Lepton flavor violation in the Littlest Higgs Model with T parity including TeV Majorana neutrinos [1]

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MSc. Iván Pacheco Zamudio[1], Dr. Pablo Roig Garcés[2]

Dept. of Physics, Center for Research and Advanced Studies of the National Polytechnic Institute

[1]ipacheco@fis.cinvestav.mx, [2]proig@fis.cinvestav.mx

Introduction

Composite Higgs models are among the most attractive candidates to solve the corresponding hierarchy problem, associated to the Higgs mass value and its stability against quantum corrections in presence of heavy new physics coupling to the Higgs proportionally to their masses. In this set of models, the Higgs boson is a pNGB of a spontaneously broken global symmetry. LHT is based upon the spontaneous collective breaking of a global symmetry group $SU(5)$ down to $SO(5)$, by a vacuum expectation value at a scale of few TeV [2]. T-parity forbids singly-produced heavy particles (odd under T) and tree level corrections to observables with only SM particles. In this work we consider the LFV effects by including inverse seesaw O(TeV) neutrino masses in LHT [3].

$\ell \to \ell'\gamma$ decays

The new interactions derived from light/heavy Majorana neutrinos and T-odd neutrinos yield

$$\mathrm{Br}(\mu \to e\gamma) = \frac{3\alpha}{2\pi}\left| W_{ej}W^{*}_{\mu j}F^{\nu}_{M}(y_j) + U_{ej}U^{*}_{\mu j}F^{\chi}_{M}(x_i) + \frac{v^2}{4f^2}V^{ej*}_{H\ell}V^{\mu j}_{H\ell}F^{\nu_H}_{M}(x_i)\right|^2 \approx \frac{3\alpha}{8\pi}\left|\theta_{ej}\theta^{\dagger}_{\mu j}\right|^2, \quad (1)$$

where $x_i = \frac{M_W^2}{M_{N_j}^2} \ll 1$ and $y_j = \frac{m^2_{\nu_j}}{M_W^2} \sim 0$, $m_{\nu_i}(M_{N_i})$ the mass of light (heavy) Majorana neutrino, W is the mixing matrix for heavy Majorana neutrinos and U is the PMNS matrix. The contribution from the third term is suppressed by $v^2/f^2 \ll 1$, so we will neglect it in the following.

Then, the 90% C.L. limits $Br(\mu \to e\gamma) < 4.2 \times 10^{-13}$, $\mathrm{Br}(\tau \to e\gamma) < 3.3 \times 10^{-8}$ and $\mathrm{BR}(\tau \to \mu\gamma) < 4.2 \times 10^{-8}$ [4, 5] bind

$$|\theta_{ej}\theta^{\dagger}_{\mu j}| < 0.14 \times 10^{-4}, \quad |\theta_{ej}\theta^{\dagger}_{\tau j}| < 0.95 \times 10^{-2}, \quad |\theta_{\mu j}\theta^{\dagger}_{\tau j}| < 0.011. \quad (2)$$

Wrong Sign decays

In addition to box diagrams in Type I and II $\ell \to \ell'\ell''\bar{\ell}'''$, there are contributions coming from box diagrams with LNV vertices

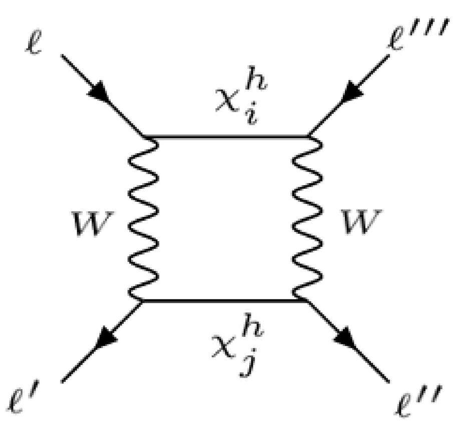

Fig. 1: Box contributions to Type III $\ell \to \ell'\ell''\bar{\ell}'''$ decays.

