A Study of $\mu N(eN) \to \tau X$ LFV Reactions

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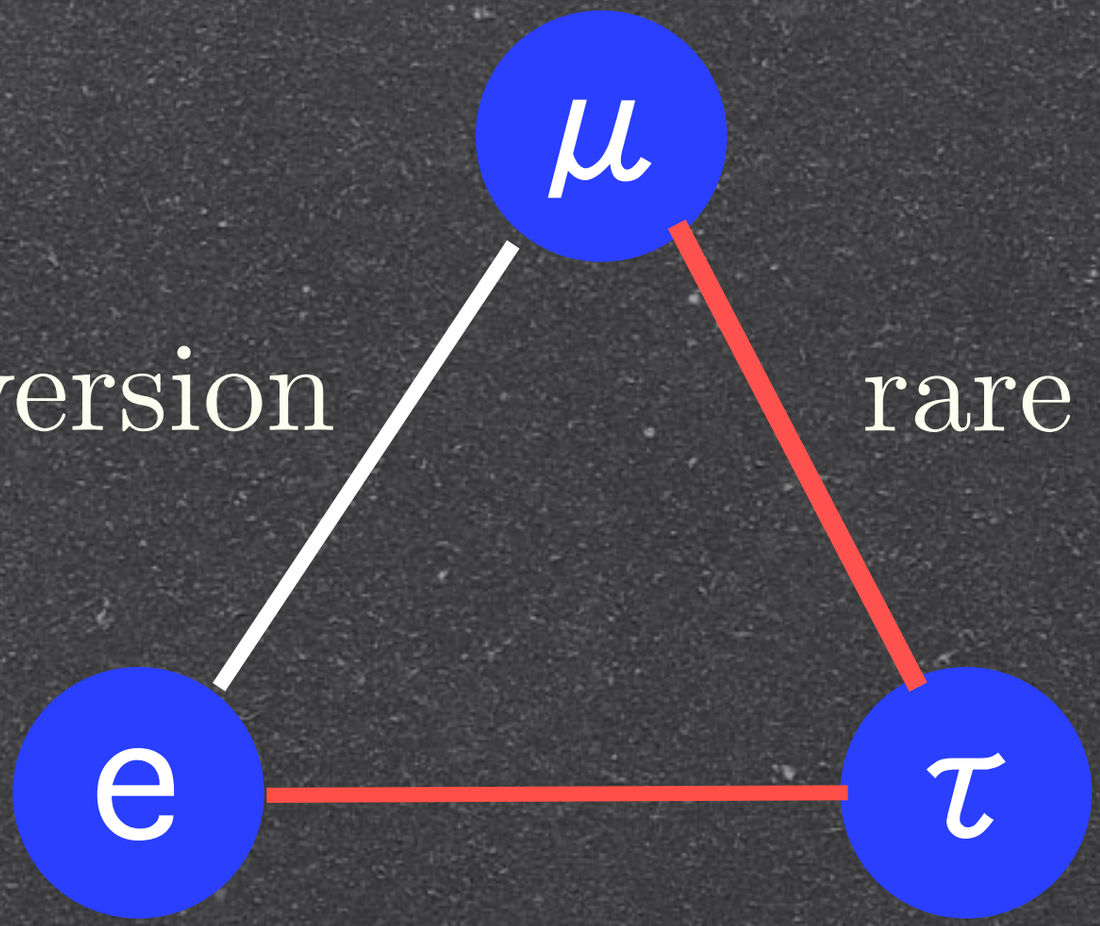
Outline

- Motivation on μN→τX reaction
- μN→τX cross section
- μN→τX cross section at DIS region
- μN→τX signal and backgrounds
- eN→τX reaction
- Summary

hep-ph/0410044

Motivation

Lepton Flavor Violation (LFV) of charged leptons is clear signature to indicate physics beyond the SM.



$\mu - e$ conversion

$\mu \to e\gamma$

rare τ decays

rare τ decays

HERA

Experimental Limits

decay modes	upper limits
$\mu \to e\gamma$	$< 1.2 \times 10^{-11}$
$\mu \to eee$	$< 1.1 \times 10^{-12}$
$\mu^- Ti \to e^- Ti$	$< 6.3 \times 10^{-13}$
$\tau \to \mu\gamma$	$< 3.1 \times 10^{-7}$
$\tau \to \mu\mu\mu$	$< 1.4 \times 10^{-7}$
$\tau \to \mu\eta$	$< 3.4 \times 10^{-7}$

