Present Status of $b \to s\ell^+\ell^-$ Anomalies

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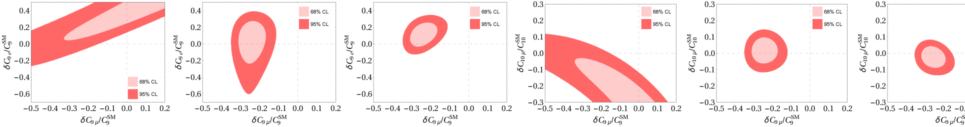
Based on arXiv:1705.06274, arXiv:1603.00865 & arXiv:1410.4545

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

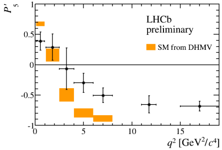


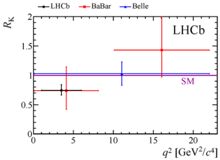
Instant workshop on B meson anomalies

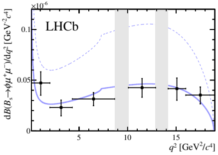
CERN, May 17-19, 2017

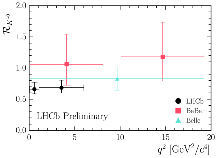
4 main LHCb anomalies:

- $B \to K^* \mu^+ \mu^-$ angular observables (P_5' / S_5,...): 3.4σ tension **JHEP 1602, 104 (2016)**
- BR($B_s \to \phi \mu^+ \mu^-$): 3.2σ tension in [1-6] GeV^2 bin **JHEP 1509 (2015) 179**
- $R_K = BR(B^+ \to K^+ \mu^+ \mu^-)/BR(B^+ \to K^+ e^+ e^-)$: 2.6$\sigma$ tension in [1-6] GeV^2 bin **PRL 113, 151601 (2014)**
- **New!** $R_K^* = BR(B^0 \to K^{*0} \mu^+ \mu^-)/BR(B^0 \to K^{*0} e^+ e^-)$: $\sim$ 2.5σ tension in [0.045-1.1] and [1.1-6] GeV^2 bins **arXiv:1705.05802**









Possible explanations:

- Statistical fluctuations $\to$ seems unlikely
- Theoretical issues $\to$ still unresolved
- New Physics! $\to$ seems plausible

In Summary:

1. **Update of the global fits**
   Important: 2 categories of observables:
   - Theoretically clean ones, namely R_K and R_{K^*}
     $\rightarrow$ Combining the three measurements gives an SM deviation of 3.6σ.
     $\rightarrow$ NP in $C_9^{e,\mu}$, $C_{10}^{e,\mu}$ are favoured $(3.6 - 4.0\sigma)$ and also $C_{LL,RR}^{e,\mu}$ $(3.9 - 4.1\sigma)$.
   - Angular observables and branching ratios
     $\rightarrow$ Issue of hadronic uncertainties (only guestimates of non-factorisable power corrections at present)
     $\rightarrow$ C_9 and C_9^{μ} solutions are favoured $(4.1$ and $4.4\sigma)$

2. **LHCb upgrade prospects**
   $\rightarrow$ only part of the 50 fb^{-1} is needed to establish NP in the $R_{K^{(*)}}$ ratios even in the pessimistic case that the systematic errors are not reduced by then at all.
   $\rightarrow$ however, it would be difficult to differentiate between the NP hypotheses

3. **Predictions for other ratios**
   $\rightarrow$ Important to cross check with other muon vs electron ratios
   $\rightarrow$ Analysis of various observables to differentiate between different NP models
   $\rightarrow$ Additional inputs are required to pinpoint NP in electron or muon sectors

Effective Hamiltonian for $b \to s$ transitions $\qquad \mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$

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

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

Transversity amplitudes:

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

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

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

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

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

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

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

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

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power corrections $\to$ **unknown**

only guesstimates possible at present
but estimates possible with some work on the theory side
(Khodjamirian et al., 1006.4945)

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power corrections $\to$ **unknown**

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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 the combined fits!

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

	b.f. value	$\chi^2_{\rm min}$	$\rm Pull_{SM}$
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

	b.f. value	$\chi^2_{\rm min}$	$\rm Pull_{SM}$
$\Delta C_9^\mu = -\Delta C_{10}^\mu$ $(\Delta C_{\rm LL}^\mu)$	-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

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

→ NP contributions in primed operators do not play a role.

→ Among the chiral Wilson coefficients, C_{LL}^μ, C_{LL}^e, C_{LR}^e, and C_{RR}^e have a SM pull of $3.9-4.1\sigma$ (the two latter however, lead to a very large NP shift in the Wilson coefficient.)

There are six favoured NP one-operator hypotheses to account for the deviations in the measured ratios $R_{K^{(*)}}$.

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

	b.f. value	$\chi^2_{\rm min}$	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

	b.f. value	$\chi^2_{\rm min}$	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

→ C_9 and C_9^μ solutions are favoured with SM pulls of 4.1 and 4.4σ

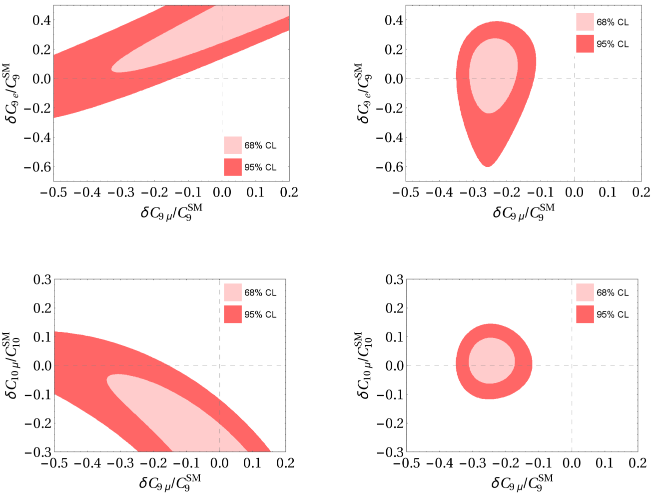
→ Primed operators have a very small SM pull

→ C_{10}-like solutions do not play a role in this global fit.

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 2σ level.

