$B \to K\nu\overline{\nu}$ measurements and new physics

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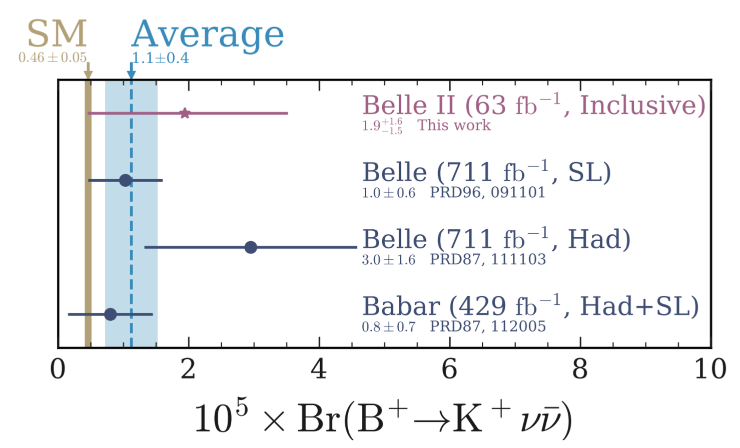
Key points

- Flavor changing neutral current transitions are suppressed in the standard model (SM) and thus are good place to look for new physics (NP) effects.
- Connections of $B \to K^{(*)}\nu\overline{\nu}$ channel with neutral current (NC) $R_{K^{(*)}}$ [1] and charged current (CC) $R(D^{(*)})$ [2] anomalies in context of 'simplified' models are studied.
- Recently used inclusive tagging technique in Belle II increases possibility to observe events in $B^+ \to K^+\nu\overline{\nu}$ mode [3].



$$R_K^\nu \equiv \frac{\mathrm{BR_{Exp}}}{\mathrm{BR_{SM}}} = 2.4 \pm 0.9$$

Is the anticipated enhancement correlated with B-anomalies?

Introduction

The most general dimension-6 effective Hamiltonian contains (axial)vector, (pseudo)scalar and tensor operators when including light right-handed neutrinos (RHNs) in the final states.

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\frac{\alpha_{\rm EM}}{4\pi}V_{tb}V_{ts}^*\left(C_{LL}^{\rm SM}\delta_{\alpha\beta}[\mathcal{O}_{LL}^V]^{\alpha\beta} + \sum_{\substack{X=S,V,T\\A,B=L,R}}[C_{AB}^X]^{\alpha\beta}[\mathcal{O}_{AB}^X]^{\alpha\beta}\right)$$

The SM contribution [4]:

$$C_{LL}^{\rm SM} = -2X_t/s_w^2$$
$$X_t = 1.469 \pm 0.017$$

Ten four-fermion NP operators:

$$[\mathcal{O}_{AB}^V]^{\alpha\beta} \equiv (\bar{s}\,\gamma^\mu P_A b)\,(\overline{\nu}^\alpha\gamma_\mu P_B\nu^\beta)$$
$$[\mathcal{O}_{AB}^S]^{\alpha\beta} \equiv (\bar{s}\,P_A b)\,(\overline{\nu}^\alpha P_B\nu^\beta)$$
$$[\mathcal{O}_{AB}^T]^{\alpha\beta} \equiv \delta_{AB}\,(\bar{s}\,\sigma^{\mu\nu}P_A b)\,(\overline{\nu}^\alpha\sigma_{\mu\nu}P_B\nu^\beta)$$

Observables: Branching ratios, differential distribution in q^2 for $B \to K^{(*)}\nu\overline{\nu}$ channels and longitudinal polarisation fraction of K^* only in the vector meson mode. The variation of all individual NP operators can achieve the expected range of R_K^ν.

New Physics: Leptoquarks & Generic Z'

♣ Leptoquark (LQ) arises in R-parity violating models, Grand Unified Theories, can turn a lepton into a quark and vice-versa. Differing in the SM gauge quantum numbers, the following six LQs contribute to $b \to s\nu\overline{\nu}$.

