Hadronic Contributions to New Physics Searches 2019

Puerto de la Cruz, 23-28 September 2019

Update on b to s anomalies after Moriond 2019

M. Fedele

based on arXiv:1512.07157 in collaboration with:

M. Ciuchini, E. Franco, S. Mishima, A. Paul, L. Silvestrini & M. Valli

on arXiv:1704.01737 and arXiv:1903.09632 in collaboration with:

M. Ciuchini, A. Coutinho, E. Franco, A. Paul, L. Silvestrini & M. Valli

UNIVERSITAT DE BARCELONA

ICCUB Institut de Ciències del Cosmos

EXCELENCIA MARÍA DE MAEZTU

Summary

- *Theoretical Framework*
- *Experimental anomalies*
- *Global fits*

Summary

- *Theoretical Framework*
- *Experimental anomalies*
- *Global fits*

The B → V(P)ll decay channel: the Hamiltonian

$$H_{eff}^{\Delta B=1} = H_{eff}^{had} + H_{eff}^{sl+\gamma}$$

$$H_{eff}^{had} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[C_1 P_1^p + C_2 P_2^p + \sum_{i=3,\ldots,6} C_i P_i + C_{8g} Q_{8g} \right]$$

$$H_{eff}^{sl+\gamma} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[C_7^{(\prime)} Q_{7\gamma}^{(\prime)} + C_9^{(\prime)} Q_{9V}^{(\prime)} + C_{10}^{(\prime)} Q_{10A}^{(\prime)} + C_S^{(\prime)} Q_S^{(\prime)} + C_P^{(\prime)} Q_P^{(\prime)} \right]$$

$$\begin{aligned}
P_1^p &= (\bar{s}_L \gamma_\mu T^a p_L)(\bar{p}_L \gamma^\mu T^a b_L) \\
P_2^p &= (\bar{s}_L \gamma_\mu p_L)(\bar{p}_L \gamma^\mu b_L) \\
P_3 &= (\bar{s}_L \gamma_\mu b_L) \textstyle\sum_q (\bar{q} \gamma^\mu q) \\
P_4 &= (\bar{s}_L \gamma_\mu T^a b_L) \textstyle\sum_q (\bar{q} \gamma^\mu T^a q) \\
P_5 &= (\bar{s}_L \gamma_{\mu 1} \gamma_{\mu 2} \gamma_{\mu 3} b_L) \textstyle\sum_q (\bar{q} \gamma^{\mu 1} \gamma^{\mu 2} \gamma^{\mu 3} q) \\
P_6 &= (\bar{s}_L \gamma_{\mu 1} \gamma_{\mu 2} \gamma_{\mu 3} T^a b_L) \textstyle\sum_q (\bar{q} \gamma^{\mu 1} \gamma^{\mu 2} \gamma^{\mu 3} T^a q)
\end{aligned}$$

$$\begin{aligned}
Q_{7\gamma} &= \frac{e}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R F^{\mu\nu} b \\
Q_{8g} &= \frac{\gamma_s}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R G^{\mu\nu} b \\
Q_{9V} &= \frac{\alpha_{em}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \ell) \\
Q_{10A} &= \frac{\alpha_{em}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \gamma^5 \ell) \\
Q_S &= \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \ell) \\
Q_P &= \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \gamma^5 \ell)
\end{aligned}$$

The B → V(P)ll decay channel: the Hamiltonian

$$H_{eff}^{\Delta B=1} = H_{eff}^{had} + H_{eff}^{sl+\gamma}$$

$$H_{eff}^{had} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[C_1 P_1^p + C_2 P_2^p + \sum_{i=3,\ldots,6} C_i P_i + C_{8g} Q_{8g} \right]$$

$$H_{eff}^{sl+\gamma} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[C_7^{(\prime)} Q_{7\gamma}^{(\prime)} + C_9^{(\prime)} Q_{9V}^{(\prime)} + C_{10}^{(\prime)} Q_{10A}^{(\prime)} + C_S^{(\prime)} Q_S^{(\prime)} + C_P^{(\prime)} Q_P^{(\prime)} \right]$$

$$\begin{aligned}
P_1^p &= (\bar{s}_L \gamma_\mu T^a p_L)(\bar{p}_L \gamma^\mu T^a b_L) \\
P_2^p &= (\bar{s}_L \gamma_\mu p_L)(\bar{p}_L \gamma^\mu b_L) \\
P_3 &= (\bar{s}_L \gamma_\mu b_L) \textstyle\sum_q (\bar{q} \gamma^\mu q) \\
P_4 &= (\bar{s}_L \gamma_\mu T^a b_L) \textstyle\sum_q (\bar{q} \gamma^\mu T^a q) \\
P_5 &= (\bar{s}_L \gamma_{\mu 1} \gamma_{\mu 2} \gamma_{\mu 3} b_L) \textstyle\sum_q (\bar{q} \gamma^{\mu 1} \gamma^{\mu 2} \gamma^{\mu 3} q) \\
P_6 &= (\bar{s}_L \gamma_{\mu 1} \gamma_{\mu 2} \gamma_{\mu 3} T^a b_L) \textstyle\sum_q (\bar{q} \gamma^{\mu 1} \gamma^{\mu 2} \gamma^{\mu 3} T^a q)
\end{aligned}$$

$$\begin{aligned}
Q_{7\gamma} &= \frac{e}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R F^{\mu\nu} b \\
Q_{8g} &= \frac{\gamma_s}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R G^{\mu\nu} b \\
Q_{9V} &= \frac{\alpha_{em}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \ell) \\
Q_{10A} &= \frac{\alpha_{em}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \gamma^5 \ell) \\
Q_S &= \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \ell) \\
Q_P &= \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \gamma^5 \ell)
\end{aligned}$$

The B → V(P)ll decay channel: the Hamiltonian

$$H_{eff}^{\Delta B=1} = H_{eff}^{had} + H_{eff}^{sl+\gamma}$$

$$H_{eff}^{had} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[C_1 P_1^p + C_2 P_2^p + \sum_{i=3,\ldots,6} C_i P_i + C_{8g} Q_{8g} \right]$$

$$H_{eff}^{sl+\gamma} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[C_7^{(\prime)} Q_{7\gamma}^{(\prime)} + C_9^{(\prime)} Q_{9V}^{(\prime)} + C_{10}^{(\prime)} Q_{10A}^{(\prime)} + C_S^{(\prime)} Q_S^{(\prime)} + C_P^{(\prime)} Q_P^{(\prime)} \right]$$

$$\begin{aligned}
P_1^p &= (\bar{s}_L \gamma_\mu T^a p_L)(\bar{p}_L \gamma^\mu T^a b_L) \\
P_2^p &= (\bar{s}_L \gamma_\mu p_L)(\bar{p}_L \gamma^\mu b_L) \\
P_3 &= (\bar{s}_L \gamma_\mu b_L) \textstyle\sum_q (\bar{q} \gamma^\mu q) \\
P_4 &= (\bar{s}_L \gamma_\mu T^a b_L) \textstyle\sum_q (\bar{q} \gamma^\mu T^a q) \\
P_5 &= (\bar{s}_L \gamma_{\mu 1} \gamma_{\mu 2} \gamma_{\mu 3} b_L) \textstyle\sum_q (\bar{q} \gamma^{\mu 1} \gamma^{\mu 2} \gamma^{\mu 3} q) \\
P_6 &= (\bar{s}_L \gamma_{\mu 1} \gamma_{\mu 2} \gamma_{\mu 3} T^a b_L) \textstyle\sum_q (\bar{q} \gamma^{\mu 1} \gamma^{\mu 2} \gamma^{\mu 3} T^a q)
\end{aligned}$$

$$\begin{aligned}
Q_{7\gamma} &= \frac{e}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R F^{\mu\nu} b \\
Q_{8g} &= \frac{\gamma_s}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R G^{\mu\nu} b \\
Q_{9V} &= \frac{\alpha_{em}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \ell) \\
Q_{10A} &= \frac{\alpha_{em}}{4\pi} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \gamma^5 \ell) \\
Q_S &= \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \ell) \\
Q_P &= \frac{\alpha_{em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{\ell} \gamma^5 \ell)
\end{aligned}$$

The B → V(P)ll decay channel: the Hamiltonian

$$H_{eff}^{\Delta B=1} = H_{eff}^{had} + H_{eff}^{sl+\gamma}$$

$$H_{eff}^{had} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left[C_1 P_1^p + C_2 P_2^p + \sum_{i=3,\ldots,6} C_i P_i + C_{8g} Q_{8g} \right]$$

$$H_{eff}^{sl+\gamma} = \frac{4G_F}{\sqrt{2}} \lambda_t \left[C_7^{(\prime)} Q_{7\gamma}^{(\prime)} + C_9^{(\prime)} Q_{9V}^{(\prime)} + C_{10}^{(\prime)} Q_{10A}^{(\prime)} + C_S^{(\prime)} Q_S^{(\prime)} + C_P^{(\prime)} Q_P^{(\prime)} \right]$$

Matrix elements of quark currents from $Q_{7,9,10,S,P}$ naively factorize:

$$\mathcal{A} \sim \langle \ell^+ \ell^- | J_{\rm lep} | 0 \rangle \langle V(P) | J_{had} | \overline{B} \rangle$$

Not possible for the hadronic Hamiltonian!

$$\tilde{h}_\lambda(q^2) \sim \epsilon_{\lambda,\mu} \int d^4x \, e^{iqx} \langle V(P) | T\{ J_{had}^{\mu,e.m.}(x) \mathcal{H}_{had}^{eff}(0) \} | B \rangle$$

The B → V(P)ll decay channel: the amplitudes

The amplitudes, in the helicity basis, are proportional to

$$
\begin{aligned}
H_\lambda^V(q^2) &\propto (C_9 - C_9')\tilde{V}_\lambda(q^2) + \frac{2m_b m_B}{q^2}(C_7 - C_7')\tilde{T}_\lambda(q^2) - 16\pi^2 \frac{m_B^2}{q^2}\tilde{h}_\lambda(q^2) \\
H_\lambda^A(q^2) &\propto (C_{10} - C_{10}')\tilde{V}_\lambda(q^2) \\
H^S(q^2) &\propto \frac{m_b}{m_W}(C_S - C_S')\tilde{S}(q^2) \\
H^P(q^2) &\propto \frac{m_b}{m_W}(C_P - C_P')\tilde{S}(q^2) + \frac{2m_\ell m_B}{q^2}(C_{10} - C_{10}')\left(1 + \frac{m_s}{m_b}\right)\tilde{S}(q^2)
\end{aligned}
$$

$$\boxed{(\lambda = 0, \pm)}$$

The main sources of uncertainties are coming from the form factors and from the hadronic parameters

The B → V(P)ll decay channel: the hadronic parameter

At first order in α_{em} we can get a contribution from current-current quark operators & QCD penguins

Loop suppressed amplitude, can be enhanced by non-perturbative QCD effects!

In particular, charm current-current insertion not further parametrically suppressed.

