UNIVERSITÄT SIEGEN

B anomalies: the PS^3 solution

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Outline

1. The flavour structure of the Standard Model

2. EFT solutions for the anomalies

3. The model building approach: from EFT to a concrete UV model

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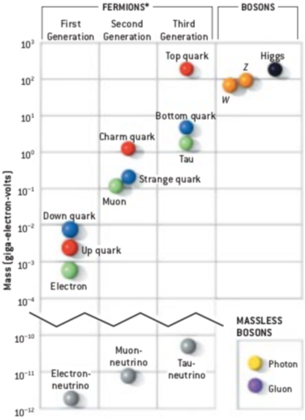
2. EFT solutions for the anomalies

3. The model building approach: from EFT to a concrete UV model

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

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

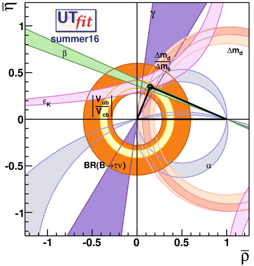
The flavour structure

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:

- Why does the flavour sector have such a peculiar structure?
  $\Rightarrow$ **flavour problem**
- Is there something else which distinguish the three generations?
  $\Rightarrow$ **NP flavour problem**

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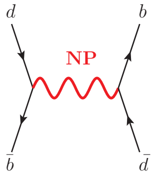
- Is there something else which distinguish the three generations?
  $\Rightarrow$ **NP flavour problem**

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.

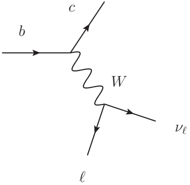
They see a few hints of **L**epton **F**lavour **U**niversality **V**iolation: channels with different lepton species in the final state behave differently

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



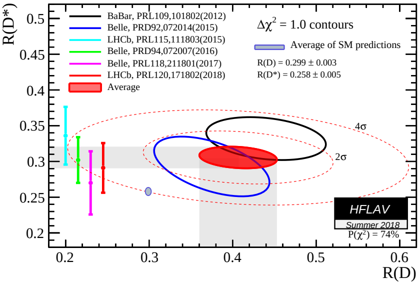
Effective hamiltonian description

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

- Clean observables: careful treatment of m_τ dependent terms

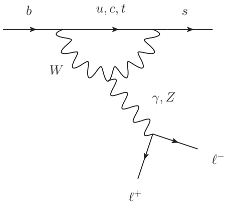
$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)} \tau \bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)} \ell \bar{\nu}_\ell)}$$

- Deviation of $\sim$ **20%** with respect to the SM predictions
- Combined significance $\sim$ $\mathbf{3.7\sigma}$



$b \to s$ semileptonic transitions

Induced at **loop** level in the SM



Effective Hamiltonian description

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

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

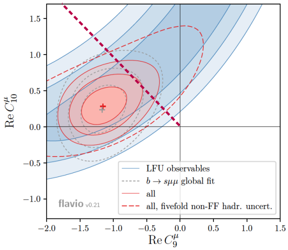
$$\boldsymbol{\mathcal{O}_{10}} = (\bar{s}\gamma^\mu P_L b)\,(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$

- Lepton Flavour Universality ratios

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

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

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



$$\boldsymbol{\Delta C_9 = -\Delta C_{10} = -0.6}$$

Approach to the anomalies

SM predictions:

- investigate SM prediction for the observable of intererest
- 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

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

- 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

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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

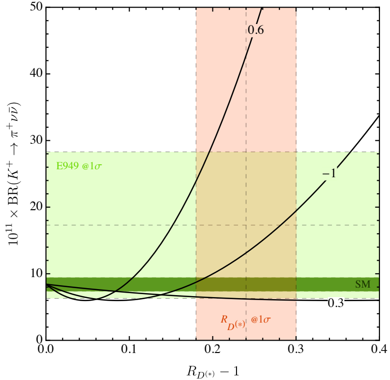
Working with flavour symmetries allows us to predict possible **correlations** between observables.

