# Update of Analysis of Long Lived Stau

4th July 2014

Physics and Software Meeting

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# Status

Wataru Yamaura has analyzed long lived stau at ILD with the fast simulation finished at 2012 spring assuming;

- Gage Mediated SUSY Braking
- $M_{stau}$ = 150 GeV and 205 GeV
- 200 fb$^{-1}$

$$\Gamma_{\tilde{\tau}\to\tilde{G}} = \frac{1}{48\pi M_p^2}\frac{m_{\tilde{\tau}}^5}{m_{\tilde{G}}^2}\left[1-\frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^2}\right]^4$$

However, Stau with those masses is excluded by LHC experiments.

So we need to analyze with lager mass.

$$m_{\tilde{\tau}_1} < m_{\tilde{e}_R}, m_{\tilde{\mu}_R} < m_{\chi_1^0},$$

1. $e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^-$
2. $e^+e^- \to \tilde{l}_R^+\tilde{l}_R^- \to l^+\tilde{\tau}_1^+\tau^-l^-\tilde{\tau}_1^-\tau^+$
3. $e^+e^- \to \chi_1^0\chi_1^0 \to \tilde{\tau}_1^+\tau^-\tilde{\tau}_1^-\tau^+$
4. $e^+e^- \to \chi_1^0\chi_1^0 \to \tilde{l}_R^+l^-\tilde{l}_R^-l^+ \to l^+\tilde{\tau}_1^+\tau^-l^-l^-\tilde{\tau}_1^-\tau^+l^+$

easily distinguished

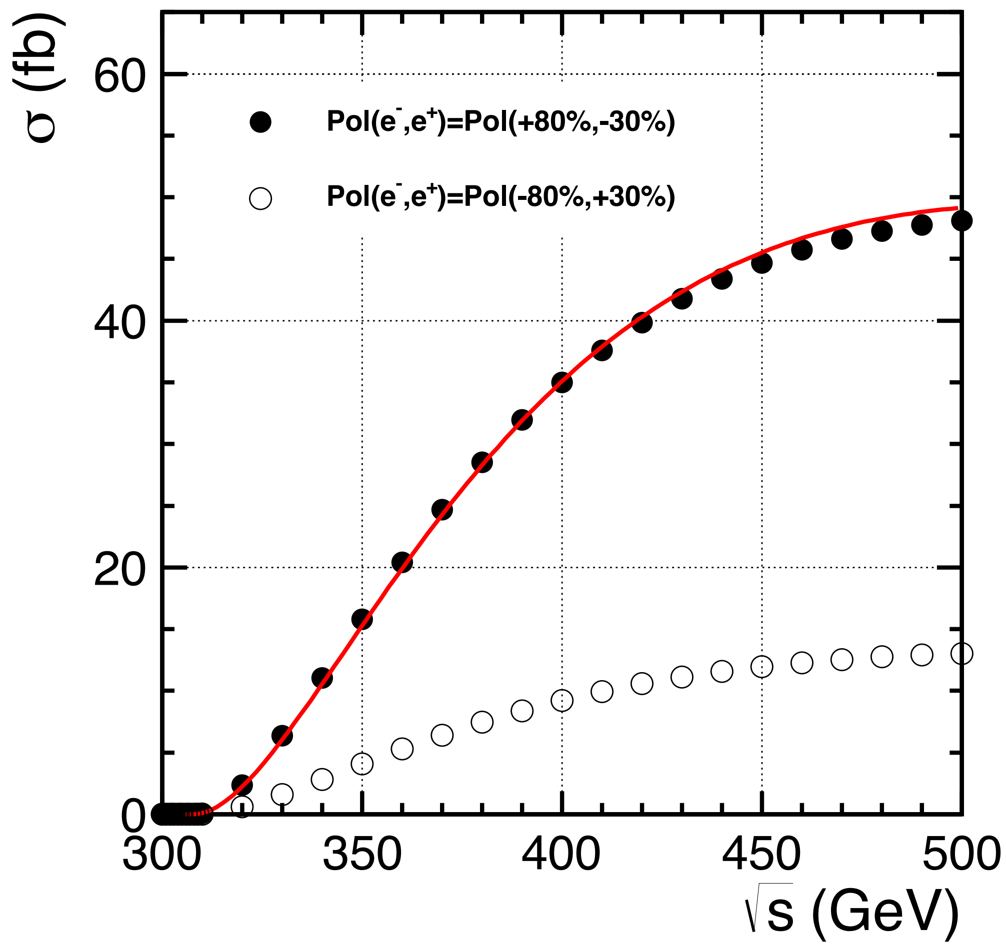
Spectra are calculated by using ISAJET.

# Energy scan of the cross section

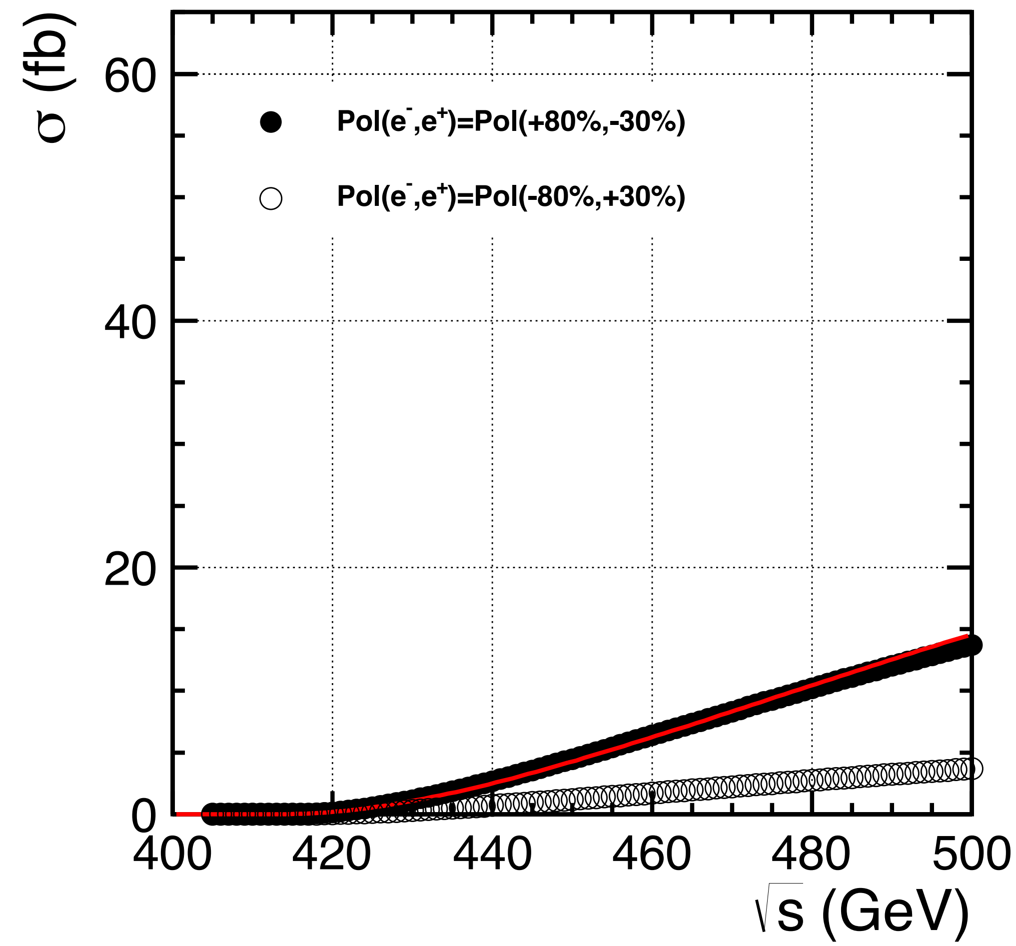
Wataru's result

## ee→$\tilde{\tau}\,\tilde{\tau}$

$M_{stau}$ = 150 GeV




$M_{stau}$ = 205 GeV




$\propto$ cube of $\sqrt{s}$

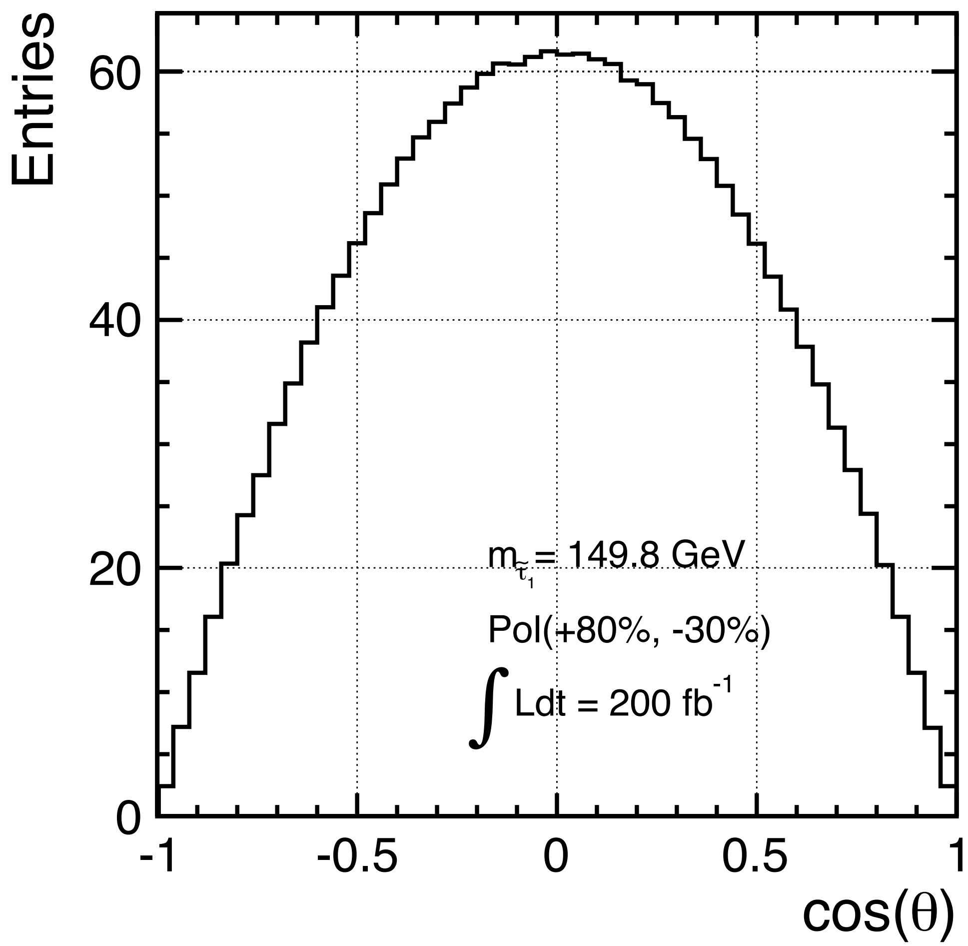
$$\frac{\sigma(\mathrm{Pol}(-80\%,+30\%))}{\sigma(\mathrm{Pol}(+80\%,-30\%))}=\frac{1}{4},$$