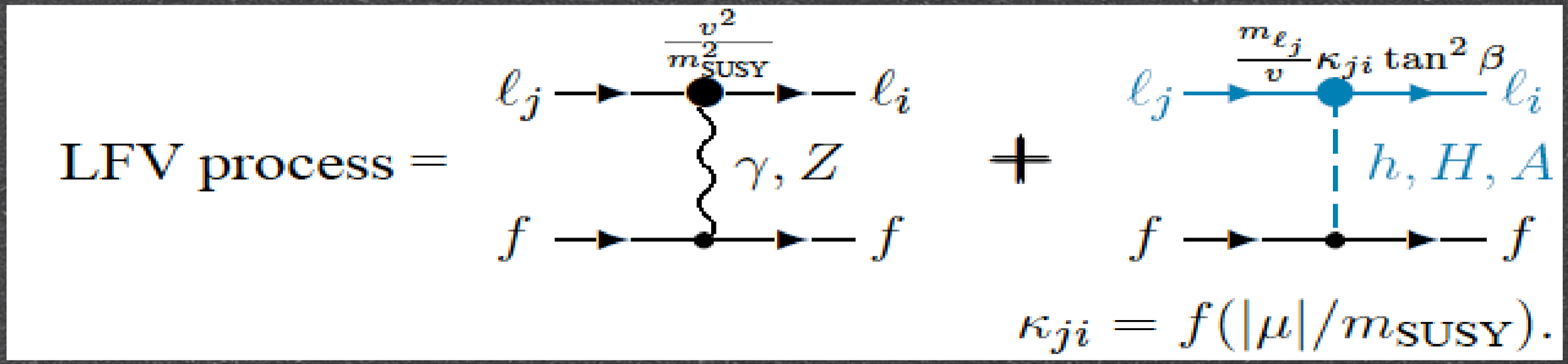
might be improved by only O(10) at super B factories, a tau-charm factory.

Alternatives ?

- In analogy to $\mu N \rightarrow eN$, $\tau N \rightarrow \mu N$?
  - No, taus are short-lived.
- How about $\mu N \rightarrow \tau N$?
  - An energetic muon beam is needed.
    The tau production threshold : $E_\mu \sim 3.5$ GeV
  - In future, a high intensity, high energy muon beam might be available at a muon collider or a neutrino factory.

LFV in SUSY Models

In SUSY models, slepton mixing induces LFV via. loop diagrams.



Gauge boson mediated :
vector, tensor couplings

Babu, Kolda
Dedes, Ellis, Raidal
Kitano et al.

Babu, Kolda:
Brignole, Rossi:

Higgs boson mediated :
(psuedo) scalar coupling

$\propto$ lepton mass$\rightarrow$
tau-associated process

not vanish for high SUSY scale (>TeV).

$\mu N \to \tau N$ vs. Rare tau Decays

Is $\mu N \to \tau N$ competitive to rare tau decays ?

Estimate the maximally allowed cross section with experimental constraints from rare tau decays.

Effective μ-τ couplings

μN→τN cross section is estimated from effective μτ coupling with the constraints from rare tau decay.

$$\mathcal{L} \sim \frac{4\pi}{\Lambda^2}(\bar{\mu}\Gamma\tau)(\bar{q}^{\alpha}\Gamma q^{\beta}) \qquad \Gamma = (1, \gamma_5, \gamma_\mu, \gamma_\mu\gamma_5, \sigma_{\mu\nu})$$

	decay mode	Λ
scalar	$\tau \rightarrow \mu\pi\pi$	2.6 TeV
psuedo-scalar	$\tau \rightarrow \mu\eta$	12 TeV
vector	$\tau \rightarrow \mu\phi$	14 TeV
tensor	$\tau \rightarrow \mu\pi$	11TeV

