Summer Institute: Flavour anomalies in B decays, light dark matter from hidden sectors and lepton dipole moments

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

and on arXiv:1904.05890 in collaboration with:

P. Arnan, F. Mescia and A. Crivellin

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Summary

- *Theoretical Framework*
- *Experimental anomalies*
- *Global fits*
- *A possible solution*

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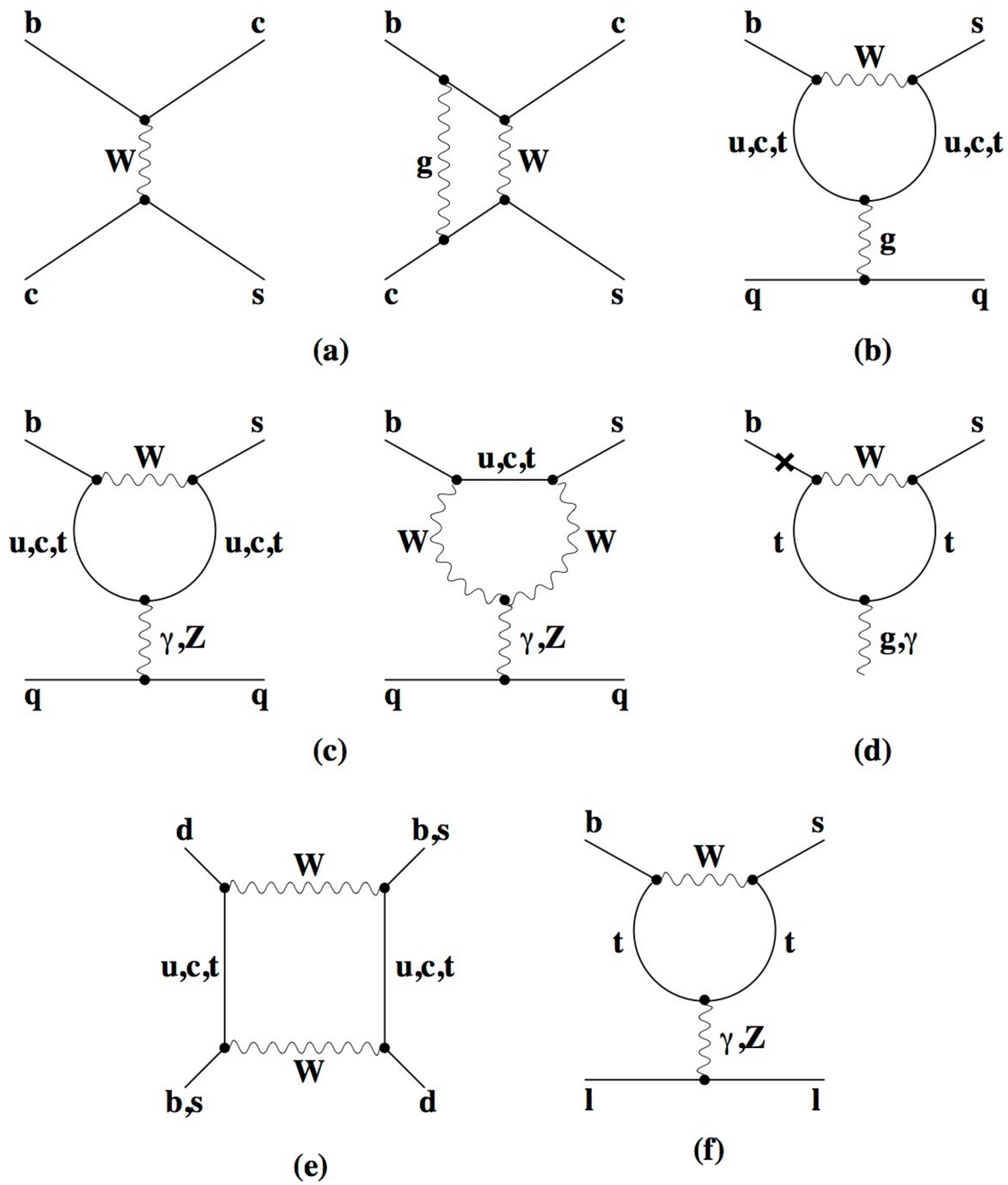
B Meson decays and the Quest for New Physics



- Absence of FCNC decays at tree-level in SM

$\Downarrow$

- Loop diagrams provide sizable contributions

$\Downarrow$

- New Physics processes might provide sizable contributions

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

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

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

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

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

$$\begin{aligned}
Q_{7\gamma} &= \frac{e}{16\pi^2} \hat{m}_b \bar{s} \sigma_{\mu\nu} P_R F^{\mu\nu} b \\
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Matrix elements of quark currents from $Q_{7,9,10,S,P}$ naively factorize:

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

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 form factors

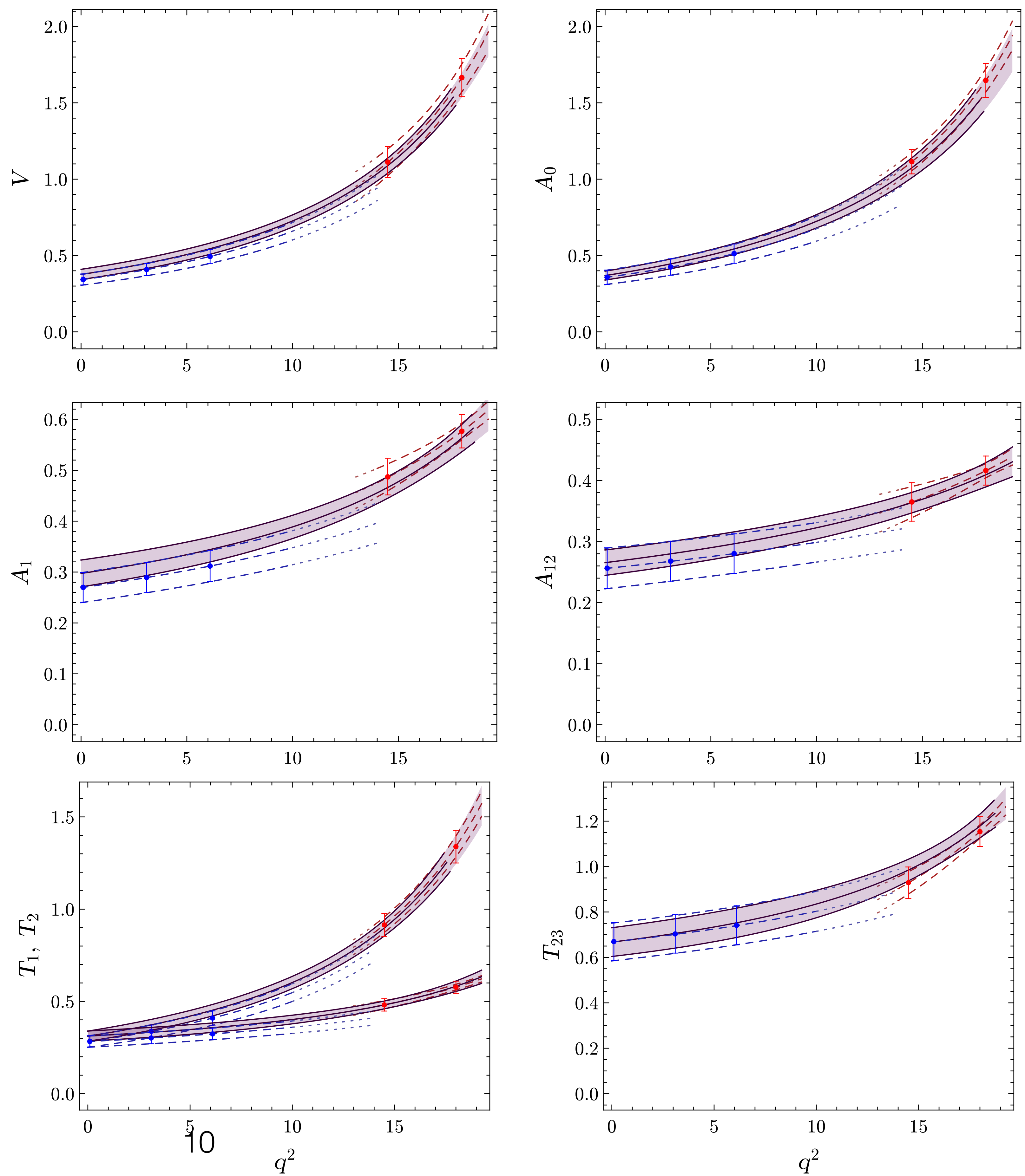
Low recoil region (Lattice, Pos Lattice2014 (2015) 372)

vs.

Large recoil region (LCSR, JHEP 08 (2016) 098)

$\Downarrow$

Full form factors, together with the *correlation matrix*, have become a reliable option



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

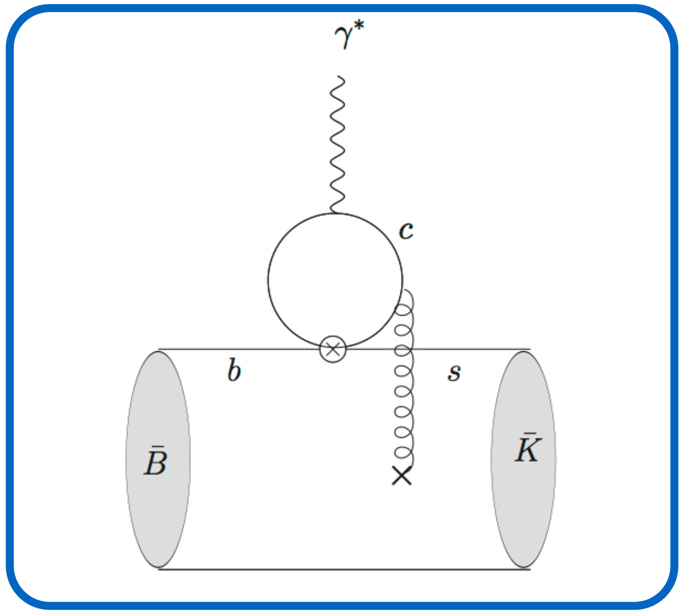
At first order in α_{em} we can get a contribution from current-current quark operators & QCD penguins

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



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

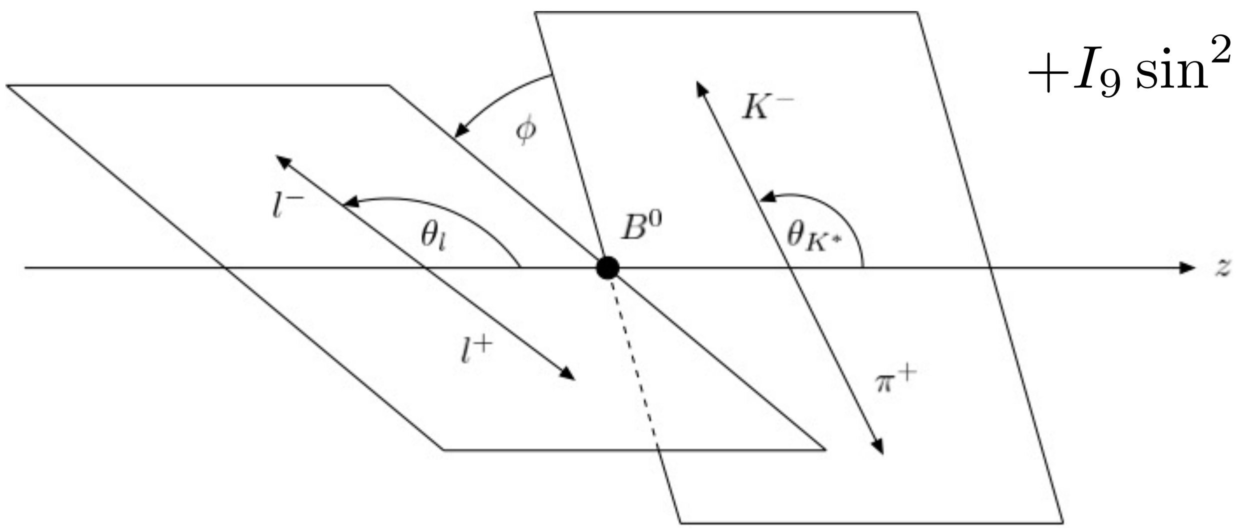
$\Rightarrow$ **Dispersion relation** in order **to extrapolate LCSR result** up to charm resonances.

$\Rightarrow$ **Single soft gluon approximation**: strictly valid only for $q^2 << 4m_c^2$!

A. Khodjamirian et al., **JHEP 1009 (2010) 089**

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

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



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

CP-Averaged

In the massless-lepton limit, 2 relations reduce the number of independent observables

$$\Sigma_{1c} = -\Sigma_{2c} \qquad\qquad \Sigma_{1s} = 3\Sigma_{2s}$$

The B -> V(P)ll decay channel: the observables

The angular coefficients are functions of the helicity amplitudes,
and the building blocks of the obs.

- BR

$$\Gamma' = \frac{1}{2}\frac{d\Gamma + d\bar{\Gamma}}{dq^2} = \Sigma_{1c} + 4\Sigma_{2s}$$

- 8 CP-Averaged angular observables

$$A_{FB} = -\frac{3\Sigma_{6s}}{4\Gamma'} \qquad F_L = \frac{\Sigma_{1c}}{\Gamma'}$$

$$S_{3,4,5,7,8,9} = \frac{\Sigma_{3,4,5,7,8,9}}{\Gamma'}$$

The B -> V(P)ll decay channel: the observables

The angular coefficients are functions of the helicity amplitudes,
and the building blocks of the obs.

- BR

$$\Gamma' = \frac{1}{2}\frac{d\Gamma + d\bar{\Gamma}}{dq^2} = \Sigma_{1c} + 4\Sigma_{2s}$$

- 8 CP-Averaged angular observables

$$P_1 = \frac{\Sigma_3}{2\Sigma_{2s}} \qquad P_2 = \frac{\Sigma_{6s}}{8\Sigma_{2s}} \qquad P_3 = -\frac{\Sigma_9}{4\Sigma_{2s}}$$

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

Summary

- *Theoretical Framework*
- *Experimental anomalies*
- *Global fits*
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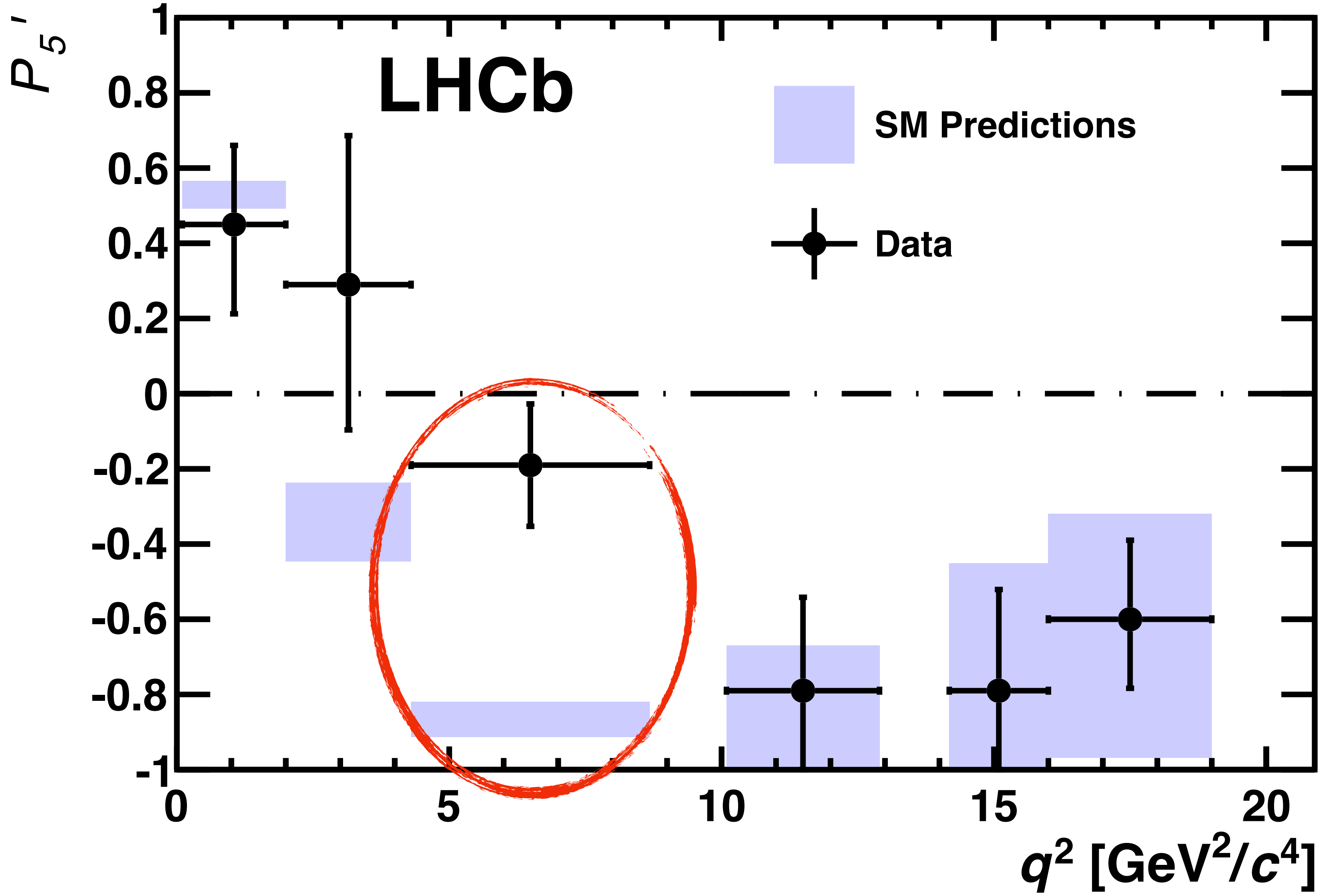
Angular analysis of $B \longrightarrow K^*\mu\mu$ (i)

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



- LHCb (1fb^{-1}, mid-Run I)
- $4.30 < q^2 / \mathrm{GeV}^2 < 8.68$
- $3.7\ \sigma$

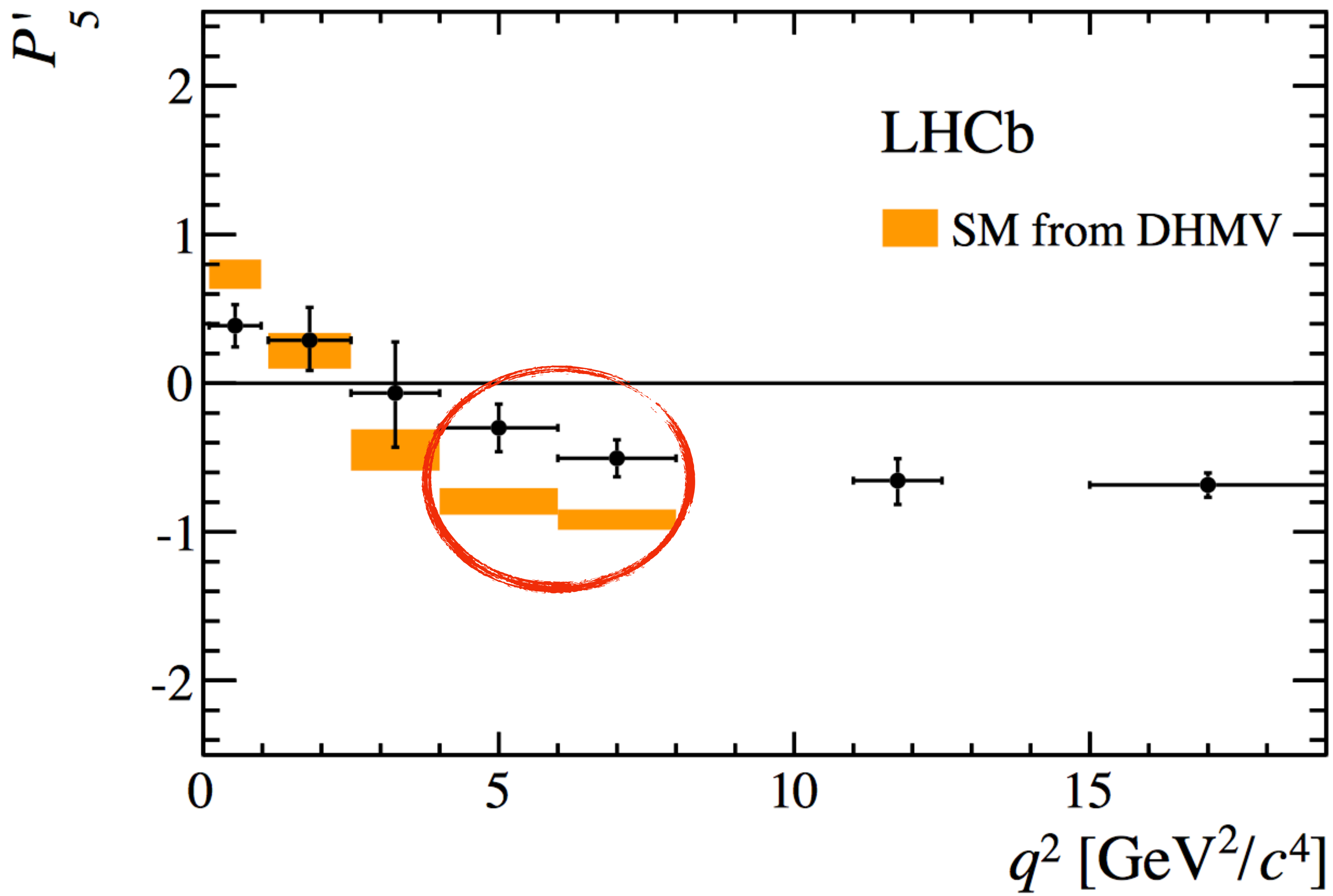
PRL 111 (2013) 191801

Potential pollution from had. cont.

