ LSP





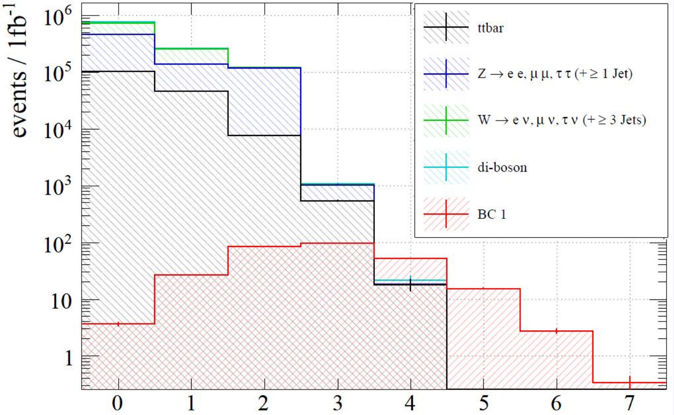
Promising LHC signatures:

$$PP \to \tilde{q}_R \tilde{q}_R$$
$$\to (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$$
$$\to (q\tau\tilde{\tau}_1)(q\tau\tilde{\tau}_1)$$
$$\xrightarrow{\lambda_{121}} (q\tau\tau\ell\ell\nu)(q\tau\tau\ell\ell\nu)$$

- Excess of electrons and muons.
- Easy to identify in early LHC data.

Electron Multiplicity at $\sqrt{S} = 7$ TeV for BC1

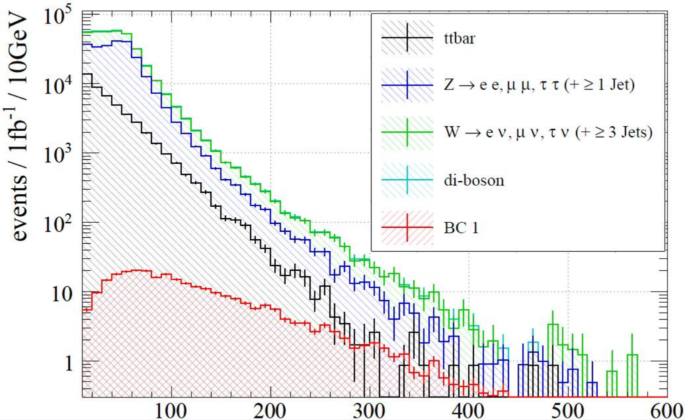
isolated electrons with $p_T > 7$ GeV and $|\eta| < 2.5$



Note: Fast detector simulation included using `Delphes`.
[Ovyn, Rouby, Lemaitre, arXiv:0903.2225 [hep-ph]]

Electron p_T Distribution at $\sqrt{S} = 7$ TeV for BC1

p_T of hardest electron



Note: Fast detector simulation included using `Delphes`.
[Ovyn, Rouby, Lemaitre, arXiv:0903.2225 [hep-ph]]

Cutflow for BC1

$\#$ events for $1\mathrm{fb}^{-1}$ at $\sqrt{S} = 7$ TeV.

cut	signal	$t\bar{t}$	$S/\sqrt{B}$
no cuts	283	156000	0.2
$p_T(1st\,\mu^{\pm}) > 40$ GeV	142	16745	0.3
$p_T(1st\,e^{\pm}) > 32$ GeV	126	1492	2.9
$p_T(2nd\,e^{\pm}) > 7$ GeV	114	166	8.4
$\sum p_T^{\ell} > 230$ GeV	86	14	22
$HT' > 300$ GeV	57	3.4	31

with HT' the p_T sum of the four hardest jets.

