Update on b to s anomalies after Moriond 2019

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based on arXiv:1512.07157 in collaboration with:
M. Ciuchini, E. Franco, S. Mishima, A. Paul, L. Silvestrini & M. Valli

on arXiv:1704.01737 and arXiv:1903.09632 in collaboration with:
M. Ciuchini, A. Coutinho, E. Franco, A. Paul, L. Silvestrini & M. Valli
Summary

- Theoretical Framework
- Experimental anomalies
- Global fits
Summary

- Theoretical Framework
- Experimental anomalies
- Global fits
The $B \to V(P)ll$ decay channel: the Hamiltonian

$$H_{\text{eff}}^{\Delta B=1} = H_{\text{eff}}^{\text{had}} + H_{\text{eff}}^{s\ell+\gamma}$$

$$H_{\text{eff}}^{\text{had}} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[ C_1 P_1^p + C_2 P_2^p + \sum_{i=3,\ldots,6} C_i P_i + C_{8g} Q_{8g} \right]$$

$$H_{\text{eff}}^{s\ell+\gamma} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[ C_7^{(l)} Q_7^{\gamma} + C_9^{(l)} Q_9^{V} + C_{10}^{(l)} Q_{10A} + C_S^{(l)} Q_S^{(l)} + C_P^{(l)} Q_P^{(l)} \right]$$

\[
\begin{align*}
P_1^p &= (\bar{s}_L\gamma_\mu T^a p_L)(\bar{p}_L\gamma^\mu T^a b_L) \\
P_2^p &= (\bar{s}_L\gamma_\mu p_L)(\bar{p}_L\gamma_\mu b_L) \\
P_3 &= (\bar{s}_L\gamma_\mu b_L) \sum_q (\bar{q} \gamma^\mu q) \\
P_4 &= (\bar{s}_L\gamma_\mu T^a b_L) \sum_q (\bar{q} \gamma^\mu T^a q) \\
P_5 &= (\bar{s}_L\gamma_\mu_1 \gamma_\mu_2 \gamma_\mu_3 b_L) \sum_q (\bar{q} \gamma_\mu_1 \gamma_\mu_2 \gamma_\mu_3 q) \\
P_6 &= (\bar{s}_L\gamma_\mu_1 \gamma_\mu_2 \gamma_\mu_3 T^a b_L) \sum_q (\bar{q} \gamma_\mu_1 \gamma_\mu_2 \gamma_\mu_3 T^a q) \\
Q_{7\gamma} &= \frac{e}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R F^{\mu\nu} b \\
Q_{8g} &= \frac{\gamma_s}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R G^{\mu\nu} b \\
Q_{9V} &= \frac{\alpha_{\text{em}}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \ell) \\
Q_{10A} &= \frac{\alpha_{\text{em}}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \gamma^5 \ell) \\
Q_S &= \frac{\alpha_{\text{em}}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \ell) \\
Q_P &= \frac{\alpha_{\text{em}}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \gamma^5 \ell)
\end{align*}
\]
The $B \rightarrow V(P)\ell\ell$ decay channel: the Hamiltonian

\[ H_{\text{eff}}^{\Delta B=1} = H_{\text{eff}}^{\text{had}} + H_{\text{eff}}^{\text{sl+}\gamma} \]

\[ H_{\text{eff}}^{\text{had}} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[ C_1 P_1^p + C_2 P_2^p + \sum_{i=3,...,6} C_i P_i + C_{8g} Q_{8g} \right] \]

\[ H_{\text{eff}}^{\text{sl+}\gamma} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[ C_7^{(t)} Q_7^{(\gamma)} + C_9^{(t)} Q_9^{(V)} + C_{10}^{(t)} Q_{10A}^{(t)} + C_S^{(t)} Q_S^{(t)} + C_P^{(t)} Q_P^{(t)} \right] \]

