SoCal BSM 2019

Hints for BSM from B-physics

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No tree-level flavor changing neutral currents
in the Standard Model (SM).

SENSITIVITY TO NEW PHYSICS (NP) !

b —> s ll transitions

EXCITING EXPERIMENTAL PICTURE

$\sim X = 3.5\,\sigma$

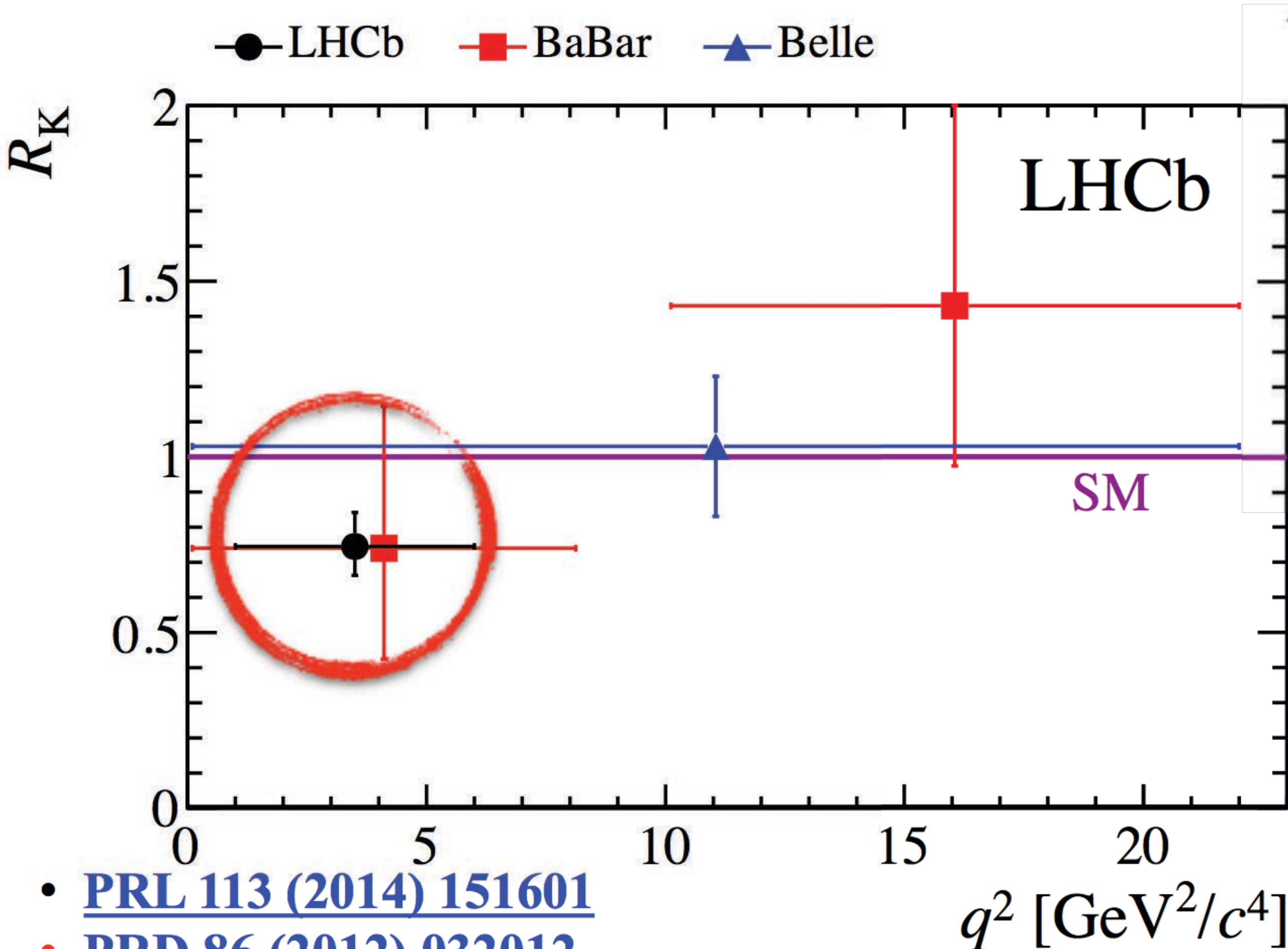
Angular analysis of $B \longrightarrow K^*\mu\mu$

$\sim 2.5\,\sigma$

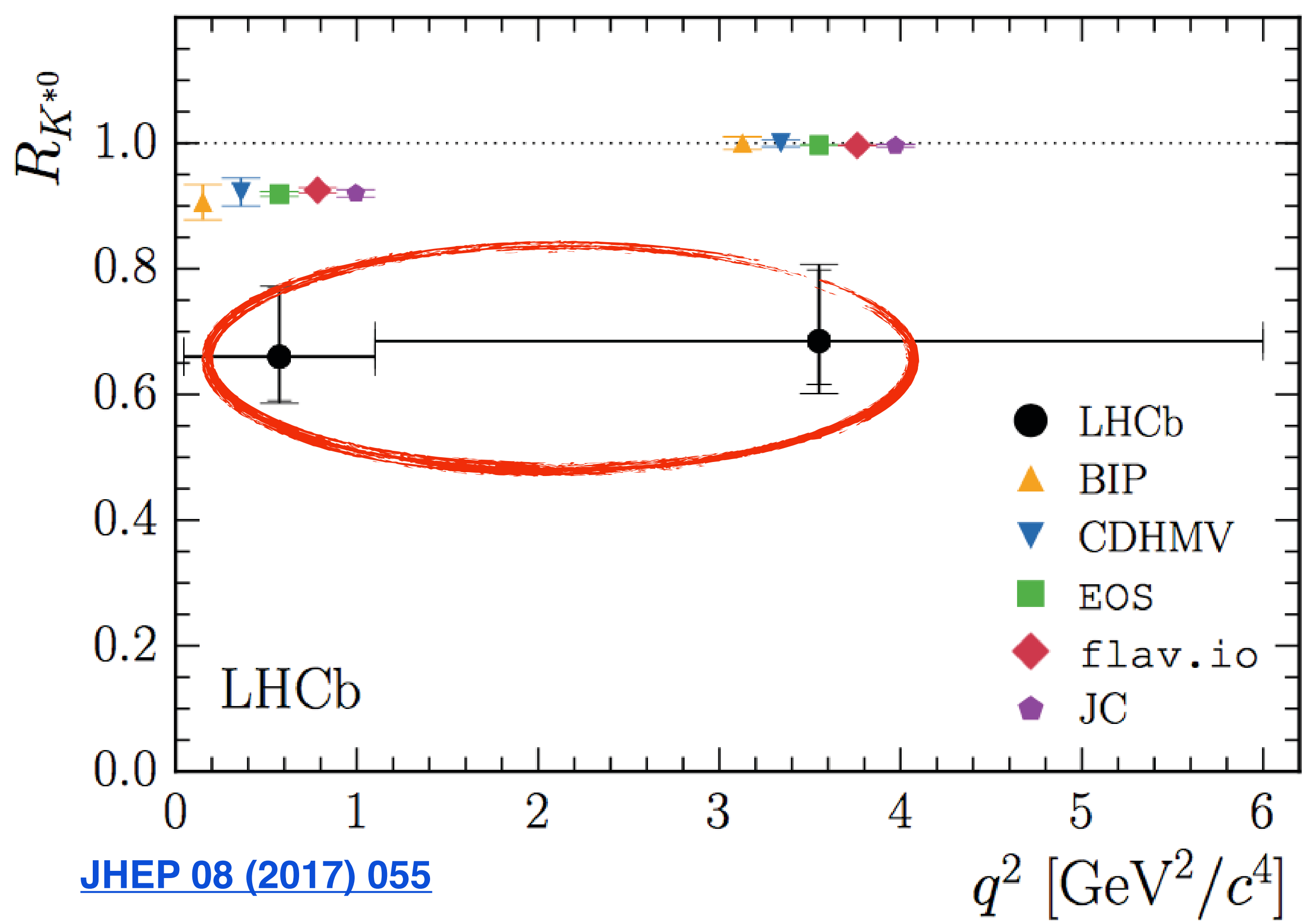
R_{K,K^*} measurements

+ deviations in BR of several modes

$$R_{K^{(*)}} \equiv \frac{Br\left(B \to K^{(*)}\mu\mu\right)}{Br\left(B \to K^{(*)}ee\right)}$$



- [PRL 113 (2014) 151601](#)
- [PRD 86 (2012) 032012](#)
- [PRL 103 (2009) 171801](#)



[JHEP 08 (2017) 055](#)

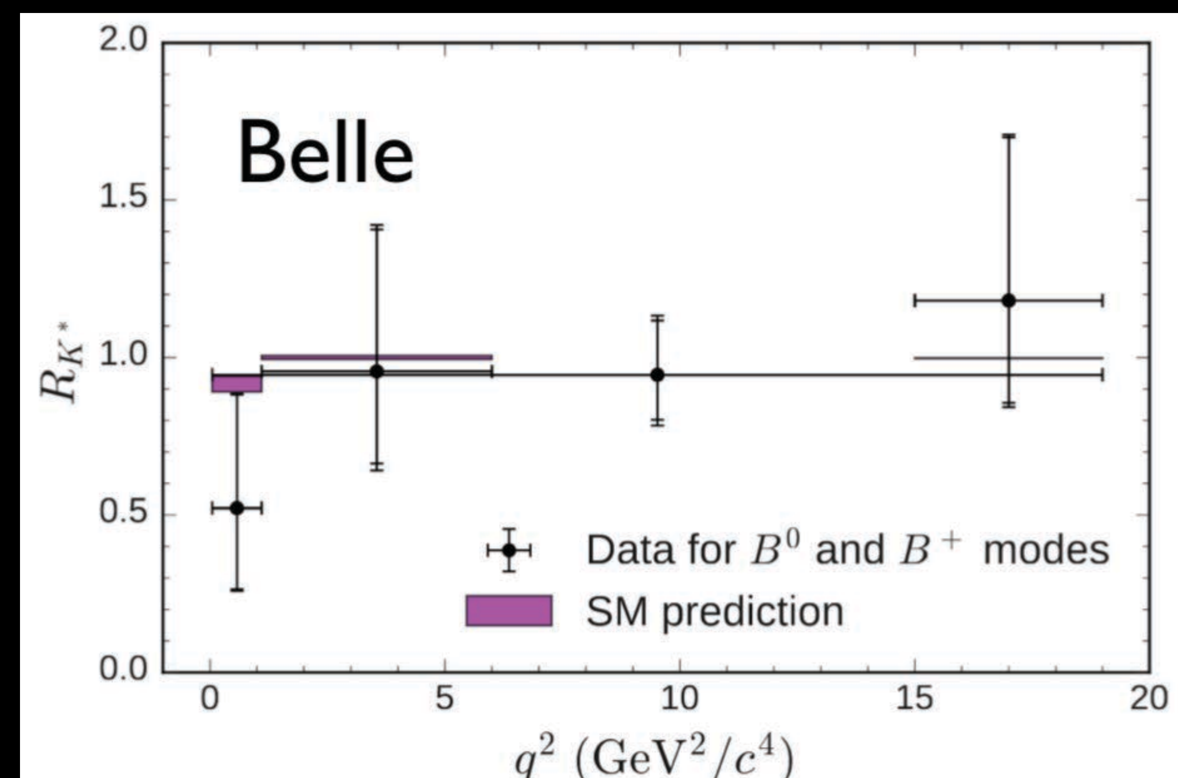
@ End of March :

Rencontres de Moriond 2019

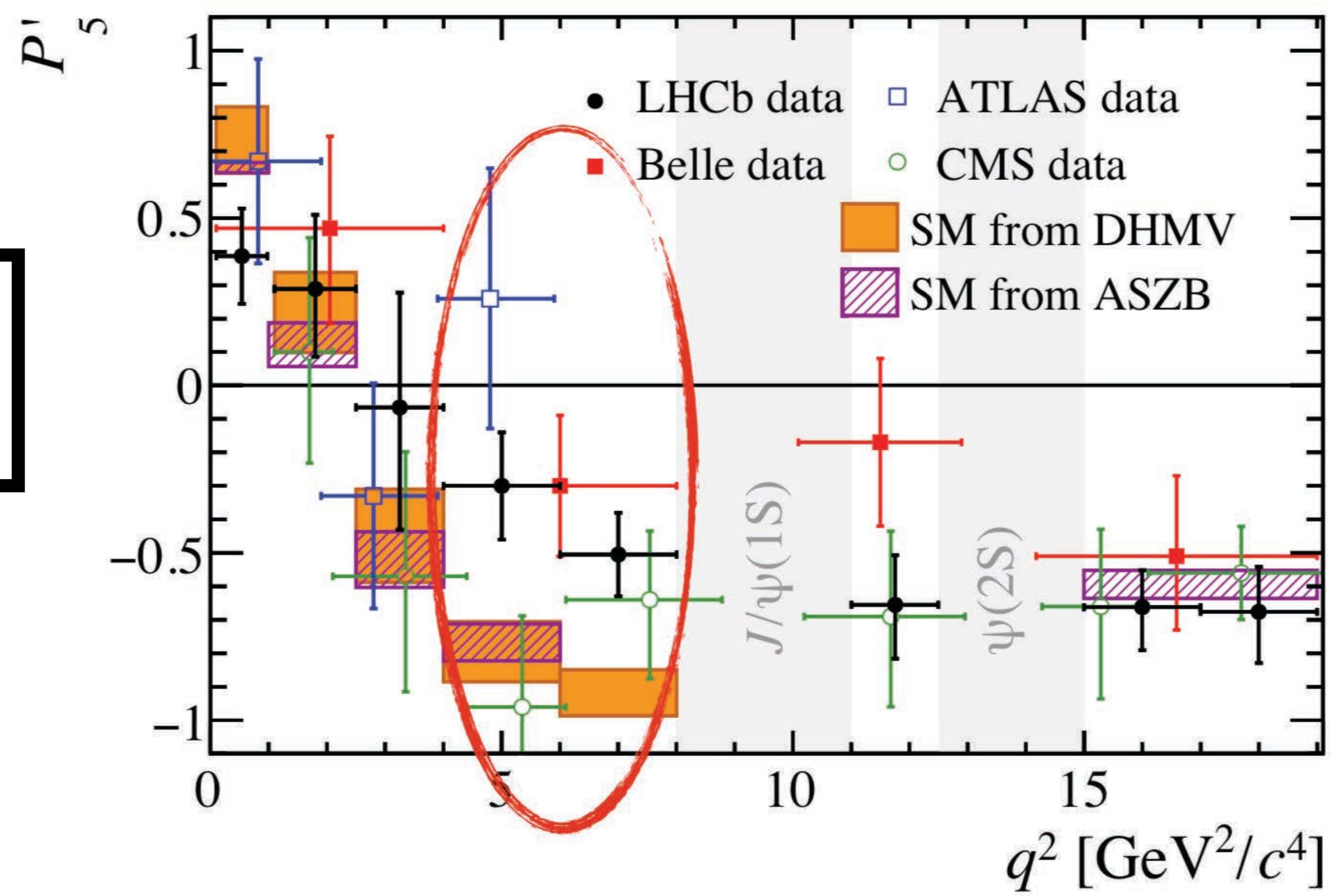
Adding 2015 and 2016 data, R_K becomes:

$$R_K = 0.846\ ^{+0.060}_{-0.054}\,(\text{stat.})\ ^{+0.016}_{-0.014}\,(\text{syst.})$$