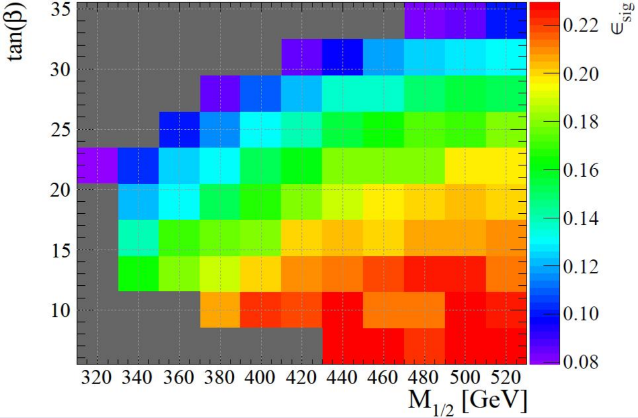
$\Rightarrow$ $S/B \approx 17$.

$\Rightarrow$ Systematic uncertainty of SM backgrounds not problematic.

$\Rightarrow$ Discovery of BC1 possible with early data!

Discovery Potential at $\sqrt{S} = 7$ TeV

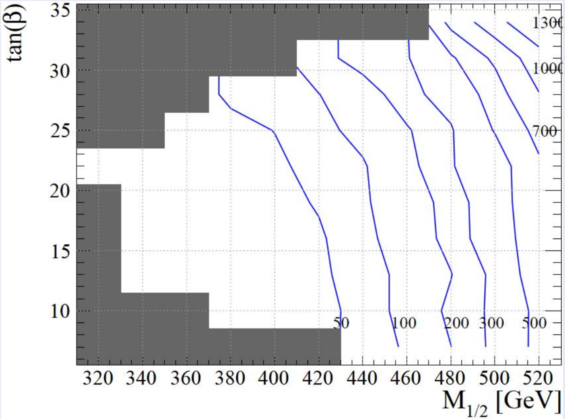
selection efficiency for signal



- Cuts work well beyond BC1.
- Efficiency better for low $\tan\beta$ ($\rightarrow$ heavier $\tilde{\tau}_1$ LSP.).

Discovery Potential at $\sqrt{S} = 7$ TeV

minimal luminosity in pb^{-1} for $S/\sqrt{B} > 5$



- Scenarios with $\tilde{m}_{\text{squark}} \lesssim 1$ TeV can be tested with $200\mathrm{pb}^{-1}$.
- Low-tan β scenarios easier to discover ($\rightarrow$ heavier $\tilde{\tau}_1$ LSP).

Summary and Outlook

Summary

- Including R-parity violation allows $\tilde{\tau}_1$ LSP in mSUGRA.
- $\tilde{\tau}_1$ LSP might decay via 4-body decay.
- Promising LHC signature for early data:
  multi-lepton final states.
- Discovery with $\mathcal{O}(10\mathrm{pb}^{-1} - 100\mathrm{pb}^{-1})$ possible.

Outlook

- Scenario BC1 will be found or excluded next year!
- Investigate other decay modes of the $\tilde{\tau}_1$ LSP,
  e.g. $\tilde{\tau}_1 \to u\bar{d}$ via λ'_{311}.
- Investigate $\tilde{e}_R$ LSP scenarios.
  [Dreiner, SG, Stefaniak, work in progress]

$\tilde{\tau}_1$ LSP Decays via LLE

Assume: $PP \to \tilde{q}\tilde{q} \to (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0) \to (q\tau\tilde{\tau}_1)(q\tau\tilde{\tau}_1)$.

