A Heavy Fourth Family Neutrino and the τ-Lifetime Discrepancy

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If there is a fourth generation, then the τ neutrino ν_τ will be a superposition of the mass eigenstates

$$\nu_\tau = U_{\tau 1}\nu_1 + U_{\tau 2}\nu_2 + U_{\tau 3}\nu_3 + U_{\tau 4}\nu_4. \tag{1}$$

It is possible that the fourth family neutrino is heavier than the τ itself, so that the τ cannot decay to this component of its wave function, resulting in a decrease in the decay probability or increase in the τ lifetime. This idea was proposed in Refs. (1) and (2) where a more complete discussion can be found. The resulting decay rate to a single mode is

$$\Gamma(\tau^- \to e^- + \bar{\nu}_e + \nu_\tau) = \frac{G_F^2 m_\tau^5}{192\pi^3}(1 - \|U_{\tau 4}\|^2), \tag{2}$$

$$\Gamma(\tau^- \to e^- + \bar{\nu}_e + \nu_\tau) = \mathrm{BR}(\tau^- \to e^- + \bar{\nu}_e + \nu_\tau)/\tau_\tau. \tag{3}$$

Scaling by the muon lifetime gives experimental numbers except for $\|U_{\tau 4}\|^2$

$$\frac{\tau_\tau}{\tau_\mu}\left(\frac{m_\tau}{m_\mu}\right)^5 (1 - \|U_{\tau 4}\|^2) = \mathrm{BR}(\tau^- \to e^- + \bar{\nu}_e + \nu_\tau). \tag{4}$$

Using experimental values from K. Hayes (this workshop) gives

$$(18.92 \pm 0.49)\%(1 - \|U_{\tau 4}\|^2) = (17.96 \pm 0.26)\% \tag{5}$$

$$\|U_{\tau 4}\|^2 = 0.051 \pm 0.028\,. \tag{6}$$

This is the same order as $\sin^2\theta_c$, and is a non-zero value at the 1.7σ level.

More accurate measurements of the lifetime and branching ratios of the τ in a τ-charm factory would allow a study of a fourth generation mixing angle, if there is a fourth neutrino heavier than the τ lepton.

(1) M. Shin and D. Silverman, Phys. Lett. **B213**, 379 (1988)
(2) S. Rajpoot and M. A. Samuel, Mod. Phys. Lett. **A3**, 1625 (1988)