Correlating flavor anomalies and dark matter in the light of scalar leptoquark

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Quick Recap of Recent Anomalies in B-sector

- Flavour Physics is going through a challenging period
- However, in last few years there are several measurements, which do not agree with the SM predictions.
- These deviations are not statistically significant enough to claim the discovery of NP. At the same time, they are not weak enough to be completely ignored.
- They may be considered as smoking-gun signals of possible NP.
- Some of these are:
  - $R_{D^{(*)}}$ Anomaly ($b \to c\ell\nu$): NP in charged currents
  - Deviations in $b \to s\mu\mu$: P_5', BR($B \to K^{(*)}\mu\mu$), $B_s \to \phi\mu\mu$ (NP in FCNC transitions)
  - $R_{K^{(*)}}$ Anomaly (Dissolved with the recent data)
- These anomalies may guide us how to probe or go beyond the SM

FCNC mediated $b \to s\ell^-\ell^+ / b \to s\nu\bar{\nu}$ transitions

- FCNC mediated rare B decays ($b \to s\ell^+\ell^-$ and $b \to s\nu\nu$) provide an ideal platform to explore NP
- They are loop suppressed in the SM $\Longrightarrow$ highly sensitive to virtual particles in the loop
- Even though $R(K^{(*)})$ and $\mathcal{B}(B_s \to \mu\mu)$ are now consistent with SM predictions, the presence of NP in $b \to s\mu\mu$ is not yet ruled out completely.
- Recently Belle II reported the BR for $B^+ \to K^+\nu\bar{\nu}$ using 362 fb^{-1} data with Hadronic and Inclusive Tagging

$$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (2.3 \pm 0.5(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})) \times 10^{-5}$$

  which has 2.7σ deviation with the SM result.
- Attractive scenarios: Additional decay channels with undetected final states, e.g., sterile neutrinos, dark matter, long-lived particles

Model description (Gauged $L_\mu - L_\tau$)

- The SM has accidental $U(1)$ global symmetries like B and L no. conservation
- However, they become anomalous if promoted into a local one
- The anomaly free situation can be obtained if instead of considering B and L separately, some combinations between them, e.g., $B - L$, $L_e - L_\mu$, $L_e - L_\tau$ or $L_\mu - L_\tau$
- For the anomaly cancellation of local $B - L$ models, one requires 3 RHNs with appropriate $B - L$ charges
- Unlike $B - L$ case, the anomaly cancellation does not require any extra chiral fermionic degrees of freedom for $L_\alpha - L_\beta$, as anomalies cancel between different leptonic generations.
- $U(1))_{L_\mu - L_\tau}$ is less constrained, as the extra Z' does not couple to electrons and quarks, $\Rightarrow$ free from any constraints from lepton and hadron colliders
- Another theoretical motivation: it can explain the muon $(g-2)$ anomaly

$L_\mu - L_\tau$ Model with Scalar LQ $S_1(\bar{3}, 1, 1/3)$ (PRD 105, 015033)

	Field	$SU(3)_C \times SU(2)_L \times U(1)_Y$	$U(1)_{L_\mu - L_\tau}$	Z_2
Fermions	$Q_L \equiv (u, d)_L^T$	$(\mathbf{3}, \mathbf{2}, 1/6)$	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_μ^i $(i = 1, 2, 3)$	$(\mathbf{1}, \mathbf{3}, 0)$	0	$+$
	B_μ	$(\mathbf{1}, \mathbf{1}, 0)$	0	$+$
	V_μ	$(\mathbf{1}, \mathbf{1}, 0)$	0	$+$

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

Lagrangian of the Model

The Lagrangian of the present model can be written as

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

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

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

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

Scalar and Fermion mixing

- The CP-even scalars h and h_2 as well as the heavy fermion states N_μ and N_τ mix with the mixing matrices given as

$$M_H^2 = \begin{pmatrix} 2\lambda_H v^2 & \lambda_{H\phi} v v_2 \\ \lambda_{H\phi} v v_2 & 2\lambda_\phi v_2^2 \end{pmatrix}, \quad M_N = \begin{pmatrix} \frac{1}{\sqrt{2}} f_\mu v_2 & M_{\mu\tau} \\ M_{\mu\tau} & \frac{1}{\sqrt{2}} f_\tau v_2 \end{pmatrix}.$$

One can diagonalize the above mass matrices using a 2×2 rotation matrix

$$U_\zeta^T M_H^2 U_\zeta = \text{diag}\,[M_{H_1}^2, M_{H_2}^2], \quad U_\beta^T M_N U_\beta = \text{diag}\,[M_-, M_+],$$

with $\zeta = \frac{1}{2}\tan^{-1}\left(\frac{\lambda_{H\phi} v v_2}{\lambda_\phi v_2^2 - \lambda_H v^2}\right)$, $\beta = \frac{1}{2}\tan^{-1}\left(\frac{2M_{\mu\tau}}{(f_\tau - f_\mu)(v_2/\sqrt{2})}\right)$.

- The lightest fermion mass eigenstate N_- considered as probable DM candidate, and M_{H_1} as the SM Higgs

M_{S_1}	M_+	M_{H_1}	M_{H_2}	$\sin\beta$	$\sin\zeta$	χ	$\alpha \times 10^4$
1200	500	125	500	1/2	$10^{-3} - 10^{-2}$	10^{-3}	$4.83 - 4.85$

Table: Values of the model parameters used in the analysis (masses are in GeV).