Black, Han, He, Sher, 2002

$\mu N \rightarrow \tau N$ Cross Section

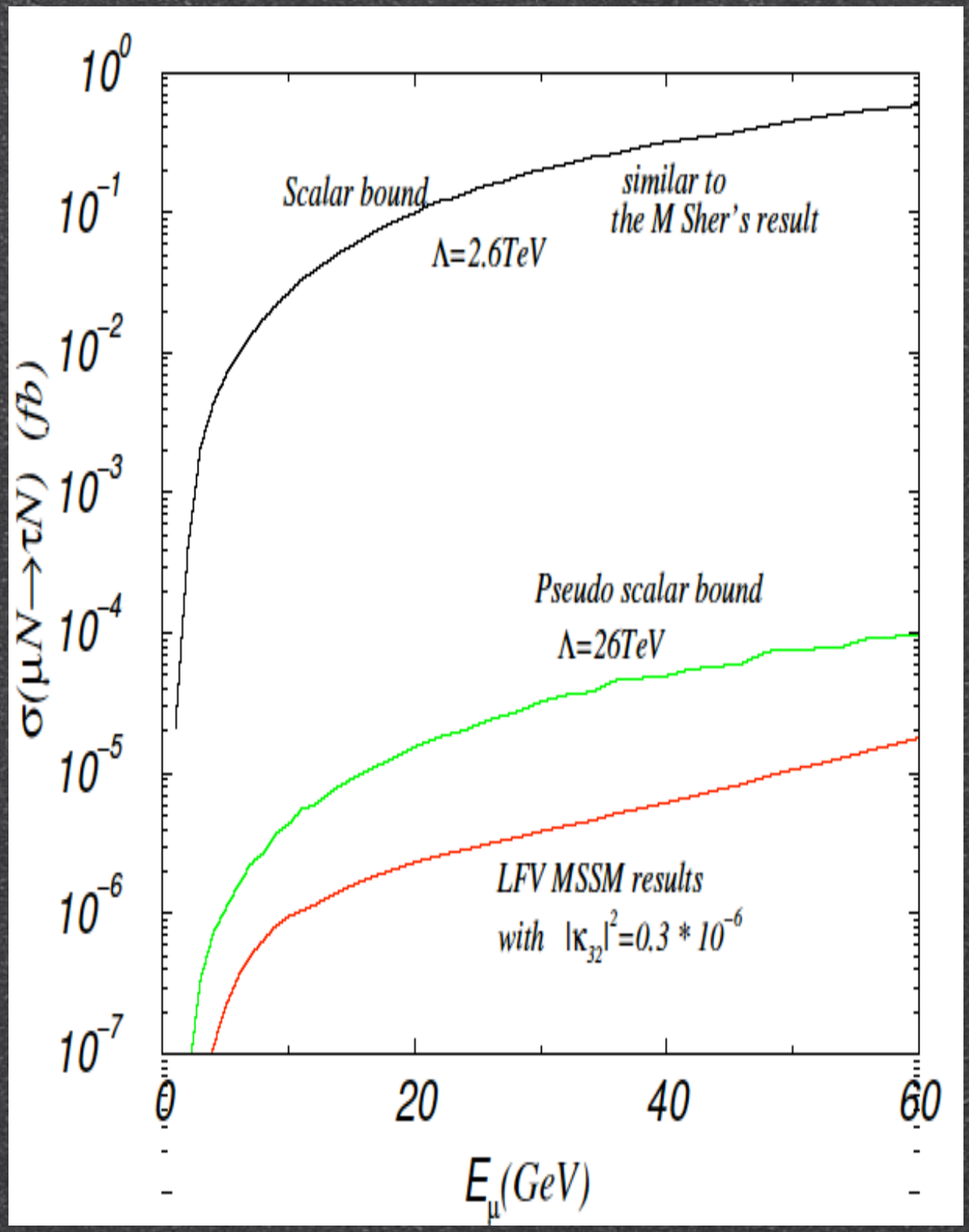
Sher, 2004

Scalar coupling
