

Updated picture of B-anomalies after Moriond

Joaquim Matias

in collaboration with: M. Algueró, B. Capdevila, A. Crivellin, S. Descotes-Genon, P. Masjuan, J. Virto.



UAB Universitat Autònoma
de Barcelona



Portoroz, 16th April 2019

Is it time to move to gravitational waves?

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Outline & Questions

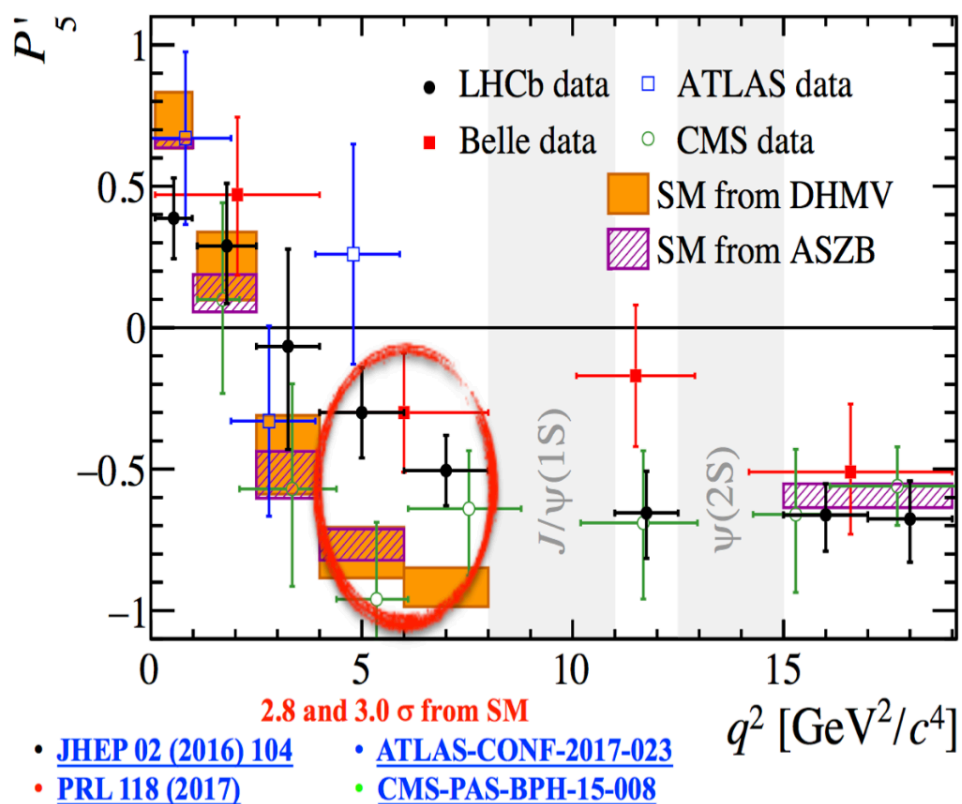
1. Diagnosis of anomalies: Where we stand?
2. A comparative study of Pre and Post Moriond
 - Are now all the global significances smaller?
 - Are new emerging hypothesis?
3. Lepton Flavour Universal (LFU) New Physics
 - Two kinds of New Physics? Maybe two scales?
4. Linking charge, neutral and LFU New Physics.
5. Conclusions

Diagnosis of anomalies in $b \rightarrow sll$

P_5' anomaly: Lepton Flavour Dependent

[SDG, JM, JV, 1207.2753]

Angular optimized observables



$$P'_5 = J_5 / 2\sqrt{-J_{2s}J_{2c}} = P_5^\infty (1 + \mathcal{O}(\alpha_s \xi_\perp) + \text{p.c.})$$

Impact of an improvement on KMPW-FF errors (50%):

- Optimized observable P'_5 (% present error size)

$$P'_{5[4,6]} = -0.82 \pm 0.08(10\%) \rightarrow 0.06(8\%)$$

→ interestingly BSZ-FF+full-FF approach finds 0.05

- Non-optimized observable S_5

$$S_{5[4,6]} = -0.35 \pm 0.12(34\%) \rightarrow 0.06(17\%)$$

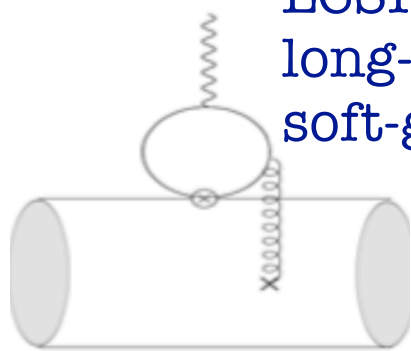
Theory: I-QCDF+SFF+KMPW+p.c.

$$C_{9i}^{\text{eff}}(q^2) = C_{9\text{SMpert}} + C_9^{\text{NP}} + s_i \delta C_{9i}^{\text{ccLD}}(q^2).$$

$$C_9^{\text{SM}} + Y(q^2)$$

1-loop ME of 4-quark op.

$$O_{1-6} + \mathcal{O}(\alpha_s)$$



LCSR to estimate long-distance with soft-gluon exchange.

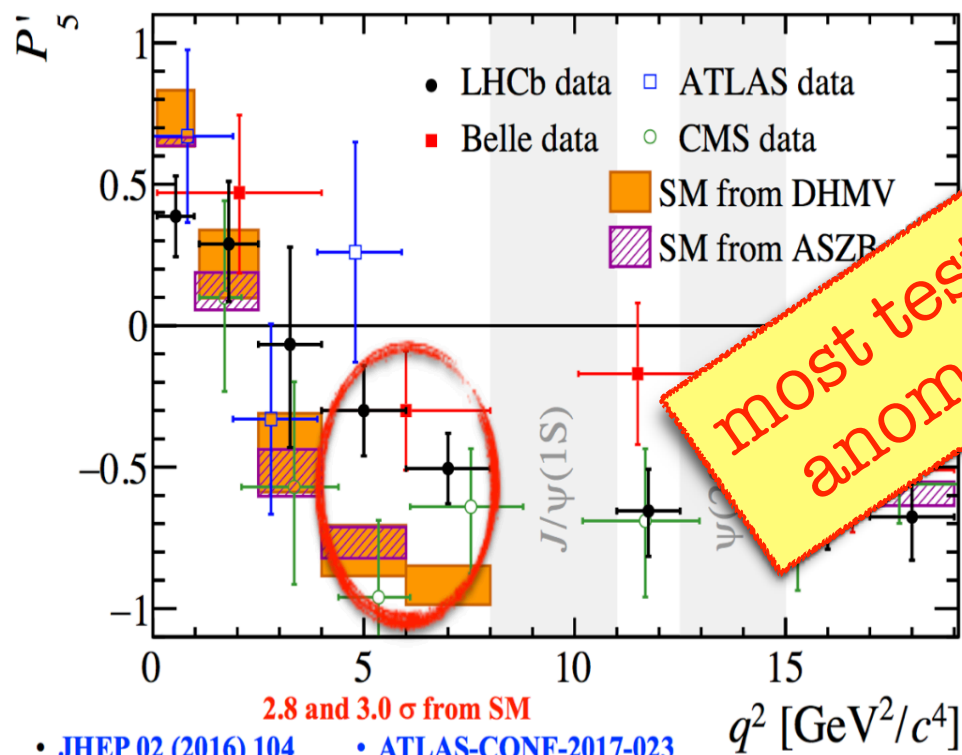
LHCb: 1/fb with 3.7σ and 3/fb 2 bins with 3σ each
Belle consistent with LHCb [4,8]
ATLAS observed the tension.

CMS compatible with our SM-prediction
 (Suggestions: extract correlations of F_L and P_1, P_5' from same PDF;
 Use analytical integration of 3D PDFs instead of numerical with RooFit)

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- [JHEP 02 \(2016\) 104](#) • [ATLAS-CONF-2017-023](#)
- [PRL 118 \(2017\)](#) • [CMS-PAS-BPH-15-008](#)

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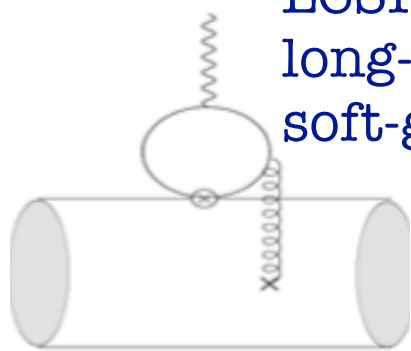
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Different theory approaches to **estimate/predict** “LD charm”:

Long distance non-factorizable :

LCSR by Khodjamirian

+ s_i const/destr interference.

Empirical model to determine the impact of resonances :

(amp. analysis+BW)

Blake et al. '17

LD effects from analyticity:

(fixes q^2 dep. up to pol. & systematic)

Bobeth et al.'18

In all theoretical estimates the anomaly remains.

