A possibility of measuring LFV coupling through the DIS process of e N → tau X

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Introduction

- LFV is a clear signal for physics beyond the SM.
- Neutrino oscillation may indicate the possibility of LFV in the charged lepton sector.
- In many new physics models, LFV can naturally appear.
  - SUSY (slepton mixing) Borzumati, Masiero; Hisano, Moroi, Tobe, Yamaguchi
  - Zee model for the ν mass Zee
  - Models of dynamical flavor violation Hill et al.
  - Little Higgs models

Tau-associated LFV processes may be interesting at a collider experiment

$\tau \Leftrightarrow e \quad \& \quad \tau \Leftrightarrow \mu$

- It is less constrained by current data as compared to the $\mu \Leftrightarrow e$ mixing

μ→eγ	1.2 ×10 ^ (- 11)
μ→ 3 e	1.1 ×10 ^ (- 12)
μTi→eTi	6.1 ×10 ^ (- 13)
τ→μγ	3.1 ×10 ^ (- 7)
τ→ 3 μ	1.4-3.1 ×10 ^ (- 7)
τ→μη	3.4 ×10 ^ (- 7)

- The Higgs mediated LFV is proportional to the Yukawa coupling $\Rightarrow$ Tau-associated LFV processes.

  Different behavior from μ e mixing case.

LFV in SUSY

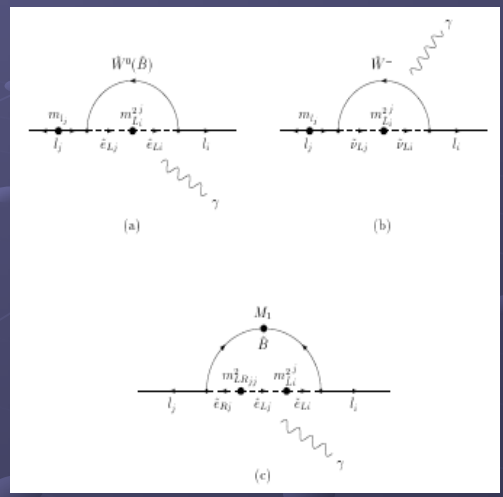
Slepton mixing induces LFV at loop.

Gauge boson mediation

Bortzmati, Masiero
Hisano, Moroi, Tobe, Yamaguchi

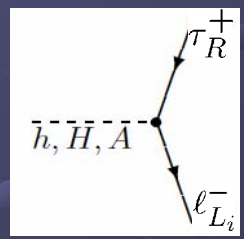
$$\mathcal{L}^{\text{tensor}}_{\bar{\ell}_i \ell_j} = e A_2^{L,R} \left(\bar{\ell}_i \frac{i m_{\ell_i} q_\nu \sigma^{\mu\nu}}{q^2} P_{L,R} \ell_j \right)$$

Form factors: $A_1{}^{L,R}{}_{ij}$, $A_2{}^{L,R}{}_{ij}$, ...



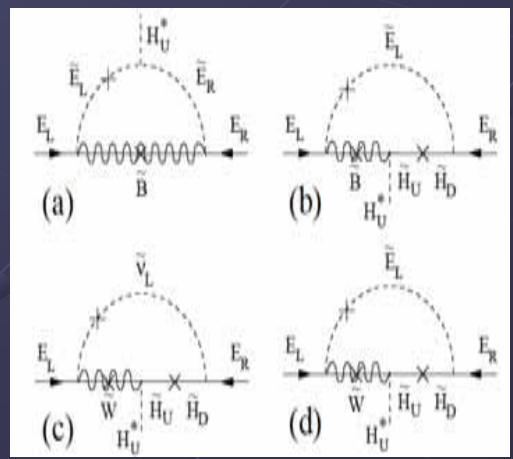
Higgs boson mediation

Babu, Kolda
Dedes, Ellis, Raidal
Kitano, Koike Okada



$$\mathcal{L}^{\text{Higgs}}_{\ell_i \ell_j} = -\frac{\kappa_{ij} m_{\ell_i}}{v \cos^2\beta} \left\{ \cos(\alpha-\beta) h^0 + \sin(\alpha-\beta) H^0 - i A^0 \right\} \left(\overline{\ell_{Ri}} \ell_{Lj} \right)$$

Form factors: κ_{ij}



Experimental bounds on LFV parameters

Gauge boson mediation

The strongest bound on $(A_2{}^{L,R})_{ij}$ comes from the $\mu \to e\gamma$, $\tau \to e\gamma$, $\tau \to \mu\gamma$ results.

Higgs boson mediation

The strongest bound on κ_{32} comes from the $\tau \to \mu\eta$, $\tau \to 3\mu$ results.

$$\mathrm{Br}(\tau \to \mu\eta) = \frac{9G_F^2 m_\tau^3 m_\eta^4 F_\eta^2 \tau_\tau}{256\pi \cos^6\beta} |\kappa_{32}|^2 \frac{\sin^2\beta}{m_A^4} \qquad < 1.5 \times 10^{-7}$$

$$\Longrightarrow \qquad |\kappa_{32}|^2 \leq 2.3 \times 10^{-4} \left(\frac{m_A}{350[\mathrm{GeV}]}\right)^4 \left(\frac{30}{\tan\beta}\right)^6$$

For κ_{31}, similar bound is obtained.