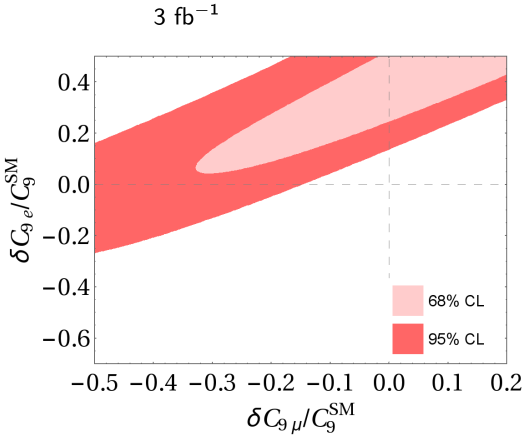
$\text{Pull}_{\rm SM}$ for the fit of Wilson coefficients based on the ratios R_K and R_{K^*}
LHCb upgrade scenarios with 50 fb^{-1} and 300 fb^{-1} luminosity collected, assuming current central values remain

50 fb^{-1}	Syst. $\text{Pull}_{\rm SM}$	Syst./2 $\text{Pull}_{\rm SM}$	Syst./3 $\text{Pull}_{\rm SM}$
ΔC_9^μ	10.4σ	11.6σ	12.9σ
ΔC_9^e	10.9σ	12.3σ	13.6σ
ΔC_{10}^μ	11.1σ	12.6σ	13.9σ
ΔC_{10}^e	11.3σ	12.8σ	14.1σ
ΔC_{LL}^μ	10.9σ	12.3σ	13.6σ
ΔC_{LL}^e	11.2σ	12.5σ	13.8σ

300 fb^{-1}	Syst. $\text{Pull}_{\rm SM}$	Syst./2 $\text{Pull}_{\rm SM}$	Syst./3 $\text{Pull}_{\rm SM}$
ΔC_9^μ	9.4σ	15.6σ	19.5σ
ΔC_9^e	10.2σ	16.6σ	20.4σ
ΔC_{10}^μ	10.6σ	17.0σ	20.8σ
ΔC_{10}^e	10.9σ	17.2σ	21.1σ
ΔC_{LL}^μ	10.2σ	16.6σ	20.5σ
ΔC_{LL}^e	11.0σ	16.9σ	20.8σ

The SM pulls for the 6 favoured one-operator NP hypotheses are all very similar in each of the upgrade scenarios.
$\rightarrow$ it would be difficult to differentiate between the NP hypotheses!
$\rightarrow$ Need other ratios!

Fit results using only R_K and R_{K^*}



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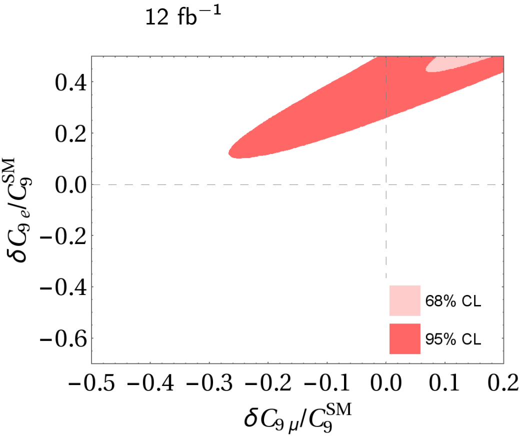

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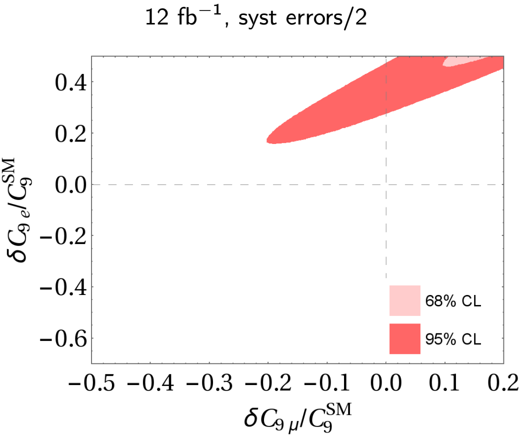

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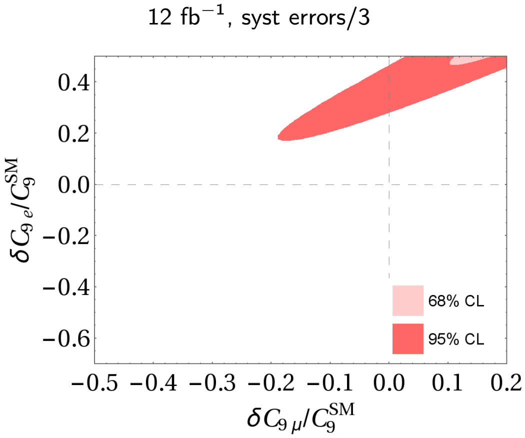

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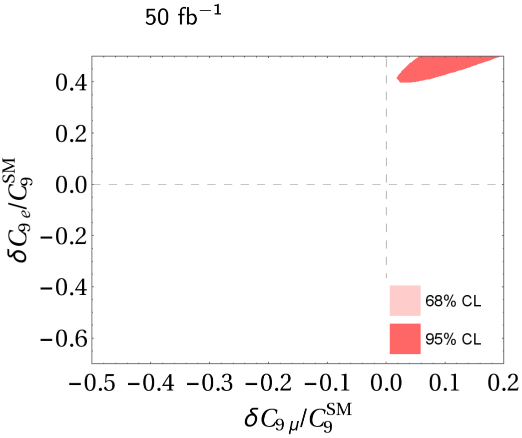

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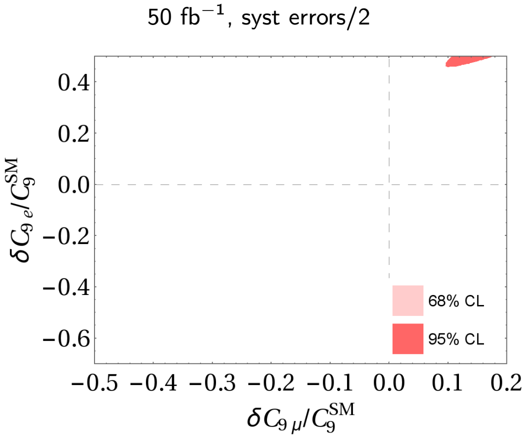

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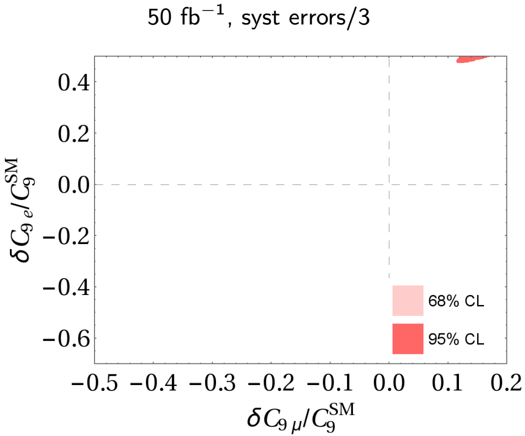
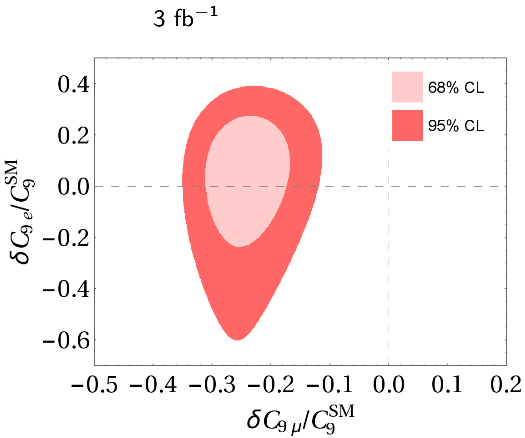


Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



assuming 10% power corrections (guesstimate)

