Semileptonic B Decays: Theory Overview

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Outline

- $|V_{cb}|$ plays an important role in the unitarity triangle analysis and the predictions of FCNC, $|V_{tb}\,V_{ts}^*|^2 \simeq |V_{cb}|^2[1+\mathcal{O}(\lambda^2)]$.

  $\Rightarrow$ Long standing tension between inclusive and exclusive determinations.

- Anomalies in tree and loop-level B decays:

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

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

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

This talk: (i) Latest V_{cb} and (ii) $R_{D^{(*)}}$ (SM and beyond).

$|V_{cb}|$: inclusive vs. exclusive

Status: HFLAV $|V_{cb}|$ averages [1612.07233]

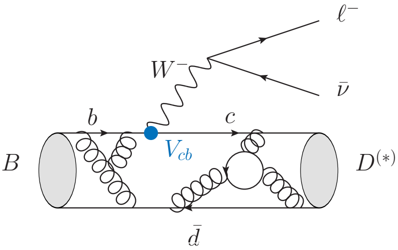
$|V_{cb}| = (42.19 \pm 0.78) \times 10^{-3}$	from $B \to X_c \ell \bar{\nu}$
$|V_{cb}| = (39.05 \pm 0.47_{\mathrm{exp}} \pm 0.58_{\mathrm{th}}) \times 10^{-3}$	from $B \to D^* \ell \bar{\nu}$
$|V_{cb}| = (39.18 \pm 0.94_{\mathrm{exp}} \pm 0.36_{\mathrm{th}}) \times 10^{-3}$	from $B \to D \ell \bar{\nu}$

$|V_{cb}|$ extracted from exclusive decays are systematically lower than the one determined from inclusive semileptonic decays.

- New $B \to D^*$ result: $|V_{cb}| = 37.4(1.3) \times 10^{-3}$ [Belle, 1702.01521]

c.f. Gambino talk at Moriond EW 2018

$B \to D^{(*)}\ell\bar{\nu}$ decays



$\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})^{\text{exp}}$ combined with $\langle D^{(*)}|\bar{c}_L\gamma^\mu b_L|B\rangle^{\text{theo.}}$ allow extracting $|V_{cb}|$.

For light (heavy) leptons:

- $B \to D$: one (two) form factors with $f_0(0) = f_+(0)$ at $q^2 = 0$;
  - Lattice QCD at $q^2 \neq q^2_{\text{max}}$ $(w \neq 1)$ for both form factors

    [MILC 2015, HPQCD 2015]

- $B \to D^*$: three (four) form factors;
  - Lattice QCD at $q^2 = q^2_{\text{max}}$ for leading form factor $[A_1(q^2_{\text{max}})]$

    [MILC 2014, HPQCD 2016]
  - Shape of leading form factor $[A_1(q^2)]$ constrained by analiticity and unitarity; Normalization by HQET, refined by LQCD.

Recent developments: Refitting Belle distribution

Results of new Belle angular analysis of $\bar{B} \to D^* \ell \bar{\nu}$ [1702.01521] revealed that $|V_{cb}|^{\rm excl}$ depends on parametrization of form factors:

$$\frac{\mathrm{d}\mathcal{B}(\bar{B} \to D^*(\to D\pi)\ell\bar{\nu})}{\mathrm{d}w\,\mathrm{d}\cos\theta_D\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\phi} \propto |V_{cb}|^2 f\left(A_1(q^2), V(q^2), A_2(q^2), m_\ell\, A_0(q^2)\right)$$
$$= |V_{cb}|^2\,|A_1(w)|^2\,\widetilde{f}\,(R_1(w), R_2(w), m_\ell\, R_0(w))$$

with $w = (m_B^2 + m_{D^*}^2 - q^2)/(2m_B m_{D^*})$.

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$$= |V_{cb}|^2\, |A_1(w)|^2\, \widetilde{f}\left(R_1(w), R_2(w), m_\ell\, R_0(w)\right)$$

with $w = (m_B^2 + m_{D^*}^2 - q^2)/(2 m_B m_{D^*})$.

