The global picture of $b \to s\ell\ell$ anomalies: A hitchhiker's guide for non-experts

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In collaboration with: **B. Capdevila, S. Descotes-Genon, L. Hofer and J. Virto**

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 (updated with final data)**, CDMV'16 and CDHM'16.

All originated in Frank Krueger, J.M., Phys. Rev. D71 (2005) 094009

This talk is divided into two parts:

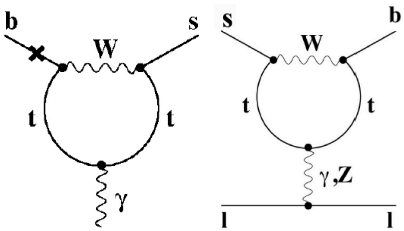
- What does the global fit on $b \to s\ell\ell$ tell us about Wilson coefficients?
  - Description of anomalies and tensions in semileptonic B decays.
  - Which Wilson coefficients/scenarios receive a dominant NP contribution?

- Anatomy of hadronic uncertainties.
  - Theoretical description of $B \to K^*\mu\mu$ at low-q^2 in a nutshell.
  - Closer and **critical** look to alternative explanations (of one anomaly) within SM.

The Goal

Analysis of FCNC in a model-independent approach, effective Hamiltonian:

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



- $\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \, (\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu}$
- $\mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b) \, (\bar{\ell}\gamma_\mu \ell)$
- $\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b) \, (\bar{\ell}\gamma_\mu \gamma_5 \ell)$, ...

• **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: $\mathcal{O}'_{7,9,10} = \mathcal{O}_{7,9,10} \; (P_L \leftrightarrow P_R)$ ...

also scalars, pseudoescalar, tensor operators...

The way to obtain information on those Wilson coefficients is via a GLOBAL FIT to the relevant processes.

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

Updated GLOBAL FIT 2016:

THE OBSERVABLES

Wrong approach

Good approach

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

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 the **full dataset**, we use **optimized** observables, we use **Khodjamirian FF**, we use **QCDF+ four types of corrections** (α_s+p.c. including long distance charm). Frequentist, $\Delta\chi^2$-fit.

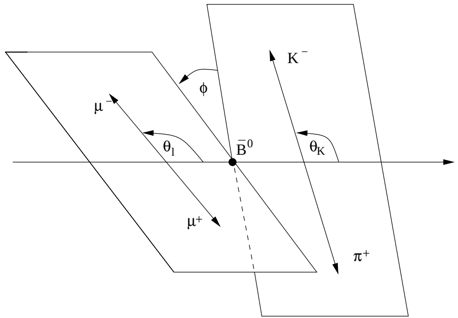
2) **Altmannshofer-Straub (AS)** and indirectly Baroucha-Zwicky for FF. They use a slightly **smaller dataset**, they use **non-optimized** observables S_i, they use **BSZ FF**, they use **full-FF** approach and include similar kind of corrections (also long-distance charm). Frequentist, $\Delta\chi^2$-fit.

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

Summary: [1] and [2] get results in very good agreement and similar for [3]. But the statistical treatment of [3] is under debate.

The **optimized observables** $P_i^{(\prime)}$ come from the angular distribution $\bar{\mathbf{B}}_\mathbf{d} \to \bar{\mathbf{K}}^{*0}(\to \mathbf{K}^-\pi^+)\mathbf{l}^+\mathbf{l}^-$ with the K^{*0} on the mass shell. It is described by $\mathbf{s} = \mathbf{q^2}$ and three angles θ_ℓ, $\theta_\mathbf{K}$ and ϕ

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



Non-optimal obs.: $S_i = (J_i + \bar{J}_i)/(d\Gamma + d\bar{\Gamma})$

θ_ℓ: Angle of emission between $\bar{K}^{*0}$ and μ^- in di-lepton rest frame.
$\theta_\mathbf{K}$: Angle of emission between $\bar{K}^{*0}$ and K^- in di-meson rest frame.
ϕ: Angle between the two planes.

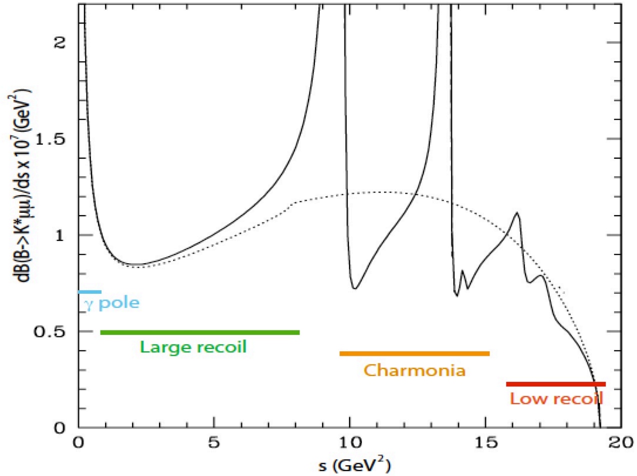
$\mathbf{q^2}$: dilepton invariant mass square.

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

$$+\sqrt{\mathbf{F_T F_L}}\left(\frac{1}{2}\mathbf{P'_4}\sin 2\theta_K \sin 2\theta_l \cos\phi + \mathbf{P'_5}\sin 2\theta_K \sin\theta_l\cos\phi\right) + 2\mathbf{P_2 F_T}\sin^2\theta_K\cos\theta_l + \frac{1}{2}\mathbf{P_1 F_T}\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$

$$-\sqrt{\mathbf{F_T F_L}}\left(\mathbf{P'_6}\sin 2\theta_K\sin\theta_l\sin\phi - \frac{1}{2}\mathbf{P'_8}\sin 2\theta_K\sin 2\theta_l\sin\phi\right) - \mathbf{P_3 F_T}\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big](1 - \mathbf{F_S}) + \frac{1}{\Gamma'_{full}}\mathbf{W_S}$$

Four regions in q^2

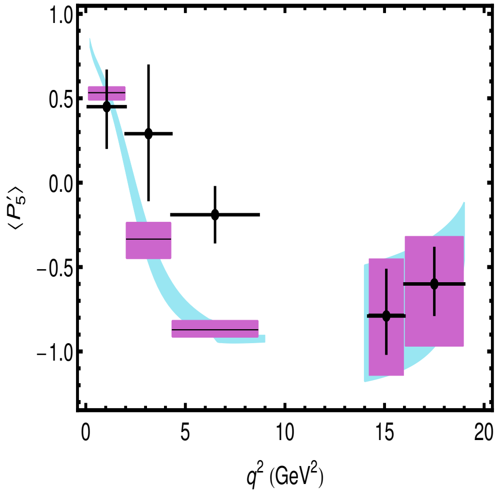


Four regions in q^2:

- **very large** K^*-recoil ($4m_\ell^2 < q^2 < 1$ GeV^2): γ almost real.
- **large** K^***-recoil/low-q**^{2}: $E_{K^*} \gg \Lambda_{QCD}$ or $4m_\ell^2 \leq q^2 < 9$ GeV^2: LCSR-FF
- charmonium region ($q^2 = m^2_{J/\Psi}, ...$) betwen $9 < q^2 < 14$ GeV^2.
- **low** K^***-recoil/large-q**^{2}: $E_{K^*} \sim \Lambda_{QCD}$ or $14 < q^2 \leq (m_B - m_{K^*})^2$: LQCD-FF

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}:



This is what a non-expert see a deviation near 4σ in one bin of an observable called P_5' out of a set of observables that describe $B \to K^* \mu\mu$.

Natural attitude of a non-expert: Skepticism.

Expected attitude of an expert: Provide with robust arguments to a non-expert to be skeptic.

... let's analyze here the robustness (or **lack of it**) of those arguments...

......let's start with what an expert should see in 2013......

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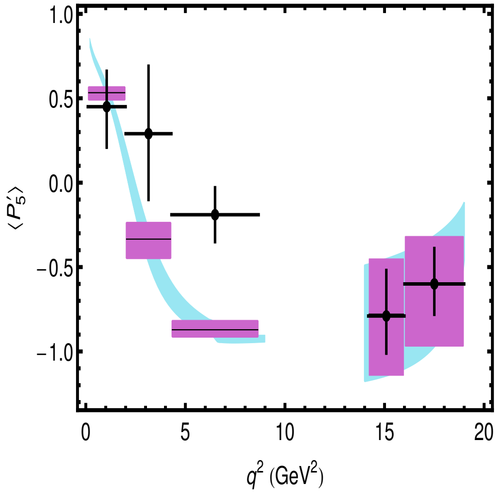

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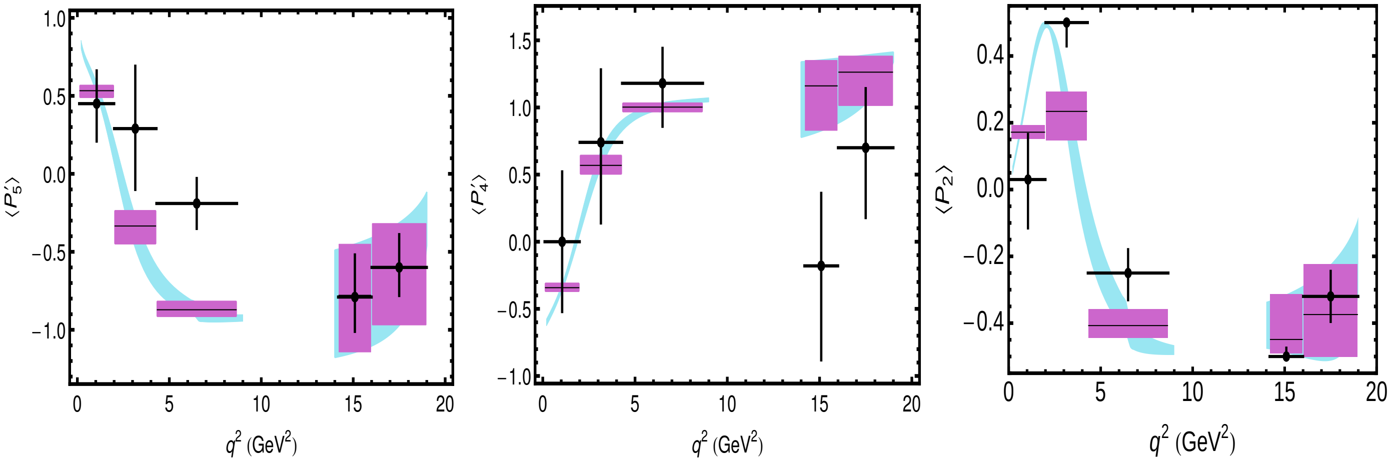

......let's start with what an expert should see...... COHERENT PATTERN [DMV'13].

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

⇒ imply relations among the observables above.

Let's assume that you do not have a clue of what these symmetries are... (see Back-up slides)

Is the anomaly in P_5' a statistical fluctuation?

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The probability is much smaller than one month ago...