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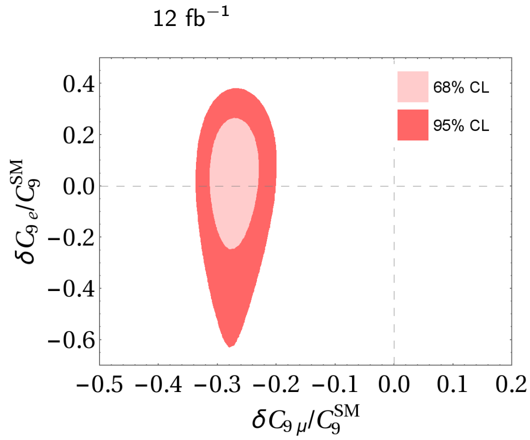

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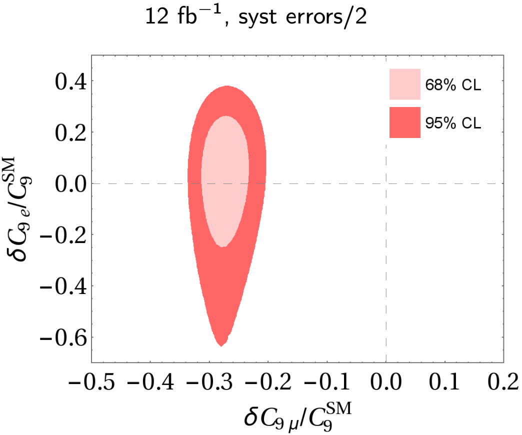

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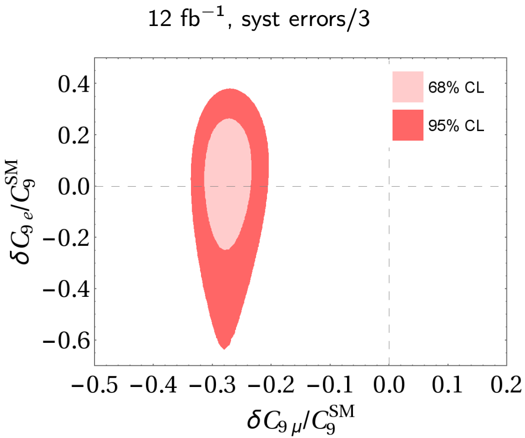

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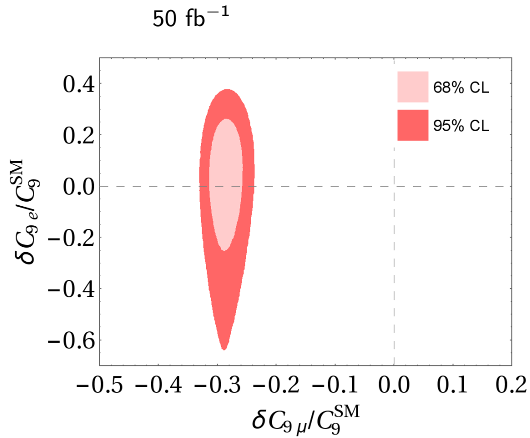

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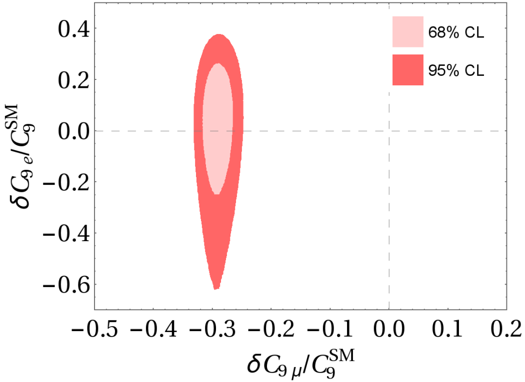
50 fb^{-1}, syst errors/2



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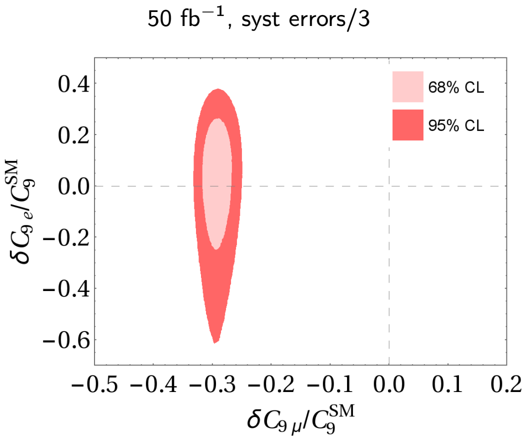

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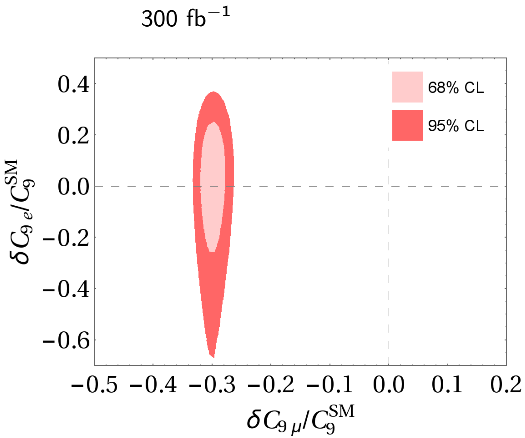

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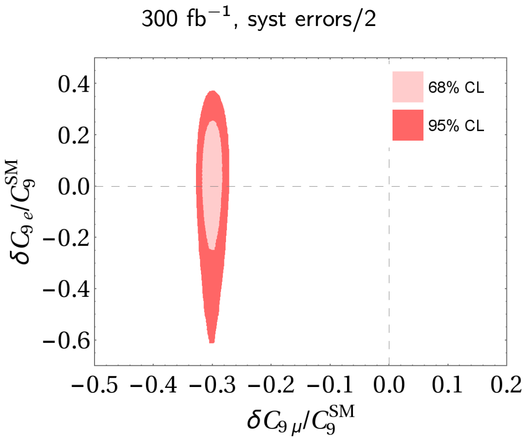

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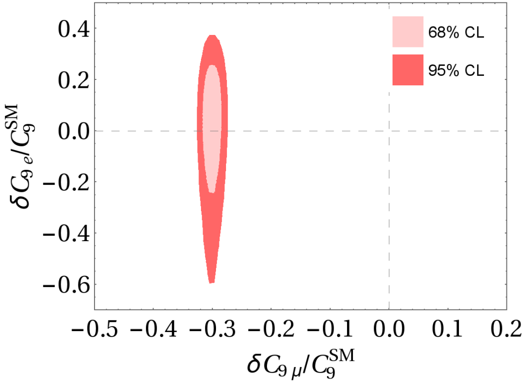

