Explaining $b \to s\ell^+\ell^-$ data by sneutrinos in the $R$-parity violating MSSM

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Abstract

The recent measurements on $b \to s\ell^+\ell^-$ processes suggest the existence of lepton-flavour-universality breaking new physics. In this work, we have explored the possibility of explaining these data by sneutrinos in the $R$-parity violating Minimal Supersymmetric Standard Model. We study the light sneutrinos, of order 1 TeV, and suppose that the rest of sfermions are much heavier than them. This setup can solve $b \to s\mu^+\mu^-$ anomaly well, and it is almost unconstrained by other related processes, such as $B_s - \bar{B}_s$ mixing, as well as $B_s^0 \to \tau^+\tau^-$, $B^+ \to K^+\tau^+\tau^-$, $B_s^0 \to \tau^\pm\mu^\mp$ and $B^+ \to K^+\tau^\pm\mu^\mp$ decays.

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1 Introduction

The rare semileptonic $b$-hadron decays induced by the flavour-changing neutral current (FCNC) transition $b \to s\ell^+\ell^-$ do not arise at tree level and are highly suppressed at higher orders within the Standard Model (SM), due to the Glashow-Iliopoulos-Maiani (GIM) mechanism [1]. New TeV-scale particles in many extensions of the SM could lead to measurable effects in these rare decays. As a consequence, they play a crucial role in testing the SM and probing various new physics (NP) scenarios beyond it [2, 3].

In recent years, several deviations from the SM predictions have been observed in $b \to s\ell^+\ell^-$ transition. Consider the ratios of the branching fractions

\[ R_K^{(\ast)} = \frac{B(B \to K^{(\ast)}\mu^+\mu^-)}{B(B \to K^{(\ast)}e^+e^-)}, \]

which have negligible theoretical uncertainties. In the range $1.1 < q^2 < 6 \text{GeV}^2/c^4$, the latest experimental data by LHCb collaboration give

\[ R_K^{[1.1,6]} = 0.846^{+0.060+0.016}_{-0.054-0.014} [4, 5], \]

but the SM predicts it to be close to one [6]. The measurement of $R_K$ is 2.5σ smaller than the SM prediction. The measurements of $R_K^{\ast}$ [7] by LHCb are

\[ R_K^{[0.045,1.1]} = 0.660^{+0.110}_{-0.070} \pm 0.024 \text{ and } R_K^{[1.1,6.0]} = 0.685^{+0.113}_{-0.069} \pm 0.05, \]

which are lower than the predicted values of the SM [6] about 2.1σ and 2.5σ, respectively. Belle collaboration also give the measurements of $R_K^{\ast}$ [8, 9], which are consistent with the SM predictions due to their large experimental errors. In addition to the tension with the SM in lepton-flavour-universality observables $R_K^{(\ast)}$, some other deviations have also been found in $b \to s\mu^+\mu^-$ transition. In particular, the form-factor-independent angular observable $P'_5$ [10–12] in the $B \to K^*\mu^+\mu^-$ decay was measured by LHCb [13, 14], CMS [15], ATLAS [16] and Belle [17, 18], showing a 2.6σ disagreement with the SM expectation [19]. Finally, LHCb has also observed a 3.3σ deficit in the $B_s^0 \to \phi\mu^+\mu^-$ decay [20, 21].

Motivated by these deviations and using the other available data on such rare $b \to s\ell^+\ell^-$ transitions, many global analyses have been carried out [19, 22–27], finding that a negative shift in a single Wilson coefficient of local operator like $O_9^{\mu\mu} = (\bar{s}\gamma^\alpha P_L b)(\bar{\mu}\gamma_\alpha\mu)$ or $O_{LL}^{\mu\mu} = (\bar{s}\gamma^\alpha P_L b)(\bar{\mu}\gamma_\alpha P_L \mu)$ leads to a consistent description of the data, with the corresponding best-fit point can improve the fit to the data by more than 5σ compared to the SM. Furthermore, the operator $O_{LL}^{\mu\mu}$ performs better than $O_9^{\mu\mu}$, mainly because there is now $\sim 2\sigma$ tension in the branching fraction of $B_s \to \mu^+\mu^-$ [22, 28–33], which is not affected by $O_9^{\mu\mu}$. In this paper, we work with the low-energy effective weak Lagrangian governing the $b \to s\mu^+\mu^-$ processes:

\[ \mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{eff}}^{\text{SM}} + \frac{4G_F}{\sqrt{2}} \eta \frac{e^2}{16\pi^2} C_{\ell\ell}^{\mu\mu} O_{LL}^{\mu\mu} + \text{h.c.}, \]  

