$B \to K^*\ell^+\ell^-$ theory and the global picture: What´s next?

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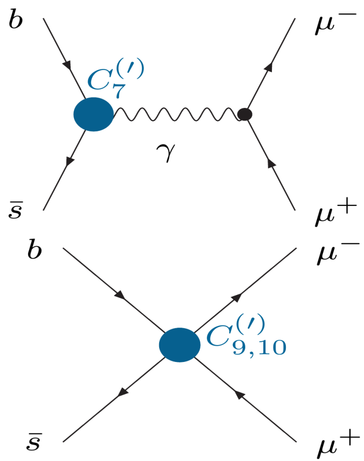
Based on: DMV'13 **PRD88 (2013) 074002**, DHMV'14 **JHEP 1412 (2014) 125**, JM'12 **PRD86 (2012) 094024** HM'15 **JHEP 1509(2015)104**, DHMV'15 **1510.04239 JHEP (2016)**, CDMV'16 and CDHM'16.

Starting point of optimized observables: Frank Krueger, J.M., Phys. Rev. D71 (2005) 094009

The Goal: NP in $b \to s\ell\ell$

Short distance physics (SM+NP) induce effective $b\bar{s}\mu^+\mu^-$ couplings:



$$b \to s\gamma^{(*)} : \mathcal{H}_{\Delta F=1}^{SM} \propto \sum_{i=1}^{10} V_{ts}^* V_{tb} \mathcal{C}_i \mathcal{O}_i + \ldots$$

- $\mathcal{O}_7^{(\prime)} = \frac{\alpha}{4\pi} m_b \, [\bar{s}\sigma^{\mu\nu} P_{R(L)} b] F_{\mu\nu}$
- $\mathcal{O}_9^{(\prime)} = \frac{\alpha}{4\pi} [\bar{s}\gamma_\mu P_{L(R)} b] \; [(\bar{\ell}\gamma_\mu \ell]$
- $\mathcal{O}_{10}^{(\prime)} = \frac{\alpha}{4\pi} [\bar{s}\gamma_\mu P_{L(R)} b] \; [\bar{\ell}\gamma_\mu\gamma_5 \ell]$, ...

• **SM** Wilson coefficients up to NNLO + e.m. corrections at $\mu_{ref} = 4.8$ GeV [Misiak et al.]:

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

• **NP** changes short distance $\mathcal{C}_i - \mathcal{C}_i^{\rm SM} = \mathcal{C}_i^{\rm NP}$ and induces

new operators: scalars, pseudoescalar, tensor operators...

Goal: *Global fit to the relevant processes to determine* $C_7^{(\prime)}$, $C_{9,10}^{(\prime)}$

DHMV'15 1510.04239 (updated with final LHCb data 1512.04442)

Updated GLOBAL FIT 2016:

THE OBSERVABLES

Wrong approach

Good approach

The forest: Rare $b \to s$ processes

- Inclusive
  - $B \to X_s\gamma$ (BR) .... $\mathcal{C}_7^{(\prime)}$
  - $B \to X_s\ell^+\ell^-$ (dBR/dq^2) .... $\mathcal{C}_7^{(\prime)}, \mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$
- Exclusive leptonic
  - $B_s \to \ell^+\ell^-$ (BR) .... $\mathcal{C}_{10}^{(\prime)}$ $\Leftarrow$
- Exclusive radiative/semileptonic
  - $B \to K^*\gamma$ (BR, S, A_I) .... $\mathcal{C}_7^{(\prime)}$
  - $B \to K\ell^+\ell^-$ (dBR/dq^2) .... $\mathcal{C}_7^{(\prime)}, \mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$ $\Leftarrow$
  - $\mathbf{B \to K^*\ell^+\ell^-}$ (dBR/dq^2, **Optimized Angular Obs.**) .. $\mathcal{C}_7^{(\prime)}, \mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$ $\Leftarrow$
  - $B_s \to \phi\ell^+\ell^-$ (dBR/dq^2, Angular Observables) .... $\mathcal{C}_7^{(\prime)}, \mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$ $\Leftarrow$
  - $\Lambda_b \to \Lambda\ell^+\ell^-$ (None so far)
  - etc.

Closer look to the structure of one of the fit's ingredient: $B \to K^*(\to K\pi)\mu\mu$

4-body angular distribution $\mathbf{\bar{B}_d} \to \mathbf{\bar{K}^{*0}}(\to \mathbf{K}^-\pi^+)\mathbf{l}^+\mathbf{l}^-$ with three angles, invariant mass of lepton-pair q^2.

$$\frac{d^4\Gamma(\bar{B}_d)}{dq^2\, d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi}\sum_i J_i(q^2) f_i(\theta_\ell, \theta_K, \phi)$$

$J_i(q^2)$ function of transversity (helicity) amplitudes of K*: $A^{L,R}_{\perp,\|,0}$ (or $H_{\pm,0}$)

depend on FF and **Wilson coefficients.**

Two options:

Non-optimal observables:

$$S_i = (J_i + \bar{J}_i)/(d\Gamma + d\bar{\Gamma})$$

Simple but very sensitive at LO to form factor details.

Optimized observables:

$$P_5' = (J_5 + \bar{J}_5)/2\sqrt{-(J_{2s} + \bar{J}_{2s})(J_{2c} + \bar{J}_{2c})}$$

Exploit symmetry relations:

$$2E_{K^*} m_B V(q^2) = (m_B + m_K^*)^2 A_1(q^2) + \mathcal{O}(\alpha_s, \Lambda/m_b)$$

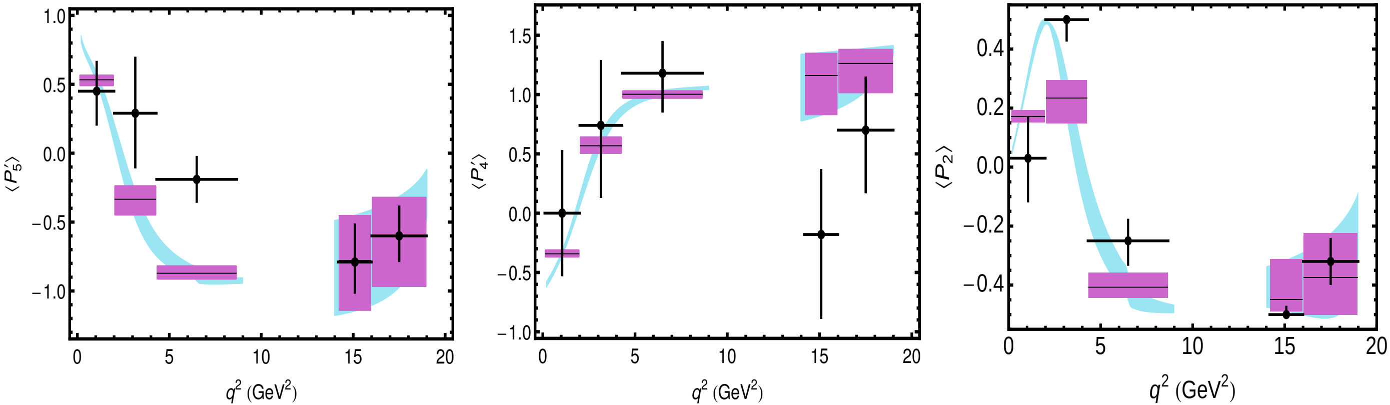
They cancel at LO the sensitivity to soft-FF.

$$\frac{1}{\Gamma'_{full}}\frac{d^4\Gamma}{dq^2\, d\cos\theta_K\, d\cos\theta_l\, d\phi} = \frac{9}{32\pi}\Bigg[\frac{3}{4}\mathbf{F_T}\sin^2\theta_K + \mathbf{F_L}\cos^2\theta_K + (\frac{1}{4}\mathbf{F_T}\sin^2\theta_K - \mathbf{F_L}\cos^2\theta_K)\cos 2\theta_l$$

$$+\sqrt{\mathbf{F_T F_L}}\left(\frac{1}{2}\mathbf{P_4'}\sin 2\theta_K \sin 2\theta_l \cos\phi + \mathbf{P_5'}\sin 2\theta_K \sin\theta_l \cos\phi\right) + 2\mathbf{P_2}\mathbf{F_T}\sin^2\theta_K\cos\theta_l + \frac{1}{2}\mathbf{P_1}\mathbf{F_T}\sin^2\theta_K\sin^2\theta_l\cos 2\phi + \cdot$$

Why so much excitement in Flavour Physics in that year?

First measurement by LHCb of the basis of optimized observables P_i with 1 fb^{-1}:



All the focus was on the optimized observable P_5' that deviated in the bin [4,8.68] GeV^2 near 4σ.

BUT the relevant point......indeed is the COHERENT PATTERN among the relevant observables [S. Descotes-Genon, J.M., J. Virto'13].

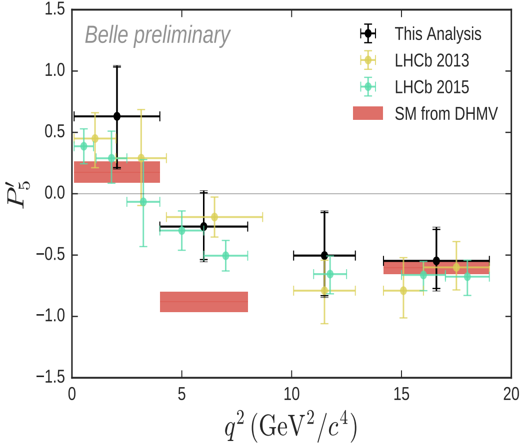
$\Rightarrow$ **Symmetries** among $A_{\perp,\|,0}$ [Egede, JM, Reece, Ramon'12] and [Serra, JM]

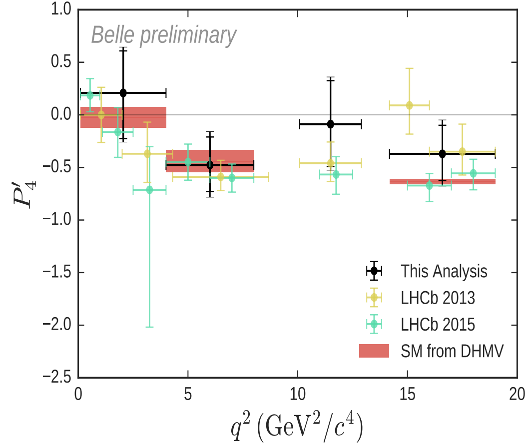
$\Rightarrow$ imply relations among the observables above.

Is the anomaly in P'_5 a statistical fluctuation?

At Moriond2015 with 3 fb^{-1} dataset LHCb confirmed the anomaly in P'_5 in 2 bins with $\sim 3\sigma$ each & few weeks ago Belle experiment confirmed the anomaly in P'_5 and absence of deviation in P'_4.

From Simon Wehle [BELLE]:

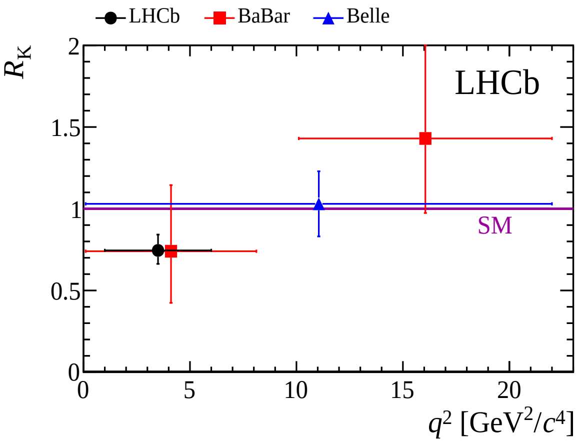




We enter a new period... besides ATLAS and CMS soon will announce results for P'_5.
Only remaining attempt of explanation within SM is that hadronic uncertainties are HUGE:

- Factorizable power corrections.
- Non-factorizable corrections/long-distance CHARM. .... back to it later on..