\[
\begin{align*}
P_1^p &= (\bar{s}_L\gamma_\mu T^a p_L)(\bar{\mu}_L\gamma^\mu T^a b_L) \\
P_2^p &= (\bar{s}_L\gamma_\mu p_L)(\bar{\mu}_L\gamma^\mu b_L) \\
P_3 &= (\bar{s}_L\gamma_\mu b_L) \sum_q (\bar{q}\gamma^\mu q) \\
P_4 &= (\bar{s}_L\gamma_\mu T^a b_L) \sum_q (\bar{q}\gamma^\mu T^a q) \\
P_5 &= (\bar{s}_L\gamma_\mu \gamma_2 \gamma_3 b_L) \sum_q (\bar{q}\gamma^\mu_1 \gamma^\mu_2 \gamma^\mu_3 q) \\
P_6 &= (\bar{s}_L\gamma_\mu \gamma_2 \gamma_3 T^a b_L) \sum_q (\bar{q}\gamma^\mu_1 \gamma^\mu_2 \gamma^\mu_3 T^a q)
\end{align*}
\]

\[
\begin{align*}
Q_{7\gamma} &= \frac{e}{16\pi^2} \hat{m}_b \bar{s}\sigma_{\mu\nu} P_R F^{\mu\nu} b \\
Q_{8g} &= \frac{\gamma_s}{16\pi^2} \hat{m}_b \bar{s}\sigma_{\mu\nu} P_R G^{\mu\nu} b \\
Q_{9V} &= \frac{\alpha_{em}}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \\
Q_{10A} &= \frac{\alpha_{em}}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma^5 \ell) \\
Q_S &= \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s}P_R b)(\bar{\ell}\ell) \\
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\end{align*}
\]
The $B \to V(P)\ell\ell$ decay channel: the Hamiltonian

\[
H^{\Delta B=1}_{\text{eff}} = H_{\text{eff}}^{\text{had}} + H_{\text{eff}}^{\text{sl+\gamma}}
\]

\[
H_{\text{eff}}^{\text{had}} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[ C_1 P_1^p + C_2 P_2^p + \sum_{i=3,\ldots,6} C_i P_i + C_{8g} Q_{8g} \right]
\]

\[
H_{\text{eff}}^{\text{sl+\gamma}} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[ C_7^{(l)} Q_{7\gamma}^{(l)} + C_9^{(l)} Q_{9V}^{(l)} + C_{10}^{(l)} Q_{10A}^{(l)} + C_S^{(l)} Q_S^{(l)} + C_P^{(l)} Q_P^{(l)} \right]
\]

\[
P_1^p = (\bar{s}_L \gamma^\mu T^a p_L) (\bar{\ell}_L \gamma^\mu T^a b_L)
\]
\[
P_2^p = (\bar{s}_L \gamma^\mu p_L) (\bar{\ell}_L \gamma^\mu b_L)
\]
\[
P_3 = (\bar{s}_L \gamma^\mu b_L) \sum_q (\bar{q} \gamma^\mu q)
\]
\[
P_4 = (\bar{s}_L \theta^a b_L) \sum_q (\bar{q} \gamma^\mu T^a q)
\]
\[
P_5 = (\bar{s}_L \gamma_1 \gamma_2 \gamma_3 b_L) \sum_q (\bar{q} \gamma^\mu_1 \gamma^\mu_2 \gamma^\mu_3 q)
\]
\[
P_6 = (\bar{s}_L \gamma_1 \gamma_2 \gamma_3 T^a b_L) \sum_q (\bar{q} \gamma^\mu_1 \gamma^\mu_2 \gamma^\mu_3 T^a q)
\]

\[
Q_{7\gamma} = \frac{e}{16\pi^2} \hat{m}_b \bar{s}_\sigma \mu \nu P_R F_{\mu \nu} b
\]
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Q_{8g} = \frac{\gamma_s}{16\pi^2} \hat{m}_b \bar{s}_\sigma \mu \nu P_R G_{\mu \nu} b
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Q_{9V} = \frac{\alpha_{em}}{4\pi} (\bar{s}_\gamma \mu P_L b)(\bar{\ell} \gamma^\mu \ell)
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Q_{10A} = \frac{\alpha_{em}}{4\pi} (\bar{s}_\gamma \mu P_L b)(\bar{\ell} \gamma^\mu \gamma^5 \ell)
\]
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Q_S = \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \ell)
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\[
Q_P = \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \gamma^5 \ell)
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The $B \to V(P)\ell\ell$ decay channel: the Hamiltonian

