Cosmological Connection at the LHC

: Stau Neutralino Co-annihilation Case

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OUTLINE

- Dark Matter (DM) in Universe
- DM Particle in SUSY
- Cosmological Connection (CC) at the LHC and $\Omega h^2$
  [Co-annihilation (CA) Case]
- Summary

Arnowitt, Dutta, Kamon, Kolev, Toback, PLB 639 (2006) 46
Arnowitt, Dutta, Gurrola, Kamon, Krislock, Toback, in preparation
Dark Matter (DM) in Universe

splitting normal matter and dark matter apart

– Another Clear Evidence of Dark Matter –

Ordinary Matter
(NASA's Chandra X Observatory)

Dark Matter (Gravitational Lensing)

Approximately the same size as the Milky Way

(8/21/06)
I’m hungry. Can you make the DM sandwich with the elementary particles?

No, sir. But with Neutrino?

**MENU**

~SPECIALS~

*Dark Energy Power Drink .. $73
  - Chef’s choice

*Dark Matter Sandwich …… $23
  - Neutral, long-lived
  - $\tilde{\chi}_1^0, \tilde{G}$ or $\tilde{\nu}$ from SUSY
  - $\gamma_{KK}$ from UED
  - Heavy $\gamma$ from LHT

*Atomic Soup ..................... $4
  - All elements in one

"I CAN'T TELL YOU WHAT'S IN THE DARK MATTER SANDWICH. NO ONE KNOWS WHAT'S IN THE DARK MATTER SANDWICH."
DM Particle

It sounds good. Extra charge?

No, sir. Free of charge.

MENU
~SPECIALS~
*Dark Energy Power Drink .. $73
  - Chef's choice
*Dark Matter Sandwich ...... $23
  - Neutral, long-lived
  - $^0\tilde{\chi}_1$, $\tilde{G}$ or $\tilde{\nu}$ from SUSY
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"I CAN'T TELL YOU WHAT'S IN THE DARK MATTER SANDWICH. NO ONE KNOWS WHAT'S IN THE DARK MATTER SANDWICH."

Cosmological Connection at the LHC: Stau Neutralino Coannihilation Case
SUSY is an interesting class of models to provide a weakly interacting massive neutral particle ($M \sim 100$ GeV).
Cosmological Connection (CC) at the LHC and $\Omega h^2$
An anatomy of $\sigma_{\text{ann}}$:

An accidental near degeneracy occurs naturally for light stau in mSUGRA.

Co-annihilation (CA) Process

Griest, Seckel '91

$\Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}^0_1}$
4 parameters + 1 sign

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{1/2}$</td>
<td>Common gaugino mass at $M_G$</td>
</tr>
<tr>
<td>$m_0$</td>
<td>Common scalar mass at $M_G$</td>
</tr>
<tr>
<td>$A_0$</td>
<td>Trilinear coupling at $M_G$</td>
</tr>
<tr>
<td>$\tan\beta$</td>
<td>$&lt;H_u&gt;/&lt;H_d&gt;$ at the electroweak scale</td>
</tr>
<tr>
<td>sign($\mu$)</td>
<td>Sign of Higgs mixing parameter ($W^{(2)} = \mu H_u H_d$)</td>
</tr>
</tbody>
</table>

**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. $0.094 < \Omega_{\tilde{\chi}_1^0} h^2 < 0.129$

iv. $(g-2)_\mu \quad [\sim 3\sigma \text{ deviation from the SM calculation}]$
DM Allowed Regions

Below is the case of mSUGRA model. However, the results can be generalized.

