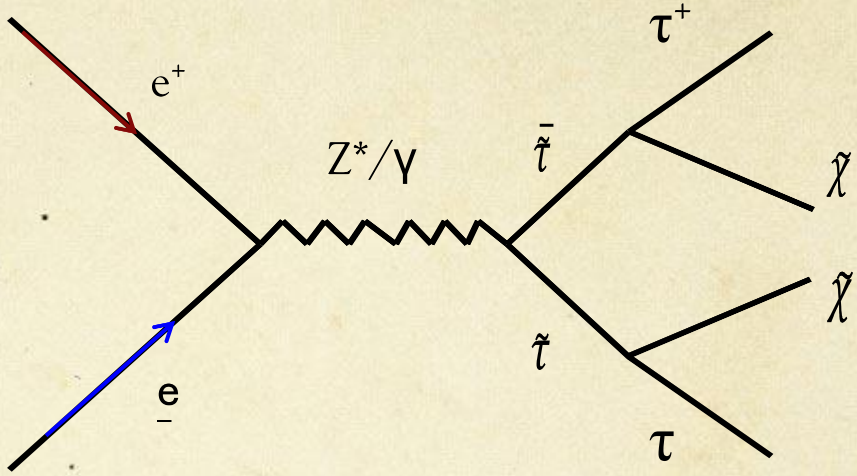


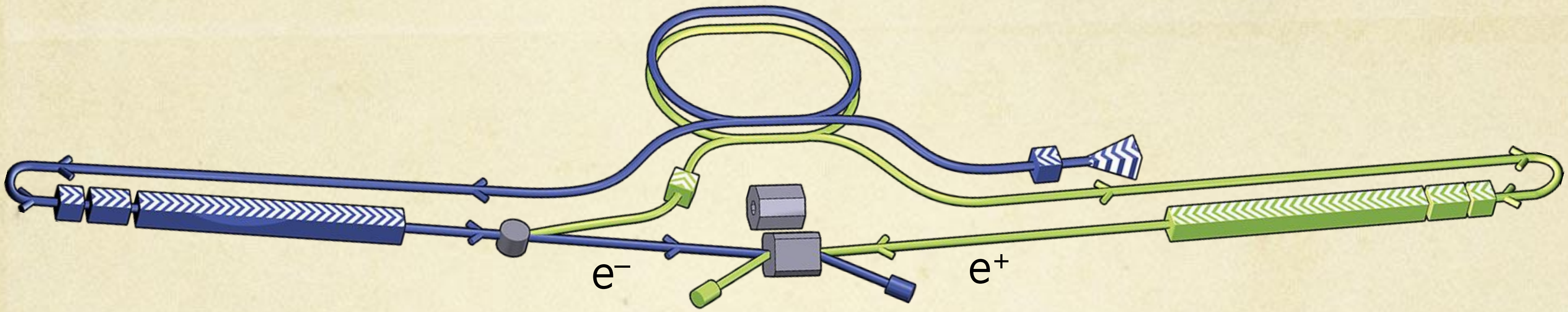
Stau Pair Production At The ILC

Tohoku University – Senior Presentation
Tran Vuong Tung

Outline

- Introduction of the International Linear Collider (ILC)
- Introduction of $(g_\mu - 2)$ in the MSSM
- Motivation
- Stau and Neutralino Reconstruction
- Results
- Summary
- Future Plans

International Linear Collider (ILC)

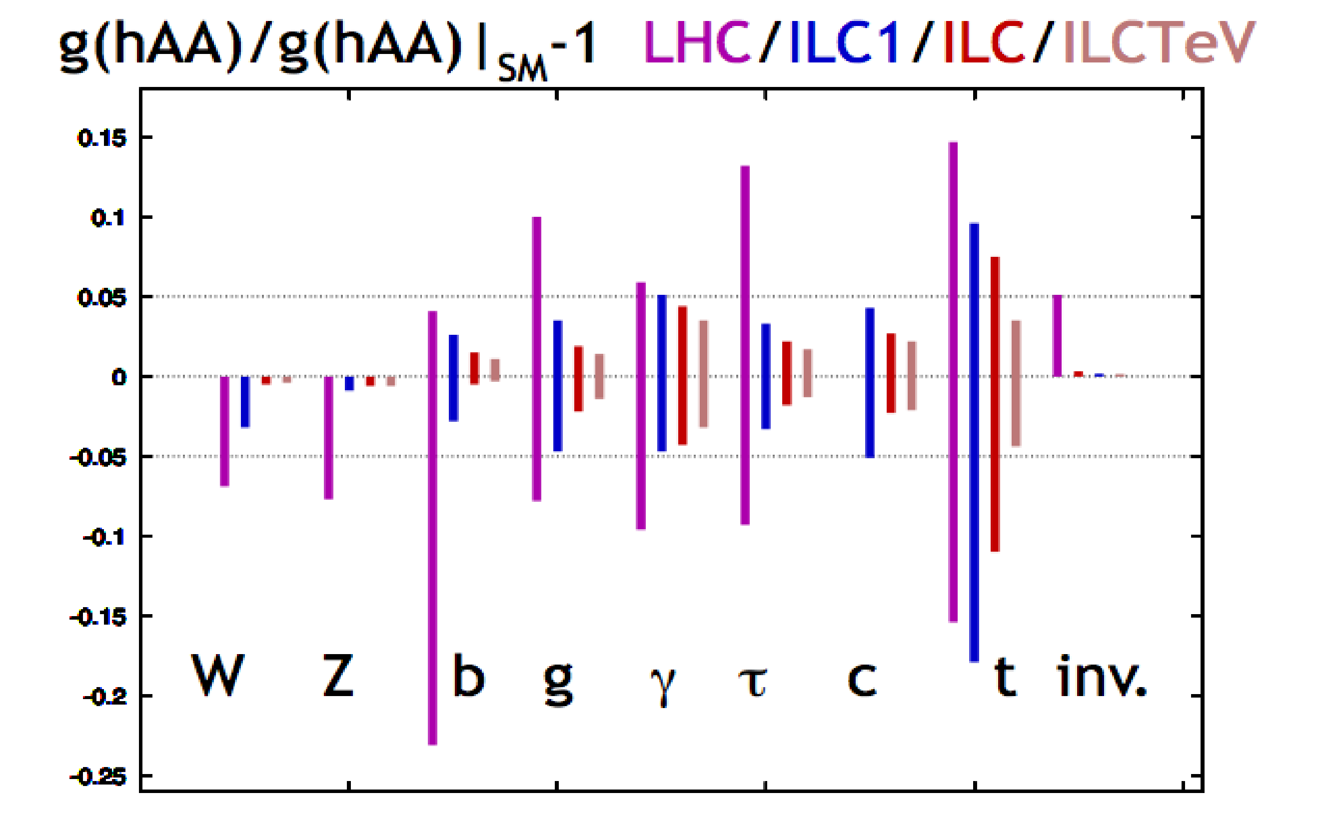


High Energy e^+ e^- Linear Collider:

- Clean background (less synchrotron radiation)
- Able to polarize electron and positron. ($P(e^-,e^+)=(0.8,-0.3)$)
- Measure the mass, spin and interaction strength of the Higgs boson.
- Able to search for extra dimension and SUSY if exist.
- Search for Neutralino (possible candidate for cold dark matter)

How good will the ILC be?

