B-anomalies from warped X-DIM

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Outline

- Introduction
- Explaining the B-anomalies
- Experimental constraints
- Concluding remarks

Based on work with:
E. Megias, G. Panico, O. Pujolas, MQ, 1608.02362
E. Megias, MQ, L. Salas, 1703.06019; 1707.08014

See also: "Instant workshop in B-meson anomalies" (CERN, 17-19 May 2017)

Introduction

- $R_{K^{(*)}}$ and $R_{B^{(*)}}$ anomalies (if confirmed) would imply New Physics w/

Lepton Flavor Universality (LFU) violation

as the production of different lepton flavors is flavor sensitive

- In particular $R_{B^{(*)}}$ anomalies imply New Physics w/

Strong dynamics

as New Physics effects have to compete with tree-level EW physics

- $R_{K^{(*)}}$ and $R_{B^{(*)}}$ anomalies do not necesssarily imply New Physics w/

Lepton Flavor Violation (LFV)

which is strongly constrained by processes as $\mu \to e\gamma$. Still it is true

$$\textit{LFV} \Rightarrow \textit{LFU}\ \text{violation}$$

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- Both phenomena strong dynamics and LFU violation do appear in theories where the naturalness problem is solved in the context of

Composite Higgs Theories ⇔ Theories with Warped dimensions

- This is independent on whether

  - The Higgs is a generic *mesonic* state: a SM $SU(2)$ doublet
  - The Higgs is a (pseudo)-Goldstone boson: gauge-Higgs unification with extended group

  - The theory is AdS$_5$ (RS) with gauge custodial symmetry in the bulk
  - The theory is a deformed AdS$_5$ in the IR brane: Asymptotically AdS$_5$

We have worked out a simple phenomenological model where conformal invariance is strongly deformed at the IR [1]

There are a number of works on the subject:

- Using a warped extra dimension conformally deformed at the IR [1]
- Using warped custodial models [2]
- Using composite Higgs models [3]

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[1] E. Megias, G. Panico, O. Pujolas, MQ, arXiv:1608.02362 [hep-ph]; E. Megias, MQ, L. Salas, arXiv:1703.06019 [hep-ph]; arXiv:1707.08014 [hep-ph]

[2] G. D'Ambrosio and A. M. Iyer, arXiv:1712.08122 [hep-ph]

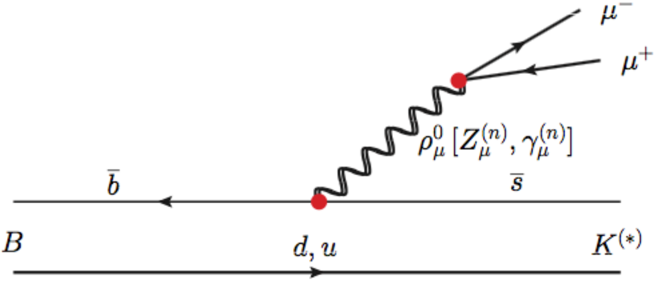
[3] C. Niehoff, P. Stangl and D. M. Straub, arXiv:1503.03865 [hep-ph];
A. Carmona and F. Goertz, arXiv:1510.07658 [hep-ph];
B. Gripaios, M. Nardecchia and S. A. Renner, arXiv:1412.1791 [hep-ph];
A. Carmona and F. Goertz, arXiv:1610.05766 [hep-ph];
A. Carmona and F. Goertz, arXiv:1712.02536 [hep-ph];
F. Sannino, P. Stangl, D. M. Straub and A. E. Thomsen, arXiv:1712.07646 [hep-ph]

Explaining the B-anomalies

The anomalies in $b \to s\ell\ell$, i.e.

$$\mathcal{O}_{9,10}^{(\prime)} = [\bar{s}_{L,R}\gamma_\mu b_{L,R}][\bar{\ell}\gamma^\mu(\gamma_5)\ell] \;\Rightarrow R_{K^{(*)}} \equiv \frac{\mathcal{B}(\bar{B} \to \bar{K}^{(*)}\mu\mu)}{\mathcal{B}(\bar{B} \to \bar{K}^{(*)}ee)}$$

