Measurement of the Superparticle Mass Spectrum in the Long-Lived Stau Scenario at the LHC

Takumi Ito
Tohoku University

In collaboration with R. Kitano and T. Moroi,
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Introduction

Supersymmetry : an important target of the LHC experiments.

Signature of SUSY at the LHC strongly depends on

what the LSP in the MSSM sector (= "MSSM-LSP") is!

Popular candidates of MSSM-LSP are:

- * The lightest neutralino $\tilde{\chi}_1^0$ — Large missing p_T
- * **The lightest stau** $\tilde{\tau}_1$ — It may have a long lifetime enough to escape from the detector. $\rightarrow$ we can observe its track.
- * ...

Introduction

Long-lived stau scenario

$\leftrightarrow$ Stau behaves as a "heavy muon" in high energy experiments.

* We can measure stau's charge, momentum, velocity and energy.

$\rightarrow$ The stau mass can be measured. [Ambrosanio et al.(01), Ellis et al.(06,07)]

$\rightarrow$ All final state particles (= SM particles & stau) in the event are visible. (Of course, except ν.)

* A slow-moving charged track (= stau) informs us a production of superparticles.

$\rightarrow$ we can reduce SM backgrounds significantly.

$\rightarrow$ **We have a opportunity to *probe the SUSY in detail!***

Introduction

Long-lived stau scenario

* It is naturally realized if tanβ is large.

* Cosmological problems can be avoided if there is weekly interacting LSP (i.e. gravitino, axino, ...).

This scenario is *not an unrealistic* scenario.

→ **We may observe *stau's track at the LHC.***

We discuss a determination of the superparticle masses at the LHC experiments in the model with the long-lived stau.

Assumptions and Outline

Assumptions

* Stau is stable in the detector.

[Ambrosanio et.al.(01)]

* Stau with $v < 0.9c$ can be identified as "**stau**", *not muon.*

* No SM backgrounds. ← Since there is at least one stau in the SUSY event.

* The stau mass has been measured. (accuracy ~ 100 MeV)

[Ambrosanio et al.(01), Ellis et al.(06,07)]

Mass Measurements

1. Neutralino ← Charge information of the stau is useful.
2. Sleptons
3. Squarks

(2., 3.:) The knowlidge of the neutralino mass helps our reconstruction.

Sample Model

GMSB [Dine,Nelson,Shirman(95)]

$\Lambda = 60\text{TeV}, M_{\text{mess}} = 900\text{TeV},$
$N_5 = 3, \tan\beta = 35, \ldots$

$\tilde{g}$	1309
$\tilde{q}_L$	1230
$\tilde{q}_R$	1180
$\tilde{W}^0$	426
$\tilde{B}$	240
$\tilde{e}_R$	194
$\tilde{\mu}_R$	193
$\tilde{\tau}_1$	149

Reduced 1 GeV by hands

MSSM-LSP

The decay products can be observed.

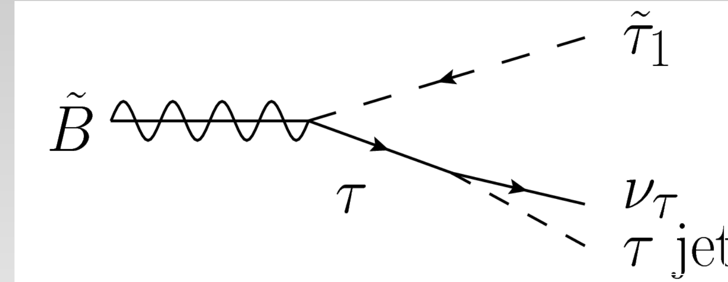
masses are in GeV

Monte Carlo Analysis

* Event Gen. by HERWIG6.510
* Fast Detector Sim. by PGS4
* 67k events are generated.

($\leftrightarrow$ 100 fb^{-1}, 14 TeV)

Neutralino Masses



The lightest neutralino (bino) decay

bino $\rightarrow$ τ + stau

We consider hadronic decay mode of τ-lepton.

↔ Some part of the energy of τ is taken away by τ-neutrino.

$$M_{\tilde{B}} = \sqrt{(p_{\tilde{\tau}_1} + p_{\tau-\mathrm{jet}} + p_{\nu_\tau})^2}$$
$$\geq \sqrt{(p_{\tilde{\tau}_1} + p_{\tau-\mathrm{jet}})^2}$$

