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

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

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

November 25, 2015

Goal of this talk

This talk will try to answer the following questions:

- What does the global fit on $b \to s\ell\ell$ tell us about Wilson coefficients?
  - Which Wilson coefficients/scenarios receive a dominant NP contribution?
  - What does other approaches using different observables and methodology obtain?
- Are the alternative explanations (factorizable power corrections and charm) raised to explain (**some**) anomaly on the fit really robust?
  - Where those ””explanations”” fail in front of a possible New Physics explanation?
- What can we expect in the near future?

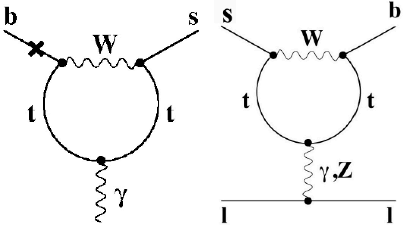
Since long time ago...

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

Analysis in a model-independent approach effective Hamiltonian:

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

- $\mathcal{O}_7 = \frac{e}{g^2} m_b \, \bar{s}\sigma^{\mu\nu}(1+\gamma_5)F_{\mu\nu} \, b$
- $\mathcal{O}_9 = \frac{e^2}{g^2} \bar{s}\gamma_\mu(1-\gamma_5)b \, \bar{\ell}\gamma_\mu\ell$
- $\mathcal{O}_{10} = \frac{e^2}{g^2} \bar{s}\gamma_\mu(1-\gamma_5)b \, \bar{\ell}\gamma_\mu\gamma_5\ell$



- **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 $\mathcal{O}'_{7,9,10} = \mathcal{O}_{7,9,10}(\gamma_5 \leftrightarrow -\gamma_5)$

Our Aim: To disentangle hadronic effects from New Physics effects.

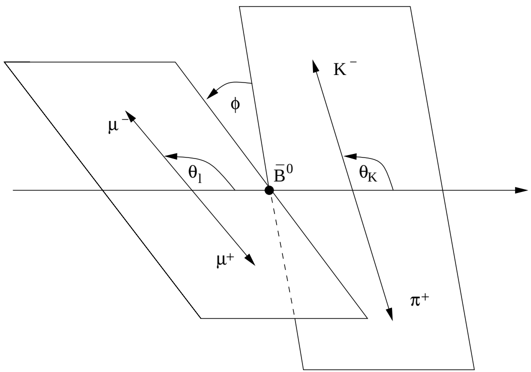
Our Tool: *A global analysis of* $\mathbf{b \to s\ell\ell}$, $\mathbf{b \to s\gamma}$ *will allow to test these Wilson coefficients with an unprecedented precision.*

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.

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

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



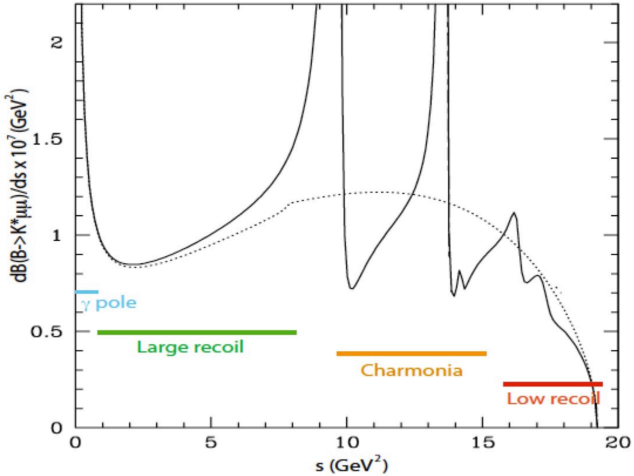
θ_ℓ: Angle of emission between $\bar{K}^{*0}$ and μ^- in di-lepton rest frame.
$\theta_\mathbf{K}$: Angle of emission between $\bar{K}^{*0}$ and K^- in di-meson rest frame.
ϕ: Angle between the two planes.

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

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

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}:

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

$$+(\frac{1}{4}\mathbf{F_T}\sin^2\theta_K - F_L\cos^2\theta_K)\cos 2\theta_l + \frac{1}{2}\mathbf{P_1}\mathbf{F_T}\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$

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

$$-\sqrt{\mathbf{F_T}\mathbf{F_L}}\left(\mathbf{P'_6}\sin 2\theta_K\sin\theta_l\sin\phi - \frac{1}{2}\mathbf{P'_8}\sin 2\theta_K\sin 2\theta_l\sin\phi\right)$$

$$+2\mathbf{P_2}\mathbf{F_T}\sin^2\theta_K\cos\theta_l - \mathbf{P_3}\mathbf{F_T}\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Bigg](1-\mathbf{F_S}) + \frac{1}{\Gamma'_{full}}\mathbf{W_S}$$

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

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

$$+\mathbf{A_S^5}\sin\theta_K\sin\theta_\ell\cos\phi + \mathbf{A_S^7}\sin\theta_K\sin\theta_\ell\sin\phi + \mathbf{A_S^8}\sin\theta_K\sin 2\theta_\ell\sin\phi\Big]$$

Basis (massless):

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

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

There are basically two theory approaches:

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

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

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

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- factorizable power corrections (using a systematic procedure for each FFp, see later)
- non-factorizable power corrections including charm-quark loops.

Minor drawback: *You should use the freedom to define $\xi_{\perp,\|}$ to identify an optimal scheme that minimizes your sensitivity to factorizable power corrections. A blind choice like in (J.C.'12 & 14) enlarges artificially their impact.*

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2. **Full FF approach**: Compute correlations from a specific LCSR computation.
   - ⇒ Parametric correlations easy, but Borel parameters choice delicate. Use of EOM.
   - ⇒ Factorizable $\mathcal{O}(\alpha_s)$ and factorizable p.c. included in a particular LCSR parametrization.
   - ⇒ **Less general**, attached to a single FF parametrization with all inner choices included.
   - ⇒ Extra pieces that **need to be added**:
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   Usually applied to $\mathbf{S_i} = (J_i + \bar{J}_i)/(d\Gamma + \bar{d}\Gamma)$ **highly dependent on FF-error estimate**.

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- **Amplitude analysis.** Not a FF treatment but a different approach to data based on **exploiting the symmetries of the distribution**.
  - They fit for the amplitudes after fixing 3 of them to zero by means of the symmetries.
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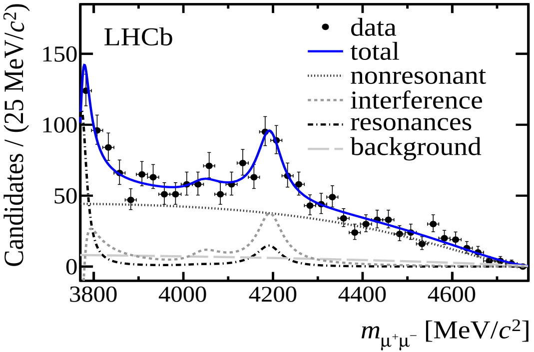
Theoretical description of $B \to K^* \ell^+ \ell^-$: large-q^2

- 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 corrections** to the OPE coeffs (Greub et al)
- **Lattice QCD form factors with correlations** (Horgan et al proceeding update)
- $\pm 10\%$ on angular observables to account for possible Duality Violations.
  $\Rightarrow$ Estimates on BR from GP (5%) and BBF (2%) using Shifman's model.

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.

