# A general overview on Lepton Flavour Universality violation in B mesons physics


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# Contents

- Lepton Flavour Universality
- B-Physics Anomalies
- Contributions to the High Energy EFT
- Phenomenology and UV scenarios

# Flavour Physics

| | $q_L$ | $l_L$ | $u_R$ | $d_R$ | $e_R$ | $H$ |
|---|---|---|---|---|---|---|
| $SU(3)_c$ | $\mathbf{3}$ | $\mathbf{1}$ | $\mathbf{3}$ | $\mathbf{3}$ | $\mathbf{1}$ | $\mathbf{1}$ |
| $SU(2)_L$ | $\mathbf{2}$ | $\mathbf{2}$ | $\mathbf{1}$ | $\mathbf{1}$ | $\mathbf{1}$ | $\mathbf{2}$ |
| $U(1)_Y$ | $\frac{1}{6}$ | $\frac{1}{2}$ | $\frac{2}{3}$ | $-\frac{1}{3}$ | $-1$ | $\frac{1}{2}$ |

$$\mathcal{L}_{SM} = \mathcal{L}_{kin} + \mathcal{L}_H + \mathcal{L}_Y + \mathcal{L}_\theta$$

# Flavour Physics

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$$\mathcal{L}_{SM} = \mathcal{L}_{kin} + \mathcal{L}_H + \mathcal{L}_Y + \mathcal{L}_\theta$$

$$\mathcal{L}_{kin} = \sum_\psi i\overline{\psi^i}\ \not{D}\psi^i - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W_j^{\mu\nu}W^j_{\mu\nu} - \frac{1}{4}G_a^{\mu\nu}G^a_{\mu\nu}$$

$$\mathcal{L}_H = (D_\mu H)^\dagger D^\mu H + m_H^2 H^\dagger H - \lambda(H^\dagger H)^2$$

$$\mathcal{L}_Y = Y_u^{ij}\ (H^c\overline{q}^i_L)u^j_R + Y_d^{ij}(H\overline{q}^i_L)d^j_R + Y_l^{ij}(H\overline{l}^i_L)e^j_R + h.c.$$

$$\mathcal{L}_\theta = \frac{\theta_3}{32\pi}\varepsilon_{\mu\nu\rho\sigma}G_a^{\mu\nu}G^{\rho\sigma\,a}$$

# Flavour Physics

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$$\mathcal{L}_{kin} = \sum_{\psi} i\overline{\psi^i}\ \not{D}\psi^i - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W_j^{\mu\nu}W_{\mu\nu}^j - \frac{1}{4}G_a^{\mu\nu}G_{\mu\nu}^a$$

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$$\mathcal{G}_F(\,Y_u,\,Y_d,\,Y_e \neq 0) = \,U(1)_B \otimes \,U(1)_e \otimes \,U(1)_\mu \otimes \,U(1)_\tau$$

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$$\mathcal{G}_F(Y_u, Y_d \neq 0,\ \ Y_e \sim 0) = U(1)_B \otimes U(1)_e \otimes U(1)_\mu \otimes U(1)_\tau \otimes$$
$$\otimes\, SU(3)_l \otimes SU(3)_e$$

# Lepton Flavour Universality (LFU)

$$\mathcal{G}_{LFU} = SU(3)_l \otimes SU(3)_e$$

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$$\mathcal{G}_{LFU} = SU(3)_l \otimes SU(3)_e$$

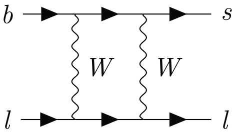
In the SM for $m_{(e/\mu/\tau)} \ll v$:

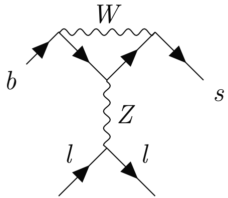
$$\frac{\mathcal{B}(\tau \to \mu\nu_\tau\overline{\nu}_\mu)}{\mathcal{B}(\tau \to e\nu_\tau\overline{\nu}_e)} = 1, \quad \frac{\mathcal{B}(\tau \to e\nu_\tau\overline{\nu}_e)}{\mathcal{B}(\mu \to e\nu_\mu\overline{\nu}_e)} = 1, \quad \frac{\mathcal{B}(J/\psi \to e^- e^+)}{\mathcal{B}(J/\psi \to \mu^-\mu^+)} = 1, \ldots$$

# B-Physics Anomalies

NC $b \to s l^+ l^-$

CC $b \to c l \nu$




$$R_K \equiv \frac{\mathcal{B}(B \to K\mu^-\mu^+)}{\mathcal{B}(B \to Ke^-e^+)}$$

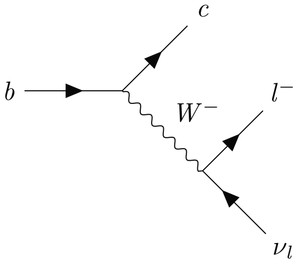
| *Observable* | *Experiment* |
|---|---|
| $R_{K^+}^{[1.1,6.0]}$ | $0.846^{+0.042+0.013}_{-0.039-0.012}$ |
| $R_{K_S^0}^{[1.1,6.0]}$ | $0.846^{+0.020+0.013}_{-0.039-0.012}$ |
| $R_{K^*}^{[0.045,1.1]}$ | $0.66^{+0.11}_{-0.07} \pm 0.03$ |
| $R_{K^*}^{[1.1,6.0]}$ | $0.69^{+0.11}_{-0.07} \pm 0.05$ |
| $R_{K^{*+}}^{[0.045,6.0]}$ | $0.70^{+0.18+0.03}_{-0.13-0.04}$ |
| $R_{pK}^{[0.1,6.0]}$ | $0.86^{+0.14}_{-0.11} \pm 0.05$ |

