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

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Supersymmetry with light gravitino at the LHC

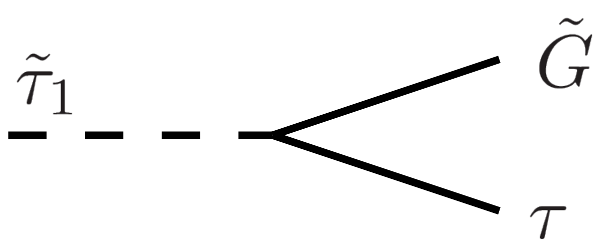
In this talk, I consider the supersymmetric model with

LSP : Gravitino mass ~ O(10) eV

NLSP : Stau mass ~ O(100) GeV

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

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



The stau decays before hitting inner detectors.

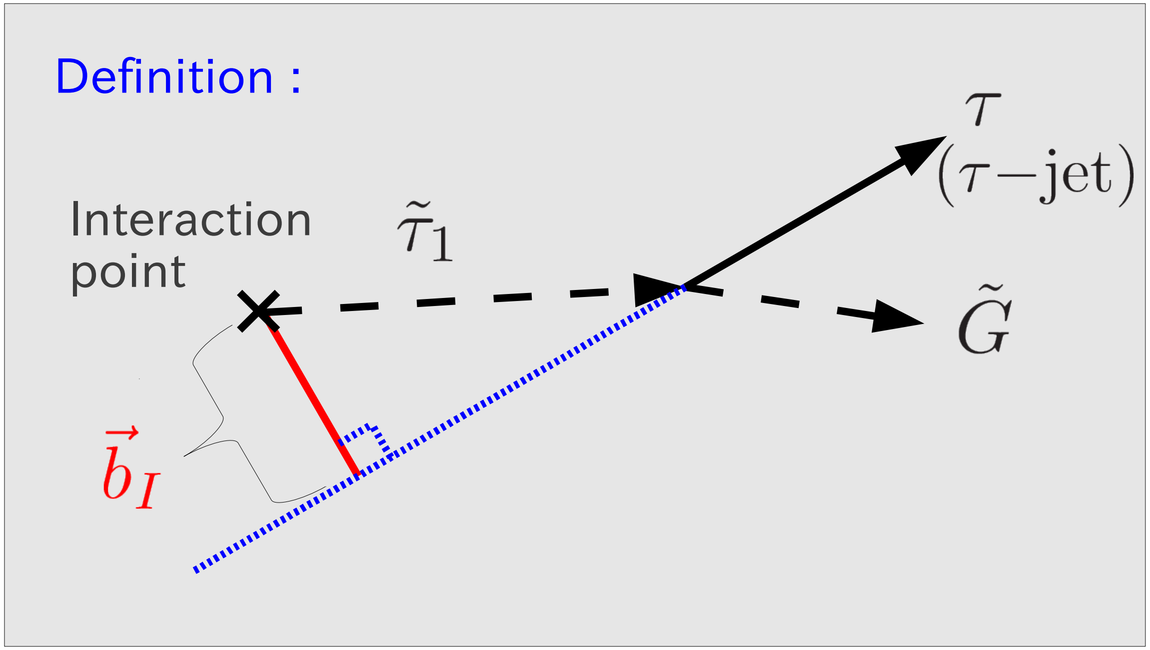
Impact parameter may be useful to probe such a signal.

Plan of talk

- Impact parameter of τ-lepton (τ-jet).

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

Impact parameter



(3-dimensional) impact parameter

$$b_I \equiv \left|\vec{b}_I\right|$$

$$\delta\left(b_I\right) \simeq 100\ \mu\mathrm{m}$$

Transverse impact parameter

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

$$\delta\left(d_I\right) \simeq 10\ \mu\mathrm{m}$$

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

Hence, we use d_I in the following.