$\sigma \sim 0.1$ fb

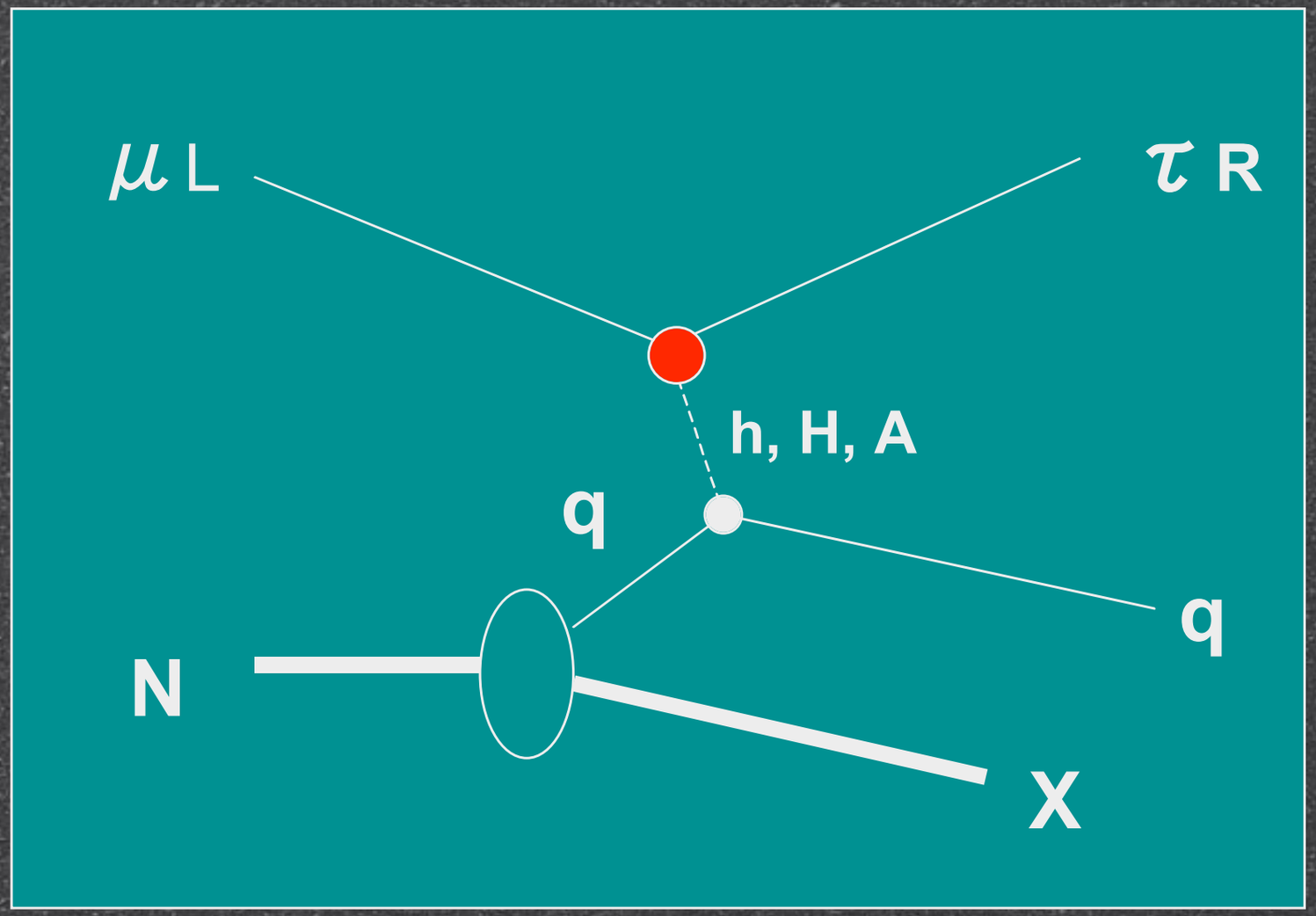
with 10^{20} muons/year,
100 g/cm^2 target mass,
10^6 events