$$\boxed{P_5' \equiv \frac{S_5}{\sqrt{F_L(1-F_L)}}}$$

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

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



- LHCb (3fb^{-1}, end-Run I)
- $4.0 < q^2 / \text{GeV}^2 < 6.0$

  $6.0 < q^2 / \text{GeV}^2 < 8.0$
- 3.4 σ

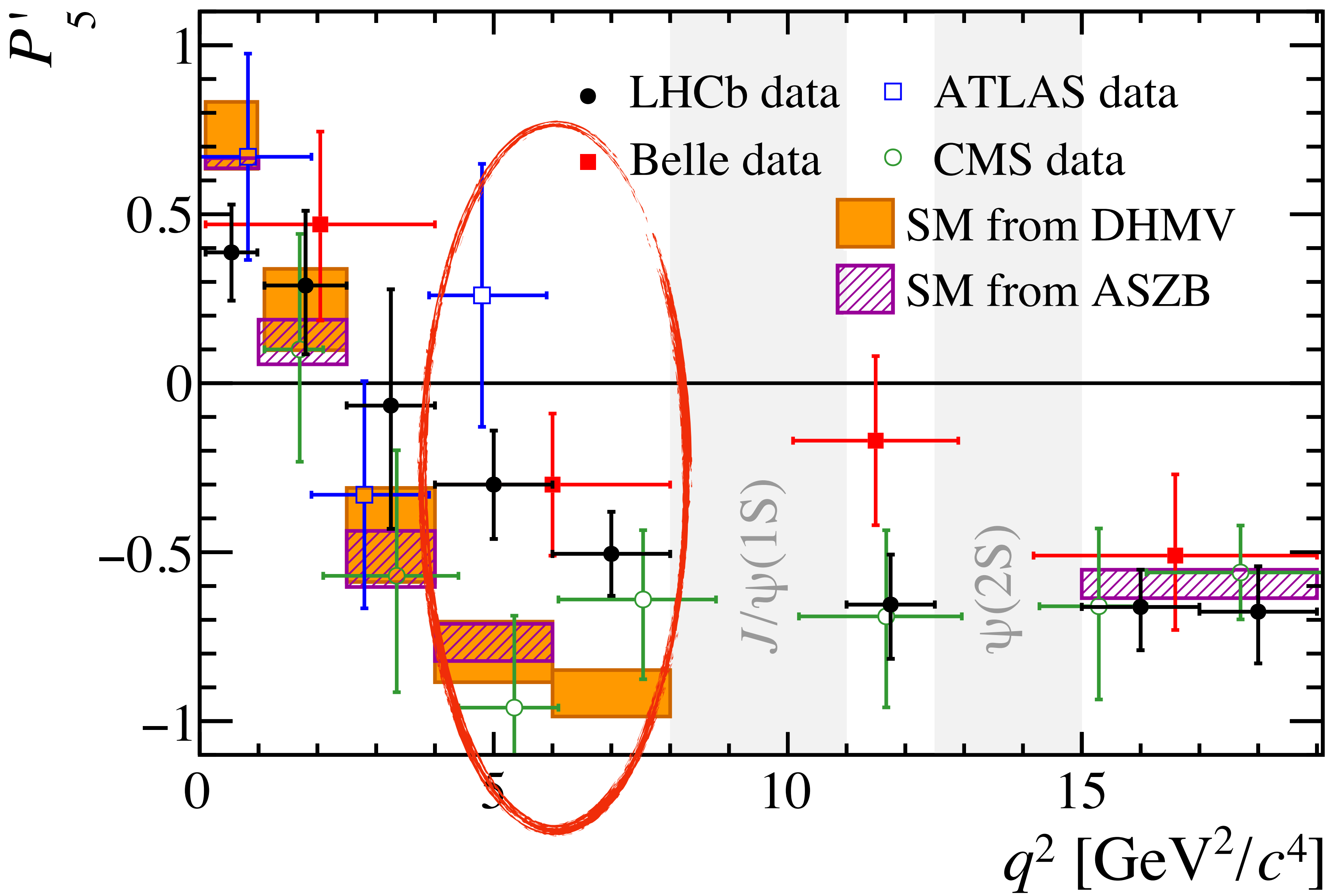
JHEP 02 (2016) 104

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

Potential pollution from had. cont.

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

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



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

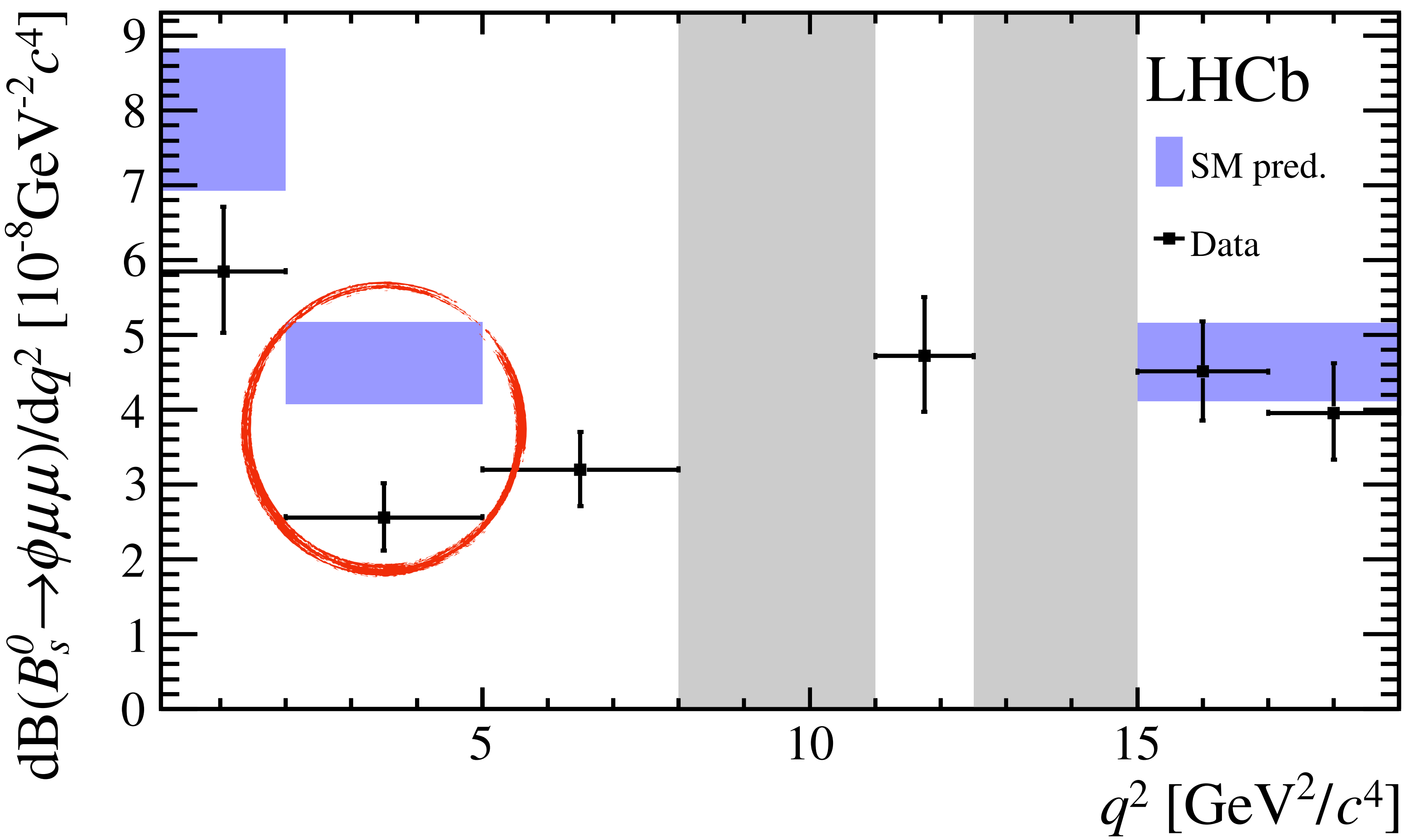
JHEP 02 (2016) 104 ATLAS-CONF-2017-023

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

Potential pollution from had. cont.

Branching Fraction of B_s —> $\phi\mu\mu$

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



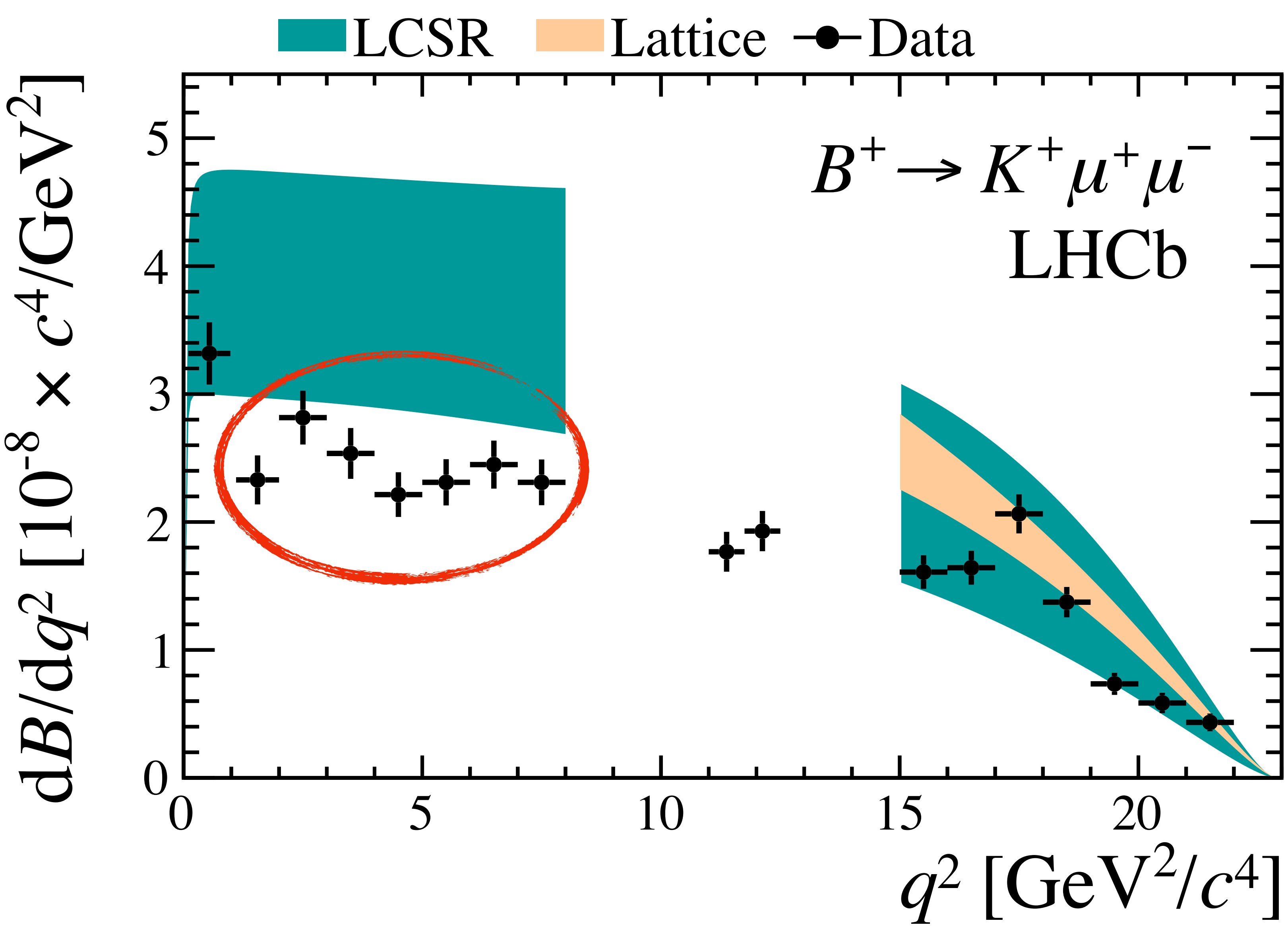
- LHCb
- $2.0 < q^2 / \text{GeV}^2 < 5.0$
- $3.0\ \sigma$

JHEP 09 (2015) 179

Potential pollution from had. cont.

Branching Fraction of $B \longrightarrow K\mu\mu$

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



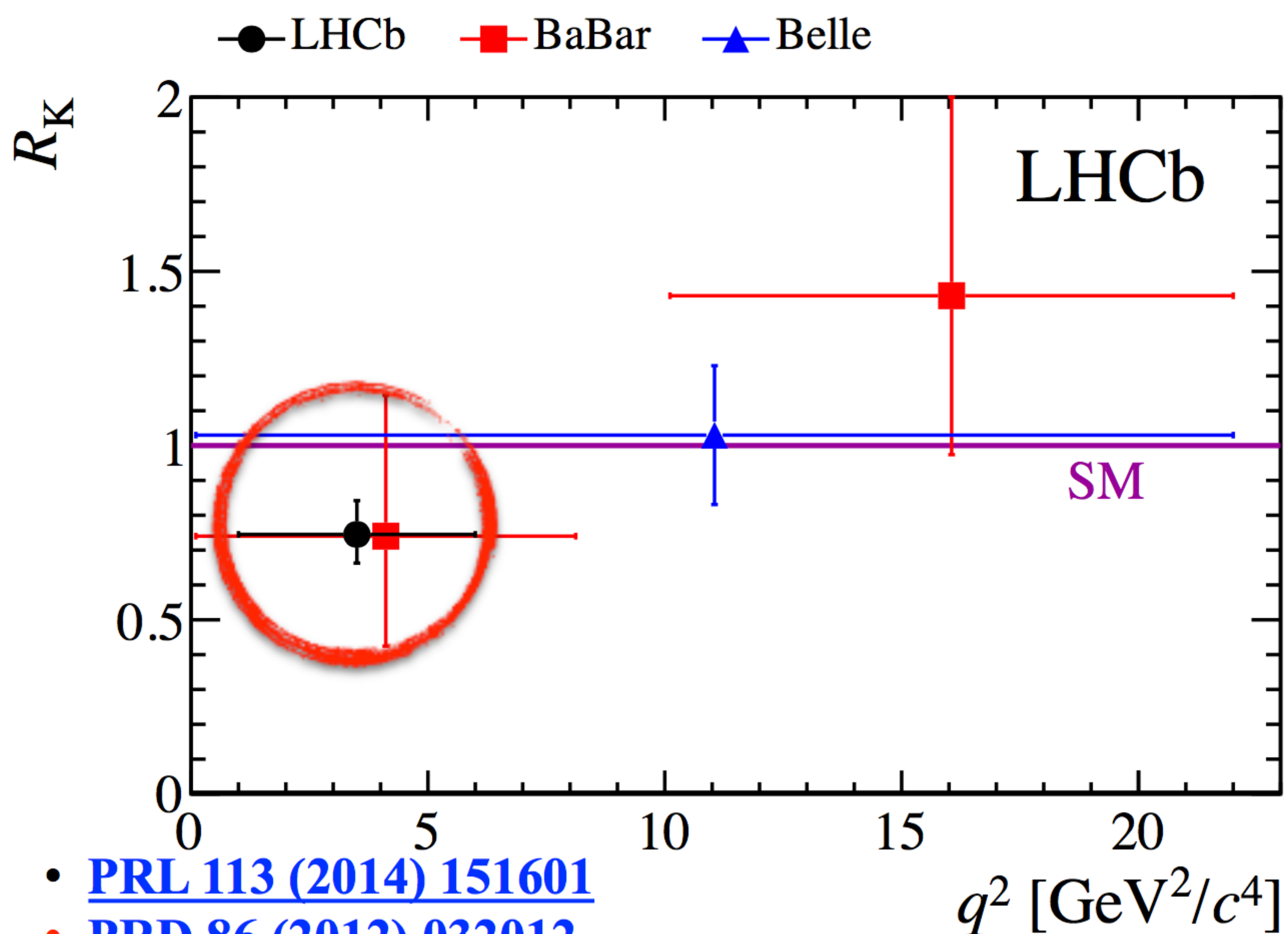
- LHCb
- Low q^2
- Consistently lower values

JHEP 06 (2014) 133

Pollution from had. cont. should be negligible

Branching Fraction ratios: R_K

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



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

- LHCb
- $1.0 < q^2 / \mathrm{GeV}^2 < 6.0$
- 2.6 σ

No pollution from had. cont.

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

Branching Fraction ratios: R_{K^*}

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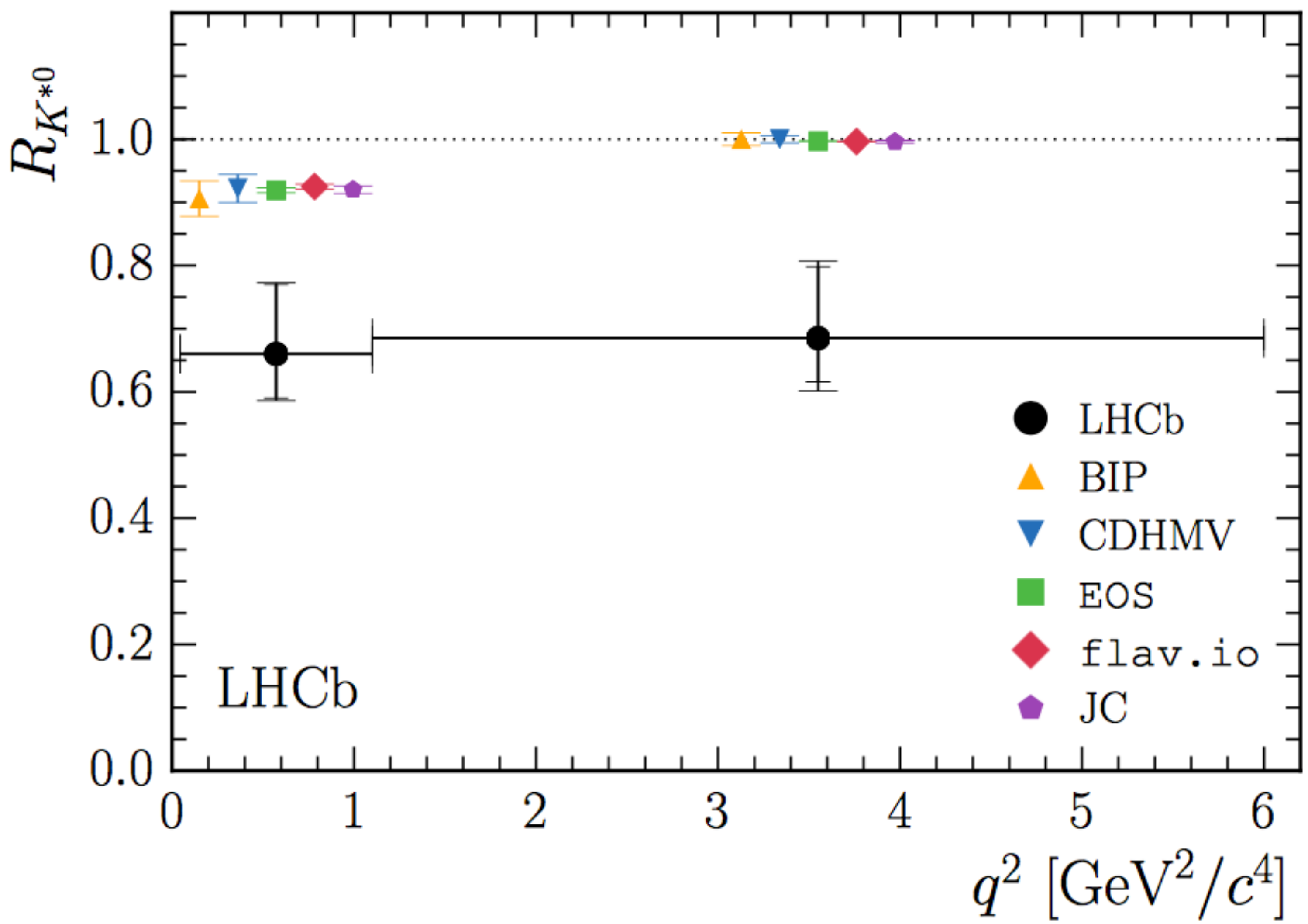


