Discriminating new physics scenarios in $b \to s \mu^+ \mu^-$ via transverse polarization asymmetry of $K^*$ in $B \to K^* \mu^+ \mu^-$ decay

Ashutosh Kumar Alok,$^1$ Suman Kumbhakar,$^2$† and S. Uma Sankar$^2$‡

$^1$Indian Institute of Technology Jodhpur, Jodhpur 342037, India
$^2$Indian Institute of Technology Bombay, Mumbai 400076, India

A global fit to current $b \to s l^+ l^-$ data suggest several new physics solutions. Considering only one operator at a time and new physics in the muon sector, it has been shown that the new physics scenarios (I) $C^{\text{NP}}_9 < 0$, (II) $C^{\text{NP}}_9 = -C^{\text{NP}}_{10}$, (III) $C^{\text{NP}}_9 = -C^{\prime \text{NP}}_9$ can account for all data in this sector. In order to discriminate between these scenarios one needs to have a handle on additional observables in $b \to s \mu^+ \mu^-$ sector. In this work we study transverse polarization asymmetry of $K^*$ polarization in $B \to K^* \mu^+ \mu^-$ decay, $A_T$, to explore such a possibility. We show that $A_T$ is a good discriminant of all the three scenarios. The measurement of this asymmetry with a percent accuracy can confirm which new physics scenario is the true solution, at better than $3 \sigma$ C.L.

I. INTRODUCTION

The quark level transition $b \to s l^+ l^-$ ($l = e, \mu$) has immense potential to probe physics beyond Standard Model (SM). This decay is forbidden at the tree level within the SM and hence is highly suppressed. Further, the same quark level transition induces several decay modes such as $B \to X_s l^+ l^-$, $B \to (K, K^*) l^+ l^-$, $B_s \to \phi l^+ l^-$, $B_s \to l^+ l^-$, thus providing a plethora of observables to probe new physics (NP). Due of these reasons, the $b \to s l^+ l^-$ sector plays a pivotal role in hunting physics beyond SM.

The importance of this sector has increased considerably over last few years due to the fact that several deviations from the SM have been observed in decay modes induced by $b \to s l^+ l^-$. These include measurements of the lepton flavor universality (LFU) violating ratios $R_K$ and $R_{K^*}$\cite{1,2}. The measured values of these observables disagree with their SM predictions of $\approx 1$ \cite{3,4} at the level of $\sim 2.5 \sigma$. This tension with the SM can be accounted by assuming new physics in $b \to s e^+ e^-$ and/or $b \to s \mu^+ \mu^-$. Further, there are a few anomalous measurements which can be

\footnotesize

$^\ast$Electronic address: akalok@iitj.ac.in
$^\dagger$Electronic address: suman@phy.iitb.ac.in
$^\ddagger$Electronic address: uma@phy.iitb.ac.in
elucidated by considering new physics only in $b \to s\mu^+\mu^-$ transition. These include measurements of branching ratio of $B_s \to \phi \mu^+\mu^-$ [5] and angular observable $P_5'$ in $B \to K^* \mu^+\mu^-$ decay [6,7]. The measured values disagree with the SM expectations at the $\sim 4\sigma$ level [8]. Hence one can account for all of these measurements simply by assuming new physics only in the muon sector.

This pile-up of anomalies in a coherent fashion can be considered as signatures of new physics which can be quantified in a model independent way, within the framework of effective field theory, by introducing new operators to the SM effective Hamiltonian. Model independent analysis serves as a guideline for constructing specific new physics models which can account for these anomalies. In order to identify the Lorentz structure of possible new physics, several groups have performed global fits to all available data in the $b \to s\mu^+\mu^-$ sector [9–16]. Most of these analyses suggested new physics solutions in the form of vector and axial-vector operators. However there is no unique solution. In the simplest approach, where only one new physics Wilson coefficient or two related new physics Wilson coefficients are considered, the following scenarios provide a good fit to all $b \to s\mu^+\mu^-$ data:

- **Scenario I:** This corresponds to contribution from the new physics operator $O_9 = (\bar{s}\gamma^\mu P_L b) (\bar{\mu}\gamma^\mu\mu)$ alone with large negative value of the corresponding Wilson coefficient $C_{NP}^{O_9}$.

