New physics from

$$B \to D^{(*)}\tau\upsilon$$

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15. april 2013, Portorož

(a). Introduction

- (semi)leptonic decays of B mesons - arena in which there is still place for effects of BSM physics
- semitauonic decays sensitive to additional form factors, not seen in case of light lepton.
- (semi)tauonic - sensitive to charged scalar contributions from 2HDMs:
- Immense literature:
- $B \to \tau \upsilon$ Hou (1992), Ackeroyd, Recksiegel (2003)..
- $B \to D\tau \upsilon$ Kiers, Soni (1997) Miki, Miura, Tanaka (2002), Nierse,Trine,Westhoff (2008), Kamenik, Mescia (2008)...
- $B \to D^{*}\tau \upsilon$ Fajfer, Kamenik, IN (2012), Crivelin, Greub, Kokulu (2012), Faller, Mannel, Turrczyk...

(b) $B \to D^* \tau \upsilon$

S. Fajfer, J.F. Kamenik, I.N, PRD85. 094025: D* and tau - richer spin structure offers several additional observables (asymmetries).

$$\frac{d^2\Gamma_\tau}{dq^2 d\cos\theta} = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{256\pi^3 m_B^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \times \Big[(1-\cos\theta)^2 |H_{++}|^2 + (1+\cos\theta)^2 |H_{--}|^2 + 2\sin^2\theta |H_{00}|^2 + \frac{m_\tau^2}{q^2}\left((\sin^2\theta(|H_{++}|^2 + |H_{--}|^2) + 2|H_{0t} - H_{00}\cos\theta|^2\right)\Big]$$

θ - angle between D* and tau three momenta in tau-neutrino rest frame

In the presence of additional terms in charged current,

$$j_{bc}^{\mu} = \bar{c}\gamma^{\mu} P_L b + g_{SL} i\partial^{\mu}(\bar{c} P_L b) + g_{SR} i\partial^{\mu}(\bar{c} P_R b)$$

only H_{0t} helicity amplitude is modified:

$$H_{0t} = H_{0t}^{SM}\left(1 + (g_{SR} - g_{SL})\frac{q^2}{m_b + m_c}\right)$$

Form factors - rely on HQET with leading order QCD and $1/m_{b(c)}$ corrections - Caprini, Lellouch, Neubert (1998), Neubert (1992)

(c) Observables

Ratio $R(D^*) = \frac{Br(B \to D^* \tau \upsilon)}{Br(B \to D^* l \upsilon)}$ in which some of the hadronic and V_{cb} uncertainties cancel

Found SM predictions: **R(D*)=0.252(3), R(D)=0.296(16).**

kamenik, mescia 2008
fajfer, kamenik, IN, 2012

Longitudinal polarizations of D*

$$R_L = \frac{Br(B \to D_L^* \tau \upsilon)}{Br(B \to D^* l \upsilon)}$$

Charged scalars do not affect helicity amplitudes of transversely polarized D*.

Angular asymmetry

$$A_\theta(q^2) \equiv \frac{\int_{-1}^{0} d\cos\theta (d^2\Gamma_\tau/dq^2 d\cos\theta) - \int_0^1 d\cos\theta (d^2\Gamma_\tau/dq^2 d\cos\theta)}{d\Gamma_\tau/dq^2}$$

$$= \frac{3}{4} \frac{|H_{++}|^2 - |H_{--}|^2 + 2\frac{m_\tau^2}{q^2}\mathrm{Re}(H_{00}H_{0t})}{\left[(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2)\left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2}\frac{m_\tau^2}{q^2}|H_{0t}|^2\right]}$$

Spin asymmetry, using spin projections of tau

$$\frac{d\Gamma_\tau}{dq^2}(\lambda_\tau = -1/2) = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{96\pi^3 m_B^2}\left(1 - \frac{m_\tau^2}{q^2}\right)^2 (H_{--}^2 + H_{++}^2 + H_{00}^2)$$

$$\frac{d\Gamma_\tau}{dq^2}(\lambda_\tau = 1/2) = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{96\pi^3 m_B^2}\left(1 - \frac{m_\tau^2}{q^2}\right)^2 \frac{m_\tau^2}{2q^2}(H_{--}^2 + H_{++}^2 + H_{00}^2 + 3H_{0t}^2)$$

$$A_\lambda(q^2) = \frac{d\Gamma_\tau/dq^2(\lambda_\tau = -1/2) - d\Gamma_\tau/dq^2(\lambda_\tau = 1/2)}{d\Gamma_\tau/dq^2}$$

previously considered for B to D case, Tanaka, Watanabe 2010

Sizable deviations from SM in all observables allowed

(d) BaBar measurement and "excess"

