



Global Fits of $b \rightarrow s \bar{\ell}\ell$ Decays

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l’Institut de Physique des 2 Infinis de Lyon

Some of the significant tensions between data and theory predictions of $b \rightarrow s\bar{\ell}\ell$ observables

July 2013

LHCb (1 fb⁻¹)

3.7 σ in P'_5

2013:

Descotes-Genon, Matias, Virto 1307.5683

Altmannshofer, Straub 1308.1501

Beaujean, Bobeth, van Dyk 1310.2478

Horgan, Liu, Meinel, Wingate 1310.3887

Hurth, Mahmoudi 1312.5267

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Global fits to $b \rightarrow s$ transitions

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3.7 σ in P'_5

LHCb (1 fb $^{-1}$)

2.6 σ in R_K

2014:

Ghosh, Nardecchia, Renner 1408.4097

Hurth, Mahmoudi, SN 1410.4545

Altmannshofer, Straub 1411.3161

...

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LHCb (1 fb^{-1})

3.7σ in P'_5

LHCb (1 fb^{-1})

2.6σ in R_K

LHCb (3 fb^{-1})

$2 \times 2.9\sigma$ in P'_5

2.5-3.5 σ in $BR(B_s \rightarrow \phi\mu\mu)$

2015 & 2016:

Altmannshofer, Straub 1503.06199

Beaujean, Bobeth, Jahn 1508.01526

Descotes-Genon, Hofer, Matias, Virto 1510.04239

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

Hurth, Mahmoudi, SN 1603.00865

Meinel, van Dyk 1603.02974

...

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Global fits to $b \rightarrow s$ transitions

Some of the significant tensions between data and theory predictions of $b \rightarrow s\bar{\ell}\ell$ observables

July 2013	June 2014	Mar./Dec. 2015	Apr. 2017
LHCb (1 fb^{-1}) 3.7σ in P'_5	LHCb (1 fb^{-1}) 2.6σ in R_K	LHCb (3 fb^{-1}) $2 \times 2.9\sigma$ in P'_5 2.5-3.5 σ in $BR(B_s \rightarrow \phi\mu\mu)$	LHCb (3 fb^{-1}) 2.3σ & 2.5σ in R_{K^*}

2017:

Capdevila, Crivellin, Descotes-Genon, Matias, Virto 1704.05340

Altmannshofer, Stangl, Straub 1704.05435

D'Amico, Nardecchia, Panci, Sannino, Strumia, Torre, Urbano 1704.05438

Geng, Grinstein, Jaeger, Camalich, Ren, Shi 1704.05446

Ciuchini, Coutinho, Fedele, Franco, Paul, Silvestrini, Valli 1704.05447

Hurth, Mahmoudi, Martinez Santos, SN 1705.06274

...

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Global fits to $b \rightarrow s$ transitions

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LHCb (3 fb^{-1})

2.3σ & 2.5σ in R_{K^*}

LHCb (5 fb^{-1})

2.5σ in R_K

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2.3σ & 2.5σ in R_{K^*}

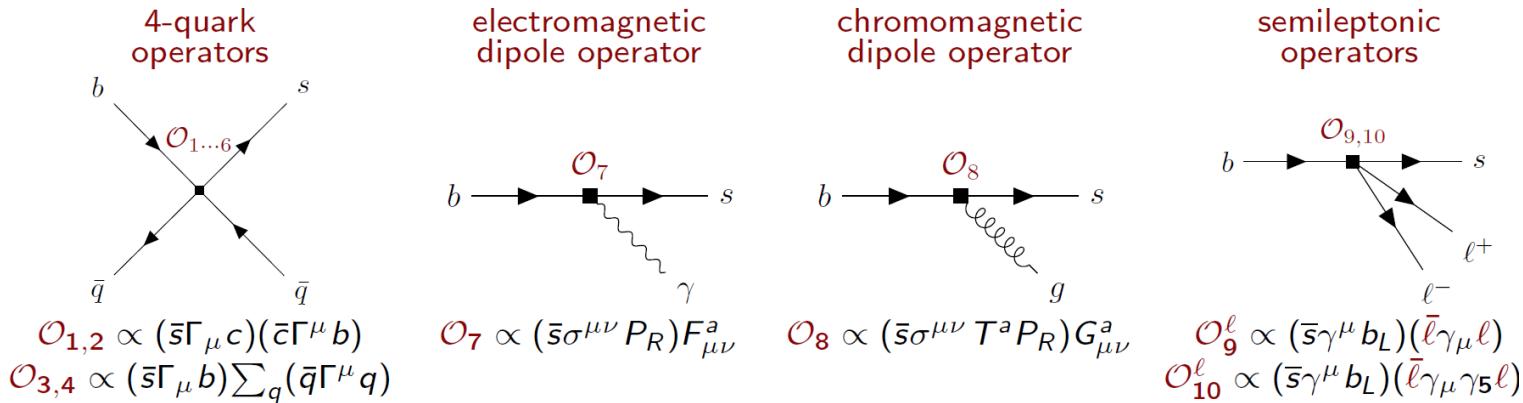
LHCb (5 fb^{-1})

2.5σ in R_K

$2.5\text{-}3.5\sigma$ in $BR(B_s \rightarrow \phi\mu\mu)$

I will only talk about recent global fits to $b \rightarrow s$ transitions including the March 2019 results in the Weak Effective Theory

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left(\sum_{i=1 \dots 10, S, P} (C_i(\mu) \mathcal{O}_i(\mu) + C'_i(\mu) \mathcal{O}'_i(\mu)) \right)$$



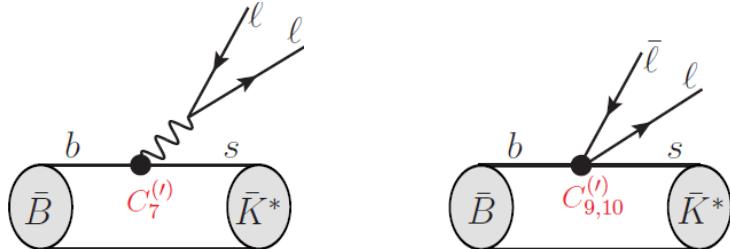
In the SM: $C_7 = -0.29$ $C_9 = 4.20$ $C_{10} = -4.01$

other operators: Chirally flipped (\mathcal{O}'_i), (pseudo)scalar (\mathcal{O}_S and \mathcal{O}_P)

Exclusive mode $B \rightarrow K^* \ell^+ \ell^-$

Effective Hamiltonian has two parts:

$$\mathcal{H}_{\text{eff}}^{\text{sl}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=7,9,10, Q_1, Q_2} C_i^{(\ell)}(\mu) O_i^{(\ell)}(\mu) \right]$$



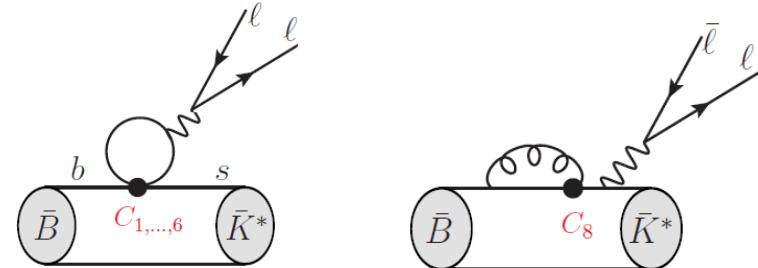
Factorisable contributions:

7 independent form factors $\tilde{V}_{\pm,0}, \tilde{T}_{\pm,0}, \tilde{S}$
or

heavy quark symm. relations: 2 soft for factors ξ_\perp, ξ_\parallel

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

$$\mathcal{H}_{\text{eff}}^{\text{had}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=1\dots 6} C_i(\mu) O_i(\mu) + C_8(\mu) O_8(\mu) \right]$$



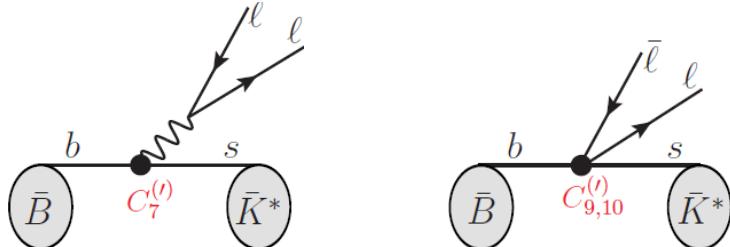
In general “naïve” factorization not applicable

$$\frac{e^2}{q^2} \epsilon_\mu L_V^\mu \left[\underbrace{Y(q^2) \tilde{V}_\lambda}_{\text{fact., perturbative}} + \underbrace{\text{LO in } \mathcal{O}\left(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}}\right)}_{\text{non-fact., QCdf}} + \underbrace{h_\lambda(q^2)}_{\substack{\text{power corrections,} \\ \text{[Beneke et al.]}}} \right]$$

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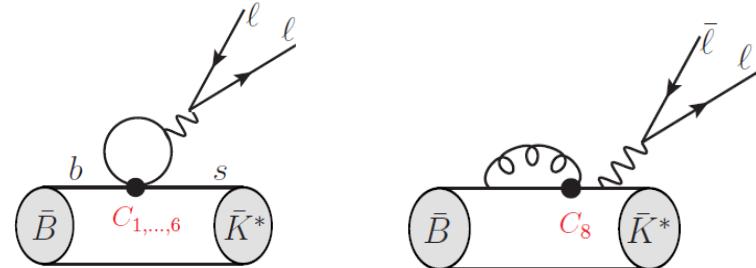
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Light-meson LCSR:
[BSZ 1503.05534]

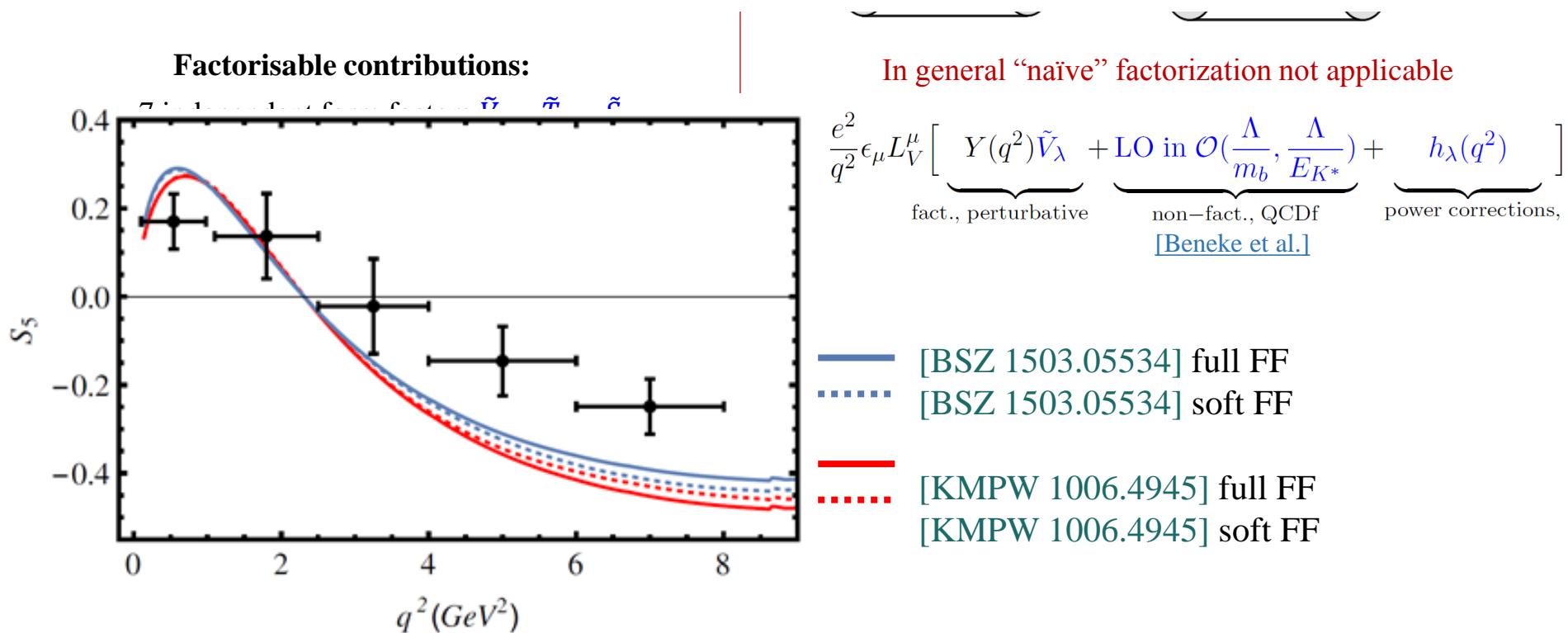
B-meson LCSR:
[KMPW 1006.4945] & [GKvD 1811.00983]

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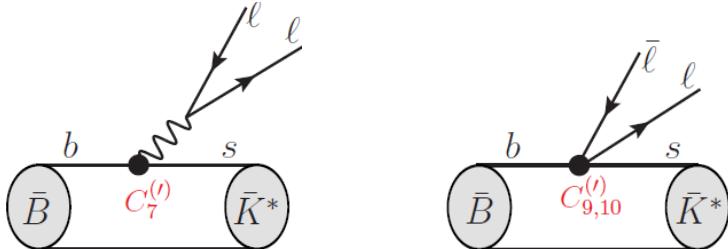
- **Observables:** $[BR, P_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, Q_i \equiv D_{P_i}$
- **Form factors:** soft FF, $B \rightarrow K^{(*)}$: B -meson LCSR [KMPW 1006.4945]+Lattice [BLMNS 1306.2384] & [HLMW 1310.3722], $B_s \rightarrow \phi$: Light-meson LCSR [BSZ 1503.05534] + Lattice [HLMW 1310.3722]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [FLAG 1902.0819]
- **Power corrections:** order of magnitude from LCSR [Khodjamirian et al. 1006.4945] w/o assumption on sign
- **Software:** private code with $\Delta\chi^2$