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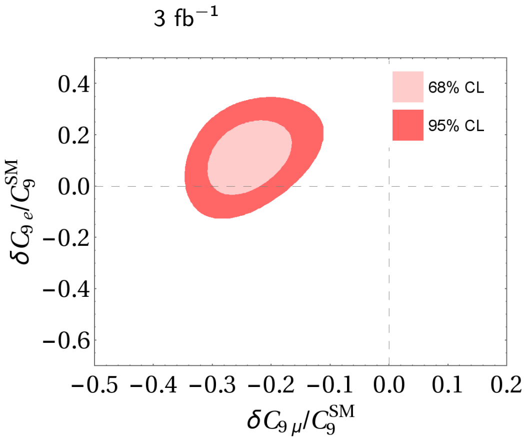
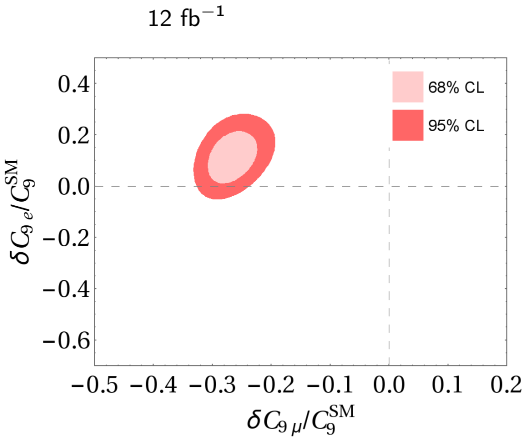


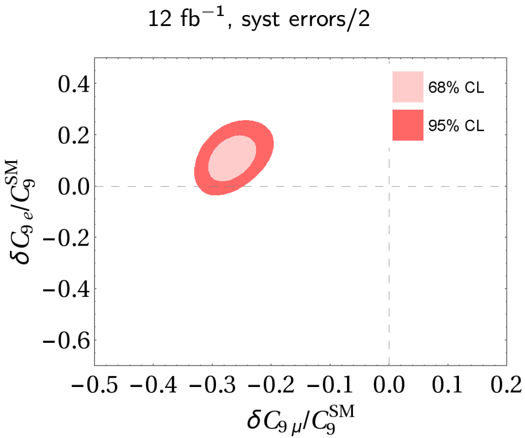
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



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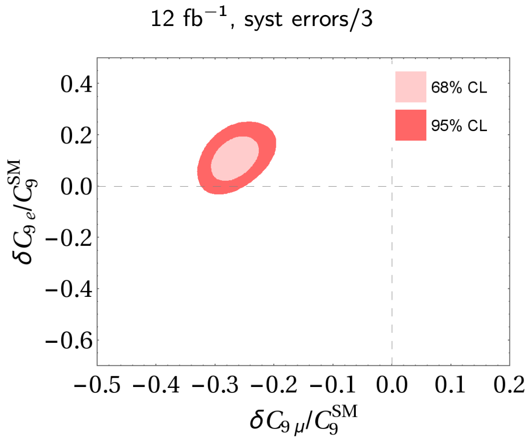
Fit results using all $b \to s\ell^+\ell^-$ observables



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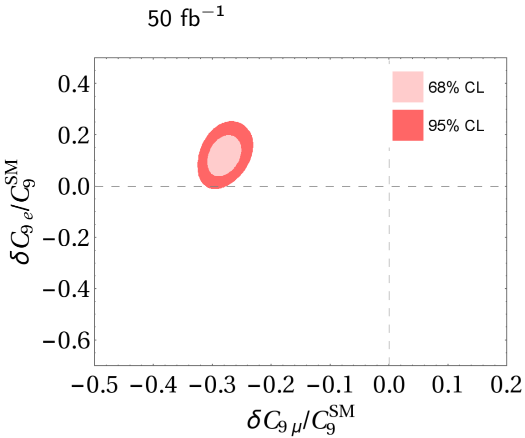
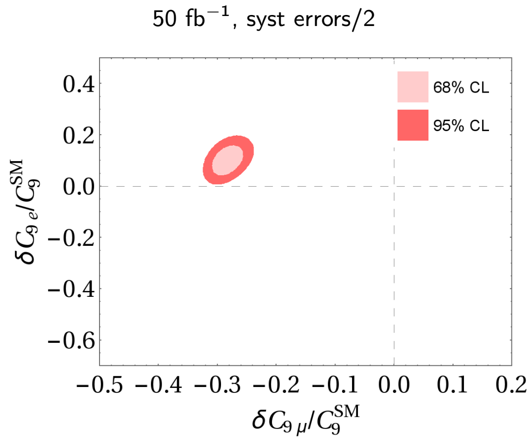
Fit results using all $b \to s\ell^+\ell^-$ observables



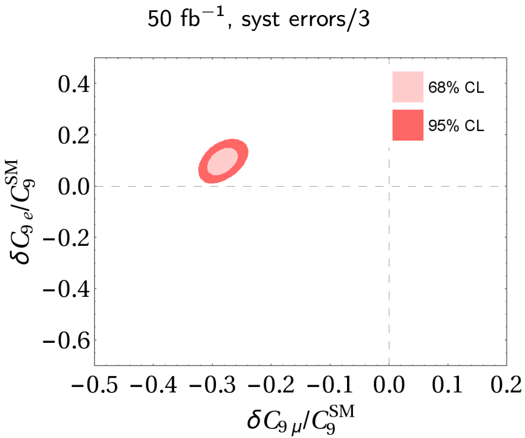
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



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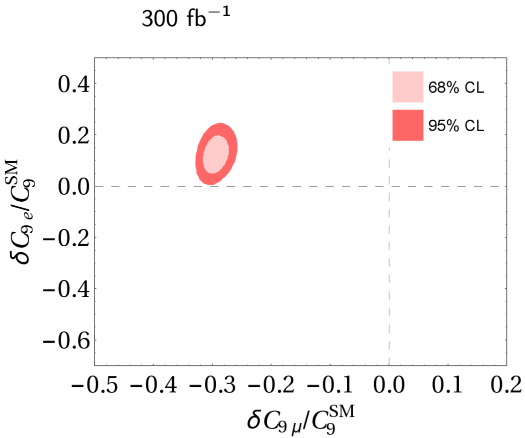
Fit results using all $b \to s\ell^+\ell^-$ observables



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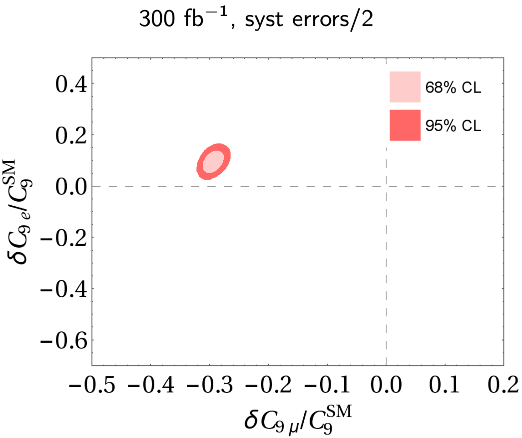
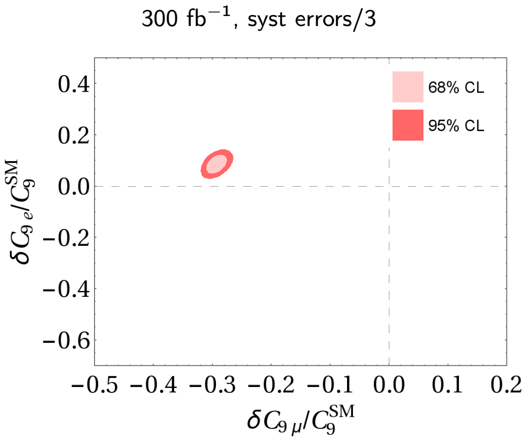
Fit results using all $b \to s\ell^+\ell^-$ observables



