Global analysis of $b \to s\ell\ell$ anomalies: The Path Towards New Physics

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

Goal of this talk

This talk will answer the following questions:

- What does the global fit on $b \to s\ell\ell$ tell us about Wilson coefficients?
  - Description of anomalies and theoretical framework of $B \to K^*\mu\mu$.
  - Which Wilson coefficients/scenarios receive a dominant NP contribution?
  - What does other approaches using different observables and methodology obtain?

- Anatomy of hadronic uncertainties. Are the alternative "explanations" (factorizable power corrections and charm) raised to explain (**some**) of the anomalies really robust?
  - I will desconstruct those """explanations""" pointing what we learn and where they fail in front of a global New Physics explanation.

- A Z' as a possible explanation?

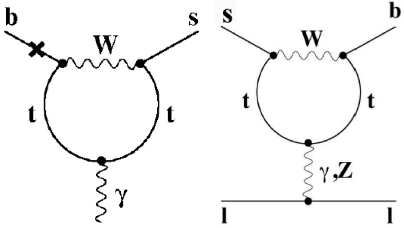
Since a long time ago...

$\Rightarrow b \to s\gamma$ and $b \to s\ell\ell$ **Flavour Changing Neutral Currents** have been used as **Our Portal** to explore the fundamental theory beyond SM.

.... with not much success till 2013.

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

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



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

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

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

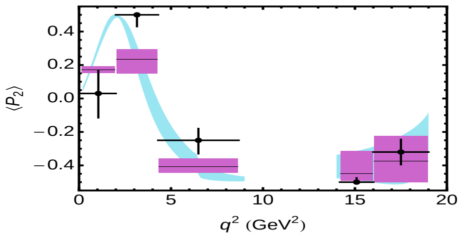
• **NP** changes short distance $\mathcal{C}_i - \mathcal{C}_i^{\rm SM} = \mathcal{C}_i^{\rm NP}$ and induce new operators, like $\mathcal{O}'_{7,9,10} = \mathcal{O}_{7,9,10}\ (P_L \leftrightarrow P_R)$

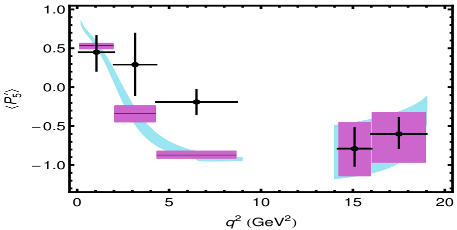
... also scalars, pseudoescalar, tensor operators...

Brief flash on the anomalies

Why so much excitement in Flavour Physics? What changed in and after 2013?

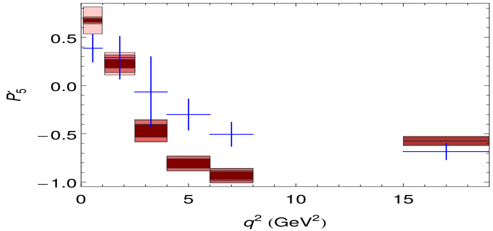
- First measurement by LHCb of the basis of optimized observables with 1 fb^{-1}:



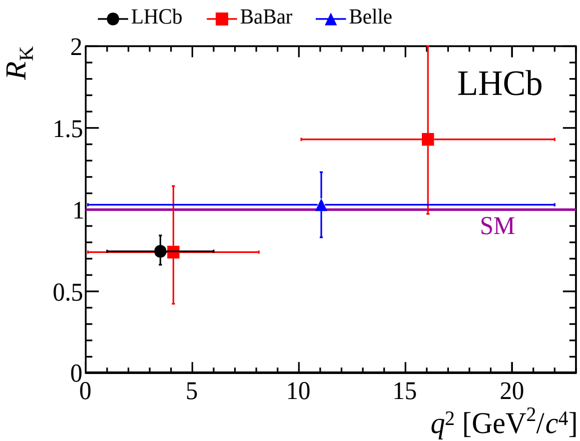


$\Rightarrow$ P_2 exhibited a **2.9**σ deviation in the bin [2,4.3] and P_5' exhibits a **3.7**σ in the [4.3,8.7] bin.

- In 2015 the so called anomaly in P_5' is confirmed with 3fb^{-1} in **2 bins** with **2.9**σ each:



$\Rightarrow$ P_2 will require a bit of patience to become more interesting (... a bit more of data)



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

- It deviates **2.6**σ from SM.
- Data on $BR(B^+ \to K^+\mu^+\mu^-)$ is below SM in **all bins** at large and low-recoil.

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	$+1.4$

Brief flash on the anomalies

$10^7 \times BR(B^0 \to K^{*0}\mu^+\mu^-)$	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 $B_s \to \phi\mu\mu$.

Option A: Global View

- (2015) $P'_{5[4,6]}$ and $P'_{5[6,8]}$ from $B \to K^* \mu\mu$ are at **2.9**σ
- (2015) R_K from $B \to K\ell\ell$ is at **2.6**σ
- (2015) $B^{[2,5]}_{B_s \to \phi\mu\mu}$ at **3.2**σ and $B^{[5,8]}_{B_s \to \phi\mu\mu}$ at **2.9**σ
- (2015) $B^{[15,19]}_{B^+ \to K^{*+}\mu\mu}$ at **2.5**σ
- (2013) $\langle P_2 \rangle_{[2,4.3]}$ of 1fb^{-1} data at **3**σ^*

$\Rightarrow$ Look for an underlying global pattern:

		R_K	$\langle P'_5 \rangle_{[4,6],[6,8]}$	$\mathcal{B}_{B_s \to \phi\mu\mu}$	
$\mathcal{C}_9^{NP}$	$+$				
	$-$	✓	✓ [100%]	✓	X
$\mathcal{C}_{10}^{NP}$	$+$	✓	[36%]	✓	
	$-$		✓ [32%]		
$\mathcal{C}_{9'}$	$+$		[21%]	✓	
	$-$	✓	✓ [36%]		
$\mathcal{C}_{10'}$	$+$	✓	✓ [75%]		
	$-$		[75%]	✓	

$\Rightarrow$ **A negative contribution to $\mathbf{C_9^{\mu}}$ alleviates all anomalies and tensions.**

Option B: Short Range View

Focus EXCLUSIVELY on one SINGLE anomaly:

led easily to errors in the evaluation of uncertainties:

- S.Jaeger, J. Camalich with power corrections.
- M. Valli, L. Silvestrini et al. with ad-hoc charm.

(To be discussed in detail later)

$\Rightarrow$ **What is more natural a solution consistent with all anomalies and tensions or an ad-hoc (and theoretically weak) partial answer different for each anomaly?**:

GLOBAL FIT:

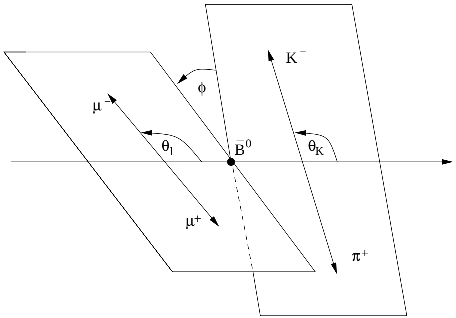
THE OBSERVABLES

- 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) .... $\mathcal{C}_7^{(\prime)}, \mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$
  - $\mathbf{B \to K^*}\ell^+\ell^-$ (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.

Optimized Basis of Angular Observables for $B \to K^*\mu\mu$

The optimized observables $P_i^{(\prime)}$ come from the angular distribution $\mathbf{\bar{B}_d} \to \mathbf{\bar{K}^{*0}}(\to \mathbf{K}^-\pi^+)\mathbf{l}^+\mathbf{l}^-$ 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

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



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.

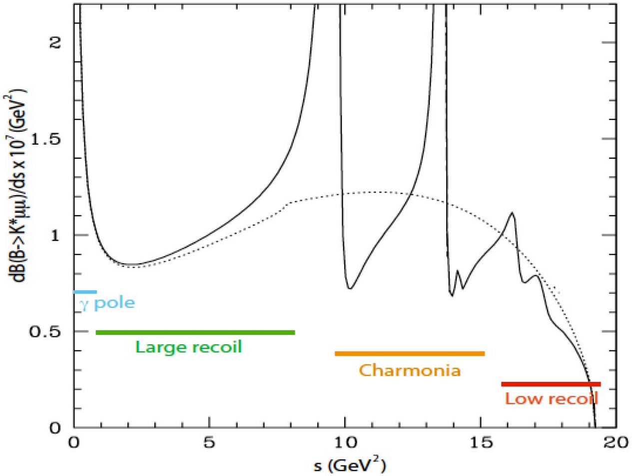
$\mathbf{q^2}$: dilepton invariant mass square.

$J_i(q^2)$ function of transversity (helicity) amplitudes of K*: $A^{L,R}_{\perp,\|,0}$ and they depend on FF and Wilson coefficients.

$$\Rightarrow A_\| = \frac{1}{\sqrt{2}}(H_{+1} + H_{-1}) \text{ and } A_\perp = \frac{1}{\sqrt{2}}(H_{+1} - H_{-1})$$

Notice LHCb uses $\theta_\ell^{LHCb} = \pi - \theta_\ell^{us}$.
Ongoing discussion on ϕ^{LHCb} versus ϕ^{theory} irrelevant for the fit (checked explicitly) (sign of $S_{7,8}$ or $P'_{6,8}$). (Zwicky)

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

The distribution (massless case) including the **S-wave** and normalized to Γ'_{full}:

$$\frac{1}{\Gamma'_{full}}\frac{d^4\Gamma}{dq^2\, d\cos\theta_K\, d\cos\theta_l\, d\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}\mathbf{F_T}\sin^2\theta_K + \mathbf{F_L}\cos^2\theta_K + (\frac{1}{4}\mathbf{F_T}\sin^2\theta_K - \mathbf{F_L}\cos^2\theta_K)\cos 2\theta_l$$
$$+\sqrt{\mathbf{F_T F_L}}\left(\frac{1}{2}\mathbf{P'_4}\sin 2\theta_K \sin 2\theta_l \cos\phi + \mathbf{P'_5}\sin 2\theta_K \sin\theta_l\cos\phi\right) + 2\mathbf{P_2 F_T}\sin^2\theta_K\cos\theta_l + \frac{1}{2}\mathbf{P_1 F_T}\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$-\sqrt{\mathbf{F_T F_L}}\left(\mathbf{P'_6}\sin 2\theta_K\sin\theta_l\sin\phi - \frac{1}{2}\mathbf{P'_8}\sin 2\theta_K\sin 2\theta_l\sin\phi\right) - \mathbf{P_3 F_T}\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big](1-\mathbf{F_S}) + \frac{1}{\Gamma'_{full}}\mathbf{W_S}$$

- in **blue** the set of relevant observables $\mathbf{P_{1,2}}$, $\mathbf{P'_{4,5}}$.
- the S-wave terms are (see discussion [M'12] & [HM'15]) not all free observables:

$$\frac{\mathbf{W_S}}{\Gamma'_{full}} = \frac{3}{16\pi}\Big[\mathbf{F_S}\sin^2\theta_\ell + \mathbf{A_S}\sin^2\theta_\ell\cos\theta_K + \mathbf{A_S^4}\sin\theta_K\sin 2\theta_\ell\cos\phi$$
$$+\mathbf{A_S^5}\sin\theta_K\sin\theta_\ell\cos\phi + \mathbf{A_S^7}\sin\theta_K\sin\theta_\ell\sin\phi + \mathbf{A_S^8}\sin\theta_K\sin 2\theta_\ell\sin\phi\Big]$$

Symmetries tells you that a complete basis (lepton masses to zero) is, for instance:

$\{\Gamma'_{K^*}, F_L, P_1, P_2, P_3, P'_4, P'_5, P'_6\}$ and only 4 of $\{F_S, A_S, A_S^4, A_S^5, A_S^7, A_S^8\}$ are independent.

1. **Improved-QCDF approach**: QCDF+exploit **symmetry relations** at large-recoil (limit) among FF:

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

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

- Our approach is completed with 4 types of corrections. From a FF decomposition (example):

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

- $\Delta V^{\alpha_s}(q^2)$: 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)

$\Rightarrow$ **IQCDF is Transparent**, valid for **ANY** FF parametrization (BZ, BSZ, **KMPW**,...).
Dominant correlations automatically implemented in a transparent way via **SYMMETRIES**.

Theoretical description of $B \to K^*\ell^+\ell^-$ @ low-q^2: Two approaches

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

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

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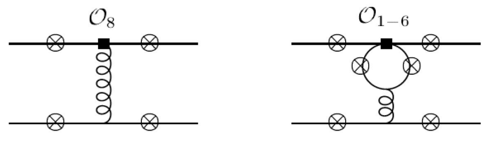
Theoretical description of $B \to K^* \ell^+ \ell^-$ @ low-q^2: Two approaches

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

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

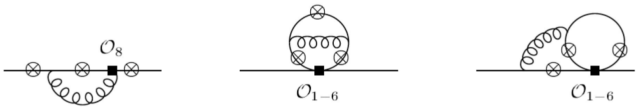
- Non-factorizable α_s corrections:

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



(a) (b)

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



(c) (d) (e)

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.

2. **Full FF approach**: (Bharucha, Straub, Zwicky):
Less general, attached to **details** of a particular LCSR computation.
   - $\Rightarrow$ ΔF^{α_s} and ΔF^{Λ} are included.
   - $\Rightarrow$ BUT **BE CAREFUL** one should add **also** to be complete:
     - Non-factorizable α_s corrections from QCDF.
     - Non-factorizable power corrections and charm-quark loop effects

   Usually applied to $\mathbf{S_i} = (J_i + \bar{J}_i)/(d\Gamma + \bar{d}\Gamma)$
   $\to$ **observables highly dependent on FF-error estimate and internal assumptions of FF computation. A small error in FF induces a small error in S_i**

   Why we prefer to work within IQCDF:

   - NATURAL FRAMEWORK for optimized observables P_i
   - CORRELATIONS ARE TRANSPARENT and easy to REPRODUCE
   - It allows us to predict observables from different set of FORM FACTORS (BZ,BSZ,KMPW) and to compare results.

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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.

