Search for Lepton Flavor Violation

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Prospects for discovery of Lepton Flavor Violation (LFV) in τ decays and production are presented. LFV in τ decays, eg. $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$, may occur at enhanced rates due to the tree level contribution from a μ-τ-Higgs (H) vertex. The high-p_T design of the ATLAS experiment makes it easier to search for LFV in τ production via $H \to \mu^\pm\tau^\mp$ process. Benchmark studies can be performed by searching for $Z \to \mu^\pm\tau^\mp$ decays, where existing limits from the LEP experiments can be significantly improved.

Introduction

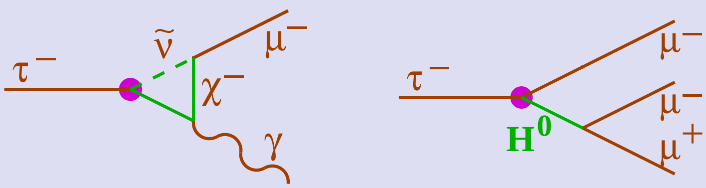
The recent discovery of ν-mixing [1] implies LFV occurs. Flavor violating processes involving charged leptons have not yet been observed, although they have long been identified as an unambiguous signature of new physics. Stringent experimental limits on LFV already exists [2]:

$\mathcal{B}(\mu^\pm \to e^\pm e^\mp e^\pm) < 1.0 \times 10^{-12}$ at 90% c.l. [SINDRUM experiment]
$\mathcal{B}(\mu^\pm \to e^\pm \gamma) < 1.2 \times 10^{-11}$ at 90% c.l. [MEGA experiment]
$\mathcal{B}(\tau^\pm \to \mu^\pm \gamma) < 4.5 \times 10^{-8}$ at 90% c.l. [Belle experiment]
$\mathcal{B}(\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm) < 1.9 \times 10^{-7}$ at 90% c.l. [BaBar experiment]
$\mathcal{B}(Z \to e^\pm \tau^\mp) < 9.8 \times 10^{-6}$ at 95% c.l. [OPAL experiment]
$\mathcal{B}(Z \to \mu^\pm \tau^\mp) < 1.2 \times 10^{-5}$ at 95% c.l. [DELPHI experiment]

The Standard Model (SM) extended to include ν-masses (seesaw mechanism) imply τ-μ mixing is generated at the one-loop level and thus suppressed by a factor of $(m_\nu^2/m_W^2)^2$, eg. $\mathcal{B}(\tau^\pm \to \mu^\pm\gamma) \sim \mathcal{O}(10^{-54})$ [3], which is far below any future experimental sensitivity. However, many new theories [4], as tabulated below, allow $\tau^\pm \to \ell^\pm\gamma$, $\tau^\pm \to \ell^\pm\ell^\mp\ell^\pm$ decays (where $\ell = e, \mu$), while respecting bounds on LFV in μ decays:

	$\mathcal{B}(\tau^\pm \to \ell^\pm\gamma)$	$\mathcal{B}(\tau^\pm \to \ell^\pm\ell^\mp\ell^\pm)$
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY + SO(10)	10^{-8}	10^{-10}
SM + seesaw	10^{-9}	10^{-10}
Non-Universal Z′	10^{-9}	10^{-8}
SUSY + Higgs	10^{-10}	10^{-7}

Feynman diagrams for $\tau^\pm \to \mu^\pm\gamma$ and $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ decays via s-neutrino mixing in mSUGRA model with heavy ν_R (seesaw mechanism) and via neutral Higgs exchange in supersymmetric model are shown below on the left and right plots, respectively.



The contribution to LFV from dipole operators via photon exchange are related as: $\mathcal{B}(\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm)_\gamma \sim 2.3 \times 10^{-3} \times \mathcal{B}(\tau^\pm \to \mu^\pm\gamma)$ [4]. However, presence of the μ-τ-Higgs ($H = h^0, H^0, A^0$) vertex enhances the rates for $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ decays, allowing for possible discovery of LFV at the LHC experiments. The contribution from scalar operators via Higgs exchange in terms of dimensionless functions of MSSM mass parameters (Δ_L, Δ_R) are:

$$\mathcal{B}(\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm) \simeq 10^{-7} \times (\frac{\tan\beta}{50})^6 \times (\frac{100GeV}{m_H})^4 \times (\frac{|50\Delta_L|^2 + |50\Delta_R|^2}{10^{-3}})$$

For large $\tan\beta \sim 50$, even if Higgs is light, there may be no direct observation of heavy $\sim \mathcal{O}(\text{TeV})$ supersymmetric particles, but $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ may be observable at LHC.

The prediction for flavor violating Higgs decay rates are also enhanced for large $\tan\beta$ [4]:

$$\mathcal{B}(H^0 \to \mu^\pm\tau^\mp) = \tan^2\beta(|\Delta_L|^2 + |\Delta_R|^2)\left[\frac{\sin(\beta-\alpha)}{\cos\alpha}\right]^2 \mathcal{B}(H^0 \to \tau^\pm\tau^\mp)$$

One could also search for $Z \to \mu^\pm\tau^\mp$ decays, which are predicted by several new models [5].

