Era of Discovery with CMS Detector

TAMU Group
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Precision Cosmology at the Large Hadron Collider

Based on plenary talks at Cosmo’08, IDM’08, Santa Fe’08, DM’08

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Texas A&M University

11th September ’08
LHC Days...

We will try to understand:

- The mechanism for generating masses
- The physics behind the scale of $W, Z$ boson mass scale
  $\sim$ electroweak scale
- Do we have any further evidence of grand unification?
- The origin of dark matter
  Is there any particle physics connection?
The Standard Model (SM) describes all these particles and 3 of 4 forces. We have confirmed the existence of those in the laboratory experiments.

+ Higgs boson

Higgs has not yet been discovered

The mass is constrained from LEP and Tevatron data:

$$114 \text{ GeV} < M_H < 154 \text{ GeV}$$
SM problems and solutions

The Standard Model:

- Cannot provide a dark matter candidate.
- Has a serious Higgs mass divergence problem due to quantum correction.
- Cannot accommodate masses for neutrinos.
- Cannot provide enough matter-antimatter asymmetry.
- **Standard Model has fallen!**

Solves the Higgs mass problem in a very elegant way.

Supersymmetric grand unified models include neutrinos!


Can produce correct matter-antimatter asymmetry

- Dutta, Kumar, PLB 643 (2006) 284

Can provide Inflation


Can provide new sources of CP violation, e.g., $B_s \rightarrow \psi \phi$


What is the new model?

Supersymmetry:

Provides a candidate for dark matter ~ neutralino.
SUSY is an interesting class of models to provide a weakly interacting massive neutral particle ($M \sim 100$ GeV).
The fundamental law(s) of nature is hypothesized to be symmetric between bosons and fermions.

Fermion $\leftrightarrow$ Boson

Have they been observed? $\Rightarrow$ Not yet.
SUSY Transition Diagrams

SUSY partner of $W$ boson: chargino

SUSY partner of $\tau$ lepton: stau

Lightest neutralinos are always in the final state! This neutralino is the dark matter candidate!!

Precision Cosmology at the LHC
The grand unification of forces occur in SUSY models.

Unification scale can also be pushed to $10^{17-18}$ GeV

Ameliorates Proton decay problem in the very successful SO(10) model


Precision Cosmology at the LHC
Search for SUSY-upcoming days

Large Hadron Collider-
susy particles will be directly produced

Existence of Higgs will be explored

- Higgs mass in the well motivated SUSY models: < 150 GeV
  Current bound: 114 - 150 GeV

Direct detection experiment, CDMS, Xenon 100, LUX etc

Indirect detection experiments, e.g., Pamela has already observed
excess of positron excess in cosmic ray

Fermi Gamma Ray Space Telescope:
  Sensitive to gamma ray from Dark Matter annihilation

IceCube: Sensitive to neutrinos from DM annihilation

Tevatron search for $B_s \rightarrow \mu^+ \mu^-$ (highest reach on SUSY masses)
SUSY at the LHC

Colored particles get produced and decay into weakly interacting stable particles.

The energy of jets and leptons depend on the sparticle masses which are given by models.

The signal: jets + leptons + missing Energy

High energy jet

[mass difference is large]

Precision Cosmology at the LHC
Excess in $E_T^{\text{miss}} + \text{Jets}$

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


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

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

$\tilde{g} \quad \tilde{g} \quad \tilde{\chi}_0^0 \quad \tilde{\chi}_1^0$

$\tilde{\chi}_1^0 \quad \tilde{\chi}_1^0$

$\tilde{g} \quad \tilde{g} \quad \tilde{\chi}_0^0 \quad \tilde{\chi}_1^0$

$\tilde{g} \quad \tilde{g} \quad \tilde{\chi}_0^0 \quad \tilde{\chi}_1^0$

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

**FIG. 1.** LHC point 1 signal and standard model backgrounds. Open circles: SUSY signal. Solid circles: $t\bar{t}$. Triangles: $W \rightarrow l\nu, \tau\nu$. Downward triangles: $Z \rightarrow \nu\bar{\nu}, \tau\bar{\tau}$. Squares: QCD jets. Histogram: sum of all backgrounds.
Relic Density and $M_{\text{eff}}$

SUSY scale can be measured with an accuracy of 10-20%.

- This measurement does not tell us whether the model can generate the right amount of dark matter.