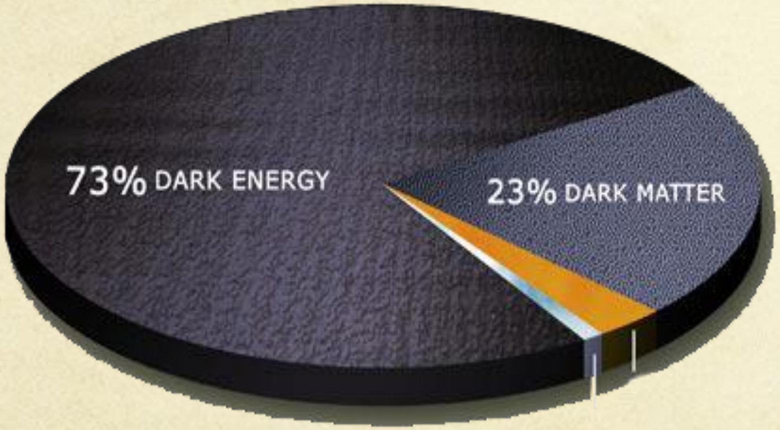
$$\frac{g(hAA)}{g(hAA)|_{SM}} - 1$$



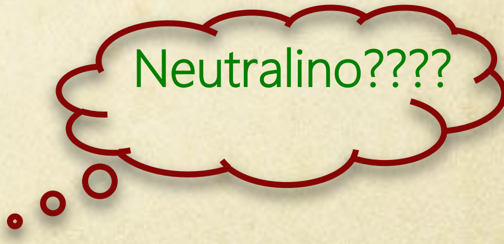
[Ref]: arXiv:1207.2516v3 [hep-ph] – M.Peskin

New Physics Beyond The Standard Model

- Incomplete of the Standard Model:
  - The hierarchy problem
  - Gravity
  - Matter/antimatter asymmetry.
  - Dark Matter (weakly interacting massive particle – WIMP)



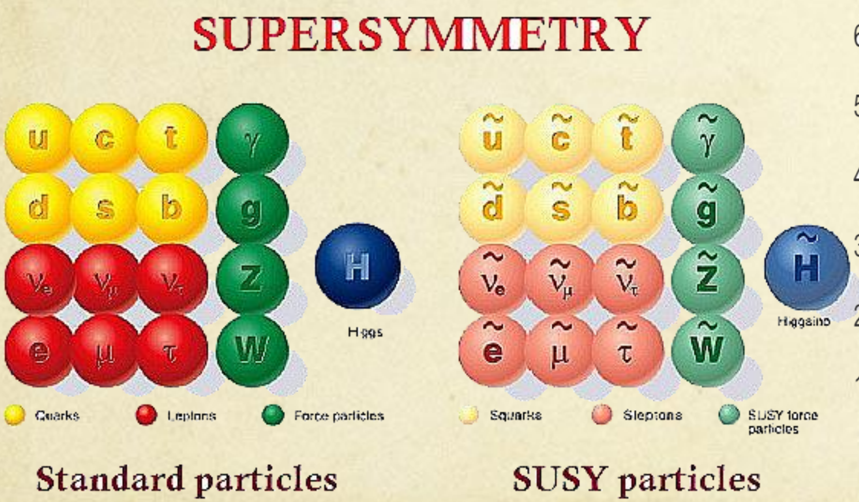
27% Matter = 4% baryonic + 23% non-baryonic

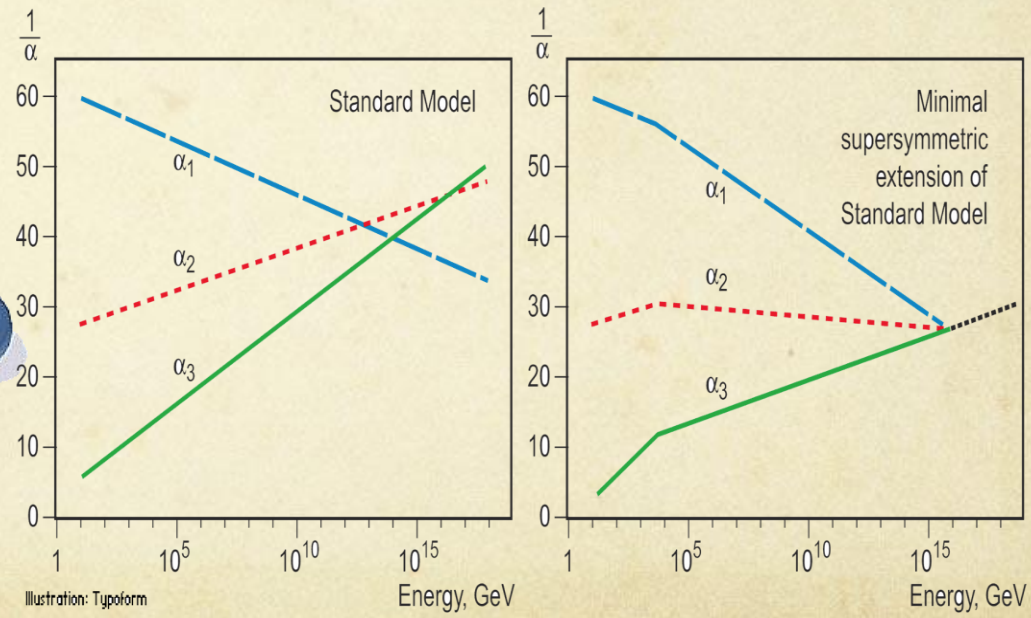


At the ILC: MSSM, SUGRA, Extra Dimensions could be test.

SUSY

- At TeV scale,
    - SUSY is the resolution of the hierarchy problem in the SM.
    - The unification of couplings (MSSM)
    - The possible candidate for dark matter
    - Low-energy SUSY is strongly suggested by string theory





$(g_\mu - 2)$ in the MSSM

- The anomalous magnetic moment in $(g_\mu\text{-}2)$: $a_\mu \equiv (g_\mu - 2)/2$

$g_\mu = 2$ (tree)
$g_\mu \neq 2$ (RC)

$$\Delta a_\mu = a_\mu(\exp) - a_\mu(SM) = (26.1 \pm 8.0) \times 10^{-10}$$

⇒ The muon g−2 anomaly indicates physics BSM at more than 3σ

[Ref]. " Muon g−2 vs LHC in SUSY Models" – M. Endo, K. Hamaguchi

- In MSSM, it is very difficult to get a Higgs boson mass as large as 115 GeV
  ⇒ The correlation between the Higgs mass and $g_\mu-2$ is significant.
- MSSM contribution to the $g_\mu-2$ are enhanced by $\tan\beta = \langle H_u\rangle/\langle H_d\rangle = O(10)$
- Non color super-partners (slepton, neutralinos and charginos) are light due to the $g_\mu-2$ discrepancy.