HQET inspired:

- CLN [Caprini et al. 1997]:

$$h_{A_1}(w) = h_{A_1}(1)\left[1 + 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right]$$
$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2$$
$$R_2(w) = R_2(1) - 0.11(w-1) - 0.06(w-1)^2$$

- BGL [Boyd et al. 1997]: do not fix shape parameters in red. Otherwise, parameterization is the same in $z = (\sqrt{w+1} - \sqrt{2})/(\sqrt{w+1} + \sqrt{2})$.

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$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2$$
$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2$$

BGL gives $R_2(1)$ larger than HQET by more than 2σ

[Bigi et al. 2017], [Grinstein et al. 2017].

$$|V_{cb}|^{\rm excl}_{\rm CLN} = (38.2 \pm 1.5) \times 10^{-3} \qquad |V_{cb}|^{\rm excl}_{\rm BGL} = (41.7^{+2.0}_{-2.1}) \times 10^{-3}$$
$$|V_{cb}|^{\rm incl}_{1S} = (42.0 \pm 0.5) \times 10^{-3} \qquad |V_{cb}|^{\rm incl}_{\rm kin} = (42.2 \pm 0.8) \times 10^{-3}$$

Both fits (using CLN or BGL) are good $\Rightarrow$ Inconclusive!

$\Rightarrow$ Belle-II will remedy the situation.

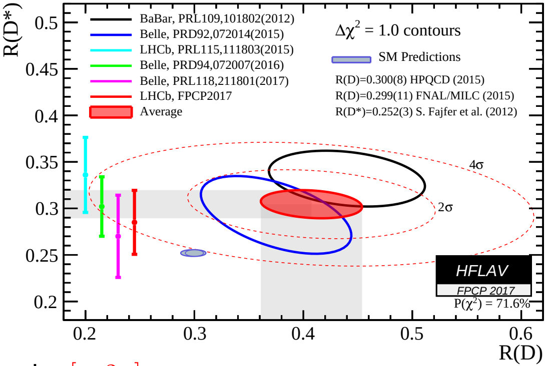
Way out: $|V_{cb}|$ from LQCD & Belle-II data at small recoil values.

Lepton flavor universality violation: $b \to c\ell\bar{\nu}$

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

Experiment

More in talks by Neubert, Owen, Simonetto and Rudolph



- R_D: B-factories $[\approx 2\sigma]$
- R_{D^*}: B-factories and LHCb $[\lesssim 3\sigma]$; dominated by BaBar
- LHCb confirmed tendency $R_{J/\psi}^{\mathrm{exp}} > R_{J/\psi}^{\mathrm{SM}}$, 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 $(R_{D_s}, R_{D_s^*}, R_{\Lambda_c} \ldots)$

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

Theory (tree-level in SM) *See talk by Bouchard*

- R_D: lattice QCD at $q^2 \neq q^2_{\max}$ $(w > 1)$ 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 $q^2 \neq q^2_{\max}$ 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?)

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.

We must wait for more exp. data and more LQCD input...

EFT description of R_D and R_{D^*}

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 $R_{D^{(*)}}$: — see e.g. [Freytsis et al. 2015]
  - e.g. $g_{V_L} \in (0.09, 0.13)$, but not only!

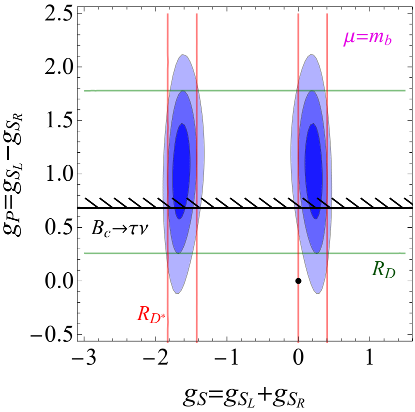
Fitting R_D and R_{D^*}: (i) (pseudo)scalar operators

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

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

NB.

