LFU in B Decays: Model Independent Lessons

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Plan of the talk

1. Experimental status and fit results for $R_K^{\mu/e}$ and $R_{D^{(*)}}^{\tau/\ell}$
2. High-energy $SU(2)_L \otimes U(1)_Y$ invariant effective Lagrangian
3. Low-energy $U(1)_{em}$ invariant effective Lagrangians
4. The importance of quantum effects:
   - Z and W leptonic coupling modifications
   - generation of a purely leptonic effective Lagrangian
   - corrections to the semileptonic effective Lagrangian
5. Observables:
   - $R_K^{\mu/e}$ and $R_{D^{(*)}}^{\tau/\ell}$
   - LFU violations in Z and τ decays: $R_Z^{\tau/\ell}$ and $R_\tau^{\tau/\ell}$
   - LFV B-decays: $B \to K\tau\mu$, $B \to K^*\tau\mu$ and $B_s \to \tau\mu$
   - LFV τ decays: $\tau \to \mu\ell\ell$, $\tau \to \mu\rho$, $\tau \to \mu\pi$ and $\tau \to \mu\eta^{(\prime)}$
6. Conclusions

Experimental status

- **LFU tests are very powerful probes of the SM as well as of NP scenarios**

- **Experimental data in B physics hints at non-standard LFU violations both in charged-current as well as neutral-current transitions:**

  - An overall 3.9σ violation from τ/ℓ universality ($\ell = \mu, e$) in the charged-current $b \to c$ decays [BaBar '13, Belle '15, LHCb '15, Fajfer, Kamenik and Nisandzic '12]

$$R^{\tau/\ell}_{D^{(*)}} = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau\bar{\nu})_{\rm exp}/\mathcal{B}(\bar{B} \to D^{(*)}\tau\bar{\nu})_{\rm SM}}{\mathcal{B}(\bar{B} \to D^{(*)}\ell\bar{\nu})_{\rm exp}/\mathcal{B}(\bar{B} \to D^{(*)}\ell\bar{\nu})_{\rm SM}}$$

$$R^{\tau/\ell}_{D} = 1.37 \pm 0.17, \qquad R^{\tau/\ell}_{D^*} = 1.28 \pm 0.08$$

  - A 2.6σ deviation from μ/e universality in the neutral-current $b \to s$ transition

$$R^{\mu/e}_{K} = \frac{\mathcal{B}(B \to K\mu^+\mu^-)_{\rm exp}}{\mathcal{B}(B \to Ke^+e^-)_{\rm exp}} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

while $(R^{\mu/e}_{K})_{SM} = 1$ up to few % corrections [Hiller et al,'07, Bordone, Isidori and Pattori, '16].

Fit results

Coeff.	best fit	1σ	2σ	$\chi^2_{\rm SM} - \chi^2_{\rm b.f.}$	pull
$C_7^{\rm NP}$	-0.04	$[-0.07, -0.01]$	$[-0.10, 0.02]$	2.0	1.4
C_7'	0.01	$[-0.04, 0.07]$	$[-0.10, 0.12]$	0.1	0.2
$C_9^{\rm NP}$	-1.07	$[-1.32, -0.81]$	$[-1.54, -0.53]$	13.7	3.7
C_9'	0.21	$[-0.04, 0.46]$	$[-0.29, 0.70]$	0.7	0.8
$C_{10}^{\rm NP}$	0.50	$[0.24, 0.78]$	$[-0.01, 1.08]$	3.9	2.0
C_{10}'	-0.16	$[-0.34, 0.02]$	$[-0.52, 0.21]$	0.8	0.9
$C_9^{\rm NP} = -C_{10}^{\rm NP}$	-0.53	$[-0.71, -0.35]$	$[-0.91, -0.18]$	9.8	3.1