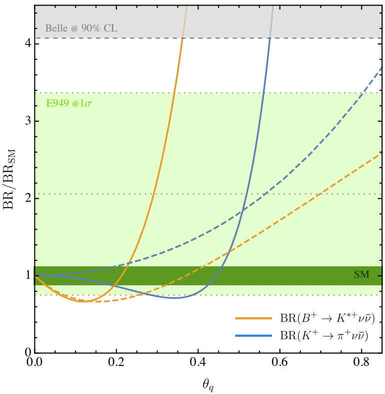
	$\mu\mu$ (ee)	$\tau\tau$	$\nu\nu$	$\tau\mu$	μe
$b \to s$	$R_{K^{(*)}}$	$B \to K^{(*)}\tau\tau$	$B \to K^{(*)}\nu\nu$	$B \to K\tau\mu$	$B \to K\mu e$
$b \to d$	$B_d \to \mu\mu$ $B \to \pi\mu\mu$ $B_s \to \overline{K}^{*0}\mu\mu$	$B \to \pi\tau\tau$	$B \to \pi\nu\nu$	$B \to \pi\tau\mu$	$B \to \pi\mu e$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

- $R_{K^{(*)}} = R_\pi$
- $B \to K^{(*)}\tau\tau \sim \mathcal{O}(100) \times$ 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 $K^+ \to \pi^+ \nu\bar{\nu}$ case

[MB, Buttazzo, Isidori, Monnard, '17]





to be probed (soon) at NA62

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.

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

The framework

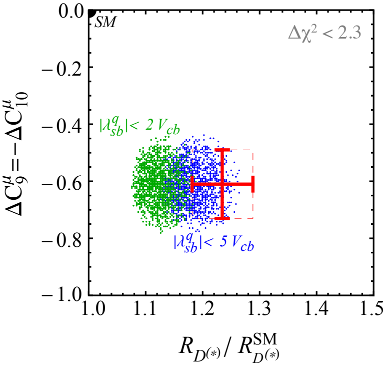
$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} - \frac{1}{v^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\left[C_T(\overline{Q}^i_L\gamma^\mu T^a Q^j_L)(\overline{L}^\alpha_L\gamma_\mu T^a L^\beta_L) + C_S(\overline{Q}^i_L\gamma^\mu Q^j_L)(\overline{L}^\alpha_L\gamma_\mu L^\beta_L)\right]$$

flavour structure $\quad$ $SU(2)$ triplet $\quad$ $SU(2)$ singlet

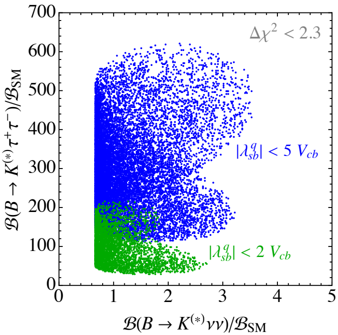
Observable	Experimental bound	Linearised expression
$R^{\tau\ell}_{D^{(*)}}$	1.237 ± 0.053	$1 + 2C_T(1 - \lambda^q_{sb}V^*_{tb}/V^*_{ts})(1 - \lambda^\ell_{\mu\mu}/2)$
$\Delta C^\mu_9 = -\Delta C^\mu_{10}$	-0.61 ± 0.12 [36]	$-\frac{\pi}{\alpha_{\text{em}}V_{tb}V^*_{ts}}\lambda^\ell_{\mu\mu}\lambda^q_{sb}(C_T + C_S)$
$R^{\mu e}_{b\to c} - 1$	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^q_{bs}, $\lambda^\ell_{\mu\mu}$.
- Fitting the CKM and Yukawa, we know that $\lambda_{bs} \sim \mathcal{O}(V_{cb})$.

