mSUGRA Signals of Supercritical String Theory at the LHC

Teruki Kamon

In collaboration with
B. Dutta, A. Gurrola, A. Krislock, and D. Nanopoulos
(Texas A&M University)

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Probing the SUSY Dark Matter

Dark Matter (DM) Particle in SUSY & Cosmological Connection

Ω_{SUSY DM} = Ω_{CDM}

SUSY Signals in “Supercritical String” Region

DM Density (Ωh^2) at the LHC

“Smoothly evolving Supercritical-String Dark Energy relaxes Supersymmetric-Dark-Matter Constraints”

A.B. Lahanas, N.E. Mavromatos, D.V. Nanopoulos

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DM Particle in SUSY

CDM = Neutralino $\tilde{\chi}_1$

$\Omega_{\tilde{\chi}_1} h^2 \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx$

$\langle \sigma_{\text{ann}} v \rangle = \frac{\pi \alpha^2}{8 M^2}$

$0.23$

$0.9 \text{ pb}$

$
\begin{align*}
\left( \Omega_{\text{CDM}} \right)^{-1} & \propto \\
+ & \\
\text{Co-annihilation (CA) Process} & \\
\tilde{\chi}_1^0 & \text{Griest, Seckel '91} \\
\tilde{\chi}_1^0 & \\
\tilde{\tau} & \\
\tilde{\tau} & \\
\Delta M & = M_{\tilde{\chi}_1} - M_{\tilde{\chi}_1^0} \\
\end{align*}$

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Is $w = -1$ for all times?

Quintessence – Scalar field dark energy

$\mathcal{W}$ varies in time.

LMD Scenario

“Smoothly evolving Supercritical-String Dark Energy relaxes Supersymmetric-Dark-Matter Constraints”

A.B. Lahanas, N.E. Mavromatos, D.V. Nanopoulos

PLB 649 (2007) 63

\[
\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle (n^2 - n_{eq}^2)
\]

\[
\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle (n^2 - n_{eq}^2) + S(\phi)
\]
Let’s look into signals in the region

SSC off-equilibrium and time-dependent-dilaton effects
→ A smoothly evolving dark energy for the last 10 billion years

\[ f(x) = \text{The supersymmetric dark matter density (neutralinos) dilute by a factor } O(10) \]

We need to anticipate searches and discoveries to discriminate between conventional cosmology and SSC.

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mSUGRA Signals of Supercritical String Theory at the LHC
$\chi_2^0$ Decay Branching Ratios

Identify and classify $\chi_2^0$ decays

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mSUGRA Signals of Supercritical String Theory at the LHC
### m\(_{1/2} = 440\) GeV; \(m_0 = 471\) GeV

Table 1: SUSY masses (in GeV) and dominant branching ratios for \(\tilde{\chi}_2^0\) for the point \(m_0 = 471\) GeV, \(m_{1/2} = 440\) GeV, \(\tan\beta = 40\), \(A_0 = 0\), and \(\mu > 0\). Notice that the \(\tilde{\chi}_2^0\) decay to \(\tilde{\tau}\) is kinematically forbidden.

<table>
<thead>
<tr>
<th>(\tilde{g})</th>
<th>(\tilde{u}_L)</th>
<th>(\tilde{t}_2)</th>
<th>(\tilde{b}_2)</th>
<th>(\tilde{e}_L)</th>
<th>(\tilde{\tau}_2)</th>
<th>(\tilde{\chi}_2^0)</th>
<th>(\mathcal{B}(\tilde{\chi}_2^0 \rightarrow h^0 + \tilde{\chi}_1^0)) (%)</th>
<th>(\mathcal{B}(\tilde{\chi}_2^0 \rightarrow Z^0 + \tilde{\chi}_1^0)) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tilde{u}_R)</td>
<td>(\tilde{t}_1)</td>
<td>(\tilde{b}_1)</td>
<td>(\tilde{e}_R)</td>
<td>(\tilde{\tau}_1)</td>
<td>(\tilde{\chi}_1^0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1041</td>
<td>1017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>954</td>
<td>768</td>
<td>899</td>
<td>557</td>
<td>532</td>
<td>341</td>
<td></td>
<td>86.8%</td>
<td></td>
</tr>
<tr>
<td>958</td>
<td></td>
<td></td>
<td>500</td>
<td>393</td>
<td>181</td>
<td></td>
<td>13.0</td>
<td></td>
</tr>
</tbody>
</table>

