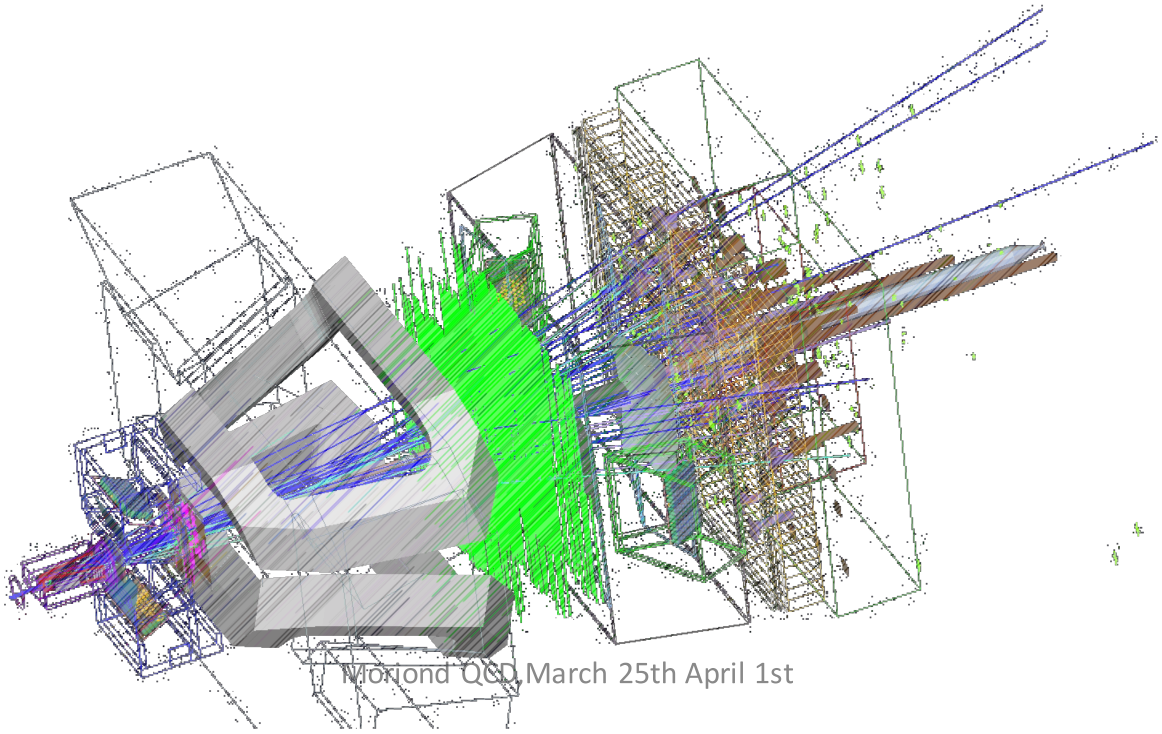
Lepton Flavour Universality tests with B decays at LHCb

Marie-Hélène Schune
Laboratoire de l'Accélérateur Linéaire, Orsay

On behalf of LHCb Collaboration

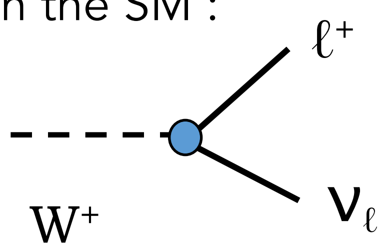


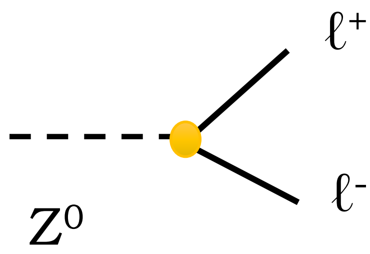
See also the talk of Marc-Olivier Bettler

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Lepton Flavour Universality tests with B decays

