Next steps and challenges in global fits for Run 2

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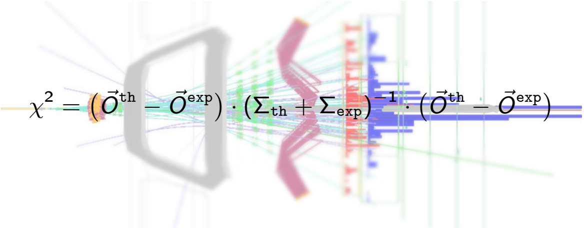
Thanks to T. Hurth, S. Neshatpour, D. Martinez Santos and V. Chobanova

arXiv:1603.00865 & arXiv:1610.SOON!



$$\chi^2 = \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right) \cdot \left(\Sigma_{\rm th} + \Sigma_{\rm exp}\right)^{-1} \cdot \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right)$$

Implications of LHCb measurements and future prospects

CERN, October 12-14, 2016

Radiative and semileptonic rare B decays are highly sensitive probes for new physics

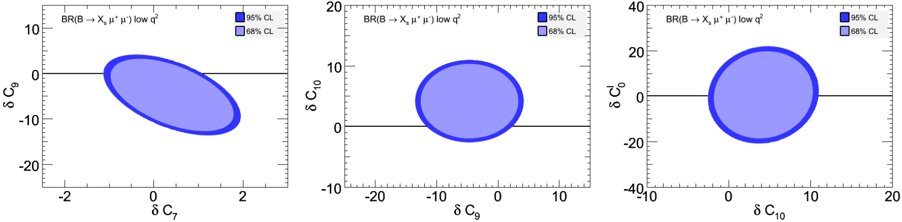
Inclusive decays $B \to X_s\gamma$ and $B \to X_s\ell^+\ell^-$

- Precise theory calculations (see e.g. Huber, Hurth, Lunghi, JHEP 1506 (2015) 176 and refs therein)
- Heavy mass expansion
- Theoretical description of power corrections available $\to$ they can be calculated or estimated within the theoretical approach
- Require Belle-II for full exploitation (complete angular analysis)

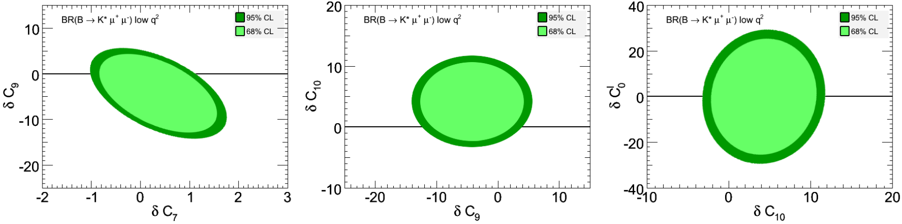
Exclusive decays

- Angular distributions of $B \to K^*\mu^+\mu^-$
  $\to$ many experimentally accessible observables
- Also: $B \to K\mu^+\mu^-$ and $B_s \to \phi\mu^+\mu^-$
- Issue of hadronic uncertainties in exclusive modes
  no theoretical description of power corrections existing within the theoretical framework of QCD factorisation and SCET

Inclusive:



Exclusive (2012):

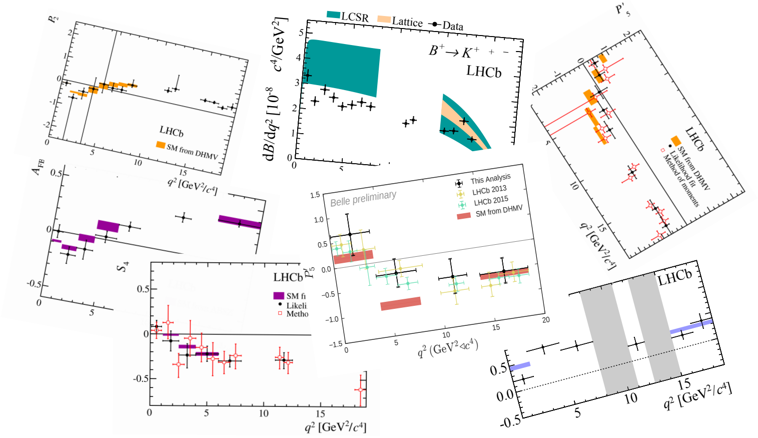


T. Hurth, FM, Nucl. Phys. B865 (2012) 461

Exclusive (2016):

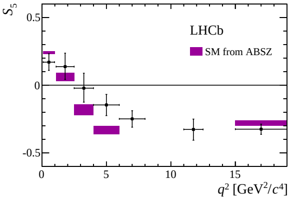
The situation has changed drastically with the measurements of many angular observables!

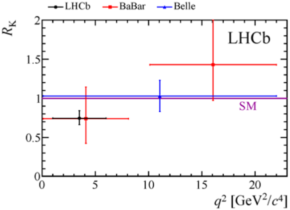
$B \to K^+\mu^+\mu^-$, $B \to K^0\mu^+\mu^-$, $B \to K^{*+}\mu^+\mu^-$, $B \to K^{*0}\mu^+\mu^-$ (F_L, A_{FB}, S_i, P_i),
$B_s \to \phi\mu^+\mu^-$, ...

