New physics fits to the latest bsll data - Moriond 19 updates

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Based on arXiv:1705.06274, arXiv:1806.02791 and arXiv:1904.08399

Thanks to A. Arbey, T. Hurth, S. Neshatpour and D. Martinez Santos

Portorož 2019

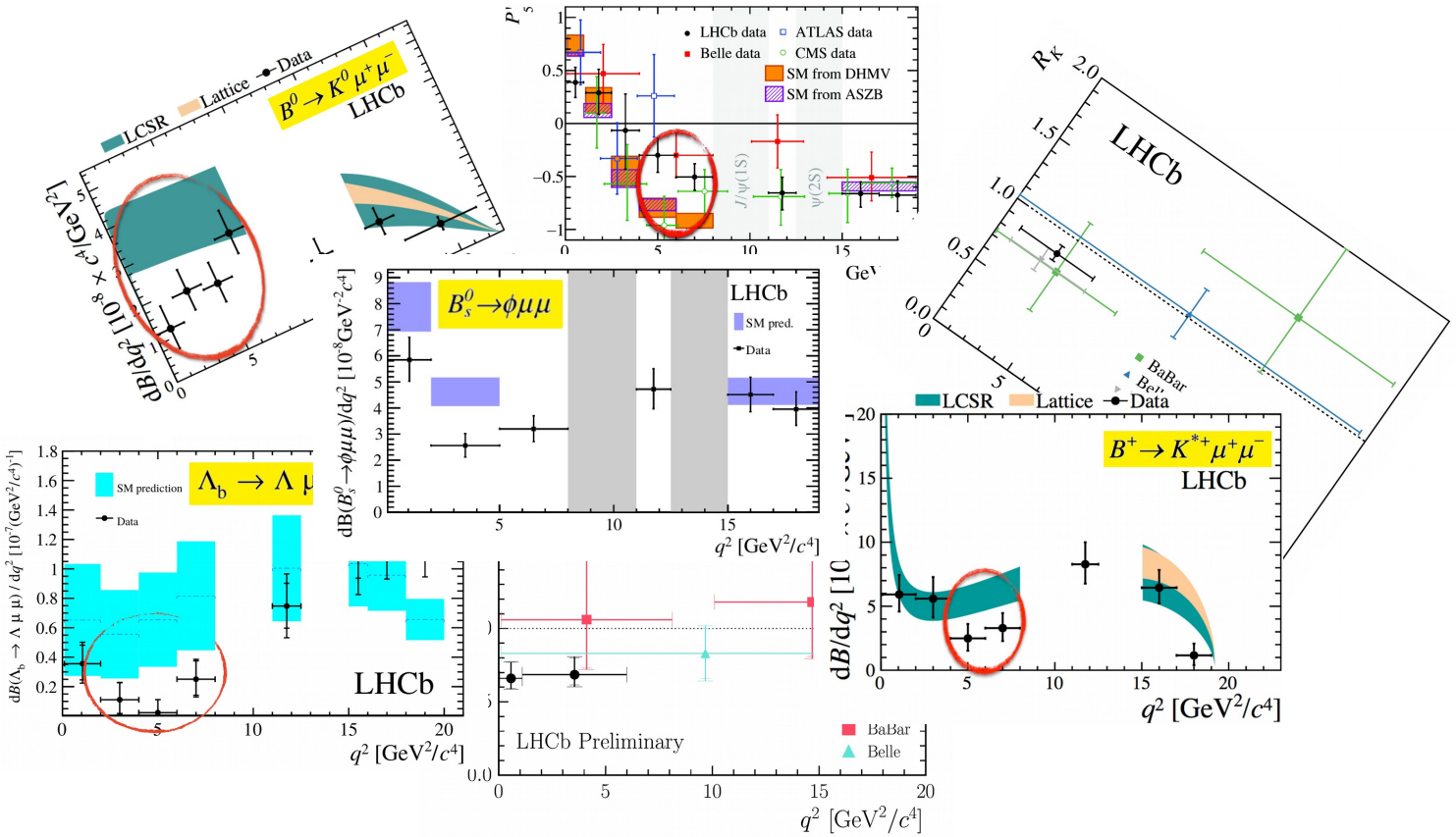
Precision era in High Energy Physics

April 16 - 19 2019, Portorož, Slovenia

$b \to s\ell\ell$ measurements

Impressive effort in studying **exclusive** $b \to s\ell\ell$ transitions at LHCb, but also ATLAS, CMS and Belle, with the measurements of a large number of independent branching ratios and angular observables!

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



Several small deviations from the SM predictions...

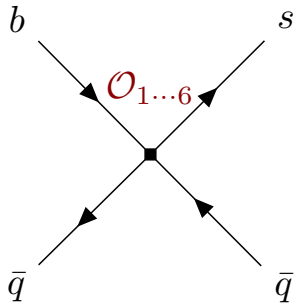
How to make sense of data?

Theoretical framework: Effective Hamiltonian

separation between low and high energies using Operator Product Expansion

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \Big(\sum_{i=1\cdots 10,S,P} \big(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu) \big) \Big)$$

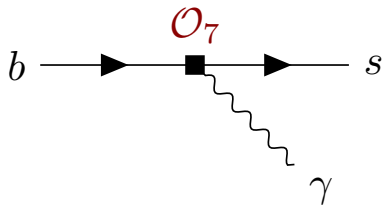
4-quark operators



$\mathcal{O}_{1,2} \propto (\bar{s}\Gamma_\mu c)(\bar{c}\Gamma^\mu b)$

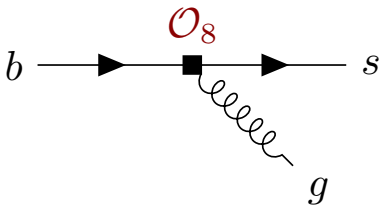
$\mathcal{O}_{3,4} \propto (\bar{s}\Gamma_\mu b)\sum_q(\bar{q}\Gamma^\mu q)$

electromagnetic dipole operator



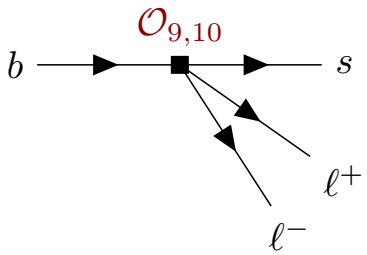
$\mathcal{O}_7 \propto (\bar{s}\sigma^{\mu\nu}P_R)F^a_{\mu\nu}$

chromomagnetic dipole operator



$\mathcal{O}_8 \propto (\bar{s}\sigma^{\mu\nu}T^aP_R)G^a_{\mu\nu}$

semileptonic operators



$\mathcal{O}_9^\ell \propto (\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\ell)$

$\mathcal{O}_{10}^\ell \propto (\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5\ell)$

In the SM: $C_7 = -0.29$ $\quad C_9 = 4.20$ $\quad C_{10} = -4.01$

New physics:

- Corrections to the Wilson coefficients: $C_i \to C_i^{\rm SM} + \delta C_i^{\rm NP}$
- Additional operators: Chirally flipped ($\mathcal{O}_i'$), (pseudo)scalar ($\mathcal{O}_S$ and $\mathcal{O}_P$)

Issue of the hadronic power corrections

Effective Hamiltonian has two parts: $\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$

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

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

Transversity amplitudes:

