Theory interpretation of $B \to K^*(\to K\pi)\mu^+\mu^-$

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Motivation

For a long time ago...

$\Rightarrow$ flavour transitions have been used as a probe to explore the fundamental theory beyond SM.

Our target: Decode the short distance physics to find a smoking gun of BSM

BUT, like in the film there is always the good, the bad and the ugly.

The good: **Wilson coefficients** of electromagnetic, semileptonic, scalars and chirally flipped operators.

$$\mathcal{O}_{7,7'} = \frac{e}{16\pi^2} m_b(\bar{s}\sigma_{\mu\nu}P_{R,L}b)F^{\mu\nu}, \quad \mathcal{O}_{9,9'} = \frac{\mathbf{e^2}}{\mathbf{16\pi^2}}(\bar{\mathbf{s}}\gamma_\mu \mathbf{P_{L,R}b})(\bar{\ell}\gamma^\mu\ell), \quad \mathcal{O}_{10,10'} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_{L,R}b)(\bar{\ell}\gamma^\mu\gamma_5\ell).$$

The bad: Matrix elements: Form Factors, ...

The ugly: Hadronic uncertainties: factorizable & non-factorizable power corrections,
duality violations at low-recoil...

Our main tool: The 4-body decay $\mathbf{B \to K^*(\to K\pi)\mu^+\mu^-}$ will allow to test Wilson coefficients with an unprecedented precision.

How to extract short distance information from $B \to K^* \mu^+ \mu^-$?

On theory side:

Traditional Analysis: BR, F_L and A_{FB}, its zero being the most interesting observable:

$$C_9^{\mathrm{eff}}(q_0^2) + 2\frac{m_b M_B}{q_0^2} C_7^{\mathrm{eff}} = 0$$

no hadronic uncertainty at LO.

First step beyond TA: $\mathbf{A_T^2}$ in 2005 (now named P_1)

...first example of a FFI (at LO) observables for $q^2 \leq 9$ GeV^2.

Next step: A set of FFI or optimized observables: $\mathbf{P_1}$, $\mathbf{P_2}$ (originally A_T^{re}), $\mathbf{P'_4}$, $\mathbf{P'_5}$, $\mathbf{P'_6}$, $\mathbf{P'_8}$ or $\mathbf{P_3}$

- An exact cancellation of soft form factor at LO (next slide).
- Good experimental accessibility.

combined with BR, F_L or A_{FB} and the S-wave observables F_S, A_S, $A_S^{4,5}$ (the rest are not independent)

On experimental side:

From **uniangular** distributions $\rightarrow$ **folded** distributions $\rightarrow$ **full** angular analysis.

Our Theoretical Framework: How to compute the P_i observables.

Large-recoil: $0.1 \leq q^2 \leq 9$ GeV^2

"Improved QCDF approach": QCDF+ symmetry relations at large-recoil among FF:

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

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

⇒ Transparent, valid for **ANY** FF parametrization (BZ, KMPW,...) and easy to reproduce.

⇒ Dominant correlations automatically implemented.

⇒ From the observation that at LO in $1/m_b$, α_s and large-recoil limit (E_K^* large):

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

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

$$A_0^{L,R} = -\frac{Nm_B(1-\hat{s})^2}{2\hat{m}_{K^*}\sqrt{\hat{s}}}\left[(\mathcal{C}_9^{\rm eff}-\mathcal{C}_9^{\rm eff\prime}) \mp (\mathcal{C}_{10}-\mathcal{C}_{10}^\prime) + 2\hat{m}_b(\mathcal{C}_7^{\rm eff}-\mathcal{C}_7^{\rm eff\prime})\right]\xi_\parallel(E_{K^*}).$$

⇒ Symmetry Breaking corrections (α_s and power corrections) are added in our computation.

Idea behind the construction of clean or **optimized** observables $P_i^{(\prime)}$:

Cancel the soft form factor dependence at LO exactly as for the zero of A_{FB}

$\Rightarrow$ natural observables in this framework.

- In summary we include in our latest predictions:
  - known α_s **factorizable** and **non-factorizable** corrections from QCDF.
  - **factorizable** power corrections (using a systematic procedure for each FF, see later)
    Other approaches uses full form factors to include it.
  - **non-factorizable** power corrections including **charm-quark** loops.

Low-recoil: $15 \leq q^2 \leq 19$ GeV^2

We have implemented Lattice Form Factors

$\Rightarrow$ Due to the presence of many $c\bar{c}$ resonances in this region
we integrate over a large bin and use duality arguments.

Uncertainties I : Form Factors+Factorizable power corrections

- Form Factors: Different parametrizations possible (BZ or KMPW).
  Goal: Minimize dependence of error predictions on the choice.

$$\mathbf{P}_5' = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R)}{\sqrt{|A_0|^2(|A_\parallel|^2 + |A_\perp|^2)}} = c_1 + \mathcal{O}(\alpha_s\, \xi_{\perp,\parallel}) \qquad \mathbf{S}_5 = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R)}{|A_\parallel|^2 + |A_\perp|^2 + |A_0|^2} = \frac{c_1 \xi_\perp \xi_\parallel}{c_2 \xi_\perp^2 + c_3 \xi_\parallel^2}$$

$\Rightarrow$ $\mathbf{S_5}$ is more sensitive to FF's choice
(idem for e.g. $\mathbf{F_L}$)

- Factorizable power corrections:

General idea: : Parametrize power corrections to FF (at large-recoil):

$$F(q^2) = F^{\rm soft}(\xi_{\perp,\parallel}(q^2)) + \Delta F^{\alpha_s}(q^2) + a_F + b_F \frac{q^2}{m_B^2} + \ldots$$

$\Rightarrow$ fit $a_F, b_F, \ldots$ to the full form factor F (taken e.g. from LCSR)