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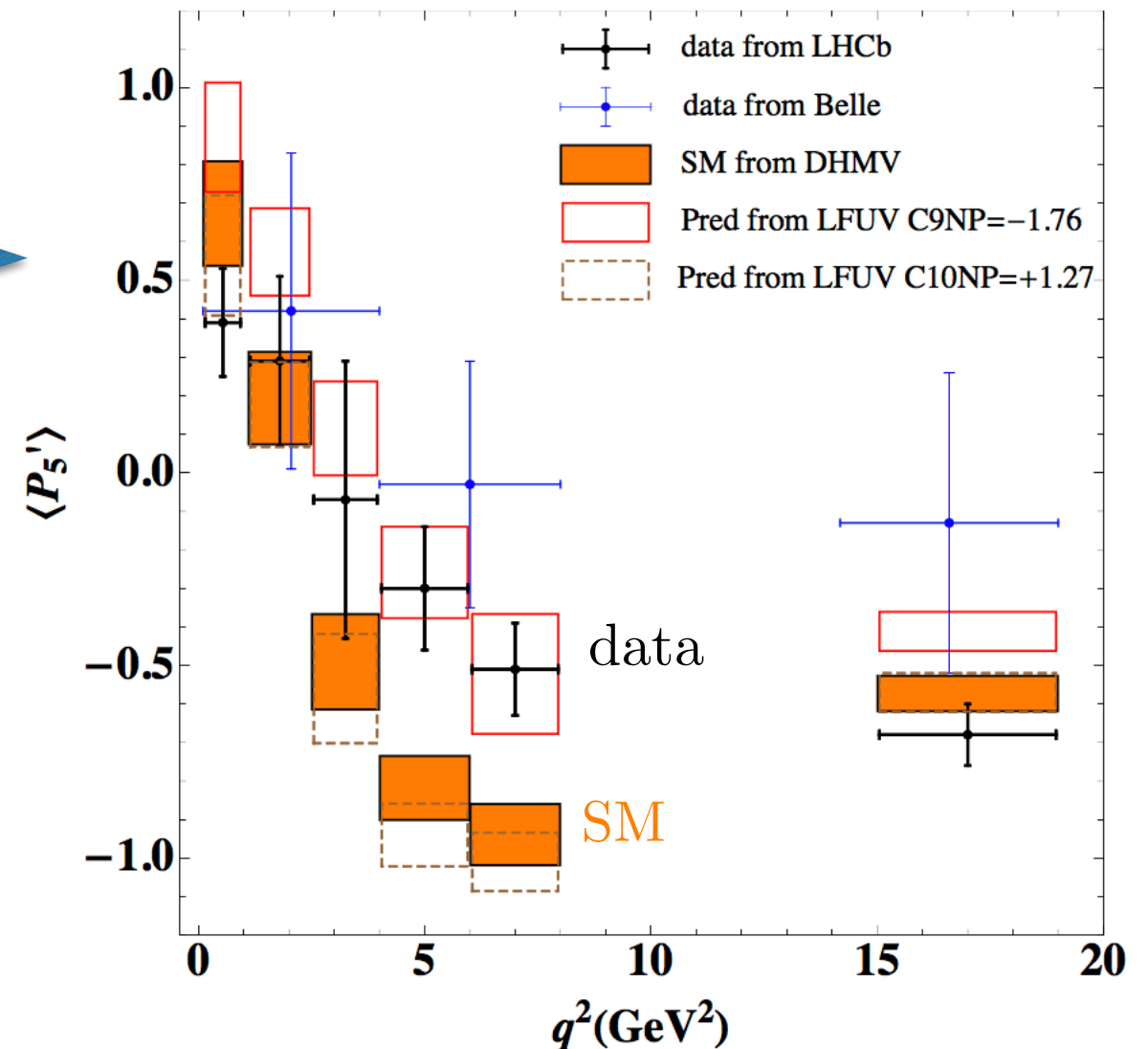
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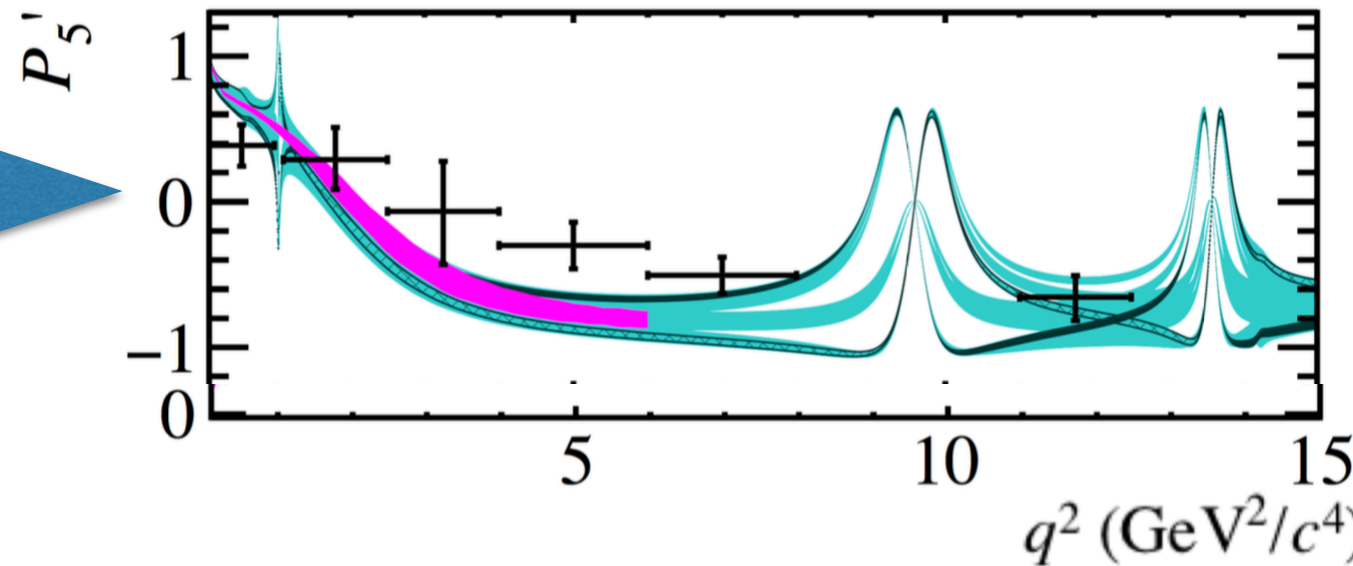
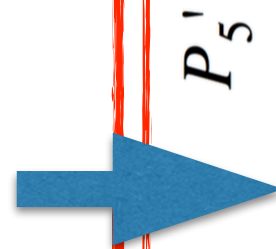
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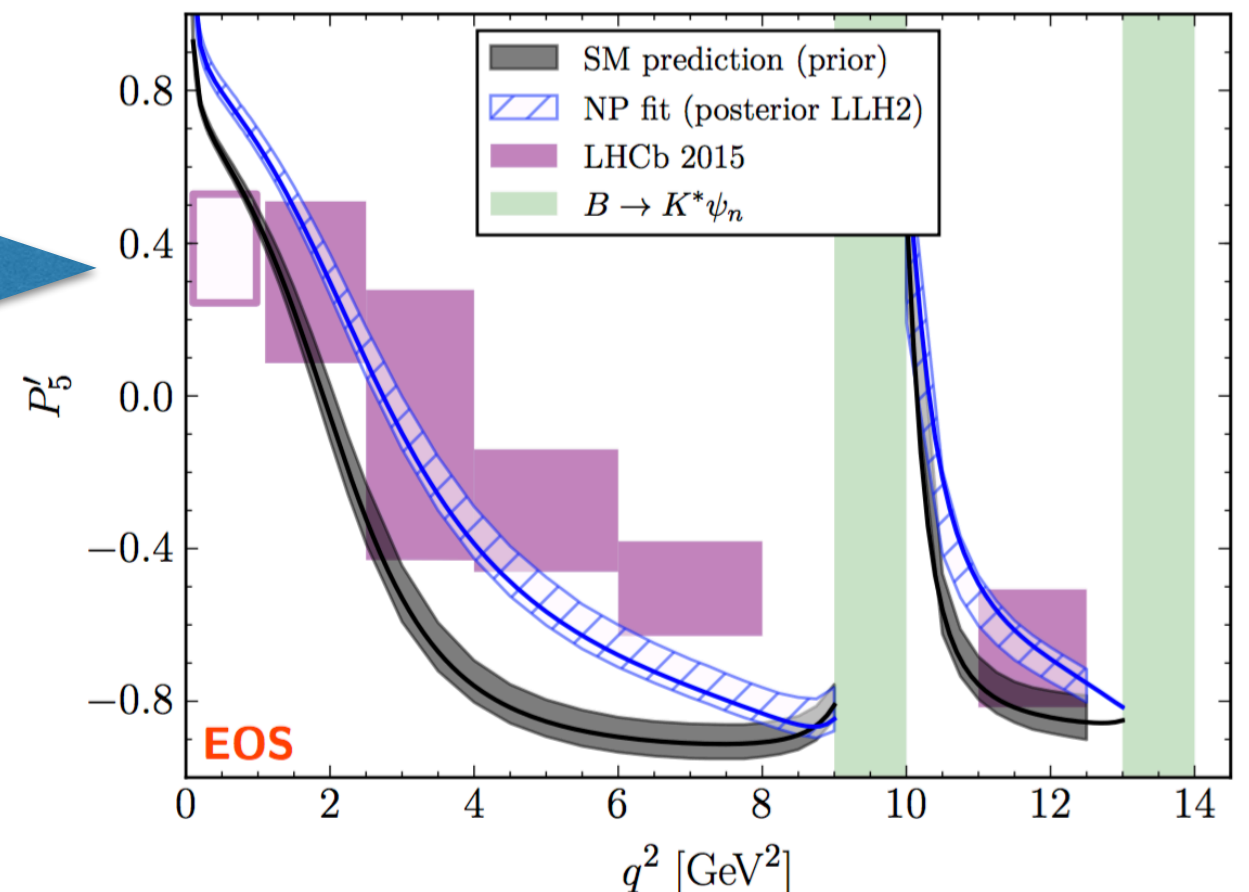
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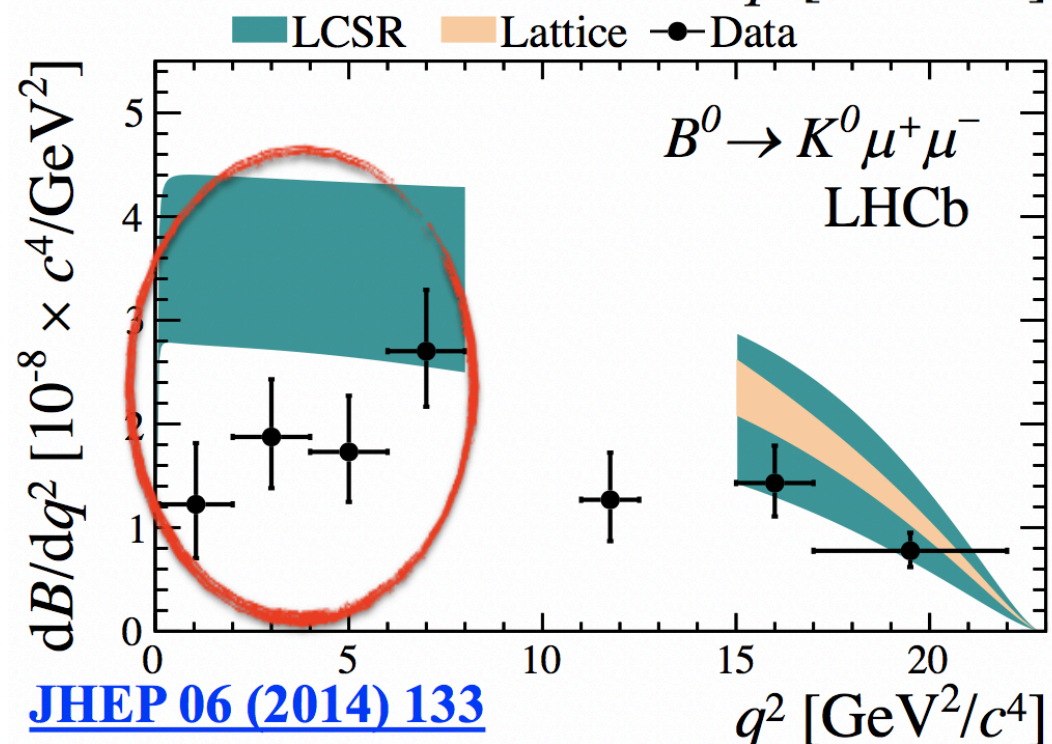
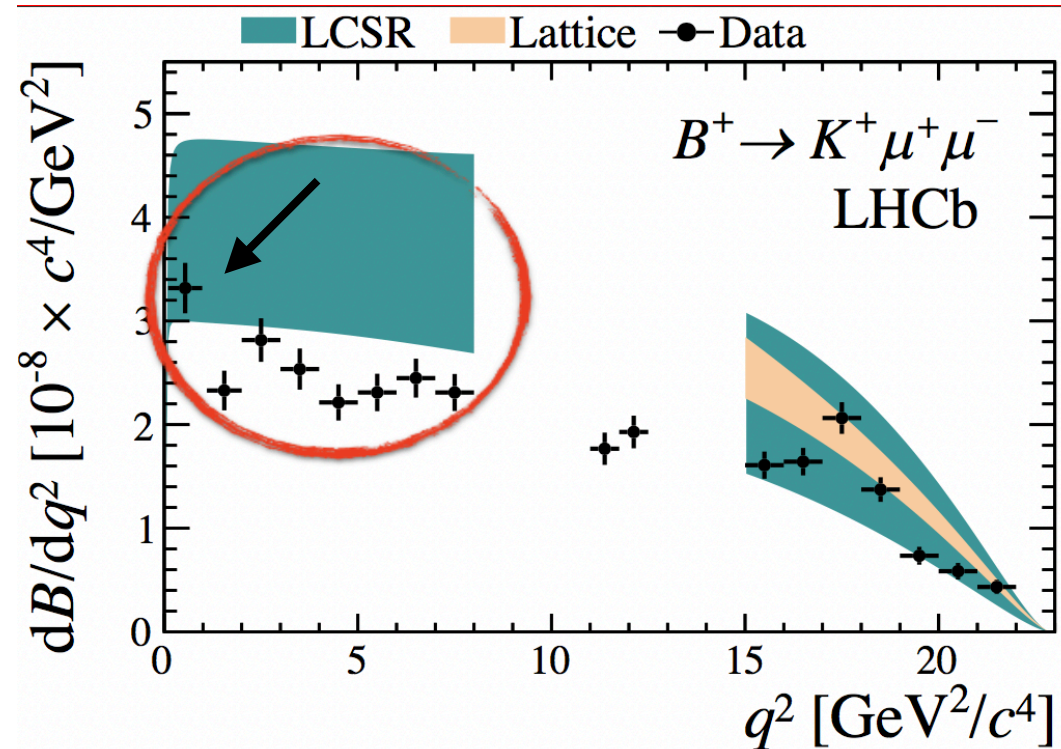
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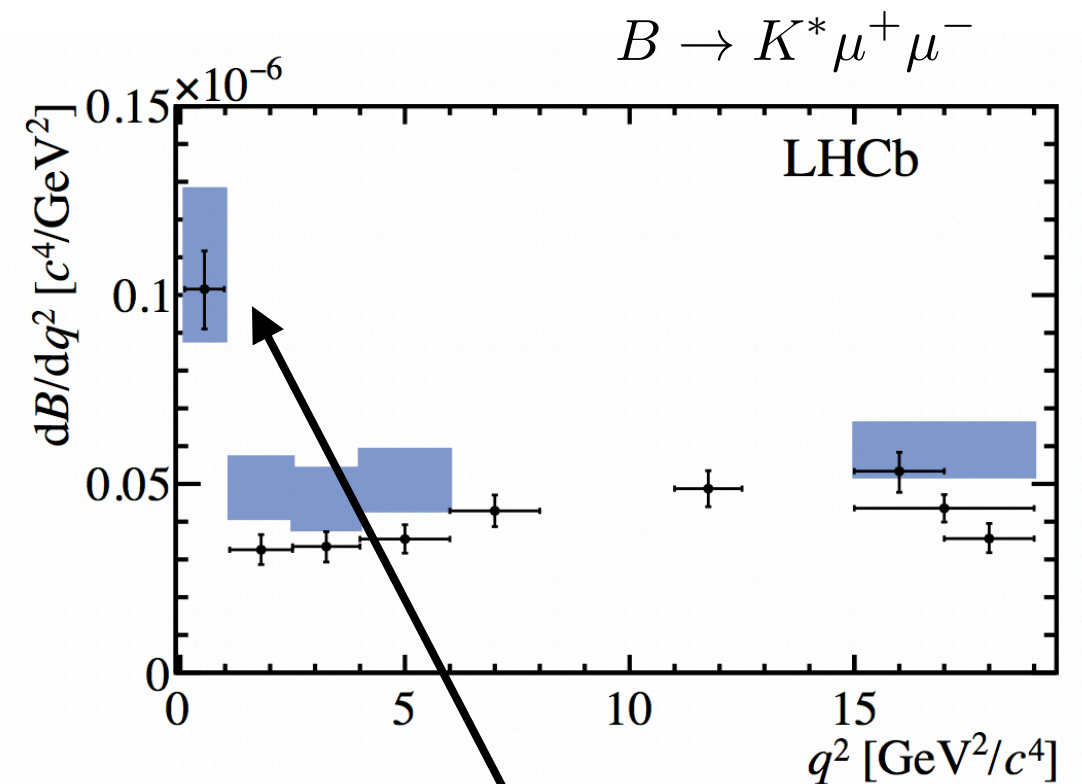
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Diff. Branching Ratios: Lepton Flavour Dependent



[JHEP 06 \(2014\) 133](#)



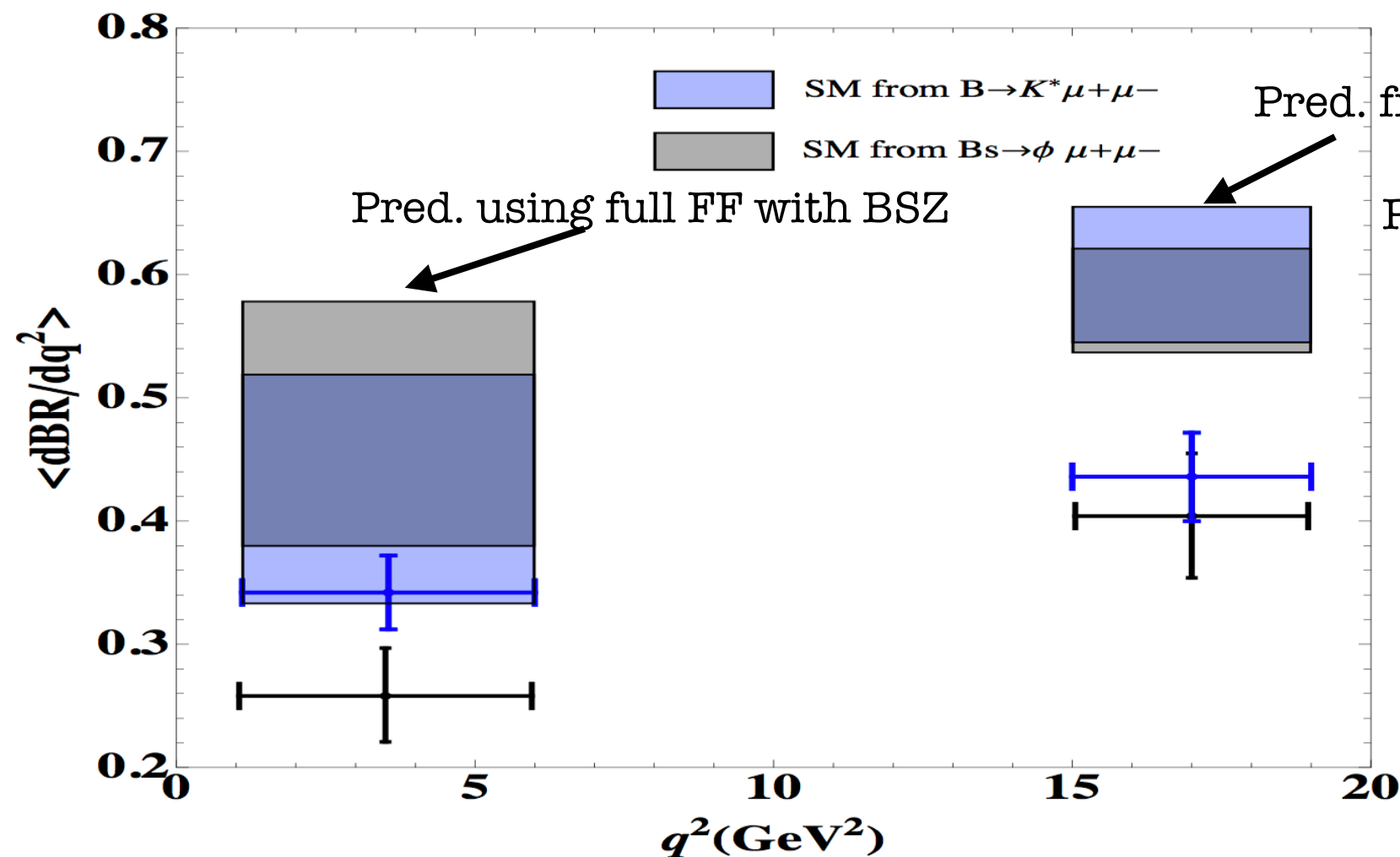
Systematic deficit in muonic channels at large and low-recoil

Possible caveat: In some muonic channels first bin is SM-like

This is **OK** if also electronic channel is SM-like (C_7 dominated). Radiative constraints are tight.

also 1st bins of opt. obs. in mild tension

$B_s \rightarrow \phi \mu \mu$ vs $B \rightarrow K^* \mu \mu$: Lepton Flavour Dependent



Tension at large and low recoil of $B(B_s \rightarrow \phi \mu \mu) \times 10^7$
 Pred. using our approach with BSZ-FF:

	SM	EXP	PULL
[0,1,2]	1.55 ± 0.34	1.11 ± 0.16	+1.2
[2,5]	1.55 ± 0.33	0.77 ± 0.14	+2.2
[5,8]	1.88 ± 0.39	0.96 ± 0.15	+2.2
[15,19]	2.20 ± 0.17	1.62 ± 0.20	+2.2

with corrected BSZ FF

Not yet significant: FF at low- q^2 for $B_s \rightarrow \phi$ (BSZ) larger than $B \rightarrow K^*$, while data is reversed. Ok at high- q^2 . **BSZ problem or statistical fluctuation?**

Our prediction for $B \rightarrow K^*$ with KMPW has larger errors so **no problem in our case.**

More data will clarify it....

