A Natural extra-dimensional origin for the LHCb anomalies

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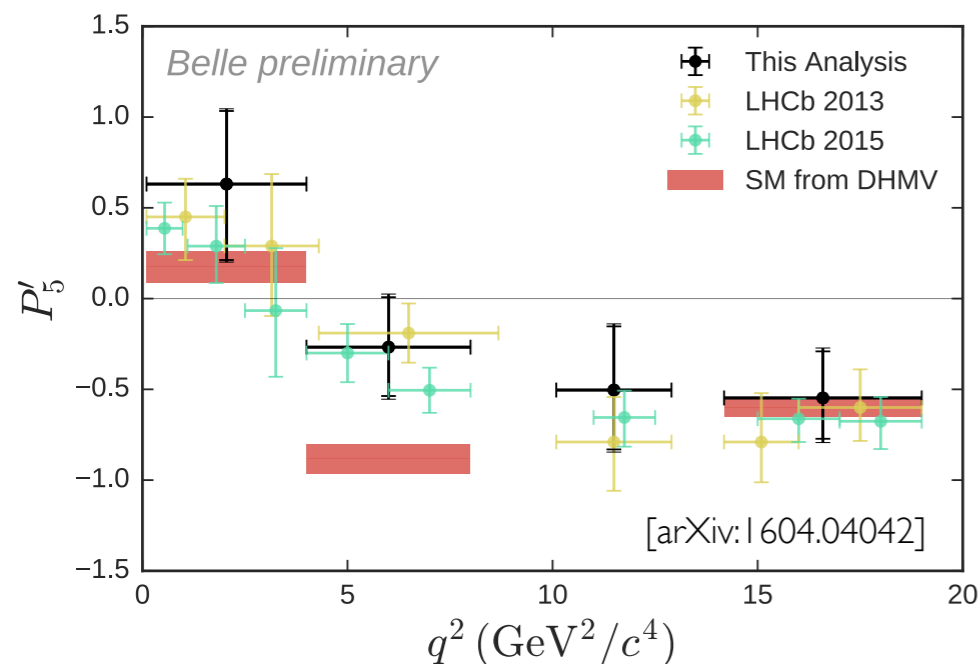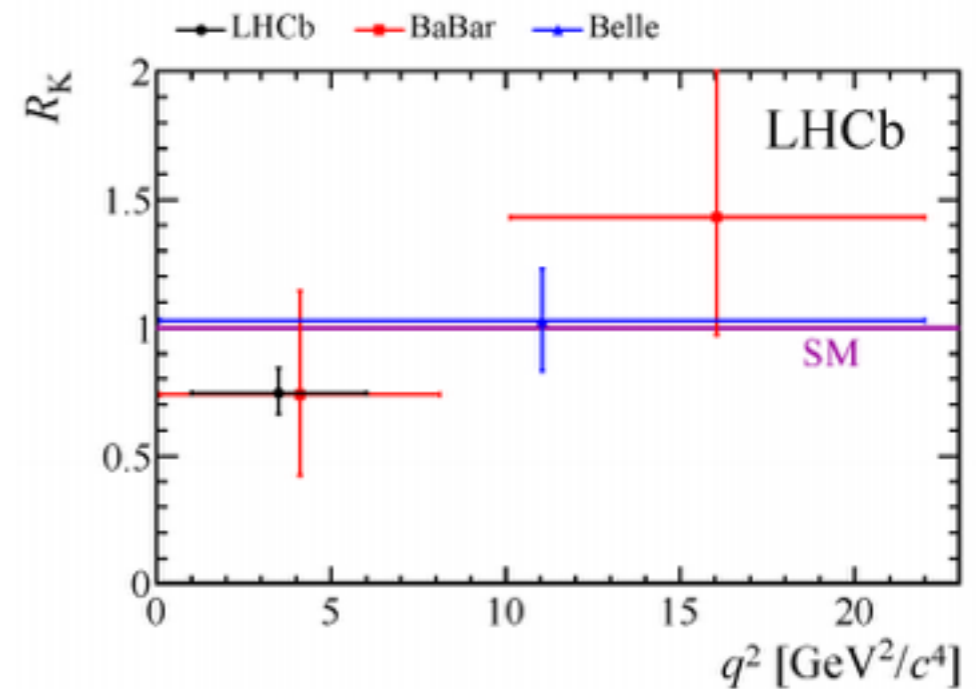
Hints of new physics in B decays

