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Flavour anomalies: a model building perspective

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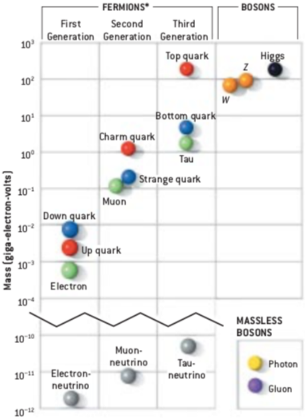
Introduction

The Standard Model

The theory that describes with success the interactions between elementary particle is the Standard Model.

- **12 gauge bosons** which mediate **strong** and **electroweak** interactions between elementary particles
- **3 generations of fermions** characterised by the **same** quantum numbers
- a **scalar field**, the Higgs, which spontaneously breaks electroweak symmetry



Gauge vs Higgs sector

$$\mathcal{L}_{\mathsf{SM}} = \mathcal{L}_{\mathsf{gauge}} + \mathcal{L}_{\mathsf{higgs}}$$

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Gauge Sector:

- completely specified by the **gauge symmetry** and the transformation properties under it of elementary particles
- interactions between gauge bosons and fermions are **universal**
- completely **degeneracy** of the three families

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Higgs Sector:

- **breaks** arbitrarily the **degeneracy** of the three families
- when EWSB happens, it contains **mass terms** for quarks and leptons

$$-\mathcal{L}_{\mathsf{higgs}} \supset Y_d^{ij} \bar{Q}_L^i H d_R^j + Y_u^{ij} \bar{Q}_L^i H^c u_R^j + Y_e^{ij} \bar{L}_L^i H e_R^j$$

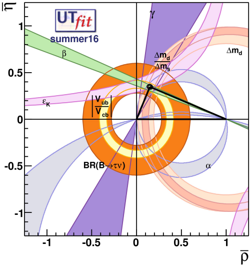
The flavour structure

The structure of the Yukawa matrices in the quark sector is rather peculiar

$$Y_q \sim$$

When we diagonalise the Yukawa matrices, we find that the flavour sector is completely specified by

- **6 eigenvalues** of the quark Yukawa matrices + **3** for charged leptons
- the **CKM mixing matrix** of the quark sector, which is completely specified by **4** parameters
- these parameters are **very well** measured



The flavour problem

Open questions:

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  $\Rightarrow$ **flavour problem**
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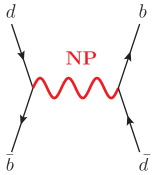
It is flavour physics the research sector which addresses such open issues.

The goal of flavour physics is investigating the **nature** and **structure** of the interactions between particle of different families in order to identify

- possible **NP scenarios** at high energies which may lead to the pattern we measure at the SM scale
- NP contribution may be suppressed by their typical energy scale $\Rightarrow$ we can probe processes and **scale beyond the reach of direct searches**



What is new?

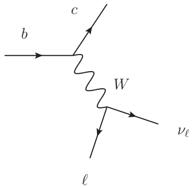
Recently, Babar, Belle and LHCb provided interesting results in B-physics.

They see a few hints of **L**epton **F**lavour **U**niversality **V**iolation: channels with different lepton species in the final state behave differently

The channels explored so far are semileptonic decays of B-meson

- Flavour changing neutral currents $\boldsymbol{b \to s}$: $\boldsymbol{\mu}$ vs $\boldsymbol{e}$
- Charged currents $\boldsymbol{b \to c}$: $\boldsymbol{\tau}$ vs $\boldsymbol{\mu/e}$

$b \to c$ semileptonic transitions



Tree-level process within the SM

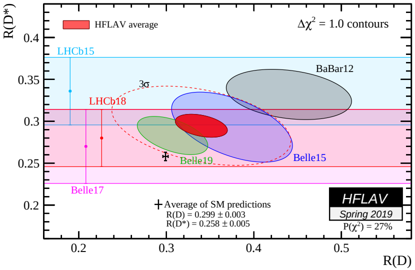
Effective hamiltonian description

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{cb} \left(\bar{c}_L \gamma_\mu b_L\right) \left(\bar{\tau}_L \gamma_\mu \nu_L\right)$$

