31st Lepton Photon Conference 2023
MELBOURNE CONVENTION & EXHIBITION CENTRE
17 - 21 JULY

Flavour anomalies, Light Dark Matter and rare B decays with missing energy in $L_\mu - L_\tau$ model

Rukmani Mohanta
School of Physics, University of Hyderabad, Hyderabad - 500 046, India **E-mail:** **rmsp@uohyd.ac.in**

Introduction

- We consider a new variant of $U(1)_{L_\mu - L_\tau}$ gauge extension of Standard Model, containing three additional neutral fermions N_e, N_μ, N_τ, along with a scalar Leptoquark $(\bar{3}, 1, 1/3)$ and an inert scalar doublet, to study the phenomenology of light dark matter, neutrino mass generation and flavour anomalies on a single platform.
- The lightest mass eigenstate of the N_μ, N_τ neutral fermions plays the role of dark matter.
- The light gauge boson associated with $U(1)_{L_\mu - L_\tau}$ gauge group mediates dark to visible sector and helps to obtain the correct relic density.
- We constrain the model parameters by using the recent flavor anomalies in $b \to s$ transitions and then show the implication on the branching ratios of some rare semileptonic $B \to (K^{(*)}, \phi)+$ missing energy, processes.

Particle Content

	Field	$SU(3)_C \times SU(2)_L \times U(1)_Y$	$U(1)_{L_\mu - L_\tau}$	Z_2
Fermions	$Q_L \equiv (u,d)^T_L$	$(\mathbf{3},\mathbf{2},1/6)$	0	+
	u_R	$(\mathbf{3},\mathbf{1},2/3)$	0	+
	d_R	$(\mathbf{3},\mathbf{1},-1/3)$	0	+
	$\ell_L \equiv e_L, \mu_L, \tau_L$	$(\mathbf{1},\mathbf{2},-1/2)$	$0,1,-1$	+
	$\ell_R \equiv e_R, \mu_R, \tau_R$	$(\mathbf{1},\mathbf{1},-1)$	$0,1,-1$	+
	N_e, N_μ, N_τ	$(\mathbf{1},\mathbf{1},0)$	$0,1,-1$	−
Scalars	H	$(\mathbf{1},\mathbf{2},\ 1/2)$	0	+
	η	$(\mathbf{1},\mathbf{2},\ 1/2)$	0	−
	ϕ_2	$(\mathbf{1},\mathbf{1},\ 0)$	2	+
	S_1	$(\bar{\mathbf{3}},\mathbf{1},1/3)$	-1	−
Gauge bosons	$W^i_\mu\ (i=1,2,3)$	$(\mathbf{1},\mathbf{3},0)$	0	+
	B_μ	$(\mathbf{1},\mathbf{1},0)$	0	+
	V_μ	$(\mathbf{1},\mathbf{1},0)$	0	+

Table 1: Fields and their charges of the proposed $U(1)_{L_\mu - L_\tau}$ model.

Lagrangian of the Model

- The Lagrangian of the present model is given as

$$\mathcal{L}_G = -\frac{1}{4}\left(\hat{\mathbf{W}}_{\mu\nu}\hat{\mathbf{W}}^{\mu\nu} + \hat{B}_{\mu\nu}\hat{B}^{\mu\nu} + \hat{V}_{\mu\nu}\hat{V}^{\mu\nu} + 2\sin\chi \hat{B}_{\mu\nu}\hat{V}^{\mu\nu}\right),$$

$$\mathcal{L}_f = -\frac{1}{2}M_{ee}\overline{N_e^c}N_e - \frac{f_\mu}{2}\left(\overline{N_\mu^c}N_\mu\phi_2^\dagger + \text{h.c.}\right) - \frac{f_\tau}{2}\left(\overline{N_\tau^c}N_\tau\phi_2 + \text{h.c.}\right)$$
$$-\frac{1}{2}M_{\mu\tau}(\overline{N_\mu^c}N_\tau + \overline{N_\tau^c}N_\mu) - \sum_{l=e,\mu,\tau}(Y_{ll}(\overline{\ell_L})_l\tilde{\eta}N_{lR} + \text{h.c}) - \sum_{q=d,s,b}(y_{qR}\ \overline{d_{qR}^c}S_1N_\mu + \text{h.c.}),$$