In the meanwhile new coherent deviations appear...



$$R_K = \frac{\mathrm{Br}\,(B^+ \to K^+\mu^+\mu^-)}{\mathrm{Br}\,(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

$\Rightarrow$ It deviates **2.6σ** from SM.

$\Rightarrow$ Conceptually very relevant:

- Very clean signal of NP
- Long-distance charm **cannot explain this tension.**

- All experimental bins of $BR(B^0 \to K^0\mu^+\mu^-)$ and $BR(B_s \to \phi\mu^+\mu^-)$ exhibit a systematic deficit with respect to SM (**1-3σ**).
- Several low-recoil bins of $B \to P$ and $B \to V$ exhibit tensions from **1.4 to 2.5σ**.

Results of the 2016 Fit:

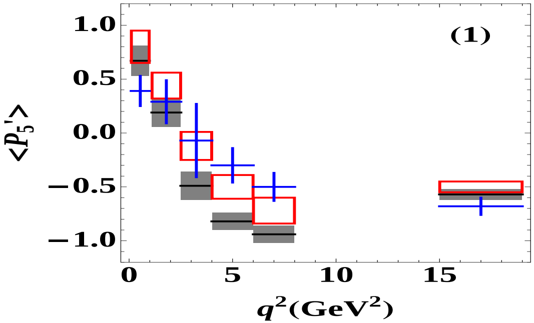
- Latest theory and experimental updates of $\mathrm{BR}(B \to X_S\gamma)$, $\mathrm{BR}(B_s \to \mu^+\mu^-)$, $B_{(s)} \to (K^*, \phi)\mu^+\mu^-)$, $\mathrm{BR}(B \to Ke^+e^-)_{[1,6]}$ (or R_K) and $B \to K^*e^+e^-$ at very low q^2
- Frequentist approach: χ^2 with all theory+experimental correlations.

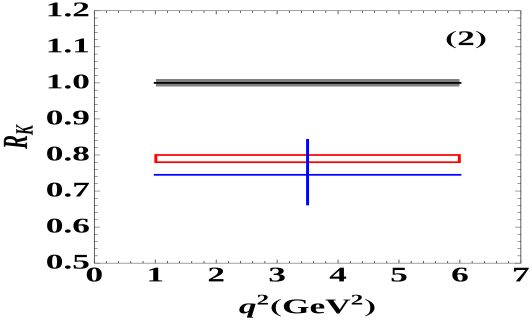
Result of the fit with 1D Wilson coefficient 2016 (included R_K)

Pull_{SM} quantify by how many σ the b.f.p. is preferred over the SM point $\{C_i^{NP} = 0\}$. A scenario with a large SM-pull $\Rightarrow$ big improvement over SM and better description of data. Hyp: Maximal LFUV.

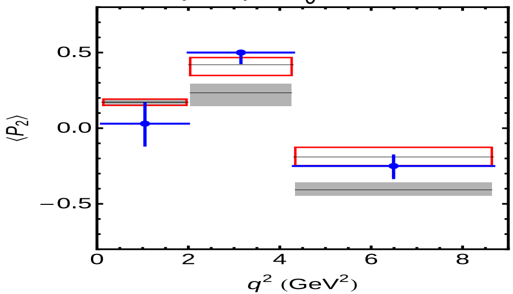
Coefficient $\mathcal{C}_i^{NP} = \mathcal{C}_i - \mathcal{C}_i^{SM}$	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_7^{\text{NP}}$	-0.02	$[-0.04, -0.00]$	$[-0.07, 0.03]$	1.2
$\mathcal{C}_{\mathbf{9}}^{\text{NP}}$	-1.11	$[-1.31, -0.90]$	$[-1.67, -0.46]$	**4.9** $\Leftarrow$ (4.5 if no R_K)
$\mathcal{C}_{10}^{\text{NP}}$	0.61	$[0.40, 0.84]$	$[-0.01, 1.34]$	3.0
$\mathcal{C}_{7'}^{\text{NP}}$	0.02	$[-0.00, 0.04]$	$[-0.05, 0.09]$	1.0
$\mathcal{C}_{9'}^{\text{NP}}$	0.15	$[-0.09, 0.38]$	$[-0.56, 0.85]$	0.6
$\mathcal{C}_{10'}^{\text{NP}}$	-0.09	$[-0.26, 0.08]$	$[-0.60, 0.42]$	0.5
$\mathcal{C}_9^{\text{NP}} = \mathcal{C}_{10}^{\text{NP}}$	-0.20	$[-0.38, -0.01]$	$[-0.70, 0.47]$	1.0
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}}$	-0.65	$[-0.80, -0.50]$	$[-1.13, -0.21]$	**4.6** $\Leftarrow$
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}$	-1.07	$[-1.25, -0.86]$	$[-1.60, -0.42]$	4.9 (low recoil)
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}} = -\mathcal{C}_{10'}^{\text{NP}}$	-0.66	$[-0.84, -0.50]$	$[-1.25, -0.20]$	4.5

Impact on the anomalies of a contribution from NP $C_9^{NP} = -1.1$





2013 theory+exp.: $C_9^{NP} = -1.5$



$b \to s\mu^+\mu^-$ (low-recoil)	bin	$SM \to NP$
$10^7 \times BR(B^0 \to K^0\mu^+\mu^-)$	[15,19]	$+1.4\sigma \to +0.3\sigma$
$10^7 \times BR(B^0 \to K^{*0}\mu^+\mu^-)$	[16,19]	$+1.7\sigma \to +0.4\sigma$
$10^7 \times BR(B^+ \to K^{*+}\mu^+\mu^-)$	[15,19]	$+2.5\sigma \to +1.2\sigma$
$10^7 \times BR(B_s \to \phi\mu^+\mu^-)$	[15,18.8]	$+2.2\sigma \to +0.5\sigma$

SM is (gray) and NP ($C_9^{NP} = -1.1$). R_K cannot be explained by charm.

All anomalies and tensions gets solved or alleviated with $C_9^{NP} \sim \mathcal{O}(-1)$

Result of the fit to the SIX Wilson coefficients free

Coefficient	1σ	2σ	3σ	
$\mathcal{C}_7^{\rm NP}$	$[-0.02, 0.03]$	$[-0.04, 0.04]$	$[-0.05, 0.08]$	no preference
$\mathcal{C}_9^{\rm NP}$	$[-1.4, -1.0]$	$[-1.7, -0.7]$	$[-2.2, -0.4]$	**negative**
$\mathcal{C}_{10}^{\rm NP}$	$[-0.0, 0.9]$	$[-0.3, 1.3]$	$[-0.5, 2.0]$	positive
$\mathcal{C}_{7'}^{\rm NP}$	$[-0.02, 0.03]$	$[-0.04, 0.06]$	$[-0.06, 0.07]$	no preference
$\mathcal{C}_{9'}^{\rm NP}$	$[0.3, 1.8]$	$[-0.5, 2.7]$	$[-1.3, 3.7]$	positive
$\mathcal{C}_{10'}^{\rm NP}$	$[-0.3, 0.9]$	$[-0.7, 1.3]$	$[-1.0, 1.6]$	$\sim$ positive

- C_9 is consistent with SM only **above 3**σ
- All other are consistent with zero at 1σ except for C_9' (at 2 σ).
- The Pull$_{SM}$ for the 6D fit is 3.6σ.

How much the fit results depend on the details?

There are only 3 updated analysis of the full set of observables of $b \to s\ell\ell$:

1) **Descotes-Hofer-Matias-Virto (DHMV).** We use for $B \to K^*$:
   Full dataset, **optimized** observables P_i , we use **Khodjamirian FF**. Frequentist, $\Delta\chi^2$-fit.

2) **Altmannshofer-Straub (AS)** and indirectly Bharucha-Zwicky for FF. They use for $B \to K^*$:
   A slightly **smaller dataset**, **non-optimized** observables S_i, they use **BSZ FF**. Frequentist, $\Delta\chi^2$-fit.

3) **Hurth-Mahmoudi-Neshatpour.** They use a mixed up both and they use absolute χ^2 method.

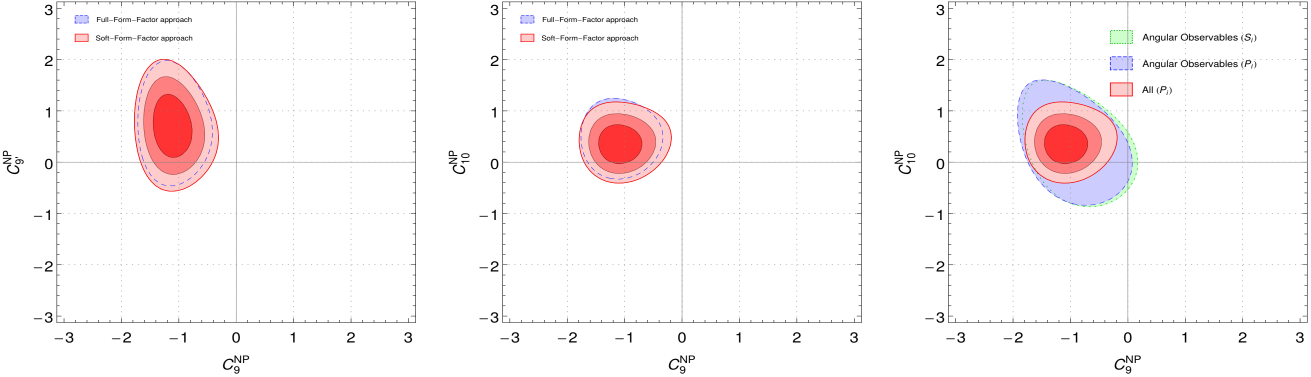


Figure: *We show the 3 σ regions allowed using FF in BSZ'15 in the full FF approach (long-dashed blue) compared to our reference fit with the SFF approach (red, with 1,2,3 σ contours).* **Both methods are in excellent agreement.**

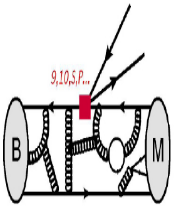
... Focus on $B \to K^* \mu\mu$ for a moment...

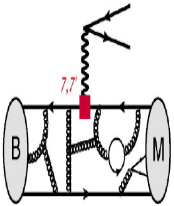
Are hadronic uncertainties correctly estimated?

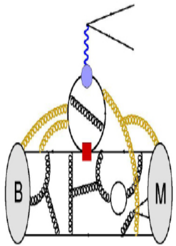
Let's analyze each error's source & comparison with other works in the literature...

