On B anomalies: *fitting outside the box*

Based on **JHEP** 1606 (2016) 116, **EPJ** C77 (2017) 688 + **work in progress**

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04/18/2018

LIO International Conference on Flavour Physics
— FROM FLAVOUR TO NEW PHYSICS —

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

➡ SENSITIVITY TO NEW PHYSICS (NP)

E.g.: in b to s ll transitions!

THESE DAYS MAY BE PARTICULARLY EXCITING:

$\sim 3.5\,\sigma$

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

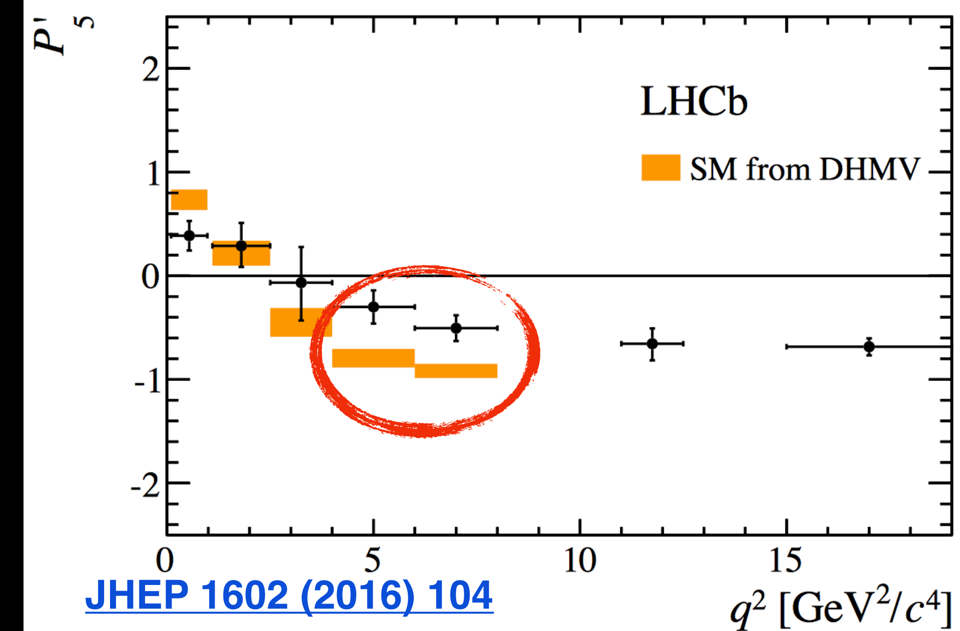
$\sim 2.5\,\sigma$

$R_{K,K^{*}}$ measurements!

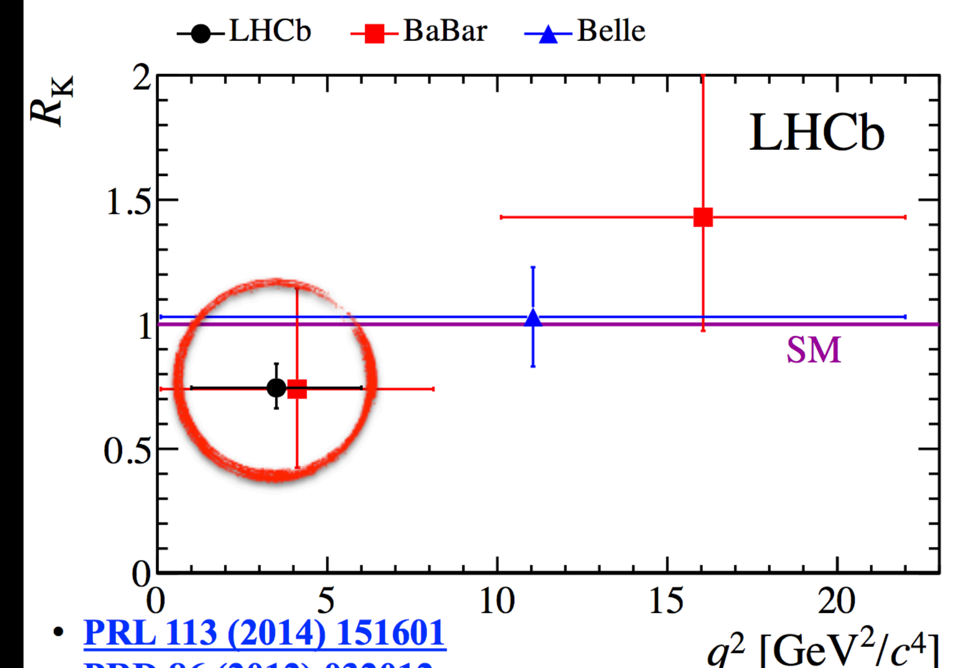
+ deviations in BR of other modes

> ALSO: POSSIBLE CORRELATION WITH b —> c IN LIGHT OF HFLAV AVERAGE ON R_D, R_{D^*} … INTRIGUING (BUT FAR FROM GRANTED)!

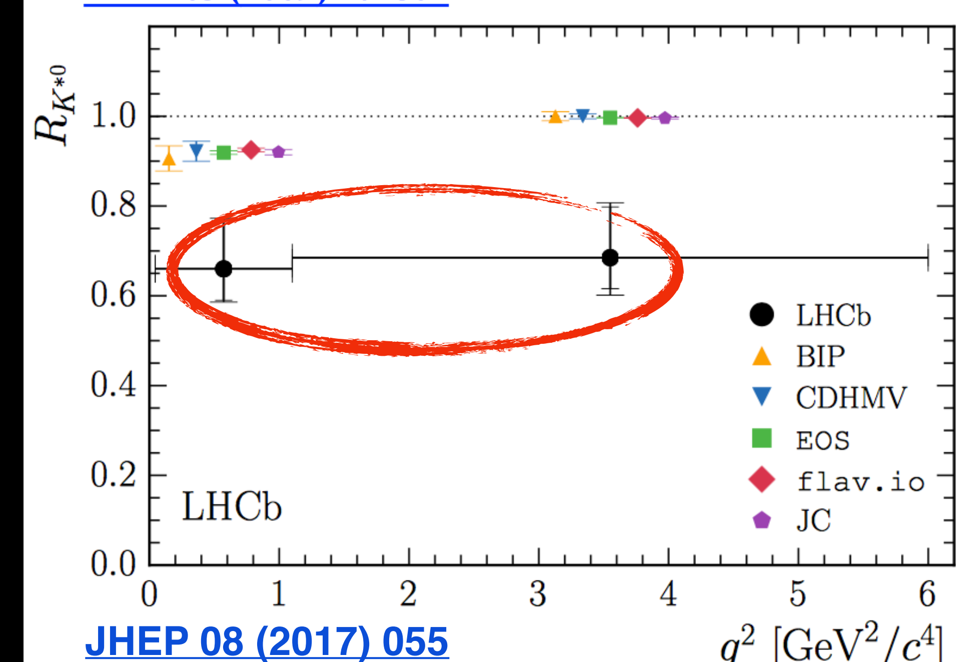
MY FOCUS HERE FALLS ON b —> s ll ANOMALIES.