coupling	$\tilde{\tau}_1^+$ decay	LHC signature
$\lambda_{121} = -\lambda_{211}$	$\tau^+\mu^+e^-\bar{\nu}_e$ $\tau^+\mu^-e^+\nu_e$ $\tau^+e^+e^-\bar{\nu}_\mu$ $\tau^+e^-e^+\nu_\mu$	$2j + 4\tau + 4\ell + \not{E}_T$
$\lambda_{122} = -\lambda_{212}$	$\tau^+\mu^+\mu^-\bar{\nu}_e$ $\tau^+\mu^-\mu^+\nu_e$ $\tau^+e^+\mu^-\bar{\nu}_\mu$ $\tau^+e^-\mu^+\nu_\mu$	with $\ell = e, \mu$
$\lambda_{131} = -\lambda_{311}$	$e^+\nu_e$	
$\lambda_{132} = -\lambda_{312}$	$\mu^+\nu_e$	
$\lambda_{231} = -\lambda_{321}$	$e^+\nu_\mu$	$2j + 2\tau + 2\ell + \not{E}_T$
$\lambda_{232} = -\lambda_{322}$	$\mu^+\nu_\mu$	
$\lambda_{123} = -\lambda_{213}$	$\mu^+\bar{\nu}_e$ $e^+\bar{\nu}_\mu$	
$\lambda_{133} = -\lambda_{313}$	$e^+\bar{\nu}_\tau$ $\tau^+\bar{\nu}_e$ $\tau^+\nu_e$	$2j + 2\tau + 2\ell + \not{E}_T$ $2j + 3\tau + 1\ell + \not{E}_T$
$\lambda_{233} = -\lambda_{323}$	$\mu^+\bar{\nu}_\tau$ $\tau^+\bar{\nu}_\mu$ $\tau^+\nu_\mu$	$2j + 4\tau + \not{E}_T$

$\tilde{\tau}_1$ LSP Decays via LQD

Assume: $PP \to \tilde{q}\tilde{q} \to (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0) \to (q\tau\tilde{\tau}_1)(q\tau\tilde{\tau}_1)$.

coupling	$\tilde{\tau}_1^+$ decay	LHC signature
λ'_{1jk}	$\tau^+\bar{u}_j d_k e^+$	
	$\tau^+ u_j \bar{d}_k e^-$	
	$\tau^+\bar{d}_j d_k \bar{\nu}_e$	$6j + 4\tau + \ell\ell$
	$\tau^+ d_j \bar{d}_k \nu_e$	$6j + 4\tau + \ell + \not{E}_T$
λ'_{2jk}	$\tau^+\bar{u}_j d_k \mu^+$	$6j + 4\tau + \not{E}_T$
	$\tau^+ u_j \bar{d}_k \mu^-$	
	$\tau^+\bar{d}_j d_k \bar{\nu}_\mu$	
	$\tau^+ d_j \bar{d}_k \nu_\mu$	
λ'_{3jk}	$u_j \bar{d}_k$	$6j + 2\tau$

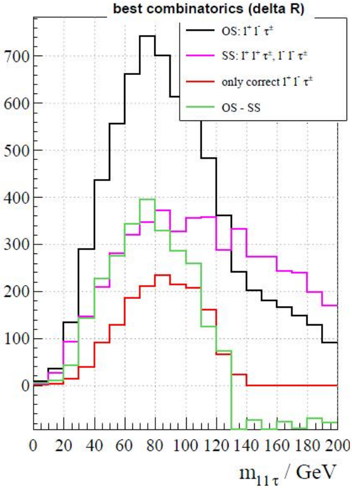
$\tilde{\tau}_1$ LSP Decays via UDD

Assume: $PP \to \tilde{q}\tilde{q} \to (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0) \to (q\tau\tilde{\tau}_1)(q\tau\tilde{\tau}_1)$.

coupling	$\tilde{\tau}_1^+$ decay	LHC signature
λ''_{ijk}	$\tau^+ u_i d_j d_k$	$8j + 2\tau$
	$\tau^+ \bar{u}_i \bar{d}_j \bar{d}_k$	