Dark Matter Relic Abundance

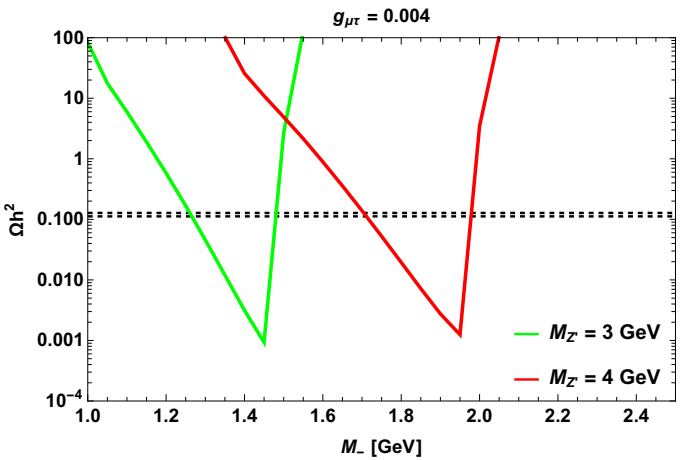
- The relic density of the light DM (N_-) is computed via freeze-out mechanism through the following decay channels:

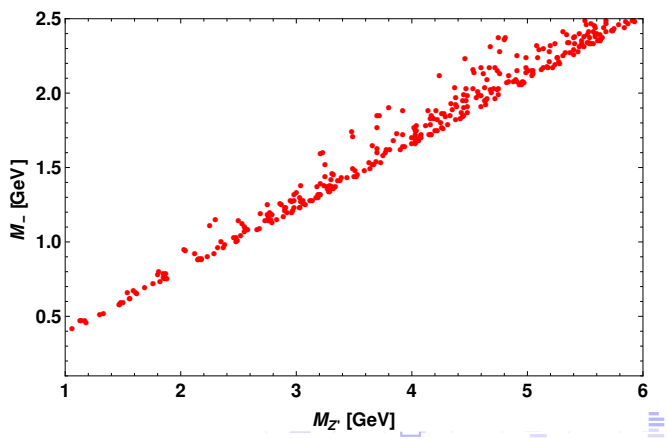
$$\begin{aligned} N_-\overline{N}_- &\rightarrow \mu\overline{\mu},\ \tau\overline{\tau},\ \nu_\mu\overline{\nu}_\mu,\ \nu_\tau\overline{\nu}_\tau \ \ (s \text{ channel } Z' \text{ and } \eta \text{ portal}) \\ &\rightarrow d\overline{d},\ s\overline{s} \ \ (t \text{ channel } SLQ(S_1) \text{ portal}) \end{aligned}$$

- DM relic density is computed by

$$\Omega h^2 = \frac{2.14\times 10^9 \mathrm{GeV}^{-1}}{g*^{1/2} M_{Pl}} \frac{1}{J(x_f)}, \qquad J(x_f) = \int_{x_f}^{\infty} \frac{\langle\sigma v\rangle(x)}{x^2} dx.$$

where $x = M_-/T$ and x_f is the freeze out parameter.





Detection prospects

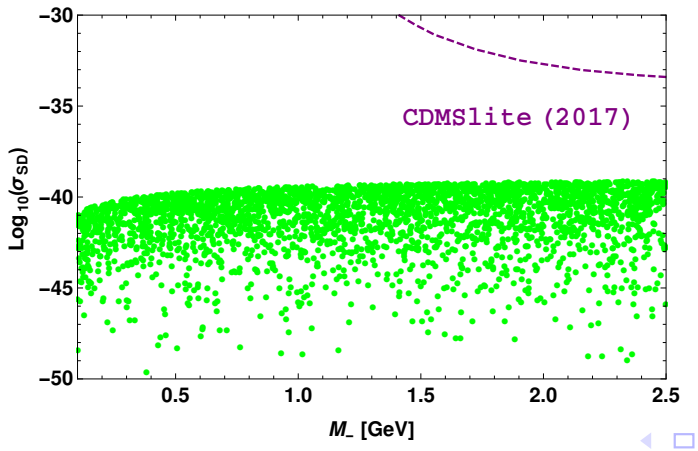
- SLQ portal spin-dependent (SD) cross section can arise from the effective interaction

$$\mathcal{L}_{\rm eff}^{\rm SD} \simeq \frac{y_{qR}^2 \cos^2\beta}{4(M_{S_1}^2 - M_-^2)} (\overline{N}_- \gamma^\mu \gamma^5 N_-)(\overline{q}\gamma_\mu \gamma^5 q)\,,$$

and the computed cross section is given as

$$\sigma_{\rm SD} = \frac{\mu_r^2}{\pi} \frac{\cos^4\beta}{(M_{S_1}^2 - M_-^2)^2} \left[y_{dR}^2 \Delta_d + y_{sR}^2 \Delta_s\right]^2 J_n(J_n+1).$$

- The WIMP-nucleon cross section via (Z, Z') portal and (H_1, H_2) portal is found to be very small and insensitive to direct detection experiments.



Constraints from Flavour sector

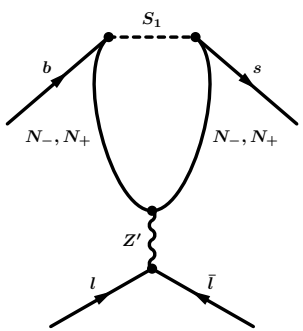
- Model parameters of LQ and Z' couplings can be constrained using $R_{K^{(*)}}$ and $\mathrm{Br}(B \to X_s\gamma)$.
- The effective Hamiltonian mediating $b \to s l^+ l^-$ is

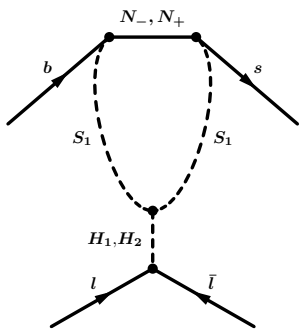
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \left[\sum_{i=1}^{6} C_i(\mu) O_i + \sum_{i=7,9,10} \left(C_i(\mu) O_i + C_i'(\mu) O_i'\right)\right],$$

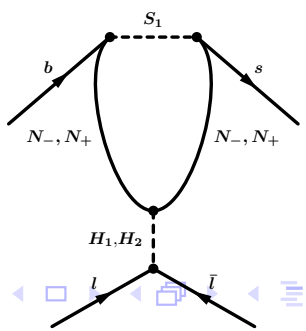
$$O_7^{(\prime)} = \frac{e}{16\pi^2}\left[\bar{s}\sigma_{\mu\nu}\left(m_s P_{L(R)} + m_b P_{R(L)}\right) b\right] F^{\mu\nu},$$

$$O_9^{(\prime)} = \frac{\alpha_{\rm em}}{4\pi}(\bar{s}\gamma^\mu P_{L(R)} b)(\bar{l}\gamma_\mu l), \qquad O_{10}^{(\prime)} = \frac{\alpha_{\rm em}}{4\pi}(\bar{s}\gamma^\mu P_{L(R)} b)(\bar{l}\gamma_\mu\gamma_5 l),$$