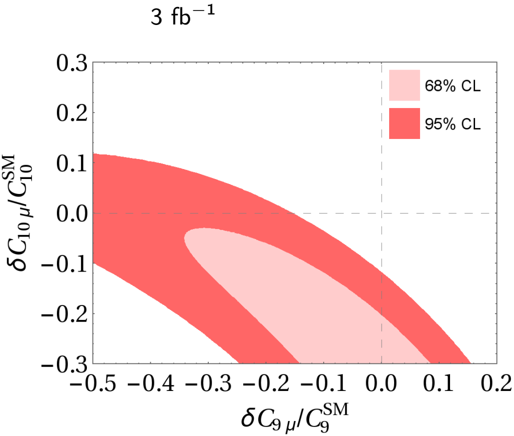
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables

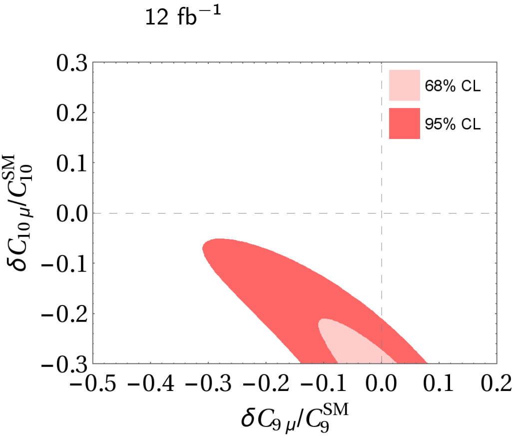


assuming 10% power corrections (guesstimate)

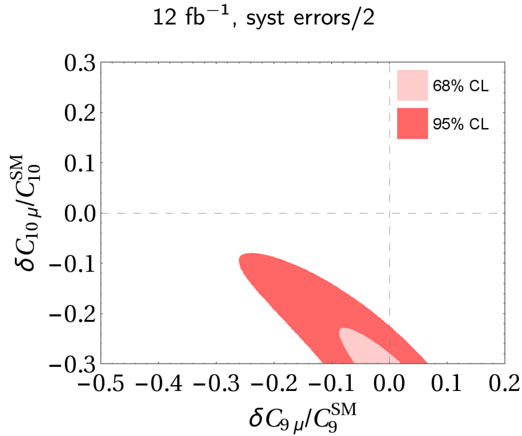
Fit results using only R_K and R_{K^*}



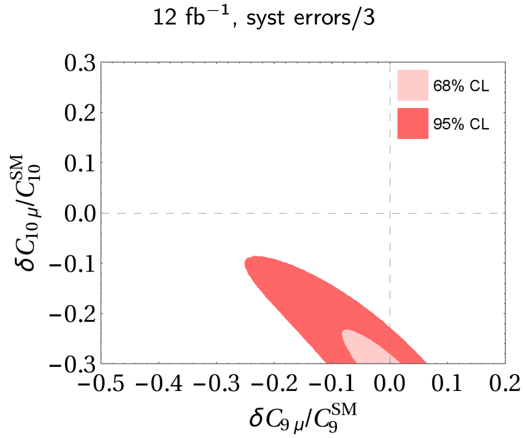
Fit results using only R_K and R_{K^*}



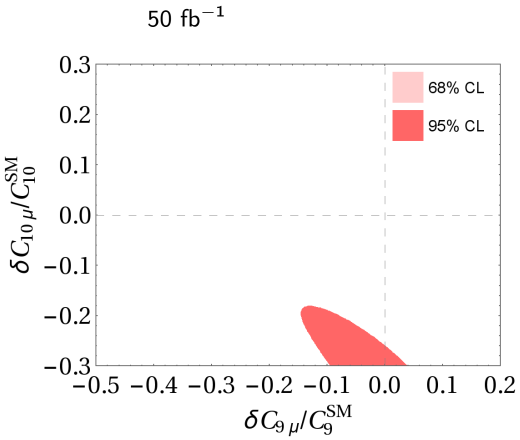
Fit results using only R_K and R_{K^*}



Fit results using only R_K and R_{K^*}



Fit results using only R_K and R_{K^*}



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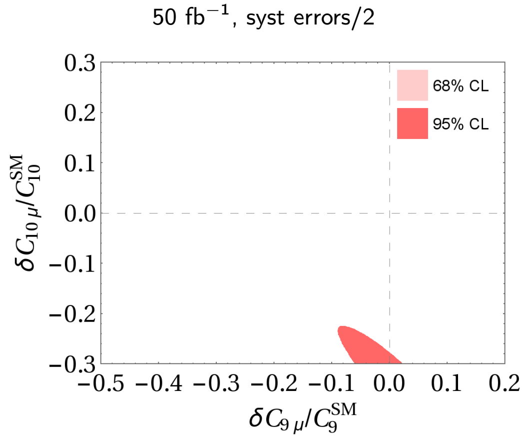
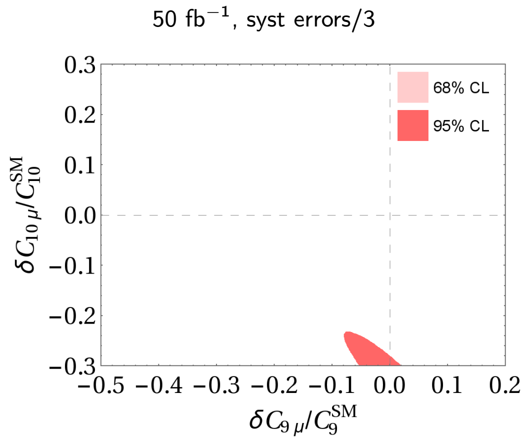
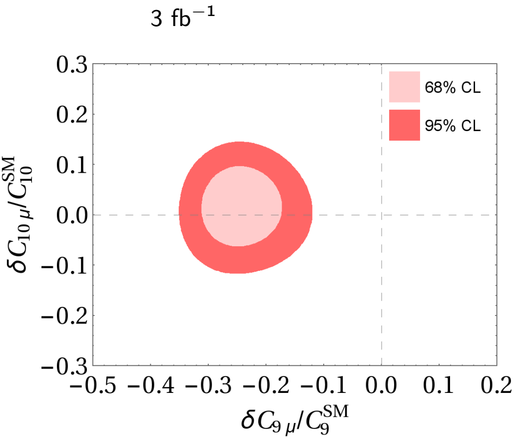


