LFU in B-sector - a global analysis of various new physics models

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based on arXiv:1704.07347

July 17, 2018

Plan of talk

Hints of Physics beyond the SM

- The lepton flavor university observable: $R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)} \mu^+ \mu^-)}{\mathcal{B}(B \to K^{(*)} e^+ e^-)}$
- $R_K^{exp} = 0.745^{+0.090}_{-0.074} \pm 0.036$ (LHCb PRL 113 (2014) 151601), implies a deviation of $\sim 2.6\sigma$ with respect to SM prediction.
- The measurement of R_{K^*} in two bins (LHCb, JHEP 1708, 055 (2017))

$$R_{K^*}^{low} = 0.660^{+0.110}_{-0.070} \pm 0.024$$
$$R_{K^*}^{central} = 0.685^{+0.113}_{-0.069} \pm 0.047$$

which shows $\sim 2.5\ \sigma$ deviation from SM.

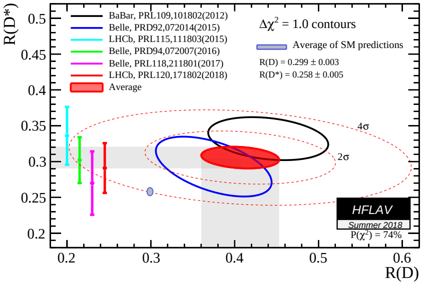
- The angular observable P_5' in $B \to K^* \mu^+ \mu^-$ disagrees with the SM predictions at the level of 4σ in the $[4.3 - 8.68] q^2$-bin.

Hints of Physics beyond the SM

- The another LFU observable

$$R_{D^{(*)}} = \frac{\Gamma(B \to D^{(*)}\tau\bar{\nu})}{\Gamma(B \to D^{(*)} l\bar{\nu})}(l = e, \mu)$$

- disagrees with the SM at the level of $\sim 4.1\sigma$



The branching ratio of $B_s \to \phi\mu^+\mu^-$ shows a deviation of 3.5σ with respect to SM. LHCb, JHEP 09 (2015) 179

New Physics

- The operator
$$\frac{G}{\Lambda^2}(\bar{b}'_L \gamma_\mu b'_L)(\bar{\tau}'_L \gamma^\mu \tau'_L).$$
was used to explain the R_K anomaly by Glashow, Guadagnoli and Lane (GGL).
- It was pointed out that LFUV $\rightarrow$ LFV.
- (Bhattacharya, Datta, London, Shivshankara, 1412.7164) considered two NP operators that are invariant which are invariant under $SU(3)_C \times SU(2)_L \times U(1)_Y$.

$$\begin{aligned} \mathcal{O}^1_{NP} &= \frac{G_1}{\Lambda^2_{NP}}(\bar{Q}'_L \gamma_\mu Q'_L)(\bar{L}'_L \gamma^\mu L'_L) \\ \mathcal{O}^2_{NP} &= \frac{G_1}{\Lambda^2_{NP}}(\bar{Q}'_L \gamma_\mu \sigma^I Q'_L)(\bar{L}'_L \gamma^\mu \sigma^I L'_L) \end{aligned}$$

Models

The following model were studied previoulsy (Bhattacharya,Datta,Guevin,London and Watanabe, 1609.09078)

- Vector boson: transform as $(\mathbf{1},\mathbf{3},\mathbf{0})$ under the SM gauge group.
- Leptoquarks:

1. Scalar singlet $S_1\,(\mathbf{3},\mathbf{1},\mathbf{4}/\mathbf{3})$.
2. Scalar triplet $S_3\,(\mathbf{3},\mathbf{3},-\mathbf{2}/\mathbf{3})$.
3. Vector singlet $U_1\,(\mathbf{3},\mathbf{1},\mathbf{4}/\mathbf{3})$.

- We renanalysed these models to check for the simultaneous explanation of $R_{K^{(*)}}$ and $R_{D^{(*)}}$.
- It is assumed a NP coupling to only third generation in the gauge basis.

