Revisiting $B \to K^{(*)}\nu\bar{\nu}$ decays in the Standard Model and beyond

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1. Introduction

In this poster we discuss the correlation between the $B \to K^{(*)}\nu\nu$ and $B \to K^{(*)}\ell\ell$ decay modes in the Standard Model (SM) and its several popular extensions. This helps obtaining a more accurate SM determination of $\mathcal{B}(B \to K^{(*)}\nu\nu)$ which is useful in view of the upcoming experimental measurement at Belle-II.

2. $B \to K^{(*)}\nu\bar{\nu}$ Decays in the SM

$$\mathcal{L}_{\text{eff}}^{b\to s\nu\nu} = \frac{4G_F}{\sqrt{2}}\lambda_t \sum_a C_a\,\mathcal{O}_a + \text{h.c.}$$

$|\lambda_t| = V_{tb}V_{ts}^* = (4.00 \pm 0.10) \times 10^{-2}$
From $B \to D$ semileptonic decays

$$C_L^{\text{SM}} = -X_t/\sin^2\theta_W \qquad \mathcal{O}_L^{\nu_i\nu_j} = \frac{e^2}{(4\pi)^2}(\bar{s}_L\gamma_\mu b_L)(\bar{\nu}_i\gamma^\mu(1-\gamma_5)\nu_j) \qquad X_t = 1.469(17)$$

$$\frac{d\mathcal{B}}{dq^2}(B \to K\nu\bar{\nu}) = \mathcal{N}_K(q^2)\,|C_L^{\text{SM}}|^2\,|\lambda_t|^2\,\left[f_+(q^2)\right]^2$$

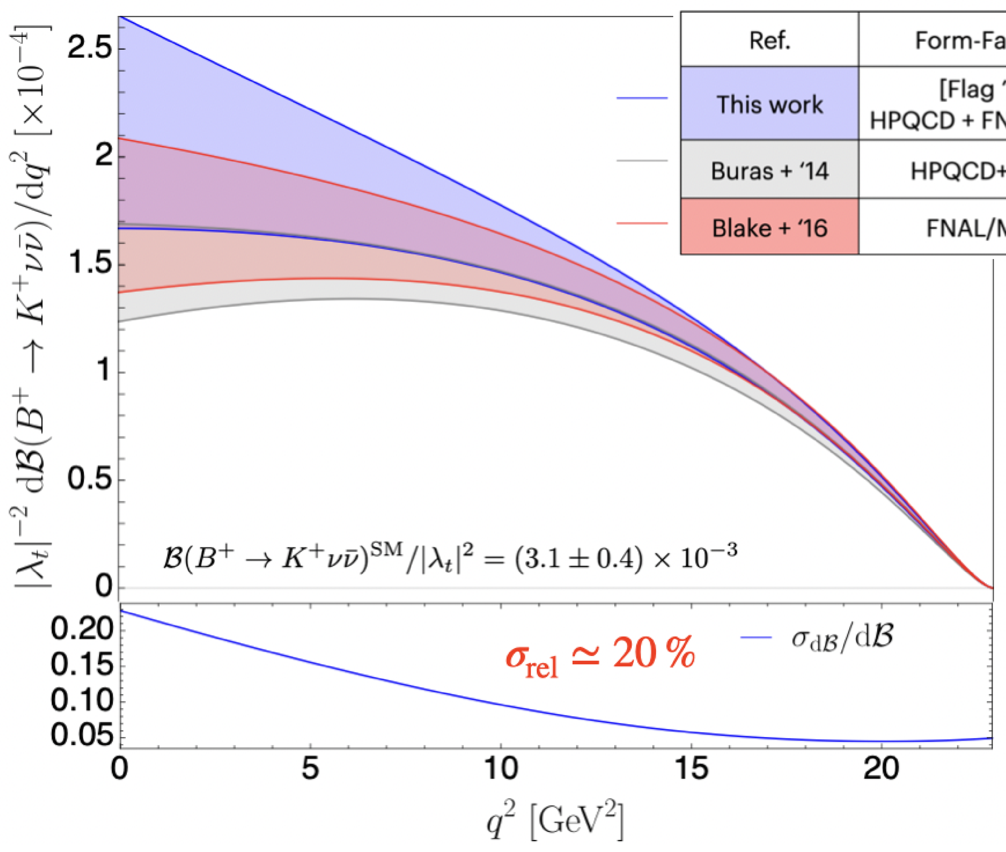
$$\mathcal{N}_K(q^2) = \tau_B \frac{G_F^2\,\alpha_{\text{em}}^2}{256\pi^5}\frac{\lambda_K^{3/2}}{m_B^3}$$