Mass Reconstruction in BC1

With 1000 signal events (after cuts):



strategy

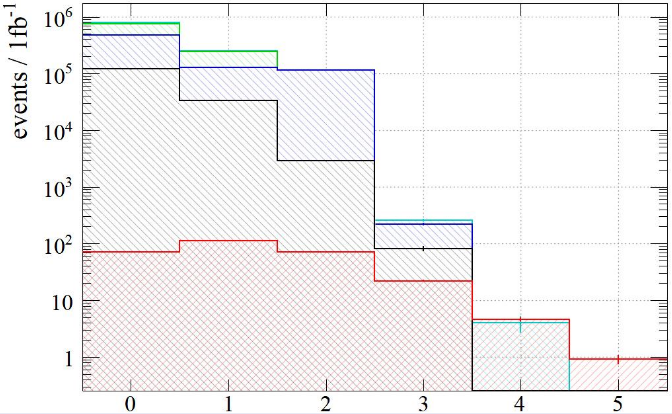
- Take hardest lepton.
- Find nearest lepton in ΔR with opposite charge.
- Find nearest tau lepton (to vector sum of leptons).

Note: $m_{\tilde{\tau}_1} = 147$ GeV.

$\Rightarrow$ Mass reconstruction difficult ($\rightarrow$ combinatorial backgrounds).

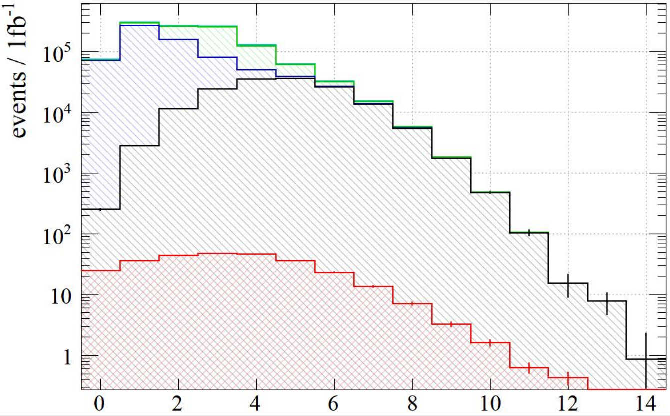
Muon Multiplicity at $\sqrt{S} = 7$ TeV for BC1

isolated muons with $p_T > 6$ GeV and $|\eta| < 2.7$



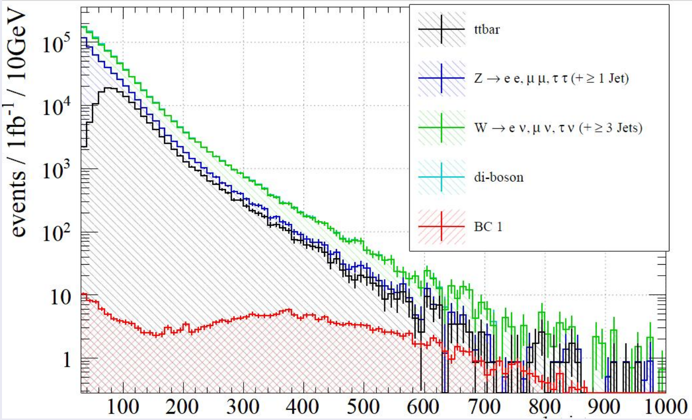
Jet Multiplicity at $\sqrt{S} = 7$ TeV for BC1

jets with $p_T > 20$ GeV and $|\eta| < 5.0$



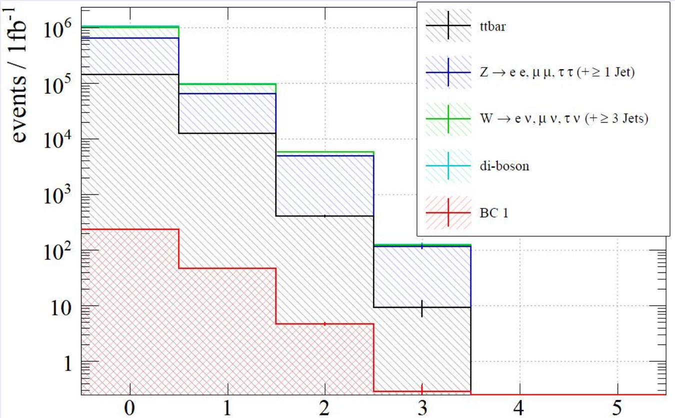
Jet p_T Distribution at $\sqrt{S} = 7$ TeV for BC1