Endpoint
⇕
Bino mass

Event Selection

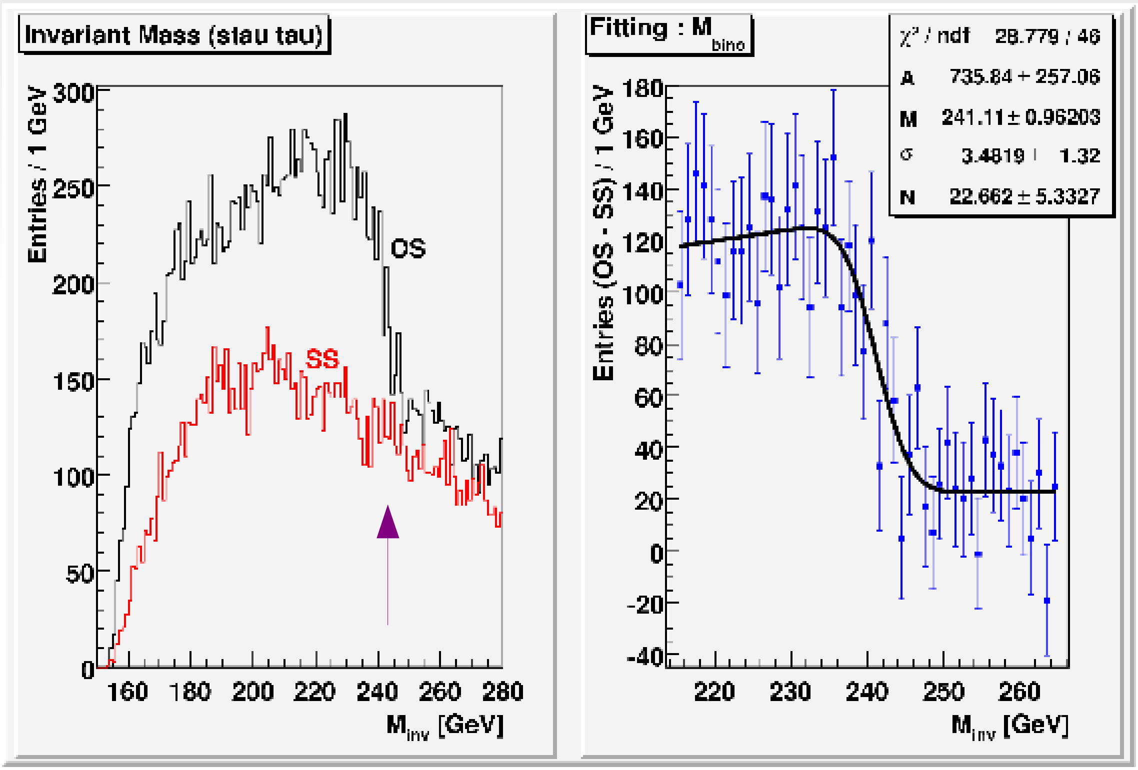
(1) At least one stau with 0.4c < v < 0.9c

(2) At least one τ-tagged jet with p_T > 15 GeV

Neutralino Masses

To reduce BGs, we adopt a charge subtraction:

OS (τ stau) – SS (τ stau) = Signal



$M_{\tilde{B}}$ = 241.1 ± 1.0 GeV
(239.5 : underlying)

