B-physics anomalies: a road to new physics

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In collaboration with

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neutrinos, dark matter & dark energy physics

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Introduction

Several discrepancies [$\approx 2-3\sigma$] appeared recently in B-meson decays:

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})}_{\ell\in(e,\mu)} \qquad \& \qquad R_{D^{(*)}}^{\text{exp}} > R_{D^{(*)}}^{\text{SM}}$$

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(B \to K^{(*)}ee)}\Bigg|_{q^2\in[q^2_{\text{min}},q^2_{\text{max}}]} \qquad \& \qquad R_{K^{(*)}}^{\text{exp}} < R_{K^{(*)}}^{\text{SM}}$$

$\Rightarrow$ Violation of **L**epton **F**lavor **U**niversality (LFU)?

NB. LFU broken in the SM by Yukawas. Well tested property only for first generations.

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- Neutrino oscillation
- Dark Matter*
- Baryon asymmetry (BAU)*
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- Hierarchy problem
- Flavor problem
- Strong CP-problem
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- Most of the theoretical effort so far was dedicated to the Higgs hierarchy problem.
- If confirmed, they will indicate the existence of new sources of flavor violation at the TeV scale

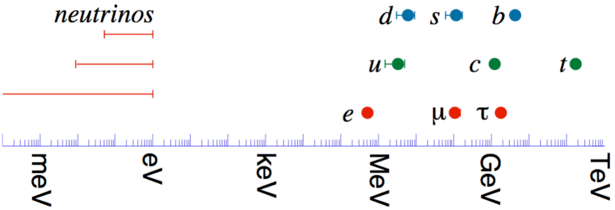
  ⇒ Paradigm shift (with far-reaching implications!)

- Flavor sector **loose**:

  ⇒ 13 free parameters (masses and quark mixing) – fixed by data.

$$\mathcal{L}_Y = -Y_\ell \, \bar{L} \, \Phi \, \ell_R - Y_d \, \bar{Q} \, \Phi \, d_R - Y_u \, \bar{Q} \, \tilde{\Phi} \, u_R + \text{h.c.}$$

- Striking hierarchy *[does not look accidental. . .]* ⇒ Flavor theory?



- Is there a Flavor Era around the corner?

Outline

i) Brief overview of the B-physics anomalies

ii) EFT implications of $R_{D^{(*)}}$

iii) From EFT to simplified models

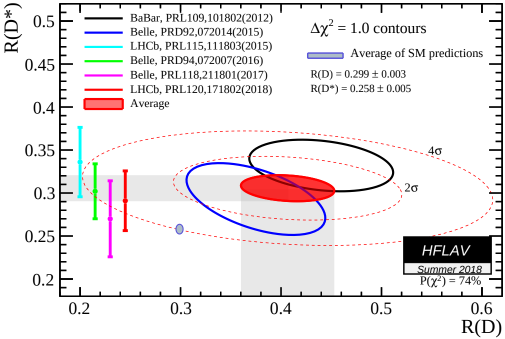
iv) Closing the U_1-leptoquark window

v) Conclusion

A brief overview of the B-anomalies

(i) $R_{D^{(*)}} = \mathcal{B}(B \to D^{(*)}\tau\bar{\nu})/\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})$

Experiment



- R_D: B-factories $[\approx 2\sigma]$
- R_{D^*}: B-factories and LHCb $[\lesssim 3\sigma]$; dominated by BaBar
- LHCb confirmed tendency $R_{J/\psi}^{\rm exp} > R_{J/\psi}^{\rm SM}$, i.e. $B_c \to J/\psi \ell\bar{\nu}$

  $\Rightarrow$ Needs confirmation from Belle-II (and LHCb run-2)!

  $\Rightarrow$ Other LFUV ratios will be a useful cross-check $(R_{D_s}, R_{D_s^*}, R_{\Lambda_c}$ ...)

(i) $R_{D^{(*)}} = \mathcal{B}(B \to D^{(*)}\tau\bar{\nu})/\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})$

Theory (tree-level in SM)

- R_D: lattice QCD at $q^2 \neq q^2_{\rm max}$ $(w > 1)$ available for both leading (vector) and subleading (scalar) form factors [MILC 2015, HPQCD 2015]

$$\langle D(k)|\bar{c}\gamma^\mu b|B(p)\rangle = \left[(p+k)^\mu - \frac{m_B^2 - m_D^2}{q^2}q^\mu\right] f_+(q^2) + q^\mu \frac{m_B^2 - m_D^2}{q^2} f_0(q^2)$$

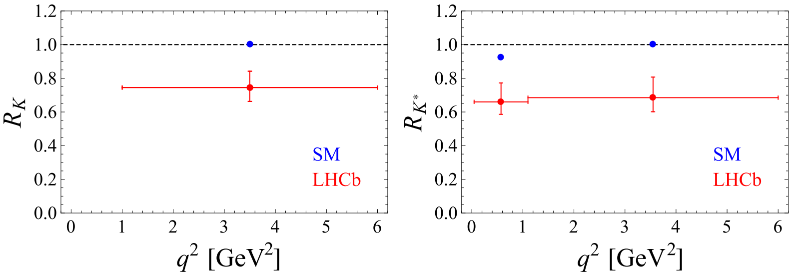
with $f_+(0) = f_0(0)$.

- R_{D^*}: lattice QCD at $q^2 \neq q^2_{\rm max}$ not available, scalar form factor $[A_0(q^2)]$ never computed on the lattice

Use decay angular distributions measured at B-factories to fit the leading form factor $[A_1(q^2)]$ and extract two others as ratios wrt $A_1(q^2)$. All other ratios from HQET (NLO in $1/m_{c,b}$) [Bernlochner et al 2017] but with more generous error bars (truncation errors?)

