# The promising $B \to K^* \nu\bar{\nu}$ in view of SMEFT


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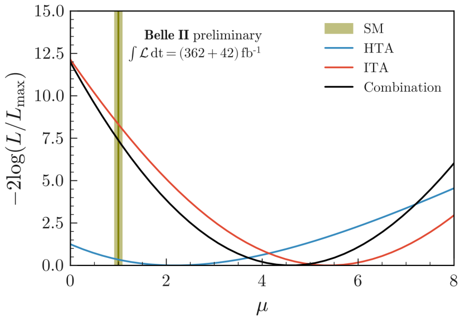
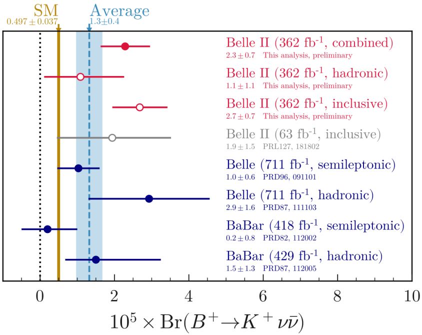
# Outline

1. Belle-II measurement vs SM prediction
2. Effective field theory
3. Matching to SMEFT
4. Results

# Combination and Comparison with other measurements




Significance of Belle-II observation is 3.6 $\sigma$ and the result is within 2.8 $\sigma$ vs SM

$$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu})_{\mathrm{exp}} = (2.3 \pm 0.7) \times 10^{-5}$$

$$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu})_{\mathrm{SM}} = (0.497 \pm 0.037) \times 10^{-5}$$

W. G. Parrott, C. Bouchard, and C. T. H. Davies, Phys. Rev. D 107, 014511 (2023)

# New Physics

- Heavy NP particles (missing energies are carried by SM neutrinos)
  - Leptoquark
  - 2HDM
  - ...
- Light NP particles (missing energies are carried by new light particles)
  - Right-handed neutrinos
  - Axion/ axion-like particles
  - Dark matter
  - ...

# Effective Field Theory

- Low-energy effective field theory (LEFT)

$$\mathcal{L}_{\rm LEFT} = \mathcal{L}_{\rm QED+QCD} + \mathcal{L}^{(3)}_{\not{L}} + \sum_i \sum_{d \geq 5} L_i^{(d)} \mathcal{O}_i^{(d)}$$

  - Symmetry: $SU(3)_C \times U(1)_{em}$
  - Scale: $\mu < \Lambda_{\rm EW}$
  - Degrees of freedom: SM particles except $W$, $Z$, $t$, $h$
  - Power counting: $L_i^{(d)} \sim 1/v^{d-4}$

- Standard Model effective field theory (SMEFT)

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \sum_{d \geq 5} C_i^{(d)} \mathcal{Q}_i^{(d)}$$

  - Symmetry: $SU(3)_C \times SU(2)_L \times U(1)_Y$
  - Scale: $\mu \in [\Lambda_{\rm EW}, \Lambda]$, $\Lambda \gg \Lambda_{\rm EW}$
  - Degrees of freedom: SM particles
  - Power counting: $C_i^{(d)} \sim 1/\Lambda^{d-4}$

- EFT extension with right-handed neutrino
  - LEFT+right-handed neutrino $N_R \to$ LNEFT
  - SMEFT+right-handed neutrino $N_R \to$ SMNEFT

# $b \to s\nu\bar{\nu}$ transition

- Effective Hamiltonian (assuming lepton flavor is conserved and no $\nu_R$), $C_{V,LL}^{\nu_\ell,\mathrm{SM}} = -6.32$, $C_{V,RL}^{\nu_\ell,\mathrm{SM}} = 0$

$$\mathcal{H}_{\mathrm{eff}} = -\frac{8G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} \left[ C_{V,LL}^{\nu_\ell} \mathcal{O}_{V,LL}^{\nu_\ell} + C_{V,RL}^{\nu_\ell} \mathcal{O}_{V,RL}^{\nu_\ell} \right] + \mathrm{h.c.}$$

$$\mathcal{O}_{V,LL}^{\nu_\ell} = (\bar{s}\gamma_\mu P_L b)(\bar{\nu}_\ell \gamma^\mu P_L \nu_\ell), \quad \mathcal{O}_{V,RL}^{\nu_\ell} = (\bar{s}\gamma_\mu P_R b)(\bar{\nu}_\ell \gamma^\mu P_L \nu_\ell)$$

- $B^+ \to K^+\nu\bar{\nu}$ and $B^0 \to K^{*0}\nu_\ell\bar{\nu}_\ell$

$$\mathcal{B}(B^+ \to K^+\nu_\ell\bar{\nu}_\ell) = 3.46 \times 10^{-8} \left| C_{V,LL}^{\nu_\ell} + C_{V,RL}^{\nu_\ell} \right|^2$$

$$\mathcal{B}(B^0 \to K^{*0}\nu_\ell\bar{\nu}_\ell) = 6.84 \times 10^{-8} \left| C_{V,LL}^{\nu_\ell} - C_{V,RL}^{\nu_\ell} \right|^2 + 1.36 \times 10^{-8} \left| C_{V,LL}^{\nu_\ell} + C_{V,RL}^{\nu_\ell} \right|^2$$

$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})_{\mathrm{exp}} < 1.8 \times 10^{-5}$ vs $\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})_{\mathrm{SM}} = (9.2 \pm 1.0) \times 10^{-6}$

- No-go scenario with a single parameter, e.g., $C_{V,LL}^{\nu_\ell} \neq 0$, $C_{V,RL}^{\nu_\ell} = 0$

$$\begin{cases} \frac{\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})}{\mathcal{B}(B^+ \to K^+\nu\bar{\nu})} = \frac{8.20\times 10^{-8} \left| C_{V,LL}^{\nu_\ell} \right|^2}{3.46\times 10^{-8} \left| C_{V,LL}^{\nu_\ell} \right|^2} \simeq 2.37 \\ \mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (2.3 \pm 0.7) \times 10^{-5} \end{cases}$$

$$\Rightarrow \quad \mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) = (5.5 \pm 1.7) \times 10^{-5} > 1.8 \times 10^{-5}$$