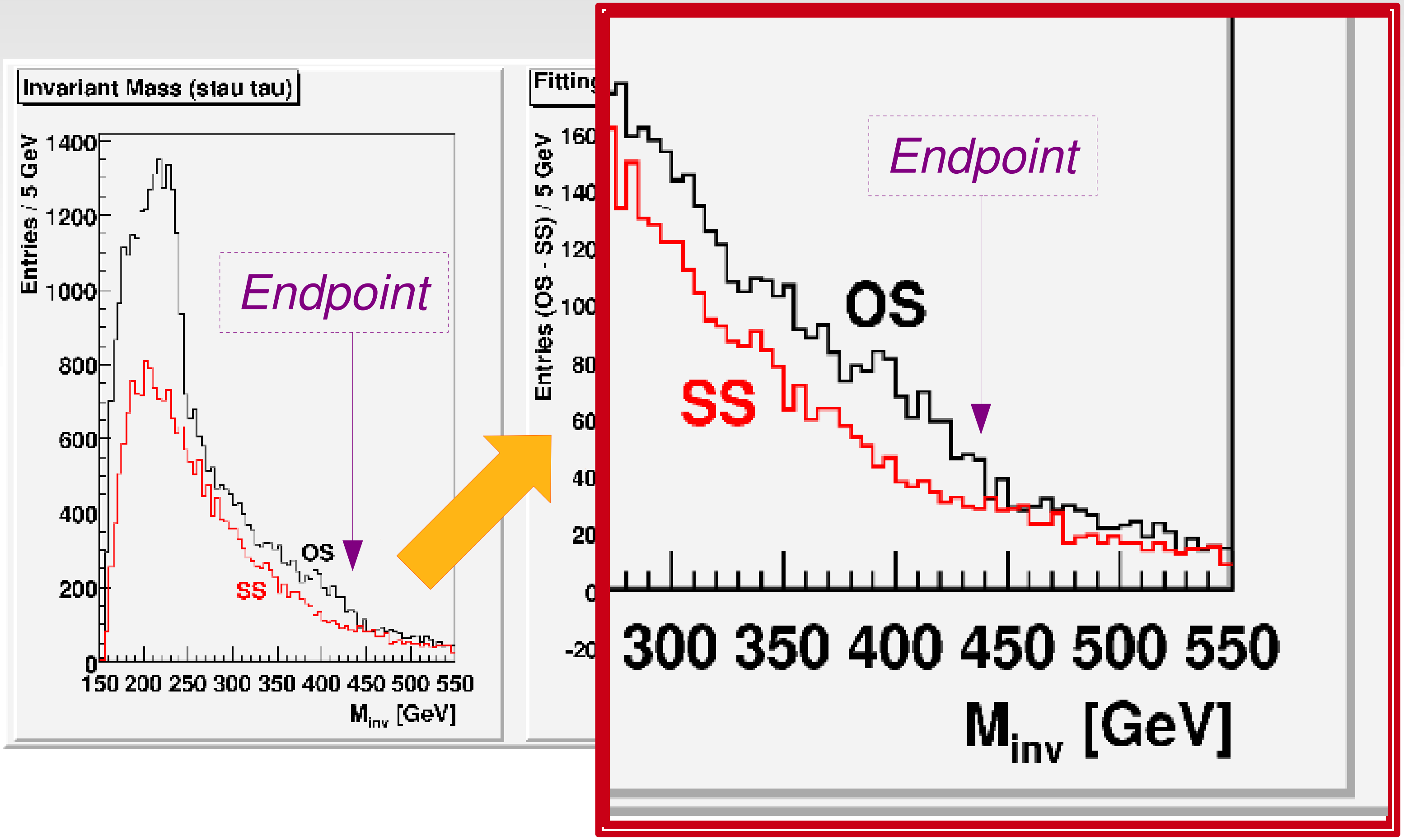
Uncertainties

* Statistics
  ± 1 GeV
* From the error of stau mass
  ± 100 MeV

→ Bino mass measurement : $\delta m_{\tilde{B}} \sim 1\ \mathrm{GeV}$

Neutralino Masses

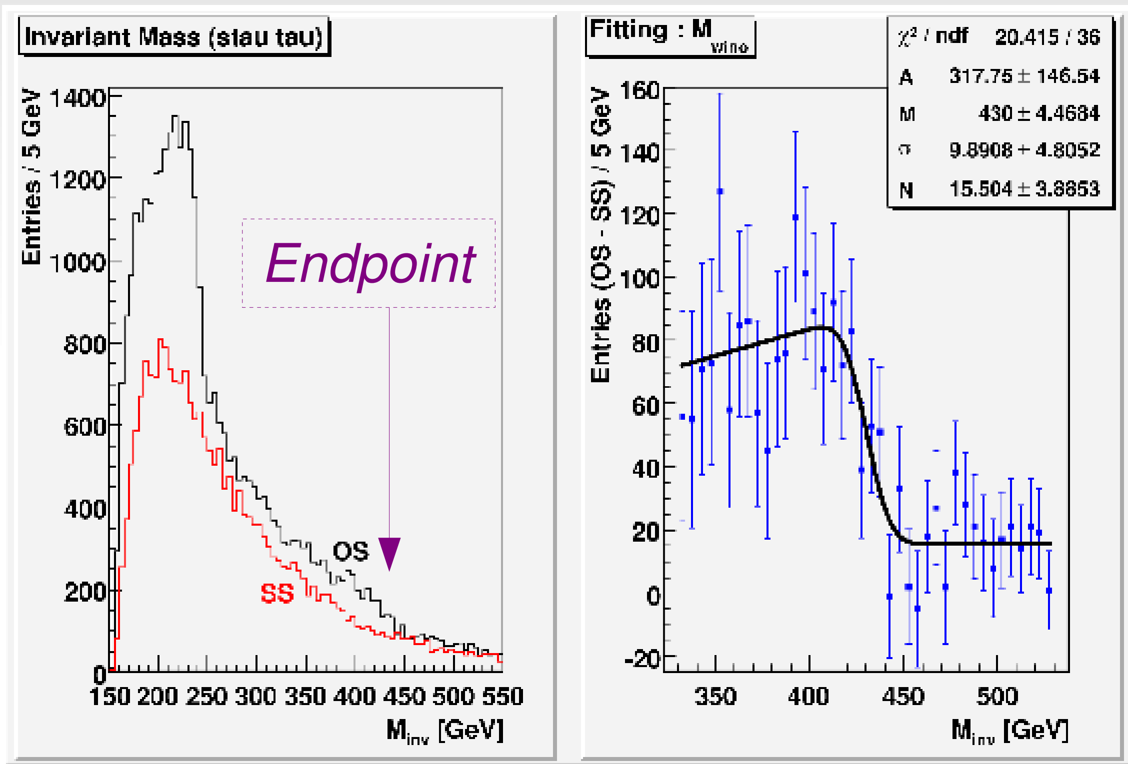
Also, wino mass can be measured by using charge subtraction.



This endpoint is not clear before we adopt charge subtraction.

Neutralino Masses

Also, wino mass can be measured by using charge subtraction.



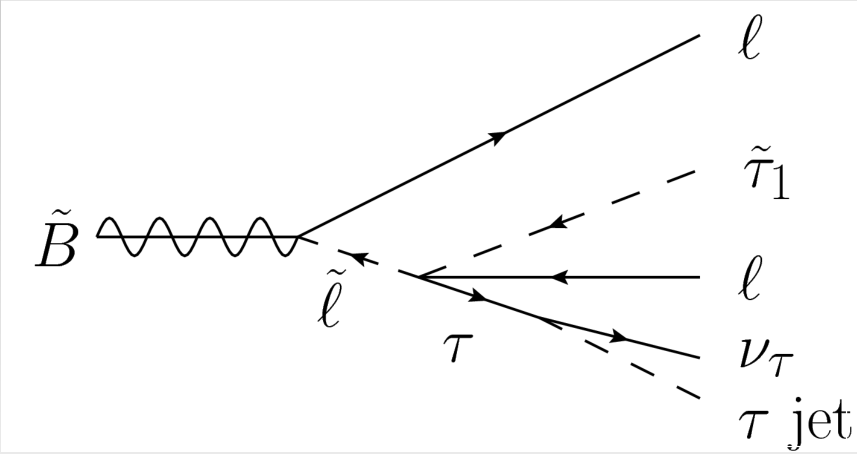
$M_{\tilde{W}^0}$ = 430.0 ± 4.5 GeV
(425.9 : underlying)

Uncertainties

* Statistics
  ± 5 GeV
* From the error of stau mass
  ± 100 MeV

$\rightarrow$ Wino mass measurement : $\delta m_{\tilde{W}^0} \sim 5$ GeV

Selectron & Smuon Masses



2-step SUSY decay chain:

bino $\rightarrow \ell$ + slepton ,

slepton $\rightarrow \ell + \tau$ + stau ; followed by $\tau \rightarrow \tau$-jet + ν_τ