\[
H^\Delta B=1_{\text{eff}} = H_{\text{eff}}^{\text{had}} + H_{\text{eff}}^{\text{sl+\gamma}}
\]

\[
H_{\text{eff}}^{\text{had}} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[ C_1 P_1^p + C_2 P_2^p + \sum_{i=3,\ldots,6} C_i P_i + C_{8g} Q_{8g} \right]
\]

\[
H_{\text{eff}}^{\text{sl+\gamma}} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[ C_7^{(l)} Q_7^{(l)} + C_9^{(l)} Q_9^{(l)} + C_{10}^{(l)} Q_{10A}^{(l)} + C_S^{(l)} Q_S^{(l)} + C_P^{(l)} Q_P^{(l)} \right]
\]

Matrix elements of quark currents from $Q_{7,9,10,S,P}$ naively factorize:

\[
\mathcal{A} \sim \langle \ell^+ \ell^- | J_{\text{lep}} | 0 \rangle \langle V(P) | J_{\text{had}} \bar{B} \rangle
\]

Not possible for the hadronic Hamiltonian!

\[
\tilde{h}_{\lambda}(q^2) \sim \epsilon_{\lambda,\mu} \int d^4 x \ e^{i q x} \langle V(P) | T \{ J_{\text{had}}^{\mu,e.m.}(x) \mathcal{H}_{\text{had}}^{\text{eff}}(0) \} | B \rangle
\]
The $B \to V(P)\ell\ell$ decay channel: the amplitudes

The amplitudes, in the helicity basis, are proportional to

\[
H^V_\lambda(q^2) \propto (C_9 - C'_9)\tilde{V}_\lambda(q^2) + \frac{2m_bm_B}{q^2}(C_7 - C'_7)\tilde{T}_\lambda(q^2) - 16\pi^2\frac{m_B^2}{q^2}\tilde{h}_\lambda(q^2)
\]

\[
H^A_\lambda(q^2) \propto (C_{10} - C'_{10})\tilde{V}_\lambda(q^2)
\]

\[
H^S(q^2) \propto \frac{m_b}{m_W}(C_S - C'_S)\tilde{S}(q^2)
\]

\[
H^P(q^2) \propto \frac{m_b}{m_W}(C_P - C'_P)\tilde{S}(q^2) + \frac{2m_\ell m_B}{q^2}(C_{10} - C'_{10})\left(1 + \frac{m_s}{m_b}\right)\tilde{S}(q^2)
\]

The main sources of uncertainties are coming from the form factors and from the hadronic parameters.
The charm-loop effect

Soft gluon emission from cc-loop estimated for $P = K$ and $V = K^*$ with LCSR + dispersion relation. **Sizable effect in $K^*$**

In particular, charm current-current insertion not further parametrically suppressed.

Soft gluon emission from cc-loop estimated for $P = K$ and $V = K^*$ with LCSR + dispersion relation. **Sizable effect in $K^*$**

- Correlator expanded on the light-cone: LCSR estimate based on small $q^2$.
- Dispersion relation in order to extrapolate LCSR result up to charm resonances.
- Single soft gluon approximation: strictly valid only for $q^2 \ll 4m_c^2$ !
The $B \to V(P)\ell\ell$ decay channel: the hadronic parameter

Two more recent studies on the subject:

- Phenomenological model obtained as a sum of Breit-Wigner, resonance data to fix the parameters (not possible to fix strong phases, agreement only with particular choices of the phases)
  
  T. Blake et al., see talk by P. Owen
  EPJC 78 (2018) 6, 453

- Similar to JHEP09(2010)089, but with dispersion relation replaced by $z$-expansion, with coeffs. constrained by analicity and $B \to K^*\psi_n$ data
  
