Flavour anomalies at the HL/HE LHC

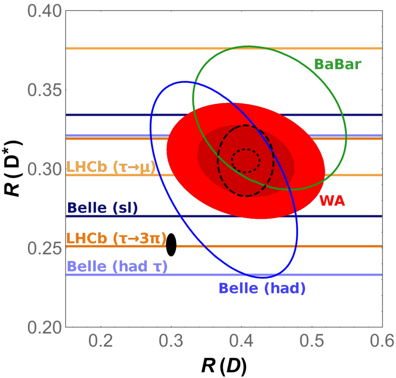
Martin Jung

"Workshop on the physics of HL-LHC,
and perspectives at HE-LHC"

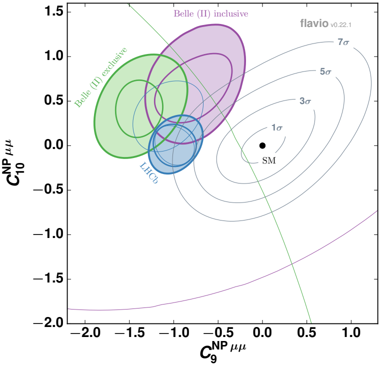
CERN, 19th of June 2018

Anomalies and projections 2018

$b \to c\tau\nu$



$b \to s\ell^+\ell^-$ [Albrecht+'17]



- Presently $\sim 4\sigma$ from SM
- Relative to tree-level
- ➥ Low NP scale?

- $\sim 5\sigma$ from SM
- Relative to EW penguin loop
- Consistent BR, angular + LFU data

If anomalies are real, they will be established before 2nd upgrade

Generalities

If anomalies are real, they will be established before 2nd upgrade

Consequently the objectives change:

- Differentiation between NP structures
  - ➥ Distributions in q^2 + angles, polarization...
  - ➥ Require analyses beyond 1/2 operators
- Flavour structure on the lepton side ($\rightarrow \tau$ vs. μ vs. e)
  - ➥ hardware improvements for electrons? ideas for τs?
- Flavour structure on the quark side (e.g. $b \rightarrow u$ vs. $b \rightarrow c$)
  - ➥ Possibilities in charm and top decays (not part of this talk)

A lot of this is not yet done, insufficient data
Close collaboration of experiment and theory necessary

Objectives of this talk:

- Examples of challenging systematics (th + exp)
- Going beyond $R(D^{(*)})$ in charged-current modes
- Identification of "clean" observables with differentiating power

What if the anomalies go away?

Think long & hard about systematic + theory uncertainties...

➥ Back to the drawing board

All these observable remain valuable! Strategies:

- Semi-true statement: "The smaller the SM rate, the larger the potential relative NP contribution"

➥ Strong motivation for (very) rare decays

- Large "Background" doesn't matter if you understand it well

➥ Motivation for tree-level modes

Theoretically, high precision can be achieved by that time:

- Basically all CC sl decays (LQCD), challenges at $\sim 1\%$-level
- Golden rare modes: $B_{d,s} \to \mu^+\mu^-$
- High-precision predictions for LFU ratios

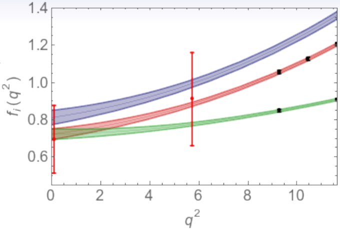
➥ Very precise, but also very specific

- Generally $b \to s(d)\ell^+\ell^-$, limits from charm-(charm+up-) quark loops, but recent proposals for control via data [Bobeth+,Blake+'18]

A couple of systematic issues

Form factors:

- V_{cb} + WCs only in combination w/ FFs
  - ➡ SM: shape from exp., normalization from non-perturbative methods
  - ➡ NP: FFs needed from theory, only!
- ➡ Reanalyses cannot resolve $R(D^{(*)})$
  [Bigi+,Grinstein+,Bernlochner+]



$B \to D$ FFs [MJ/Straub'18]

Branching ratio measurements: [MJ'15]

- Implicit isospin assumption in extraction of BRs at B factories
  - ➡ Affects BRs @ LHC, improvable with Belle (II) data
- ➡ Address isospin for high-precision measurements (e.g. f_u/f_d)

Implicit SM assumptions:

- Signal shape assumptions in CC sl decays
  - ➡ Has to be avoided for high precision NP analyses
  - ➡ Not trivial! How to present data model-independently?