Collinear approximation; $p_\tau = r p_{\tau-\mathrm{jet}} \ (r \geq 1)$

The value of r is determined by the condition:

$$m_{\tilde{B}}^2 = (p_{\ell^+} + p_{\ell^-} + r p_{\tau-\mathrm{jet}} + p_{\tilde{\tau}_1})^2$$

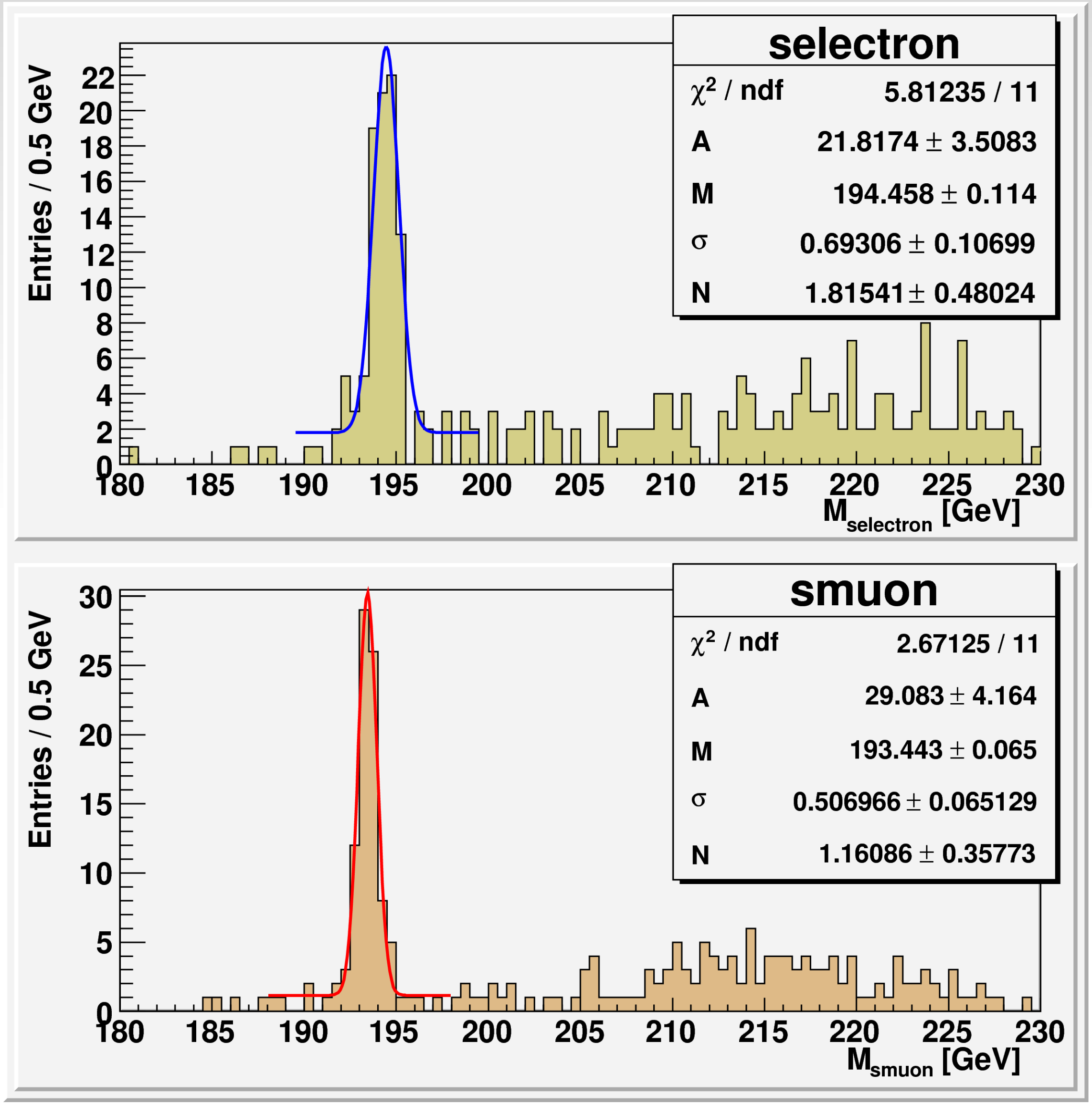
Then, $\rightarrow$ $M_{\tilde{\ell}} = \sqrt{(p_\ell + r p_{\tau-\mathrm{jet}} + p_{\tilde{\tau}_1})^2}$

Event Selection

(1)(2) At least one pair of stau and τ-tagged jet (OS)

(3) At least one pair of leptons(SF,OS) with $p_T > 15$ GeV

Selectron & Smuon Masses



$M_{\tilde{e}}$ = 194.5 ± 0.1 GeV

(194.4 : underlying)

$M_{\tilde{\mu}}$ = 193.4 ± 0.1 GeV

(193.4 : underlying)