  C. Bobeth et al.,
  EPJC 78 (2018) 6, 451

Problem of multiple soft-gluon emission still open…
The $B \to V(P)\pi$ decay channel: the kinematic distribution

\[
\frac{d^{(4)} \Gamma}{dq^2 d(\cos \theta_\ell)d(\cos \theta_K)d\phi} = \frac{9}{32 \pi} \left( I_1^s \sin^2 \theta_K + I_1^c \cos^2 \theta_K + (I_2^s \sin^2 \theta_K + I_2^c \cos^2 \theta_K) \cos 2\theta_\ell \right.
\]

\[
+ I_3 \sin^2 \theta_K \sin^2 \theta_\ell \cos 2\phi + I_4 \sin 2\theta_K \sin 2\theta_\ell \cos \phi
\]

\[
+ I_5 \sin 2\theta_K \sin \theta_\ell \cos \phi + (I_6^s \sin^2 \theta_K + I_6^c \cos^2 \theta_K) \cos \theta_\ell
\]

\[
+ I_7 \sin 2\theta_K \sin \theta_\ell \sin \phi + I_8 \sin 2\theta_K \sin 2\theta_\ell \sin \phi
\]

\[
+ I_9 \sin^2 \theta_K \sin^2 \theta_\ell \sin 2\phi \bigg).
\]

\[
\sum_i = \frac{I_i + \bar{I}_i}{2} \quad \text{CP-Averaged}
\]

\[
\Gamma' = \frac{1}{2} \left( \frac{d\Gamma + d\bar{\Gamma}}{dq^2} \right) = \sum_{1c} + 4\sum_{2s} \quad P_1 = \frac{\sum_3}{2\sum_{2s}} \quad P_2 = \frac{\sum_{6s}}{8\sum_{2s}} \quad P_3 = -\frac{\sum_9}{4\sum_{2s}}
\]

\[
P_4' = \frac{\sum_{4}}{\sqrt{-\sum_{2s} \sum_{2c}}} \quad P_5' = \frac{\sum_{5}}{2\sqrt{-\sum_{2s} \sum_{2c}}} \quad P_6' = -\frac{\sum_{7}}{2\sqrt{-\sum_{2s} \sum_{2c}}} \quad P_8' = -\frac{\sum_{8}}{\sqrt{-\sum_{2s} \sum_{2c}}}
\]
Summary

- Theoretical Framework
- Experimental anomalies
- Global fits
Angular analysis of $B \to K^*\mu\mu$ (iii)

INTRIGUING SET OF “ANOMALIES” IN DATA OF EXCLUSIVE B RARE DECAYS

- LHCb
  - $4.0 < q^2 / \text{GeV}^2 < 6.0$
  - $6.0 < q^2 / \text{GeV}^2 < 8.0$
  - $3.4 \sigma$

- ATLAS
  - $4.0 < q^2 / \text{GeV}^2 < 6.0$
  - $2.7 \sigma$

- BELLE
  - $4.0 < q^2 / \text{GeV}^2 < 8.0$
  - $2.6 \sigma$

- CMS
  - No discrepancies!

Potential pollution from had. cont.
Branching Fractions of $B_s \rightarrow \phi \mu \mu$ and $B \rightarrow K \mu \mu$

INTRIGUING SET OF "ANOMALIES" IN DATA OF EXCLUSIVE B RARE DECAYS

- $2.0 < q^2 / \text{GeV}^2 < 5.0$
- $3.0 \sigma$

Potential pollution from had. cont.

JHEP 09 (2015) 179

- Low $q^2$
- Consistently lower values

Pollution from had. cont. ~ negligible

JHEP 06 (2014) 133
Branching Fraction ratios: $R_K$ & $R_{K^*}$ After Moriond 2019

INTRIGUING SET OF "ANOMALIES" IN DATA OF EXCLUSIVE B RARE DECAYS

$$R_{K^*} = \frac{Br(B \rightarrow K^{(*)}\mu\mu)}{Br(B \rightarrow K^{(*)}ee)}$$

No pollution from had. cont.
Summary

- Theoretical Framework
- Experimental anomalies
- Global fits
A fascinating solution: C9μ

It is possible to explain everything simply requiring NP effect in C9μ

JHEP 01 (2018) 093


Yet another analysis: why?

The first analysis addressing the $B \rightarrow K^*\mu\mu$ angular anomaly where performed employing the LCSR estimate for the hadronic contribution

Single soft gluon approximation: strictly valid only for $q^2 << 4m^2_c$!