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



$\Rightarrow$ (Pseudo)scalar operators in tension with τ_{B_c} constraint: $\mathcal{B}(B_c \to \tau\bar{\nu}) \lesssim 30\%$

[Alonso et al. 2016], see also [Akeroyd 2017]

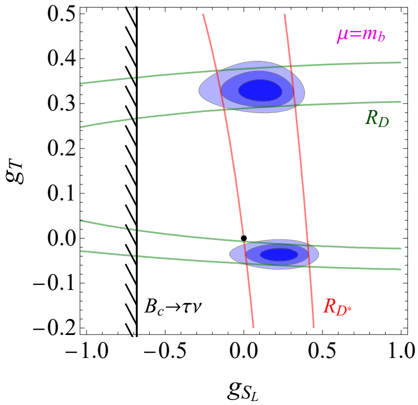
$$\mathcal{B}(B_c \to \tau\bar{\nu}) = \frac{\tau_{B_c} m_{B_c} f_{B_c}^2 G_F^2 |V_{cb}|^2}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_{B_s}^2}\right)^2 \left|1 + g_P \frac{m_{B_c}^2}{m_\tau (m_b + m_c)}\right|^2$$

Fitting R_D and R_{D^*}: (ii) scalar and tensor operators

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

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

$\mathcal{O}_{S_L}$ and $\mathcal{O}_T$ mix via EW RGEs [Gonzáles-Alonso et al. 2017].



⇒ 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!

- Several scenarios can accommodate R_D and R_{D^*}.

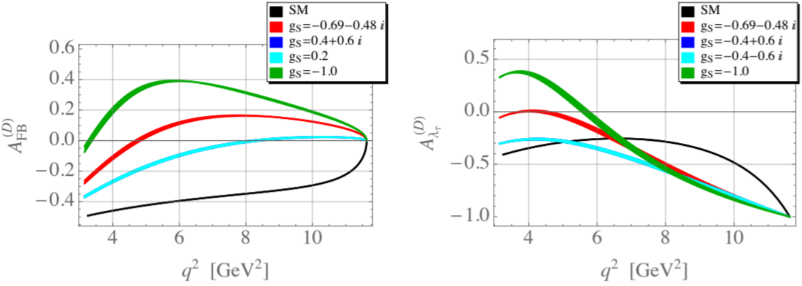
$\Rightarrow$ More exp. information is needed to distinguish among them:

- Several scenarios can accommodate R_D and R_{D^*}.

$\Rightarrow$ More exp. information is needed to distinguish among them:

i) Many angular observables (e.g. A_{fb}, τ-polarization asymmetry)

[Becirevic et al. 2016], [Alonso et al. 2016]



◦ First measurement: $P_\tau = -0.44 \pm 0.47^{+0.20}_{-0.17}$ [Belle, 1608.0391]

ii) Other LFUV ratios (e.g. $R_{J/\Psi}$, R_{D_s}, $R_{D_s^*}$, R_{Λ_c})

LHCb confirmed tendency in: [LHCb, 2017]

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

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

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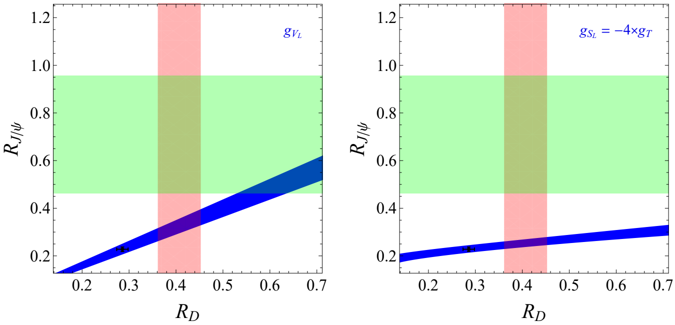
⇒ Larger than SM estimates $R_{J/\Psi}^{\text{SM}} \approx 0.22 - 0.28$; large exp/th errors.