LFV in τ decays

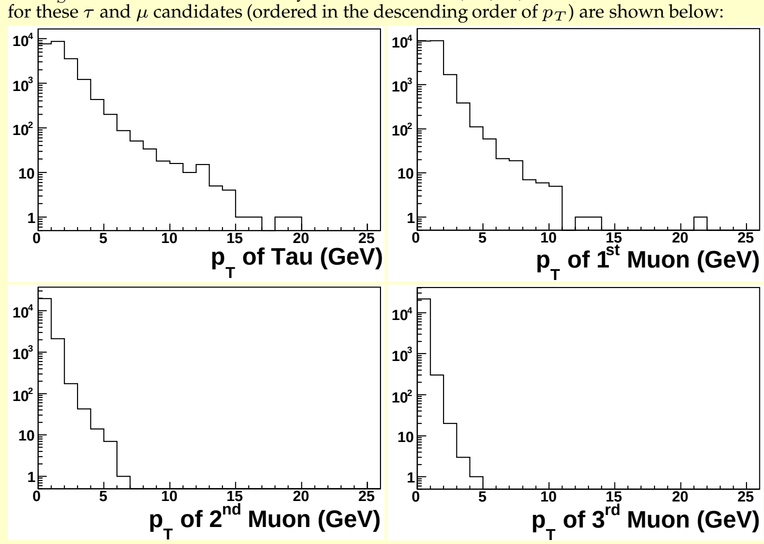
The SM cross-section for inclusive τ production at 14 TeV is $\sigma(pp \to \tau + X) \simeq 120\mu b$. Number of τ's produced according to Pythia 6.4 Monte Carlo predictions, are listed in the adjacent table. About 77% of the $\tau^\pm$ leptons are produced from leptonic decays of the $D_S^\pm$ meson, while the others arise mostly from semi-leptonic b and c decays. The prompt τ production is likely to have a much reduced contribution to total N_τ as $\sigma(pp \to W \to \tau\nu) \simeq 15$ nb.

	N_τ / 10 fb^{-1}
$W \to \tau\nu$	1.5×10^8
$Z \to \tau\tau$	8.0×10^8
$B_S^0 \to \tau X$	7.9×10^{10}
$B^0 \to \tau X$	4.0×10^{11}
$B^\pm \to \tau X$	3.8×10^{11}
$D_S^\pm \to \tau X$	1.5×10^{12}

Thus, lots of τ leptons will be produced, making LHC experiments an interesting laboratory to search for LFV in τ decays. However, as opposed to the case of τ-pair production in e^+e^- annihilations where the energy of the τ is known from the beam energy of collision, the energy of the τ leptons produced in hadron collisions are not known. Also, radiative W and Z decays contribute significantly toward irreducible backgrounds in $\tau^\pm \to \mu^\pm\gamma$ search. Limits from the first study on LFV at ATLAS, using τ from W decays as the primary source of signal, are $\mathcal{B}(\tau^\pm \to \mu^\pm\gamma) < 1.0 \times 10^{-6}$ at 90% c.l. [6], where the search is limited by high backgrounds from radiative $W \to \mu\nu\gamma$ and $W \to \tau(\to \mu\nu\overline{\nu})\nu\gamma$ decays.

$\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ decays

The dominant τ source, $D_S^\pm$ decays, is studied here as the primary source of the signal. Athena 12.0.7 is used to generate 100K $pp \to c\overline{c}$ events using the Pythia 6.4 Monte Carlo. A GeneratorFilter is used to select $D_S^\pm$ decays occurring in 22% of the generated events, where the $D_S^\pm$ have been selected to decay into $\tau^\pm\nu$, $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ final states. Distributions for these τ and μ candidates (ordered in the descending order of p_T) are shown below:



Efficiency of the lowest p_T muon candidate to be greater than a reasonable trigger cut of 3 GeV is 2×10^{-4}, which translates into $\mathcal{O}(1)$ events for an assumed $\mathcal{B}(\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm) = 1 \times 10^{-8}$. Potential background processes from $D_S^\pm \to \mu^\pm\nu M$, $M \to \mu^+\mu^-\gamma$ (where $M = \phi/\eta/\eta'$) decays are also found to have similar p_T distributions.

In conclusion, the τ's and the subsequent μ's produced from D_S meson decays are found to be too soft to pass the ATLAS trigger and still yield reasonably observable statistics.

LFV in τ production

On the other hand, the τ's produced from W and Z decays have high p_T. Thus, the natural trigger design of the ATLAS experiment makes it easier to search for LFV in τ production, eg. via $Z \to \mu^\pm\tau^\mp$ process. Given that 10^8 τ's are produced from Z decays, even with a modest 1% efficiency, one can expect to discover LFV if $\mathcal{B}(Z \to \mu^\pm\tau^\mp) \simeq 10^{-6}$, which is consistent with the existing limits from the LEP experiments, or improve the limits by an order of magnitude. The $H \to \mu^\pm\tau^\mp$ signal would yield a 5σ significance for a value of LFV parameter $\kappa_{\mu\tau} \in [0.18, 1.0]$ and a Higgs boson mass between 120 GeV and 160 GeV with 30 fb^{-1} and 100 fb^{-1} of data per LHC experiment for $\tan\beta$ = 10 and 45, respectively [7].

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