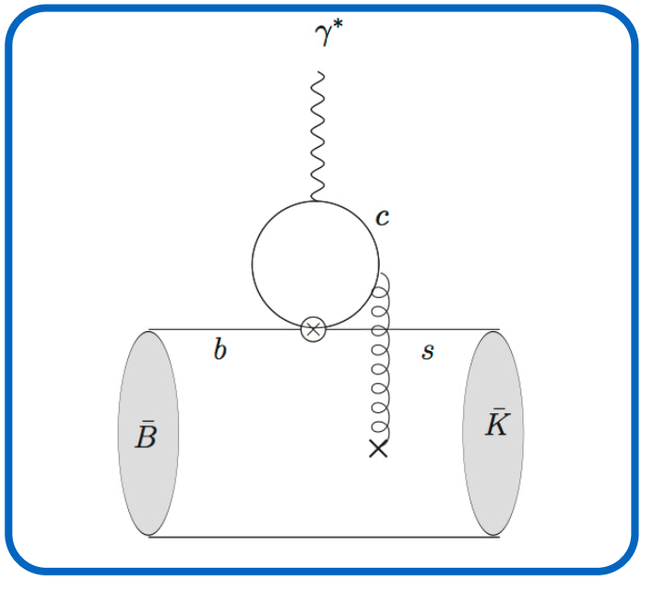
Soft gluon emission from cc-loop estimated for P = K and V = K* with LCSR + dispersion relation. **Sizable effect in K***

The charm-loop effect

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

⇒ **Dispersion relation** in order **to extrapolate LCSR result** up to charm resonances.

⇒ **Single soft gluon approximation**: strictly valid only for $q^2 << 4m^2_c$!



A. Khodjamirian et al., **JHEP 09 (2010) 089**

The B → V(P)ll decay channel: the hadronic parameter

Two more recent studies on the subject:

- Phenomenological model obtained as a sum of Breit-Wigner, resonance data to fix the parameters (not possible to fix strong phases, agreement only with particular choices of the phases)

  T. Blake et al., see talk by P. Owen
  EPJC 78 (2018) 6, 453

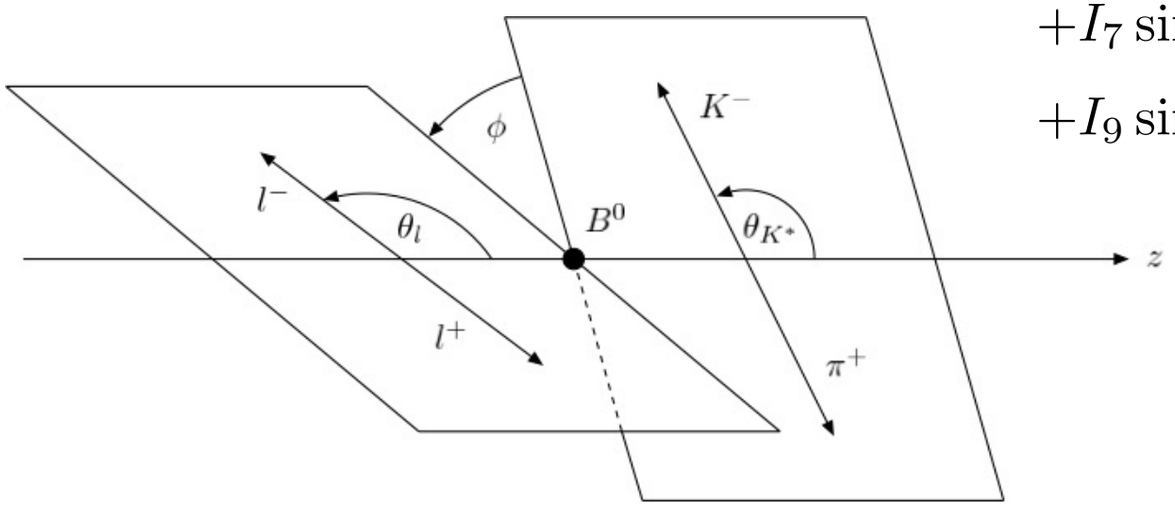
- Similar to JHEP09(2010)089, but with dispersion relation replaced by z-expansion, with coeffs. constrained by analicity and $B \to K^* \psi_n$ data

  C. Bobeth et al.,
  EPJC 78 (2018) 6, 451

Problem of multiple soft-gluon emission still open…

The B → V(P)ll decay channel: the kinematic distribution

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



$$\Sigma_i = \frac{I_i + \bar{I}_i}{2}$$

CP-Averaged

$$\Gamma' = \frac{1}{2}\frac{d\Gamma + d\bar{\Gamma}}{dq^2} = \Sigma_{1c} + 4\Sigma_{2s} \quad P_1 = \frac{\Sigma_3}{2\Sigma_{2s}} \quad P_2 = \frac{\Sigma_{6s}}{8\Sigma_{2s}} \quad P_3 = -\frac{\Sigma_9}{4\Sigma_{2s}}$$

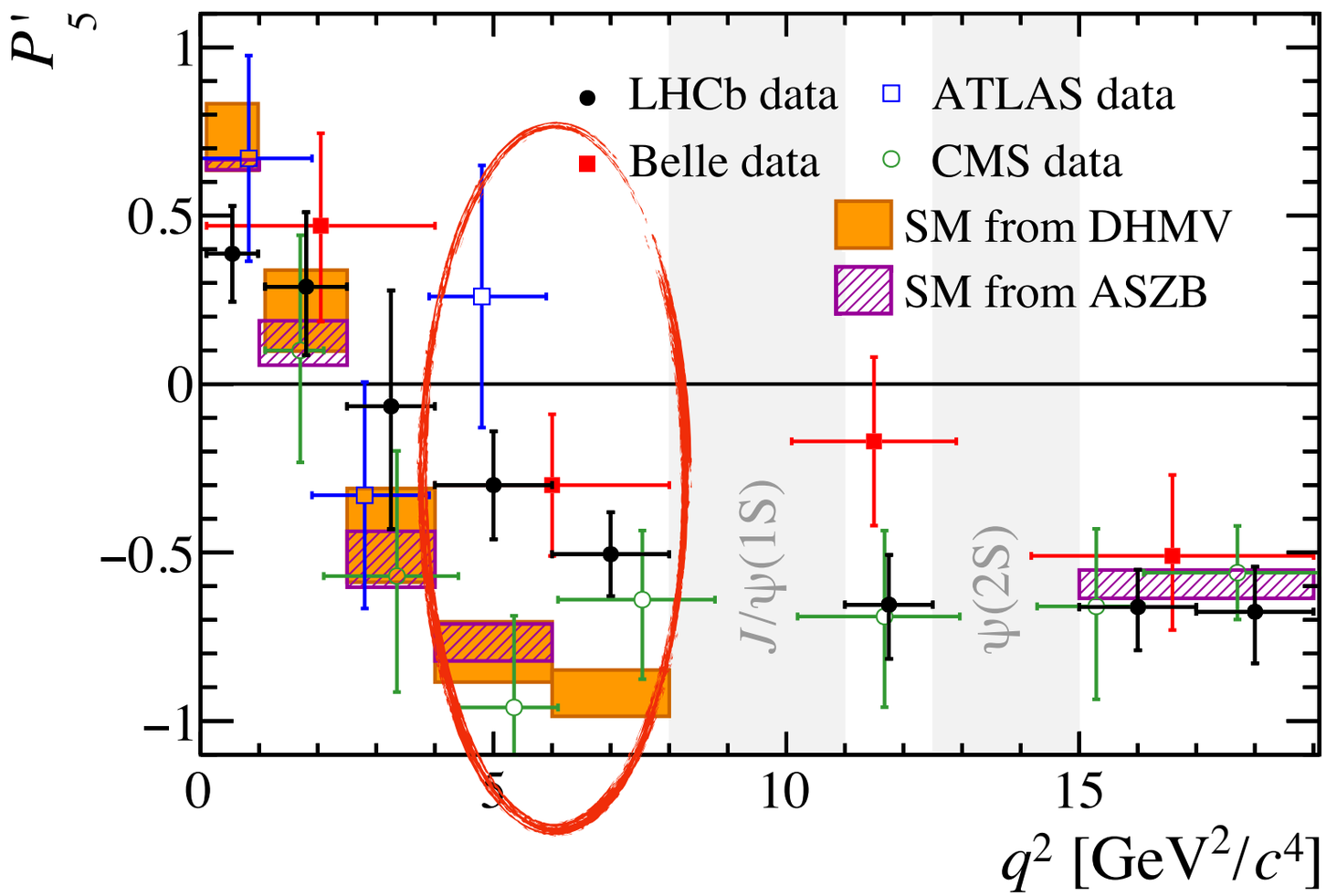
$$P_4' = \frac{\Sigma_4}{\sqrt{-\Sigma_{2s}\Sigma_{2c}}} \quad P_5' = \frac{\Sigma_5}{2\sqrt{-\Sigma_{2s}\Sigma_{2c}}} \quad P_6' = -\frac{\Sigma_7}{2\sqrt{-\Sigma_{2s}\Sigma_{2c}}} \quad P_8' = -\frac{\Sigma_8}{\sqrt{-\Sigma_{2s}\Sigma_{2c}}}$$

Summary

- *Theoretical Framework*
- *Experimental anomalies*
- *Global fits*

Angular analysis of $B \to K^* \mu\mu$ (iii)

INTRIGUING SET OF "ANOMALIES" IN DATA OF EXCLUSIVE B RARE DECAYS



- 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!

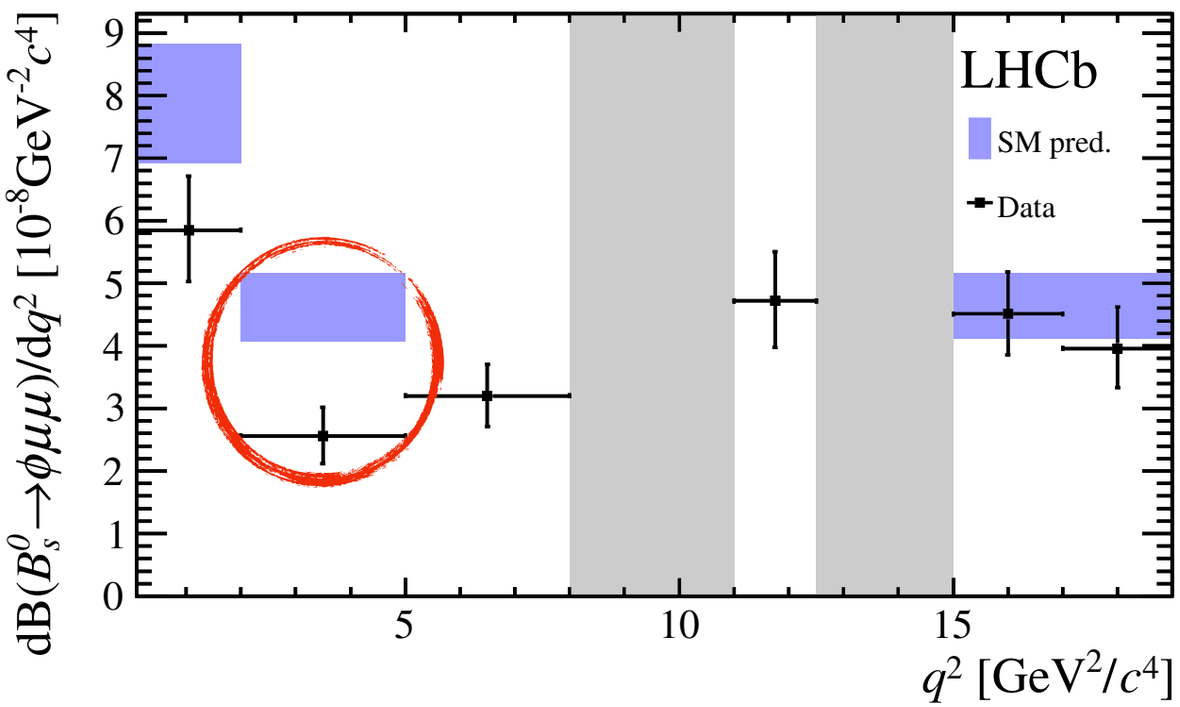
JHEP 02 (2016) 104 ATLAS-CONF-2017-023

PRL 118 (2017) 111801 CMS-PAS-BPD-15-008

Potential pollution from had. cont.

