The flavour anomalies: SM vs NP

M. Bordone, D. Buttazzo, A. Greljo, G. Isidori,
D. Marzocca, A. Pattori, S. Trifinopoulos

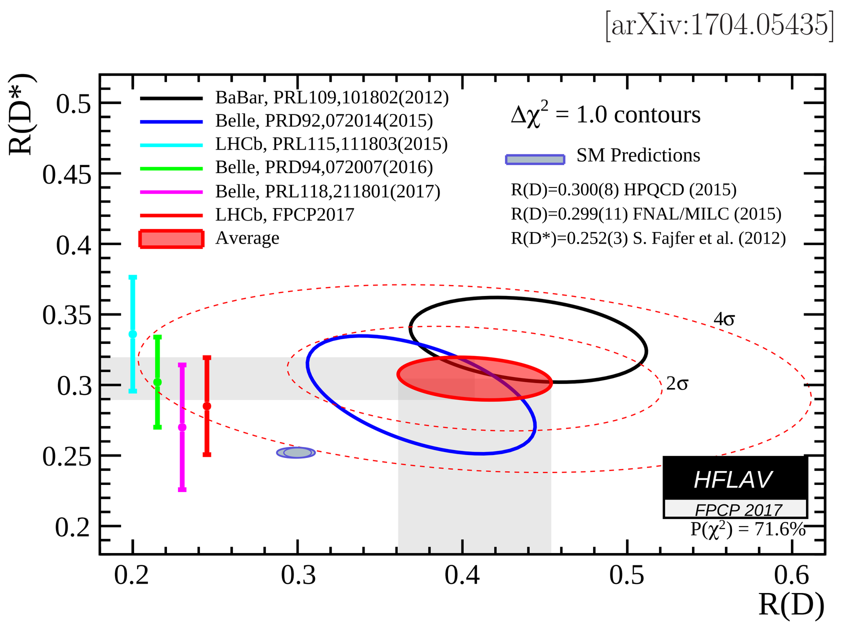
Physik Institut, Universität Zürich

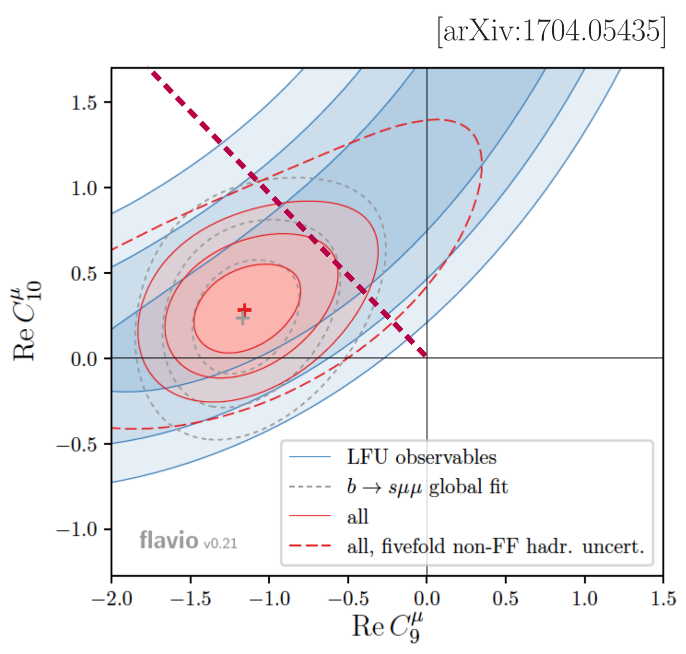
University of Zurich[UZH]

1) Motivation

Hints of **L**epton **F**lavour **U**niversality **V**iolation in

- $b \to s$ neutral currents: μ vs e
- $b \to c$ charged currents: τ vs light leptons (μ, e)





Two-fold approach:

- Standard Model (SM) predictions for the flavour observables
- New Physics (NP) model to address the anomalies

2) Radiative Correction on R_K and R_{K^*}

LFU in $b \to s$ neutral currents is probed via the observables $R_{K^{(*)}} = \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)}$ → essential to estimate their SM errors.

