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# Towards establishing New Physics in $B^0 \to K^* ll$ decays

A. Mauri

based on arXiv:1805.06401 (Mauri, Serra, Silva Coutinho)
arXiv:1805.06378 (Chrzaszcz, Mauri, Serra, Silva Coutinho, van Dyk)

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# $b \to sll$ anomalies: is this New Physics…?

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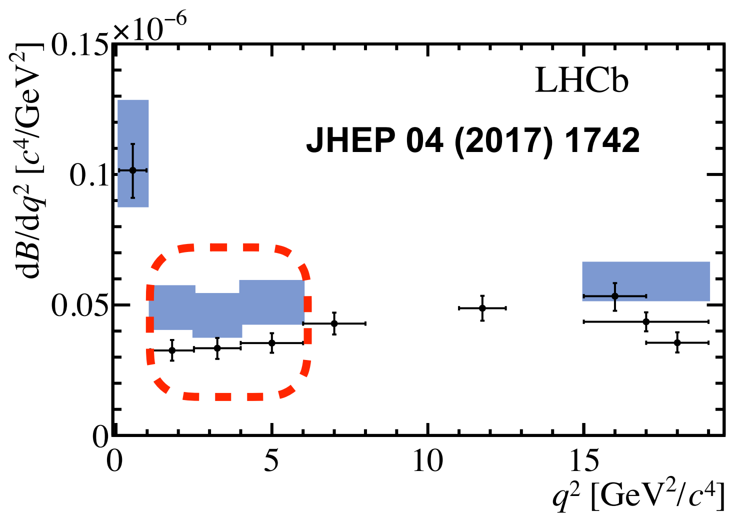
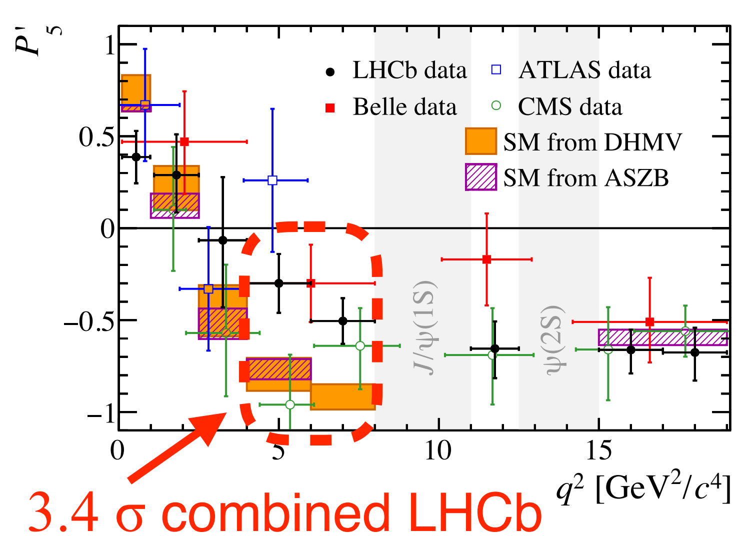
## $B^0 \to K^*\mu\mu$

- Form factor uncertainties
- Theory discussion on the size of charm-loop effects

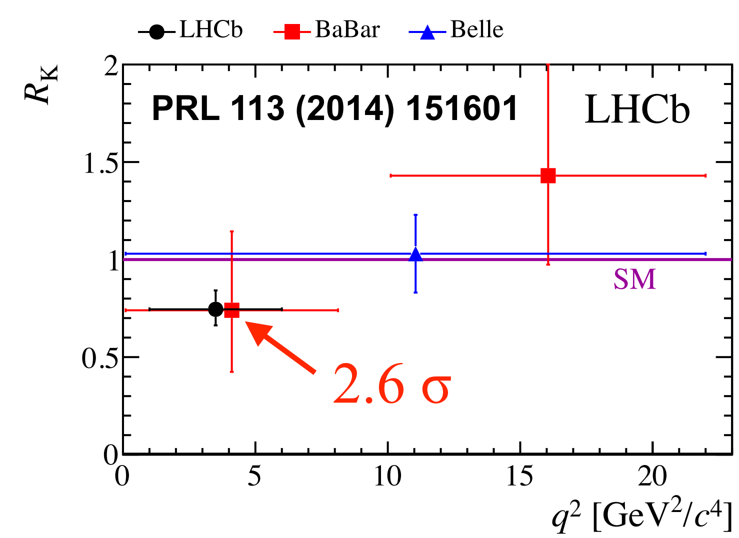


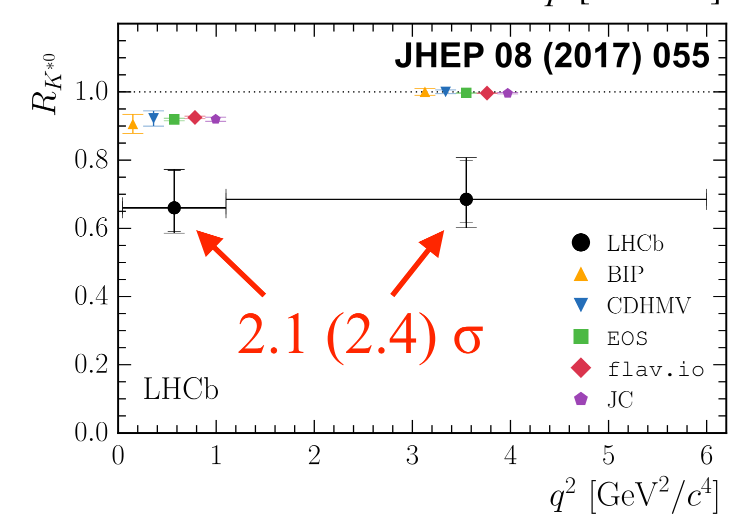




## LFU test

$$\frac{b \to s\mu\mu}{b \to see}$$

- Clean observables
  - lower statistics due to worse electron efficiency in LHCb

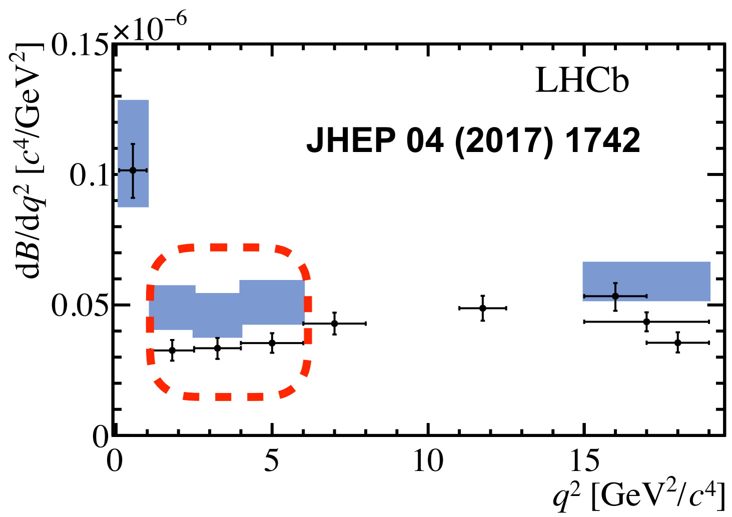


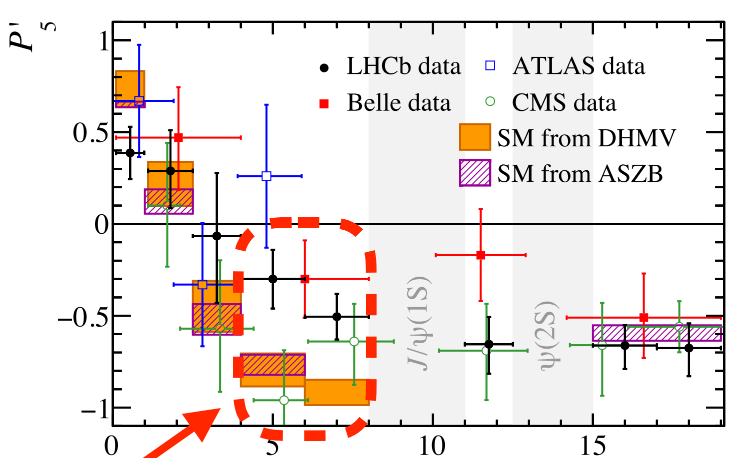



# $b \to s\ell\ell$ anomalies: is this New Physics…?

## $B^0 \to K^*\mu\mu$

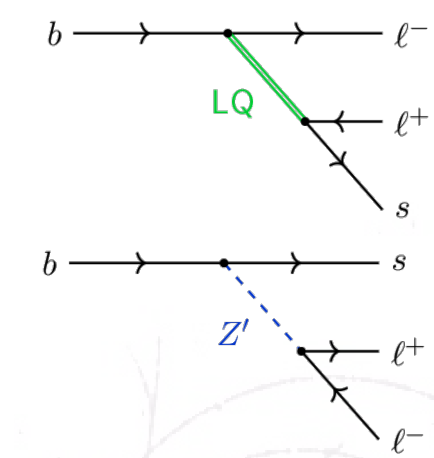
- Form factor uncertainties
- Theory controversy on the size of charm-loop effects




3.4 σ combined LHCb

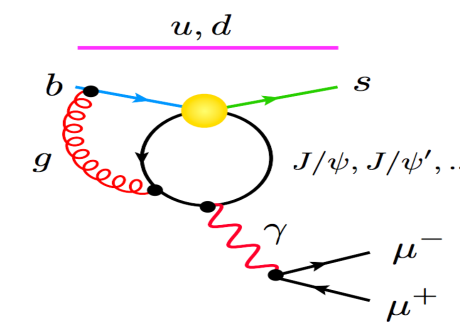
New Physics




can affect both $C_9$ and $C_{10}$

or

"charm loop"




pollutes only $C_9$ (vector structure)

**Part I**: based on arxiv:1805.06378

- What are the prospects for an unbinned amplitude fit to $B^0 \to K^*\mu\mu$ decays?
  - analytical parametrization of the charm-loop [arxiv:1707.07305]
- Can we access quantitatively the model dependency (systematic) associated to the charm-loop?

