PROCEEDINGS OF SCIENCE

Probing new physics in $\tau - \mu$ sector through the LFU ratios $R^{\tau\mu}$

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We investigate the potential of the ratios $R^{\tau\mu}$ in $B \to K\ell\ell$ and $B \to K^*\ell\ell$ decays ($\ell = \mu, \tau$) to probe new physics in the $\tau - \mu$ sector. We find that this ratio deviates from their SM prediction even for universal couplings. This implies that the bare deviation of these ratios from their SM predictions cannot confirm the nature of possible new physics. For this, we need to compare the allowed range of $R^{\tau\mu}$ for a class of solutions with only universal couplings to leptons and solutions having both universal and non-universal components. By comparing the predictions of $R_K^{\tau\mu}$ and $R_{K^*}^{\tau\mu}$ for the two class of solutions using the current data, we find that the solutions with only universal couplings and solutions having both universal and non-universal couplings can be discriminated if the measured value of $R_{K^*}^{\tau\mu}$ is greater than the SM prediction.

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1. Introduction

The alluring quest for lepton flavor universality violating (LFUV) new physics finds a captivating avenue through the lepton flavor ratios of the $B \to K^{(*)}\ell^+\ell^-$ ($\ell = e, \mu, \tau$) decay modes. The ratios $R_K \equiv \Gamma(B^+ \to K^+\mu^+\mu^-)/\Gamma(B^+ \to K^+e^+e^-)$ and $R_{K^*} \equiv \Gamma(B^0 \to K^{*0}\mu^+\mu^-)/\Gamma(B^0 \to K^{*0}e^+e^-)$ can unfurl the intriguing interplay between muon and electron modes. The deviation of these ratios from their standard model (SM) values can be interpreted as a tantalizing hint for LFUV new physics. We show that, in contrast, the lepton flavor ratios in the $\tau-\mu$ sector may deviate from its SM value even for a lepton flavor universal (LFU) coupling [1]. For the current $b \to s\ell\ell$ data, we also demonstrate the ability to differentiate between solutions featuring solely universal couplings to leptons and those involving both universal and non-universal components.

2. Methodology

We assume new physics (NP) in the form of vector and axial-vector for which the effective Hamiltonian for $b \to s\ell^+\ell^-$ decay can be written as

$$\begin{aligned}\mathcal{H}_{\rm eff}^{\rm NP} &= -\frac{\alpha_{\rm em}G_F}{\sqrt{2}\pi}V_{ts}^*V_{tb}\Big[C_{9\ell}(\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu\ell) + C_{10\ell}(\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu\gamma_5\ell)\\ &\quad + C'_{9\ell}(\bar{s}\gamma^\mu P_R b)(\bar{\ell}\gamma_\mu\ell) + C'_{10\ell}(\bar{s}\gamma^\mu P_R b)(\bar{\ell}\gamma_\mu\gamma_5\ell)\Big] + H.c.\,,\end{aligned}$$

where $C_{(9,10)\ell}$ and $C'_{(9,10)\ell}$ are NP WCs having both universal and non-universal components:

$$\begin{aligned}C_{(9,10)e} &= C_{(9,10)\tau} = C^U_{(9,10)}\,, \quad C'_{(9,10)e} = C'_{(9,10)\tau} = C'^U_{(9,10)}\,,\\ C_{(9,10)\mu} &= C^U_{(9,10)} + C^V_{(9,10)\mu}\,, \quad C'_{(9,10)\mu} = C'^U_{(9,10)} + C'^V_{(9,10)\mu}\,.\end{aligned}$$

Now there can be following possibilities:

- $C^U_{(9,10)} = C'^U_{(9,10)} = 0$, i.e we only have non-universal couplings. This is disfavoured by the updated measurements of R_K & R_{K^*} by the LHCb collaboration in December 2022 [2].
- $C^V_{(9,10)\mu} = C'^V_{(9,10)\mu} = 0$, i.e we only have universal couplings. We call this as framework F-I.
- Both universal as well as non-universal couplings are present. We call this as framework F-II.

The parameter space of the WCs are constrained through a global fit to 179 observables in $b \to s\ell^+\ell^-$ decay. This includes the latest measurements of R_K and R_{K^*} by the LHCb Collaboration. The fit results for F-I and F-II frameworks, taken from refs. [3–5], are listed in Table I.