# Matching to SMEFT

| $b \to s\ell^+\ell^-$ | | SMEFT | | $b \to s\nu\bar{\nu}$ |
|---|---|---|---|---|
| $\mathcal{O}^{\ell}_{V,LL}$ | $\longleftarrow$ | $[\mathcal{O}^{(1)}_{\ell q}]_{\ell\ell 23}$ | $\longrightarrow$ | $\mathcal{O}^{\nu_\ell}_{V,LL}$ |
| $\mathcal{O}^{\ell}_{V,LL}$ | $\longleftarrow$ | $[\mathcal{O}^{(3)}_{\ell q}]_{\ell\ell 23}$ | $\longrightarrow$ | $-\mathcal{O}^{\nu_\ell}_{V,LL}$ |
| $\mathcal{O}^{\ell}_{V,RL}$ | $\longleftarrow$ | $[\mathcal{O}_{\ell d}]_{\ell\ell 23}$ | $\longrightarrow$ | $\mathcal{O}^{\nu_\ell}_{V,RL}$ |
| $\mathcal{O}^{\ell}_{V,LR}$ | $\longleftarrow$ | $[\mathcal{O}_{qe}]_{23\ell\ell}$ | | |
| $\mathcal{O}^{\ell}_{V,RR}$ | $\longleftarrow$ | $[\mathcal{O}_{ed}]_{\ell\ell 23}$ | | |

$$[\mathcal{O}^{(3)}_{\ell q}]_{\ell\ell 23} \longrightarrow \sum_i 2V_{is}(\bar{\ell}\gamma_\mu P_L \nu_\ell)(\bar{u}_i \gamma_\mu P_L b)$$

where ($Q_i = [(V^\dagger u_L)_i, d_{Li}]$)

$$\mathcal{O}^{\ell}_{V,LL} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu P_L \ell),$$
$$\mathcal{O}^{\ell}_{V,RL} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu P_L \ell),$$
$$\mathcal{O}^{\ell}_{V,LR} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu P_R \ell),$$
$$\mathcal{O}^{\ell}_{V,RR} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu P_R \ell),$$

$$[\mathcal{O}^{(1)}_{\ell q}]_{prst} = (\bar{L}_p \gamma^\mu L_r)(\bar{Q}_s \gamma_\mu Q_t),$$
$$[\mathcal{O}^{(3)}_{\ell q}]_{prst} = (\bar{L}_p \gamma^\mu \tau^I L_r)(\bar{Q}_s \gamma_\mu \tau^I Q_t),$$
$$[\mathcal{O}_{\ell d}]_{prst} = (\bar{L}_p \gamma^\mu L_r)(\bar{d}_{Rs} \gamma_\mu d_{Rt}),$$
$$[\mathcal{O}_{qe}]_{prst} = (\bar{Q}_p \gamma^\mu Q_r)(\bar{e}_{Rs} \gamma_\mu e_{Rt}),$$
$$[\mathcal{O}_{ed}]_{prst} = (\bar{e}_{Rp} \gamma^\mu e_{Rr})(\bar{d}_{Rs} \gamma_\mu d_{Rt}),$$

$$\mathcal{O}^{\nu_\ell}_{V,LL} = (\bar{s}\gamma_\mu P_L b)(\bar{\nu}_\ell \gamma^\mu P_L \nu_\ell)$$
$$\mathcal{O}^{\nu_\ell}_{V,RL} = (\bar{s}\gamma_\mu P_R b)(\bar{\nu}_\ell \gamma^\mu P_L \nu_\ell)$$

# $b \to s\ell^+\ell^-$ and $b \to u_i \ell \nu_\ell$

- $b \to s\ell^+\ell^-$

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} \sum_i \left[ C_i^\ell \mathcal{O}_i^\ell + C_i^{\ell\prime} \mathcal{O}_i^{\ell\prime} \right] + \text{h.c.}$$

where $(\mathcal{O}_{9,10}^\ell = \mathcal{O}_{V,LR}^\ell \pm \mathcal{O}_{V,LL}^\ell\,, \quad \mathcal{O}_{9,10}^{\ell\prime} = \mathcal{O}_{V,RR}^\ell \pm \mathcal{O}_{V,RL}^\ell)$

$$\mathcal{O}_9^\ell = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad \mathcal{O}_9^{\ell\prime} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,,$$
$$\mathcal{O}_{10}^\ell = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \qquad \mathcal{O}_{10}^{\ell\prime} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,,$$

Observables: $B_s \to \ell^+\ell^-$, $R_{K^{(*)}}$, $\Lambda_b \to \Lambda \ell^+\ell^-$ $\cdots$

- $b \to u_i \ell \nu_\ell$

$$\mathcal{H}_{\rm eff} = \frac{4G_F}{\sqrt{2}} V_{ib} \left[ C_{V,LL}^{\ell u_i} \mathcal{O}_{V,LL}^{\ell u_i} + C_{V,RL}^{\ell u_i} \mathcal{O}_{V,RL}^{\ell u_i} \right]$$

where

$$\mathcal{O}_{V,LL}^{\ell u_i} = (\bar{c}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu P_L \nu_\ell), \qquad \mathcal{O}_{V,RL}^{\ell u_i} = (\bar{c}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu P_L \nu_\ell) \tag{1}$$

Observables: $R_{D^{(*)}}$, $B_c^+ \to \tau^+\nu_\tau$, $B^+ \to \tau^+\nu_\tau$, $\cdots$

# RGE and Wilson coefficient matching relation

- Small RG running effects between $\mu_b$ and $\mu_{EW}$

$$\mu \frac{dC^{\ell}_{V,XY}}{d\mu} = \pm 12 q_d q_e \frac{\alpha_{em}}{4\pi} C^{\ell}_{V,XY}, \qquad (+ \text{ for } XY = LL, RR, \; - \text{ for } XY = LR, RL)$$

$$\mu \frac{dC^{\ell u_i}_{V,XY}}{d\mu} = \pm 6 q_u q_e \frac{\alpha_{em}}{4\pi} C^{\ell u_i}_{V,XY}, \qquad (+ \text{ for } XY = LL, \; - \text{ for } XY = RL)$$

$$\mu \frac{dC^{\nu_\ell}_{V,XY}}{d\mu} = 0, \qquad (\text{for } XY = LL, RL)$$

- Matching to SMEFT ($\ell = e, \mu, \tau$)

$$\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha}{4\pi} (C^{\ell}_9 - C^{\ell}_{10}) = [C^{(1)}_{\ell q}]_{\ell\ell 23} + [C^{(3)}_{\ell q}]_{\ell\ell 23}, \qquad \frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha}{4\pi} (C^{\ell}_9 + C^{\ell}_{10}) = [C_{qe}]_{23\ell\ell},$$

$$\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha}{4\pi} (C^{\ell\prime}_9 + C^{\ell\prime}_{10}) = [C_{ed}]_{\ell\ell 23}, \qquad \frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha}{4\pi} (C^{\ell\prime}_9 - C^{\ell\prime}_{10}) = [C_{\ell d}]_{\ell\ell 23},$$

$$\frac{8G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha}{4\pi} C^{\nu_\ell}_{V,LL} = [C^{(1)}_{\ell q}]_{\ell\ell 23} - [C^{(3)}_{\ell q}]_{\ell\ell 23}, \qquad \frac{8G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha}{4\pi} C^{\nu_\ell}_{V,RL} = [C_{\ell d}]_{\ell\ell 23},$$

$$\frac{4G_F}{\sqrt{2}} \frac{V_{ib}}{2V_{is}} C^{\ell u_i}_{V,LL} = [C^{(3)}_{\ell q}]_{\ell\ell 23},$$