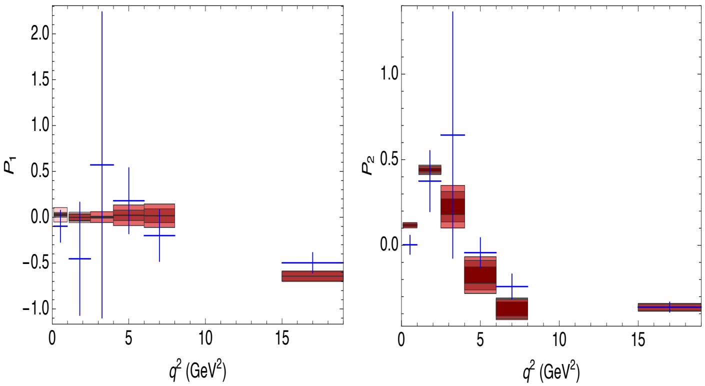


A few properties of the relevant observables $P_{1,2}$

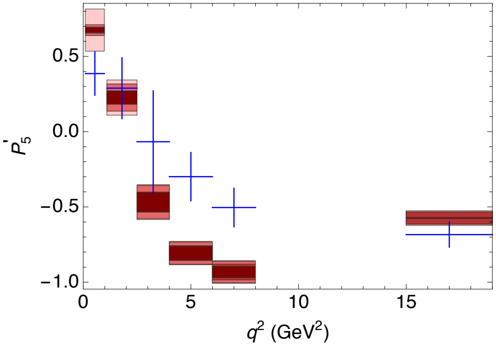
The idea of **exact cancellation of the poorly known soft form factors at LO** at the zero of A_{FB} was incorporated in the construction of the transverse asymmetry (this is the meaning of the word "**clean**")

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

- **P₁**: Proportional to $|A_\perp|^2 - |A_{||}|^2$
  - Test the LH structure of SM and/or existence of RH currents that breaks $A_\perp \sim -A_{||}$
- **P₂**: 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.

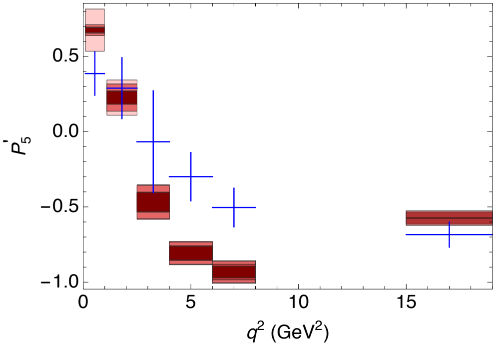


P'_5 was proposed for the first time in **DMRV, JHEP 1301(2013)048**

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

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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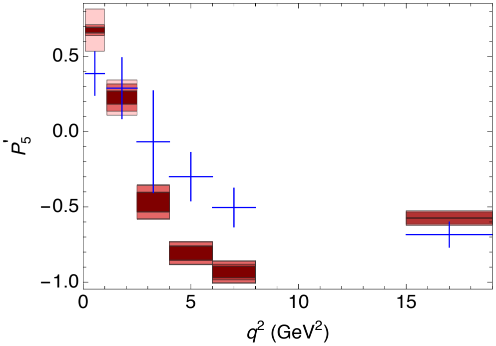
In the large-recoil limit with no RHC

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

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

- 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.



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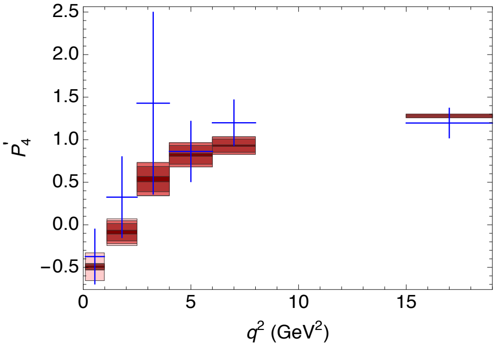
- If no-RHC $|n_\perp| \simeq |n_\parallel|$ ($H_{+1} \simeq 0$) $\Rightarrow P'_5 \propto \cos\theta_{\mathbf{0},\perp}(\mathbf{q^2})$

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.



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

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

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

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

From recent Bobeth's talk at cern

year	arXiv:	group/programs	authors	method
2010	**1006.5013**	**EOS**	CB/Hiller/van Dyk	$\Delta\chi^2$
2011	**1104.3342**	**DGMR**	Descotes-Genon/Ghosh/JM/Ramon	$\Delta\chi^2$
	1105.0376	**EOS**	CB/Hiller/van Dyk	$\Delta\chi^2$
	1111.1257	**APS**	Altmannshofer/Paradisi/Straub	$\Delta\chi^2$
	1111.2558	**EOS**	CB/Hiller/van Dyk/Wacker	$\Delta\chi^2$
2012	**1205.1838**	**EOS**	Beaujean/CB/van Dyk/Wacker	bayesian
	1206.0273	**AS**	Altmannshofer/Straub	$\Delta\chi^2$
	1207.0688	**SuperISO**	Hurth/Mahmoudi	$\Delta\chi^2$
	1207.2753	**DMRV**	Descotes-Genon/JM/Ramon/Virto	$\Delta\chi^2$

$\Delta\chi^2$ means frequentist.

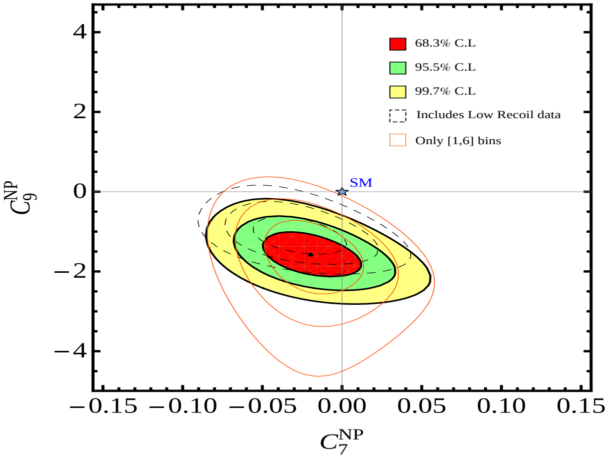
- global fits: combination of observables governed by $b \to s\ell\ell$ and $b \to s\gamma$
- Public software: EOS, SuperIso, HEPfit and private codes DHMV, AS,...

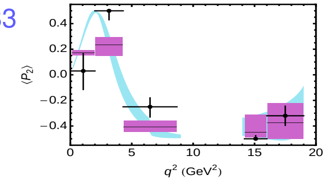
History of global $b \to s\ell\ell$ fits (II)

year	arXiv:	group/programs	authors	method
2013	**1307.5683**	**DMV**	Descotes-Genon/JM/Virto	$\Delta\chi^2$ **Anomaly**
	1308.1501	**AS**	Altmannshofer/Straub	$\Delta\chi^2$
	1310.2478	**EOS**	Beaujean/CB/van Dyk	bayesian
	1310.3887	**HLMW**	Horgan/Liu/Meinel/Wingate	$\Delta\chi^2$
	1312.5267	**SuperISO**	Hurth/Mahmoudi	$\Delta\chi^2$
2014	**1408.4097**	**GNR**	Ghosh/Nardecchia/Renner	bayesian
	1410.4545	**SuperIso**	Hurth/Mahmoudi/Neshatpour	$\Delta\chi^2$
	1411.3161/1503.06199	**AS**	Altmannshofer/Straub	$\Delta\chi^2$
2015	**1508.01526**	**EOS**	Beaujean/CB/Jahn	bayesian
	$\Rightarrow$ **1510.04239**	**DHMV**	Descotes-Genon/Hofer/Matias/Virto	$\Delta\chi^2$

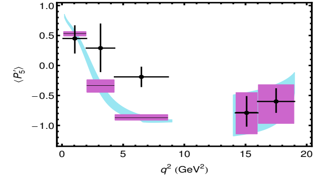
- 1/fb dataset from LHCb first analysis done using **optimized observables**
  $\Rightarrow$ **the "$B \to K^*\mu^+\mu^-$ anomaly** is described in 1307.5683
- 3/fb dataset from LHCb **the anomaly is confirmed.**

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

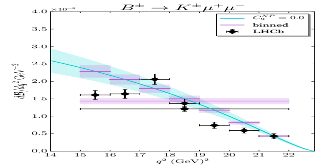




[2.9σ in second bin]



[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

see talk J. Virto

- $BR(B \to X_s\gamma)$
  - 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

Frequentist approach:

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

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

For the Fit:

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

In a model with a single free param. C_9 the fit result $\Rightarrow$ measurement of C_9 (confidence interval).
Pull$_{SM}$ tells you how much in this model the measured value of C_9 is in tension with $C_9 = C_9^{SM}$

