EPJ Web of Conferences **192**, 00025 (2018) https://doi.org/10.1051/epjconf/201819200025
QCD@Work 2018

Scalar leptoquarks: From GUT to B anomalies

Svjetlana Fajfer[1,*]

[1]Department of Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia and Jožef Stefan Institute, Jamova 39, P. O. Box 3000, 1001 Ljubljana, Slovenia

Abstract. Leptoquarks are often used to explain B meson anomalies. The minimalistic approach assumes only one light leptoquark explaining both puzzles. However, one scalar leptoquark cannot explain both anomalies. Two relatively light leptoquarks can be accommodated within $SU(5)$ GUT and might nicely explain both anomalies not being in a conflict with any low-energy flavour constraints or LHC results.

1 Introduction

Several experimental results points towards the possible violation of the lepton number universality in the B meson semileptonic decays. The charge current anomaly indicates the deviation from the measured and theoretically predicted ratios $R_{D^{(*)}} = \mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)/\mathcal{B}(B \to D^{(*)}l\bar{\nu}_l)$, $l = e, \mu$. It was found that the measured ratios are larger than the Standard Model predictions $R^{\rm SM}_{D^{(*)}}$. The experimental results on R_D [1–3] differ by $\sim 2\,\sigma$ with respect to the SM prediction [4] and by $\sim 3\,\sigma$ in the case of R_{D^*} [5–7]. The similar deviations were found in transitions $b \to c\ell\nu$ ($\ell = \mu, \tau$), observed in $R_{J/\psi}$ ratio between $B_c \to J/\psi\ell\nu$ decay widths [8].

In the case of flavour changing neutral current transition (FCNC) $b \to s\mu^+\mu^-$ the LHCb experiment has measured ratios $R_{K^{(*)}} = \mathcal{B}(B \to K^{(*)}\mu\mu)/\mathcal{B}(B \to K^{(*)}ee)$ at low di-lepton invariant mass. Interestingly, these ratios were found to be systematically lower than expected in the SM. In the case of the K meson in the final state, the ratio R_K was measured in the kinematical region $q^2 \in [1.1, 6]$ GeV^2 [9], while R_{K^*} was measured in the region $q^2 \in [0.045, 1.1]$ GeV^2 [10]. The three measured $R_{K^{(*)}}$ deviate from the SM predictions at $\sim 2.5\,\sigma$ level [11, 12].

2 B meson anomalies and leptoquarks

Both B anomalies are usually explained by contributions of New Physics (NP). The effective Lagrangian studies suggest that NP appears at TeV scale [12–15]. Most of these approaches favour the left-handed fermionic interactions. In addition, this new interaction prefers interactions of third fermion generation. As suggested in Ref. [16] the scale of such NP, accommodating the $R_{D^{(*)}}$ anomaly, can be introduced as

$$\mathcal{L}^{D^{(*)}}_{NP} = \frac{2}{\Lambda_{D^{(*)}}}\,\bar{c}_L\gamma_\mu b_L\,\tau_L\gamma^\mu\nu_L\,, \tag{1}$$

*e-mail: svjetlana.fajfer@ijs.si

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

The experimental data can be explained for the scale $\Lambda_{D^{(*)}} \sim 3$ TeV. The $R_{K^{(*)}}$ anomaly can be explained by the Lagrangian

$$\mathcal{L}_{NP}^{K^{(*)}} = \frac{1}{\Lambda_{K^{(*)}}} \bar{s}_L \gamma_\alpha b_L \, \bar{\mu}_L \gamma^\alpha \mu_L \,, \tag{2}$$

from which one finds that the scale of NP is $\Lambda_{K^{(*)}} \sim 30$ TeV. Obviously, by requiring that the same model of NP explains both anomalies, that the NP in $R_{K^{(*)}}$ should be suppressed in comparison with $R_{D^{(*)}}$. The suppression can be realised in a number of different ways. For example $R_{D^{(*)}}$ receives contribution of NP at tree level, while in $R_{K^{(*)}}$ NP enters at loop level in particular model of leptoquarks [17, 18]. The approach of [12, 13] assumes that the second generation of quarks and leptons couples to a NP mediator weakly in comparison with the coupling to third generation. The third possibility is a "Cabibbo mechanism" [19, 20] in which $\cos\theta$ ($\sin\theta$) can determine size of NP contribution. Among many NP proposals, leptoquarks (LQs) explanations are very appealing due to their interactions with quarks and leptons they are natural candidates. Leptoquarks can have spin-0 or spin-1.