### m\(_{1/2} = 600\) GeV; \(m_0 = 440\) GeV

Table 3: SUSY masses (in GeV) and dominant branching ratios for \(\tilde{\chi}_2^0\) for the point \(m_0 = 440\) GeV, \(m_{1/2} = 600\) GeV, \(\tan\beta = 40\), \(A_0 = 0\), and \(\mu > 0\).

<table>
<thead>
<tr>
<th>(\tilde{g})</th>
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<th>(\tilde{e}_L)</th>
<th>(\tilde{\tau}_2)</th>
<th>(\tilde{\chi}_2^0)</th>
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<tbody>
<tr>
<td>(\tilde{u}_R)</td>
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<td>(\tilde{b}_1)</td>
<td>(\tilde{e}_R)</td>
<td>(\tilde{\tau}_1)</td>
<td>(\tilde{\chi}_1^0)</td>
<td></td>
<td></td>
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<tr>
<td>1366</td>
<td>1252</td>
<td>1153</td>
<td>1153</td>
<td>594</td>
<td>574</td>
<td>462</td>
<td></td>
<td>20.5</td>
</tr>
<tr>
<td>1211</td>
<td>1211</td>
<td>957</td>
<td>1094</td>
<td>494</td>
<td>376</td>
<td>249</td>
<td></td>
<td>77.0%</td>
</tr>
</tbody>
</table>
Supercritical String

\[ m_{1/2} = 440, \ m_0 = 471, \ \tan \beta = 40, \ m_{\text{top}} = 175 \]

(SSC Ref. Point)

\[ \tilde{g} \]

1041

\[ \tilde{u}_L \]

1044

\[ \tilde{u} \]

1044

\[ \tilde{\chi}_2^0 \]

341

\[ \tilde{\chi}_2^0 \]

341

\[ \tilde{\chi}_1^0 \]

181

\[ \tilde{\chi}_1^1 \]

462

\[ h \]

114

\[ Z \]

91

\[ e_R \]

500

\[ \tau_1 \]

393

\[ \gamma \]
Event Selections

\[ E_T^{\text{miss}} > 180 \text{ GeV}; \ N(\text{jet}) \geq 2 \ \text{with} \ E_T > 200 \text{ GeV}; \]

\[ E_T^{\text{miss}} + E_T^{j1} + E_T^{j2} > 600 \text{ GeV} \]

\[ N(b) \geq 2 \ \text{with} \ P_T > 100 \text{ GeV}; \ 0.4 < \Delta R_{bb} < 1 \]

Side-band BG subtraction
4 Functions

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

\[ M_{\text{eff}} \equiv E_T^{j1} + E_T^{j2} + E_T^{j3} + E_T^{j4} + E_T^{\text{miss}} \, \text{[No } b \text{ jets; } \varepsilon_b \sim 50\%]\]

\[ M_{\text{eff}}^{(b)} \equiv E_T^{j1=b} + E_T^{j2} + E_T^{j3} + E_T^{j4} + E_T^{\text{miss}} \]

\[ M_{\text{eff}}^{(bb)} \equiv E_T^{j1=b} + E_T^{j2=b} + E_T^{j3} + E_T^{j4} + E_T^{\text{miss}} \]
Band = Error with 1000 fb$^{-1}$
Determining mSUGRA Parameters

