Sensitivity to scalar contributions in $b \to c(u)\tau\nu$ decays

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AC, M. Jung, X-Q. Li, A. Pich, Phys.Lett. B771 (2017) 168-179 [arXiv:1612.07757]

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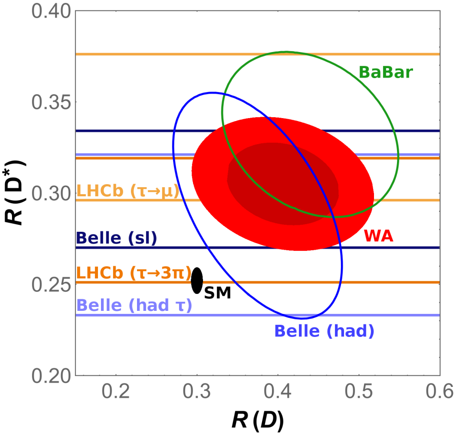
Motivation: $R(D)$ and $R(D^*)$ in 2017

$$R(D^{(*)}) = \frac{\mathrm{Br}(B \to D^{(*)}\tau\nu)}{\mathrm{Br}(B \to D^{(*)}\ell\nu)}$$



contours: 68% CL, filled: 95(68)% CL

Framework

Parametrization of **charged scalar** contributions

$$\mathcal{L}_{\text{eff}} = -\frac{4 G_F V_{q_u q_d}}{\sqrt{2}} \left[\bar{q}_u (g_L^{q_u q_d \ell} \mathcal{P}_L + g_R^{q_u q_d \ell} \mathcal{P}_R) q_d \right] [\bar{\ell} \mathcal{P}_L \nu_\ell]$$

Assume colour-neutral scalar exchange

$$g_{L,R}^{q_u q_d \ell} = g_{L,R}^{q_u q_d} g_L^\ell$$

Flavour ansatz (relating $b \to c$ and $b \to u$):

$$\frac{g_L^{cb}}{g_L^{ub}} = \frac{m_c}{m_u}\,, \qquad\qquad \frac{g_R^{cb}}{g_R^{ub}} = 1$$

realized in 2HDMs with natural flavour conservation and in the aligned 2HDM.

Observables

$\underline{b \to c}$

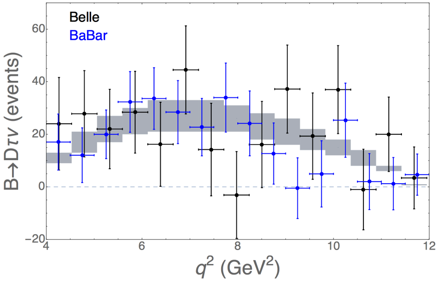
- $R(D^{(*)})$ and q^2 distribution in $B \to D^{(*)}\tau\nu$
- τ polarization asymmetry
- B_c meson lifetime
- $R(X_c) \equiv \dfrac{\mathrm{Br}(B \to X_c\tau\nu)}{\mathrm{Br}(B \to X_c\ell\nu)}$

$\underline{b \to u}$

- $R(\tau) \equiv \dfrac{\mathrm{Br}(B \to \tau\nu)}{\mathrm{Br}(B \to \pi\ell\nu)}$
- $R(\pi) \equiv \dfrac{\mathrm{Br}(B \to \pi\tau\nu)}{\mathrm{Br}(B \to \pi\ell\nu)}$ *exp. upper bound*

Analysis of $b \to c$ sector

- $\underline{B \to D\ell\nu}$: Boyd-Grinstein-Lebed form factor parametrization, following *Bigi-Gambino (2016)*
- $\underline{B \to D^*\ell\nu}$: Caprini-Lellouch-Neubert parametrization with data input, $R_3(1)$ from HQET relation to order $\alpha_s, 1/m_{b,c}$ and enhanced uncertainty following *Fajfer-Kamenik-Nisandzic (2012)*
- $\underline{q^2 \text{ distribution in } B \to D^{(*)}\tau\nu}$:
  Normalization is kept floating in the fit.