$M_{SUSY} = O(100\text{ GeV})$ for $\tan\beta = O(10)$

Motivation for Stau pair production

- R-parity: $R = (-1)^{3B+L+2S}$
  - The super-partners have $R = -1$
  - The SM particles have $R = +1$
  - There is no interaction coupling a single super-partner with two SM particles

B: Baryon number
L: Lepton number
S: Spin

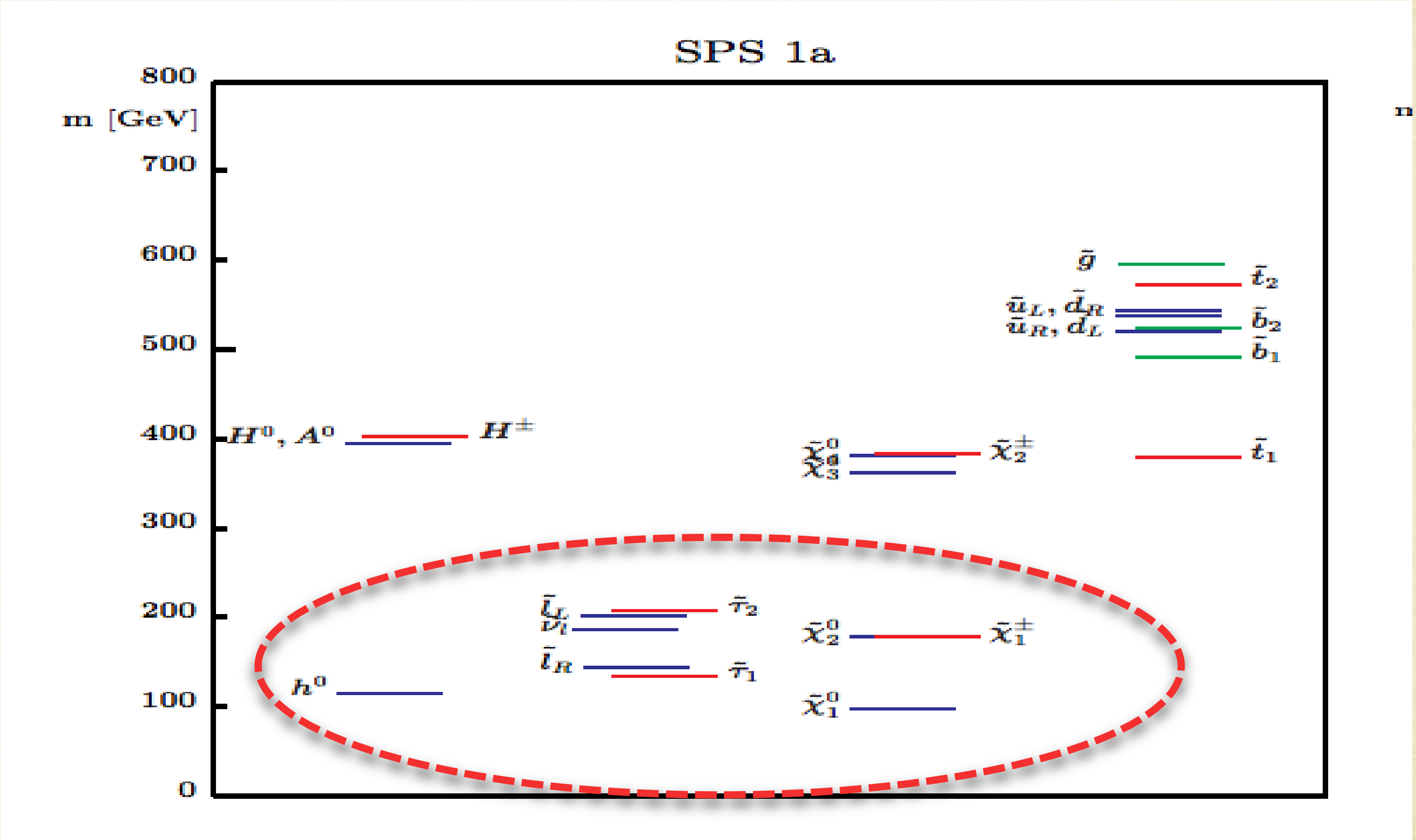
→ SUSY particles can only be created into pair or even numbers

The lightest SUSY particle (LSP) is absolutely stable O(100 GeV～1 TeV), interact weakly (WIMP).

The next lightest SUSY particle (NLSP) is believed that is Stau

These two masses could be reached in ILC's range! ($\sqrt{s}$=250, 350, 500 GeV)

Benchmarks for SUSY searches

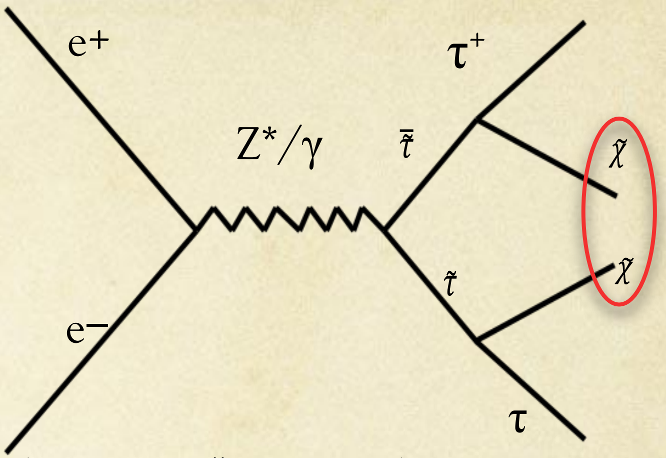


[Ref]: "The Snowmass Points and Slopes: Benchmarks for SUSY Searchs" – arVix: hep-ph/0202233v1

Method

(Using Physsim and Whizard to create the cross-section for Stau)