- Following one loop diagrams provide non-zero contribution to the rare $b \to s l l$ processes (2nd and 3rd diagrams $\propto m_q M_\pm / M_{S_1}^2$)







- Z' exchange penguin diagram gives the transition amplitude of $b \to sll$ process

$$\mathcal{M} = \frac{1}{2^5\pi^2}\frac{y_{qR}^2 g_{\mu\tau}^2}{(q^2 - M_{Z'}^2)}\mathcal{V}_{sb}(\chi_-,\chi_+)\Big[\bar{u}(p_B)\gamma^\mu(1+\gamma_5)u(p_K))\Big]\Big[\bar{v}(p_2)\gamma_\mu u(p_1))\Big],$$

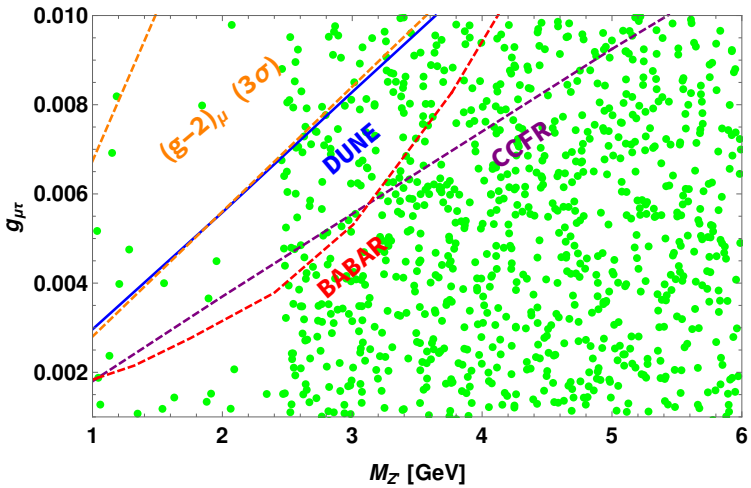
which provides additional primed Wilson coefficient

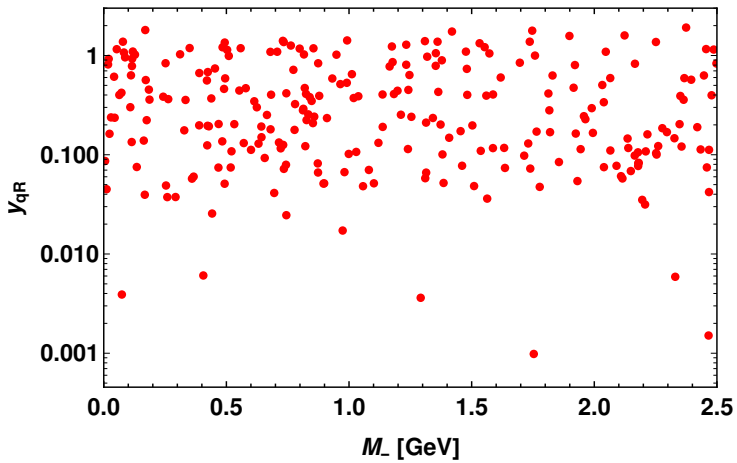
$$C_9'^{\rm NP} = \frac{\sqrt{2}}{2^4\pi G_F \alpha_{\rm em} V_{tb}V_{ts}^*}\frac{y_{qR}^2 g_{\mu\tau}^2}{(q^2 - M_{Z'}{}^2)}\mathcal{V}_{sb}\left(\chi_-,\chi_+\right),$$

$\mathcal{V}_{sb}\left(\chi_-,\chi_+\right)$ is the loop function and $\chi_\pm = M_\pm^2/M_{S_1}^2$.

- As only $C_9'^{\rm NP}$ involves, $B_s \to \mu\mu(\tau\tau)$ won't play any role in constraining the new parameters.
- Absence of $Z'\mu\tau$ coupling $\Rightarrow$ LFV decays like $B \to K^{(*)}\mu\tau$, $\tau \to \mu\gamma$ and $\tau \to 3\mu$ are not allowed

- Thus, using R_K/R_{K*} and $\mathrm{Br}(B \to X_s\gamma)$ observables, the $g_{\mu\tau}$, $M_{Z'}$ and the y_{qR}, M_- allowed regions are shown below





- 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: 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

$$\mathcal{H}_{eff} = \frac{-4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left(C_L^\nu \mathcal{O}_L^\nu + C_R^\nu \mathcal{O}_R^\nu \right) + h.c.,$$

where

$$\mathcal{O}_L^\nu = \frac{\alpha_{\rm em}}{4\pi} \left(\bar{s}_R \gamma_\mu b_L \right) \left(\bar{\nu} \gamma^\mu \left(1 - \gamma_5 \right) \nu \right), \quad \mathcal{O}_R^\nu = \frac{\alpha_{\rm em}}{4\pi} \left(\bar{s}_L \gamma_\mu b_R \right) \left(\bar{\nu} \gamma^\mu \left(1 - \gamma_5 \right) \nu \right),$$

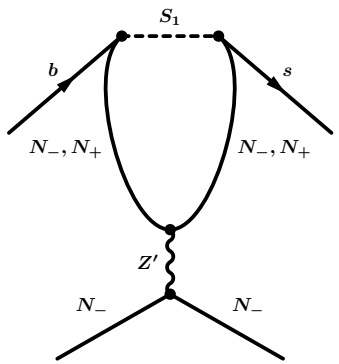
$$C_L^\nu = -X(x_t)/\sin^2\theta_w \,, \qquad X(x_t) = X_0(x_t) + \frac{\alpha_s}{4\pi} X_1(x_t),$$

- In this model, the additional process involved is

$$b \to s + \text{missing energy} = b \to s\nu\nu + b \to sN_- N_-$$

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

- The relevant one-loop diagram for $b \to s N_- N_-$ is



- Thus, e.g., the amplitude of $B \to K N_- N_-$ process from the Z' exchanging diagram is

