Expression of interest in design and construction of an experiment to search for $\mu + N \to \tau + N$ conversion with the intense cern sps muon beam

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Expression of Interest in Design and Construction of an Experiment to Search for $\mu + N \rightarrow \tau + N$ Conversion with the intense CERN SPS muon beam.

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Abstract

We investigate the possibility of performing a "missing energy" type experiment at the CERN SPS muon beam with the purpose to search for lepton-flavor violating $\mu - \tau$ conversion on nucleons in the 10-100 GeV energy range. The experiment can be performed in the near future with a sensitivity which cannot be reached at any of the existing high energy particle accelerators due to the high performance of the existing intense high energy muon beam at CERN SPS. Such an experiment would be an important component of the global program of searching for lepton-flavor violating transitions at low energies, LHC or at a future neutrino factory. It could be a natural start up for developing particle physics techniques for a similar experiment at a future neutrino factory.

1 Introduction

In the Standard Model (SM) lepton flavor is conserved. However many extensions of the SM, including grand unified theories, models based on SUSY,

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compositeness or technicolor involve lepton-flavor violating interactions at fundamental levels.

The biggest surprise in our understanding of flavor physics in the past decade has been the experimental discovery the neutrino mixing. This mixing indicates that analogous mixing in the charged lepton sector could be substantial and that the searches for charged lepton flavor violation will be crucial in determining the origin of flavor violation. The most promising such searches are i) the $\mu + N \to e + N$ conversion (MECO) experiment at BNL, and ii) the $\mu \to e + \gamma$ decay (MEG) experiment at PSI, recently discussed at the **Workshop on Physics with a Multi-MW Proton Source** at CERN. In the first process, low energy muons are stopped in a nuclear target, captured by a nucleus and then yield distinctive 105 MeV electrons.

The SuperK observation of large $\nu_\mu - \nu_\tau$ mixing gives strong motivation for considering similar transitions between the muon and tau. The process analogous to MECO, $\tau + N \to \mu + N$ is experimentally inconvenient, due to short lifetime of tau's. However, the inverse process $\mu + N \to \tau + N$ might be possible. Unlike MECO, this cannot occur for muons at rest, but in a high energy muon beam, one can look for such events. Such a high energy, high intensity and high quality beam is available at CERN [1] or is expected at neutrino factories (or early stages of muon factories).

In this Memo, which is based mainly on work of refs. [2,3] we suggest looking for flavor violating interactions by searching for $\mu - \tau$ conversion at the SPS muon beam [1] presently used by the experiment COMPASS.

The effective four-fermion interaction responsible for such conversion could be written in the form

$$\frac{4\pi}{\Lambda^2}(\bar{\mu}\Gamma\tau)(\bar{q}^\alpha\Gamma q^\beta) \qquad (1)$$

where Γ contains various combinations of Dirac gamma matrices and q^α is any combination of the six quarks. For instance, for the scalar -scalar interaction of diagonal quarks

$$\frac{4\pi}{\Lambda^2}(\bar{\mu}\tau)(\bar{q}q) \qquad (2)$$

where q is u or d quark. The existence of the process $\mu + N \to \tau + N$ implies that there will be muon and tau number violating rare τ-decays, such as $\tau \to \mu\pi,\ \tau \to \mu\pi\pi,\ \tau \to \mu\rho$ etc. The non-observation of these decay modes implies that $\Lambda \geq 2.6\ TeV$ [4]. Note that this limit is only valid for the vertex involving valence quarks.

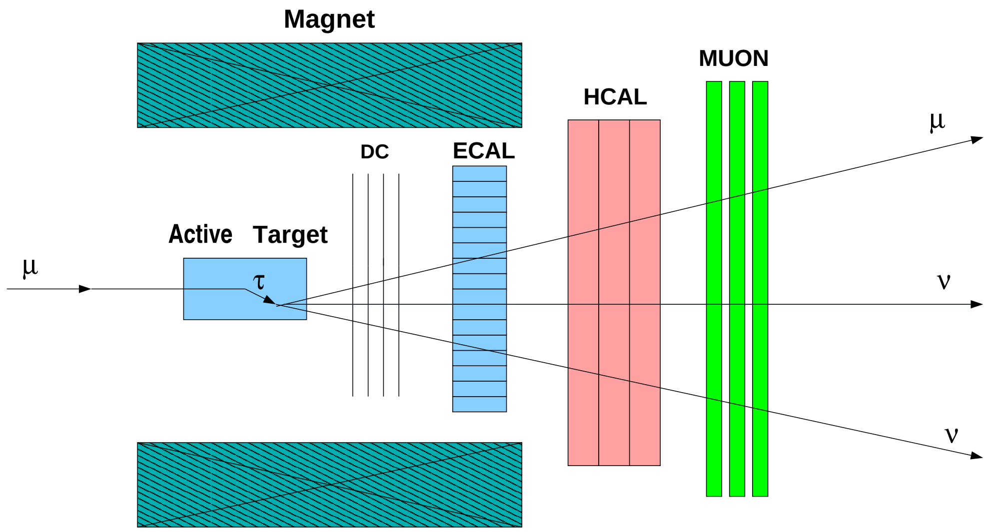

Fig. 1. *Schematic illustration of the "missing energy" type experiment on production of* τ *via* $\mu \to \tau$ *conversion in the active target and its detection via* $\tau \to \mu\nu\nu$ *decay. The experimental signature of the* $\mu \to \tau$ *conversion is a single muon in the final state with a catastrophic energy loss in the target. The muon momentum is measured by the drift chamber (DC) spectrometer. The muon is accompanied by no significant activity in the electromagnetic calorimeter (ECAL) and hadronic calorimeter (HCAL).*

For the effective interactions of the type

$$\bar{\mu}\tau[\frac{4\pi}{\Lambda_1^2}\bar{u}c + \frac{4\pi}{\Lambda_2^2}\bar{d}b + \frac{4\pi}{\Lambda_3^2}\bar{s}b] \tag{3}$$

bounds on Λ_i are much weaker due to trivial kinematics constraint, for instance, $\tau \to \mu + D$ decay cannot occur, because of $m_\tau < m_\mu + m_D$, see ref. [2] for discussion of current experimental bounds [2]. This provides a substantial advantage and allows potentially a much higher event rate.