$$\mathcal{L}_{G-f} = -g_{\mu\tau}\overline{\mu}\gamma^\mu\mu\hat{V}_\mu + g_{\mu\tau}\overline{\tau}\gamma^\mu\tau\hat{V}_\mu - g_{\mu\tau}\overline{\nu_\mu}\gamma^\mu(1-\gamma^5)\nu_\mu\hat{V}_\mu$$
$$+g_{\mu\tau}\overline{\nu_\tau}\gamma^\mu(1-\gamma^5)\nu_\tau\hat{V}_\mu - g_{\mu\tau}\overline{N_\mu}\hat{V}_\mu\gamma^\mu\gamma^5N_\mu + g_{\mu\tau}\overline{N_\tau}\hat{V}_\mu\gamma^\mu\gamma^5N_\tau,$$

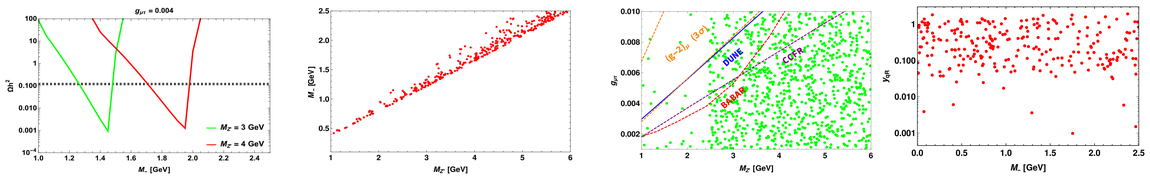
$$\mathcal{L}_S = \left|\left(i\partial_\mu - \frac{g}{2}\boldsymbol{\tau}^a\cdot\hat{\mathbf{W}}^a_\mu - \frac{g'}{2}\hat{B}_\mu\right)\eta\right|^2 + \left|\left(i\partial_\mu - \frac{g'}{3}\hat{B}_\mu + g_{\mu\tau}\hat{V}_\mu\right)S_1\right|^2$$
$$+\left|\left(i\partial_\mu - 2g_{\mu\tau}\hat{V}_\mu\right)\phi_2\right|^2 - V(H,\eta,\phi_2,S_1).$$

Model Framework and Constraints on Model Parameters

- Mixing in Gauge sector : The mixing of W^3_μ and the $U(1)_Y$ & $U(1)_{L_\mu - L_\tau}$ gauge bosons gives $(Z,\ Z',\ \gamma)$.
- Scalar and Fermion sectors: The mixing of CP even components of H and ϕ_2 gives the SM Higgs H_1 and a heavy Higgs H_2. Mixing of N_μ and N_τ gives two mass eigenstates, the lightest one N_- considered as probable DM candidate.
- The relic density of the light DM (N_-) is computed via freeze-out mechanism through the following decay channels:

  $N_-\overline{N}_- \to \mu\overline{\mu},\ \tau\overline{\tau},\ \nu_\mu\overline{\nu}_\mu,\ \nu_\tau\overline{\nu}_\tau$ (s channel Z' and η portal), and $N_-\overline{N}_- \to d\overline{d},\ s\overline{s}$ (t channel SLQ (S_1) portal)

- Constraints from Flavor sector: The $b \to sll$ transition occurs at 1-loop with SLQ and heavy fermions and the parameters of LQ and Z' couplings can be constrained using $R_{K^{(*)}}$ and $\text{Br}(B \to X_s\gamma)$



- The allowed range of all the four new parameters consistent with flavor phenomenology

Parameters	y_{qR}	$g_{\mu\tau}$	M_- (GeV)	$M_{Z'}$ (GeV)
Allowed range	$0-2.0$	$0-0.01$	$0-2.5$	$1-6$

Table 2: The allowed regions of y_{qR}, $g_{\mu\tau}$, M_- and $M_{Z'}$ parameters.

