SUSY vs UED Spins at the LHC

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- Spin correlations in SUSY and UED models
- Event and detector simulation
- Conclusions

Spin Correlations in SUSY & UED

- **SUSY:** new particles are superpartners
  \[ q \leftrightarrow \tilde{q}, \quad g \leftrightarrow \tilde{g}, \quad l \leftrightarrow \tilde{l}, \quad (\gamma, Z, \ldots) \leftrightarrow (\tilde{\chi}_1^0, \tilde{\chi}_2^0, \ldots) \]
  ➔ spins differ by one-half

- **UED:** new particles are KK excitations
  \[ q \leftrightarrow q^*, \quad g \leftrightarrow g^*, \quad l \leftrightarrow l^*, \quad (\gamma, Z, \ldots) \leftrightarrow (\gamma^*, Z^*, \ldots) \]
  ➔ spins are the same!

- Suppose masses have been measured: how could we distinguish?
  ➔ need evidence on spins to be sure
SUSY and UED decay chains

Two distinct helicity structures, with different spin correlations:

- Process 1: \( \{q, l^{\text{near}}, l^{\text{far}}\} = \{q_L, l^-_L, l^+_L\} \) or \( \{\bar{q}_L, l^+_L, l^-_L\} \) or \( \{q_L, l^+_R, l^-_R\} \) or \( \{\bar{q}_L, l^-_R, l^+_R\} \);

- Process 2: \( \{q, l^{\text{near}}, l^{\text{far}}\} = \{q_L, l^+_L, l^-_L\} \) or \( \{\bar{q}_L, l^-_L, l^+_L\} \) or \( \{q_L, l^-_R, l^+_R\} \) or \( \{\bar{q}_L, l^+_R, l^-_R\} \).
Distinguishing Spins in Supersymmetric and Universal Extra Dimension Models at the Large Hadron Collider

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UED and SUSY mass spectra

- **UED models tend to have quasi-degenerate spectra**

<table>
<thead>
<tr>
<th>$\gamma^*$</th>
<th>$Z^*$</th>
<th>$q_L^*$</th>
<th>$l_R^*$</th>
<th>$l_L^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>501</td>
<td>536</td>
<td>598</td>
<td>505</td>
<td>515</td>
</tr>
</tbody>
</table>

**Table 1: UED masses in GeV, for**

$R^{-1} = 500\text{GeV}$, $\Lambda R = 20$, $m_h = 120\text{GeV}$, $\bar{m}_h^2 = 0$ and vanishing boundary terms at cut-off scale $\Lambda$.

- **SUSY spectra typically more hierarchical**

<table>
<thead>
<tr>
<th>$\tilde{\chi}_1^0$</th>
<th>$\tilde{\chi}_2^0$</th>
<th>$\tilde{u}_L$</th>
<th>$\tilde{e}_R$</th>
<th>$\tilde{e}_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>96</td>
<td>177</td>
<td>537</td>
<td>143</td>
<td>202</td>
</tr>
</tbody>
</table>

**Table 2: SUSY masses in GeV, for**

SPS point 1a.

($M_n \sim n/R$ broken by boundary terms and loops, with low cutoff)

(high-scale universality)
## Production cross sections (pb)

<table>
<thead>
<tr>
<th>Masses</th>
<th>Model</th>
<th>$\sigma_{\text{all}}$</th>
<th>$\sigma_{q^*}$</th>
<th>$\sigma_{\bar{q}^*}$</th>
<th>$f_q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>UED</td>
<td>UED</td>
<td>253</td>
<td>163</td>
<td>84</td>
<td>0.66</td>
</tr>
<tr>
<td>UED</td>
<td>SUSY</td>
<td>28</td>
<td>18</td>
<td>9</td>
<td>0.65</td>
</tr>
<tr>
<td>SPS 1a</td>
<td>UED</td>
<td>433</td>
<td>224</td>
<td>80</td>
<td>0.74</td>
</tr>
<tr>
<td>SPS 1a</td>
<td>SUSY</td>
<td>55</td>
<td>26</td>
<td>11</td>
<td>0.70</td>
</tr>
</tbody>
</table>

$\sigma_{\text{UED}} \gg \sigma_{\text{SUSY}}$ for same masses (100 pb = 1/sec)

$q^*/\bar{q}^* \sim 2 \Rightarrow$ charge asymmetry
Angular variables

\[ \tilde{\chi}_2^0/Z^* \]

\[ \tilde{\chi}_1^0/\gamma^* \]

\[ \tilde{q} \]

\[ \tilde{l}/l^* \]

\[ \tilde{l}/l^* \]

\[ \theta^* \text{ defined in } \tilde{\chi}_2^0/Z^* \text{ rest frame} \]

\[ \theta, \phi \text{ defined in } \tilde{l}/l^* \text{ rest frame} \]
Invariant masses

