Flavour $b \to sll$ Anomalies: New Physics Fits

and

A Systematic Approach to Hadronic Contributions

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Universität Bern

Moriond QCD 2017 – March 27, 2017

Based on:

Descotes-Genon, Hofer, Matias, Virto, 1510.04239 [hep-ph]

Bobeth, Chrzaszcz, van Dyk, Virto, 1704.xxxxx [hep-ph]
:: Effective Theory for $b \to s$ Transitions

For $\Lambda_{EW}, \Lambda_{NP} \gg M_B$ : General model-independent parametrization of NP :

$$\mathcal{L}_W = \mathcal{L}_{QCD} + \mathcal{L}_{QED} + \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu) \mathcal{O}_i(\mu)$$

\begin{align*}
\mathcal{O}_1 &= (\bar{c} \gamma_\mu P_L b)(\bar{s} \gamma^\mu P_L c) \\
\mathcal{O}_7 &= \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu} \\
\mathcal{O}_9^\ell &= \frac{\alpha}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \ell) \\
\mathcal{O}_{10}^\ell &= \frac{\alpha}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \gamma_5 \ell)
\end{align*}

\begin{align*}
\mathcal{O}_2 &= (\bar{c} \gamma_\mu P_L T^a b)(\bar{s} \gamma^\mu P_L T^a c) \\
\mathcal{O}_{7'} &= \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_L b) F^{\mu\nu} \\
\mathcal{O}_{9'}^\ell &= \frac{\alpha}{4\pi} (\bar{s} \gamma_\mu P_R b)(\bar{\ell} \gamma^\mu \ell) \\
\mathcal{O}_{10'}^\ell &= \frac{\alpha}{4\pi} (\bar{s} \gamma_\mu P_R b)(\bar{\ell} \gamma^\mu \gamma_5 \ell),
\end{align*}

SM contributions to $C_i(\mu_b)$ known to NNLL

Bobeth, Misiak, Urban '99; Misiak, Steinhauser '04, Gorbahn, Haisch '04; Gorbahn, Haisch, Misiak '05; Czakon, Haisch, Misiak '06

$C_{7\text{eff}}^{SM} = -0.3, \ C_9^{SM} = 4.1, \ C_{10}^{SM} = -4.3, \ C_1^{SM} = 1.1, \ C_2^{SM} = -0.4, \ C_{\text{rest}}^{SM} \lesssim 10^{-2}$
:: Effective Theory for $b \to s$ Transitions

For $\Lambda_{EW}, \Lambda_{NP} \gg M_B$ : General model-independent parametrization of NP :

\[
\mathcal{L}_W = \mathcal{L}_{QCD} + \mathcal{L}_{QED} + \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu) O_i(\mu)
\]

- $O_1 = (\bar{c}\gamma_\mu P_L b)(\bar{s}\gamma^\mu P_L c)$
- $O_2 = (\bar{c}\gamma_\mu P_LT^a b)(\bar{s}\gamma^\mu P_LT^a c)$
- $O_7 = \frac{e}{16\pi^2} m_b(\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu}$
- $O_7' = \frac{e}{16\pi^2} m_b(\bar{s}\sigma_{\mu\nu} P_L b) F^{\mu\nu}$
- $O_9_\ell = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)$
- $O_9'_\ell = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)$
- $O_{10_\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$
- $O_{10_\ell}' = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$

* Important operators in this talk.