NO SINGLE MEASUREMENT

HAVE A PULL LARGER THAN 3.3σ (several deviations 2-3σ)

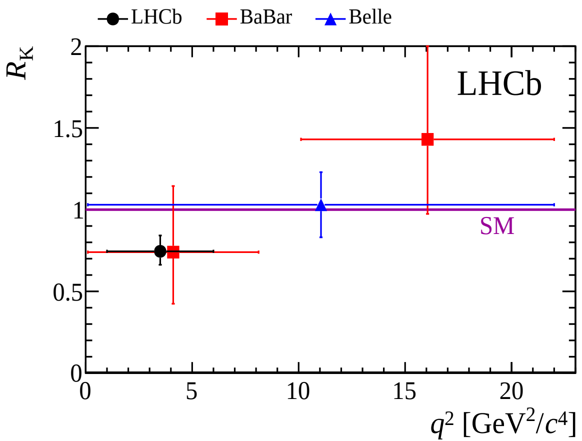
GLOBAL ANALYSIS TELLS YOU

HOW MUCH $C_i^{\rm NP} = 0$ (SM) (i=9 for instance) IS

DISFAVOURED COMPARED TO THE **BEST FIT POINT**

$\Downarrow$

THIS OBVIOUSLY CAN BE **LARGER THAN 3σ if deviations are consistent**



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

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

Also neutral mode:

$10^7 \times BR(B^0 \to K^0\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	0.63 ± 0.18	0.23 ± 0.11	$+1.9$
$[2, 4]$	0.65 ± 0.21	0.37 ± 0.11	$+1.2$
$[4, 6]$	0.64 ± 0.22	0.35 ± 0.10	$+1.2$
$[6, 8]$	0.64 ± 0.24	0.54 ± 0.12	$+0.4$
$[15, 19]$	0.90 ± 0.13	0.67 ± 0.12	$+1.4$

THERE ARE COMMON NEW PHYSICS

MECHANISMS ABLE TO EXPLAIN

P_5' and R_K

$10^7 \times BR(B^0 \to K^{*0}\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	1.26 ± 1.03	1.14 ± 0.18	$+0.1$
$[2, 4.3]$	0.84 ± 0.59	0.69 ± 0.12	$+0.2$
$[4.3, 8.68]$	2.52 ± 2.09	2.15 ± 0.31	$+0.2$
$[16, 19]$	1.66 ± 0.15	1.23 ± 0.20	**$+1.7$**
$10^7 \times BR(B^+ \to K^{*+}\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	1.31 ± 1.08	1.12 ± 0.27	$+0.2$
$[2, 4]$	0.79 ± 0.55	1.12 ± 0.32	-0.5
$[4, 6]$	0.94 ± 0.71	0.50 ± 0.20	$+0.6$
$[6, 8]$	1.15 ± 0.95	0.66 ± 0.22	$+0.5$
$[15, 19]$	2.59 ± 0.24	1.60 ± 0.32	**$+2.5$**
$10^7 \times BR(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2.]$	1.81 ± 0.36	1.11 ± 0.16	**$+1.8$**
$[2., 5.]$	1.88 ± 0.31	0.77 ± 0.14	**$+3.3$**
$[5., 8.]$	2.25 ± 0.41	0.96 ± 0.15	**$+3.0$**
$[15, 18.8]$	2.20 ± 0.16	1.62 ± 0.20	**$+2.3$**

SM predictions and Pulls 2015: $P_i(B \to K^*\mu\mu)$ and $P_i(B_s \to \Phi\mu\mu)$

New 3fb^{-1} dataset confirms the anomaly in P_5' in bins [4,6] and [6,8]

$P_1(B \to K^*\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[15, 19]$	-0.64 ± 0.05	-0.50 ± 0.11	-1.2

$P_2(B \to K^*\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 0.98]$	0.12 ± 0.02	0.00 ± 0.05	$+2.0$
$[6, 8]$	-0.38 ± 0.08	-0.24 ± 0.07	-1.2

$P_5'(B \to K^*\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 0.98]$	0.67 ± 0.14	0.39 ± 0.14	$+1.4$
$[2.5, 4]$	-0.49 ± 0.13	-0.07 ± 0.34	-1.2
$[4, 6]$	-0.82 ± 0.08	-0.30 ± 0.16	-2.9
$[6, 8]$	-0.94 ± 0.08	-0.50 ± 0.13	-2.9
$[15, 19]$	-0.57 ± 0.05	-0.68 ± 0.08	$+1.2$

$P_1(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[15, 18.8]$	-0.69 ± 0.03	-0.25 ± 0.34	-1.3

$P_4'(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[15, 18.8]$	1.30 ± 0.01	0.62 ± 0.49	$+1.4$

Result of the fit with 1D Wilson coefficient 2015

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	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_7^{\rm NP}$	-0.02	$[-0.04, -0.00]$	$[-0.07, 0.04]$	1.1
$\mathcal{C}_9^{\rm NP}$	-1.11	$[-1.32, -0.89]$	$[-1.71, -0.40]$	**4.5** $\Leftarrow$
$\mathcal{C}_{10}^{\rm NP}$	0.58	$[0.34, 0.84]$	$[-0.11, 1.41]$	2.5
$\mathcal{C}_{7'}^{\rm NP}$	0.02	$[-0.01, 0.04]$	$[-0.05, 0.09]$	0.7
$\mathcal{C}_{9'}^{\rm NP}$	0.49	$[0.21, 0.77]$	$[-0.33, 1.35]$	1.8
$\mathcal{C}_{10'}^{\rm NP}$	-0.27	$[-0.46, -0.08]$	$[-0.84, 0.28]$	1.4
$\mathcal{C}_9^{\rm NP} = \mathcal{C}_{10}^{\rm NP}$	-0.21	$[-0.40, 0.00]$	$[-0.74, 0.55]$	1.0
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP}$	-0.69	$[-0.88, -0.51]$	$[-1.27, -0.18]$	**4.1** $\Leftarrow$
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP}$	-1.09	$[-1.28, -0.88]$	$[-1.62, -0.42]$	**4.8** $\Leftarrow$ **(no R_K)**
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP} = -\mathcal{C}_{10'}^{\rm NP}$	-0.68	$[-0.49, -0.49]$	$[-1.36, -0.15]$	3.9

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

Coefficient	Best Fit Point	Pull_{SM}	p-value (%)
$(\mathcal{C}_7^{\text{NP}}, \mathcal{C}_9^{\text{NP}})$	$(-0.00, -1.11)$	**4.1**	60.0
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{10}^{\text{NP}})$	$(-1.16, 0.35)$	**4.3**	67.0
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{7'}^{\text{NP}})$	$(-1.16, 0.02)$	**4.2**	63.0
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{9'}^{\text{NP}})$	$(-1.15, 0.77)$	**4.5**	71.0
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{10'}^{\text{NP}})$	$(-1.23, -0.38)$	**4.5**	72.0
$(\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}, \mathcal{C}_{10}^{\text{NP}} = \mathcal{C}_{10'}^{\text{NP}})$	$(-1.17, 0.26)$	**4.6**	73.0
$(\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}, \mathcal{C}_{10}^{\text{NP}} = -\mathcal{C}_{10'}^{\text{NP}})$	$(-1.14, 0.04)$	**4.5**	69.0
$(\mathcal{C}_9^{\text{NP}} = \mathcal{C}_{9'}^{\text{NP}}, \mathcal{C}_{10}^{\text{NP}} = \mathcal{C}_{10'}^{\text{NP}})$	$(-0.68, -0.26)$	3.8	54.0
$(\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}}, \mathcal{C}_{9'}^{\text{NP}} = \mathcal{C}_{10'}^{\text{NP}})$	$(-0.74, 0.26)$	3.7	52.0

- 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.

QUESTION 1: Branching Ratios versus Angular Observables P_i?

