Zurich Phenomenology Workshop 2018
Flavours: light, heavy and dark

Discussion session on theory errors on the anomalies

Tobias Hurth, JGU Mainz

Two questions :

- How reliable are the SM theory predictions on which we base the evidence of these so-called anomalies ?
- How reliably can we extract information about New Physics ?

No really controversal issues in this respect

Power corrections in QCD improved factorization

$$\mathcal{T}_a^{(i)} = \xi_a C_a^{(i)} + \phi_B \otimes T_a^{(i)} \otimes \phi_{a,K^*} + O(1/m_b)$$ BBNS 1999

Power corrections cannot be calculated within QCDf in general.

→ Significance of the tensions in the angular observables depend on the assumptions on the power corrections.

Fit of the power corrections to the data:

Ciuchini et al. (arXiv:1512.07157): Fit produces 20-50% nonfact. power corrections on the observable level in the critical bins.

Variation of power corrections $(1 + C_i)$ or more sophisticated ansatz:

Hurth et al. (arXiv:1603.00865): Assumption of 60% (10%) nonfact. power corrections on the amplitude level lead to 17-20% (3%) on the observable level (S_3, S_4, S_5) only.

Do large power corrections at $\mathcal{O}(50\%)$ - on the observable level - question the validity of the QCDf ansatz?

New physics or hadronic effects

Hurth, Mahmoudi, Neshatpour, Chobanova, Martinez Santos arXiv:1702.02234

Hadronic power correction effect:

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

set $h_{\lambda=0}^{(0)} = 0$

New Physics effect:

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

and similarly for C_7

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

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

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

Wilk's test

q^2 up to 8 GeV^2

	2 (δC_9)	4 ($\delta C_7, \delta C_9$)	18 ($h_{+,-,0}^{(0,1,2)}$)
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 δC_9 improves over the SM hypothesis by 4.1σ
→ Including in addition δC_7 or hadronic parameters improves the situation only mildly
→ One cannot rule out the hadronic option

Adding 16 more parameters does not really improve the fit

The situation is still inconclusive

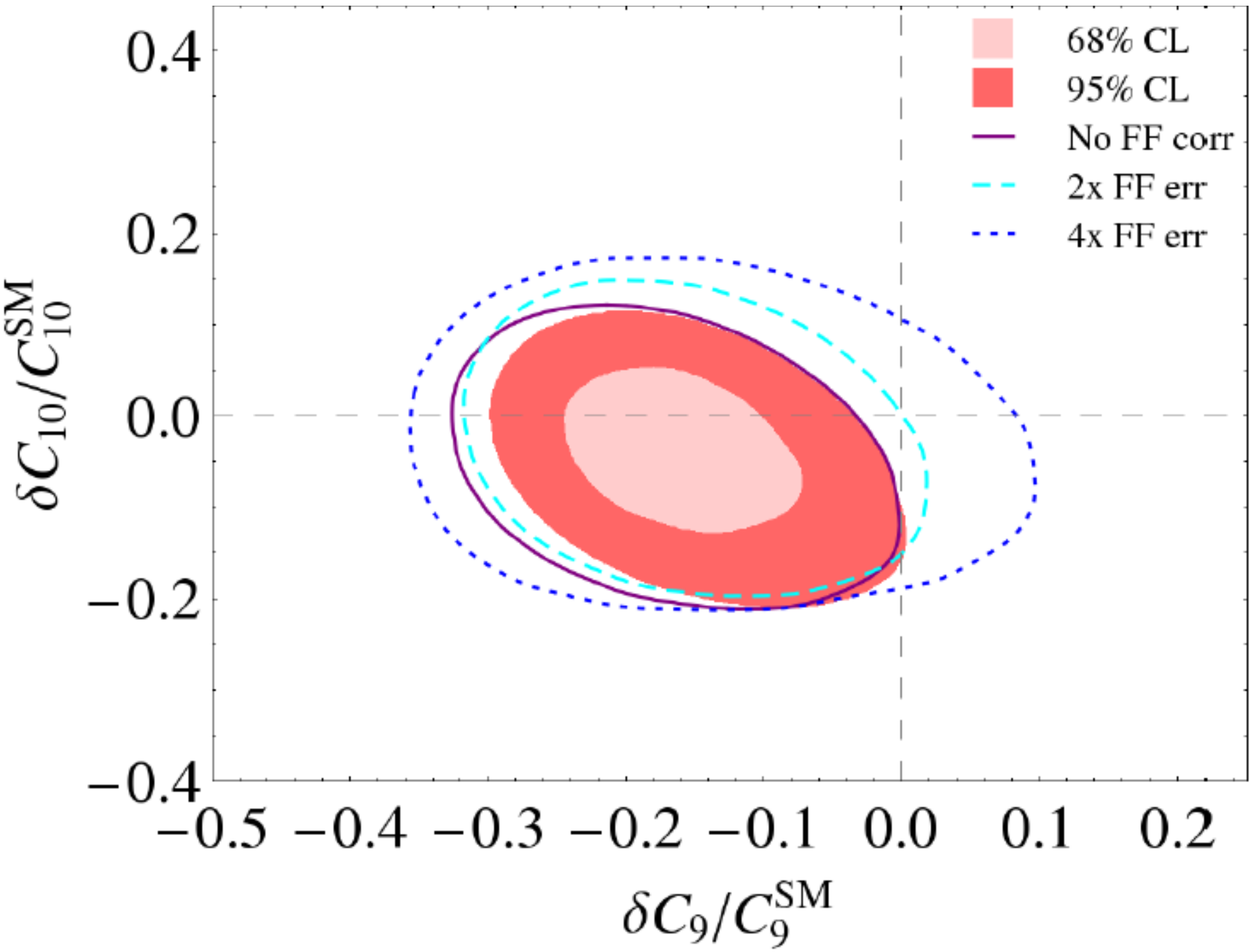
Circumstantial evidence is not sufficient to establish NP.

(LHCb upgrade prospects: NP versus hadronic effects 34 σ)

Form factors in $B \to K^{*}\ell^{+}\ell^{-}$

Hurth,Mahmoudi,Neshatpour arXiv:1603.00865

Fits assuming different form factor uncertainties



(LCSR-calculation Zwicky et al. arXiv:1503.0553)

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

Towards complete SM predictions for the angular observables

LCOPE in the euclidean and then analytical continuation to the physical region (disperson relation or z-expansion).

Methods offered in the analysis of $B \to K\ell^+\ell^-$ to calculate power corrections Kjodjamirian et al. arXIv: 1211.0234, also 1006.4945

Most recently: Estimate of power corrections based on analyticity structure Bobeth et al. arXiv:1707.07305

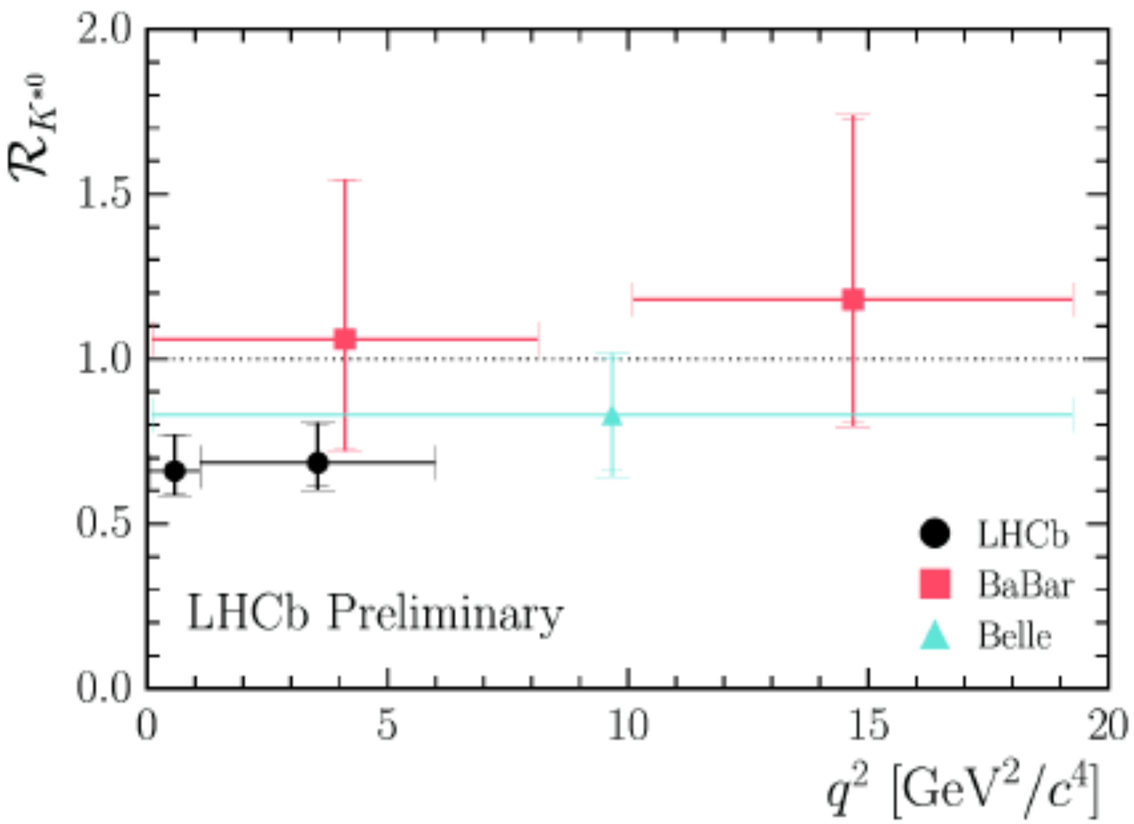
Lepton flavour universality in $B^0 \to K^{*0}\ell^+\ell^-$