$$\frac{d\mathcal{B}}{dq^2}(B \to K^*\nu\bar{\nu}) = \mathcal{N}_{K^*}(q^2)|C_L^{\text{SM}}|^2|\lambda_t|^2\left[\mathcal{F}(q^2)\right]^2$$

$$\mathcal{N}_{K^*}(q^2) = \tau_B \frac{G_F^2\,\alpha_{\text{em}}^2}{128\pi^5}\frac{\lambda_{K^*}^{1/2}q^2}{m_B}\left(1+\frac{m_{K^*}}{m_B}\right)^2$$

$$\mathcal{F}(q^2) = [A_1(q^2)]^2 + 32\frac{m_{K^*}^2 m_B^2}{q^2(m_B+m_{K^*})^2}[A_{12}(q^2)]^2 + \frac{\lambda_{K^*}}{(m_B+m_{K^*})^4}[V(q^2)]^2\,,$$

3. Predictions



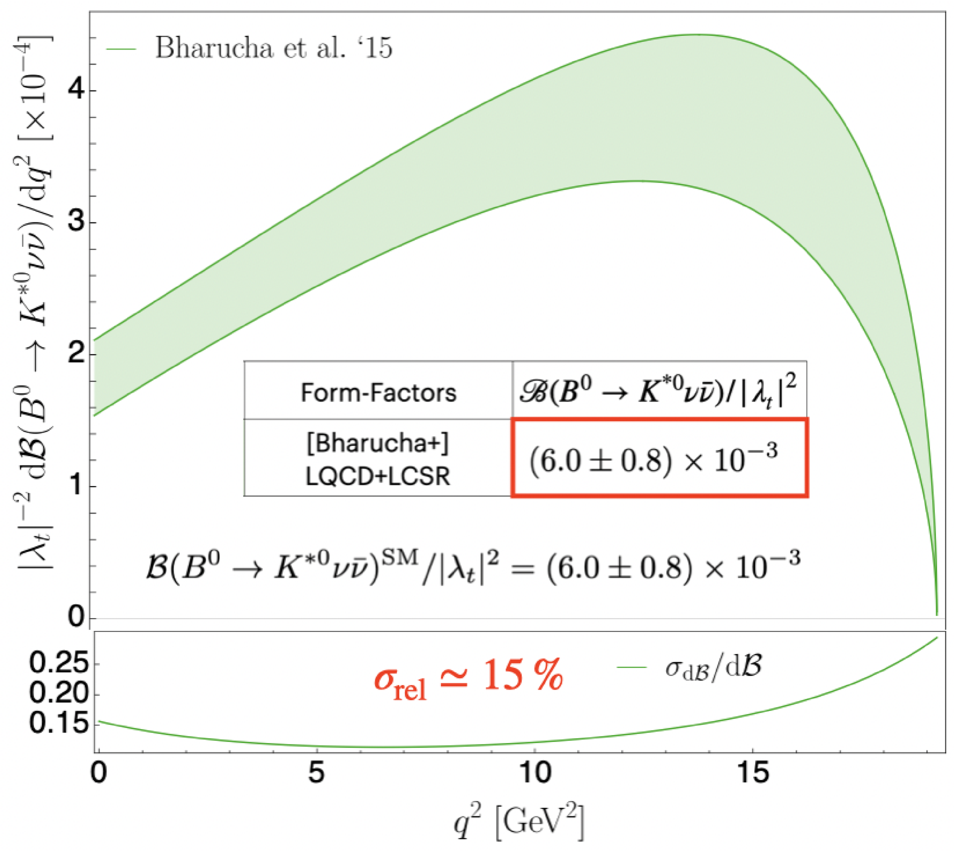
Ref.	Form-Factors	$\mathcal{B}(B^+ \to K^+\nu\bar{\nu})/\lvert\lambda_t\rvert^2$
This work	[Flag '21] HPQCD + FNAL/MILC	$(3.1 \pm 0.4) \times 10^{-3}$
Buras + '14	HPQCD+LCSR	$(2.5 \pm 0.3) \times 10^{-3}$
Blake + '16	FNAL/MILC	$(2.8 \pm 0.3) \times 10^{-3}$