JHEP 1602 (2016) 104

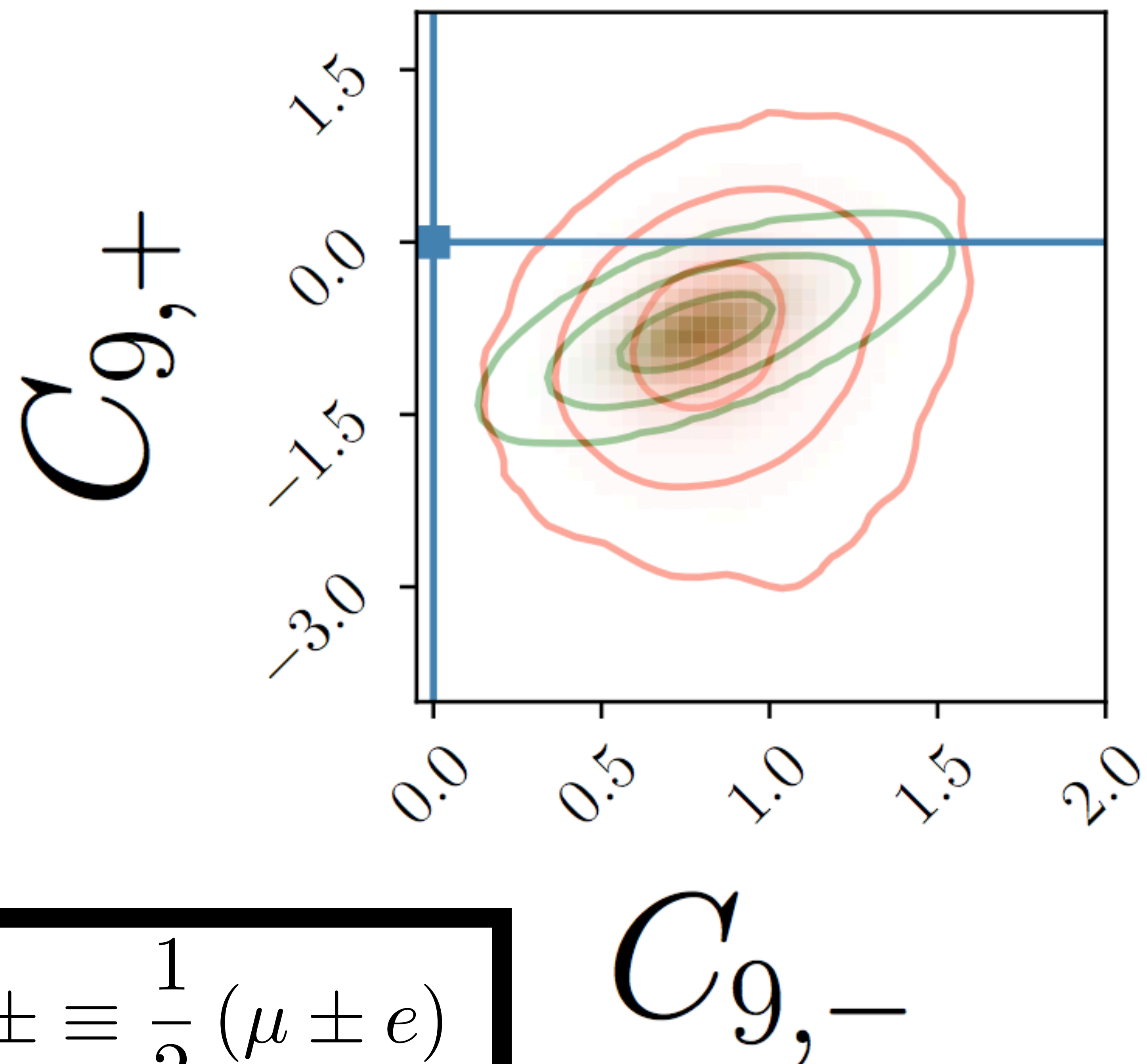


- PRL 113 (2014) 151601
- PRD 86 (2012) 032012
- PRL 103 (2009) 171801



JHEP 08 (2017) 055

A GLIMPSE ON WHAT WE WILL TALK ABOUT.



$$C_{9,\ell} \leftrightarrow \underline{\underline{\bar{s}_L \gamma_\mu b_L \bar{\ell} \gamma^\mu \ell}} \quad Q_{9,\ell}$$

"optimistic" approach to QCD effects

conservative approach to QCD effects

$$\pm \equiv \frac{1}{2}(\mu \pm e)$$

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

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

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

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

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

- SHORT DISTANCE @ DIM 6
  SM Wilson coeffs @ ~ m_b : C_7 ~ -1/3 , C_9 ~ 4 , C_{10} ~ -4
- 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.

BAYESIAN FIT OF $B \rightarrow K^{(*)} \ell\ell$

- HELICITY AMPLITUDES FROM STATE-OF-THE-ART OF THE THEORY:

Z-EXPANSION FROM LCSR / LQCD
(Bayley et al.`15, Bharucha et al.`15)

QCD FACTORIZATION COMPUTATIONS
(Beneke et al.`01, Beneke et al.`09)

PHENOMENOLOGICAL APPROACH FOR
NON-FACTORIZABLE POWER CORRECTIONS

NEW PHYSICS WILSON COEFFICIENTS

HEPfit

57 TO **77** PARAMETERS
VARIED IN b—> s ll FITS
(PRIORS: GAUSSIAN/FLAT)

- FIT AVAILABLE EXP INFO. IN THIS TALK THE FOCUS WILL BE ON:

LHCb CP-CONSERVING ANGULAR OBS + BRs FOR K(*) MODES AT
LARGE RECOIL, BELLE DATA ON P'_4 & P'_5 , $B_s \rightarrow \ell\ell$ FROM HFLAV.

- BAYESIAN MODEL COMPARISON WITH INFORMATION CRITERION:

$$IC \equiv -2\overline{\ln \mathcal{L}} + 4\sigma^2_{\ln \mathcal{L}}$$

DICHOTOMY OF $B \to K^* \ell\ell$ IN THE SM

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 ΔC_7

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

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

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

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

WE CONSTRAIN THIS SET REQUIRING TO MATCH AS ABSOLUTE VALUE LCSR RESULTS **ONLY** FOR $q^2 \leq$ GeV^2 (*Khodjamirian et a.`10*).

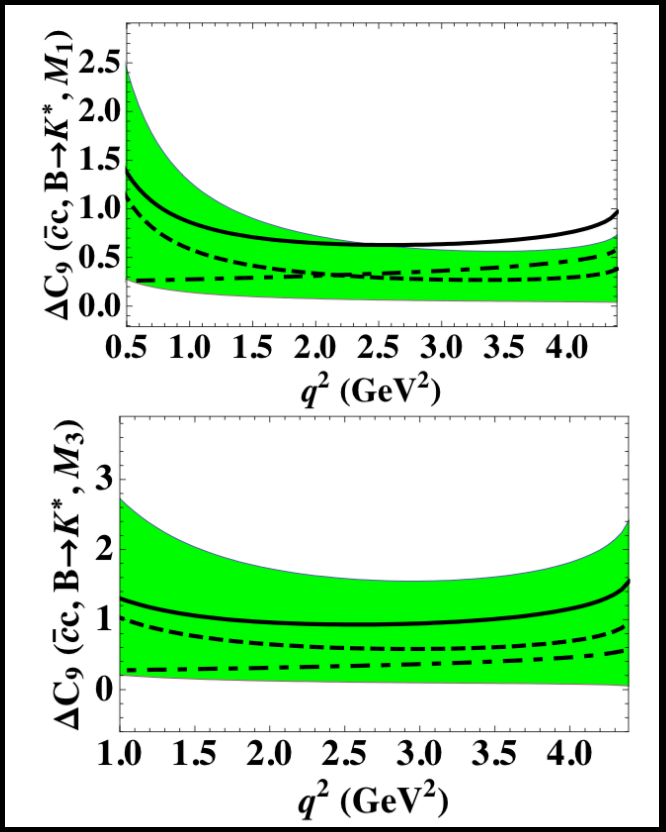
WE ALSO REQUIRE |h+/h-| << 1 AT LARGE RECOIL (*Jager & Camalich`14*).

DICHOTOMY OF $B \to K^* \ell\ell$ IN THE SM

Phenomenological Model Driven (PMD)

NEW HERE

WE DO NOT LONGER TRANSLATE THIS INTO "THEORY DATA POINTS". (as in Ciuchini`17 et al.)



LCSR COMPUTATION + DISPERSION REL.

Khodjamirian et al. `10

Results recently corroborated by:

Bobeth et al. `17

Blake et al. `17

WE NOW ADOPT THE PARAMETRIZATION FOR THE DISPERSION RELATION:

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

$i = 1, 2, 3$

AS ABSOLUTE VALUE (TIMES PHASE FACTOR), ASSIGNING FLAT PRIORS.

DICHOTOMY OF $B \to K^* \ell\ell$ IN THE SM

update of Ciuchini `16

Phenomenological Model Driven (PMD)

$$\overline{\ln \mathcal{L}} = -48.7$$

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

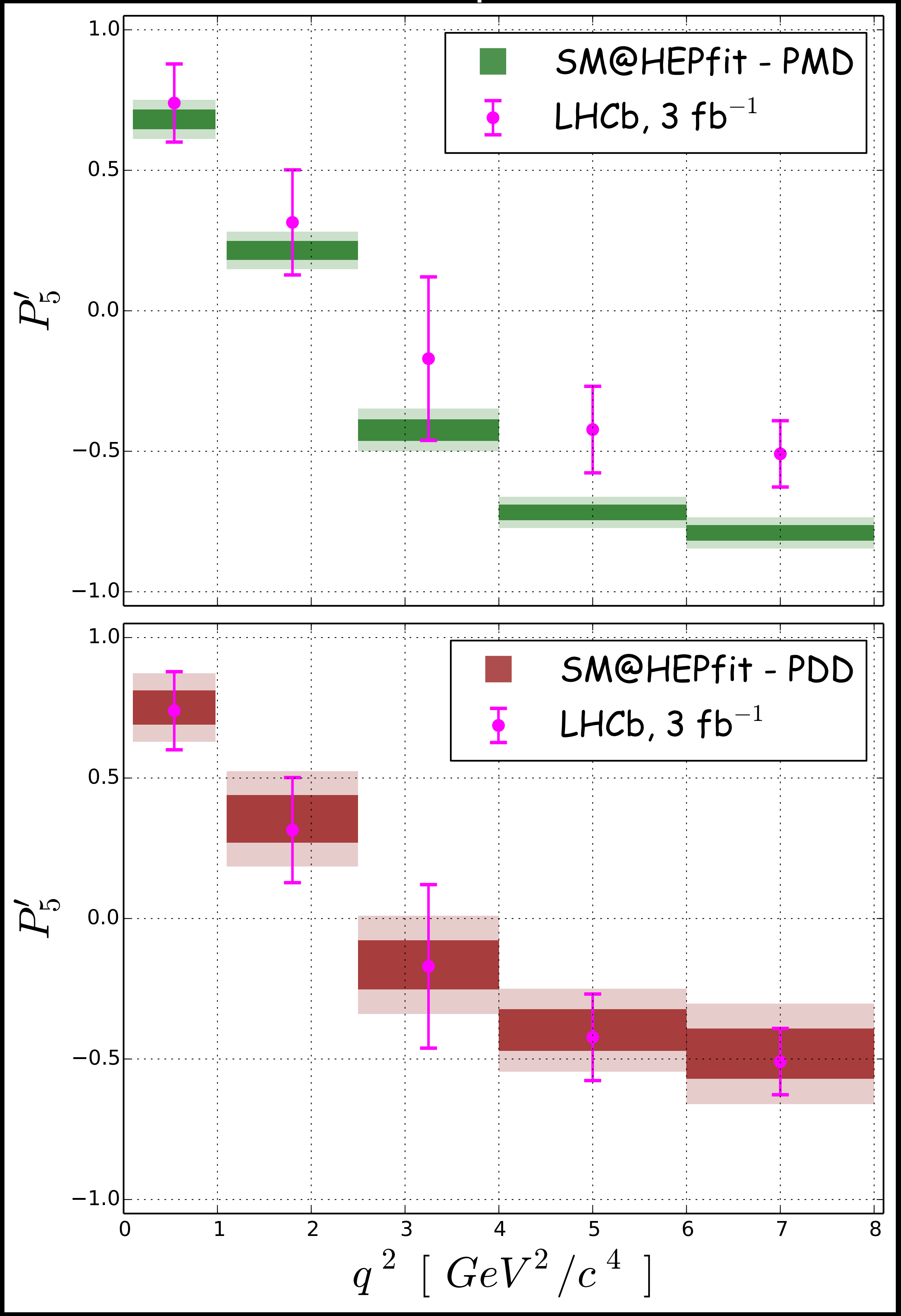
$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