$\sim$ **2.5** $\boldsymbol{\sigma}$ from SM. **LHCb**

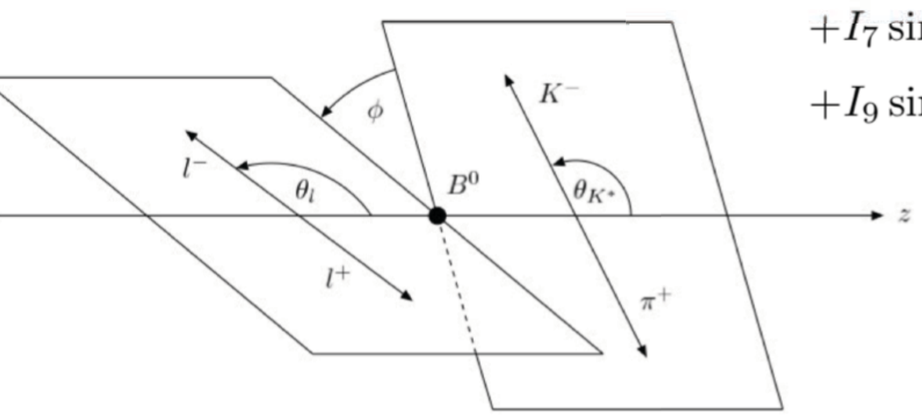


ANGULAR ANALYSIS OF $B \to K^{*} \mu \mu$

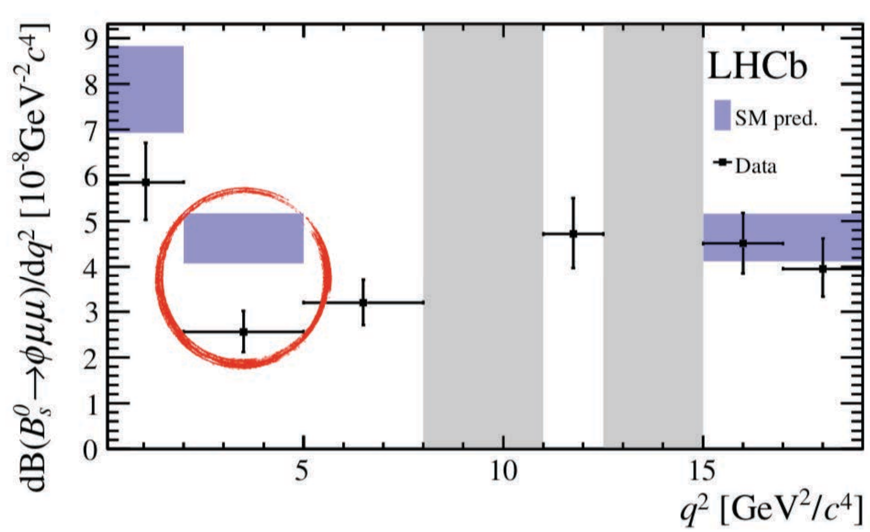


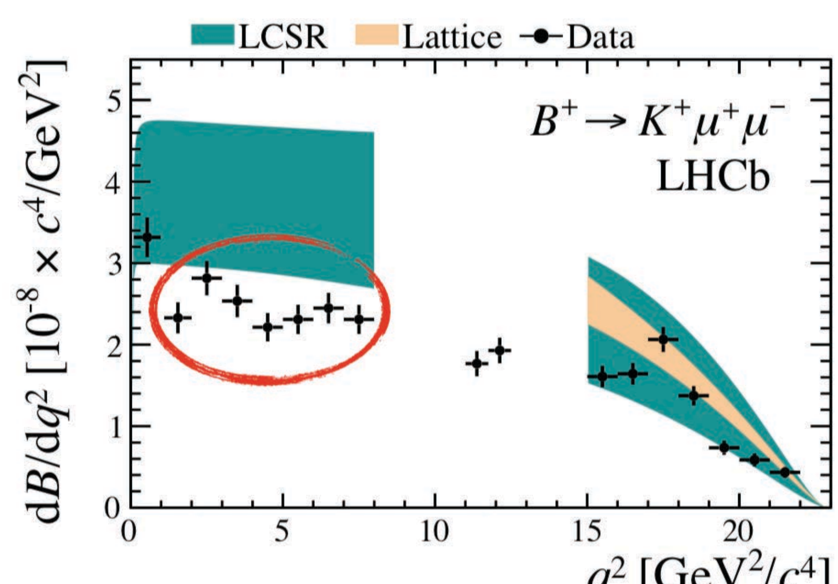
- LHCb
- $4.0 < q^2 / \mathrm{GeV}^2 < 6.0$
  $6.0 < q^2 / \mathrm{GeV}^2 < 8.0$
- 3.4 σ
- ATLAS
- $4.0 < q^2 / \mathrm{GeV}^2 < 6.0$
- 2.7 σ
- BELLE
- $4.0 < q^2 / \mathrm{GeV}^2 < 8.0$
- 2.6 σ
- CMS
- No discrepancies!

$$\frac{d^{(4)}\Gamma}{dq^2 d(\cos\theta_\ell) d(\cos\theta_K) d\phi} = \frac{9}{32\pi}\Big(I_1^s \sin^2\theta_K + I_1^c \cos^2\theta_K + (I_2^s \sin^2\theta_K + I_2^c \cos^2\theta_K)\cos 2\theta_\ell$$
$$+ I_3 \sin^2\theta_K \sin^2\theta_\ell \cos 2\phi + I_4 \sin 2\theta_K \sin 2\theta_\ell \cos\phi$$
$$+ I_5 \sin 2\theta_K \sin\theta_\ell \cos\phi + (I_6^s \sin^2\theta_K + I_6^c \cos^2\theta_K)\cos\theta_\ell$$
$$+ I_7 \sin 2\theta_K \sin\theta_\ell \sin\phi + I_8 \sin 2\theta_K \sin 2\theta_\ell \sin\phi$$
$$+ I_9 \sin^2\theta_K \sin^2\theta_\ell \sin 2\phi\Big).$$



DISCREPANCIES ALSO IN BRs, SAME q^2 BIN!





Anatomy of $B \to K^{(*)}\ell\ell$

$$H_\lambda^{(V)}(q^2) \propto 2\frac{m_b m_B}{q^2}\left(C_7^{\rm eff} + \Delta C_{7,\lambda}^{\rm QCDf}(q^2)\right)\tilde{T}_\lambda(q^2) + C_9^{\rm eff}(q^2)\tilde{V}_\lambda(q^2)$$

HELICITY AMPLITUDES : $\lambda = \pm, 0\,.$

$$+\Delta C_{9,\lambda}^{\rm QCDf}(q^2) + 16\pi^2\frac{m_B^2}{q^2}\tilde{h}_\lambda(q^2)\,,$$

$$H^{(P)}(q^2) \propto 2\frac{m_\ell m_B}{q^2}C_{10}\left(1+\frac{m_s}{m_b}\right)\tilde{S}(q^2)\,, \qquad H_\lambda^{(A)}(q^2) \propto C_{10}\,\tilde{V}_\lambda(q^2)\,.$$

- SHORT DISTANCE @ DIM 6

SM Wilson coeffs @ ~ m_b : C_7 ~ -1/3 , C_9 ~ 4 , C_{10} ~ -4

FOCUS ON LFUV —> NP IN SEMILEPTONIC OPERATORS

SHIFTS OF SM WILSON COEFFS @ LOW ENERGY

$$O_{9[10],\ell}^{(\prime)} = \bar{s}_{L(R)}\gamma_\mu[\gamma_5]b_{L(R)}\bar{\ell}\gamma^\mu[\gamma_5]\ell \;\leftrightarrow\; C_{9[10],\ell}^{(\prime)}$$

ANATOMY OF $B \to K^{(*)}\ell\ell$

$$H_\lambda^{(V)}(q^2) \propto 2\frac{m_b m_B}{q^2}\left(C_7^{\rm eff} + \Delta C_{7,\lambda}^{\rm QCDf}(q^2)\right)\boxed{\tilde{T}_\lambda(q^2)} + C_9^{\rm eff}(q^2)\boxed{\tilde{V}_\lambda(q^2)}$$

HELICITY AMPLITUDES : $\lambda = \pm, 0\,.$

$$+\Delta C_{9,\lambda}^{\rm QCDf}(q^2) + 16\pi^2\frac{m_B^2}{q^2}\boxed{\tilde{h}_\lambda(q^2)}\,,$$

$$H^{(P)}(q^2) \propto 2\frac{m_\ell m_B}{q^2}C_{10}\left(1+\frac{m_s}{m_b}\right)\boxed{\tilde{S}(q^2)}\,, \qquad H_\lambda^{(A)}(q^2) \propto C_{10}\boxed{\tilde{V}_\lambda(q^2)}\,.$$

- SHORT DISTANCE @ DIM 6

  SM Wilson coeffs @ ~ m_b : C_7 ~ -1/3 , C_9 ~ 4 , C_{10} ~ -4

- FORM FACTORS FOR B —> $K^{(*)}$

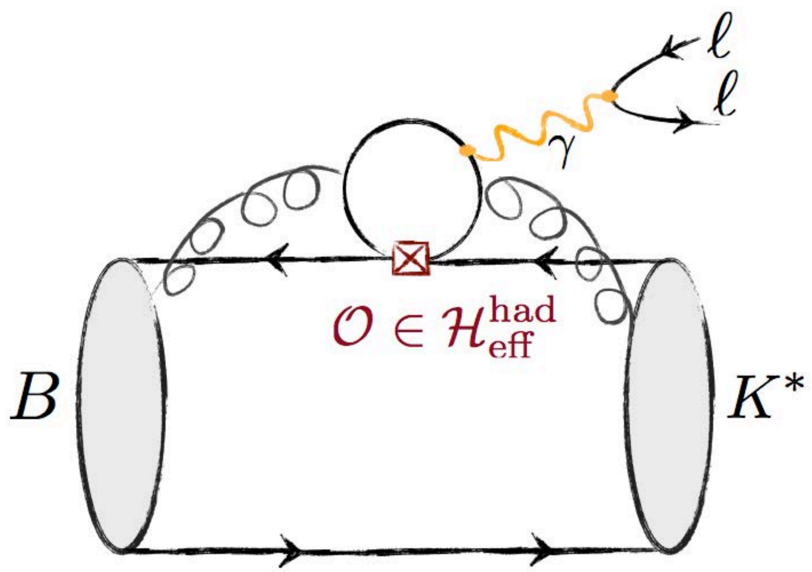
  state-of-the-art from LQCD & LCSR computations

- QCD CONTRIBUTIONS FROM C x C & PENGUINS

  QCD factorization for leading effects of $O(\Lambda_{QCD}/m_b)$,

  but non-factorizable power corrections also present.

KNOWN UKNOWNS IN $B \to K^* \ell\ell$

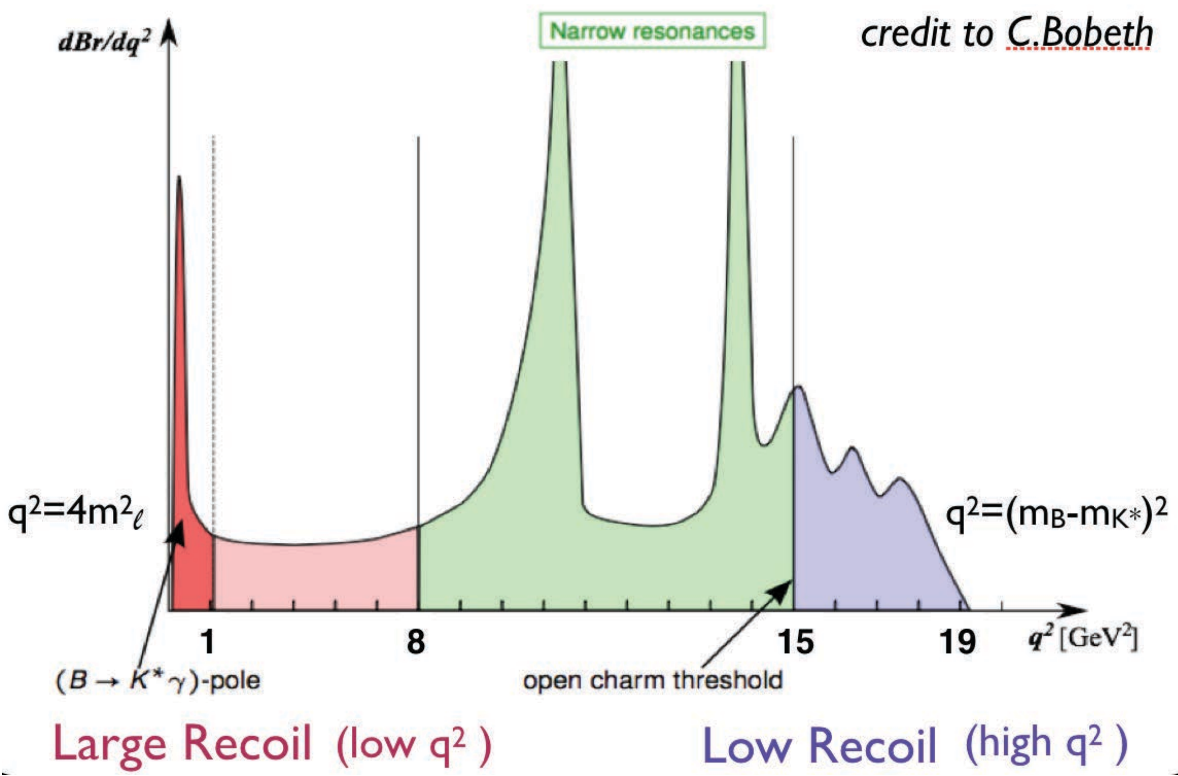


$$h_\lambda(q^2) = \frac{\epsilon^*_\mu(\lambda)}{m_B^2} \int d^4x e^{iqx} \langle \bar{K}^* | T\{ j^\mu_{\rm em}(x) \mathcal{H}_{\rm eff}^{\rm had}(0) \} | \bar{B} \rangle$$

i) LCSR estimate based on small q²

ii) Single soft gluon approximation

iii) Dispersion relations



Khodjamirian et al. `10

$$\Delta C_{9,i}^{(c\bar{c})}(q^2) = \frac{r_{1,i}\left(1 - \frac{\bar{q}^2}{q^2}\right) + \Delta C_{9,i}^{(c\bar{c})}(\bar{q}^2)\frac{\bar{q}^2}{q^2}}{1 + r_{2,i}\frac{\bar{q}^2 - q^2}{m_{J/\psi}^2}}$$

Similar results more recently found in:
Blake et al. `17, Bobeth et al. `17

"OPTIMISTIC" VIEW = TRUST LCSR COMPLETELY!

—> Phenomenological Model Driven (PMD)

KNOWN UKNOWNS IN $B \to K^* \ell\ell$

Phenomenological Data Driven (PDD)

$$\tilde{h}_\lambda(q^2) = \sum_k \tilde{h}_\lambda^{(k)} \left(\frac{q^2}{\mathrm{GeV}^2}\right)^k$$

up to $k = 2$, 16 real coeffs are involved

ΔC_9 (V semi-lep operator) ΔC_7 (e.m. dipole operator)

$$\left\{\left(C_9^{\text{eff}} + h_-^1\right) V_{L-} + \frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\text{eff}} + h_-^0\right) T_{L-} - 16\pi^2 h_-^2\, q^4\right]\right\}$$

$$\left\{\left(C_9^{\text{eff}} + h_-^1\right) \tilde{V}_{L0} + \frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\text{eff}} + h_-^0\right) \tilde{T}_{L0} - 16\pi^2 \left(\tilde{h}_0^0 + \tilde{h}_0^1\, q^2\right)\right]\right\}$$

$$\left\{\left(C_9^{\text{eff}} + h_-^1\right) V_{L+} + \frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\text{eff}} + h_-^0\right) T_{L+} - 16\pi^2 \left(h_+^0 + h_+^1\, q^2 + h_+^2\, q^4\right)\right]\right\}$$

DO NOT HAVE $C_{7,9}$ SHORT-DISTANCE COUNTERPART!