- **[Focus point region]**
  - The lightest neutralino has a larger Higgsino component

- **[A-annihilation funnel region]**
  - This appears for large values of $m_{1/2}$

- **[Stau-Neutralino CA region]**

- **[Bulk region]** almost ruled out
Cosmological Connection at the LHC: Stau Neutralino Coannihilation Case

**Mass of Squarks and Sleptons**

- **Excluded (Higgs mass)**
- **Excluded (Magnetic Moment of Muon)**
- **Co-annihilation Region**
- **No CDM Candidate**

**Mass of Gauginos**

- **CDM allowed region**

**CA Regions - Illustration**

- **Higgs Mass \( (M_h) \)**
- **Branching Ratio \( b \rightarrow s\gamma \)**
- **Magnetic Moment of Muon**

Illustration:

- Dark Energy 73%
- Cold Dark Matter 23%
- Excluded (Higgs mass) 4%

Diagram:

- \( b \rightarrow s\gamma \)
- \( \gamma \)
- \( \tilde{\chi}_1^\pm \)
- \( \tilde{\tau} \)
- \( \tilde{\nu} \)
- \( \mu \)

**CDM allowed region**
Can we measure $\Delta M$ at colliders?

Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
Excess in $E_T^{\text{miss}} + \text{Jets} + X$

$X = \text{Dilepton mass endpoint from } \chi_2^0 \text{ decay to reconstruct the SUSY masses}$

$X = ee, \mu\mu, \tau\tau$

large $\tan\beta$

$X = \tau\tau$

$\Delta M = 5-10 \text{ GeV}$

$\Omega h^2$?
Excess in $E_T^{\text{miss}} + \text{Jets}$

- Excess in $E_T^{\text{miss}} + \text{Jets} \rightarrow \text{R-parity conserving SUSY}$
- $M_{\text{eff}} \rightarrow \text{Measurement of the SUSY scale at 10-20\%}.$


- $E_T^{j1} > 100 \text{ GeV}, \quad E_T^{j2,3,4} > 50 \text{ GeV}$
- $M_{\text{eff}} > 400 \text{ GeV} (M_{\text{eff}} \equiv E_T^{j1} + E_T^{j2} + E_T^{j3} + E_T^{j4} + E_T^{\text{miss}})$
- $E_T^{\text{miss}} > \text{max}[100, 0.2 \ M_{\text{eff}}]$}

The heavy SUSY particle mass is measured by combining the final state particles

The heavy SUSY particle mass is measured by combining the final state particles

$\tilde{g} \tilde{g}$

$\tilde{\chi}_0^1 \rightarrow qq$

$\tilde{\chi}_1^0 \rightarrow q\bar{q}$

HM1: High Mass Scenario 1

$m_{1/2} = 250, \ m_0 = 60; \ \sigma = 45 \text{ fb}$

$M(\text{gluino}) = 1886; \ M(\text{squark}) = 1721$
DM content $\rightarrow$ Measurements of the SUSY masses [e.g., M.M. Nojiri, G. Polesselo, D.R. Tovey, JHEP 0603 (2006) 063]

- Dilepton “edge” in the $\chi_2^0$ decay in dilepton ($ee, \mu\mu, \tau\tau$) channels for reconstruction of decay chain.

**LM1:**
(Low Mass Case 1)
$m_{1/2} = 180$, $m_0 = 850$;
$\sigma = 55$ pb
[post-WMAP benchmark point $B'$]
M(gluino) = 611
M(squark) = 559
gluino $\rightarrow$ squark+quark
B(X02 $\rightarrow$ slep_R lept) = 11.2%
B(X02 $\rightarrow$ stau_1 tau) = 46%
B(X+1 $\rightarrow$ sneut_L lept) = 36%

- SFOS dilepton+jets+$E_T^{miss}$
- $tt\bar{t}$: $WW$+j:Z+j:other $\sim$ 6:1:1:1
- flavor subtraction ($e^-\mu^+$ + $e^+\mu^-$) to suppress chargino, $W$, $tt\bar{t}$, $WW$, “other”
- L1+HLT trigger path required
- overall systematic on the background 20% (JES dominated)
- $5\sigma$ discovery with $\sim$ 20 pb$^{-1}$ (of data understood as expected with 1 fb$^{-1}$)
In the CA region, however, the $ee$ and $\mu\mu$ channels are almost absent. We are in a different game:

$$\text{Br}(\chi_{2}^{0} \rightarrow ee, \mu\mu) \sim 0\%$$
$$\text{Br}(\chi_{2}^{0} \rightarrow \tau\tau) \sim 100\%$$
$$\Delta M = 5-15 \text{ GeV}$$

