# Long-lived Stau

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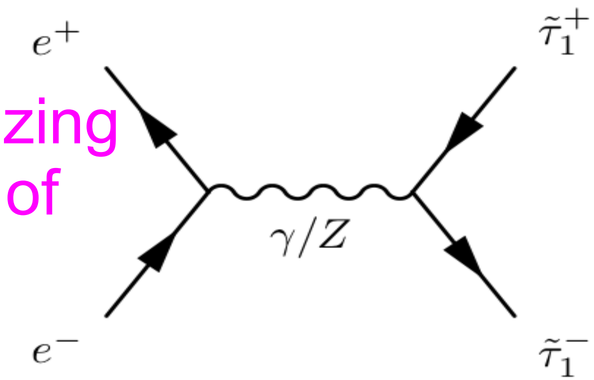
# Introduction

- In the GMSB scenario,the stau can be lighter than the lightest neutralino. When the stau is lighter than the neutralino and it is long lived,the neutralino can decay into the stau and be observable.
- Stau interacts with detector and can be discovered with a good accuracy.
- Long-lived stau is important not only to determine its properties but also quantum numbers of neutralino.

·We study such a stau and neutralino decaying into a stau and a tau,emphasizing feasibilities of precision measurements of their masses,using the MC simulations.

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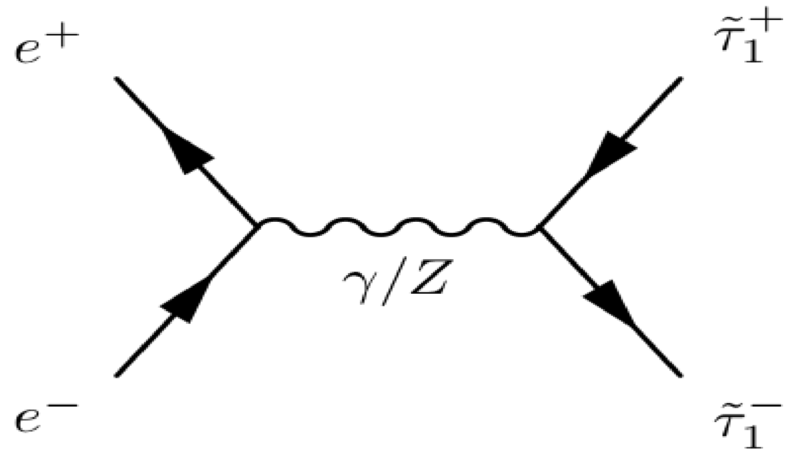
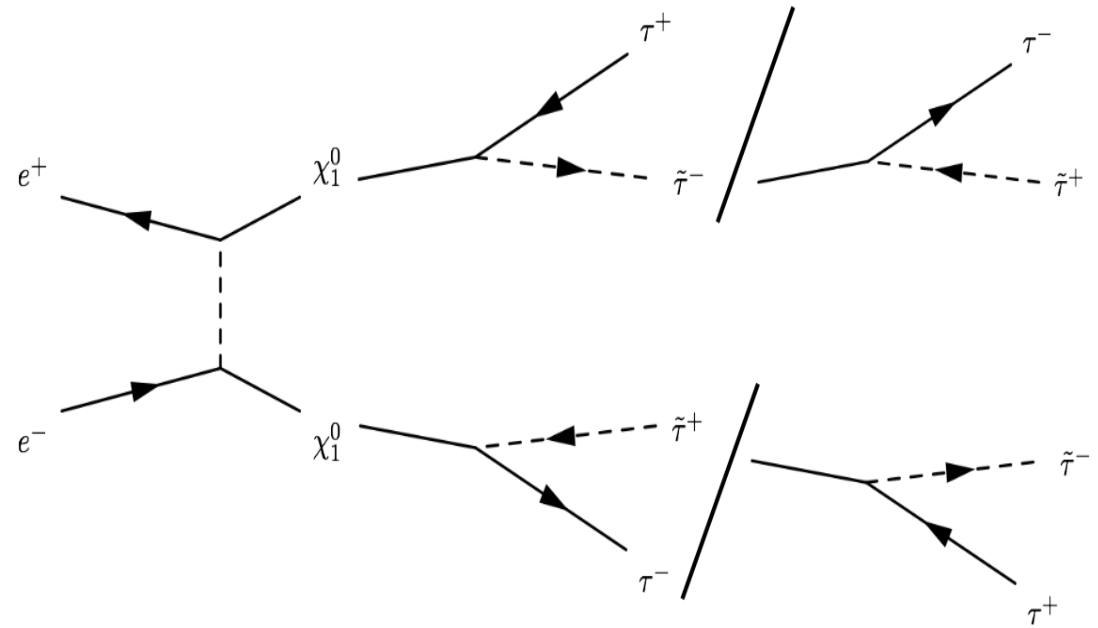
# Decay Mode

- Stau pair mode
- Via Neutralino mode




**Stau pair mode**

·This mode determines stau mass, spin.

· $m_{\tilde{\tau}_1}$ can be determined from dE/dx ,TOF and threshold scan.

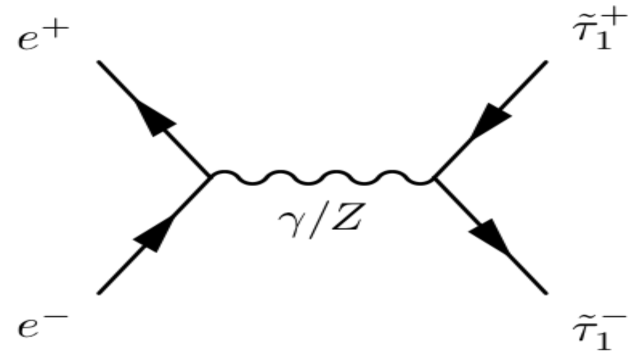
·Life time of stau is measured at HCAL.