"CONSERVATIVE" APPROACH = TRUST LCSR RESULTS **ONLY** AT $q^2 \leq$ GeV^2.

REQUIRE ALSO |h+/h-| << 1 AT LARGE RECOIL (*Jager & Camalich`14*).

BAYESIAN ANALYSIS OF $B \to K^{(*)}\ell\ell$

https://github.com/silvest/HEPfit

HEPfit

57 TO **77** PARAMETERS **VARIED** IN $b \to s\,\ell\ell$ FITS (PRIORS: GAUSSIAN/FLAT)

- **FIT AVAILABLE EXPERIMENTAL INFO. IN PARTICULAR, FOCUS ON:**

LHCb CP-CONSERVING ANGULAR OBS + BRs FOR K(*) MODES AT LARGE RECOIL + CMS & ATLAS MEASUREMENTS, BELLE DATA ON P'_4 & P'_5 , UPDATE ON $B_s \to \mu\mu$

- **BAYESIAN MODEL COMPARISON WITH INFORMATION CRITERION:**

$$IC \equiv -2\overline{\ln \mathcal{L}} + 4\sigma^2_{\ln \mathcal{L}}$$ **(BEST MODEL <—> LOWEST *IC* VALUE)**

THIS IS NOT ABOUT LIVER PROBLEMS …

HEP-FIT SYRUP

Natural hepatoprotective

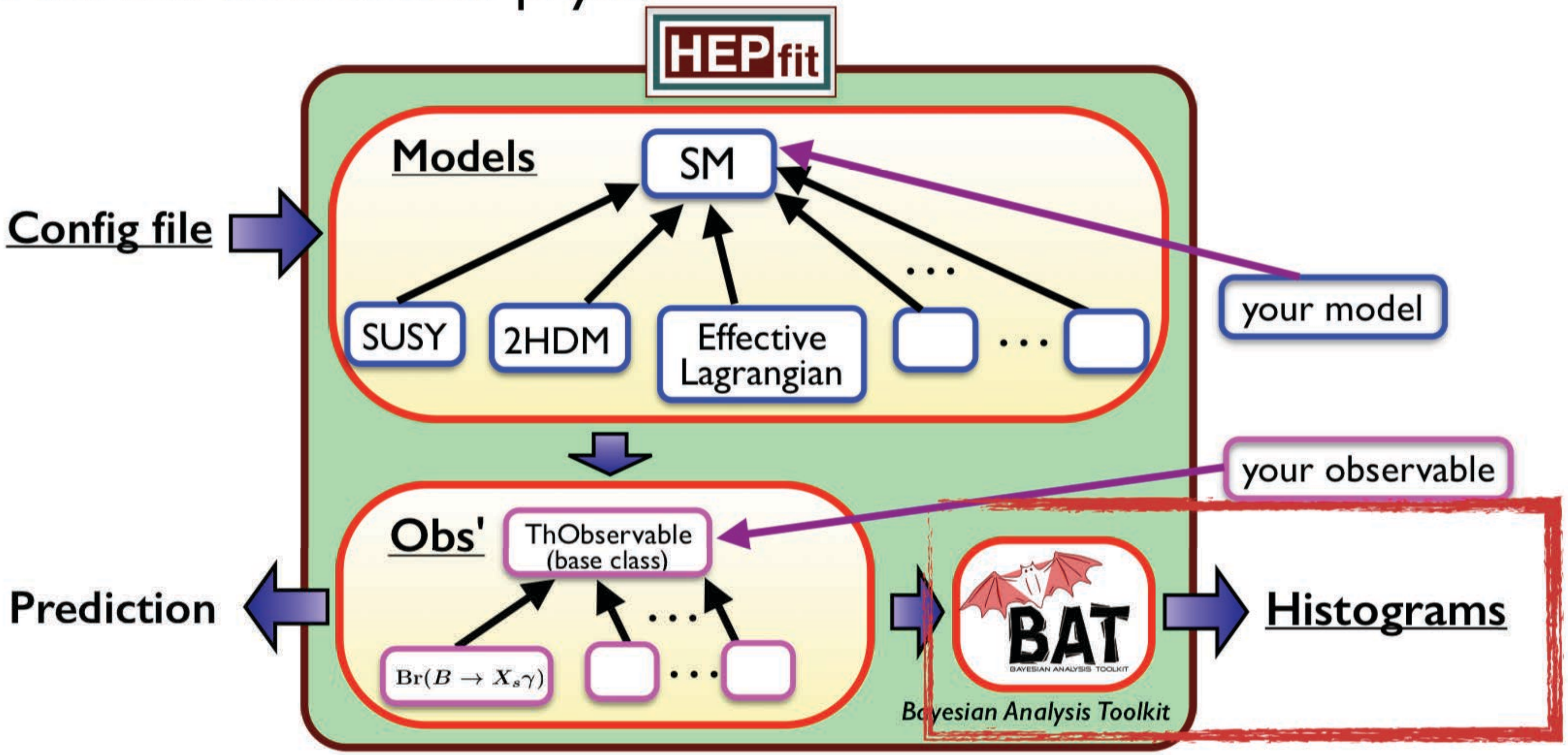
Helps in proper functioning of the liver

Combats the liver inflammation(chronic or acute)

Empairs enlarged liver

THE HEPfit CODE

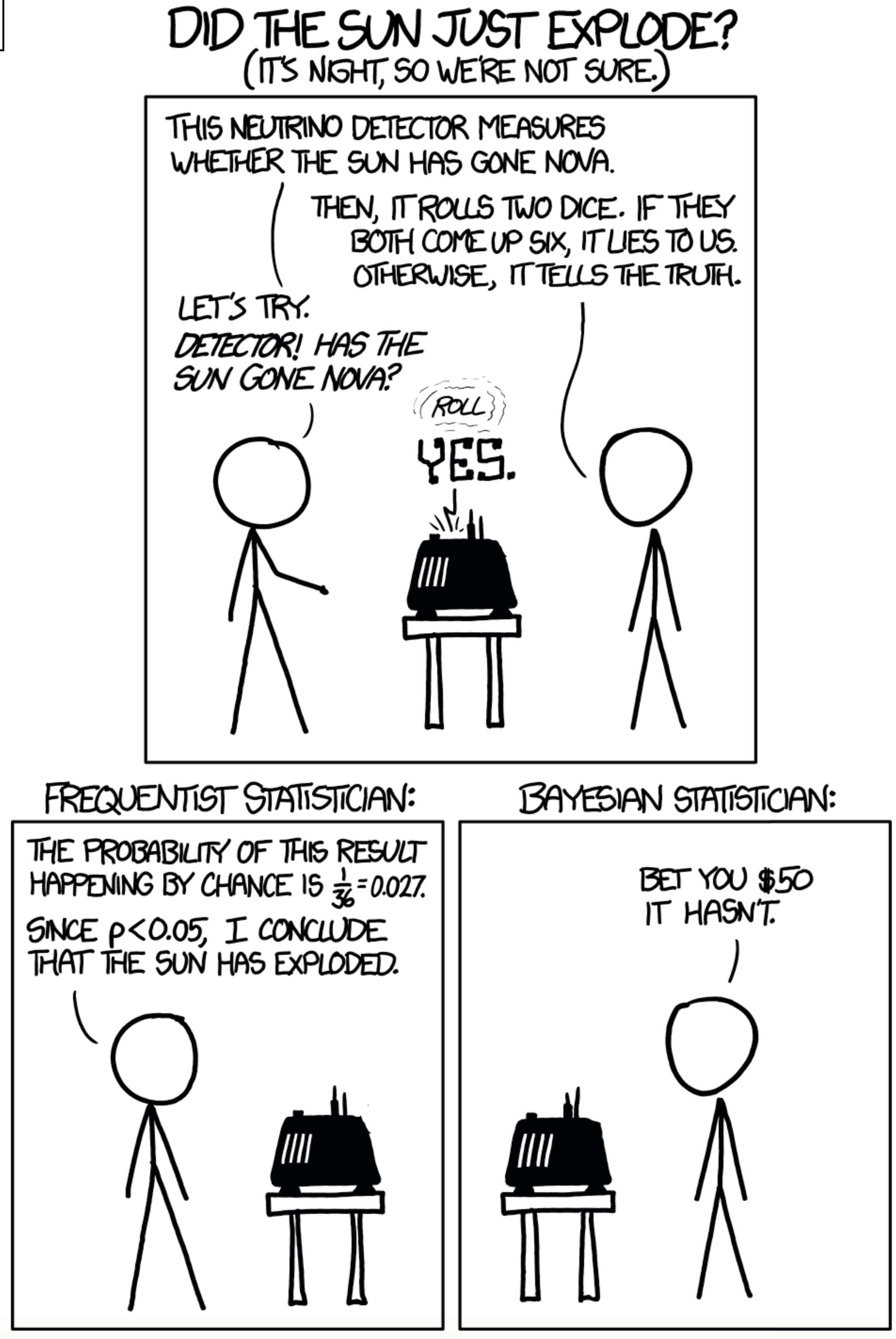
- General **H**igh **E**nergy **P**hysics **fit**ting tool to combine indirect and direct searches of new physics



- Flexible open-source C++ code
- Stand-alone and library modes to compute observables in the SM & beyond
- Add new models and/or observables as external modules
- Optional Bayesian Statistical Analysis framework (supports MPI parallelization)

http://hepfit.roma1.infn.it https://github.com/silvest/HEPfit

Frequentists vs. Bayesians



About the Angular Analysis of $B \longrightarrow K^{*}\mu\mu$

Anomalies in $B \to K^* \mu\mu$?

JHEP 1606 (2016) 116
arXiv:1512.07157

Phenomenological Model Driven (PMD)

$$\overline{\ln \mathcal{L}} = -48.7$$
$$\sigma^2_{\ln \mathcal{L}} = 6.9$$

IC = 125

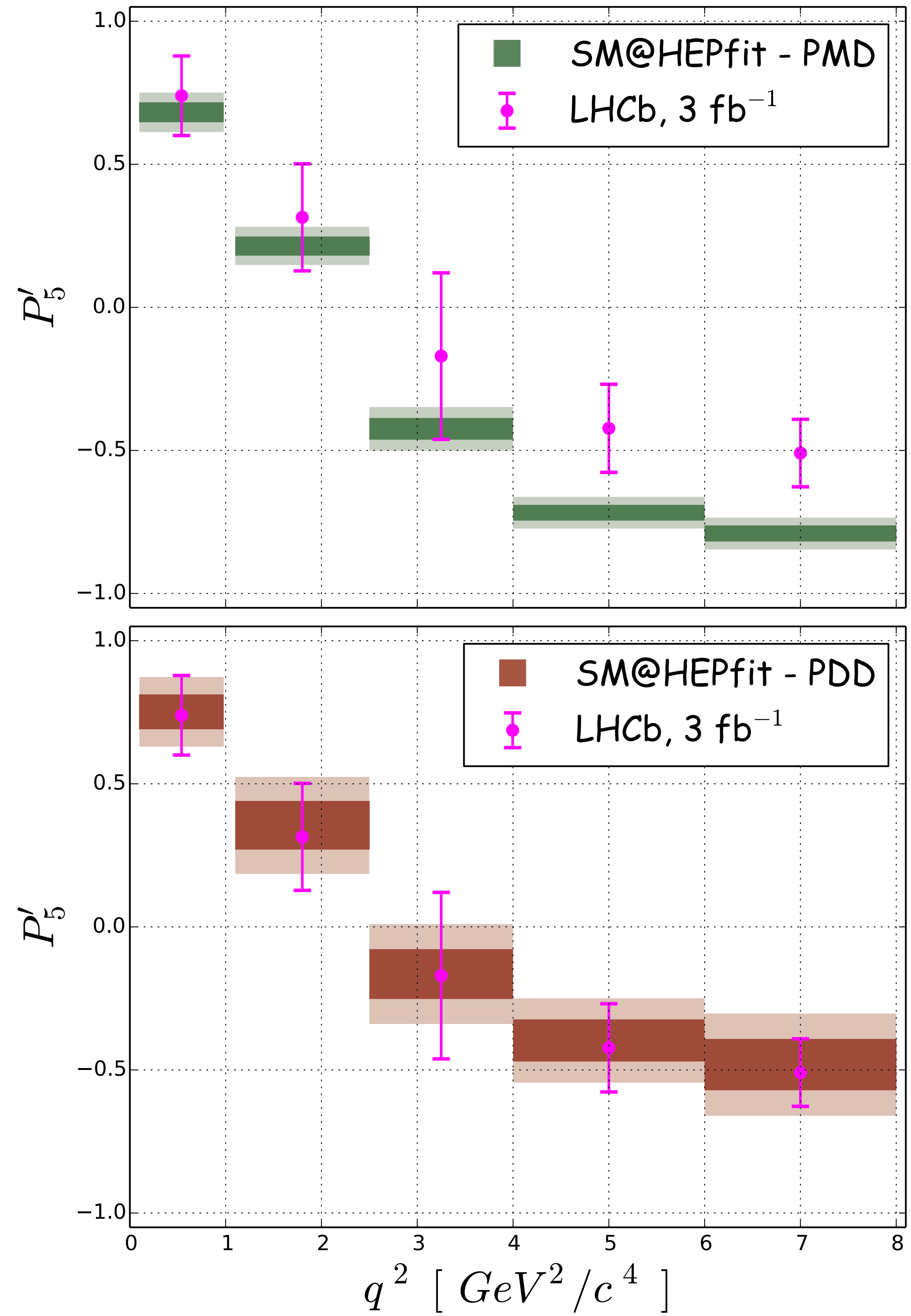
$$P'_5 = \frac{S_5}{\sqrt{F_L(1 - F_L)}}$$