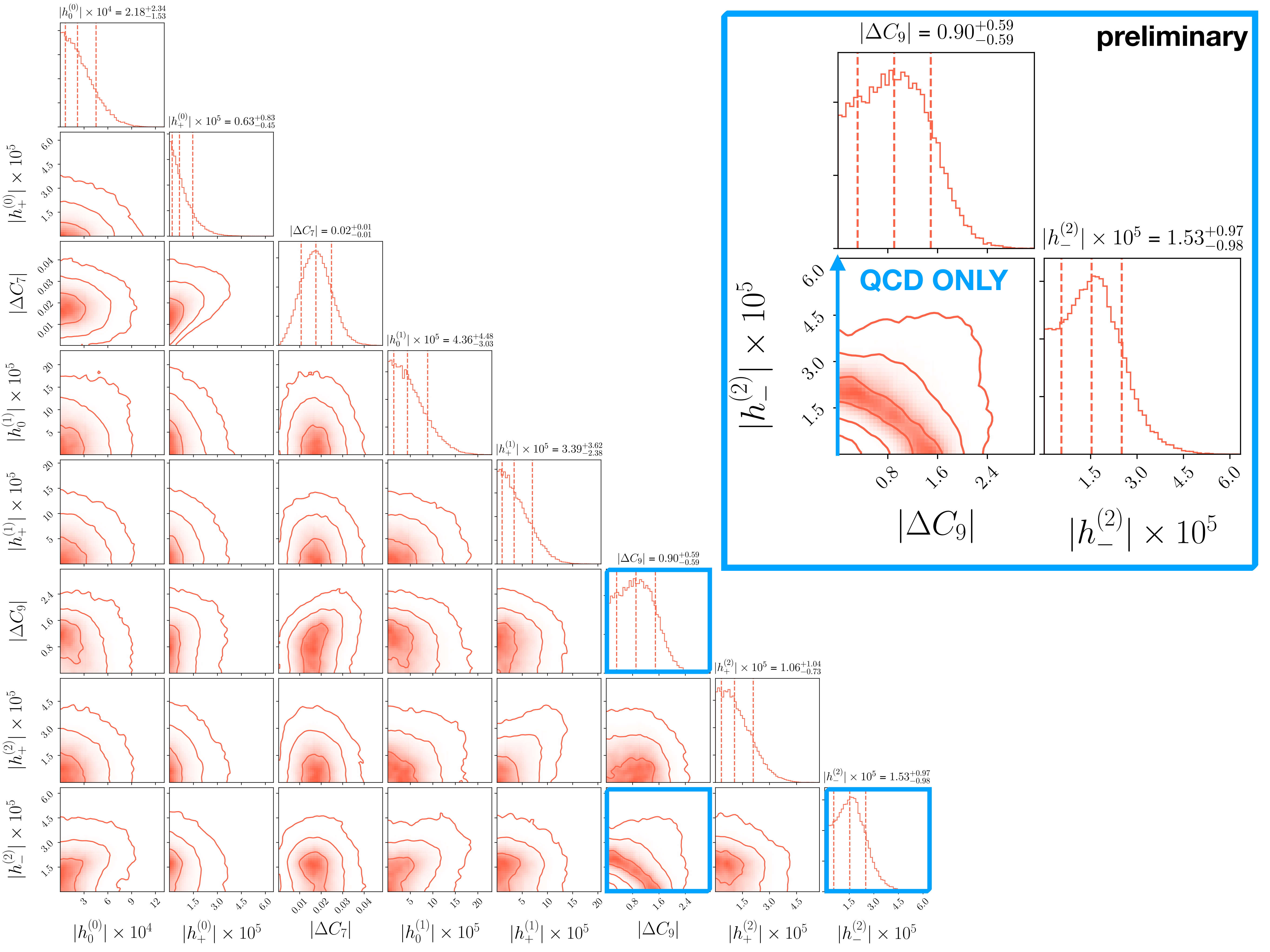
Matias et al. `12

Phenomenological Data Driven (PDD)