# $b \to sll$ anomalies: is this New Physics…?

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| $B^0 \to K^*\mu\mu$ | LFU test |
| --- | --- |
| ✦ Form factor uncertainties<br>✦ Theory controversy on the size of charm-loop effects | ✦ Clean observables<br>❖ lower statistics due to worse electron efficiency in LHCb |

**Part II**: based on arxiv:1805.06401

- Simultaneous amplitude fit to $B^0 \to K^*\mu\mu$ and $B^0 \to K^*ee$ decays?
  - uncertainties on the charm-loop cancel out
- Great model independency

# Amplitude fit: controlling the charm loop

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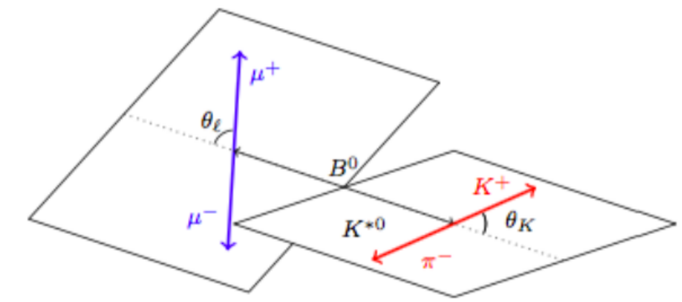
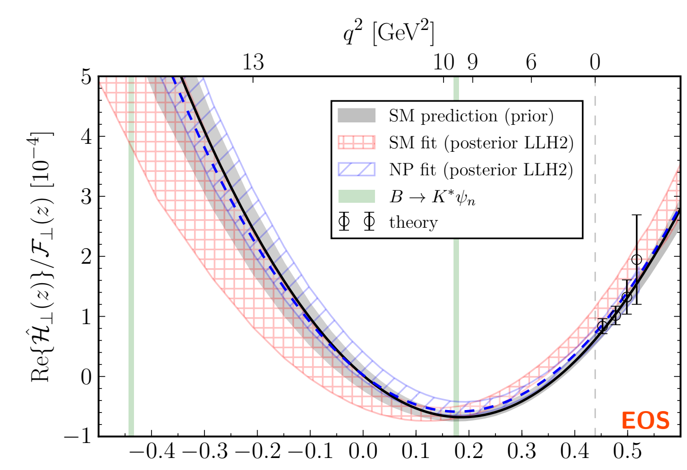
- ✳ Extended unbinned amplitude fit: $\frac{1}{\Gamma}\frac{d^4\Gamma}{dq^2\, d\Omega}$




- ✳ Parametrization introduced by Bobeth et al. [arxiv:1707.07305]

$$\mathcal{A}_\lambda^{L,R} = N_\lambda \left\{ (C_9 \mp C_{10})\mathcal{F}_\lambda(q^2) + \frac{2m_b M_B}{q^2}\left[ C_7 \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b}\mathcal{H}_\lambda(q^2)\right]\right\}$$

- ✦ Wilson coefficients
- ✦ Form factors
- ✦ Non-local hadronic matrix elements ("charm loop")




mapping: $q^2 \longrightarrow z(q^2)$

$$\mathcal{H}_\lambda(z) = \frac{1 - z z^*_{J/\psi}}{z - z_{J/\psi}}\,\frac{1 - z z^*_{\psi(2S)}}{z - z_{\psi(2S)}}\,\hat{\mathcal{H}}_\lambda(z)$$

extract the poles

polynomial expansion →

$$\hat{\mathcal{H}}_\lambda(z) = \left[\sum_k \alpha_k^{(\lambda)} z^k\right]\mathcal{F}_\lambda(z)$$

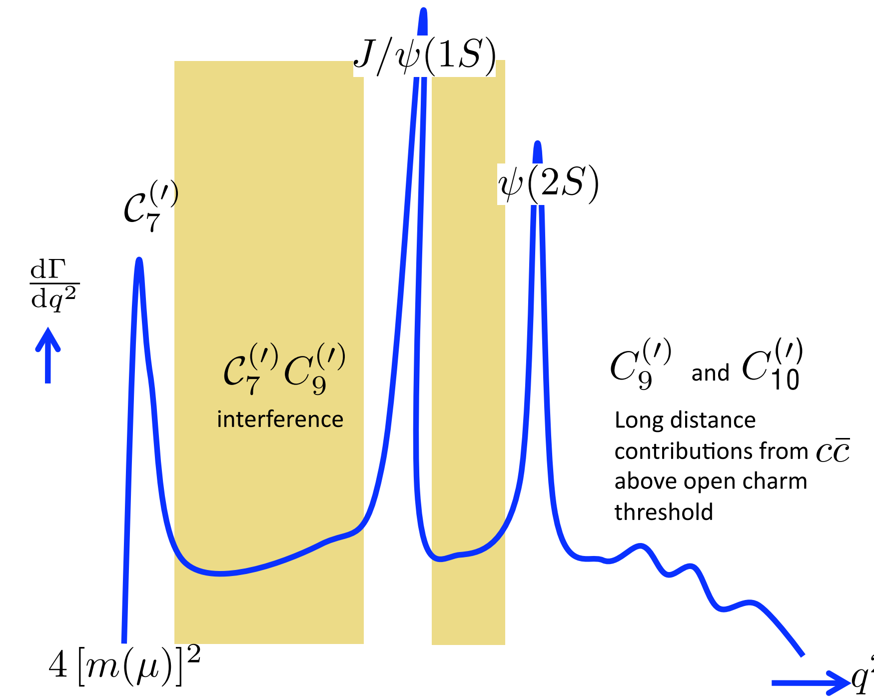
- ✳ analytic within $|z| = 1$
- ✳ **truncation at order $z^k$**
  - ➡ which order of $z$ describes well nature is a-priori unknow

**Chapter 1**: **Amplitude fit to $B \to K^*\mu\mu$ decays** [based on arxiv:1805.06378]

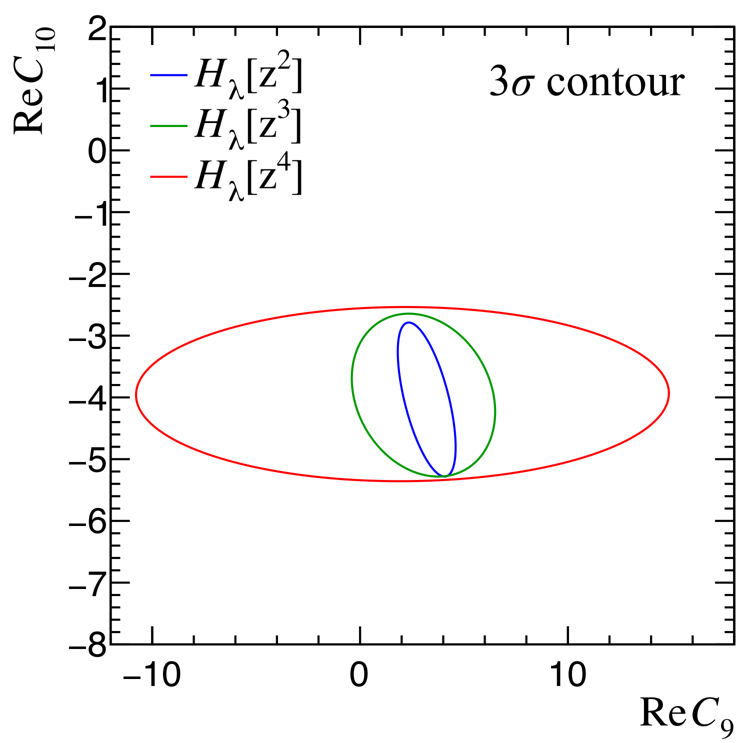
- What are the prospects for disentangling the charm loop from possible New Physics effects?
- Can we access quantitatively the model dependency (systematic) associated to the charm loop?

