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Theoretical studies in B physics: current and future status

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Abstract In recent times, several hints of lepton flavor universality (LFU) violation have been observed in semileptonic B decays at the level of $(2 \to 3)\sigma$, both in the rare flavor changing neutral current (NC) transitions $b \to s\ell\ell$ and charged current (CC) transitions $b \to c\ell\nu$. Although the recent results from LHCb on the measurement of the LFU violating observables $R_{K^{(*)}}$ associated with $b \to s\ell\ell$ transition are in agreement with the Standard Model (SM) predictions, there are several other observables in $b \to s\mu\mu$ processes, which show significant deviations from their SM values. These tantalizing signals point toward the possible existence of New Physics beyond the Standard Model. Numerous studies have been performed to understand these anomalies in various new physics models as well as in model-independent approaches. Since the new physics scales involved in the CC and NC sectors are significantly different from each other, explanation of these intriguing sets of discrepancies in a coherent manner using a single framework is rather challenging. We show that the model with a vector leptoquark U_1 could be a potential candidate for successfully accounting for these anomalies.

1 Introduction

Despite the overwhelming success of the Standard Model (SM), still there are many open issues for which it does not provide any satisfactory explanation. These include the origin of small but non-zero neutrino masses, nature and existence of the dark matter, observed baryon asymmetry of the universe, etc., demonstrating the presence of physics beyond the SM. Though the LHC Run-II has marked the start of a new era in terms of energy, luminosity, and discovery potential, so far, there is no clear evidence for any kind of unambiguous signal of new physics (NP) beyond the Standard Model (BSM). On the other hand, several intriguing hints of discrepancies between the observed data and the SM predictions have been reported in the last few years by the B-factory experiments: Belle, BABAR, and LHCb. These discrepancies are mainly in the form of lepton flavor universality violations in semileptonic B decays associated with the charged current (CC) transition $b \to c\ell\bar{\nu}$ [1–4] and neutral current (NC) transition $b \to s\ell^+\ell^-$ [5–9], though the later has been substantially weakened in the last year due to the particle identification problems found at LHCb in the electronic channels [10, 11]. Additionally, there are also quite a few other deviations at the level of $(3-4)\sigma$ from the SM expectations in the measurement involving $b \to s\mu\mu$ transition, such as the branching fractions of $B \to K^{(*)}\mu^+\mu^-$, $B_s \to \phi\mu^+\mu^-$ [12–14], the form factor independent (FFI) observables $P'_{4,5}$ in the angular distributions of $B \to K^*\mu^+\mu^-$ [15, 16], etc. In the absence of any direct NP signal at the LHC experiment, these tantalizing hints of LFU violating observables play a crucial role in exploring the BSM physics and thus have attracted immense attention in the last few years.

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2 Anomalies in $b \to c\ell\nu$ transitions

In the charged current transitions $b \to c\ell\bar{\nu}_\ell$, sizeable deviations have been observed in the lepton flavor universality (LFU) violating observables, which are characterized as the ratios of branching fractions

$$R_{D^{(*)}} \equiv \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})}, \tag{1}$$

with $\ell = e$ or μ. These observables are considered to be the clean probes of NP as the hadronic uncertainties inherent in individual branching fraction predictions canceled out to a large extent. The present world averages of $R_{D^{(*)}}$ measurements, performed by the Heavy Flavor Averaging Group (HFLAV) [17]

$$R_D^{\rm exp} = 0.357 \pm 0.029, \quad R_{D^*}^{\rm exp} = 0.284 \pm 0.012,$$

have 3.3σ deviations (considering their correlation of -0.37) from the corresponding SM predictions $R_D^{\rm SM} = 0.298 \pm 0.004$ (2.0σ) and $R_{D^*}^{SM} = 0.254 \pm 0.005$ (2.2σ). In the same line, the measured ratio $R_{J/\psi} \equiv \frac{\mathcal{B}(B_c \to J/\psi\tau\bar{\nu})}{\mathcal{B}(B_c \to J/\psi\mu\bar{\nu})} = 0.71 \pm 0.17 \pm 0.18$ [18] also has 1.7σ deviation from its SM prediction, $R_{J/\psi}^{\rm SM} = 0.289 \pm 0.010$. In addition, the recent measurement of the longitudinal polarization of D^* meson in $B^0 \to D^{*-}\tau^+\bar{\nu}$ by Belle collaboration, $F_L^{D^*} = 0.60 \pm 0.08 \pm 0.04$ [19], also shows deviation from its SM value 0.46 ± 0.04 by 1.6σ. These deviations primarily hint toward the presence of NP in $b \to c\tau\bar{\nu}$ decay channels.