Branching Fractions of $B_s \to \phi\mu\mu$ and $B \to K\mu\mu$

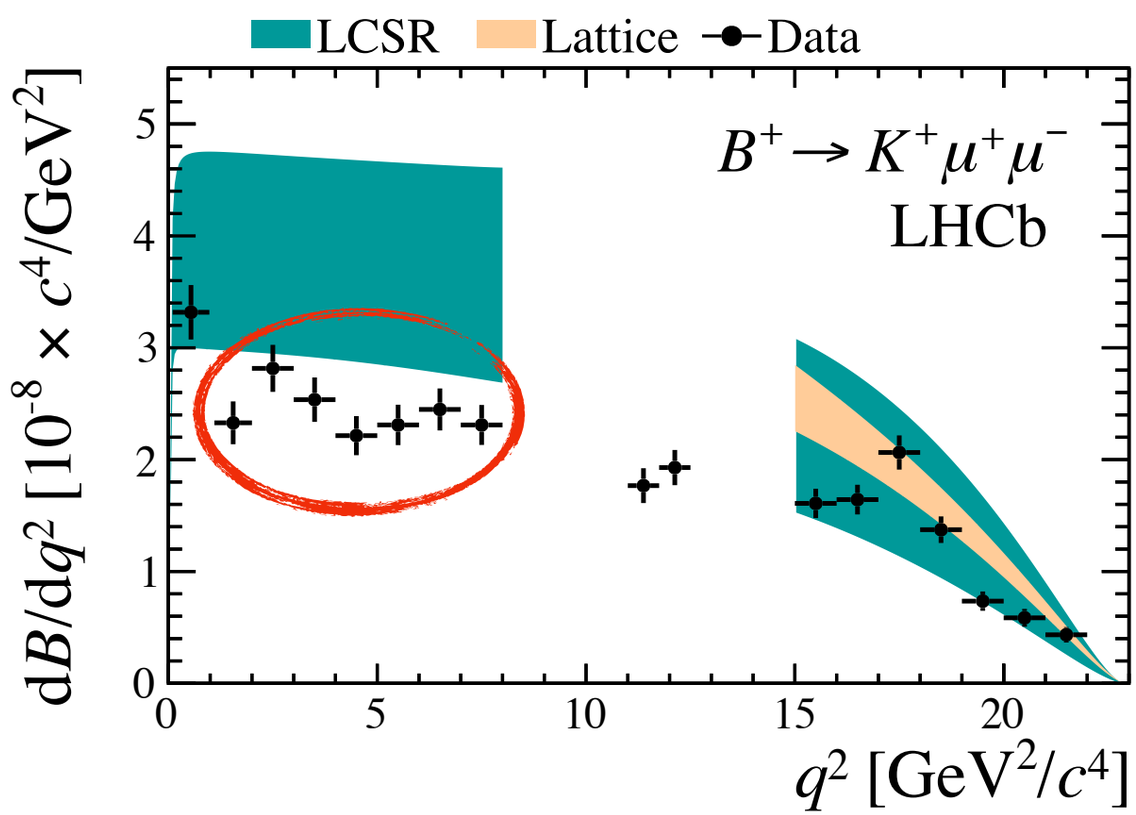
INTRIGUING SET OF "ANOMALIES" IN DATA OF EXCLUSIVE B RARE DECAYS



- $2.0 < q^2 / \mathrm{GeV}^2 < 5.0$
- 3.0 σ

JHEP 09 (2015) 179

Potential pollution from had. cont.



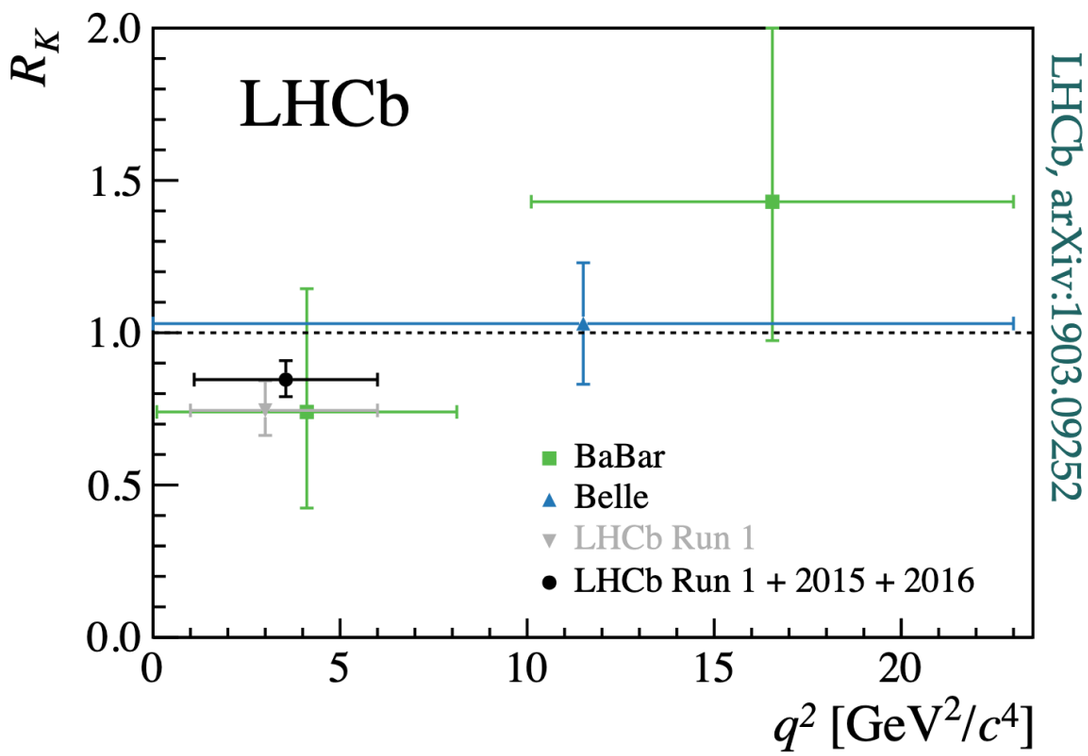
- Low q^2
- Consistently lower values

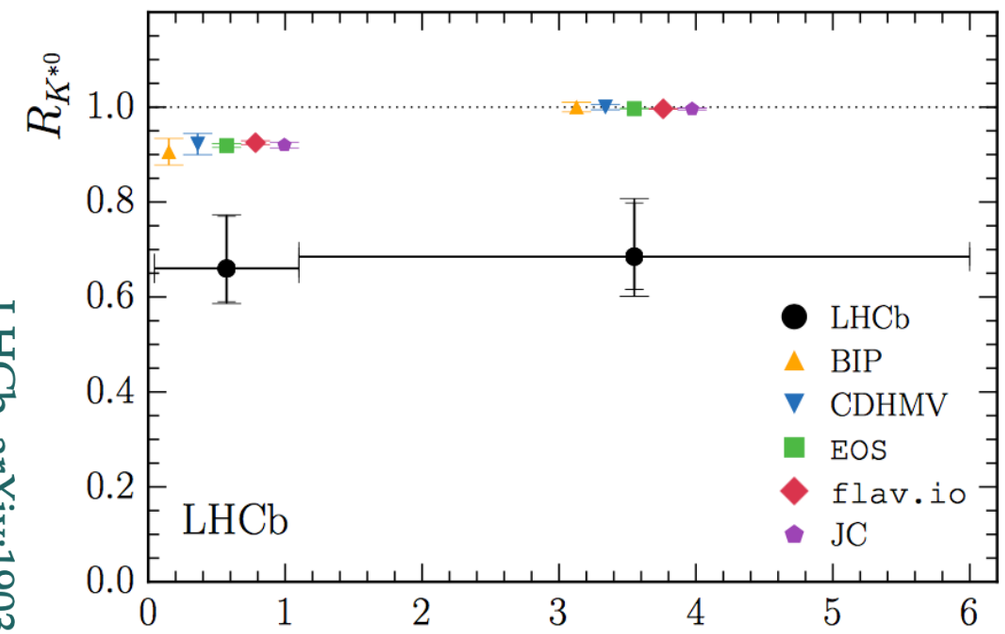
JHEP 06 (2014) 133

Pollution from had. cont. ~ negligible

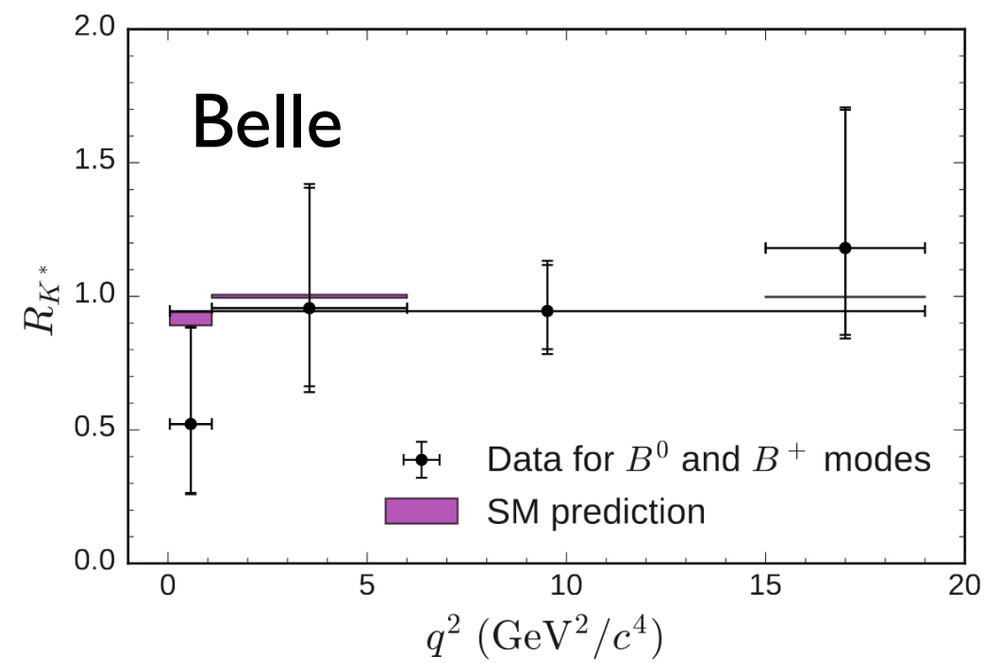
Branching Fraction ratios: R_K & R_{K^*} After Moriond 2019

INTRIGUING SET OF "ANOMALIES" IN DATA OF EXCLUSIVE B RARE DECAYS





~ 2.5 σ



$R_{K^{(*)}} = Br(B \longrightarrow K^{(*)}\mu\mu) / Br(B \longrightarrow K^{(*)}ee)$

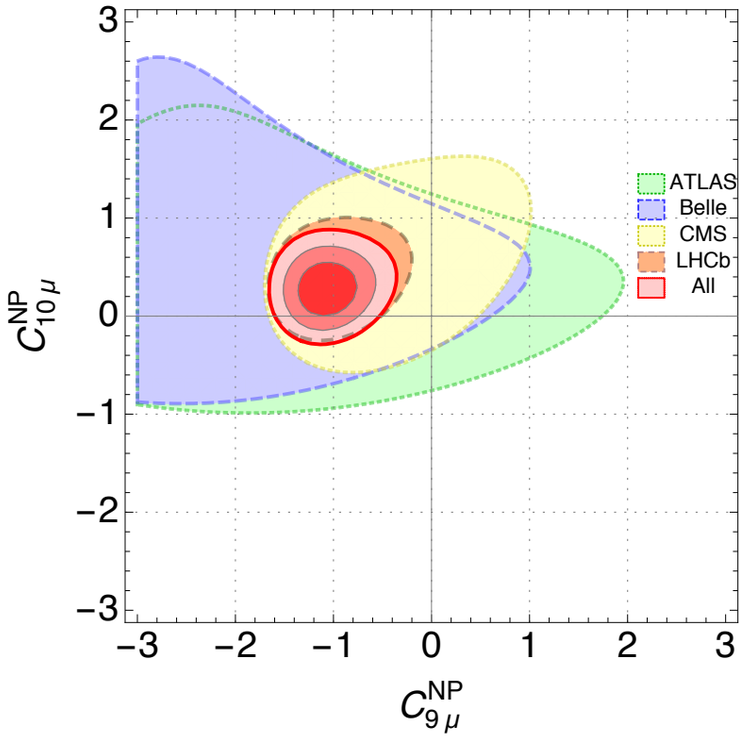
No pollution from had. cont.