A coherent pattern of deviations in B-meson physics seems to emerge from the flavour measurements

✦ hints of **lepton universality violation** in clean observable R_K

$$R_K = \frac{\mathrm{BR}(B^+ \to K^+ \mu^+ \mu^-)}{\mathrm{BR}(B^+ \to K^+ e^+ e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

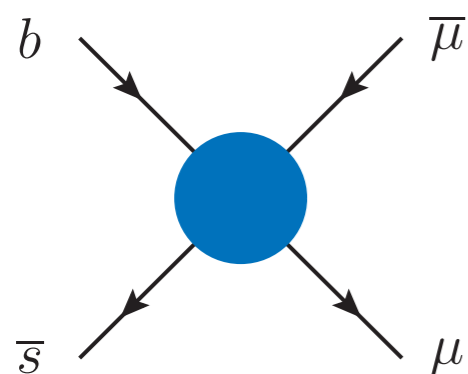✦ consistent deviations in other process related to the $b \to s\mu\mu$ transition

[arXiv:1604.04042]

A simple pattern?

Compatibility with the data can be significantly improved if sizeable contributions to O_9 (possibly correlated to O_{10}) are present

[Descotes-Genon, Matias, Virto '13, '15]

$$\Delta C_9 \in [-1.67, -0.39]$$

$$\Delta C_9 = -\Delta C_{10} \in [-1.23, -0.18]$$

$3\,\sigma$ intervals

see talk by J. Matias

Many BSM models have been proposed to explain the anomalies

see talks by A. Crivellin and O. Sumensari

- leptoquarks   [Kosnik '12, Hiller, Schmaltz '14; Sahoo, Mohanta '15; Becirevic, Fajfer, Kosnik '15; …]

- heavy Z' vectors   [Altmannshofer et al '13; Gauld, Goertz, Haisch '13; Altmannshofer et al '14; Crivellin et al. '15; Sierra, Straub, Vicente '15; Celis, Fuentes-Martin, Jung, Serodio '15; Falkowski, Nardecchia, Ziegler '15; Descotes-Genon, Hofer, Matias, Virto '15; …]

- …

Looking for a bigger picture

Sizeable contributions are needed to reproduce the anomalies

⬇

generic feature of new physics: **new states with a mass ~TeV**
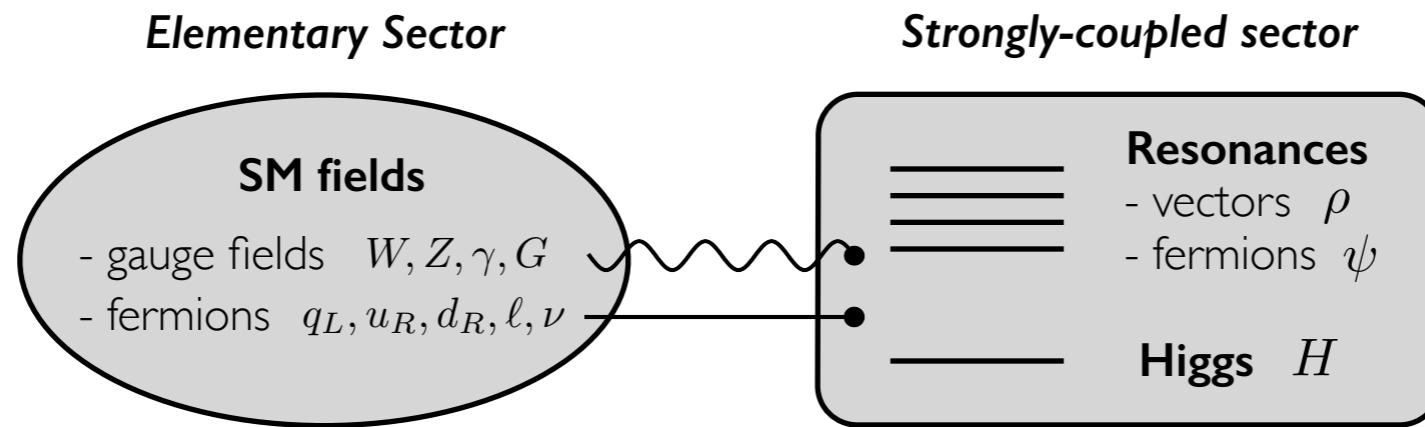
Could it be first hint of a bigger picture?