# B-Physics Anomalies

NC $b \to s l^+ l^-$

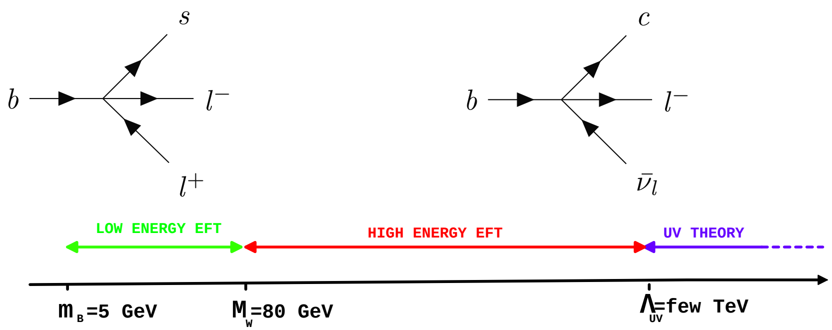
CC $b \to c l \nu$

$$R_D \equiv \frac{\mathcal{B}(B \to D\tau\nu)}{\frac{1}{2}\sum_{l=e,\mu}\mathcal{B}(B \to Dl\nu)}$$




| *Observable* | *Experiment* | *SM* |
|---|---|---|
| $R_D$ | 0.337(30) | 0.299(3) |
| $R_{D^*}$ | 0.298(14) | 0.258(5) |
| $\rho$ | $-0.42$ | $-$ |

# New Physics Effective Field theory



# Semileptonic operators

$$q_L^i = \begin{pmatrix} V^{*ij} u_{LJ} \\ d_L^i \end{pmatrix}, \quad l_L^i = \begin{pmatrix} \nu_L^i \\ e_L^i \end{pmatrix}.$$

$$\begin{aligned}
\mathcal{O}_S &= (q_L^\dagger \overline{\sigma}^\mu q_L)\ (l_L^\dagger \overline{\sigma}_\mu l_L), & \mathcal{O}_T &= (q_L^\dagger \overline{\sigma}^\mu \sigma_a q_L)\ (l_L^\dagger \overline{\sigma}_\mu \sigma^a l_L), \\
\mathcal{O}_{LR1} &= (q_L^\dagger \overline{\sigma}^\mu q_L)\ (e_R^\dagger \sigma_\mu e_R), & \mathcal{O}_{LR2}^{u/d} &= (q_R^\dagger \sigma^\mu q_R)\ (l_L^\dagger \overline{\sigma}_\mu l_L) \\
\mathcal{O}_S^u &= (q_L^\dagger u_R)\ \varepsilon\ (l_L^\dagger e_R), & \mathcal{O}_S^d &= (q_L^\dagger d_R)\ (e_R^\dagger l_L) \\
\mathcal{O}_T^u &= (q_L^\dagger \sigma^{\mu\nu} u_R)\ \varepsilon (l_L^\dagger \sigma_{\mu\nu} e_R), & \mathcal{O}_T^d &= (q_L^\dagger \sigma^{\mu\nu} d_R)\ (e_R^\dagger \overline{\sigma}_{\mu\nu} l_L) \\
\mathcal{O}_{LQ} &= e_R^\dagger q_L\ \varepsilon\ u_R^\dagger l_L
\end{aligned}$$

# Heavy Bosons

| *Bosons* | *SM Currents* |
|---|---|
| $B' \sim (1,1)_0$ | $(\psi^\dagger \sigma^\mu \psi)\ \forall \psi \in SM$ |
| $W' \sim (1,3)_0$ | $(q_L^\dagger \overline{\sigma_\mu} \sigma_a q_L);\quad (l_L^\dagger \overline{\sigma_\mu} \sigma_a l_L)$ |
| $U_1 \sim (3,1)_{2/3}$ | $(q_L^\dagger \overline{\sigma}^\mu l_L);\quad (d_R^\dagger \sigma^\mu e_R)$ |
| $U_3 \sim (3,3)_{2/3}$ | $(q_L^\dagger \overline{\sigma}^\mu \sigma_a l_L)$ |
| $S_1 \sim (3^*,1)_{1/3}$ | $(q_L^{c\,\dagger} \varepsilon l_L);\ (d_R^{c\,\dagger} e_R);\ (q_L^{j\,\dagger} \varepsilon q_L^{c\,k})\varepsilon_{ijk}$ |
| $R_2 \sim (3,2)_{7/6}$ | $(u_R^\dagger \varepsilon l_L);\ (q_L^\dagger e_R)$ |
| $\widetilde{R_2} \sim (3,2)_{1/6}$ | $(d_R^\dagger l_L)$ |
| $S_3 \sim (3^*,3)_{1/3}$ | $(q_L^{c\,\dagger} \sigma^a \varepsilon l_L);\ (q_L^{j\,\dagger} \sigma^a \varepsilon q_L^{c\,k})\varepsilon_{ijk}$ |

