A UV-complete model for B anomalies and SM flavor hierarchies

Javier Fuentes-Martín
Physik-Institut, Universität Zürich, CH-8057 Zürich, Switzerland

In this talk I present a "flavor decontruction" of the Pati-Salam gauge group as a possible description for the hints of lepton-flavor non-universality in B decays. The model connects the observed pattern of "anomalies" to the origin of the Standard Model Yukawa couplings, while being consistent with low- and high-energy bounds. Particularly interesting are the predictions of large Lepton Flavor Violation, in particular in processes such as $\tau \to \mu\gamma$, $B \to K\tau\mu$, and $B_s \to \tau\mu$. The model also predicts a rich spectrum of new states at the TeV scale that could be probed in the near future by high-p_T searches at the LHC.

1 Introduction

Current data on semileptonic B decays point to anomalous violations of Lepton Flavor Universality (LFU) of short-distance origin. The individual statistical significance of each observable does not exceed the 3σ level, but the overall set of deviations from the Standard Model (SM) predictions is very consistent. The evidences collected so far can naturally be grouped into two categories, according to the underlying quark-level transition: i) deviations from τ/μ (and τ/e) universality in $b \to c\ell\nu$ charged currents found in $R_{D^{(*)}}$ [1–4]; ii) deviations from μ/e universality in $b \to s\ell\ell$ neutral currents measured in $R_{K^{(*)}}$ [5, 6]. The latter is also consistent (see e.g. [7]) with the anomalies reported in the angular distributions of the $B^0 \to K^{*0}\mu^+\mu^-$ decay [8, 9].

A common origin of the two set of anomalies is not obvious, but it is very appealing from the theoretical point of view. Among the models aimed to provide a combined explanation of the two effects, those based on a TeV-scale vector leptoquark (LQ) mediator, $U_\mu \sim (\mathbf{3}, \mathbf{1})_{2/3}$, have been show to be particularly successful [10–17]. Ultraviolet completions for the vector LQ mediator U_μ naturally point to the Pati-Salam (PS) gauge group, PS=SU(4) $\times$ SU(2)$_\mathrm{L}$ $\times$ SU(2)$_\mathrm{R}$ [18], that contains a massive gauge field with these quantum numbers. The original (family-universal) PS model does not work since the LQ field has to be very heavy in order to satisfy the tight flavor bounds arising from the coupling to light generations. A way to circumvent this problem consists in assuming variations of the PS gauge group in which the TeV-scale new physics (NP) is coupled mainly to third generation SM fermions, with subleading effects on the light generations controlled by the breaking of the approximate U(2)^5 flavor symmetry of the SM Yukawas [19]. Assuming such connection between the SM Yukawas and the "flavor anomalies", opens the possibility to establish a possible origin to the SM flavor structure.

In a recent paper [20] we proposed a model based on the flavor non-universal gauge group $\mathrm{PS}^3 \equiv \mathrm{PS}_1 \times \mathrm{PS}_2 \times \mathrm{PS}_3$, where each PS group acts on a single fermion family. This model offers an interesting framework to test the aforementioned connection of the PS gauge group with the hints of NP in B meson decays and the SM flavor hierarchies. In the PS^3 model the approximate U(2)^5 flavor symmetry arises as an accidental symmetry of the gauge sector of the theory (below about 100 TeV). The breaking of this accidental symmetry, and hence the NP couplings and SM Yukawas to light generations, is controlled in this model by the spontaneous symmetry breaking (SSB) $\mathrm{PS}^3 \to \mathrm{SM}$, yielding at the TeV scale the required (mostly) third-generation LQ.[a]

[a] An additional feature of the PS^3 model, inherited from the flavor-universal PS, is the appearance of baryon and lepton numbers as accidental global symmetries, making the proton stable even in the presence of LQ intreactions.