# Amplitude fit to $B \to K^*\mu\mu$ decays

- signal yield fitted to $\mathcal{BR}$
- full set of parameters floating:
  - CKM, FF $\longrightarrow$ multi-Gauss. constraints
  - H $\longrightarrow$ free floating
- sensitivity based in signal-only toys
  - no experimental effects (*e.g.* background, s-wave, acceptance, efficiency)




[1.1, 9.0] & [10.0, 13.0] GeV$^2$




**Scanning the order of the $z$-expansion:**

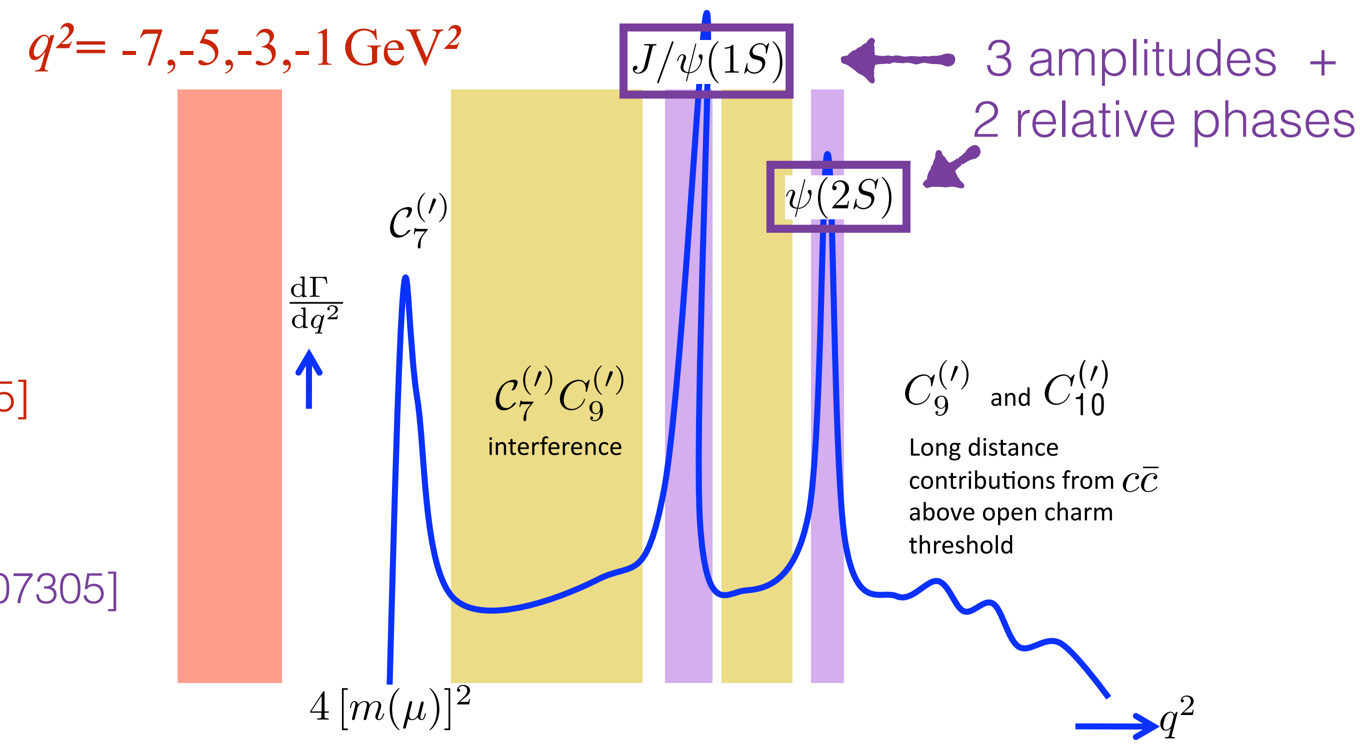
- $C_9$: Strong dependence on the cut-off ✗
- $C_{10}$: unaffected! ✓

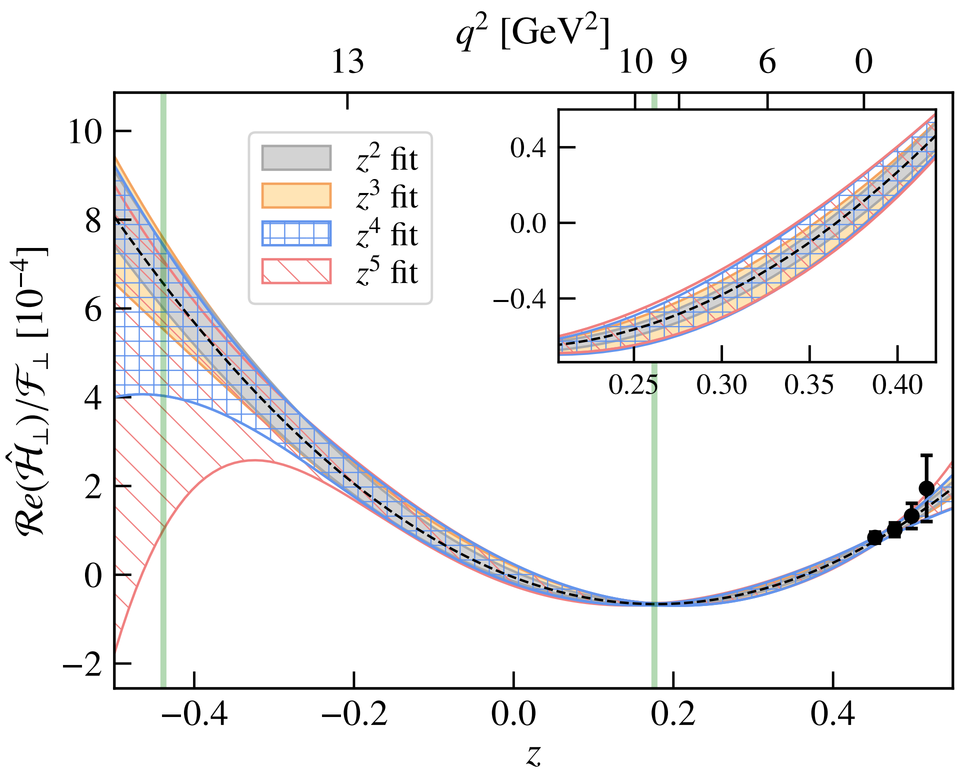
✳ Direct fits to with different approaches have been proposed in JHEP 11 (2017) 176 and EPJ C78 (2018) n.6 453

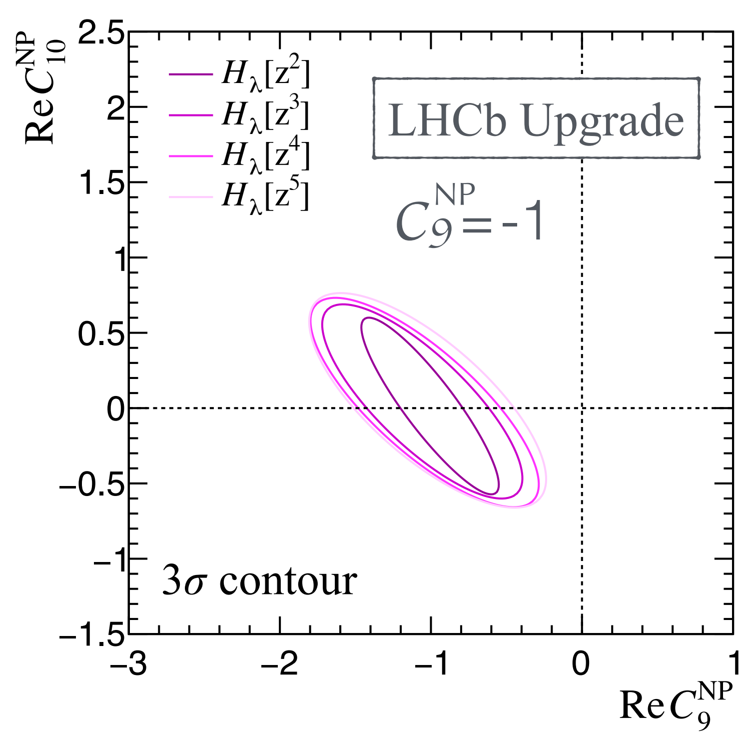
# Combined fit to $B \to K^*\mu\mu$ decays and theory

Combined fit to:

- semi-muonic $B \to K^*\mu\mu$ decays
- theory points at negative $q^2$
  - reliable theory predictions [arxiv:1707.07305]
- hadronic $B \to K^*\{J/\psi,\ \psi_{(2S)}\}$ decays
  - sets of 5 pseudo-observables [arxiv:1707.07305]



