Challenges in Flavor Physics

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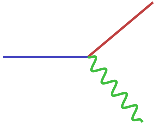
SM Flavor

Nutshell: How do we describe quark/lepton interactions?

SM EW Lagrangian:

$$\mathcal{L}_{\rm EW} = \frac{g_2}{\sqrt{2}} \begin{pmatrix} u & c & t \end{pmatrix} \not{W} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



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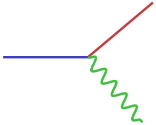


CKM matrix
3×3 unitary $\sim$

$$\begin{pmatrix} 1 & 0.2 & 4\,10^{-3} \\ 0.2 & 1 & 4\,10^{-2} \\ 4\,10^{-3} & 4\,10^{-2} & 1 \end{pmatrix}$$

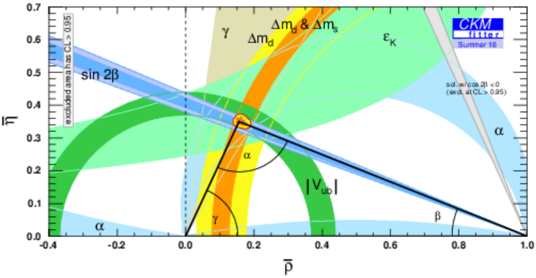
In the SM:

- Flavor changing processes through electroweak charged currents (CC)
- No tree-level flavor changing neutral currents (FCNC)
- Similar story for charged leptons with ν masses

Flavor Data

Can test SM flavor structure with CKM unitarity triangles, e.g.

$$V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 0$$



CKMfitter

- Huge multitude of physical observables projected onto CKM parameter plane (from decays, (in)direct CP violation, mass splittings Δm. . .)
- SM $\Longrightarrow$ all allowed regions should intersect. Lesson: Good agreement with SM flavor structure
- Leads to powerful constraints and powerful discovery potential

New Physics (NP) Constraints

History:

- $n \to pe\nu$: Energy scale $\sim$ MeV, probes EW current at ~ 100 GeV!
- $\Delta m_K / m_K \simeq 7 \times 10^{-15}$ predicted charm, $m_c \sim 1$–2GeV

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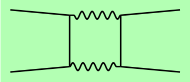
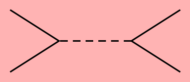
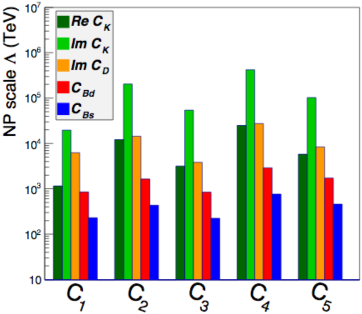
Constraints on 4-Fermi FCNC operators from e.g. meson mixing

$$\frac{(\overline{q}\Gamma q')(\overline{q}'\Gamma' q)}{\Lambda^2}$$ via:  vs 

UTfit 1411.7233



Indirect access to scales $\sim 10^4$ TeV far above LHC direct production!

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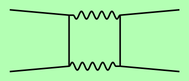
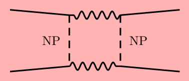
$$\frac{V_{td} V_{ts}}{16\pi^2} \frac{(\bar{q}\Gamma q')(\bar{q}'\Gamma' q)}{\Lambda^2}$$ via:  vs 

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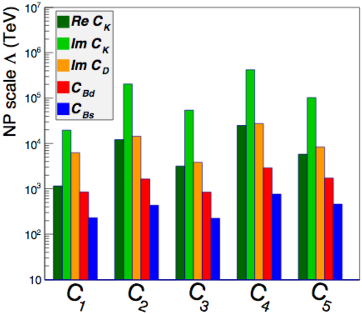
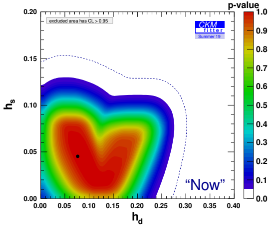


Indirect access to scales $\sim 10^4$ TeV far above LHC direct production!

But, with loop + CKM suppression: NP/SM $\sim$ 20% in FCNC still compatible!

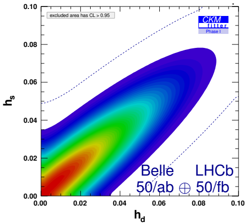
Loop-level sensitivities

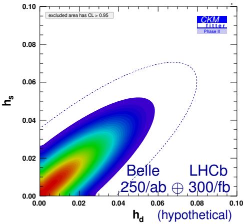
Future sensitivity to NP in B mixing



- What NP parameter space can be probed?
- $h_{d,s} \Leftrightarrow$ NP scale: $h \simeq \frac{|C_{ij}|^2}{|V_{ti}^* V_{tj}|^2} \left(\frac{4.5\ \text{TeV}}{\Lambda} \right)^2$ [2006.04824]

Couplings	NP loop order	Sensitivity for Summer 2019 [TeV]		Phase I Sensitivity [TeV]		Phase II Sensitivity [TeV]	
		B_d mixing	B_s mixing	B_d mixing	B_s mixing	B_d mixing	B_s mixing
$\lvert C_{ij}\rvert = \lvert V_{ti}V_{tj}^*\rvert$	tree level	9	13	17	18	20	21
(CKM-like)	one loop	0.7	1.0	1.3	1.4	1.6	1.7
$\lvert C_{ij}\rvert = 1$	tree level	1×10^3	3×10^2	2×10^3	4×10^2	2×10^3	5×10^2
(no hierarchy)	one loop	80	20	2×10^2	30	2×10^2	40





Big improvements in 2020s

Complementary to high-p_T searches

Then theory improves or progress slows

Courtesy Z Ligeti

ZL – p. 22

Lepton Flavor Universality

LFU tested to great precision

LFU tests with 1st/2nd gen.