✓ Solved by inverting the following functions:

\[ M_{jbb}^{\text{end point}} = X_1(m_{1/2}, m_0) \]
\[ M_{\text{eff}}^{\text{peak}} = X_2(m_{1/2}, m_0) \]
\[ M_{\text{eff}}^{(b) \text{peak}} = X_3(m_{1/2}, m_0, \tan \beta, A_0) \]
\[ M_{\text{eff}}^{(bb) \text{peak}} = X_4(m_{1/2}, m_0, \tan \beta, A_0) \]
Determining mSUGRA Parameters

✓ Solved by inverting the following functions:

\[ \begin{align*}
    M_{jbb}^{\text{end point}} &= \mathcal{X}_1(m_{1/2}, m_0) \\
    M_{\text{peak}}^{\text{eff}} &= \mathcal{X}_2(m_{1/2}, m_0) \\
    M_{(b)\text{ peak}}^{\text{eff}} &= \mathcal{X}_3(m_{1/2}, m_0, \tan \beta, A_0) \\
    M_{(bb)\text{ peak}}^{\text{eff}} &= \mathcal{X}_4(m_{1/2}, m_0, \tan \beta, A_0)
\end{align*} \]

\[ \begin{align*}
    m_0 &= 472 \pm 50 \\
    m_{1/2} &= 440 \pm 15 \\
    A_0 &= 0 \pm 95 \\
    \tan \beta &= 39 \pm 18
\end{align*} \]

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

\[ \Delta \Omega \tilde{\chi}_1^0 h^2 / \Omega \tilde{\chi}_1^0 h^2 \sim 150\% \]

Note: These regions have large \( \Omega h^2 \) if one just calculate based on standard cosmology. We put a factor of 0.1 for this non-standard cosmology.

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Co-annihilation region

\[ m_{1/2} = 360, \ m_0 = 215, \ \tan \beta = 40, \ m_{\text{top}} = 175 \]

\[(\text{Arnowitt-Dutta-Kamon Ref. Point})\]

\[ \tilde{g} \rightarrow \tilde{\chi}_1^0 \rightarrow \tilde{\nu}_L \]

Supercritical String

\[ m_{1/2} = 600, \ m_0 = 440, \ \tan \beta = 40, \ m_{\text{top}} = 175 \]

\[(\text{SSC Ref. Point})\]

\[ \tilde{g} \rightarrow \tilde{u}_L \]

Follow the 1st talk ...

Probing the SUSY Dark Matter

Dark Matter (DM) Particle in SUSY
& Cosmological Connection

$\Omega_{\text{SUSY DM}} = \Omega_{\text{CDM}}$

SUSY Signal in Co-annihilation (CA) Region
DM Density ($\Omega h^2$) at the LHC

Arnowitt, Dutta, Gurrola, Kamon, Krislock, Toback

For earlier studies, see Arnowitt et al., PLB 649 (2007) 73; Arnowitt et al., PLB 639 (2006) 46
Determining mSUGRA Parameters

✓ Solved by inverting the following functions:

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

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

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

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

\[L = 500 \text{ fb}^{-1}\]

b/c stau helps to determine tan\beta accurately.

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Summary

Cosmology ... Dark Matter (DM) and Dark Energy (DE)

Supercritical-String-Cosmology (SSC)
Scalar Field DE

... Smoothly evolving DE for 10 B years

Translating to Particle Physics:

\[ \sigma_{\text{CDM(SSC)}} \sim \sigma_{\text{CDM}} / 10 \]

Implication at the LHC
SUSY masses will be heavier than those in co-annihilation region

- Search for \( \chi_2^0 \) decays to \( Higgs \)
  \[ \delta\Omega_{\text{CDM}} / \Omega_{\text{CDM}} \sim 150\% \ (1000 \text{ fb}^{-1}) \]

- Search for \( \chi_2^0 \) decays to \( stau \)
  \[ \delta\Omega_{\text{CDM}} / \Omega_{\text{CDM}} \sim 20\% \ (500 \text{ fb}^{-1}) \]