- **Scenario II:** A combination of operators $O_9$ and $O_{10} = (\bar{s}\gamma^\mu P_L b) (\bar{\mu}\gamma^\mu\gamma^5\mu)$ with $C_{NP}^{O_9} = -C_{NP}^{O_{10}}$ can also account for all $b \to s\mu^+\mu^-$ data. Here $C_{NP}^{O_{10}}$ is the Wilson coefficient corresponding to the operator $O_{10}$.

- **Scenario III:** A combination of $O_{9}' = (\bar{s}\gamma^\mu P_R b) (\bar{\mu}\gamma^\mu\mu)$ (the chirality flipped counterpart of $O_9$) and $O_9$ with $C_{NP}^{O_9} = -C_{NP}^{O_9'}$ also provide a good fit to the data. Here $C_{NP}^{O_9'}$ is the Wilson coefficient corresponding to the operator $O_{9}'$.

Therefore one of the key open problems is to uniquely identify the Lorentz structure of new physics in $b \to s\mu^+\mu^-$ decay. Therefore one needs additional observables to discriminate between various possible solutions. This can be achieved by analyzing new decay modes in $b \to s\mu^+\mu^-$ sector or constructing new observables in the existing decay modes [17–21]. In this work we explore this direction by analyzing transverse polarization asymmetry of $K^*$ in $B \to K^* \mu^+\mu^-$ decay.

The paper is organized as follows. In sec. II, we define the transverse asymmetry $A_T$ along with the corresponding amplitudes. In sec. III, we obtain predictions for $A_T$ in the SM as well as for
the allowed new physics scenarios. Further, we discuss the capability $A_T$ to discriminate between the new physics solutions. In sec. IV, we present our conclusions.

II. TRANSVERSE POLARIZATION ASYMMETRY OF $K^*$ MESON

In the SM, the effective Hamiltonian for $b \to s \mu^+ \mu^-$ transition is

$$\mathcal{H}_{SM} = -\frac{4G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} \left[ \sum_{i=1}^{6} C_i(\mu) O_i(\mu) + C_7 \frac{e}{16\pi^2} [\bar{s}\gamma_\mu(m_s p_L + m_b p_R) b] F^{\mu\nu} \right. + \left. C_9 \frac{\alpha e m}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\mu}_\gamma \mu) + C_{10} \frac{\alpha e m}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\mu}_\gamma \gamma_5 \mu) \right],$$

(1)

where $G_F$ is the Fermi constant, $V_{ts}$ and $V_{tb}$ are the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements and $P_{L,R} = (1 \mp \gamma^5)/2$ are the projection operators. The effect of the operators $O_i$, $i = 1 - 6, 8$ can be embedded in the redefined effective Wilson coefficients as $C_7(\mu) \to C^\text{eff}_7(\mu, q^2)$ and $C_9(\mu) \to C^\text{eff}_9(\mu, q^2)$.

Using the SM Hamiltonian, the SM amplitude for the $B \to K^* \mu^+ \mu^-$ decay can be written as

$$\mathcal{M} = \frac{G_F \alpha}{\sqrt{2}\pi} V_{ts}^* V_{tb} \left[ C_{9} \langle K^* | [\bar{s} \gamma_\mu P_L b] | B(\mu) \rangle \langle \bar{\mu}_\gamma \mu \rangle + C_{10} \langle K^* | [\bar{s} \gamma_\mu P_L b] | B(\mu) \rangle \langle \bar{\mu}_\gamma \gamma_5 \mu \rangle \right. - \left. \frac{2m_b}{q^2} C^\text{eff}_7 \langle K^* | [\bar{s} \gamma_\mu P_L b] | B(\mu) \rangle \langle \bar{\mu}_\gamma \mu \rangle \right],$$