- LHCb
- $0.045 < q^2 / \mathrm{GeV}^2 < 1.1$

  $1.1 < q^2 / \mathrm{GeV}^2 < 6.0$
- $2.2\ \sigma$, $2.5\ \sigma$

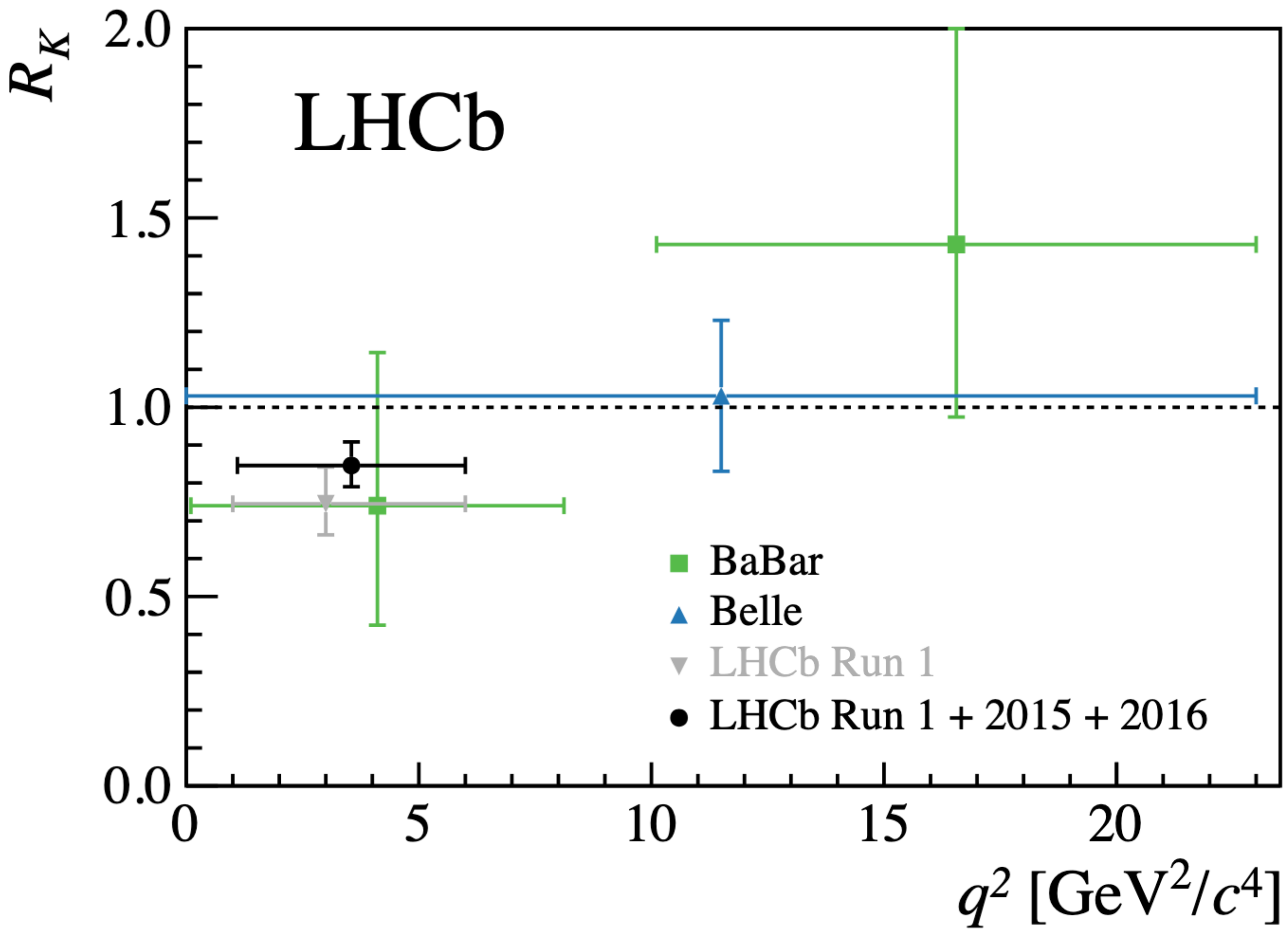
JHEP 08 (2017) 055

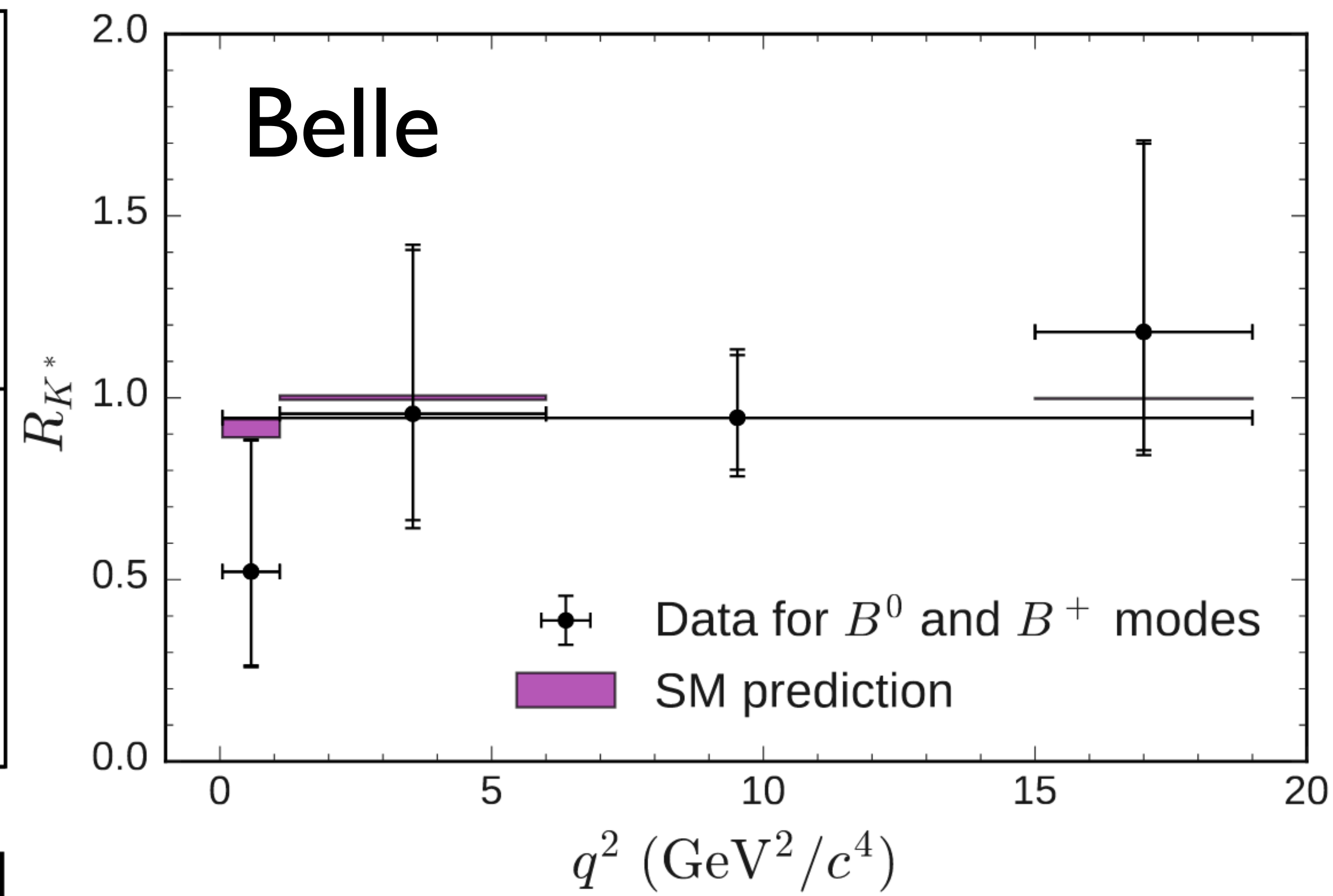
No pollution from had. cont.

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

R_K & R_{K^*} After Moriond 2019

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





No pollution from had. cont.

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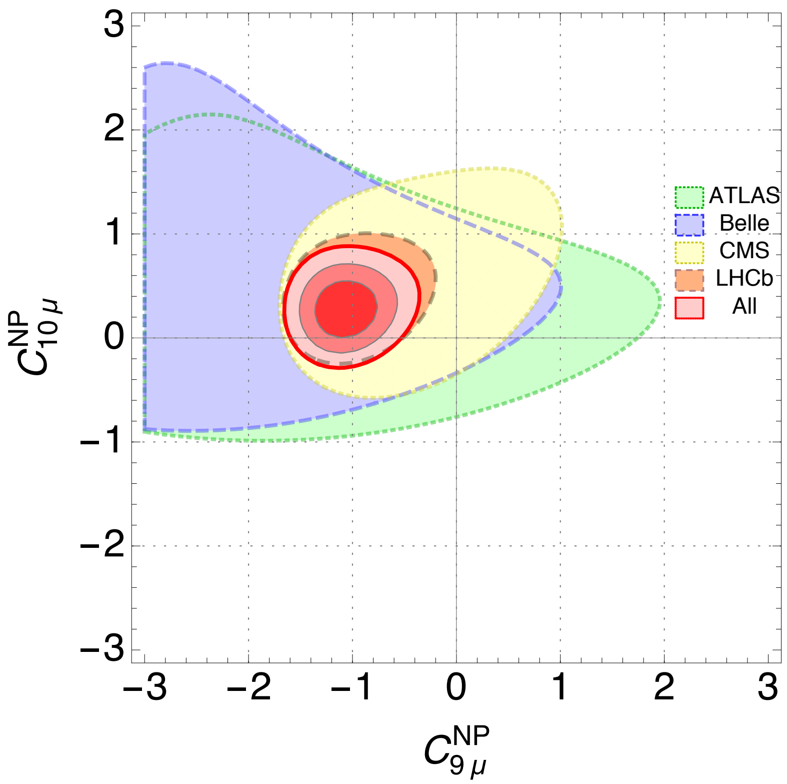
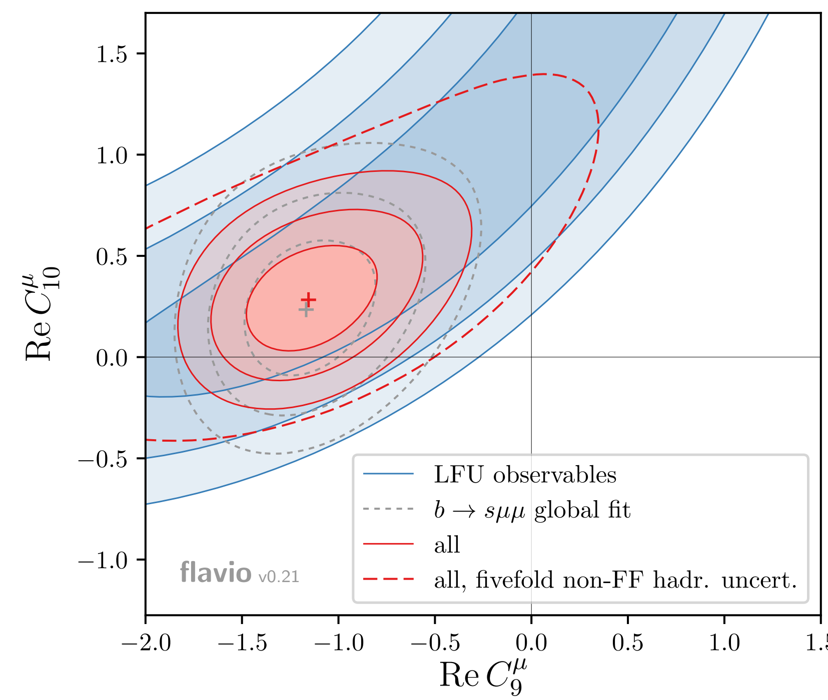
A fascinating solution: C9μ

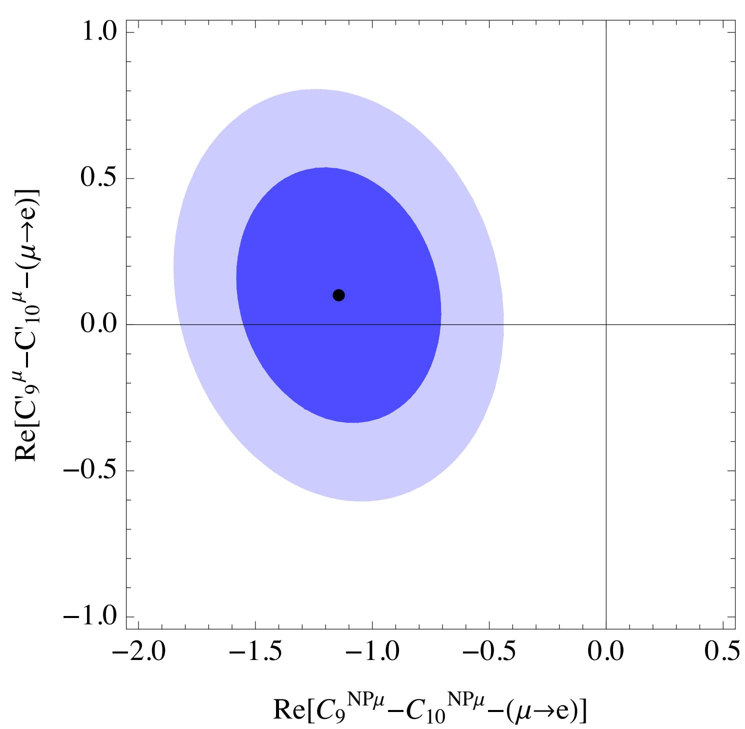
It is possible to explain everything simply requiring NP effect in C9μ



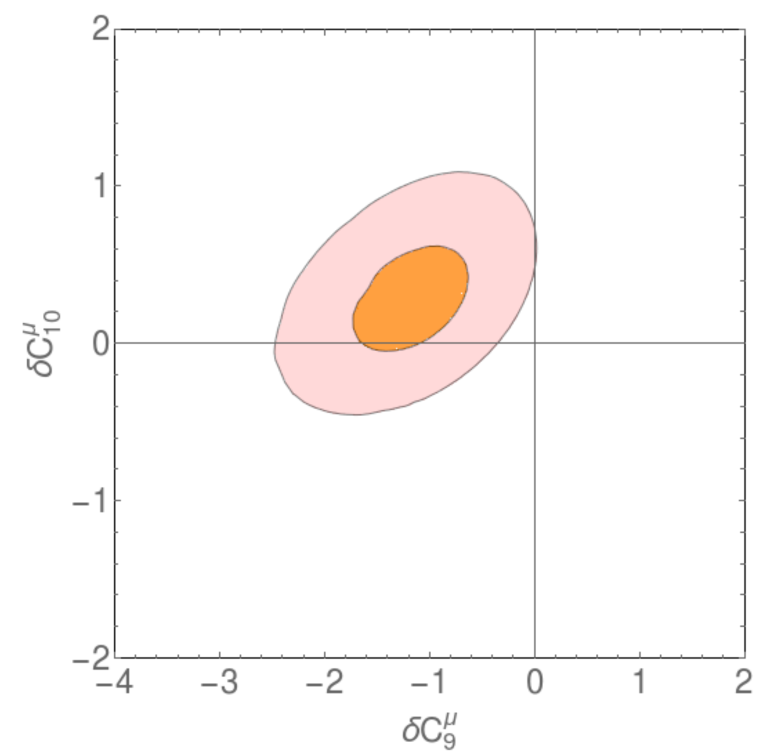
[JHEP 01 (2018) 093]



[Phys. Rev. D96 (2017) 055008]



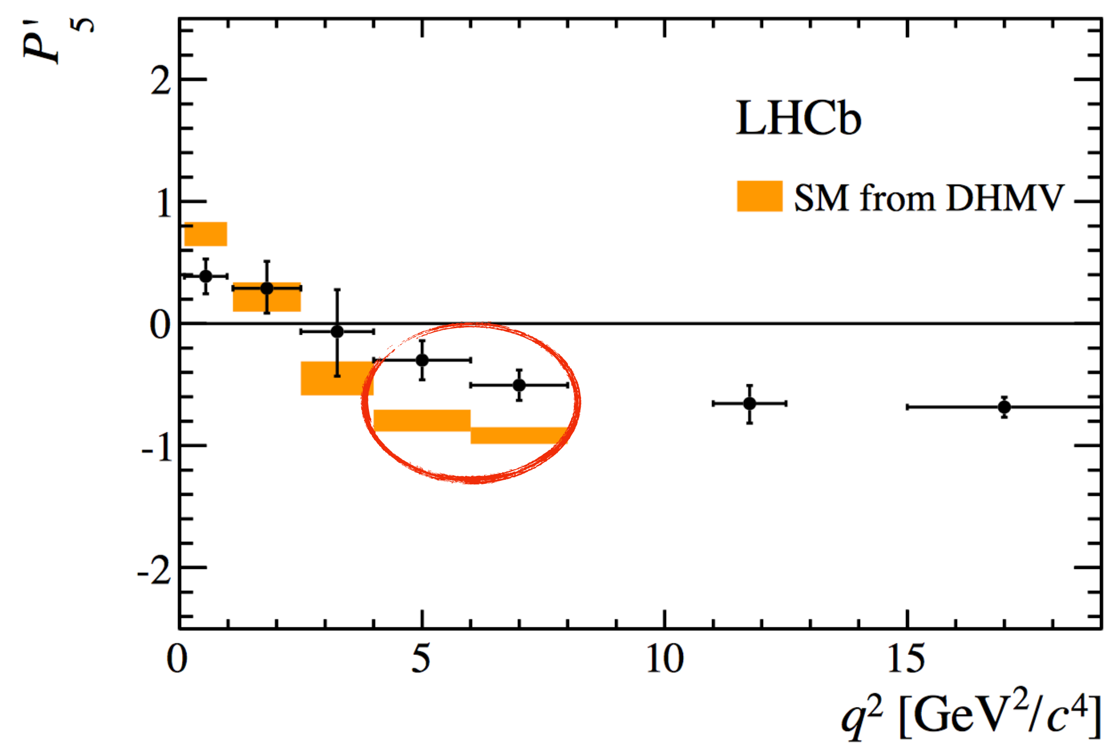
[Phys. Rev. D96 (2017) 035003]



[Phys. Rev. D96 (2017) 093006]

A new 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 $\mathbf{q^2 << 4\,m^2_c}$!