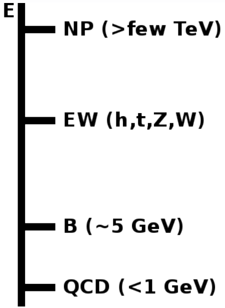
Spectroscopic Information:

$B \to D^{**}$ badly understood $\to$ measurements with D^{**}, $B_c \to J/\psi\tau\nu$

Higgs EFT(s)

Apparent gap between EW and NP scales:

- EFT approach at the electroweak scale:
  - ✓ SM particle content
  - ✓ SM gauge group
  - ? Embedding of h
  - ? Power-counting
  - Formulate NLO



Linear embedding of h:

- h part of doublet H
- Appropriate for weakly-coupled NP
- Power-counting: dimensions
  - Finite powers of fields
- LO: SM

Non-linear embedding of h:

- h singlet, U Goldstones
- Appropriate for strongly-coupled NP
- Power-counting: loops ($\sim \chi$PT)
  - Arbitrary powers of $h/v, \phi$
- LO: SM + modified Higgs-sector

Implications of the Higgs EFT for flavour [Cata/MJ'15]

$q \to q'\ell\ell$:

- Tensor operators absent in linear EFT for $d \to d'\ell\ell$ [Alonso+'14]
  ➥ Present in general! (already in linear EFT for $u \to u'\ell\ell$)
- Scalar operators: linear EFT $C_S^{(d)} = -C_P^{(d)}$, $C_S'^{(d)} = C_P'^{(d)}$ [Alonso+'14]
  ➥ Analogous for $u \to u'\ell\ell$, but no relations in general!

$q \to q'\ell\nu$:

- Relations between different transitions: weak doublets
  C_{V_R} is lepton-flavour universal [see also Cirigliano+'09]
  Relations between charged- and neutral-current processes, *e.g.*
  $\sum_{U=u,c,t} \lambda_{Us} C_{S_R}^{(U)} = -\frac{e^2}{8\pi^2}\lambda_{ts} C_S^{(d)}$ [see also Cirigliano+'12,Alonso+'15]
- These relations are again absent in the non-linear EFT

Flavour physics sensitive to Higgs embedding!
➥ Surprising, since no Higgs is involved
➥ Difficult differently [e.g. Barr+, Azatov+'15]

For NP below 1 TeV, SMEFT not really the best framework

Differentiating models with $b \to c\tau\nu$ observables

Large $R(D^*)$ possible with NP in V_L ($\hat{R}(X) = R(X)/R(X)_{SM} \sim 1.25$):

- can be related to anomaly in $B \to K^{(*)}\ell^+\ell^-$ modes
- $\hat{R}(X_c) = 0.99 \pm 0.10$ measured by LEP, oversaturation
- issues with $\tau \to \mu\nu\nu$ [Feruglio+'16] and $b\bar{b} \to X \to \tau^+\tau^-$ [Faroughy+'16]

Scalar NP: $R(D^*)$ limited by $\Gamma(B_c)$, worse issue w/ $b\bar{b} \to X \to \tau^+\tau^-$

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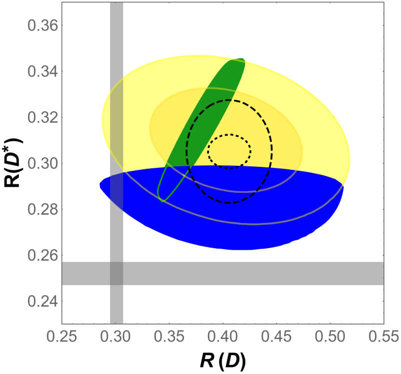
Fit results for the two scenarios for $B \to D^{(*)}\tau\nu$:



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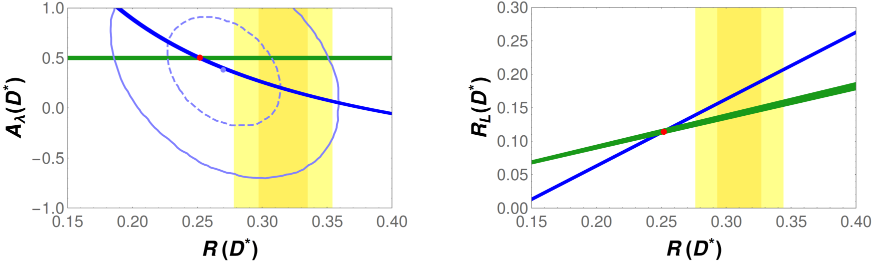
Scalar NP: $R(D^*)$ limited by $\Gamma(B_c)$, worse issue w/ $b\bar{b} \to X \to \tau^+\tau^-$

Fit predictions for polarization-dependent $B \to D^*\tau\nu$ observables:



Combination independent of scalar NP: [Celis/MJ/Li/Pich'13]

$$X_2^{D^{(*)}}(q^2) \equiv R_{D^{(*)}}(q^2)\left[A_\lambda^{D^{(*)}}(q^2) + 1\right] = X_{2,SM}^{D^{(*)}}(q^2)$$