The low energy effects of this construction were analyzed in depth in [21]. Among those, the most prominent signatures are related with the presence of vector LQ couplings not only to left-handed currents, but also to right-handed ones. This additional coupling structure gives rise to scalar contributions after fierzing, yielding important NP effects in R_D as well as in LFV transitions. The model also predicts two other TeV-scale fields: a color octet, G', and a Z', that can mediate flavor-changing processes and which are subject to direct searches at the LHC.

2 The PS^3 model

As already stated, the gauge symmetry of the model at high energies is a three-site version of the PS gauge group, i.e. $\mathrm{PS}^3 \equiv \mathrm{PS}_1 \times \mathrm{PS}_2 \times \mathrm{PS}_3$, with $\mathrm{PS}_i = \mathrm{SU}(4)_i \times [\mathrm{SU}(2)_\mathrm{L}]_i \times [\mathrm{SU}(2)_\mathrm{R}]_i$. The fermion content is the same as in the SM plus three right-handed neutrinos, such that each fermion family is embedded in left- and right-handed multiplets of a given PS_i subgroup: $\Psi_L^i \sim (\mathbf{4},\mathbf{2},\mathbf{1})_i$, and $\Psi_R^i \sim (\mathbf{4},\mathbf{1},\mathbf{2})_i$. The subindex $i = 1,2,3$ denotes the site that, before any symmetry breaking, can be identified with the generation index.

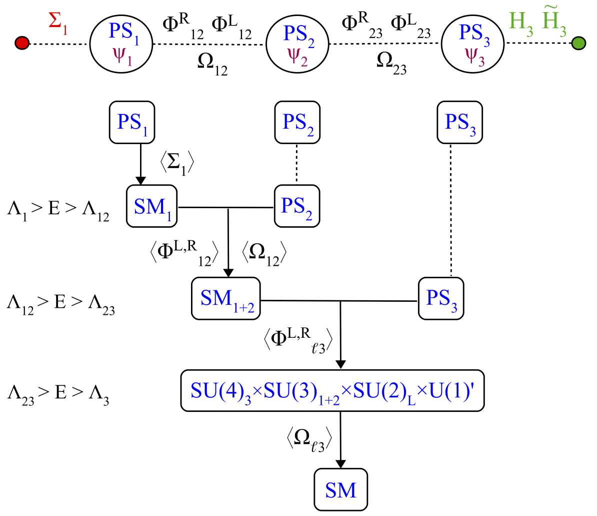

Figure 1 – Moose diagram of the model (up) and symmetry breaking sequence $\mathrm{PS}^3 \to \mathrm{SM}$.