- The dark matter content is measured to be 23% with an accuracy less than 4% at WMAP.

Question:
To what accuracy can we calculate the relic density based on the measurements at the LHC?
Anatomy of $\sigma_{\text{ann}}$

\[ \Omega_{\tilde{\chi}_1^0 h^2} \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx \quad < \sigma_{\text{ann}} v > \sim \frac{\alpha^2}{M^2} \sim 1 \text{ pb} \]

\[ (\Omega_{\text{CDM}})^{-1} \propto \begin{bmatrix}
\tilde{\chi}_{1}^0 \\
\tilde{\chi}_{1}^0 \\
\text{h, H, A, Z} \\
\tilde{f} \\
f \\
\tilde{f} \\
+ \\
\tilde{f} \\
+ \ldots
\end{bmatrix}^2 \]

Co-annihilation (CA) Process

\[ e^{-\Delta M / k T_f} \]

A near degeneracy occurs naturally for light stau in mSUGRA.
Minimal Supergravity (mSUGRA)

SUSY model in the framework of unification:

\[ \beta = \frac{\langle H_u \rangle}{\langle H_d \rangle} \text{ at } M_Z \]

4 parameters + 1 sign

- \( \tan \beta \)
- \( m_{1/2} \):
  Common gaugino mass at \( M_{\text{GUT}} \)
- \( m_0 \):
  Common scalar mass at \( M_{\text{GUT}} \)
- \( A_0 \):
  Trilinear coupling at \( M_{\text{GUT}} \)
- \( \text{sign}(\mu) \):
  Sign of \( \mu \) in \( W^{(2)} = \mu H_u H_d \)

Key Experimental Constraints

- \( M_{\text{Higgs}} > 114 \text{ GeV} \)
- \( M_{\text{chargino}} > 104 \text{ GeV} \)
- \( 2.2 \times 10^{-4} < B(b \rightarrow s \gamma) < 4.5 \times 10^{-4} \)
- \( (g-2)_{\mu} : 3 \sigma \text{ deviation from SM} \)
- \( 0.094 < \Omega_{\tilde{\chi}_1^0} h^2 < 0.129 \)


Precision Cosmology at the LHC
DM Allowed Regions in mSUGRA

[Focus point region] the lightest neutralino has a larger Higgsino component

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


[Bulk region] is almost ruled out

Overdense region
Signals of the Allowed Regions

✓ Neutralino-stau coannihilation region: jets + taus (low energy) + missing energy


✓ Focus point: jets+ leptons +missing energy

[Crockett, Dutta, Flanagan, Gurrola, Kamon, Kolev, VanDyke, 08; Tovey, PPC 2007; Baer, Barger, Salughnessy, Summy, Wang , PRD, 75, 095010 (2007)]

✓ Bulk region: jets+ leptons +missing energy [Nojiri, Polsello, Tovey’05]

✓ Annihilation funnel: mass of pseudo scalar Higgs

   = 2 mass of DM

Goal for the analysis

- Establish the “dark matter allowed region” signal
- Measure SUSY masses
- Determine mSUGRA parameters
- Predict $\Omega_\chi h^2$ and compare with $\Omega_{CDM} h^2$
Low energy taus exist in the CA region
However, one needs to measure the model parameters to predict the dark matter content in this scenario

\[ \Delta M = M_{\tilde{\chi}_1} - M_{\tilde{\chi}_1^0} = 5 \sim 15 \text{ GeV} \]
Low energy $\tau$'s are an enormous challenge for the detectors.

We need to involve the low energy $\tau$'s in our analysis.

\[ \tilde{\chi}_2^0 \rightarrow \tau \tilde{\chi}_1 \rightarrow \tau \tau \tilde{\chi}_1^0 \]
\[ (\Delta M = 5.7 \text{ GeV}) \]

\[ \tilde{g} = 831 \text{ GeV} \]
\[ \tilde{\chi}_2^0 = 264 \text{ GeV} \]
\[ \tilde{\chi}_1^0 = 137.4 \text{ GeV} \]
\[ \tilde{\tau}_1 = 143.1 \text{ GeV} \]

End point = 62.0 GeV

Arnowitt, Dutta, Kamon, Kolev, Toback PLB 639 (2006) 46

Precision cosmology at the LHC
$E_T^{\text{miss}} + 2\tau + 2j$ Analysis

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

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

$E_T^{\text{miss}} + E_T^{j1} + E_T^{j2} > 600$ 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