**Via neutralino mode**

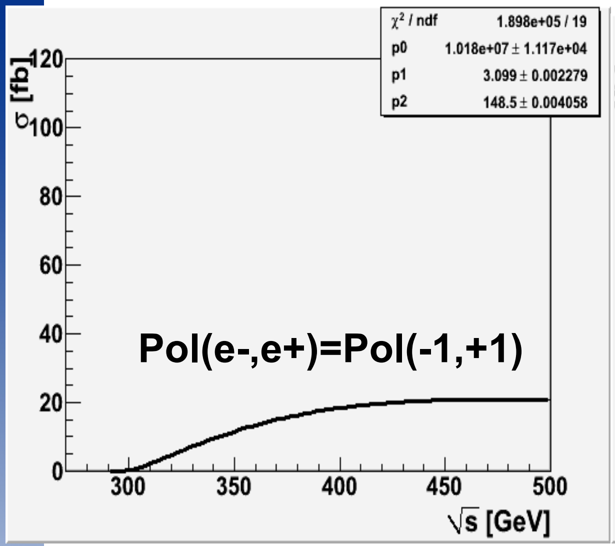
·Neutralino decays into stau and tau.

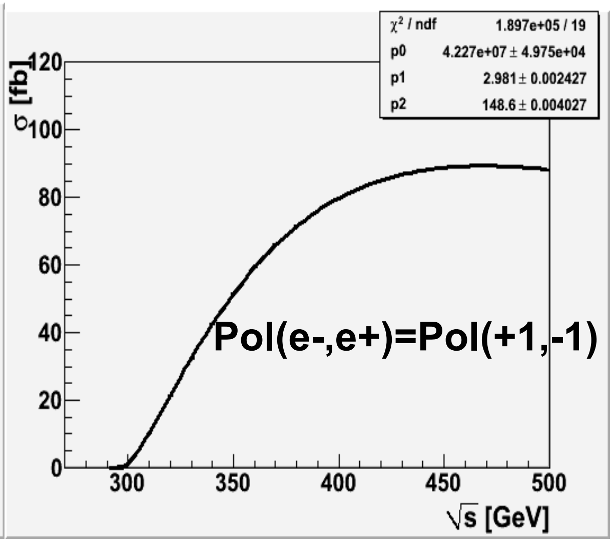
·This mode determines neutralino mass.

# Stau Pair Mode



# Stau Pair Mode

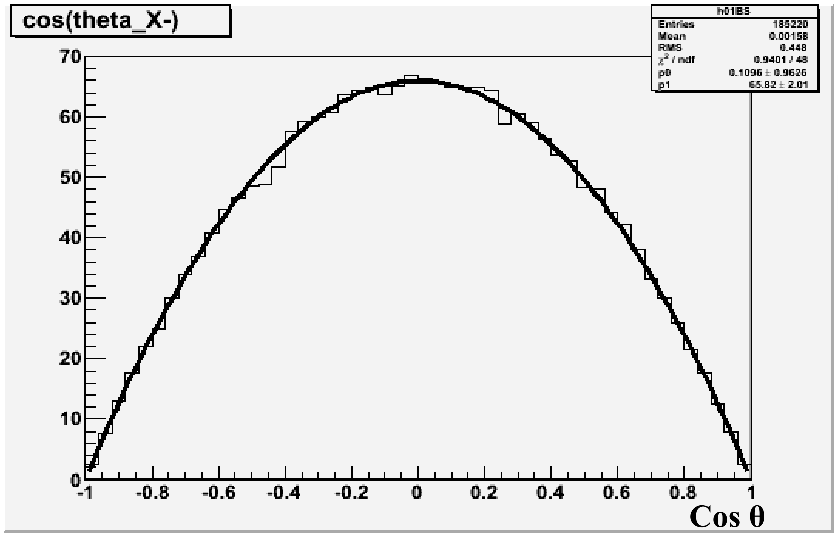



Cross section in the case of right handed electron is bigger than that in case of left handed electron.

**Cross section of stau pair mode**

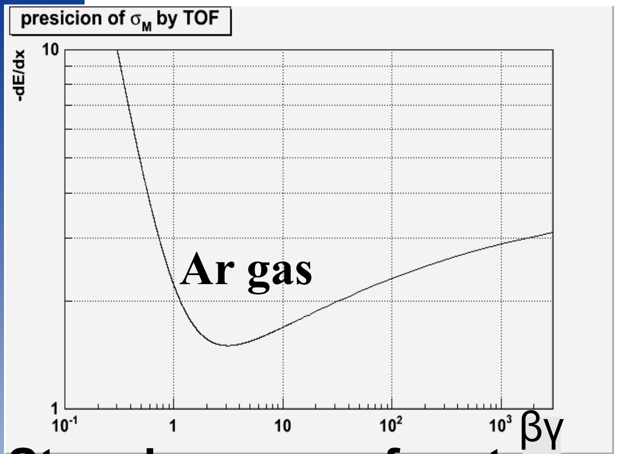
**Stau mass : 148.83 GeV**




Many staus reach the barrel.
It is evidence that stau's spin is 0.