To **0.28%** in Z decays: $\frac{\Gamma_{Z\to\mu\mu}}{\Gamma_{Z\to ee}} = 1.0009 \pm 0.0028$ — LEP, Phys. Rept. 427 (2006) 257

To **0.8%** in W decays: $\frac{\mathscr{B}(W\to e\nu)}{\mathscr{B}(W\to \mu\nu)} = 1.004 \pm 0.008$ — CDF + LHC, JPG: NPP, 46, 2 (2019)

$\frac{\Gamma_{J/\psi\to\mu\mu}}{\Gamma_{J/\psi\to ee}} = 1.0016 \pm 0.0031$ — PDG (BESIII), RPP, Chin. Phys. C40 (2016) 100001

To **0.31%** in meson decays: $\frac{\Gamma_{K\to e\nu}}{\Gamma_{K\to\mu\nu}} = (2.488 \pm 0.009)\times 10^{-5}$ — PDG (NA62), RPP, Chin. Phys. C40 (2016) 100001

$\frac{\Gamma_{\pi\to e\nu}}{\Gamma_{\pi\to\mu\nu}} = (1.230 \pm 0.004)\times 10^{-4}$ — PiENu, Phys. Rev. Lett. 115, 071801 (2015)

To **0.14%** in $\tau\to\ell\nu\nu$: $g_\mu/g_e = 1.0018 \pm 0.0014$ — PDG, A. Pich, Prog. Part. Nucl. Phys. 75 (2014) 41

LFU tests with 3rd gen.

To **0.32%** in Z decays: $\frac{\Gamma_{Z\to\tau\tau}}{\Gamma_{Z\to ee}} = 1.0019 \pm 0.0032$ — LEP, Phys. Rept. 427 (2006) 257

2.6σ tension in W decays: $\frac{\Gamma_{W\to\tau\nu}}{\Gamma_{W\to\mu\nu}} = 1.070 \pm 0.026$ — LEP, Phys. Rept. 532 (2013) 119,

To **1.3%** in W decays: $\frac{\Gamma_{W\to\tau\nu}}{\Gamma_{W\to\mu\nu}} = 0.992 \pm 0.013$ — ATLAS, arXiv:2007.14040

To **6.1%** in D_s decays: $\frac{\Gamma_{D_s\to\tau\nu}}{\Gamma_{D_s\to\mu\nu}} = 9.95 \pm 0.61$ — HFLAV, Eur. Phys. J. C77 (2017) 895

To **0.15%** in $\tau\to\ell\nu\nu$ (with τ_τ): $g_\tau/g_\mu = 1.0030 \pm 0.0015$ — PDG, S. Pich, Prog. Part. Nucl. Phys. 75 (2014) 41

Manuel Franco Sevilla — $\mathscr{R}(D^{(*)})$, $\mathscr{R}_{K^{(*)}}$, and their cousins: update on the continued challenges to LFU — Slide 6

Courtesy M Franco Sevilla

(Rough) Perspectives on Flavor Probes

NP

Smoking Guns

Enhancement of
rare/forbidden SM

Flavor symmetry violation

- $K \to \pi\nu\nu$
- $\mu \to e$
- $b \to c\ell\nu$: τ vs e,μ
- $b \to s\ell\ell$: e vs μ
- CKM Unitarity
- ...

Theoretically
Clean

Precision Th.
Control

Tensions:
Measurements vs predictions

- $|V_{cb}|$, $|V_{ub}|$
- $(g-2)_\mu$
- ΔA_{CP} in charm
- $b \to s\mu\mu$
- ...

Precision Flavor

Constrain high NP scales
(no obs $\gg$ SM prediction)

- $B_s \to \mu\mu$
- $\Delta M_{s,d}$
- $b \to s\nu\nu$
- ...