The structure of $B \to K^* \ell^+ \ell^-$

$$\boxed{\mathcal{M} \propto (\mathcal{A}_V^\mu + \mathcal{H}_V^\mu)\bar{\ell}\gamma_\mu \ell + \mathcal{A}_A^\mu \bar{\ell}\gamma_\mu\gamma_5 \ell}$$







$$\mathcal{A}_V^\mu = C_7 \frac{2 i m_b}{q^2} q_\rho \langle \bar{K}^* | \bar{s}\sigma^{\rho\mu} P_R b | \bar{B} \rangle + C_9 \langle \bar{K}^* | \bar{s}\gamma^\mu P_L b | \bar{B} \rangle$$

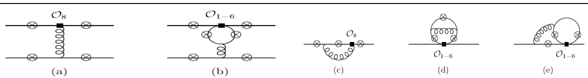
$$\mathcal{A}_A^\mu = C_{10} \langle \bar{K}^* | \bar{s}\gamma^\mu P_L b | \bar{B} \rangle$$

$$\mathcal{H}_V^\mu \propto i \int d^4x \, e^{iq\cdot x} \langle \bar{K}^* | T[\bar{c}\gamma^\mu c]\mathcal{H}_c | \bar{B} \rangle$$

IQCDF: QCDF + symmetries among FF
At LO in α_s and Λ/m_b:

$$\frac{m_B}{m_B+m_{K^*}} \mathbf{V}(\mathbf{q^2}) = \frac{m_B+m_{K^*}}{2E} \mathbf{A_1}(\mathbf{q^2}) = \mathbf{T_1}(\mathbf{q^2}) = \frac{m_B}{2E} \mathbf{T_2}(\mathbf{q^2}) = \xi_\perp(E)$$

$$\frac{m_{K^*}}{E} \mathbf{A_0}(\mathbf{q^2}) = \frac{m_B+m_{K^*}}{2E} \mathbf{A_1}(\mathbf{q^2}) - \frac{m_B-m_{K^*}}{m_B} \mathbf{A_2}(\mathbf{q^2}) = \frac{m_B}{2E} \mathbf{T_2}(\mathbf{q^2}) - \mathbf{T_3}(\mathbf{q^2}) = \xi_\|(E)$$

4-types of corrections included	Factorizable	Non-Factorizable
α_s-QCDF	$\Delta F^{\alpha_s}(q^2)$	
power-corrections	$\Delta F^\Lambda(q^2)$	LCSR with single soft gluon contribution

FF decomposition: $\mathbf{F^{full}}(\mathbf{q^2}) = F^{soft}(\xi_\perp, \xi_\|) + \Delta F^{\alpha_s}(q^2) + \Delta F^\Lambda(q^2)$

Different Form Factor determinations

B-meson distribution amplitudes.

FF-KMPW	$F^i_{BK^{(*)}}(0)$	b^i_1
f^+_{BK}	$0.34^{+0.05}_{-0.02}$	$-2.1^{+0.9}_{-1.6}$
f^0_{BK}	$0.34^{+0.05}_{-0.02}$	$-4.3^{+0.8}_{-0.9}$
f^T_{BK}	$0.39^{+0.05}_{-0.03}$	$-2.2^{+1.0}_{-2.00}$
V^{BK^*}	$\mathbf{0.36^{+0.23}_{-0.12}}$	$-4.8^{+0.8}_{-0.4}$
$A_1^{BK^*}$	$\mathbf{0.25^{+0.16}_{-0.10}}$	$0.34^{+0.86}_{-0.80}$
$A_2^{BK^*}$	$0.23^{+0.19}_{-0.10}$	$-0.85^{+2.88}_{-1.35}$
$A_0^{BK^*}$	$0.29^{+0.10}_{-0.07}$	$-18.2^{+1.3}_{-3.0}$
$T_1^{BK^*}$	$0.31^{+0.18}_{-0.10}$	$-4.6^{+0.81}_{-0.41}$
$T_2^{BK^*}$	$0.31^{+0.18}_{-0.10}$	$-3.2^{+2.1}_{-2.2}$
$T_3^{BK^*}$	$0.22^{+0.17}_{-0.10}$	$-10.3^{+2.5}_{-3.1}$

Table: The $B \to K^{(*)}$ form factors from LCSR and their z-parameterization.

Light-meson distribution amplitudes+EOM.

- Interestingly in BSZ (update from BZ) most relevant FF from BZ moved towards KMPW. For example:

$$V^{BZ}(0) = 0.41 \to 0.37 \quad T_1^{BZ}(0) = 0.33 \to 0.31$$

- The size of uncertainty in *BSZ* = size of error of p.c.

FF-BSZ	$B \to K^*$	$B_s \to \phi$	$B_s \to K^*$
$A_0(0)$	0.391 ± 0.035	0.433 ± 0.035	0.336 ± 0.032
$A_1(0)$	$\mathbf{0.289 \pm 0.027}$	0.315 ± 0.027	0.246 ± 0.023
$A_{12}(0)$	0.281 ± 0.025	0.274 ± 0.022	0.246 ± 0.023
$V(0)$	$\mathbf{0.366 \pm 0.035}$	0.407 ± 0.033	0.311 ± 0.030
$T_1(0)$	0.308 ± 0.031	0.331 ± 0.030	0.254 ± 0.027
$T_2(0)$	0.308 ± 0.031	0.331 ± 0.030	0.254 ± 0.027
$T_{23}(0)$	0.793 ± 0.064	0.763 ± 0.061	0.643 ± 0.058

Table: Values of the form factors at $q^2 = 0$ and their uncertainties.

$\Rightarrow$ **Relevant for BSZ users**: R. Zwicky found a small error in a Distribution Amplitude used in the literature that he used as an input. This affects in particular the error of twist-4 at $\mathcal{O}(\alpha_s)$ for BSZ FF.
Implications:

Predictions	[Bharucha, Straub, Zwicky'15.]	[Hofer, Descotes, Matias, Virto'16]
FFD observables $B \to K^*$ Branching ratios and S_i	changes of $\mathcal{O}(\Lambda/m_b)$ or a bit more in some FFD.	unchanged (KMPW)
FFI observables $B \to K^*$ optimized P_i	changes $\leq \mathcal{O}(\Lambda/m_b)$ robustness of P_i	unchanged (KMPW)
FFD observables $B_s \to \phi$ Branching ratios	changes of $\mathcal{O}(\Lambda/m_b)$	changes of $\mathcal{O}(\Lambda/m_b)$ (BSZ)
Global analysis	Changes of $\mathcal{O}(0.5\sigma)$ expected?	The impact of a reduction of 1σ from $B_s \to \phi$ implies a change of $\lesssim 0.2\sigma$ in the global fit for C_9 (irrelevant).

BUT **any paper in literature** relying heavily on BSZ for $B \to K^*\mu\mu$ has to **evaluate and check the impact of this correction** (see BACK-UP).

What are Factorizable power corrections and how they emerge? (JC'12)

$$F^{full}(q^2) = F^{\rm soft}(\xi_{\perp,\parallel}(q^2)) + \Delta F^{\alpha_s}(q^2) + \Delta F^{\Lambda} \quad \text{with} \quad \Delta F^{\Lambda} = a_F + b_F \frac{q^2}{m_B^2} + c_F \frac{q^4}{m_B^4}$$

- Take your favorite full-FF and **compute** ΔF^{Λ} from a fit in $q^2/m_B^2 \Rightarrow$ central values a_F, b_F, c_F. Ex: (**DHMV'14**)

$$\Delta A_1/A_1|_{q^2=4GeV^2} = 6\%$$

- Scheme: choice of definition for the two soft FF:

$$\{\xi_\perp, \xi_\parallel\} = \{V, A_1 + A_2\}, \{T_1, A_0\}, \{...\}...$$

- Observables are **scheme independent** BUT **the procedure to compute** them can be either scheme-independent or not. THE KEYPOINT: **CORRECT** treatment of ΔF^{Λ} errors!

Model independent ⟷ Full LCSR information

ΔF^{Λ} Errors are taken **uncorrelated** to be $\mathcal{O}(\Lambda/m_b) \times \mathrm{FF} \simeq 0.1\mathrm{FF}$ consistently with fit to LCSR results $\rightarrow$**BAD scheme's choice inflates artificially error**.

ΔF^{Λ} Errors are totally correlated by particular LCSR. $\rightarrow$ **scheme independent but strongly sensitive to FF computation details/assumptions.**

Why JC'14 has FFI observables with huge errors and FFD smaller errors?

1) **Power correction error size**: In JC'14 they take uncorrelated errors for ΔF^{Λ} BUT their scheme choice inflates error **artificially** due to a **bad scheme's choice**.

ONLY power correction error of $\langle P_5' \rangle_{[4,6]}$	error of f.f.+p.c. scheme-1 in transversity basis **DHMV'14**	error of f.f.+p.c. scheme-2 in helicity basis **JC'14**
NO correlations among errors of p.c. (hyp. 10%)	± 0.05	$\pm$**0.12**
WITH correlations among errors of p.c.	± 0.03	± 0.03

2) **Parametric errors** from (m_q, f_{K^*}, μ, a_i,...) and soft FF. Numerical instabilities of log[x]/x?

- DHMV'14 a random scan over all parameters and take max and min.
- JC'12 (same approach) error is factor 2 larger than: DHMV'14, BSZ'15 and also Bobeth et al.'13.

$$err[\langle P_5' \rangle_{[4,6]}^{DHMV'16}] = \pm\mathbf{0.08}(\pm 0.11 \,\mathrm{flat\,DHMV'14}) \quad err[\langle P_5' \rangle_{[4,6]}^{BSZ}] = \pm\mathbf{0.07} \quad err[\langle P_5' \rangle_{[5,6]}^{JC'14}] = \pm\mathbf{0.35}$$

1) and 2) explains the artificially large errors in FFI observables P_i in JC'12 and '14.

Why JC'14 has FFI observables with huge errors and FFD smaller errors?

1) **Power correction error size**: In JC'14 they take uncorrelated errors for ΔF^{Λ} BUT their scheme choice inflates error **artificially** due to a **bad scheme's choice.**

ONLY power correction error of $\langle P_5' \rangle_{[4,6]}$	error of f.f.+p.c. scheme-1 in transversity basis **DHMV'14**	error of f.f.+p.c. scheme-2 in helicity basis **JC'14**
NO correlations among errors of p.c. (hyp. 10%)	± 0.05	$\pm \mathbf{0.12}$
WITH correlations among errors of p.c.	± 0.03	± 0.03

2) **Parametric errors** from (m_q, f_{K^*}, μ, a_i,...) and soft FF. Numerical instabilities of log[x]/x?

- DHMV'14 a random scan over all parameters and take max and min.
- JC'12 (same approach) error is factor 2 larger than: DHMV'14, BSZ'15 and also Bobeth et al.'13.

$$err[\langle P_5' \rangle_{[4,6]}^{DHMV'16}] = \pm \mathbf{0.08} (\pm 0.11 \text{ flat DHMV'14}) \quad err[\langle P_5' \rangle_{[4,6]}^{BSZ}] = \pm \mathbf{0.07} \quad err[\langle P_5' \rangle_{[5,6]}^{JC'14}] = \pm \mathbf{0.35}$$

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DHMV: $\xi_\perp = \mathbf{0.31}^{+0.20}_{-0.10}$ from KMPW $V = 0.36^{+0.23}_{-0.12} \rightarrow err[\langle F_L \rangle_{[0.1,0.98]}^{DHMV'16}] = \pm \mathbf{0.25}$

JC'14: $\xi_\perp = \mathbf{0.31} \pm \mathbf{0.04}$ spread of **only** central values (KMPW,BZ,..) no error! $\rightarrow err[\langle F_L \rangle_{[0.1,0.98]}^{JC'14}] = \pm \mathbf{0.18}$.

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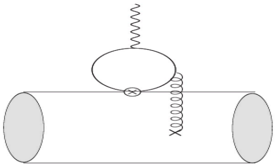
Long-distance contributions from $c\bar{c}$ loops where the lepton pair is created by an electromagnetic current.