The SM gauge group is a subgroup of the diagonal one, $\mathrm{PS} \equiv \mathrm{PS}_{1+2+3}$, which corresponds to the original (family-universal) PS gauge group. The SSB $\mathrm{PS}^3 \to \mathrm{PS}$ is triggered by vacuum expectation values (vev) of scalar "link fields", charged under the bifundamental of adjacent PS_i groups, i.e. $\Phi_{ij}^L \sim (\mathbf{1},\mathbf{2},\mathbf{1})_i \times (\mathbf{1},\bar{\mathbf{2}},\mathbf{1})_j$, $\Phi_{ij}^R \sim (\mathbf{1},\mathbf{1},\mathbf{2})_i \times (\mathbf{1},\mathbf{1},\bar{\mathbf{2}})_j$, and $\Omega_{ij} \sim (\mathbf{4},\mathbf{2},\mathbf{1})_i \times (\bar{\mathbf{4}},\bar{\mathbf{2}},\mathbf{1})_j$. The breaking of the PS group to the SM one is triggered by the vev of a scalar field charged only under PS_1 (or localized in the first site): $\Sigma_1 \sim (\mathbf{4},\mathbf{1},\mathbf{2})_1$. Being localized in the first site, this field triggers the breaking $\mathrm{PS}_1 \to \mathrm{SM}_1$, which is transmitted to the other sites at subsequently lower energies through the action of the link fields (see Fig. 1). The assumed breaking pattern is such that the gauge symmetry holding at a scale Λ_{12} is $\mathrm{SM}_{1+2} \times \mathrm{PS}_3$. Assuming this NP scale to be sufficiently high (i.e. $\Lambda_{12} \sim 100$ TeV) we can ignore the NP effects of the initial PS^3 gauge group, and focus instead in $\mathrm{SM}_{1+2} \times \mathrm{PS}_3$, even for rare processes such as $K_L \to \mu e$ or K–$\bar{K}$ mixing. A key aspect of the $\mathrm{SM}_{1+2} \times \mathrm{PS}_3$ *local* symmetry is that it presents an accidental $\mathrm{U}(2)^5 \equiv \mathrm{U}(2)_q \times \mathrm{U}(2)_\ell \times \mathrm{U}(2)_u \times \mathrm{U}(2)_d \times \mathrm{U}(2)_e$ *global* flavor symmetry acting on the first two generations of SM fermions. The $\mathrm{U}(2)^5$ symmetry ensures an additional flavor protection for the NP at this scale against stringent flavor observables. This global symmetry is only broken by the link fields, whose vev is responsible for the SSB $\mathrm{SM}_{1+2} \times \mathrm{PS}_3 \to \mathrm{SM}$, below the scale $\Lambda_{23} = \text{few} \times 10$ TeV. We assume that this vevs obey the hierarchical pattern $\langle \Phi_{L,R} \rangle > \langle \Omega_{23} \rangle$, such that the heavy fields with masses proportional to $\langle \Phi_{L,R} \rangle = \mathcal{O}(10\ \text{TeV})$ can be safely decoupled due to their heavy mass and the $\mathrm{U}(2)^5$ flavor symmetry.

The gauge bosons responsible for the flavor anomalies, and potentially relevant in many flavor observables, are those acquiring mass in the last step of the breaking chain $\mathrm{SU}(4)_3 \times \mathrm{SU}(3)_{1+2} \times \mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)' \to$ SM, triggered by $\langle \Omega_{23} \rangle \neq 0$ around the TeV scale. The 15 broken generators give rise to the following massive spin-1 fields: a leptoquark, $U \sim (\mathbf{3},\mathbf{1})_{2/3}$, a coloron, $G' \sim (\mathbf{8},\mathbf{1})_0$, and a $Z' \sim (\mathbf{1},\mathbf{1})_0$. The spectrum also contains scalars and fermions with masses of the order of a few TeV. However, these play no direct role in low-energy observables.

Finally, the breaking of the electroweak symmetry takes place through the vev of four SM-like

Higgs fields that are embedded in the following two scalars: $H \sim (\mathbf{1},\mathbf{2},\bar{\mathbf{2}})_3$, and $\widetilde{H} \sim (\mathbf{15},\mathbf{2},\bar{\mathbf{2}})_3$, with $\langle H_{15}\rangle$ aligned along the T^{15} generator of $\mathrm{SU}(4)_3$. Being singlets of SM_{1+2}, these fields allow us to extend the $\mathrm{U}(2)^5$ symmetry also to the Yukawa sector, which remains exact at the level of renormalizable operators.

The accidental $\mathrm{U}(2)^5$ flavor symmetry of the gauge and Higgs sector, has profound implications in the Yukawa structure of the model. In particular only third-generation Yukawas are generated at the renormalizable level, while the Yukawa couplings for the light generations and, more generally, the breaking of the $\mathrm{U}(2)^5$ symmetry, arise from higher-dimensional operators generated at the scale Λ_{23} involving the link fields Ω_{23} and $\Phi_{23}^{L,R}$.[b] Taking into account the effect of operators up to $d=7$, quark and charged-lepton Yukawa couplings assume the following general parametric structure

$$Y_f \sim \begin{pmatrix} \frac{\langle\Phi_{23}^L\rangle\langle\Phi_{23}^R\rangle}{\Lambda_{23}^{\prime 2}} & \frac{\langle\Omega_{23}\rangle}{\Lambda_{23}} \\ \frac{\langle\Phi_{23}^L\rangle\langle\Phi_{23}^R\rangle\langle\Omega_{23}\rangle}{\Lambda_{23}^{\prime\prime 3}} & y_3^f \end{pmatrix} . \tag{1}$$