We use ISAJET + PGS4

Arnowitt, Dutta, Kamon, Kolev, Toback

PLB 639 (2006) 46

Precision Cosmology at the LHC
**OS–LS $M_{\tau\tau}$ Distribution**

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

\[ M_{\tau\tau}^{\text{peak}} \propto M_{\tau\tau}^{\text{max}} \]

**Clean peak even for low $\Delta M$**

\[ \Delta M = 10.6 \text{ GeV} \]

<table>
<thead>
<tr>
<th>$\tilde{g}$</th>
<th>$\tilde{u}_L$</th>
<th>$\tilde{c}_2$</th>
<th>$\tilde{b}_2$</th>
<th>$\tilde{e}_L$</th>
<th>$\tilde{\tau}_2$</th>
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<td>$\tilde{u}_R$</td>
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<td>561</td>
<td>645</td>
<td>251</td>
<td>151.3</td>
<td>140.7</td>
</tr>
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</table>

Counts / (10 fb$^{-1} \times$ 10 GeV)

$M_{\tilde{\chi}_2}^0 = 260.3 \text{ GeV}$

$M_{\tilde{\chi}_2} = 321.5 \text{ GeV}$

Larger $\tilde{\chi}^0_2$ Mass → Larger $M_{\tau\tau}$
SUSY Anatomy

Precision Cosmology at the LHC
$M_{\text{eff}}, M_{\text{eff}} (b)$ Distribution

- $E_{T}^{j1} > 100$ GeV, $E_{T}^{j2,3,4} > 50$ GeV
- [No $e$’s, $\mu$’s with $p_{T} > 20$ GeV]
- $M_{\text{eff}} > 400$ GeV
- $(M_{\text{eff}} \equiv E_{T}^{j1} + E_{T}^{j2} + E_{T}^{j3} + E_{T}^{j4} + E_{T}^{\text{miss}}$ [No $b$ jets; $\epsilon_{b} \sim 50\%$])
- $E_{T}^{\text{miss}} > \max [100, 0.2 M_{\text{eff}}]$

At Reference Point $M_{\text{eff}}^{\text{peak}} = 1274$ GeV

$M_{\text{eff}}^{(b)} > 400$ GeV
$(M_{\text{eff}}^{(b)} \equiv E_{T}^{j1=b} + E_{T}^{j2} + E_{T}^{j3} + E_{T}^{j4} + E_{T}^{\text{miss}}$ [j1 = b jet])

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

$M_{\text{eff}}^{(b)}$ can be used to determine $A_{0}$ and $\tan \beta$

Arnowitt, Dutta, Gurrola, Kamon, Krislock, Toback, PRL, 100, (2008)

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Precision Cosmology at the LHC
1. Sort $\tau$’s by $E_T$ ($E_T^1 > E_T^2 > ...$)
   - Use OS–LS method to extract $\tau$ pairs from the decays

   $$N_{\tau^+\tau^-} - N_{\tau^+\tau^+}$$

   SM+SUSY Background gets reduced

   - Ditau invariant mass: $M_{\tau\tau}$
   - Jet-$\tau$-$\tau$ invariant mass: $M_{j_{\tau\tau}}$
   - Jet-$\tau$ invariant mass: $M_{j_{\tau}}$
   - $P_T$ of the low energy $\tau$
   - $M_{\text{eff}}$: 4 jets +missing energy
   - $M_{\text{eff}}(b)$: 4 jets +missing energy

All these variables depend on masses $\rightarrow$ model parameters

Since we are using 7 variables, we can measure the model parameters and the grand unified scale symmetry (a major ingredient of this model)
Determining SUSY Masses (10 fb$^{-1}$)

7 Eqs (as functions of SUSY parameters)

$M_{\tau\tau}^{\text{peak}} = f_1(\Delta M, \tilde{\chi}_2^0, \tilde{\chi}_1^0)$

Slope $= f_2(\Delta M, \tilde{\chi}_1^0)$

$M_{j\tau\tau}^{(2)\text{peak}} = f_3(\tilde{q}_L, \tilde{\chi}_2^0, \tilde{\chi}_1^0)$

$M_{j\tau_1}^{(2)\text{peak}} = f_4(\tilde{q}_L, \Delta M, \tilde{\chi}_2^0, \tilde{\chi}_1^0)$