**Angular distribution**

# Precision of Stau Mass Measurement by dE/dx

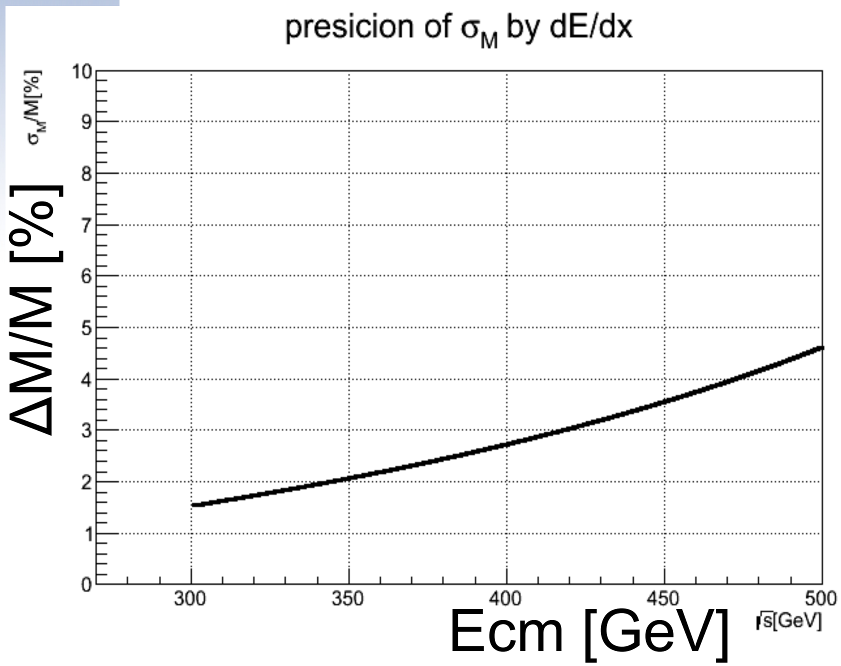



Stopping power for stau

Energy loss for heavy charged particles is measured at TPC. By energy loss measurement,stau mass can be measured.

$$M = E \cdot \sqrt{1-\beta^2}$$

Assuming energy loss measurement has 5% resolution.



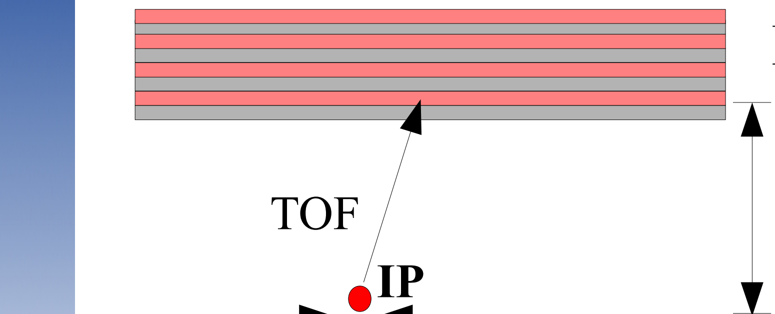

This figure mass resolution by dE/dx as a function of center of mass energy.

From this figure,mass measurement by dE/dx is best at energy threshold.
Then,

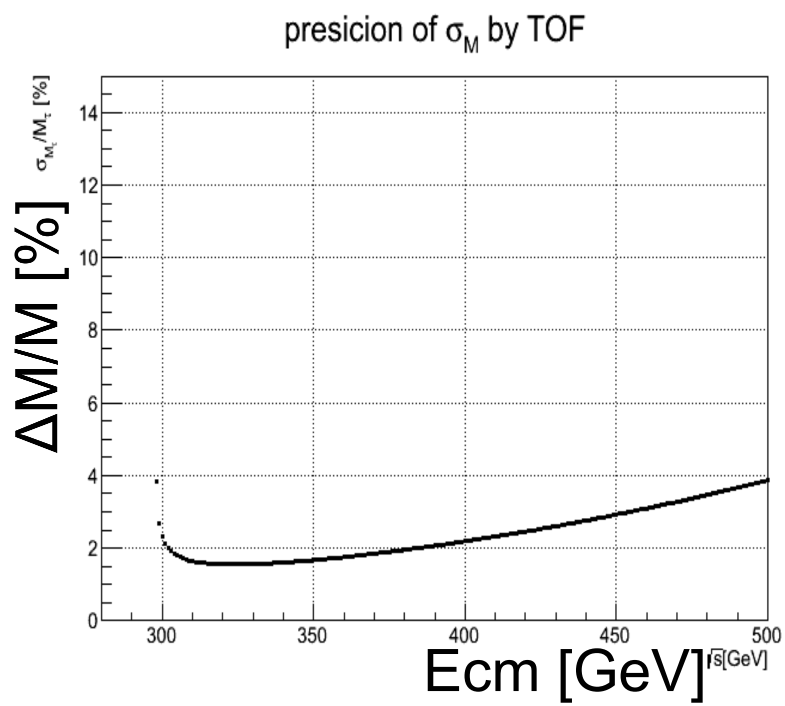
$$\frac{\Delta M}{M} = 1.4\ \%$$

# Precision of Stau Mass Measurement by TOF

Stau mass is given by Time Of Flight measurement,as well. If we can measure TOF precisely,stau mass is determined in good accuracy. ECAL is superior to TPC or SET for the time resolution,so we measure TOF at ECAL.



