Optimizing the basis of $B \to K^* l^+ l^-$ in the full kinematic range

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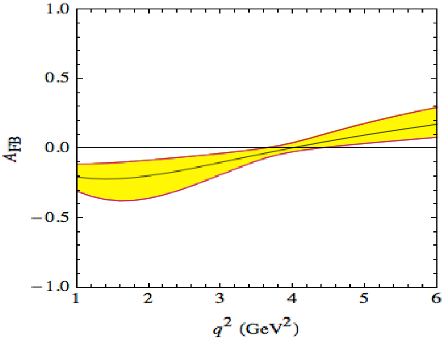
For a long time huge efforts were devoted (still now) to measure the position of the zero of the forward-backward asymmetry A_{FB} of $B \to K^* \mu^+ \mu^-$.



Reason:

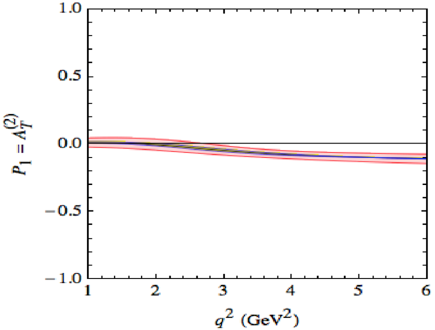
- At LO the soft form factor dependence cancels exactly at q_0^2 (dependence appears at NLO).
- A relation among $\mathbf{C_9^{eff}}$ and $\mathbf{C_7^{eff}}$ arises at the zero:

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

A similar idea was incorporated in the construction of the transverse asymmetry

[Kruger, J.M'05]

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



where $A_{\perp,||}$ correspond to two transversity amplitudes of the K^*.

- **Big advantage with respect to** A_{FB}: Cancellation of soft form factors at LO happens for all low-q^2 range ($0.1 - 6$ GeV^2) and not only at one point. **First example of a clean observable**.
- $A_\perp \sim -A_{||}$ in the SM ($A_T^{(2)} \sim 0$) due to its LH structure.
- $P_2 = -\frac{2A_{FB}}{3F_T} = \frac{1}{2}A_T^{re}$ is a clean version of A_{FB} with same information.

[Egede, Hurth, JM, Ramon, Reece'08, and '10]

• Later on a set of **transverse asymmetries** called $\mathbf{A_T^{(3,4,5)}}$ were proposed

$$\mathbf{A_T^{(3)}} = \frac{|A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R|}{\sqrt{|A_0|^2 |A_\perp|^2}} \quad \mathbf{A_T^{(4)}} = \frac{|A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R|}{|A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R|} \quad \mathbf{A_T^{(5)}} = \frac{|A_\perp^L A_\parallel^{R*} + A_\perp^{R*} A_\parallel^L|}{|A_\perp|^2 + |A_\parallel|^2}$$

[Bobeth, Hiller, Dyk,'10]

• Also at the low-recoil a set of clean observables called $\mathbf{H_T^{(1,2,3)}}$ were proposed that correspond to $P_{4,5,6}$ at large-recoil.

$$\mathbf{H_T^{(1)}} = \frac{\mathrm{Re}(A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R)}{\sqrt{|A_0|^2 |A_\parallel|^2}}, \quad \mathbf{H_T^{(2)}} = \frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R)}{\sqrt{|A_0|^2 |A_\perp|^2}}, \quad \mathbf{H_T^{(3)}} = \frac{\mathrm{Re}(A_\parallel^L A_\perp^{L*} - A_\parallel^{R*} A_\perp^R)}{\sqrt{|A_\parallel|^2 |A_\perp|^2}}$$

[Altmannshofer, Ball, Bharucha, Buras, Straub, Wick'09]

• Finally, a set of CP-conserving and CP-violating observables $\mathbf{S_i}$ and $\mathbf{A_i}$ were constructed directly from the coefficients of the distribution, easy to measure

$$\mathbf{S_i} = \frac{\int_{bin} dq^2 [J_i + \bar{J}_i]}{d\Gamma/dq^2 + d\bar{\Gamma}/dq^2}, \quad \mathbf{A_i} = \frac{\int_{bin} dq^2 [J_i - \bar{J}_i]}{d\Gamma/dq^2 + d\bar{\Gamma}/dq^2}.$$

but sensitive already at LO to hadronic form factor uncertainties.

All those observables comes from the decay $\mathbf{\bar{B}_d} \to \mathbf{\bar{K}^{*0}}(\to \mathbf{K}^- \pi^+)\mathbf{l}^+\mathbf{l}^-$ with the K^{*0} on the mass shell. It is described by $s = q^2$ and three angles $\theta_\mathbf{l}$, $\theta_\mathbf{K}$ and ϕ

$$\frac{d^4\Gamma(\bar{B}_d)}{dq^2\, d\cos\theta_l\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi} J(q^2, \theta_l, \theta_K, \phi)$$

The differential distribution splits in J_i coefficients:

$$J(q^2, \theta_l, \theta_K, \phi) =$$
$$J_{1s}\sin^2\theta_K + J_{1c}\cos^2\theta_K + (J_{2s}\sin^2\theta_K + J_{2c}\cos^2\theta_K)\cos 2\theta_l + J_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+ J_4\sin 2\theta_K\sin 2\theta_l\cos\phi + J_5\sin 2\theta_K\sin\theta_l\cos\phi + (J_{6s}\sin^2\theta_K + J_{6c}\cos^2\theta_K)\cos\theta_l$$
$$+ J_7\sin 2\theta_K\sin\theta_l\sin\phi + J_8\sin 2\theta_K\sin 2\theta_l\sin\phi + J_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\,.$$

The decay rate $\bar{\Gamma}(B_d)$ is obtained replacing within our conventions:

[Bobeth, Hiller, Piranishvili'08]

$$J_{1,2,3,4,7} \to \bar{J}_{1,2,3,4,7} \quad \text{and} \quad J_{5,6,8,9} \to -\bar{J}_{5,6,8,9}$$

The information on

- the helicity/transversity amplitudes of the K^* ($H_{\pm 1,0}$ or $A_{\perp,\|,0}$) is inside the coefficients J_i.
- short distance physics C_i is encoded in ($H_{\pm 1,0}$ or $A_{\perp,\|,0}$)

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

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

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

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

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

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

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

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

In red lepton mass terms.

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

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

Transformation of amplitudes leaving distribution invariant.

Symmetries determine the minimal # observables for each scenario:

$$n_{obs} = 2n_A - n_S$$

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

All symmetries (massive and scalars) were found explicitly later on.

[JM, Mescia, Ramon, Virto'12]

Symmetries $\Rightarrow$ # of observables $\Rightarrow$ determine a **basis**: each angular observable constructed can be expressed in terms of this basis.

Optimal basis of observables, a compromise between:

- *Excellent experimental accessibility and simplicity of the fit.*
- *Reduced FF dependence (in the low-q^2 (or large-recoil) region).*

Our proposal for **CP-conserving basis**:

$$\left\{ \frac{d\Gamma}{dq^2}, F_L, P_1, P_2, P_3, P_4', P_5', P_6' \right\}$$

where $P_1 = A_T^2$ [Kruger, J.M'05], $P_2 = \frac{1}{2} A_T^{\rm re}$, $P_3 = -\frac{1}{2} A_T^{\rm im}$ [Becirevic, Schneider'12] and $P'_{4,5,6}$ [Descotes, JM, Ramon, Virto'13])

and the corresponding **CP-violating basis**:

$$\left\{ A_{CP}, F_L^{CP}, P_1^{CP}, P_2^{CP}, P_3^{CP}, P_4'^{CP}, P_5'^{CP}, P_6'^{CP} \right\}$$

Besides one may include a redundant observable (in absence of scalars) $P_8' = Q'$ and a corresponding $P_8'^{CP}$.