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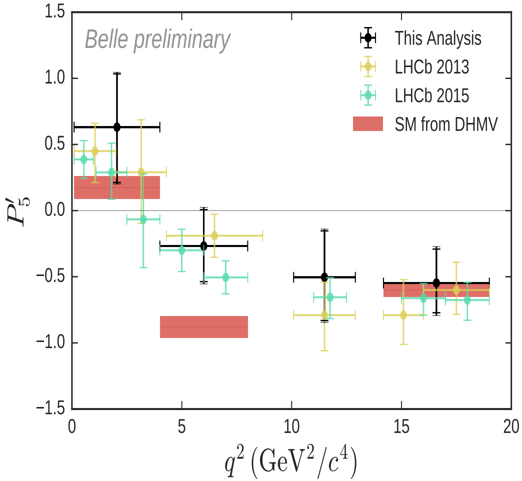
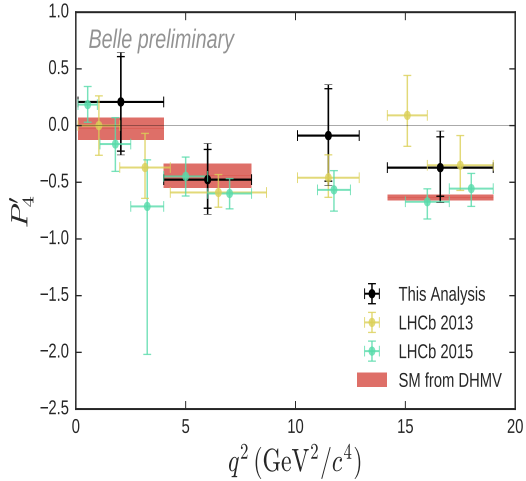
Is the anomaly in P'_5 a statistical fluctuation?

The probability is much smaller than one month ago...

At Moriond in 2015 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'.



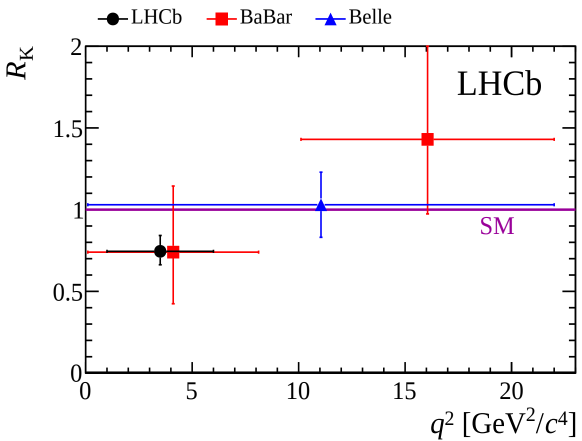


We enter a new period... besides ATLAS and CMS soon will announce results for P_5'.

Only remaining explanation within SM is that hadronic uncertainties are HUGE and out of control:

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

In the meanwhile new coherent deviations appear...



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

- It deviates **2.6**σ from SM.
- Conceptually very relevant: Very clean + exclude A CHARM EXPLANATION.

Also BR of neutral mode:

$10^7 \times BR(B^0 \to K^0\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	0.62 ± 0.19	0.23 ± 0.11	$+1.8$
$[2, 4]$	0.65 ± 0.21	0.37 ± 0.11	$+1.2$
$[4, 6]$	0.64 ± 0.22	0.35 ± 0.10	$+1.2$
$[6, 8]$	0.63 ± 0.23	0.54 ± 0.12	$+0.4$
$[15, 19]$	0.91 ± 0.12	0.67 ± 0.12	$+1.4$

$10^7 \times BR(B^0 \to K^{*0}\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	1.30 ± 1.00	1.14 ± 0.18	$+0.2$
$[2, 4.3]$	0.85 ± 0.59	0.69 ± 0.12	$+0.3$
$[4.3, 8.68]$	2.62 ± 4.92	2.15 ± 0.31	$+0.1$
$[16, 19]$	1.66 ± 0.15	1.23 ± 0.20	$+\mathbf{1.7}$

$10^7 \times BR(B^+ \to K^{*+}\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	1.35 ± 1.05	1.12 ± 0.27	$+0.2$
$[2, 4]$	0.80 ± 0.55	1.12 ± 0.32	-0.5
$[4, 6]$	0.95 ± 0.70	0.50 ± 0.20	$+0.6$
$[6, 8]$	1.17 ± 0.92	0.66 ± 0.22	$+0.5$
$[15, 19]$	2.59 ± 0.24	1.60 ± 0.32	$+\mathbf{2.5}$

$10^7 \times BR(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2.]$	1.81 ± 0.36	1.11 ± 0.16	$+\mathbf{1.8}$
$[2., 5.]$	1.88 ± 0.32	0.77 ± 0.14	$+\mathbf{3.2}$
$[5., 8.]$	2.25 ± 0.41	0.96 ± 0.15	$+\mathbf{2.9}$
$[15, 18.8]$	2.20 ± 0.17	1.62 ± 0.20	$+\mathbf{2.2}$

Also $BR(B \to V\mu\mu)$ exhibit a systematic deficit with respect to SM, particularly $B_s \to \phi\mu\mu$.

Results of the 2016 Fit:

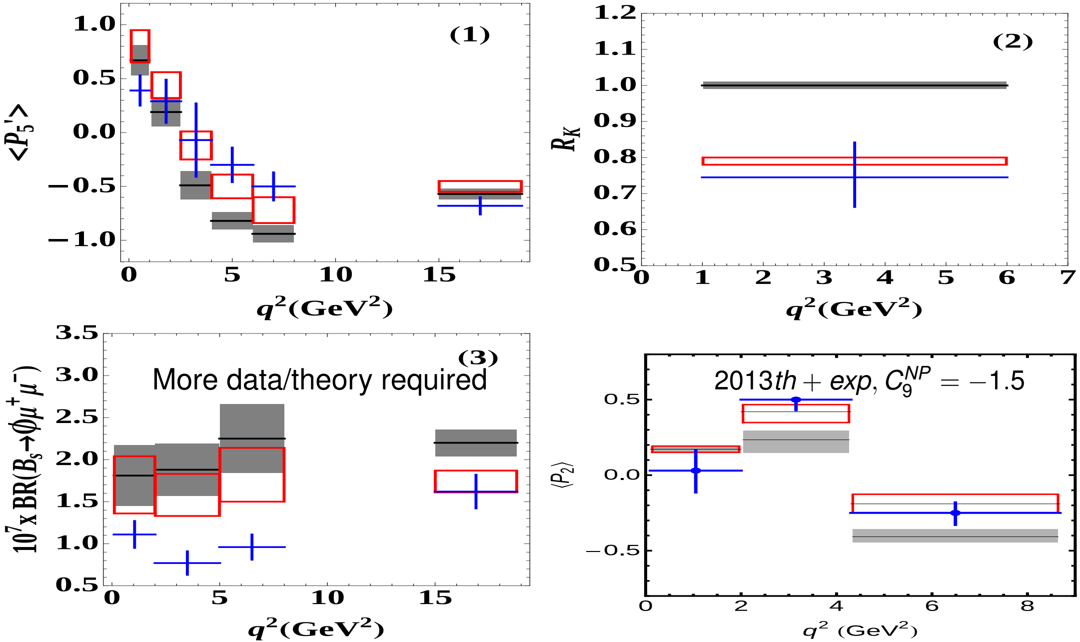
- Latest theory and experimental updates of $\mathrm{BR}(B \to X_S\gamma)$, $\mathrm{BR}(B_s \to \mu^+\mu^-)$, $B_{(s)} \to (K^*, \phi)\mu^+\mu^-)$, $\mathrm{BR}(B \to Ke^+e^-)_{[1,6]}$ (or R_K) and $B \to K^*e^+e^-$ at very low q^2
- Frequentist approach: χ^2 with all theory+experimental correlations.

Result of the fit with 1D Wilson coefficient 2016 (e^+e^- mode not included)

Pull$_{\rm SM}$ 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.

Coefficient $\mathcal{C}_i^{NP} = \mathcal{C}_i - \mathcal{C}_i^{SM}$	Best fit	1σ	3σ	Pull$_{\rm SM}$
$\mathcal{C}_7^{\rm NP}$	-0.02	$[-0.04, -0.00]$	$[-0.07, 0.03]$	1.2
$\mathcal{C}_{\mathbf{9}}^{\rm NP}$	-1.09	$[-1.29, -0.87]$	$[-1.67, -0.39]$	**4.5** $\Leftarrow$
$\mathcal{C}_{10}^{\rm NP}$	0.56	$[0.32, 0.81]$	$[-0.12, 1.36]$	2.5
$\mathcal{C}_{7'}^{\rm NP}$	0.02	$[-0.01, 0.04]$	$[-0.06, 0.09]$	0.6
$\mathcal{C}_{9'}^{\rm NP}$	0.46	$[0.18, 0.74]$	$[-0.36, 1.31]$	1.7
$\mathcal{C}_{10'}^{\rm NP}$	-0.25	$[-0.44, -0.06]$	$[-0.82, 0.31]$	1.3
$\mathcal{C}_9^{\rm NP} = \mathcal{C}_{10}^{\rm NP}$	-0.22	$[-0.40, -0.02]$	$[-0.74, 0.50]$	1.1
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP}$	-0.68	$[-0.85, -0.50]$	$[-1.22, -0.18]$	**4.2** $\Leftarrow$
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP}$	-1.06	$[-1.25, -0.86]$	$[-1.60, -0.40]$	4.8 (low recoil)
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP} = -\mathcal{C}_{10'}^{\rm NP}$	-0.69	$[-0.89, -0.51]$	$[-1.37, -0.16]$	4.1

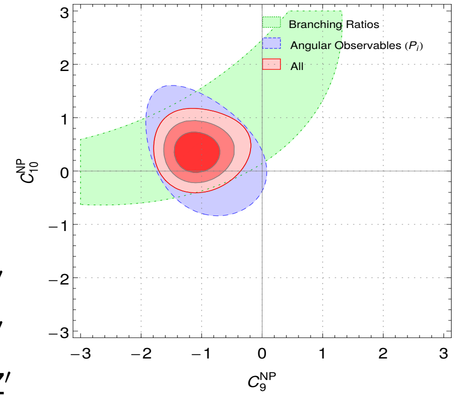
Impact on the anomalies of a contribution from NP $C_9^{NP} = -1.1$



(1),(2) and (3) use 3 fb^{-1} dataset but more data for R_K required. SM is (gray) and NP ($C_9^{NP} = -1.1$).

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

Coefficient	Best Fit Point	Pull$_{\mathrm{SM}}$	
$(\mathcal{C}_7^{\mathrm{NP}}, \mathcal{C}_9^{\mathrm{NP}})$	$(-0.00, -1.07)$	**4.1**	
$(\mathcal{C}_9^{\mathrm{NP}}, \mathcal{C}_{10}^{\mathrm{NP}})$	$(-1.08, 0.33)$	**4.3**	
$(\mathcal{C}_9^{\mathrm{NP}}, \mathcal{C}_{7'}^{\mathrm{NP}})$	$(-1.09, 0.02)$	**4.2**	
$(\mathcal{C}_9^{\mathrm{NP}}, \mathcal{C}_{9'}^{\mathrm{NP}})$	$(-1.12, 0.77)$	**4.5**	
$(\mathcal{C}_9^{\mathrm{NP}}, \mathcal{C}_{10'}^{\mathrm{NP}})$	$(-1.17, -0.35)$	**4.5**	
$(\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{9'}^{\mathrm{NP}}, \mathcal{C}_{10}^{\mathrm{NP}} = \mathcal{C}_{10'}^{\mathrm{NP}})$	$(-1.15, 0.34)$	**4.7**	no-Z'
$(\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{9'}^{\mathrm{NP}}, \mathcal{C}_{10}^{\mathrm{NP}} = -\mathcal{C}_{10'}^{\mathrm{NP}})$	$(-1.06, 0.06)$	**4.4**	Z'
$(\mathcal{C}_9^{\mathrm{NP}} = \mathcal{C}_{9'}^{\mathrm{NP}}, \mathcal{C}_{10}^{\mathrm{NP}} = \mathcal{C}_{10'}^{\mathrm{NP}})$	$(-0.64, -0.21)$	3.9	Z'
$(\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{10}^{\mathrm{NP}}, \mathcal{C}_{9'}^{\mathrm{NP}} = \mathcal{C}_{10'}^{\mathrm{NP}})$	$(-0.72, 0.29)$	3.8	no-Z'



- C_9^{NP} always play a dominant role
- All 2D scenarios above 4σ are quite indistinguishable. We have done a systematic work to check what are the most relevant Wilson Coefficients to explain all deviations, by allowing progressively different WC to get NP contributions and compare the pulls.