I. Respect correlations among $a_{F_i}, b_{F_i}, \ldots$. Power corrections are constrained from:
  - exact kinematic FF relations at $q^2 = 0$. Example $a_{T1} = a_{T2}$ from $T_1(0) = T_2(0)$
  - definition of input scheme to fix $\xi_{\perp,\parallel}$. Example $a_{A2} = \frac{m_B + m_{K*}}{m_B - m_{K*}} a_{A1}$ from $\xi_\parallel \equiv c_1 A_1(q^2) + c_2 A_2(q^2)$

II. Choose the most appropriate scheme to reduce the impact of power corrections:
  - input of J.C. '12 and '14 : $\{T_1, A_0\}$ to define $\{\xi_\perp, \xi_\parallel\} \Rightarrow$ power corrections eliminated in T_1 and A_0
  - our input: $\{V, c_1 A_1 + c_2 A_2\} \Rightarrow$ power corrections eliminated in V and minimized in A_1, A_2

Uncertainties II: Non-factorizable power corrections including charm-loop

- $\mathcal{O}(\Lambda/m_b)$ non-fact. corrections to the amplitudes beyond QCDF (not part of FF).

$\Rightarrow$ We single out the pieces not associated to FF $\mathcal{T}_i^{\rm had} = \mathcal{T}_i|_{C_7^{(\prime)}\to 0}$ entering $\langle K^*\gamma^*|H_{eff}|B\rangle$ and multiply each of them with a complex q^2-dependent factor:

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

with

$$r_i(s) = r_i^a e^{i\phi_i^a} + r_i^b e^{i\phi_i^b}(s/m_B^2) + r_i^c e^{i\phi_i^c}(s/m_B^2)^2.$$

$r_i^{a,b,c} \in [0, 0.1]$ and $\phi_i^{a,b,c} \in [-\pi, \pi]$: random scan and take the maximum deviation from the central values $r_i(q^2) \equiv 0$ to each side, to obtain asymmetric error bars.

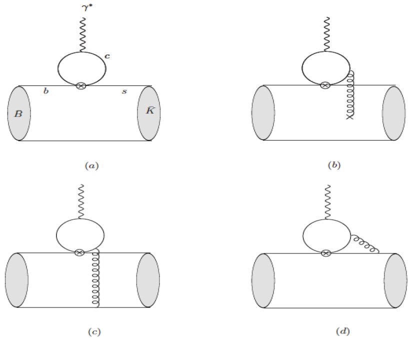

Figure 1: *Charm-loop effect in $B \to K^{(*)}\ell^+\ell^-$: (a)-the leading-order factorizable contribution; (b) nonfactorizale soft-gluon emission, (c),(d)-hard gluon exchange.*

Charm loop: Insertion of 4-quark operators ($\mathcal{O}_{1,2}^c$) or penguin operators ($\mathcal{O}_{3-6}$) induces a positive contribution in $C_9^{\rm eff}$. **We followed LCSR partial computation and prescription** from KMPW to recast the effect inside $C_9^{\rm eff}$.

$$\mathcal{C}_9 \to \mathcal{C}_9 + s_i \delta C_9^{KMPW}(q^2)$$

even if KMPW says $s_i = 1$, we allow s_i in a range $[-1, 1]$.

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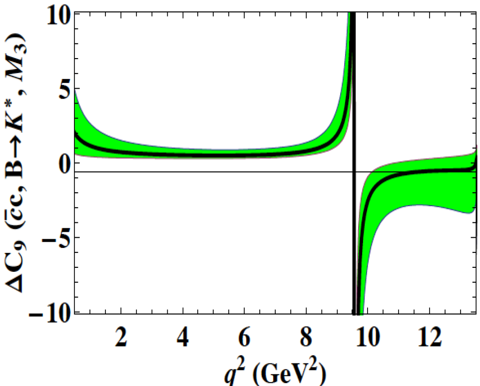

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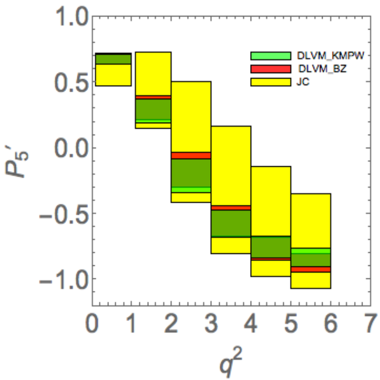
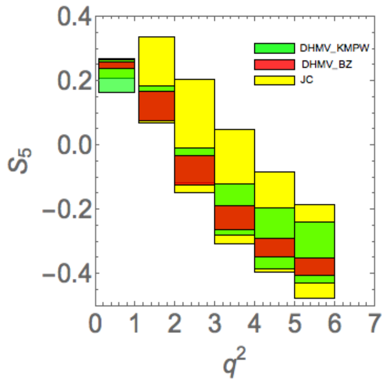
Tests on alternative explanations

Suspect 1: **Factorizable power corrections (affect both P_i and S_i)**





P_5', S_5 computed with our method:

- GREEN is KMPW FF
- RED is BZ FF

YELLOW in P_5' is error computed by JC'12&'14. Non optimal scheme for P_5' is used.

YELLOW in S_5 is error computed from JC (assuming $\delta F_L = 0$ + correl.)

- P_5': **Size of errors** for KMPW or BZ predictions **are the same** (shift is due to central values shift).
- S_5: **Size of errors are different** using KMPW or BZ (source: form factor errors).
- The predictions for S_5 or P_5' using our method with BZ (red boxes) and the predictions from BZ-FF (B.S.Z.'15) approach (not shown in plot) are in **excellent agreement**.
- Consistency tests with **lattice form factors** can also be used to discern the size of errors.

