Flavor Anomalies in Composite Higgs models

Adrián Carmona

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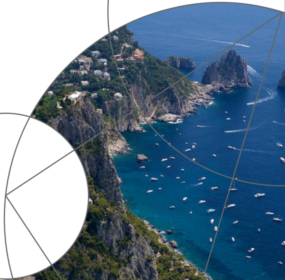


Flavor Anomalies

There are several B-physics anomalies which could point to NP

1. A combined $\sim 4\,\sigma$ anomaly on charged current semileptonic $\bar{B} \to D^{(*)}$ decays

$$R_D^{(*)} = \frac{\Gamma(\bar{B} \to D^{(*)}\tau\bar{\nu})}{\Gamma(\bar{B} \to D^{(*)}\ell\bar{\nu})}; \quad R_D = 1.37 \pm 0.17 \quad R_D^{*} = 1.28 \pm 0.08$$

2. A very clean $2.6\,\sigma$ hint of violation of LFU in the ratio

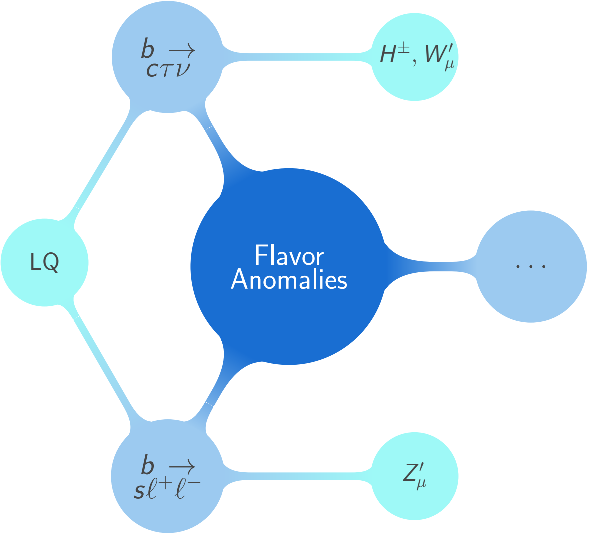
$$R_K = \left.\frac{\Gamma(\bar{B} \to \bar{K}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}e^+e^-)}\right|_{q^2 \in [1,6]\ \mathrm{GeV}} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

3. Other $b \to s\ell^+\ell^-$ observables like P_5'

4. $h \to \mu\tau$, ...

NP explanations

There has been a lot of model building activity



NP explanations

A very popular solution, motivated by the global fit to the data, is to consider NP leading only to

$$\mathcal{O} = (\bar{s}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu P_L \mu),$$

i.e., $C_{9,\mu}^{\rm NP} = -C_{10,\mu}^{\rm NP}$. This is a very wise thing to do, but ...

- Not all observables are equally clean/trustworthy
- We should also complement this 'un-biased' bottom-up approach with some top-down perspective
- Naturalness can be usefull to rank all this information

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I will take the (minimal) composite Higgs model as a case study

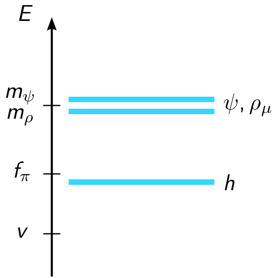
The case for R_K

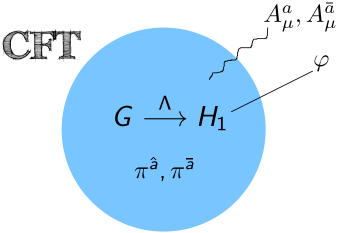
From the NP point of view, R_K stands out for several reasons

1. It is a very clean observable!
   - Perturbative and non-perturbative QCD contributions cancel
   - $\log(m_\ell)$ enhanced QED corrections are at the $\mathcal{O}(1\%)$ level [Bordone, Isidori, Pattori, 16]
2. It is a loop level effect in the SM
3. It probes a somehow fundamental feature of the SM: lepton flavor universality!