Binned BR

q^2-bin [GeV^2]	$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) \times 10^6$	$\sigma_{\mathcal{B}_K}/\mathcal{B}_K$	$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) \times 10^6$	$\sigma_{\mathcal{B}_{K^*}}/\mathcal{B}_{K^*}$
$[0,4]$	$(1.32 \pm 0.26 \pm 0.08)$	0.26	$(1.45 \pm 0.19 \pm 0.09)$	0.19
$[4,8]$	$(1.19 \pm 0.17 \pm 0.07)$	0.20	$(1.95 \pm 0.22 \pm 0.12)$	0.17
$[8,12]$	$(1.04 \pm 0.10 \pm 0.06)$	0.16	$(2.35 \pm 0.29 \pm 0.15)$	0.18
$[12,16]$	$(0.82 \pm 0.05 \pm 0.05)$	0.12	$(2.45 \pm 0.39 \pm 0.15)$	0.21
$[16,q^2_{\max}]$	$(0.62 \pm 0.03 \pm 0.04)$	0.11	$(1.35 \pm 0.30 \pm 0.08)$	0.28
$[0,q^2_{\max}]$	$(5.00 \pm 0.59 \pm 0.30)$	0.18	$(9.55 \pm 1.28 \pm 0.59)$	0.19

★ $\mathcal{B}(B^+ \to K^+\nu\bar{\nu})^{\text{SM}} = (5.0 \pm 0.6_{\text{had}} \pm 0.3_{\text{par}}) \times 10^{-6}$

★ $\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})^{\text{SM}} = (9.6 \pm 1.3_{\text{had}} \pm 0.6_{\text{par}}) \times 10^{-6}$



Form-Factors	$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})/\lvert\lambda_t\rvert^2$
[Bharucha+] LQCD+LCSR	$(6.0 \pm 0.8) \times 10^{-3}$

4. Improved Strategies

★ $B \to K\nu\bar{\nu}$ at high $-\, q^2$:

- $f_+(q^2)$ is precisely determined in this region in lattice computations. SM prediction under better theoretical control.
- Less statistics would be available in the experimental measurement.

$$\mathcal{B}(B^+ \to K^+\nu\bar{\nu})^{\text{SM}}_{\text{bin I}} = (1.44 \pm 0.08 \pm 0.09) \times 10^{-6} \quad q^2 \geq 12\ \text{GeV}^2\ (\text{bin I})$$

$$\mathcal{B}(B^+ \to K^+\nu\bar{\nu})^{\text{SM}}_{\text{bin II}} = (0.62 \pm 0.03 \pm 0.04) \times 10^{-6} \quad q^2 \geq 16\ \text{GeV}^2\ (\text{bin II})$$

★ $$\left.\frac{\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})}{\mathcal{B}(B \to K^{(*)}ll)}\right|_{[1.1,6]\ \text{GeV}^2} : \qquad \mathcal{R}^{(\nu/l)}_{K\,\text{SM}}[1.1,6] = 6.81 \pm 0.16 \qquad \mathcal{R}^{(\nu/l)}_{K^*\,\text{SM}}[1.1,6] = 8.5 \pm 0.4$$