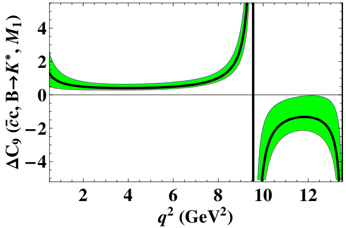
$$C_9^{\rm eff\,i} = C_9^{\rm eff}{}_{\rm SM\,pert}(q^2) + C_9^{\rm NP} + s_i \delta C_9^{c\bar{c}(i)}{}_{\rm KMPW}(q^2)$$

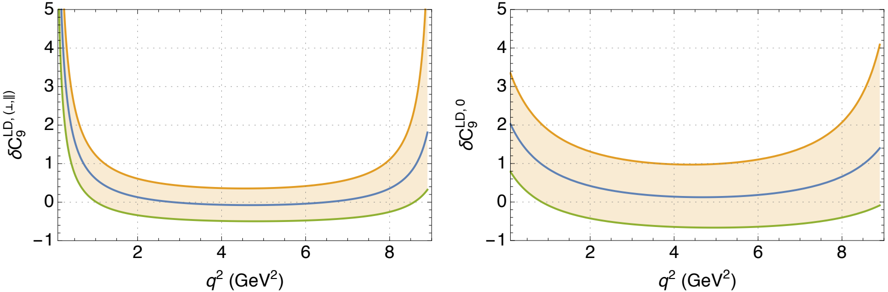
KMPW implies $s_i = 1$, but we vary $s_i = 0 \pm 1$, $i = 0, \perp, \|$.

$$\delta C_9^{\rm LD,(\perp,\|)}(q^2) = \frac{a^{(\perp,\|)} + b^{(\perp,\|)} q^2 [c^{(\perp,\|)} - q^2]}{b^{(\perp,\|)} q^2 [c^{(\perp,\|)} - q^2]}$$

$$\delta C_9^{\rm LD,0}(q^2) = \frac{a^0 + b^0 [q^2 + s_0][c^0 - q^2]}{b^0 [q^2 + s_0][c^0 - q^2]}$$







Obtained from fitting the long-distance part to KMPW.

Literature estimates -based on real computations- of long-distance charm

Different parametrization and estimates of the soft gluon emission and the charmonium effect.

- **Comparison of non-factorizable** including long-distance charm-loop error **estimates of 3 papers**:

Focus only on non-factorizable error of common bins [2,4.3], [4,6] and the bin [1,6] of P'_5

	bin[2,4.3]	bin[1,6]	bin[4,6]
DHMV'14	$^{+0.098+0.016}_{-0.114-0.020} \to \pm\mathbf{0.11}$	$^{+0.088+0.014}_{-0.102-0.017} \to \pm\mathbf{0.10}$	$^{+0.069+0.007}_{-0.082-0.008} \to \pm\mathbf{0.08}$
JC'12	± 0.10	± 0.09	—
BSZ'15	[2,3],[3,4] $\to \pm 0.08$	[1,2],[2,3],..[5,6] $\to \pm 0.06$	± 0.05

How much shall we arbitrarily increase charm error in order to explain the anomaly in bin [4,6] of P'_5?

$\Rightarrow$ LHCb measurement is $\mathbf{-0.30 \pm 0.16}$ after adding quadratically all other errors one would STILL need to increase non-factorizable error (including long-distance charm) by **5-6 to get agreement with SM!**

How can we test if charm-loops have been correctly estimated?

Is there a clear signal of a q^2 dependence after including KMPW long-distance computation?

Compute C_9^{NP} bin-by-bin, if the values obtained are flat, charm is well estimated.

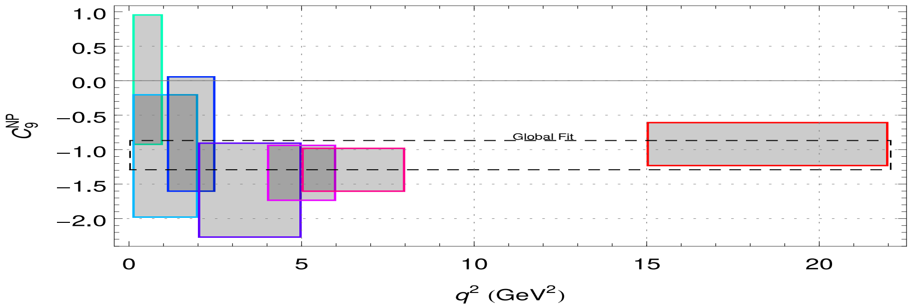


Figure: *Determination of $\mathcal{C}_9$ from the reference fit restricted to the data available in a given q^2-region.*

- Notice we use KMPW for $B \to K^*$. We force in this plot all New Physics in C_9!!
- **Notice the excellent agreement of bins [2,5], [4,6], [5,8].** $C_9^{NP\,[2,5]} = -1.6 \pm 0.7$, $C_9^{NP\,[4,6]} = -1.3 \pm 0.4$, $C_9^{NP\,[5,8]} = -1.3 \pm 0.3$
- **First bin is afflicted by lepton-mass effects.**
- **We do not find any indication for a q^2-dependence in $\mathcal{C}_9$ neither in the plots nor in a 6D fit adding $a^i + b^i s$ to $C_9^{\rm eff}$ for $i = K^*, K, \phi$.** $\to$ disfavours again charm explanation.

NEXT STEP?

NATURE shows two different faces.....

The strongest signal of New Physics is in C_9 the most difficult coefficient

- The only coefficient affected by long-distance charm contributions.
- Maybe for this reason it hidden for so long...

There are clear indications that NP is lepton-flavour non-universal

- These observables are free from long-distance charm pollution in the SM in C_9
  $\Rightarrow$ the discovery of NP in C_9 is then out of question.

[Capdevila, SDG, JM, Virto'16]

Can one construct observables able to probe:

a) *only the short distance part* of C_9^ℓ.

$\to$ fully *free from long distance charm* effects in the **SM.**

b) the *amount of lepton flavour non-universality* between electrons and muons?

Answer: Of course yes: R_K, R_{K^*}, R_ϕ.

A clear deviation is an unquestionable signal of flavour non-universal New Physics:

CHANGE: NP or charm by NP $\times$ charm

ONLY in presence of New Physics charm reemerges ...

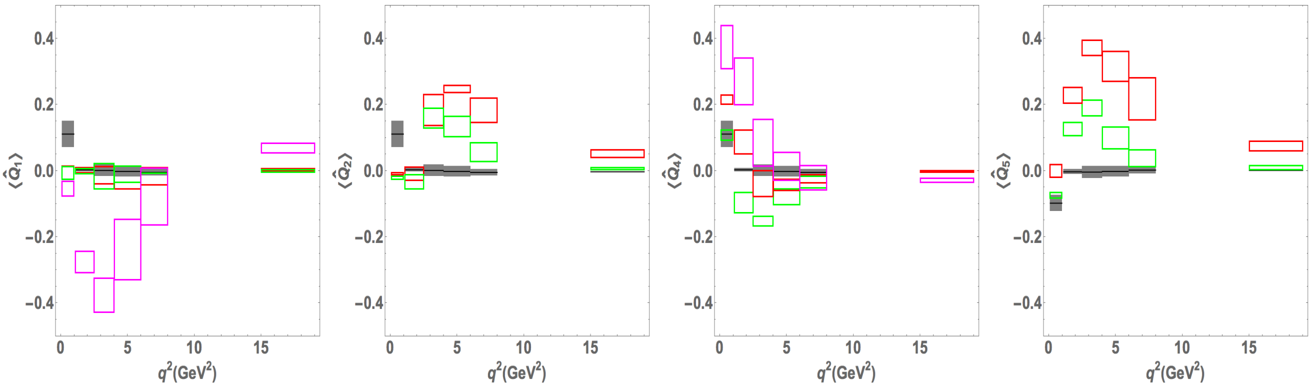
.... can we add to a) and b) the excellent properties of optimized observables?

$$\left\langle \hat{Q}_i \right\rangle = \langle P_i^\mu \rangle - \langle P_i^e \rangle \qquad \text{but also} \qquad \langle B_i \rangle = \frac{\langle J_i^\mu \rangle}{\langle J_i^e \rangle} - 1\,, \quad \left\langle \widetilde{B}_i \right\rangle = \frac{\langle J_i^\mu / \beta_\mu^2 \rangle}{\langle J_i^e / \beta_e^2 \rangle} - 1, \quad M\,(\widetilde{M})$$

$\hat{}$ means correcting for lepton-mass effects in the 1st bin. **Charm discussion in SM become obsolete!**

Category-I: Q_i observables. Disentangling scenarios

SM predictions (grey boxes),
NP: $C_{9\mu}^{\rm NP} = -1.11$ Sc-1, $C_{9\mu}^{\rm NP} = -C_{10\mu}^{\rm NP} = -0.65$ Sc-2, $C_{9\mu}^{\rm NP} = -C_{9\mu}^{\prime\rm NP} = -1.18$, $C_{10\mu}^{\rm NP} = C_{10\mu}^{\prime\rm NP} = 0.38$ Sc-4.



$Q_1 = P_1^{\mu} - P_1^{e}$ $\quad Q_2 = P_2^{\mu} - P_2^{e}$ $\quad Q_4 = P_4^{\prime\mu} - P_4^{\prime e}$ $\quad Q_5 = P_5^{\prime\mu} - P_5^{\prime e}$

- Q_1 and Q_4 are excellent probes of existence of RHC with flat signature in scenario 1 (Q_1, Q_4) and 2 (Q_1) but not in scenario 4.
- Q_2, Q_4 and Q_5 show a distinctive signature for scenario 1 and 2.
- Q_5 very clean: error SM=10% of P_5', error NP=50% of P_5'. **More in BACK-UP...**

Conclusions

- The global analysis of $b \to s\ell^+\ell^-$ with 3 fb^{-1} dataset **shows that the solution** we proposed in 2013 to solve the anomaly with a contribution $\mathbf{C_9^{\rm NP} \simeq -1}$ **is confirmed** and reinforced.

- The **fit result is very robust** and does not show a significant dependence nor on the theory approach used neither on the observables used once correlations are taken into account.
  $\Rightarrow$ **IQCDF and FULL-FF** are nicely complementary methods.

- We have shown that the **treatment of uncertainties** entering the observables in $B \to K^*\mu\mu$ is indeed **under excellent control** and the **alternative explanations** to New Physics are indeed **not in very solid ground**. We have proven:
  - **Factorizable p.c.**: While using power corrections with uncorrelated errors is perfectly fine we have shown that an inadequate scheme's choice (JC'14) inflates artificially errors.
  - **Charm-loops**: They all predict bin [6,8] above [4,6] against data. Long-distance charm cannot explain nor R_K neither any LFUV observable (miss the global picture). It would require to multiply by 5-6 charm error from KMPW to get agreement with SM.

- We propose a new generation of **super-optimized observables** sensitive to LFUV, soft form factor independent at LO and insensitive to long distance charm in the SM. Those will help to fully confirm the NP signal observed in P_5'.

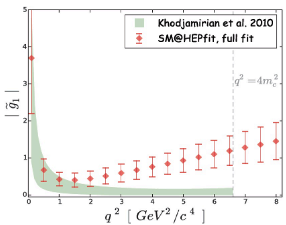
BACK-UP SLIDES

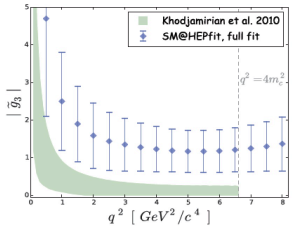
[Ciuchini, **Fedele**, Franco, Mishima, Paul, Silvestrini, Valli'15].

- **They missed global picture: No explanation for R_K, any future LFUV, low-recoil,....**
- They fit 18 free parameters to data $h_\lambda = h_\lambda^{(0)} + h_\lambda^{(1)} q^2 + h_\lambda^{(2)} q^4$. 1) **KM**PW consider it arbitrary. Not surprising to fit any shape with so many parameters. **2) Those numbers ARE NOT PREDICTIONS but just a fit to LHCb data, namely LHCb data (or new data comes) $\rightarrow$ those fit numbers change**

v1: I showed **using the symmetries of the distribution** that they had internal inconsistencies of more than 4 σ.

v2: All their fit based on FFD observables (S_i) rely fully on old BSZ-FF: **need to be recomputed** with **corrected** BSZ...
v3?. Even though there are other more serious problems:





Forcing the fit at very low-q^2 (RED plot) tilts the rest of the fit $\rightarrow$ incorrect interpretation of result,..
Moreover, **lepton-mass effects at 1st bin totally missing**.
v4: suggestion cross-check with KMPW-FF (with l.r. correl.)