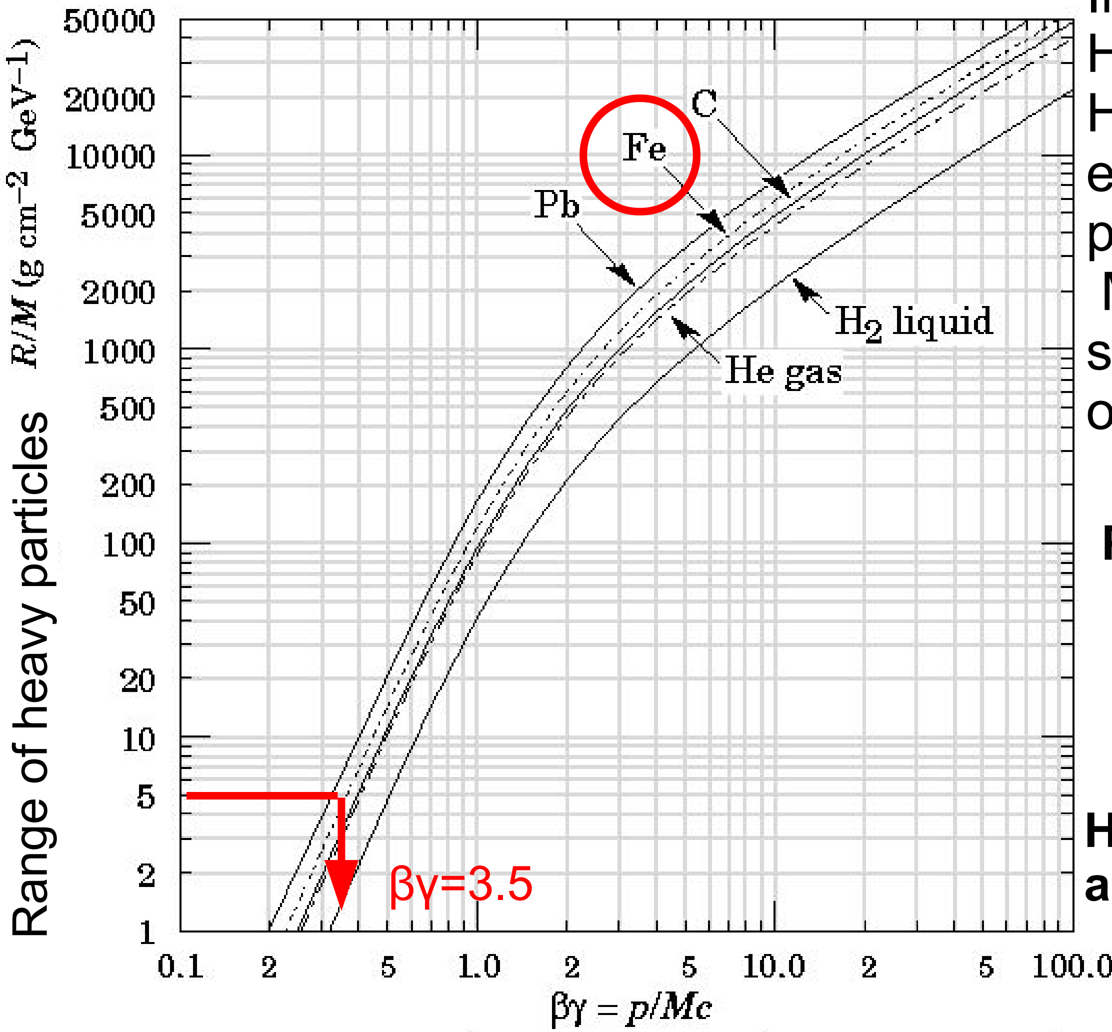

$$\beta = \frac{R}{TOF} \quad , \quad M = E \cdot \sqrt{1-\beta^2}$$




ScECAL has about 1ns time resolution. Stau mass is determined good accuracy when beam energy is about 320-330 GeV.

$$\frac{\Delta M}{M} = 1.5\ \%$$

# Life Time




In order to measured stau life time in HCAL,staus should be stopped in HCAL. Because of tunable beam energy, ILC allows us to control decay place of stau.

Maximum beam energy when a stau stops in HCAL is calculated from range of heavy particles.

**Precision of life time measurement**

$$\frac{\sigma_\tau}{\tau} = \frac{1}{\sqrt{L \cdot \sigma_s}}$$

$L = 200\,\mathrm{fb}^{-1}$

$\sigma_s$: Cross section

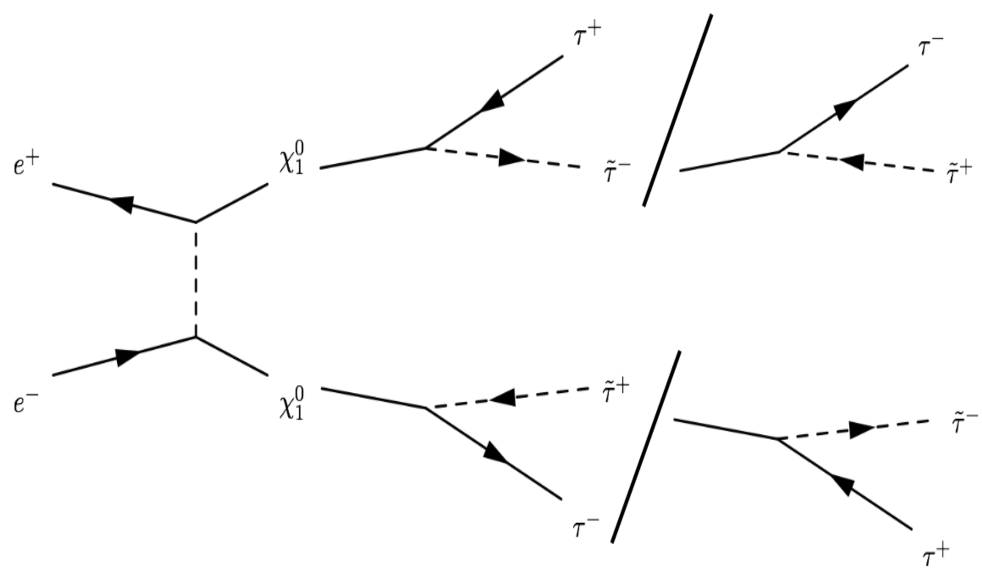
**HCAL consists of 48 steel plates, and each plate has 20mm thickness.**

