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Fermion mass hierarchy in an extended left-right symmetric model

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We present a Left-Right symmetric model that explains the mass hierarchy of charged fermions within the Standard Model. The explanation uses both tree-level and radiative seesaw mechanisms. It introduces a three-loop radiative inverse seesaw mechanism to generate the small masses of light neutrinos, with Dirac and Majorana submatrices forming at the one-loop level. The model also includes a global $U(1)_X$ symmetry, which stabilizes Dark Matter candidates after spontaneous breaking. The model is consistent with electroweak precision observables, the electron and muon anomalous magnetic moments as well as with the constraints arising from charged lepton flavor violation, dark matter and the 95 GeV diphoton excess.

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	Q_{L_n}	Q_{L_3}	Q_{R_i}	L_{L_i}	L_{R_i}	T_{L_n}	T_{R_1}	T_{R_2}	B_L	B_R	T'_L	T'_R	B'_{L_n}	B'_{R_n}	E_L	E_R	E'_{L_n}	E'_{R_n}	N_{R_i}	Ω_{R_n}
$SU(3)_C$	**3**	**3**	**3**	**1**	**1**	**3**	**3**	3	**3**	**3**	**3**	**3**	**3**	**3**	**1**	**1**	**1**	**1**	**1**	**1**
$SU(2)_L$	**2**	**2**	**1**	**2**	**1**	**1**	**1**	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
$SU(2)_R$	**1**	**1**	**2**	**1**	**2**	**1**	**1**	1	**1**	**1**	1	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
$U(1)_{B-L}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	-1	-1	$\frac{4}{3}$	$\frac{4}{3}$	$\frac{4}{3}$	$-\frac{2}{3}$	$-\frac{2}{3}$	$\frac{4}{3}$	$\frac{4}{3}$	$-\frac{2}{3}$	$-\frac{2}{3}$	-2	-2	-2	-2	0	0
$U(1)_X$	2	0	0	0	-2	0	0	2	0	0	-1	1	1	3	-2	0	-1	1	2	-3

Table 1: Fermion charge assignments under the $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times U(1)_X$ symmetry. Here, $i = 1, 2, 3$ and $n = 1, 2$.

1. Introduction

Despite the remarkable accomplishments of the Standard Model (SM) in describing the fundamental interactions, it fails to address several profound inquiries that remain unanswered. In the context of the present work, we plan to address specific questions such as the SM flavor structure, the origin of Dark Matter and the parity violation in weak interactions, whose answers lie certainly beyond the SM. Even though the energy scale of New Physics is still a mystery, current experimental searches keep restricting the possibilities for new phenomena at experimentally accessible energy scales and pushing potential New Physics signatures towards high energies. For this reason, it is interesting to look into well motivated SM extensions, whose signatures dwells at energies much higher than the electroweak scale, such as for instance the Left-Right (LR) symmetric models. These are particularly interesting since they provide a robust explanation of parity violation in weak interactions, as a low-energy effect of the spontaneously broken at high scales LR-symmetry [1].

2. The model

The model under consideration is based on the gauge symmetry $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ supplemented by the global $U(1)_X$ symmetry [1]. The spontaneous breaking of the global $U(1)_X$ symmetry is assumed to occur together with the LR symmetry breaking at the same energy scale. With the scalar field assignments given in Table 2, the global $U(1)_X$ symmetry is spontaneously broken down to a preserved Z_2 discrete symmetry defined as $M_P = (-1)^{X+2s}$. That preserved Z_2 discrete symmetry allows a successful implementation of a radiative seesaw mechanism at one-loop level, that generates masses of the light (up, down and strange) quarks, as well as those of electron and muon. Furthermore, thanks to the preserved Z_2 symmetry, the masses of the light active neutrinos arise from a three-loop inverse seesaw mechanism, while the masses of the third family of SM charged fermions as well the charm quark mass are generated by means of a seesaw mechanism responsible for their tree-level mixing with heavy charged vector-like fermions. The fermion assignments under the $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times U(1)_X$ group are displayed in Table 1. The allowed charged-fermion and neutrino Yukawa interactions are,