When they do not tilt the fit at low-q^2 (BLUE plot) then their interpretation is correct:

RESULTS FOR THE HADRONIC PARAMETERS h_λ (again)

Parameter	Absolute value	Phase (rad)
$h_0^{(0)}$	$(5.8 \pm 2.1) \cdot 10^{-4}$	3.54 ± 0.56
$h_0^{(1)}$	$(2.9 \pm 2.1) \cdot 10^{-4}$	0.2 ± 1.1
$h_0^{(2)}$	$(3.4 \pm 2.8) \cdot 10^{-5}$	-0.4 ± 1.7
$h_+^{(0)}$	$(4.0 \pm 4.0) \cdot 10^{-5}$	0.2 ± 1.5
$h_+^{(1)}$	$(1.4 \pm 1.1) \cdot 10^{-4}$	0.1 ± 1.7
$h_+^{(2)}$	$(2.6 \pm 2.0) \cdot 10^{-5}$	3.8 ± 1.3
$h_-^{(0)}$	$(2.5 \pm 1.5) \cdot 10^{-4}$	$-1.53 \pm 0.75 \cup 1.85 \pm 0.45$
$h_-^{(1)}$	$(1.2 \pm 0.9) \cdot 10^{-4}$	$-0.90 \pm 0.70 \cup 0.80 \pm 0.80$
$h_-^{(2)}$	$(2.2 \pm 1.4) \cdot 10^{-5}$	0.0 ± 1.2

$|h_-^{(2)}|$ *differs from zero* at more than 68.3% probability, *thus* no firm conclusion *on the interpretation of the hadronic correction* can be drawn

CFFMPSV-II

At Lathuile conference 2016 I proved **using the symmetries of angular distribution** *that Ciuchini et al. paper had internal inconsistencies of more than 4σ and that the paper should be put in quarantene...*

<u>From Marco Fedele's talk</u> @ Rare B decays: Theory and Experiment 2016 Workshop...

Results are different from the ones we put on arXiv due to a wrong factor in S_4. We thank Joaquim Matias to point us to an inconsistency in our results due to this wrong factor.

Symmetry transformations of $A_{\perp,\|,0}$ led to a **consistency relation**: **[Serra-Matias'14]**

$$P_2^{rel} = \frac{1}{2}\left[P'_4 P'_5 + \delta_a + \frac{1}{\beta}\sqrt{(-1+P_1+P'^2_4)(-1-P_1+\beta^2 P'^2_5)+\delta_b}\right] \qquad P_i \to \langle P_i \rangle\,(\Delta)$$

where δ_a and δ_b are function of product of tiny P'_6, P'_8, P_3.

This **must hold** *independently of any crazy non-factorizable, factorizable, or New Physics (with no weak phases $P_i^{CP}=0$ or new scalars) that is included inside the H_λ (or $A_{\perp,\|,0}$)*

Example: $\Rightarrow$ Using theory predictions (DHMV'15) for **bin [4,6]** one has:

$$\langle P_1 \rangle = 0.03 \quad \langle P'_4 \rangle = +0.82 \quad \langle P'_5 \rangle = -0.82 \quad \langle P_2 \rangle = \mathbf{-0.18}$$

consistency relation $\Rightarrow \langle P_2 \rangle^{rel} = \mathbf{-0.17}$ ($\Delta = \mathbf{0.01}$ from binning). Perfect agreement. If $A_{\rm FB} = f(F_L, S_i)$

		$CFFMPSV_{predictions}$	$CFFMPSV_{full\ fit}$	SM-BSZ ($\delta_i = 0$)	SM-DHMV
$[4,6]$	$\langle A_{\rm FB} \rangle^{rel}$	$\mathbf{-0.14 \pm 0.04}$	$\mathbf{-0.16 \pm 0.03}$	$+0.11 \pm 0.05$	$+0.05 \pm 0.19$
	$\langle A_{\rm FB} \rangle$	$\mathbf{+0.05 \pm 0.04 \Rightarrow 3.4\sigma}$	$\mathbf{+0.04 \pm 0.03 \Rightarrow 4.7\sigma}$	$+0.12 \pm 0.04 \Rightarrow \mathbf{0.2\sigma}$	$+0.08 \pm 0.11 \Rightarrow \mathbf{0.1\sigma}$
$[6,8]$	$\langle A_{\rm FB} \rangle^{rel}$	-0.27 ± 0.08	-0.15 ± 0.05	$--$	$+0.17 \pm 0.18$
	$\langle A_{\rm FB} \rangle$	$+0.12 \pm 0.08 \Rightarrow 3.4\sigma$	$+0.13 \pm 0.03 \Rightarrow 4.8\sigma$	$--$	$+0.21 \pm 0.21 \Rightarrow \mathbf{0.1\sigma}$

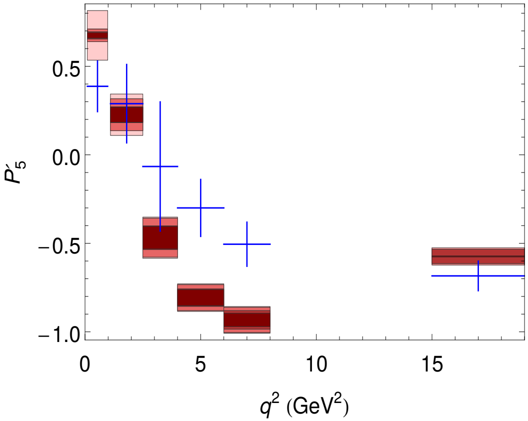
This pointed to a problem in the dictionary of inputs. All tables of predictions for the observables has been recomputed and a new version produced, but with the wrong BSZ-FF, so again it has to be recomputed... still the main conceptual errors remain (arbitritariness+interpretation+wrong tilt).

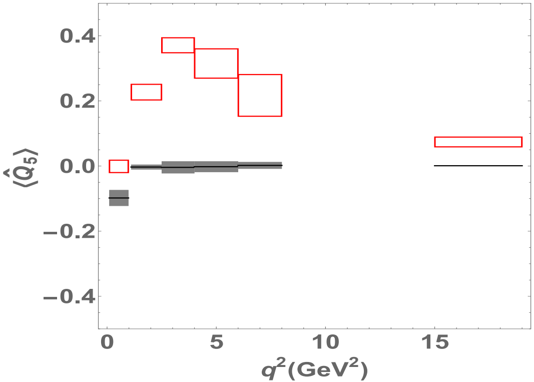
Prediction from CFFMPSV* of $S_5^{[4,6]}$: -0.200 ± 0.046 (Prediction? row Table 2)
Prediction from BSZ of $S_5^{[4,6]}$: -0.329 ± 0.039
Prediction from DHMV of $S_5^{[4,6]}$: -0.35 ± 0.12

- BSZ and DHMV are in excellent agreement (central value difference is 6%).
- Large error differences is due to the use of different Form Factors in BSZ and DHMV.
- Our error size is substantially larger than CFFMPSV's one ....
- **Central value of Luca differs by more than 50% with BSZ and us. And BSZ and CFFMPSV uses the SAME FORM FACTORS. All the difference is coming from huge long distance charm??**
- Same exercise with P_5' gives pretty similar error size due to P_5' properties. (c.v. BSZ and DHMV 6%)

$$P_5'^{CFFMPSV} = -0.43 \pm 0.10,\ P_5'^{BSZ} = -0.77 \pm 0.07,\ P_5'^{DHMV} = -0.82 \pm 0.08$$

P_5' versus $Q_5 = P_5'^{\mu} - P_5'^{e}$





- Soft form factor independent at LO exactly.
- As explained long-distance charm is included in a very conservative way.
- Large sensitivity to C_9.

$\rightarrow$ SM:

$$\left\langle P_5' \right\rangle_{[4,6]} = -0.82 \pm 0.08$$
$$\left\langle P_5' \right\rangle_{[6,8]} = -0.94 \pm 0.08$$

- Soft form factor independent at LO exactly.
- Long-distance charm insensitive in the SM, milder dependence in presence of NP.
- Large sensitivity to lepton flavour non-universality δC_9.

$\rightarrow$ SM:

$$\left\langle \hat{Q}_5 \right\rangle_{[4,6]} = -0.002 \pm 0.017 \pm 0.000$$
$$\left\langle \hat{Q}_5 \right\rangle_{[6,8]} = +0.002 \pm 0.010 \pm 0.000$$

Let us write

$$C_{je} = C_j \quad C_{j\mu} = C_j + \delta C_j \qquad j \neq 9$$
$$C^i_{9e} = C_9 + \Delta C^i_9 \quad C_{9\mu} = C_9 + \delta C_9 + \Delta C^i_9 \qquad i = \perp, \|, 0$$

- δC_i measure the LFU violation and C_{ie} can include LFU NP effects.
- ΔC^i_9 is a long-distance contributions from $c\bar{c}$ loops and identical for C_{9e} and $C_{9\mu}$. Two types:
  - Transversity-dependent long distance charm: $\Delta C_9^{\perp,\|,0}$ all different.
  - Transversity-independent long distance charm:$\Delta C_9^{\perp} = \Delta C_9^{\|} = \Delta C_9^0 = \Delta C_9$

$$\beta_\ell J_{6s} - 2iJ_9 = 16\beta_\ell^2 N^2 m_B^2 (1-\hat{s})^2 C_{10}^\ell \left[2C_7 \frac{\hat{m}_b}{\hat{s}} + C_9^\ell\right] \xi_\perp^2 + \ldots$$
$$\beta_\ell J_5 - 2iJ_8 = 8\beta_\ell^2 N^2 m_B^2 (1-\hat{s})^3 \frac{\hat{m}_{K^*}}{\sqrt{\hat{s}}} C_{10}^\ell \left[C_7 \hat{m}_b \left(\frac{1}{\hat{s}} + 1\right) + C_9^\ell\right] \xi_\perp \xi_{||} + \ldots$$

There are two observables:

$$B_5 = \frac{J_5^\mu}{J_5^e} - 1 \quad B_{6s} = \frac{J_{6s}^\mu}{J_{6s}^e} - 1$$

- Soft form factor independent at LO + long-distance charm insensitive in the SM and linear in δC_9.

Category-II: Linear dependence on C_9

- Lepton-mass differences generates a contribution different from zero in the first bin.