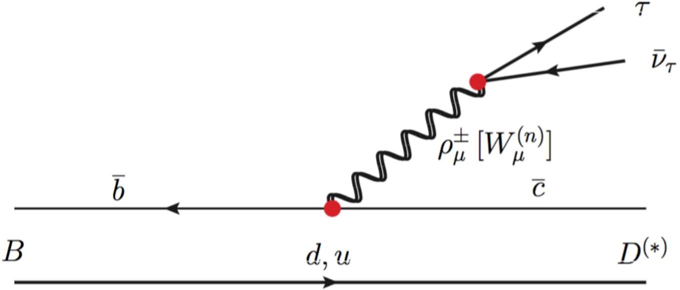
come from the diagrams



The anomalies in $b \to c\ell\bar{\nu}_\ell$, i.e.

$$\mathcal{O}^\ell = (\bar{c}\gamma^\nu P_L b)(\bar{\ell}\gamma_\nu \nu_\ell) \;\Rightarrow R_{D^{(*)}} \equiv \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^- \bar{\nu}_\ell)}$$

come from the diagrams



The model parameters are:

1. The unitary matrices $V_{d_{L,R}}$ and $V_{u_{L,R}}$ diagonalizing quark matrices
2. The degree of compositeness of different chiral fermions. The relevant involved fermions being

$$b_{L,R}, \tau_{L,R}, \mu_{L,R}$$

- We will assume that unitary matrices $V_{d_{L,R}}$ and $V_{u_{L,R}}$ diagonalizing the down and up quark matrices take Wolfenstein-like forms with $V_{CKM} \equiv V^\dagger_{u_L} V_{d_L}$
- The main parameter is the ratio

$$r = \frac{(V^\dagger_{u_L})_{23}}{(V_{CKM})_{cb}}$$

- The degree of compositeness of different chiral fermions f, characterized by a parameter c_f, is related to the localization along the extra dimension and to the fermion mass

$c_f > 1/2 \Rightarrow f$ is elementary (localized towards the UV brane)

$c_f < 1/2 \Rightarrow f$ is composite (localized towards the IR brane)

- Because $c_{b_L} = c_{t_L}$ we will consider

$$c_{b_L} < c_{b_R}$$

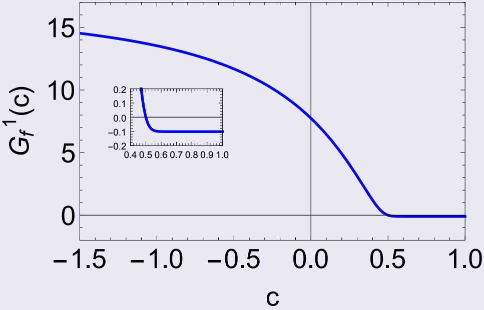
- To fit experimental data on $R_{K^{(*)}}$ ($C_9 = -C_{10}$) and $R_{D^{(*)}}$ (sensitive only to τ_L) we will consider

$$c_{\tau_L} < c_{\tau_R}, \quad c_{\mu_L} < c_{\mu_R}$$

The coupling with fermions is non-universal (c-dependent)

$$G_f^n(c_{L,R})\, g^{SM}_{f_{L,R}}\, A^n_\mu \bar{f}_{L,R}\gamma^\mu f_{L,R}$$

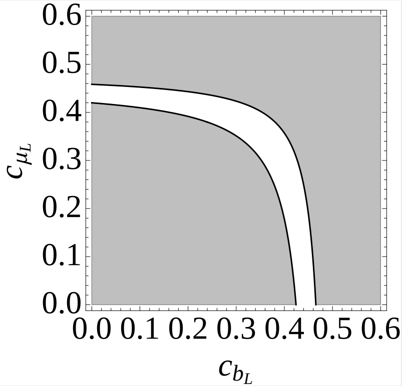
- The interaction of gauge KK modes with leptons is Lepton Flavor Non-Universal, depending on the values of $c_{\ell_{L,R}}$ $(\ell = \tau, \mu, e)$



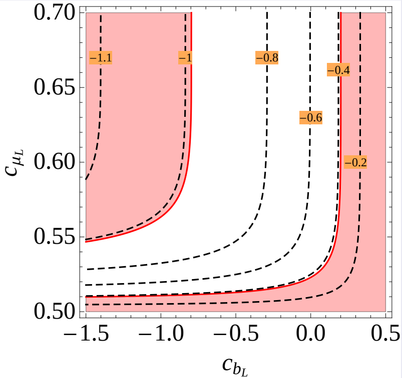
- The coupling with IR localized (composite, $c < 1/2$) fermions is stronger than the one with UV localized (elementary, $c > 1/2$) ones

- The region allowed by $b \to s\ell\ell$ data ($R_{K^{(*)}}$) is makes the difference between the two regions: $r < 1$ & $r > 1$