Helicity Form Factors

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

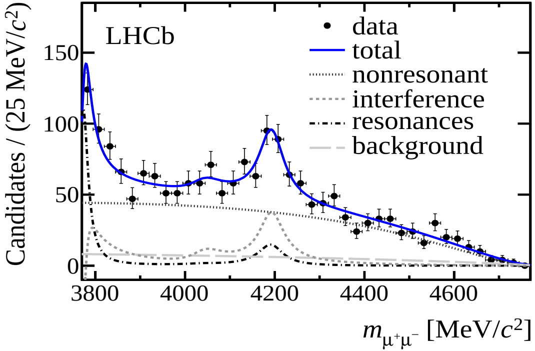
But some people prefer (at their own risk) to use an helicity basis:

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

Theoretical description of $B \to K^* \ell^+ \ell^-$ @ large-q^2

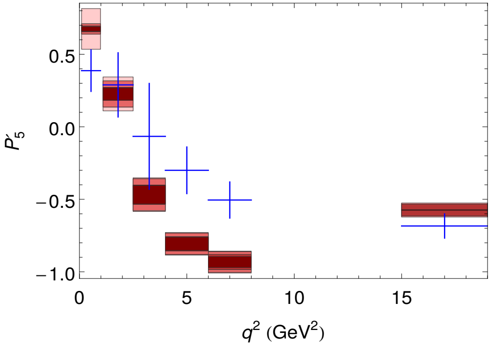
- It corresponds to **large** $\sqrt{q^2} \sim \mathcal{O}(m_b)$ above Ψ' mass, i.e., E_K is around GeV or below.
- OPE in $E_K/\sqrt{q^2}$ or $\Lambda_{QCD}/\sqrt{q^2}$ (Buchalla et al). **NLO QCD correct.** to the OPE coeffs (Greub et al)
- **Lattice QCD form factors with correlations** (Horgan et al proceeding update)
- Estimates on BR from GP (5%) and BBF (2%) using Shifman's model.
  $\Rightarrow \pm 10\%$ on angular observables to account for possible Duality Violations.

Existence of $c\bar{c}$ **resonances** in this region (clearly seen $\psi(4160)$ in $B^- \to K^- \mu^+ \mu^-$),
$\Rightarrow$ require to take a long bin.



... but this region is neither the most sensitive to New Physics nor where interesting things happen!

Brief Discussion on: P_5' and P_4'

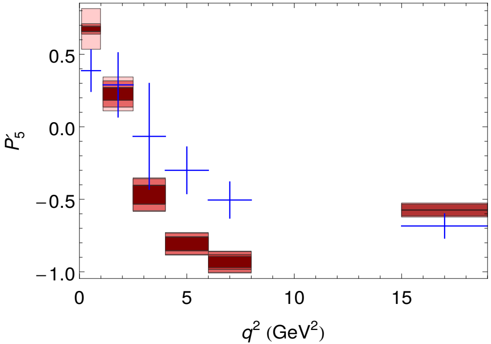


P_5' was proposed for the first time in **DMRV, JHEP 1301(2013)048**

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

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



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

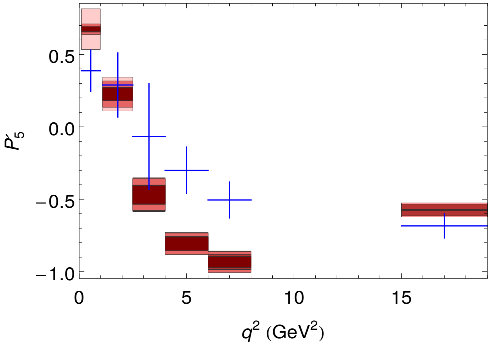
In the large-recoil limit with no RHC

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

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

- 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.

Brief Discussion on: P_5' and P_4'



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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

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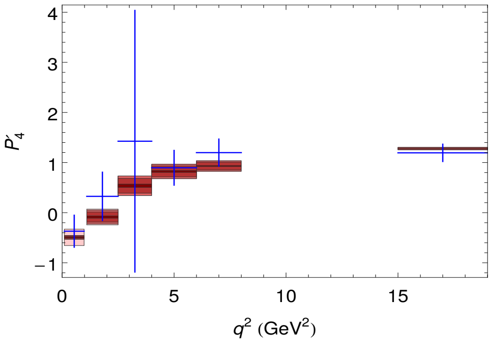
$$A_0^L \propto -\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*}) \quad A_0^R \propto -\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\parallel(E_{K^*})$$

- 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_4' was proposed for the first time in **DMRV, JHEP 1301(2013)048**

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

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 $|n_\perp| \simeq |n_\|| \ (H_{+1} \simeq 0) \Rightarrow P_4' \propto \cos\theta_{\mathbf{0},\|}(\mathbf{q^2})$

In the large-recoil limit with no RHC

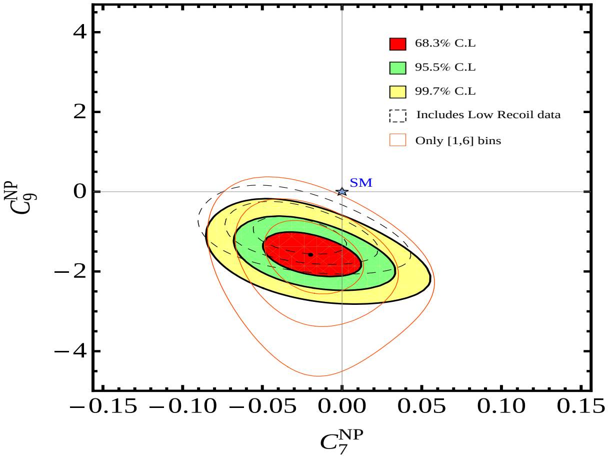
$$A^L_{\perp,\|} \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*}) \qquad A^R_{\perp,\|} \propto (1,-1)\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + \frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\rm eff}\right]\xi_\perp(E_{K^*})$$

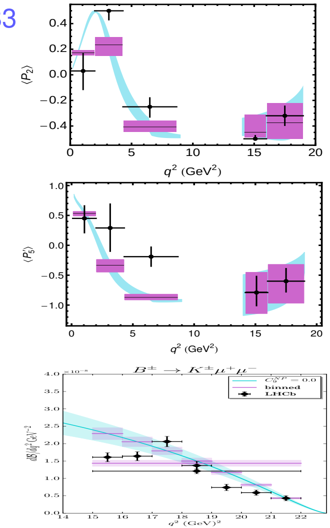
$$A_0^L \propto -\left[\mathcal{C}_9^{\rm eff} - \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\|(E_{K^*}) \quad A_0^R \propto -\left[\mathcal{C}_9^{\rm eff} + \mathcal{C}_{10} + 2\hat{m}_b\mathcal{C}_7^{\rm eff}\right]\xi_\|(E_{K^*})$$

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

Global Fits to Wilson coefficients: History and Results 2013 with 1fb^{-1}

Situation in 2013: Descotes-Genon, Matias, Virto 1307.5683





[2.9σ in second bin]

[3.7 σ third bin],

[low-recoil $\Rightarrow C_9^{NP} < 0$],

Our statement in July 2013 DMV'13:
"We found that the Standard Model hypothesis $C_7^{\rm NP} = 0$, $C_9^{\rm NP} = 0$ has a pull of 4.5σ".

Other groups later on confirmed the relevance of C_9 using FFD-observables (Altmannshofer, Straub 1308.1501), low-recoil (Horgan et al. 1310.3887), Bayesian approach (Beaujean, Bobethm Van Dyk 1310.2478).

FIT 2015

Theory and experimental updates in 2015 fit

- $BR(B \to X_s \gamma)$
  - New theory update: $\mathcal{B}_{s\gamma}^{\text{SM}} = (3.36 \pm 0.23) \cdot 10^{-4}$ (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

Fit 2015: Statistical Approach

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$_{SM}$: Example

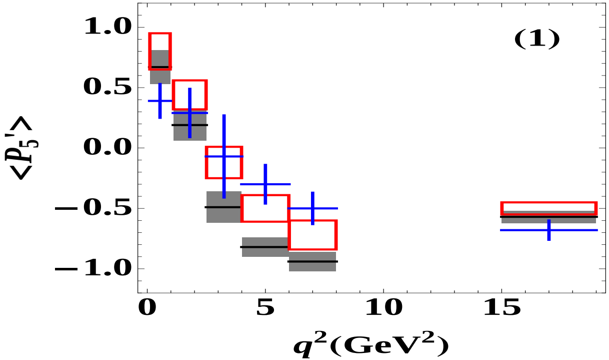
In a model with a single free parameter C_9 the χ^2 minimisation allows us to determine (within a confidence interval) C_9. (We determine indeed C_9^{NP})

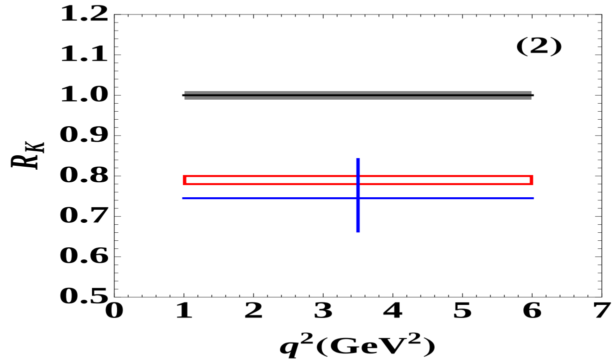
Pull$_{SM}$ tells you how much in this model the value of C_9 preferred by data is in tension with $C_9 = C_9^{SM}$.

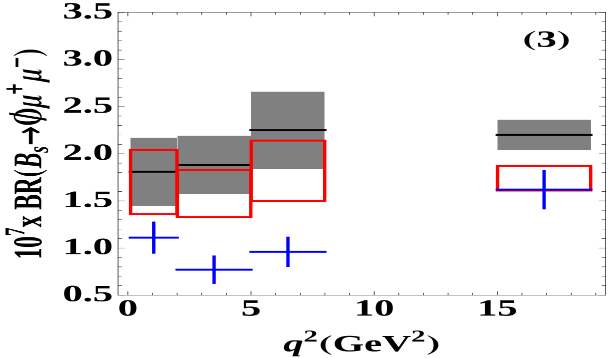
This is the first analysis: - using the basis of **optimized observables** ($B \to K^* \mu\mu$ and $B_s \to \phi\mu\mu$)
- using the **full dataset** of 3fb^{-1}:

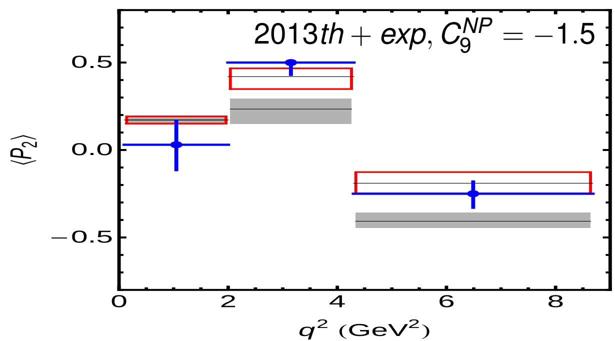
Coefficient $\mathcal{C}_i^{NP} = \mathcal{C}_i - \mathcal{C}_i^{SM}$	Best fit	1σ	3σ	Pull$_{\mathrm{SM}}$
$\mathcal{C}_7^{\mathrm{NP}}$	-0.02	$[-0.04, -0.01]$	$[-0.07, 0.03]$	1.3
$\mathcal{C}_9^{\mathrm{NP}}$	-1.09	$[-1.30, -0.88]$	$[-1.68, -0.40]$	**4.5** $\Leftarrow$
$\mathcal{C}_{10}^{\mathrm{NP}}$	0.56	$[0.33, 0.81]$	$[-0.11, 1.37]$	2.5
$\mathcal{C}_{7'}^{\mathrm{NP}}$	0.02	$[-0.00, 0.04]$	$[-0.05, 0.10]$	0.8
$\mathcal{C}_{9'}^{\mathrm{NP}}$	0.44	$[0.17, 0.72]$	$[-0.37, 1.29]$	1.6
$\mathcal{C}_{10'}^{\mathrm{NP}}$	-0.25	$[-0.44, -0.07]$	$[-0.83, 0.30]$	1.4
$\mathcal{C}_9^{\mathrm{NP}} = \mathcal{C}_{10}^{\mathrm{NP}}$	-0.22	$[-0.41, -0.02]$	$[-0.74, 0.49]$	1.1
$\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{10}^{\mathrm{NP}}$	-0.68	$[-0.86, -0.51]$	$[-1.23, -0.18]$	**4.2** $\Leftarrow$
$\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{9'}^{\mathrm{NP}}$	-1.05	$[-1.24, -0.85]$	$[-1.59, -0.40]$	4.8 $\Leftarrow$ (no R_K)
$\mathcal{C}_9^{\mathrm{NP}} = -\mathcal{C}_{10}^{\mathrm{NP}} = -\mathcal{C}_{9'}^{\mathrm{NP}} = -\mathcal{C}_{10'}^{\mathrm{NP}}$	-0.68	$[-0.88, -0.50]$	$[-1.35, -0.16]$	4.0

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









(1),(2) and (3) use 3 fb^{-1} dataset and latest theory prediction for SM (gray) and NP ($C_9^{NP} = -1.1$).

