$b \to s\ell^+\ell^-$ ANOMALIES FROM DYNAMICAL YUKAWAS

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The LHCb Collaboration has recently reported hints for New Physics in $b \to s\ell^+\ell^-$ transitions that point to a large violation of flavor universality in the lepton sector. Motivated by them, we present a framework able to accommodate the experimental anomalies while, at the same time, addressing the flavor puzzle of the Standard Model. This framework is based on the hypothesis of dynamical Yukawas, where it is assumed that these couplings are generated by the vacuum expectation value of dynamical fields charged under a local non-Abelian flavor symmetry. The proposed framework has a rich phenomenology and predicts striking collider signatures that will be tested in the near future.

1 Introduction

While most measurements agree very well with the Standard Model (SM), current $b \to s\ell^+\ell^-$ data show a consistent pattern of deviations that might be pointing to New Physics (NP). In particular, the LHCb and Belle collaborations have reported discrepancies with the SM predictions at the level of $3\,\sigma$ in the decay $B \to K^*\mu^+\mu^-$ (mainly in the angular observable P_5') [1,2], and in the differential $\mathrm{Br}[B_s \to \phi\mu^+\mu^-]$ [3]. In addition, deviations are also found in lepton flavor universality tests such as the ratio $R_K = \mathrm{Br}[B \to K\mu^+\mu^-]/\mathrm{Br}[B \to Ke^+e^-]$, whose experimental value[4] is $2.6\,\sigma$ away from the theoretically clean SM prediction, $R_K^{\mathrm{SM}} = 1.00{\pm}0.01$ [5]. The same pattern of deviations has also been reported in the recent measurement of R_{K^*} [6], analogous to R_K but with different final-state meson, which deviates around $3\,\sigma$ from the SM prediction. Even though each measurement is not significant enough to claim NP, in combination they constitute an intriguing set of anomalies. It is compelling that all these discrepancies can be explained in a model-independent approach by a rather large NP contribution to a single effective operator, with other NP contributions still allowed by the data. This solution is preferred over the SM hypothesis by more than $5\,\sigma$, see [7,8] and references therein.

Several NP models have been proposed to accommodate the anomalies, see e.g. [9,10]. If a new theory of flavor emerges as a result of these experimental measurements, it is quite likely that it will be connected to other long-standing problems of the SM. In this respect, the flavor puzzle –the lack of explanation within the SM for the peculiar structure of fermion masses and mixing angles– could also be pointing to the same NP.

In this proceeding we explore the possibility of explaining both hints of NP from the hypothesis of dynamical Yukawas.

2 Dynamical Yukawas and lowest-lying Z' bosons

A promising direction in the explanation of the flavor structure of the SM is provided by the hypothesis of dynamical Yukawas, where these couplings are promoted to dynamical fields charged under a flavor symmetry that is realized at high energies. It is then expected that the Yukawa structure arises from the minimum of a generic potential invariant under this flavor symmetry. Interestingly, it was shown in [11] that the most general potential invariant under the $[\mathrm{SU}(3)]^5 \times \mathcal{O}(3)$ flavor symmetry has a natural minimum that explains the generic features of the Yukawa matrices, both in the quark and lepton sectors. Introducing small perturbations to this minimum (e.g. via extra scalar fields [12,13]) allows to fit the observed masses and mixing angles, and triggers a full breaking of the residual flavor symmetry.

In this framework it is common to assume that the flavor symmetry is local, therefore avoiding the presence of unseen Goldstone bosons. This assumption leads to new gauge bosons whose phenomenology can be of interest for the $b \to s\ell^+\ell^-$ anomalies. The complete spectrum of the corresponding massive vector bosons is quite complicated and may span several orders of magnitude. However, under reasonable assumptions on the perturbations of the natural minimum, only a subgroup of the flavor symmetry remains unbroken at low energies, $\mathrm{U}(1)_{B_1+B_2-2B_3} \times \mathrm{U}(1)_{\mu-\tau}$, while the other flavor gauge bosons are much heavier and decouple at the electroweak scale. For more details we refer the reader to [10], where a specific model realization is also provided.