$$\overline{\ln \mathcal{L}} = -38.5$$

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



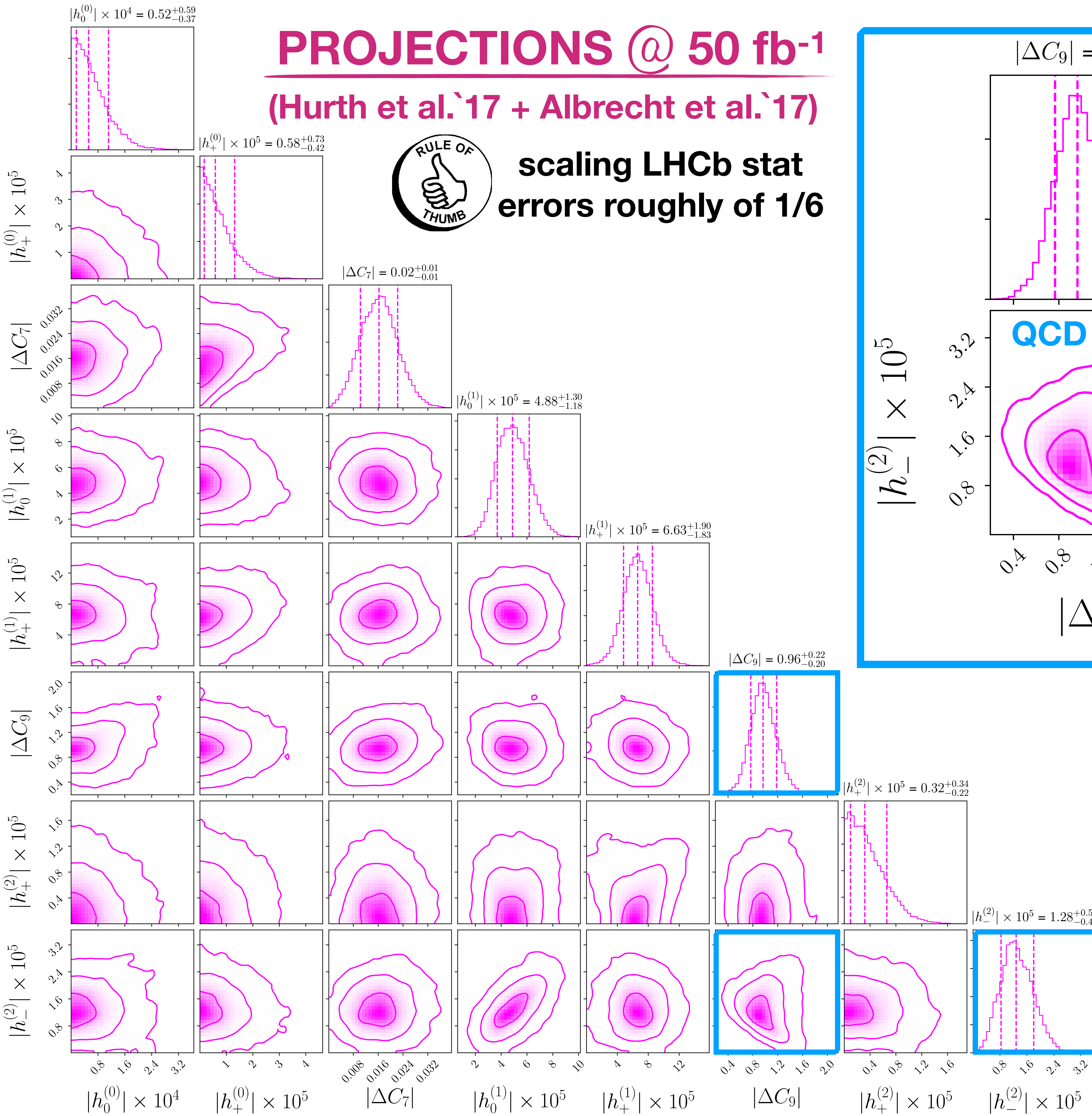


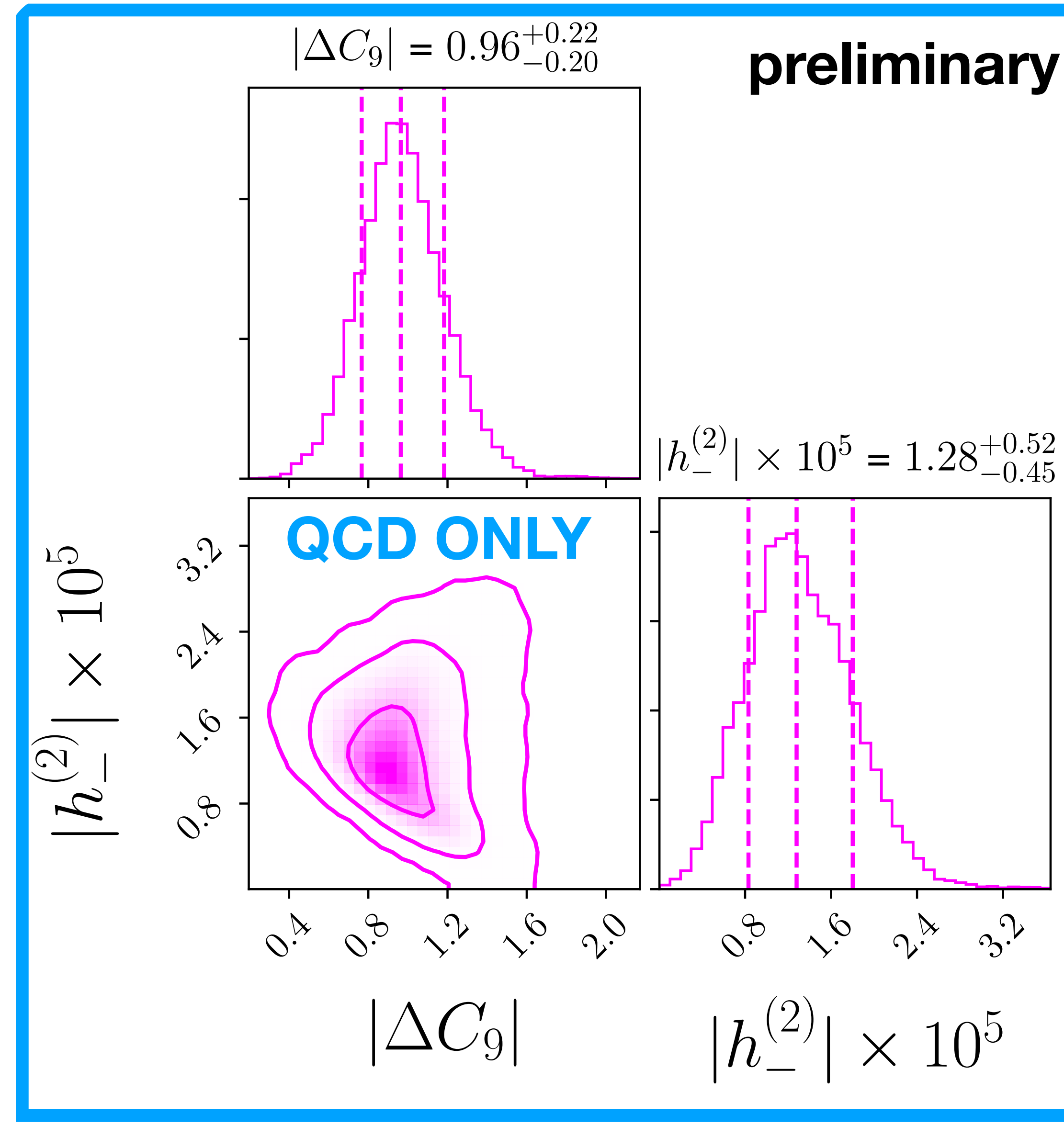
preliminary
QCD ONLY
$|h_0^{(0)}| \times 10^4 = 2.18^{+2.34}_{-1.53}$
$|h_+^{(0)}| \times 10^5 = 0.63^{+0.83}_{-0.45}$
$|\Delta C_7| = 0.02^{+0.01}_{-0.01}$
$|h_0^{(1)}| \times 10^5 = 4.36^{+4.48}_{-3.03}$
$|h_+^{(1)}| \times 10^5 = 3.39^{+3.62}_{-2.38}$
$|\Delta C_9| = 0.90^{+0.59}_{-0.59}$
$|h_+^{(2)}| \times 10^5 = 1.06^{+1.04}_{-0.73}$
$|h_-^{(2)}| \times 10^5 = 1.53^{+0.97}_{-0.98}$
$|h_0^{(0)}| \times 10^4$
$|h_+^{(0)}| \times 10^5$
$|\Delta C_7|$
$|h_0^{(1)}| \times 10^5$
$|h_+^{(1)}| \times 10^5$
$|\Delta C_9|$
$|h_+^{(2)}| \times 10^5$
$|h_-^{(2)}| \times 10^5$

PROJECTIONS @ 50 fb^{-1}

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

scaling LHCb stat errors roughly of 1/6





NOW …

State-of-the-art global analyses of b —> s ll measurements show evidence for NP at the 5σ - 6σ level, commonly associated to $Q_{9,\mu}$.

Altmannshofer et al. '17
Capdevila et al. '17
Ciuchini et al. '17
D'Amico et al. '17
Geng et al. '17
Hiller & Nisandzic '17
… + many others!

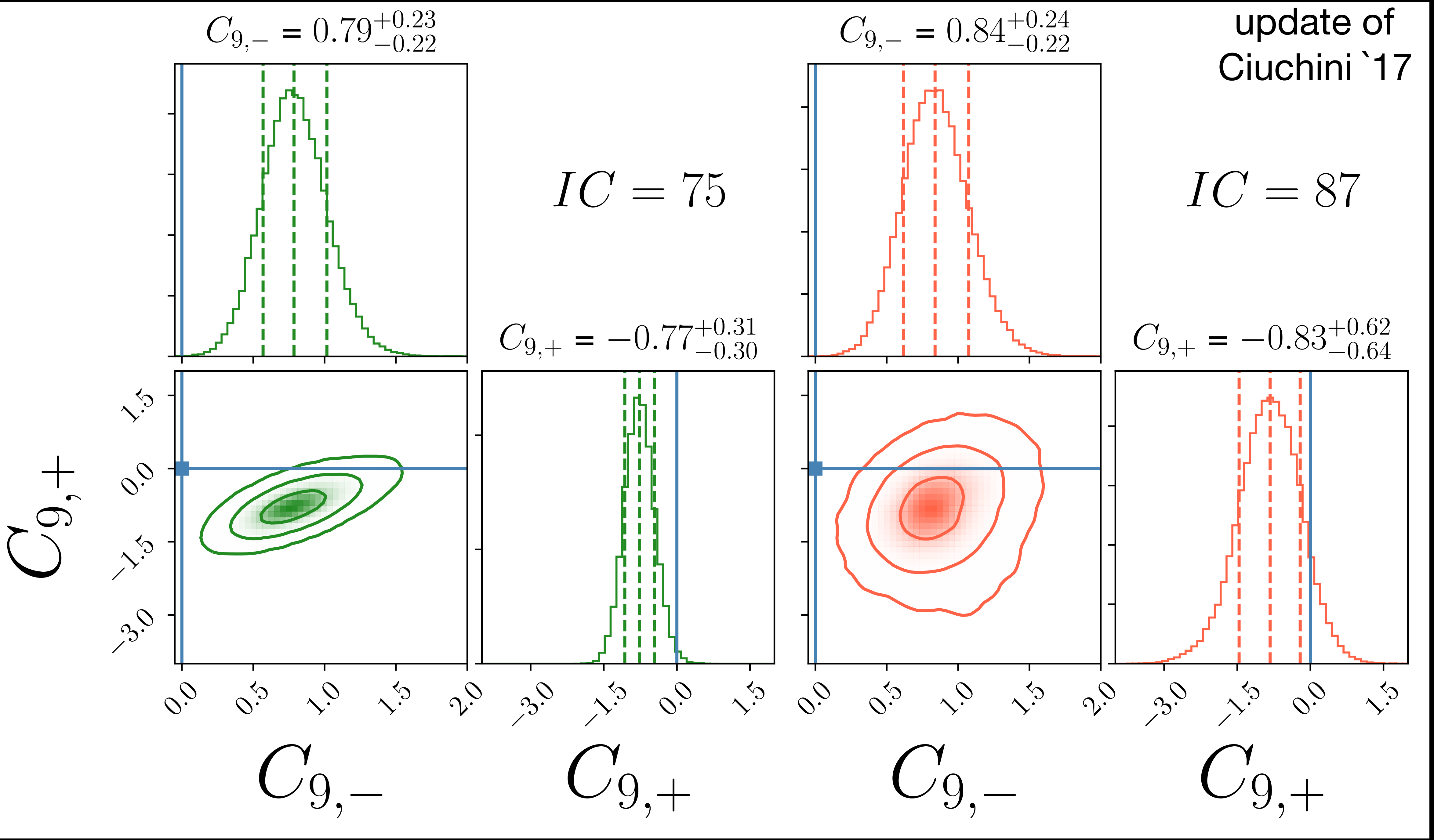
BUT …

I) Are data unambiguously pointing to NP in muonic vectorial current?

II) What is the role of unknown QCD power corrections in this business?