- $ql^{\text{near}}$: $m_{ql}/(m_{ql})_{\text{max}} = \sin(\theta^*/2)$

- $ll^{\text{near}}ll^{\text{far}}$: $m_{ll}/(m_{ll})_{\text{max}} = \sin(\theta/2)$

- $ql^{\text{far}}$: $m_{ql}/(m_{ql})_{\text{max}} = \frac{1}{2} \left[ (1 - y)(1 - \cos \theta^* \cos \theta) + (1 - y)(\cos \theta^* - \cos \theta) - 2\sqrt{y} \sin \theta^* \sin \theta \cos \phi \right]^{\frac{1}{2}}$

where $x = m_{Z^*}^2/m_{q^*}^2$, $y = m_{l^*}^2/m_{Z^*}^2$, $z = m_{\gamma^*}^2/m_{l^*}^2$
Helicity dependence

- Process 1 (SUSY)

- Process 1 (UED, transverse $Z^*$: $P_T/P_L = 2x$)

Both prefer high $(ql^-)^{near}$ invariant mass
UED and SUSY not distinguishable for UED masses
**$q_L^{\text{far}}$ mass distribution**

**UED masses**

- $q_L^{1_-}$
- $q_L^{1_+}$

**SPS 1a masses**

- $q_L^{1_-}$
- $q_L^{1_+}$

**Correlation weak but slightly enhances UED-SUSY difference**
Jet + lepton mass distribution

UED masses

Not resolvable for UED masses, maybe for SUSY masses

Charge asymmetry due to quark vs antiquark excess
HERWIG Event Generator

- Most important SM & MSSM processes at LO
  - spin correlations included
  - parton showers at leading log (LL)
  - no showering from SUSY particles
- MC@NLO provides some SM processes at NLO
  - see S Frixione & BW, hep-ph/0506182 & refs therein
- UED model put in ‘by hand’ at present
- Interface to CHARYBDIS black hole generator
Charge Asymmetry

\[ A = \frac{(j_{l+}) - (j_{l-})}{(j_{l+}) + (j_{l-})} \]

UED masses

SPS Ia masses

Similar form, different magnitude

Not detectable for UED masses
Dilepton mass distribution

\[ \frac{dP^{\text{UED}}}{d\hat{m}_{ll}} = \frac{4\hat{m}_{ll}}{(2 + y)(1 + 2z)} \left[ y + 4z + (2 - y)(1 - 2z)\hat{m}_{ll}^2 \right] \]

- \( y = \frac{m_i^2}{m_Z^2} \) and \( z = \frac{m_{\gamma}^2}{m_i^2} \)
- **UED:** \( y = 0.92 \) \( z = 0.95 \)
- **SPS Ia:** \( y = 0.65 \) \( z = 0.45 \)

→ Sensitivity greatest at small \( y \) and \( z \)
Dilepton mass distribution (2)

No sensitivity for these masses!
Dilepton mass distribution (3)

\[ y = \frac{m_l^2}{m_Z^2} = 0.65, \quad z = \frac{m_\gamma^2}{m_l^2} = 0.95 - 0.05 \]

→ Independent of masses and spins at \( \hat{m} = 1/\sqrt{2} \) (\( \theta = \pi/2 \))
Barr’s spin analyses (I)

  \[ \tilde{q}_L \to \tilde{\chi}_2^0 q_L \to \tilde{l}_R^\pm l^\mp q_L \]

- Different MSSM point

- Compares with no spin (phase space) only

- More careful study of background and detector effects

- Points are for 500 fb\(^{-1}\)

**Diagram:**
- Parton level x 0.6
- Detector level
- No spin
Barr’s spin analyses (2)

- hep-ph/0511115 considers slepton pair production
  \[ q\bar{q} \rightarrow Z^0/\gamma \rightarrow \tilde{\ell}^+\tilde{\ell}^- \rightarrow \tilde{\chi}_1^0\ell^+ \tilde{\chi}_1^0\ell^- \]

- Distribution of \( \cos \theta_{\ell\ell}^* \equiv \tanh(\Delta \eta_{\ell^+\ell^-}/2) \)
  is well correlated with \( Z^0/\gamma \) decay angle \( \theta^* \)

(neglects KKlepton polarisation)
Barr’s spin analyses (3)

- Outer error bars: after SUSY & SM background subtraction
Conclusions

- Distinguishing SUSY from UED at LHC will be difficult
  - jet+lepton charge asymmetry similar in shape
  - dilepton distributions clean but not very sensitive

- If masses favour UED, spin confirmation very difficult
  - little sensitivity to spins
  - jets typically have low energy
  - other methods may be better ($Z_2^*$, ...)

- If masses favour SUSY, spin sensitivity is better
  - good prospect of excluding UED spins