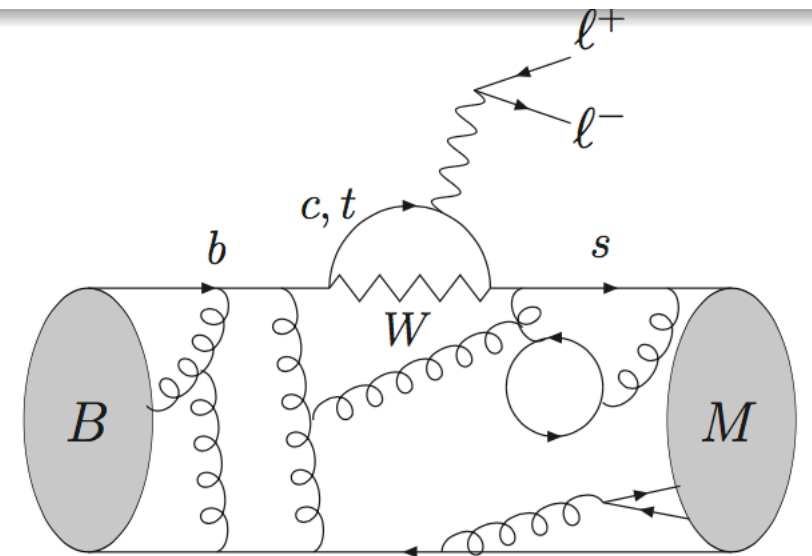
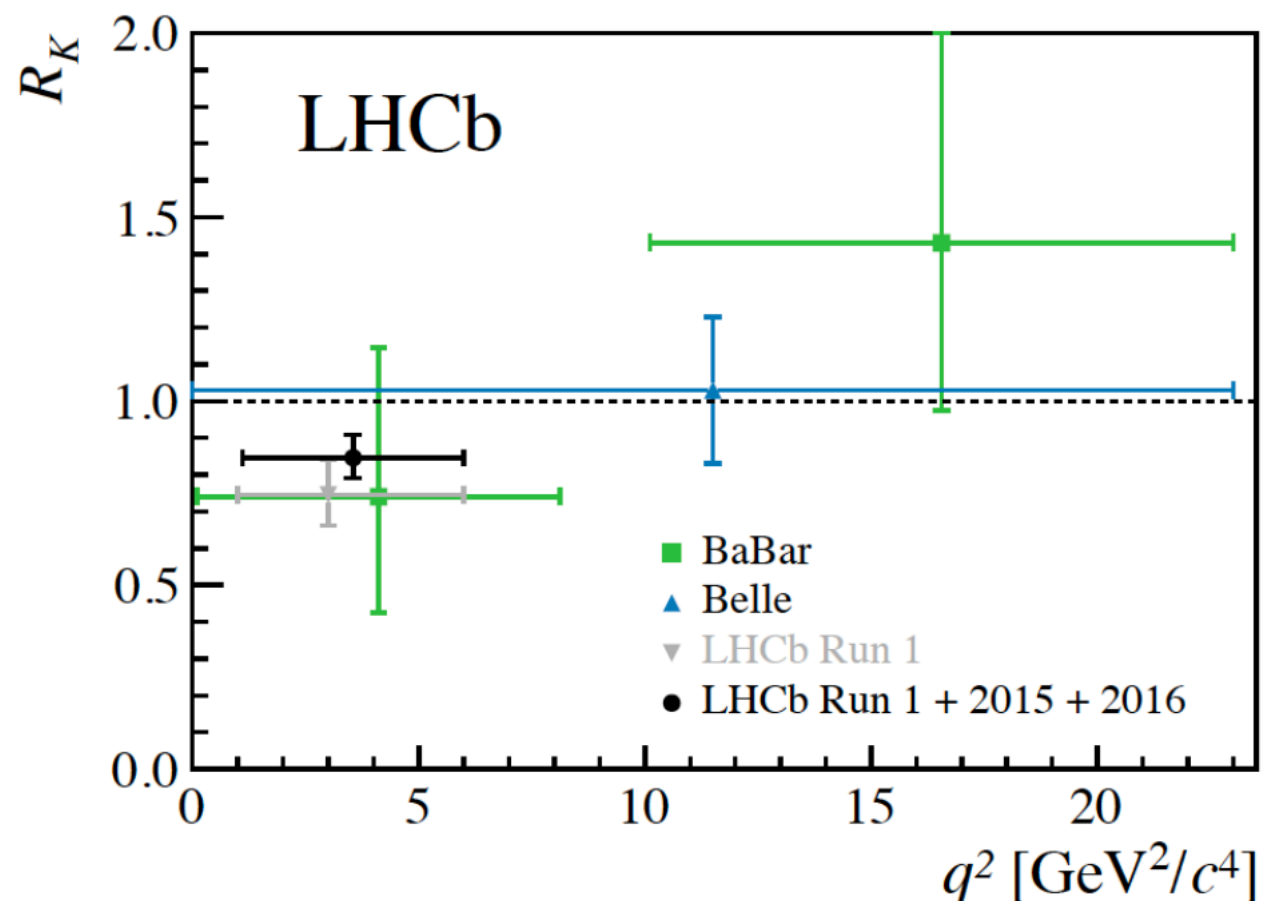
R_K : Lepton Flavour Universality Violation

FCNC, test of universality of lepton coupling, potential high sensitivity to NP contributions.

First possible signal of LFUV ... after LHCb update

$$R_K^{[1.1,6]} = \frac{\mathcal{B}(B \rightarrow K \mu^+ \mu^-)}{\mathcal{B}(B \rightarrow K e^+ e^-)} = 0.846_{-0.054}^{+0.060} {}_{-0.014}^{+0.016}$$

still at 2.5σ from SM



Simple structure of BR: $f_{+,0,T} \rightarrow f_+$

dominates while the other two suppressed by lepton mass or C_7 .

=> **Good observable in presence NP**

=> tensions cannot be explained by FF or charm. Electromagnetic small.

[Isidori et al.]

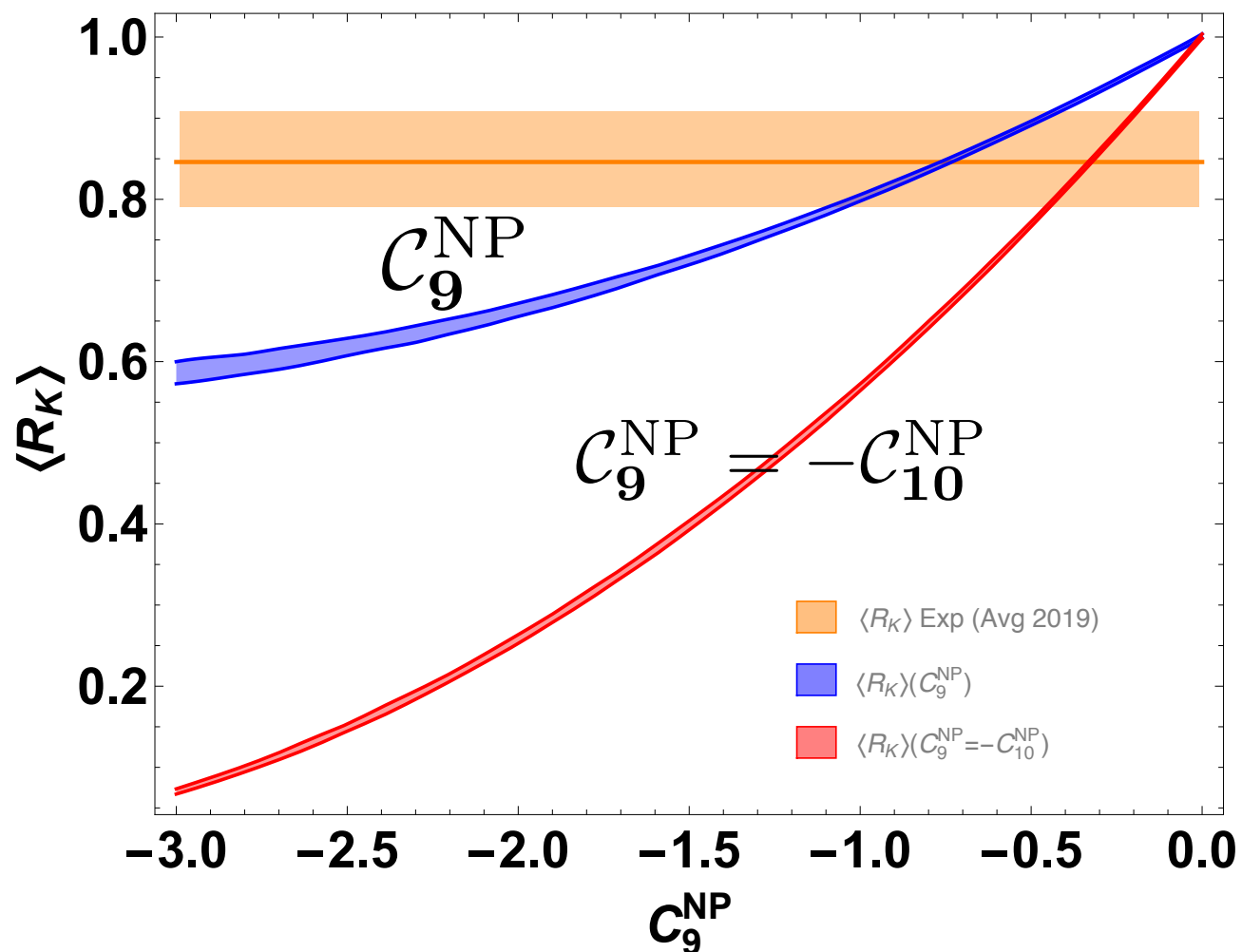
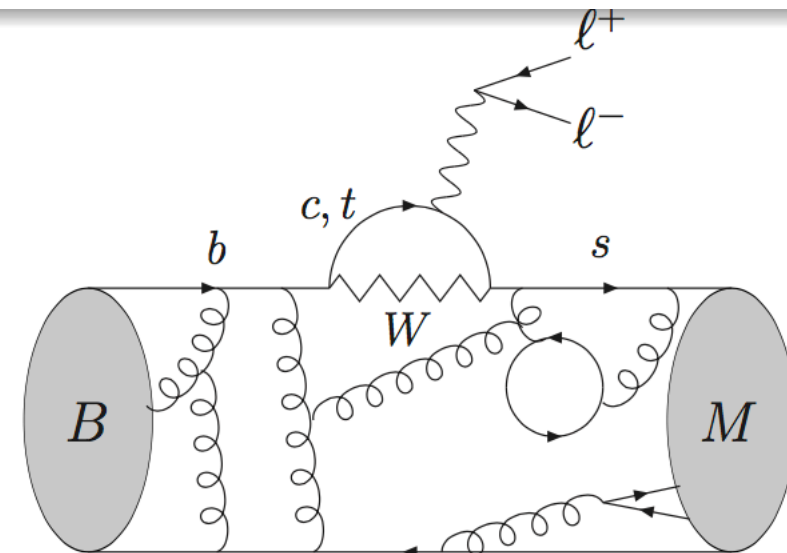
Does a more SM-like central value imply a reduction in significance?

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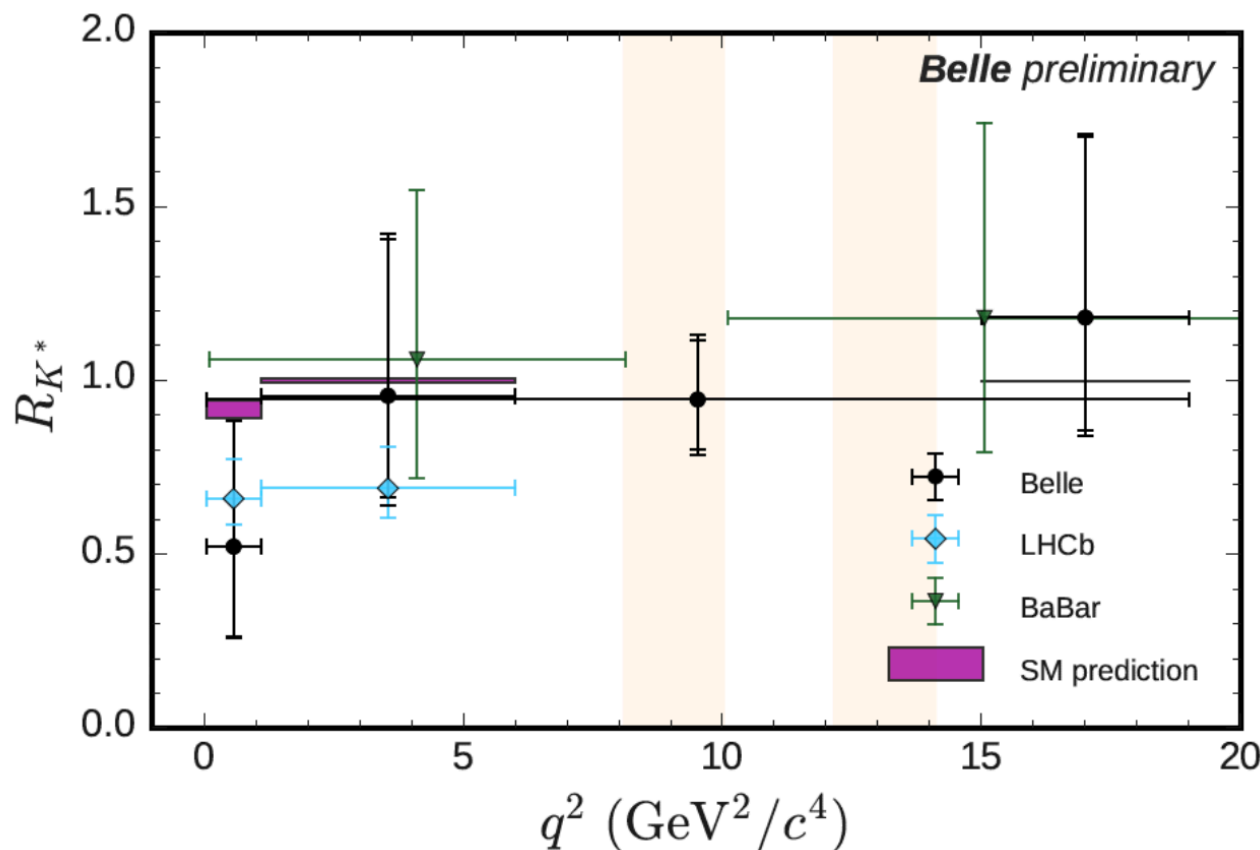
[Isidori et al.]

Does a more SM-like central value imply a reduction in significance?

R_{K^*} : Lepton Flavour Universality Violation

FCNC, second test of universality of lepton coupling.

$$R_{K^*} = \frac{Br(B^0 \rightarrow K^{*0} \mu^+ \mu^-)}{Br(B^0 \rightarrow K^{*0} e^+ e^-)}$$



different mechanisms?

pulls	$R_{K^*}^{[0.045,1.1]}$	$R_{K^*}^{[1.1,6]}$
Exp.	$0.66^{+0.113}_{-0.074}$	$0.685^{+0.122}_{-0.083}$
SM	0.92 ± 0.02	1.00 ± 0.01

LHCb:

Belle combined data on charged and neutral channels:

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

$$R_{K^*}^{[1.1,6]} = 0.96^{+0.45}_{-0.29} \pm 0.11$$

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

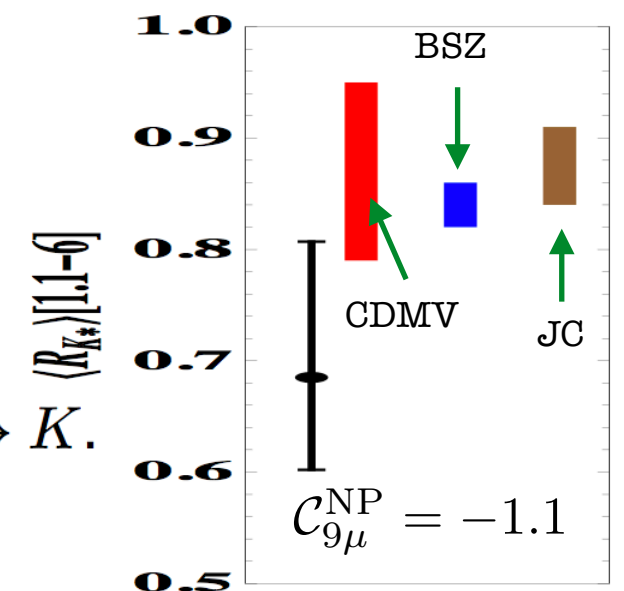
Th: Nuisance parameter required

Example of NP:

R_{K^*} : More complex structure, 6-8 Amplitudes and 7 form factors.

Impact of long-distance charm from KMPW on $B \rightarrow K^*$ larger than on $B \rightarrow K$.

- In presence of NP or for $q^2 < 1 \text{ GeV}^2$ **hadronic uncertainties return.**



Updated global analysis of $b \rightarrow sll$

2017 → [JHEP 1801(2018) 093]

2019 → [Addendum: 1903.09578]



... hopefully now the race for the right pattern

include additional interesting horses than just the old guys: C_9 and $C_9 = -C_{10}$!

