Generating Sneutrino LSPs with R-parity Violation at the GUT scale

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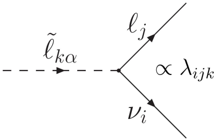
   - Minimal supergravity (mSUGRA) with RPV
2. Sneutrino LSP parameter space
3. Phenomenology of a sneutrino LSP scenario
   - Sparticle pair production
   - Single sparticle production
4. Summary and Outlook

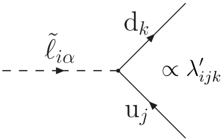
MSSM with R-parity violation (RPV)

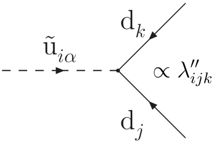
General Superpotential of the Minimal Supersymmetric extension of the SM (MSSM):

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

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







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]

Minimal Supergravity (mSUGRA) with RPV

number of new parameters

$\mathcal{O}(100)/\mathcal{O}(200)$ if R-Parity is conserved/violated.

Assume simple boundary conditions at the scale $M_{GUT} = \mathcal{O}(10^{16})$ GeV.

mSUGRA parameter space with RPV

- M_0 : Universal soft breaking scalar mass.
- $M_{1/2}$: Universal gaugino soft breaking mass.
- A_0 : Universal trilinear scalar interaction.
- $\tan\beta$: Ratio of vevs. of the two Higgs doublets H_u, H_d.
- $\text{sgn}\,\mu$: Solution of EW symmetry breaking scalar potential.
- $\mathbf{\Lambda}$: One R-Parity violating coupling $\mathbf{\Lambda} \in \{\lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk}\}$

Parameters at the scale $M_{EW} = \mathcal{O}(10^2)$ GeV are obtained by RGEs.
Programs: `Softsusy`, `SPheno`, `Suspect`, `Isajet` etc.

Effects of RPV

What will change due to one additional RPV coupling at the GUT scale?

- The lightest supersymmetric particle is not stable anymore.
- Sparticles can be produced singly, possible on resonance.
- Neutrino masses can be generated.
- The RGEs get additional contributions.

  $\rightarrow$ Additional RPV couplings at M_{EW}.

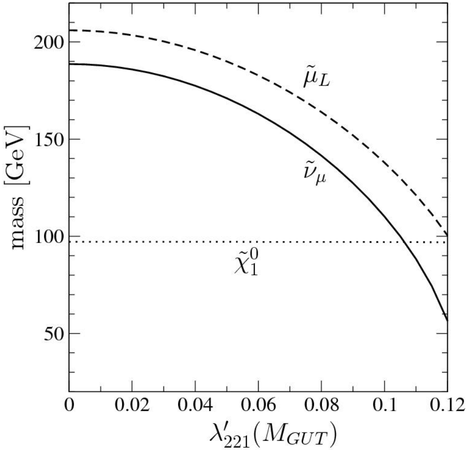
  $\rightarrow$ Sparticle masses can change at M_{EW}.

running sneutrino mass

$$
\begin{aligned}
16\pi^2 \frac{d(m^2_{\tilde{\nu}_i})}{dt} &= -\left(\frac{6}{5} g_1^2 |M_1|^2 + 6 g_2^2 |M_2|^2 + \frac{3}{5} g_1^2 S\right) \\
&\quad + 6\lambda'^2_{ijk} \left[m^2_{\tilde{\nu}_i} + (\mathbf{m}^2_{\tilde{\mathbf{Q}}})_{jj} + (\mathbf{m}^2_{\tilde{\mathbf{D}}})_{kk} \right] + 6(\mathbf{h}_{\mathbf{D}^k})^2_{ij} \\
\text{with} \quad (\mathbf{h}_{\mathbf{D}^k})_{ij} &= \lambda'_{ijk} \cdot A_0 \quad \text{at } M_{GUT}
\end{aligned}
$$

What is the LSP?