(2)

where $q$ is the four-momentum of the final state lepton pair. The hadronic matrix elements in Eq. 2 can be parametrized in terms of different form factors. The definitions of these form factors are given by [22]

$$\langle K^*(p_{K^*}) | [\bar{s} \gamma_\mu P_{L,R} b] | B(p_B) \rangle = i\epsilon_{\mu\alpha\beta} \epsilon^{\nu\lambda} p_B^\alpha q_\beta \frac{V(q^2)}{m_B + m_{K^*}} \pm \frac{1}{2} \left[ \epsilon^{*}_{\mu}(m_B + m_{K^*}) A_1(q^2) - (\epsilon^{*}\cdot q)(2p_B - q)_\mu \frac{A_2(q^2)}{m_B + m_{K^*}} - \frac{2m_{K^*}}{q^2} (\epsilon^{*}\cdot q) \times \right] \left\{ A_3(q^2) - A_0(q^2) \right\} q_\mu,$$

(3)

where

$$A_3(q^2) = \frac{m_B + m_{K^*}}{2m_{K^*}} A_1(q^2) - \frac{m_B - m_{K^*}}{2m_{K^*}} A_2(q^2)$$

(4)

and

$$\langle K^*(p_{K^*}) | [\bar{s} i \sigma_{\mu\nu} q^\nu P_{L,R} b] | B(p_B) \rangle = -i\epsilon_{\mu\alpha\beta} \epsilon^{*\nu} p_B^\alpha q_\beta T_1(q^2) \pm \frac{1}{2} \left\{ \epsilon^{*}_{\mu}(m_B^2 - m_{K^*}^2) \right. - (\epsilon^{*}\cdot q)(2p_B - q)_\mu \left. \frac{T_2(q^2)}{m_B^2 - m_{K^*}^2} \times \right] \left\{ q_\mu - \frac{q^2}{m_B^2 - m_{K^*}^2}(2p_B - q)_\mu \right\} T_3(q^2).$$

(5)
The vector, axial-vector and tensor form factors of $B \to K^* \mu^+ \mu^-$ decay are $V(q^2)$, $A_{1,2}(q^2)$ and $T_{1,2,3}(q^2)$, respectively [23, 24]. These form factors can be calculated using different techniques. We use the numerical values of these form factors from Ref. [24] which are calculated by doing a combined fit to lattice QCD (LQCD) and light cone sum rule (LCSR) approaches.

The new physics solutions which can explain all the $b \to s \mu^+ \mu^-$ data are only in the form of vector and axial-vector operators. Hence we consider the addition of only these operators to the SM Hamiltonian for both left and right chiral quark currents. Therefore, the new physics effective Hamiltonian for $b \to s \mu^+ \mu^-$ process takes the form

$$\mathcal{H}_{NP} = \frac{-\alpha_{em} G_F}{\sqrt{2\pi}} V_{ts}^* V_{tb} \left[ C_{9,10}^{NP} (\bar{s} \gamma^\mu P_L b)(\bar{\mu} \gamma_\mu \gamma_5 \mu) + C_{9,10}^{NP} (\bar{s} \gamma^\mu P_R b)(\bar{\mu} \gamma_\mu \gamma_5 \mu) \right],$$

where $C_{9,10}^{NP}$ are the new physics Wilson coefficients. These Wilson coefficients have been determined by a global fit to the all $b \to s \mu^+ \mu^-$ data by different groups. A common conclusion of these global fits is that there are three new physics solutions to $b \to s \mu^+ \mu^-$ anomalies. These scenarios along with the fit values of Wilson coefficients are listed in Table I.