There is a correspondence between $\mathbf{P_i^{(\prime)}}$ and $\mathbf{J_k}$ (β_ℓ^2 absorbed here in $F_{L,T}$)

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

$$\mathbf{J_3} + \mathbf{\bar{J}_3} = \frac{1}{2}\mathbf{P_1}\mathbf{F_T}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}} \qquad \mathbf{J_3} - \mathbf{\bar{J}_3} = \frac{1}{2}\mathbf{P_1^{CP}}\mathbf{F_T}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

$$\mathbf{J_{6s}} + \mathbf{\bar{J}_{6s}} = 2\mathbf{P_2}\mathbf{F_T}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}} \qquad \mathbf{J_{6s}} - \mathbf{\bar{J}_{6s}} = 2\mathbf{P_2^{CP}}\mathbf{F_T}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

$$\mathbf{J_9} + \mathbf{\bar{J}_9} = -\mathbf{P_3}\mathbf{F_T}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}} \qquad \mathbf{J_9} - \mathbf{\bar{J}_9} = -\mathbf{P_3^{CP}}\mathbf{F_T}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

$$\mathbf{J_4} + \mathbf{\bar{J}_4} = \frac{1}{2}\mathbf{P_4'}\sqrt{\mathbf{F_T F_L}}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}} \qquad \mathbf{J_4} - \mathbf{\bar{J}_4} = \frac{1}{2}\mathbf{P_4'^{CP}}\sqrt{\mathbf{F_T F_L}}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

$$\mathbf{J_5} + \mathbf{\bar{J}_5} = \mathbf{P_5'}\sqrt{\mathbf{F_T F_L}}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}} \qquad \mathbf{J_5} - \mathbf{\bar{J}_5} = \mathbf{P_5'^{CP}}\sqrt{\mathbf{F_T F_L}}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

$$\mathbf{J_7} + \mathbf{\bar{J}_7} = -\mathbf{P_6'}\sqrt{\mathbf{F_T F_L}}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}} \qquad \mathbf{J_7} - \mathbf{\bar{J}_7} = -\mathbf{P_6'^{CP}}\sqrt{\mathbf{F_T F_L}}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

where each $\mathbf{P_i^{(\prime)}}$ and $\mathbf{P_i^{(\prime)CP}}$ encodes the information that can be extracted *cleanly* at large-recoil inside each $\mathbf{J_k}$ and define the simplest possible fit besides S_i, A_i. The **brown** and **blue** pieces are strongly FF-dependent pieces.

Massive observables

- In the construction of the $P_{1,2,3}$, $P'_{4,5,6}$ *all m_ℓ corrections* are included.
- Still from the first couple of J's: $\mathbf{J_{1c}}$ and $\mathbf{J_{1s}}$ it is possible to construct a couple more of observables (and CP) to take into account their m_ℓ terms.
- The simplest way to do it is to define an extra $\mathbf{\hat{F}_T}$ and $\mathbf{\hat{F}_L}$ (FF dependent)

$$(\mathbf{J_{1s}} + \mathbf{\bar{J}_{1s}}) = \frac{3}{4}\mathbf{\hat{F}_T}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}} \qquad (\mathbf{J_{1c}} + \mathbf{\bar{J}_{1c}}) = \mathbf{\hat{F}_L}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

such that $\mathbf{\hat{F}_L}/\mathbf{F_L} = \frac{1}{\beta_\ell^2}(1 + \mathbf{M_2})$ and $\mathbf{\hat{F}_T}/\mathbf{F_T} = \frac{1}{3\beta^2}(2 + (1 + 4\mathbf{M_1})\beta_\ell^2)$.
Those $\mathbf{M_{1,2}}$ can be added to the basis.

Redundancy

- If no scalars are present there is one redundant observable ($P'_8 = Q'$, P'^{CP}_8)

$$\mathbf{J_8} + \mathbf{\bar{J}_8} = -\frac{1}{2}\mathbf{P'_8}\sqrt{\mathbf{F_T F_L}}\frac{\mathbf{d\Gamma + d\bar{\Gamma}}}{\mathbf{dq^2}}$$

$$P'_8 = \frac{2}{\sqrt{1-P_1}}\Big\{(P_2P_6 - P_3P_4) + \eta[(P_2P_6 - P_3P_4)^2 + P_5(P_2P_4 + P_3P_6)\sqrt{1-P_1^2} + \frac{1}{4}(1 - \sum_{i=4}^{6} P_i^2)(1-P_1^2) - P_2^2 - P_3^2]^{\frac{1}{2}}\Big\}$$

Folded distributions

BIG STEP: Substitute *uniangular distributions* $\to$ *folded distributions*

The **identification** of $\phi \leftrightarrow \phi + \pi$ $(\phi < 0)$ produces a "**folded**" angle $\hat{\phi} \in [0, \pi]$ in terms of which a (folded) differential rate $d\hat{\Gamma}(\hat{\phi}) = d\Gamma(\phi) + d\Gamma(\phi - \pi)$ is:

$$\frac{d^4\hat{\Gamma}}{dq^2\, d\cos\theta_K\, d\cos\theta_l\, d\hat{\phi}} = \frac{9}{16\pi}\Big[\mathbf{J_{1c}}\cos^2\theta_K + \mathbf{J_{1s}}(1-\cos^2\theta_K) +$$
$$+\mathbf{J_{2c}}\cos^2\theta_K\cos 2\theta_\ell + \mathbf{J_{2s}}(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + \mathbf{J_3}\sin^2\theta_K(1-\cos^2\theta_\ell)\cos 2\hat{\phi}$$
$$+\mathbf{J_{6s}}(1-\cos^2\theta_K)\cos\theta_\ell + \mathbf{J_9}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big]\mathbf{X} + \mathbf{W_1}$$

with

$$\mathbf{X} = \int dm^2_{K\pi}\,|BW_{K^*}(m^2_{K\pi})|^2$$

being a correction to consider the width of the resonance. **Advantages**:

- Folding reduces the # of coefficients to a manageable experimentally subset. In this case: 11 J + 8 $\tilde{J}$ $\to$ 7 J + 4 $\tilde{J}$
- Unwanted S-wave pollution has a distinct angular dependence:

$$\mathbf{W_1} = \frac{1}{2\pi}\left[\tilde{\mathbf{J}}^{\mathbf{c}}_{\mathbf{1a}} + \tilde{\mathbf{J}}^{\mathbf{c}}_{\mathbf{1b}}\cos\theta_K + \left(\tilde{\mathbf{J}}^{\mathbf{c}}_{\mathbf{2a}} + \tilde{\mathbf{J}}^{\mathbf{c}}_{\mathbf{2b}}\cos\theta_K\right)(2\cos^2\theta_\ell - 1)\right]$$

Or in terms of observables generalizing LHCb note (CONF-2012-008) to include lepton mass corrections and the S-wave pollution in a minimal form [JM'12]

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_K\, d\cos\theta_l\, d\hat{\phi}} = \frac{9}{16\pi}\Big[\hat{\mathbf{F}}_{\mathbf{L}}\cos^2\theta_K + \frac{3}{4}\hat{\mathbf{F}}_{\mathbf{T}}(1-\cos^2\theta_K) - \mathbf{F}_{\mathbf{L}}\cos^2\theta_K\cos 2\theta_\ell$$
$$+\frac{1}{4}\mathbf{F}_{\mathbf{T}}(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + \frac{1}{2}\mathbf{P}_{\mathbf{1}}\mathbf{F}_{\mathbf{T}}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi}$$
$$+2\mathbf{P}_{\mathbf{2}}\mathbf{F}_{\mathbf{T}}(1-\cos^2\theta_K)\cos\theta_\ell - \mathbf{P}_{\mathbf{3}}\mathbf{F}_{\mathbf{T}}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big]\frac{\mathbf{d\Gamma_{K*}}}{\mathbf{dq^2}} + \mathbf{W_1}$$

where

$$\frac{\mathbf{d\Gamma_{K*}}}{\mathbf{dq^2}} = \frac{1}{4}(3J_{1c} + 6J_{1s} - J_{2c} - 2J_{2s})\mathbf{X}$$

Notation: β_ℓ^2 is included inside $F_{L,T}$ ($F_{L,T} = \beta_\ell^2 \tilde{F}_{L,T}$ as compared to notation [JM'12]) and the P_i are the massive versions defined previously (for instance P_2 corresponds to $P_2^{m_\ell\neq 0}$ in [JM'12]).