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.

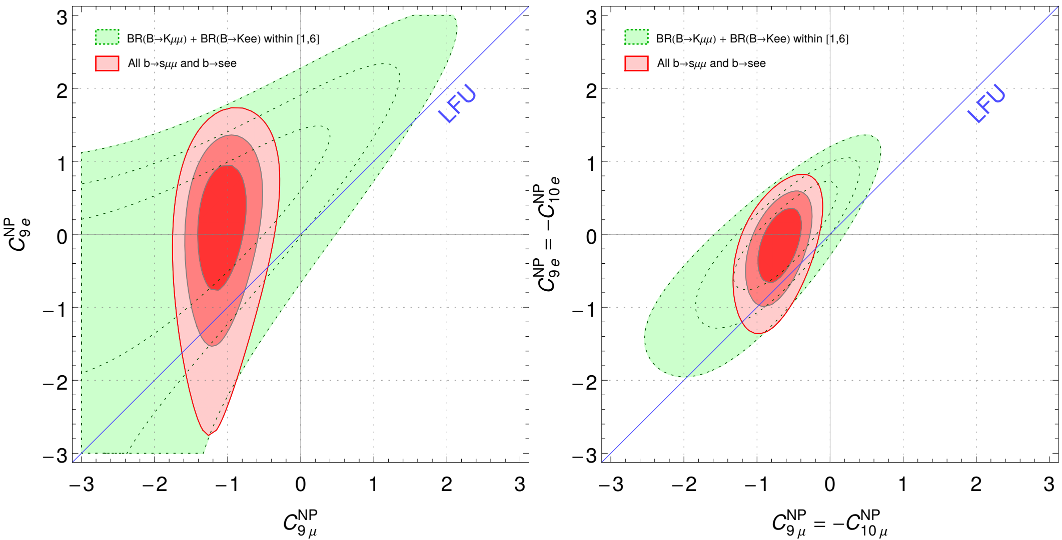
Impact of $B \to Ke^+e^-$ under hypothesis of maximal Lepton Flavour Universal Violation

1D-Coefficient	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_9^{\text{NP}}$	-1.11	$[-1.31, -0.90]$	$[-1.67, -0.46]$	**4.5 → 4.9**
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}}$	-0.65	$[-0.80, -0.50]$	$[-1.13, -0.21]$	**4.2 → 4.6**
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}$	-1.07	$[-1.25, -0.86]$	$[-1.60, -0.42]$	4.9
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}} = -\mathcal{C}_{10'}^{\text{NP}}$	-0.66	$[-0.84, -0.50]$	$[-1.25, -0.20]$	**4.1 → 4.5**

2D-Coefficient	Best Fit Point	Pull_{SM}
$(C_7^{\text{NP}}, C_9^{\text{NP}})$	$(-0.00, -1.10)$	**4.1 → 4.6**
$(C_9^{\text{NP}}, C_{10}^{\text{NP}})$	$(-1.06, 0.33)$	**4.3 → 4.8**
$(C_9^{\text{NP}}, C_{7'}^{\text{NP}})$	$(-1.16, 0.02)$	**4.2 → 4.7**
$(C_9^{\text{NP}}, C_{9'}^{\text{NP}})$	$(-1.15, 0.64)$	**4.5 → 4.9**
$(C_9^{\text{NP}}, C_{10'}^{\text{NP}})$	$(-1.23, -0.29)$	**4.5 → 4.9**
$(C_9^{\text{NP}} = -C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-1.18, 0.38)$	**4.7 → 5.1**
$(C_9^{\text{NP}} = -C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = -C_{10'}^{\text{NP}})$	$(-1.11, 0.04)$	**4.5**
$(C_9^{\text{NP}} = C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-0.64, -0.11)$	**3.9 → 4.3**
$(C_9^{\text{NP}} = -C_{10}^{\text{NP}}, C_{9'}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-0.69, 0.27)$	**3.8 → 4.2**

- The strong correlations among form factors of $B \to K\mu\mu$ and $B \to Kee$ assuming no NP in $B \to Kee$ enhances the NP evidence in muons.
- Notice that we use all bins in $B \to K\mu\mu$ while R_K is only [1,6]. **All theory correlations included**.
- Only scenarios explaining R_K get an extra enhancement of +0.4-0.5 σ

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.

⇒ 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.

How much the fit results depend on the details?

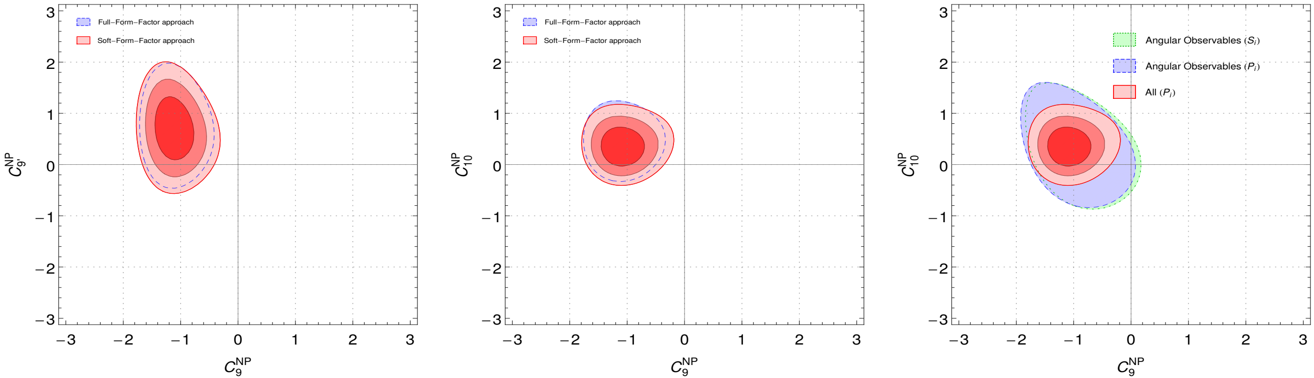


Figure: *We show the 3 σ regions allowed using form factors in BSZ'15 in the full form factor approach (long-dashed blue) compared to our reference fit with the soft form factor approach (red, with 1,2,3 σ contours).*

- The results of the fit using (IQCDF-KMPW) or (Full-FF-BSZ) and/or different set of observables are perfectly consistent once all correlations are included. But the individual observables...

anomaly [4,6] bin	P_5' error SIZE [pull]	S_5 error SIZE [pull]
Full-FF-**BSZ** (1503.05534)	8.6% [2.7σ]	12% [2.0σ]
IQCDF-**KMPW** (1510.04239)	10% [2.9σ]	40% [1.2σ]

Theoretical description of $B \to K^* \ell^+ \ell^-$

@ low-q^2 in a nutshell

Improved-QCDF approach

- QCDF framework.
- Exploit **symmetry relations** between hadronic form factors when initial hadron is heavy and final meson has a large energy.
  At LO in α_s and Λ/m_b:

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

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

Dominant correlations automatically implemented in a transparent way via **SYMMETRIES.**

Construction of optimized observables $\mathbf{P_i^{(\prime)}}$: at LO in $1/m_b$, α_s and large-recoil limit (E_K^* large):

$$A_\perp^{L,R} \propto \xi_\perp \quad A_\parallel^{L,R} \propto \xi_\perp \quad A_0^{L,R} \propto \xi_\parallel$$

$\Rightarrow$ Our approach is completed with 4 types of corrections.

From a FF decomposition (example):

$$\mathbf{V(q^2)} = \frac{m_B+m_{K^*}}{m_B}\xi_\perp(q^2) + \Delta V^{\alpha_s}(q^2) + \Delta V^{\Lambda}(q^2)$$

- $\Delta V^{\alpha_s}(q^2)$: Known Factorizable α_s breaking corrections at NLO from QCDF.
- $\Delta V^{\Lambda}(q^2)$: Factorizable power corrections (using a systematic procedure for each FF, see later)

  QCDF provides a systematic framework: $\langle \ell^+\ell^- \bar{K}^*_a | H_{\rm eff} | \bar{B}\rangle = \mathcal{C}_a \xi_a + \Phi_B \otimes T_a \otimes \Phi_{K^*}$ with $a = \perp, \parallel$
- Non-factorizable α_s corrections. Example: spectator quark participates in the hard scattering.
- Non-factorizable power corrections including long-distance charm-quark loops.

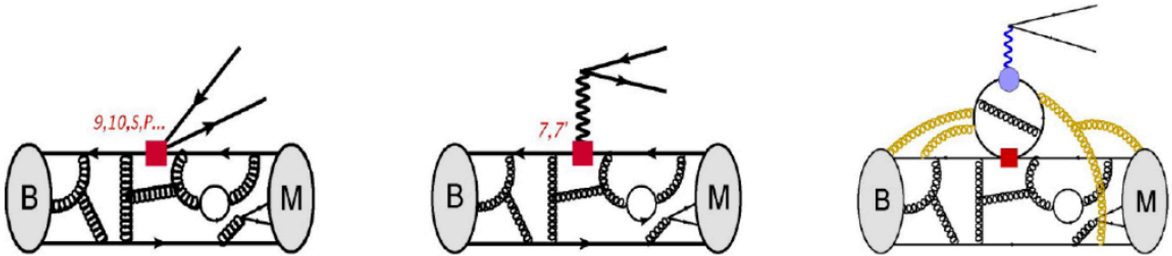


Figure 2 – Illustration of factorizable (first two diagrams) and non-factorizable (third diagram) QCD corrections to exclusive $B \to M\ell^+\ell^-$ matrix elements.

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^*}	$\mathbf{0.36^{+0.23}_{-0.12}}$	$-4.8^{+0.8}_{-0.4}$
$A^{BK^*}_1$	$\mathbf{0.25^{+0.16}_{-0.10}}$	$0.34^{+0.86}_{-0.80}$
$A^{BK^*}_2$	$0.23^{+0.19}_{-0.10}$	$-0.85^{+2.88}_{-1.35}$
$A^{BK^*}_0$	$0.29^{+0.10}_{-0.07}$	$-18.2^{+1.3}_{-3.0}$
$T^{BK^*}_1$	$0.31^{+0.18}_{-0.10}$	$-4.6^{+0.81}_{-0.41}$
$T^{BK^*}_2$	$0.31^{+0.18}_{-0.10}$	$-3.2^{+2.1}_{-2.2}$
$T^{BK^*}_3$	$0.22^{+0.17}_{-0.10}$	$-10.3^{+2.5}_{-3.1}$

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.