- Clean observables: careful treatment of m_τ dependent terms

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)} \tau \bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)} \ell \bar{\nu}_\ell)}$$

- Deviation of $\sim$ **10%-15%** with respect to the SM predictions
- Combined significance $\sim \boldsymbol{3.1\sigma}$

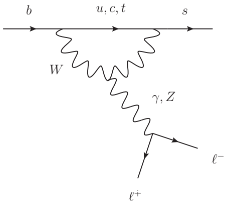


$b \to s$ semileptonic transitions

Induced at **loop** level in the SM

Effective Hamiltonian description

$$\mathcal{H}_{\text{eff}} = -4\frac{G_F}{\sqrt{2}} V_{tb}V_{ts}^* \left[\cdots + C_9\mathcal{O}_9 + C_{10}\mathcal{O}_{10}\right]$$



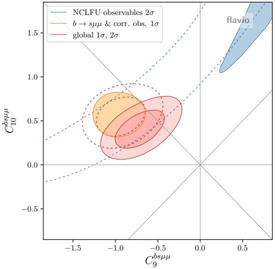
$$\mathcal{O}_9 = (\bar{s}\gamma^\mu P_L b)\,(\bar{\ell}\gamma_\mu \ell)$$
$$\mathcal{O}_{10} = (\bar{s}\gamma^\mu P_L b)\,(\bar{\ell}\gamma_\mu\gamma_5 \ell)$$

- Lepton Flavour Universality ratios

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \qquad \sim \mathbf{2.1\text{-}2.6\sigma}$$

- Angular Observables in $B \to K^*\mu^+\mu^-$

$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}} \qquad \sim \mathbf{3\sigma}$$



[Straub at al, '19]

$$\Delta C_9 \neq 0 \qquad \Delta C_{10} \neq 0$$

Approach to the anomalies

SM predictions:

- investigate SM predictions for the observables of interest
- provide prediction for new channels/observables to get complementary informations

Model building:

- the effective scale of NP which could explain FCNC and CC anomalies is rather different

$$\Lambda \sim \begin{cases} \text{few } \times \text{TeV} & \text{for CC} \\ \text{few } \times 10 \text{ TeV} & \text{for FCNC} \end{cases}$$

- from EFT analysis we see that [MB, Isidori, Trifinopoulos Buttazzo,Greljo,Isidori,Marzocca]
  - FCNC and CC anomalies are addressed as a coherent pattern where NP is mainly coupled to the 3rd generation
  - a flavour symmetry is required to suppress the couplings with light generations and provides a link to the Yukawa couplings

Non-trivial flavour structure needed

Are these signals of NP?

- After the analyses of 2019 we still don't see a clear sign of New Physics.
- Data will (eventually) lead us to a clear conclusion:
  - LHCb still has a large amount of data to be analysed for $b \to s\ell\ell$
  - Update of $R_{K^{(*)}}$ most likely to be ready in one year time
  - An update for R_{D^*} from LHCb is also due
  - New observables like $R(\Lambda_c)$ should be (soon) released
  - Belle II is taking data
  - Both ATLAS and CMS are building an interesting B-physics program

We need to keep looking

From the EFT to UV complete models

The EFT approach

- EFT approach allows for a model **independent combined analysis** of the anomalies
- The leading NP must couple mainly to the **3rd generation** of quarks and leptons
- A flavour symmetry suppresses and controls the couplings between NP and light generations: an interesting choice is $\boldsymbol{U(2)}$ flavour symmetry

The $U(2)^n$ flavour symmetry

$U(2)^n$ flavour symmetry provides **natural** link to the Yukawa couplings.