- An intermediate massless-improved limit can be easily defined by

$$\hat{F}_T \to \frac{F_T}{\beta_\ell^2}, \qquad \hat{F}_L \to 1 - \frac{F_T}{\beta_\ell^2}$$

where the error induced by this approximation is below 2%.

In this improved limit 6 observables (one less): $\{\ F_{L,T},\ P_{1,2,3},\ \frac{d\Gamma_{K*}}{dq^2}\ \} + 4\ \tilde{J}$

Other double folded distributions can be **more selective** and allow to extract other sets of observables of the optimal basis. For examples: [JM'12]

Identify $\phi \leftrightarrow -\phi$ ($\phi < 0$) and $\theta_\ell \leftrightarrow \theta_\ell - \frac{\pi}{2}$ ($\theta_\ell > \frac{\pi}{2}$) with $\hat{\phi} \in [0, \pi]$, $\hat{\theta}_\ell \in [0, \pi/2]$ and the corresponding folded distribution is:

$$d\hat{\Gamma} = d\Gamma(\hat{\phi}, \hat{\theta}_\ell, \theta_K) + d\Gamma(\hat{\phi}, \hat{\theta}_\ell + \frac{\pi}{2}, \theta_K) + d\Gamma(-\hat{\phi}, \hat{\theta}_\ell, \theta_K) + d\Gamma(-\hat{\phi}, \hat{\theta}_\ell + \frac{\pi}{2}, \theta_K)$$

$$\frac{d^4\hat{\Gamma}}{dq^2\, d\cos\theta_K\, d\cos\hat{\theta}_l\, d\hat{\phi}} = \frac{9}{32\pi}\Big[\frac{1}{2}(4\mathbf{\hat{F}_L} + 3\mathbf{\hat{F}_T} + (4\mathbf{\hat{F}_L} - 3\mathbf{\hat{F}_T})\cos 2\theta_K) +$$
$$+ 2\sqrt{\mathbf{F_L F_T}}\mathbf{P'_5}\cos\hat{\phi}\sin 2\theta_K(\sin\hat{\theta}_\ell + \cos\hat{\theta}_\ell) +$$
$$+ \mathbf{F_T}\sin^2\theta_K(\mathbf{P_1}\cos 2\hat{\phi} + 4\mathbf{P_2}(\cos\hat{\theta}_\ell - \sin\hat{\theta}_\ell))\Big]\frac{\mathbf{d\Gamma_{K*}}}{\mathbf{dq^2}} + \mathbf{W_{13}}$$

where $\mathbf{W_{13}} = \frac{1}{2\pi}\left[2\tilde{J}^c_{1a} + 2\tilde{J}^c_{1b}\cos\theta_K + \tilde{J}_5\cos\hat{\phi}\sin\theta_k(\cos\hat{\theta}_\ell + \sin\hat{\theta}_\ell)\right]$

Again $\mathbf{F_{L,T}}$ absorbed a β_ℓ^2 piece and $\mathbf{P_2}$ and $\mathbf{P'_5}$ are the massive version.

Form Factor Treatment

Large-recoil

- ET: QCDF/SCET. Soft form factors $\xi_{\perp,\parallel}(q^2)$ from

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

  - q^2-dependence of form factors is reproduced using a SE with single pole.
  - FF at $q^2 = 0$ and slope parameters are computed by [Khodjamirian et al.'10] (**KMPW**) using light-cone sum rules.

The wide spread of different errors in literature associated to FF:

$V(0) = 0.31 \pm 0.04$ and $A(0) = 0.33 \pm 0.03$ [W. Altmannshofer et al.'09]
$V(0) = 0.36 \pm 0.17$ and $A(0) = 0.29 \pm 0.10$ [A. Khodjamirian et al. '10].
Even central values have shifted significantly, for instance $V(0) = 0.41 \pm 0.05$ [P. Ball and R. Zwicky,'05] (**BZ**).

It is essential to be conservative: We choose KMPW in our analysis since all other parametrizations for $V, A_{1,2}(q^2)$ always fall inside error bars of KMPW.

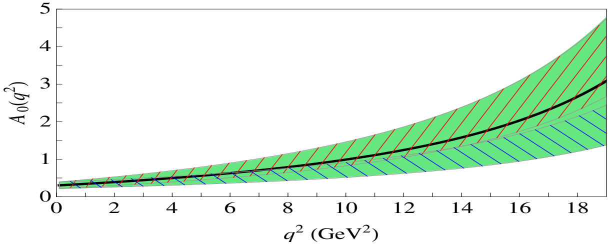
Once $\xi_\perp(q^2)$ and $\xi_\parallel(q^2)$ are defined all form factors follow

$$A_1(q^2) = \frac{2E}{m_B + m_{K^*}}\xi_\perp(q^2) + \Delta A_1 + \mathcal{O}(\Lambda/m_b)$$

$$A_2(q^2) = \frac{m_B}{m_B - m_{K^*}}[\xi_\perp(q^2) - \xi_\parallel(q^2)] + \frac{m_B}{2E}\frac{m_B + m_{K^*}}{m_B - m_{K^*}}\Delta A_1 + \mathcal{O}(\Lambda/m_b)$$

$$A_0(q^2) = \frac{E}{m_{K^*}}\frac{\xi_\parallel(q^2)}{\Delta_\parallel(q^2)} + \mathcal{O}(\Lambda/m_b)$$

$A_{1,2}(q^2)$ have good agreement with KMPW. But $A_0(q^2)$ require an enlarged error bar to get agreement between both determinations (enters only A_t).



Tensor form factors $\mathcal{T}_{\perp,\parallel}$ are computed in QCDF following [Beneke, Feldmann, Seidel'01,'05] including factorizable and non-factorizable contributions.

Low-recoil

- LCSR are valid up to $q \leq 14$ GeV^2. We extend FF determination [Bobeth & Hiller & Dyk'10] till 19 Gev^2 and cross check the consistency with **lattice** QCD. In HQET one expects the ratios to be near one

$$\mathbf{R_1} = \frac{\mathbf{T_1(q^2)}}{\mathbf{V(q^2)}}\,, \qquad \mathbf{R_2} = \frac{\mathbf{T_2(q^2)}}{\mathbf{A_1(q^2)}}\,, \qquad \mathbf{R_3} = \frac{q^2}{m_B^2}\frac{T_3(q^2)}{A_2(q^2)}\,.$$

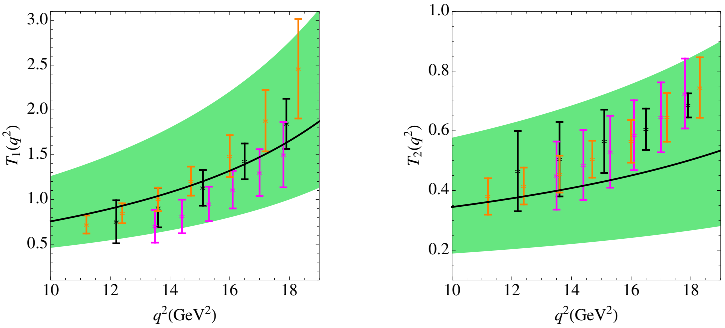
- BZ was problematic with R_3.