Table: Constraints on real WCs. The pull is defined as $\sqrt{\chi^2_{\rm SM} - \chi^2_{\rm b.f.}}$. [Altmannshofer & Straub, '15]

$$\mathcal{L}_{\rm eff}^{\rm NC} = \frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i') + \text{h.c.}$$

$$O_7^{(\prime)} = \frac{m_b}{e} (\bar{s}\sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}, \quad O_9^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \ell), \quad O_{10}^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

[see also Hiller et al., '14, Hurth et al., '14, Descotes-Genon et al., '15]

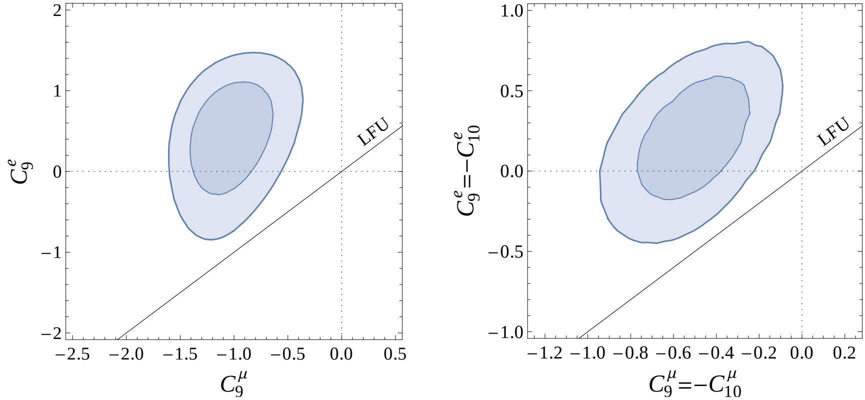


Figure: Allowed regions in the plane C_9^μ vs. C_9^e (left) and the plane of the $SU(2)_L$ invariant combinations $C_9^\mu = -C_{10}^\mu$ vs. $C_9^e = -C_{10}^e$ (right). The blue contours correspond to the 1 and 2σ best fit regions. The diagonal line corresponds to lepton flavour universality.

[Altmannshofer & Straub, '15]

[see also Hiller et al., '14, Hurth et al., '14, Descotes-Genon et al., '15]

High-energy effective Lagrangian

- The explanation of the $R_K^{\mu/e}$ anomaly favours an effective 4-fermion operator involving left-handed currents, $(\bar{s}_L\gamma_\mu b_L)(\bar{\mu}_L\gamma_\mu\mu_L)$ [Hiller et al., '14, Hurth et al.,'14, Altmannshofer and Straub '14, Descotes-Genon et al., '15, ...]

- This naturally suggests to account also for the charged-current anomaly through a left-handed operator $(\bar{c}_L\gamma_\mu b_L)(\bar{\tau}_L\gamma_\mu\nu_L)$ which is related to $(\bar{s}_L\gamma_\mu b_L)(\bar{\mu}_L\gamma_\mu\mu_L)$ by the $SU(2)_L$ gauge symmetry [Bhattacharya et al., '14].

- This picture can works only if NP couples much more strongly to the third generation than to the first two. Two interesting scenarios are:

  - **Lepton Flavour Violating case:** NP couples in the interaction basis only to third generations. Couplings to lighter generations are generated by the misalignment between the mass and the interaction bases through small flavour mixing angles. LFU violation necessarily implies LFV [Glashow, Guadagnoli and Lane, '14] .

  - **Lepton Flavour Conserving case:** NP couples to different fermion generations proportionally to their mass squared [Alonso, '15]. The non-abelian leptonic flavour group is broken but $U(1)_e \times U(1)_\mu \times U(1)_\tau$ is preserved.