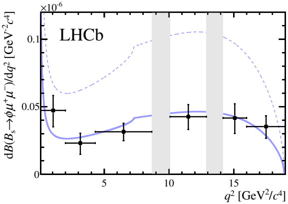


3 main LHCb anomalies:

- $B \to K^* \mu^+ \mu^-$ angular observables (P'_5 / S_5,...): 3.4σ tension $\leftarrow$ supported by Belle
- $R_K = BR(B^+ \to K^+ \mu^+ \mu^-)/BR(B^+ \to K^+ e^+ e^-)$: 2.6$\sigma$ tension in [1-6] GeV^2 bin
- BR($B_s \to \phi \mu^+ \mu^-$): 3.2σ tension in [1-6] GeV^2 bin







New Physics or theoretical issues?

Effective Hamiltonian for $b \to s$ transitions

$$\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$$

$$\mathcal{H}_{\rm eff}^{\rm sl} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \Big[\sum_{i=7,9,10} C_i^{(\prime)} O_i^{(\prime)} \Big]$$

$\langle \bar{K}^* | \mathcal{H}_{\rm eff}^{\rm sl} | \bar{B} \rangle$: $B \to K^*$ form factors $V, A_{0,1,2}, T_{1,2,3}$

Transversity amplitudes:

$$A_\perp^{L,R} \simeq N_\perp \left\{ (C_9^+ \mp C_{10}^+) \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2} C_7^+ T_1(q^2) \right\}$$

$$A_\parallel^{L,R} \simeq N_\parallel \left\{ (C_9^- \mp C_{10}^-) \frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2} C_7^- T_2(q^2) \right\}$$

$$A_0^{L,R} \simeq N_0 \Big\{ (C_9^- \mp C_{10}^-) \left[(\ldots) A_1(q^2) + (\ldots) A_2(q^2) \right] + 2m_b C_7^- \left[(\ldots) T_2(q^2) + (\ldots) T_3(q^2) \right] \Big\}$$

$$A_S = N_S (C_S - C_S') A_0(q^2)$$

$$\left(C_i^\pm \equiv C_i \pm C_i' \right)$$

Theoretical framework

Effective Hamiltonian for $b \to s$ transitions

$$\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$$

$$\mathcal{H}_{\rm eff}^{\rm had} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=1\ldots6} C_i O_i + C_8 O_8 \right]$$

$$\begin{aligned}
\mathcal{A}_\lambda^{\rm (had)} &= -\,i\frac{e^2}{q^2} \int d^4x e^{-iq\cdot x} \langle \ell^+\ell^- | j_\mu^{\rm em,lept}(x)|0\rangle \\
&\times \int d^4y\, e^{iq\cdot y} \langle \bar{K}_\lambda^* | T\{ j^{\rm em,had,\mu}(y) \mathcal{H}_{\rm eff}^{\rm had}(0)\} | \bar{B}\rangle \\
&\equiv \frac{e^2}{q^2} \epsilon_\mu L_V^\mu \Big[\underbrace{\text{LO in } \mathcal{O}(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}})}_{\text{Non-Fact., QCDf}} + \underbrace{h_\lambda(q^2)}_{\text{power corrections}} \Big]
\end{aligned}$$

Effective Hamiltonian for $b \to s$ transitions

$$\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$$

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$$\begin{aligned}\mathcal{A}_\lambda^{(\rm had)} = & - i \frac{e^2}{q^2} \int d^4x e^{-iq\cdot x} \langle \ell^+ \ell^- | j_\mu^{\rm em,lept}(x) | 0 \rangle \\ & \times \int d^4y \, e^{iq\cdot y} \langle \bar{K}_\lambda^* | T\{ j^{\rm em,had,\mu}(y) \mathcal{H}_{\rm eff}^{\rm had}(0) \} | \bar{B} \rangle \\ \equiv & \frac{e^2}{q^2} \epsilon_\mu L_V^\mu \Big[\underbrace{\text{LO in } \mathcal{O}(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}})}_{\text{Non-Fact., QCDf}} + \underbrace{h_\lambda(q^2)}_{\substack{\text{power corrections} \\ \to \textbf{ unknown}}} \Big]\end{aligned}$$

Effective Hamiltonian for $b \to s$ transitions

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Anomalies can be explained with 20-50% non-factorisable power corrections at the observable level in the critical bins (Ciuchini et al., 1512.07157)

This corresponds to more than 150% error at the amplitude level for the critical bins!

