Diagnosis of Supersymmetry Breaking Mediation Schemes by Mass Reconstruction at the LHC

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Spaatind 2012 - Nordic Conference on Particle Physics
Outline

1. SUSY and SUSY Breaking at LHC
   - Motivation
   - Kinematic Observables @ LHC

2. Results
   - Diagnosis of SUSY Breaking Mediation
   - Additional Result: Third Generation Squarks
## Supersymmetry Flash Review

**SM fermions**

<table>
<thead>
<tr>
<th>Quarks</th>
<th>SUSY bosons</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u$</td>
<td>$\tilde{u}$</td>
</tr>
<tr>
<td>$c$</td>
<td>$\tilde{c}$</td>
</tr>
<tr>
<td>$t$</td>
<td>$\tilde{t}$</td>
</tr>
<tr>
<td>$d$</td>
<td>$\tilde{d}$</td>
</tr>
<tr>
<td>$s$</td>
<td>$\tilde{s}$</td>
</tr>
<tr>
<td>$b$</td>
<td>$\tilde{b}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leptons</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$e$</td>
<td>$\tilde{e}$</td>
</tr>
<tr>
<td>$\mu$</td>
<td>$\tilde{\mu}$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>$\tilde{\tau}$</td>
</tr>
<tr>
<td>$\nu_e$</td>
<td>$\tilde{\nu_e}$</td>
</tr>
<tr>
<td>$\nu_\mu$</td>
<td>$\tilde{\nu_\mu}$</td>
</tr>
<tr>
<td>$\nu_\tau$</td>
<td>$\tilde{\nu_\tau}$</td>
</tr>
</tbody>
</table>

**SM (gauge) bosons**

<table>
<thead>
<tr>
<th>SUSY gauginos</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g$</td>
</tr>
<tr>
<td>$W^\pm$</td>
</tr>
<tr>
<td>$Z^0$</td>
</tr>
<tr>
<td>$h_1^0$</td>
</tr>
<tr>
<td>$h_2^0$</td>
</tr>
<tr>
<td>$h_1^+$</td>
</tr>
<tr>
<td>$h_2^-$</td>
</tr>
</tbody>
</table>
SUSY and SUSY Breaking at LHC
Results
Motivation
Kinematic Observables @ LHC

SUSY Breaking

SUSY breaking schemes for gaugino masses

- $M_a / g_a$ does not run at one loop in MSSM.
- Tree-level gauge-kinetic dominant + universal
  $\Rightarrow$ mSUGRA $\rightarrow M_1 : M_2 : M_3 \simeq 1 : 2 : 6$
- One-loop conformal anomaly dominant
  $\Rightarrow$ Anomaly $\rightarrow M_1 : M_2 : M_3 \simeq 3.3 : 1 : 9$
- Mirage mediation: a mix of mSUGRA and anomaly
  \[
  \frac{M_a(\mu)}{g_a^2(\mu)} = \left( 1 + \frac{\ln(M_p/m_3/2)}{16\pi^2} g_{GUT}^2 b_\alpha \right) \frac{M_0}{g_{GUT}^2}
  \]
  $\Rightarrow M_1 : M_2 : M_3 \simeq (1 + 0.66\alpha) : (2 + 0.2\alpha) : (6 - 1.8\alpha)$

All we must do is find the gaugino masses!
We choose some benchmarks and demonstrate using
ISASUGRA, PYTHIA, and PGS4.
Dominant production at LHC is $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, or $\tilde{q}\tilde{q}$

\[ \tilde{q}_L \rightarrow q \]

\[ \tilde{\chi}_2^0 \rightarrow \tau^\mp \]

\[ \tilde{\tau}_1^\pm \rightarrow \tau^\pm \]

\[ \tilde{\chi}_1^0 \quad E_T \]
Making use of Opposite Sign (OS) – Like Sign (LS) subtraction:

\[ \tilde{q}_L \rightarrow q \]
\[ \tilde{\chi}_2^0 \rightarrow \tau^{\mp} \]
\[ \tilde{\tau}_1^{\pm} \rightarrow \tau^{\pm} \]
\[ \tau^{\pm} \]

\[ M_{\tau\tau}^{\mathrm{OS}} - M_{\tau\tau}^{\mathrm{LS}} = M_{\tau\tau}^{\mathrm{OS}} - M_{\tau\tau}^{\mathrm{LS}} \]
Making use of Opposite Sign (OS) – Like Sign (LS) subtraction:

\[ \tilde{q}_L \rightarrow q \]

\[ \tilde{\chi}_2^0 \rightarrow \tau^\mp \]

\[ \tilde{\tau}_1^\pm \rightarrow \tau^\pm \]

\[ \tau^\pm \rightarrow \tilde{\chi}_1^0 \]

\[ M_{\tau\tau}^{\text{OS}} - M_{\tau\tau}^{\text{LS}} = \text{Background OS} \]
Making use of Opposite Sign (OS) – Like Sign (LS) subtraction:

\[ \tilde{q}_L \rightarrow q \]

\[ \tilde{\chi}_2^0 \rightarrow \tau^{\mp} \]

\[ \tilde{\tau}_1^{\pm} \rightarrow \tau^{\pm} \]

\[ \tau^{\pm} \]

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

\[ M^{\text{OS}}_{\tau\tau} - M^{\text{LS}}_{\tau\tau} \]
Making use of Opposite Sign (OS) – Like Sign (LS) subtraction:

\[
\begin{align*}
\tilde{q}_L & \rightarrow q \\
\tilde{\chi}_2^0 & \rightarrow \tau^{\mp} \\
\tilde{\tau}_1^{\pm} & \rightarrow \tau^{\pm} \\
\tau^{\pm} & \rightarrow \tilde{\chi}_1^0
\end{align*}
\]

\[
M_{\tau\tau}^{\text{OS}} - M_{\tau\tau}^{\text{LS}} = M_{\tau\tau}^{\text{OS-LS}}
\]
Ditau Invariant Mass

Counts / 5 GeV

M_{\tau\tau} (GeV)

M_{\tau\tau}^{OS}

M_{\tau\tau}^{LS}

M_{\tau\tau}^{OS-LS}
\[ \tau \rho_T \] variables

\[ \rho_{T,\text{AM}} \equiv \frac{1}{2} (\text{slope}(\rho_{T,\text{high}}) + \text{slope}(\rho_{T,\text{low}})) \]

\[ \rho_{T,\text{diff}} \equiv \frac{1}{2} (\text{slope}(\rho_{T,\text{high}}) - \text{slope}(\rho_{T,\text{low}})) \]
Making use of BEST:

\[ \tilde{q}_L \rightarrow q \]

\[ \tilde{\chi}_2^0 \rightarrow \tau^\pm \]

\[ \tilde{\tau}_1^\pm \rightarrow \tau^\pm \]

\[ q \]

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

\[ M_{j\tau\tau}^{\text{Same}} \]
Making use of BEST:

\[ \tilde{q}_L \rightarrow q \]

\[ \tilde{\chi}_2^0 \rightarrow \tau^{\mp} \]

\[ \tilde{\tau}_1^{\pm} \rightarrow \tau^{\pm} \]

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

\[ M^\text{Same}_{jj\tau\tau} \quad M^\text{Bi}_{jj\tau\tau} \]
Making use of BEST:

\[ \tilde{q}_L \rightarrow q \]

\[ \tilde{\chi}^0_2 \rightarrow \tau^\pm \]

\[ \tilde{\tau}^\pm_1 \rightarrow \tau^\pm \]

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

\[ M^{\text{Same}}_{j\tau\tau} - N_{\text{BEST}} M^{\text{Bi}}_{j\tau\tau} = M^{\text{BEST}}_{j\tau\tau} \]

Bi-Event

\[ q \quad q \quad q \]

