Cosmology and Colliders

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Stau neutralino coannihilation in minimal supergravity (mSUGRA) model

Prospects of detection of SUSY in coannihilation region at the ILC

Prospects of detection at the LHC

Conclusion

Can the mSUGRA naturally provide small $\Delta M$?

$\Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0}$

Griest, Seckel’91
Minimal Supergravity (mSUGRA)

4 parameters + 1 sign

\( m_{1/2} \) Common gaugino mass at \( M_G \)
\( m_0 \) Common scalar mass at \( M_G \)
\( A_0 \) Trilinear coupling at \( M_G \)
\( \tan \beta \) \(<H_u>/<H_d>\) at the electroweak scale
\( \text{sign}(\mu) \) Sign of Higgs mixing parameter \((W^{(2)} = \mu H_u H_d)\)

Experimental Constraints

i. \( M_{\text{Higgs}} > 114 \text{ GeV} \quad M_{\text{chargino}} > 104 \text{ GeV} \)
ii. \( 2.2 \times 10^{-4} < Br (b \rightarrow s \gamma) < 4.5 \times 10^{-4} \)
iii. \( 0.094 < \Omega_{\tilde{\chi}_1^0} h^2 < 0.129 \)  \quad \text{iv. } (g-2)_\mu
Stau Neutralino Coannihilation and GUT Scale

In mSUGRA model the lightest stau seems to be naturally close to the lightest neutralino mass especially for large tan\(\beta\)

For example, the lightest selectron mass is related to the lightest neutralino mass in terms of GUT scale parameters:

\[
m_0^2 \tilde{E}_c^2 = m_0^2 + 0.15 m_1^2 + (37 \text{ GeV})^2 \quad m_0^2 \tilde{\chi}_1^0 = 0.16 m_1^2
\]

Thus for \(m_0 = 0\), the mass of \(\tilde{E}_c^2\) becomes degenerate with the \(\tilde{\chi}_1^0\) mass at \(m_1/2 = 370\) GeV, i.e. the coannihilation region begins at

\[m_1/2 = (370-400)\) GeV\]

For larger \(m_1/2\) the degeneracy is maintained by increasing \(m_0\) and we get a corridor in the \(m_0 - m_1/2\) plane.

The coannihilation channel occurs in most SUGRA models with non-universal soft breaking,
Can we measure $\Delta M$ at colliders?
Can we discovery the signals in the coannihilation region at the LHC?

What will be $\delta \Delta M / \Delta M$?
SUSY Signature at the LHC

Squark-Gluino Production

\[ \tilde{\chi}^0_2 \rightarrow \tau^+ + \tilde{\tau}_1^- \rightarrow \tau^+ + \tau^- \tilde{\chi}^0_1 \]

Triggering the jets and missing \( E_T \) \[ E_T^{\text{miss}} + \text{jets} + \tau's \]
**$E_T^{\text{miss}} + 2j + 2\tau$ Analysis (I)**

[1] ISAJET + ATLFAST sample of $E_T^{\text{miss}}$, 2 jets, and at least 2 taus with $p_T^{\text{vis}} > 40, 20$ GeV and $\mathcal{E}_\tau = 50\%$, fake ($f_{j\rightarrow\tau} = 1\%$). Optimized cuts:

$E_T^{\text{jet1}} > 100$ GeV; $E_T^{\text{jet2}} > 100$ GeV; $E_T^{\text{miss}} > 180$ GeV; $E_T^{\text{jet1}} + E_T^{\text{jet2}} + E_T^{\text{miss}} > 600$ GeV

[2] Number of SUSY and SM events (10 fb$^{-1}$):

- **Top**: 115 events
- **$W$+jets**: 44 events
- **SUSY**: 590 events

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**Top**

**SUSY**

$M_{\text{gluino}} = 830$ GeV  
$(\Delta M = 10.6$ GeV)
**Analysis (II)**

1. **How to Establish the Discovery**
   - **[1]** \(N_{\text{OS-LS}}\) (Number of OS–LS counts)
   - **[2]** Clear peak (\(M_{\text{peak}}\)) and end-point (\(M_{\text{max}}\)) in di-tau mass distribution for OS–LS pairs
   - **[3]** \(M_{\text{peak}}\) is used to determine \(\Delta M\)

\[
p_T^{\tau} > 20 \text{ GeV} \text{ is essential!}
\]
A small $\Delta M$ can be detected in first few years of LHC.