**Maximum beam energy: √s=315.4±1.0[GeV]**

**Cross section: σ＝ 9.3±0.3[fb]**

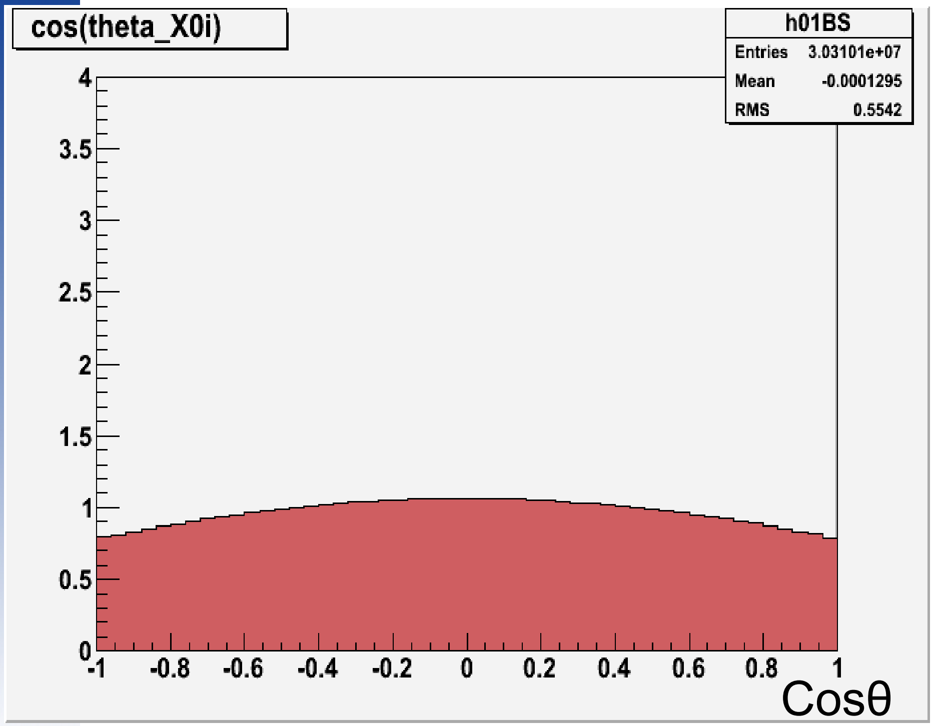
$$\frac{\sigma_\tau}{\tau} = 2.4 \pm 0.1\ \%$$

# Neutralino Mode

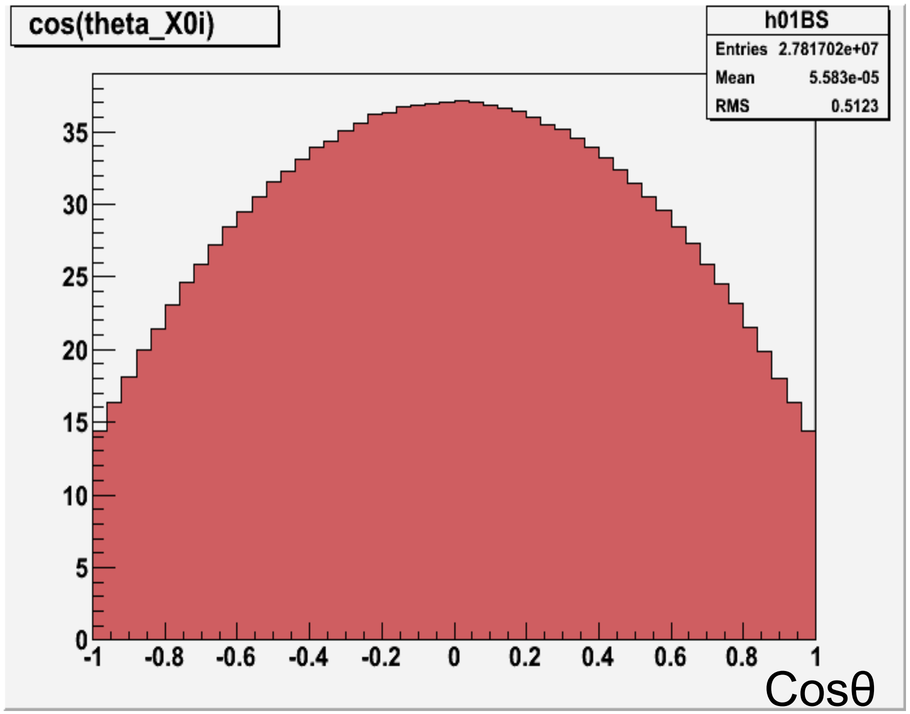


# Neutralino Angular Distribution

These are neutralino's angular distribution for each polarization




Pol(e-,e+)=Pol(-1,+1)




Pol(e-,e+)=Pol(+1,-1)

it is almost flat.

Many neutralinos reach the barrel.

Cross section in the case of right handed electron is bigger than that in case of left handed electron.