- In the energy window between the EW scale v and the NP scale Λ, NP effects are described by $\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm NP}$ with $\mathcal{L}$ invariant under $SU(2)_L \otimes U(1)_Y$.

$$\mathcal{L}_{\rm NP} = \frac{C_1}{\Lambda^2}\left(\bar{q}_{3L}\gamma^\mu q_{3L}\right)\left(\bar{\ell}_{3L}\gamma_\mu \ell_{3L}\right) + \frac{C_3}{\Lambda^2}\left(\bar{q}_{3L}\gamma^\mu \tau^a q_{3L}\right)\left(\bar{\ell}_{3L}\gamma_\mu \tau^a \ell_{3L}\right).$$

- After EWSB we move from the interaction to the mass basis through the unitary transformations ($V_u^\dagger V_d = V_{\rm CKM} \equiv V$) [Calibbi, Crivellin, Ota, '15]

$$u_L \to V_u u_L \qquad d_L \to V_d d_L \qquad \nu_L \to U_e \nu_L \qquad e_L \to U_e e_L\,,$$

$$\begin{aligned}\mathcal{L}_{\rm NP} = \frac{1}{\Lambda^2}[&(C_1 + C_3)\,\lambda^u_{ij}\lambda^e_{kl}\,(\bar{u}_{Li}\gamma^\mu u_{Lj})(\bar{\nu}_{Lk}\gamma_\mu \nu_{Ll}) + \\ &(C_1 - C_3)\,\lambda^u_{ij}\lambda^e_{kl}\,\bar{(}u_{Li}\gamma^\mu u_{Lj})(\bar{e}_{Lk}\gamma_\mu e_{Ll}) + \\ &(C_1 - C_3)\,\lambda^d_{ij}\lambda^e_{kl}\,(\bar{d}_{Li}\gamma^\mu d_{Lj})(\bar{\nu}_{Lk}\gamma_\mu \nu_{Ll}) + \\ &(C_1 + C_3)\,\lambda^d_{ij}\lambda^e_{kl}\,(\bar{d}_{Li}\gamma^\mu d_{Lj})(\bar{e}_{Lk}\gamma_\mu e_{Ll}) + \\ &2C_3\left(\lambda^{ud}_{ij}\lambda^e_{kl}\,(\bar{u}_{Li}\gamma^\mu d_{Lj})(\bar{e}_{Lk}\gamma_\mu \nu_{Ll}) + h.c.\right)]\end{aligned}$$

$$\lambda^q_{ij} = V^*_{q3i}V_{q3j} \qquad \lambda^e_{ij} = U^*_{e3i}U_{e3j} \qquad \lambda^{ud}_{ij} = V^*_{u3i}V_{d3j}$$

- The hermitian matrices λs satisfy the relations $\lambda^u = V\lambda^d V^\dagger$ and $\lambda^{ud} = V\lambda^d$, $\lambda^f\lambda^f = \lambda^f$ and ${\rm tr}\lambda^f = 1$. The free parameters are $(C_{1,3})/\Lambda^2$, λ^d and λ^e.

Construction of the low-energy effective Lagrangian: running and matching

- We use the renormalization group equations (RGEs) to evolve the effective lagrangian $\mathcal{L}_{\rm NP}$ from $\mu \sim \Lambda$ down to $\mu \sim 1$ GeV. This is done is three steps:
  - In the first step, the RGEs in the unbroken phase of the $SU(2) \otimes U(1)$ theory are used to compute the coefficients in the effective lagrangian down to a scale $\mu \sim m_Z$.
  - In the second step, the coefficients are matched to those of an effective lagrangian for the theory in the broken symmetry phase of $SU(2) \otimes U(1)$, that is $U(1)_{el}$.
  - In the third step, the coefficients of this effective lagrangian are computed at $\mu \sim 1$ GeV using the RGEs for the theory with only $U(1)_{el}$ gauge group.
- Then we take matrix elements of the relevant operators, using perturbative QCD for heavy quarks and chiral perturbation theory for light quark loops.The scale dependence of the RGE contributions cancels with that of the matrix elements.