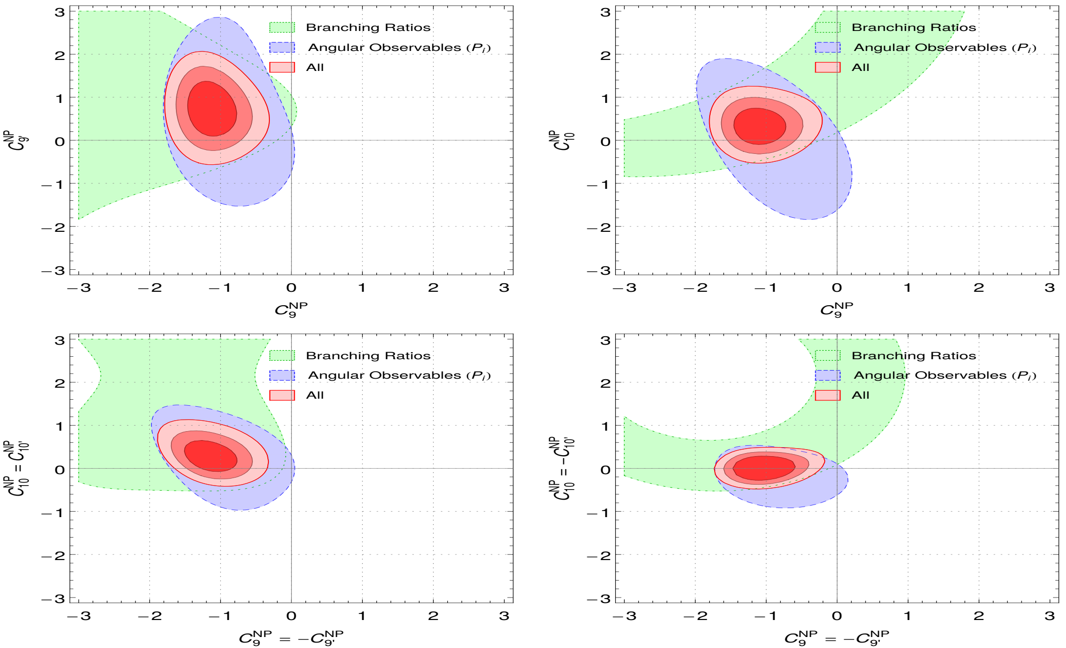


Figure: *Angular observables (FFI at LO P_i) dominates clearly over Branching ratios*

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

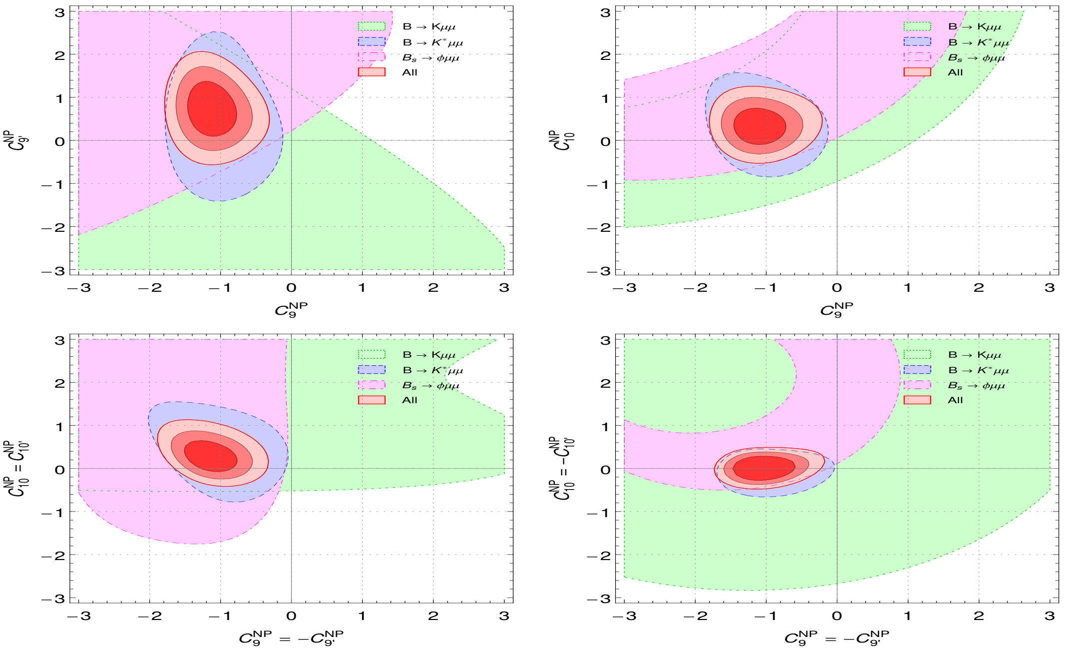


Figure: *The hierarchy of importance for the fit: $B \to K^*\mu\mu$, $B_s \to \phi\mu\mu$ and $B \to K\mu\mu$*

QUESTION 3: Which information and constraints provide each region?

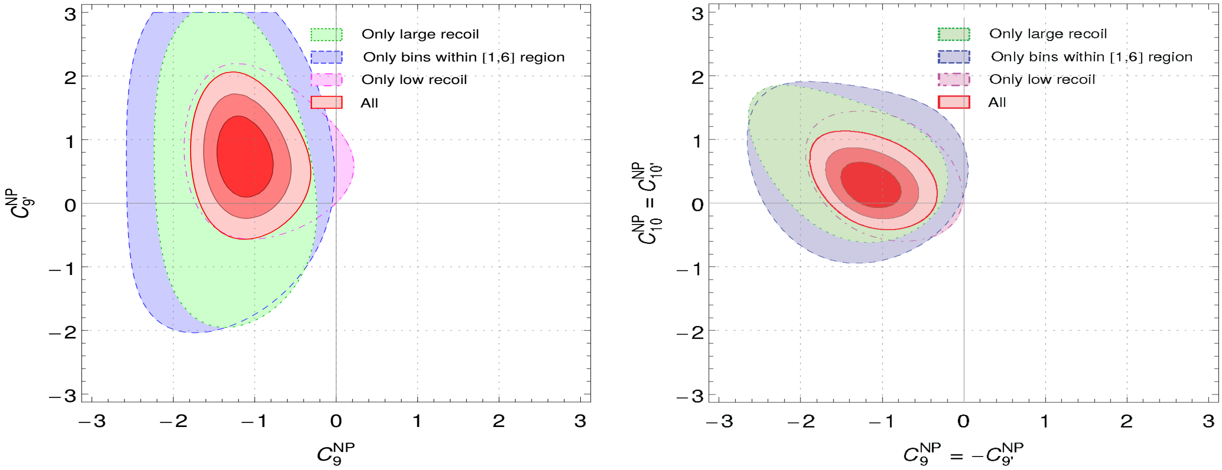


Figure: *We show the 3 σ regions allowed by large-recoil only (dashed green), by bins in the [1-6] range (long-dashed blue), by low recoil (dot-dashed purple) and by considering all data (red, with 1,2,3 σ contours).*

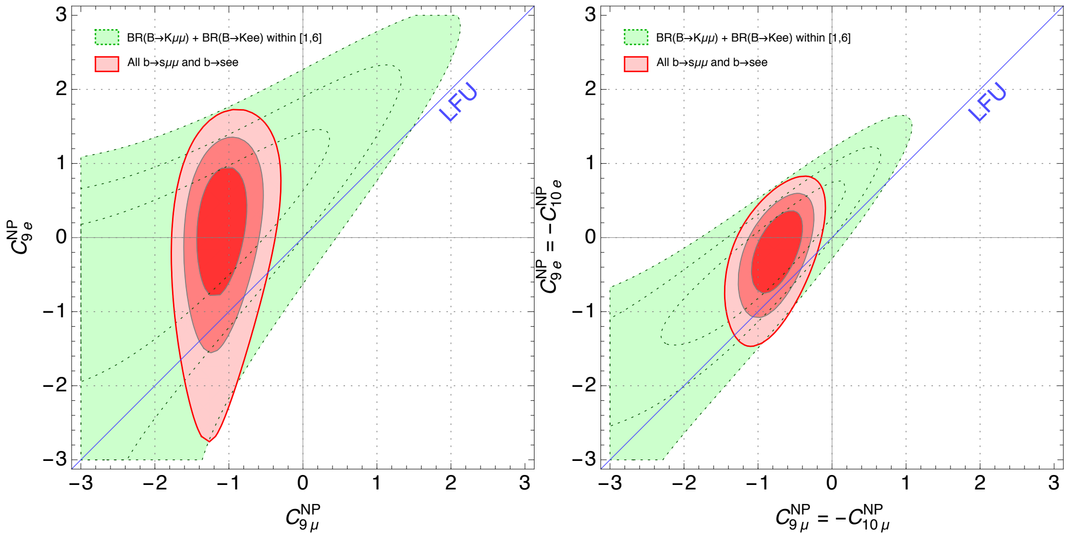
- Low-recoil is strongly constraining! Important implications for power corrections and charm.
- Bins [1,6] are perfectly coherent with the full large-recoil.