$\Rightarrow$ 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

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

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

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

The SM analysis, case PDD

EXPERIMENTAL WEIGHTS :

q² experimental binning

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

correlated in each bin of q^2

[0.1, 0.98], [1.1, 2.5], [2.5, 4.0] [4.0, 6.0], [6.0, 8.0]

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

[0.1, 2], [2, 4.3], [4.3, 8.68]

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

kinematical endpoint

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

[0.03, 1], [0.002, 1.12]

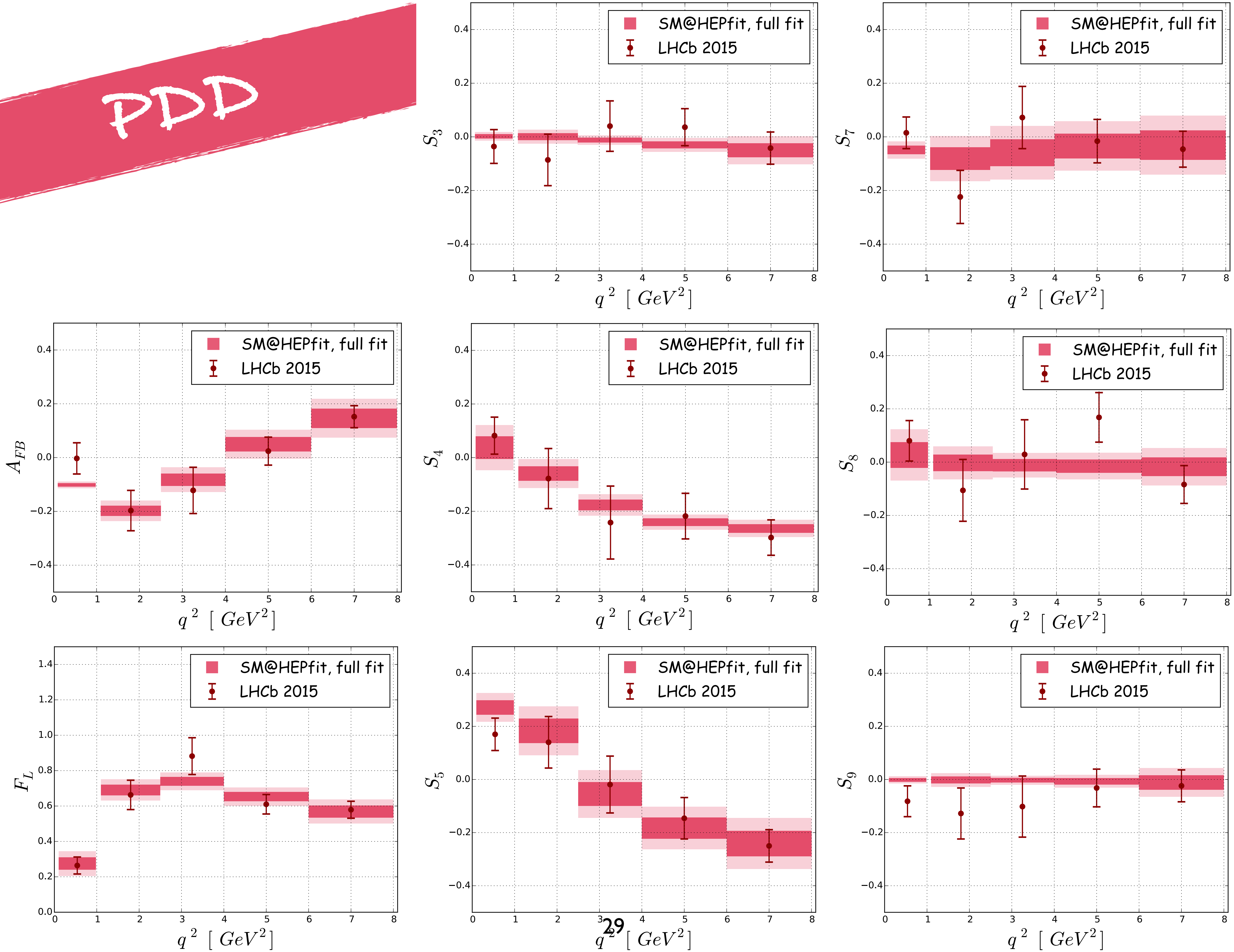
THEORY WEIGHTS :

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

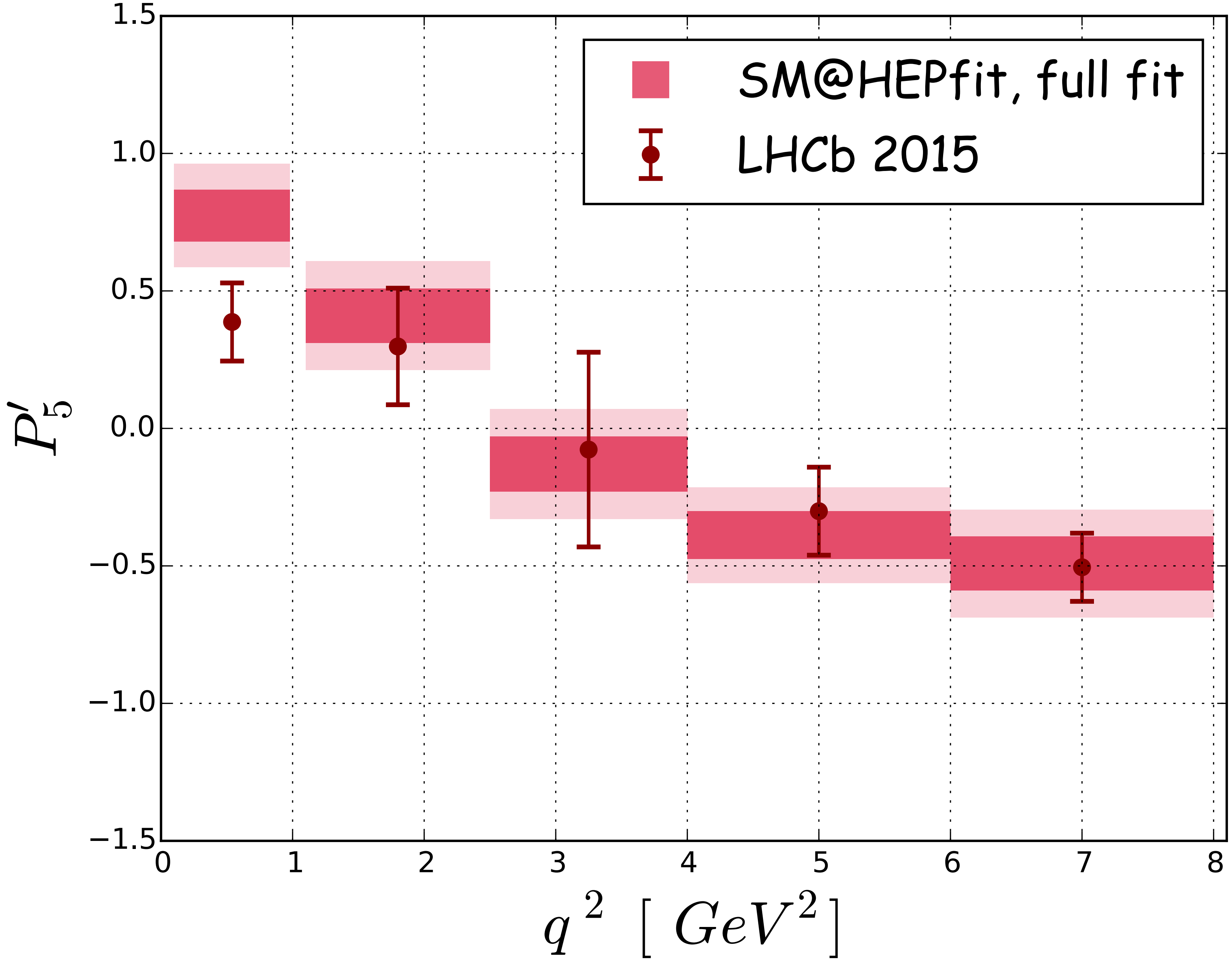
Amplitude helicity suppression at kinematical endpoint

Khodjamirian et al. constraint **ONLY for $q^2 \lesssim 1$ GeV²**

PDD



WHAT ABOUT THE OPTIMIZED OBSERVABLES … ?



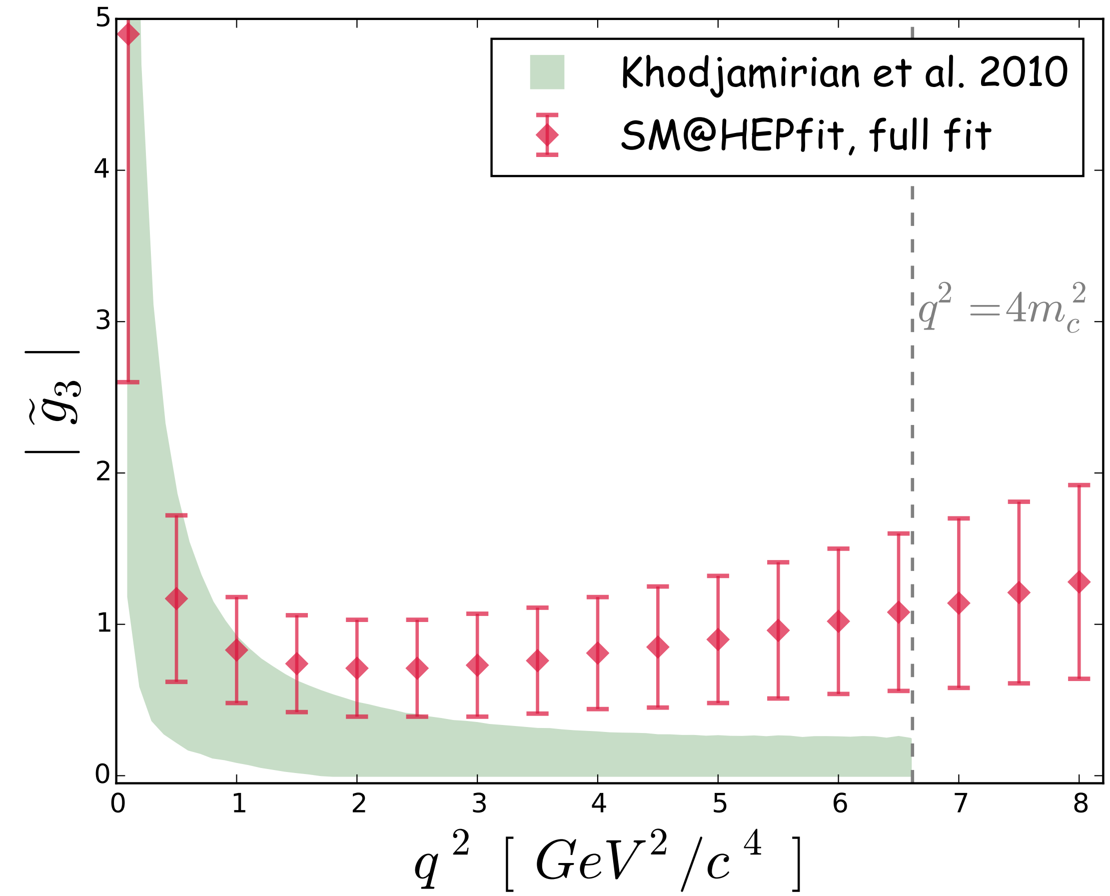
$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

No anomalies in P'_5 …!

EXTRACTING THE NON-PERTURBATIVE HADRONIC CONTRIBUTION

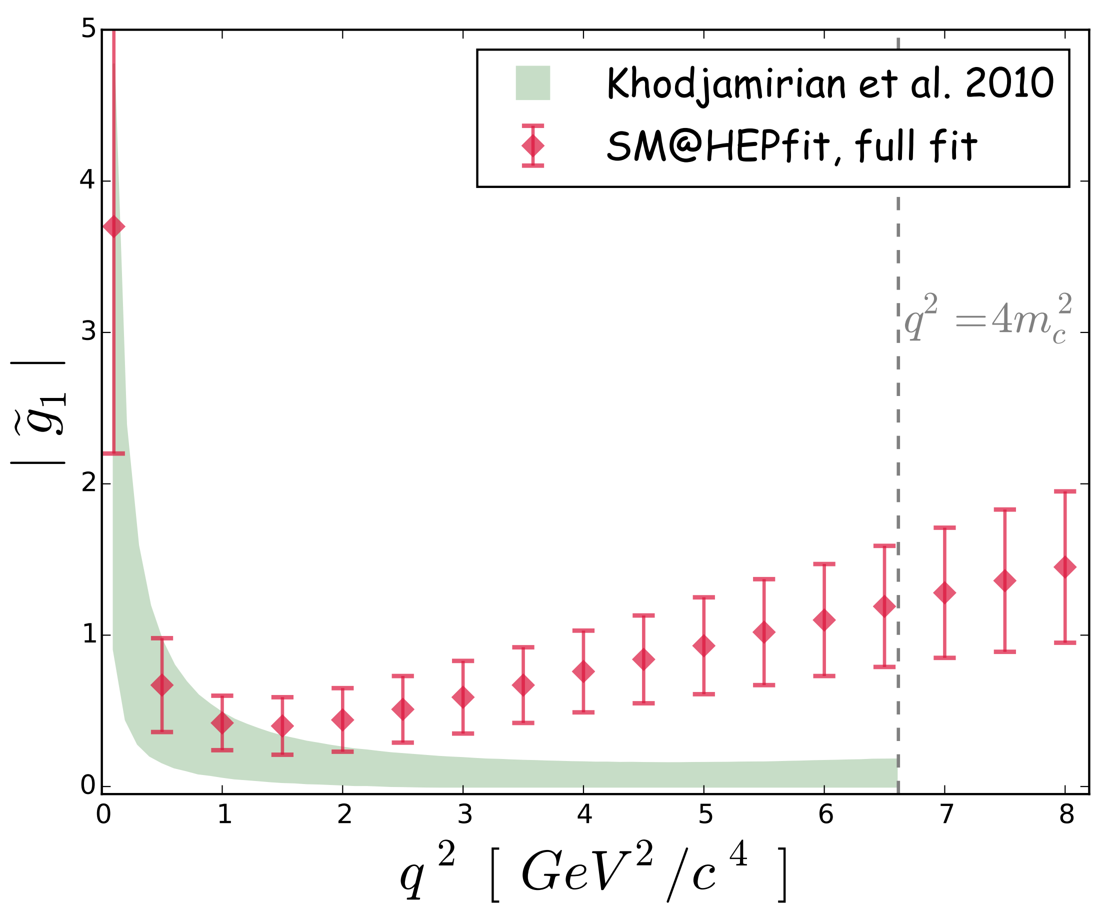
$$\tilde{g} \equiv \Delta C_9^{(\text{non pert.})} / (2C_1)$$

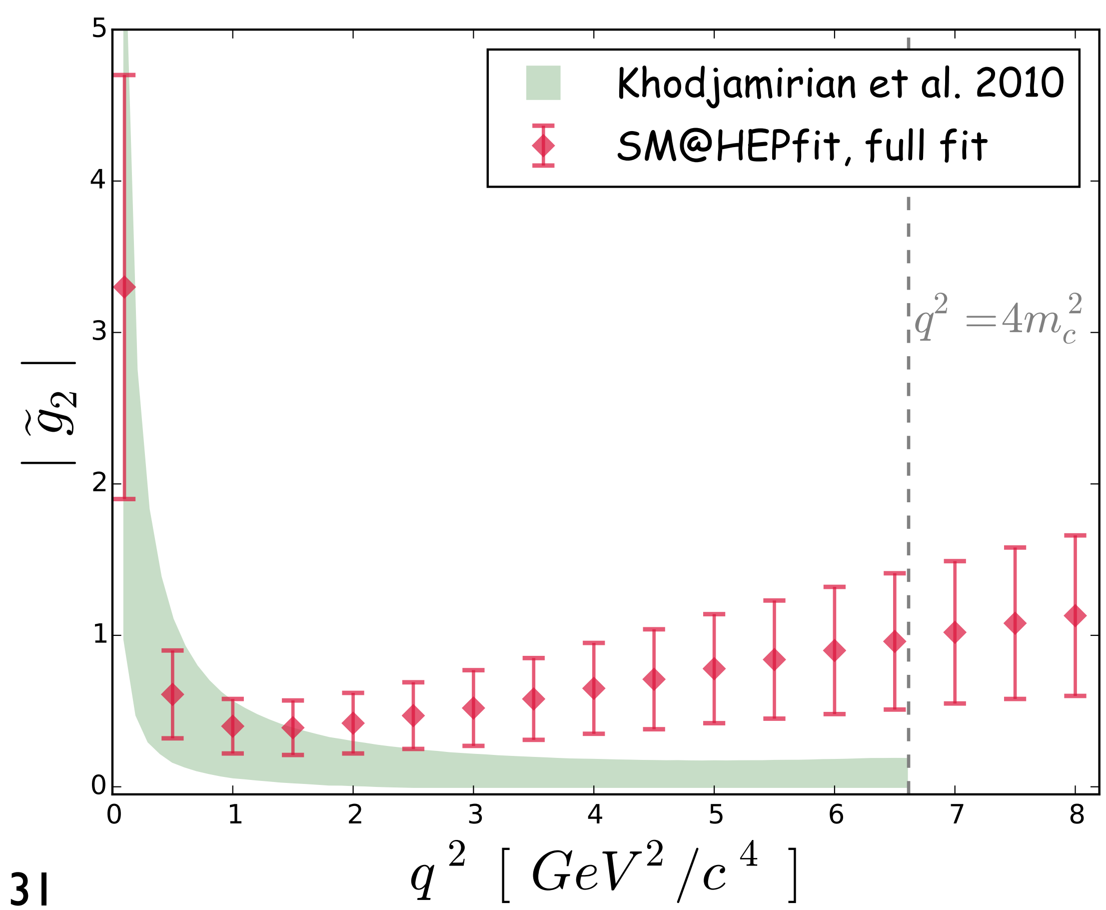
see *arXiv:1006.4945*



DISCLAIMER

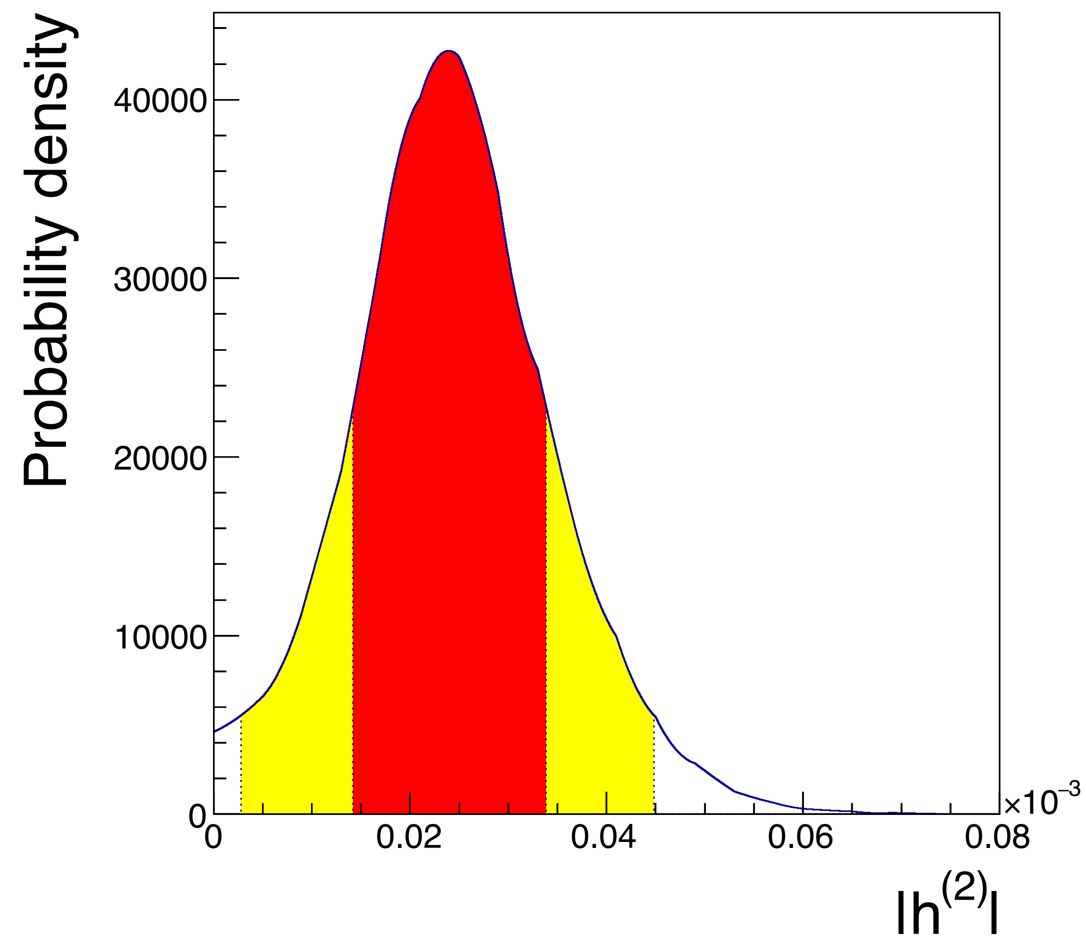
NP contribution in C_7 and/or C_9 cannot reproduce such a q^2 behaviour