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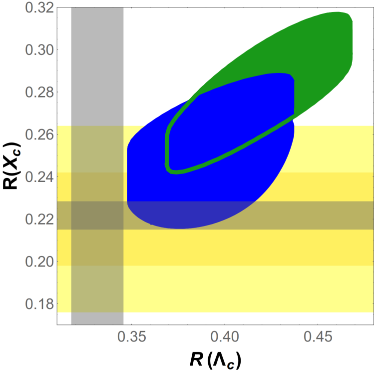
Scalar NP: $R(D^*)$ limited by $\Gamma(B_c)$, worse issue w/ $b\bar{b} \to X \to \tau^+\tau^-$

Fit predictions for $B \to X_c\tau\nu$ and $\Lambda_b \to \Lambda_c\tau\nu$:



Quark flavour structure: NP in $b \to u\tau\nu$ transitions

$b \to u\tau\nu$ less explored experimentally, $|V_{ub}/V_{cb}|^2 \lesssim 1\%$:

- $R(\tau) \equiv BR(B \to \tau\nu)/BR(B \to \pi\ell\nu)$ about 1.8σ from SM
- $R(\pi)$ not significantly measured yet

➥ Data consistent with SM as well as sizable NP

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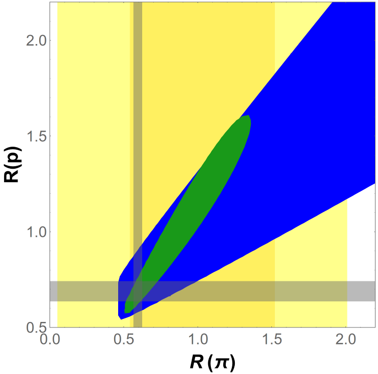
Analyse $b \to u\tau\nu$ individually:

➥ $R(\tau)$ yields correlation between $R(\pi)$ and $R(p)$



More observables needed!

Λ_b provides uncommon parameter combinations

$B_s \to K^{(*)}\tau\nu$ decays competitive?

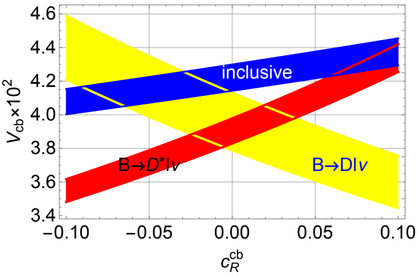
Detector requirements?

Pionic final states possible?

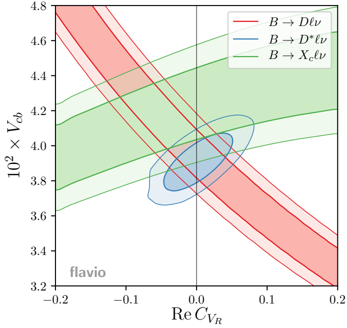
Lepton flavour structure: $b \to c\ell\nu$ decays [MJ/Straub'18]

Left-handed vector currents: $\tilde{V}^e_{cb}/\tilde{V}^\mu_{cb} = 1.011 \pm 0.012$

Right-handed vector currents: Affect $V_{cb}^{incl.}$ vs. $V_{cb}^{excl.}$ [e.g. Voloshin'97]



[Plot: updated from Crivellin/Pokorski'14]



Scalar currents: $q^2_{\rm max}$ $(B \to D)$ highly sensitive to NP [see also Nierste+'08]

Tensor currents: $q^2_{\rm min}$ $(B \to D^*)$ highly sensitive to NP

Similar to what we want to do for $b \to c\tau\nu$.

➥ Large impact of differential distributions

Prospects $b \to (u, c)(e, \mu)\nu$ @ LHCb

Potential unambiguous $|V_{xb}|$ determination before phase-II upgrade

➥ Measuring $b \to u, c\ell\nu$ not about this

Instead, model-independent determinations of NP contributions

- If FNU in $b \to c$ is confirmed, expect "something" in $b \to u$
- Also, with $b \to c\tau\nu$ affected, μ vs. e important to check
- Universality checks of right-handed currents interesting

$|V_{ub}/V_{cb}|$ from Λ_b important ingredient right now...

- Tests different NP combinations than mesonic modes
- Which observables are measurable?
- How much can we reduce the systematics?
- FFs need improvement, but not the main issue

$B_s \to K\ell\nu$ essentially probes the same physics as $B \to \pi\ell\nu$

➥ direct competition with Belle II

$B \to pp\ell\nu$ interesting new idea

➥ Challenging, qualititative theory progress required!