Result of the fit with 2D Wilson coefficient constrained and unconstrained

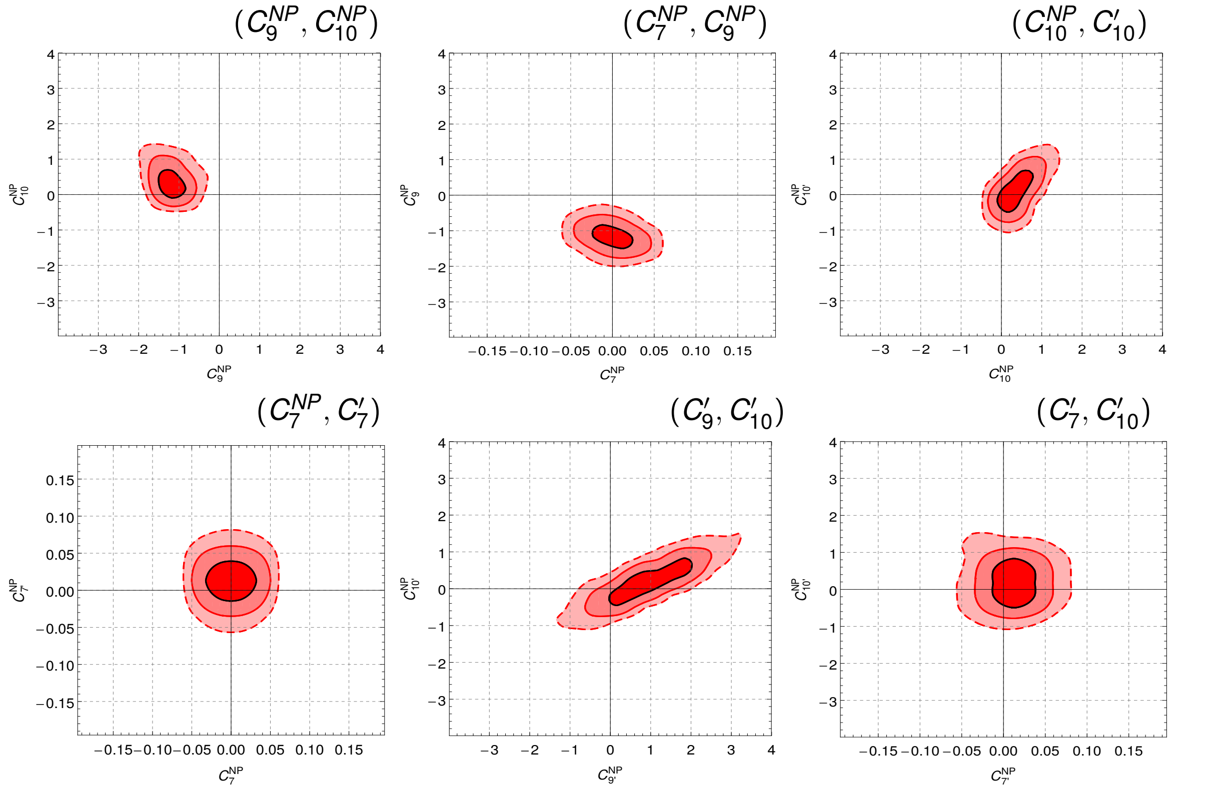
Coefficient	Best Fit Point	$\mathrm{Pull_{SM}}$	p-value (%)
$(\mathcal{C}_7^{\rm NP}, \mathcal{C}_9^{\rm NP})$	$(-0.00, -1.09)$	**4.1**	55.0
$(\mathcal{C}_9^{\rm NP}, \mathcal{C}_{10}^{\rm NP})$	$(-1.07, 0.34)$	**4.4**	62.0
$(\mathcal{C}_9^{\rm NP}, \mathcal{C}_{7'}^{\rm NP})$	$(-1.11, 0.03)$	**4.3**	59.0
$(\mathcal{C}_9^{\rm NP}, \mathcal{C}_{9'}^{\rm NP})$	$(-1.11, 0.68)$	**4.5**	66.0
$(\mathcal{C}_9^{\rm NP}, \mathcal{C}_{10'}^{\rm NP})$	$(-1.16, -0.35)$	**4.5**	66.0
$(\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP}, \mathcal{C}_{10}^{\rm NP} = \mathcal{C}_{10'}^{\rm NP})$	$(-1.13, 0.29)$	**4.6**	68.0
$(\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP}, \mathcal{C}_{10}^{\rm NP} = -\mathcal{C}_{10'}^{\rm NP})$	$(-1.04, 0.03)$	**4.4**	63.0
$(\mathcal{C}_9^{\rm NP} = \mathcal{C}_{9'}^{\rm NP}, \mathcal{C}_{10}^{\rm NP} = \mathcal{C}_{10'}^{\rm NP})$	$(-0.68, -0.25)$	3.9	49.0
$(\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP}, \mathcal{C}_{9'}^{\rm NP} = \mathcal{C}_{10'}^{\rm NP})$	$(-0.74, 0.26)$	3.8	48.0

- 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

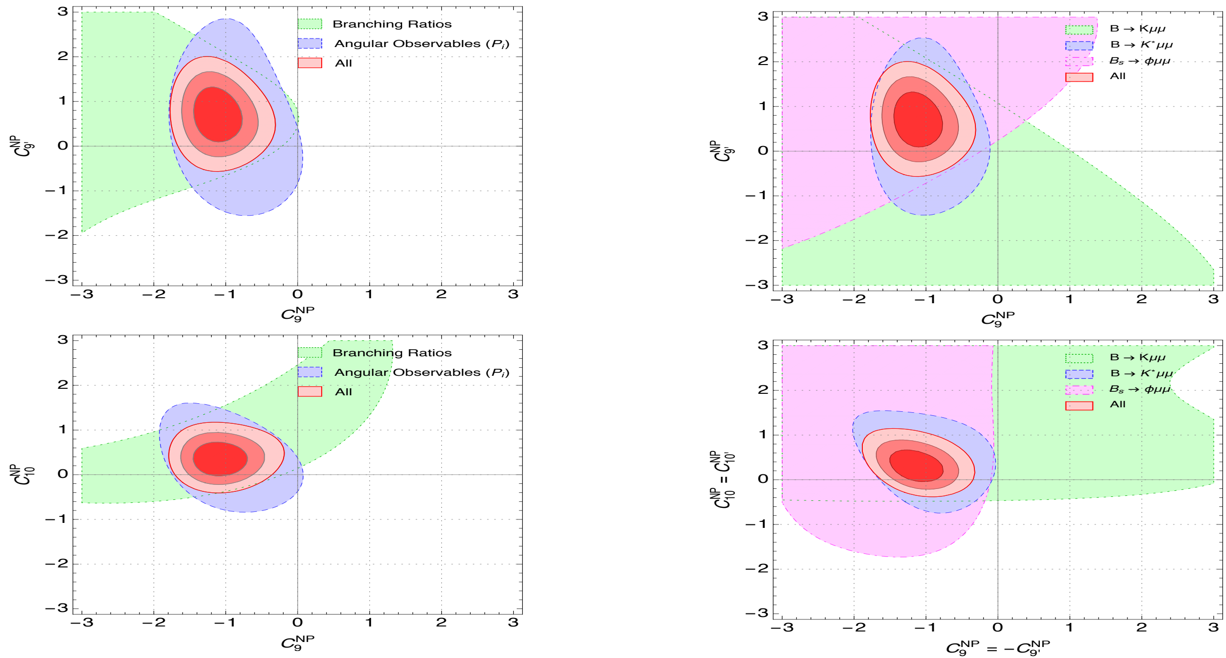
Coefficient	1σ	2σ	3σ
$\mathcal{C}_7^{\rm NP}$	$[-0.02, 0.02]$	$[-0.04, 0.04]$	$[-0.06, 0.06]$
$\mathcal{C}_9^{\rm NP}$	$[-1.4, -0.9]$	$[-1.6, -0.6]$	$[-1.9, -0.3]$
$\mathcal{C}_{10}^{\rm NP}$	$[-0.2, 0.7]$	$[-0.4, 1.1]$	$[-0.5, 1.6]$
$\mathcal{C}_{7'}^{\rm NP}$	$[-0.01, 0.05]$	$[-0.03, 0.07]$	$[-0.06, 0.09]$
$\mathcal{C}_{9'}^{\rm NP}$	$[0.2, 1.6]$	$[-0.7, 2.4]$	$[-1.4, 3.3]$
$\mathcal{C}_{10'}^{\rm NP}$	$[-0.4, 0.6]$	$[-0.8, 1.0]$	$[-1.1, 1.6]$

- 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 3.7σ.



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

Who drives the fit?



Angular observables (P_i) dominates over BR

The hierarchy of importance for the fit:
$B \to K^*\mu\mu$, $B_s \to \phi\mu\mu$ *and* $B \to K\mu\mu$

Impact of $B \to Ke^+e^-$

under hypothesis of maximal

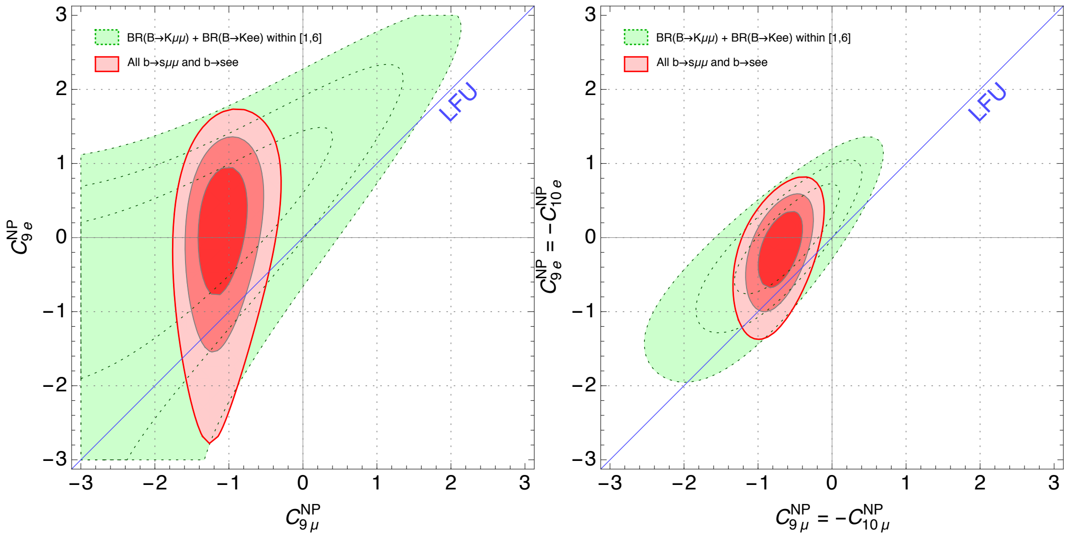
Lepton Flavour Universal Violation

1D-Coefficient	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_9^{\text{NP}}$	-1.12	$[-1.31, -0.91]$	$[-1.68, -0.47]$	**4.5 → 5.0**
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}}$	-0.65	$[-0.81, -0.50]$	$[-1.13, -0.22]$	**4.2 → 4.6**
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}$	-1.06	$[-1.24, -0.85]$	$[-1.59, -0.41]$	4.9
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}} = -\mathcal{C}_{10'}^{\text{NP}}$	-0.66	$[-0.83, -0.49]$	$[-1.23, -0.20]$	**4.0 → 4.5**

2D-Coefficient	Best Fit Point	Pull_{SM}
$(C_7^{\text{NP}}, C_9^{\text{NP}})$	$(-0.01, -1.12)$	**4.1 → 4.6**
$(C_9^{\text{NP}}, C_{10}^{\text{NP}})$	$(-1.10, 0.29)$	**4.4 → 4.8**
$(C_9^{\text{NP}}, C_{7'}^{\text{NP}})$	$(-1.14, 0.03)$	**4.3 → 4.8**
$(C_9^{\text{NP}}, C_{9'}^{\text{NP}})$	$(-1.16, 0.58)$	**4.5 → 4.9**
$(C_9^{\text{NP}}, C_{10'}^{\text{NP}})$	$(-1.18, -0.28)$	**4.5 → 4.9**
$(C_9^{\text{NP}} = -C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-1.20, 0.35)$	**4.6 → 5.0**
$(C_9^{\text{NP}} = -C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = -C_{10'}^{\text{NP}})$	$(-1.03, 0.05)$	**4.5**
$(C_9^{\text{NP}} = C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-0.67, -0.15)$	**3.9 → 4.3**
$(C_9^{\text{NP}} = -C_{10}^{\text{NP}}, C_{9'}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-0.66, 0.17)$	**3.8 → 4.3**

- 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.

Prediction for LFU tests observables

	$R_K[1,6]$	$R_{K^*}[1.1,6]$	$R_\phi[1.1,6]$
SM	1.00 ± 0.01	1.00 ± 0.01 $[1.00 \pm 0.01]$	1.00 ± 0.01
$\mathcal{C}_9^{\rm NP} = -1.11$	0.79 ± 0.01	0.87 ± 0.08 $[0.84 \pm 0.02]$	0.84 ± 0.02
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP} = -1.09$	1.00 ± 0.01	0.79 ± 0.14 $[0.74 \pm 0.04]$	0.74 ± 0.03
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP} = -0.69$	0.67 ± 0.01	0.71 ± 0.03 $[0.69 \pm 0.01]$	0.69 ± 0.01
$\mathcal{C}_9^{\rm NP} = -1.15, \mathcal{C}_{9'}^{\rm NP} = 0.77$	0.91 ± 0.01	0.80 ± 0.12 $[0.76 \pm 0.03]$	0.76 ± 0.03
$\mathcal{C}_9^{\rm NP} = -1.16, \mathcal{C}_{10}^{\rm NP} = 0.35$	0.71 ± 0.01	0.78 ± 0.07 $[0.75 \pm 0.02]$	0.76 ± 0.01
$\mathcal{C}_9^{\rm NP} = -1.23, \mathcal{C}_{10'}^{\rm NP} = -0.38$	0.87 ± 0.01	0.79 ± 0.11 $[0.75 \pm 0.02]$	0.76 ± 0.02
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP} = -1.17$, $\mathcal{C}_{10}^{\rm NP} = \mathcal{C}_{10'}^{\rm NP} = 0.26$	0.88 ± 0.01	0.76 ± 0.12 $[0.71 \pm 0.04]$	0.71 ± 0.03

Table: *Predictions for R_K, R_{K^*}, R_ϕ at the best fit point of different scenarios of interest, assuming that NP enters only in the muon sector, and using the inputs of our reference fit, in particular the KMPW form factors for $B \to K$ and $B \to K^*$, and BSZ for $B_s \to \phi$. In the case of $B \to K^*$, we also indicate in brackets the predictions using the form factors in BSZ.*

A CRUCIAL QUESTION:

How much the fit results depend on the details?

