Search for Lepton Flavor Violation in the $\mu + N \rightarrow \tau + N$ conversion (preliminary)

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Outline

- Introduction
- μ+N->τ+N conversion
- Choice of signature
- Experimental setup
- Signal/Background simulations
- Results
- Summary

Introduction

- SuperK'98 result: ν_u and/or ν_τ are not massless, ν_u-ν_τ mixing is large.
  First observation of the LFV process with neutral leptons.
  SM has no LFV: New physics.

- Suggests LFV for associated μ, τ –leptons

- LFV involving charged leptons has never been observed.
  In many models LVF is natural
  - SUSY
  - Left-Right Symmetric Model
  - Top seesaw,
  - Extra dimensions
  - Higgs mediated LFV

- In some models LFV processes for tau are enhanced over muon processes

Experimental Limits on LFV

Reaction	90% CL Upper Limit
$\mu^+ \to e^+ \gamma$	1.2×10^{-11}
$\mu^+ \to e^+ e^- e^+$	1.0×10^{-12}
$\mu^- Ti \to e^- Ti$	4.3×10^{-12}
$\mu^- Pb \to e^- Pb$	4.6×10^{-11}
$\mu^- Au \to e^- Au$	$4.4 \sim 6.8 \times 10^{-13}$
$\mu^- Ti \to e^+ Ca$	3.6×10^{-11}
$\mu^- e^+ \to \mu^+ e^-$	8.3×10^{-11}
$\tau \to e \gamma$	2.7×10^{-6}
$\tau \to \mu \gamma$	1.1×10^{-6}
$\tau \to e e e$	2.9×10^{-6}
$\tau \to \mu \mu \mu$	1.9×10^{-6}
$K_L \to \mu e$	4.7×10^{-12}
$K_L \to \pi^0 \mu e$	6.2×10^{-9}
$K^+ \to \pi^+ \mu e$	2.8×10^{-11}
$D^0 \to \mu e, \varphi \mu e$	$8.1 \times 10^{-6}, 3.4 \times 10^{-5}$
$B \to \mu e, K \mu e$	$1.5 \times 10^{-6}, 8 \times 10^{-7}$
$Z \to \mu e, \tau e, \tau\mu$	$1.7 \times 10^{-6}, 9.8 \times 10^{-6}, 1.2 \times 10^{-5}$
$J/\psi \to \mu \tau, e \tau$	$2.0 \times 10^{-6}, 8.3 \times 10^{-6}$

Future Plans

Focus on μ-e sector:

BNL: $\mu^- + Al \to e^- + Al < 10^{-16}$

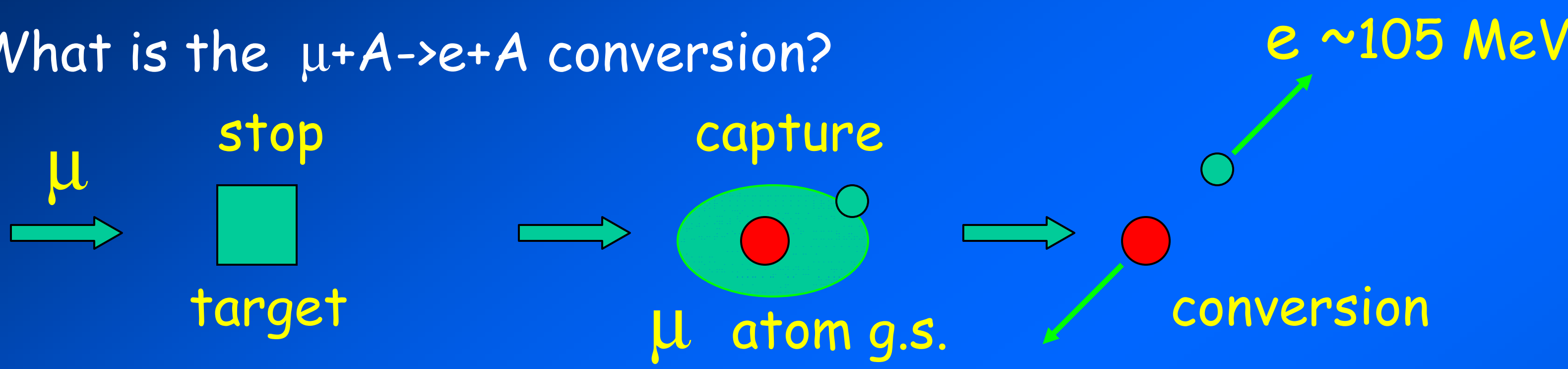
PSI: $\mu^- \to e^- + \gamma < 10^{-14}$

J- Parc : $\mu^- \to e^- < 10^{-18}$

For $\mu - \tau$ sector limits are quite modest

Why $\mu + N \to \tau + N$?

- What is the $\mu+A \to e+A$ conversion?