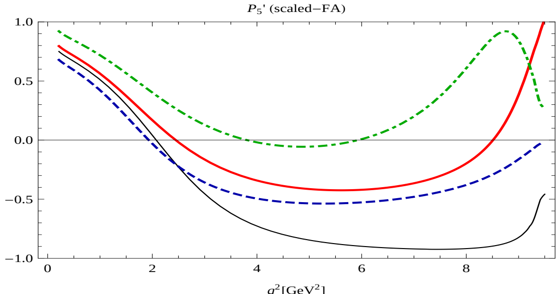
Tests on alternative explanations

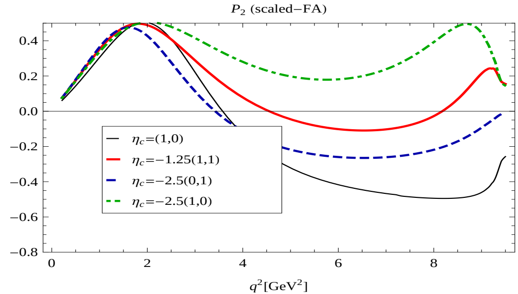
Suspect 2: **Huge Charm-loop effect (affect both P_i and S_i)** in [Lyon,Zwicky, hep-ph 1406.0566]

In practical terms shift explanation from global C_9^{NP} to modified q^2 dep. 4-quark charm-loop $h(q^2)$ in

$$C_9^{\rm eff}(\eta) = C_9^{SM} + C_9^{NP} + \eta\, h(q^2) \text{ and in } C_9'(\eta') \quad \text{with} \quad \eta + \eta' = -2.5$$

modification of h comes from the extrapolation of the low-recoil $c\bar{c}$ resonances to large-recoil.



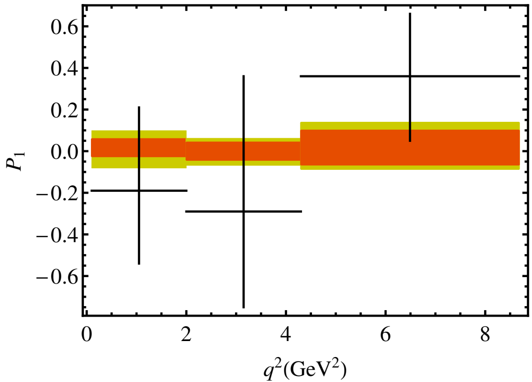


Implications:

normal scenario is black line

- The structure in the region $4 \le q^2 \le 9$ GeV^2 altered: P_2 and P_5' has more zeroes. If this effect should be correct one expects $P'_{5[6,8]}$ **above or equal to** $P'_{5[4,6]}$, a global effect (like normal scenario or C_9^{NP}) predicts $P'_{5[6,8]}$ **below** $P'_{5[4,6]}$.
- The maximum of P_2 weakly shifted by charm to the right direction if one imposes the experimental constraint from the zero of P_2. Instead for a global effect both maximum and zero of P_2 shift.
- R_K: **universal character of this charm effect cannot explain this tension**. On the other hand, it can be explained by a NP scenario also explaining the $B \to K^*\mu\mu$ anomaly, if NP couplings preferentially to muons.

2013 data:



Definition:

$$P_1 = A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$$

Information: In SM the s quark is produced in helicity $-1/2$ by weak int. combined with light quark $\Rightarrow H_{+1} = 0$ which implies $|A_\perp| \simeq |A_\parallel|$.

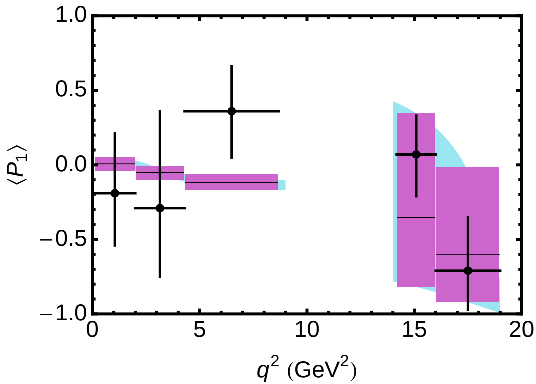
$P_1 \neq 0$ *Test presence of RHC.*

These tables inform of the shift with respect to the SM of a certain observable if you change one by one $\Delta C_{7,7'} = \pm 0.1$ and $\Delta C_{9,10,9',10'} = \pm 1$. First row for positive change of corresponding Wilson coefficient, second for the negative. In green are the shifts in data direction (**use only with 2015 data**).

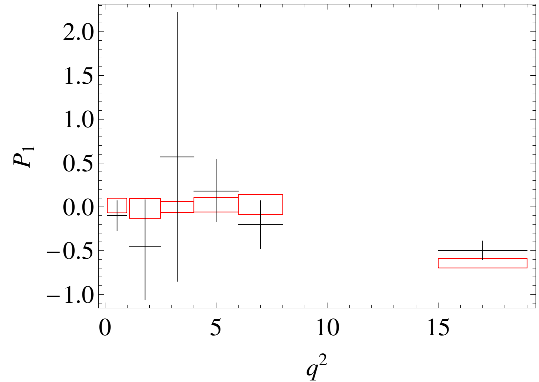
$\langle P_1^{\rm SM}\rangle_{[6,8]} = +0.018$	$\Delta C_7 = \pm 0.1$	$\Delta C_9 = \pm 1$	ΔC_{10}	$\Delta C_7'$	$\Delta C_9'$	$\Delta C_{10}'$
+	−−	−−	−−	+0.11	+0.16	**−0.37**
−	−−	−−	−−	**−0.12**	**−0.16**	+0.37

P_1 and P_4' in 2013 and 2015

2013 data:



2015 data:



All bins consistent with SM (large errors).