Questions:
1. How can we establish the dark matter allowed regions?
2. To what accuracy can we calculate the relic density based on the measurements at the LHC?
Our Reference Point

\[ m_{1/2} = 351, \ m_0 = 210, \ \tan \beta = 40, \ \mu > 0, \ A_0 = 0 \]

[ISAJET version 7.69]

TABLE I: Masses (in GeV) of SUSY particles for our reference point \( m_{1/2} = 351 \) GeV, \( m_0 = 210 \) GeV, \( \tan \beta = 40, \ \mu > 0, \) and \( A_0 = 0 \). We use ISAJET v7.69 The \( \tilde{q}_L \) and \( \tilde{q}_R \) masses are represented by the \( \tilde{u}_L \) and \( \tilde{u}_R \) masses. \( \Delta M = 10.6 \) GeV.

<table>
<thead>
<tr>
<th>( \tilde{g} )</th>
<th>( \tilde{q}_L )</th>
<th>( \tilde{q}_R )</th>
<th>( \tilde{t}_2 )</th>
<th>( \tilde{t}_1 )</th>
<th>( \tilde{b}_2 )</th>
<th>( \tilde{b}_1 )</th>
<th>( \tilde{e}_L )</th>
<th>( \tilde{e}_R )</th>
<th>( \tilde{\tau}_2 )</th>
<th>( \tilde{\tau}_1 )</th>
<th>( \tilde{\chi}^0_2 )</th>
<th>( \tilde{\chi}^0_1 )</th>
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<tbody>
<tr>
<td>831</td>
<td>748</td>
<td>728</td>
<td>705</td>
<td>319</td>
<td>329</td>
<td>260.3</td>
<td>140.7</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>831</td>
<td>725</td>
<td>561</td>
<td>645</td>
<td>251</td>
<td>151.3</td>
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</tbody>
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Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
Smoking Gun of CA Region

Unique kinematics

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

(CDM)

2 quarks + 2 \( \tau \)'s + CDM particle

SUSY Masses

Cosmological Connection at the LHC: Stau Neutralino Coannihilation Case
SUSY Anatomy

Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case

(SUSY Masses)

Meff

M(ττ)

ETmiss + jets + ≥2τ

12/17/07
$\tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$

(from $\tilde{\chi}_2^0$ decays)

Number of Counts / 2 GeV vs Visible $P_T(\tau)$ (GeV)

$\tilde{\chi}_2^0 \rightarrow \tau \tilde{\tau}_1 \rightarrow \tau \tau \tilde{\chi}_1^0$

($\Delta M = 5.7$ GeV)

$p_T$ and $M_{\tau\tau}$ distributions in true di-$\tau$ pairs from neutralino decay with $|\eta| < 2.5$

Slope of $p_T$ distribution of “soft $\tau$” contains $\Delta M$ information

Low energy $\tau$'s are an enormous challenge for the detectors

$\tilde{g} = 831$ GeV

$\tilde{\chi}_2^0 = 264$ GeV

$\tilde{\chi}_1^0 = 137.4$ GeV

$\tilde{\tau}_1 = 143.1$ GeV

End point = 62.0 GeV
Warming-up Quizzes

I. Hadronic or leptonic?
- Hadronic, because $e$ or $\mu$ does not tell us the evidence of tau leptons

II. How low in $p_T$?
- CDF: $p_T^{\text{vis}} > 15-20$ GeV

III. Worries about triggers?
- $E_T^{\text{miss}} + \text{jet trigger for SUSY}$
- Lepton+tau trigger for $Z$’s (calibration)

[Assumption] $\varepsilon_\tau = 50\%$, fake rate 1\%
$E_T^{\text{miss}} + 2j + 2\tau$ Analysis Path

Cuts to reduce the SM backgrounds ($W$+jets, ...)