[Assumption] The gluino mass is measured with $\delta M/M_{\text{gluino}} = \pm 5\%$ in a separate analysis.

Negligible $f_{j\rightarrow \tau}$ dependence
$E_T^{\text{miss}} + 1j + 3\tau$ Analysis

Much smaller SM background, but a lower acceptance

[1] ISAJET + PGS sample of $E_T^{\text{miss}}$, 1 jet and at least 3 taus with $p_T^{\text{vis}} > 40$, $40$, $20$ GeV and $\varepsilon_\tau = 50\%$, fake ($f_{j\rightarrow\tau}$) = 1%. Final cuts:

- $E_T^{\text{jet1}} > 100$ GeV,
- $E_T^{\text{miss}} > 100$ GeV,
- $E_T^{\text{jet1}} + E_T^{\text{miss}} > 400$ GeV

[2] Select OS low di-tau mass pairs, subtract off LS pairs

Small dependence on the uncertainty of $f_{j\rightarrow\tau}$

Note: $f_{j\rightarrow\tau} = 0\% \rightarrow 1.6$ counts/fb$^{-1}$
3τ Analysis: Combined Results

- Use $N_{\text{OS-LS}}$ and $M_{\tau\tau}$ to independently measure $\Delta M$
- Both produce high quality measurements
- As in the 2τ analysis, we assume a gluino mass

- Dominant uncertainty
  - 5% uncertainty on $M_{\text{gluino}}$

- Combined results: $\Delta M = 10 \pm 1.3 \text{ GeV (30 fb}^{-1})$
3$\tau$ Analysis (cont’d)

- Next: combine $N_{\text{OS-LS}}$ and $M_{\tau\tau}$ values to measure $\Delta M$ and $M_{\text{gluino}}$ simultaneously.

Counts drop with $M_{\text{gluino}}$

Mass rises with $M_{\text{gluino}}$

$\delta \Delta M/\Delta M \sim 15\%$ and $\delta M_{\text{gluino}}/M_{\text{gluino}} \sim 6\%$

$\Delta M = 9$ GeV

$L = 30$ fb$^{-1}$

$M_g = 850$ GeV

$L = 30$ fb$^{-1}$

Constant $M_{\tau\tau}$

Constant # of OS-LS Counts
Conclusion

Signals in the stau-neutralino coannihilation region are studied using mSUGRA model as a benchmark scenario ($\Delta M \sim 10$ GeV)

LHC: Two analyses with visible $p_T^\tau > 20$ GeV:

- **2$\tau$ analysis**: Discovery with $10$ fb$^{-1}$
  - $\delta \Delta M / \Delta M \sim 18\%$ using $M_{\text{peak}}$ with 5\% gluino mass error

- **3$\tau$ analysis**: Combine $N_{\text{OS-LS}}$ and $M_{\text{peak}}$ measurements
  - $\delta \Delta M / \Delta M \sim 13\%$ with $30$ fb$^{-1}$ and 5\% gluino mass error
  - $\delta \Delta M / \Delta M \sim 15\%$ and $\delta M_{\text{gluino}} / M_{\text{gluino}} \sim 6\%$ with no gluino mass assumption

  (It may be hard to measure the gluino mass otherwise due to the low energy taus in the signal.)

- The analyses can be done for the other models that don’t suppress $\chi_2^0$ production.

 ✓ **Comparison**: $\delta \Delta M / \Delta M \sim 10\%$ (500 fb$^{-1}$) at the ILC if we implement a very forward calorimeter to reduce two-$\gamma$ background.