Prospects $b \to (s, d)\ell\ell'$ @ LHC

Again, model-independent determinations of NP contributions

- If NP in $b \to s$ is confirmed, expect "something" in $b \to d$
  - ➥ $|V_{td}/V_{ts}|^2 \sim 1/34 \to$ high luminosity important
- With $b \to s\mu\mu$ affected, μ vs. τ, e important to check
  - ➥ Angular analysis in $b \to see$
  - ➥ Golden Channel $b \to s\tau\tau$: improvements possible?
- Also $b \to (d, s)\nu\nu$ important $\to$ Belle II
- Other FCNCs partly related, $s \to d, t \to c, u, c \to u$

LFV: "generic" implication of NP in $\bar{\ell}\ell$ [Glashow+'15]

➥ Not always true, see e.g. [Celis/Fuentes-Martín/MJ/Serôdio,Alonso+'15]

➥ In any case worth looking for

Conclusions

Excellent physics potential for LHCb beyond Run 4

- $b \to c\ell\nu$ + $b \to s\ell\ell$: indications of lepton-non-universal NP
  - New measurements/observables constrain NP more severely
- Unprecendented control over uncertainties necessary
- Should tensions be real, they're established by LS 3
  - Expect smaller deviations anyway (smaller $R(D^*)$ would improve most NP interpretations)
  - Need to pin down precise strucure of NP (Dirac, flavour)
  - Need for distributions + polarization measurements
  - $b \to c\ell\nu$ shows potential
- Clean observables available to differentiate between different NP
- We start to constrain $b \to u$ + $b \to d$ transitions now
  - Experimentally challenging, HL indispensable

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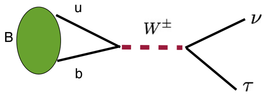
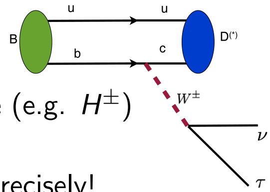
Thank you for your attention!

Importance of (semi-)leptonic hadron decays



In the Standard Model:

- Determination of $|V_{ij}|$ (7/9)



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
  ➡ Need to understand the SM very precisely!
- NP: Relative to tree, τ least constrained

Key advantages:

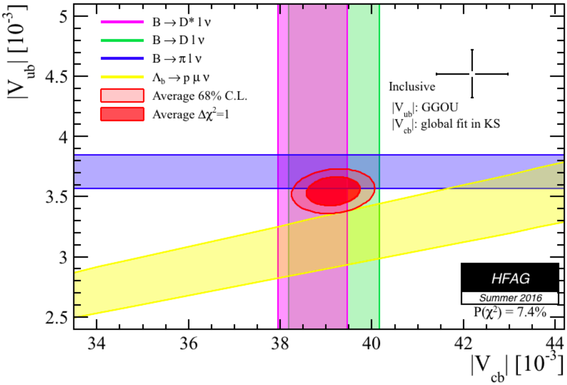
- Large rates
- Minimal hadronic input

➡ This input is systamatically improvable

Additionally: (almost) all flavour anomalies involve leptons

$|V_{xb}|$: inclusive versus exclusive

Long-standing problem:



- Very hard to explain by NP [Crivellin/Pokorski'15] (but see [Colangelo/de Fazio'15])

➥ Likely experimental/theoretical systematics

$|V_{xb}|$: Recent developments

V_{cb}:

Recent Belle $B \to D, D^* \ell\nu$ analyses

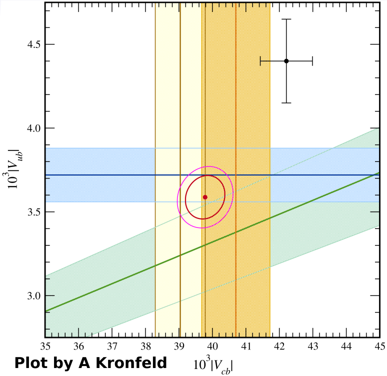
Recent lattice results for $B \to D$ [FNAL/MILC, HPQCD, RBC/UKQCD (ongoing)]

- $B \to D$ between incl. + $B \to D^*$

New lattice result for $B \to D^*$ [HPQCD]

- $V_{cb}^{\rm incl}$ cv, compatible with old result

$B \to D^* \ell\nu$ re-analyses with CLN, $|V_{cb}| = 39.3(1.0)10^{-2}$ [Bernlochner+'17] + BGL [Bigi+,Grinstein+'17] (Belle only), $|V_{cb}| = 40.4(1.7)10^{-2}$

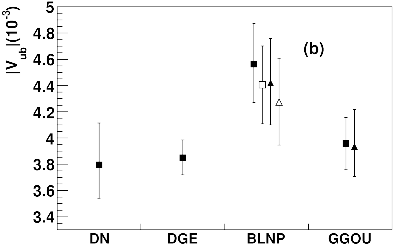


Plot by A Kronfeld

New BaBar analysis of V_{ub} incl.:

Dependence on theory treatment!