$\langle P_1^{\rm SM}\rangle_{[6,8]} = +0.018$	$\Delta C_7 = \pm 0.1$	$\Delta C_9 = \pm 1$	ΔC_{10}	$\Delta C_7'$	$\Delta C_9'$	$\Delta C_{10}'$
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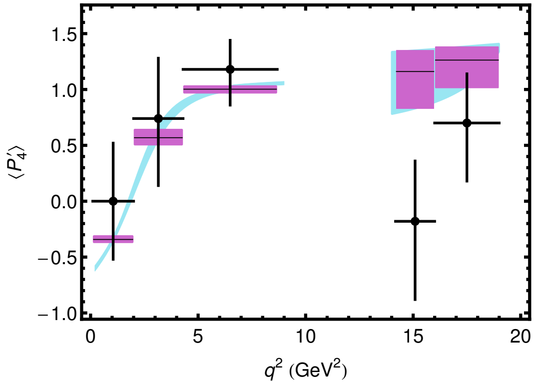
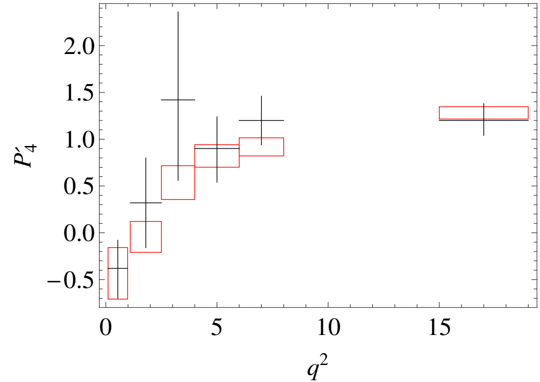
P_4' in 2013 and 2015

2013 data:



2015 data:



Definition:

$$P_4' = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\parallel^{L*} + A_0^R A_\parallel^{R*})}{\{|A_0|^2 \times (|A_\perp|^2 + |A_\parallel|^2)\}^{\frac{1}{2}}}$$

Information: Important observable for consistency check of the data.

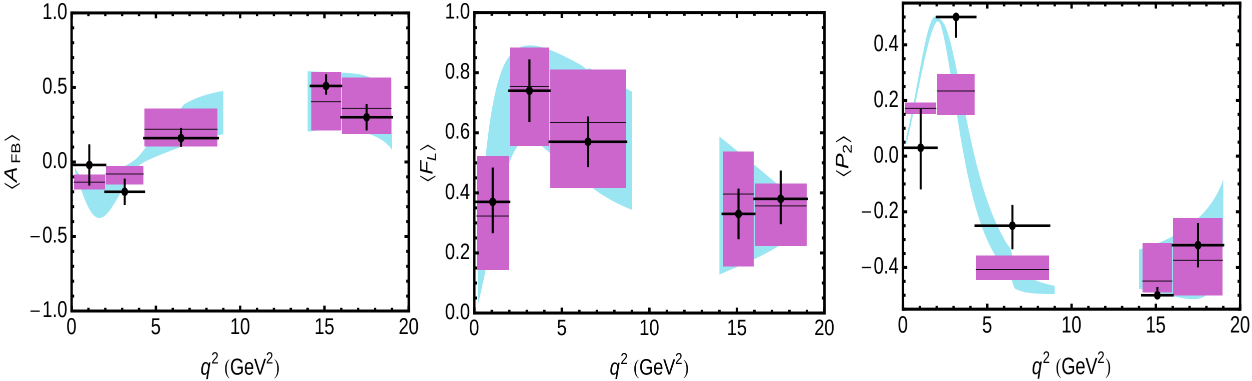
- Upper bound on P_1 from:

$$\mathbf{P_5'^2 - 1 \leq P_1 \leq 1 - P_4'^2}$$

  - Relevant for [4,6] and [6,8] bins.
  - Relevant at low-recoil.

- Enters two important tests on P_2 (to be described in short)

2013 data:



Deviation in $\langle P_2\rangle_{[2,4.3]}$ in excellent agreement with anomaly in P_5'

Definition:

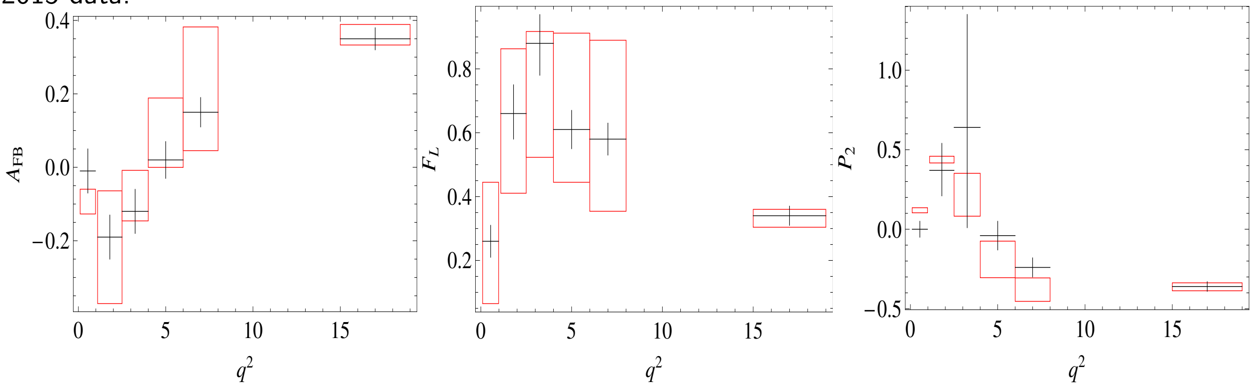
$$P_2 = \frac{\mathrm{Re}(A_\parallel^L A_\perp^{L*} - A_\parallel^R A_\perp^{R*})}{|A_\parallel|^2 + |A_\perp|^2}$$

Information: P_2 (orig. A_T^{re}) is the clean version of A_{FB} and contains two important observables:

- **Position of zero:** $q^2_{0\,LO} = -2\frac{m_b M_B C_7^{\mathrm{eff}}}{C_9^{\mathrm{eff}}(q_0^2)}$ (if $C_i' = 0$). Same as A_{FB}.
- **Position and value of maximum of P_2:** $q^2_{1\,LO} = -2\frac{m_b M_B C_7^{\mathrm{eff}}}{\mathrm{Re}C_9^{\mathrm{eff}}(q_1^2) - C_{10}}$ (if $C_i' = 0$ and $\mathrm{Im}(C_9^{eff})^2 \sim 0$)