The effective Hamiltonian responsible for the CC-mediated $b \to c\tau\bar{\nu}_l$ quark-level transition is given by [20]

$$\mathcal{H}_{\rm eff}^{\rm CC} = \frac{4G_F}{\sqrt{2}} V_{cb} \Big[(\delta_{l\tau} + C_{V_L}^l) \mathcal{O}_{V_L}^l + C_{V_R}^l \mathcal{O}_{V_R}^l + C_{S_L}^l \mathcal{O}_{S_L}^l + C_{S_R}^l \mathcal{O}_{S_R}^l + C_T^l \mathcal{O}_T^l \Big], \tag{2}$$

where C_X^l are the Wilson coefficients, with $X = V_{L,R}, S_{L,R}, T$. These coefficients are zero in the SM and can arise only in the presence of NP. The corresponding dimension-six four-fermion operators $\mathcal{O}_X^l$ are expressed as

$$\begin{aligned} \mathcal{O}_{V_L(V_R)}^l &= [\bar{c}_L \gamma^\mu b_L(b_R)][\bar{\tau}_L \gamma_\mu \nu_{lL}], \\ \mathcal{O}_{S_L(S_R)}^l &= [\bar{c}_R b_L(b_R)][\bar{\tau}_R \nu_{lL}], \\ \mathcal{O}_T^l &= [\bar{c}_R \sigma^{\mu\nu} b_L][\bar{\tau}_R \sigma_{\mu\nu} \nu_{lL}], \end{aligned} \tag{3}$$

where $f_{L(R)} = P_{L(R)} f$ are the chiral fermion (f) fields with $P_{L(R)} = (1 \mp \gamma_5)/2$ being the projection operators. Numerous studies have been performed in the literature to explain these anomalies both in model-independent [21–26] and model-dependent [27–33] approaches. Model independent analysis shows that NP contributions having the same Lorentz structure as the SM operator (O_{V_L}) are the most preferred scenarios [23]. Concerning $\mathcal{O}_{V_R}$, it gives the additional contributions to $R_{D^{(*)}}$ as $R_D \propto (1 + C_{V_R})^2$, whereas $R_{D^*} \propto (1 - C_{V_R})^2$, and hence, it is arduous to find a common solution to both R_D and R_{D^*}. Though the scalar and pseudoscalar NP structures can also accommodate the observed anomalies, they are constrained by the lifetime of B_c meson. Large value of tensor operator predicts small $F_L^{D^*}$ but provides a decent description to the observed data. However, such operators not easily generated by NP theories at EW scale. In some cases, they appear due to RG evolution from EW scale to b quark scale, with strong correlation with scalar operators.

3 Anomalies in $b \to s\mu^+\mu^-$ transitions

The rare decay processes mediated through flavor changing neutral current transitions $b \to s\ell^+\ell^-$ are loop suppressed in the SM, and hence are highly sensitive to new NP. In this sector, there are a plethora of observables which exhibit deviations from their SM predictions at the level of $(2-4)\sigma$. The main candidates among them were known to be the LFU violating observables R_K and R_{K^*}, defined as