(ii) $R_{K^{(*)}} = \mathcal{B}(B \to K^{(*)}\mu\mu)/\mathcal{B}(B \to K^{(*)}ee)$

Experiment $[\approx 4\sigma]$



⇒ Needs confirmation from Belle-II!

Theory (loop induced in SM)

- Hadronic uncertainties cancel to a large extent
  ⇒ Clean observables! [*working below the narrow $c\bar{c}$ resonances*]
- QED corrections important, $R_{K^{(*)}} = 1.00(1)$, [Bordone et al. 2016]

Relevant questions:

- Is there a **model of New Physics** to explain these anomalies?
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What is the scale of New Physics?

- ◦ $R_{D^{(*)}}^{\text{exp}} > R_{D^{(*)}}^{\text{SM}} \quad \Rightarrow \quad \Lambda_{\text{NP}} \lesssim 3$ TeV [perturbative couplings]
- ◦ $R_{K^{(*)}}^{\text{exp}} < R_{K^{(*)}}^{\text{SM}} \quad \Rightarrow \quad \Lambda_{\text{NP}} \lesssim 30$ TeV see also [Di Luzio et al. 2017]

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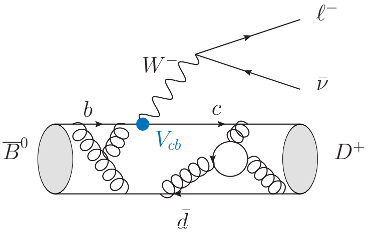
$R_{D^{(*)}}^{\text{exp}}$ will be the main guideline of my discussion

EFT implications of $R_{D^{(*)}}$



[Feruglio, Paradisi, OS. 1806.10155]

Effective theory for $b \to c\tau\bar{\nu}$

$$\mathcal{L}_{\rm em} = -2\sqrt{2}G_F\,V_{cb}\Big[(1+g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma^\mu\nu_L) + g_{V_R}\,(\bar{c}_R\gamma_\mu b_R)(\bar{\ell}_L\gamma^\mu\nu_L)$$
$$+ g_{S_R}\,(\bar{c}_L b_R)(\bar{\ell}_R\nu_L) + g_{S_L}\,(\bar{c}_R b_L)(\bar{\ell}_R\nu_L) + g_T\,(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\Big] + \text{h.c.}$$

General messages:

- Perturbativity $\Rightarrow \Lambda_{\rm NP} \lesssim 3$ TeV — see also [Di Luzio et al. 2017]
- $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge invariance:
  $\Rightarrow g_{V_R}$ is LFU at dimension 6 ($W\,\bar{c}_R b_R$ vertex).
  $\Rightarrow$ Four coefficients left: g_{V_L}, g_{S_L}, g_{S_R} and g_T.
- Several viable solutions to $R_{D^{(*)}}$: — [Freytsis et al. 2015]
  - e.g. $g_{V_L} \in (0.09, 0.13)$, but not only!

see also [Angelescu, Becirevic, Faroughy, OS. 1808.08179]

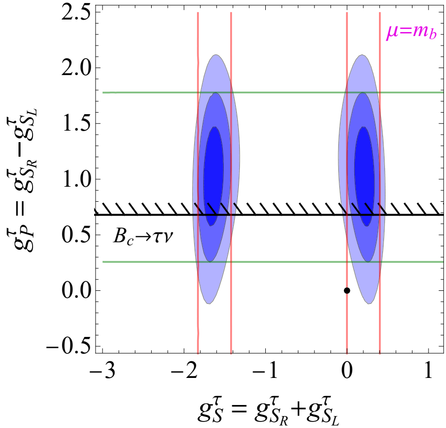
Illustration: (i) (pseudo)scalar operators

$$\mathcal{O}_{S_L} = (\bar{c}_R b_L)(\bar{\ell}_R \nu_L)$$

$$\mathcal{O}_{S_R} = (\bar{c}_L b_R)(\bar{\ell}_R \nu_L)$$

NB.

$$\langle D|\bar{c}\gamma_5 b|B\rangle = \langle D^*|\bar{c} b|B\rangle = 0$$



$\Rightarrow$ Tension with τ_{B_c} constraint: $\mathcal{B}(B_c \to \tau\bar{\nu}) \lesssim 30\%$

$$\mathcal{B}(B_c \to \tau\bar{\nu}) = \frac{\tau_{B_c} m_{B_c} f_{B_c}^2 G_F^2 |V_{cb}|^2}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_{B_c}^2}\right)^2 \left|1 + g_P \frac{m_{B_c}^2}{m_\tau(m_b + m_c)}\right|^2$$

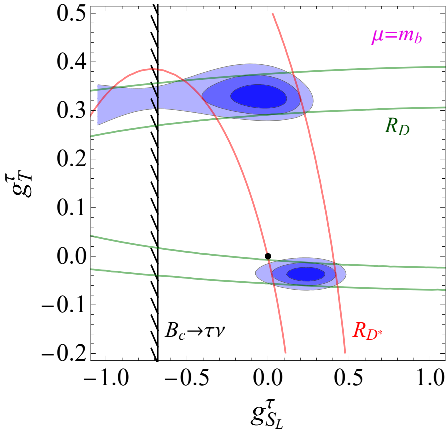
[Alonso et al. 16'], see also [Akeroyd et al. 17']

Illustration: (ii) scalar/tensor operators

$$\mathcal{O}_{S_L} = (\bar{c}_R b_L)(\bar{\ell}_R \nu_L)$$

$$\mathcal{O}_T = (\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\ell}_R \sigma^{\mu\nu} \nu_L)$$

[Feruglio, Paradisi, OS. 1806.10155]



⇒ R_{D^*} is highly sensitive to tensor contributions

⇒ Scalar and tensor operators provide a good fit – case of scalar leptoquarks $S_1 = (\bar{3}, 1, 1/3)$ and $R_2 = (3, 2, 7/6)$. τ_{B_c} is not a problem here!