We investigate the polarizations of $K^*$ meson of $B \to K^* \mu^+ \mu^-$ decay to distinguish between the three allowed new physics solutions. The vector $K^*$ meson has three polarization components:

- one longitudinal polarization $\lambda_{K^*} = 0$
- two transverse polarizations $\lambda_{K^*} = +1, -1$.

The longitudinal polarization fraction can be a very good discriminant only for the tensor and scalar new physics interactions [25]. The transverse amplitudes of $B \to K^* \mu^+ \mu^-$ can be a very effective tool to probe new physics [26–28]. In particular, these are sensitive to the right handed quark currents [26]. Therefore, we study the transverse polarization components to explore whether it can serve as an effective discriminating tool for the existing new physics solutions in the $b \to s \mu^+ \mu^-$ sector. The sum of these three polarization fractions should give unity, $F_L + F_T^+ + F_T^- = 1$. Hence only two of them should be independent. Here we construct an asymmetry between the two transverse polarizations of $K^*$ meson which can be defined as

$$A_T = F_T^+ - F_T^- = \frac{|H_+|^2 - |H_-|^2}{|H_0|^2 + |H_+|^2 + |H_-|^2},$$

where the $H_{0,+,-}$ are the helicity amplitudes for the three helicity components of $K^*$ meson. Instead of using the helicity amplitudes, a very popular notation in literature is the transversity amplitudes.
These two kind of amplitudes are related by

\[ A_{\perp,\parallel} = \left( H_+ \mp H_- \right) / \sqrt{2}, \quad A_0 = H_0. \] (8)

Now we can express the transverse polarization asymmetry in terms of the transversity amplitudes as

\[ A_T = \frac{2 \text{Re} \left( A_{\parallel} A_{\perp}^* \right)}{|A_{\parallel}|^2 + |A_{\perp}|^2 + |A_0|^2}, \] (9)

where

\[ A_i A_j^* = A_{iL} A_{jL}^* + A_{iR} A_{jR}^*, \quad (i, j = 0, \perp, \parallel). \] (10)

The expressions for these transversity amplitudes are given by [23]

\[ A_{\perp,\parallel} = N \sqrt{2} \lambda^{1/2} \left[ \left( C_{9}^{\text{eff}} + C_{9}^{\text{eff}} \right) \mp \left( C_{9}^{\text{eff}} + C_{9}^{\text{eff}} \right) \right] \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2} (C_{7}^{\text{eff}} + C_{7}^{\text{eff}}) T_1(q^2), \]

\[ A_{\parallel,\parallel} = -N \sqrt{2}(m_B^2 - m_{K^*}^2) \left[ \left( C_{9}^{\text{eff}} - C_{9}^{\text{eff}} \right) \mp \left( C_{9}^{\text{eff}} - C_{9}^{\text{eff}} \right) \right] \frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2} (C_{7}^{\text{eff}} - C_{7}^{\text{eff}}) T_2(q^2), \]

\[ A_{0,\parallel} = \frac{-N}{2m_{K^*} \sqrt{q^2}} \left[ \left( C_{9}^{\text{eff}} - C_{9}^{\text{eff}} \right) \mp \left( C_{9}^{\text{eff}} - C_{9}^{\text{eff}} \right) \right] \left\{ \left( m_B^2 - m_{K^*}^2 - q^2 \right) (m_B + m_{K^*}) A_1(q^2) \right. \]

\[ -\lambda \frac{A_2(q^2)}{m_B + m_{K^*}} + 2m_b (C_{7}^{\text{eff}} - C_{7}^{\text{eff}}) \left\{ \left( m_B^2 + 3m_{K^*}^2 - q^2 \right) T_2(q^2) - \frac{\lambda}{m_B^2 - m_{K^*}^2} T_3(q^2) \right\}, \] (11)

where

\[ N = V_{tb} V_{ts} \left[ \frac{G_F^2 \alpha_s^2 q^2 \lambda^{1/2} \beta_\mu}{2^{10} 3 \pi^3 m_B^3} \right]^{1/2}, \] (12)

with \( \lambda = m_2^4 + m^4 + q^4 - 2(m_B^2 m_{K^*}^2 + m_{K^*}^2 q^2 + m_B^2 q^2) \) and \( \beta_\mu = \sqrt{1 - 4m_\mu^2/q^2} \). In the next section we obtain predictions for \( A_T \) within the SM as well as for various new physics scenarios.