- LHCb measurement (April 2017): JHEP 08 (2017) 055

$$R_{K^*} = BR(B^0 \to K^{*0}\mu^+\mu^-)/BR(B^0 \to K^{*0}e^+e^-)$$

- Two q^2 regions: [0.045-1.1] and [1.1-6.0] GeV^2

2.2-2.5σ tension with the SM predictions in each bin



$$R_{K^*}^{\text{exp,bin1}} = 0.660^{+0.110}_{-0.070}(\text{stat}) \pm 0.024(\text{syst})$$

$$R_{K^*}^{\text{exp,bin2}} = 0.685^{+0.113}_{-0.069}(\text{stat}) \pm 0.047(\text{syst})$$

$$R_{K^*}^{\text{SM,bin1}} = 0.906 \pm 0.020_{\text{QED}} \pm 0.020_{\text{FF}}$$

$$R_{K^*}^{\text{SM,bin2}} = 1.000 \pm 0.010_{\text{QED}}$$

Bordone, Isidori, Pattori, arXiv:1605.07633

BaBar, PRD 86 (2012) 032012; Belle, PRL 103 (2009) 171801

- R_K and R_{K^*} ratios are theoretically very clean
- The tensions cannot be explained by hadronic uncertainties

Is low-bin below 1 GeV^2 not consistent with the other two bins ?

Separate NP fits with a single operator

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

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

	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
ΔC_9	-0.48	18.3	0.3σ
$\Delta C_9'$	$+0.78$	18.1	0.6σ
ΔC_{10}	-1.02	18.2	0.5σ
$\Delta C_{10}'$	$+1.18$	17.9	0.7σ
ΔC_9^μ	-0.35	5.1	3.6σ
ΔC_9^e	$+0.37$	3.5	3.9σ
ΔC_{10}^μ	-1.66 -0.34	2.7	4.0σ
ΔC_{10}^e	-2.36 $+0.35$	2.2	4.0σ

Best fit values considering all observables besides R_K and R_{K^*}

(under the assumption of 10% non-factorisable power corrections)

	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
ΔC_9	-0.24	70.5	4.1σ
$\Delta C_9'$	-0.02	87.4	0.3σ
ΔC_{10}	-0.02	87.3	0.4σ
$\Delta C_{10}'$	$+0.03$	87.0	0.7σ
ΔC_9^μ	-0.25	68.2	4.4σ
ΔC_9^e	$+0.18$	86.2	1.2σ
ΔC_{10}^μ	-0.05	86.8	0.8σ
ΔC_{10}^e	-2.14 $+0.14$	86.3	1.1σ

NP in the ratios would indirectly confirm the NP interpretation of the anomalies in the angular observables (if there is a coherent picture)

Other ratios allow to discriminate between the NP options

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

	Predictions assuming 12 fb^{-1} luminosity			
Obs.	C_9^μ	C_9^e	C_{10}^μ	C_{10}^e
$R_{F_L}^{[1.1,6.0]}$	$[0.785, 0.913]$	$[0.909, 0.933]$	$[1.005, 1.042]$	$[1.001, 1.018]$
$R_{A_{FB}}^{[1.1,6.0]}$	$[6.048, 14.819]$	$[-0.288, -0.153]$	$[0.816, 0.928]$	$[0.974, 1.061]$
$R_{S_5}^{[1.1,6.0]}$	$[-0.787, 0.394]$	$[0.603, 0.697]$	$[0.881, 1.002]$	$[1.053, 1.146]$
$R_{F_L}^{[15,19]}$	$[0.999, 0.999]$	$[0.998, 0.998]$	$[0.997, 0.998]$	$[0.998, 0.998]$
$R_{A_{FB}}^{[15,19]}$	$[0.616, 0.927]$	$[1.002, 1.061]$	$[0.860, 0.994]$	$[1.046, 1.131]$
$R_{S_5}^{[15,19]}$	$[0.615, 0.927]$	$[1.002, 1.061]$	$[0.860, 0.994]$	$[1.046, 1.131]$
$R_{K^*}^{[15,19]}$	$[0.621, 0.803]$	$[0.577, 0.771]$	$[0.589, 0.778]$	$[0.586, 0.770]$
$R_K^{[15,19]}$	$[0.597, 0.802]$	$[0.590, 0.778]$	$[0.659, 0.818]$	$[0.632, 0.805]$
$R_\phi^{[1.1,6.0]}$	$[0.748, 0.852]$	$[0.620, 0.805]$	$[0.578, 0.770]$	$[0.578, 0.764]$
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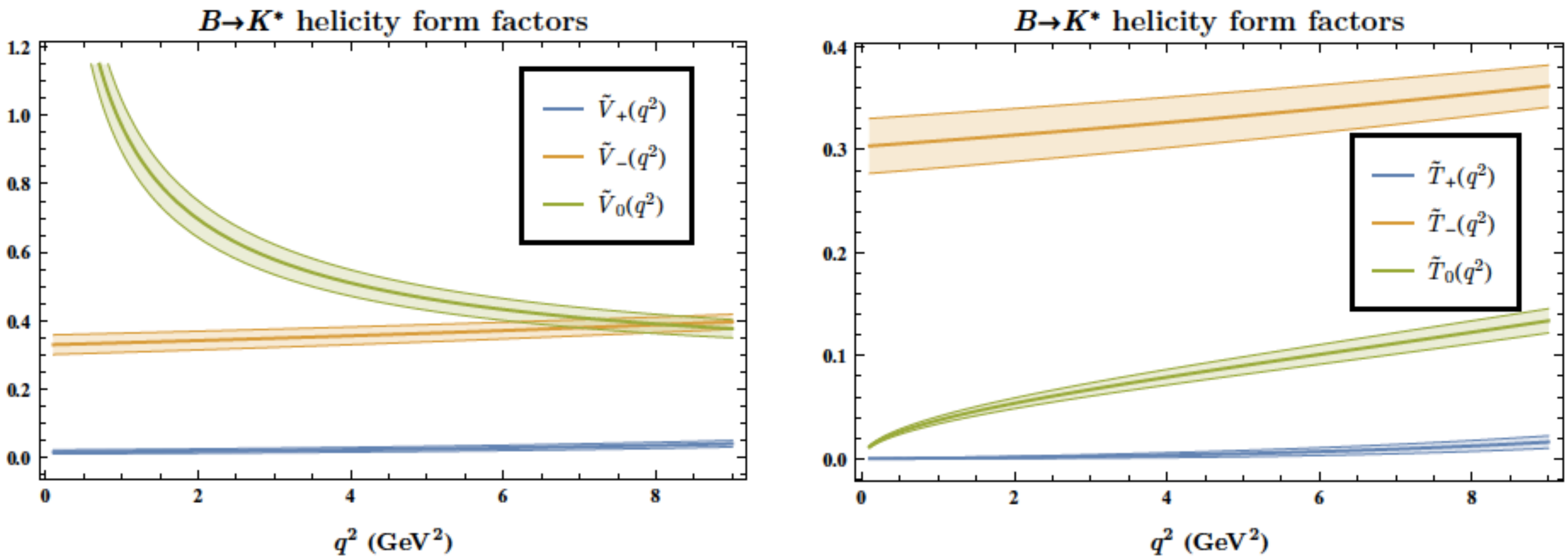
Extra Slides



$\Longrightarrow$ 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 $h_\lambda^{(0,1,2)}$

Future prospects

Future LHCb prospects for ratios R_K and R_{K^*}

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

Pull_{SM} for the fit to ΔC_9^μ based on the ratios R_K and R_{K^*} for the LHCb upgrade

Assuming current central values remain.

ΔC_9^μ	Syst. Pull_{SM}	Syst./2 Pull_{SM}	Syst./3 Pull_{SM}
12 fb^{-1}	6.1σ (4.3σ)	7.2σ (5.2σ)	7.4σ (5.5σ)
50 fb^{-1}	8.2σ (5.7σ)	11.6σ (8.7σ)	12.9σ (9.9σ)
300 fb^{-1}	9.4σ (6.5σ)	15.6σ (12.3σ)	19.5σ (16.1σ)

(): assuming 50% correlation between each of the R_K and R_{K^*} measurements

There is the possibility to establish NP already with 12 fb^{-1}

Future LHCb prospects for ratios R_K and R_{K*}

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(): assuming 50% correlation between each of the R_K and R_{K^*} measurements

However, with R_K and R_{K*} only, significance for all 6 favored NP scenarios, $\Delta C_9^{e,\mu}$, $\Delta C_{10}^{e,\mu}$, $\Delta C_{LL}^{e,\mu}$ very similar.

$B_s \to \mu\mu$ will not help in the future to decide which NP option is realized!