(1.1)

where $\mathcal{L}_{\text{eff}}^{\text{SM}}$ represents contributions from the SM, and the remaining terms contain possible
NP contributions. The CKM factor $\eta_t = V_{tb}V_{ts}^* \approx -0.04$ [34]. The best-fit point performed by Ref. [22] is $C^{\mu\mu}_{LL} = -1.06$, with the 2$\sigma$ range being $-1.38 < C^{\mu\mu}_{LL} < -0.74$. We find that such $C^{\mu\mu}_{LL}$ can be generated naturally in the $R$-parity violating Minimal Supersymmetric Standard Model (MSSM) [35] by exchanging smuon and winos.

Before we start our discussion, let’s briefly review some of the work on $b \to s\mu^+\mu^-$ anomaly within the context of $R$-parity violating MSSM [36–41]. For example, the authors in Ref. [37] attempted to explain $b \to s\mu^+\mu^-$ anomaly via one-loop contributions involving right-handed down type squarks $\tilde{d}_R$, which can help solve $R(D^*)$ anomaly at tree level [37, 40, 42–46]. However, they note that it is difficult to find a viable explanation due to the severe constraints from the upper limit on the branching fraction of $B \to K^{(*)}\nu\bar{\nu}$ decays. In addition to $\tilde{d}_R$, the authors in Ref. [38] also consider the contribution to $b \to s\mu^+\mu^-$ transition from the box diagrams with a left-handed up type squark $\tilde{u}_L$ and sneutrino $\tilde{\nu}_L$ in the loop. They find that this new contribution could help explain $b \to s\mu^+\mu^-$ anomaly, while satisfying the constraint from $B \to K^{(*)}\nu\bar{\nu}$ and $D^0 \to \mu^+\mu^-$ decays as well as $B_s - \bar{B}_s$ mixing. In Ref. [39], the authors focus on parameters for which diagrams involving winos $\tilde{W}$, which have not been considered before, make significant effects. They set the masses of $\tilde{W}$ and three $\tilde{u}_L$ to be light, of order 1 TeV, and at the same time, they consider heavy $\tilde{\nu}_L$ and $\tilde{d}_R$, of order 10 TeV. In this scenario, the $b \to s\mu^+\mu^-$ anomaly may be explained by large values of $\lambda^\prime$, but the available parameter space is very small due to the constraints from relevant processes, such as $\tau \to 3\mu$, $B_s - \bar{B}_s$ mixing and direct LHC searches. The restriction from $B \to K^{(*)}\nu\bar{\nu}$ decay is negligible because of the large mass of $\tilde{d}_R$.

There are two kinds of sfermions participating in the $\tilde{W}$ box diagrams, namely $\tilde{u}_L$ and $\tilde{\nu}_L$. As an alternative, in this paper, we study the light $\tilde{\nu}_L$, of order 1 TeV, and suppose that the rest of sfermions are much heavier compared to it. This scenario can well produce the $C^{\mu\mu}_{LL}$ needed to explain $b \to s\mu^+\mu^-$ anomaly, and the corresponding parameter space is not constrained by other related processes, such as $B_s - \bar{B}_s$ mixing, as well as $B_s^0 \to \tau^+\tau^-$, $B^+ \to K^+\tau^+\tau^-$, $B_s^0 \to \tau^\pm \mu^\mp$ and $B^+ \to K^+\tau^\pm \mu^\mp$ decays.

Our paper is organized as follows. In section 2, we first set up our scenario and then discuss the explanation of $b \to s\mu^+\mu^-$ anomaly in the $R$-parity violating MSSM. The other potential constraints are studied in section 3. Our conclusions are finally made in section 4.
2 Contributions to $b \rightarrow s\mu^+\mu^-$ processes from $R$-parity violating MSSM

The superpotential of the relevant $R$-parity violating terms in the MSSM is given by [35]

$$W_{RPV} = \mu_i L_i H_u + \frac{1}{2} \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2} \lambda''_{ijk} U^c_i D^c_j D^c_k,$$