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

Impact parameter is useful for the signal with $c\tau_{\mathrm{NLSP}} \gtrsim 100\ \mu\mathrm{m}$

(Notice that $c\tau_\tau$ = 80 μm)

Monte Carlo study

* Sample spectrum (GMSB)

gluino ... 1096 GeV

squark_R ... 920 GeV

neutralino_1 ... 197 GeV

stau_1 ... 126 GeV

gravitino ... $\sim$ 0 GeV

($\leftrightarrow c\tau_{NLSP} = 500\ \mu$m)

* Total SUSY cross section ... 2.7 pb

(pp, $\sqrt{s} = 14$ TeV)

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

* Resolution of the impact parameter is included in our simulation.

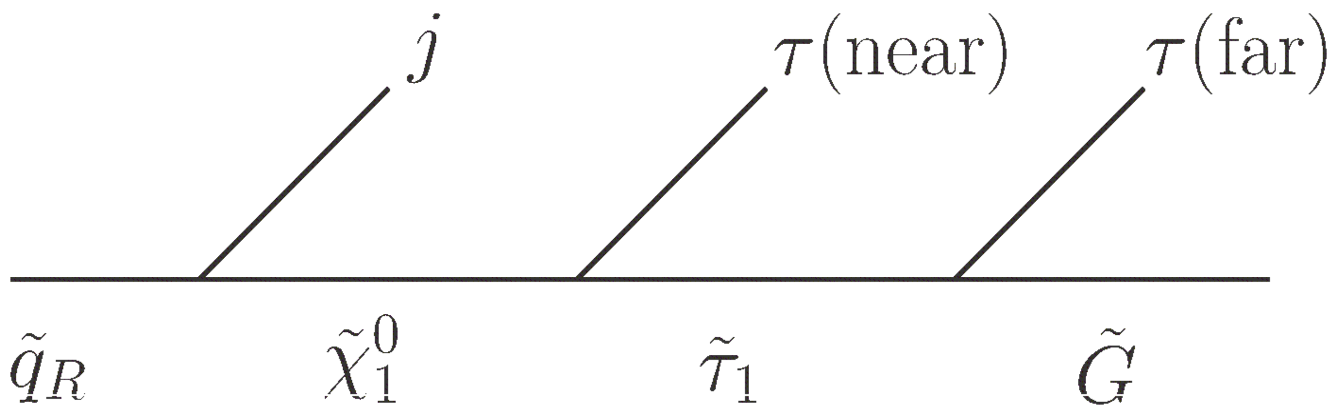
$$\delta\left(d_I\right) = 10\ \mu\text{m}$$

Basic cut	SUSY	$t\bar{t}$
(Integrated luminosity of 100 fb^{-1})	273,600	49,610,000
$\not{p}_T > 150$ GeV	190,504	1,644,160
The number of lepton-like objects ≥ 4	70,641	55,537
The number of b-jets $= 0$	56,228	41,673
The first jet with $p_T > 200$ GeV	49,819	5,915
The second jet with $p_T > 100$ GeV	41,007	1,984

After cut

Mass measurement of M$_{squark}$, M$_{bino}$ and M$_{stau}$

SUSY cascade decay chain :



$M_{\tau\tau}$

$M_{j\tau(\mathrm{near})}$

$M_{j\tau(\mathrm{far})}$

$M_{j\tau\tau}$

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

⋮

* Hadronic decaying τ ("τ-jet") is used.