# Backgrounds

Signal

$e^+ e^- \rightarrow \chi_1^0 \chi_1^0 \rightarrow \tilde{\tau}_1^\pm \tilde{\tau}_1^\pm \tau^\mp \tau^\mp$ **2 staus and 2 tauons**

Regarded background

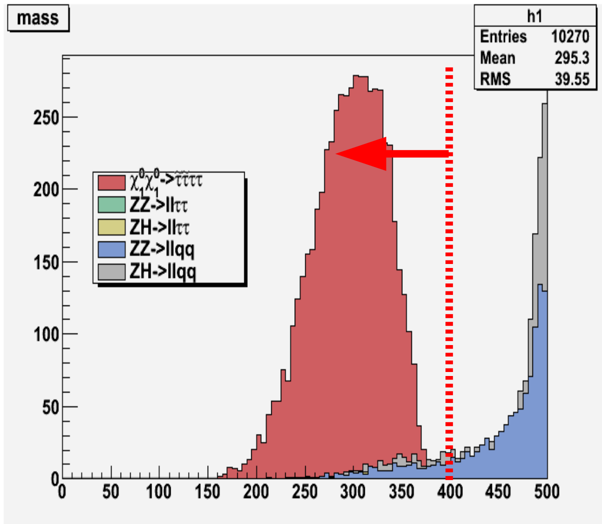
**e+e- →ZZ**
**e+e- →ZH** → **2 leptons and 2 jets**

| | Cross section (fb) at 500GeV | |
|---|---|---|
| | Pol(-0.8,+0.3) | Pol(+0.8,-0.3) |
| $\chi_1^0 \chi_1^0 \rightarrow \tilde{\tau}_1^\pm \tilde{\tau}_1^\pm \tau^\mp \tau^\mp$ | 3.191 | **34.484** |
| $ZZ \rightarrow l\, l\, \tau\, \tau$ | 4.073 | 2.349 |
| $ZH \rightarrow l\, l\, \tau\, \tau$ | 4.983 | 3.744 |
| $ZZ \rightarrow l\, l\, q\, q$ | 18.991 | 10.874 |
| $ZH \rightarrow l\, l\, q\, q$ | 4.623 | 24.178 |

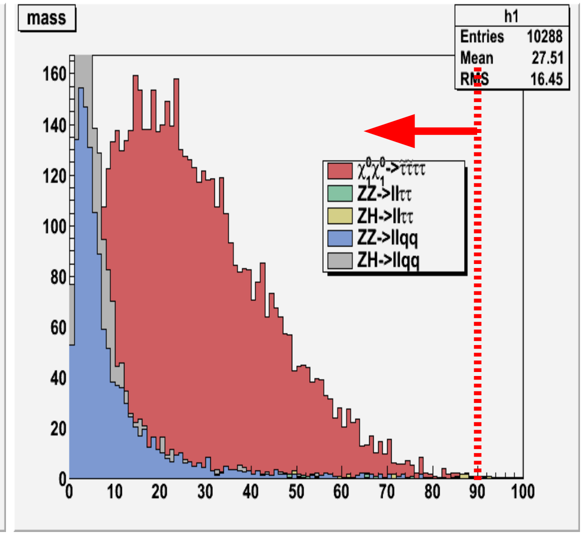
Pol(e-,e+)

Should use Right-handed electron!