Other ratios allow to discriminate between the NP options

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

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Obs.	C_9^μ	C_9^e	C_{10}^μ	C_{10}^e
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Back to the

Problem of nonfactorizable power corrections in angular observables

Crosscheck with $R_{\mu,e}$ ratios

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

- R_K and R_{K^*} ratios are theoretically very clean
- The tensions cannot be explained by hadronic uncertainties

NP in the ratios would indirectly confirm the NP interpretation

of the anomalies in the angular observables

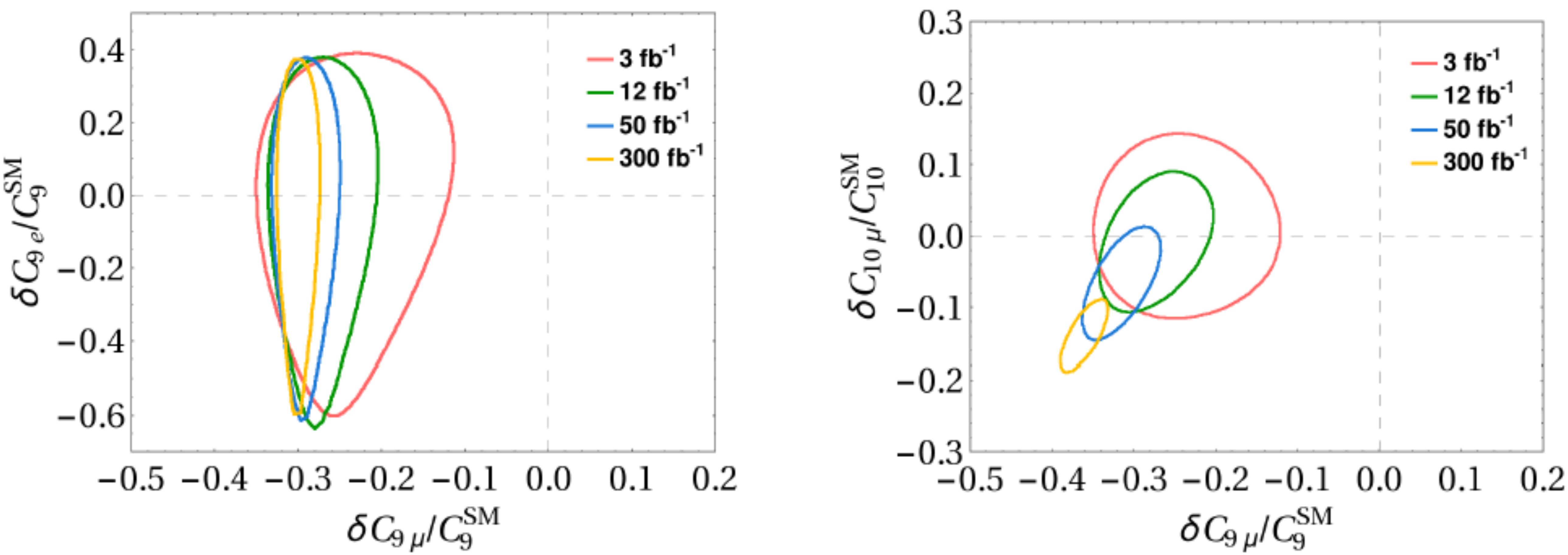
(if there is a coherent picture)

Future LHCb prospects for the angular observables

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

Global fits using the angular observables only (NO theoretically clean *R* ratios)

Considering several luminosities, assuming the current central values

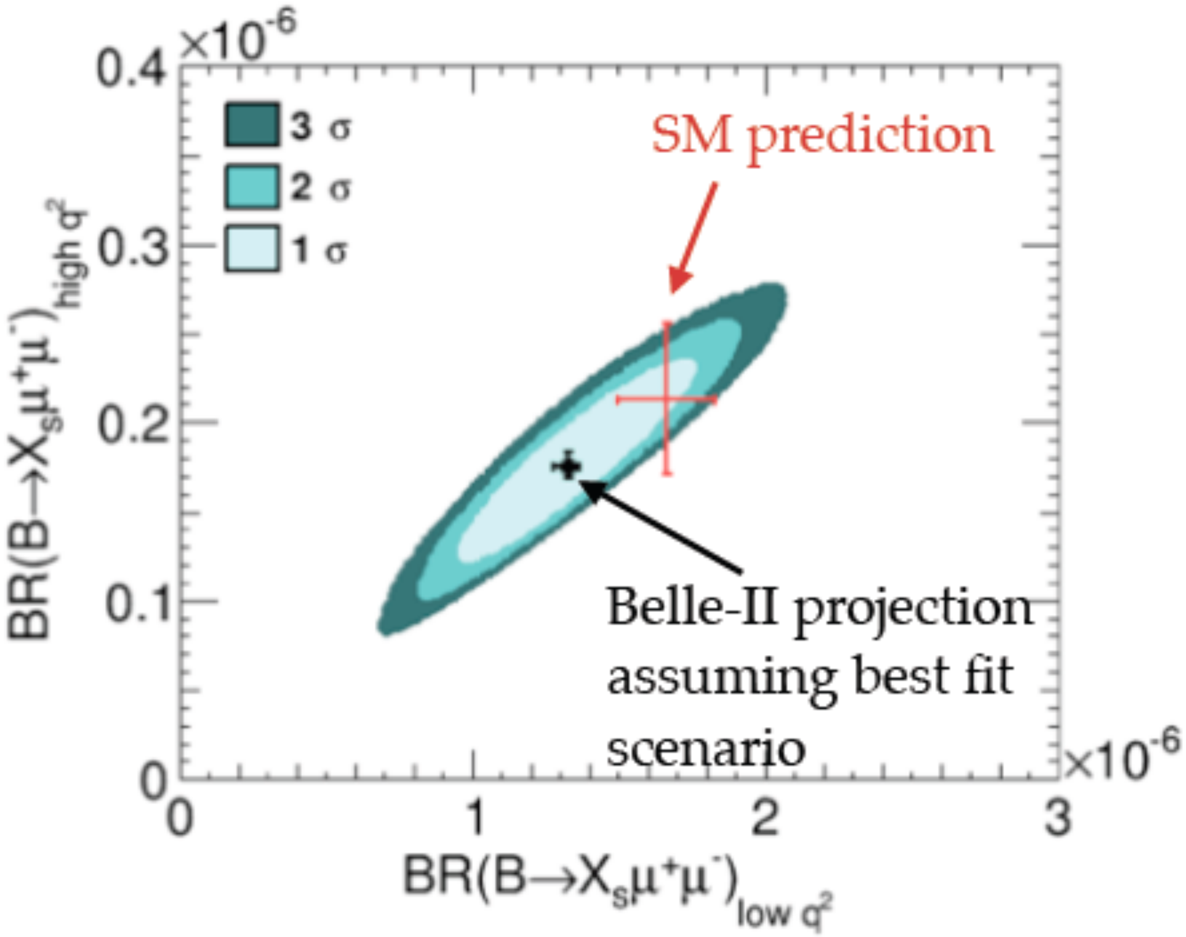


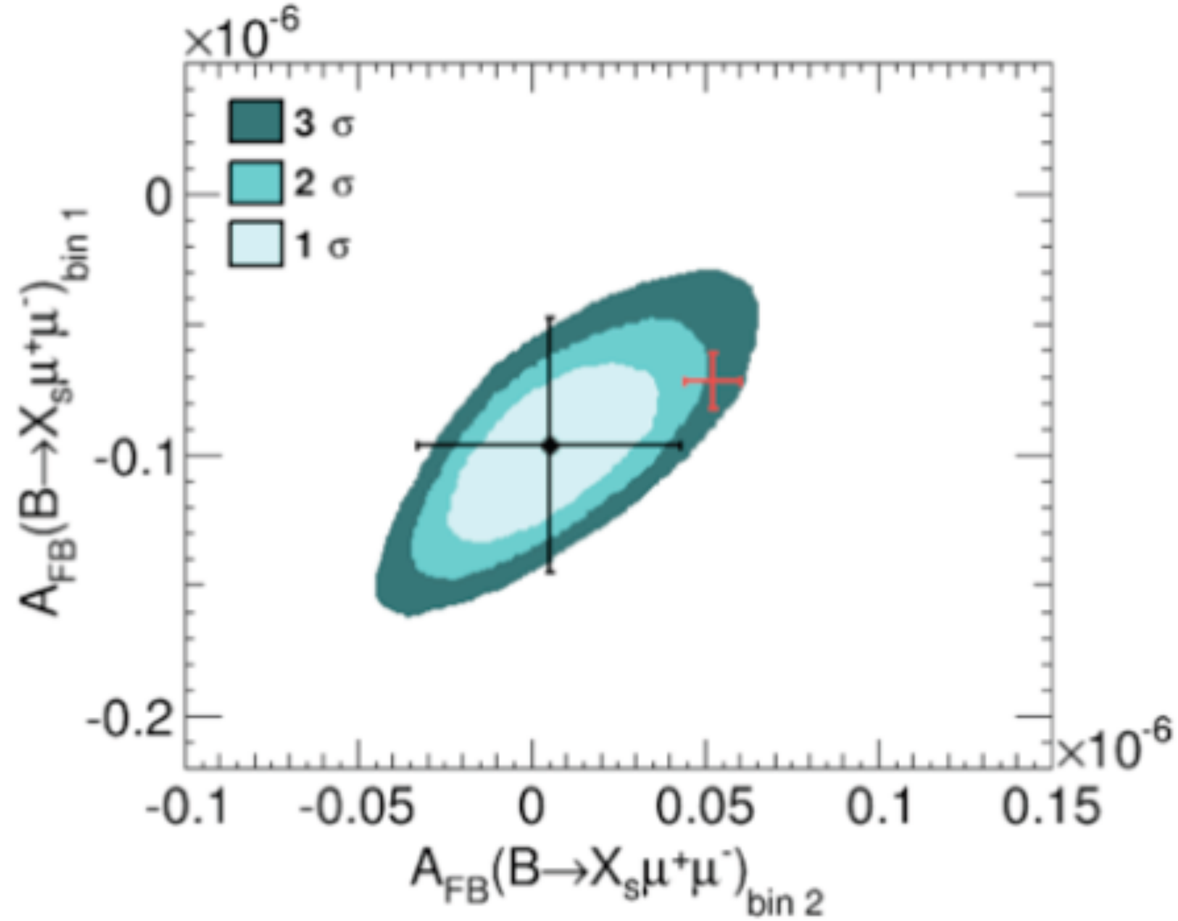
LHCb upgrade will be able to distinguish between NP and hadronic effects within the angular observables – even without any theoretical progress

Crosscheck of LHCb anomalies with inclusive modes

Hurth, Mahmoudi, Neshatpour, arXiv:1410.4545

if SM deviations in R_K and P_5' persist until Belle-II





If NP then the effect of C_9 and C_9' are large enough to be checked at Belle-II with theoretically clean modes.