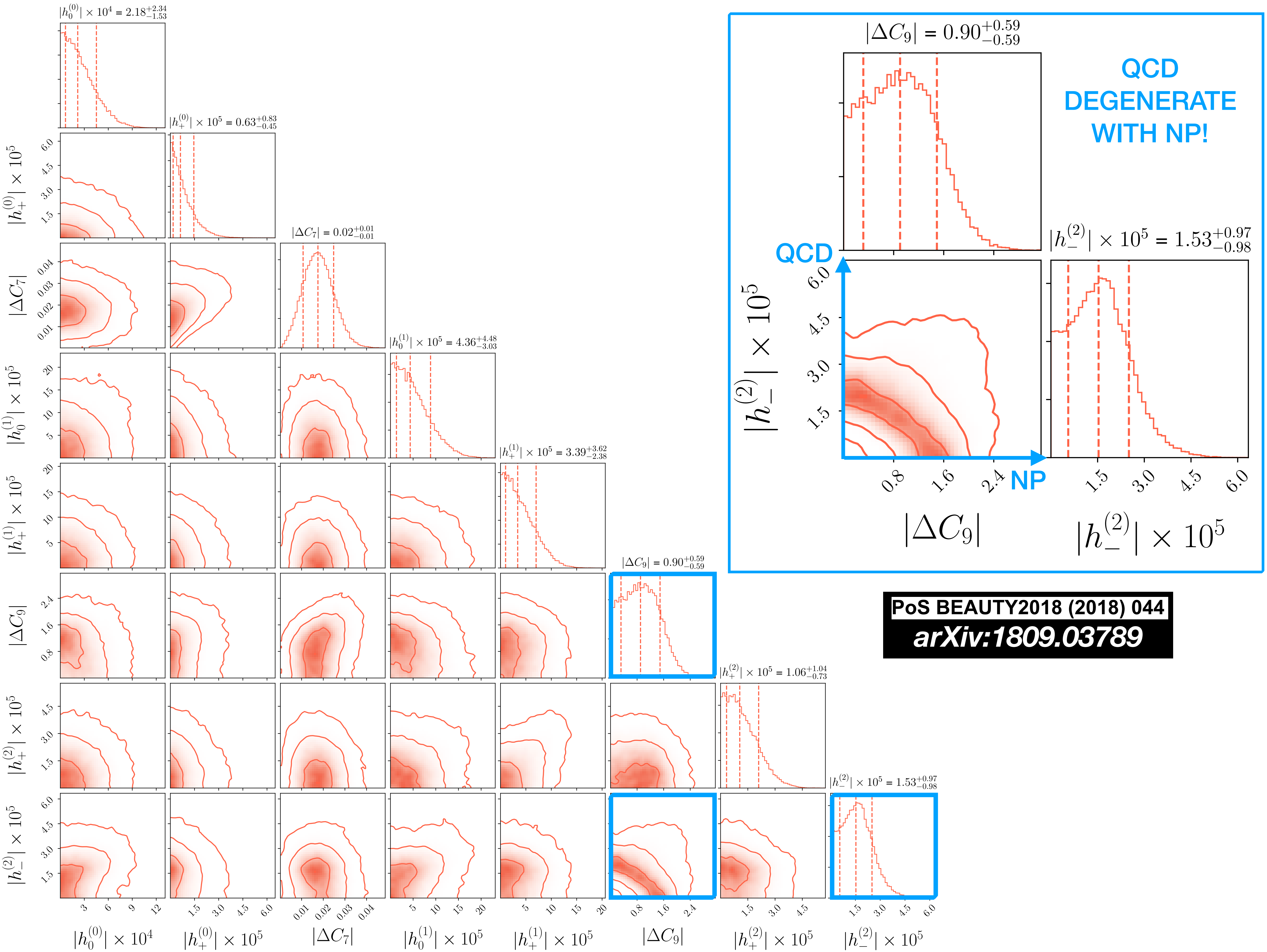
Descotes-Genon et al. 2013

Phenomenological Data Driven (PDD)

$$\overline{\ln \mathcal{L}} = -38.5$$
$$\sigma^2_{\ln \mathcal{L}} = 6.1$$

IC = 101



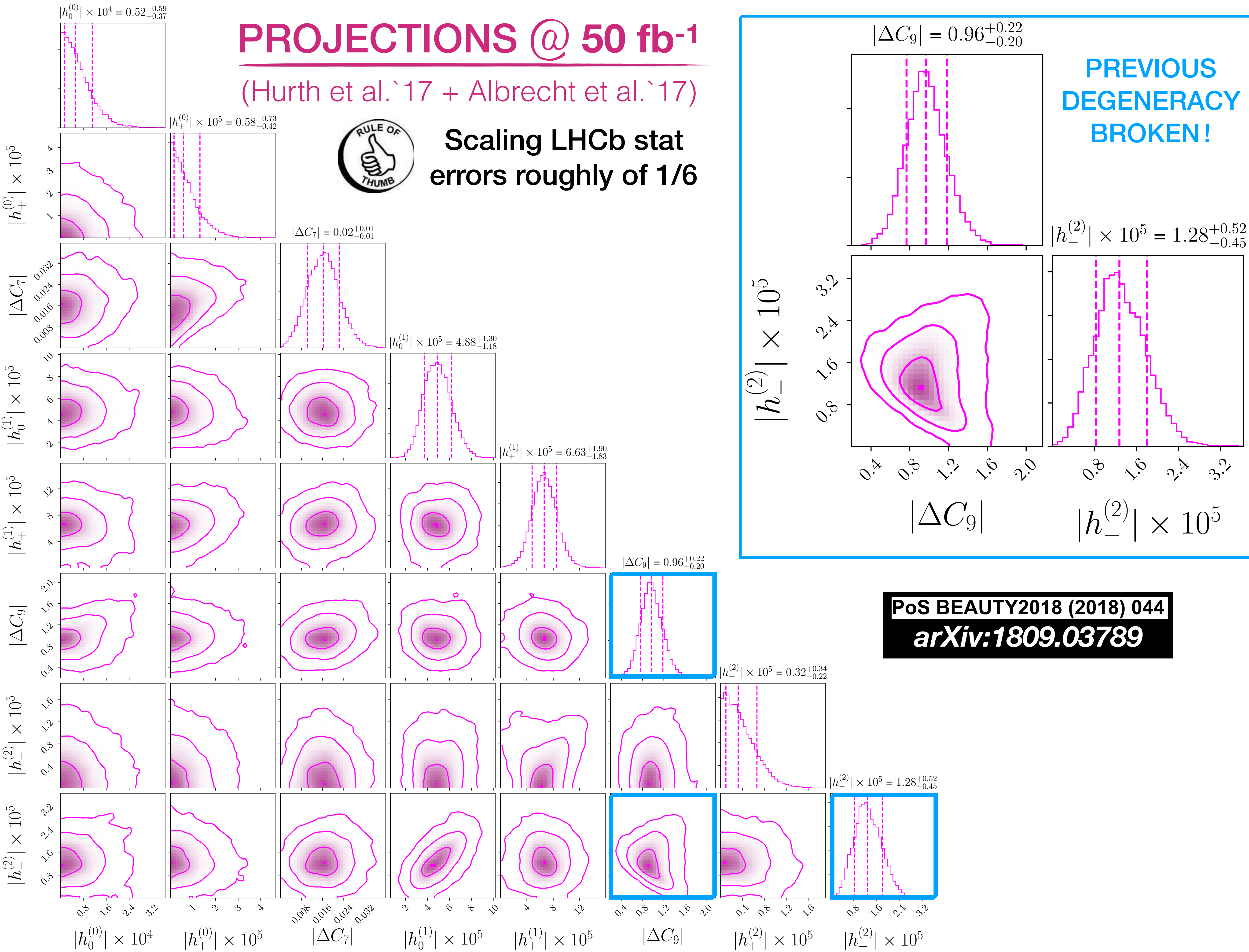


$|h_0^{(0)}| \times 10^4 = 2.18^{+2.34}_{-1.53}$
$|h_+^{(0)}| \times 10^5 = 0.63^{+0.83}_{-0.45}$
$|\Delta C_7| = 0.02^{+0.01}_{-0.01}$
$|h_0^{(1)}| \times 10^5 = 4.36^{+4.48}_{-3.03}$
$|h_+^{(1)}| \times 10^5 = 3.39^{+3.62}_{-2.38}$
$|\Delta C_9| = 0.90^{+0.59}_{-0.59}$
$|h_+^{(2)}| \times 10^5 = 1.06^{+1.04}_{-0.73}$
$|h_-^{(2)}| \times 10^5 = 1.53^{+0.97}_{-0.98}$
$|h_0^{(0)}| \times 10^4$
$|h_+^{(0)}| \times 10^5$
$|\Delta C_7|$
$|h_0^{(1)}| \times 10^5$
$|h_+^{(1)}| \times 10^5$
$|\Delta C_9|$
$|h_+^{(2)}| \times 10^5$
$|h_-^{(2)}| \times 10^5$
QCD
DEGENERATE
WITH NP!
QCD
NP
PoS BEAUTY2018 (2018) 044
arXiv:1809.03789

PROJECTIONS @ 50 fb^{-1}

(Hurth et al.`17 + Albrecht et al.`17)

Scaling LHCb stat errors roughly of 1/6



PoS BEAUTY2018 (2018) 044

arXiv:1809.03789

A Global Analysis for New Physics in $b \longrightarrow s\,ll$

Educated Guesses for NP

1) P'_5 in K^* angular analysis very sensitive to $C_{9,\mu}$

Altmannshofer & Straub 2015, Descotes-Genon et al. 2015, Jager & Camalich 2016

2) LFUV ratios essentially constrain (μ - e) combination

***2)** and **3)** originally from*
Hiller** & **Schmaltz 2014

$C^{(\prime)}{}_{9,10,\,\mu-e}$

D'Amico et al. 2016
Mauri et al. 2018
Ciuchini et al. 2018

3) Ratio of LFUV ratios can spot handness of b-to-s current

$$R_{K^*}[1.1,6]/R_K[1.1,6] \simeq 0.86 \pm 0.13$$

see discussion in *Ciuchini et al. 2019*

4) $B_{(s)} \longrightarrow ll$ good probe of axial leptonic coupling

Tension in $B_s \longrightarrow \mu\mu$, see discussion in *Aebischer et al. 2019*

Results in the Weak Effective Theory

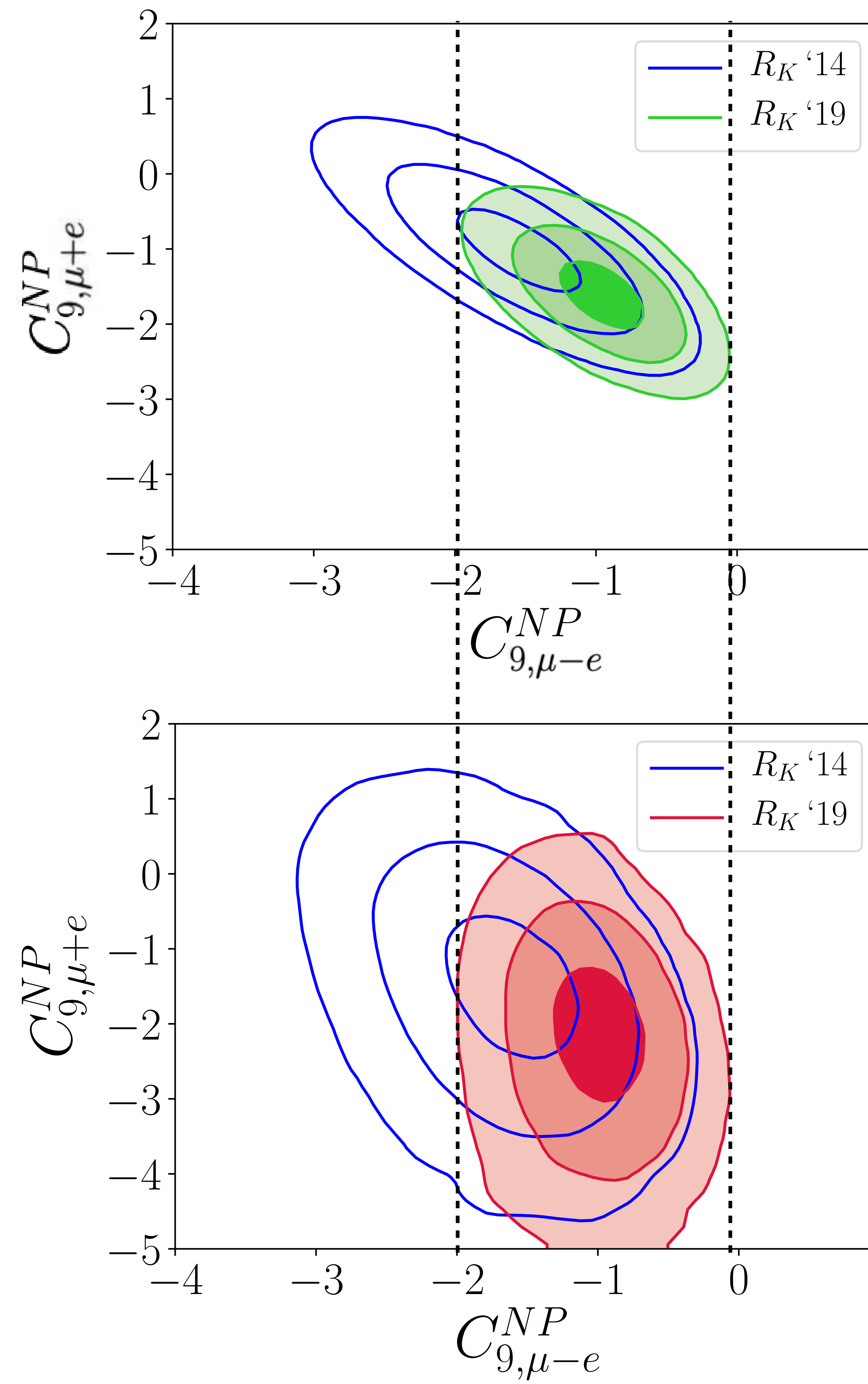
EPJC 79 (2019) no.8 ,719
arXiv: 1903.09632

PDD / PMD		mean(rms)	ΔIC
$C^{\rm NP}_{9,\mu}$	PDD	-1.20(27)	14
	PMD	-1.21(16)	50
$C^{\rm NP}_{10,e}$	PDD	-0.87(24)	15
$(C^{\rm NP}_{9,\mu}, C^{\rm NP}_{9,e})$	PDD	(-1.61(48), -0.56(53))	13
	PMD	(-1.28(18), -0.27(34))	48
$(C^{\rm NP}_{9,\mu}, C'^{,\rm NP}_{9,\mu})$	PDD	(-1.61(33), 0.72(34))	17
	PMD	(-1.30(15), 0.53(24))	54
$(C^{\rm NP}_{9,\mu}, C'^{,\rm NP}_{10,\mu})$	PDD	(-1.55(32), -0.44(14))	24
	PMD	(-1.38(16), -0.37(12))	61

$$\Delta IC = IC_{\rm SM} - IC_{\rm NP}$$

1 to 3	Not worth more than a bare mention
3 to 20	Positive
20 to 150	Strong
>150	Very strong