P_2 and A_{FB} in 2013 and 2015

2015 data:



Unfortunate fluctuation up of FL affects $\langle P_2 \rangle_{[2.5,4]}$. **This may change with other binning or more data.**

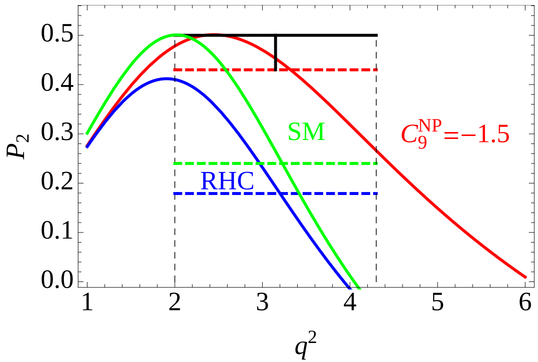
Definition:

$$P_2 = \frac{\mathrm{Re}(A_\parallel^L A_\perp^{L*} - A_\parallel^R A_\perp^{R*})}{|A_\parallel|^2 + |A_\perp|^2}$$

Information: P_2 (orig. $A_T^{\rm re}$ D.B. et al.) is the clean version of A_{FB} contains two important observables:

- **Position of zero:** $q^2_{0\,LO} = -2\frac{m_b M_B C_7^{\rm eff}}{C_9^{\rm eff}(q_0^2)}$ (if $C_i' = 0$). Same as A_{FB}.
- **Position and value of maximum of** P_2**:** $q^2_{1\,LO} = -2\frac{m_b M_B C_7^{\rm eff}}{\mathrm{Re} C_9^{\rm eff}(q_1^2) - C_{10}}$ (if $C_i' = 0$ and $\mathrm{Im}(C_9^{eff})^2 \sim 0$)

L. Hofer, J.M'15



- ⇒ Only presence of RHC reduces $P_2^{maximum}$ below 1/2. NP in $C_{9,10}$ or $C_7^{\rm eff}$ only shift the position of maximum but not its value.
- ⇒ RHC difficult to disentangle from SM with present binning.
- ⇒ 1 GeV^2 bins much better for P_2 than long bins. stay tuned.... for $\langle P_2\rangle_{[2,3]}$ and $\langle P_2\rangle_{[3,4]}$

$$q_0^{2SM} \simeq 4 \text{ GeV}^2 \text{ and } q_1^{2SM} \simeq 2 \text{ GeV}^2$$

$\langle P_2\rangle_{[3,4]} = 0.15$	$\mathbf{\Delta C_7 = \pm 0.1}$	$\mathbf{\Delta C_9 = \pm 1}$	ΔC_{10}	$\Delta C_7'$	$\Delta C_9'$	$\Delta C_{10}'$
+	−0.30	−0.22	**+0.04**	– –	– – –	– – –
−	**+0.23**	**+0.18**	−0.03	−0.03	– – –	– – –

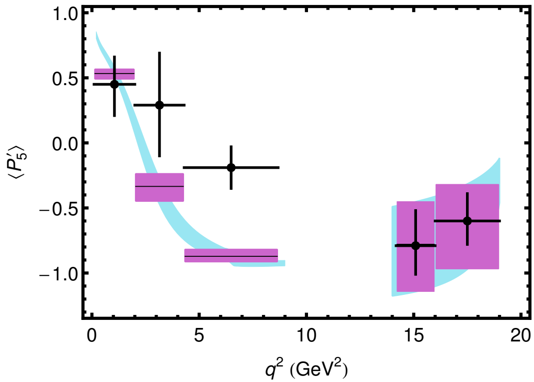
$\langle P_2\rangle_{[6,8]} = -0.38$	$\mathbf{\Delta C_7 = \pm 0.1}$	$\mathbf{\Delta C_9 = \pm 1}$	ΔC_{10}	$\Delta C_7'$	$\Delta C_9'$	$\Delta C_{10}'$
+	−0.07	−0.09	−0.06	– – –	– – –	– – –
−	**+0.11**	**+0.17**	**+0.05**	– – –	– – –	– – –

The anomaly gets confirmed....

.... and consistency tests improved

P_5' in 2013 and 2015

2013 data:



Definition:

$$P_5' = \sqrt{2}\frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*})}{\{|A_0|^2 \times (|A_\perp|^2 + |A_\parallel|^2)\}^{\frac{1}{2}}}$$

Information: In SM $C_9^{SM} \sim -C_{10}^{SM}$ this cancellation suppresses $A^R_{\perp,\parallel,0} \ll A^L_{\perp,\parallel,0}$ when semileptonic dominates $q^2 > 5-6$ GeV^2. NP may alter this cancellation, leading to a sensitivity to right-handed amplitudes for $q^2 > 5-6$ GeV^2.

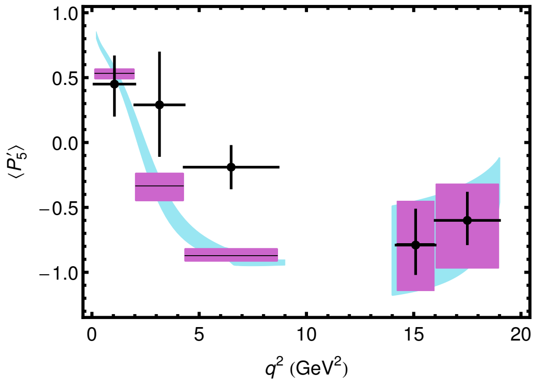
Consistency with other data: $P_4'^2(q_0^2) + P_5'^2(q_0^2) = 1 + \eta(q_0^2)$

with $\eta(q_0^2) \sim 10^{-3}$ if no RHC. Nicely fulfilled by many data points in the bin [4-6].