(2.1)

where $L$, $H_u$, $E^c$, $Q$, and $D^c$ are the chiral superfields for the MSSM multiplet, and we denote the generation indices by $i,j,k = 1,2,3$. The summation is applied for the repeated indices throughout this paper unless otherwise stated. The first three terms in Eq. (2.1) destroy the lepton number and the last term violates the baryon number. We will assume that $\lambda''$ coupling is zero to prevent rapid proton decay. In this work, we limit ourselves to consider the $\lambda'_{ijk} L_i Q_j D^c_k$ term as the source of $R$-parity violating NP, because of the $b \rightarrow s\mu^+\mu^-$ processes involve both leptons and quarks. The effects of $\lambda$ and $\lambda'$ terms simultaneously on $b \rightarrow s\mu^+\mu^-$ processes have been studied in such as Ref. [40, 41]. Expanding the chiral superfields in terms of their fermions and sfermions, one has

$$\mathcal{L} = \lambda'_{ijk} \left( \bar{\nu}_{Li} \tilde{d}_{Rk} d_{Lj} + \tilde{d}_{Lj} d_{Rk} \nu_{Li} + \tilde{d}^*_{Rk} \bar{\nu}^c_{Li} d_{Lj} - \tilde{l}_{Li} \tilde{d}_{Rk} u_{Lj} - \bar{u}_{Lj} \tilde{d}^*_{Rk} \nu_{Li} - \tilde{d}^*_R \bar{\nu}^c_{Li} d_{Lj} \right).$$

(2.2)

We will also assume that all sfermions are so heavy that they are decoupled, except for sneutrinos $\tilde{\nu}_{Li}$ of order 1 TeV. Under this assumption, only the $\lambda'_{ijk} \tilde{\nu}_{Li} \tilde{d}_{Rk} d_{Lj}$ term in Eq. (2.2) can lead to a valuable effect. In this paper we focus our attention on a parameter space where the $\lambda'_{ij3}$ couplings are large, i.e., keep $\lambda'_{ij1} = \lambda'_{ij2} = 0$ all the time. We will assume sneutrinos are in their mass eigenstate basis and nearly degenerate, and the degenerate mass is denoted as $m_{\tilde{\nu}}$.

The $b \rightarrow s\mu^+\mu^-$ processes can occur at one-loop level by exchanging smuon and winos, see Fig. 1a. After integrating out smuon and winos we are left with the effective operator $O_{LL}^{\mu\mu}$, as
Figure 2: Example figure showing the parameter space in $m_{\tilde{\nu}} - \lambda'_{233} \lambda'^*_{223}$ plane explaining $b \to s \mu^+ \mu^-$ anomaly. We set $m_{\tilde{W}} = 0.3$ TeV.

well as the corresponding Wilson coefficient given by

$$C_{LL}^{\mu\mu} = -\frac{\sqrt{2} \lambda'_{233} \lambda'^*_{223}}{16 G_F \sin^2 \theta_W \eta m_{\tilde{\nu}}^2} x_{\tilde{\nu}} f(x_{\tilde{\nu}}) ,$$

(2.3)

where the loop function $f(x_{\tilde{\nu}}) \equiv \frac{1-x_{\tilde{\nu}} + \log x_{\tilde{\nu}}}{(1-x_{\tilde{\nu}})^2}$ and $x_{\tilde{\nu}} \equiv m_{\tilde{\nu}}^2 / m_{\tilde{W}}^2$. To explain $b \to s \mu^+ \mu^-$ anomaly, we need to take the product $\lambda'_{233} \lambda'^*_{223} > 0$ to make $C_{LL}^{\mu\mu}$ negative. Consider the 2$\sigma$ range $-1.38 < C_{LL}^{\mu\mu} < -0.74$ [22], we have

$$-1.74 < \frac{x_{\tilde{\nu}} f(x_{\tilde{\nu}}) \lambda'_{233} \lambda'^*_{223}}{(m_{\tilde{\nu}}/\text{TeV})^2} < -0.93 .$$

(2.4)

The corresponding parameter space is shown in Fig. 2.

