Feasibility studies for a $\mu \to \tau$ conversion experiment

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Flavour in the Era of the LHC, CERN, February 6-8 2006

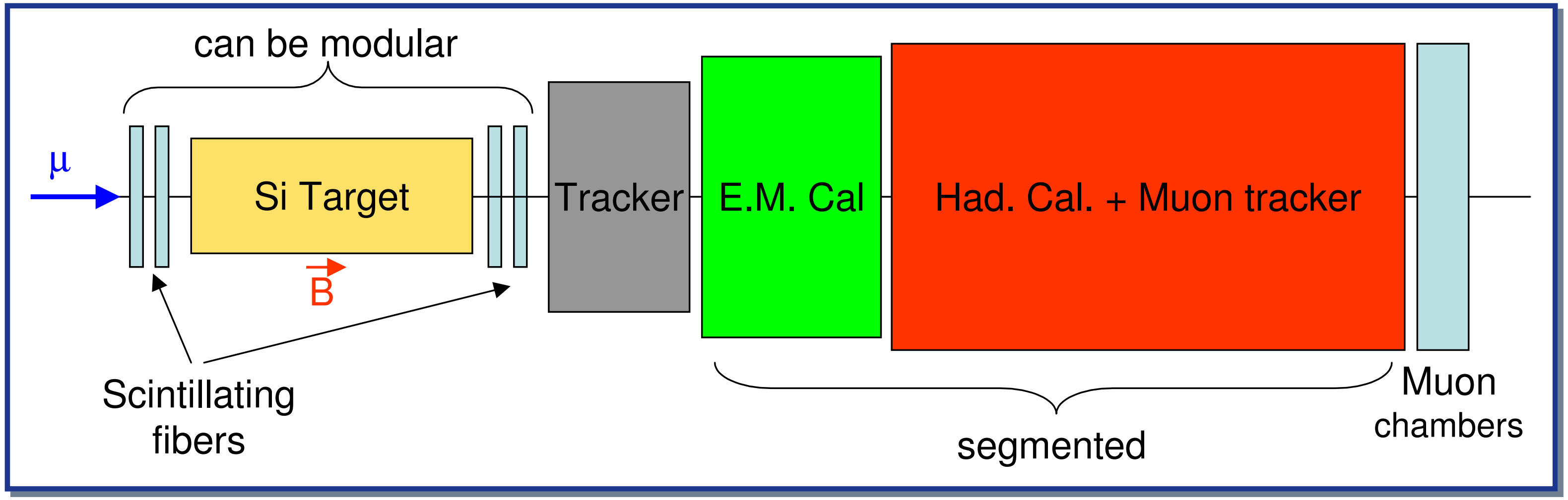
Introduction

- Lepton Flavour Violation powerful probe for New Physics effects
  - LFV tau processes may be enhanced w.r.t. e, μ (e.g. Higgs mediation)
- Use fixed target $\mu N \to \tau X$ conversion experiment to probe tau-related LFV?
- Outline
  - summarize G.Marchiori's talk at previous meeting (November 2005)
    - existing experimental limits on $\sigma_{\mu\to\tau}$
    - conceptual design of an experimental apparatus
  - investigate feasibility of an experimental apparatus
    - Tracker
    - Calorimeters
    - Trigger
  - Conclusions