Assuming the following hierarchy among NP scales: $\langle\Omega_{23}\rangle/\Lambda_{23} \sim |V_{ts}| \approx 4\times 10^{-2}$, $\langle\Phi_{23}^L\rangle\langle\Phi_{23}^R\rangle/\Lambda_{23}^{\prime 2} \sim m_c(v)/v \approx 5\times 10^{-3}$, one is able to accommodate the SM Yukawa structure with order one couplings.

An important aspect for the low-energy phenomenology of the model is that the $\mathrm{U}(2)^5$ breaking introduced by the effective operators is not confined only to the Yukawa sector. Additional breaking arises as $d=6$ operators that are responsible of inducing (small) effective interactions among the new vectors and the light-generation fermions. An important phenomenological assumption, which we term as *minimal breaking structure* consists in assuming that the $\mathrm{U}(2)^5$ breaking introduced by these operators is $\mathrm{U}(2)_{\mathrm{q}}$-preserving and hence it does not induce excessively large effects in $\Delta F=2$ transitions. With this assumption, the only relevant flavor parameter arising from these higher-dimensional operators is ϵ_U, that controls the breaking of $\mathrm{U}(2)^5$ in the couplings of the TeV-scale LQ.

3 Low-energy constraints

Despite the seemly complicated structure of the PS^3 model, its NP effects at low energies are highly constrained thanks to the underlaying $\mathrm{U}(2)^5$ symmetry. In particular, its low-energy phenomenology is dominated by the three vectors: U, Z' and G', which are dominantly coupled to the third generation. Their NP scale is encoded in the adimensional parameters C_U, $C_{Z'}$ and $C_{G'}$, that play an analogous role to that of the Fermi constant. Due to the gauge $\mathrm{SU}(4)_3$ symmetry, the masses of these vectors are constrained to remain close to each other, resulting in relations among $C_{U,Z',G'}$. The relevant interactions of the vector with light fermions are determined by four parameters: two mixing angles and a phase (s_b, ϕ_b, and s_τ), that control the breaking of the $\mathrm{U}(2)^5$ symmetry in the quark and lepton sectors; and ϵ_U, that was already introduced in the previous section and that parametrize the corresponding $\mathrm{U}(2)^5$ breaking in the LQ sector. In what follows we discuss the main constraints on these parameters arising from low-energy observables.

$\Delta F = 2$ transitions. Here we focus in $\Delta B=2$, and refer the reader to [21] for a full analysis. The most severe constraints are obtained from the mass differences ΔM_q, we have

$$C_{B_d} \equiv \frac{\Delta M_d}{\Delta M_d^{\mathrm{SM}}} \approx \left|1+\frac{\mathcal{A}_{\mathrm{NP}}}{R_{\mathrm{loop}}^{\mathrm{SM}}}\right| , \qquad C_{B_s} \equiv \frac{\Delta M_s}{\Delta M_s^{\mathrm{SM}}} \approx \left|1+\frac{\mathcal{A}_{\mathrm{NP}}}{R_{\mathrm{loop}}^{\mathrm{SM}}}\left(1+f(\theta_{bs}^R)\right)\right| , \tag{2}$$

with $R_{\mathrm{loop}}^{\mathrm{SM}} \approx 1.6\times 10^{-3}$, $\mathcal{A}_{\mathrm{NP}} = e^{-2i\phi_b}\,(s_b/|V_{ts}|)^2\,(C_{Z'}+C_{G'}/3)$, and where $f(\theta_{bs}^R)$ describes the contributions from the right-handed flavor rotations. In the limit where we neglect contributions

[b] For a discussion on the possible origin of this effective operators from dynamical degrees of freedom we refer the reader to [17,20,21].

to the Yukawa couplings from $d = 7$ effective operators in (1), the right-handed rotation angle is unambiguously fixed and $f(\theta_{bs}^R) \approx 0.4$.