Kass and Raftery '95



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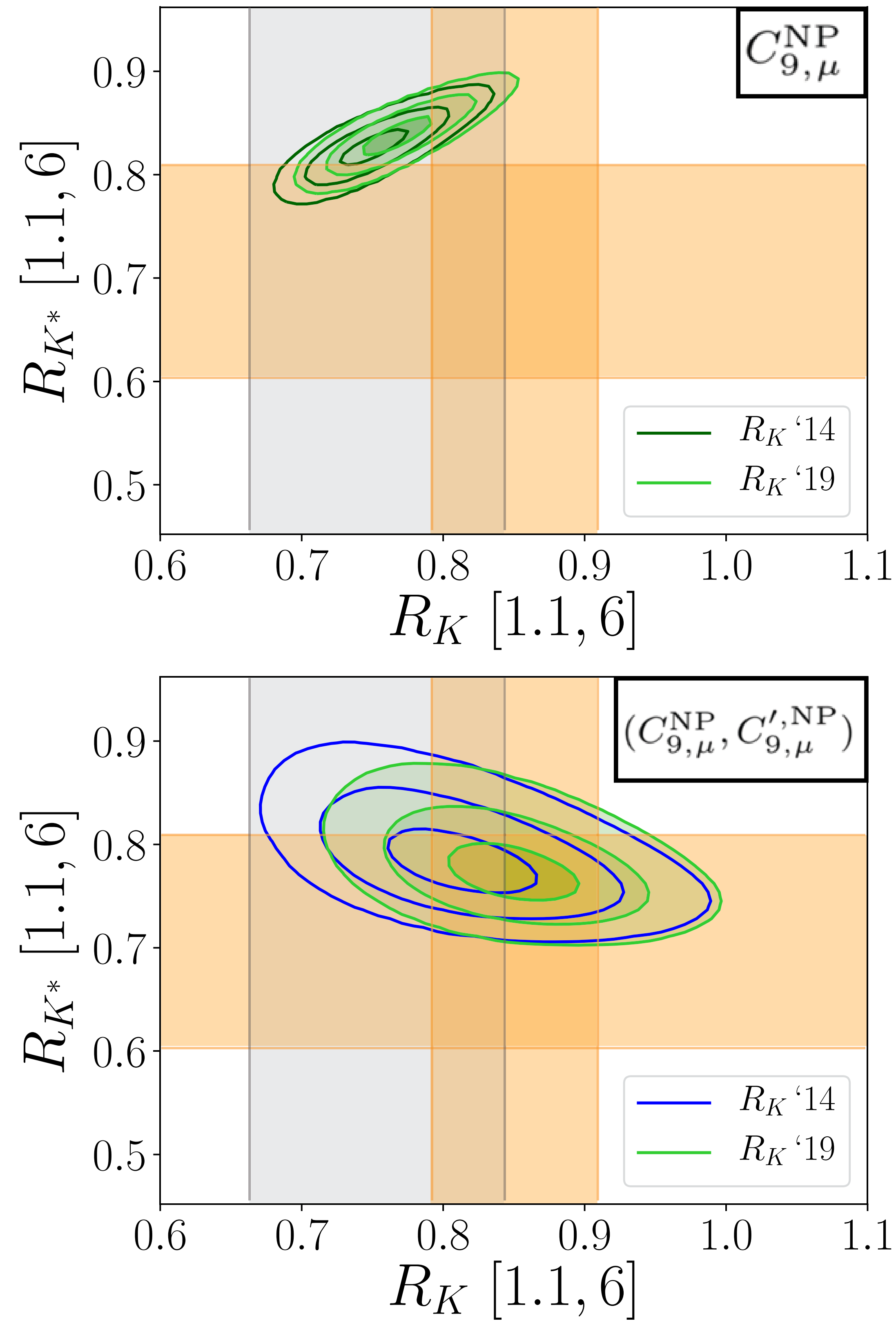
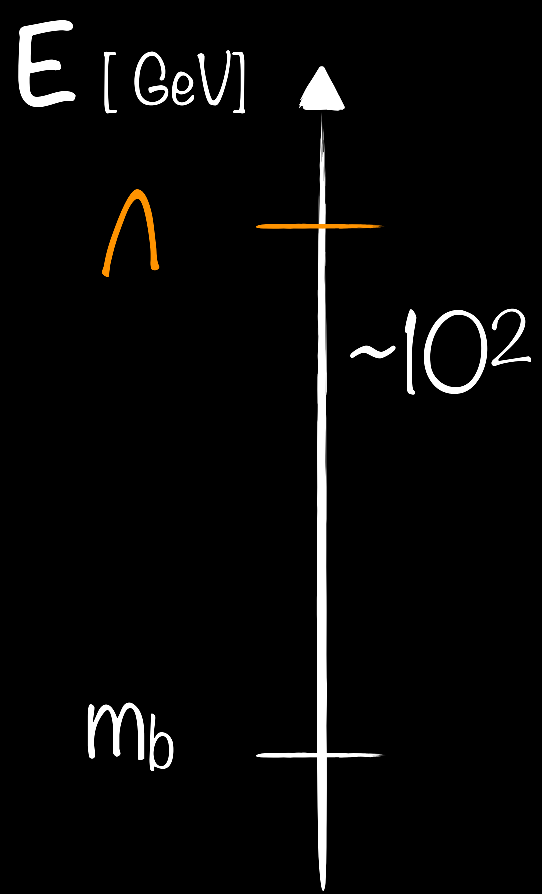


SMEFT —> $SU(2)_L \otimes U(1)_Y$ CORRELATIONS

ABOVE THE EW SCALE ONE MAY ENFORCE LINEARLY REALIZED SM GAUGE SYMMETRY



$$O^{LQ^{(1)}}_{ijkl} = (\bar{L}_i \gamma_\mu L_j)(\bar{Q}_k \gamma^\mu Q_l)$$
$$O^{LQ^{(3)}}_{ijkl} = (\bar{L}_i \gamma_\mu \tau^A L_j)(\bar{Q}_k \gamma^\mu \tau^A Q_l)$$
$$O^{Qe}_{ijkl} = (\bar{Q}_i \gamma_\mu Q_j)(\bar{e}_k \gamma^\mu e_l)$$
$$O^{Ld}_{ijkl} = (\bar{L}_i \gamma_\mu L_j)(\bar{d}_k \gamma^\mu d_l)$$
$$O^{ed}_{ijkl} = (\bar{e}_i \gamma_\mu e_j)(\bar{d}_k \gamma^\mu d_l)$$
$$O^{LedQ}_{ijkl} = (\bar{L}_i e_j)(\bar{d}_k Q_l)$$

<u>CAPITAL CASE</u>

$SU(2)_L$ Doublets

<u>LOWER CASE</u>

$SU(2)_L$ singlets

See, e.g.:

Alonso et al. 2014, Aebischer et al. 2016, Celis et al. 2017

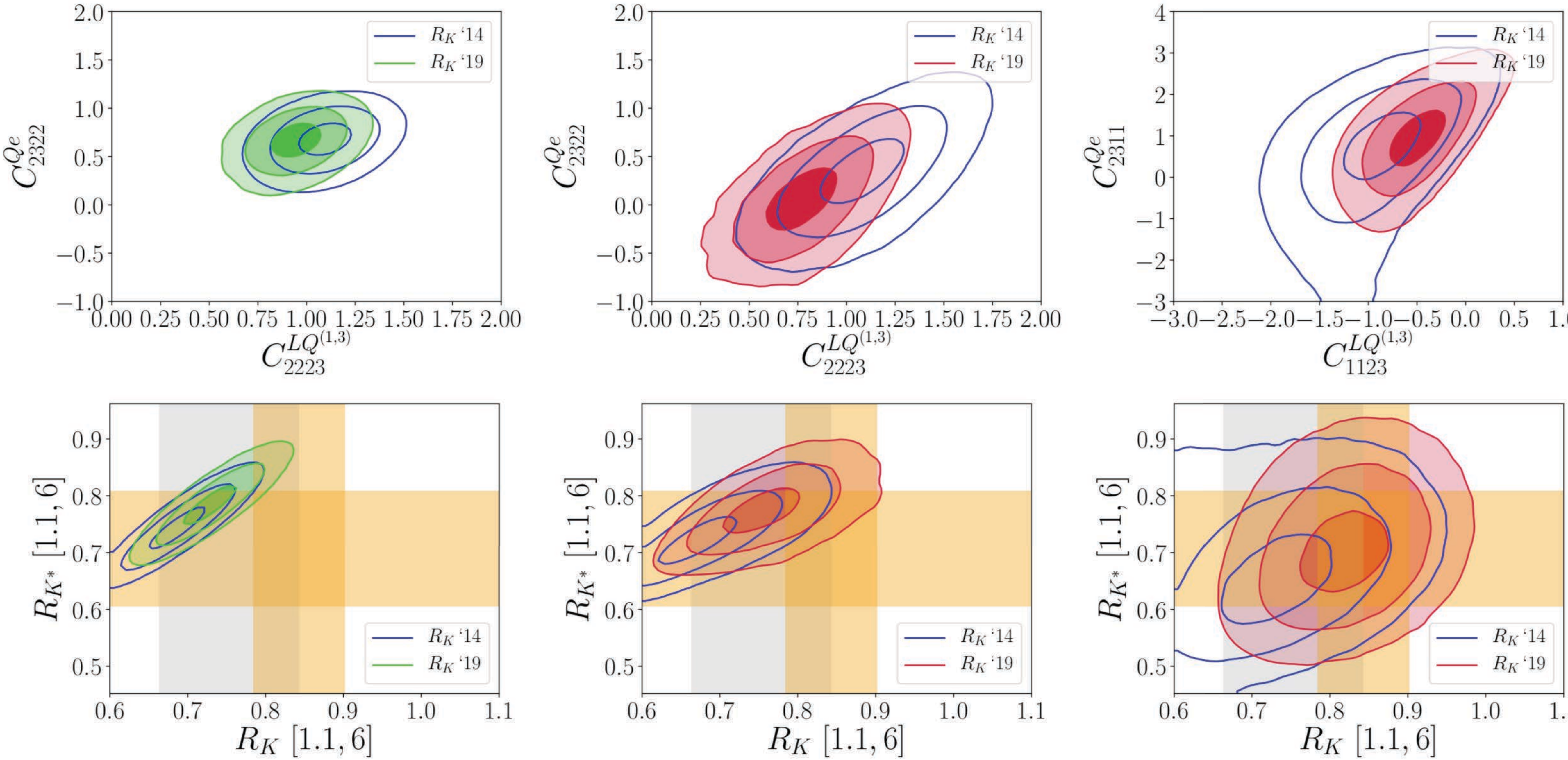
$O^{LQ(1,3)}$ —> $C_9 = -\ C_{10}$, O^{Ld} —> $C'_9 = -\ C'_{10}$

O^{Qe} —> $C_9 = +\ C_{10}$, O^{ed} —> $C'_9 = +\ C'_{10}$

Scalar operators are well constrained by B —> ll . They cannot address R_{K^*} .

EPJC 79 (2019) no.8 ,719
arXiv: 1903.09632

b —> s Anomalies: C9 vs C10



ΔIC = 50 **ΔIC = 21** **ΔIC = 12**

arXiv: 1812.10913

Model-independent Bounds on the Standard Model Effective Theory from Flavour Physics

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[2] Theoretical Physics Department, CERN, Geneva, Switzerland
[3] Department of Physics and Astronomy, University of California, Irvine, CA 92697 USA

$\square$ $K-\bar{K}$ mixing

$\diamond$ $D-\bar{D}$ mixing

$\triangle$ $B_d-\bar{B}_d$ mixing

$\triangledown$ $B_s-\bar{B}_s$ mixing

ijkl	$C_{ijkl}^{ud(1)}$ [TeV^{-2}] Y_D diag	$C_{ijkl}^{ud(1)}$ [TeV^{-2}] Y_U diag	$C_{ijkl}^{ud(8)}$ [TeV^{-2}] Y_D diag	$C_{ijkl}^{ud(8)}$ [TeV^{-2}] Y_U diag
1112	$(\varnothing, 1.1^{\square})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, 1.9^{\square})\,10^{-1}$
1212	$(\varnothing, 2.5^{\square})\,10^{-1}$	$(\varnothing, 2.5^{\square})\,10^{-1}$	$(99^{\square}, 0.45^{\square})\,10^{-1}$	$(99^{\square}, 0.45^{\square})\,10^{-1}$
1213	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, 7.0^{\square})$	$(\varnothing, \varnothing)$
1221	$(360^{\square}, 0.95^{\square})\,10^{-2}$	$(\varnothing, 4.6^{\square})$	$(38^{\square}, 0.17^{\square})\,10^{-2}$	$(\varnothing, 8.3^{\square})\,10^{-1}$
1222	$(\varnothing, 11^{\square})$	$(\varnothing, 11^{\square})$	$(\varnothing, 3.6^{\square})$	$(\varnothing, 3.6^{\square})$
1223	$(\varnothing, 4.7^{\square})$	$(\varnothing, \varnothing)$	$(\varnothing, 1.6^{\square})$	$(\varnothing, \varnothing)$
1231	$(2.8^{\triangle}, 2.7^{\triangle})$	$(\varnothing, \varnothing)$	$(2.1^{\triangle}, 1.7^{\triangle})$	$(12^{\diamond}, \varnothing)$
1232	$(7.1^{\triangledown}, 5.8^{\triangledown})$	$(7.9^{\diamond}, \varnothing)$	$(2.7^{\diamond}, 5.1^{\triangledown})$	$(2.7^{\diamond}, 6.0^{\diamond})$
1233	$(3.5^{\diamond}, 7.8^{\diamond})$	$(\varnothing, \varnothing)$	$(1.2^{\diamond}, 2.6^{\diamond})$	$(\varnothing, \varnothing)$
1312	$(\varnothing, 5.7^{\square})$	$(6.6^{\square}, 0.21^{\square})\,10^{-1}$	$(\varnothing, 1.0^{\square})$	$(12^{\square}, 0.37^{\square})\,10^{-2}$
1313	$(2.2^{\triangle}, 2.1^{\triangle})$	$(2.2^{\triangle}, 2.1^{\triangle})$	$(1.7^{\triangle}, 1.3^{\triangle})$	$(1.7^{\triangle}, 1.3^{\triangle})$
1321	$(1.4^{\square}, 1.1^{\square})\,10^{-3}$	$(6.6^{\square}, 5.4^{\square})\,10^{-1}$	$(2.5^{\square}, 2.0^{\square})\,10^{-4}$	$(1.2^{\square}, 0.97^{\square})\,10^{-1}$
1331	$(1.9^{\triangle}, 1.8^{\triangle})\,10^{-1}$	$(\varnothing, \varnothing)$	$(1.5^{\triangle}, 1.2^{\triangle})\,10^{-1}$	$(\varnothing, \varnothing)$
1332	$(5.7^{\triangledown}, 4.9^{\triangledown})\,10^{-1}$	$(\varnothing, \varnothing)$	$(5.1^{\triangledown}, 4.4^{\triangledown})\,10^{-1}$	$(\varnothing, \varnothing)$
2212	$(83^{\square}, 0.22^{\square})\,10^{-2}$	$(83^{\square}, 0.22^{\square})\,10^{-2}$	$(89^{\square}, 0.4^{\square})\,10^{-3}$	$(89^{\square}, 0.4^{\square})\,10^{-3}$
2213	$(4.6^{\triangle}, 4.5^{\triangle})\,10^{-1}$	$(\varnothing, \varnothing)$	$(3.7^{\triangle}, 2.8^{\triangle})\,10^{-1}$	$(\varnothing, 11)$
2223	$(28^{\triangledown}, 9.7^{\triangledown})\,10^{-1}$	$(\varnothing, \varnothing)$	$(25^{\triangledown}, 8.6^{\triangledown})\,10^{-1}$	$(\varnothing, \varnothing)$
2312	$(\varnothing, 5.1^{\square})\,10^{-2}$	$(6.1^{\square}, 0.19^{\square})\,10^{-3}$	$(200^{\square}, 0.92^{\square})\,10^{-2}$	$(11^{\square}, 0.33^{\square})\,10^{-4}$
2313	$(1.9^{\triangle}, 1.9^{\triangle})\,10^{-2}$	$(1.9^{\triangle}, 1.9^{\triangle})\,10^{-2}$	$(1.5^{\triangle}, 1.2^{\triangle})\,10^{-2}$	$(1.5^{\triangle}, 1.2^{\triangle})\,10^{-2}$
2321	$(3.2^{\square}, 2.6^{\square})\,10^{-4}$	$(3.2^{\square}, 2.6^{\square})\,10^{-4}$	$(5.7^{\square}, 4.6^{\square})\,10^{-5}$	$(5.7^{\square}, 4.6^{\square})\,10^{-5}$
2323	$(12^{\triangledown}, 0.40^{\triangledown})\,10^{-1}$	$(12^{\triangledown}, 0.40^{\triangledown})\,10^{-1}$	$(1.0^{\triangledown}, 0.36^{\triangledown})\,10^{-1}$	$(1.0^{\triangledown}, 0.36^{\triangledown})\,10^{-1}$
2331	$(5.5^{\triangle}, 5.3^{\triangle})\,10^{-2}$	$(8.1^{\square}, 7.0^{\square})$	$(3.8^{\triangledown}, 3.3^{\triangledown})\,10^{-2}$	$(1.5^{\square}, 1.3^{\square})$
2332	$(2.4^{\triangledown}, 0.81^{\triangledown})\,10^{-1}$	$(\varnothing, \varnothing)$	$(2.1^{\triangledown}, 0.72^{\triangledown})\,10^{-1}$	$(\varnothing, \varnothing)$
3311	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(3.3^{\square}, \varnothing)$
3312	$(7.3^{\square}, 5.9^{\square})\,10^{-3}$	$(2.6^{\square}, 2.2^{\square})\,10^{-5}$	$(1.3^{\square}, 1.3^{\square})\,10^{-3}$	$(4.6^{\square}, 4.0^{\square})\,10^{-6}$
3313	$(2.3^{\triangle}, 2.2^{\triangle})\,10^{-3}$	$(2.3^{\triangle}, 2.2^{\triangle})\,10^{-3}$	$(1.7^{\triangle}, 1.4^{\triangle})\,10^{-3}$	$(1.7^{\triangle}, 1.4^{\triangle})\,10^{-3}$
3322	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(3.3^{\square}, \varnothing)$
3323	$(9.9^{\triangledown}, 3.4^{\triangledown})\,10^{-3}$	$(9.9^{\triangledown}, 3.4^{\triangledown})\,10^{-3}$	$(8.7^{\triangledown}, 3.0^{\triangledown})\,10^{-3}$	$(8.7^{\triangledown}, 3.0^{\triangledown})\,10^{-3}$