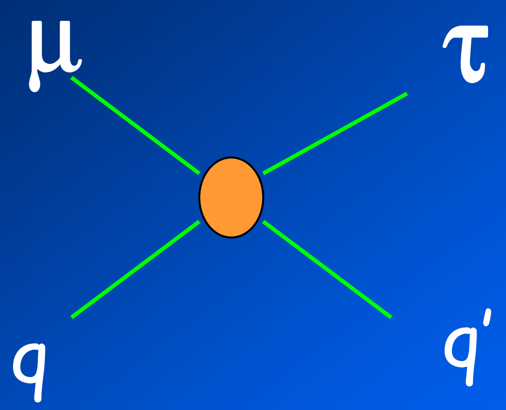
- The similar experiment to search for $\tau+A \to \mu+A$ would be very interesting, but too short τ-lifetime (< 0.3 ps) makes it unrealistic.

- Inverse process $\mu+ N \to \tau+N$ is possible for muon energy $E_\mu > \sim 3$ GeV at p or n.

- Is it interesting?
  Gninenko at el.(2002), Sher & Turan. (2004)

- More theoretical attention is required compare to $\mu+A \to e+A$

Phenomenology



$1/\Lambda^2(\mu\,\Gamma\,\tau)\,(q^\alpha\,\Gamma\,q^\beta)$

$\tau \to c$: week limit on Λ for $(\mu\tau)(u\,c)$

- enhances motivation to search for μ–τ conversion
- emphasizes need to test LFV in both rare τ decays and in μ–τ conversion at high energies

Note: $\Lambda \sim Br(\tau\text{->}\ldots)^{-1/4}$

Limits on Λ

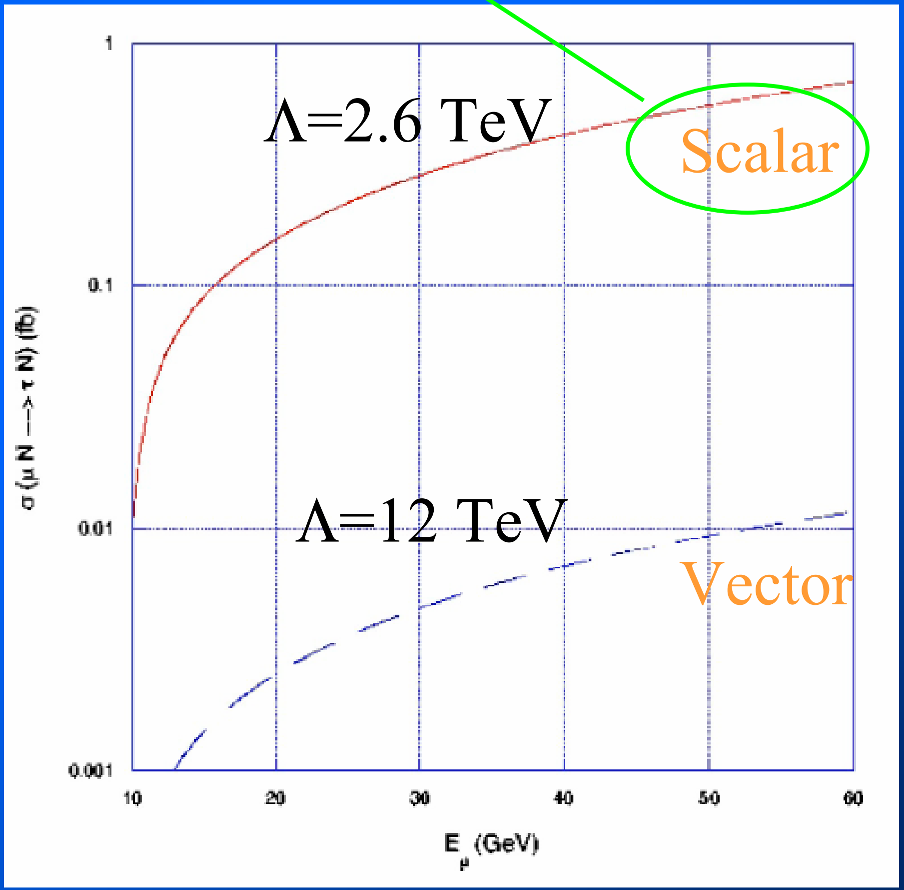
Black et al.