$C_{7_{\text{eff}}}^{\text{SM}} = -0.3$, $C_9^{\text{SM}} = 4.1$, $C_{10}^{\text{SM}} = -4.3$, $C_1^{\text{SM}} = 1.1$, $C_2^{\text{SM}} = -0.4$, $C_{\text{rest}}^{\text{SM}} \lesssim 10^{-2}$
Constraining Effective coefficients

- **Inclusive**
  - \( B \to X_s \gamma \) (BR) .......................................................... \( C_7^{(i)}, C_{1,2} \)
  - \( B \to X_s \ell^+ \ell^- \) (dBR/dq^2) ............................................ \( C_7^{(i)}, C_9^{(i)}, C_{10}^{(i)}, C_{1,2} \)

- **Exclusive leptonic**
  - \( B_s \to \ell^+ \ell^- \) (BR) .......................................................... \( C_{10}^{(i)} \)

- **Exclusive radiative/semileptonic**
  - \( B \to K^* \gamma \) (BR, S, A_I) .......................................................... \( C_7^{(i)}, C_{1,2} \)
  - \( B \to K \ell^+ \ell^- \) (dBR/dq^2) ............................................ \( C_7^{(i)}, C_9^{(i)}, C_{10}^{(i)}, C_{1,2} \)
  - \( B \to K^* \ell^+ \ell^- \) (dBR/dq^2, Angular Observables) ............ \( C_7^{(i)}, C_9^{(i)}, C_{10}^{(i)}, C_{1,2} \)
  - \( B_s \to \phi \ell^+ \ell^- \) (dBR/dq^2, Angular Observables) .............. \( C_7^{(i)}, C_9^{(i)}, C_{10}^{(i)}, C_{1,2} \)

Exclusive decay modes have huge weight in fits.
1. Superluminal Review of New Physics Fits

Descotes-Genon, Matias, Virto, 1307.5683 [hep-ph]
Descotes-Genon, Hofer, Matias, Virto, 1510.04239 [hep-ph]
The $P'_5$ Anomaly

$P'_5$ is an “optimized” angular observable in $B \to K^* \mu^+ \mu^-$ defined originally in Descotes-Genon, Matias, Ramon, Virto, 1207.2753 [hep-ph]

LHCb 2013 + 2015, Belle 2016 + Recent ATLAS + CMS Moriond 2017!

Word of caution: CMS results take $F_L$ and S-wave from separate analysis.

But $P'_5$ is not the only observable ....
:: Global Fits to all $b \rightarrow s$ data

All include $B \rightarrow X_s \gamma$, $B \rightarrow K^* \gamma$, $B_s \rightarrow \mu^+ \mu^-$, $B \rightarrow X_s \mu^+ \mu^-$ by default.

- **Fit 1** *(Canonical):* $B_{(s)} \rightarrow (K^{(*)}, \phi) \mu^+ \mu^-$, BR’s and $P_i$’s, All $q^2$ *(91 obs)*
- **Fit 2:** Branching Ratios only *(27 obs)*
- **Fit 3:** $P_i$ Angular Observables only *(64 obs)*
- **Fit 4:** $S_i$ Angular Observables only *(64 obs)*
- **Fit 5:** $B \rightarrow K \mu^+ \mu^-$ only *(14 obs)*
- **Fit 6:** $B \rightarrow K^* \mu^+ \mu^-$ only *(57 obs)*
- **Fit 7:** $B_s \rightarrow \phi \mu^+ \mu^-$ only *(20 obs)*
- **Fit 8:** Large Recoil only *(74 obs)*
- **Fit 9:** Low Recoil only *(17 obs)*
- **Fit 10:** Only bins within $[1,6]$ GeV$^2$ *(39 obs)*
- **Fits 11:** Bin-by-bin analysis.
- **Fit 12:** Full form factor approach [a la ABSZ] *(91 obs)*
- **Fit 13:** Enhanced Power Corrections *(91 obs)*
- **Fit 14:** Enhanced Charm loop effect *(91 obs)*
All 6 WCs free (but real).