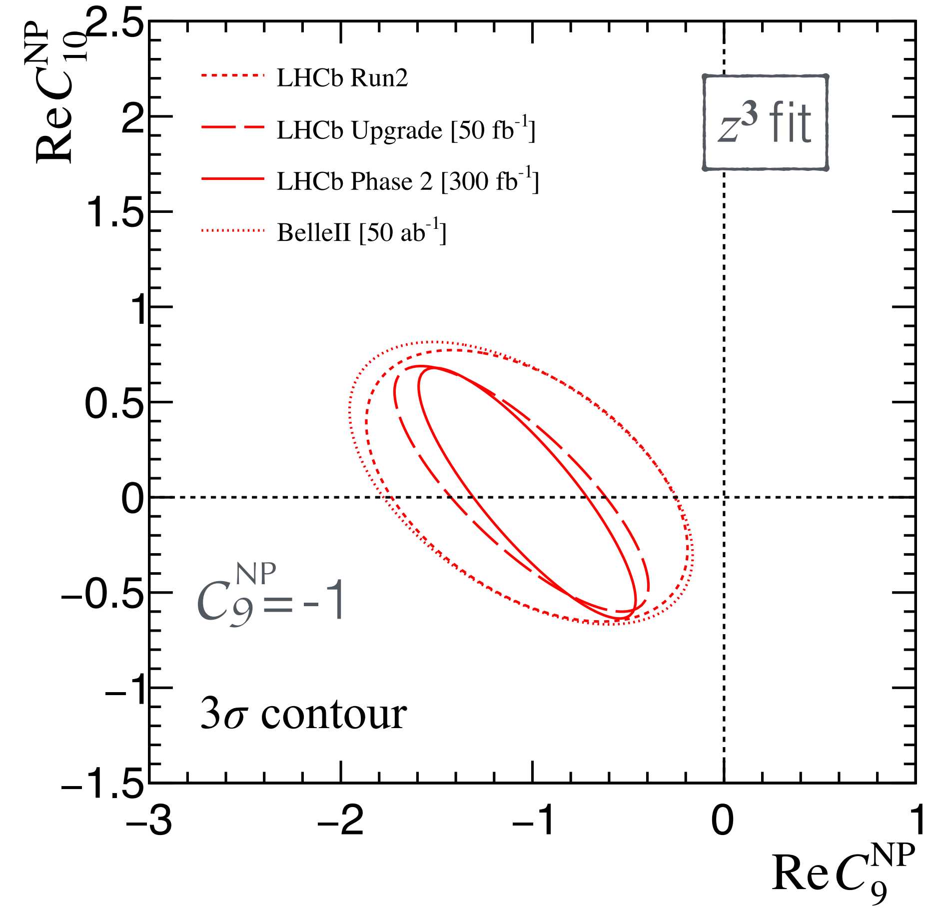




- Uncertainty only slightly increases after $z^3$ fits
- We can access in a quantitative way this model-dependency

# Discovery potential of NP in $C_{10}$

- Measurement of $C_{10}$ independent on the lack of knowledge on the charm-loop
- Precision saturates due to the form factors uncertainty after LHCb Run II
  - we have been very conservative doubling the FF uncertainty of JHEP 08, 098 (2016)
- Possible $3\sigma$ observation after LHCb Run II (depending on the NP scenario…)

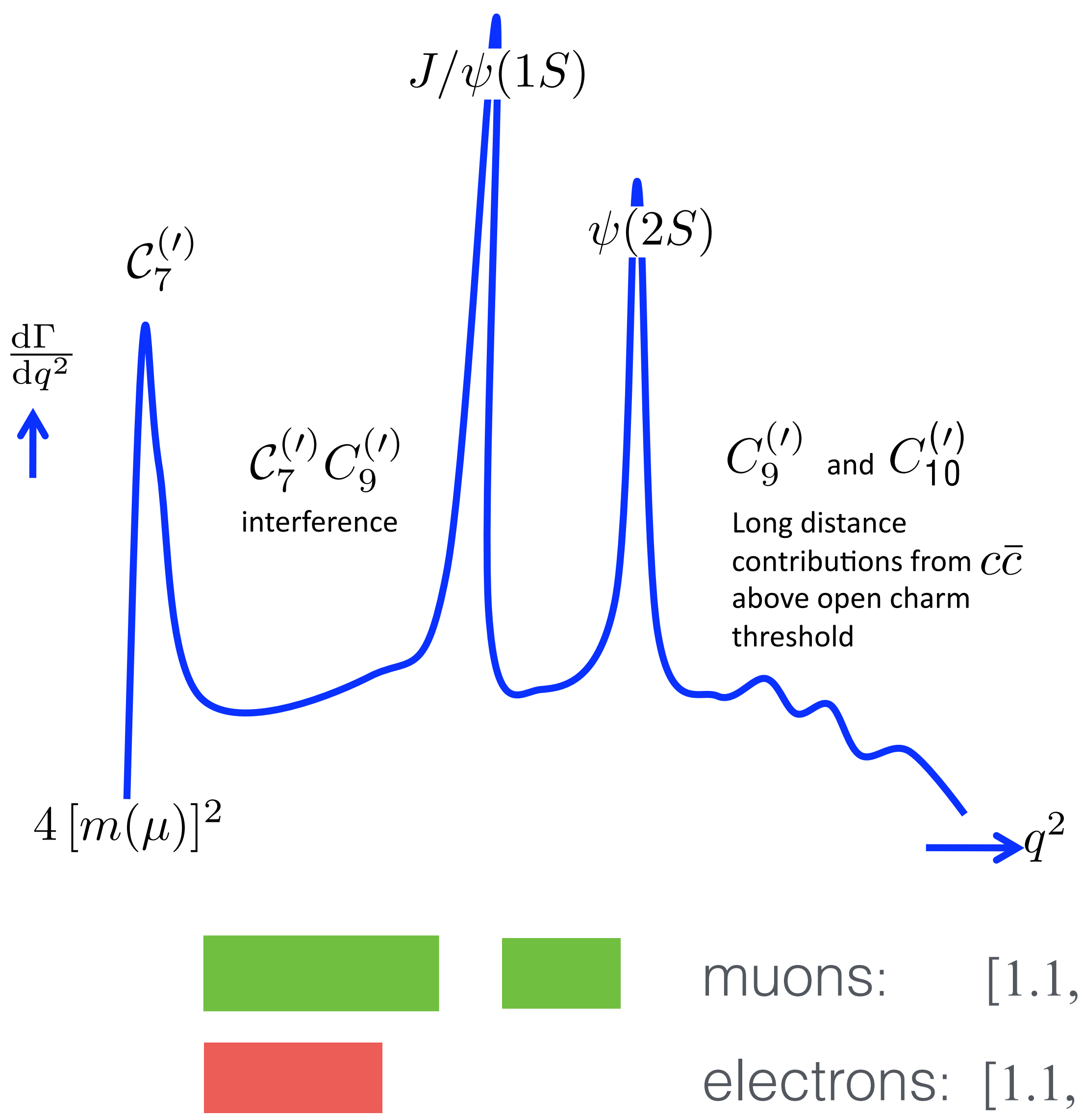
Sensitivity for different statistical scenarios



**<u>Chapter 2</u>: Test of LFU in $B \to K^*ll$ decays** [based on arxiv:1805.06401]

- Simultaneous amplitude fit to $B^0 \to K^*\mu\mu$ and $B^0 \to K^*ee$ decays?