- GGOU 2σ lower than WA
- Compatible w/ PDG exclusive avg



Hints towards resolution, not yet conclusive

New systematics: BR measurements and isospin violation

Branching ratio measurements require normalization...

- B factories: depends on $\Upsilon \to B^+B^-$ vs. $B^0\bar{B}^0$
- LHCb: normalization mode, usually obtained from B factories

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Assumptions entering this normalization:

- PDG: assumes $r_{+0} \equiv \Gamma(\Upsilon \to B^+B^-)/\Gamma(\Upsilon \to B^0\bar{B}^0) \equiv 1$
- LHCb: (mostly) assumes $f_u \equiv f_d$, uses $r_{+0}^{\mathrm{HFAG}} = 1.058 \pm 0.024$

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Both approaches problematic: [MJ'16 [1510.03423]]

- Potential large isospin violation in $\Upsilon \to BB$ [Atwood/Marciano'90]
- Measurements in r_{+0}^{HFAG} assume isospin in exclusive decays
  - ➥ This is one thing we want to test!

➥ Avoiding this assumption yields $r_{+0} = 1.027 \pm 0.037$

- Isospin asymmetries test NP with $\Delta I = 1, 3/2$ (e.g. $b \to s\bar{u}u$)
  - ➥ Isospin asymmetry $B \to J/\psi K$: $A_I = -0.009 \pm 0.024$

Affects every percent-level BR measurement
$B \to J/\Psi K$ can be used to determine f_u/f_d!

SM predictions

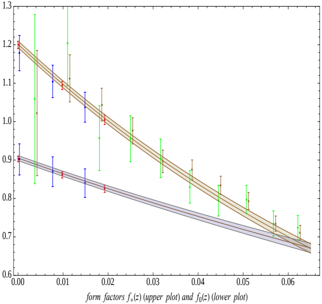
SI amplitude: kinematics $\times$ FC coupling (SM: CKM) $\times$ form factor

Strategy SM predictions: V_{cb} + leading FF cancels
data + theoretical input from LQCD/HQET for FF ratios

$B \to D$: 2 form factors $f_{+,0}$

- Data determines shape of $f_+(q^2)$
- LQCD required for f_0: fit HPQCD + FNAL/MILC, use $f_+(0) = f_0(0)$

➥ $R(D) = 0.301 \pm 0.003$ [Bigi/Gambino'16]



$B \to D^*$: 4 form factors $V, A_{0,1,2}$

- 3/4 $\to$ data (+HQET, unitarity $\to$ CLN)
- HQET for A_0 [Falk/Neubert] , enhance uncertainty [Fajfer/Kamenik]

➥ $R(D^*) = 0.252 \pm 0.003$, (0.257 from re-analysis [Bernlochner+'17])

- LQCD for non-maximal recoil underway

(Very) good control, effect too large to be in CLN relations

NP in (semi-)leptonic decays

EFT for $b \to c\tau\nu$ transitions (no light ν_R, SM: $C_{V_L} = 1, C_{i\neq V_L} = 0$):

$$\mathcal{L}_{\rm eff}^{b\to c\tau\nu} = -\frac{4G_F}{\sqrt{2}} V_{cb} \sum_j^5 C_j \mathcal{O}_j \,, \qquad \text{with}$$

$$\mathcal{O}_{V_{L,R}} = (\bar{c}\gamma^\mu P_{L,R} b)\bar{\tau}\gamma_\mu\nu \,, \; \mathcal{O}_{S_{L,R}} = (\bar{c}P_{L,R}b)\bar{\tau}\nu \,, \; \mathcal{O}_T = (\bar{c}\sigma^{\mu\nu}P_L b)\bar{\tau}\sigma_{\mu\nu}\nu \,.$$

NP models typically generate subsets; for a charged scalar:
NP couplings $C_{S_{L,R}}$ (complex), $C_{V_L} = C_{V_L}^{\rm SM} = 1$, $C_{V_R} = C_T = 0$

