Deviations in Flavour Physics

Presented by David M. Straub

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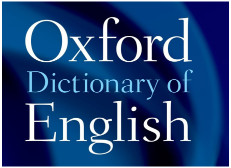
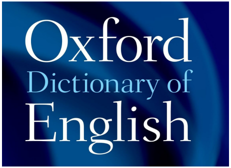
Oxford Dictionary of English

deviation



deviation

1. The action of departing from an established course or accepted standard.



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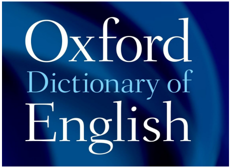

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2. The amount by which a single measurement differs from a fixed value such as the mean.

Oxford Dictionary of English

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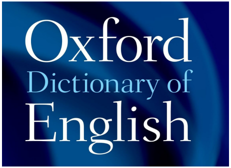
   - **Statistical fluctuation**



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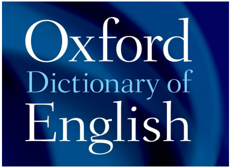

deviation

1. The action of departing from an established course or accepted standard.
   - **New physics!**
2. The amount by which a single measurement differs from a fixed value such as the mean.
   - **Statistical fluctuation**
3. The deflection of a ship's compass needle caused by iron in the ship.
   - **Underestimated systematics** (th/ex)

Outline

1. Semi-leptonic tree-level B decays
2. Rare B decays
3. Dimuon asymmetry
4. Direct CP violation in $K \to \pi\pi$

1. Semi-leptonic tree-level B decays
   - V_{cb} inclusive vs. exclusive
   - V_{ub} inclusive vs. exclusive
   - $B \to D^{(*)}\tau\nu$ vs. $B \to D^{(*)}\ell\nu$
2. Rare B decays
   - $B_d \to \mu^+\mu^-$
   - Exclusive $b \to s\ell^+\ell^-$ branching ratios
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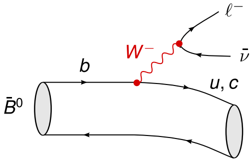
V_{cb} and V_{ub}

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



- Measured from tree-level B decays
- crucial inputs to probe new physics
  - $|\epsilon_K|$: $\mathrm{Im}\left[(V_{ts}V_{td}^*)^2\right] \propto V_{cb}^4 \sin(2\beta)$
  - $b \to s$: $|V_{tb}V_{ts}^*|^2 \approx V_{cb}^2$
  - $b \to d$: $|V_{tb}V_{td}^*|^2 \approx V_{cb}^2 V_{us}^2 + |V_{ub}|^2 + \ldots$

V_{cb} inclusive vs. exclusive

- inclusive: $\Gamma(B \to X_c \ell \nu) = \Gamma(b \to c \ell \nu) + O(\Lambda_{\text{QCD}}/m_b)$
  - Systematic expansion in powers of $1/m_b$, α_s
  - State of the art: $V_{cb}^{\text{in}} = (42.2 \pm 0.8) \times 10^{-3}$ Alberti et al. 1411.6560
- exclusive: $B \to D^* \ell \nu$, $B \to D \ell \nu$
  - requires knowledge of form factors, e.g. from lattice QCD
  - PDG 2014: $V_{cb}^{\text{ex}} = (39.5 \pm 0.8) \times 10^{-3}$
- 2.4σ tension

$B \to D\ell\nu$ recent developments

- FNAL/MILC 2015 with BaBar data: Bailey et al. 1503.07237

$$V_{cb}^{D} = (39.6 \pm 1.7) \times 10^{-3}$$

- HPQCD 2015 with BaBar data Na et al. 1505.03925

$$V_{cb}^{D} = (40.2 \pm 2.1) \times 10^{-3}$$

- New Belle analysis Oct. 2015, using FNAL/MILC & HPQCD Glattauer et al. 1510.03657

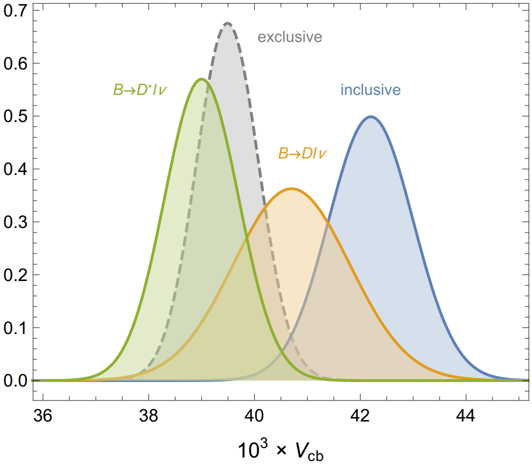
$$V_{cb}^{D} = (40.7 \pm 1.1) \times 10^{-3}$$

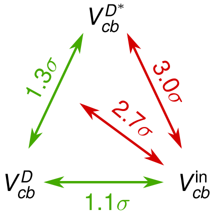
$B \to D^* \ell \nu$

- FNAL/MILC 2014 Bailey et al. 1403.0635

$$V_{cb}^{D^*} = (39.0 \pm 0.7) \times 10^{-3}$$

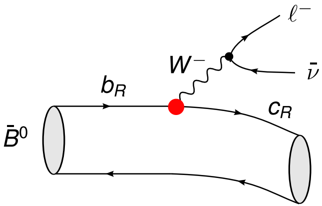
Summary: V_{cb} tension end 2015





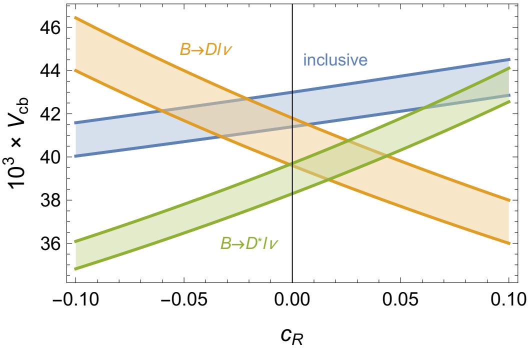
New physics?