Flavor Models

Explain SM hierarchies:
Quark/lepton mass and mixing
Can imply NP signals

SM

(Rough) Perspectives on Flavor Probes

Precision Th. Control

NP

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Today: mainly look at challenges in Heavy Flavor

els
ies:
mixing
Can imply NP signals

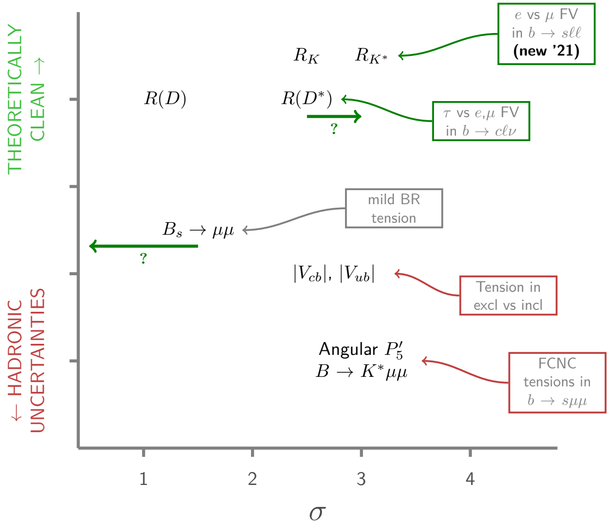
SM

Theoretically Clean

See also Bhupal Dev's talk on Monday; Sheldon Stone's talk today

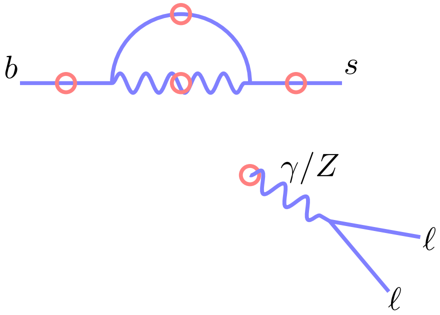
Space of Heavy Flavor Anomalies

Involving $B_q = (bq)$ mesons



Adapted from Z Ligeti and W Altmannshofer

Rare decays: $b \to s\ell\ell$



- Loop (penguin) process

$$\mathcal{M} \sim \frac{1}{16\pi^2}\frac{g^4}{m_W^2}V_{ts}V_{tb}\frac{m_t^2}{m_W^2}$$

- Experimentally clean signal: $B \to K^{(*)}\ell\ell$

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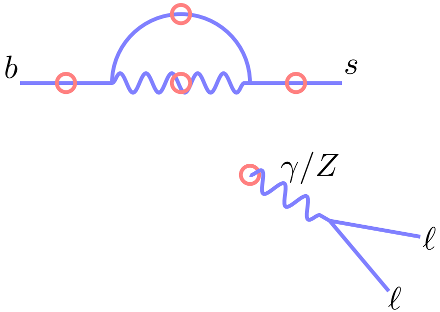

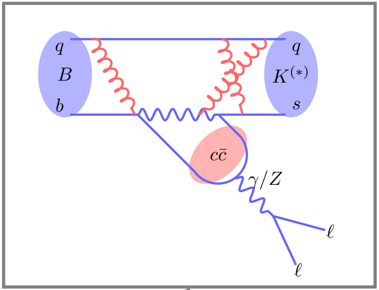

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- Experimentally clean signal: $B \to K^{(*)}\ell\ell$
- But hadronic uncertainties less clear (long distance $c\bar{c}$)

Lepton Universality Tests

Factor out hadronic uncertainties: Consider ratio

$$R_{K^{(*)}} = \frac{B \to K^{(*)}\mu\mu}{B \to K^{(*)}ee} \qquad \text{(in various } q^2 \text{ binnings)}$$

Should be 1.00 ± 0.01 in SM!

Bordone, Isidori, Pattori [1605.07633]

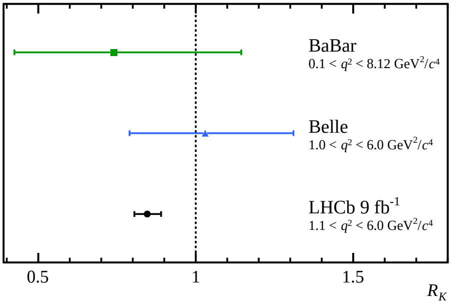
New Run II result from LHCb; $1.1 \leq q^2 \leq 6\,\text{GeV}^2$

Prior: $R_{K^+} = 0.846^{+0.060+0.016}_{-0.054-0.014}$

Updated: $R_{K^+} = 0.846^{+0.042+0.013}_{-0.039-0.012}$

Tension now at $2.5 \to 3.1\sigma$

[For eagle-eyed, central value remained the same despite shifts in the *Kee* fit, likely because of slight changes in analysis technique]



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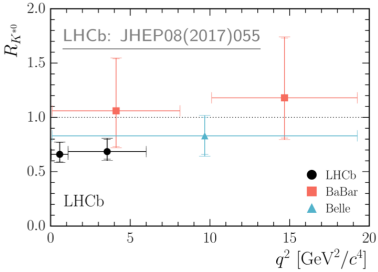
Lepton Universality Tests

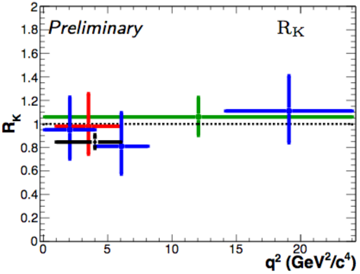
Also in the $1.1 \leq q^2 \leq 6\,\text{GeV}^2$ bin

$$R_{K^{*0}} = 0.71^{+0.12}_{-0.09}$$

https://hflav.web.cern.ch/

- LHCb update of $R_{K^{*0}}$ in the near term?
- Belle, BaBar in other q^2 bins compatible with SM