Many observables $\rightarrow$ **Global fits** of the latest LHCb data

Relevant $\mathcal{O}$perators:

$$\mathcal{O}_7,\ \mathcal{O}_8,\ \mathcal{O}^{(\prime)}_{9\mu,e}\ ,\ \mathcal{O}^{(\prime)}_{10\mu,e} \quad \text{and} \quad \mathcal{O}_{S-P} \propto (\bar{s}P_R b)(\bar{\mu}P_L\mu) \equiv \mathcal{O}'_0$$

NP manifests itself in the shifts of individual coefficients with respect to the SM values:

$$C_i(\mu) = C_i^{\rm SM}(\mu) + \delta C_i$$

$\rightarrow$ Scans over the values of δC_i

$\rightarrow$ Parametrisation of power correction uncertainties $\frac{\delta A_\lambda}{A_\lambda} = a_\lambda e^{i\phi_\lambda} + \frac{q^2}{6{\rm GeV}^2} b_\lambda e^{i\theta_\lambda}$ with $a_k(b_k)$ varied between $-X\%(\times 2.5)$ and $+X\%(\times 2.5)$

Several groups doing global fits:

Using the latest LHCb results:

Ciuchini, Fedele, Franco, Mishima, Paul, Silvestrini, Valli, 1512.07157

Hurth, Mahmoudi, Neshatpour, 1603.00865

Descotes-Genon, Hofer, Matias, Virto, 1510.04239v2

Previous studies:

Beaujean, Bobeth, Jahn, 1508.01526

Altmannshofer, Straub, 1503.06199, 1411.3161

Hurth, Mahmoudi, Neshatpour, 1410.4545

...

Global fits

Global fits of the observables by minimisation of

$$\chi^2 = \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right) \cdot (\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1} \cdot \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right)$$

$(\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1}$ is the inverse covariance matrix.

More than 100 observables relevant for leptonic and semileptonic decays:

- $\mathrm{BR}(B \to X_s\gamma)$
- $\mathrm{BR}(B \to X_d\gamma)$
- $\Delta_0(B \to K^*\gamma)$
- $\mathrm{BR}^{\rm low}(B \to X_s\mu^+\mu^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s\mu^+\mu^-)$
- $\mathrm{BR}^{\rm low}(B \to X_s e^+e^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s e^+e^-)$
- $\mathrm{BR}(B_s \to \mu^+\mu^-)$
- $\mathrm{BR}(B_d \to \mu^+\mu^-)$
- $\mathrm{BR}(B \to K^{*+}\mu^+\mu^-)$
- $\mathrm{BR}(B \to K^0\mu^+\mu^-)$
- $\mathrm{BR}(B \to K^+\mu^+\mu^-)$
- $\mathrm{BR}(B \to K^*e^+e^-)$
- R_K
- $B \to K^{*0}\mu^+\mu^-$: BR, F_L, A_{FB}, S_3, S_4, S_5, S_7, S_8, S_9
  in 8 low q^2 and 4 high q^2bins
- $B_s \to \phi\mu^+\mu^-$: BR, F_L, , S_3, S_4, S_7
  in 3 low q^2 and 2 high q^2bins

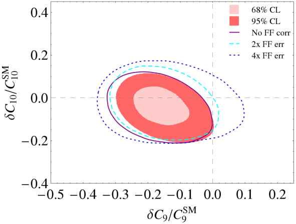
Calculations done using SuperIso

Fit results for two operators: form factor dependence

Fits with different assumptions for the form factor uncertainties:

- correlations ignored (solid line)
- normal form factor errors (filled areas)
- 2 × form factor errors (dashed line)
- 4 × form factor errors (dotted line)

$(C_9 - C_{10})$ $(C_9 - C_9')$ $(C_9^e - C_9^\mu)$



T. Hurth, FM, S. Neshatpour, Nucl. Phys. B909 (2016) 737

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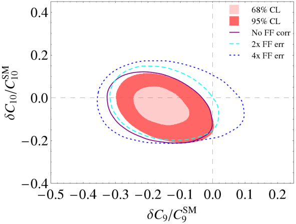
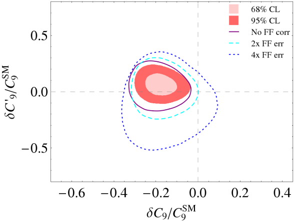
$(C_9 - C_{10})$



$(C_9 - C_9')$



$(C_9^e - C_9^\mu)$

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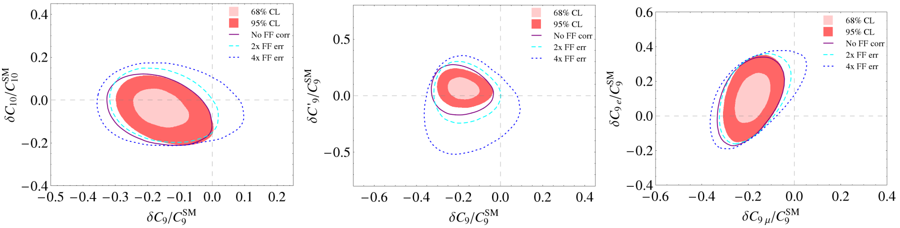

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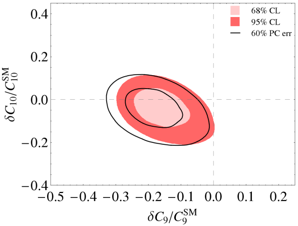
The size of the form factor errors has a crucial role in constraining the allowed region!