	S	PS	V	A
$\bar{u}u$	2.6 TeV ($\tau \to \mu\pi^+\pi^-$)	12 TeV ($\tau \to \mu\pi^0$)	12 TeV ($\tau \to \mu\rho$)	11 TeV ($\tau \to \mu\pi^0$)
$\bar{d}d$	2.6 TeV ($\tau \to \mu\pi^+\pi^-$)	12 TeV ($\tau \to \mu\pi^0$)	12 TeV ($\tau \to \mu\rho$)	11 TeV ($\tau \to \mu\pi^0$)
$\bar{s}s$	1.5 TeV ($\tau \to \mu K^+K-$)	9.9 TeV ($\tau \to \mu\eta$)	14 TeV ($\tau \to \mu\phi$)	9.5 TeV ($\tau \to \mu\eta$)
$\bar{s}d$	2.3 TeV ($\tau \to \mu K^+\pi^-$)	3.7 TeV ($\tau \to \mu K^0$)	13 TeV ($\tau \to \mu K^\star$)	3.6 TeV ($\tau \to \mu K^0$)
$\bar{b}d$	2.2 TeV ($B \to \pi\mu\tau$)	9.3 TeV ($B \to \mu\tau$)	2.2 TeV ($B \to \pi\mu\tau$)	8.2 TeV ($B \to \mu\tau$)
$\bar{b}s$	2.6 TeV ($B \to K\mu\tau$)	2.8 TeV ($B_s \to \mu\tau$)	2.6 TeV ($B \to K\mu\tau$)	2.5 TeV ($B_s \to \mu\tau$)
$\bar{t}c$	190 GeV ($t \to c\mu\tau$)	190 GeV ($t \to c\mu\tau$)	310 GeV ($B \to \mu\tau$)	310 GeV ($B \to \mu\tau$)
$\bar{t}u$	190 GeV ($t \to u\mu\tau$)	190 GeV ($t \to u\mu\tau$)	650 GeV ($B \to \mu\tau$)	650 GeV ($B \to \mu\tau$)
$\bar{c}u$	⋆	⋆	550 GeV ($\tau \to \mu\phi$)	550 GeV ($\tau \to \mu\phi$)
$\bar{c}c$	⋆	⋆	1.1 TeV ($\tau \to \mu\phi$)	1.1 TeV ($\tau \to \mu\phi$)
$\bar{b}b$	⋆	⋆	180 GeV ($\Upsilon \to \mu\tau$)	⋆
$\bar{t}t$	⋆	⋆	75 GeV ($B \to \mu\tau$)	120 GeV ($B \to \mu\tau$)

Cross section for DIS μ + N -> τ + N

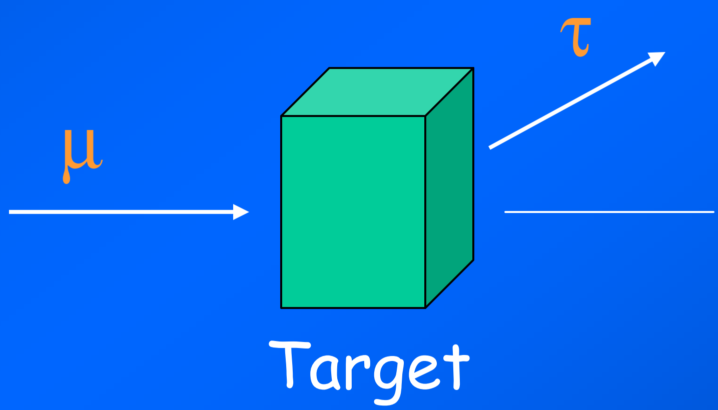
$$\sigma(\mu + q \rightarrow \tau + q) = \left(\frac{\pi s}{3\Lambda^4}\right)\left(1 - \frac{m_\tau^2}{s}\right)^2\left(1 + \frac{m_\tau^2}{2s}\right)$$

- cross section is model dependent
- S cross section is ~ 1fb at ~100 GeV
- V cross section is suppressed by the limit on Λ, $\sigma \sim 1/\Lambda^4$
- primary muon energy should be more than ~20 GeV



Rate estimate for $\mu + N \to \tau + N$

$$N_{\mu\to\tau} = N_\mu \; \sigma \, L \, \rho \, N_A \, Br(\tau\to..) \, \varepsilon$$



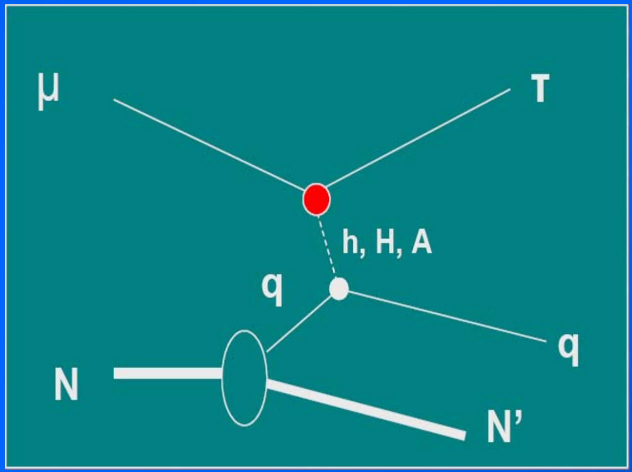
- muon energy E_μ=100 GeV
- cross section $\sigma \sim 1$ fb
- muon integral flux $N_\mu = 10^{15}$
- target length L = 100 cm
- target density $\rho \sim 10$ g/cm^3, e.g. PWO crystals
- branching ratio $Br(\tau\to..) \sim$ 17 %
  - $\tau\to\mu \nu \nu$ 17%
  - $\tau\to e\nu \nu$ 17%
  - $\tau\to\pi \nu$ 11%
- efficiency $\varepsilon \sim 100$ %

