Analysis of $B \to K^{(*)}\nu\bar{\nu}$ decays

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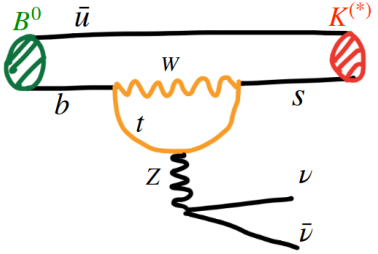
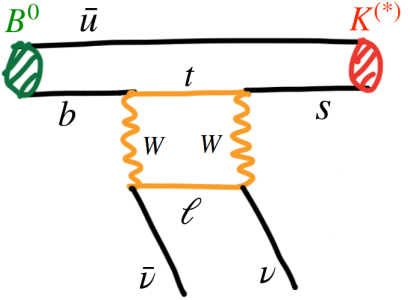
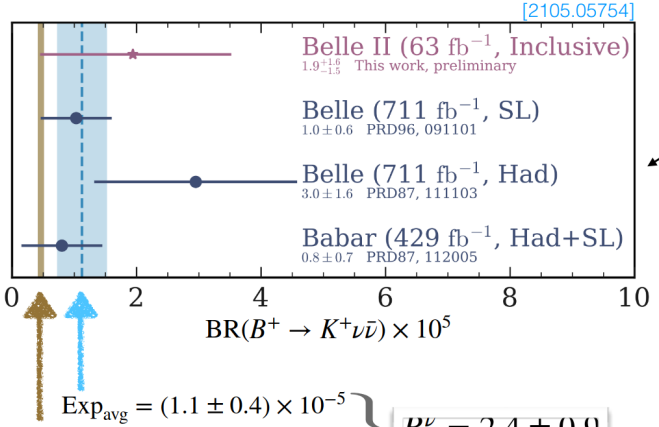
FCNC transitions

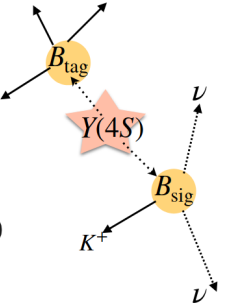




- $B \to K^{(*)}\nu\bar{\nu}$ theoretically much cleaner than $B \to K^* l^+ l^-$;
- Experimentally quite challenging due to two missing neutrinos — No signal has been observed so far.

- Inclusive tagging technique from Belle II has higher efficiency $\sim 4\%$





$\mathrm{Exp}_{\mathrm{avg}} = (1.1 \pm 0.4) \times 10^{-5}$

$\mathrm{SM} = (4.6 \pm 0.5) \times 10^{-6}$

$$R_K^{\nu} = 2.4 \pm 0.9$$

Hamiltonian

- Effective Hamiltonian with all possible dim-6 operators for $b \to s\nu\bar{\nu}$ transitions

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}}\frac{\alpha_{EM}}{4\pi}V_{tb}V_{ts}^*\left(C_L^{SM}\delta_{\alpha\beta}O_L^{\alpha\beta} + \sum_{\alpha\beta}\sum_{i=L^{(\prime)},R^{(\prime)}} C_i^{\alpha\beta}O_i^{\alpha\beta}\right) + \text{h.c.}, \qquad (1)$$

SM FCNC contribution

$$C_L^{SM} = -2X_t/s_w^2 = -12.7$$

Includes light right-handed neutrinos

$$O_L^{\alpha\beta} = (\bar{s}_L\gamma^\mu b_L)(\bar{\nu}^\alpha\gamma_\mu(1-\gamma_5)\nu^\beta),$$
$$O_R^{\alpha\beta} = (\bar{s}_R\gamma^\mu b_R)(\bar{\nu}^\alpha\gamma_\mu(1-\gamma_5)\nu^\beta),$$
$$O_L^{'\alpha\beta} = (\bar{s}_L\gamma^\mu b_L)(\bar{\nu}^\alpha\gamma_\mu(1+\gamma_5)\nu^\beta),$$
$$O_R^{'\alpha\beta} = (\bar{s}_R\gamma^\mu b_R)(\bar{\nu}^\alpha\gamma_\mu(1+\gamma_5)\nu^\beta)$$

- Observables: Branching ratios, differential distribution in q^2, Longitudinal polarization fraction in $B \to K^*\nu\bar{\nu}$