I'm afraid if incomplete polarization does not effect on 1/4

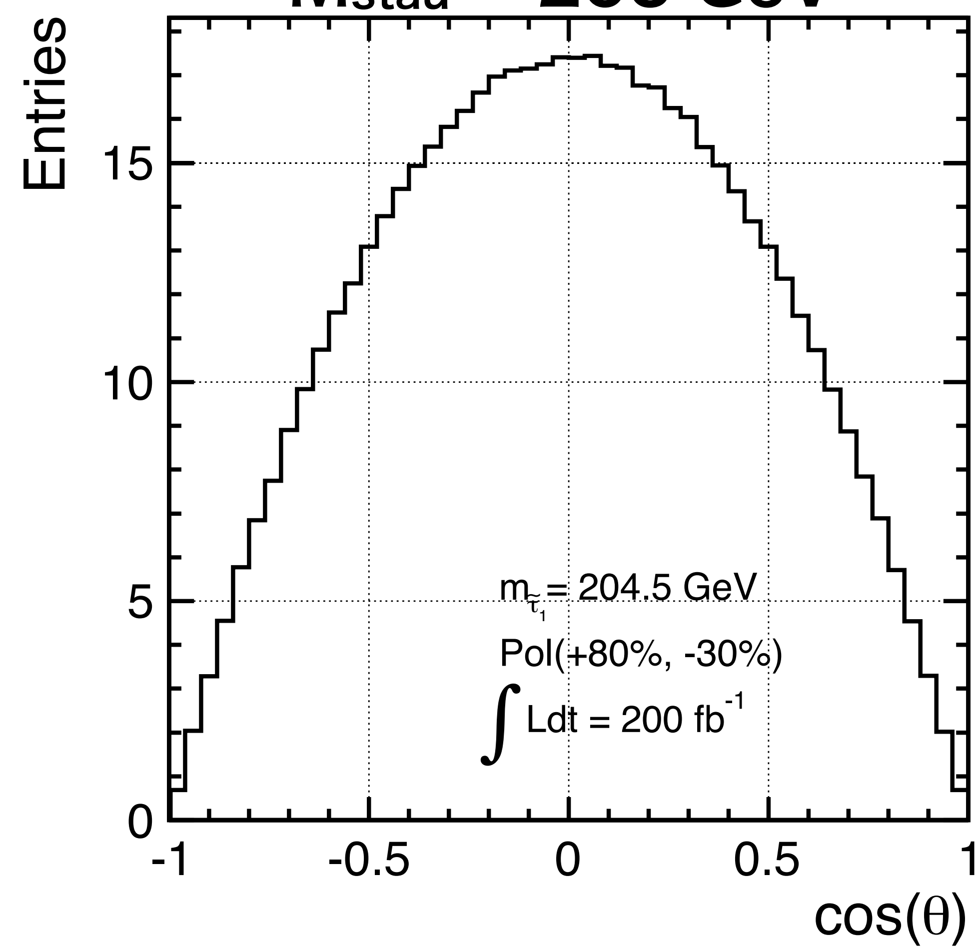
# Angular distribution of ee → $\tilde{\tau}\,\tilde{\tau}$

**Wataru's result**

**$M_{stau}$ = 150 GeV**




**$M_{stau}$ = 205 GeV**

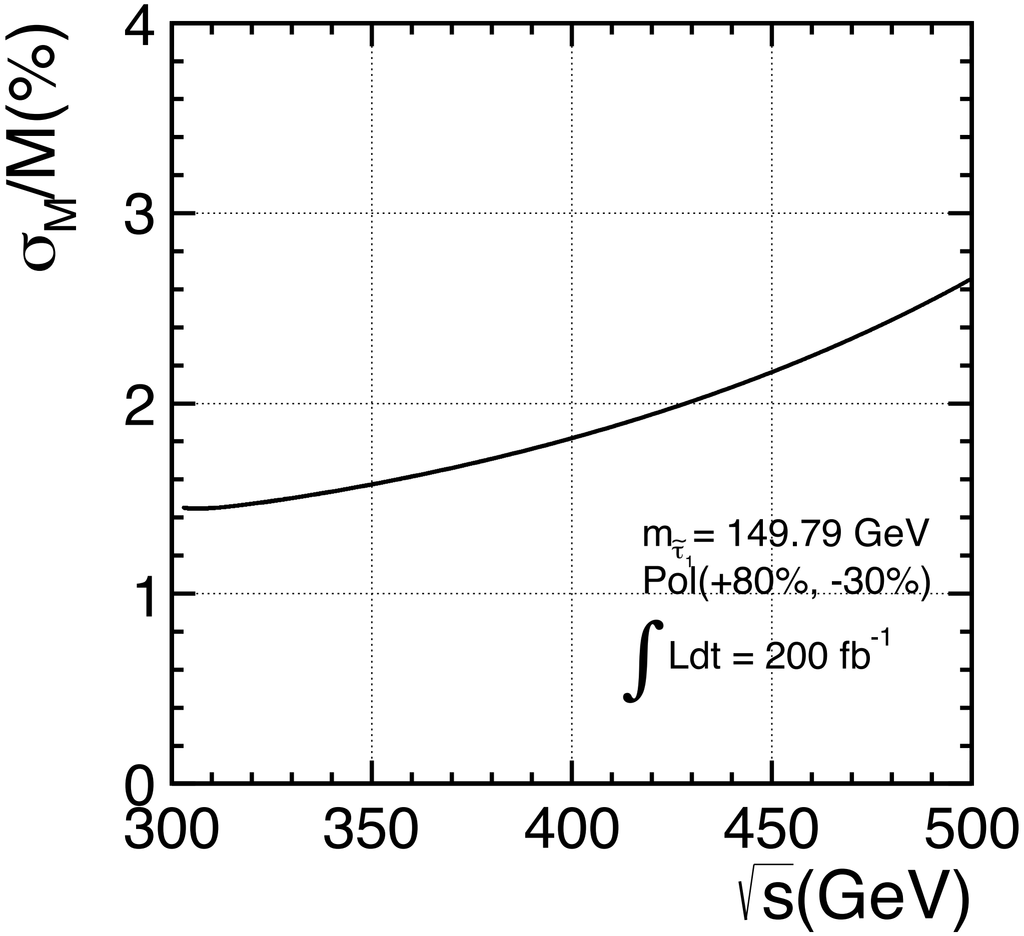



**(spin = 1) x 1 → (spin = 0) x 2**

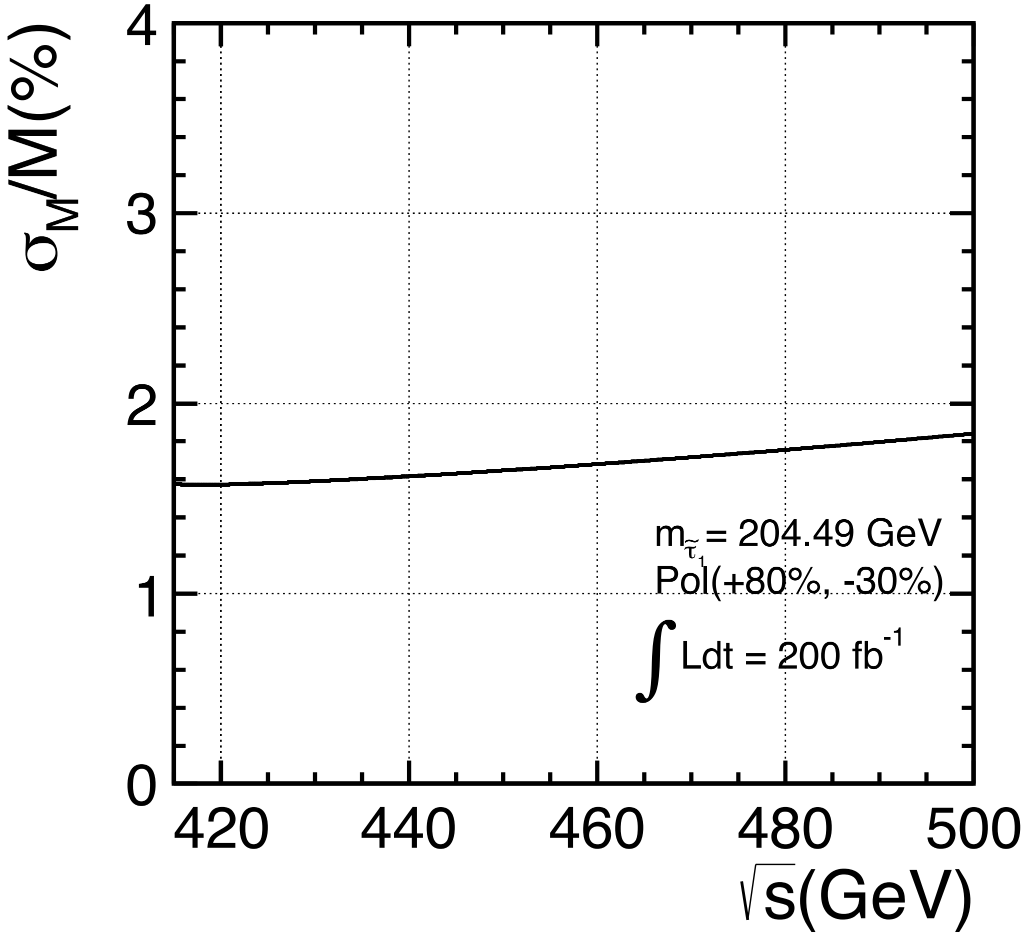
# Uncertainty of M$\tilde{\tau}$ measured by TOF to ECAL

Wataru's result

M$_{stau}$ = 150 GeV




M$_{stau}$ = 205 GeV




$\Delta$M$_{stau}$/M$_{stau}$ = 1.5%

$\Delta$M$_{stau}$/M$_{stau}$ = 1.6%

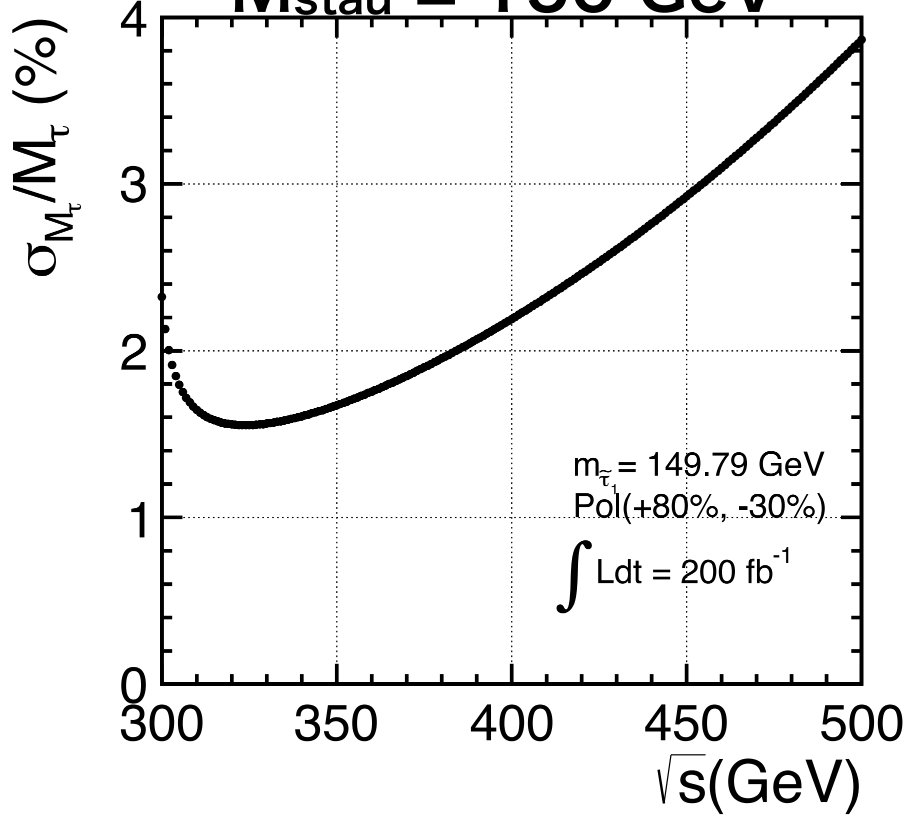
1 ns ScECAL timing resolution is assumed

Results come from compensation between increasing cross-section and increasing uncertainty of timing resolution ration as the center of mass energy increases.

