OUTLINE

➤ Cosmology, SUSY, WIMP

➤ Stau neutralino coannihilation in minimal supergravity (mSUGRA) model

➤ Prospects of detection at the LHC and determination of masses

➤ Determination of $\Omega \tilde{\chi}_i^0 h^2$

➤ Conclusion

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

Griest, Seckel '91

Experimental Constraints

i. $M_{\text{Higgs}} > 114$ GeV  
    $M_{\text{chargino}} > 104$ GeV

ii. $2.2 \times 10^{-4} < Br (b \rightarrow s \gamma) < 4.5 \times 10^{-4}$

iii. $0.094 < \Omega \chi^0 / h^2 < 0.129$

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:

$$m_{\tilde{E}^c}^2 = m_0^2 + 0.15m_{1/2}^2 + (37 \text{ GeV})^2$$

Thus for $m_0 = 0$, $m_{\tilde{E}^c}^2$ becomes degenerate with $m_{\tilde{\chi}_1^0}^2$ at $m_{1/2} = 370$ GeV, i.e. the coannihilation region begins at

$$m_{1/2} = (370-400) \text{ GeV}$$

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,

Cosmologically Allowed Region

$\tan\beta = 40, \mu > 0, A_0 = 0$

Can we measure $\Delta M$ at colliders?
**SUSY Signature at the LHC**

**Squark-Gluino Production**

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

Triggering the jets and missing \( E_T \) \( \rightarrow E_T^{\text{miss}} + \text{jets} + \tau^0 \)

10/31/06  
Stau-Neutralino Coannihilation at the Collider

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**\( M_{\tau\tau}^{\text{vis}} \) in ISAJET**

Version 7.69 \((m_{1/2} = 347.88, m_0 = 201.06) \rightarrow M_{\text{gluino}} = 831\)

Chose di-\( \tau \) pairs from neutralino decays with

(a) \(|\eta| < 2.5\)

(b) \(\tau = \) hadronically-decaying tau

\[ \begin{align*}
\tilde{\chi}_2^0 &= 264.116 \\
\tilde{\tau}_1^0 &= 137.441 \\
\tau_1 &= 143.141 \\
E_T^{\text{vis(true)}} &= 62.01
\end{align*} \]

\( E_T^{\tau} > 20 \text{ GeV} \) is essential!
$E_T^{\text{miss}} + 1j + 3\tau$ Analysis: $M_{\tau\tau}$

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 $E_T^{\text{vis}} > 40, 40, 20$ GeV and $\varepsilon_\tau = 50\%$, fake ($f_{\tau\rightarrow \tau}$) = 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

![Graph showing opposite-signed and like-signed pairs]

- Large $\Delta M$
  - Many events
  - Large mass

- Small $\Delta M$
  - Few events
  - Small mass

Note: $f_{\tau\rightarrow \tau} = 0\% \rightarrow 1.6$ counts/fb$^{-1}$ for $\Delta M=10$ GeV

Small dependence on the uncertainty of $f_{\tau\rightarrow \tau}$
3τ Analysis: Combined Results

- Use \( N_{\text{OS-LS}} \) and \( M_{\tau\tau} \) to independently measure \( \Delta M \)
- Both produce high quality measurements
- We assume a gluino mass
- Dominant uncertainty
  - 5% uncertainty on \( M_{\text{gluino}} \)

- Combined results:
  \[ \Delta M = 10 \pm 1.3 \text{ GeV (30 fb}^{-1}) \]

3τ 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 \( M_{\text{gluino}} \)

\[ \frac{\delta \Delta M}{\Delta M} \sim 15\% \text{ and } \frac{\delta M_{\text{gluino}}}{M_{\text{gluino}}} \sim 6\% \]
**Determination of \( m_0 \) and \( m_{1/2} \)**

\[ \Delta M \text{ and } M_{\text{gluino}} \rightarrow m_0 \text{ and } m_{1/2} \]

(for fixed \( A_0 \) and \( \tan \beta \))

\[
\begin{align*}
\frac{\delta m_0}{m_0} & \approx 5\% \\
\frac{\delta m_{1/2}}{m_{1/2}} & \approx 6\%
\end{align*}
\]

with \( L = 30 \text{ fb}^{-1} \) (for \( A_0 = 0, \tan \beta = 40 \))

**Determination of \( \Omega_{\tilde{\chi}_0^0 h^2} \)**

\[ \Delta M \text{ and } M_{\text{gluino}} \rightarrow \Omega_{\tilde{\chi}_0^0 h^2} \]

(for fixed \( A_0 \) and \( \tan \beta \))

\[
\delta \Omega_{\Omega_{\tilde{\chi}_0^0 h^2}} \approx 20\% \text{ with } L = 30 \text{ fb}^{-1}
\]

(for \( A_0 = 0, \tan \beta = 40 \))
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 $E_T^\tau > 20$ 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
  - $\delta \Delta M / \Delta M \sim 15\%$ 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 $\chi^0_2$ 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.

- \( \delta m_0 / m_0 \sim 4\% \), \( \delta \Omega h^2 / \Omega h^2 \sim 20\% \) for $A_0=0$, $\tan \beta=40$ with $L=30$ fb$^{-1}$.
3\tau Analysis: Accuracy in $\Delta M$ & $M_{\text{gluino}}$

$\Delta M = 9$ GeV
$M_g = 850$ GeV
Combined Measurement

$\rightarrow$ 22\% - 15\%
(10 - 30 fb$^{-1}$)

$\rightarrow$ 9\% - 6\%
(10 - 30 fb$^{-1}$)