Observable	SM prediction LQCD+LCSR	Exp. constraint (90% CL)	Belle II 5ab^{-1}	Belle II 50ab^{-1}
$\mathcal{B}(B^0 \to K^0 \nu\bar{\nu}) \cdot 10^{-6}$	4.1 ± 0.5	< 26		
$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) \cdot 10^{-6}$	4.6 ± 0.5	11 ± 4, < 19	30%	11%
$\mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu}) \cdot 10^{-6}$	9.6 ± 0.9	< 18	26%	9.6%
$\mathcal{B}(B^+ \to K^{*+} \nu\bar{\nu}) \cdot 10^{-6}$	9.6 ± 0.9	< 61	25%	9.3%
$F_L(B \to K^* \nu\bar{\nu})$	0.47 ± 0.03			0.079
$R_K^{\nu\bar{\nu}}(B^+)$	1	2.4 ± 0.9		
$R_{K^*}^{\nu\bar{\nu}}(B^0)$	1	< 1.9		

Таблица: Observables for $b \to s\nu\bar{\nu}$. The last two columns list the Belle II sensitivities to exclusive B-meson decays to a $K^{(*)}$ meson [Belle-II:2018jsg] if the respective SM predictions are assumed. We estimate $R_{K^{(*)}}$ from the values in the second and third columns for the corresponding modes. The current constraint for $B^+ \to K^+ \nu\bar{\nu}$ is the world average for the branching fraction presented in [Dattola:2021cmw].

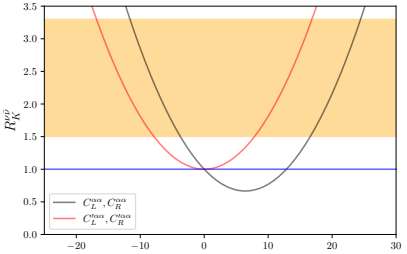
Numerical equations

$$R_K^{\nu\bar{\nu}} = \Bigg[1 - 0.1041 \sum_{\alpha} \mathrm{Re}\,(C_L^{\alpha\alpha} + C_R^{\alpha\alpha}) + 0.0081 \sum_{\alpha\beta} \Big\{ \underbrace{\left|C_L^{\alpha\beta} + C_R^{\alpha\beta}\right|^2}_{\text{LH neutrino}} + \underbrace{\left|C_L^{'\alpha\beta} + C_R^{'\alpha\beta}\right|^2}_{\text{RH neutrino}} \Big\} \Bigg], \tag{2}$$

$$R_{K^*}^{\nu\bar{\nu}} = \Bigg[1 - 0.1041 \sum_{\alpha} \mathrm{Re}\,(C_L^{\alpha\alpha}) + 0.0692 \sum_{\alpha} \mathrm{Re}\,(C_R^{\alpha\alpha}) + 0.00135 \sum_{\alpha\beta} \Big\{ \underbrace{\left|C_R^{\alpha\beta} + C_L^{\alpha\beta}\right|^2}_{\text{LH neutrino}} + \underbrace{\left|C_R^{'\alpha\beta} + C_L^{'\alpha\beta}\right|^2}_{\text{RH neutrino}} \Big\} + 0.00675 \sum_{\alpha\beta} \Big\{ \underbrace{\left|C_R^{\alpha\beta} - C_L^{\alpha\beta}\right|^2}_{\text{LH neutrino}} + \underbrace{\left|C_R^{'\alpha\beta} - C_L^{'\alpha\beta}\right|^2}_{\text{RH neutrino}} \Bigg], \tag{3}$$

$$R_{F_L}^{\nu\bar{\nu}} \cdot R_{K^*}^{\nu\bar{\nu}} = \Bigg[1 + 0.1041 \sum_{\alpha} \mathrm{Re}\,(C_R^{\alpha\alpha} - C_L^{\alpha\alpha}) + 0.0081 \sum_{\alpha\beta} \left[|C_L^{\alpha\beta} - C_R^{\alpha\beta}|^2 + |C_L^{'\alpha\beta} - C_R^{'\alpha\beta}|^2 \right] \Bigg]. \tag{4}$$

One operator analysis



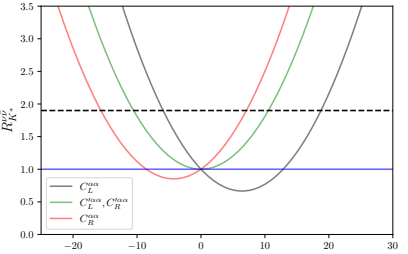


Рис.: Variations of flavor diagonal individual NP Wilson coefficients (assuming contributions from all three generations are equal) are shown for the observables $R_K^{\nu\bar{\nu}}$ and $R_{K*}^{\nu\bar{\nu}}$ in the left and right panels, respectively. The orange band in the left panel show the $\pm 1\sigma$ signal strength quoted in Tab.1, whereas the black dashed line in the right panel is the upper bound given in Tab.1.