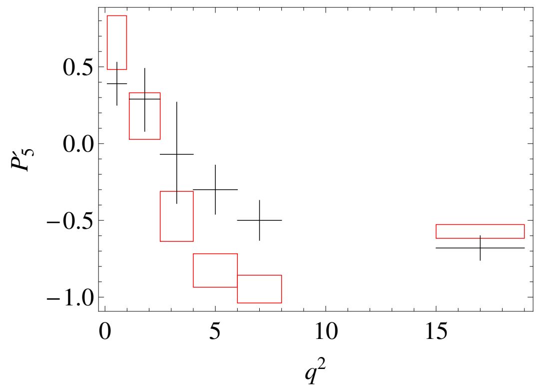
$\langle P_5'^{SM}\rangle_{[4,6]} = -0.82$	$\Delta C_7 = \pm 0.1$	$\Delta C_9 = \pm 1$	ΔC_{10}	$\Delta C_7'$	$\Delta C_9'$	$\Delta C_{10}'$
+	-0.11	-0.15	-0.10	-0.11	-0.06	$+0.21$
−	$+0.16$	$+0.28$	$+0.09$	$+0.15$	$+0.10$	-0.21

P'_5 in 2013 and 2015

2013 data:



2015 data:



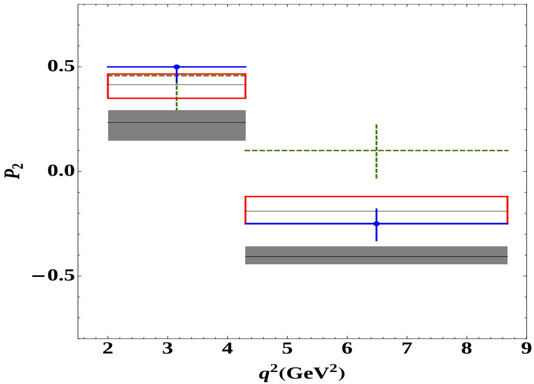
Example of error size of bin [4,6]: $-0.816^{+0.029+0.017+0.061+0.007+0.069}_{-0.061-0.017-0.060-0.008-0.082}$ (PAR+FF+FAC+NF+CHARM)

Consistency with other data: $P'^2_4(q_0^2) + P'^2_5(q_0^2) = 1 + \eta(q_0^2)$

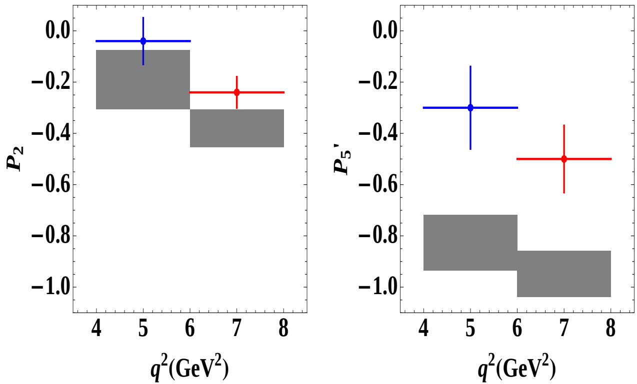
with $\eta(q_0^2) \sim 10^{-3}$ if no RHC. Nicely fulfilled by many data points in the bin [4-6].

$\langle P'^{SM}_5 \rangle_{[6,8]} = -0.94$	$\Delta C_7 = \pm 0.1$	$\Delta C_9 = \pm 1$	ΔC_{10}	$\Delta C'_7$	$\Delta C'_9$	$\Delta C'_{10}$
+	−0.04	−0.07	−0.07	−0.08	−0.08	+0.19
−	+0.07	+0.19	+0.09	+0.10	+0.11	−0.18

2013 data (to be updated):



2015 data:



Consistency test on data compare $\mathbf{P_2^{exp}}$ with $\mathbf{P_2 = f(P_1^{exp}, P_{4,5}^{\prime exp})}$ (assume: no new weak phases, scalars):

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

- If $P_2 = -\epsilon$ and $P_4' = 1 + \delta$ ($P_1 < -2\delta$) then $\mathbf{P_5' \leq -2\epsilon/(1+\delta)}$

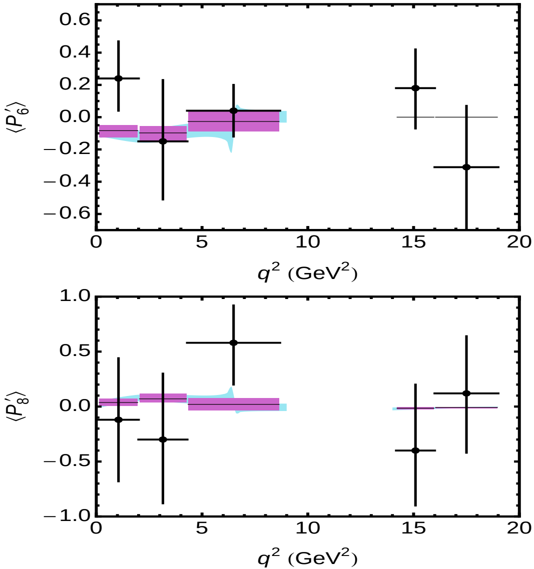
2013: $\langle P_2\rangle_{[4.3,8.68]} \sim -0.25$ and $\langle P_5'\rangle_{[4.3,8.68]} \sim -0.19$ approx. $\epsilon = -0.25$ and $\langle P_5'\rangle_{[4.3,8.68]} \leq -0.42$

2015: $\langle P_2\rangle_{[6,8]} \sim -0.24$ and $\langle P_5'\rangle_{[6,8]} \sim -0.5$ approx. $\epsilon = -0.24$ and $\langle P_5'\rangle_{[6,8]} \leq -0.4$