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

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

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

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

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

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

$$\mathcal{A}_\lambda^{(\rm had)} = -i \frac{e^2}{q^2} \int d^4x e^{-iq\cdot x} \langle \ell^+ \ell^- | j_\mu^{\rm em,lept}(x) | 0 \rangle \times \int d^4y\, e^{iq\cdot y} \langle \bar{K}_\lambda^* | T\{ j^{\rm em,had,\mu}(y) \mathcal{H}_{\rm eff}^{\rm had}(0) \} | \bar{B} \rangle$$

$$\equiv \frac{e^2}{q^2} \epsilon_\mu L_V^\mu \Big[\underbrace{\text{LO in } \mathcal{O}\Big(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}}\Big)}_{\text{Non-Fact., QCDf}} + \underbrace{h_\lambda(q^2)}_{\text{power corrections}} \Big]$$

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$\to$ **unknown**

only guesstimates possible at present
but estimates possible with some work on the theory side

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$\to$ **unknown**

only guesstimates possible at present
but estimates possible with some work on the theory side

The significance of the anomalies depends on the assumptions made for the unknown power corrections!

This does not affect R_K and R_{K^*}

$\to$ Separate R_K and R_{K^*} from the less clean observables

Global fits

Many observables $\rightarrow$ **Global fits**

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

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

$\rightarrow$ Scans over the values of δC_i
$\rightarrow$ Calculation of flavour observables

Global fits of the observables obtained by minimisation of

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

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

Computations performed using SuperIso public program

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Theoretical uncertainties and correlations

- Monte Carlo analysis
- variation of the "standard" input parameters: masses, scales, CKM, ...
- decay constants taken from the latest lattice results
- $B \to K^{(*)}$ and $B_s \to \phi$ form factors are obtained from the lattice+LCSR combinations (1411.3161, 1503.05534), including all the correlations
- Parameterisation of uncertainties from power corrections:

$$A_k \to A_k \left(1 + a_k \exp(i\phi_k) + \frac{q^2}{6\ \mathrm{GeV}^2} b_k \exp(i\theta_k)\right)$$

$|a_k|$ between 10 to 60%, $b_k \sim 2.5 a_k$
Low recoil: $b_k = 0$

$\Rightarrow$ Computation of a (theory + exp) correlation matrix

Best fit values considering all observables besides R_K and R_{K^*}
(under the assumption of 10% non-factorisable power corrections)

All $b \to s$ data except $R_{K^{(*)}}$		$(\chi^2_{\rm SM} = 98.1)$	
	b.f. value	$\chi^2_{\rm min}$	$\rm Pull_{SM}$
δC_9	-1.02 ± 0.20	79.7	4.3σ
δC_{10}	0.18 ± 0.25	97.6	0.8σ
δC_9^μ	-1.05 ± 0.19	77.5	4.5σ
δC_9^e	0.72 ± 0.58	96.9	1.1σ
δC_{10}^μ	0.27 ± 0.25	96.8	1.1σ
δC_{10}^e	-0.56 ± 0.50	97.1	1.0σ

$\to$ C_9 and C_9^μ solutions are favoured with SM pulls of 4.3 and 4.5σ

$\to$ C_{10}-like solutions do not play a role

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Best fit values in the one operator fit considering *only* R_K and R_{K^*}

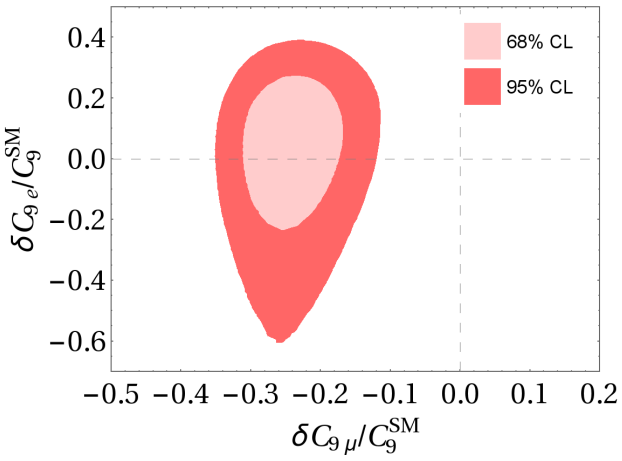
Only R_K and R_{K^*}		($\chi^2_{\rm SM} = 18.7$)	
	b.f. value	$\chi^2_{\rm min}$	$\rm Pull_{SM}$
δC_9	-1.99 ± 5.81	18.6	0.3σ
δC_{10}	4.09 ± 12.23	18.5	0.5σ
δC_9^μ	-1.47 ± 0.52	5.3	3.7σ
δC_9^e	1.58 ± 0.49	3.6	3.9σ
δC_{10}^μ	1.38 ± 0.44	2.8	4.0σ
δC_{10}^e	-1.44 ± 0.44	2.3	4.1σ

$\to$ NP in C_9^e, C_9^μ, C_{10}^e, or C_{10}^μ are favoured by the $R_{K^{(*)}}$ ratios (significance: $3.7 - 4.1\sigma$)

Picture before Moriond – two operator fits

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

using all but R_K and R_{K^*}



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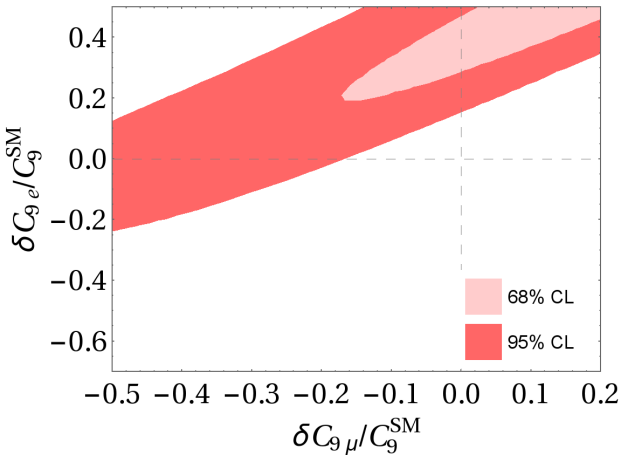

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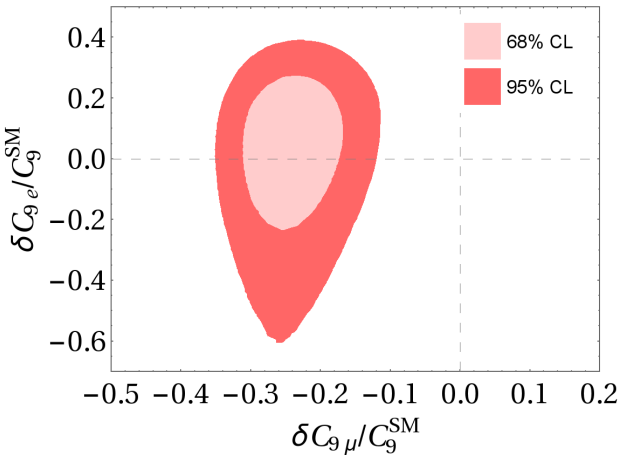

