Lepton Flavor Violation Higgs Decays in the Scotogenic model

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Abstract

The Scotogenic model is a minimal extension to the Standard Model, which allows describing neutrino masses induced at one loop level. In addition, this model contains a scalar or fermionic Dark matter candidate. The inclusion of a second Higgs doublet inert and heavy right-handed neutrinos, both odd under Z_2 symmetry, allow these new physics issues. In the scalar sector, new interactions appear, among them, the interaction of charged scalar with leptons, which induces the decay of $h \to l_a l_b$ at one loop level which is not allowed on the SM. We study these signals in this framework, and we obtain large $\mathcal{BR}(h \to l_a l_b)$ in the Scotogenic model in comparison to the SM plus three right-handed Dirac neutrinos.

Introduction

Recent search for LFV Higgs decays at LHC, with center-of-mass energy $\sqrt{s} = 13$ TeV, and an integrated luminosity of 36.1 fb^{-1}, has provided stronger bounds for the corresponding branching ratios. In particular, **ATLAS reports $\mathcal{BR}(\mathbf{h \to e\tau}) = \mathbf{0.47\%(0.34^{0.13}_{-0.10})\%}$, $\mathcal{BR}(\mathbf{h \to \mu\tau}) = \mathbf{0.28\%(0.37^{0.14}_{-0.10}\%)}$ [1]**, which are consistent with a zero value. In turn, CMS reports (expected) upper limits on the production cross section times the branching fraction, which vary from 51.9 (57.4) fb to 1.6 (2.1) fb for the $\mu\tau$ and from 94.1 (91.6) fb to 2.3 (2.3) fb for the decay mode $e\tau$ [5].

New Physics models often include a Higgs boson with new features, for instance, besides SM deviations for the Flavor-Conserving (FC) Higgs-fermion couplings, it is possible to have Flavor-Violating (FV) Higgs-fermions interactions. These FV Higgs couplings could arise at tree-level, as in the Two-Higgs Doublet Model (2HDM) of type III, or they could be induced at loop-levels, as in the Minimal SUSY SM (MSSM).

Model

The matter content of the Scotogenic Model with the group $SU(2)_L \otimes U(1)_Y \otimes Z_2$ is given by [4]:

$$(\nu_{La}, l_{La}) \sim (2, -1/2, +), \quad l_{Ra} \sim (1, 1, +), \quad N_{Rk} \sim (1, 0, -),$$
$$(\phi^+, \phi^0) \sim (2, 1/2, +), \quad (\eta^+, \eta^0) \sim (2, 1/2, -),$$

where an inert doublet η and three right-handed neutrinos N_{Ri} odd under Z_2 symmetry have been included. Yukawa sector allows the interaction between left and right-handed neutrinos with scalar doublet η:

$$\mathcal{L}_Y = f_{ab}\left(\phi^- \nu_{La} + \overline{\phi_0} l_{La}\right) l_{Rb} + Y'_{ab}\left(\nu_{La}\eta_0 - l_{La}\eta^+\right) N_{Rb} + \frac{1}{2} M_k \overline{N_{Rk}}^c N_{Rk} + \text{H. c.} \quad (1)$$

being M_k the mass of N_{Rk}. In this case, the more general scalar potential under Z_2 symmetry is as follows,

$$V(\Phi, \eta) = \mu_1^2\left(\Phi^\dagger\Phi\right) + \mu_2^2\left(\eta^\dagger\eta\right) + \frac{\lambda_1}{2}\left(\Phi^\dagger\Phi\right)^2 + \frac{\lambda_2}{2}\left(\eta^\dagger\eta\right)^2$$
$$+ \lambda_3\left(\Phi^\dagger\Phi\right)\left(\eta^\dagger\eta\right) + \lambda_4\left(\Phi^\dagger\eta\right)\left(\eta^\dagger\Phi\right) + \frac{\lambda_5}{2}\left[\left(\Phi^\dagger\eta\right)^2 + \text{H. c.}\right]. \quad (2)$$