p_T of hardest jet

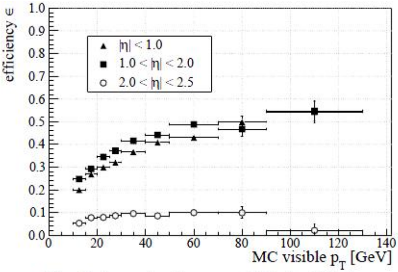


Tau Multiplicity at $\sqrt{S} = 7$ TeV for BC1

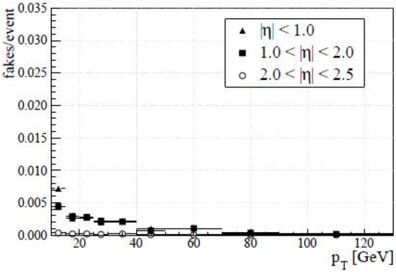
jets with $p_T > 10$ GeV and $|\eta| < 2.5$



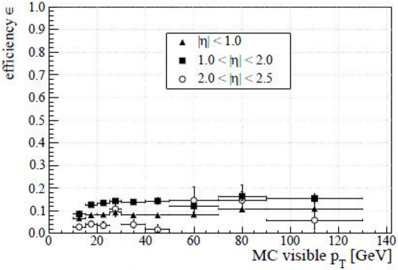
Tau ID with Delphes



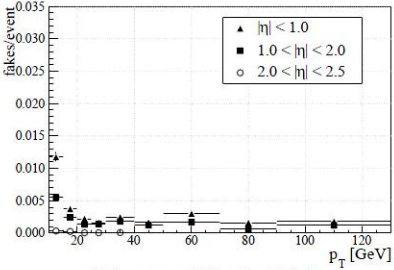
ID efficiency in $Z \to \tau\tau + 1\text{jet}$ for Delphes



Fake rate in $Z \to \tau\tau + 1\text{jet}$ for Delphes

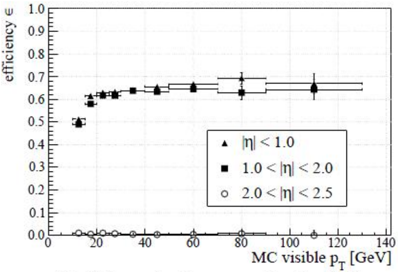


ID efficiency in BC 1 for Delphes

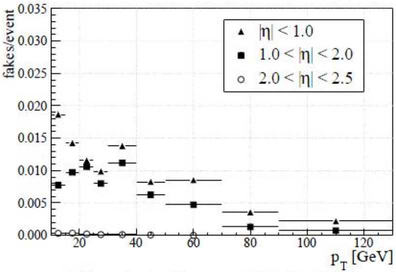


Fake rate in BC 1 for Delphes

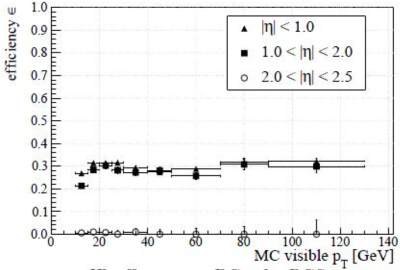
Tau ID with PGS



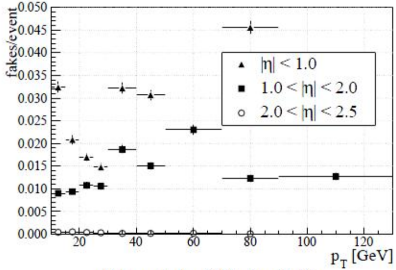
ID efficiency in $Z \to \tau\tau + 1$jet for PGS