# Global fits of new physics in $b \to s$ after the $R_{K^{(*)}}$ 2022 release

Qiaoyi Wen, Fanrong Xu, Phys.Rev.D 108 (2023) 9, 095038

effective Hamiltonian: $\mathscr{H} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i \mathcal{O}_i + C_i' \mathcal{O}_i') + h.c.$

high energy information

$C_i^{(\prime)\ell} = C_i^{(\prime)\ell;\mathrm{SM}} + \Delta C_i^{(\prime)\ell;\mathrm{NP}} = C_i^{(\prime)\ell;\mathrm{SM}} + \Delta C_i^{(\prime)\ell}$

QCDF

decay amplitude:

SM

$$\mathcal{O}_7 = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_R b)F^{\mu\nu}, \qquad \mathcal{O}_7' = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_L b)F^{\mu\nu},$$
$$\mathcal{O}_8 = \frac{g_s m_b}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_R b)G_a^{\mu\nu}, \qquad \mathcal{O}_8' = \frac{g_s m_b}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_L b)G_a^{\mu\nu},$$
$$\mathcal{O}_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell), \qquad \mathcal{O}_9' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell),$$
$$\mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell), \qquad \mathcal{O}_{10}' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell),$$
$$\mathcal{O}_S = m_b(\bar{s}P_R b)(\bar{\ell}\ell), \qquad \mathcal{O}_S' = m_b(\bar{s}P_L b)(\bar{\ell}\ell),$$
$$\mathcal{O}_P = m_b(\bar{s}P_R b)(\bar{\ell}\gamma_5 \ell), \qquad \mathcal{O}_P' = m_b(\bar{s}P_L b)(\bar{\ell}\gamma_5 \ell).$$

' in leading logarithmic (LL), next-to-leading logarithmic (NLL) and
ers listed in Table II are used.

| | | | | | $C_5$ | $C_6$ | $C_7^{\mathrm{eff}}$ | $C_8^{\mathrm{eff}}$ | $C_9$ | $C_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| LL | −0.5093 | 1.0256 | −0.0050 | −0.0686 | 0.0005 | 0.0010 | −0.3189 | −0.1505 | 2.0111 | 0 |
| NLL | −0.3001 | 1.0080 | −0.0047 | −0.0827 | 0.0003 | 0.0009 | −0.2969 | −0.1642 | 4.1869 | −4.3973 |
| NNLL | – | – | – | – | – | – | – | – | 4.2607 | −4.2453 |