Models

- It is assumed that the mixing only between second and third generation, so that the matrices D and L can be defined using the two rotation angles θ_{bs} and $\theta_{\mu\tau}$.
- Therefore, in the mass basis, the new physics couplings can be written as,

$$G^{ijkl}_{(1,2)} = g_{(1,2)} X^{ij} Y^{kl},$$

$$X = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \sin^2\theta_{bs} & -\sin\theta_{bs}\cos\theta_{bs} \\ 0 & -\sin\theta_{bs}\cos\theta_{bs} & \cos^2\theta_{bs} \end{bmatrix},$$

$$Y = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \sin^2\theta_{\mu\tau} & -\sin\theta_{\mu\tau}\cos\theta_{\mu\tau} \\ 0 & -\sin\theta_{\mu\tau}\cos\theta_{\mu\tau} & \cos^2\theta_{\mu\tau} \end{bmatrix}.$$

SM-like vector bosons

- The interaction Lagrangian in the gauge basis:

$$\mathcal{L}_V^{eff} = g_{qV}^{33}(\bar{Q}'_{L3}\gamma^\mu\sigma^I Q'_{L3})V_\mu^I + g_{LV}^{33}(\bar{L}'_{L3}\gamma^\mu\sigma^I L'_{L3})V_\mu^I$$

- Integrating out the heavy vector boson, it turns out $g_1 = 0$ and $g_2 = -g_{LQ}\, g_{LV}$ and we take $g_{LQ} = g_{LV} = \sqrt{0.5}$.

Introducing a new heavy vector boson give rise to non-standard model contributions to the flavor violating transitions of various types.

- The vector boson model gives the contribution in four fermion operator at the tree level so it contributes to additionaly in $\tau \to 3\mu$, $B_s - \bar{B}_s$ mixing.

Leptoquarks

- The interaction Lagrangian in the gauge basis:

$$\begin{aligned}
\mathcal{L}^{eff}_{U_1} &= g^{33}_{U_1}(\bar{Q}^{'}_{L3}\gamma^{\mu}L^{'}_{L3})U_{1\mu} + h.c. \\
\mathcal{L}^{eff}_{S_3} &= g^{33}_{S_3}(\bar{Q}^{'}_{L3}\gamma^{\mu}L^{'}_{L3})S_{3\mu} + h.c. \\
\mathcal{L}^{eff}_{U_3} &= g^{33}_{U_3}(\bar{Q}^{'}_{L3}\gamma^{\mu}L^{'}_{L3})U_{3\mu} + h.c.
\end{aligned}$$

- We can identify the couplings g_1 and g_2 for various LQ models as,

$$U_1 : g_1 = g_2 = -\frac{1}{2}|g^{33}_{U_1}|^2 < 0$$

$$S_3 : g_1 = 3g_2 = \frac{3}{4}|g^{33}_{S_3}|^2 > 0$$

$$U_3 : g_1 = -3g_2 = -\frac{3}{2}|g^{33}_{U_3}|^2 < 0$$

NP wilson coefficients

- New Physics contributions to the Wilson coefficients,

$$C_9^{\mu\mu} = -C_{10}^{\mu\mu} = -\frac{\pi}{\sqrt{2}\alpha G_F V_{tb} V_{ts}^*} \frac{(g_1 + g_2)}{\Lambda^2} \left(\sin\theta_{bs}\cos\theta_{bs}\sin^2\theta_{\mu\tau}\right),$$

$$C_V^{ij} = -\frac{1}{2\sqrt{2} G_F V_{cb}} \frac{2g_2}{\Lambda^2} \Big(- V_{cs}\sin\theta_{bs}\cos\theta_{bs} + V_{cb}\cos^2\theta_{bs}\Big) Y^{ij},$$

$$C_L^{ij} = -\frac{\pi}{\sqrt{2}\alpha G_F V_{tb} V_{ts}^*} \frac{(g_1 - g_2)}{\Lambda^2} \left(\sin\theta_{bs}\cos\theta_{bs}\right) Y^{ij}.$$

Methodology

- We perform three kinds of fit:

- Fit 1 : Global fit by taking all the relevant data in B-sector
- Fit 2 : Fit with only clean observables
- Fit 3 : Fit with excluding $b \to c\tau\bar{\nu}$ data

- We do a χ^2 fit using CERN minimization code MINUIT.
- The χ^2 function is defined as

$$\chi^2(C_i) = (\mathcal{O}_{th}(C_i) - \mathcal{O}_{exp})^T \, \mathcal{C}^{-1} \, (\mathcal{O}_{th}(C_i) - \mathcal{O}_{exp}) \, .$$

Observables in the fit

- The measurement of $R_{K^{(*)}}$.
- The measurement of $R_{D^{(*)}}$.