WC	Current bound Value	NP scale (TeV)	Observable	Future Sensitivity (50ab^{-1}) Value	NP scale (TeV)
$C_L^{\alpha\alpha} > 0$	26 (16) 19	6.7 (8.6) 8	$B \to K$ $B \to K^*$	15	8.9
$C_L^{\alpha\alpha} < 0$	13 (4) 6	8.5 (17) 14	$B \to K$ $B \to K^*$	3	20
$C_R^{\alpha\alpha} > 0$	26 (16) 7	6.7 (8.6) 13	$B \to K$ $B \to K^*$	3.2	19
$C_R^{\alpha\alpha} < 0$	13 (4) 16	8.5 (17) 8.6	$B \to K$ $B \to K^*$	11.7	10
$C_{L(R)}^{\alpha\neq\beta}, C_{L(R)}^{\prime\alpha\beta}$	18 (8) 10	8 (12) 11	$B \to K$ $B \to K^*$	6.1	13.9

Таблица: Bounds imposed on the absolute value of the respective Wilson coefficients if only one of them gets (sizeable) contributions from new physics at a time, both for the current situation and for the projections for the 50ab^{-1} Belle II data set. In the latter case we assume that future measurement would confirm the SM predictions and $R_{K^{(*)}} > 1.3$ is excluded at $\approx 3\sigma$. We also provide rough estimates for the corresponding new physics scale and the observables from which the respective bound arises. Note that, we give upper (lower) current bounds on WCs for $B \to K$, originating from $B^+ \to K^+\nu\bar{\nu}$ world average.

Two operator analysis

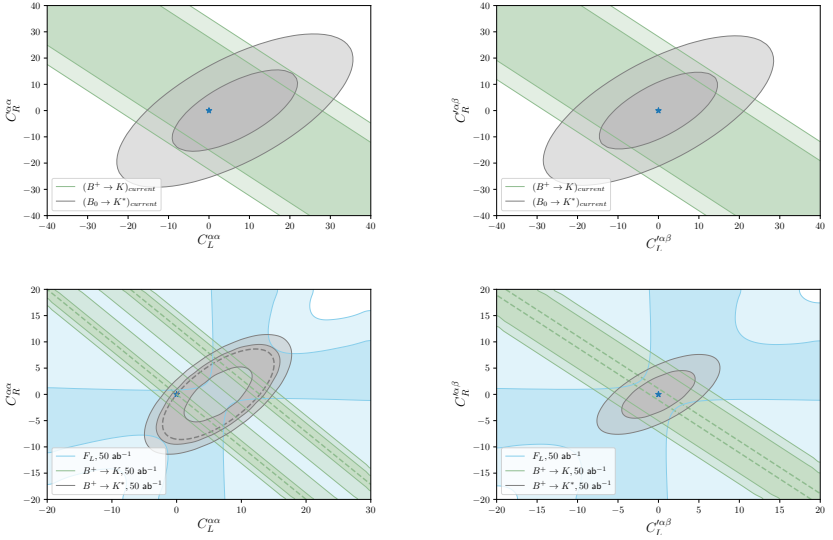


Рис.: Parameter space which is compatible with the 1(3)σ current (future) bounds on $B^+ \to K^+\nu\bar{\nu}$ and $B^+ \to K^*\nu\bar{\nu}$.

Results

- $B \to K^{(*)}\nu\bar{\nu}$ are important probe for new physics
- Experimental challenges might be overcome with inclusive tag technique@Belle II — expecting signal soon?!
- Constraints on New physics contributing to $b \to s\nu\bar{\nu}$ observables by currents bounds
- Improvements can be expected from the projected measurement of these processes at Belle II
- Have found regions in the space of WC compatible with current and future experimental bounds

Thank you for your attention!