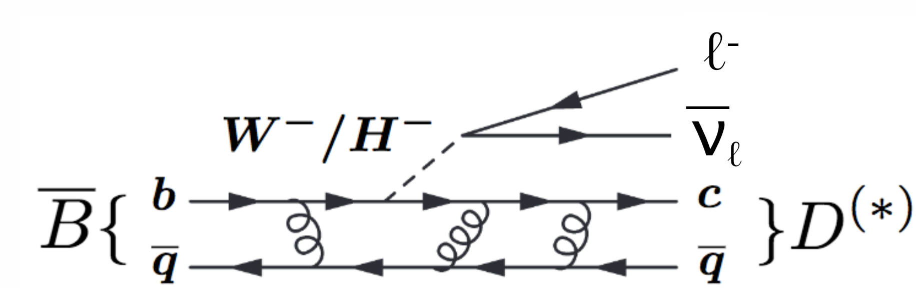
In the SM :

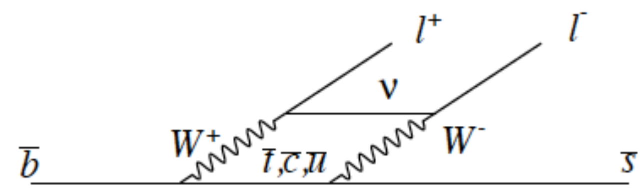


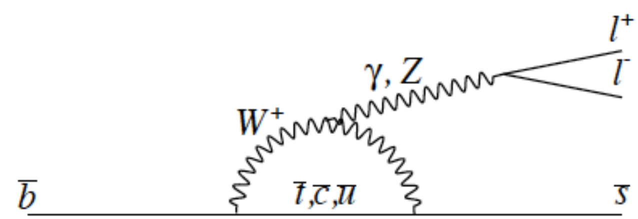


ℓ=e, μ or τ

… → R(D*) and R(K)







$$R(D^*) = \frac{B \rightarrow D^* \tau \nu}{B \rightarrow D^* \mu \nu}$$

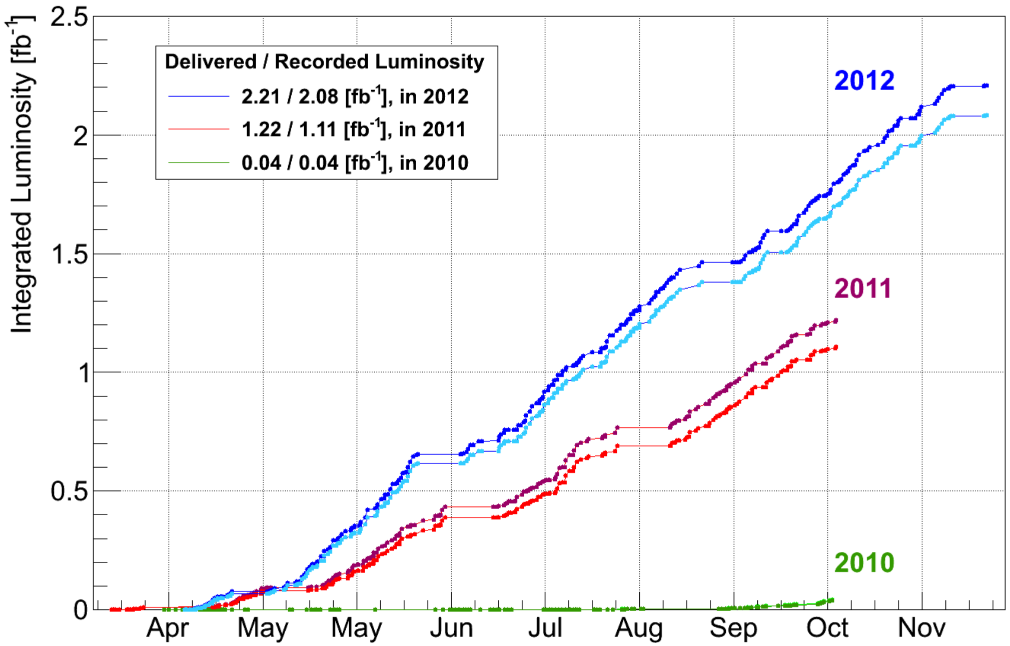
$$R(K) = \frac{B \rightarrow K \mu \mu}{B \rightarrow K e e}$$