$E_T^{\text{miss}} > 180$ GeV, $N(\text{jet}) \geq 2$ with $E_T > 100$ GeV

$E_T^{\text{miss}} + E_T^{i1} + E_T^{i2} > 600$ GeV; $N(\tau) \geq 2$ with $P_T > 40, 20$ GeV

CATEGORIZE opposite sign (OS) and like sign (LS) ditau events

**OS $\tau\tau$**

$M_{\tau\tau}$ histogram

**LS $\tau\tau$**

$M_{\tau\tau}$ histogram

$\{\text{OS mass}\} \xrightarrow{} \text{OS–LS mass} \xrightarrow{} \text{LS mass}\{
**$M_{\tau\tau}$ Distribution**

$$M_{\tau\tau}^{\text{max}} = M_{\tilde{\chi}_2^0} \sqrt{1 - \frac{M_{\tilde{\tau}_1}^2}{M_{\tilde{\chi}_2^0}^2}} \sqrt{1 - \frac{M_{\tilde{\chi}_1^0}^2}{M_{\tilde{\tau}_1}^2}}$$

*Clean peak even for low $\Delta M$  \quad Larger $\tilde{\chi}_2^0$ Mass $\rightarrow$ Larger $M_{\tau\tau}$*

We choose the peak position as an observable.

**Cosmological Connection at the LHC: Stau Neutralino Coannihilation Case**

12/17/07
$E_T^{\text{miss}} + 2j + 2\tau$ Analysis Path

Cuts to reduce the SM backgrounds ($W$+jets, ...)

$E_T^{\text{miss}} > 180$ GeV, $N(\text{jet}) \geq 2$ with $E_T > 100$ GeV

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CATEGORIZE opposite sign (OS) and like sign (LS) ditau events

OS $\tau\tau$
- Low $p_T$ histogram
- High $p_T$ histogram

LS $\tau\tau$
- Low $p_T$ histogram
- High $p_T$ histogram

Low OS

Low OS–LS

High OS

High OS–LS

Low LS

High LS
\[ \Delta M = 10.6 \text{ GeV} \]
\[ M_{\tilde{g}} = 831 \text{ GeV} \]

\[ M_{\tau\tau} < M_{\tau\tau} \text{ end point} \]

Cosmological Connection at the LHC: Stau Neutralino Coannihilation Case

12/17/07
We can still see the dependence of the $p_T$ slope on $\Delta M$ using OS–LS method.

$M_{\tilde{g}} = 831 \text{ GeV}$

$M_{\tilde{\chi}_2^0} = 260.286 \text{ GeV}$

- $\Delta M = 5.7 \text{ GeV}$
- $\Delta M = 10.6 \text{ GeV}$
- $\Delta M = 15.0 \text{ GeV}$
$M_{\tau\tau}^{\text{peak}}$ vs. $X$

Uncertainty Bands with 10 fb$^{-1}$

Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
**Slope**($p_T^{soft}$) vs. $X$

**Uncertainty Bands with 10 fb$^{-1}$**

- **Left Top**:
  - $\Delta M$ (GeV): 6 to 15
  - $p_T$ Slope:
    - $-0.1$ to $-0.12$

- **Right Top**:
  - $\chi_1^0$ (GeV): 100 to 180
  - $p_T$ Slope:
    - $-0.04$ to $-0.06$
    - $\Delta M = 10.6$ GeV
    - $M_{\chi_2} = 260.3$ GeV
    - $M_\chi = 831.0$ GeV

- **Left Bottom**:
  - $M_{\chi_2}$ (GeV): 200 to 340
  - $p_{T_{run}}$ Slope:
    - $-0.08$ to $-0.12$

- **Right Bottom**:
  - $\tilde{g}$ (GeV): 750 to 950
  - $p_T$ Slope:
    - $-0.04$ to $-0.08$
    - $\Delta M = 10.6$ GeV
    - $M_{\chi_1} = 140.7$ GeV
    - $M_{\chi_2} = 260.3$ GeV

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**Cosmological Connection at the LHC:**
Stau Neutralino Coannihilation Case