Main idea: 3rd generation of fermions are complete **singlets** under $U(2)^n$ while the light generation have **non trivial** transformation properties under $U(2)^n$.

unbroken symmetry **$U(2)$ breaking terms**

$$Y_u = y_t \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad \Rightarrow \quad \begin{pmatrix} \Delta & V \\ 0 & 1 \end{pmatrix} \equiv$$

[Barbieri, Isidori, Jones-Perez, Lodone, Straub, '11]

The same symmetry-breaking pattern control the **mixing** 3rd -1st, 2nd generation for the NP responsible for the anomalies.

A good fit with data is obtained if $|V| \sim |V_{ts}| \sim 0.04$ and $\Delta \sim y_c \sim 0.006$.

$U(2)$ correlations: FCNC

Working with flavour symmetries allows us to predict possible **correlations** between observables.

	$\mu\mu$ (ee)	$\tau\tau$	$\nu\nu$	$\tau\mu$	μe
$b \to s$	$R_{K^{(*)}}$	$B \to K^{(*)}\tau\tau$	$B \to K^{(*)}\nu\nu$	$B \to K\tau\mu$	$B \to K\mu e$
$b \to d$	$B_d \to \mu\mu$ $B \to \pi\mu\mu$ $B_s \to \bar{K}^{*0}\mu\mu$	$B \to \pi\tau\tau$	$B \to \pi\nu\nu$	$B \to \pi\tau\mu$	$B \to \pi\mu e$
$s \to d$			$K \to \pi\nu\nu$		$K \to \mu e$

- $R_{K^{(*)}} = R_\pi$
- $B \to K^{(*)}\tau\tau \sim \mathcal{O}(100) \times$ SM, $B \to \pi\tau\tau \sim \mathcal{O}(100) \times$ SM
- $B \to K^{(*)}\nu\nu \sim \mathcal{O}(1) \times$ SM, $B \to \pi\nu\nu \sim \mathcal{O}(1) \times$ SM, $K \to \pi\nu\nu \sim \mathcal{O}(1) \times$ SM
- non-zero contribution to LFV processes

The Zurich's Guide

[Buttazzo,Grejlo,Isidori,Marzocca, JHEP 1711 (2017)]

- 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 $U(2)_q \times U(2)_\ell$, softly broken by two leading spurions V_q and V_ℓ for the quarks and the leptons sector, respectively.

$$
\begin{aligned}
q_{3L} &\sim (\mathbf{1}, \mathbf{1}) & \qquad \ell_{3L} &\sim (\mathbf{1}, \mathbf{1}) \\
Q_L = (Q_L^1, Q_L^2) &\sim (\bar{\mathbf{2}}, \mathbf{1}) & \qquad L_L = (\ell_L^1, \ell_L^2) &\sim (\mathbf{1}, \bar{\mathbf{2}}) \\
V_q &\sim (\mathbf{2}, \mathbf{1}) & \qquad V_\ell &\sim (\mathbf{1}, \mathbf{2})
\end{aligned}
$$

