Search for R-Parity Violation in Multi-lepton Final State at Tevatron

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• Introduction
• DØ Detector
• Analysis
• Conclusion
**SUSY Framework**

SUSY is an attractive theory. Adds super symmetric partner (sparticle) to every SM particle.

- MSSM (Minimal Super Symmetric Model) is the simplest of all SUSY models
- Adds an extra Higgs Doublet
- Supersymmetrization of gauge interactions

**Standard Model Particles**

Gauge/Higgs Bosons: $\gamma, Z^0, W^\pm, h^0, H^0, H^\pm, A^0, g$

Quarks/Leptons: $(\nu, e)_L, e_R, (u, d)_L, u_R, d_R$

**Super Symmetric Particles**

Gauginos/Higgisnos: $\tilde{\chi}^0_{1-4}, \tilde{\chi}^\pm_{1-2}, \tilde{g}$

Squarks/Sleptons: $(\tilde{\nu}, \tilde{e})_L, \tilde{e}_R, (\tilde{\nu}, \tilde{d})_L, \tilde{u}_R, \tilde{d}_R$
mSUGRA Model

mSUGRA model has 4 continuous and one discrete parameter:

- $m_0$ – Universal scalar mass
- $m_{1/2}$ – Universal gaugino mass
- $A_0$ – Tri-linear coupling interaction term
- $\tan\beta$ – Ratio of v.e.v. of 2 Higgs doublets
- $\text{Sign}(\mu)$

Most SUSY models assume R-parity conservation ($R_p = (-1)^{2S+3B+L}$).

- $R_p = +1$ for SM particles and $-1$ for sparticles.

R-parity conservation implies:

- SUSY particles can only be pair produced.
- Heavy Sparticle decays to lighter Sparticle.
- LSP is stable (Resulting in $M_{E_T}$).
R = (-1)^{3B+L+2S}

Most general Superpotential can be written as:

\[ W = W_{MSSM} + W_{RP} \]

\[ W_{RP} = \lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda''_{ijk} U_i D_j D_k \]

There can be 45 coupling terms

\[ 9 \lambda_{ijk}, \ 27 \lambda'_{ijk}, \ 9 \lambda''_{ijk} \]
Consequences of R-Parity violation

- LSP is no longer stable and SUSY particles can decay into SM particles
- Pair production of SUSY particles is no longer necessary

Assumption for the Analysis:

- R-parity violating couplings are soft, causing only LSP decay.
- LSP is assumed to be neutralino
- Only one R-parity violating term dominates
- R-parity couplings are strong enough to cause LSP decay close to vertex, so that it can be detected within detector.
R-parity Violating Couplings

- B-violating $\lambda''$ terms lead to events with multi jet final state
- L-violating $\lambda$ and $\lambda'$ type couplings give multi lepton and multi jet final states

$R_p$ violating analyses at DØ concentrate on $\lambda$ and $\lambda'$ couplings, with leptonic final states.
DØ Detector
R-Parity Violating SUSY

Concentrating only on \( \lambda \) coupling, resulting in multi-lepton final state.

Event Selection:

- 3 Leptons
  - \( eee, eem, e\mu\mu, \mu\mu\mu \)
- Missing \( E_T \)
- Topological cuts

Looked at whole of Run-I data from DØ detector.
## R-Parity Violating SUSY

### Backgrounds

<table>
<thead>
<tr>
<th></th>
<th>$eee$</th>
<th>$ee\mu$</th>
<th>$e\mu\mu$</th>
<th>$\mu\mu\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity (pb$^{-1}$)</td>
<td>98.7</td>
<td>98.7</td>
<td>93.1</td>
<td>78.3</td>
</tr>
<tr>
<td>Events Observed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Exp. Background</td>
<td>0.34±0.07</td>
<td>0.61±0.36</td>
<td>0.11±0.04</td>
<td>0.20±0.04</td>
</tr>
</tbody>
</table>

The null result can be interpreted to set the limits on the SUSY parameter space.
R-Parity Violating SUSY

**Signal Event Generation**

- Events generated for various points in the $m_0$- $m_{1/2}$ parameter space using values of $\tan\beta = 5 & 10 : A_0 = 0$ and for both signs of $\mu$.

- **ISAJET** modified for allowing LSP to decay used for the event generation.

