Sensitivity to scalar contributions in 
\[ b \to c(\mu)\tau\nu \text{ decays} \]

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

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

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

Parametrization of **charged scalar** contributions

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

Assume colour-neutral scalar exchange

\[ g_{q_u q_d}^{q_u q_d L} = g_{L, R}^{q_u q_d} g_L^L \]

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

\[ \frac{g_{L}^{cb}}{g_{L}^{ub}} = \frac{m_c}{m_u}, \quad \frac{g_{R}^{cb}}{g_{R}^{ub}} = 1 \]

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

\( b \rightarrow c \)

- \( R(D^*) \) and \( q^2 \) distribution in \( B \rightarrow D^*(\tau \nu) \)
- \( \tau \) polarization asymmetry
- \( B_c \) meson lifetime
- \( R(X_c) \equiv \frac{\text{Br}(B \rightarrow X_c\tau\nu)}{\text{Br}(B \rightarrow X_c\ell\nu)} \)

\( b \rightarrow u \)

- \( R(\tau) \equiv \frac{\text{Br}(B \rightarrow \tau\nu)}{\text{Br}(B \rightarrow \pi\ell\nu)} \)
- \( R(\pi) \equiv \frac{\text{Br}(B \rightarrow \pi\tau\nu)}{\text{Br}(B \rightarrow \pi\ell\nu)} \)

exp. upper bound
Analysis of $b \rightarrow c$ sector

- $B \rightarrow D \ell \nu$: Boyd-Grinstein-Lebed form factor parametrization, following Bigi-Gambino (2016)

- $B \rightarrow D^* \ell \nu$: 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)

- $q^2$ distribution in $B \rightarrow D^{(*)}\tau\nu$: Normalization is kept floating in the fit.
Analysis of $b \rightarrow c$ sector

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


**Conservative limit:** $\text{Br}(B_c \rightarrow \tau \nu) \leq 40\%$ (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

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

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

\[
\delta^\ell_{cb} \equiv \frac{(g_L^{cbl} + g_R^{cbl})(m_B - m_D)^2}{m_\ell (\bar{m}_b - \bar{m}_c)}, \quad \Delta^\ell_{cb} \equiv \frac{(g_L^{cbl} - g_R^{cbl})m_B^2}{m_\ell (\bar{m}_b + \bar{m}_c)},
\]
Analysis of $b \rightarrow c$ sector

Green: allowed by $R(D^{(*)})$, but excluded by the shape information
Analysis of $b \rightarrow c$ and $b \rightarrow u$ sectors

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

\[
\delta^\ell_{cb} \equiv \frac{(g^{cb\ell}_L + g^{cb\ell}_R)(m_B - m_D)^2}{m_\ell (\bar{m}_b - \bar{m}_c)}; \quad \frac{g^{cb}_L}{g^{ub}_L} = \frac{m_c}{m_u}, \quad \frac{g^{cb}_R}{g^{ub}_R} = 1
\]
Predictions

\[ R(\Lambda_c) \equiv \frac{\text{Br}(\Lambda_b \to \Lambda_c \tau \nu)}{\text{Br}(\Lambda_b \to \Lambda_c \ell \nu)} \quad \text{and} \quad R(p) \equiv \frac{\text{Br}(\Lambda_b \to p \tau \nu)}{\text{Br}(\Lambda_b \to p \ell \nu)} \]

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 $b \rightarrow c$ sector

\[ \mathcal{L}_{\text{eff}} = -\frac{4G_F V_{quqd}}{\sqrt{2}} \left[ \bar{q}_u (g_L^{quqd} P_L) q_d \right] [\bar{\ell} P_L \nu_\ell] \]
Analysis of $b \rightarrow c$ sector

dashed contour (68% CL) from $\tau$ polarization asymmetry
Analysis of $b \rightarrow c$ sector

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