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}\,. \tag{4}$$

In 2014, the measurement on $R_K = 0.745^{+0.090}_{-0.074} \pm 0.036$, in the low $q^2 \in [1, 6]$ GeV^2 region by the LHCb experiment [5] attracted considerable attention, as it manifested 2.6σ discrepancy from its SM prediction, which is expected to be of order unity. The updated LHCb measurement of R_K in the $q^2 \in [1.1,\, 6]$ GeV^2 bin by combining the Run 1 data with 2 fb^{-1} of Run 2 data: $R_K^{\rm LHCb} \;=\; 0.846^{+0.060+0.016}_{-0.054-0.014}$ [7], also had a discrepancy of 2.5σ. Additionally, the observable R_{K^*} measured by the LHCb Collaboration in two bins of low-q^2 (in GeV^2) region [6]

$$R_{K^*} = \begin{cases} 0.660^{+0.110}_{-0.070} \pm 0.024, & q^2 \in [0.045,\, 1.1]\ {\rm GeV}^2 \\ 0.685^{+0.113}_{-0.069} \pm 0.047, & q^2 \in [1.1,\, 6.0]\ {\rm GeV}^2\,, \end{cases}$$

delineates 2.2σ and 2.4σ deviations from their corresponding SM results. These discrepancies are generally attributed to the presence of NP in $b \to s\mu\mu$ processes. However, in December 2022, LHCb updated their results, and the new measurements [10, 11] are now almost consistent with the SM predictions

$$\text{low-}\ q^2 \begin{cases} R_K = 0.994^{+0.090}_{-0.082}(\text{stat })^{+0.029}_{-0.027}(\text{syst}), \\ R_{K^*} = 0.927^{+0.093}_{-0.087}(stat)^{+0.036}_{-0.035}(\text{syst})\,, \end{cases}$$

$$\text{central-}\ q^2 \begin{cases} R_K = 0.949^{+0.042}_{-0.041}(stat)^{+0.022}_{-0.022}(\text{syst}), \\ R_{K^*} = 1.027^{+0.072}_{-0.068}(stat)^{+0.027}_{-0.026}(\text{syst})\,, \end{cases}$$

where the q^2 interval $(0.1 < q^2 < 1.1)$ GeV^2 refers to as low-q^2, while the interval $(1.1 < q^2 < 6)$ GeV^2 corresponds to central-q^2.

These new results open up a new window in the exploration of new physics beyond the standard model, which becomes evident from the fact that there are several other observables associated with $b \to s\mu^+\mu^-$ transitions, e.g., the branching fractions of $B_s \to \phi\mu\mu$, $B \to K^*\mu\mu$, the FFI observables $P'_{4,\,5}$ in $B \to K^*\mu\mu$ angular distributions, which deviate significantly from their SM predictions. These observations lead to the fact, in addition to the lepton flavor universal new physics component, that contributes equally to both electron and muon channels, there should be additional new contribution specifically related to the muon sector, as well. Additionally, the recent results on the branching fraction of $B_s \to \mu^+\mu^-$ by LHCb and CMS collaborations [34, 35] $\mathcal{B}(B_s \to \mu^+\mu^-) = \big(3.09^{+0.46+0.15}_{-0.43-0.11}\big) \times 10^{-9}$, consistent with its SM value $\mathcal{B}(B_s \to \mu^+\mu^-)|^{\rm SM} = (3.66 \pm 0.14) \times 10^{-9}$ [36], indicate that the NP should couple vectorially to the lepton pair, thus, evading any conflict with the above measurements.

The SM effective Hamiltonian responsible for $b \to s\ell^+\ell^-$ transition can be expressed as [37, 38]

$$\mathcal{H}_{\rm eff}^{\rm SM} = -\frac{\alpha G_F}{\sqrt{2}\pi} V_{tb} V_{ts}^* \Big[2\frac{C_7^{\rm eff}}{q^2} [\bar{s}\sigma^{\mu\nu} q_\nu (m_s P_L + m_b P_R) b]\ (\bar{\ell}\gamma_\mu \ell) + C_9^{\rm eff} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell) + C_{10} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma_5 \ell) \Big], \tag{5}$$

where $C_7^{\rm eff}$, $C_9^{\rm eff}$ and C_{10} are the Wilson coefficients, evaluated at the m_b scale. It should be noted that the coefficient $C_9^{\rm eff}$ contains both short-distance contributions from the four-quark operators, away from the charmonium resonance domain, and the long distance part associated with real $c\bar{c}$ intermediate states.