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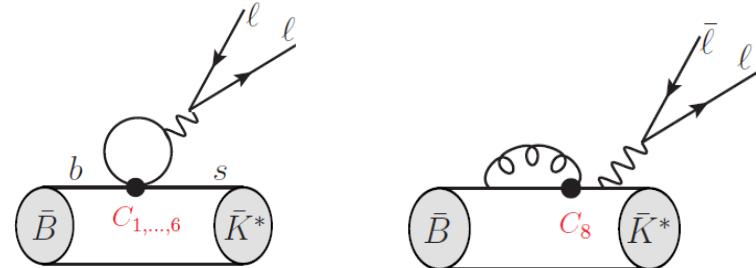
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In general “naïve” factorization not applicable

$$\frac{e^2}{q^2} \epsilon_\mu L_V^\mu \left[\underbrace{Y(q^2) \tilde{V}_\lambda}_{\text{fact., perturbative}} + \underbrace{\text{LO in } \mathcal{O}\left(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}}\right)}_{\text{non-fact., QCdf}} + \underbrace{h_\lambda(q^2)}_{\text{power corrections,}} \right]$$

[\[Beneke et al.\]](#)

not calculable in QCdf
often “guesstimated”

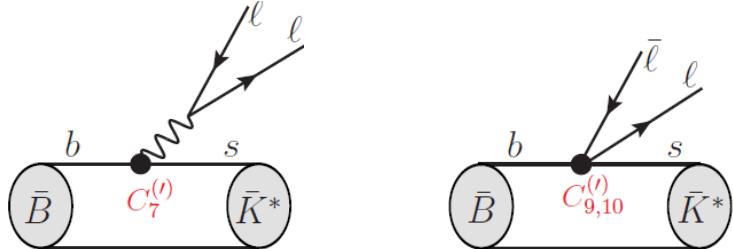
power corrections:

- partial calculation using LCSR and dispersion relations [Khodjamirian et al. 1006.4945]
- recent progress by exploiting analyticity of amplitudes [Bobeth et al. 1707.07305]
 - ↘ correlation among parameters not publicly available

Exclusive mode $B \rightarrow K^* \ell^+ \ell^-$

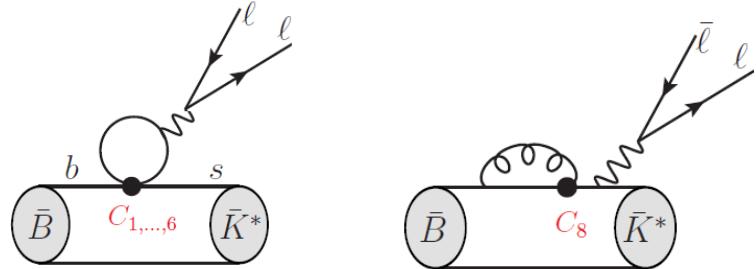
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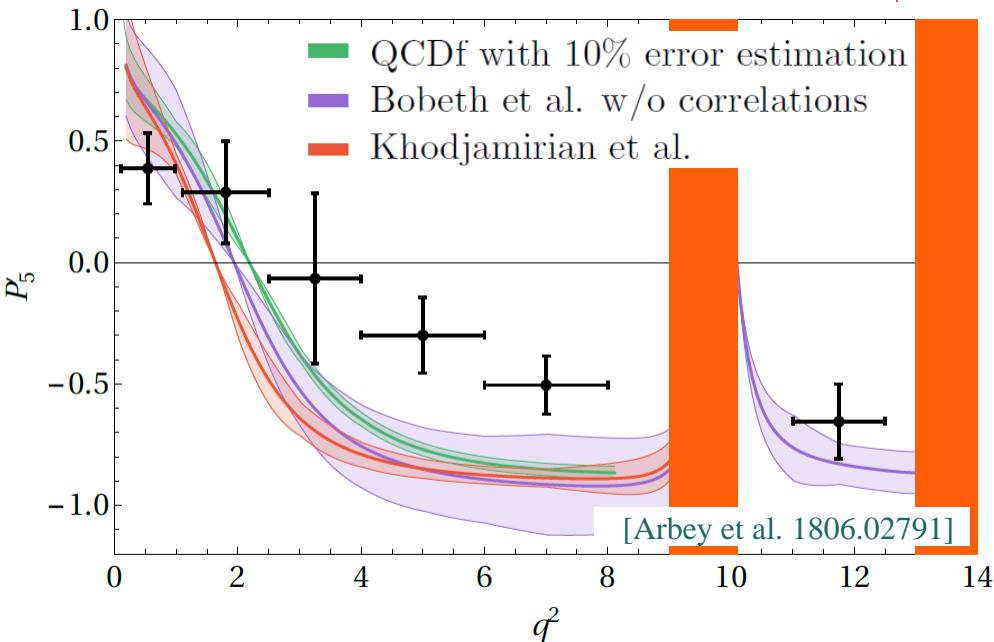
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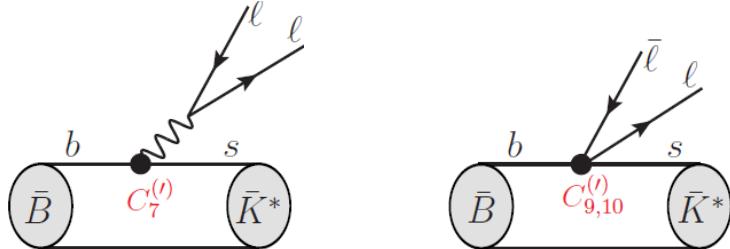
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often “guesstimated”



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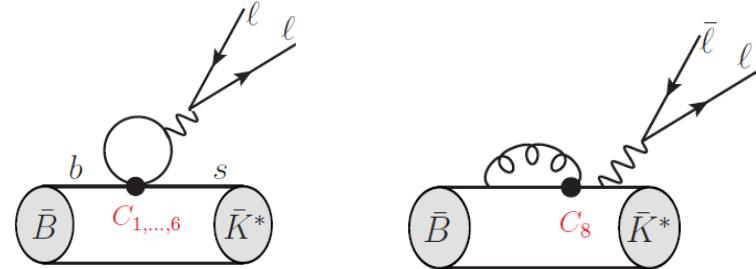
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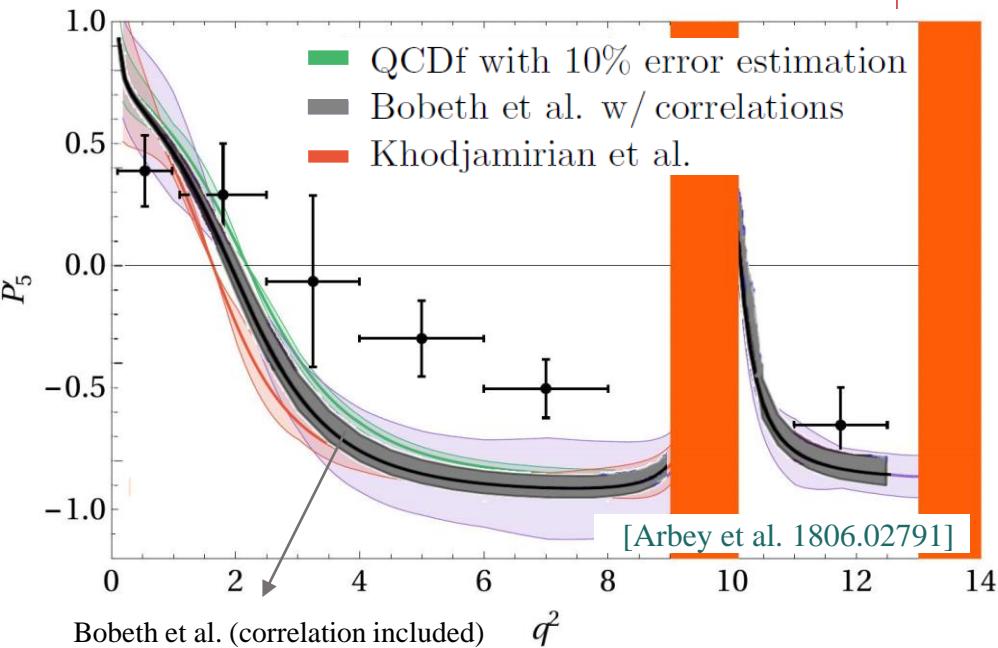


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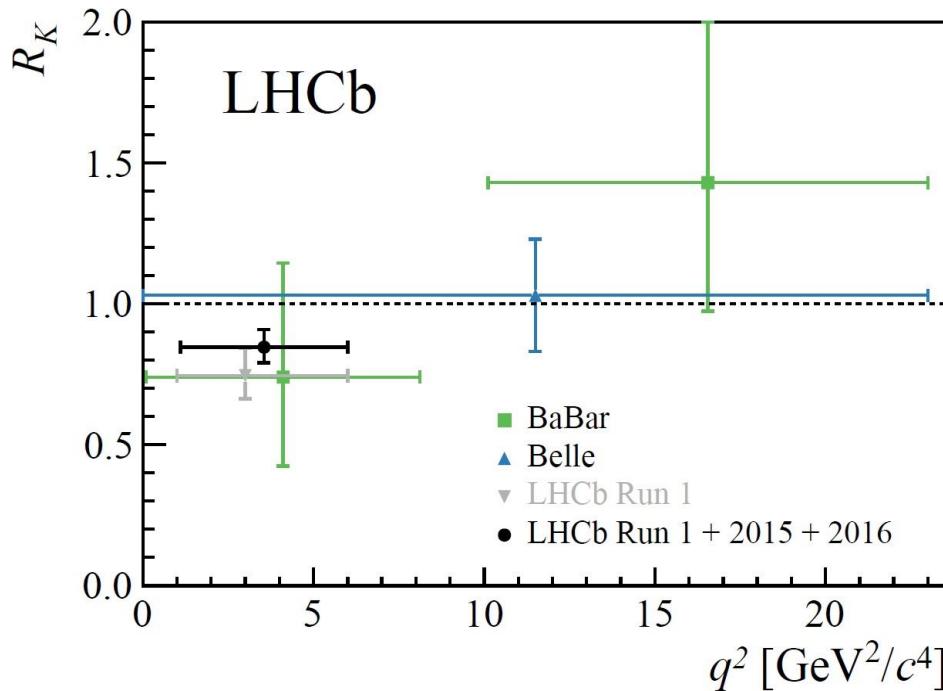
[Beneke et al.](#)

not calculable in QCDF
often “guesstimated”



- significance of the anomalies depends on the assumptions made for the power corrections
- power corrections do not affect R_K and R_{K^*}

1) Lepton flavour universality in $B^+ \rightarrow K^+ \bar{\ell} \ell$ - LHCb



$$R_K^{\text{SM}}([1.1, 6.0] \text{ GeV}^2) = 1.006 \pm 0.004$$

Run 1 [PRL 113, 151601 (2014)]:
 $R_K([1.1, 6.0] \text{ GeV}^2) = 0.745^{+0.090}_{-0.074} \pm 0.036$
 $\rightarrow 2.6\sigma$ tension

Run 1 (re-optimized):
 $R_K([1.1, 6.0] \text{ GeV}^2) = 0.717^{+0.083+0.017}_{-0.071-0.016}$

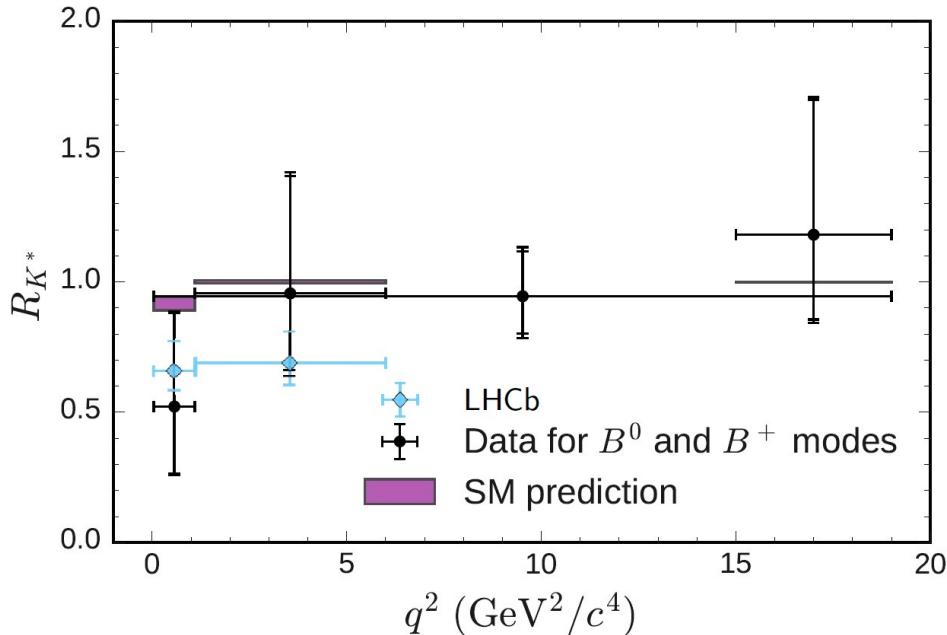
Run 2:
 $R_K([1.1, 6.0] \text{ GeV}^2) = 0.928^{+0.089+0.020}_{-0.076-0.017}$

Combined result [PRL 122, 191801 (2019)]:

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

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.

