Scalar Contributions to Tree-Level Observables

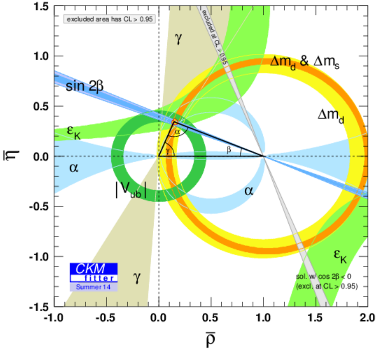
Martin Jung

Talk at Portorož 2015
10th of April 2015

The Flavour Problem

Consistency of the SM Flavour Sector:

- K and B agree
- ➡ Confirmation of KM mechanism
- NP influence expected
- Many measurements confirm SM
- So far only a few "puzzles"
- ➡ Flavour Problem

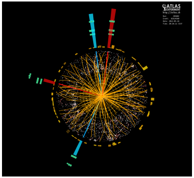


Challenge: small NP effects

Consequences of the Flavour Problem

Higher precision necessary

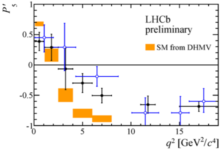
- Experimental challenge:
  Control systematics at high luminosities
- Theoretical challenge:
  Reduce hadronic uncertainties



More complex analyses, e.g.

- Inclusion of neglected contributions
- Differential distributions even for rare decays

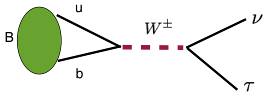
➥ Possible due to experimental advances!



Combination of many observables

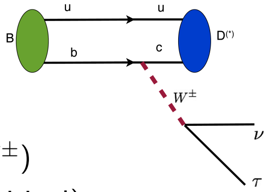
- Use more available information
- Tests of more realistic models
  - ➥ Danger of higher model-dependence
- Model-independent analyses e.g. in HEFT
  - ➥ Rather weak statements regarding flavour

Importance of (semi-)leptonic meson decays



In the Standard Model:

- Determination of $|V_{ij}|$ (7/9)
  - ➥ Minimal hadronic input
  - ➥ Systematic improvements possible



Beyond the Standard Model:

- Leptonic decays $\sim m_l^2$
  - ➥ large relative NP influence possible (e.g. $H^\pm$)
- NP in semi-leptonic decays moderate ($\to$ precision!)
- New measurements at LHC (e.g. search for $t \to H^\pm b$)

One of the remaining puzzles [Lees et al.'12,'13] :

$$R(D) \equiv \frac{\mathrm{Br}(\bar{B} \to D\tau^- \bar{\nu}_\tau)}{\mathrm{Br}(\bar{B} \to D\ell^- \bar{\nu}_\ell)} = 0.440 \pm 0.058 \pm 0.042 \; (\sim 2\sigma)\,,$$

$$R(D^*) \equiv \frac{\mathrm{Br}(\bar{B} \to D^*\tau^- \bar{\nu}_\tau)}{\mathrm{Br}(\bar{B} \to D^*\ell^- \bar{\nu}_\ell)} = 0.332 \pm 0.024 \pm 0.018 \; (\sim 2.7\sigma)\,.$$

Charged scalar effects in (semi-)leptonic decays

A charged scalar generally results in

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

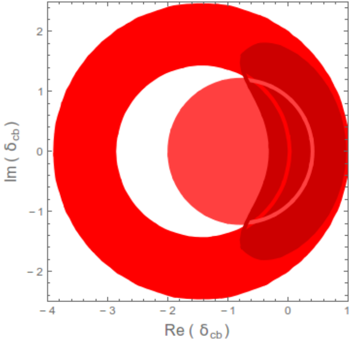
- Model-independent as long as $g_{L,R}^{q_u q_d l}$ general
  - ➥ connects processes/observables with identical transition
  - ➥ Phenomenologically $g_{L,R}^{q_u q_d l} \sim m_{q_{ud}} m_l$ (e.g. Type III)
- "Universal" models, e.g. Type I,II,X,Y, MFV, A2HDM, . . . :

$$\boxed{g_{L,R}^{q_u q_d l} / g_{L,R}^{q'_u q'_d l'} = m_{q_{u,d}} m_l / (m_{q'_{u,d}} m_{l'})}$$

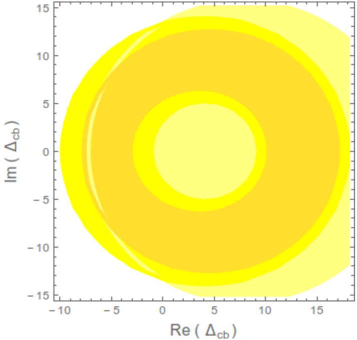
  - ➥ no FCNCs, connects all (semi-)leptonic decays
  - ➥ $g_{L,R}^{q_u q_d l}$ can be complex