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

where

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

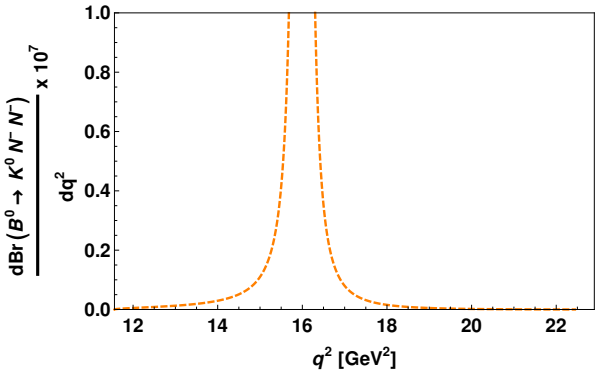
Predicted Results for $b \to s + \not{E}$ decay modes

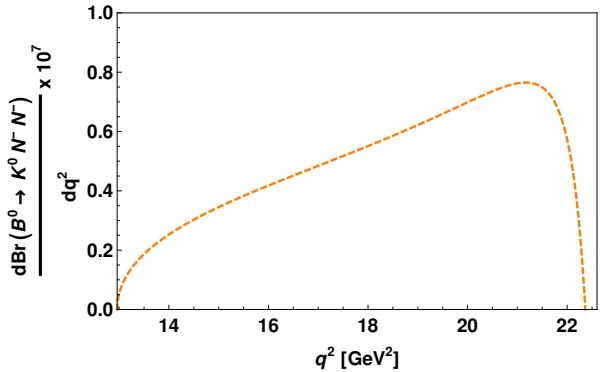
- We use two sets of benchmark values of new parameters, allowed by both the DM and flavor phenomenology

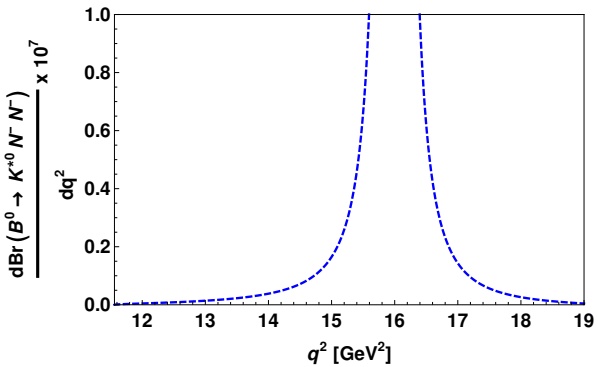
Benchmark	y_{qR}	$g_{\mu\tau}$	M_- (GeV)	$M_{Z'}$ (GeV)
Benchmark-I	2.0	0.002	1.7	4
Benchmark-II	2.0	0.008	1.8	4.8

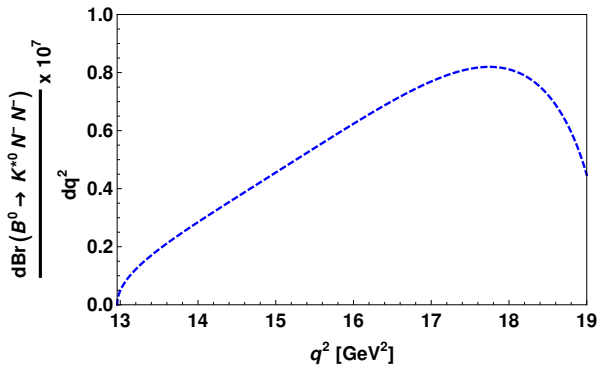
Table: Benchmark values of y_{qR}, M_-, $g_{\mu\tau}$ and $M_{Z'}$ parameters used in our analysis.

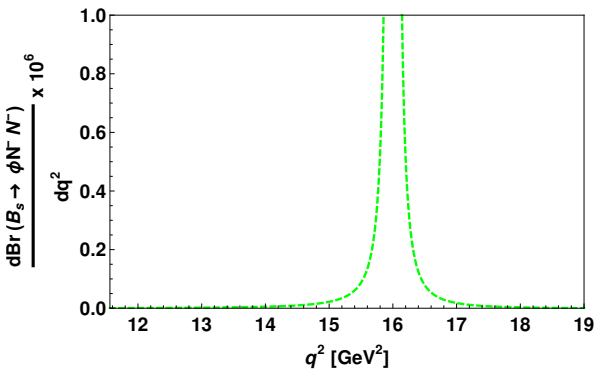
Predicted Results for $b \to s + \not{E}$ decay modes

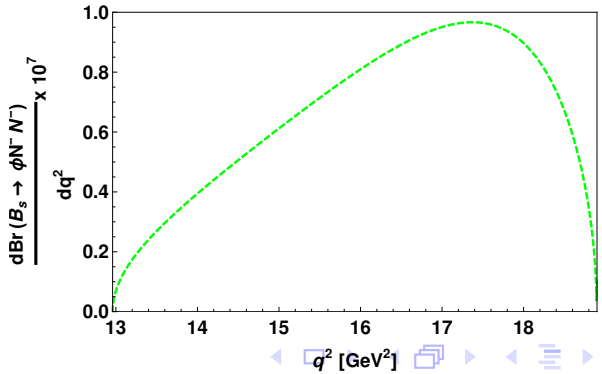












$L_e - L_\mu$ model with $\tilde{R}_2$ Leptoquark : arXiv:2409.16961

	Field	$SU(3)_C \times SU(2)_L \times U(1)_Y$	$U(1)_{L_e - L_\mu}$	Z_2
Fermions	$Q_L \equiv (u, d)_L^T$	$(\mathbf{3}, \mathbf{2}, 1/6)$	0	$+$
	u_R	$(\mathbf{3}, \mathbf{1}, 2/3)$	0	$+$
	d_R	$(\mathbf{3}, \mathbf{1}, -1/3)$	0	$+$
	$\ell_{\alpha L} \equiv (\nu_\alpha, \alpha)_L,$	$(\mathbf{1}, \mathbf{2}, -1/2)$	$1, -1, 0$	$+$
	$\ell_R \equiv \alpha_R,$	$(\mathbf{1}, \mathbf{1}, -1)$	$1, -1, 0$	$+$
	N_e, N_μ, N_τ	$(\mathbf{1}, \mathbf{1}, 0)$	$1, -1, 0$	$-$
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	$+$
	$\tilde{R}_2$	$(\mathbf{3}, \mathbf{2}, 1/6)$	1	$-$

Table: Fields in the chosen $U(1)_{L_e - L_\mu}$ model.

