Phenomenology of Flavour Anomalies

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The experimental measurements on flavour physics, in tension with Standard Model predictions, exhibit large sources of Lepton Flavour Universality violation. An analysis of the effects of the global fits to the Wilson coefficients, assuming a model independent effective Hamiltonian approach, is summarized.

Several low-energy flavour measurements performed in the recent years at LHC and other experiments exhibit some discrepancies with the Standard Model (SM) predictions. Particularly interesting are the semileptonic B meson decays. Some of these decays allow us to build optimised observables, as ratios of these decays, that are theoretically clean observables, with the advantage that a large part of the hadronic form factor uncertainties cancels out. For the ratios of branching fractions $R_{K^{(*)}}$,

$$R_{K^{(*)}} = \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)} \,, \qquad (1)$$

the latest experimental results from LHCb, in the specified regions of q^2 di-lepton invariant mass, have reported sizeable violations of Lepton Universality at the $2.3 - 3.1\,\sigma$ level [1, 2] that may represent an indirect signal of New Physics (NP). It is well known that in the SM, as a consequence of Lepton Flavour Universality, $R_K = R_{K^*} = 1$.

Sizeable deviations from their predicted SM values, $R_D^{\ell\,\mathrm{SM}} = 0.299 \pm 0.003$, $R_{D^*}^{\ell\,\mathrm{SM}} = R_{D^*}^{\mu\,\mathrm{SM}} = 0.258 \pm 0.005$ [3], have also been found in the ratios,

$$R^{\mu}_{D^{(*)}} = \frac{\mathrm{BR}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathrm{BR}(B \to D^{(*)}\ell\bar{\nu}_\ell)} \ (\ell = e, \mu)\,. \qquad (2)$$

The experimental averages, as obtained by the Heavy Flavour Averaging Group (HFLAV) [3], exhibit a $3.1\,\sigma$ discrepancy with the SM predictions.

Effective Field Theories are one of the most widely used tools to study any possible NP contribution aiming to explain the above experimental results. The effective Hamiltonian approach allows us to perform a model-independent analysis of NP effects. The above decays are then described with a model-independent approach, using an effective Operator Product Expansion, such that the Lagrangian is defined as a sum of current-current operators multiplied by the complex coefficients C_i, the so-called Wilson coefficients. Those effective operators affect a large number of observables which are interconnected via the Wilson coefficients.Therefore, in order to have a complete analysis of the implications of the experimental measurements in flavour physics observables, a global fit should be considered.

A global fit to the updated experimental information has been presented in [4, 5], where an extensive list of references to previous analyses is included. The main results obtained in these two articles are summarised here. The global fit includes $b \to s\mu\mu$ observables; i.e. $R_{K^{(*)}}$, the angular observables P_5', the branching ratio of $B_s \to \mu\mu$, as well as $R_{D^{(*)}}$, $b \to s\nu\bar{\nu}$, and finally the electroweak precision observables (W and Z decay widths and branching ratios to leptons). We found out that the electroweak precision observables play an important role on this fit. The goodness of each fit is evaluated with its difference of χ^2 with respect to the SM value.

At energy scales relevant for flavour processes it is convenient to work at an energy scale below the electroweak scale, for example $\mu_{\mathrm{WET}} = m_b$, and with the top quark, Higgs, W and Z bosons being integrated out. Motivated by the fact that the most prominent discrepancies between SM predictions and experimental measurements, namely $R_{K^{(*)}}$ and $R_{D^{(*)}}$, affect the third quark generation, we will restrict to operators including only third generation quarks and same-generation leptons. The notation used for the Wilson coefficients is $C^e_{\ell q}, C^\mu_{\ell q}, C^\tau_{\ell q}$. We define the $C_{\ell q}$ operators at $\Lambda = 1$TeV, computing their running down to $\mu_{\mathrm{EW}} = M_Z$, then match them with the electroweak operators and finally run the down to $\mu = m_b$, where the B-physics observables are computed. It implies some necessary relations between the Wilson coefficients at high and low energies.

For the phenomenological analysis we consider different scenarios such that NP contributions only modifies the $C_{\ell q}$ operators in one lepton flavour at a time, two of the Wilson coefficients receive NP contributions simultaneously and finally, three of the $C^i_{\ell q}$ operators receive NP contributions. For all scenarios we compare the results of the global fit with respect to the SM predictions.