$M_{j\tau_2}^{(2)\text{peak}} = f_5(\tilde{q}_L, \Delta M, \tilde{\chi}_2^0, \tilde{\chi}_1^0)$

$M_{\text{eff}}^{\text{peak}} = f_6(\tilde{g}, \tilde{q}_L)$

$M_{\text{eff}}(b) = f_7(\tilde{g}, \tilde{q}_L, t, \tilde{b})$

Invert the equations to determine the masses

$M_{\tilde{q}_L} = 748 \pm 25; \ M_{\tilde{g}} = 831 \pm 21; \ M_{\tilde{\chi}_2^0} = 260 \pm 15; \ M_{\tilde{\chi}_1^0} = 141 \pm 19; \ \Delta M = 10.6 \pm 2.0$

$M_{\tilde{g}} / M_{\tilde{\chi}_2^0} = 3.1 \pm 0.2 \ (\text{theory} = 3.19)$

$M_{\tilde{g}} / M_{\tilde{\chi}_1^0} = 5.9 \pm 0.8 \ (\text{theory} = 5.91)$

Arnowitt, Dutta, Gurrola, Kamon, Krislock, Toback

We can probe the physics at the Grand unified theory (GUT) scale

Use the masses measured at the LHC and evolve them to the GUT scale using mSUGRA

The masses $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{g}$ unify at the grand unified scale in SUGRA models

Gaugino universality test at $\sim 15\%$ (10 fb$^{-1}$)

Another evidence of a symmetry at the grand unifying scale!
DM Relic Density in mSUGRA

\[ M_{\tilde{g}} = 831 \text{ GeV} \]
\[ M_{\tilde{\chi}^0_2} = 260 \text{ GeV} \]
\[ M_{\tilde{\tau}} = 151.3 \text{ GeV} \]
\[ M_{\tilde{\chi}^0_1} = 140.7 \text{ GeV} \]

[1] Established the CA region by detecting low energy \( \tau \)'s \((p_T^{\text{vis}} > 20 \text{ GeV})\)

[2] Determined SUSY masses using:

\[ M_{\tau \tau}, \text{Slope}, M_{j \tau \tau}, M_{j \tau}, M_{\text{eff}} \]

\[ \text{e.g., Peak}(M_{\tau \tau}) = f(M_{\text{gluino}}, M_{\text{stau}}, M_{\tilde{\chi}^0_2}, M_{\tilde{\chi}^0_1}) \]

[3] Predict the dark matter relic density by determining \(m_0, m_{1/2}, \tan\beta, \text{and } A_0\)

\[ \Omega_{\tilde{\chi}^0_1}h^2 = \]

[4] We can also predict the dark matter-nucleon scattering cross section \(\sigma_{\chi_1^0-p}\) but it has large theoretical error
Determining mSUGRA Parameters

✓ Solved by inverting the following functions:

\[ M_{j\tau\tau} = f_1(m_{1/2}, m_0) \]
\[ M_{\tau\tau} = f_2(m_{1/2}, m_0, \tan \beta, A_0) \]
\[ M_{\text{eff}} = f_3(m_{1/2}, m_0) \]
\[ M^{(b)}_{\text{eff}} = f_4(m_{1/2}, m_0, \tan \beta, A_0) \]

\[ \begin{align*}
    m_0 &= 210 \pm 5 \\
    m_{1/2} &= 350 \pm 4 \\
    A_0 &= 0 \pm 16 \\
    \tan \beta &= 40 \pm 1 \\
\end{align*} \]

\[ \Omega_{\tilde{\chi}_1^0} h^2 = Z(m_0, m_{1/2}, \tan \beta, A_0) \]

\[ \frac{\delta \Omega_{\tilde{\chi}_1^0} h^2}{\Omega_{\tilde{\chi}_1^0} h^2} = 6.2\% \ (30 \text{ fb}^{-1}) = 4.1\% \ (70 \text{ fb}^{-1}) \]

\[ \frac{\delta \sigma_{\tilde{\chi}_1^0 - p}}{\sigma_{\tilde{\chi}_1^0 - p}} \approx 7\% \ (30 \text{ fb}^{-1}) \]


Precision Cosmology at the LHC
✓ $m_0$ is large, $m_{1/2}$ can be small,
  e.g., $m_0 = 3550$ GeV, $m_{1/2} = 314$ GeV, $\tan \beta = 10$, $A_0 = 0$