A source of slepton mixing in the MSSM+RN

- Slepton mixing induces both the Higgs mediated LFV and the gauge mediation.
- The off-diagonal elements in the slepton mass matrix can be induced at low energies, even when it is diagonal at the GUT scale.
- RGE

$$\frac{d(m^2_{\tilde{L}})_{ij}}{d\log\mu} = \text{diag} + \frac{1}{(4\pi)^2}\left\{m^2_{\tilde{L}}Y^\dagger_\nu Y_\nu + Y^\dagger_\nu Y_\nu m^2_{\tilde{L}} + 2\left(Y^\dagger_\nu m^2_{\tilde{\nu}} Y_\nu + m^2_{H_u} Y^\dagger_\nu Y_\nu + A^\dagger_\nu A_\nu\right)\right\}_{ij}$$

Decoupling property of LFV

- Gauge boson mediation :

$$\mathcal{L} \simeq \frac{m_{\ell_i}}{M_{SUSY}^2} \bar{\ell}_i \sigma^{\mu\nu} \ell_j F_{\mu\nu}$$

Decouple in the large MSUSY limit

- Higgs boson mediation : LFV Yukawa coupling

$$\mathcal{L} \simeq \frac{m_{\ell_i}}{v} \kappa_{ij} (\tan^2\beta)\, \bar{\ell}_i \ell_j \Phi, \quad (\Phi = h, H, A)$$

$$\Rightarrow \quad \kappa_{ij} \sim f\left(\frac{|\mu|}{M_{SUSY}}\right)$$

NOT always decouple in the large MSUSY limit

Why no LFV found ?

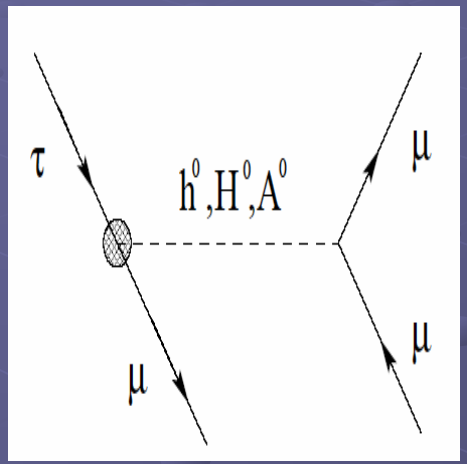
- It is known that sizable LFV can be induced at loop due to slepton mixing.
- Up to now, however, no LFV evidence has been observed at experiments. $\mu \to e\ \gamma$, $\mu \to eee$, ….

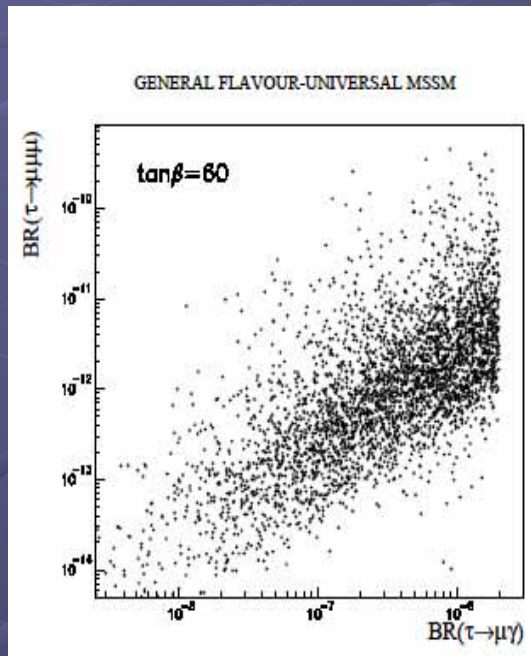
- Why? Maybe large M_{SUSY}, so that the SUSY effects (including LFV phenomena) decouple?

  Even in such a case, we may be able to search LFV via the Higgs boson mediation, which does not necessarily decouple for a large M_{SUSY} limit.

The correlation between the gauge boson mediation and the Higgs mediation

For relatively low m_{SUSY}, the Higgs mediated LFV
is constrained by current data for the gauge mediated LFV.





Scatter plot of Higgs-mediated $\mathrm{Br}(\tau \to 3\mu)$ against $\mathrm{Br}(\tau \to \mu\gamma)$ in GFU-MSSM.

$m_0^{\tilde{q}}, m_0^{\tilde{l}}, m_0^{H_d}, m_0^{H_u} < 700$ GeV

$\mathrm{Br}(\tau \to \mu\gamma)$ strongly constrains $\mathrm{Br}(\tau \xrightarrow{\text{Higgs}} 3\mu)$.

Dedes Ellis Raidal

For $m_{SUSY} >$ O(1)TeV, the gauge mediation becomes suppressed, while the Higgs mediated LFV can be substantial.

