NP evidences + hadronic uncertainties in $b \to s\ell\ell$: The state-of-the-art

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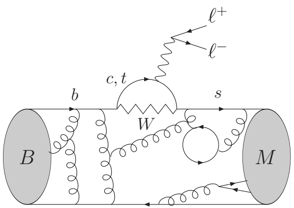
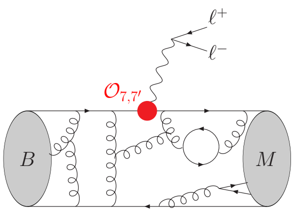
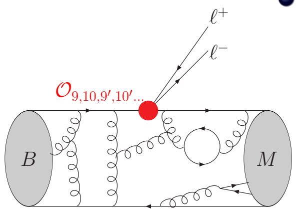
Based on: CDVM'16 (JHEP 1610 (2016) 075) and CDHM'17 arXiv:1701.08672 (to appear in JHEP).

Present situation concerning evidences of NP in $b \to s\ell\ell$

$b \to s\mu\mu$ effective Hamiltonian







$$b \to s\gamma(^*) : \mathcal{H}^{SM}_{\triangle F=1} \propto \sum V^*_{ts} V_{tb} \mathcal{C}_i \mathcal{O}_i + \ldots$$

separate short and long distances ($\mu_b = m_b$)

- $\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \, \bar{s}\sigma^{\mu\nu}(1+\gamma_5)F_{\mu\nu}\, b$ [real or soft photon]
- $\mathcal{O}_9 = \frac{e^2}{16\pi^2} \bar{s}\gamma_\mu(1-\gamma_5)b \; \bar{\ell}\gamma^\mu \ell$ [$b \to s\mu\mu$ via Z/hard $\gamma \ldots$]
- $\mathcal{O}_{10} = \frac{e^2}{16\pi^2} \bar{s}\gamma_\mu(1-\gamma_5)b \; \bar{\ell}\gamma^\mu\gamma_5 \ell$ [$b \to s\mu\mu$ via Z]

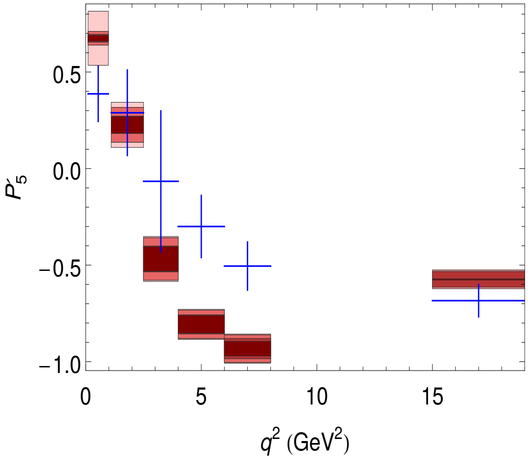
$$\mathcal{C}_7^{\rm SM} = -0.29,\ \mathcal{C}_9^{\rm SM} = 4.1,\ \mathcal{C}_{10}^{\rm SM} = -4.3$$

A= $\mathcal{C}_i$ (short dist) $\times$ Hadronic quantities (long dist)

NP changes short-distance $\mathcal{C}_i$ for SM or involve additional operators $\mathcal{O}_i$

- Chirally flipped ($W \to W_R$) $\quad \mathcal{O}_{7'} \propto \bar{s}\sigma^{\mu\nu}(1-\gamma_5)F_{\mu\nu}\, b$
- (Pseudo)scalar ($W \to H^+$) $\quad \mathcal{O}_S \propto \bar{s}(1+\gamma_5)b\bar{\ell}\ell, \mathcal{O}_P$
- Tensor operators ($\gamma \to T$) $\quad \mathcal{O}_T \propto \bar{s}\sigma_{\mu\nu}(1-\gamma_5)b \; \bar{\ell}\sigma_{\mu\nu}\ell$

Using symmetries in $E_{K^*} \to \infty$ and HQL: A_i, V_i, T_i full-FF $\to \xi_{\perp,\parallel}$ (SFF)



P_5' was proposed in **DMRV, JHEP 1301(2013)048**

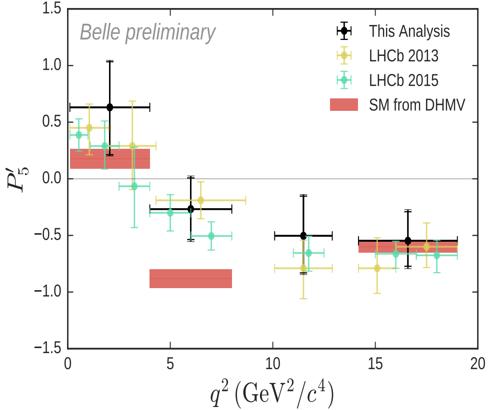
$$P_5' = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*})}{\sqrt{|A_0|^2(|A_\perp|^2 + |A_\parallel|^2)}} = P_5^\infty \left(1 + \mathcal{O}(\alpha_s \xi_\perp) + \mathrm{p.c.}\right) .$$

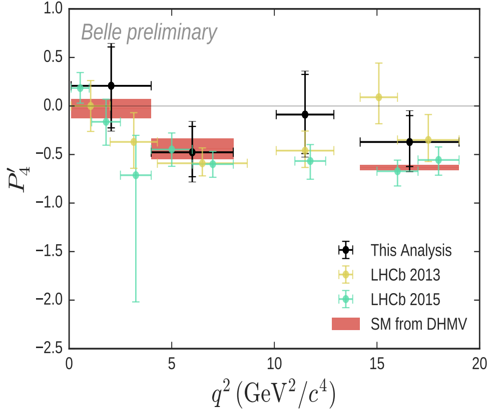
Optimized Obs.: Soft form factor ($\xi_\perp$) cancellation at LO.

- 2013: 1fb^{-1} dataset LHCb found 3.7σ
- 2015: 3fb^{-1} dataset LHCb (**in blue**) found 3σ in 2 bins.

$\Rightarrow$ Predictions (**in red**) from DHMV.

Belle confirmed it in a bin [4,8] few months ago.





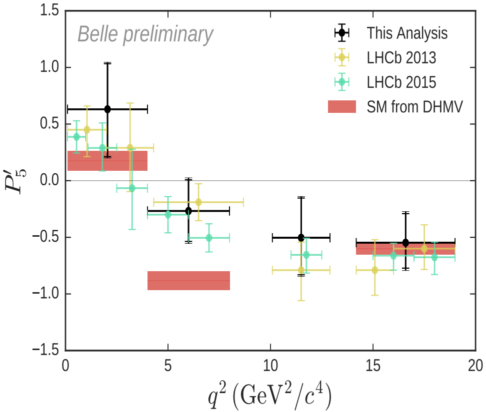
- *High sensitivity to C_9 and lower to C_{10}:*

$$P_5'|_\infty = -\frac{1}{\mathcal{N}}\mathrm{Re}\left[(C_{9-}^{\mathrm{eff}} + 2\hat{m}_b C_7^{\mathrm{eff}})(C_{9-}^{\mathrm{eff}*} + 2\frac{\hat{m}_b}{\hat{s}} C_7^{\mathrm{eff}}) - (C_{9+}^{\mathrm{eff}} + 2\hat{m}_b C_7^{\mathrm{eff}})(C_{9+}^{\mathrm{eff}*} + 2\frac{\hat{m}_b}{\hat{s}} C_7^{\mathrm{eff}*})\right]$$

where $C_{9\pm}^{\mathrm{eff}} = C_9^{\mathrm{eff}} \pm C_{10}$

- *A possible interpretation: in absence of RHC, cosine of the relative angle between $n_\perp = (A_\perp^L, -A_\perp^{R*})$ and the longitudinal $n_0 = (A_0^L, A_0^{R*})$.*

P_5' anomaly (Preludio)