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i) Many angular observables (e.g., $A_{\rm fb}$, polarization asymmetries)
[Becirevic et al. '16]

First measurements:

- $P_\tau(D^*)^{\rm exp} = -0.38 \pm 0.51^{+0.21}_{-0.16}$ [Belle '17]
- $F_L(D^*)^{\rm exp} = 0.60 \pm 0.08 \pm 0.03$ [Belle '18] see Adamczyk's talk at CKM

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- $R_{J/\psi}$, R_{D_s}, $R_{D_s^*}$, $R_{\Lambda_c}\dots$

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LHCb confirmed tendency in: [LHCb, 2017]

$$R_{J/\Psi}^{\exp} = \frac{\mathcal{B}(B_c \to J/\Psi\tau\bar{\nu})}{\mathcal{B}(B_c \to J/\Psi\ell\bar{\nu})} = 0.71(17)(18)$$

$\Rightarrow$ Larger than SM estimates $R_{J/\Psi}^{\mathrm{SM}} \approx 0.22 - 0.28$; large exp/th errors.

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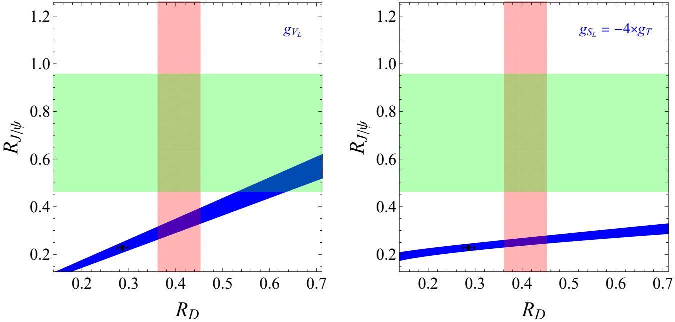
⇒ Larger than SM estimates $R_{J/\Psi}^{\mathrm{SM}} \approx 0.22 - 0.28$; large exp/th errors.

⇒ Useful information to distinguish among NP scenarios:

[Melic, Becirevic, Leljak, OS. to appear]



More exp. data and LQCD results are more than welcome here!

See [HPQCD, 1611.01987] for preliminary LQCD results for $V(q^2)$ and $A_1(q^2)$.

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ii) Other LFUV ratios:

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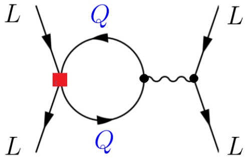
iii) Leptonic observables (via electroweak RGE effects)

- $\mathcal{B}(\tau \to \mu\bar{\nu}\nu)/\mathcal{B}(\tau \to e\bar{\nu}\nu)$
- $\mathcal{B}(Z \to \tau\tau)/\mathcal{B}(Z \to \mu\mu)$
- $\dots$

e.g.



Electroweak corrections

see also [Jenkins et al. '13]

- *Interesting*: $V-A$ operators (g_{V_L}) can induce sizable electroweak corrections to $Z\to\ell\ell$ and $\tau\to\mu\nu\bar{\nu}$ [Feruglio et al. '16,'17]

$$\mathcal{O}_{lq}^{(3)} = \left(\overline{Q}\gamma^\mu\tau^a Q\right)\left(\overline{L}\gamma_\mu\tau^a L\right)$$
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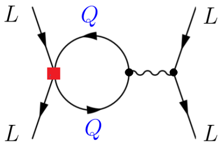

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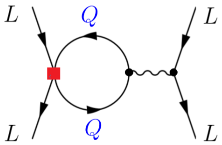

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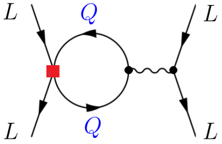

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A first step: [Gonzáles-Alonso et al. '17]

$$\vec{c}(m_Z) \approx \begin{pmatrix} 1.19 & 0 & 0 \\ 0 & 1.2 & -0.2 \\ 0 & -0.004 & 1.0 \end{pmatrix} \vec{c}(1\ \text{TeV})$$

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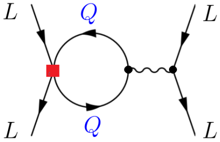

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Which (non-semileptonic) operators are induced via RGE?

Scalar/tensor scenario: [Feruglio, Paradisi, OS. 1806.10155]

$$\mathcal{L}_{\rm NP} \supset \frac{C_{S_L}^{\ell}}{\Lambda^2}(\overline{L}\ell_R)i\sigma_2(\overline{Q}u_R) + \frac{C_T^{\ell}}{\Lambda^2}(\overline{L}\sigma_{\mu\nu}\ell_R)i\sigma_2(\overline{Q}\sigma^{\mu\nu}u_R) + \text{h.c.}$$

[flavor indices omitted]

Matching: $g_{S_L} \Leftrightarrow C_{S_L}$, $g_T \Leftrightarrow C_T$; + neutral components

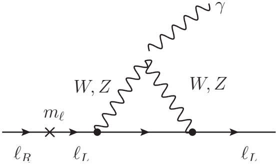
(Minimal) flavor assumptions: cf. back-up

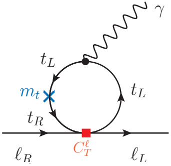
- Coupling to 3rd fermion generation (flavor basis).
- Negligible RH lepton mixing.
- Nonzero angle $\theta_U \equiv \theta_{23}$ for RH quarks.