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

1D-Coefficient	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_9^{\text{NP}}$	-1.14	$[-1.34, -0.93]$	$[-1.71, -0.47]$	**4.5 → 4.9**
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}}$	-0.66	$[-0.81, -0.50]$	$[-1.15, -0.21]$	**4.1 → 4.6**
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}$	-1.09	$[-1.28, -0.88]$	$[-1.62, -0.43]$	**4.9**
$\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}} = -\mathcal{C}_{10'}^{\text{NP}}$	-0.65	$[-0.83, -0.49]$	$[-0.19, -0.19]$	4.4

2D-Coefficient	Best Fit Point	Pull_{SM}
$(C_7^{\text{NP}}, C_9^{\text{NP}})$	$(0.00, -1.13)$	**4.1 → 4.6**
$(C_9^{\text{NP}}, C_{10}^{\text{NP}})$	$(-1.11, 0.32)$	**4.3 → 4.8**
$(C_9^{\text{NP}}, C_{7'}^{\text{NP}})$	$(-1.20, 0.03)$	**4.2 → 4.7**
$(C_9^{\text{NP}}, C_{9'}^{\text{NP}})$	$(-\mathbf{1.23}, \mathbf{0.61})$	**4.5 → 4.9**
$(C_9^{\text{NP}}, C_{10'}^{\text{NP}})$	$(-1.32, -0.34)$	**4.5 → 4.9**
$(C_9^{\text{NP}} = -C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-1.23, 0.39)$	**4.6 → 5.0**
$(C_9^{\text{NP}} = -C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = -C_{10'}^{\text{NP}})$	$(-0.99, 0.03)$	**4.5**
$(C_9^{\text{NP}} = C_{9'}^{\text{NP}}, C_{10}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-0.70, -0.22)$	**3.8 → 4.3**
$(C_9^{\text{NP}} = -C_{10}^{\text{NP}}, C_{9'}^{\text{NP}} = C_{10'}^{\text{NP}})$	$(-0.69, 0.27)$	**3.7 → 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



- 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.*

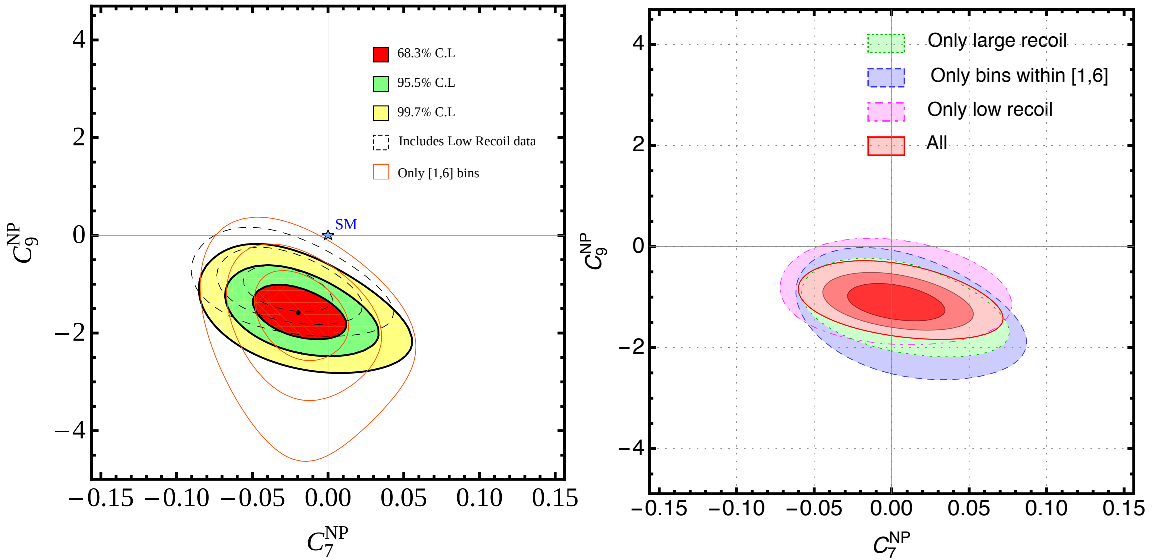


Figure: *For the scenario where NP occurs in the two Wilson coefficients $\mathcal{C}_7$ and $\mathcal{C}_9$, we compare the situation from the analysis in Fig. 1 of Ref. DMV'13(on the left) and the current situation (on the right). On the right, we show the 3 σ regions allowed by large-recoil only (dashed 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).*

A CRUCIAL QUESTION:

How much the fit results depend on the details?

Two first strong tests

Two examples of Form Factor determinations (left KMPW, right BSZ):

form factor	$F^i_{BK^{(*)}}(0)$	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.

- Interestingly in this update from BZ to BSZ, 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. we use.

	$B \to K^*$	$B_s \to \phi$	$B_s \to K^*$
$A_0(0)$	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.

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

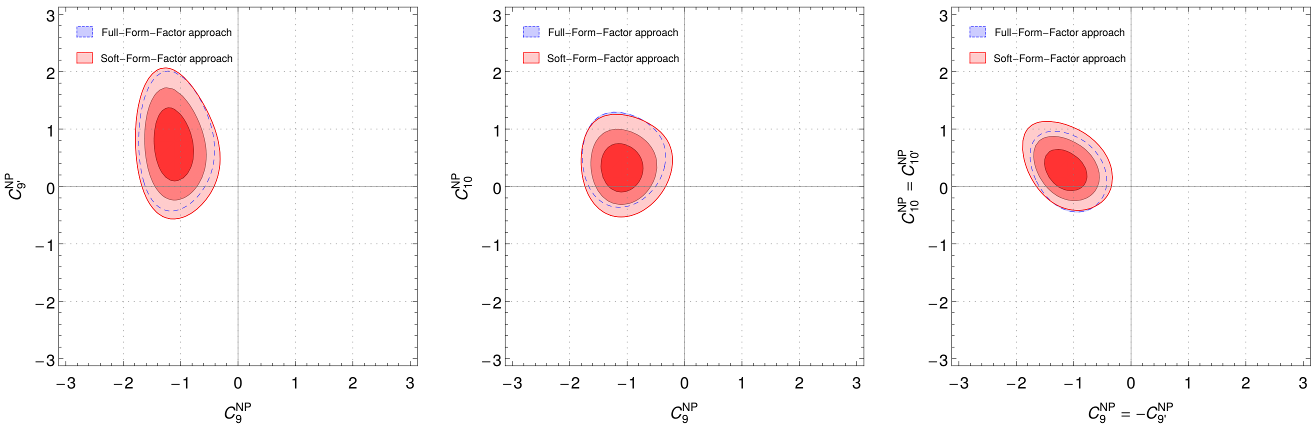
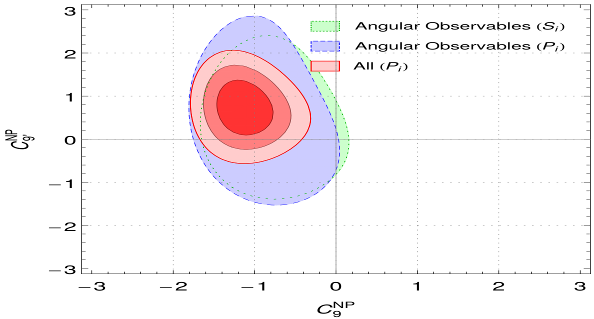
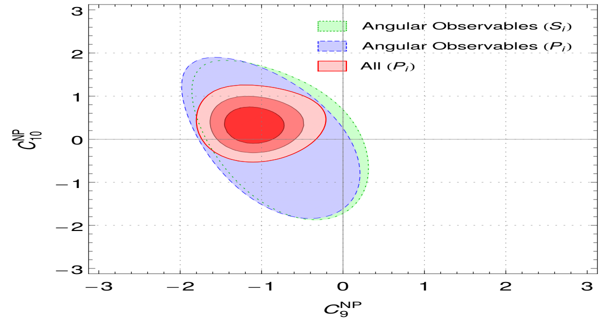


Figure: *We show the 3 σ regions allowed using form factors in BSZ'15 in the full form factor approach (long-dashed blue) compared to our reference fit with the soft form factor approach (red, with 1,2,3 σ contours).*

- 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 significantly on **FF choice**?