Fake rate in $Z \to \tau\tau + 1$jet for PGS

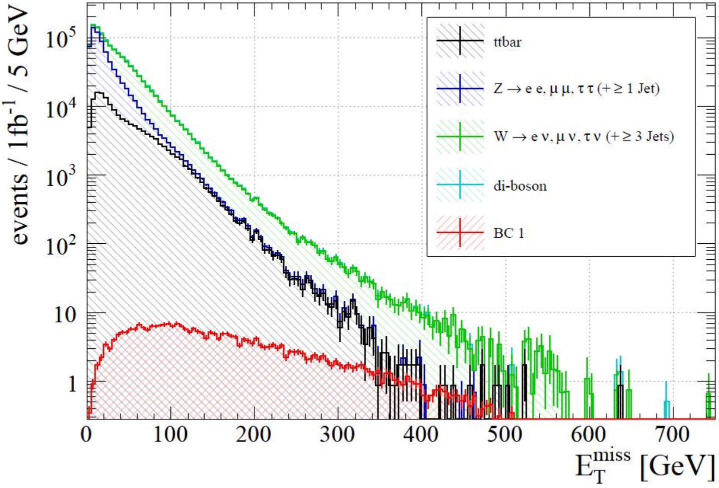


ID efficiency in BC 1 for PGS



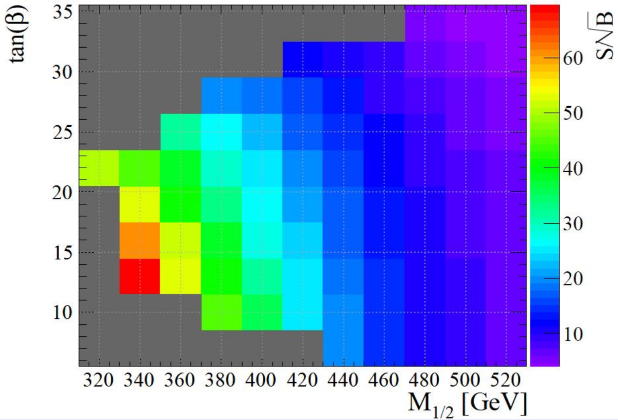
Fake rate in BC 1 for PGS

Missing Energy in BC1



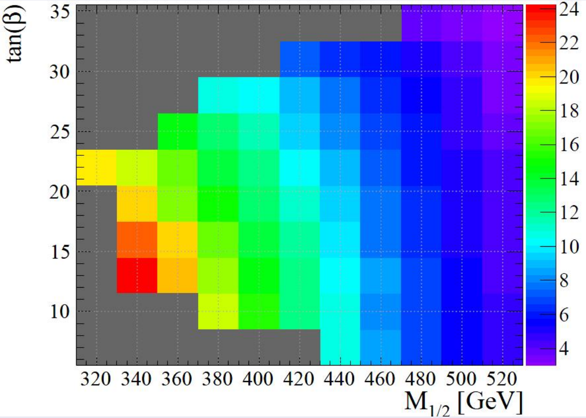
Discovery Potential at $\sqrt{S} = 7$ TeV

$S/\sqrt{B}$ for fb^{-1} at $\sqrt{S} = 7$ TeV.



Discovery Potential at $\sqrt{S} = 7$ TeV

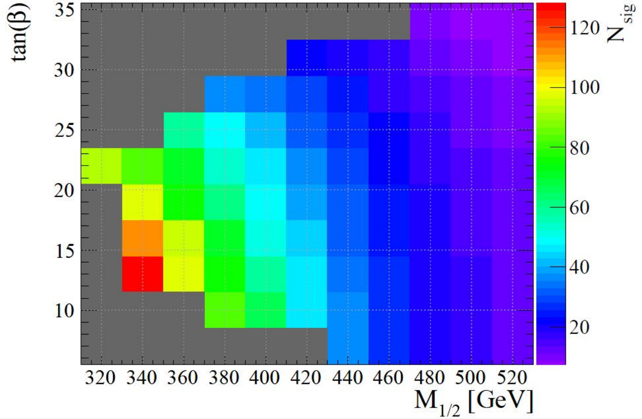
significance for fb^{-1} at $\sqrt{S} = 7$ TeV.