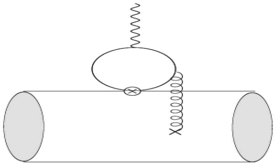
$B \to K^*\ell^+\ell^-$: Impact of long-distance $c\bar{c}$ loops – DHMV

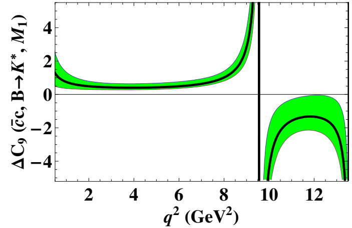
Inspired by Khodjamirian et al (KMPW): $C_9^{\rm eff\, i} = C_9^{\rm eff}{}_{\rm SM\, pert}(q^2) + C_9^{\rm NP} + s_i \delta C_9^{c\bar{c}(i)}{}_{\rm KMPW}(q^2)$

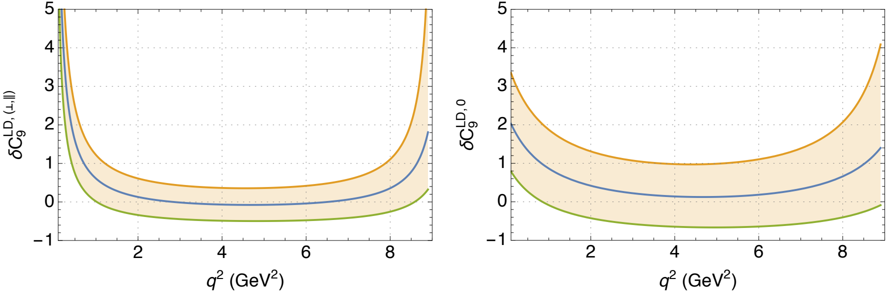
Notice that KMPW implies $s_i = 1$, but we vary it independently $s_i = 0 \pm 1$, $i = 0, \perp, \|$ (Zwicky)

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

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

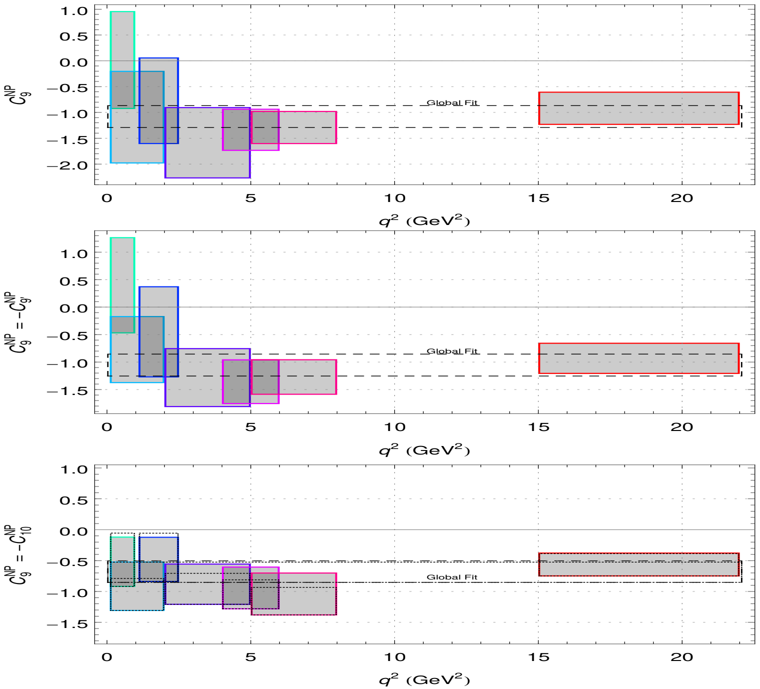






Obtaining from fitting the long-distance part to KMPW.

Cross check: Bin by Bin analysis of C_9 in three scenarios



Result of bin-by-bin analysis of C_9 in 3 scenarios.

- **Notice the excellent agreement of bins [2,5], [4,6], [5,8].** *Strong argument in favour of including the [5,8] region-bin.*
- **First bin is afflicted by lepton-mass effects.** (see Back-up slides)
- **We do not find indication for a q^2-dependence in C_9 neither in the plots nor in a 6D fit adding $a^i + b^i s$ to $C_9^{\rm eff}$ for $i = K^*, K, \phi$.**
  $\rightarrow$ disfavours again charm explanation.
- 2nd and 3rd plots test if you allow for NP in other WC the agreement of C_9 bin by bin improves as compared to 1st plot.

Factorizable Power Corrections

...the mistery (if any) solved....

What are Factorizable power corrections and how they emerge?

- Appear when expressing the full form factor in a soft form factor piece + corrections (JC'12):

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

How one can compute central value of power corrections?

(DHMV'14)

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

Errors are taken **uncorrelated** to be $\mathcal{O}(\Lambda/m_b) \times \mathrm{FF} \simeq 0.1\mathrm{FF}$ (same size of the **full**-FF error in BSZ).

Why? to minimize sensitivity/dependence on FF computational details.

	$\hat{a}_F^{(1)}$	$\hat{b}_F^{(1)}$	$\hat{c}_F^{(1)}$	$r(0\,\mathrm{GeV}^2)$	$r(4\,\mathrm{GeV}^2)$	$r(8\,\mathrm{GeV}^2)$
A_1(KMPW)	-0.01 ± 0.03	-0.06 ± 0.02	0.16 ± 0.02	5%	6%	5%
A_1(BZ)	-0.01 ± 0.03	0.04 ± 0.02	0.08 ± 0.02	3%	1%	3%

$r = (a_F + b_F q^2/m_B^2 + c_F q^4/m_B^4)/FF(q^2)$ is the percentage of p.c. found to be $\leq 10\%$

$\rightarrow$ JC'14 followed similar strategy

and considered also **uncorrelated errors** of 10% but central values were set to zero.

Role played by scheme's choice when p.c. errors are taken uncorrelated.

1.) P_i and P_i' observables are **scheme independent**. Scheme choice means:

$$\xi_\perp^{(1)}(q^2) \equiv \frac{m_B}{m_B + m_{K^*}} V(q^2) \quad \xi_\parallel^{(1)}(q^2) \equiv \frac{m_B + m_{K^*}}{2E} A_1(q^2) - \frac{m_B - m_{K^*}}{m_B} A_2(q^2), \quad \text{(Beneke et al. 05)}$$

or

$$\xi_\perp^{(2)}(q^2) \equiv T_1(q^2), \qquad \xi_\parallel^{(2)}(q^2) \equiv \frac{m_{K^*}}{E} A_0(q^2). \quad \text{(old Beneke et al. 01)}$$

or

$$\xi_\perp^{(n)}(q^2) \equiv \alpha_1 V(q^2) + \alpha_2 T_1(q^2), \qquad \xi_\parallel^{(n)}(q^2) \equiv \beta_1 A_0(q^2) + ... \qquad \alpha_1 + \alpha_2 = 1$$

CDHM'16 (to appear soon)

2.) The **procedure to compute** it MAY or MAY NOT BE SCHEME INDEPENDENT:

- **OPTION 1**: Include **all correlations among p.c. errors**. PRO: Procedure scheme independent. DRAWBACK: You are exposed to all hypothesis and details of FF.
  $\rightarrow$ scheme does not matter.

- **OPTION 2**: Assign a **large uncorrelated error of 10%** (as large as the whole error in BSZ). PRO: You are insensitive to details of FF. DRAWBACK: **Error larger BUT careful choice of scheme COMPULSORY**
  $\rightarrow$ scheme choice matters + inadequate scheme's choice inflates artificially errors.

The 1st big difference with JC'14 (overvaluation).

We realized the importance of scheme choice in OPTION 2. Let's see an example:

$\langle P_5' \rangle_{[4,6]}$	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

The difference between 0.05 and 0.03 is the price to pay if you DO NOT want your results to be too sensitive to details and assumption of FF computations. I am glad to pay it....

Summary:

- AT OPTION 2 (DHMV or JC'14) then one has to be VERY careful with the choice of scheme. **A NON-OPTIMAL SCHEME'S CHOICE INFLATE artificially errors.**

One can order the impact of different schemes in a line of sensitivity to power correction:

Optimal Our $(V, A_{1,2})$ JC (T_1, A_0) Scheme-3$(\alpha_1 V + \alpha_2 T_1)$ .....

$\Downarrow$ $\Downarrow$ $\Downarrow$ $\Downarrow$

X————————————————————————-

MINIMAL MAXIMAL Sensitivity to power corrections for P_i $\Rightarrow$

The 2nd big difference with JC'14 (undervaluation). Error of soft form factor:

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 may induce an undervaluation in JC'14 of the errors for FFD observables**: S_i and F_L.

The third difference with JC'14:

Parametric errors from (masses, decay constants, renormalization scale, Gegenbauers).

- We did in DHMV'14 a random scan over all parameters within uncertainties (keeping the rest fixed) and take maximum and minimum.
- JC'12 error (same approach) is factor 2 larger than us, BSZ but also Bobeth et al. (total error)!!!

Considering all those differences one finds....

Our total error for P_5' bin [4,6] (**KMPW+α_s+p.c.-scheme1**+long distance charm): $\pm$**0.08** (at most 0.11 with flat scan DHMV'14).

Let's check a FFD observable: $error(F_L^{[0.1,0.98]}) = \pm\mathbf{0.25}$

Total error for P_5' bin [4,6] (**BSZ+full-FF-scheme-indep**+long distance charm): $\pm$**0.07**

Let's check a FFD observable: $error(F_L^{[0.1,0.98]}) = \pm\mathbf{0.06}$

Total error for P_5' bin [5,6] (**JC+α_s+p.c.-scheme2**+long distance charm): $\pm$**0.35** (sym.)

Let's check a FFD observable: $error(F_L^{[0.1,0.98]}) = \pm\mathbf{0.18}$ (sym)

Total error for P_5' with scheme-3 ($\alpha_1 = \alpha_2 = 1/2$) will be larger!!!!

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:*

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

$$+ \quad \frac{aV_0 - aT_0}{\xi_\|} 2 C_7^{\rm eff} \frac{C_{9,\perp} C_{9,\|} - C_{10}^2}{(C_{9,\|}^2 + C_{10}^2)(C_{9,\perp} + C_{9,\|})} + \mathcal{O}\left(\frac{m_{K^*}^2}{m_B^2}, \frac{q^2}{m_B^2}\right)\Big]$$

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:

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

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

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

Long distance charm

Two options:

A) Bother you with the details of two papers...(Zwicky et al. and Ciuchini et al.)

B) Construct observables insensitive to charm testing the violation of lepton-flavour universality. [CDMV-arXiv:1605.03156]

OPTION A: A huge charm-loop or unknown non-factorizable p.c?

Two attempts:

Attempt 1 (Lyon, Zwicky'14 unpublished):

- Using $e^+e^- \to$ hadrons to build a model of $c\bar{c}$ resonances at low-recoil in $B \to K\mu\mu$.
  Conceptual problem: **extrapolate result** at large-recoil and assume it holds the same for $B \to K^*\mu\mu$.

$\Rightarrow$ **Interesting observation:** Phase of helicity amplitudes $e^{i\delta_{J/\Psi K^*}}$ from $\delta_{J/\Psi K^*} \simeq 0$ (KMPW) to π
$\to$ we introduce s_i.

