

## *B* anomalies in an EFT approach

M. BORDONE

*Universität Zürich - Zürich, Switzerland*

received 21 April 2018

**Summary.** — We present a general EFT framework based in  $U(2)^n$  flavour symmetry applied to the light generations of SM fermions to address the hints of Lepton Flavour Universality violation in  $B$  decays observed in the recent years. In particular we analyse the constraints from the low energy observables in  $B$  and  $\tau$  physics. We show that a consistent picture can be achieved introducing a moderate fine tuning and additional dynamical assumptions which aim to the New Physics (NP) being coupled mostly to the third generation of SM fermions.

### 1. – Introduction

The data collected in the recent years by LHCb, BaBar and Belle point to a few anomalies in  $B$  decays. Concerning the charged current  $b \rightarrow c\bar{\nu}_\ell$ , the universality ratios  $R_{D^{(*)}}$  show a discrepancy with respect to the theory predictions [1, 2] of about  $4\sigma$  [3]. As regards the Flavor-changing neutral currents (FCNC)  $b \rightarrow s\ell^+\ell^-$ , the universality ratio  $R_K$  is found in disagreement with the standard model prediction [4] of  $2.6\sigma$  [5]. Moreover, looking at exclusively the  $b \rightarrow s\mu^+\mu^-$  data, further discrepancies are found. The most significative one is represented by the so-called angular observable  $P'_5$ , which differs from the SM prediction of about  $3\sigma$  [6].

These anomalies triggered many attempts of being addressed through the presence of NP. The features of the hypothetical NP sector are well defined:

- it has to modify both charged and neutral currents;
- it couples mainly to the third generation of quark and leptons;
- the naive effective scale of NP required to explain  $R_{D^{(*)}}$  and the  $b \rightarrow s\ell\ell$  data are substantially different, since in the SM the former process arises at tree level while the latter is generated at least at 1 loop. Qualitatively the effective scale  $\Lambda$  required to address  $R_{D^{(*)}}$  it is  $\Lambda \sim 1$  TeV, while to fit for  $R_{K^{(*)}}$  it is  $\Lambda \sim 10$  TeV.

If a model-dependent approach to address the anomalies depends highly on the different assumptions behind the model itself, an EFT analysis is much more powerful. In

fact, it allows to derive model-independent constraints on NP arising from the anomalies. Of course, the only EFT is not enough, we need also to assign a flavour group which enhances the interactions of the NP with the third generation of both quarks and leptons. Our choice is introducing a  $U(2)^n$  flavour group, which is described more in details in the next section.

## 2. – An EFT based on the flavour symmetry $U(2)^n$

The EFT we want to build is made up by the following ingredients: the SM field content, the SM symmetry ( $SU(3)_c \times SU(2)_L \times U(1)_Y$ ) and a global flavour symmetry  $\mathcal{G}_{\text{flavour}}$ . We can decompose the global flavour symmetry as

$$(1) \quad \mathcal{G}_{\text{flavour}} = U(2)_q \times U(2)_\ell \times \mathcal{G}_R.$$

The SM left-handed fermions are singlets under  $\mathcal{G}_R$ , while their transformation properties under  $U(2)_q \times U(2)_\ell$  read

$$(2) \quad \begin{aligned} q_L^3 &= (1, 1), & Q &= (q_L^1, q_L^2) = (2, 1), \\ \ell_L^3 &= (1, 1), & L &= (\ell_L^1, \ell_L^2) = (1, 2), \end{aligned}$$

where with  $q_L^i$  and  $\ell_L^i$  we indicate the  $SU(2)_L$  doublet associated with the  $i$  family, respectively, of quarks and leptons. Concerning the right-handed fermion of third generation, they are singlet under the complete flavour symmetry  $\mathcal{G}_{\text{flavour}}$ , while for the light generation we assumed a MFV structure [7].

In order then to get the interactions of interest to fix the anomalies, the flavour symmetry must be broken. One way of doing that is introducing two spurions,  $V_Q$  in the quark sector and  $V_L$  in the lepton sector. They transform under  $U(2)_q \times U(2)_\ell$  as  $V_Q \sim (2, 1)$ , and  $V_L \sim (1, 2)$ , while they are singlets under  $\mathcal{G}_R$ . The structure of  $V_Q$  can be linked with the CKM matrix up to an overall normalisation, while we can choose to align  $V_L$  completely to the muon direction. Moreover, as regards the quark sector, we choose to work in the down-quark basis.