We are just considering the contribution coming from heavy Majorana neutrinos. Therefore (C.L = 90%):

$$\mathrm{Br}(\tau \to ee\bar{\mu}) < 1.6 \times 10^{-9}, \quad \mathrm{Br}(\tau \to \mu\mu\bar{e}) < 1.6 \times 10^{-9} \quad (3)$$

LNV couplings

$$|\theta_{ei}\theta_{\tau i}| < 9 \times 10^{-4}, \quad |\theta_{\mu i}\theta_{\mu i}| < 4 \times 10^{-2}, \quad |\theta_{\mu i}\theta_{\tau i}| < 2 \times 10^{-3}, \quad |\theta_{ei}\theta_{ei}| < 2 \times 10^{-2}. \quad (4)$$

Inverse seesaw neutrino masses in the LHT model

In the lepton sector, each SM doublet $l_L = (\nu_L\ \ell_L)^T$ is mirrored by introducing two incomplete quintuplets Ψ_1 and Ψ_2 in $SU(5)$. Symmetry allows a large vector-like mass (M) for the lepton singlets χ_R as well, by combining directly with a LH singlet χ_L. χ_L is $SU(5)$ singlet, so it is natural to include a small Majorana mass (μ) for it. The resulting (T-even) neutrino mass matrix reduces to the inverse see-saw one [3]:

$$\mathcal{L}^{\nu}_{M} = -\frac{1}{2}\left(\overline{\nu^c_l}\ \overline{\chi_R}\ \overline{\chi^c_L}\right)\mathcal{M}^{T-even}_{\nu}\begin{pmatrix}\nu_L\\ \chi^c_R\\ \chi_L\end{pmatrix} + h.c., \text{ with } \mathcal{M}^{T-even}_{\nu} = \begin{pmatrix} 0 & i\kappa^{*} f \sin\left(\frac{v}{\sqrt{2}f}\right) & 0\\ i\kappa^{\dagger} f \sin\left(\frac{v}{\sqrt{2}f}\right) & 0 & M^{\dagger}\\ 0 & M^{*} & \mu\end{pmatrix}, \quad (5)$$

In the inverse see-saw, the hierarchy $\mu << \kappa << M$. The mass eigenstates of this matrix are

$$\sum_{j=1}^{3} U_{ij}\nu^{l}_{Lj} = \sum_{j=1}^{3}[\mathbf{1}_{3\times 3} - \frac{1}{2}(\theta\theta^{\dagger})]_{ij}\nu_{Lj} - \sum_{j=1}^{3}\theta_{ij}\chi_{Lj}, \quad \chi^{h}_{Li} = \sum_{j=1}^{3}[\mathbf{1}_{3\times 3} - \frac{1}{2}(\theta^{\dagger}\theta)]_{ij}\chi_{Lj} + \sum_{j=1}^{3}\theta^{\dagger}_{ij}\nu_{Lj}, \quad (6)$$

where θ matrix gives the mixing between light and heavy (quasi-Dirac) neutrinos to leading order.

Joint Analysis for $Z \to \bar{\ell}\ell'$, Type I and II $\ell \to \ell'\ell''\bar{\ell}'''$ decays and $\mu \to e$ conversion in nuclei

For this analysis we categorize the LFV processes according their neutral coupling: $(\theta S\theta^{\dagger})_{e\mu}$, $(\theta S\theta^{\dagger})_{e\tau}$, and $(\theta S\theta^{\dagger})_{\mu\tau}$ –processes.

Processes which share the neutral coupling $(\theta S\theta^{\dagger})_{e\mu}$ are strongly correlated.