Fit results



0.0
−0.2
−0.4
−0.6
−0.8
−1.0
1.0
1.1
1.2
1.3
1.4
1.5
SM
$\Delta\chi^2 < 2.3$
$|\lambda^q_{sb}| < 2\, V_{cb}$
$|\lambda^q_{sb}| < 5\, V_{cb}$
$\Delta C_9^\mu = -\Delta C_{10}^\mu$
$R_{D^{(*)}} / R_{D^{(*)}}^{SM}$



0
100
200
300
400
500
600
700
0
1
2
3
4
5
$\Delta\chi^2 < 2.3$
$|\lambda^q_{sb}| < 5\, V_{cb}$
$|\lambda^q_{sb}| < 2\, V_{cb}$
$\mathcal{B}(B \to K^{(*)}\tau^+\tau^-)/\mathcal{B}_{SM}$
$\mathcal{B}(B \to K^{(*)}\nu\nu)/\mathcal{B}_{SM}$

Single particle solution

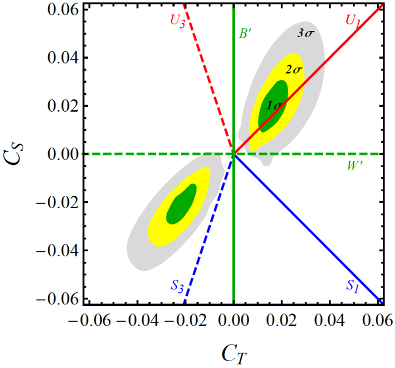
[Buttazzo,Grejlo,Isidori,Marzocca, JHEP 1711 (2017)]

- 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



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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; 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 $\sim 100\,\mathrm{TeV}$

A three site model

[MB, Cornella, Fuentes-Martín, Isidori]

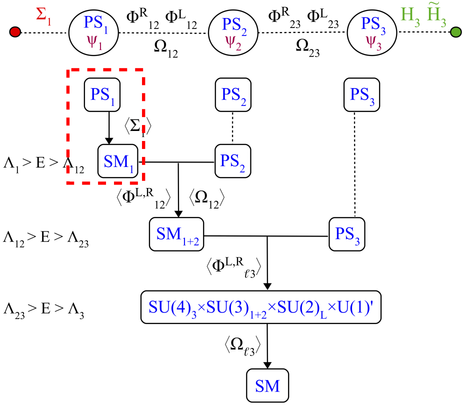
- The gauge group we adopt is $\mathrm{PS}^3 \equiv \mathrm{PS}_1 \times \mathrm{PS}_2 \times \mathrm{PS}_3$, where each PS_i acts on a **single fermion** family
- The spontaneous symmetry breaking to the SM group happens through different steps characterised by **different energy scales**
  - **decoupling** of heavy exotic fields coupled to the first two generations
- The gauge group that controls TeV-scale dynamics contains a LQ field coupled mainly to **third generation**
- The choice for the Higgs sector provides naturally an **hierarchical structure** of the Yukawa couplings
  - as a consequence, a residual $U(2)_q \times U(2)_\ell$ flavour symmetry appears as a subgroup of the approximate flavour symmetry $U(2)^5$ which appears at low energies

combined explanation of anomalies and yukawa hierarchies

High-scale vertical breaking

$\boldsymbol{\Lambda_1 \sim \mathcal{O}(10^3\ \textbf{TeV})}$

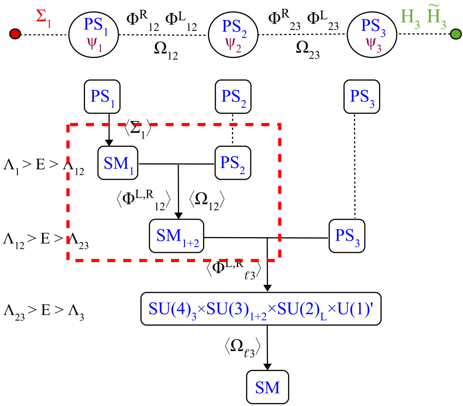
- $\mathsf{PS}_1 \to \mathsf{SM}_1 \equiv SU(3)_1 \times [SU(2)_L]_1 \times [U(1)_Y]_1$
- The breaking occurs via the field $\Sigma_1 \sim (4,1,2)_1$ charged only under PS_1
- After the breaking, 9 gauge massive fields appear, namely 6 LQ, $W_R^{\pm}$, Z' charged only under PS_1. However, their mass is heavy and they decouple.