BaBar Collaboration, Phys.Rev.Lett 109 (2012) 101802. BaBar measures the excess in semitauonic B decays.
Taking isospin averages gives:

$$R(D) = 0.440 \pm 0.058 \pm 0.042$$
$$R(D^*) = 0.332 \pm 0.024 \pm 0.018$$

combined
3.4 sigmas
excess

To compare with SM prediction:

$$R(D)^{SM} = 0.296 \pm 0.016$$
$$R(D^*)^{SM} = 0.252 \pm 0.003$$

BaBar also simulate the effects of charged scalars; Conclude that type II 2HDM is is not compatible with the measurements, for any values of tan beta and m_H.

(e) accommodation in SM?

Becirevic, Kosnik, Tayduganov, Phys. Rev.Lett B716 208 (2012) combining the experimental input and lattice studies (at high q^2 region) $B \to D\tau\upsilon$ discrepancy with SM below 2 sigmas.

FermiLab Lattice and MILC Collaborations: new calculation, discrepancy in $B \to D\tau\upsilon$ reduced to about 1.7 sigma.

(f) could it be the new physics?

Many papers appeared with attempts to accommodate the anomaly.

S. Fajfer, J.F. Kamenik, I.N, J.Zupan Phys.Rev.Lett 109 161801 - rely on model independent, EFT analysis.

If confirmed, the excess signals the violation of lepton flavor universality (LFU) in b to c transitions.

LFU for first two generations tested to percent level and found in excellent agreement with SM

In the fits, we also include hints of LFUV in b to u transitions:

The most recent world average:

$$Br(B \to \tau\upsilon) = (11.4 \pm 2.3) \times 10^{-5}$$

larger than SM prediction with V_{ub} from global fit.

(g) Lepton Flavor Universality Violation (LFUV)?

On the other hand, agreement with SM in:

$$Br(\overline{B_0} \to \pi^+ l^- \upsilon) = (14.6 \pm 0.7) \times 10^{-5}$$

We use the following ratio in which V_{ub} dependence cancels:

$$R^{\pi} = \frac{\tau(B^0)}{\tau(B^-)} \frac{Br(B \to \tau\upsilon)}{Br(B \to \pi l \upsilon)} = 0.73 \pm 0.15$$

while SM prediction is $R^{\pi}_{SM} = 0.31(6)$ - discrepancy of 2.6 sigma (1,6 sigma for high q^2)

all together combined 3.9 (3.4 sigma)

Supplement SM Lagrangian with set of higher dimensional operators:

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_a \frac{z_a}{\Lambda^{d_a-4}} \mathcal{O}_i + h.c.$$