There is also a contribution from the photonic penguin, which is shown in Fig. 1b. In fact, this contribution is lepton-flavour-universality for the SM photon. Using FeynCalc [47, 48] and Package-X [49, 50] packages, we can obtain the effective operators $O_{9}^{\ell\ell}$ and $O_{7} = \frac{m_b}{\epsilon} (\bar{s}\sigma^{\alpha\beta}P_R b) F_{\alpha\beta}$ after integrating out sneutrinos, and the corresponding Wilson coefficients given by

$$C_{9}^{\ell\ell} = -\frac{\sqrt{2} \lambda'_{333} \lambda'^*_{223}}{36 G_F \eta \eta m_{\tilde{\nu}}^2} \left[ \frac{4}{3} + \log \left( \frac{m_b^2}{m_{\tilde{\nu}}^2} \right) \right] ,$$

(2.5)

$$C_{7} = \frac{\sqrt{2} \lambda'_{333} \lambda'^*_{223}}{144 G_F \eta \eta m_{\tilde{\nu}}^2} .$$

(2.6)
Our results are consistent with those in Ref. [51]. Comparing with Ref. [39], we find that the result of $C_7$ is consistent, but the result of $C_9^{\ell\ell}$ is different by a negative sign. All in all, we should suppress the effect of photonic penguin by setting $\lambda'_{i33}\lambda'_{i23} = 0$ in order to take advantage of only nonzero $C_{LL}^{\mu\mu}$ scenario, which has the largest pull-value in single Wilson coefficient global analyses [22]. We also calculate the contribution of Z-penguin and find that it can be ignored due to the negligible down type quark masses.

3 Other possible constraints

In our scenario, several other processes may also obtain the effects of $R$-parity violating interactions, and the corresponding constraints should be taken into account. Next, we mainly study the constraints on $\lambda'_{i23}$ and $\lambda'_{i33}$ couplings, which play the key role in solving $b \to s\mu^+\mu^-$ anomaly.

3.1 Tree level decays

Exchanging sneutrinos and performing Fierz rearrangement, one obtains the following four fermion operators at tree level

$$\mathcal{L}_{\text{tree}}^{\text{eff}} = \frac{\lambda'_{ij3} \lambda'_{ij3}^*}{m_{\tilde{\nu}}^2} (\bar{d}_R d_j) (\bar{d}_j' b_R) . \quad (3.1)$$

There is no valid constraint here. In addition, keeping $\lambda'_{i33}\lambda'_{i23} = 0$ can prevent the occurrence of dangerous $\Upsilon - B_s$ mixing.

3.2 Loop level decays

The potential constraint may come from $B_s - \bar{B}_s$ mixing, which can obtain the $R$-parity violating contributions by exchanging two sneutrinos in the loop. This NP contribution can lead to the same effective operator as the SM. The contributions of $R$-parity violating interactions are given by

$$\mathcal{L}_\Delta^{F=2} = -\frac{\lambda'_{ij3} \lambda'_{ij3}^* \lambda'_{i33} \lambda'_{i23}}{128\pi^2 m_{\tilde{\nu}}^2} (\bar{s} \gamma^\alpha P_L b) (\bar{s} \gamma^\alpha P_L b) + \text{h.c.} . \quad (3.2)$$

Because we keep $\lambda'_{i33} \lambda'_{i23} = 0$, these contributions go away.

In fact, in addition to muon channel, the nonzero $\lambda'_{i23}$ and $\lambda'_{i33}$ couplings can also induce $b \to s\ell^+_i \ell^-_j$ processes by exchanging sneutrinos and winos, as shown in Fig. 1a. The corresponding
Wilson coefficients $C_{ij}^{LL}$ can be obtained by replacing $\lambda'_{233}\lambda'_{223}$ with $\lambda'_{333}\lambda'_{223}$ in Eq. (2.3). In order for the NP to have no effect on $b \to se^+e^-$ processes we should keep $C_{ee}^{ee} = \lambda'_{133}\lambda'_{123} \approx 0$, which means $\lambda'_{133} \approx 0$ or $\lambda'_{123} \approx 0$. Combining $\lambda'_{333}\lambda'_{223} = 0$, we predict the same size of $C_{ij}^{uu}$ and $C_{ij}^{LL} \propto \lambda'_{333}\lambda'_{233}$, with similar result in the PS$^3$ model [52]. Such $C_{ij}^{LL}$ satisfies the upper limit of $B(B^+ \to K^+\tau^+\tau^-) < 2.25 \times 10^{-3}$ [53] measured by BaBar at 90% confidence level (CL) and $B(B^0_s \to \tau^+\tau^-) < 6.8 \times 10^{-3}$ [54] measured by LHCb at 95% CL.