NP in $B \to K^{(*)} \ell\ell$ from Vectorial Couplings

preliminary update of Ciuchini `17

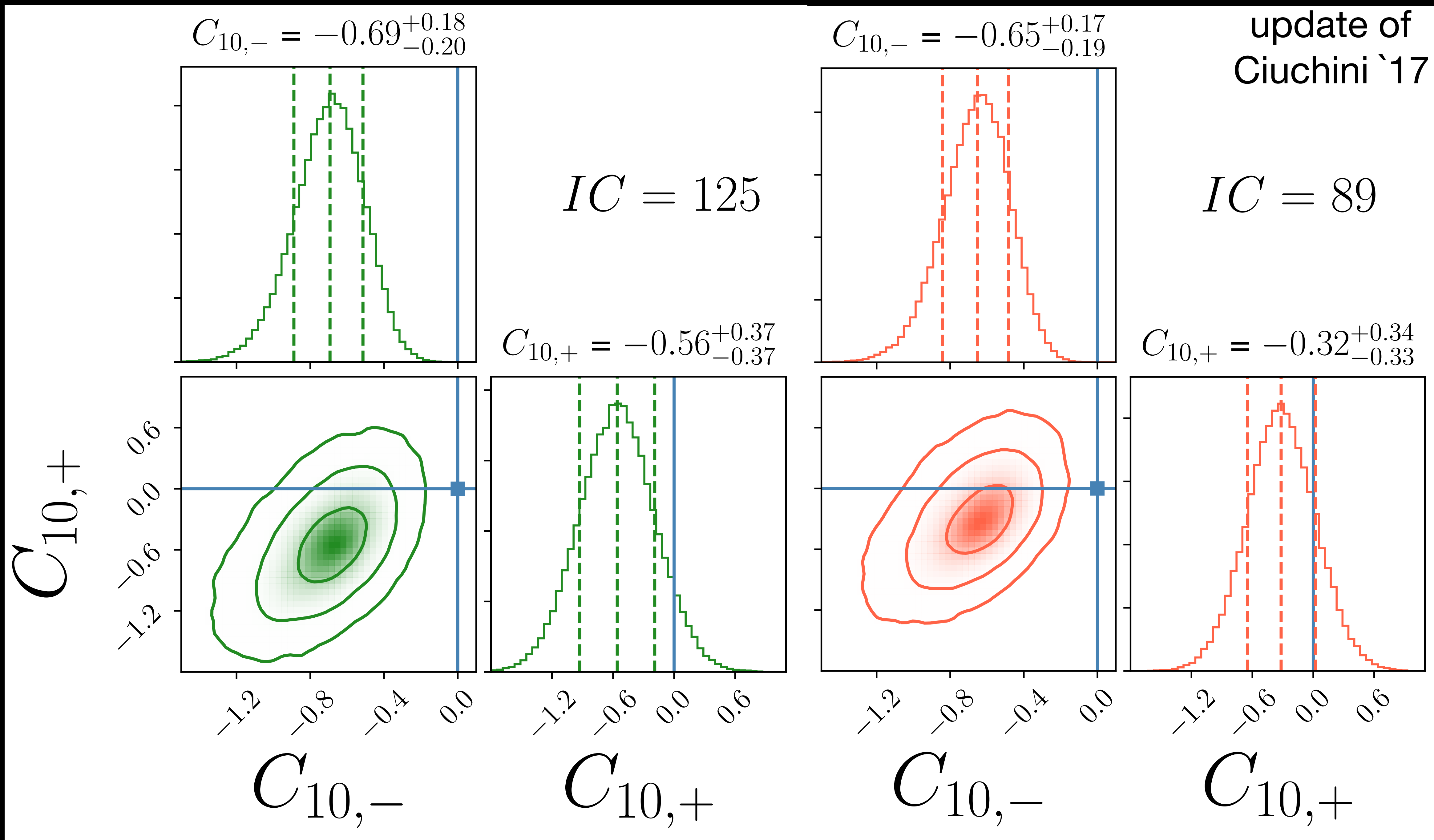


MINUS COEFFICIENT IS PROBED BY LUV OBS.
MINIMALITY CURRENTLY REWARDS PMD.

NP in $B \to K^{(*)} \ell\ell$ from Axial Couplings

preliminary

update of Ciuchini `17

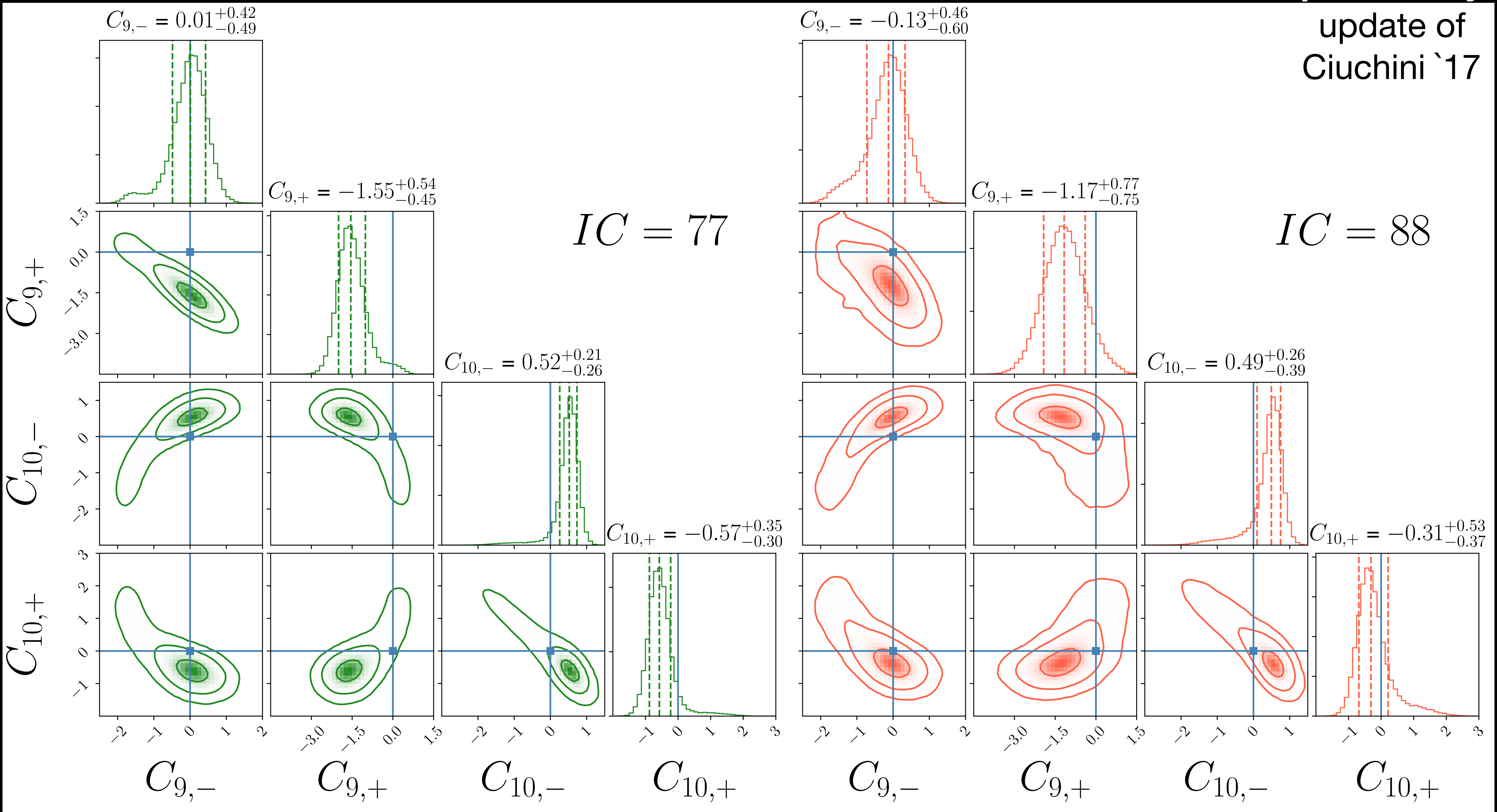


MINUS COMBINATION DETERMINED AGAIN BY LUV.

IN PDD AXIAL SOLUTION AS VIABLE AS VECTOR ONE.

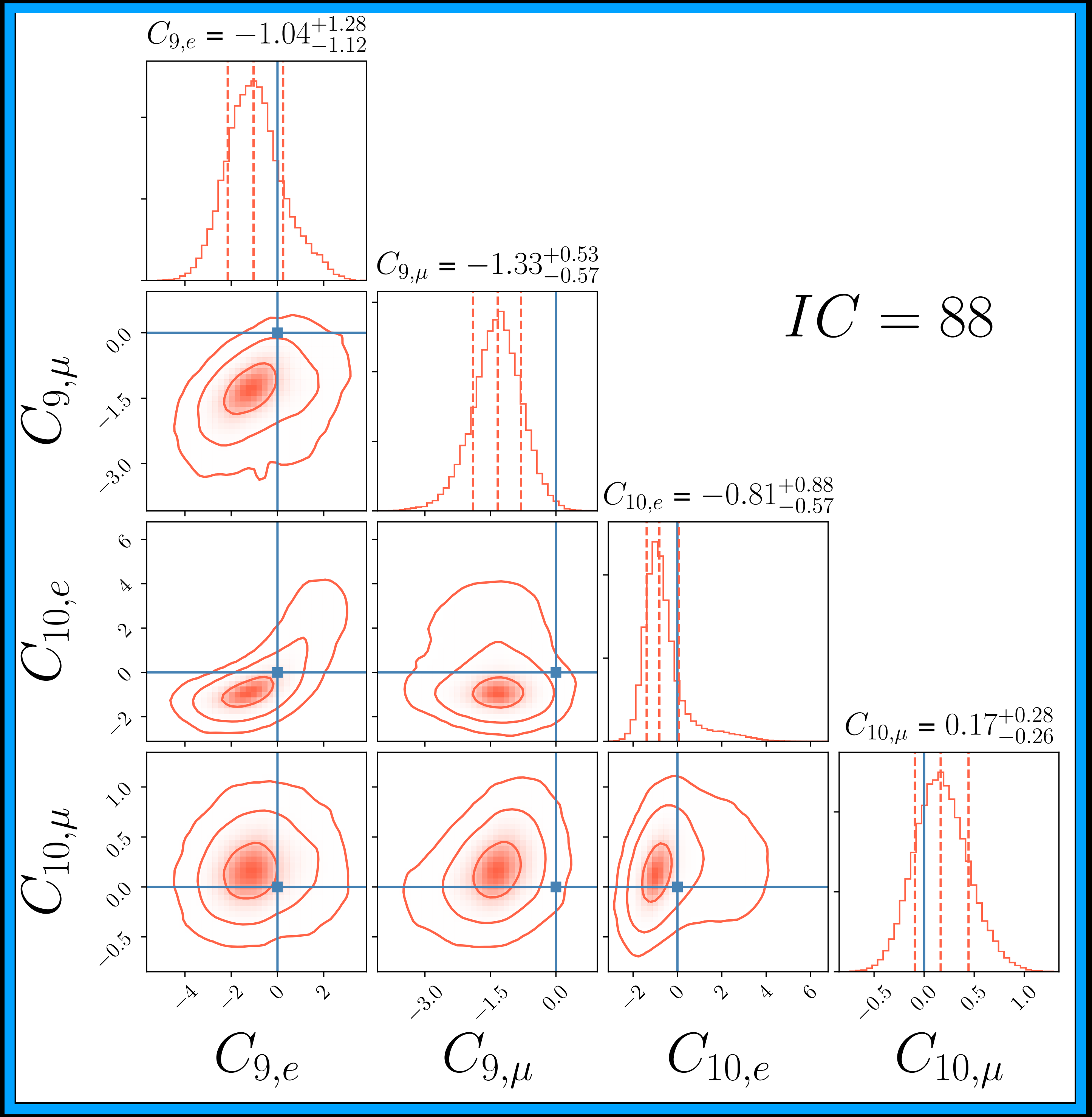
AXIAL & VECTOR NP IN $B \to K^{(*)} \ell\ell$