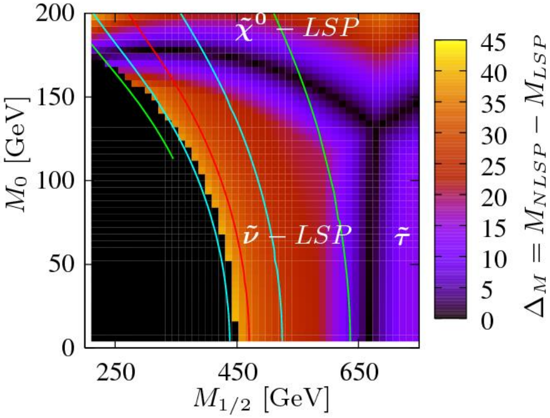
A non-vanishing coupling $\lambda'_{221}(M_{GUT})$ leads to a new LSP candidate.
For SPS1a:



$\Rightarrow$ $\tilde{\nu}_\mu$ LSP; also possible: $\tilde{\nu}_e$ & $\tilde{\nu}_\tau$ LSP.

$\tilde{\nu}_\mu$ LSP parameter space: M_0-$M_{1/2}$ plane

$$\lambda'_{221}(M_{GUT}) = 0.1,\ A_0 = -500 \text{ GeV},\ \tan\beta = 10,\ \mu > 0.$$



$\tilde{\nu}_\mu$ LSP parameter space: M_0-$M_{1/2}$ plane

Different LSP regions because:

- $m^2_{\tilde{\tau}_R} = M_0^2 + 0.15 M_{1/2}^2 + \dots$.
  (right-handed stau couples only via U(1) charges.)
- $m^2_{\tilde{\nu}_\mu} = M_0^2 + 0.52 M_{1/2}^2 + \dots$.
  (left-handed sneutrino couples via U(1) & SU(2) charges.)
- $m^2_{\tilde{\chi}_1^0} \simeq M_1^2 = 0.17 M_{1/2}^2$.
  ($\tilde{\chi}_1^0$ is bino-like.)

[Ibanez, Lopez, Munoz, Nucl.Phys.B256,1985]

What is the phenomenology of a sneutrino LSP at hadron colliders?

- Sparticle pair production.
- Resonant single slepton production.

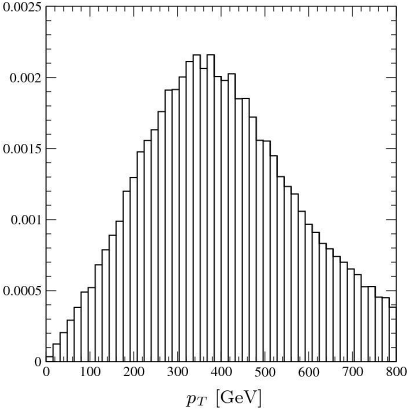
Note: $\lambda' = \mathcal{O}(0.1)$ to obtain a sneutrino LSP.

$\lambda'_{221}(M_{GUT}) = 0.1$, $M_0 = 110$ GeV, $M_{1/2} = 440$ GeV, $A_0 = -500$ GeV, $\tan\beta = 10$, $\mu > 0$.
$\Rightarrow \sigma_{LHC}(PP \to 2 \text{ Sparticles}) = 3.2$ pb

	mass	channel	BR
$\tilde{\nu}_\mu$	135	$\bar{s}d$	100 %
$\tilde{\mu}_L^-$	157	$\bar{c}d$	100 %
$\tilde{d}_R$	881	$\mu^- c$	44 %
		$\nu_\mu s$	44 %
		$\tilde{\chi}_1^0 d$	12 %
$\tilde{c}_L$	931	$\tilde{\chi}_1^+ s$	55 %
		$\tilde{\chi}_2^0 c$	27 %
		$\mu^+ d$	17 %

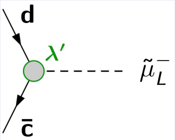
characteristic signatures

- Not necessarily $\not{p}_T$ (22% of events).
- 4-7 non b-jets and 0-2 b-jets.
- High p_T muons (10% of events).



Muon p_T from the decays $\tilde{d}_R \to \mu^- c$ and $\tilde{c}_L \to \mu^+ d$.