**III. RESULTS AND DISCUSSIONS**

The plots of \( q^2 \) distribution of the transverse polarization asymmetry of \( K^* \) in \( B \to K^* \mu^+ \mu^- \) decay, \( A_T(q^2) \), are shown in Fig. 1 for the SM as well as for the three allowed new physics solutions listed in Table II. These predictions are calculated for the low-\( q^2 \) region which corresponds to \( 1 \text{GeV}^2 \leq q^2 \leq 6 \text{GeV}^2 \). Within the SM, \( A_T(q^2) \) is negative in the entire low-\( q^2 \) region. Further, the peak value of \( A_T(q^2) \) in the SM is \(-0.13\) which is at \( q^2 \approx 2.2 \text{GeV}^2 \).

The new physics scenarios I and III make the values of \( A_T(q^2) \) even lower than those of SM and scenario I in the entire low-\( q^2 \) region. The change is largest for the new physics scenario III.
FIG. 1: The SM and NP predictions of the transverse asymmetry $A_T(q^2)$ as a functions of $q^2$ in GeV$^2$. The color code for each case is shown in the figure. The band in each curve, representing 1σ range, is mainly due to the uncertainties in various hadronic form factors and is obtained by adding these errors in quadrature.

The peak value of $A_T(q^2)$ for scenarios I and III are $-0.19$ and $-0.22$, respectively. Thus we see that scenarios I and III can provide large deviations in $A_T(q^2)$, the deviation being largest for the scenario III. For scenario II, $A_T(q^2)$ prediction is similar to that of the SM for $q^2 \geq 3$ GeV$^2$. For $q^2 \leq 3$ GeV$^2$, $A_T(q^2)$ is suppressed. However the suppression is less as compared to that of scenarios I and III. An accurate measurement of $q^2$ distribution of the transverse polarization asymmetry of $K^\ast$ in $B \to K^\ast \mu^+ \mu^-$ decay can therefore discriminate between all the three allowed new physics solutions in the $b \to s \mu^+ \mu^-$ sector.

| NP scenarios | Best fit value | pull | $\langle |A_T| \rangle$ in % |
|--------------|----------------|------|--------------------------|
| SM           | 0              | 0    | 20.7 ± 0.48              |
| (I) $C_9^{NP}$ | -1.09 ± 0.18  | 6.24 | 24.9 ± 0.57              |
| (II) $C_9^{NP} = -C_{10}^{NP}$ | -0.53 ± 0.09  | 6.40 | 21.3 ± 0.50              |
| (III) $C_9^{NP} = -C_{9'}^{NP}$ | -1.12 ± 0.17  | 6.43 | 28.4 ± 0.66              |

TABLE I: The predictions of $A_T$, averaged over the low $q^2$ range for the SM and for the three new physics solutions. The best fit values of the Wilson coefficients and the corresponding pull values are taken from Ref. [10], where pull value $= \sqrt{\chi^2_{SM} - \chi^2_{NP}}$.

This is also evident from the integrated values of $A_T(q^2)$, $A_T$, within $q^2$ range of $1–6$ GeV$^2$ which are given in Table I. The uncertainty in $\langle |A_T| \rangle$ is calculated taking into account the uncertainties
in both the new physics Wilson coefficients and the form factors. From this table it can be seen that the prediction of $\langle |A_T| \rangle$ for each new physics solution is substantially different from that of the other two NP solutions. Hence, an accurate measurement of this transverse asymmetry, at the level of a percent, can uniquely identify the new physics solution at better than 3σ.