Limits on $\sigma_{\mu\to\tau}$

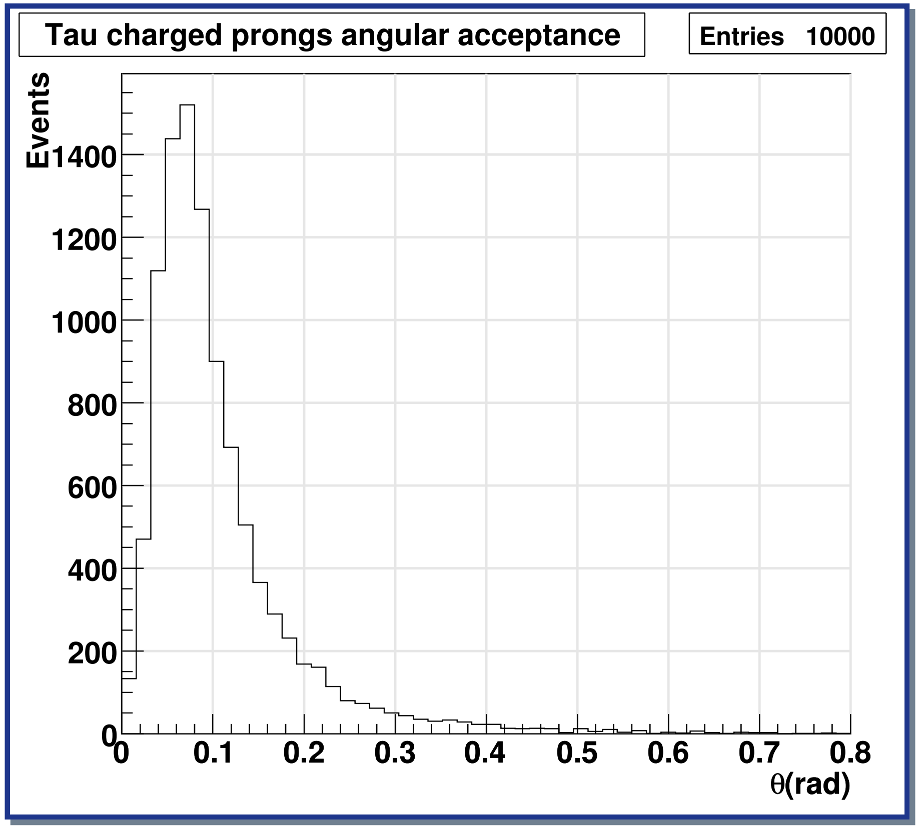
- BABAR & Belle: upper limits on tau LFV BRs $\approx 10^{-7}$ now, $\approx 10^{-8}$ in 2008-2010
- model independent conversion to limits on $\sigma\,(\mu N \to \tau X)$:
  - Sher & Turan, PRD69:017302,2004 – Black et al., PRD66:053002,2002
  - $\mathrm{BR}(\tau \to \mu X) < 10^{-8} \longrightarrow \boxed{\sigma_{\mu\to\tau} < 3.5\,\mathrm{ab}}$ $(E_\mu = 100\,\mathrm{GeV},\ \boxed{\sigma_{\mu\to\tau} \propto E_\mu})$

Experimental apparatus conceptual design



- silicon target 100×100 cm^2, 10 cm deep (330 planes, 300 μm each)
- $\boxed{1000\ \mu \to \tau \text{ events/year for } \sigma_{\mu\to\tau} = 1\text{ ab}}$ ➔ $\boxed{6{\cdot}10^{20}\text{ muons/year}}$ (E_μ = 100 GeV)
- with E_μ = 200 GeV ➔ $\boxed{3{\cdot}10^{20}\text{ muons/year}}$ are enough
- $3{\cdot}10^{20}$ muons/year, 10% duty cycle, 1 year = 10^7 s ➔ $\boxed{3{\cdot}10^{14}\text{ muons/s}}$

Detector acceptance



- ◆ $\mu N \to \tau X$: max angle of tau decay prongs
- ◆ detector xy size $\approx 1\text{m} + 2 \cdot \boxed{0.2\text{(rad)}} \cdot L_z\text{(m)}$ (typical fixed target detector, LHCb)

Interaction rate

- μN Deep Inelastic Scattering from $\boxed{\text{LEPTO}}$: $\sigma_{\mu N \to \mu X} = 47\,\text{nb}$
- Parameters: $\boxed{\min q^2 = 4\,\text{GeV}^2}$ $\boxed{\min W = 3\,\text{GeV}}$
- istantaneous rate, no. of DIS interactions every ΔT=25 ns:

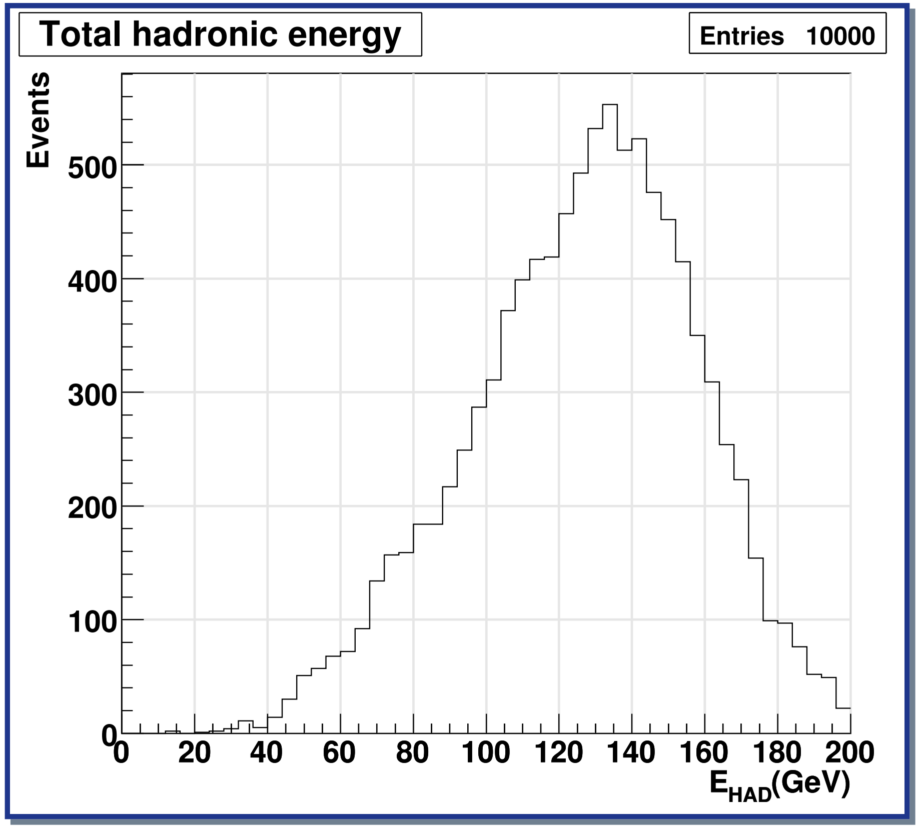
  $N_{\text{DIS},\Delta T} = N_\mu/\text{s} \cdot \Delta T \cdot N_N \cdot \left(\sigma_{\mu N \to \mu X}/\text{area}\right) = 0.176$ $\boxed{\text{less than LHC}}$

Dissipated power on target

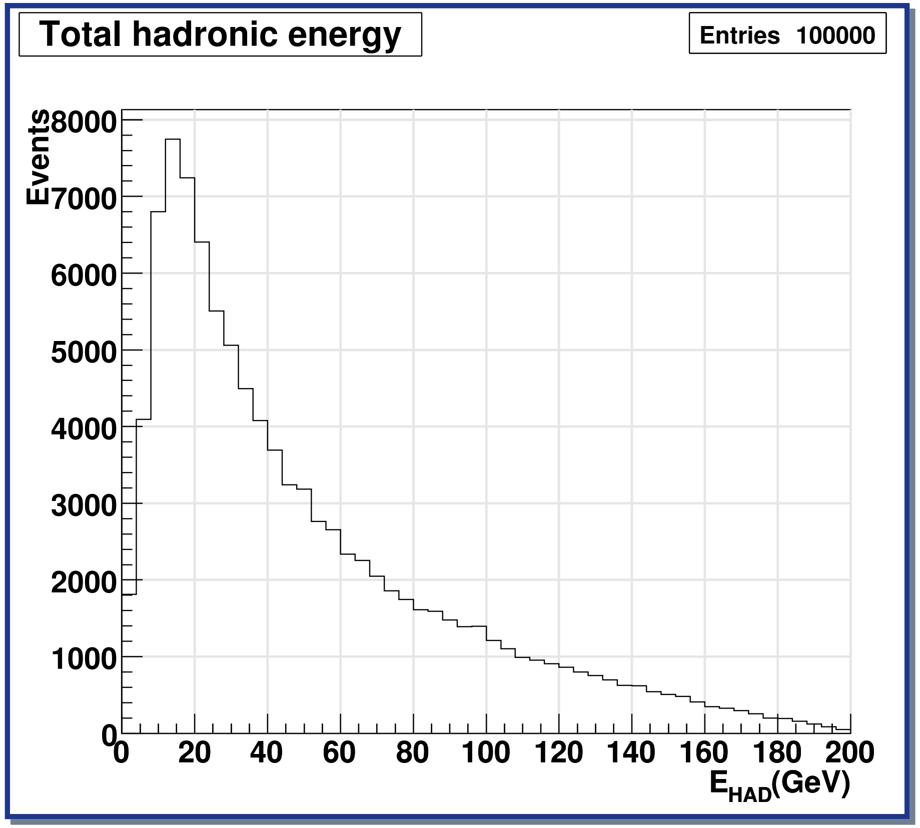
- Energy loss of 200 GeV muons on material $\approx$ 1.7 MeV/(g/cm^2)
- averaging over spill cycle, muons/s = $3{\cdot}10^{13}$
- power = $1.7{\cdot}10^6 \cdot 10 \cdot 2.33 \cdot 3{\cdot}10^{13} \cdot 1.6{\cdot}10^{-19} = \boxed{190\,\mathrm{W}}$ (0.58W per plane)
- factor $V_{BIAS}/3.6V$ for silicon detectors