	χ_L	χ_R	ϕ_L	ϕ_R	σ	ρ	φ
$SU(3)_C$	**1**	**1**	**1**	**1**	**1**	**1**	**1**
$SU(2)_L$	**2**	**1**	**2**	**1**	**1**	**1**	**1**
$SU(2)_R$	**1**	**2**	**1**	**2**	**1**	**1**	**1**
$U(1)_{B-L}$	1	1	1	1	0	0	0
$U(1)_X$	0	0	−1	−1	−2	−6	−1

Table 2: Scalar boson charge assignments under the $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times U(1)_X$ symmetry.

$$
\begin{aligned}
-\mathcal{L}_Y &= x_3^{(T)}\overline{Q}_{L_3}\widetilde{\chi}_L T_{R_1} + \sum_{i=1}^{3} z_{1i}^{(T)}\overline{T}_{L_1}\widetilde{\chi}_R^{\dagger}Q_{R_i} + x_3^{(B)}\overline{Q}_{L_3}\chi_L B_R + \sum_{i=1}^{3} z_i^{(B)}\overline{B}_L\chi_R^{\dagger}Q_{R_i} \\
&+ \sum_{n=1}^{2} x_n^{(T)}\overline{Q}_{L_n}\widetilde{\chi}_L T_{R_2} + \sum_{i=1}^{3} z_{2i}^{(T)}\overline{T}_{L_2}\widetilde{\chi}_R^{\dagger}Q_{R_i} + \sum_{n=1}^{2} w_n^{(T')}\overline{Q}_{L_n}\widetilde{\phi}_L T'_R + \sum_{i=1}^{3} r_i^{(T')}\overline{T}'_L\widetilde{\phi}_R^{\dagger}Q_{R_i} \\
&+ \sum_{n=1}^{2}\sum_{m=1}^{2} w_{nm}^{(B')}\overline{Q}_{L_n}\phi_L B'_{R_m} + \sum_{n=1}^{2}\sum_{i=1}^{3} r_{ni}^{(B')}\bar{B}'_{L_n}\phi_R^{\dagger}Q_{R_i} + m_T\overline{T}_{L_1}T_{R_1} + y_T\overline{T}_{L_2}\sigma T_{R_2} \\
&+ y_{T'}\bar{T}'_L\sigma T'_R + \sum_{n=1}^{2}\sum_{m=1}^{2}(y_{B'})_{nm}\,\bar{B}'_{L_n}\sigma B'_{R_m} + m_B\overline{B}_L B_R + y_E\overline{E}_L\sigma E_R \\
&+ \sum_{n=1}^{2}\sum_{m=1}^{2}(y_{E'})_{nm}\,\bar{E}'_{L_n}\sigma E'_{R_m} + \sum_{i=1}^{3} x_i^{(E)}\overline{L}_{L_i}\chi_L E_R + \sum_{j=1}^{3} z_j^{(E)}\overline{E}_L\chi_R^{\dagger}L_{R_j} \\
&+ \sum_{i=1}^{3}\sum_{n=1}^{2} w_{in}^{(E')}\overline{L}_{L_i}\phi_L E'_{R_n} + \sum_{n=1}^{2}\sum_{j=1}^{3} r_{nj}^{(E')}\bar{E}'_{L_n}\phi_R^{\dagger}L_{R_j} + \sum_{i=1}^{3}\sum_{j=1}^{3} x_{ij}^{(N)}\overline{N_{R_i}^C}\widetilde{\chi}_R^{\dagger}L_{R_j} \\
&+ \sum_{n=1}^{2}(y_\Omega)_n\,\overline{\Omega}_{R_n}\Omega_{R_n}^C\rho + \sum_{i=1}^{3}\sum_{k=1}^{2} x_{ik}^{(\Omega)}\overline{N}_{R_i}\Omega_{kR}^C\varphi + H.c. \qquad (1)
\end{aligned}
$$

Together, these interactions are responsible for generating the Feynman diagrams of Fig. 1 contributing to the entries of the SM charged fermion mass matrices shown as well as those ones of Fig. 2 that yield the Dirac neutrino and lepton number violating Majorana neutrino mass submatrices.

