Recent news on the $\mathcal{R}(D^{(*)})$ anomaly

Monika Blanke

Karlsruher Institut für Technologie

Collaborative Research Center TRR 257
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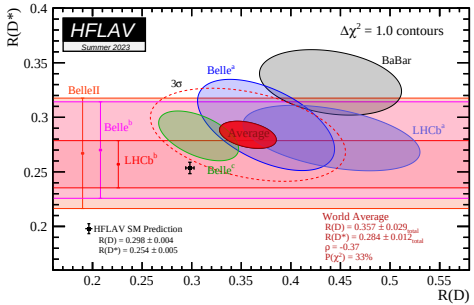
The $\mathcal{R}(D^{(*)})$ anomaly

Test of lepton flavour universality in semi-leptonic B decays

$$\mathcal{R}(D^{(*)}) = \frac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)} \qquad (\ell = e, \mu)$$



- theoretically clean, as hadronic and $|V_{cb}|$ uncertainties largely cancel in ratio
- measurements by BaBar, Belle, and LHCb in decent agreement with each other
- LHCb found $\mathcal{R}(J/\psi)$ to be larger than expected in SM

➢ **persisting 3.3σ anomaly**

caveat: $\mathcal{R}(\Lambda_c) < \mathcal{R}(\Lambda_c)_{\mathrm{SM}}$

➢ see poster by Fedele/Iguro

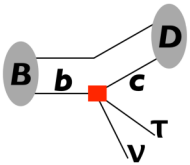
Effective Hamiltonian for $b \to c\tau\nu$

New Physics above B meson scale described model-independently[1] by

$$\mathcal{H}_{\text{eff}} = 2\sqrt{2} G_F V_{cb} \Big[(1 + C_V^L) O_V^L + C_S^R O_S^R + C_S^L O_S^L + C_T O_T \Big]$$

with the vector, scalar and tensor operators

$$O_V^L = (\bar{c}\gamma^\mu P_L b)\,(\bar{\tau}\gamma_\mu P_L \nu_\tau)$$
$$O_S^R = (\bar{c} P_R b)\,(\bar{\tau} P_L \nu_\tau)$$
$$O_S^L = (\bar{c} P_L b)\,(\bar{\tau} P_L \nu_\tau)$$
$$O_T = (\bar{c}\sigma^{\mu\nu} P_L b)\,(\bar{\tau}\sigma_{\mu\nu} P_L \nu_\tau)$$



Note: $(\bar{c}\gamma^\mu P_R b)\,(\bar{\tau}\gamma_\mu P_L \nu_\tau)$ not generated at dimension-six level in the $SU(2)_L \times U(1)_Y$-invariant theory

[1] assuming heavy/no ν_R and NP only in τ channel

Possible single-particle explanations

Possiblle New Physics scenarios (tree level!)

C_V^L vector SU(2)$_L$-triplet W' boson

➢ disfavoured by EW precision tests & LHC searches ✗

Faroughy, Greljo, Kamenik (2016); Ferruglio, Paradisi, Pattori (2017)

$(C_S^R,\, C_S^L)$ charged Higgs boson ✓

$(C_V^L,\, C_S^R)$ SU(2)$_L$-singlet vector leptoquark ✓

$(C_V^L,\, C_S^L = -4C_T)$ SU(2)$_L$-singlet scalar leptoquark ✓

$(\mathrm{Re}[C_S^L = 4C_T],\ \mathrm{Im}[C_S^L = 4C_T])$ scalar SU(2)$_L$-doublet leptoquark with CP-violating couplings ✓

see MB, Crivellin, de Boer, Kitahara, Moscati, Nierste, Nišandžić (2018)

A closer look at the charged Higgs solution

Complementary modes: $B_c \to \tau\nu$

- before 2019: large $\mathcal{R}(D^*)$ required sizeable $C_S^L - C_S^R$ contribution
  - ➢ implies large leptonic decay rate BR$(B_c \to \tau\nu)$
  - ➢ some tension with estimated bounds ☹
- more recent data: anomaly shifted from $\mathcal{R}(D^*)$ to $\mathcal{R}(D)$
  - ➢ BR$(B_c \to \tau\nu)$ safely small ✓

