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# Lepton flavor changing Higgs boson decays in some extensions of the Standard Model

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**Abstract.** We present our results for the one-loop contributions to the Higgs boson flavor-changing decays  $h \rightarrow \mu\tau$  in two extensions of the Standard Model: the Little Higgs Model with T-parity and the Two Higgs Doublet Model with a fourth generation of fermions. In both cases we find that the respective branching ratio  $\text{BR}(h \rightarrow \mu\tau)$  is of order  $10^{-4} - 10^{-6}$ . In the case of the 4G2HDM, the one-loop radiative correction is of the same order of magnitude as the tree level branching ratio. We find that in both models the branching ratios for the decay modes  $h \rightarrow e\tau$ ,  $e\mu$  are even more suppressed.

## 1. Introduction

In the Standard Model (SM) the flavor-changing Higgs decays  $h \rightarrow \mu\tau$ ,  $e\tau$  and  $e\mu$  are forbidden at tree level due to the Glashow-Iliopoulos-Maiani mechanism [1]. The one-loop contributions to these decay channels in the SM with massive neutrinos are highly suppressed, of order  $10^{-29}$  [2]. Due to this expectation, the excess reported by the CMS [3] and the ATLAS [4] Collaborations for the branching ratio  $\text{BR}(h \rightarrow \mu\tau)$  stimulated great interest among theoreticians [7–11]. In particular, in some extensions of the SM this branching ratio could be at the level of few percent, close to the upper limits included in the first reports of CMS and ATLAS [9–11]. Recently, CMS have published new results on this decay mode; however, their search does not throw a clear conclusion [5, 6] and the respective branching ratio now has an upper limit of about  $10^{-3}$ .

In general the amplitude of the  $h \rightarrow \ell_i \ell_j$  decay is given by:

$$\mathcal{M} = i\bar{u}(p_1, m_i)(A + iB\gamma_5)u(p_2, m_j), \quad (1)$$

where  $A$  and  $B$  are one-loop form factors, while  $m_k$  is the mass of the lepton  $\ell_k$ . In the approximation of massless external leptons the decay width can be written as:

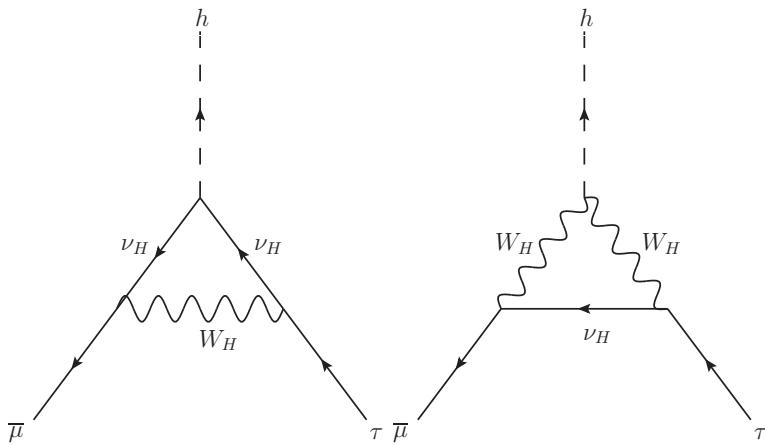
$$\Gamma(h \rightarrow \tau\mu) = \frac{m_h}{8\pi} (|A|^2 + |B|^2), \quad (2)$$

in the next sections we mention the potential some results of two extensions of the SM; the Littlest Higgs Model with T-parity (LHM+T), and the Two Higgs doublet model with fourth family (4GTHDM).

The present report is organized as follow. In section we mention some general aspect of the LHM with T-parity and its respective contribution to  $h \rightarrow \tau\mu$ . In section 3 we analyzed the fermionic fourth family in the context of the Two Higgs doublet model, as well as the results for  $h \rightarrow \ell_i\ell_j$  decays. Finally, our conclusions and outlook are presented in the section 3.

## 2. The Littlest Higgs Model with T-Parity

The LHM+T comes from a Littlest Higgs model type proposed by Cheng and Low [12], which finally protects the mass of the Higgs boson and gives a more elegant solution to the problem of the precision electroweak that had the LHM initially. This model is based of nonlinear sigma model with a global  $SU(5)$  symmetry, which is broken down to its subgroup  $SO(5)$  via a vacuum expectation value of order  $f \sim \mathcal{O}(TeV)$ . At the same time a subgroup  $[SU(2) \otimes U(1)]^2$  is also broken in the SM gauge group. By introducing an additional symmetry, the T-parity can relax the constraint of the EW precision data, leading to a scale  $f$  as 500 GeV. The T-parity exchange the two  $SU(2) \otimes U(1)$  factors, thus the number of parameters are reduced. To implement the T-parity the introduction of mirror fermions is required in an extra multiplet, which are necessary in order to eliminate possible quadratic divergences in the Higgs mass. Now the SM-gauge light bosons are T-even while the new heavy bosons are T-odd; also fermions are T-even.



**Figure 1.** Feynman diagrams inducing the  $h \rightarrow \tau\mu$  decay in the LHM with T-parity. We show only the contribution induced by the heavy charged gauge boson  $W_H$  and the heavy mirror neutrino  $\nu_H$ . Also bubble diagrams are necessary to remove the divergence.

The new particles of the gauge boson sector of this model includes  $W_H$ ,  $Z_H$  and  $A_H$  with masses of order  $f$ . There are also heavy charged mirror leptons ( $\ell_H$ ) and neutrinos ( $\nu_H$ ) with mass of the same order of magnitude as the heavy gauge bosons. Due to the T-parity symmetry,

the heavy charged mirror leptons do not couple directly with the SM Higgs boson [13, 14].