IV. CONCLUSIONS

The current anomalies in the $b \to s \mu^+ \mu^-$ sector can be accommodated by assuming new physics in the form of vector and axial-vector operators. However there are three different allowed solutions: (I) $C_{9}^{\text{NP}} < 0$, (II) $C_{9}^{\text{NP}} = -C_{10}^{\text{NP}}$, (III) $C_{9}^{\text{NP}} = -C_{9}^{\text{NP}}'$. In this work we consider asymmetry between two transverse components (+1 and −1) of $K^*$ polarization in $B \to K^* \mu^+ \mu^-$ decay to discriminate between these new physics solutions. We show that a measurement of this asymmetry to 1% level can uniquely identify the new physics solution.

[1] R. Aaij et al. [LHCb Collaboration], “Test of lepton universality with $B^0 \to K^{*0}\ell^+\ell^-$ decays”, JHEP 1708, 055 (2017) [arXiv:1705.05802 [hep-ex]].
[2] R. Aaij et al. [LHCb Collaboration], “Search for lepton-universality violation in $B^+ \to K^+\ell^+\ell^-$ decays”, Phys. Rev. Lett. 122, no. 19, 191801 (2019) [arXiv:1903.09252 [hep-ex]].
[3] G. Hiller and F. Kruger, “More model-independent analysis of $b \to s$ processes”, Phys. Rev. D 69, 074020 (2004) [hep-ph/0310219].
[4] M. Bordone, G. Isidori and A. Pattori, “On the Standard Model predictions for $R_K$ and $R_{K^*}$,” Eur. Phys. J. C 76, no. 8, 440 (2016) [arXiv:1605.07633 [hep-ph]].
[5] R. Aaij et al. [LHCb Collaboration], “Angular analysis and differential branching fraction of the decay $B_s^0 \to \phi\mu^+\mu^-$”, JHEP 1509, 179 (2015) [arXiv:1506.08777 [hep-ex]].
[6] R. Aaij et al. [LHCb Collaboration], “Measurement of Form-Factor-Independent Observables in the Decay $B^0 \to K^{*0}\mu^+\mu^-$”, Phys. Rev. Lett. 111, 191801 (2013) [arXiv:1308.1707 [hep-ex]].
[7] R. Aaij et al. [LHCb Collaboration], “Angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay using 3 fb$^{-1}$ of integrated luminosity”, JHEP 1602, 104 (2016) [arXiv:1512.04442 [hep-ex]].
[8] 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 1305, 137 (2013) [arXiv:1303.5794 [hep-ph]].
[9] M. Alguer, B. Capdevila, A. Crivellin, S. Descotes-Genon, P. Masjuan, J. Matias and J. Virto, “Emerging patterns of New Physics with and without Lepton Flavour Universal contributions,” Eur. Phys. J. C 79 (2019) no.8, 714 [arXiv:1903.09578 [hep-ph]].
[10] 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 1906, 089 (2019) [arXiv:1903.09617 [hep-ph]].

[11] M. Ciuchini, A. M. Coutinho, M. Fedele, E. Franco, A. Paul, L. Silvestrini and M. Valli, “New Physics in $b \rightarrow s\ell^+\ell^-$ confronts new data on Lepton Universality,” Eur. Phys. J. C 79 (2019) no.8, 719 [arXiv:1903.09632 [hep-ph]].

[12] G. D’Amico, M. Nardecchia, P. Panci, F. Sannino, A. Strumia, R. Torre and A. Urbano, “Flavour anomalies after the $R_{K^*}$ measurement”, JHEP 1709, 010 (2017) [arXiv:1704.05438 [hep-ph]].

[13] J. Aebischer, W. Altmannshofer, D. Guadagnoli, M. Reboud, P. Stangl and D. M. Straub, “B-decay discrepancies after Moriond 2019”, arXiv:1903.10434 [hep-ph].