Search for LFV at the ILC

- LFV in electron-positron (electron) collision

$$e^{\pm}e^{-} \to \tilde{\ell}_i^{\pm}\tilde{\ell}_j^{-} \ (\chi_1^{+}\chi_2^{-}) \ \to \ell^{\pm}e^{\mp} + jets + E_T$$

$$e^{+}e^{-} \to \ell^{\pm}e^{\mp}, \quad e^{-}e^{-} \to \ell^{-}e^{-}$$

N. Krasnikov 1996,
N. Arkani-Hamed et al. 1996
M. Hirouchi, M Tanaka 1998
J. Hisano et al. 1999
M. Guchait, J. Kalinowski, P. Roy 2002

M. Cannoni, St. Kolb, O. Penella 2003

- Direct LFV Yukawa determination via the Higgs boson decays

$$h^0, H^0, A^0 \to \tau^{\pm}\mu^{\mp}, \quad \tau^{\pm}e^{\mp}$$

A. Brignole, A. Rossi (MSSM) 2003

K.Arganda., A. Curiel, M.Herrero, D. Temes, 2004

LHC search: Assamagan et al. (THDM) 2002
LC Search: S.K., K. Matsuda, T. Ota,
K.Tsumura,T. Shindou, E. Takasugi (MSSM) 2004
S.K., T. Ota, K. Tsumura (THDM) 2005

- LFV in a deep inelastic scattering process at a fixed target experiment

$$e^{-}N \to \tau^{-}X, \quad \mu^{-}X$$

M. Sher, I. Turan (muon beam) 2003

S.K., Y. Kuno, M. Kuze, T. Ota 2004

S.K., Y. Kuno, M. Kuze, T. Ota, T. Takai

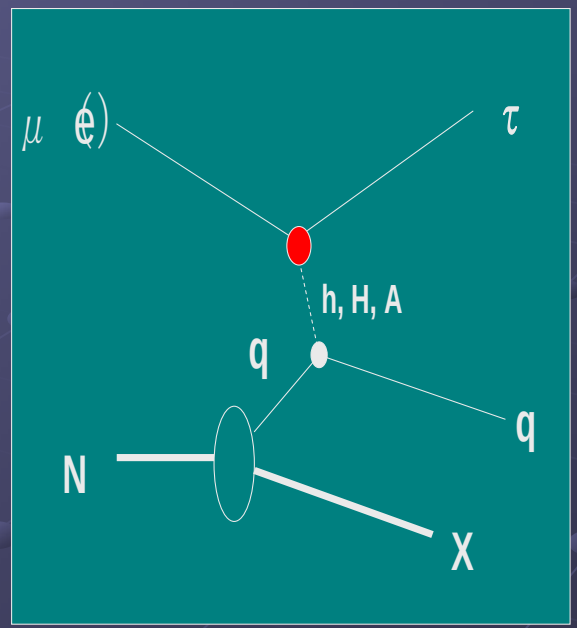
Deep inelastic scattering LFV process at a Linear Collider

- At future ν factories (μ colliders) , 10^{20} muons of energy 50 GeV (100-500GeV) can be available.

  DIS $\mu N \rightarrow \tau X$ process

  M. Sher

  S.K., Y. Kuno, M. Kuze, T. Ota



- At a LC (E_{cm}=500GeV, L=10^{34}/cm^2/s)

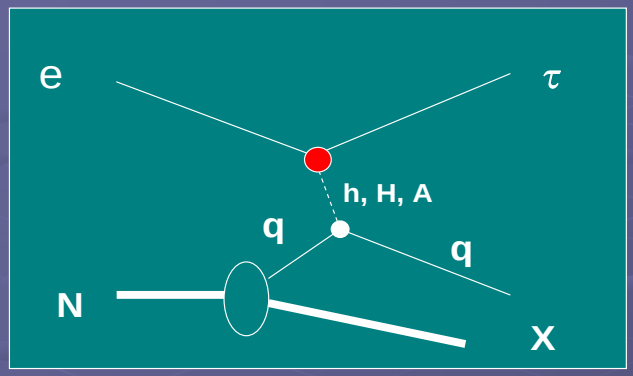
  10^{22} of 250GeV electrons available.