2) Lepton flavour universality in $B^0 \rightarrow K^{*0} \bar{\ell}\ell$ - Belle



Belle - combined neutral and charged mode [1904.02440]:

$$R_{K^*}([0.045, 1.1] \text{ GeV}^2) = 0.52^{+0.36}_{-0.26} \pm 0.05,$$

$$R_{K^*}([1.1, 6.0] \text{ GeV}^2) = 0.96^{+0.45}_{-0.29} \pm 0.11,$$

$$R_{K^*}([15, 19] \text{ GeV}^2) = 1.18^{+0.52}_{-0.32} \pm 0.10,$$

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

[Bordone, Isidori, Pattori, EPJ C76 (2016) 8, 440]

$$R_{K^*}^{\text{SM}}([1.1, 6.0] \text{ GeV}^2) = 1.000 \pm 0.010$$

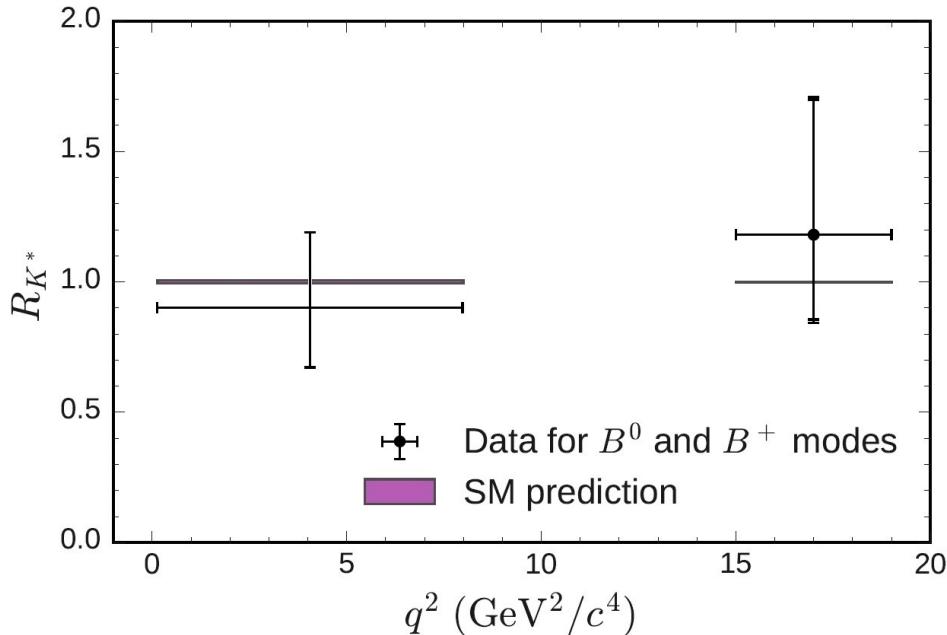
LHCb [JHEP 08 (2017) 055]:

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

$$R_{K^*}([1.1, 6.0] \text{ GeV}^2) = 685^{+0.113}_{-0.069} \pm 0.047$$

$\rightarrow 2.3 \text{ \& } 2.5\sigma$ tensions

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$$R_{K^*}([0.045, 1.1] \text{ GeV}^2) = 0.52^{+0.36}_{-0.26} \pm 0.05,$$

$$R_{K^*}([0.1, 8] \text{ GeV}^2) = 0.90^{+0.27}_{-0.21} \pm 0.10,$$

$$R_{K^*}([1.1, 6.0] \text{ GeV}^2) = 0.96^{+0.45}_{-0.29} \pm 0.11,$$

$$R_{K^*}([15, 19] \text{ GeV}^2) = 1.18^{+0.52}_{-0.32} \pm 0.10,$$

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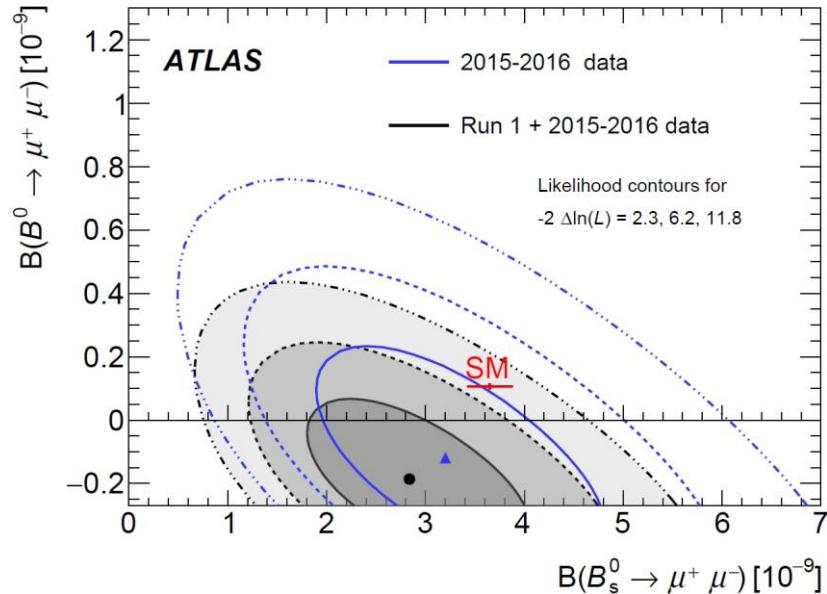
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→ 2.3 & 2.5σ tensions

- While the other bins are all well in agreement with the SM at 1σ -level, the very low- q^2 bin has a tension with the SM prediction slightly more than 1σ
- Choice of bin; $[0.1, 8]$ GeV 2 vs $[0.045, 1.1]$ GeV 2 & $[1.1, 6.0]$ GeV 2 can have slight impact on the fits

3) $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ - ATLAS



ATLAS [JHEP 04 (2019) 098]:

$$\text{BR}(B_s \rightarrow \mu\mu) = (2.8^{+0.8}_{-0.7}) \times 10^{-9}$$

LHCb [PRL 118 (2017) 191801]:

$$\text{BR}(B_s \rightarrow \mu\mu) = (3.0 \pm 0.6^{+0.6}_{-0.2}) \times 10^{-9}$$

CMS [PRL 111 (2013) 101804]:

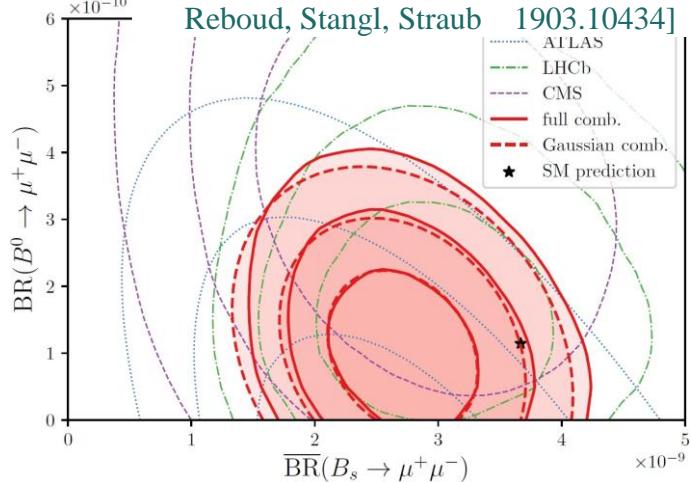
$$\text{BR}(B_s \rightarrow \mu\mu) = (3.0^{+1.0}_{-0.7}) \times 10^{-9}$$

Recent results

3) $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ combining the 2D likelihood of $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$, $\text{BR}(B_d \rightarrow \mu^+ \mu^-)$

[Aebischer, Altmannshofer, Guadagnoli,

Reboud, Stangl, Straub 1903.10434]



$$\text{BR}(B_s \rightarrow \mu\mu)_{\text{comb.}}^{\text{exp.}} = (2.65^{+0.46}_{-0.33}) \times 10^{-9}$$

$$\text{BR}(B_s \rightarrow \mu\mu)^{\text{SM}} = (3.67 \pm 0.15) \times 10^{-9}$$

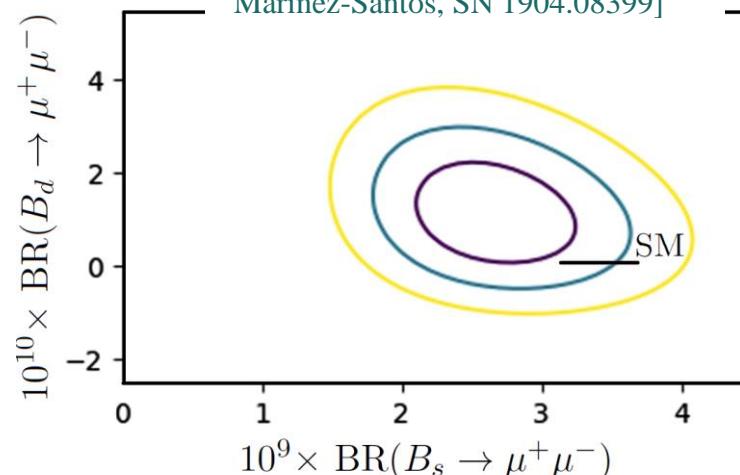
$\rightarrow \sim 2\sigma$ discrepancy

combination using naïve weighted average: $\text{BR}(B_s \rightarrow \mu\mu)_{\text{comb.}}^{\text{exp.}} = (2.94 \pm 0.43) \times 10^{-9}$

$\rightarrow \sim 1.8\sigma$ discrepancy

[Arbey, Hurth, Mahmoudi,

Marinez-Santos, SN 1904.08399]



$$\text{BR}(B_s \rightarrow \mu\mu)_{\text{comb.}}^{\text{exp.}} = (2.65^{+0.43}_{-0.39}) \times 10^{-9}$$

$$\text{BR}(B_s \rightarrow \mu\mu)^{\text{SM}} = (3.41 \pm 0.28) \times 10^{-9}$$

$\rightarrow 1.5\sigma$ discrepancy

Depending on

- Combination of experimental results
- Theory prediction (decay const., choice of scale, other inputs)
- ⇒ significance of discrepancy for SM prediction and measurement different; impacts the fits specially C_{10}

Updated global fits

[Aebischer, Altmannshofer, Guadagnoli, Reboud, Stangl, Straub 1903.10434]

- **Observables:** $[BR, S_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, D_{P_i} \equiv Q_i, [BR, A_{FB}] \Lambda_b \rightarrow \Lambda\mu^+\mu^-$
- **Form factors:** full FF, $B_{(s)} \rightarrow K^*(\phi)$: Light-meson LCSR [BSZ 1503.05534] + Lattice [BSZ 1503.05534],
 $B \rightarrow K$: B -meson LCSR [GKvD 1811.00983] + Lattice [BLMNS 1306.2384]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [FLAG 1902.0819]
- **Power corrections:** percentage compared to amplitude $C_7^{\text{eff}} \rightarrow C_7^{\text{eff}} \left[1 + a_\ell e^{i\phi_{a_\ell}} + b_\ell e^{i\phi_{b_\ell}} \left(\frac{q^2}{6 \text{ GeV}^2} \right) \right]$ $a_\pm \in [0, 0.05], b_\pm \in [0, 0.2]$
 $a_0 \in [0, 0.2], b_0 \in [0, 0.05]$
- **Software:** [flavio](#) ▪ **Method:** $\Delta\chi^2$

Updated global fits – 1D

[Aebischer, Altmannshofer, Guadagnoli, Reboud, Stangl, Straub 1903.10434]

- **Observables:** $[BR, S_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, D_{P_i} \equiv Q_i, [BR, A_{FB}] \Lambda_b \rightarrow \Lambda\mu^+\mu^-$
- **Form factors:** full FF, $B_{(s)} \rightarrow K^*(\phi)$: Light-meson LCSR [BSZ 1503.05534] + Lattice [BSZ 1503.05534],
 $B \rightarrow K$: B -meson LCSR [GKvD 1811.00983] + Lattice [BLMNS 1306.2384]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [FLAG 1902.0819]
- **Power corrections:** percentage compared to amplitude $C_7^{\text{eff}} \rightarrow C_7^{\text{eff}} \left[1 + a_\ell e^{i\phi_{a_\ell}} + b_\ell e^{i\phi_{b_\ell}} \left(\frac{q^2}{6 \text{ GeV}^2} \right) \right]$ $a_\pm \in [0, 0.05], b_\pm \in [0, 0.2]$
 $a_0 \in [0, 0.2], b_0 \in [0, 0.05]$
- **Software:** [flavio](#) ▪ **Method:** $\Delta\chi^2$

NP in muon sector				NP in electron sector			
Coeff.	best fit	1σ	pull	Coeff.	best fit	1σ	pull
$C_9^{bs\mu\mu}$	-0.97	[-1.12, -0.81]	5.9σ	C_9^{bsee}	+0.93	[+0.66, +1.17]	3.5σ
$C_9'^{bs\mu\mu}$	+0.14	[-0.03, +0.32]	0.8σ	$C_9'^{bsee}$	+0.39	[+0.05, +0.65]	1.2σ
$C_{10}^{bs\mu\mu}$	+0.75	[+0.62, +0.89]	5.7σ	C_{10}^{bsee}	-0.83	[-1.05, -0.60]	3.6σ
$C_{10}'^{bs\mu\mu}$	-0.24	[-0.36, -0.12]	2.0σ	$C_{10}'^{bsee}$	-0.27	[-0.57, -0.02]	1.1σ
$C_9^{bs\mu\mu} = C_{10}^{bs\mu\mu}$	+0.20	[+0.06, +0.36]	1.4σ	$C_9^{bsee} = C_{10}^{bsee}$	-1.49	[-1.79, -1.18]	3.2σ
$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$	-0.53	[-0.61, -0.45]	6.6σ	$C_9^{bsee} = -C_{10}^{bsee}$	+0.47	[+0.33, +0.59]	3.5σ

$$\text{Pull} \equiv \sqrt{\chi_{\text{SM}}^2 - \chi_{\text{b.f.}}^2}$$

in 1-dim.