# Uncertainty of M$\tilde{\tau}$ measured by energy loss in TPC (dE/dx)

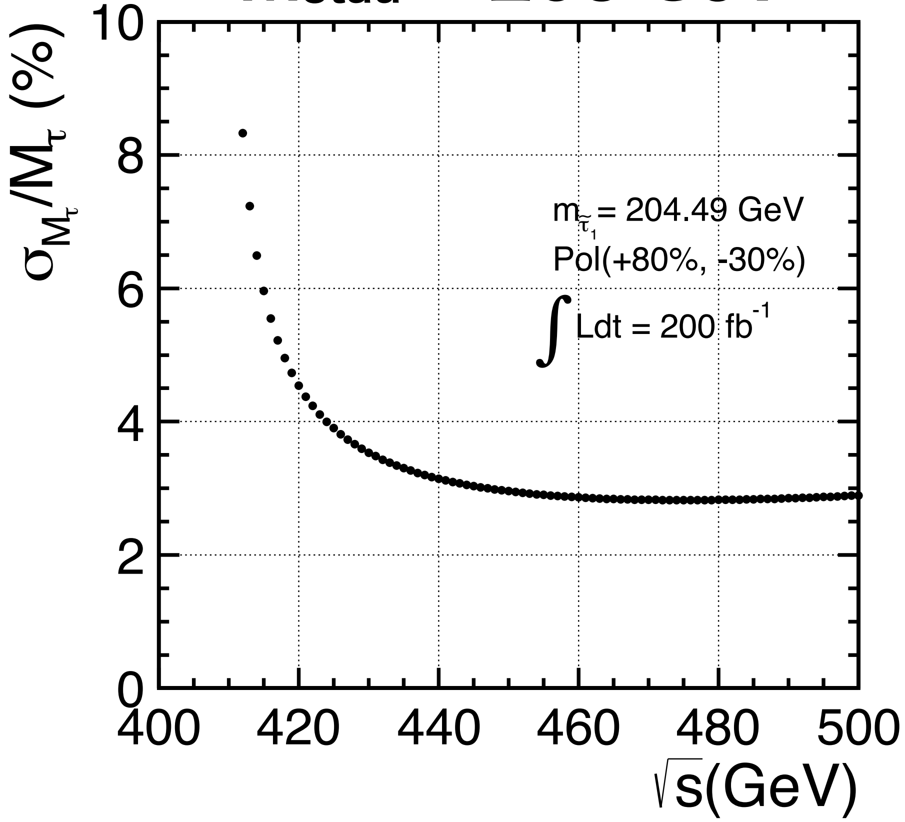
Wataru's result

Mstau = 150 GeV

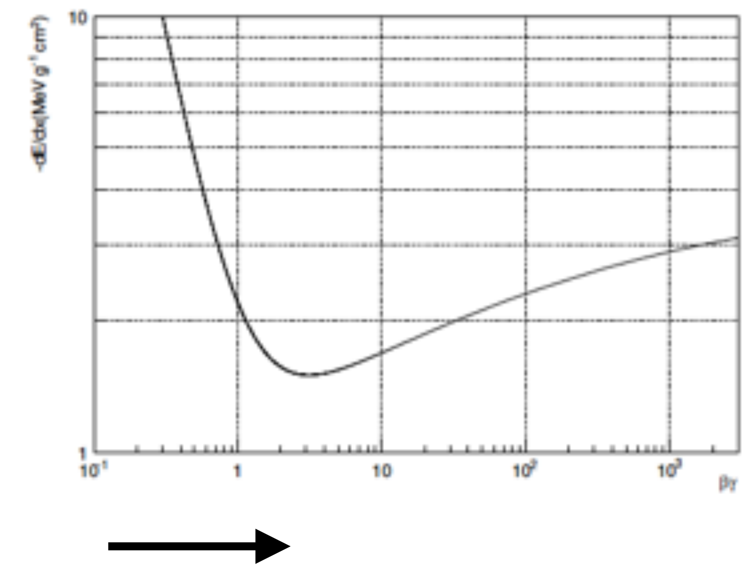



ΔMstau/Mstau = 1.5%

Mstau = 205 GeV




ΔMstau/Mstau = 2.8%



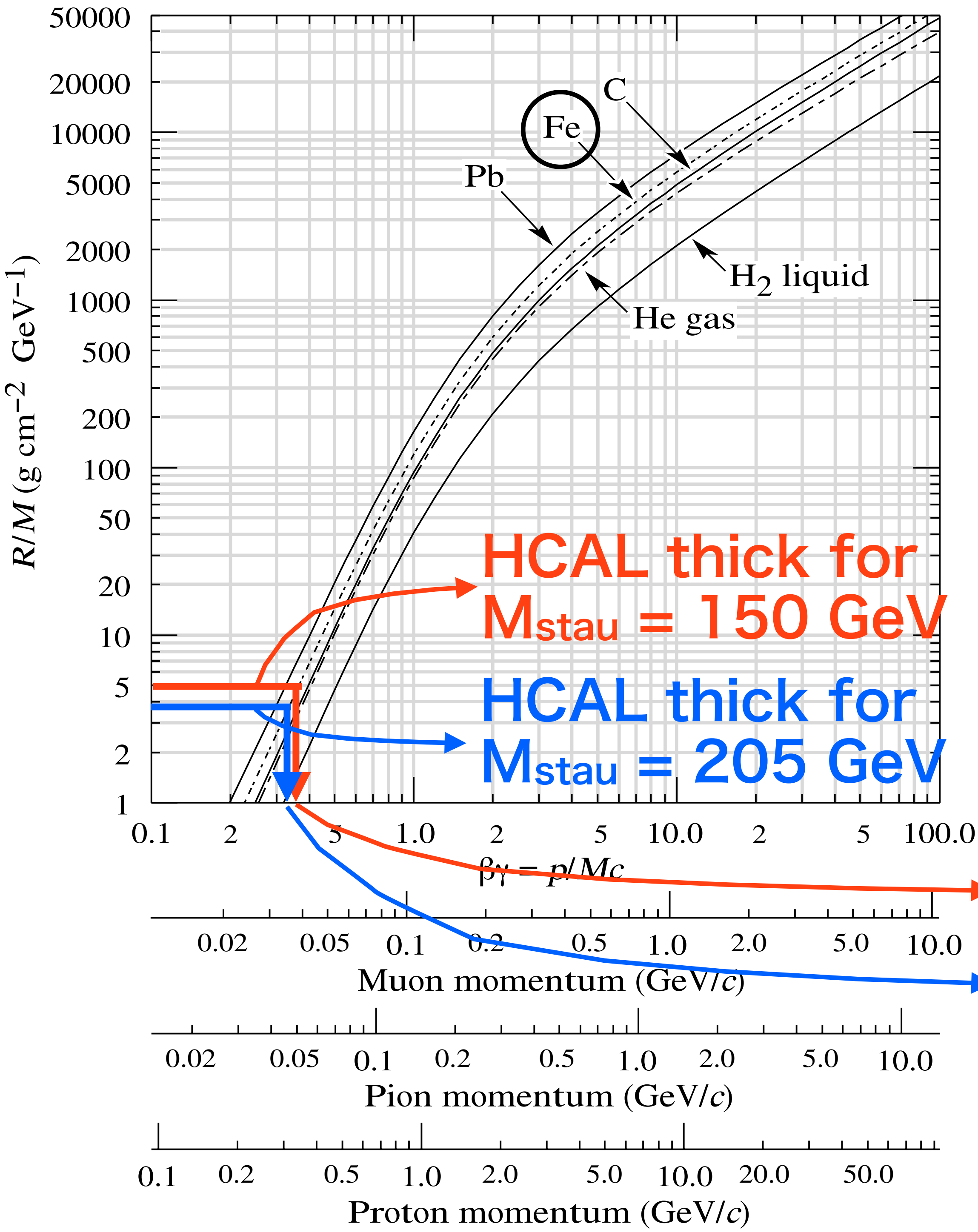
Δβ/(ΔdE/dx) ↗

0.5% Δ(dE/dx) is assumed.

Results come from compensation between increasing cross-section (N) and degrading β as the function of dE/dx.

# Life time of $\tilde{\tau}$

**Wataru's result**




$\Delta$Life/Life = $1/\sqrt{N}$

Tune $\sqrt{s}$

Momentum to stop Staus in HCAL

$M_{stau}$ = 150 GeV

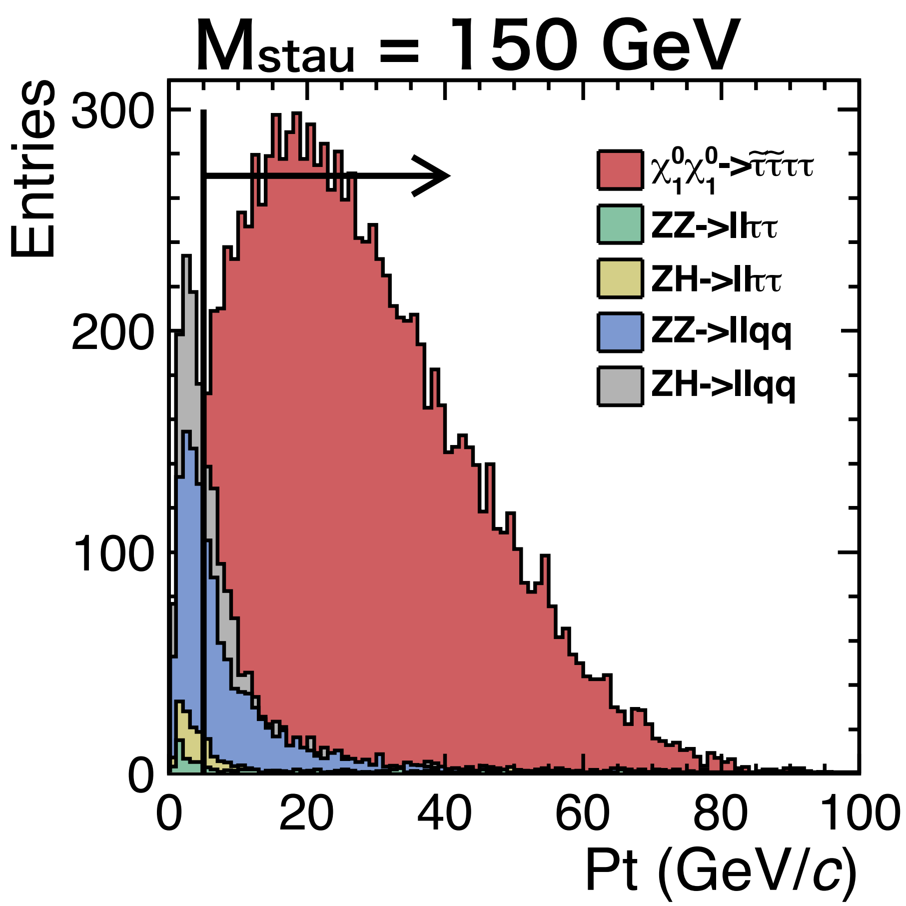
$\Delta$Life/Life = 1.9±0.1% @ $\sqrt{s}$ = 317 GeV