Fit results using only R_K and R_{K^*}

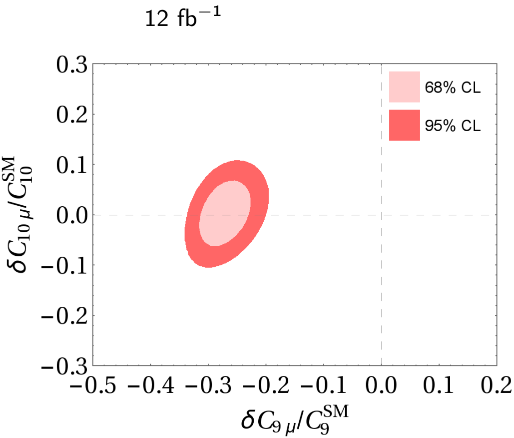


Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



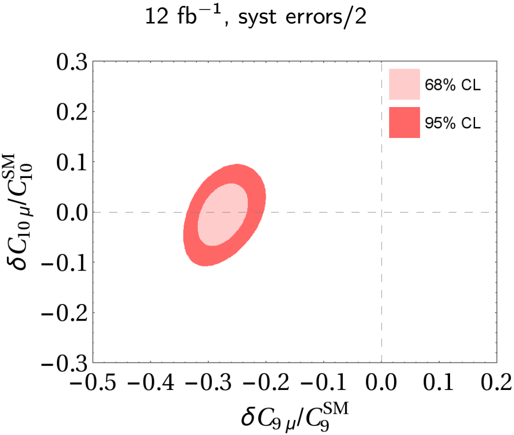
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



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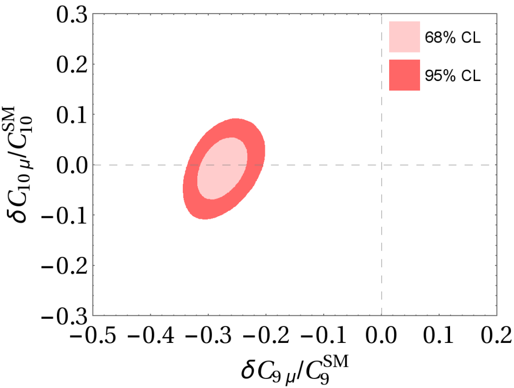
Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}

$12\ \mathrm{fb}^{-1}$, syst errors/3



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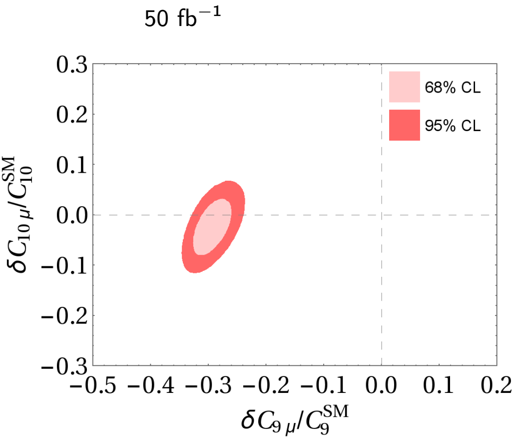
Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



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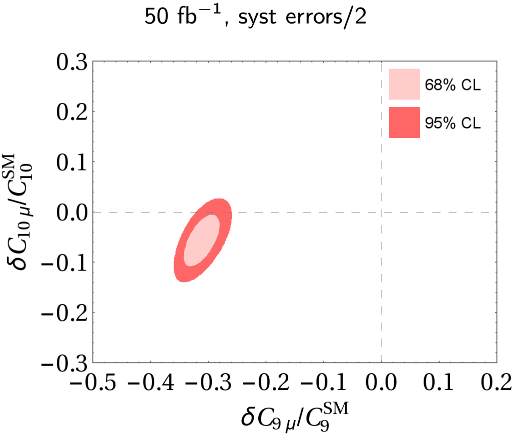
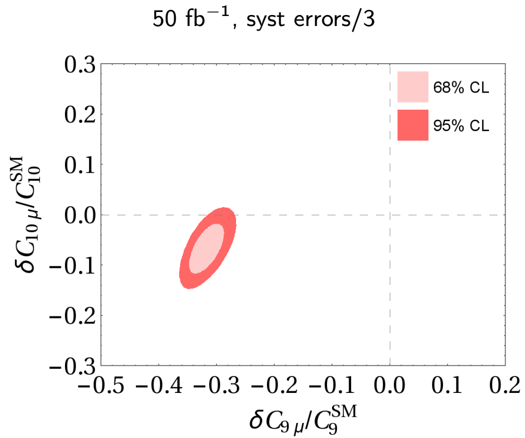
Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



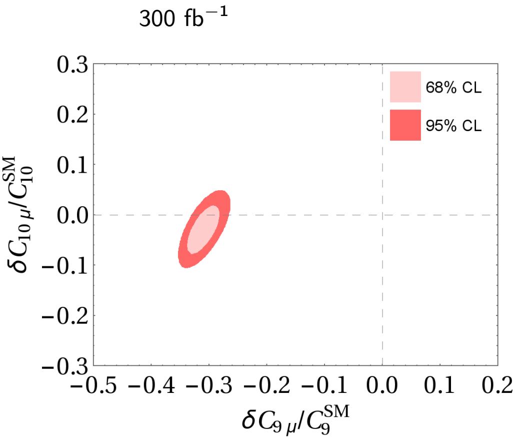
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



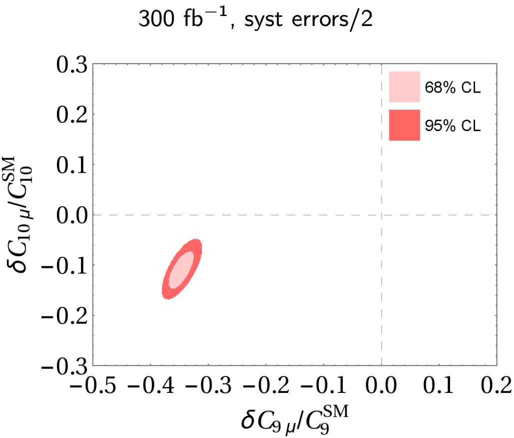
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



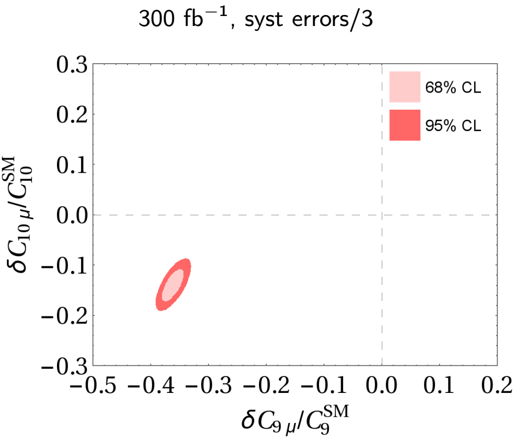
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables but R_K and R_{K^*}



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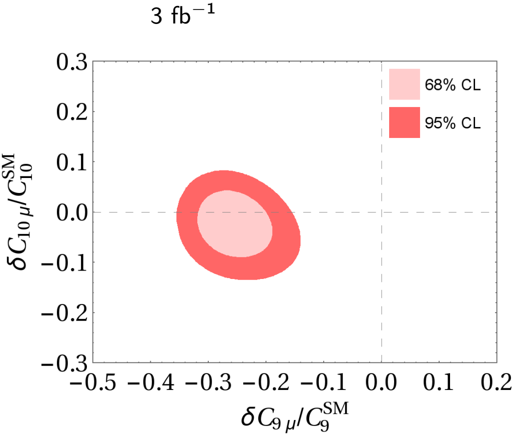
Fit results using all $b \to s\ell^+\ell^-$ observables