- scenarios with NP in electron sector less significant; only explain ratios $R_{K^{(*)}}$ and not rest of the data

Updated global fits – 1D

[Aebischer, Altmannshofer, Guadagnoli, Reboud, Stangl, Straub 1903.10434]

- **Observables:** $[BR, S_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, D_{P_i} \equiv Q_i, [BR, A_{FB}] \Lambda_b \rightarrow \Lambda\mu^+\mu^-$
- **Form factors:** full FF, $B_{(s)} \rightarrow K^*(\phi)$: Light-meson LCSR [BSZ 1503.05534] + Lattice [BSZ 1503.05534],
 $B \rightarrow K$: B -meson LCSR [GKvD 1811.00983] + Lattice [BLMNS 1306.2384]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [FLAG 1902.0819]
- **Power corrections:** percentage compared to amplitude $C_7^{\text{eff}} \rightarrow C_7^{\text{eff}} \left[1 + a_\ell e^{i\phi_{a_\ell}} + b_\ell e^{i\phi_{b_\ell}} \left(\frac{q^2}{6 \text{ GeV}^2} \right) \right]$ $a_\pm \in [0, 0.05], b_\pm \in [0, 0.2]$
 $a_0 \in [0, 0.2], b_0 \in [0, 0.05]$
- **Software:** [flavio](#) ▪ **Method:** $\Delta\chi^2$

NP in muon sector				NP in electron sector			
Coeff.	best fit	1σ	pull	Coeff.	best fit	1σ	pull
$C_9^{bs\mu\mu}$	-0.97	[-1.12, -0.81]	5.9σ	C_9^{bsee}	+0.93	[+0.66, +1.17]	3.5σ
$C_9^{bs\mu\mu}$	+0.14	[-0.03, +0.32]	0.8σ	C_9^{bsee}	+0.39	[+0.05, +0.65]	1.2σ
$C_{10}^{bs\mu\mu}$	+0.75	[+0.62, +0.89]	5.7σ	C_{10}^{bsee}	-0.83	[-1.05, -0.60]	3.6σ
$C_{10}^{bs\mu\mu}$	-0.24	[-0.36, -0.12]	2.0σ	C_{10}^{bsee}	-0.27	[-0.57, -0.02]	1.1σ
$C_9^{bs\mu\mu} = C_{10}^{bs\mu\mu}$	+0.20	[+0.06, +0.36]	1.4σ	$C_9^{bsee} = C_{10}^{bsee}$	-1.49	[-1.79, -1.18]	3.2σ
$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$	-0.53	[-0.61, -0.45]	6.6σ	$C_9^{bsee} = -C_{10}^{bsee}$	+0.47	[+0.33, +0.59]	3.5σ

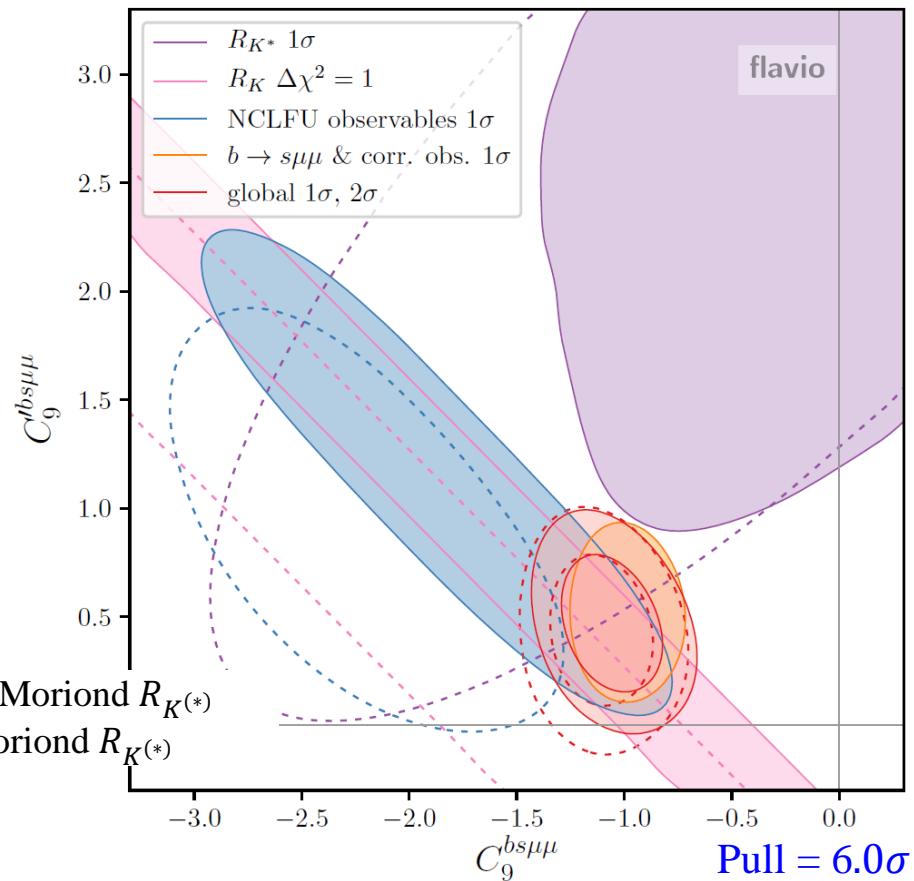
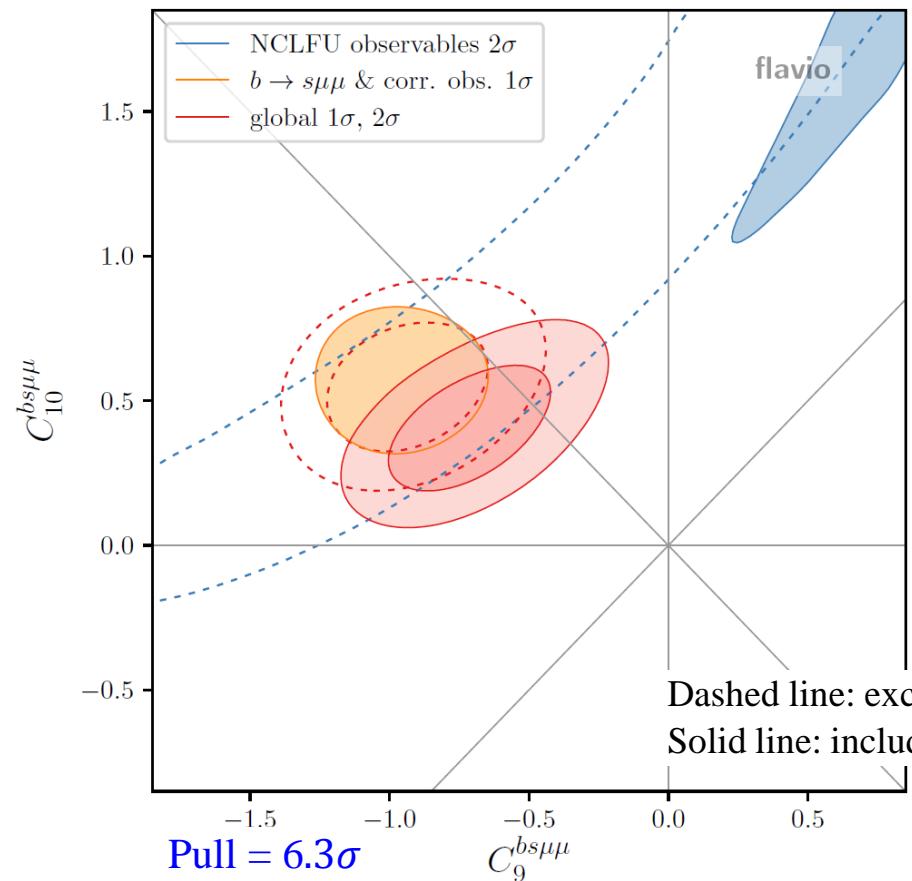
$$\text{Pull} \equiv \sqrt{\chi_{\text{SM}}^2 - \chi_{\text{b.f.}}^2}$$

in 1-dim.

- scenarios with NP in electron sector less significant; only explain ratios $R_{K^{(*)}}$ and not rest of the data
- most favoured scenario NP in chiral basis $C_9^\mu = -C_{10}^\mu$ followed by C_9^μ
- scenarios with right-handed currents (primed coefficients) are not favoured

Updated global fits – 2D

[Aebischer, Altmannshofer, Guadagnoli, Reboud, Stangl, Straub 1903.10434]



Both scenarios give good fits to the data

➤ best fit points now closer to the SM

➤ Slight preference for $C'_9 > 0$

Updated global fits

[Alguero, Capdevila, Crivelin, Descotes-Genon, Masjuan, Matias, Virto 1903.09578]

- **Observables:** $[BR, P_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, Q_i \equiv D_{P_i}$
- **Form factors:** soft FF, $B \rightarrow K^{(*)}$: B -meson LCSR [[KMPW 1006.4945](#)]+Lattice [[BLMNS 1306.2384](#)] & [[HLMW 1310.3722](#)],
 $B_s \rightarrow \phi$: Light-meson LCSR [[BSZ 1503.05534](#)] + Lattice [[HLMW 1310.3722](#)]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [[FLAG 1902.0819](#)]
- **Power corrections:** order of magnitude from LCSR [[Khodjamirian et al. 1006.4945](#)] w/o assumption on sign
- **Software:** private code ▪ **Method:** $\Delta\chi^2$

Updated global fits – 1D

[Alguero, Capdevila, Crivelin, Descotes-Genon, Masjuan, Matias, Virto 1903.09578]

- **Observables:** $[BR, P_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, Q_i \equiv D_{P_i}$
- **Form factors:** soft FF, $B \rightarrow K^{(*)}$: B -meson LCSR [KMPW 1006.4945]+Lattice [BLMNS 1306.2384] & [HLMW 1310.3722], $B_s \rightarrow \phi$: Light-meson LCSR [BSZ 1503.05534] + Lattice [HLMW 1310.3722]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [FLAG 1902.0819]
- **Power corrections:** order of magnitude from LCSR [Khodjamirian et al. 1006.4945] w/o assumption on sign
- **Software:** private code ▪ **Method:** $\Delta\chi^2$

One-dim fit

1D Hyp.	Best fit	1σ	Pull _{SM}	p-value
$\mathcal{C}_{9\mu}^{\text{NP}}$	-0.98	$[-1.15, -0.81]$	5.6	65.4 %
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}$	-0.46	$[-0.56, -0.37]$	5.2	55.6 %
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}$	-0.99	$[-1.15, -0.82]$	5.5	62.9 %
$\mathcal{C}_{9\mu}^{\text{NP}} = -3\mathcal{C}_{9e}^{\text{NP}}$	-0.87	$[-1.03, -0.71]$	5.5	61.9 %

Updated global fits – 1D

[Alguero, Capdevila, Crivelin, Descotes-Genon, Masjuan, Matias, Virto 1903.09578]

- **Observables:** $[BR, P_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, Q_i \equiv D_{P_i}$
- **Form factors:** soft FF, $B \rightarrow K^{(*)}$: B -meson LCSR [KMPW 1006.4945]+Lattice [BLMNS 1306.2384] & [HLMW 1310.3722], $B_s \rightarrow \phi$: Light-meson LCSR [BSZ 1503.05534] + Lattice [HLMW 1310.3722]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [FLAG 1902.0819]
- **Power corrections:** order of magnitude from LCSR [Khodjamirian et al. 1006.4945] w/o assumption on sign
- **Software:** private code ▪ **Method:** $\Delta\chi^2$

One-dim fit

1D Hyp.	Best fit	1σ	Pull _{SM}	p-value
$C_{9\mu}^{\text{NP}}$	-0.98	$[-1.15, -0.81]$	5.6	65.4 %
$C_{9\mu}^{\text{NP}} = -C_{10\mu}^{\text{NP}}$	-0.46	$[-0.56, -0.37]$	5.2	55.6 %
$C_{9\mu}^{\text{NP}} = -C_{9'\mu}$	-0.99	$[-1.15, -0.82]$	5.5	62.9 %
$C_{9\mu}^{\text{NP}} = -3C_{9e}^{\text{NP}}$	-0.87	$[-1.03, -0.71]$	5.5	61.9 %

- NP in C_9^μ is favoured over other scenarios; significance decreased 0.3σ compared to pre-Moriond
- Besides the C_9^μ and $C_9^\mu = -C_{10}^\mu$ two other similarly significant 1D scenarios are favoured

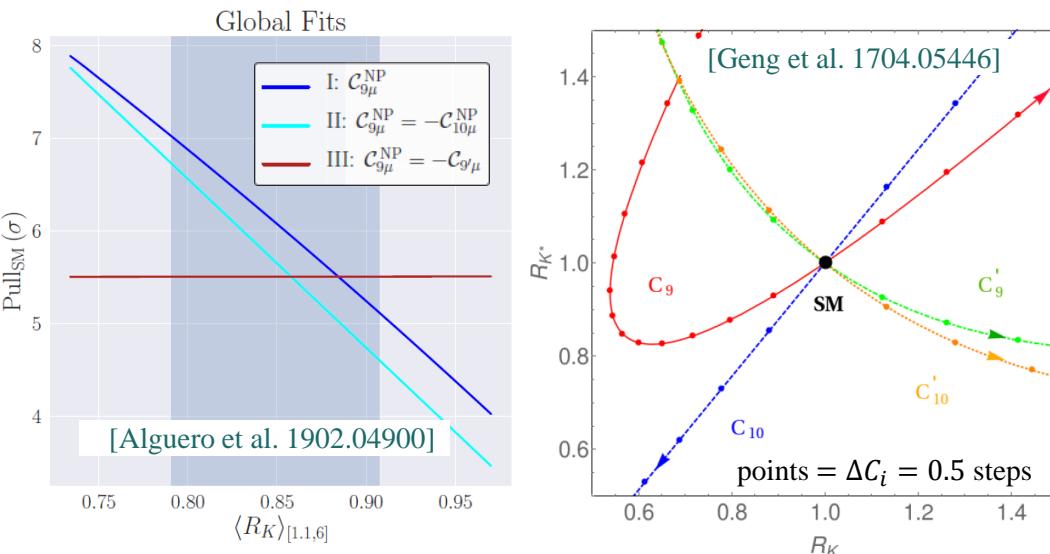
Updated global fits – 1D

[Alguero, Capdevila, Crivelin, Descotes-Genon, Masjuan, Matias, Virto 1903.09578]