# Example of a tree-level matching

$$\mathcal{L}_{UV} \supset -\frac{1}{2}\, U^{\dagger}_{1\mu\nu}\, U_1^{\mu\nu} + M^2_{U_1}\, U^{\dagger}_{1\mu}\, U_1^{\mu} + g_{U_1}\left[\, U_{1\mu}\left( q_L^{\dagger}\beta^L_{U_1}\,\overline{\sigma}^{\mu}\, l_L + d_R^{\dagger}\beta^R_{U_1}\,\sigma^{\mu}\, e_R\right) + h.c.\right]$$

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$$\frac{\delta \mathcal{L}}{\delta U^{\dagger}_{1\mu}} = 0 = M^2_{U_1} U_1^{\mu} + g_{U_1} \left[ l_L^{\dagger} \beta^{\dagger L}_{U_1} \overline{\sigma}^{\mu} q_L + e_R^{\dagger} \beta^{\dagger R}_{U_1} \sigma^{\mu} d_R \right] \rightarrow$$

$$U_1^{\mu} = -\frac{g_{U_1}}{M^2_{U_1}} \left[ l_L^{\dagger} \beta^{\dagger L}_{U_1} \overline{\sigma}^{\mu} q_L + e_R^{\dagger} \beta^{\dagger R}_{U_1} \sigma^{\mu} d_R \right]$$

# Example of a tree-level matching

$$\mathcal{L}_{UV} \supset -\frac{1}{2}\,U^\dagger_{1\mu\nu}\,U_1^{\mu\nu} + M^2_{U_1}\,U^\dagger_{1\mu}\,U_1^\mu + g_{U_1}\left[U_{1\mu}\left(q_L^\dagger\beta^L_{U_1}\overline{\sigma}^\mu\,l_L + d_R^\dagger\beta^R_{U_1}\sigma^\mu\,e_R\right) + h.c.\right]$$

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$$U_1^\mu = -\frac{g_{U_1}}{M^2_{U_1}}\left[l_L^\dagger\beta^{\dagger L}_{U_1}\overline{\sigma}^\mu\,q_L + e_R^\dagger\beta^{\dagger R}_{U_1}\sigma^\mu\,d_R\right]$$

$$\begin{aligned}\mathcal{L}_{EFT} \supset &- G_{U_1}\Big[(l_L^\dagger\beta^L_{U_1}\overline{\sigma}^\mu\,q_L)\;(q_L^\dagger\beta^{\dagger L}_{U_1}\overline{\sigma}_\mu\,l_L) + \\ &+ [(q_L^\dagger\beta^L_{U_1}\overline{\sigma}^\mu\,l_L)\;(e_R^\dagger\beta^{\dagger R}_{U_1}\sigma_\mu\,d_R)\; + h.c.] + \;(e_R^\dagger\beta^R_{U_1}\sigma^\mu\,d_R)\;(d_R^\dagger\beta^{\dagger R}_{U_1}\sigma^\mu\,e_R)\Big]\end{aligned}$$

# Example of a tree-level matching

$$
\begin{aligned}
\mathcal{L}_{UV} \supset & -\frac{1}{2} U^\dagger_{1\mu\nu} U_1^{\mu\nu} + M^2_{U_1} U^\dagger_{1\mu} U_1^\mu + g_{U_1}\left[U_{1\mu}\left(q_L^\dagger \beta^L_{U_1} \overline{\sigma}^\mu l_L + d_R^\dagger \beta^R_{U_1} \sigma^\mu e_R\right) + h.c.\right] \\
\frac{\delta \mathcal{L}}{\delta U^\dagger_{1\mu}} = & 0 = M^2_{U_1} U_1^\mu + g_{U_1}\left[l_L^\dagger \beta^{\dagger L}_{U_1} \overline{\sigma}^\mu q_L + e_R^\dagger \beta^{\dagger R}_{U_1} \sigma^\mu d_R\right] \rightarrow \\
U_1^\mu = & -\frac{g_{U_1}}{M^2_{U_1}}\left[l_L^\dagger \beta^{\dagger L}_{U_1} \overline{\sigma}^\mu q_L + e_R^\dagger \beta^{\dagger R}_{U_1} \sigma^\mu d_R\right] \\
\mathcal{L}_{EFT} \supset & - G_{U_1}\left[(l_L^\dagger \beta^L_{U_1} \overline{\sigma}^\mu q_L)\ (q_L^\dagger \beta^{\dagger L}_{U_1} \overline{\sigma}_\mu l_L) + \right. \\
& \left. + \left[(q_L^\dagger \beta^L_{U_1} \overline{\sigma}^\mu l_L)\ (e_R^\dagger \beta^{\dagger R}_{U_1} \sigma_\mu d_R)\ + h.c.\right] + \ (e_R^\dagger \beta^R_{U_1} \sigma^\mu d_R)\ (d_R^\dagger \beta^{\dagger R}_{U_1} \sigma^\mu e_R)\right]
\end{aligned}
$$