- The branching ratio depends upon the LSP composition which in turn depends on the SUGRA parameters. (Ref. PRD 49, 3270, 1994. H Dreiner, M. Guchait, D.P. Roy)

- The MC events generated are then passed through Detector simulation package.
R-Parity Violating SUSY

• All possible production and decay modes of the SUSY particles were simulated.

• Analysis sensitive only to states with highest $e, \mu$ multiplicity, when there is no $\tau$ in the LSP decay.

• Detection efficiency highest for $\lambda_{121}$ and least for $\lambda_{133}, \lambda_{233}$

$\tilde{\chi}_1^0 \rightarrow \nu_i l^+_{jk} l^-_k$

\[\tilde{\chi}_1 \rightarrow \nu_l l^+ \mu\]
R-Parity Violating SUSY

$A_0 = 0$, $\tan\beta = 5$, $\mu < 0$

$A_0 = 0$, $\tan\beta = 5$, $\mu > 0$
R-Parity Violating SUSY

\[ A_0 = 0, \tan \beta = 10, \mu < 0 \]

\[ A_0 = 0, \tan \beta = 10, \mu > 0 \]
Conclusions

• We reinterpreted the results of the earlier DØ search for SUSY in the tri-lepton final state in terms of R-Parity violating SUSY models.

• A large domain of mSUGRA parameter space can be excluded provided that R-Parity violation is accompanied by lepton number non-conservation and $\lambda$ couplings greater than $\sim 10^{-4}$.

• Upgraded Tevatron and Detector along with improved particle-id is expected to extend the reach of DØ in exploring the SUSY parameter space in Run-II.
DØ Detector

**TRACKING**
- $\sigma$(vertex) = 6 mm
- $\sigma(r\phi)$ = 60 $\mu$m (VTX)
  - = 180 $\mu$m (CDC)
  - = 200 $\mu$m (FDC)

**CALORIMETRY**
- $|\eta| < 4$
- $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
- $\sigma$(EM) = 15%/$\sqrt{E}$
- $\sigma$(HAD) = 50%/$\sqrt{E}$

**MUON**
- $|\eta| < 3.3$
- $\delta p / p = 0.2 \oplus 0.01p$
Conclusions

- DØ explored lots of SUSY parameter space and set most stringent limits at times on it.
- STILL WE CANNOT EXCLUDE SUSY.
- With Upgraded Tevatron and detector, RunII offers many exciting discovery possibilities.
- SUSY hunting ground is also that for non-SUSY models like technicolor, extra dimensions along with beyond MSSM extensions containing leptoquarks, extra gauge bosons etc.
- DØ will try to probe all these models simultaneously by adopting signature based approach which is much less model dependent than the model-based one.
R-Parity Violation in Run II

Neutralino is the LSP and decays inside the fiducial volume, i.e. \( \lambda' > 10^{-3} \), within SUGRA framework.

Studies done on the basis of the Run-I analysis.

Cuts:
- \( \geq 2l \) with \( E_T > 15,20 \text{ GeV} \ |\eta|<2.3-2.5 \)
- \( \geq 4 \) jets with \( E_T > 15 \text{ GeV} \ |\eta|<2.5 \)
- Z(\ll) Veto

Backgrounds:
- DY + 4jets
- \( tt \rightarrow l+jets \)
- Fakes (in the electron Channel)
R-Parity Violation in Run II
R-Parity Violation in Run II

Plan to explore like-sign lepton channels accessible via squark decays.

\[ p\bar{p} \rightarrow \tilde{q}\tilde{q} \rightarrow (q\tilde{\chi}_1^0)(\tilde{q}\tilde{\chi}_1^0) \rightarrow \left[ p \rightarrow q(q\bar{q}'l^\pm)\bar{q}(q\bar{q}'l^\pm) \right. \]

\[ p\bar{p} \rightarrow l^+l^+ \text{ or } l^-l^-+\geq 2 \text{ jets, } l=e,\mu \]

Like sign leptons can appear since neutralino is a Majorana particle.

Very low backgrounds.

Studies done by CDF based on their Run I analysis show expected sensitivity to squark masses upto 400GeV/c^2.

[M. Chertok, in hep-ph/9906224]

Also plan to extend search for \( \lambda \) couplings to multilepton final states.