The T-parity forbids any contribution at tree level that includes heavy gauge bosons, then in the LHM+T the decay mode  $h \rightarrow \mu\tau$  is induced at one loop-level by the heavy gauge bosons  $W_H$  and  $Z_H$  with its respective mirror leptons. We considered a symmetry breaking scale  $f$  between 500 and 2000 GeV. Our results indicate that main contribution comes of the heavy charged gauge boson  $W_H^\pm$ , where the respective branching ratio is given by  $(10^{-3} - 10^{-1})|V_{H\mu}V_{H\tau}|^2$ , where the mixing matrices  $V_{H\ell}$  correspond to the mixing of the heavy gauge bosons of the model and they satisfy the relation  $V_{H\nu}V_{H\ell} = V_{PMNS}$ , i.e., the Pontecorvo-Maki-Nakagata-Saki matrix. However, this result decreases with reasonable scenarios for these mixing matrices [15].

### 3. Two Higgs Doublet Model with a fourth Generation

In this model the flavor changing transitions involving the SM model Higgs boson are induced at tree level and, of course, also at one-loop level. We choose the 4G2HDM version, where the heavy scalar bosons couple only to the fourth generation fermions while the SM Higgs boson couples only to the light fermions. This guarantees that the 4G2HDM is in concordance with the known data coming from the LHC and the electroweak precision observables [16,17].

The fourth generation can be implemented in three different scenarios, we considered only the scenario where one of the two Higgs doublets ( $\phi_1$ ) gives masses only to the 4th family fermions and the other one ( $\phi_2$ ) generates the masses of the rest of the known fermions. However, there is a Flavor Changing Neutral Couplings (FCNC) induced at tree level between scalar bosons and fermions. The Lagrangians that describe the change of flavor through neutral and charged currents, are respectively

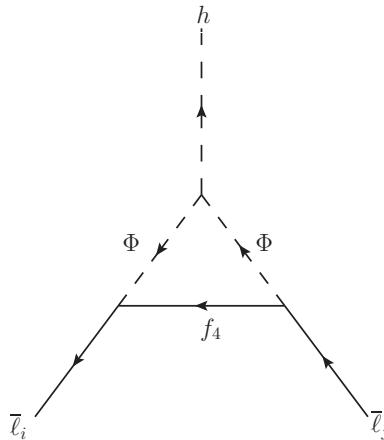
$$\mathcal{L}_{NC} = \frac{g}{4m_W} g_\phi \bar{\ell}_i \left[ \left( g_s^\phi \right)_{ij} + \left( g_p^\phi \right)_{ij} \gamma_5 \right] \ell_j \phi, \quad (3)$$

$$\mathcal{L}_{CC} = \frac{g}{2\sqrt{2}m_W} g_\phi \bar{\nu}_i \left[ \left( g_s^\phi \right)_{ij} + \left( g_p^\phi \right)_{ij} \gamma_5 \right] \ell_j H^+, \quad (4)$$

where  $\phi$  is any neutral scalar boson and  $i, j$  run for for each generation of fermions,  $g_s$  and  $g_p$  are the scalar and pseudoscalar coupling constants. While  $g_\phi$  is a constant that takes different values for each scalar bosons, the explicit form of these constants can be found in [17].

The 4G2HDM has several free parameters such as the masses of the new scalar bosons and the heavy fermions, as well as  $\tan\beta = v_1/v_2$ , the ratio of the vacuum expectation values of the two Higgs doublets, and additional mixing matrices among the known fermions and the new 4th generation fermions. In our calculation we considered the mass range for the 4th family lepton between 100 and 350 GeV and for the heavy neutral Higgs boson between 200 and 700 GeV. In the 4G2HDM scenario considered  $\tan\beta$  should be of order unit [17].

Our results indicate that the dominant contribution to the one-loop radiative correction to the  $BR(h \rightarrow \mu\tau)$  in this model is associated with the virtual exchange of the heavy charged Higgs boson  $H^\pm$  in a wide range of the free parameters involved in this model [16,17]. We also calculated the one-loop contribution coming from the virtual exchange of heavy neutral bosons



**Figure 2.** Feynman diagram inducing the  $h \rightarrow \ell_i \ell_j$  decay in the 4GTHDM, where for  $\Phi = h^0$ ,  $H^0$ ,  $A^0$  we have  $f_4 = \ell_4$  and for  $\Phi = H^\pm$  we have  $f_4 = \nu_4$ .

but they are smaller than the heavy charged Higgs boson contribution.

It is interesting to note that the 4G2HDM allows a tree level FCNC coupling that induces a branching ratio for the decay mode  $h \rightarrow \mu\tau$  of the same order of magnitude than the charged Higgs boson one-loop contribution. However, the tree level results depends on the  $\chi$  parameter that involves the mixing angles involved in the model and thus the respective predictions can be highly suppressed [16].

#### 4. The decay modes $h \rightarrow e\tau$ , $e\mu$

It is possible to use or results for the decay mode  $h \rightarrow \mu\tau$  in order to obtain the respective branching ratios expected in both models for the other two FCNC decay modes  $h \rightarrow e\tau$ ,  $e\mu$ . Since our  $h \rightarrow e\tau$  results for the one-loop contributions to the case  $h \rightarrow \mu\tau$  involve exact analytical expressions, the respective results for the other two FCNC decay modes are easily obtained by just substituting the new masses and coupling constants. Our results indicate that these two decay modes are even more highly suppressed:  $\text{BR}(h \rightarrow e\mu) \sim 10^{-11}$  [16].

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