✦ intriguing possibility:

relate the anomalies to the **Naturalness Problem**

▸ in this talk: explore this possibility in the context of scenarios
with a composite Higgs and new stongly-coupled dynamics

Model-independent overview

Composite Higgs: General features

Elementary Sector *Strongly-coupled sector*

SM fields
- gauge fields W, Z, γ, G
- fermions q_L, u_R, d_R, ℓ, ν

Resonances
- vectors ρ
- fermions ψ

Higgs H

New strongly-coupled dynamics at a scale $\Lambda \sim \mathrm{TeV}$

✦ **composite** Higgs boson H

- EW scale naturally of order Λ ⟶ solution of the **Naturalness Problem**

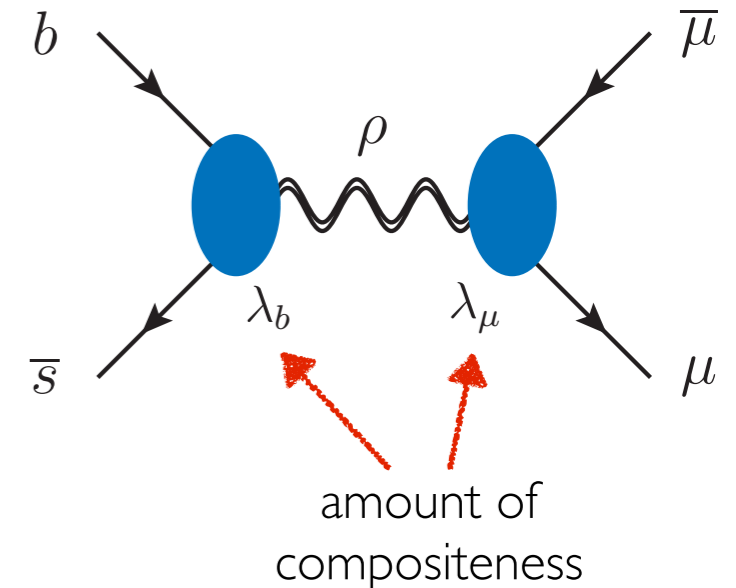✦ new **massive resonances** $m \sim \mathrm{TeV}$

- heavy vectors ρ (same quantum numbers as SM gauge fields)

- fermionic partners ψ (mixed with SM fermions: **partial compositeness**)

The $b \rightarrow s\ell\ell$ transition

see also [Niehoff, Strangl, Straub '15]

Vector resonances generate contributions to the O_9 and O_{10} operators

$$C_{9,10} \sim \frac{\sqrt{2}\pi}{G_F \alpha_{em}} \frac{g_\rho^2}{m_\rho^2} \lambda_b \lambda_\mu \simeq 100 \lambda_b \lambda_\mu \left(\frac{g_\rho \cdot 1\,\mathrm{TeV}}{m_\rho} \right)^2$$

