Search for Resonant Slepton Production
with 375 pb$^{-1}$

Analysis & Talk structure:
- Theoretical introduction to R-parity violation
- Data samples
- Object identification; muons and jets
- Event selection
- Model independent cross section limits
- Interpretation within mSUGRA
R-Parity Violation Supersymmetry

**R-parity:** \( R_P = (-1)^{3B+L+2S} \)

- \( S \) is the particle spin,
- \( B \) is the baryon number,
- \( L \) is the lepton number

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

\[
W_{R_P} = \frac{1}{2} \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k
\]

**R-parity violating extension of the MSSM**

- \( i,j,k = 1,2,3 \) generation indices

- **R-parity conserving production**
- **associated/pair** production of gauginos
- **decay** via \( \lambda_{ijk} \) into 4 charged leptons

→ require 3 charged leptons for analysis

→ Anne-Marie, Daniela, Anne-Catherine, PRL paper in preparation

- **Resonant** production via \( \lambda'_{211} \) of smuon or sneutrino
- Cascade decay to LSP (neutralino)
- **decay** via \( \lambda'_{211} \) into 2 jets & 1 lepton
- \( \sigma \propto (\lambda'_{211})^2 \)

**Chiral superfields:**
- \( L \): lepton doublet superfield
- \( E \): lepton singlet superfield
- \( Q \): quark doublet superfield
- \( D \): down-like quark singlet superfield
- \( \lambda, \lambda', \lambda'' \): Yukawa couplings
Slepton Production and Decay

→ 2 jets and 0, 1 or 2 μ

Require 2 muons to control the QCD multijet background
→ Possible to reconstruct the neutralino and the slepton mass
→ But only ~25% branching ratio
Signal Channels

Final state: 2-muon & 2-jet
Three dominant signal channels:

1. \( \tilde{\mu} \to \tilde{\chi}_1^0 \mu \)
2. \( \tilde{\mu} \to \tilde{\chi}_2^0 \mu \)
3. \( \tilde{\nu}_\mu \to \tilde{\chi}_1^\pm \mu \)

→ Analyze each channel separately
→ Give limit on \( \sigma \times \text{BR} \) for each channel, depends only on masses, not models!
Pass II data from April 2002 – August 2004

good recorded luminosity: $374 \pm 24 \text{ pb}^{-1}$

"Preselection Sample"

Any Di-muon trigger has fired

Veto against cosmic muons (scintillator timings)

2 good muons with $p_T > 15 \text{ GeV}$, $p_T > 8 \text{ GeV}$

central track match & isolation for both muons

$[\text{isolation: } E_T(\text{cone0.4}) - E_T(\text{cone0.1}) < 2.5 \text{ GeV} \text{ & } p_T(\text{cone0.5}) < 2.5 \text{ GeV}]$

$\rightarrow$ 23 206 events,

expected background: $22 699 \pm 71(\text{stat}) \pm 2907(\text{syst})$ events

Corrected for

Di-muon trigger efficiency

Muon reconstruction efficiencies

Isolation efficiencies

$\rightarrow$ all sources for systematic uncertainties
Use data events with 2 **loose isolated** muons:

\[ \sum_{cone\ r=0.5} p_T < 10 \text{ GeV} \quad \text{and} \quad \sum_{hollow\ R=0.4} E_T < 10 \text{ GeV} \]

- one criterion of any muon must be > 2.5 GeV, so that the QCD sample is **orthogonal** to data/signal

- Enrich QCD events (bbbar) by requiring a loose **b-tag**

- Jet multiplicity is affected by b-tag; **reweighted** according to a QCD sample without b-tag requirement

- **Good description** of data in 2µ, 2µ+jet and 2µ+2jet sample

- Assign a systematic **uncertainty of 20 %** of the so determined QCD background
QCD estimation is a trade-off between good description and good statistics. There is no perfect sample.
## Corrections & Systematic error sources