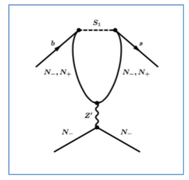
Footprints on $b \to s+$ $\not{E}$ decay modes

- In SM, $b \to s+$ missing energy can be described by the $b \to s\nu\bar{\nu}$
- The effective Hamiltonian in SM : $\mathcal{H}_{eff} = \frac{-4G_F}{\sqrt{2}}V_{tb}V^*_{ts}\left(C^\nu_L\mathcal{O}^\nu_L + C^\nu_R\mathcal{O}^\nu_R\right) + h.c.,$
- In this model, the additional process involved is : $b \to s +$ missing energy $= b \to s\nu\nu + b \to sN_-N_-$
  - Thus, e.g., the amplitude of $B \to KN_-N_-$ process from the Z' exchanging diagram is

    $$\mathcal{M} = C^{\text{NP}}(q^2)[\bar{u}(p_B)\gamma^\mu(1+\gamma_5)u(p_K))][\bar{v}(p_2)\gamma_\mu u(p_1))]$$

    where

    $$C^{\text{NP}}(q^2) = \frac{1}{2^5\pi^2}\frac{y^2_{qR}g^2_{\mu\tau}\cos 2\beta\cos\alpha\sec\chi}{q^2 - M^2_{Z'}}\mathcal{V}_{sb}(\chi_-,\chi_+),$$



  - We use two sets of benchmark values of new parameters, allowed by both the DM and flavor phenomenology

Benchmark	y_{qR}	$g_{\mu\tau}$	M_- (GeV)	$M_{Z'}$ (GeV)
Benchmark-I	2.0	0.002	1.7	4
Benchmark-II	2.0	0.008	1.8	4.8

Table: Benchmark values of y_{qR}, M_-, $g_{\mu\tau}$ and $M_{Z'}$ parameters used in our analysis.

Br($b \to s\not{E}$)	SM value	Benchmark-I	Benchmark-II	Experimental Limit
Br($B^0 \to K^0\not{E}$)	$(0.45 \pm 0.03) \times 10^{-5}$	0.645×10^{-5}	0.457×10^{-5}	$< 2.6 \times 10^{-5}$
Br($B^+ \to K^+\not{E}$)	$(0.49 \pm 0.03) \times 10^{-5}$	0.697×10^{-5}	0.516×10^{-5}	$< 1.6 \times 10^{-5}$
Br($B^0 \to K^{*0}\not{E}$)	$(0.95 \pm 0.07) \times 10^{-5}$	1.271×10^{-5}	0.981×10^{-5}	$< 1.8 \times 10^{-5}$
Br($B^+ \to K^{*+}\not{E}$)	$(1.03 \pm 0.06) \times 10^{-5}$	1.381×10^{-5}	1.066×10^{-5}	$< 4.0 \times 10^{-5}$
Br($B_s \to \phi\not{E}$)	$(1.2 \pm 0.07) \times 10^{-5}$	1.618×10^{-5}	1.24×10^{-5}	$< 5.4 \times 10^{-3}$

Table: The predicted branching ratios of $b \to s\not{E}$ processes for two different benchmark values of new parameters.

Conclusion

- We explored GeV scale dark matter and flavour anomalies in a $U(1)_{L_\mu - L_\tau}$ gauge extension of SM with an additional $(\bar{\mathbf{3}},\mathbf{1},\ 1/3)$ SLQ.
- Shown the impact on rare B decays with $\not{E}$, observation of which would provide strong hints for the existence of light fermionic DM.

⋆ **Reference: S. Singirala, S. Sahoo and R. Mohanta, Phys. Rev. D 105, 015033 (2022)**