preliminary update of Ciuchini `17



"POLLUTED" PLUS-DIRECTION IN C_9 IS SELECTED BY DATA IN STRONG CORRELATION WITH AXIAL COEFFICENTS.

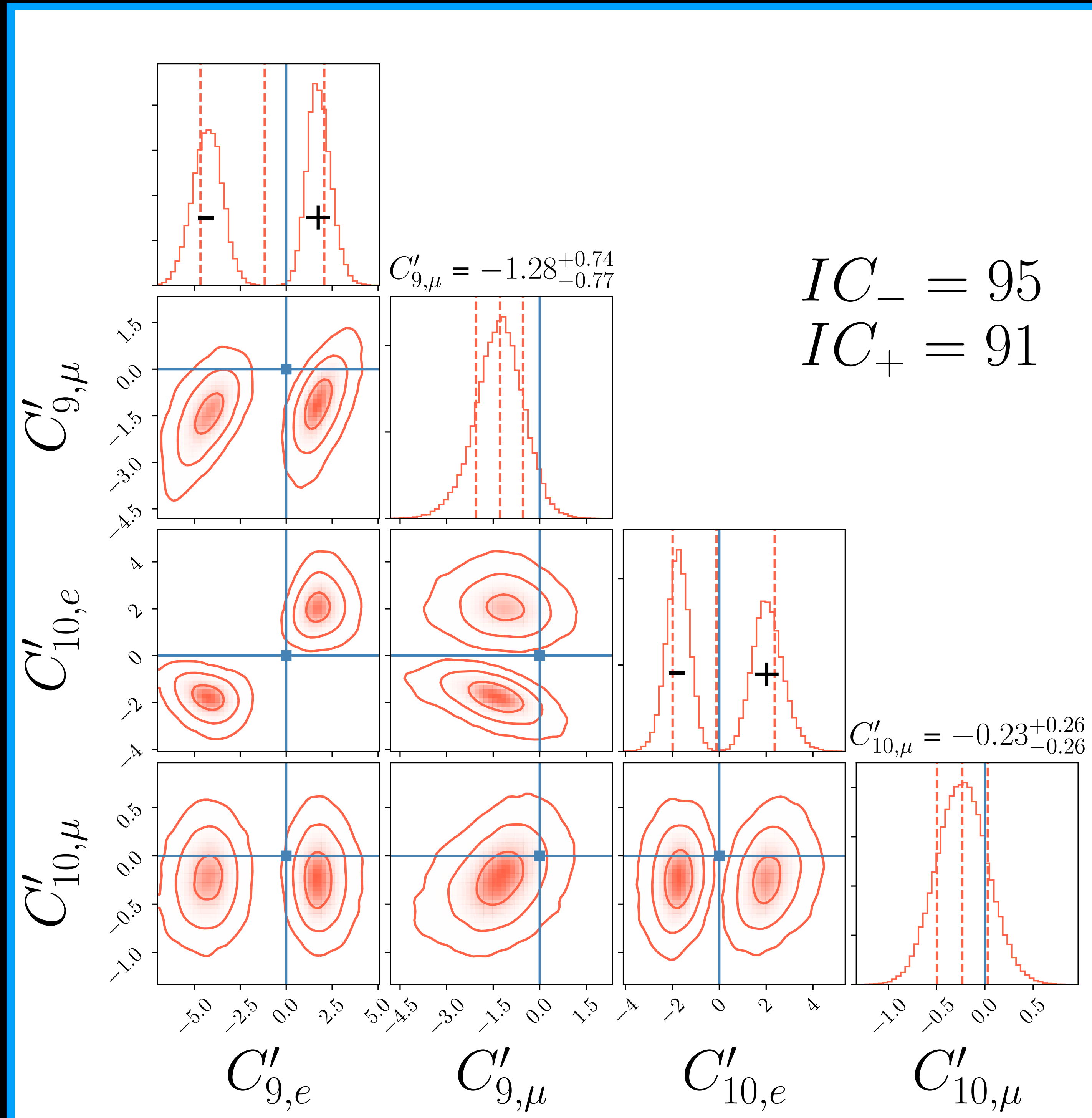
AXIAL & VECTORIAL NP IN $B \to K^{(*)} \ell\ell$



preliminary
update of
Ciuchini `17

BACK TO LEPTON-FLAVORED BASIS, SUCH CORRELATIONS HIGHLIGHT PREFERENCE FOR MUONIC VECTORIAL NP.

(AXIAL & VECTORIAL)' NP IN $B \to K^{(*)} \ell\ell$



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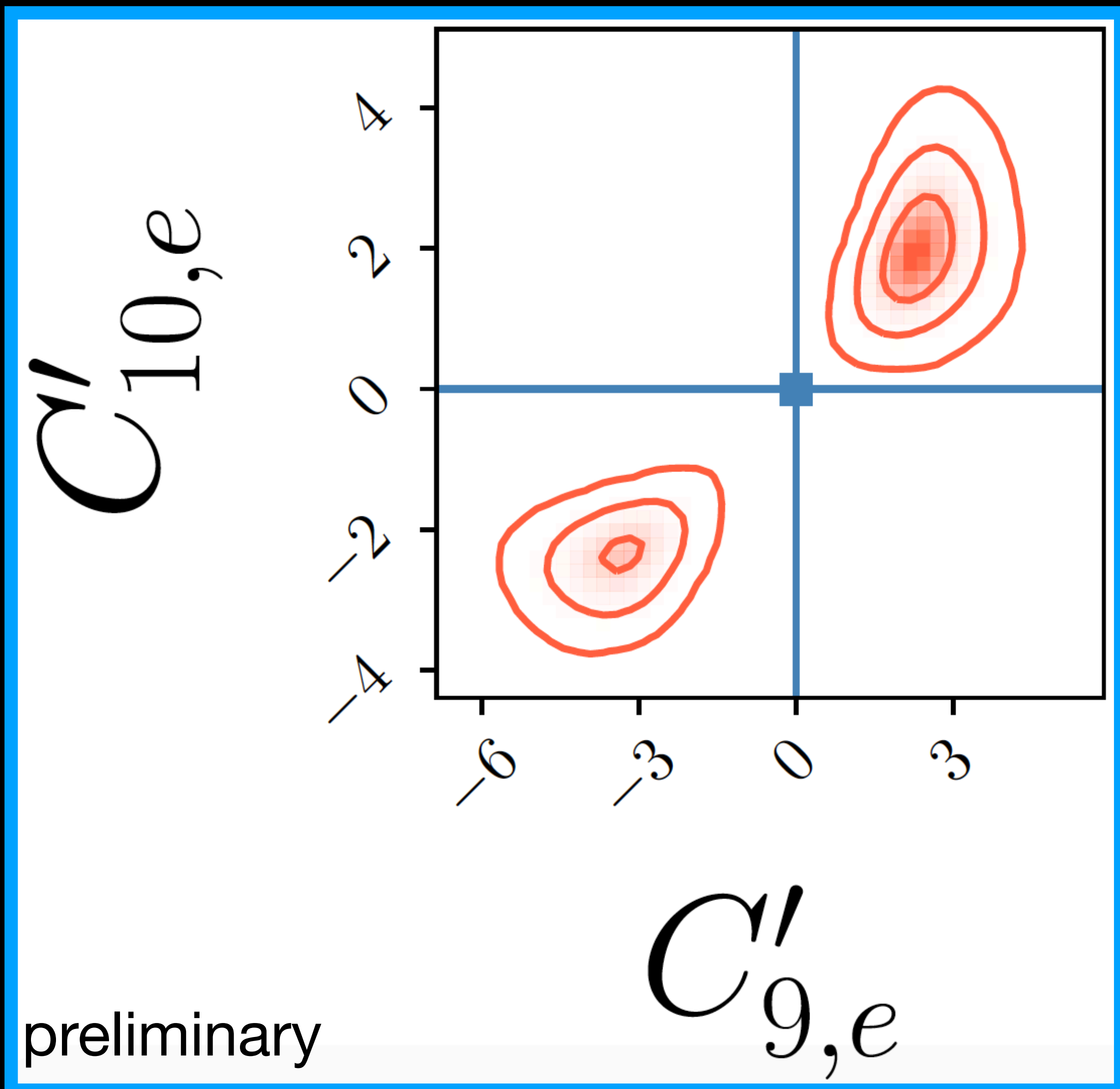
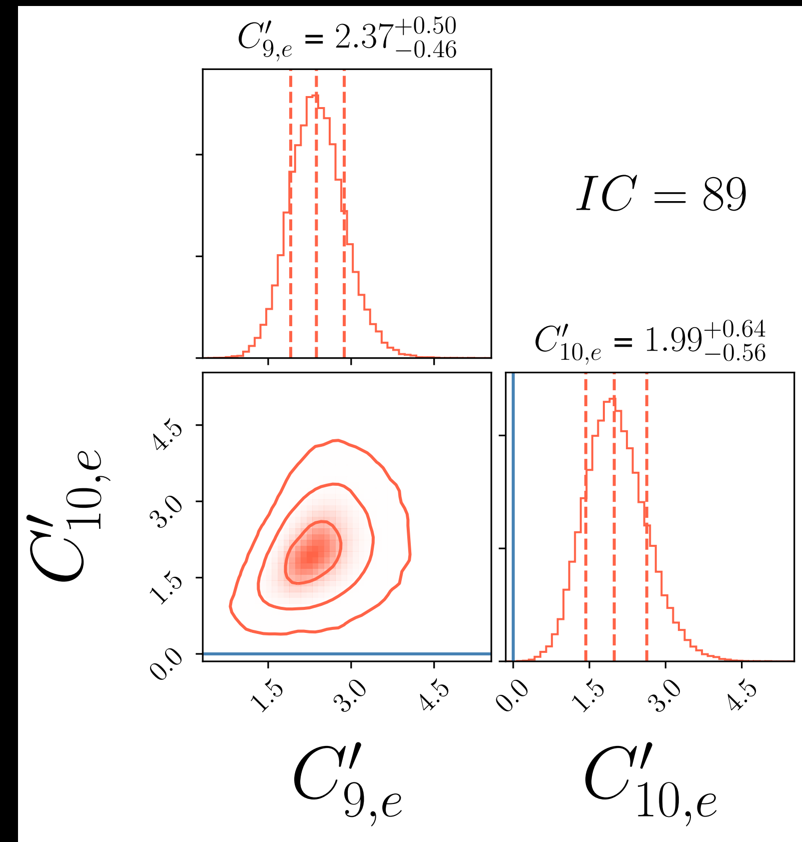
DETERMINATION OF ELECTRON COEFFS STANDS OUT.
BUT EVEN IN PDD V+A b TO s CURRENT (A BIT) DISFAVORED.