$r < 1$: $r = 0.75$, $c_{e_L} = 0.5$



$r > 1$: $r = 2.3$, $c_{e_L} = 0.5$

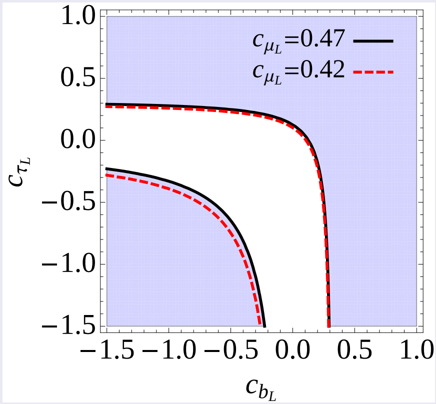


- Consistent within 1σ with the observed $B_s^0 \to \mu^+\mu^-$ branching ratio

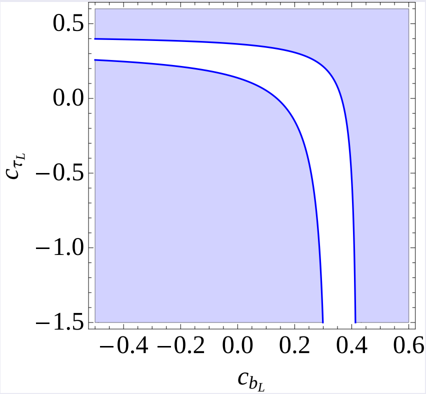
b_L is composite and μ_L is composite (elementary) for $r < 1$ ($r > 1$)

- The region allowed by $R_{D^{(*)}}$ data is the white region

$r = 0.75$



$r = 2.3$



- The relevant parameters here are c_{b_L}, c_{τ_L}

For $r < 1$ τ_L and b_L are more composite than for $r > 1$

Constraints

The main constraints are those from

- The experimental value of the coupling $g^Z_{\tau_L}$ [a]

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[a] S. Schael et al. (SLD Electroweak Group, DELPHI, ALEPH, SLD, SLD Heavy Flavour Group, OPAL, LEP Electroweak Working Group, L3), Phys. Rept. 427, 257 (2006)

- LFU tests, as e.g. $\tau \to \mu\nu\bar{\nu}$ Vs $\mu \to e\nu\bar{\nu}$ [a]

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[a] F. Feruglio, P. Paradisi, and A. Pattori, Phys. Rev. Lett. 118, 011801 (2017); F. Feruglio, P. Paradisi, and A. Pattori (2017), 1705.00929; A. Pich, Prog. Part. Nucl. Phys. 75, 41 (2014)

- Constraints from flavor physics [a]

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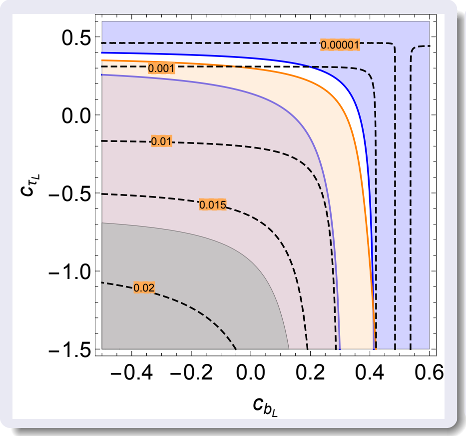
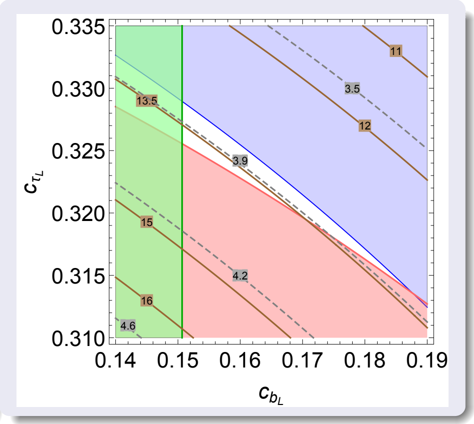
[a] G. Isidori, Flavour Physics and Implication for New Phenomena, Adv. Ser. Direct. High Energy Phys. 26 (2016) 339-355, [1507.00867]

- The constraints considerably reduce the available space left by experimental data: case $r > 1$ favored (for $r = 2.3$)





Left panel: Blue: $R_{D^{(*)}}$; Orange: g_τ^Z; Brown: $bb \to Z^{(n)}/\gamma^{(n)} \to \tau\tau$