Global analysis of $b \rightarrow s\ell\ell$

178 observables from (LHCb, Belle, ATLAS and CMS, no CP-violating obs)

- $B \rightarrow K^* \mu\mu$ ($P_{1,2}, P'_{4,5,6,8}, F_L$ in 5 large-recoil bins + 1 low-recoil bin)+available electronic obs.

...latest update $\text{Br}(B \rightarrow K^* \mu\mu)$ in small bins.

...LHCb results on R_{K^*}

- $B_s \rightarrow \phi \mu\mu$ ($P_1, P'_{4,6}, F_L$ in 3 large-recoil bins + 1 low-recoil bin)

- $B^+ \rightarrow K^+ \mu\mu, B^0 \rightarrow K^0 \ell\ell$ (BR) ($\ell = e, \mu$) (new average $R_K = 0.846^{+0.060+0.016}_{-0.054-0.014}$)

- $B \rightarrow X_s \gamma, B \rightarrow X_s \mu\mu, B_s \rightarrow \mu\mu$ (BR).

- Radiative decays: $B^0 \rightarrow K^{*0} \gamma$ (A_I and $S_{K^* \gamma}$), $B^+ \rightarrow K^{*+} \gamma, B_s \rightarrow \phi \gamma$

- ▶ Belle measurements for the isospin-averaged but lepton-flavour dependent ($Q_{4,5} = P'_{4,5}{}^\mu - P'_{4,5}{}^e$):
[3rd test of LFUV]

$$P_i{}^\ell = \sigma_+ P_i{}^\ell(B^+) + (1 - \sigma_+) P_i{}^\ell(\bar{B}^0) \quad \sigma_+ = 0.5 \pm 0.5$$

similar treatment of new Belle isospin-averaged result on R_{K^*} (3-bins)

- ▶ ATLAS measurement of whole basis of P_i and CMS measurements of P_1 and P'_5 .

- ▶ ATLAS update of $B_s \rightarrow \mu\mu$ (averaged with LHCb & CMS) and latest f_{B_s} lattice update.

Model independent approach to $b \rightarrow s \ell \ell$

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i \mathcal{O}_i$$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu},$$

$$\mathcal{O}_{7'} = \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_L b) F^{\mu\nu},$$

$$\mathcal{O}_{9\ell} = \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu P_L b) (\bar{\ell} \gamma^\mu \ell),$$

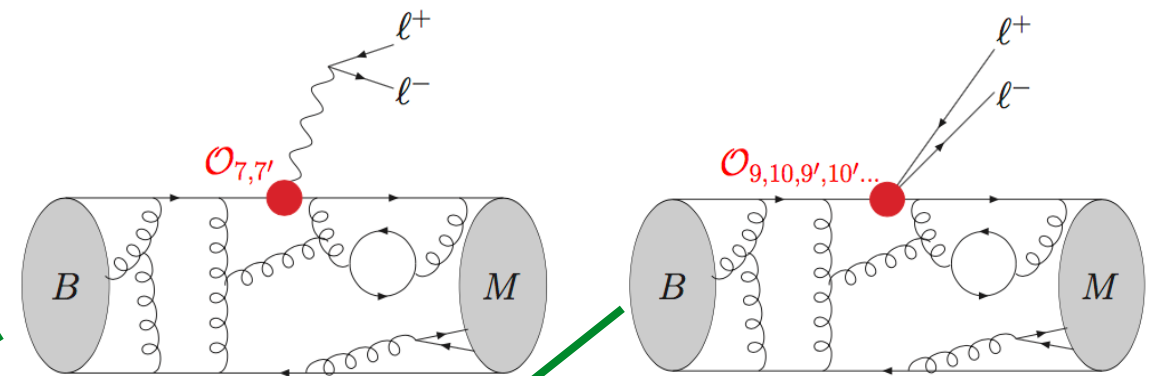
$$\mathcal{O}_{9\ell'} = \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu P_R b) (\bar{\ell} \gamma^\mu \ell),$$

$$\mathcal{O}_{10\ell} = \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu P_L b) (\bar{\ell} \gamma^\mu \gamma_5 \ell),$$

$$\mathcal{O}_{10\ell'} = \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu P_R b) (\bar{\ell} \gamma^\mu \gamma_5 \ell),$$

At the $\mu_b = 4.8$ GeV scale:

$$C_7^{\text{SM}} = -0.29, \quad C_9^{\text{SM}} = 4.1, \quad C_{10}^{\text{SM}} = -4.3$$



Interesting Directions:

$$C_9 = -C_{10} \quad \Rightarrow \quad L_q \otimes L_\ell$$

$$C_{9'} = -C_{10'} \quad \Rightarrow \quad R_q \otimes L_\ell$$

$$C_9 = -C_{9'} \quad \Rightarrow \quad A_q \otimes V_\ell$$

We explore not only directions BUT new BASIS

=> standard muon and electron basis

=> new LFUV and LFU basis

Implications of the new updates on R_K , R_{K^*} , $B_s \rightarrow \mu\mu$

$\text{Pull}_{\text{SM}} : \chi^2_{\text{SM}}(C_i=0) - \chi^2_{\text{min}}(C_i^{\text{HIF}})$ considering N_{dof}

2017		All					LFUV				
1D Hyp.	Best fit	1 σ	2 σ	Pull_{SM}	p-value	Best fit	1 σ	2 σ	Pull_{SM}	p-value	
$C_{9\mu}^{\text{NP}}$	-1.11	[-1.28, -0.94]	[-1.45, -0.75]	5.8	68	-1.76	[-2.36, -1.23]	[-3.04, -0.76]	3.9	69	
$C_{9\mu}^{\text{NP}} = -C_{10\mu}^{\text{NP}}$	-0.62	[-0.75, -0.49]	[-0.88, -0.37]	5.3	58	-0.66	[-0.84, -0.48]	[-1.04, -0.32]	4.1	78	
$C_{9\mu}^{\text{NP}} = -C'_{9\mu}$	-1.01	[-1.18, -0.84]	[-1.34, -0.65]	5.4	61	-1.64	[-2.13, -1.05]	[-2.52, -0.49]	3.2	32	
$C_{9\mu}^{\text{NP}} = -3C_{9e}^{\text{NP}}$	-1.07	[-1.24, -0.90]	[-1.40, -0.72]	5.8	70	-1.35	[-1.82, -0.95]	[-2.38, -0.59]	4.0	72	

2019		All			LFUV			
1D Hyp.	Best fit	1 σ / 2 σ	Pull_{SM}	p-value	Best fit	1 σ / 2 σ	Pull_{SM}	p-value
$C_{9\mu}^{\text{NP}}$	-1.02	[-1.18, -0.85] [-1.34, -0.68]	5.8	65.1 %	-1.02	[-1.38, -0.69] [-1.80, -0.40]	3.5	50.6 %
$C_{9\mu}^{\text{NP}} = -C_{10\mu}^{\text{NP}}$	-0.49	[-0.59, -0.40] [-0.69, -0.30]	5.4	55.5 %	-0.44	[-0.55, -0.32] [-0.68, -0.21]	4.0	74.0 %
$C_{9\mu}^{\text{NP}} = -C'_{9\mu}$	-1.02	[-1.18, -0.85] [-1.33, -0.67]	5.7	61.3 %	-1.66	[-2.15, -1.05] [-2.54, -0.47]	3.1	35.4 %
$C_{9\mu}^{\text{NP}} = -3C_{9e}^{\text{NP}}$	-0.92	[-1.08, -0.76] [-1.23, -0.60]	5.7	62.7 %	-0.76	[-1.02, -0.52] [-1.30, -0.30]	3.5	50.8 %

- Hierarchy remains invariant except $C_{9\mu} = -C'_{9\mu}$ scenario ($R_K \approx 1$)
 - Scenario $C_{9\mu}$ preferred in “All” fit
 - Scenario $C_{9\mu} = -C_{10\mu}$ preferred in “LFUV” fit.
- Best fit points for All and LFUV fits in scen. $C_{9\mu}$ in nice agreement
- Scenario $C_{10\mu}$ stays at a significance of $\approx 4\sigma$ for All and LFUV fits.

Implications of the new updates on $R_K, R_{K^*}, B_s \rightarrow \mu\mu$

Interesting surprises in 2D updates...

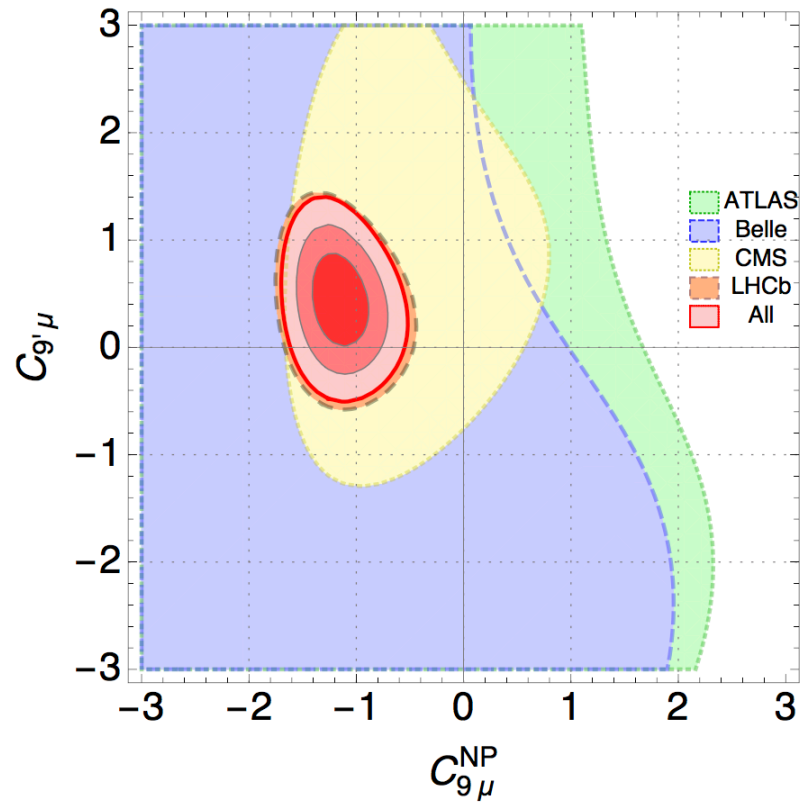
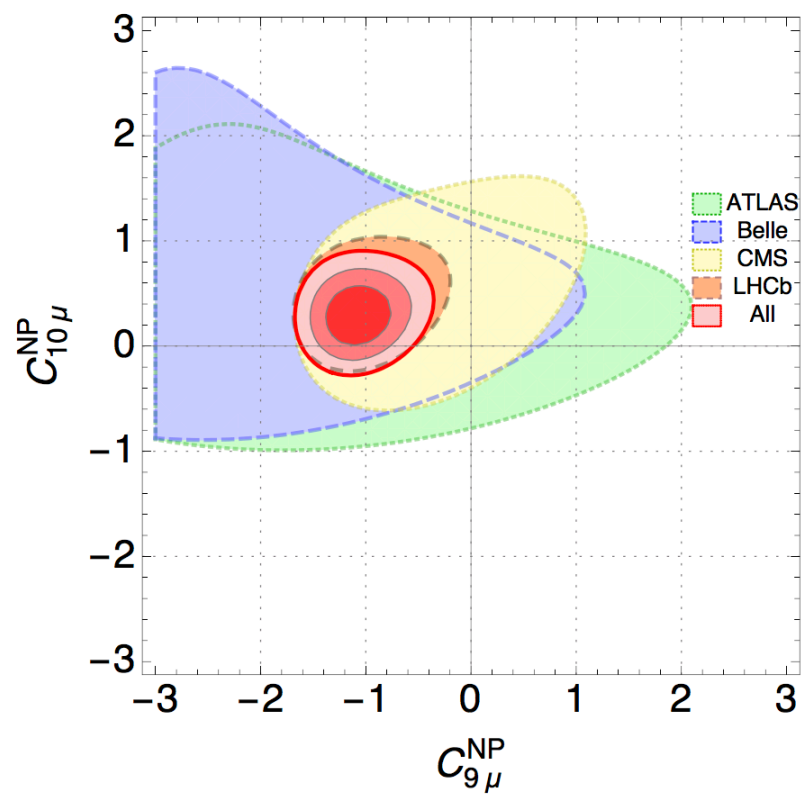
2017	All			LFUV		
	Best fit	Pull _{SM}	p-value	Best fit	Pull _{SM}	p-value
$(C_{9\mu}^{NP}, C_{10\mu}^{NP})$	(-1.01,0.29)	5.7	72	(-1.30,0.36)	3.7	75
$(C_{9\mu}^{NP}, C_7')$	(-1.13,0.01)	5.5	69	(-1.85,-0.04)	3.6	66
$(C_{9\mu}^{NP}, C_{9'\mu})$	(-1.15,0.41)	5.6	71	(-1.99,0.93)	3.7	72
$(C_{9\mu}^{NP}, C_{10'\mu})$	(-1.22,-0.22)	5.7	72	(-2.22,-0.41)	3.9	85
$(C_{9\mu}^{NP}, C_{9e}^{NP})$	(-1.00,0.42)	5.5	68	(-1.36,0.46)	3.5	65
Hyp. 1	(-1.16,0.38)	5.7	73	(-1.68,0.60)	3.8	78
Hyp. 2	(-1.15, 0.01)	5.0	57	(-2.16,0.41)	3.0	37
Hyp. 3	(-0.67,-0.10)	5.0	57	(0.61,2.48)	3.7	73
Hyp. 4	(-0.70,0.28)	5.0	57	(-0.74,0.43)	3.7	72

2019	All			LFUV		
	Best fit	Pull _{SM}	p-value	Best fit	Pull _{SM}	p-value
$(C_{9\mu}^{NP}, C_{10\mu}^{NP})$	(-0.95,0.20)	5.7	69.5 %	(-0.30,0.52)	3.6	74.5 %
$(C_{9\mu}^{NP}, C_7')$	(-1.03,0.02)	5.6	68.2 %	(-1.03,-0.04)	3.1	53.7 %
$(C_{9\mu}^{NP}, C_{9'\mu})$	(-1.13,0.54)	5.9	74.5 %	(-1.88,1.14)	3.6	75.7 %
$(C_{9\mu}^{NP}, C_{10'\mu})$	(-1.17,-0.34)	6.1	78.1 %	(-2.07,-0.63)	4.0	92.8 %
$(C_{9\mu}^{NP}, C_{9e}^{NP})$	(-1.04,-0.11)	5.5	65.3 %	(-0.76,0.25)	3.1	50.8 %
Hyp. 1	(-1.09,0.28)	6.0	75.8 %	(-1.69,0.32)	3.6	77.1 %
Hyp. 2	(-1.00,0.09)	5.4	63.9 %	(-2.00,0.26)	3.3	61.2 %
Hyp. 3	(-0.50,0.08)	5.1	55.8 %	(-0.43,-0.09)	3.6	74.5 %
Hyp. 4	(-0.52,0.11)	5.2	58.7 %	(-0.50,0.15)	3.7	81.9 %
Hyp. 5	(-1.17,0.24)	6.1	78.2 %	(-2.20,0.52)	4.1	93.8 %

- **Increase in significance in scenarios with RHC**
- R_K more SM-like better described if $C_{9'\mu} > 0$ and $C_{10'\mu} < 0$
- A $R_q \otimes L_\ell$ structure for primed operators prefers a V over a L_ℓ structure for leptons.
- Hyp.1 is SM-like for $B_s \rightarrow \mu\mu$ but perfect for R_K !