  DIS process $eN \rightarrow \tau X$ process S.K., Y. Kuno, M. Kuze, T. Ota

A fixed target experiment option of a LC

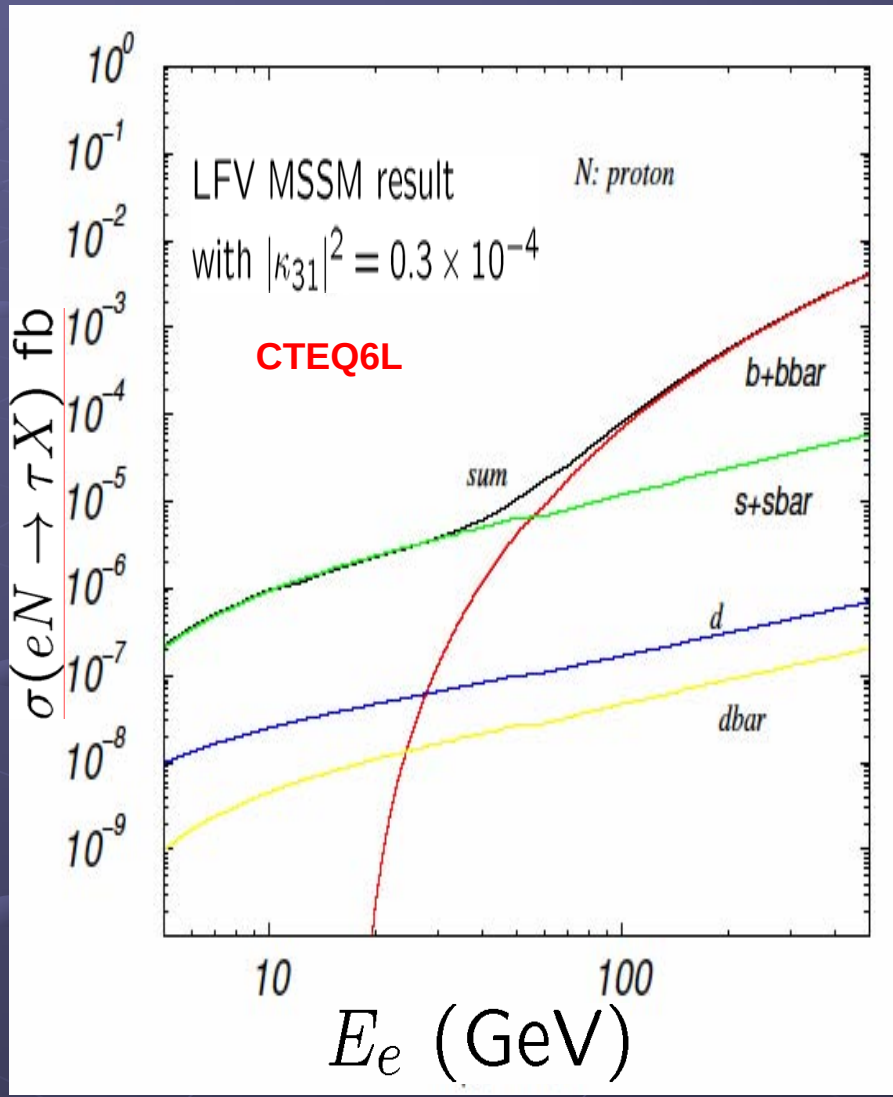
Enhancement of cross section in SUSY

Higgs mediated LFV process



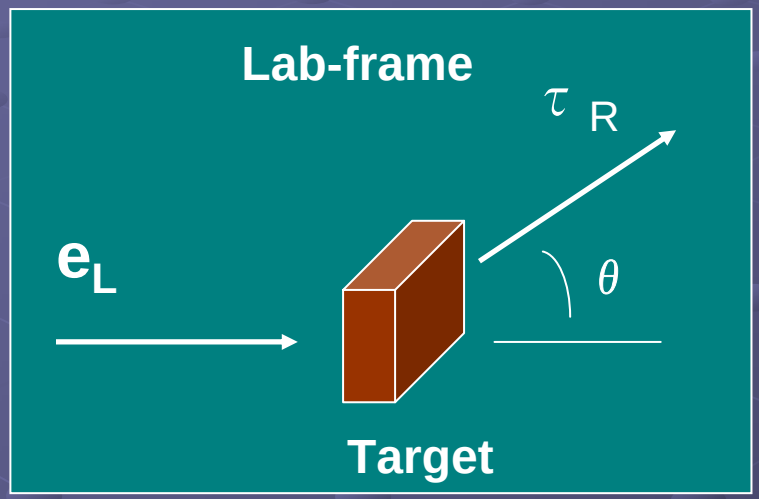
- Sub-process $e^- q \rightarrow \tau^- q$ is proportional to the down-type quark mass.
- Probability for the b-quark is larger for higher energies.
- For Ee > 60 GeV, the total cross section is enhanced due to the b-quark sub-process

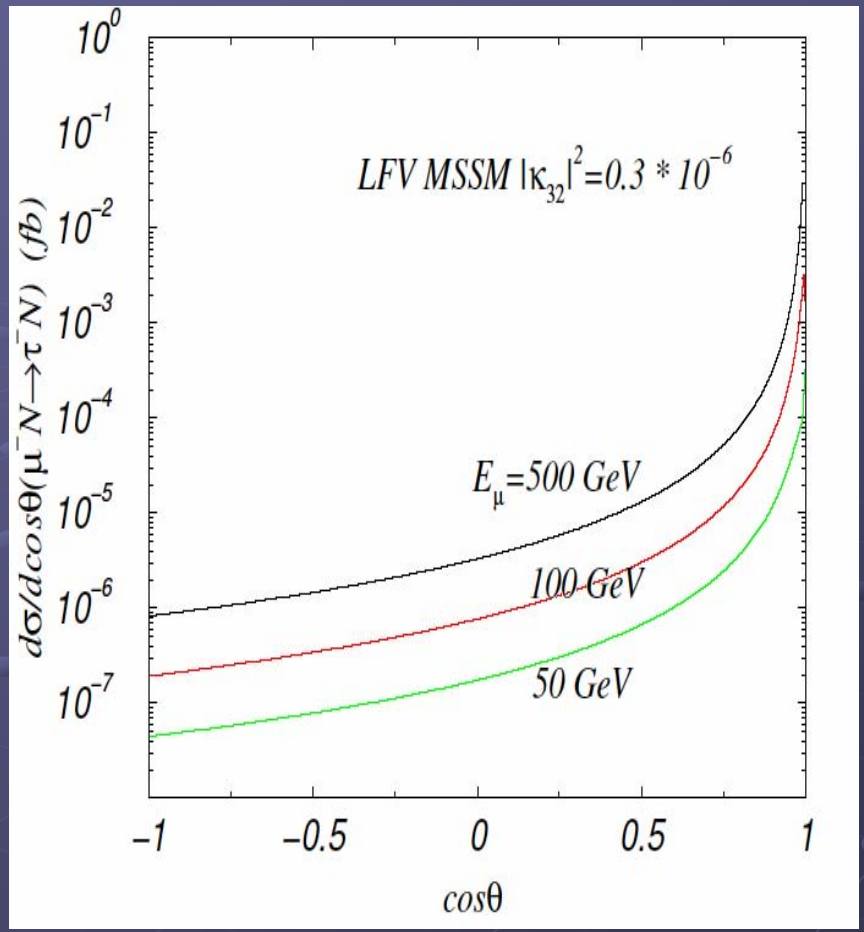
Ee = 50 GeV	10^{-5} fb
100 GeV	10^{-4} fb
250 GeV	10^{-3} fb