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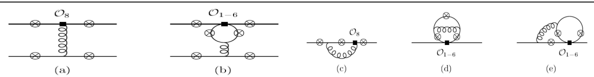
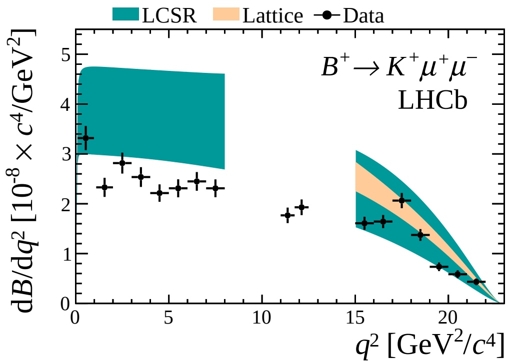
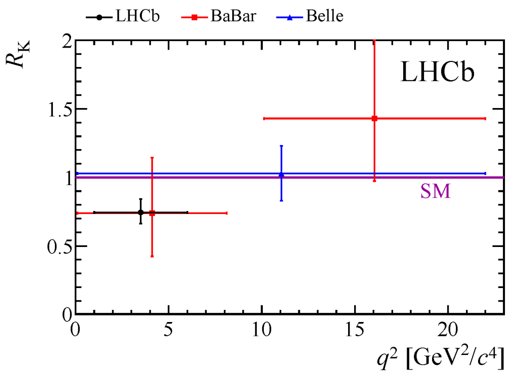
Large-recoil for K^*: $4m_\ell^2 \leq q^2 \leq 9$ GeV^2 and low-recoil: 14 GeV$^2 \leq q^2 \leq^2 (m_B - m_K)^2$.

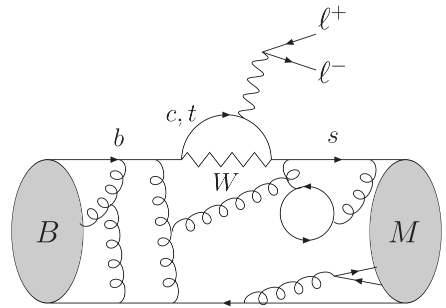
$\boxed{1}$ Computed in i-QCDF + KMPW+ 4-types of correct. $\mathbf{F^{full}(q^2)} = F^{soft}(\xi_\perp, \xi_{||}) + \triangle F^{\alpha_s}(q^2) + \triangle F^{p.c.}(q^2)$

type of correction	Factorizable	Non-Factorizable
α_s-QCDF	$\triangle F^{\alpha_s}(q^2)$	
power-corrections	$\triangle F^{p.c.}(q^2)$	LCSR with single soft gluon contribution

More Anomalies in $B \to K\ell\ell$







- q^2 invariant mass of $\ell\ell$ pair
- $Br(B \to K\mu\mu)$ too low compared to SM
- $R_K = \frac{Br(B \to K\mu\mu)}{Br(B \to Kee)}\Big|_{[1,6]} = 0.745^{+0.090}_{-0.074} \pm 0.036$
- equals to 1 in SM (universality of lepton coupling), 2.6 σ dev
- NP coupling $\neq$ to μ and e

Other tensions beyond P_5' and R_K

Systematic low-recoil small tensions (EXP too low compared with SM in several BR_μ also at large-recoil):

$b \to s\mu^+\mu^-$ (low-recoil)	bin	SM	EXP	Pull
$10^7 \times \mathrm{BR}(B^0 \to K^0\mu^+\mu^-)$	[15,19]	0.91 ± 0.12	0.67 ± 0.12	+1.4
$10^7 \times \mathrm{BR}(B^0 \to K^{*0}\mu^+\mu^-)$	[16,19]	1.66 ± 0.15	1.23 ± 0.20	+1.7
$10^7 \times \mathrm{BR}(B^+ \to K^{*+}\mu^+\mu^-)$	[15,19]	2.59 ± 0.25	1.60 ± 0.32	**+2.5**
$10^7 \times \mathrm{BR}(B_s \to \phi\mu^+\mu^-)$	[15,18.8]	2.20 ± 0.17	1.62 ± 0.20	**+2.2**

After including the BSZ DA correction that affected the error of twist-4:

$10^7 \times \mathrm{BR}(B_s \to \phi\mu^+\mu^-)$	SM	EXP	Pull
[0.1,2]	1.56 ± 0.35	1.11 ± 0.16	+1.1
[2,5]	1.55 ± 0.33	0.77 ± 0.14	**+2.2**
[5,8]	1.89 ± 0.40	0.96 ± 0.15	**+2.2**

A precise measurement of F_L (to near to 1) around [1-2.5] GeV^2 will impact P_2
$\Rightarrow$ will have a strong impact in the global analysis pull.

Global analysis of $b \to s\mu\mu$ anomalies

[Descotes, Hofer, JM, Virto]

96 observables in total (LHCb for exclusive, no CP-violating obs)

- $B \to K^*\mu\mu$ ($P_{1,2}$, $P'_{4,5,6,8}$, F_L in 5 large-recoil bins + 1 low-recoil bin)+available electronic observables.
- $B_s \to \phi\mu\mu$ (P_1, $P'_{4,6}$, F_L in 3 large-recoil bins + 1 low-recoil bin)
- $B^+ \to K^+\mu\mu$, $B^0 \to K^0\ell\ell$ (BR) ($\ell = e, \mu$)
- $B \to X_s\gamma$, $B \to X_s\mu\mu$, $B_s \to \mu\mu$ (BR), $B \to K^*\gamma$ (A_I and $S_{K^*\gamma}$)

Various tools

- inclusive: OPE
- excl large-meson recoil: QCD fact, Soft-collinear effective theory
- excl low-meson recoil: Heavy quark eff th, Quark-hadron duality

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Frequentist analysis

- $\mathcal{C}_i(\mu_{ref}) = \mathcal{C}_i^{SM} + \mathcal{C}_i^{NP}$, with $\mathcal{C}_i^{NP}$ assumed to be real (no CPV)
- Experimental correlation matrix provided
- Theoretical inputs (form factors...) with correlation matrix computed treating all theo errors as Gaussian random variables
- Hypotheses “NP in some $\mathcal{C}_i$ only” (1D, 2D, 6D) to be compared with SM

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Updated result pre-R_{K^*} and pre-Q_i

Includes updated $\mathrm{BR}(B \to K^* \mu^+\mu^-)$ + corrected BSZ for $B_s \to \phi\mu^+\mu^-$. $P_5'^{\mu\mathrm{BELLE}}$ would add +0.1 to +0.3σ.
A scenario with a large SM-pull $\Rightarrow$ big improvement over SM and better description of data.

Coefficient	Best fit	1σ	$\mathrm{Pull_{SM}}$ (σ)
$\mathcal{C}_7^{\mathrm{NP}}$	-0.02	$[-0.04, -0.00]$	1.1
$\mathcal{C}_9^{\mathrm{NP}}$	-1.05	$[-1.25, -0.85]$	4.7
$\mathcal{C}_{10}^{\mathrm{NP}}$	0.55	$[0.34, 0.77]$	2.8
$\mathcal{C}_{7'}^{\mathrm{NP}}$	0.02	$[-0.00, 0.04]$	0.9
$\mathcal{C}_{9'}^{\mathrm{NP}}$	0.06	$[-0.18, 0.30]$	0.3
$\mathcal{C}_{10'}^{\mathrm{NP}}$	-0.03	$[-0.20, 0.14]$	0.2
$\mathcal{C}_9^{\mathrm{NP}} = \mathcal{C}_{10}^{\mathrm{NP}}$	-0.18	$[-0.36, 0.02]$	0.9
$\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{10}^{\mathrm{NP}}$	-0.59	$[-0.74, -0.44]$	4.3
$\mathcal{C}_{9'}^{\mathrm{NP}} = -\mathcal{C}_{10'}^{\mathrm{NP}}$	0.03	$[-0.08, 0.13]$	0.2
$\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{9'}^{\mathrm{NP}}$	-1.00	$[-1.20, -0.78]$	4.4
$\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{10}^{\mathrm{NP}} = -\mathcal{C}_{9'}^{\mathrm{NP}} = -\mathcal{C}_{10'}^{\mathrm{NP}}$	-0.61	$[-0.45, -0.45]$	4.3