For $(\mu \tau)(q q)$, q=u,d
$N_{\mu\to\tau}$ = 120 events

For $(\mu \tau)(u c)$ $N_{\mu\to\tau}$
could be much higher

$\mu + N \to \tau + N$: Choice of the Signature

- DIS: $\mu + N \to \tau + X$ ($e, \gamma, \mu, h, ..$)
  - for any τ decay mode, the μ photoproduction is the main source of background, $\sigma(\mu-\tau)/\sigma_{\mu}(\gamma) < 10^{-10}$
  - complicated final state and analysis
  - many possibilities for background



- quasi-elastic (QE) $\mu + N \to \tau + N'$, and/or coherent $\mu + A \to \tau + A$ (?)
  - two-body reaction,
  - low momentum transfer
  - smaller cross sections
  - enhancement for coherent $\mu-\tau$?
  - monoenergetic τ
  - small energy of N' or N* , < ~ 1 GeV

So far $\tau \to \mu\nu\nu, \pi\nu$

Signature:

- single μ, π
- large missing E
- missing Pt
- small E_{TARGET}

Comment on background

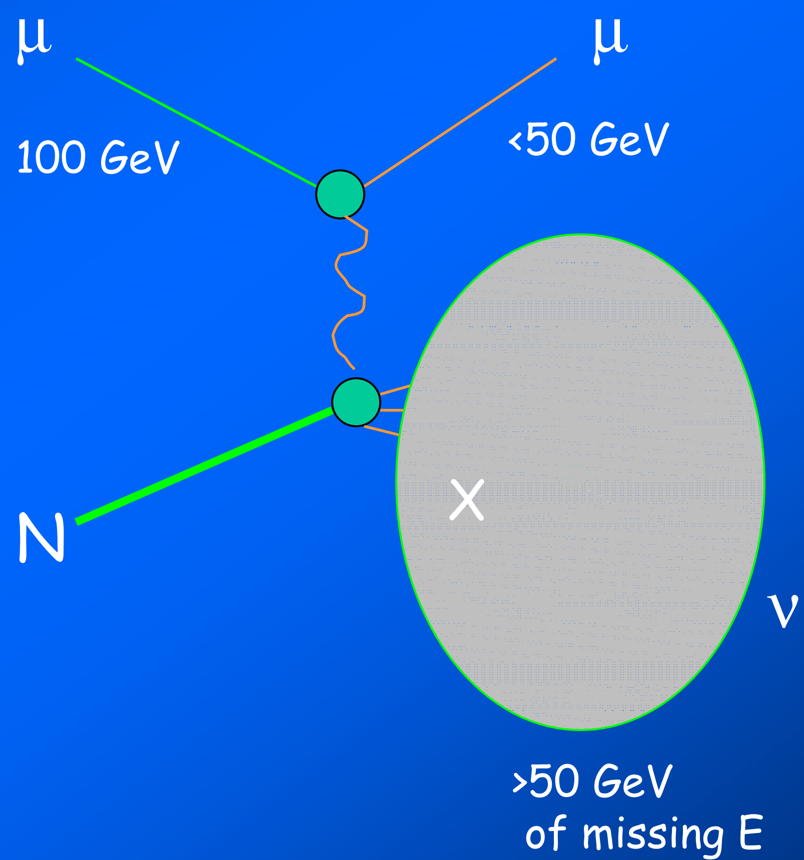
Large missing energy is one of the keys, good hermiticity is important

If detector is hermetic- leakages are mostly due to X neutrino decays: X -> ν + L_ν (associated lepton, LF conservation !).

If neutrino energy is ~a few 10s GeV, small E_L from X -> ν + L_ν is very unlikely.

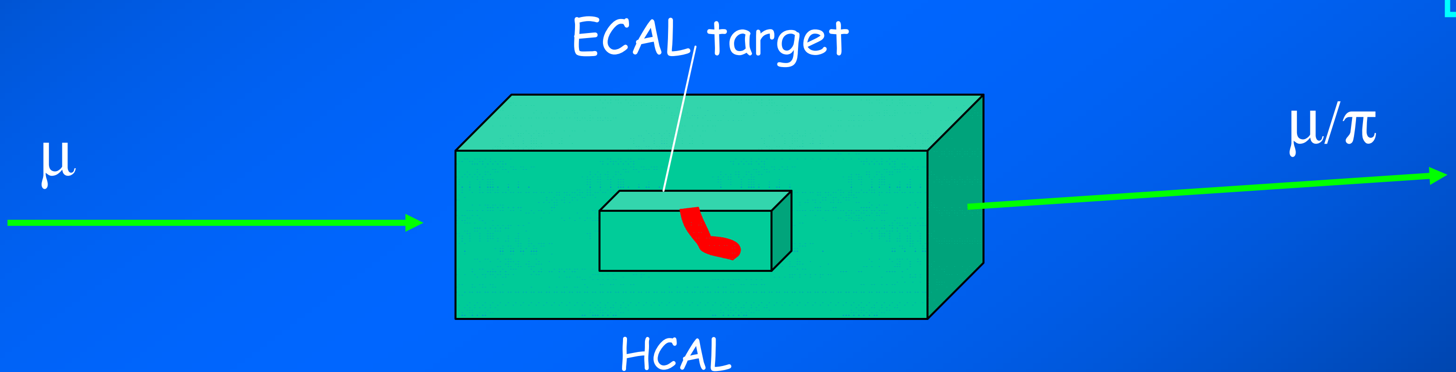
High suppression of photoproduction.