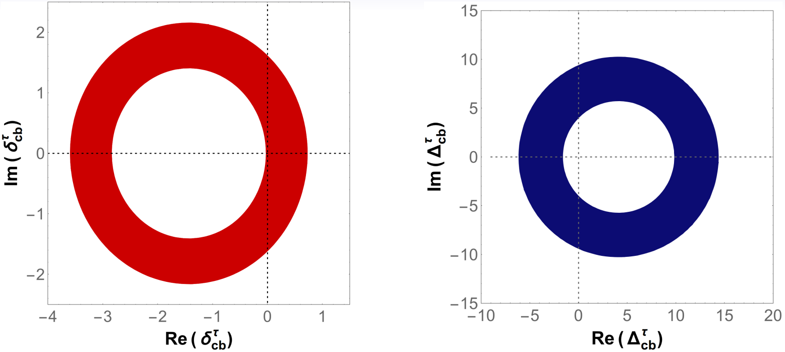
- Model-independent subclass as long as $C_{S_{L,R}}$ general
- Phenomenologically $C_{SL,R}^{q_u q_d l} \sim m_{q_{ud}} m_l$ (e.g. Type III)

➡ Used to illustrate here, appearing combinations:

$$R(D):\; \delta^{cbl} \equiv \frac{(C_{S_L}+C_{S_R})(m_B-m_D)^2}{m_l(\bar{m}_b-\bar{m}_c)} \qquad R(D^*):\Delta^{cbl} \equiv \frac{(C_{S_L}-C_{S_R})m_B^2}{m_l(\bar{m}_b+\bar{m}_c)}$$

Can trivially explain $R(D^{(*)})$! Exclusion possible with specific flavour structure or more $b \to c\tau\nu$ observables!

$b \to c\tau\nu$ data and scalar NP [Celis/MJ/Li/Pich'17]



$R(D), R(D^*)$:

- $R(D)$ compatible with SM at $\sim 2\sigma$
- Preferred scalar couplings from $R(D^*)$ huge ($|C_{S_L} - C_{S_R}| \sim 1 - 5$)
- Can't go beyond circles with just $R(D, D^*)$!

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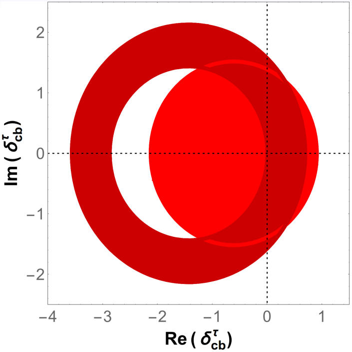
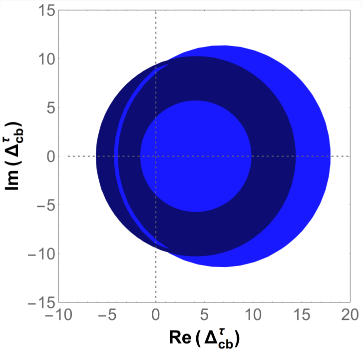
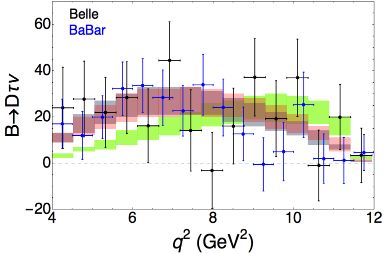


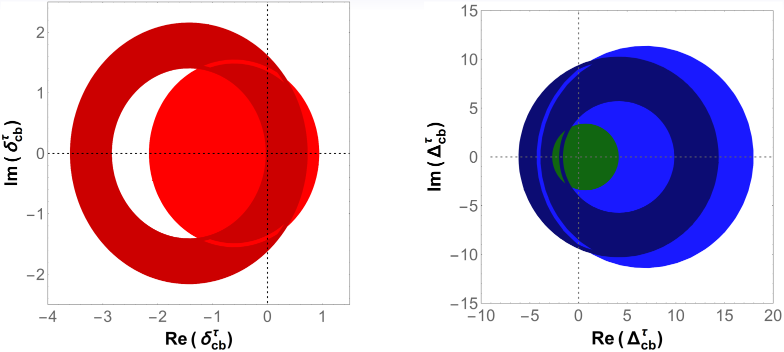


Differential rates:

- compatible with SM and NP
- already now constraining, especially in $B \to D\tau\nu$
- "theory-dependence" of data needs addressing [Bernlochner+'17]



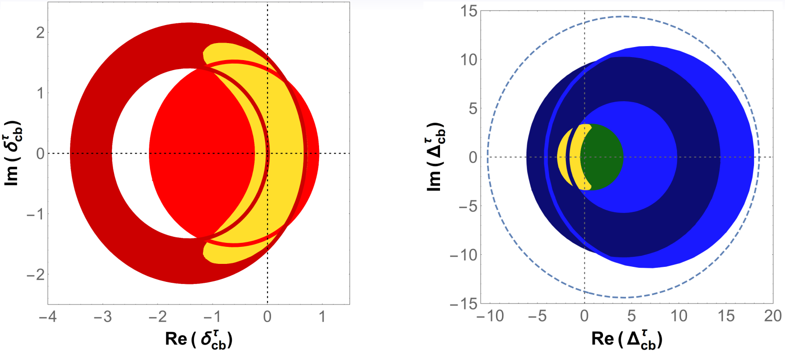
$b \to c\tau\nu$ data and scalar NP [Celis/MJ/Li/Pich'17]



