μ τ flavor violation

Muon collider workshop
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Motivation for μ τ flavor violation

- **Incorrect motivation (but often stated):**

  Neutrino oscillations show that there is mixing in the neutrino sector, so shouldn't there be mixing in the charged lepton sector (leading to μ N --> e N, for example)?

No. Neutrino oscillations tell us that there is mixing in the charged weak current. It could be due to mixing in the neutrino mass matrix, the charged lepton mass matrix, or both.

Motivation for μ τ flavor violation

- Neutrino oscillations demonstrate mixing in the charged weak current. This would lead to mixing in the neutral weak current through a loop. Of course, there could be other sources of mixing in neutral currents
- No evidence exists to date of any mixing in leptonic neutral currents.
- The most precise measurements of such mixing would be in the charged lepton sector.
- If the mixing is larger for larger masses, then μ τ violation would be the place to look

Two papers will be briefly discussed

Scalar mediated FCNC at the first muon collider.
MS, Phys.Lett.B487:151-154,2000.

μ + N ---> τ + N at a muon or neutrino factory.
MS, Ismail Turan, Phys.Rev.D69:017302,2004.

Two-Higgs Doublet Models

- In general, fermion mass matrices are the sum of two Yukawa coupling matrices. They will not generally be simultaneously diagonalizable, leading to tree-level Higgs-mediated FCNC. Serious constraints for K-Kbar mixing.

Three approaches:

Model I: All fermions couple to only one Higgs doublet.

Model II: All I=1/2 fermions couple to one doublet, and the I=-1/2 fermions couple to the other. (This is SUSY)

Variations: Sometimes, leptons can couple differently from quarks (see B. Thomas' talk here, for example).

Model III: No restrictions. TP Cheng and MS argued that the most plausible FCNC coupling was the geometric mean of the individual couplings, so it is small for the kaon system, but larger for b's, τ's, tops.

Model III parametrization (Cheng, MS): FCNC coupling of H to f_a and f_b is $\lambda_{ab} (m_a m_b)^{1/2}/v$ where we expect λ_{ab} to be O(1)

- To test Model III, one should look at (a,b) = (t,c), (b,s), (μ,τ) and see if one can probe λ= O(1)
- Looking for t -> cH or H ->t c at the LHC is difficult, but not completely impossible (Aguilar-Saavedra, Branco)
- Looking for H ->b s is also difficult, and B_s mixing is already maximal
- Looking for τ μ transitions in rare τ decays is orders of magnitude short.
- The muon collider will be able to definitively test the Model.

$\mu^+\mu^- \text{--->} H \text{--->} \mu^+\tau^-, \mu^-\tau^+$

- For an integrated luminosity of 1 fb^{-1}, a resolution of R = 0.005%, the process is easily detectable with no substantial background for $m_H < 150$ GeV.

(MS-2000, model-independent analysis by Cotti, et al., 2003)

- Failure to observe a signal, coupled with a failure to observe t --> c H at the LHC, would rule out Model III.
- For $m_H > 180$ GeV, the best test would be from $\mu^+\mu^- \text{--->} H \text{--->} t\, c$ (Atwood, Reina, Soni, 1995)

II. μ N --> τ N

Strongest constraints on μ-e transitions come from μ N --> eN

So what about μ N --> τ N ?

Need a very intense muon beam.

First two studies looked at general operator:

$(1/\Lambda^2)\ (\bar{q}_i\ q_j)\ (\bar{\mu}\ \tau)$

Operator: $(1/\Lambda^2)$ $(q_i\ q_j)$ $(\mu\ \tau)$

(MS, Turan) q_iq_j=u or d, current bound on Λ is 2.6 TeV. For 10^{20} muons on target for a 50 GeV beam, get 3×10^6 ρ events per year. The τ pair background is small. How does one detect the τ ? Leptonic decays are swamped by backgrounds, single pion decays will have high backgrounds in an intense muon beam. Three charged pions at the end of a short track (decay distance is at best a cm.)?

More study needed.

Operator: $(1/\Lambda^2)\ (q_i\ q_j)\ (\mu\ \tau)$

Gninenko, et al. Let $q_i q_j$ = uc. The operator is completely unbounded (Λ could be tens of GeV). Much higher signal. They explored the $\mu \to \tau \to \mu\nu\nu$ decay chain, looking for energy depletion. Did a detailed phenomenological analysis for a 20 GeV muon beam with the NOMAD detector. Claimed that one might reach Λ = 800 GeV sensitivity.

Finally, Kanemura et al. consider the μN - τN signal in a supersymmetric model. For a 300 GeV muon beam and 10^{20} muons on target, they found 10,000 events per year. Realistic Monte Carlo studies are needed (Some studies using the LQGENEP generator have been performed, but I couldn’t find the results).

Summary

- Two ideas --
- 1. $\mu^+\mu^-$ --> H --> $\mu^+\tau^-$, $\mu^-\tau^+$. If not seen, the Model III 2HDM is ruled out (if the H mass is below 150 GeV)
- 2 μ N --> τ N. Need much more study of tau detection possibilities.