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

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Motivation

The alluring quest for lepton flavor violating 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 and R_{K^*} 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 lepton flavor violating 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 coupling.

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.

Methodology

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

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

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

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

- $C^V_{(9,10)\mu} = C'^V_{(9,10)\mu} = 0$, i.e we only have universal couplings (F-I).
- Both universal as well as non-universal couplings are present (F-II).

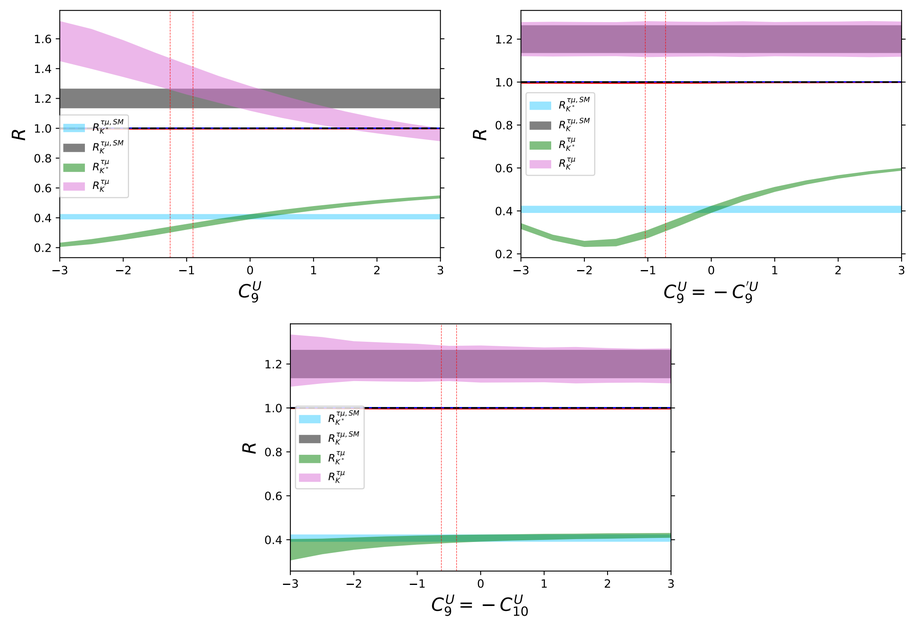
The parameter space of the WCs are constrained through a global fit to 179 observables in $b \to s\ell^+\ell^-$ decay. This includes the latest measurements of R_K and R_{K^*} by the LHCb Collaboration in December 2022.

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	$C^V_{9\mu}$ $C^V_{10\mu}$ $C_9^U = C_{10}^U$	(-1.31, -0.53) (-0.66 ,0.07) (-0.13 ,0.58)	20.25
S-VI	$C^V_{9\mu} = -C^V_{10\mu}$ $C_9^U = C_{10}^U$	(-0.33,-0.20) (-0.43, -0.17)	16.81
S-VII	$C^V_{9\mu}$ C_9^U	(-0.43, -0.08) (-1.07, -0.58)	30.25
S-VIII	$C^V_{9\mu} = -C^V_{10\mu}$ C_9^U	(-0.18, -0.05) (-1.15,-0.77)	31.36
S-IX	$C^V_{9\mu} = -C^V_{10\mu}$ C_{10}^U	(-0.27,-0.12) (-0.09,0.27)	12.96
S-X	$C^V_{9\mu}$ C_{10}^U	(-0.72,-0.41) (0.05,0.34)	21.16
S-XI	$C^V_{9\mu}$ C'^U_{10}	(-0.82, -0.51) (-0.26,-0.04)	21.16
S-XIII	$C^V_{9\mu}$ $C'^V_{9\mu}$ C^U_{10} C'^U_{10}	(-0.96,-0.60) (0.22,0.63) (0.01,0.38) (-0.08,0.24)	26.01

Viable new physics 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 $\chi^2_{\rm SM} \approx 184$.

Variation of $R^{\tau\mu}_{K^{(*)}}$ with universal WCs

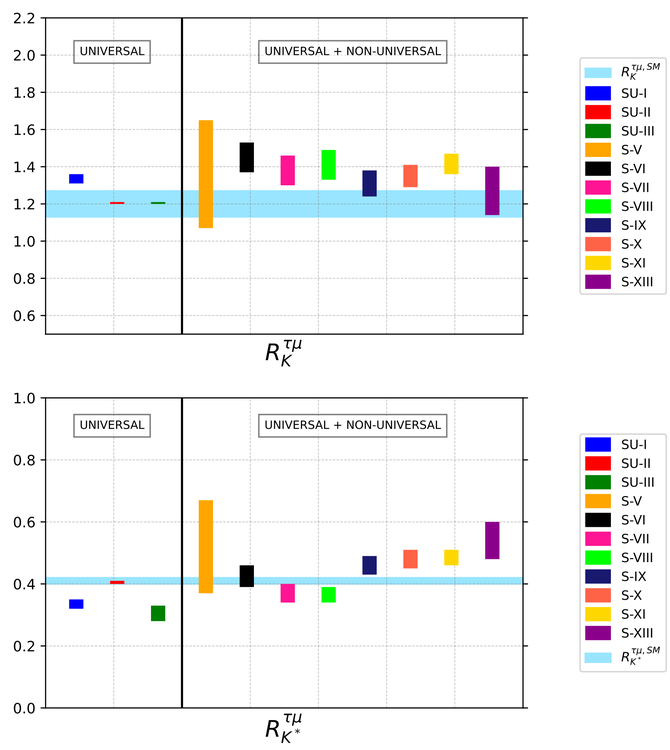
Variation of $R^{\tau\mu}$ with universal couplings for new physics different scenarios:



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

Differentiating the nature of new physics

A careful anatomization of these observables for the solutions corresponding to the two classes of new physics will be required to identify the new physics type:



Conclusions

- 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 new physics can be achieved by comparing the predictions of $R^{\tau\mu}_{K^{(*)}}$ for the currently allowed solutions.