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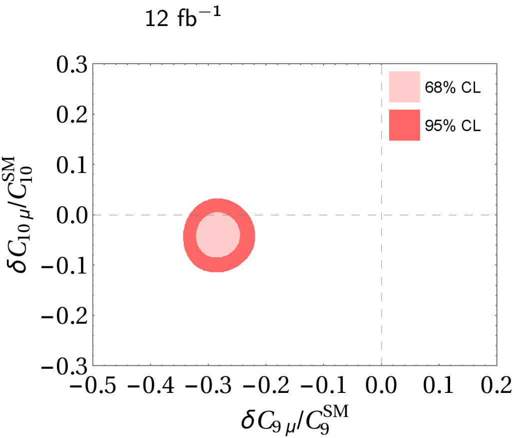
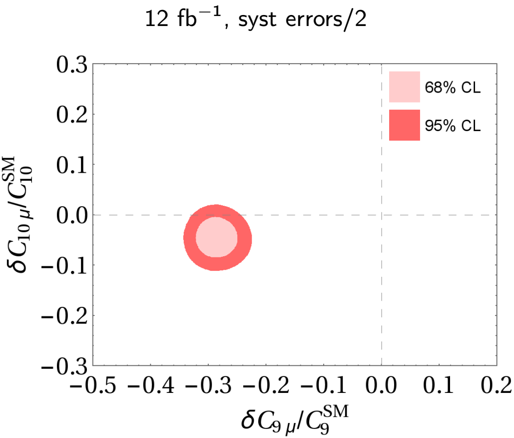
Fit results using all $b \to s\ell^+\ell^-$ observables



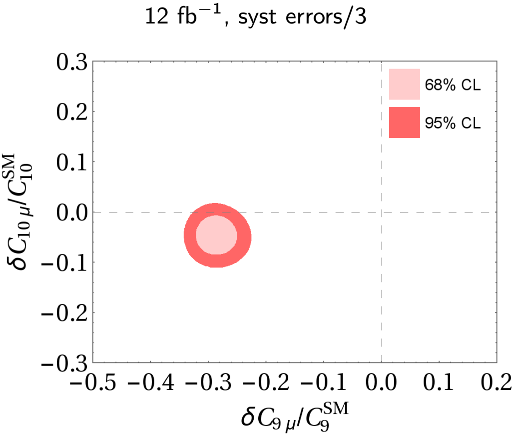
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



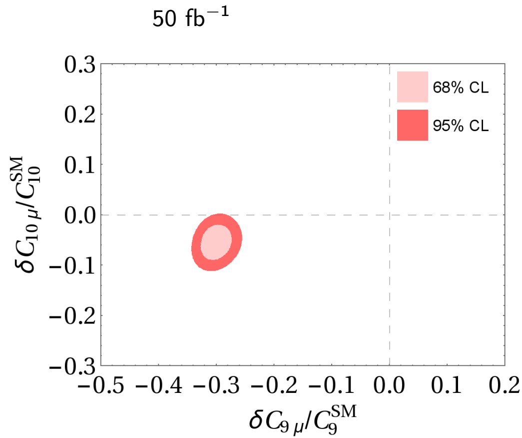
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



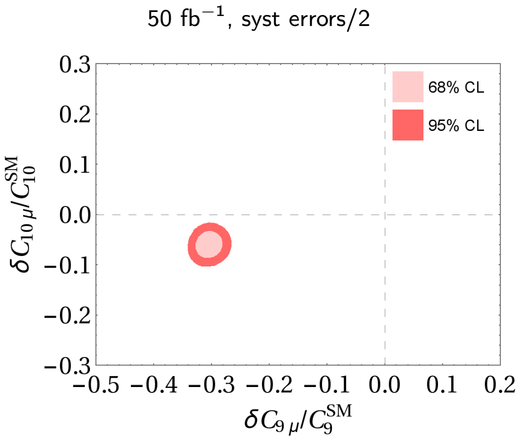
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



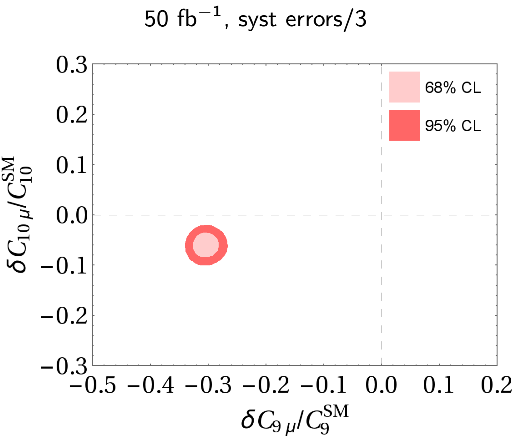
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



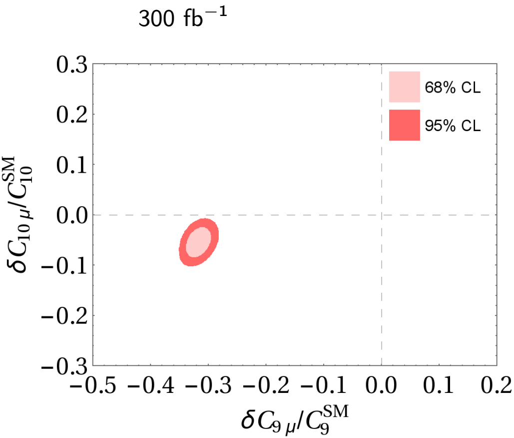
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



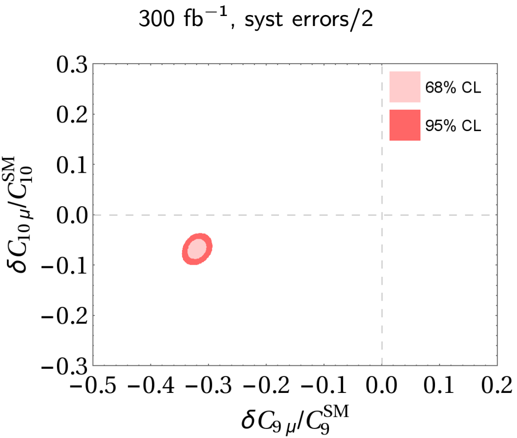
assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



assuming 10% power corrections (guesstimate)

Fit results using all $b \to s\ell^+\ell^-$ observables



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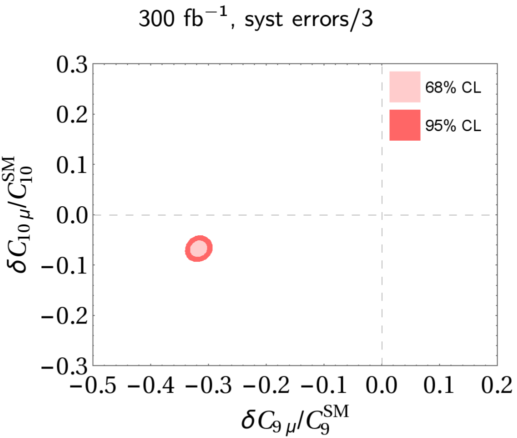
Fit results using all $b \to s\ell^+\ell^-$ observables



assuming 10% power corrections (guesstimate)

Outcome of the exercise:

The (C_9^e-C_9^μ) fit tells us that:

Based on *only* R_K and R_{K^*}, assuming the current central values remain

just with 12 fb^{-1} we show that New Physics scenarios

can improve the fit over the SM by 6.4 σ!