The remaining potential constraints come from several lepton-flavour-violation decays $B^0_s \to \tau^\pm \mu^\mp$ and $B^+ \to K^+\tau^\pm\mu^\mp$. Those decays governed by the low-energy effective weak Lagrangian

$$\mathcal{L}_{\text{eff}} = \frac{\alpha}{16\pi\sin^2\theta_W} \frac{\lambda'_{333}\lambda'_{223}}{m_B^2} x_\nu f(x_\nu) O_{iL}^{ij} + \text{h.c.},$$

with $i \neq j$. The branching fractions of leptonic $B^0_s \to \tau^\pm\mu^\mp$ decays given by

$$B(B^0_s \to \tau^\pm\mu^\mp(\tau^\pm\tau^-)) = \frac{\alpha^2\tau_B f_B^2 \lambda_{\tau\mu} x_\tau^2 f^2(x_\tau) |\lambda'_{333}\lambda'_{223}|^2 |(\lambda'_{333}\lambda'_{223})|^2}{128\pi^3 m_B^2 \sin^4\theta_W m_{\tau}^4},$$

where $\lambda_{\tau\mu} \equiv \sqrt{m_{B_s}^2 + m_\tau^2 + m_\mu^2 - 2m_{B_s}^2 m_\tau^2 - 2m_{B_s}^2 m_\mu^2 - 2m_\tau^2 m_\mu^2 - m_{B_s}^2 (m_\tau^2 + m_\mu^2) - (m_\tau^2 - m_\mu^2)^2}$. In our numerical analysis, we take as input the decay constant $f_{B_s} = 0.2272(34)$ GeV, the lifetime $\tau_{B_s} = 1.510(4)$ ps, as well as the mass $m_{B_s} = 5.367$ GeV, $m_\tau = 1.777$ GeV and $m_\mu = 0.1057$ GeV [34]. Lately, the upper limit on these branching fractions are measured by LHCb collaboration. At 95% CL one has [55]

$$B(B^0_s \to \tau^\pm\mu^\mp)_{\text{exp}} < 4.2 \times 10^{-5}. $$

This induces the constraints

$$\frac{|x_\nu f(x_\nu)|\lambda'_{333}\lambda'_{223}(\lambda'_{333}\lambda'_{223})}{(m_\nu/\text{TeV})^2} < 108.15. $$

For semi-leptonic $B^+ \to K^+\tau^\pm\mu^\mp$ decays, we can obtain

$$\frac{|x_\nu f(x_\nu)|\lambda'_{333}\lambda'_{223}(\lambda'_{333}\lambda'_{223})}{(m_\nu/\text{TeV})^2} < 92.24, $$

$$\frac{|x_\nu f(x_\nu)|\lambda'_{333}\lambda'_{223}(\lambda'_{333}\lambda'_{223})}{(m_\nu/\text{TeV})^2} < 117.53, $$

by directly using the upper bound results of the Wilson coefficients given in Ref. [56]. The Eq. (3.7) has a stronger constraint than Eq. (3.6) but Eq. (3.8) has a weaker constraint than it. Obviously, under these constraints the Eq. (2.4) and relation $\lambda'_{233}\lambda'_{223} \approx -\lambda'_{333}\lambda'_{233}$ (for keeping $\lambda'_{333}\lambda'_{223} = 0$) are easy to implement.
4 Conclusions

Recently, several deviations from the SM predictions in \(b \to s\ell^+\ell^-\) data hint to exist lepton-flavour-universality breaking NP. Many global analyses show that a negative shift in Wilson coefficient \(C_{LL}^{\mu\mu}\) can explain these data well, and the corresponding best-fit point can improve the fit to the data by more than \(5\sigma\) compared to the SM. This suggests that the NP primarily affects the \(b \to s\mu^+\mu^-\) processes. Based on these knowledge, in this work we have explored the possibility of explaining \(b \to s\mu^+\mu^-\) anomaly by sneutrinos in the \(R\)-parity violating MSSM.