Mediators	Spin	Interaction terms	Operators
$S_3(\bar{3},3,1/3)$	0	$+\overline{Q^c}\,Y_{S_3}\,i\tau_2\,\boldsymbol{\tau}\cdot\mathbf{S_3}\,L$	$\mathcal{O}_{LL}^V$
$\tilde{R}_2(3,2,1/6)$	0	$-\bar{d}_R\,Y_{\tilde{R}_2}\,\tilde{R}_2^T\,i\tau_2 L + \overline{Q}\,Z_{\tilde{R}_2}\,\tilde{R}_2\,\nu_R$	$\mathcal{O}_{RL}^V, \mathcal{O}_{LR}^V, \mathcal{O}_{LL}^{S,T}, \mathcal{O}_{RR}^{S,T}$
$S_1(\bar{3},1,1/3)$	0	$+\overline{Q^c}\,i\tau_2\,Y_{S_1}L\,S_1 + \overline{u_R^c}\,\tilde{Y}_{S_1}\,S_1\,e_R + \overline{d_R^c}\,Z_{S_1}\,S_1\,\nu_R$	$\mathcal{O}_{RR}^{S,V,T}, \mathcal{O}_{LL}^{S,V,T}$
$U_3^\mu(3,3,2/3)$	1	$+\overline{Q}\,\gamma^\mu\tau^a\,Y_{U_1}L\,U_{1\mu}^a$	$\mathcal{O}_{LL}^V$
$V_2^\mu(\bar{3},2,5/6)$	1	$+\overline{d_R^c}\,\gamma^\mu Y_{V_2}V_{2\mu}^T i\tau_2\,L + \overline{Q_L^c}\,\gamma^\mu\tilde{Y}_{V_2}i\tau_2\,V_{2\mu}e_R$	$\mathcal{O}_{RL}^S$
$\bar{U}_1^\mu(3,1,-1/3)$	1	$+\bar{d}_R\,Z_{\bar{U}_1}\,\gamma^\mu\bar{U}_{1\mu}\,\nu_R$	$\mathcal{O}_{RR}^V$

The first generation entries in the LQ Yukawa coupling matrices are stringently constrained from Kaon and lepton physics [5]. We choose minimal set of non-zero couplings relevant for one or both kind(s) of B-anomalies.

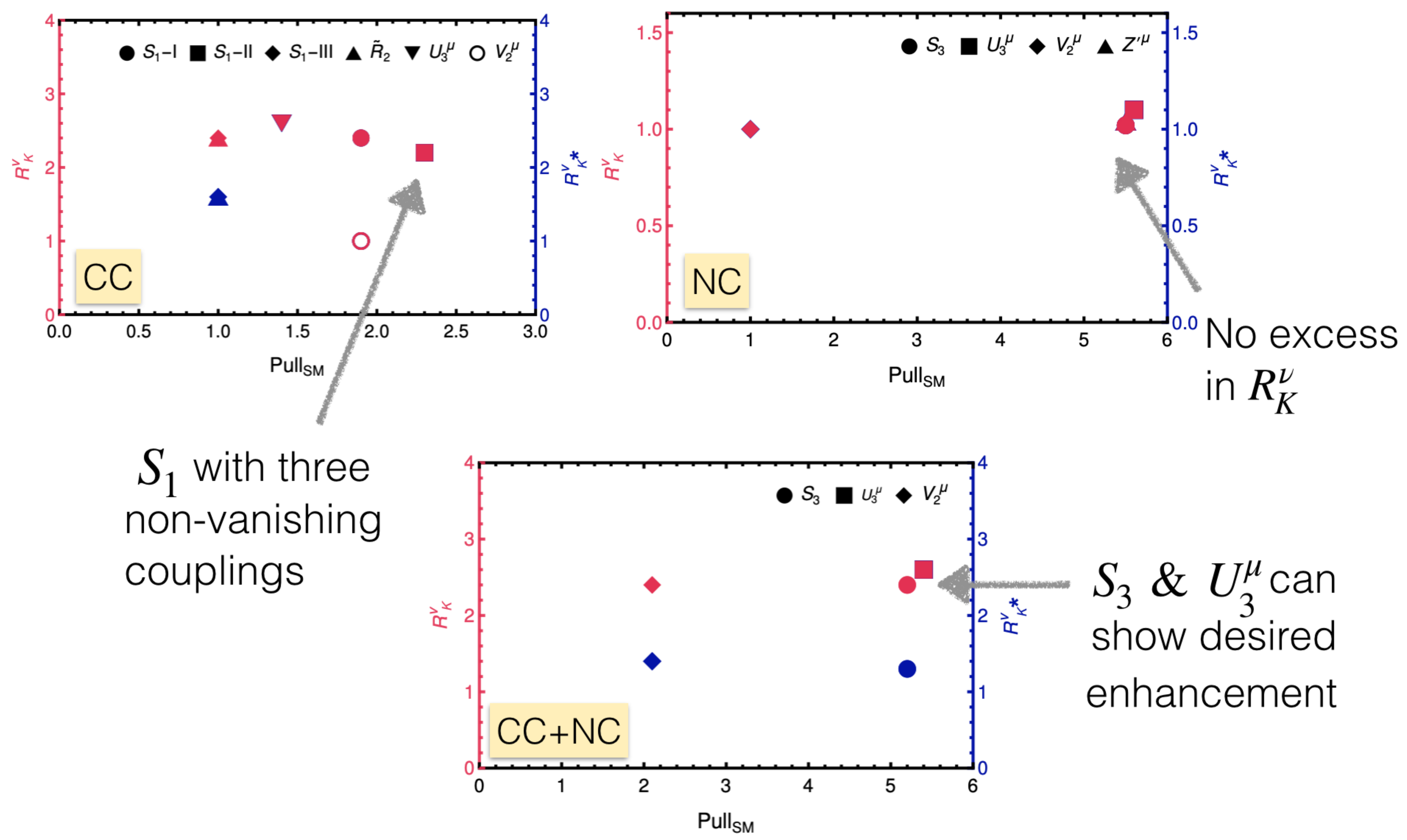
Mediators	Spin	R_K	R_{K^*}	$R(D)$	$R(D^*)$	R_K^ν
$S_3(\bar{3},3,1/3)$	0	✓	✓	✗	✗	✓
$\tilde{R}_2(3,2,1/6)$	0	✓	✗ $R_{K^*}^{[1,6]} > 1$	— no effect —		no effect
+ RHN				✗	✗ ←	✓
$S_1(\bar{3},1,1/3)$	0	— no effect —		✓	✓	✓
+ RHN				✗	✗ ←	✓
$U_3^\mu(3,3,2/3)$	1	✓	✓	✗	✗ ←	✓
$V_2^\mu(\bar{3},2,5/6)$	1	✗	✗	✓	✗	✓
$\bar{U}_1^\mu(3,1,-1/3)$	1	— no effect —		— no effect —		✓

