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Flavor Anomalies in Minimal Fundamental Partial Compositeness

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Outline

1. Motivation
2. Fundamental Partial Compositeness
3. Analysis
4. Results
5. Summary

Based on:

Francesco Sannino, PS, David M. Straub, Anders E. Thomsen [arXiv:1712.07646]

Outline

Flavor anomalies

$b \to s\,\mu^+\mu^-$ anomaly

Several LHCb measurements deviate from Standard model (SM) predictions by 2-3σ:

- Angular observable P_5' in $B \to K^*\mu^+\mu^-$. LHCb, arXiv:1512.04442
- Branching ratios of $B \to K\mu^+\mu^-$, $B \to K^*\mu^+\mu^-$, and $B_s \to \phi\mu^+\mu^-$.

LHCb, arXiv:1403.8044, arXiv:1506.08777, arXiv:1606.04731

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Hints for LFU violation in neutral current decays

Measurements of lepton flavor universality (LFU) ratios $R_K^{[1,6]}$, $R_{K^*}^{[0.045,1.1]}$, $R_{K^*}^{[1.1,6]}$ show deviations from SM by about 2.5σ each. LHCb, arXiv:1406.6482, arXiv:1705.05802

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Hints for LFU violation in charged current decays

Measurements of LFU ratios R_D and R_{D^*} by BaBar, Belle, and LHCb show combined deviation from SM by 4σ.

BaBar, arXiv:1205.5442, arXiv:1303.0571
LHCb, arXiv:1506.08614, arXiv:1708.08856
Belle, arXiv:1507.03233, arXiv:1607.07923, arXiv:1612.00529
HFLAV, arXiv:1612.07233

Explaining the anomalies

Construct model to address flavor anomalies

- Plethora of models constructed to specifically address flavor anomalies.

This talk: analyze potential of existing model to explain anomalies

- Model originally constructed to address **naturalness problem** of SM.
- UV completion of **composite Higgs model**:
  Minimal Fundamental Partial Compositeness.

Outline

Composite Higgs models

Solving the naturalness problem

- Higgs not elementary but bound state of new strong interaction.
- Lightness of Higgs compared to new physics scale: **Higgs as pseudo-Nambu-Goldstone boson** (pNGB) of spontaneously broken global symmetry.

Kaplan, Georgi, Phys.Lett. B136 (1984) 183
Dugan, Georgi, Kaplan, Nucl.Phys. B254 (1985) 299

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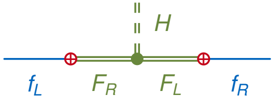
$$\mathcal{L} = \mathcal{L}_{elemenary} + \mathcal{L}_{composite} + \mathcal{L}_{mixing}$$

Avoiding flavor constraints

- Elementary fermions couple linearly to composite fermions.
- Mass eigenstates are mixture of both: **partial compositeness**.

Kaplan, Nucl. Phys. B365 (1991) 259–278



Fundamental partial compositeness

Sannino, Strumia, Tesi, Vigiani, arXiv:1607.01659

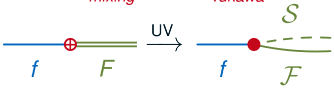
- New strong interaction: “Technicolor” (TC).
- SM fermions and vector bosons + “technifermions” $\mathcal{F}$ + “techniscalars” $\mathcal{S}$.
- Higgs: $(\mathcal{F}\mathcal{F})$ bound state.
- Composite fermions: $(\mathcal{F}\mathcal{S})$ bound states.

Comparison with effective composite Higgs models

$$\mathcal{L}_{elemenary} \xrightarrow{\text{UV}} \mathcal{L}_{elemenary}$$

$$\mathcal{L}_{composite} \xrightarrow{\text{UV}} \mathcal{L}_{TC}$$

$$\mathcal{L}_{mixing} \xrightarrow{\text{UV}} \mathcal{L}_{Yukawa}$$



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Observables

Electroweak (EW) scale observables

- Use effective theory at EW scale: **MFPC-EFT**.
  Cacciapaglia, Gertov, Sannino, Thomsen, arXiv:1704.07845
- Most important constraints: ***Z* partial widths** (measured at LEP).

Low-energy flavor observables

- Match MFPC-EFT to weak effective Hamiltonian (WEH).
- **Meson-antimeson mixing**
  - Most important constraint: ϵ_K (indirect CP violation in Kaon mixing).
- **Charged-current semi-leptonic decays**
  - Constraining CKM elements.
  - Constraining e-μ universality.
  - Predictions for LFU observables $R_{D^{(*)}}$.
- **Neutral-current semi-leptonic decays**
  - Predictions for LFU observables $R_{K^{(*)}}$.

Numerical method

Parameter scan challenging

37 parameters (1 for strong coupling scale, 22 for fundamental Yukawa couplings, 14 for Wilson coefficients of MFPC-EFT)

Strategy

To find **viable parameter points** satisfying all constraints:

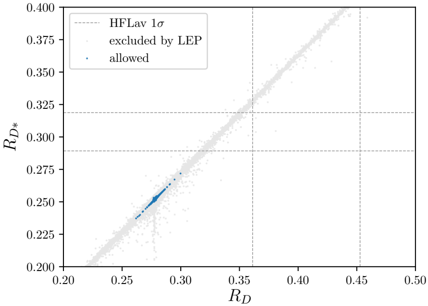
- Step 1
  - Construct $\chi^2_{\mathrm{mass,CKM}}$ function for quark masses and CKM elements depending only on 19 parameters.
  - Numerically minimize $\chi^2_{\mathrm{mass,CKM}}$ for 100 k random starting points.
  - Sample regions around local minima using Markov Chains from `pypmc` package to yield 10 k points for each minimum.