Attempt 2 (Ciuchini, Fedele, Franco, Mishima, Paul, Silvestrini, Valli'15 -CFFMPSV):

- Introduce a fully arbitrary parametrization for non-factorizable power correction:

$$H_\lambda \to H_\lambda + h_\lambda \text{ where } h_\lambda = h_\lambda^{(0)} + h_\lambda^{(1)} q^2 + h_\lambda^{(2)} q^4 \qquad \text{and} \quad h_\lambda^{(0)} \to C_7^{NP}, h_\lambda^{(1)} \to C_9^{\rm NP}$$

  with $(\lambda = 0, \pm)$.
  Fundamental problems: complete lack of theory input/output $\Rightarrow$ **no predictivity** with 18 free parameters (any shape). **Specific problems...**

$$C_9 - C_9^{SM} \simeq \text{constant+KMPW } \textbf{similar to us!!}\text{. So what is this constant } C_9^{\rm NP} \text{ or } h_\lambda^{(1)}?$$

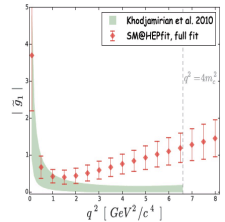
They only consider $B \to K^*\mu\mu$ @ large-recoil. They cannot explain deviations @ low-recoil and @ R_K @ any future LFU violating observable.

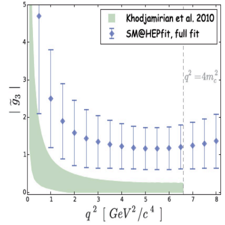
At Lathuile conference 2016 I proved **using the symmetries of angular distribution** *that Ciuchini et al. paper had internal inconsistencies of more than 4σ and that the paper should be put in quarantene...*

From Marco Fedele's talk @ 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.

In brief they had two conclusions in their talk: $h_\lambda = h_\lambda^{(0)} + h_\lambda^{(1)} q^2 + h_\lambda^{(2)} q^4$ and $h_\lambda^{(0)} \to C_7^{NP}, h_\lambda^{(1)} \to C_9^{NP}$ with $(\lambda = 0, \pm)$, $h_\lambda^{(2)}$ is the supposed charm-q^2 part.





1) The wrong one (forcing the fit to fulfill KMPW at very-low q^2). Khodjamirian was present and said explicitly to them "this is incorrect":

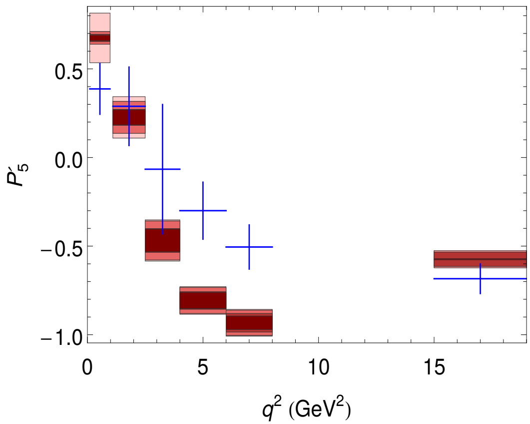
$|h_-^{(2)}|$ *differs from zero* **at more than 95.45% probability,** *thus* **disfavouring** *the interpretation of the hadronic correction as* **NP contributions in C_7 and/or C_9**

2) The correct one (just a fit with no constraint):

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

Parameter	Absolute value
$h_0^{(0)}$	$(5.8 \pm 2.1) \cdot 10^{-4}$
$h_0^{(1)}$	$(2.9 \pm 2.1) \cdot 10^{-4}$
$h_0^{(2)}$	$(3.4 \pm 2.8) \cdot 10^{-5}$
$h_+^{(0)}$	$(4.0 \pm 4.0) \cdot 10^{-5}$
$h_+^{(1)}$	$(1.4 \pm 1.1) \cdot 10^{-4}$
$h_+^{(2)}$	$(2.6 \pm 2.0) \cdot 10^{-5}$
$h_-^{(0)}$	$(2.5 \pm 1.5) \cdot 10^{-4}$
$h_-^{(1)}$	$(1.2 \pm 0.9) \cdot 10^{-4}$
$h_-^{(2)}$	$(2.2 \pm 1.4) \cdot 10^{-5}$

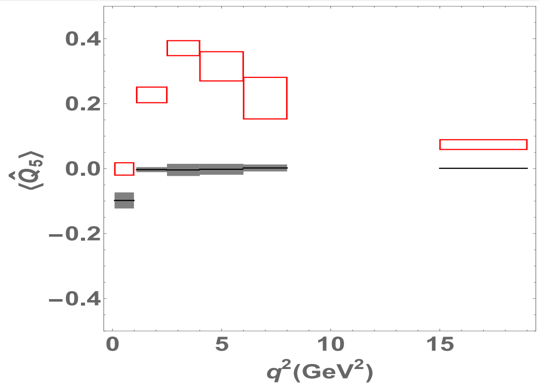
Example of option B: P_5' versus $Q_5 = P_5'^{\mu} - P_5'^{e}$



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

→ SM:

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



- 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.

→ SM:

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

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.
  $\Rightarrow$ **lQCDF 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. Also fundamental problems detected in most analysis.

- Long-distance charm cannot explain nor R_K neither any LFUV observable. 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 close the P_5' discussion.

PART-II

Option B: A new generation of observables

Three main properties:

- Insensitivity to long-distance charm effects in the SM.

  ... a clear deviation is an unambiguous signal of New Physics.
- Probing lepton flavour non-universality.
- In presence of New Physics charm sensitivity reemerge... but we are in a different league.

Some known examples...

$\Rightarrow$ R_K cannot be explained by charm due to universality of the charm contribution.

$\Rightarrow$ Other ratios R_{K^*}, R_ϕ will be measured in the short term.

R_{K^*}				
Bin	$[0.1, 2]$	$[2, 4.3]$	$[4.3, 8.68]$	$[16., 19.]$
SM	$0.988 \pm 0.007 \pm 0.001$	$1.000 \pm 0.006 \pm 0.000$	$1.000 \pm 0.005 \pm 0.000$	$0.998 \pm 0.000 \pm 0.000$
Scen.1	$0.951 \pm 0.096 \pm 0.021$	$0.871 \pm 0.093 \pm 0.009$	$0.813 \pm 0.026 \pm 0.029$	$0.786 \pm 0.001 \pm 0.004$
Scen.2	$0.889 \pm 0.102 \pm 0.008$	$0.737 \pm 0.028 \pm 0.005$	$0.701 \pm 0.016 \pm 0.045$	$0.701 \pm 0.003 \pm 0.006$
Scen.3	$0.898 \pm 0.142 \pm 0.039$	$0.780 \pm 0.142 \pm 0.018$	$0.747 \pm 0.090 \pm 0.045$	$0.692 \pm 0.006 \pm 0.013$
Scen.4	$0.890 \pm 0.149 \pm 0.043$	$0.742 \pm 0.123 \pm 0.019$	$0.690 \pm 0.059 \pm 0.052$	$0.655 \pm 0.005 \pm 0.015$

Option B: A new generation of observables

But one can go much beyond....

$\Rightarrow$ Exploit the full angular analysis of $B \to K^*\ell\ell$ decays + add one property:

$$Q_{F_L} = F_L^\mu - F_L^e \,, \quad Q_i = P_i^\mu - P_i^e \,, \quad T_i = \frac{S_i^\mu - S_i^e}{S_i^\mu + S_i^e} \,, \quad B_i = \frac{J_i^\mu}{J_i^e} - 1 \,, \quad \widetilde{B}_i = \frac{\beta_e^2}{\beta_\mu^2} \frac{J_i^\mu}{J_k^e} - 1 \,, \quad M\,(\widetilde{M})$$

20 new observables to measure.....

Example: $Q_5 = P_5^\mu - P_5^e$ should be zero in SM with high-precision up to lepton-mass effects.

And add a fourth property:

- Independence of soft form factor at LO:

$\to$ true for all except for T_i and Q_{FL} that has still lepton mass sensitivity via the normalization.

Category-I: Q_i observables. $C_{9\mu}^{\rm NP} = -1.11$ versus $C_{9\mu}^{\rm NP} = -C_{10\mu}^{\rm NP} = -0.65$

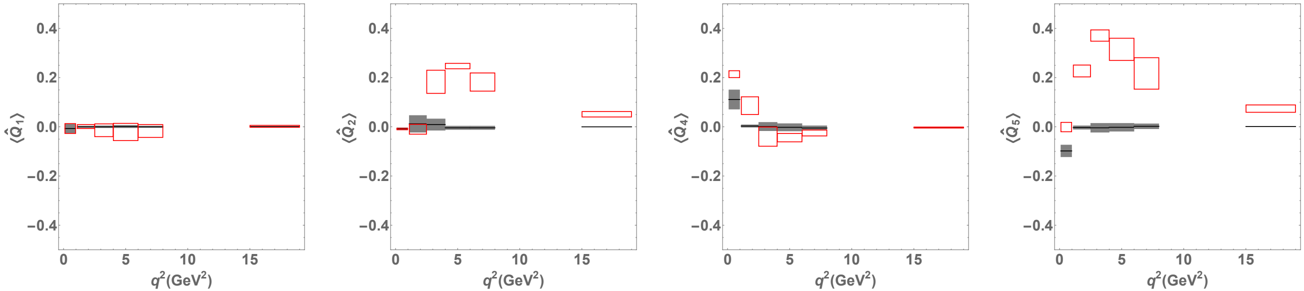


Figure: *Scenario 1*. SM predictions (grey boxes) and NP predictions (red boxes), assuming $C_{9\mu}^{\rm NP} = -1.11$.

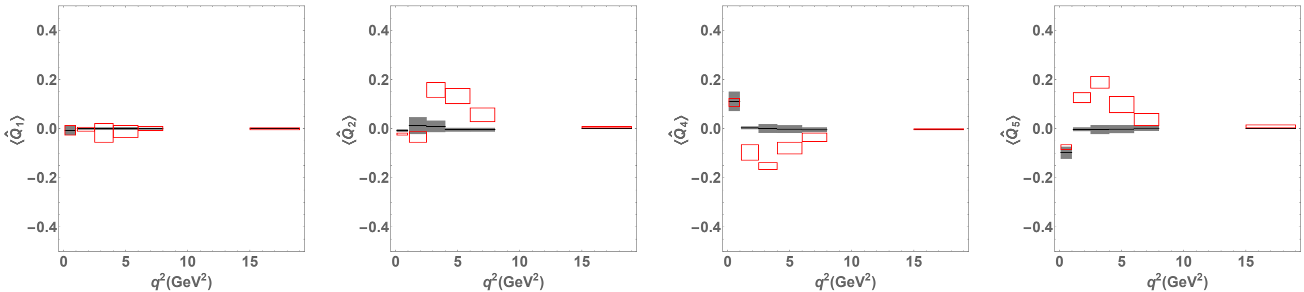


Figure: *Scenario 2*. SM predictions (grey boxes) and NP predictions (red boxes), assuming $C_{9\mu}^{\rm NP} = -C_{10\mu}^{\rm NP} = -0.65$.

Category-I: Q_i observables. $C_{9\mu}^{\rm NP} = -C_{9'\mu}^{\rm NP} = -1.07$ versus all Wilson coef.