Current lattice data [22] point to a deficit in the experimental values of $\Delta M_{d,s}$ with respect to the SM prediction (or equivalently to values of $C_{B_{s,d}}$ smaller than one). Interestingly, the presence of the free phase, ϕ_b, allows the model to accommodate this deficit, even for small departures from $\phi_b = \pi/2$, while satisfying the bounds from CP violation (see Ref. [23] for a similar discussion). The mixing angle s_b is constrained to be up to $0.2\,|V_{ts}|$ (depending on ϕ_b), indicating a mild alignment of the leading $\mathrm{U(2)_q}$ breaking spurion in the down sector. As we discuss next, in our framework the vector LQ provides a good fit of the semileptonic anomalies irrespective of the value of ϕ_b (contrary to the case discussed in Ref. [23]). We thus conclude that the model leads to a good description of $\Delta B = 2$ observables, possibly improved compared to the SM case.

$b \to s\ell\ell$. After imposing the constraints from $\Delta B = 2$ observables, the Z'-mediated contributions to $b \to s\ell\ell$ amplitudes turn out to be well below those mediated by the vector LQ. This is because the $\Delta B = 2$ constraints require the effective bsZ' coupling to be either very small or almost purely imaginary (hence with a tiny interference with the SM contribution). As a result, the following approximate relations hold [c]

$$\mathrm{Re}\,(\Delta\mathcal{C}_9^{\mu\mu}) \approx -\,\mathrm{Re}\,(\Delta\mathcal{C}_{10}^{\mu\mu}) \approx -\frac{2\,\pi}{\alpha_{\rm em}}\,\frac{s_\tau\,\epsilon_U}{|V_{ts}|}\,C_U\,, \quad \mathrm{Re}\,(\Delta\mathcal{C}_9^{\tau\tau}) \approx -\,\mathrm{Re}\,(\Delta\mathcal{C}_{10}^{\tau\tau}) \approx -\mathrm{Re}\,(\Delta\mathcal{C}_9^{\mu\mu})\,, \tag{3}$$

where $\Delta\mathcal{C}_i^{\alpha\alpha} = \mathcal{C}_i^{\alpha\alpha} - \mathcal{C}_i^{\rm SM}$, and $\Delta\mathcal{C}_9^{ee} \approx \Delta\mathcal{C}_{10}^{ee} \approx 0$. Contrary to other models aiming at a combined explanation of the anomalies, we predict $\mathrm{Re}\,(\Delta\mathcal{C}_{9,10}^{\mu\mu})$ and $\mathrm{Re}\,(\Delta\mathcal{C}_{9,10}^{\tau\tau})$ to be of similar size. Moreover due to its underlaying flavor structure, the model predicts large LFV signatures in $\tau \to \mu$ transitions. The dominant contribution is again mediated by the LQ, leading to

$$\mathrm{Re}(\mathcal{C}_9^{\mu\tau}) \approx -\mathrm{Re}(\mathcal{C}_{10}^{\mu\tau}) \approx -\frac{\mathrm{Re}\,(\Delta\mathcal{C}_9^{\mu\mu})}{s_\tau}\,, \qquad \mathrm{Re}(\mathcal{C}_S^{\mu\tau}) = -\mathrm{Re}(\mathcal{C}_P^{\mu\tau}) \approx -\frac{2\,\eta_S\,\mathrm{Re}\,(\Delta\mathcal{C}_9^{\mu\mu})}{s_\tau}\,. \tag{4}$$