Global fit: Results

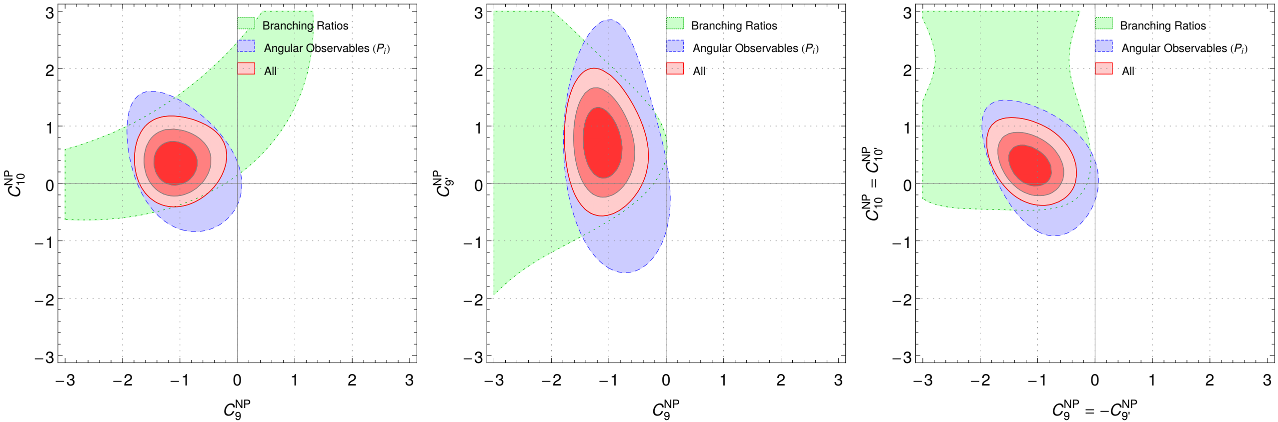
All deviations add up constructively

- A NP contribution to $C_{9,\mu}$=-1.1 with a pull-SM above 4.5σ alleviates all anomalies and tensions.
- NP contributions to the rest of Wilson coefficient are not (**for the moment**) yet significantly different from zero.

See A. Crivellin's, Panico's,... talk for models.

Beyond 1D several favoured scenarios

Allowing for more than one Wilson coefficient to vary different scenarios with pull-SM beyond 4σ pop-up:

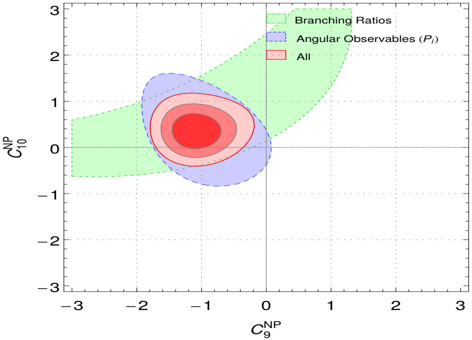


(C_9, C_{10}) (C_9, C_9') $(C_9 = -C_9' \;\&\; C_{10} = C_{10}')$

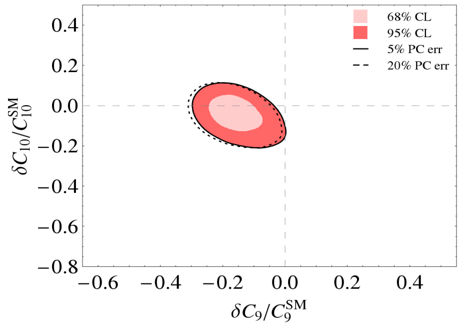
- BR and angular observables both favour $C_9^{\rm NP} \simeq -1$ in all 'good scenarios'.

....*My personal understanding (see back-up) from the analysis of each anomaly/tension is that with more data/precision ALL Wilson coefficients will switch on (including small contrib. primes and radiatives) in delicated cancellations in each observable.*

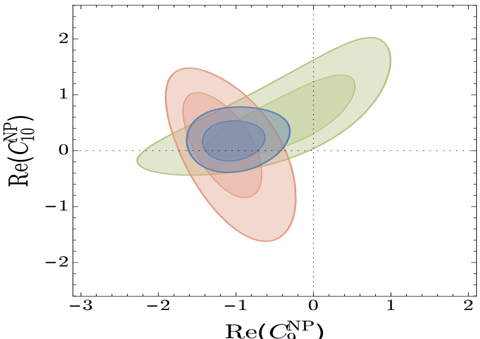
Results in agreement with different analyses, regions and channels



[Descotes, Hofer, JM, Virto]



[Hurth, Mahmoudi, Neshatpour]



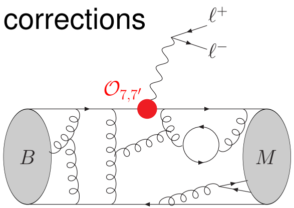
[Altmanshoffer, Straub]

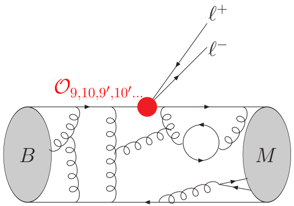
- Different observables (LHCb only or averages, P_i or J_i)
- Different form factor inputs
- Different treatments of hadronic corrections
- Same pattern of NP scenarios favoured (here, $\mathcal{C}_9^{\rm NP}, \mathcal{C}_{10}^{\rm NP}$)

But also consistency between low and large recoil and between different modes.

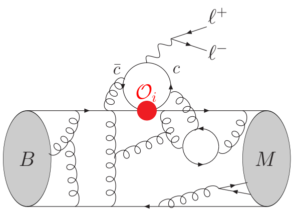
There have been some **attempts** by a few groups to try to explain **a subset of** the previous **anomalies** using two arguments:

- huge factorizable power corrections





- or unknown charm contributions...



$\rightarrow$ we will show (using illustrative examples) in a pedagogical way where these attempts fail.
[See 1701.08672 for all details.]

We will first discuss the theoretical arguments to deconstruct these 'explanations' and later see what type of experimental evidences will help in fully closing the discussion (with the help of Nature).

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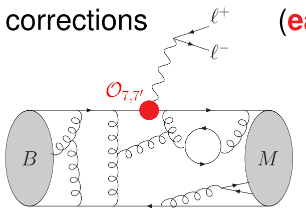
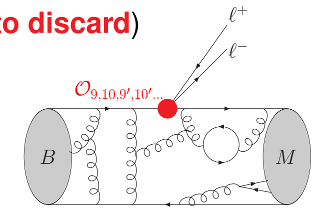
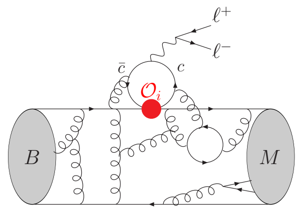




- or unknown charm contributions... (**more difficult to discard but also possible**)



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Can factorizable power corrections be an acceptable explanation?

NO. Two main reasons:

$$\mathbf{F^{full}(q^2)} = F^{soft}(\xi_\perp, \xi_\|) + \triangle F^{\alpha_s}(q^2) + \mathbf{\triangle F^{\Lambda}(q^2)} \qquad \triangle F^{\Lambda} = (a_F + \triangle a_F) + (b_F + \triangle b_F) q^2/m_B^2 + \ldots$$

$\boxed{1}$ **Scheme dependence**: choice of definition of SFF $\xi_{\perp,\|}$ in terms of full-FF.

ALERT: Observables are scheme independent only if all correlations (including correlations of $\triangle a_F$...) are included.

Not including the later ones [Jaeger et.al. and DHMV] $\triangle F^{\rm PC} = F \times \mathcal{O}(\Lambda/m_B)$ require careful scheme choice:

$\rightarrow$ risk to inflate artificially the error in observables.