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$$\mathcal{L}_{UV} \supset -\frac{1}{2}U^\dagger_{1\mu\nu}U_1^{\mu\nu} + M^2_{U_1}U^\dagger_{1\mu}U_1^\mu + g_{U_1}\left[U_{1\mu}\left(q_L^\dagger\beta^L_{U_1}\overline{\sigma}^\mu l_L + d_R^\dagger\beta^R_{U_1}\sigma^\mu e_R\right) + h.c.\right]$$

$$\frac{\delta\mathcal{L}}{\delta U^\dagger_{1\mu}} = 0 = M^2_{U_1}U_1^\mu + g_{U_1}\left[l_L^\dagger\beta^{\dagger L}_{U_1}\overline{\sigma}^\mu q_L + e_R^\dagger\beta^{\dagger R}_{U_1}\sigma^\mu d_R\right] \to$$

$$U_1^\mu = -\frac{g_{U_1}}{M^2_{U_1}}\left[l_L^\dagger\beta^{\dagger L}_{U_1}\overline{\sigma}^\mu q_L + e_R^\dagger\beta^{\dagger R}_{U_1}\sigma^\mu d_R\right]$$

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$$+\left[(q_L^\dagger\beta^L_{U_1}\overline{\sigma}^\mu l_L)\ (e_R^\dagger\beta^{\dagger R}_{U_1}\sigma_\mu d_R)\ + h.c.\right] + \ (e_R^\dagger\beta^R_{U_1}\sigma^\mu d_R)\ (d_R^\dagger\beta^{\dagger R}_{U_1}\sigma^\mu e_R)\Big]$$

$$\overline{\sigma}^\mu_{\dot\alpha\alpha}\sigma_\mu^{\beta\dot\beta} = 2\delta^\beta_\alpha\delta^{\dot\beta}_{\dot\alpha}, \quad \sigma^\mu_{\alpha\dot\alpha}\sigma_{\mu\ \beta\dot\beta} = -\sigma^\mu_{\alpha\dot\beta}\sigma_{\mu\beta\dot\alpha} \quad \overline{\sigma}^\mu_{\dot\alpha\alpha}\overline{\sigma}_{\mu\ \dot\beta\beta} = -\overline{\sigma}^\mu_{\dot\alpha\beta}\overline{\sigma}_{\mu\,\dot\beta\alpha}$$

$$\sigma^i_{ad}\sigma_{i\,cb} = 2\delta_{ab}\delta_{cd} - \delta_{ad}\delta_{bc} \to \delta_{ab}\delta_{cd} = \frac{\sigma^i_{ad}\sigma_{i\,cb} + \delta_{ad}\delta_{cb}}{2}$$

# Example of a tree-level matching

$$\mathcal{L}_{UV} \supset -\frac{1}{2}\, U^{\dagger}_{1\mu\nu}\, U_1^{\mu\nu} + M^2_{U_1}\, U^{\dagger}_{1\mu}\, U_1^{\mu} + g_{U_1}\left[U_{1\mu}\left(q_L^{\dagger}\beta^L_{U_1}\overline{\sigma}^{\mu}\, l_L + d_R^{\dagger}\beta^R_{U_1}\sigma^{\mu}\, e_R\right) + h.c.\right]$$

$$\frac{\delta\mathcal{L}}{\delta\, U^{\dagger}_{1\mu}} = 0 = M^2_{U_1}\, U_1^{\mu} + g_{U_1}\left[l_L^{\dagger}\beta^{\dagger L}_{U_1}\overline{\sigma}^{\mu}\, q_L + e_R^{\dagger}\beta^{\dagger R}_{U_1}\sigma^{\mu}\, d_R\right] \rightarrow$$

$$U_1^{\mu} = -\frac{g_{U_1}}{M^2_{U_1}}\left[l_L^{\dagger}\beta^{\dagger L}_{U_1}\overline{\sigma}^{\mu}\, q_L + e_R^{\dagger}\beta^{\dagger R}_{U_1}\sigma^{\mu}\, d_R\right]$$

$$\mathcal{L}_{EFT} \supset -\, G_{U_1}\left[(l_L^{\dagger}\beta^L_{U_1}\overline{\sigma}^{\mu}\, q_L)\ (q_L^{\dagger}\beta^{\dagger L}_{U_1}\overline{\sigma}_{\mu}\, l_L) + \right.$$

$$\left. + \left[(q_L^{\dagger}\beta^L_{U_1}\overline{\sigma}^{\mu}\, l_L)\ (e_R^{\dagger}\beta^{\dagger R}_{U_1}\sigma_{\mu}\, d_R)\ + h.c.\right] + \ (e_R^{\dagger}\beta^R_{U_1}\sigma^{\mu}\, d_R)\ (d_R^{\dagger}\beta^{\dagger R}_{U_1}\sigma^{\mu}\, e_R)\right]$$

$$\overline{\sigma}^{\mu}_{\dot{\alpha}\alpha}\sigma_{\mu}^{\beta\dot{\beta}} = 2\delta^{\beta}_{\alpha}\delta^{\dot{\beta}}_{\dot{\alpha}}, \quad \sigma^{\mu}_{\alpha\dot{\alpha}}\sigma_{\mu\ \beta\dot{\beta}} = -\sigma^{\mu}_{\alpha\dot{\beta}}\sigma_{\mu\beta\dot{\alpha}} \quad \overline{\sigma}^{\mu}_{\dot{\alpha}\alpha}\overline{\sigma}_{\mu\ \dot{\beta}\beta} = -\overline{\sigma}^{\mu}_{\alpha\dot{\beta}}\overline{\sigma}_{\mu\beta\dot{\alpha}}$$