The resulting framework predicts two Z' bosons around the TeV scale: one leptophilic, Z_ℓ, associated to $\mathrm{U}(1)_{\mu-\tau}$, and the other quarkphilic, Z_q, corresponding to the $\mathrm{U}(1)_{B_1+B_2-2B_3}$ symmetry. In the minimal model, the new gauge bosons present a natural suppression of the Flavor Changing Neutral Currents (FCNC) in the quark sector and yield no Lepton Flavor Violation (LFV) in the charged lepton sector. At the scale where the two U(1) symmetries are broken, the corresponding Z' bosons can mix leading to the following mass eigenstates [a]

$$\begin{pmatrix} Z_1 \\ Z_2 \end{pmatrix} = \begin{pmatrix} \cos\xi & \sin\xi \\ -\sin\xi & \cos\xi \end{pmatrix} \begin{pmatrix} \hat{Z}_\ell \\ \hat{Z}_q \end{pmatrix} . \tag{1}$$

Here the mass-mixing angle is defined as

$$\xi \simeq -\frac{\hat{M}_{Z_q}\,\hat{M}_{Z_\ell}}{\hat{M}^2_{Z_q} - \hat{M}^2_{Z_\ell}}\,\epsilon + \mathcal{O}\left(\epsilon^2\right) , \tag{2}$$

where ϵ is a small parameter that characterizes the mixing and $\hat{M}_{Z_{q,\ell}}$ is the mass of the corresponding gauge bosons in the absence of mixing.

3 Low-energy implications

- $\boldsymbol{b \to s\ell^+\ell^-}$ **transitions:** In this framework NP only yields a relevant contribution to the operator $\mathcal{O}_9^{\mu\mu} \equiv (\bar{s}\gamma_\mu P_L b)\,(\mu\gamma^\mu P_L \mu)$ through the tree-level exchange of the additional gauge bosons. Expanding in ϵ, we get for its Wilson coefficient

$$C_9^{\mu\mu}|_{\mathrm{NP}} = -\frac{\Gamma^*_{bs}}{V_{tb}V^*_{ts}} \left(\frac{g_q\Lambda_v}{M_{Z_2}}\right) \left(\frac{g_\ell\Lambda_v}{M_{Z_1}}\right) \epsilon + \mathcal{O}(\epsilon^2) , \tag{3}$$

  where $\Lambda_v \simeq 7$ TeV, $g_{q,\ell}$ are the gauge couplings of the corresponding Z' bosons and Γ^*_{bs} is a coupling of $\mathcal{O}(V_{tb}V^*_{ts})$.

- $\boldsymbol{\Delta F = 2}$ **processes:** The new gauge bosons also induce a tree level contribution to $B_s - \bar{B}_s$ mixing. Requiring NP contributions to the amplitude to be at most $\mathcal{O}(10\%)$, we get the bound

$$\left| \frac{\Gamma_{bs}}{V_{tb}V^*_{ts}} \frac{g_q\Lambda_v}{M_{Z_2}} \right| \lesssim 0.7 . \tag{4}$$

[a] For simplicity, we assume that the new gauge bosons do not have any relevant kinetic or mass mixing with the SM gauge fields. We also neglect kinetic mixing among the new gauge bosons, which turns out to be irrelevant for the explanation of the anomalies.