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

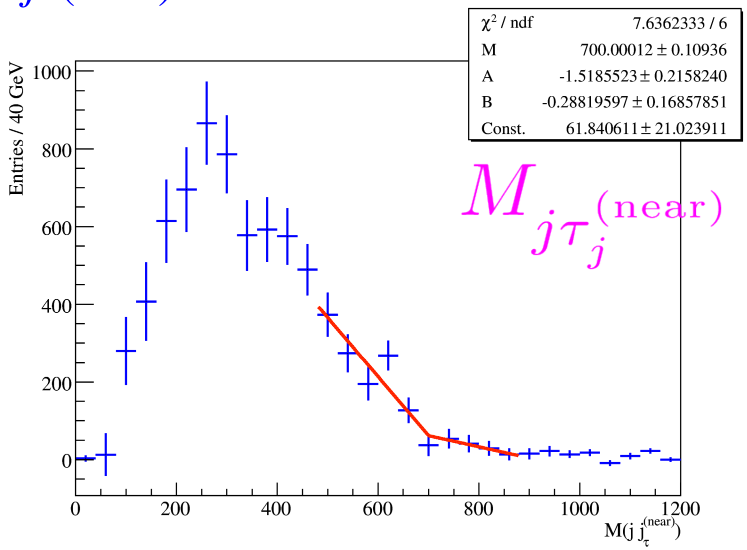
$$d_I(\tau^{(\mathrm{near})}) \quad < \quad d_I(\tau^{(\mathrm{far})}).$$

* Fake τ-jets can be removed by the charge subtraction, i.e.,

$$(\mathrm{Signal}) = \underbrace{(\tau^+\tau^- + \tau^-\tau^+)}_{\mathrm{OS}} - \underbrace{(\tau^+\tau^+ + \tau^-\tau^-)}_{\mathrm{SS}}$$

RESULT : Mass measurement of M_{squark}, M_{bino} and M_{stau}

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



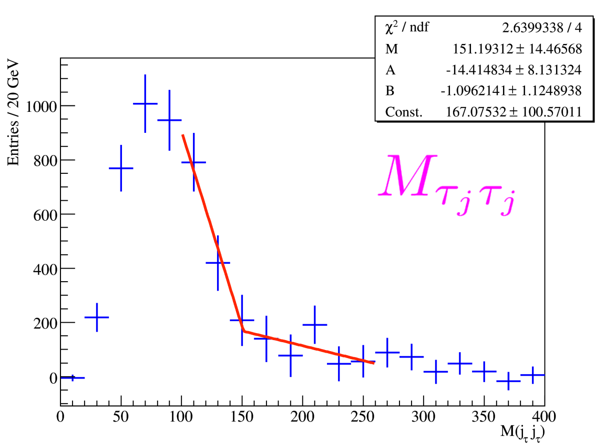
Assuming $m_{3/2}$ = 0, we obtain

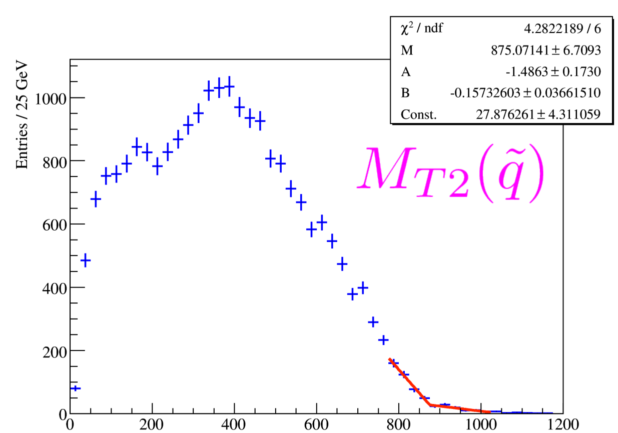
$$M_{\tilde{q}} = 916 \pm 6 \text{ GeV}$$
$$(m_{\tilde{q}} = 922 \text{ GeV})$$

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

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

In addition, two endpoints are studied.