Effective Lagrangian

The effective Lagrangian of the model

$$
\begin{aligned}
\mathcal{L} &= \mathcal{L}_{\rm SM} - \frac{1}{4} Z'_{\mu\nu} Z'^{\mu\nu} - g_{e\mu} \overline{\ell_{eL}} \gamma^\mu \ell_{eL} Z'_\mu - g_{e\mu} \overline{e}_R \gamma^\mu e_R Z'_\mu + g_{e\mu} \overline{\ell_{\mu L}} \gamma^\mu \ell_{\mu L} Z'_\mu \\
&+ g_{e\mu} \overline{\mu}_R \gamma^\mu \mu_R Z'_\mu + \overline{N}_e \left(i\partial\!\!\!/ - g_{e\mu} Z'_\mu \gamma^\mu \right) N_e + \overline{N}_\mu \left(i\partial\!\!\!/ + g_{e\mu} Z'_\mu \gamma^\mu \right) N_\mu + \overline{N}_\tau i\partial\!\!\!/ N_\tau \\
&- \frac{f_e}{2} \left(\overline{N_e^c} N_e \phi_2^\dagger + \text{h.c.} \right) - \frac{f_\mu}{2} \left(\overline{N_\mu^c} N_\mu \phi_2 + \text{h.c.} \right) - \frac{1}{2} M_{\tau\tau} \overline{N_\tau^c} N_\tau - M_{e\mu} \left(\overline{N_e^c} N_\mu + \overline{N_\mu^c} N_e \right) \\
&- \sum_{\alpha,\beta=e,\mu,\tau} \left(Y_{\alpha\beta} \overline{\ell_{L\alpha}} \tilde{\eta} N_{\beta R} + \text{h.c.} \right) - \left(y_{qRN} \overline{Q_L} \tilde{R}_2 N_{\mu R} + \text{h.c.} \right) \\
&+ \left| \left(i\partial_\mu - \frac{g}{2} \boldsymbol{\tau}^a \cdot \mathbf{W}_\mu^a - \frac{g'}{6} B_\mu + g_{e\mu} Z'_\mu \right) \tilde{R}_2 \right|^2 + \left| \left(i\partial_\mu - 2 g_{e\mu} Z'_\mu \right) \phi_2 \right|^2 \\
&+ \left| \left(i\partial_\mu - \frac{g}{2} \boldsymbol{\tau}^a \cdot \mathbf{W}_\mu^a - \frac{g'}{2} B_\mu \right) \eta \right|^2 - V(H, \tilde{R}_2, \eta, \phi_2),
\end{aligned}
$$

Scalar and Fermion mixing

- The CP-even scalars h and h_2 as well as the heavy fermion states N_e and N_μ mix with the mixing matrices given as

$$M_S^2 = \begin{pmatrix} 2\lambda_H v^2 & \lambda_{H\phi} v v_2 \\ \lambda_{H\phi} v v_2 & 2\lambda_\phi v_2^2 \end{pmatrix}, \quad M_N = \begin{pmatrix} \frac{1}{\sqrt{2}} f_e v_2 & M_{e\mu} \\ M_{e\mu} & \frac{1}{\sqrt{2}} f_\mu v_2 \end{pmatrix}.$$

  One can diagonalize the above mass matrices using a 2×2 rotation matrix

$$U_\zeta^T M_S^2 U_\zeta = \text{diag}\,[M_{H_1}^2, M_{H_2}^2], \qquad U_\delta^T M_N U_\delta = \text{diag}\,[M_1, M_2],$$

  with $\zeta = \frac{1}{2}\tan^{-1}\left(\frac{\lambda_{H\phi} v v_2}{\lambda_\phi v_2^2 - \lambda_H v^2}\right)$, $\beta = \frac{1}{2}\tan^{-1}\left(\frac{2M_{e\mu}}{(f_\mu - f_e)(v_2/\sqrt{2})}\right)$.

- The lightest fermion mass eigenstate N_1 considered as probable DM candidate, and M_{H_1} as the SM Higgs

Dark Matter Relic Abundance

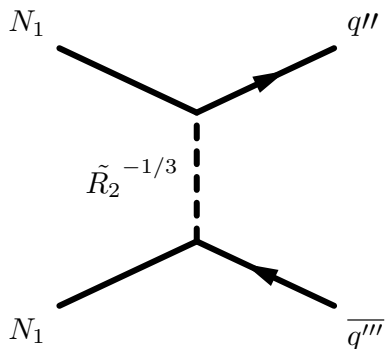
- The relic density of the light DM (N_1) is computed via freeze-out mechanism through the following decay channels:

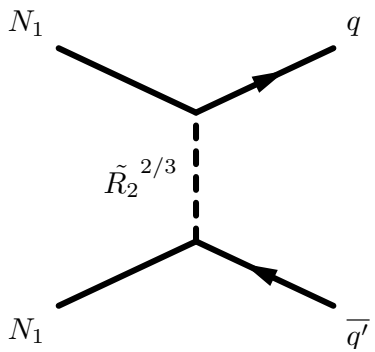
$$N_1\overline{N}_1 \rightarrow \mu^-\mu^+,\ e^-e^+,\ \nu_\mu\overline{\nu}_\mu,\ \nu_e\overline{\nu}_e \ \ (s \text{ channel } Z' \text{ portal})$$
$$\rightarrow (d,s,b)(\bar{d},\bar{s},\bar{b}),\ (u,c,t)(\bar{u},\bar{c},\bar{t}) \ \ (t \text{ channel } LQ(\tilde{R_2}^{-1/3},\ \tilde{R_2}^{2/3}) \text{ portal})$$

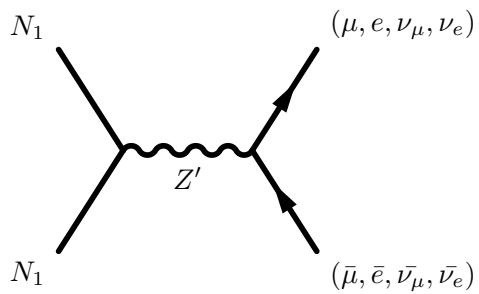
- DM relic density is computed by

$$\Omega h^2 = \frac{1.07\times 10^9 \mathrm{GeV}^{-1}}{g*^{1/2}\, M_{Pl}}\,\frac{1}{J(x_f)}, \qquad J(x_f) = \int_{x_f}^{\infty}\frac{\langle\sigma v\rangle(x)}{x^2}\,dx.$$

where $x = M_1/T$ and x_f is the freeze out parameter.