amount of compositeness

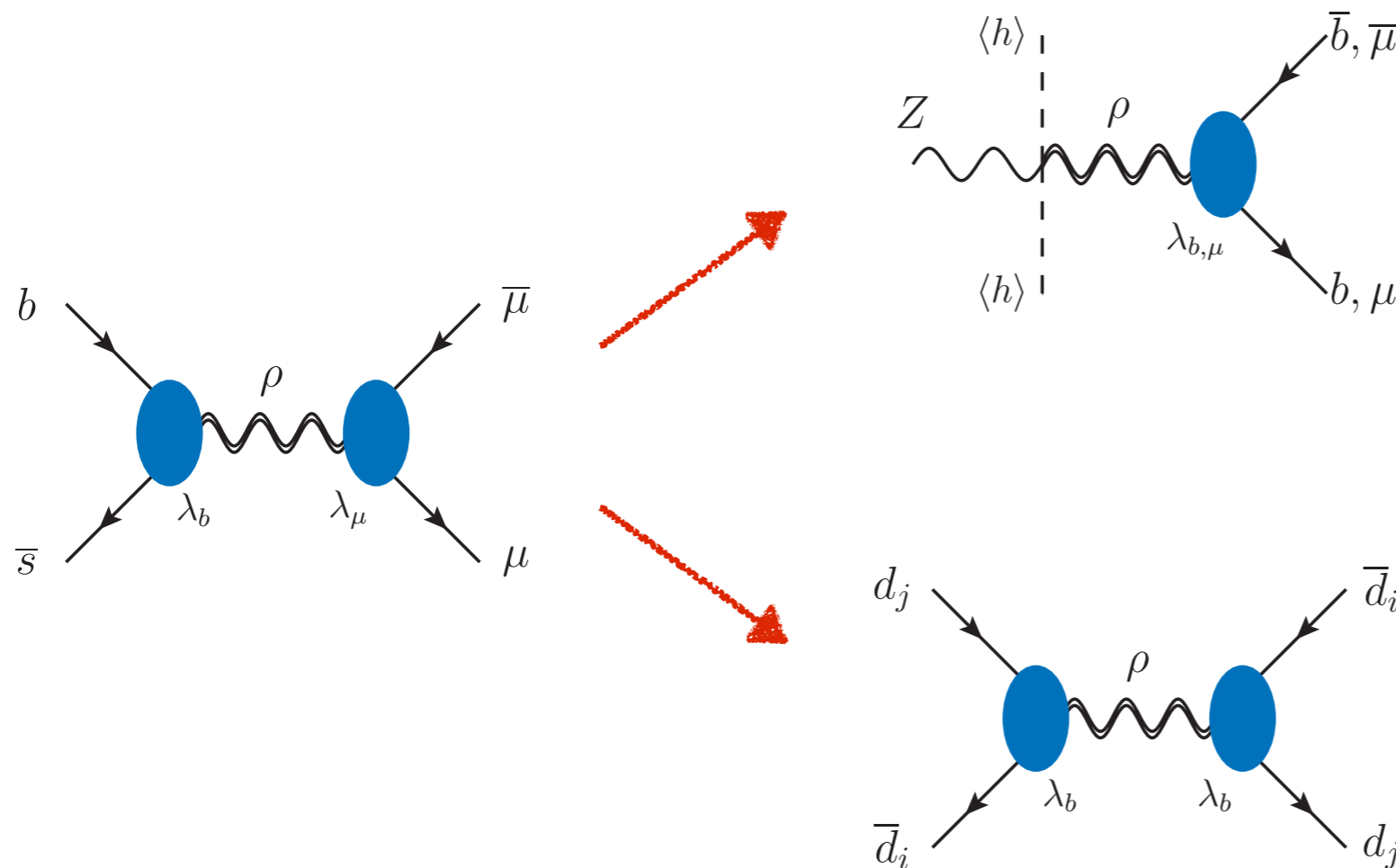✦ the B anomalies can be easily reproduced if the b and the μ have some amount of compositeness

$$\lambda_b \times \lambda_\mu \sim 0.01 \qquad (m_\rho \sim few\,\mathrm{TeV}, \quad g_\rho \sim few)$$

▸ electron almost elementary: **violation of lepton universality**

✦ possible pattern: **left-handed compositeness**

$$\lambda_{b_L}, \lambda_{\mu_L} \sim 0.1 \qquad \lambda_{b_R}, \lambda_{\mu_R} \ll 0.1 \qquad \longrightarrow \qquad C_9 \simeq -C_{10}$$
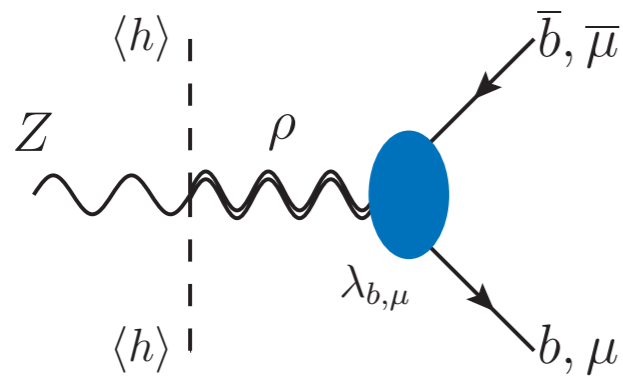
Implications for flavour and EW physics