Leptoquarks are listed by quantum numbers of $SU(3)_c$ colour, electroweak quantum numbers of $SU(2)_L$ and hypercharge $U(1)_Y$ [21]. The hypercharge is defined as $Y = Q - I_3$. According to their SM quantum numbers, scalar leptoquarks are: one weak triplet $S_3 = (\bar{3}, 3, 1/3)$, two weak doublets $R_2 = (3, 2, 7/6)$, $\tilde{R}_2 = (3, 2, 1/6)$ and three singlets $\tilde{S}_1 = (\bar{3}, 1, 4/3)$, $S_1 = (\bar{3}, 1, 1/3)$ and $\bar{S}_1 = (\bar{3}, 1, -2/3)$. Among all these states only weak doublet R_2 and $\tilde{R}_2$ do not cause proton decay at tree level [21, 22]. The rest of leptoquarks, might mediate proton decay at tree level if there is no additional symmetry forbidding it. For example it was noticed in [22, 23] that within particular $SU(5)$ GUT model S_3 does not cause proton decay. Spin-1 leptoquarks are following: $U_3 = (3, 3, 2/3)$, $V_2 = (\bar{3}, 2, 5/6)$, $\tilde{V}_2 = (\bar{3}, 2, -1/6)$, $\tilde{U}_1 = (3, 1, 5/3)$, $U_1 = (3, 1, 2/3)$ and $\bar{U}_1 = (3, 1, -1/3)$. Among all these states it was found that U_1 leptoquarks coupling to the left handed quarks and leptons [12, 13] can relatively good explain both anomalies. This state gives only V-A form of the interaction with quarks and leptons.

The scalar leptoquark S_3, being a weak triplet, can couple only to the left-handed quarks and leptons. It can alone well explain $R_{K^{(*)}}$ puzzle. In the model presented in [24] we succeeded to accommodate $b \to s\ell^+\ell^-$ sector. Because of its weak triplet nature it couples also to up-type quarks and neutrinos which is a couplings needed to address $R_{D^{(*)}}$. If one explains $R_{D^{(*)}}$ puzzle, S_3 then inevitably contributes to other well constrained flavour observables. For example, after detailed study we have demonstrated [24] that the most constraining are bounds from $R_{\nu\nu}^{(*)} = \mathcal{B}(B \to K^{(*)}\bar{\nu}\nu)/\mathcal{B}(B \to K^{(*)}\bar{\nu}\nu)_{SM}$ and Δm_s, allow only for minor improvement of $R_{D^{(*)}}$ puzzle.

The $\tilde{R}_2 = (3, 2, 1/6)$ leptoquark can accommodate $R_{D^{(*)}}$ by the coupling to a right-handed neutrino [26]. Such mechanism induces contributions which is not interfering with SM. In this year the idea of right-handed neutrino contributing to $R_{D^{(*)}}$ was further explored by [27–29]. The $\tilde{R}_2 = (3, 2, 1/6)$ leptoquark can explain R_K while it cannot accommodate R_{K^*} [26]. Namely R_K, due to the matrix element of two pseudoscalar is blind on the axial part of the current and therefore the measurement of R_{K^*} helps to distinguish between the chiralities of NP operators [30].

The $S_1 = (\bar{3}, 1, 1/3)$ letoquark was extensively explored by [17]. Being a weak singlet this leptoquark has left-handed and right-handed couplings. Unfortunately, this state is severely constrained by the low-energy flavour dynamics [18]. Among scalar letoquarks remaining states are $\tilde{S}_1 = (\bar{3}, 1, 4/3)$ and $\bar{S}_1 = (\bar{3}, 1, -2/3)$. The chirality of the charged leptons of the $\tilde{S}_1$ is not adequate for the $R_{K^{(*)}}$explanation, while $\bar{S}_1$ cannot couple to charge leptons (see e.g. [21]).

As noticed in the studies of [13] and [25] one scalar leptoquark cannot satisfactory described both anomalies without being in a conflict with all low-energy constraints. Two light leptoquark can also generate neutrino masses [23]. Even more, two relatively light leptoquarks can be accommodated within GUT theories [21]. These are additional arguments why scenarios with two leptoquarks are appealing.