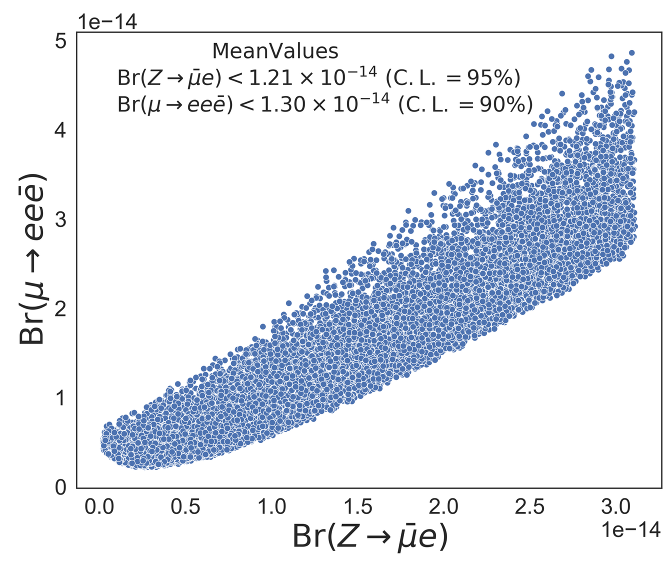

Fig. 2: $\mathrm{Br}(Z \to \bar{\mu}e)$ vs. $\mathrm{Br}(\mu \to ee\bar{e})$.

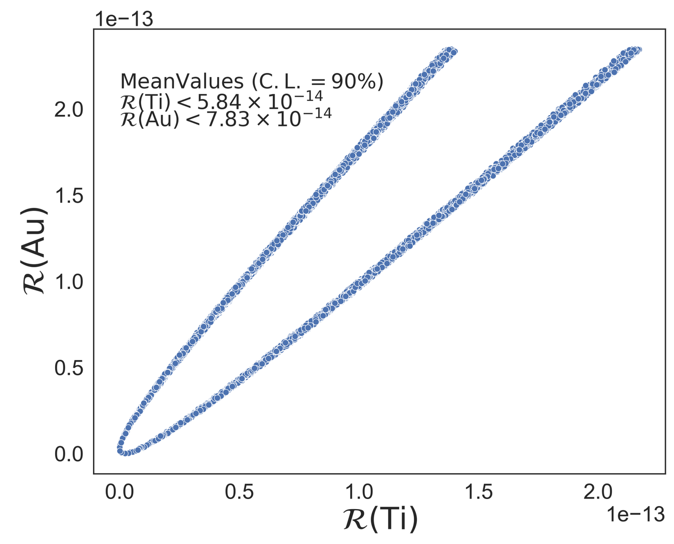

Fig. 3: $\mathcal{R}$(Ti) vs. $\mathcal{R}$(Au).

Decays whose behavior is described by $(\theta S\theta^{\dagger})_{e\tau}$ are correlated as we show in following figures

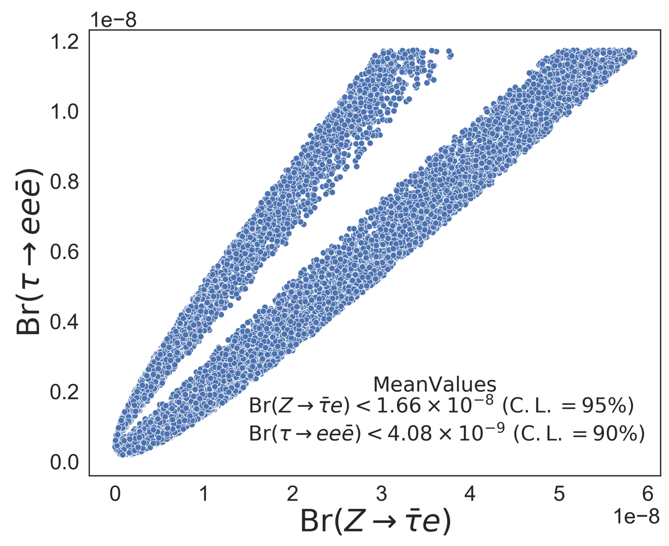

Fig. 4: $\mathrm{Br}(Z \to \bar{\tau}e)$ vs. $\mathrm{Br}(\tau \to ee\bar{e})$.