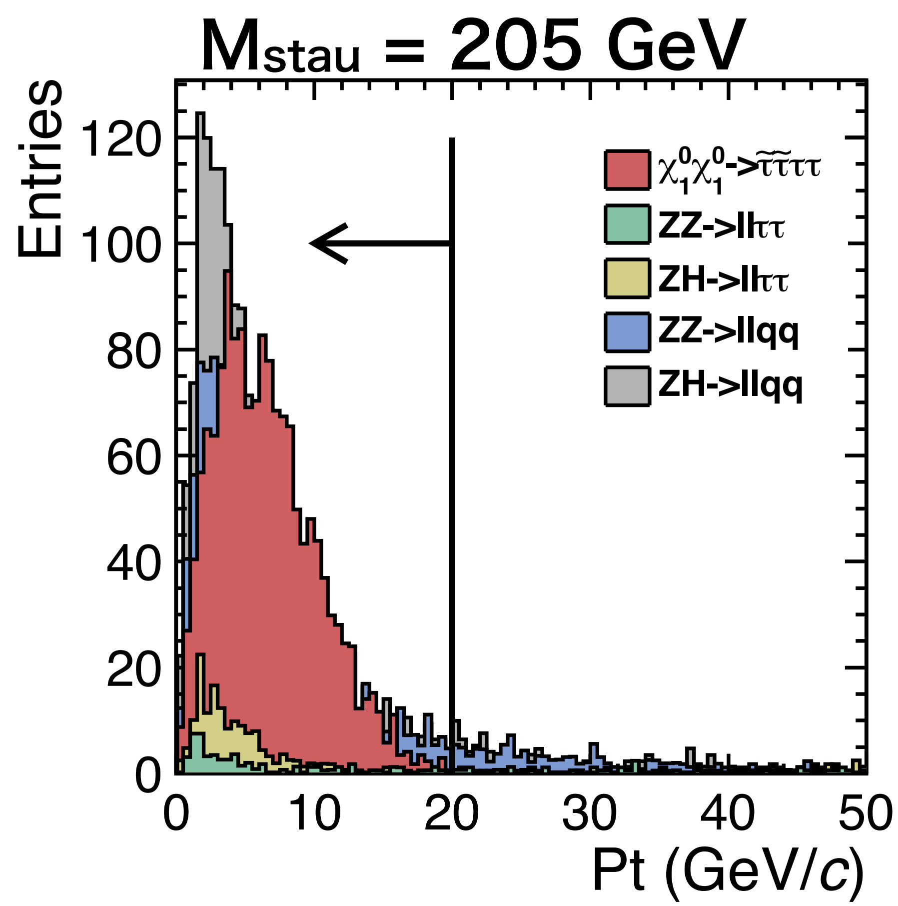
$M_{stau}$ = 205 GeV

$\Delta$Life/Life = 2.8±0.1% @ $\sqrt{s}$ = 431 GeV

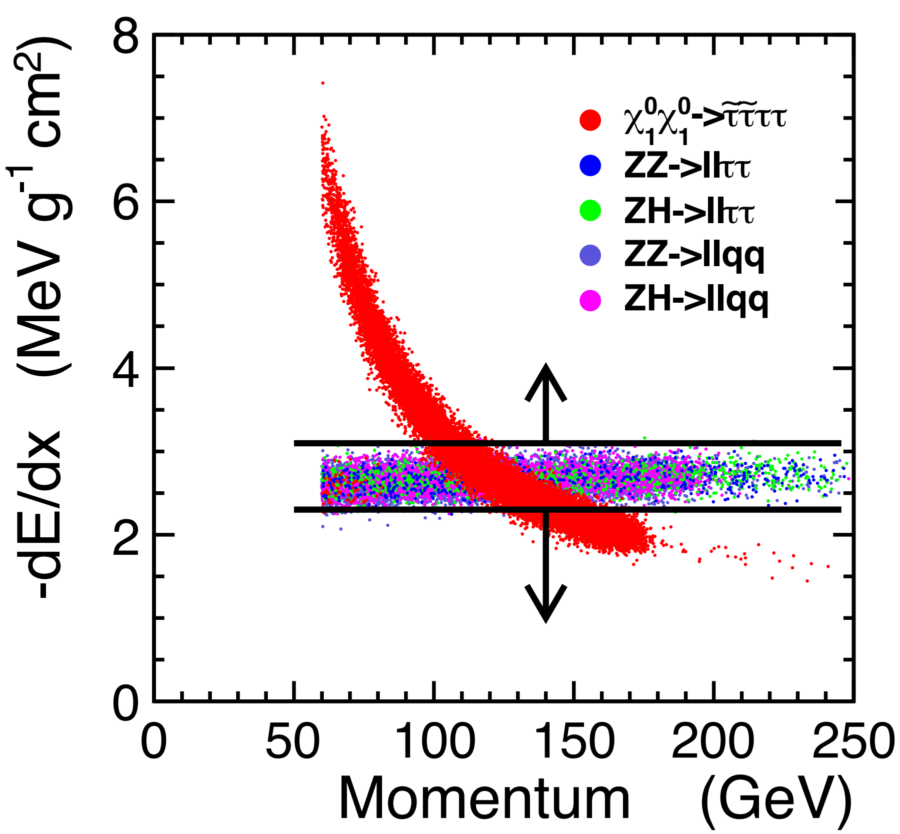
# staus from $\chi^0_1 \rightarrow$ meas. $M_{\chi 0}$

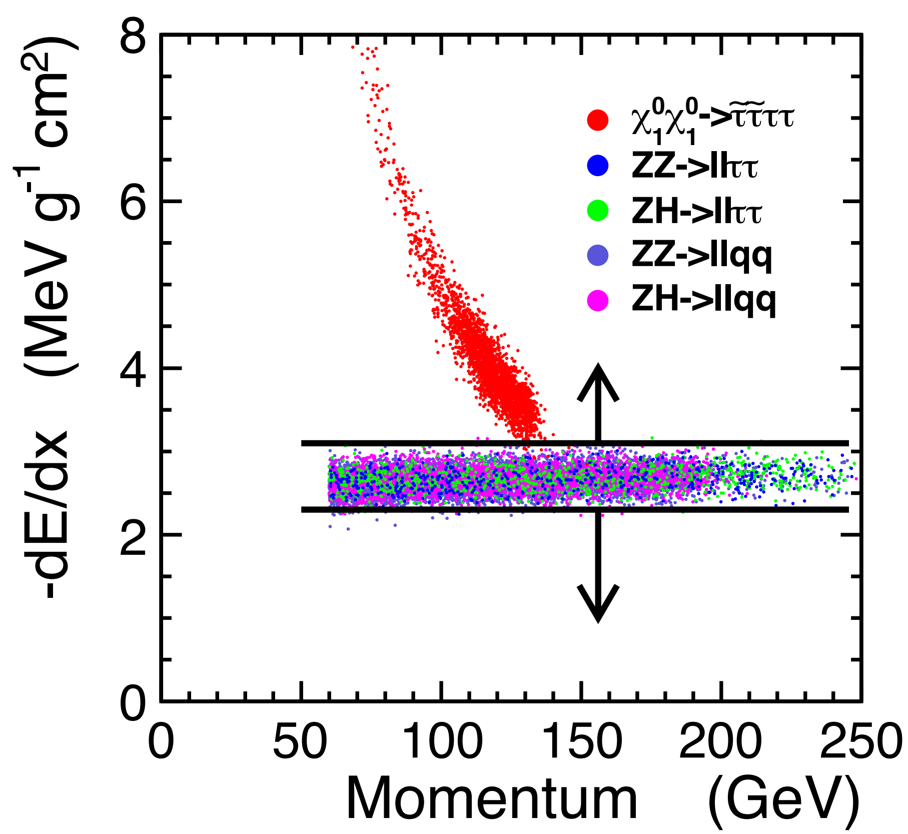
**Wataru's result**




Event selection by Pt




Event selection by dE/dx

# Effect of the selection criteria

$M_{stau}$ = 150 GeV

| | signal | $ZZ \to l^+l^-\tau^+\tau^-$ | $ZZ \to l^+l^-q\bar{q}$ | $ZH \to l^+l^-\tau^+\tau^-$ | $ZH \to l^+l^-q\bar{q}$ |
|---|---|---|---|---|---|
| all | 13460 | 470 | 2175 | 749 | 4836 |
| # of tracks = 2 | 13457 | 466 | 2153 | 732 | 4821 |
| # of jets = 2 | 13364 | 451 | 2086 | 720 | 4785 |
| $P_t > 5$ GeV | 12689 | 321 | 1218 | 364 | 2314 |
| $\lvert dE/dx\rvert^*$ | 4760 | 1 | 5 | 1 | 4 |
| efficiency(%) | 35.3 | 0.2 | 0.2 | 0.1 | 0.1 |