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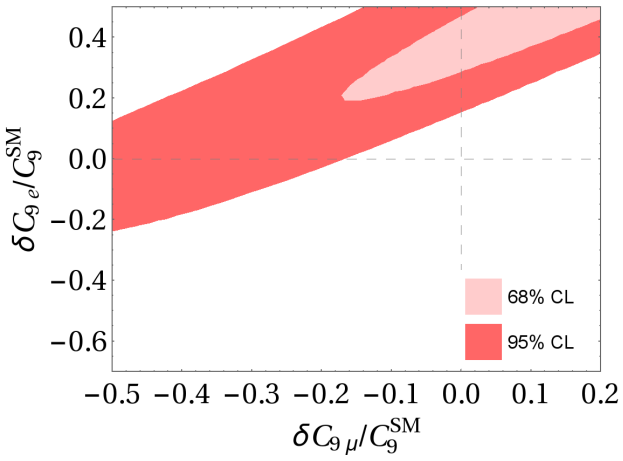
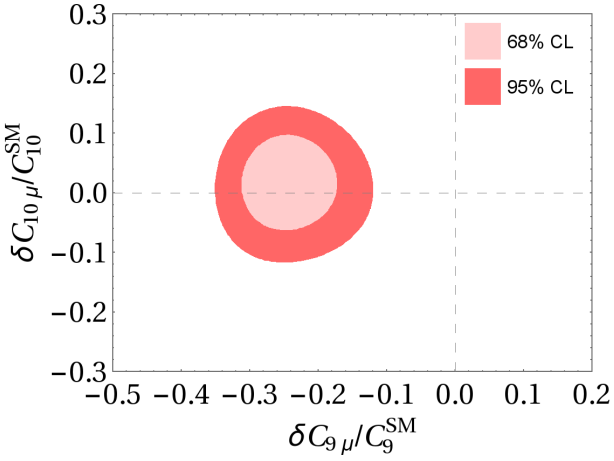
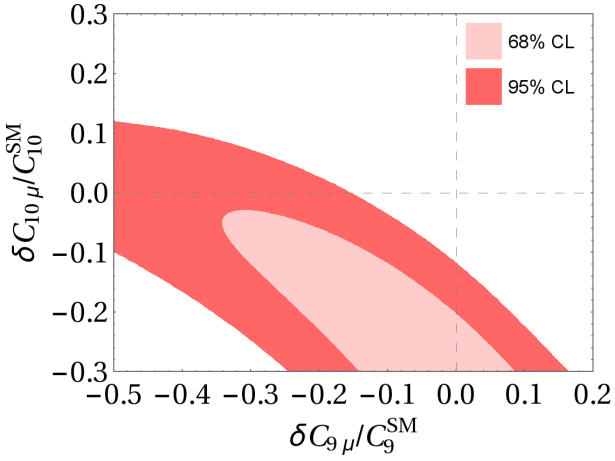


$(C_9^\mu - C_{10}^\mu)$

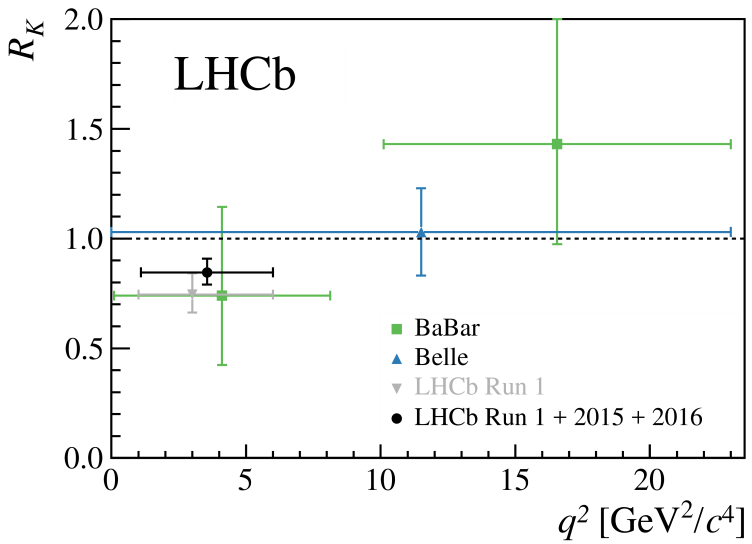




The two sets are compatible at least at the 2σ level.

1 Lepton flavour universality in $B^+ \to K^+\ell^+\ell^-$

$$R_K = BR(B^+ \to K^+\mu^+\mu^-)/BR(B^+ \to K^+e^+e^-)$$



Run 1 (PRL 113, 151601 (2014)):
$R_K([1.1, 6.0]\,\mathrm{GeV}^2) = 0.717^{+0.083+0.017}_{-0.071-0.016}$

Run 2 (arXiv:1903.09252):
$R_K([1.1, 6.0]\,\mathrm{GeV}^2) = 0.928^{+0.089+0.020}_{-0.076-0.017}$

$R_K^{\mathrm{SM}} = 1.0006 \pm 0.0004$

Bordone, Isidori, Pattori, Eur.Phys.J. C76 (2016) 8, 440

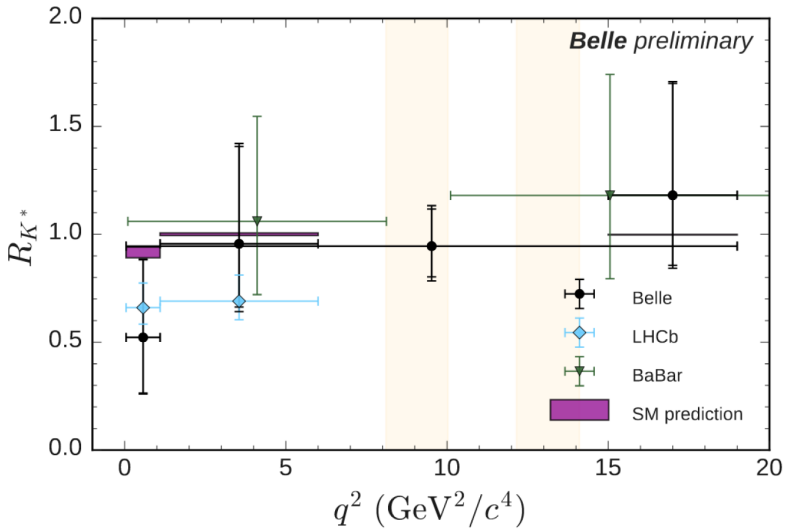
Combined result (arXiv:1903.09252):

$$R_K([1.1, 6.0]\,\mathrm{GeV}^2) = 0.846^{+0.060+0.016}_{-0.054-0.014}$$

Central value is now closer to the SM prediction, but the tension is still 2.5σ due to the smaller uncertainty of the new measurement.