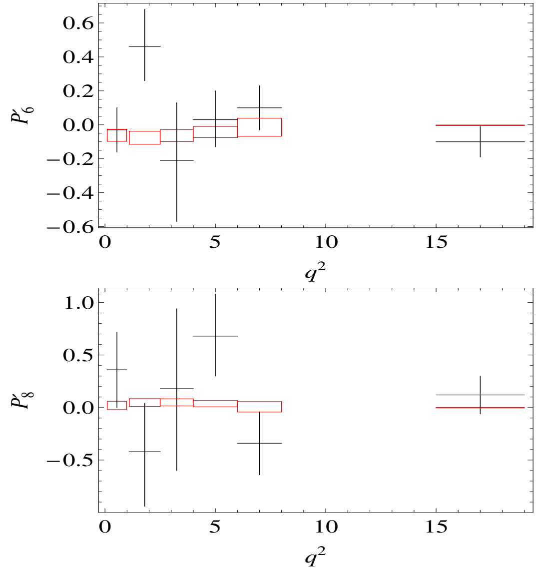
Now P_2 and P_5' bins have the expected order! (in both [4,6] and [6,8] bins)

The basis is completed by P_6' and P_8' observables (or P_3). They are sensitive to **new weak phases**.

2013 data:



2015 data:



They are quite compatible with SM, besides some local fluctuation.

Fit 2015: Standard χ^2 frequentist approach

Relevant Observables included: $B \to K^*\mu^+\mu^-$ ($P_{1,2}$, $P'_{4,5,6,8}$, F_L in all 5 large-recoil + low-recoil), $B^+ \to K^+\mu^+\mu^-$ and $B^0 \to K^0\mu^+\mu^-$, $\mathcal{B}_{B\to X_s\gamma}$, $\mathcal{B}_{B\to X_s\mu^+\mu^-}$, $\mathcal{B}_{B_S\to\mu^+\mu^-}$, $A_I(B \to K^*\gamma)$, $S_{K^*\gamma}$

Description of the method:

- minimisation of χ^2 in order to determine the confidence regions under different hypotheses
- computation of pulls to compare different NP hypotheses.

Result (VERY PRELIMINARY NO CORRELATIONS INCLUDED!!)

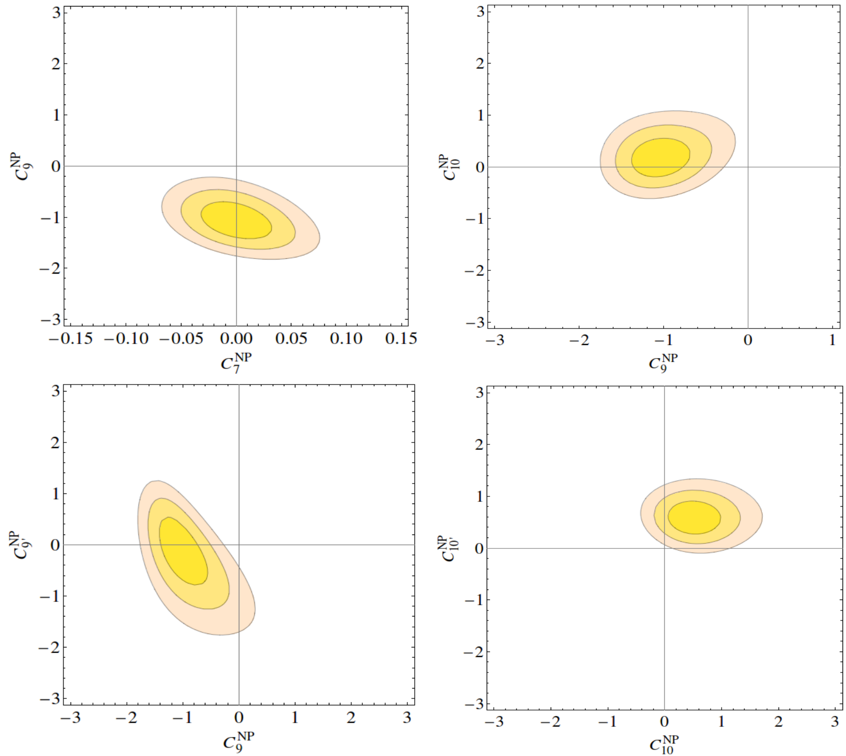
Hypothesis	Best fit	pull
$C_9^{\rm NP}$	-1.1	**4.6**
$C_{10}^{\rm NP}$	0.62	2.4
C'_9	-1.0	3.4
C'_{10}	0.61	3.3

Hypothesis	Best fit	pull
$C_9^{\rm NP} = -C_{10}^{\rm NP}$	-0.62	**4.0**
$C_9^{\rm NP} = C_{10}^{\rm NP}$	-0.37	1.7
$C'_9 = C'_{10}$	0.32	1.3
$C_9^{\rm NP} = C'_9$	-0.67	**4.3**
$C'_9 = -C'_{10}$	-0.42	3.6

Summary

- The best hypothesis is $C_9^{NP} < 0$
- Two other scenarios are also highlighted corresponding to different patterns of Z' couplings:
  - $C_9^{\rm NP} = -C_{10}^{\rm NP}$. (left-handed $\mu\mu$ and bs).
  - $C_9^{\rm NP} = C'_9$. (vector $\mu\mu$ and bs)