Significance includes 50% systematic uncertainty for SM backgrounds.

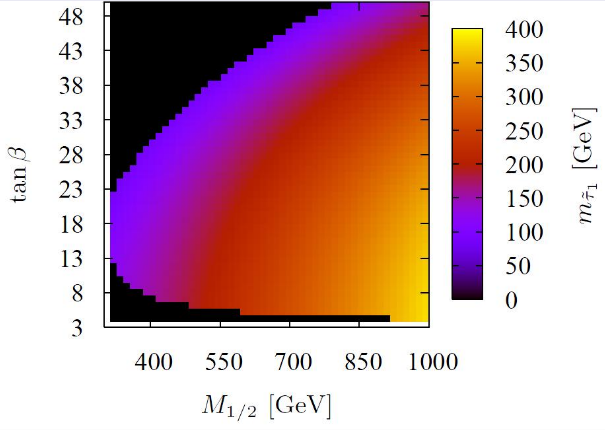
Discovery Potential at $\sqrt{S} = 7$ TeV

selected signal events for fb^{-1} at $\sqrt{S} = 7$ TeV.

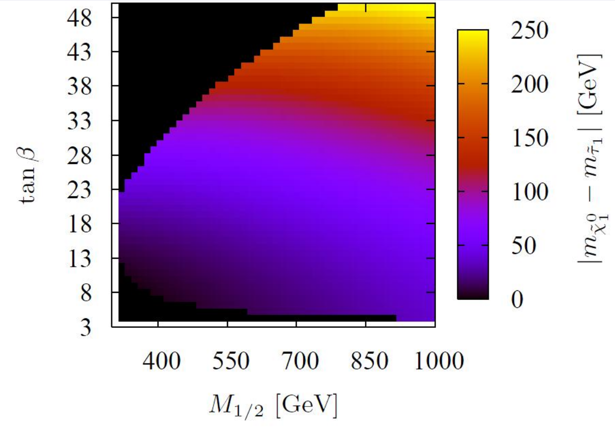


$\tilde{\tau}_1$ LSP Parameter Space

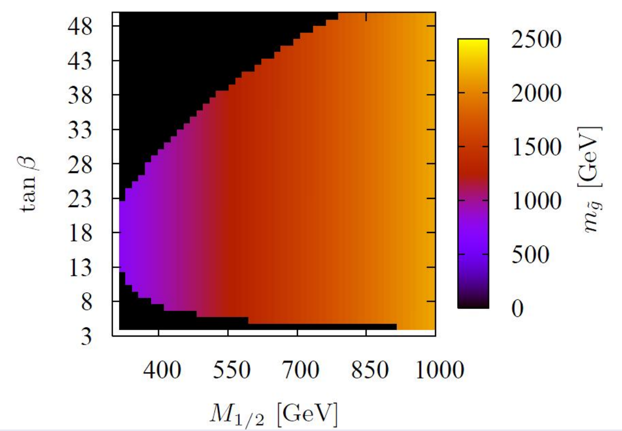
LSP mass



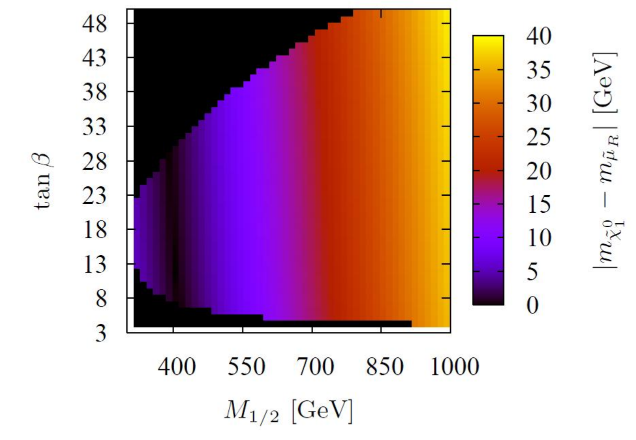
$\tilde{\tau}_1$ LSP Parameter Space



$\tilde{\tau}_1$ LSP Parameter Space



$\tilde{\tau}_1$ LSP Parameter Space



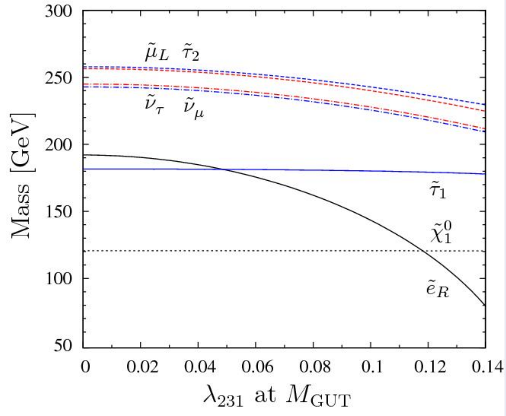
What is the $\tilde{e}_R$ LSP discovery potential with early LHC data?

[Dreiner, SG, Stefaniak, work in progress]

$\tilde{e}_R$ LSP in R-Parity Violating mSUGRA

Large R-Parity couplings can change RGE running of the $\tilde{e}_R$ mass.
[Dreiner, SG, Phys.Lett.B679:45-50,2009]

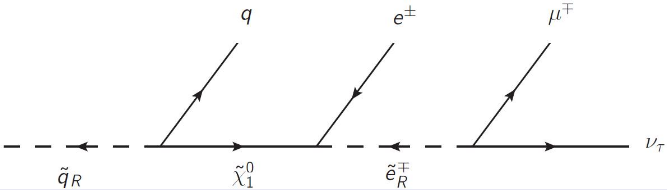
$M_0 = 150$ GeV, $M_{1/2} = 300$ GeV, $A_0 = -1000$ GeV, $\tan\beta = 10$, sgn(μ)=+1