Angular distribution

Higgs mediation
→ chirality flipped
→ $(1-\cos\theta_{SM})^2$



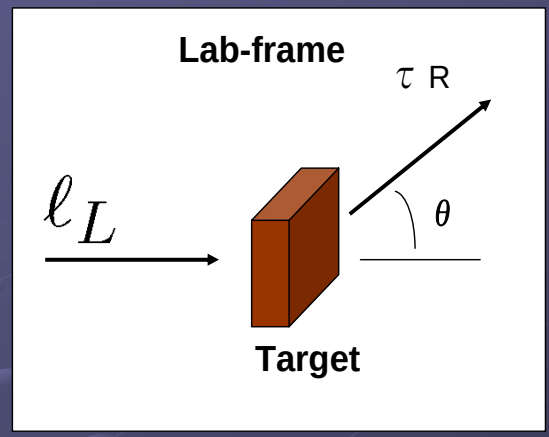


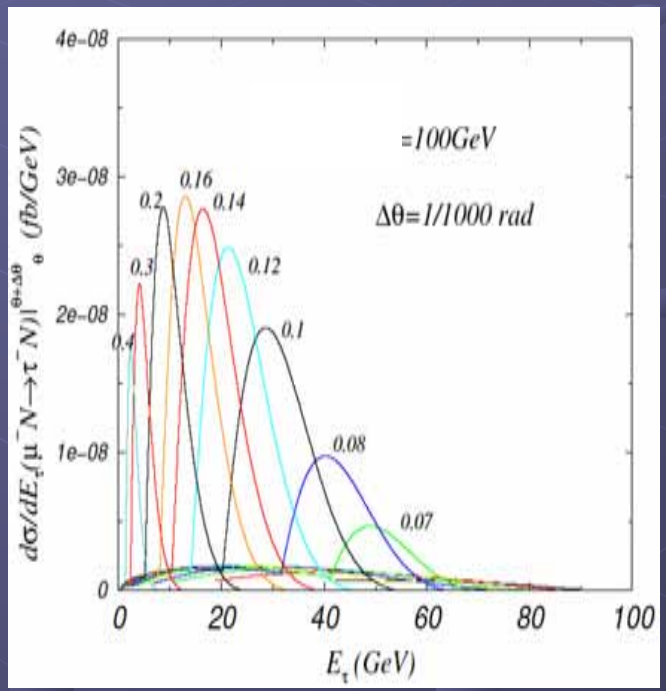
Lab-frame

- From the e_L beam, τ_R is emitted to the backward direction due to $(1-\cos\theta_{CM})^2$ nature in CM frame.
- In Lab-frame, tau is emitted forward direction with some P_T.

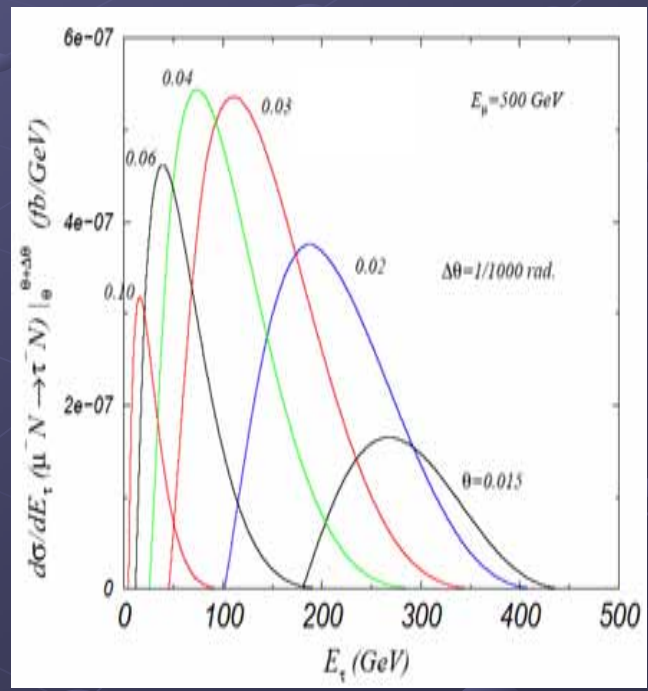
Energy distribution for each angle

- From the e_L beam, τ_R is emitted to the backward direction due to $(1 - \cos\theta_{CM})^2$ nature in the CM frame.
- In Lab-frame, tau is emitted forward direction but with large angle with a PT.





E＝100 GeV



E＝500 GeV

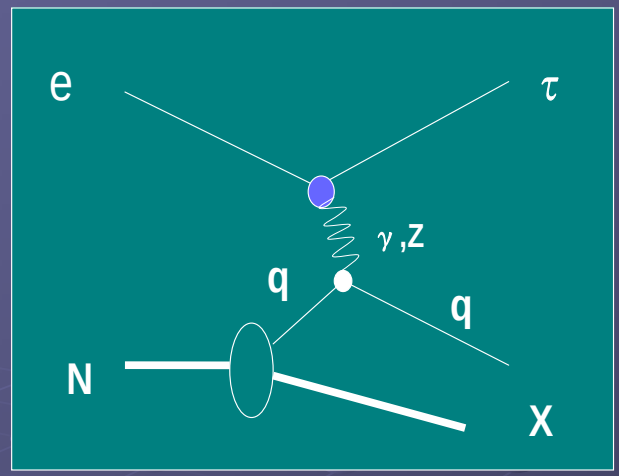
Contribution of the gauge boson mediation