$\boxed{2}$ **Correlations** among observables via (a_F,...) power corrections. Require a global view.

Two methods:

- *Our I-QCDF using SFF+corrections+KMPW-FF* [Descotes-Genon, Hofer, Matias, Virto]
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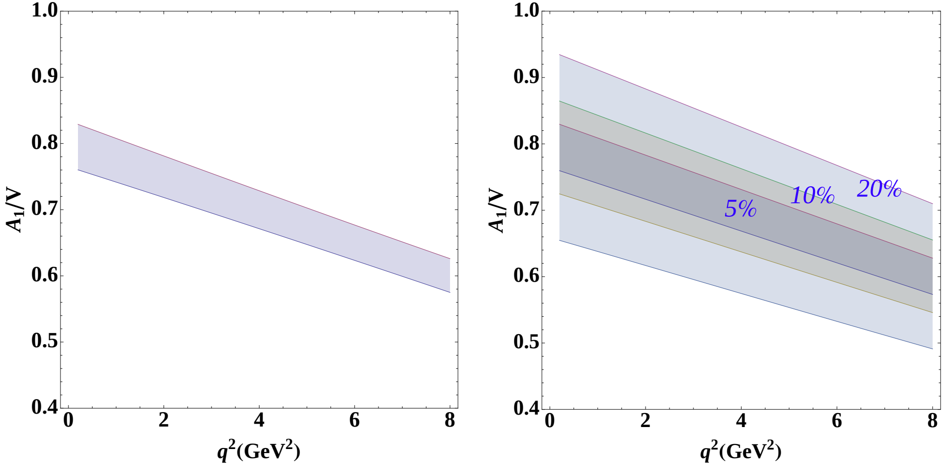
radically different treatment of factorizable p.c. give SM-predictions for P_5' in very good agreement (1σ or smaller).

Compare the ratio A_1/V (that controls P_5') computed using BSZ (including correlations) and computed with our approach for different size of power corrections.



Assigning a 5% error (we take 10%) to the power correction error reproduces the full error of the full-FF!!!

Let's illustrate now points 1 and 2 with two examples.

Scheme-dependence (illustrative example-I)

Model independent ⟷ Full LCSR information

$\boxed{1}$

★ $\triangle F^{\rm PC} = F \times \mathcal{O}(\Lambda/m_B)$
$\sim F \times 10\%$

★ **correlations** from large-recoil sym.
$\to \xi_{\perp,\|}, \triangle F^{\rm PC}$ uncorr.

$\boxed{2}$

★ $\triangle F^{\rm PC}$ from fit to LCSR

★ **correlations** from large-recoil sym.
$\to \xi_{\perp,\|}, \triangle F^{\rm PC}$ uncorr.

$\boxed{3}$

★ $\triangle F^{\rm PC}$from fit to LCSR

★ **correlations** from LCSR
$\to \xi_{\perp,\|}, \triangle F^{\rm PC}$ corr.

$P_5'[4.0,6.0]$	scheme 1 [CDHM]	scheme 2 [JC]
$\boxed{1}$	$-0.72 \pm \mathbf{0.05}$	$-0.72 \pm \mathbf{0.12}$
$\boxed{2}$	-0.72 ± 0.03	-0.72 ± 0.03
$\boxed{3}$	-0.72 ± 0.03	-0.72 ± 0.03
full BSZ	$-0.72 \pm \mathbf{0.03}$	

errors only from pc with BSZ form factors

[Capdevila, Descotes, Hofer, JM]

- [Bharucha, Straub, Zwicky] as example (correlation provided)
- scheme indep. restored if $\triangle F^{\rm PC}$ from fit to LCSR, with expected magnitude
- sensitivity to scheme can be understood analytically
- no uncontrolled large power corrections for $P_{5'}$

Correlations (illustrative example-II)

- How much I need to inflate the errors from factorizable p.c. to get 1-σ agreement with data for $P'_{5[4,6]}$ and $P_{1[4,6]}$ individually?

  $\star$ One needs near **40%** p.c. for $P'_{5[4,6]}$ and 0% for $P_{1[4,6]}$.

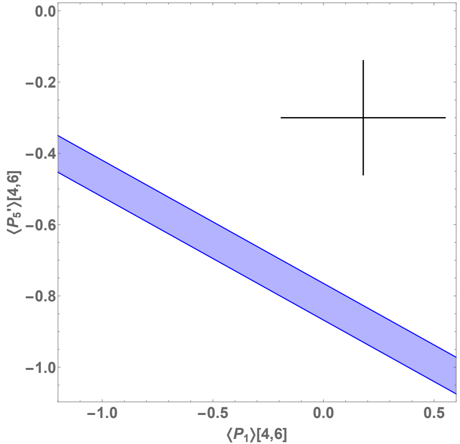
  $\star$ This would be in direct conflict with the two existing LCSR computations: KMPW and BSZ.

- But including the **strong correlation between p.c. of $P'_{5[4,6]}$ and $P_{1[4,6]}$ [CDHM] more than 60% ($>$ 80% in bin [6,8]) is required!!!**

$$P'_5 = P'_5|_\infty \left(1 + \frac{2a_{V_-} - 2a_{T_-}}{\xi_\perp} \frac{C_7^{\rm eff}(C_{9,\perp}C_{9,\|} - C_{10}^2)}{(C_{9,\perp}+C_{9,\|})(C_{9,\perp}^2 + C_{10}^2)} \frac{m_b m_B}{q^2} - \frac{\mathbf{2a_{V_+}}}{\xi_\perp} \frac{\mathbf{C_{9,\|}}}{\mathbf{C_{9,\perp} + C_{9,\|}}} + \ldots\right.$$

$$P_1 = -\frac{\mathbf{2a_{V_+}}}{\xi_\perp} \frac{(\mathbf{C_9^{\rm eff} C_{9,\perp} + C_{10}^2})}{\mathbf{C_{9,\perp}^2 + C_{10}^2}} + \ldots$$

The leading term **in red** in P'_5 is missing in JC'14.



Can charm-loop contribution be the answer to the anomalies?

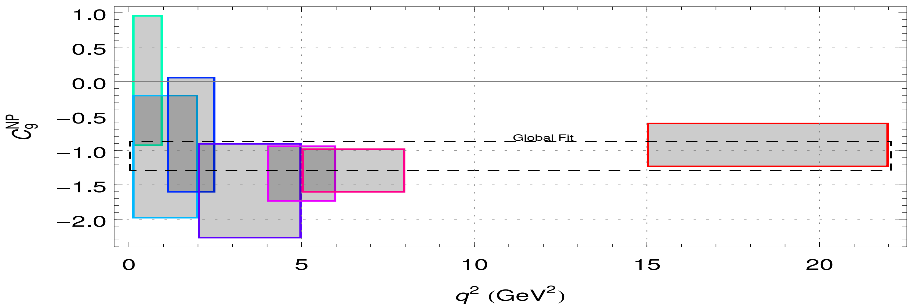
Problem: Charm-loop yields q^2- and hadronic-dependent contribution with $O_{7,9}$ structures that may mimic New Physics.

$$C_{9i}^{\rm eff}(q^2) = C_{9\,\rm SMpert} + C_9^{\rm NP} + \mathbf{C_{9i}^{c\bar{c}}(q^2)}. \qquad \mathbf{i} = \perp, \|, \mathbf{0}$$

How to disentangle? Is our long-dist $c\bar{c}$ estimate using KMPW as order of magnitude correct?

$\boxed{1}$ Fit to C_9^{NP} bin-by-bin of $b \to s\mu\mu$ data:

- NP is universal and q^2-independent.
- Hadronic effect associated to $c\bar{c}$ dynamics is (likely) q^2-dependent.