Indeed R_3 originates from the scaling laws of form factors [Grinstein, Pirjol'04] and it is a bit more complicated:

$$R_3{}^{GP} = \frac{q^2}{m_B^2}\frac{T_3}{2\frac{m_V}{m_B}\mathbf{A_0(q^2)} - \left(1+\frac{m_V}{m_B}\right)\mathbf{A_1(q^2)} + \left(1-\frac{m_V}{m_B}\right)\mathbf{A_2(q^2)}}\,.$$

If one applies strictly the different order in m_b of FF in the denominator then $R_3^{GP} \to R_3$ However effectively the three terms are numerically competing. For this reason we prefer **not to use** nor R_3 neither R_3^{GP} to get T_3 from A_2.

Our approach: we determine $T_{1,2}$ by exploiting the ratios $R_{1,2}$ allowing for up to a 20% breaking, i.e., $R_{1,2} = 1 + \delta_{1,2}$. All other form factors extrapolated from KMPW.

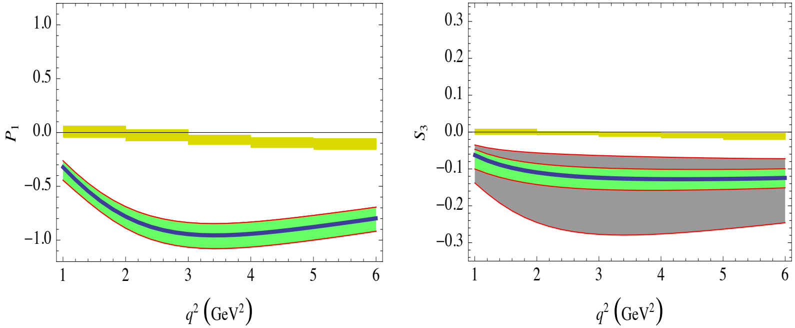


- We find excellent agreement between our determination of $T_{1,2}$ using $R_{1,2}$ and lattice data.
- This serves as a test of validity of the extrapolation of KMPW for $V(q^2)$ and $A_1(q^2)$.
- T_3 only in $A_0^{L,R}$ and multiplied by $\lambda(q^2)$ such that vanishes at the no-recoil endpoint $\rightarrow$ T_3 plays only a marginal role.

The benefit of using clean observables: The case of S_3 vs P_1

The choice at large-recoil of FF (KMPW or BZ) has a marginal impact on clean observables, but an important one (in presence of NP) for LO-FF dependent observables (like S_3).

- The SM prediction for P_1 is insensitive to the choice of form factors. Also S_3 is insensitive due to the fact that $S_3 \sim 0$.
- The NP predictions for P_1 is insensitive to the choice of form factors. S_3 is very sensitive and the hadronic form factors x3, reducing the ability of S_3 to disentangle among different NP curves. FF code: **BZ**, **KMPW**:



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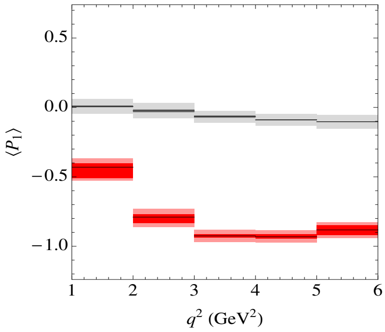
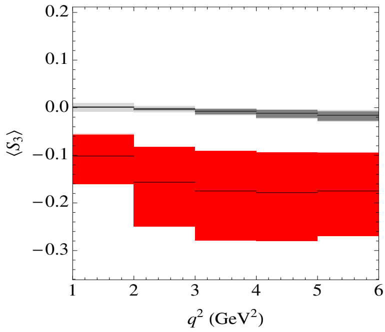


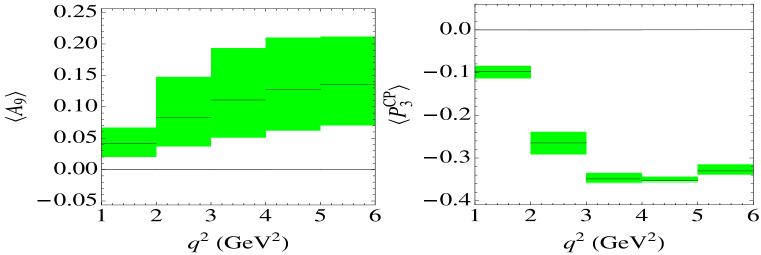


[S.Descotes, T. Hurth, JM, J. Virto'13]

Similar conclusion arises in CP violating observables. Let's focus on J_9 in the **large-recoil region**. We can construct:

$$\mathbf{A_9} = \frac{[J_i - \bar{J}_i]}{d\Gamma/dq^2 + d\bar{\Gamma}/dq^2} \qquad \mathbf{P_3^{\rm CP}} = -\frac{1}{4}\frac{[J_9 - \bar{J}_9]}{[J_{2s} + \bar{J}_{2s}]}$$

where $P_3^{\rm CP}$ is clean and A_9 is sensitive to FF at LO. Take a point of NP $\delta C'_{10} = -1.5 + 2i$ and compute the binned observables with KMPW.

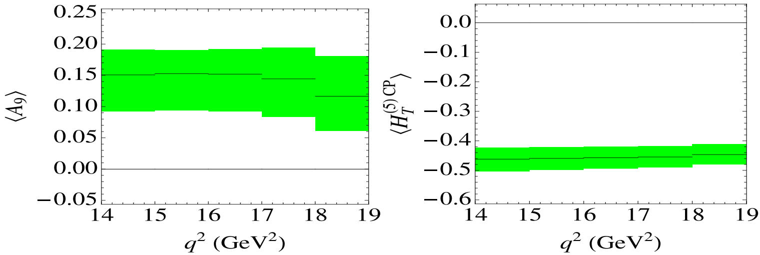


The difference in sensitivity to NP for the same point of NP is self-evident in favor of P_3^{CP}

Similar conclusion arises in CP violating observables. Let's focus on J_9 in the **low-recoil region**. We can construct:

$$\mathbf{A_9} = \frac{[J_i - \bar{J}_i]}{d\Gamma/dq^2 + d\bar{\Gamma}/dq^2} \qquad \mathbf{H_T^{(5)\mathrm{CP}}} = -\frac{[J_9 - \bar{J}_9]}{\sqrt{4([J_{2s} + \bar{J}_{2s}])^2 - ([J_3 + \bar{J}_3])^2}}$$

where P_3^{CP} is clean and A_9 is sensitive to FF at LO. Take a point of NP $\delta C'_{10} = -1.5 + 2i$ and compute the binned observables with KMPW.



In conclusion P_3^{CP} and $H_T^{(5)\mathrm{CP}}$ are much more sensitive to NP than A_9 due to their reduced hadronic uncertainties.

Integrated observables

Contact theory and experiment:

Indeed the observables are measured in bins.

Present bins: [0.1,2], [2,4.3], [4.3,8.68], [1,6], [14.18,16], [16,19] GeV^2.