Two first strong tests

TEST 1: Does the fit result depend on method IQCDF-KMPW or Full-FF-BSZ?
NO

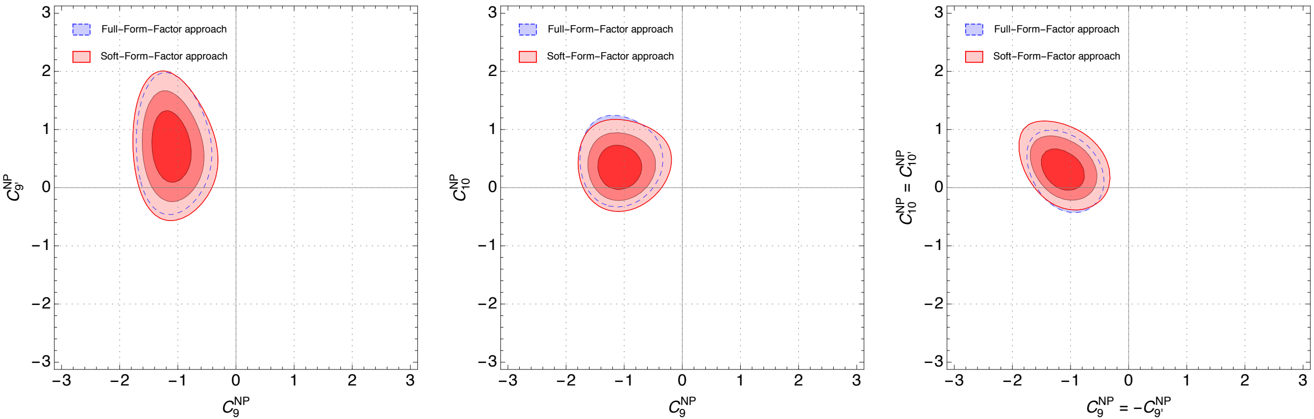
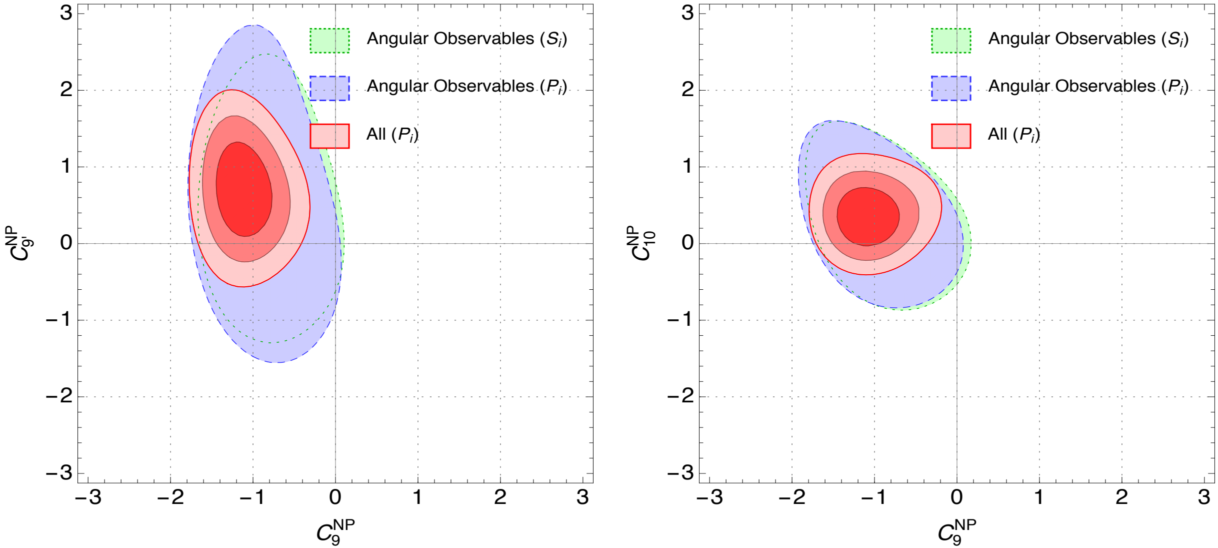


Figure: *We show the 3 σ regions allowed using form factors in BSZ'15 in the full form factor approach (long-dashed blue) compared to our reference fit with the soft form factor approach (red, with 1,2,3 σ contours).*

- The results of the fit using (IQCDF-KMPW) or (Full-FF-BSZ) are perfectly consistent.
- The fact that our regions are slightly larger points that our estimate of uncertainties (power corrections, etc.) is conservative.

TEST 2: Does the fit result depend on using P_i or S_i observables? **NO**



- The results of the fit using P_i observables or S_i observables are perfectly consistent.
- The highest sensitivity to NP of the optimized observables due to the shielding on FF details
  $\Rightarrow$ induces a **small albeit systematic improvement in significance** for the P_i.

Does the error predictions on individual observables depend on **FF choice**?**YES**

Only in a **global fit** thanks to correlations it is basically the same to use:

- Optimized observables $\mathbf{P_i}$.
- FF dependent observables $\mathbf{S_i}$.

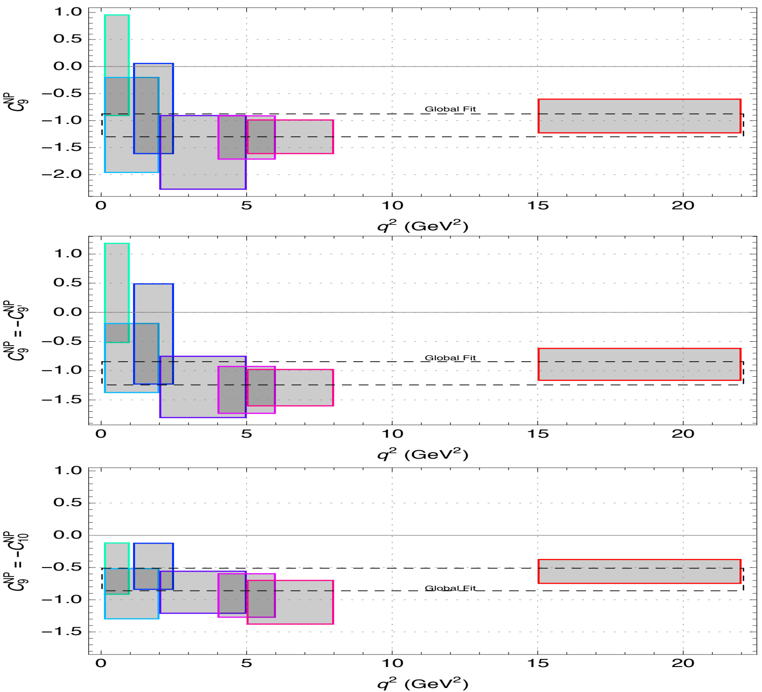
BUT when testing **individual observables** with data:

- Optimized observables $\mathbf{P_i}$ are robust $\mathcal{O}(\alpha_s\,\xi_{\perp,\|})$.
- FF dependent observables $\mathbf{S_i}$ are largely FF-choice dependent $\mathcal{O}(\xi_{\perp,\|})$.

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]

Shift of central values by 6%.

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 plot test if you allow for NP in other WC the agreement of C_9 bin by bin improves as compared to 1st plot.

Deconstructing naïve (wrong) statements (arguments)
or
How robust are the criticisms?

Discussion of Criticism from 3 (unpublished) papers: Lyon-Zwicky, arXiv: **1406.0566** (**LZ'14**)
Jaeger-Camalich, arXiv: **1412.3183** (**JC'14**)
Ciuchini-Silvestrini-Valli et al. arXiv: **1512.07157** (**CSV**)

Frequent naïve statement: Uncertainties are underestimated?

It is important to understand first what the uncertainties are and how they are treated.

Hadronic Uncertainties I:

Factorizable power corrections

Criticism 1: Factorizable Power Corrections ΔF^{Λ} give a huge contribution?

What are Factorizable power corrections and how they emerge?

Appear when expressing the full form factor in a soft form factor piece + corrections:

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

$\Rightarrow$ ΔF^{Λ} deviation between known SFF (F^{soft})+ known α_s (ΔF^{α_s}) and the computed full FF (e.g. LCSR).
Example:

$$\mathbf{A_1(q^2)} = \frac{2E}{m_B + m_{K^*}} \xi_\perp(q^2) + \Delta A_1^{\alpha_s}(q^2) + \Delta A_1^{\Lambda}(q^2)\,,$$

How one can obtain power corrections?. Example: (DHMV'14)

	$\hat{a}_F^{(1)}$	$\hat{b}_F^{(1)}$	$\hat{c}_F^{(1)}$	$r(0\,\mathrm{GeV}^2)$	$r(4\,\mathrm{GeV}^2)$	$r(8\,\mathrm{GeV}^2)$
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 $\leq 10\%$

Remark: **In our analysis we perform a fit to second order in q^2/m_B^2 and keep the correlated results a_F , b_F , c_F as central values for ΔF^{Λ}**. Errors are taken uncorrelated to be $\mathcal{O}(\Lambda/m_b) \times \mathrm{FF} \simeq 0.1\mathrm{FF}$.

Later on JC'14 followed same strategy.

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Remark: **In our analysis we perform a fit to second order in q^2/m_B^2 and keep the correlated results a_F , b_F , c_F as central values for ΔF^{Λ}.** Errors are taken uncorrelated to be $\mathcal{O}(\Lambda/m_b) \times \mathrm{FF} \simeq 0.1\mathrm{FF}$.

Later on JC'14 followed same strategy.

How $\xi_{\perp,\|}$ are defined?

Soft FF can be naturally defined (at all orders) in many different ways. Example:

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

or

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

This is the **choice of scheme.** Illustrative example (using BSZ for a moment):

$\langle P_5' \rangle_{[4,6]}$	error of f.f.+p.c. scheme-1 in transversity basis	error of f.f.+p.c. scheme-2 in helicity basis
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

FULL FF scheme indep.	± 0.03

Conclusions:

- Scheme dependence: Observables does not depend on the scheme choice **if correlations are included** but they depend on the choice in the uncorrelated case.
- Conservative errors:
  - A fit to BSZ p.c. predicts typically 5% $\Rightarrow$ our 10% estimate is already very conservative.
  - An estimate of 10% in helicity basis in scheme-2 (JC'14) is **inflated by a factor 4** w.r.t. full-FF case.

$\Rightarrow$ in absence of correlations (as in JC'14 or DHMV'14) the choice of scheme matters a lot!

Why scheme-2 **is not** an appropriate scheme?

In the old scheme used by (also JC'14): $\xi_\perp^{(2)}(\mathbf{q^2}) \equiv \mathbf{T_1}(\mathbf{q^2})$, $\xi_\parallel^{(2)}(\mathbf{q^2}) \equiv \frac{\mathbf{m_{K^*}}}{\mathbf{E}}\mathbf{A_0}(\mathbf{q^2})$.

$\Rightarrow$ Power corrections associated to $\Delta T_1^\Lambda(q^2)$ and $\Delta A_0^\Lambda(q^2)$ are absorbed in $\xi_{\perp,\parallel}$.

Problems of T_1 choice: (see back-up slides for more problems)

- Taking T_1 from LCSR and use it to define $\xi_\perp$ is **non-optimal** (as done in JC'14).

$$A_\perp^{L,R} = \mathcal{N}_\perp \left[\mathcal{C}_{9\pm 10}[\mathbf{V}^{\mathbf{sff}+\alpha_s}(\mathbf{q^2}) + \Delta V^\Lambda] + \mathcal{C}_7[\mathbf{T_1^{sff}}^{+\alpha_s}(\mathbf{q^2}) + \Delta T_1^\Lambda]\right] + \mathcal{O}(\alpha_s, \Lambda/m_b, ...)$$

where $\Delta V^\lambda = a_V + ...$ and $\Delta T_1^\Lambda = a_{T1} + ...$

- in scheme-1, $a_V = 0$ (ours) in transversity basis: $\Rightarrow A_\perp^{L,R} \propto \mathcal{C}_7\, a_{T_1}$ and $C_7 \sim -0.3$
- in scheme-2, $a_{T1} = 0$ (JC'14) in helicity basis two problems:

$\Rightarrow A_\perp^{L,R} \propto \mathcal{C}_{9\pm 10}\, a_V$ where $\mathcal{C}_{9-10} \sim 8$

$\Rightarrow a_V = (a_{V-} - a_{V+})\frac{m_B}{m_B - m_K^*}$ uncorrelated in helicity 10% implies 20%!!

Problem of A_0 choice:

P_i observables do not depend on $A_0(q^2)$ FF. $\Rightarrow A_0$ choice would be only a good choice for lepton-mass suppressed observables.

Two last important problems in JC'14:

I) P_5' is claimed to be scheme independent **in their approach** in JC'14.

This is wrong consequence of using helicity basis + restricted set of schemes.

Proven numerically in DLMV'14 and analytically in (CDLMV'16) $\Rightarrow$ missing term.

II) Undervalutation of the error of $\xi_\perp$ in JC'14 (affects F_L and S_i):

- $\xi_\perp = 0.31 \pm 0.04$ in JC'14: from spread of **only** central values of BZ,KMPW,DSE.
- $\xi_\perp = 0.31^{+0.20}_{-0.10}$ is our input using KMPW but including errors!