$$\sigma^{i}_{ad}\sigma_{cb\, i} = 2\delta_{ab}\delta_{cd} - \delta_{ad}\delta_{bc} \rightarrow \delta_{ab}\delta_{cd} = \frac{\sigma^{i}_{ad}\sigma_{cb\, i} + \delta_{ad}\delta_{cb}}{2}$$

$$\mathcal{L}_{EFT} \supset -G_{U_1}\left[\frac{1}{2}\beta^L_{U_1}\beta^{\dagger L}_{U_1}(\mathcal{O}_S + \mathcal{O}_T) + \beta^R_{U_1}\beta^{\dagger R}_{U_1}\mathcal{O}^d_R - 2\beta^R_{U_1}\beta^{\dagger L}_{U_1}\mathcal{O}^d_S + \right]$$

# NP Contributions

| | $B'$ | $W'$ | $U_1$ | $U_3$ |
|---|---|---|---|---|
| $C_S$ | $-2\,G_{B'}\lambda^q_B\lambda^l_B$ | $\emptyset$ | $-\frac{1}{2}\,G_{U_1}\beta^{L\dagger}_{U_1}\beta^L_{U_1}$ | $-\frac{3}{2}\,G_{U_3}\beta_{U_3}\beta^\dagger_{U_3}$ |
| $C_T$ | $\emptyset$ | $-4G_{W'}\lambda^q_W\lambda^l_W$ | $-\frac{1}{2}\,G_{U_1}\beta^{L\dagger}_{U_1}\beta^L_{U_1}$ | $\frac{1}{2}\,G_{U_3}\beta_{U_3}\beta^\dagger_{U_3}$ |
| $C_{LR1}$ | $-2\,G_{B'}\lambda^q_B\lambda^e_B$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^u_{LR2}$ | $-2\,G_{B'}\lambda^u_B\lambda^l_B$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^d_{LR2}$ | $-2\,G_{B'}\lambda^d_B\lambda^l_B$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^u_R$ | $-2\,G_{B'}\lambda^u_B\lambda^e_B$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^d_R$ | $-2\,G_{B'}\lambda^d_B\lambda^e_B$ | $\emptyset$ | $-\,G_{U_1}\beta^{R\dagger}_{U_1}\beta^R_{U_1}$ | $\emptyset$ |
| $C_{LQ}$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^u_S$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^d_S$ | $\emptyset$ | $\emptyset$ | $2\,G_{U_1}\beta^R_{U_1}\beta^{L\dagger}_{U_1}$ | $\emptyset$ |

# NP Contributions

| | $S_1$ | $R_2$ | $\widetilde{R}_2$ | $S_3$ |
|---|---|---|---|---|
| $C_S$ | $\frac{1}{4}\,G_{S_1}\beta^L_{S_1}\beta^{L\dagger}_{S_1}$ | $\emptyset$ | $\emptyset$ | $\frac{3}{4}\,G_{S_3}\beta^\dagger_{S_3}\beta_{S_3}$ |
| $C_T$ | $-\frac{1}{4}\,G_{S_1}\beta^{L\dagger}_{S_1}\beta^L_{S_1}$ | $\emptyset$ | $\emptyset$ | $\frac{1}{4}\,G_{S_3}\beta^\dagger_{S_3}\beta_{S_3}$ |
| $C_{LR1}$ | $\emptyset$ | $-\frac{1}{2}\,G_{R_2}\beta^l_{R_2}\beta^{q\dagger}_{R_2}$ | $\emptyset$ | $\emptyset$ |
| $C^u_{LR2}$ | $\emptyset$ | $\frac{1}{2}\,G_{R_2}\beta^{l\dagger}_{R_2}\beta^l_{R_2}$ | $\emptyset$ | $\emptyset$ |
| $C^d_{LR2}$ | $\emptyset$ | $\emptyset$ | $\frac{1}{2}\,G_{\widetilde{R}_2}\beta^\dagger_{\widetilde{R}_2}\beta_{\widetilde{R}_2}$ | $\emptyset$ |
| $C^u_R$ | $\frac{1}{2}\,G_{S_1}\beta^{R\dagger}_{S_1}\beta^R_{S_1}$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^d_R$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C_{LQ}$ | $-G_{S_1}\beta^{R\dagger}_{S_1}\beta^L_{S_1}$ | $-G_{R_2}\beta^{q\dagger}_{R_2}\beta^q_{R_2}$ | $\emptyset$ | $\emptyset$ |
| $C^u_S$ | $G_{S_1}\beta^{R\dagger}_{S_1}\beta^L_{S_1}$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $C^d_S$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |

# Left Handed Framework

$$\Gamma(B \to K^* l^+ l^-) = \frac{1}{2m_B} \int |\mathcal{M}|^2 \frac{d^3 p_{K^*}}{(2\pi)^3 \; 2E_{K^*}} \frac{d^3 p_{l+}}{(2\pi)^3 \; 2E_{l+}} \frac{d^3 p_{l-}}{(2\pi)^3 \; 2E_{l-}}$$