Semileptonic effective Lagrangian

- Effective Lagrangian for $b \to s\ell\ell$ and $b \to s\nu\nu$ [Buchalla et al., '95]

$$\mathcal{L}_{\rm eff}^{\rm NC} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left(C_\nu^{ij} \mathcal{O}_\nu^{ij} + C_9^{ij} \mathcal{O}_9^{ij} + C_{10}^{ij} \mathcal{O}_{10}^{ij} \right) + h.c. \,,$$

$$\mathcal{O}_\nu^{ij} = \frac{e^2}{(4\pi)^2} (\bar{s}_L \gamma_\mu b_L)(\bar{\nu}_i \gamma^\mu (1-\gamma_5) \nu_j) \,, \qquad \mathcal{O}_{9(10)}^{ij} = \frac{e^2}{(4\pi)^2} (\bar{s}_L \gamma_\mu b_L)(\bar{e}_i \gamma^\mu (\gamma_5) e_j)$$

- By matching $\mathcal{L}_{\rm eff}^{\rm NC}$ with $\mathcal{L}_{\rm NP}$ [Alonso, Grinstein, Camalich, '14, '15 & Calibbi, Crivellin, Ota, '15]

$$(C_9)_{ij} = - \, C_{10}^{ij} = \frac{4\pi^2}{e^2 \, V_{tb} \, V_{ts}^*} \frac{v^2}{\Lambda^2} \, (C_1 + C_3) \, \lambda_{23}^d \lambda_{ij}^e + \cdots \,,$$

$$(C_\nu)_{ij} = \frac{4\pi^2}{e^2 \, V_{tb} \, V_{ts}^*} \frac{v^2}{\Lambda^2} \, (C_1 - C_3) \, \lambda_{23}^d \lambda_{ij}^e + \cdots$$

- Effective Lagrangian for $b \to c\ell\nu$ [Buchalla et al., '95]

$$\mathcal{L}_{\rm eff}^{\rm CC} = -\frac{4G_F}{\sqrt{2}} \, V_{cb} \, (C_L^{cb})_{ij} \, (\bar{c}_L \gamma_\mu b_L) \, (\bar{e}_{Li} \gamma^\mu \nu_{Lj}) + h.c.$$

- By matching $\mathcal{L}_{\rm eff}^{\rm CC}$ with $\mathcal{L}_{\rm NP}$ [Alonso, Grinstein, Camalich, '14, '15 & Calibbi, Crivellin, Ota, '15]

$$(C_L^{cb})_{ij} = \delta_{ij} - \frac{v^2}{\Lambda^2} \frac{\lambda_{23}^{ud}}{V_{cb}} \, C_3 \, \lambda_{ij}^e$$

- $\mathcal{L}_{\rm NP}$ induces modification of the W and Z couplings

$$\mathcal{L}_{\rm NP} = \frac{1}{\Lambda^2}[(C_1 + C_3)\,\lambda^u_{ij}\lambda^e_{kl}\,(\bar{u}_{Li}\gamma^\mu u_{Lj})(\bar{\nu}_{Lk}\gamma_\mu \nu_{Ll}) + (C_1 - C_3)\,\lambda^u_{ij}\lambda^e_{kl}\,(\bar{u}_{Li}\gamma^\mu u_{Lj})(\bar{e}_{Lk}\gamma_\mu e_{Ll}) + \ldots]$$

$$\mathcal{L}_Z = \frac{g_2}{c_W}\bar{e}_i\left(\not{Z} g^{ij}_{\ell L} P_L + \not{Z} g^{ij}_{\ell R} P_R\right) e_j + \frac{g_2}{c_W}\bar{\nu}_{Li}\,\not{Z}\,g^{ij}_{\nu L}\,\nu_{Lj}$$

$$\Delta g^{ij}_{\ell L} \simeq \frac{v^2}{\Lambda^2}\left(3y_t^2(C_1 - C_3)\lambda^u_{33} + g_2^2 C_3\right)\log\left(\frac{\Lambda}{m_Z}\right)\frac{\lambda^e_{ij}}{16\pi^2}$$

$$\Delta g^{ij}_{\nu L} \simeq \frac{v^2}{\Lambda^2}\left(3y_t^2(C_1 + C_3)\lambda^u_{33} - g_2^2 C_3\right)\log\left(\frac{\Lambda}{m_Z}\right)\frac{\lambda^e_{ij}}{16\pi^2}$$