The vector resonances give rise to other unavoidable effects

distortion of the Z couplings

$\Delta F = 2$ transitions

After EW symmetry breaking the Z mixes with the vector resonances

the mixing gives rise to distortions of the SM gauge couplings

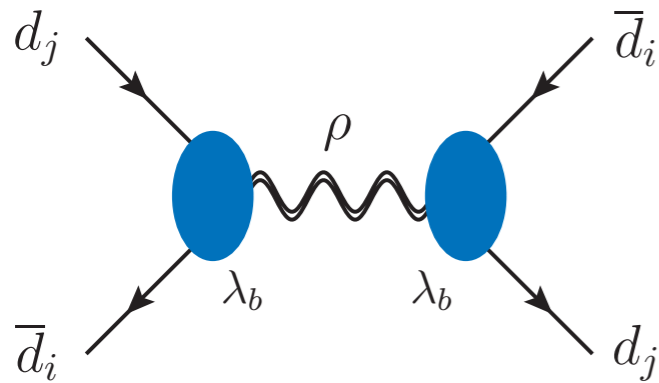$$\frac{\delta g_{Zff}}{g_{Zff}^{\mathrm{SM}}} \sim \lambda_f \frac{m_Z^2}{m_\rho^2} \simeq 0.01\, \lambda_f \left(\frac{1\,\mathrm{TeV}}{m_\rho}\right)^2$$

from the current constraints one finds an upper bound on the amount of b and μ compositeness

$$\frac{\delta g_{Zff}}{g_{Zff}^{\mathrm{SM}}} \lesssim few \times 10^{-3} \quad \longrightarrow \quad \lambda_b\,,\lambda_\mu \lesssim 0.2$$

➡ constraints close to values needed to explain B anomalies

$\Delta F = 2$ transitions

Vector resonances also mediate $\Delta F = 2$ effective interactions

$$\mathcal{O}_{\Delta F=2} \sim \lambda_b^2 \frac{g_\rho^2}{m_\rho^2} \left(V_{3i}^* V_{3j}\right)^2 \left(\overline{d}_i\, \gamma^\mu\, d_j\right) \left(\overline{d}_i\, \gamma_\mu\, d_j\right)$$

✦ current flavor bounds imply the constraint

$$\lambda_b^2 \frac{g_\rho^2}{m_\rho^2} \lesssim \frac{1}{(5\,\mathrm{TeV})^2} \quad \longrightarrow \quad \lambda_b \lesssim 0.2$$

➡ constraints close to values needed to explain B anomalies
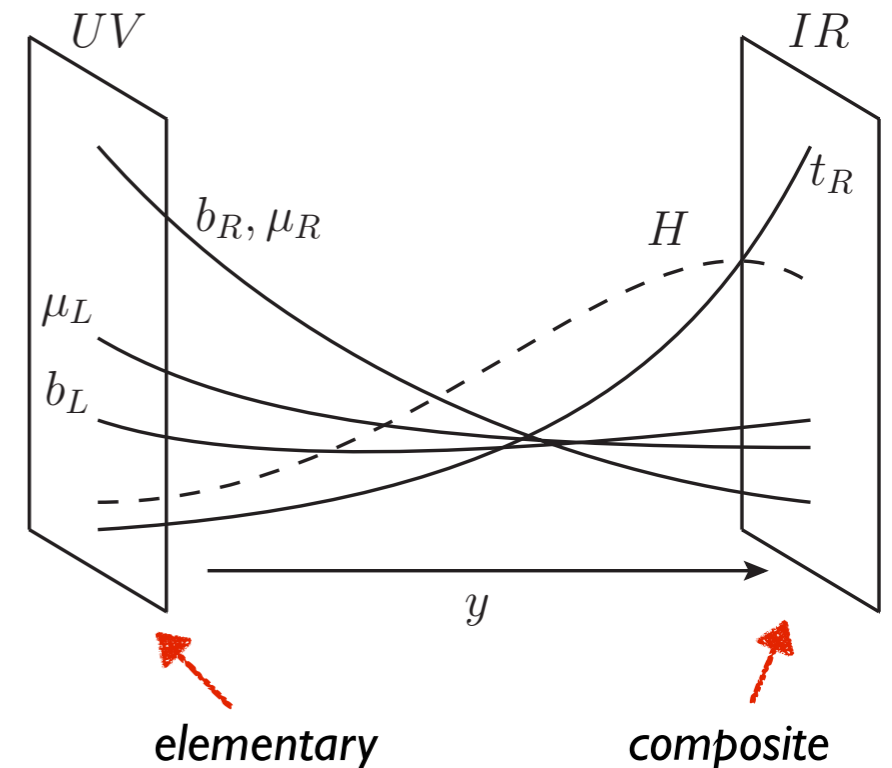
An explicit model