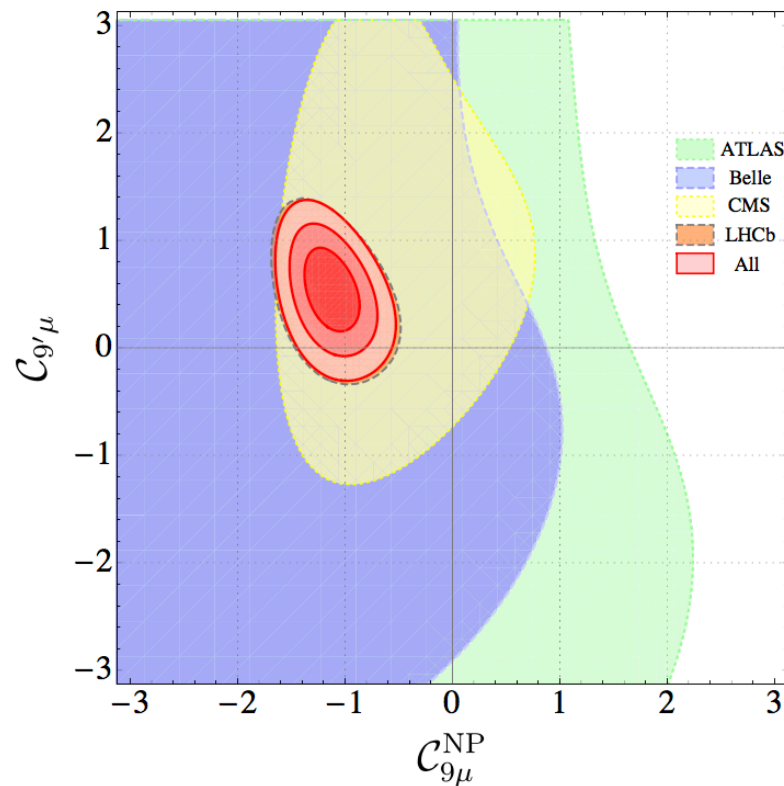
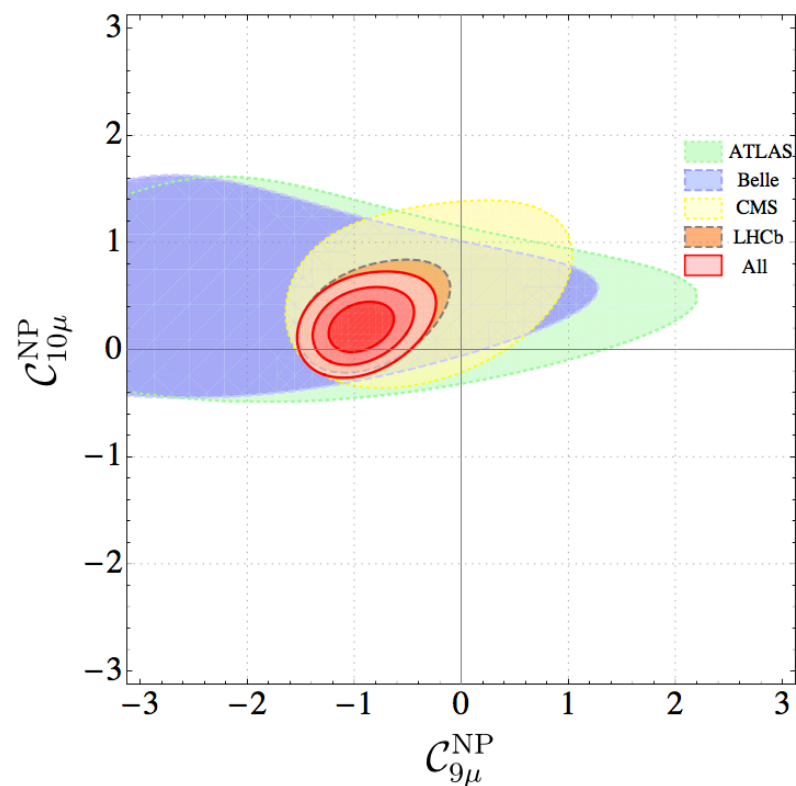
- Hyp. 1: $(C_{9\mu}^{NP} = -C_{9'\mu}, C_{10\mu}^{NP} = C_{10'\mu})$,
- Hyp. 2: $(C_{9\mu}^{NP} = -C_{9'\mu}, C_{10\mu}^{NP} = -C_{10'\mu})$,
- Hyp. 3: $(C_{9\mu}^{NP} = -C_{10\mu}^{NP}, C_{9'\mu} = C_{10'\mu})$,
- Hyp. 4: $(C_{9\mu}^{NP} = -C_{10\mu}^{NP}, C_{9'\mu} = -C_{10'\mu})$
- Hyp. 5: $(C_{9\mu}^{NP}, C_{9'\mu} = -C_{10'\mu})$.

Implications of the new updates on $R_K, R_{K^*}, B_s \rightarrow \mu\mu$



2017

-Differences among the 2D scenarios pre and after Moriond are very tiny.



2019

-A $C_{9\mu} > 0$ gets slightly more significant after Moriond.

Implications of the new updates on R_K , R_{K^*} , $B_{S \rightarrow \mu\mu}$

Let's check how the 6D fit has evolved:

2017	C_7^{NP}	$C_{9\mu}^{\text{NP}}$	$C_{10\mu}^{\text{NP}}$	$C_{7'}$	$C_{9'\mu}$	$C_{10'\mu}$
Best fit	+0.03	-1.12	+0.31	+0.03	+0.38	+0.02
1 σ	[-0.01, +0.05]	[-1.34, -0.88]	[+0.10, +0.57]	[+0.00, +0.06]	[-0.17, +1.04]	[-0.28, +0.36]
2 σ	[-0.03, +0.07]	[-1.54, -0.63]	[-0.08, +0.84]	[-0.02, +0.08]	[-0.59, +1.58]	[-0.54, +0.68]
2019	C_7^{NP}	$C_{9\mu}^{\text{NP}}$	$C_{10\mu}^{\text{NP}}$	$C_{7'}$	$C_{9'\mu}$	$C_{10'\mu}$
Best fit	+0.02	-1.13	+0.21	+0.02	+0.39	-0.12
1 σ	[-0.01, +0.05]	[-1.28, -0.91]	[+0.04, +0.42]	[+0.00, +0.04]	[-0.09, +0.96]	[-0.40, +0.17]
2 σ	[-0.03, +0.06]	[-1.48, -0.71]	[-0.12, +0.61]	[-0.02, +0.06]	[-0.56, +1.14]	[-0.57, +0.34]

$C_{10\mu} - C'_{10\mu}$ stays the same

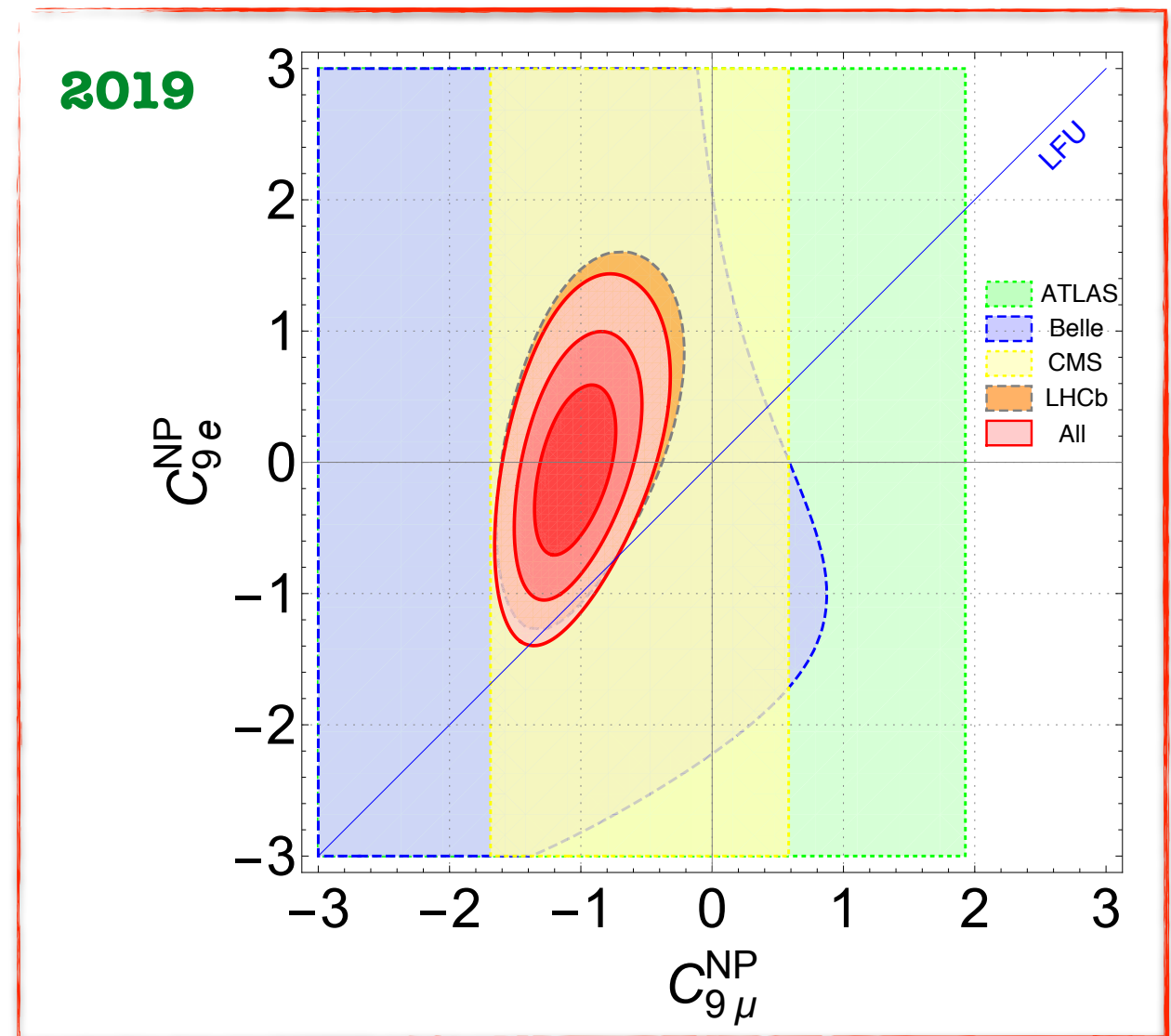
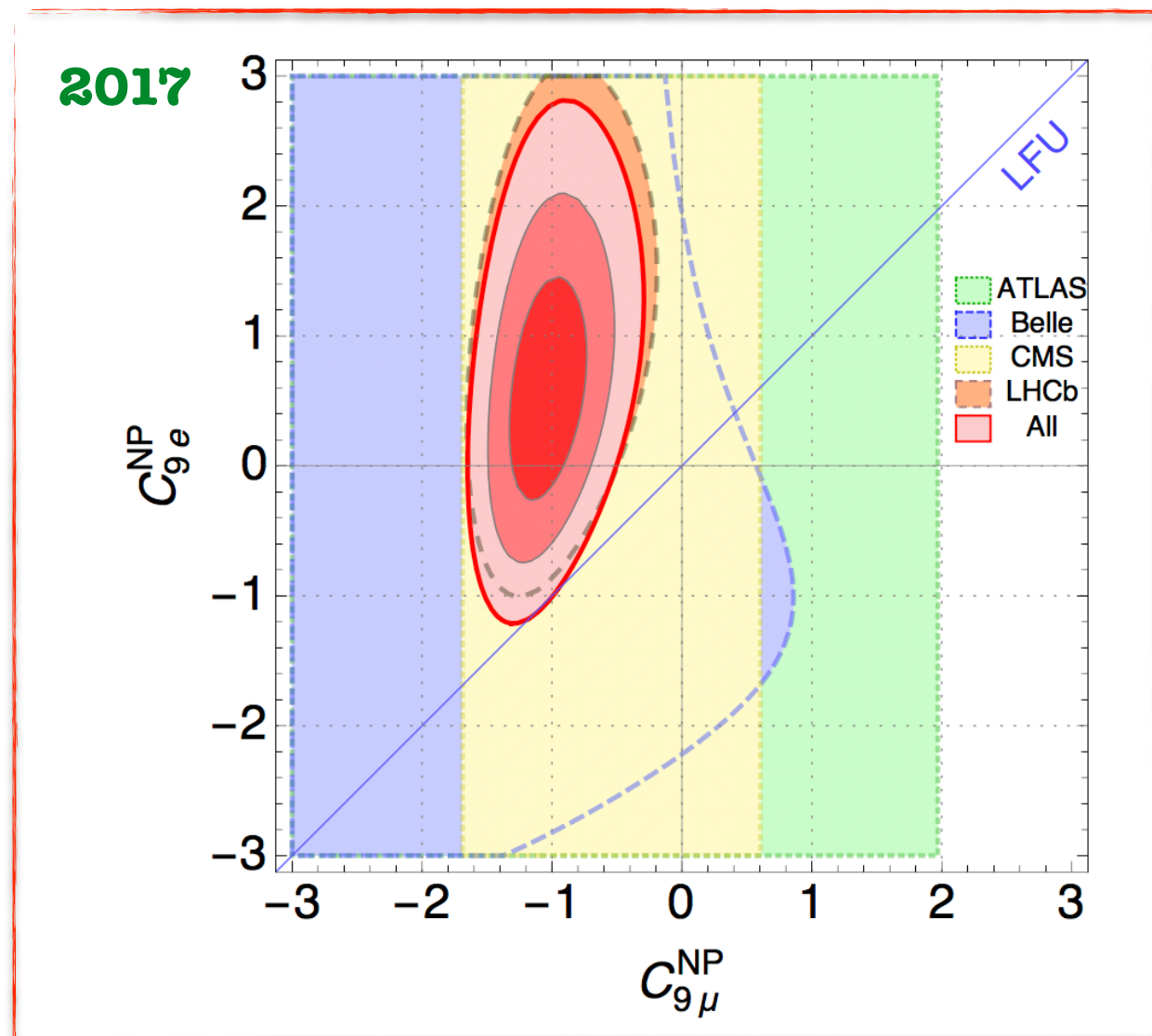
- Again **same picture**,
 - except change in sign of bfp of $C_{10'\mu}$
 - except significance $5.0\sigma \rightarrow 5.3\sigma$

Implications of the new updates on $R_K, R_{K^*}, B_s \rightarrow \mu\mu$

New Physics in electrons slightly more compatible with zero.

[JHEP 1801(2018) 093]

[Addendum: 1903.09578]



It is then natural to expect some impact in the significance of LFUV+LFU scenarios

Are we overlooking Lepton Flavour Universal NP?

[Algueró, Capdevila, SDG,
Masjuan, JM, PRD'19]

Hypothesis: Lepton Flavour Universality

[Algueró, Capdevila, SDG,
Masjuan, JM, PRD'19]

We traded the usual controversy:

Is this New Physics or long-distance charm?

by a more constructive question:

Are we observing two kinds of New Physics?

$$C_{il}^{NP} = C_{il}^V + C_i^U \quad \text{with } i = 9, 10 \quad \ell = e, \mu$$
$$C_{ie}^V = 0$$

Lepton Flavour **Universal** NP

Lepton Flavour Universal **Violating** NP

....extended to primed operators in [Addendum: 1903.09578v3]

Motivation:

- We have LFUV and LFD observables, then it is natural to split:

$$C_{il}^V$$

$$C_{il}^V + C_i^U$$

- New mechanism to fulfill $B_s \rightarrow \mu\mu$

Is this the same as adding NP in electrons?