Detection prospects

- SLQ portal spin-dependent (SD) cross section can arise from the effective interaction

$$\mathcal{L}_{\rm eff} \simeq \frac{y_{qRN}^2 \sin^2\delta}{4M_{\rm LQ}^2}\overline{N_1}\gamma^\mu\gamma^5 N_1\ \bar{q}\gamma_\mu\gamma^5 q\,,$$

and the computed cross section is given as

$$\sigma_{\rm SD} = \frac{\mu_r^2}{\pi}\frac{\sin^4\delta}{M_{\rm LQ}^4} y_{qRN}^4\,[\Delta_d + \Delta_d + \Delta_s]^2\, J_n(J_n+1).$$

- Spin-independent DM-nucleon cross section in Higgs portal comes from the effective Lagrangian

$$\mathcal{L}_{\rm eff} \simeq a_q \overline{N_1} N_1 q\bar{q},$$

and the corresponding WIMP-neucleon cross section reads as

$$\sigma_{\rm SI} = \frac{4\mu_r^2}{\pi} f_p^2\ .$$

Constraints from Flavour sector

- Z' exchange penguin diagram gives dominant contribution to $b \to sll$ process

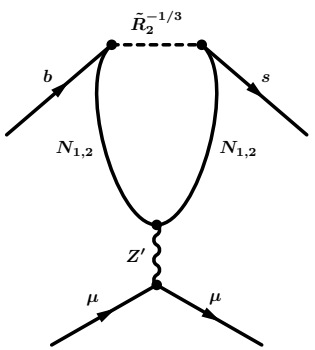
$$\mathcal{M} = -\frac{1}{(4\pi)^2}\frac{y_{qRN}^2 g_{e\mu}^2 (\sin 2\delta)^2}{4}\frac{\mathcal{R}(a,b)}{m_{Z'}^2}[\bar{s}(p')\gamma^\ell P_L b(p)][\bar{\ell}(q_2)\gamma_\ell \ell(q_1))],$$

which provides additional primed Wilson coefficient

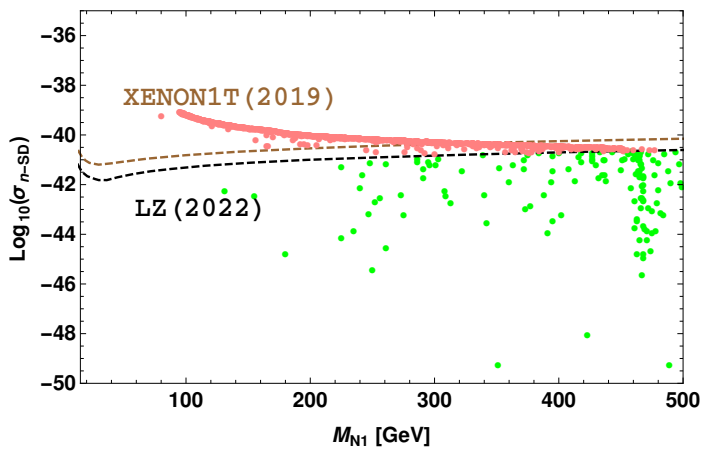
$$C_9^{\rm NP} = -\frac{1}{4\pi}\frac{\sqrt{2}}{4G_F m_{Z'}^2}\frac{1}{\alpha_{em}}\frac{y_{qRN}^2 g_{e\mu}^2}{V_{tb}V_{ts}^*}\mathcal{R}(a,b), ,$$

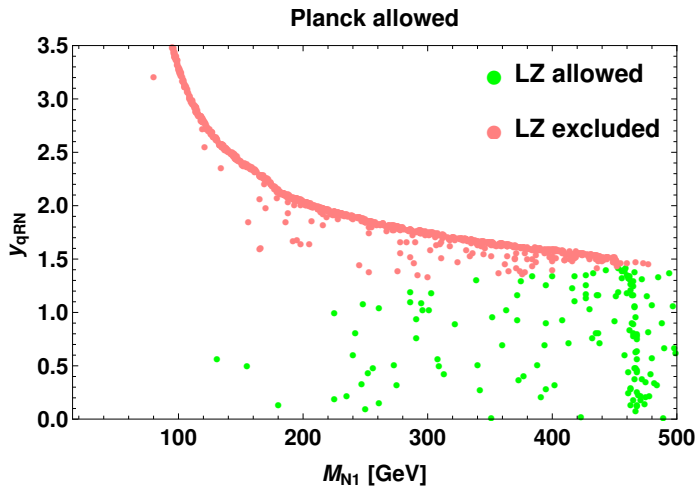
$\mathcal{R}(a,b)$ is the loop function with $a = \frac{m_{N_1}^2}{m_{LQ}^2}$ and $b = \frac{m_{N_2}^2}{m_{LQ}^2}$.

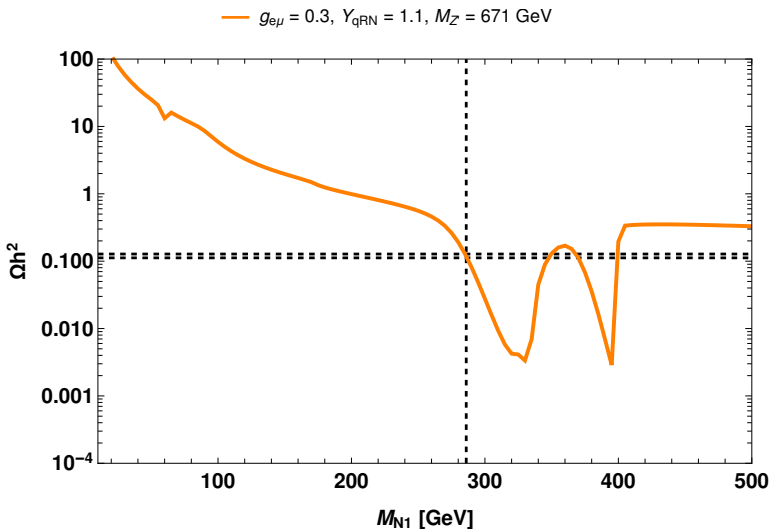
- We include all the observables associated with $b \to s\mu\mu$ transitions for constraining the NP parameter space