- Scalar/tensor operators: no interference with SM, cannot change incl. vs. excl.
- "Right-handed W coupling": $i(\tilde{H}^\dagger D_\mu H)(\bar{u}_i \gamma^\mu d_j) \to (\bar{c}_R \gamma^\mu b_R)(\bar{\ell}_L \gamma_\mu \nu_L)$
  Crivellin 0907.2461



Impact of right-handed W coupling on V_{cb}

updated (and corrected) version of plot in Crivellin and Pokorski 1407.1320



Doesn't improve the situation

1. Semi-leptonic tree-level B decays
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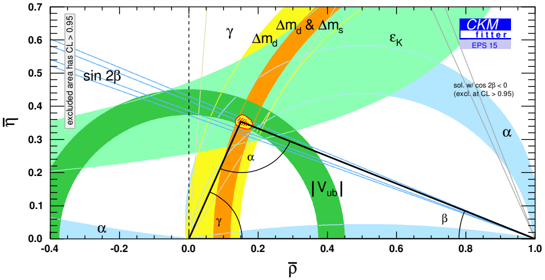
V_{ub}

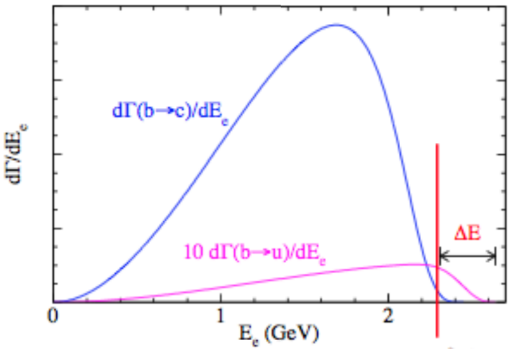
$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



- PDG 2014: $V_{ub}^{\text{in}} = (4.41 \pm 0.22) \times 10^{-3}$, $V_{ub}^{\pi} = (3.28 \pm 0.29) \times 10^{-3}$
- 3.1σ tension

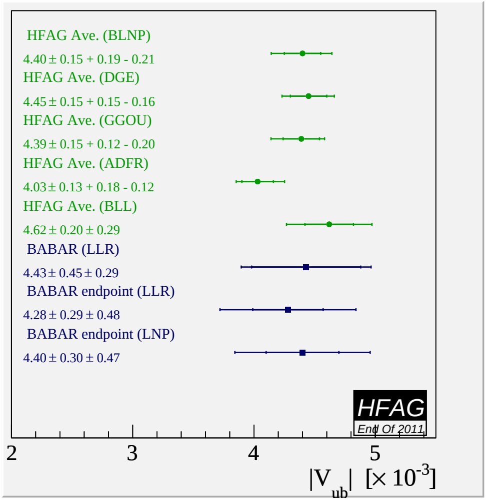
Inclusive V_{ub}: the challenge

- $B \to X_u \ell \nu$ swamped by $B \to X_c \ell \nu$ background except at endpoint region
- Cutting away most of the spectrum spoils convergence of OPE



[plot by B. Pecjak]

Inclusive V_{ub}: status



Exclusive V_{ub}: $B \to \pi\ell\nu$ recent developments

- FNAL/MILC 2015 Bailey et al. 1503.07839

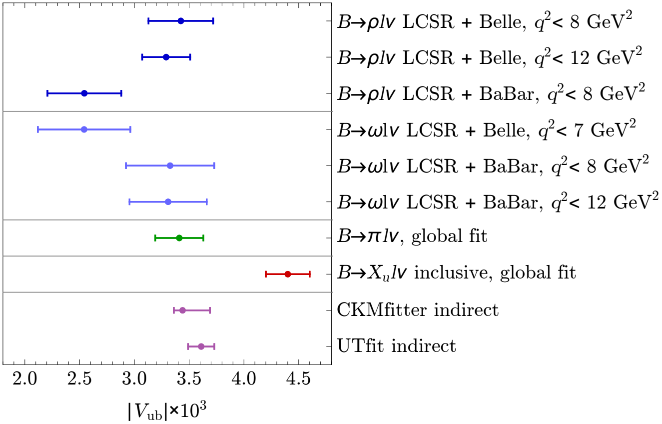
$$V_{ub}^{\pi} = (3.72 \pm 0.16) \times 10^{-3}$$

- RBC-UKQCD 2015 Flynn et al. 1501.05373

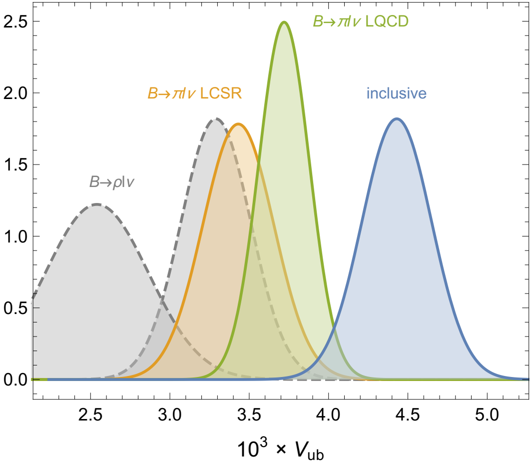
$$V_{ub}^{\pi} = (3.61 \pm 0.32) \times 10^{-3}$$

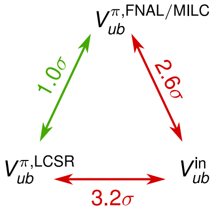
Exclusive V_{ub}: $B \to (\omega, \rho)\ell\nu$ recent developments

- Using a LCSR computation of $B \to$vector form factors, BaBar & Belle data on $B \to \omega\ell\nu$ and $B \to \rho\ell\nu$ can be used to extract V_{ub} Bharucha et al. 1503.05534



Summary: V_{ub} tension end 2015

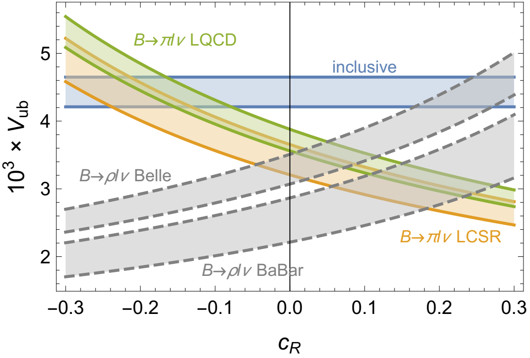




New physics?