In collider experiment LSP will carry away P^{μ} while escaping detector

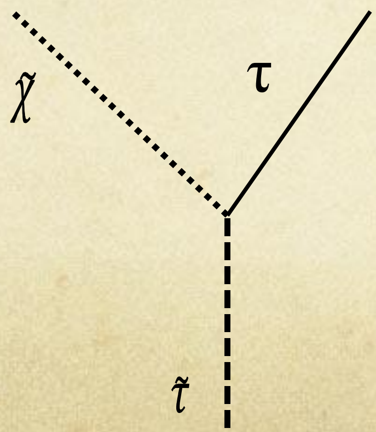


➡ Super-partners ➔ LSP+SM particle

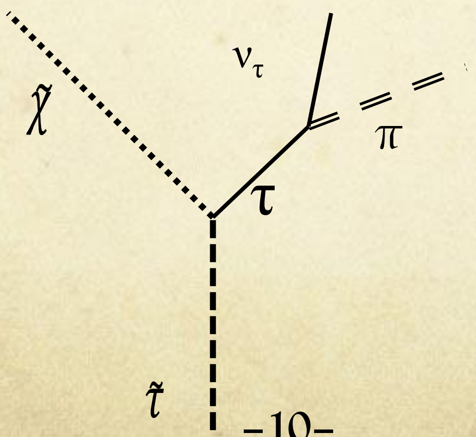
Calculating tau decay modes using Tauola

[Ref]: "Long life stau in the MSSM"– T. Jittoh, J.Sato

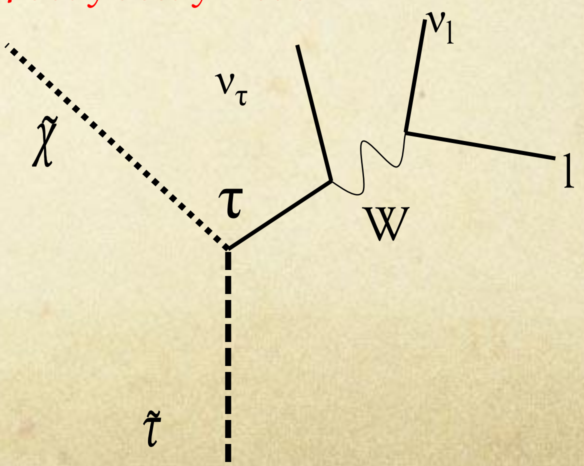
2-body decay mode



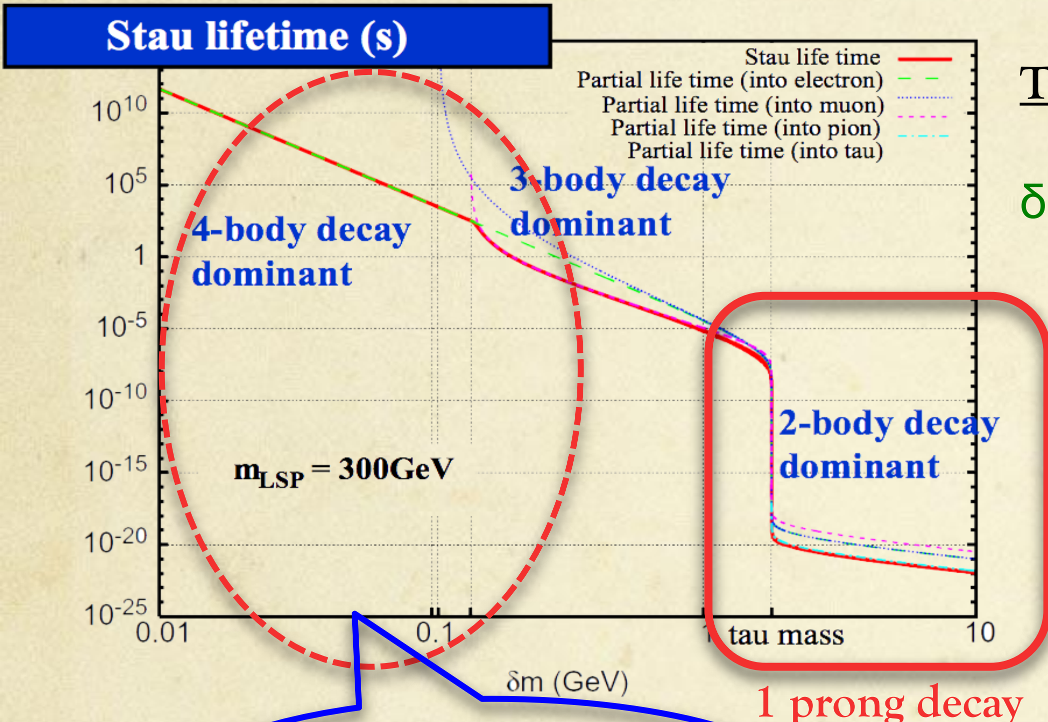
3-body decay mode



4-body decay mode

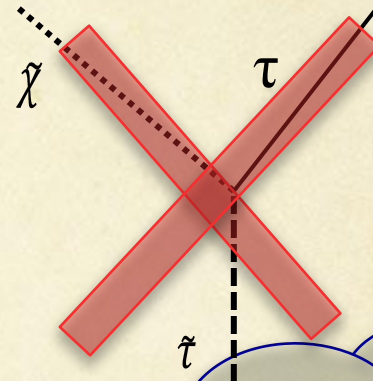


Study at neutralino mass = 300 GeV



The parameter region:

δ m= Stau−mass − Neutralino−mass



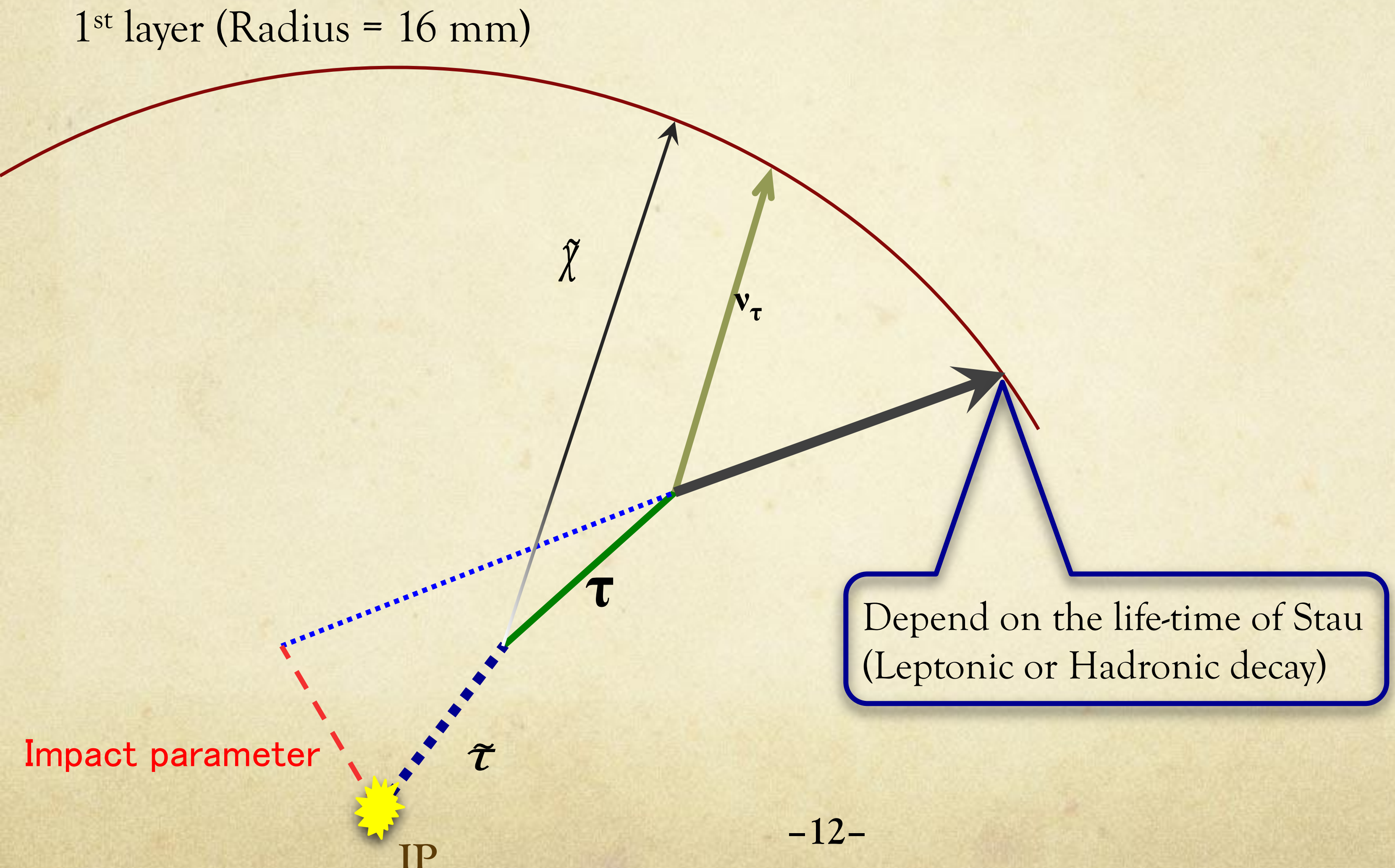
Lepton Flavor Violation Sector

The life−time of the lightest slepton shows good sensitivity to LFV parameter

δm < tau-mass → Strongly suppress 2-body decays mode

→ Lepton Flavor Violation Decay

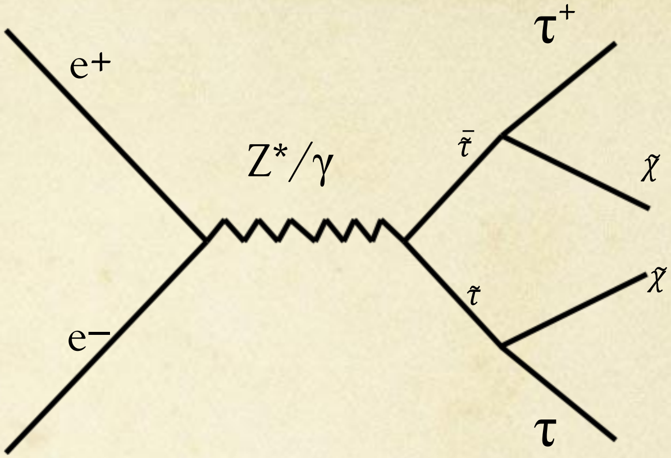
Stau Search At The ILC



Simulation

Signal:

$$e^+e^- \rightarrow \tilde{\tau}\bar{\tilde{\tau}} \rightarrow \tau^+\tau^-\tilde{\chi}\tilde{\chi}$$



Back ground:

$$e^+e^- \rightarrow WW \rightarrow ll\nu\nu$$

$$e^+e^- \rightarrow ZZ \rightarrow ll\nu\nu$$

$$e^+e^- \rightarrow Z^*/\gamma^* \rightarrow ll$$

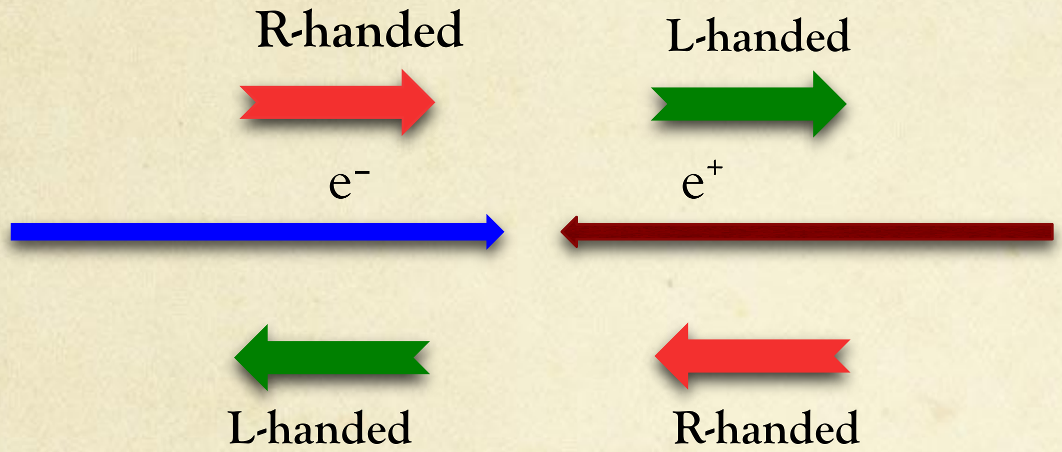
$$e^+e^- \rightarrow \tau\tau$$

$$e^+e^- \rightarrow bhabha$$

Set up:

$\sqrt{s}$ =250, 350, 500 GeV
Beam polarization: $P(e^-,e^+)=(0.8, -0.3)$
Stau mass = **120 ～ 240** GeV
θ_τ= **0 ～ π** rad
Neutralino mass = 100 GeV
Luminosity = 250 fb^{-1}, 350 fb^{-1}, 500 fb^{-1}
tanβ= 5, 10

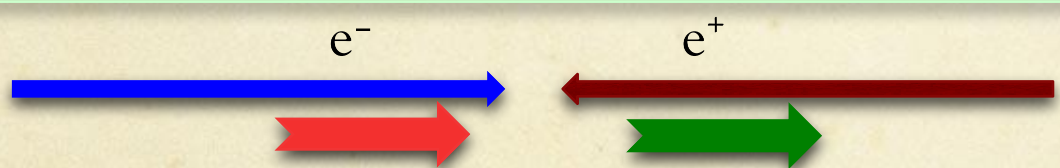
Polarization And Cross-section



R-handed: +1
L-handed: −1

$$P = \frac{N_R - N_L}{N_R + N_L}$$

P(e⁻,e⁺) = (0.8,−0.3) → Strongly suppress the background of WW (R-handed particles do not couple with W)