After a brief introduction to the relevant terms in the superpotential of \(R\)-parity violating MSSM, we present our scenario, that is, we consider the light \(\tilde{\nu}_L\) of order 1 TeV and the other sfermions are so heavy that they are decoupled. We find that a positive product \(\lambda'_{233}\lambda'_{223}\) can explain \(b \to s\mu^+\mu^-\) anomaly, and the parameter space satisfied by \(\lambda'_{233}\lambda'_{223}\) and \(m_{\tilde{\nu}}\) is shown in Fig. 2. After that, we consider the other possible constraints, including tree level and one-loop level decays. Keeping \(\lambda'_{333}\lambda'_{223} = 0\) can inhibit the contribution of \(R\)-parity violating NP to \(B_s - \bar{B}_s\) mixing and the photonic penguin of \(b \to s\ell^+\ell^-\) processes, and prevents the emergence of dangerous \(\Upsilon - B_s\) mixing. We predict \(C_{LL}^{\tau\tau} \approx -C_{LL}^{\mu\mu}\) which satisfies the upper limit of the branching fractions of \(B^+ \to K^+\tau^+\tau^-\) and \(B^0_s \to \tau^+\tau^-\) decays. Furthermore, we discuss the potential constraints come from several lepton-flavour-violation decays \(B^0_s \to \tau^\pm\mu^\mp\) and \(B^+ \to K^+\tau^\pm\mu^\mp\), and find that the experimental upper limit of these processes does not effectively exclude the parameter space needed to explain \(b \to s\mu^+\mu^-\) anomaly.

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References

[1] S. L. Glashow, J. Iliopoulos and L. Maiani, *Weak Interactions with Lepton-Hadron Symmetry*, Phys. Rev. D2 (1970) 1285.

[2] T. Hurth and M. Nakao, *Radiative and Electroweak Penguin Decays of B Mesons*, Ann. Rev. Nucl. Part. Sci. 60 (2010) 645 [1005.1224].
[3] T. Blake, G. Lanfranchi and D. M. Straub, *Rare Decays as Tests of the Standard Model*, Prog. Part. Nucl. Phys. **92** (2017) 50 [1606.00916].

[4] LHCb collaboration, *Search for lepton-universality violation in $B^+ \to K^+ \ell^+\ell^-$ decays*, Phys. Rev. Lett. **122** (2019) 191801 [1903.09252].

[5] LHCb collaboration, *Test of lepton universality using $B^+ \to K^+ \ell^+\ell^-$ decays*, Phys. Rev. Lett. **113** (2014) 151601 [1406.6482].

[6] M. Bordone, G. Isidori and A. Pattori, *On the Standard Model predictions for $R_K$ and $R_{K^*}$*, Eur. Phys. J. **C76** (2016) 440 [1605.07633].

[7] LHCb collaboration, *Test of lepton universality with $B^0 \to K^* \ell^+\ell^-$ decays*, JHEP **08** (2017) 055 [1705.05802].

[8] BELLE collaboration, *Test of lepton flavor universality in $B \to K\ell^+\ell^-$ decays*, arXiv:1908.01848.

[9] BELLE collaboration, *Test of lepton flavor universality in $B \to K^*\ell^+\ell^-$ decays at Belle*, arXiv:1904.02440.

[10] S. Descotes-Genon, J. Matias, M. Ramon and J. Virto, *Implications from clean observables for the binned analysis of $B \to K^{*}\mu^+\mu^-$ at large recoil*, JHEP **01** (2013) 048 [1207.2753].

[11] S. Descotes-Genon, T. Hurth, J. Matias and J. Virto, *Optimizing the basis of $B \to K^{*}ll$ observables in the full kinematic range*, JHEP **05** (2013) 137 [1303.5794].

[12] Q.-Y. Hu, X.-Q. Li and Y.-D. Yang, $B^0 \to K^{*0}\mu^+\mu^-$ decay in the Aligned Two-Higgs-Doublet Model, Eur. Phys. J. **C77** (2017) 190 [1612.08867].

[13] LHCb collaboration, *Angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay using 3 fb$^{-1}$ of integrated luminosity*, JHEP **02** (2016) 104 [1512.04442].

[14] LHCb collaboration, *Measurement of Form-Factor-Independent Observables in the Decay $B^0 \to K^{*0}\mu^+\mu^-$, Phys. Rev. Lett. **111** (2013) 191801 [1308.1707].

[15] CMS collaboration, *Angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ from $pp$ collisions at $\sqrt{s} = 8$ TeV*, Phys. Lett. **B753** (2016) 424 [1507.08126].
ATLAS collaboration, *Angular analysis of \( B^0_d \rightarrow K^* \mu^+ \mu^- \) decays in pp collisions at \( \sqrt{s} = 8 \) TeV with the ATLAS detector*, *JHEP* **10** (2018) 047 [1805.04000].

BELLE collaboration, *Lepton-Flavor-Dependent Angular Analysis of \( B \rightarrow K^* \ell^+ \ell^- \)*, *Phys. Rev. Lett.* **118** (2017) 111801 [1612.05014].