Uncertainties

* Statistics

± 100 MeV

* From the error of stau mass

± 100 MeV

* From the error of bino mass

± 1 GeV

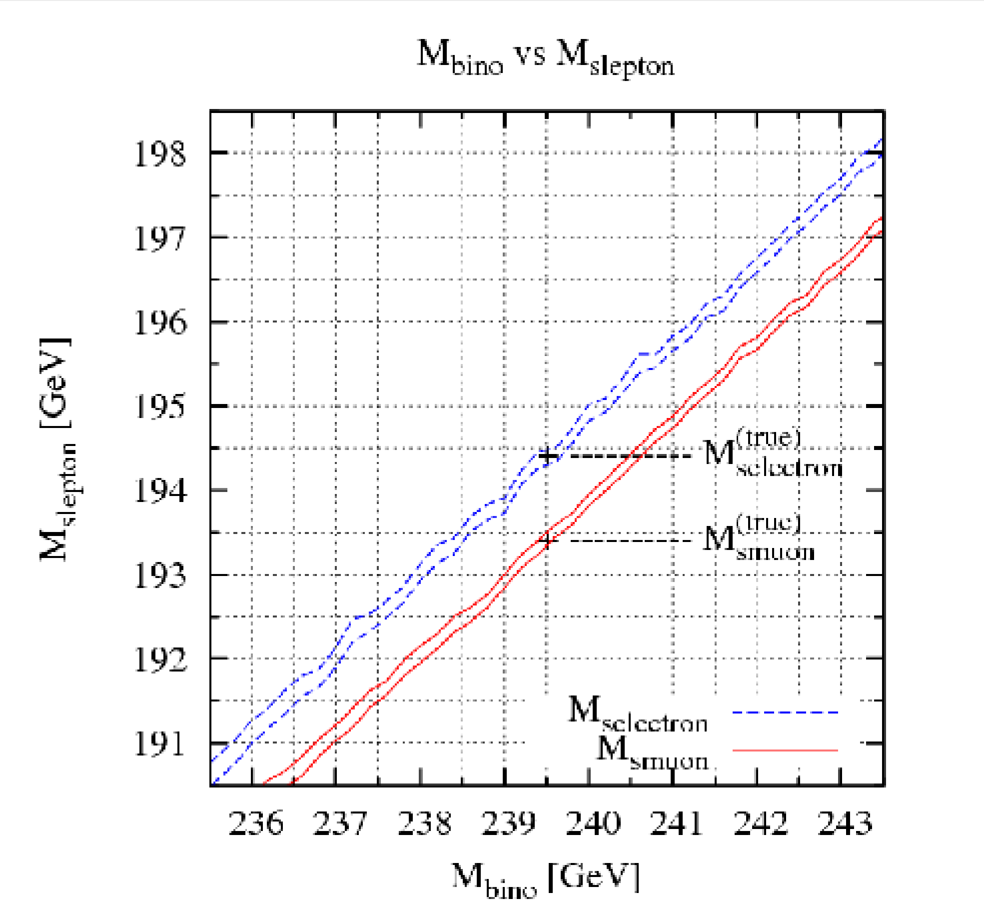
→ Slepton masses :

$$\delta m_{\tilde{e}} \sim \delta m_{\tilde{\mu}} \sim 1 \text{ GeV}$$

Selectron & Smuon Masses

The mass difference of two sleptons, $M_{\tilde{e}} - M_{\tilde{\mu}}$,

is not sensitive to the uncertainty of the bino mass.



$\rightarrow$ Mass difference :

$$\delta(m_{\tilde{e}} - m_{\tilde{\mu}})$$

$$\sim 100 \text{ MeV}$$

Good accuracy!

Selectron & Smuon Masses

The mass difference measurements with the good accuracy.

→ Implications for the SUSY breaking mechanism

* Loop effects to the slepton masses (Yukawa interaction)

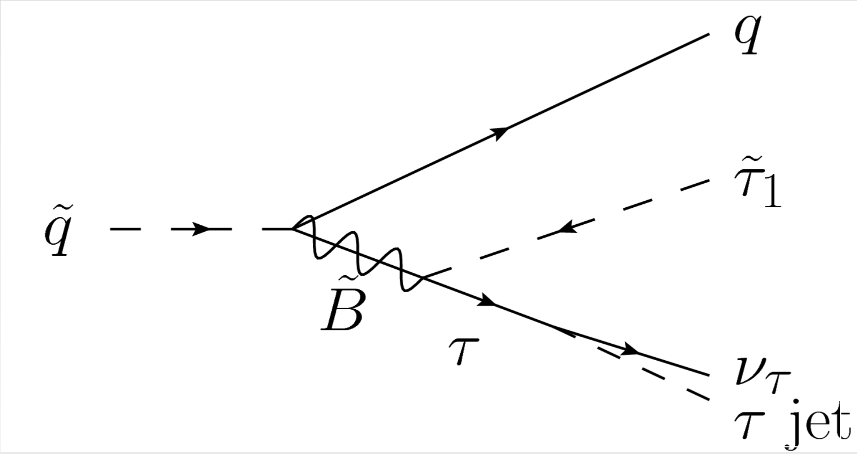
$\rightarrow$ $M_{\tilde{\mathrm{e}}} - M_{\tilde{\mu}} \sim O(100)\ \mathrm{MeV}$ for the large tanβ

* The size of SUGRA effects are estimated $\sim m_{3/2}^2 / m_{\tilde{\ell}}$

$\rightarrow$ if $m_{3/2} \sim$ a few GeV, $M_{\tilde{\mathrm{e}}} - M_{\tilde{\mu}} \sim O(100)\ \mathrm{MeV}$

$\rightarrow$ *These effects are detectable.*

Squark Masses



2-step SUSY decay chain:

squark $\rightarrow$ q + bino,

bino $\rightarrow$ τ + stau ; followed by τ $\rightarrow$ τ-jet + ν_τ

τ's momentum is reconstructed by $m_{\tilde{B}}^2 = (r p_{\tau-\mathrm{jet}} + p_{\tilde{\tau}_1})^2$

Then, $\rightarrow$ $M_{\tilde{q}} = \sqrt{(p_{\mathrm{jet}} + r p_{\tau-\mathrm{jet}} + p_{\tilde{\tau}_1})^2}$

