Supersymmetry with Trilinear R-Parity Violation at the LHC

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What do we want the LHC to Discover?

- Officially: the Higgs
- ATLAS — “A Tool for Locating Any Supersymmetry”
- E.g. R-Parity Violating SUSY
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B and L Violating Couplings.

\[ \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \mu_i H L_i \]

\( L_i, Q_i, H \) – lepton, quark, Higgs doublets
\( E_i, D_i, U_i \) – lepton, down, up quark singlets
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Bilinear Lepton number violating couplings; induces neutrino–neutralino mixing. Not our primary focus
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Trilinear Lepton number violating couplings
B and L Violating Couplings.

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Trilinear Lepton number violating couplings

Trilinear Baryon number violating couplings
The Studied Scenario

- Neutralino NLSP
- (Gravitino LSP – for Dark Matter)
- Pair production of squarks and gluinos
- Cascade decay down to neutralino
- Three-body decay of neutralino
- Try to determine operator hierarchies
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\[
\tilde{q}, \tilde{g} \rightarrow \chi_0^1
\]
Lots of leptons ⇒ easy background suppression
Neutrinos ⇒ no peaks or clear edges in Invariant mass distributions
Need to know the expected distributions!
LL̅E

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Need to know the expected distributions!
Theoretical Invariant Mass Distributions
Theoretical Invariant Mass Distributions

![Graph showing invariant mass distributions](image)
Invariant Mass Distributions

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Invariant Mass Distributions

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Supersymmetry with Trilinear R-Parity Violation at the LHC
Neutralino $\rightarrow$ lepton + 2 jets, neutrino + 2 jets

- $L_{1,2}Q_{1,2}ar{D}_3 \Rightarrow$ lepton + b-jet + light jet
- taus $\Rightarrow$ loss of information (momentum) through neutrinos
- $Q_3 \Rightarrow$ only neutrino + 2 jets (at least one b-jet)
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$LQ\bar{D}$

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Need to suppress $t\bar{t}$ background; require 2 Same-sign leptons.
Invariant Masses – $L_1 Q_1 \bar{D}_2$: electron - 2 jets

\begin{figure}
\centering
\includegraphics[width=\textwidth]{Invariant_Masses.png}
\end{figure}
Invariant Masses – $L_1 Q_1 \bar{D}_3$: electron - b-jet - jet
Invariant Masses – $L_3 Q_1 D_3$: tau-jet - b-jet

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Supersymmetry with Trilinear R-Parity Violation at the LHC
Difficult! : $\chi_1^0 \rightarrow 3$ jets

Exception: $\bar{U}_3 \Rightarrow \begin{cases} M_{\chi_1^0} < M_{\text{top}} & \Rightarrow \chi_1^0 \text{ escapes} \\ M_{\chi_1^0} > M_{\text{top}} & \Rightarrow \chi_1^0 \rightarrow t(\bar{t}) + 2 \text{ (soft) jets} \end{cases}$

$\chi_1^0 \rightarrow t(\bar{t}) + 2j \Rightarrow tt$ and $\bar{tt}$ events $\Rightarrow 2$ same-sign leptons
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### What can we identify?

<table>
<thead>
<tr>
<th>coupling</th>
<th>identifiable</th>
<th>remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>$LLE$</td>
<td>✓</td>
<td>For all flavours</td>
</tr>
<tr>
<td>$L_{1,2}Q\bar{D}$</td>
<td>✓</td>
<td>Cannot identify light quark flavors</td>
</tr>
<tr>
<td>$L_3Q\bar{D}$</td>
<td>?</td>
<td>More difficult with $\tau$</td>
</tr>
<tr>
<td>$LQ\bar{D}_3$</td>
<td>✓</td>
<td>Better identification with b-jet</td>
</tr>
<tr>
<td>$LQ_3\bar{D}$</td>
<td>?</td>
<td>No charged lepton</td>
</tr>
<tr>
<td>$\bar{U}_{1,2}\bar{D}\bar{D}$</td>
<td>✓</td>
<td>But difficult</td>
</tr>
<tr>
<td>$\bar{U}_3\bar{D}\bar{D}$</td>
<td>✓ (?)</td>
<td>Only if $M_{\chi_1^0} &gt; M_{top}$</td>
</tr>
</tbody>
</table>
Conclusions

- Three-body decays of the neutralino allows us to study all 45 trilinear R-Parity violating operators simultaneously and to measure flavour hierarchies.
- Most operators can be successfully detected and the neutralino mass can be measured.
- Difficult cases include $L_3 Q \bar{D}$, $LQ_3 \bar{D}$ and some cases with $\bar{U}D\bar{D}$.
- The prospects for determining the full hierarchy of RPV couplings are good.
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