# Left Handed Framework

$$\Gamma(B \to K^* l^+ l^-) = \frac{1}{2m_B} \int |\mathcal{M}|^2 \frac{d^3 p_{K^*}}{(2\pi)^3 \; 2E_{K^*}} \frac{d^3 p_{l+}}{(2\pi)^3 \; 2E_{l+}} \frac{d^3 p_{l-}}{(2\pi)^3 \; 2E_{l-}}$$

$$|\mathcal{M}|^2 \propto |C_{SM}^{NC} + (C_S)^{bsll} + (C_T)^{bsll} + (C_{LR2}^{d})^{bsll}|^2 + | \; . \; . \; . \; |^2$$

# Left Handed Framework

$$\Gamma(B \to K^* l^+ l^-) = \frac{1}{2m_B} \int |\mathcal{M}|^2 \frac{d^3 p_{K^*}}{(2\pi)^3 \; 2E_{K^*}} \frac{d^3 p_{l+}}{(2\pi)^3 \; 2E_{l+}} \frac{d^3 p_{l-}}{(2\pi)^3 \; 2E_{l-}}$$

$$|\mathcal{M}|^2 \propto |C_{SM}^{NC} + (C_S)^{bsll} + (C_T)^{bsll} + (C_{LR2}^{d})^{bsll}|^2 + | \; . \; . \; . \; |^2$$

$$\mathcal{O} = \mathcal{O}_q(\{q\}) \cdot \mathcal{O}_l(\{l\}) \to \mathcal{M} = (-i) \langle B | \mathcal{O}_q | K^* \rangle \langle 0 | \mathcal{O}_l | l^+ l^- \rangle$$

# Left Handed Framework

$$\Gamma(B \to K^* l^+ l^-) = \frac{1}{2m_B} \int |\mathcal{M}|^2 \frac{d^3 p_{K^*}}{(2\pi)^3\ 2E_{K^*}} \frac{d^3 p_{l+}}{(2\pi)^3\ 2E_{l+}} \frac{d^3 p_{l-}}{(2\pi)^3\ 2E_{l-}}$$

$$|\mathcal{M}|^2 \propto |C_{SM}^{NC} + (C_S)^{bsll} + (C_T)^{bsll} + (C_{LR2}^d)^{bsll}|^2 + |\ \ldots\ |^2$$

$$\mathcal{O} = \mathcal{O}_q(\{q\}) \cdot \mathcal{O}_l(\{l\}) \to \mathcal{M} = (-i) \langle B| \mathcal{O}_q |K^*\rangle \langle 0| \mathcal{O}_l |l^+ l^-\rangle$$

$$\mathcal{O}_l = (l\gamma^\mu P_L\ l) \to \mathcal{O}_q = (b\gamma_\mu(\alpha_{NP} + \beta_{NP}\gamma^5)\ s)$$

$$\langle B| \mathcal{O}_A |K^*\rangle \equiv A(q^2), \quad \langle B| \mathcal{O}_V |K^*\rangle = 0$$

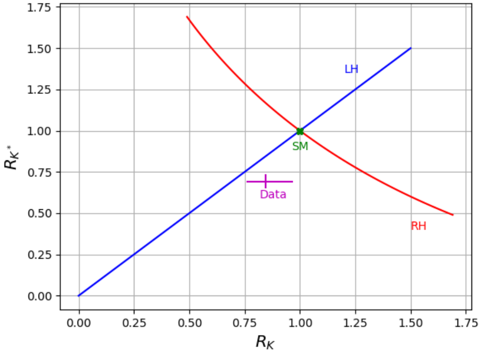
$$\langle B| \mathcal{O}_V |K\rangle \equiv V(q^2), \qquad \langle B| \mathcal{O}_A |K\rangle = 0$$

# Left Handed Framework

$$\frac{R_{K^*}}{R_K} = \frac{|(-C_{SM}^{NC} + \beta_{NP})A|^2}{|(C_{SM}^{NC} + \alpha_{NP})V|^2} \frac{|C_{SM}^{NC} V|^2}{|C_{SM}^{NC} A|^2} = \left| \frac{C_{SM}^{NC} - \beta_{NP}}{(C_{SM}^{NC} - \beta_{NP}) + \alpha_{NP} + \beta_{NP}} \right|^2$$

# Left Handed Framework

$$\frac{R_{K^*}}{R_K} = \frac{|(-C_{SM}^{NC} + \beta_{NP})A|^2}{|(C_{SM}^{NC} + \alpha_{NP})V|^2}\frac{|C_{SM}^{NC}V|^2}{|C_{SM}^{NC}A|^2} = \left|\frac{C_{SM}^{NC} - \beta_{NP}}{(C_{SM}^{NC} - \beta_{NP}) + \alpha_{NP} + \beta_{NP}}\right|^2$$



# Left Handed Framework

$$R_K \equiv \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)} = \frac{|C_{SM}^K + C_S^{bs\mu\mu} + C_T^{bs\mu\mu}|^2}{|C_{SM}^K|^2}$$

$$= |1 + \frac{C_S^{bs\mu\mu} + C_T^{bs\mu\mu}}{C_{SM}^K}|^2 \equiv |1 + \frac{\delta C^{NC}}{C_{SM}^K}|^2$$