Belle EPS-HEP [Choudhury]

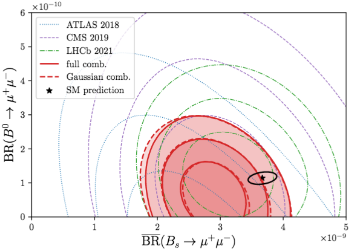
Rare Leptonic Decays

Associated meas. of $B_{(s)} \to \mu\mu$

Combination ALTAS+CMS+LHCb:

$$BR_{\text{exp}}(B_s \to \mu\mu) = (2.93 \pm 0.35) \times 10^{-9}$$
$$BR_{\text{SM}}(B_s \to \mu\mu) = (3.67 \pm 0.15) \times 10^{-9}$$

Approx 2σ tension



Altmannshofer, Stangl 2103.13370

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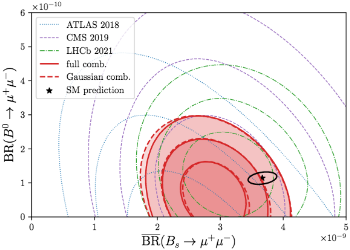

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Caveat: The SM prediction

$$BR_{\rm SM}(B_s \to \mu\mu) \sim |\, C_{10}^{\rm SM}\, V_{tb}\, V_{ts}\,|^2 f_{B_s}\,(\ldots)$$

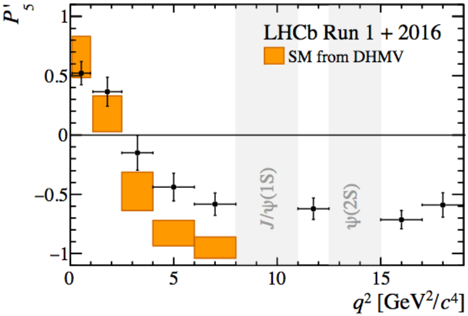
Wilson Coeff known to high precision

$b - s$ CKM unitarity: Sensitive to $|V_{cb}|$ incl-excl. tension (below)! [Using exclusive $|V_{cb}|$ determination could relax BR tension entirely?!]

Puzzle: Precision moments

Measure angular distributions in

$$B \to K^*(\to K\pi)\mu\mu$$



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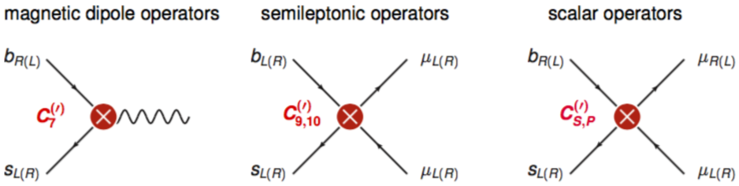
Deviations of about 2.5σ in several q^2 bins, but SM predictions are hard. [see also 'ASZB' SM predictions]

NP Explanations?



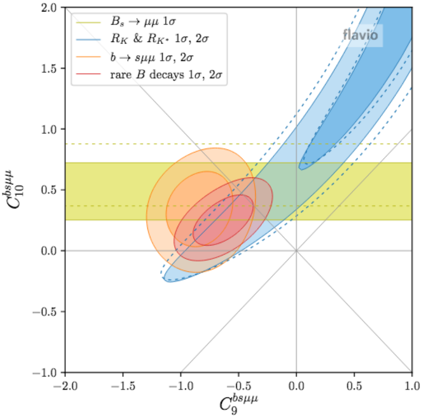
Courtesy W Altmannshofer

SM-like SL operators at dimension-6:

$$\frac{C_9^{(\prime)}}{\Lambda^2}(\bar{s}\gamma_\mu P_{L(R)} b)(\mu\gamma^\mu\mu) + \frac{C_{10}^{(\prime)}}{\Lambda^2}(\bar{s}\gamma_\mu P_{L(R)} b)(\mu\gamma^\mu\gamma^5\mu)$$

Normalized against loop SM: $\Lambda \sim 4\pi v/\sqrt{V_{tb}V_{ts}} \sim 10\,\mathrm{TeV}$.
Expect 10 TeV scale NP

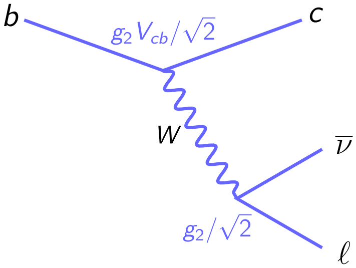
Global NP Fit



Altmannshofer, Stangl 2103.13370

- Large amount of NP model building
- Typically leptoquarks or Z' models (e.g. gauged $L_\mu - L_\tau$)
- Some attempts to relate to $R(D^{(*)})$ [Next!]

Semileptonic Decays: $b \to c\ell\nu$



- Tree-level W exchange (in the SM)
- Approx. 25% of all B decays: huge statistics!