2 Experimental search for $\mu \to \tau$ conversion.

We have simulated the search for $\mu \to \tau$ conversion at a high purity sign-selected 50 GeV muon beam, with a detector analogous to the one used by the experiment NOMAD (WA-96), to search for $\nu_\mu \to \nu_\tau$ oscillations at the SPS neutrino beam - see Figure 1. The simulations were partly based on the Monte Carlo program used at NOMAD for the standard neutrino interactions.

[2] For a recent review of flavor violation, see for instance, ref.[5]

The detector consists of a number of sub-detectors, most of which are located inside a $\simeq 0.5$ T dipole magnet: drift chambers (DC) with an average density of 0.1 g/cm^3 and a total thickness of about 0.2 radiation lengths followed by a lead-glass electromagnetic calorimeter (ECAL). A hadron calorimeter (HCAL) and muon stations are located just after the ECAL. For simplicity, we have assumed that the primary muon interactions occur in a fully active dense target which is, e.g. a block of lead glass, so that the energy deposition in the target is measured.

The sensitivity to $\mu \to \tau$ conversion and background level were studied for events with a simple topology of the final state. Namely, we consider quasi-elastic (QE) $\mu \to \tau$ conversion $\mu + N \to \tau + N$ at a single nucleon N with the subsequent $\tau \to \mu\nu\nu$ decay in the target. Since τ-leptons are very short lived particles - even at energy of $\simeq 100$ GeV the average decay length of τ lepton is of the order of a millimetre - their detection is impractical. The experimental signature of their presence in the beam would be a signal of fractional "disappearance" of the primary muon beam energy in the detector. Indeed, two neutrinos from the $\tau \to \mu\nu\nu$ decay would penetrate any type of calorimeter without significant attenuation and cannot be observed. Hence, the only visible energy is the energy associated with the decay muons. The experimental signature for the $\mu \to \tau$ conversion in the detector is a single muon of the same sign and with energy less than that from the primary muon beam, Figure 1.

3 Expected Results

Preliminary simulation results on signal and background estimates, can be found in ref.[2]. Using the effective four-fermion interactions (1) one can obtain that for the case of valence quarks the cross section of the reaction $\mu+q \to \tau+q$ is [3]:

$$\sigma(\mu + q \to \tau + q) = \frac{\pi s}{s\Lambda^4}\Big(1 - \frac{m_\tau^2}{s}\Big)^2\Big(1 + \frac{m_\tau^2}{2s}\Big)^2 \qquad (4)$$

Taking into account the lower limit on Λ of 2.6 TeV results in the total cross section $\sigma(\mu + N \to \tau + N) \simeq 0.55$ pb per nucleon for a 50 GeV muon beam. This corresponds to approximately $3 \times 10^{-14} \times \rho$ of $\mu + N \to \tau + N$ reactions per meter of target. Here, ρ is the density of the target in g/cm^3. With $\simeq 10^{15}$ muons on target delivered by the SPS during a year, there will be around 30 $\mu \to \tau$ conversion events per meter of target. Thus, in the case of valence quarks we can test flavor changing interactions with Λ up to $O(10\ TeV)$ provided we can get read of background discussed in ref. [2]. Note, that from nonobservations of leptonic τ-decays $\tau \to \mu\mu\mu, \mu\mu e, \mu ee$ the corresponding bounds on the scale of the four-fermion operators $\bar{\tau}\mu\bar{\mu}\mu$,$\bar{\tau}\mu\bar{\mu}e$, $\bar{\tau}\mu\bar{e}e$ are $\Lambda \geq O(20\ TeV)$ [4].

In the case when the four-fermion interaction of Eq.(3), e.g. $(\bar{\mu}\tau)(\bar{u}c)$, dominates, Λ cannot be bounded by τ-decays and the cross-section of Eq.(4) can be much higher. Thus, $\mu + N \rightarrow \tau + N$ conversion may occur at a rate within few orders of magnitude of the present experimental upper limit for the case of valence quarks. This result enhances the motivation for the search for $\mu + N \rightarrow \tau + N$ conversion and makes it the very interesting and exiting. It also emphasizes the need to test lepton flavor violation in both rare τ-decays and $\mu + N \rightarrow \tau + N$ conversion.

Note that, if the signal is not found, a limit on the corresponding cross section, say 1 pb, would give much better bound on the strengths of the interaction of Eq.(3) then any other experiment.

4 Collaboration

The list of possible participants in this experiment is under construction.

The design of the experiment is assumed to be performed in the framework of the collaboration between the groups from the LAPP(Annecy) and INR(Moscow).

The part of this project related to the more accurate simulations of the signal and background is agreed to be performed in collaboration with the Prof. A. Rubbia's group (ETH Zürich). Because of the large number of interactions in the target material the detail study of the background requires very large number of events resulting in prohibitively large amount of computer time. This work is still in progress.

Several experimental groups including one from the College of William & Mary (Williamsburg, USA) have also expressed their interest to this project.

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