Prior to the latest results on $R_{K^{(*)}}$ by LHCb [10, 11], considering new physics contributions present in $b \to s\mu^+\mu^-$ processes, the global fit to all the anomalies provides the best-fit values for the preferred solutions as [39]

$$\begin{aligned} &(i)\ C_{9\mu}^{\rm NP} = -1.06, \quad (ii)\ C_{9\mu}^{\rm NP} = -C_{10\mu}^{\rm NP} = -0.44, \\ &(iii)\ C_{9\mu}^{\rm NP} = -C_{9'\mu}^{\rm NP} = -1.11. \end{aligned} \tag{6}$$

Incorporating the updated LHCb results on $R_{K^{(*)}}$, all the anomalies associated with $b \to s\mu\mu$ transitions can be explained in the following two scenarios, with the best-fit values of the Wilson coefficients as [40]:

- Scenario-I: ($C_9^{\rm univ}$, $\Delta C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$).
  In this scenario, there will be universal NP contributions both μ and e channels preserving the lepton flavor universality i.e., $C_9^{\rm univ} = C_9^{bs\mu\mu} = C_9^{bsee} = 0.64 \pm 0.22$. In addition, there will be extra contributions only to muon channels, for accommodating the anomalies strictly associated with $b \to s\mu\mu$ channels, with the corresponding best-fit values: $\Delta C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu} = -0.11 \pm 0.06$.

- Scenario II: $C_9^{\rm univ} = -C_{10}^{\rm univ}$ and $\Delta C_9^{bs\mu\mu} = -\Delta C_{10}^{bs\mu\mu}$).
  This scenario corresponds to the case, where NP couples purely to left-handed SM fields. The non-zero $C_9^{\rm univ} = -C_{10}^{\rm univ}$ can consistently explain the $b \to s\mu\mu$ anomalies, while the LFU violating purely muonic contribution to $\Delta C_9^{bs\mu\mu} = -\Delta C_{10}^{bs\mu\mu}$ is compatible with zero at 1σ level. The corresponding best-fit values are found to be

$$\begin{aligned} C_9^{\rm univ} &= -\, C_{10}^{\rm univ} = -0.29 \pm 0.13, \\ \Delta C_9^{bs\mu\mu} &= -\, \Delta C_{10}^{bs\mu\mu} = -0.08 \pm 0.07, \end{aligned} \tag{7}$$

  with a correlation coefficient $\rho = -0.54$.

4 Anomalies in $b \longrightarrow s\nu\bar{\nu}$ transitions

The long-standing anomalies associated with the FCNC transitions $b \to s\mu^+\mu^-$ have been recently augmented by the first evidence of $B^+ \to K^+\nu\bar{\nu}$ decay from the Belle-II collaboration $\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (2.4 \pm 0.7) \times 10^{-5}$ [41] which deviates by 2.8σ from the SM prediction $\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (4.29 \pm 0.13) \times 10^{-6}$. Since the ratios of muon to electron branching fractions in $b \to s\ell\ell$ transitions, $R_{K^{(*)}}$ are consistent with lepton universality, requisite universality violation to address the data could arise from tau-flavors. More general explanations could also involve lepton flavor violation involving τ lepton in the final state. In addition, this result also indicates the possible existence of light sterile neutrino [42].

5 Possible NP scenarios for the explanation of flavor anomalies

Attempts to explain one or both sets of anomalies have stimulated an intense theoretical activity, which ranges from pure Effective Field Theory approaches to the formulation of motivated completions of the SM. As the $b \to c\ell\bar{\nu}$ CC transitions occur at the tree level, while the NC transitions $b \to s\ell^+\ell^-$ appear one-loop level, the anomalies associated with these transitions probe essentially different scales of NP. Thus, finding a common platform for explaining these anomalies in a coherent manner is rather challenging, e.g., the tree-level contribution with single mediator like W' for $b \to c\ell\nu$ and Z' for $b \to s\ell\ell$ transitions will not provide the common solution. However, some of the leptoquark models with generation-dependent couplings could provide a common explanation to the observed anomalies in both the sectors. In particular, models containing a TeV-scale vector leptoquark, $U_1 \sim (3, 1, 2/3)$, as the main mediator are particularly appealing. Besides connecting both sets of anomalies, such models can connect them to an underlying theory of flavor.

