Radiative Neutrino Masses, Lepton Anomalous Magnetic Moments and Dark Matter

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Proposal

A simultaneous explanation of three of the pervading issues of the standard model *viz.*

- SM neutrino masses
- Anomalous magnetic moments of electron and muon
- Dark matter relic density

via introduction of vector-like fermions and an inert scalar-doublet.

Model

SM Sector under $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes Z_2$
$l_{iL} \equiv (\nu_{iL}\ \ e_{iL})^T : (1,2,-1/2,+)$, $e_{iR} : (1,1,-1,+)$
$q_{iL} \equiv (u_{iL}\ \ d_{iL})^T : (3,2,1/6,+)$
$u_{iR} : (3,1,2/3,+)$, $d_{iR} : (3,1,-1/3,+)$
$H \equiv \left(h^+\ \ [h+i\eta]/\sqrt{2}\right)^T : (1,2,1/2,+)$

Exotic Sector under $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes Z_2$
$L_{\alpha L/R} \equiv \left(N^D_{\alpha L/R}\ \ E^D_{\alpha L/R}\right)^T : (1,2,-1/2,-)$
$E^S_{\alpha L/R} : (1,1,-1,-)$, $N^S_{\alpha R} : (1,1,0,-)$
$Q_{\alpha L/R} \equiv \left(U^D_{\alpha L/R}\ \ D^D_{\alpha L/R}\right)^T : (3,2,1/6,-)$
$U^S_{\alpha L/R} : (3,1,2/3,-)$, $D^S_{\alpha L/R} : (3,1,-1/3,-)$
$\Phi \equiv \left(\phi^+\ \ [\phi_S + i\phi_P]/\sqrt{2}\right)^T : (1,2,1/2,-)$

Table: *Field content of the model along with their quantum numbers.*

Lagrangian

$$\mathcal{L}_{\rm Mass} \supset m_Q^{\alpha\beta}\,\overline{Q_{\alpha L}}Q_{\beta R} + m_U^{\alpha\beta}\,\overline{U^S_{\alpha L}}U^S_{\beta R} + m_D^{\alpha\beta}\,\overline{D^S_{\alpha L}}D^S_{\beta R} + m_L^{\alpha\beta}\,\overline{L_{\alpha L}}L_{\beta R} + m_E^{\alpha\beta}\,\overline{E^S_{\alpha L}}E^S_{\beta R} + \frac{1}{2}m_N^{\alpha\beta}\,\overline{\left(N^S_{\alpha R}\right)^c}\,N^S_{\beta R} + \text{H.c.,} \quad (1)$$

$$\mathcal{L}^H_{\rm Yuk} \supset z^{\alpha\beta}_{LU}\,\overline{Q_{\alpha L}}\tilde{H}U^S_{\beta R} + z^{\alpha\beta}_{RU}\,\overline{Q_{\alpha R}}\tilde{H}U^S_{\beta L} + z^{\alpha\beta}_{LD}\,\overline{Q_{\alpha L}}HD^S_{\beta R} + z^{\alpha\beta}_{RD}\,\overline{Q_{\alpha R}}HD^S_{\beta L} + z^{\alpha\beta}_{LN}\,\overline{L_{\alpha L}}\tilde{H}N^S_{\beta R} + z^{\alpha\beta}_{LE}\,\overline{L_{\alpha L}}HE^S_{\beta R} + z^{\alpha\beta}_{RE}\,\overline{L_{\alpha R}}HE^S_{\beta L} + \text{H.c.} \quad (2)$$

$$\mathcal{L}^\Phi_{\rm Yuk} \supset y^{i\alpha}_{qU}\,\overline{q_{iL}}\tilde{\Phi}U^S_{\alpha R} + y^{i\alpha}_{uQ}\,\overline{u_{iR}}\tilde{\Phi}^\dagger Q_{\alpha L} + y^{i\alpha}_{qD}\,\overline{q_{iL}}\Phi D^S_{\alpha R} + y^{i\alpha}_{dQ}\,\overline{d_{iR}}\Phi^\dagger Q_{\alpha L} + y^{i\alpha}_{lN}\,\overline{l_{iL}}\tilde{\Phi}N^S_{\alpha R} + y^{i\alpha}_{lE}\,\overline{l_{iL}}\Phi E^S_{\alpha R} + y^{i\alpha}_{eL}\,\overline{e_{iR}}\Phi^\dagger L_{\alpha L} + \text{H.c.,} \quad (3)$$

$$V(H,\Phi) = -\mu_H^2 H^\dagger H + \lambda_H \left(H^\dagger H\right)^2 + \mu_\Phi^2\left(\Phi^\dagger\Phi\right) + \lambda_\Phi\left(\Phi^\dagger\Phi\right)^2 + \lambda_1\left(H^\dagger H\right)\left(\Phi^\dagger\Phi\right) + \lambda_2\left|H^\dagger\Phi\right|^2 + \lambda_3\left[(H^\dagger\Phi)^2 + h.c.\right]. \quad (4)$$

