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A flavor-safe composite explanation of R_K

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Abstract

In these proceedings we discuss a flavor-safe explanation of the anomaly found in $R_K = \mathcal{B}(B \to K\mu^+\mu^-)/\mathcal{B}(B \to Ke^+e^-)$ by LHCb, within the framework of composite Higgs models. We present a model featuring a non-negligible degree of compositeness for all three generations of right-handed leptons, which leads to a violation of lepton-flavor universality in neutral current interactions while other constraints from quark- and lepton-flavor physics are met. Moreoever, the particular embedding of the lepton sector considered in this setup provides a parametrically enhanded contribution to the Higgs mass that can weak considerably the need for ultra-light top partners.

Keywords: Flavor physics, Composite Higgs models, Violation of Lepton Flavor Universality

1. Introduction

Composite Higgs models provide an elegant explanation to the hierarchy problem by protecting the Higgs mass by its finite size [1, 2]. In addition, a sizable mass gap between the electroweak (EW) and the compositeness scale $\Lambda \approx 4\pi f_\pi$ can be achieved if one assumes the Higgs to be a pseudo Nambu-Goldstone boson (pNGB) of some global symmetry of the strong sector [3, 4, 5]. One typical assumption is that this global symmetry is only broken by the weak couplings of the elementary SM-like degrees of freedom, corresponding to the SM fermions – with the possible exception of the right-handed (RH) top quark – and gauge bosons, which generates a Higgs potential radiatively and triggers the electroweak symmetry breaking (EWSB). Within the paradigm of *partial compositeness*, where one assumes linear mixings of the SM-like fermions with their composite counterparts, the light mass eigenstates become mixtures of elementary and composite degrees of freedom, tying together the dynamics behind the observed flavor pattern and EWSB. Since the Yukawa couplings are generated through such linear couplings after integrating out the corresponding composite counterparts, it is usually thought that only third generation quarks will exhibit a sizable degree of compositeness and will be relevant for EWSB. However, the fact that neutrinos may have Majorana masses, together with the observed non-hierarchical mixing pattern in the PMNS matrix, can change this situation for the lepton sector, see e.g. [6, 7]. In these proceedings we will discuss a very minimal implementation of leptons in composite Higgs models, where neutrino masses are generated via a type-III seesaw mechanism and the RH lepton sector is unified by embedding the RH charged leptons and the RH neutrinos in a *single* representation of the global group $\mathcal{G}$ (for each generation) [8]. Linked to this unification, our setup predicts a violation of lepton-flavor universality (LFU) in neutral current interactions, while LFU is basically respected in charged currents, providing a natural and compelling explanation for the $2.6\,\sigma$ deviation observed by LHCb [9] in the very clean ratio [10, 11, 12]

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$$R_K = \left.\frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)}\right|^{\text{exp}}_{q^2\in[1,6]\,\text{GeV}} = 0.745^{+0.090}_{-0.074} \pm 0.036\,. \quad (1)$$

As we will see, this can be done in a completely flavor-save manner, due to the possibility of implementing a very economical flavor symmetry, which avoids the appearance of new sources of flavor-changing neutral currents (FCNC) to very good approximation. Since the lepton sector features a sizable degree of compositeness and the RH lepton unification requires the presence of non-minimal representations of $\mathcal{G}$, it will provide a parametrically enhanced correction to the Higgs mass, such that the need for ultra-light top partners is weakened considerably, linking the mass of the latter with the size of the neutrino masses.

2. Setup

Let us consider the so-called minimal composite Higgs model (MCHM), where the global symmetry of the strong sector $\mathcal{G} = SO(5)$ is broken by the strong dynamics to $\mathcal{H} = SO(4)$, delivering four Goldstone bosons that will be identified with the Higgs doublet. We consider the *minimal* custodial embedding of the SM lepton sector including three RH fermion triplets with zero hypercharge, $\Sigma_{\ell R}$, with $\ell = e, \mu, \tau$. If these new degrees of freedom have Majorana masses of order $\mathcal{O}(M_{\text{GUT}})$, the observed tiny neutrino masses can be explained with $\mathcal{O}(1)$ Yukawa couplings via the (type-III) *seesaw* mechanism. In the framework of the MCHM, or its five dimensional (5D) holographic dual [13, 14, 15, 16], this is realized by embedding every generation of RH leptons in a symmetric representation (**14**) of $SO(5)$, whereas every left-handed (LH) doublet is embedded in a fundamental representation (**5**) of $\mathcal{G}$. In terms of the different 5D bulk fields transforming under $SO(5)\times U(1)_X$, such embedding of the lepton sector reads $\zeta_1^\ell \sim \mathbf{5_{-1}}$ and $\zeta_2^\ell \sim \mathbf{14}_{-1}$, for $\ell = e, \mu, \tau$, [1]