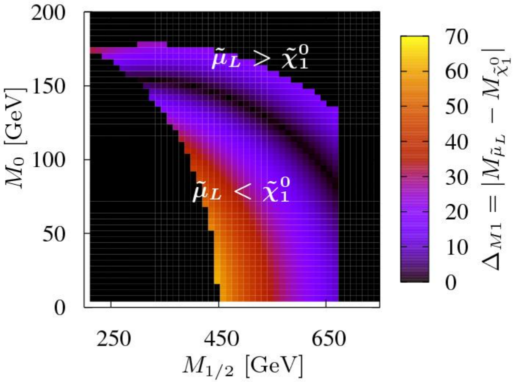
Single $\tilde{\mu}_L$ and $\tilde{\nu}_\mu$ production via λ'_{221}



$\Rightarrow$

$$PP(\bar{P}) \to \tilde{\nu}_\mu$$
$$\hookrightarrow \bar{s}d$$

$$PP(\bar{P}) \to \tilde{\mu}_L^-$$
$$\hookrightarrow \bar{c}d$$
$$\hookrightarrow \tilde{\chi}_1^0 \, \mu^-$$
$$\hookrightarrow \tilde{\nu}_\mu \nu_\mu$$
$$\hookrightarrow \bar{s}d$$



Single $\tilde{\mu}_L$ and $\tilde{\nu}_\mu$ production via λ'_{221}

$\lambda'_{221}(M_{GUT}) = 0.1$, $M_0 = 170$ GeV, $M_{1/2} = 300$ GeV, $A_0 = -500$ GeV, $\tan\beta = 10$, $\mu > 0$.

$\Rightarrow M_{\tilde{\mu}_L} = 140$ GeV, $M_{\tilde{\chi}_1^0} = 120$ GeV

Tevatron

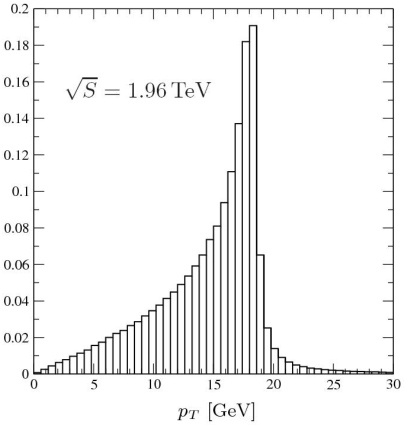
$\sigma(P\bar{P} \to \tilde{\mu}_L \to \tilde{\chi}_1^0 \mu) = 1.2$ pb.

LHC

$\sigma(PP \to \tilde{\mu}_L \to \tilde{\chi}_1^0 \mu) = 29$ pb.

$\Rightarrow \tilde{\nu}$ LSP scenarios might be found at the Tevatron!

Bottleneck: Small p_T of muons.



Muon p_T from $P\bar{P} \to \tilde{\mu}_L \to \tilde{\chi}_1^0 \mu$ at the Tevatron.

Summary and Outlook

Summary

- Including R-parity violation changes RGEs in mSUGRA.
- Nature of LSP can be changed.
  $\lambda'_{ijk}(M_{GUT}) \Rightarrow \tilde{\nu}$ LSP in mSUGRA.
- Promising hadron collider signatures are: high-p_T muons, muons from single slepton production.
- Tevatron might find $\tilde{\nu}$ LSP scenarios.

Outlook

- Detailed anlaysis including background, detector simulations and data.
- Additional LSP candidates: $\tilde{e}_R$ with λ, $\tilde{t}_1$ with λ''.

backup slides

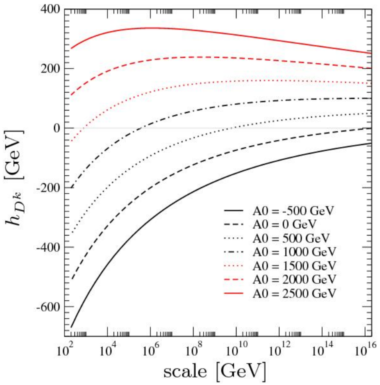
RPV couplings leading to a sneutrino LSP