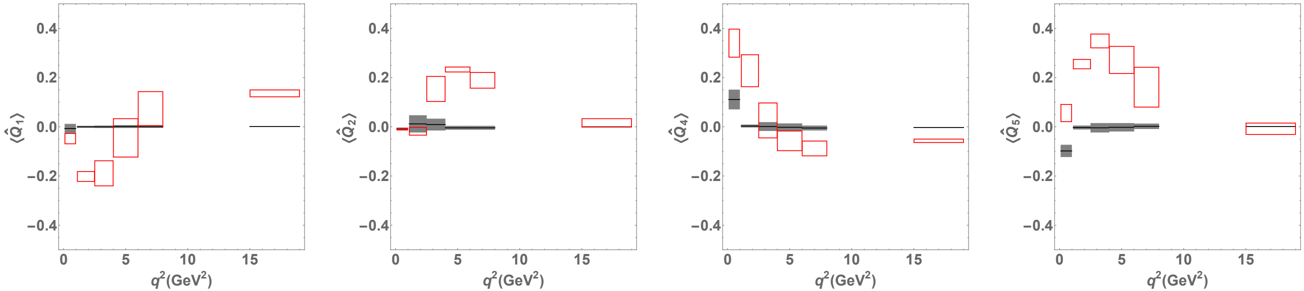


Figure: *Scenario 3*. SM predictions (grey boxes) and NP predictions (red boxes), assuming $C_{9\mu}^{\rm NP} = -C_{9'\mu}^{\rm NP} = -1.07$.

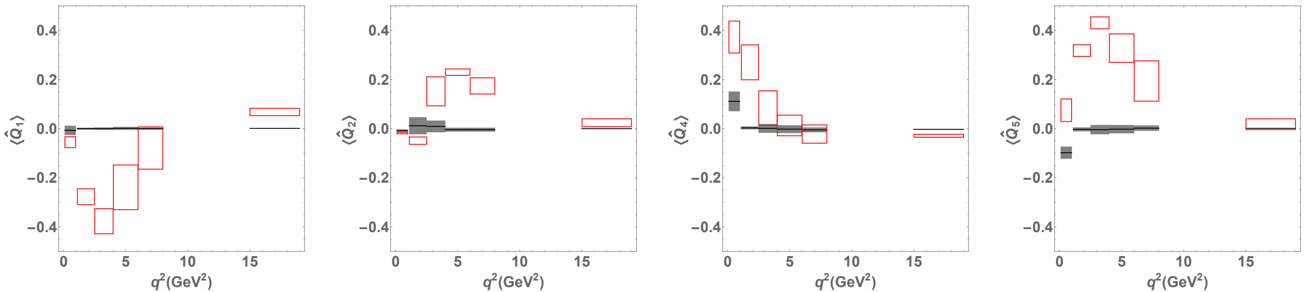


Figure: *Scenario 4*. SM predictions and NP predictions, $C_{9\mu}^{\rm NP} = -C_{9'\mu}^{\rm NP} = -1.18$ and $C_{10\mu}^{\rm NP} = C_{10'\mu}^{\rm NP} = 0.38$.

Category-II: Linear dependence on C_9

Let us write

$$\begin{aligned} C_{je} &= C_j \quad C_{j\mu} = C_j + \delta C_j \qquad j \neq 9 \\ C_{9e}^i &= C_9 + \Delta C_9^i \quad C_{9\mu} = C_9 + \delta C_9 + \Delta C_9^i \qquad i = \perp, \|, 0 \end{aligned}$$

- δC_i measure the LFU violation
- C_{ie} can include LFU NP effects.
- ΔC_9^i is a long-distance contributions from $c\bar{c}$ loops where the lepton pair is created by an electromagnetic current, and thus identical for C_{9e} and $C_{9\mu}$. There are two possible types:
  - Transversity-dependent long distance charm: $\Delta C_9^{\perp,\|,0}$ all different.
  - Transversity-independent long distance charm: $\Delta C_9^{\perp} = \Delta C_9^{\|} = \Delta C_9^0 = \Delta C_9$

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

Category-II: Linear dependence on C_9

There are two observables:

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

- Soft form factor independent at LO + long-distance charm insensitive in the SM.
- Lepton-mass differences generates a contribution different from zero in the first bin.

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

$$\widetilde{B_5} = \frac{J_5^\mu \beta_\mu^2}{J_5^e \beta_e^2} - 1 \quad \widetilde{B_{6s}} = \frac{J_{6s}^\mu \beta_\mu^2}{J_{6s}^e \beta_e^2} - 1$$

- Prediction in SM: $\widetilde{B}_i = 0.000 \pm 0.000 \pm 0.000$.
- Poles in presence of NP at 2nd bin ($\widetilde{B_5}$), 3rd and 4th bin ($\widetilde{B_{6s}}$) assuming no NP in electronic mode.
- Transversity-independent charm (ΔC_9) reduced:

$$\widetilde{B_5} = \frac{\delta C_9 \hat{s}}{(C_7 \hat{m}_b (1+\hat{s}) + (C_9 + \Delta C_9)\hat{s})} + \ldots \quad \widetilde{B_{6s}} = \frac{\delta C_9 \hat{s}}{(2 C_7 \hat{m}_b + (C_9 + \Delta C_9)\hat{s})} + \ldots$$

but also transversity dependent $\Delta C_9^{\perp,\|,0}$ kinematically suppressed at low-q^2.

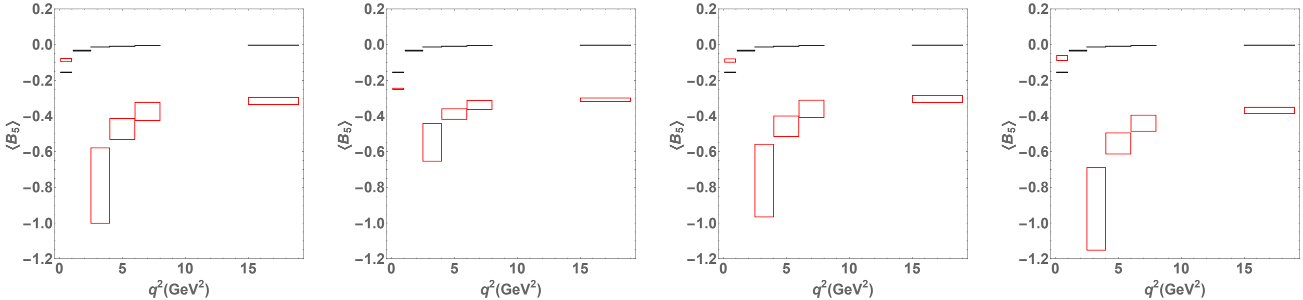


Figure: SM predictions (grey boxes) and NP predictions (red boxes) for B_5 in the 4 scenarios.

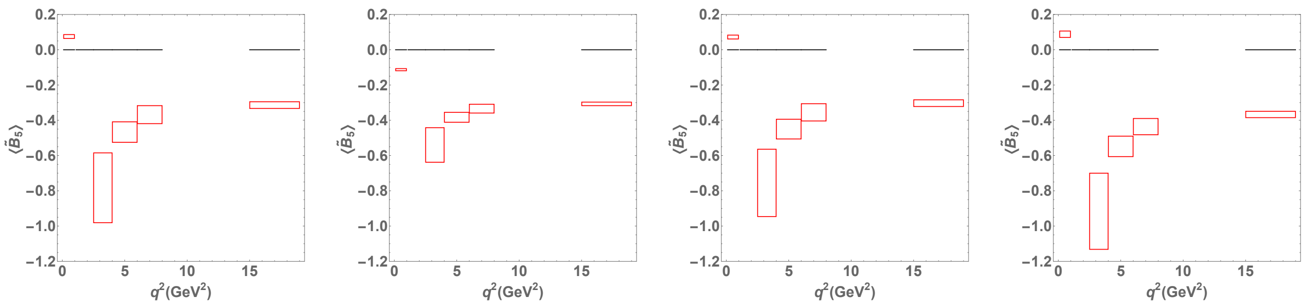


Figure: SM predictions (grey boxes) and NP predictions (red boxes) for $\widetilde{B_5}$ in the 4 scenarios.

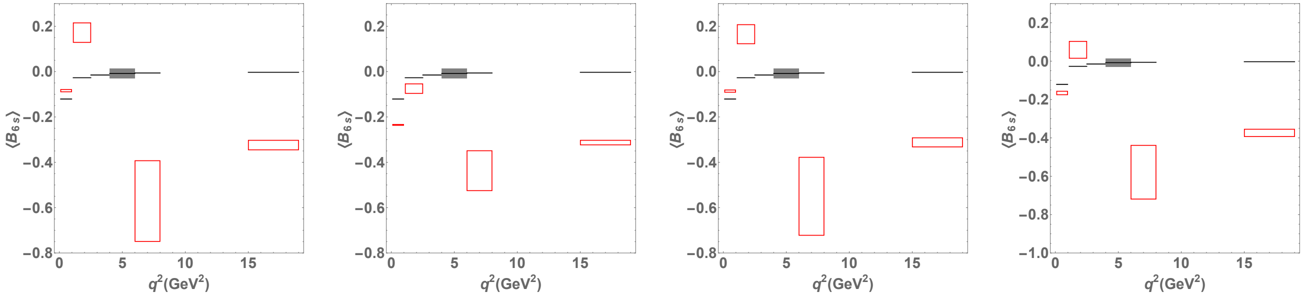


Figure: SM predictions (grey boxes) and NP predictions (red boxes) for B_{6s} in the 4 scenarios.

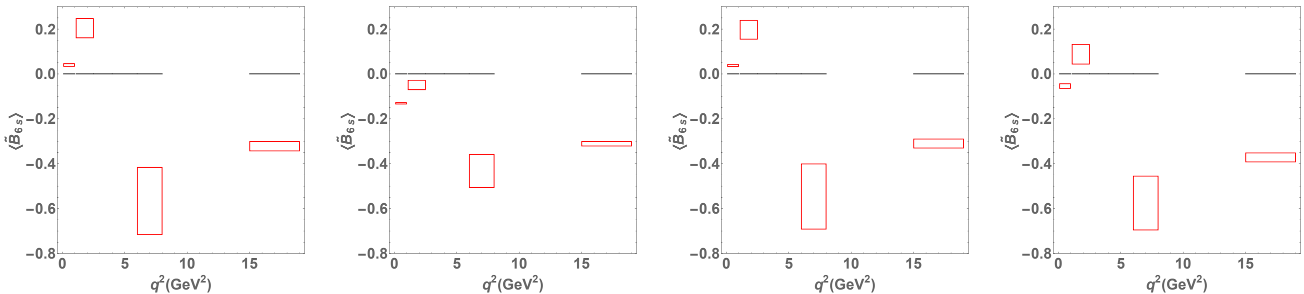


Figure: SM predictions (grey boxes) and NP predictions (red boxes) for $\widetilde{B_{6s}}$ in the 4 scenarios.

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:

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

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).

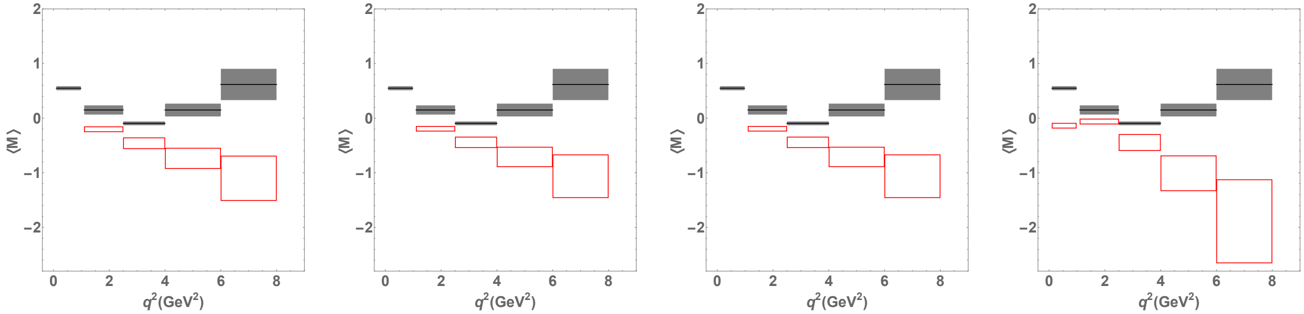


Figure: SM predictions (grey boxes) and NP predictions (red boxes) for M in the 4 scenarios.