3 $SU(5)$ GUT scenario with R_2 and S_3

In order to build an UV complete model the simplest proposal is to construct $SU(5)$ GUT models [19]. In the simplest $SU(5)$ scenario one can accommodate both R_2 and S_3 to be relativrey light, masses being in the TeV regime. In this scenario scalar sector needs to contain 45 and 50 representations, whereas the SM fermions are set in $\bar{5}$ and 10 (for details see [19]).The interactions of R_2 and S_3 with the SM fermions are

$$\mathcal{L} \supset Y_R^{ij}\bar{Q}'_i \ell'_{Rj} R_2 + Y_L^{ij} \bar{u}'_{Ri} \widetilde{R}_2^\dagger L'_j + Y^{ij} \bar{Q}_i'^C i\tau_2 (\tau_k S_3^k) L'_j, \tag{3}$$

where Y_L, Y_R, and Y are Yukawa matrices, τ_k denote the Pauli matrices.For the Yukawa matrices we use $Y_R = Y_R^T$, $\quad Y = -Y_L$ and assume that the matrix $(Y_R E_R^\dagger)_{33} = y_R^{b\tau}$, and $(U_R Y_L)_{22} = y_L^{c\mu}$ and $(U_R Y_L)_{23} = y_L^{c\tau}$, with the rest being negligible small.

Following [19], we allow the two R_2 scalars be members of representations 45 in 50. They can mix (for details see [19]) allowing us to end up with the two light scalars, i.e., R_2 and S_3, and one heavy R_2. The heavy R_2 state is completely decoupled from the low-energy spectrum. The relevant lagrangian, in the mass eigenstate basis of the two light LQs, is we write Lagrangian

$$\begin{aligned}
\mathcal{L} \supset \ & + \quad s_\phi (V b E_R^\dagger)^{ij} \bar{u}_{Li} \ell_{Rj} R_2^{\frac{5}{3}} + s_\phi (b E_R^\dagger)^{ij} \bar{d}_{Li} \ell_{Rj} R_2^{\frac{2}{3}} \\
& + \quad c_\phi (U_R a U)^{ij} \bar{u}_{Ri} \nu_{Lj} R_2^{\frac{2}{3}} - c_\phi (U_R a)^{ij} \bar{u}_{Ri} \ell_{Lj} R_2^{\frac{5}{3}} \\
& + \quad 2^{-\frac{1}{2}} (a U)^{ij} \bar{d}_{Li}^C \nu_{Lj} S_3^{\frac{1}{3}} - (V^* a U)^{ij} \bar{u}_{Li}^C \nu_{Lj} S_3^{-\frac{2}{3}} \\
& + \quad a^{ij} \bar{d}_{Li}^C \ell_{Lj} S_3^{\frac{4}{3}} + 2^{-\frac{1}{2}} (V^* a)^{ij} \bar{u}_{Li}^C \ell_{Lj} S_3^{\frac{1}{3}},
\end{aligned} \tag{4}$$

where we define the mixing angle between the two R_2's to be ϕ. It is now easy to derive $Y = -a/\sqrt{2}$, $Y_L = c_\phi a$, and $Y_R = Y_R^T = s_\phi b$. For the maximal mixing $s_\phi = c_\phi = 1/\sqrt{2}$ for both R_2 states we can recover relation $Y_R = Y_R^T$, $Y = -Y_L$. Obviously, the two $SU(5)$ operators proportional to a and b might to generate three Yukawa matrices Y, Y_L, and Y_R. After such set-up, we consider the NP parameters m_{R_2}, m_{S_3}, $y_R^{b\tau}$, $y_L^{c\mu}$, $y_L^{c\tau}$, and θ. With this set-up we find out that the low-energy Yukawa couplings can originate from $SU(5)$. Even more, we checked weather the Yukawa couplings have perturbative nature, meaning that $y_R^{b\tau}$, $y_L^{c\mu}$, and $y_L^{c\tau}$ remain below $\sqrt{4\pi}$. Therefore, we have checked the renormalization group running from the electroweak to the GUT scale 5×10^{15} GeV. For example, as we mentioned in [19] the running of the Yukawa coupling $y_R^{b\tau}$, crucial in explaining the $R_{D^{(*)}}$ puzzle is given by

$$16\pi^2 \frac{d \ln y_R^{b\tau}}{d \ln \mu} = |y_L^{c\mu}|^2 + |y_L^{c\tau}|^2 + \frac{9}{2} |y_R^{b\tau}|^2 + \frac{1}{2} y_t^2 + \ldots, \tag{5}$$

where y_t is the top Yukawa coupling.