Total width of B_c:

- $B_c \to \tau\nu$ is an obvious $b \to c\tau\nu$ transition
  - ➥ not measurerable in foreseeable future
  - ➥ can oversaturate total width of B_c! [X.Li+'16]
- Excludes second real solution in Δ^{τ}_{cb} plane (even scalar NP for $R(D^*)$? [Alonso+'16])

$b \to c\tau\nu$ data and scalar NP [Celis/MJ/Li/Pich'17]



τ polarization:

- So far not constraining (shown: $\Delta\chi^2 = 1$)
- Differentiate NP models: with scalar NP [Celis/MJ/Li/Pich'13]

$$X_2^{D^{(*)}}(q^2) \equiv R_{D^{(*)}}(q^2)\left[A_\lambda^{D^{(*)}}(q^2)+1\right] = X_{2,SM}^{D^{(*)}}(q^2)$$

Consistent explanation in 2HDMs possible, flavour structure?

Generic features and issues in 2HDMs

Charged Higgs possible as explanation of $b \to c\tau\nu$ data...
However, typically expect $\Delta R(D^*) < \Delta R(D)$

Generic feature: Relative influence larger in leptonic decays!

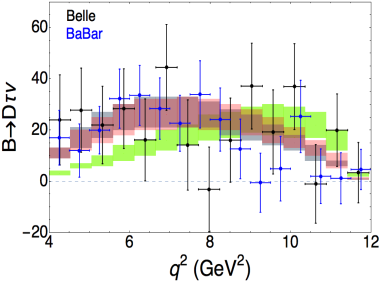
- No problem in $b \to c\tau\nu$ since $B_c \to \tau\nu$ won't be measured
- Large charm coupling required for $R(D^*)$
- ➥ Embedding $b \to c\tau\nu$ into a viable model complicated!
- ➥ $D_{d,s} \to \tau, \mu\nu$ kill typical flavour structures with $C_{S_{L,R}} \sim m$
- ➥ Only fine-tuned models survive all (semi-)leptonic constraints

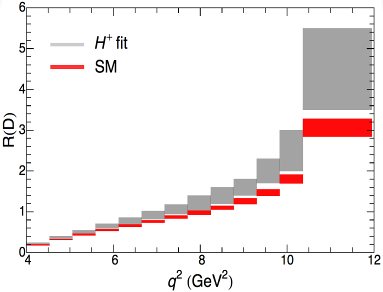
$b \to s\ell\ell$ very complicated to explain with scalar NP
➥ 2HDM alone tends to predict $b \to s\ell\ell$ to be QCD-related

$b\bar{b} \to (H, A) \to \tau^+\tau^-$ poses a severe constraint [Faroughy+'16]

2HDMs strongly prefer a smaller value for $R(D^*)$!

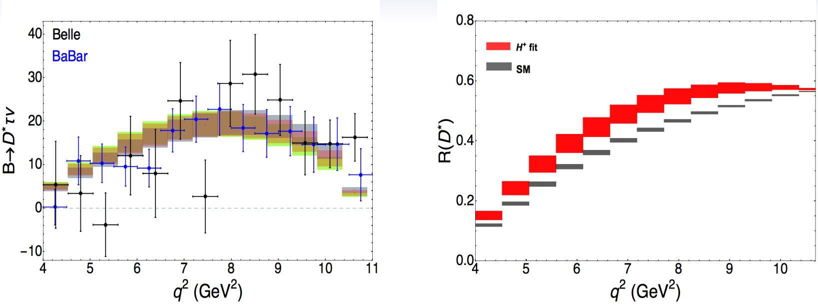
The differential distributions $d\Gamma(B \to D^{(*)}\tau\nu)/dq^2$





- Data stat. uncertainties only, BaBar rescaled
- Bands 68% CL (bins highly correlated):
  Grey: NP fit including $R(D)$
  Red: SM fit (distributions only)
  Green: Allowed by $R(D)$, excluded by distribution
- Need better experimental precision, ideally $dR(D)/dq^2$
- Parts of NP parameter space clearly excluded

The differential distributions $d\Gamma(B \to D^{(*)}\tau\nu)/dq^2$



- Data stat. uncertainties only, BaBar rescaled
- Bands 68% CL (bins highly correlated):
  Grey: NP fit including $R(D^*)$
  Red: SM fit (distributions only)
  Green: Allowed by $R(D^*)$, excluded by distribution
- Need better experimental precision, ideally $dR(D^*)/dq^2$
- Not very restrictive at the moment