Comments on the bins:

- Ultralow bin region **[0.1,1]** including light-resonances analyzed in [S. Jager, JM Camalich]'12. Binning tends to wash out the resonances.
- The region $q^2 \sim 6 - 8.68$ GeV^2 can be affected by charm-loop effects. [Khodjamirian, Mannel, Pivovarov, Wang'10]
- The middle bin $[\mathbf{10.09}, \mathbf{12.89}]$ GeV^2 between J/Ψ and $\Psi(2s)$. Charm-loop effects lead to a destructive interference (raw estimate). We treat it as a simple interpolation.
- Suggestion to experimentalists on binning: **[1,2], [2,4.3], [4.3,6]**

Integrated observables

Contact theory and experiment:

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This requires a **redefinition** of observables in **bins**:

$$\left\langle A_T^{(2)} \right\rangle_{\rm bin} \equiv \langle P_1 \rangle_{\rm bin} = \frac{\int_{\rm bin} dq^2 [J_3 + \bar{J}_3]}{2 \int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]} = \frac{\int_{\rm bin} dq^2 F_T \mathbf{P_1} \frac{d\Gamma + d\bar{\Gamma}}{dq^2}}{\int_{\rm bin} dq^2 F_T \frac{d\Gamma + d\bar{\Gamma}}{dq^2}},$$

$$\langle P_2 \rangle_{\rm bin} = \frac{\int_{\rm bin} dq^2 [J_{6s} + \bar{J}_{6s}]}{8 \int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]} = \frac{\int_{\rm bin} dq^2 F_T \mathbf{P_2} \frac{d\Gamma + d\bar{\Gamma}}{dq^2}}{\int_{\rm bin} dq^2 F_T \frac{d\Gamma + d\bar{\Gamma}}{dq^2}},$$

$$\langle P_3 \rangle_{\rm bin} = -\frac{\int_{\rm bin} dq^2 [J_9 + \bar{J}_9]}{4 \int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]} = \frac{\int_{\rm bin} dq^2 F_T \mathbf{P_3} \frac{d\Gamma + d\bar{\Gamma}}{dq^2}}{\int_{\rm bin} dq^2 F_T \frac{d\Gamma + d\bar{\Gamma}}{dq^2}}.$$

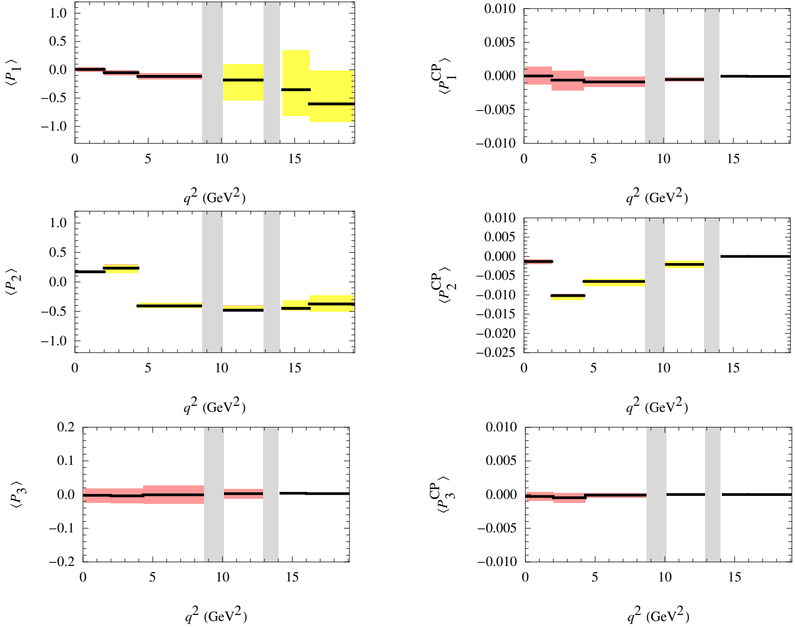
where β_ℓ^2 is included in F_T. Similar definitions for $\left\langle P_i^{CP} \right\rangle_{\rm bin}$ with $J_i - \bar{J}_i$.

They are indirectly measured via S_3, A_{im}, A_{FB}, F_L

(**and already provide constraints**).

BUT it is urgent to get direct experimental measurements of $P_{1,2,3}$ (preliminary results on $P_{1,2}$ last week)

Binned SM predictions for $\langle P_{1,2,3} \rangle$ and $\left\langle P_{1,2,3}^{(\mathrm{CP})} \right\rangle$ arXiv:1303.5794



The integrated version of observables $P'_{4,5,6}$ are defined by

$$\langle P'_4 \rangle_{\rm bin} = \frac{1}{\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_4 + \bar{J}_4] \,, \quad \left\langle P_4'^{CP} \right\rangle_{\rm bin} = \frac{1}{\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_4 - \bar{J}_4] \,,$$

$$\langle P'_5 \rangle_{\rm bin} = \frac{1}{2\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_5 + \bar{J}_5] \,, \quad \left\langle P_5'^{CP} \right\rangle_{\rm bin} = \frac{1}{2\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_5 - \bar{J}_5] \,,$$

$$\langle P'_6 \rangle_{\rm bin} = \frac{-1}{2\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_7 + \bar{J}_7] \,, \quad \left\langle P_6'^{CP} \right\rangle_{\rm bin} = \frac{-1}{2\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_7 - \bar{J}_7] \,,$$

where the normalization $\mathcal{N}'_{bin}$ is defined as

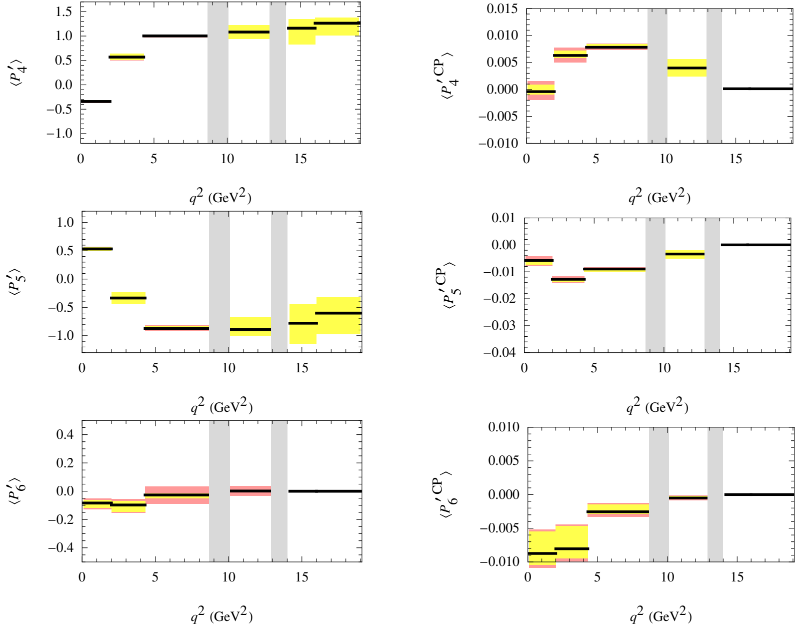
$$\mathcal{N}'_{bin} = \sqrt{- \int_{bin} dq^2 [J_{2s} + \bar{J}_{2s}] \int_{\rm bin} dq^2 [J_{2c} + \bar{J}_{2c}]} \,.$$

- They are **not yet measured** but the **double-folded distributions** give access to these observables.
- There is also a **redundant** clean observable $P'_8 = Q'$ (if there are no scalars) associated to J_8 that can be introduced for practical reasons:

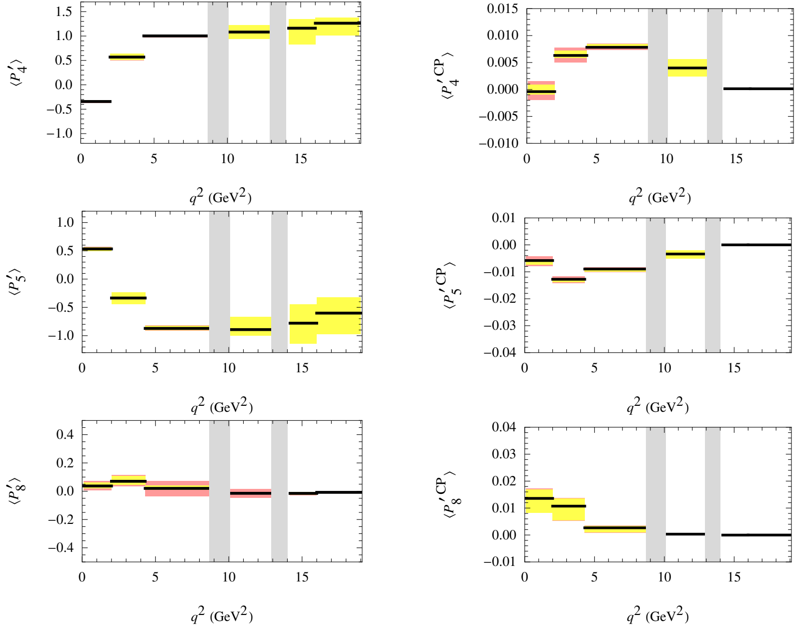
$$\langle P'_8 = Q' \rangle_{\rm bin} = \frac{-1}{\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_8 + \bar{J}_8] \,, \quad \left\langle P_8'^{CP} \right\rangle_{\rm bin} = \frac{-1}{\mathcal{N}'_{bin}} \int_{\rm bin} dq^2 [J_8 - \bar{J}_8] \,.$$

Notice that $Q' = f(P_i)$ **but** $\langle Q' \rangle_{\rm bin} \neq f(\langle P_i \rangle_{\rm bin})$.