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>$1\sigma$</th>
<th>$2\sigma$</th>
<th>$3\sigma$</th>
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<tbody>
<tr>
<td>$C_7^{NP}$</td>
<td>$[-0.02, 0.03]$</td>
<td>$[-0.04, 0.04]$</td>
<td>$[-0.05, 0.08]$</td>
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<tr>
<td>$C_9^{NP}$</td>
<td>$[-1.4, -1.0]$</td>
<td>$[-1.7, -0.7]$</td>
<td>$[-2.2, -0.4]$</td>
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<tr>
<td>$C_{10}^{NP}$</td>
<td>$[-0.0, 0.9]$</td>
<td>$[-0.3, 1.3]$</td>
<td>$[-0.5, 2.0]$</td>
</tr>
<tr>
<td>$C_7'^{NP}$</td>
<td>$[-0.02, 0.03]$</td>
<td>$[-0.04, 0.06]$</td>
<td>$[-0.06, 0.07]$</td>
</tr>
<tr>
<td>$C_9'^{NP}$</td>
<td>$[0.3, 1.8]$</td>
<td>$[-0.5, 2.7]$</td>
<td>$[-1.3, 3.7]$</td>
</tr>
<tr>
<td>$C_{10}'^{NP}$</td>
<td>$[-0.3, 0.9]$</td>
<td>$[-0.7, 1.3]$</td>
<td>$[-1.0, 1.6]$</td>
</tr>
</tbody>
</table>

- $C_9$ consistent with SM only above $3\sigma$.
- All others consistent with the SM at $1\sigma$, except for $C_9'$ at $2\sigma$.
- $\text{Pull}_{SM}$ for the 6D fit is $3.6\sigma$. 
Pull$_{SM}$: $\sim \chi^2_{SM} - \chi^2_{min}$ (metrology: how less likely is SM vs. best fit?)

p-value: $p(\chi^2_{min}, N_{dof})$ (goodness of fit: is the best fit a good fit?)

Contribution $C^{NP}_9 < 0$ always favoured.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Best fit</th>
<th>3$\sigma$</th>
<th>Pull$_{SM}$</th>
<th>p-value (%)</th>
</tr>
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<tbody>
<tr>
<td>SM</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>16.0</td>
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<tr>
<td>$C^{NP}_7$</td>
<td>-0.02</td>
<td>[-0.07, 0.03]</td>
<td>1.2</td>
<td>17.0</td>
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<tr>
<td>$C^{NP}_9$</td>
<td>-1.09</td>
<td>[-1.67, -0.39]</td>
<td>4.5</td>
<td>63.0</td>
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<tr>
<td>$C^{NP}_{10}$</td>
<td>0.56</td>
<td>[-0.12, 1.36]</td>
<td>2.5</td>
<td>25.0</td>
</tr>
<tr>
<td>$C^{NP}_{7'}$</td>
<td>0.02</td>
<td>[-0.06, 0.09]</td>
<td>0.6</td>
<td>15.0</td>
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<tr>
<td>$C^{NP}_{9'}$</td>
<td>0.46</td>
<td>[-0.36, 1.31]</td>
<td>1.7</td>
<td>19.0</td>
</tr>
<tr>
<td>$C^{NP}_{10'}$</td>
<td>-0.25</td>
<td>[-0.82, 0.31]</td>
<td>1.3</td>
<td>17.0</td>
</tr>
<tr>
<td>$C^{NP}<em>9 = C^{NP}</em>{10}$</td>
<td>-0.22</td>
<td>[-0.74, 0.50]</td>
<td>1.1</td>
<td>16.0</td>
</tr>
<tr>
<td>$C^{NP}<em>9 = -C^{NP}</em>{10}$</td>
<td>-0.68</td>
<td>[-1.22, -0.18]</td>
<td>4.2</td>
<td>56.0</td>
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<tr>
<td>$C^{NP}<em>{9'} = C^{NP}</em>{10'}$</td>
<td>-0.07</td>
<td>[-0.86, 0.68]</td>
<td>0.3</td>
<td>14.0</td>
</tr>
<tr>
<td>$C^{NP}<em>{9'} = -C^{NP}</em>{10'}$</td>
<td>0.19</td>
<td>[-0.17, 0.55]</td>
<td>1.6</td>
<td>18.0</td>
</tr>
<tr>
<td>$C^{NP}<em>9 = -C^{NP}</em>{9'}$</td>
<td>-1.06</td>
<td>[-1.60, -0.40]</td>
<td>4.8</td>
<td>72.0</td>
</tr>
</tbody>
</table>
Consistency of different fits

- $3\sigma$ constraints, always including $b \to s\gamma$ and inclusive.