Psuedo-scalar coupling
$\sigma \sim 10^{-5}$ fb

In SUSY, scalar coupling = psuedo-scalar coupling, cross section smaller by 10^{-4}.

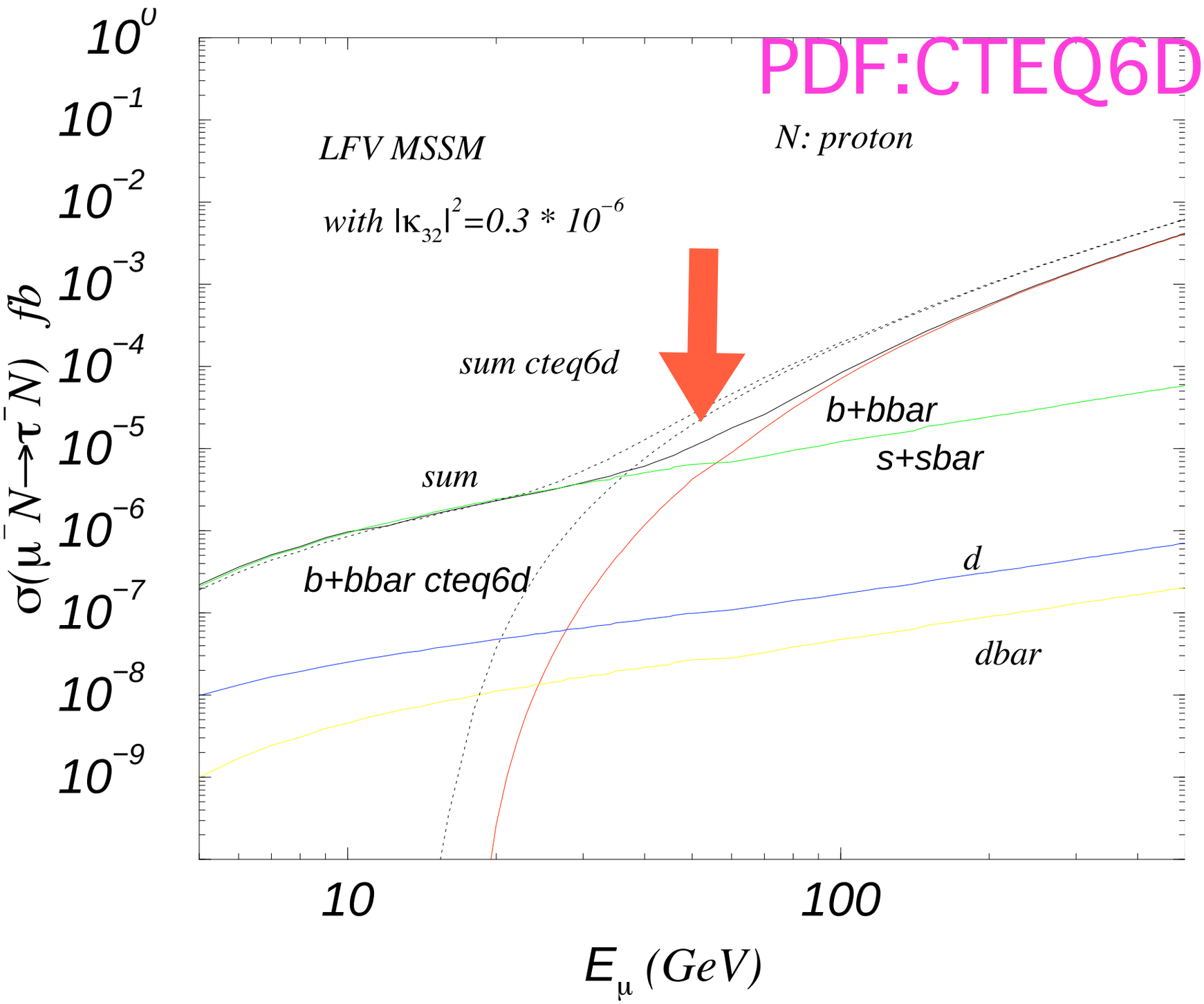


$\mu N \to \tau X$ DIS reaction



At high muon energy, deep inelastic scattering (DIS) is important. Not $\mu N \to \tau N$, but $\mu N \to \tau X$.

DIS Cross Section



Higgs mediated SUSY case

Sea b-quark contribution becomes significant at energy higher than 50 GeV.

Estimated Event Rates

With 10^{20} muons/year and
proton target mass of $O(10^2)$ g/cm^2

Acceptance ~ 0.01

Emu	cross section	# of taus	# observed
50 GeV	10^{-5}fb	$O(10^2)$	$O(1)$
100 GeV	10^{-4}fb	$O(10^3)$	$O(10)$
300 GeV	10^{-3}fb	$O(10^4)$	$O(10^2)$

For nucleus target, multiplied by # of nucleons

Angular Distribution

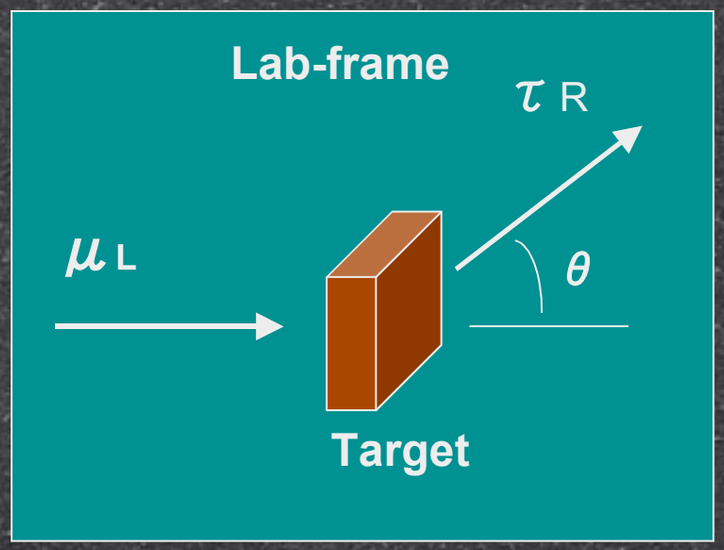
Higgs mediated→
chirality flipped.

