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

**Introduction**

The recent discovery of $\nu$-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]:

$$B(\mu^+ \rightarrow e^+\tau^\pm\tau^\mp) < 1.0 \times 10^{-12} \text{ at 90\% c.l. [SINDRUM experiment]}$$

$$B(\mu^- \rightarrow e^-\tau^\pm\tau^\mp) < 1.2 \times 10^{-11} \text{ at 90\% c.l. [MEG experiment]}$$

$$B(\tau^+ \rightarrow \mu^+\tau^-\mu^-) < 4.5 \times 10^{-10} \text{ at 90\% c.l. [Belle experiment]}$$

$$B(\tau^+ \rightarrow \tau^+\tau^-\mu^-) < 1.9 \times 10^{-7} \text{ at 90\% c.l. [Belle experiment]}$$

$$B(Z \rightarrow \tau^+\tau^-) < 2.6 \times 10^{-3} \text{ at 95\% c.l. [OPAL experiment]}$$

$$B(Z \rightarrow \mu^+\tau^-) < 1.2 \times 10^{-2} \text{ at 95\% c.l. [DELPHI experiment]}$$

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

<table>
<thead>
<tr>
<th>Model</th>
<th>$B(\tau^+ \rightarrow \mu^+\tau^-\mu^-)$</th>
<th>$B(\tau^+ \rightarrow \mu^+\tau^-\mu^-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>mSUGRA + seesaw</td>
<td>$10^{-10}$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>SUSY + SO(10)</td>
<td>$10^{-8}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>SM + seesaw</td>
<td>$10^{-10}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>SU5 + Universal' Z</td>
<td>$10^{-9}$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>SUSY + Higgs</td>
<td>$10^{-10}$</td>
<td>$10^{-12}$</td>
</tr>
</tbody>
</table>

Feynman diagrams for $\tau^+ \rightarrow \mu^+\tau^- \rightarrow e^+\tau^\pm\tau^\mp$ via $\nu$-neutrino mixing in mSUGRA model with heavy $\nu_\theta$ (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: $B(\tau^+ \rightarrow \mu^+\tau^-\mu^-) \sim 2.3 \times 10^{-3} \times B(\tau^+ \rightarrow \mu^-\tau^- \gamma) [4]$. However, presence of the $\tau$-mu-Higgs ($H = h^*, H^0, A^0$) vertex enhances the rates for $\tau^+ \rightarrow \mu^+\tau^-\mu^-\mu^\pm$ decays, allowing for possible discovery of LFV at the LHC experiments. The prediction from scalar operators via Higgs exchange in terms of dimensionless functions of MSSM mass parameters ($\Delta L, \Delta \mu$) are:

$$B(\tau^+ \rightarrow \mu^+\tau^-\mu^-\mu^\pm) \sim 10^{-7} \times (\tan \beta/50)^3 \times (1000 GeV^3/m_H) \times (50\Delta L^2 + 50\Delta \mu^2)/10^{-3}.$$  

For large $\tan \beta \sim 50$, even if Higgs is light, there may be no direct observation of heavy $\Delta \mu$ supersymmetric particles, but $\tau^+ \rightarrow \mu^+\tau^-\mu^-\mu^\pm$ may be observable at LHC.

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

$$B(\tau^+ \rightarrow \mu^+\tau^-) \sim \tan^2 \beta (|\Delta L|^2 + |\Delta \mu|^2)^2 \cos \alpha$$

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

**LFV in τ production**

The SM cross-section for inclusive τ production at 14 TeV is $\sigma(pp \rightarrow \tau + X) \approx 120 \mu$b. Number of τ’s produced according to Pythia 6.4 Monte Carlo predictions, are listed in the adjacent table. About 77% of the τ’s lepton are produced from leptonic decays of the $D^+_S$ meson, while the others arise mostly from semi-leptonic $\beta$ and $\gamma$ decays. The prompt τ production is likely to have a much reduced contribution to total $N_{\tau}$, as $\sigma(pp \rightarrow W + \tau \nu) \approx 15$ fb.

Thus, lots of τ’s lepton 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 $\tau^+ \rightarrow \mu^+\tau^-\mu^-$. Limits from the first study on LFV at ATLAS, using τ from W decays as the primary source of signal, are $B(\tau^+ \rightarrow \mu^+\tau^-\mu^-) < 1.0 \times 10^{-12} \text{ at 90\% c.l. [6]}$, where the search is limited by high backgrounds from radiative W → μνγ and W → τμτγ decays.

**References**