12/17/07
SUSY Anatomy

Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
\[ M_{j\tau\tau}^{\text{end}} = M_\tilde{q} \sqrt{1 - \frac{M^2}{M_{\tilde{q}}^2}} \sqrt{1 - \frac{M_{\tilde{\chi}_2^0}^2}{M_{\tilde{\chi}_1^0}^2}} \]

\[
M_{\tau\tau} < M_{\tau\tau}^{\text{endpoint}}
\]

Jets with \( E_T > 100 \text{ GeV} \)

\( J\tau\tau \) masses for each jet

Choose the 2\text{nd} large value

Peak value \(~\) True Value

\(
\rightarrow \text{We take the peak value as an observable.}
\)

Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
**M_{j\tau\tau} Distribution**

\[ M_{j\tau\tau}^{\text{end}} = M_\tilde{q} \sqrt{1 - \frac{M_0^2}{M_\tilde{q}^2}} \sqrt{1 - \frac{M_0^2}{M_\tilde{\chi}_2^2}} \]

\[ M^{\text{peak}}_{j\tau\tau} \propto M_{j\tau\tau}^{\text{end}} \]

\[ M_{\tau\tau} < M_{\tau\tau}^{\text{endpoint}} \]

Jets with \( E_T > 100 \text{ GeV} \)

J\( \tau\)\( \tau \) masses for each jet

Choose the 2\textsuperscript{nd} large value

\( \Delta M = 10.6 \text{ GeV} \)

\( M_{\tilde{\chi}_4} = 140.7 \text{ GeV} \)

\( M_{\tilde{\chi}_2} = 260.3 \text{ GeV} \)

Squark Mass = 660 GeV

Squark Mass = 840 GeV

Peak value depends on squark mass

We choose the peak position as an observable.

Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
Cosmological Connection at the LHC: Stau Neutralino Coannihilation Case

$M_{\tilde{\tau}_\tau}^{\text{peak}}$ vs. $X$
4 observables defined as functions of 5 masses

\[ N_{OS-LS} = f(\tilde{g}, \tilde{q}_L, \Delta M, \tilde{\chi}_2^0, \tilde{\chi}_1^0) \]

\[ M_{\tau\tau}^{peak} = h(\tilde{g}, \Delta M, \tilde{\chi}_2^0, \tilde{\chi}_1^0) \]

\[ \text{Slope} = w(\tilde{g}, \Delta M, \tilde{\chi}_2^0, \tilde{\chi}_1^0) \]

\[ M_{j\tau \tau}^{peak} = \gamma(\tilde{g}, \tilde{q}_L, \Delta M, \tilde{\chi}_2^0, \tilde{\chi}_1^0) \]

Invert the equations to determine the masses as functions of the observables

\[ \tilde{g} = f'(N_{OS-LS}, M_{\tau\tau}^{peak}, \text{Slope}, M_{j\tau \tau}^{peak}) \]

\[ \tilde{q}_L = 0.9 \cdot \tilde{g} \]

\[ \Delta M = h'(N_{OS-LS}, M_{\tau\tau}^{peak}, \text{Slope}, M_{j\tau \tau}^{peak}) \]

\[ \tilde{\chi}_2^0 = w'(N_{OS-LS}, M_{\tau\tau}^{peak}, \text{Slope}, M_{j\tau \tau}^{peak}) \]

\[ \tilde{\chi}_1^0 = \gamma'(N_{OS-LS}, M_{\tau\tau}^{peak}, \text{Slope}, M_{j\tau \tau}^{peak}) \]

5th observable \((M_{j\tau \tau})\) is not ready for this talk. We assume:

\[ \tilde{q}_L = 0.9 \cdot \tilde{g} \]

[This assumption will be removed once the \(M_{j\tau \tau}\) study is ready.]
We test a gaugino universality.