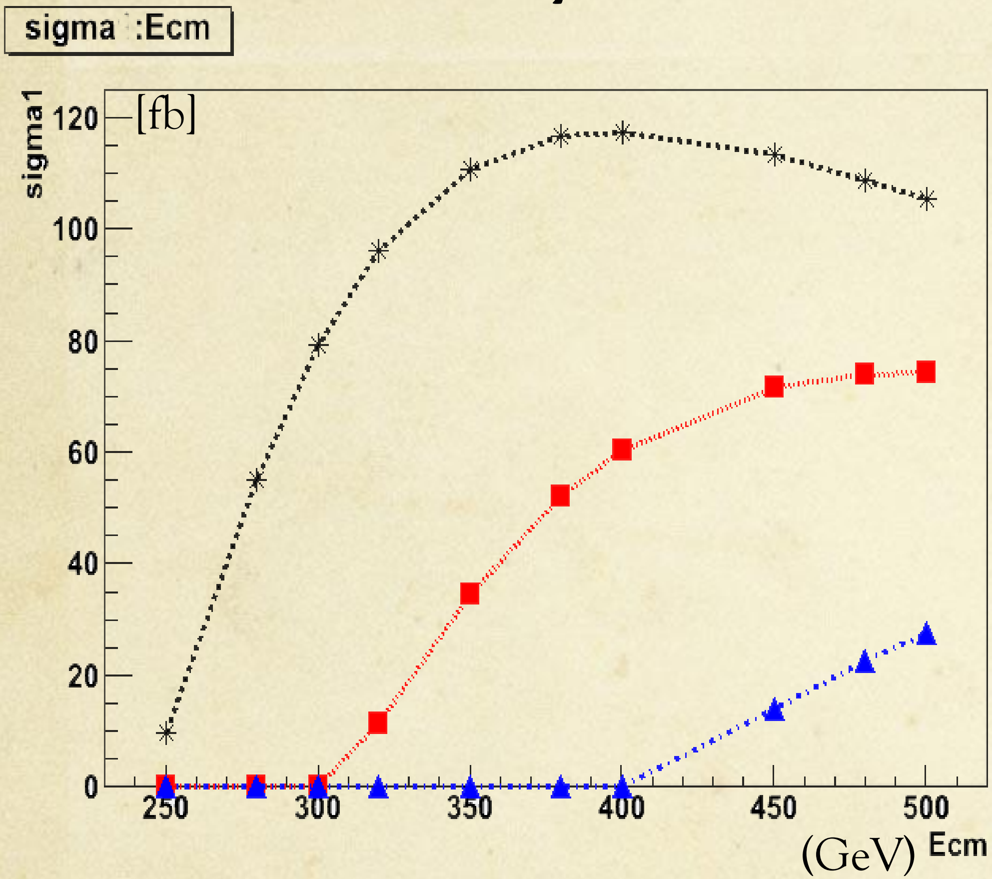
Case1: (0.8,−0.3) 90% 65% = 58.5%

Case2 : (−0.8,0.3) 10% 35% = 3.5%

Total cross−section:
=(Case1 x 0.585 + Case2 x 0.035)x2

(In Physsim, positron can not be polarized)

Physsim Simulation(1)



Generating cross–section of Stau: Check!

S-channel liked processes = OK!

Figure1: Relation of cross-section and central mass energy corresponding to different stau masses.
(Mixing angle is set at 0)

Black: M–stau = 120 GeV
Red: M–stau = 150 GeV
Blue: M–stau = 200 GeV

Physsim Simulation(2)

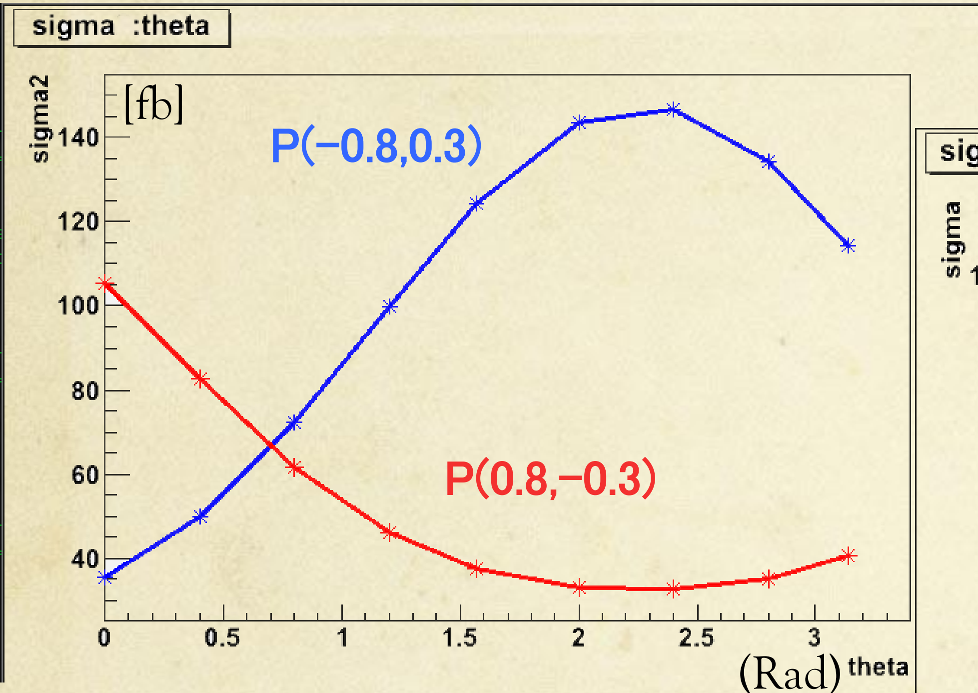


Figure2: Relation of cross-section and mixing-angle of stau1 and stau2 (Ecm = 500 GeV, M-stau =120 GeV)

Red: P(0.8,−0.3)

Blue: P(−0.8,0.3)

$$\begin{pmatrix}\tilde{\tau}_1\\ \tilde{\tau}_2\end{pmatrix} = \begin{pmatrix}\cos\theta_\tau & -\sin\theta_\tau\\ \sin\theta_\tau & \cos\theta_\tau\end{pmatrix}\begin{pmatrix}\tilde{\tau}_L\\ \tilde{\tau}_R\end{pmatrix}$$

