Searches for Gauge Mediated SUSY Breaking at

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SUSY06, UC Irvine, June 14

- Searches for topologies with a neutralino NLSP using both ECAL and HCAL
- Searches for topologies with a slepton NLSP covering all slepton lifetimes
- Scan over the GMSB parameter space
- Summary and outlook

All limits are at 95% C.L. All results are preliminary.
L3 Experiment at LEP2

619 pb^{-1} at √s = 189 - 208 GeV collected in 1998-2000

- Electromagnetic calorimeter: 11,000 BGO crystals
- Hadron calorimeter: uranium absorber and wire chambers
Minimal GMSB model phenomenology is driven by 6 parameters:

\[ \sqrt{F}, M_{\text{mess}}, N_5, \Lambda, \tan\beta, \text{sign}(\mu) \]

- Gravitino is always LSP with a mass \( 10^{-2} < m_G < 10^4 \) eV
NLSP can either a neutralino or slepton (stau)

\[ e^+ e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma \gamma \tilde{G} \tilde{G} \quad \text{or} \quad e^+ e^- \rightarrow \tilde{\ell}_R \tilde{\ell}_R \rightarrow \ell \ell \tilde{G} \tilde{G} \]

\[ L = 1.76 \cdot 10^{-3} (\kappa_\gamma)^{-1} \left( \frac{s}{4 m_{\tilde{\chi}_1^0}^2} - 1 \right)^{1/2} \left( \frac{100 \text{ GeV}}{m_{\tilde{\chi}_1^0}} \right)^5 \left( \frac{m_{\tilde{G}}}{1 \text{ eV}} \right)^2 \text{cm} \]

<table>
<thead>
<tr>
<th>lifetime</th>
<th>( \tilde{\chi}_1^0 ) NLSP</th>
<th>Slepton NLSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>short</td>
<td>acoplanar photons</td>
<td>acoplanar leptons</td>
</tr>
<tr>
<td>( cT \sim 0 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>non-pointing photons</td>
<td>kinked track</td>
</tr>
<tr>
<td>( 0 &lt; cT &lt; \infty )</td>
<td></td>
<td>large impact parameter</td>
</tr>
<tr>
<td>long</td>
<td></td>
<td>anomalous ( dE/dx )</td>
</tr>
<tr>
<td>( cT = \infty )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Short-Lived Neutralinos

SM background $e^+ e^- \rightarrow \nu \bar{\nu} \gamma \gamma$

$E_2 = 38.6 \text{ GeV}$
$E_1 = 63.9 \text{ GeV}$
$P_{miss} = 45.2 \text{ GeV}$

Signal is easy to separate
Efficiency $\sim 60-70\%$

$\sqrt{s} = 189-208 \text{ GeV}$
$m_{\chi_2^0} = 90 \text{ GeV}$

L3 Preliminary

Events / 4 GeV

Recoil Mass (GeV)

Events / 2 GeV

$E_{\gamma_2} (\text{GeV})$
Short-Lived Neutralinos

Cross Section Limit

\[ \sigma_{\tilde{\chi}_1^0\tilde{\chi}_1^0} \cdot Br(\tilde{\chi}_1^0 \rightarrow \tilde{\gamma}\tilde{\gamma}) \text{ (pb)} \]

- \[ e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{\gamma}\tilde{\gamma}\gamma \]
- Excluded at 95% C.L.

\[ \sqrt{s} = 207 \text{ GeV} \]

- Yellow: Observed
- Dashed: Expected

GMSB Interpretation

- \[ e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{\gamma}\tilde{\gamma}\gamma \]
- \[ m_{\tilde{e}_R} < m_{\tilde{\chi}_1} \]

- CDF
- Excluded at 95% C.L.

\[ m_{\tilde{\chi}_1} > 99.5 \text{ GeV} \]
Intermediate Neutralino Lifetimes

- Non-pointing photons in ECAL: \( R=0.5 \text{ m} \) and \( L=1.5 \text{ m} \)
- Photons in HCAL: \( 1 \text{ m} < R < 2 \text{ m} \) and \( L=5 \text{ m} \)
Non-Pointing Photons in the ECAL

Significant background comes from cosmic muons. Rejected by muon chambers, scintillator counters and tracker.

Transverse shower profile

Roundness \equiv \frac{\text{Minor Axis}}{\text{Major Axis}}
Standard Model background completely suppressed. Selection efficiency depends on the neutralino mass.

\[ \text{Data} \]

- **SM Bkgd**
- **\( m_{\tilde{\chi}^0_1} = 90 \text{ GeV} \)**

![Graph showing shower roundness vs. events/0.05](image)

![Graph showing selection efficiency vs. mean decay length](image)

- **Non-pointing photons in BGO**
- **Standard multi-photon**

\[ e^+ e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{G}\tilde{G}\gamma\gamma \]

\( \sqrt{s} = 207 \text{ GeV} \)

\[ m_{\tilde{\chi}^0_1} = 95 \text{ GeV} \]

\[ 50 \text{ GeV} \]
Photons in the HCAL

- Selected a sample of HCAL Bhabhas in the 1995 data.
- Data 1110 and MC 1048 events, energy resolution 23%.
- Shower profile and trigger efficiency also in agreement.