First analysis of the $B \rightarrow K^*\mu\mu$ decay channel only, aiming to extract the hadronic contribution from data and compare it with LCSR estimate

Global fit of the $b \rightarrow s$ anomalies, without forgetting what we learnt from the previous analysis
Parameterizing the hadronic contribution

\[ H^V_\lambda (q^2) \propto C_9 \tilde{V}_\lambda (q^2) + \frac{2m_b m_B}{q^2} C_7 \tilde{T}_\lambda (q^2) - 16\pi^2 \frac{m_B^2}{q^2} \tilde{h}_\lambda (q^2) \]

\[ H^A_\lambda (q^2) \propto C_{10} \tilde{V}_\lambda (q^2) , \quad H^P (q^2) \propto \frac{2m_\ell m_B}{q^2} C_{10} \left( 1 + \frac{m_s}{m_b} \right) \tilde{S}(q^2) \]

We parameterized the hadronic contribution in order to have a term that cannot be reinterpreted as a NP contribution

\[ \tilde{h}_\lambda (q^2) = \sum_i \tilde{h}_\lambda^{(i)} \left( \frac{q^2}{GeV^2} \right)^i \]

\[ i = 0 \leftrightarrow C_{7}^{NP} \]
\[ i = 1 \leftrightarrow C_{9}^{NP} \]

**OBS:** \( i = 2 \) gives a potential discriminator (\( q^2 \) dependence in FFs being fairly mild).

\[ \rightarrow \] hadronic effects may show important dependence on \( q^2 \) and on helicity as well
The SM analysis, PDD vs. PMD

EXPERIMENTAL WEIGHTS:

\[ F_L, A_{FB}, S_{3,4,5,7,8,9} \]

\[ \mathcal{B}(B \to K^* \mu\mu) \]

\[ \mathcal{B}(B \to K^* \gamma), \mathcal{B}(B \to K^* ee), F_L, P_{1,2,3} \]

correlated in each bin of \( q^2 \)

THEORY WEIGHTS:

LCSR FFs with correlation matrix for low \( q^2 \) region only

Amplitude helicity suppression at kinematical endpoint

only for \( q^2 \leq 1 \) GeV\(^2\) (PDD)

only for “all” \( q^2 \) (PMD)

JHEP 09(2010)089 constraint

Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)
The SM analysis, PDD vs. PMD

No anomalies in $P'_5$ …!

Anomaly strikes back in $P'_5$ …!

Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)
NP contribution in $C_7$ and/or $C_9$ cannot reproduce such a $q^2$ behaviour.
### RESULTS FOR THE HADRONIC PARAMETERS $h_{\lambda}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Absolute value</th>
<th>Phase (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_0^{(0)}$</td>
<td>$(5.7 \pm 2.0) \cdot 10^{-4}$</td>
<td>$3.57 \pm 0.55$</td>
</tr>
<tr>
<td>$h_0^{(1)}$</td>
<td>$(2.3 \pm 1.6) \cdot 10^{-4}$</td>
<td>$0.1 \pm 1.1$</td>
</tr>
<tr>
<td>$h_0^{(2)}$</td>
<td>$(2.8 \pm 2.1) \cdot 10^{-5}$</td>
<td>$-0.2 \pm 1.7$</td>
</tr>
<tr>
<td>$h_\perp^{(0)}$</td>
<td>$(7.9 \pm 6.9) \cdot 10^{-6}$</td>
<td>$0.1 \pm 1.7$</td>
</tr>
<tr>
<td>$h_\perp^{(1)}$</td>
<td>$(3.8 \pm 2.8) \cdot 10^{-5}$</td>
<td>$-0.7 \pm 1.9$</td>
</tr>
<tr>
<td>$h_\perp^{(2)}$</td>
<td>$(1.4 \pm 1.0) \cdot 10^{-5}$</td>
<td>$3.5 \pm 1.6$</td>
</tr>
<tr>
<td>$h_-^{(0)}$</td>
<td>$(5.4 \pm 2.2) \cdot 10^{-5}$</td>
<td>$3.2 \pm 1.4$</td>
</tr>
<tr>
<td>$h_-^{(1)}$</td>
<td>$(5.2 \pm 3.8) \cdot 10^{-5}$</td>
<td>$0.0 \pm 1.7$</td>
</tr>
<tr>
<td>$h_-^{(2)}$</td>
<td>$(2.5 \pm 1.0) \cdot 10^{-5}$</td>
<td>$0.09 \pm 0.77$</td>
</tr>
</tbody>
</table>

$|h_-^{(2)}|$ differs from zero at more than 95.45% probability, thus disfavouring the interpretation of the hadronic correction as NP contributions in $C_7$ and/or $C_9$. 

Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)
Time for a $b \to s$ global analysis

Once we add the ratios in the analysis, it is not possible for the hadronic contributions to account for all the anomalies.

- Interesting interplay between hadronic contribution and NP effects

- Is NP in the muon channel the only viable scenario?
Set of measurements included in our global analysis

<table>
<thead>
<tr>
<th>LHCb</th>
<th>ATLAS</th>
<th>CMS</th>
<th>Belle</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_L$, $A_{FB}$, $S_{3,4,5,7,8,9}$</td>
<td>$F_L$, $A_{FB}$, $S_{3,4,5,7,8}$</td>
<td>$P_1, P'<em>5, F_L, A</em>{FB}, \mathcal{B}(B \to K^* \mu\mu)$</td>
<td>$P'_5(\mu,e)$</td>
</tr>
<tr>
<td>i.e. available angular info for $K^{(*)}\phi$ modes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B \to K^{(*)}\ell\ell, \gamma)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \to \phi \mu\mu, \gamma)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_K,[1,6], R_{K^*},[0.045,1.1],[1.1,6]$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We use data in the large recoil region only, i.e. where anomalies show up.

We always take into account theory/experimental correlations when provided.
Global fits before Moriond 2019

1) VECTORIAL NP SCENARIO

\[ C_7^{NP} \]

\[ C_{9,\mu}^{NP} \]

\[ C_{9,e}^{NP} \]

\[ C_{9,\mu}^{NP} = -1.66^{+0.29}_{-0.29} \]

\[ C_{9,e}^{NP} = -1.55^{+0.60}_{-0.65} \]

\[ C_{9,\mu}^{NP} = -1.55^{+0.60}_{-0.65} \]

\[ C_{9,e}^{NP} = -0.19^{+0.46}_{-0.44} \]

\[ C_{9,e}^{NP} = -0.09^{+0.62}_{-0.62} \]

Significance of NP affected by non-factorizable QCD power corrections!

- PDD approach
- PMD approach

dashed lines in 1D histograms
16th, 50th, 84th percentiles
2D joint probability density
1,2,3 $\sigma$ contours (darker to lighter)
blue lines and blue square
SM limit of NP Wilson coeffs

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1704.05447)
Global fits before Moriond 2019

II) **Correlated NP Scenario**

\[ C^N_P = 0.01^{+0.01}_{-0.01} \]

\[ C^N_P, C^N_{9,\mu,e}, C^N_{10,\mu,e} \]

- \[ C^N_{9,\mu} = -0.54^{+0.17}_{-0.17} \]
- \[ C^N_{10,\mu} = -0.43^{+0.22}_{-0.23} \]
- \[ C^N_{10,e} = -0.08^{+0.24}_{-0.25} \]
- \[ C^N_{9,e} = -0.21^{+0.28}_{-0.29} \]

Significance of NP affected by non-factorizable QCD power corrections!

- PDD approach
- PMD approach

- Dashed lines in 1D histograms
- 16th, 50th, 84th percentiles
- 2D joint probability density
- 1, 2, 3 \( \sigma \) contours (darker to lighter)
- Blue lines and blue square
- SM limit of NP Wilson coeffs
Global fits before Moriond 2019

III) Axial NP Scenario

\[ C_{7}^{NP}, C_{10,\mu}^{NP}, C_{10,e}^{NP}. \]

- Dashed lines in 1D histograms 16th, 50th, 84th percentiles
- 2D joint probability density 1, 2, 3 σ contours (darker to lighter)
- Blue lines and blue square SM limit of NP Wilson coeffs

Significance of NP affected by non-factorizable QCD power corrections!