4 B anomalies in GUT scenario

4.1 Charged-current decays

The relevant effective Lagrangian for (semi-)leptonic decays is

$$\mathcal{L}_{eff}^{d\to u\ell\bar{\nu}} = -\frac{4\,G_F}{\sqrt{2}} V_{ud}\big[(1+g_{V_L})(\bar{u}_L\gamma_\mu d_L)(\bar{\ell}_L\gamma^\mu\nu_L)$$
$$+g_{S_L}(\mu)\,(\bar{u}_R d_L)(\bar{\ell}_R\nu_L) + g_T(\mu)\,(\bar{u}_R\sigma_{\mu\nu}d_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\big]\,, \tag{6}$$

where neutrinos are in the flavor basis. The effective Wilson coefficients of $d \to u\ell\bar{\nu}_{\ell'}$ are related to the LQ couplings at the matching scale $\Lambda(\approx 1\,\text{TeV})$ via the expression

$$g_{S_L}(\Lambda) = 4\,g_T(\Lambda) = \frac{y_L^{u\ell'}\,y_R^{d\ell *}}{4\sqrt{2}\,m_{R_2}^2\,G_F V_{ud}}\,, \tag{7}$$

$$g_{V_L} = -\frac{y^{d\ell'}\,(Vy^*)^{u\ell}}{4\sqrt{2}\,m_{S_3}^2 G_F V_{ud}}\,. \tag{8}$$

From the above equations we learn that the only transitions affected by R_2 in our scenario are $b \to c\tau\bar{\nu}_\ell$. S_3, on the other hand, contributes to processes involving u, c, s, b, and $\ell, \ell' = \mu, \tau$, but gives a negligibly small contribution to $R_{D^{(*)}}$.

To compute R_D we employ the $B \to D$ form factors calculated using the lattice QCD [4, 31], resulting in prediction $R_D^{\text{SM}} = 0.29(1)$ which is $\approx 2\,\sigma$ below the experimental average $R_D^{\text{exp}} = 0.41(5)$ [32–34]. On the other hand, the $B \to D^*$ form factors have never been computed on the lattice at nonzero recoil. Thus, for R_{D^*} we consider the leading form factors extracted from the $B \to D^* l\bar{\nu}$ ($l = e, \mu$) spectra [35], which are combined with the ratios $A_0(q^2)/A_1(q^2)$ and $T_{1-3}(q^2)/A_1(q^2)$ computed in Ref. [6]. We obtain the value $R_{D^*}^{\text{SM}} = 0.26(1)$ which is $\approx 3\,\sigma$ below the experimental average $R_{D^*}^{\text{exp}} = 0.30(2)$ [35]. Moreover, the scalar (tensor) effective coefficients in Eq. 7 have to account for the SM running from the matching scale $\mu = \Lambda$ down to $\mu = m_b$. In the case of the vector coefficient there is no QCD running effects.

Following analysis of Ref. [24] our fit includes constraints from several (semi-)leptonic decays. Interestingly, the ratios for the light leptons, the analog of the one with τ and μ, $R_{D^{(*)}}^{\mu/e} = \mathcal{B}(B \to D^{(*)}\mu\bar{\nu})/\mathcal{B}(B \to D^{(*)}e\bar{\nu})$ gives very important constraint. [18]. We also consider $\mathcal{B}(B \to \tau\bar{\nu})$ as well as the kaon ratio $R_{e/\mu}^K = \Gamma(K^- \to e^-\bar{\nu})/\Gamma(K^- \to \mu^-\bar{\nu})$, which both agrees with their SM predictions (see for details [24]).

4.2 Neutral-current decays

The standard effective Hamiltonian for the $b \to s$ (semi-)leptonic transition can be written as

$$\mathcal{H}_{eff}^{b\to sll} = -\frac{4G_F\lambda_t}{\sqrt{2}} \sum_{i=7,9,10} C_i(\mu)O_i(\mu)\,, \tag{9}$$

where $\lambda_t = V_{tb}V_{ts}^*$. The relevant operators for our discussion are

$$O_{9(10)} = \frac{e^2}{(4\pi)^2}\,(\bar{s}_L\gamma_\mu b_L)(\bar{l}\gamma^\mu(\gamma^5)l)\,. \tag{10}$$

In our scenario, only S_3 contributes at tree-level [24]

$$\delta C_9^{\mu\mu} = -\delta C_{10}^{\mu\mu} = \frac{\pi}{\lambda_t\alpha_{\text{em}}}\frac{v^2}{m_{S_3}^2}\,y^{b\mu}(y^{s\mu})^*\,. \tag{11}$$

Relying on the results of [36, 37] the $1\,\sigma$ interval $C_9^{\mu\mu} = -C_{10}^{\mu\mu} \in (-0.85, -0.50)$ is obtained by performing a fit to the clean $b \to sll$ observables, namely, R_K, R_{K^*}, and $\mathcal{B}(B_s \to \mu\mu)$ [36, 37].