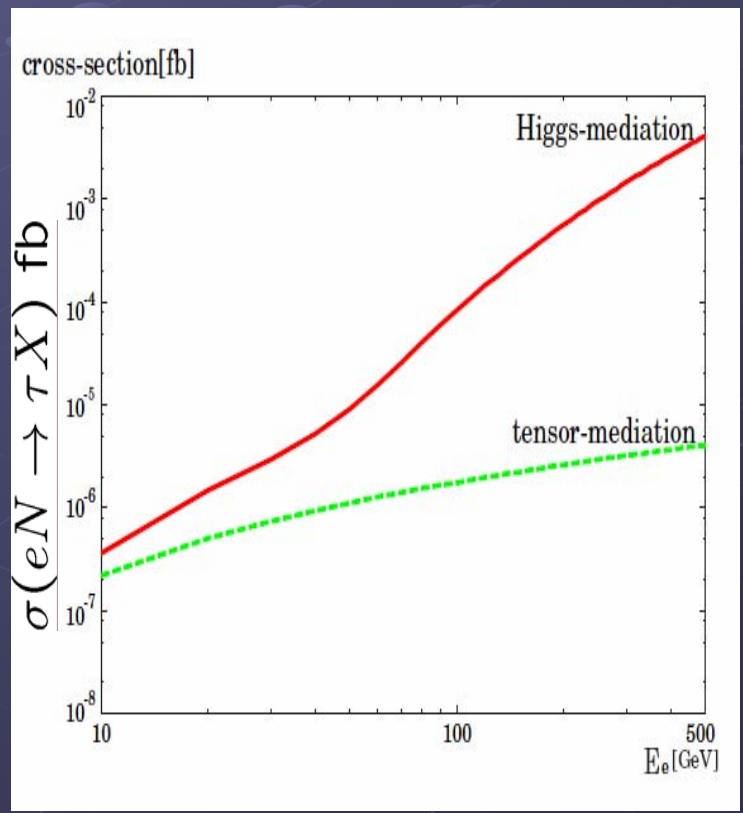
$$Br(\tau \to e\gamma) < 3 \times 10^{-7} \text{ (Belle)}$$

$\tau \to e\,\gamma$ results gives the upper bound on the tensor coupling, therefore on the $e\,N \to \tau\,X$ cross section

Gauge mediated LFV
$\Rightarrow$ No bottom Yukawa enhancement

At high energy
DIS $e\,N \to \tau\,X$ process is more sensitive to the Higgs mediation than the gauge mediation.





Number of produced taus

Ee＝250 GeV,

L =10^{34} /cm^2/s, ⇒ 10^{22} electrons

In a SUSY model with $|\kappa_{31}|^2 = 0.3 \times 10^{-6}$:

$\sigma = 10^{-3}$ fb = 6 x 10^{-42} cm^2

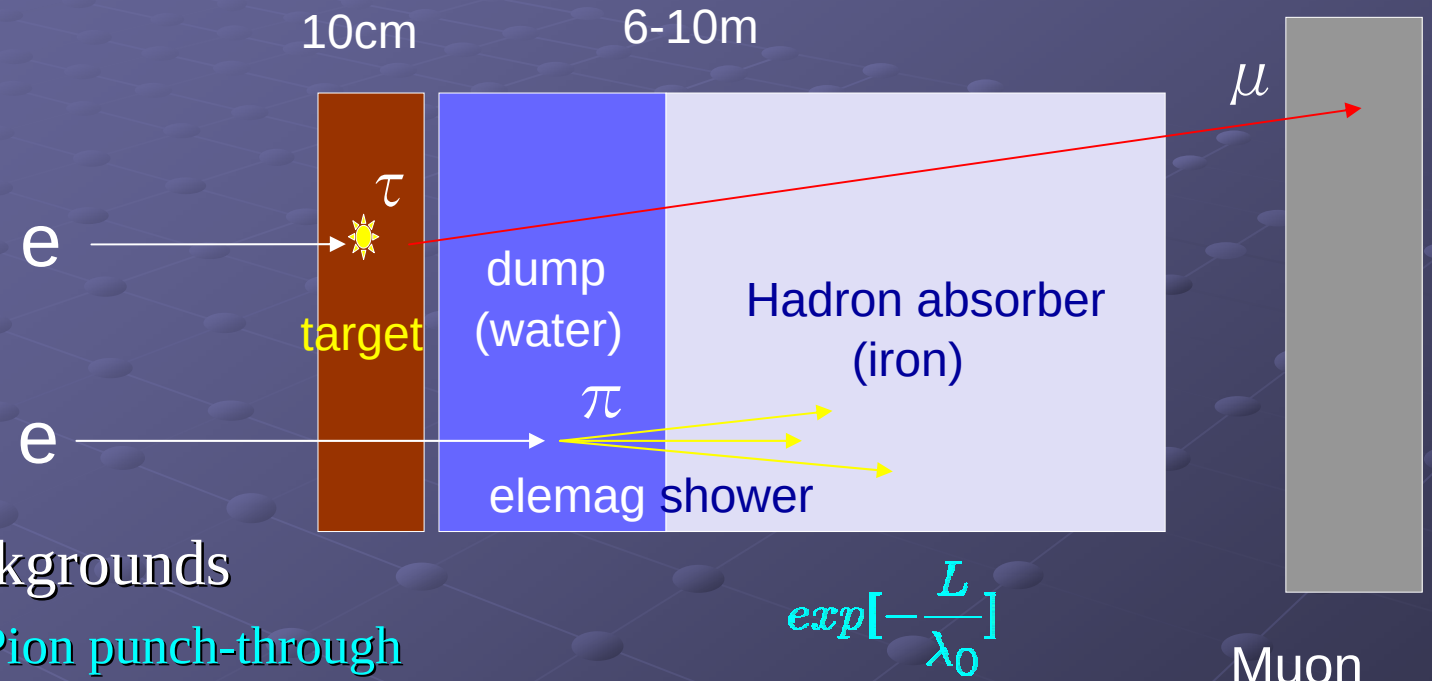
$N_\tau = \rho\ N_A\ Ne\ \sigma$

$N_A = 6 \times 10^{23}$

10^5 of τ leptons are produced for the target of ρ =10 g/cm^2

Naively, non-observation of the high energy muons from the tau of the e N → τ X process may improve the current upper limit on the e τ Φ coupling^2 by around 4 orders of magnitude.

- High energy muon from tau can be a signal
- Geometry (picture) ex) target ρ =10g/cm^2



- Backgrounds
  - Pion punch-through
  - Muons from Pion decay-in-flight
  - Muon from the muon pair production
  - …….

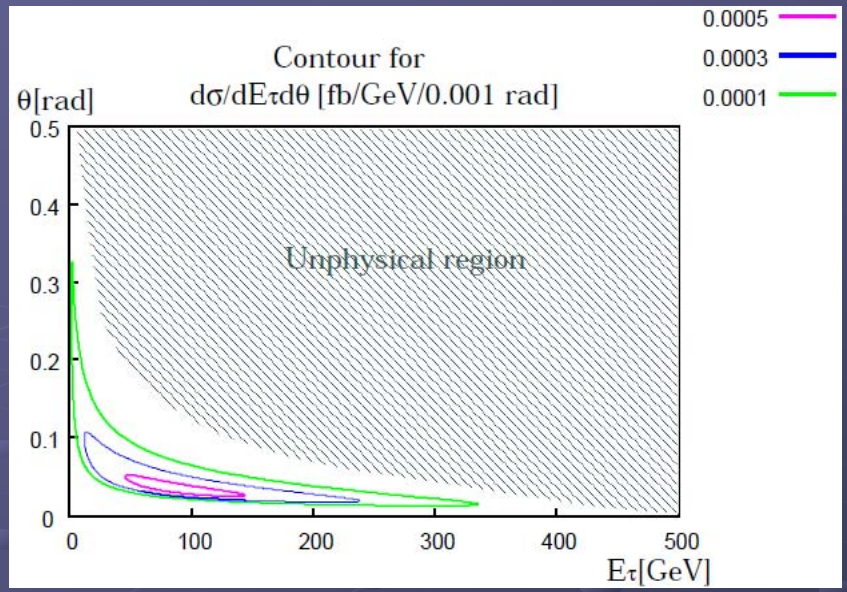
Monte Carlo simulation is being done. GEANT4,…