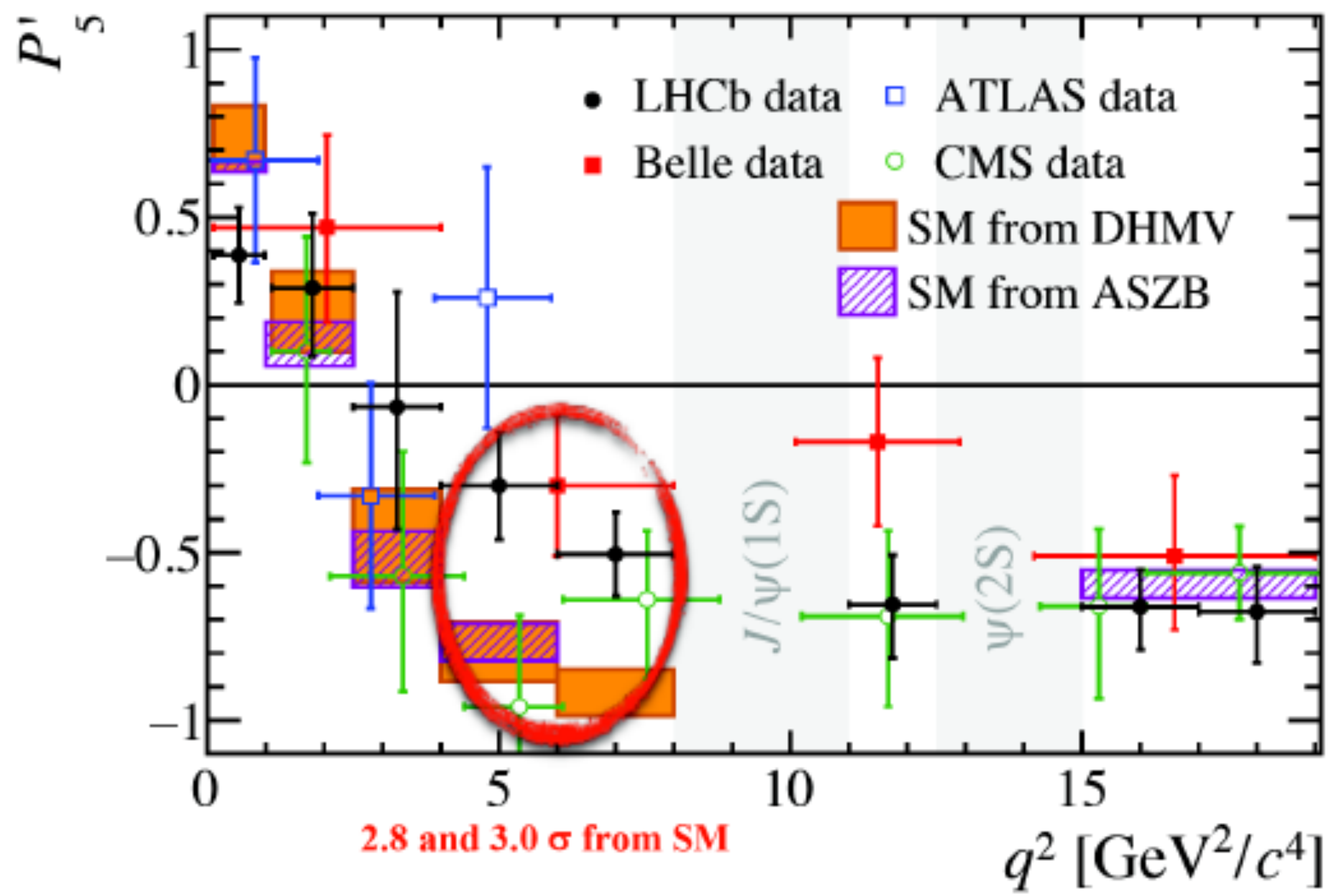
Hurth, Mahmoudi, arXiv:1312.5267 Experimental extrapolation by Kevin Flood

The LHCb Anomalies

Anomalies in $B \to K^* \mu^+ \mu^-$ angular observables, in particular P'_5 ; S_5

Long standing anomaly **2-3σ**:

- 2013 (1 fb^{-1}): disagreement with the SM for P_2 and P'_5 (PRL 111, 191801 (2013))
- March 2015 (3 fb^{-1}): confirmation of the deviations (LHCb-CONF-2015-002)
- Dec. 2015: 2 analysis methods, both show the deviations (JHEP 1602, 104 (2016))



LHCb, JHEP 02 (2016) 104; Belle, PRL 118 (2017); ATLAS, ATLAS-CONF-2017-023; CMS, CMS-PAS-BPH-15-008

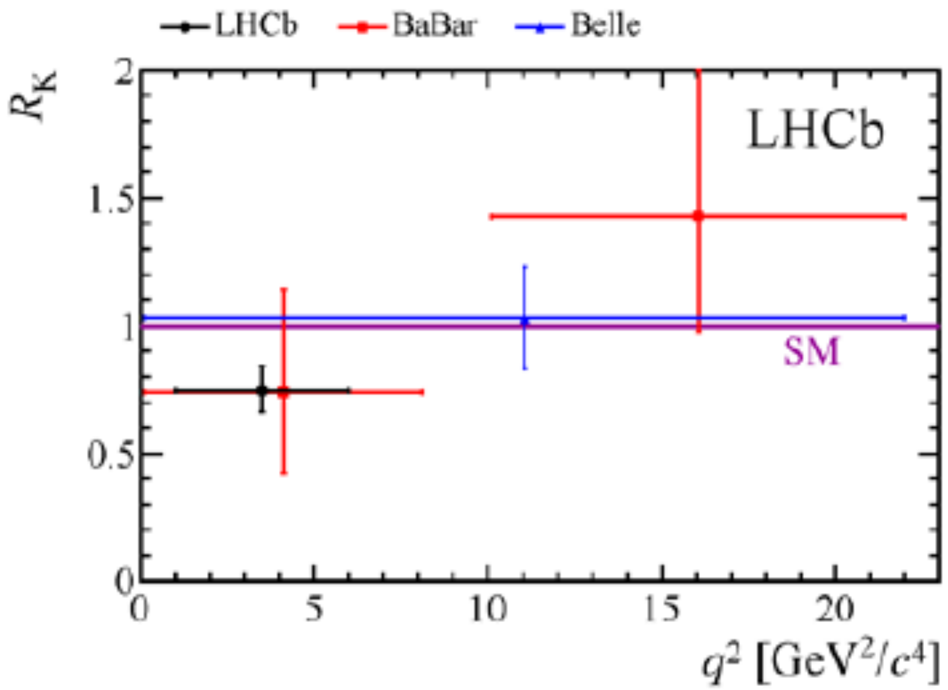
- Also measured by ATLAS, CMS and Belle

New Physics or underestimated hadronic uncertainties

(form factors, power corrections) ?

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

- June 2014 (3 fb^{-1}): measurement of R_K in the [1-6] GeV^2 bin (PRL 113, 151601 (2014)):
  2.6σ tension in [1-6] GeV^2 bin
- SM prediction very accurate (leading corrections from QED, giving rise to large logarithms involving the ratio $m_B/m_{\mu,e}$)