Composite Higgs

- One interesting solution to the hierarchy problem is making the Higgs composite, the remnant of some new strong dynamics
  [Kaplan, Georgi '84]
- It is particularly compelling when the Higgs is the pNGB of some new strong interaction. Something like pions in QCD
  [Agashe, Contino, Pomarol '04]





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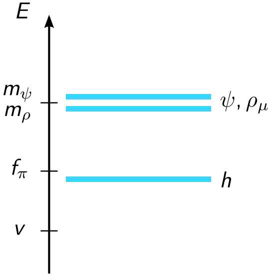

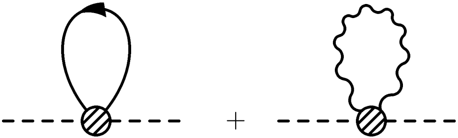

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Talking to Fermions

A priori, we have two different ways of introducing the mixing with the elementary fermions:

1. Quadratically, à la Technicolor

$$\frac{\lambda}{\Lambda^\gamma}\bar{q}_L t_R \mathcal{O}(x), \quad [\mathcal{O}(x)] = 1+\gamma \Longrightarrow m_q \sim f\frac{4\pi}{\sqrt{N}}\left(\frac{\mu}{\Lambda}\right)^\gamma$$

2. Linearly, via partial compositeness [Kaplan '91]

$$\frac{\lambda_L}{\Lambda^{\gamma_L}} q_L \mathcal{O}_L(x), \quad \frac{\lambda_R}{\Lambda^{\gamma_R}} t_R \mathcal{O}_R(x), \quad [\mathcal{O}_{L,R}(x)] = 5/2 + \gamma_{L,R}$$

$$\Rightarrow m_q \sim v\frac{\sqrt{N}}{4\pi}\left(\frac{\mu}{\Lambda}\right)^{\gamma_L+\gamma_R} \quad \text{or} \quad m_q \sim v\frac{4\pi}{\sqrt{N}}\sqrt{\gamma_L\gamma_R}$$

Very well mimicked by Randal-Sundrum models!

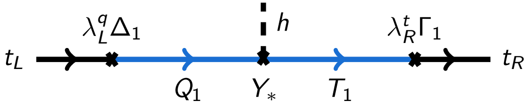
We could also have both at the same time [Cacciapaglia et al '15]

Partial Compositeness

The linear mixings with the strong sector

$$\mathcal{L} \supset \bar{q}_L \lambda_L^q \Delta_1 Q_R + \lambda_R^t \Gamma_1 \bar{t}_R T_L + \text{h.c}$$

will generate the fermion Yukawas



$$y_t \sim \frac{\lambda_L^q \Delta_1}{m_{Q_1}} \frac{\lambda_R^t \Gamma_1}{m_{T_1}} \frac{Y_*}{f_\pi} \sim g_* \epsilon_L^q \epsilon_R^t$$

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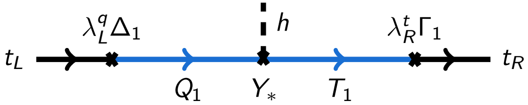

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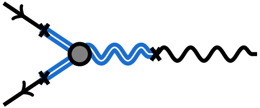
$\sim g_\rho^2 / m_\rho^2 \ \epsilon^i \epsilon^j \epsilon^k \epsilon^l$

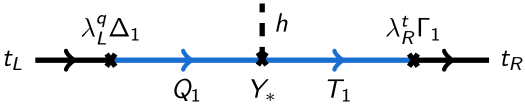


$\sim g_\rho \epsilon^i \epsilon^j v / m_\rho^2 (g_\rho^2 / (16\pi^2))$

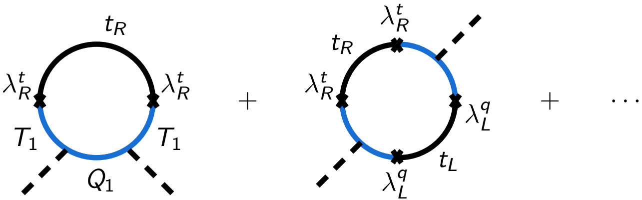
Higgs mass

- The gauge contribution is aligned in the direction that preserves the gauge symmetry [Witten '83]