Which operators are generated by RGE effects?

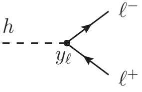
- Large enhancement ($\propto m_t/m_\tau$) of $(g-2)_\tau$ and $\mathcal{B}(H \to \tau\tau)$:

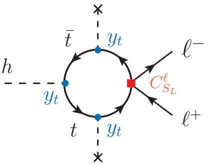
(i) $\delta\mathcal{L}_{\rm dip} \propto C_T^\ell \, m_t \, \dfrac{\log(\Lambda/m_t)}{16\pi^2\Lambda^2} \, \overline{\ell_L}\sigma_{\mu\nu}\ell_R F^{\mu\nu} + \dots$

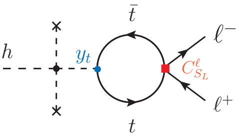




(ii) $\delta\mathcal{L}_H \propto C_{S_L}^\ell \, y_t(y_t^2 - \lambda) \, \dfrac{\log(\Lambda/m_t)}{16\pi^2\Lambda^2} \, (H^\dagger H)(\overline{L}\ell_R H) + \text{h.c.}$



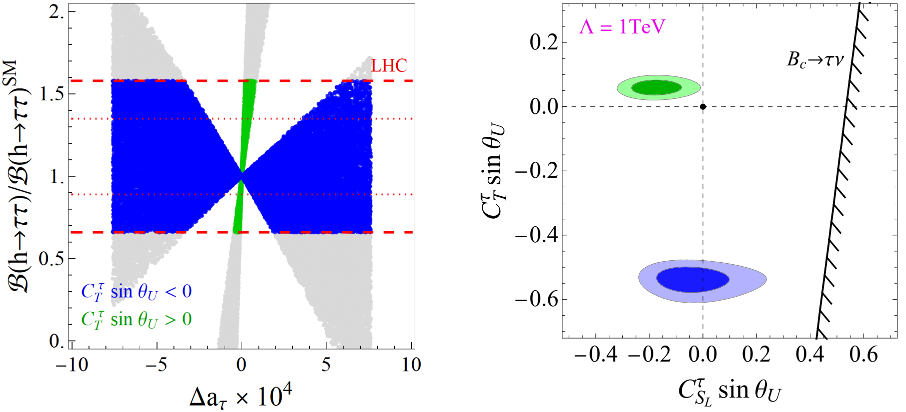




- On the other hand, no sizable modification of W and Z couplings!

Predictions

Loops effects can be large!



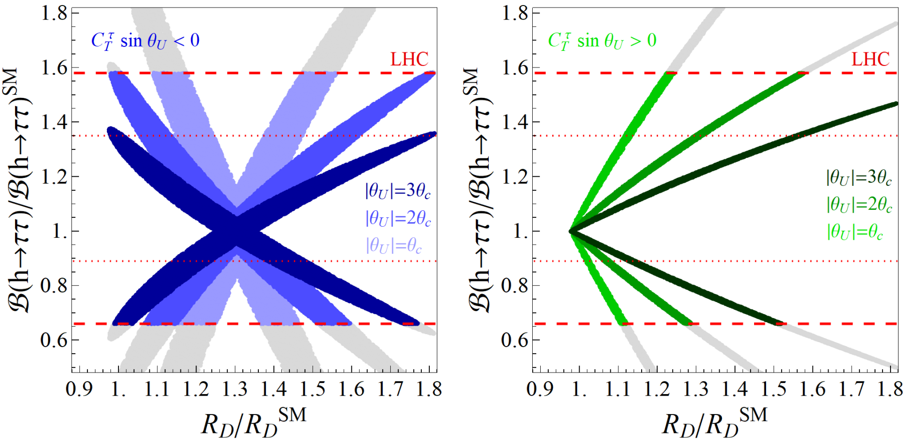
- Current constraints on $h \to \tau\tau$ are already useful: [PDG]

$$\mu_{\tau\tau}^{\rm exp} = \frac{\sigma \cdot \mathcal{B}(h \to \tau\tau)}{\sigma_{\rm SM} \cdot \mathcal{B}(h \to \tau\tau)_{\rm SM}} = 1.12(23)$$

- Δa_τ can be as large as 8×10^{-4} ! cf. e.g. [Eidelman et al. '16]

  Just below LEP & SLD limit: $-0.007 < a_\tau^{\rm exp} < 0.004$

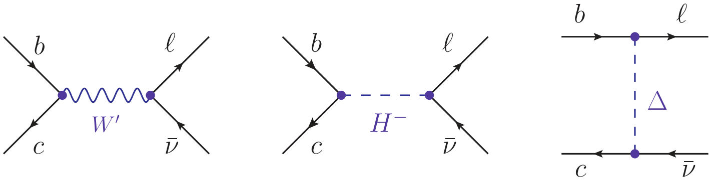
For fixed values of RH mixing:



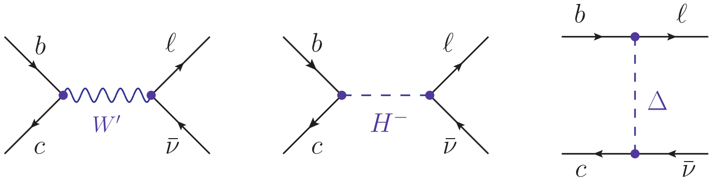
⇒ Correlation between semileptonic observables with Higgs decays!