Neutrino mass is generated by a radiative See-Saw mechanism and is given by

$$\mathcal{M}_\nu = \mathbf{Y'}\mathbf{D}_\Lambda\mathbf{Y'}^\top$$
$$\mathbf{D}_\Lambda = \text{diag}(\Lambda_1, \Lambda_2, \Lambda_3), \quad (3)$$
$$\Lambda_k = \frac{M_k}{16\pi^2}\left[\left(\frac{m_R^2}{M_k^2 - m_R^2}\log\frac{m_R^2}{M_k^2}\right) - \left(\frac{m_I^2}{M_k^2 - m_I^2}\log\frac{m_I^2}{M_k^2}\right)\right].$$

where m_R, m_I, m_η and M_k are the masses of η_R, η_I, $\eta^\pm$ and N_{Ri} respectively. Also, k index runs over heavy neutrino masses. Then, if we choose the basis where Yukawa matrix $\mathbf{Y'}$ is diagonal, $\mathcal{M}_\nu$ is diagonal too. So, we can rewrite the Yukawa matrix as follows,

$$\mathbf{Y'} = \text{diag}\left(\sqrt{\frac{m_{\nu_1}}{\Lambda_1}}, \sqrt{\frac{m_{\nu_2}}{\Lambda_2}}, \sqrt{\frac{m_{\nu_3}}{\Lambda_3}}\right) \quad \text{or} \quad Y'_{ij} = \sqrt{\frac{m_{\nu_i}}{\Lambda_i}}\delta_{ij}, \quad (4)$$

where m_{ν_i} $(i, j = 1, 2, 3)$ are the light neutrino masses in normal order. However, as we have noticed, in this basis the matrix to diagonalize the neutrino mass matrix, $\mathbf{V}_L^\nu$ is equal to identity. On the other hand, the mass matrix of charged leptons will be rotated by $\mathbf{V}_L^l$ to go to the physical basis. Thus, the neutrino mixing matrix is $\mathbf{U}_{\text{PMNS}} = \mathbf{V}_L^{\nu\dagger}\mathbf{V}_L^l = \mathbf{V}_L^l$. Finally, in the physical basis, new Yukawa couplings for the interaction between left-handed lepton doublet and singlet neutrinos given by

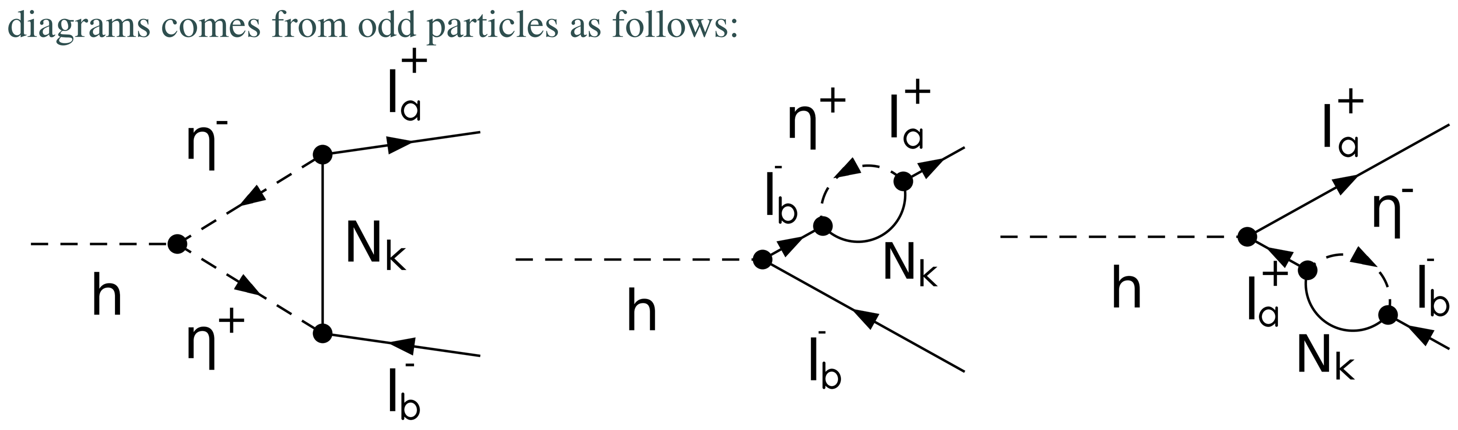
$$\mathbf{Y} = \mathbf{Y'}\mathbf{U}_{\text{PMNS}}. \quad (5)$$

