UNIVERSITÄT SIEGEN

An EFT framework combined with a FN like power counting for flavour and B anomalies

in collaboration with O. Cata and T. Feldmann

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Hadronic Contributions to New Physics Searches 2019

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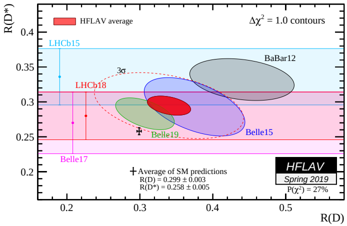
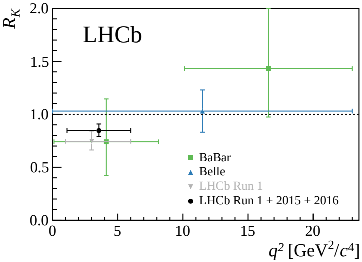
Motivation

- How to parametrise NP in flavour processes
  - how to classify possible NP operators
  - how big are the entries in flavour space of NP operators
- Anomalies in B decays



$\sim 3.1\sigma$



$\sim 4-5\sigma$

[See Marco Fedele talk tomorrow]

EFT for New Physics

Let's take the following example:

$$\frac{1}{\Lambda^2}[\mathcal{C}_{ql}^{(1)}]^{ij\alpha\beta}(\bar{Q}_i\gamma_\mu Q_j)(\bar{L}_\alpha\gamma^\mu L_\beta)$$

How large can $[\mathcal{C}_{ql}^{(1)}]^{ij\alpha\beta}$ be?

- A flavour symmetry enhances/suppresses the various entries
  - an example is the $U(2)^5$ flavour symmetry
    [R. Barbieri, G. Isidori, J. Jones-Perez, P. Lodone, and D. M. Straub, 2011]
- Make assumption on how flavour is broken for the NP
  - Minimal Flavour Violation: the Yukawa are the only source of flavour breaking
    [G. D'Ambrosio, G. F. Giudice, G. Isidori, and A. Strumia, 2002]

How to generalise the MFV idea?

Our approach

- No assumption about how flavour is broken in the NP sector
- We start from bilinears constructed with SM fermion fields only
- We list all the possible spurions according to
  - the SM gauge group
  - the SM (unbroken) flavour symmetry
  - tree level exchange only

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Dirac bilinear	$SU(3)\times SU(2)\times U(1)$	Flavour spurion	$\mathcal{G}_f$	$(\Delta B;\Delta L)$
$\bar{Q}\gamma^\mu L$	$(3, 1\oplus 3, \frac{2}{3})$	Δ_{QL}	$(3,1,1)(\bar{3},1)$	$(\frac{1}{3};-1)$
$\bar{U}\gamma^\mu E$	$(3,1,\frac{5}{3})$	Δ_{UE}	$(1,3,1)(1,\bar{3})$	$(\frac{1}{3};-1)$
$\bar{D}\gamma^\mu E$	$(3,1,\frac{2}{3})$	Δ_{DE}	$(1,1,3)(1,\bar{3})$	$(\frac{1}{3};-1)$
$\bar{Q}E$	$(3,2,\frac{7}{6})$	S_{QE}	$(3,1,1)(1,\bar{3})$	$(\frac{1}{3};-1)$
$\bar{U}L$	$(3,2,\frac{7}{6})$	S_{UL}	$(1,3,1)(\bar{3},1)$	$(\frac{1}{3};-1)$
$\bar{D}L$	$(3,2,\frac{1}{6})$	S_{DL}	$(1,1,3)(\bar{3},1)$	$(\frac{1}{3};-1)$
$\bar{Q}^c\gamma^\mu E$	$(\bar{3},1,\frac{5}{6})$	Δ_{QE}	$(\bar{3},1,1)(1,\bar{3})$	$(-\frac{1}{3};-1)$
$\bar{U}^c\gamma^\mu L$	$(3,2,\frac{1}{6})$	Δ_{UL}	$(1,3,1)(3,1)$	$(-\frac{1}{3};-1)$
$\bar{D}^c\gamma^\mu L$	$(\bar{3},1,\frac{5}{6})$	Δ_{DL}	$(1,1,\bar{3})(\bar{3},1)$	$(-\frac{1}{3};-1)$
$\bar{Q}^c L$	$(\bar{3},1\oplus 3,\frac{1}{3})$	S_{QL}	$(\bar{3},1,1)(\bar{3},1)$	$(-\frac{1}{3};-1)$
$\bar{U}^c E$	$(\bar{3},1,\frac{1}{3})$	S_{UE}	$(1,\bar{3},1)(1,\bar{3})$	$(-\frac{1}{3};-1)$
$\bar{D}^c E$	$(\bar{3},1,\frac{4}{3})$	S_{DE}	$(1,1,\bar{3})(1,\bar{3})$	$(-\frac{1}{3};-1)$

The Froggatt-Nielsen mechanism

[Froggatt, Nielesen, '79]