- **Observables:** $[BR, P_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}, Q_i \equiv D_{P_i}$
- **Form factors:** soft FF, $B \rightarrow K^{(*)}$: B -meson LCSR [KMPW 1006.4945]+Lattice [BLMNS 1306.2384] & [HLMW 1310.3722], $B_s \rightarrow \phi$: Light-meson LCSR [BSZ 1503.05534] + Lattice [HLMW 1310.3722]
- **Decay constant:** f_{B_s} from Lattice update for $N_f = 2 + 1 + 1$ [FLAG 1902.0819]
- **Power corrections:** order of magnitude from LCSR [Khodjamirian et al. 1006.4945] w/o assumption on sign
- **Software:** private code ▪ **Method:** $\Delta\chi^2$

One-dim fit

1D Hyp.	Best fit	1σ	Pull _{SM}	p-value
$C_{9\mu}^{\text{NP}}$	-0.98	$[-1.15, -0.81]$	5.6	65.4 %
$C_{9\mu}^{\text{NP}} = -C_{10\mu}^{\text{NP}}$	-0.46	$[-0.56, -0.37]$	5.2	55.6 %
$C_{9\mu}^{\text{NP}} = -C_{9'\mu}^{\text{NP}}$	-0.99	$[-1.15, -0.82]$	5.5	62.9 %
$C_{9\mu}^{\text{NP}} = -3C_{9e}^{\text{NP}}$	-0.87	$[-1.03, -0.71]$	5.5	61.9 %



- NP in C_9^μ is favoured over other scenarios; significance decreased 0.3σ compared to pre-Moriond
- Besides the C_9^μ and $C_9^\mu = -C_{10}^\mu$ two other similarly significant 1D scenarios are favoured
- The $C_9^\mu = -C_{9'}^\mu$ scenario favours SM-like value for $R_K^{[1.1,6]}$

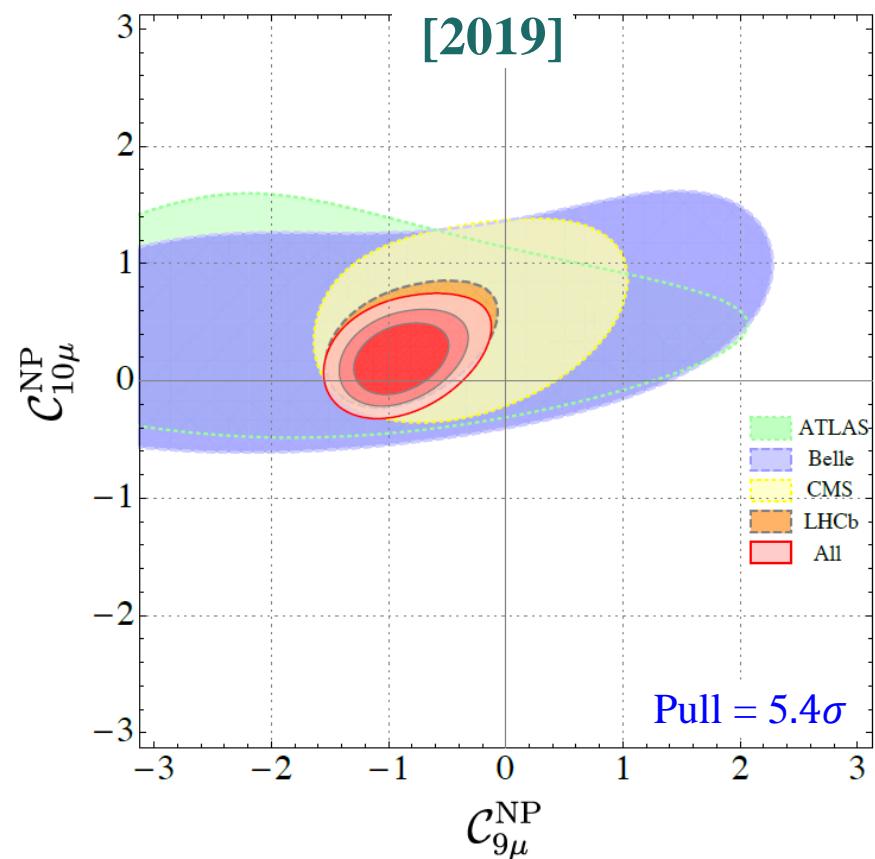
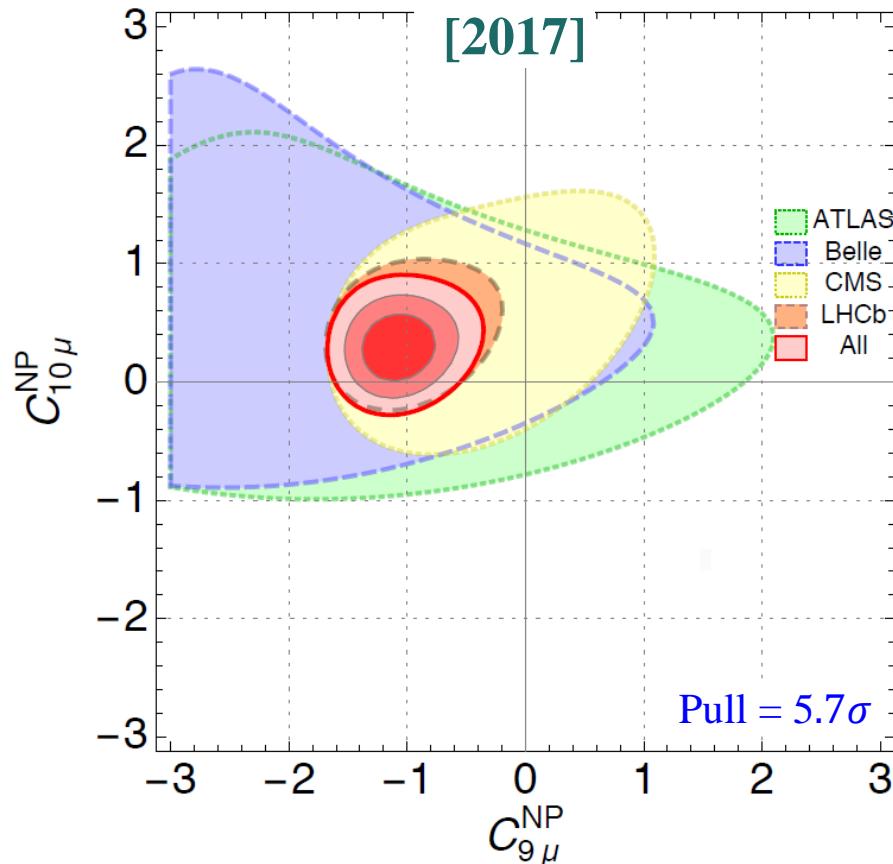
$$R_K[1.1, 6] \simeq \left\{ 1 + 0.23(C_{9,\mu} + C'_{9,\mu}) - 0.25(C_{10,\mu} + C'_{10,\mu}) + 0.057(C_{9,\mu}C'_{9,\mu} + C_{10,\mu}C'_{10,\mu}) + 0.029 [(C_{9,\mu})^2 + (C'_{9,\mu})^2 + (C_{10,\mu})^2 + (C'_{10,\mu})^2] \right\} / \{1 + \mu \rightarrow e\}$$

[Ciuchini et al. 1903.09632]

see also [Alguero et al. 1903.09578]

Updated global fits – 2D

[Alguero, Capdevila, Crivelin, Descotes-Genon, Masjuan, Matias, Virto 1903.09578]



- The pre-Moriond preferred scenario $(C_{9\mu}^{NP}, C_{10\mu}^{NP})$ has now a slightly smaller pull

Updated global fits – 2D, further patterns

[Alguero, Capdevila, Crivelin, Descotes-Genon, Masjuan, Matias, Virto 1903.09578]

2D Hyp.	All		
	Best fit	Pull _{SM}	p-value
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{10\mu}^{\text{NP}})$	(-0.91, 0.18)	5.4	68.7 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{7'}^{\text{NP}})$	(-1.00, 0.02)	5.4	67.9 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9'\mu}^{\text{NP}})$	(-1.10, 0.55)	5.7	75.1 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{10'\mu}^{\text{NP}})$	(-1.14, -0.35)	5.9	78.6 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9e}^{\text{NP}})$	(-1.05, -0.23)	5.3	66.2 %
Hyp. 1	(-1.06, 0.26)	5.7	75.7 %
Hyp. 2	(-0.97, 0.09)	5.3	65.2 %
Hyp. 3	(-0.47, 0.06)	4.8	55.7 %
Hyp. 4	(-0.49, 0.12)	5.0	59.3 %
Hyp. 5	(-1.14, 0.24)	5.9	78.7 %

Hyp. 1: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{\text{NP}} = \mathcal{C}_{10'\mu})$

Hyp. 2: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{\text{NP}} = -\mathcal{C}_{10'\mu})$

Hyp. 3: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}, \mathcal{C}_{9'\mu}^{\text{NP}} = \mathcal{C}_{10'\mu})$

Hyp. 4: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}, \mathcal{C}_{9'\mu}^{\text{NP}} = -\mathcal{C}_{10'\mu})$

Hyp. 5: $(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9'\mu}^{\text{NP}} = -\mathcal{C}_{10'\mu})$

- The pre-Moriond preferred scenario $(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{10\mu}^{\text{NP}})$ has now a slightly smaller pull
- Most favoured 2-dim scenarios $(\mathcal{C}_9^{\mu}, \mathcal{C}'_{10}{}^\mu)$ and Hyp. 5: $(\mathcal{C}_9^{\mu}, \mathcal{C}'_9{}^\mu = -\mathcal{C}'_{10}{}^\mu)$ have now slightly larger pull
- Favoured scenarios all include \mathcal{C}_9^{μ} accompanied by right-handed currents
 - Post-Moriond data indicates preference for (small) NP in right-handed currents

Updated global fits

[Arbey, Hurth, Mahmoudi, Martinez-Santos, SN 1904.08399]

- **Observables:** $[BR, S_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}$
- **Form factors:** full FF, $B_{(s)} \rightarrow K^*(\phi)$: combination of Light-meson LCSR [BSZ 1503.05534] + Lattice [BSZ 1503.05534],
 $B \rightarrow K$: Light-meson LCSR [BZ 0406232] + Lattice [BLMNS 1306.2384] combination [AS 1411.3161]
- **Decay constant:** f_{B_s} from Lattice [FLAG 1607.00299]
- **Power corrections:** 10% compared to QCD factorisation $\left(1 + a_k \exp(i\phi_k) + b_k \frac{q^2}{6 \text{ GeV}^2} \exp(i\theta_k)\right)$ a_k 10%, $b_k \sim 2.5 a_k$
- **Software:** [SuperIso](#) ▪ **Method:** $\Delta\chi^2$

Updated global fits – 1D

[Arbey, Hurth, Mahmoudi, Martinez-Santos, SN 1904.08399]

- **Observables:** $[BR, S_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, B \rightarrow K^*\gamma, BR(B \rightarrow X_s(\ell\ell, \gamma)), R_{K^{(*)}}$
- **Form factors:** full FF, $B_{(s)} \rightarrow K^*(\phi)$: combination of Light-meson LCSR [BSZ 1503.05534] + Lattice [BSZ 1503.05534], $B \rightarrow K$: Light-meson LCSR [BZ 0406232] + Lattice [BLMNS 1306.2384] combination [AS 1411.3161]
- **Decay constant:** f_{B_s} from Lattice [FLAG 1607.00299]
- **Power corrections:** 10% compared to QCD factorisation:
- **Software:** [SuperIso](#) ▪ **Method:** $\Delta\chi^2$

$$\left(1 + a_k \exp(i\phi_k) + b_k \frac{q^2}{6 \text{ GeV}^2} \exp(i\theta_k) \right) \quad a_k \text{ 10\%, } b_k \sim 2.5 a_k$$

Using all the relevant data on $b \rightarrow s$ transitions

All observables ($\chi^2_{\text{SM}} = 117.03$)			
	b.f. value	χ^2_{min}	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
δC_{LL}^μ	-0.41 ± 0.10	96.6	4.5σ
δC_{LL}^e	0.40 ± 0.13	105.8	3.3σ

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

- most preferred scenario is NP in C_9^μ ; significance is 0.5σ reduced compared to pre-Moriond

Updated fits – 1D

[Arbey, Hurth, Mahmoudi, Martinez-Santos, SN 1904.08399]

Comparison of one-operator fits, separating clean observables from the rest:

All observables except R_K, R_{K^*} ($\chi^2_{\text{SM}} = 100.2$)			
	b.f. value	χ^2_{min}	Pull _{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
δC_{LL}^μ	-0.48 ± 0.15	89.1	3.3σ
δC_{LL}^e	0.33 ± 0.29	99.0	1.1σ

Only R_K, R_{K^*} ($\chi^2_{\text{SM}} = 16.9$)			
	b.f. value	χ^2_{min}	Pull _{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
δC_{LL}^μ	-0.37 ± 0.12	7.0	3.1σ
δC_{LL}^e	0.41 ± 0.15	6.8	3.2σ

- two sets of observables are not completely coherent, especially regarding C_{10}^μ , however, tension between the two sets are now less than pre-Moriond data

Updated fits – 1D

[Arbey, Hurth, Mahmoudi, Martinez-Santos, SN 1904.08399]

Comparison of one-operator fits, separating clean observables from the rest:

All observables except $R_K, R_{K^*}, B_{s,d} \rightarrow \mu^+ \mu^-$ ($\chi^2_{\text{SM}} = 99.7$)			
	b.f. value	χ^2_{min}	Pull _{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
δC_{LL}^μ	-0.50 ± 0.16	88.8	3.3σ
δC_{LL}^e	0.33 ± 0.29	98.6	1.1σ