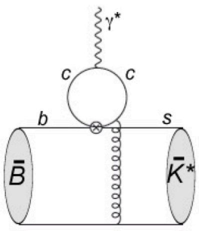
- **Positive outcome**: New ingredient added in JC'12: **factorizable power corrections.**
- **Error of JC'12 and JC'14**: **missing the keypoint of scheme dependence that leads them to** artificially inflate errors.
- Our contribution DHMV'14:
  - **Systematic computation of p.c.**
  - **Identification of the relevance of the scheme choice with uncorrelated p.c.**
  - **Correct evaluation of impact in observables**

In summary, we have shown that to take power corrections uncorrelated and $\mathcal{O}(\Lambda/m_b)$ is perfectly fine (even recommended to be on a conservative side) **but always** *using an appropriate scheme choice.*

Hadronic Uncertainties II:

Non-factorizable power corrections and long distance charm contributions

- **Non-factorizable power corrections (amplitudes)**: subleading new unknown non-perturbative. BEYOND SCET/QCDF at leading power in $1/m_b$: Factorization of matrix elements into form factors, light-cone distribution amplitudes and hard-scattering kernels.
- $c\bar{c}$ **loops**



$\Rightarrow$ Single out in the amplitude $\mathcal{T}_i$ in $\langle K^*\gamma^*|H_{eff}|B\rangle$ the piece not associated to FF: $\mathcal{T}_i^{\rm had} = \mathcal{T}_i|_{C_7^{(\prime)}\to 0}$

Multiply each amplitude $i = 0, \perp, \|$ with a complex q^2-dependent factor.

$$\mathcal{T}_i^{\rm had} \to \left(1 + r_i(q^2)\right) \mathcal{T}_i^{\rm had}$$

where $r_i(s) = r_i^a e^{i\phi_i^a} + r_i^b e^{i\phi_i^b}(s/m_B^2) + r_i^c e^{i\phi_i^c}(s/m_B^2)^2$ and $r_i^{a,b,c} \in [0, 0.1]$ and $\phi_i^{a,b,c} \in [-\pi, \pi]$

Charm-loop contributions

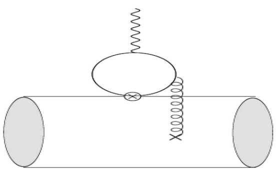
General considerations on resonances:

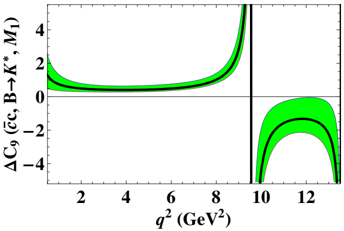
- Focus on low-q^2: $q^2 \leq 7-8$ GeV^2 to limit impact of J/ψ tail.

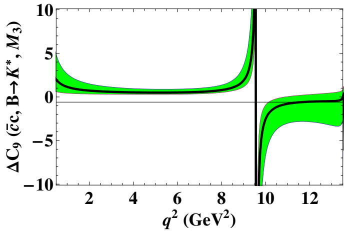
  $\Rightarrow$ LHCb interesting test split $[4.3, 8.68] \to [4,6], [6,8]$

At large-recoil two type of contributions: $\Delta C_9^{BK^*} = \delta C_{9,\text{pert}}^{BK^{(*)}} + s_i \delta C_{9,\text{non pert}}^{BK^{(*)},i}$

- Short distance (hard-gluons)
  - LO included in $C_9 \to C_9 + Y(q^2)$
  - higher-order corrections via QCDF/HQET.
- Long distance (soft-gluons)
  - Only existing computation KMPW'10 using LCSR.
  - Partial computation yields $\Delta C_9^{BK^*} > 0$ ($s_i = 1$) $\Rightarrow$ enlarges the anomaly. **Our central value is $s_i = 0$ to be conservative**







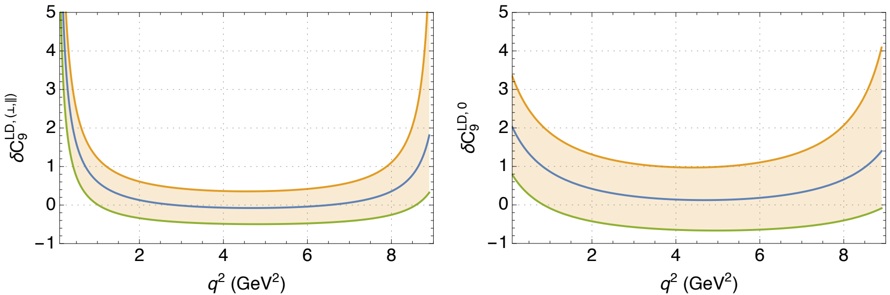
$B \to K^* \ell^+ \ell^-$: Impact of long-distance $c\bar{c}$ loops – DHMV

Inspired by Khodjamirian et al (KMPW): $C_9 \to C_9 + s_i \, \delta C_9^{\mathrm{LD}(i)}(q^2)$

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

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

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



Obtaining from fitting the long-distance part to KMPW.

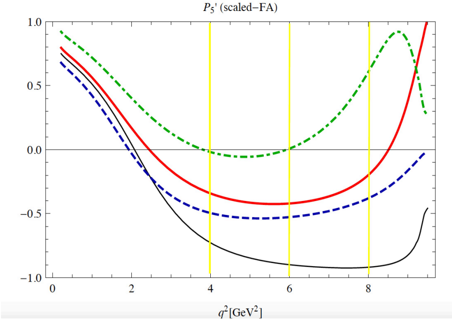
Criticism 2: A huge non-factorizable (charm contribution) can explain P_5'?

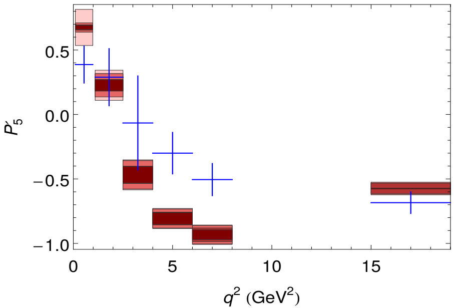
Attempt 1 (Lyon, Zwicky'14 unpublished):

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

  Left: Different predictions from LZ'14 for P_5' corresponding to different hypothesis of extrapolation from high-q^2 to low-q^2: in all cases LZ'14 predicts bin [6,8] above [4,6].

  • **Positive outcome:** Phase of helicity amplitudes $e^{i\delta_{J/\Psi K^*}}$ from $\delta_{J/\Psi K^*} \simeq 0$ (KMPW) to π.





Data tell us: Smooth behaviour of 3 fb^{-1} data where bin [6,8] is not above [4,6] does not favour claims on large-long distance charm q^2 effects in [6,8] bin.

• Our contribution DHMV'14&15: **We include a free parameter s_i for each amplitude from -1 to 1**

Indeed, **our charm error estimate @anomaly is more conservative than BSZwicky estimate.**

Criticism 2: Is reasonable to expect a huge non-factorizable contribution?

Attempt 2 (Valli, Silvestrini et al.):

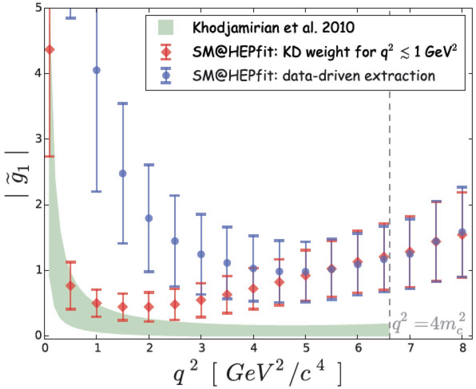
- Introduce an arbitrary parametrization for non-factorizable

$$H_\lambda \to H_\lambda + h_\lambda \text{ where } h_\lambda = h_\lambda^{(0)} + h_\lambda^{(1)} q^2 + h_\lambda^{(2)} q^4$$

with $(\lambda = 0, \pm)$ (copied from JC'14)

List of problems:

1. Complete Lack of theory input/output $\Rightarrow$ **no predictivity** with 18 free parameters (any shape).



- $\tilde{g} = \Delta C_9^{non\,pert.}/(2C_1)$
- 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 $h_\lambda^{(1)}$?

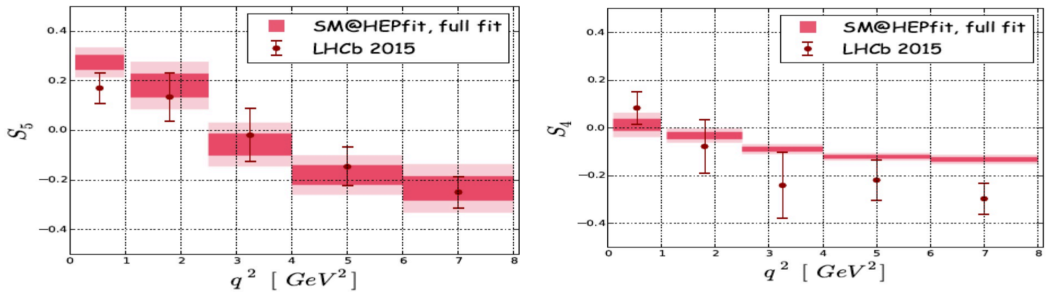
2. If the answer is $h_\lambda^{(1)}$ you are unable to explain many data, if it is $C_9^{NP} = -1.1$ "yes you can":

- nor R_K (solved with $C_9^{NP} = -1.1$) neither any LFVU observable like R_{K^*} due to charm universality.
- any tiny tension in the low-recoil region of $B^0 \to K^{*0}\mu\mu$ (1.7 $\to$ **0.3**σ), $B^+ \to K^{*+}\mu\mu$ (2.5 $\to$ **1.2**σ), $B_s \to \phi\mu\mu$ (2.3 $\to$ **0.5**σ). Also the old bin [2,4.3] of P_2 of 2013 cannot be explained.
- ... (stay tunned)

Contradictory statements:

- "*No deviation is present once all the theoretical uncertainties are taken into account*".

$\Rightarrow$ By forcing the fit they induce a problem (**2.7**σ) in S_4 a fully SM-like observable (us and BSZ we both find good agreement with SM in all bins!)



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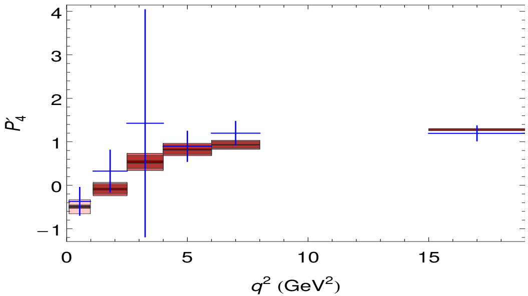
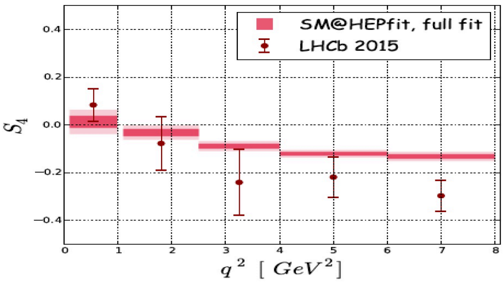
- any tiny tension in the low-recoil region of $B^0 \to K^{*0}\mu\mu$ ($1.7 \to \mathbf{0.3}\sigma$), $B^+ \to K^{*+}\mu\mu$ ($2.5 \to \mathbf{1.2}\sigma$), $B_s \to \phi\mu\mu$ ($2.3 \to \mathbf{0.5}\sigma$).
- ... (stay tunned)

Contradictory statements:

- "*No deviation is present once all the theoretical uncertainties are taken into account*".

$\Rightarrow$ By forcing the fit **they induce a problem (2.7σ)** in S_4 in an otherwise fully SM-like observable (us and BSZ we find at most 0.8σ in all S_4 bins!)





3. Symmetries are powerful friends... if no new scalars and no new weak phases are introduced **any consistent computation should fulfill UNAVOIDABLY**: [Serra-Matias'14]

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

where δ_a and δ_b are function of product of tiny P_6', P_8', P_3.

This is true independently of any crazy non-factorizable, factorizable, or New Physics (with no weak phases) 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.

$\Rightarrow$ Using CSV theory "predictions":

$$\langle S_3 \rangle = -0.03 \pm 0.02 \quad \langle S_4 \rangle = -0.12 \pm 0.01 \quad \langle S_5 \rangle = -0.20 \pm 0.05 \quad \langle P_2 \rangle = -\mathbf{0.11} \pm \mathbf{0.07}$$

consistency relation $\Rightarrow \langle P_2 \rangle^{rel} = +\mathbf{0.26} \pm \mathbf{0.07}$ ($\Delta = \mathbf{0.37}$!!) $\Rightarrow$ **3.7σ violation of consistency**
$\Rightarrow$ **4.6σ** if full fit numbers used.

Summary: *This* **hard violation of consistency relation** *in the bin [4,6] (also [6,8]) points to an important problem of CSV. Moreover, are these really predictions (same set of theory inputs)?*

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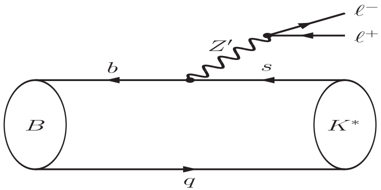
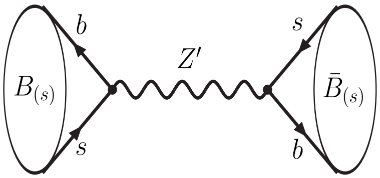
Z' particle a possible explanation?

In [**DMV'13**] we proposed to explain the anomaly in $B \to K^* \mu\mu$ with a Z' **gauge boson** contributing to

$$\mathcal{O}_9 = e^2/(16\pi^2)\,(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,,$$

with specific couplings as a possible explanation of the anomaly in P_5'.





Using the notation of Buras'12,'13

$$\mathcal{L}^q = \left(\bar{s}\gamma_\nu P_L b \Delta_L^{sb} + \bar{s}\gamma_\nu P_R b \Delta_R^{sb} + h.c.\right) Z'^\nu \quad \mathcal{L}^{lep} = (\bar{\mu}\gamma_\nu P_L \mu \Delta_{\mathbf{L}}{}^{\mu\bar{\mu}} + \bar{\mu}\gamma_\nu P_R \mu \Delta_{\mathbf{R}}{}^{\mu\bar{\mu}} + \ldots)\, Z'^\nu$$

The Wilson coefficients of the semileptonic operators are:

$$\mathcal{C}^{\rm NP}_{\{9,10\}} = -\frac{1}{s_W^2 g_{SM}^2}\frac{1}{M_{Z'}^2}\frac{\Delta_L^{sb}\Delta^{\mu\mu}_{\{\mathbf{V},\mathbf{A}\}}}{\lambda_{ts}}\,, \quad \mathcal{C}^{\rm NP}_{\{9',10'\}} = -\frac{1}{s_W^2 g_{SM}^2}\frac{1}{M_{Z'}^2}\frac{\Delta_R^{sb}\Delta^{\mu\mu}_{\{\mathbf{V},\mathbf{A}\}}}{\lambda_{ts}}\,,$$

with the vector and axial couplings to muons: $\Delta^{\mu\mu}_{\mathbf{V},\mathbf{A}} = \Delta^{\mu\mu}_{\mathbf{R}} \pm \Delta^{\mu\mu}_{\mathbf{L}}$.