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

Yes for S_i,
Not for P_i.

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.
- FF dependent observables $\mathbf{S_i}$ are largely choice dependent.

Hadronic Uncertainties:

Power corrections and charm loop

Frequent naïve statement: Uncertainties are underestimated?
It is important to understand what the uncertainties are
and how they are treated before been able to ***ask*** *the question.*

While in the past focusing in one single anomaly was logical...,

now it is not a good idea neither an acceptable approach
to focus all the attention on one single observable.

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now it is not a good idea neither an acceptable approach
to focus all the attention on one single observable

BECAUSE now we have several deviations so **a global view** is compulsory. The correction question is:

What is more natural a solution consistent with all anomalies and tensions or an ad-hoc (and unclear) solution different for each anomaly?

Hadronic Uncertainties I:

Factorizable Power corrections

Factorizable Power Corrections

General idea: : Parametrize power corrections to form factors:

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

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

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

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

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

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

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

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

STEP 2: The **CHOICE of scheme** is fundamental

⇒ will yield accurate predictions for different observables depending on the scheme choice

⇒ if not all correlations among errors are known not all choices are appropriate.

In the scheme we use (Beneke-Feldmann'01) SFF are defined by:

$$\xi_\perp^{(1)}(q^2) \equiv \frac{m_B}{m_B + m_{K^*}} V(q^2) \qquad \xi_\parallel^{(1)}(q^2) \equiv \frac{m_B + m_{K^*}}{2E} A_1(q^2) - \frac{m_B - m_{K^*}}{m_B} A_2(q^2),$$

⇒ Power corrections $\Delta V^\Lambda(q^2)$ and a combination of $\Delta A_1^\Lambda(q^2)$ and $\Delta A_2^\Lambda(q^2)$ are absorbed in $\xi_{\perp,\parallel}$.

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- **Size of power corrections**: The fit to the difference between SFF+ΔF^{α_s} and full-FF is $\mathcal{O}(\Lambda/m_b)$ and is scheme dependent.

	$\hat{a}_F^{(1)}$	$\hat{b}_F^{(1)}$	$\hat{c}_F^{(1)}$	$r(0\,\mathrm{GeV}^2)$	$r(4\,\mathrm{GeV}^2)$	$r(8\,\mathrm{GeV}^2)$
A_1(KMPW)	-0.013 ± 0.025	-0.056 ± 0.018	0.158 ± 0.021	5%	6%	5%
A_1(BZ)	-0.009 ± 0.027	0.042 ± 0.018	0.078 ± 0.017	3%	1%	3%
A_2(KMPW)	-0.018 ± 0.023	-0.105 ± 0.022	0.192 ± 0.028	8%	11%	10%
A_2(BZ)	-0.012 ± 0.024	0.037 ± 0.029	0.239 ± 0.034	5%	1%	5%
T_1(KMPW)	-0.006 ± 0.031	-0.012 ± 0.054	-0.034 ± 0.095	2%	2%	2%
T_1(BZ)	-0.024 ± 0.032	-0.019 ± 0.045	-0.014 ± 0.092	8%	7%	6%

where $r = (a_F + b_F q^2/m_B^2 + c_F/m_B^4)/FF(q^2)$ represents the percentatge of p.c.

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$\Rightarrow$ *This confirms* **power corrections are typically of order** $\lesssim 10\%$ *(or smaller in BZ) for* **relevant FF** *as expected from dimensional arguments.*

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In the older scheme (first Beneke-Feldmann) SFF are defined by (also JC'14):

$$\xi_\perp^{(2)}(\mathbf{q^2}) \equiv \mathbf{T_1}(\mathbf{q^2}), \qquad \xi_\parallel^{(2)}(\mathbf{q^2}) \equiv \frac{\mathbf{m_{K^*}}}{\mathbf{E}}\mathbf{A_0}(\mathbf{q^2}).$$

$\Rightarrow$ 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 $C_7^{(\prime)}$
  2) 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).

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

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 (minor):

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.

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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

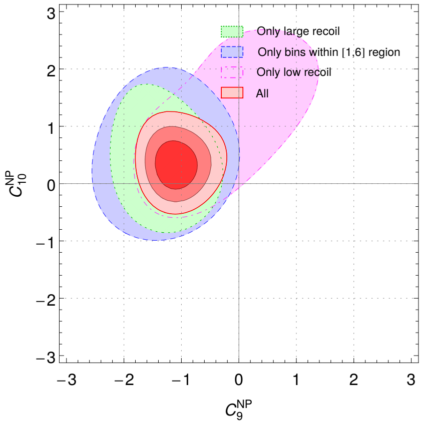
$$\begin{aligned} \hat{a}_F - \Delta\hat{a}_F \leq & \quad a_F & \leq \hat{a}_F + \Delta\hat{a}_F \ , \\ \hat{b}_F - \Delta\hat{b}_F \leq & \quad b_F & \leq \hat{b}_F + \Delta\hat{b}_F , \\ \hat{c}_F - \Delta\hat{c}_F \leq & \quad c_F & \leq \hat{c}_F + \Delta\hat{c}_F \ . \end{aligned}$$

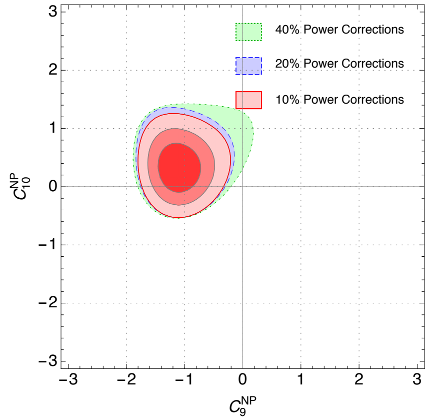
comes from $\Delta F^\Lambda \sim F \times \mathcal{O}(\Lambda/m_b) \sim 0.1 F \Rightarrow$ error assignment larger than size of p.c. itself for $\Delta\hat{a}$.

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.*

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





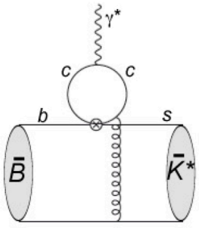
- We show the impact **in the fit** of increasing power corrections up to 40%
- At a certain point p.c.-sensitive observable become subdominant and low-recoil dominates.
  $\to$ even if power corrections diverge we still get a pull from low-recoil.

Hadronic Uncertainties II:

Non-factorizable power corrections and long distance charm contributions

- **Non-factorizable power corrections (amplitudes)**: subleading new unknown non-perturbative. 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** (resonant and non-resonant contributions)



$\Rightarrow$ 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 $i = 0, \perp, \parallel$ 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 $\phi_i^{a,b,c} \in [-\pi, \pi]$

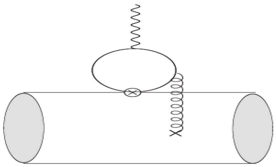
Charm-loop contributions

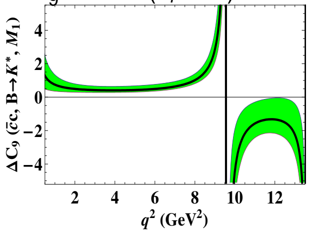
General considerations on resonances:

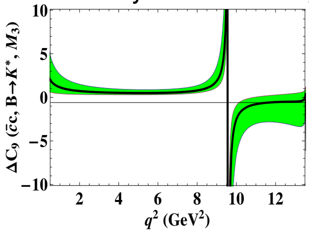
- Low-q^2: $q^2 \leq 7-8$ GeV^2 to limit impact of J/ψ tail.
  $\Rightarrow$ LHCb interesting test split $[4.3, 8.68] \to [4, 6], [6, 8]$
- Large-q^2: quark-hadron duality violations
  - Model estimate yield 2-5% for BR($B \to K\mu\mu$) [BBF, GP]
  - Assumed similar size for BR and angular observables $B \to K^*\mu\mu$.
  $\Rightarrow$ We enlarge it up to 10% as a correction to each amplitude.