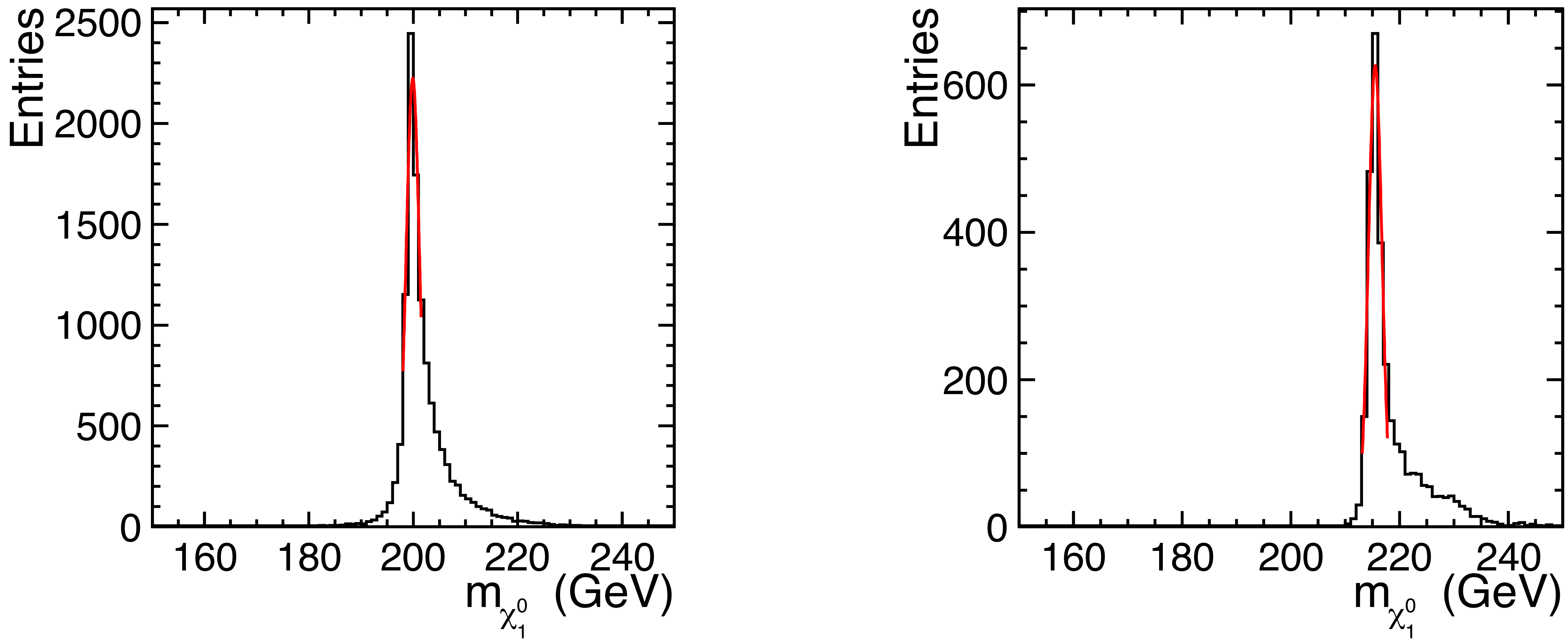
$M_{stau}$ = 205 GeV

| | signal | $ZZ \to l^+l^-\tau^+\tau^-$ | $ZZ \to l^+l^-q\bar{q}$ | $ZH \to l^+l^-\tau^+\tau^-$ | $ZH \to l^+l^-q\bar{q}$ |
|---|---|---|---|---|---|
| all | 2625 | 470 | 2175 | 749 | 4836 |
| # of tracks = 2 | 2601 | 466 | 2153 | 732 | 4821 |
| # of jets = 2 | 2576 | 451 | 2086 | 720 | 4785 |
| $P_t < 20$ GeV | 2555 | 421 | 1918 | 664 | 4514 |
| $\lvert dE/dx\rvert^*$ | 2538 | 1 | 3 | 1 | 4 |
| efficiency(%) | 96.7 | 0.2 | 0.2 | 0.1 | 0.1 |

# Wataru's result(angular dist.)

$$m_{\chi_1^0} = \sqrt{(E_{\tilde{\tau}_1} + E_\tau)^2 - |\mathbf{P}_{\tilde{\tau}_1} + \mathbf{P}_\tau|^2}$$

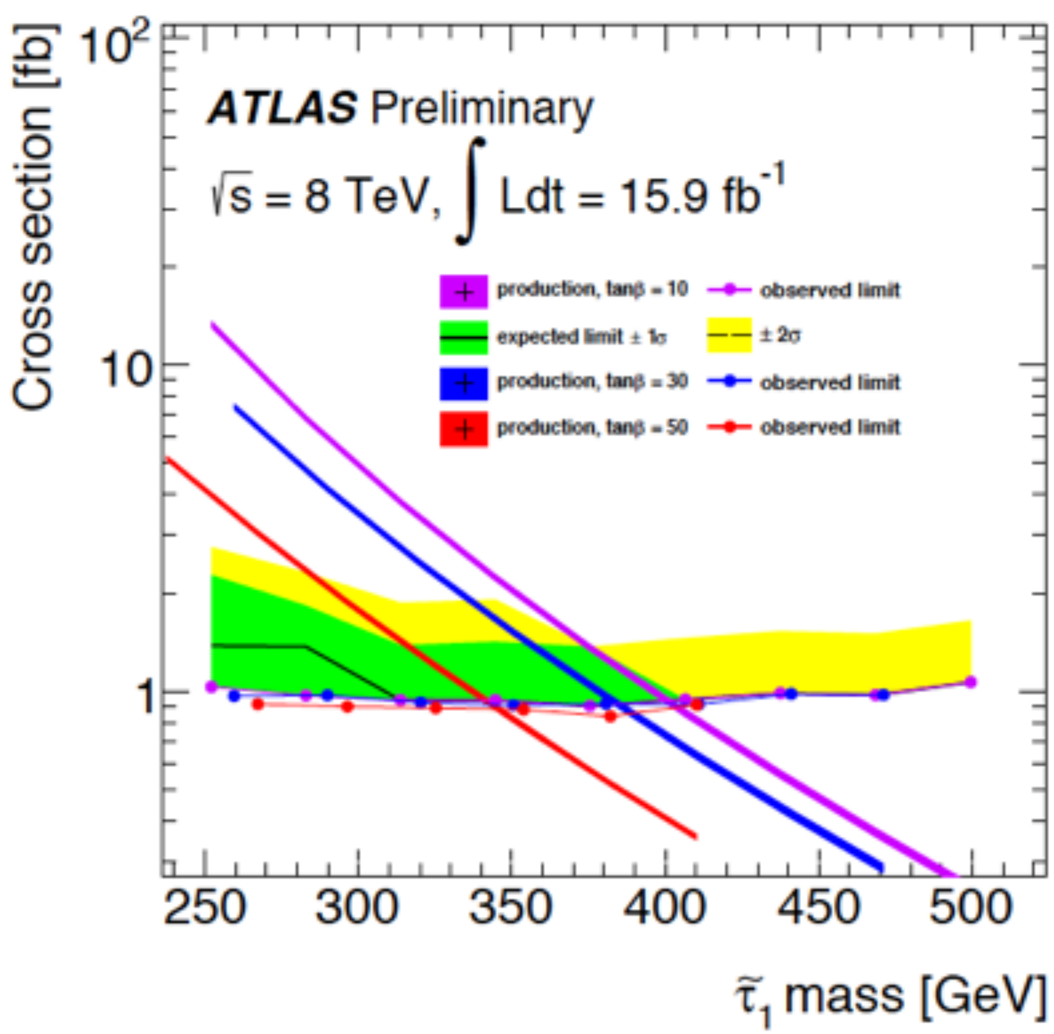
$$E_\tau = \frac{\sqrt{s}}{2} - E_{\tilde{\tau}_1},$$
$$|\mathbf{P}_\tau| = \sqrt{E_\tau^2 - m_\tau^2},$$