- Good consistency between BRs and Angular observables ($P_i$'s dominate).
- Good consistency between different modes ($B \to K^*$ dominates).
- Good consistency between different $q^2$ regions (Large-R dominates, [1,6] bulk).
- Remember: Quite different theory issues in each case!
A NP contribution $\mathcal{C}_{9\mu}^{\text{NP}} \sim -1$ gives a substantially improved fit for

- $B \to K\mu\mu$, $B \to K^*\mu\mu$ and $B_s \to \Phi\mu\mu$
- BRs and angular observables (including $P'_5$)
- Low $q^2$ and large $q^2$
- $R_K$

All these receive, in general, quite different contributions from hadronic operators.

Different fits with similar results:

- Descotes-Genon, Matias, Virto, 1307.5683 [hep-ph]
- Altmannshofer, Straub, 1308.1501 [hep-ph], 1411.3161 [hep-ph]
- Beaujean, Bobeth, van Dyk, 1310.2478 [hep-ph]
- Horgan, Liu, Meinel, Wingate, 1310.3887 [hep-ph]
- Hurth, Mahmoudi, Neshatpour, 1410.4545[hep-ph], 1603.00865 [hep-ph]

But the Devil’s in the details...
2. A Systematic Approach to Hadronic Contributions

Bobeth, Chrzaszcz, van Dyk, Virto (w.i.p.)
:: Theory calculation for $B \to M \ell^+ \ell^-$

$$\mathcal{M}_\lambda = \frac{G_F \alpha}{\sqrt{2\pi}} V_{tb} V_{ts}^* \left[ (A_\lambda^\mu + H_\lambda^\mu) \bar{u}_\ell \gamma_\mu v_\ell + B_\lambda^\mu \bar{u}_\ell \gamma_\mu \gamma_5 v_\ell \right] + \mathcal{O}(\alpha^2)$$

Local:

$$A_\lambda^\mu = -\frac{2m_b q_\nu}{q^2} C_7 \langle M_\lambda | \bar{s} \sigma^{\mu\nu} P_R b | B \rangle + C_9 \langle M_\lambda | \bar{s} \gamma^\mu P_L b | B \rangle$$

$$B_\lambda^\mu = C_{10} \langle M_\lambda | \bar{s} \gamma^\mu P_L b | B \rangle$$

Non-Local:

$$H_\lambda^\mu = -\frac{16i\pi^2}{q^2} \sum_{i=1..6,8} C_i \int dx^4 e^{iq \cdot x} \langle M_\lambda | T \{ \mathcal{J}_{em}^\mu (x), O_i (0) \} | B \rangle$$

Two theory issues:

1. **Form Factors** (LCSRs, LQCD, symmetry relations . . .
2. **Hadronic contribution** (SCET/QCDF, OPE, LCOPE . . . **THIS TALK**)
\[ H^\mu(q^2) \equiv i \int d^4x \ e^{iq\cdot x} \langle \bar{K}^*(k, \eta)|T\{\bar{c}\gamma^\mu c(x), C_1\mathcal{O}_1 + C_2\mathcal{O}_2(0)\}|\bar{B}(p)\rangle \]

\[ \equiv M_B^2 \eta^*_\alpha \left[ S^\alpha_{\perp} H_{\perp} - S^\alpha_{\parallel} H_{\parallel} - S^\alpha_0 H_0 \right] \]

- \( S^\alpha_{\lambda} \) – basis of Lorentz structures (carefully chosen)
- \( H_\lambda \) – Lorentz invariant correlation functions
- \( \lambda \) – polarization states (\( \perp, \parallel, 0 \))