From EFT to simplified models

$R_{D^{(*)}}^{\text{exp}} > R_{D^{(*)}}^{\text{SM}}$ require new bosons at the TeV scale:



$R^{\rm exp}_{D^{(*)}} > R^{\rm SM}_{D^{(*)}}$ require new bosons at the TeV scale:



Challenges for New Physics:

- Loop constraints: e.g. $\tau \to \mu\nu\bar{\nu}$, $Z \to \ell\ell$ [Feruglio et al., '16]
- LHC direct and indirect bounds [Greljo et al. '15, Faroughy et al., '16]

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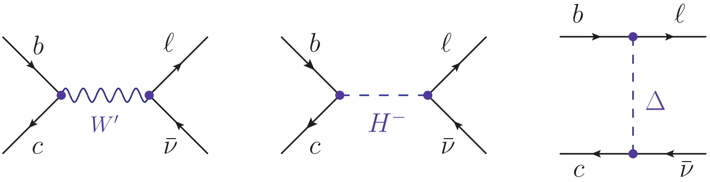

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In Summary:

- Charged Higgs solutions are in tension with τ_{B_c} constraint [Alonso et al. '16]
- Minimal W' models: tension with high-p_T ditau constraints
  $\Rightarrow$ *Still viable in models with* ν_R [Greljo et al. '18, Asadi et al. '18]
- Scalar and vector **leptoquarks (LQ)** are the **best candidates** so far.

Leptoquarks for $R_{D^{(*)}}$

NB. w/o ν_R

Model	$g_{\text{eff}}^{b\to c\tau\bar{\nu}}(\mu = m_\Delta)$	$R_{D^{(*)}}$
$S_1 = (\bar{3}, 1, 1/3)$	$g_{V_L},\ g_{S_L} = -4\, g_T$	✓
$R_2 = (3, 2, 7/6)$	$g_{S_L} = 4\, g_T$	✓
$S_3 = (\bar{3}, 3, 1/3)$	g_{V_L}	✗
…	…	…
$U_1 = (3, 1, 2/3)$	$g_{V_L},\ g_{S_R}$	✓
$U_3 = (3, 3, 2/3)$	g_{V_L}	✗
…	…	…

Viable models for $R_{D^{(*)}}$: [Angelescu, Becirevic, Faroughy, OS. 1808.08179]

- U_1 (g_{V_L}), S_1 (g_{V_L} and $g_{S_L} = -4\, g_T$), and R_2 ($g_{S_L} = 4\, g_T \in \mathbb{C}$)
- Some models are excluded by other flavor constraints: $B \to K\nu\bar{\nu}$, Δm_{B_s}...
- Possibility to distinguish them by using other $b \to c\ell\nu$ observables!

Leptoquarks for $R_{D^{(*)}}$ and $R_{K^{(*)}}$

[Angelescu, Becirevic, Faroughy, OS. 1808.08179]
see also [Barbieri et al. '15, Greljo et al. '17]

Model	$R_{D^{(*)}}$	$R_{K^{(*)}}$	$R_{D^{(*)}}$ & $R_{K^{(*)}}$
$S_1 = (\bar{3}, 1, 1/3)$	✓	✗*	✗*
$R_2 = (3, 2, 7/6)$	✓	✗*	✗
$S_3 = (\bar{3}, 3, 1/3)$	✗	✓	✗
$U_1 = (3, 1, 2/3)$	✓	✓	✓
$U_3 = (3, 3, 2/3)$	✗	✓	✗

- Building a model that can solve all anomalies is a very challenging task!
- Only U_1 can do it, but UV completion needed (more parameters).
  $\Rightarrow$ Possible in Pati-Salam models: [Di Luzio et al. '17, Bordone et al. '17...]
- Two scalar LQs can also do the job (no extra parameters):
  $\Rightarrow$ S_1 and S_3 [Crivellin et al. '17, Marzocca. '18], R_2 and S_3 [Becirevic et al. '18].

Closing the U_1-leptoquark window

[Angelescu, Becirevic, Faroughy, OS. 1808.08179]

Motivation

- U_1 LQ provides an elegant solution to the B-physics anomalies

  [Barbieri et al. '15, Greljo et al. '17]

- But UV completion needed $\Rightarrow$ model dependent (more degrees of freedom, more parameters...) [Di Luzio et al. '17, Bordone et al. '17. . .]

- Can we test it by only using tree-level observables (at low and high-energies)? Cross-check of leading log radiative constraints.

  cf. e.g. [Greljo et al. '17]

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Our setup

[Angelescu, Becirevic, Faroughy, OS. 1808.08179]

$$\mathcal{L} = x_L^{ij}\, \bar{Q}_i \gamma_\mu U_1^\mu L_j + x_R^{ij}\, \bar{d}_{Ri} \gamma_\mu U_1^\mu \ell_{Rj} + \text{h.c.}\,,$$

Assumptions:

$$x_L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & x_L^{s\mu} & x_L^{s\tau} \\ 0 & x_L^{b\mu} & x_L^{b\tau} \end{pmatrix}\,, \qquad x_R \approx 0\,.$$

Low-energy phenomenology

- $b \to c\tau\bar{\nu}$:

$$g_{V_L} = \frac{v^2}{2m_{U_1}^2}\left(x_L^{b\tau}\right)^*\left(x_L^{b\tau} + \frac{V_{cs}}{V_{cb}}x_L^{s\tau}\right) \neq 0$$

$$x_L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & x_L^{s\mu} & x_L^{s\tau} \\ 0 & x_L^{b\mu} & x_L^{b\tau} \end{pmatrix}$$

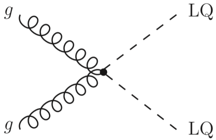
- $b \to s\mu\mu$:

$$C_9^{\mu\mu} = -C_{10}^{\mu\mu} \propto -\frac{\pi v^2}{m_{U_1}^2}\left(x_L^{b\mu}\right)^* x_L^{s\mu} \neq 0$$

- Other observables: $\tau \to \mu\phi$, $B \to \tau\bar{\nu}$, $D_{(s)} \to \mu\bar{\nu}$, $D_s \to \tau\bar{\nu}$, $K \to \mu\bar{\nu}/K \to e\bar{\nu}$, $\tau \to K\bar{\nu}$ and $B \to D^{(*)}\mu\bar{\nu}/B \to D^{(*)}e\bar{\nu}$.