  Yields 100 M points predicting correct quark masses and CKM elements.
- Step 2
  - Randomly choose remaining 18 parameters for each point.
  - Calculate EW scale and flavor observables using `flavio` code.

Outline

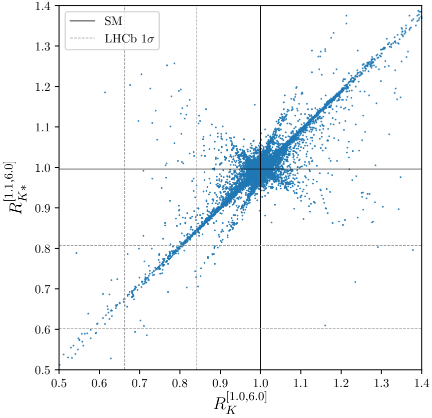
Results

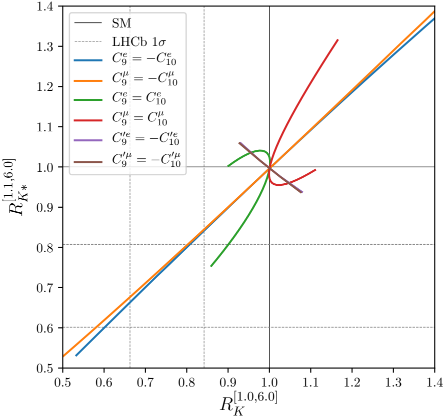
- ϵ_K provides very strong constraint, but can be satisfied by large number of parameter points.
- Tests of e-μ universality are important constraints due to generic LFU violation from partial compositeness.
- Large deviation of $R_{D^{(*)}}$ from SM value is in conflict with Z partial widths (modified $Z\tau\tau$ coupling).



Results

- Anomalies in rare B decays can be explained!





Outline

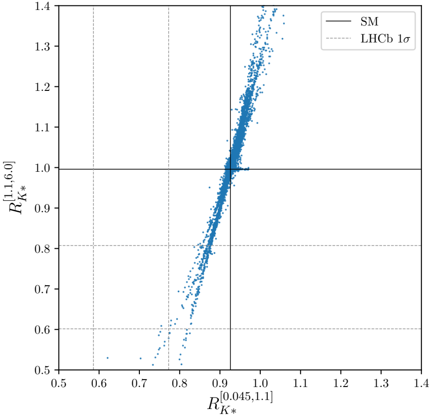
Summary

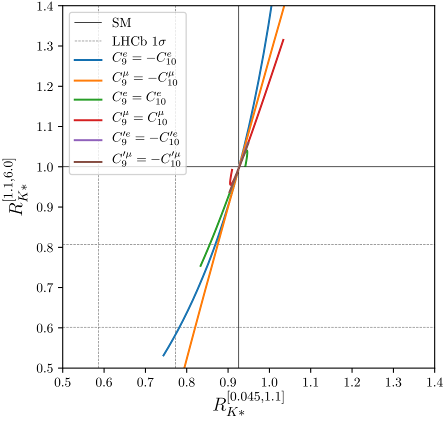
Performed comprehensive numerical analysis of flavor and EW scale effects of MFPC model.

- Numerical method allows for scan of high dimensional parameter space.
- Strongest constraints from ϵ_K, but satisfied by large number of parameter points.
- Large deviation of $R_{D^{(*)}}$ from SM value is in conflict with Z partial widths.
- Anomalies in rare B decays can be explained.

Backup slides

R_{K*} predictions





MFPC particle content

	Q	$\bar{u}$	$\bar{d}$	L	$\bar{\nu}$	$\bar{e}$	$\mathcal{F}_{\updownarrow}$	$\bar{\mathcal{F}}_{\uparrow}$	$\bar{\mathcal{F}}_{\downarrow}$	$\mathcal{S}_q$	$\mathcal{S}_l$
$\mathrm{Sp}(N)_{\mathrm{TC}}$	**1**	**1**	**1**	**1**	**1**	**1**	**N**	**N**	**N**	**N**	**N**
$\mathrm{SU}(3)_{\mathrm{C}}$	**3**	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$	**1**	**1**	**1**	**1**	**1**	**1**	$\bar{\mathbf{3}}$	**1**
$\mathrm{SU}(2)_{\mathrm{L}}$	**2**	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**1**	**1**	**1**
$\mathrm{U}(1)_{\mathrm{Y}}$	$\frac{1}{6}$	$-\frac{2}{3}$	$\frac{1}{3}$	$-\frac{1}{2}$	0	1	0	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{6}$	$\frac{1}{2}$
N_{g}	3	3	3	3	3	3	1	1	1	3	3

Table: Quantum numbers of SM fields, TC fermions, and TC scalars in MFPC. The last line gives the number of generations N_{g}. All fermion fields are left-handed Weyl spinors.

Flavor constraints

Meson-antimeson mixing

- The parameter ϵ_K measuring indirect CP violation in K^0 mixing.
- The mixing-induced CP asymmetry $S_{\psi K_S}$ in $B_d \to J/\psi\, K_S$.
- The mixing-induced CP asymmetry $S_{\psi\phi}$ in $B_s \to J/\psi\, \phi$.
- The mass differences ΔM_d and ΔM_s in the B_d and B_s systems.

Charged current semi-leptonic decays

- The branching ratio of $\pi^+ \to e\nu$, which is based on the $d \to u\ell\nu$ transition.
- The branching ratio of $K^+ \to \mu\nu$ and the ratio of $K^+ \to \ell\nu$ branching ratios with $\ell \in \{e, \mu\}$, which are based on the $s \to u\ell\nu$ transition.
- The branching ratios of $B \to D\ell\nu$ with $\ell \in \{e, \mu\}$, which are based on the $b \to c\ell\nu$ transition.