- The excellent agreement of bins [2,5], [4,6], [5,8]: $C_9^{NP\,[2,5]} = -1.6 \pm 0.7$, $C_9^{NP\,[4,6]} = -1.3 \pm 0.4$, $C_9^{NP\,[5,8]} = -1.3 \pm 0.3$ shows **no indication of <u>additional</u> q^2- dependence.**

[Ciuchini et al.] introduced a polynomial in each amplitudes and fitted the $h_i^{(K)}$ ($i = \perp, \|, 0$ and $K = 0, 1, 2$):

$$A^0_{L,R} = A^0_{L,R}(Y(q^2)) + \frac{N}{q^2}\left(h_0^{(0)} + \frac{q^2}{1GeV^2}h_0^{(1)} + \frac{q^4}{1GeV^4}h_0^{(2)}\right)$$

THIS IS A FIT to LHCb data NOT A PREDICTION!

$\boxed{2}$ Unconstrained Fit finds constant contribution similar for all helicity-amplitudes.

→ In full agreement with our global fit.
→ Problem: They interpret this constant universal contribution as of unknown hadronic origin??
Interestingly: the same constant also explains R_K ONLY if it is of NP origin and NOT if hadronic origin.

Constrained Fit: Imposing SM+ $C_{9i}^{c\bar{c}}$ (from KMPW) at $q^2 < 1$ GeV^2 is highly controversial:

→ arbitrary choice that tilts the fit, inducing spurious **large** q^4-dependence.
→ fit to first bin that misses the lepton mass approximation by LHCb
→ Imposing $|C_{9i}^{c\bar{c}}|_{fitted} = |C_{9i}^{c\bar{c}}|_{KMPW}$, is inconsistent since $Im[C_{9i}^{c\bar{c}}]$ was not computed in KMPW!!

In [1611.04338] same authors claim that absence of large-q^4 terms also leads to acceptable fit.

• Notice that a NP contribution to C_7 and $C_9 \Rightarrow$

induces ALWAYS a small q^4 contribution because:

$$\mathcal{C}_i^{\rm NP} \times FF(q^2)$$

$\rightarrow$ In [Ciuchini et al.] it is explicitly stated that q^4 can only come from hadronic effects....

$\boxed{3}$ We repeated the fit using Frequentist and KMPW-FF comparing fits with higher-order polynomials.

Conclusion: data require constant and linear contributions in q^2, in agreement with KMPW.

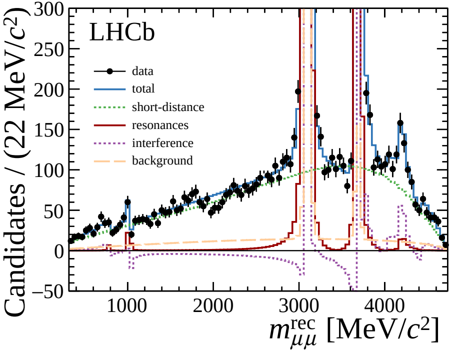
- $\rightarrow$ no improvement in the quality of the fit by adding **large**-q^4 terms (associated to $h_\lambda^{(2)}$) or higher-orders.
- $\rightarrow$ if $C_9^{\rm NP} = -1.1$ is used the fit improves substantially (more than adding 12 indep. parameters).

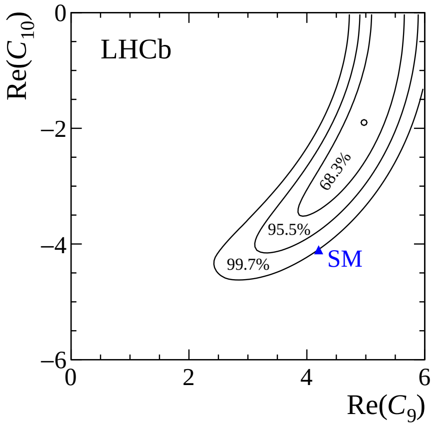
[Capdevila, Hofer, JM, S. Descotes; Hurth, Mahmoudi, Neshatpour]

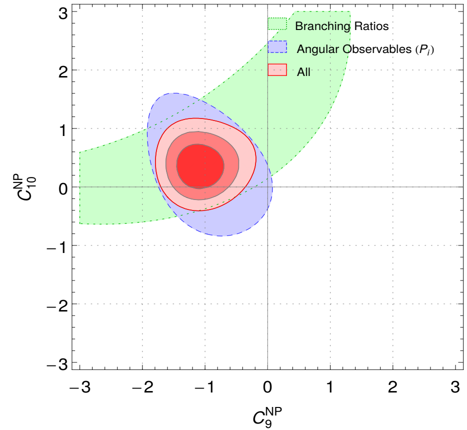
$\boxed{4}$ LHCb also performed in [1612.06764] a measurement of phase difference between:

$$C_9^{\text{eff}} = C_9^{\text{short distance}} + \sum \text{Breit} - \text{Wigner resonances}\,(\omega, \rho^0, \phi, \ldots)$$

- Focus on the channel $B^+ \to K^+\mu^+\mu^-$. FF from lattice and extrapolated on the whole q^2 range.
- *Conclusion*:
  - The measured phases gives a **tiny interference** between short and long-distance far from their pole mass. No significant contribution of the tails of charmonia at low q^2. Result agrees with KMPW estimates.
  - LHCb fits coupling, phases and C_9 and C_{10}. 3σ deviation w.r.t SM in $C_9 - C_{10}$ plane. SM. If $C_{10} = C_{10}^{\text{SM}}$ then $C_9 < C_9^{SM}$ in agreement with our fits.
- Same exercise for $B \to K^*\mu\mu$?







Is there also an alternative path to close the discussion?

Exploring Lepton Flavour non-Universality

Observables sensitive to the difference between $b \to s\mu\mu$ and $b \to see$:

1. They cannot be explained by neither factorizable power corrections nor long-distance charm.
2. They share same explanation than P'_5 anomaly, assuming NP in e-mode is suppressed (OK with fit).

Example-I: R_K and R_{K^*}

Three main types:

- Ratios of Branching Ratios [Bobeth, Hiller et al. '07,'10]:

$$R_K = \frac{\mathrm{BR}(B \to K\mu\mu)}{\mathrm{BR}(B \to Kee)} \qquad R_{K^*} = \frac{\mathrm{BR}(B \to K^*\mu\mu)}{\mathrm{BR}(B \to K^* ee)}$$

$$R_\phi = \frac{\mathrm{BR}(B_s \to \phi\mu\mu)}{\mathrm{BR}(B_s \to \phi ee)}$$

- Difference of Optimized observables: $Q_i = P_i^\mu - P_i^e$

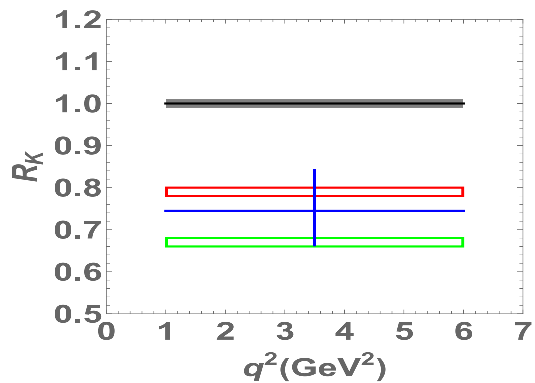
$\to$ Inheritate the excellent properties of optimized observables

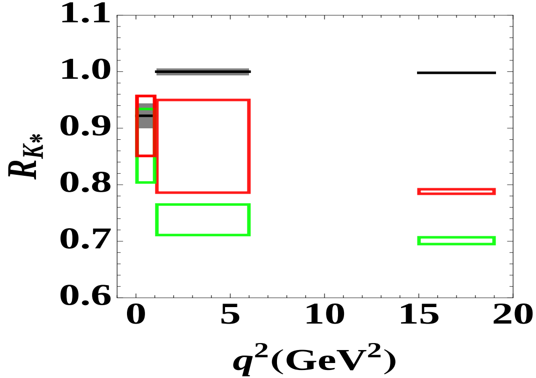
- Ratios of coefficients of angular distribution. $B_i = J_i^\mu / J_i^e - 1$ with i=5,6s.