⇒ Useful information to distinguish among NP scenarios:

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

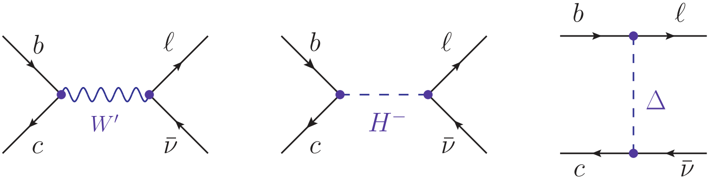


More exp. data and LQCD results are more than welcome here! See [HPQCD, 1611.01987] for preliminary LQCD results for $V(q^2)$ and $A_1(q^2)$.

Concrete New Physics Scenarios for $R_{D^{(*)}}$

[Fajfer et al. 2012, 2015], [Celis et al. 2012, 2016 and 2017], [De Fazio et al. 2013], [He et al. 2012], [Sakaki et al. 2013], [Bhattacharya et al. 2014], [Ghosh 2015], [Soni et al. 2015], [Bauer et al. 2015], [Ligeti et al. 2016] [Greljo et al. 2015 and 2018], [Guadagnoli et al. 2015], [Becirevic et al. 2012, 2016], [Barbieri et al. 2015 and 2017], [Li et al. 2016], [Boucenna et al. 2016], [Crivellin et al.], [Feruglio et al. 2015 and 2017] [Buttazzo et al. 2017], [Di Luzio et al. 2017], [D'Ambrosio et al. 2017], [Blanke et al. 2018], [Asadi et al. 2018], [Buttazzo 2018]...

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



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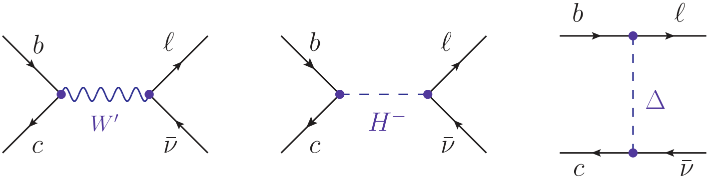

Challenges for New Physics:

- Loop constraints: e.g. $\tau \to \mu\nu\bar{\nu}$, $Z \to \ell\ell$ [Feruglio et al., 2016]
  See Feruglio talk
- LHC direct and indirect bounds [Greljo et al. 2015, Faroughy et al., 2016]
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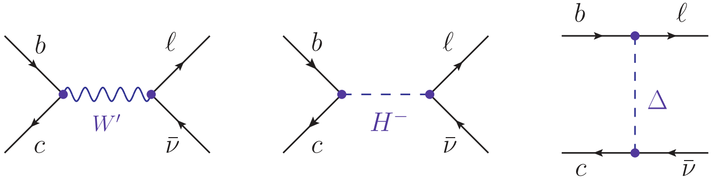

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  See Greljo talk

In Summary:

- Charge Higgs solutions are in tension with τ_{B_c} constraint
- Minimal W' models: tension with high-p_T ditau constraints
  $\Rightarrow$ *Still viable in models with* ν_R [Greljo et al. 2018, Asadi et al. 2018]
- Scalar and vector **leptoquarks (LQ)** are the **best candidates** so far.

LQ models for $R_{D^{(*)}}$

NB. w/o ν_R

Model	$g_{\mathrm{eff}}^{b\to c\tau\bar\nu}(\mu=m_\Delta)$	$R_{D^{(*)}}$
$S_1=(\bar 3,1)_{1/3}$	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}	✓
$V_2=(3,1)_{2/3}$	g_{S_R}	✗
$\widetilde{V}_2=(\bar 3,2)_{-1/6}$	g_{S_L}	✗
$U_3=(3,3)_{2/3}$	g_{V_L}	✗