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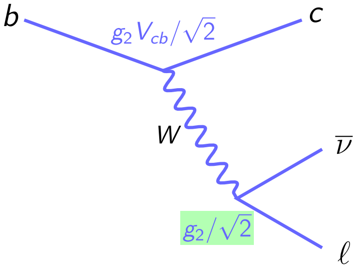

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- Theoretically clean:

Probe of lepton flavor universality

g_2 ($\ell = e, \mu, \tau$) up to masses:

$m_\tau \simeq 1777$MeV vs $m_\mu = 105$MeV;

PS and hadronic effects

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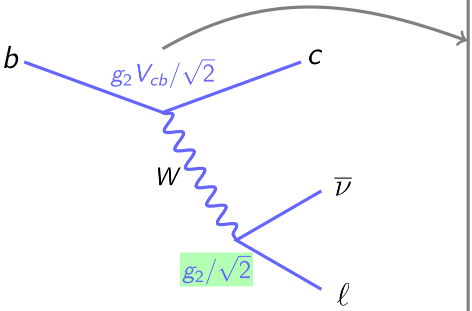

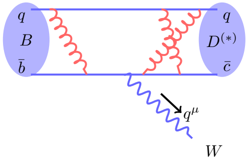

NB: Hadronic decays:

$B \to D^{(*,**)}$ (spin 0, 1, ...)

$\Lambda_b \to \Lambda_c^{(*)}$ (spin 1/2, ...)

...

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Probe of lepton flavor universality g_2 ($\ell = e, \mu, \tau$) up to masses: $m_\tau \simeq 1777$MeV vs $m_\mu = 105$MeV; PS and hadronic effects

Measurement of $|V_{cb}|$ inclusively (OPE)

Hadronic matrix elements $\Longrightarrow$ measure $|V_{cb}|$ in exclusive $l = e, \mu$ modes

Two Anomalies/Puzzles

1. Inclusive $B \to X_c l\nu$ versus exclusive $B \to D^* l\nu$

   Measurement is done with $l = e, \mu$: The τ mode involves more ν's from τ decays and less statistics

$$|V_{cb}|_{X_c} \simeq (42.2 \pm 0.8) \times 10^{-3}$$
$$|V_{cb}|_{D^*} \simeq (38.7 \pm 0.7) \times 10^{-3}$$

   A 3σ tension?!?

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$\mathrm{BR_{SM}}(B_s \to \mu\mu) = 3.08(12) \times 10^{-9}$ versus $2.93(35) \times 10^{-9}$.
No more anomaly!?
Cf $|V_{ts}| \sim 38.8(1) \times 10^{-3}$ in PDG

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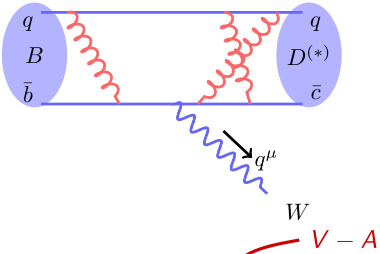
2. Factor out $|V_{cb}|$, measure lepton flavor universality violation (LFUV) ratios

$$R(H_c) \equiv \frac{\Gamma[H_b \to H_c \tau\nu]}{\Gamma[H_b \to H_c l\nu]}, \qquad l = e, \mu\,.$$

H_b :	B	B_s	Λ_b	B_c
H_c :	D, D^*, D^{**}	$D_s^{(*,**)}$	Λ_c, Λ_c^*	J/ψ

Puzzle: Hadronic Matrix Elements

For exclusive processes: Main theory uncertainty is mapping partons → hadrons:



- $|V_{cb}|$: Need SM predictions for $\langle D^{(*)} | \bar{c}\,\Gamma\, b | \bar{B} \rangle$
- $R(D^{(*)})$: Some SM matrix elements couple $\sim m_\tau$. Suppressed in e, μ.
- $R(D^{(*)})$: Need NP predictions for $\langle D^{(*)} | \bar{c}\,\Gamma\, b | \bar{B} \rangle$ for any NP current

  $V \pm A$, S, P or T

- Use parametrizations of form factors. Ultimate(?): Lattice calculations

$|V_{cb}|$ Determination

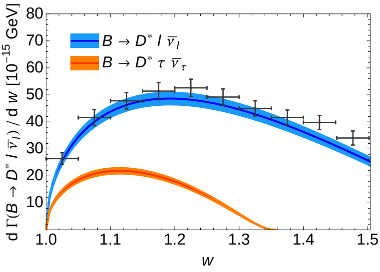
Represent $B \to D^*$ matrix elements wrt form factors (FF):

$$\langle D^* | \bar{c}\Gamma^\mu b | \bar{B}\rangle \sim FF_\varepsilon(q^2)\,\varepsilon^\mu + FF_B(q^2)\,p_B^\mu + FF_{D^*}(q^2)\,p_{D^*}^\mu\,,$$

$$\frac{d\Gamma[B \to D^* l\nu]}{dw} \sim |V_{cb}|^2\sqrt{w^2-1} \times \mathcal{F}(w)^2\,, \qquad w = (m_B^2 + m_{D^*}^2 - q^2)/(2m_B m_{D^*})$$

Phase space $\to 0$ as $w \to 1$

Comb. of FFs. $\mathcal{F}(1)$ computed by lattice



- Obtain $|V_{cb}|\mathcal{F}(1)$ by fitting $d\Gamma/dw$ and extrapolating to $w = 1$
- $\mathcal{F}(1)$ from lattice $\implies |V_{cb}|$
- Extrapolation into low stats region highly sensitive to FF fit
- Care with choice of FF parametrization and theory inputs!