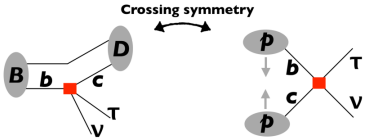
Beyond decay rates: $F_L(D^*)$

- CKM 2018: Belle reported first measurement of longitudinal D^* polarisation $F_L(D^*)$
  - ➢ indicates substantial enhancement w. r. t. SM prediction
  - ➢ can *only* be explained by scalar operator contribution, i. e. charged Higgs ✓✓

➢ **charged Higgs is currently the preferred solution to the $\mathcal{R}(D^{(*)})$ anomaly**

Complementary LHC searches

- crossing symmetry relates $b \to c\tau\nu$ to $pp \to X\tau\nu$
- mono-τ + $\not{E}_T$ signature probes NP models for $\mathcal{R}(D^{(*)})$



➢ **EFT analysis: LHC has become competitive in testing NP behind anomaly**

Greljo, Martin Camalich, Ruiz-Alvarez (2018)

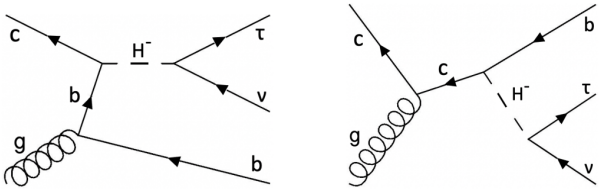
Charged Higgs in mono-τ final state

- charged Higgs produced as s-channel resonance
  ➢ significant deviation from EFT analysis
- mass-dependent constraint from recasting $W' \to \tau\nu$ searches
  ➢ charged Higgs solution to $\mathcal{R}(D^{(*)})$ ruled out for $m_{H^-} > 400\,\text{GeV}$

Iguro, Omura, Takeuchi (2018)

What about a light charged Higgs?

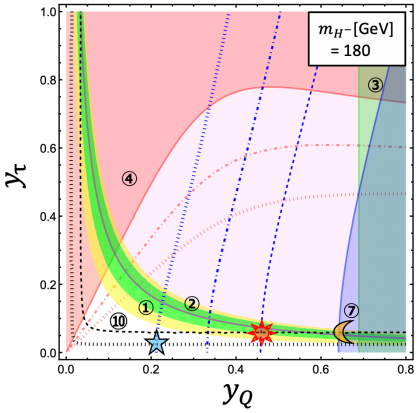
- light charged Higgs ($m_{H^-} < 400\,\text{GeV}$) not excluded by mono-$\tau$ data due to huge $W \to \tau\nu$ background
- efficient background suppression by requiring additional b-tagged jet



➢ **Is this sufficient to exclude the charged Higgs solution to the $\mathcal{R}(D^{(*)})$ anomaly?**

MB, Iguro, Zhang (2022)

Reach of the $b\tau\nu$ signature

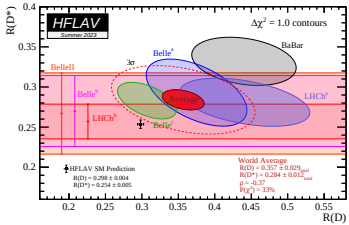


Minimal coupling scenario MB, Iguro, Zhang (2022)
(additional couplings do not alter conclusions)

$$\mathcal{L}_{\text{int}} = +y_Q H^-(\bar{b}P_R c) - y_\tau H^-(\bar{\tau}P_L\nu_\tau)$$

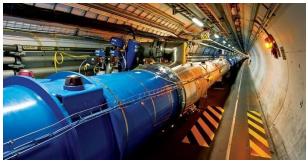
- H^- close to top threshold most difficult to test
- relevant constraints from SUSY stau and (flavoured) dijet searches at the LHC Iguro (2022)
- performing (flavoured) dijet and **proposed $b\tau\nu$ search** with Run 2 data would *almost* exclude charged Higgs solution for $\mathcal{R}(D^{(*)})$
- **final verdict** from future LHC runs

Summary & outlook



$\mathcal{R}(D^{(*)})$ **anomaly** persists at the 3σ level

global analysis of $b \to c\tau\nu$ data hints at **charged Higgs solution**



scrutinised by ongoing **LHC searches**