Due to the s_τ^{-1} enhancement (s_τ is constrained by $\tau \to \mu\gamma$ to be of $\mathcal{O}(10^{-1})$) and the additional scalar contribution, large NP effects in $\mathcal{B}(B_s \to \tau\mu)$ and in $\mathcal{B}(B \to K\tau\mu)$ are expected. Interestingly, the possible NP enhancements in $R_{D^{(*)}}$ and $R_{K^{(*)}}$ are completely fixed in our model in terms of NP effects in LFV transitions. The following approximate relations hold to a good accuracy

$$\left(\frac{\Delta R_D}{0.2}\right)^2\left(\frac{\Delta R_K}{0.3}\right)^2 \approx 3\left[\frac{\mathcal{B}(B \to K\tau^+\mu^-)}{3\times 10^{-5}}\right]\left[\frac{\mathcal{B}(\tau \to \mu\gamma)}{5\times 10^{-8}}\right] \approx \left[\frac{\mathcal{B}(B_s \to \tau^\pm\mu^\mp)}{2\times 10^{-4}}\right]\left[\frac{\mathcal{B}(\tau \to \mu\gamma)}{5\times 10^{-8}}\right]. \tag{5}$$

$b \to c(u)\tau\nu$. The violation of LFU in $b \to c\ell\nu$ transitions, measured via the ratios R_D and R_{D^*}, sets the scale of NP (or the preferred value of C_U). In the PS^3 model NP effects in $b \to c(u)\tau\nu$ transitions are described by the following effective operators

$$\mathcal{L}(b \to u_i\tau\bar\nu) = -\frac{4G_F}{\sqrt{2}}\left(\left[\mathcal{C}_{\nu edu}^{\rm V,LL}\right]_{333i}^*(\bar\tau_L\gamma^\mu\nu_{L3})(\bar u_L^i\gamma_\mu b_L) + \left[\mathcal{C}_{\nu edu}^{\rm S,RL}\right]_{333i}^*(\bar\tau_R\,\nu_{L3})(\bar u_L^i b_R)\right)\,, \tag{6}$$

where $i = 1(2)$ for up (charm) quarks. At $\Lambda = M_U$ we have to a good approximation $\left[\mathcal{C}_{\nu edu}^{\rm S,RL}\,(M_U)\right]_{333i} = 2\left[\mathcal{C}_{\nu edu}^{\rm V,LL}\,(M_U)\right]_{333i} \approx 2\,C_U\,V_{ib}^*$. Renormalization Group (RG) running (due to QCD) introduces an important correction to the scalar operator contributions. To account for these effects we define the following RG factor $\left[\mathcal{C}_{\nu edu}^{\rm S,RL}\,(m_b)\right]_{333i} = \eta_S\left[\mathcal{C}_{\nu edu}^{\rm S,RL}\,(M_U)\right]_{333i}$, which is found to be $\eta_S \approx 1.4$ for $M_U = 2$ TeV using DsixTools [24]. On the other hand, the running of the vector operator, being a conserved current for QCD, is very small and can be neglected.

[c] As commonly done in the literature, the NP effects in $b \to s\ell\ell$ transitions are encoded as shifts in the Wilson Coefficients, $\mathcal{C}_{9,10}^{\mu}$, of an effective Hamiltonian, see Appendix D.1 in [21] for more details.