\[ \frac{M_{\tilde{g}}}{M_{\tilde{\chi}^0_2}} \sim 3.12 \]
\[ \frac{M_{\tilde{g}}}{M_{\tilde{\chi}^0_1}} \sim 5.90 \]
Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
\[ M_{\text{eff}} \text{ Distribution} \]

\[ E_T^{j1} > 100 \text{ GeV}, \quad E_T^{j2,3,4} > 50 \text{ GeV} \quad [\text{No } e\text{'s, } \mu\text{'s with } p_T > 20 \text{ GeV}] \]

\[ M_{\text{eff}} > 400 \text{ GeV} \quad (M_{\text{eff}} \equiv E_T^{j1} + E_T^{j2} + E_T^{j3} + E_T^{j4} + E_T^{\text{miss}}) \quad [\text{No } b \text{ jets; } \varepsilon_b \sim 50\%] \]

\[ E_T^{\text{miss}} > \max [100, 0.2 \times M_{\text{eff}}] \]

At Reference Point

\[ M_{\text{eff}}^{\text{peak}} = 1274 \text{ GeV} \]

\[ M_{\text{eff}}^{\text{peak}} = 1220 \text{ GeV} \quad (m_{1/2} = 335 \text{ GeV}) \]

\[ M_{\text{eff}}^{\text{peak}} = 1331 \text{ GeV} \quad (m_{1/2} = 365 \text{ GeV}) \]
$M_{\text{eff}}^{\text{peak}}$ vs. $X$

\begin{align*}
M_{\text{eff}}^{\text{peak}} \ldots & \text{Very insensitive to } A_0 \text{ and } \tan\beta.
\end{align*}

$m_{1/2}$ (GeV) \hspace{1cm} m_0$ (GeV)
\[ M_{\text{eff}}^{(b)} \] Distribution

- \( E_{T}^{j1} > 100 \text{ GeV}, \quad E_{T}^{j2,3,4} > 50 \text{ GeV} \) [No \( e^{'s}, \mu^{'s} \text{ with } p_{T} > 20 \text{ GeV} \)]
- \( M_{\text{eff}}^{(b)} > 400 \text{ GeV} \) (\( M_{\text{eff}}^{(b)} = E_{T}^{j1=b}+E_{T}^{j2}+E_{T}^{j3}+E_{T}^{j4}+E_{T}^{\text{miss}} \) [\( j1 = b \text{ jet} \)])
- \( E_{T}^{\text{miss}} > \text{max} \left[ 100, 0.2 \ M_{\text{eff}} \right] \)

At Reference Point

\[ M_{\text{eff}}^{(b)\text{peak}} = 1026 \text{ GeV} \]

\[ M_{\text{eff}}^{(b)\text{peak}} = 933 \text{ GeV} \quad M_{\text{eff}}^{(b)\text{peak}} = 1122 \text{ GeV} \]

\( m_{1/2} = 335 \text{ GeV} \quad m_{1/2} = 365 \text{ GeV} \)
$M_{\text{eff}}^{(b)\text{peak}}$ vs. $X$

$m_{1/2}$

$m_0$

$A_0$

$tan\beta$

$M_{\text{eff}}^{(b)\text{peak}}$ .... Sensitive to $A_0$ and $tan\beta$. 

Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case
DM Connection

[1] Detection of low energy $\tau$'s ($p_T > 20$ GeV) in the stau-neutralino CA region.

[2] Construction of observables: $N_{OS-LS}$, $M_{j\tau\tau}$, $M_{\tau\tau}$, Slope, $M_{\text{eff}}$, $M_{\text{eff}}^{(b)}$

[3] Reconstruction of SUSY masses using:
   e.g., $\text{Peak}(M_{\tau\tau}) = f(M_{\text{gluino}}, M_{\text{stau}}, M_{\tilde{\chi}_2^0}, M_{\tilde{\chi}_1^0})$

[4] $N_{OS-LS}$, $M_{j\tau\tau}$, Slope, $M_{\text{eff}}$, to solve for $m_0$ and $m_{1/2}$
   e.g., Gaugino universality test