- Using again a "right-handed W coupling":

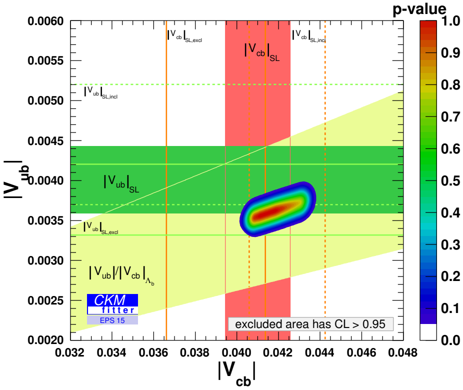
$$i(\tilde{H}^\dagger D_\mu H)(\bar{u}_i\gamma^\mu d_j) \to (\bar{u}_R\gamma^\mu b_R)(\bar{\ell}_L\gamma_\mu\nu_L)$$



updated version of plot in Crivellin and Pokorski 1407.1320

V_{ub}/V_{cb} from b-baryon decays

- LHCb recently measured the ratio of $\Lambda_b \to p\mu\nu$ vs. $\Lambda_b \to \Lambda_c\mu\nu$
- Can be used to extract V_{ub}/V_{cb}
- Relies on a single lattice form factor calculation Detmold et al. 1503.01421



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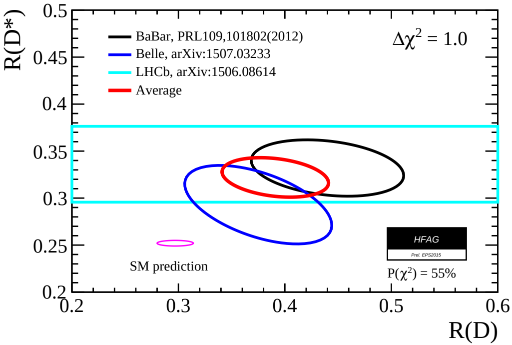
Lepton flavour (non-)universality in $b \to c\ell\nu$

$$R_{D^{(*)}} = \frac{\text{BR}(B \to D^{(*)}\tau\nu)}{\text{BR}(B \to D^{(*)}\ell\nu)}; \qquad \ell = e, \mu$$



R_D : 1.7σ $\quad$ R_{D^*} : 3.0σ $\quad$ combined: 3.9σ

New physics?

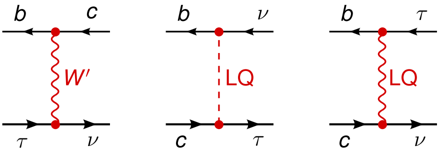
$$O_V^{(\prime)} = (\bar{c}_{L,R}\gamma^\mu b_{L,R})(\bar{\ell}_L\gamma^\mu \nu_L)$$
$$O_S^{(\prime)} = (\bar{c}_{R,L} b_{L,R})(\bar{\ell}_R \nu_L)$$
$$O_T = (\bar{c}_R \sigma^{\mu\nu} b_L)(\bar{\ell}_R \sigma_{\mu\nu} \nu_L)$$

- O_S can be generated by scalar exchange in two Higgs doublet models
  - but does not agree with the q^2 shape of the measurement
- O_V gives good fit – could stem from W' exchange
- Good fit also with $(\bar{\tau}_R c_L^c)(\bar{b}_R^c \nu_L) = -\frac{1}{2} O_S + \frac{1}{8} O_T$
  - generated by scalar leptoquark exchange

cf. Freytsis et al. 1506.08896

Models explaining $R_{D^{(*)}}$: W' or leptoquarks

Spin	Quantum numbers
1	$(1, \mathbf{3})_0$
0	$(\bar{\mathbf{3}}, 1)_{1/3}$
0	$(\bar{\mathbf{3}}, \mathbf{3})_{1/3}$
1	$(\bar{\mathbf{3}}, 1)_{2/3}$
1	$(\bar{\mathbf{3}}, \mathbf{3})_{2/3}$



see e.g. Greljo et al. 1506.01705, Calibbi et al. 1506.02661, Freytsis et al. 1506.08896, Bauer and Neubert 1511.01900, Fajfer and Košnik 1511.06024, Barbieri et al. 1512.01560

Relation to V_{cb} tension?

- If $B \to X_c \tau\nu$ is truly enhanced relative to the SM expectation, background to $B \to X_c \ell\nu$ from $B \to X_c \tau(\to X\ell\nu\nu)\nu$ might have been underestimated.
- This would not affect the exclusive decays

Greljo et al. 1506.01705

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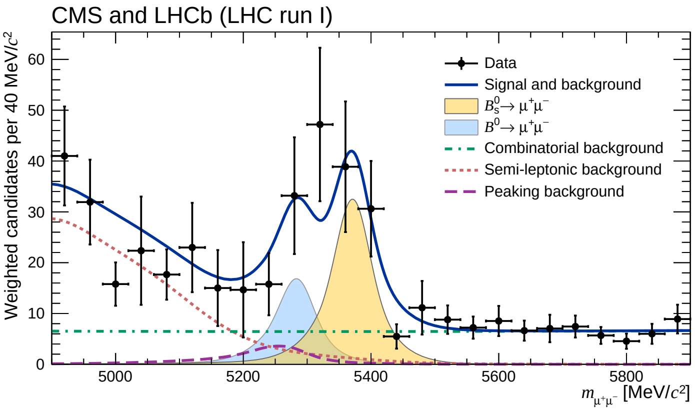
$B_q \to \mu^+\mu^-$: LHCb & CMS



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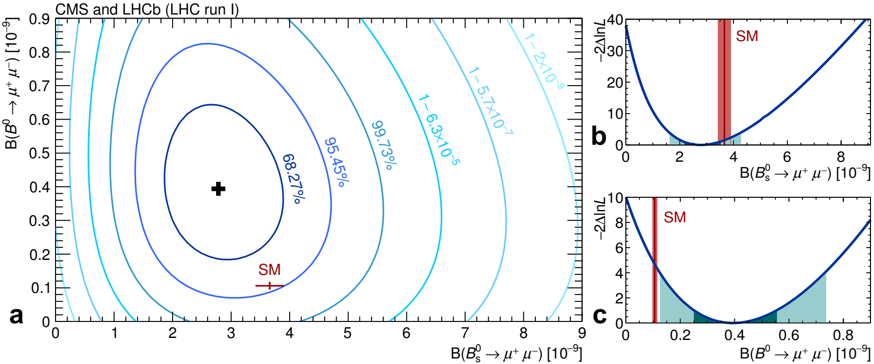
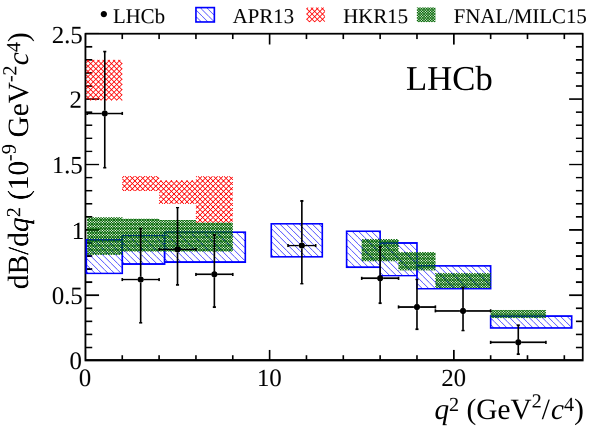