Model-independent interpretation of $R(D^{(*)})$

$R(D)$



$R(D^*)$ [Celis/MJ/Li/Pich('15)]



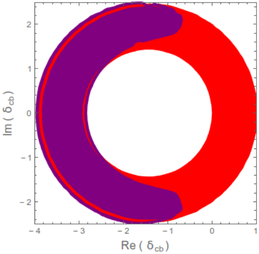
$$\delta^{cbl} \equiv \frac{(g_L^{cbl}+g_R^{cbl})(m_B-m_D)^2}{m_l(\bar{m}_b-\bar{m}_c)} \qquad \Delta^{cbl} \equiv \frac{(g_L^{cbl}-g_R^{cbl})m_B^2}{m_l(\bar{m}_b+\bar{m}_c)}$$

Rings: $R(D^{(*)})$; Disks: q^2 shapes [BaBar'13] ; Dark: combinations

- q^2 shape important! [Hagiwara+'89,Körner+'90,Nierste+'08,Fajfer+'12,. . .]
- $B \to D\tau\nu$: improved SM compatibility
- $B \to D^*\tau\nu$: requires huge couplings

Consequences of the q^2 shape [Celis/MJ/Li/Pich('15)]

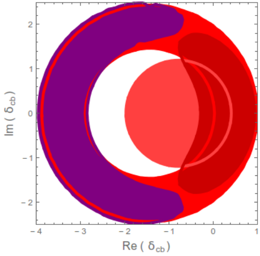
Assume universality for $b \to q_u \tau\nu \Longrightarrow$ include $B \to \tau\nu$:



- $BR(B \to \tau\nu) = (1.07 \pm 0.21) \times 10^{-4}$
- Purple: Solution for B observables $(R(D), R(D^*), B \to \tau\nu)$

Consequences of the q^2 shape [Celis/MJ/Li/Pich('15)]

Assume universality for $b \to q_u \tau\nu \implies$ include $B \to \tau\nu$:

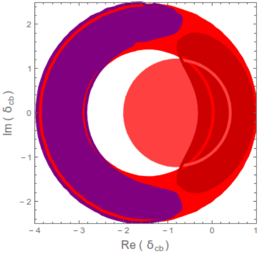


- $BR(B \to \tau\nu) = (1.07 \pm 0.21) \times 10^{-4}$
- Purple: Solution for B observables ($R(D), R(D^*), B \to \tau\nu$)

➥ Excluded by the q^2-dependent measurement!

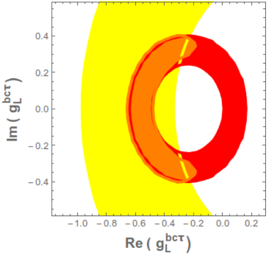
Consequences of the q^2 shape [Celis/MJ/Li/Pich('15)]

Assume universality for $b \to q_u \tau \nu \implies$ include $B \to \tau\nu$:



- $BR(B \to \tau\nu) = (1.07 \pm 0.21) \times 10^{-4}$
- Purple: Solution for B observables $(R(D), R(D^*), B \to \tau\nu)$
- ➥ Excluded by the q^2-dependent measurement!

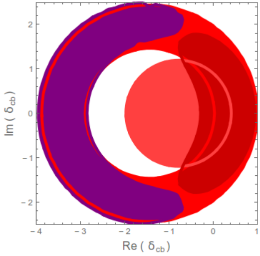
Description with $g_L^{cb\tau}$ only:



- Relates $\delta^{cb\tau}$ and $\Delta^{cb\tau}$
- Possible with $R(D^{(*)})$ [Crivellin+'13]

Consequences of the q^2 shape [Celis/MJ/Li/Pich('15)]

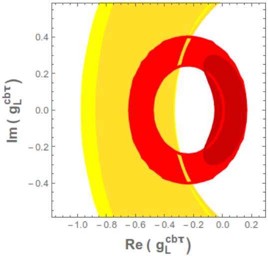
Assume universality for $b \to q_u \tau\nu \Longrightarrow$ include $B \to \tau\nu$:



- $BR(B \to \tau\nu) = (1.07 \pm 0.21) \times 10^{-4}$
- Purple: Solution for B observables $(R(D), R(D^*), B \to \tau\nu)$

➥ Excluded by the q^2-dependent measurement!