B-anomalies from RS

A modified RS scenario

An explicit realization can be obtained in an extra-dimensional scenario a la Randall-Sundrum

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

elementary   composite

✦ **Higgs** is a composite state
   ⟶ localized towards the IR brane

✦ **fermion compositeness** controlled by the bulk mass c_f

- almost elementary $c_f > 0.5$ (eg. 1st gen., b_R, μ_R)
  (UV localized)

- sizeable compositeness $c_f \lesssim 0.5$ (eg. top, b_L, μ_L)
  (IR localized)

EW correction to oblique S,T parameters under control by small deformation of the metric close to IR

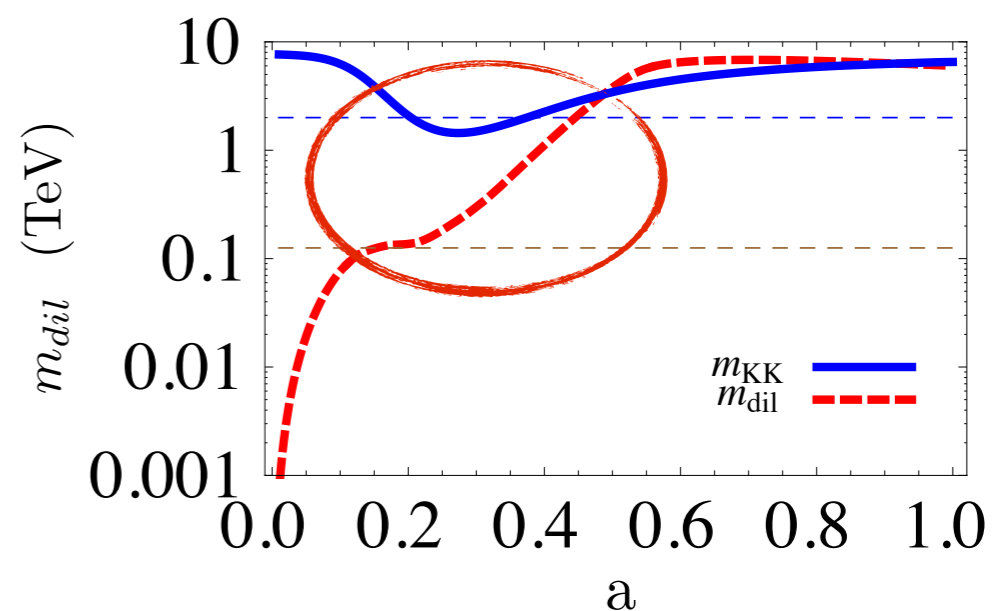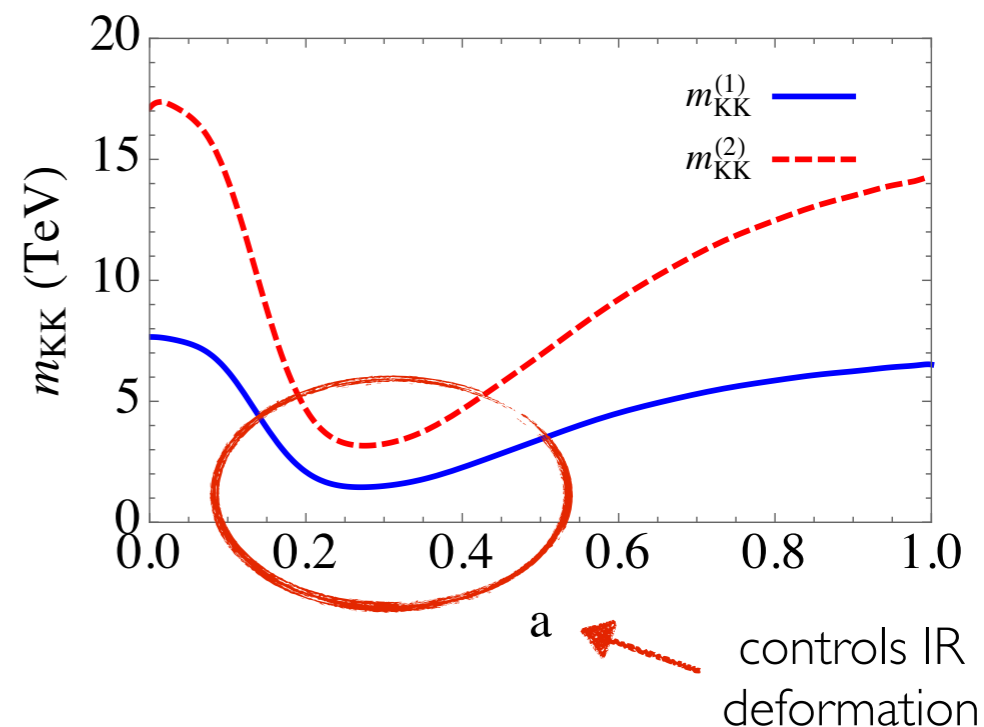typical mass of the **lightest gauge KK's**