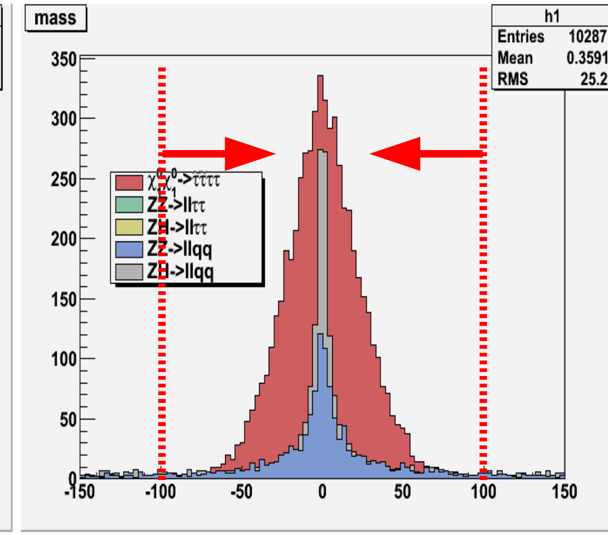
# Event Selection



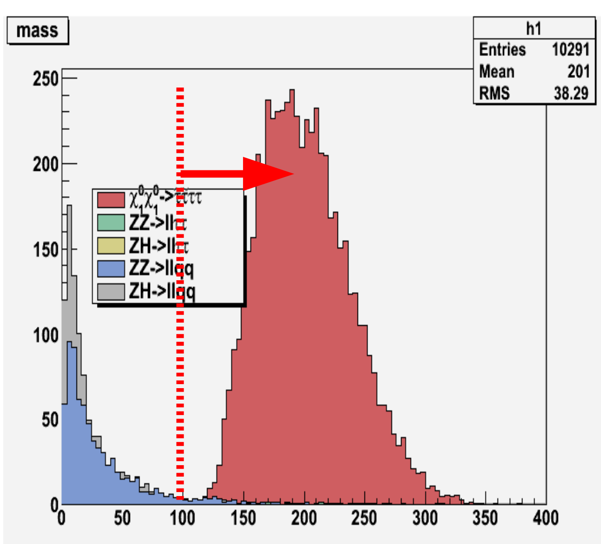

Visible energy<400GeV



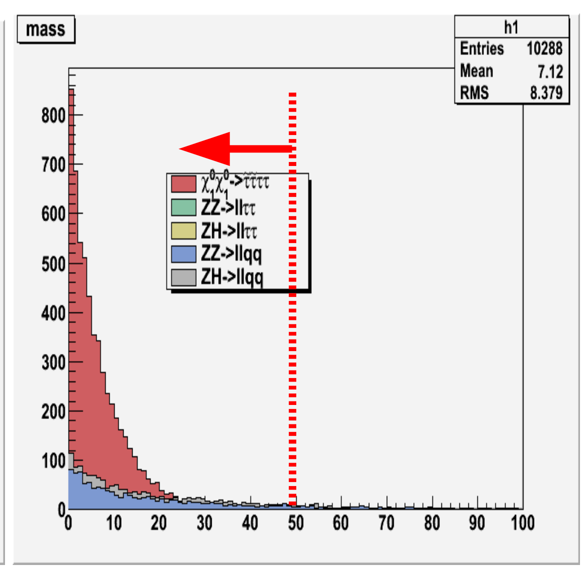

Pt<90GeV




|Pl|<100GeV



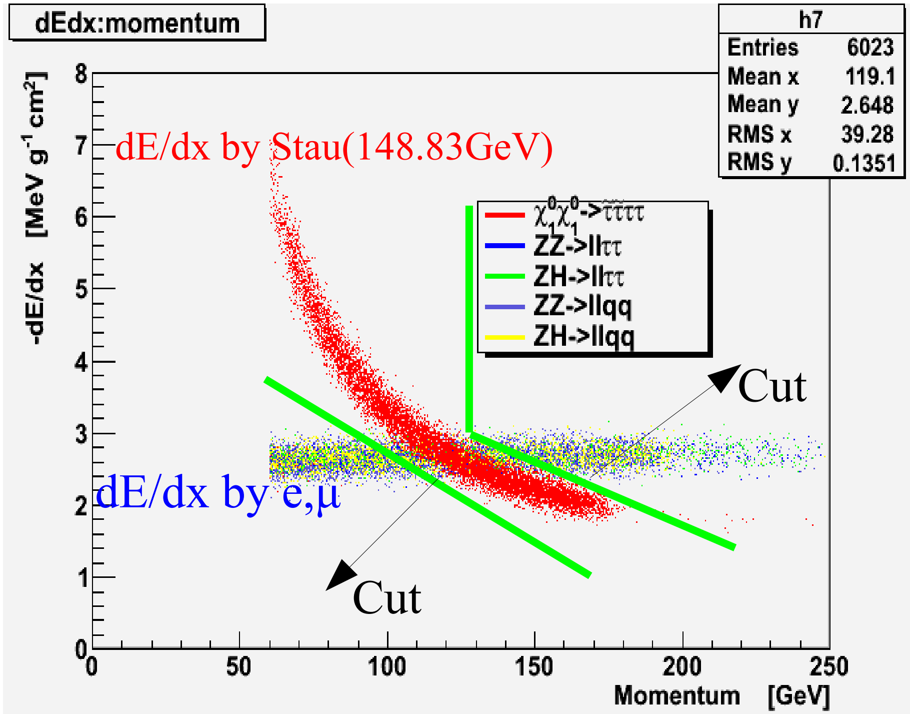

Missing mass>100GeV

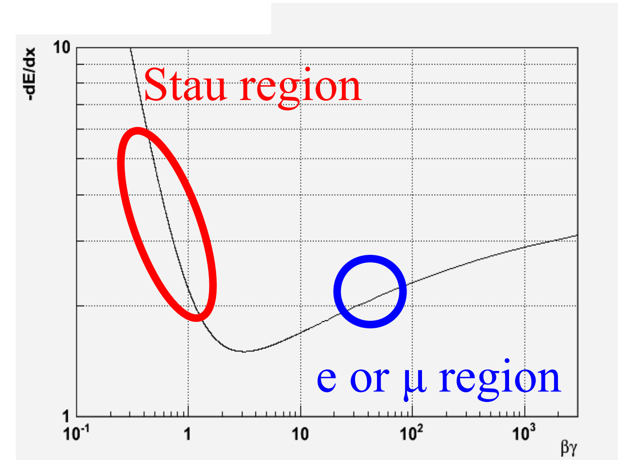



Acoplanarity<50

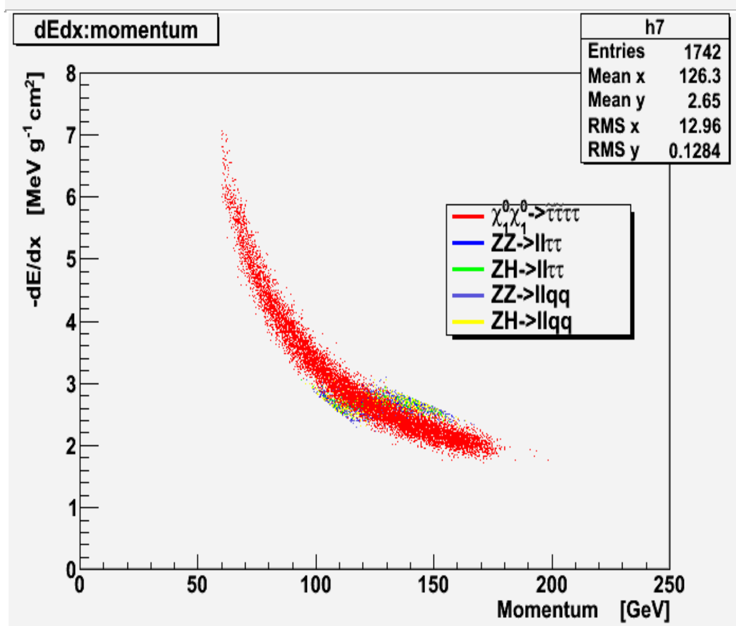
$\chi_1^0 \chi_1^0 \rightarrow \tilde{\tau}_1^\pm \tilde{\tau}_1^\pm \tau^\mp \tau^\mp$

# dE/dx Cut




stau and lepton Region




Distribution of dE/dx by stau,muon and electron for momentum are different. So,it is possible to separate stau from muon/electron.