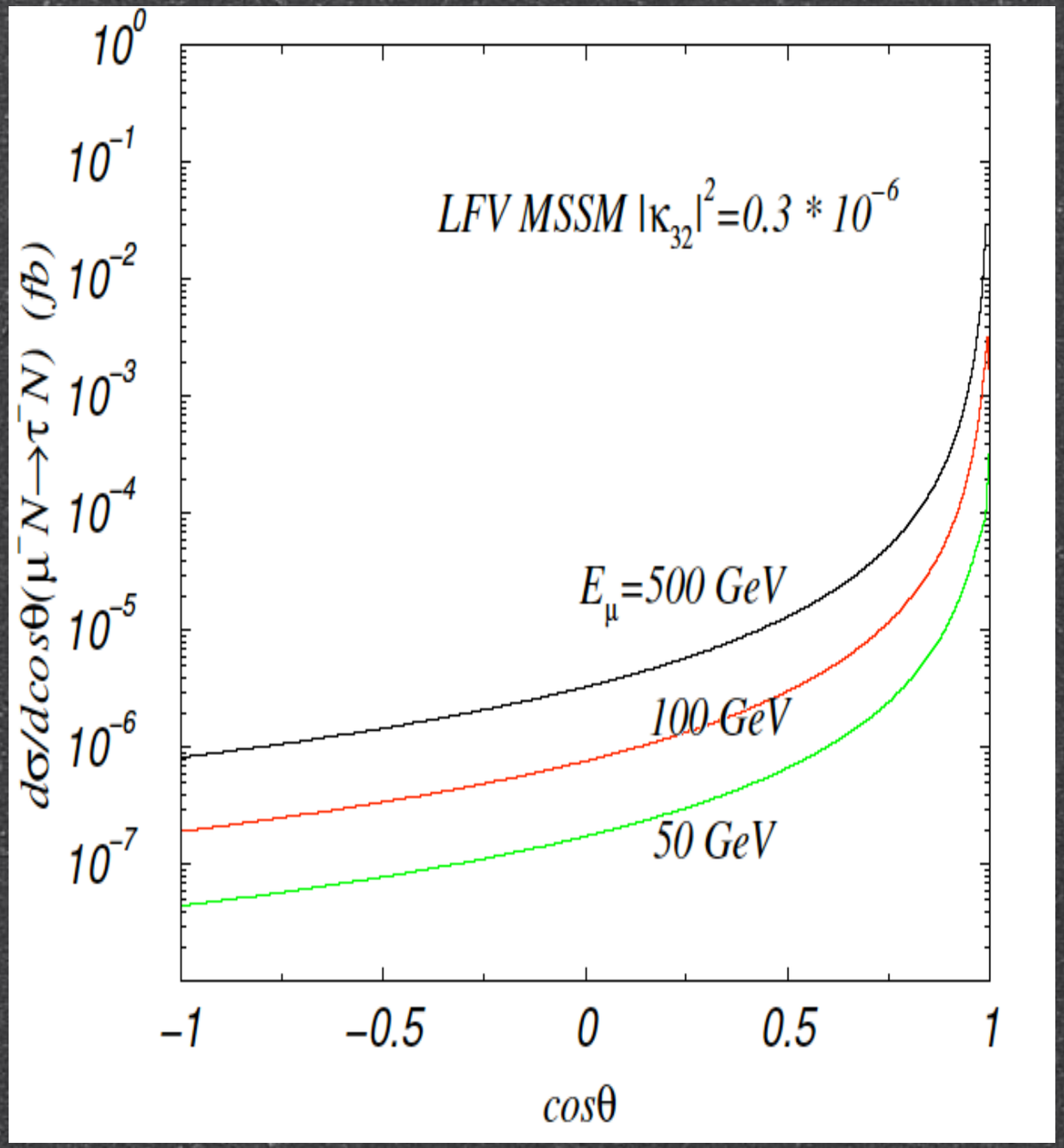
$$1 - \cos^2\theta_{CM}$$

$$\mu_L \to \tau_R$$

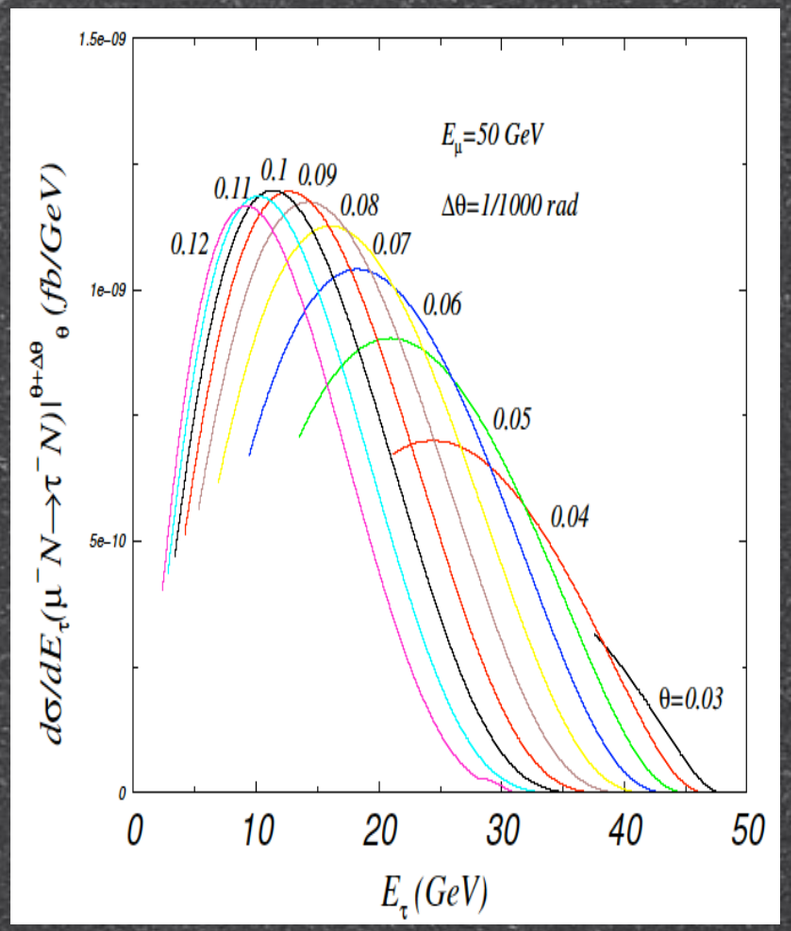