Fits assuming different power correction uncertainties:

- 10% uncertainty (filled areas)
- 60% uncertainty (solid line)

$(C_9 - C_{10})$



$(C_9 - C_9')$

$(C_9^e - C_9^\mu)$

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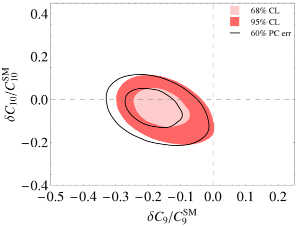
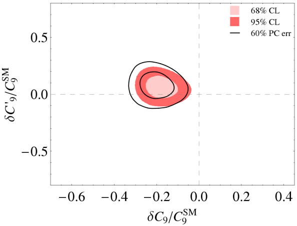


$(C_9 - C_9')$



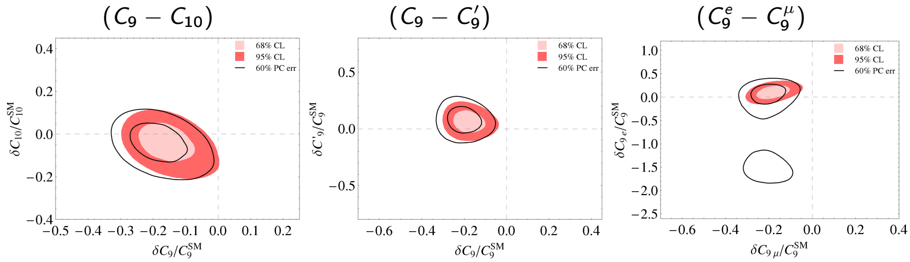
$(C_9^e - C_9^\mu)$

T. Hurth, FM, S. Neshatpour, Nucl. Phys. B909 (2016) 737

Fit results for two operators: effect of power corrections

Fits assuming different power correction uncertainties:

- 10% uncertainty (filled areas)
- 60% uncertainty (solid line)



T. Hurth, FM, S. Neshatpour, Nucl. Phys. B909 (2016) 737

Not a huge impact!

60% power correction uncertainty leads to only 20% error at the observable level.

Hadronic effects

Description also possible in terms of helicity amplitudes:

$$H_V(\lambda) = -i\,N'\Big\{C_9\,\tilde V_{L\lambda}(q^2) + C_9'\,\tilde V_{R\lambda}(q^2) + \frac{m_B^2}{q^2}\Big[\frac{2\,\hat m_b}{m_B}(C_7\,\tilde T_{L\lambda}(q^2) + C_7'\,\tilde T_{R\lambda}(q^2)) - 16\pi^2\mathcal{N}_\lambda(q^2)\Big]\Big\}$$

$$H_A(\lambda) = -i\,N'(C_{10}\,\tilde V_{L\lambda}(q^2) + C_{10}'\,\tilde V_{R\lambda}(q^2)),$$

$\mathcal{N}_\lambda(q^2) =$ leading nonfact. $+\, h_\lambda$

$$H_S = i\,N'\frac{\hat m_b}{m_W}(C_S - C_S')\tilde S(q^2)$$

$$\left(N' = -\frac{4G_F\,m_B}{\sqrt{2}}\frac{e^2}{16\pi^2}V_{tb}V_{ts}^*\right)$$

Helicity FFs $\tilde V_{L/R}, \tilde T_{L/R}, \tilde S$ are combinations of the standard FFs $V, A_{0,1,2}, T_{1,2,3}$

A possible parametrisation of the non-factorisable power corrections $h_{\lambda(=+,-,0)}(q^2)$:

$$h_\lambda(q^2) = h_\lambda^{(0)} + \frac{q^2}{1\mathrm{GeV}^2}h_\lambda^{(1)} + \frac{q^4}{1\mathrm{GeV}^4}h_\lambda^{(2)}$$

S. Jäger and J. Camalich, Phys.Rev. D93 (2016) 014028, M. Ciuchini et al., JHEP 1606 (2016) 116

It seems

$$h_\lambda^{(0)} \longrightarrow C_7^{NP}, \qquad h_\lambda^{(1)} \longrightarrow C_9^{NP}$$

However, $\tilde V_{L(R)\lambda}$ and $\tilde T_{L(R)\lambda}$ both have a q^2 dependence

$\Longrightarrow q^4$ terms can rise due to terms which multiply Wilson coefficients

$\Longrightarrow C_7^{\rm NP}$ and $C_9^{\rm NP}$ can each cause effects similar to $h_\lambda^{(0,1,2)}$

Description also possible in terms of helicity amplitudes:

$$H_V(\lambda) = -\,i\,N'\Big\{C_9\,\tilde{V}_{L\lambda}(q^2) + C_9'\,\tilde{V}_{R\lambda}(q^2) + \frac{m_B^2}{q^2}\Big[\frac{2\,\hat{m}_b}{m_B}(C_7\,\tilde{T}_{L\lambda}(q^2) + C_7'\,\tilde{T}_{R\lambda}(q^2)) - 16\pi^2\mathcal{N}_\lambda(q^2)\Big]\Big\}$$

$$H_A(\lambda) = -i\,N'(C_{10}\,\tilde{V}_{L\lambda}(q^2) + C_{10}'\,\tilde{V}_{R\lambda}(q^2)),$$

$\mathcal{N}_\lambda(q^2) =$ leading nonfact. $+\, h_\lambda$

$$H_S = i\,N'\frac{\hat{m}_b}{m_W}(C_S - C_S')\tilde{S}(q^2)$$

$$\left(N' = -\frac{4G_F\,m_B}{\sqrt{2}}\frac{e^2}{16\pi^2}V_{tb}V_{ts}^*\right)$$