Summary

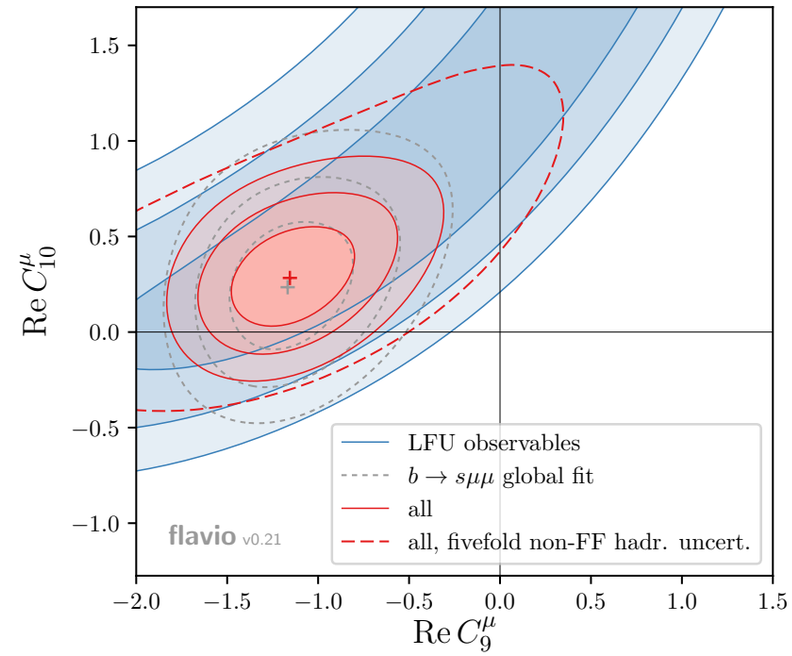
- *Theoretical Framework*
- *Experimental anomalies*
- *Global fits*

A fascinating solution: C9μ

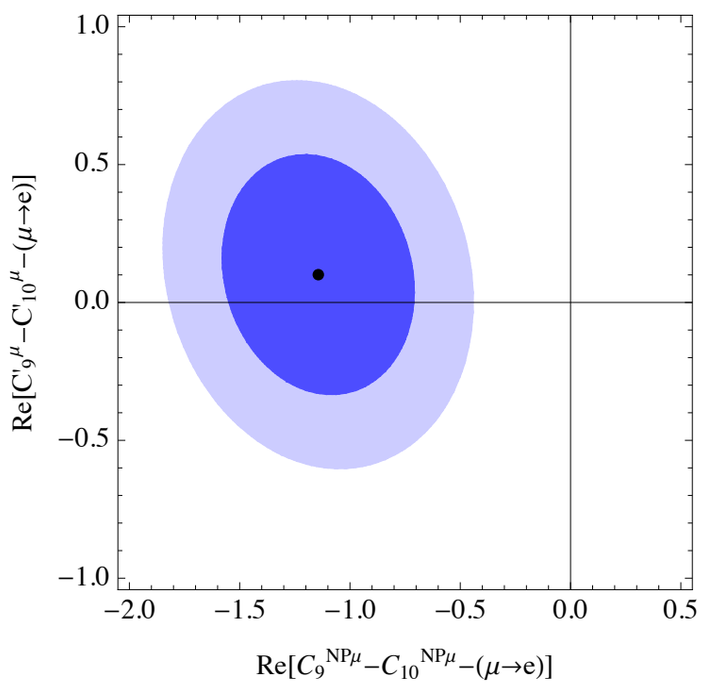
It is possible to explain everything simply requiring NP effect in C9μ



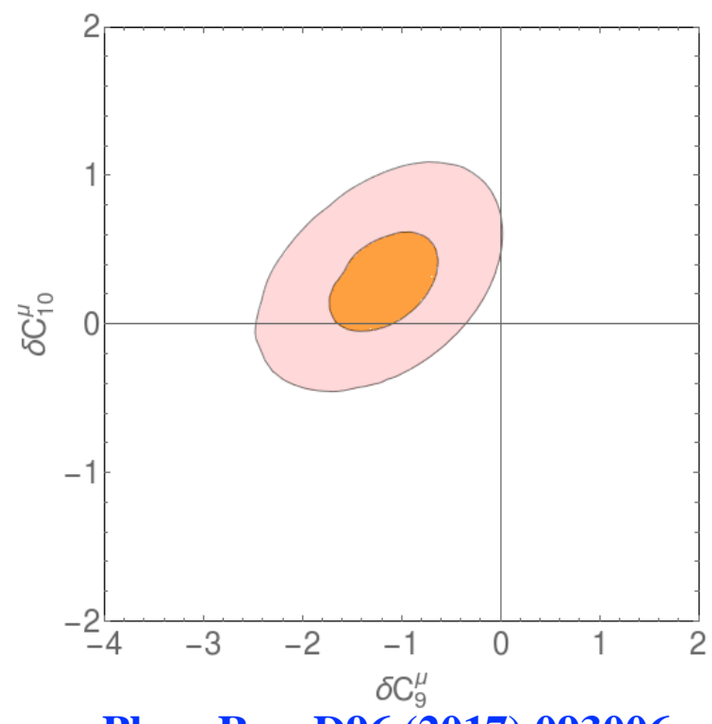
JHEP 01 (2018) 093



Phys. Rev. D96 (2017) 055008



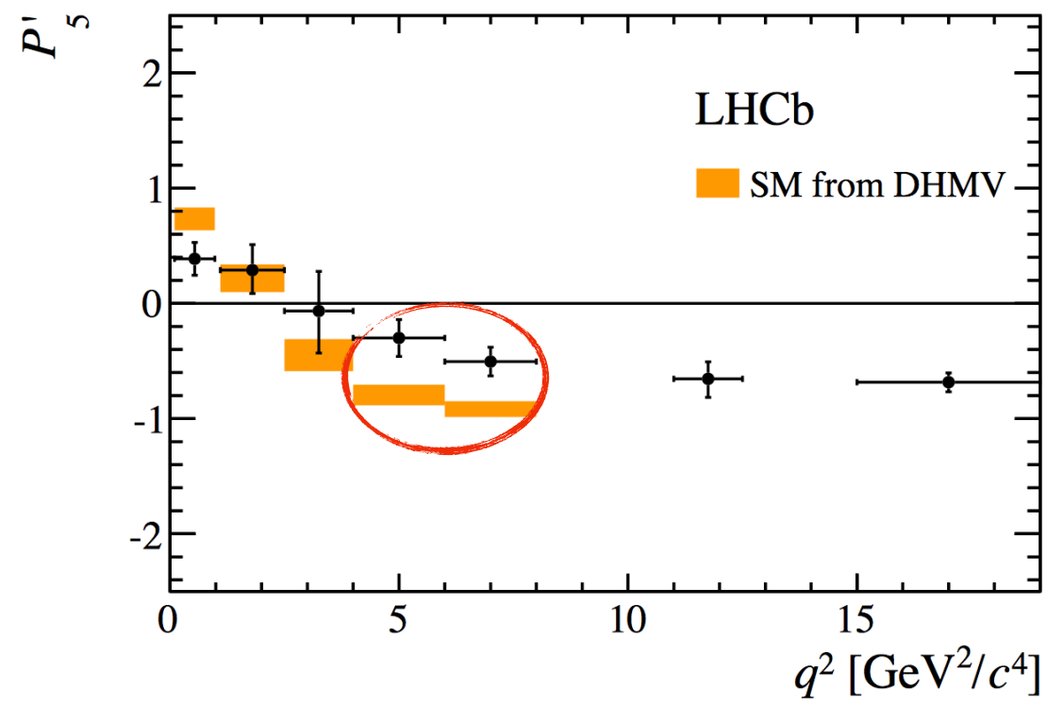
Phys. Rev. D96 (2017) 035003



Phys. Rev. D96 (2017) 093006

Yet another analysis: why?

The first analysis addressing the $B \longrightarrow K^*\mu\mu$ angular anomaly where performed employing the **LCSR estimate** for the hadronic contribution



Single soft gluon approximation: strictly valid only for $\mathbf{q^2 << 4m^2_c}$!

$\Rightarrow$ First analysis of the $B \longrightarrow K^*\mu\mu$ decay channel only, aiming to extract the hadronic contribution from data and compare it with LCSR estimate

$\Rightarrow$ Global fit of the $b \longrightarrow s$ anomalies, without forgetting what we learnt from the previous analysis

Parameterizing the hadronic contribution

$$H_\lambda^V(q^2) \quad \propto \quad C_9 \tilde{V}_\lambda(q^2) + \frac{2 m_b m_B}{q^2} C_7 \tilde{T}_\lambda(q^2) - 16\pi^2 \frac{m_B^2}{q^2} \tilde{h}_\lambda(q^2)$$

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

We parameterized the hadronic contribution in order to have a term that cannot be reinterpreted as a NP contribution

$$\tilde{h}_\lambda(q^2) = \sum_i \tilde{h}_\lambda^{(i)} \left(\frac{q^2}{GeV^2}\right)^i \qquad \begin{array}{l} i = 0 \;\leftrightarrow\; C_7^{NP} \\ i = 1 \;\leftrightarrow\; C_9^{NP} \end{array}$$

OBS: $i = 2$ gives a potential discriminator (q^2 dependence in FFs being fairly mild).
—> hadronic effects may show important dependence on q^2 and on helicity as well

Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)

The SM analysis, PDD vs. PMD

EXPERIMENTAL WEIGHTS :

$$F_L, A_{FB}, S_{3,4,5,7,8,9}$$

correlated in each bin of q^2

$$\mathcal{B}(B \to K^* \mu\mu)$$

$$\mathcal{B}(B \to K^* \gamma)$$

$$\mathcal{B}(B \to K^* ee), F_L, P_{1,2,3}$$

THEORY WEIGHTS :