Interactions

The interactions involved in LFV Higgs decays are summarized as follows

Vertex	Coupling	Vertex	Coupling
hG^+G^-	$-i\frac{m_h^2}{v}$	$h\eta^+\eta^-$	$-\frac{2i\left(m_\eta^2 - \mu_2^2\right)}{v}$
$G^-l_a^+\nu_k$	$i\frac{\sqrt{2}}{v}m_a U_{ka}^* P_L$	$G^+l_b^-\nu_k$	$i\frac{\sqrt{2}}{v}m_b U_{kb} P_R$
hG^+W^-	$-\frac{i}{2}g(p_+ - p_0)_\mu$	hW^+G^-	$-\frac{i}{2}g(p_0 - p_-)_\mu$
$W^-l_a^+\nu_k$	$-i\frac{g}{\sqrt{2}}U_{ka}^*\gamma_\mu P_L$	$W^+l_b^-\nu_k$	$-i\frac{g}{\sqrt{2}}U_{kb}\gamma_\mu P_L$
$\eta^-l_a^+N_k$	$iY_{ka}^* P_R$	$\eta^+l_a^-N_k$	$iY_{kb} P_L$
$hW_\mu^+W_\nu^-$	$igm_W g_{\mu\nu}$		

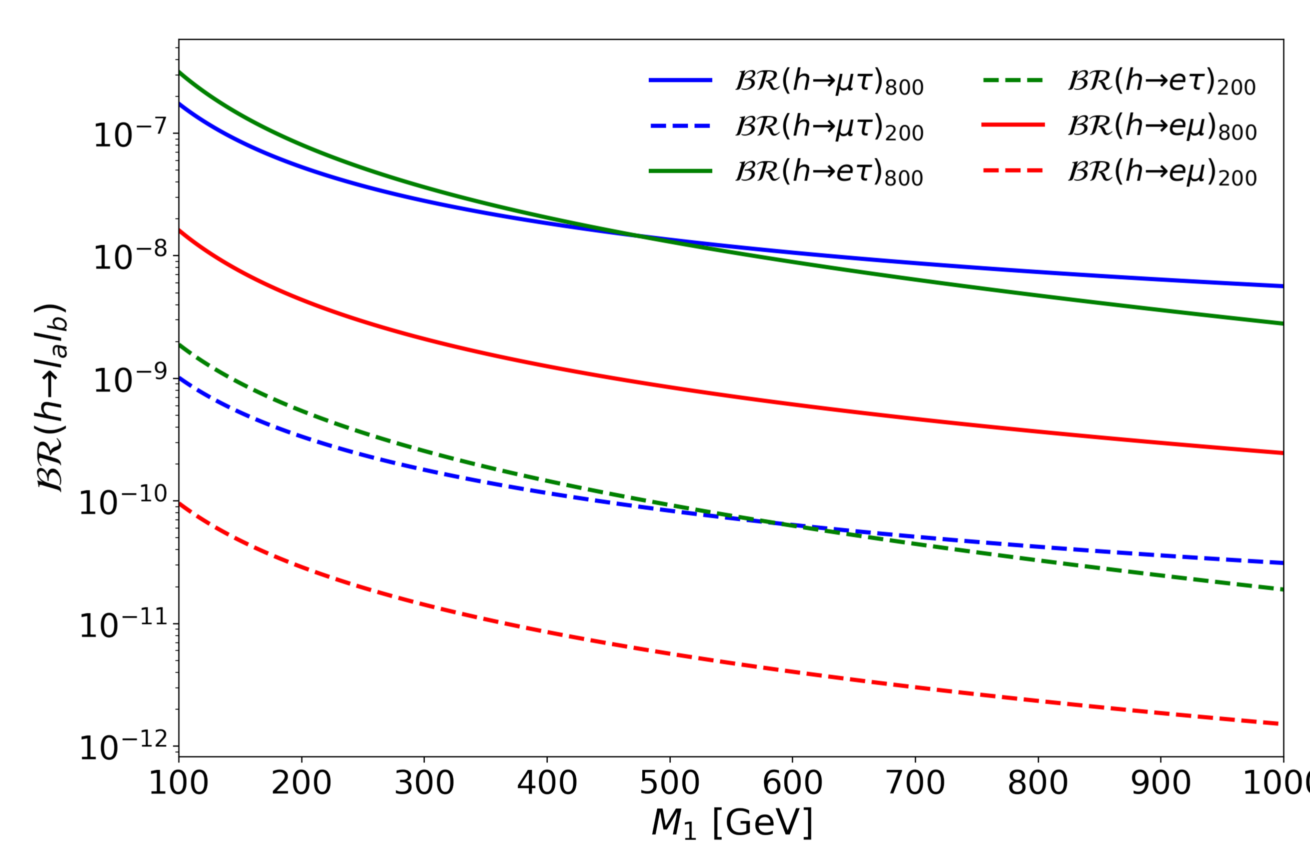
In this model, the LFV Higgs decays are not allowed at tree level, the most important one loop diagrams comes from odd particles as follows:



Results

We consider three main constraints to the Scotogenic model, viz, **relic density of dark matter**, considering N_1 as the dark matter candidate; **electroweak parameters** and experimental upper bound for **radiative decays** $\mu \to e\gamma$. Then we assume that the masses of N_1, η_R, $\eta^\pm$, must be of the order of $O(10^2)$ GeV, and $\lambda_5 \approx 10^{-10}$. For heavy neutrinos $N_1 << N_{2,3}$, then, we fix $M_2 = 10^4$ GeV, $M_3 = 10^5$ GeV. Finally, we also fix $\mu_2 = 1$ GeV without loss of generality,

We consider two cases to $\mathcal{BR}(h \to l_a l_b)$ for the Scotogenic model (i) for $m_\eta = 800$ GeV, $m_R = 805$ GeV (solid lines); and (ii) for $m_\eta = 200$ GeV, $m_R = 205$ GeV (dashed lines).



Conclusiones

- The largest values of $\mathcal{BR}(h \to l_a l_b)$ are reached for $M_1 = 100$ GeV, which are: $\mathcal{BR}(h \to \mu\tau)_{800} \approx \mathcal{BR}(h \to e\tau)_{800} \approx 10^{-7}$ and $\mathcal{BR}(h \to e\mu)_{800} \approx 10^{-8}$, also $\mathcal{BR}(h \to \mu\tau)_{200} \approx \mathcal{BR}(h \to e\tau)_{200} \approx 10^{-9}$ and $\mathcal{BR}(h \to e\mu)_{200} \approx 10^{-10}$.
- In the Scotogenic model the LFV Higgs decays are larger than the derived from the SM plus direac neutrinos which is the order of $\mathcal{BR}(h \to l_a l_b)_{\text{SM}} \approx 10^{60} < \mathcal{BR}(h \to l_a l_b)_{\text{Scoto}}$.
- Our results are in agreement with the aproximate results of [2, 3].

References

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