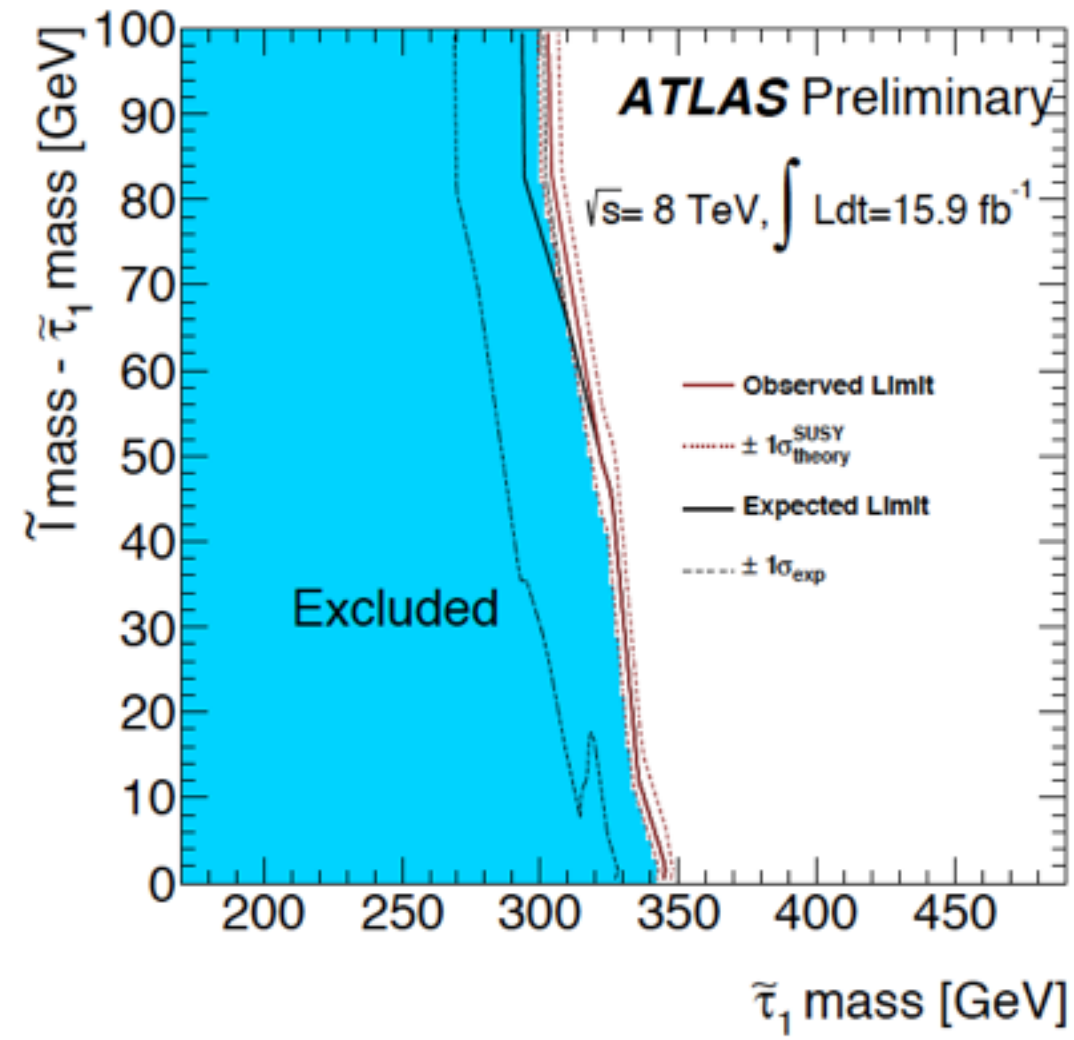



**$\Delta M_{\chi 0}/M_{\chi 0}$ = 0.6%**

# Update

# Exclusion by ATLAS




August 2013 using 16 fb$^{-1}$ 95% CL

GMSB scenario

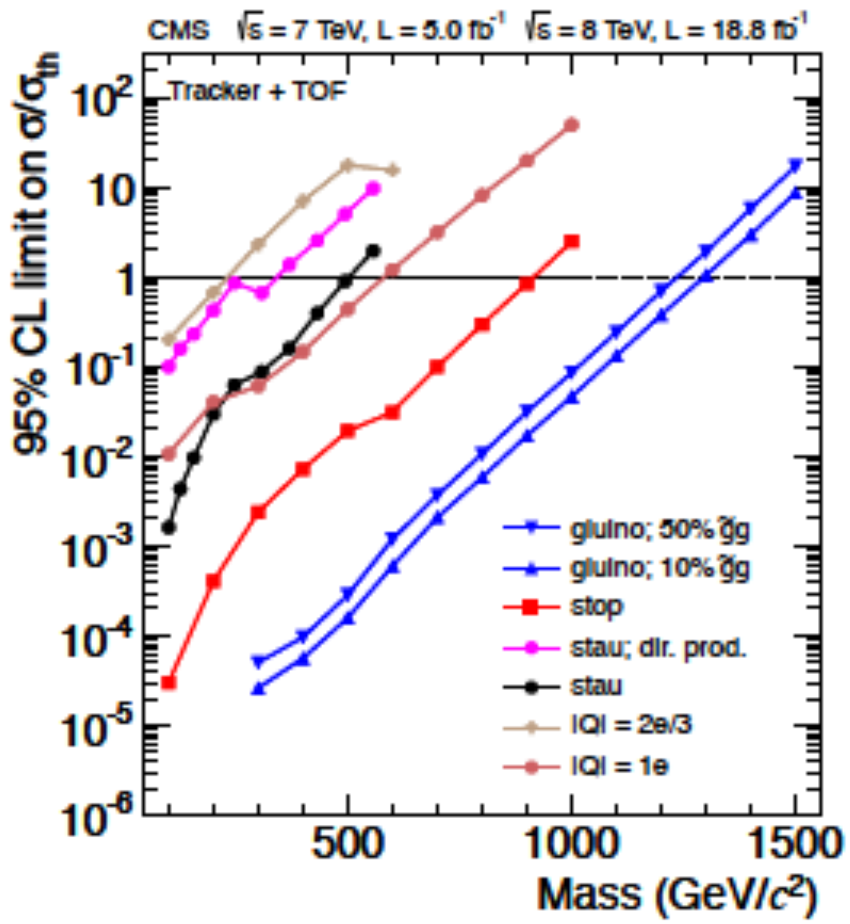
391(5), 402(10), 392(20), 382(30), 366(40),347(50) GeV (tan$\beta$)

Directly produced sleptons

Considering squarks and gluinos suppressed due to their large masses

Excluded $M_{stau}$ 300 - 345 GeV

# Exclusion by CMS




30th July 2013 using
5.0 $fb^{-1}$ ( 7 TeV)
18.8 $fb^{-1}$ ( 8 TeV)

Direct + indirect

Excluded $M_{stau}$ < 500 GeV

Directly produced sleptons

Excluded $M_{stau}$ < 339 GeV

# Status

Keita Kasama has reanalyzed long lived stau at ILD

- Gage Mediated SUSY Braking
- $M_{stau}$ = 350 GeV (scenario 1), 500 GeV (scenario 2)
- $M_{\chi 0}$ = 599 GeV (scenario 1), 888 GeV (scenario 2),

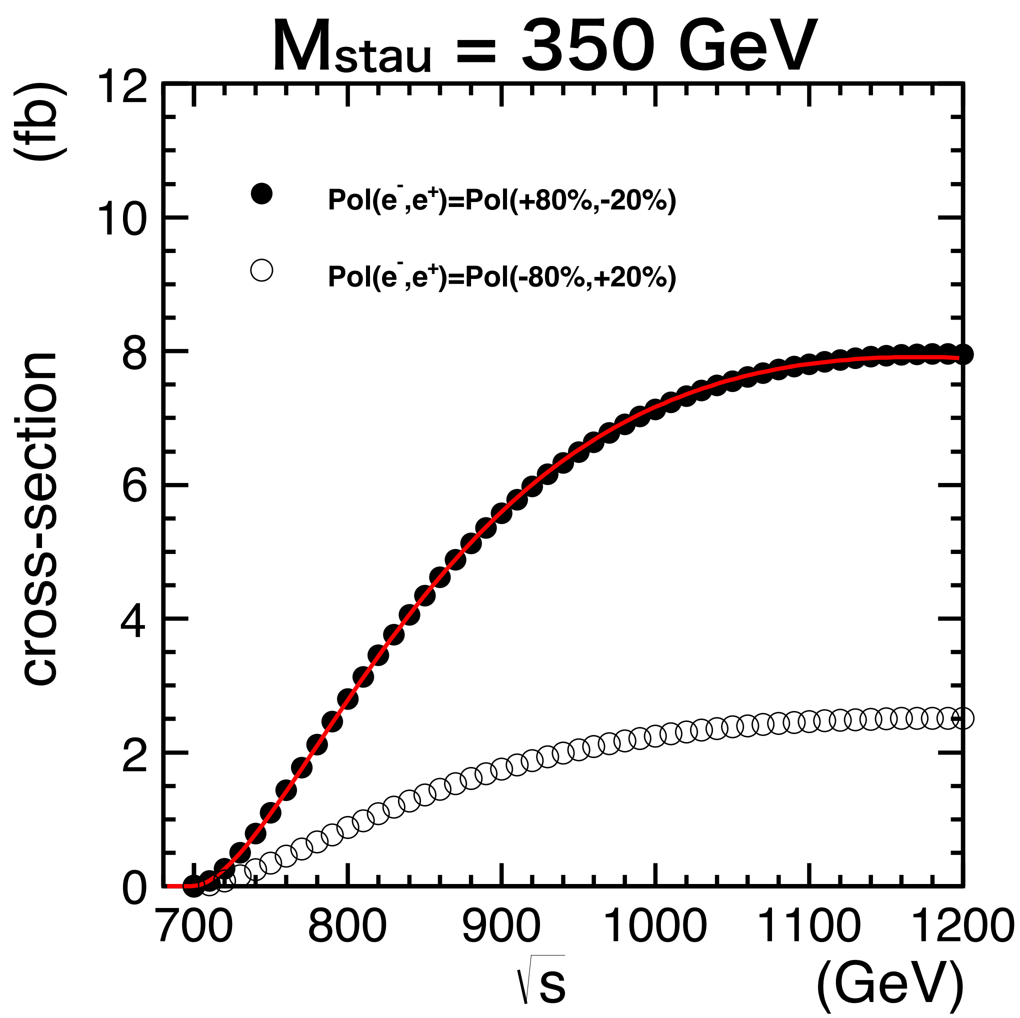
$$m_{\tilde{\tau}_1} < m_{\tilde{e}_R}, m_{\tilde{\mu}_R} < m_{\chi_1^0},$$

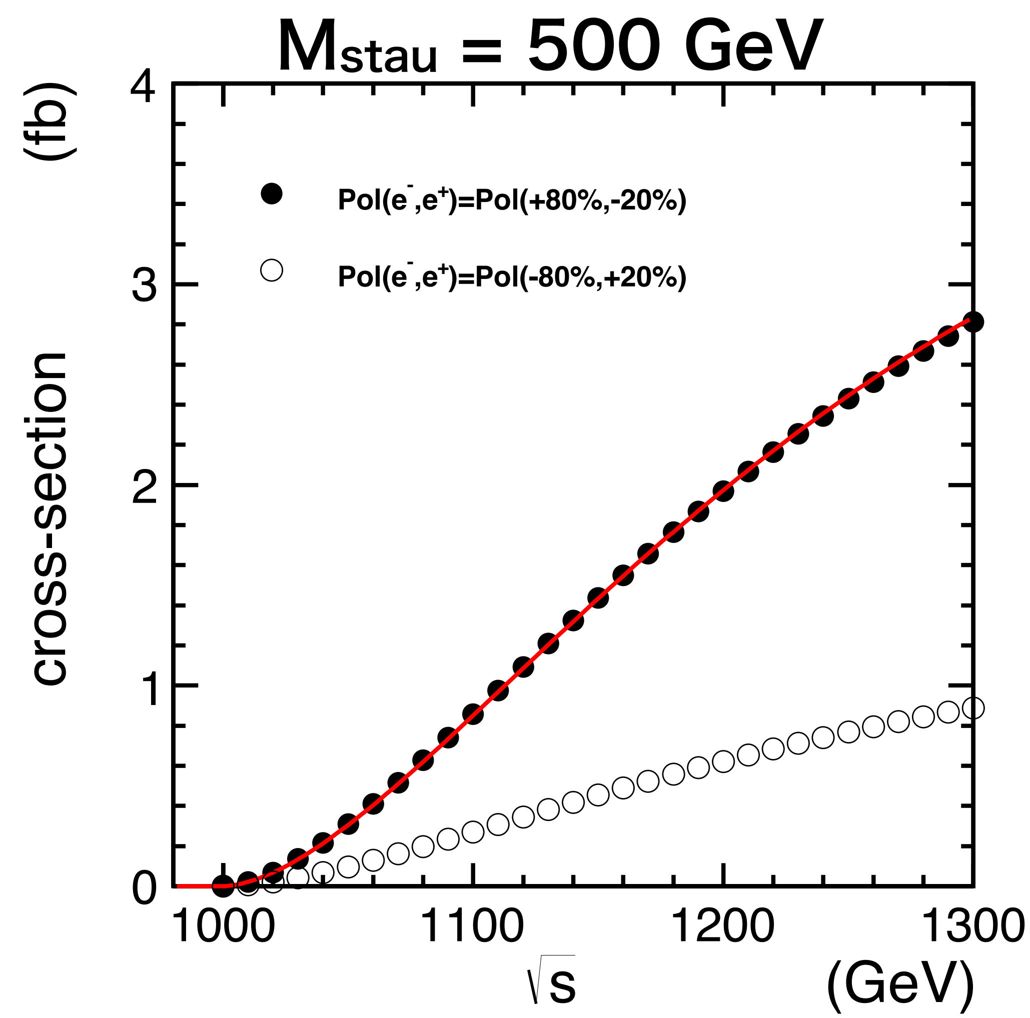
1. $e^+e^- \rightarrow \tilde{\tau}_1^+\tilde{\tau}_1^-$ — easily distinguished
2. $e^+e^- \rightarrow \tilde{l}_R^+\tilde{l}_R^- \rightarrow l^+\tilde{\tau}_1^+\tau^- l^-\tilde{\tau}_1^-\tau^+$ — too heavy at 1 TeV ILC
3. ~~$e^+e^- \rightarrow \chi_1^0\chi_1^0 \rightarrow \tilde{\tau}_1^+\tau^-\tilde{\tau}_1^-\tau^+$~~ — we give up $M_{\chi 0}$ meas.
4. $e^+e^- \rightarrow \chi_1^0\chi_1^0 \rightarrow \tilde{l}_R^+ l^- \tilde{l}_R^- l^+ \rightarrow l^+\tilde{\tau}_1^+\tau^- l^- l^-\tilde{\tau}_1^-\tau^+ l^+$

Spectra are calculated by using ISAJET 7.82.