Predictions of ratios of observables with muons in the final state to electrons in the final state, based on the ratios R_K and R_{K^*} in the 95% confidence level, considering one operator fits.

	$R_{A_{FB}}^{[1.1,6.0]}$	$R_{S_5}^{[1.1,6.0]}$	$R_{F_L}^{[1.1,6.0]}$	$R_{K^*}^{[15,19]}$	$R_{\phi}^{[1.1,6.0]}$	$R_{\phi}^{[15,19]}$
C_{LL}^e	$[-1.52,-0.21]\cup$ $[-0.0430,-0.0427]$	$[0.36,0.37]\cup$ $[0.65,0.86]$	$[0.96,0.97]\cup$ $[1.47,1.59]$	$[0.53,0.84]\cup$ $[0.53,0.78]$	$[0.41,0.56]\cup$ $[0.54,0.85]$	$[0.52,0.84]\cup$ $[0.53,0.77]$
C_{LL}^μ	$[2.51,7.50]$	$[0.29,0.83]$	$[0.90,0.97]$	$[0.52,0.85]$	$[0.58,0.86]$	$[0.52,0.85]$
C_9^e	$[-0.46,-0.14]$	$[0.59,0.76]$	$[0.91,0.95]$	$[0.52,0.84]$	$[0.56,0.87]$	$[0.52,0.84]$
C_9^μ	$[4.05,19.16]$	$[-1.45,0.64]$	$[0.71,0.94]$	$[0.57,0.87]$	$[0.74,0.90]$	$[0.57,0.87]$
C_{10}^e	$[-1.10,-0.95]\cup$ $[0.95,1.10]$	$[-1.19,-1.03]\cup$ $[1.03,1.19]$	$[0.99,1.02]\cup$ $[0.99,1.02]$	$[0.53,0.84]\cup$ $[0.53,0.84]$	$[0.52,0.83]\cup$ $[0.52,0.83]$	$[0.53,0.84]\cup$ $[0.53,0.84]$
C_{10}^μ	$[-0.93,-0.70]\cup$ $[0.70,0.93]$	$[-1.01,-0.75]\cup$ $[0.75,1.01]$	$[1.00,1.06]\cup$ $[1.00,1.06]$	$[0.53,0.84]\cup$ $[0.53,0.84]$	$[0.52,0.84]\cup$ $[0.52,0.84]$	$[0.53,0.84]\cup$ $[0.53,0.84]$

Important cross check will become possible in the future

$R_{A_{FB}}$ has already the potential to differentiate between different hypothesis

To conclude...

- Still some tensions with the SM predictions in the full LHCb Run 1 results in the angular observables in $B \to K^* \mu\mu$ decays and branching ratios of $B_s \to \phi\mu\mu$
- Significance of these anomalies depends on the assumptions on the power corrections
- claims of $> 5\,\sigma$ deviations from the SM based on all observables including $R_{K^{(*)}}$ ratios are misleading
- To resolve the issue of power corrections:
  - In principle there are methods on the market to replace the guesstimates of power corrections to real estimates
    $\to$ more effort here is needed
  - The LHCb upgrade can provide enough precision to establish the NP option
- The future measurements of the clean R_X ratios have the potential to unambiguously establish lepton non-universal new physics in the near future
- Such a finding can indirectly establish the new physics explanation of the present anomalies in the less clean observables if there is a coherent NP picture of both sets of observables.

Backup

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

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

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

$\to$ 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

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

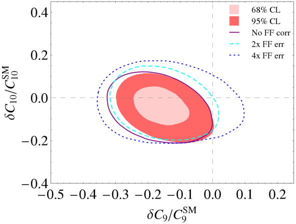
+ CP violating clean observables and other combinations

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

Fits with different assumptions for the form factor uncertainties:

- correlations ignored (solid line)
- normal form factor errors (filled areas)
- 2 $\times$ form factor errors (dashed line)
- 4 $\times$ 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

Fits with different assumptions for the form factor uncertainties:

- correlations ignored (solid line)
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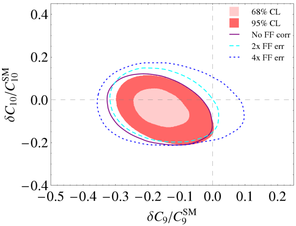
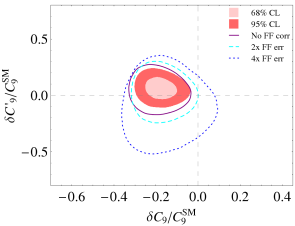
- 4 × form factor errors (dotted line)

$(C_9 - C_{10})$



$(C_9 - C_9')$



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

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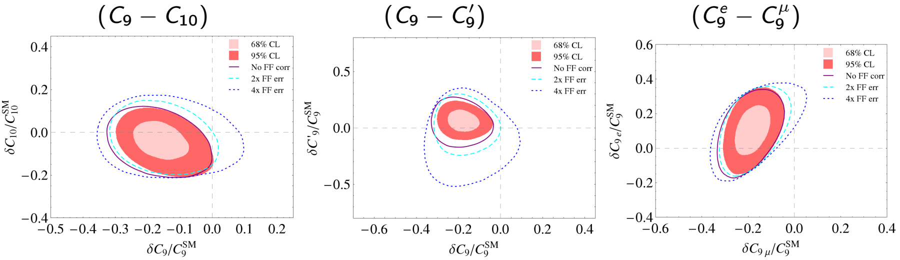
Fit results for two operators: form factor dependence

Fits with different assumptions for the form factor uncertainties:

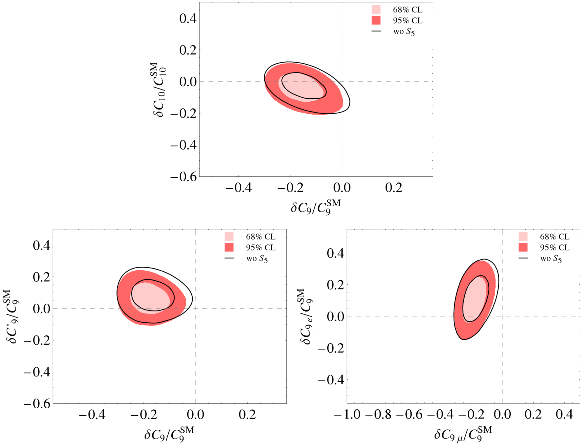
- correlations ignored (solid line)
- normal form factor errors (filled areas)
- 2 × form factor errors (dashed line)
- 4 × form factor errors (dotted line)



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

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

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!