Δ_L^{sb} with same phase as $\lambda_{ts} = V_{tb}V_{ts}^*$ (to avoid ϕ_s) like in MFV. Main constraint from ΔM_{B_s} ($\Delta^{sb}_{L,R}$).

A Z' model can belong to the following categories:

	no-coupling	non-zero couplings	$\mathrm{Pull}_{\mathrm{SM}}$
C_9	**no**-right-handed quark & no-muon-axial coupling	$\Delta_L^{sb} \neq 0$, $\Delta_V^{\mu\mu} \neq 0$	5.0σ
(C_9, C_{10})	**no**-right-handed quark coupling	$\Delta_L^{sb} \neq 0$, $\Delta_V^{\mu\mu} \neq 0$, $\Delta_A^{\mu\mu} \neq 0$	4.8σ
(C_9, C_9')	**no**-muon-axial coupling	$\Delta_L^{sb} \neq 0$, $\Delta_R^{sb} \neq 0$,, $\Delta_V^{\mu\mu} \neq 0$	4.9σ
(C_{10}, C_{10}')	**no**-muon-vector coupling	$\Delta_L^{sb} \neq 0$, $\Delta_R^{sb} \neq 0$, $\Delta_A^{\mu\mu} \neq 0$	...
(C_9', C_{10}')	**no**-left-handed quark coupling	$\Delta_R^{sb} \neq 0$, $\Delta_V^{\mu\mu} \neq 0$, $\Delta_A^{\mu\mu} \neq 0$	...

Example: $C_9^{\rm NP} = -1.1$, $\Delta_V^{\mu\mu}/M_Z' = -0.6\ \mathrm{TeV}^{-1}$ and $\Delta_L^{bs}/M_Z' = 0.003\ \mathrm{TeV}^{-1}$

- If NP enters **all** four semileptonic coefficients, the following relationships hold:

$$\frac{\mathcal{C}_9^{\rm NP}}{\mathcal{C}_{10}^{\rm NP}} = \frac{\mathcal{C}_{9'}^{\rm NP}}{\mathcal{C}_{10'}^{\rm NP}} = \frac{\Delta_V^{\mu\mu}}{\Delta_A^{\mu\mu}}, \qquad \frac{\mathcal{C}_9^{\rm NP}}{\mathcal{C}_{9'}^{\rm NP}} = \frac{\mathcal{C}_{10}^{\rm NP}}{\mathcal{C}_{10'}^{\rm NP}} = \frac{\Delta_L^{sb}}{\Delta_R^{sb}}.$$

Many ongoing attempts to embed this kind of Z' inside a model [U.Haisch, W.Altmannshofer, A.Buras, D. Straub,..]

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 $\mathbf{C_9^{NP} \simeq -1}$ **is confirmed** and reinforced. We include all type of corrections: (non)-factorizable of α_s and power correction type including long-distance charm.
  $\to$ We use full dataset, optimized basis of observables and latest theory updates.

- 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 (redressing the reassessing...) :
  - **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. They cannot explain LFVU. Also fundamental consistency problems detected.

- Near future? Maybe C_{10}^{NP} or the prime coefficients can become significant soon.
  A heavy Z′ (1-2 TeV) with bs-coupling is a **viable explanation** for many (not all) scenarios.

Thank you!

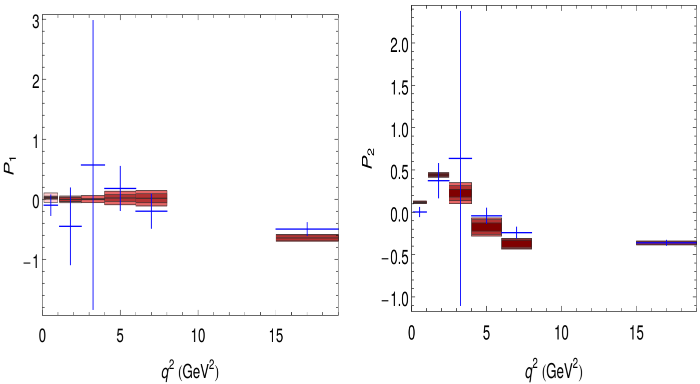
Back-up slides

A few properties of the relevant observables $P_{1,2}$

The idea of **exact cancellation of the poorly known soft form factors at LO** at the zero of A_{FB} was incorporated in the construction of the P_i (this is why they are "**clean**" compared to the S_i)

P_1 and P_2 observables function of $A_\perp$ and $A_{||}$ amplitudes

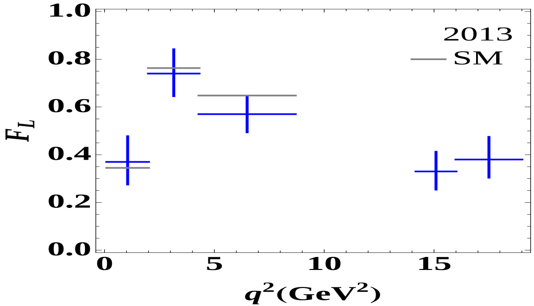
- **P_1**: Proportional to $|A_\perp|^2 - |A_{||}|^2$
  - Test the LH structure of SM.
    The existence of RH currents breaks the SM relation $A_\perp \sim -A_{||}$
- **P_2**: Proportional to $\mathrm{Re}(A_i A_j)$
  - Zero of P_2 at the same position as the zero of A_{FB}
  - P_2 is the clean version of A_{FB}. Their different normalizations offer different sensitivities.

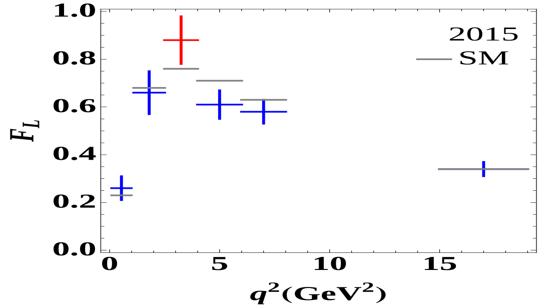


- P_3 and $P'_{6,8}$ are proportional to $\mathrm{Im} A_i A_j$ and small if there are no large phases. All are < 0.1.
- P_i^{CP} are all negligibly small if there is no New Physics in weak phases.

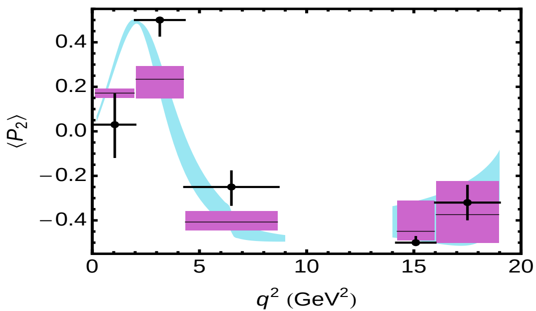
What happened to P_2 in 2015?

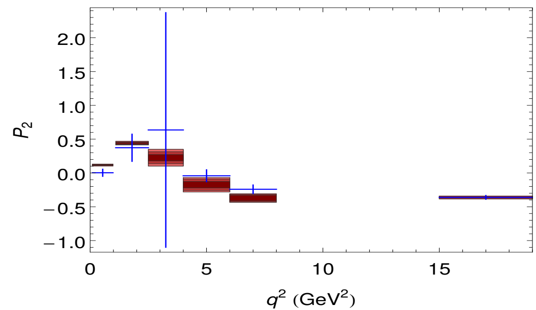
The new binning of F_L in 2015 had a temporary effect on the very interesting bin [2.5,4]





Tiny unfortunate fluctuation up.





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

More data (in this bin) is crucial.

Updated plot of 2015

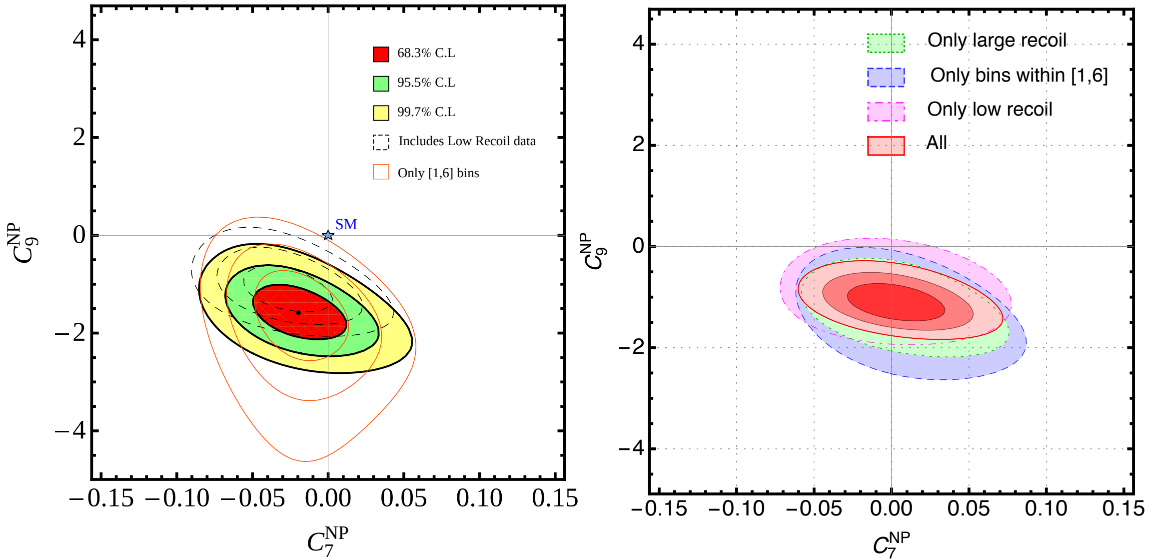


Figure: *For the scenario where NP occurs in the two Wilson coefficients $\mathcal{C}_7$ and $\mathcal{C}_9$, we compare the situation from the analysis in Fig. 1 of Ref. DMV'13(on the left) and the current situation (on the right). On the right, we show the 3 σ regions allowed by large-recoil only (dashed green), by bins in the [1-6] range (long-dashed blue), by low recoil (dot-dashed purple) and by considering all data (red, with 1,2,3 σ contours).*

Bin (0.1,0.98) lepton-mass effect

LHCb naturally given the limited statistics takes the massless lepton limit. They measure:

$$\frac{1}{d(\Gamma+\bar\Gamma)/dq^2}\frac{d^3(\Gamma+\bar\Gamma)}{d\Omega} = \frac{9}{32\pi}\Big[\ \frac{3}{4}(1-F_L^{LHCb})\sin^2\theta_K + F_L^{LHCb}\cos^2\theta_K + \frac{1}{4}(1-F_L^{LHCb})\sin^2\theta_K\cos 2\theta_l - F_L^{LHCb}\cos^2\theta_K\cos 2\theta_l + ...\Big]$$

which is modified once lepton masses are considered

$$\frac{1}{d(\Gamma+\bar\Gamma)/dq^2}\frac{d^3(\Gamma+\bar\Gamma)}{d\Omega} = \frac{9}{32\pi}\Big[\ \frac{3}{4}\hat F_T\sin^2\theta_K + \hat F_L\cos^2\theta_K + \frac{1}{4}F_T\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l + ...\Big]$$

where $\hat F_{T,L}$ and $F_{L,T}$ are [**JM'12**]. All our observables are thus written and computed in terms of the longitudinal and transverse polarisation fractions $F_{L,T}$

$$F_L = -\frac{J_{2c}}{d(\Gamma+\bar\Gamma)/dq^2} \qquad F_T = 4\frac{J_{2s}}{d(\Gamma+\bar\Gamma)/dq^2} \qquad \Rightarrow \qquad \hat F_L = \frac{J_{1c}}{d(\Gamma+\bar\Gamma)/dq^2}$$

WHEN measured value $\hat F_L$ is used instead of F_L SM prediction is shifted towards the data in 1st bin

$$\langle F_L\rangle_{[0.1,0.98]} = 0.21 \to 0.26\,, \qquad \langle P_2\rangle_{[0.1,0.98]} = 0.12 \to 0.09\,,$$
$$\langle P_4'\rangle_{[0.1,0.98]} = -0.49 \to -0.38\,, \qquad \langle P_5'\rangle_{[0.1,0.98]} = 0.68 \to 0.53\,.$$