$\Delta M(\chi_3^0 - \chi_1^0) = 81$ GeV,
$\Delta M(\chi_2^0 - \chi_1^0) = 59$ GeV,
$\Delta M(\chi_3^0 - \chi_2^0) = 22$ GeV

$\text{Br}(g \rightarrow \chi_2^0 \bar{t}t) = 10.2\%$
$\text{Br}(g \rightarrow \chi_2^0 \bar{u}u) = 0.8\%$
$\text{Br}(g \rightarrow \chi_3^0 \bar{t}t) = 11.1\%$
$\text{Br}(g \rightarrow \chi_3^0 \bar{u}u) = 0.009\%$
Dilepton Mass at FP

OSSF – OSDF \((e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp)\)

- \(M(\tilde{\chi}_2^0) - M(\tilde{\chi}_1^0) = 59\text{ GeV}\)
- \(M(\tilde{\chi}_3^0) - M(\tilde{\chi}_1^0) = 81\text{ GeV}\)

Relic density calculation depends on \(\mu\), \(\tan\beta\) and \(m_{1/2}\).

\(m_{1/2}\), \(\mu\) and \(\tan\beta\) can be solved from \(M(\text{gluino})\), \(\Delta M (\chi_3^0 - \chi_1^0)\) and \(\Delta M (\chi_2^0 - \chi_1^0)\).

Errors of \((300 \text{ fb}^{-1})\):
- \(M(\text{gluino})\): \(4.5\%\)
- \(\Delta M (\chi_3^0 - \chi_1^0)\): \(1.2\%\)
- \(\Delta M (\chi_2^0 - \chi_1^0)\): \(1.7\%\)
- \(\tan\beta\): \(22\%\)
- \(\mu\): \(0.1\%\)

Chargino masses can be measured! Work in Progress

- Tovey, talk at PPC 2007
- Baer, Barger, Salughnessy, Summy, Wang, PRD 75, 095010 (2007)
- Crockett, Dutta, Flanagan, Gurrola, Kamon, Kolev, Krislock, VanDyke (2008)

Precision Cosmology at the LHC
The most part of this region in mSUGRA is experimentally (Higgs mass limit, $b \rightarrow s \gamma$) ruled out

Relic density is mostly satisfied by t channel selectron, stau and sneutrino exchange

Perform the end point analysis to determine the masses

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<td>$\tilde{\tau}$</td>
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<td>$\tilde{u}_L$</td>
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<td>$M_{lq}(\text{max})$</td>
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<td>$M_{llq}(\text{min})$</td>
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<td>1.9</td>
</tr>
<tr>
<td>$M_{\tau\tau}(\text{max})$</td>
<td>62.2</td>
<td>5.0</td>
</tr>
</tbody>
</table>

The error of relic density: $0.108 \pm 0.1\text{(stat + sys)}$

Includes: $(+0.00, -0.002)M(A); \ (+0.001, -0.011)\tan \beta; \ (+0.002, -0.005)\ m(\tilde{\tau}_2)$

[With a luminosity 300 fb$^{-1}$, $\tau\tau$ edge controlled to 1 GeV]
Overdense Region

Overdense region (Large $m_0$): Too much dark matter

The final states contain $Z$, Higgs, staus

In some models, this overdense region is not really overdense, e.g.,

Dilaton effect creates new parameter space


Precision Cosmology at the LHC
Observables involving Z and Higgs

Observables:
✓ Effective mass: $M_{\text{eff}}$ (peak): $f_1(m_0,m_{1/2})$

✓ Effective mass with 1 b jet: $M_{\text{eff}}(b)$ (peak): $f_2(m_0,m_{1/2}, A_0, \tan \beta)$

✓ Effective mass with 2 b jets: $M_{\text{eff}}(2b)$ (peak): $f_3(m_0,m_{1/2}, A_0, \tan \beta)$

✓ Higgs plus jet invariant mass: $M_{bbj}(\text{end-point}): f_4(m_0,m_{1/2})$

We can solve for masses by using the end-points

4 observables => 4 mSUGRA parameters

Dutta, Gurrola, Kamon, Krislock, Lahanas, Mavromatos, Nanopoulos, arXiv:0808.1372