<table>
<thead>
<tr>
<th>Correction Method</th>
<th>Method</th>
<th>Correction</th>
<th>Systematic error size in 2μ+2jet sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet energy scale</td>
<td>variation by ±1 σ, total propagation</td>
<td>JES group</td>
<td><strong>SM:</strong> 13.7 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>signal:</strong> 1-26%</td>
</tr>
<tr>
<td>di-muon ID</td>
<td>tag &amp; probe</td>
<td>η-dependent</td>
<td><strong>SM:</strong> 7.8 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>signal:</strong> 7.8 %</td>
</tr>
<tr>
<td>Luminosity</td>
<td>lumi group</td>
<td></td>
<td><strong>SM:</strong> 5.5 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>signal:</strong> 6.5 %</td>
</tr>
<tr>
<td>MC σ, K-factor</td>
<td>signal σ decreased by error, according to note 4618</td>
<td></td>
<td><strong>SM:</strong> 3.7 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>signal:</strong> 5.0 %</td>
</tr>
<tr>
<td>QCD</td>
<td>flat 20% uncertainty</td>
<td>scaled</td>
<td><strong>SM:</strong> 3.1 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>signal:</strong> –</td>
</tr>
<tr>
<td>MC statistics</td>
<td></td>
<td></td>
<td><strong>SM:</strong> 2.2 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>signal:</strong> 3-30%</td>
</tr>
<tr>
<td>muon p_T smearing</td>
<td>variation by ±1 σ, total propagation</td>
<td>muon ID package</td>
<td><strong>SM:</strong> 0.1 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>signal:</strong> 0-14%</td>
</tr>
</tbody>
</table>
Preselection “control plots”  1/4

Invariant di-muon mass

Signal reference point (always): $m(\tilde{T}) = 260$ GeV  $m(\tilde{\chi}) = 100$ GeV

$\tilde{\chi} \rightarrow \mu\nu, \chi \rightarrow \tilde{\chi}_{1,2}\mu$

Search for Resonant Slepton

Christian Autermann  
All D0 meeting

Inv. di-muon mass [GeV]

number of events / 3.6 GeV

0 500 1000 1500 2000 2500

0 20 40 60 80 100 120 140 160 180

data  
signal x 100  
$Z/\gamma^* 60-130$ GeV  
$Z/\gamma^* 15-60$ GeV  
QCD, b-tag data  
tt$\rightarrow ll$

RunII preliminary

Data 100, #58

Stat.  ± syst.  ± SM

$\tilde{\mu} \rightarrow \tilde{\chi}_1\mu$  
$\tilde{\mu} \rightarrow \tilde{\chi}_{2,3,4}\mu$  
$\tilde{\nu}_\mu \rightarrow \tilde{\chi}^{+}_{1,2}\mu$
Preselection “control plots” 2/4

Transverse momentum of the next-to-leading muon

\[ \tilde{\mu} \rightarrow \tilde{\chi}_1^0 \mu \]
\[ \tilde{\mu} \rightarrow \tilde{\chi}_{2,3,4}^0 \mu \]
\[ \tilde{\nu}_\mu \rightarrow \tilde{\chi}_{1,2}^+ \mu \]
Preselection “control plots” 3/4

Missing transverse energy

\[ \tilde{\mu} \to \tilde{\chi}_1^0 \mu \quad \tilde{\mu} \to \tilde{\chi}_{2,3,4}^0 \mu \quad \tilde{\nu}_\mu \to \tilde{\chi}_{1,2}^+ \mu \]
Reconstructed neutralino mass

\[ \mu \rightarrow \tilde{\chi}_1^0 \mu, \quad \mu \rightarrow \tilde{\chi}_{2,3,4}^0 \mu, \quad \tilde{\nu}_\mu \rightarrow \tilde{\chi}_{1,2}^+ \mu \]
Final selection – variable cuts in 2D planes

Possible “2D cuts”:
1. slepton – neutralino mass plane
2. $p_T(\mu_1) + p_T(\mu_2)$ (this cut is only 1D)
3. di-$\mu$ mass – $p_T(\mu_1) + p_T(\mu_2)$
4. di-jet mass – $p_T(jet_1) + p_T(jet_2)$
5. di-$\mu$ mass – $p_T(jet_1) + p_T(jet_2)$
6. di-$\mu$ mass – $\Delta R (jet_1, jet_2)$

For channel 1 cuts 1 & 2 are sufficient, for channel 2 & 3 all cuts are applied

Each 2D cut is optimized with respect to signal efficiency · purity on a training sample

→ High signal purity can be achieved
→ Strong dependence on neutralino & slepton masses
→ Optimize all cut parameters for each 2D cut and each point
Example: point \( m(\tilde{\tau}) = 260 \, \text{GeV} \)
\( m(\tilde{\chi}) = 100 \, \text{GeV} \) channel \( \tilde{\mu} \rightarrow \tilde{\chi}_1^0 \mu \)

Final selection – cut flow
For channel \( \tilde{\mu} \rightarrow \tilde{\chi}_1^0 \mu \) a cut in the \( m(\tilde{\tau})-m(\tilde{\chi}) \)-plane (1.) and on \( p_T(\mu_1) + p_T(\mu_2) \) (2.) is sufficient.