BaBar, PRD 86 (2012) 032012; Belle, PRL 103 (2009) 171801

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

$$R_K^{\rm exp} = 0.745^{+0.090}_{-0.074}({\rm stat}) \pm 0.036({\rm syst})$$

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

Bordone, Isidori, Pattori, arXiv:1605.07633

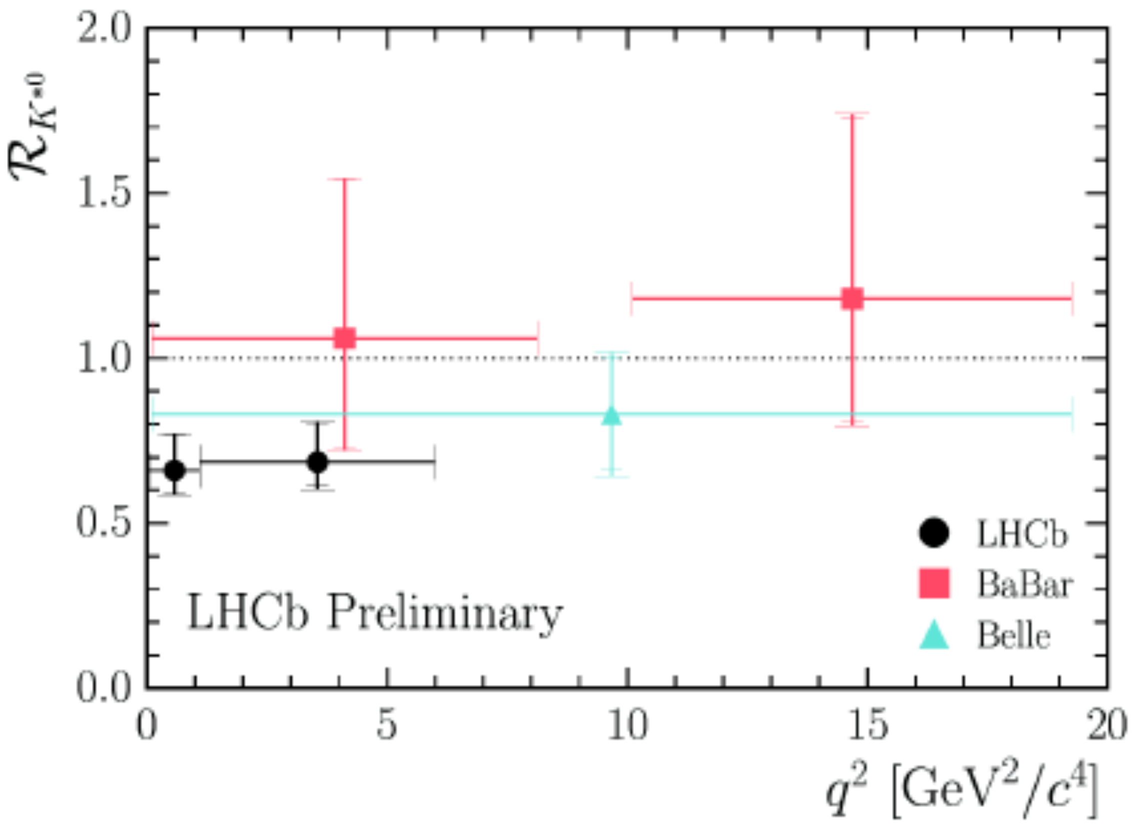
Would be a spectacular fall of the SM !

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

- LHCb measurement (April 2017): JHEP 08 (2017) 055

$$R_{K^*} = BR(B^0 \to K^{*0}\mu^+\mu^-)/BR(B^0 \to K^{*0}e^+e^-)$$

- Two q^2 regions: [0.045-1.1] and [1.1-6.0] GeV^2



BaBar, PRD 86 (2012) 032012; Belle, PRL 103 (2009) 171801

$$R_{K^*}^{\text{exp,bin1}} = 0.660^{+0.110}_{-0.070}(\text{stat}) \pm 0.024(\text{syst})$$

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Bordone, Isidori, Pattori, arXiv:1605.07633

2.2-2.5σ tension with the SM predictions in each bin

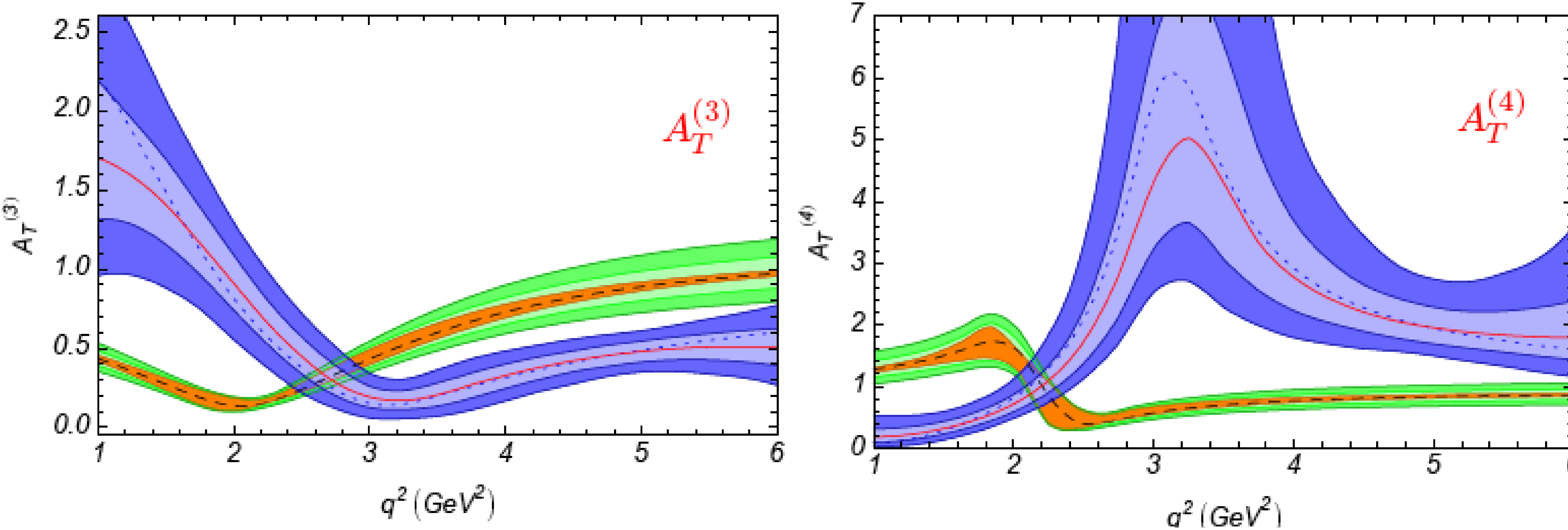
Previous predictions versus LHCb Monte Carlo (10 fb^1)

Egede,Hurth,Matias,Ramon,Reece,arXiv:0807.2589,arXiv:1005.0571

– unknown Λ/m_b power corrections

$A_{\perp,\|,0} = A^0_{\perp,\|,0}\left(1 + c_{\perp,\|,0}\right)$ vary c_i in a range of $\pm10\%$ and also of $\pm5\%$

Guesstimate



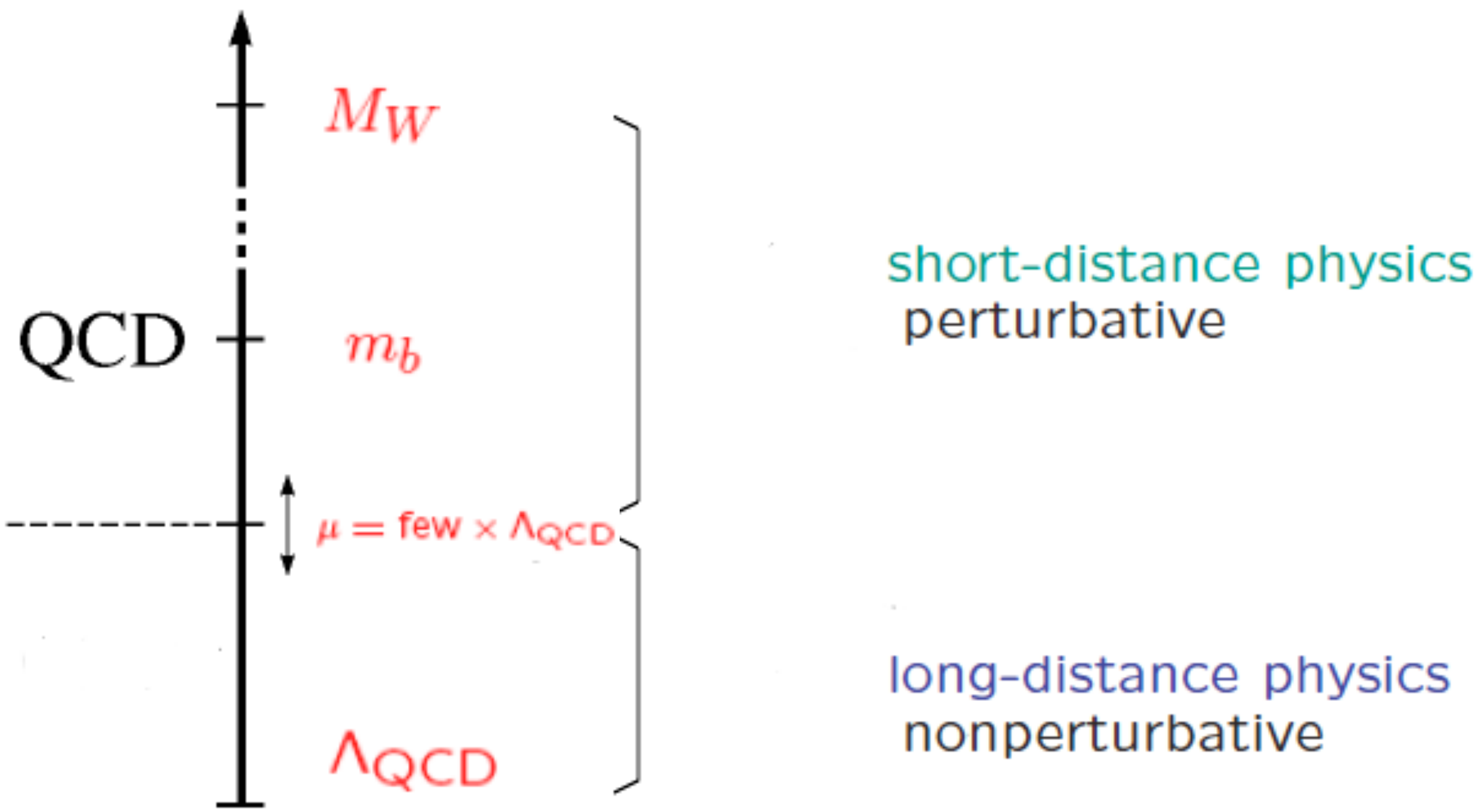
The experimental errors assuming SUSY scenario (b) with large-gluino mass and positive mass insertion, is compared to the theoretical errors assuming the SM.