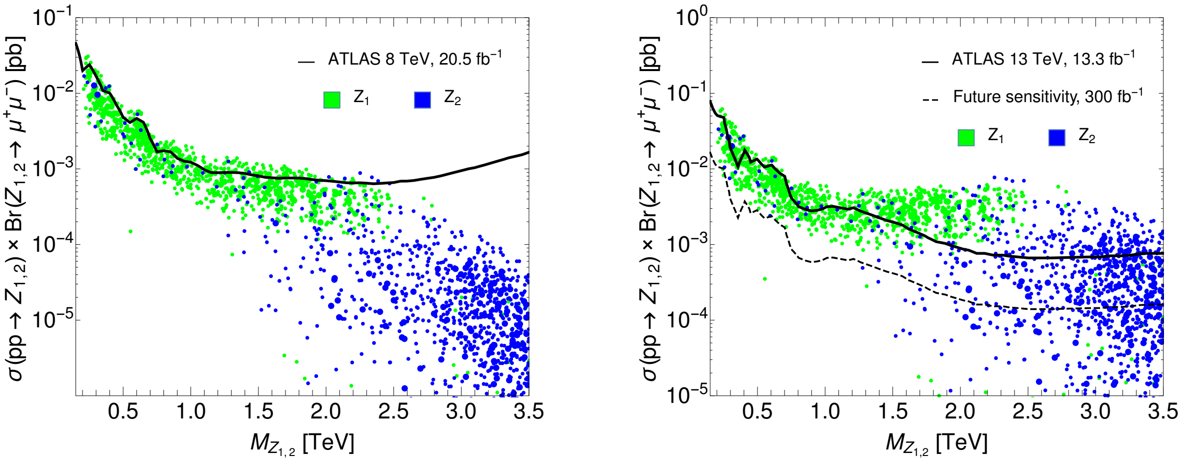

Figure 1 – Predictions for the LHC signals ($\sigma \times \mathrm{Br}$) at 8 TeV (left) and 13 TeV (right) for $\mu^+\mu^-$ resonance searches for Z_1 (green) and Z_2 (blue). Present limits are shown with solid line, and projected sensitivity with dashed line.

It is worth noting that, in the absence of right-handed FCNCs, the contribution to $\Delta F = 2$ processes have necessarily constructive interference and are minimal flavor violating (i.e. a similar relative correction compared to the SM is also expected in $B_d - \overline{B}_d$ and Kaon mixing). The contribution to these processes from flavon fields is suppressed and can be neglected.

- **Neutrino Trident Production:** Z' diagonal couplings to muons can be constrained from neutrino trident production: $\nu_\mu N \to \nu N \mu^+\mu^-$. Requiring the bound from the CCFR collaboration [14] to be satisfied at the $2\,\sigma$ level, we obtain the following constraint

$$\left| \frac{g_\ell \Lambda_v}{M_{Z_1}} \right| \lesssim 12 \,. \tag{5}$$

Using the limits in Eqs. (4) and (5), and plugging them in Eq. (3), we find the following NP contribution to $C_9^{\mu\mu}$

$$C_9^{\mu\mu}|_{\mathrm{NP}} \simeq -8 \times \epsilon \,, \tag{6}$$

to be compared with the result of the fit to $b \to s\ell^+\ell^-$ data. In [7] the authors give $C_9^{\mu\mu}|_{\mathrm{NP}} = -1.10^{+0.18}_{-0.17}$ at $1\,\sigma$ for the one-dimensional fit to this coefficient. We therefore conclude that this framework can account for the $b \to s\ell^+\ell^-$ anomalies provided $\epsilon \sim \mathcal{O}(0.1)$.

4 Direct searches at LHC

The two Z' bosons predicted in this scenario can be searched at LHC. The most stringent bounds come from direct searches with dimuon final states. In Fig. 1 we show the corresponding predictions for $\sigma \times \mathrm{Br}$ for dimuon resonance searches at ATLAS at 8 TeV [15] and 13 TeV [16]. We find that the most plausible scenario is the one with a mass hierarchy between the gauge bosons, $M_{Z_1} < M_{Z_2}$, and with small mass mixing. That is, the lighter vector Z_1 is predominantly $\hat{Z}_\ell$, while the heavier Z_2 is predominantly $\hat{Z}_q$. Interestingly enough, the unpublished 13 TeV dimuon resonance search [16] is already probing the relevant region, with conclusive answers expected in the near-future data. On the other hand, the impact of the present (and future) $\bar{t}t$ and jj searches are found to be less relevant. We restricted our scan to the mass range of dimuon resonance searches reported by ATLAS (namely $M_{Z'} \geq 150$ GeV) but it is interesting to note that a very light (almost leptophilic) Z_1 could evade the experimental bounds provided its gauge coupling is sufficiently small.

5 Summary and conclusions

The assumption of dynamically generated Yukawa couplings provides a natural explanation to the observed pattern of fermion masses and mixing angles, both in the quark and lepton sectors [11]. This hypothesis requires the sequential breaking of a flavor symmetry that, under reasonable assumptions, can also yield an explanation to the observed $b \to s\ell^+\ell^-$ anomalies.

The proposed framework predicts two Z' bosons at low-energies: one almost leptophilic and the other mostly quarkphilic. A small but non-vanishing mass mixing among the Z' bosons is required in order to accommodate the flavor anomalies. Moreover the residual flavor symmetry ensures a partial protection for quark FCNCs, which turn out to be sufficiently small to avoid the tight existing constraints while allowing for sizable effects in $b \to s\mu^+\mu^-$, and no LFV in the minimal implementations. Direct searches at LHC allow for a very light (almost leptophilic) Z' together with a heavier one (mostly quarkphilic) in the TeV range. This full region of the parameter space will be explored in the near future by dimuon searches.

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