Oblique parameters The extra scalars affect the oblique corrections of the SM, whose values are measured in high precision experiments. Consequently, they act as a further constraint on the validity of any New Physics model. The oblique corrections are parametrized in terms of the three well-known quantities T, S and U. As shown in the left-panel of Figure 3 our model is consistent with the constraints arising from the experimental measurements of the oblique T, S and U parameters.

The 95 GeV diphoton excess In what follows we discuss the possibility that the excess of events in the diphoton final state at the invariant mass of about 95 GeV [2] be due to the real component σ_R of the scalar singlet σ of the model under consideration, whose mass is assumed to be equal to 95 GeV. The EW scalar singlet σ_R is mainly produced via a gluon fusion mechanism, involving the heavy exotic T_2, T' and B'_n $(n = 1, 2)$ quarks running in the internal lines of the triangular loop. The diphoton decay of the scalar singlet σ_R is mediated by triangular loops involving the

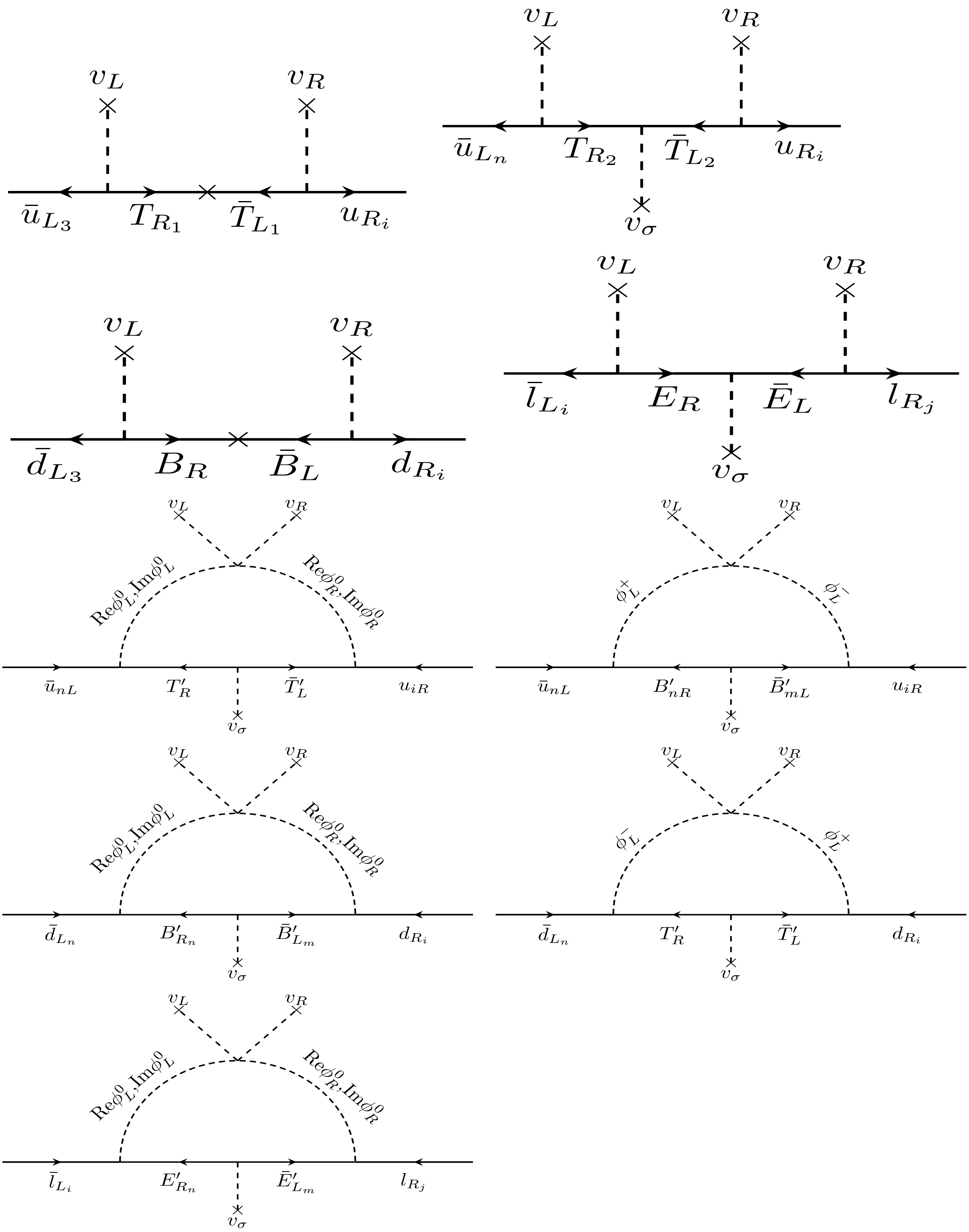