R(D*)=0.252 +- 0.003

R=1 (at 10^{-3}) in the SM

Phys.Rev.D85(2012) 094025

Practical considerations



Extremely challenging analyses :

R(D*)

Neutrinos in the final state
Trigger
background levels

R(K$^{(*)}$)

Rare decays
Differences between μ and e
Bremsstrahlung
Reconstruction
Trigger

Analyses presented today based on the Run 1 dataset

R(D*)

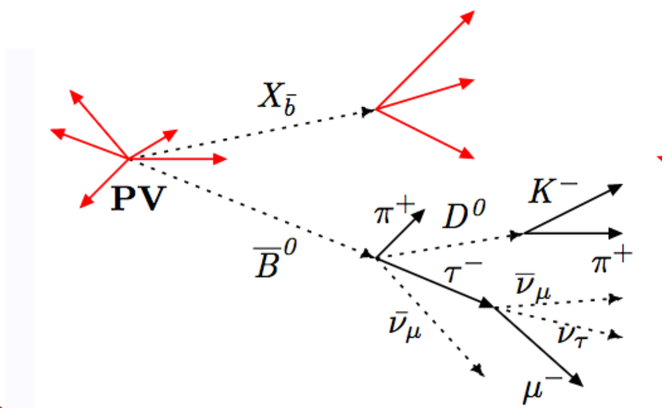
$$R(D^\star) \equiv \frac{\mathcal{B}(B \to D^\star \tau \nu)}{\mathcal{B}(B \to D^\star \mu \nu)}$$

BR(τ→μνν) ~ 17 %

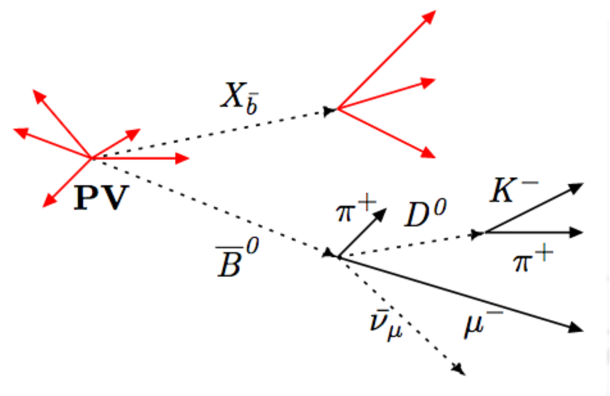
Identical final states

No sharp peak
Background from partially reconstructed B decay

Signal



Normalisation



Known B flight direction, approximate the B momentum $(\gamma\beta_z)_{B^0} \equiv (\gamma\beta_z)_{D^\star\mu}$

Large statistics :