| Params | S-I' | S-II' | S-III' | S-IV' | S-I | S-II | S-III | S-IV | ADCMN [23] | AS [24] | HMMN [25] | GGJLCS [26] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduced $\chi^2$ | 183.404/(n-12) | 197.556/(n-12) | 182.869/(n-16) | 176.807/(n-20) | 190.044/(n-12) | 177.891/(n-12) | 185.386/(n-16) | 178.953/(n-20) | 260.66/(254-6) | | 179.1/(183-20) | 96.88/90 |
| $\chi^2_{\mathrm{min}}$/d.o.f | = 0.970 | = 1.045 | = 0.988 | = 0.977 | = 0.995 | = 0.931 | = 0.991 | = 0.978 | = 1.05 | | = 1.1 | = 1.08 |
| $\Delta C_7$ | $-0.003^{+0.020}_{-0.019}$ | $-0.001^{+0.015}_{-0.015}$ | ⋯ | $0.001^{+0.016}_{-0.015}$ | $-0.000^{+0.020}_{-0.020}$ | $-0.001^{+0.015}_{-0.015}$ | ⋯ | $-0.000^{+0.016}_{-0.015}$ | $0.00^{+0.01}_{-0.02}$ | ⋯ | $0.06^{+0.03}_{-0.03}$ | ⋯ |
| $\Delta C_7'$ | $0.017^{+0.018}_{-0.019}$ | $0.020^{+0.014}_{-0.015}$ | ⋯ | $0.020^{+0.014}_{-0.014}$ | $0.017^{+0.020}_{-0.018}$ | $0.020^{+0.015}_{-0.014}$ | ⋯ | $0.023^{+0.014}_{-0.016}$ | $+0.00^{+0.02}_{-0.01}$ | ⋯ | $-0.01^{+0.01}_{-0.01}$ | ⋯ |
| $\Delta C_8$ | $-0.788^{+0.595}_{-0.514}$ | $-0.885^{+0.435}_{-0.398}$ | ⋯ | $-0.773^{+0.451}_{-0.449}$ | $-0.995^{+0.540}_{-0.463}$ | $-0.921^{+0.443}_{-0.378}$ | ⋯ | $-0.773^{+0.465}_{-0.424}$ | ⋯ | ⋯ | $-0.80^{+0.40}_{-0.40}$ | ⋯ |
| $\Delta C_8'$ | $-0.073^{+1.089}_{-1.000}$ | $-0.093^{+0.921}_{-0.831}$ | ⋯ | $-0.089^{+0.996}_{-0.922}$ | $-0.080^{+1.046}_{-0.942}$ | $-0.076^{+0.893}_{-0.833}$ | ⋯ | $-0.258^{+1.007}_{-0.802}$ | ⋯ | ⋯ | $-0.30^{+1.30}_{-1.30}$ | ⋯ |
| $\Delta C_9^\mu$ | $-0.806^{+0.257}_{-0.272}$ | $-0.795^{+0.205}_{-0.210}$ | $-1.068^{+0.161}_{-0.164}$ | $-0.863^{+0.214}_{-0.227}$ | $-0.752^{+0.262}_{-0.265}$ | $-0.789^{+0.198}_{-0.210}$ | $-1.054^{+0.163}_{-0.171}$ | $-0.872^{+0.215}_{-0.215}$ | $-1.08^{+0.18}_{-0.17}$ | $-0.82^{+0.23}_{-0.23}$ | $-1.14^{+0.19}_{-0.19}$ | $-1.07^{+0.29}_{-0.29}$ |
| $\Delta C_9'^\mu$ | $0.194^{+0.395}_{-0.416}$ | $0.056^{+0.338}_{-0.342}$ | $0.112^{+0.393}_{-0.397}$ | $0.020^{+0.346}_{-0.362}$ | $0.174^{+0.434}_{-0.441}$ | $0.048^{+0.338}_{-0.348}$ | $0.130^{+0.439}_{-0.437}$ | $0.088^{+0.342}_{-0.378}$ | $0.16^{+0.37}_{-0.36}$ | $-0.10^{+0.34}_{-0.34}$ | $0.05^{+0.32}_{-0.32}$ | $0.32^{-0.21}_{+0.21}$ |
| $\Delta C_{10}^\mu$ | $0.236^{+0.216}_{-0.193}$ | $0.145^{+0.166}_{-0.156}$ | $0.164^{+0.181}_{-0.180}$ | $0.213^{+0.166}_{-0.155}$ | $-0.019^{+0.206}_{-0.175}$ | $0.163^{+0.165}_{-0.160}$ | $0.112^{+0.166}_{-0.184}$ | $0.171^{+0.157}_{-0.175}$ | $0.15^{+0.13}_{-0.13}$ | $+0.14^{+0.23}_{-0.23}$ | $0.21^{-0.20}_{+0.20}$ | $0.21^{-0.14}_{+0.14}$ |
| $\Delta C_{10}'^\mu$ | $-0.096^{+0.251}_{-0.237}$ | $-0.108^{+0.186}_{-0.177}$ | $-0.115^{+0.200}_{-0.198}$ | $-0.089^{+0.177}_{-0.176}$ | $-0.118^{+0.266}_{-0.247}$ | $-0.093^{+0.183}_{-0.179}$ | $-0.115^{+0.215}_{-0.213}$ | $-0.062^{+0.197}_{-0.180}$ | $-0.18^{+0.20}_{-0.18}$ | $-0.33^{+0.23}_{-0.23}$ | $-0.03^{+0.19}_{-0.19}$ | $-0.26^{-0.14}_{+0.14}$ |
| $\Delta C_S^\mu$ | $0.066^{+1.091}_{-1.142}$ | $-0.004^{+1.102}_{-1.131}$ | $-0.008^{+0.883}_{-0.899}$ | $-0.043^{+0.842}_{-0.875}$ | $0.023^{+1.064}_{-1.097}$ | $0.060^{+1.188}_{-1.230}$ | $-0.066^{+0.944}_{-0.929}$ | $0.009^{+0.858}_{-0.845}$ | ⋯ | ⋯ | $0.01^{+0.05}_{-0.05}$ | ⋯ |
| $\Delta C_S'^\mu$ | $0.065^{+1.087}_{-1.140}$ | $0.003^{+1.103}_{-1.126}$ | $-0.002^{+0.873}_{-0.936}$ | $-0.059^{+0.844}_{-0.869}$ | $0.014^{+1.064}_{-1.086}$ | $0.061^{+1.188}_{-1.225}$ | $-0.070^{+0.957}_{-0.930}$ | $0.012^{+0.858}_{-0.862}$ | ⋯ | ⋯ | $-0.01^{+0.05}_{-0.05}$ | ⋯ |
| $\Delta C_P^\mu$ | $0.167^{+1.172}_{-1.225}$ | $1.017^{+0.735}_{-0.816}$ | $0.092^{+1.076}_{-0.994}$ | $0.117^{+0.847}_{-0.894}$ | $0.079^{+1.159}_{-1.146}$ | $0.478^{+0.808}_{-0.899}$ | $0.189^{+1.018}_{-1.028}$ | $0.124^{+0.902}_{-0.910}$ | ⋯ | ⋯ | $-0.04^{+0.02}_{-0.02}$ | ⋯ |
| $\Delta C_P'^\mu$ | $0.053^{+1.169}_{-1.227}$ | $0.891^{+0.729}_{-0.812}$ | $0.010^{+1.083}_{-1.002}$ | $0.040^{+0.854}_{-0.895}$ | $-0.032^{+1.158}_{-1.145}$ | $0.370^{+0.803}_{-0.897}$ | $0.098^{+1.009}_{-1.024}$ | $0.038^{+0.894}_{-0.913}$ | ⋯ | ⋯ | $-0.04^{+0.02}_{-0.02}$ | ⋯ |
| $\Delta C_9^e$ | ⋯ | $-0.795^{+0.205}_{-0.210}$ | $-1.753^{+0.781}_{-0.772}$ | $-1.551^{+0.627}_{-0.599}$ | ⋯ | $-0.789^{+0.198}_{-0.210}$ | $-1.623^{+0.662}_{-0.734}$ | $-1.511^{+0.561}_{-0.533}$ | ⋯ | $-0.24^{+1.17}_{-1.17}$ | $-6.50^{+1.90}_{-1.90}$ | ⋯ |
| $\Delta C_9'^e$ | ⋯ | $0.056^{+0.338}_{-0.342}$ | $1.725^{+1.724}_{-2.286}$ | $1.710^{+1.466}_{-1.764}$ | ⋯ | $0.048^{+0.338}_{-0.348}$ | $1.090^{+1.610}_{-1.793}$ | $0.864^{+1.483}_{-1.608}$ | ⋯ | ⋯ | $1.40^{+2.30}_{-2.30}$ | ⋯ |
| $\Delta C_{10}^e$ | ⋯ | $0.145^{+0.166}_{-0.156}$ | $0.108^{+1.456}_{-0.661}$ | $0.058^{+1.193}_{-0.661}$ | ⋯ | $0.163^{+0.165}_{-0.160}$ | $0.555^{+1.042}_{-0.576}$ | $0.383^{+0.840}_{-0.424}$ | ⋯ | $-0.24^{+0.78}_{-0.78}$ | ∼0 | ⋯ |
| $\Delta C_{10}'^e$ | ⋯ | $-0.108^{+0.186}_{-0.177}$ | $0.600^{+1.208}_{-1.099}$ | $0.655^{+0.958}_{-0.841}$ | ⋯ | $-0.093^{+0.183}_{-0.179}$ | $0.088^{+0.969}_{-0.956}$ | $0.002^{+0.881}_{-0.815}$ | ⋯ | ⋯ | ∼0 | ⋯ |
| $\Delta C_S^e$ | ⋯ | $-0.004^{+1.102}_{-1.131}$ | $-0.719^{+1.861}_{-1.227}$ | $-0.549^{+1.602}_{-1.232}$ | ⋯ | $0.060^{+1.188}_{-1.230}$ | $-0.952^{+2.122}_{-1.139}$ | $-0.806^{+1.900}_{-1.238}$ | ⋯ | ⋯ | $-0.38^{+0.41}_{-0.41}$ | ⋯ |
| $\Delta C_S'^e$ | ⋯ | $0.003^{+1.103}_{-1.126}$ | $-0.699^{+1.837}_{-1.224}$ | $-0.550^{+1.618}_{-1.326}$ | ⋯ | $0.061^{+1.188}_{-1.225}$ | $-1.051^{+2.251}_{-1.075}$ | $-0.803^{+1.861}_{-1.194}$ | ⋯ | ⋯ | $-0.36^{+0.50}_{-0.50}$ | ⋯ |
| $\Delta C_P^e$ | ⋯ | $1.017^{+0.735}_{-0.816}$ | $-1.592^{+1.552}_{-1.079}$ | $-1.688^{+1.366}_{-0.978}$ | ⋯ | $0.478^{+0.808}_{-0.899}$ | $-1.568^{+1.544}_{-1.149}$ | $-1.837^{+1.376}_{-0.930}$ | ⋯ | ⋯ | $-0.98^{+0.21}_{-0.21}$ | ⋯ |
| $\Delta C_P'^e$ | ⋯ | $0.891^{+0.729}_{-0.812}$ | $-1.360^{+1.318}_{-1.149}$ | $-1.431^{+1.212}_{-1.017}$ | ⋯ | $0.370^{+0.803}_{-0.897}$ | $-1.477^{+1.409}_{-1.083}$ | $-1.652^{+1.200}_{-0.979}$ | ⋯ | ⋯ | $-0.95^{+0.29}_{-0.29}$ | ⋯ |