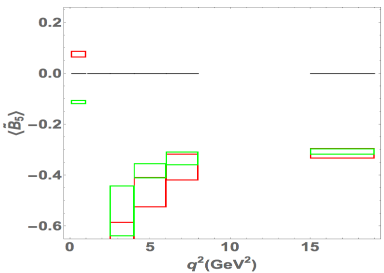
....but if on an event-by-event basis experimentalist can measure $\langle J_i^\mu/\beta_\mu^2\rangle$

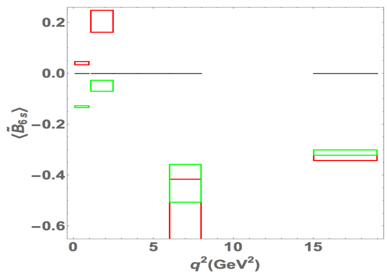
$$\left\langle \widetilde{B_5}\right\rangle = \frac{\langle J_5^\mu/\beta_\mu^2\rangle}{\langle J_5^e/\beta_e^2\rangle} - 1 \qquad \left\langle \widetilde{B_{6s}}\right\rangle = \frac{\langle J_{6s}^\mu/\beta_\mu^2\rangle}{\langle J_{6s}^e/\beta_e^2\rangle} - 1$$

SM Prediction: $\widetilde{B}_i = 0.00 \pm 0.00$. Transversity-dependent $\Delta C_{9,\perp,\|,0}$ kinematically suppressed ($\hat{s} \to 0$):

$$\widetilde{B_5} = \frac{\delta C_{10}}{C_{10}} + \frac{2(C_{10}+\delta C_{10})\delta C_9 \hat{s}}{C_{10}(2C_7\hat{m}_b(1+\hat{s}) + (2C_9 + \Delta C_{9,0} + \Delta C_{9,\perp})\hat{s})} + \ldots$$

$$\widetilde{B_{6s}} = \frac{\delta C_{10}}{C_{10}} + \frac{2(C_{10}+\delta C_{10})\delta C_9 \hat{s}}{C_{10}(4C_7\hat{m}_b + (2C_9 + \Delta C_{9,0} + \Delta C_{9,\|})\hat{s})} + \ldots (\mathrm{assume\,no-RHC})$$





- When $\hat{s} \to 0$ then $\widetilde{B_5} = \widetilde{B_{6s}} = \delta C_{10}/C_{10}$
- Possibility to disentangle $\delta C_9^{\rm NP} = -1.11$ from $\delta C_9^{\rm NP} = -\delta C_{10}^{\rm NP} = -0.65$ using 1st bins

Category-III: A first attempt versus removing charm at very-low q^2

Aim:

- to construct an observable M and more interesting $\widetilde{M}$ such that it cancels exactly at LO the dependence on transversity-independent charm ΔC_9 (transversity-dependent cannot be removed).
- a clean observable in presence of New Physics (at least in some scenario).

$$M = \frac{(J_5^\mu - J_5^e)(J_{6s}^\mu - J_{6s}^e)}{J_{6s}^\mu J_5^e - J_{6s}^e J_5^\mu}, \quad \widetilde{M} = \frac{(\beta_e^2 J_5^\mu - \beta_\mu^2 J_5^e)(\beta_e^2 J_{6s}^\mu - \beta_\mu^2 J_{6s}^e)}{\beta_e^2 \beta_\mu^2 (J_{6s}^\mu J_5^e - J_{6s}^e J_5^\mu)} .$$

Let's focus on $\widetilde{M}$:

PROS At LO and in presence of NP only in δC_9 it cancels exactly ΔC_9:

$$\widetilde{M} = -\frac{\delta C_9 \hat{s}}{C_7 \hat{m}_b (1-\hat{s})} + \ldots$$

PROS It shows a maximal sensitivity to NP at very low-q^2 (first bin) (scenario 1 versus 2).

CONS In presence of NP in δC_{10} long distance charm reemerge.

CONS It becomes too uncertain when $B_5 \simeq B_{6s}$ (low-recoil for example).

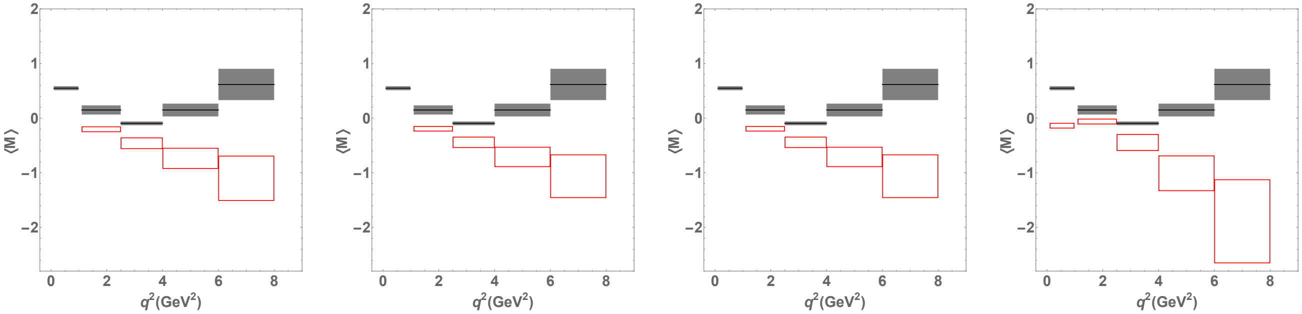


Figure: SM predictions (grey boxes) and NP predictions (red boxes) for M in the 4 scenarios.

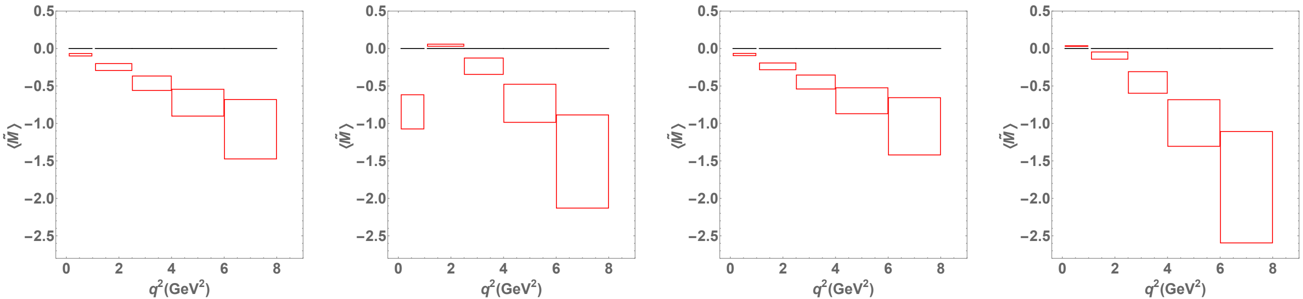


Figure: SM predictions (grey boxes) and NP predictions (red boxes) for $\widetilde{M}$ in the 4 scenarios.

JC-I: Without leaving any loose ends... Is the procedure to compute P_5' accidentally scheme independent? NO if errors are taken uncorrelated

CDHM'16: *In JC'14 the computation of P_5' is argued to be scheme independent. In helicity basis we find:*

$$P_5' = P_5'|_\infty\Big[1 + \frac{\mathbf{aV}_- - \mathbf{aT}_-}{\xi_\perp}\frac{m_B}{|k|}\frac{m_B^2}{q^2}C_7^{\rm eff}\frac{C_{9,\perp}C_{9,\|}-C_{10}^2}{(C_{9,\perp}^2+C_{10}^2)(C_{9,\perp}+C_{9,\|})} - \frac{\mathbf{aV}_+}{\xi_\perp}\frac{\mathbf{2C_{9,\|}}}{\mathbf{C_{9,\perp}+C_{9,\|}}}$$
$$+ \frac{aV_0 - aT_0}{\xi_\|}2C_7^{\rm eff}\frac{C_{9,\perp}C_{9,\|}-C_{10}^2}{(C_{9,\|}^2+C_{10}^2)(C_{9,\perp}+C_{9,\|})} + \mathcal{O}\left(\frac{m_{K^*}^2}{m_B^2},\frac{q^2}{m_B^2}\right)\Big]$$

OK with JC'14 except for the missing term $\mathbf{aV}_+$. Choosing a scheme with $\mathbf{aV}_-$ or $\mathbf{aT}_-$ is equivalent.

Only apparently a scheme independent computation in helicity basis for a subset of schemes!
The computation should be scheme independent in any basis!!!!

In transversity basis becomes obvious that scheme's choice matters if no correlations are considered:

$$P_5' = P_5'|_\infty\Big[1 + \frac{\mathbf{aV}}{\xi_\perp}\frac{C_{9,\|}}{C_{9,\perp}+C_{9,\|}} + \frac{\mathbf{aV} - 2\mathbf{aT_1}}{\xi_\perp}\frac{m_B^2}{q^2}C_7^{\rm eff}\frac{C_{9,\perp}C_{9,\|}-C_{10}^2}{(C_{9,\perp}^2+C_{10}^2)(C_{9,\perp}+C_{9,\|})} - \frac{aA_1}{\xi_\perp}\frac{C_{9,\perp}C_{9,\|}+C_{10}^2}{2(C_{9,\perp}^2+C_{10}^2)} + \ldots$$

The weights of $\mathbf{aV}$ & $\mathbf{aT_1}$ are MANIFESTLY different: $P_5'^{(q^2=6)} = P_5'|_\infty(1 + [\mathbf{0.82}\,\mathbf{aV} - \mathbf{0.24}\,\mathbf{aT_1}]/\xi_\perp(6) + \ldots$

$\xi_\perp^{(1)}(q^2) \equiv \frac{m_B}{m_B + m_{K^*}}V(q^2) \Rightarrow \mathbf{aV} = 0\ (our)$ *or* $\xi_\perp^{(2)}(q^2) \equiv T_1(q^2) \Rightarrow \mathbf{aT_1} = \mathbf{0}\ (JC) > 3$ *times bigger*

3) **Soft form factor error** (undervaluated error):

DHMV: $\xi_\perp = \mathbf{0.31}^{+0.20}_{-0.10}$ from Full-FF of KMPW $V = 0.36^{+0.23}_{-0.12}$ with error included.

JC'14: $\xi_\perp = \mathbf{0.31} \pm \mathbf{0.04}$ (spread of **only** central values (KMPW,BZ,..) no error taken!).

FF budget:

$$A_1 = A_1^{soft} + \Delta A_1^{\alpha_s} + \Delta A_1^{\Lambda}$$

$$A_1 = \mathbf{0.25}^{+0.16}_{-0.10}\,(\mathrm{KMPW})$$

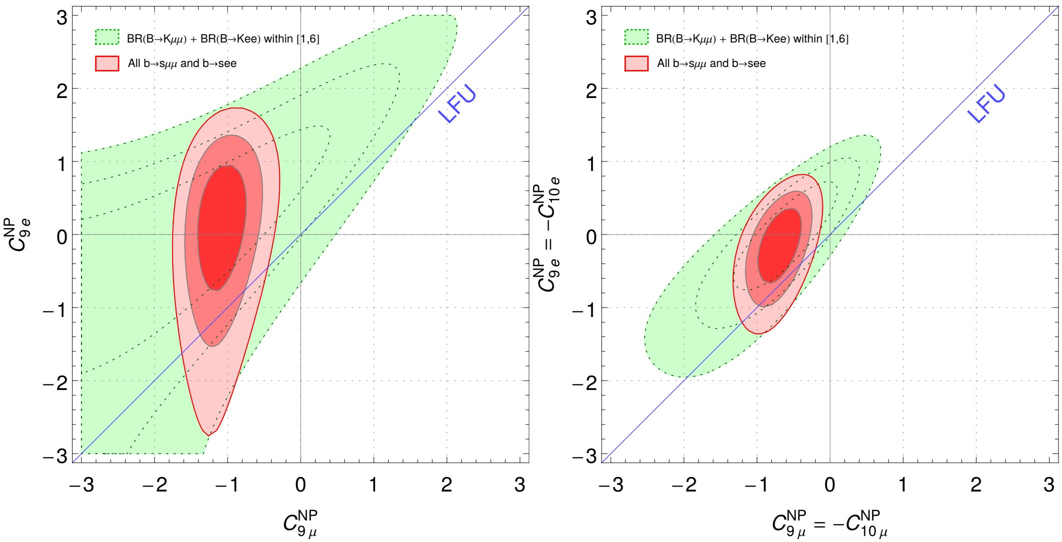
- Our error budget:
  - $A_1^{soft} = \frac{m_B}{m_B+m_K^*}\xi_\perp(0) = \mathbf{0.26}^{+0.17}_{-0.09}$ (KMPW)
  - $\Delta A_1^{\alpha_s}$ is $\mathcal{O}(\alpha_s)$ and ΔA_1^{Λ} is $\mathcal{O}(\Lambda/m_b) \times \mathrm{FF} \simeq 0.1\mathrm{FF}$ of full-FF.
- JC error budget:
  - $A_1^{soft} = \frac{m_B}{m_B+m_K^*}\xi_\perp(0) = \mathbf{0.26} \pm \mathbf{0.03}$
  - $\Delta A_1^{\alpha_s}$ is $\mathcal{O}(\alpha_s)$ and ΔA_1^{Λ} is $\mathcal{O}(\Lambda/m_b) \times \mathrm{FF} \simeq 0.1\mathrm{FF}$ of full-FF.

$\Rightarrow$ **This choice of error in $\xi_\perp$ induces an undervaluation in JC'14 of the errors for FFD observables**: A_{FB}, F_L and S_i.