5 cut parameters: \( x, y, r_1, r_2, \) ellipse angle

1 cut parameter: \( x \)

The cut parameters are optimized on a training sample.
Example: point $m(\tilde{t}) = 260$ GeV

$m(\tilde{\chi}) = 100$ GeV

channel $\tilde{\mu} \rightarrow \tilde{\chi}_2^0 \mu$

Final selection – cut flow (all 2D cuts are applied for channel $\tilde{\mu} \rightarrow \tilde{\chi}_2^0 \mu$ and $\tilde{\nu}_\mu \rightarrow \tilde{\chi}_1^+ \mu$)
Cut flow for an example point

<table>
<thead>
<tr>
<th>Cut</th>
<th>Data</th>
<th>SM Exp.</th>
<th>Signal eff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2µ pre-selection</td>
<td>23 206</td>
<td>22 699±71±2905</td>
<td>5.5 ± 0.7 %</td>
</tr>
<tr>
<td>p_T jet_1 &gt; 15 GeV</td>
<td>3 852</td>
<td>3 764 ± 35 ± 559</td>
<td>4.8 ± 0.6 %</td>
</tr>
<tr>
<td>p_T jet_1 &gt; 15 GeV</td>
<td>538</td>
<td>504 ± 11 ± 96</td>
<td>2.5 ± 0.3 %</td>
</tr>
<tr>
<td>0.5 &lt; ΔR_{jet1,jet2} &lt; 3.2</td>
<td>475</td>
<td>432 ± 11 ± 83</td>
<td>2.4 ± 0.3 %</td>
</tr>
</tbody>
</table>

From this stage 3 independent analyses
Final selection with 2D cuts
Results for all points

Scanned slepton &
neutralino mass
→ Analyzed
117 points
→ independently
for 3 channels

“Deviation” $d$ of
Data $n_d$ and SM expectation $b$:

$$d = \frac{n_{data} - b}{\sqrt{\sigma_b^2 + b}}$$

with $\sigma_b$ total error

1. $\mu \rightarrow \chi^0_1 \mu$
   - $\sigma = 0.8$
   - $\text{mean} = 0.2$

2. $\tilde{\mu} \rightarrow \chi^0_2 \mu$
   - $\sigma = 0.6$
   - $\text{mean} = -0.0$

3. $\nu_\mu \rightarrow \chi^0_1 \mu$
   - $\sigma = 0.9$
   - $\text{mean} = 0.4$

Point #12
$d = 2$
$b = 0.1^{+0.4}_{-0.1}$
Limit calculation

No excess in the data or sign for SUSY found
→ set limits with CLs – method (TJunk’s TLimit)

\[
CL_{s+b} = \sum_{X(d'_i) \leq X(d_i)} \prod_{i=1}^{n} \frac{e^{-(s_i+b_i)}(s_i + b_i)^{d'_i}}{d'_i !} \quad CL_s = \frac{CL_{s+b}}{CL_b}
\]

→ Easy to combine multiple channels, since Likelihoods are multiplicative
→ modified version (V.Büscher) of TLimit considers asymmetric errors
→ Considering systematic uncertainties on SM and signal expectation as 100% correlated
Model-Independent Limits
on $\sigma \times BR$ [pb]
$\tilde{\mu} \rightarrow \tilde{\chi}_1^0 \mu$

Mass [GeV]

$\tilde{\mu}$ mass [GeV]

$\tilde{\chi}_1^0$ mass [GeV]

Limit $\sigma(pp\rightarrow \tilde{\mu}) \times BR(\tilde{\mu} \rightarrow \tilde{\chi}_1^0 \mu)$ [pb]

D0 RunII preliminary

Generated points

LEP
\[ \tilde{\mu} \rightarrow \tilde{\chi}_2^{0} \rightarrow \tilde{\chi}_{2,3,4}^{0} \mu \]
\( \tilde{\nu}_\mu \rightarrow \tilde{\chi}_1^{\pm} \mu \)
Combined Limits
with the assumption of mSUGRA

Excluded areas for specific couplings $\lambda'_{211}$
Systematic errors on signal cross section

- Decrease Signal cross section by absolute uncertainty on $\sigma$ → most conservative handling of syst. errors
- Estimate signal k-factor by a conservative, constant $k = 1.4$