![Diagram of HCAL with energy levels and trigger efficiency graph]
Neutralino Decays in the HCAL

- Spectacular signature.
- Efficiency does not depend on the neutralino mass.
- Radial segmentation of HCAL would provide a measurement of $\tau$.
- No Standard Model background.
- Cosmics rejected using muon chambers and filter.
Non-Pointing Photons

No candidates found and limits derived for decay lengths 1-300 m

\[ e^+ e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{\chi} \tilde{\chi} \gamma \gamma \]

\[ \sqrt{s} = 207 \text{ GeV} \quad m_{\tilde{\chi}_1}^0 = 95 \text{ GeV} \]

![Graph showing selection efficiency and mean decay length for different calorimeters (HCAL, BGO, HCAL & BGO)]

![Graph showing exclusion limits for MGM model with decay chain \[ e^+ e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{\chi} \tilde{\chi} \gamma \gamma \]. Excluded at 95% C.L. at c\tau values up to 300 m and m_{\tilde{\chi}_1}^0 values up to 100 GeV.]
• Prompt decays: search for events with acoplanar leptons
• Intermediate lifetime: search for kinked tracks
• Long decay length: search for tracks with anomalous dE/dx
Scalar taus lighter than 80 GeV are excluded.
Scan of the GMSB parameter space
6 million points simulated with ISAJET

GMSB All NLSP Scenarios

$\sqrt{s} = 192-208$ GeV

Excluded at 95% C.L.

Preliminary

$1 \leq N \leq 5$

$1.5 \leq \tan \beta \leq 40$

$10 \text{ TeV} \leq M \leq 10^9 \text{ TeV}$

$\text{sign}(\mu) = \pm 1$

$1 \text{ TeV} \leq \Lambda \leq \min(\sqrt{F}, M)$
Scan of the GMSB Parameter Space

GMSB All NLSP Scenarios

Neutralino NLSP with L < 100 m

<table>
<thead>
<tr>
<th>N_{mess}</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Λ (TeV)</td>
<td>61.5</td>
<td>36.3</td>
<td>25.5</td>
<td>20.3</td>
</tr>
<tr>
<td>M_{mess} (TeV)</td>
<td>75</td>
<td>130</td>
<td>10^5</td>
<td>5.6 \cdot 10^6</td>
</tr>
<tr>
<td>m_{χ^0} (eV)</td>
<td>1.1</td>
<td>1.2</td>
<td>620</td>
<td>2.7 \cdot 10^4</td>
</tr>
<tr>
<td>m_{χ^0} (GeV)</td>
<td>78.6</td>
<td>83.8</td>
<td>88.0</td>
<td>104.2</td>
</tr>
<tr>
<td>m_{τ} (GeV)</td>
<td>82.1</td>
<td>87.1</td>
<td>90.8</td>
<td>106.3</td>
</tr>
<tr>
<td>m_{χ^0, m_{τ}} (GeV)</td>
<td>107.6</td>
<td>102.2</td>
<td>92.1</td>
<td>107.1</td>
</tr>
</tbody>
</table>

All NLSP scenarios

<table>
<thead>
<tr>
<th>N5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Λ (TeV/c^2)</td>
<td>47.25</td>
<td>25.5</td>
<td>16.75</td>
<td>13.0</td>
<td>11.0</td>
</tr>
<tr>
<td>M_{mess} (TeV/c^2)</td>
<td>56</td>
<td>32</td>
<td>24</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>m_{χ^0} (eV/c^2)</td>
<td>0.63</td>
<td>0.19</td>
<td>0.11</td>
<td>0.1</td>
<td>0.066</td>
</tr>
<tr>
<td>m_{χ^0} (GeV/c^2)</td>
<td>62.16</td>
<td>65.91</td>
<td>65.64</td>
<td>65.22</td>
<td>72.23</td>
</tr>
<tr>
<td>m_{τ} (GeV/c^2)</td>
<td>62.28</td>
<td>62.17</td>
<td>62.25</td>
<td>62.70</td>
<td>62.84</td>
</tr>
<tr>
<td>m_{χ^0, m_{τ}} (GeV/c^2)</td>
<td>89.60</td>
<td>73.62</td>
<td>71.15</td>
<td>66.94</td>
<td>67.11</td>
</tr>
</tbody>
</table>
LEP Combinations

Combinations performed by the LEP SUSY working group
http://lepsusy.web.cern.ch/lepsusy/

Scan in GMSB parameter space following

Example: N=2, medium M, μ > 0, short lifetime

$\tan(\beta) = 15 \Rightarrow \Lambda > 35.5 \text{ TeV/c}^2$
Prospects at the LHC (ATLAS)

D. Prieur hep-ph/0507083

- Reconstruct decay vertex
  - Impact position
  - Photon direction $\alpha$
  - Time of arrival $t_\gamma$

- Resolution on $c\tau$ better than 8% for $L=0.1-2$ m

$$\frac{\Delta m_\chi}{m_\chi} \approx 2\%$$
$$\frac{\Delta \sqrt{F_0}}{\sqrt{F_0}} \approx 4\%$$
$$\frac{\Delta m_G}{m_G} \approx 8\%$$

hep-ph/0010081: Decay lengths 0.5m – 1km considered

Measuring stau lifetime gives ~10% precision on $\sqrt{F}$
Extensive searches for GMSB signals were performed
New method developed to search for neutralino NLSP scenario ($L < 300$ m) using L3 hadron calorimeter (suitable for CMS ?)
Exciting prospects waiting at the LHC
My collaborators: L. Xia, H. Yang and S. Rosier
LEP SUSY Working Group
http://lepsusy.web.cern.ch/lepsusy/