Horizontal breaking 1-2

$\boldsymbol{\Lambda_{12} \sim 10^2}$ **TeV**

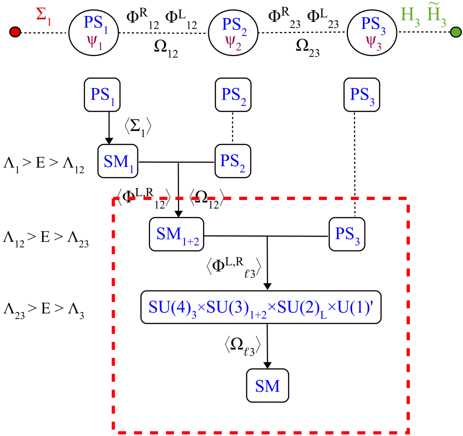
- $\mathrm{SM}_1 \times \mathrm{PS}_2 \to \mathrm{SM}_{1+2}$
- We introduce the **link fields**, which are charged **both** under the first and the second sites.
- 9 exotic gauge fields coupled mainly to the second generation and 12 SM-like gauge field coupled non universally to first and second generation decouple.
- Below the scale $\Lambda_{12} \Rightarrow \boldsymbol{U(2)^5}$ flavour symmetry acting on the the first and second generation of SM fermions.



Horizontal breaking 2-3

from $\boldsymbol{\Lambda_{23} \sim}$ **30 TeV** to $\boldsymbol{\Lambda_3 \sim}$ **1 TeV**

- SM$_{1+2}$ $\times$ PS$_3$ $\rightarrow$ SM
- At $\Lambda_{23} > E > \Lambda_3$ we decouple a $W_L^\pm$, $W_R^\pm$ and a Z' too heavy to be probed at collider, being left with the group $\mathcal{G} =$ SU$(4)_3 \times$ SU$(3)_{1+2} \times$ SU$(2)_L \times$ U$(1)'$.
- The final step $\mathcal{G} \rightarrow$ SM gives rise to 15 gauge bosons with a mass of $\mathcal{O}(1$ TeV): **6 LQs**, **8 colorons** and a $\boldsymbol{Z'}$.

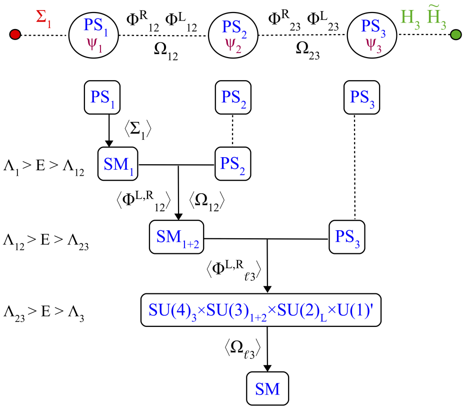


Low scale vertical breaking

- The EWSB is achieved through the lightest component from the two sets of fields:

$$H_3 \sim (15, 2, \overline{2})_3 \qquad \tilde{H}_3 \sim (1, 2, \overline{2})_3$$

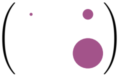
- Both H_3 and $\tilde{H}_3$ are localised on the 3rd brane ($\Rightarrow$ Yukawa couplings)



Yukawa structure

- Since the Higgs is localised in the third brane, the only dim-4 Yukawa terms allowed involve **only** fermions of from the **3rd** generation
- The Yukawa terms for light generations arise with operators of dim$=5,6$ and they are **suppressed** by the breaking scales
- The Yukawa pattern appears to be:

$$Y_f = \begin{pmatrix} y_\ell^f \frac{\langle \Phi^L_{\ell 3}\rangle \langle \Phi^R_{3\ell}\rangle}{\Lambda_{23}^2} & y^f_{3\ell}\frac{\langle \Omega_{\ell 3}\rangle}{\Lambda_{23}} \\ 0 & y_3^f \end{pmatrix} \quad \Rightarrow \quad Y_q \sim$$