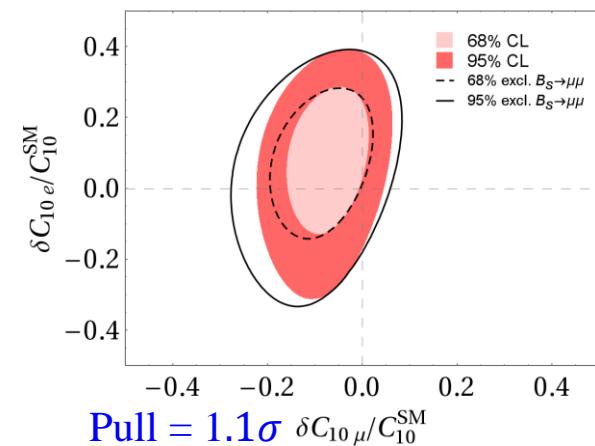
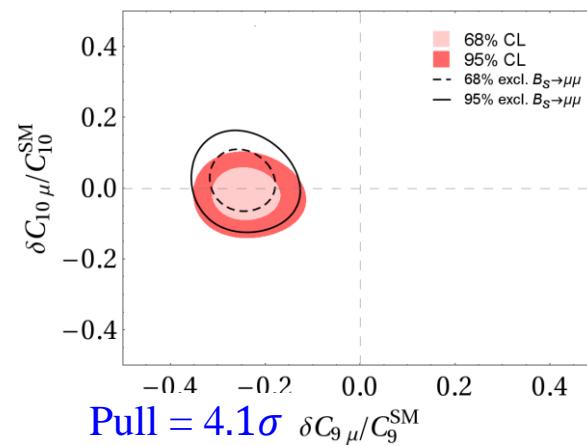
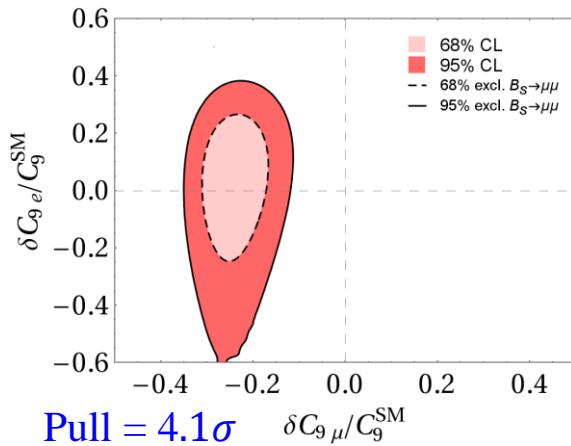
Only $R_K, R_{K^*}, B_{s,d} \rightarrow \mu^+ \mu^-$ ($\chi^2_{\text{SM}} = 19.0$)			
	b.f. value	χ^2_{min}	Pull _{SM}
δC_9	-2.04 ± 5.93	18.9	0.3σ
δC_9^μ	-0.74 ± 0.28	10.6	2.9σ
δC_9^e	0.79 ± 0.29	9.9	3.0σ
δC_{10}	0.43 ± 0.32	17.0	1.4σ
δC_{10}^μ	0.65 ± 0.20	6.9	3.5σ
δC_{10}^e	-0.78 ± 0.27	8.2	3.3σ
δC_{LL}^μ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

- two sets of observables are not completely coherent, especially regarding C_{10}^μ , however, tension between the two sets are now less than pre-Moriond data
- $\text{BR}(B_s \rightarrow \mu\mu)$ does not play a major role in the somewhat incoherence of the sets of observables
- tension of $\text{BR}(B_s \rightarrow \mu\mu)$ measurement with the SM, suggest same direction for C_{10}^μ as is preferred by the $R_{K^{(*)}}$

Updated fits – 2D

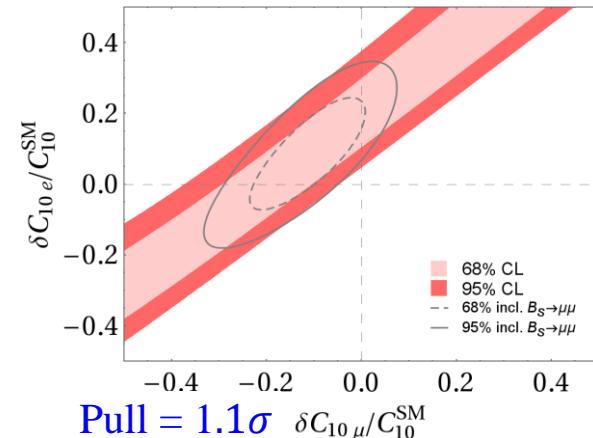
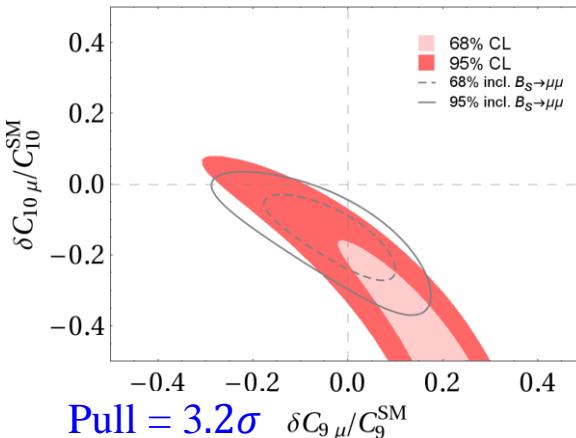
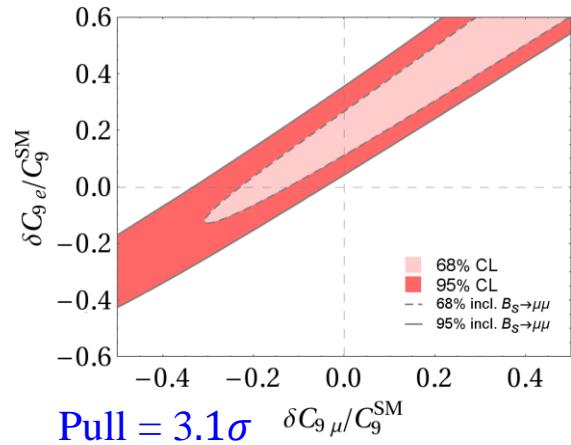
[Arbey, Hurth, Mahmoudi, Martinez-Santos, SN 1904.08399]

All observables except R_K and R_{K^*}



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

Only data on R_K and R_{K^*}



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

Updated global fits

[Alok, Dighe, Gangal, Kumar, Sessolo 1903.09617]

- **Observables:** $[BR, \text{ang. obs.}]$ exclusive $b \rightarrow s\bar{\ell}\ell, BR(B \rightarrow X_s\bar{\ell}\ell), R_{K^{(*)}}$
- **Software:** [flavio](#)-based ▪ **Method:** $\Delta\chi^2$
- $BR(B_s \rightarrow \mu\mu)_{\text{exp}}$ from [Aeibischer et al. 1903.10434]

[Kowalska, Kumar, Sessolo 1903.10932]

- **Observables:** $[BR, S_i]$ exclusive $b \rightarrow s\bar{\ell}\ell, BR(B \rightarrow X_s\bar{\ell}\ell), R_{K^{(*)}}, [BR, A_{FB}] \Lambda_b \rightarrow \Lambda\mu^+\mu^-$
- **Software:** [flavio](#)-based ▪ **Method:** Bayesian
- $BR(B_s \rightarrow \mu\mu)_{\text{exp}}$ from [CMS+LHCb 1411.4413]

➤ In the 1-dim fit scenario with NP in $C_9^\mu = -C_{10}^\mu$ is slightly favoured over C_9^μ

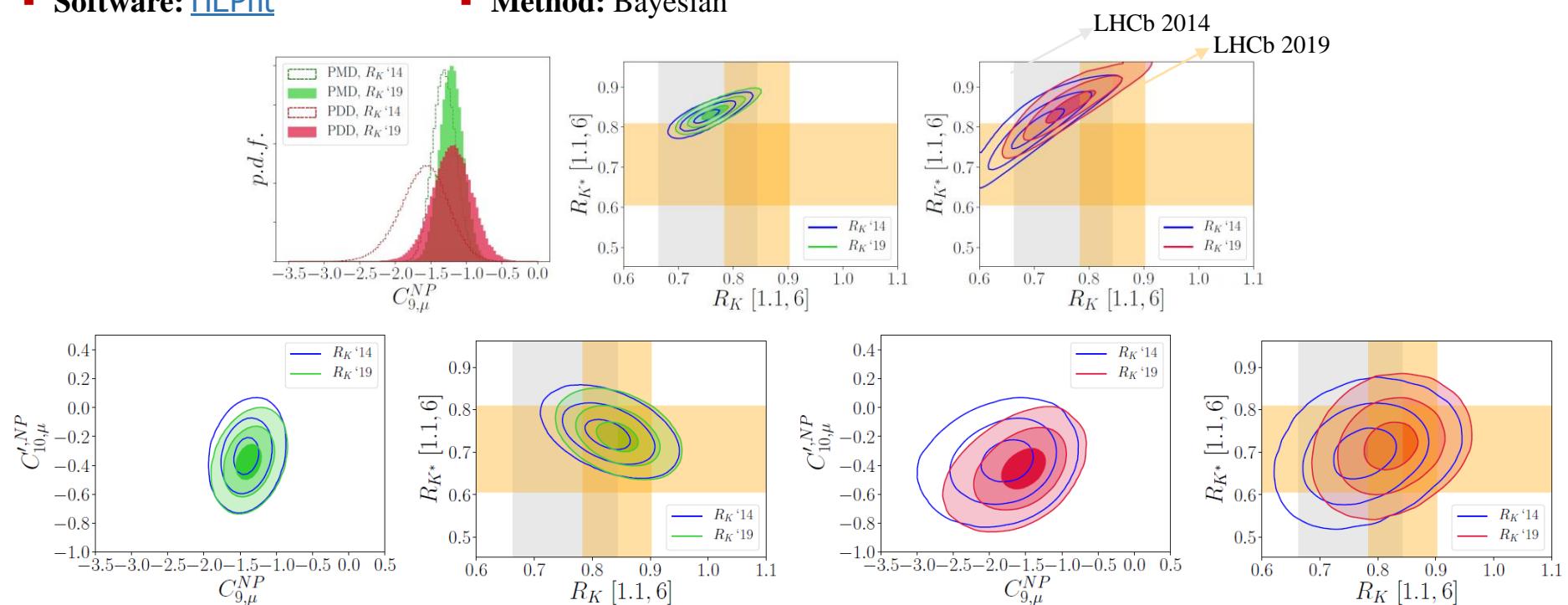
[D'Amico, Nardecchia, Panci, Sannino, Strumia, Torre, Urbano 1704.05438 update]

- **Software:** [flavio](#)-based ▪ **Method:** Bayesian
- In the 1-dim fit, NP in C_9^μ is favoured over $C_9^\mu = -C_{10}^\mu$

Updated global fits

[Ciuchini, Coutinho, Fedele, Franco, Paul, Silvestrini, Valli 1903.09632]

- **Observables:** $[BR, S_i]$ exclusive $b \rightarrow s\bar{\ell}\ell$ (low q^2 – bins), $B_s \rightarrow \phi\gamma$, $B \rightarrow K^*\gamma$, $BR(B \rightarrow X_s(\ell\ell, \gamma))$, $R_{K^{(*)}}$,
- **Form factors:** full FF, $B_{(s)} \rightarrow K^*(\phi)$: Light-meson LCSR [BSZ 1503.05534], $B \rightarrow K$: Lattice [Bailey et al. 1509.06235]
- **Power corrections:** *Pheno. Model Driven (PMD)*: pheno. model of LCSR [Khodjamirian 1006.4945] \times complex phases
Pheno. Data Driven (PDD): q^2 -expansion of h_λ with 16 free params.+LCSR [Khodjamirian 1006.4945] at $q^2 = 0, 1$ GeV 2
- **Software:** [HEPfit](#)
- **Method:** Bayesian



- Purely left-handed currents not favoured by recent results on R_K
- Inclusion of right-handed currents give better description of data

One operator fit summary– post Moriond

Group Wilson coeff.	Aebischer et al.	Alguero et al.	Alok et al	Arbey et al.	D'Amico. al.	Kowalska et al.
C_9^μ	5.9σ	5.6σ	" 6.2σ "	5.3σ	6.5σ	4.7σ
C_{10}^μ	5.7σ	—	" 5.7σ "	3.3σ	4.4σ	—
$C_9^\mu = -C_{10}^\mu$	6.6σ	5.2σ	" 6.4σ "	4.5σ	5.9σ	4.8σ
other significant scenarios		$C_9^\mu = -C_9'^\mu$ 5.5σ	$C_9^\mu = -C_9'^\mu$ "6.4σ"	C_9 4.2σ		

- ❑ All groups find preference for NP scenario compared to SM with significant Pull_{SM} ($4.8 - 6.6\sigma$)

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- ❑ All groups find preference for NP scenario compared to SM with significant Pull_{SM} ($4.8 - 6.6\sigma$)
- ❑ Some slight disagreement for the hierarchy of best scenario 1-dim. fit:
 - Aeibischer et al., Alok et al., Kowaloska et al. → $C_9^\mu = -C_{10}^\mu$
 - Alguero et al., Arbey et al. and D'Amico et al. → C_9^μ

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software	flavio	private code	flavio-based	SuperIso	flavio-based	flavio-based
method	$\Delta\chi^2$	$\Delta\chi^2$	$\Delta\chi^2$	$\Delta\chi^2$	Bayesian	Bayesian
tension in $BR(B_s \rightarrow \mu\mu)$	$\sim 2\sigma$	1.8σ	$\sim 2\sigma$	1.5σ		1.2σ
$\Lambda_b \rightarrow \Lambda\mu\mu$ obs.	✓	✗	✗	✗	✗	✓

❑ All groups find preference for NP scenario compared to SM with significant $Pull_{SM}$ ($4.8 - 6.6\sigma$)

❑ Some slight disagreement for the hierarchy of the best 1-dim. fit:

- Aeibischer et al., Alok et al., Kowaloska et al. → $C_9^\mu = -C_{10}^\mu$
- Alguero et al., Arbey et al. and D'Amico et al. → C_9^μ

potential reasons:

- tension considered for $BR(B_s \rightarrow \mu\mu)$
- including $\Delta F = 2$ ($\varepsilon_K, \Delta M_s, \dots$) observables in the likelihood function assuming they are SM-like
- including the baryonic $\Lambda_b \rightarrow \Lambda\mu\mu$ obs.
- ...