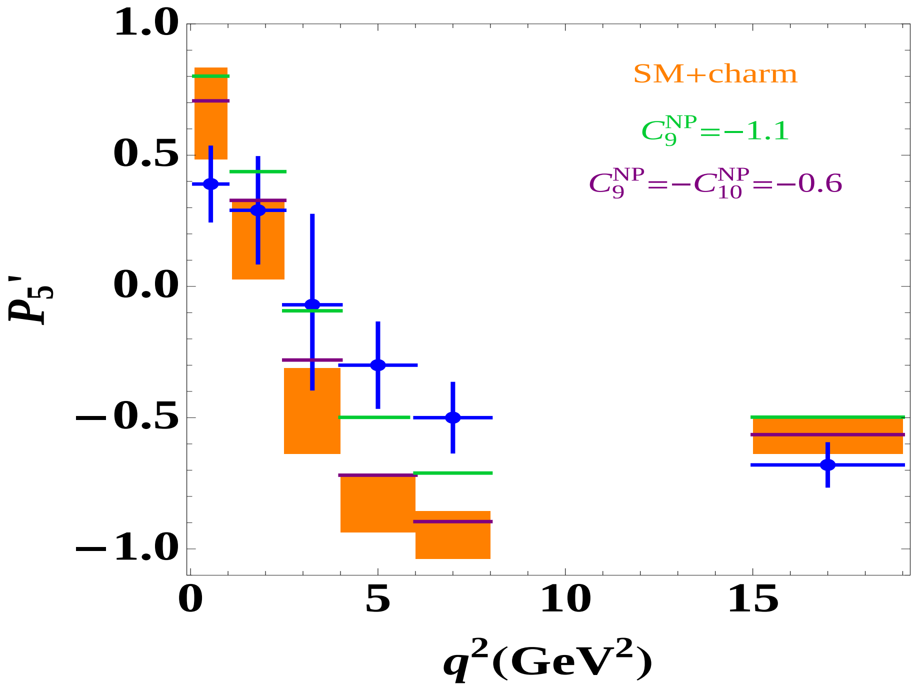
Letting two Wilson coefficients free



Be aware: Correlations (not yet included) possibly will have a large impact on these plots and the pulls!

Hypothesis	Best fit	pull
(C_7^{NP}, C_9^{NP})	(0.0, -1.1)	**4.2**
(C_9^{NP}, C_{10}^{NP})	(-1.1, 0.2)	**4.2**
(C_9^{NP}, C_9')	(-1.0, -0.1)	**4.2**
(C_{10}^{NP}, C_{10}')	(0.5, 0.6)	**3.4**

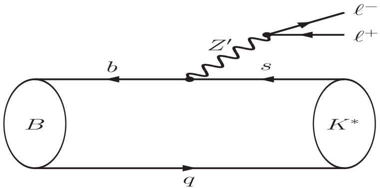
Again the main effect comes from C_9.

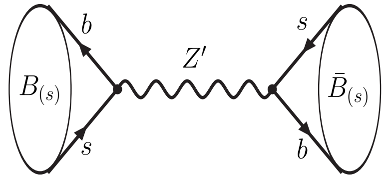


SM+charm means that we take KMPW adding long-distance charm (with both signs). Our third scenario (not in the plot) is in between the green and red NP predictions.

Z' particle couplings

- In DMV'13 we proposed 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:





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

notation from 1211.1896

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

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}.

Examples of the different scenarios for a $M_{Z'} = 1$ TeV:

- SC1: $C_9^{\rm NP} = -1.1$, $\Delta_V^{\mu\mu} = 0.6$ and $\Delta_L^{bs} = -0.003$
- SC2: $C_9^{\rm NP} = -C_{10}^{\rm NP} = -0.62$, LHC to quarks and leptons, $\Delta_V^{\mu\mu} = -\Delta_A^{\mu\mu} = 0.37$ and $\Delta_L^{bs} = -0.003$
- SC3: $C_9^{\rm NP} = C'_9 = -0.67$, VC to quarks and leptons, $\Delta_V^{\mu\mu} = 0.52$ and $\Delta_L^{bs} = \Delta_R^{bs} = -0.007$

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

Conclusions

- The anomaly in the third bin of P_5' has been nicely confirmed by LHCb with 3fb^{-1} data in two bins [4,6] and [6,8]. Also some shift in P_2 is observed.

- All consistency tests we have done so far are nicely fulfilled with 3 fb^{-1} showing robustness of data.

- A global analysis including all new 3 fb^{-1} data coming from $B \to K^* \mu\mu$, $B \to K \mu\mu$, $B_s \to \mu\mu$ and radiative confirms the solution $C_9^{\rm NP} < 0$ found with 1fb^{-1}, other alternative scenarios like $C_9^{\rm NP} = -C_{10}^{NP}$ or $C_9^{\rm NP} = C_9'$ also emerge.

  - Is this all within $B \to K^* \mu\mu$? Not yet, P_2 (zero and **maximum**) provides the most important cross check of the anomaly in P_5' and can help to disentangle NP from an hadronic effect. New bins and/or amplitude analysis can recover P_2^{max}. Stay tuned...

  - NP explanation: a Z′ particle remains a possibility to explain the observed discrepancies also in R_K (coupling only to μ)

- An hadronic effect in C_9 is mode dependent and q^2-dependent while $C_9^{\rm NP}$ is a global effect. A separate analysis of exclusive modes under the hypothesis that only C_9 gets a contribution can provide a consistency check of a global NP explanation. Already now the use of the [6,8] bin of 3fb^{-1} data in $B \to K^* \mu\mu$ challenges alternative explanations like a huge charm effect.

... when you have eliminated all the

Standard Model explanations, whatever remains,

however improbable, must be New Physics.

Inspired by A. Conan Doyle

not yet there but maybe not too far...stay tunned for 1 GeV^2 bins.

Other theoretical approaches:

2. "BZ-FF" approach: Compute correlations using a specific LCSR computation.

   ⇒ Factorizable $\mathcal{O}(\alpha_s)$ and factorizable p.c. included in a particular LCSR parametrization.
   ⇒ Result attached to a single form factor parametrization with all choices (Borel param.,..).
   ⇒ Extra pieces to be included/estimated in the predictions for S_i observables (used here):

   - known α_s non-factorizable corrections from QCDF.
   - non-factorizable power corrections and charm-quark loop effects

   Summary: Main cross check of no errors here requires to compare it with 1 (restricting 1 to the subclass of same LCSR).

3. "Lattice" approach. Naturally set up for large-q^2 but can be extend it to low-q^2.

   ⇒ More free from model dependences than 2.
   ⇒ Extrapolation at low-q^2 has to be done carefully.
   ⇒ Same additions as in 2 are required.

4. "Imperial" approach. This is 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.
   - The outcome is a set of parameters α, β, γ that contain the information on WC and FF.
   - They naturally produce unbinned results.