Fit	$\mathcal{C}_{9\ \text{Bestfit}}^{\text{NP}}$	1σ	Pull_{SM}	N_{dof}	p-value (%)
All $b \to s\mu\mu$ in SM	–	–	–	96	16.0
All $b \to s\mu\mu$	-1.09	$[-1.29, -0.87]$	4.5	95	63.0
All $b \to s\ell\ell$, $\ell = e, \mu$	-1.11	$[-1.31, -0.90]$	4.9	101	74.0
All $b \to s\mu\mu$ excluding [6,8] region	-1.03	$[-1.26, -0.79]$	4.0	77	39.0
Only $b \to s\mu\mu$ BRs	-1.58	$[-2.22, -1.07]$	3.7	31	43.0
Only $b \to s\mu\mu$ P_i's	-1.01	$[-1.25, -0.73]$	3.1	68	75.0
Only $b \to s\mu\mu$ S_i's	-0.95	$[-1.19, -0.68]$	2.9	68	96.0
Only $B \to K\mu\mu$	-0.85	$[-1.67, -0.20]$	1.4	18	20.0
Only $B \to K^*\mu\mu$	-1.05	$[-1.27, -0.80]$	3.7	61	74.0
Only $B_s \to \phi\mu\mu$	-1.98	$[-2.84, -1.29]$	3.5	24	94.0
Only $b \to s\mu\mu$ at large recoil	-1.30	$[-1.57, -1.02]$	4.0	78	61.0
Only $b \to s\mu\mu$ at low recoil	-0.93	$[-1.23, -0.61]$	2.8	21	75.0
Only $b \to s\mu\mu$ within [1,6]	-1.30	$[-1.66, -0.93]$	3.4	43	73.0
Only $BR(B \to K\ell\ell)_{[1,6]}$, $\ell = e, \mu$	-1.55	$[-2.73, -0.81]$	2.4	10	76.0
All $b \to s\mu\mu$ excluding large-recoil $B_s \to \phi\mu\mu$	-1.04	$[-1.26, -0.81]$	4.0	80	55.0
All $b \to s\ell\ell$, $\ell = e, \mu$ excluding large-recoil $B_s \to \phi\mu\mu$	-1.06	$[-1.26, -0.84]$	4.5	86	35.0

Fit	$\mathcal{C}_{9\ \mathrm{Bestfit}}^{\mathrm{NP}}$	1σ	$\mathrm{Pull}_{\mathrm{SM}}$	N_{dof}	p-value (%)
All $b \to s\mu\mu$ in SM	–	–	–	96	16.0
All $b \to s\mu\mu$, 20% PCs	-1.10	$[-1.31, -0.87]$	4.3	95	69.0
All $b \to s\mu\mu$, 40% PCs	-1.08	$[-1.32, -0.82]$	3.8	95	73.0
All $b \to s\mu\mu$, charm$\times$2	-1.12	$[-1.33, -0.89]$	4.4	95	73.0
All $b \to s\mu\mu$, charm$\times$4	-1.06	$[-1.29, -0.82]$	4.0	95	81.0
Only $b \to s\mu\mu$ within [0.1,6]	-1.21	$[-1.57, -0.84]$	3.1	60	30.0
Only $b \to s\mu\mu$ within [0.1,0.98]	0.08	$[-0.92, -0.92]$	0.1	13	33.0
Only $b \to s\mu\mu$ within [0.1,2]	-1.03	$[-1.98, -0.20]$	1.3	22	4.6
Only $b \to s\mu\mu$ within [1.1,2.5]	-0.74	$[-1.60, 0.06]$	0.9	13	85.0
Only $b \to s\mu\mu$ within [2,5]	-1.56	$[-2.27, -0.91]$	2.5	23	95.0
Only $b \to s\mu\mu$ within [4,6]	-1.34	$[-1.73, -0.94]$	3.1	16	93.0
Only $b \to s\mu\mu$ within [5,8]	-1.30	$[-1.60, -0.98]$	3.5	22	96.0

Fits considering Lepton Flavour (non-) Universality

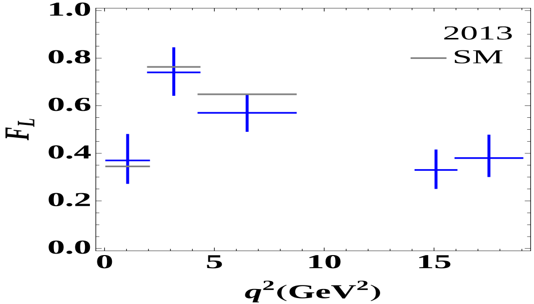


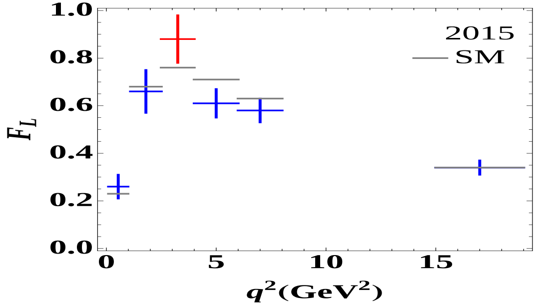
- If NP-LFUV is assumed, NP may enter both $b \to see$ and $b \to s\mu\mu$ decays with different values.

$\Rightarrow$ For each scenario, we see that there is no clear indication of a NP contribution in the electron sector, whereas one has clearly a non-vanishing contribution for the muon sector, with a deviation from the Lepton Flavour Universality line.

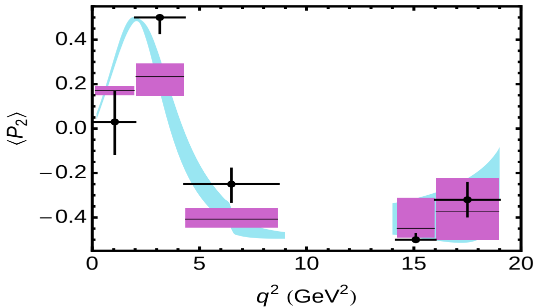
What happened to P_2 in 2015?

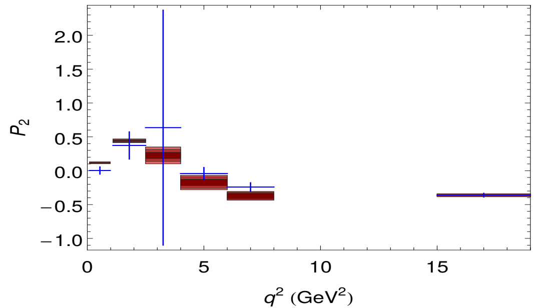
The new binning of F_L in 2015 had a temporary effect on the very interesting bin [2.5,4]





Tiny fluctuation??



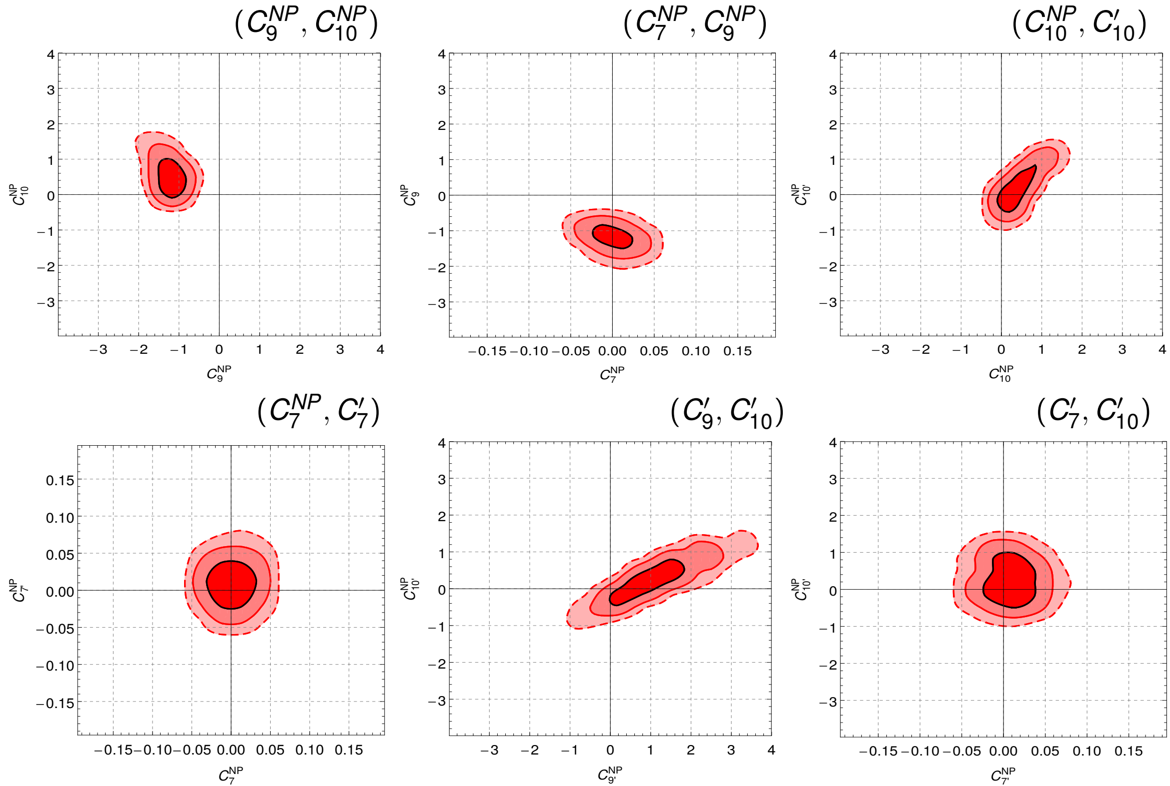


$$P_2 \propto \frac{1}{(1-F_L)}$$

More statistics is necessary to confirm or disprove the deviation in that bin of P_2.

Theory and experimental updates in 2016 fit

- $BR(B \to X_s\gamma)$
  - New theory update: $\mathcal{B}_{s\gamma}^{\rm SM} = (3.36 \pm 0.23) \cdot 10^{-4}$ (Misiak et al 2015)
  - $+6.4\%$ shift in central value w.r.t 2006 $\to$ excellent agreement with WA
- $BR(B_s \to \mu^+\mu^-)$
  - New theory update (Bobeth et al 2013), New LHCb+CMS average (2014)
- $BR(B \to X_s\mu^+\mu^-)$
  - New theory update (Huber et al 2015)
- $BR(B \to K\mu^+\mu^-)$:
  - LHCb 2014 + Lattice form factors at large q^2 (Bouchard et al 2013, 2015)
- $B_{(s)} \to (K^*, \phi)\mu^+\mu^-$: BRs & Angular Observables
  - LHCb 2015 + Lattice form factors at large q^2 (Horgan et al 2013)
- $BR(B \to Ke^+e^-)_{[1,6]}$ (or R_K) and $B \to K^*e^+e^-$ at very low q^2
  - LHCb 2014, 2015



(C_9^{NP}, C_{10}^{NP})
C_9^{NP}
C_{10}^{NP}
(C_7^{NP}, C_9^{NP})
C_7^{NP}
C_9^{NP}
(C_{10}^{NP}, C'_{10})
C_{10}^{NP}
$C_{10'}^{NP}$
(C_7^{NP}, C'_7)
C_7^{NP}
$C_{7'}^{NP}$
(C'_9, C'_{10})
$C_{9'}^{NP}$
$C_{10'}^{NP}$
(C'_7, C'_{10})
$C_{7'}^{NP}$
$C_{10'}^{NP}$

Symmetries of the angular distribution $B \to K^*(\to K\pi)\mu^+\mu^-$

[Egede, Hurth, JM, Ramon, Reece'10]

An important step forward was the identification of the **symmetries** of the distribution:

Transformation of amplitudes leaving distribution invariant.