Analysis of $b \to c$ sector

- τ polarization asymmetry first measurement by Belle (2016), provides important handle to discriminate NP scenarios but statistical error is still large

- Indirect bound from the B_c lifetime

  discussed in: *Li-Yang-Zhang (2016)* & *Alonso-Grinstein-Camalich (2016)*

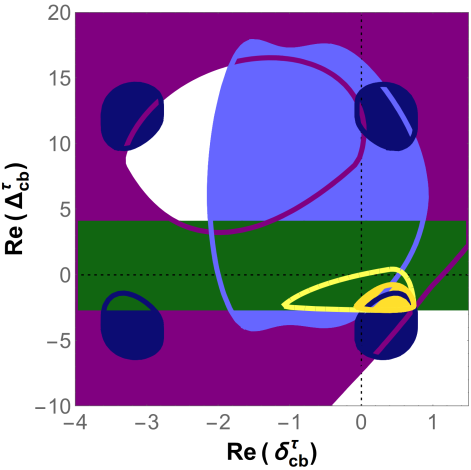
  Conservative limit: $\mathrm{Br}(B_c \to \tau\nu) \leq 40\%$ (in SM $\sim 2\%$)
  derived from the measured B_c lifetime and theory input for its decay rate *Beneke-Buchalla (1996)*

- $R(X_c)$
  Constraint derived from LEP measurement

$$\mathrm{Br}(b \to \tau\nu + X) = (2.41 \pm 0.23)\%$$

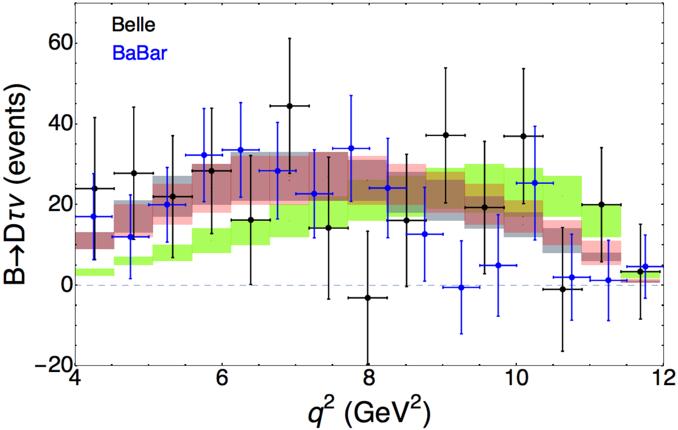
  dominated by $b \to X_c\tau\nu$ because of $|V_{ub}|^2/|V_{cb}|^2 \sim 1\%$.

Analysis of $b \to c$ sector



$$\delta^\ell_{cb} \equiv \frac{(g_L^{cb\ell} + g_R^{cb\ell})(m_B - m_D)^2}{m_\ell\,(\bar{m}_b - \bar{m}_c)}, \qquad \Delta^\ell_{cb} \equiv \frac{(g_L^{cb\ell} - g_R^{cb\ell})m_B^2}{m_\ell\,(\bar{m}_b + \bar{m}_c)},$$

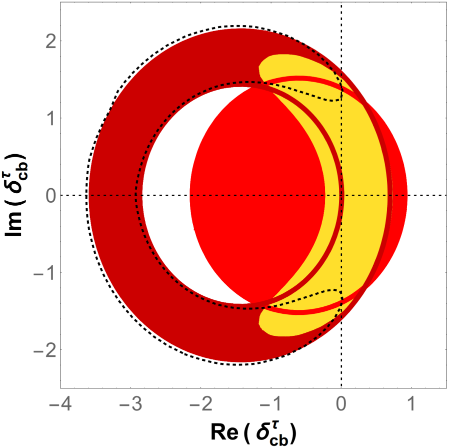
Analysis of $b \to c$ sector



Green: allowed by $R(D^{(*)})$, but excluded by the shape information

Analysis of $b \to c$ and $b \to u$ sectors

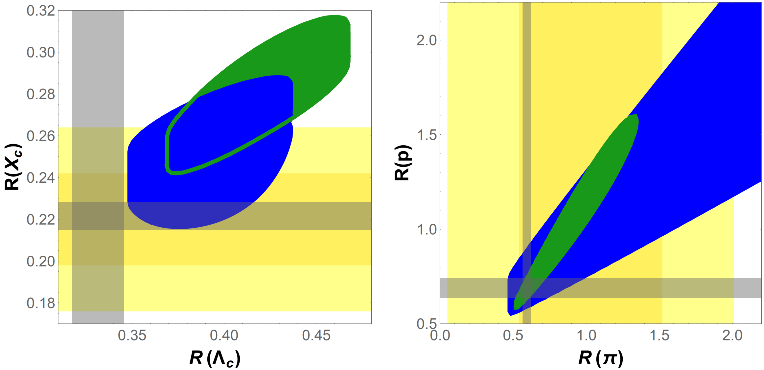
dotted contour: $R(D^{(*)})$ and $R(\tau)$



$$\delta_{cb}^{\ell} \equiv \frac{(g_L^{cb\ell} + g_R^{cb\ell})(m_B - m_D)^2}{m_\ell\,(\bar{m}_b - \bar{m}_c)}\,; \qquad \frac{g_L^{cb}}{g_L^{ub}} = \frac{m_c}{m_u}\,, \qquad \frac{g_R^{cb}}{g_R^{ub}} = 1$$