Figure 1: Feynman diagrams contributing to the entries of the SM charged fermion mass matrices. Here, $n, m = 1, 2$ and $i, j = 1, 2, 3$.

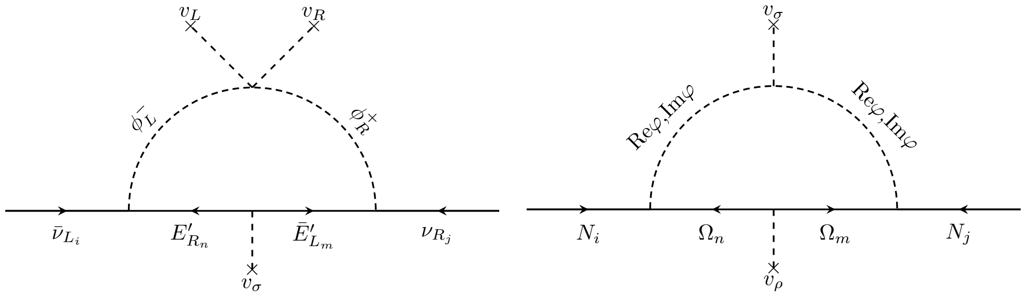

Figure 2: Feynman diagrams contributing to the Dirac neutrino and lepton number violating Majorana neutrino mass submatrices $m_{\nu D}$ and μ. Here, $n, m = 1, 2$ and $i, j = 1, 2, 3$.

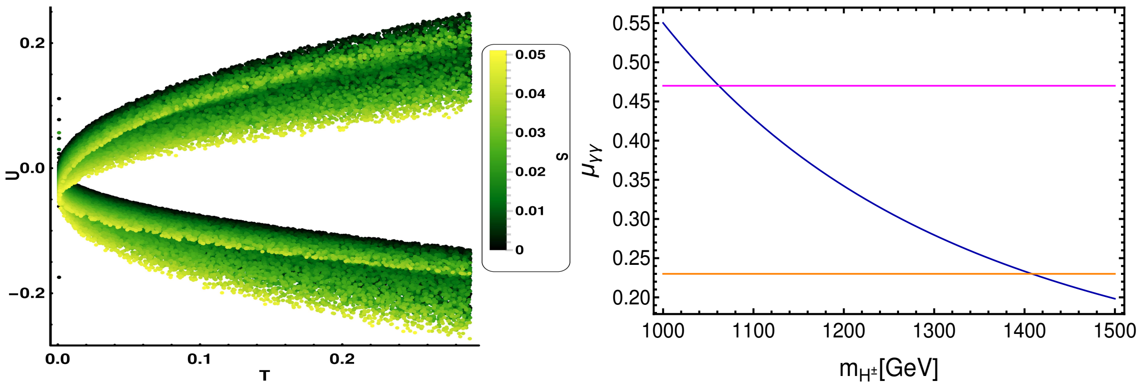

Figure 3: Correlation between the oblique T and U parameters (left-panel). Diphoton signal strength for a hypothetical 95 GeV scalar resonance as a function of the charged scalar mass $m_{H^\pm}$ (right-panel). The magenta and orange horizontal lines correspond to the upper and lower 1σ experimental limits.

virtual exchange of vector-like quarks, charged vector-like leptons E and E' and electrically charged scalars. Figure 3 (right panel) displays the diphoton signal strength for a hypothetical 95 GeV scalar resonance as a function of the charged scalar mass $m_{H^\pm}$. The magenta and orange horizontal lines correspond to the upper and lower experimental limits within the 1σ range, respectively. As seen from the right-panel of Figure 3, our model successfully accommodates the 95GeV diphoton excess.