- However, the linear mixings needed to generate the fermion masses



will be also responsible for a viable EWSB



Light Top Partners

The large value of the top quark mass

$$m_{\rm top} \sim \frac{v}{\sqrt{2}} Y_* \frac{\lambda_L^q \Delta_1}{M_Q} \frac{\lambda_R^t \Gamma_1}{M_T}$$

make the top contribution (typically) responsible for triggering the EWSB [Contino,da Rold,Pomarol, '06]

$$V(h) \cong \frac{N_c m_*^4}{16\pi^2} \left[\alpha \sin^2(h/f_\pi) - \beta \sin^2(h/f_\pi) \cos^2(h/f_\pi)\right]$$

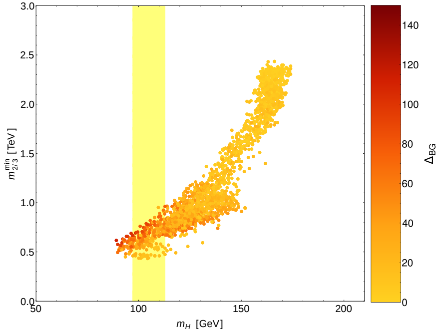
Since the Higgs mass scales with

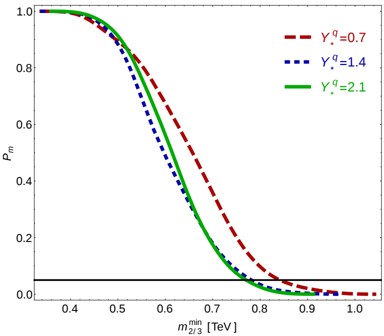
$$\sqrt{\beta} \sim |\lambda|^2/g_*^2$$

We expect to have anomalously light top partners $M_\Psi \ll m_* = g_* f_\pi$

Light Top Partners at the LHC

We can see e.g. the MCHM_5, [AC, Goertz, **JHEP 1505 (2015) 002**]

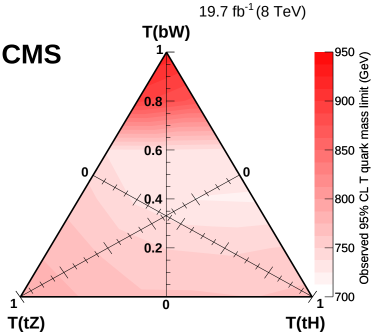


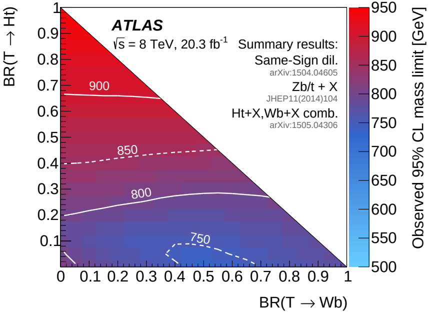


$f_\pi = 0.8$ TeV, $g_\psi \sim 4.4$. $Y_q^* = 0.7$ is the maximum allowed "Yukawa"

Light Top Partners at the LHC

This leads to some tension with current top partner searches performed by ATLAS and CMS





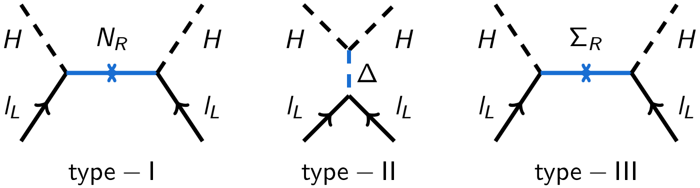
arXiv:1509.04177

arXiv:1505.04306

Leptons can play a role

Leptons are typically disregarded since one could naively expect $\epsilon^{\ell} \ll 1$.
However,

- They are not just a scaled version of the quark sector
- The mixing angles in the lepton sector are highly non-hierarchical
- Neutrinos could have Majorana masses!