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However, $\tilde{V}_{L(R)\lambda}$ and $\tilde{T}_{L(R)\lambda}$ both have a q^2 dependence

$\Longrightarrow$ q^4 terms can rise due to terms which multiply Wilson coefficients

$\Longrightarrow$ $C_7^{\rm NP}$ and $C_9^{\rm NP}$ can each cause effects similar to $h_\lambda^{(0,1,2)}$

Hadronic power correction effect:

$$\delta H_V^{\rm p.c.}(\lambda) = iN' m_B^2 \frac{16\pi^2}{q^2} h_\lambda(q^2) = iN' m_B^2 \frac{16\pi^2}{q^2}\left(h_\lambda^{(0)} + q^2 h_\lambda^{(1)} + q^4 h_\lambda^{(2)}\right)$$

New Physics effect:

$$\delta H_V^{C_9^{\rm NP}}(\lambda) = -iN' \tilde{V}_L(q^2) C_9^{\rm NP} = iN' m_B^2 \frac{16\pi^2}{q^2}\left(a_\lambda C_9^{\rm NP} + q^2 b_\lambda C_9^{\rm NP} + q^4 c_\lambda C_9^{\rm NP}\right)$$

and similarly for C_7

$\Rightarrow$ NP effects can be embedded in the hadronic effects.

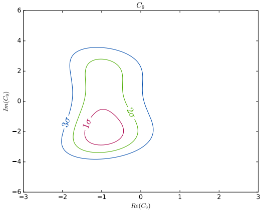
We can do a fit for both (hadronic quantities $h^{(0,1,2)}_{+,-,0}$ (18 parameters)
and Wilson coefficients $C_i^{\rm NP}$(2 or 4 parameters))

Due to this embedding the two fits can be compared with the Wilk's test

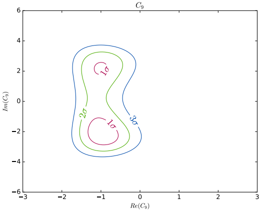
Fit with 2 parameters (complex C_9)

Preliminary

low q^2 bins up to 6 GeV^2

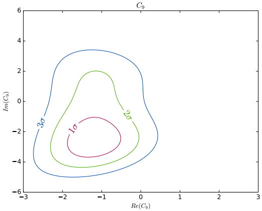


low q^2 bins up to 8 GeV^2

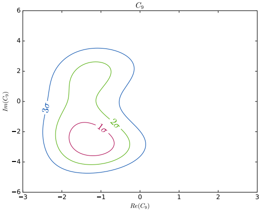


Fit with 4 parameters (complex C_7 and C_9)

low q^2 bins up to 6 GeV^2



low q^2 bins up to 8 GeV^2



SM vs 2 parameters and 4 parameters p-values were independently computed through 2D profile likelihood integration, and they give similar results

q^2 up to 6 GeV^2

Preliminary

	2	4	18
0	4.5×10^{-3} (2.8σ)	9.4×10^{-3} (2.6σ)	6.2×10^{-2} (1.9σ)
2	–	0.27 (1.1σ)	0.37 (0.89σ)
4	–	–	0.41 (0.86σ)

q^2 up to 8 GeV^2

	2	4	18
0	3.7×10^{-5} (4.1σ)	6.3×10^{-5} (4.0σ)	6.1×10^{-3} (2.7σ)
2	–	0.13 (1.5σ)	0.45 (0.76σ)
4	–	–	0.61 (0.52σ)

Adding 16 more parameters does not really improve the fits

Cross-check with other $R_{\mu/e}$ ratios

Hiller & Kruger 0310219, Altmannshofer & Straub 1411.3161, Jäger & Camalich 1412.3183

- R_K is theoretically very clean compared to the angular observables
- Its tension cannot be explained by power corrections
- All tensions could be explained by new physics in C_9^μ

Cross-checks needed with other ratios. Our predictions (within the $\{C_9^\mu, C_9^e\}$ set):