$|V_{cb}|$ Developments

- "Traditional" experimental approach uses "CLN" param: HQET plus QCD sum rules (actually inconsistent with heavy quark expansion, but can be repaired Bernlochner, Ligeti, Papucci, DR [1703.05330])

$$|V_{cb}|_{\text{`CLN'}} = (38.2 \pm 1.5) \times 10^{-3}\,, \quad \text{1702.01521 [Belle]}$$

- Unfolded $B \to D^* l \nu$ Belle dataset 1702.01521. Permitted fits to different FF param choices: "BGL" param using only analyticity and unitarity

$$|V_{cb}|_{\text{`BGL'}} = (41.7^{+2.0}_{-2.1}) \times 10^{-3}\,, \quad \text{1703.06124, 1707.09509 [Bigi, Gambino, Schacht]}$$
$$|V_{cb}|_{\text{`BGL'}} = (41.9^{+2.0}_{-1.9}) \times 10^{-3}\,, \quad \text{1703.08170 [Grinstein, Kobach]}$$

- $|V_{cb}|_{\text{incl}} = (42.2 \pm 0.8) \times 10^{-3}$: Resolves $|V_{cb}|$ incl vs excl tension? The fits lifting $|V_{cb}|$ led to HQET tensions BLPR [1708.07134, 1902.09553].
- Subsequent Belle untagged analysis:

$$|V_{cb}|_{\text{`BGL'}} = (38.4 \pm 0.7) \times 10^{-3} \quad \text{Belle 1809.03290}$$

- But: Sensitive to truncation order of the BGL expansion BLPR [1902.09553]

$|V_{cb}|$ Developments

- "Traditional" experimental approach uses "CLN" param: HQET plus QCD sum rules (actually inconsistent with heavy quark expansion, but can be repaired Bernlochner, Ligeti, Papucci, DR [1703.05330])

$$|V_{cb}|_{\text{`CLN'}} = (38.2 \pm 1.5) \times 10^{-3}$$

- Unfolded $B \to D^* l\nu$ Belle dataset 1702.0152
FF param choices: "BGL" param using only

$$|V_{cb}|_{\text{`BGL'}} = (41.7^{+2.0}_{-2.1}) \times 10^{-3}\,, \quad \text{1703.06124,}$$
$$|V_{cb}|_{\text{`BGL'}} = (41.9^{+2.0}_{-1.9}) \times 10^{-3}\,, \quad \text{1703.08170}$$

- $|V_{cb}|_{\text{incl}} = (42.2 \pm 0.8) \times 10^{-3}$: Resolves $|V$
fits lifting $|V_{cb}|$ led to HQET tensions BLPR
- Subsequent Belle untagged analysis:

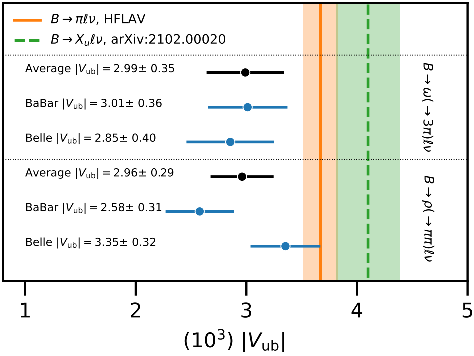
$$|V_{cb}|_{\text{`BGL'}} = (38.4 \pm 0.7) \times 10^{-3} \quad \text{Belle 1809.03290}$$

- But: Sensitive to truncation order of the BGL expansion
BLPR [1902.09553]

> - Anticipated precision data will help resolve this (plus tools to allow different FF exp fits: [Hammer])
> - Debate: How big are $1/m_c^2$ terms in heavy quark expansion?
> - Growing evidence of well controlled HQET expansion at $1/m_c^2$ (cf. $R(D^{(*)})$ predictions)
>   Bernlochner, Ligeti, DR [1808.09464], Bordone, Jung, van Dyk [1908.09398], more soon!

$|V_{ub}|$ Tensions

- There is a similar tension in V_{ub} from $b \to u l \nu$ exclusive vs inclusive
- Eg $B \to \rho/\omega l \nu$ or $B \to \pi l \nu$

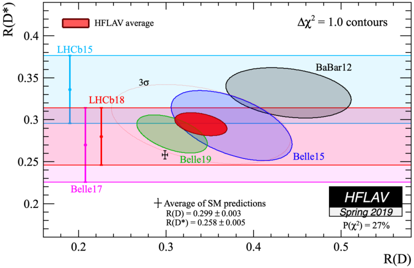


Bernlochner, Prim, DR [2104.05739]