Neutrino Masses

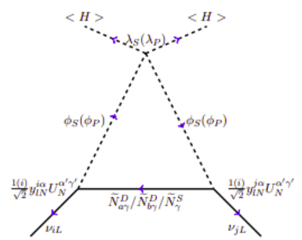

Figure: Feynman diagrams generating neutrino masses at 1-loop level.

$$\frac{m_\nu}{\langle H\rangle^2} = \frac{\lambda_3}{16\pi^2}\,y_{lN}M_\Delta^{-1}y_{lN}^T \quad (5)$$

$$y_{lN} = \left(\frac{4\pi}{v}\lambda_3^{-\frac{1}{2}}\right)U^*_{MNS}\,D_{\sqrt{\nu}}\,R\,M_{\sqrt{\Delta}} \quad (6)$$

In the *simplified scenario* (*i.e.*, $m_L = \widetilde{m}_L \times I_{n\times n}$ and $m_N = \widetilde{m}_N \times I_{n\times n}$)

$$M_{\sqrt{\Delta}} = \left[\frac{\widetilde{m}_N}{I\left(\frac{m^2_{\phi_S}}{\widetilde{m}^2_N}\right)}\right]^{\frac{1}{2}} \times \mathrm{I}_{n\times n} \quad (7)$$

Lepton Flavor Violation & Anomalous Magnetic Moments

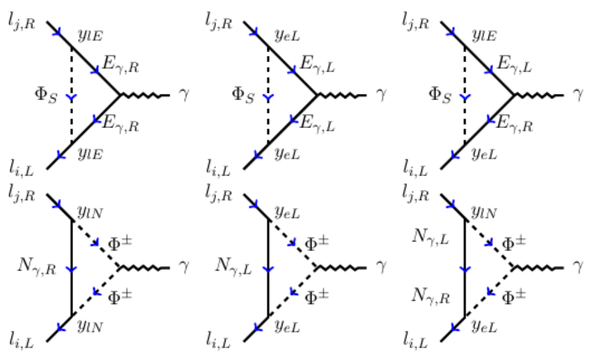

Figure: Feynman diagrams generating the process $l_j \to l_i\gamma$.

Discrepancies $\Delta a_\mu = 2.61\times10^{-9}$ and $\Delta a_e = -0.88\times10^{-12}$ [1] are explained at 1-loop level as shown above while surviving constraints from LFV decays.

Dark Matter Relic Density

With **DM candidate** as an admixture of singlet-doublet Z_2-odd neutral fermions, $\Omega h^2 = 0.119$ [2] is explained.

$$z_{LN} = z.\begin{pmatrix}1 & 1\\ 1 & 1\end{pmatrix},\quad z_{LE} = 0.3\begin{pmatrix}1 & -1\\ 1 & 1\end{pmatrix},\quad y_{lE} = \begin{pmatrix}0.1 & -0.1\\ 1 & 1\\ 0.0 & 0.0\end{pmatrix} \quad (8)$$

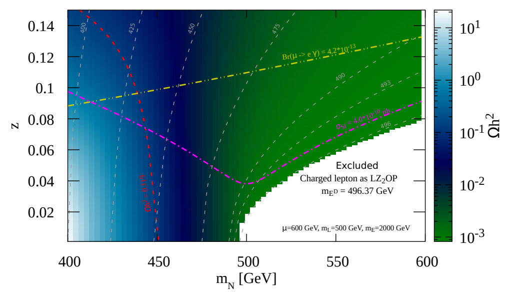

Figure: Relic density plot for fermionic DM.

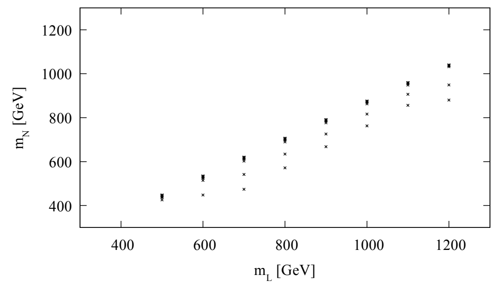

Figure: Values of $\widetilde{m}_L$ and $\widetilde{m}_N$ satisfying relic density of DM for fixed parameters μ_Φ=1200 GeV, z_{LE}=0.3, z_{LN}=0.001 and $\widetilde{m}_E$=500-2000 GeV.

Conclusion

With the available particle spectrum, a feasible parameter space exists whereby it is possible to generate neutrino masses, address the discrepancy in anomalous magnetic moment of muon and electron as well as explain the observed relic density of dark matter within the purview of constraints from lepton flavour violating decays and direct detection of dark matter.

References

[1] P. A. Zyla *et al.* [Particle Data Group], PTEP **2020**, no.8, 083C01 (2020) doi:10.1093/ptep/ptaa104

[2] M. Tanabashi *et al.* [Particle Data Group], Phys. Rev. D **98**, no.3, 030001 (2018) doi:10.1103/PhysRevD.98.030001