Within the SM, we can identify the following sources of LFUV:

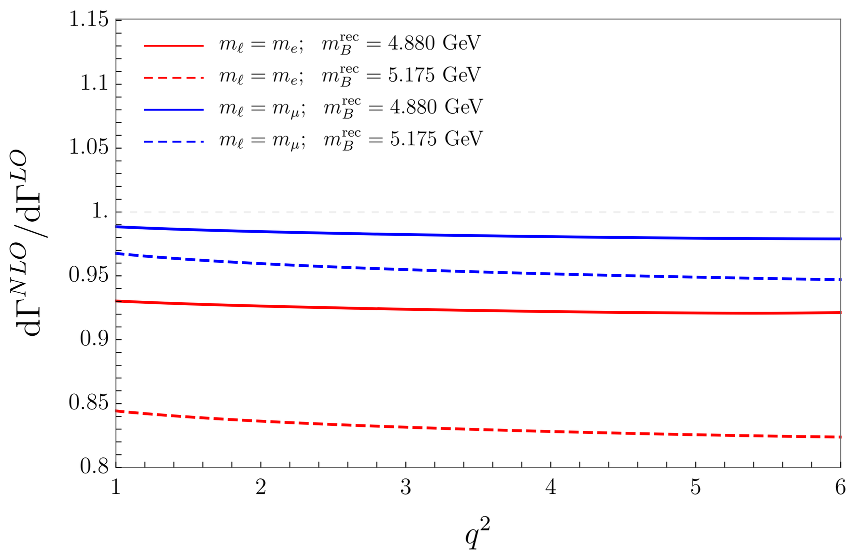
- kinematics and form factors effects $\sim \frac{m_\ell^2}{q^2}$;
- QED corrections $\sim \frac{\alpha}{\pi}\log(\frac{m_\ell^2}{q^2})$;
- interplay between the two effects.

In order to have a better understanding of these effects, we performed a **semi-analytical calculation of radiative corrections**. This allows us to:

- crosscheck the montecarlo PHOTOS (used in the LHCb analysis);
- estimate the residual theory error.

3) Results for the central q^2 bin

In the central bin, defined as $q^2 \in [1, 6]$ GeV^2, we find:



- the J/Ψ resonance **does not affect** the distribution;
- QED corrections can in principle be **sizeable**; however, the kinematical cuts applied in the experimental analysis **reduce** their size;
- leading effect **well described** by PHOTOS.

Our result for the exp. measured quantity is [1]

$$R_{K^*}[1,6]^{\rm SM} = 1.00 \pm 0.01$$

4) Results for the low q^2 bin

The low q^2 bin, where $q^2 \in [0.045, 1.1]$ GeV^2, is of great importance since NP effects can be different compared to the central bin.
This bin is accessible only for R_{K^*} [→ K^* a vector particle].

Two main effects:

- kinematic effects are **non universal** for electrons and muons and they may cause distortions,
- light-quark resonances (η, f_0, $\cdots$) provide **non-bremsstrahlung** terms not included in PHOTOS.

As a benchmark, we estimate the effect in the η case, finding a 2% shift for R_{K^*}, leading to the prediction [1]:

$$R_{K^*}[0.045, 1.1]^{\rm SM} = 0.91 \pm 0.02_{\rm QED} \pm 0.02_{\rm FF}$$

Concluding remarks:

- **The SM predictions for the universality ratios $R_{K^{(*)}}$ are solid.**
- **The status of experimental data points to NP.**