[14] K. Kowalska, D. Kumar and E. M. Sessolo, “Implications for new physics in $b \rightarrow s\mu\mu$ transitions after recent measurements by Belle and LHCb”, Eur. Phys. J. C 79, no. 10, 840 (2019) [arXiv:1903.10932 [hep-ph]].

[15] A. Arbey, T. Hurth, F. Mahmoudi, D. M. Santos and S. Neshatpour, “Update on the $b \rightarrow s$ anomalies”, Phys. Rev. D 100, no. 1, 015045 (2019) [arXiv:1904.08399 [hep-ph]].

[16] B. Grinstein and J. Martin Camalich, “Weak Decays of Excited B Mesons”, Phys. Rev. Lett. 116, no. 14, 141801 (2016) [arXiv:1509.05049 [hep-ph]].

[17] D. Kumar, J. Saini, S. Gangal and S. B. Das, “Probing new physics through $B_\ast^\pm \rightarrow \mu^\mp\mu^-\nu$ decay”, Phys. Rev. D 97, no. 3, 035007 (2018) [arXiv:1711.01989 [hep-ph]].

[18] S. Kumbhakar and J. Saini, “New physics effects in purely leptonic $B_\ast^\pm$ decays,” Eur. Phys. J. C 79, no. 5, 394 (2019) [arXiv:1807.04055 [hep-ph]].

[19] M. Wirbel, B. Stech and M. Bauer, “Exclusive Semileptonic Decays of Heavy Mesons,” Z. Phys. C 29 (1985) 637.

[20] W. Altmannshofer, P. Ball, A. Buarucha, A. J. Buras, D. M. Straub and M. Wick, “Symmetries and Asymmetries of $B \rightarrow K^*\mu^\pm\mu^-$ Decays in the Standard Model and Beyond”, JHEP 0901, 019 (2009) [arXiv:0811.1214 [hep-ph]].

[21] A. Bharucha, D. M. Straub and R. Zwicky, “$B^0 \rightarrow \ell^+\ell^-\gamma$ as a test of lepton flavor universality,” JHEP 1711, 184 (2017) [arXiv:1708.02649 [hep-ph]].

[22] G. Abbas, A. K. Alok and S. Gangal, “New physics effects in radiative leptonic $B_\ast$ decay,” arXiv:1805.02265 [hep-ph].

[23] M. Altarelli, M. Bauer, A. Buarucha, A. J. Buras, D. M. Straub and M. Wick, “Symmetries and Asymmetries of $B \rightarrow K^*\mu^+\mu^-$ Decays in the Standard Model and Beyond”, JHEP 0901, 019 (2009) [arXiv:0811.1214 [hep-ph]].

[24] A. Bharucha, D. M. Straub and R. Zwicky, “$B \rightarrow V\ell^+\ell^-$ in the Standard Model from light-cone sum rules”, JHEP 1608, 098 (2016) [arXiv:1503.05534 [hep-ph]].

[25] A. K. Alok, D. Kumar, S. Kumbhakar and S. U. Sankar, “$D^*$ polarization as a probe to discriminate new physics in $\bar{B} \rightarrow D^*\tau\nu$,” Phys. Rev. D 95 (2017) no.11, 115038 [arXiv:1606.03164 [hep-ph]].

[26] D. Melikhov, N. Nikitin and S. Simula, “Probing right-handed currents in $B \rightarrow K^*\ell^+\ell^-$ transitions,” Phys. Lett. B 442, 381 (1998) [hep-ph/980746].
[27] F. Kruger and J. Matias, “Probing new physics via the transverse amplitudes of $B^0 \rightarrow K^{*0}(\rightarrow K^-\pi^+)l^+l^-$ at large recoil,” Phys. Rev. D 71, 094009 (2005) [hep-ph/0502060].

[28] D. Becirevic and E. Schneider, “On transverse asymmetries in $B \rightarrow K^*l^+l^-$,” Nucl. Phys. B 854, 321 (2012) [arXiv:1106.3283 [hep-ph]].