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**

The SM analysis, case PMD

EXPERIMENTAL WEIGHTS :

q^2 experimental binning

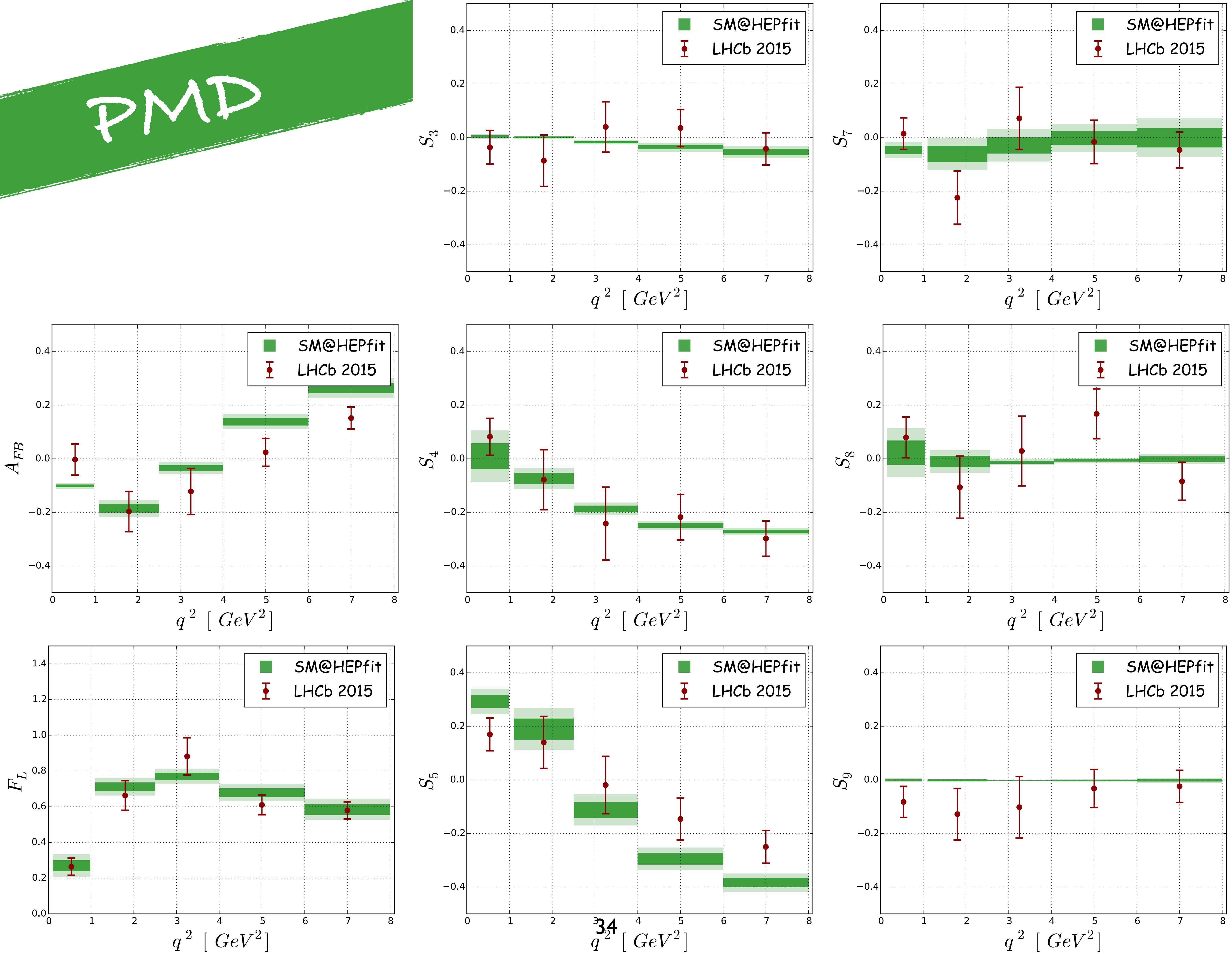
$F_L, A_{FB}, S_{3,4,5,7,8,9}$ *correlated in each bin of q^2*	[0.1, 0.98], [1.1, 2.5], [2.5, 4.0] [4.0, 6.0], [6.0, 8.0]
$\mathcal{B}(B \to K^* \mu\mu)$	[0.1, 2], [2, 4.3], [4.3, 8.68]
$\mathcal{B}(B \to K^* \gamma)$	kinematical endpoint
$\mathcal{B}(B \to K^* ee), F_L, P_{1,2,3}$	[0.03, 1], [0.002, 1.12]

THEORY WEIGHTS :

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

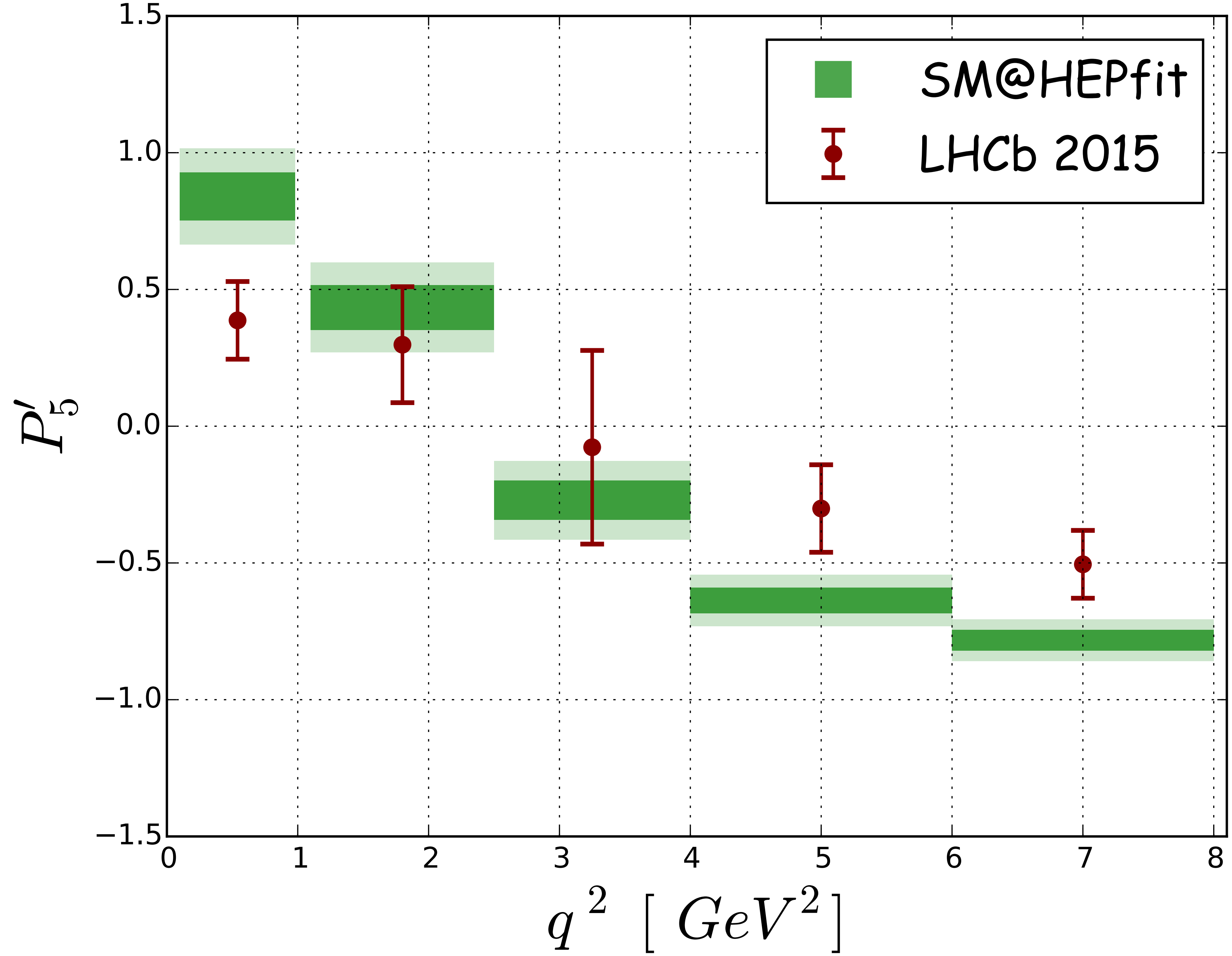
Amplitude helicity suppression at kinematical endpoint

Khodjamirian et al. constraint **for "all" q^2**



SM@HEPfit
LHCb 2015
S_3
S_7
A_{FB}
S_4
S_8
F_L
S_5
S_9
q^2 [GeV^2]

WHAT ABOUT THE OPTIMIZED OBSERVABLES … ?



Anomaly strikes back in P'₅ …!

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

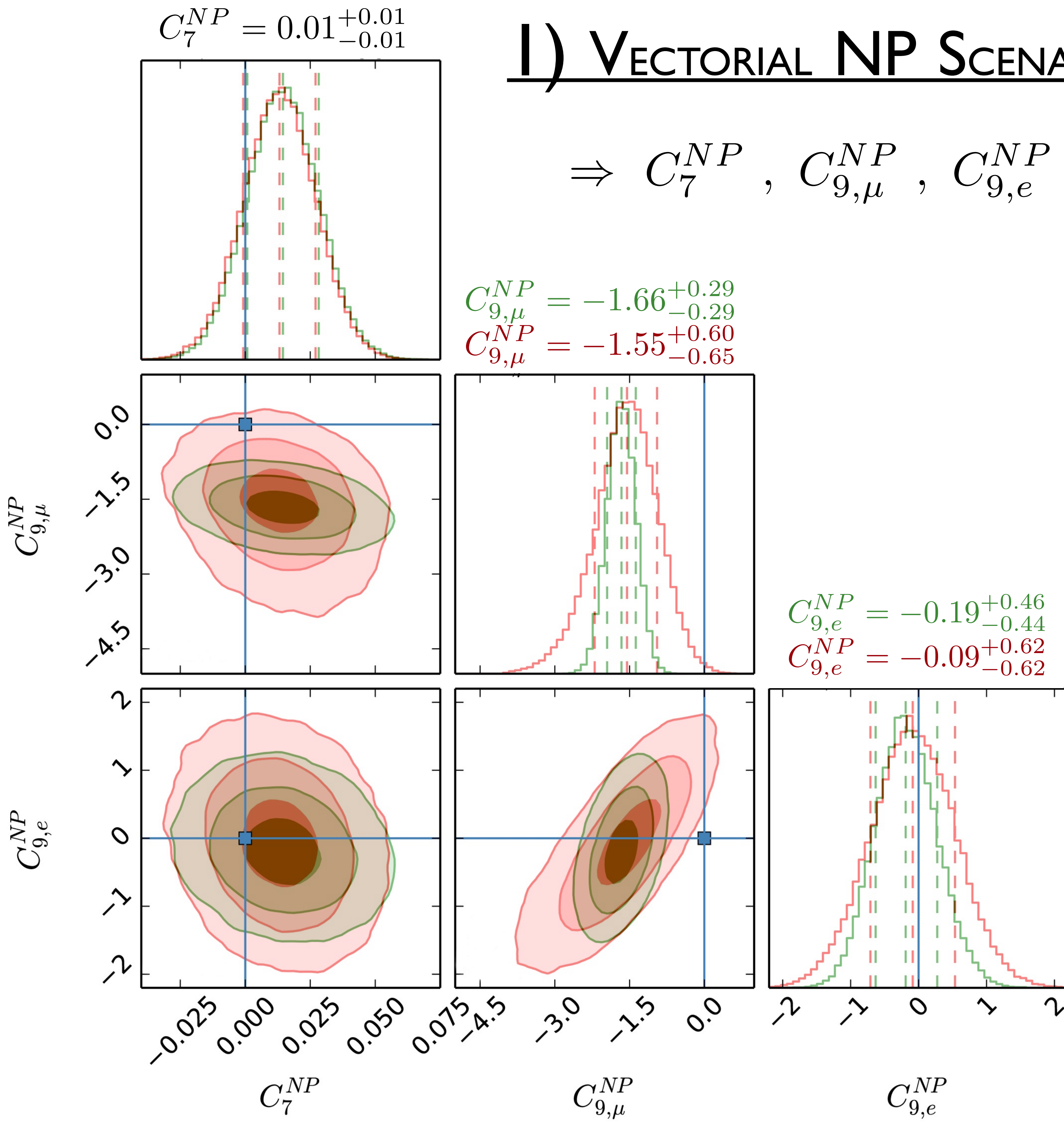
I) Vectorial NP Scenario

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

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

Global fits before Moriond 2019

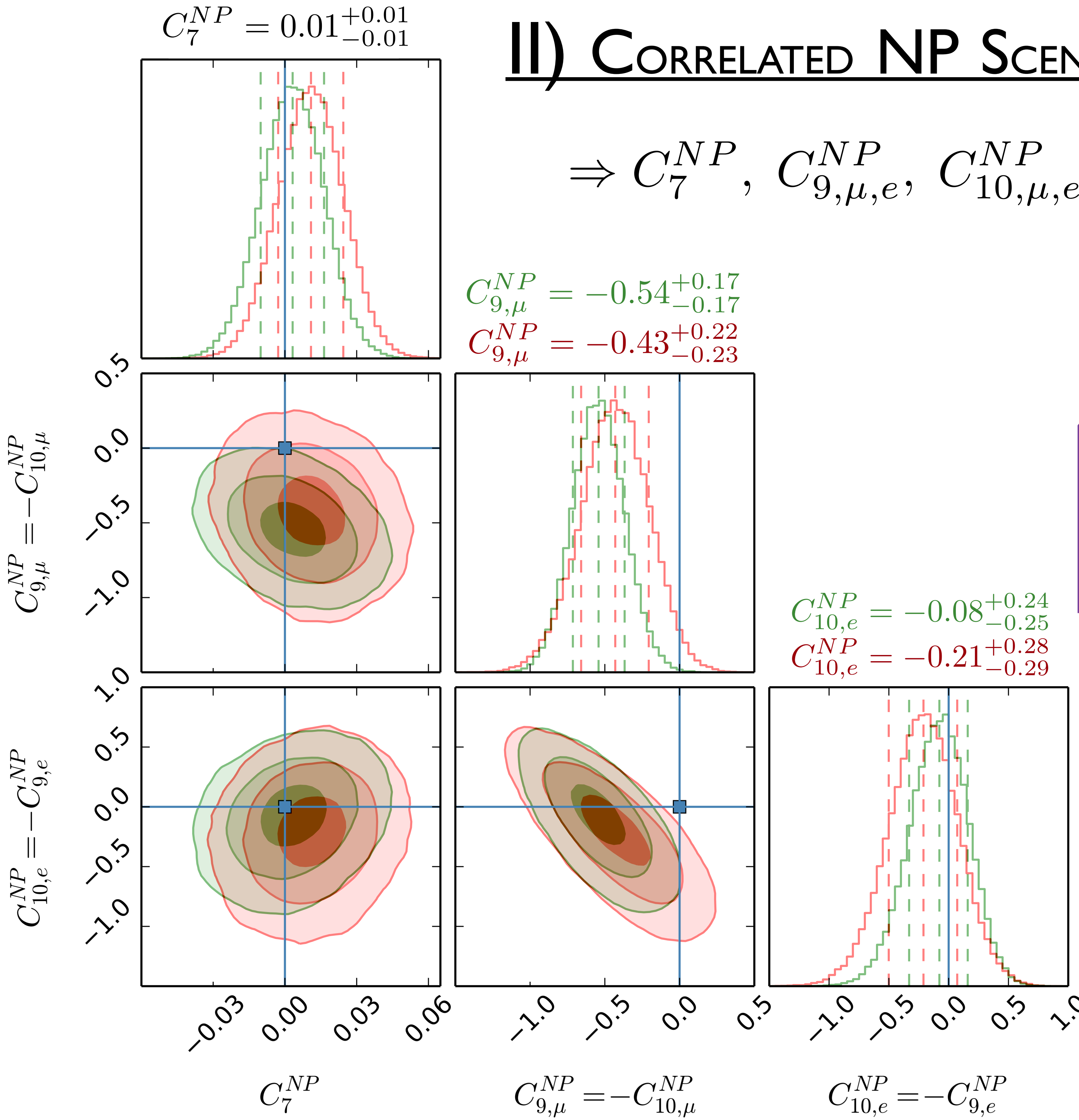
II) Correlated NP Scenario

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

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

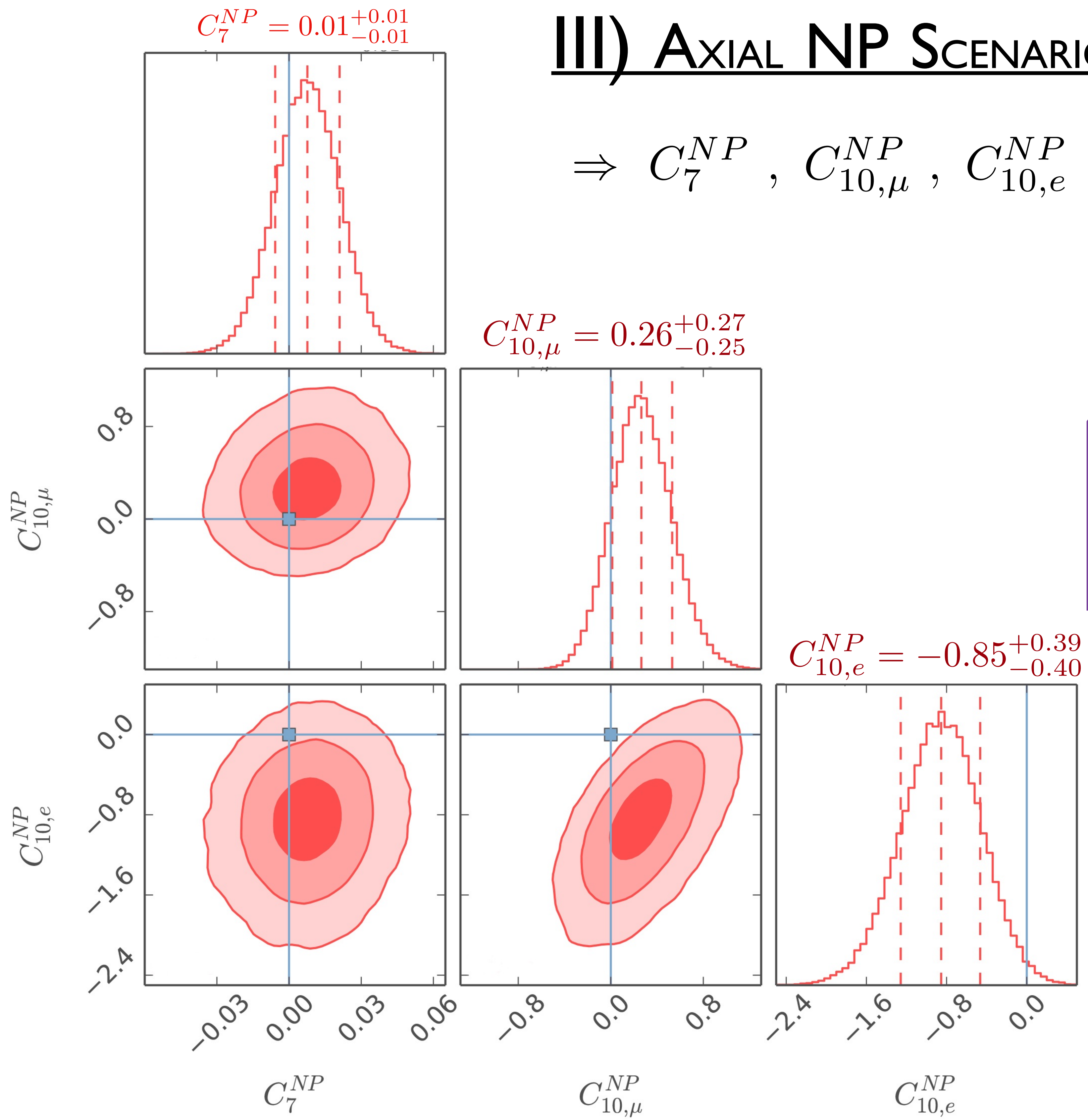


Significance of NP affected by non-factorizable QCD power corrections !

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

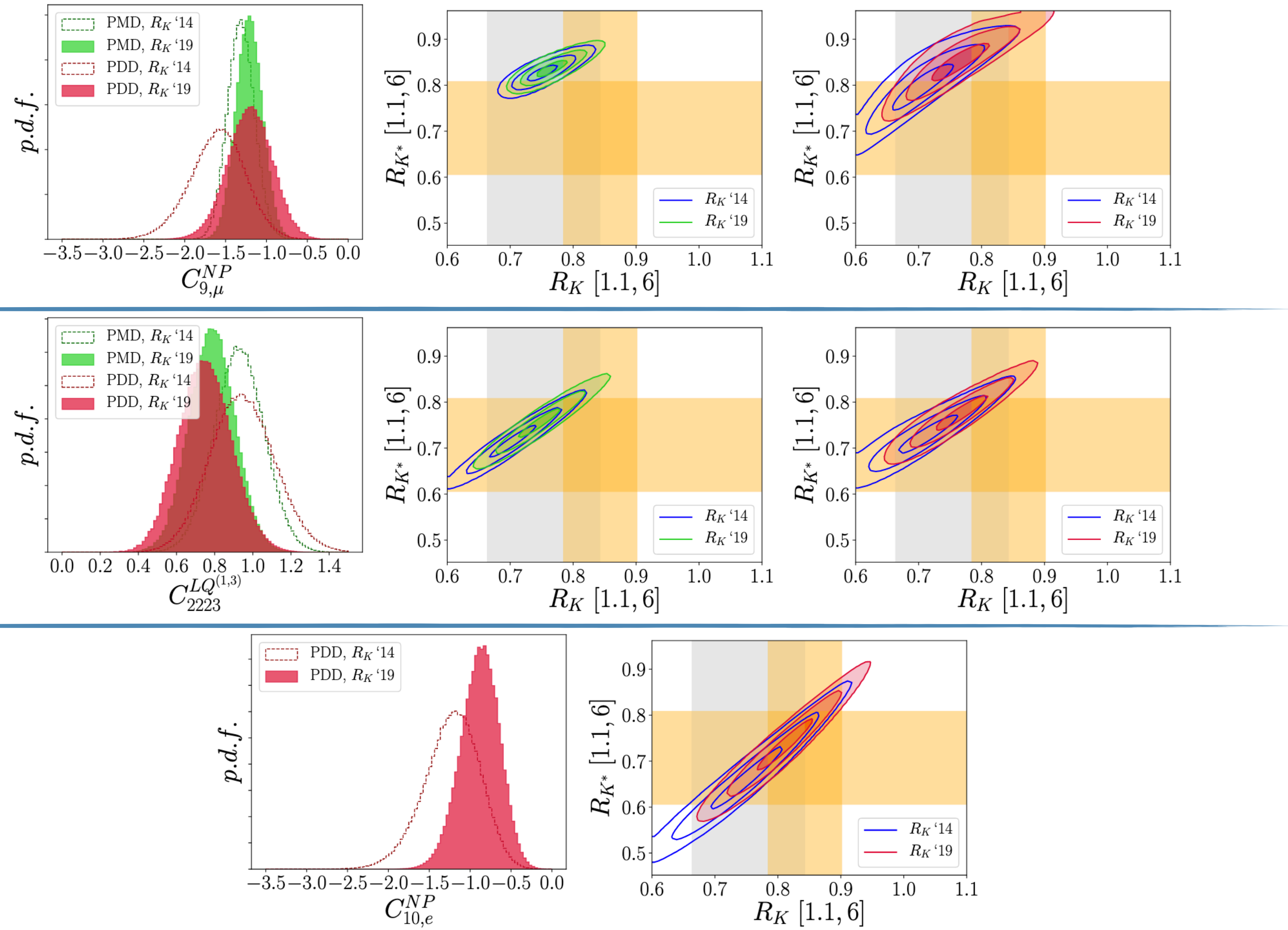
Significance of NP affected by non-factorizable QCD power corrections !