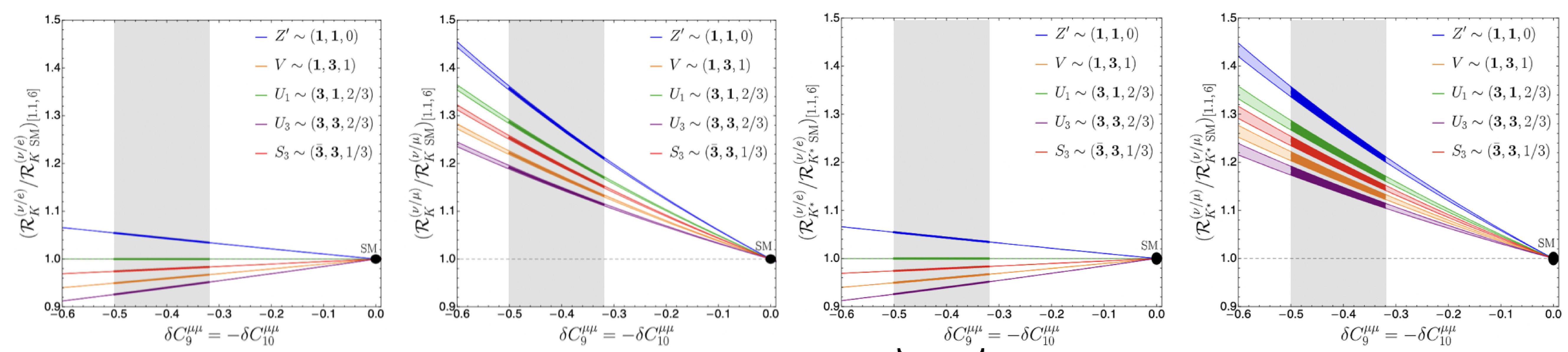
- Cancellation of CKM, good cancellation of FFs in the ratio since $m_\ell \ll m_B$. $\sigma_{\text{rel}}: 20\,\% \to 2\,\%$, $\sigma^*_{\text{rel}}: 15\,\% \to 6\,\%$,
- Long-distance contributions to C_9 ($c\bar{c}$ resonances) can shift the central value. We consider only perturbative contributions to C_9

5. BSM effects on $\mathcal{R}^{(\nu/l)}_{K^{(*)}}$

- $Z' \sim (\mathbf{1},\mathbf{1},0)$ $\quad C_{lq}^{(1)} \neq 0\,, \quad C_{lq}^{(3)} = 0$
- $V \sim (\mathbf{1},\mathbf{3},1)$ $\quad C_{lq}^{(1)} = 0\,, \quad C_{lq}^{(3)} \neq 0$
- $S_3 \sim (\bar{\mathbf{3}},\mathbf{3},1/3)$ $\quad C_{lq}^{(1)} = 3\,C_{lq}^{(3)}$
- $U_1 \sim (\mathbf{3},\mathbf{1},2/3)$ $\quad C_{lq}^{(1)} = C_{lq}^{(3)}$
- $U_3 \sim (\mathbf{3},\mathbf{3},2/3)$ $\quad C_{lq}^{(1)} = -3\,C_{lq}^{(3)}$

$$[\mathcal{O}_{lq}^{(1)}]_{ijkl} = (\bar{L}_i\gamma^\mu L_j)(\bar{Q}_k\gamma_\mu Q_l)\,,$$

$$[\mathcal{O}_{lq}^{(3)}]_{ijkl} = (\bar{L}_i\gamma^\mu\tau^I L_j)(\bar{Q}_k\tau^I\gamma_\mu Q_l)$$



$$\delta C_9^{\mu\mu} = -\delta C_{10}^{\mu\mu} = -0.41 \pm 0.09$$

Motivated BSM scenarios predict different patterns for the effective coefficients $C_{lq}^{(1)}, C_{lq}^{(3)}$ —>model-dependent correlations between $b \to s\ell\ell$ and $b \to s\nu_\ell\nu_\ell$.

$$C_9^{\ell_i\ell_i} - C_{10}^{\ell_i\ell_i} = \frac{2\pi}{\alpha_{\text{em}}\lambda_t}\frac{v^2}{\Lambda^2}\left\{[C_{lq}^{(1)}]_{ii23} + [C_{lq}^{(3)}]_{ii23}\right\}$$

$$\mathcal{R}^{(\nu/l)}_{K^{(*)}}[q_0^2,q_1^2] \equiv \frac{\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})_{\text{SM}}\,(1+\delta_{\nu\nu})}{\mathcal{B}(B \to K^{(*)}ll)_{\text{SM}}\,(1+\delta_{ll})} = \mathcal{R}^{(\nu/l)}_{K^{(*)}}\Big|_{\text{SM}}\left(1+\delta\mathcal{R}^{(\nu/l)}_{K^{(*)}}\right)$$

6. Conclusions

Besides the theoretical accuracy of the (ν/μ) ratios, which is improved compared to the separate branching fractions, the ratios proposed also allow to increase the sensitivity to New Physics effects, with contributions of $\mathcal{O}(10\%)$ for the electron case, and $\mathcal{O}(40\%)$ for the muon case.

This project has received support from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860881-HIDDeN.