The idea:

- Understand analytic structure of \( H_\lambda(q^2) \) to write a general parametrisation consistent with QCD.
- Use suitable experimental information to constrain the correlator.
- Use theory to constrain the correlator in suitable kinematic points.
Hadronic correlator: Analytic structure

Bobeth, Chrzaszcz, van Dyk, Virto

- narrow charmonia, assumed to be stable

\[ \text{Re } q^2 \]

\[ \text{Im } q^2 \]

\[ -4 \quad -2 \quad 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad 14 \quad 16 \quad 18 \quad 20 \]

\[ 0 \]

\[ \bar{B} \rightarrow s \]

Transitions: NP Fits and Hadronic effects

March 27, 2017
Hadronic correlator: Analytic structure

Bobeth, Chrzaszcz, van Dyk, Virto

- narrow charmonia, assumed to be stable
- red branch cut from $D \bar{D}$ production
- broad charmonia, decaying to $D \bar{D}$
- potential mirror poles

Diagram:

- $B$ to $O_i$ to $K^*$ trajectory
- $D \bar{D}$ branch cut
- $J^{\mu}_{em}$ interaction
:: Hadronic correlator: Analytic structure

Bobeth, Chrzaszcz, van Dyk, Virto

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  - broad charmonia, decaying to $D\bar{D}$
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- blue branch cut from light hadrons

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\[ \bullet \]

\[ \times \]

\[ \circ \]

$b \rightarrow s$ Transitions: NP Fits and Hadronic effects

Javier Virto (Uni Bern)
Hadronic correlator: Analytic structure

Bobeth, Chrzaszcz, van Dyk, Virto

- narrow charmonia, assumed to be stable
- red branch cut from $D\bar{D}$ production
  - broad charmonia, decaying to $D\bar{D}$
  - potential mirror poles
- blue branch cut from light hadrons
- green $q^2$-dep. imaginary due to branch cut in $p^2$
:: Understanding the $p^2$ cut
Bobeth, Chrzaszcz, van Dyk, Virto

Trick: Add spurious momentum $h$ to $\mathcal{O}_i$; Recover physical kinematics as $h \to 0$

\[
\begin{align*}
\Delta s &\sim p^2 \text{ independent of } t \sim q^2. \\
\text{Cut in } P^2 &\text{ does not translate into cut in } Q^2.
\end{align*}
\]

- Two correlators:
  \[
  \mathcal{H}_\lambda(q^2) \to \mathcal{H}_\lambda^{\text{real}}(q^2) + i \mathcal{H}_\lambda^{\text{imag}}(q^2)
  \]

- Both $\mathcal{H}_\lambda^{\text{real}}(q^2)$ and $\mathcal{H}_\lambda^{\text{imag}}(q^2)$ are analytic at $q^2 \leq 0$
- Both $\mathcal{H}_\lambda^{\text{real}}(q^2)$ and $\mathcal{H}_\lambda^{\text{imag}}(q^2)$ have branch cuts at $q^2 > 0$
Parametrization A: $J/\psi, \psi(2s)$ poles + $D \bar{D}$ cut

Bobeth, Chrzaszcz, van Dyk, Virto

Motivated by famous “z-parametrization” of form factors.  
Boyd et al ’94, Bourelly et al ’08

1. extract the poles

$$H_\lambda(q^2) = \frac{1}{q^2 - M_{J/\psi}^2} \frac{1}{q^2 - M_{\psi(2S)}^2} \hat{H}_\lambda(q^2)$$

2. $\hat{H}_\lambda(q^2)$ is analytic except for $D \bar{D}$ cut.

3. Perform conformal mapping $q^2 \mapsto z(q^2)$.

4. $\hat{H}_\lambda(z)$ analytic within unit circle.