$\Rightarrow$ good description of the SM Yukawa couplings in terms of $\mathcal{O}(1)$ parameters and vev ratios

- The low energy dynamics is described by a small number of free parameters, everything else is fixed by the Yukawa

Gauge boson spectrum at TeV scale

- We introduce a PS^3 gauge group
- We define a breaking chain such that low energy pheno is governed only by the step at $\mathcal{O}(\mathrm{TeV})$ scale, all the other exotic massive gauge bosons decouple
- At low energies
  - We recover the SM gauge bosons
  - We are left with additional massive vector bosons relevant at this energies, namely

$$U_1 \sim (\mathbf{3}, \mathbf{1})_{2/3} \qquad G' \sim (\mathbf{8}, \mathbf{1})_0 \qquad Z' \sim (\mathbf{1}, \mathbf{1})_0$$

- If we know look at the LQ interaction with the fermions, we have

$$\mathcal{L}_U \supset \frac{g_c^{(3)}}{\sqrt{2}} \left(\overline{q}'_L N_U^L \gamma_\mu \ell'_L + \overline{u}'_R N_U^R \gamma_\mu \nu'_R + \overline{d}'_R N_U^R \gamma_\mu e'_R \right) U^\mu + \text{h.c.}$$

- $N_U^{L,R}$ is a diagonal matrix in flavour space

$$N_U^L \sim \text{diag}(0, \epsilon, 1) \qquad N_U^R \sim \text{diag}(0, 0, 1) \qquad \text{and} \qquad \epsilon \equiv -\frac{1}{2} C_\Omega \frac{\langle \Omega_{\ell 3} \rangle^2}{\Lambda_{23}^2}$$

Constraints on $B \to D^{(*)}\tau\nu$

- The presence of right-handed terms in the LQ coupling with fermions induces at low energy an effective **scalar operator**

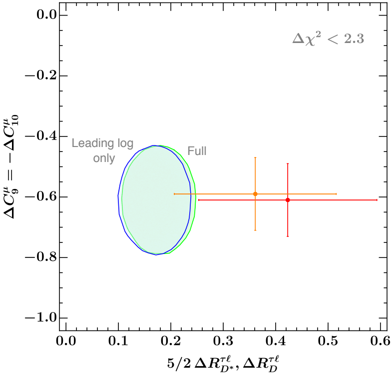
$$\mathcal{L}(b \to c\tau\nu) = -V_{cb}\left(\frac{4G_F}{\sqrt{2}} + C_U\right)(\bar{c}_L\gamma^\mu b_L)(\bar{\tau}_L\gamma_\mu\nu_{\tau_L}) \boldsymbol{- 2V_{cb}C_U(\bar{c}_L b_R)(\bar{\tau}_R\nu_L)}$$

- The scalar operator is more important in the case of $B \to D\tau\nu$ than in $B \to D^*\tau\nu$ decay, in fact

$$\Delta R^{\tau\ell}_{D^*} = R^{\tau\ell}_{D^*} - 1 \sim 2[1 + 0.17]C_U$$
$$\Delta R^{\tau\ell}_{D} = R^{\tau\ell}_{D} - 1 \sim 2[1 + \mathbf{2.1}]C_U$$

- Non-trivial correlation $\boldsymbol{\Delta R^{\tau\ell}_{D} \sim \frac{5}{2}\Delta R^{\tau\ell}_{D^*}}$