Event Selection

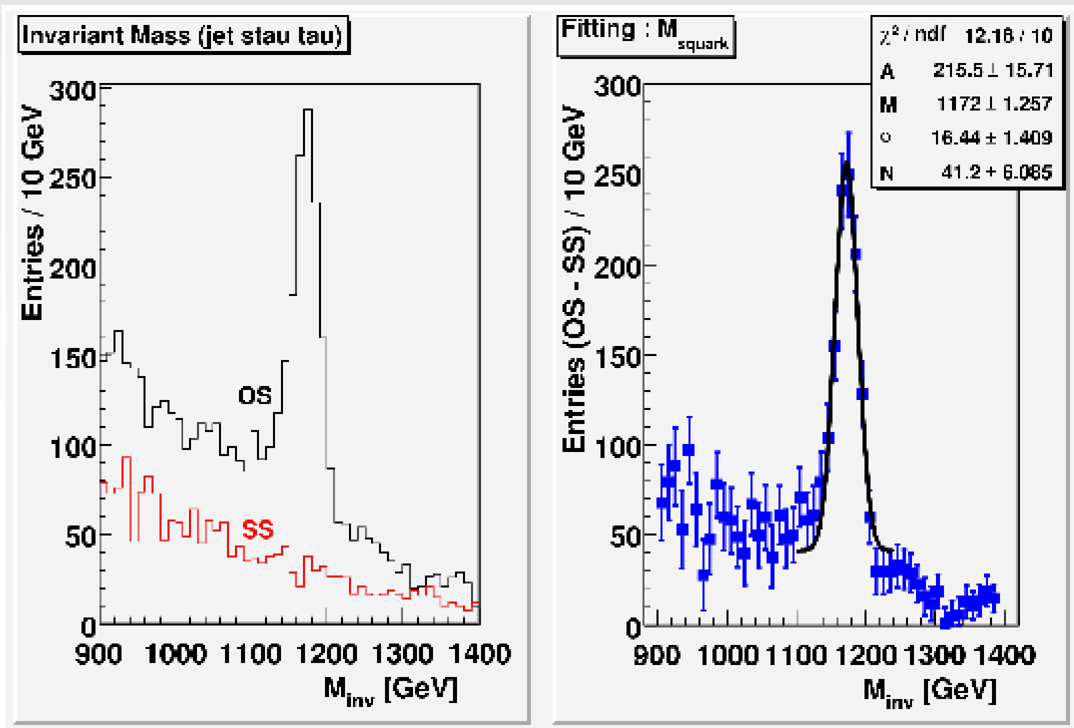
(1)(2) At least one pair of stau and τ-tagged jet

(3) At least one jet with p_T > 100 GeV

(4) No isolated leptons with p_T > 15 GeV

Squark Masses

We use upto leading 4 high-p_T jets, and perform charge subtraction.



$M_{\tilde{q}}$ = 1172 ± 1 GeV

(1180 : Squark(R))

$$[\mathrm{BR}(\tilde{q}_R \to q\tilde{\chi}_1^0) \simeq 100\%]$$

Uncertainties

* Statistics + *Systematics*

  (± 1 GeV) + (- 8 GeV)

* From the error of stau mass

  ± 100 MeV

* From the error of bino mass

  ± 1 GeV

$\to$ Squark mass measurement : $\delta m_{\tilde{q}} \sim 10\ \mathrm{GeV}$

Conclusions

We have discussed mass measurements of superparticles

in the long-lived stau scenario at the LHC experiments.

* Neutralino Masses

by endpoint analysis : $\delta m_{\tilde{B}} \sim 1 \text{ GeV}, \ \delta m_{\tilde{W}^0} \sim 5 \text{ GeV}$

charge subtraction method is useful.

* Selectron & Smuon Masses ($m_{\tilde{B}} > m_{\tilde{\ell}_R} > m_{\tilde{\tau}_1}$)

by peak analysis: $\delta m_{\tilde{e}} \sim \delta m_{\tilde{\mu}} \sim 1 \text{ GeV}$

* mass difference : $\delta(m_{\tilde{e}} - m_{\tilde{\mu}}) \sim 100 \text{ MeV}$