5. Taylor expand $\hat{H}_\lambda(z)$ around $z = 0$.

6. Good convergence expected since $|z| < 0.42$ for $-5 \text{GeV}^2 \leq q^2 \leq 14 \text{GeV}^2$
Experimental constraints on the correlator

Bobeth, Chrzaszcz, van Dyk, Virto

The correlators $\mathcal{H}_\lambda$ can be related to observables in the decays $B \to K^* J/\psi, K^* \psi(2S)$

- Independent of short-distance contributions ($C_7$, $C_9$, etc) in $B \to K^* \{\gamma, \mu^+ \mu^-\}$
- Important constraints at $q^2 \simeq 9$ GeV$^2$ and $q^2 \simeq 14$ GeV$^2$.

Details:

- Residues of the correlator can be expressed in terms of $B \to K^* \psi$ amplitudes.
  Khodjamirian et. al. 2010
- $B$ and 4 angular observables measured in $B \to K^* J/\psi$ and $B \to K^* \psi(2S)$
  LHCb 2013, BaBar 2007
- Allows to constrain all moduli and two relative phases of the amplitudes, and therefore of the residues of the correlator.
Theory constraints on the correlator

Bobeth, Chrzaszcz, van Dyk, Virto

The correlator can be calculated at $q^2 < 0$ reliably by means of a light-cone OPE

Khodjamirian et al. 2010

Using $\mathcal{H}_{\perp}(q^2)$ as an example:

$$\mathcal{H}_{\perp}(q^2) = \# \times g(q^2, m_c^2) \mathcal{F}_{\perp}(q^2) + \# \times \tilde{V}_1(q^2) + \text{NLO}_{\alpha_s}$$

- first term is usual form-factor-like contribution
- second term arises from soft-gluon effects only
- third term arises from NLO corrections (produces $p^2$ cut !!)

We use this to constrain the correlators at $q^2 = -1$ GeV$^2$ and $q^2 = -5$ GeV$^2$. 
Results Parametrization A

Bobeth, Chrzaszcz, van Dyk, Virto

Results for $\text{Re}(\mathcal{H}_\perp/F_\perp)$:

Discrete ambiguity in phases of the residues: (only two shown)

**Left:** $\phi_{J/\psi} = \pi$, $\phi_{\psi(2S)} = 0$

**Right:** $\phi_{J/\psi} = \phi_{\psi(2S)} = \pi$
SM predictions for $P_5'$

**Left:** $\phi_{J/\psi} = \pi$, $\phi_{\psi(2S)} = 0$

**Right:** $\phi_{J/\psi} = \phi_{\psi(2S)} = \pi$

▷ first-time use of inter-resonance bin: great potential!!
:: Confronting $B \to K^*\mu\mu$ data

Bobeth, Chrzaszcz, van Dyk, Virto

Global fit to all $B \to K^*\{\gamma, \mu^+\mu^-, J/\psi, \psi(2S)\}$ data using Parametrization A

**Scenario A3**

Left: $\phi_{J/\psi} = \pi$, $\phi_{\psi(2S)} = 0$

Right: $\phi_{J/\psi} = \phi_{\psi(2S)} = \pi$

**Scenario A4**
Systematic framework to access nonlocal correlator

- First approach to use both theory inputs and experimental constraints in fit
- Can accommodate existing and future theory results (systematically improvable)
- Provides model-independent prior predictions for $B \rightarrow K^{(*)}\mu^+\mu^-$
- Can be easily embedded in global fits

Present data in tension with parametrization A

- Favours NP interpretation with $> 4\sigma$

Other results not disclosed here: see Bobeth, Chrzaszcz, van Dyk, Virto

- Complex parametrization A: needs analytic NLO Greub, Virto w.i.p.
- Parametrization B: includes light-hadron cut from $\psi$ decay

Keep an eye on this !!
Back-up
Hadronic correlator: are we missing something?