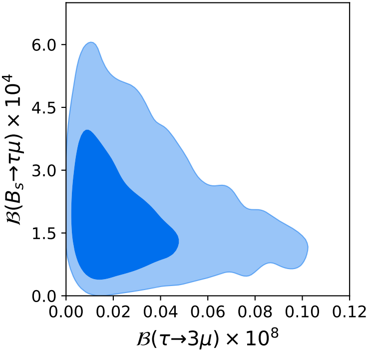
Results

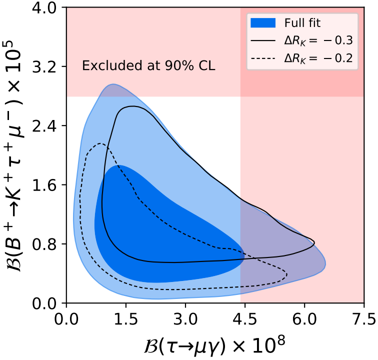


- The model can potentially reduce the tension with data
- The constraints from from LFU tests and $\mathcal{B}(B_{c,u} \to \tau\nu)$ prevent the fit to fulfil the central value for $R_{D^{(*)}}$
- We compute the leading finite part to the one loop corrections to W and Z coupling to τ and they can partially alleviate the tension with LFU tests in τ physics
- Due to the same scalar operator arising in $b \to c\tau\nu$ decays, we expect a $\sim 60\%$ enhancement in $\mathcal{B}(B_{c,u} \to \tau\nu)$, which is consistent with data

Other constraints

- The model succeeds to pass constraints from other flavour processes
- The expected mass of the leptoquark is of order $M_U \sim 2 - 2.5\,\mathrm{TeV}$
- Interesting correlation between LFV decays





new LFV limits soon to be published

What is still to be done?

- Vector LQ U_1 seems to be the better candidate to fit the anomalies but
  - UV completion based on PS-like scenario have a rather complicated structure and,
  - they introduce unwanted states which might be dangerous for high-p_T physics
- $W' + Z'$ solution are appealing but they are in 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]**
- Scalar leptoquarks are interesting but
  - we need to tune their couplings to avoid proton decay **[Beciveric et al,'18]**
  - they bring a tension with B-$\overline{B}$ mixing **[Marzocca,'18]**

It seems like there is no 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 we will be able to disentangle the type of NP needed.

Don't forget to keep working on SM predictions!

Summary

The hints of LFUV in B-physics form an interesting and exciting pattern of anomalies.

Even though we don't have enough sensitivity yet to claim a discovery of a beyond SM sector, it is worth to investigate better the nature of the anomalies.

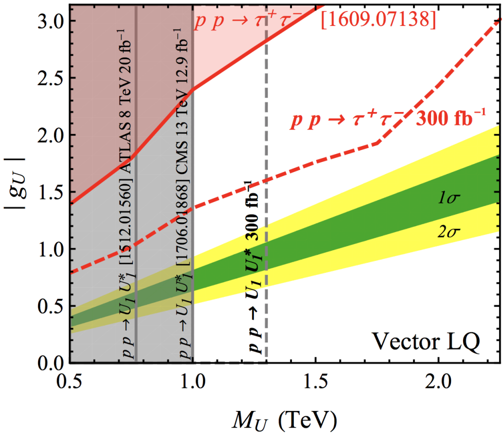
The model building approach is challenging but viable.

- The EFT based on $U(2)$ flavour symmetry singles out the vector LQ U_1 as best solution for the anomalies.
- PS^3 model represents an interesting attempt to connect the anomalies with the hierarchy of Yukawa couplings
- This model provides interesting predictions and correlations between observable. Their measurements can confirm or falsify such scenario.

Appendix

High-p_T

LQ searches



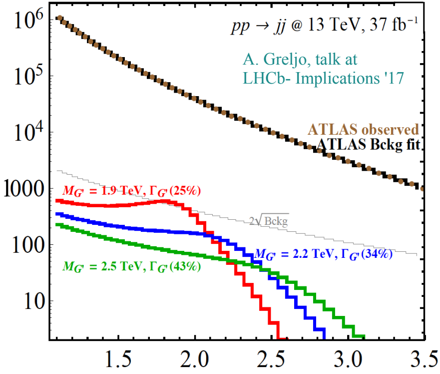
Two processes to take into account:

- QCD pair production
- τ pair production

For a gauge leptoquark

$$M_U \geq 1.3 \text{ TeV}$$

Coloron searches



- The searches performed so far focus on narrow states (bump searches)
- If the width is large (our case $\Gamma_{G'}/M_{G'} \sim 0.22$), the signal is hidden below the QCD background.

Dedicated studies are ongoing