Contributions to the left-handed current operators in $b \to sll$ transition immediately contribute to $B \to K^{(*)}\nu\nu$ decay amplitudes which are well constrained by experiments. These decays are governed by

$$\mathcal{L}_{\rm eff}^{b\to s\nu\nu} = \frac{\sqrt{2}G_F\alpha_{\rm em}\lambda_t}{\pi}\, C_L^{ij}\, (\bar{s}_L\gamma_\mu b_L)(\bar{\nu}_{L\,i}\gamma^\mu\nu_{L\,j})\,, \tag{12}$$

with $C_L^{ij} = \delta_{ij}C_L^{\rm SM} + \delta C_L^{ij}$ being the Wilson coefficient with the SM contributions $C_L^{\rm SM} = -6.38(6)$ [38] and the contribution δC_L^{ij} from NP. Similarly as in the $b \to sll$ transition, the only tree-level contribution to $b \to s\nu\bar{\nu}$ comes from the S_3 state and reads [24]

$$\delta C_L^{ij} = \frac{\pi}{2\alpha_{\rm em}\lambda_t}\frac{v^2}{m_{S_3}^2}\, y^{bj}(y^{si})^*\,, \quad i,j=\mu,\tau\,. \tag{13}$$

These effective coefficients modify the ratios $R_{\nu\nu}^{(*)} = \mathcal{B}(B \to K^{(*)}\nu\nu)/\mathcal{B}(\mathcal{B} \to \mathcal{K}^{(*)}\nu\nu)^{\mathcal{SM}}$ in the following way

$$R_{\nu\nu}^{(*)} = \frac{\sum_{ij}|\delta_{ij}C_L^{SM} + \delta C_L^{ij}|^2}{3|C_L^{\rm SM}|^2}. \tag{14}$$

In our fit we use experimental bounds $R_{\nu\nu} < 3.9$ and $R_{\nu\nu}^* < 2.7$ [39] and data on the $B_s - \bar{B}_s$ mixing amplitude as in [19], modified by the box-diagrams containing two S_3, leading to the proportionality to $[(yy^\dagger)^{bs}]^2/m_{S_3}^2$. Then we explore the experimental limits on LFV τ decays, $\mathcal{B}(\tau \to \mu\phi)^{\rm exp} < 8.4 \times 10^{-8}$ and $\mathcal{B}(\tau \to \mu\gamma)^{\rm exp} < 4.4 \times 10^{-8}$ [40], muon anomalous magnetic moment with the $\approx 3.6\,\sigma$ discrepancy with respect to the SM [41]. In out approach, however, $(g-2)_\mu$ receives very small corrections. Then we explored bounds on the $Z \to l^+l^-$ couplings measured at LEP [42]. Namely, both R_2 and S_3 contribute at on loop level to these decays. The strong constraints come from the measured $D - \bar{D}$ mixing parameters and we have checked that our model is not in a conflict with experimental results obtained for the charm meson mixing.

5 Constraints and predictions

The observables we described above were used in the fit described in [19] by varying the parameters $y_R^{b\tau}$, $y_L^{c\mu}$, $y_L^{c\tau}$ and θ. First we learn that our fit requires S_3 to have larger mass than than R_2. The masses m_{R_2} and m_{S_3} we consider to be the lowest values allowed by projected LHC constraints with $m_{R_2} = 800\,\rm GeV$ and $m_{S_3} = 2\,\rm TeV$. Very interesting feature of our model is that $y_R^{b\tau}$ should be a complex number [19]. The complex phase does not induce any observable CP violation. In our study the LHC constraints are taken into account [19]. Our best fit points are

$$\mathrm{Re}[g_{S_L}] = 0,\ |\mathrm{Im}[g_{S_L}]| = 0.59\begin{pmatrix}+0.13\\-0.14\end{pmatrix}_{1\,\sigma}\begin{pmatrix}+0.20\\-0.29\end{pmatrix}_{2\,\sigma}\,. \tag{15}$$

We find very interesting prediction for the lepton flavour violating process $\mathcal{B}(B \to K\mu\tau)$ which is found to be bounded, as presented in Fig. 2. At $1\,\sigma$ level we find

$$1.1 \times 10^{-7} \le \mathcal{B}(B \to K\mu^\pm\tau^\mp) \le 6.5 \times 10^{-7}\,. \tag{16}$$

This value is bellow the current bound $\mathcal{B}(B \to K\mu\tau)^{\rm exp} < 4.8 \times 10^{-5}$ [32].