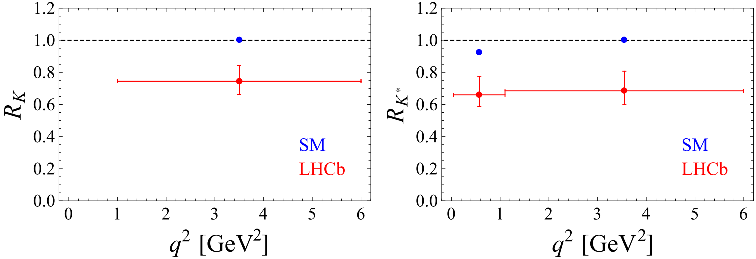
Viable models for $R_{D^{(*)}}$:

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

A pattern of LFUV? *Talks by Feruglio, Tetlalmatzi-Xolocotzi, Ciuchini and Mahmoudi*

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

Experiment



$\Rightarrow$ Needs confirmation from Belle-II!

Theory (loop induced in SM)

- Hadronic uncertainties cancel to a large extent $\Rightarrow$ Clean observables!
- QED corrections important, $R_{K^{(*)}} = 1.00(1)$, [Bordone et al. 2016]

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

NB. w/o ν_R, tree-level

Model	$R_{D^{(*)}}$	$R_{K^{(*)}}$	$R_{D^{(*)}}$ & $R_{K^{(*)}}$
$S_1 = (\bar{3}, 1)_{1/3}$	✓	✗	✗
$R_2 = (3, 2)_{7/6}$	✓	✗*	✗
$S_3 = (\bar{3}, 3)_{1/3}$	✗	✓	✗
$U_1 = (3, 1)_{2/3}$	✓	✓	✓
$V_2 = (3, 1)_{2/3}$	✗	✗	✗
$\widetilde{V}_2 = (\bar{3}, 2)_{-1/6}$	✗	✗	✗
$U_3 = (3, 3)_{2/3}$	✗	✓	✗

Models for $R_{D^{(*)}}$ & $R_{K^{(*)}}$:

- Building a model that can solve all anomalies is a very challenging task!
- Only U_1 can do it, but UV completion needed [Buttazzo et al. 2017]
  $\Rightarrow$ Possible in Pati-Salam models: [Di Luzio et al. 2017], [Bordone et al. 2017]...
- Two scalar LQs can also do the job: S_1 and S_3 [Marzocca, 2018], R_2 and S_3 [Becirevic, Dorsner, Fajfer, Faroughy, Kosnik, OS, to appear].

Summary and perspectives

Summary and Perspectives

- Important progress in understanding the uncertainties for $B \to D^* \ell \bar{\nu}$, but the V_{cb} puzzle remains.

  Wait for LQCD & Belle-II data at small recoils.

- SM prediction for R_D is robust (LQCD). Hadronic uncertainties entering R_{D^*} need to be better understood, but anomalies persist.

  More LQCD input necessary.

- Several viable New Physics scenarios can accommodate $R_{D^{(*)}}$.

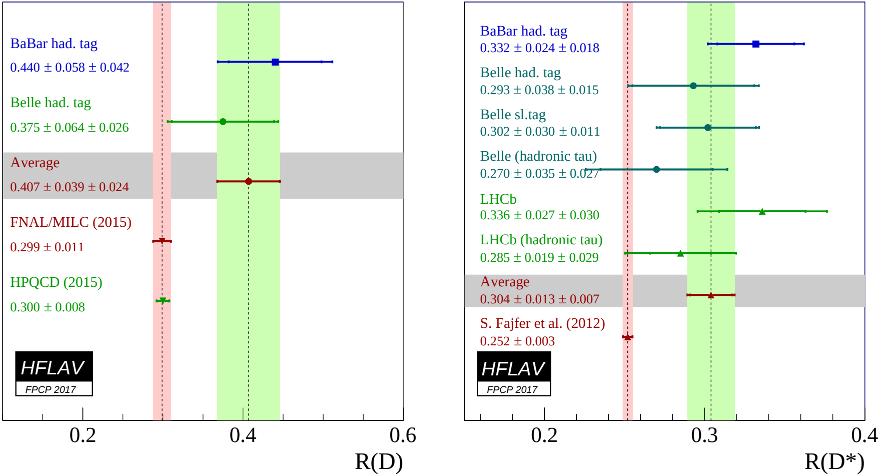
  More exp. info. is needed: ang. distributions, other LFUV ratios etc.