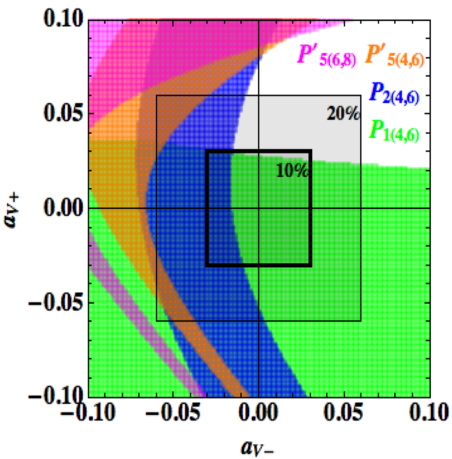
		$\lvert\delta\mathcal{C}_7\rvert = 0.1$	$\lvert\delta\mathcal{C}_9\rvert = 1$	$\lvert\delta\mathcal{C}_{10}\rvert = 1$	$\lvert\delta\mathcal{C}_{7'}\rvert = 0.1$	$\lvert\delta\mathcal{C}_{9'}\rvert = 1$	$\lvert\delta\mathcal{C}_{10'}\rvert = 1$
$\langle P_1\rangle_{[0.1,.98]}$	$+\lvert\delta C_i\rvert$	$--$	$--$	$--$	-0.53	-0.05	$--$
	$-\lvert\delta C_i\rvert$	$--$	$--$	$--$	$+0.52$	$+0.05$	$--$
$\langle P_1\rangle_{[6,8]}$	$+\lvert\delta C_i\rvert$	$--$	$--$	$--$	$+0.11$	$+0.16$	$-\mathbf{0.37}$
	$-\lvert\delta C_i\rvert$	$--$	$--$	$--$	$-\mathbf{0.12}$	$-\mathbf{0.17}$	$+0.37$
$\langle P_1\rangle_{[15,19]}$	$+\lvert\delta C_i\rvert$	$--$	$--$	$--$	$+\mathbf{0.03}$	$+\mathbf{0.15}$	-0.14
	$-\lvert\delta C_i\rvert$	$--$	$--$	$--$	-0.03	-0.11	$+\mathbf{0.19}$
$\langle P_2\rangle_{[2.5,4]}$	$+\lvert\delta C_i\rvert$	-0.31	-0.21	$+\mathbf{0.05}$	$--$	$--$	$--$
	$-\lvert\delta C_i\rvert$	$+\mathbf{0.19}$	$+\mathbf{0.15}$	-0.04	-0.03	$--$	$--$
$\langle P_2\rangle_{[6,8]}$	$+\lvert\delta C_i\rvert$	-0.07	-0.09	-0.06	$--$	$--$	$--$
	$-\lvert\delta C_i\rvert$	$+\mathbf{0.11}$	$+\mathbf{0.17}$	$+\mathbf{0.05}$	$--$	$--$	$--$
$\langle P_2\rangle_{[15,19]}$	$+\lvert\delta C_i\rvert$	$--$	$--$	$--$	$--$	-0.05	$+0.06$
	$-\lvert\delta C_i\rvert$	$--$	$+0.04$	$--$	$--$	$+0.05$	-0.06
$\langle P_4'\rangle_{[6,8]}$	$+\lvert\delta C_i\rvert$	$+\mathbf{0.04}$	$--$	$--$	-0.11	-0.10	$+\mathbf{0.17}$
	$-\lvert\delta C_i\rvert$	-0.05	$--$	$--$	$+\mathbf{0.09}$	$+\mathbf{0.10}$	-0.20
$\langle P_4'\rangle_{[15,19]}$	$+\lvert\delta C_i\rvert$	$--$	$--$	$--$	$--$	$-\mathbf{0.06}$	$+0.05$
	$-\lvert\delta C_i\rvert$	$--$	$--$	$--$	$--$	$+0.04$	$-\mathbf{0.08}$
$\langle P_5'\rangle_{[4,6]}$	$+\lvert\delta C_i\rvert$	-0.11	-0.15	-0.10	-0.11	-0.06	$+\mathbf{0.21}$
	$-\lvert\delta C_i\rvert$	$+\mathbf{0.16}$	$+\mathbf{0.28}$	$+\mathbf{0.09}$	$+\mathbf{0.15}$	$+\mathbf{0.10}$	-0.21
$\langle P_5'\rangle_{[6,8]}$	$+\lvert\delta C_i\rvert$	-0.04	-0.07	-0.07	-0.08	-0.08	$+\mathbf{0.19}$
	$-\lvert\delta C_i\rvert$	$+\mathbf{0.07}$	$+\mathbf{0.19}$	$+\mathbf{0.09}$	$+\mathbf{0.10}$	$+\mathbf{0.11}$	-0.18

Correlations play a central role

If one wants to solve the anomalies exhibited in $b \to s\mu\mu$ processes through power corrections, it is important not to focus on one single observable, like P_5', alone but on the full set.

Illustrative example. Let's do the following exercise: Assume you take the non-optimal scheme-2 as in (JC'14) and helicity basis

$$a_{V_\pm} = \frac{1}{2}\left[\left(1+\frac{m_{K^*}}{m_B}\right)a_1 \mp \left(1-\frac{m_{K^*}}{m_B}\right)a_V\right].$$



- Notice that taking a_{V-} in a range ± 0.1 correspond to an absurd 33% power correction in KMPW.
  - $\to$ because a 10% in KMPW corresponds to 0.03 in a_{V-}.
  - $\to$ accepting values like ($a_{V-} = -0.1$, $a_{V+} = 0$) would imply that **BSZ computation of $A_1(q^2)$ is wrong by several sigmas.**
- An explanation of $\langle P_5' \rangle_{[4,6]}$, $\langle P_2 \rangle_{[4,6]}$ and $\langle P_1 \rangle_{[4,6]}$ within SM requires a 20% correction. Adding $\langle P_5' \rangle_{[6,8]}$ no common solution found even beyond 20%.

$$J_{1s} = \frac{(2+\beta_\ell^2)}{4}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L\to R)\right] + \frac{4m_\ell^2}{q^2}\mathrm{Re}\left(A_\perp^L A_\perp^{R^*} + A_\parallel^L A_\parallel^{R^*}\right),$$

$$J_{1c} = |A_0^L|^2 + |A_0^R|^2 + \frac{4m_\ell^2}{q^2}\left[|A_t|^2 + 2\mathrm{Re}(A_0^L A_0^{R^*})\right] + \beta_\ell^2|A_S|^2,$$

$$J_{2s} = \frac{\beta_\ell^2}{4}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L\to R)\right], \quad J_{2c} = -\beta_\ell^2\left[|A_0^L|^2 + (L\to R)\right],$$

$$J_3 = \frac{1}{2}\beta_\ell^2\left[|A_\perp^L|^2 - |A_\parallel^L|^2 + (L\to R)\right], \quad J_4 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Re}(A_0^L A_\parallel^{L^*}) + (L\to R)\right],$$

$$J_5 = \sqrt{2}\beta_\ell\left[\mathrm{Re}(A_0^L A_\perp^{L^*}) - (L\to R) - \frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}(A_\parallel^L A_S^* + A_\parallel^R A_S^*)\right],$$

$$J_{6s} = 2\beta_\ell\left[\mathrm{Re}(A_\parallel^L A_\perp^{L^*}) - (L\to R)\right], \quad J_{6c} = 4\beta_\ell\frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}\left[A_0^L A_S^* + (L\to R)\right],$$

$$J_7 = \sqrt{2}\beta_\ell\left[\mathrm{Im}(A_0^L A_\parallel^{L^*}) - (L\to R) + \frac{m_\ell}{\sqrt{q^2}}\mathrm{Im}(A_\perp^L A_S^* + A_\perp^R A_S^*)\right],$$

$$J_8 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Im}(A_0^L A_\perp^{L^*}) + (L\to R)\right], \quad J_9 = \beta_\ell^2\left[\mathrm{Im}(A_\parallel^{L^*} A_\perp^L) + (L\to R)\right]$$

In red lepton mass terms and $\beta_\ell = \sqrt{1 - 4m_\ell^2/q^2}$

The corresponding spin amplitudes $A_\perp, A_\|, A_0$ are function:

- Wilson Coefficients: $\mathcal{C}_7^{\rm eff}, \mathcal{C}_7^{\rm eff\prime}, \mathcal{C}_9^{\rm eff}, \mathcal{C}_{10}$
- Form factors $A_{1,2}(s)$, $V(s)$, $T_{1,2,3}(s)$

$$\mathbf{A}_{\perp \mathbf{L},\mathbf{R}} = N\sqrt{2}\lambda^{1/2}\left[(\mathcal{C}_9^{\rm eff} \mp \mathcal{C}_{10})\frac{V(q^2)}{m_B + m_K^*} + \frac{2m_b}{q^2}(\mathcal{C}_7^{\rm eff} + \mathcal{C}_7^{\rm eff\prime})T_1(q^2)\right]$$

$$\mathbf{A}_{\| \mathbf{L},\mathbf{R}} = -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left[(\mathcal{C}_9^{\rm eff} \mp \mathcal{C}_{10})\frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2}(\mathcal{C}_7^{\rm eff} - \mathcal{C}_7^{\rm eff\prime})T_2(q^2)\right],$$

$$\begin{aligned}\mathbf{A}_{0\mathbf{L},\mathbf{R}} \quad = \quad & -\frac{N}{2m_{K^*}\sqrt{q^2}} \times \left[(\mathcal{C}_9^{\rm eff} \mp \mathcal{C}_{10})\left\{(m_B^2 - m_{K^*}^2 - q^2)(m_B + m_{K^*})A_1(q^2) - \right.\right.\\ & \left. -\lambda\frac{A_2(q^2)}{m_B + m_{K^*}}\right\} + 2m_b(\mathcal{C}_7^{\rm eff} - \mathcal{C}_7^{\rm eff\prime})\left\{(m_B^2 + 3m_{K^*}^2 - q^2)T_2(q^2) - \right.\\ & \left.\left. -\frac{\lambda}{m_B^2 - m_{K^*}^2}T_3(q^2)\right\}\right],\end{aligned}$$

The **hadronic matrix elements** are in naive factorization:

$$\langle K^*(p_{K^*})|\bar{s}\gamma_\mu P_{L,R} b|B(p)\rangle = i\epsilon_{\mu\nu\alpha\beta}\epsilon^{\nu *}p^\alpha q^\beta \frac{V(q^2)}{m_B+m_{K^*}} \mp$$
$$\mp\frac{1}{2}\Big\{\epsilon^*_\mu(m_B+m_{K^*})A_1(q^2) - (\epsilon^*\cdot q)(2p-q)_\mu \frac{A_2(q^2)}{m_B+m_{K^*}} -$$
$$-\frac{2m_{K^*}}{q^2}(\epsilon^*\cdot q)[A_3(q^2)-A_0(q^2)]q_\mu\Big\},$$

$$\langle K^*(p_{K^*})|\bar{s}i\sigma_{\mu\nu}q^\nu P_{R,L} b|B(p)\rangle = -i\epsilon_{\mu\nu\alpha\beta}\epsilon^{\nu *}p^\alpha q^\beta T_1(q^2) \pm$$
$$\pm\frac{1}{2}\Big\{[\epsilon^*_\mu(m_B^2-m_{K^*}^2) - (\epsilon^*\cdot q)(2p-q)_\mu] T_2(q^2) +$$
$$+(\epsilon^*\cdot q)\left[q_\mu - \frac{q^2}{m_B^2-m_{K^*}^2}(2p-q)_\mu\right]T_3(q^2)\Big\}.$$

where $A_3(q^2) = \frac{m_B+m_{K^*}}{2m_{K^*}}A_1(q^2) - \frac{m_B-m_{K^*}}{2m_{K^*}}A_2(q^2)$

K^* Spin Amplitudes ($A_{0,\perp,\|}$) related Helicity Amplitudes ($H_{0,\pm}$):

$$A_0 = H_0 \quad A_{\perp,\|} = \frac{H_+ \mp H_-}{\sqrt{2}}$$

They follow in naive factorisation a Λ/m_b hierarchy:

$$H_0 : H_- : H_+ = 1 : \frac{\Lambda}{m_b} : \left(\frac{\Lambda}{m_b}\right)^2$$

due to *spectator quark flip*, broken by electromagnetic effects.
At quark level in SM in the limit $m_B \to \infty$ and $E_K^* \to \infty$:

$$H_+ = 0 \quad \Rightarrow \quad A_\perp = -A_\|$$

At hadron level $A_\perp \approx -A_\|$.

Criticism 1: Factorizable Power Corrections gives a huge contribution

General idea: : Parametrize power corrections to form factors:

$$F(q^2) = F^{\rm soft}(\xi_{\perp,\|}(q^2)) + \Delta F^{\alpha_s}(q^2) + a_F + b_F \frac{q^2}{m_B^2} + c_F \frac{q^4}{m_B^4} \dots \ (\mathbf{JC'12})$$

$\Rightarrow a_F, b_F, c_F \dots$ represent the deviation to the SFF+ known α_s in the full form factor **F** (taken e.g. from LCSR)

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

$$\mathbf{A_1(q^2)} = \frac{2E}{m_B + m_{K^*}} \xi_\perp(q^2) + \Delta A_1^{\alpha_s}(q^2) + \Delta A_1^\Lambda(q^2),$$

$$\mathbf{A_2(q^2)} = \frac{m_B}{m_B - m_{K^*}} \left[\xi_\perp(q^2) - \xi_\|(q^2)\right] + \Delta A_2^{\alpha_s}(q^2) + \Delta A_2^\Lambda(q^2),$$

$$\mathbf{A_0(q^2)} = \frac{E}{m_{K^*}} \xi_\|(q^2) + \Delta A_0^{\alpha_s}(q^2) + \Delta A_0^\Lambda(q^2),$$

$$\mathbf{T_1(q^2)} = \xi_\perp(q^2) + \Delta T_1^{\alpha_s}(q^2) + \Delta T_1^\Lambda(q^2) \dots$$

STEP 1: Define the SFF $\xi_{\perp,\|}$ to all orders by means of a factorisation scheme CHOICE.

STEP 3: A **correct treatment** of power corrections require to respect **the correlations** among them:

a) *kinematic correlations* among QCD form factors at maximum recoil

b) from the *renormalization scheme definition* of the soft form factors $\xi_\perp$ and $\xi_\|$.

STEP 4: The error estimate in previous table

$$\begin{aligned} \hat{a}_F - \Delta\hat{a}_F \leq \quad a_F \quad &\leq \hat{a}_F + \Delta\hat{a}_F \ , \\ \hat{b}_F - \Delta\hat{b}_F \leq \quad b_F \quad &\leq \hat{b}_F + \Delta\hat{b}_F , \\ \hat{c}_F - \Delta\hat{c}_F \leq \quad c_F \quad &\leq \hat{c}_F + \Delta\hat{c}_F \ . \end{aligned}$$

comes from $\Delta F^\Lambda \sim F \times \mathcal{O}(\Lambda/m_b) \sim 0.1 F \Rightarrow$ error assignment larger than size of p.c. itself for $\Delta\hat{a}$.

IN SUMMARY:

- *Each set of observables has an optimal scheme choice, a non-optimal choice may induce artificially large corrections.*
- *Interestingly an independent computation using full-FF (BSZ) that has embedded the correlations of a specific LCSR computation gives predictions in good agreement with us for the P_i.*

Factorizable power corrections:

- The fit to factorizable power corrections show they are of order 10% as expected from dimensional arguments.
- The freedom to define $\xi_{\perp,\|}$ allows you find an optimal scheme with minimal sensitivity to power corrections.
- Our results are in excellent agreement with a different approach/methodology/FF set.

In summary a careful computation of power corrections shows they are perfectly under control.

Charm-loop contributions:

- R_K, nor the future R_{K^*} or R_ϕ cannot be explained with a charm contribution.
- The behaviour of bin [6,8] versus [4,6] in observables like P_5' precludes it.
- A 6-D fit or a bin-by-bin analysis does not find indication for a q^2-dependence in C_9.