Binned SM predictions for $\left\langle P'_{4,5,6} \right\rangle$ and $\left\langle P'^{(\mathrm{CP})}_{4,5,6} \right\rangle$ arXiv:1303.5794



Binned SM predictions for $\left\langle P'_{4,5,8} \right\rangle$ and $\left\langle P'^{(\mathrm{CP})}_{4,5,8} \right\rangle$ arXiv:1303.5794



S-wave pollution

[S. Descotes, T. Hurth, JM, J. Virto'13], [J.M'12]

- Another possible source of uncertainty is the **S-wave contribution** coming from $B \to K_0^* l^+ l^-$ decay. [Becirevic, Tayduganov '13], [Blake et al.'13]
- We will assume that both P and S waves are described by q^2-dependent FF times a Breit-Wigner function.
- The **distinct** angular dependence of the S-wave terms in **folded** distributions allow to disentangle the signal of the P-wave from the S-wave: $P_i^{(\prime)}$ *can be* **disentangled** *from S-wave pollution* [JM'12].

Problem: Changing the normalization used for the distribution from

$$\frac{d\Gamma_K^*}{dq^2} \equiv \Gamma'_{K^*} \to \Gamma'_{full}$$

introduces a $(1 - \mathbf{F_S})$ in front of the P-wave.

$$\Gamma'_{full} = \Gamma'_{K^*} + \Gamma'_S$$

and the longitudinal polarization fraction associated to Γ'_S is

$$\mathbf{F_S} = \frac{\Gamma'_S}{\Gamma'_{full}} \quad \text{and} \quad 1 - \mathbf{F_S} = \frac{\Gamma'_{K^*}}{\Gamma'_{full}}$$

The modified distribution including the **S-wave** and new normalization Γ'_{full}:

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

in the massless case and where the polluting terms are

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

We can get **bounds** on the size of the S-wave polluting terms.
Let's take for instance A_S

$$\mathbf{A_S} = 2\sqrt{3}\frac{1}{\Gamma'_{full}}\int \mathrm{Re}\left[({A'_0}^L A_0^{L*} + {A'_0}^R A_0^{R*}) BW_{K_0^*}(m^2_{K\pi}) BW^\dagger_{K^*}(m^2_{K\pi})\right] dm^2_{K\pi}$$

where

$$\mathbf{F_S} = \frac{8}{3}\frac{\tilde{J}^c_{1a}}{\Gamma'_{full}} = \frac{|{A'_0}^L|^2 + |{A'_0}^R|^2}{\Gamma'_{full}}\mathbf{Y} \qquad \mathbf{Y} = \int dm^2_{K\pi} |BW_{K_0^*}(m^2_{K\pi})|^2$$

Y factor included to take into account the width of scalar resonance K_0^*

A bound is obtained once we define the $S-P$ interference integral

$$\mathbf{Z} = \int \left| BW_{K_0^*}(m^2_{K\pi}) BW^\dagger_{K^*}(m^2_{K\pi})\right| dm^2_{K\pi}$$

and use the bound from the Cauchy-Schwartz inequality

$$\left|\int (\mathrm{Re},\mathrm{Im}) \left[({A'_0}^L A_j^{L*} \pm {A'_0}^R A_j^{R*}) BW_{K_0^*}(m^2_{K\pi}) BW^\dagger_{K^*}(m^2_{K\pi})\right] dm^2_{K\pi}\right| \leq \mathbf{Z} \times \sqrt{[|{A'_0}^L|^2 + |{A'_0}^R|^2][|A_j^L|^2 + |A_j^R|^2]}$$

From the definitions of $\mathbf{F_S}$ and $\mathbf{F_L}$ and $\mathbf{P_1}$ one gets the following bound:

$$|\mathbf{A_S}| \leq 2\sqrt{3}\sqrt{\mathbf{F_S}(1-\mathbf{F_S})\mathbf{F_L}}\,\frac{\mathbf{Z}}{\sqrt{\mathbf{XY}}}$$

the factor $(1-F_S)$ in the bound arises due to the fact that $\mathbf{F_L}$ is defined with respect to Γ'_{K*} rather than Γ'_{full}.

$$\begin{aligned}
|\mathbf{A_S^4}| &\leq \sqrt{\frac{3}{2}}\sqrt{\mathbf{F_S}(1-\mathbf{F_S})(1-\mathbf{F_L})\left(\frac{1-\mathbf{P_1}}{2}\right)}\,\frac{\mathbf{Z}}{\sqrt{\mathbf{XY}}} \\
|\mathbf{A_S^5}| &\leq 2\sqrt{\frac{3}{2}}\sqrt{\mathbf{F_S}(1-\mathbf{F_S})(1-\mathbf{F_L})\left(\frac{1+\mathbf{P_1}}{2}\right)}\,\frac{\mathbf{Z}}{\sqrt{\mathbf{XY}}} \\
|\mathbf{A_S^7}| &\leq 2\sqrt{\frac{3}{2}}\sqrt{\mathbf{F_S}(1-\mathbf{F_S})(1-\mathbf{F_L})\left(\frac{1-\mathbf{P_1}}{2}\right)}\,\frac{\mathbf{Z}}{\sqrt{\mathbf{XY}}} \\
|\mathbf{A_S^8}| &\leq \sqrt{\frac{3}{2}}\sqrt{\mathbf{F_S}(1-\mathbf{F_S})(1-\mathbf{F_L})\left(\frac{1+\mathbf{P_1}}{2}\right)}\,\frac{\mathbf{Z}}{\sqrt{\mathbf{XY}}}
\end{aligned}$$

Coefficient	Large recoil ∞ Range	Low recoil ∞ Range	Large Recoil Finite Range	Low Recoil Finite Range
$\lvert A_S \rvert$	0.33	0.25	0.67	0.49
$\lvert A_S^4 \rvert$	0.05	0.10	0.11	0.19
$\lvert A_S^5 \rvert$	0.11	0.11	0.22	0.23
$\lvert A_S^7 \rvert$	0.11	0.19	0.22	0.38
$\lvert A_S^8 \rvert$	0.05	0.06	0.11	0.11

Table : Illustrative values of the size of the bounds for the choices of F_S, F_L, P_1 and $\mathbf{F} = \mathbf{Z}/\sqrt{\mathbf{XY}}$

- **Large-recoil**: $F_S \sim 7\%$ (like $B^0 \to J/\psi K^+\pi^-$), $F_L \sim 0.7$ and $P_1 \sim 0$
- **Low-recoil**: $F_S \sim 7\%$, $F_L \sim 0.38$ and $P_1 \sim -0.48$.

We take the maximal value for $Z/\sqrt{XY}$ factor in two cases:

"infinite range" $\to$ integrals in the whole $m_{K\pi}$ range

"finite range" $\to$ integrals around $m_{K^*} \pm 0.1$ GeV.