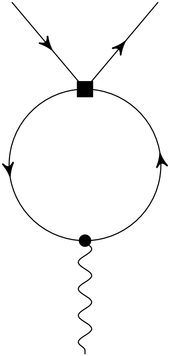


Figure: The square is a 4-fermion interaction in $\mathcal{L}_{\rm NP}$

- These expressions provide a good approximation of the **exact results** obtained adding to the **RGE** contributions from gauge and top yukawa interactions the **one-loop matrix element** with the Z four-momentum set on the mass-shell.
- The scale dependence of the RGE contribution cancels with that of the matrix element dominated by a quark loop.

Purely leptonic effective Lagrangian

- Quantum effects generate also a purely leptonic effective Lagrangian, as well as corrections to the semileptonic interactions.

$$\mathcal{L}_{\rm eff}^{\rm NC} = -\frac{4G_F}{\sqrt{2}}\lambda^e_{ij}\left[(\bar e_{Li}\gamma_\mu e_{Lj})\sum\nolimits_\psi \bar\psi\gamma^\mu\psi\,(2g^{\rm Z}_\psi \mathbf{c^e_t} - Q_\psi \mathbf{c^e_\gamma}) + h.c.\right]$$

$$\mathcal{L}_{\rm eff}^{\rm CC} = -\frac{4G_F}{\sqrt{2}}\lambda^e_{ij}\left[\mathbf{c^{cc}_t}(\bar e_{Li}\gamma_\mu \nu_{Lj})(\bar\nu_{Lk}\gamma^\mu e_{Lk} + \bar u_{Lk}\gamma^\mu V_{kl} d_{Ll}) + h.c.\right]$$

where $\psi = \{\nu_{Lk}, e_{Lk,Rk}, u_{L,R}, d_{L,R}, s_{L,R}\}$ and $g^{\rm Z}_\psi = T_3(\psi) - Q_\psi \sin^2\theta_W$.

$$\mathbf{c^e_t} = \mathbf{y_t^2}\frac{3}{32\pi^2}\frac{v^2}{\Lambda^2}(C_1 - C_3)\lambda^u_{33}\log\frac{\Lambda^2}{m_t^2} \qquad \mathbf{c^{cc}_t} = \mathbf{y_t^2}\frac{3}{16\pi^2}\frac{v^2}{\Lambda^2}C_3\,\lambda^u_{33}\log\frac{\Lambda^2}{m_t^2}$$

$$\mathbf{c^e_\gamma} = \frac{\mathbf{e^2}}{48\pi^2}\frac{v^2}{\Lambda^2}\left[(3C_3 - C_1)\log\frac{\Lambda^2}{\mu^2} - (C_1 + C_3)\lambda^d_{33}\log\frac{m_b^2}{\mu^2}\right.$$
$$\left. + 2(C_1 - C_3)\left(\lambda^u_{33}\log\frac{m_t^2}{\mu^2} + \lambda^u_{22}\log\frac{m_c^2}{\mu^2}\right)\right]$$

- The top-quark yukawa interactions affect both the neutral and charged currents.
- The gauge interactions are proportional to e^2 and to the e.m. current.
- The residual scale dependence is removed by the matrix elements in the low energy theory. For simplicity, we assume a common mass $m_{u,d,s} = \mu \approx 1$ GeV.