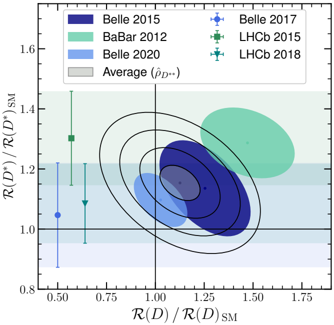
$R(D^{(*)})$ anomaly

Persistent hints of lepton flavor universality violation for 8+ years
Approx 10-20% upward deviations

HFLAV combination: 3.1σ



But: exp-exp correlations from $B \to (D^{**} \to D^*\pi\ldots)l\nu$ feed-down backgrounds

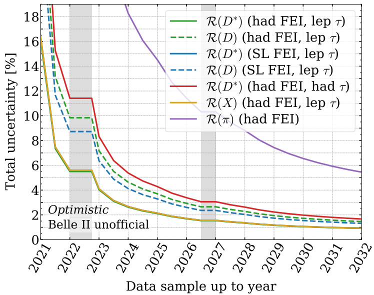


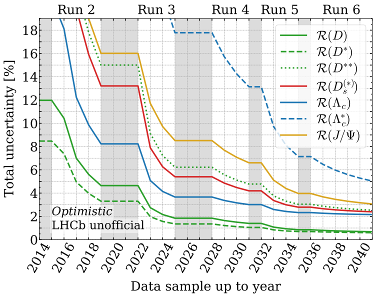
Combination: 3.6σ

Bernlochner, Franco Sevilla, DR, Wormser 2101.08326

Forecasts

Huge amount of data from LHCb and Belle II: $R(H_c)$ to percent level in some modes! Optimistic forecast:





$\mathcal{O}(\%)$ $R(D^{(*)})$ measurements $\to$ excellent control of systematics

- Large MC datasets
- Control of $B \to D^{**} l \nu$ excited state decays
- Consistent treatment of $D^{**} \to D^{(*)}\pi(\pi)$ branching fractions

Bernlochner, Franco Sevilla, DR, Wormser 2101.08326

Example Theory Systematic

- $R(D^{**})$ is a crucial input! [Two broad and two narrow modes: D_0^*, D_1^*, D_1' and D_2^*]
  - Belle: average $R(D^{**}) = 0.15$ [1910.05864]
  - Babar: average $R(D^{**}) = 0.18$ [1303.0571]
  - LHCb: $R(D^{**}) = 0.12$ [1506.08614]

- Data driven theory predictions Bernlochner, Ligeti, DR [1711.03110]

$$R(D_0^*) = 0.08(3), \quad R(D_1') = 0.05(2),$$
$$R(D_1) = 0.10(2), \quad R(D_2^*) = 0.07(1)\,.$$

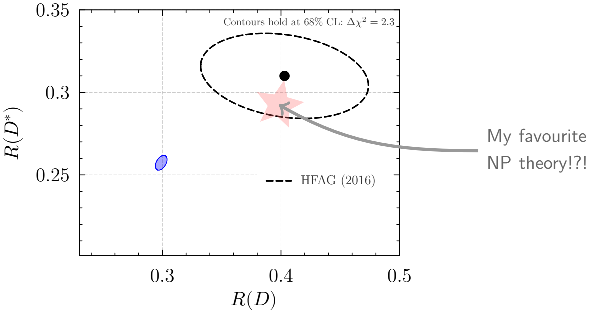
- About 50% smaller! Would drive measured $R(D^{(*)})$ higher by 0.5σ [2101.08326]

Global NP fit strategy

General 4-Fermi basis: At dimension-6, there are 5 NP operators for left-handed ν's (and 5 NP operators for right-handed ν's)

$$\mathcal{O}_6 \sim \frac{C}{\Lambda^2}\left(\bar{c}\Gamma b\right)\left(\bar{\tau}\Gamma'\nu\right) \qquad \Lambda \sim [2\sqrt{2}G_F/V_{cb}]^{-1/2} \sim 0.9\,\text{TeV}$$

- Calculate predictions for NP $B \to D^{(*)}\tau\nu$ rates
- Fit to the measured $R(D^{(*)})$ data (and other measurements)



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- Calculate predictions for NP $B \to D^{(*)}\tau\nu$ rates
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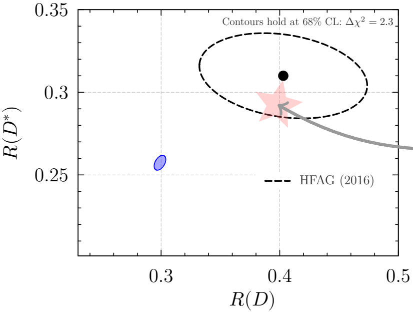
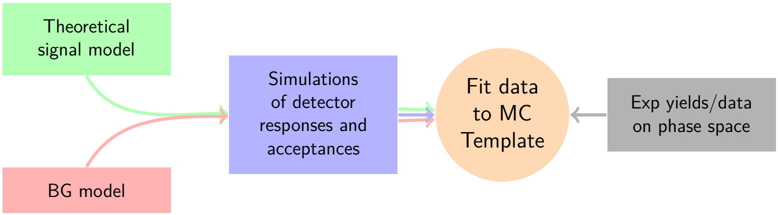
- This procedure is* susceptible to biases. It is not the same as fitting NP Wilson coefficients to the experimental data!
- Black ellipse tells us confidence to reject SM, not confidence to accept NP



My favourite NP theory!?!