# Event Selection

| | No Cut | evis | pt | \|pl\| | dE/dx | Number of leptons = 2 | Number of jets =2 |
|---|---|---|---|---|---|---|---|
| $\chi_1^0\chi_1^0 \rightarrow \tilde{\tau}\tilde{\tau}\tau\tau$ | 6897 | 6864 | 6863 | 6773 | 6373 | 6099 | 5940 |
| **ZZ->llll** | 470 | 275 | 225 | 106 | 21 | 4 | 4 |
| **ZH->llll** | 749 | 276 | 180 | 161 | 32 | 5 | 5 |
| **ZZ->llqq** | 2175 | 1367 | 1364 | 359 | 14 | 6 | 5 |
| **ZH->llqq** | 4835 | 1437 | 1221 | 273 | 11 | 7 | 4 |

| | missing mass | acopranarity | efficiency |
|---|---|---|---|
| $\chi_1^0\chi_1^0 \rightarrow \tilde{\tau}\tilde{\tau}\tau\tau$ | 5933 | 5904 | 85.6% |
| **ZZ->llll** | 1 | 1 | 0.21% |
| **ZH->llll** | 3 | 2 | 0.27% |
| **ZZ->llqq** | 2 | 1 | 0.05% |
| **ZH->llqq** | 1 | 1 | 0.02% |

► Good efficiency

► Well rejected

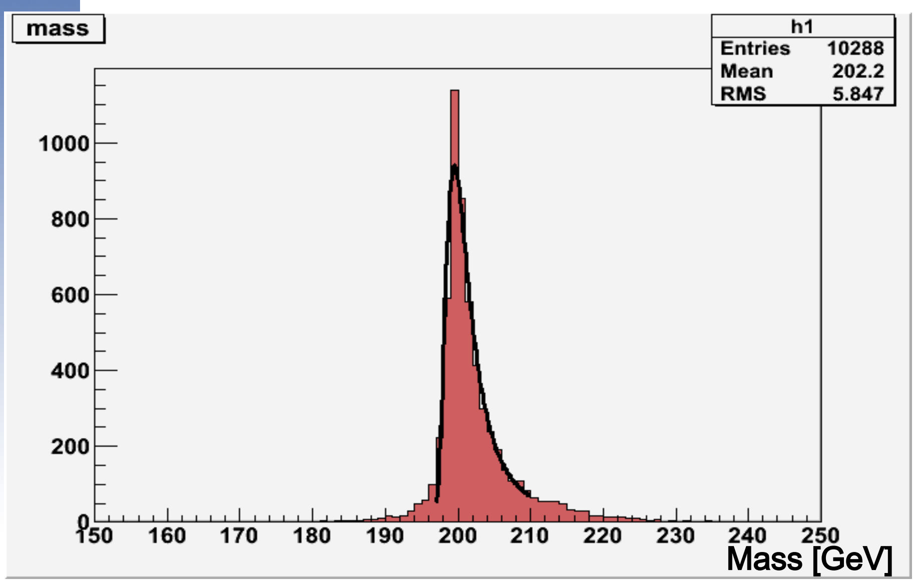
Pol(+0.8,-0.3), Integrated luminosity : 200 $fb^{-1}$

# Neutralino mass

We can calculate neutralino mass by 4 momenta of tau jet and stau.

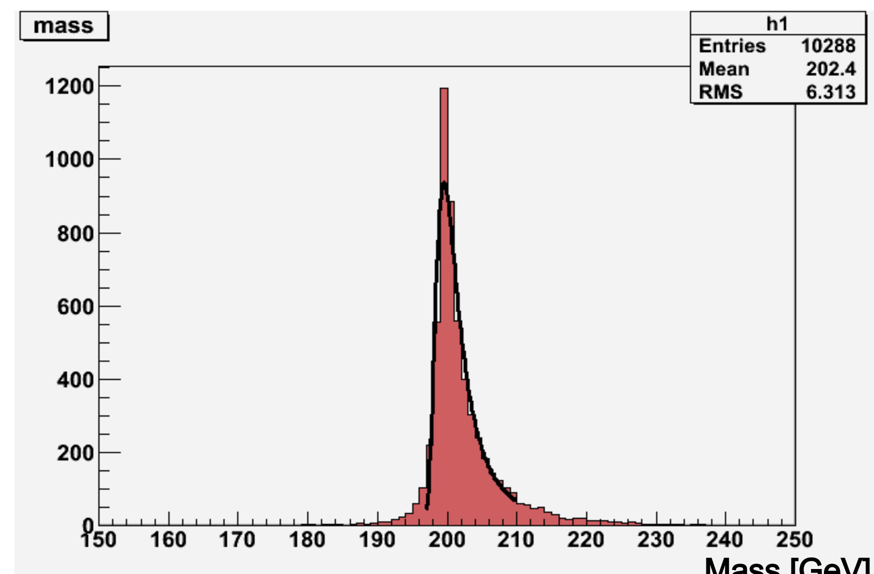
$$M_{j_\tau \tilde{\tau}} \equiv \sqrt{\left(p_{j_\tau} + p_{\tilde{\tau}}\right)^2} = m_{\chi_1^0}$$

Input value of $m_{\chi_1^0}$ is 200.0 GeV




$m_{\chi_1^0} = 199.74 \pm 0.05$ GeV

Deviation from input value:0.10%




$m_{\chi_1^0} = 199.72 \pm 0.05$ GeV

Deviation from input value:0.14%

# Summary&Plan

## Summary

· Properties of a stau determined from stau pair mode.

· Stau mass can be measured by dE/dx and TOF.

· If we can stop stau at HCAL, we observe stau's decay.

· Neutralino decay into a stau and tau have a good efficiency.

## Future plan

·Should determine a stau mixing angle from polarization.