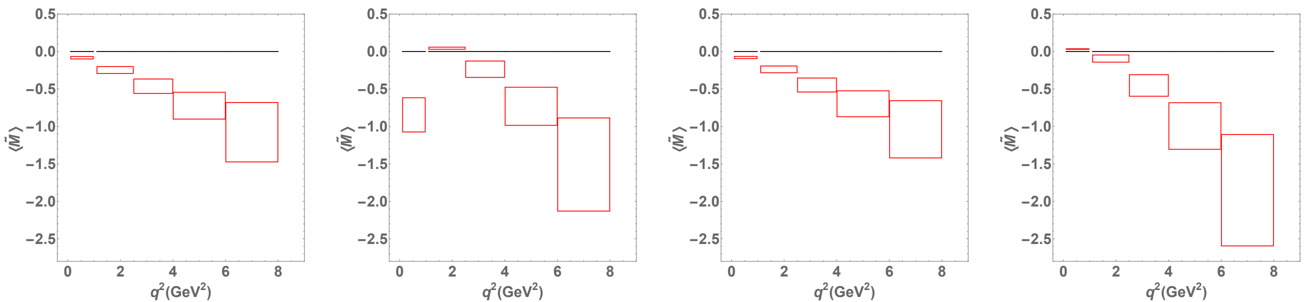
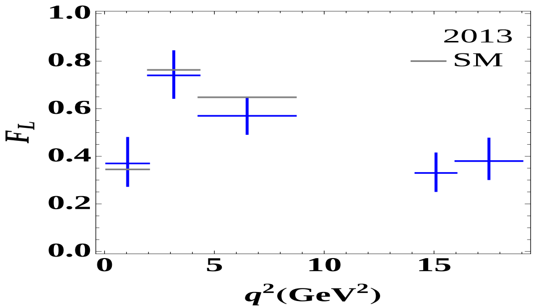


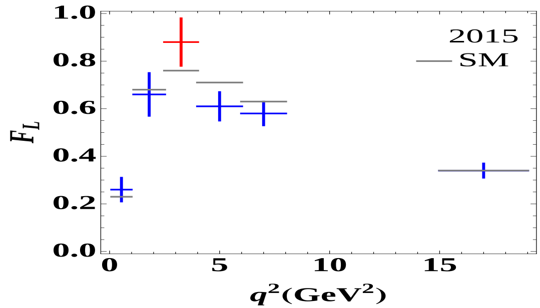
Figure: SM predictions (grey boxes) and NP predictions (red boxes) for $\widetilde{M}$ in the 4 scenarios.

BACK-UP SLIDES

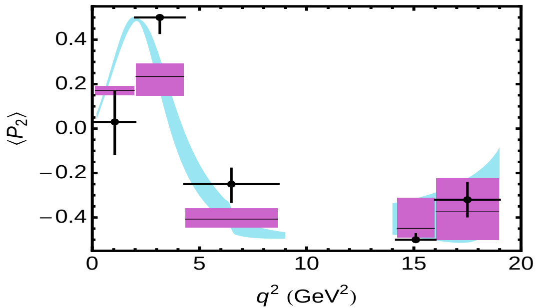
What happened to P_2 in 2015?

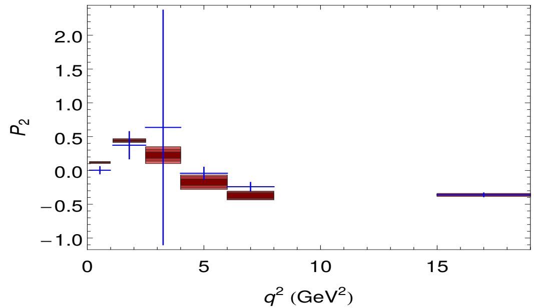
The new binning of F_L in 2015 had a temporary effect on the very interesting bin [2.5,4]





Tiny fluctuation??





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

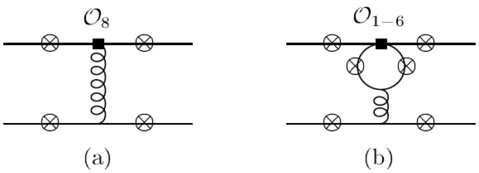
More statistics is necessary to confirm or disprove the deviation in that bin of P_2.

QCDF provides a systematic framework to include α_s (factorizable and non-factorizable) corrections.
Amplitude is represented by:

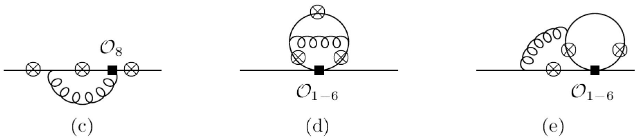
$$\langle \ell^+ \ell^- \bar{K}_a^* | H_{\text{eff}} | \bar{B} \rangle = \mathcal{C}_a \xi_a + \Phi_B \otimes T_a \otimes \Phi_{K^*} \text{ with } a = \perp, \parallel$$

- Non-factorizable α_s corrections:

⇒ First class: spectator quark in the B meson participates in the hard scattering: (T_a)



⇒ Second class: Matrix elements of four-quark operators and the chromomagnetic dipole op.: ($\mathcal{C}_a$)



BUT also **we include** a second type of power corrections:

- Non-factorizable power corrections including charm-quark loops.

All four (non-)factorizable α_s and power corrections are included in our predictions.

Helicity Form Factors

All FF determinations are computed in the transversity basis ($A_{\perp,\|,0}$) and correspond to $V, A_{0,1,2}, T_{1,2,3}$.

But some people prefer to use an helicity basis:

$$
\begin{aligned}
V_\pm(q^2) &= \frac{1}{2}\left[\left(1+\frac{m_V}{m_B}\right)A_1(q^2) \mp \frac{\lambda^{1/2}}{m_B(m_B+m_V)}V(q^2)\right],\\
V_0(q^2) &= \frac{1}{2m_V\lambda^{1/2}(m_B+m_V)}\left[(m_B+m_V)^2(m_B^2-q^2-m_V^2)A_1(q^2)-\lambda A_2(q^2)\right],\\
T_\pm(q^2) &= \frac{m_B^2-m_V^2}{2m_B^2}T_2(q^2) \mp \frac{\lambda^{1/2}}{2m_B^2}T_1(q^2),\\
T_0(q^2) &= \frac{m_B}{2\,m_V\lambda^{1/2}}\left[(m_B^2+3m_V^2-q^2)T_2(q^2)-\frac{\lambda}{(m_B^2-m_V^2)}T_3(q^2)\right],\\
S(q^2) &= A_0(q^2),
\end{aligned}
\tag{31}
$$

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

Frequentist approach:

$$\chi^2(C_i) = [O_{\rm exp} - O_{\rm th}(C_i)]_j \, [Cov^{-1}]_{jk} \, [O_{\rm exp} - O_{\rm th}(C_i)]_k$$

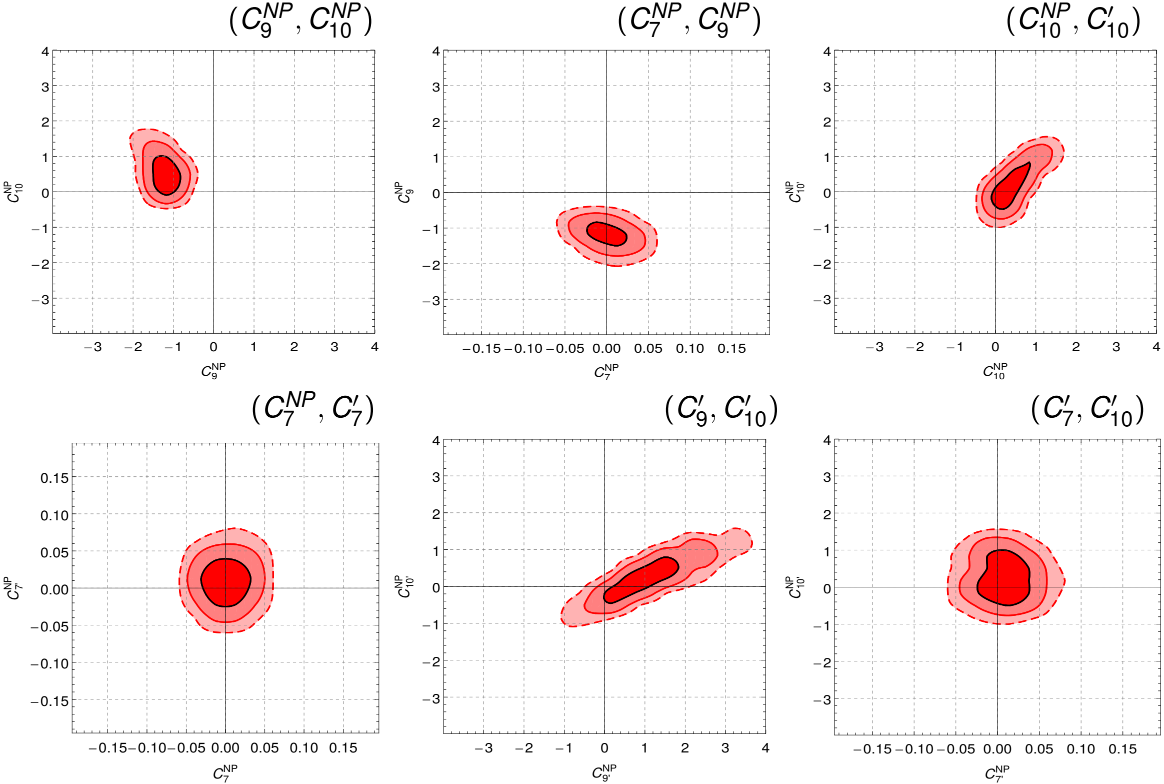
- **Cov** $=$ **Cov**$^{\rm exp}$ $+$ **Cov**$^{\rm th}$. We have $Cov^{\rm exp}$ for the first time
- Calculate $Cov^{\rm th}$: correlated multigaussian scan over all nuisance parameters
- $Cov^{\rm th}$ depends on C_i: Must check this dependence

For the Fit:

- Minimise $\chi^2 \to \chi^2_{\rm min} = \chi^2(C_i^0)$ (Best Fit Point = C_i^0)
- Confidence level regions: $\chi^2(C_i) - \chi^2_{\rm min} < \Delta\chi_{\sigma,n}$

Definition of Pull$_{SM}$:

Pull$_{SM}$ tells you how much in a model defined by a set of free Wilson coefficients C_i the value preferred by data for these Wilson coefficients is in tension with C_i^{SM}.