Week $\mu \rightarrow \nu$ reactions are another source of background, $\sigma(\mu \rightarrow \tau)/\sigma(\mu \rightarrow \nu) \sim 10^{-4} - 10^{-2}$



Experimental Setup

- high rate capability: simple design
- active target with low energy threshold
- hermetic (good ~4π coverage) detector
- electromagnetic & hadronic calorimeter energy resolution, granularity
- high in/out going muon momentum resolution
- particles ID



Signature:

- single μ, π
- large missing E
- missing Pt
- small E_{TARGET}
- no E_{HCAL}

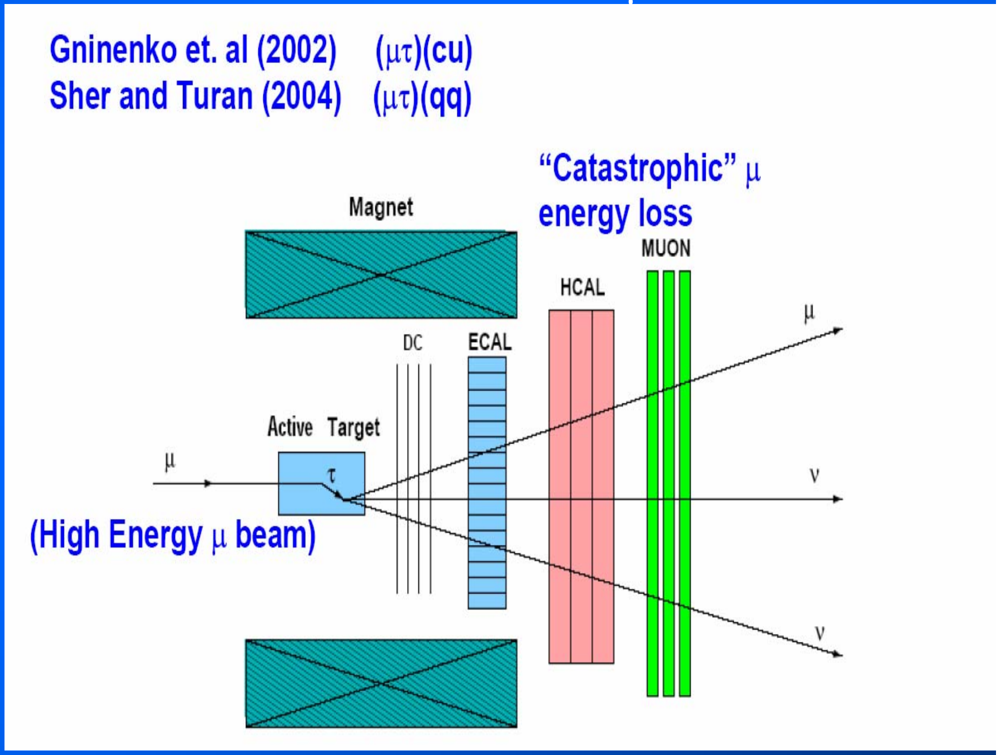
Hermiticity might confront μ/π precision measurements

Simulations

Analogy with ν–induced reactions used in simulations, e.g. :