All are useful to find deviations from SM with tiny uncertainty, but to disentangle different NP scenarios Q_i and B_i are key observables. For instance,

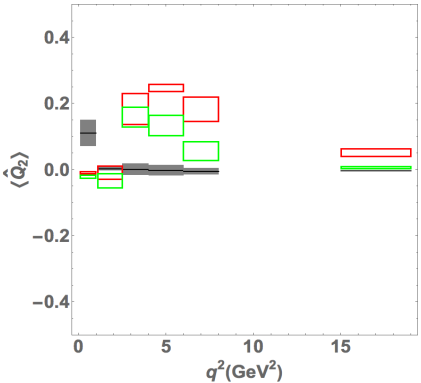
$C_{9\mu}^{\rm NP} = -1.1, C_{9e}^{\rm NP} = 0$ **and** $C_{9\mu}^{\rm NP} = -C_{10\mu}^{\rm NP} = -0.65, C_{9,10e}^{\rm NP} = 0$

(Predictions for R_{K^*} in [1701.08672])

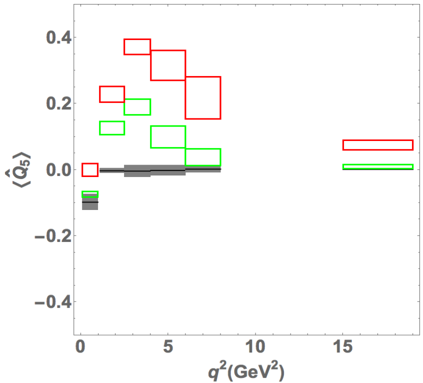




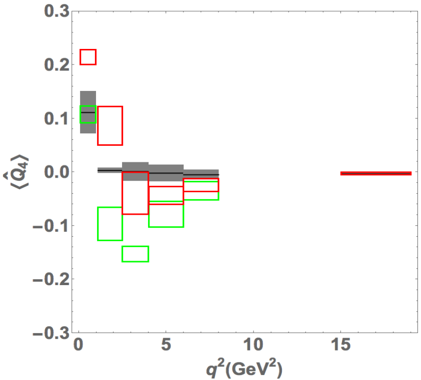
SM predictions (grey boxes),
NP: $C_{9,\mu}^{\rm NP} = -1.11$ (scenario1) & $C_{9,\mu}^{\rm NP} = -C_{10,\mu}^{\rm NP} = -0.65$ (scenario 2) with $\delta C_i = C_{i,\mu} - C_{i,e}$ (and $C_{i,e}$ SM)



$Q_2 = P_2^\mu - P_2^e$



$Q_5 = P_5^{\prime\mu} - P_5^{\prime e}$



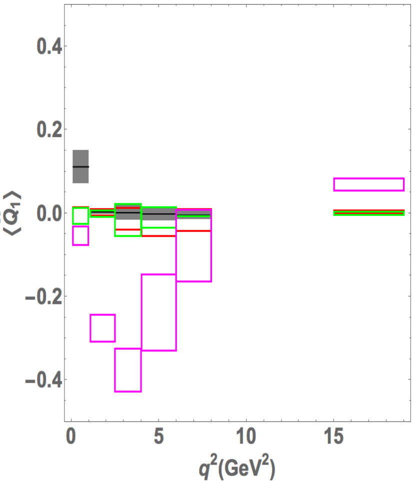
$Q_4 = P_4^{\prime\mu} - P_4^{\prime e}$

⇒ Q_2, Q_4 & Q_5 show distinctive signatures for the two NP scenarios considered.

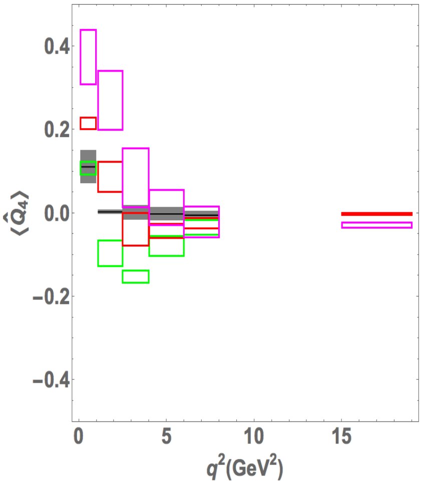
- Differences in the high-q^2 bins of the large recoil region of Q_2 & Q_5 are quite significant. Lack of difference between scenario 2 and SM same reason why P_5' in scenario 2 is worst than scenario 1.
- Q_4 at very low-q^2 (second bin) is very promising to disentangle scenario 1 from 2.

SM predictions (grey boxes),
NP: $C^{\rm NP}_{9,\mu} = -1.11$ & $C^{\rm NP}_{9,\mu} = -C^{\rm NP}_{10,\mu} = -0.65$ & $C^{\rm NP}_{9,\mu} = -C'^{\rm NP}_{9,\mu} = -1.18$ & $C^{\rm NP}_{10,\mu} = C'^{\rm NP}_{10,\mu} = 0.38$.

with $\delta C_i = C_{i,\mu} - C_{i,e}$ (and $C_{i,e}$ SM)



$Q_1 = P_1^{\mu} - P_1^{e}$



$Q_4 = P_4'^{\mu} - P_4'^{e}$

⇒ $Q_{1,4}$ provide excellent opportunities to probe RHC in $C'_{9,\mu}$ & $C'_{10,\mu}$.

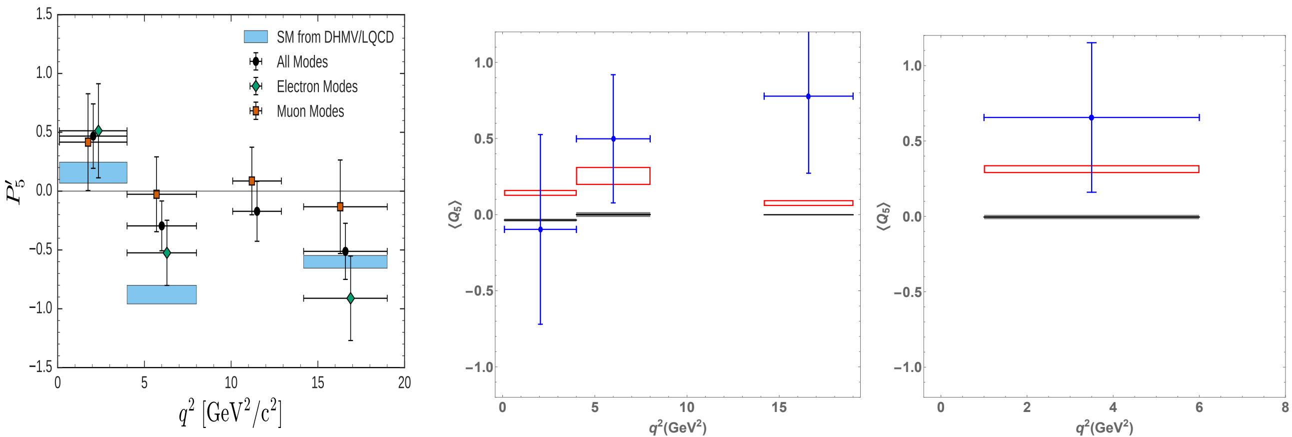
- Q_1 shows significant deviations in presence of RHC. If $C'_7 = 0$ at LO

$$s_0^{LO} = -2\frac{C_7 \delta C'_9 m_b M_B}{C_{10,\mu}\delta C'_{10} + {\rm Re} C_{9,\mu}\delta C'_9}$$

  IT HAS a zero (besides $s = 0$) if $\delta C'_9 \neq 0$.

- Q_4 also at low-q^2 exhibits deviations if $C'_{9,10,\mu} \neq 0$ when accurate precision in measurements is achieved.

First hint from Belle?