5.1 $U_1(3,\, 1,\, 2/3)$ vector LQ: a possible explanation to the flavor anomalies

The vector leptoquark (VLQ) $U_1(3, 1, 2/3)$ is a color triplet and $SU(2)_L$ singlet gauge boson with hypercharge 2/3 encountered in many extensions of the SM. This VLQ can explain the anomalies in both $b \to c\tau\bar{\nu}$ and $b \to s\mu^+\mu^-$ transitions [43]. The interaction Lagrangian of U_1 LQ with the SM fermions can be written as

$$\mathcal{L}_{\rm LQ}^{U_1} = \lambda_{ij}^L \bar{Q}_{iL}\gamma_\mu L_{jL} U_1^\mu + \lambda_{ij}^R \bar{d}_{iR}\gamma_\mu l_{jR} U_1^\mu + h.c., \tag{8}$$

where $\lambda_{ij}^{L,\,R}$ are the couplings of U_1 to quark and lepton pairs, with i, j being the generation indices. The Lagrangian (8) is written in the weak basis of the fermion fields, which, after transformation into the mass basis and using the Fierz identities, yields the new Wilson coefficients for the process $b \to c\tau\bar{\nu}$

$$\begin{aligned} C_{V_L}^{\rm NP} &= \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} V_{k3} \frac{\lambda_{2l}^L \lambda_{k3}^{L\,*}}{M_{\rm LQ}^2}, \\ C_{S_R}^{\rm NP} &= -\frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} V_{k3} \frac{2\lambda_{2l}^L \lambda_{k3}^{R\,*}}{M_{\rm LQ}^2}, \end{aligned} \tag{9}$$

where $M_{\rm LQ}$ denotes the mass of the leptoquark. The model also provides additional contributions to the $b \to s\ell_i^- \ell_j^+$ processes in the form of new Wilson coefficients $C_i^{(\prime){\rm NP}}$ ($i = 9,\, 10,\, S,\, P$), as

$$
\begin{aligned}
C_9^{\rm NP} &= -C_{10}^{\rm NP} = \frac{\pi}{\sqrt{2} G_F V_{tb} V_{ts}^* \alpha} \sum_{m,\,n=1}^{3} V_{m3} V_{n2}^* \frac{\lambda^L_{ni} \lambda^{L\,*}_{mj}}{M_{\rm LQ}^2}\,, \\
C_9^{\prime{\rm NP}} &= C_{10}^{\prime{\rm NP}} = \frac{\pi}{\sqrt{2} G_F V_{tb} V_{ts}^* \alpha} \sum_{m,\,n=1}^{3} V_{m3} V_{n2}^* \frac{\lambda^R_{ni} \lambda^{R\,*}_{mj}}{M_{\rm LQ}^2}\,, \\
C_P^{\rm NP} &= -C_S^{\rm NP} = -\frac{\sqrt{2}\pi}{G_F V_{tb} V_{ts}^* \alpha} \sum_{m,\,n=1}^{3} V_{m3} V_{n2}^* \frac{\lambda^L_{ni} \lambda^{R\,*}_{mj}}{M_{\rm LQ}^2}\,, \\
C_P^{\prime{\rm NP}} &= C_S^{\prime{\rm NP}} = \frac{\sqrt{2}\pi}{G_F V_{tb} V_{ts}^* \alpha} \sum_{m,\,n=1}^{3} V_{m3} V_{n2}^* \frac{\lambda^R_{ni} \lambda^{L\,*}_{mj}}{M_{\rm LQ}^2}\,.
\end{aligned}
\tag{10}
$$

The values of these NP couplings are constrained for a TeV-scale leptoquark, using various flavor observables and the details can be found in Ref. [43]. For illustration, we consider the example of the presence of new physics which is vectorial in nature with LL coupling, i.e., it will induce new physics coupling $C_{V_1}^{\rm LQ}$ to $b \to c\tau\bar{\nu}_\tau$ transition and $C_9^{\rm LQ} = -C_{10}^{\rm LQ}$ for $b \to s\ell\ell$ processes. For constraining the various new Wilson coefficients or LQ couplings, we consider the following combination of data sets and perform a χ^2-fit to obtain their best-fit values:

C-I: Includes measurement on B decay modes with only third-generation leptons in the final state

- C-Ia: Only $b \to c\tau\bar{\nu}_\tau$.
- C-Ib: Both $b \to c\tau\bar{\nu}_\tau$ and $b \to s\tau^+\tau^-$.