❷ Lepton flavour universality in $B^0 \to K^{*0}\ell^+\ell^-$

$$R_{K^*} \equiv \mathrm{BR}(B \to K^*\mu^+\mu^-)/\mathrm{BR}(B \to K^*e^+e^-)$$



LHCb (JHEP 08 (2017) 055):

$$R_{K^*}([0.045, 1.1]\,\mathrm{GeV}^2) = 0.660^{+0.110}_{-0.070} \pm 0.024$$

$$R_{K^*}([1.1, 6]\,\mathrm{GeV}^2) = 0.685^{+0.113}_{-0.069} \pm 0.047$$

$$R^{\mathrm{SM}}_{K^*}([0.045, 1.1]\,\mathrm{GeV}^2) = 0.906 \pm 0.028$$

$$R^{\mathrm{SM}}_{K^*}([1.1, 6]\,\mathrm{GeV}^2) = 1.000 \pm 0.010$$

Belle (arXiv:1904.02440):

$$R_{K^*}([0.045, 1.1]\,\mathrm{GeV}^2) = 0.52^{+0.36}_{-0.26} \pm 0.05, \quad R_{K^*}([1.1, 6.0]\,\mathrm{GeV}^2) = 0.96^{+0.45}_{-0.29} \pm 0.11,$$

$$R_{K^*}([0.1, 8]\,\mathrm{GeV}^2) = 0.90^{+0.27}_{-0.21} \pm 0.10, \quad R_{K^*}([15, 19]\,\mathrm{GeV}^2) = 1.18^{+0.52}_{-0.32} \pm 0.10.$$

The very low-q^2 bin has a tension with the SM prediction slightly more than 1σ, while the other bins are all well in agreement with the SM at the 1σ-level.

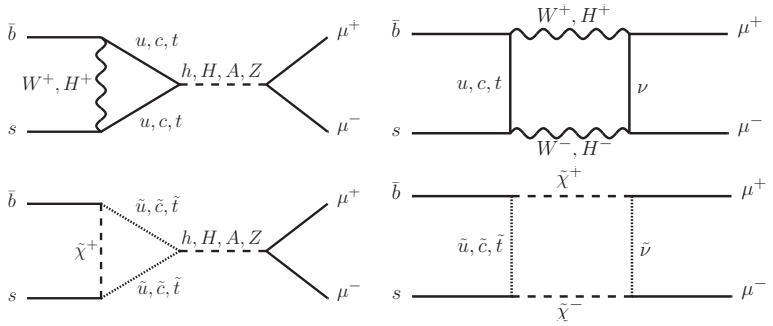
❸ BR($B_s \to \mu^+\mu^-$)

Relevant operators:

$$\mathcal{O}_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

$$\mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell)$$

$$\mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\gamma_5\ell)$$



$$\mathrm{BR}(B_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_s}^2 \tau_{B_s} m_{B_s}^3 |V_{tb}V_{ts}^*|^2 \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}}$$
$$\times \left\{ \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) |C_S - C_S'|^2 + \left|(C_P - C_P') + 2(C_{10} - C_{10}')\frac{m_\mu}{m_{B_s}}\right|^2 \right\}$$

Possible cancellation between $(C_{10} - C_{10}')$ and $(C_P - C_P')$!

SM prediction: $\mathrm{BR}(B_s \to \mu^+\mu^-) = (3.41 \pm 0.27) \times 10^{-9}$

SuperIso v4.1
Bobeth et al., Phys. Rev. Lett. 112 (2014) 101801, ...
Fleischer et al., Phys.Rev.Lett. 109 (2012) 041801, JHEP 1705 (2017) 156, ...

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$$\mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell)$$

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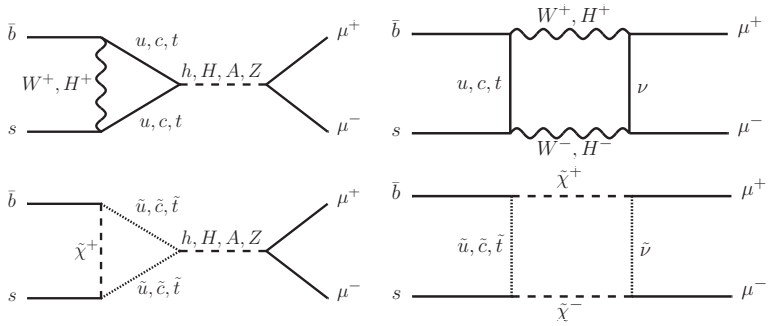


$$\mathrm{BR}(B_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_s}^2 \tau_{B_s} m_{B_s}^3 |V_{tb}V_{ts}^*|^2 \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}}$$
$$\times \left\{ \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) |C_S - C_S'|^2 + \left|(C_P - C_P') + 2(C_{10} - C_{10}')\frac{m_\mu}{m_{B_s}}\right|^2 \right\}$$

Possible cancellation between $(C_{10} - C_{10}')$ and $(C_P - C_P')$!

SM prediction: $\mathrm{BR}(B_s \to \mu^+\mu^-) = (3.41 \pm 0.27) \times 10^{-9}$

SuperIso v4.1
Bobeth et al., Phys. Rev. Lett. 112 (2014) 101801, ...
Fleischer et al., Phys.Rev.Lett. 109 (2012) 041801, JHEP 1705 (2017) 156, ...

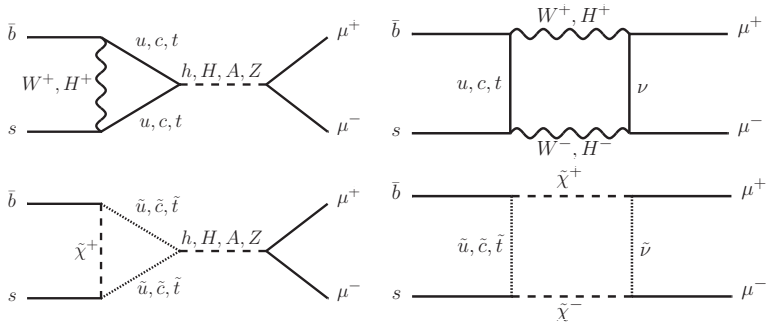
❸ BR($B_s \to \mu^+\mu^-$)

Relevant operators:

$$\mathcal{O}_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

$$\mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell)$$

$$\mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\gamma_5\ell)$$



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BR($B_s \to \mu^+\mu^-$)

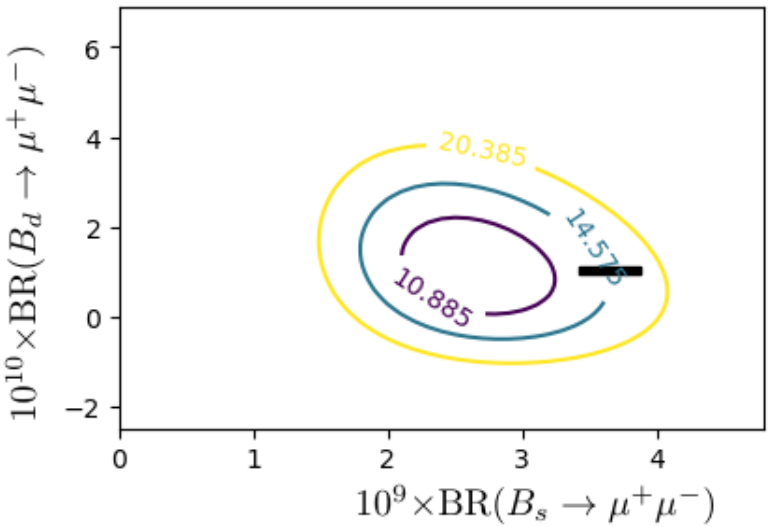
New experimental data on $B_{s,d} \to \mu^+\mu^-$ by ATLAS (1812.03017):

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = 2.8^{+0.8}_{-0.7} \times 10^{-9}, \quad \mathrm{BR}(B_d \to \mu^+\mu^-) < 2.1 \times 10^{-10}$$

Combined with CMS and LHCb (our average):