# Left Handed Framework

$$R_K \equiv \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)} = \frac{|C_{SM}^K + C_S^{bs\mu\mu} + C_T^{bs\mu\mu}|^2}{|C_{SM}^K|^2}$$

$$= |1 + \frac{C_S^{bs\mu\mu} + C_T^{bs\mu\mu}}{C_{SM}^K}|^2 \equiv |1 + \frac{\delta C^{NC}}{C_{SM}^K}|^2$$

$$R_D \equiv \frac{\mathcal{B}(B \to D^*\tau\overline{\nu})}{\frac{1}{2}\left[\mathcal{B}(B \to D^* e\overline{\nu}) + \mathcal{B}(B \to D^*\mu\overline{\nu})\right]} =$$

$$= \frac{|C_{SM}^{CC} + 2C_T^{bs\tau\tau}V_{cs}^* + 2C_T^{bb\tau\tau}V_{cb}^*|^2 \cdot \eta_\tau^D}{\frac{1}{2}\left[|C_{SM}^{CC}|^2 + |C_{SM}^{CC} + 2C_T^{bs\mu\mu}V_{cs}^* + 2C_T^{bb\mu\mu}V_{cb}^*|^2\right]} =$$

$$\equiv \frac{|C_{SM}^{CC} + \delta C^{CC}|^2 \cdot \eta_\tau^D}{\frac{1}{2}\left[|C_{SM}^{CC}|^2 + |C_{SM}^{CC} + \delta C^{CC\mu}|^2\right]}$$

# Left Handed Framework

$$\mathcal{B}(B \to K^*\overline{\nu}\nu)_{exp} < 5.2\ \mathcal{B}(B \to K^*\overline{\nu}\nu)_{SM}$$

$$|C^\nu|^2 + |C^\nu + (C_S - C_T)^{bs\mu\mu}| + |C^\nu + (C_S - C_T)^{bs\tau\tau}| \equiv$$

$$\equiv |C^\nu|^2 + |C^\nu + \delta C^{\nu_\mu}| + |C^\nu + \delta C^{\nu_\tau}| < 5.2 \cdot 3|C^\nu|^2$$

# Left Handed Framework

$$\mathcal{B}(B \to K^*\overline{\nu}\nu)_{exp} < 5.2\ \mathcal{B}(B \to K^*\overline{\nu}\nu)_{SM}$$

$$|C^\nu|^2 + |C^\nu + (C_S - C_T)^{bs\mu\mu}| + |C^\nu + (C_S - C_T)^{bs\tau\tau}| \equiv$$

$$\equiv |C^\nu|^2 + |C^\nu + \delta C^{\nu_\mu}| + |C^\nu + \delta C^{\nu_\tau}| < 5.2 \cdot 3|C^\nu|^2$$

$$R^{\mu e}_{D^*} = \frac{\mathcal{B}(B \to D^*\mu\overline{\nu})}{\mathcal{B}(B \to D^* e\overline{\nu})} = \frac{|C^{CC}_{SM} + 2(C_T^{bs\mu\mu} V^*_{cs} + C_T^{bb\mu\mu} V^*_{cb})|^2}{|C^{CC}_{SM}|^2} =$$

$$= \left|1 + \frac{\delta C^{CC\mu}}{C^{CC}_{SM}}\right|^2_{exp} = 1.00 \pm 0.02$$

$$\to \frac{\delta C^{CC\mu}}{C^{CC}_{SM}} \ll 1$$

# Left Handed Framework

$$\mathcal{B}(B \to K^* \overline{\nu}\nu)_{exp} < 5.2\ \mathcal{B}(B \to K^* \overline{\nu}\nu)_{SM}$$

$$|C^\nu|^2 + |C^\nu + (C_S - C_T)^{bs\mu\mu}| + |C^\nu + (C_S - C_T)^{bs\tau\tau}| \equiv$$

$$\equiv |C^\nu|^2 + |C^\nu + \delta C^{\nu_\mu}| + |C^\nu + \delta C^{\nu_\tau}| < 5.2 \cdot 3|C^\nu|^2$$

$$R_{D^*}^{\mu e} = \frac{\mathcal{B}(B \to D^* \mu\overline{\nu})}{\mathcal{B}(B \to D^* e\overline{\nu})} = \frac{|C_{SM}^{CC} + 2(C_T^{bs\mu\mu} V_{cs}^* + C_T^{bb\mu\mu} V_{cb}^*)|^2}{|C_{SM}^{CC}|^2} =$$

$$= \left|1 + \frac{\delta C^{CC\mu}}{C_{SM}^{CC}}\right|^2_{exp} = 1.00 \pm 0.02$$

$$\to \frac{\delta C^{CC\mu}}{C_{SM}^{CC}} \ll 1$$

$$R_D \simeq \frac{|C_{SM}^{CC} + 2C_T^{bs\tau\tau} V_{cs}^* + 2C_T^{bb\tau\tau} V_{cb}^*|^2\ \eta_\tau^D}{|C_{SM}^{CC}|^2} = \left|1 + \frac{\delta C^{CC}}{C_{SM}^{CC}}\right|^2 \cdot \eta_\tau^D .$$