Trigger rate

◆ Consider LHCb L0 trigger (E_T with calorimeters), just trigger on total E_{HAD}, E_{EM}



$\tau \to$ 3-prong



minimum bias

Trigger rate

- requiring $E_{HAD} > 60\,\text{GeV} \longrightarrow \approx 1/3$ events, $\sigma \approx 15\,\text{nb}$
- $\longrightarrow$ L0 trigger rate $= 0.176/3/\left(25{\cdot}10^{-9}\right) = \boxed{2.3\,\text{MHz}}$ (LHCb: 1 MHz)

Radiation

- average flux $\boxed{3{\cdot}10^{16}\,\text{muon}/\text{cm}^2/\text{year}}$
- corresponds to $\approx$80 MRad/y energy loss in any material
- Zero Degree Calorimeters for LHC anticipate similar fluences
- LHC inner trackers 1 MeV-neutron-fluences: $\sim 10^{14}$, SuperLHC $\sim 10^{16}$
- for silicon, 1 MeV-neutron-fluences probably smaller than muon fluences

Muon beam occupancy on tracker

- require $\boxed{\text{occupancy} < 1\%}$ per channel over integration time
- fastest conceivable tracker: $\boxed{10\,\text{ns integration time}}$
- How much segmentation needed?
  - $0.01 = N_\mu/s \cdot \Delta T/N_\text{cells}$
    $N_\text{cells} = N_\mu/s \cdot \Delta T/0.01 = 3{\cdot}10^{14} \cdot 10{\cdot}10^{-9}/0.01 = 3{\cdot}10^{8}$
- Silicon strips or scintillating fibers size: $\approx 0.003\,\mu$m $\boxed{\text{too small}}$
- Silicon pixels size: $\approx 60\,\mu$m $\boxed{\text{feasible}}$
  - but large cost for 330 planes 1m^2 each

Data rate from muons per tracker plane

- hits/s = $3{\cdot}10^{14}$ assuming automatic zero suppression
- bits = $\ln N_{\text{cells}} / \ln 2 = \ln 3{\cdot}10^8 / \ln 2 \approx 28$
- bits/s $\approx 28 \cdot 3{\cdot}10^{14} = 8.4{\cdot}10^{15}$
- 10 GHz optical fibers ⟶ $8.4{\cdot}10^5$ fibers per plane too many
- get tracker data for L0 triggers only? (assume 1MHz L0 trigger)
- hits/trigger = $1\% \cdot 3{\cdot}10^8 = 3{\cdot}10^6$
- bits/s = $28 \cdot 3{\cdot}10^8 \cdot 1{\cdot}10^6 = 8.4{\cdot}10^{13}$
- 10 GHz optical fibers ⟶ 8400 fibers (× 330 planes) feasible?

ECAL energy per tower from muons

- LHCb ECAL: 66 layers, 2 mm lead, 4 mm scint., 4×4 cm^2 lateral size, 25 ns int.time
  - high radiation doses ⟶ quartz fibers considered for LHC ZDC
- muon ECAL energy ≈ muon energy loss on ECAL (≈ on ECAL lead)
- $E_\mu = 1.7\,\text{MeV} \cdot 66 \cdot 0.2 \cdot 11.35 \approx 255\,\text{MeV}$
- $N_\mu = 3{\cdot}10^{14} \cdot (4{\cdot}4)/(100{\cdot}100) \cdot 25{\cdot}10^{-9} \approx 12000$
- $E_\text{tower} = E_\mu \cdot N_\mu \approx 3\,\text{TeV}$
- $\Delta E_\text{tower} = E_\text{tower}/\sqrt{N_\mu} \approx 27\,\text{GeV}$ too much?