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

  Data driven model building!

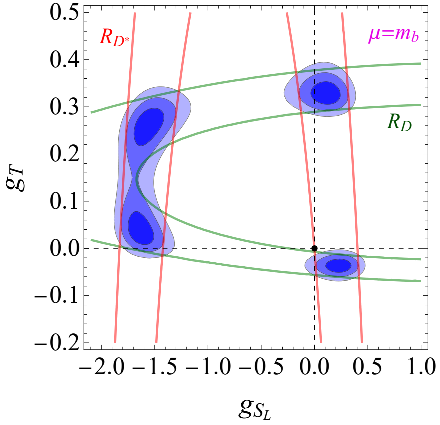
Thank you!

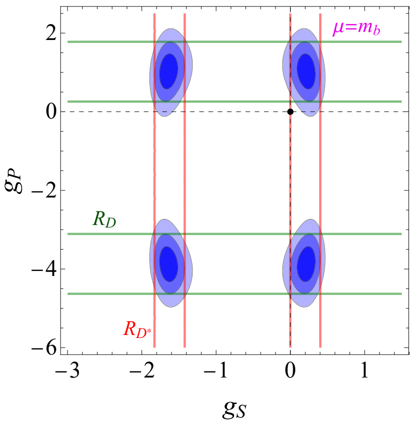
Back-up



- 3.9σ combined deviation from the SM [theory error under control?]
- 2.2σ deviation if only R_D is considered.
- 2σ deviation in $R_{J/\Psi}(?)$

Fitting the anomalies: R_D and R_{D^*}





SMEFT:

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

$SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge invariant operators:

Warsaw basis: [Grzadkowski et al. 1008.4884]

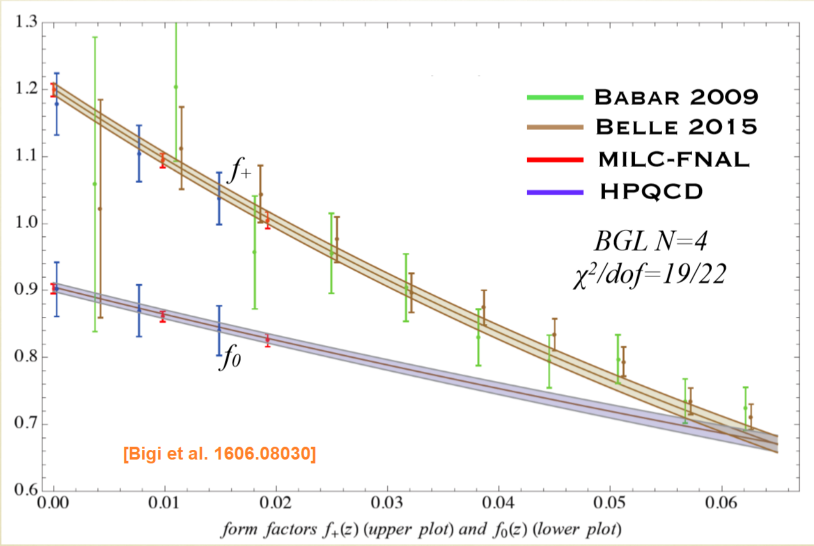
$$C_{\ell q}^{(3)} = \big(\bar{l}_p \gamma_\mu \tau^I l_r\big)\big(\bar{q}_s \gamma^\mu \tau^I q_t\big) \quad \Longrightarrow \quad g_{V_L}$$

$$C_{\ell edq} = \big(\bar{l}_p^j e_r\big)\big(\bar{d}_s q_{tj}\big) \quad \Longrightarrow \quad g_{S_R}$$

$$C_{\ell equ}^{(1)} = \big(\bar{l}_p^j e_r\big) \epsilon_{jk} \big(\bar{q}_s^k u_t\big) \quad \Longrightarrow \quad g_{S_L}$$

$$C_{\ell equ}^{(3)} = \big(\bar{l}_p^j \sigma_{\mu\nu} e_r\big) \epsilon_{jk} \big(\bar{q}_s^k \sigma^{\mu\nu} u_t\big) \quad \Longrightarrow \quad g_T$$