## 3. – Observables and results

Several observables are concerned in this framework and for a complete analysis we refer to [8]. A summary can be found in table I. The main conclusions that we draw are the following:

- The operators that modify the  $b \rightarrow c\tau\bar{\nu}_\tau$  current have a V-A structure as in the SM, while the contribution of scalar operators can be considered negligible.
- The operators that modify the  $b \rightarrow c\ell\bar{\nu}_\ell$ , with  $\ell = e, \mu$  are negligible.
- The running effects described in [9] affect mainly the decay  $\tau \rightarrow \mu\nu_\tau\bar{\nu}_\mu$ : we impose a  $\mathcal{O}(10\%)$  cancellation between the NP Wilson coefficients and the running effects.
- The  $B_{s,d}$  mixing imposes a well-defined alignment in flavour space, which we can quantify with a  $\mathcal{O}(10\%)$  tuning.
- We expect a tension of  $\mathcal{O}(1\%)$  in the  $|V_{us}|$  determination from  $\tau$  and  $K$  decays.

TABLE I. – *Most relevant constraints on the Wilson coefficients. In the last two columns we report the parametric scaling of the (leading) Wilson coefficients and the order of magnitude following from the overall EFT scale and the choice of the  $\epsilon_i$  reported in eqs. (3), (4).*

Process	Combination	Constraint	Parametric scaling	Order of magnitude
$R_{D^{(*)}}$	$\Re(C_{02}^q + V_{Q_s} C_{12}^q \frac{V_{cs}}{V_{cb}})$	$0.09 \pm 0.04$	1	$10^{-1}$
$B \rightarrow D\mu\nu_\mu$	$\Re(C_{04}^q + V_{Q_s} C_{14}^q \frac{V_{cs}}{V_{cb}})$	$-(0.8 \pm 2.5) \times 10^{-2}$	$(\epsilon_L^\ell)^2$	$10^{-2}$
$\tau \rightarrow \mu\nu\bar{\nu}$	$\Re(C_{04}^\ell)$	$-(1.2 \pm 0.5) \times 10^{-2}$	$(\epsilon_L^\ell)^2 r_{q\ell}$	$10^{-2} r_{q\ell}$
$R_{sd}^{\tau/\mu}$	$\Re[C_{08}^q - C_{06}^q + (C_{14}^q - C_{12}^q) V_{Q_s} V_{ub}/V_{us} ]$	$(0.7 \pm 0.4) \times 10^{-2}$	$(\epsilon_L^q)^2$	$\leq 10^{-2}$
$\tau \rightarrow \mu ee$ $\tau \rightarrow 3\mu$	$ V_L  \times ( C_{13}^\ell + C_{14}^\ell ^2 + C_{R2}^\ell ^2 +  C_{T2}^\ell ^2)^{1/2}$	$\leq 3.2 \times 10^{-4}$	$\epsilon'_\ell (\epsilon_{L,R}^\ell)^2 r_{q\ell}$	$10^{-3} (\frac{\epsilon'_\ell}{0.1}) r_{q\ell}$
$\tau \rightarrow \rho\mu$	$ C_{24}^q   V_L $	$\leq 1.4 \times 10^{-4}$	$\epsilon'_\ell (\epsilon_L^q)^2$	$\leq 10^{-3} (\frac{\epsilon'_\ell}{0.1})$
$\tau \rightarrow \omega\mu$	$ C_{23}^q   V_L $	$\leq 3.2 \times 10^{-4}$	$\epsilon'_\ell (\epsilon_L^q)^2$	$\leq 10^{-3} (\frac{\epsilon'_\ell}{0.1})$
$B \rightarrow K\nu\bar{\nu}$	$\Re(C_{11}^q - C_{12}^q)$	$(2.2 \pm 4.5) \times 10^{-2}$	$\epsilon'_q$	$10^{-2} (\frac{\epsilon'_q}{0.1})$
$B^0 - \bar{B}^0$	$ C_{01}^{qq} + C_{02}^{qq} $	$\leq 0.42 \times 10^{-3}$	$(\epsilon'_q)^2 r_{q\ell}^{-1}$	$10^{-3} (\frac{\epsilon'_q}{0.1})^2 r_{q\ell}^{-1}$
$B \rightarrow K^{(*)}\mu\bar{\mu}$	$\Re(C_{13}^q + C_{14}^q)$ $\Re(C_{r5}^q)$	$-(0.8 \pm 0.3) \times 10^{-3}$ $-(0.4 \pm 0.3) \times 10^{-3}$	$\epsilon'_q (\epsilon_L^\ell)^2$ $\epsilon'_q (\epsilon_R^\ell)^2$	$10^{-3} (\frac{\epsilon'_q}{0.1})$
$B_d \rightarrow \tau\mu$	$ C_{31}^q + C_{32}^q $	$\leq 4.5 \times 10^{-2}$	$\epsilon'_q \epsilon'_\ell$	$10^{-3} (\frac{\epsilon'_q \epsilon'_\ell}{10^{-2}})$