3. Results

In this next section, we analyze the potential of $R_K^{\tau\mu}$ and $R_{K^*}^{\tau\mu}$ ratios to probe LFU violation in the $\tau-\mu$ sector. Similar to $R_K^{\mu e} \equiv R_K$ and $R_{K^*}^{\mu e} \equiv R_{K^*}$, these observables are expected to elucidate potential discrepancies within the $\tau-\mu$ sector. Therefore, it is reasonable to assume that $R_{K^{(*)}}^{\tau\mu}$ should align with SM predictions for universal NP. However, from Fig. 1, it is evident that unlike R_K and R_{K^*}, the LFU ratios $R_K^{\tau\mu}$ and $R_{K^*}^{\tau\mu}$ may render values different from their SM predictions even for NP solutions having only universal component:

F-I Solutions	WCs	1σ range	$\Delta\chi^2$
SU-I	C_9^U	-1.08 ± 0.18	27.90
SU-II	$C_9^U = -C_{10}^U$	-0.50 ± 0.12	18.85
SU-III	$C_9^U = -C_9'^U$	-0.88 ± 0.16	26.92
F-II Solutions	**WCs**	**1σ range**	**$\Delta\chi^2$**
S-V	$C_{9\mu}^V$	(-1.31, -0.53)	
	$C_{10\mu}^V$	(-0.66 ,0.07)	20.25
	$C_9^U = C_{10}^U$	(-0.13 ,0.58)	
S-VI	$C_{9\mu}^V = -C_{10\mu}^V$	(-0.33,-0.20)	
	$C_9^U = C_{10}^U$	(-0.43, -0.17)	16.81
S-VII	$C_{9\mu}^V$	(-0.43, -0.08)	
	C_9^U	(-1.07, -0.58)	30.25
S-VIII	$C_{9\mu}^V = -C_{10\mu}^V$	(-0.18, -0.05)	
	C_9^U	(-1.15,-0.77)	31.36
S-IX	$C_{9\mu}^V = -C_{10\mu}^V$	(-0.27,-0.12)	
	C_{10}^U	(-0.09,0.27)	12.96
S-X	$C_{9\mu}^V$	(-0.72,-0.41)	
	C_{10}^U	(0.05,0.34)	21.16
S-XI	$C_{9\mu}^V$	(-0.82, -0.51)	
	$C_{10}'^U$	(-0.26,-0.04)	21.16
S-XIII	$C_{9\mu}^V$	(-0.96,-0.60)	
	$C_{9\mu}'^V$	(0.22,0.63)	
	C_{10}^U	(0.01,0.38)	
	$C_{10}'^U$	(-0.08,0.24)	26.01

Table 1: Viable NP solutions in F-I and F-II frameworks, where $\Delta\chi^2 = \chi^2_{\rm SM} - \chi^2_{\rm bf}$, with $\chi^2_{\rm bf}$ denoting the best-fit point and $\chi^2_{\rm SM} \approx 184$.

- C_9^U scenario: $R^{\tau\mu}_{K^{(*)}}$ deviates from the SM.
- $C_9^U = -C_9^{U'}$ scenario: $R^{\tau\mu}_K$ aligns with the SM values, while $R^{\tau\mu}_{K^*}$ deviates from the SM.
- $C_9^U = -C_{10}^U$ scenario: $R^{\tau\mu}_{K^{(*)}}$ closely matches the SM predictions.

Therefore mere deviation of these observables from the SM cannot determine the nature of NP in $\tau-\mu$ sector, i.e if any experiment measures $R^{\tau\mu}_K$ and $R^{\tau\mu}_{K^*}$ with a value different from their SM predictions, we cannot conclusively attribute such a deviation to LFUV-type NP. For such a discrimination, additional analysis would be required.

A careful anatomization of these observables for the solutions corresponding to the two classes of new physics will be required to identify the NP type. By comparing the predictions of $R^{\tau\mu}_{K^{(*)}}$ for the current allowed solutions, we find that two classes of solutions can be discriminated if the measured value of $R^{\tau\mu}_{K^*}$ is greater than the SM prediction [1].