- different systematics than LHCb (combination of channels).
- Belle has found for $\langle P_5' \rangle^{\mu}_{[4,8]}$ a 2.6σ deviation while 1.3σ for $\langle P_5' \rangle^{e}_{[4,8]}$
- Q_5 points in the same direction as $C_{9\mu}^{\rm NP} = -1.1$ scenario (in red).

More data needed for confirmation...

Example-III: B_5 & B_{6s} Observables (unique properties)

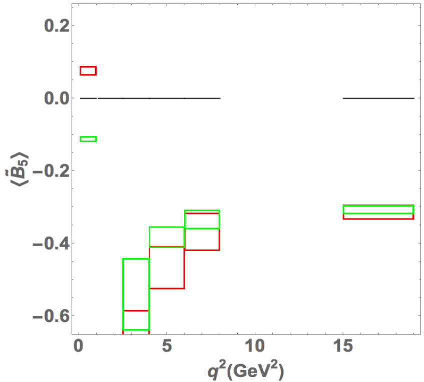
Idea: Combine J_i^μ & J_i^e to build combinations sensitive to some C_i, with controlled sensitivitiy to long-distance charm.

Lepton mass differences generates a non-zero contribution mainly in the first bin.

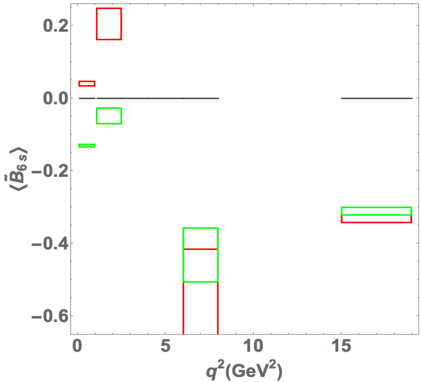
$\Rightarrow$ If on an event-by-event basis experimentalist can measure $\langle J_i^\mu/\beta_\mu^2\rangle$:

$$\langle \widetilde{B}_5\rangle = \frac{\langle J_5^\mu/\beta_\mu^2\rangle}{\langle J_5^e/\beta_e^2\rangle} - 1 \quad \langle \widetilde{B}_{6s}\rangle = \frac{\langle J_{6s}^\mu/\beta_\mu^2\rangle}{\langle J_{6s}^e/\beta_e^2\rangle} - 1$$

- SM Predictions: $\langle \widetilde{B}_i\rangle = 0.00 \pm 0.00$.



$\widetilde{B}_5$



$\widetilde{B}_{6s}$

- When $\hat{s} \to 0$, $\widetilde{B}_5 = \widetilde{B}_{6s} = \delta C_{10}/C_{10} \Rightarrow$ Sensitivity to δC_{10}! If β_ℓ removed same conclusion but a bit shifted.
- 1st Bins: Capacity to distinguish $C_{9,\mu}^{\rm NP} = -1.11$ from $C_{9,\mu}^{\rm NP} = -C_{10,\mu}^{\rm NP} = -0.65$.

- Global point of view: We have shown that the same NP solution $C_{9,\mu}^{\rm NP} = -1.1$, $C_{9,e}^{\rm NP} = 0$ alleviates all tensions: P_5', R_K, low-recoil, $B_s \to \phi\mu^+\mu^-$,...with a global pull-SM of 4.7σ
  $\to$ SM 'alternative explanations' are in trouble from a global point of view.
  $\to$ **an experimental update of $B \to K^*\mu\mu$ from LHCb is of utmost importance now**.

- Local point of view (closing eyes to all deviations except P_5'):
  - Factorizable p.c.: We have proven that an inappropriate scheme's choice if correlations among p.c. are not considered inflates artificially the errors.
  - Long-distance charm: Explicit computation by KMPW do not explain the anomaly and neither a bin-by-bin analysis nor a fit to $h_\lambda^{(i)}$ does not find any indication for a large unaccounted q^4-dep. ($h_\lambda^{(2)} \simeq 0$).

- Different sets of **ULFV observables comparing** $B \to K^*ee$ & $B \to K^*\mu\mu$ (totally free from any long distance charm in the SM):
  - Q_i Observables: $Q_i \leftrightsquigarrow P_i^\ell$
  - $C_{9\ell}$ linear Observables: $B_{5,6s}$, $\tilde{B}_{5,6s} \leftrightsquigarrow J_{5,6s}$
  - R_{K^*}, R_ϕ,...

  can have a deep impact on the global significance of the fit and help in disentangling scenarios.

Exciting times from ULFV observables (R_{K^*}, Q_i,...) to come.

Back-UP slides

Criteria: An appropriate scheme is a scheme that naturally minimizes the sensitivity to power corrections in the relevant observables if you take $\triangle a_F$ uncorrelated.

A simple numerical example:

Evaluate P_5' at $q^2 = 6\,\text{GeV}^2$ and remember that JC and DHMV takes error of p.c. UNCORRELATED:

$$P_5'(6\,\text{GeV}^2) = P_5'|_\infty(6\,\text{GeV}^2)\left(1 + 0.18\,\frac{a_{A_1} + a_V - 2a_{T_1}}{\xi_\perp} - 0.73\,\frac{a_{A_1} - a_V}{\xi_\perp} + \ldots\right)$$

Focus on the leading term and check what happens under the two schemes:

- Scheme-I (our) define $\xi_\perp = V \Rightarrow a_V = 0$ then leading term has

$$-0.73(\triangle a_{A_1})/\xi_\perp$$

- Scheme-II (JC) define $\xi_\perp = T_1 \Rightarrow a_{T_1} = 0$ then leading term has

$$-0.73(\triangle a_{A_1} - \triangle a_V)/\xi_\perp$$

Being uncorrelated effectively Scheme-II induces a factor 2 larger error than Scheme-I.

Already found numerically in 1407.8526.

Anyway there is a positive evolution of predictions in JC that has drastically decreased from 1412.3183:

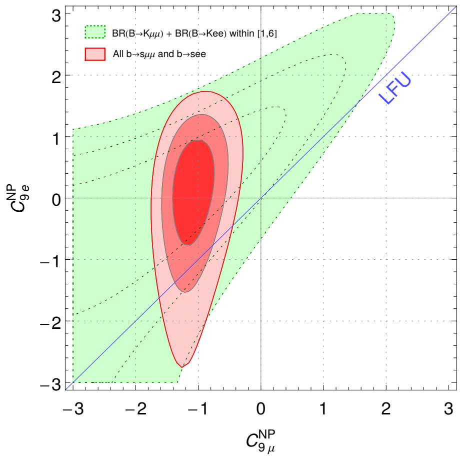
TABLE III. Binned results in the SM for the branching fraction, the longitudinal polarization fraction F_L and the angular observables in the $P_i^{(\prime)}$ basis (using the LHCb conventions [45, 49]). For the electronic mode we give predictions for the bin $[0.0020^{+0.0008}_{-0.0008},\ 1.12^{+0.06}_{-0.06}]$ [91].