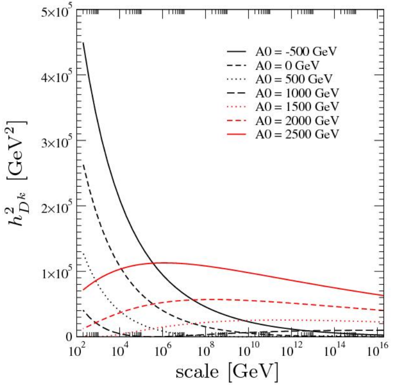
strongest bounds at M_{EW}
(for $m_{\tilde{\ell}} = 200$ GeV, $m_{\tilde{q}} = 500$ GeV)

coupling	bound	LSP
λ'_{112}	0.10	$\tilde{\nu}_e$
λ'_{121}	0.15	$\tilde{\nu}_e$
λ'_{131}	0.15	$\tilde{\nu}_e$
λ'_{212}	0.30	$\tilde{\nu}_\mu$
λ'_{221}	0.37	$\tilde{\nu}_\mu$
λ'_{231}	0.90	$\tilde{\nu}_\mu$
λ'_{312}	0.37	$\tilde{\nu}_\tau$
λ'_{321}	0.37	$\tilde{\nu}_\tau$
λ'_{331}	1.60	$\tilde{\nu}_\tau$

and up-mixing.

Running of $(h_{D^k})_{ij}$ $\lambda'_{ijk}(M_{GUT}) = 0.1,\ M_{1/2} = 500$ GeV

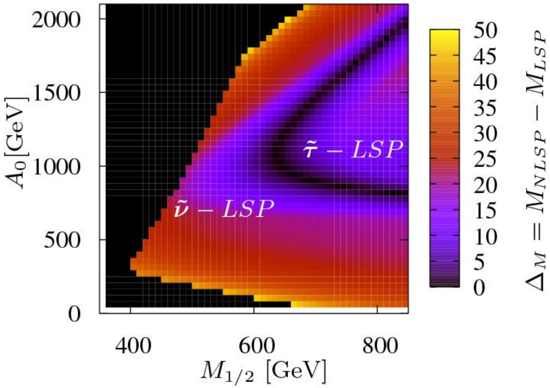




$$16\pi^2 \frac{d(\mathbf{h_{D^k}})_{ij}}{dt} = -(\mathbf{h_{D^k}})_{ij}\left(\frac{7}{15}g_1^2 + 3g_2^2 + \frac{16}{3}g_3^2\right) + \lambda'_{ijk}\left(\frac{14}{15}M_1^2 + 6M_2^2 + \frac{32}{3}M_3^2\right).$$

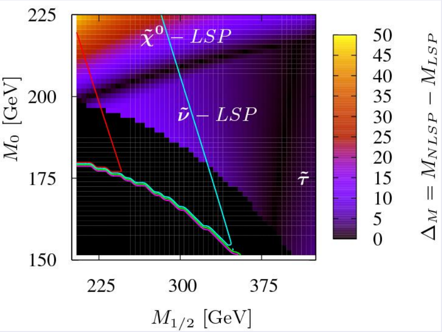
A_0 dependence

$\lambda'_{221}(M_{GUT}) = 0.149$, $M_0 = 50$ GeV, $\tan\beta = 10$.

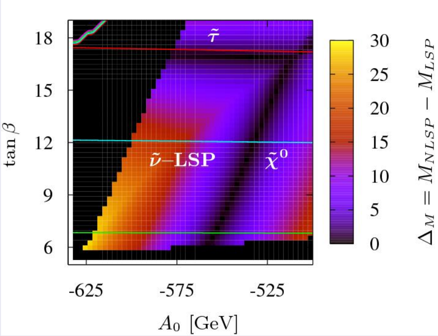


$\tilde{\nu}_\tau$ LSP parameter space

$\lambda'_{331}(M_{GUT}) = 0.12,\ A_0 = -550$ GeV, $\tan\beta = 14,\ \mu > 0$.



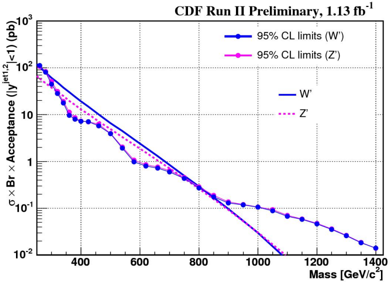
$\lambda'_{331}(M_{GUT}) = 0.12,\ M_0 = 200$ GeV, $M_{1/2} = 270$ GeV, $\mu > 0$.