LCSR FFs with correlation matrix for low q^2 region only

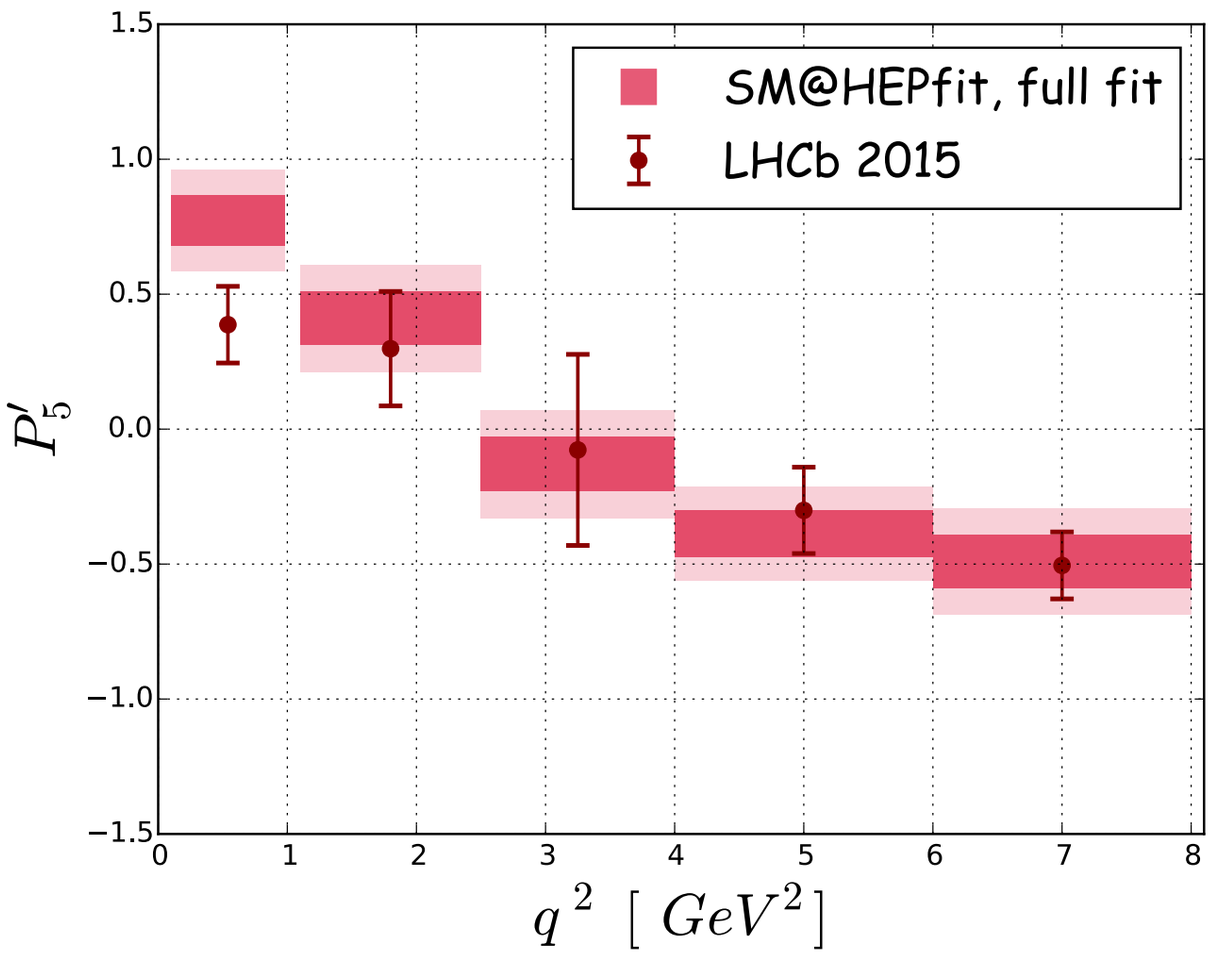
Amplitude helicity suppression at kinematical endpoint

JHEP 09(2010)089 *constraint* → only for $q^2 \lesssim 1$ GeV^2 (PDD)

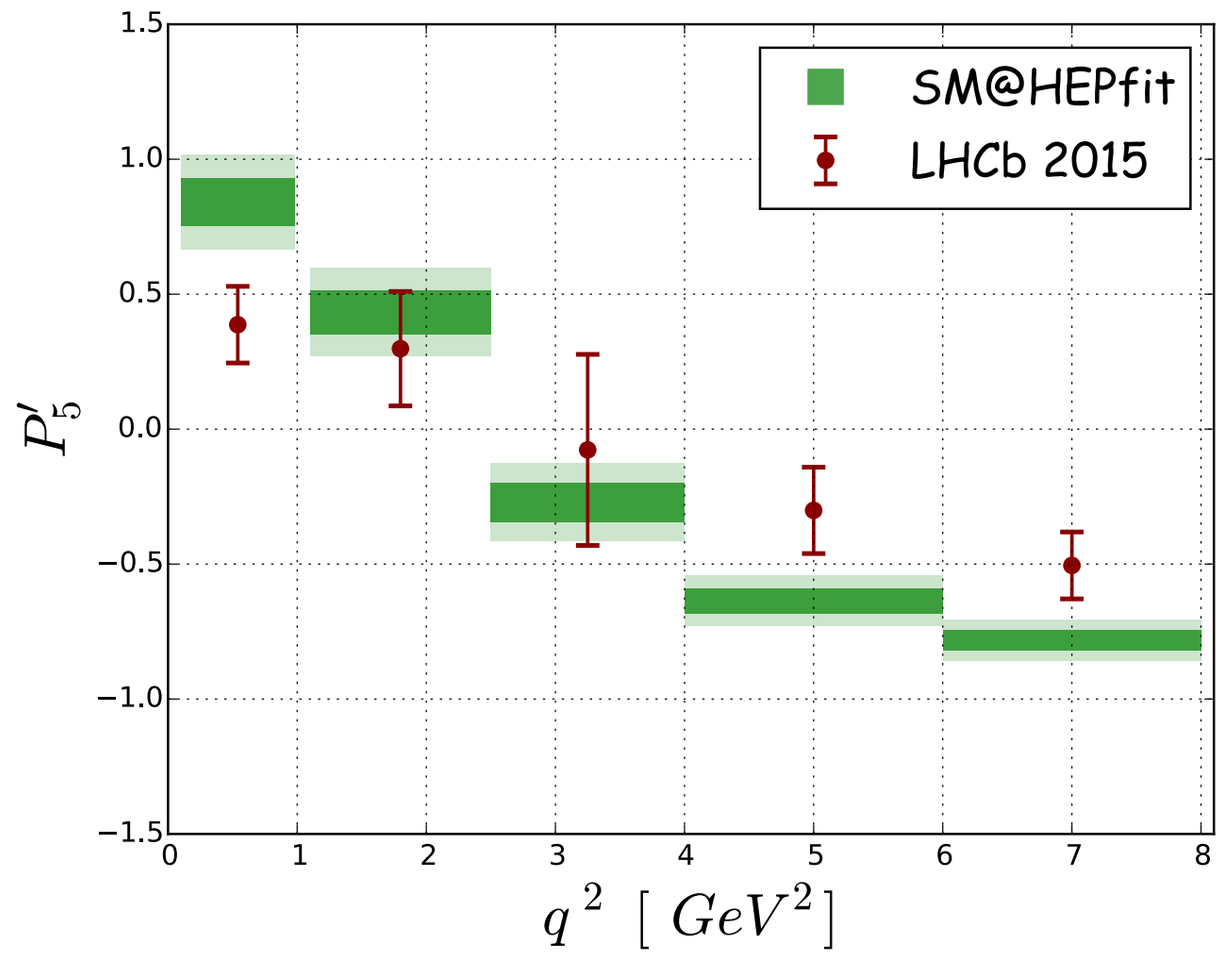
→ for "all" q^2 (PMD)

Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)

The SM analysis, PDD vs. PMD



No anomalies in P'$_5$ …!



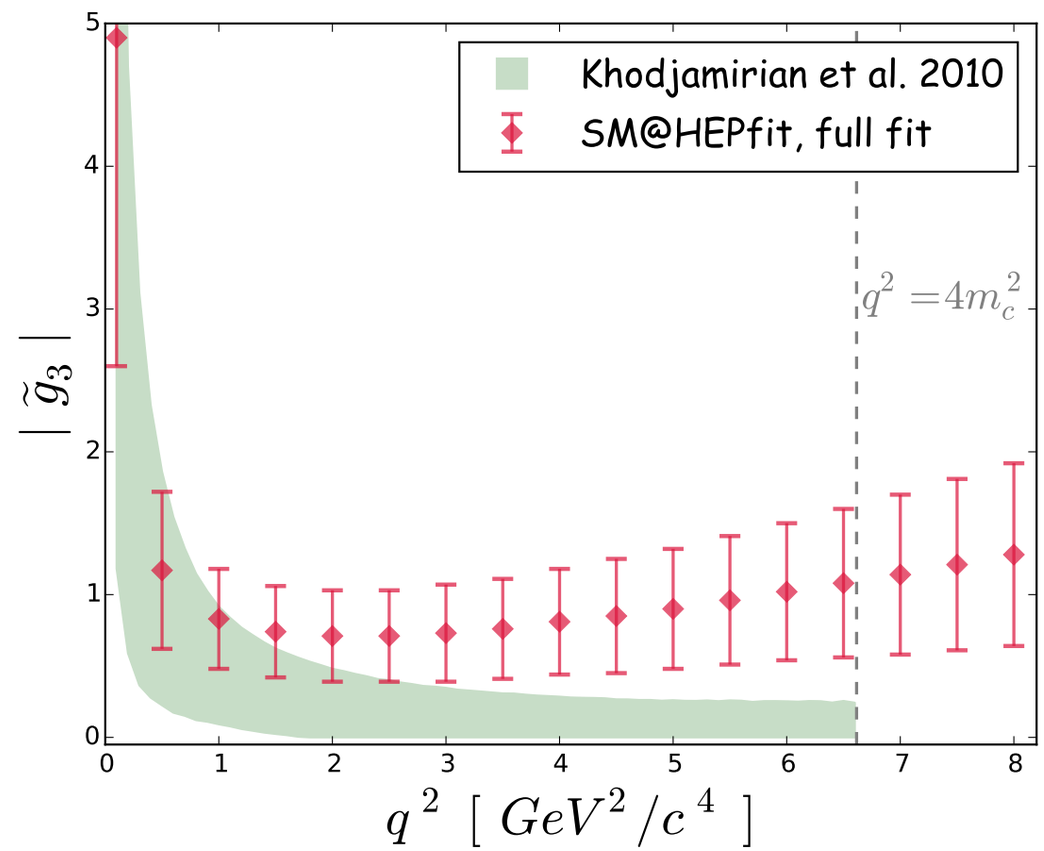
Anomaly strikes back in P'$_5$ …!

Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)

EXTRACTING THE NON-PERTURBATIVE HADRONIC CONTRIBUTION

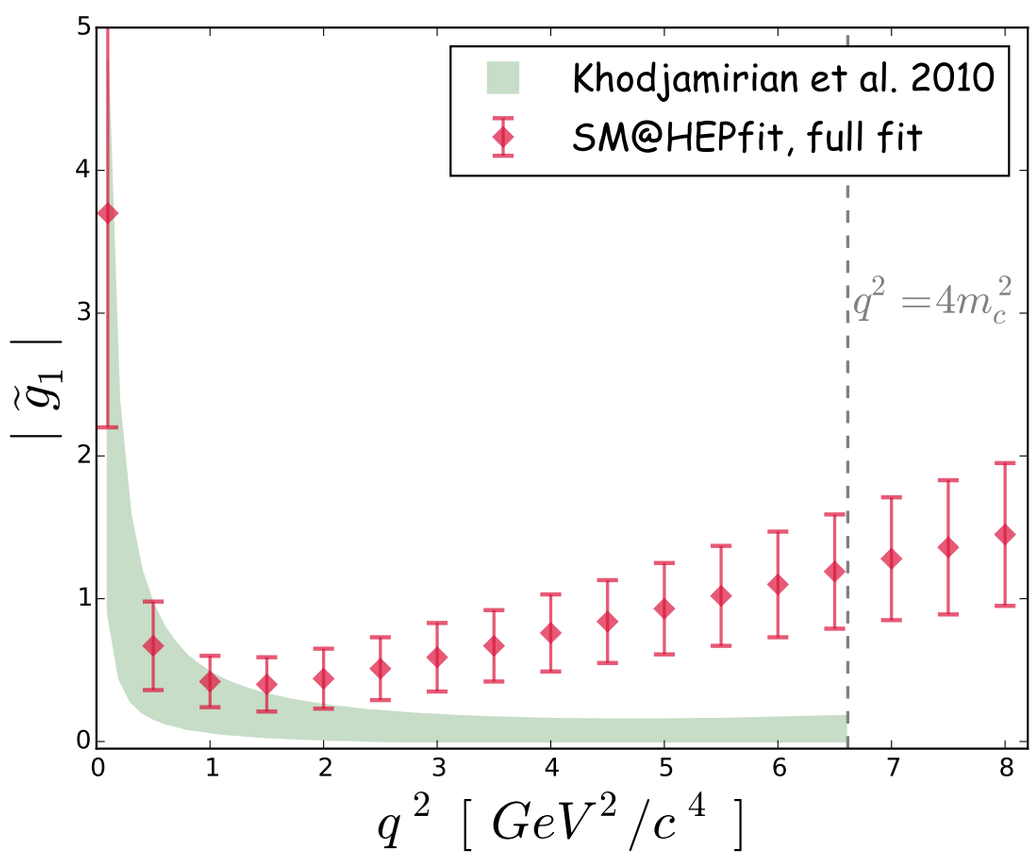
$$\tilde{g} \equiv \Delta C_9^{(\text{non pert.})} / (2C_1)$$