- The main goal of FN mechanism is to explain the mass hierarchies between quarks
- The main point is enlarging the gauge group adding an additional $U(1)$ and extra heavy fermions
- The SM fermions are charged under the $U(1)$, and the charges are generation dependent
- The $U(1)$ is spontaneously broken by a new scalar field ϕ_{FN}
- The Yukawa scale as the parameter $\lambda = \langle\phi_{FN}\rangle/\Lambda_{FN} \ll 1$

Froggatt-Nielsen power counting

SM fields charges

$$Q^i : b_Q^i \qquad L^i : b_L^i$$
$$u_R^i : b_U^i \qquad D^i : b_D^i \qquad e_R^i : b_E^i$$

According to the assignment of charges of the SM fields, we have:

$$(Y_U)_{ij} \sim \lambda^{|b_Q^i - b_U^j|}$$
$$(Y_D)_{ij} \sim \lambda^{|b_Q^i - b_D^j|}$$
$$(Y_E)_{ij} \sim \lambda^{|b_L^i - b_E^j|}$$

In order to reproduce the CKM

$$(V_{\mathsf{CKM}})_{ij} = (Y_U Y_D^\dagger)_{ij} \sim \lambda^{|b_Q^i - b_Q^j|} \qquad \lambda = \sin^2\theta_c \sim 0.2$$

Constraining FN charges

There is no first principle which determines the FN charges.

Quarks

- CKM $\Rightarrow$ set the charges of the left-handed doublets
- quark masses $\Rightarrow$ we reduce the number of possible charges to two values for each right-handed quark

Lepton

- lepton masses masses $\Rightarrow$ constraining only differences of left-handed and right-handed charges

More pheno constraints are needed

- Using low energy pheno implies choosing a particular set of spurions to describe data
- This affects heavily the choices for lepton charges
- A driving role is played by B anomalies

Which scenario?

Colourless solutions

- W' and Z' models are in tension with high-p_T data [Greljo,Isidori,Marzocca,'15]
- We don't add right-handed neutrinos

Leptoquark solutions

Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
S_1	✗*	✓	✗*
R_2	✗*	✓	✗
$\widetilde{R}_2$	✗	✗	✗
S_3	✓	✗	✗
U_1	✓	✓	✓
U_3	✓	✗	✗

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S_3	✓	✗	✗
U_1	✓	✓	✓
U_3	✓	✗	✗

A U_1 simplified model

No UV completion discussed, interactions with fermion only:

$$\mathcal{L}_{U_1} = \Delta_{QL}^{i\alpha} \bar{Q}^i \gamma_\mu L^\alpha U_1^\mu + \Delta_{DE}^{i\alpha} \bar{d}_R^i \gamma_\mu e_R^\alpha U_1^\mu + \text{h.c.}$$

$$c_{QL}^{i\alpha} \lambda^{|b_Q^i - b_L^\alpha|} \qquad c_{DE}^{i\alpha} \lambda^{|b_D^i - b_E^\alpha|}$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} - \frac{1}{\Lambda^2} \Big\{ [\mathcal{C}_{lq}^{(3)}]^{ij\alpha\beta} (\bar{Q}^i \gamma^\mu \sigma^a Q^j)(\bar{L}^\alpha \gamma_\mu \sigma^a L^\beta) + [\mathcal{C}_{lq}^{(1)}]^{ij\alpha\beta} (\bar{Q}^i \gamma^\mu Q^j)(\bar{L}^\alpha \gamma_\mu L^\beta)$$

$$+ [\mathcal{C}_{ed}]^{ij\alpha\beta} (\bar{d}_R^i \gamma^\mu d_R^j)(\bar{e}_R^\alpha \gamma_\mu e_R^\beta) + [\mathcal{C}_{ledq}]^{ij\alpha\beta} (\bar{Q}_L^i d_R^j)(\bar{e}_R^\alpha L^\beta) + \text{h.c.} \Big\},$$

Tree-level matching

$$\begin{aligned} [\mathcal{C}_{lq}^{(1)}]^{ij\alpha\beta} = [\mathcal{C}_{lq}^{(3)}]^{ij\alpha\beta} &= + \Delta_{QL}^{i\alpha} \Delta_{QL}^{*j\beta}, \\ [\mathcal{C}_{leqd}]^{ij\alpha\beta} &= - 2 \Delta_{QL}^{i\alpha} \Delta_{DE}^{*j\beta}, \\ [\mathcal{C}_{ed}]^{ij\alpha\beta} &= + \Delta_{DE}^{i\alpha} \Delta_{DE}^{*j\beta}. \end{aligned}$$

Model dependent constraints for FN charges

Two step approach to study low energy phenomenology

- We determine the FN charges
  - We use the decays $Z \to \nu\nu$, $b \to s\mu^+\mu^-$, $b \to c\tau\bar{\nu}$, $B_d \to \tau^-\mu^+$, $B_s \to \tau^\pm\mu^\mp$, $K_L \to \mu^\pm e^\mp$ to select charges compatible with experimental limits
  - The combination of model dependent and independent constraints gives possible 24 scenarios.
- Fit to a larger set of observables for each of the 24 scenarios