ij	$C_{ij}^{HQ(1,3)}$ [TeV^{-2}] Y_D diag	$C_{ij}^{HQ(1,3)}$ [TeV^{-2}] Y_U diag
11	$\varnothing$	$2.3^{\triangle}\,10^{-3}$
12	$(5.1^{\square}, 4.4^{\square})\,10^{-4}$	$(5.7^{\square}, 4.4^{\square})\,10^{-4}$
13	$(8.6^{\triangle}, 7.2^{\triangle})\,10^{-3}$	$(8.8^{\triangle}, 7.4^{\triangle})\,10^{-3}$
22	$\varnothing$	$2.3^{\square}\,10^{-3}$
23	$(3.0^{\triangledown}, 1.1^{\triangledown})\,10^{-2}$	$(3.1^{\triangledown}, 1.0^{\triangledown})\,10^{-2}$
33	$\varnothing$	$6.4^{\triangle}\,10^{-1}$

ijkl	C_{ijkl}^{LeQu} [TeV^{-2}] Y_D diag	C_{ijkl}^{LedQ} [TeV^{-2}] Y_U diag
2221	$(2.9^{\diamond}, 1.4^{\diamond})\,10^{-1}$	$(2.4^{\square}, 0.14^{\square})\,10^{-1}$
2222	$(13^{\diamond}, 6.2^{\diamond})\,10^{-1}$	$(10^{\square}, 0.59^{\square})\,10^{-1}$
2223	$(\varnothing, \varnothing)$	$(2.5^{\square}, 1.8^{\square})$
3321	$(1.7^{\diamond}, 0.84^{\diamond})\,10^{-2}$	$(14^{\square}, 0.8^{\square})\,10^{-3}$
3322	$(7.5^{\diamond}, 3.6^{\diamond})\,10^{-2}$	$(5.9^{\square}, 0.35^{\square})\,10^{-2}$
3323	$(1.8^{\diamond}, 1.5^{\diamond})$	$(1.4^{\square}, 1.1^{\square})\,10^{-1}$
3331	$(\varnothing, 8.5^{\diamond})$	$(4.9^{\triangle}, 6.6^{\triangle})$
3332	$(\varnothing, \varnothing)$	$(\varnothing, 8.9^{\triangledown})$

ijkl	$C_{ijkl}^{QuQd(1)}$ [TeV^{-2}] Y_D diag	$C_{ijkl}^{QuQd(1)}$ [TeV^{-2}] Y_U diag	$C_{ijkl}^{QuQd(8)}$ [TeV^{-2}] Y_D diag	$C_{ijkl}^{QuQd(8)}$ [TeV^{-2}] Y_U diag
1111	$(\varnothing, \varnothing)$	$(\varnothing, 4.8^{\square})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
1112	$(92^{\square}, 0.41^{\square})\,10^{-1}$	$(5.4^{\square}, 0.31^{\square})$	$(\varnothing, 0.49^{\square})\,10^{-1}$	$(\varnothing, 1.6^{\square})$
1113	$(2.3^{\diamond}, 5.2^{\diamond})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
1121	$(\varnothing, 3.2^{\diamond})$	$(\varnothing, 1.1^{\diamond})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
1122	$(\varnothing, 7.1^{\diamond})$	$(\varnothing, 1.6^{\square})$	$(\varnothing, 8.6^{\diamond})$	$(\varnothing, \varnothing)$
1123	$(5.3^{\diamond}, 12^{\diamond})\,10^{-1}$	$(\varnothing, \varnothing)$	$(6.4^{\diamond}, \varnothing)$	$(\varnothing, \varnothing)$
1133	$(12^{\diamond}, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
1211	$(3.0^{\diamond}, 1.4^{\diamond})$	$(95^{\square}, 0.43^{\square})\,10^{-1}$	$(\varnothing, 7.5^{\diamond})$	$(\varnothing, 5.1^{\square})\,10^{-1}$
1212	$(210^{\square}, 0.96^{\square})\,10^{-2}$	$(22^{\square}, 0.1^{\square})\,10^{-1}$	$(\varnothing, 1.1^{\square})\,10^{-1}$	$(\varnothing, 1.2^{\square})\,10^{-1}$
1213	$(8.9^{\triangle}, 3.5^{\diamond})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
1221	$(\varnothing, 10^{\diamond})$	$(220^{\square}, 0.98^{\square})\,10^{-2}$	$(\varnothing, \varnothing)$	$(\varnothing, 1.2^{\square})\,10^{-2}$
1222	$(1.8^{\diamond}, 1.9^{\diamond})\,10^{-1}$	$(7.8^{\square}, 0.4^{\square})\,10^{-2}$	$(\varnothing, 9.8^{\diamond})\,10^{-1}$	$(5.8^{\square}, 0.54^{\square})\,10^{-2}$
1223	$(22^{\diamond}, 0.69^{\diamond})\,10^{-1}$	$(\varnothing, \varnothing)$	$(\varnothing, 4.3^{\diamond})\,10^{-1}$	$(\varnothing, \varnothing)$
1231	$(1.9^{\diamond}, 1.6^{\diamond})$	$(7.6^{\square}, 0.23^{\square})$	$(12^{\diamond}, 9.5^{\diamond})$	$(\varnothing, 2.8^{\square})$
1232	$(2.4^{\diamond}, 1.9^{\diamond})\,10^{-2}$	$(3.8^{\square}, 8.4^{\square})\,10^{-2}$	$(1.4^{\diamond}, 1.1^{\diamond})\,10^{-1}$	$(6.7^{\square}, 15^{\square})\,10^{-3}$
1233	$(5.2^{\diamond}, 1.4^{\diamond})\,10^{-3}$	$(\varnothing, \varnothing)$	$(6.2^{\diamond}, 5.1^{\diamond})\,10^{-2}$	$(\varnothing, \varnothing)$
1311	$(\varnothing, \varnothing)$	$(6.1^{\square}, 5.0^{\square})\,10^{-3}$	$(\varnothing, \varnothing)$	$(7.3^{\square}, 6.0^{\square})\,10^{-2}$
1312	$(\varnothing, 2.2^{\square})\,10^{-1}$	$(27^{\square}, 8.5^{\square})\,10^{-4}$	$(\varnothing, 2.6^{\square})$	$(3.2^{\square}, 0.1^{\square})\,10^{-1}$
1313	$(3.7^{\triangle}, 2.8^{\triangle})\,10^{-1}$	$(3.9^{\triangle}, 2.9^{\triangle})\,10^{-1}$	$(2.2^{\triangle}, 2.1^{\triangle})\,10^{-1}$	$(2.4^{\triangle}, 2.3^{\triangle})\,10^{-1}$
1321	$(\varnothing, \varnothing)$	$(1.4^{\square}, 1.1^{\square})\,10^{-3}$	$(\varnothing, \varnothing)$	$(1.7^{\square}, 1.4^{\square})\,10^{-2}$
1322	$(\varnothing, \varnothing)$	$(12^{\square}, 0.37^{\square})\,10^{-2}$	$(\varnothing, \varnothing)$	$(23^{\square}, 0.74^{\square})\,10^{-3}$
1323	$(\varnothing, \varnothing)$	$(4.5^{\triangle}, 4.2^{\triangle})\,10^{-1}$	$(\varnothing, \varnothing)$	$(3.4^{\triangle}, 2.6^{\triangle})\,10^{-1}$
1331	$(\varnothing, \varnothing)$	$(3.2^{\square}, 2.7^{\square})\,10^{-2}$	$(\varnothing, \varnothing)$	$(3.9^{\square}, 3.2^{\square})\,10^{-1}$
1332	$(\varnothing, \varnothing)$	$(2.8^{\square}, 0.16^{\square})\,10^{-4}$	$(\varnothing, \varnothing)$	$(3.4^{\square}, 0.12^{\square})\,10^{-4}$
1333	$(\varnothing, \varnothing)$	$(0.99^{\triangle}, 1.3^{\triangle})\,10^{-1}$	$(\varnothing, \varnothing)$	$(1.2^{\triangle}, 1.6^{\triangle})\,10^{-1}$
2111	$(\varnothing, 3.15^{\diamond})$	$(\varnothing, 1.1^{\square})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
2112	$(\varnothing, 7.1^{\diamond})\,10^{-1}$	$(\varnothing, 3.2^{\square})$	$(\varnothing, 8.6^{\diamond})$	$(\varnothing, 9.5^{\square})$
2113	$(5.3^{\diamond}, 12^{\diamond})\,10^{-1}$	$(\varnothing, \varnothing)$	$(6.4^{\diamond}, \varnothing)$	$(\varnothing, \varnothing)$
2121	$(\varnothing, 2.4^{\square})\,10^{-1}$	$(\varnothing, 2.6^{\square})\,10^{-1}$	$(\varnothing, 2.9^{\square})$	$(\varnothing, 3.1^{\square})$
2122	$(5.3^{\diamond}, 0.17^{\diamond})$	$(5.1^{\diamond}, 0.16^{\diamond})$	$(\varnothing, 2.0^{\diamond})$	$(\varnothing, 1.9^{\diamond})$
2123	$(1.2^{\diamond}, 2.7^{\diamond})\,10^{-1}$	$(1.2^{\diamond}, 2.6^{\diamond})\,10^{-1}$	$(1.5^{\diamond}, 3.3^{\diamond})$	$(1.4^{\diamond}, 3.1^{\diamond})$
2131	$(\varnothing, \varnothing)$	$(\varnothing, 6.0^{\square})$	$(\varnothing, \varnothing)$	$(\varnothing, 6.0^{\square})$
2132	$(\varnothing, \varnothing)$	$(\varnothing, 3.7^{\diamond})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
2133	$(2.8^{\diamond}, 6.2^{\diamond})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
2211	$(\varnothing, 7.3^{\diamond})$	$(22^{\square}, 0.1^{\square})\,10^{-1}$	$(\varnothing, \varnothing)$	$(\varnothing, 1.2^{\square})\,10^{-1}$
2212	$(1.1^{\diamond}, 0.52^{\diamond})$	$(1.3^{\square}, 0.11^{\square})\,10^{-2}$	$(8.1^{\diamond}, 9.9^{\diamond})\,10^{-1}$	$(28^{\square}, 0.13^{\square})\,10^{-1}$
2213	$(\varnothing, 8.6^{\diamond})\,10^{-1}$	$(4.6^{\triangle}, 6.1^{\triangle})$	$(9.0^{\diamond}, 0.28^{\diamond})$	$(\varnothing, \varnothing)$
2221	$(48^{\square}, 0.22^{\square})\,10^{-2}$	$(51^{\square}, 0.23^{\square})\,10^{-2}$	$(58^{\square}, 0.26^{\square})\,10^{-1}$	$(61^{\square}, 0.27^{\square})\,10^{-1}$
2222	$(6.7^{\diamond}, 6.0^{\diamond})\,10^{-1}$	$(4.7^{\square}, 0.38^{\square})\,10^{-2}$	$(3.5^{\diamond}, 2.1^{\diamond})$	$(2.5^{\square}, 0.16^{\diamond})\,10^{-1}$
2223	$(9.6^{\diamond}, 0.30^{\diamond})$	$(\varnothing, 7.1^{\triangledown})$	$(\varnothing, 3.4^{\diamond})$	$(\varnothing, \varnothing)$
2231	$(8.4^{\diamond}, 2.2^{\square})$	$(18^{\square}, 0.53^{\square})\,10^{-1}$	$(\varnothing, \varnothing)$	$(\varnothing, 0.64^{\square})$
2232	$(1.0^{\diamond}, 0.83^{\diamond})\,10^{-1}$	$(1.6^{\square}, 1.4^{\square})\,10^{-1}$	$(6.1^{\diamond}, 5.0^{\diamond})\,10^{-1}$	$(2.9^{\square}, 6.3^{\square})\,10^{-2}$
2233	$(2.2^{\diamond}, 0.61^{\diamond})\,10^{-2}$	$(\varnothing, \varnothing)$	$(2.7^{\diamond}, 2.2^{\diamond})\,10^{-1}$	$(\varnothing, \varnothing)$
2311	$(\varnothing, \varnothing)$	$(1.4^{\square}, 1.1^{\square})\,10^{-3}$	$(\varnothing, \varnothing)$	$(1.7^{\square}, 1.4^{\square})\,10^{-2}$
2312	$(\varnothing, \varnothing)$	$(6.1^{\square}, 0.2^{\square})\,10^{-3}$	$(\varnothing, \varnothing)$	$(3.4^{\square}, 0.1^{\square})\,10^{-2}$
2313	$(\varnothing, \varnothing)$	$(8.9^{\triangle}, 6.7^{\triangle})\,10^{-2}$	$(\varnothing, \varnothing)$	$(4.4^{\triangle}, 3.7^{\triangle})\,10^{-1}$
2321	$(3.1^{\square}, 2.5^{\square})\,10^{-4}$	$(3.3^{\square}, 2.7^{\square})\,10^{-4}$	$(3.7^{\square}, 3.0^{\square})\,10^{-3}$	$(3.9^{\square}, 3.2^{\square})\,10^{-3}$
2322	$(\varnothing, \varnothing)$	$(27^{\square}, 0.83^{\square})\,10^{-3}$	$(\varnothing, \varnothing)$	$(33^{\square}, 1.0^{\square})\,10^{-2}$
2323	$(5.7^{\triangledown}, 2.0^{\triangledown})\,10^{-1}$	$(3.9^{\triangle}, 2.1^{\triangledown})\,10^{-1}$	$(3.1^{\triangledown}, 1.1^{\triangledown})$	$(2.3^{\triangle}, 1.1^{\triangledown})$
2331	$(3.1^{\square}, 2.7^{\square})\,10^{-1}$	$(7.3^{\square}, 6.3^{\square})\,10^{-3}$	$(3.7^{\square}, 3.2^{\square})$	$(8.8^{\square}, 7.6^{\square})\,10^{-2}$
2332	$(\varnothing, \varnothing)$	$(11^{\square}, 0.7^{\square})\,10^{-4}$	$(\varnothing, \varnothing)$	$(14^{\square}, 0.52^{\square})\,10^{-4}$
2333	$(\varnothing, \varnothing)$	$(4.1^{\triangle}, 1.7^{\triangle})\,10^{-1}$	$(\varnothing, \varnothing)$	$(5.2^{\triangle}, 2.1^{\triangledown})\,10^{-1}$
3112	$(\varnothing, \varnothing)$	$(3.6^{\square}, 8.2^{\square})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
3113	$(12^{\diamond}, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
3121	$(\varnothing, \varnothing)$	$(\varnothing, 6.0^{\square})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
3122	$(\varnothing, 3.7^{\diamond})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
3123	$(2.8^{\diamond}, 6.2^{\diamond})$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$	$(\varnothing, \varnothing)$
3211	$(\varnothing, \varnothing)$	$(7.7^{\square}, 0.23^{\square})$	$(7.8^{\diamond}, 6.3^{\diamond})$	$(\varnothing, 2.8^{\square})$
3212	$(2.8^{\diamond}, 2.3^{\diamond})\,10^{-1}$	$(1.7^{\square}, 3.8^{\square})\,10^{-3}$	$(9.4^{\diamond}, 7.7^{\diamond})\,10^{-2}$	$(1.0^{\square}, 2.3^{\square})\,10^{-2}$
3213	$(2.1^{\diamond}, 1.0^{\diamond})\,10^{-2}$	$(\varnothing, \varnothing)$	$(2.5^{\diamond}, 0.6^{\diamond})\,10^{-2}$	$(\varnothing, \varnothing)$
3221	$(\varnothing, 2.2^{\square})$	$(18^{\square}, 0.53^{\square})\,10^{-2}$	$(\varnothing, \varnothing)$	$(\varnothing, 0.64^{\square})\,10^{-2}$
3222	$(1.2^{\diamond}, 0.98^{\diamond})$	$(7.3^{\square}, 16^{\square})\,10^{-3}$	$(4.1^{\diamond}, 3.3^{\diamond})$	$(0.46^{\square}, 1.1^{\square})\,10^{-1}$
3223	$(8.9^{\diamond}, 4.4^{\diamond})\,10^{-2}$	$(\varnothing, \varnothing)$	$(1.1^{\diamond}, 0.26^{\diamond})\,10^{-1}$	$(\varnothing, \varnothing)$
3231	$(4.6^{\triangle}, 3.5^{\triangle})\,10^{-1}$	$(4.6^{\triangle}, 3.5^{\triangle})\,10^{-1}$	$(2.8^{\triangle}, 2.7^{\triangle})\,10^{-1}$	$(2.8^{\triangle}, 2.7^{\triangle})\,10^{-1}$
3232	$(2.3^{\diamond}, 1.1^{\diamond})$	$(1.7^{\square}, 6.5^{\square})\,10^{-1}$	$(\varnothing, 5.8^{\diamond})$	$(2.1^{\square}, 5.8^{\square})$
3233	$(2.3^{\diamond}, 2.7^{\diamond})\,10^{-1}$	$(\varnothing, \varnothing)$	$(1.4^{\diamond}, 1.4^{\diamond})$	$(\varnothing, \varnothing)$
3311	$(\varnothing, \varnothing)$	$(3.2^{\square}, 2.7^{\square})\,10^{-2}$	$(\varnothing, \varnothing)$	$(3.8^{\square}, 3.3^{\square})\,10^{-1}$
3312	$(\varnothing, \varnothing)$	$(7.0^{\square}, 0.26^{\square})\,10^{-5}$	$(\varnothing, \varnothing)$	$(8.4^{\square}, 21^{\square})\,10^{-4}$
3313	$(\varnothing, \varnothing)$	$(2.5^{\triangle}, 3.3^{\triangle})\,10^{-2}$	$(\varnothing, \varnothing)$	$(3.0^{\triangle}, 3.3^{\triangle})\,10^{-1}$
3321	$(3.1^{\square}, 2.7^{\square})\,10^{-1}$	$(7.3^{\square}, 6.3^{\square})\,10^{-3}$	$(3.7^{\square}, 3.2^{\square})$	$(8.8^{\square}, 7.6^{\square})\,10^{-2}$
3322	$(\varnothing, \varnothing)$	$(2.9^{\square}, 0.11^{\square})\,10^{-4}$	$(\varnothing, \varnothing)$	$(3.5^{\square}, 8.2^{\square})\,10^{-3}$
3323	$(\varnothing, \varnothing)$	$(1.1^{\triangle}, 0.44^{\triangledown})\,10^{-1}$	$(\varnothing, \varnothing)$	$(1.2^{\triangledown}, 0.41^{\triangledown})$
3331	$(4.9^{\triangle}, 4.0^{\triangle})\,10^{-2}$	$(4.9^{\triangle}, 4.0^{\triangle})\,10^{-2}$	$(3.2^{\triangle}, 3.1^{\triangle})\,10^{-1}$	$(3.2^{\triangle}, 3.1^{\triangle})\,10^{-1}$
3332	$(2.6^{\triangledown}, 0.89^{\triangledown})\,10^{-1}$	$(4.1^{\square}, 3.1^{\square})\,10^{-4}$	$(1.4^{\triangledown}, 0.48^{\triangledown})$	$(2.2^{\square}, 1.6^{\square})\,10^{-3}$
3333	$(\varnothing, \varnothing)$	$(2.0^{\triangle}, 0.83^{\triangledown})$	$(\varnothing, \varnothing)$	$(8.5^{\triangle}, 3.6^{\triangledown})$

