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

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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.
- SUSY particles have masses expected between 100 GeV and 1 TeV.
- Neutralinos are the lightest SUSY particle (LSP) and a suitable candidate for cold dark matter (CDM).
  - \( \Omega_{\text{LSP}} \) falls in the range of \( \Omega_{\text{CDM}} \) (\( \Omega \equiv \) relic density).
- Small \( \Delta M \) allows \( \tilde{\tau}_1 \) and \( \tilde{\chi}_1^0 \) to coannihilate, contributing to current amount of CDM.
Minimal Supergravity (mSUGRA)

- mSUGRA as benchmark in many LHC and ILC studies
- Depends on only four parameters and one sign:
  - $m_{1/2}$: Common gaugino (spin=1/2) mass (GeV)
  - $m_0$: Common scalar (spin=0) mass (GeV)
  - $\tan \beta$: Ratio of 2 v.e.v.’s
    - (2 Higgs doublets; $H_u$ & $H_d$)
  - sign($\mu$): Sign of Higgs mixing parameter $\mu$ (GeV)
    - We choose $\mu > 0$
  - $A_0$: Trilinear coupling (GeV)
    - We choose $A_0 = 0$
mSUGRA Constraints

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

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

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SUSY Signature at ILC

- Look for final state

\[ \tau^+ \tau^- + E_{\text{MISS}} \]

\[ \Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} \]
Complications

- SM backgrounds at ILC include 4-fermion WW, ZZ, Z\nuν 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
- \( N_{2\tau}(500 \text{ fb}^{-1}) \approx 13M \text{ events!} \)

We need to detect e\(^-\) and e\(^+\) 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 $\Delta M$ by fitting the effective mass of $\tau^+ \tau^- + E_{\text{MISS}}$ system.

### Accuracy of Mass Determination

<table>
<thead>
<tr>
<th>$\Delta M$ ($m_0$) [GeV]</th>
<th>$N_{500 \text{ fb}^{-1}}$</th>
<th>$\Delta M$ (&quot;500 fb$^{-1}$ experiment&quot;)</th>
</tr>
</thead>
<tbody>
<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>$12.5^{+1.4}_{-1.4}$ GeV</td>
</tr>
<tr>
<td>14.27 (215)</td>
<td>1138</td>
<td>$14.5^{+1.4}_{-1.4}$ GeV</td>
</tr>
</tbody>
</table>

- NEED: 1° coverage at 500-GeV LC
- $\delta(\Delta M)/\Delta M \sim 10\%$ → Good accuracy
800 GeV Analysis

- $\Delta M$ measurement with new version of ILC detector simulation package
- What is the optimized forward detector design? Is $1^\circ$ sufficient? $0.5^\circ$?
- A quick look at e- angular distribution in $\gamma\gamma$ background:

<table>
<thead>
<tr>
<th>Mask</th>
<th>% detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 GeV</td>
<td>$1^\circ$</td>
</tr>
<tr>
<td>500 GeV</td>
<td>$0.5^\circ$</td>
</tr>
<tr>
<td>500 GeV</td>
<td>$1^\circ$</td>
</tr>
</tbody>
</table>

800 GeV allows larger parameter space
Summary

- 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 ($\Omega_{\chi_1^0}$)
- A study shows it is possible to measure $\Delta M$ to 10% accuracy at 500 GeV LC (Phys. Lett. B. 618 (2005) 182)
- Next: Need to study at 800 GeV (larger reach of SUSY parameter space)
References