Agreement with SM:

1.2σ for $B_s \to \mu^+\mu^-$, 2.2σ for $B_d \to \mu^+\mu^-$, 2.3σ for the ratio

$B \to \pi\mu^+\mu^-$



- Looks OK inspite of considerable hadronic uncertainties
  - If large enhancement in $B_d \to \mu^+\mu^-$, more likely from scalar operators

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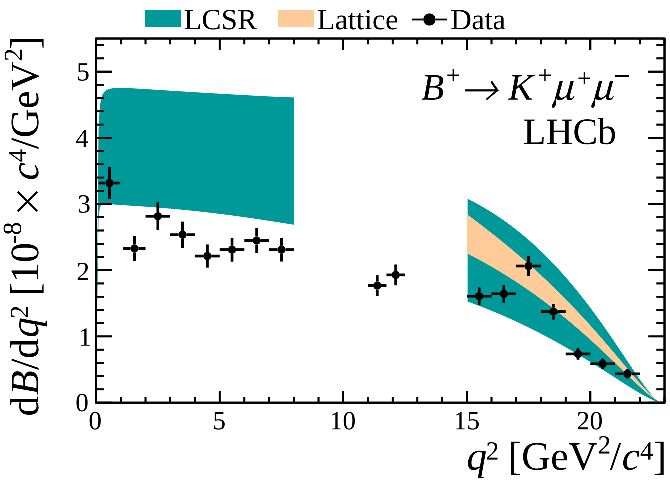
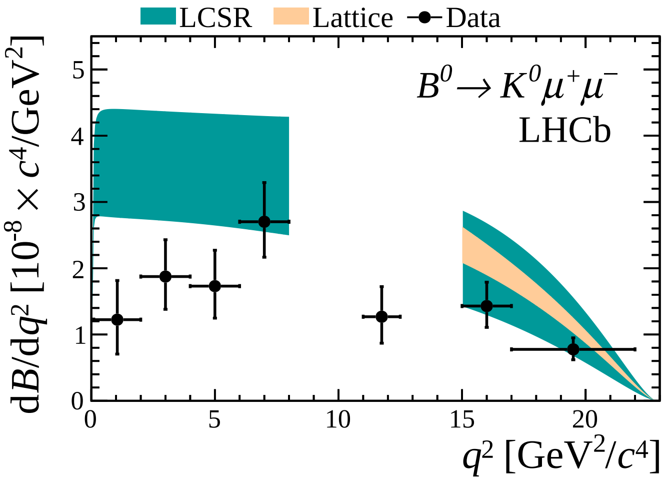
$B^+ \to K^+\mu^+\mu^-$ (3 fb^{-1})



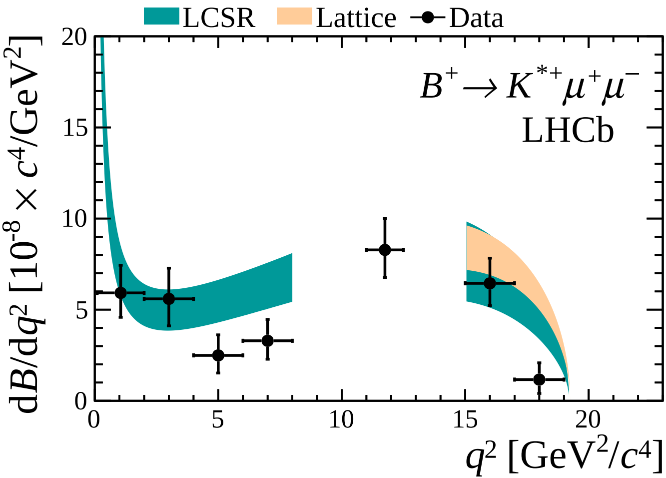
[4–5] GeV^2: 1.5σ local Altmannshofer and Straub 1411.3161

$B^0 \to K^0\mu^+\mu^-$ (3 fb^{-1})



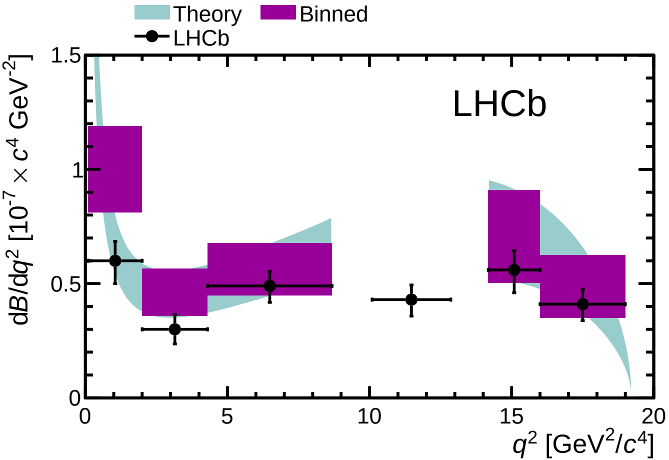
[0.1–2] GeV^2: 1.9σ local Altmannshofer and Straub 1411.3161

$B^+ \to K^{*+}\mu^+\mu^-$ (3 fb^{-1})



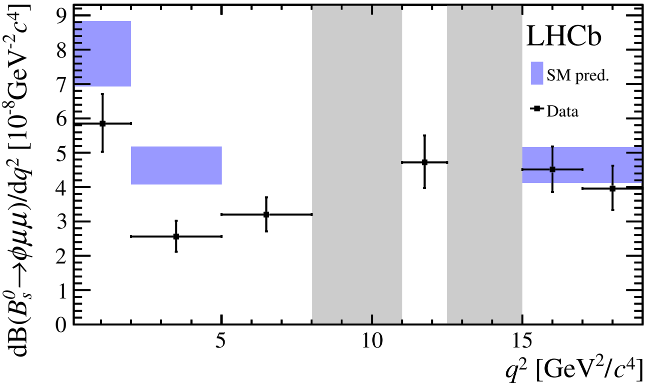
[4–6] GeV^2: 2.1σ local Altmannshofer and Straub 1411.3161