# Discussion

- Global fit results show that, for $\ell = e, \mu$ Qiaoyi Wen, Fanrong Xu, Phys.Rev.D 108 (2023) 9, 095038

$$C_9^\ell \neq 0\,, \quad C_9^{\ell\prime} \sim C_{10}^\ell \sim C_{10}^{\ell\prime} \sim 0$$

$$\Rightarrow \quad [C_{qe}]_{23\ell\ell} = [C_{\ell q}^{(1)}]_{\ell\ell 23} + [C_{\ell q}^{(3)}]_{\ell\ell 23}\,, \quad [C_{ed}]_{\ell\ell 23} = [C_{\ell d}]_{\ell\ell 23} = 0\,, \quad C_{V,RL}^{\nu_\ell} = 0$$

- For $\ell = \tau$, all WCs are free parameters, The SMEFT WCs that simultaneously contribute to both $b \to s\ell^+\ell^-$ and $b \to s\nu\bar{\nu}$ are $[C_{\ell q}^{(1)}]_{3323}, [C_{\ell q}^{(3)}]_{3323}, [C_{\ell d}]_{3323}$:

$$\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} (C_9^\tau - C_{10}^\tau) = [C_{\ell q}^{(1)}]_{3323} + [C_{\ell q}^{(3)}]_{3323}\,, \quad \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} (C_9^{\tau\prime} - C_{10}^{\tau\prime}) = [C_{\ell d}]_{3323}\,,$$

$$\frac{8G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} C_{V,LL}^{\nu_\tau} = [C_{\ell q}^{(1)}]_{3323} - [C_{\ell q}^{(3)}]_{3323}\,, \quad \frac{8G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} C_{V,RL}^{\nu_\tau} = [C_{\ell d}]_{3323}$$

- $[C_{\ell q}^{(3)}]_{3323}$ also contributes to $b \to u_i \tau \nu_\tau$

$$\frac{4G_F}{\sqrt{2}} \frac{V_{ib}}{2V_{is}} C_{V,LL}^{\tau u_i} = [C_{\ell q}^{(3)}]_{3323}$$

# Wilson coefficients summary

| Parameter | Process |
|---|---|
| $C_9^{\ell} = \dfrac{[C_{\ell q}^{(1)}]_{\ell\ell 23} + [C_{\ell q}^{(3)}]_{\ell\ell 23}}{\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi}}$, | $(b \to s\ell^+\ell^-,\ \ell = e, \mu)$ |
| $C_{V,LL}^{\nu_\ell} = \dfrac{[C_{\ell q}^{(1)}]_{\ell\ell 23} - [C_{\ell q}^{(3)}]_{\ell\ell 23}}{\frac{8G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi}}$, | $(b \to s\nu_\ell\bar{\nu}_\ell,\ \ell = e, \mu, \tau)$ |
| $C_{V,RL}^{\nu_\tau} = \dfrac{[C_{\ell d}]_{3323}}{\frac{8G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi}}$, | $(b \to s\nu_\tau\bar{\nu}_\tau)$ |
| $C_{V,LL}^{\tau u_i} = \dfrac{[C_{\ell q}^{(3)}]_{3323}}{\frac{4G_F}{\sqrt{2}} \frac{V_{ib}}{2V_{is}}},\ C_{V,RL}^{\tau u_i}$ | $(b \to u_i\tau\nu_\tau)$ |
| $C_9^{\tau} - C_{10}^{\tau} = \dfrac{[C_{\ell q}^{(1)}]_{3323} + [C_{\ell q}^{(3)}]_{3323}}{\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi}}$, | $(b \to s\tau^+\tau^-)$ |
| $C_9^{\tau\prime} - C_{10}^{\tau\prime} = \dfrac{[C_{\ell d}]_{3323}}{\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi}}$, | $(b \to s\tau^+\tau^-)$ |

# Observables summary

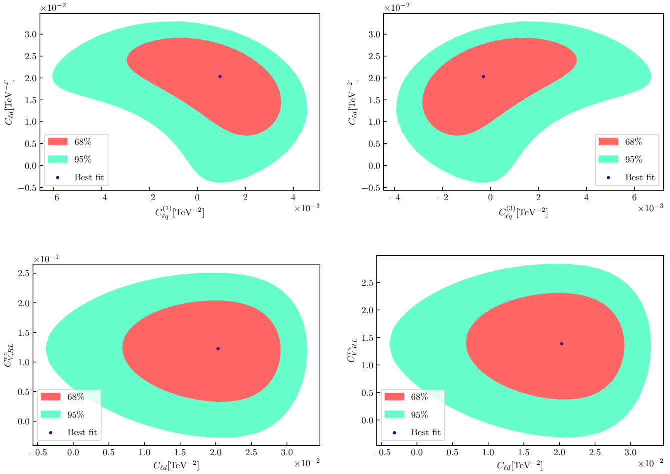
$$
\begin{aligned}
\mathcal{B}(B^+ \to K^+ \nu_\ell \bar{\nu}_\ell) &= 3.46 \times 10^{-8} \left| C^{\nu_\ell}_{V,LL} + C^{\nu_\ell}_{V,RL} \right|^2 \\
\mathcal{B}(B^0 \to K^{*0} \nu_\ell \bar{\nu}_\ell) &= 6.84 \times 10^{-8} \left| C^{\nu_\ell}_{V,LL} - C^{\nu_\ell}_{V,RL} \right|^2 + 1.36 \times 10^{-8} \left| C^{\nu_\ell}_{V,LL} + C^{\nu_\ell}_{V,RL} \right|^2 \\
R_D &= R_D^{\rm SM} \left[ 1 + 1.5 \mathrm{Re} \left( C^{\tau c}_{V,RL} + C^{\tau c}_{V,LL} \right) + 1.0 \left| C^{\tau c}_{V,RL} + C^{\tau c}_{V,LL} \right|^2 \right] \\
R_{D^*} &= R_{D^*}^{\rm SM} \left[ 1 + 0.12 \mathrm{Re} \left( C^{\tau c}_{V,RL} - C^{\tau c}_{V,LL} \right) + 0.05 \left| C^{\tau c}_{V,RL} - C^{\tau c}_{V,LL} \right|^2 \right] \\
\mathcal{B}(B_c^+ \to \tau^+ \nu_\tau) &= 2.32 \times 10^{-2} \left| (1 + C^{\tau c}_{V,LL}) - C^{\tau c}_{V,RL} \right|^2 \\
\mathcal{B}(B^+ \to \tau^+ \nu_\tau) &= 8.88 \times 10^{-5} \left| (1 + C^{\tau u}_{V,LL}) - C^{\tau u}_{V,RL} \right|^2 \\
\mathcal{B}(B_s \to \tau^+ \tau^-) &= 1.41 \times 10^{-8} \left| m_\tau (C^{\tau}_{10} - C^{\tau\prime}_{10}) \right|^2
\end{aligned}
$$