Leptons can play a role

1. A lepton sector featuring a type-III seesaw can be embedded with only two conformal operators (per generation)

$$\mathcal{L} \supset \frac{\lambda_L^\ell}{\Lambda^{\gamma_L^\ell}} \bar{l}_{\ell L} \mathcal{O}_{\ell L} + \frac{\lambda_R^\ell}{\Lambda^{\gamma_R^\ell}} \bar{\Psi}_{\ell R} \mathcal{O}_{\ell R} - \frac{1}{2} M_\Sigma^{\ell\ell'} \mathrm{Tr}\left(\bar{\Sigma}^c_{\ell R} \Sigma_{\ell' R}\right) + \text{h.c.}$$

with $\Psi_R \supset \ell_R, \Sigma_R$, if $\mathcal{O}_{\ell L} \sim \mathbf{5}$ and $\mathcal{O}_{\ell R} \sim \mathbf{14}$

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2. Since $\|M_\Sigma\| \sim M_{\mathrm{Pl}}$, avoiding too small neutrino masses,

$$\mathcal{M}_\nu \sim v^2 \epsilon_{\ell L} \epsilon_{\ell R} \left(M_\Sigma\right)^{-1}_{\ell\ell'} \epsilon_{\ell' L} \epsilon_{\ell' R}, \quad \epsilon_{\ell L,R} \sim \lambda_{L,R}^\ell \left(\frac{\mu}{\Lambda}\right)^{\gamma_{L,R}^\ell}$$

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3. Then

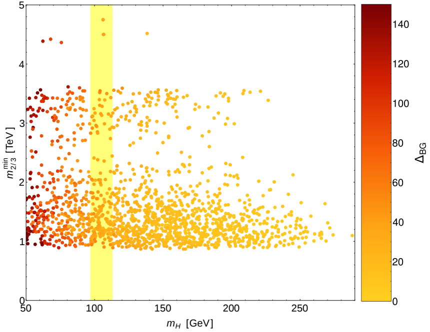
$$\mathcal{M}_e \sim v \epsilon_{\ell L} \Rightarrow \epsilon_{eL} \ll \epsilon_{\mu L} \ll \epsilon_{\tau L} \ll 1 \quad \text{and} \quad \epsilon_{\ell L} \epsilon_{\ell R} \sim \text{constant}$$

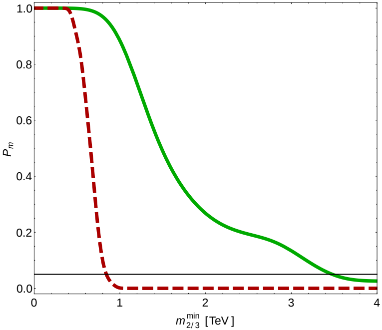
and thus $0 \ll \epsilon_{\tau R} \ll \epsilon_{\mu R} \ll \epsilon_{eR}$

Lifting the top partners

This is really interesting since

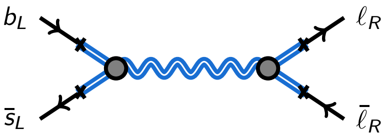
- The three charged lepton RH fields will contribute to the potential
- Since the contribution to $\sin^4(h/f)$ from the **14** arises at $\mathcal{O}(\epsilon^2)$, moderate degrees of compositeness can have an impact



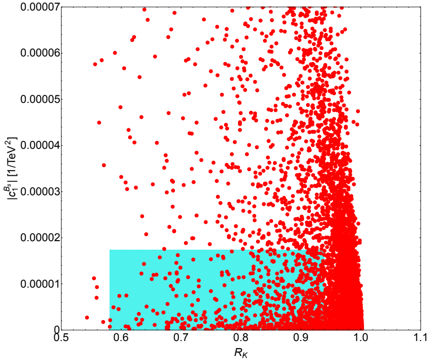


Violation of LFU

Since $\epsilon_{\tau R} \ll \epsilon_{\mu R} \ll \epsilon_{eR}$, we predict violation of LFU



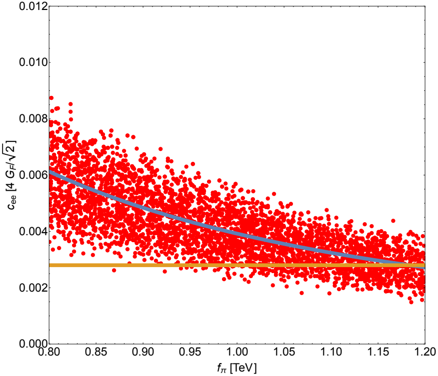
$$\sim g_\rho^2/m_\rho^2\ (\epsilon_{s_L}\epsilon_{b_L}\epsilon_{\ell_R}^2)$$