$B^0 \to K^{*0}\mu^+\mu^-$ (1 fb^{-1})



[2–4.3] GeV^2: 1.8σ local Altmannshofer and Straub 1411.3161

$B_s \to \phi\mu^+\mu^-$ (3 fb^{-1})



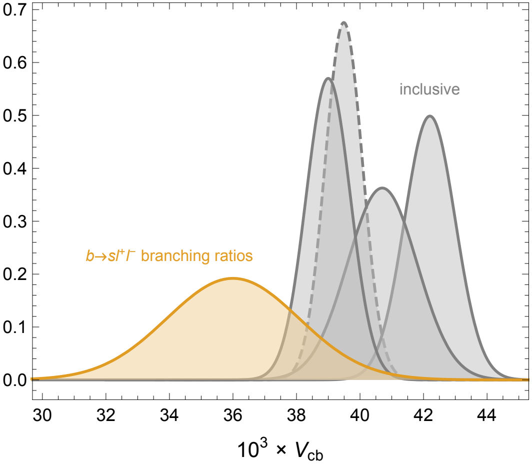
[1–6] GeV^2: 3.3σ Bharucha et al. 1503.05534

$b \to s$ branching ratios vs. V_{cb}

- SM predictions depend on $|V_{tb}V_{ts}^*|$
- Expressed in terms of "tree" quantities:

$$|V_{tb}V_{ts}^*| = V_{cb}\left(1 - \frac{V_{us}^2}{2} + V_{us}\cos\gamma\,\frac{|V_{ub}|}{V_{cb}} + O(\lambda^4)\right) = (0.983 \pm 0.003)\, V_{cb}$$

Extracting V_{cb} from $b \to s\ell^+\ell^-$ BRs



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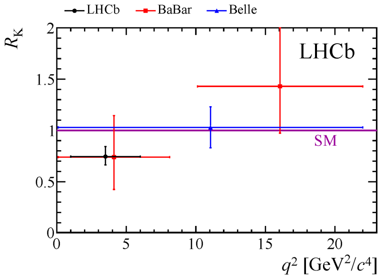
R_K: lepton flavour (non-)universality in $B \to K\ell^+\ell^-$



$$R_K = \frac{\text{BR}(B \to K\mu^+\mu^-)_{[1,6]}}{\text{BR}(B \to Ke^+e^-)_{[1,6]}} = 0.745^{+0.090}_{-0.074} \pm 0.036\,, \qquad R_K^{\text{SM}} \simeq 1.00$$

- 2.6σ deviation from lepton flavour universality (LFU)
- Cannot be explained by a parametric or hadronic effect!

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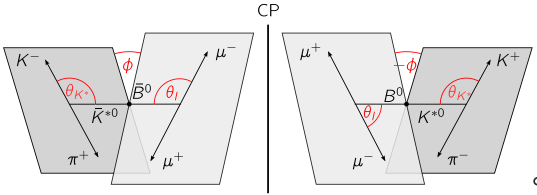
$B \to K^*(\to K\pi)\mu^+\mu^-$ angular decay distribution



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$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} \times$$

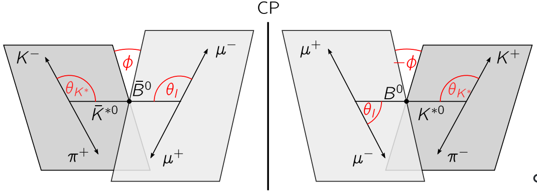
$$\Big\{ I_1^s \sin^2\theta_{K^*} + I_1^c \cos^2\theta_{K^*} + (I_2^s \sin^2\theta_{K^*} + I_2^c \cos^2\theta_{K^*}) \cos 2\theta_l$$

$$+ I_3 \sin^2\theta_{K^*} \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_{K^*} \sin 2\theta_l \cos\phi$$

$$+ I_5 \sin 2\theta_{K^*} \sin\theta_l \cos\phi + \left(I_6^s \sin^2\theta_{K^*} + I_6^c \cos^2\theta_{K^*}\right) \cos\theta_l$$

$$+ I_7 \sin 2\theta_{K^*} \sin\theta_l \sin\phi + I_8 \sin 2\theta_{K^*} \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_{K^*} \sin^2\theta_l \sin 2\phi \Big\}$$

$B \to K^*(\to K\pi)\mu^+\mu^-$ angular decay distribution



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$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} \times$$

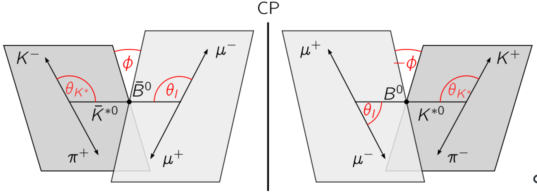
$$\Big\{ + I_2^s \sin^2\theta_{K^*}(3+\cos 2\theta_l) - I_2^c 2\cos^2\theta_{K^*}\sin^2\theta_l$$

$$+ I_3 \sin^2\theta_{K^*}\sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_{K^*}\sin 2\theta_l \cos\phi$$

$$+ I_5 \sin 2\theta_{K^*}\sin\theta_l\cos\phi + I_6 \sin^2\theta_{K^*}\cos\theta_l$$

$$+ I_7 \sin 2\theta_{K^*}\sin\theta_l \sin\phi + I_8 \sin 2\theta_{K^*}\sin 2\theta_l\sin\phi + I_9 \sin^2\theta_{K^*}\sin^2\theta_l \sin 2\phi \Big\}$$

$B \to K^*(\to K\pi)\mu^+\mu^-$ angular decay distribution



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$$\frac{d^4\bar{\Gamma}}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} \times$$

$$\Big\{ + \bar{I}_2^s \sin^2\theta_{K^*}(3+\cos 2\theta_l) - \bar{I}_2^c 2\cos^2\theta_{K^*}\sin^2\theta_l$$

$$+ \bar{I}_3 \sin^2\theta_{K^*}\sin^2\theta_l \cos 2\phi + \bar{I}_4 \sin 2\theta_{K^*}\sin 2\theta_l \cos\phi$$

$$- \bar{I}_5 \sin 2\theta_{K^*}\sin\theta_l\cos\phi - \bar{I}_6 \sin^2\theta_{K^*}\cos\theta_l$$

$$+ \bar{I}_7 \sin 2\theta_{K^*}\sin\theta_l\sin\phi - \bar{I}_8 \sin 2\theta_{K^*}\sin 2\theta_l\sin\phi - \bar{I}_9 \sin^2\theta_{K^*}\sin^2\theta_l \sin 2\phi \Big\}$$