# Inputs

| | |
|---|---|
| $\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (2.3 \pm 0.7) \times 10^{-5}$, | Belle II 2311.14647 |
| $\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) < 1.8 \times 10^{-5}$ (90%$CL$), | Belle Phys.Rev.D 97, 09902 (2018) |
| $\mathcal{B}(B_s \to \tau^+\tau^-) < 6.8 \times 10^{-3}$, | LHCb Phys.Rev.Lett 118 (2017) 14647 |
| $\mathcal{B}(B^+ \to \tau^+\nu_\tau) = (1.25 \pm 0.39) \times 10^{-4}$, | Belle Phys.Rev.D 92, 051102 |
| $R_D = 0.357 \pm 0.029$, | HFLAV Phys.Rev.D 107 052008 |
| $R_{D^*} = 0.284 \pm 0.012$ | HFLAV Phys.Rev.D 107 052008 |
| $C_9^\mu = -0.789^{+0.198}_{-0.210}$ | Q. Wen and F. Xu Phys.Rev.D 108 (2023) 9, 095038 |

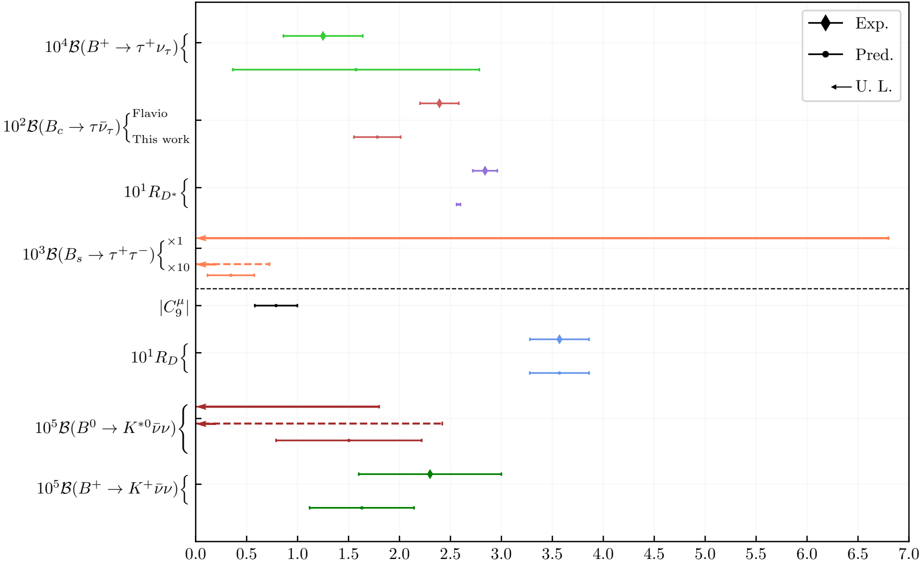
# Results

| WC ($\mathrm{GeV}^{-2}$) | Value |
|---|---|
| $[C_{\ell q}^{(1)}]_{2223}$ | $(0.9 \pm 2.2) \times 10^{-3}$ |
| $[C_{\ell q}^{(3)}]_{2223}$ | $(-0.3 \pm 2.2) \times 10^{-3}$ |
| $[C_{\ell d}]_{3323}$ | $(2 \pm 0.8) \times 10^{-2}$ |
| $C_{V,RL}^{\tau c}$ | $0.12 \pm 0.06$ |
| $C_{V,RL}^{\tau u}$ | $1.4 \pm 0.7$ |



# Remake predictions

| Observable | prediction | measurement |
|---|---|---|
| $\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$ | $(1.63 \pm 0.51) \times 10^{-5}$ | $(2.3 \pm 0.7) \times 10^{-5}$ |
| $\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})$ | $(1.50 \pm 0.72) \times 10^{-5}$ | $< 1.8 \times 10^{-5}$ |
| $\mathcal{B}(B_s \to \tau^+\tau^-)$ | $(3.45 \pm 2.34) \times 10^{-5}$ | $< 6.8 \times 10^{-3}$ |
| $\mathcal{B}(B^+ \to \tau^+\nu_\tau)$ | $(1.57 \pm 1.21) \times 10^{-4}$ | $(1.25 \pm 0.39) \times 10^{-4}$ |
| $\mathcal{B}(B_c^+ \to \tau^+\nu_\tau)$ | $0.018 \pm 0.02$ | $0.024 \pm 0.02$ |
| $R_D$ | $0.357 \pm 0.029$ | $0.357 \pm 0.029$ |
| $R_{D*}$ | $0.258 \pm 0.002$ | $0.284 \pm 0.012$ |
| $C_9^\mu$ | $-0.789 \pm 0.210$ | $-0.789^{+0.198}_{-0.210}$ |


$10^4\mathcal{B}(B^+ \to \tau^+\nu_\tau)$
Flavio
This work
$10^2\mathcal{B}(B_c \to \tau\bar{\nu}_\tau)$
$10^1 R_{D^*}$
×1
×10
$10^3\mathcal{B}(B_s \to \tau^+\tau^-)$
$|C_9^\mu|$
$10^1 R_D$
$10^5\mathcal{B}(B^0 \to K^{*0}\bar{\nu}\nu)$
$10^5\mathcal{B}(B^+ \to K^+\bar{\nu}\nu)$
Exp.
Pred.
U. L.
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