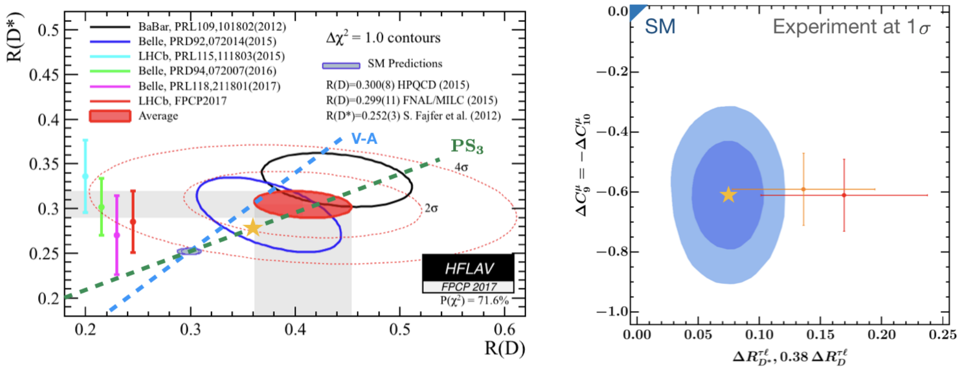

Figure 2 – Left: $R_{D^{(*)}}$ measurements with the HFLAV world average [26] and SM predictions. NP physics projections for the PS^3 model and the $V-A$ solution are overlaid. Right: Model prediction for $\Delta C_9^\mu = -\Delta C_{10}^\mu$, ΔR_{D^*}, and ΔR_D for the 1σ (dark blue) and 2σ (light blue) fit regions. The 1σ experimental data are shown by the two crosses. Predictions and results for ΔR_D (orange cross) are scaled by 0.38 compared to ΔR_{D^*} (red cross), in accordance with the model prediction. The best fit point is represented by a star.

Due to the presence of the scalar operator, we predict departures from a pure $V-A$ structure, hence different NP contributions to R_D and R_{D^*} (see Fig. 2 left). Defining the relative NP contribution to these observables as $\Delta R_{D^{(*)}} = R_{D^{(*)}}/R^{\rm SM}_{D^{(*)}} - 1$ and using [25] for the scalar form factors, we find

$$\Delta R_D \approx 2\,C_U \times (1+2.1)\,, \qquad\qquad \Delta R_{D^*} \approx 2\,C_U \times (1+0.17)\,, \tag{7}$$

which imply a 25% (10%) NP effect in R_D (R_{D^*}) for $C_U \approx 0.04$ (compatible with the stringent bounds from LFU tests in τ decays arising at one-loop, see [21] for more details).

The NP contribution to $\mathcal{B}(B_c \to \tau\nu)$ induced by the scalar operator is chirally enhanced, yielding an enhancement of $\mathcal{O}(100\%)$ compared to the SM prediction. However, given the low experimental accuracy in this observable, this does not pose any significant bound on the model. Similarly, large (chirally-enhanced) NP enhancements would also be expected in $\mathcal{B}(B \to \tau\nu)$, however due to possible parametric suppressions in the model one finds significant attenuations of the NP enhancement resulting in this case in $\mathcal{O}(30\%)$ NP effects.

Overall, the PS^3 model is found to be in good agreement with experimental data. As depicted in Fig. 2 (right), a fit to low-energy data shows that the model can fully accommodate the hints of NP in $b \to s\ell\ell$ transitions. The complete explanation of the $R_{D^{(*)}}$ anomaly in this framework is however limited by LFU tests in τ decays. Since the low-energy observables constrain only the effective Fermi couplings, $C_{U,Z',G'}$, there is some uncertainty on the masses of the heavy vector bosons. Still, we can derive a well-defined range for vector boson masses: setting the NP coupling to lie in $2.5 \leq g_U \leq 3.0$, the masses of Z', U, and G' range between 2 and 3 TeV, i.e at the reach of future searches at the LHC. An important feature of these new vector states is their large width, generically $\Gamma/M \sim 30\%$, making their possible detection in certain channels more involved.

4 Conclusions

If unambiguously confirmed as beyond-the-SM signals, the recent B-physics anomalies would lead to a significant shift in our understanding of fundamental interactions. They could imply abandoning the assumption of flavor universality of gauge interactions, which implicitly holds in the SM and in its most popular extensions. In this paper we have presented a model where the idea of flavor non-universal gauge interactions is pushed to its extreme consequences, with an independent gauge group for each fermion family.