Observable	95% C.L. prediction
$\mathrm{BR}(B \to X_s \mu^+\mu^-)/\mathrm{BR}(B \to X_s e^+e^-)_{q^2 \in [1,6](\mathrm{GeV})^2}$	$[0.61, 0.93]$
$\mathrm{BR}(B \to X_s \mu^+\mu^-)/\mathrm{BR}(B \to X_s e^+e^-)_{q^2 > 14.2(\mathrm{GeV})^2}$	$[0.68, 1.13]$
$\mathrm{BR}(B^0 \to K^{*0}\mu^+\mu^-)/\ \mathrm{BR}(B^0 \to K^{*0}e^+e^-)_{q^2 \in [1,6](\mathrm{GeV})^2}$	$[0.65, 0.96]$
$\langle F_L(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle F_L(B^0 \to K^{*0}e^+e^-)\rangle_{q^2 \in [1,6](\mathrm{GeV})^2}$	$[0.85, 0.96]$
$\langle A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle A_{FB}(B^0 \to K^{*0}e^+e^-)\rangle_{q^2 \in [4,6](\mathrm{GeV})^2}$	$[-0.21, 0.71]$
$\langle S_5(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle S_5(B^0 \to K^{*0}e^+e^-)\rangle_{q^2 \in [4,6](\mathrm{GeV})^2}$	$[0.53, 0.92]$
$\mathrm{BR}(B^0 \to K^{*0}\mu^+\mu^-)/\ \mathrm{BR}(B^0 \to K^{*0}e^+e^-)_{q^2 \in [15,19](\mathrm{GeV})^2}$	$[0.58, 0.95]$
$\langle F_L(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle F_L(B^0 \to K^{*0}e^+e^-)\rangle_{q^2 \in [15,19](\mathrm{GeV})^2}$	$[0.998, 0.999]$
$\langle A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle A_{FB}(B^0 \to K^{*0}e^+e^-)\rangle_{q^2 \in [15,19](\mathrm{GeV})^2}$	$[0.87, 1.01]$
$\langle S_5(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle S_5(B^0 \to K^{*0}e^+e^-)\rangle_{q^2 \in [15,19](\mathrm{GeV})^2}$	$[0.87, 1.01]$
$\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)/\ \mathrm{BR}(B^+ \to K^+e^+e^-)_{q^2 \in [1,6](\mathrm{GeV})^2}$	$[0.58, 0.95]$
$\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)/\ \mathrm{BR}(B^+ \to K^+e^+e^-)_{q^2 \in [15,22](\mathrm{GeV})^2}$	$[0.58, 0.95]$

T. Hurth, FM, S. Neshatpour, Nucl. Phys. B909 (2016) 737

Cross-check with other $R_{\mu/e}$ ratios

Hiller & Kruger 0310219, Altmannshofer & Straub 1411.3161, Jäger & Camalich 1412.3183

- R_K is theoretically very clean compared to the angular observables
- Its tension cannot be explained by power corrections
- All tensions could be explained by new physics in C_9^μ

Cross-checks needed with other ratios. Our predictions (within the $\{C_9^\mu, C_9^e\}$ set):

Observable	95% C.L. prediction
$\mathrm{BR}(B \to X_s \mu^+\mu^-)/\mathrm{BR}(B \to X_s e^+e^-)_{q^2\in[1,6](\mathrm{GeV})^2}$	$[0.61, 0.93]$
$\mathrm{BR}(B \to X_s \mu^+\mu^-)/\mathrm{BR}(B \to X_s e^+e^-)_{q^2>14.2(\mathrm{GeV})^2}$	$[0.68, 1.13]$
$\mathrm{BR}(B^0 \to K^{*0}\mu^+\mu^-)/\ \mathrm{BR}(B^0 \to K^{*0}e^+e^-)_{q^2\in[1,6](\mathrm{GeV})^2}$	$[0.65, 0.96]$
$\langle F_L(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle F_L(B^0 \to K^{*0}e^+e^-)\rangle_{q^2\in[1,6](\mathrm{GeV})^2}$	$[0.85, 0.96]$
$\langle A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle A_{FB}(B^0 \to K^{*0}e^+e^-)\rangle_{q^2\in[4,6](\mathrm{GeV})^2}$	$[-0.21, 0.71]$
$\langle S_5(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle S_5(B^0 \to K^{*0}e^+e^-)\rangle_{q^2\in[4,6](\mathrm{GeV})^2}$	$[0.53, 0.92]$
$\mathrm{BR}(B^0 \to K^{*0}\mu^+\mu^-)/\ \mathrm{BR}(B^0 \to K^{*0}e^+e^-)_{q^2\in[15,19](\mathrm{GeV})^2}$	$[0.58, 0.95]$
$\langle F_L(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle F_L(B^0 \to K^{*0}e^+e^-)\rangle_{q^2\in[15,19](\mathrm{GeV})^2}$	$[0.998, 0.999]$
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$\langle S_5(B^0 \to K^{*0}\mu^+\mu^-)\rangle/\langle S_5(B^0 \to K^{*0}e^+e^-)\rangle_{q^2\in[15,19](\mathrm{GeV})^2}$	$[0.87, 1.01]$
$\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)/\ \mathrm{BR}(B^+ \to K^+e^+e^-)_{q^2\in[1,6](\mathrm{GeV})^2}$	$[0.58, 0.95]$
$\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)/\ \mathrm{BR}(B^+ \to K^+e^+e^-)_{q^2\in[15,22](\mathrm{GeV})^2}$	$[0.58, 0.95]$

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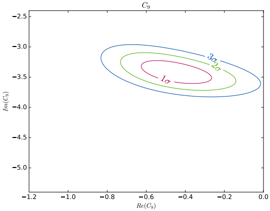
Assuming a possible future upgrade, with an integrated luminosity of 300 fb^{-1}

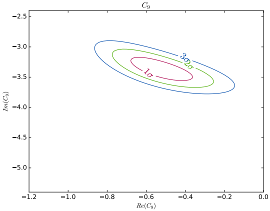
$\rightarrow$ Scaling down the present LHCb uncertainties by a factor 10,
assuming the current central values

Fit with 2 parameters (complex C_9)

low q^2 bins up to 6 GeV^2



low q^2 bins up to 8 GeV^2



Preliminary

LHCb upgrade would clear up the situation!