This may help in estimating the **systematics** associated to S-wave.

All these analyses have a clear goal: To get tight constraints on the WC and/or discover NP.

Discussion on constraints on WC from radiative and leptonic B decays should be addressed in a given framework, specific scenarios & observables

S. Descotes, D. Ghosh, JM., M. Ramon, '11

- Framework: NP in C_7, C_9, C_{10} and $C_{7'}, C_{9'}, C_{10'}$ [chirally-flipped operators $\gamma_5 \to -\gamma_5$] as a real shift in the Wilson coefficients
- Scenarios (depending on the specific model)
  - A : NP in 7,7' only
  - B : NP in 7,7', 9,10 only
  - B': NP in 7,7', 9',10' only
  - C : NP in 7,7',9,10,9',10' only
- Classes within a Framework
  - I: observables sensitive only to 7,7'
  - II: observables sensitive only to 7,7',9,9',10,10'
  - III: observables sensitive to 7,7',9,9',10,10' and more (scalars...)

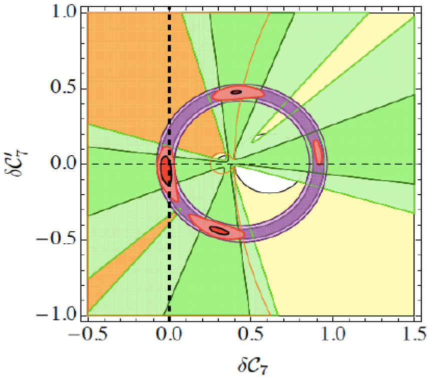
Other model-independent analysis:

Bobeth, Hiller, van Dyk 1105.0376
Altmannshofer, Paradisi, Straub 1111.1257
Bobeth, Hiller, van Dyk,Wacker 1111.2558
Beaujean, Bobeth, van Dyk,Wacker 1205.1838
Altmannshofer, Straub 1206.0273
Becirevic, Kou, Le Yaouanc,Tayduganov 12061502
....

Also specific model analysis:

M. Blanke, B. Shakya, P. Tanedo, Y. Tsai, 1203.6650
F. Mahmoudi, S. Neshatpour and J. Orloff, 1205.1845
Nejc Kosnik, 1206.2970
T. Hurth and F. Mahmoudi, 1207.0688
....

$\delta C_7 - \delta C_{7'}$ plane : constraints at 68.3% and 95.5% C.L.



S. Descotes, JM., J. Virto, M. Ramon '12

Class I observables (only $O_{7,7'}$)

dark 68.3%, light 95.5% CL

- A_I (yellow)
- B($B \to X_s\gamma$) (purple)
- $S_{K^*\gamma}$ (green)

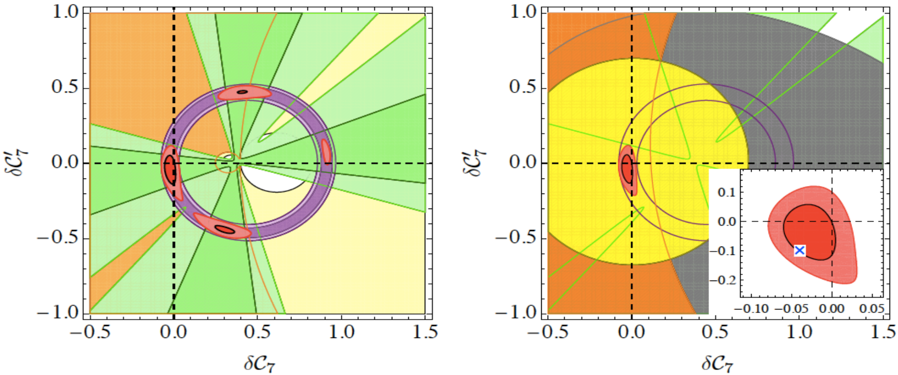
Overlap regions (red dark and light)

- Region around SM favoured: solid black countour red dark $(\delta C_7, \delta C_{7'}) \sim (0,0)$.
- three non-SM solutions also allowed $(\delta C_7, \delta C_{7'}) \simeq (-C_7^{SM}, \pm 0.4), (0.9, 0)$

- A_I disfavours at 68.3% CL changed-sign solution $(C_7, C_{7'}) = (C_7^{SM} + 0.9, 0)$

  $\Longrightarrow$Same conclusion as [Gambino, Haisch, Misiak], without using Class-III $B \to X_s \ell^+\ell^-$. Constraints independent of other WCs.

Scenario A ($C_{7,7'}$) : class I and class-III observables



$\Longrightarrow$class-III observables ($< A_{\mathrm{FB}} >_{[1,6]}$, $< F_{\mathrm{L}} >_{[1,6]}$, $\mathrm{BR}(B \to X_s l^+ l^-)$) constrain further the shifts $\delta C_7, \delta C_{7'}$ (if all other NP WC to zero))

- $\mathrm{BR}(B \to X_s \mu^+ \mu^-)$ favours SM-like region and two non-SM regions.
- $< A_{\mathrm{FB}} >_{[1,6]}$ selects SM region and one non-SM region. $< F_{\mathrm{L}} >_{[1,6]}$ does not discriminate any region.
- All combined observables disfavour changed sign solution at more than 95.5 % CL

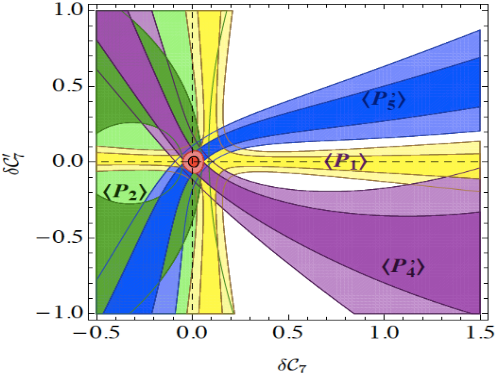


Figure : Individual constraints in the $\delta\mathcal{C}_7 - \delta\mathcal{C}'_7$ plane from hypothetical measurements of the observables $\langle P_1\rangle_{[2,4.3]}$, $\langle P_2\rangle_{[2,4.3]}$, $\langle P'_4\rangle_{[2,4.3]}$ and $\langle P'_5\rangle_{[2,4.3]}$, corresponding to central values equal to the SM predictions and an experimental uncertainty $\sigma_{exp} = 0.10$. The combined 68.3% (dark red) and 95.5% (light red) C.L. regions are also shown.

Conclusions

- We have presented an optimal basis of CP-conserving and CP-violating observables and computed their SM predictions in both large and low recoil regions:

$$\left\{ \frac{d\Gamma}{dq^2}, A_{FB} \text{ or } F_L, P_1, P_2, P_3, P'_4, P'_5, P'_6 \right\}$$

  and the corresponding **CP-violating basis**:

$$\left\{ A_{CP}, A_{FB}^{CP} \text{ or } F_L^{CP}, P_1^{CP}, P_2^{CP}, P_3^{CP}, P_4^{\prime CP}, P_5^{\prime CP}, P_6^{\prime CP} \right\}$$

  where one can add also the massive $M_{1,2}$. They can be measured using folded distributions. **It is important to get them all measured!!**.

- We have discussed and show explicitly the benefits of using clean observables to disentangle possible NP (both for CP conserving and violating observables).

- We provide first bounds on the S-wave polluting terms coming from the interference between S and P waves originating from the companion decay $B \to K_0^* \mu^+ \mu^-$ important to evaluate the systematic errors.

- $P_{1,2,3}$, $P'_{4,5,6}$ can produce the strongest constraints on WC $\to$ slice parameters space of models or signal New Physics in a clear way.

BACK-UP SLIDES

General Considerations for the Construction of Clean Observables

- J_i contain short distance Wilson coefficients ($C^{(\prime)}_{7,9,10}$) and long distances quantities (FF in particular).
- Effective Theories (QCDF/SCET or HQET) allow to relate FF and reduce inputs. Extra precision at low-q^2 including hard-gluon corrections.