informations for the ~~SUSY~~

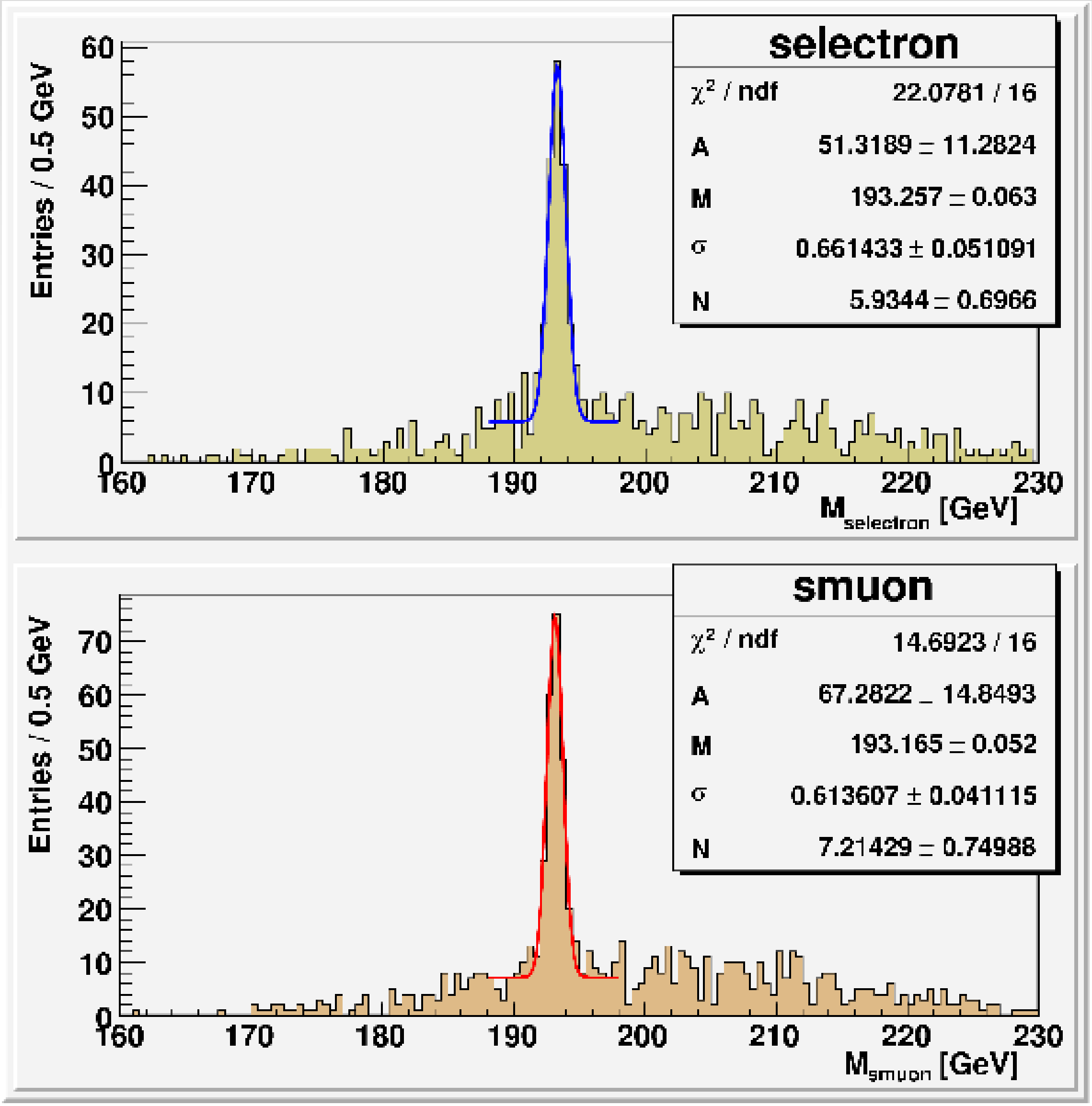
* Squark Masses

by peak analysis: $\delta m_{\tilde{q}} \sim 10 \text{ GeV}$

backup

Another Example; Sweet Spot Model [Ibe,Kitano(07)]