Conclusion

- The full LHCb Run 1 results still show some tensions with the SM predictions
- Significance of the anomalies depends on the assumptions on the power corrections
- We compared the fits for the NP and hadronic parameters through the Wilk's test
- At the moment adding the hadronic parameters does not improve the fit compared to the new physics fit, but the situation is inconclusive
- The LHCb upgrade will have enough precision to distinguish between NP and power corrections
- If the issue remains, Belle-II will be able to resolve it
  (see T. Hurth, FM, S. Neshatpour, JHEP 1412 (2014) 053)
- Confirmation of R_K by other rations would indirectly confirm NP also in angular observables

Backup

Dilepton invariant mass spectrum: $\frac{d\Gamma}{dq^2} = \frac{3}{4}(J_1 - \frac{J_2}{3})$

Forward backward asymmetry:

$$A_{\rm FB}(q^2) \equiv \left[\int_{-1}^{0} - \int_{0}^{1}\right] d\cos\theta_l \, \frac{d^2\Gamma}{dq^2\, d\cos\theta_l} \Big/ \frac{d\Gamma}{dq^2} = \frac{3}{8} J_6 \Big/ \frac{d\Gamma}{dq^2}$$

Forward backward asymmetry zero-crossing: $q_0^2 \simeq -2 m_b m_B \frac{C_9^{\rm eff}(q_0^2)}{C_7} + O(\alpha_s, \Lambda/m_b)$

→ fix the sign of C_9/C_7

Polarization fractions:

$$F_L(q^2) = \frac{|A_0|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2},\; F_T(q^2) = 1 - F_L(q^2) = \frac{|A_\perp|^2 + |A_\parallel|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2}$$

$$\langle P_1 \rangle_{\rm bin} = \frac{1}{2} \frac{\int_{\rm bin} dq^2 [J_3 + \bar{J}_3]}{\int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]} \qquad \langle P_2 \rangle_{\rm bin} = \frac{1}{8} \frac{\int_{\rm bin} dq^2 [J_{6s} + \bar{J}_{6s}]}{\int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]}$$

$$\langle P'_4 \rangle_{\rm bin} = \frac{1}{\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_4 + \bar{J}_4] \qquad \langle P'_5 \rangle_{\rm bin} = \frac{1}{2\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_5 + \bar{J}_5]$$

$$\langle P'_6 \rangle_{\rm bin} = \frac{-1}{2\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_7 + \bar{J}_7] \qquad \langle P'_8 \rangle_{\rm bin} = \frac{-1}{\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_8 + \bar{J}_8]$$

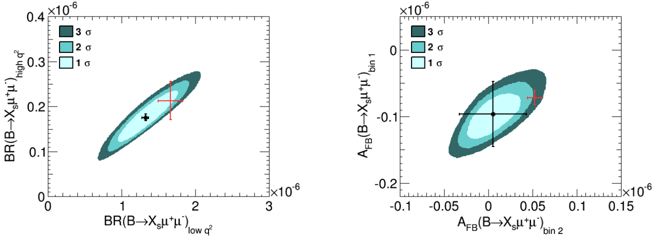
with

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

+ CP violating clean observables and other combinations

U. Egede et al., JHEP 0811 (2008) 032, JHEP 1010 (2010) 056
J. Matias et al., JHEP 1204 (2012) 104
S. Descotes-Genon et al., JHEP 1305 (2013) 137

At Belle-II, for inclusive $b \to s\ell\ell$:
expected uncertainty of 2.9% (4.1%) for the branching fraction in the low- (high-)q^2 region, absolute uncertainty of 0.050 in the low-q^2 bin 1 ($1 < q^2 < 3.5$ GeV^2), 0.054 in the low-q^2 bin 2 ($3.5 < q^2 < 6$ GeV^2) for the *normalised* A_{FB}



T. Hurth, FM, JHEP 1404 (2014) 097
T. Hurth, FM, S. Neshatpour, JHEP 1412 (2014) 053

Predictions based on our model-independent analysis

black cross: future measurements at Belle-II assuming the best fit solution
red cross: SM predictions

→ inclusive mode will lead to very strong constraints

Effective Hamiltonian for $b \to s$ transitions

$$\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$$

$$\mathcal{H}_{\rm eff}^{\rm sl} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \Big[\sum_{i=7,9,10} C_i^{(\prime)} O_i^{(\prime)} \Big]$$

Transversity amplitudes:

$$A_\perp^{L,R} = N_\perp \left\{ (C_9^+ \mp C_{10}^+) \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2} C_7^+ T_1(q^2) \right\} + \delta A_\perp(q^2)$$

$$A_\parallel^{L,R} = N_\parallel \left\{ (C_9^- \mp C_{10}^-) \frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2} C_7^- T_2(q^2) \right\} + \delta A_\parallel(q^2)$$

$$A_0^{L,R} = N_0 \Big\{ (C_9^- \mp C_{10}^-) \left[(\ldots) A_1(q^2) + (\ldots) A_2(q^2) \right] + 2m_b C_7^- \left[(\ldots) T_2(q^2) + (\ldots) T_3(q^2) \right] \Big\} + \delta A_0(q^2)$$