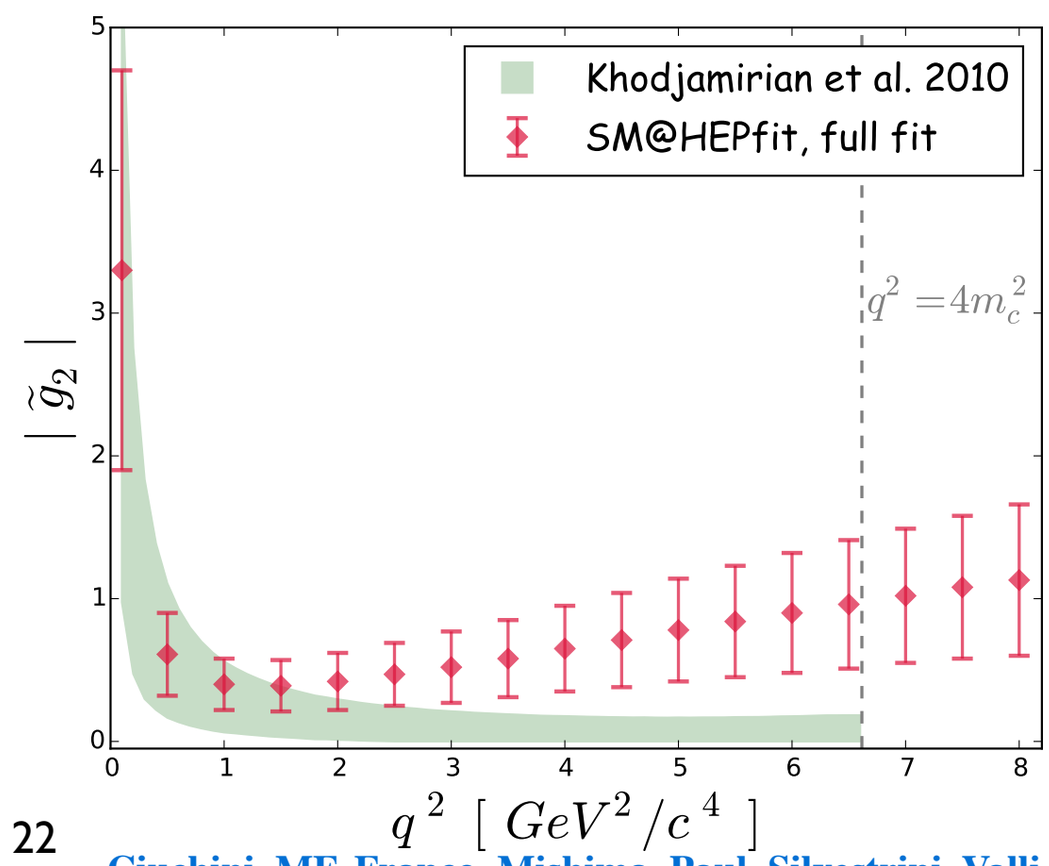
see *arXiv:1006.4945*



DISCLAIMER

NP contribution in C_7 and/or C_9 cannot reproduce such a q^2 behaviour

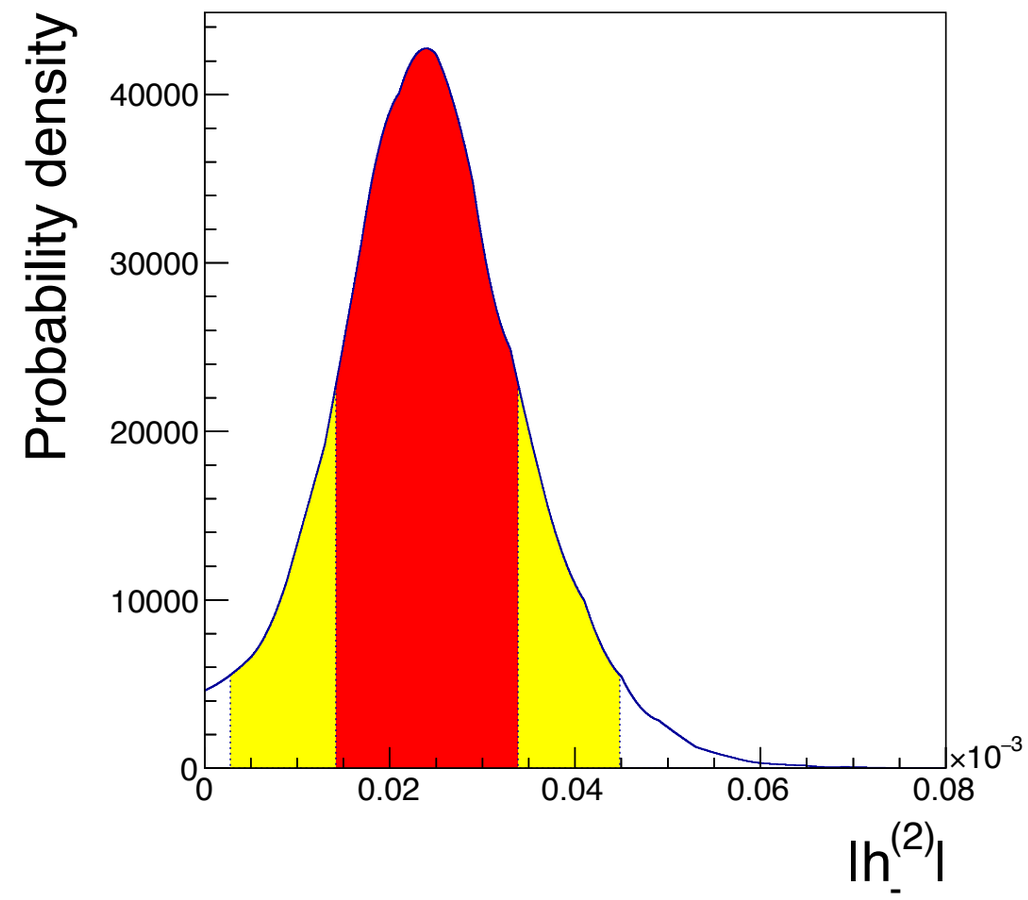




Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)

RESULTS FOR THE HADRONIC PARAMETERS h_λ

Parameter	**Absolute value**	**Phase** (rad)
$h_0^{(0)}$	$(5.7 \pm 2.0) \cdot 10^{-4}$	3.57 ± 0.55
$h_0^{(1)}$	$(2.3 \pm 1.6) \cdot 10^{-4}$	0.1 ± 1.1
$h_0^{(2)}$	$(2.8 \pm 2.1) \cdot 10^{-5}$	-0.2 ± 1.7
$h_+^{(0)}$	$(7.9 \pm 6.9) \cdot 10^{-6}$	0.1 ± 1.7
$h_+^{(1)}$	$(3.8 \pm 2.8) \cdot 10^{-5}$	-0.7 ± 1.9
$h_+^{(2)}$	$(1.4 \pm 1.0) \cdot 10^{-5}$	3.5 ± 1.6
$h_-^{(0)}$	$(5.4 \pm 2.2) \cdot 10^{-5}$	3.2 ± 1.4
$h_-^{(1)}$	$(5.2 \pm 3.8) \cdot 10^{-5}$	0.0 ± 1.7
$h_-^{(2)}$	$(2.5 \pm 1.0) \cdot 10^{-5}$	0.09 ± 0.77



$|h_-^{(2)}|$ *differs from zero* **at more than 95.45% probability,**
thus **disfavouring** *the interpretation of the hadronic correction*
as **NP contributions in C_7 and/or C_9**

Ciuchini, MF, Franco, Mishima, Paul, Silvestrini, Valli (1512.07157)

Time for a $b \to s$ global analysis

- Once we add the ratios in the analysis, it is not possible for the hadronic contributions to account for all the anomalies

- Interesting interplay between hadronic contribution and NP effects

- Is NP in the muon channel the only viable scenario?

Set of measurements included in our global analysis

LHCb	$F_L, A_{FB}, S_{3,4,5,7,8,9}$ i.e. available angular info for $K^{(*)}, \phi$ modes $\mathcal{B}(B \to K^{(*)}\ell\ell, \gamma)$ $\mathcal{B}(B_s \to \phi\,\mu\mu, \gamma)$ $R_{K,[1,6]}, R_{K^*,[0.045,1.1],[1.1,6]}$	JHEP 1611 (2016) 047 JHEP 1602 (2016) 104 JHEP 1509 (2015) 179 JHEP 1504 (2015) 064 Nucl.Phys. B867 (2013) 1-18 PRL 113 (2014) 151601 arXiv:1705.05802
ATLAS	$F_L, A_{FB}, S_{3,4,5,7,8}$	ATLAS-CONF-2017-023
CMS	$P_1, P_5', F_L, A_{FB}, \mathcal{B}(B \to K^*\mu\mu)$	CMS-PAS-BPH-15-008 twiki.cern/…/CMSPublic/…
Belle	$P'_{5\,(\mu,e)}$	PRL 118 (2017) 111801

We use data in the large recoil region only, i.e. where anomalies show up.

We always take into account theory/experimental correlations when provided.