Many previous works already included NP in electrons:

Mahmoudi et al. (large and low recoil data)

London et al. (large and low recoil data)

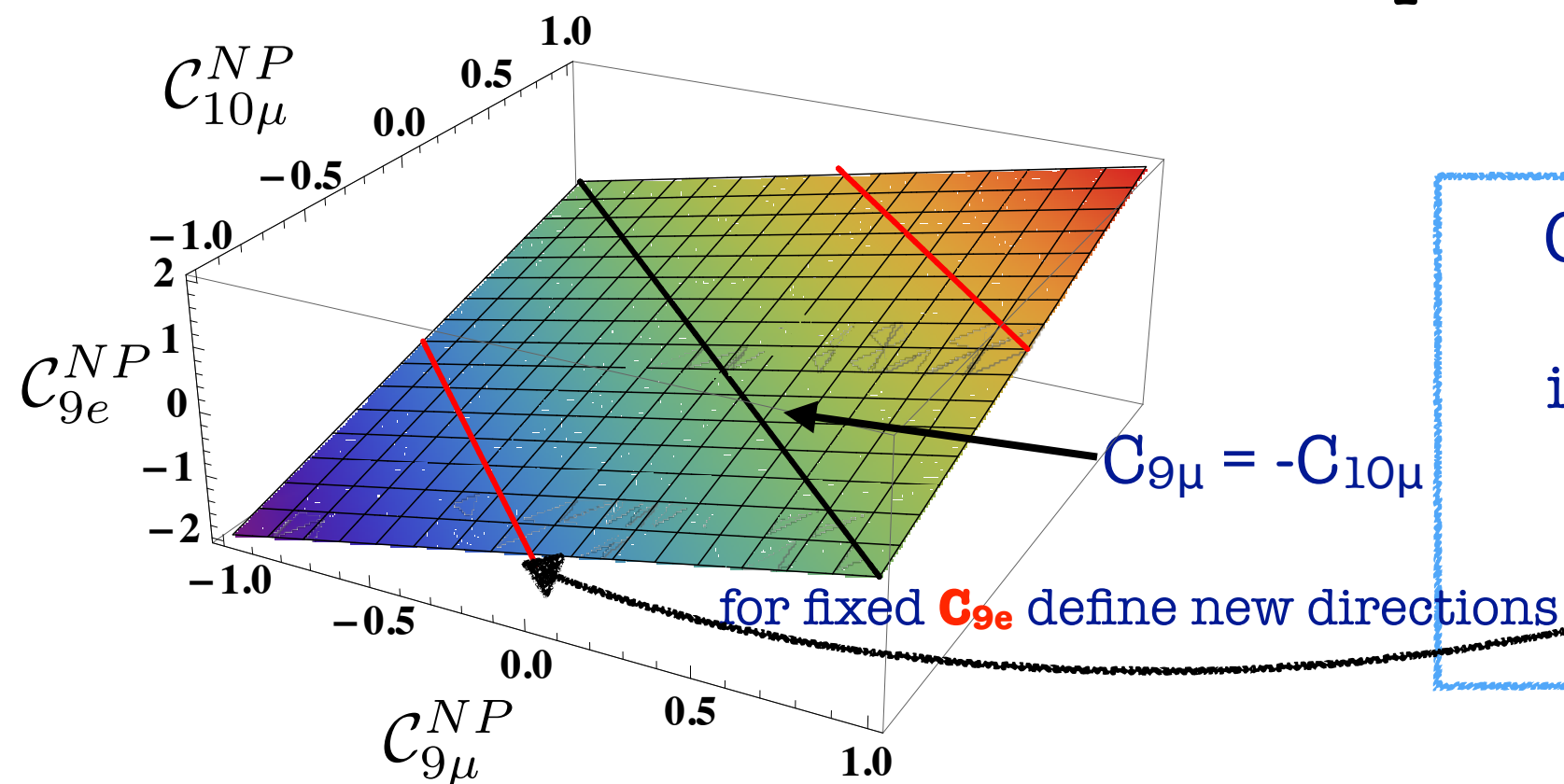
Ciuchini et al. (only large recoil data)

....

Which is the difference with our proposal?

All previous analyses only explored directions within 2D planes in coordinates $(C_{9\mu}, C_{10\mu})$ and (C_{9e}, C_{10e})

instead the plane in coordinates (C_9^V, C_{10}^V) in presence for instance of C_9^U LFU can translate in a tilted plane in $(C_{9\mu}, C_{10\mu}, C_{9e})$ coordinates



Example:

$$C_{9\mu}^V = -C_{10\mu}^V \quad \text{with } C_9^U$$

implies in the old language

$$C_{9\mu} = -C_{10\mu} + C_{9e}$$

... in summary this is **NOT** simply a reparametrization

LFU updates

2017		Best-fit point	1σ	Pull _{SM}	p-value
Sc. 5	$C_{9\mu}^V$	-0.16	[-0.94, +0.46]	5.8	78%
	$C_{10\mu}^V$	+1.00	[+0.18, +1.59]		
	$C_9^U = C_{10}^U$	-0.87	[-1.43, -0.14]		
Sc. 6	$C_{9\mu}^V = -C_{10\mu}^V$	-0.64	[-0.77, -0.51]	6.0	79%
	$C_9^U = C_{10}^U$	-0.44	[-0.58, -0.29]		
Sc. 7	$C_{9\mu}^V$	-1.57	[-2.14, -1.06]	5.7	72%
	C_9^U	+0.56	[+0.01, +1.15]		
Sc. 8	$C_{9\mu}^V = -C_{10\mu}^V$	-0.42	[-0.57, -0.27]	5.8	74%
	C_9^U	-0.67	[-0.90, -0.42]		

Changed

Sc. 7: If only V-NP preference for LFUV-NP

$$C_{9\mu}^V + C_9^U = -0.98$$

Unchanged

Sc. 8: Presence of V-LFU favours slightly $L_q \otimes L_\ell$

2019		Best-fit point	1σ	Pull _{SM}	p-value
Sc. 5	$C_{9\mu}^V$	-0.34	[-0.93, +0.19]	5.5	72%
	$C_{10\mu}^V$	+0.69	[+0.21, +1.12]		
	$C_9^U = C_{10}^U$	-0.50	[-0.92, +0.02]		
Sc. 6	$C_{9\mu}^V = -C_{10\mu}^V$	-0.52	[-0.64, -0.41]	5.8	71%
	$C_9^U = C_{10}^U$	-0.37	[-0.52, -0.22]		
Sc. 7	$C_{9\mu}^V$	-0.91	[-1.25, -0.58]	5.5	65%
	C_9^U	-0.08	[-0.46, +0.31]		
Sc. 8	$C_{9\mu}^V = -C_{10\mu}^V$	-0.33	[-0.45, -0.22]	5.9	74%
	C_9^U	-0.72	[-0.93, -0.47]		

- **LFU-NP is quite dependent on structure of LFUV-NP**

LFU updates 2019

Scenario	Best-fit point	1σ	Pull _{SM}	p-value	
Sc. 9	$C_{9\mu}^V = -C_{10\mu}^V$ C_{10}^U	-0.63 -0.39	[-0.79, -0.47] [-0.65, -0.13]	5.3	73.4 %
Sc. 10	$C_{9\mu}^V$ C_{10}^U	-0.99 +0.29	[-1.17, -0.80] [0.10, 0.48]	5.7	69.7 %
Sc. 11	$C_{9\mu}^V$ $C_{10'}^U$	-1.07 -0.31	[-1.25, -0.88] [-0.48, -0.13]	5.9	73.9 %
Sc. 12	$C_{9'\mu}^V$ C_{10}^U	-0.05 +0.43	[-0.23, 0.14] [0.22, 0.65]	1.7	13.1 %
Sc. 13	$C_{9\mu}^V$ $C_{9'\mu}^V$ C_{10}^U $C_{10'}^U$	-1.12 +0.48 +0.26 -0.05	[-1.29, -0.94] [0.19, 0.85] [0.01, 0.50] [-0.28, 0.18]	5.6	78.7 %

Changed

Sc. 7: If only V-NP preference for LFUV-NP

$$C_{9\mu}^V + C_9^U = -0.98$$

Unchanged

Sc. 8: Presence of LFU favours slightly A-NP

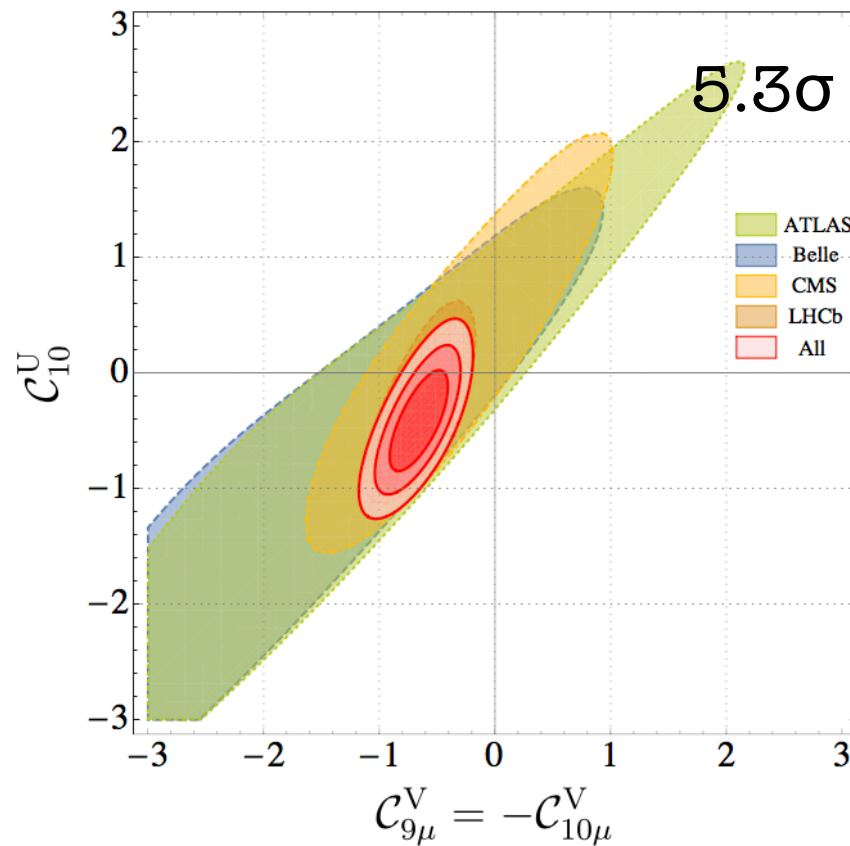
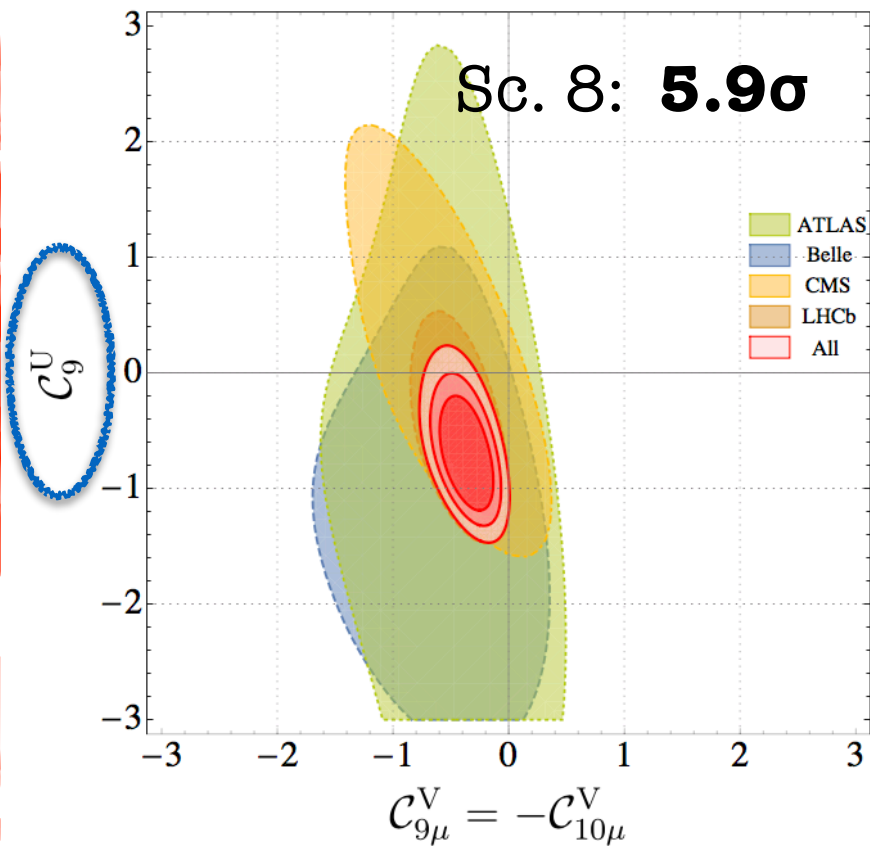
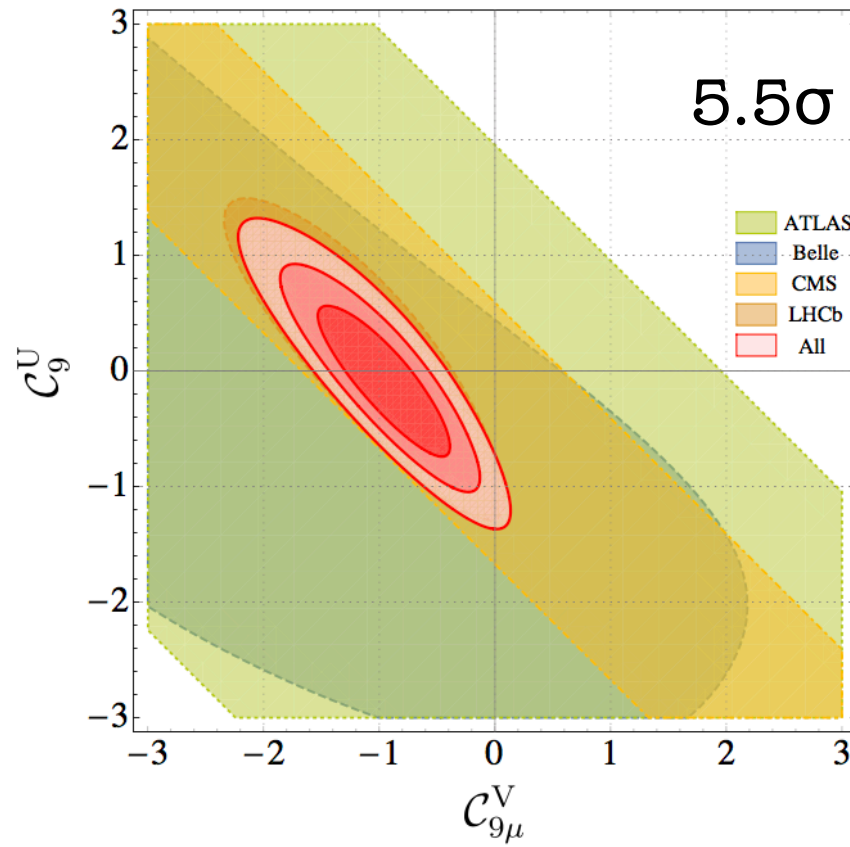
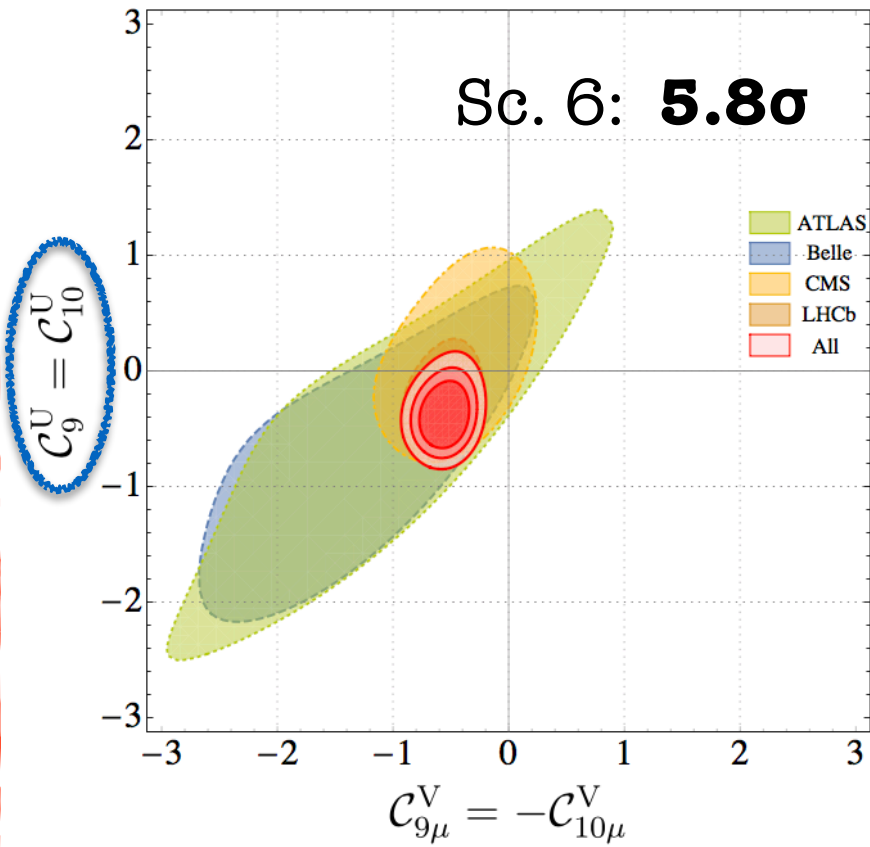
New

Sc.9-13: We extend the universal contribution also to **primed universal coefficients** associated to models.