- the differential branching ratio of $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^{*+}\mu^+\mu^-$ measured by LHCb ,
- the CP-averaged differential angular distribution for $B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$,
- the differential branching ratio of $B^0 \to K^0\mu^+\mu^-$ and $B^+ \to K^+\mu^+\mu^-$ measured by LHCb and CDF,

Observables in the fit

- the differential branching ratio of $B_s^0 \to \phi\mu^+\mu^-$ by LHCb and CDF and the angular observables measured by LHCb,
- the differential branching ratio of $B \to X_s\mu^+\mu^-$ measured by BaBar ,
- the recent data by ATLAS and CMS for the angular observables in $B^0 \to K^{*0}\mu^+\mu^-$ decay.

- Mass difference ΔM_s in B_s-$\bar{B}_s^0$ mixing .
- The branching ratio of $B_s^0 \to \mu^+\mu^-$,

Results

Global fit :

- VB model violates the upper bound on $\mathcal{B}(\tau \to 3\mu)$ so this is inconsistent with the present data. $\mathcal{B}(\tau \to 3\mu) < 2.1 \times 10^{-8}$, *PLB*687, 139(2010)
- The best fit results for U_1 model with $\chi^2/dof = 117.70/113$

Observable		$R_{K[1.0-6.0]}$	$R_{K^*[0.045-1.1]}$	$R_{K^*[1.1-6.0]}$	$P'_{5[4.0-6.0]}$	R_D^{ratio}	$R_{D^*}^{ratio}$
Measurement		0.75 ± 0.09	0.66 ± 0.09	0.69 ± 0.10	-0.30 ± 0.16	1.29 ± 0.17	1.21 ± 0.06
Standard Model		1.0	0.93	0.99	-0.82	1.0	1.0
$\theta_{\mu\tau}(rad.)$	$\theta_{bs}(rad.)$						
0.355 ± 0.215	0.008 ± 0.009	0.72	0.87	0.73	-0.69	1.04	1.04
χ^2		0.06	5.10	0.22	4.72	2.15	7.97

- U_1, S_3 and U_3 models are also unable to accommodate the $R_{K^{(*)}}$ and $R_{D^{(*)}}$ simultaneously within 1σ.
- $R_{J/\psi}$, τ polarization and D^* polarization in $B \to D^* \tau \bar{\nu}$ are almost same as SM at the best fit points as NP lorentz structure of these models is same as SM.

Results

- Explanation of $R_{D^{(*)}}$ implies a very large enhancement in all the processes induced by the quark level transition $b \to s\tau^+\tau^+$.

  B. Capdevila,A. Crivellin,S. Descotes-Genon,L. Hofer, and J. Matias, PRL 120,181802(2018)

- A large enhancement in the branching ratios of $B_s \to \phi\tau^+\tau^-$,$B \to (K, K^*)\tau^+\tau^-$ and $B_s \to \tau^+\tau^-$ above their SM values are not possible.
- Fit with only $b \to s\mu^+\mu^-$ data can accomodate $R_{K^{(*)}}$ data except R_{K^*} in low-q^2 bin.
- The contribution to χ^2 due to $R_{D^{(*)}}$ become worse for LQ models in fit 3, indicating that within this framework the $b \to s\mu^+\mu^-$ data do not confront $R_{D^{(*)}}$ excess.
- For the fit with only clean observables, the results are found to be very similar to that of Global fits.

Summary

- we look for simultaneous explanations of $R_{K^{(*)}}$ and $R_{D^{(*)}}$ measurements in VB, U_1, S_3 and U_3 models.
- Performed 'a global fit' to all relevant data in the B sector

- The vector boson model violates the upper bound on the branching ratio of $\tau \to 3\mu$ and hence is inconsistent with the present data.
- The three LQ models could not accommodate $R_{D^{(*)}}$ and $R_{K^{(*)}}$ simultaneously.
- The enhancement of $b \to s\tau^+\tau^-$ processes above their SM values are not possible in these LQ models.

For the fits with only '$b \to s\mu^+\mu^-$' data. We find,

- The U_1, S_3 and U_3 models can accommodate $R_{K^{(*)}}$ data within 1 σ except R_{K^*} in the low q^2 bin (0.045, 1.1).
- This framework the $b \to s\mu^+\mu^-$ data do not confront $R_{D^{(*)}}$ excess.

Thank You