# Summary

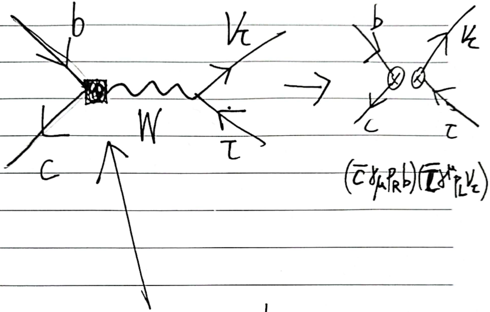
- We have used SMEFT to link $B^+ \to K^+ \nu\bar{\nu}$ and $B^0 \to K^{*0}\nu\bar{\nu}$ to $C_9^\mu$, $R_{D^{(*)}}$, $B_s \to \tau^+\tau^-$, and $B^+_{u,c} \to \tau^+\nu_\tau$, the best fit values of parameters are obtained by using the maximum likelihood function, we also remake predictions on these observables by using the fit results;
- All observables except $R_{D^*}$ are consistent with current experimental bounds; our prediction on $B_c^+ \to \tau^+\nu_\tau$ also deviate from the result of Flavio;
- The value of $|C_9^\mu|$ almost overlaps with the one of our previous work;
- The upper limit of $B^0 \to K^{*0}\nu\bar{\nu}$ is slightly larger than the one of current experiment;
- Our prediction on $B_s \to \tau^+\tau^-$ is about two order of magnitude more stringent than the current upper limit, which may be checked by the future experiment, e.g., CEPC.

# Backup

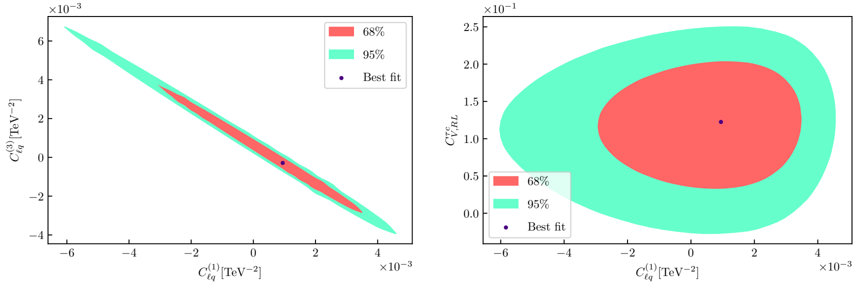
In the flavor basis with diagonal down-type quark Yukawa matrix (CKM matrix element in the upper component: $Q_i = [(V^\dagger u_L)_i, d_{Li}]^T$)

$$
\begin{aligned}
[\mathcal{O}_{\ell q}^{(3)}]_{prst} =& (\bar{L}_p \gamma^\mu \tau^I L_r)(\bar{Q}_s \gamma_\mu \tau^I Q_t) \\
=& \left[ (\bar{\nu}_{Lp}, \bar{\ell}_{Lp}) \gamma^\mu \tau^I \begin{pmatrix} \nu_{Lr} \\ \ell_{Lr} \end{pmatrix} \right] \left[ (\bar{u}_{Li} V_{is}, \bar{d}_{Ls}) \gamma^\mu \tau^I \begin{pmatrix} V_{tj}^\dagger u_{Lj} \\ d_{Lt} \end{pmatrix} \right] \\
=& V_{is} (V_{jt})^\dagger \left[ (\bar{\nu}_{Lp} \gamma^\mu \nu_{Lr})(\bar{u}_{Li} \gamma_\mu u_{Lj}) - (\bar{\ell}_{Lp} \gamma^\mu \ell_{Lr})(\bar{u}_{Li} \gamma_\mu u_{Lj}) \right] \\
& + 2 V_{is} (\bar{\ell}_{Lp} \gamma^\mu \nu_{Lr})(\bar{u}_{Li} \gamma_\mu d_{Lt}) + 2 (V_{jt})^\dagger (\bar{\nu}_{Lp} \gamma^\mu \ell_{Lr})(\bar{d}_{Ls} \gamma_\mu u_{Lj}) \\
& + (\bar{\ell}_{Lp} \gamma^\mu \ell_{Lr})(\bar{d}_{Ls} \gamma_\mu d_{Lt}) - (\bar{\nu}_{Lp} \gamma^\mu \nu_{Lr})(\bar{d}_{Ls} \gamma_\mu d_{Lt}) \\
\Rightarrow \quad [\mathcal{O}_{\ell q}^{(3)}]_{3323} =& V_{is} (V_{jb})^\dagger \left[ (\bar{\nu}_{\tau L} \gamma^\mu \nu_{\tau L})(\bar{u}_{Li} \gamma_\mu u_{Lj}) - (\bar{\tau}_L \gamma^\mu \tau_L)(\bar{u}_{Li} \gamma_\mu u_{Lj}) \right] \\
& + 2 V_{is} (\bar{\tau}_L \gamma^\mu \nu_{\tau L})(\bar{u}_{Li} \gamma_\mu b_L) + 2 (V_{jb})^\dagger (\bar{\nu}_{\tau L} \gamma^\mu \tau_L)(\bar{s}_L \gamma_\mu u_{Lj}) \\
& + (\bar{\tau}_L \gamma^\mu \tau_L)(\bar{s}_L \gamma_\mu b_L) - (\bar{\nu}_{\tau L} \gamma^\mu \nu_{\tau L})(\bar{s}_L \gamma_\mu b_L) \\
\text{with} \quad 2 V_{is} (\bar{\tau}_L \gamma^\mu \nu_{\tau L})(\bar{u}_{Li} \gamma_\mu b_L) =& 2 V_{us} (\bar{\tau}_L \gamma^\mu \nu_{\tau L})(\bar{u}_L \gamma_\mu b_L) + 2 V_{cs} (\bar{\tau}_L \gamma^\mu \nu_{\tau L})(\bar{c}_L \gamma_\mu b_L) \\
& + 2 V_{ts} (\bar{\tau}_L \gamma^\mu \nu_{\tau L})(\bar{t}_L \gamma_\mu b_L)
\end{aligned}
$$

$$
[Q_{Hud}]_{pr} = i(\tilde{H}^\dagger D_\mu H)(\bar{u}_{Rp} \gamma^\mu d_{Rr}) \quad \rightarrow \quad [\mathcal{O}_{RL}^{\ell}]_{pr} = (\bar{u}_p \gamma_\mu P_R d_r)(\bar{\ell} \gamma^\mu P_L \nu_\ell)
$$



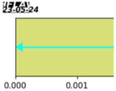

$$C_{Hud} = (i\tilde{H}^\dagger D_\mu H)(\bar{u}_R \gamma^\mu d_R)$$


$\times 10^{-3}$
68%
95%
Best fit
$C_{\ell q}^{(3)}$ [TeV$^{-2}$]
$C_{\ell q}^{(1)}$ [TeV$^{-2}$]
$\times 10^{-3}$
$\times 10^{-1}$
$C_{V,RL}^{\tau c}$
68%
95%
Best fit
$C_{\ell q}^{(1)}$ [TeV$^{-2}$]
$\times 10^{-3}$

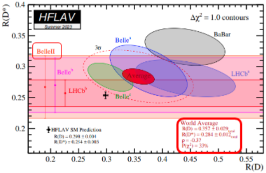
$(2.3 \pm 0.7) \times 10^{-5}$ for the $B^+ \to K^+ \nu\bar{\nu}$ decay branching

$\mathcal{B}(B^0 \to K^{0*}\nu\bar{\nu}) \leq 1.8 \times 10^{-5}$ (90% c.l.).