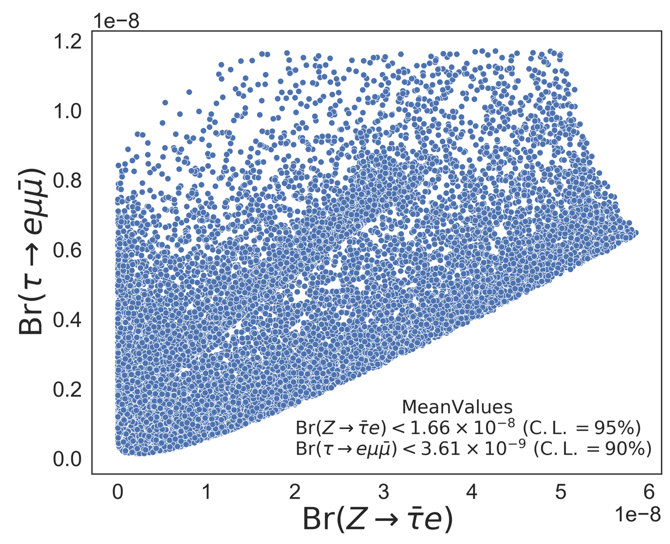

Fig. 5: $\mathrm{Br}(Z \to \bar{\tau}e)$ vs. $\mathrm{Br}(\tau \to e\mu\bar{\mu})$.

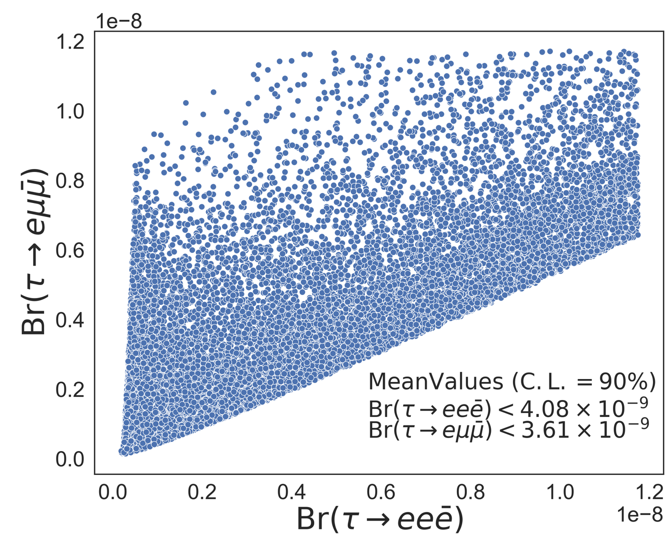

Fig. 6: $\mathrm{Br}(Z \to ee\bar{e})$ vs. $\mathrm{Br}(\tau \to e\mu\bar{\mu})$.

There is a sizeable correlation among Br's for processes with the same neutral coupling $(\theta S\theta^{\dagger})_{\mu\tau}$.

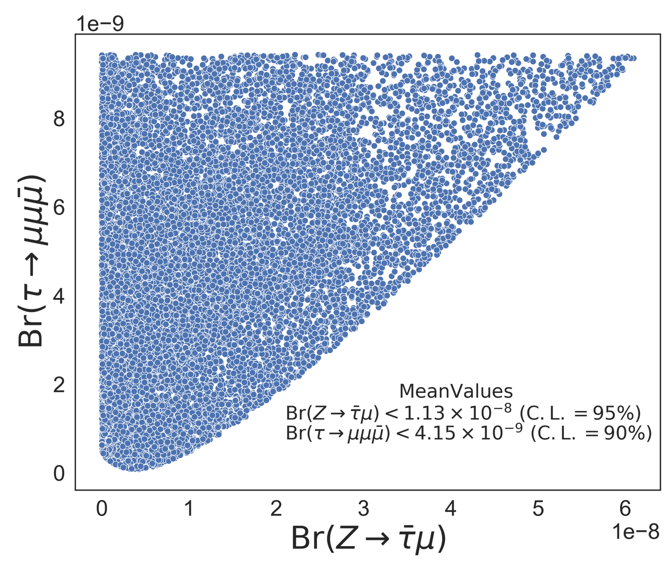

Fig. 7: $\mathrm{Br}(Z \to \bar{\tau}\mu)$ vs. $\mathrm{Br}(\tau \to \mu\mu\bar{\mu})$.