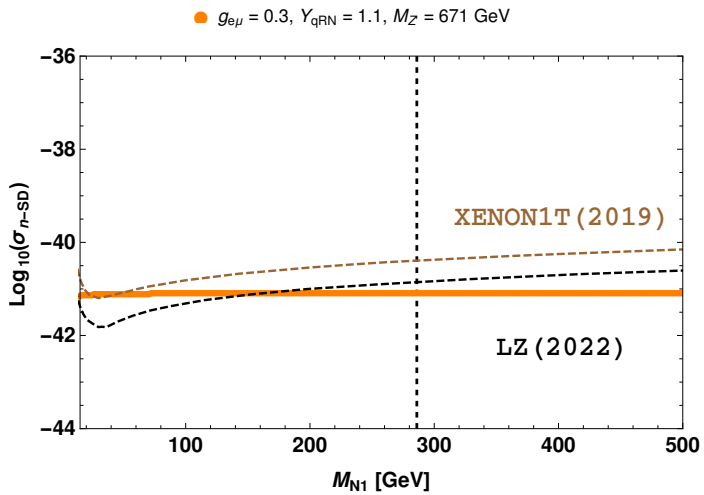


Allowed parameter space from Dark Matter sector









Allowed parameter space from Flavor and Dark sectors

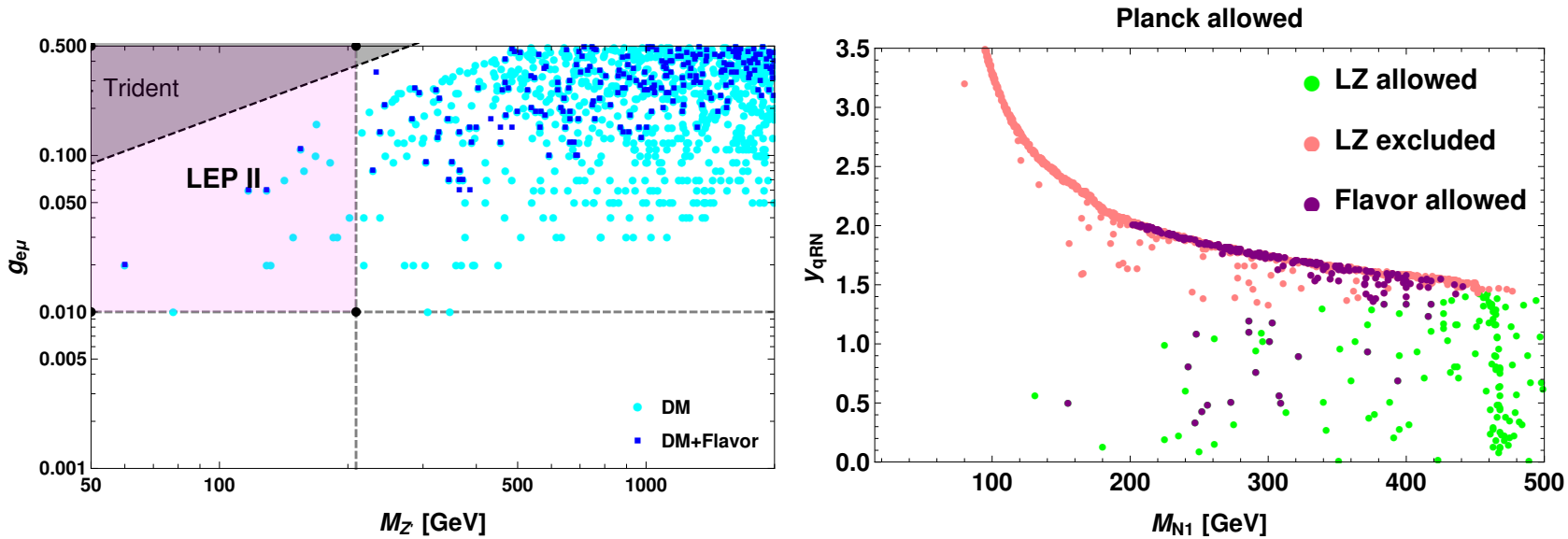


Figure: Allowed parameter space consistent with $b \to s\mu\mu$ observables and Dark Matter sector.

Parameter	y_{qRN}	$g_{e\mu}$	$M_{Z'}$ [GeV]	M_{N1} [GeV]
Bechmark	1.1	0.3	671	286

Implications in $\Lambda_b \to \Lambda^*(1520)(\to pK^-)\ell^+\ell^-$ decays

- The four-fold angular distribution for the exclusive $\Lambda_b \to \Lambda^*(\to pK^-)\ell^+\ell^-$ decay mode can be expressed as

$$\begin{aligned}\frac{d^4\mathcal{B}}{dq^2 d\cos\theta_\ell d\cos\theta_{\Lambda^*} d\phi} = \frac{3}{8}\Bigg[&\left(\mathcal{K}_{1c}\cos\theta_\ell + \mathcal{K}_{1cc}\cos^2\theta_\ell + \mathcal{K}_{1ss}\sin^2\theta_\ell\right)\cos^2\theta_{\Lambda^*} \\ &+ \left(\mathcal{K}_{2c}\cos\theta_\ell + \mathcal{K}_{2cc}\cos^2\theta_\ell + \mathcal{K}_{2ss}\sin^2\theta_\ell\right)\sin^2\theta_{\Lambda^*} \\ &+ \left(\mathcal{K}_{3ss}\sin^2\theta_\ell\right)\sin^2\theta_{\Lambda^*}\cos\phi + \left(\mathcal{K}_{4ss}\sin^2\theta_\ell\right)\sin^2\theta_{\Lambda^*}\sin\phi\cos\phi \\ &+ \left(\mathcal{K}_{5s}\sin\theta_\ell + \mathcal{K}_{5sc}\sin\theta_\ell\cos\theta_\ell\right)\sin\theta_{\Lambda^*}\cos\theta_{\Lambda^*}\cos\phi \\ &+ \left(\mathcal{K}_{6s}\sin\theta_\ell + \mathcal{K}_{6sc}\sin\theta_\ell\cos\theta_\ell\right)\sin\theta_{\Lambda^*}\cos\theta_{\Lambda^*}\sin\phi\Bigg].\end{aligned}$$