Basis of observables

- CP-averaged angular coefficients

$$S_i^{(a)}(q^2) = \left(I_i^{(a)}(q^2) + \bar{I}_i^{(a)}(q^2)\right) \Bigg/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2}$$

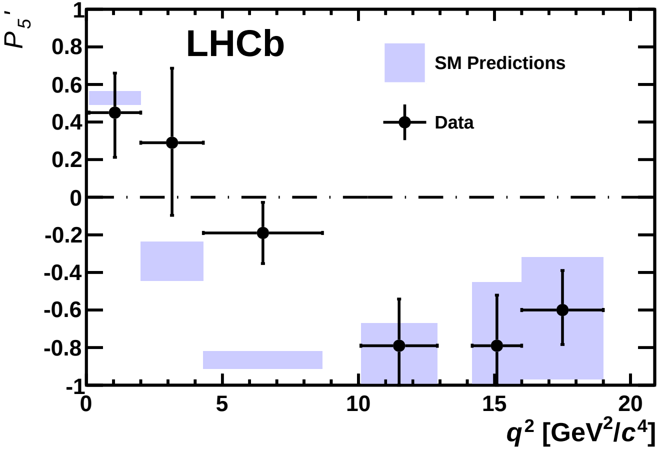
- CP asymmetries

$$A_i^{(a)}(q^2) = \left(I_i^{(a)}(q^2) - \bar{I}_i^{(a)}(q^2)\right) \Bigg/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2}$$

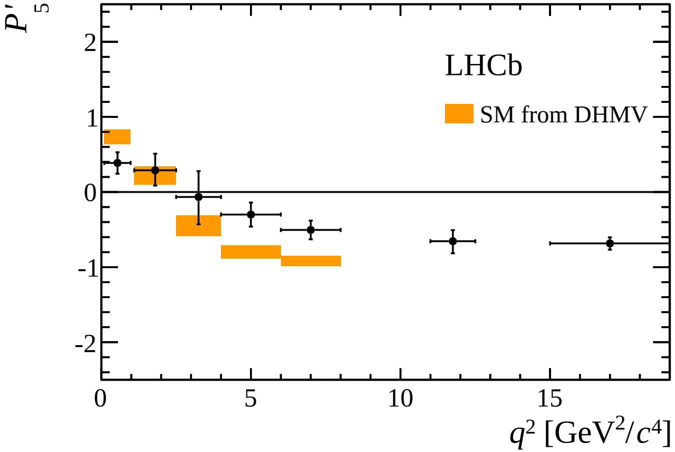
- Alternative basis S. Descotes-Genon et al. 1303.5794

$$P_4' = \frac{2\,S_4}{\sqrt{F_L(1-F_L)}} \qquad P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}} \qquad \ldots$$

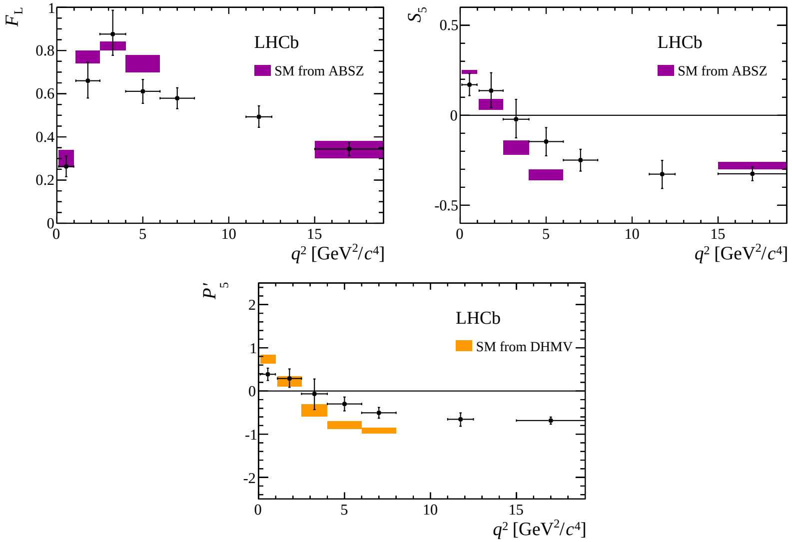
"$B \to K^* \mu^+ \mu^-$ anomaly" after 1/fb



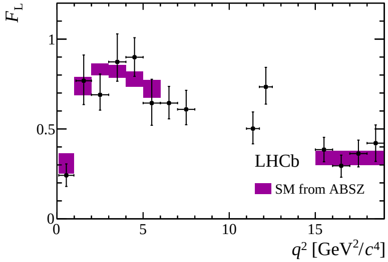
"$B \to K^* \mu^+ \mu^-$ anomaly" after 3/fb

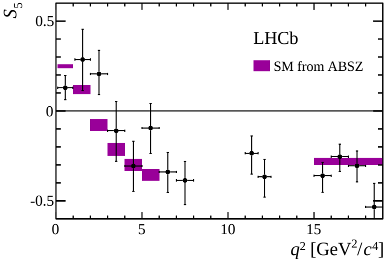


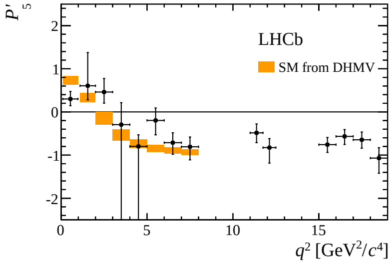
Deviations in $B \to K^* \mu^+ \mu^-$



“Method of moments”







New physics?