MC Template Dependence

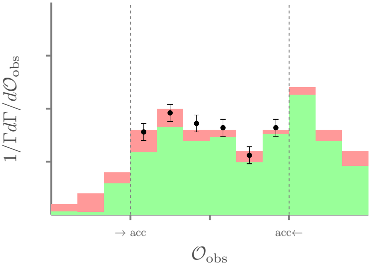
Have to translate experimental yields into theoretically well-defined parameters



Parametrization of SM signal and BG model folded into detector sim

Provides a MC template to be fit to data

Differential signal yields → extract theory parameters



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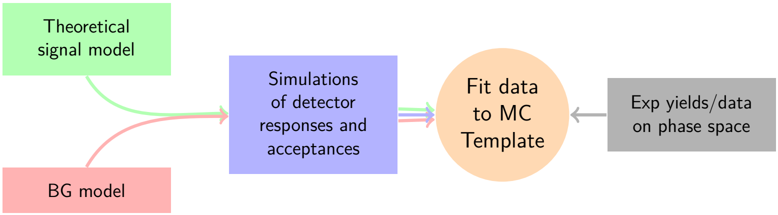

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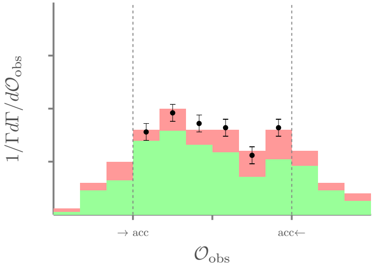


NP modifies signal and BG models!

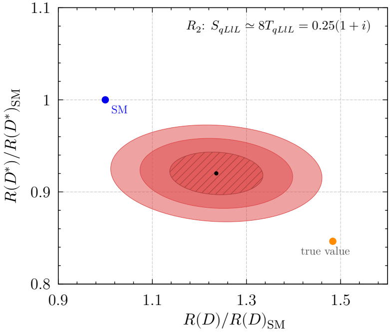
Generically alter decay distributions and acceptances

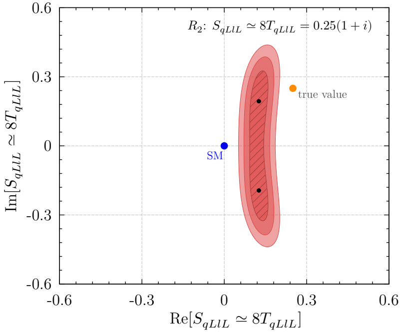
The extracted signal yield is different to the SM template!

SM Template $R(D^{(*)})$ biases

How big are these potential biases?

- Using `Hammer` library: hammer.physics.lbl.gov
- Inject truth R_2 model: $S_{qLlL} \simeq 8\,T_{qLlL} = 0.25(1+i)$. Fit SM Template.
- Allow $B \to D^{(*)} l\nu$ rates to float independently in the fit





Extracted $R(D^{(*)})$ sig. biased versus 'true' ratio!

Fit of R2 WC to extracted $R(D^{(*)})$ sig. biased versus 'true' WC!

Bernlochner, Duell, Ligeti, Papucci, DR [2002.00020]

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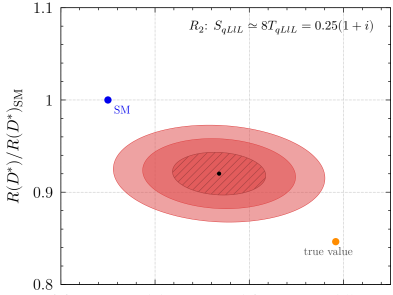

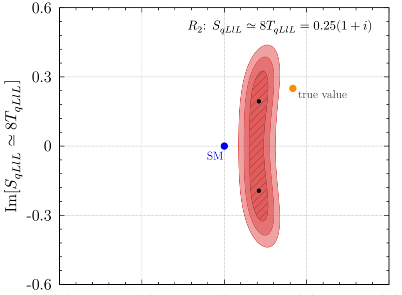

- Actual biases will depend on details of experimental acceptances and efficiencies
- To avoid NP-NP mismatches, LHCb and Belle II will eventually have to carry out an analysis with the full set of NP operators.
- Caution for interpretation of theory NP global fits of Wilson coefficients

Bernlochner, Duell, Ligeti, Papucci, DR [2002.00020]

Summary

- Space of smoking guns and precision measurements: lots of heavy flavor mysteries to be understood (and how they could be related)!
- $R_{K^{(*)}}$ anomalies appear very clean: Are there crucial subtleties missing? Care is also needed with interpretation of $B_s \to \mu\mu$ and angular $b \to s\mu\mu$.
- Precision tensions in $|V_{cb}|$ will be established or resolved with more data (cf also $|V_{ub}|$ inclusive vs exclusive)
- Percent level measurement of $R(D^{(*)})$ will require precision control of various theory systematics. The anomalies suggest NP, but more careful, self-consistent study is needed by experiments

Thanks!