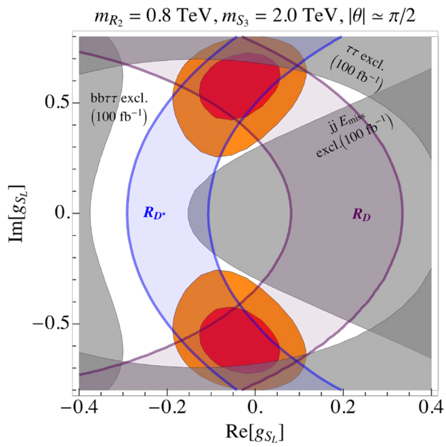

Figure 1. The flavor fit constraints on the g_{S_L} plane for the transition $b \to c\tau\bar{\nu}_\tau$. The allowed $1\,\sigma(2\,\sigma)$ regions are rendered in red (orange). Separate constraints from R_D and R_{D^*} to $2\,\sigma$ accuracy are shown by the blue and purple regions, respectively. The LHC exclusion area are presented by the grey colour.

It is easy to obtain the bound $\mathcal{B}(B \to K^*\mu\tau) \approx 1.9 \times \mathcal{B}(B \to K\mu\tau)$ and $\mathcal{B}(B_s \to \mu\tau) \approx 0.9 \times \mathcal{B}(B \to K\mu\tau)$ [43–45]. We also predict about $\sim 50\%$ enhancement of the ratio $\mathcal{B}(B \to K^{(*)}\nu\nu)$, which can be tested in the near future at Belle-II. Remarkably, these two observables are highly correlated as depicted in Fig. 2. Within our scenario we make prediction for $\mathcal{B}(\tau \to \mu\gamma)$, which lies just below the current experimental limit

$$\mathcal{B}(\tau \to \mu\gamma) \sim 1.5 \times 10^{-8}\,. \tag{17}$$

Finally, our description of the B-physics anomalies, and most particularly $R_{D^{(*)}}$, strongly depends on the assumption that the LQ states are not too far from the TeV scale. Thus, these particles are necessarily accessible at the LHC, yielding also predictions for the direct searches [19].

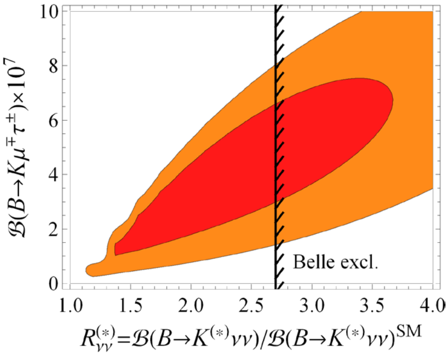

Figure 2. $\mathcal{B}(B \to K\mu\tau)$ is presented. $R_{\nu\nu} = \mathcal{B}(B \to K^{(*)}\nu\bar{\nu})/\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})^{\rm SM}$ for the $1\,\sigma$ (red) and $2\,\sigma$ (orange) regions of Fig. 1. The black line denotes the current experimental limit, $R^*_{\nu\nu} < 2.7$ [39].

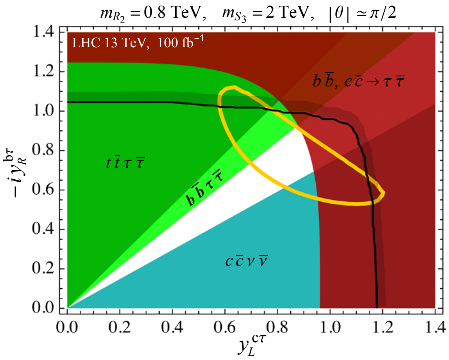

Figure 3. The flavor fit constraints on the g_{S_L} plane for the transition $b \to c\tau\bar{\nu}_\tau$. The allowed $1\,\sigma(2\,\sigma)$ regions are rendered in red (orange). Separate constraints from R_D and R_{D^*} to $2\,\sigma$ accuracy are shown by the blue and purple regions, respectively. The LHC exclusion area are presented by the gray colour.