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = 2.65^{+0.43}_{-0.39} \times 10^{-9}, \quad \mathrm{BR}(B_d \to \mu^+\mu^-) = 1.09^{+0.74}_{-0.68} \times 10^{-10}$$

Based on a joint 2D likelihood with common f_d/f_s and $\mathrm{BR}(B^+ \to J/\psi K^+) \times \mathrm{BR}(J/\psi \to \mu^+\mu^-)$



Contours: 1, 2 & 3σ (in terms of $\Delta\chi^2$)
Numbers: the absolute χ^2
Black box: SM prediction

Updated fits - single operators

Comparison of one-operator NP fits:

All observables except R_K, R_{K^*} ($\chi^2_{\rm SM} = 100.2$)			
	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_9	-1.00 ± 0.20	82.5	4.2σ
δC_9^μ	-1.03 ± 0.20	80.3	4.5σ
δC_9^e	0.72 ± 0.58	98.9	1.1σ
δC_{10}	0.25 ± 0.23	98.9	1.1σ
δC_{10}^μ	0.32 ± 0.22	98.0	1.5σ
δC_{10}^e	-0.56 ± 0.50	99.1	1.0σ
$\delta C_{\rm LL}^\mu$	-0.48 ± 0.15	89.1	3.3σ
$\delta C_{\rm LL}^e$	0.33 ± 0.29	99.0	1.1σ

Only R_K, R_{K^*} ($\chi^2_{\rm SM} = 16.9$)			
	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_9	-2.04 ± 5.93	16.8	0.3σ
δC_9^μ	-0.74 ± 0.28	8.4	2.9σ
δC_9^e	0.79 ± 0.29	7.7	3.0σ
δC_{10}	4.10 ± 11.87	16.7	0.5σ
δC_{10}^μ	0.77 ± 0.26	6.1	3.3σ
δC_{10}^e	-0.78 ± 0.27	6.0	3.3σ
$\delta C_{\rm LL}^\mu$	-0.37 ± 0.12	7.0	3.1σ
$\delta C_{\rm LL}^e$	0.41 ± 0.15	6.8	3.2σ

$\delta C_{\rm LL}^\ell$ basis corresponds to $\delta C_9^\ell = -\delta C_{10}^\ell$.

Reduced NP significance of the ratios compared to before

NP analyses of the two sets of observables are less coherent than often stated, especially regarding the coefficients $C_{10}^{\mu,e}$.

Updated fits - single operators

Comparison of one-operator NP fits:

All observables except $R_K, R_{K^*}, B_{s,d} \to \mu^+\mu^-$ ($\chi^2_{\rm SM} = 99.7$)			
	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_9	-1.03 ± 0.20	81.0	4.3σ
δC_9^μ	-1.05 ± 0.19	78.8	4.6σ
δC_9^e	0.72 ± 0.58	98.5	1.1σ
δC_{10}	0.27 ± 0.28	98.7	1.0σ
δC_{10}^μ	0.38 ± 0.28	97.7	1.4σ
δC_{10}^e	-0.56 ± 0.50	98.7	1.0σ
$\delta C_{\rm LL}^\mu$	-0.50 ± 0.16	88.8	3.3σ
$\delta C_{\rm LL}^e$	0.33 ± 0.29	98.6	1.1σ

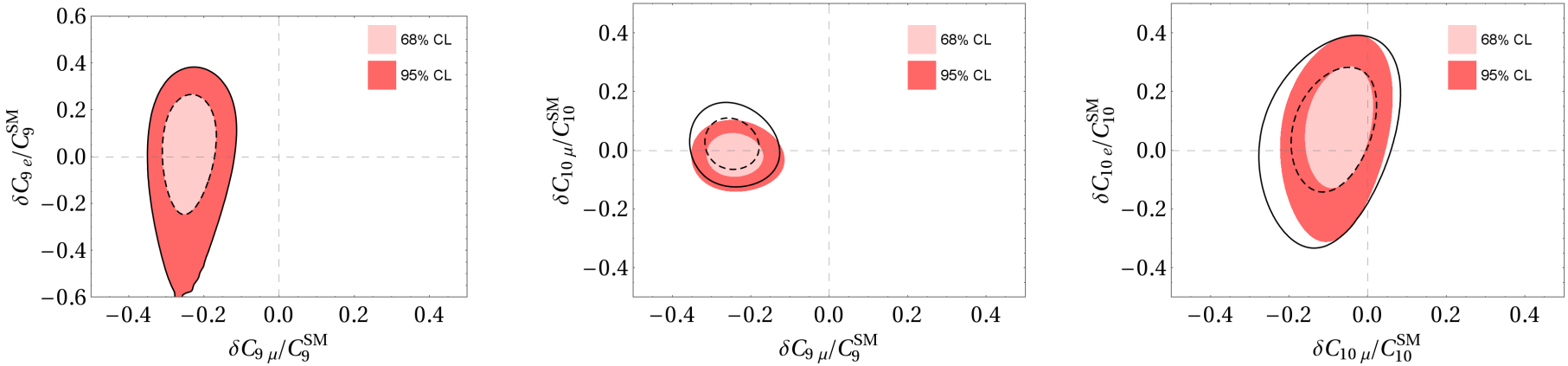
Only $R_K, R_{K^*}, B_{s,d} \to \mu^+\mu^-$ ($\chi^2_{\rm SM} = 19.0$)			
	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_9	-2.04 ± 5.93	18.9	0.3σ
δC_9^μ	-0.74 ± 0.28	10.6	2.9σ
δC_9^e	0.79 ± 0.29	9.9	3.0σ
δC_{10}	0.43 ± 0.32	17.0	1.4σ
δC_{10}^μ	0.65 ± 0.20	6.9	3.5σ
δC_{10}^e	-0.78 ± 0.27	8.2	3.3σ
$\delta C_{\rm LL}^\mu$	-0.37 ± 0.11	7.2	3.4σ
$\delta C_{\rm LL}^e$	0.41 ± 0.15	9.0	3.2σ

$\delta C_{\rm LL}^\ell$ basis corresponds to $\delta C_9^\ell = -\delta C_{10}^\ell$.

Within the one-operator fits, $B_{s,d} \to \mu^+\mu^-$ do not play a major role!