$$m_\rho^{(1)} \sim 2 - 3 \text{ TeV}$$
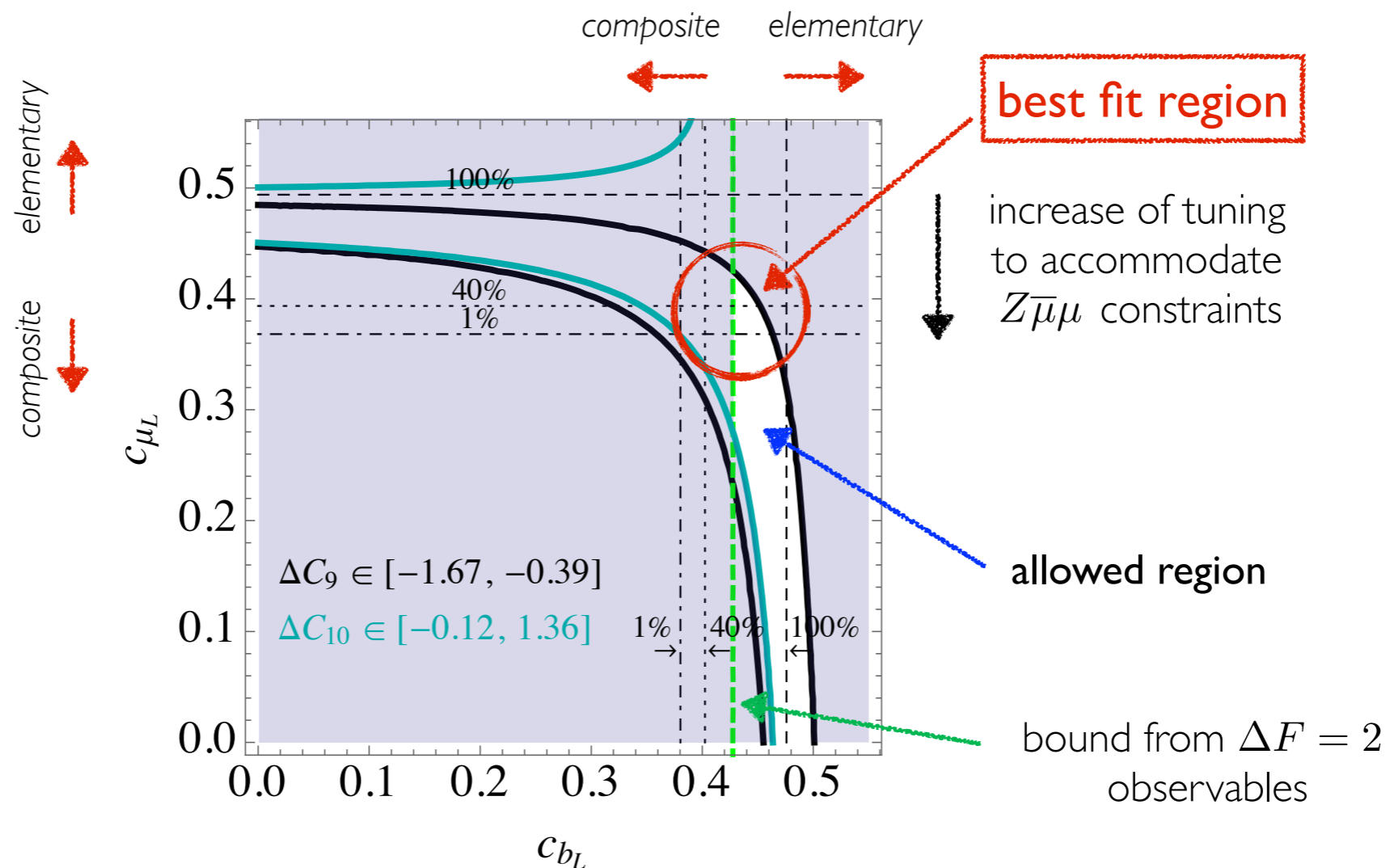

controls IR deformation

a **light dilaton** could also be present

$$m_{dil} \sim 0.1 - 3 \text{ TeV}$$

➡ still allowed due to reduced couplings to SM

Reproducing the B anomalies

- ✦ the B anomalies can be easily reproduced

- ✦ compelling scenario with b and μ localization fixed

  - • correlated effects in $\Delta F = 2$ transitions and Z couplings close to experimental bounds

Additional signatures

✦ **Heavy gluon KK modes:** expected to have a mass comparable with the EW gauge resonances

- copiously produced at LHC: current bounds $m_{KK} \gtrsim 2 \text{ TeV}$

- natural region of parameter space testable soon

✦ **EW gauge KK modes:** enhanced couplings to muons

- harder to produce, possibly visible if light quarks are not too elementary

✦ **Fermionic KK modes**

- typical mass in the few TeV region

- quark KK partners testable in future LHC runs

Conclusions

Conclusions