The framework

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

flavour structure — ***SU*(2) triplet** — ***SU*(2) singlet**

Observable	Experimental bound	Linearised expression
$R^{\tau\ell}_{D^{(*)}}$	1.237 ± 0.053	$1 + 2C_T(1 - \lambda^q_{sb}V^*_{tb}/V^*_{ts})(1 - \lambda^\ell_{\mu\mu}/2)$
$\Delta C^\mu_9 = -\Delta C^\mu_{10}$	-0.61 ± 0.12 [36]	$-\frac{\pi}{\alpha_{\text{em}}V_{tb}V^*_{ts}}\lambda^\ell_{\mu\mu}\lambda^q_{sb}(C_T + C_S)$
$R^{\mu e}_{b\to c} - 1$	0.00 ± 0.02	$2C_T(1 - \lambda^q_{sb}V^*_{tb}/V^*_{ts})\lambda^\ell_{\mu\mu}$
$B_{K^{(*)}\nu\bar{\nu}}$	0.0 ± 2.6	$1 + \frac{2}{3}\frac{\pi}{\alpha_{\text{em}}V_{tb}V^*_{ts}C^{\text{SM}}_\nu}(C_T - C_S)\lambda^q_{sb}(1 + \lambda^\ell_{\mu\mu})$
$\delta g^Z_{\tau_L}$	-0.0002 ± 0.0006	$0.033C_T - 0.043C_S$
$\delta g^Z_{\nu_\tau}$	-0.0040 ± 0.0021	$-0.033C_T - 0.043C_S$
$\lvert g^W_\tau / g^W_\ell \rvert$	1.00097 ± 0.00098	$1 - 0.084C_T$
$\mathcal{B}(\tau \to 3\mu)$	$(0.0 \pm 0.6) \times 10^{-8}$	$2.5 \times 10^{-4}(C_S - C_T)^2(\lambda^\ell_{\tau\mu})^2$

- Neglecting mixing with first generation, the parameters needed are 4: C_T, C_S, λ_{bs}, $\lambda_{\mu\mu}$.
- Fitting the CKM and Yukawa, we know that $\lambda_{bs} \sim \mathcal{O}(V_{cb})$.

Single particle solution

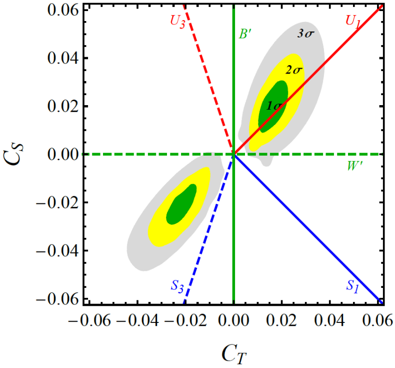
[Buttazzo,Grejlo,Isidori,Marzocca, JHEP 1711 (2017)]

- Based on $U(2)^n$ flavour symmetry
- No contradiction between LFU anomalies and constraints from EWPT, flavour observables or hight-p_T data
- Possible one particle solution:

	Singlet	Triplet
Scalar LQ:	S_1	S_3
Vector LQ:	U_1	U_3
Colorless vector:	B'	W'

- The most promising single-mediator solution is the vector leptoquark $U_\mu \sim (3,1)_{2/3}$

UV completion needed



A UV completion for $U_\mu \sim (3,1)_{2/3}$

Two possibilities:

- Mediator of a composite state of a new strongly interacting sector
- Massive gauge boson of a spontaneously broken gauge theory

[Di Luzio, Grejlo, Nardecchia; Blanke, Crivellin; Fornal, Gadam, Grinstein; Di Luzio, Fuentes-Martín, Grejlo, Nardecchia, Renner]

The natural choice: Pati-Salam group $\Rightarrow$ PS $\equiv SU(4) \times SU(2)_L \times SU(2)_R$

[Pati,Salam, Phys. Rev. D 10 (1974) 275]

- Quarks and leptons are part of the **same multiplet** of $SU(4) \Rightarrow$ lepton are seen as the **4th colour**
- No proton decay

$$\Psi_L = \begin{pmatrix} Q_L^\alpha \\ Q_L^\beta \\ Q_L^\gamma \\ L_L \end{pmatrix}$$

Main problems:

- the LQ coupling with the heavy and light generations is **flavour blind**
- tights constrains in processes as $K_L \to \mu e \Rightarrow$ LQ mass $\sim 100\,\mathrm{TeV}$

The “4321” model

$$SU(4) \times SU(3)' \times SU(2)_L \times U(1)'$$

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

At low energies we have:

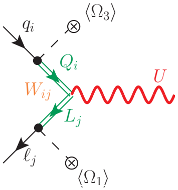
- the SM
- the LQ U_1 with a mass $\mathcal{O}(1\,\text{TeV})$
- inevitably a massive color octect G' and a Z' with masses of $\mathcal{O}(1\,\text{TeV})$