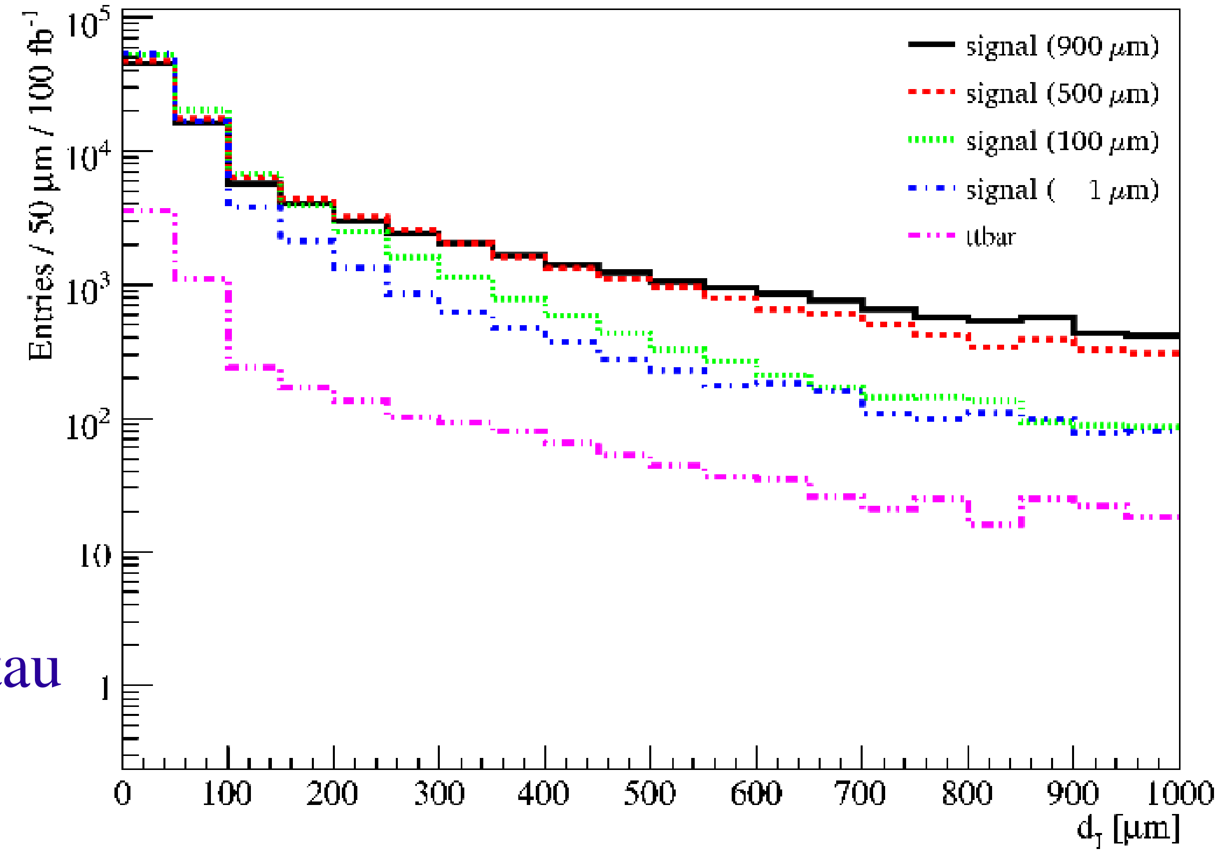




Distribution of the transverse impact parameter, d_I

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

→ $c\tau_{\mathrm{NLSP}}$ = 1, 100, 500, 900 μm.



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* $c\tau_{\mathrm{NLSP}}$.

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

Lifetime determination

Here, we perform simple MC analysis as a demonstration.