Furthermore, for our framework to be consistent, we need to justify the hierarchy between the various Wilson coefficients associated with the operators that we introduced. To be able to do so, we can get inspired by dynamical assumptions, according to which the new sector couples directly to quarks and leptons of the third generation, while the interactions with the light families happen only through small mixing angles. This can be achieved by re-scaling the fields associated to light generations of leptons and quarks if they appear in the operators without a spurion, as in the following:

$$(3) \quad L \rightarrow \epsilon_L^\ell L, \quad Q \rightarrow \epsilon_L^q Q, \quad E_R \rightarrow \epsilon_R^q E_R.$$

Also, concerning the size of both lepton and quark spurions, we implement the following rescaling:

$$(4) \quad V_L \rightarrow \epsilon'_\ell, \quad |V_Q| \rightarrow \epsilon'_q |V_{ts}|.$$

As can be seen from the last column of table I, the re-scaling allows to motivate the hierarchy of the Wilson coefficients.

Finally we can check if our analysis fits the global fits to  $b \rightarrow s\ell\ell$  data. In order to do so we need to introduce new operators, which arise at least at the order  $\mathcal{O}(|V_L|^2|V_Q|)$ . In fact, only at this order in the spurions we can distinguish the muons and electrons final state at the tree level. If we now take into account the most favoured benchmark of the global fits  $C_9^{\text{NP}} = -C_{10}^{\text{NP}} \approx -1$  [10], the central value of  $R_K$  can be obtained consistently with the parametric scaling introduced previously, without adding any further source of fine tuning.

\* \* \*

The author acknowledge G. Isidori and S. Trinopoulos for developing together this interesting work. This research was supported in part by the Swiss National Science Foundation (SNF) under contract 200021-159720.

#### REFERENCES

- [1] BIGI D. and GAMBINO P., *Phys. Rev. D*, **94** (2016) 094008.
- [2] FAJFER S., KAMENIK J. F. and NISANDZIC I., *Phys. Rev. D*, **85** (2012) 094025.
- [3] AMHIS Y. *et al.*, arXiv:1612.07233 (2016).
- [4] BORDONE M., ISIDORI G. and PATTORI A., *Eur. Phys. J. C*, **76** (2016) 440.
- [5] LHCb COLLABORATION (AAIJ R. *et al.*), *Phys. Rev. Lett.*, **113** (2014) 151601.
- [6] LHCb COLLABORATION (AAIJ R. *et al.*), *JHEP*, **02** (2016) 104.
- [7] D'AMBROSIO G., GIUDICE G. F., ISIDORI G. and STRUMIA A., *Nucl. Phys. B*, **645** (2002) 155.
- [8] BORDONE M., ISIDORI G. and TRIFINOPOULOS S., arXiv:1702.07238 [hep-ph] (2017).
- [9] FERUGLIO F., PARADISI P. and PATTORI A., *Phys. Rev. Lett.*, **118** (2017) 011801.
- [10] DESCOTES-GENON S., HOFER L., MATIAS J. and VIRTO J., *JHEP*, **06** (2016) 092.