C-II: Includes measurement on B decay modes with only second-generation leptons in the final state, i.e., $b \to s\mu^+\mu^-$.
C-III: Includes measurement on B decay modes, which decay either to third-generation or second-generation leptons, i.e., $b \to c\tau\bar{\nu}_\tau$, $b \to s\tau^+\tau^-$ and $b \to s\mu^+\mu^-$.

The constraints on new leptoquark couplings are shown in Fig. 1, using different data sets of above discussed observables and LQ mass $M_{\rm LQ}$ as 1.2 TeV. The constraint plots for the new couplings for C-Ia (left), C-Ib (middle), and C-II (right) cases are presented in the top panel. The bottom panel of Fig. 1 represents the constraint plots for C-III in the $\lambda^L_{33} - \lambda^L_{23}$ (left) and $\lambda^L_{32} - \lambda^L_{22}$ (right) panels. In each plot of Fig. 1, different colors represent the 1σ, 2σ, and 3σ contours and the black dots stand for the best-fit values. The corresponding best-fit values obtained for various cases are presented in Table 1. It should be noted that the results obtained for C-II and C-III cases might be slightly changed if we incorporate the updated measurement of $R_{K^{(*)}}$.

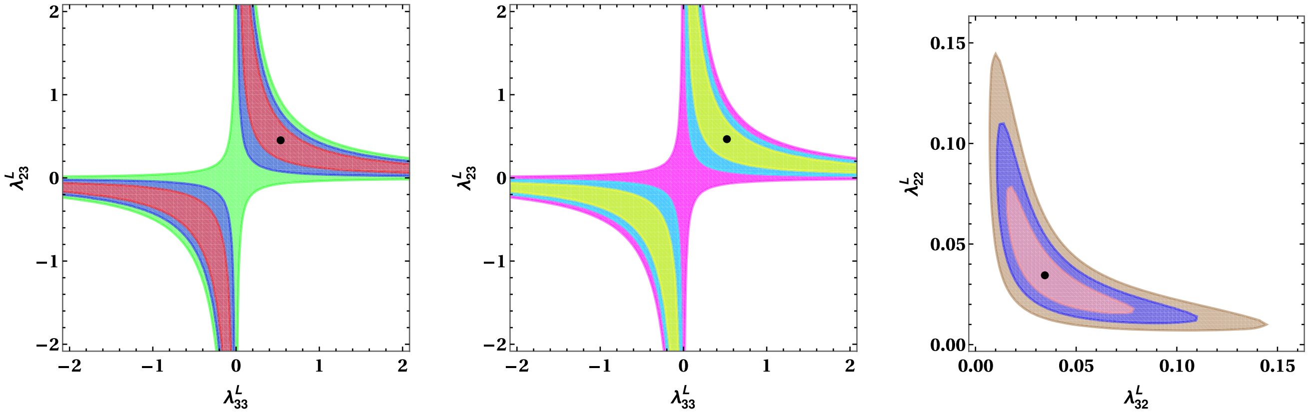
Thus, it is found that for a TeV-scale VLQ, only the LL-type couplings can simultaneously explain both $b \to s\ell^+\ell^-$ and $b \to c\tau\bar{\nu}_\tau$ anomalies. In addition, the model predicts significantly large branching fractions for the lepton flavor violating B-meson and τ-lepton decays, such as $B_s \to \ell_i^+\ell_j^-$, $B_s \to K^{(*)}\ell_i^+\ell_j^-$, $B_s \to \phi\ell_i^+\ell_j^-$, $\tau \to \mu\phi$, $\tau \to \mu\gamma$, etc., which can be used to test this scenario in the future B-physics experiments, such as LHCb upgrade and Belle-II. Another interesting feature of the model is that augmenting it with a color-sextet scalar diquark (**6**, **1**, 4/3) can explain the neutrino mass at two-loop level.

6 Conclusion

Semileptonic B meson decays play an important role in exploring physics beyond the Standard Model.