One operator fit summary– post Moriond

Group Wilson coeff.	Aebischer et al.	Alguero et al.	Alok et al	Arbey et al.	D'Amico. al.	Kowalska et al.
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software	flavio	private code	flavio-based	SuperIso	flavio-based	flavio-based
method	$\Delta\chi^2$	$\Delta\chi^2$	$\Delta\chi^2$	$\Delta\chi^2$	Bayesian	Bayesian
tension in $BR(B_s \rightarrow \mu\mu)$	$\sim 2\sigma$	1.8σ	$\sim 2\sigma$	1.5σ		1.2σ
$\Lambda_b \rightarrow \Lambda\mu\mu$ obs.	✓	✗	✗	✗	✗	✓

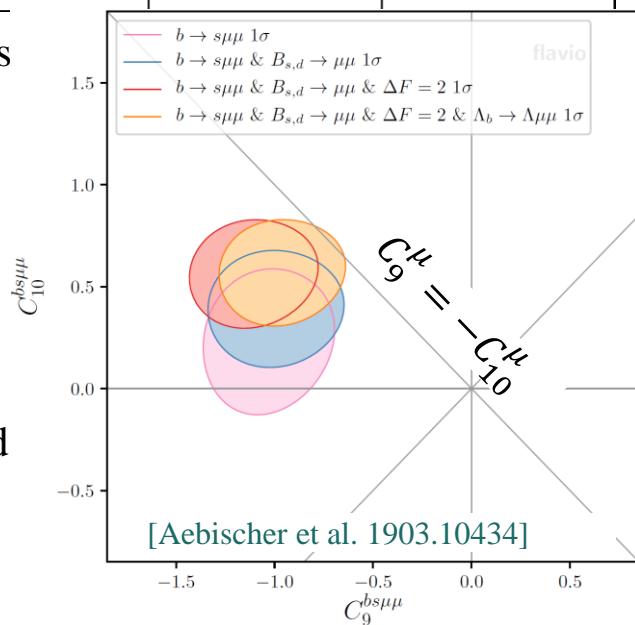
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- Aeibischer et al., Alok et al., Kowaloska et al. $\rightarrow C_9^\mu = -C_{10}^\mu$
- Alguero et al., Arbey et al. and D'Amico et al. $\rightarrow C_9^\mu$

potential reasons:

- tension considered for $BR(B_s \rightarrow \mu\mu)$
- including $\Delta F = 2$ ($\varepsilon_K, \Delta M_s, \dots$) observables in the likelihood function assuming they are SM-like
- including the baryonic $\Lambda_b \rightarrow \Lambda\mu\mu$ obs.
- ...



Two operator fit summary– post Moriond

Group Wilson coeff.	Aebischer et al.	Alguero et al.	Alok et al.	Arbey et al.	Kowalska et al.
(C_9^μ, C_{10}^μ)	6.3σ	5.4σ	“ 6.4σ ”	4.9σ	4.7σ
$(C_9^\mu, C_9'^\mu)$	6.0σ	5.7σ	“ 6.8σ ”	5.3σ	5.0σ
other significant scenarios		$(C_9^\mu, C_{10}'^\mu)$ 5.9σ	$(C_9^\mu, C_{10}'^\mu)$ “ 7.2σ ”		

- ❑ Slight differences in the hierarchy of the NP scenarios also exist in 2-dim fit
- ❑ Alguero et al. and Alok et al. both find the most favoured 2-dim scenario to be $(C_9^\mu, C_{10}'^\mu)$
- ❑ All groups get large significance when including right-handed currents

Lepton-Flavour Universality “Violating and Conserving” NP

New Physics can be both LFU and LFUV : $C_{i\ell} = C_{i\ell}^U + C_{i\ell}^V$ [Alguero et al. 1809.08447]

Several such scenarios considered in [Alguero et al. 1903.09578]

Scenario	Best-fit point	1σ	Pull _{SM}	p-value
$C_{9\mu}^V$	-0.36	$[-0.86, +0.10]$		
$C_{10\mu}^V$	+0.67	$[+0.24, +1.03]$	5.2	71.2 %
$C_9^U = C_{10}^U$	-0.59	$[-0.90, -0.12]$		
$C_{9\mu}^V = -C_{10\mu}^V$	-0.50	$[-0.61, -0.38]$	5.5	71.0 %
$C_9^U = C_{10}^U$	-0.38	$[-0.52, -0.22]$		
$C_{9\mu}^V$	-0.78	$[-1.11, -0.47]$	5.3	66.2 %
C_9^U	-0.20	$[-0.57, +0.18]$		
$C_{9\mu}^V = -C_{10\mu}^V$	-0.30	$[-0.42, -0.20]$	5.7	75.2 %
C_9^U	-0.74	$[-0.96, -0.51]$		
$C_{9\mu}^V = -C_{10\mu}^V$	-0.57	$[-0.73, -0.41]$	5.0	60.2 %
C_{10}^U	-0.34	$[-0.60, -0.07]$		
$C_{9\mu}^V$	-0.95	$[-1.13, -0.76]$	5.5	69.5 %
C_{10}^U	+0.27	$[0.08, 0.47]$		
$C_{9\mu}^V$	-1.03	$[-1.22, -0.84]$	5.6	73.6 %
$C_{10'}^U$	-0.29	$[-0.47, -0.12]$		

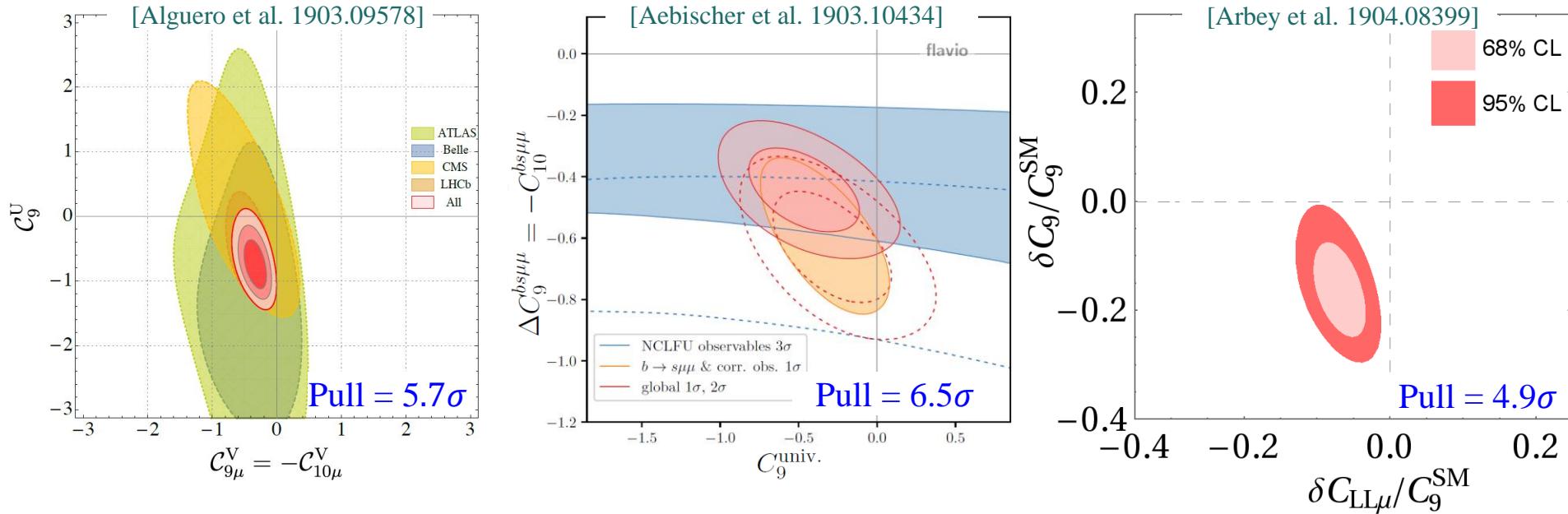
$$\left. \begin{array}{l} C_9^\mu = C_9^U + C_{9\mu}^V \\ C_9^e = C_9^U \\ C_{10}^\mu = 0 + C_{10\mu}^V (= -C_{9\mu}^V) \\ C_{10}^e = 0 \end{array} \right\}$$

- Such effects could explain the somewhat incoherent results of LFU probing observables ($R_{K^{(*)}}$) with the rest of the mostly muonic $b \rightarrow s\bar{\ell}\ell$ observables [Aebischer et al. 1903.10434]
- favoured scenario: LFU contribution to C_9^U and a chiral LFUV contribution to the muonic sector $C_{10\mu}^V (= -C_{9\mu}^V)$ → (can be realized in lepto-quark models [Crivelin et al. 1807.02068])

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- All groups find larger contributions to LFU C_9^U compared to LFUV $C_{9\mu}^V (= -C_{10\mu}^V)$

Conclusions

- ❑ Best fit points are now slightly closer to SM
- ❑ All groups find NP scenarios with $\sim 5\sigma$ significance or larger
- ❑ Most favoured 1-D scenarios are NP in C_9^μ or in $C_9^\mu = -C_{10}^\mu$
- ❑ Most favoured 2-D scenarios are NP in (C_9^μ, C_{10}^μ) or $(C_9^\mu, C_9^{\prime\mu})$ or $(C_9^\mu, C_{10}^{\prime\mu})$
- ❑ New data indicates preference for small right-handed contributions in two-operator fits
- ❑ Significant pull for fits when assuming both LFU and LFUV new physics contributions

Thank you for listening!

Multi-dimensional fits

- ❖ Four- and eight-dim. fits in [Kowalska et al.]; most likely scenario $\{C_9^\mu, C_{10}^\mu, C_9'^\mu, C_{10}'^\mu\}$ with pull = 5.1σ
- ❖ Six-dim. fit in [Alguero et al.]; $\{C_9^\mu, C_{10}^\mu, C_9'^\mu, C_{10}'^\mu, C_7, C_7'\}$ with pull = 5.1σ

	C_7^{NP}	$C_{9\mu}^{\text{NP}}$	$C_{10\mu}^{\text{NP}}$	$C_{7'}$	$C_{9'\mu}$	$C_{10'\mu}$
Best fit	+0.01	-1.10	+0.15	+0.02	+0.36	-0.16
$1\ \sigma$	$[-0.01, +0.05]$	$[-1.28, -0.90]$	$[-0.00, +0.36]$	$[-0.00, +0.05]$	$[-0.14, +0.87]$	$[-0.39, +0.13]$
$2\ \sigma$	$[-0.03, +0.06]$	$[-1.44, -0.68]$	$[-0.12, +0.56]$	$[-0.02, +0.06]$	$[-0.49, +1.23]$	$[-0.58, +0.33]$

All observables with $\chi^2_{\text{SM}} = 117.03$ $(\chi^2_{\text{min}} = 71.96; \text{Pull}_{\text{SM}} = 3.3 \text{ (3.8)}\sigma)$			
δC_7	δC_8		
-0.01 ± 0.04	0.82 ± 0.72		
$\delta C'_7$	$\delta C'_8$		
0.01 ± 0.03	-1.65 ± 0.47		
δC_9^μ	δC_9^e	δC_{10}^μ	δC_{10}^e
-1.37 ± 0.25	-6.55 ± 2.37	-0.11 ± 0.27	2.34 ± 3.11
$\delta C_9'^\mu$	$\delta C_9'^e$	$\delta C_{10}'^\mu$	$\delta C_{10}'^e$
0.23 ± 0.62	0.75 ± 2.82	-0.16 ± 0.36	1.67 ± 3.05
$C_{Q_1}^\mu$	$C_{Q_1}^e$	$C_{Q_2}^\mu$	$C_{Q_2}^e$
-0.01 ± 0.09	undetermined	-0.05 ± 0.19	undetermined
$C_{Q_1}'^\mu$	$C_{Q_1}'^e$	$C_{Q_2}'^\mu$	$C_{Q_2}'^e$
0.13 ± 0.09	undetermined	-0.18 ± 0.20	undetermined

- ❖ Twenty-dim. fit [Arbey et al.] with pull = 5.1σ

➤ Best fit points agree with each other within their 1σ ranges

Multidimensional fits

Wilson coefficients sensitive to NP: $\delta C_7, C_8, \delta C_9^\ell, \delta C_{10}^\ell, C_{Q_1}^\ell, C_{Q_2}^\ell$

➤ 10 independent Wilson coefficients (considering $\ell = e, \mu$)

✚ 10 primed Wilson coefficients

109 observables

Set of WC	Nr. parameters	χ^2_{\min}	Pull _{SM}	Improvement
SM	0	118.8	-	-
C_9^μ	1	85.1	5.8σ	5.8σ
$C_9^{(e,\mu)}$	2	83.9	5.6σ	1.1σ
$C_7, C_8, C_9^{(e,\mu)}, C_{10}^{(e,\mu)}$	6	81.2	4.8σ	0.5σ
All non-primed WC	10	81.0	4.1σ	0.0σ
All WC (incl. primed)	20	70.2	3.6σ	0.9σ

A. Arbery, T. Hurth, F. Mahmoudi, SN, PRD 98, 095027 (2018)

- No significant improvement when going beyond the scenario with NP in δC_9^μ
- Pull with the SM decreases when all Wilson coefficients are varied

Hadronic uncertainty dependence

1. Different assumptions on the form factor uncertainties

Filled area: global fit with normal form factor error

[Bharucha, Straub, Zwicky: 1503.05534](#)