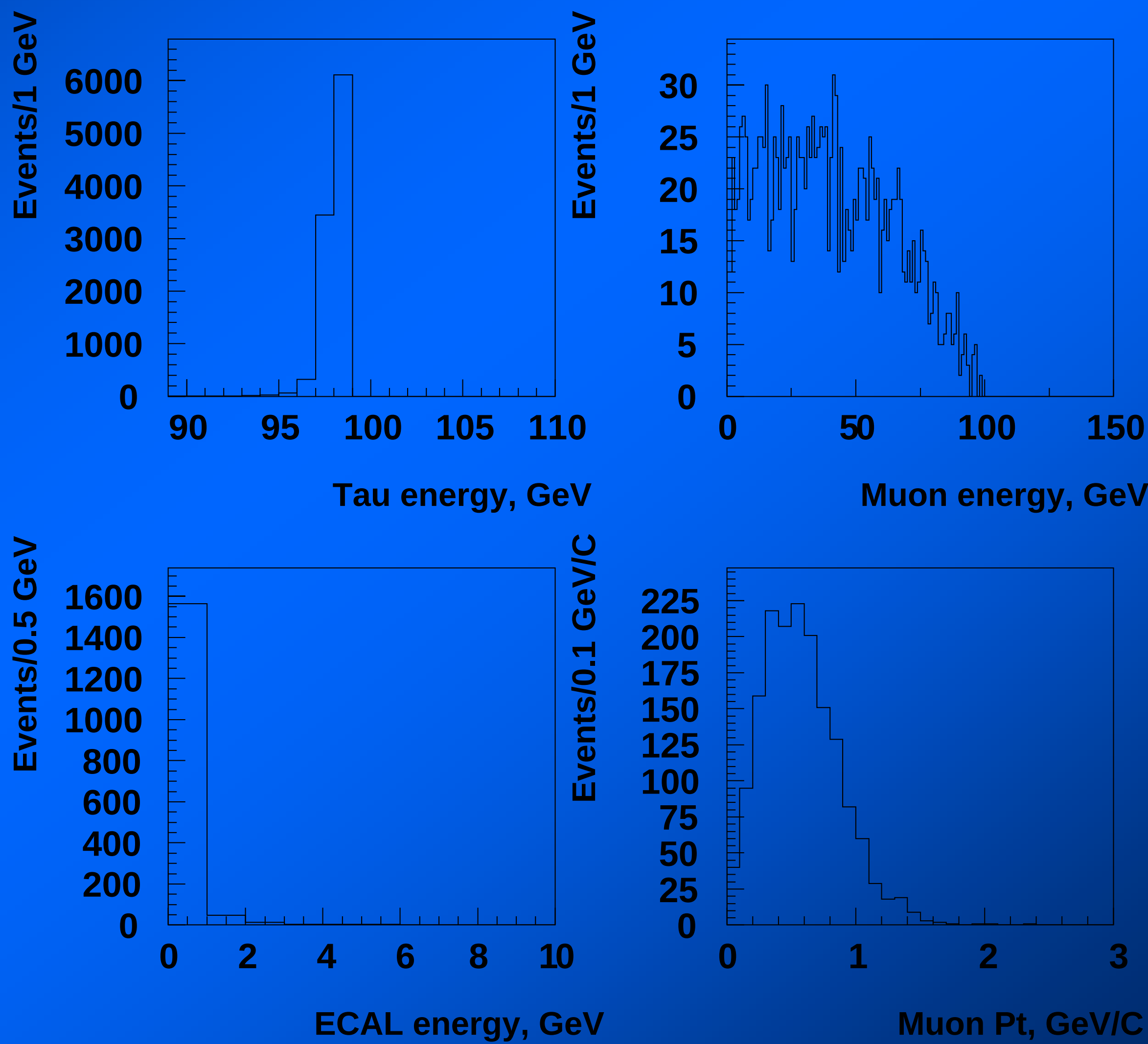
- ν_τ + n -> τ + p
  $\Updownarrow$ $\Updownarrow$
  μ + n -> τ + n
- ν_τ + p -> τ + n
  $\Updownarrow$ $\Updownarrow$
  μ + p -> τ + p
- νCC $\Longleftrightarrow$ μCC
- . . . . . .

Nomad configuration/software
(WA-96, Search for $\nu_\mu \to \nu_\tau$)



QE: μ+ N–>τ+N signal simulation
$\searrow \mu\ \nu\ \nu$

- monochromatic τ
- ~60% μ below 50 GeV
- ECAL energy <1 GeV
- Pt < 1.5 GeV/c



Background sources for QE ($\mu \to \tau$) + $\tau \to \mu\, \nu\, \nu$

The goal is to search for a few, at most ~100 $\mu - \tau$ induced events among ~10^{12} μ interactions. Background sources have to be explored down to 10^{-12}

- Beam related:

- low energy tail E < 50 GeV

- π /K decays in flight:

  $f_\pi \times P_{Dec} \times P_\mu(E<E\ cut) \times P_{ECAL}$

K decays are more dangerous

- DIS like QEL

- $\mu+N \to \mu' +$ neutrals + leakage

- $\mu+N \to \mu' + X \to L + \nu + \ldots\ldots$

$\mu\, \nu\, \nu$ final state

- μCC: $\mu+N \to \nu+X \to \mu+ \ldots$
- QE or Coherent trilepton

  production $\mu+A \to \mu+\nu+\nu+A$

- Coherent π production

  $\mu+A \to \nu+\pi+A$

  ($\pi \to \mu+\nu$)

- Single charm production:

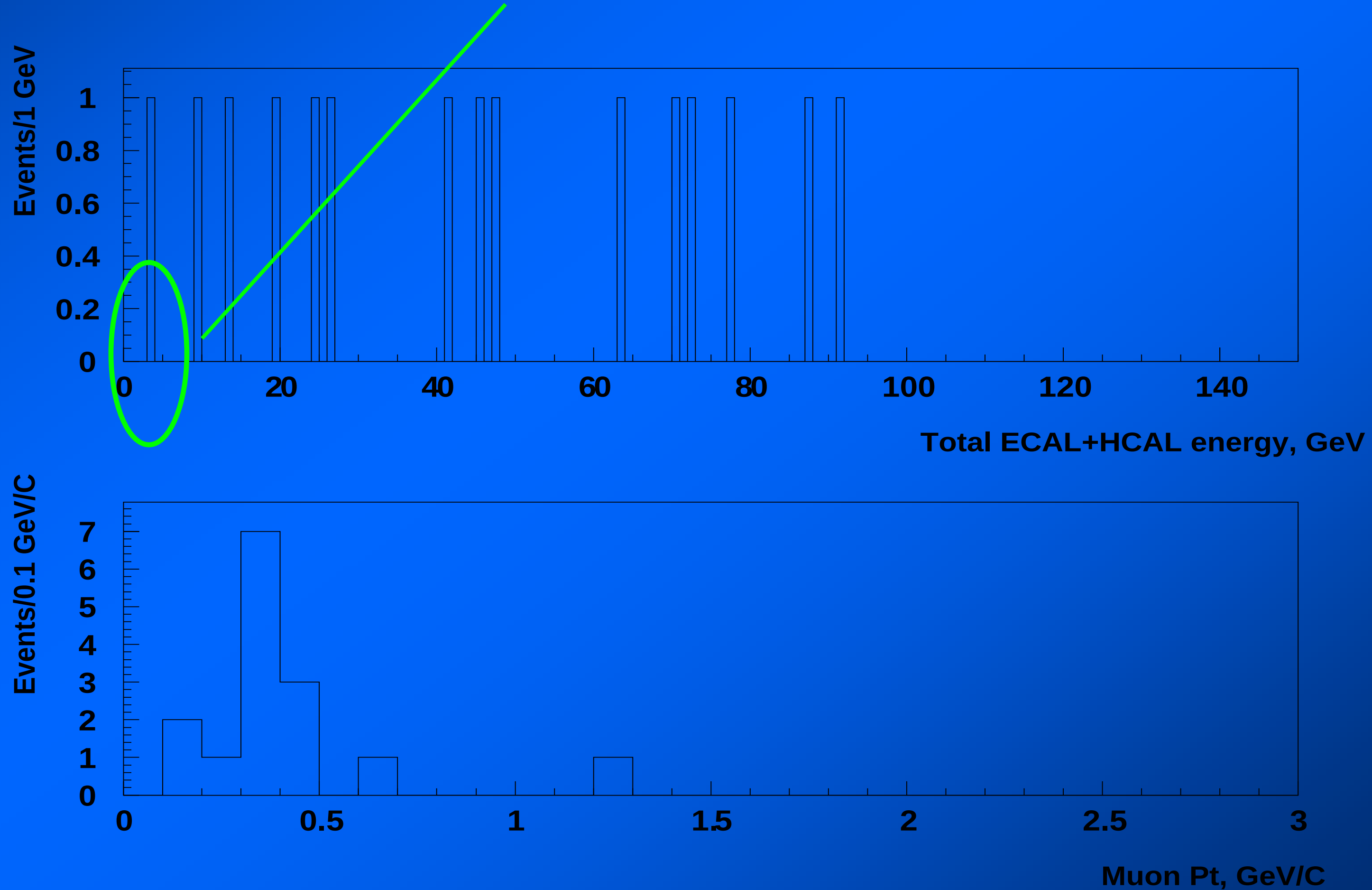
  $\mu+d,s \to \nu+c \to s+\mu+\nu$

  (beam sign is important !)

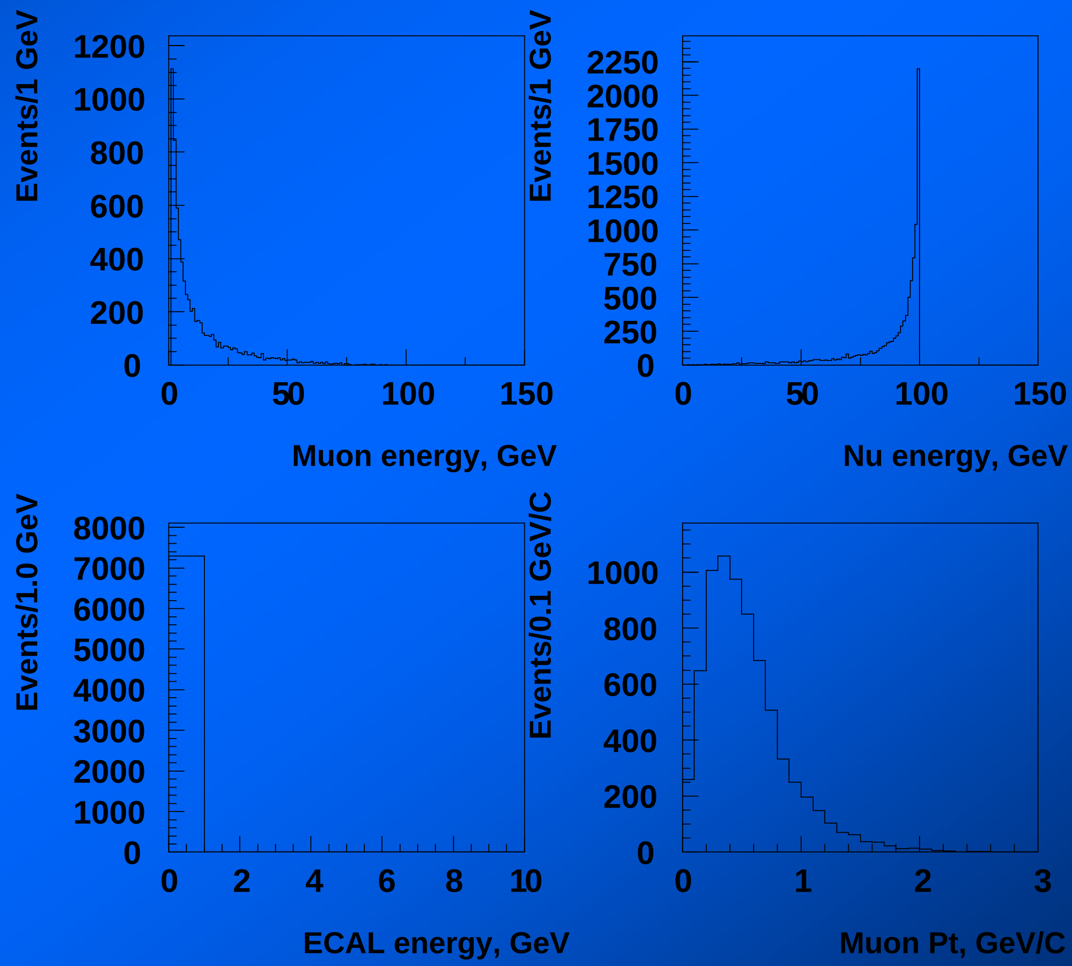
- . . . .