- Sc. 9 versus Sc.10 preference of C_9^V versus $C_9^V = -C_{10}^V$ in presence of C_{10}^U , opposite to the case of C_9^U (sc.7-8).
- Sc. 10 versus Sc.11 shows the dominance of C_9^V & slight preference of $C_{10'}^U$ over C_{10}^U .
- Sc.12 irrelevance of RHC without C_9^V . If $C_{10}^U \rightarrow C_9^U$ then 4σ

- **Sc.7-10 show LFU-NP is quite dependent on structure of LFUV-NP**

LFU updates 2019



Assuming loop-level scale of NP and no MFV

$$\Lambda_i^L \sim \frac{v}{s_w g} \frac{1}{\sqrt{2|V_{tb}V_{ts}^*|}} \frac{1}{|C_i^{NP}|^{1/2}}$$

Mild preference

Scenario 6:

$$C_{9\mu}^V = -C_{10\mu}^V$$

$$C_9^U = C_{10}^U$$

LFUV-NP $L_q \otimes L_\ell$

$$\Lambda_i^{LFUV} \sim 3.9 \text{ TeV}$$

LFU-NP $L_q \otimes R_\ell$

$$\Lambda_i^{LFU} \sim 4.6 \text{ TeV}$$

Scenario 8:

$$C_{9\mu}^V = -C_{10\mu}^V$$

$$C_9^U$$

LFUV-NP $L_q \otimes L_\ell$

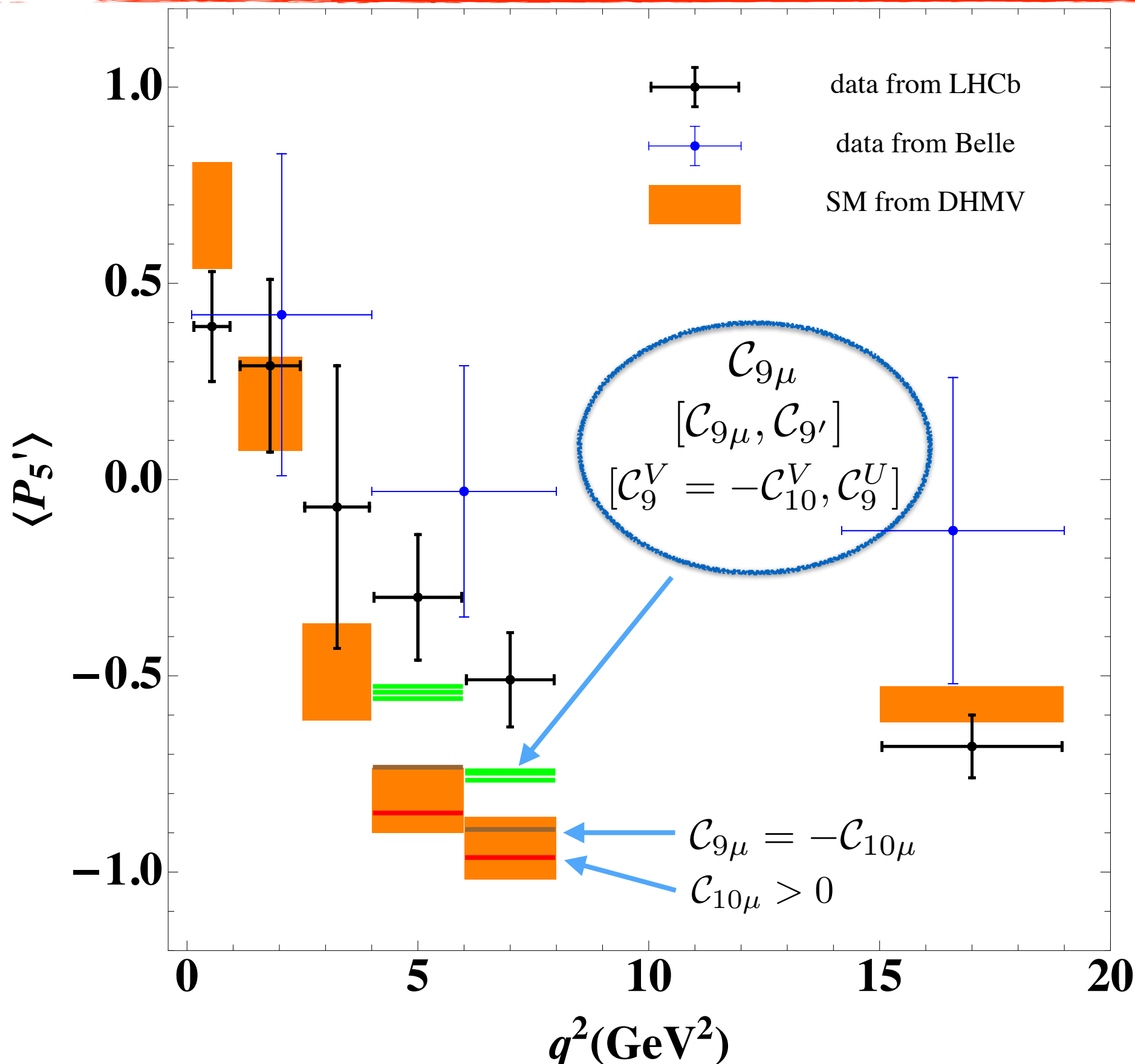
$$\Lambda_i^{LFUV} \sim 4.6 \text{ TeV}$$

LFU-NP $L_q \otimes V_\ell$

$$\Lambda_i^{LFU} \sim 3.3 \text{ TeV}$$

- If we are in presence of two types and scales of NP, their hierarchy depend on the LFU

P'_5 under different scenarios



In

[Algueró, Capdevila, SDG, Masjuan, JM, PRD'19]

it was found:

Only in presence of LFU-NP a scenario $C_9^V = -C_{10}^V$ can work.

for NP points (green, blue, red) only central values are depicted here

Linking charge and neutral anomalies and LFU NP

Linking charged and neutral anomalies (step 1)

Let's move to SMEFT ($\Lambda_{NP} \gg m_{t,W,Z}$)

[Grzadkowski, Iskrzynski, Misiak, Rosiek; Alonso, Grinstein, Camalich]

- **NP contribution to** : $[\bar{c}\gamma^\mu \mathbf{P}_L b][\bar{\tau}\gamma_\mu \mathbf{P}_L \nu_\tau] \longrightarrow R_{J/\psi}/R_{J/\psi}^{SM} = R_D/R_D^{SM} = R_{D^*}/R_{D^*}^{SM}$
 G_F rescaling

BUT who order that

(at high energy)? Only Two $SU(2)_L$ invariant operators in SMEFT @ 1st order

$$\mathcal{O}_{ijkl}^{(1)} = [\bar{Q}_i \gamma_\mu Q_j][\bar{L}_k \gamma^\mu L_l],$$

$$\mathcal{O}_{ijkl}^{(3)} = [\bar{Q}_i \gamma_\mu \sigma^I Q_j][\bar{L}_k \gamma^\mu \sigma^I L_l],$$

After EWSB $i=2, j=k=l=3$

if $C(1)=C(3)$

[Capdevila, Crivellin, SDG, Hofer, JM]

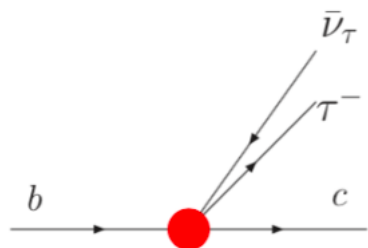
$b \rightarrow c$

$b \rightarrow s$

Accommodate charged $R_{D(*)}$.

OK **constraints**:

- B_c lifetime, q^2 distributions, but also **$B \rightarrow K^* \bar{\nu}\nu$** , direct searches and EWP data.



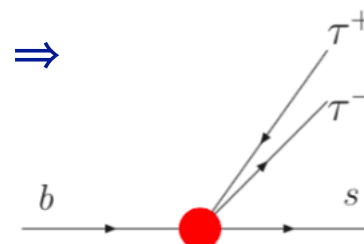
Contribution to neutral $b \rightarrow s \tau\tau$

with a pattern: $C_{9(10)\tau} \simeq C_{9,10}^{SM} - (+)\Delta$

$$\Delta = 2 \frac{\pi}{\alpha_{em}} \frac{V_{cb}}{V_{tb} V_{ts}^*} \left(\sqrt{\frac{R_X}{R_X^{SM}}} - 1 \right) \simeq \mathcal{O}(100)$$

- 10% NP w.r.t. tree-level SM \Rightarrow

Huge contrib. w.r.t. loop-induced SM.



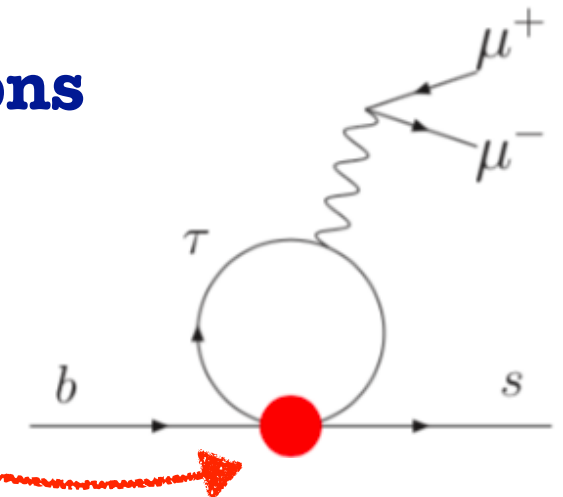
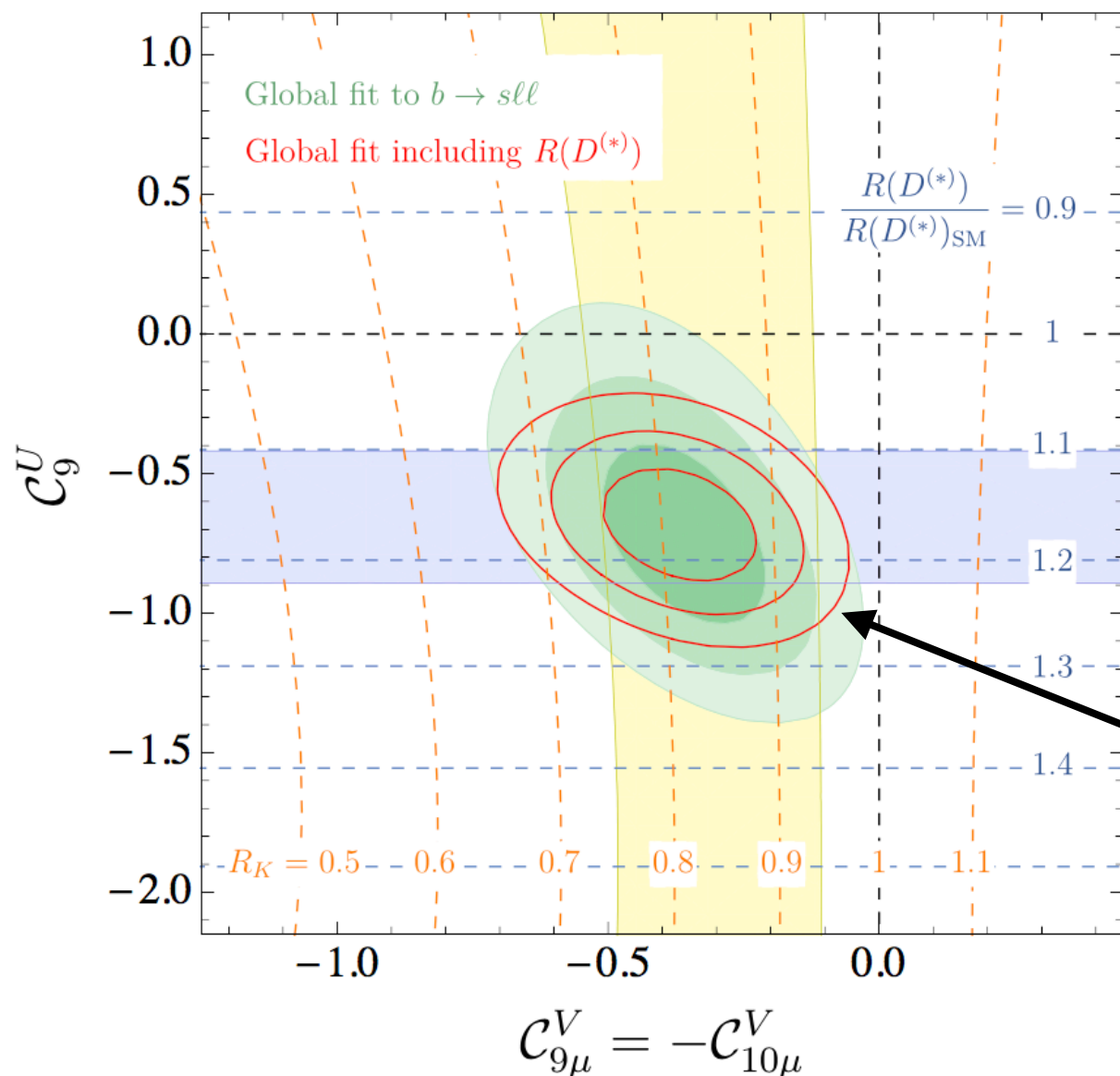
Linking anomalies with LFU NP (step 2)

Scenario 8 well motivated to link charged/neutral anomalies with LFU

$$C_{9\mu}^V = -C_{10\mu}^V$$

- LFUV: $C_{9\mu}^V = -C_{10\mu}^V$ from O_{2322}

- LFU: $C_{9\mu}^U$ from radiative corrections with insertion of O_{2333}



Assuming a generic flavour structure and NP at the scale Λ :

$$C_9^U \approx 7.5 \left(1 - \sqrt{\frac{R_{D^{(*)}}}{R_{D^{(*)};SM}}} \right) \left(1 + \frac{\log(\Lambda^2/(1\text{TeV}^2))}{10.5} \right)$$

Agreement region including new $R_{D^{(*)}}$ from Belle, $bs \rightarrow ll$ LFUV and LFU-NP: NP hyp. 7σ

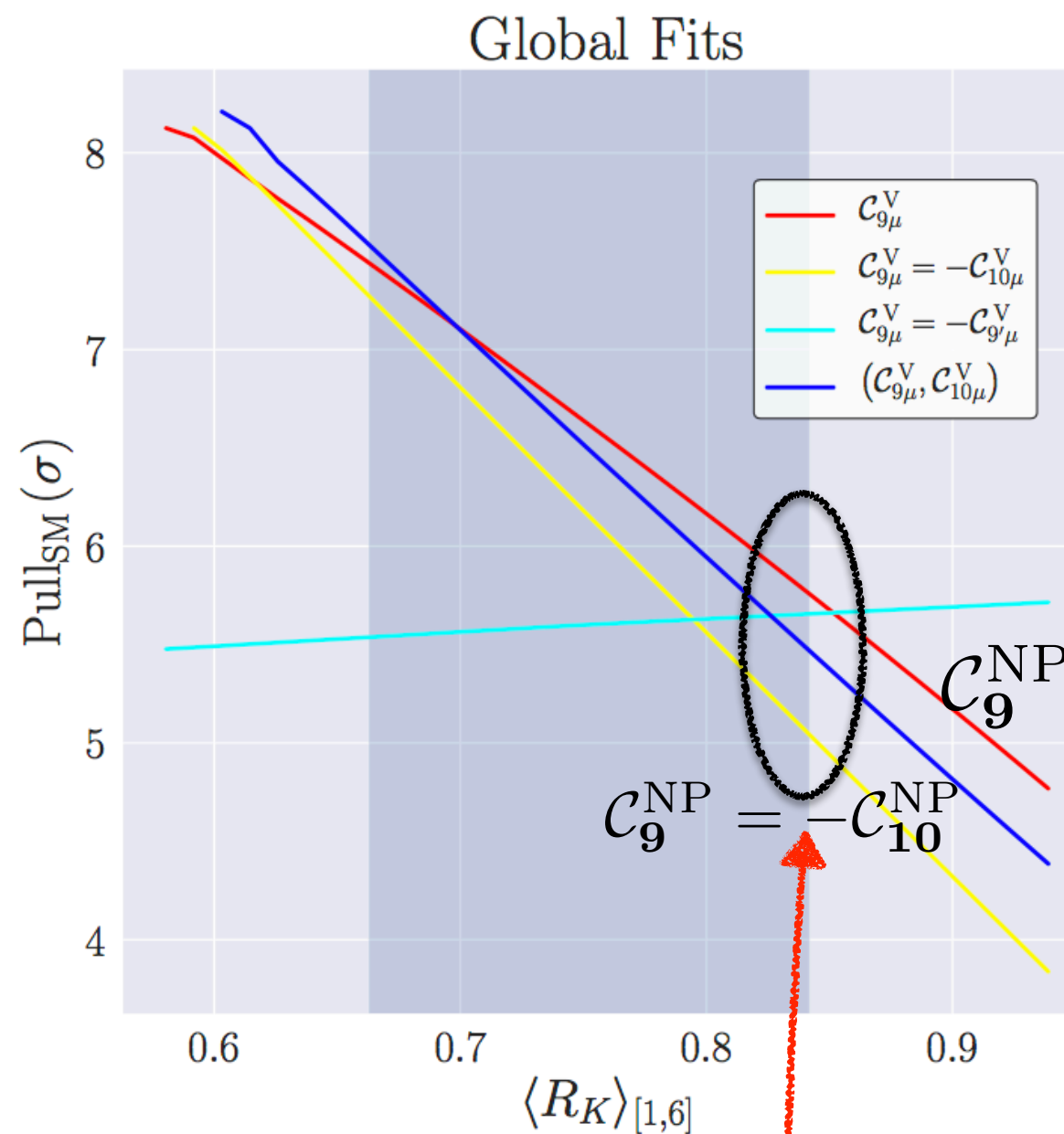
See talk by G. Isidori for explicit UV realisations and A. Crivellin et al. PRL 2019.