LHCb, HFLAV	$\mathcal{B}(B_s \to \mu\mu), \mathcal{B}(B \to X_s\gamma)$	LHCB-PAPER-2017-001 FERMILAB-PUB-16-611-ND

Global fits before Moriond 2019

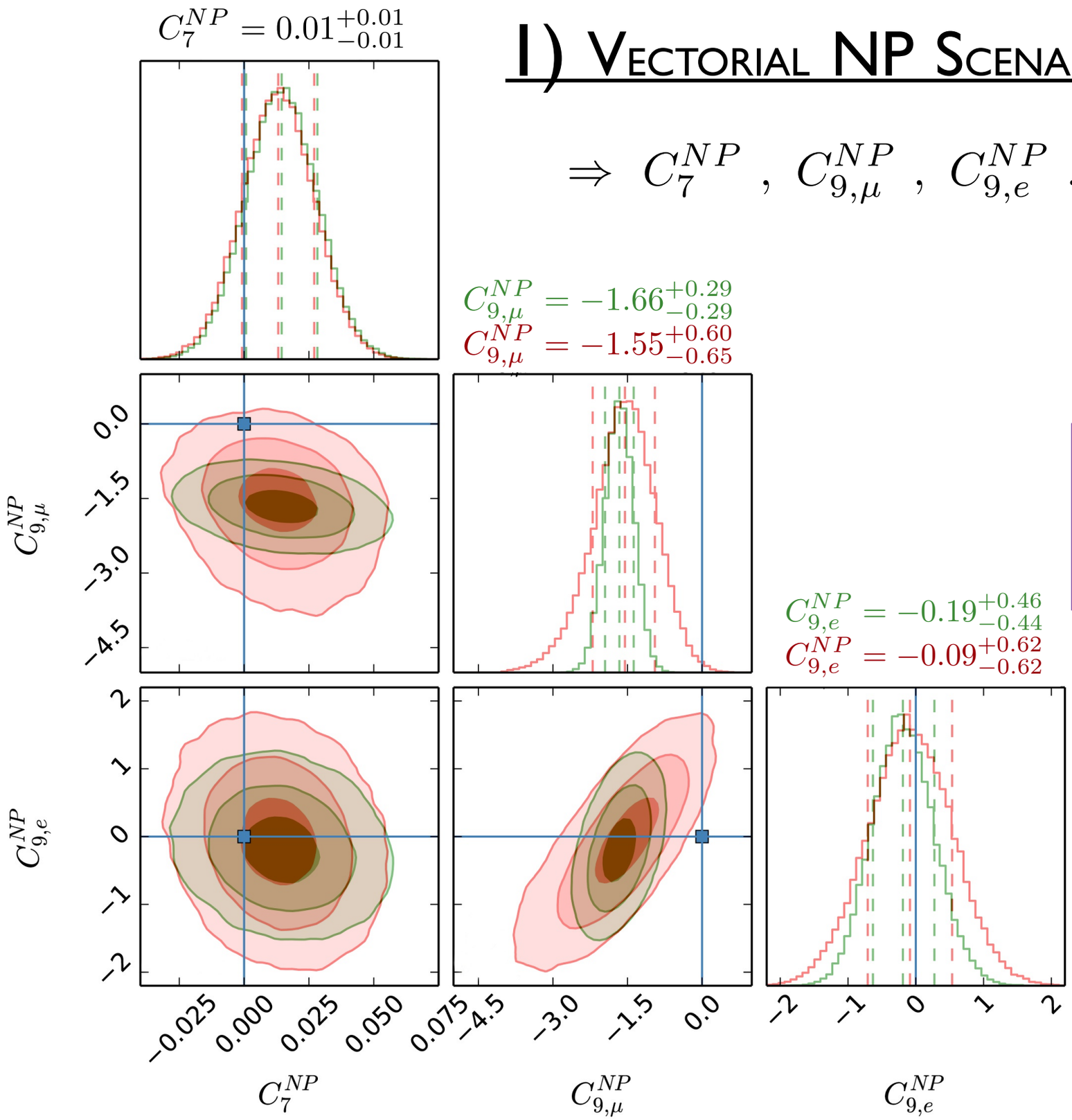
1) Vectorial NP Scenario

$$\Rightarrow \; C_7^{NP} \; , \; C_{9,\mu}^{NP} \; , \; C_{9,e}^{NP} \; .$$

dashed lines in 1D histograms
16th, 50th, 84th percentiles

2D joint probability density
1,2,3 σ contours (darker to lighter)

blue lines and blue square
SM limit of NP Wilson coeffs



Significance of NP affected by non-factorizable QCD power corrections !

PDD approach

PMD approach

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1704.05447)

Global fits before Moriond 2019

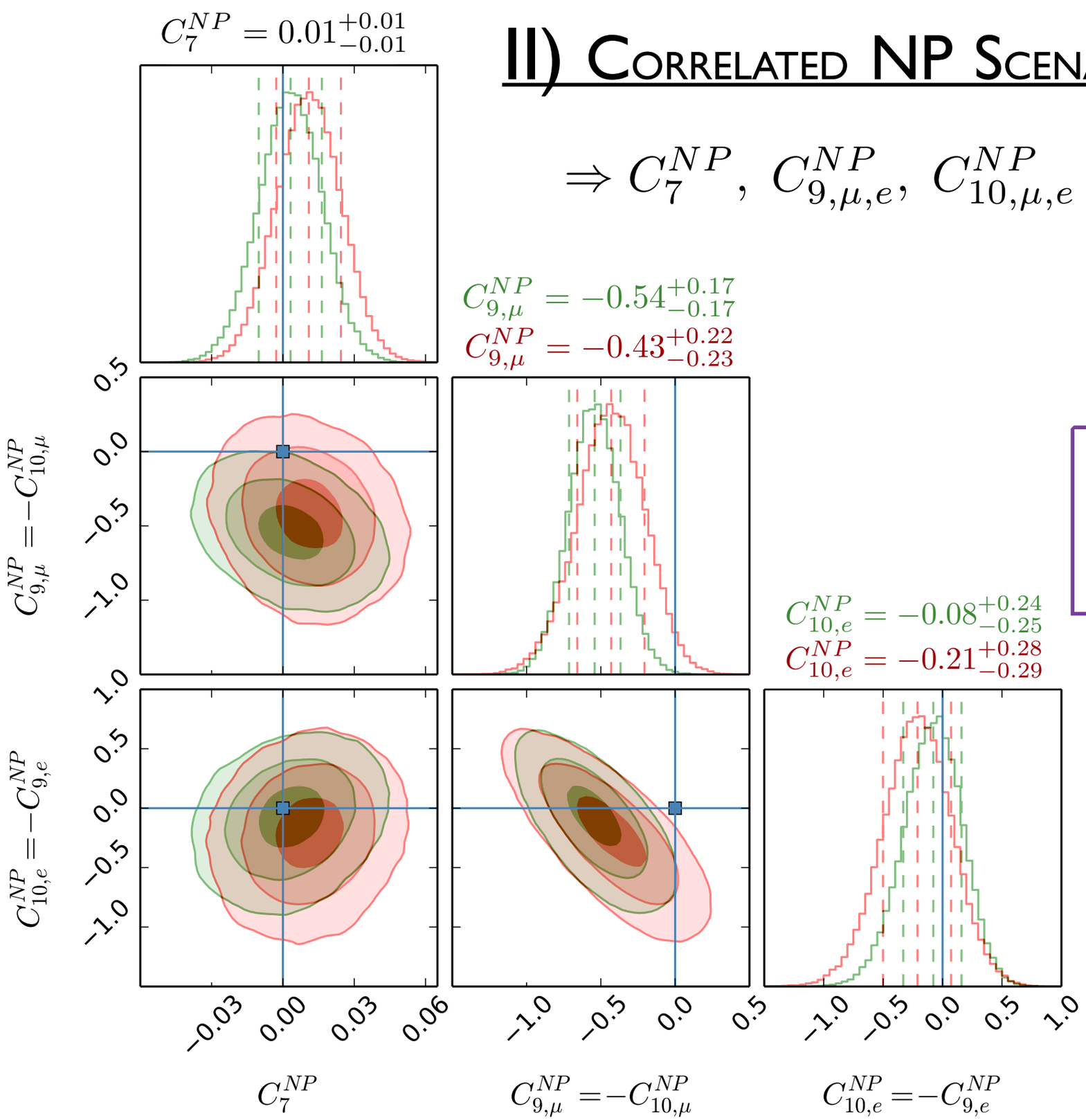
II) Correlated NP Scenario

$$\Rightarrow C_7^{NP},\ C_{9,\mu,e}^{NP},\ C_{10,\mu,e}^{NP}$$

dashed lines in 1D histograms
16th, 50th, 84th percentiles

2D joint probability density
1,2,3 σ contours (darker to lighter)

blue lines and blue square
SM limit of NP Wilson coeffs



Significance of NP affected by non-factorizable QCD power corrections !

PDD approach

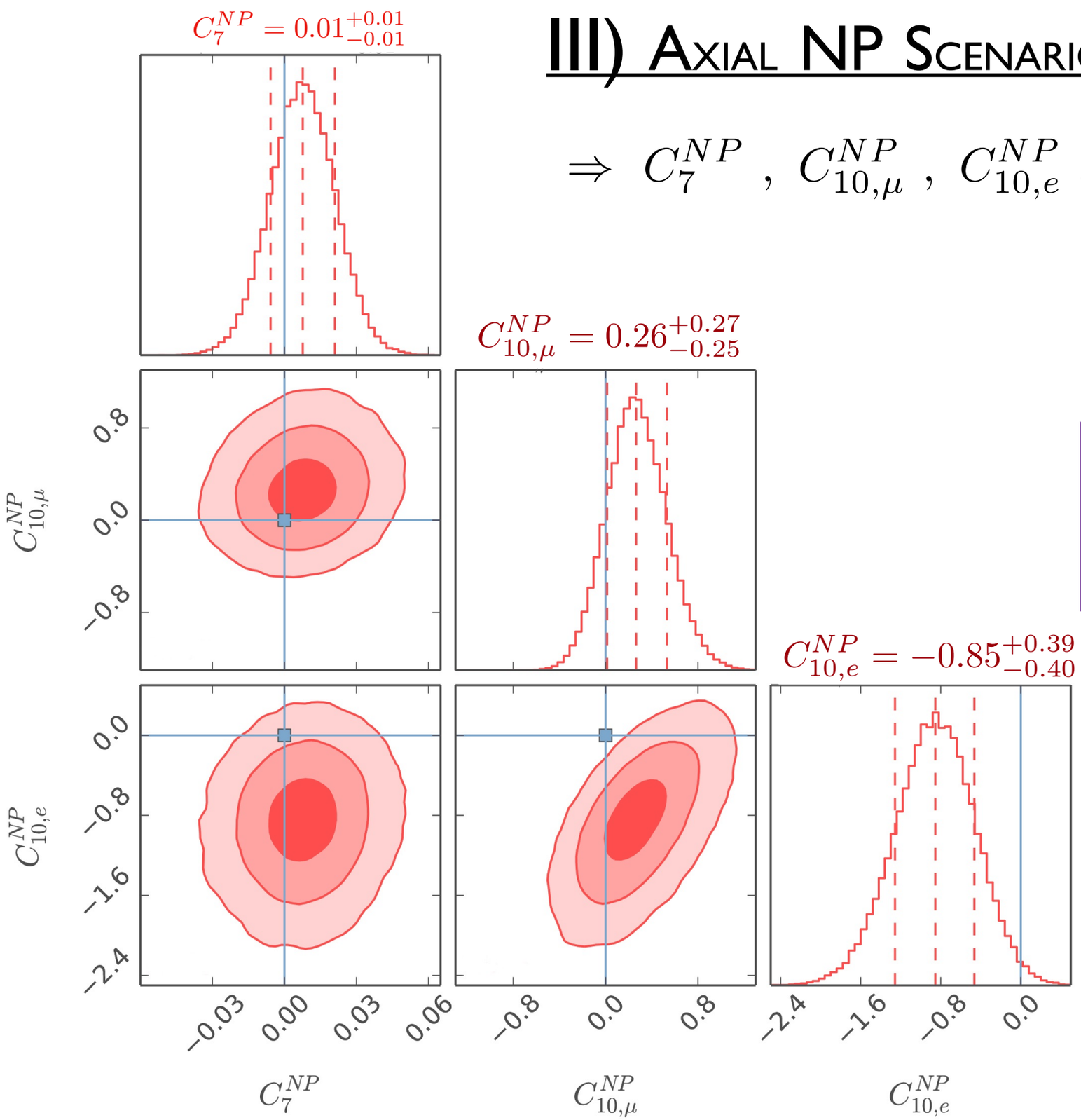
PMD approach

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1704.05447)

Global fits before Moriond 2019

III) Axial NP Scenario

$$\Rightarrow \; C_7^{NP} \; , \; C_{10,\mu}^{NP} \; , \; C_{10,e}^{NP} \; .$$



dashed lines in 1D histograms
16th, 50th, 84th percentiles

2D joint probability density
1,2,3 σ contours (darker to lighter)

blue lines and blue square
SM limit of NP Wilson coeffs

Significance of NP affected by non-factorizable QCD power corrections !