# Energy scan of the cross section

## Keita's result



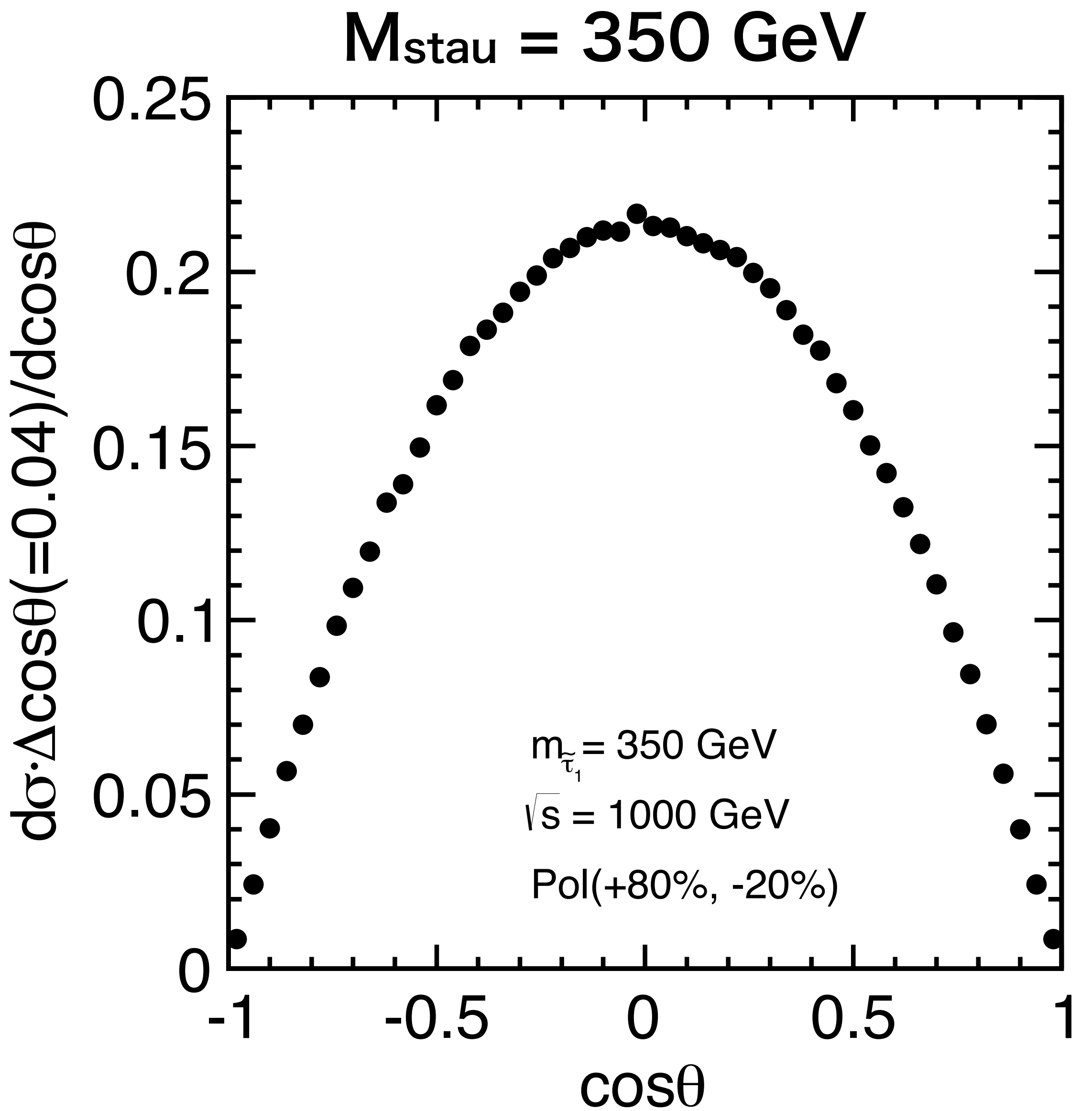




$\propto$ cube of $\sqrt{s}$

$$\frac{\sigma(\mathrm{Pol}(-80\%,+20\%))}{\sigma(\mathrm{Pol}(+80\%,-20\%))} = \frac{1}{3.2}, \qquad \left(\frac{\sigma(\mathrm{Pol}(-80\%,+30\%))}{\sigma(\mathrm{Pol}(+80\%,-30\%))} = \frac{1}{4},\right)$$

# Angular distribution of ee → $\tilde{\tau}\,\tilde{\tau}$

**Keita's result**

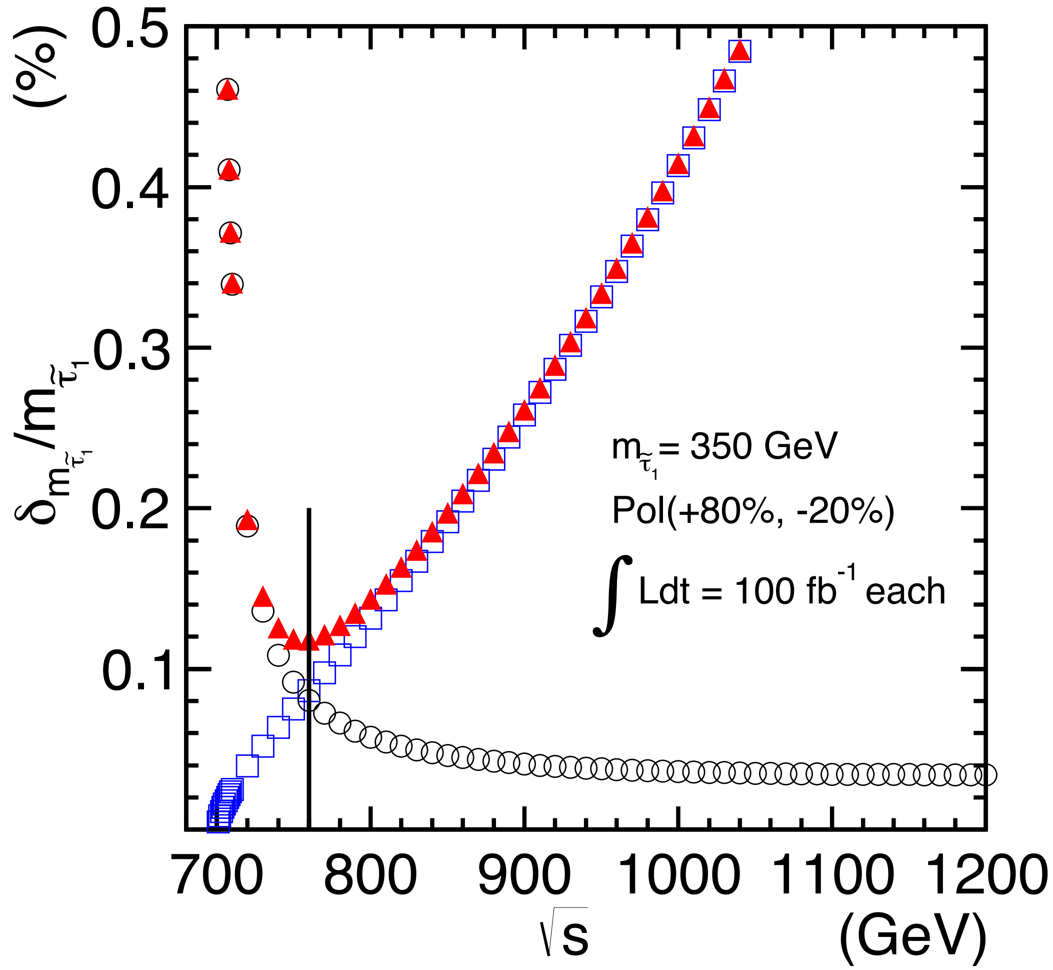



(spin = 1) x 1 → (spin = 0) x 2

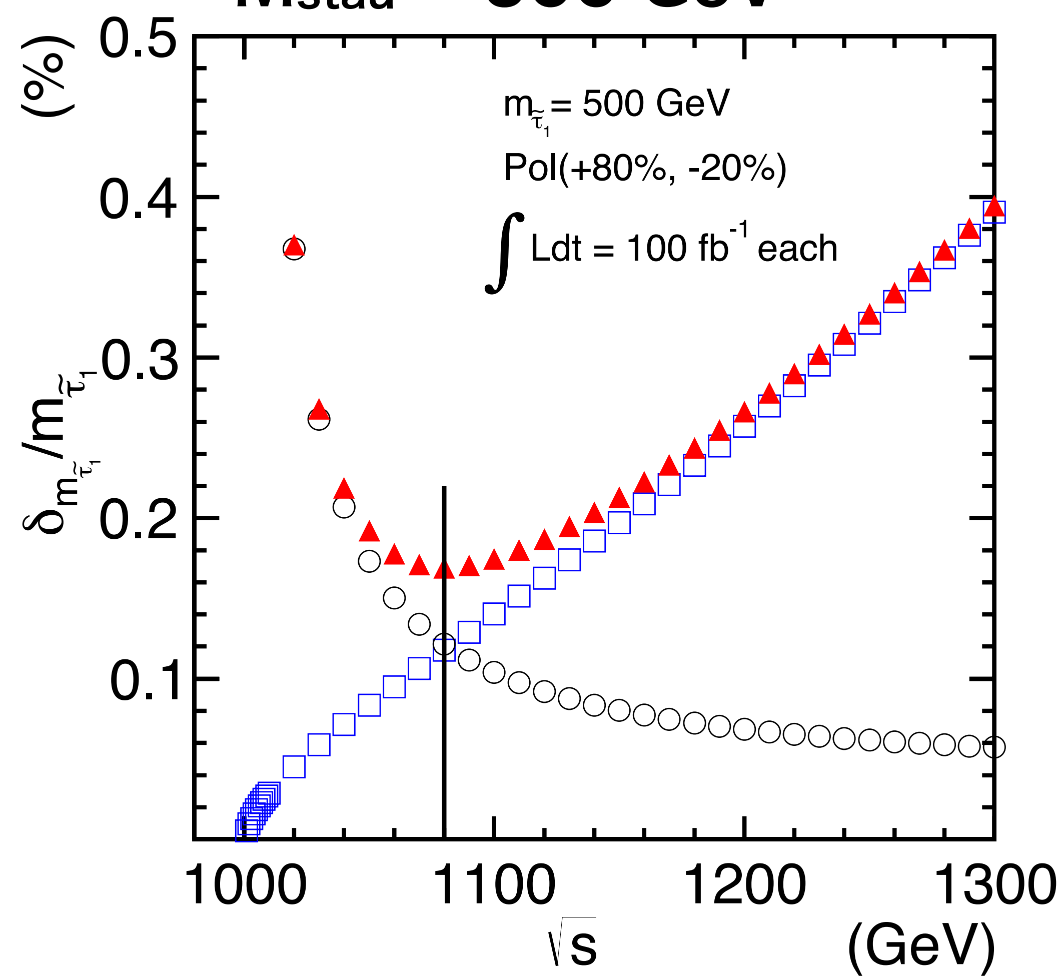
# Uncertainty of M$\tilde{\tau}$ measured by TOF to ECAL