Implications of the Higgs EFT for Flavour: $q \to q' \ell \nu$

$b \to c\tau\nu$ transitions (SM: $C_{V_L} = 1, C_{i \neq V_L} = 0$):

$$\mathcal{L}_{\text{eff}}^{b\to c\tau\nu} = -\frac{4G_F}{\sqrt{2}} V_{cb} \sum_j^5 C_j \mathcal{O}_j \,, \qquad \text{with}$$

$$\mathcal{O}_{V_{L,R}} = (\bar{c}\gamma^\mu P_{L,R} b)\bar{\tau}\gamma_\mu \nu \,, \qquad \mathcal{O}_{S_{L,R}} = (\bar{c} P_{L,R} b)\bar{\tau}\nu \,,$$

$$\mathcal{O}_T = (\bar{c}\sigma^{\mu\nu} P_L b)\bar{\tau}\sigma_{\mu\nu}\nu \,.$$

- All operators are independently present already in the linear EFT
- However: Relations between different transitions:
  C_{V_R} is lepton-flavour universal [see also Cirigliano+'09]
  Relations between charged- and neutral-current processes, *e.g.*
  $\sum_{U=u,c,t} \lambda_{Us} C_{S_R}^{(U)} = -\frac{e^2}{8\pi^2} \lambda_{ts} C_S^{(d)}$ [see also Cirigliano+'12,Alonso+'15]
- These relations are again absent in the non-linear EFT

Matching for $b \to c\ell\nu$ transitions

$$
\begin{aligned}
C_{V_L} &= -\mathcal{N}_{\rm CC}\left[C_L + \frac{2}{v^2}c_{V5} + \frac{2V_{cb}}{v^2}c_{V7}\right], \\
C_{V_R} &= -\mathcal{N}_{\rm CC}\left[\hat{C}_R + \frac{2}{v^2}c_{V6}\right], \\
C_{S_L} &= -\mathcal{N}_{\rm CC}\left(c'_{S1} + \hat{c}'_{S5}\right), \\
C_{S_R} &= 2\,\mathcal{N}_{\rm CC}\left(c_{LR4} + \hat{c}_{LR8}\right), \\
C_T &= -\mathcal{N}_{\rm CC}\left(c'_{S2} + \hat{c}'_{S6}\right),
\end{aligned}
$$

where $\mathcal{N}_{\rm CC} = \frac{1}{2V_{cb}}\frac{v^2}{\Lambda^2}$, $C_L = 2c_{LL2} - \hat{c}_{LL6} + \hat{c}_{LL7}$ and $\hat{C}_R = -\frac{1}{2}\hat{c}_{Y4}$.

List of minimal χ^2 values

Scenario	χ^2_{min}	# obs.	# pars.	central values (δ^τ_{cb}, Δ^τ_{cb})
		$R(D^{(*)})$ only		
SM	23.1	2	0	—
S1	0	2	4	$(0.2 + 0.7i, 10.0 - 6.3i)$
S1 real	0	2	2	$(0.4, -3.6)$
$g_L^{cb\tau}$	0	2	2	$g_L^{cb\tau} = -1.3 - 0.6i$
$g_R^{cb\tau}$	9.1	2	2	$g_R^{cb\tau} = 0.3 + 0.i$
g_{V_L}	0.2	2	1	$\lvert g_{V_L}\rvert = 1.12$
		$R(D^{(*)})$, $d\Gamma/dq^2$, Γ_{B_c}		
SM	65.9	61	4	—
S1	49.2	61	8	$(0.4 + 0.i, -2.4 + 0.i)$
S1 real	49.2	61	6	$(0.4, -2.4)$
$g_L^{cb\tau}$	55.4	61	6	$g_L^{cb\tau} = -0.4 + 0.8i$
$g_R^{cb\tau}$	55.4	61	6	$g_R^{cb\tau} = 0.3 + 0.i$
g_{V_L}	42.4	61	5	$\lvert g_{V_L}\rvert = 1.12$
		$R(D^{(*)})$, $d\Gamma/dq^2$, Γ_{B_c}, $R(X_c)$		
SM	65.9	62	4	—
S1	50.4	62	8	$(0.3 + 0.i, -2.4 + 0.i)$
S1 real	50.4	62	6	$(0.3, -2.4)$
$g_L^{cb\tau}$	55.4	62	6	$g_L^{cb\tau} = -0.4 - 0.8i$
$g_R^{cb\tau}$	56.1	62	6	$g_R^{cb\tau} = 0.2 + 0.i$
g_{V_L}	46.7	62	5	$\lvert g_{V_L}\rvert = 1.10$