$$c_a = z_a \left(\frac{v}{\Lambda}\right)^{d_a-4}$$

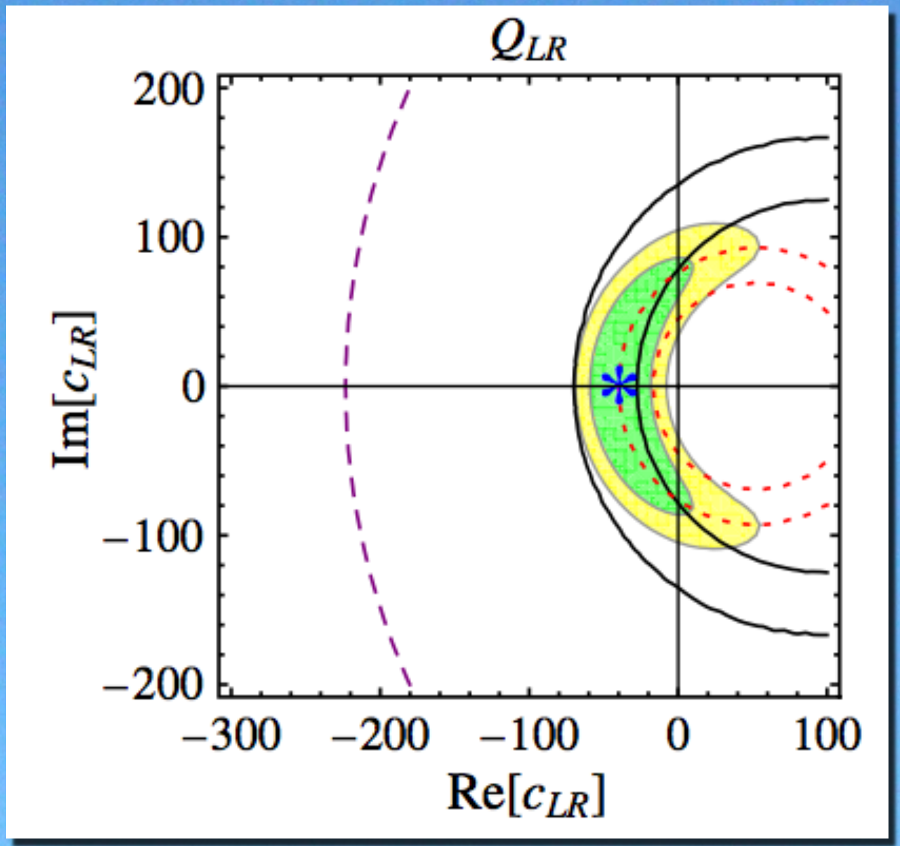
Chose the operators with requirements of no down-type FCNCs and no LFUV in pion and kaon sectors:

$$\begin{aligned}
\mathcal{Q}_L &= (\bar{q}_3 \gamma_\mu \tau^a q_3) \mathcal{J}^\mu_{3,a}\,, \\
\mathcal{Q}^i_R &= (\bar{u}_{R,i} \gamma_\mu b_R)(H^\dagger \tau^a \tilde{H}) \mathcal{J}^\mu_{3,a} \\
\mathcal{Q}_{LR} &= i\partial_\mu (\bar{q}_3 \tau^a H b_R) \textstyle\sum_j \mathcal{J}^\mu_{j,a}\,, \\
\mathcal{Q}^i_{RL} &= i\partial_\mu (\bar{u}_{R,i} \tilde{H}^\dagger \tau^a q_3) \textstyle\sum_j \mathcal{J}^\mu_{j,a}\,,
\end{aligned}$$

$$\mathcal{J}^\mu_{j,a} = \bar{l}_j \gamma^\mu \tau_a l_j$$

MFV

MFV case not preferred.