Electrons from muon decay

- assume muons travel 4 m before ECAL
- $N_e = 3{\cdot}10^{14} \cdot 25{\cdot}10^{-9} \cdot 4/c/(\tau_\mu \cdot \gamma) \approx 24$ electrons every 25 ns
- $N_e/\mathrm{tower} = N_e \cdot (4{\cdot}4)/(100{\cdot}100) \approx 0.04$ electrons per tower every 25 ns
- → cannot rely on ECAL for triggers

HCAL energy per tower from muons

- LHCb HCAL: 75 layers, 16 mm iron, 4 mm scint., $13 \times 13\,\text{cm}^2$ lateral size, 25 ns int.time
  - high radiation doses ⟶ quartz fibers considered for LHC ZDC
- muon HCAL energy $\gtrsim$ muon energy loss on HCAL ($\approx$ on HCAL iron)
- $E_\mu = 1.7\,\text{MeV} \cdot 75 \cdot 1.6 \cdot 7.9 \approx 1.6\,\text{GeV}$
- $N_\mu = 3{\cdot}10^{14} \cdot (13{\cdot}13)/(100{\cdot}100) \cdot 25{\cdot}10^{-9} \approx 127000$
- $E_\text{tower} = E_\mu \cdot N_\mu \approx 200\,\text{TeV}$
- $\Delta E_\text{tower} = E_\text{tower}/\sqrt{N_\mu} \approx 560\,\text{GeV}$ too much!

Power due to muon beam on ECAL/HCAL towers

- Average over whole duty cycle ⟶ muons/s $= 0.1 \cdot 3{\cdot}10^{14} = 3{\cdot}10^{13}$
- $P(\text{ECAL tower}) = 0.1 \cdot 3{\cdot}10^{12}/25{\cdot}10^{-9} \cdot 1.6{\cdot}10^{-19} \approx 1.9\,\text{W}$
- $P(\text{ECAL}) = P(\text{ECAL tower}) \cdot (100{\cdot}100)/(4{\cdot}4) \approx 1.2\,\text{kW}$
- $P(\text{HCAL tower}) = 0.1 \cdot 200{\cdot}10^{12}/25{\cdot}10^{-9} \cdot 1.6{\cdot}10^{-19} \approx 128\,\text{W}$
- $P(\text{HCAL}) = P(\text{HCAL tower}) \cdot (100{\cdot}100)/(4{\cdot}4) \approx 7.5\,\text{kW}$
- dissipated power on ECAL/HCAL looks treatable

Conclusion for $3{\cdot}10^{14}$ muons/s/m^2

- dissipated power on detector OK
- LHC or super-LHC like radiation dose rates
- too high data rate on tracker ⟶ requires calorimeter trigger
- muon flux (and decays) prevent effective calorimeter trigger
- experiment appears unfeasible because of the muon flux
  - distribute muon flux over larger surface ⟶ proportional increase in cost
  - consider less ambitious flux of $3{\cdot}10^{11}$ muons/s/m^2

$3{\cdot}10^{11}$ muons/s/m^2, calorimeters

- calorimeter energy fluctuations scale with $\sqrt{N_\mu}$
- ECAL $\Delta E_{\text{tower}} \approx 27\,\text{GeV}/\sqrt{1000} \approx 0.85\,\text{GeV}$ OK
- electrons from muon decay, 1000 times less, ≈ 1 MHz rate on detector tough
- HCAL $\Delta E_{\text{tower}} \approx 560\,\text{GeV}/\sqrt{1000} \approx 18\,\text{GeV}$ problematic

$3{\cdot}10^{11}$ muons/s/m^2, tracker

- Assuming a 1 MHz calorimetric trigger, tracker data rate per plane →
  → 8.4 10 GHz fibers per tracker plane × 330 planes Challenging. . .

Conclusion

- detector for $3{\cdot}10^{14}$ muons/s/m^2 appears unfeasible
- detector for $3{\cdot}10^{11}$ muons/s/m^2 not unfeasible but challenging and expensive
- need to investigate attainable signal efficiency and purity