Descotes-Genon, Hofer, Matias, Virto

\[ \mathcal{T}_\mu = -\frac{16i\pi^2}{q^2} \sum_{i=1..6,8} C_i \int d^4x e^{iq\cdot x} \langle M_\lambda | T \{ \mathcal{J}_\mu^{\em}(x) \mathcal{O}_i(0) \} | B \rangle \] is \( q^2 \)-dependent

\[ \Rightarrow \text{No evidence for} \ q^2 \text{-dependence} \rightarrow \text{Good crosscheck of hadronic contribution!} \]
## Overview of exp. constraints on Correlator

Bobeth, Chrzaszcz, van Dyk, Virto

<table>
<thead>
<tr>
<th>name</th>
<th>observables</th>
<th>degrees of freedom</th>
<th>source</th>
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<tbody>
<tr>
<td>$\bar{B} \to \bar{K}^* J/\psi$</td>
<td>$\mathcal{B}, F_\perp, F_\parallel, \delta_\perp, \delta_\parallel$</td>
<td>5</td>
<td>BaBar</td>
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<td>$\mathcal{B}, F_\perp, F_\parallel, \delta_\perp, \delta_\parallel$</td>
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<td>Belle</td>
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<td>$\mathcal{B}, F_\perp, F_0, \delta_\perp, \delta_\parallel$</td>
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<td>$F_\perp, F_0, \delta_\perp, \delta_\parallel$</td>
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<td>$\bar{B} \to \bar{K}^* \psi(2S)$</td>
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<td>BaBar</td>
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<td>$\mathcal{B}$</td>
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<td>$\bar{B} \to \bar{K}^* \gamma$</td>
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<td>$\mathcal{B}, S_{K^* \gamma}$</td>
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<td>Belle</td>
</tr>
<tr>
<td>$\bar{B} \to \bar{K}^* \mu^+ \mu^-$</td>
<td>$\mathcal{B}, F_L, S_3, S_4, S_5, A_{FB}, S_7, S_8, S_9$</td>
<td>$4 \times 9$</td>
<td>LHCb</td>
</tr>
<tr>
<td>$\bar{B} \to \bar{K}^* \mu^+ \mu^-$ “inter-resonance”</td>
<td>$\mathcal{B}, F_L, S_3, S_4, S_5, A_{FB}, S_7, S_8, S_9$</td>
<td>9</td>
<td>LHCb</td>
</tr>
</tbody>
</table>
Anomaly patterns

<table>
<thead>
<tr>
<th>$R_K$</th>
<th>$\langle P'<em>5 \rangle</em>{[4,6],[6,8]}$</th>
<th>$BR(B_s \to \phi \mu \mu)$</th>
<th>low recoil $BR$</th>
<th>Best fit now</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{9}^{NP}$</td>
<td>$+$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
</tr>
<tr>
<td>$C_{10}^{NP}$</td>
<td>$-$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
</tr>
<tr>
<td>$C_{9'}^{NP}$</td>
<td>$+$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
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<tr>
<td>$C_{10'}^{NP}$</td>
<td>$-$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
<td>$\checkmark$</td>
</tr>
</tbody>
</table>

- $C_9 < 0$ consistent with all the anomalies
- No consistent and global alternative from long-distance dynamics.
:: Outlook: Potential of inclusive measurements at Belle-2

If the (current) exclusive fit is accurate, inclusive $b \rightarrow s\ell\ell$ Belle-2 measurements alone have the potential for a NP discovery:

![Graph showing Belle-2 Projections: Inclusive $b \rightarrow s\ell\ell$]

Huber, Ishikawa, Virto '2016
Contours: SM Pull with 50/ab: BR & AFB
Red: Exclusive Fit (arXiv:1510.04239 [hep-ph])

Belle-2 Projections: Inclusive $b \rightarrow s\ell\ell$

Huber, Ishikawa, Virto '2016
Contours: SM Pull with 50/ab: BR & AFB
Red: Exclusive Fit (arXiv:1510.04239 [hep-ph])