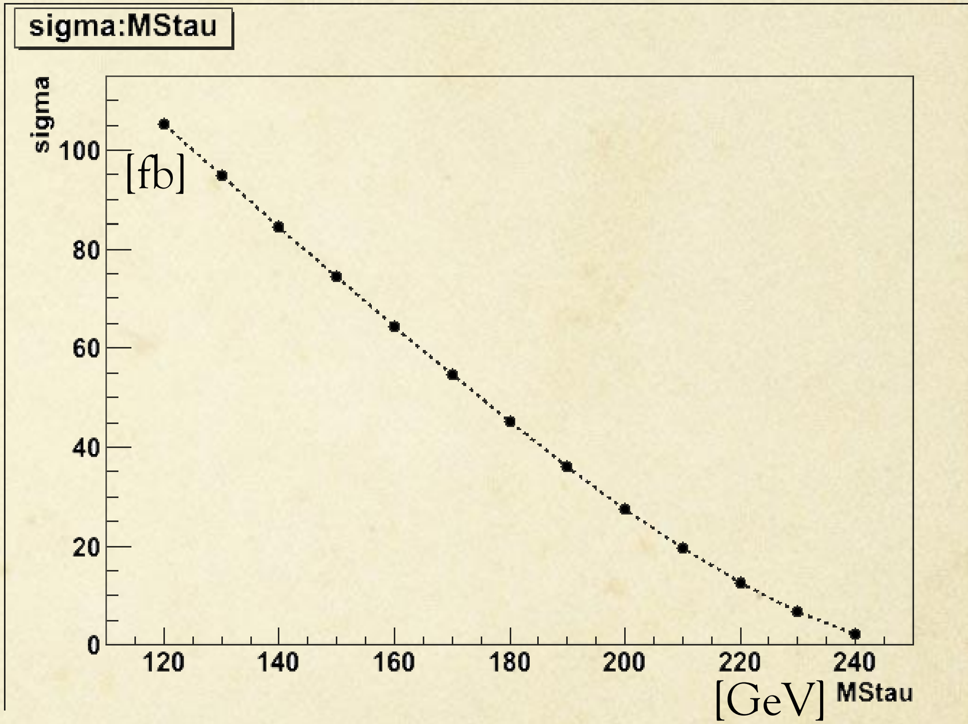


Figure3: Relation of cross-section and stau mass (Ecm = 500 GeV, θ_τ= 0)

Whizard Simulation(1)

- Whizard provides more variation on parameters
  - Difficult to handle many parameters simultaneously
  - More study is required in order to be able to determine the parameters

Studying Susy-hit for testing muon g-2 in the MSSM

- M_1 = 90.8 GeV (Bino ≈ Neutralino)
- M_2 = μ= 1000 GeV (supposed to be unobservable – heavier than Neutralinos and Charginos)
- Γ(stau1) = 1.97956261 x 10^{-02} GeV
- Γ(stau2) = 7.34654619 x 10^{-01} GeV
- Branching ratio
  - BR(stau1 → χ_{10} τ^-) = 100%
  - BR(stau2 → χ_{10} τ^-) = 85.8%
  - BR(stau2 → snu_tauL W^-) = 12.9%
  - BR(snu_tauL → χ_{10} nu_tau) = 100%

(After discussing with Motoi Endo San)

Whizard Simulation(2)

(Simulation using stau1stau1_tau-tau process in MSSM model)

Stau-width for 2-body decay dominance ($\delta m > m_\tau$):

$$\Gamma_{2-body} \approx \frac{g_2^2 \tan^2\theta_W}{2\pi m_{\tilde{\tau}_1}} \delta m \sqrt{(\delta m)^2 - m_\tau^2} \sim \mathcal{O}(10^{-2}) GeV$$

$$\delta m \equiv m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0}$$

Whizard

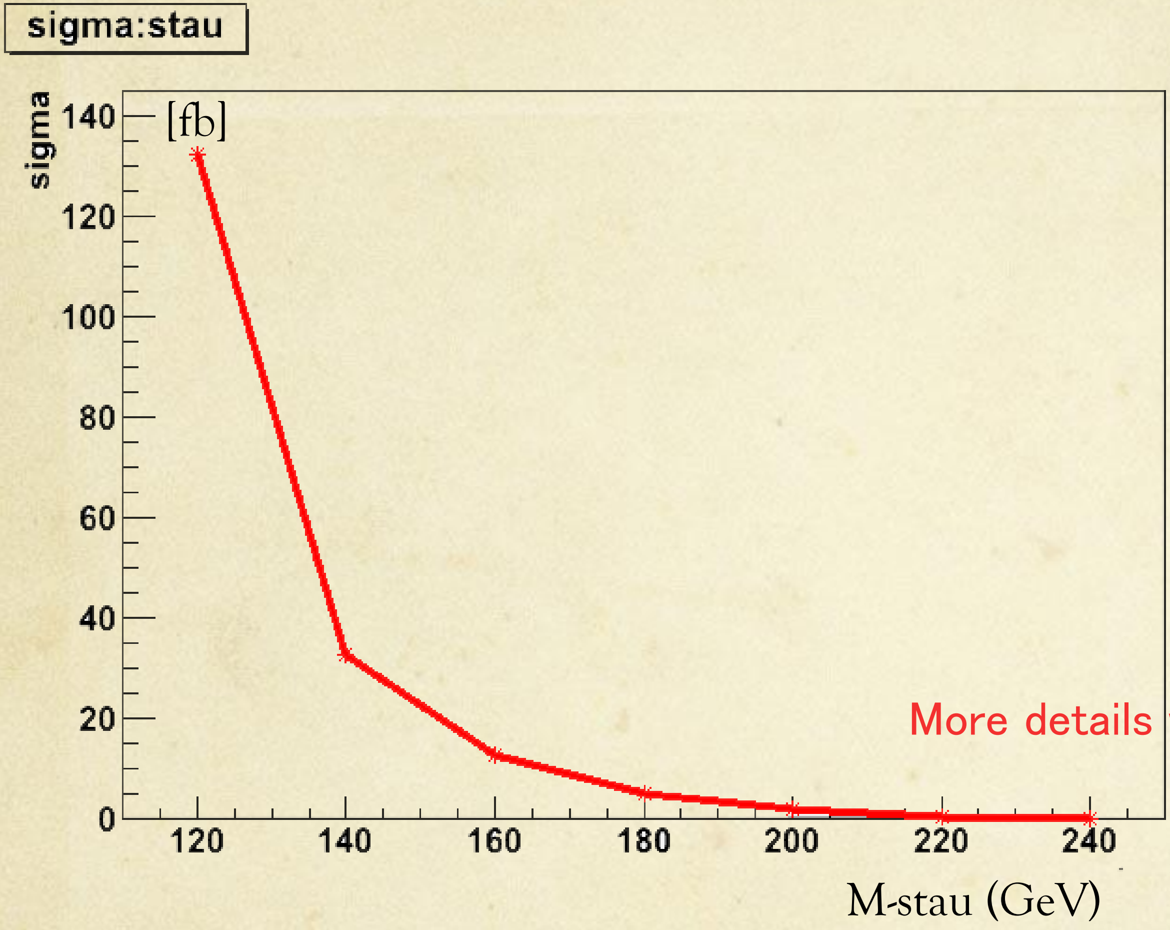
$\Gamma \sim O(10^{-2})$ GeV

The $\tan\beta$= 6.1 and $\sin\theta_W$ = 0.23116 (LEP) are set up for muon g-2 in the MSSM

→ Changing width leads to the change of Stau−mass or Neutralino mass

Studying Susy-hit to understand more about parameters used in Whizard

Whizard Simulation(3)



- Ecm = 500 GeV
- P(e^-,e^+)=(0.8,-0.3)
- Mixing angle = 0
- Neutralino mass = 100 GeV
- Stau mass = 120 – 240 GeV
- SUSY Soft Breaking = 200 GeV

More details will be simulated later !