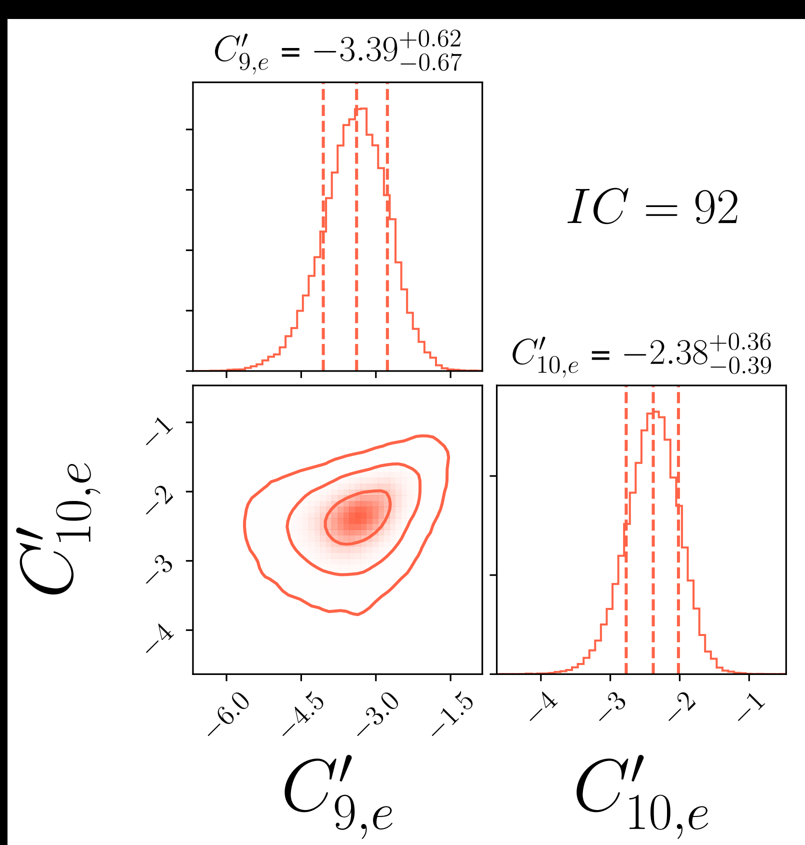




BIMODALITY DRIVEN BY $P'^{\text{BELLE}}_{4,5}$.

MODES CAN BE SEPARATELY INVESTIGATED.

V+A WITH NP IN ELECTRONS



— IN PMD BOTH SOLUTIONS ARE STRONGLY DISFAVORED.

— IN PDD BOTH SOLUTIONS ARE ACTUALLY AVAILABLE.

BELLE & LHCb DATA ON ELECTRONS MILDLY POINT TO SCENARIO $C'_{9,10\,e} > 0$.

CONCLUSIONS

I) A CONSERVATIVE APPROACH TO HADRONIC UNCERTAINTIES HIGHLIGHTS THE CRUCIAL ROLE OF LUV MEASUREMENTS IN THE ANALYSIS OF NP EFFECTS IN b —> s ll TRANSITIONS

II) AS THE MOST ECONOMIC SOLUTION, NP IN $Q_{9,\mu}$ IS PREFERRED BY DATA.

III) OTHER NP SCENARIOS MAY BE OF INTEREST IF WE HAVE GOOD REASONS TO DISCARD "OCCAM'S RAZOR" ARGUMENT

(NOTE THAT NONE OF THEM PROVIDES AN EXPLANATION FOR THE FIRST BIN OF R_{K^*}!)

IV) LHCb UPGRADE (+ BELLE II) WILL HAVE THE SENSITIVITY TO PIN DOWN QCD POWER CORRECTIONS + IMPROVE LUV DATASET.

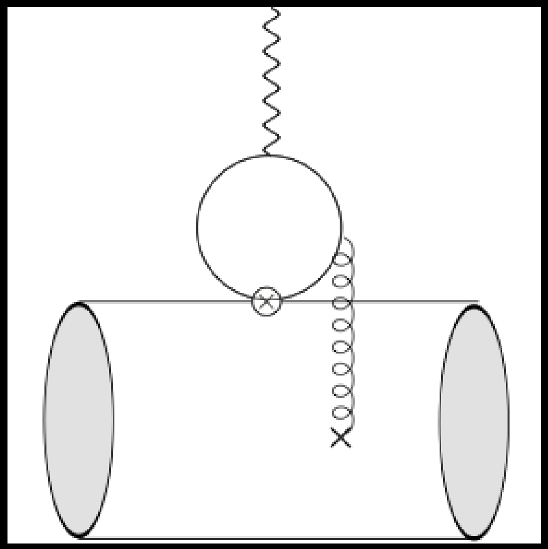
EXCITING TIMES AHEAD!

Thank You !

BACK-UP

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

The "charm-loop" effect



Khodjamirian et al. `10

Correlator expanded on the light-cone: **LCSR estimate based on small q^2**.

Single soft gluon approximation, i.e. first term of expansion in Λ^2_{QCD} / **($4\ m^2_c - q^2$)**

Dispersion relation in order **to extrapolate to physical charm resonances**

THE OUTCOME MORE RECENTLY RE-INVESTIGATED BY:

1) pheno model using resonance data over the full di-muon spectrum

Blake et al. `17

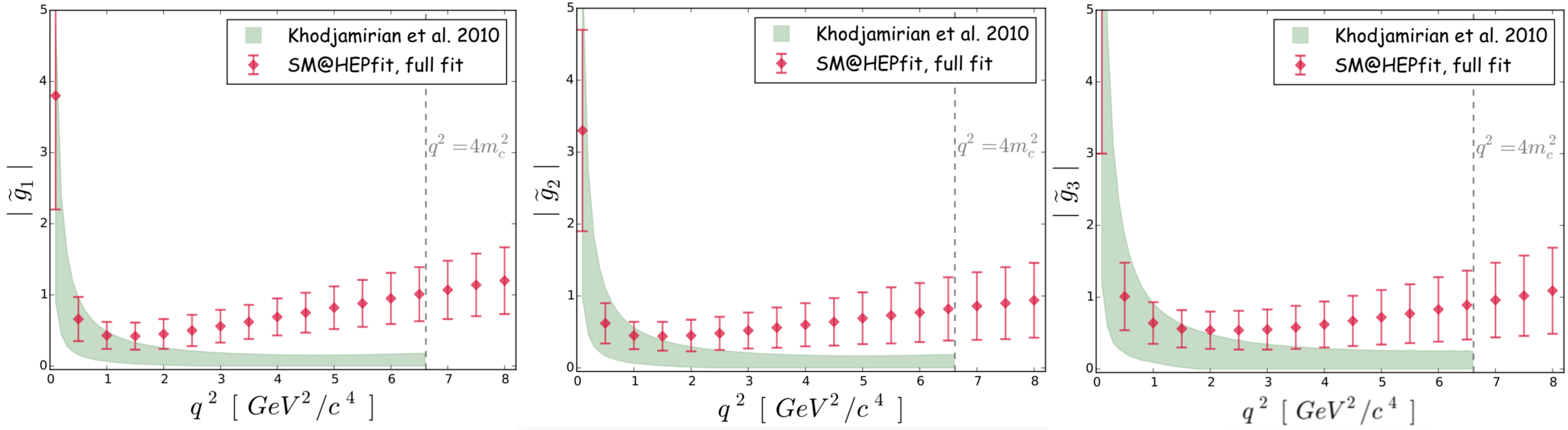
2) replacing dispersion relation with z-expansion, constraining coefficients via analyticity + B —> Ψ(n) K* data + QCDF & LCSR at small q^2.