Near Future next test: $Q_5 = P'_{5\mu} - P'_{5e}$

What can we learn?

Q_5 can disentangle relevant scenarios?

R_K (if no-RHC are included) cannot distinguish among relevant scenarios.



[Alguerò, Capdevila, SDG, Masjuan, JM: 1902.04900]

The main 1D scenarios with present value of R_K are still too packed within 0.5σ to disentangle the correct pattern.

Q_5 can disentangle relevant scenarios?

Only Belle has been able to measure Q_5 up to now: $Q_5^{[1,6]}{}^{\text{Belle}} = 0.656 \pm 0.496$

[S. Wehle et al. PRL118 (2017)]

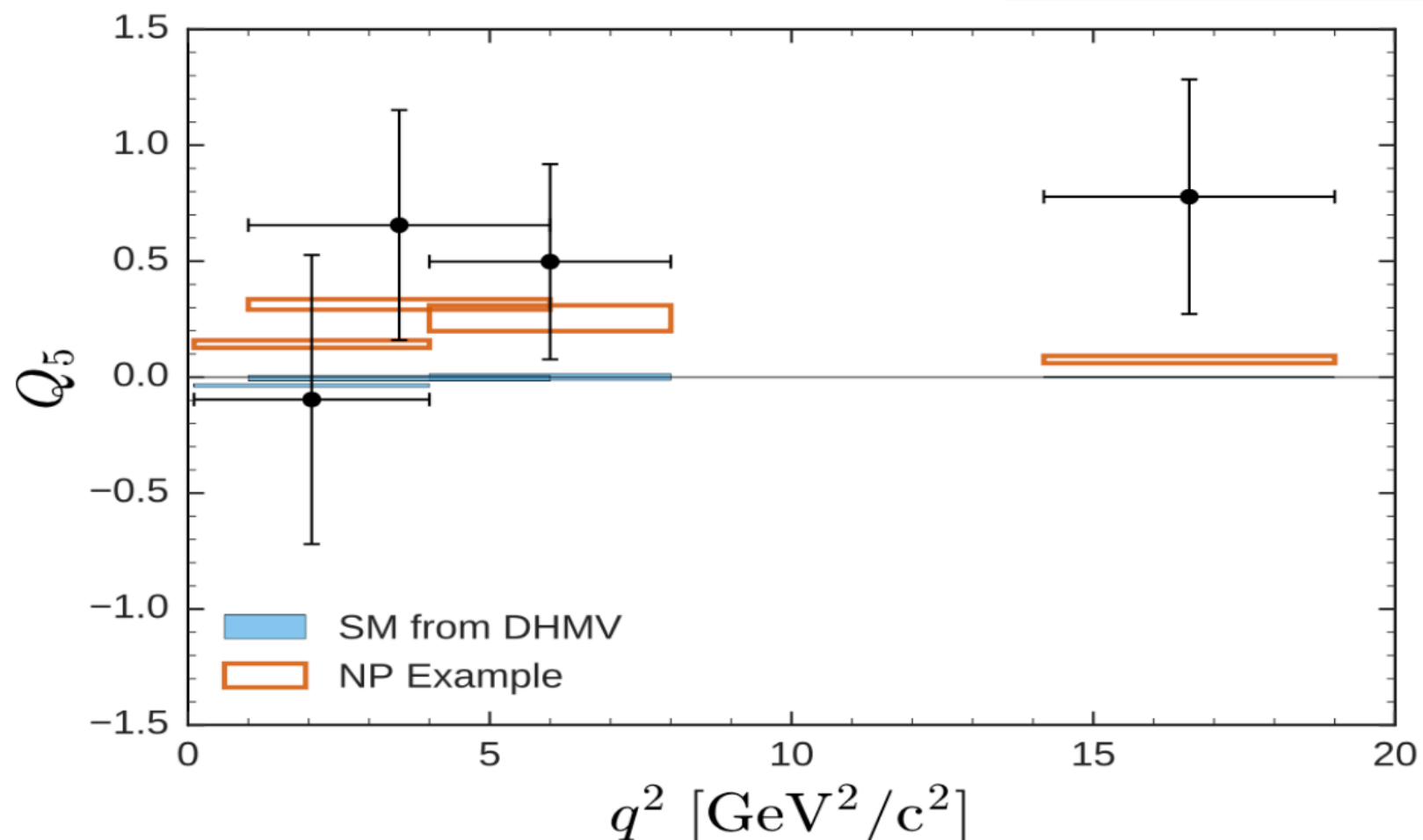


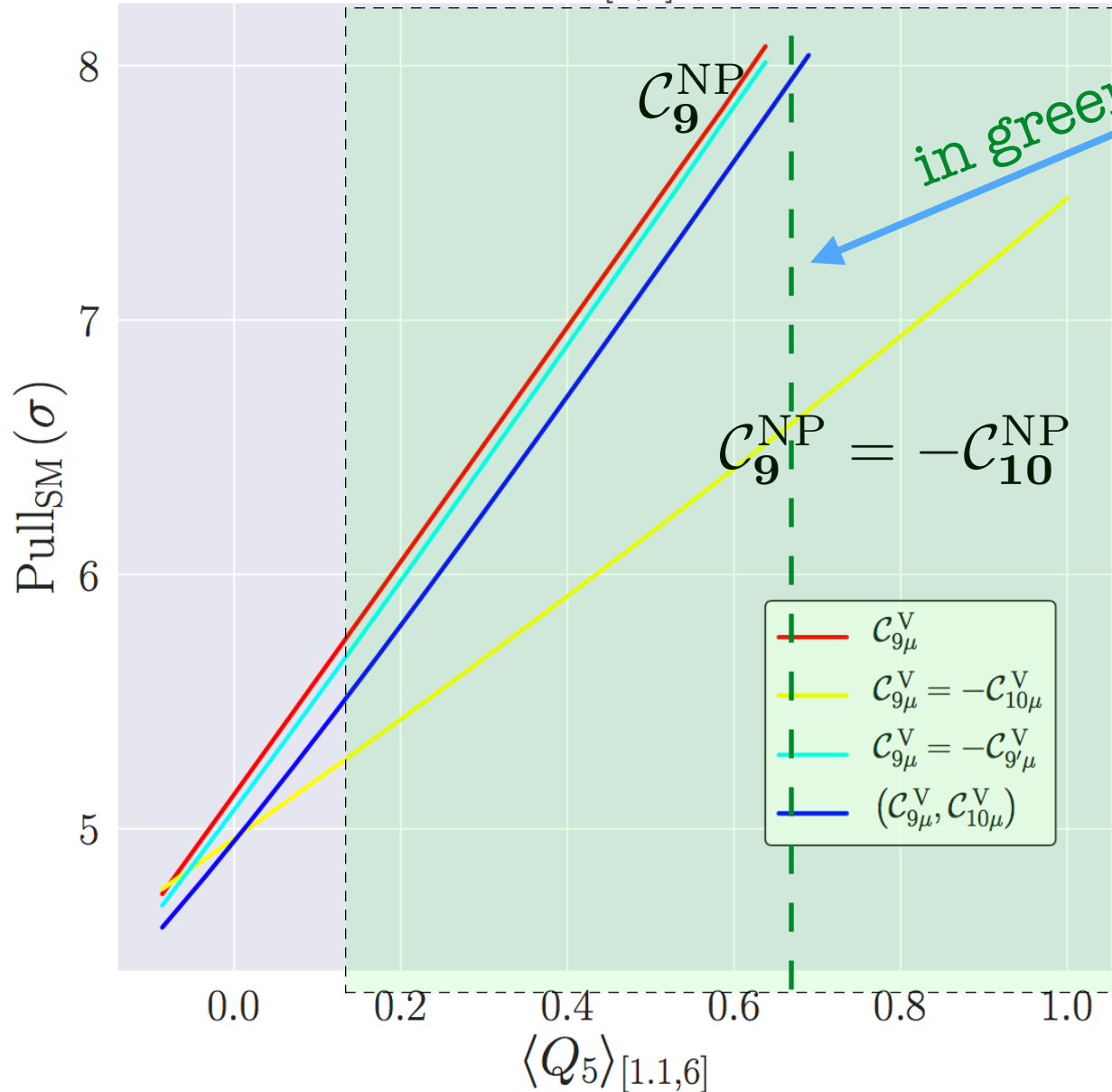
Table 2: Results for the lepton-flavor-universality-violating observables Q_4 and Q_5 . The first uncertainty is statistical and the second systematic.

q^2 in GeV^2/c^2	Q_4	Q_5
[1.00, 6.00]	$0.498 \pm 0.527 \pm 0.166$	$0.656 \pm 0.485 \pm 0.103$
[0.10, 4.00]	$-0.723 \pm 0.676 \pm 0.163$	$-0.097 \pm 0.601 \pm 0.164$
[4.00, 8.00]	$0.448 \pm 0.392 \pm 0.076$	$0.498 \pm 0.410 \pm 0.095$
[14.18, 19.00]	$0.041 \pm 0.565 \pm 0.082$	$0.778 \pm 0.502 \pm 0.065$

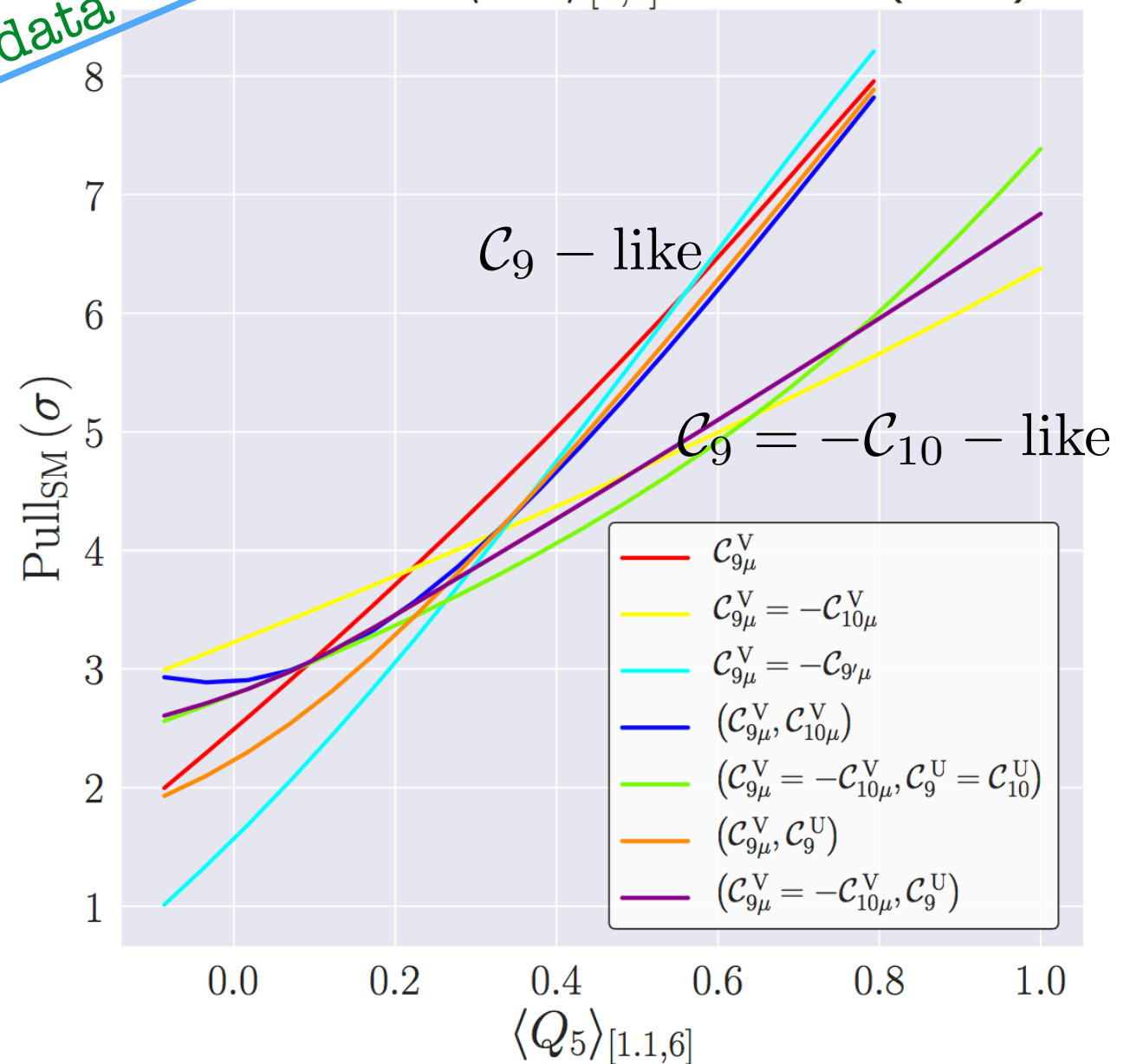
Q_5 can disentangle relevant scenarios?

Instead Q_5 groups relevant scenarios differently. $Q_{5[1,6]}^{\text{Belle}} = 0.656 \pm 0.496$

Global Fits $\langle R_K \rangle_{[1,6]} = 0.842 (+1\sigma)$



LFUV Fits $\langle R_K \rangle_{[1,6]} = 0.842 (+1\sigma)$



All scenarios with $C_{9\mu}^V$ **are packed** as well as those with $C_{9\mu}^V = -C_{10\mu}^V$ **BUT in two different sets. Also:**

- * **if $Q_5 \geq 0.3$ $C_{9\mu}^V$ scenarios are preferred.**
- * **if $Q_5 < 0$ then a scenario with only $C_{10} > 0$ can work.**

Conclusions

- After the updates of R_{K} (LHCb), R_{K^*} (Belle) and $B_s \rightarrow \mu\mu$ we find:
 - **no dramatic changes** in the hierarchy of 1D hypothesis:
 - C_9 and $C_9 = -C_9'$ preferred with All fit [178 obs] significance 5.8 (5.7) σ
 - $C_9 = -C_{10}$ preferred with LFUV fit [20 obs] significance 4.0 σ
 - 2D **new emerging scenarios including RHC** with $C_9' > 0$ & $C_{10}' < 0$:
($C_{9\mu}, C'_{9\mu} = -C'_{10\mu}$) (6.1 σ)
 - LFU-NP structure is **quite dependent** on LFUV-NP structure:
A $C_9^V = -C_{10}^V$ struct. is preferred in All-fit only in presence of C_9^U
 - We have found a link of charged & neutral anomalies & LFU NP in scn 8.
 - While R_{K} cannot disentangle scenarios, **a measurement of Q_5** such that:
 - $Q_5 \geq 0.3$ would **favour** scenarios with $C_{9\mu} < -1$
 - $Q_5 < 0$ would **favour** scenarios with $C_{10\mu} > 0$
- new data on Q_5 , R_ϕ , updated optimized observables is essential.
Belle II inputs are also crucial.