♣ Interaction terms for a generic flavor changing Z'

$$\mathcal{L}\left(Z'\right) = \Delta_L^{ij}\overline{\psi}_L^i\gamma^\mu P_L\psi_L^j Z'_\mu + \Delta_R^{ij}\overline{\psi}_R^i\gamma^\mu P_R\psi_R^j Z'_\mu\,.$$

While contribution to $R(D^{(*)})$ is absent, Z' generates $C_9^{\rm NP} = -C_{10}^{\rm NP}$ for $R_{K^{(*)}}$. The $B_s^0 - \overline{B}_s^0$ mixing data restricts $\Delta_L^{sb} \lesssim \mathcal{O}(10^{-2})$ [6] implying even with $\Delta_L^{\mu\mu} \simeq \mathcal{O}(1)$, at best-fit $R_K^\nu = 1.05 \pm 0.03$. Switching on right-handed quark coupling does not improve the situation for R_K^ν.

Summary



- Possibilities to connect the indicated excess in $B^+ \to K^+\nu\overline{\nu}$ with both NC and CC B-anomalies in 'simplified' models.
- RHN explanations to $R(D^{(*)})$ are excluded for S_1 and $\tilde{R}_2$ LQs by $B \to K\nu\overline{\nu}$ data.
- Heavy Z' explaining NC anomalies with minimal setup can not enhance R_K^ν value.
- S_1 explaining CC B-anomalies & S_3 in NC+CC framework can produce expected enhancement in R_K^ν.
- Other links- Dark Matter connection?!

Reference

[1] R. Aaij *et al.* [LHCb], [arXiv:2103.11769 [hep-ex]];
R. Aaij *et al.* [LHCb], JHEP **08**, 055 (2017).

[2] Y. S. Amhis *et al.* [HFLAV], [arXiv:1909.12524 [hep-ex]].

[3] F. Abudinén *et al.* [Belle-II], Phys. Rev. Lett. **127**, no.18, 181802 (2021).

[4] A. J. Buras, J. Girrbach-Noe, C. Niehoff and D. M. Straub, JHEP **02**, 184 (2015).

[5] R. Mandal and A. Pich, JHEP **12**, 089 (2019).

[6] L. Di Luzio, M. Kirk, A. Lenz and T. Rauh, JHEP **12**, 009 (2019).