$\mathcal{B}(B_s^0 \to \tau^+\tau^-)$




| Experiment | Measurement [$10^{-3}$] |
|---|---|
| Average | < 5.2 |
| PDG | < 6.8 |
| LHCb | < 5.2 |




| $\Delta C_9^\mu$ | $-0.752^{+0.262}_{-0.265}$ | $-0.789^{+0.198}_{-0.210}$ | $-1.054^{+0.163}_{-0.171}$ | $-0.872^{+0.215}_{-0.215}$ |
|---|---|---|---|---|

$$\mathcal{B}(B^+ \to K^+\bar{\nu}\nu) = (2.3 \pm 0.7) \times 10^{-5},$$
$$\mathcal{B}(B^0 \to K^{*0}\bar{\nu}\nu) < 1.8 \times 10^{-5}\ (90\%\ \text{C.L}),$$
$$\mathcal{B}(B_s \to \tau^+\tau^-) < 6.8 \times 10^{-3},$$

$$R_D = 0.357 \pm 0.029,$$
$$R_{D^*} = 0.284 \pm 0.012,$$
$$C_9^\mu = -0.789^{+0.198}_{-0.210}.$$

$$\mathscr{B}(B^+ \to \tau^+\nu_\tau) = [1.25 \pm 0.28(\text{stat.}) \pm 0.27(\text{syst.})] \times 10^{-4}.$$

$\mathcal{B}(B^0 \to K^{0*}\nu\bar{\nu}) \leq 1.8 \times 10^{-5}$ (90% c.l.).


[13] J. Grygier et al. (Belle), Phys. Rev. D **96**, 091101 (2017), [Addendum: Phys.Rev.D 97, 099902 (2018)], 1702.03224.


$(2.3 \pm 0.7) \times 10^{-5}$ for the $B^+ \to K^+ \nu\bar{\nu}$ decay branching

**Belle. 2311.14647**

$\mathcal{B}(B_s \to \tau^+\tau^-) < 6.8 \times 10^{-3}$ (95%C.L.)

**LHCb. Phys.Rev.Lett. 118 (2017) 25, 251802**

https://hflav-eos.web.cern.ch/hflav-eos/rare/Apr2023/html/Bs/index.html

$R_{D^{(*)}}$

/Users/mrotondo/WORK/HFLAV/RDs_summer23/rdrds_summer2023_preliminary_new.pdf (cern.ch)

https://hflav-eos.web.cern.ch/hflav-eos/semi/summer23/html/RDsDsstar/RDRDs.html

| | | | | | |
|---|---|---|---|---|---|
| LHCb$^b$ | 0.257 ± 0.012 ± 0.018 | - | - | input | Accepted by PRD [arXiv:2305.01463] |
| Belle II | 0.267 ($^{+0.041}_{-0.039}$) ($^{+0.028}_{-0.033}$) | - | - | input | Presented at Lepton Photon 2023 Lepton Photon's talk |

| Experiment | R(D*) | R(D) | Rescaled Correlation (stat/syst/total) | Inputs | Remarks |
|---|---|---|---|---|---|
| BaBar | 0.332 ± 0.024 ± 0.018 | 0.440 ± 0.058 ± 0.042 | -0.45/-0.07/-0.27 | input | Phys.Rev.Lett. 109,101802 (2012) arXiv:1205.5442 [hep-ex] Phys.Rev.D 88, 072012 (2013) arXiv:1303.0571 [hep-ex] |
| BELLE$^a$ | 0.293 ± 0.038 ± 0.015 | 0.375 ± 0.064 ± 0.026 | -0.56/-0.11/-0.49 | input | Phys.Rev.D 92, 072014 (2015) arXiv:1507.03233 [hep-ex] |
| BELLE$^b$ | 0.270 ± 0.035 $^{+0.028}_{-0.025}$ | - | - | input | Phys.Rev.Lett.118,211801 (2017) arXiv:1612.00529 [hep-ex] Phys.Rev.D 97, 012004 (2018) arXiv:1709.00129 [hep-ex] |
| BELLE$^c$ | 0.283 ± 0.018 ± 0.014 | 0.307 ± 0.037 ± 0.016 | -0.53/-0.51/-0.51 | input | Phys.Rev.Lett. 124 (2020) 16, 161803 arXiv:1910.05864 [hep-ex] |
| LHCb$^a$ | 0.281 ± 0.018 ± 0.024 | 0.441 ± 0.060 ± 0.066 | -0.49/-0.39/-0.43 | input | Accepted by PRL [arXiv:2302.02886] |
| LHCb$^b$ | 0.257 ± 0.012 ± 0.018 | - | - | input | Accepted by PRD [arXiv:2305.01463] |
| Belle II | 0.267 ($^{+0.041}_{-0.039}$) ($^{+0.028}_{-0.033}$) | - | - | input | Presented at Lepton Photon 2023 Lepton Photon's talk |
| **Average** .txt | **0.284 ± 0.012** | **0.357 ± 0.029** | **-0.37** | **chi2/dof = 10.3/9 (CL = 0.33)** | R(D)-R(D*), $\Delta\chi^2$=1 contours rdrds.pdf (dashed curves correspond to 3 σ contour) R(D)-R(D*), 68% C.L. contours rdrds.pdf<br>R(D) .pdf (with the SM predictions)<br>R(D) .pdf<br>R(D*) .pdf (with the SM predictions)<br>R(D*) .pdf |

$$\mathscr{B}(B^+ \to \tau^+\nu_\tau) = [1.25 \pm 0.28(\text{stat.}) \pm 0.27(\text{syst.})] \times 10^{-4}.$$

**Belle. Phys. Rev. D 92, 051102(R)**

https://pdglive.lbl.gov/BranchingRatio.action?pdgid=S041.184&home=MXXX045