LHC constraints

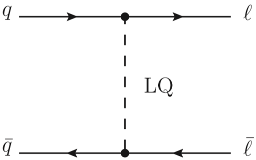
- LQ pair-production via QCD: [CMS-PAS-EXO-17-003]

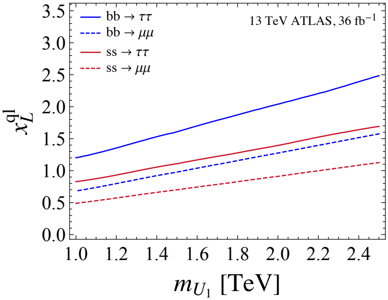


$m_{U_1} \gtrsim 1.5$ TeV

[*assuming* $\mathcal{B}(U_1 \to b\tau) \approx 0.5$]

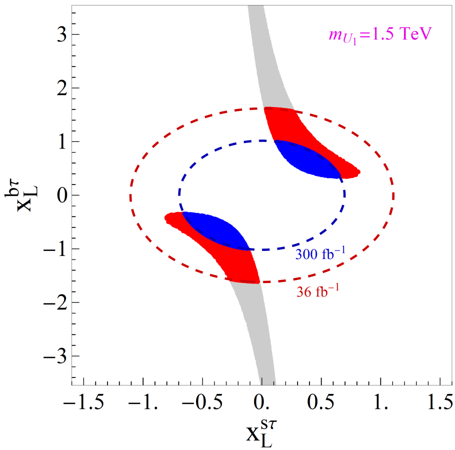
- Di-lepton tails at high-pT: [ATLAS. 1707.02424,1709.07242]





[Angelescu, Becirevic, Faroughy, OS. '18]
[see also Faroughy et al. '15]

Combining low and high-energy constraints



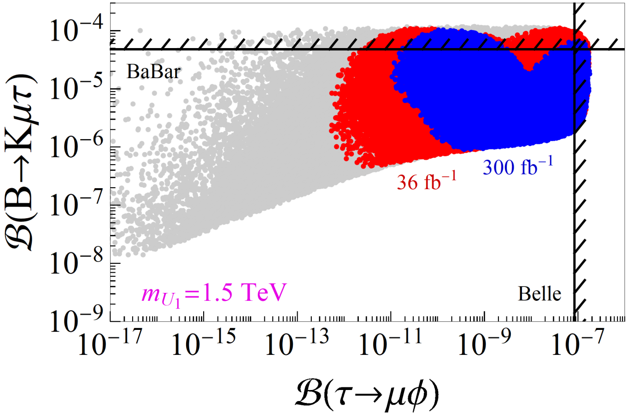
$R_{D^{(*)}}$ depends on:

$$g_{V_L} = \frac{v^2}{2m_{U_1}^2}\left(x_L^{b\tau}\right)^*\left(x_L^{b\tau} + \frac{V_{cs}}{V_{cb}} x_L^{s\tau}\right)$$

Same couplings probed by $\underline{pp \to \tau\tau}$:
36 fb^{-1} (blue) and 300 fb^{-1} (red).

$\Rightarrow$ Upper limit on $|x_L^{b\tau}|$ implies a nonzero lower limit on $|x_L^{s\tau}|$!

- High-p_T constraints set a model independent lower bound $\mathcal{B}(B \to K\mu\tau) \gtrsim \text{few} \times 10^{-7}$ (to be improved with more data!)

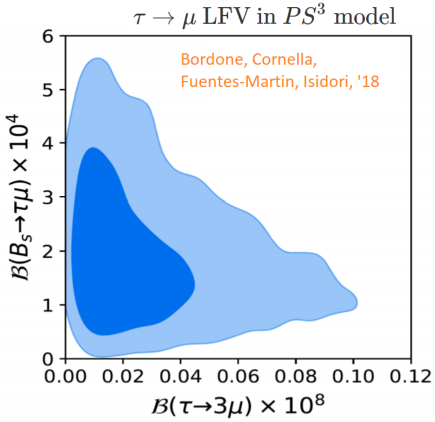


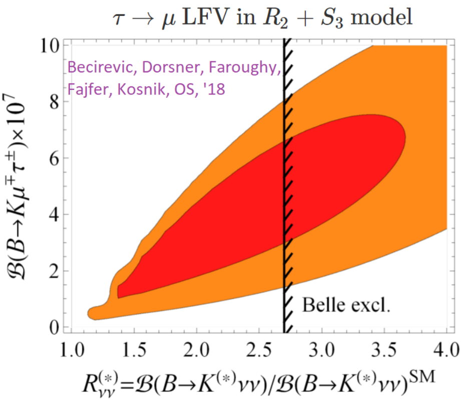
- BaBar: $\mathcal{B}(B \to K\mu\tau) < 4.8 \times 10^{-5}$ (90% CL). Can LHCb do better?

NB. $\mathcal{B}(B \to K^*\mu\tau)/\mathcal{B}(B \to K\mu\tau) \approx 1.8$, $\mathcal{B}(B \to K\mu\tau)/\mathcal{B}(B_s \to \mu\tau) \approx 1.25$

[Becirevic, OS, Zukanovich. 1602.00881]

$B_s \to \mu\tau$ and $B \to K^{(*)}\mu\tau$ are a crucial test to many (all?) other solutions to the B-anomalies!