5) Effective Field Theory approach for NP

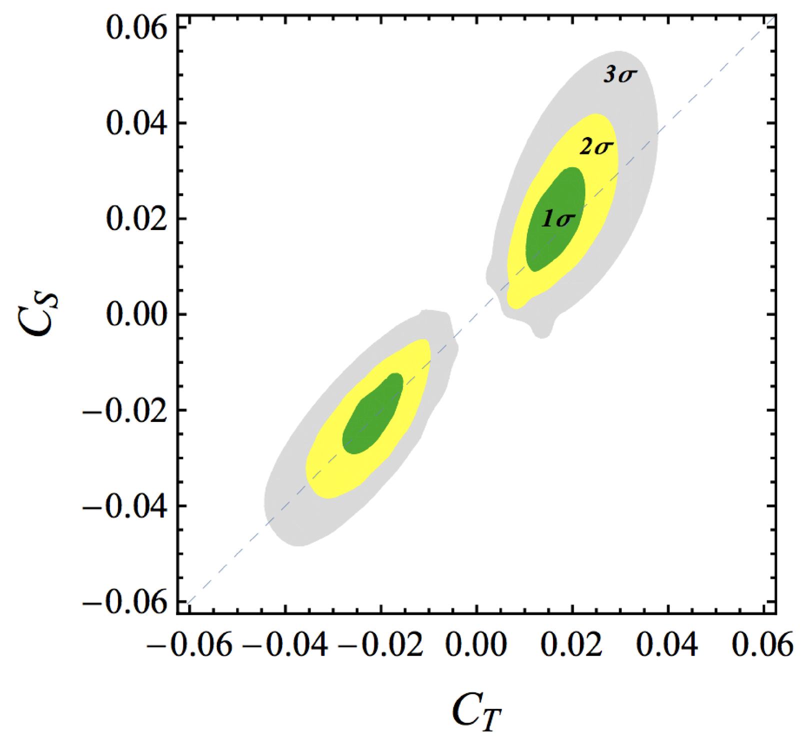
A combined solution to the anomalies is provided by an Effective Field Theory (EFT) based on few assumptions [2, 3]:

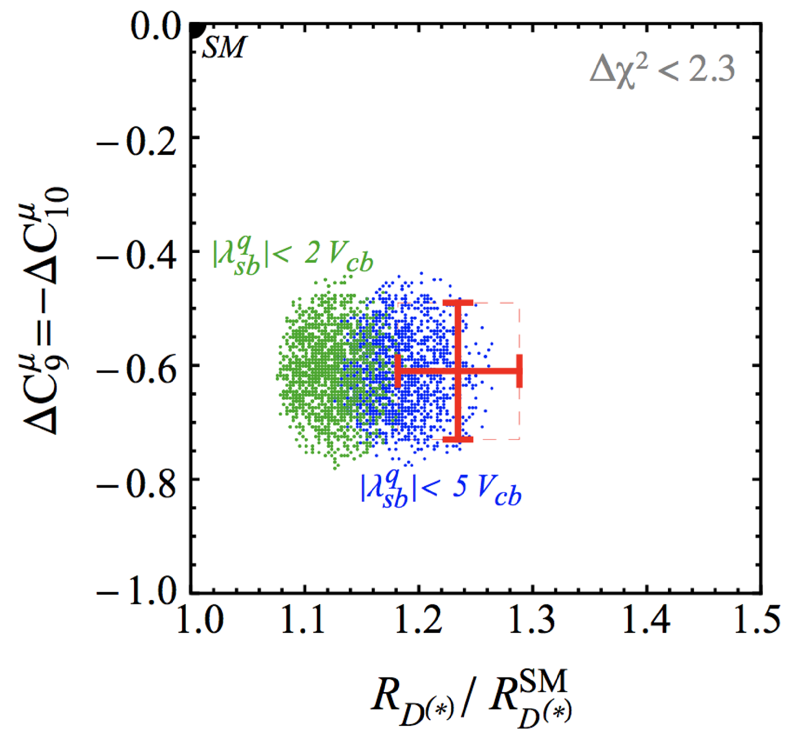
- NP only in **left-handed** operators,
- the leading NP effects arise in the **3rd generation** of quarks and leptons only,
- the couplings to light generations are controlled by a $U(2)_q \times U(2)_\ell$ **flavour symmetry** minimally broken [→ link to the SM Yukawa coupl.]

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \frac{1}{\Lambda^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\Big[C_T(\bar{Q}^i_L\gamma^\mu T^a Q^j_L)(\bar{L}^\alpha_L\gamma_\mu T^a L^\beta_L) + C_S(\bar{Q}^i_L\gamma^\mu Q^j_L)(\bar{L}^\alpha_L\gamma_\mu L^\beta_L)\Big]$$

The free parameters of $\mathcal{L}_{\rm eff}$ are C_T, C_S, λ^q_{ij} and $\lambda^\ell_{\alpha\beta}$. However, there are **non-trivial** constraints coming from electroweak precision tests, flavour observables and high-p_T data.