$$\begin{aligned}
\zeta_1^\ell &= \ell_1'[-,+] \oplus \begin{pmatrix} \nu_1^\ell[+,+] & \tilde{\ell}_1[-,+] \\ \ell_1[+,+] & \tilde{Y}_1^\ell[-,+] \end{pmatrix}, \\
\zeta_2^\ell &= \ell_2'[-,-] \oplus \begin{pmatrix} \nu_2^\ell[+,-] & \tilde{\ell}_2[+,-] \\ \ell_2[+,-] & \tilde{Y}_2^\ell[+,-] \end{pmatrix} \\
&\oplus \begin{pmatrix} \hat{\lambda}_2^\ell[-,-] & \nu_2^{\ell\prime\prime}[+,-] & \ell_2^{\prime\prime\prime}[+,-] \\ \hat{\nu}_2^\ell[-,-] & \ell_2^{\prime\prime}[+,-] & Y_2^{\ell\prime\prime\prime}[+,-] \\ \hat{\ell}_2[-,-] & Y_2^{\ell\prime\prime}[+,-] & \Theta_2^{\ell\prime\prime\prime}[+,-] \end{pmatrix},
\end{aligned} \quad (2)$$

[1]For simplicity, we will be rather schematic in the description of the 5D setup. We thus refer the reader to Ref. [8] for further details.

where we have explicitly shown the decomposition under $SU(2)_L\times SU(2)_R \cong SO(4) = \mathcal{H}$ (with the bidoublet being represented by a 2×2 matrix on which the $SU(2)_L$ rotation acts vertically and the $SU(2)_R$ one horizontally) and the signs in square brackets denote the boundary conditions at the UV and IR branes. A Dirichlet boundary condition for the RH/LH chirality is denoted by $[+/-]$, with LH/RH zero modes being present for fields with $[+,+]/[-,-]$ boundary conditions. Finally, since the lepton sector will produce an additional non-negligible contribution to the Higgs potential, we can consider for the quark sector the previously disregarded minimal model consisting of a fully composite t_R and a LH doublet q_L^3 embedded in a **5** of $\mathcal{G}$. More specifically, we consider $\xi_1^i \sim \mathbf{5}_{2/3}$, $\xi_2^i \sim \mathbf{1}_{2/3}$, $\xi_3^i \sim \mathbf{5}_{-1/3}$, $\xi_4^i \sim \mathbf{1}_{-1/3}$, $i = 1, 2, 3$, or

$$\begin{aligned}
\xi_1^i &= \begin{pmatrix} \tilde{\Lambda}^i[-,+] & u_1^i[+,+] \\ \tilde{u}^i[-,+] & d_1^i[+,+] \end{pmatrix} \oplus u_1^{i\prime}[-,+], \\
\xi_2^i&[-,-], \\
\xi_3^i &= \begin{pmatrix} u_3^i[-,+] & \tilde{d}^i[-,+] \\ d_3^i[-,+] & \tilde{\Xi}^i[-,+] \end{pmatrix} \oplus d_3^{i\prime}[-,+], \\
\xi_4^i&[-,-].
\end{aligned} \quad (3)$$

This minimal realization of composite leptons naturally allows for a very strong flavor protection, requiring any lepton flavor violating (LFV) process to be mediated by extremely suppressed neutrino-mass insertions and leading in particular to the absence of dangerous FCNCs in the lepton sector to excellent approximation. To this end, we promote the accidental $SU(3)_1\times SU(3)_2$ flavor symmetry of the lepton sector in the decompactified or conformal limit (arising from the arbitrary rotation of ξ_1 and ξ_2 in the family space) to a 5D gauge group only broken at the UV brane (i.e., by the elementary sector) and the vacuum expectation value (vev) of some non-dynamical field $\mathcal{Y}$ [17, 18]. The bulk fields in the lepton sector will thus transform as $\zeta_1 \sim (\mathbf{3}, \mathbf{1})$ and $\zeta_2 \sim (\mathbf{1}, \mathbf{3})$, whereas $\mathcal{Y} \sim (\mathbf{3}, \bar{\mathbf{3}})$. Therefore, the corresponding bulk masses will be given by

$$c_1 = \eta_1 \mathbf{1} + \rho_1 \mathcal{Y}\mathcal{Y}^\dagger, \qquad c_2 = \eta_2 \mathbf{1} + \rho_2 \mathcal{Y}^\dagger \mathcal{Y}, \quad (4)$$

whereas the IR brane masses will read

$$a^4 \left[\omega_S \left(\bar{\zeta}_{1L}^{(\mathbf{1},\mathbf{1})} \mathcal{Y} \zeta_{2R}^{(\mathbf{1},\mathbf{1})}\right) + \omega_B (\bar{\zeta}_{1L}^{(\mathbf{2},\mathbf{2})} \mathcal{Y} \zeta_{2R}^{(\mathbf{2},\mathbf{2})})\right]\Big|_{R'} + \text{h.c.}, \quad (5)$$

with $\eta_{1,2}, \rho_{1,2} \in \mathbb{R}$, $\omega_{S,B} \in \mathbb{C}$, $a(z) = R/z$ the warp factor, $z \in [R, R']$ the coordinate of the extra dimension and the superscripts $(\mathbf{1}, \mathbf{1})$ and $(\mathbf{2}, \mathbf{2})$ denoting the singlet and the bidoublet components of the corresponding multiplets. Since, as mentioned, the elementary sector represented