6 Conclusions

We find out that the simple $SU(5)$ GUT model might accommodate two light scalar leptoquarks that can explain all measured B meson anomalies. Therefore, our scenario gives the explanation of the possible lepton flavour universality violation. The model is not in a conflict with low-energy phenomenology or with direct search constraints at the LHC. It is significant that all Yukawa couplings remain perturbative up to the unification scale. The model predicts the branching ratio for the lepton flavour violating decays $B \to K\mu\tau$, $B \to K^{(*)}\nu\nu$ and $\tau \to \mu\gamma$ as well as indicates their correlation.

Acknowledgements

My thanks goes to Damir Bečirević, Ilja Doršner, Darius Faroughy, Nejc Košnik and Olcyr Sumensari from whom I benefit so much about the topic considered in this contribution. I also acknowledge support of the Slovenian Research Agency under the core funding grant P1-0035.

References

[1] J. P. Lees *et al.* [BaBar Collaboration], Phys. Rev. D **88**, no. 7, 072012 (2013) [arXiv:1303.0571 [hep-ex]].
[2] S. Hirose *et al.* [Belle Collaboration], Phys. Rev. Lett. **118**, no. 21, 211801 (2017) [arXiv:1612.00529 [hep-ex]].
[3] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **115**, no. 11, 111803 (2015) Erratum: [Phys. Rev. Lett. **115**, no. 15, 159901 (2015)] [arXiv:1506.08614 [hep-ex]].
[4] J. A. Bailey *et al.* [MILC Collaboration], Phys. Rev. D **92**, no. 3, 034506 (2015) [arXiv:1503.07237 [hep-lat]].
[5] S. Fajfer, J. F. Kamenik and I. Nisandzic, Phys. Rev. D **85**, 094025 (2012) [arXiv:1203.2654 [hep-ph]].
[6] F. U. Bernlochner, Z. Ligeti, M. Papucci and D. J. Robinson, Phys. Rev. D **95**, no. 11, 115008 (2017) Erratum: [Phys. Rev. D **97**, no. 5, 059902 (2018)] [arXiv:1703.05330 [hep-ph]].

[7] D. Bigi, P. Gambino and S. Schacht, Phys. Lett. B **769**, 441 (2017) [arXiv:1703.06124 [hep-ph]].
[8] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **120**, no. 12, 121801 (2018) [arXiv:1711.05623 [hep-ex]].
[9] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **113**, 151601 (2014) [arXiv:1406.6482 [hep-ex]].
[10] R. Aaij *et al.* [LHCb Collaboration], JHEP **1708**, 055 (2017) [arXiv:1705.05802 [hep-ex]].
[11] G. Hiller and F. Kruger, Phys. Rev. D **69**, 074020 (2004) [hep-ph/0310219].
[12] M. Bordone, G. Isidori and A. Pattori, Eur. Phys. J. C **76**, no. 8, 440 (2016) [arXiv:1605.07633 [hep-ph]].
[13] D. Buttazzo, A. Greljo, G. Isidori and D. Marzocca, JHEP **1711**, 044 (2017) [arXiv:1706.07808 [hep-ph]].
[14] B. Bhattacharya, A. Datta, D. London and S. Shivashankara, Phys. Lett. B **742**, 370 (2015) [arXiv:1412.7164 [hep-ph]].
[15] F. Feruglio, P. Paradisi and A. Pattori, Phys. Rev. Lett. **118**, no. 1, 011801 (2017) [arXiv:1606.00524 [hep-ph]].
[16] L. Di Luzio and M. Nardecchia, Eur. Phys. J. C **77**, no. 8, 536 (2017) doi:10.1140/epjc/s10052-017-5118-9 [arXiv:1706.01868 [hep-ph]].
[17] M. Bauer and M. Neubert, Phys. Rev. Lett. **116**, no. 14, 141802 (2016) doi:10.1103/PhysRevLett.116.141802 [arXiv:1511.01900 [hep-ph]].
[18] D. Bečirević, N. Košnik, O. Sumensari and R. Zukanovich Funchal, JHEP **1611**, 035 (2016) doi:10.1007/JHEP11(2016)035 [arXiv:1608.07583 [hep-ph]].
[19] D. Bečirević, I. Doršner, S. Fajfer, N. Košnik, D. A. Faroughy and O. Sumensari, Phys. Rev. D **98**, 055003 (2018) doi:10.1103/PhysRevD.98.055003 [arXiv:1806.05689 [hep-ph]].
[20] L. Di Luzio, J. Fuentes-Martin, A. Greljo, M. Nardecchia and S. Renner, arXiv:1808.00942 [hep-ph].
[21] I. Doršner, S. Fajfer, A. Greljo, J. F. Kamenik and N. Košnik, Phys. Rept. **641**, 1 (2016) [arXiv:1603.04993 [hep-ph]].
[22] I. Doršner, S. Fajfer and N. Košnik, Phys. Rev. D **86**, 015013 (2012) [arXiv:1204.0674 [hep-ph]].
[23] I. Doršner, S. Fajfer and N. Košnik, Eur. Phys. J. C **77**, no. 6, 417 (2017) [arXiv:1701.08322 [hep-ph]].
[24] I. Doršner, S. Fajfer, D. A. Faroughy and N. Košnik, JHEP **1710**, 188 (2017) [arXiv:1706.07779 [hep-ph]].
[25] A. Crivellin, D. Müller and T. Ota, JHEP **1709**, 040 (2017) [arXiv:1703.09226 [hep-ph]].
[26] D. Bečirević, S. Fajfer, N. Koňik and O. Sumensari, Phys. Rev. D **94**, no. 11, 115021 (2016) [arXiv:1608.08501 [hep-ph]].
[27] A. Greljo, D. J. Robinson, B. Shakya and J. Zupan, arXiv:1804.04642 [hep-ph].
[28] D. Robinson, B. Shakya and J. Zupan, arXiv:1807.04753 [hep-ph].
[29] A. Azatov, D. Bardhan, D. Ghosh, F. Sgarlata and E. Venturini, arXiv:1805.03209 [hep-ph].
[30] G. Hiller and M. Schmaltz, JHEP **1502**, 055 (2015) doi:10.1007/JHEP02(2015)055 [arXiv:1411.4773 [hep-ph]].
[31] H. Na *et al.* [HPQCD Collaboration], **92**, no. 5, 054510 (2015) Erratum: [Phys. Rev. D **93**, no. 11, 119906 (2016)] [arXiv:1505.03925 [hep-lat]].