PDD approach

No means to explain angular analysis in PMD

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1704.05447)

(Re)parameterizing the hadronic contribution

$$h_-(q^2) = -\frac{m_b}{8\pi^2 m_B}\widetilde{T}_{L-}(q^2)\underline{h_-^{(0)}} - \frac{\widetilde{V}_{L-}(q^2)}{16\pi^2 m_B^2}\underline{h_-^{(1)}}q^2 + h_-^{(2)}q^4 + \mathcal{O}(q^6)$$

$$h_+(q^2) = -\frac{m_b}{8\pi^2 m_B}\widetilde{T}_{L+}(q^2)\underline{h_-^{(0)}} - \frac{\widetilde{V}_{L+}(q^2)}{16\pi^2 m_B^2}\underline{h_-^{(1)}}q^2 + h_+^{(0)} + h_+^{(1)}q^2 + h_+^{(2)}q^4 + \mathcal{O}(q^6)$$

$$h_0(q^2) = -\frac{m_b}{8\pi^2 m_B}\widetilde{T}_{L0}(q^2)\underline{h_-^{(0)}} - \frac{\widetilde{V}_{L0}(q^2)}{16\pi^2 m_B^2}\underline{h_-^{(1)}}q^2 + h_0^{(0)}\sqrt{q^2} + h_0^{(1)}(q^2)^{\frac{3}{2}} + \mathcal{O}((q^2)^{\frac{5}{2}})$$

$$H_V^- \propto \left\{ \left(C_9^{\rm SM} + h_-^{(1)}\right)\widetilde{V}_{L-} + \frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\rm SM} + h_-^{(0)}\right)\widetilde{T}_{L-} - 16\pi^2 h_-^{(2)}q^4\right]\right\}$$

$$H_V^+ \propto \left\{ \left(C_9^{\rm SM} + h_-^{(1)}\right)\widetilde{V}_{L+} + \frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\rm SM} + h_-^{(0)}\right)\widetilde{T}_{L+} - 16\pi^2\left(h_+^{(0)} + h_+^{(1)}q^2 + h_+^{(2)}q^4\right)\right]\right\}$$

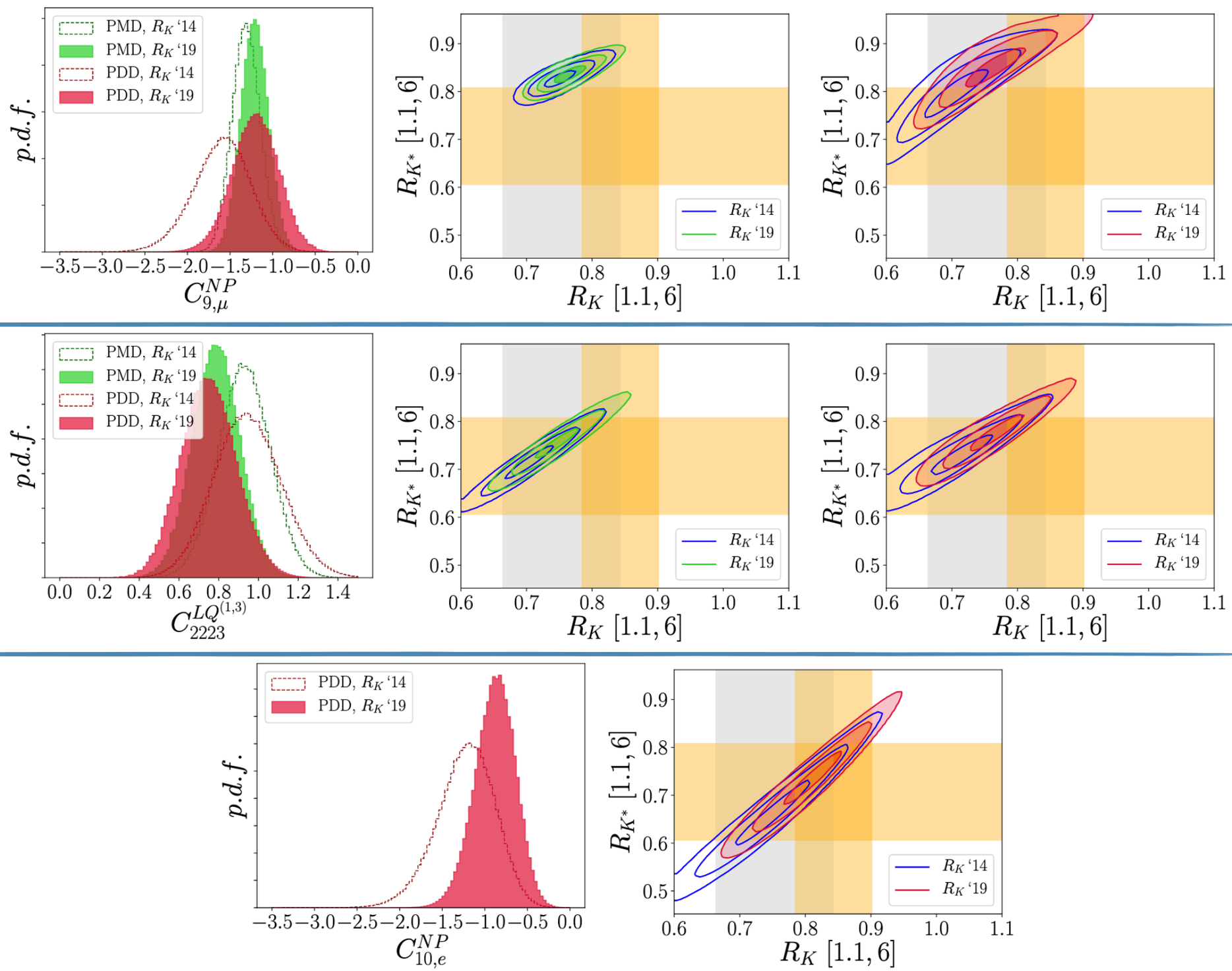
$$H_V^0 \propto \left\{ \left(C_9^{\rm SM} + h_-^{(1)}\right)\widetilde{V}_{L0} + \frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\rm SM} + h_-^{(0)}\right)\widetilde{T}_{L0} - 16\pi^2\sqrt{q^2}\left(h_0^{(0)} + h_0^{(1)}q^2\right)\right]\right\}$$

Can be interpreted as LFU NP!

see talk by G. Isidori and C. Cornella

Global fits after Moriond 2019

Purely left-handed solutions are no longer preferred by data:

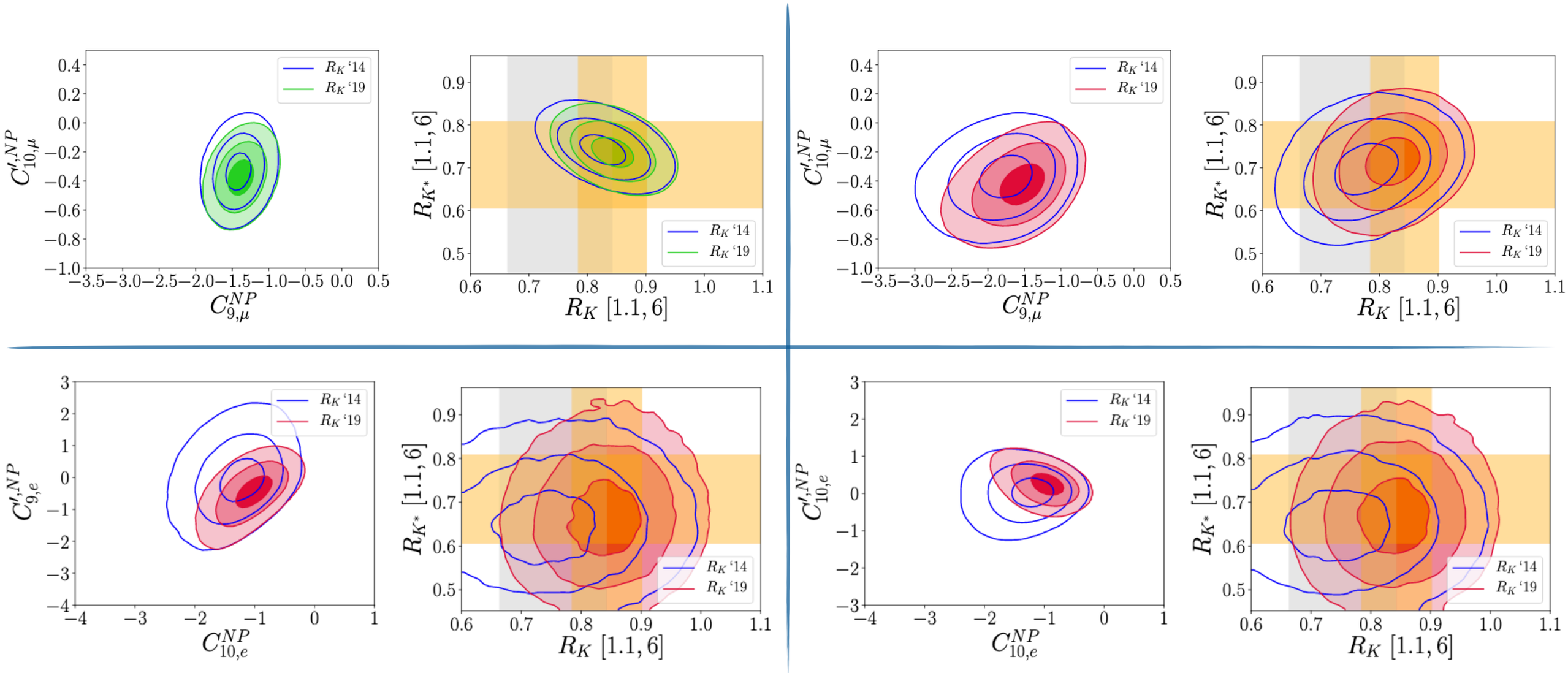


$$R_{K^*}[1.1,6]/R_K[1.1,6] \simeq 0.86 \pm 0.13$$

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1903.09632)

Global fits after Moriond 2019

The inclusion of right-handed currents better reproduce data!



$$R_K \propto C_i + C_i'$$

$$R_{K^*} \propto C_i - C_i'$$

Similar findings by Algueró et al., Alok et al., Aebischer et al., Kowalska et al., …

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

Ciuchini, Coutinho, MF, Franco, Paul, Silvestrini, Valli (1903.09632)

Conclusions

- Hadronic contributions are important in B to V ll amplitude.
  —> present estimate of "charm-loop effect" limited to $q^2 << 4m^2_c$.

- Unknown QCD power corrections may also mimic NP effects.
  —> hard to call for NP in standalone study of $K^*\mu\mu$ angular obs!

Evidence for q^2 dependence beyond the first order in a power expansion in q^2 of the hadronic correlator

$$\tilde{h}_\lambda(q^2) \sim \epsilon_{\lambda,\mu} \int d^4x\, e^{iqx} \langle \overline{V}(P)|T\{J^{\mu,e.m.}_{had}(x)\mathcal{H}^{eff}_{had}(0)\}|\overline{B}\rangle$$

may definitely discriminate genuine NP effects with the advent of more data from LHCb / Belle2.

- $R_{K^{(*)}}$ anomalies (if not stat fluke/exp issue) undoubtedly require NP, both in left handed and right handed currents

A conservative approach to hadronic effects in b —> s ll global fits impacts significances + leaves room for different NP interpretations of current data.