Precision Cosmology at the LHC
Determining mSUGRA Parameters

✓ Solved by inverting the following functions:

\[
M_{\text{end point}}^{jbb} = X_1(m_{1/2}, m_0)
\]

\[
M_{\text{peak}}^{\text{eff}} = X_2(m_{1/2}, m_0)
\]

\[
M_{\text{(b) peak}}^{\text{eff}} = X_3(m_{1/2}, m_0, \tan \beta, A_0)
\]

\[
M_{\text{(bb) peak}}^{\text{eff}} = X_4(m_{1/2}, m_0, \tan \beta, A_0)
\]

\[
m_0 = 472 \pm 50
\]

\[
m_{1/2} = 440 \pm 15
\]

\[
A_0 = 0 \pm 95
\]

\[
\tan \beta = 39 \pm 18
\]

\[
1000 \text{ fb}^{-1}
\]

\[
\Omega \tilde{\chi}_1^0 h^2 = Z(m_0, m_{1/2}, \tan \beta, A_0)
\]

\[
\delta \Omega \tilde{\chi}_1^0 h^2 / \Omega \tilde{\chi}_1^0 h^2 \sim 150\%
\]
2 tau + missing energy dominated regions:

✓ Solved by inverting the followingObservables:

\[
M_{j\tau\tau}^{(2)\text{peak}} = X_1(m_{1/2}, m_0)
\]
\[
M_{\text{peak eff}} = X_2(m_{1/2}, m_0)
\]
\[
M_{\text{peak eff}}^{(b)} = X_3(m_{1/2}, m_0, \tan\beta, A_0)
\]
\[
M_{\tau\tau}^{\text{peak}} = X_4(m_{1/2}, m_0, \tan\beta, A_0)
\]

\[
\begin{align*}
 m_0 & = 440 \pm 23 \\
 m_{1/2} & = 600 \pm 6 \\
 A_0 & = 0 \pm 45 \\
 \tan\beta & = 40 \pm 3 
\end{align*}
\]

\[
\delta \Omega_{\tilde{\chi}_1^0} h^2 / \Omega_{\tilde{\chi}_1^0} h^2 \sim 19\%
\]

For 500 fb⁻¹ of data

Dutta, Gurrola, Kamon, Krislock, Lahanas, Mavromatos, Nanopoulos, arXiv:0808.1372

Precision Cosmology at the LHC
The measurement at the LHC will pinpoint the parameters of SUSY models. We can predict the direct detection probability of dark matter particles.

(* The TAMU group is one of the leading institutions in the US.)
Status - Direct Detection

Ongoing/future projects: CDMS, LUX, XENON100, ZEPLIN

Status:

- **DAMA** group (Italy) – claims to have observed some events.
- **CDMS, ZEPLIN, XENON100, Cogent** – dispute their claim.

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Accomando, Arnowitt, Dutta, Santosos, NPB 585 (2000) 124

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Close to the current sensitivity
Conclusion

- **SM of particle physics has fallen.**
- Supersymmetry seems to be natural in the rescue act and the dark matter content of the universe can be explained in this theory.
- The minimal SUGRA model is consistent with the existing experimental results.

[1] LHC can probe the minimal SUGRA model directly.
- All the dark matter allowed regions can be probed at the LHC
- The dark matter content can be measured with an accuracy of 6% in the stau-neutralino coannihilation region
- This accuracy depends on the final states

[2] This analysis can be applied to any SUSY model
Concussion...

[3] Direct detection experiments will simultaneously confirm the existence of these models.

[4] Indirect detection experiments will also confirm the existence of SUSY

[5] Very exciting time ahead...

Precision Cosmology at the LHC
An August the largest particle accelerator ever built will begin operations, testing the limits of the standard model of particle physics, but who knows what will really happen.

Once the Large Hadron Collider gets going...

It could theoretically create a black hole or “strangely” that would devour the earth.

Inevitable protests...

I'm not made of string.

Brahma is the higher dimension.

I'm not made of string.

"Thou shalt not commit the Bavarian or the Verron. For it is an abomination in my eyes."

- Deuteronomy 9:12

"Woe to the one who bothers the Lord’s law."  - Deuteronomy 30:19

We should not have meddled!

There are things man was not meant to know!

There's a 4.2 x 10^-7 probability that this baby will create a black hole that destroys the earth.

Wow, what's the chance it will do something useful?

Well, there's a 4.2 x 10^-7 chance that we'll be rid of Paris Hilton.

My eyes.
Conclusion...

“All of these will be supersymmetry phenomenology/model papers”