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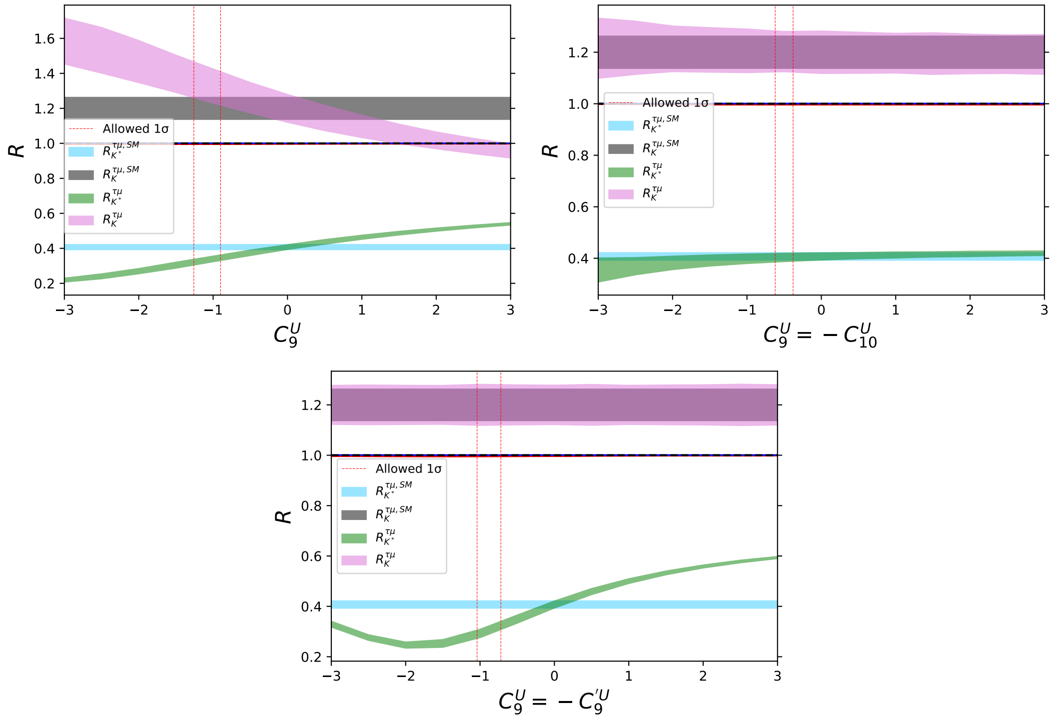

Figure 1: Illustration of the functional dependence of $R^{\tau\mu}$ ratios on the new physics WCs having only universal components. The three depicted scenarios are favored by the current $b \to s\ell\ell$ ($\ell = e,\ \mu$) data.

4. Conclusions

We show that unlike R_K and R_{K^*}, deviation in the lepton flavor ratio $R^{\tau\mu}_{K^{(*)}}$ from its SM value does not necessarily imply non-universal couplings. A discrimination between the two classes of NP can be achieved by comparing $R^{\tau\mu}_{K^{(*)}}$ predictions for the currently allowed solutions.

References

[1] A. K. Alok, N. R. Singh Chundawat and A. Mandal, To appear in Phys. Lett. B (2023) [arXiv:2303.16606 [hep-ph]].

[2] [LHCb], [arXiv:2212.09152 [hep-ex]].

[3] N. R. Singh Chundawat, Phys. Rev. D **107**, no.5, 055004 (2023) [arXiv:2212.01229 [hep-ph]].

[4] N. R. Singh Chundawat, Phys. Rev. D **107** (2023), 075014 [arXiv:2207.10613 [hep-ph]].

[5] A. K. Alok, N. R. Singh Chundawat, S. Gangal and D. Kumar, Eur. Phys. J. C **82** (2022) no.10, 967 [arXiv:2203.13217 [hep-ph]].

[6] D. M. Straub, arXiv:1810.08132 [hep-ph].

[7] A. Bharucha, D. M. Straub and R. Zwicky, JHEP **08**, 098 (2016) [arXiv:1503.05534 [hep-ph]].

[8] N. Gubernari, A. Kokulu and D. van Dyk, JHEP **01**, 150 (2019) [arXiv:1811.00983 [hep-ph]].

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