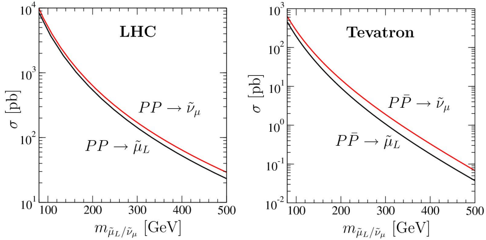


muon anomalus magnetic moment: $\delta a_\mu = a_\mu|_{exp} - a_\mu|_{SM} = 2.95 \times 10^{-9}$.
$\Leftrightarrow$ 3.4σ deviation to SM prediction!

$\delta a_\mu|_{SUSY} = 2.95 \times 10^{-9}$ (red line), $\pm 1\sigma$, $\pm 2\sigma$.

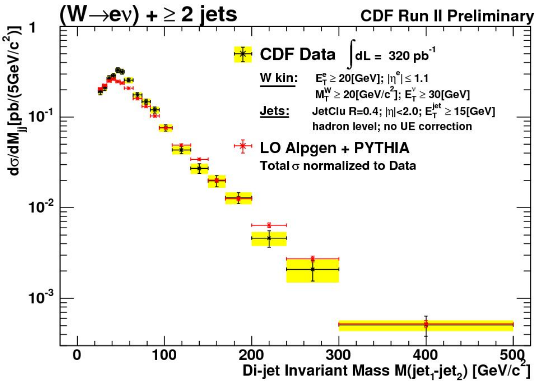
Single $\tilde{\mu}_L$ and $\tilde{\nu}_\mu$ production via λ'_{221}



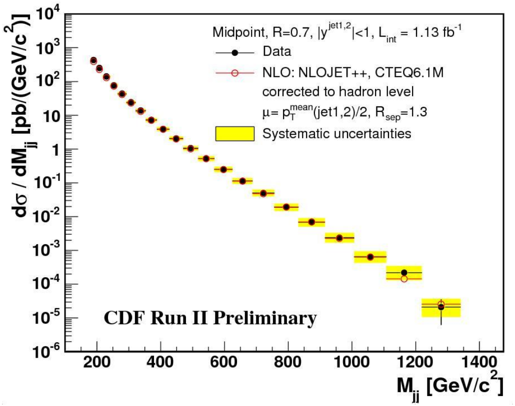


Problem: Large QCD background.

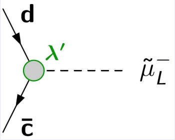
$W+ \geq 2$ jets at the Tevatron



Dijet production at the Tevatron



Single $\tilde{\mu}_L$ and $\tilde{\nu}_\mu$ production via λ'_{221}

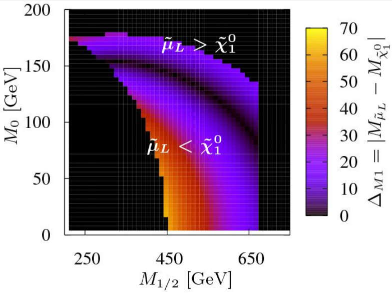


$\Rightarrow$

$$PP(\bar{P}) \to \tilde{\nu}_\mu + X$$
$$\hookrightarrow \bar{d}_j d_k$$

$$PP(\bar{P}) \to \tilde{\mu}_L^- + X$$
$$\hookrightarrow \bar{u}_j d_k$$
$$\hookrightarrow \tilde{\chi}_1^0 \; \mu^-$$
$$\hookrightarrow \tilde{\nu}_\mu \nu_\mu$$
$$\hookrightarrow \bar{d}_j d_k$$

$\lambda'_{221}(M_{GUT}) = 0.1,\ A_0 = -500$ GeV, $\tan\beta = 10,\ \mu > 0$.



$\lambda'_{221}(M_{GUT}) = 0.1,\ M_0 = 50$ GeV, $M_{1/2} = 500$ GeV, $\mu > 0$.