All physical information of the massless distribution encoded in 3 moduli + 3 complex scalar products - 1 constraint (**relation among** n_i): $3 + 3 \times 2 - 1 = 8$

$$|n_{\|}|^2 = \frac{2}{3}J_{1s} - J_3\,, \qquad |n_\perp|^2 = \frac{2}{3}J_{1s} + J_3\,, \qquad |n_0|^2 = J_{1c}$$

$$n_\perp^\dagger n_{\|} = \frac{J_{6s}}{2} - iJ_9\,, \qquad n_0^\dagger n_{\|} = \sqrt{2}J_4 - i\frac{J_7}{\sqrt{2}}\,, \qquad n_0^\dagger n_\perp = \frac{J_5}{\sqrt{2}} - i\sqrt{2}J_8$$

where $n_{\|}^\dagger = (A_{\|}^L, A_{\|}^{R*})$, $n_\perp^\dagger = (A_\perp^L, -A_\perp^{R*})$ and $n_0^\dagger = (A_0^L, A_0^{R*})$.

$$\text{Symmetries of Massless Case}: \qquad n_i' = U n_i = \begin{bmatrix} e^{i\phi_L} & 0 \\ 0 & e^{-i\phi_R} \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \cosh i\tilde\theta & -\sinh i\tilde\theta \\ -\sinh i\tilde\theta & \cosh i\tilde\theta \end{bmatrix} n_i\,.$$

Symmetries determine the minimal # observables for each scenario:

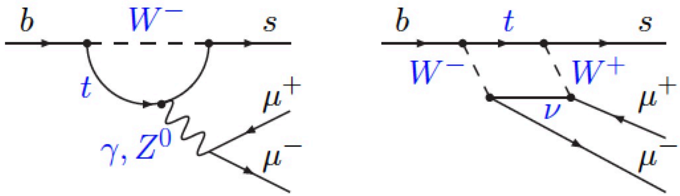
$$n_{obs} = 2n_A - n_S \qquad n_{obs} = n_{Ji} - n_{dep}$$

Case	Coefficients J_i	Amplitudes	Symmetries	Observables	Dependencies
$m_\ell = 0,\ A_S = 0$	11	6	4	**8**	3
$m_\ell = 0$	11	7	5	**9**	2
$m_\ell > 0,\ A_S = 0$	11	7	4	**10**	1
$m_\ell > 0$	12	8	4	**12**	0

All symmetries (massive and scalars) were found explicitly later on. [JM, Mescia, Ramon, Virto'12]

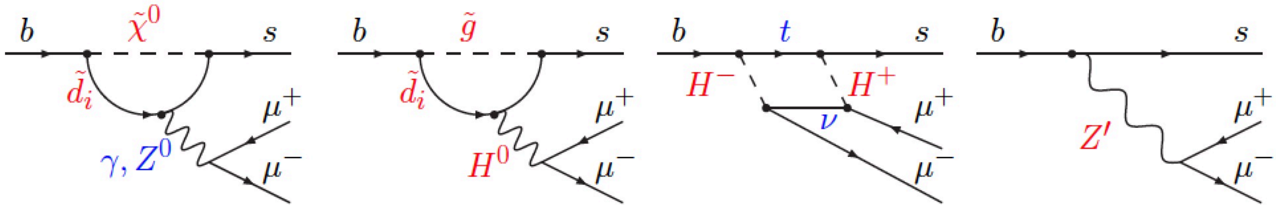
Symmetries $\Rightarrow$ # of observables $\Rightarrow$ determine a **basis**:

- Flavour changing neutral current transitions only occur at loop order (and beyond) in the SM.



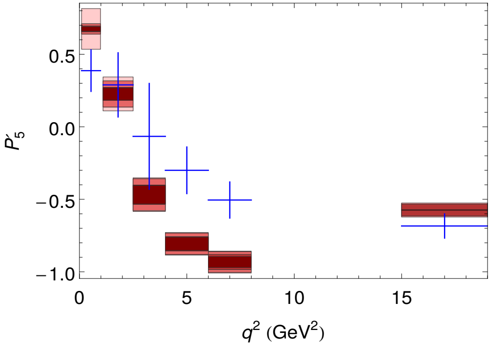
SM diagrams involve the charged current interaction.

- New particles can contribute at loop or tree level:



- Enhancing/suppressing decay rates, introducing new sources of CP violation or modifying the angular distribution of the final-state particles

Brief Discussion on: P'_5 and P'_4 (driving the ambulance)

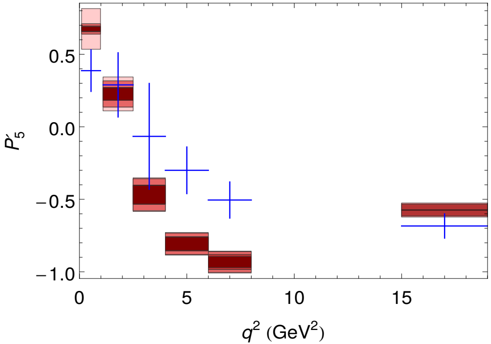


P'_5 was proposed for the first time in **DMRV, JHEP 1301(2013)048**

$$P'_5 = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*})}{\sqrt{|A_0|^2(|A_\perp|^2 + |A_\parallel|^2)}} = \sqrt{2}\frac{\mathrm{Re}[n_0 n_\perp^\dagger]}{\sqrt{|n_0|^2(|n_\perp|^2 + |n_\parallel|^2)}}\,.$$

with $n_0 = (A_0^L, A_0^{R*})$, $n_\perp = (A_\perp^L, -A_\perp^{R*})$ and $n_\parallel = (A_\parallel^L, A_\parallel^{R*})$

- If no-RHC $|n_\perp| \simeq |n_\parallel|$ $(H_{+1} \simeq 0) \Rightarrow P'_5 \propto \cos\theta_{\mathbf{0},\perp}(\mathbf{q^2})$



P_5' was proposed for the first time in **DMRV, JHEP 1301(2013)048**

$$P_5' = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*})}{\sqrt{|A_0|^2(|A_\perp|^2+|A_\parallel|^2)}} = \sqrt{2}\frac{\mathrm{Re}[n_0 n_\perp^\dagger]}{\sqrt{|n_0|^2(|n_\perp|^2+|n_\parallel|^2)}}.$$

with $n_0 = (A_0^L, A_0^{R*})$, $n_\perp = (A_\perp^L, -A_\perp^{R*})$ and $n_\parallel = (A_\parallel^L, A_\parallel^{R*})$

- If no-RHC $|n_\perp| \simeq |n_\parallel|$ $(H_{+1} \simeq 0) \Rightarrow P_5' \propto \cos\theta_{0,\perp}(\mathbf{q^2})$

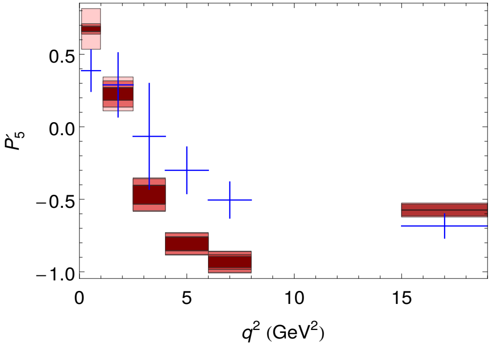
In the large-recoil limit with no RHC

$$A_{\perp,\parallel}^L \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*}) \qquad A_{\perp,\parallel}^R \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*})$$

$$A_0^L \propto -\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*}) \quad A_0^R \propto -\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*})$$

- In SM $\mathcal{C}_9^{SM} + \mathcal{C}_{10}^{SM} \simeq 0 \to |A_{\perp,\parallel}^R| \ll |A_{\perp,\parallel}^L|$
- **In P_5': If $C_9^{NP} < 0$ then** $A_{0,\parallel}^R \uparrow$, $|A_\perp^R| \uparrow$ and $|A_{0,\parallel}^L| \downarrow$, $A_\perp^L \downarrow$ and due to $-$, $|P_5'|$ gets **strongly** reduced.

Brief Discussion on: P_5' and P_4' (driving the ambulance)



P_5' was proposed for the first time in **DMRV, JHEP 1301(2013)048**

$$P_5' = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*})}{\sqrt{|A_0|^2(|A_\perp|^2 + |A_\parallel|^2)}} = \sqrt{2}\frac{\mathrm{Re}[n_0 n_\perp^\dagger]}{\sqrt{|n_0|^2(|n_\perp|^2 + |n_\parallel|^2)}}.$$

with $n_0 = (A_0^L, A_0^{R*})$, $n_\perp = (A_\perp^L, -A_\perp^{R*})$ and $n_\parallel = (A_\parallel^L, A_\parallel^{R*})$

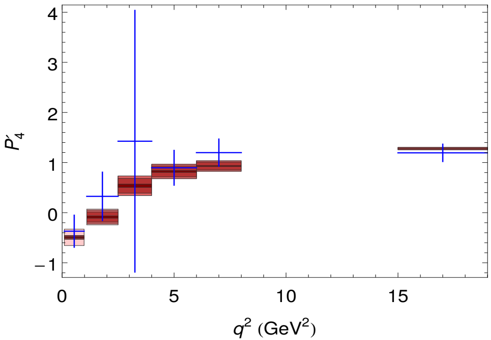
- If no-RHC $|n_\perp| \simeq |n_\parallel|$ $(H_{+1} \simeq 0) \Rightarrow P_5' \propto \cos\theta_{0,\perp}(\mathbf{q^2})$

In the large-recoil limit with no RHC

$$A_{\perp,\parallel}^L \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*}) \qquad A_{\perp,\parallel}^R \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*})$$

$$A_0^L \propto -\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*}) \quad A_0^R \propto -\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*})$$

- In SM $\mathcal{C}_9^{SM} + \mathcal{C}_{10}^{SM} \simeq 0 \rightarrow |A_{\perp,\parallel}^R| \ll |A_{\perp,\parallel}^L|$
- **In P_5': If $C_9^{NP} < 0$** then $A_{0,\parallel}^R \uparrow$, $|A_\perp^R| \uparrow$ and $|A_{0,\parallel}^L| \downarrow$, $A_\perp^L \downarrow$ and due to $-$, $|P_5'|$ gets **strongly** reduced.



P_4' was proposed for the first time in **DMRV, JHEP 1301(2013)048**

$$P_4' = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\parallel^{L*} + A_0^R A_\parallel^{R*})}{\sqrt{|A_0|^2(|A_\perp|^2+|A_\parallel|^2)}} = \sqrt{2}\frac{\mathrm{Re}[n_0 n_\parallel^\dagger]}{\sqrt{|n_0|^2(|n_\perp|^2+|n_\parallel|^2)}}.$$

with $n_0 = (A_0^L, A_0^{R*})$, $n_\perp = (A_\perp^L, -A_\perp^{R*})$ and $n_\parallel = (A_\parallel^L, A_\parallel^{R*})$

- If no-RHC $|n_\perp| \simeq |n_\parallel|$ $(H_{+1} \simeq 0) \Rightarrow P_4' \propto \cos\theta_{0,\parallel}(\mathbf{q^2})$

In the large-recoil limit with no RHC

$$A_{\perp,\parallel}^L \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*}) \qquad A_{\perp,\parallel}^R \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*})$$

$$A_0^L \propto -\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*}) \quad A_0^R \propto -\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*})$$

- In SM $\mathcal{C}_9^{SM} + \mathcal{C}_{10}^{SM} \simeq 0 \to |A_{\perp,\parallel}^R| \ll |A_{\perp,\parallel}^L|$
- **In** P_4' :If $C_9^{NP} < 0$ then $A_{0,\parallel}^R \uparrow$, $|A_\perp^R| \uparrow$ and $|A_{0,\parallel}^L| \downarrow$, $A_\perp^L \downarrow$ due to $+$ what L loses R gains (little change).