$B \to D$ form factors



BGL parametrization

[BGL. hep-ph:9705252,9412324,9504235]

$$f_i(z) = \frac{1}{B_i(z)\phi_i(z)} \sum_{n=0}^{\infty} a_n^i z^n$$

$$z = \frac{\sqrt{1+w} - \sqrt{2}}{\sqrt{1+w} + \sqrt{2}}, \qquad w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

- $B \to D^*$: $z_{\max} = 0.056 \Rightarrow$ truncation at $N = 2$ is enough
- $B_i(z)$: removes poles
- $\phi_i(z)$: phase-space factors.

$$\langle \bar{D}^*(k,\varepsilon)|\bar{c}\gamma^\mu b|\bar{B}(p)\rangle = \varepsilon^{\mu\nu\rho\sigma}\varepsilon^*_\nu p_\rho k_\sigma \frac{2\,V(q^2)}{m_B + m_{D^*}}\,,$$

$$\begin{aligned}\langle \bar{D}^*(k,\varepsilon)|\bar{c}\gamma^\mu\gamma_5 b|\bar{B}(p)\rangle &= i\varepsilon^{*\mu}(m_B + m_{D^*})A_1(q^2) - i(p+k)^\mu(\varepsilon^*\cdot q)\frac{A_2(q^2)}{m_B + m_{D^*}} \\ &- iq^\mu(\varepsilon^*\cdot q)\frac{2m_{D^*}}{q^2}\left[A_3(q^2) - A_0(q^2)\right],\end{aligned}$$

[Bigi, Gambino. 1703.06124]

BGL Fit:	Data + lattice	Data + lattice + LCSR
χ^2/dof	27.9/32	31.4/35
$\lvert V_{cb}\rvert$	$0.0417\,(^{+20}_{-21})$	$0.0404\,(^{+16}_{-17})$
a_0^f	0.01223(18)	0.01224(18)
a_1^f	$-0.054\,(^{+58}_{-43})$	$-0.052\,(^{+27}_{-15})$
a_2^f	$0.2\,(^{+7}_{-12})$	$1.0\,(^{+0}_{-5})$
$a_1^{\mathcal{F}_1}$	$-0.0100\,(^{+61}_{-56})$	$-0.0070\,(^{+54}_{-52})$
$a_2^{\mathcal{F}_1}$	0.12 (10)	$0.089\,(^{+96}_{-100})$
a_0^g	$0.012\,(^{+11}_{-8})$	$0.0289\,(^{+57}_{-37})$
a_1^g	$0.7\,(^{+3}_{-4})$	$0.08\,(^{+8}_{-22})$
a_2^g	$0.8\,(^{+2}_{-17})$	$-1.0\,(^{+20}_{-0})$

CLN Fit:	Data + lattice	Data + lattice + LCSR
χ^2/dof	34.3/36	34.8/39
$\lvert V_{cb}\rvert$	0.0382 (15)	0.0382 (14)
$\rho^2_{D^*}$	$1.17\,(^{+15}_{-16})$	1.16 (14)
$R_1(1)$	$1.391\,(^{+92}_{-88})$	1.372 (36)
$R_2(1)$	$0.913\,(^{+73}_{-80})$	$0.916\,(^{+65}_{-70})$
$h_{A_1}(1)$	0.906 (13)	0.906 (13)

see also [Grinstein, Kobach,1703.08170]