[32] J. P. Lees *et al.* [BaBar Collaboration], Phys. Rev. D **86**, 012004 (2012) [arXiv:1204.2852 [hep-ex]].

[33] M. Huschle *et al.* [Belle Collaboration], Phys. Rev. D **92**, no. 7, 072014 (2015) [arXiv:1507.03233 [hep-ex]].

[34] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. D **97**, no. 7, 072013 (2018) [arXiv:1711.02505 [hep-ex]].

[35] Y. Amhis *et al.* [HFLAV Collaboration], Eur. Phys. J. C **77**, no. 12, 895 (2017) [arXiv:1612.07233 [hep-ex]].

[36] G. D'Amico, M. Nardecchia, P. Panci, F. Sannino, A. Strumia, R. Torre and A. Urbano, JHEP **1709**, 010 (2017) [arXiv:1704.05438 [hep-ph]].

[37] B. Capdevila, A. Crivellin, S. Descotes-Genon, J. Matias and J. Virto, JHEP **1801**, 093 (2018) [arXiv:1704.05340 [hep-ph]].

[38] W. Altmannshofer, A. J. Buras, D. M. Straub and M. Wick, JHEP **0904**, 022 (2009) [arXiv:0902.0160 [hep-ph]].

[39] J. Grygier *et al.* [Belle Collaboration], Phys. Rev. D **96**, no. 9, 091101 (2017) Addendum: [Phys. Rev. D **97**, no. 9, 099902 (2018)] [arXiv:1702.03224 [hep-ex]].

[40] C. Patrignani *et al.* [Particle Data Group], Chin. Phys. C **40**, no. 10, 100001 (2016).

[41] J. Beringer *et al.* [Particle Data Group], Phys. Rev. D **86**, 010001 (2012).

[42] S. Schael *et al.* [ALEPH and DELPHI and L3 and OPAL and SLD Collaborations and LEP Electroweak Working Group and SLD Electroweak Group and SLD Heavy Flavour Group], Phys. Rept. **427**, 257 (2006) [hep-ex/0509008].

[43] D. Bečirević, O. Sumensari and R. Zukanovich Funchal, Eur. Phys. J. C **76**, no. 3, 134 (2016) [arXiv:1602.00881 [hep-ph]].

[44] S. L. Glashow, D. Guadagnoli and K. Lane, Phys. Rev. Lett. **114** (2015) 091801 [arXiv:1411.0565 [hep-ph]].

[45] D. Guadagnoli and K. Lane, Phys. Lett. B **751** (2015) 54 [arXiv:1507.01412 [hep-ph]].