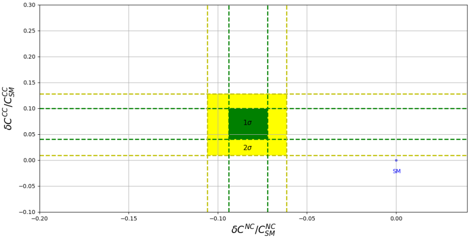
# Numerical analysis

$$R_K = \left| 1 + \frac{\delta C^{NC}}{C_{SM}^{NC}} \right|^2, \quad \frac{R_D}{\eta_\tau} = \left| 1 + \frac{\delta C^{CC}}{C_{SM}^{CC}} \right|^2$$

# Numerical analysis

$$R_K = \left|1 + \frac{\delta C^{NC}}{C^{NC}_{SM}}\right|^2, \quad \frac{R_D}{\eta_\tau} = \left|1 + \frac{\delta C^{CC}}{C^{CC}_{SM}}\right|^2$$

| *Observable* | *Experiment* |
|---|---|
| $R^{[1.1,6.0]}_{K+}$ | $0.846^{+0.042+0.013}_{-0.039-0.012}$ |
| $R^{[1.1,6.0]}_{K^0_S}$ | $0.846^{+0.020+0.013}_{-0.039-0.012}$ |
| $R^{[1.1,6.0]}_{K*}$ | $0.69^{+0.11}_{-0.07} \pm 0.05$ |
| $R^{[0.045,6.0]}_{K*+}$ | $0.70^{+0.18+0.03}_{-0.13-0.04}$ |
| $R^{[0.1,6.0]}_{pK}$ | $0.86^{+0.14}_{-0.11} \pm 0.05$ |
| $R_D/\eta^D_\tau$ | $0.337(30)/0.299(3)$ |
| $R_{D*}/\eta^{D*}_\tau$ | $0.298(14)/0.258(5)$ |



# Numerical Analysis

$$C_{SM}^{NC} = -V_{tb}V_{ts}^{*}\frac{e^2}{8\pi^2}\cdot(8.314)\,v^{-2},\; C_{SM}^{CC} = -2\,V_{cb}^{*}v^{-2}\,,\, C_{SM}^{\nu} = 12.8\;V_{ts}^{*}V_{tb}\frac{e^2}{8\pi^2}\;v^{-2}$$

| | $\delta C^{NC}$ | $\delta C^{CC}$ | $\delta C^{\nu_\mu(\nu_\tau)}$ |
|---|---|---|---|
| $B'$ | $-2G_{B'}(\lambda_B^q)^{bs}(\lambda_B^l)^{\mu\mu}$ | $\varnothing$ | $-2G_{B'}(\lambda_B^q)^{bs}(\lambda_B^l)^{\mu\mu(\tau\tau)}$ |
| $W'$ | $-4G_{W'}(\lambda_W^q)^{bs}(\lambda_W^l)^{\mu\mu}$ | $-8G_{W'}V_{cb}^{*}(\lambda_{W'}^l)^{\tau\tau}((\lambda_W^q)^{bb}\frac{V_{cs}^*}{V_{cb}^*}+(\lambda_W^q)^{ss})$ | $4G_{W'}(\lambda_W^q)^{bs}(\lambda_W^l)^{\mu\mu(\tau\tau)}$ |
| $U_1$ | $-G_{U_1}(\beta_{U_1}^L)^{b\mu}(\beta_{U_1}^{L*})^{s\mu}$ | $-G_{U_1}V_{cb}^{*}(\beta_{U_1}^L)^{b\tau}[(\beta_{U_1}^{L*})^{s\tau}\frac{V_{cs}^*}{V_{cb}^*}+(\beta_{U_1}^{L*})^{b\tau}]$ | $\varnothing$ |
| $U_3$ | $-G_{U_3}(\beta_{U_3})^{b\mu}(\beta_{U_3}^*)^{s\mu}$ | $G_{U_3}V_{cb}^{*}(\beta_{U_3})^{b\tau}[(\beta_{U_3}^*)^{s\tau}\frac{V_{cs}^*}{V_{cb}^*}+(\beta_{U_3}^*)^{b\tau}]$ | $-2G_{U_3}(\beta_{U_3})^{b\mu}(\beta_{U_3}^*)^{s\mu}$ |
| $S_1$ | $\varnothing$ | $-\frac{1}{2}G_{S_1}V_{cb}^{*}(\beta_{S_1}^L)^{b\tau}[(\beta_{S_1}^{L*})^{s\tau}\frac{V_{cs}^*}{V_{cb}^*}+(\beta_{S_1}^{L*})^{b\tau}]$ | $G_{S_1}(\beta_{S_1})^{b\mu}(\beta_{S_1}^{L*})^{s\mu}$ |
| $S_3$ | $G_{S_3}(\beta_{S_3})^{b\mu}(\beta_{S_3}^*)^{s\mu}$ | $G_{S_3}V_{cb}^{*}(\beta_{S_3})^{b\tau}[(\beta_{S_3}^*)^{s\tau}\frac{V_{cs}^*}{V_{cb}^*}+(\beta_{S_3}^*)^{b\tau}]$ | $\frac{1}{2}G_{S_3}(\beta_{S_3})^{b\mu}(\beta_{S_3}^*)^{s\mu}$ |
| | $(0.60, 0.79)\frac{e^2}{8\pi^2}V_{ts}^*V_{tb}\,v^{-2}$ | $(-0.20;-0.08)V_{cb}^*v^{-2}$ | $< 3.8C_{SM}^{\nu}$ |