PDD approach

No means to explain angular analysis in PMD

Global fits after Moriond 2019

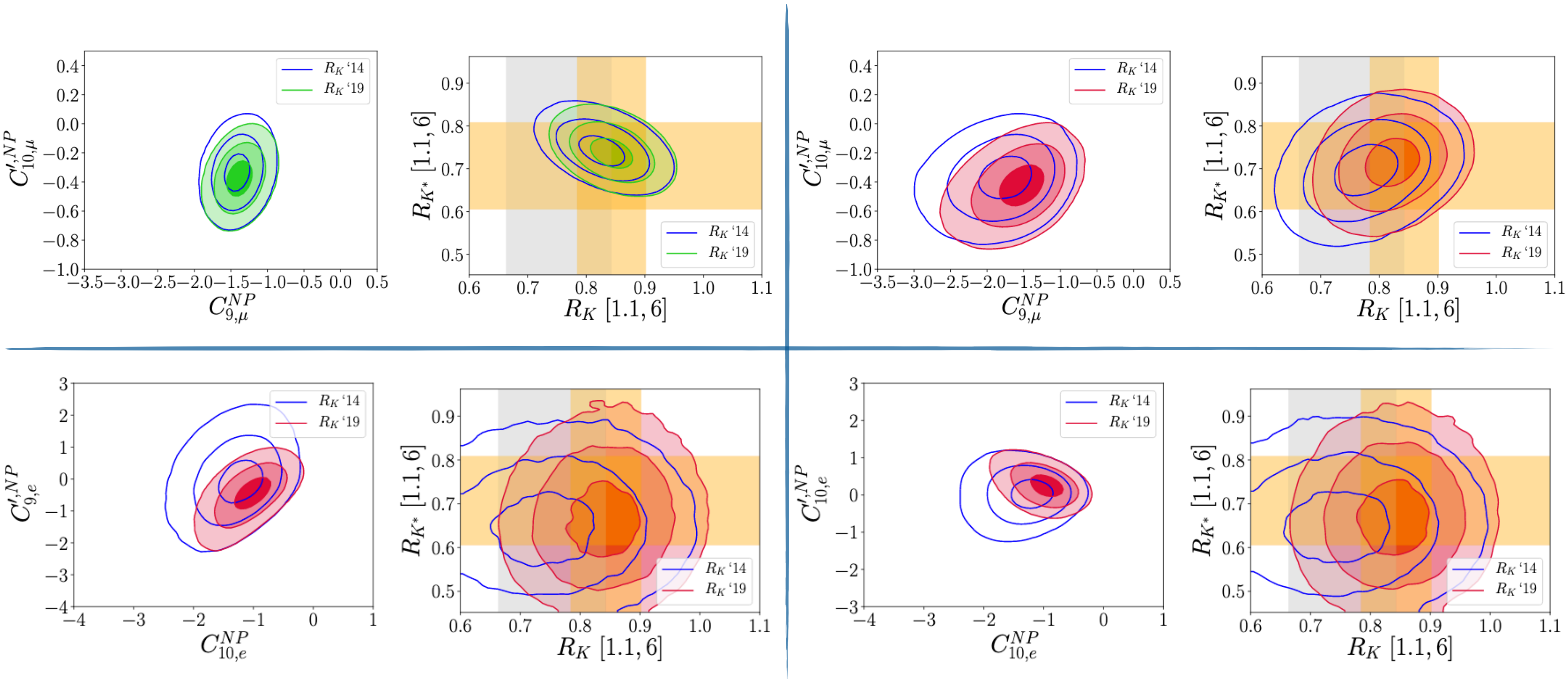
Purely left-handed solutions are no longer preferred by data:



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

Global fits after Moriond 2019

The inclusion of right-handed currents better reproduce data!



$$\boxed{R_K \propto C_i + C_i'}$$

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

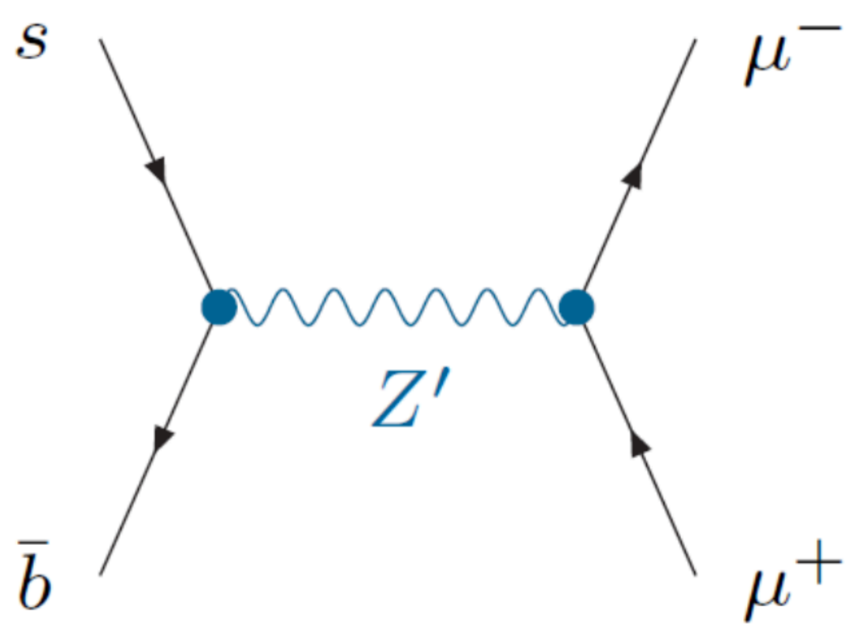
$$R_{K^*}[1.1,6]/R_K[1.1,6] \simeq 0.86 \pm 0.13$$

Summary

- *Theoretical Framework*
- *Experimental anomalies*
- *Global fits*
- *A possible solution*

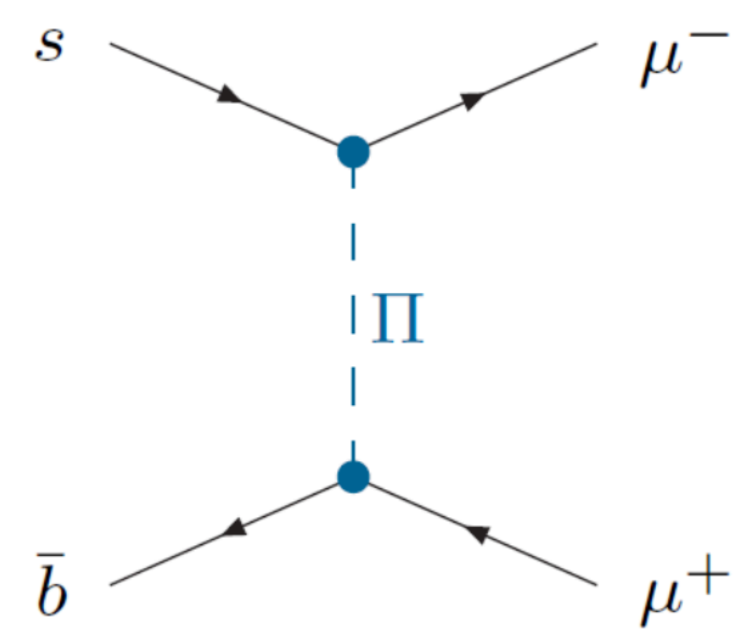
Tree-Level Models

Many possible solutions investigated so far involve tree-level NP



Z' models

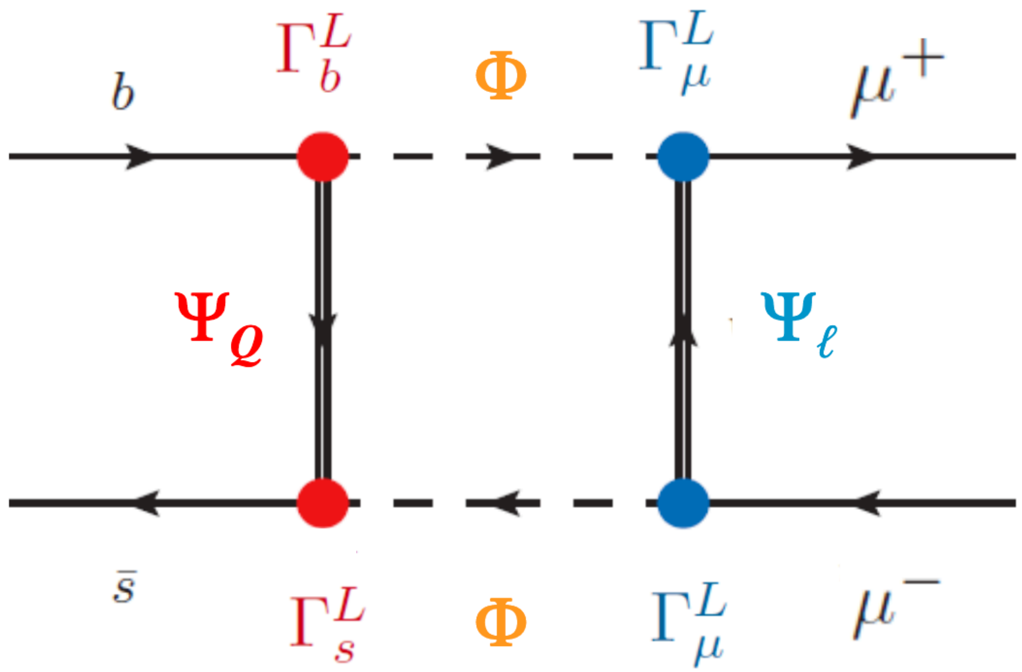
Allanach, Bordone, Buras, Crivellin, D'Ambrosio, De Fazio, Di Luzio, Falkowski, Fuentes-Martin, Gori, Isidori, Nierste, Vicente, …



Lepto-Quarks

Becirevic, Bordone, Crivellin, Di Luzio, Fajfer, Faroughy, Isidori, Kosnik, Marzocca, Sumensari, …

Loop Models

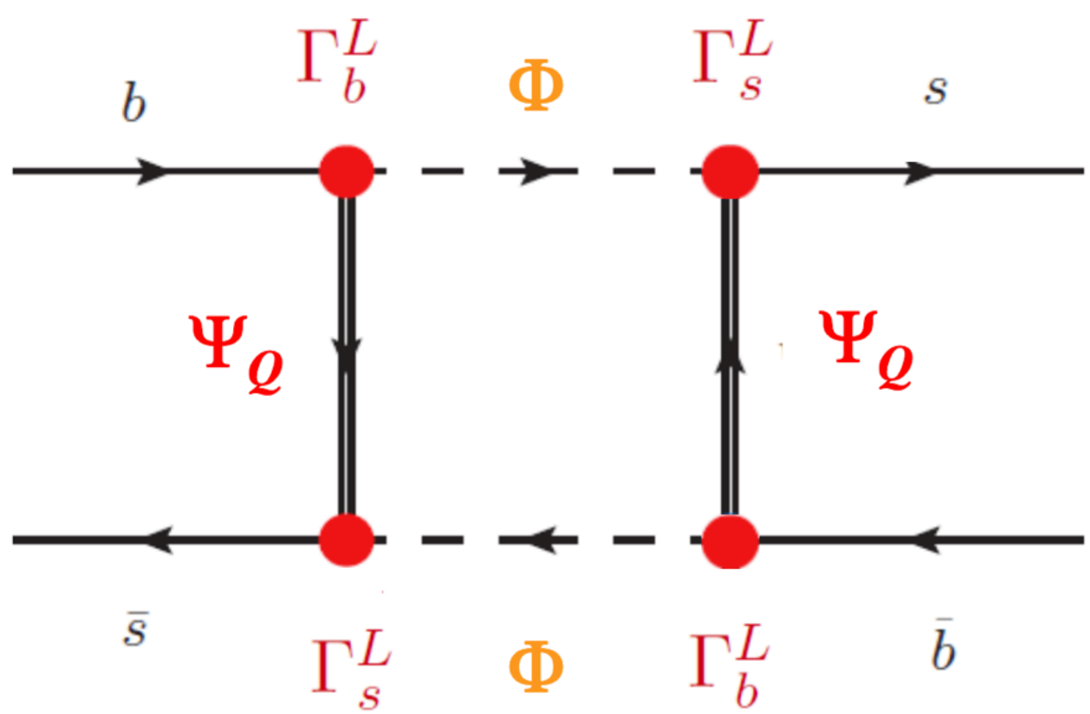


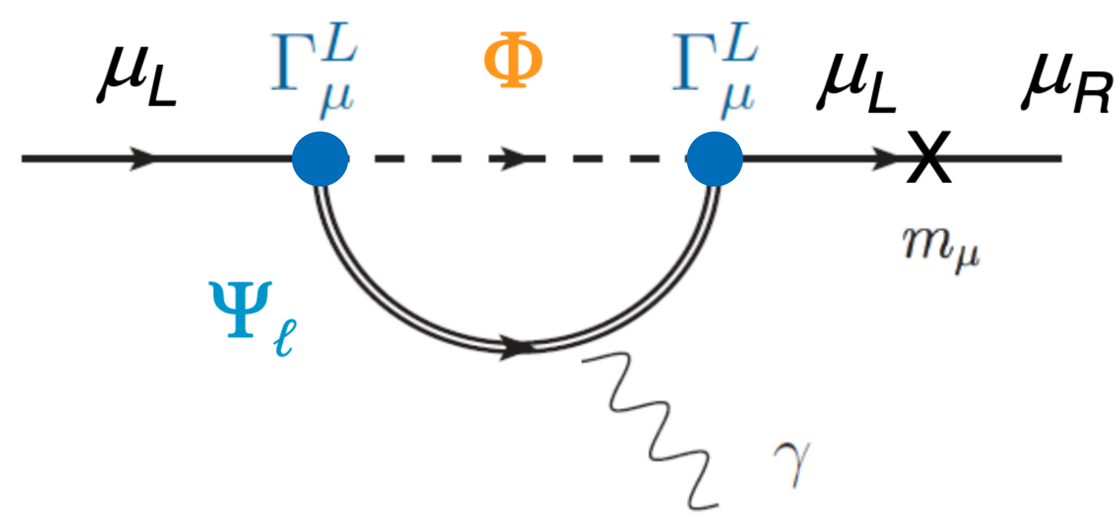
One scalar and 2 vector-like fermions (or vice versa)

$\Rightarrow$ $\boxed{C9 = -C10}$

Gripaios, Nardecchia, Renner '15
Arnan, Crivellin, Hofer, Mescia '16

Induces contributions to ΔMs and muon g-2





It is not possible to address everything with O(1) couplings and viable masses

Our Generic Loop Model

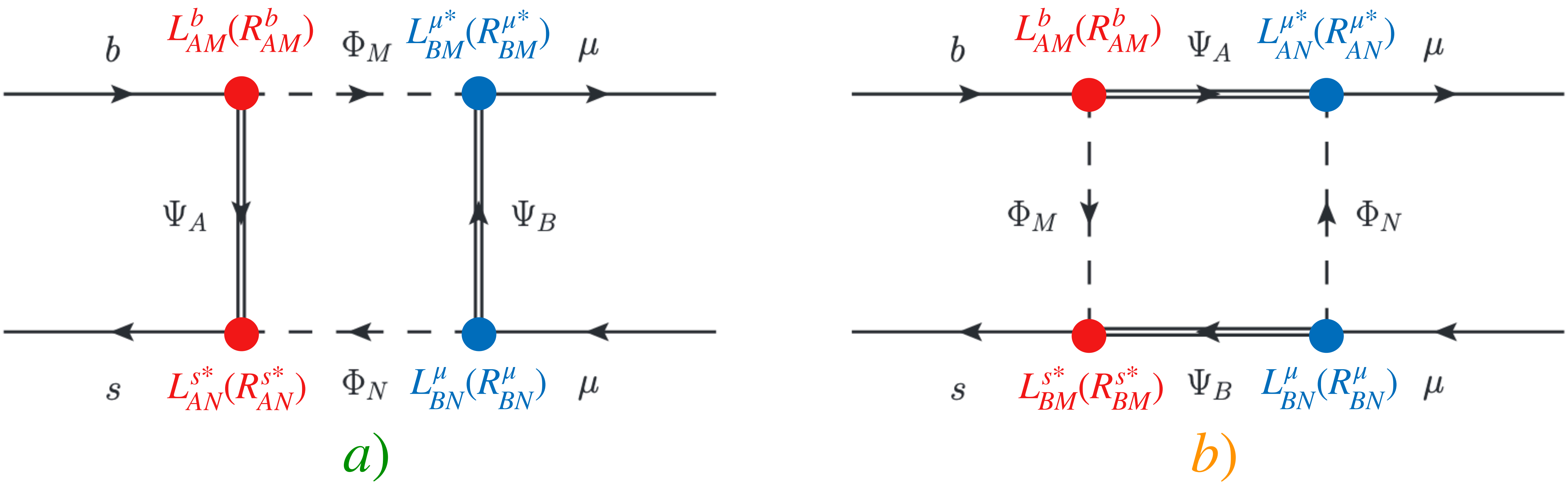
$$\boxed{\begin{aligned}\mathcal{L}_{\rm int} = \Big[& \bar{\Psi}_A \left(L^b_{AM} P_L b + L^s_{AM} P_L s + L^\mu_{AM} P_L \mu \right) \Phi_M \\ & + \bar{\Psi}_A \left(R^b_{AM} P_R b + R^s_{AM} P_R s + R^\mu_{AM} P_R \mu \right) \Phi_M \Big] + \text{h.c.}\end{aligned}}$$

Ψ_A, Φ_M : Generic lists containing an arbitrary number of fields

$L^{b,s,\mu}_{AM}, R^{b,s,\mu}_{AM}$: Generic matrices in (A-M) space

- A and M also include implicitly SU(3) indices
- Non-vanishing entries of the coupling matrices ensure the preservation of colour and electric charge

$b \to s\mu\mu$



Two distinct solution, whether the fermion or the scalar is the NP field that couples to both quarks and leptons

$$x_{AM} \equiv (m_{\Psi_A}/m_{\Phi_M})^2$$

$$C_9^{\text{box},\,a)} = -\mathcal{N}\frac{\chi L^{s*}_{AN}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{BM}L^{\mu}_{BN} + R^{\mu*}_{BM}R^{\mu}_{BN}\right]F(x_{AM},x_{BM},x_{NM})$$

$$C_{10}^{\text{box},\,a)} = \mathcal{N}\frac{\chi L^{s*}_{AN}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{BM}L^{\mu}_{BN} - R^{\mu*}_{BM}R^{\mu}_{BN}\right]F(x_{AM},x_{BM},x_{NM})$$