Predictions

$$R(\Lambda_c) \equiv \frac{\mathrm{Br}(\Lambda_b \to \Lambda_c \tau \nu)}{\mathrm{Br}(\Lambda_b \to \Lambda_c \ell \nu)} \text{ and } R(p) \equiv \frac{\mathrm{Br}(\Lambda_b \to p \tau \nu)}{\mathrm{Br}(\Lambda_b \to p \ell \nu)}$$



Scalar (blue) vs SM-like operator (green)

form factors for baryonic decays from lattice QCD

Detmold-Lehner-Meinel (2015)

Conclusions

We performed a global analysis of $b \to c$ and $b \to u$ transitions considering **generic contributions from a charged Higgs**

Important tensions are observed between $R(D^{(*)})$, the indirect bound from the B_c lifetime and the q^2 distribution in $B \to D^{(*)}\tau\nu$

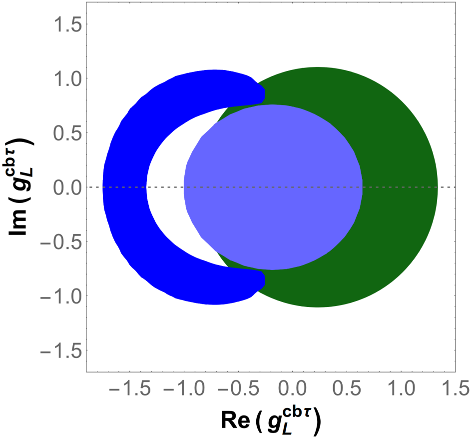
Depending on the flavour structure, tensions also arise between the $b \to c$ and $b \to u$ sectors due to $R(\tau)$

Additional decays provide complementary tests of Lepton Universality Violation in charged-current mediated processes, e.g. $R(\Lambda_c)$ & $R(p)$

Interesting measurements expected from LHCb and Belle(-II)

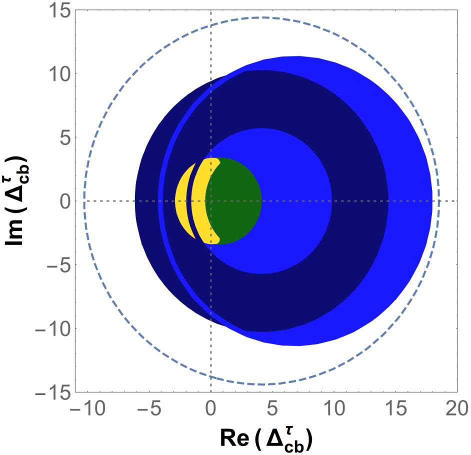
Extra Slides

Analysis of $b \to c$ sector



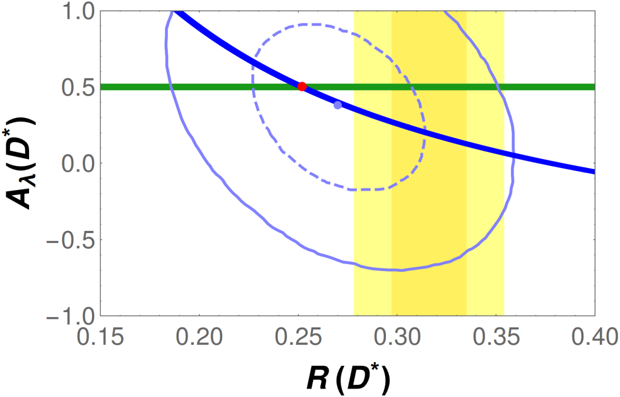
$$\mathcal{L}_{\rm eff} = -\frac{4G_F V_{q_u q_d}}{\sqrt{2}} \left[\bar{q}_u (g_L^{q_u q_d \ell} \mathcal{P}_L) q_d\right] [\bar{\ell} \mathcal{P}_L \nu_\ell]$$

Analysis of $b \to c$ sector



dashed contour (68% CL) from τ polarization asymmetry

Analysis of $b \to c$ sector



Scalar (blue) vs SM-like operator (green)

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