$$\mu_R \to \tau_L$$

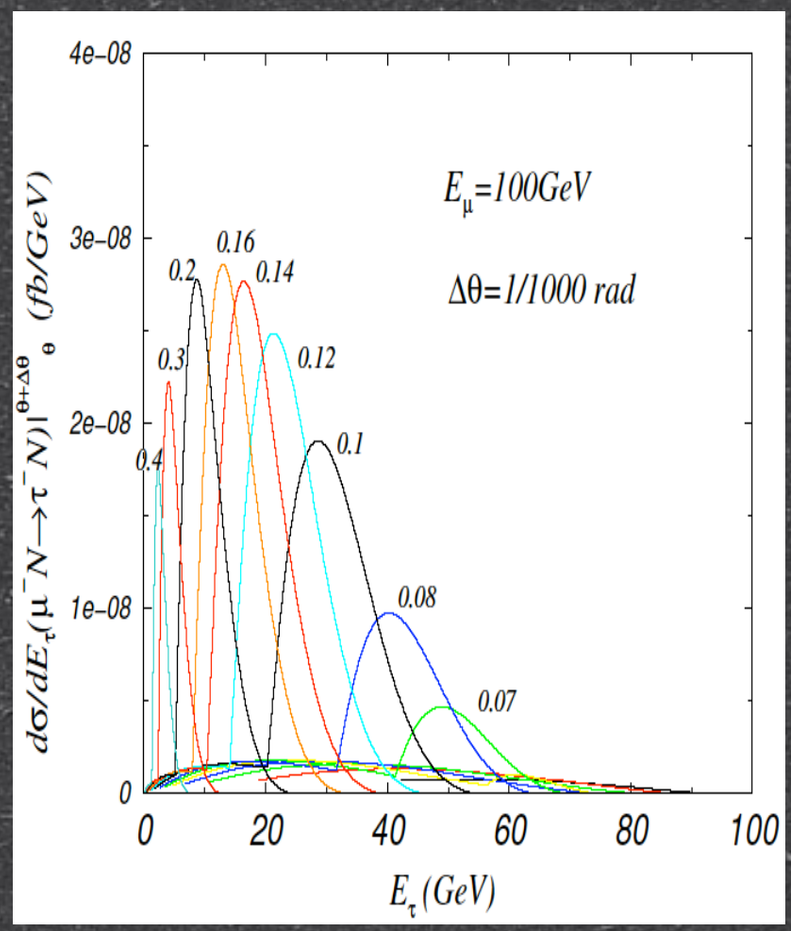
backward at CM, may useful for identification.