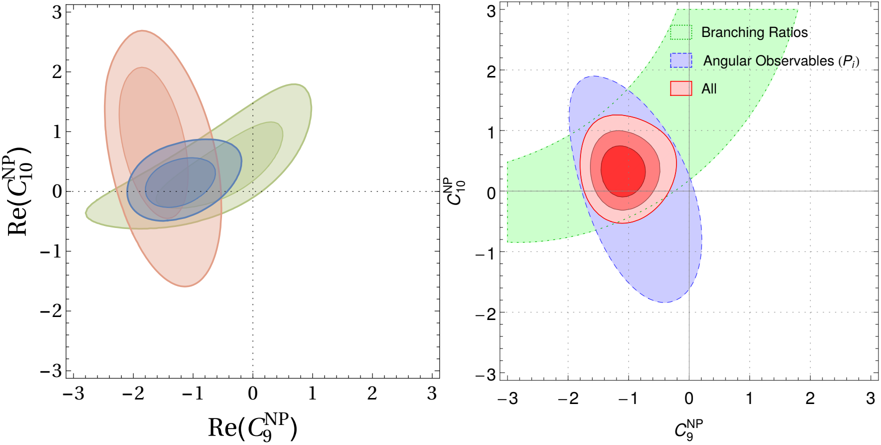
$$O_{AB} \propto (\bar{s}_A \gamma^\mu b_A)(\bar{\mu}_B \gamma_\mu \mu_B)$$

- Significance of global fit improvement over the SM

C_{LV}	**3.7σ**
C_{LA}	2.0σ
C_{LR}	0.9σ
C_{LL}	**3.1σ**
C_{RV}	0.8σ
C_{RA}	0.9σ
C_{RR}	0.3σ
C_{RL}	0.9σ

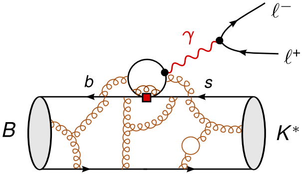
Global fit results

$$C_9 = C_{LV},\ C_{10} = C_{LA}$$



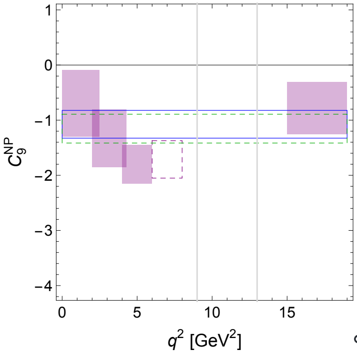
Altmannshofer and Straub 1411.3161, Descotes-Genon et al. 1510.04239

Physics beyond the SM or unexpected hadronic effect?



- Hadronic effects are photon-mediated $\Rightarrow$ vector-like coupling to leptons
  - just like $C_9 = C_{LV}$
- How to disentangle NP $\leftrightarrow$ QCD?
  - Hadronic effect can have different q^2 dependence
  - Hadronic effect is lepton flavour universal ($\rightarrow R_K$!)
  - Hadronic effect is does not introduce new CP phases

q^2 dependence of C_9 best fit



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- New physics interpretation: should be q^2-independent. Consistent at $\sim 1\sigma$
- q^2 dependence could also be indicative of hadronic effect

Predictions for LFU violation

Observable	Ratio of muon vs. electron mode			
	$C_9^{\rm NP} = -1.5$	-1.5	-0.7	-1.3
	$C_9' = 0$	0.8	0	0
	$C_{10}^{\rm NP} = 0$	0	0.7	0.3
$10^7\ \frac{dBR}{dq^2}(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[1,6]}$	0.83	0.77	0.79	0.81
$10^7\ \frac{dBR}{dq^2}(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[15,22]}$	0.76	**0.69**	0.76	0.75
$A_{\rm FB}(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[4,6]}$	**0.18**	**0.10**	0.75	**0.27**
$S_5(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[4,6]}$	**0.66**	**0.66**	0.93	0.71
$10^8\ \frac{dBR}{dq^2}(B^+ \to K^+\ell^+\ell^-)_{[1,6]}$	0.75	0.82	0.77	0.74
$10^8\ \frac{dBR}{dq^2}(B^+ \to K^+\ell^+\ell^-)_{[15,19]}$	0.75	0.83	0.77	0.75

Altmannshofer and Straub 1411.3161

Tree-level models explaining $b \to s\ell^+\ell^-$ data

- Z' or leptoquarks

Spin	Quantum numbers
1	$(1, 1)_0$
1	$(1, \mathbf{3})_0$
0	$(\bar{\mathbf{3}}, \mathbf{3})_{1/3}$
1	$(\bar{\mathbf{3}}, 1)_{2/3}$
1	$(\bar{\mathbf{3}}, \mathbf{3})_{2/3}$

Simultaneous explanation of $R_{D^{(*)}}$, R_K, etc.

- For a single tree-level mediator and arbitrary (tuned couplings), one can go with
  - triplet vector (W', Z')
  - scalar $(\bar{\mathbf{3}}, \mathbf{3})_{1/3}$ leptoquark
  - vector $(\bar{\mathbf{3}}, 1)_{2/3}$ or $(\bar{\mathbf{3}}, \mathbf{3})_{2/3}$ leptoquark
- Models motivated by dominant couplings to the 3rd generation work with Calibbi et al. 1506.02661, Barbieri et al. 1512.01560
  - triplet vector (W', Z')
  - vector $(\bar{\mathbf{3}}, 1)_{2/3}$ leptoquark
- scalar $(\bar{\mathbf{3}}, 1)_{1/3}$ leptoquark: works as well, contribution to $b \to s\mu^+\mu^-$ loop-induced Bauer and Neubert 1511.01900

see also Fajfer and Košnik 1511.06024, Greljo et al. 1506.01705

Observables

- CP asymmetry in flavour-specific $B_{d,s}$ decays (a.k.a. semi-leptonic asymmetry)

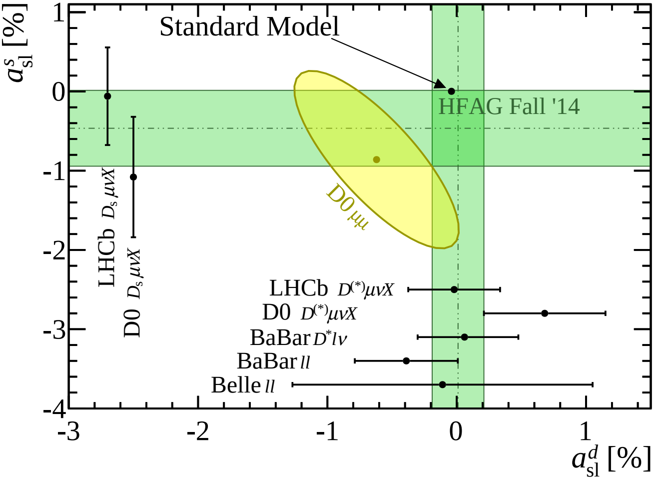
$$a_{\text{fs}}^q \equiv a_{\text{sl}}^q = \frac{\Gamma(\bar{B}_q^0(t) \to f) - \Gamma(B_q^0(t) \to \bar{f})}{\Gamma(\bar{B}_q^0(t) \to f) + \Gamma(B_q^0(t) \to \bar{f})}$$

- Dimuon asymmetry

$$A_{\text{CP}} = \frac{N^{\mu^+\mu^+} - N^{\mu^-\mu^-}}{N^{\mu^+\mu^+} + N^{\mu^-\mu^-}} + \dots$$

$$A_{\text{CP}} = C_d a_{\text{sl}}^d + C_s a_{\text{sl}}^s + \frac{1}{2} C_{\Delta\Gamma_d} \frac{\Delta\Gamma_d}{\Gamma_d}$$

Experimental situation



Artuso et al. 1511.09466

New physics?