The PS leptoquark introduces always new states

The original "4321"

[Di Luzio, Greljo,Nardecchia, '17;
Di Luzio, Fuentes-Martín, Greljo, Nardecchia, Renner, '18]

- The SM particles are charged only under the 321 component
- New vector-like are charged under the $SU(4)$
- The mixing between the vector-like and the SM fields induces effective SM-U_1 couplings



- The effective interactions between the SM fields and U_1 are mainly left-handed
- Using the freedom on the vector-like couplings it's possible to have a good fit to low energy data and avoid most of the constraints

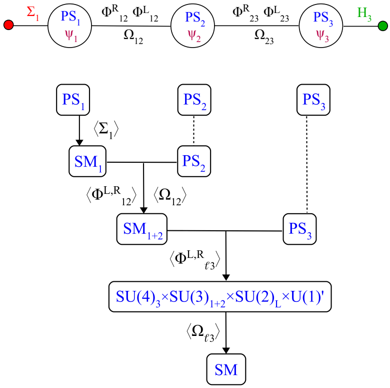
A three-site model

[MB, Cornella, Fuentes-Martín, Isidori, '17, '18]

Main Idea: at high energies the 3 families are charged under 3 independent gauge groups

$$\mathbf{PS^3 = PS_1 \times PS_2 \times PS_3}$$

- The breaking controls the hierarchy of the Yukawa couplings
- Low energy pheno is governed by the $\mathcal{O}$(**TeV**) **breaking only**
- At low scale we recover the SM + 1 LQ + 1 Z' and a coloron
- The LQ couples to both LH and RH fermions



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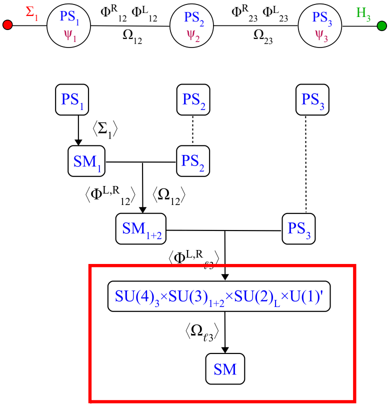
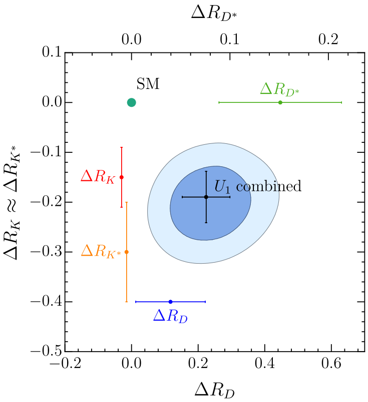
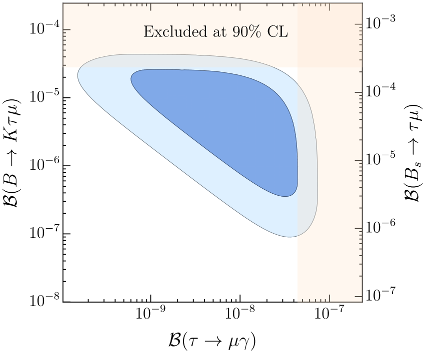


Fit to low energy data

[MB, Cornella, Fuentes-Martín, Isidori, '17, '18]

[Cornella, Fuentes-Martín, Isidori, '19]



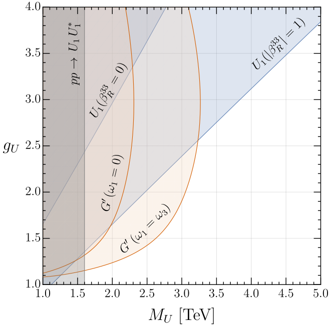


- Good fit to low energy data within the 1σ region
- RH currents help to ease the tension with $R_{D^{(*)}}$ and rise the NP scale