BEST

Eats BG
Jet + Ditau Invariant Mass

Counts / 50 GeV

M_{\text{same } j\tau\tau}
M_{\text{bi } j\tau\tau}
M_{\text{BEST } j\tau\tau}

M_{j\tau\tau} (GeV)

Abram Krislock January 4 Spaatind 2012 Diagnosis of SUSY Breaking Schemes at LHC
4 Jets + $\not{E}_T$ Signal

Dominant production at LHC is $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, or $\tilde{q}\tilde{q}$

\[
\begin{align*}
\tilde{g} &\rightarrow q & &\text{Soft Jet} \\
\tilde{q}_R &\rightarrow q & &\text{Hard Jet} \\
\tilde{\chi}^0 & & &\not{E}_T \\
\tilde{\chi}_1 & & &
\end{align*}
\]

\[
M_{\text{eff}} \equiv \sum_{i=1}^{4} (p_{T,\text{jet } i}) + \not{E}_T
\]
Goal: Gaugino Masses

Equations to solve

\[ M_{\tau\tau}^{\text{end}} = f_1(m_{\tilde{\chi}^0_2}, m_{\tilde{\tau}_1}, m_{\tilde{\chi}^0_1}) \]
\[ p_{T,AM} = f_2(m_{\tilde{\chi}^0_2}, m_{\tilde{\chi}^0_1}) \]
\[ p_{T,diff} = f_3(m_{\tilde{\chi}^0_2}, m_{\tilde{\tau}_1}, m_{\tilde{\chi}^0_1}) \]
\[ M_{j\tau\tau}^{\text{end}} = f_4(m_{\tilde{q}_L}, m_{\tilde{\chi}^0_2}, m_{\tilde{\chi}^0_1}) \]
\[ M_{\text{peak}}^{\text{eff}} = f_5(m_{\tilde{q}}, m_{\tilde{g}}) \]

- Find f’s using MC simulation.
- Measure observables.
- Invert and solve for masses.
Result: Mirage Scale

The graph shows the relationship between the logarithm of the mu parameter ($\log(\frac{\mu}{\text{GeV}})$) and the mass of the Higgs boson ($H_{\text{GeV}}$) and the L mass ($L_{\text{GeV}}$). The lines and shaded regions indicate the range of values for different SUSY breaking schemes at the LHC.
4 Jets (at least one $b$-Jet) + $E_T$ Signal

Decay Chain:

$\tilde{g} \rightarrow b$

$\tilde{b}_1 \rightarrow W$

$\tilde{t}_1 \rightarrow c$

$\tilde{\chi}_0^1$
Decay Chain:

\[ \tilde{g} \rightarrow b \]

\[ \tilde{b}_1 \rightarrow W \]

\[ \tilde{t}_1 \rightarrow c \]

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

\[ M_{bW}^{\text{end}} \]
4 Jets (at least one b-Jet) + $\not{E}_T$ Signal

Decay Chain:

$\tilde{g} \rightarrow b$

$\tilde{b}_1 \rightarrow W$

$\tilde{t}_1 \rightarrow c$

$\tilde{\chi}_1^0$

$M_{bw}^{end}$

$M_{jW}^{end}$
Results

Diagnosis of SUSY Breaking Mediation

Additional Result: Third Generation Squarks

$M_{bW}^{\text{end}}$ and $M_{jW}^{\text{end}}$

![Histograms of $M_{bW}$ and $M_{jW}$]

- $M_{bW}^{\text{same}}$
- $M_{bW}^{\text{bi}}$
- $M_{bW}^{\text{BEST}}$

- $M_{jW}^{\text{same}}$
- $M_{jW}^{\text{bi}}$
- $M_{jW}^{\text{BEST}}$
Way too many results for one talk!!

arXiv:1112.3966

- Gaugino masses for multiple benchmark points. ⇒ SUSY Breaking Mechanism.
- Third generation Squark masses.
- Relic Density of Dark Matter from Model Parameters. (DarkSUSY)

Thanks for your attention!!