$\Delta F = 2$ CONSTRAINTS ON

$\Delta F = 0, 1$ FROM SMEFT RGE !

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arXiv: 1903.09632

b —> s Anomalies: SMEFT@ 1-Loop

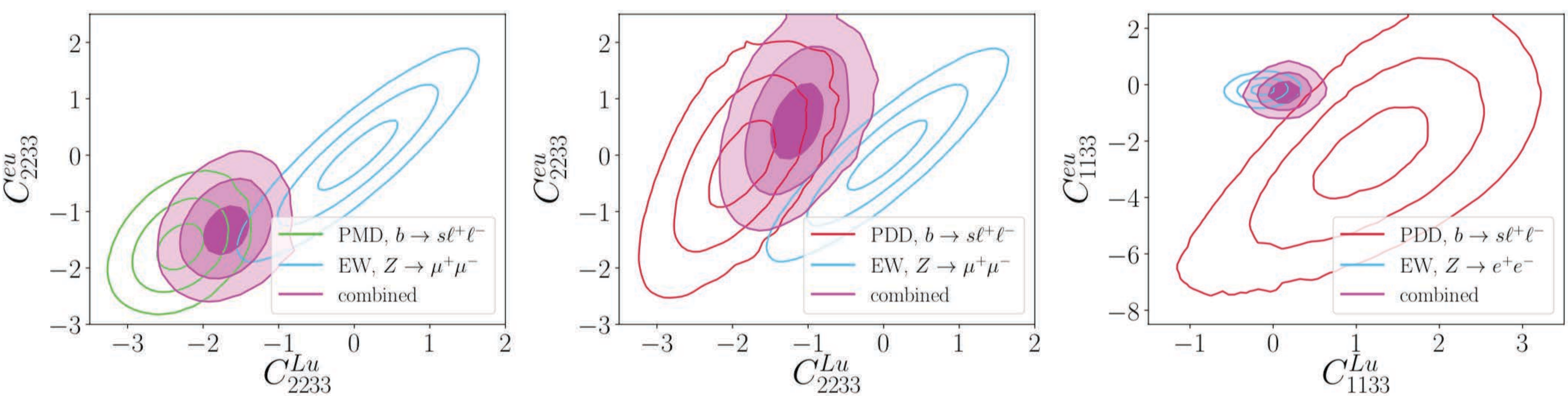
$$C_{9,\ell} = \mathcal{N}_\Lambda \, \lambda_t \left(\frac{y_t}{4\pi}\right)^2 \log\left(\frac{\Lambda}{\mu_{\rm EW}}\right) \left(C_{\ell\ell}^{HL^{(3)}} - C_{\ell\ell}^{HL^{(1)}} - C_{\ell\ell}^{He} + C_{\ell\ell 33}^{Lu} + C_{\ell\ell 33}^{eu}\right)$$

$$C_{10,\ell} = \mathcal{N}_\Lambda \, \lambda_t \left(\frac{y_t}{4\pi}\right)^2 \log\left(\frac{\Lambda}{\mu_{\rm EW}}\right) \left(C_{\ell\ell}^{HL^{(1)}} - C_{\ell\ell}^{HL^{(3)}} - C_{\ell\ell}^{He} - C_{\ell\ell 33}^{Lu} + C_{\ell\ell 33}^{eu}\right)$$

with $\mathcal{N}_\Lambda \equiv (\pi v^2)/(\alpha_e \lambda_t \Lambda^2)$.

—> **INTERESTING SCENARIOS:** NP AROUND TEV COUPLING TO TOP QUARKS!

(See also Celis et al. 2017, Camargo-Molina et al. 2018, Coy et al. 2019)



What To Bring Back Home

— *LFUV measurements are golden channels to spot NP*

— *Hadronic uncertainties do matter in the b to s ll global fit*

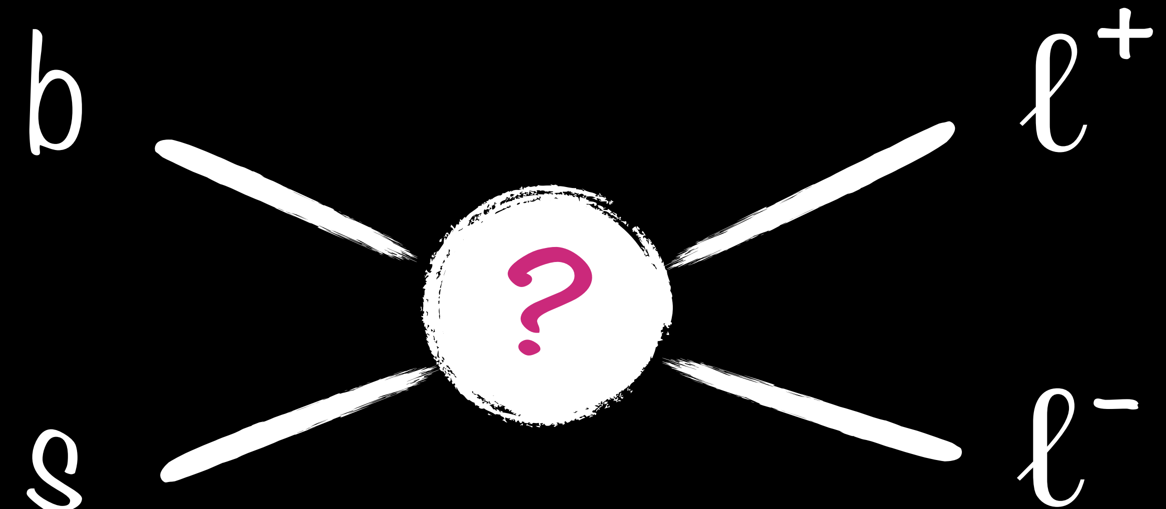
— *Forthcoming updates / new data from B-factories / LHCb will have a final word on this pattern of FCNC anomalies*

