Search for Dark Matter in $\tilde{\tau}_1 - \tilde{\chi}_1^0$.
Coannihilation Region at 500/800 GeV
ILC

Blair Jasper †, Mauricio Barbi †, Bhaskar Dutta ‡, Teruki Kamon ‡,
Vadim Khotilovich ‡, Nikolay Kolev †

†University of Regina
‡ Texas A&M University

Blair Jasper (University of Regina)
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Outline

- Physics Motivation
  - Dark Matter, SUSY, Minimal Supergravity motivated study

- Measuring CDM Relic Density at ILC

- Complications
  - Two-photon background

- 500 GeV Analysis

- 800 GeV Analysis

- Summary
Standard Cosmological Model

- 23% of universe composed of “Dark Matter” (DM)
- Does not emit or reflect EM radiation
- Presence inferred by cosmic microwave background (CMB) (e.g., WMAP), gravitational effects (e.g., rotational curves), collision of galaxies, etc.
SUSY as a Candidate for DM

- In supersymmetric (SUSY) theories, every fundamental fermion has a bosonic superpartner, and vice-versa.

- Lightest SUSY particle (LSP) is a suitable candidate for cold dark matter (CDM).
  - $\Omega_{\text{LSP}}$ falls in the range of $\Omega_{\text{CDM}}$ ($\Omega \equiv$ relic density).

\[
\left(\Omega_{\text{CDM}}\right)^{-1} \propto e^{-\Delta M / 20}
\]

Where $\Delta M = M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0}$
Minimal Supergravity (mSUGRA)

- mSUGRA as benchmark in many LHC and ILC studies
- Depends on only four parameters and one sign:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{1/2}$</td>
<td>Common gaugino (spin=1/2) mass (GeV)</td>
</tr>
<tr>
<td>$m_0$</td>
<td>Common scalar (spin=0) mass (GeV)</td>
</tr>
<tr>
<td>$\tan\beta$</td>
<td>Ratio of 2 v.e.v.'s</td>
</tr>
<tr>
<td></td>
<td>(2 Higgs doublets; $H_u$ &amp; $H_d$)</td>
</tr>
<tr>
<td>$\text{sign}(\mu)$</td>
<td>Sign of Higgs mixing parameter $\mu$ (GeV)</td>
</tr>
<tr>
<td>$A_0$</td>
<td>Trilinear coupling (GeV)</td>
</tr>
</tbody>
</table>

- LSP is the neutralino: $\tilde{\chi}_1^0$; NLSP is the stau: $\tilde{\tau}_1$
- Small $\Delta M$ allows $\tilde{\tau}_1$ and $\tilde{\chi}_1^0$ to coannihilate, contributing to current amount of CDM
mSUGRA Constraints

\[ \tan \beta = 40, \mu > 0, A_0 = 0 \]

\[ \Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} = 5 \sim 15 \text{ GeV} \]

\[ \tilde{\tau}_1^- \rightarrow \tau^- \tilde{\chi}_1^0 \]
SUSY Signature at ILC

- Look for final state $\tau^+ \tau^- + E_{\text{MISS}}$

$\Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}^0_1} = 5 \sim 15 \text{ GeV}$
Complications

- SM backgrounds at ILC include 4-fermion WW, ZZ, Zνν production; $\gamma\gamma$ process

Polarized beams suppress 4-fermion bkg.

Two-photon ($\gamma\gamma$) process
\[ e^+ e^- \rightarrow \gamma\gamma e^+ e^- \rightarrow \tau^+ \tau^- e^+ e^- \]

@ 500 GeV:
- Lower energy $\tau$'s
- $N_{2\gamma}(500 \text{ fb}^{-1}) \approx 13M \text{ events!}$

We need to detect $\tau^+$ and $\tau^-$ going very close to the beam direction (down to $1^\circ$).

- Polarization does not reduce $\gamma\gamma$ background
- $\gamma\gamma$ cross-section is large
- If we don’t detect $e^+$ and $e^-$ along the beamline, the event appears as $\tau^+ \tau^- + E_{\text{MISS}}$
500 GeV Analysis

- Assume 1° forward detector (for forward e⁺e⁻ detection)
- Optimize selection cuts (kinematical, topological)
- maximize sensitivity to signal events
- Extract ΔM by fitting the effective mass of τ⁺τ⁻ + E_{MISS} system.

Accuracy of Mass Determination

<table>
<thead>
<tr>
<th>ΔM (mₐ) [GeV]</th>
<th>N_{500 fb⁻¹}</th>
<th>ΔM (&quot;500 fb⁻¹ experiment&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2° Detector</td>
<td>1° Detector</td>
</tr>
<tr>
<td>4.76 (205)</td>
<td>122</td>
<td>Not determined</td>
</tr>
<tr>
<td>9.53 (210)</td>
<td>787</td>
<td>9.5^{+1.0}_{-1.0} GeV</td>
</tr>
<tr>
<td>12.37 (213)</td>
<td>1027</td>
<td>12.5^{+1.1}_{-1.1} GeV</td>
</tr>
<tr>
<td>14.27 (215)</td>
<td>1138</td>
<td>14.5^{+1.1}_{-1.1} GeV</td>
</tr>
</tbody>
</table>

NEED: 1° coverage at 500-GeV LC

δ(ΔM)/ΔM ~ 10% → Good accuracy
800 GeV Analysis

- $\Delta M$ measurement with new version of ILC detector simulation package
- What is the optimized forward detector design? Is 1° sufficient? 0.5°?

800 GeV allows larger parameter space
Neutralinos are suitable candidates for CDM

Small $\Delta M$ allows for coannihilation

Careful measurements of $\Delta M$ and other SUSY parameters at ILC can lead to measurement of relic neutralino density $\Omega_{\chi_1^0}$

Preliminary results show it is possible to measure $\Delta M$ to 10% accuracy at 500 GeV LC

Next: Need to study at 800 GeV (large reach of SUSY parameter space)
References