Physical Observables

- The differential branching ratio:

$$\frac{d\mathcal{B}}{dq^2} = \frac{1}{3}\Big[K_{1cc} + 2K_{1ss} + 2K_{2cc} + 4K_{2ss} + 2K_{3ss}\Big]$$

- The lepton polarization asymmetry:

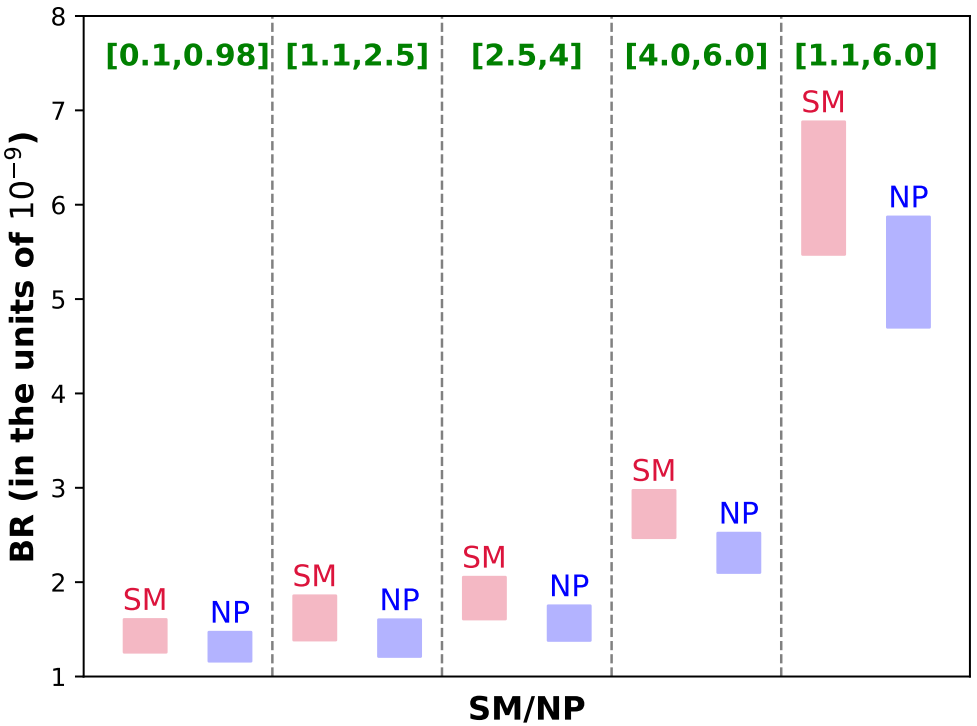
$$F_L(q^2) = 1 - \frac{2(K_{1cc} + 2K_{2cc})}{K_{1cc} + 2(K_{1ss} + K_{2cc} + 2K_{2ss} + K_{3ss})}$$

- The forward-backward asymmetry:

$$A_{\rm FB}^{\ell}(q^2) = \frac{3(K_{1c} + 2K_{2c})}{2\big[K_{1cc} + 2(K_{1ss} + K_{2cc} + 2K_{2ss} + K_{3ss})\big]}$$

- The lepton flavor universality violation observable:

Results on Branching Fraction



Results on F_L and FB Asymmetry

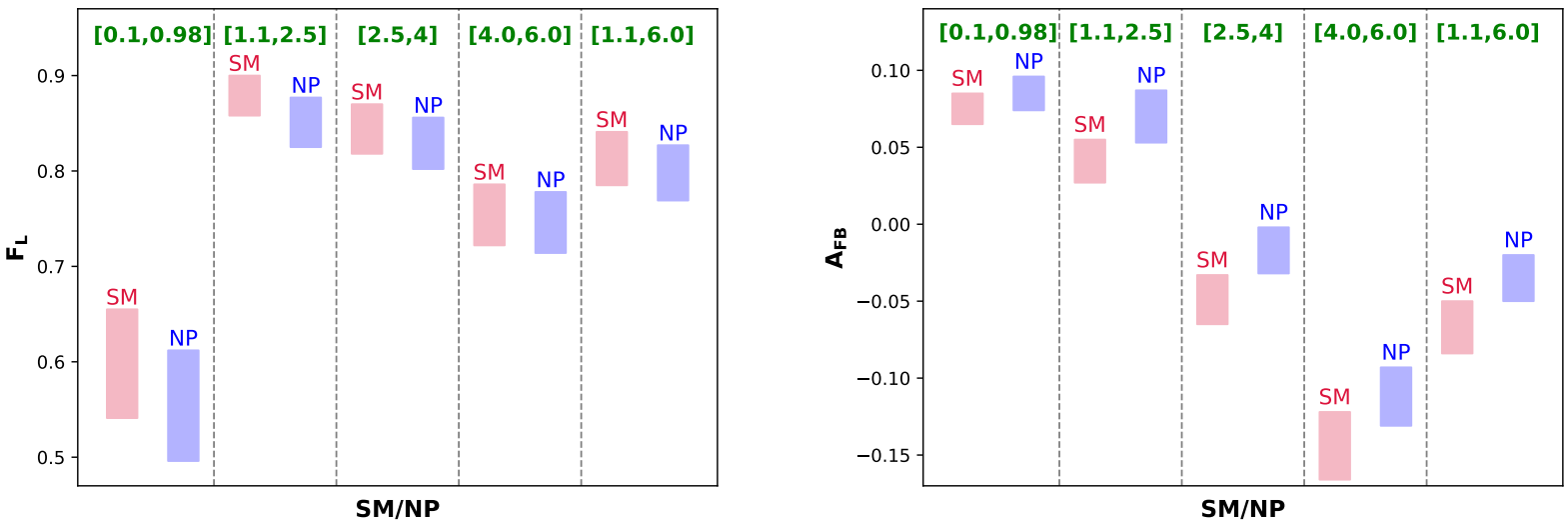


Figure: Prediction for F_L and FB Asymmetry

Summary

- Current anomalies in the Flavor sector provide an ideal platform to look for New Physics.
- They have huge impact on model building and also in the searches new particle like Leptoquarks, Z', Heavy Neutral Leptons.
- Models with $L_\alpha - L_\beta$ gauge symmetry along with leptoquarks can successfully address the flavour anomalies and the dark sector.

Thank you for your attention!