slepton masses

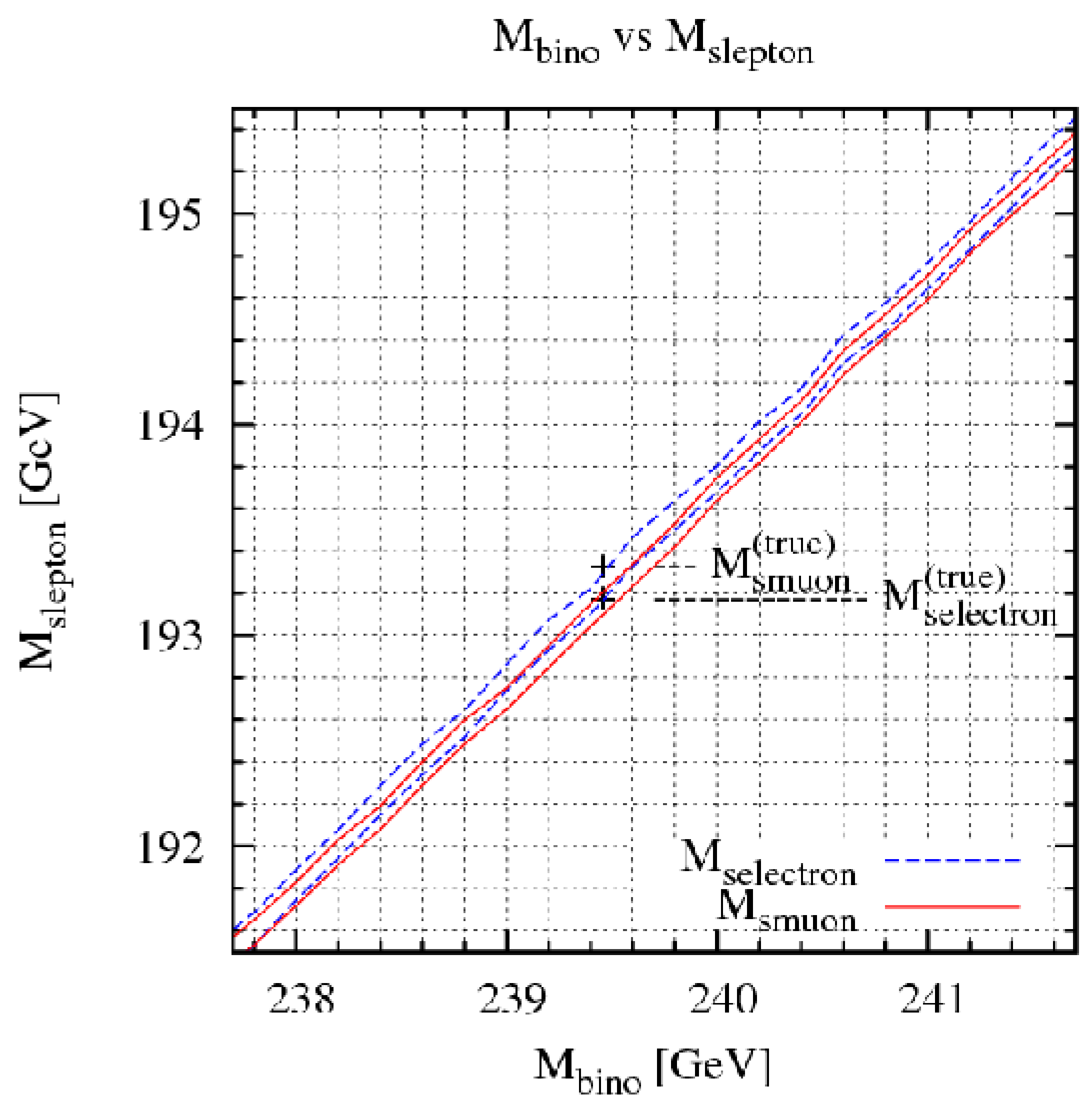


Another Example; Sweet Spot Model [Ibe,Kitano(07)]

bino mass

vs

slepton mass



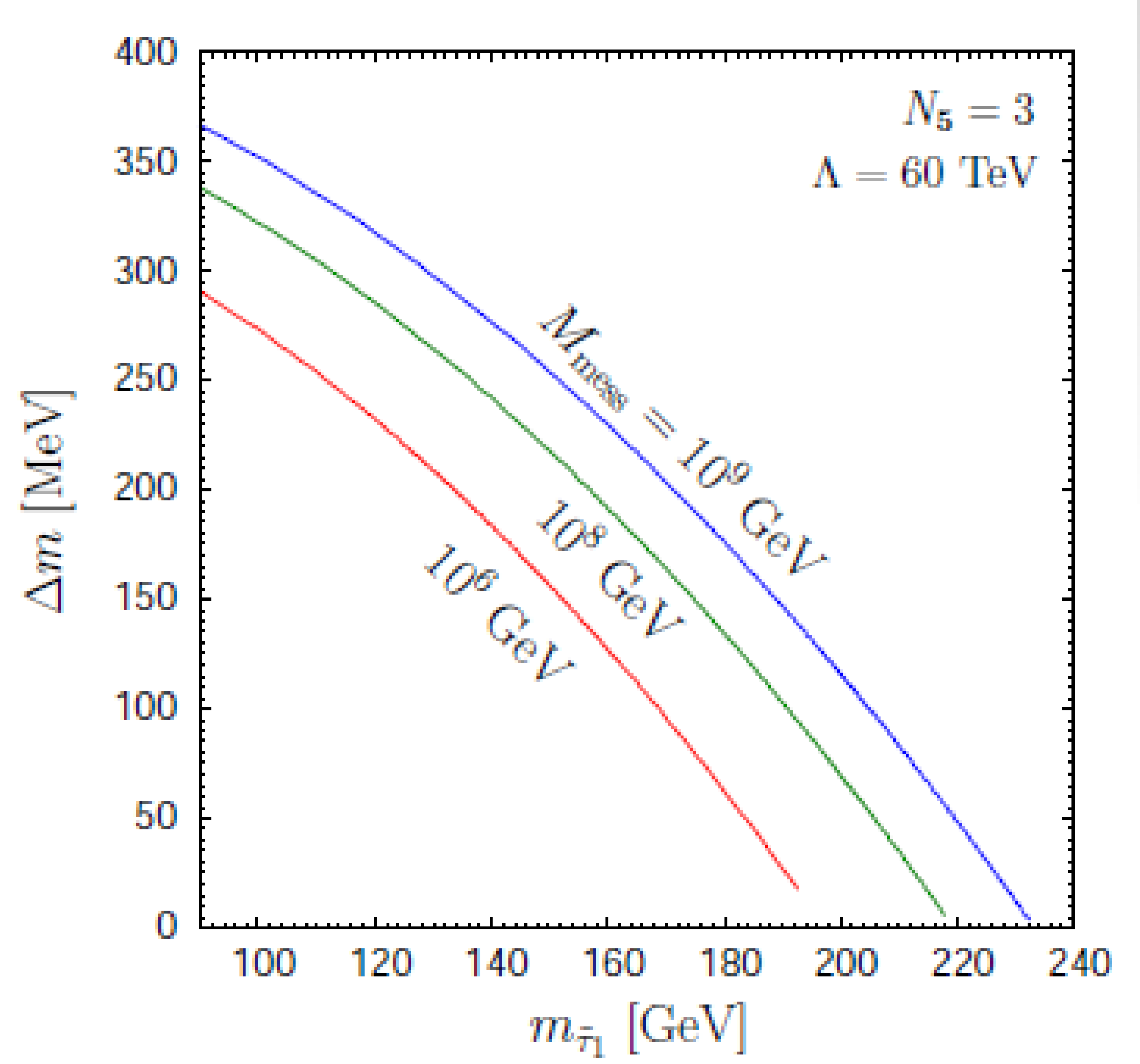
Another Example; Sweet Spot Model [Ibe,Kitano(07)]

The size of

the mass difference

(for the fixed

N_5 and Λ)



Introduction

Supersymmetry : A famous extension of the Standard Model

There are several reasons to consider SUSY seriously.

* Gauge coupling unification at the very high energy scale (*GUT*)

* Candidates of Dark Matter of the Universe

* Predicts a light higgs (prefered by EW precision measurements)

* Naturally solves gauge hierarchy problem

$\rightarrow$ It will appear around TeV scale.

$\leftrightarrow$ in the energy range of the LHC experiments!

So, Question is

What is a signature of SUSY at the LHC?