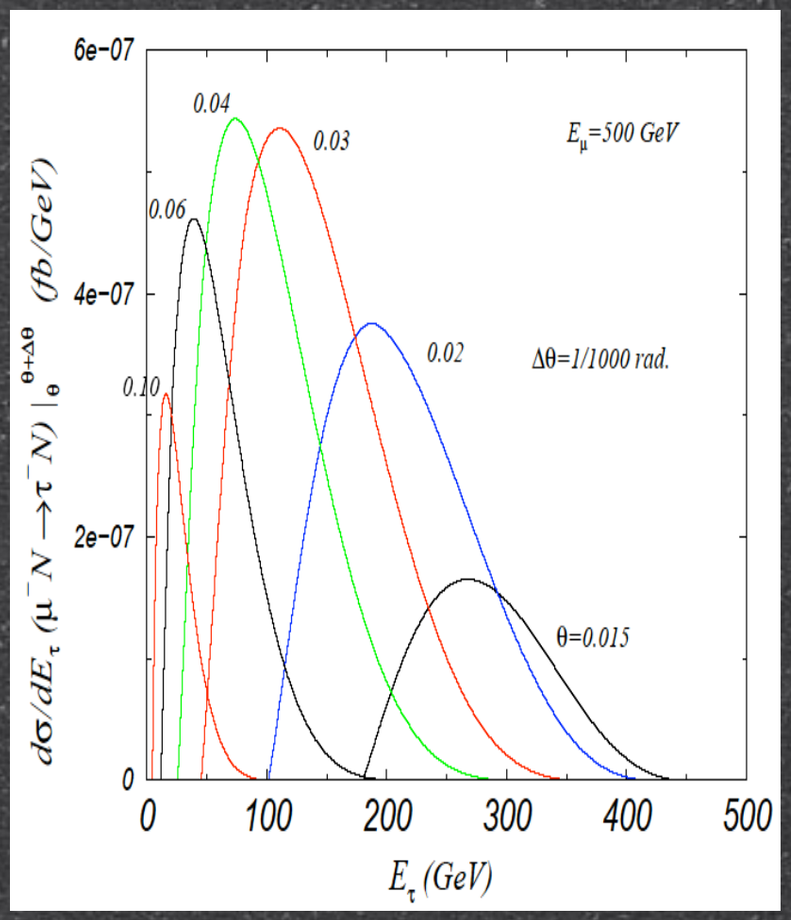




Energy-Anglar Distribution





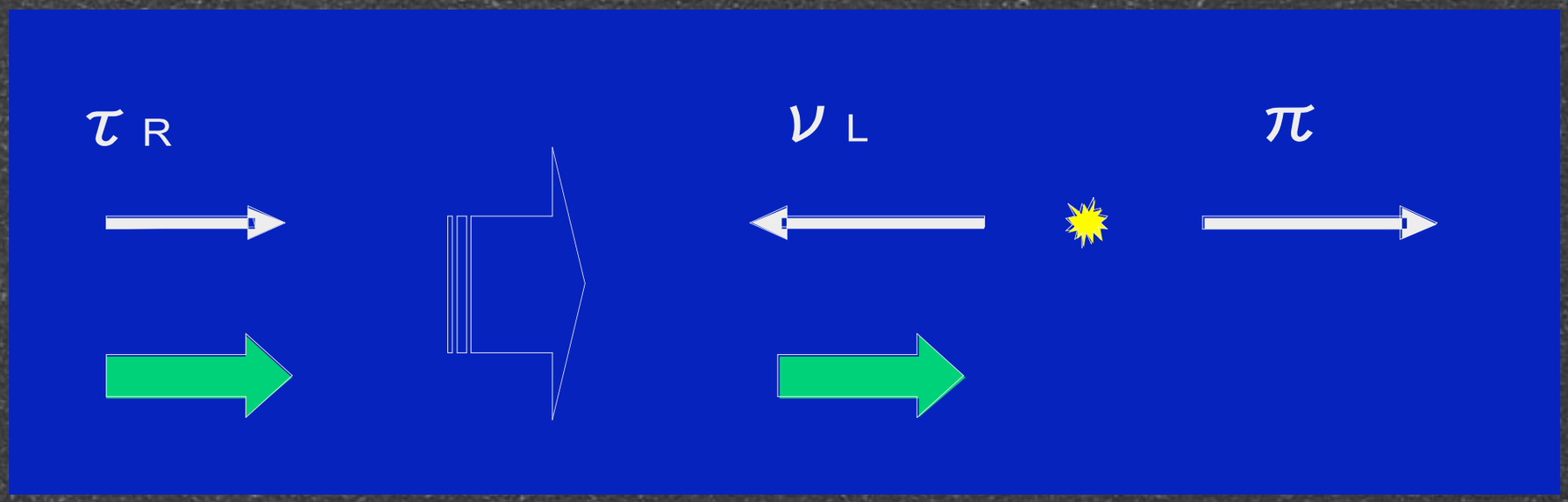


E μ =50 GeV E μ =100 GeV E μ =500 GeV

In Lab. frame, taus are emitted forward, but still with large P_T.

Signals

- For instance, use two-body haronic decay of tau leptons.
- $\tau \rightarrow \pi\nu(\rho\nu...) + \text{missing neutrino energy}$
- tau decay products
- a hadron from the right-handed tau with highenergy is emitted forward



Backgrounds

- Muons from elastic or inelastic scattering off target ($\mu N \rightarrow \mu X$) would become backgrounds, if they are misindentified as pions.
  - forward-peaked → rejected by emission angles.
  - highly-efficient PID (pions from muons)
- Hadrons from target might be soft in energy.

Need Realistic Detector Layout and Simulation

Chirality / T-odd

Model Discrimination

	$\mu_L N \to \tau_R X$	$\mu_R N \to \tau_L X$
left-handed slepton mixing	exits	vanishes
right-handed slepton mixing	vanishes	exists

T-odd correlations

$$\vec{s}_\tau \cdot (\vec{p}_\mu \times \vec{p}_\tau)$$

CP violation in LFV

$eN \to \tau X$ DIS Reaction

- In similar to $\mu N \to \tau X$ reacion, $eN \to \tau X$ DIS reaction can be considered. The same argument can be applied, if the ... sition is in the same magnitude ... ng.
- At an electron-posit... er (E=500 GeV, $L=10^{34}$/... ar are available.
- With 10... ss,

	...ection	# of taus	# observed
250 ...eV	10^{-3}fb	$O(10^{4\text{-}5})$	$O(10^{2\text{-}3})$

Most promising so far,
Background studies has to be done.

For nucleus target, multiplied by # of nucleons

$eN \rightarrow \tau X$ **Open Issues**

- Incident $e^{\pm}$ makes electromagnetic shower in a fixed target, losing energy.
  - no lengthy target (100 $g/cm^2 \rightarrow 10 g/cm^2$?)
- Photo-production of taus as background ?
- Simulation studies are needed.

.... Near Future

- In non-SUSY, cross section with scalar coupling is less constrained. → σ~0.1fb

with 10^{15} muons/year and 100 g/cm^2 target mass, about 10~100 events

- CERN SPS
  - S.N. Gninenko et al. CERN-SPSC-2004-016, SPSC-EOI-004
  - SPS muon beam 10-100 GeV
  - quasi-elastic scattering μN→τN
- J-LAB

Summary

- We consider the possibility of LFV μN→τX and eN→τX reactions in the DIS region at a muon collider and electron linear collider.
- SUSY LFV with Higgs mediation can be studied in these reactions. (SUSY scale > TeV)
- Constraints in SUSY case from τ→μη is tight.
- at Eμ>50 GeV, b-quark contribution is found to enhance the cross section significantly.
- Improvement of everal orders of magnitude can be expected. It is competitive to super B factories and a tau-charm factory.