Keita's result

Mstau = 350 GeV




Mstau = 500 GeV




□ :from TOF, ○ :from N of events, ▲ :total

ΔMstau/Mstau = 0.11%

ΔMstau/Mstau = 0.17%

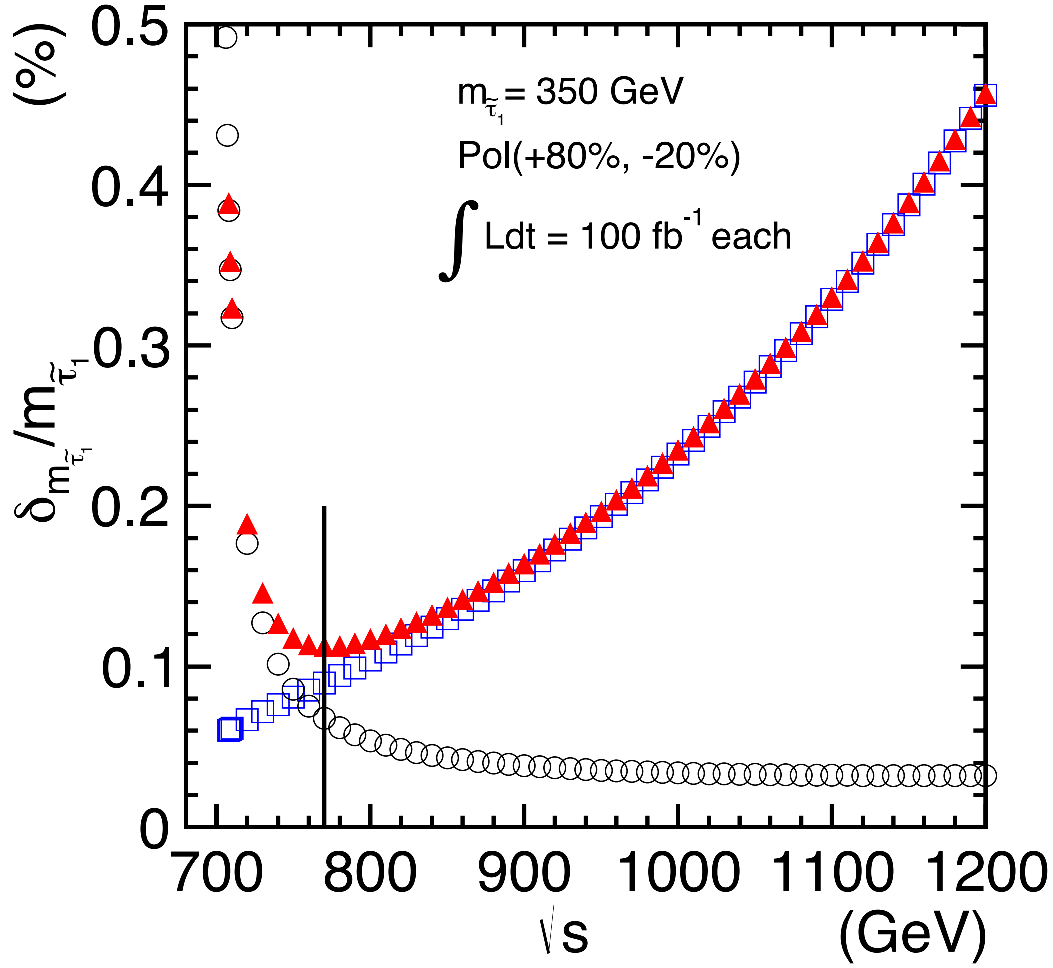
1 ns ScECAL timing resolution is assumed

Although 1000 fb$^{-1}$ is planed at 1 TeV, we assume 100 fb$^{-1}$ for those special runs

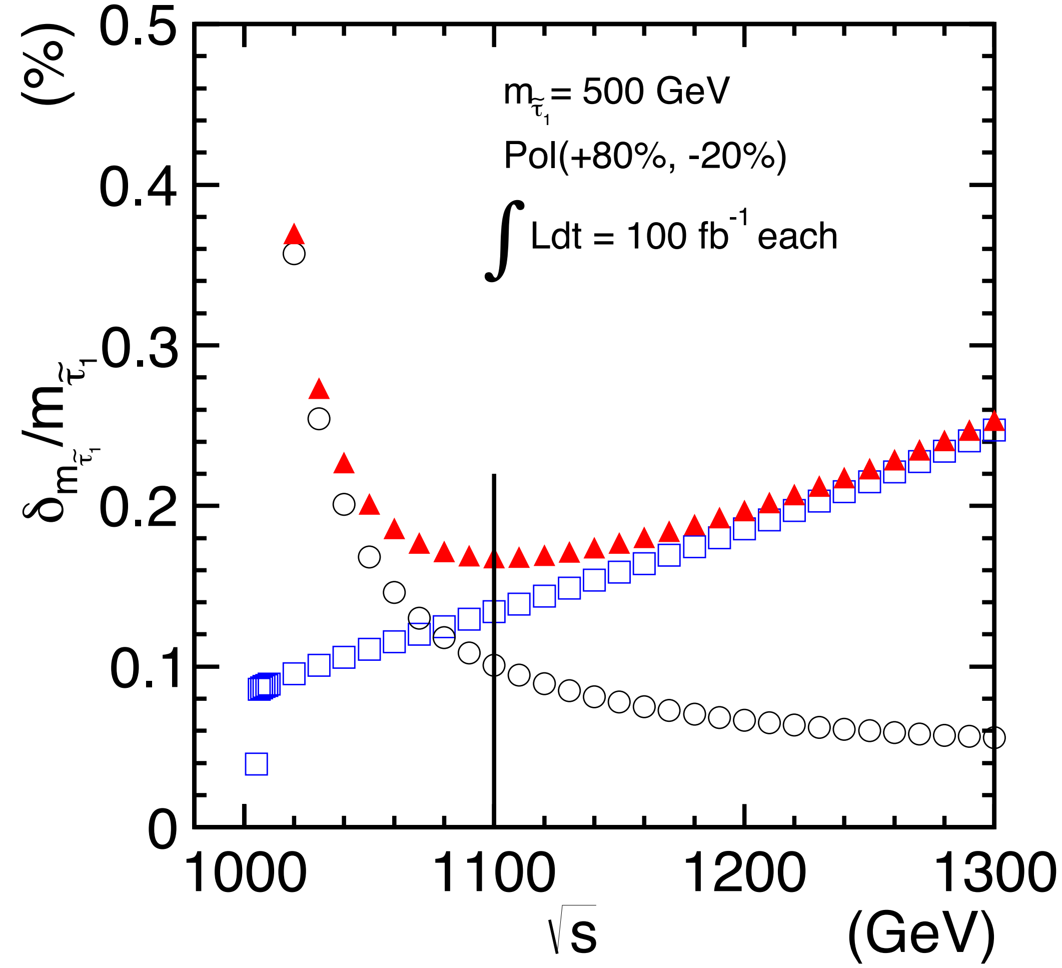
# Uncertainty of M$\tilde{\tau}$ measured by energy loss in TPC (dE/dx)

Keita's result

Mstau = 350 GeV




Mstau = 500 GeV




□ :from dE/dx, ○ :from N of events, ▲ :total

ΔMstau/Mstau = 0.11%

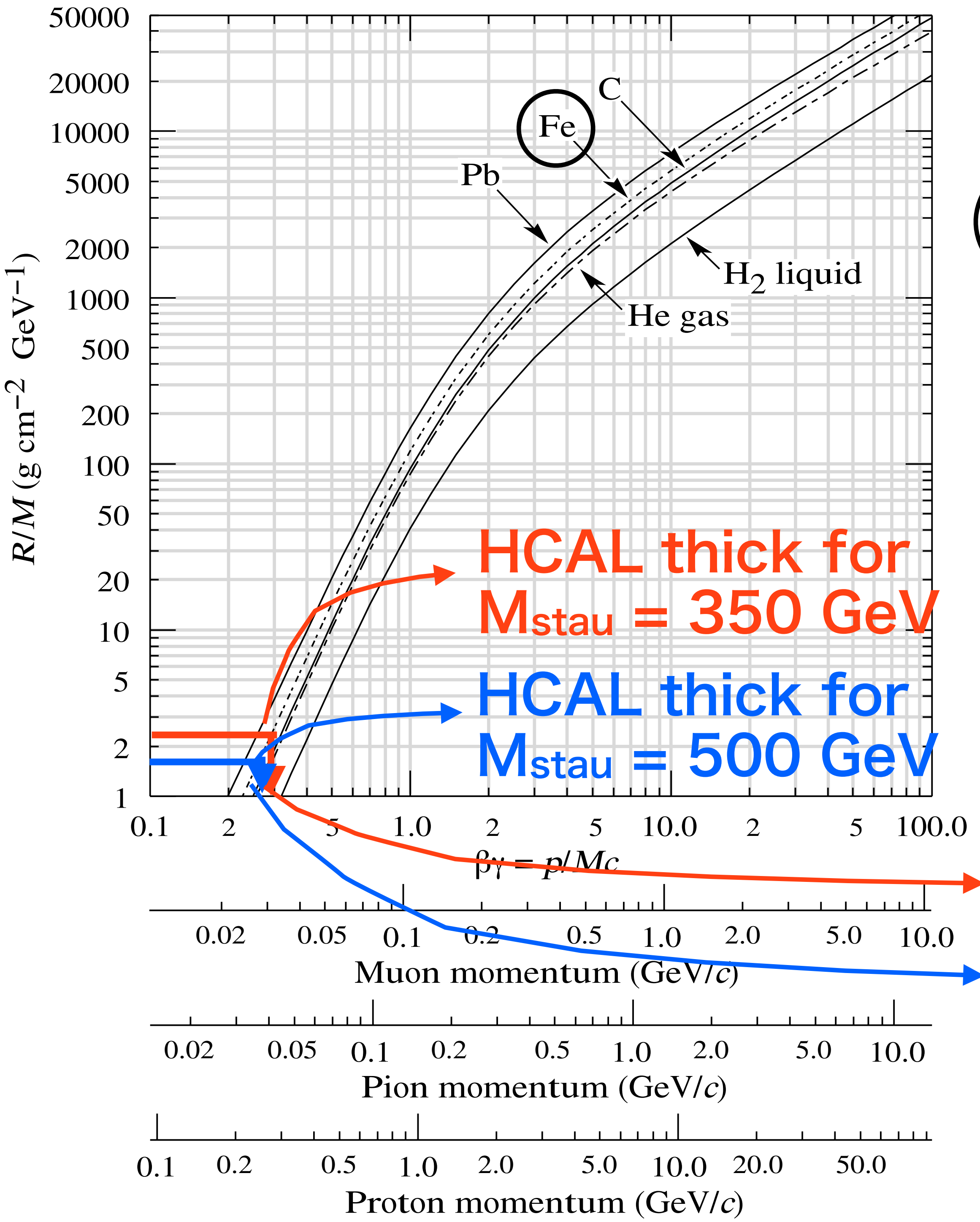
ΔMstau/Mstau = 0.17%

0.5% Δ(dE/dx) is assumed.

Although 1000 fb$^{-1}$ is planed at 1 TeV, we assume 100 fb$^{-1}$ for those special runs

# Life time of $\tilde{\tau}$

Keita's result




ΔLife/Life = 1/√N

Tune √s

Momentum to stop Staus in HCAL

Req 100 fb$^{-1}$

$M_{stau}$ = 350 GeV

ΔLife/Life = 15±2% @ √s = 727 GeV

$M_{stau}$ = 500 GeV

ΔLife/Life = 27±7% @ √s = 1031 GeV

# Summary

Analysis of the long lived stau was updated due to the exclusion of Mass limit by LHC.

Two scenario, $M_{stau}$ = 350 GeV and 500 GeV are studied.

ΔMstau/Mstau =
0.11%, and 0.17% for $M_{stau}$ = 350 GeV and 500 GeV, respectively
with both TOF technique and dE/dx technique.

ΔLife/Life =
15±2% and 27±7% for $M_{stau}$ = 350 GeV and 500 GeV, respectively