Description with $g_L^{cb\tau}$ only:



- Relates $\delta^{cb\tau}$ and $\Delta^{cb\tau}$
- Possible with $R(D^{(*)})$ [Crivellin+'13]

➥ Excluded by the q^2 shape

➥ Most general fit remains possible

➥ Alternatives: Exp. (D^{**})? NP'? [Doršner+'13,Sakaki+'14,...]

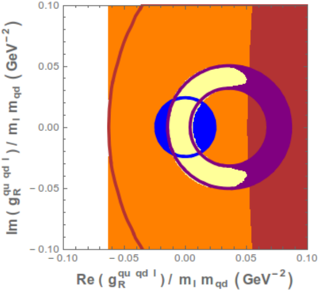
Fits in universal models [MJ/Pich/Tuzón'10,Celis/MJ/Li/Pich'13('15)]

For $M_{H^\pm} \leq m_t$: search for $t \to bH^+(\to (\bar{s}, \bar{b})c, \bar{\tau}\nu)$:
[ATLAS'13'14,CMS'14]

- Excludes $M_{H^\pm} < m_t$ for appreciable coupling
- Universal models: correlates δ and Δ for $M_{H^\pm} < m_t$
  ➥ Improvement of global fits

Global fit: include leptonic B, D, K, π, τ decays (+collider)
➥ Assume $R(D^*)$ due to experimental issues

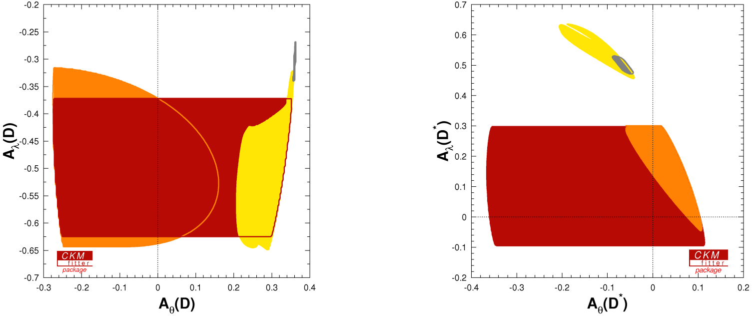
- Compatible with the SM and 2HDM
  ➥ due to $B \to \tau\nu$,$dBR/dq^2(B \to D\tau\nu)$
- Collider/Flavour complementary
- Not shown: g_L from charm decays, tiny for $M_{H^\pm} < m_t$



Differentiating the SM and different NP scenarios I

How can we tell for sure?

- Improvement of the measurements (Belle (II), LHCb)
- Measurements of other processes ($\Lambda_b \to \Lambda_c \tau \nu$ [Datta+'15])
- Consider additional observables:[Korner/Schuler'88,Hagiwara et al.'89]
    - Forward-backward asymmetry A_θ
    - τ-spin asymmetry A_λ
    - Longitudinal polarization fraction R_L in $B \to D^*$

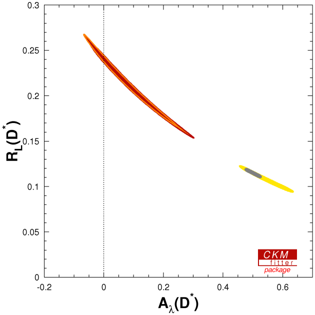


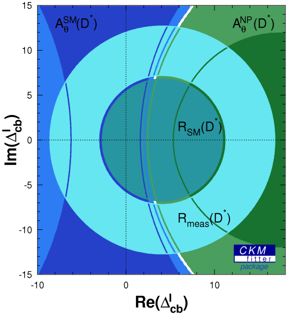
(Data from 2013, not yet updated)

Differentiating the SM and different NP scenarios II

Generic statements for scalar NP in these modes:

- $B \to D^{(*)}$ depend on one complex parameter each $(\Delta^\tau_{cb}, \delta^\tau_{cb})$
- $R(D^{(*)}), R_L(D^*), A_\lambda(D^{(*)})$ depend on the same combination
  - ➥ Combinations independent of scalar NP
  - ➥ To determine $\Delta^\tau_{cb}/\delta^\tau_{cb}$, $A_{fb}(R^{(*)})$ important observable





Conclusions

- SM still prevails, flavour problem requires new strategies
- $B \to D^{(*)}\tau\nu$ "rule out" SM and universal scalar NP
  ➥ wait for checks of especially $R(D^*)$
- q^2 shapes important, already ruling out scenarios
- Collider and flavour complementary in global fits
- Additional observables / more precise data...
  - help to tell experimental issues from theoretical ones
  - can distinguish between various scalar NP scenarios
  - can distinguish between scalar NP and other contributions

➥ Charged current (semi-)leptonic decays remain important

We will soon know more!