We found that, when NP contributes to only one lepton flavour operator at a time, the largest pull from the SM prediction, almost $3\ \sigma$, appears when the coupling to electrons is added independently. In those scenarios in which NP is present in two of the Wilson coefficients simultaneously, the best fit corresponds to the scenario where the contributions to $C^e_{\ell q}$ and $C^\mu_{\ell q}$ are favoured (Scenario IV) with a pull of $4.97\ \sigma$ with respect to the SM. Finally, the prediction of the $R_{D^{(*)}}$ and $R_{K^{(*)}}$ observables is improved in the scenario in which the three $C_{\ell q}$ operators receive independent NP contributions (Scenario VII). In this case, the pull from the SM is 4.97 σ and the predictions for the $R_{K^{(*)}}$ observables are very similar to the case of Scenario IV, but a better fit to $R_{D^{(*)}}$ observables, and specially to R_D^ℓ, is obtained. Therefore, for a simultaneous analysis of predictions for the $R_{D^{(*)}}$ and $R_{K^{(*)}}$ observables, the scenarios with three non-universal Wilson coefficients are favoured. We also found that an scenario (Scenario IX) within the condition $C^e_{\ell q} = -C^\mu_{\ell q} = C^\tau_{\ell q}$ imposed, provides a similar goodness fit with a smaller set of free parameters. In this case, there is a disagreement with the SM as large as $5.54\,\sigma$. This result shows that a relation $C^e_{\ell q} = -C^\mu_{\ell q}$ is favoured by the global fits.

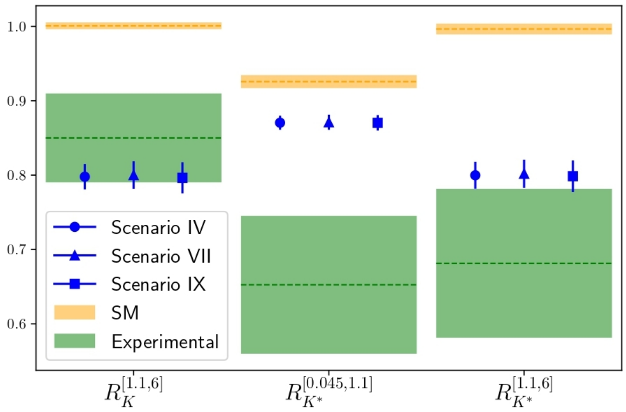

Figure 1: Central value and 1σ uncertainty of the $R_{K^{(*)}}$ observable in scenarios IV, VII and IX (blue lines), compared to the SM prediction (yellow) and experimental measurements (green).

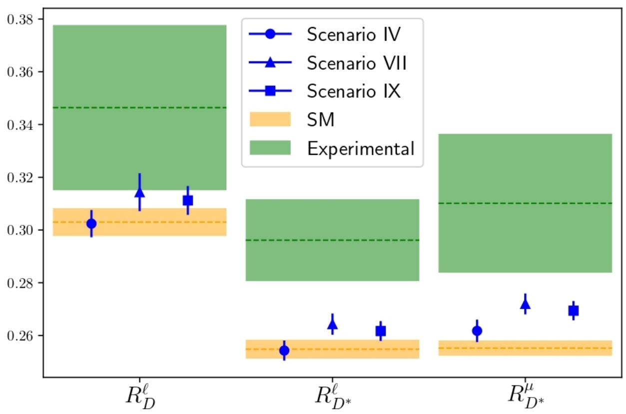

Figure 2: Central value and 1σ uncertainty of the $R_{D^{(*)}}$ observables. Details as in Figure 1.

The results for $R_{K^{(*)}}$ and $R_{D^{(*)}}$ observables (central value and $1\,\sigma$ uncertainty) in the mentioned scenarios with best pulls, Scenarios IV, VII and IX, are presented in Figure 1 and 2, respectively. Results are compared to the SM prediction (yellow area) and experimental measurements (green area). It is clear that these three scenarios reproduce the experimental value of $R_K^{[1.1,6]}$ and reduce the tension in $R_{K^*}^{[1.1,6]}$. For the $R_{D^{(*)}}$ ratios, the $C^\tau_{\ell q}$ contributions are needed. Since Scenario IV has no NP contribution in the τ sector, it predicts SM-like R_D^ℓ and $R_{D^*}^\ell$ ratios. Scenario VII has a large contribution to $C^\tau_{\ell q}$ and is able to produce a prediction for R_D^ℓ compatible with the experimental results, and significantly improve the predictions for $R_{D^*}^\ell$ and $R_{D^*}^\mu$. Scenario IX has an intermediate value of $C^\tau_{\ell q}$, and consequently its predictions for the $R_{D^{(*)}}$ ratios are not as good as in the previous case.

Clearly, it is difficult to find an easy common explanation for all flavour anomalies. Both new experimental inputs and, consequently, new global fits are needed in order to clarify the situation. On one side, the LHC and Belle collaborations are actively working in order to improve the present situation. On the other side, future colliders as the linear lepton colliders ILC and CLIC, should provide valuable new information to cast light on the B anomalies. Improved precision in electroweak observables will help constrain the global fits in a complementary way to B-physics experiments.

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Notes

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