The new BR($B_s \to \mu^+\mu^-$) shows a tension of 1.5σ with the SM prediction, which suggests the same direction for C_{10}^μ as it is preferred by the $R_{K^{(*)}}$ fit.

all observables except R_K and R_{K^*} (with the assumption of 10% power corrections)



Pull: 4.1σ 4.1σ 1.1σ

[Black contours: without BR($B_{s,d} \to \mu^+\mu^-$)]

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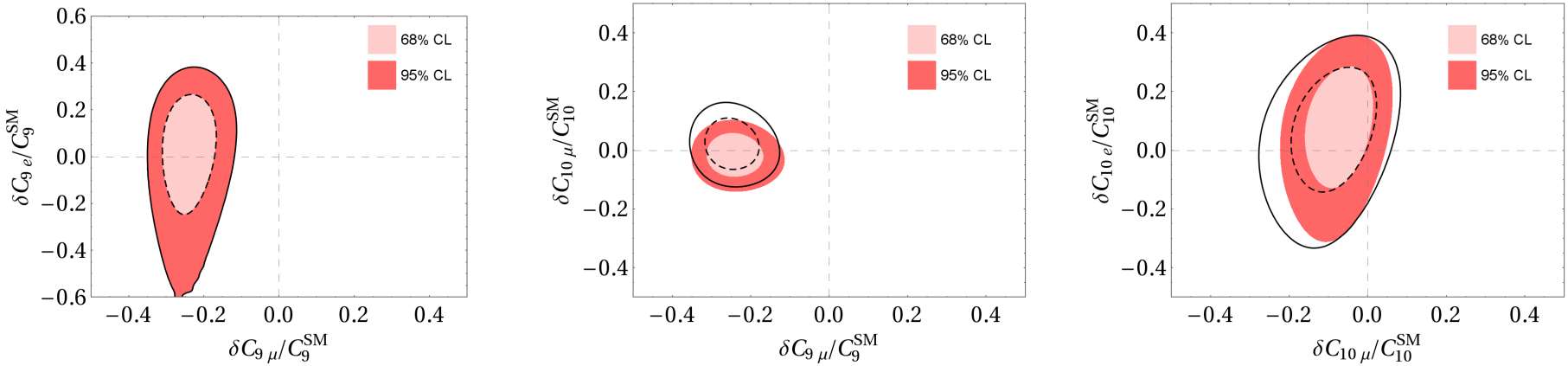
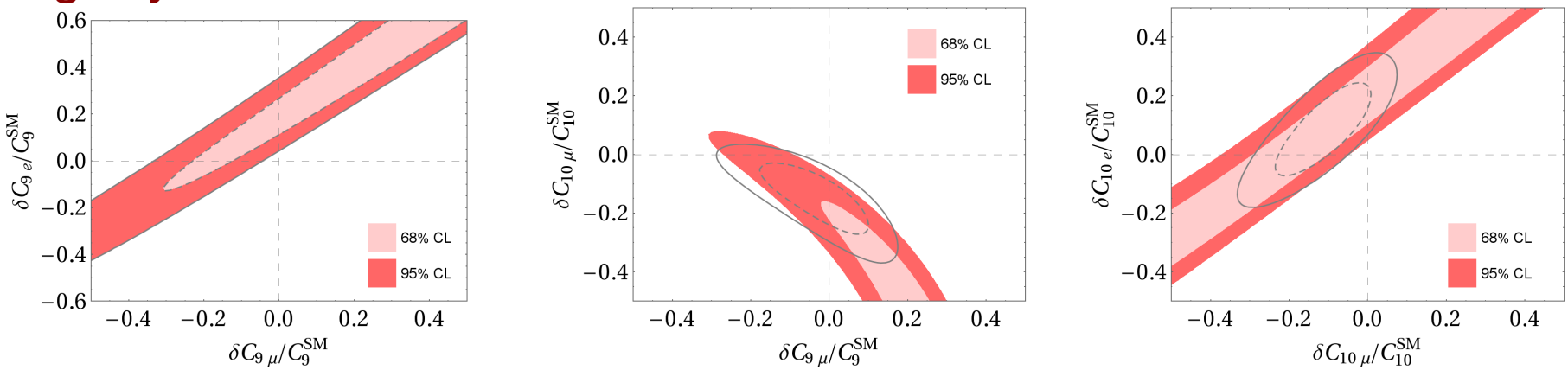


Pull: 4.1σ 4.1σ 1.1σ

[Black contours: without BR($B_{s,d} \to \mu^+\mu^-$)]

Using only the data on R_K and R_{K^*}



Pull: 3.1σ 3.2σ 3.1σ

[Gray contours: with BR($B_{s,d} \to \mu^+\mu^-$)]

Using all the relevant data on $b \to s$ transitions:

assuming 10% error for the power corrections

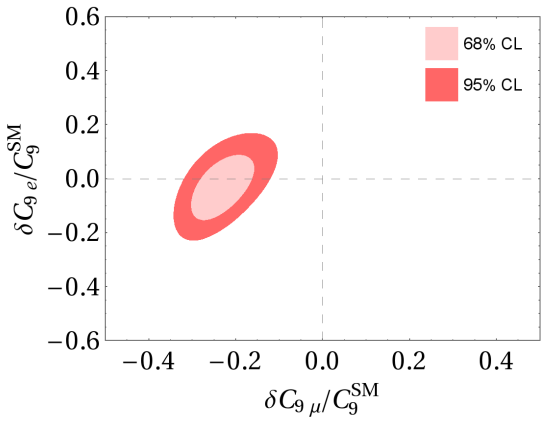
All observables ($\chi^2_{\rm SM} = 117.03$)			
	b.f. value	$\chi^2_{\rm min}$	$\rm Pull_{SM}$
δC_9	-1.01 ± 0.20	99.2	4.2σ
δC_9^μ	-0.93 ± 0.17	89.4	5.3σ
δC_9^e	0.78 ± 0.26	106.6	3.2σ
δC_{10}	0.25 ± 0.23	115.7	1.1σ
δC_{10}^μ	0.53 ± 0.17	105.8	3.3σ
δC_{10}^e	-0.73 ± 0.23	105.2	3.4σ
$\delta C_{\rm LL}^\mu$	-0.41 ± 0.10	96.6	4.5σ
$\delta C_{\rm LL}^e$	0.40 ± 0.13	105.8	3.3σ

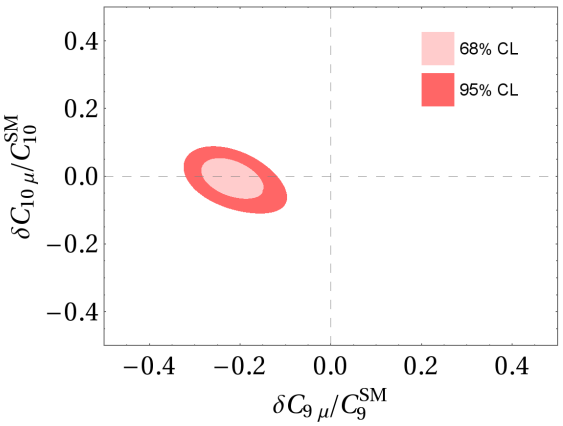
The NP significance is reduced by at least 0.5σ compared to before.

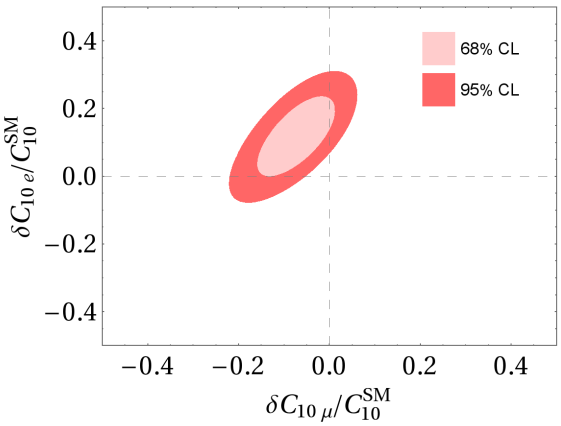
In cases of flavour-symmetric C_9 and C_{10}, which are independent from the changes in the ratios, one finds the same NP significance as expected.