PDD approach

No means to explain angular analysis in PMD

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1704.05447)
(Re)parameterizing the hadronic contribution

\[ h_-(q^2) = -\frac{m_b}{8\pi^2 m_B} \widetilde{T}_{L-}(q^2) h_0^{(0)} - \frac{\widetilde{V}_{L-}(q^2)}{16\pi^2 m_B^2} h_1^{(1)} q^2 + h_2^{(2)} q^4 + \mathcal{O}(q^6) \]

\[ h_+(q^2) = -\frac{m_b}{8\pi^2 m_B} \widetilde{T}_{L+}(q^2) h_0^{(0)} - \frac{\widetilde{V}_{L+}(q^2)}{16\pi^2 m_B^2} h_1^{(1)} q^2 + h_0^{(0)} q^2 + h_+^{(1)} q^4 + \mathcal{O}(q^6) \]

\[ h_0(q^2) = -\frac{m_b}{8\pi^2 m_B} \widetilde{T}_{L0}(q^2) h_0^{(0)} - \frac{\widetilde{V}_{L0}(q^2)}{16\pi^2 m_B^2} h_1^{(1)} q^2 + h_0^{(0)} \sqrt{q^2} + h_0^{(1)} (q^2)^{3/2} + \mathcal{O}((q^2)^{5/2}) \]

\[ H_V^- \propto \left\{ \left( C_9^{SM} + h_1^{(1)} \right) \widetilde{V}_{L-} + \frac{m_B^2}{q^2} \left[ \frac{2m_b}{m_B} \left( C_7^{SM} + h_0^{(0)} \right) \widetilde{T}_{L-} - 16\pi^2 h_2^{(2)} q^4 \right] \right\} \]

\[ H_V^+ \propto \left\{ \left( C_9^{SM} + h_1^{(1)} \right) \widetilde{V}_{L+} + \frac{m_B^2}{q^2} \left[ \frac{2m_b}{m_B} \left( C_7^{SM} + h_0^{(0)} \right) \widetilde{T}_{L+} - 16\pi^2 \left( h_0^{(0)} + h_1^{(1)} q^2 + h_2^{(2)} q^4 \right) \right] \right\} \]

\[ H_V^0 \propto \left\{ \left( C_9^{SM} + h_1^{(1)} \right) \widetilde{V}_{L0} + \frac{m_B^2}{q^2} \left[ \frac{2m_b}{m_B} \left( C_7^{SM} + h_0^{(0)} \right) \widetilde{T}_{L0} - 16\pi^2 \sqrt{q^2} \left( h_0^{(0)} + h_1^{(1)} q^2 \right) \right] \right\} \]

Can be interpreted as LFU NP!

see talk by G. Isidori and C. Cornella
Global fits after Moriond 2019

Purely left-handed solutions are no longer preferred by data:

\( R_{K^*[1.1,6]} / R_K [1.1,6] \approx 0.86 \pm 0.13 \)

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1903.09632)
The inclusion of right-handed currents better reproduce data!

\[ R_K \propto C_i + C_i' \]

\[ R_{K^*} \propto C_i - C_i' \]

Similar findings by Algueró et al., Alok et al., Aebischer et al., Kowalska et al., …

\[ R_{K^*}[1.1, 6]/R_K[1.1, 6] \simeq 0.86 \pm 0.13 \]
Conclusions

Hadronic contributions are important in B to V ll amplitude.
—> present estimate of “charm-loop effect” limited to $q^2 \ll 4m^2_c$.

Unknown QCD power corrections may also mimic NP effects.
—> hard to call for NP in standalone study of $K^* \mu \mu$ angular obs!

Evidence for $q^2$ dependence beyond the first order in a power expansion in $q^2$ of the hadronic correlator

$$\tilde{h}_\lambda(q^2) \sim \epsilon_{\lambda,\mu} \int d^4x \ e^{iqx} \langle \bar{V}(P)|T\{J_{\mu,e.m.}^{\text{had}}(x)H_{\text{had}}^{\text{eff}}(0)\}|\bar{B}\rangle$$

may definitely discriminate genuine NP effects with the advent of more data from LHCb / Belle2.

$R_{K^*(s)}$ anomalies (if not stat fluke/exp issue) undoubtedly require NP, both in left handed and right handed currents

A conservative approach to hadronic effects in $b \rightarrow s$ ll global fits impacts significances + leaves room for different NP interpretations of current data.