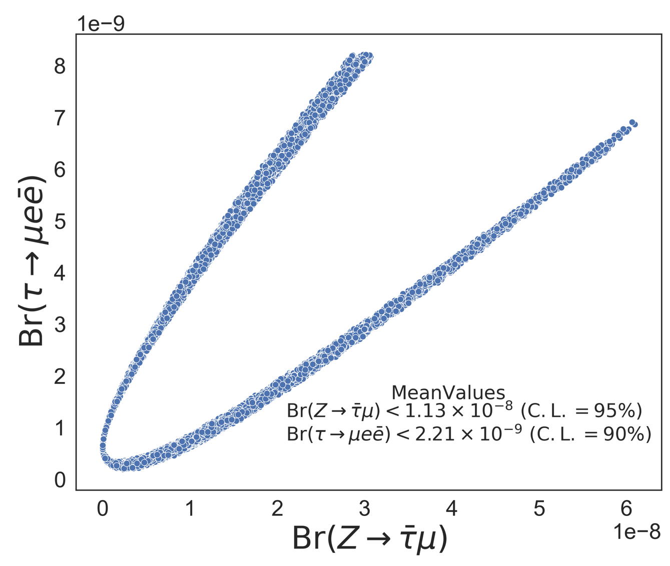

Fig. 8: $\mathrm{Br}(Z \to \bar{\tau}\mu)$ vs. $\mathrm{Br}(\tau \to \mu e\bar{e})$.

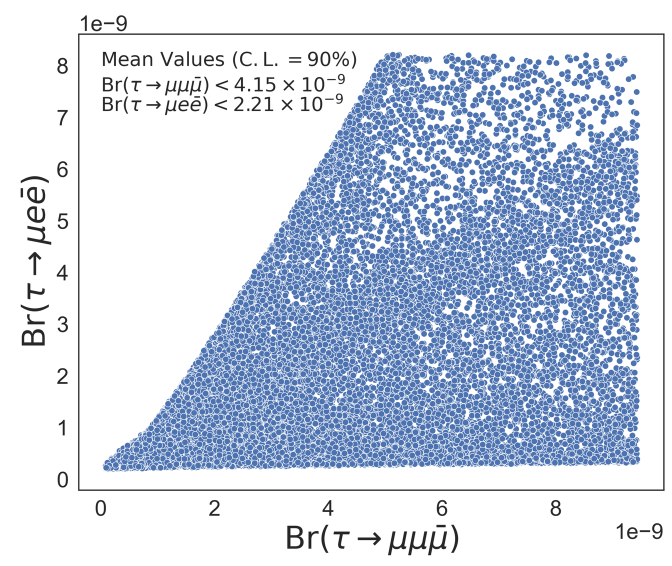

Fig. 9: $\mathrm{Br}(\tau \to \mu\mu\bar{\mu})$ vs. $\mathrm{Br}(\tau \to \mu e\bar{e})$.

Solutions for heavy Majorana masses in [3,5] TeV are found, with little correlation among them.

Conclusions

- In $\tau \to \ell'\ell''\ell'''$ -including wrong sign decays-, $\mu \to e$ conversion in Ti ($\mu \to ee\bar{e}$, $Z \to \tau^{-}\ell$, $\mu \to$ e conversion in Au) processes we obtained BR's within one (two) order(s) of magnitude of the current U.L.
- The pattern of correlations among processes is completely different to the 'traditional' LHT (without heavy Majorana neutrinos), where for instance wrong-sign decays are negligible, and the correlation between $L \to \ell\gamma$ and $L \to \ell\ell'\bar{\ell}''$ decays, which is a celebrated signature distinguishing underlying models producing the LFV, here is broken. So it will be straightforward to distinguish this scenario to traditional LHT or other models due to this particular pattern of correlations.

References

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