The FCNC-mediated decay processes $b \to s\ell^+\ell^-$ occur at one-loop level in the SM and, hence, are quite sensitive to NP. Deviations at the level of (2-4)σ have been reported in several observables, which include $\mathcal{B}(B \to K\mu\mu)$, $\mathcal{B}(B_s \to \phi\mu\mu)$ and $P'_{4,5}$. It is worth emphasizing that these discrepancies can be coherently explained in a simple NP scenario without violating the bounds from other observables. In particular, the two leading scenarios are $C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$ and $C_9^{\rm univ}$ with pull values of $\sim 6\sigma$ [44].

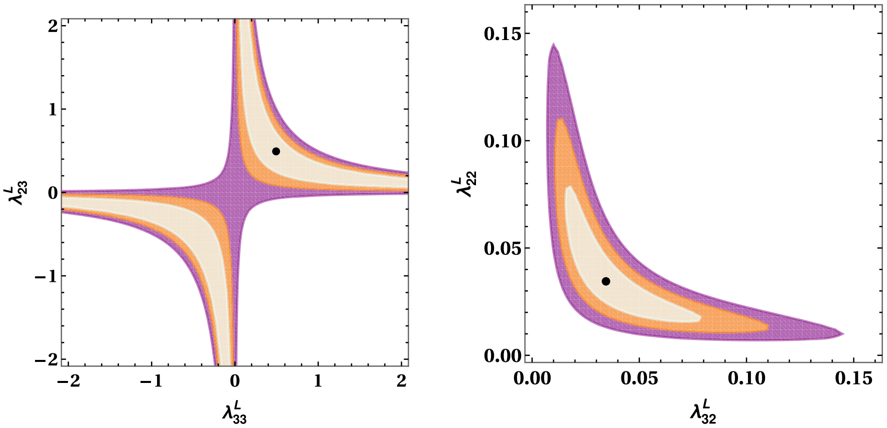
The tree-level charged current transition process $b \to c\tau\nu$ have sizable decay rates and the ratios $R_{D^{(*)}}$ point toward the violation of LFU. Although, it is possible to explain these anomalies with scalar currents, at the same time slightly improving the polarization observables, the best fit is achieved via a left-handed NP contribution of



(a) C-Ia case

(b) C-Ib case

(c) C-II case



(d) C-III case in $\lambda^L_{33} - \lambda^L_{23}$ plane

(e) C-III case in $\lambda^L_{32} - \lambda^L_{22}$ plane

Fig. 1 Constraints on new VLQ couplings which include only *LL* type operators (Scenario-I) for different sets of observables. Different colors represent the 1σ, 2σ, and 3σ contours and the black dot stands for the best-fit value

Table 1 Best-fit values of the LQ couplings for different cases for $M_{\rm LQ} = 1.2$ TeV

Cases	Couplings	Best-fit values
C-Ia	$(\lambda^L_{33},\ \lambda^L_{23})$	(0.451, 0.631)
C-Ib	$(\lambda^L_{33},\ \lambda^L_{23})$	(0.475, 0.595)
C-II	$(\lambda^L_{32},\ \lambda^L_{22})$	(0.035, 0.035)
C-III	$(\lambda^L_{33},\ \lambda^L_{23})$	(0.56, 0.51)
C-III	$(\lambda^L_{32},\ \lambda^L_{22})$	(0.0351, 0.0351)

$\sim 10\%$ to the SM operator, i.e., C_{V_L} resulting in a significance of 4σ. Such an operator can be generated in the leptoquark models, preferably vector leptoquark $U_1(3,\ 1,\ 2/3)$.

It should be worth emphasizing that if $R_{D^{(*)}}$ anomalies can be explained through the new physics contributions arising from left-handed vector current, due to $SU(2)_L$ invariance, $b \to s\tau^+\tau^-/b \to s\nu_\tau\nu_\tau$ processes can also be significantly enhanced from their SM predictions. The recent Belle results on $\mathcal{B}(B \to K\nu\nu)$ which has 2.8σ enhancement from its SM predictions support this scenario. Thus, search for different observables associated with $b \to s\tau^+\tau^-$ transitions is highly recommended to corroborate or rule out this scenario.

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Data availability No data are associated in the manuscript.

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