Solid contour: removing form factor error correlations

Dashed contour: 2 x form factor errors

Dotted contour: 4 x form factor errors

- Only when assuming $4 \times$ form factor errors tensions goes below 2σ

2. Different assumptions on the size of the non-factorisable power corrections

Filled area: 10% power correction

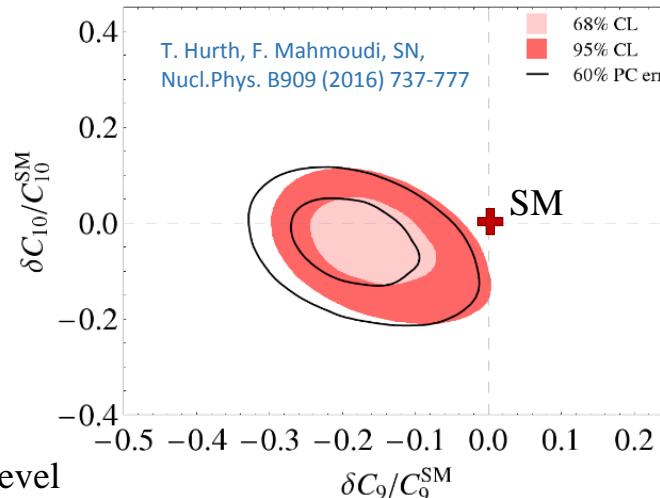
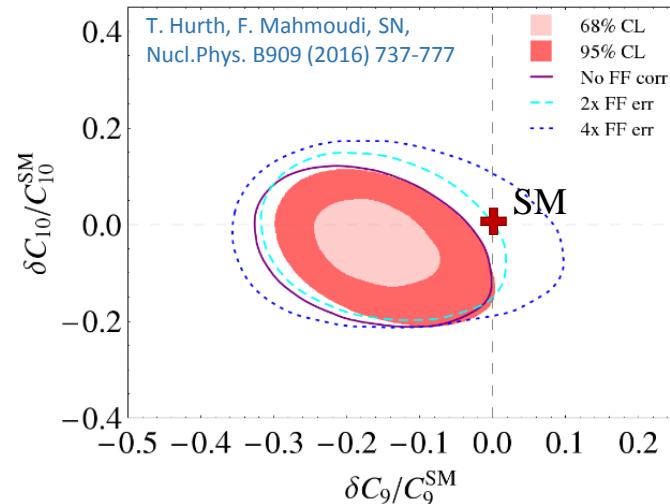
Solid contour: 60% power correction

“Guesstimate” of unknown power corrections:

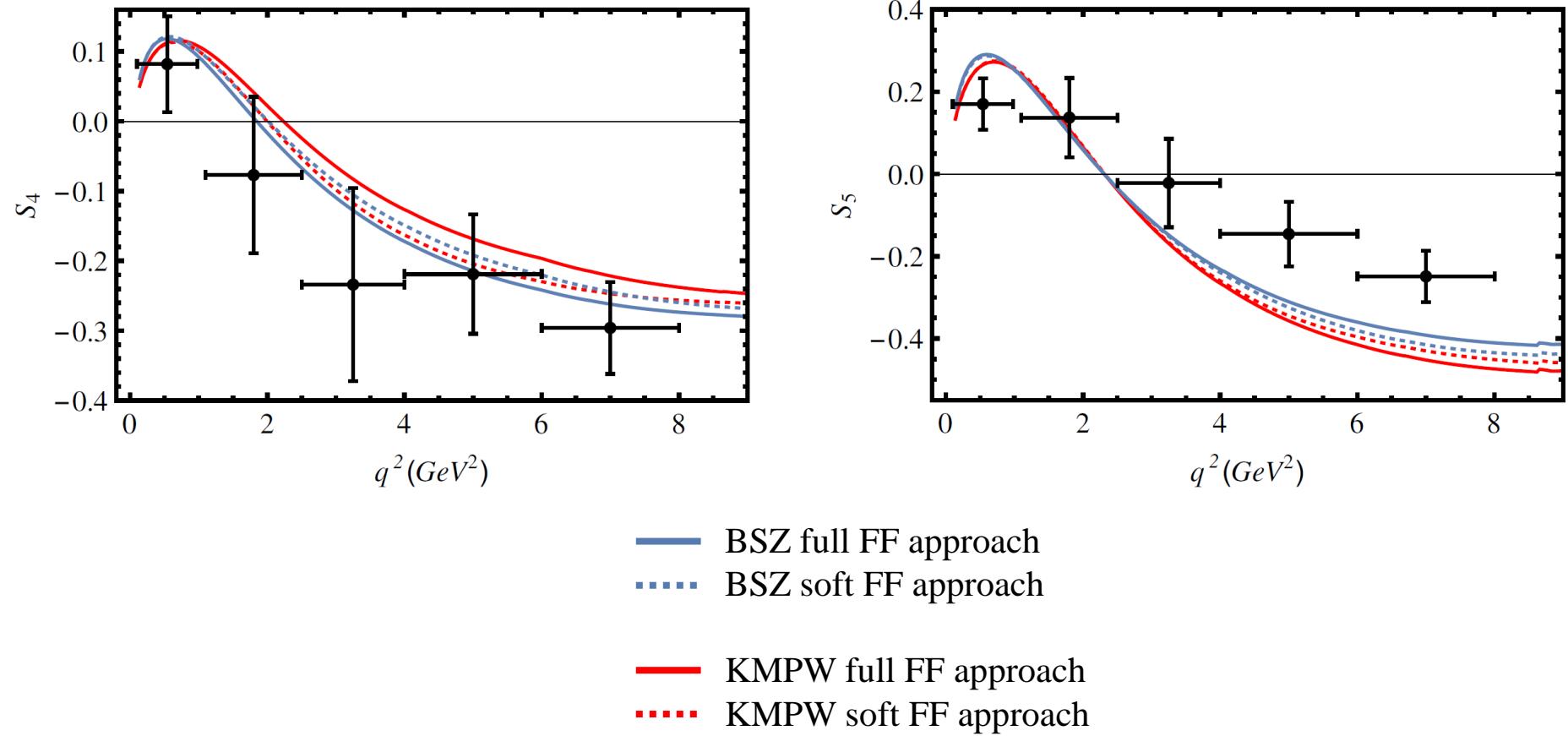
$$\text{Leading Order QCDf of non-factorisable piece} \times \left(1 + a_k \exp(i\phi_k) + b_k \frac{q^2}{6 \text{ GeV}^2} \exp(i\theta_k) \right)$$

with $a_k(b_k)$ varied between $-X\%(\times 2.5)$ and $+X\%(\times 2.5)$

- Tension not significantly reduced with 60% power correction
- 60% power corrections at amplitude level \Rightarrow 17-20% on the observable level
- Large enough hadronic power corrections required to remove tension amount to more than 150% at the amplitude level in the critical bins (20-50% on the observable level)



Impact of choice of form factor (BSZ vs KMPW) and approach (full FF , soft FF)

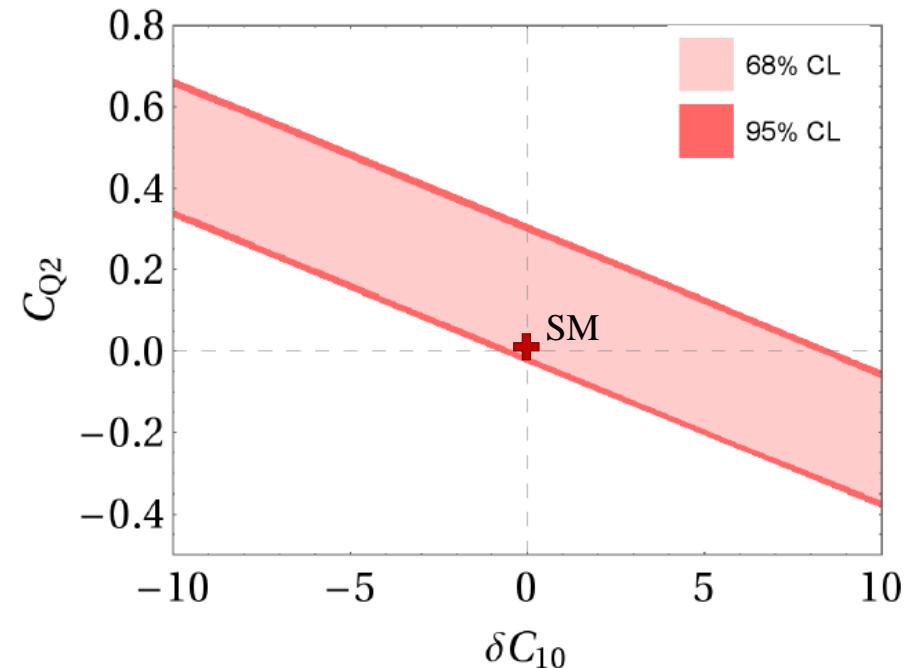
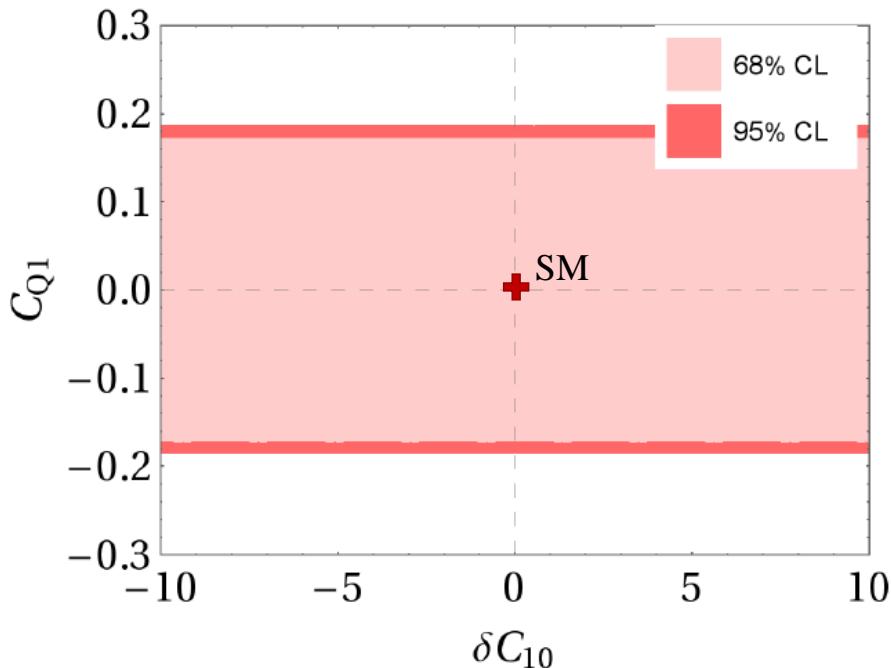


Scalar and pseudoscalar contributions

$\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ can be used to put strong constraints on C_{10}, C_{Q_1}, C_{Q_2}

→ Not simultaneously for all three Wilson coefficients

$$\text{BR}(B_s \rightarrow \mu^+ \mu^-) = \frac{G_F^2 \alpha^2}{64\pi^2} f_{B_s}^2 m_{B_s}^3 |V_{tb} V_{ts}^*|^2 \tau_{B_s} \left\{ |C_{Q_1} - C'_{Q_1}|^2 + \left| (C_{Q_2} - C'_{Q_2}) + 2(C_{10} - C'_{10}) \frac{m_\mu}{m_{B_s}} \right|^2 \right\}$$



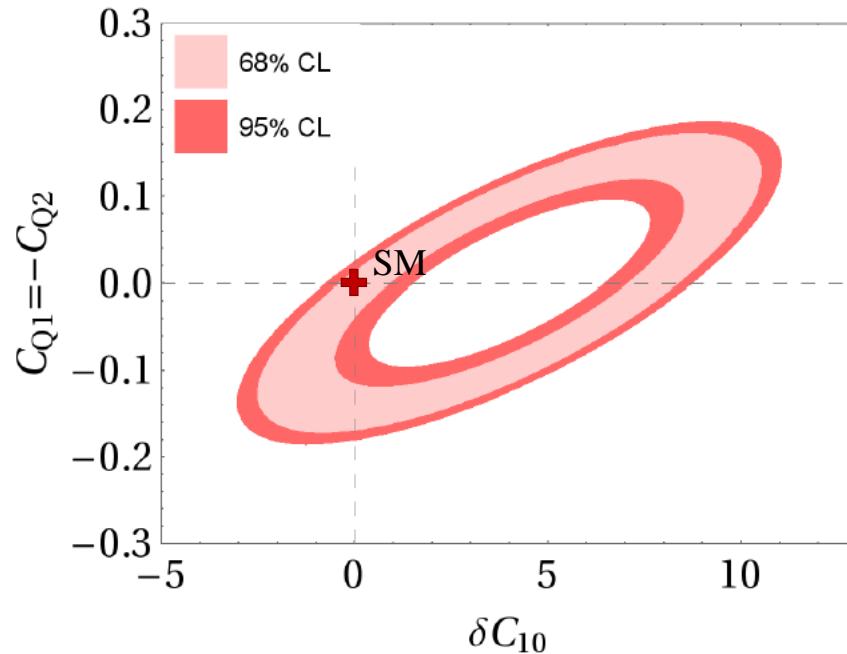
- Degeneracy among C_{10} and $C_{Q_2} \Rightarrow$ possible to have large contributions in C_{10} and C_{Q_2}
- Other observables such as $F_H(B \rightarrow K \mu^+ \mu^-)$ can resolve the issue ← further experimental data needed

Scalar and pseudoscalar contributions

$\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ can be used to put strong constraints on C_{10}, C_{Q_1}, C_{Q_2}

→ when having $C_{Q_1} = -C_{Q_2}$

$$\text{BR}(B_s \rightarrow \mu^+ \mu^-) = \frac{G_F^2 \alpha^2}{64\pi^2} f_{B_s}^2 m_{B_s}^3 |V_{tb} V_{ts}^*|^2 \tau_{B_s} \left\{ |C_{Q_1} - C'_{Q_1}|^2 + \left| (C_{Q_2} - C'_{Q_2}) + 2(C_{10} - C'_{10}) \frac{m_\mu}{m_{B_s}} \right|^2 \right\}$$



- Degeneracy among C_{10} and C_{Q_2} is broken \Rightarrow still possible to have large contributions in C_{10}
→ can be constrained with other $b \rightarrow s$ data