# Simultaneous fit of $B \to K^*\mu\mu$ and $B \to K^*ee$




muons: $[1.1, 8.0]$ & $[11.0, 12.5]$ GeV$^2$

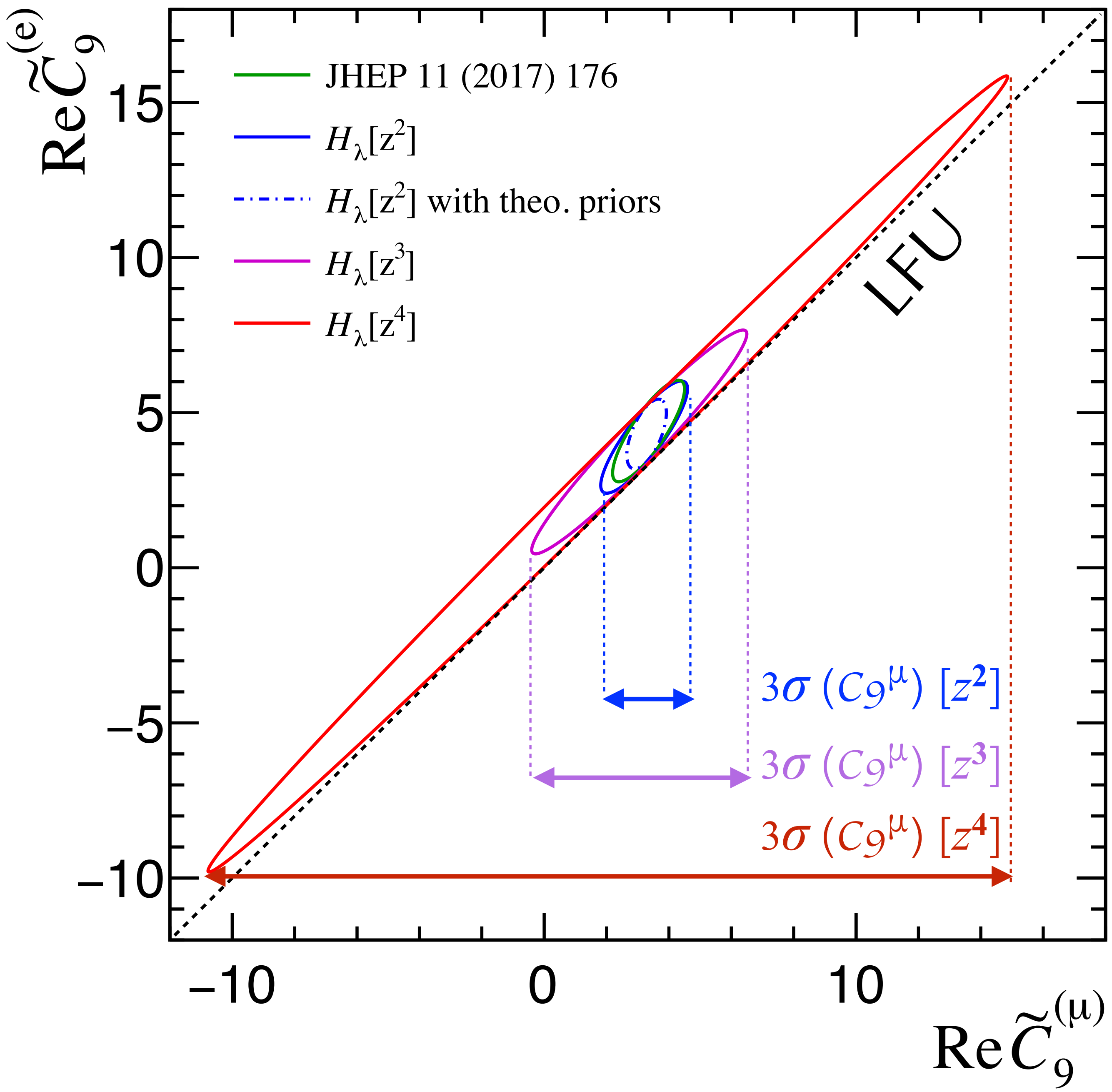
electrons: $[1.1, 7.0]$ GeV$^2$

<u>Simultaneous unbinned amplitude fit:</u>

- All nuisance parameters are shared between muons and electrons
  - CKM, local (FF) and non-local (charm-loop) hadronic
- Only $C_9^{(\mu,e)}$ and $C_{10}^{(\mu,e)}$ are treated differently between muons and electrons
- Extended maximum likelihood fit
  → include $\mathcal{R}_{K^*}$ information

# The correlation that enables LFU test

$C9_{\mu}^{NP} = C9_{\mu}^{SM}$ -1




- $C9^{(\ell)}$ strongly model-dependent
- **Model-independent** determination of the **difference** between electron and muon **WCs**

$$\Delta C_i = C_i^{(\mu)} - C_i^{(e)}$$

- Insensitive to the parametrization of the charm loop
- Significance wrt LFU hypothesis is unbiased

# $\Delta C_9$ - $\Delta C_{10}$ LFU test of SM

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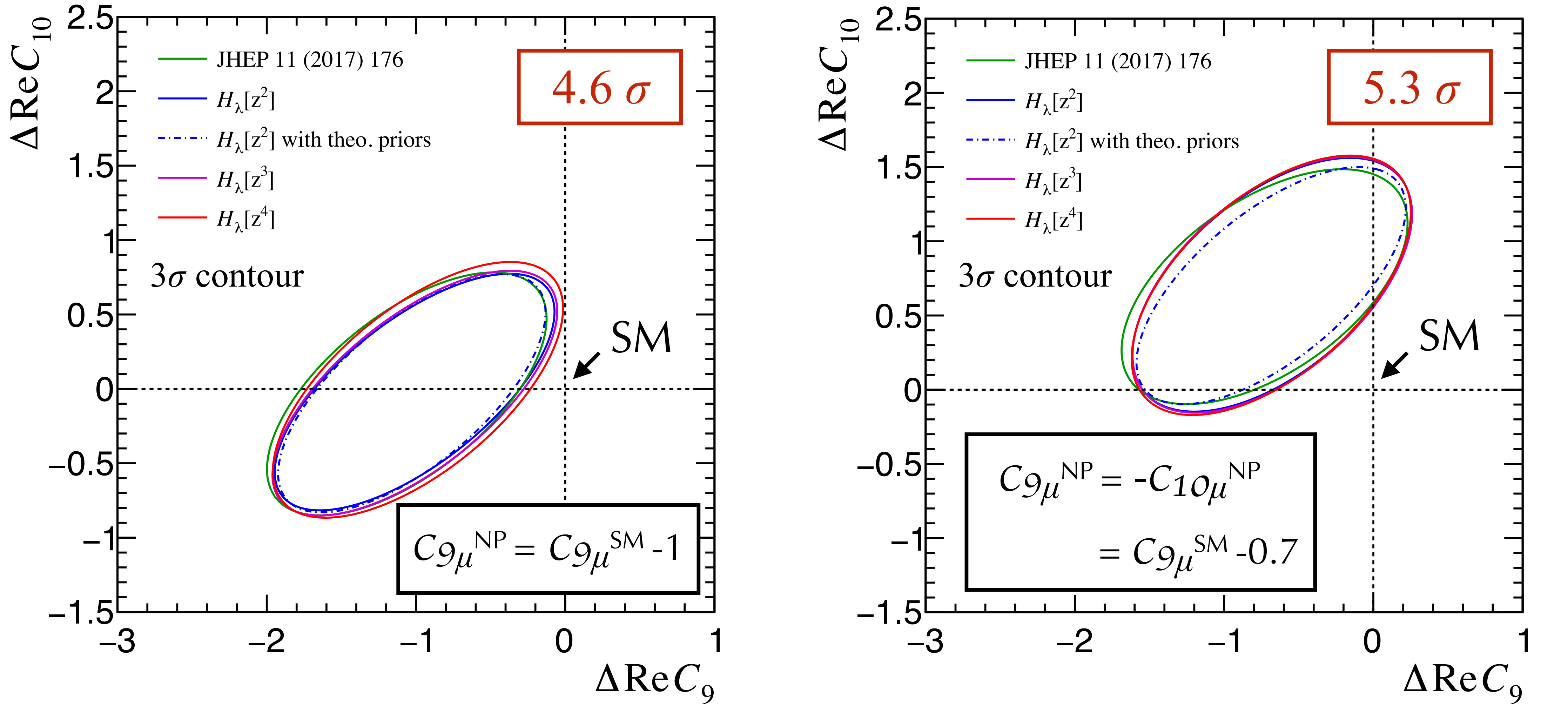
- Sensitivity for the expected statistics at LHCb Run II




Determination of $\Delta C_9$ and $\Delta C_{10}$ is model-independent

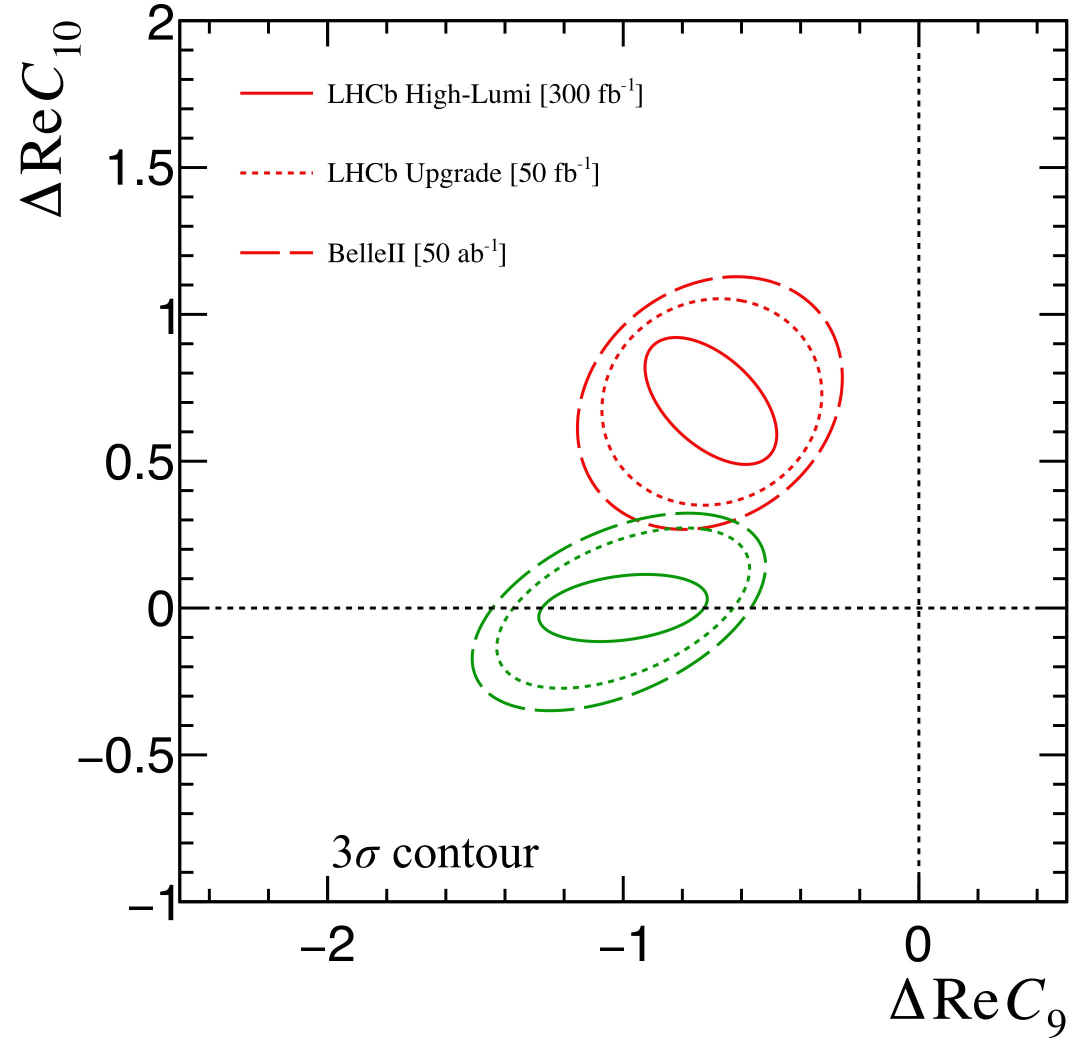
Early observation of LFU violation can be seen with LHCb Run II dataset