Construction of clean observables based on

cancellation of FF at LO in the relevant ET.

$$
\begin{aligned}
A_\perp^{L,R} &= \mathcal{N}_\perp \left[\mathcal{C}^{+}_{9\mp 10} \mathbf{V}(\mathbf{q}^2) + \mathcal{C}^{+}_{7} \mathbf{T}_1(\mathbf{q}^2) \right] + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots) \\
A_\parallel^{L,R} &= \mathcal{N}_\parallel \left[\mathcal{C}^{-}_{9\mp 10} \mathbf{A}_1(\mathbf{q}^2) + \mathcal{C}^{-}_{7} \mathbf{T}_2(\mathbf{q}^2) \right] + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots) \\
A_0^{L,R} &= \mathcal{N}_0 \left[\mathcal{C}^{-}_{9\mp 10} \mathbf{A}_{12}(\mathbf{q}^2) + \mathcal{C}^{-}_{7} \mathbf{T}_{23}(\mathbf{q}^2) \right] + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)
\end{aligned}
$$

where $\mathcal{C}^{\pm}_{7,9\mp 10}$ contain the WC and $\mathbf{A}_{12} = f(A_1, A_2)$, $\mathbf{T}_{23} = f(T_2, T_3)$.

The key observation is that the ratios

$$\mathbf{R_1} = \mathbf{T_1}/\mathbf{V} \quad \mathbf{R_2} = \mathbf{T_2}/\mathbf{A_1} \quad \tilde{\mathbf{R}}_3 = \mathbf{T_{23}}/\mathbf{A_{12}}$$

have well-defined limiting values in both regimes

$$\mathbf{R_{1,2}} = 1 + \text{corrections} \;, \quad \tilde{\mathbf{R}}_3 = \frac{q^2}{m_B^2} + \text{corrections} \;.$$

Using these ratios to eliminate T_1, T_2, T_{23} the transversity amplitudes turns out

$$\begin{aligned}
A_\perp^{L,R} &= X_\perp^{L,R}(C_i, R_1)\, \mathbf{V(q^2)} + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots) \\
A_\parallel^{L,R} &= X_\parallel^{L,R}(C_i, R_2)\, \mathbf{A_1(q^2)} + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots) \\
A_0^{L,R} &= X_0^{L,R}(C_i, \tilde{R}_3)\, \mathbf{A_{12}(q^2)} + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)
\end{aligned}$$

Two consequences (case massless) from structure of J_i + symmetries:

- Low-recoil: 5 observables canceling FF at LO, 3 not canceling FF.
- Large-recoil: one extra relation

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

  Additional clean observables at large recoil can be constructed (i.e., $P_1 = A_T^2$) not clean at low-recoil.

All observables that are clean at low-recoil are clean at large-recoil.

Observables

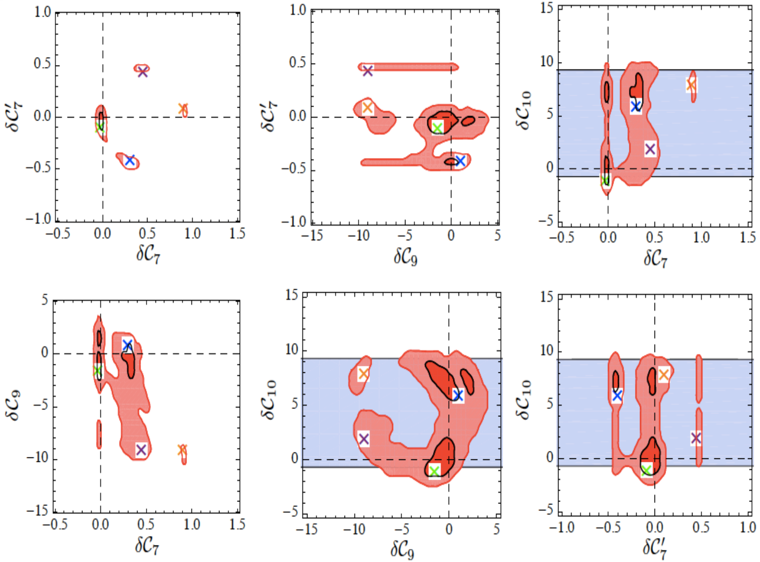
Limited sensitivity to hadronic inputs, or strong impact on analysis

- Class-I
  - $\mathcal{B}(B \to X_s\gamma)$ with $E_\gamma > 1.6\,\mathrm{GeV}$ [Misiak, Steinhauser, Haisch]
  - exclusive time-dependent CP asymmetry $S_{K^*\gamma}$
  - isospin asymmetry $A_I(B \to K^*\gamma)$ [Beneke, Feldman, Seidel] [Kagan, Neubert, Feldman, J.M.]
- Class-II
  - Integrated transverse asymmetries $\tilde{A}_{\mathrm{T}}^2 = P_1$, P_2 and P_3 in $B \to K^* l^+ l^-$ over low-q^2 region in bins. [Kruger and J.M.]
- Class-III
  - $\mathcal{B}(B \to X_s l^+ l^-)$ [Bobeth et al., Huber, Lunghi et al.]
  - Integrated $\tilde{F}_{\mathrm{L}}$ and $\tilde{A}_{\mathrm{FB}}$ in $B \to K^* l^+ l^-$ [1-6 GeV^2]

Simple numerical parametrisation as $\delta C_i = C_i(\mu_b) - C_i^{SM}(\mu_b)$

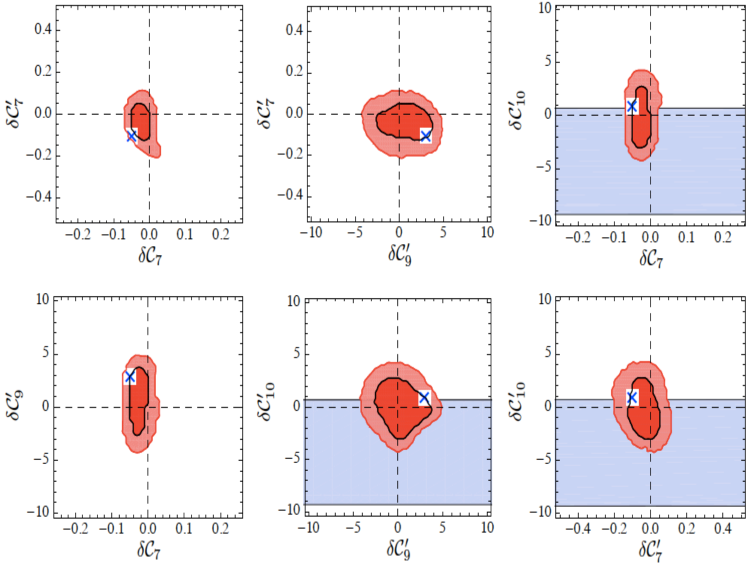
We provide the numerical expressions for the integrated observables $\langle A_{FB}\rangle, \langle F_L\rangle, \langle P_{1,2,3}\rangle$ and $\langle P_{4',5',6'}\rangle$ as a function of the NP Wilson coefficients, for different choices of the q^2-binning. S. Descotes, JM., J. Virto, M. Ramon '12

Scenario B ($C_{7,7',9,10}$) with all constraints



Four islands in the space of Wilson Coefficients ("four benchmark points" projected in all planes). Blue band is $BR(B_s \to \mu^+\mu^-)$ constraint.

Scenario B' ($C_{7,7',9',10'}$) with all constraints



One island in the space of WCs. Blue band is $BR(B_s \to \mu^+\mu^-)$ constraint. Changed-sign solution for C_7 reduce its statistical significance.

Scenario C ($C_{7,7',9,10,9',10'}$) with all constraints