Charged lepton flavor violation These sterile neutrinos, as well as the light active neutrinostogether with the SM W gauge and heavy W' gauge bosons, induce the $l_i \to l_j \gamma$ decay at one loop level that can be use to test our model. Figure 4 shows the correlation between the branching ratio for the $\mu \to e\gamma$ decay and the mass m_N of the sterile neutrinos. As indicated by the left-panel Figure 4, the obtained values for the $\mu \to e\gamma$ decay branching ratio are below its experimental upper bound of 4.2×10^{-13} and are within the reach of future experimental sensitivity.

Dark matter In this model there is a residual matter parity symmetry, surviving the spontaneous breaking of the global $U(1)_X$ group. This symmetry is responsible for stabilizing the dark matter particle candidate in the our model. In this case, the fields that compose the dark sector have no electric charge and are odd under the matter parity symmetry. Notice that the Majorana fermions N_{R_i} mix the with active neutrinos, which will cause their decay. For this reason, the N_{R_i} are discarded as dark matter candidates. Therefore, the dark matter candidate in this model has a scalar

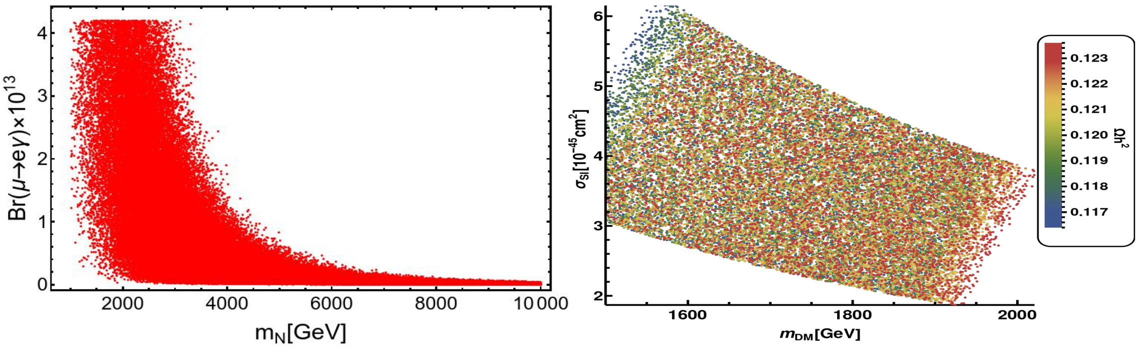

Figure 4: Correlation between the branching ratio for the $\mu \rightarrow e\gamma$ decay and the mass m_N of the sterile neutrinos (left-panel). Correlation of the spin independent cross section σ_{SI} with the dark matter mass m_{DM} (right panel).

nature and would be the lightest neutral component of the scalars $(\phi_L^0, \phi_R^0, \varphi)$. We display in Figure 4 (right-panel) the correlation of the spin independent cross section with the dark matter mass. As indicated in Figure 4 our model is consistent with the constraints arising from dark matter direct detection and can successfully reproduce the experimental values of the dark matter relic density.

3. Conclusion

We have investigated a renormalizable extended Left-Right symmetric theory with an additional global $U(1)_X$ symmetry, capable of explaining and accommodating the observed SM fermion mass hierarchy and the tiny values of the light active neutrino masses. Furthermore, the model is consistent with the current amount of dark matter relic density observed in the Universe, the muon anomalous magnetic moment, the oblique T, S and U parameters, as well as the 95 GeV diphoton excess.

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