**K-Factor $d\bar{d} \rightarrow \nu$ (QCD Corrections)**

**$d\bar{d} \rightarrow \nu : Scaledependence$ (with CTEQ 4)**

Calculations by M. Trenkel, M. Kramer
## Combination for an example point

$m(\tilde{l}) = 260$ GeV  
$m(\tilde{\chi}) = 100$ GeV

### Search for Resonant Slepton Production

<table>
<thead>
<tr>
<th>Process</th>
<th>Data</th>
<th>SM Exp.</th>
<th>Signal $\varepsilon$</th>
<th>$\sigma$ [pb]</th>
<th>Limit [pb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{\mu} \rightarrow \tilde{\chi}_1^0 \mu$</td>
<td>14</td>
<td>10.0\pm1.9^{+1.2}_{-1.6}</td>
<td>$3.0 \pm 0.4$ %</td>
<td>1.10</td>
<td>1.53</td>
</tr>
<tr>
<td>$\tilde{\mu} \rightarrow \tilde{\chi}_{2,3,4}^0 \mu$</td>
<td>28</td>
<td>24.6\pm3.2^{+7.2}_{-4.0}</td>
<td>$2.3 \pm 0.4$ %</td>
<td>0.98</td>
<td>3.06</td>
</tr>
<tr>
<td>$\tilde{\nu}<em>\mu \rightarrow \tilde{\chi}</em>{1,2}^\pm \mu$</td>
<td>8</td>
<td>8.3\pm1.9^{+1.0}_{-2.4}</td>
<td>$2.6 \pm 0.3$ %</td>
<td>1.74</td>
<td>2.24</td>
</tr>
</tbody>
</table>

### Smuon Production

- $\tilde{\mu} \rightarrow X$
  - Overlapping events:
    - Data: 0
    - SM Exp.: 0.0
    - $\sigma$ [pb]: 3.15
    - Limit [pb]: 3.33

### Slepton Production

- $\tilde{l} \rightarrow X$
  - Overlapping events:
    - Data: 4
    - SM Exp.: 3.8
    - $\sigma$ [pb]: 6.06
    - Limit [pb]: 1.17

mSUGRA relates masses of $\tilde{\mu}, \tilde{\nu}, \tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$ and predicts cross section & branching ratio.
Combination within mSUGRA

$\tan \beta = 5$

$\text{sign } \mu = -1$

$\tilde{\tau}$ is the LSP

D0 RunII preliminary

95% CL Exclusion Contour for $\lambda_{211}$

$\tilde{q} = 300 \text{ GeV}$

$\tilde{q} = 400 \text{ GeV}$

$\chi^0 = 75 \text{ GeV}$

$\chi^0 = 100 \text{ GeV}$

$\tilde{q} = 800 \text{ GeV}$

LEP limit

Not allowed

+ Generated points
Combination within mSUGRA

slepton – neutralino mass plane

slepton mass < 210 GeV for $\lambda^{'}_{211} \geq 0.06$
330 GeV for $\lambda^{'}_{211} \geq 0.08$
358 GeV for $\lambda^{'}_{211} \geq 0.12$

slepton – down quark mass plane

squark mass < 408 GeV for $\lambda^{'}_{211} \geq 0.06$
430 GeV for $\lambda^{'}_{211} \geq 0.10$
445 GeV for $\lambda^{'}_{211} \geq 0.14$
Projection on constant neutralino mass

neutralino mass = 75 GeV

\[ \tan \beta = 5 \]

sign \( \mu = -1 \)

neutralino mass = 100 GeV

\[ \tan \beta = 5 \]

sign \( \mu = -1 \)
Projection on constant slepton mass

slepton mass = 200 GeV

\[ \tan \beta = 5 \]
\[ \text{sign } \mu = -1 \]

slepton mass = 300 GeV

\[ \tan \beta = 5 \]
\[ \text{sign } \mu = -1 \]
Conclusion

- Presented search for resonant slepton production
- Well understood data sample
- No excess found
- **Model independent cross section limits** on 
  \[ \tilde{\mu} \to \tilde{\chi}_1^0 \mu \quad \tilde{\mu} \to \tilde{\chi}_{2,3,4}^0 \mu \quad \tilde{\nu}_\mu \to \tilde{\chi}_{1,2}^\pm \mu \]  have been set
- **Combination and interpretation** of the results within mSUGRA
- Set limits on coupling \( \lambda'_{211} \)

- Run I set a limit \( \lambda'_{211} \leq 0.09 \) 
  for \( m(l) = 263 \) GeV and \( m(\chi) = 100 \) GeV 
  The limit is now \( \lambda'_{211} \leq 0.028 \) 
  Since \( \sigma \propto (\lambda'_{211})^2 \) an **improvement of 1 : 10.3**

- Analysis Note and PRL draft are available from the EB032 webpage