This was the dream in 2008

see also Altmannshofer et al.,arXiv:0811.1214; Bobeth et al.,arXiv:0805.2525

Theoretical Tools

Theoretical tools for flavour precision observables



Factorization theorems: separating long- and short-distance physics

- Electroweak effective Hamiltonian: $H_{eff} = -\frac{4G_F}{\sqrt{2}} \sum C_i(\mu, M_{heavy})\ \mathcal{O}_i(\mu)$

- $\mu^2 \approx M_{New}^2 >> M_W^2$: 'new physics' effects: $C_i^{SM}(M_W) + C_i^{New}(M_W)$

How to compute the hadronic matrix elements $\mathcal{O}_i(\mu = m_b)$?

Exclusive modes $B \to K^{(*)}\ell\ell$

QCD-improved factorization: BBNS 1999

$$\mathcal{T}_a^{(i)} = C_a^{(i)} \xi_a + \phi_B \otimes T_a^{(i)} \otimes \phi_{a,K^*} + O(\Lambda/m_b)$$

(Soft-collinear effective theory)

– Separation of perturbative hard kernels from process-independent nonperturbative functions like form factors

– Relations between formfactors in large-energy limit

– Limitation: insufficient information on power-suppressed Λ/m_b terms (breakdown of factorization: 'endpoint divergences')

"Full formfactor approach" Altmannshofer et al., arXiv:0811.1214

- we have factorizable and nonfactorizable power corrections
- using full QCD formfactors in the factorization formula takes factorizable power corrections into account automatically
- nonfactorizable contributions generated by four-quark and $\mathcal{O}_8$ operators

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

(This does not affect R_K and R_K^* of course, but does affect combined fits!)

Exclusive modes $B \to K^{(*)}\ell\ell$

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Effective Hamiltonian for $b \to s\ell\ell$ 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:

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

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

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

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

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

Effective Hamiltonian for $b \to s\ell\ell$ transitions

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

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

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

Beneke et al.:
106067; 0412400

Model independent Analysis

Model-independent global fits to $b \to s$ data

Relevant operators: $\mathcal{O}_7, \mathcal{O}_8, \mathcal{O}'_{9\mu,e}, \mathcal{O}'_{10\mu.e}$

Scan over the values of δC_i: $C_i(\mu) = C_i^{\mathrm{SM}} + \delta C_i$

More than 100 observables included

Experimental and theoretical correlations considered

Several groups doing global fits.

Global fits to $\leq$ 2016 data

Hurth et al. arXiv:1603.00865
Descotes-Genon et al. arXiv:1510.04239
Ciuchini et al. arXiv:1512.07157
Beaujean et al. arXiv:1508.01526
Altmannshofer et al. arXiv:1503.06199
Alonso et al. arXiv:1407.7044

Fits to the data including R_{K^*} of 2017

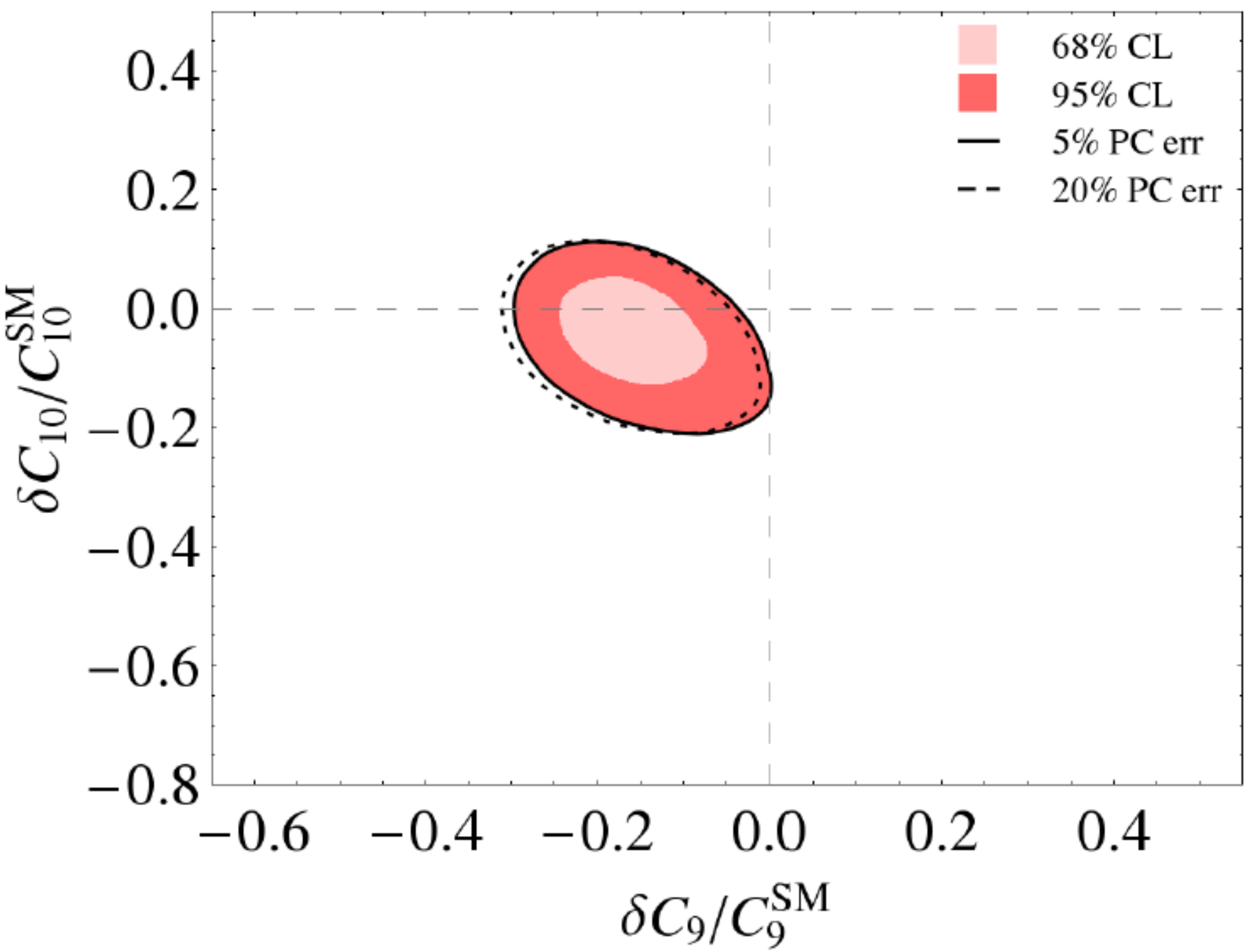
Capdevilla et al. arXix:1704.05340
Geng et al. arXiv:1704.05446
Altmannshofer et al. arXiv:1704.05435
D'Amico et al. arXiv:1704.05438
Ciuchini et al. arXiv:1704.05447
Hurth et al. arXiv:1705.06274