Full fit to the allowed scenarios

- We parametrise the Wilson coefficients as

$$c_{QL}^{i\alpha} = \pm \mathcal{C}_{QL} \qquad c_{DE}^{i\alpha} = \pm \mathcal{C}_{DE}$$

The FN power counting is the only mechanism responsible of suppression/enhancement of the different flavour entries

- We choose the following to be able to fit phenomenology

$$c_{QL}^{32} < 0 \qquad c_{DE}^{33} < 0$$

$C_9^{\mu} < 0$ (for $c_{QL}^{32} < 0$)

constructive interference $R_{D^{(*)}}$ (for $c_{DE}^{33} < 0$)

- We set $\Lambda = 2\,\mathrm{TeV}$

- Larger set of observables: LFV B decays, W LFU, universality in V_{cb}.

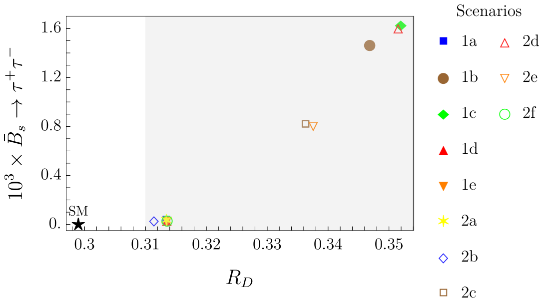
Fit results

Scenario	b_L^1	b_D^1	b_D^2	b_D^3	b_E^1	b_E^2	b_E^3	$\mathcal{C}_{QL}$	$\mathcal{C}_{DE}$
1a	-2	10	-3	-3	-11	4	-2	1.10 ± 0.07	0.72 ± 0.22
1b		10	7	-3	-11	-6	-2	1.07 ± 0.08	6.4 ± 1.8
1c		10	7	3	-11	-6	4	1.07 ± 0.08	7.2 ± 2.1
1d		-4	-3	-3	-11	4	-2	1.10 ± 0.09	0.74 ± 0.28
1e		-4	-3	-3	7	4	-2	1.10 ± 0.09	0.73 ± 0.28
2a	$+8$	10	-3	-3	17	4	-2	1.10 ± 0.10	0.74 ± 0.26
2b		10	7	-3	-1	-6	-2	1.09 ± 0.09	0.42 ± 0.25
2c		10	7	-3	17	-6	-2	1.08 ± 0.09	4.6 ± 1.4
2d		10	7	3	-1	-6	4	1.07 ± 0.10	7.1 ± 2.0
2e		10	7	3	17	-6	4	1.08 ± 0.09	4.8 ± 1.3
2f		-4	-3	-3	17	4	-2	1.10 ± 0.09	0.74 ± 0.28

Common features:

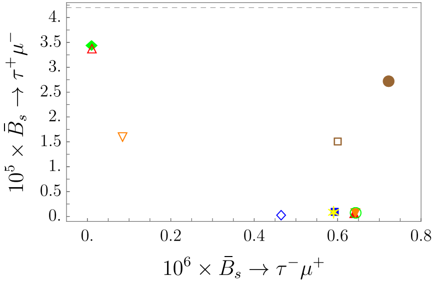
- $b \to s\mu^+\mu^-$ dominated by left-handed operator
- $b \to s e^+ e^-$ is negligible
- B_c life time is not spoiled
- $\Delta\chi^2 = \chi^2|_{\text{SM}} - \chi^2|_{\text{NP}} \sim 30$

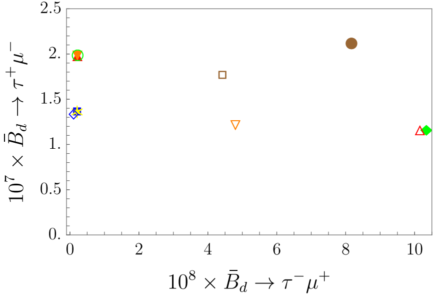
Fit results



- High correlation between R_D and $\bar{B}_s \to \tau^+\tau^-$ due to sizeable scalar contributions
- Better measurements of $\bar{B}_s \to \tau^+\tau^-$ provide a strong indication on the chirality of the NP operators in $R_{D^{(*)}}$

Fit results





- LFV B decays constitute an important signature of this scenarios
- For both the $\bar{B}_{d,s}$ modes, the final state with a τ^+ is enhanced with respect to final state with a τ^-
- Especially for the $\bar{B}_s$ initial state, the predictions approach the current experimental limit

Conclusions

- We propose a complete classification of spurions for NP
- We present a FN inspired power counting
- We studied in details the example of the vector LQ U_1
  - There exist at least 11 viable scenarios
  - They predict asymmetric contributions to $\bar{B}_{d,s} \to \tau^+\mu^-$ and $\bar{B}_{d,s} \to \tau^-\mu^+$
  - Future experimental analysis where the two modes are separated can confirm/reject these scenarios