The three-site Pati-Salam gauge symmetry, with a suitable symmetry breaking sector, could naturally describe the observed Yukawa hierarchies and explain at the same time the recent B-physics anomalies, while being consistent with the tight constraints from other low- and high-energy measurements. Particularly interesting are the predictions of large $\tau \to \mu$ LFV, which can be tested in the very near future. Besides LFV processes, the model also predicts interesting non-standard effects in $\Delta F = 1$ and $\Delta F = 2$ observables, with non-trivial correlations. Also relevant and distinctive are the predictions for the violations of LFU in charged currents due to the presence of right-handed currents: $\Delta R_D \approx 2.6\,\Delta R_{D^*}$, and a possible large enhancement of $\mathcal{B}(B \to \tau\nu)$. The model presented here also exhibits a rich TeV-scale phenomenology that can be probed in the near future by high-p_T experiments at the LHC.

Most of the low-energy predictions of the PS^3 model differ with respect to what is expected in other models proposed for a combined explanation of the B anomalies. The corresponding measurements would therefore be of great value in shedding light on the dynamics behind the anomalies, and clarify their possible link to the origin of quark and lepton masses.

Acknowledgments

I am grateful to Marzia Bordone, Claudia Cornella and Gino Isidori for the collaborations that led to the work presented here. I also thank the organizers the great environment during the conference. This research was supported in part by the Swiss National Science Foundation (SNF) under contract 200021-159720.

References

1. J. P. Lees *et al.* [BaBar Collaboration], Phys. Rev. D **88** (2013) no.7, 072012
2. R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **115** (2015) no.11, 111803 Erratum: [Phys. Rev. Lett. **115** (2015) no.15, 159901]
3. S. Hirose *et al.* [Belle Collaboration], Phys. Rev. Lett. **118** (2017) no.21, 211801
4. R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. D **97** (2018) no.7, 072013
5. R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **113** (2014) 151601
6. R. Aaij *et al.* [LHCb Collaboration], JHEP **1708** (2017) 055
7. B. Capdevila, et al., JHEP **1801** (2018) 093
8. R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **111** (2013) 191801
9. R. Aaij *et al.* [LHCb Collaboration], JHEP **1602** (2016) 104
10. R. Barbieri, G. Isidori, A. Pattori and F. Senia, Eur. Phys. J. C **76** (2016) no.2, 67
11. D. Buttazzo, A. Greljo, G. Isidori and D. Marzocca, JHEP **1711** (2017) 044
12. L. Calibbi, A. Crivellin and T. Ota, Phys. Rev. Lett. **115** (2015) 181801
13. R. Barbieri, C. W. Murphy and F. Senia, Eur. Phys. J. C **77** (2017) no.1, 8
14. L. Di Luzio, A. Greljo and M. Nardecchia, Phys. Rev. D **96** (2017) no.11, 115011
15. R. Barbieri and A. Tesi, Eur. Phys. J. C **78** (2018) no.3, 193
16. M. Blanke and A. Crivellin, arXiv:1801.07256 [hep-ph].
17. A. Greljo and B. A. Stefanek, Phys. Lett. B **782** (2018) 131
18. J. C. Pati and A. Salam, Phys. Rev. D **10** (1974) 275
19. R. Barbieri, et al., Eur. Phys. J. C **71** (2011) 1725
20. M. Bordone, C. Cornella, J. Fuentes-Martín and G. Isidori, Phys. Lett. B **779** (2018) 317
21. M. Bordone, C. Cornella, J. Fuentes-Martín and G. Isidori, arXiv:1805.09328 [hep-ph].
22. A. Bazavov *et al.* [Fermilab/MILC Collaborations], Phys. Rev. D **93** (2016) no.11, 113016
23. L. Di Luzio, M. Kirk and A. Lenz, Phys. Rev. D **97** (2018) no.9, 095035
24. A. Celis, J. Fuentes-Martín, A. Vicente and J. Virto, Eur. Phys. J. C **77** (2017) no.6, 405
25. S. Fajfer, J. F. Kamenik and I. Nisandzic, Phys. Rev. D **85** (2012) 094025
26. Y. Amhis *et al.* [HFLAV Collaboration], Eur. Phys. J. C **77** (2017) no.12, 895