Semileptonic observables

- $B \to K \ell \bar{\ell}$

$$R_K^{\mu/e} \approx \frac{|C_9^{\mu\mu} + C_9^{\rm SM}|^2}{|C_9^{ee} + C_9^{\rm SM}|^2} \approx 1 - 0.28\, \frac{(C_1 + C_3)}{\Lambda^2({\rm TeV})} \frac{\lambda_{23}^d\, |\lambda_{23}^e|^2}{10^{-3}}$$

$$R_K^{\mu/e} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

- $R_{D^{(*)}}^{\tau/\ell}$

$$R_{D^{(*)}}^{\tau/\ell} = \frac{\sum_j |(C_L^{cb})_{3j}|^2}{\sum_j |(C_L^{cb})_{\ell j}|^2} \approx 1 - \frac{0.12\, C_3}{\Lambda^2({\rm TeV})} \left(1 + \frac{\lambda_{23}^d}{V_{cb}}\right) \lambda_{33}^e$$

$$R_D^{\tau/\ell} = 1.37 \pm 0.17, \qquad R_{D^*}^{\tau/\ell} = 1.28 \pm 0.08$$

- $B \to K \nu \bar{\nu}$

$$R_K^{\nu\nu} = \frac{\mathcal{B}(B \to K\nu\bar{\nu})}{\mathcal{B}(B \to K\nu\bar{\nu})_{\rm SM}} = \frac{\sum_{ij} |C_\nu^{\rm SM}\, \delta^{ij} + C_\nu^{ij}|^2}{3|C_\nu^{\rm SM}|^2} \le 4.3$$

$$\approx 1 + \frac{0.6\,(C_1 - C_3)}{\Lambda^2({\rm TeV})} \left(\frac{\lambda_{23}^d}{0.01}\right) + \frac{0.3\,(C_1 - C_3)^2}{\Lambda^4({\rm TeV})} \left(\frac{\lambda_{23}^d}{0.01}\right)^2$$

  - B-physics anomalies accommodated for: i) $C_1 = 0$ and $C_3 \neq 0$ and ii) $C_1 = C_3$.
  - The correct pattern of deviation from the SM is reproduced for $C_3 < 0$, $\lambda_{23}^d < 0$ and $|\lambda_{23}^d / V_{cb}| < 1$. For $|C_3| \sim \mathcal{O}(1)$, we need $\Lambda \sim 1$ TeV and $|\lambda_{23}^e| \gtrsim 0.1$.

- **LEP bounds on non-universal leptonic Z couplings** [PDG]

$$\frac{v_\tau}{v_e} = 0.959\,(29)\,, \qquad \frac{a_\tau}{a_e} = 1.0019\,(15)$$

$v_\ell = g^{\ell\ell}_{\ell L} + g^{\ell\ell}_{\ell R}$ and $a_\ell = g^{\ell\ell}_{\ell L} - g^{\ell\ell}_{\ell R}$ are the vector and axial-vector couplings

$$\frac{v_\tau}{v_e} \simeq 1 - \frac{2\,\Delta g^{33}_{\ell L}}{(1-4s^2_W)} \approx 1 - 0.05\,\frac{(c_- + 0.2\,C_3)}{\Lambda^2(\mathrm{TeV})}$$
$$\frac{a_\tau}{a_e} \simeq 1 - 2\,\Delta g^{33}_{\ell L} \approx 1 - 0.004\,\frac{(c_- + 0.2\,C_3)}{\Lambda^2(\mathrm{TeV})}\,,$$

- **Number of neutrinos N_ν from the invisible Z decay width**

$$N_\nu = 2 + \left(\frac{g^{33}_{\nu L}}{g^{\mathrm{SM}}_{\nu L}}\right)^2 \simeq 3 + 4\,\Delta g^{33}_{\nu L} \approx 3 + 0.008\,\frac{(c_+ - 0.2\,C_3)}{\Lambda^2(\mathrm{TeV})}$$

to be compared with the experimental result [PDG]

$$N_\nu = 2.9840 \pm 0.0082$$

- $\mathcal{B}(Z \to \mu^\pm \tau^\mp)$ is always well below the current experimental bound.

