Probing Supersymmetry with Very Light Gravitino by Using Impact Parameter at the LHC

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Supersymmetry with light gravitino at the LHC

In this talk, I consider the supersymmetric model with

- **LSP**: Gravitino mass \( \sim O(10) \text{ eV} \)
- **NLSP**: Stau mass \( \sim O(100) \text{ GeV} \)

(Such a spectrum is realized, e.g., in low-scale gauge mediation models.)

\[
c\tau_{\tilde{\tau}} \simeq 2 \text{ mm} \times \left( \frac{m_{3/2}}{10 \text{ eV}} \right)^2 \left( \frac{m_{\tilde{\tau}}}{100 \text{ GeV}} \right)^{-5}
\]

The stau decays before hitting inner detectors. 
**Impact parameter** may be useful to probe such a signal.
Plan of talk

- Impact parameter of $\tau$-lepton ($\tau$-jet).

- Mass determination in SUSY cascade
  - squark, bino, stau

- Stau lifetime determination
Impact parameter

Definition:

(3-dimensional) impact parameter

\[ b_I \equiv \left| \vec{b}_I \right| \]

\[ \delta (b_I) \simeq 100 \, \mu m \]

Transverse impact parameter

\[ d_I \equiv \left| \left( \vec{b}_I \right)_T \right| \]

\[ \delta (d_I) \simeq 10 \, \mu m \]

Better resolution. (c.f., arXiv:0901.0512[hep-ex])

Hence, we use \( d_I \) in the following.

Typically, \( d_I \sim O(c\tau_{\text{NLSP}}) \) for \( \tau \)-jet from the stau decay.

Impact parameter is useful for the signal with \( c\tau_{\text{NLSP}} \gtrsim 100 \, \mu m \)

(Notice that \( c\tau_\tau = 80 \, \mu m \))
Monte Carlo study

* Sample spectrum (GMSB)
  - gluino ... 1096 GeV
  - squark\textsubscript{R} ... 920 GeV
  - neutralino\textsubscript{1} ... 197 GeV
  - stau\textsubscript{1} ... 126 GeV
  - gravitino ... \sim 0 GeV
    \((\leftrightarrow c\tau_{\text{NLSP}} = 500 \mu m)\)

* Total SUSY cross section ... 2.7 pb
  \((pp, \sqrt{s} = 14 \text{ TeV})\)

* Event generation ... HERWIG6.510
* Detector simulation ... PGS4

* Resolution of the impact parameter is included in our simulation.
  \[
  \delta (d_I) = 10 \mu m
  \]

<table>
<thead>
<tr>
<th>Basic cut</th>
<th>SUSY</th>
<th>(\bar{t}t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Integrated luminosity of 100 fb(^{-1}))</td>
<td>273,600</td>
<td>49,610,000</td>
</tr>
<tr>
<td>(p_T &gt; 150 \text{ GeV})</td>
<td>190,504</td>
<td>1,644,160</td>
</tr>
<tr>
<td>The number of lepton-like objects (\geq 4)</td>
<td>70,641</td>
<td>55,537</td>
</tr>
<tr>
<td>The number of b-jets = 0</td>
<td>56,228</td>
<td>41,673</td>
</tr>
<tr>
<td>The first jet with (p_T &gt; 200 \text{ GeV})</td>
<td>49,819</td>
<td>5,915</td>
</tr>
<tr>
<td>The second jet with (p_T &gt; 100 \text{ GeV})</td>
<td>41,007</td>
<td>1,984</td>
</tr>
</tbody>
</table>
Mass measurement of $M_{\text{squark}}, M_{\text{bino}}$ and $M_{\text{stau}}$

SUSY cascade decay chain:

* Hadronically decaying $\tau$ ("$\tau$-jet") is used.

* $\tau^{(\text{near})}$ and $\tau^{(\text{far})}$ will be distinguished by

$$dI(\tau^{(\text{near})}) < dI(\tau^{(\text{far})}).$$

* Fake $\tau$-jets can be removed by the charge subtraction, i.e.,

$$(\text{Signal}) = (\tau^+\tau^- + \tau^-\tau^+) - (\tau^+\tau^+ + \tau^-\tau^-)$$

OS  SS
RESULT: Mass measurement of $M_{\text{squark}}$, $M_{\text{bino}}$ and $M_{\text{stau}}$

Thanks to $dI$ information, $M_{j\tau (\text{near})}$ endpoint is available.

Assuming $m_{3/2} = 0$, we obtain

$M_{\tilde{q}} = 916 \pm 6$ GeV \quad (m_{\tilde{q}} = 922$ GeV$)$

$M_{\tilde{B}} = 193 \pm 20$ GeV \quad (m_{\tilde{B}} = 197$ GeV$)$

$M_{\tilde{\tau}} = 121 \pm 18$ GeV \quad (m_{\tilde{\tau}} = 126$ GeV$)$

In addition, two endpoints are studied.

\begin{align*}
\chi^2 / \text{ndf} &= 2.6399338 / 4 \\
M & = 151.9312 \pm 14.46566 \\
A & = -1.414834 \pm 8.133254 \\
B & = -1.096214 \pm 1.1248938 \\
\text{Const.} & = 167.07512 \pm 100.57011
\end{align*}

\begin{align*}
\chi^2 / \text{ndf} &= 4.2622899 / 4 \\
M & = 875.07141 \pm 6.7095 \\
A & = -1.4863 \pm 0.1730 \\
B & = 0.1573203 \pm 0.00661310 \\
\text{Const.} & = 27.872061 \pm 4.311059
\end{align*}
Distribution of the transverse impact parameter, $d_I$

Here, we treat the gravitino mass as a free parameter.

→ $c\tau_{NLSP} = 1, 100, 500, 900 \mu m$.

$d_I$ depends on

- NLSP lifetime, and
- Lorentz boost factor of stau

After mass measurements, one would perform the MC simulation and obtain a template of $d_I$ distribution for a hypothetical $c\tau_{NLSP}$.

NLSP lifetime is determined by comparing a real data with the template.
Lifetime determination

Here, we perform simple MC analysis as a demonstration.

Making templates of the $dI$ distribution

- Taking some hypothetical lifetime, $cτ_{NLSP} (= 10, 20, \ldots, \mu m)$.
- The stau is produced at the origin with some fixed $β$.
- Then, the stau decay into tau & gravitino is simulated.
- We obtain the template of the $dI$ distribution.

We perform $χ^2$-test.

The $dI$ distribution of the “signal” is compared to the templates.
RESULT: Lifetime determination

* "Signal" (all SUSY events): $c\tau_{NLSP} = 100, 300, 500, 700, 900$ μm.
* In order to enhance the signal, $\chi^2$-test is performed in the range $0.5 \times c\tau < dI < 2 \times c\tau$, for each $c\tau$. 
# Summary

* I have discussed LHC phenomenology on SUSY with light gravitino-LSP and stau-NLSP.

* For $m_{3/2} = O(10)$ eV case, impact parameter information will be useful to detect a NLSP decay.
  
  - Mass measurements (squark, bino, stau)
  - Lifetime determination (stau)
BACKUP
Mass measurements (including gravitino)

$M_{T2}(\tilde{q})$

$M_{\tau_j \tau_j}$

$M_{j\tau_j \tau_j}$

$M_{j\tau_j}^{(\text{near})}$