Using <u>all</u> the relevant data on $b \to s$ transitions:

assuming 10% error for the power corrections







Pull: 4.9σ 4.9σ 3.2σ

More complete analyses

In a New Physics model:

- new vector bosons: C_7, C_9, C_{10}
- new fermions: C_7, C_8, C_9, C_{10}
- extended Higgs sector/new scalars: C_S, C_P

e.g. in the MSSM, 2HDM, ...: $C_7, C_8, C_9, C_{10}, C_S, C_P$

Considering only one or two Wilson coefficients may not give the full picture!

$C_{S,P}$ are usually assumed to be highly constrained by BR($B_s \to \mu^+\mu^-$)

$\to$ not considered in the global fits

Not quite true!

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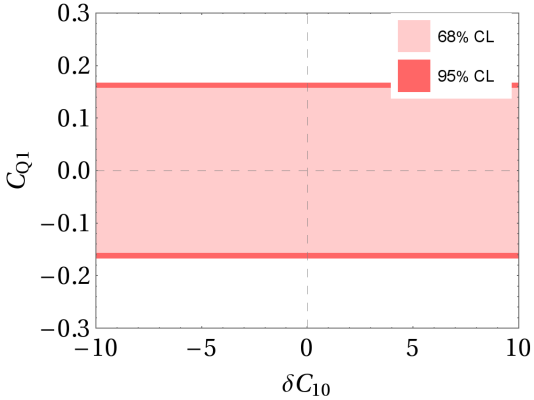
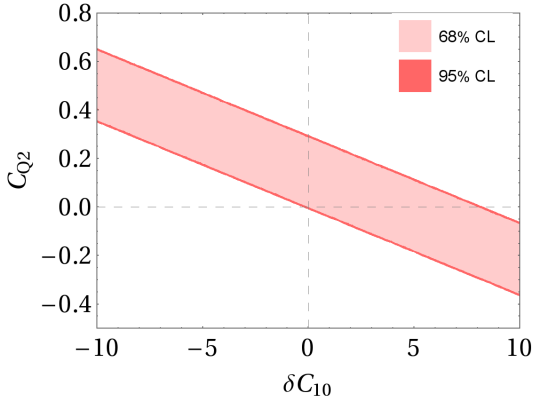
The role of (pseudo)scalar operators

Imposing BR($B_s \to \mu^+\mu^-$), if C_S and C_P independent, there exists a degeneracy between C_{10} and C_P so that large values for C_P are possible





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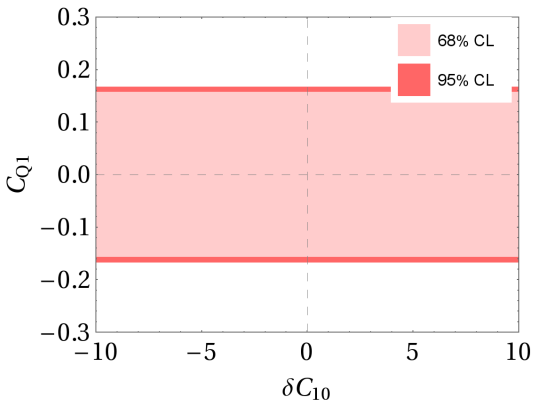
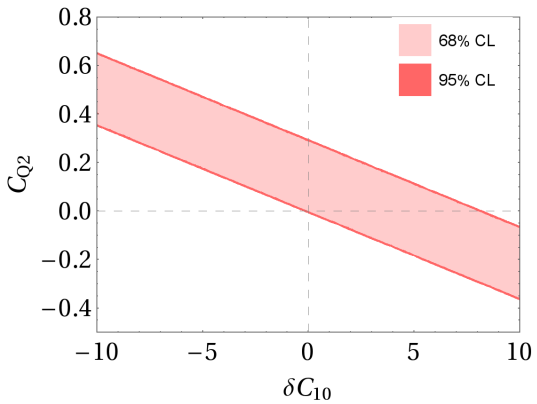
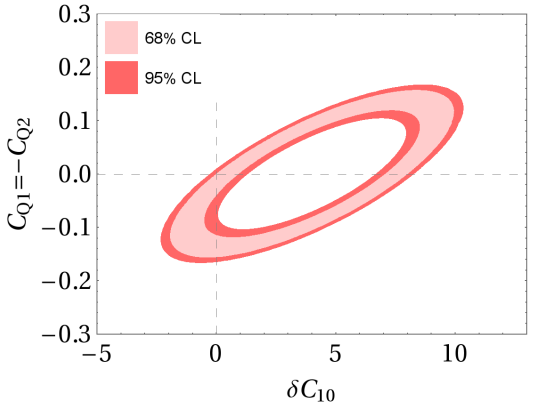




Even if $C_S = -C_P$, allowing for small variations of $C_{S,P}$ alleviates the constraints from $B_s \to \mu^+\mu^-$ on C_{10}



Full fit

A generic set of Wilson coefficients:

$$\text{complex } C_7, C_8, C_9^\ell, C_{10}^\ell, C_S^\ell, C_P^\ell + \text{primed coefficients}$$

The available observables are mainly insensitive to the imaginary parts, one can limit the set to

$$\text{real } C_7, C_8, C_9^\ell, C_{10}^\ell, C_S^\ell, C_P^\ell + \text{primed coefficients}$$

corresponding to 20 degrees of freedom.

Some of the coefficients may have only weak effects on the observables, and affect the number of dof without affecting the χ^2, acting as *spurious* degrees of freedom.

effective degrees of freedom (e-dof): degrees of freedom minus the parameters δC_i only weakly affecting the χ^2, defined such as

$$|\chi^2(\delta C_i = 1) - \chi^2(\delta C_i = 0)| < 1$$

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$$|\chi^2(\delta C_i = 1) - \chi^2(\delta C_i = 0)| < 1$$

Full fit - results

Set: real $C_7, C_8, C_9^\ell, C_{10}^\ell, C_S^\ell, C_P^\ell$ + primed coefficients (20 (16) degrees of freedom)

All observables with $\chi^2_{\rm SM} = 117.03$ ($\chi^2_{\rm min} = 71.96$; $\mathrm{Pull}_{\rm SM} = 3.3$ (3.8)σ)	
δC_7 -0.01 ± 0.04	δC_8 0.82 ± 0.72
$\delta C_7'$ 0.01 ± 0.03	$\delta C_8'$ -1.65 ± 0.47

δC_9^μ -1.37 ± 0.25	δC_9^e -6.55 ± 2.37	δC_{10}^μ -0.11 ± 0.27	δC_{10}^e 2.34 ± 3.11
$\delta C_9'^\mu$ 0.23 ± 0.62	$\delta C_9'^e$ 0.75 ± 2.82	$\delta C_{10}'^\mu$ -0.16 ± 0.36	$\delta C_{10}'^e$ 1.67 ± 3.05
$C_{Q_1}^\mu$ -0.01 ± 0.09	$C_{Q_1}^e$ undetermined	$C_{Q_2}^\mu$ -0.05 ± 0.19	$C_{Q_2}^e$ undetermined
$C_{Q_1}'^\mu$ 0.13 ± 0.09	$C_{Q_1}'^e$ undetermined	$C_{Q_2}'^\mu$ -0.18 ± 0.20	$C_{Q_2}'^e$ undetermined

Wilks' test:

- No real improvement in the fits when going beyond the C_9^μ case
- Pull with the SM decreases when all WC are varied
- Many parameters are very weakly constrained

Cooking scenarios

Model-independent approach

$\downarrow$

gives us the ingredients
C_9, a bit of C_{10},...