- **LFU breaking effects in $\tau \to \ell\bar{\nu}\nu$**

$$R_\tau^{\tau/e} = \frac{\mathcal{B}(\tau \to \mu\nu\bar{\nu})_{\rm exp}/\mathcal{B}(\tau \to \mu\nu\bar{\nu})_{\rm SM}}{\mathcal{B}(\mu \to e\nu\bar{\nu})_{\rm exp}/\mathcal{B}(\mu \to e\nu\bar{\nu})_{\rm SM}}$$

$$R_\tau^{\tau/\mu} = \frac{\mathcal{B}(\tau \to e\nu\bar{\nu})_{\rm exp}/\mathcal{B}(\tau \to e\nu\bar{\nu})_{\rm SM}}{\mathcal{B}(\mu \to e\nu\bar{\nu})_{\rm exp}/\mathcal{B}(\mu \to e\nu\bar{\nu})_{\rm SM}}$$

- **Experimental data on $R_\tau^{\tau/\ell}$** [HFAG, '14]

$$R_\tau^{\tau/\mu} = 1.0022 \pm 0.0030\,, \quad R_\tau^{\tau/e} = 1.0060 \pm 0.0030$$

- **NP effects in $R_\tau^{\tau/\ell}$**

$$R_\tau^{\tau/\ell} \simeq 1 + 2\, c_t^{cc} \lambda_{33}^e \approx 1 + \frac{0.008\, C_3}{\Lambda^2(\mathrm{TeV})}\, \lambda_{33}^e$$

- **Correlation between $R_\tau^{\tau/\ell}$ and $R_{D^{(*)}}^{\tau/\ell}$**

$$R_{D^{(*)}}^{\tau/\ell} \approx 1 - \frac{0.12\, C_3}{\Lambda^2(\mathrm{TeV})} \left(1 + \frac{\lambda_{23}^d}{V_{cb}}\right) \lambda_{33}^e$$

- **LFV τ decays**

$$\mathcal{B}(\tau \to 3\mu) \approx 5 \times 10^{-8} \frac{c_-^2}{\Lambda^4(\mathrm{TeV})} \left(\frac{\lambda_{23}^e}{0.3}\right)^2$$

$$\mathcal{B}(\tau \to \mu\rho) \approx 5 \times 10^{-8} \frac{(c_- - 0.28 C_3)^2}{\Lambda^4(\mathrm{TeV})} \left(\frac{\lambda_{23}^e}{0.3}\right)^2$$

$$\mathcal{B}(\tau \to \mu\pi) \approx 8 \times 10^{-8} \frac{c_-^2}{\Lambda^4(\mathrm{TeV})} \left(\frac{\lambda_{23}^e}{0.3}\right)^2$$

- **LFV B decays**

$$\mathcal{B}(B \to K\tau\mu) \approx 4 \times 10^{-8} \left|C_9^{\mu\tau}\right|^2 \approx 10^{-7} \left|\frac{C_9^{\mu\mu}}{0.5}\right|^2 \left|\frac{0.3}{\lambda_{23}^e}\right|^2 ,$$

since $C_9^{\mu\mu}/C_9^{\mu\tau} \approx \lambda_{23}^e$ and $|C_9^{\mu\mu}| \approx 0.5$ from $R_K^{e/\mu} \approx 0.75$.

- **Experimental bounds** [HFAG]:

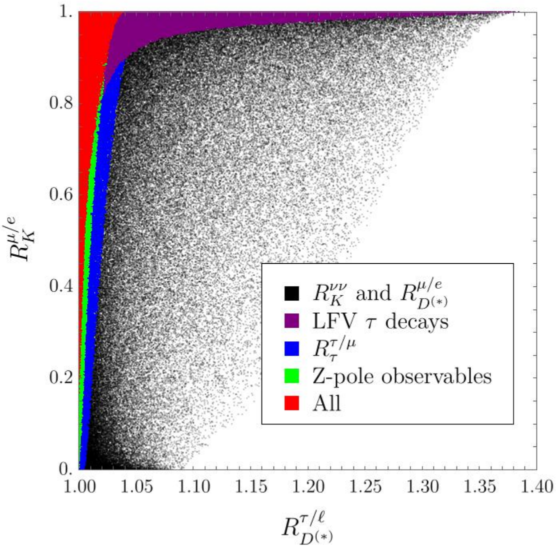
$$\mathcal{B}(\tau \to 3\mu)_{\mathrm{exp}} \leq 2.1 \times 10^{-8}$$