In summary three arguments **against a large-charm explanation** of all the anomalies.

Even if one can try to find alternative explanations for individual deviations (with not much success...), at the end of the day one has to rely on a different explanation for each deviation, contrary to a shift in the Wilson Coefficients which explains all at the same time.

A glimpse into the future: Wilson coefficients versus Anomalies

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

Table: *A checkmark (✓) indicates that a shift in the Wilson coefficient with this sign moves the prediction in the right direction to solve the corresponding anomaly. $\mathcal{B}_{B_s\to\mu\mu}$ is not an anomaly but a very mild tension.*

- $\mathcal{C}_9^{NP} < 0$ is consistent with all anomalies. This is the reason why it gives a strong pull.
- $\mathcal{C}_{10}^{NP}$, $C'_{9,10}$ fail in some anomaly. BUT
  - $\Rightarrow$ $\mathcal{C}_{10}^{NP}$ is the most promising coefficient after $\mathcal{C}_9$.
  - $\Rightarrow$ C'_9, C'_{10} seems quite inconsistent between the different anomalies and the global fit.

QUESTION 1: Branching Ratios versus Angular Observables P_i?

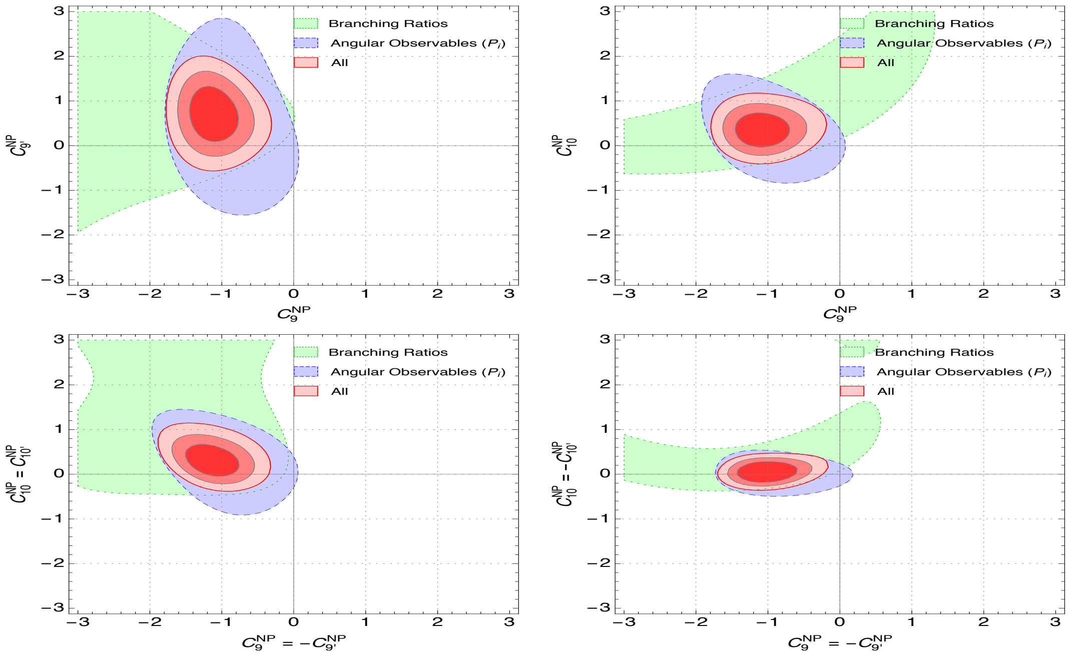


Figure: *Angular observables (FFI at LO P_i) dominates clearly over Branching ratios*

QUESTION 2: $B \to K^*\mu\mu$, $B \to K\mu\mu$ and $B_s \to \phi\mu\mu$?

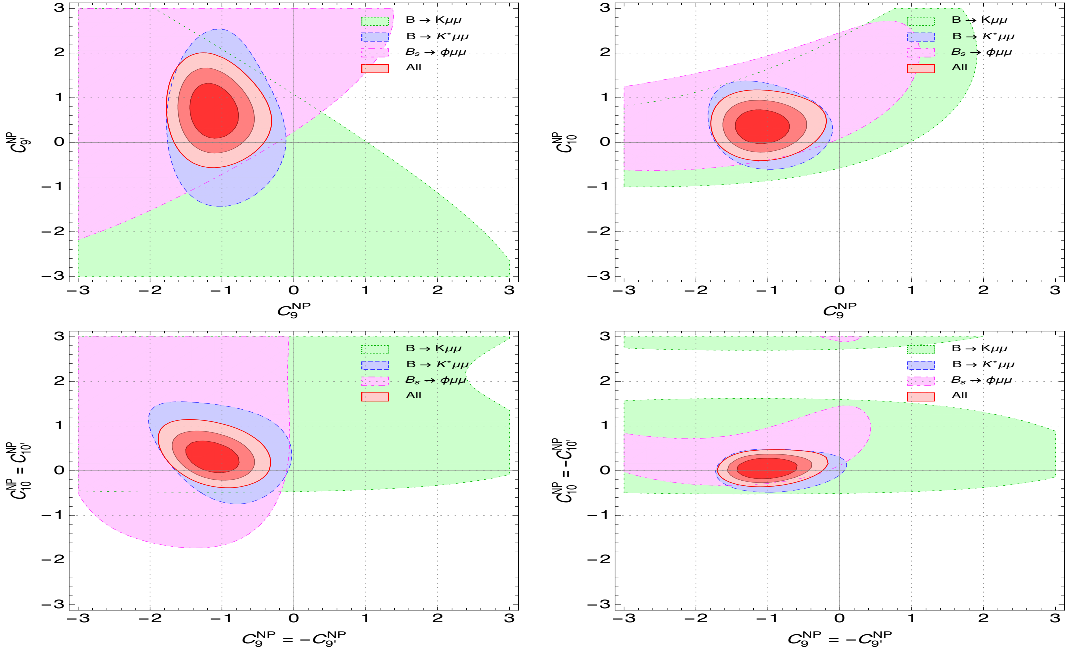


Figure: *The hierarchy of importance for the fit: $B \to K^*\mu\mu$, $B_s \to \phi\mu\mu$ and $B \to K\mu\mu$*

QUESTION 3: Which information and constraints provide each region?

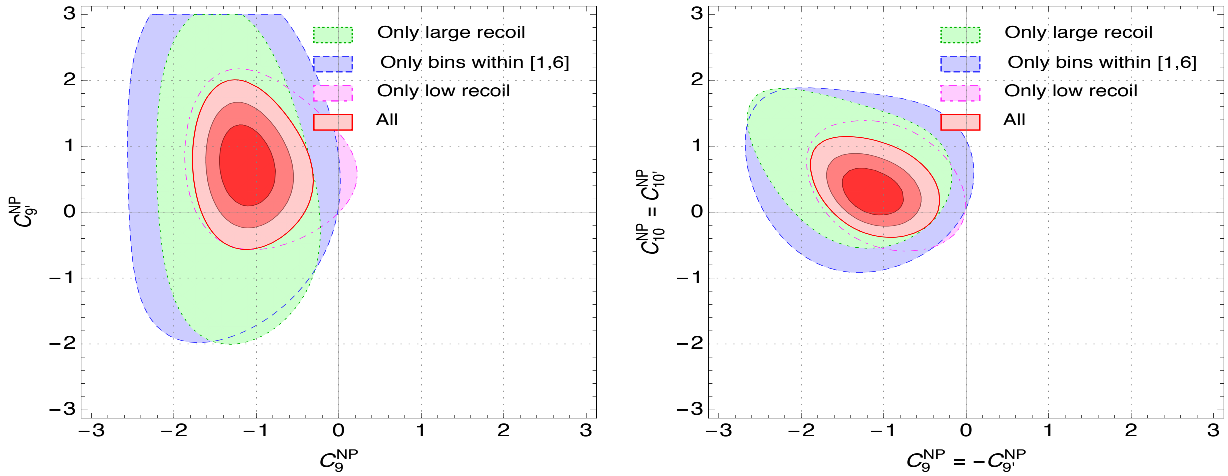


Figure: *We show the 3 σ regions allowed by large-recoil only (dashed green), by bins in the [1-6] range (long-dashed blue), by low recoil (dot-dashed purple) and by considering all data (red, with 1,2,3 σ contours).*

- Low-recoil is strongly constraining! Important implications for power corrections and charm.
- Bins [1,6] are perfectly coherent with the full large-recoil.

More technical arguments why scheme-2 **is not** an appropriate scheme

In the old scheme used by (also JC'14): $\xi_\perp^{(2)}(\mathbf{q^2}) \equiv \mathbf{T_1}(\mathbf{q^2})$, $\xi_\parallel^{(2)}(\mathbf{q^2}) \equiv \frac{\mathbf{m_{K^*}}}{\mathbf{E}}\mathbf{A_0}(\mathbf{q^2})$.

$\Rightarrow$ Power corrections associated to $\Delta T_1^\Lambda(q^2)$ and $\Delta A_0^\Lambda(q^2)$ are absorbed in $\xi_{\perp,\parallel}$.

Problems of T_1 choice:

- Extracting $T_1(0)$ from data on $B \to K^*\gamma$ is plagued of assumptions (as done in JC'12):
  1) assumption of no NP in $C_7^{(\prime)}$ + ignoring possible non-factorizable power corrections.
- Taking T_1 from LCSR and use it to define $\xi_\perp$ is also **non-optimal** (as done in JC'14).

$$A_\perp^{L,R} = \mathcal{N}_\perp \left[\mathcal{C}^+_{9\pm10}[\mathbf{V}^{\mathbf{sff}+\alpha_s}(\mathbf{q^2}) + \Delta V^\Lambda] + \mathcal{C}_7^+[\mathbf{T_1}^{\mathbf{sff}+\alpha_s}(\mathbf{q^2}) + \Delta T_1^\Lambda]\right] + \mathcal{O}(\alpha_s, \Lambda/m_b, ...)$$

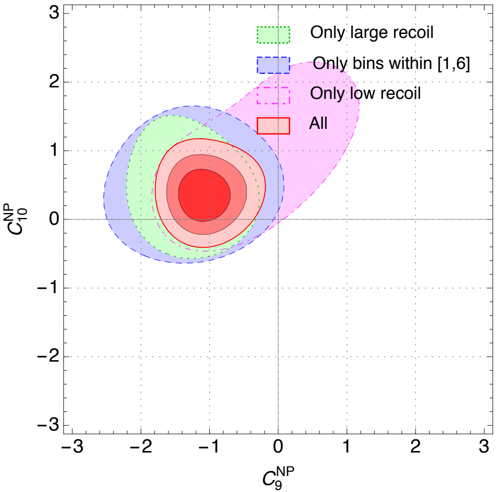
If one is interested in obtaining accurated predictions for observables dominated by C_9 (like P_5') better to have a good control of p.c on V than in T_1.

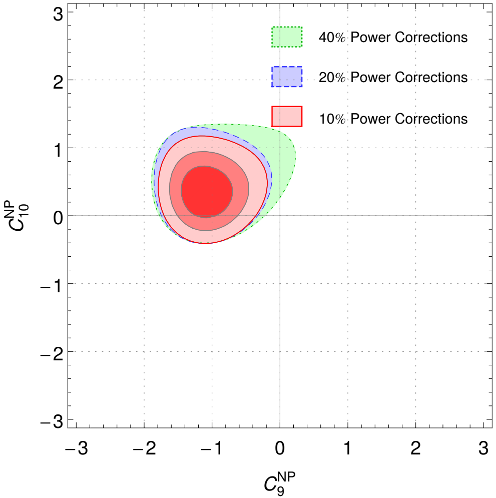
$\Rightarrow$ T_1 may be a good choice for observables dominated by C_7.

Problem of A_0 choice:

P_i observables do not depend on $A_0(q^2)$ FF. $\Rightarrow$ A_0 choice would be a good choice for lepton-mass suppressed observables.

What does the fit tells you about IMPACT of POWER CORRECTIONS:





- We show the impact **in the fit** of increasing power corrections up to 40%
- At a certain point p.c.-sensitive observable become subdominant and low-recoil dominates.
  $\rightarrow$ even if power corrections diverge we still get a pull from low-recoil.

4. Long list of wrong and misleading statements in CSV: (few examples)

- " Since observables cannot depend on arbitrary scheme definitions, their deviation from the infinite mass limit cannot be reduced in this way".

  Trivial and misleading: It is an obvious statement but it refers to a computation where power corrections are taken **uncorrelated** (JC or us) so as already demonstrated the scheme matters.

- $h_\lambda^{(0)}$ mimics a contribution to $C_7^{\rm eff}$ and it cannot be separated from a NP contribution:

  Wrong: Using radiative constraints $B \to X_s\gamma$, $A_I(B \to K^*\gamma)$, $S_{K^*\gamma}$ can be disentangled.

- $h_\lambda^{(2)} = (2.5\pm1.5)\times10^{-5}$ that gives the q^2-dependence (not using KMPW) deviates from zero by 1.6σ!!

Comparison of theory "predictions" from BSZ (using BSZ) and CSV "postdiction" (using BSZ)

q^2 bin	S_5 BSZ	S_5 CSV	dev.	S_4 BSZ	S_4 CSV	dev.
[0.1,0.98]	$+0.247 \pm 0.010$	$+0.302 \pm 0.026$	$+0.5\sigma$	$+0.097 \pm 0.004$	-0.012 ± 0.025	$+\mathbf{4.3}\sigma$!!
[1.1,2.5]	$+0.059 \pm 0.030$	$+0.217 \pm 0.061$	$+\mathbf{2.3}\sigma$	-0.009 ± 0.017	-0.041 ± 0.018	$+1.3\sigma$
[2.5,4]	-0.182 ± 0.040	-0.066 ± 0.049	$+\mathbf{1.8}\sigma$	-0.135 ± 0.026	-0.088 ± 0.011	$+1.7\sigma$
[4,6]	-0.329 ± 0.039	-0.200 ± 0.046	$+\mathbf{2.1}\sigma$	-0.213 ± 0.025	-0.119 ± 0.009	$+\mathbf{3.5}\sigma$!!

Positive outcome: what do we learnt from that paper??