$$A_S = N_S (C_S - C_S') A_0(q^2)$$

$$V_\pm(q^2) = \frac{1}{2}\left[\Big(1+\frac{m_V}{m_B}\Big)A_1(q^2) \mp \frac{\lambda^{1/2}}{m_B(m_B+m_V)}V(q^2)\right],$$

$$V_0(q^2) = \frac{1}{2m_V\lambda^{1/2}(m_B+m_V)}\left[(m_B+m_V)^2(m_B^2-q^2-m_V^2)A_1(q^2) - \lambda A_2(q^2)\right],$$

$$T_\pm(q^2) = \frac{m_B^2-m_V^2}{2m_B^2}T_2(q^2) \mp \frac{\lambda^{1/2}}{2m_B^2}T_1(q^2),$$

$$T_0(q^2) = \frac{m_B}{2\,m_V\lambda^{1/2}}\left[(m_B^2+3m_V^2-q^2)\,T_2(q^2) - \frac{\lambda}{(m_B^2-m_V^2)}T_3(q^2)\right],$$

$$S(q^2) = A_0(q^2),$$

$$V_0(q^2) = \frac{2m_B\sqrt{q^2}}{\lambda^{1/2}}\tilde{V}_0(q^2),$$

$$T_0(q^2) = \frac{2m_B^3}{\sqrt{q^2}\lambda^{1/2}}\tilde{T}_0(q^2),$$

$$S(q^2) = -\frac{2m_B(m_b+m_s)}{\lambda^{1/2}}\tilde{S}(q^2),$$

$$V_{\pm1}(q^2) = \tilde{V}_{\pm1}(q^2),$$

$$T_{\pm1}(q^2) = \tilde{T}_{\pm1}(q^2),$$

where $V_{R\lambda} = -V_{-\lambda}$, $T_{R\lambda} = -T_{-\lambda}$, $S_R = -S_L$.

The form factors $V_{\pm,0}$ and $T_{\pm,0}$ when using the updated results from version 2 of Zwicky et al.

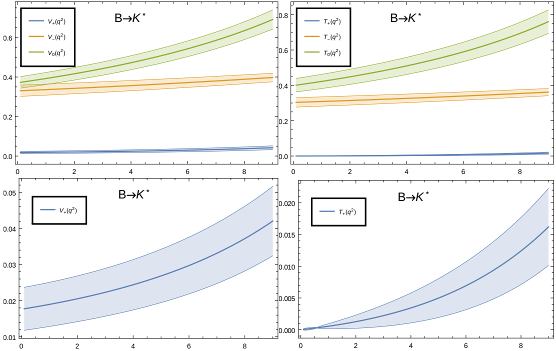


Figure: The central values and uncertainties of the helicity form factors $V_{\pm,0}$ and $T_{\pm,0}$ for $B \to K^*$ using form factor results of $V, A_{1,2}$ and $T_{1,2,3}$ from version 2 of Zwicky et al.

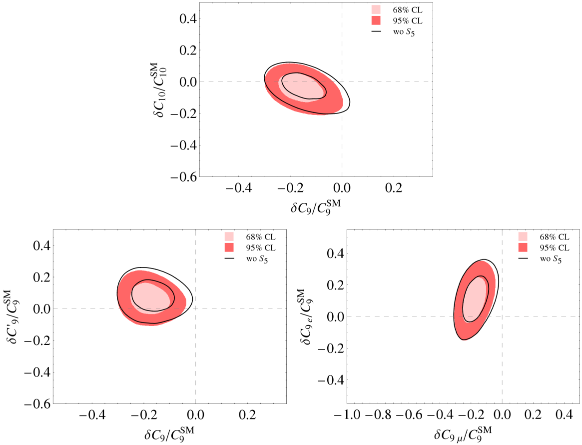
Traditional form factors:

$$\langle \bar{K}^* | \bar{s}\gamma^\mu b | \bar{B} \rangle \longrightarrow V(q^2)$$
$$\langle \bar{K}^* | \bar{s}\gamma^\mu \gamma_5 b | \bar{B} \rangle \longrightarrow A_0(q^2), A_1(q^2), A_2(q^2)$$
$$\langle \bar{K}^* | \bar{s}\sigma^{\mu\nu} b | \bar{B} \rangle \longrightarrow T_1(q^2), T_2(q^2), T_3(q^2)$$

Helicity form factors:

$$\langle \bar{K}^*_\lambda | \bar{s} \not\epsilon^*(\lambda) P_{L(R)} b | \bar{B} \rangle \longrightarrow \tilde{V}_{L(R)\lambda}(q^2)$$
$$\epsilon^*(\lambda) q^\nu \langle \bar{K}^*_\lambda | \bar{s}\sigma_{\mu\nu} P_{L(R)} b | \bar{B} \rangle \longrightarrow \tilde{T}_{L(R)\lambda}(q^2)$$
$$\langle \bar{K}^*_{\lambda(=0)} | \bar{s} P_{L(R)} b | \bar{B} \rangle \longrightarrow \tilde{S}(q^2)$$

Removing S_5 from the fit:



While the tension of $C_9^{\rm SM}$ and best fit point value of C_9 is slightly reduced in the various two operator fits, still the tension exists at more than 2σ

$\rightarrow$ **S_5 is not the only observable which drives C_9 to negative values!**