μ+ N >ν+X (μCC) sample
⎿→ μ+...

10^4 simulated events at 100 GeV
1 event found



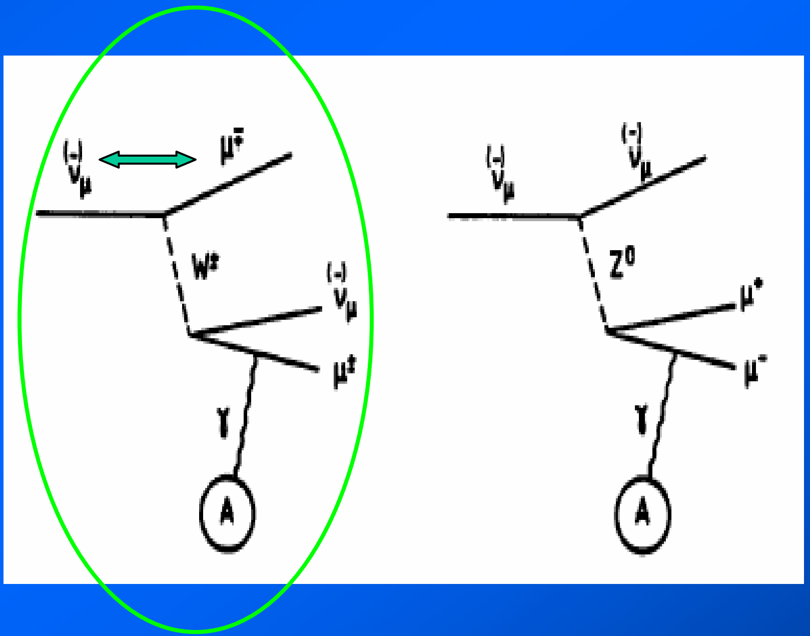
Coherent $\mu + A \to \nu + \pi + A$
$\hookrightarrow \mu + \nu$



- Additional suppression due to π decay in flight
- ~50% μ < 10 GeV
- ECAL < 1 GeV
- Pt < 1.5 GeV/c

Coherent trilepton production
$\mu + A \to \nu + \mu + \nu + A$

CHARM II '91: $\sigma \sim 0.03$ fb
at $\langle E \rangle \sim 24$ GeV



Summary of background for the QE reaction : $\mu + N \rightarrow \tau + N \rightarrow \mu \nu \nu + N$

Source of background	Rate per μ interaction (very preliminary)
E< ~50 GeV muons in the beam from π/K decays	tbd
μ photoproduction	tbd
DIS μ CC	$\sim 10^{-14}$
Coherent trilepton $\mu + A \rightarrow \mu + \nu + \nu + A$	$\sim 10^{-14}$
Coherent π production $\mu + A \rightarrow \nu + \pi + A$	$\sim 10^{-15}$
single charm in μCC	$< 10^{-14}$

People/Institutes involved

Experimental groups

- LAPP, Annecy
- INR, Moscow
- IHEP, Protvino
- ETH, Zurich (help/experience with simulations, A.Rubbia's group)

Theoretical groups

- College William and Merry, Williamsburg
- INR, Moscow

Also,

- Osaka Univ. , S. Kanemura et al., talk at Tau'04, 16 Sept. 2004.
- JINR, Dubna, S. Kovalenko
- H. Kosmas's group (Ioannina and Tuebingen) , coherent $\mu-\tau$ cross section

Summary

- search for LFV in muon to tau conversion would be interesting and challenging

- further work is required to study
  - muon beam : energy, intensity, purity, …
  - target: composition, mass, …
  - detector: rate capability, precision, ...
  - production mechanism and cross sections
  - best experimental signature
  - signal/background: MC simulations, tools, …

  and demonstrate feasibility of the experiment