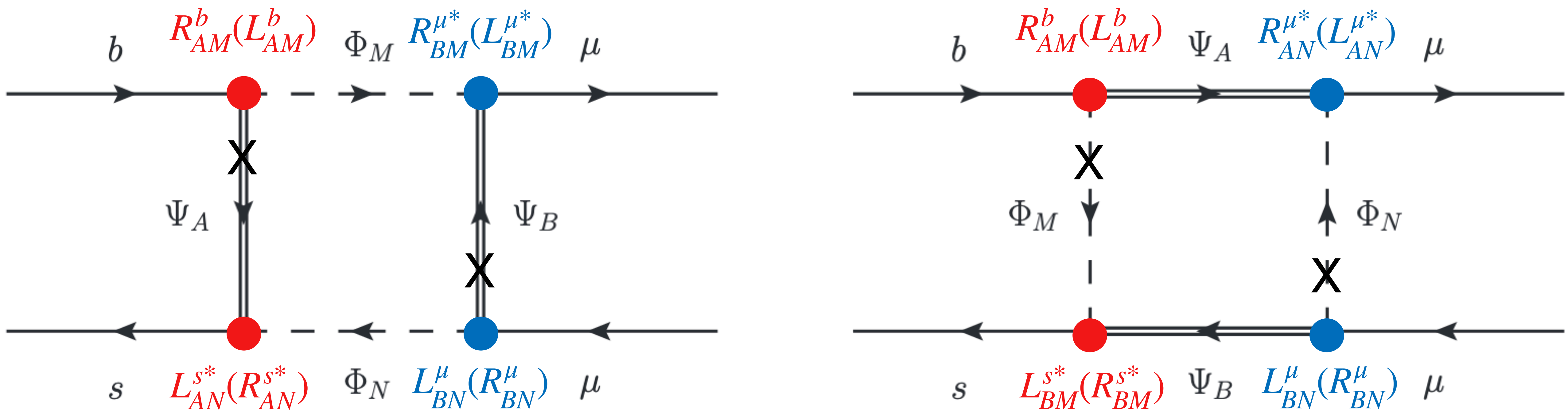
$$C'^{\text{box}}_{9(10)} = \pm\, C^{\text{box}}_{9(10)}(L \leftrightarrow R)$$

$$x_{NM} \equiv (m_{\Phi_N}/m_{\Phi_M})^2$$

$$C_9^{\text{box},\,b)} = -\mathcal{N}\frac{\chi L^{s*}_{BM}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) - R^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

$$C_{10}^{\text{box},\,b)} = \mathcal{N}\frac{\chi L^{s*}_{BM}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) + R^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

$b \to s\mu\mu$



a) *b)*

$$C_S^{\text{box},\,a)} = -\mathcal{N}\frac{\chi L^{s*}_{AN}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{BM}L^{\mu}_{BN} + L^{\mu*}_{BM}R^{\mu}_{BN}\right]\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})$$

$$C_P^{\text{box},\,a)} = \mathcal{N}\frac{\chi L^{s*}_{AN}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{BM}L^{\mu}_{BN} - L^{\mu*}_{BM}R^{\mu}_{BN}\right]\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})$$

$$C'^{\text{box}}_{S,T(P)} = \pm\, C^{\text{box}}_{S,T(P)}(L \leftrightarrow R)$$

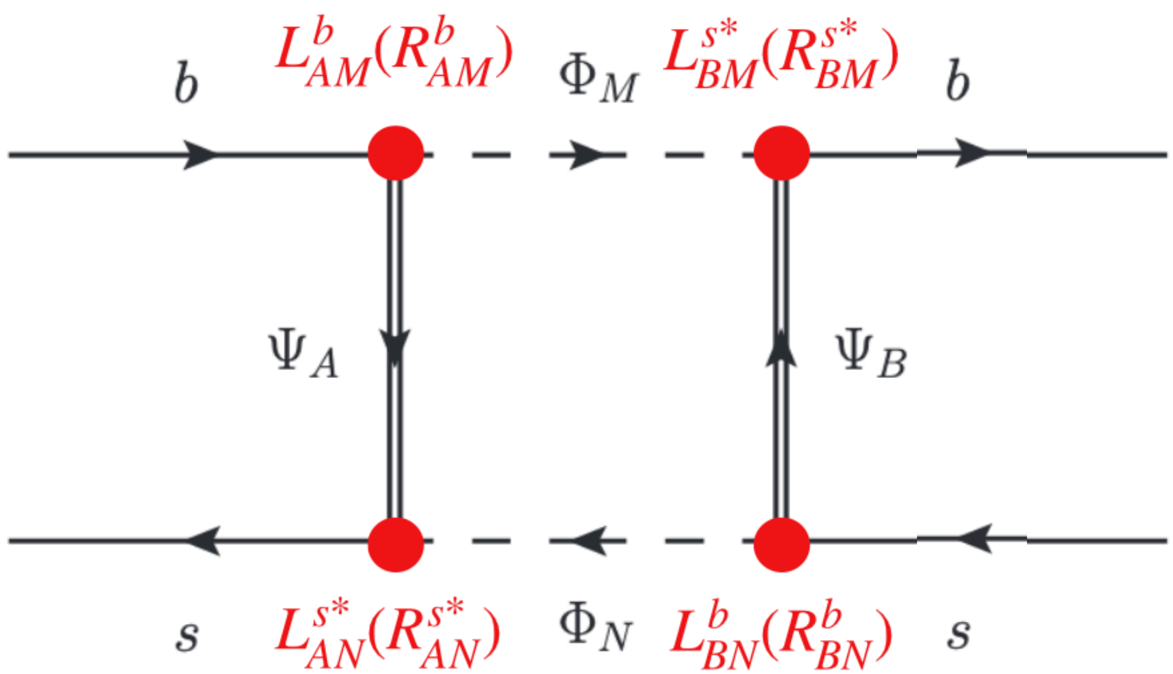
$$C_S^{\text{box},\,b)} = \mathcal{N}\frac{\chi L^{s*}_{BM}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) + L^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{2m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

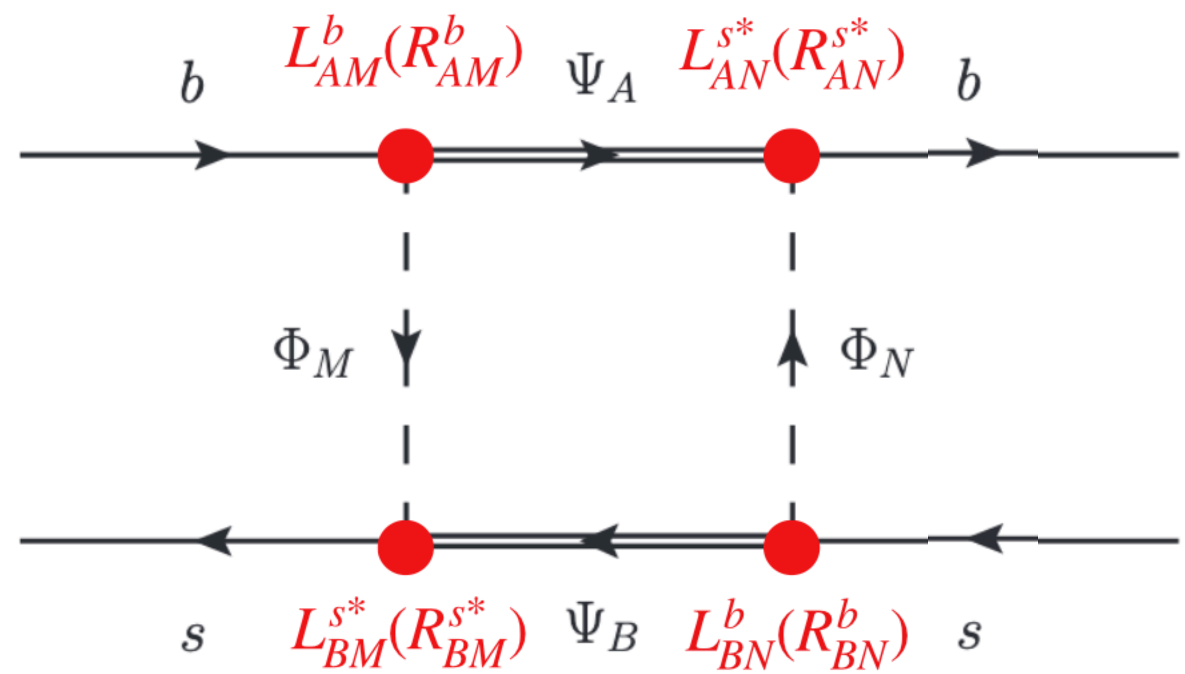
$$C_P^{\text{box},\,b)} = -\mathcal{N}\frac{\chi L^{s*}_{BM}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) - L^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{2m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

$$C_T^{\text{box},\,b)} = -\mathcal{N}\frac{\chi L^{s*}_{BM}R^b_{AM}L^{\mu*}_{AN}R^{\mu}_{BN}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})$$

Additional WC present <u>only</u> in the presence of additional SU(2) breaking effects

ΔMs





Both diagrams appear, independently on b→s$\mu\mu$, since no leptons are involved in this channel

$$C_1 = (\chi_{BB} + \tilde{\chi}_{BB}) \frac{L^{s*}_{AN} L^b_{AM} L^{s*}_{BM} L^b_{BN}}{128\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_2 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

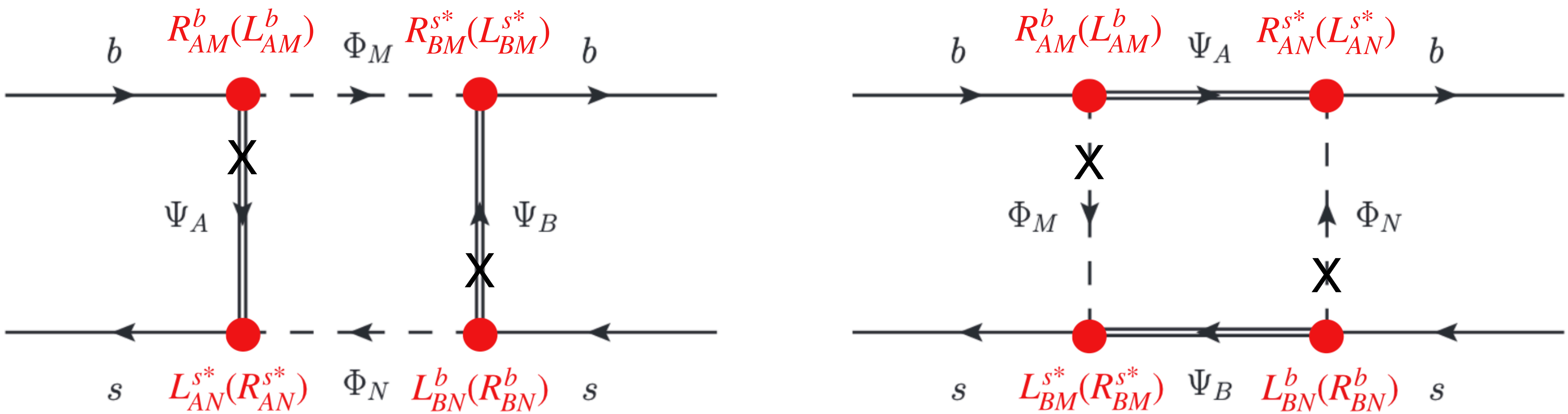
$$C_3 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$\widetilde{C}_{1,2,3} = C_{1,2,3}\,(L \leftrightarrow R)$$

$$C_4 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \tilde{\chi}_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_5 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \chi_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

ΔMs



Both diagrams appear, independently on b→sμμ, since no leptons are involved in this channel

$$C_1 = (\chi_{BB} + \tilde{\chi}_{BB}) \frac{L^{s*}_{AN} L^b_{AM} L^{s*}_{BM} L^b_{BN}}{128\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_2 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_3 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

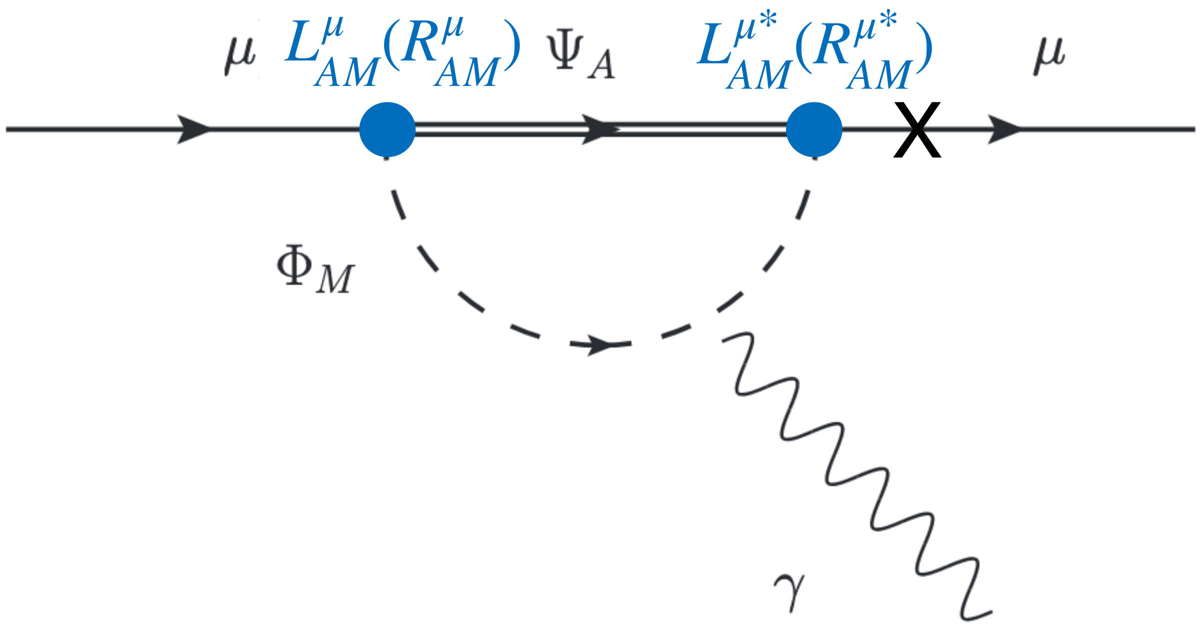
$$\widetilde{C}_{1,2,3} = C_{1,2,3} \, (L \leftrightarrow R)$$

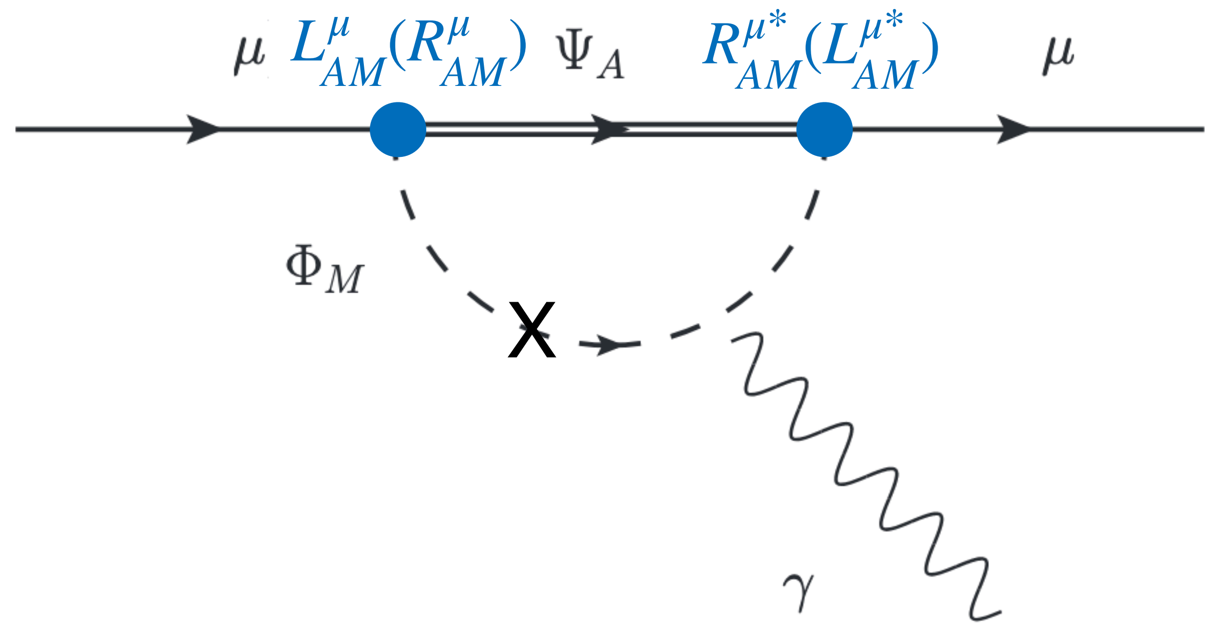
$$C_4 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM})$$
$$- \tilde{\chi}_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_5 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM})$$
$$- \chi_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

Additional contributions to WC present in the presence of additional SU(2) breaking effects

g-2





$$\Delta a_\mu = \frac{\chi_{a_\mu} m_\mu^2}{8\pi^2 m_{\Phi_M}^2} \Big[\left(L^{\mu*}_{AM} L^\mu_{AM} + R^{\mu*}_{AM} R^\mu_{AM}\right) \left(Q_{\Phi_M} \widetilde{F}_7(x_{AM}) - Q_{\Psi_A} F_7(x_{AM})\right) + \left(L^{\mu*}_{AM} R^\mu_{AM} + R^{\mu*}_{AM} L^\mu_{AM}\right) \frac{2 m_{\Psi_A}}{m_\mu} \left(Q_{\Phi_M} \widetilde{G}_7(x_{AM}) - Q_{\Psi_A} G_7(x_{AM})\right) \Big]$$

Additional term induced by SU(2) breaking, and chirally enhanced

4th Generation Model

$$L^{4\text{th}} = \sum_i \left(\Gamma^L_{q_i}\bar{\Psi}_q P_L q_i + \Gamma^L_{\ell_i}\bar{\Psi}_\ell P_L \ell_i + \Gamma^R_{u_i}\bar{\Psi}_u P_R u_i + \Gamma^R_{d_i}\bar{\Psi}_d P_R d_i + \Gamma^R_{e_i}\bar{\Psi}_e P_R e_i\right)\Phi + \text{h.c.}$$
$$+ \sum_{C=L,R}\left(\lambda^U_C\bar{\Psi}_q P_C \tilde{h}\Psi_u + \lambda^D_C\bar{\Psi}_q P_C h\Psi_d + \lambda^E_C\bar{\Psi}_\ell P_C h\Psi_e\right) + \text{h.c.}$$
$$+ \sum_{F=q,\ell,u,d,e} M_F\bar{\Psi}_F\Psi_F + \kappa\, h^\dagger h\,\Phi^\dagger\Phi + m^2_\Phi\Phi^\dagger\Phi$$

We start writing down the most general Lagrangian before EWSB including a 4th vector-like generation and a neutral scalar

	$SU(3)$	$SU(2)$	$U(1)$	$U'(1)$
Ψ_q	3	2	1/6	Z
Ψ_u	3	1	2/3	Z
Ψ_d	3	1	$-1/3$	Z
Ψ_ℓ	1	2	$-1/2$	Z
Ψ_e	1	1	-1	Z
Φ	1	1	0	$-Z$

NB. We work in the basis with diagonal down-type quarks

4th Generation Model

$$
\begin{aligned}
L^{4\text{th}} = & \sum_i \left(\Gamma^L_{q_i}\bar{\Psi}_q P_L q_i + \Gamma^L_{\ell_i}\bar{\Psi}_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i}\bar{\Psi}_u P_R u_i} + \Gamma^R_{d_i}\bar{\Psi}_d P_R d_i + \Gamma^R_{e_i}\bar{\Psi}_e P_R e_i\right)\Phi + \text{h.c.} \\
& + \sum_{C=L,R}\left(\cancel{\lambda^U_C\bar{\Psi}_q P_C \tilde{h}\Psi_u} + \lambda^D_C\bar{\Psi}_q P_C h\Psi_d + \lambda^E_C\bar{\Psi}_\ell P_C h\Psi_e\right) + \text{h.c.} \\
& + \sum_{F=q,\ell,u,d,e} M_F\bar{\Psi}_F\Psi_F + \kappa\, h^\dagger h\,\Phi^\dagger\Phi + m^2_\Phi\Phi^\dagger\Phi
\end{aligned}
$$

We're interested only in couplings to bottom, strange, muon

4th Generation Model

$$L^{4\text{th}} = \sum_i \left(\Gamma^L_{q_i}\bar{\Psi}_q P_L q_i + \Gamma^L_{\ell_i}\bar{\Psi}_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i}\bar{\Psi}_u P_R u_i} + \Gamma^R_{d_i}\bar{\Psi}_d P_R d_i + \Gamma^R_{e_i}\bar{\Psi}_e P_R e_i\right)\Phi + \text{h.c.}$$

$$+ \sum_{C=L,R}\left(\cancel{\lambda^U_C \bar{\Psi}_q P_C \tilde{h}\Psi_u} + \cancel{\lambda^D_C \bar{\Psi}_q P_C h \Psi_d} + \lambda^E_C \bar{\Psi}_\ell P_C h \Psi_e\right) + \text{h.c.}$$

$$+ \sum_{F=q,\ell,u,d,e} M_F \bar{\Psi}_F \Psi_F + \kappa\, h^\dagger h\, \Phi^\dagger \Phi + m^2_\Phi \Phi^\dagger \Phi$$

We're interested only in couplings to bottom, strange, muon

We neglect SU(2) breaking for down-type quarks
(responsible for phenomenological un-relevant scalar/tensor operators)

4th Generation Model

$$L^{4\text{th}} = \sum_i \left(\Gamma^L_{q_i}\bar\Psi_q P_L q_i + \Gamma^L_{\ell_i}\bar\Psi_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i}\bar\Psi_u P_R} u_i + \Gamma^R_{d_i}\bar\Psi_d P_R d_i + \Gamma^R_{e_i}\bar\Psi_e P_R e_i\right)\Phi + \text{h.c.}$$

$$+ \sum_{C=L,R}\left(\cancel{\lambda^U_C\bar\Psi_q P_C\tilde h}\Psi_u + \cancel{\lambda^D_C\bar\Psi_q P_C h}\Psi_d + \boxed{\lambda^E_C\bar\Psi_\ell P_C h\Psi_e}\right) + \text{h.c.}$$

$$+ \sum_{F=q,\ell,u,d,e} \boxed{M_F\bar\Psi_F\Psi_F} + \kappa\, h^\dagger h\,\Phi^\dagger\Phi + m^2_\Phi\Phi^\dagger\Phi$$

We're interested only in couplings to bottom, strange, muon

We neglect SU(2) breaking for down-type quarks
(responsible for phenomenological un-relevant scalar/tensor operators)

We need to diagonalise the lepton sector!