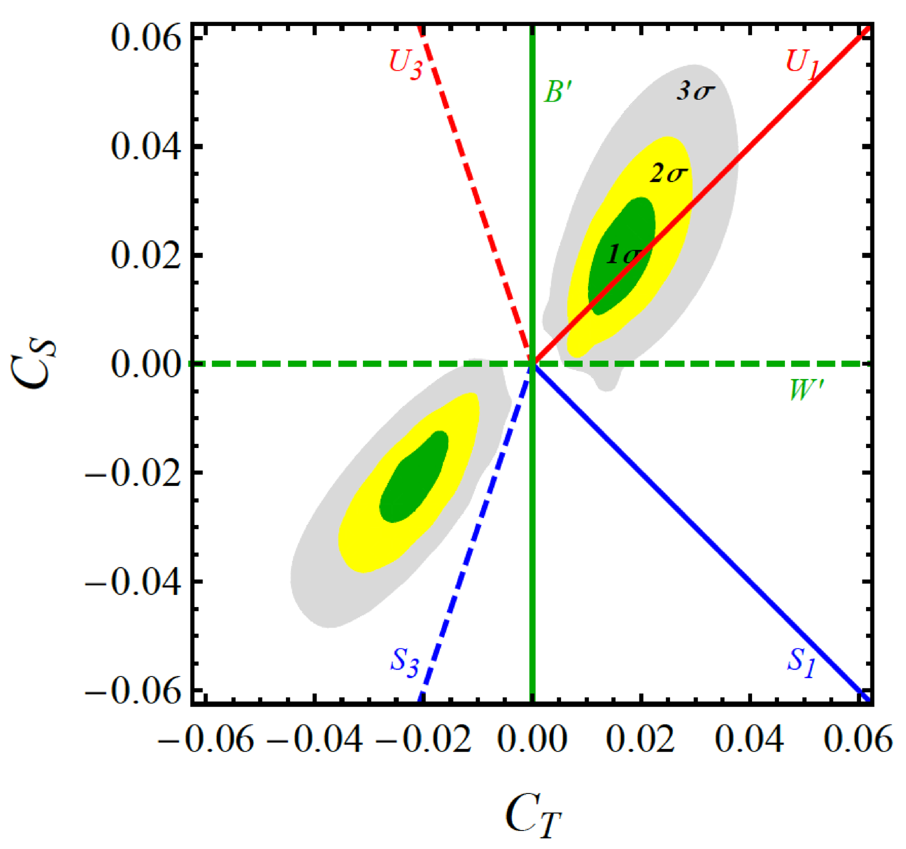
6) Fit of the EFT parameters to data





- We get an excellent fit to **both** anomalies.
- The constraints from flavour observables, electroweak precision tests and high-p_T data are **fulfilled** without introducing fine tuning.
- The effective scale Λ of NP is of the order $\Lambda \sim 1.5$ TeV.

7) From EFT to simplified models



Only few new mediators can generate this EFT:

- **Vector Leptoquark** U_1 and U_3,
- **Scalar Leptoquark** S_1 and S_3,
- **Colorless vector** B' and W'.

Among them, only the vector leptoquark U_1 requires no tuning.

Concluding remarks:

- **No contradiction between LFU anomalies and constraints from electroweak precision tests, flavour observables, or high-p_T data.**
- **A TeV-scale vector leptoquark is a very good candidate to explain the anomalies.**

References

[1] M. Bordone, G. Isidori, and A. Pattori, "On the Standard Model predictions for R_K and R_{K^*}," *Eur. Phys. J.* **C76** no. 8, (2016) 440, `arXiv:1605.07633 [hep-ph]`.

[2] D. Buttazzo, A. Greljo, G. Isidori, and D. Marzocca, "B-physics anomalies: a guide to combined explanations," *JHEP* **11** (2017) 044, `arXiv:1706.07808 [hep-ph]`.

[3] M. Bordone, G. Isidori, and S. Trifinopoulos, "Semileptonic *B*-physics anomalies: A general EFT analysis within $U(2)^n$ flavor symmetry," *Phys. Rev.* **D96** no. 1, (2017) 015038, `arXiv:1702.07238 [hep-ph]`.