Right panel: Red: $R_\tau^{\tau/\mu}$; Green: flavor

Concluding remarks

- To prevent strong bounds from

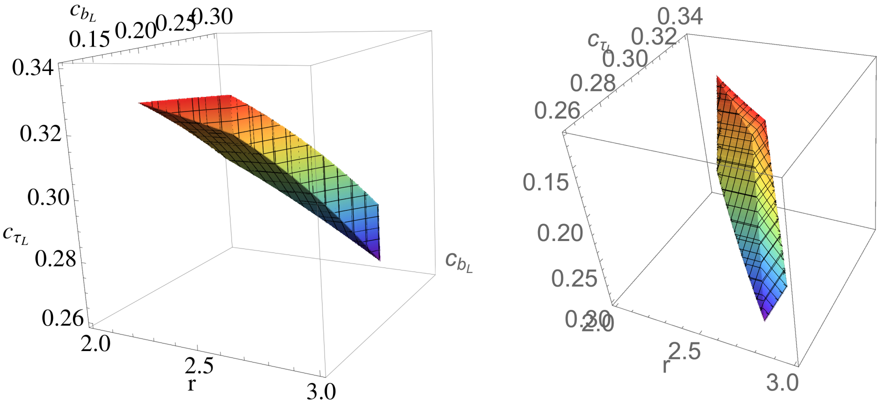
$$\mu \to e\gamma,\ \tau \to \mu\gamma, \ldots$$

  we have assumed no Lepton Flavor Violation (LFV)
- We are assuming that the 5D Yukawa couplings are such that the charged leptons are diagonal in the weak basis, so that $V_{\ell_{L,R}} \simeq 1$
- The required alignment in the lepton sector depends on the UV completion of the theory.
- This can be obtained e.g. by imposing a

$$U(1)^3$$

  flavor symmetry in the lepton sector broken only by the tiny effects due to the neutrino masses

The available 3D volume in the space (r, c_{b_L}, c_{τ_L})



The range of possible values of r consistent with all experimental data

$$2.2 < r < 2.8$$

- We find agreement with $R_{K^{(*)}}$ and $R_{D^{(*)}}$ data at 95% CL, provided the third generation of left-handed fermions is composite, as

$$0.14 < c_{b_L} < 0.28, \quad \& \quad 0.265 < c_{\tau_L} < 0.33$$

- First and second generations of quarks and leptons are elementary
- We obtain the absolute limits from experimental constraints

$$R_{K^{(*)}} > 0.79 \quad \& \quad R_{D^{(*)}}/R_{D^{(*)}}^{\rm SM} < 1.13$$

as compared with the experimental data (at 1σ)

$$0.664 < R_K < 0.841, \quad 0.601 < R_{K^*} < 0.807$$
$$1.20 < R_D/R_D^{\rm SM} < 1.54, \quad 1.20 < R_{D^*}/R_{D^*}^{\rm SM} < 1.36$$

- Finally our model predicts, for any value of the parameters the absolute range at 95% CL for the branching ratio $\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})$

$$1.14 \times 10^{-5} \lesssim \mathcal{B}(B \to K\nu\bar{\nu}) \lesssim 2.55 \times 10^{-5}$$

$$2.70 \times 10^{-5} \lesssim \mathcal{B}(B \to K^{*}\nu\bar{\nu}) \lesssim 5.79 \times 10^{-5}$$

much larger than the SM prediction

$$\mathcal{B}(B \to K\nu\bar{\nu})_{\rm SM} = (3.98 \pm 0.47) \times 10^{-6}$$

as compared with experimental bounds (at 90% CL) from Belle

$$\mathcal{B}(B \to K\nu\bar{\nu}) < 1.6 \times 10^{-5}$$

$$\mathcal{B}(B \to K^{*}\nu\bar{\nu}) < 2.7 \times 10^{-5}$$

- Therefore...

... on the verge of experimental discovery/exclusion!!

- A similar analysis can be done with the branching ratio $\mathcal{B}(B \to K\tau\tau)$, as measured by the BaBar Collaboration providing the 90% CL bound,

$$\mathcal{B}(B \to K\tau\tau) < 2.25 \times 10^{-3}$$

much larger than the SM prediction

$$\mathcal{B}(B \to K\tau\tau)_{\rm SM} = (1.44 \pm 0.15) \times 10^{-7}$$

- The model predicts, for any value of the parameters the absolute range at 95% CL

$$1.9 \times 10^{-6} \lesssim \mathcal{B}(B \to K\tau\tau) \lesssim 2.0 \times 10^{-6}$$

much larger than the SM prediction but still far from experimental bounds!