BELLE collaboration, *Angular analysis of \( B^0 \rightarrow K^*(892)^0 \ell^+ \ell^- \)*, in *Proceedings, LHCSki 2016 - A First Discussion of 13 TeV Results: Obergurgl, Austria, April 10-15, 2016*, 2016, 1604.04042.

M. Algueró, B. Capdevila, A. Crivellin, S. Descotes-Genon, P. Masjuan, J. Matias et al., *Emerging patterns of New Physics with and without Lepton Flavour Universal contributions*, *Eur. Phys. J.* **C79** (2019) 714 [1903.09578].

LHCb collaboration, *Angular analysis and differential branching fraction of the decay \( B^0_s \rightarrow \phi \mu^+ \mu^- \)*, *JHEP* **09** (2015) 179 [1506.08777].

LHCb collaboration, *Differential branching fraction and angular analysis of the decay \( B^0_s \rightarrow \phi \mu^+ \mu^- \)*, *JHEP* **07** (2013) 084 [1305.2168].

J. Aebischer, W. Altmannshofer, D. Guadagnoli, M. Reboud, P. Stangl and D. M. Straub, *B-decay discrepancies after Moriond 2019*, 1903.10434.

A. K. Alok, A. Dighe, S. Gangal and D. Kumar, *Continuing search for new physics in \( b \rightarrow s \mu \mu \) decays: two operators at a time*, *JHEP* **06** (2019) 089 [1903.09617].

M. Ciuchini, A. M. Coutinho, M. Fedele, E. Franco, A. Paul, L. Silvestrini et al., *New Physics in \( b \rightarrow s \ell^+ \ell^- \) confronts new data on Lepton Universality*, *Eur. Phys. J.* **C79** (2019) 719 [1903.09632].

A. Arbey, T. Hurth, F. Mahmoudi, D. M. Santos and S. Neshatpour, *Update on the \( b \rightarrow s \) anomalies*, *Phys. Rev.* **D100** (2019) 015045 [1904.08399].

B. Capdevila, U. Laa and G. Valencia, *Fitting in or odd one out? Pulls vs residual responses in \( b \rightarrow s \ell^+ \ell^- \)*, 1908.03338.

S. Bhattacharyya, A. Biswas, S. Nandi and S. K. Patra, *Exhaustive Model Selection in \( b \rightarrow s \ell \ell \) Decays: Pitting Cross-Validation against AICc*, 1908.04835.
[28] LHCb collaboration, Measurement of the $B^0_s \rightarrow \mu^+\mu^-$ branching fraction and search for $B^0 \rightarrow \mu^+\mu^-$ decays at the LHCb experiment, Phys. Rev. Lett. 111 (2013) 101805 [1307.5024].

[29] CMS collaboration, Measurement of the $B^0_s \rightarrow \mu^+\mu^-$ Branching Fraction and Search for $B^0 \rightarrow \mu^+\mu^-$ with the CMS Experiment, Phys. Rev. Lett. 111 (2013) 101804 [1307.5025].

[30] CMS, LHCb collaboration, Observation of the rare $B^0_s \rightarrow \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data, Nature 522 (2015) 68 [1411.4413].

[31] ATLAS collaboration, Study of the rare decays of $B^0_s$ and $B^0$ into muon pairs from data collected during the LHC Run 1 with the ATLAS detector, Eur. Phys. J. C76 (2016) 513 [1604.04263].

[32] LHCb collaboration, Measurement of the $B^0_s \rightarrow \mu^+\mu^-$ branching fraction and effective lifetime and search for $B^0 \rightarrow \mu^+\mu^-$ decays, Phys. Rev. Lett. 118 (2017) 191801 [1703.05747].

[33] ATLAS collaboration, Study of the rare decays of $B^0_s$ and $B^0$ mesons into muon pairs using data collected during 2015 and 2016 with the ATLAS detector, JHEP 04 (2019) 098 [1812.03017].

[34] Particle Data Group collaboration, Review of Particle Physics, Phys. Rev. D98 (2018) 030001.

[35] R. Barbier et al., R-parity violating supersymmetry, Phys. Rept. 420 (2005) 1 [hep-ph/0406039].

[36] S. Biswas, D. Chowdhury, S. Han and S. J. Lee, Explaining the lepton non-universality at the LHCb and CMS within a unified framework, JHEP 02 (2015) 142 [1409.0882].