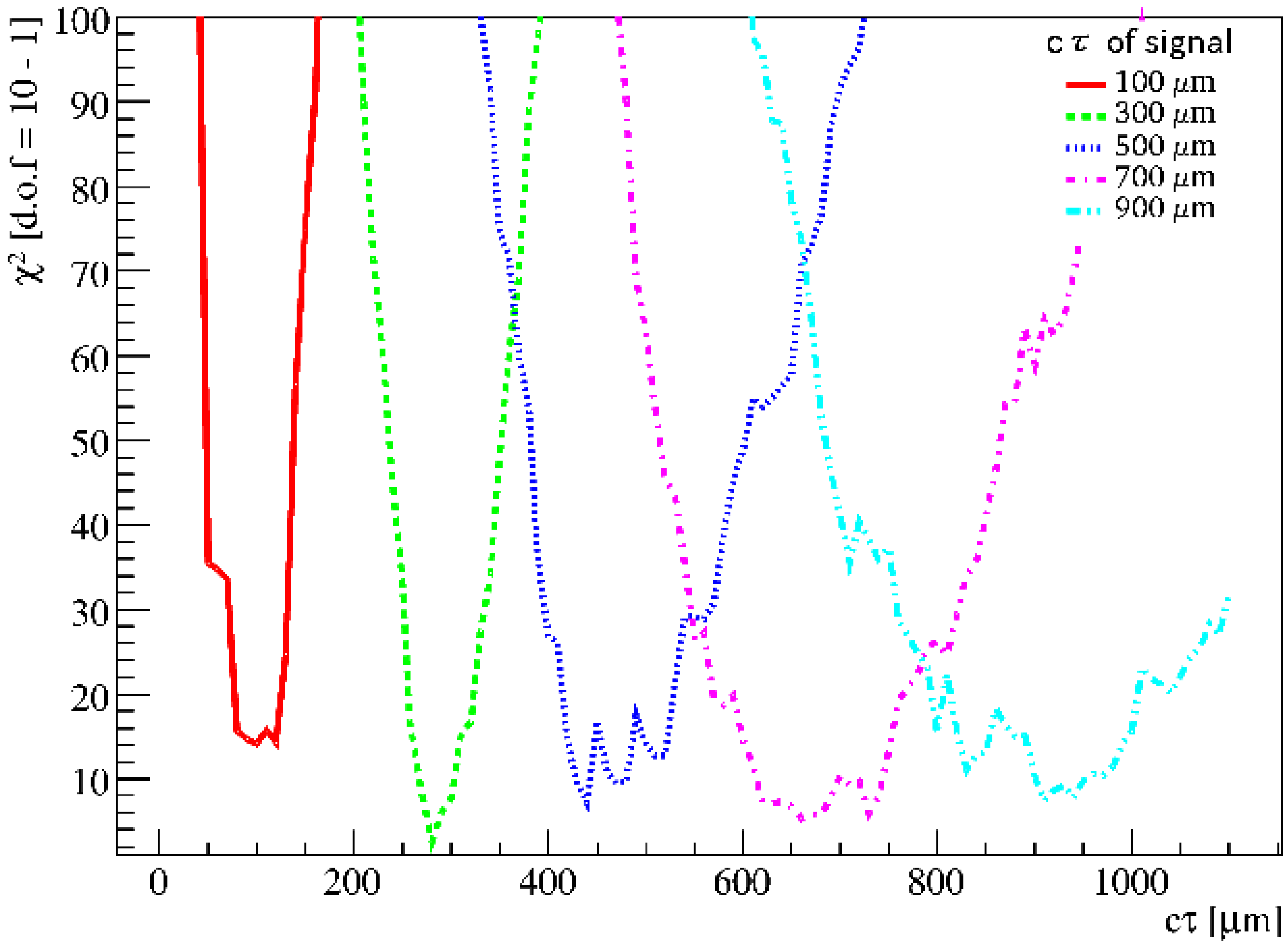
Making templates of the d_I distribution

- Taking some hypothetical lifetime, $c\tau_{\mathrm{NLSP}}$ (= 10, 20, …, μm).
- 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 d_I distribution.

We perform χ^2-test.

The d_I distribution of the “signal” is compared to the templates.

RESULT : Lifetime determination



* "Signal" (all SUSY events) : $c\tau_{\mathrm{NLSP}}$ = 100, 300, 500, 700, 900 μm.

* In order to enhance the signal, χ^2-test is performed in the range
  $0.5 \times c\tau < d_I < 2 \times c\tau$, 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)