AT PRESENT

EFT analysis points to NP in $C_{9,\mu}$ together with $C^{(\prime)}_{10,\mu}$

BUT …

… "NP IN ELECTRONS" CANNOT BE DISREGARDED IN LIGHT OF HADRONIC UNCERTAINTIES



tree-level: *Z'* or *leptoquark*

loop-level: ***which SM extension?***

BACK-UP

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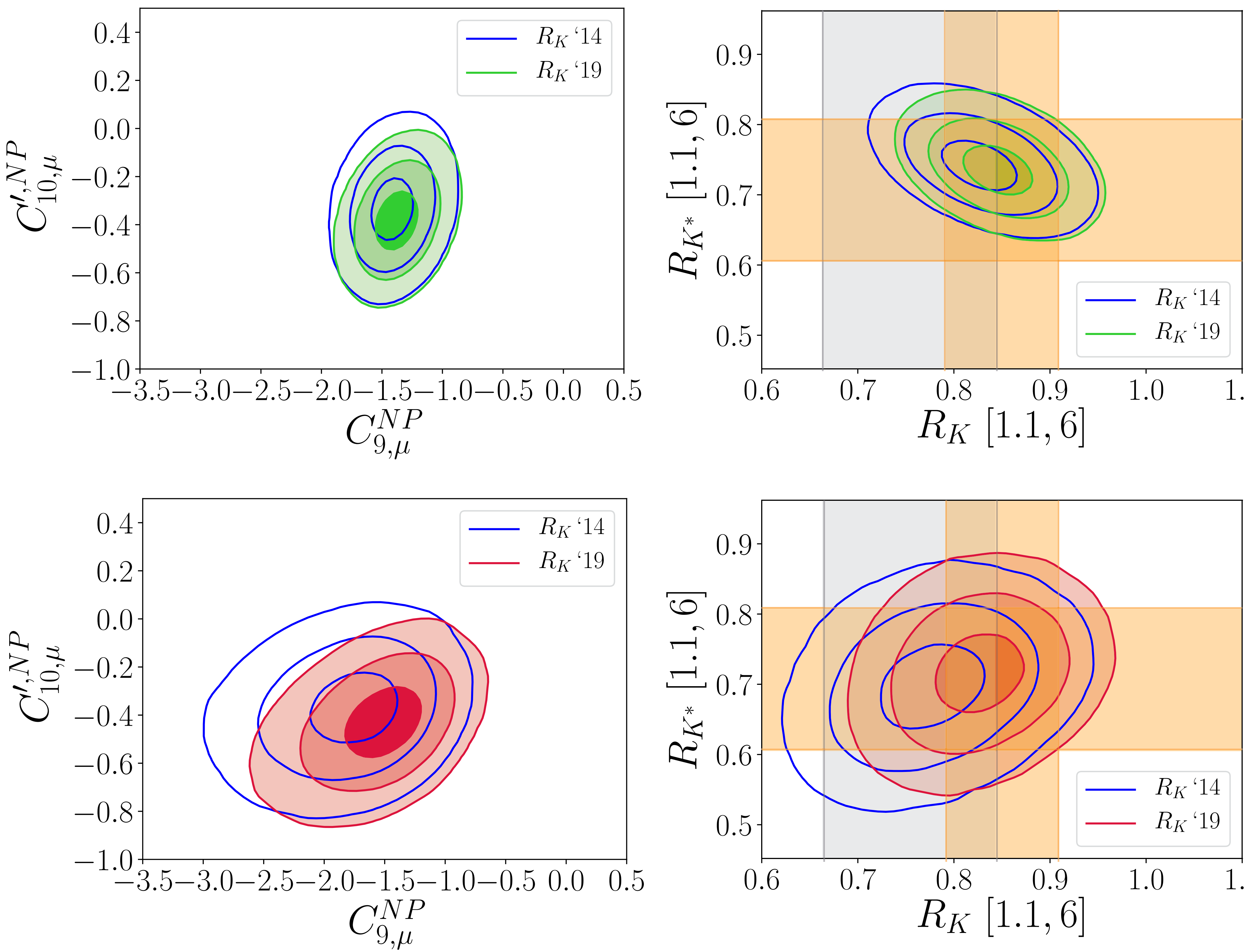
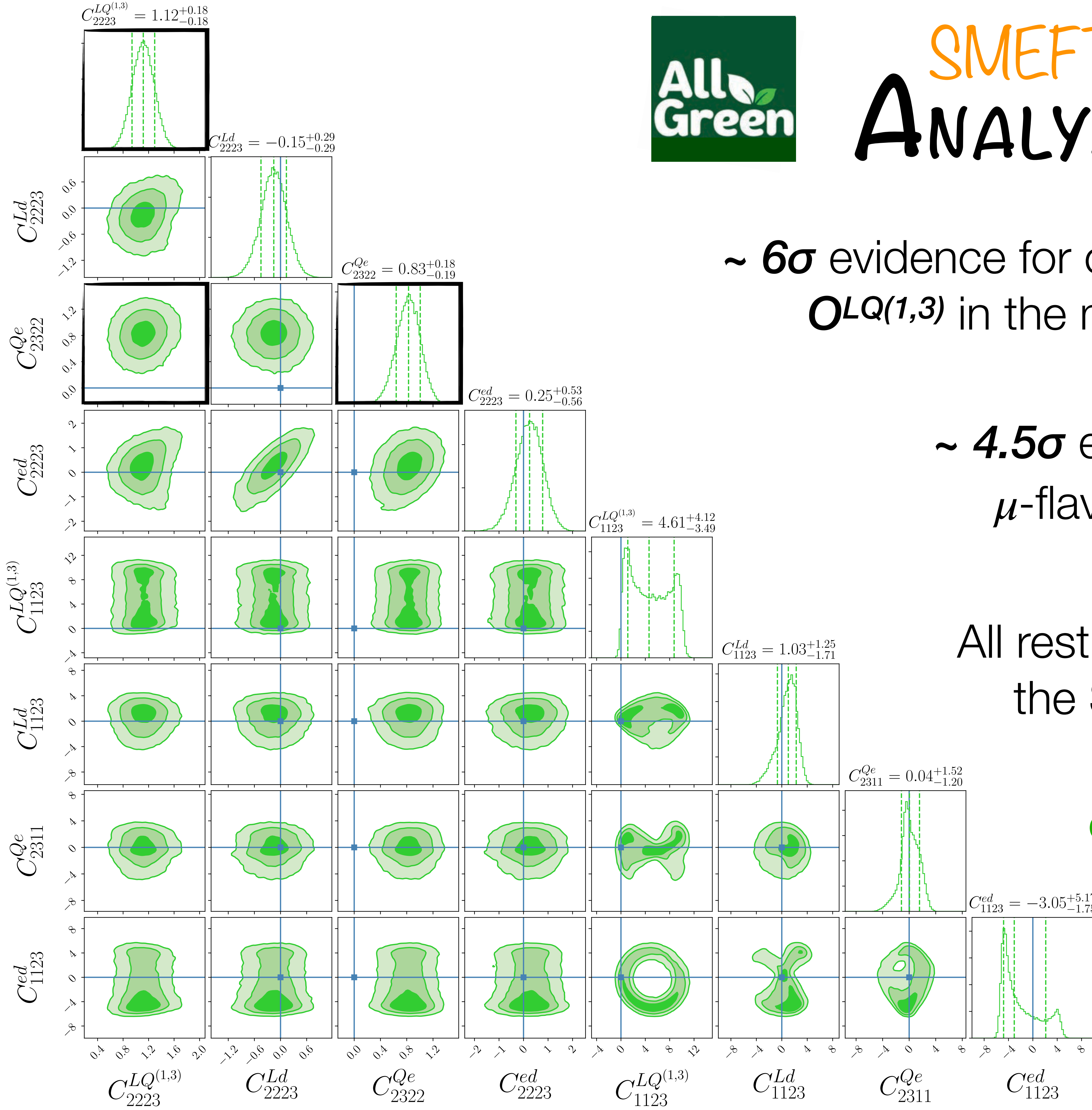
arXiv: 1903.09632

Hint for b—>s Right-Handed Current



SMEFT Analysis in PMD

$\Lambda = 30$ TeV



~ ***6σ*** evidence for contribution from ***O^LQ(1,3)*** in the muon channel.

~ ***4.5σ*** evidence for ***O^Qe*** μ-flavoured as well.

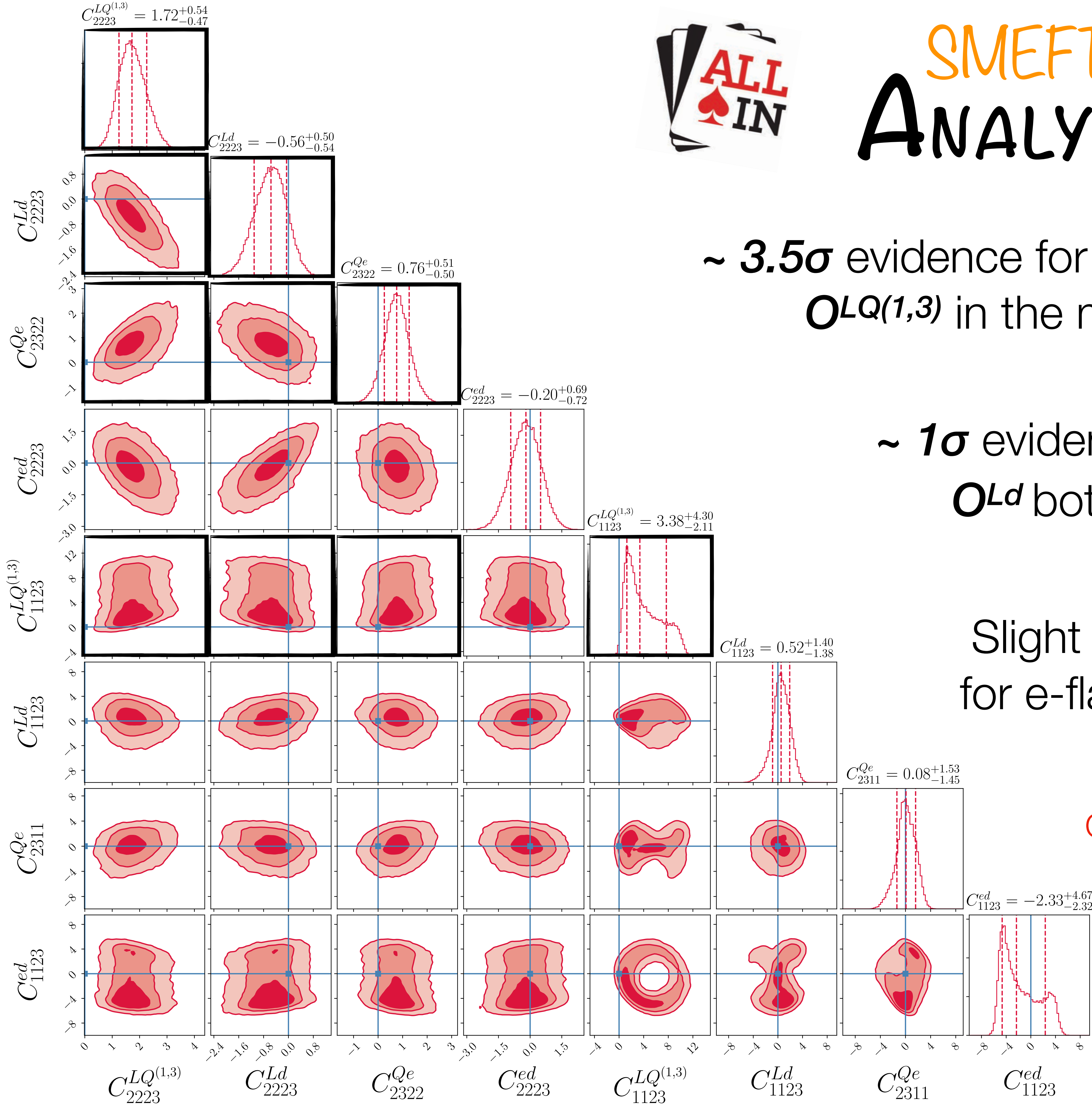
All rest compatible with the SM within *1σ*.

OUTCOME POINTING TO

$C_{9,\mu}$

SMEFT $\Lambda = 30$ TeV

Analysis in PDD



~ ***3.5σ*** evidence for contribution from ***O***$^{LQ(1,3)}$ in the muon channel.

~ ***1σ*** evidence for ***O***^{Qe} and ***O***^{Ld} both μ-flavoured.

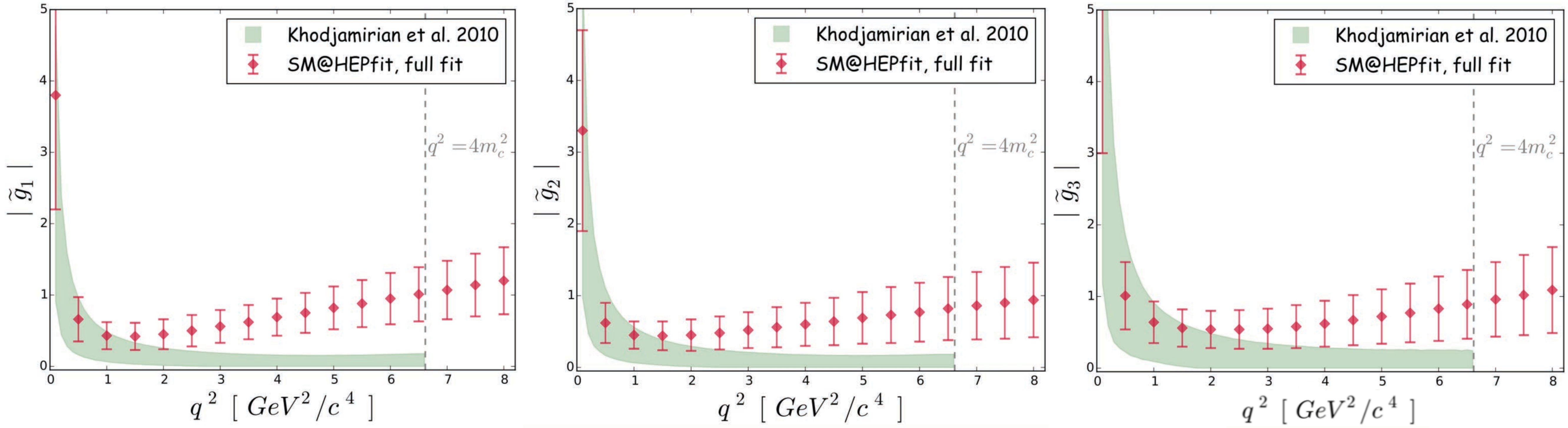
Slight preference also for e-flavoured ***O***$^{LQ(1,3)}$.

OUTCOME POINTING TO

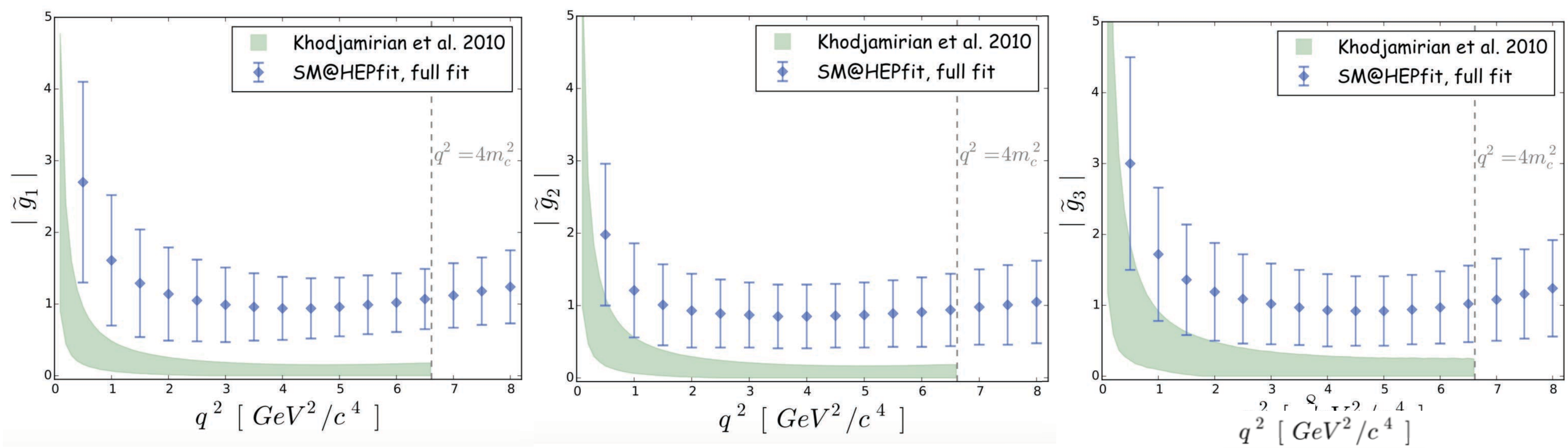
$$C_{9,\mu} = -C_{10,\mu}$$

About the inferred q² dependence from the "charm-loop" effect.

update of Ciuchini et al.2016



THE OUTCOME DEPENDS ON OUR THEORY INPUT FROM LCSR AT q² < GeV² :

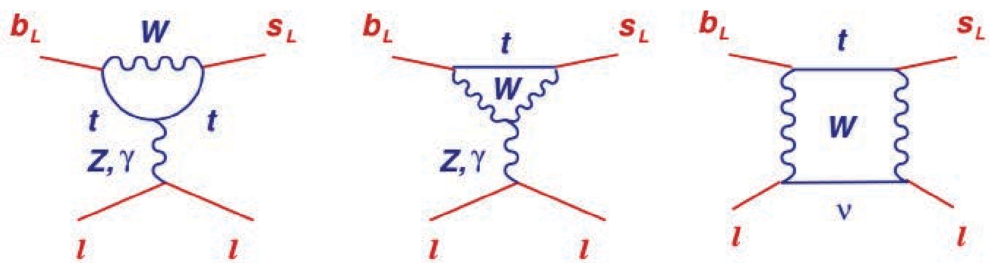


credit to
B. Grinstein
Instant Workshop on
B Physics Anomalies
CERN, 17 May, 2017

Why the Excitement on Anomalies in B decays?

Slide for "executives"

The SM of EW intearctions predicts



$$\Rightarrow \qquad G_F\, V_{tb}\, V_{ts}^* \frac{\alpha}{4\pi} C_{9(10)}\, \bar{s}_L \gamma^\mu b_L\, \bar{\ell}\gamma_\mu(\gamma_5)\ell$$

- This is same for all lepton flavors: lepton univesality (LU)
- LU violation (LUV) reported by LHCb in $b \to s\mu\mu$ vs $b \to see$
- LUV could arise from new physics (NP):
  - At very short distances, with SM below scale $\Lambda \gg M_W$
  - Short distances at SM scale, $\Lambda \sim M_W$ (*e.g.*, strongly coupled EW symmetry breaking)
  - Long distances: new light particles
- Worse case scenario: $\Lambda \gg M_W$: $NP = \frac{g^2}{\Lambda^2}\, \bar{s}_L \gamma^\mu b_L\, \bar{\ell}\gamma_\mu(\gamma_5)\ell$
- Fits of reported LUV require

$$\frac{g^2}{\Lambda^2} \approx 0.25 \times G_F\, V_{tb}\, V_{ts}^* \frac{\alpha}{4\pi} C_{9(10)} \qquad \Rightarrow \qquad \frac{\Lambda}{g} \approx 28 \text{ TeV}$$

- Best argument to build VLHC! (or find NP sooner!!)