SK, Y. Kuno, M. Kuze, T. Ota, T. Takai

Signal $\dfrac{d^2\sigma}{dE_\tau d\theta}$

$eN \to \tau X$

Higgs boson mediation

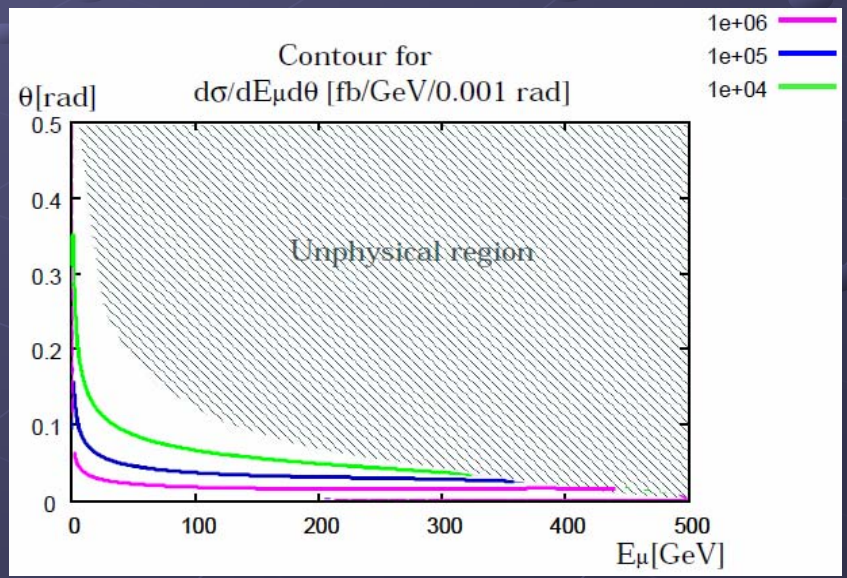


Backgrounds $\dfrac{d^2\sigma}{dE_e d\theta}$

$eN \to eX$

photon mediation

usual DIS



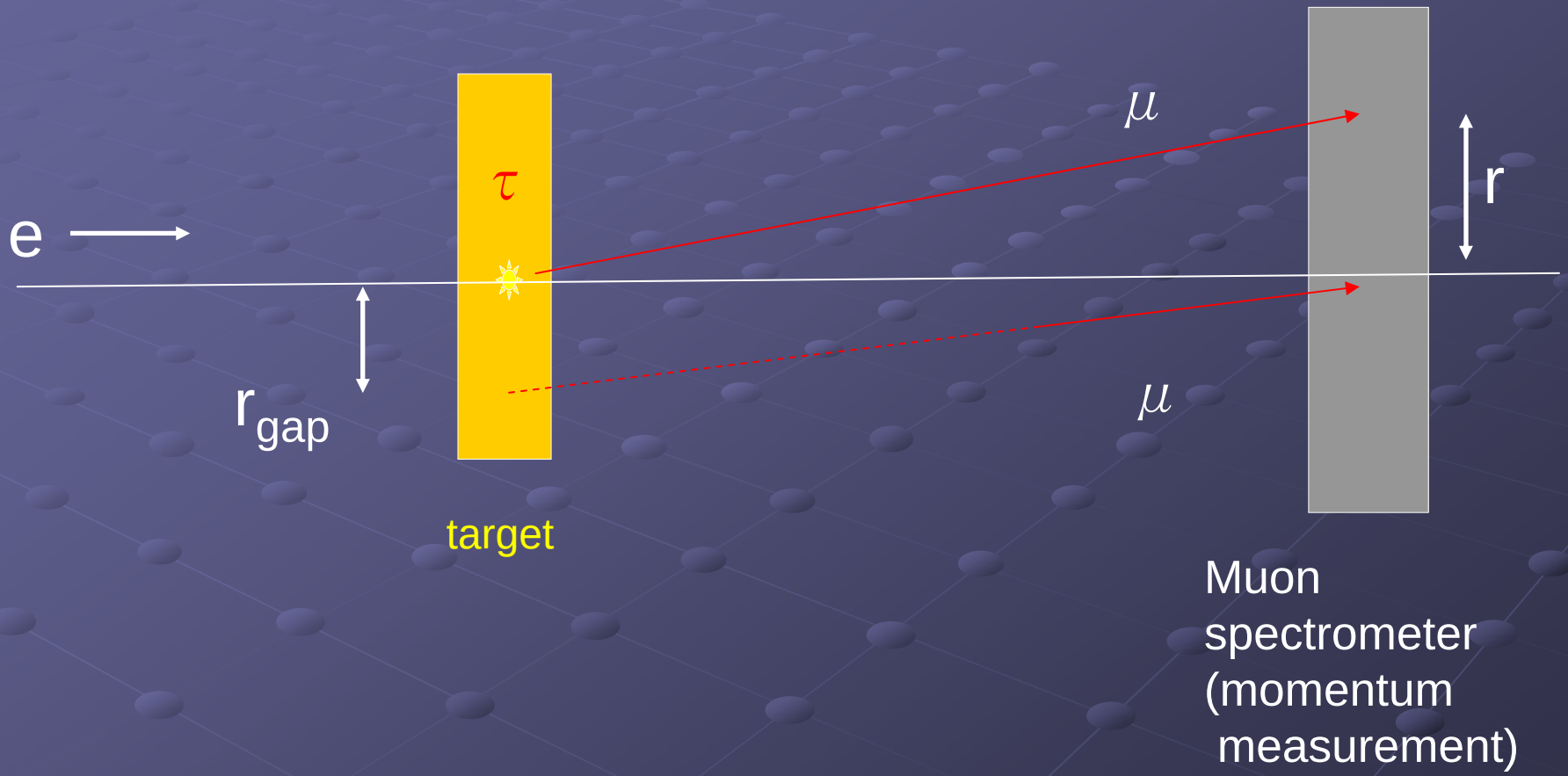
Different distribution

$\Rightarrow$ BG reduction by E_τ, θ_τ cuts

Preliminary MC analysis

- LC Ee=1.5TeV, 10^{22} electrons per year
- Signal muons from LFV DIS
  - $e\,N \rightarrow \tau\,X$ with $\tau \rightarrow \mu\ \nu\ \nu$
  - 10^5 muons/year
- Background muons from γ DIS
- muon energy, P_T or r, r_{gap} (extrapolate back)
- $S/N > 10^{-4}$, $S/\sqrt{N} > O(1)$
- More MC events needed

Cuts: E_{μ}, r, r_{gap} (extrapolate back)



Q^2>10GeV^2
Signal : 1,000,000(177,116)events
5×10^{-2}fb
Background : 100,000,000(1360,000)events
3.5×10^{7}fb

8m

By T. Takai

- 300<E<450, r>180, $0<r_{gap}<150$
- 450<E<600, r>90
- E>600, r>70

→Signal : 1047events, Background : 1events

Beam Energy	Signal	Background (γ-DIS)	S/N
1.5TeV	4.4×10^{-5}fb	0.35fb	1.4×10^{-4}fb

Summary

DIS process $e\,N \rightarrow \tau\,X$:

- Possibility of a fixed target experiment at a LC
- The cross section is enhanced due to the sub-process of Higgs mediation with sea b-quarks
- At a LC with Ecm=500GeV $\Rightarrow\ \sigma = 10^{-3}$ fb

  $L=10^{34}/cm^2/s \Rightarrow 10^{22}$ electrons available

  10^5 of taus are produced for $\rho = 10\ g/cm^2$
- Non-observation of the signal (high-energy muons) would improve the current limit by several orders.
- MC simulation
  - Background from γ DIS can be rejected.
  - work in progress