Note: very conservative NP scenarios → $\mathcal{R}_{K^*} \sim 0.85\ (0.75)$ [$\mathcal{R}_{K^*}^{(\text{LHCb Run I})} = 0.69 \pm 0.12$]

# Distinguishing NP models

$\Delta C_i$ parameters are found to be independent on both local (form-factor) and non-local (charm loop) hadronic effects

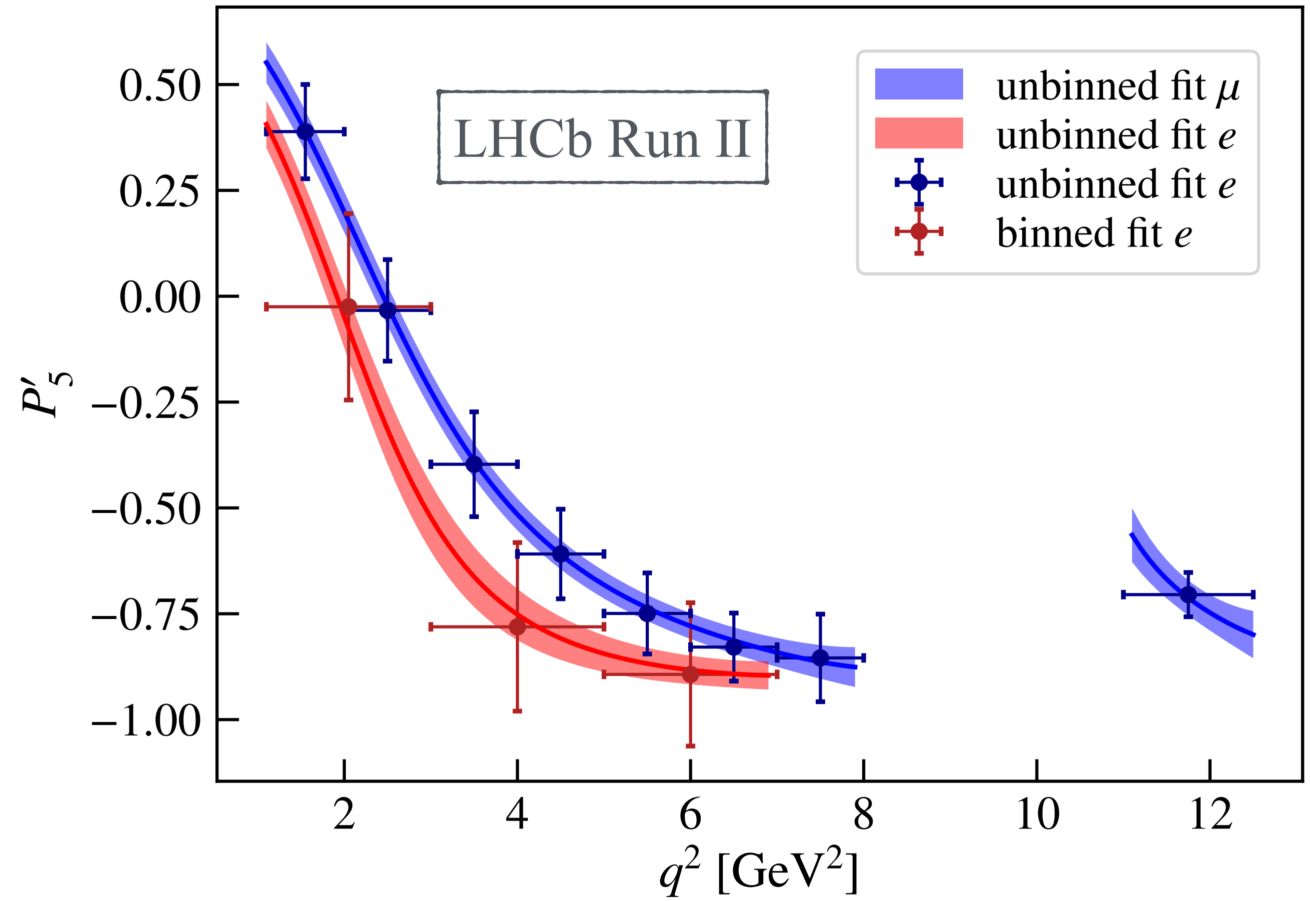
This method allows to separate the nature of NP directly from data



# Corollary measurements

From the fit results we can obtain the classic angular observables

- and compare to the (folded) binned fit




Note: an amplitude fit to the electron channel is only possible thanks to the fact that the determination of all the nuisance parameters is completely dominated by the large muon sample

# Conclusion chapter 1

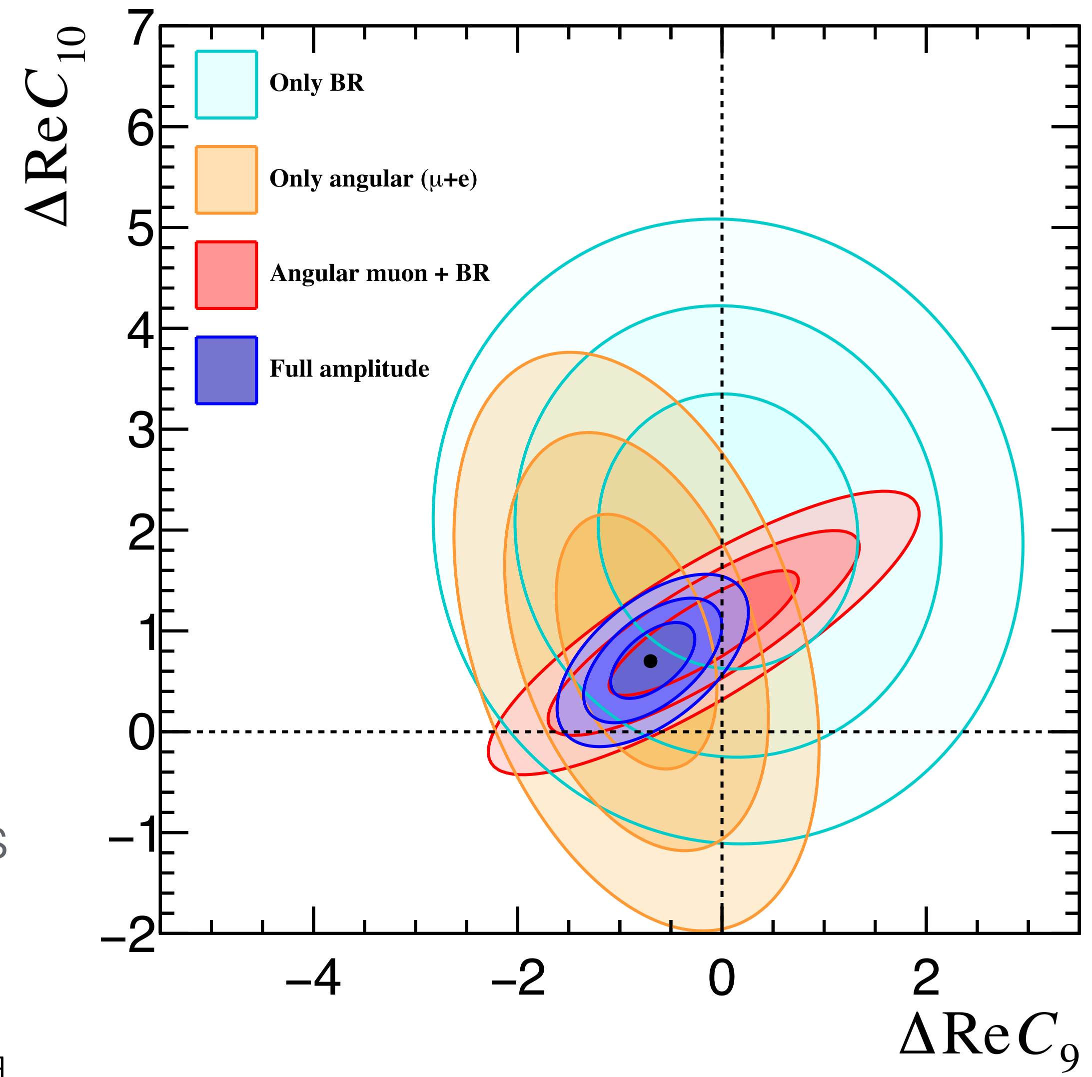
- A combined fit to $B \to K^*\mu\mu$ decays, theory and hadronic decays strongly reduce the model-bias on $C_9$ introduced by the truncation of the $z$-expansion
  - studying the behaviour of the series expansion at different order can allow to access in a quantitative way this model-dependency