$\Rightarrow$ $\tilde{e}_R$ good candidate for LSP.

LHC Phenomenology of $\tilde{e}_R$ LSP

decay chain for $\tilde{q}_R$



Promising LHC signatures:

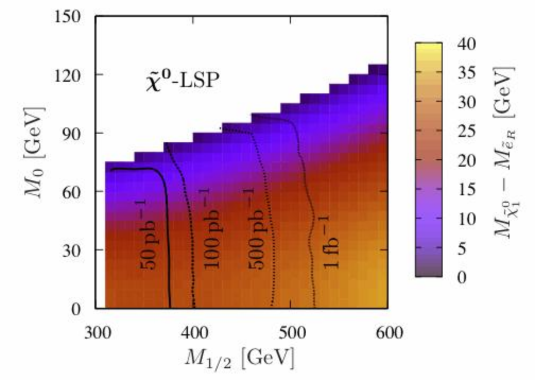
$$PP \to \tilde{q}_R \tilde{q}_R$$
$$\to (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$$
$$\to (qe\tilde{e}_R)(qe\tilde{e}_R)$$
$$\xrightarrow{\lambda_{231}} (qe\mu\nu_\tau)(qe\tau\nu_\mu)$$

- 4 charged leptons in the final state.
- Easy to identify in early LHC data.

Discovery Potential at $\sqrt{S} = 7$ TeV

Cuts: $N_\ell \geq 3$, $N_j \geq 2$, $M_Z + 10\mathrm{GeV} \leq M_{\ell^+\ell^-} \leq M_Z - 10\mathrm{GeV}$, $M_{\mathrm{eff}} > 300\mathrm{GeV}$.

minimal luminosity for 5σ excess.



- Scenarios with $\tilde{m}_{\mathrm{squark}} \lesssim 1$ TeV can be tested with $500\mathrm{pb}^{-1}$.
- Smaller significances for $m_{\tilde{e}_R} \approx m_{\tilde{\chi}_1^0}$.