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

- 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 c.v. is $s_i = 0$ to be conservative**





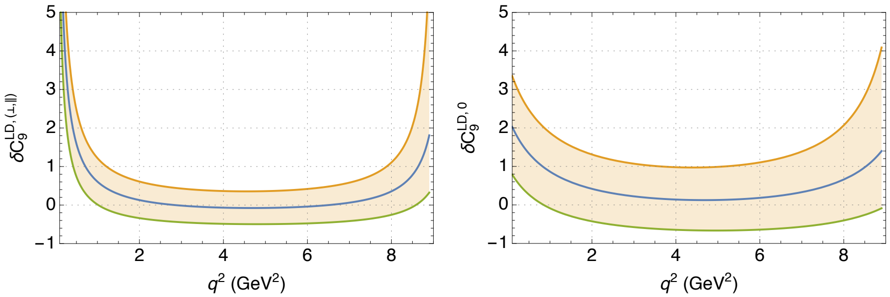


Inspired by Khodjamirian et al (KMPW): $C_9 \to C_9 + s_i\, \delta C_9^{\mathrm{LD}(i)}(q^2)$

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

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

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

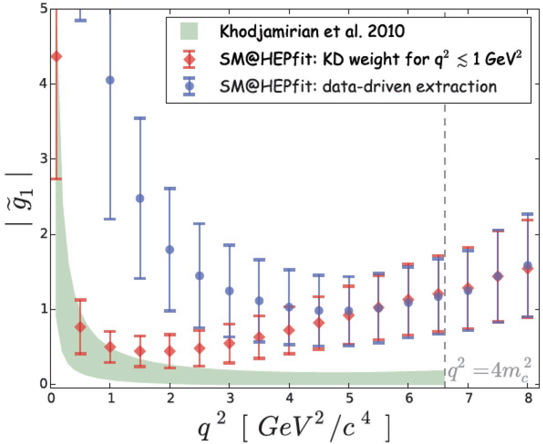


Obtaining from fitting the long-distance part to KMPW.

Is reasonable to expect a huge-charm contribution??

Attempt 1 (Valli, Silvestrini et al.):

- Introduce an arbitrary parametrization of charm-loop $h_\lambda = h_\lambda^{(0)} + h_\lambda^{(1)} q^2 + h_\lambda^{(2)} q^4$ with $(\lambda = 0, \pm)$
  - So many free parameters allows to fit any shape $\Rightarrow$ predictivity is rather low.
  - **This approach is in trouble if R_K and other sensitive LFV observables like R_{K^*} are confirmed.**

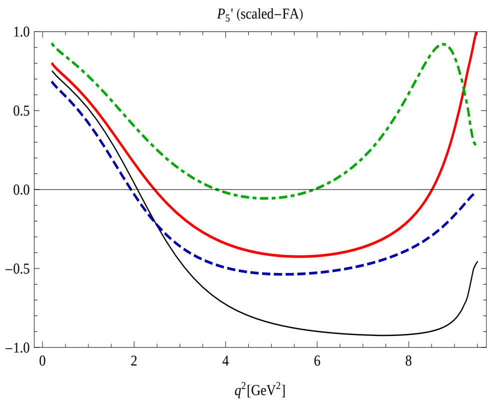


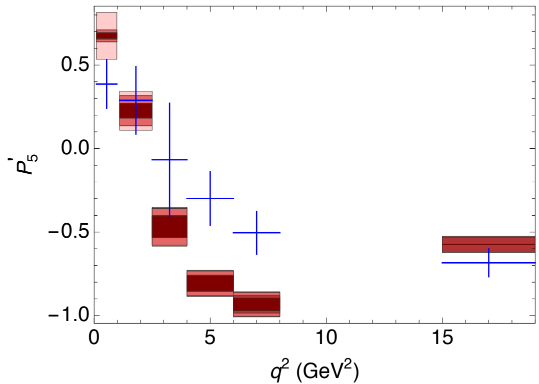
- $\tilde{g} = \Delta C_9^{non\,pert.}/(2C_1)$
- They force the fit (red points) to agree on the very low-q^2 with KMPW. This has two problems:
  - At very low-q^2 there are other problems they forgot (lepton mass effects).
  - By forcing the fit to agree at very low-q^2 can induce an artificial tilt 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!!**.

Attempt 2 (Lyon, Zwicky'14 unpublished):

- An attempt more near to a prediction was presented by LZ'14 (left plot). Using $e^+e^- \to$ hadrons to build a model of $c\bar{c}$ resonances at low-recoil in $B \to K\mu\mu$, then extrapolating it at large-recoil via dispersion relations, and assuming that it holds in the same way for $B \to K^*\mu\mu$
  $\Rightarrow$ However a large charm contribution (q^2) should be seen in bin [6,8] being above [4,6] bin.

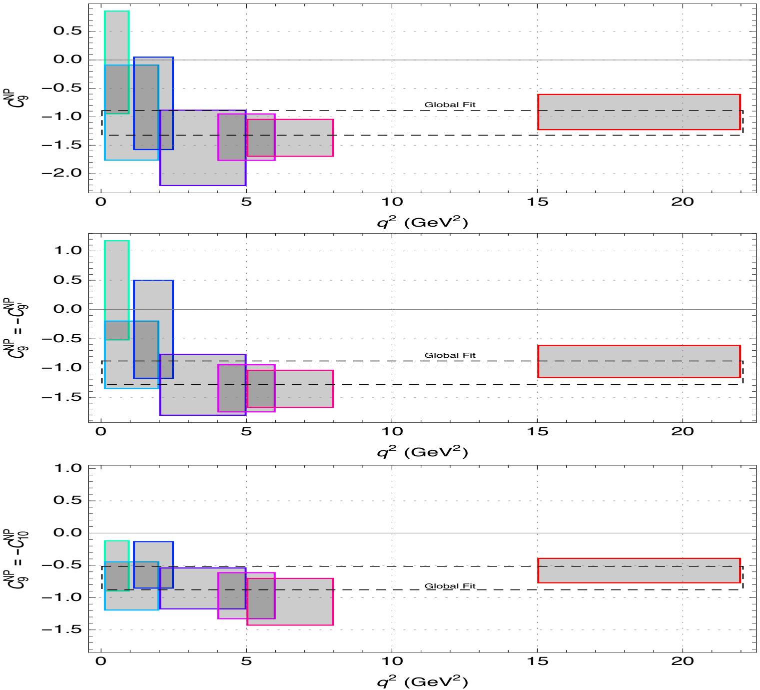




Different curves on left correspond to different hypothesis of the impact at low-q^2 from high-q^2.

Smooth behaviour of data does not favour claims on large-long distance charm q^2 effects in [6,8] bin.

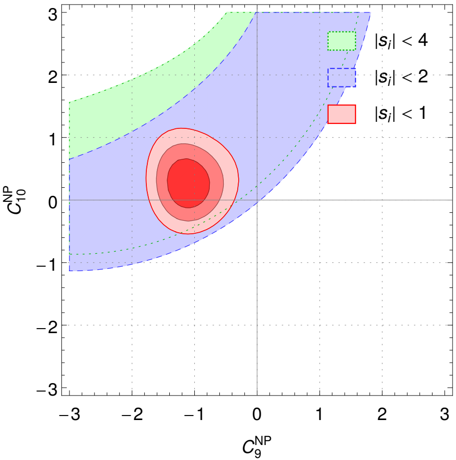
Cross check: Bin by Bin analysis of C_9 in three scenarios



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.