Bobeth et al. `17

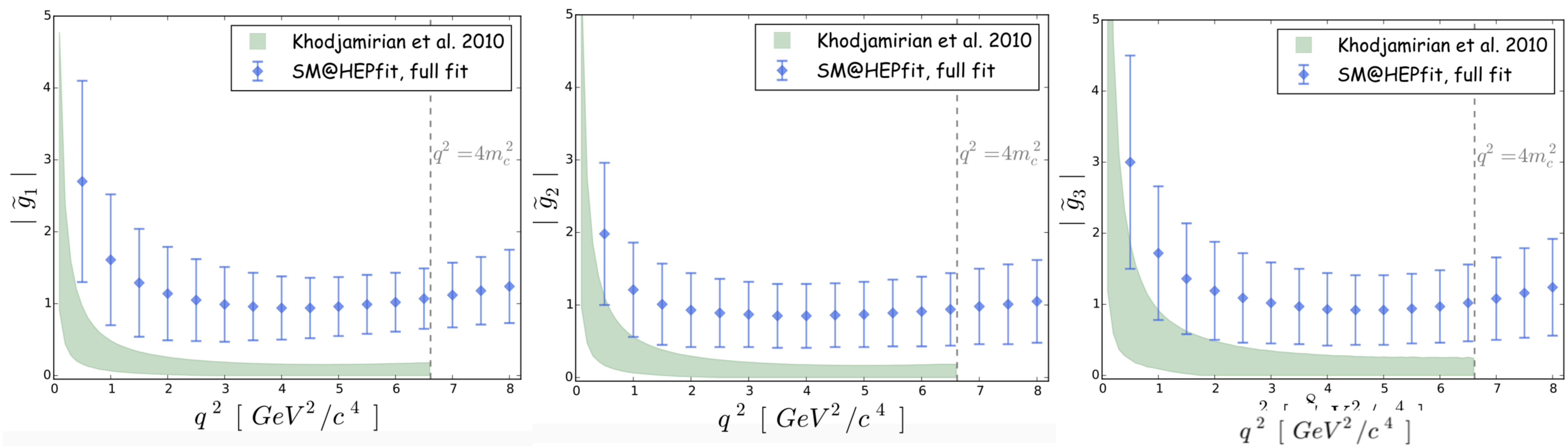
1) AND 2) ARE NOT FREE FROM ASSUMPTIONS / APPROXIMATIONS.

As an overall shift on C_9 , our result comes with some q^2 dependence:

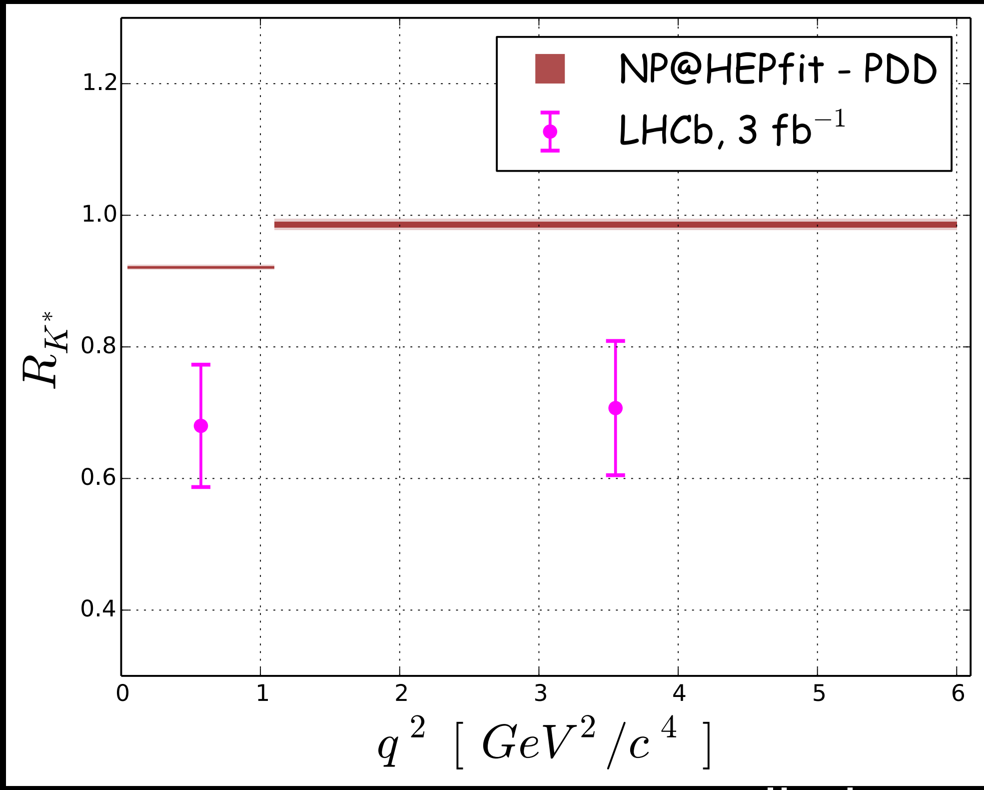
update of Ciuchini et al.`16



HOWEVER, THIS DEPENDS ON OUR THEORY INPUT FROM LCSR AT q^2 < GeV^2 :



OTHER POSSIBILITIES ?



preliminary

(PSEUDO)-SCALAR OPERATORS

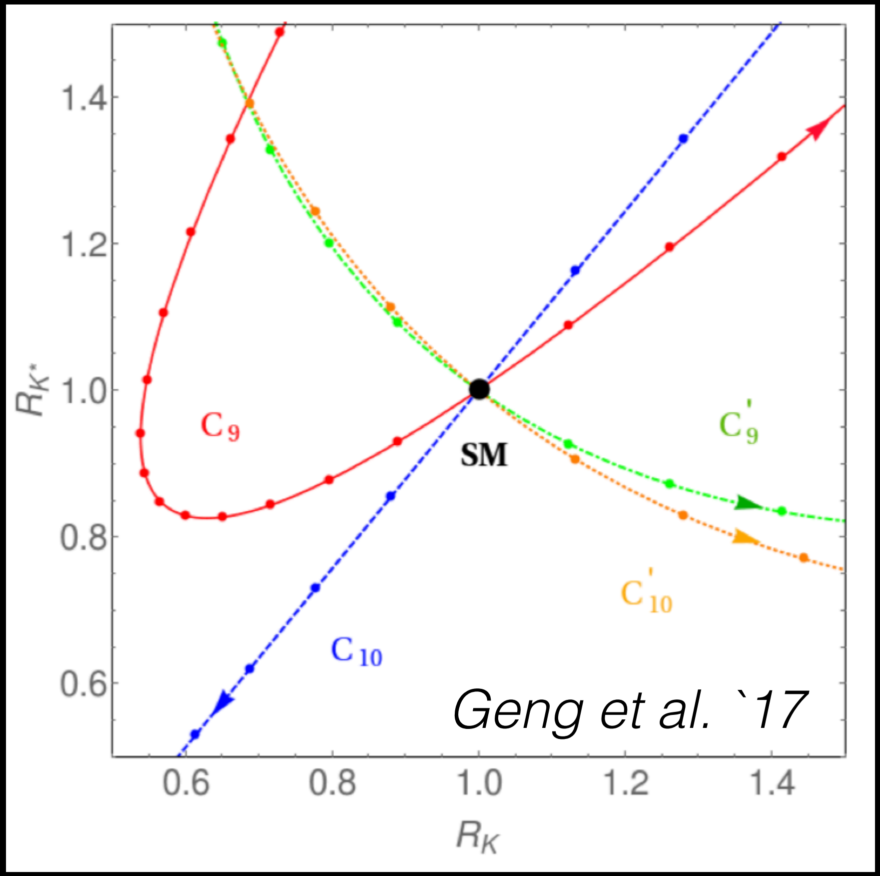
— 4 OPERATORS FOR LEPTON FLAVOR

— CONSTRAINTS FROM B_s —> ll

— ANGULAR OBSERVABLES INFORMATIVE AS WELL

THEY MAY ADDRESS R_K (see, e.g., *Bobeth et al. `07*).

IN PDD, THIS SCENARIO IS ACTUALLY IN TENSION "ONLY" WITH R_{K^*}.



AXIAL / VECTOR-LIKE OPERATORS INVOLVING RH b —> s CURRENTS:

OUTCOME FROM SINGLE-OPERATOR STUDY NOT VERY ENCOURAGING …

… BUT MULTIPLE COMBINATIONS WOULD ALSO BE POSSIBLE!