NB. LQs: $\tau \to \mu\gamma$ and $\tau \to 3\mu$ are loop-suppressed, while $b \to s\mu\tau$ is not!

[see also Guadagnoli et al. '14]

Summary and perspectives

- Inclusion of quantum corrections is crucial to assess the viability of a given EFT and it induces correlations to other observables.

  Scalar/tensor operators can generate large $\mathcal{B}(h \to \tau\tau)$ and $(g-2)_\tau$

- We identify/summarize the viable single mediator explanations to $R_{K^{(*)}}$ and/or $R_{D^{(*)}}$.

  Only the vector U_1 is viable. Two scalar LQs can do the job too.

- U_1 model: we show a pronounced complementarity of flavor physics constraints with those obtained from the direct searches at the LHC.

  LHC ditau constraints $\Rightarrow$ lower bound $\mathcal{B}(B \to K\mu\tau) \gtrsim$ few $\times\, 10^{-7}$

- Building a concrete model to simultaneously explain $R_{K^{(*)}}$ and $R_{D^{(*)}}$ remains a very challenging task.

  Data-driven model building!

Thank you!

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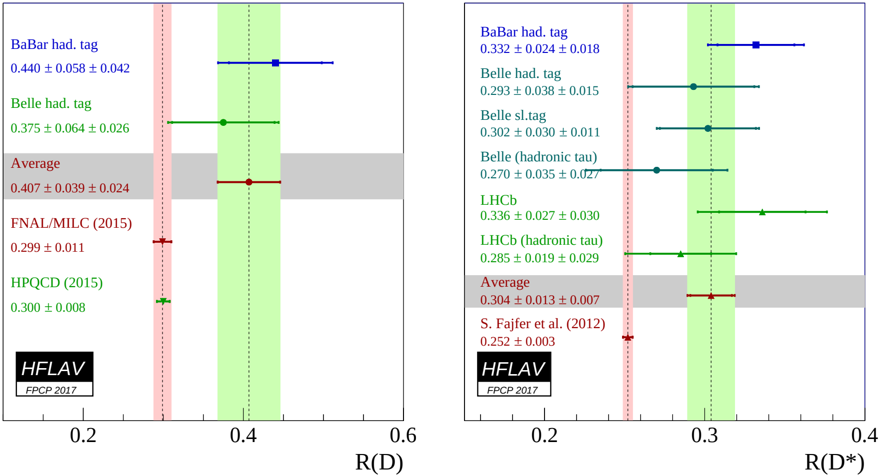
Back-up



- 3.9σ combined deviation from the SM [theory error under control?]
- Discrepancy driven by oldest exp. results (BaBar and LHCb).
- Needs confirmation from Belle-II (and LHCb run-2)!

SM predictions for $R_{D^{(*)}}$

Ref.	R_D	R_{D^*}	dev. (R_D)	dev. (R_{D^*})
Exp. [HFLAV]	$0.41(5)$	$0.304(15)$	–	–
LQCD [FLAG]	$0.300(8)$	–	2.3σ	–
Fajfer et al. '12	$0.296(16)$	$0.252(3)$	2.3σ	3.4σ
Bigi et al. '16	$0.299(3)$	–	2.3σ	–
Bigi et al. '17	–	$0.260(8)$	–	2.6σ
Bernlochner et al. '17	$0.298(3)$	$0.257(3)$	2.4σ	3.1σ

- Larger errors in [Bigi et al.] for R_{D^*}. Good agreement for R_D.
- LQCD determination of $A_0(q^2)$ would be very helpful.
- Soft photon corrections: first steps in [de Boer et al. 2018] Disentangling structure dependent terms, important!? – More work needed.

[Feruglio, Paradisi, OS. 1806.10155]

$$\frac{R_{D^{(*)}}}{R^{\mathrm{SM}}_{D^{(*)}}} = 1 + a_S^{D^{(*)}}\,|g_S^\tau|^2 + a_P^{D^{(*)}}\,|g_P^\tau|^2 + a_T^{D^{(*)}}\,|g_T^\tau|^2$$

$$+\, a_{SV_L}^{D^{(*)}}\,\mathrm{Re}\,[g_S^\tau] + a_{PV_L}^{D^{(*)}}\,\mathrm{Re}\,[g_P^\tau] + a_{TV_L}^{D^{(*)}}\,\mathrm{Re}\,[g_T^\tau]\ ,$$

Decay mode	a_S^M	$a_{SV_L}^M$	a_P^M	$a_{PV_L}^M$	a_T^M	$a_{TV_L}^M$
$B \to D$	$1.08(1)$	$1.54(2)$	0	0	$0.83(5)$	$1.09(3)$
$B \to D^*$	0	0	$0.0473(5)$	$0.14(2)$	$17.3(16)$	$-5.1(4)$

Our EFT setup

[Feruglio, Paradisi, OS. 1806.10155]

$$\mathcal{L}^0_{\mathrm{NP}} = \frac{C_{S_L}^{prst}}{\Lambda^2}\left[\mathcal{O}^{(1)}_{\ell equ}\right]_{prst} + \frac{C_T^{prst}}{\Lambda^2}\left[\mathcal{O}^{(3)}_{\ell equ}\right]_{prst} + \mathrm{h.c.}\,,$$