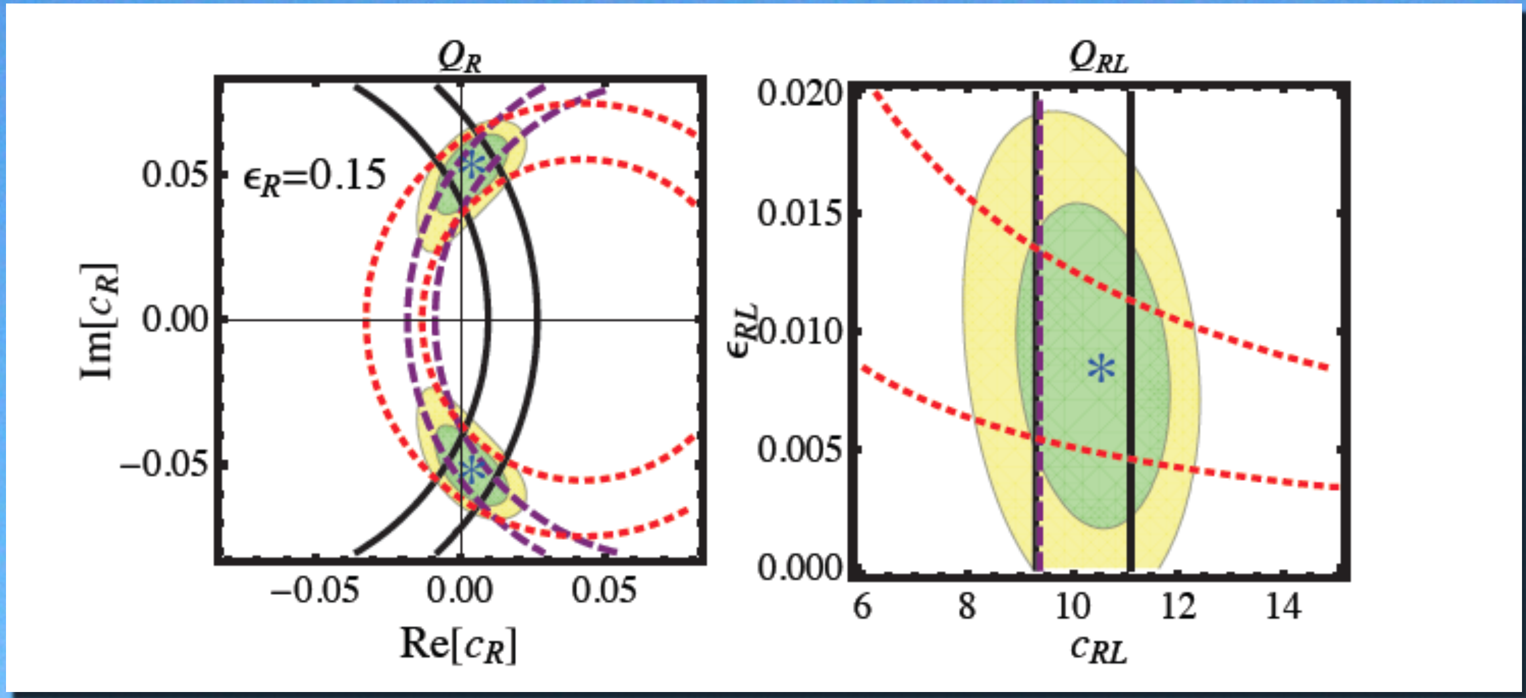


the best fit leads toward low eff. scale $v|c_{LR}|^{-1/4} \simeq 72GeV$

Generic flavor structure

better fits, R(pi) not related to R(D) and R(D*)

$$b \to c \quad z_A^c = c_A(\Lambda/v)^2$$
$$b \to u \quad z_A^u = \epsilon_A(z_a)^c$$



Q_R -> large CPV contributions, eff. scale 0.36 TeV
Q_{RL}, effective scale 97 GeV

(h) Specific models

Q_{LR} and Q_{RL} -> both generated in 2HDM

No good fit for natural flavor conserving type I, type II, lepton specific and flipped.

2HDM with general flavor violation gives good fits but needs order of magnitude cancellations to avoid conflict with neutral meson mixings.

Future

In awaiting of new results by Belle.
Measurements of some of asymmetries is welcome.
Also $Br(B \to \pi\tau\upsilon)/Br(B \to \pi l\upsilon)$ and $B_c \to \tau\upsilon$ would illuminate the case and be interesting co compare with the SM

Thanks for your attention

backup slides

$$H_{\pm\pm}^{\rm SM}(q^2) = (m_B + m_{D^*})A_1(q^2) \mp \frac{2m_B}{m_B + m_{D^*}}|\mathbf{p}|V(q^2)\,,$$

$$H_{00}^{\rm SM}(q^2) = \frac{1}{2m_{D^*}\sqrt{q^2}}\left[(m_B^2 - m_{D^*}^2 - q^2)(m_B + m_{D^*})A_1(q^2) - \frac{4m_B^2|\mathbf{p}|^2}{m_B + m_{D^*}}A_2(q^2)\right]$$

$$H_{0t}^{\rm SM}(q^2) = \frac{2m_B|\mathbf{p}|}{\sqrt{q^2}}A_0(q^2)\,.$$

$$A_0(q^2) = \frac{R_0(w)}{R_{D^*}}h_{A_1}(w)\,,$$

$$A_2(q^2) = \frac{R_2(w)}{R_{D^*}}h_{A_1}(w)\,,$$

$$V(q^2) = \frac{R_1(w)}{R_{D^*}}h_{A_1}(w)\,,$$

$$R_3(1) \equiv \frac{R_2(1)(1-r) + r[R_0(1)(1+r) - 2]}{(1-r)^2} = 0.97$$