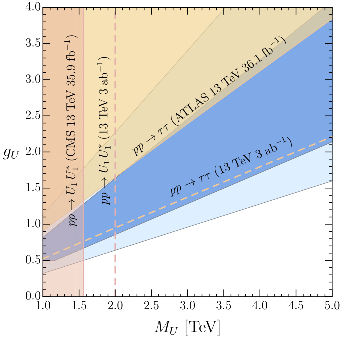
- RH currents generate interesting contributions in B_s decays
- LFV processes are a smoking gun of this model

High-p_T constraints on PS models

- The most stringent bound on U_1 comes from $pp \to \tau\tau$
- The bound on Z' are weaker
- Bounds on G' come from $pp \to \bar{t}t$ but it becomes weaker as the width increases
- The relation between M_U and $M_{G'}$ in PS^3 helps to create combined exclusion limits



[Baker, Fuentes-Martín, Isidori, König, '19]



$g_U \sim 3 \Rightarrow M_U \gtrsim 3.8$ GeV

A Froggatt-Nielsen based idea

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

$$Q^i : b_Q^i \qquad L^i : b_L^i$$

$$u_R^i : b_U^i \qquad d_R^i : b_D^i \qquad e_R^i : b_E^i$$

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

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

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

A U_1 simplified model

No UV completion discussed, interactions with fermion only:

$$\mathcal{L}_{U_1} = \underset{\underset{c_{QL}^{i\alpha}\lambda^{|b_Q^i - b_L^\alpha|}}{\uparrow}}{\Delta_{QL}^{i\alpha}} \bar{Q}^i \gamma_\mu L^\alpha U_1^\mu + \underset{\underset{c_{DE}^{i\alpha}\lambda^{|b_D^i - b_E^\alpha|}}{\uparrow}}{\Delta_{DE}^{i\alpha}} \bar{d}_R^i \gamma_\mu e_R^\alpha U_1^\mu + \text{h.c.}$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} - \frac{1}{\Lambda^2}\Big\{ [\mathcal{C}_{lq}^{(3)}]^{ij\alpha\beta} (\bar{Q}^i \gamma^\mu \sigma^a Q^j)(\bar{L}^\alpha \gamma_\mu \sigma^a L^\beta) + [\mathcal{C}_{lq}^{(1)}]^{ij\alpha\beta} (\bar{Q}^i \gamma^\mu Q^j)(\bar{L}^\alpha \gamma_\mu L^\beta)$$
$$+ [\mathcal{C}_{ed}]^{ij\alpha\beta} (\bar{d}_R^i \gamma^\mu d_R^j)(\bar{e}_R^\alpha \gamma_\mu e_R^\beta) + [\mathcal{C}_{ledq}]^{ij\alpha\beta} (\bar{Q}_L^i d_R^j)(\bar{e}_R^\alpha L^\beta) + \text{h.c.} \Big\},$$

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

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

$C_9^\mu < 0$

constructive interference $R_{D^{(*)}}$

- We set $\Lambda = 2\,\text{TeV}$
- Larger set of observables: LFV B decays, W LFU, universality in V_{cb}.

Fit results

[MB, Catà, Feldmann, '19]

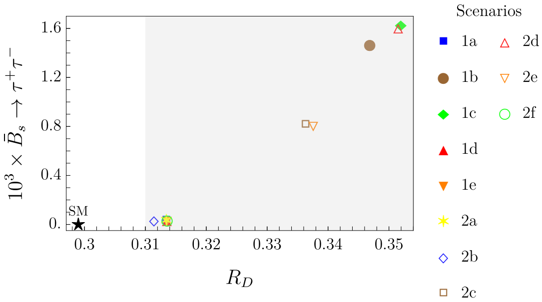
Scenario	b_L^1	b_D^1	b_D^2	b_D^3	b_E^1	b_E^2	b_E^3	$\mathcal{C}_{QL}$	$\mathcal{C}_{DE}$
1a		10	-3	-3	-11	4	-2	1.10 ± 0.07	0.72 ± 0.22
1b		10	7	-3	-11	-6	-2	1.07 ± 0.08	6.4 ± 1.8
1c	-2	10	7	3	-11	-6	4	1.07 ± 0.08	7.2 ± 2.1
1d		-4	-3	-3	-11	4	-2	1.10 ± 0.09	0.74 ± 0.28
1e		-4	-3	-3	7	4	-2	1.10 ± 0.09	0.73 ± 0.28
2a		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	$+8$	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
- $b \to se^+e^-$ is negligible
- B_c life time is not spoiled
- $\Delta\chi^2 = \chi^2|_{\mathsf{SM}} - \chi^2|_{\mathsf{NP}} \sim 30$