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

[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): $3 + 3 \times 2 - 1 = 8$

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

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

where $n_\parallel^\dagger = (A_\parallel^L, A_\parallel^{R*})$, $n_\perp^\dagger = (A_\perp^L, -A_\perp^{R*})$ 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:

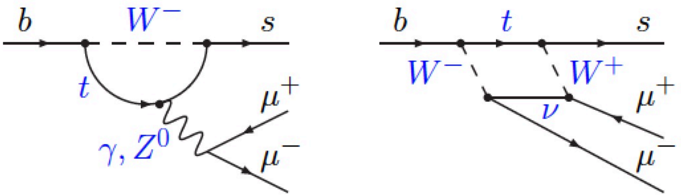
$$n_{obs} = 2n_A - n_S \qquad n_{obs} = n_{Ji} - n_{dep}$$

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]

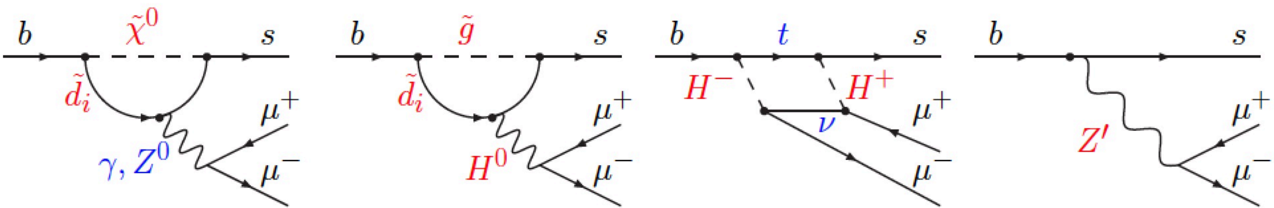
Symmetries $\Rightarrow$ # of observables $\Rightarrow$ determine a **basis**:

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

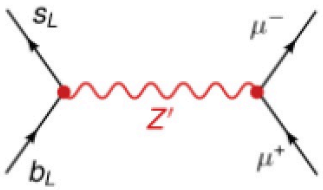


SM diagrams involve the charged current interaction.

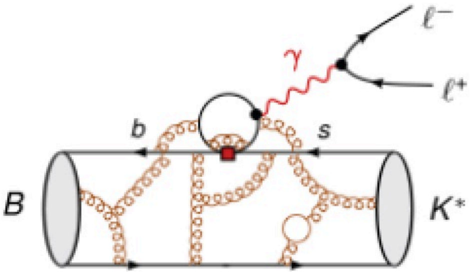
- New particles can contribute at loop or tree level:

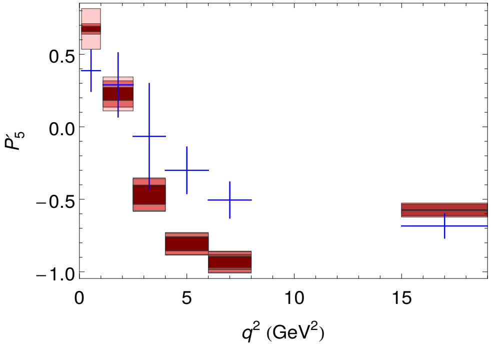


- Enhancing/suppressing decay rates, introducing new sources of CP violation or modifying the angular distribution of the final-state particles



Vector-like contribution could come from new tree level contribution from a Z' with a mass of a few TeV (the Z' will also contribute to mixing, a challenge for model builders)



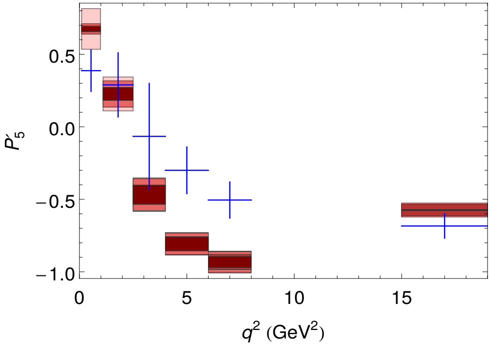


P_5' was proposed for the first time in **DMRV, JHEP 1301(2013)048**

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

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 $|n_\perp| \simeq |n_\parallel|$ ($H_{+1} \simeq 0$) $\Rightarrow P_5' \propto \cos\theta_{0,\perp}(q^2)$



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

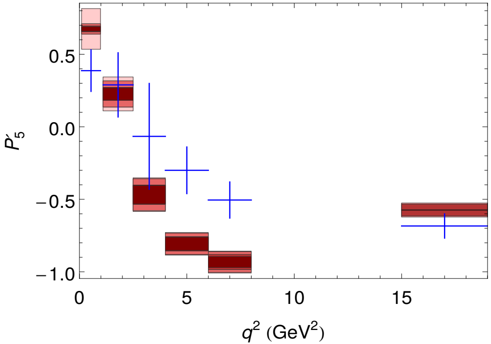
- If no-RHC $|n_\perp| \simeq |n_\parallel|$ $(H_{+1} \simeq 0) \Rightarrow P_5' \propto \cos\theta_{\mathbf{0},\perp}(\mathbf{q^2})$

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.



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

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

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

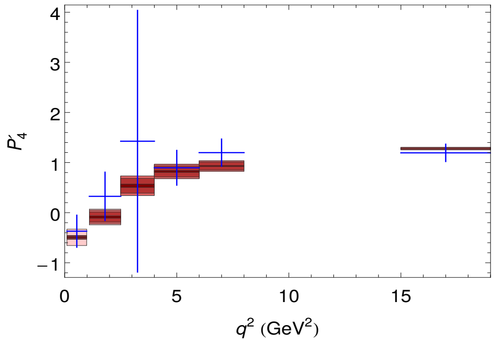
- If no-RHC $|n_\perp| \simeq |n_\|\|$ ($H_{+1} \simeq 0$) $\Rightarrow P_5' \propto \cos\theta_{0,\perp}(\mathbf{q^2})$

In the large-recoil limit with no RHC

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

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

- In SM $\mathcal{C}_9^{SM} + \mathcal{C}_{10}^{SM} \simeq 0 \to |A_{\perp,\|}^R| \ll |A_{\perp,\|}^L|$
- **In P_5':** If $C_9^{NP} < 0$ then $A_{0,\|}^R \uparrow$, $|A_\perp^R| \uparrow$ and $|A_{0,\|}^L| \downarrow$, $A_\perp^L \downarrow$ 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 $|n_\perp| \simeq |n_\parallel|$ $(H_{+1} \simeq 0) \Rightarrow P'_4 \propto \cos\theta_{\mathbf{0},\parallel}(\mathbf{q^2})$

In the large-recoil limit with no RHC

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

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

- In SM $\mathcal{C}_9^{SM} + \mathcal{C}_{10}^{SM} \simeq 0 \to |A^R_{\perp,\parallel}| \ll |A^L_{\perp,\parallel}|$
- **In** P'_4 :If $C_9^{NP} < 0$ then $A^R_{0,\parallel}\uparrow$, $|A^R_\perp|\uparrow$ and $|A^L_{0,\parallel}|\downarrow$, $A^L_\perp\downarrow$ due to $+$ what L loses R gains (little change).

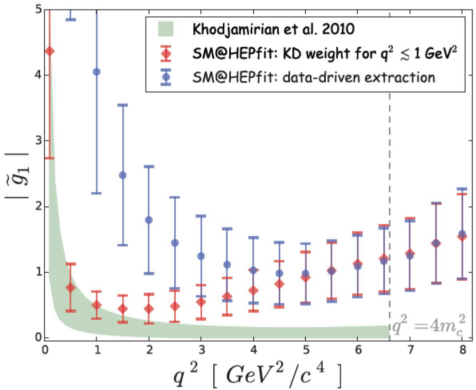
Prediction from CFFMPSV* of $S_5^{[4,6]}$: -0.200 ± 0.046 (Prediction? row Table 2)
Prediction from BSZ of $S_5^{[4,6]}$: -0.329 ± 0.039
Prediction from DHMV of $S_5^{[4,6]}$: -0.35 ± 0.12

- 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%)

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

* Their table of predictions are all being recomputed because v1 violated the consistency relation (Serra-Matias). An important problem in their dictionary for one of the relevant observables (see back-up).

$$P_2^{rel} = \frac{1}{2}\left[P_4' P_5' + \delta_a + \frac{1}{\beta}\sqrt{(-1 + P_1 + P_4'^2)(-1 - P_1 + \beta^2 P_5'^2) + \delta_b}\right] \qquad P_i \to \langle P_i \rangle \; (\Delta)$$



- $\tilde{g} = \Delta C_9^{non\,pert.}/(2C_1)$
- They force the fit (red points) to agree on the very low-q^2 with KMPW. This has two problems:
  - At very low-q^2 there are other problems **they forgot (lepton mass effects)**.
  - By forcing the fit to agree at very low-q^2 can induce an artificial tilt of your fit.
- More interestingly the blue points where KMPW is not imposed is perfectly compatible with

$C_9 - C_9^{SM} \simeq$ constant+KMPW **similar to us!!**.

So what is this constant $C_9^{\rm NP}$ or $h_\lambda^{(1)}$?

Notice that C_9^{NP} is a universal quantity entering all amplitudes, in CFFMPSV indeed the structure of charm is different for each amplitude so a big conspiracy is required to get THE SAME contribution to all amplitudes.

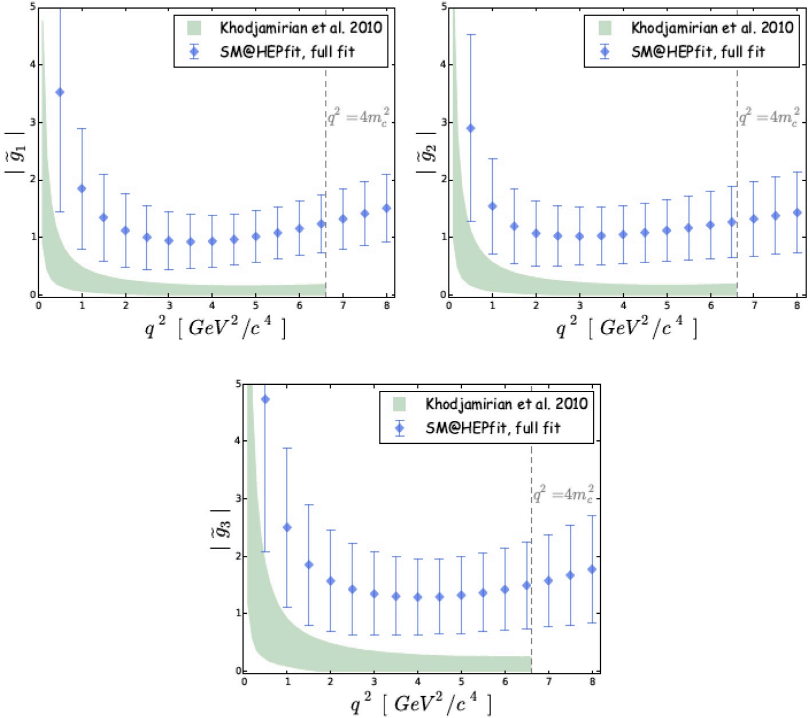


Figure 4. *Same plots as in figure 3 obtained without using the results of ref. [47] for $q^2 \leq 1$ GeV^2*

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

$$P_2^{rel} = \frac{1}{2}\left[P_4' P_5' + \delta_a + \frac{1}{\beta}\sqrt{(-1 + P_1 + P_4'^2)(-1 - P_1 + \beta^2 P_5'^2) + \delta_b}\right] \qquad P_i \to \langle P_i \rangle \ (\Delta)$$

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 a problem in the dictionary of inputs.
All tables of predictions for the observables are being recomputed.