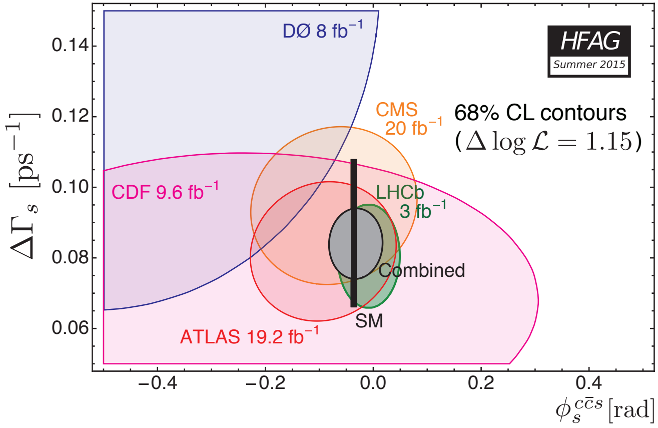
$$A_{\text{CP}} = C_d a_{\text{sl}}^d + C_s a_{\text{sl}}^s + \frac{1}{2} C_{\Delta\Gamma_d} \frac{\Delta\Gamma_d}{\Gamma_d}$$

$$a_{\text{sl}}^q = \frac{\Delta\Gamma_q}{\Delta M_q} \tan \phi_{12}^q$$

- Large modification of ϕ_{12}^s now ruled out since

$$\phi_{12}^s - [\phi_{12}^s]_{\text{SM}} = \phi_s^{c\bar{c}s} - [\phi_s^{c\bar{c}s}]_{\text{SM}}$$

ϕ_s from $b \to c\bar{c}s$



Can the dimuon asymmetry be due to new physics?

$$A_{\text{CP}} = C_d a_{\text{sl}}^d + C_s a_{\text{sl}}^s + \frac{1}{2} C_{\Delta\Gamma_d} \frac{\Delta\Gamma_d}{\Gamma_d}$$

- Modification of $\Delta\Gamma_d/\Gamma_d$? Possible with
  - modified tree-level decays $b \to c\bar{c}d$ Brod et al. 1412.1446
  - modified FCNC decays $b \to d\tau^+\tau^-$ Bobeth et al. 1404.2531
- Look for modification of these decays directly

1. Semi-leptonic tree-level B decays
   - V_{cb} inclusive vs. exclusive
   - V_{ub} inclusive vs. exclusive
   - $B \to D^{(*)}\tau\nu$ vs. $B \to D^{(*)}\ell\nu$
2. Rare B decays
   - $B_d \to \mu^+\mu^-$
   - Exclusive $b \to s\ell^+\ell^-$ branching ratios
   - R_K
   - Angular observables in $B \to K^*\mu^+\mu^-$
3. Dimuon asymmetry
4. **Direct CP violation in $K \to \pi\pi$**

Direct (ϵ') vs. indirect (ϵ) CPV in $K \to \pi\pi$

$$(\epsilon'/\epsilon)_{\text{exp}} = (16.6 \pm 2.3) \times 10^{-4}$$

- First lattice computation by RBC-UKQCD Bai et al. 1505.07863

$$(\epsilon'/\epsilon)_{\text{SM}} = (1.4 \pm 6.8) \times 10^{-4}$$

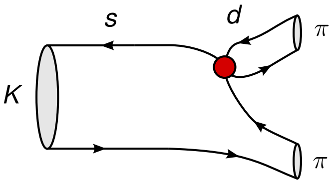
  - 2.1σ
- Improved estimate Buras, Gorbahn, et al. 1507.06345
  - assuming real parts of amplitudes to be dominated by SM

$$(\epsilon'/\epsilon)_{\text{SM}} = (1.9 \pm 4.5) \times 10^{-4}$$

  - 2.9σ

New Physics?

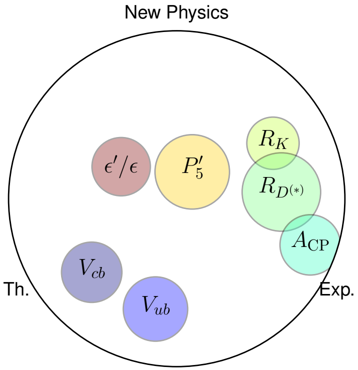
- Yes, by generating some $(\bar{s}d)(\bar{q}q)$ penguin operator



- In many models, correlated with $K_L \to \pi^0 \nu\bar{\nu}$

see e.g. Buras, Buttazzo, et al. 1507.08672

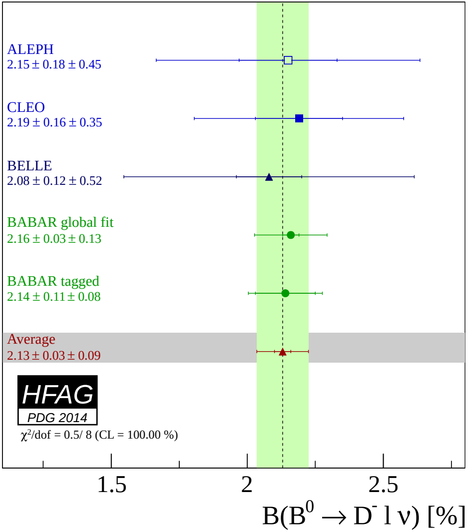
Instead of a summary



- just my (strongly biased) GUT feeling!
- radius $\propto$ significance in σ
- Th./Ex.: underestimated theoretical/experimental systematic

Backup

Experiment: $B \to D\ell\nu$



Experiment: $B \to D^* \ell \nu$