Hurth,Mahmoudi,Neshatpour arXiv:1603.00865

Fit results for two operators

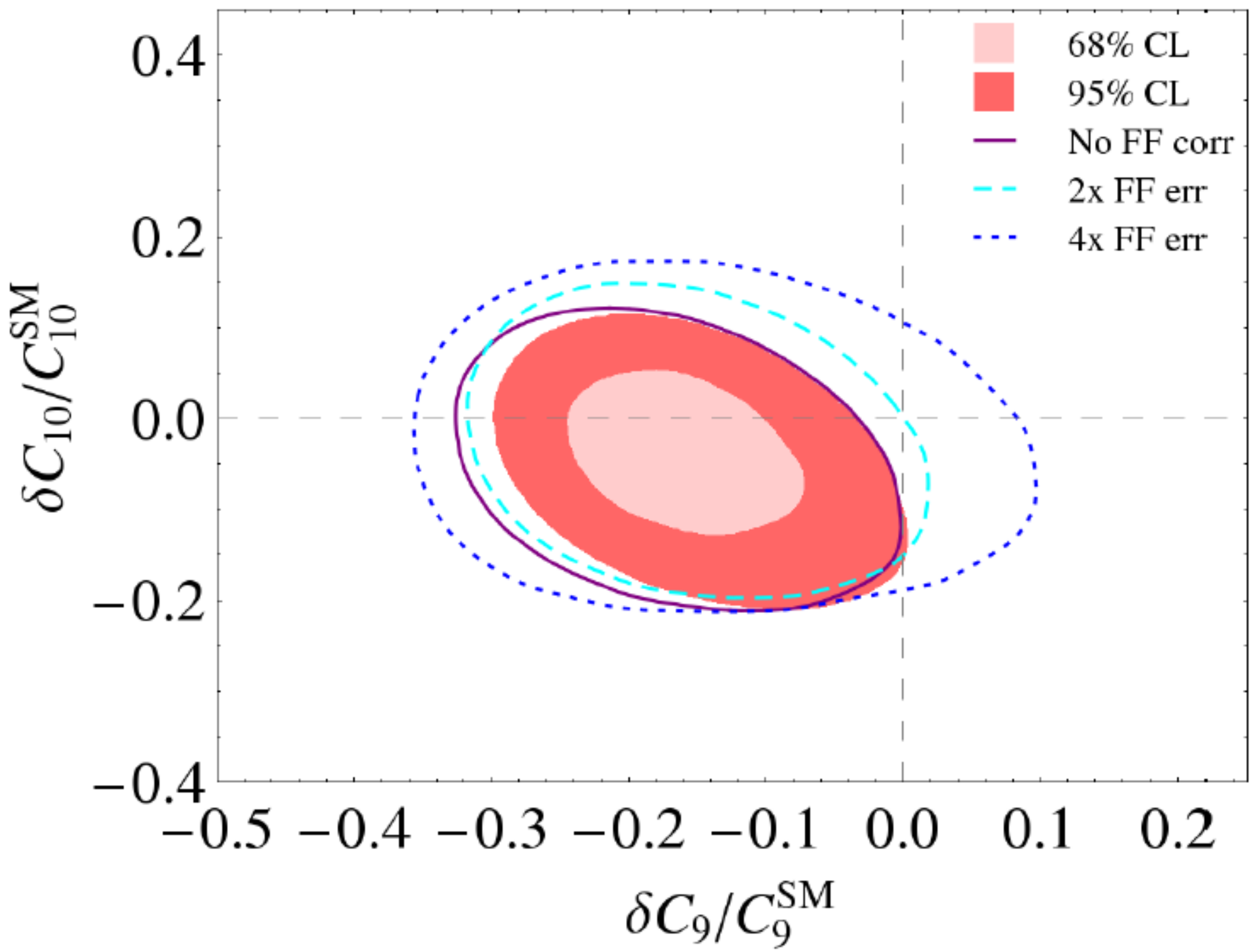
data of 2015/2016

$\{C_9, C_{10}\}$



Hurth,Mahmoudi,Neshatpour arXiv:1603.00865

Fits assuming different form factor uncertainties

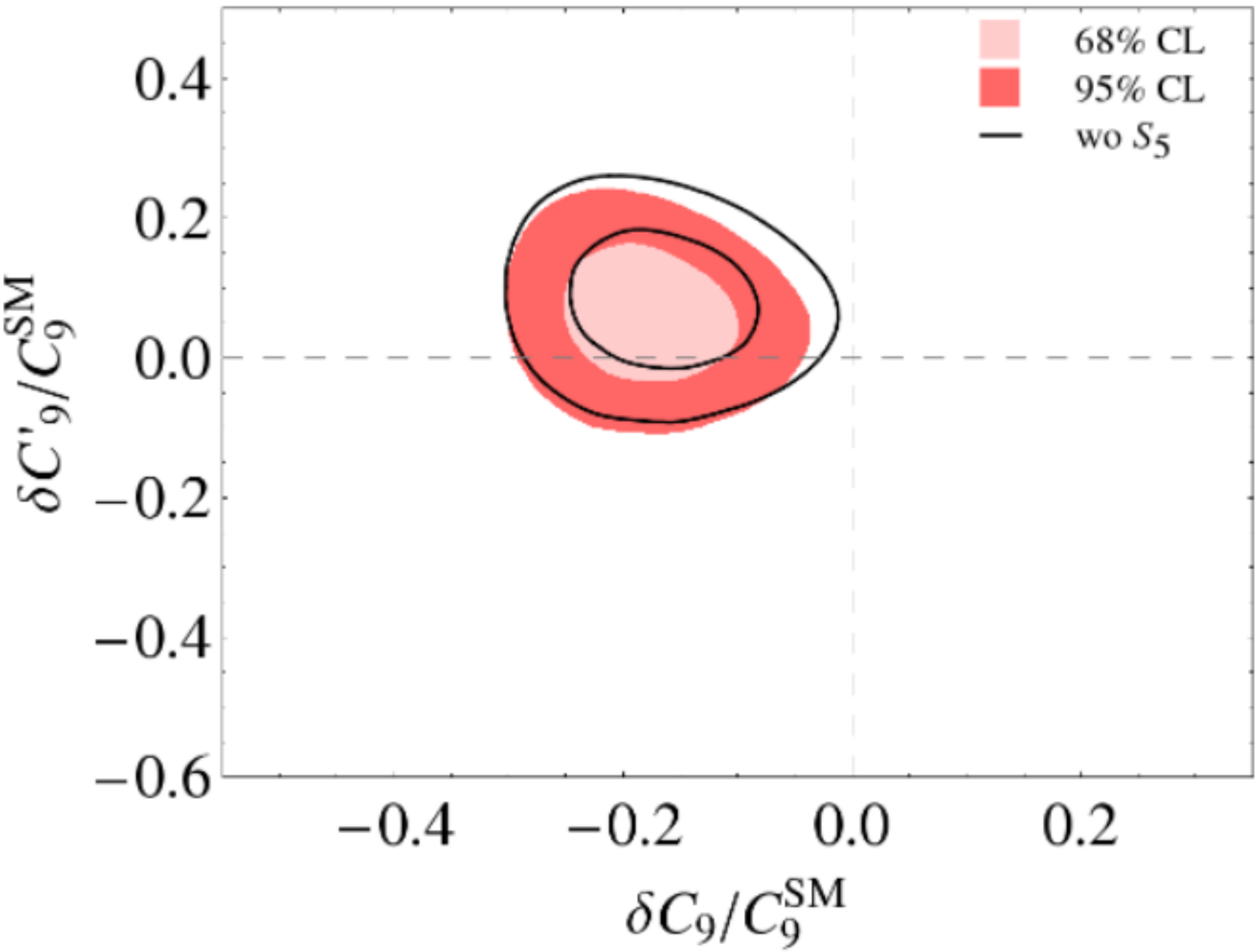


The size of the form factor errors has a crucial role in constraining the allowed region (LCSR-calculation Zwicky et al. arXiv:1503.0553)

Hurth,Mahmoudi,Neshatpour arXiv:1603.00865

Omitting S_5 from the fit

data of 2015/2016



S_5 is not the only observable which drives $\delta C_9/C_9^{SM}$ to negative values

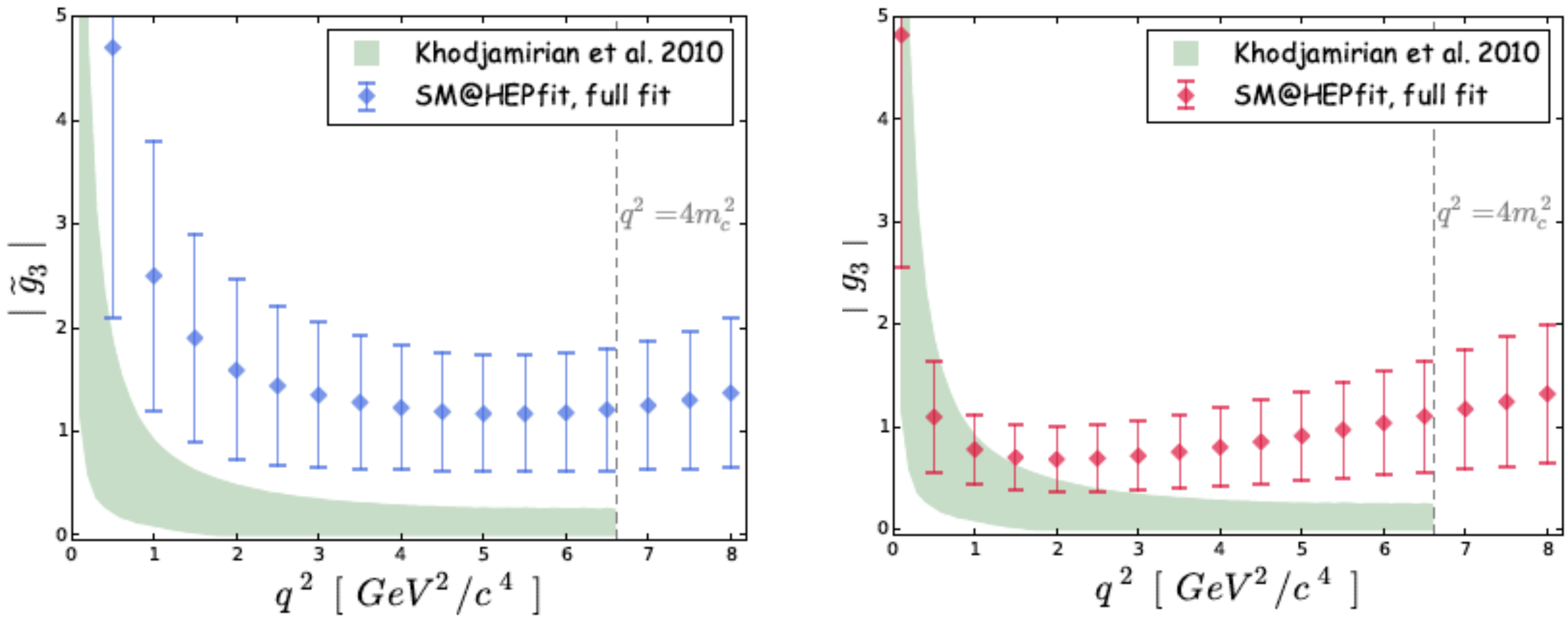
Fit the unknown power corrections to the data

Ciuchini et al. arXiv:1512.07157

data of 2015/2016

Leading SCET amplitude with general ansatz with 18 parameters
for power corrections Camalich,Jäger arXiv:1212.2263

Fit needs 20 – 50% power corrections (on the observable level)



No sign for q^2 dependence in the theory-independent fit

Significant q^2 dependence if power corrections are fixed at 1GeV
via result of LCSR calculation Kjodjamirian et al. arXiv:1211.0234

New physics or hadronic effects

Hurth, Mahmoudi, Neshatpour, Chobanova, Martinez Santos arXiv:1702.02234

Hadronic power correction effect:

data of 2015/2016

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

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 $h_{+,-,0}^{(0,1,2)}$ (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

Wilk's test

Hurth, Mahmoudi, Neshatpour, Chobanova, Martinez Santos arXiv:1702.02234

data of 2015/2016

q^2 up to 8 GeV^2

	2 (δC_9)	4 ($\delta C_7, \delta C_9$)	18 ($h^{(0,1,2)}_{+,-,0}$)
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 δC_9 improves over the SM hypothesis by 4.1σ
→ Including in addition δC_7 or hadronic parameters improves the situation only mildly
→ One cannot rule out the hadronic option

Adding 16 more parameters does not really improve the fit

The situation is still inconclusive

(LHCb upgrade prospects: NP versus hadronic effects 34 σ)

Separate NP fits with a single operator

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

data of 2017 (with R_{K^*} !)