Violation of LFU

The biggest tension arises from EWPD on four-fermion interactions

$$(e_R \gamma_\mu e_R)(e_R \gamma^\mu e_R) \sim \frac{g_\rho^2}{m_\rho^2} (\epsilon_{e_R})^4$$

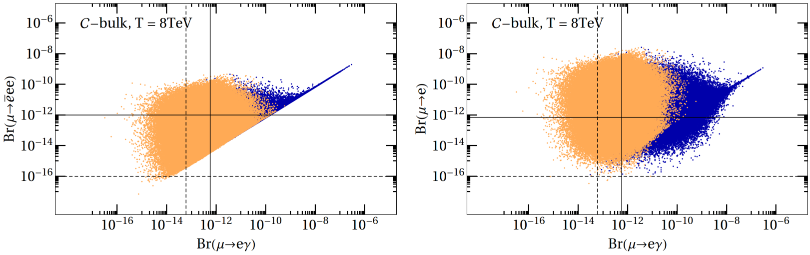


What about LFV?

In principle, one expects to generate dangerous FCNCs leading to extremely constrained lepton flavor violating processes

$$\mu \to e\gamma, \quad \mu \to 3e, \quad \tau \to \mu\gamma, \quad \ldots$$

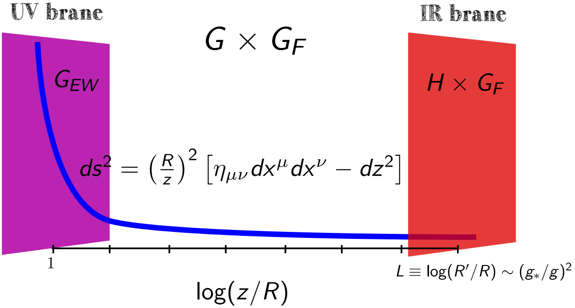
Some of them are an issue even for elementary leptons!



[Beneke, Moch, Rohrwild, arXiv:1508.01705]

A flavor protection

We would like to have a global flavor symmetry in the Composite Sector $\longleftrightarrow$ gauge symmetry in the bulk and the IR brane [Perez, Randall, 08]



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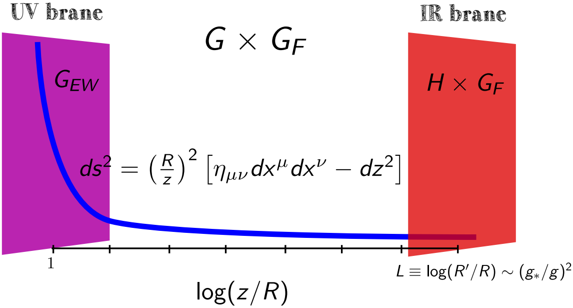

Since we only have two 5D multiplets: $\zeta_{\ell L} \sim \mathbf{5}$ and $\zeta_{\ell R} \sim \mathbf{14}$, we make them triplets of $G_F = SU(3)_L \times SU(3)_R$

$$\zeta_L \sim (\mathbf{3}, \mathbf{1}) \qquad \zeta_R \sim (\mathbf{1}, \mathbf{3})$$

A flavor protection

We can then assume that all the breaking of G_F comes from one spurion

$$\mathcal{Y} \sim (\mathbf{3}, \bar{\mathbf{3}})$$

such that

$$c_L \equiv M_L R \sim \mathbf{1} + \mathcal{Y}\mathcal{Y}^\dagger \qquad c_R \equiv M_R R \sim \mathbf{1} + \mathcal{Y}^\dagger \mathcal{Y}$$

and

$$m_S \sim \mathcal{Y} \qquad m_B \sim \mathcal{Y}$$

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Then, all the flavor mixing comes via the Majorana masses!

Conclusions

- Complementing the bottom-up approach with some top-down perspective can be helfpul
- In CHMs, the absence of top partners can be translated into ~~LFU~~!
- Therefore, R_K could be the first probe of the dynamics of EWSB
- Departing from the minimal model (750?) can also give us additional dof which may play a relevant role in other anomalies!

Thanks!