Cooking scenarios

Model-independent approach

↓

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Simplified models

↓

Z', Lepto quarks, ...

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Simplified models

↓

Z', Lepto quarks, ...

UV-complete theory

↓

The real model

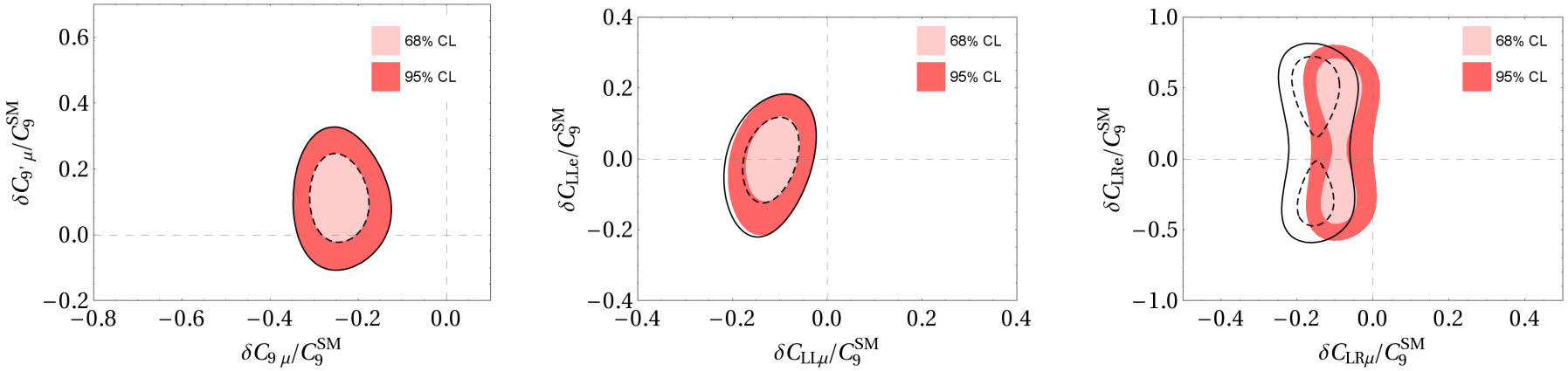
Conclusion

- The LHCb Run 1 results together with the partial Run 2 results still show some tensions with the SM predictions
- Overall picture of the $b \to s$ anomalies remains the same as before taking into account the new results from LHCb, Belle and ATLAS on R_K, R_{K^*} and $B_s \to \mu^+\mu^-$
- Significance of the new physics description of the $R_K{}^{(*)}$ data is now reduced by more than half a σ
- The tension with the SM including all observables (assuming 10% non-factorisable power corrections) and all relevant Wilson coefficents is 3.8σ at the moment.
- Future measurements of the theoretically very clean ratios and similar observables which are sensitive to lepton flavour non-universality have a great potential to unambiguously establish new physics in these decays.

Backup

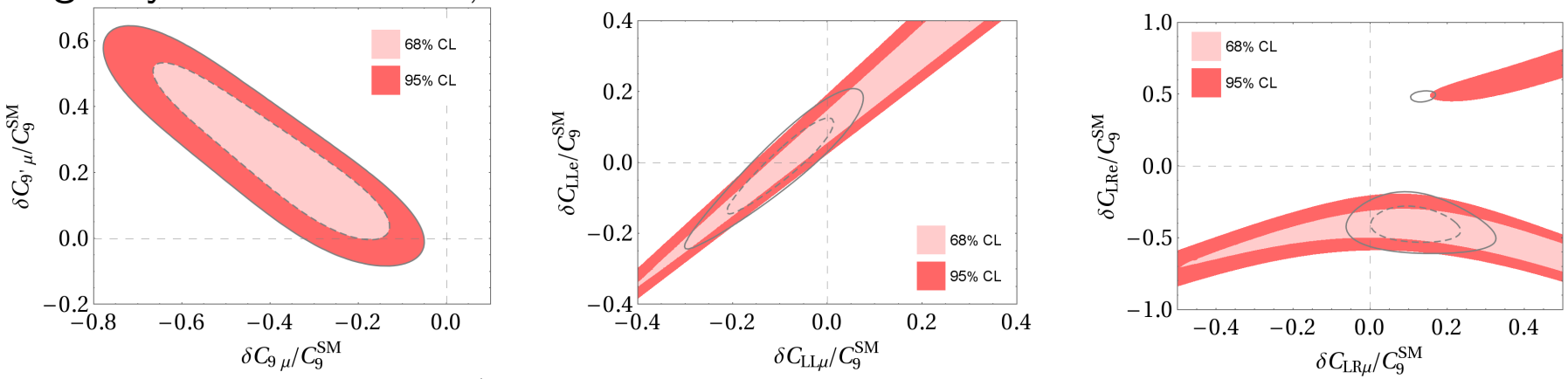
Two operator fits to NP:

all observables except R_K and R_{K^*} (with the assumption of 10% power corrections)



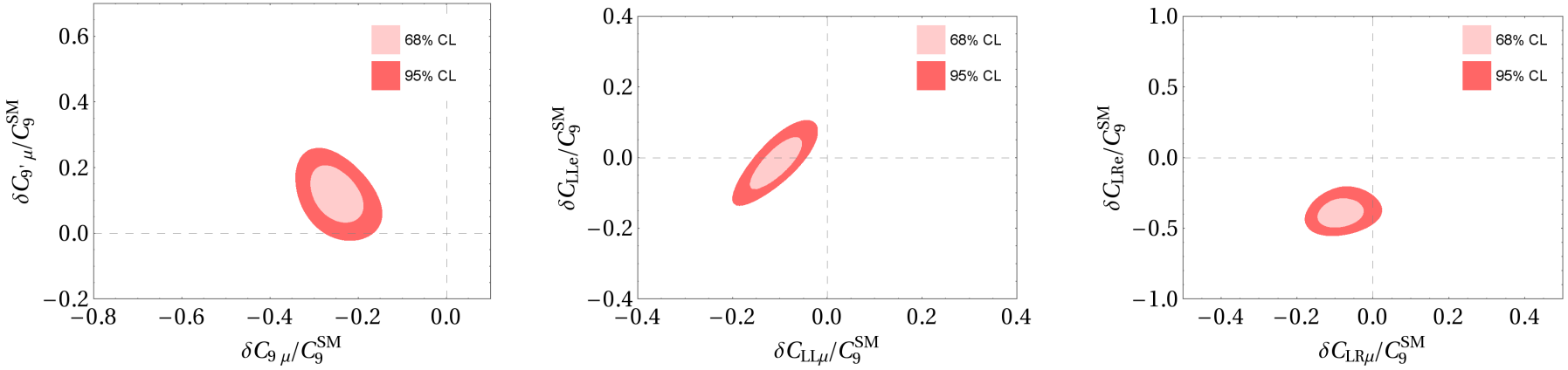
[Black contours: without BR($B_{s,d} \to \mu^+\mu^-$)]

Using only the data on R_K, R_{K^*}



[Gray contours: with BR($B_{s,d} \to \mu^+\mu^-$)]

Updated fits

Using **all** the relevant data on $b \to s$ transitions

assuming 10% error for the power corrections