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

	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
ΔC_9	-0.48	18.3	0.3σ
$\Delta C_9'$	$+0.78$	18.1	0.6σ
ΔC_{10}	-1.02	18.2	0.5σ
$\Delta C_{10}'$	$+1.18$	17.9	0.7σ
ΔC_9^μ	-0.35	5.1	3.6σ
ΔC_9^e	$+0.37$	3.5	3.9σ
ΔC_{10}^μ	-1.66 -0.34	2.7	4.0σ
ΔC_{10}^e	-2.36 $+0.35$	2.2	4.0σ

$\rightarrow$ NP in C_9^e, C_9^μ, C_{10}^e, or C_{10}^μ are favoured by the $R_{K^{(*)}}$ ratios (significance: $3.6-4.0\sigma$)

$\rightarrow$ NP contributions in primed operators do not play a role.

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

	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
ΔC_9	-0.24	70.5	4.1σ
$\Delta C_9'$	-0.02	87.4	0.3σ
ΔC_{10}	-0.02	87.3	0.4σ
$\Delta C_{10}'$	$+0.03$	87.0	0.7σ
ΔC_9^μ	-0.25	68.2	4.4σ
ΔC_9^e	$+0.18$	86.2	1.2σ
ΔC_{10}^μ	-0.05	86.8	0.8σ
ΔC_{10}^e	-2.14 $+0.14$	86.3	1.1σ

$\rightarrow$ C_9 and C_9^μ solutions are favoured with SM pulls of 4.1 and 4.4σ

$\rightarrow$ Primed operators have a very small SM pull

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

Separate NP fits with a single operator

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

data of 2017 (with R_{K^*} !)

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Slight decoherence between the two subsets

Separate NP fits with a single operator

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

data of 2017 (with R_{K^*} !)

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

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

Within chiral basis: Slight decoherence between the two subsets again

	b.f. value	$\chi^2_{\rm min}$	$\text{Pull}_{\rm SM}$
$\Delta C_9^\mu = -\Delta C_{10}^\mu$ $(\Delta C_{\rm LL}^\mu)$	-0.16	3.4	3.9σ
$\Delta C_9^e = -\Delta C_{10}^e$ $(\Delta C_{\rm LL}^e)$	$+0.19$	2.8	4.0σ
$\Delta C_9^{\mu\prime} = -\Delta C_{10}^{\mu\prime}$ $(\Delta C_{\rm RL}^\mu)$	-0.01	18.3	0.4σ
$\Delta C_9^{e\prime} = -\Delta C_{10}^{e\prime}$ $(\Delta C_{\rm RL}^e)$	$+0.01$	18.3	0.4σ
$\Delta C_9^\mu = +\Delta C_{10}^\mu$ $(\Delta C_{\rm LR}^\mu)$	$+0.09$	17.5	1.0σ
$\Delta C_9^e = +\Delta C_{10}^e$ $(\Delta C_{\rm LR}^e)$	-0.55	1.4	4.1σ
$\Delta C_9^{\mu\prime} = +\Delta C_{10}^{\mu\prime}$ $(\Delta C_{\rm RR}^\mu)$	-0.01	18.4	0.2σ
$\Delta C_9^{e\prime} = +\Delta C_{10}^{e\prime}$ $(\Delta C_{\rm RR}^e)$	$+0.61$	2.0	4.1σ

	b.f. value	$\chi^2_{\rm min}$	$\text{Pull}_{\rm SM}$
$\Delta C_9^\mu = -\Delta C_{10}^\mu$ $(\Delta C_{\rm LL}^\mu)$	-0.10	79.4	2.8σ
$\Delta C_9^e = -\Delta C_{10}^e$ $(\Delta C_{\rm LL}^e)$	$+0.08$	86.3	1.1σ
$\Delta C_9^{\mu\prime} = -\Delta C_{10}^{\mu\prime}$ $(\Delta C_{\rm RL}^\mu)$	-0.01	87.3	0.4σ
$\Delta C_9^{e\prime} = -\Delta C_{10}^{e\prime}$ $(\Delta C_{\rm RL}^e)$	-0.01	87.0	0.7σ
$\Delta C_9^\mu = +\Delta C_{10}^\mu$ $(\Delta C_{\rm LR}^\mu)$	-0.12	79.5	2.8σ
$\Delta C_9^e = +\Delta C_{10}^e$ $(\Delta C_{\rm LR}^e)$	$+0.50$ -1.12	85.8 86.7	1.3σ 0.9σ
$\Delta C_9^{\mu\prime} = +\Delta C_{10}^{\mu\prime}$ $(\Delta C_{\rm RR}^\mu)$	$+0.03$	87.1	0.6σ
$\Delta C_9^{e\prime} = +\Delta C_{10}^{e\prime}$ $(\Delta C_{\rm RR}^e)$	-0.54	86.3	1.1σ

Adding the observable $B_s \to \mu\mu$ as C_{10}-discriminator to ratios has only a very mild effect.

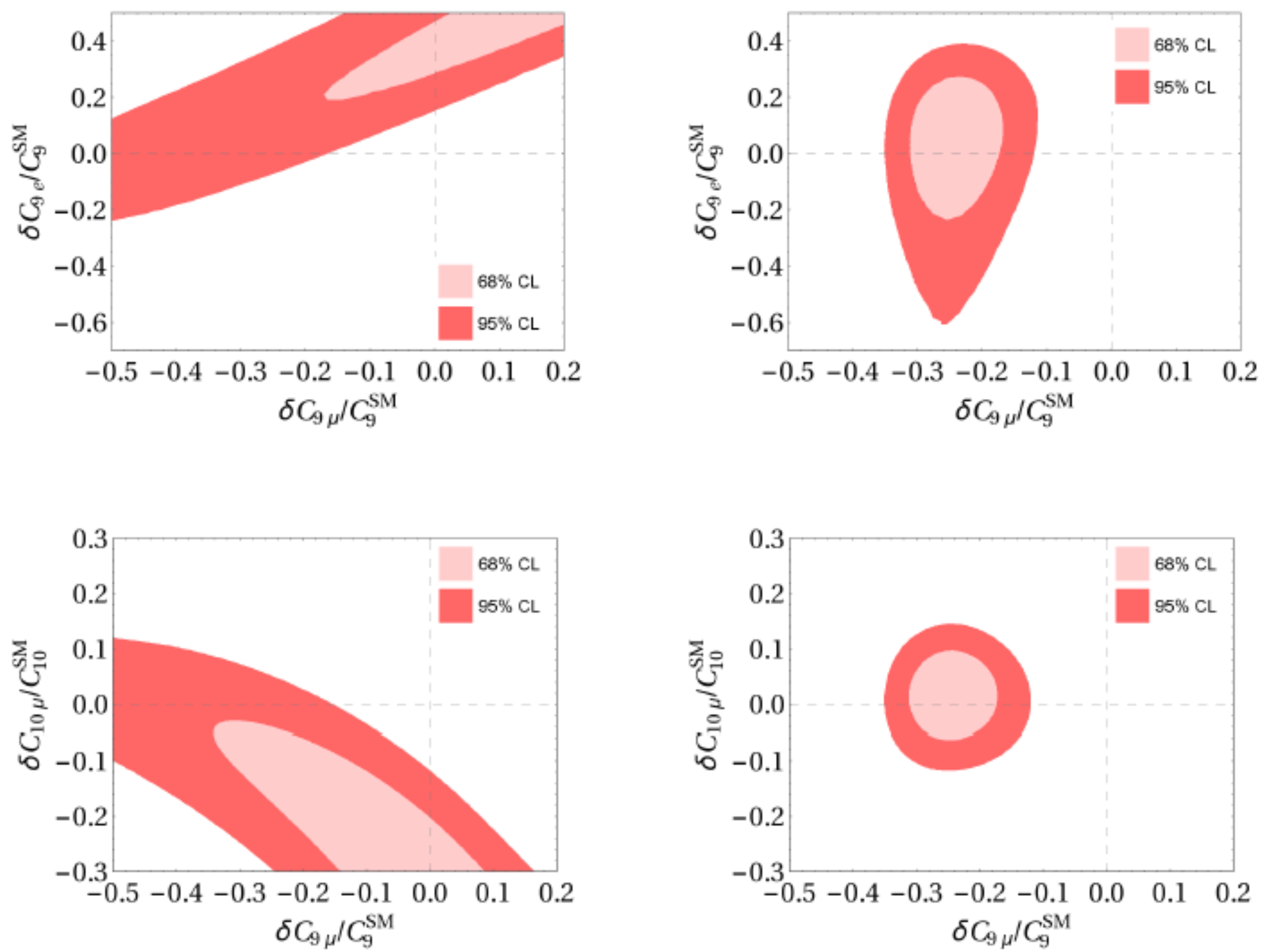
Separate NP fits with two operators

Hurth, Mahmoudi, Martinez Santos, Neshatpour arXiv: 1705.06274

using only R_K and R_{K^*} | using all but R_K and R_{K^*}

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

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



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