[37] N. G. Deshpande and X.-G. He, Consequences of R-parity violating interactions for anomalies in $\bar{B} \rightarrow D^{(*)}\tau\bar{\nu}$ and $b \rightarrow s\mu^+\mu^-$, Eur. Phys. J. C77 (2017) 134 [1608.04817].

[38] D. Das, C. Hati, G. Kumar and N. Mahajan, Scrutinizing R-parity violating interactions in light of $R_{K^{(*)}}$ data, Phys. Rev. D96 (2017) 095033 [1705.09188].
[39] K. Earl and T. Grégoire, *Contributions to $b \rightarrow s\ell\ell$ Anomalies from R-Parity Violating Interactions*, JHEP 08 (2018) 201 [1806.01343].

[40] S. Trifinopoulos, *Revisiting R-parity violating interactions as an explanation of the B-physics anomalies*, Eur. Phys. J. C78 (2018) 803 [1807.01638].

[41] S. Trifinopoulos, *B-physics anomalies: The bridge between R-parity violating Supersymmetry and flavoured Dark Matter*, 1904.12940.

[42] N. G. Deshpande and A. Menon, *Hints of R-parity violation in B decays into $\tau\nu$*, JHEP 01 (2013) 025 [1208.4134].

[43] J. Zhu, H.-M. Gan, R.-M. Wang, Y.-Y. Fan, Q. Chang and Y.-G. Xu, *Probing the R-parity violating supersymmetric effects in the exclusive $b \rightarrow c\ell^-\bar{\nu}_\ell$ decays*, Phys. Rev. D93 (2016) 094023 [1602.06491].

[44] W. Altmannshofer, P. S. Bhupal Dev and A. Soni, *$R_{D(\star)}$ anomaly: A possible hint for natural supersymmetry with R-parity violation*, Phys. Rev. D96 (2017) 095010 [1704.06659].

[45] Q.-Y. Hu, X.-Q. Li, Y. Muramatsu and Y.-D. Yang, *R-parity violating solutions to the $R_{D(\star)}$ anomaly and their GUT-scale unifications*, Phys. Rev. D99 (2019) 015008 [1808.01419].

[46] Q.-Y. Hu, X.-Q. Li and Y.-D. Yang, *$b \rightarrow c\tau\nu$ transitions in the standard model effective field theory*, Eur. Phys. J. C79 (2019) 264 [1810.04939].

[47] R. Mertig, M. Bohm and A. Denner, *FEYN CALC: Computer algebraic calculation of Feynman amplitudes*, Comput. Phys. Commun. 64 (1991) 345.

[48] V. Shtabovenko, R. Mertig and F. Orellana, *New Developments in FeynCalc 9.0*, Comput. Phys. Commun. 207 (2016) 432 [1601.01167].

[49] H. H. Patel, *Package-X: A Mathematica package for the analytic calculation of one-loop integrals*, Comput. Phys. Commun. 197 (2015) 276 [1503.01469].

[50] H. H. Patel, *Package-X 2.0: A Mathematica package for the analytic calculation of one-loop integrals*, Comput. Phys. Commun. 218 (2017) 66 [1612.00009].
[51] A. de Gouvea, S. Lola and K. Tobe, *Lepton flavor violation in supersymmetric models with trilinear R-parity violation*, Phys. Rev. D63 (2001) 035004 [hep-ph/0008085].

[52] M. Bordone, C. Cornella, J. Fuentes-Martín and G. Isidori, *Low-energy signatures of the PS$^3$ model: from B-physics anomalies to LFV*, JHEP 10 (2018) 148 [1805.09328].

[53] BaBar collaboration, *Search for $B^+ \rightarrow K^+\tau^+\tau^-$ at the BaBar experiment*, Phys. Rev. Lett. 118 (2017) 031802 [1605.09637].

[54] LHCb collaboration, *Search for the decays $B_s^0 \rightarrow \tau^+\tau^-$ and $B^0 \rightarrow \tau^+\tau^-$*, Phys. Rev. Lett. 118 (2017) 251802 [1703.02508].

[55] LHCb collaboration, *Search for the lepton-flavour-violating decays $B_s^0 \rightarrow \tau^\pm\mu^\mp$ and $B^0 \rightarrow \tau^\pm\mu^\mp$, Phys. Rev. Lett. 123 (2019) 211801 [1905.06614].

[56] R. Barbieri and R. Ziegler, *Quark masses, CKM angles and Lepton Flavour Universality violation*, JHEP 07 (2019) 023 [1904.04121].