Fit results

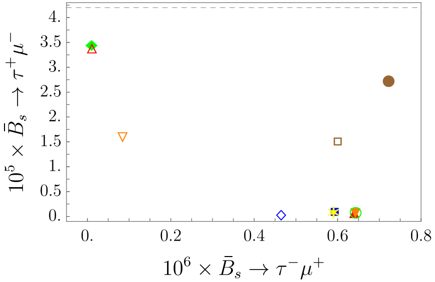
[MB, Catà, Feldmann, '19]

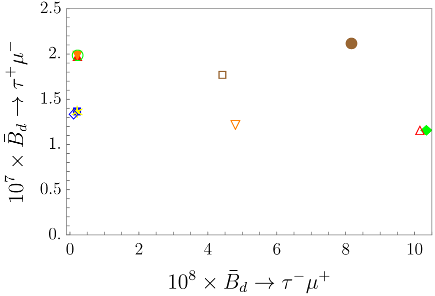


- High correlation between R_D and $\bar{B}_s \to \tau^+\tau^-$ due to sizeable scalar contributions
- Better measurements of $\bar{B}_s \to \tau^+\tau^-$ provide a strong indication on the chirality of the NP operators in $R_{D^{(*)}}$

Fit results

[MB, Catà, Feldmann, '19]





- 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

Scalar solutions

With scalars LQ, we need at least **two** mediators

- Composite scenario: $S_1{+}S_3$ **[D.Marzocca]**
  - Strong dynamics not known
  - B_s mixing + EWPT create tension with $R_{D^{(*)}}$
  - Need to enforce some couplings to be zero to avoid proton decay
- GUT inspired scenarios: $S_3 + R_2$ **[Bečiveríc, Doršner, Fajfer, Faroughy,Košnik,Sumensari]**
  - Predicts interesting LFV signals
  - No explicit realisation so far which avoids proton decay

What is still to be done?

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

- Colourless solution $W' + Z'$: tension with high-p_T searches with $\tau_L \tau_L$ or $b_L b_L$ final states [Greljo,Isidori,Marzocca,'15]

- Solutions with right-handed neutrino are motivated and help to ease the tension with $b \to c\tau\nu$ data but they are most likely to be excluded from high-p_T [Greljo, Camalich,Ruiz-Álvarez,'18]

It seems like there is not much space left...

What are we looking for?

...but data can help us!

If the anomalies are trues, NP **must** appear somewhere else.

A full dedicated flavour physics program run by LHCb, Belle II but also experiments like NA62 is needed to

- determine the flavour structure of the NP sector;
- different correlations among low energy observable can help to distinguish the possible models.

Only with such programs will we be able to determine what type of NP is realised in nature.

Summary

- Anomalies in B-physics are an interesting puzzle
- It is not clear yet if these are the first hints of NP
- BSM scenarios are viable and testable both in direct and indirect searches
    - The U_1 vector leptoquark seems to be the most favoured solution
    - A UV completion based on the Pati-Salam gauge group provides a combined explanation of LFU violation and the hierarchy of the Yukawa couplings
    - A new idea based on Froggatt-Nielsen mechanism gives viable results
    - All these scenario provide interesting signatures as LFV B decays