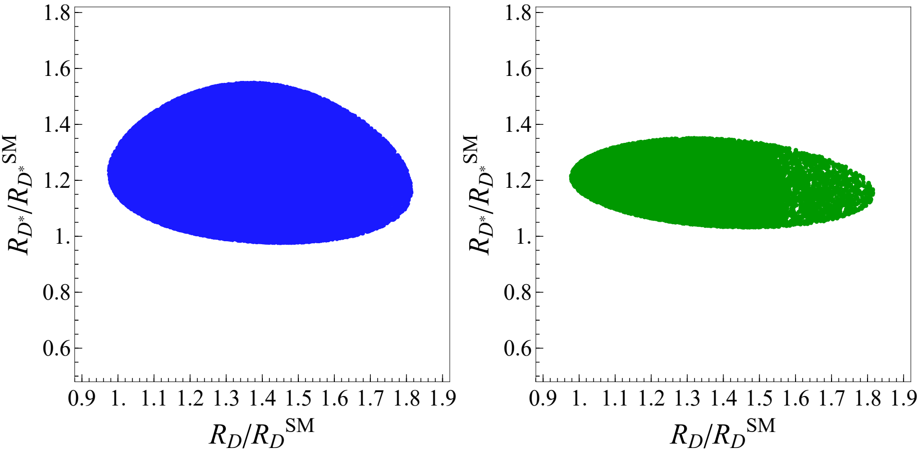
$$\left[\mathcal{O}^{(1)}_{\ell equ}\right]_{prst} = \left(\overline{L'_p}^a e'_{rR}\right)\varepsilon_{ab}\left(\overline{Q'_s}^b u'_{tR}\right)\,,$$

$$\left[\mathcal{O}^{(3)}_{\ell equ}\right]_{prst} = \left(\overline{L'_p}^a \sigma_{\mu\nu} e'_{rR}\right)\varepsilon_{ab}\left(\overline{Q'_s}^b \sigma^{\mu\nu} u'_{Rt}\right)\,,$$

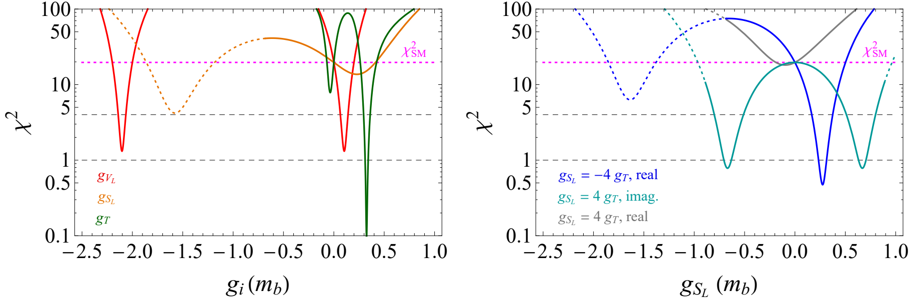
with $C_i^{prst} = C_i\,\delta_{p3}\,\delta_{r3}\,\delta_{s3}\,\delta_{t3}$

Flavor to mass basis rotations:

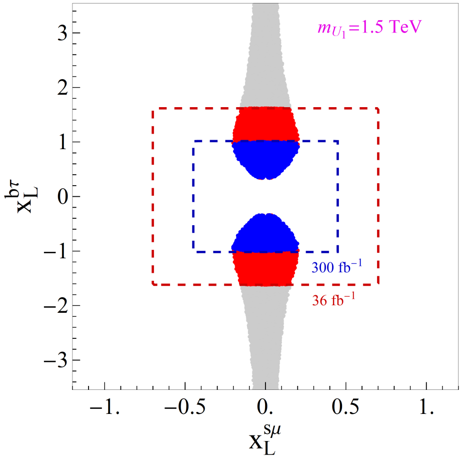
$$U_{R,u} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_U & -\sin\theta_U \\ 0 & \sin\theta_U & \cos\theta_U \end{pmatrix}\,, \qquad U_{R,d} = U_{R,\ell} = \mathbb{1}\,.$$

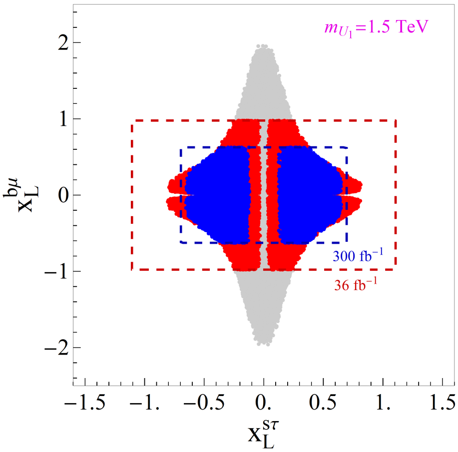


[Feruglio, Paradisi, OS. 1806.10155]



[Angelescu, Becirevic, Faroughy, OS. 2018]





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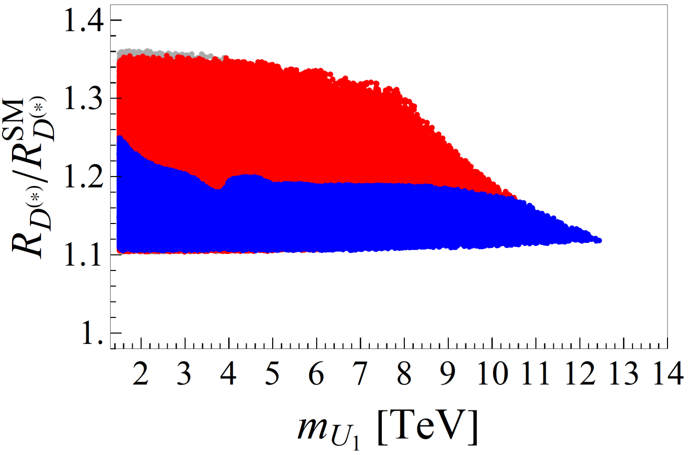

[Angelescu, Becirevic, Faroughy, OS. 2018]