[5] $M_{\tau\tau}$, $M_{\text{eff}}^{(b)}$ to solve $\tan\beta$ and $A_0$

[6] Dark matter content in mSUGRA

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<tr>
<td>$M_{g}$</td>
<td>831 GeV</td>
</tr>
<tr>
<td>$M_{\tilde{\chi}_2^0}$</td>
<td>260 GeV</td>
</tr>
<tr>
<td>$M_{\tilde{\tau}}$</td>
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<tr>
<td>$M_{\tilde{\chi}_1^0}$</td>
<td>140.7 GeV</td>
</tr>
<tr>
<td>$m_0$</td>
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<tr>
<td>$m_{1/2}$</td>
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<tr>
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<tr>
<td>$A_0$</td>
<td>0</td>
</tr>
<tr>
<td>$\text{sgn}(\mu)$</td>
<td>&gt; 0</td>
</tr>
</tbody>
</table>

$\Omega_{\tilde{\chi}_1^0} h^2 = 0.1$
We have made a determination of the masses

\[ \tilde{g} = f'(N_{OS-LS}, M_{\text{peak}}^\tau, \text{Slope} M_{j\tau}) \]

\[ \Delta M = h'(N_{OS-LS}, M_{\text{peak}}^\tau, \text{Slope} M_{j\tau}) \]

\[ \tilde{\chi}_2^0 = w'(N_{OS-LS}, M_{\text{peak}}^\tau, \text{Slope} M_{j\tau}) \]

\[ \tilde{\chi}_1^0 = y'(N_{OS-LS}, M_{\text{peak}}^\tau, \text{Slope} M_{j\tau}) \]

The gaugino masses determine \( m_{1/2} \)

\[ \tilde{g} = f_1(m_{1/2}), \tilde{\chi}_2^0 = f_2(m_{1/2}), \tilde{\chi}_1^0 = f_3(m_{1/2}) \]

Incorporating the \( M_{\text{eff}} \) and \( M_{\text{eff}}^{(b)} \) observables

\[ M_{\text{eff}} = f_4(m_{1/2}, m_0), M_{\text{eff}}^{(b)} = f_5(m_{1/2}, m_0, \tan \beta, A_0) \]

Writing \( \Delta M \) as a function of the model parameters:

\[ \Delta M = f_6(m_0, m_{1/2} \tan \beta, A_0) \]

\[ \delta m_0 / m_0 \sim 4.9 \% \]

\[ \delta m_{1/2} / m_{1/2} \sim 3 \% \]

\[ \delta \tan \beta / \tan \beta \sim 7.8 \% \]

\[ \delta A_0 \sim \pm 25 \text{ GeV} \]
We have made a determination of the mSUGRA model parameters

\[ m_{1/2} = f''(\tilde{g}, \tilde{\chi}_2, \tilde{\chi}_1) \]
\[ m_0 = h''(M_{\text{eff}}, \tilde{g}, \tilde{\chi}_2, \tilde{\chi}_1) \]
\[ \tan \beta = w''(\Delta M, \tilde{g}, \tilde{\chi}_2, \tilde{\chi}_1, M_{\text{eff}}, M_{\text{eff}}^{(b)}) \]
\[ A_0 = y''(\Delta M, \tilde{g}, \tilde{\chi}_2, \tilde{\chi}_1, M_{\text{eff}}, M_{\text{eff}}^{(b)}) \]

The Dark Matter relic density depends on the model parameters:

\[ \Omega h^2 = f'''(m_0, m_{1/2} \tan \beta, A_0) \]

We can determine \( \Delta M \) to \( \sim 17 \% \) accuracy and \( \Omega h^2 \) to \( \sim 35 \% \)
Summary

This talk is about a cosmological connection at the LHC in the case of co-annihilation (CA).

The LHC should be able to uncover the striking small $\Delta M$ signature (smoking gun in the CA region) with $\sim 10$ fb$^{-1}$ of data in multi-$\tau$ final states and make high quality measurements with the first few years of running.

With the mSUGRA model in the CA region, the dark matter content can be measured with an accuracy of $\sim 40\%$. 
Cosmological Connection at the LHC:
Stau Neutralino Coannihilation Case 44

The University of New Mexico
Albuquerque, USA
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I WANT YOU
TO HELP SOLVE THE PUZZLE OF
THE UNIVERSE.