$$\mathcal{B}(\tau \to \mu\rho)_{\mathrm{exp}} \leq 1.2 \times 10^{-8}$$

$$\mathcal{B}(\tau \to \mu\pi)_{\mathrm{exp}} \leq 2.7 \times 10^{-8}$$

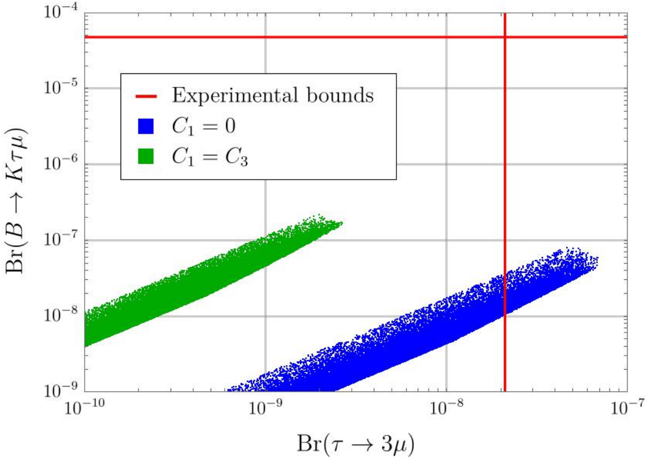
$$\mathcal{B}(B \to K\tau\mu)_{\mathrm{exp}} \leq 4.8 \times 10^{-5}$$

$R_K^{\mu/e}$ vs. $R_{D^{(*)}}^{\tau/\ell}$



$R_K^{\mu/e}$ vs. $R_{D^{(*)}}^{\tau/\ell}$ for $C_1 = 0$, $|C_3| \leq 3$, $|\lambda_{23}^d| \leq 0.04$ and $|\lambda_{23}^e| \leq 1/2$.
The allowed regions are coloured according to the legend.

$\mathcal{B}(B \to K\tau\mu)$ vs. $\mathcal{B}(\tau \to 3\mu)$



$\mathcal{B}(B \to K\tau\mu)$ vs. $\mathcal{B}(\tau \to 3\mu)$ for $|\lambda^d_{23}| = 0.01$, $C_1 = C_3$ (green points) or $C_1 = 0$ (blue points) imposing all the experimental bounds except $R^{\tau/\ell}_{D^{(*)}}$.

Conclusions

- We revisited LFU in B-decays model-independently assuming gauge invariant semileptonic operators at the NP scale $\Lambda \gg v$.
- We constructed the low-energy effective Lagrangian taking into account the running effects from Λ down to v through the one-loop RGEs in the limit of exact electroweak symmetry and QED RGEs from v down to the 1 GeV scale.
- At the quantum level, the leptonic couplings of the W and Z vector bosons are modified. Moreover, quantum effects generate a purely leptonic effective Lagrangian and corrections to the semileptonic interactions.
- At the quantum level, the leptonic couplings of the W and Z vector bosons are modified. Moreover, quantum effects generate a purely leptonic effective Lagrangian as well as corrections to the semileptonic interactions.
- Large LFU breaking effects in Z and τ decays and τ LFV processes are generated and they challenge an explanation of the current B-anomalies.
- Interestingly, if LFU breaking effects arise from LFV sources, the most sensitive LFV channels are not B-decays, as commonly claimed in the literature but, instead, τ decays such as $\tau \to \mu\ell\ell$ and $\tau \to \mu\rho$.