Anomalies in B physics seem to follow a coherent pattern, possibly pointing to violation of lepton universality

Models with a **composite Higgs** and new strong dynamics can explain the anomalies and link them to the **Naturalness Problem**

- ✦ generic features:

  - sizeable **muon** and **bottom compositeness**
  - related **deviations** in Z couplings and $\Delta F = 2$ transitions
  - **heavy resonances at the TeV scale** testable at the LHC
    (heavy gluons, heavy vectors, fermionic partners)

- ✦ predictive explicit implementations in extra-dimensions

Additional developments:
$R_{D^{(*)}}$ anomalies can also be explained by tau compositeness
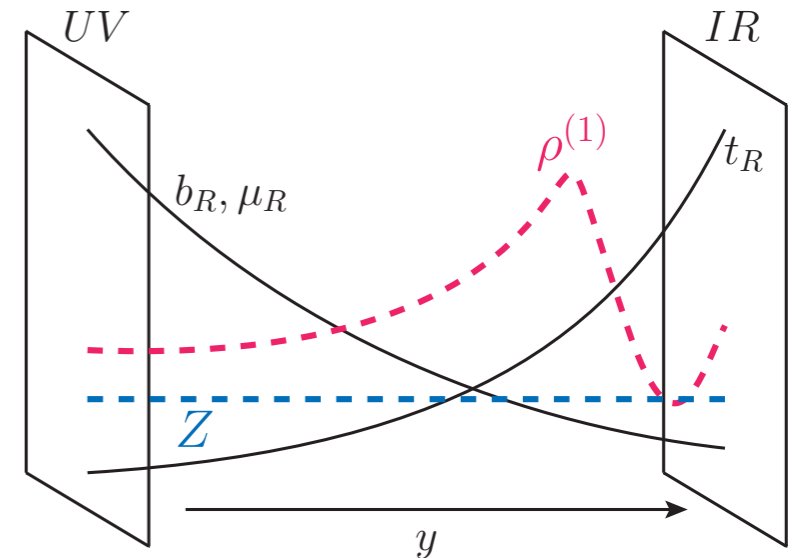
[Megías, Quirós, Salas '17]

Backup

SM gauge fields (KK zero modes) have flat profiles

$\downarrow$

flavor-universal couplings
(up to small corrections after EWSB)

Massive KK modes have a non-trivial profile: IR localized

$\downarrow$

stronger couplings with composite fields:
universality violation