Bin [GeV^2]	Br [10^{-8}]	F_L	P_1	P_2	P_3^{CP} [10^{-4}]	P_4'	P_5'	P_6'	P_8'
[0.1, 0.98]	$8.6^{+4.5}_{-3.1}$	$0.26^{+0.21}_{-0.14}$	$0.03^{+0.06}_{-0.05}$	$-0.175^{+0.039}_{-0.041}$	$0.2^{+1.1}_{-0.8}$	$0.19^{+0.06}_{-0.08}$	$0.56^{+0.13}_{-0.14}$	$0.04^{+0.08}_{-0.08}$	$0.00^{+0.09}_{-0.09}$
[1.1, 2]	$3.4^{+2.9}_{-1.5}$	$0.68^{+0.17}_{-0.23}$	$0.04^{+0.11}_{-0.11}$	$-0.83^{+0.16}_{-0.09}$	$0.4^{+3.4}_{-2.3}$	$0.04^{+0.16}_{-0.18}$	$0.35^{+0.30}_{-0.32}$	$0.06^{+0.19}_{-0.19}$	$0.01^{+0.11}_{-0.11}$
[2, 3]	$3.4^{+3.4}_{-1.5}$	$0.78^{+0.13}_{-0.21}$	$0.01^{+0.12}_{-0.15}$	$-0.84^{+0.39}_{-0.14}$	$0.4^{+4.3}_{-2.9}$	$-0.19^{+0.23}_{-0.20}$	$-0.10^{+0.47}_{-0.42}$	$0.06^{+0.26}_{-0.27}$	$0.02^{+0.09}_{-0.09}$
[3, 4]	$3.6^{+3.8}_{-1.8}$	$0.77^{+0.14}_{-0.24}$	$-0.03^{+0.27}_{-0.27}$	$-0.21^{+0.50}_{-0.53}$	$0.3^{+3.4}_{-2.6}$	$-0.37^{+0.23}_{-0.16}$	$-0.49^{+0.52}_{-0.36}$	$0.05^{+0.27}_{-0.28}$	$0.01^{+0.06}_{-0.06}$
[4, 5]	$4.0^{+4.3}_{-2.1}$	$0.73^{+0.18}_{-0.28}$	$-0.06^{+0.34}_{-0.32}$	$0.30^{+0.35}_{-0.52}$	$0.2^{+2.3}_{-2.1}$	$-0.45^{+0.20}_{-0.12}$	$-0.69^{+0.48}_{-0.30}$	$0.04^{+0.25}_{-0.26}$	$0.01^{+0.05}_{-0.05}$
[5, 6]	$4.6^{+5.1}_{-2.6}$	$0.68^{+0.22}_{-0.30}$	$-0.07^{+0.39}_{-0.38}$	$0.59^{+0.23}_{-0.40}$	$0.1^{+1.7}_{-1.6}$	$-0.48^{+0.17}_{-0.10}$	$-0.80^{+0.43}_{-0.27}$	$0.03^{+0.23}_{-0.24}$	$0.01^{+0.05}_{-0.06}$
[1.1, 6]	19^{+19}_{-9}	$0.73^{+0.17}_{-0.25}$	$-0.02^{+0.23}_{-0.24}$	$-0.10^{+0.41}_{-0.39}$	$0.3^{+2.7}_{-1.9}$	$-0.30^{+0.21}_{-0.16}$	$-0.38^{+0.46}_{-0.34}$	$0.05^{+0.24}_{-0.25}$	$0.01^{+0.06}_{-0.05}$
Electron	23^{+10}_{-8}	$0.12^{+0.14}_{-0.07}$	$0.03^{+0.05}_{-0.05}$	$-0.080^{+0.017}_{-0.016}$	$0.3^{+1.0}_{-0.7}$	$0.19^{+0.06}_{-0.07}$	$0.52^{+0.12}_{-0.12}$	$0.04^{+0.07}_{-0.07}$	$0.00^{+0.08}_{-0.08}$

to very recent predictions in 1604.04042

TABLE VI. Results of the angular analysis. The first errors of the measurement are the statistical and the second the systematic error. Observables are compared to SM predictions provided by the authors of Refs. [20, 22, 23].

q^2 in GeV$^2/c^4$	Observable	Measurement	DHMV	BSZ	JC
[0.10, 4.00]	P_4'	$0.208^{+0.400}_{-0.434} \pm 0.070$	-0.026 ± 0.098	-0.029 ± 0.103	$-0.010^{+0.060}_{-0.060}$
	P_5'	$0.631^{+0.403}_{-0.419} \pm 0.067$	0.175 ± 0.086	0.199 ± 0.077	$0.200^{+0.110}_{-0.110}$
	P_6'	$-0.670^{+0.419}_{-0.387} \pm 0.194$	-0.055 ± 0.018	-0.056 ± 0.018	$0.040^{+0.060}_{-0.060}$
	P_8'	$-0.309^{+0.519}_{-0.472} \pm 0.210$	-0.030 ± 0.017	-0.031 ± 0.016	$0.006^{+0.033}_{-0.033}$



- A separated fit to $C_{9\mu}^{\rm NP}$ and $C_{9e}^{\rm NP}$ including $\mathcal{B}_{B\to Kee}$ + large-recoil $B \to K^* ee$ observables finds:
  - Preference for LFU violation with no-NP in $b \to see$.
  - Increase SM pull by $\sim +0.5\sigma$ (from 4.2σ to 4.7σ)

Observables sensitive to the difference between $b \to s\mu\mu$ and $b \to see$ processes open a new window of clean observables.

1. They cannot be explained by neither factorizable power corrections nor long-distance charm.
2. They share same explanation than the P_5' anomaly, assuming NP in electronic mode is suppressed.

Fit	$\mathcal{C}_{9\,\mathrm{Bestfit}}^{\mathrm{NP}}$	1σ	$\mathrm{Pull}_{\mathrm{SM}}$	N_{dof}
All $b \to s\mu\mu$	-1.09	$[-1.29, -0.87]$	4.5	95
All $b \to s\ell\ell$, $\ell = e, \mu$	-1.11	$[-1.31, -0.90]$	4.9	101
All $b \to s\mu\mu$ excl. [5,8] region and also excl. R_K	-0.99	$[-1.23, -0.75]$	3.8	77
Only $b \to s\mu\mu$ BRs	-1.58	$[-2.22, -1.07]$	3.7	31
Only $b \to s\mu\mu$ P_i's	-1.01	$[-1.25, -0.73]$	3.1	68
Only $B \to K^*\mu\mu$	-1.05	$[-1.27, -0.80]$	3.7	61
Only $B_s \to \phi\mu\mu$	-1.98	$[-2.84, -1.29]$	3.5	24
Only $b \to s\mu\mu$ at large recoil	-1.30	$[-1.57, -1.02]$	4.0	78
Only $b \to s\mu\mu$ at low recoil	-0.93	$[-1.23, -0.61]$	2.8	21
Only $b \to s\mu\mu$ within [1,6]	-1.30	$[-1.66, -0.93]$	3.4	43
Only $BR(B \to K\ell\ell)_{[1,6]}$, $\ell = e, \mu$	-1.55	$[-2.73, -0.81]$	2.4	10

Base analysis
all $b \to s\mu\mu$: $+4.5\sigma$

Add:

- electronic mode (R_K): $+0.4$ to 0.5σ
- excl. region [5,8]: -0.6 to -0.7σ

A glimpse into the future: Wilson coefficients versus Anomalies

		R_K	$\langle P_5' \rangle_{[4,6],[6,8]}$	$\mathcal{B}_{B_s\to\phi\mu\mu}$	$\mathcal{B}_{B_s\to\mu\mu}$	low-recoil	best-fit-point
$\mathcal{C}_9^{NP}$	+						
	−	✓	✓ [100%]	✓		✓	X
$\mathcal{C}_{10}^{NP}$	+	✓	[36%]	✓	✓	✓	X
	−		✓ [32%]				
$\mathcal{C}_{9'}$	+		[21%]	✓		✓	X
	−	✓	✓ [36%]				
$\mathcal{C}_{10'}$	+	✓	✓ [75%]				
	−		[75%]	✓	✓	✓	X
But also $\mathcal{C}_7^{NP}, \mathcal{C}_7', \ldots$							

Table: (✓) *indicates that a shift in the Wilson coefficient with this sign moves the prediction in the right direction.*

- $\mathcal{C}_9^{NP} < 0$ is consistent with all anomalies. This is the reason why it gives a strong pull.
- $\mathcal{C}_{10}^{NP}$, $C'_{9,10}$ fail in some anomaly. BUT
  - $\Rightarrow$ $\mathcal{C}_{10}^{NP}$ is the most promising coefficient after $\mathcal{C}_9$, but not enough.
  - $\Rightarrow$ C'_9, C'_{10} seems quite inconsistent between the different anomalies and the global fit.
- Conspiracies among Wilson coefficients change the situation, i.e., $C_{10} - C'_{10} > 0$ is ok, both +.