Impact on the fit: Charm-loop dependence



- $\Delta C_9^{BK^*} = \delta C_{9,\mathrm{pert}}^{BK^{(*)}} + s_i \delta C_{9,\mathrm{non\ pert}}^{BK^{(*)},i}$ (same for $B_s \to \phi$)
- Increasing the range allowed for s_i makes low-recoil and $B \to K\mu\mu$ dominate more and more

A comparison of our charm error estimate with other estimates (BSZ) shows a good agreement even if systematically we take a larger error size and we have an extra non-factorizable error. Example in the anomaly bin $P'_{5[4,6]}$:

- our estimate hep-ph/1503.03328 is $^{+0.07}_{-0.08}$
- BSZ estimate in hep-ph/1503.05534 is ± 0.05

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.

Does the **alternative explanations** to NP

raised in literature:

factorizable power corrections and charm

stand a serious and accurate analysis?

NO

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.*

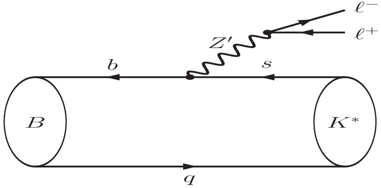
- $\mathcal{C}_9^{NP} < 0$ is consistent with all anomalies. This is the reason why it gives a strong pull.
- $\mathcal{C}_{10}^{NP}$, $C'_{9,10}$ fail in some anomaly. BUT
  - $\Rightarrow$ $\mathcal{C}_{10}^{NP}$ is the most promising coefficient after $\mathcal{C}_9$.
  - $\Rightarrow$ C'_9, C'_{10}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

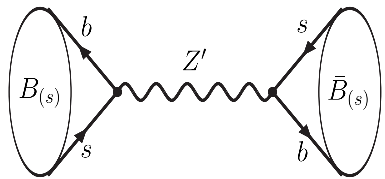
Z' particle a possible explanation

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'.





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

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	Pull$_{\rm SM}$
C_9	**no**-right-handed quark & no-muon-axial coupling	$\Delta_L^{sb} \neq 0$, $\Delta_V^{\mu\mu} \neq 0$	4.9σ
(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: $C_9^{\rm NP} = -1.1$, $\Delta_V^{\mu\mu}/M_Z' = -0.6$ TeV^{-1} and $\Delta_L^{bs}/M_Z' = 0.003$ 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 of this talk

- 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 $\mathbf{C_9^{NP}} \simeq -\mathbf{1}$ **is confirmed** and reinforced.
  $\to$ We take full dataset and optimized basis of observables.

- The **fit result is very robust** and does not show a significant dependence nor on the method used to compute observables neither on the observables used once correlations are correctly included.

- We have shown that the **treatment of uncertainties** entering the observables in $B \to K^*\mu\mu$ is indeed **under good control** and the **alternative explanations** to New Physics are indeed **not in very solid ground**.

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

TECHNICAL Conclusions of this talk

- Robustness of the FIT:
  - The results of the fit using P_i (optimized-FFI) or S_i (FFD) and IQCDF-KMPW or Full-FF-BSZ results are in very good agreement. **Low sensitivity to details of FF computation**.
  - Any scenario including C_9^{NP} gets a large-pull. 2D scenarios still indistinguishable $\Rightarrow$ More data needed.

- Robustness of hadronic uncertainties of OBSERVABLES:
  - Factorizable power corrections:
    - The **Fit** to full FF in an **appropriate scheme** gives $\leq$ 10% in agreement with dimensional arguments.
    - A correct FF choice + correlations among p.c. is essential not to artificially inflate errors.
  - $c\bar{c}$ loops: We include LO and NLL perturbative contributions to $C_9^{\rm eff}$ also long distance (following KMPW) with both signs to be conservative.
    - Three reasons why a huge charm contribution cannot explain all deviations: R_K cannot be explained. The behaviour of bin [6,8] versus [4,6] in observables like P_5'. A 6-D fit or a bin-by-bin analysis does not find evidence for a new-q^2 dependence.
  - Any set of observables is equivalent in terms of accuracy for the predictions on individual observables? NO, P_i observables are stable under FF changes, S_i depend largely on the choice.

Back-up slides

Bin (0.1,0.98) lepton-mass effect

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

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

which is modified once lepton masses are considered

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

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

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

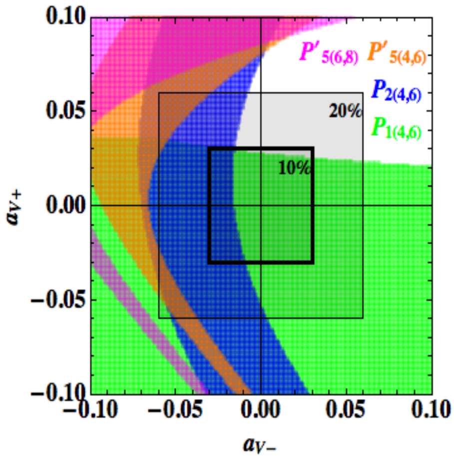
		$\|\delta\mathcal{C}_7\| = 0.1$	$\|\delta\mathcal{C}_9\| = 1$	$\|\delta\mathcal{C}_{10}\| = 1$	$\|\delta\mathcal{C}_{7'}\| = 0.1$	$\|\delta\mathcal{C}_{9'}\| = 1$	$\|\delta\mathcal{C}_{10'}\| = 1$
$\langle P_1\rangle_{[0.1,.98]}$	$+\|\delta C_i\|$	−−	−−	−−	−0.53	−0.05	−−
	$-\|\delta C_i\|$	−−	−−	−−	+0.52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

Another important aspect is the error associated to SFF.

- Our error comes from KMPW. Example: $\xi_\perp(\mathbf{0}) = \mathbf{0.31}^{+\mathbf{0.20}}_{-\mathbf{0.10}}$
- On the contrary in (JC'14): Error from **spread of central values with different inputs** and **not considering errors**, $\xi_\perp(\mathbf{0}) = \mathbf{0.31} \pm \mathbf{0.04}$. Factor of 5 to 3 smaller error than us.

  $\rightarrow$ This will give a **very small error** (due to this error definition) for FFD observables.

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

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

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

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

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

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

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

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

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

The corresponding spin amplitudes $A_\perp, A_\parallel, A_0$ 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 $A_{1,2}(s)$, $V(s)$, $T_{1,2,3}(s)$

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

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

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

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 $A_\perp \approx -A_\|$.

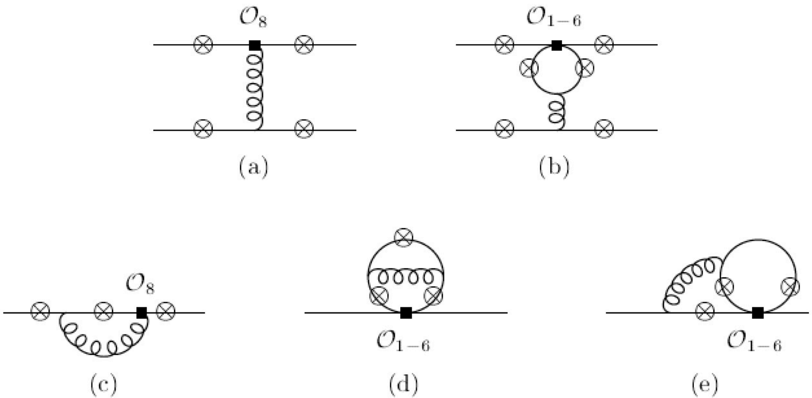


Figure 2: Non-factorizable contributions to $\langle \gamma^* \bar{K}^* | H_{\text{eff}} | \bar{B} \rangle$. The circled cross marks the possible insertions of the virtual photon line. Diagrams that follow from (c) and (e) by symmetry are not shown. Upper line: hard spectator scattering. Lower line: diagrams involving a $B \to K^*$ form factor (the spectator quark line is not drawn for these diagrams).