4th Generation Model

$$L^{4\text{th}} = \sum_i \left(\Gamma^L_{q_i}\bar\Psi_q P_L q_i + \Gamma^L_{\ell_i}\bar\Psi_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i}\bar\Psi_u P_R} u_i + \Gamma^R_{d_i}\bar\Psi_d P_R d_i + \Gamma^R_{e_i}\bar\Psi_e P_R e_i\right)\Phi + \text{h.c.}$$

$$+ \sum_{C=L,R}\left(\cancel{\lambda^U_C\bar\Psi_q P_C \tilde h \Psi_u} + \cancel{\lambda^D_C\bar\Psi_q P_C h\Psi_d} + \lambda^E_C\bar\Psi_\ell P_C h\Psi_e\right) + \text{h.c.}$$

$$+ \sum_{F=q,\ell,u,d,e} M_F\bar\Psi_F\Psi_F + \kappa\, h^\dagger h\,\Phi^\dagger\Phi + m^2_\Phi\Phi^\dagger\Phi$$

Below EWSB:

$$L^{4\text{th}}_{\text{mass}} = \begin{pmatrix}\bar\Psi_{\ell,2}\\ \bar\Psi_e\end{pmatrix}^T \begin{pmatrix} M_\ell & \sqrt2 v\lambda^E_R \\ \sqrt2 v\lambda^{E*}_L & M_e\end{pmatrix} P_L \begin{pmatrix}\Psi_{\ell,2}\\ \Psi_e\end{pmatrix} \Rightarrow \boxed{\begin{array}{l} P_L\begin{pmatrix}\Psi_{\ell,2}\\ \Psi_e\end{pmatrix}_I \to W^{E_L}_{IJ}\Psi^{E_L}_J \\[2ex] \begin{pmatrix}\bar\Psi_{\ell,2}\\ \bar\Psi_e\end{pmatrix}^T_I P_L \to \bar\Psi^{E_R}_J W^{E_R}_{IJ}\end{array}}$$

4th Generation Model

$$L^{4\text{th}} = \sum_{i} \left(\Gamma^L_{q_i}\bar{\Psi}_q P_L q_i + \Gamma^L_{\ell_i}\bar{\Psi}_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i}\bar{\Psi}_u P_R u_i} + \Gamma^R_{d_i}\bar{\Psi}_d P_R d_i + \Gamma^R_{e_i}\bar{\Psi}_e P_R e_i\right)\Phi + \text{h.c.}$$

$$\boxed{\begin{array}{l} P_L \begin{pmatrix} \Psi_{\ell,2} \\ \Psi_e \end{pmatrix}_I \to W^{E_L}_{IJ}\Psi^{E_L}_J \\[2ex] \begin{pmatrix} \bar{\Psi}_{\ell,2} \\ \bar{\Psi}_e \end{pmatrix}^T_I P_L \to \bar{\Psi}^{E_R}_J W^{E_R}_{IJ} \end{array}}
\qquad
\boxed{\begin{array}{l} P_L \begin{pmatrix} \Psi_{q,2} \\ \Psi_d \end{pmatrix}_I \to \delta_{IJ}\Psi^{D_L}_J \\[2ex] \begin{pmatrix} \bar{\Psi}_{q,2} \\ \bar{\Psi}_d \end{pmatrix}^T_I P_L \to \bar{\Psi}^{D_R}_J \delta_{IJ} \end{array}}$$

$$\begin{aligned} L^{4\text{th}}_{\text{int}} &= \left(L^b_1\bar{\Psi}^D_1 P_L b + L^s_1\bar{\Psi}^D_1 P_L s + L^\mu_I\bar{\Psi}^E_I P_L \mu\right)\Phi \\ &\quad + \left(R^b_2\bar{\Psi}^D_1 P_R b + R^s_2\bar{\Psi}^D_1 P_R s + R^\mu_I\bar{\Psi}^E_I P_R \mu\right)\Phi \end{aligned}$$

$$L^s_1 = \Gamma^L_s\,, \qquad L^b_1 = \Gamma^L_b\,, \qquad R^s_2 = \Gamma^R_s\,, \qquad R^b_2 = \Gamma^R_b\,,$$

$$L^\mu_1 = \Gamma^L_\mu \cos\theta_L\,, \qquad L^\mu_2 = -\Gamma^L_\mu \sin\theta_L\,, \qquad R^\mu_1 = \Gamma^R_\mu \sin\theta_R\,, \qquad R^\mu_2 = \Gamma^R_\mu \cos\theta_R$$

4th Generation Model - WC

$$\boxed{\Gamma^L \equiv L_1^b L_1^{s*}\,, \qquad \Gamma^R \equiv R_2^b R_2^{s*}}$$

- $b \to s\mu\mu$

$$C_9^{\rm box} = -\mathcal{N}\frac{\Gamma^L}{32\pi\alpha_{\rm EM}m_\Phi^2}\left(|\Gamma_\mu^L|^2+|\Gamma_\mu^R|^2\right)F(x_D,x_E)$$

$$C_{10}^{\rm box} = \mathcal{N}\frac{\Gamma^L}{32\pi\alpha_{\rm EM}m_\Phi^2}\left(|\Gamma_\mu^L|^2-|\Gamma_\mu^R|^2\right)F(x_D,x_E)$$

$$C_{9(10)}^{\prime\rm box} = \pm\, C_{9(10)}^{\rm box}(L\leftrightarrow R)$$

- ΔM_S

$$C_1 = \frac{|\Gamma^L|^2}{128\pi^2 m_\Phi^2}F(x_D)\,, \quad C_5 = -\frac{\Gamma^L\Gamma^R}{32\pi^2 m_\Phi^2}F(x_D)\,, \quad \widetilde{C}_1 = \frac{|\Gamma^R|^2}{128\pi^2 m_\Phi^2}F(x_D)$$

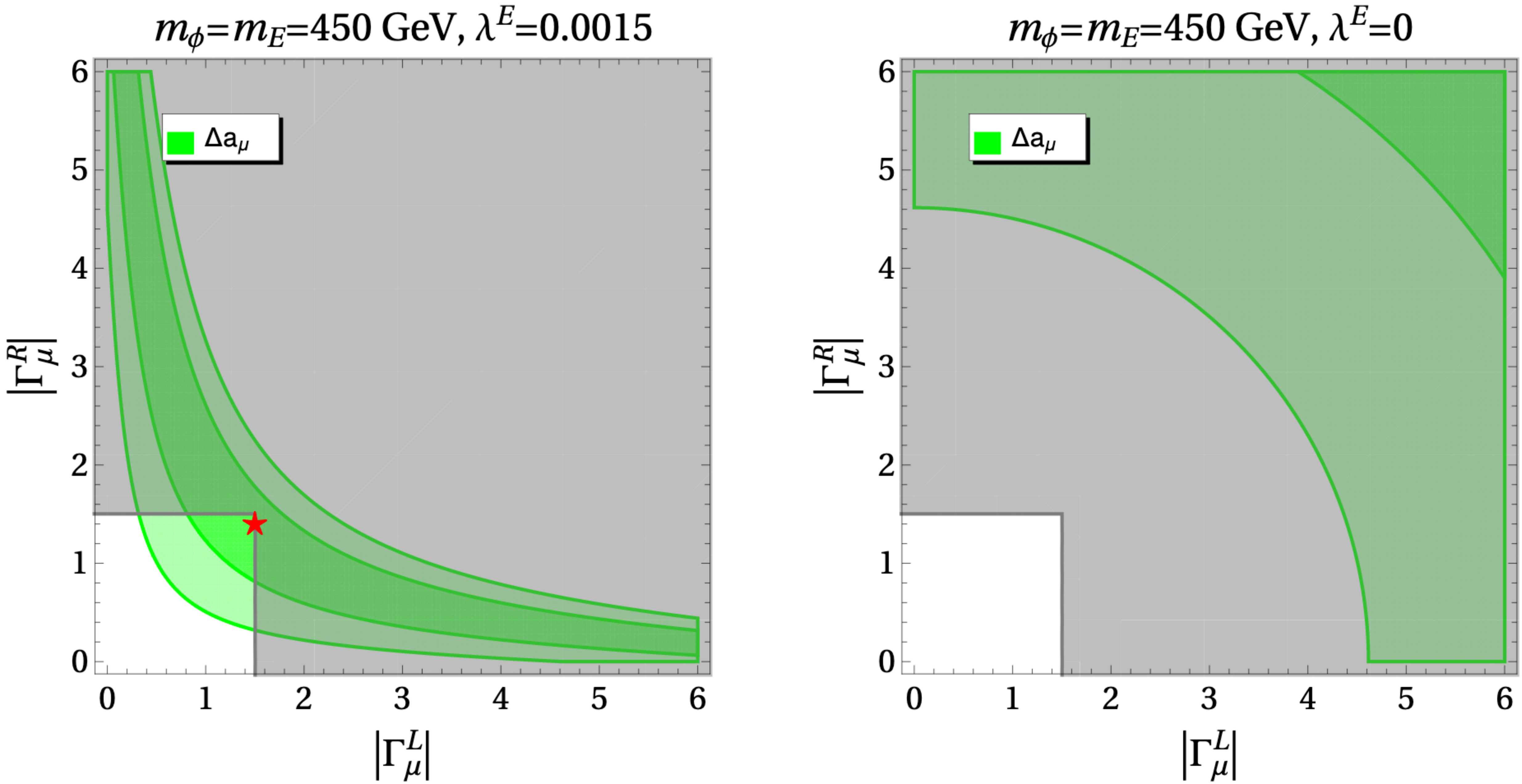
- g-2

$$\boxed{\lambda_R^E = -\lambda_L^E \equiv \lambda^E}$$

$$\Delta a_\mu = \frac{m_\mu^2}{8\pi^2 m_\Phi^2}\left[\left(|\Gamma_\mu^L|^2+|\Gamma_\mu^R|^2\right)F_7\left(x_E\right)+\frac{8}{\sqrt{2}}\frac{v\,\lambda^E}{m_\mu}\Gamma_\mu^L\Gamma_\mu^R G_7\left(x_E\right)\right]$$

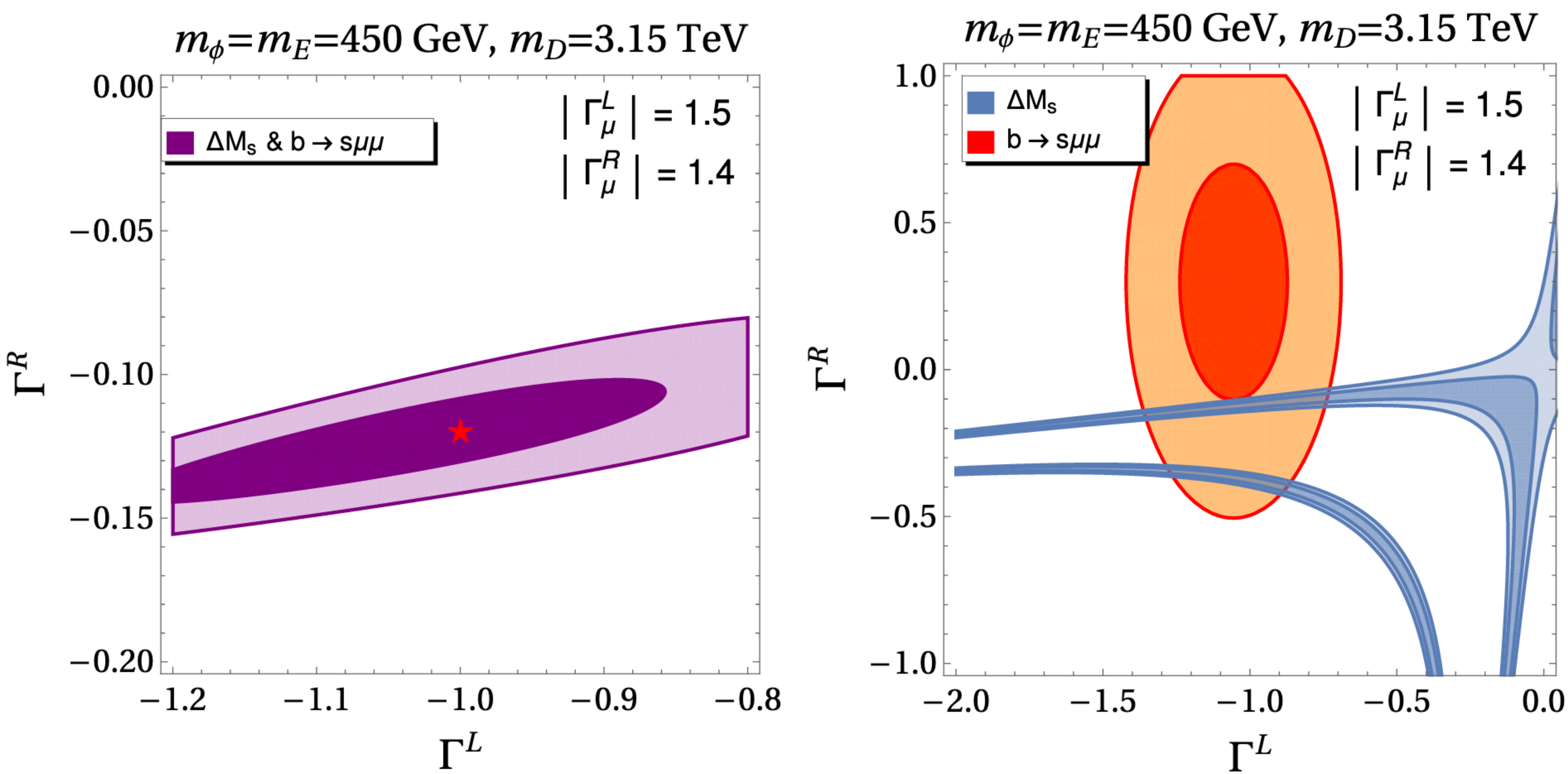
$$\boxed{|\Gamma_\mu^L| = 1.5\,, \qquad |\Gamma_\mu^R| = 1.4\,, \qquad \lambda^E = 0.0015\,, \qquad \Gamma^L = -1.0\,, \qquad \Gamma^R = -0.12}$$

Fit g-2



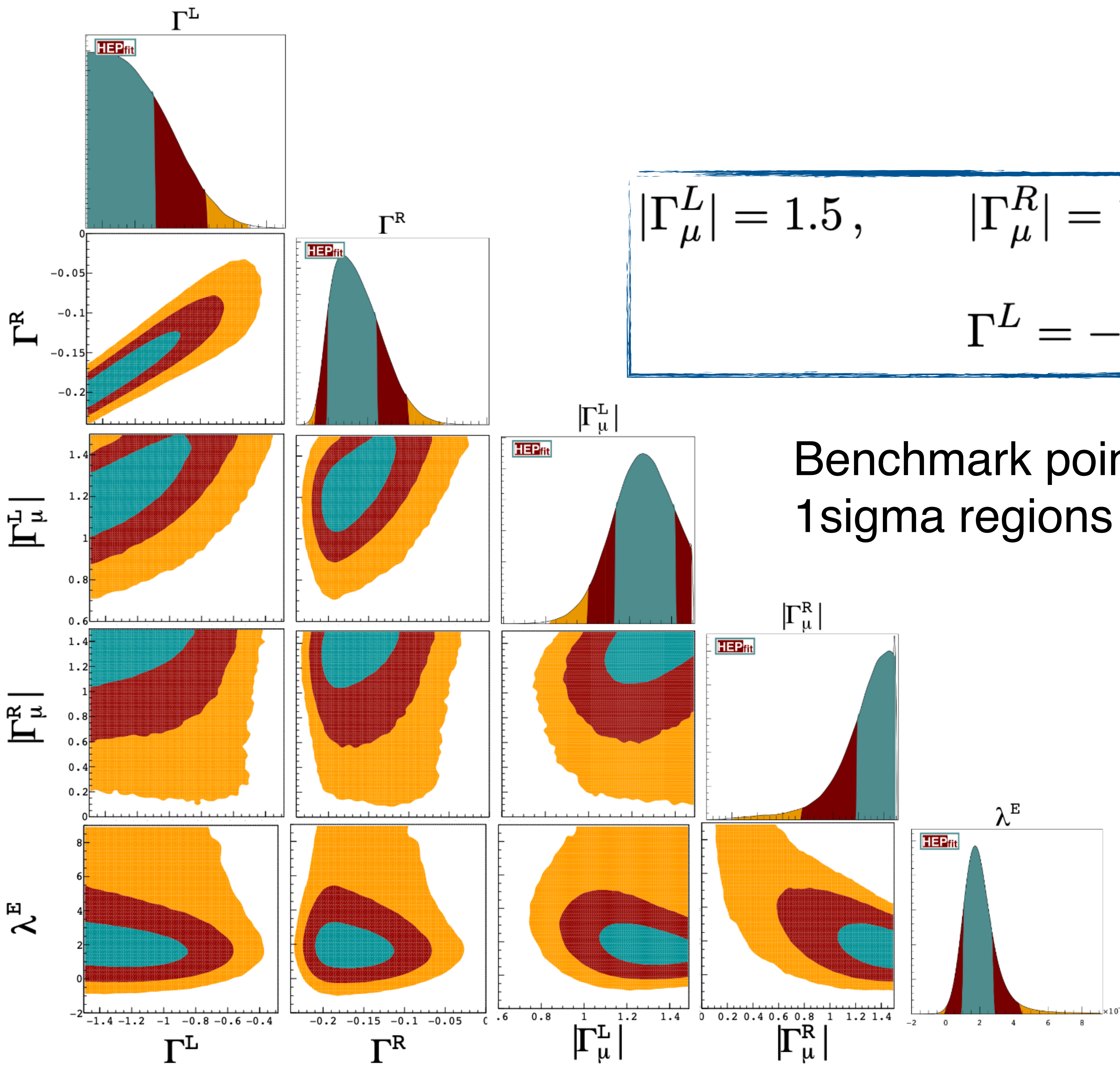
Right-handed coupling and SU(2) breaking both fundamental!

Fit B decays



Right-handed coupling fundamental!

Global Fit



$$|\Gamma^L_\mu| = 1.5\,, \qquad |\Gamma^R_\mu| = 1.4\,, \qquad \lambda^E = 0.0015$$

$$\Gamma^L = -1.0\,, \qquad \Gamma^R = -0.12$$

Benchmark point, compatible with all 1sigma regions of combined pdf

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

$$\tilde{h}_\lambda(q^2) \sim \epsilon_{\lambda,\mu} \int d^4x\, e^{iqx} \langle \not{V}(P)|T\{J^{\mu,e.m.}_{had}(x)\mathcal{H}^{eff}_{had}(0)\}|\bar{B}\rangle$$

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.

Conclusions

- We have provided analytical formulae for studying B anomalies, BBbar mixing and g-2 in the context of general loop models

- We have investigated the additional effects provided by right-handed couplings and additional SU(2) breaking effects

- We have investigated the phenomenology in a specific model, i.e. 4th generations of vector-like fermions + neutral scalar, and addressed all the above anomalies with viable masses and O(1) couplings

- The neutral scalar is a viable (stable) DM candidate, which however require a further detailed analysis still to be addressed