- Γ (stau1) is stau-mass dependent
- Neutralino mass matrix is from GMSB

Summary

- ($g_\mu-2$) in the MSSM is one of among BSMs that could contain possible candidate for dark matter.
- Investigating how to detect stau pair creation at the ILC.
- Calculating the relation of cross-section with center mass energy, mixing angle and stau-mass (physsim).
- Calculating the relation of stau-mass and cross-section using Whizard.

Future Plan

- Studying how to generate the signal and reduce BG using Whizard and Marlin.
- More precise analysis of branching ratio and momentum distribution of sleptons for SUSY particles
- Studying of other decay modes of stau.
- Studying of SUGRA and extra dimension (the valuable tests for String theory – AdS/CFT)

Thank you for listening!

Back Up

In the MSSM, 2HDM: $H_u = \begin{pmatrix} H^+ \\ H_u^o \end{pmatrix}$ $H_d = \begin{pmatrix} H_d^0 \\ H^- \end{pmatrix}$

At the minimum of the potential $H_u = \begin{pmatrix} 0 \\ \nu_u \end{pmatrix}$ $H_d = \begin{pmatrix} \nu_d \\ 0 \end{pmatrix}$

$$\boldsymbol{\nu_{SUSY}^2 = \nu_u^2 + \nu_d^2 \qquad tan\beta = \frac{\nu_u}{\nu_d}}$$

- Neutralino is the combination of $\widetilde{H}_u^o, \widetilde{H}_d^o, \widetilde{B}, \widetilde{W}^o$ (L-type spinor field)
- The soft SUSY-breaking mass terms: $-\frac{1}{2}M_1\widetilde{B}.\widetilde{B} - \frac{1}{2}M_2\widetilde{W}^0.\widetilde{W}^0 + h.c$

$$\widetilde{G}^0 = \begin{pmatrix} \widetilde{B} \\ \widetilde{W}^o \\ \widetilde{H}_d^o \\ \widetilde{H}_u^o \end{pmatrix} \qquad M_{\widetilde{G}^0} = \begin{pmatrix} M_1 & 0 & -cos\beta sin\theta_W m_Z & sin\beta sin\theta_W m_Z \\ 0 & M_2 & cos\beta cos\theta_W m_Z & -sin\beta cos\theta_W m_Z \\ -cos\beta sin\theta_W m_Z & cos\beta cos\theta_W m_Z & 0 & -\mu \\ sin\beta sin\theta_W m_Z & -sin\beta cos\theta_W m_Z & -\mu & 0 \end{pmatrix}$$

Stau Reconstruction(1)

- The $(\text{mass})^2$ matrix for measuring the stau masses

$$\mathbf{M}^{\mathbf{2}}_{\tilde{\tau}} = \begin{pmatrix} m^2_{\tilde{\tau}_L} + m^2_{\tau} + \Delta_{\tilde{e}_L} & m_\tau(A_o - \mu tan\beta) \\ m_\tau(A_o - \mu tan\beta) & m^2_{\tilde{\tau}_R} + m^2_{\tau} + \Delta_{\tilde{e}_R} \end{pmatrix}$$

Where,

$$\Delta_{\tilde{e}_L} = \left(-\frac{1}{2} + sin^2\theta_W\right) m_Z^2 cos2\beta$$

$$\Delta_{\tilde{e}_R} = \frac{1}{3} sin^2\theta_W m_Z^2 cos2\beta$$

The M^2 can be diagonalized by the orthogonal transformation

$$\begin{pmatrix} \tilde{\tau}_{\mathbf{1}} \\ \tilde{\tau}_{\mathbf{2}} \end{pmatrix} = \begin{pmatrix} cos\theta_\tau & -sin\theta_\tau \\ sin\theta_\tau & cos\theta_\tau \end{pmatrix} \begin{pmatrix} \tilde{\tau}_{\boldsymbol{L}} \\ \tilde{\tau}_{\boldsymbol{R}} \end{pmatrix}$$

The eigenvalues are: $m^2_{\tilde{\tau}_1}, m^2_{\tilde{\tau}_2} (m^2_{\tilde{\tau}_1} < m^2_{\tilde{\tau}_2})$

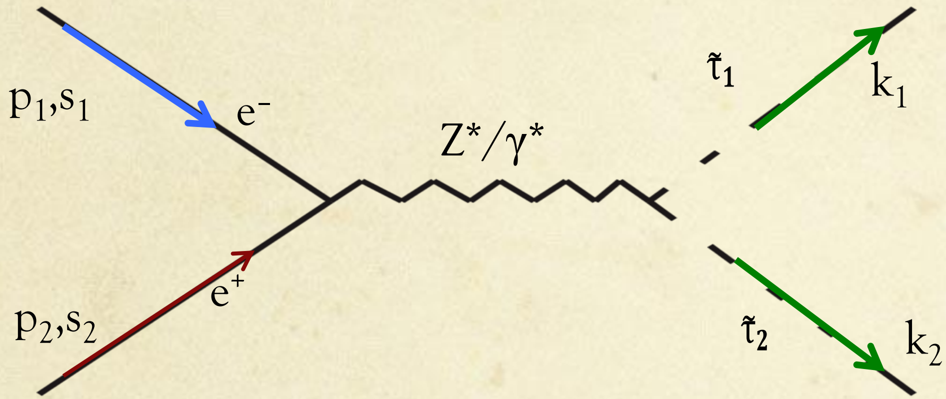
This is what we are looking for!

Stau Reconstruction(2)

The cross-section for stau pair production:

$$\frac{d\sigma}{dt}(e_L^+ e_R^- \to \tilde{\tau}_1 \bar{\tilde{\tau}}_2) = \frac{\pi\alpha^2}{4\hat{s}^2}\frac{sin^2 2\theta_\tau}{cos^4\theta_W}\frac{1}{(s-m_Z^2)^2 + m_Z^2\Gamma_Z^2}(tu - m_{\tilde{\tau}_1}^2 m_{\tilde{\tau}_2}^2)$$

[Ref]: "SUSY in the MSSM"– I.Aitchison



$s = (p_1 + p_2)^2$ $\quad t = (p_1 - k_1)^2$ $\quad u = (p_1 - k_2)^2$

$\alpha_e = \frac{g}{4cos\theta_W}(4sin^2\theta_W - 1)$ $\quad \beta_e = \frac{g}{4cos\theta_W}$