- $C_{10}$ is independent on the lack of knowledge on the charm-loop
  - promising sensitivity for LHCb Run II

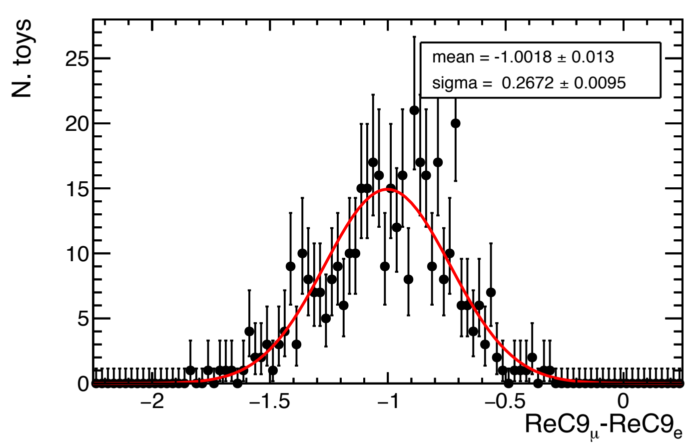
# Conclusion chapter 2

The proposed new parameters $\Delta C_i$ combine all the information from $B \to K^* ll$ decays

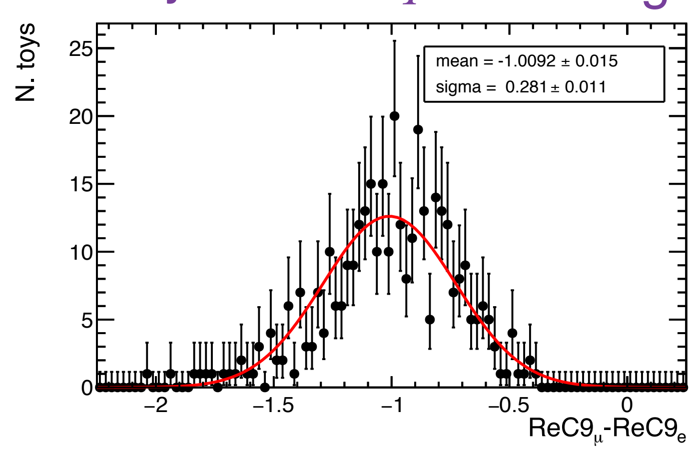
- independent from both local (form-factors) and non-local (charm-loop) hadronic effects
  - all nuisance parameters shared between the two modes
- many advantages
  - combine $\mathcal{R}_{K^*}$ and angular analysis sensitivity
  - robust against theory and experimental effects




Perfect $q^2$ resolution



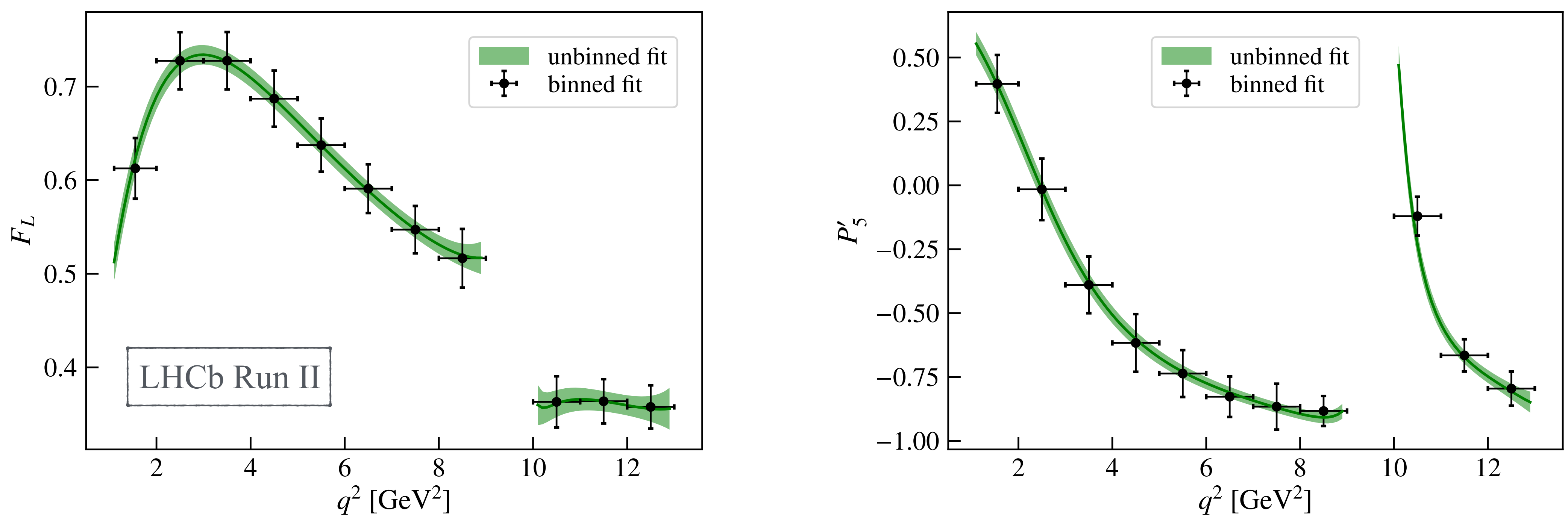

Asymmetric $q^2$ smearing



Thank you!

# Angular observables

We derive a-posteriori the standard angular observables $S_i$, $P'_i$



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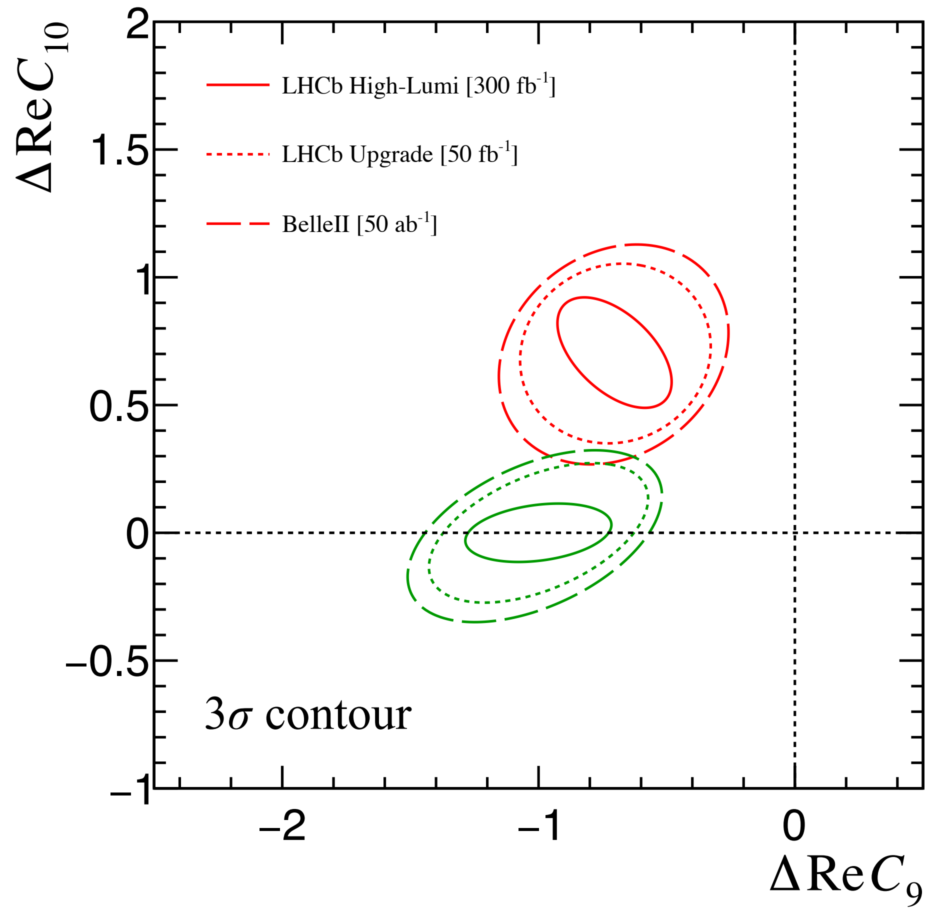
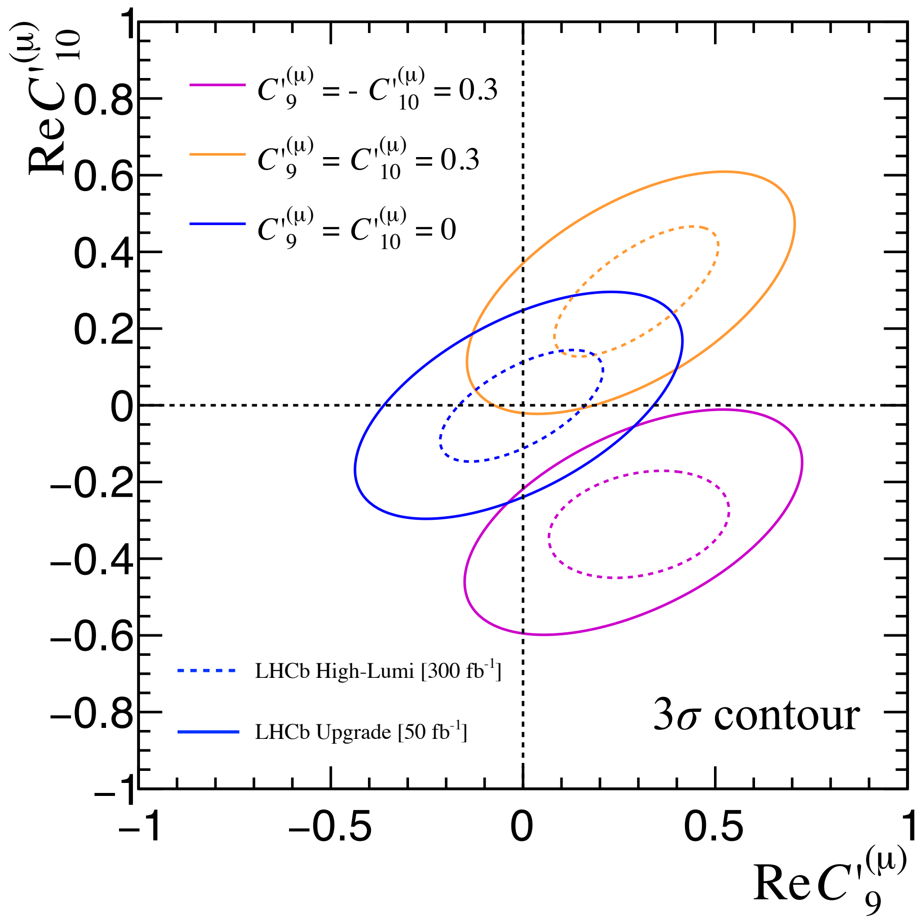


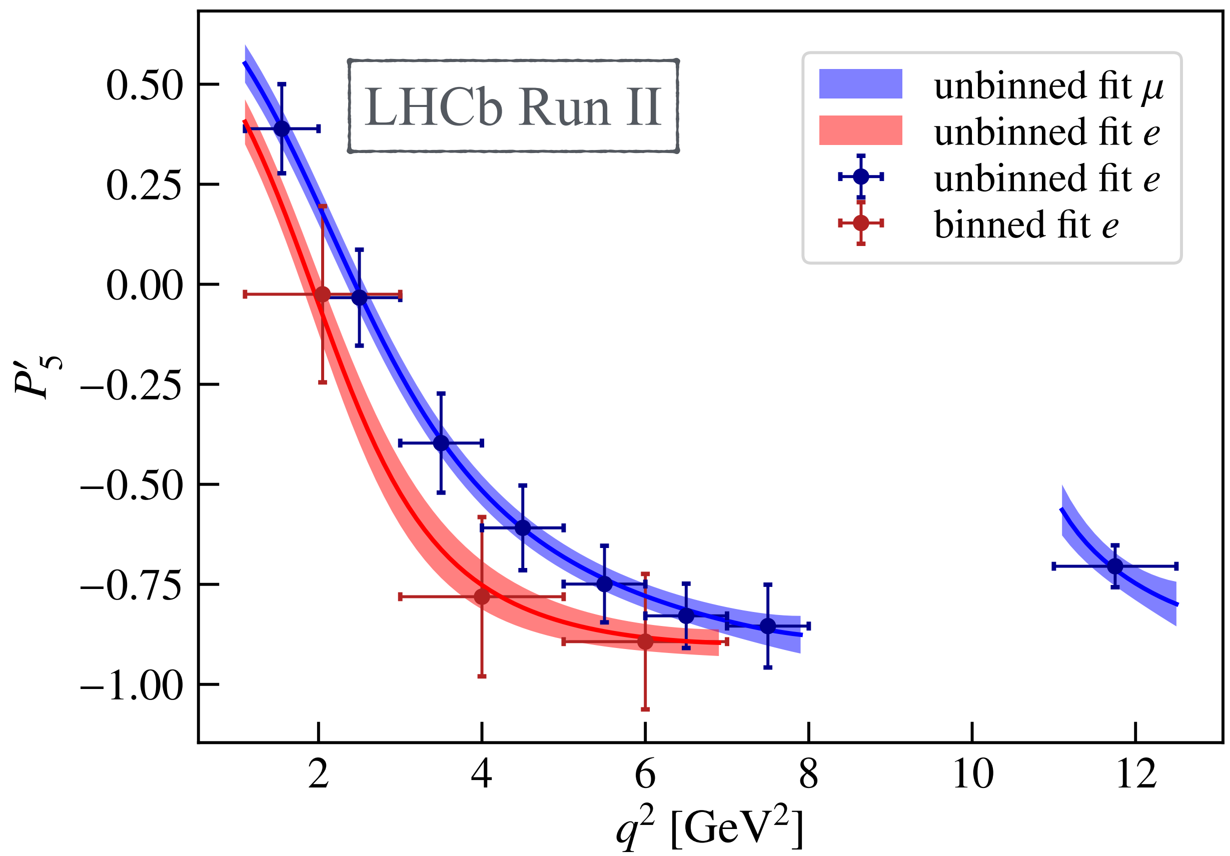



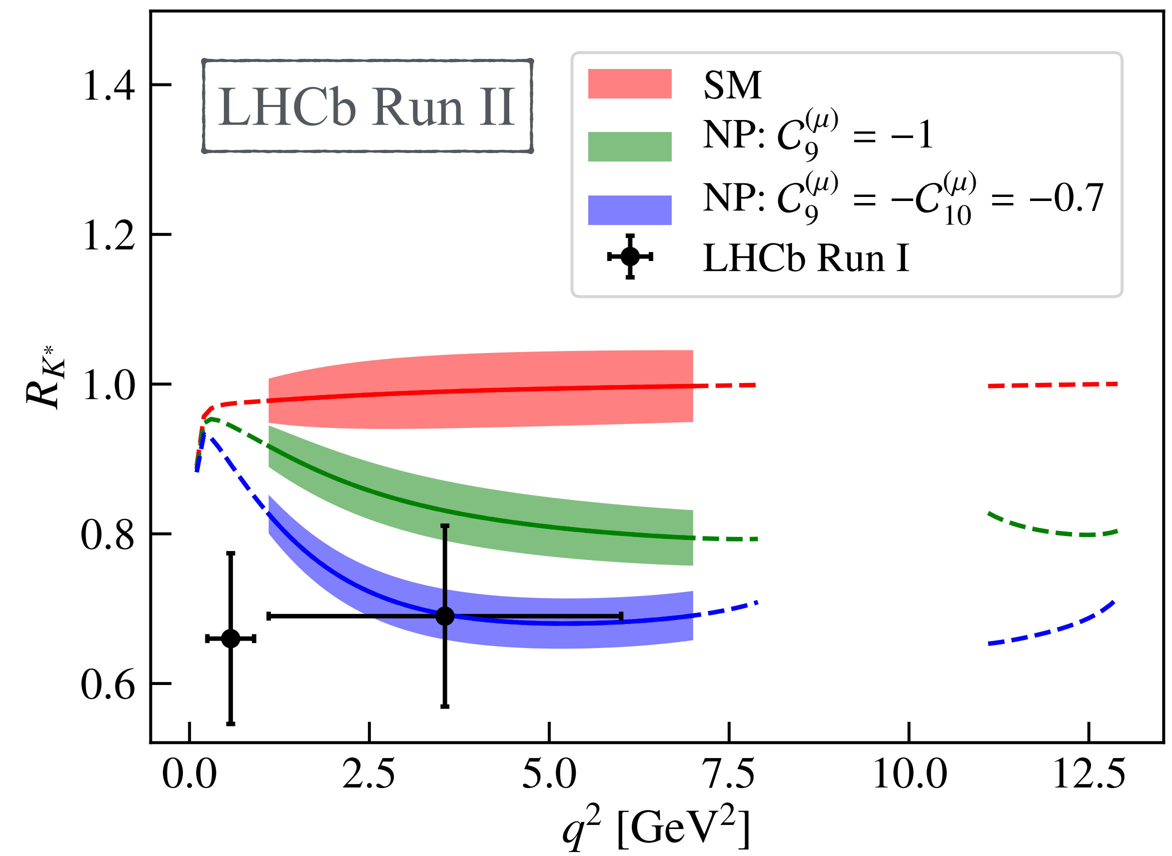

This method allows to separate the nature of NP directly from data

# Corollary measurements

From the fit results we can obtain the classic angular observables for the two channels

- ✦ and compare to the (folded) binned fit
- ✦ and compare for different NP models

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