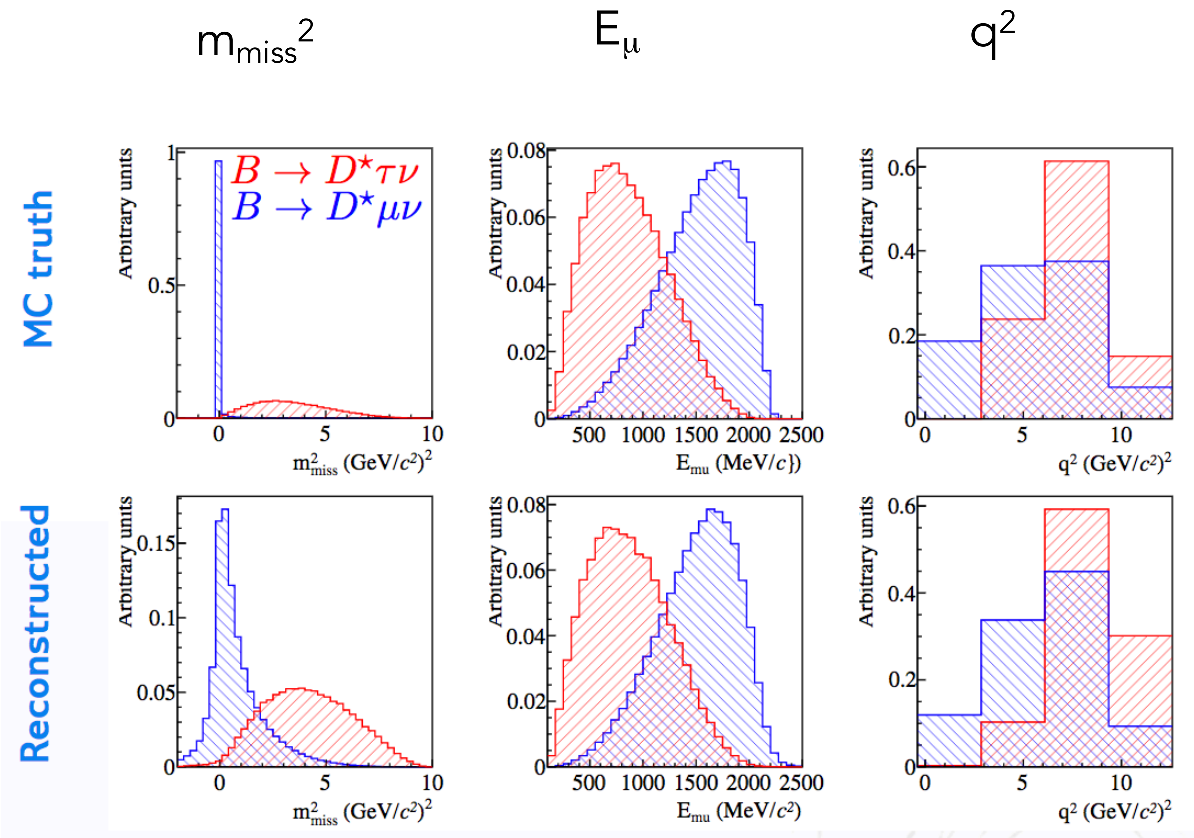
$$N(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu) = 363000$$

$$\frac{N(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{N(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)} = (4.54 \pm 0.46) \times 10^{-2}$$

R(D*)

3 discriminating variables (B rest frame)

- $q^2 = |p_B - p_D|^2,$
- $m^2_{\rm miss} = |p_B - p_D - p_\mu|^2$
- E^*_μ

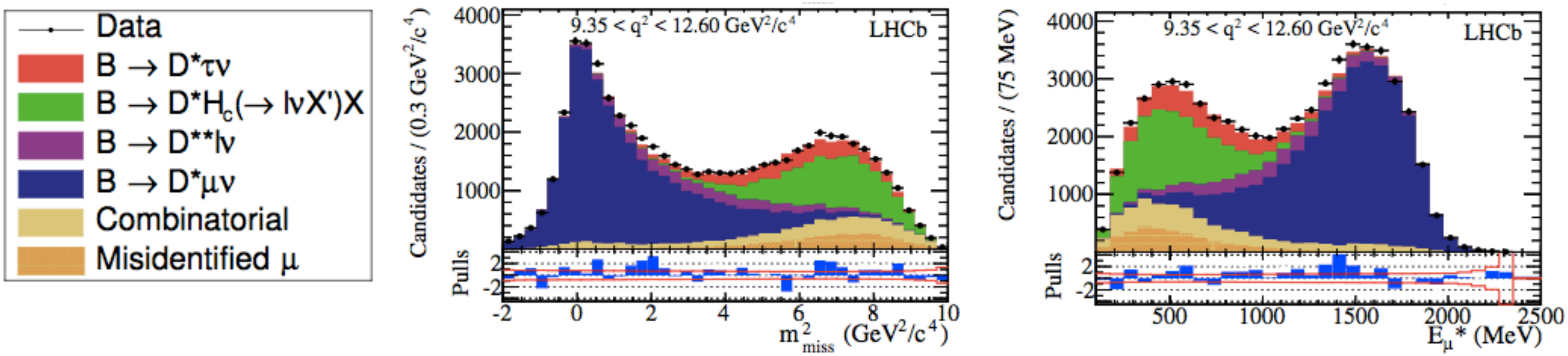


Phys. Rev. Lett. 115 (2015) 111803

Templated fit in 4 bins of q^2 (with different S/B)

Form factor uncertainties folded in the fit

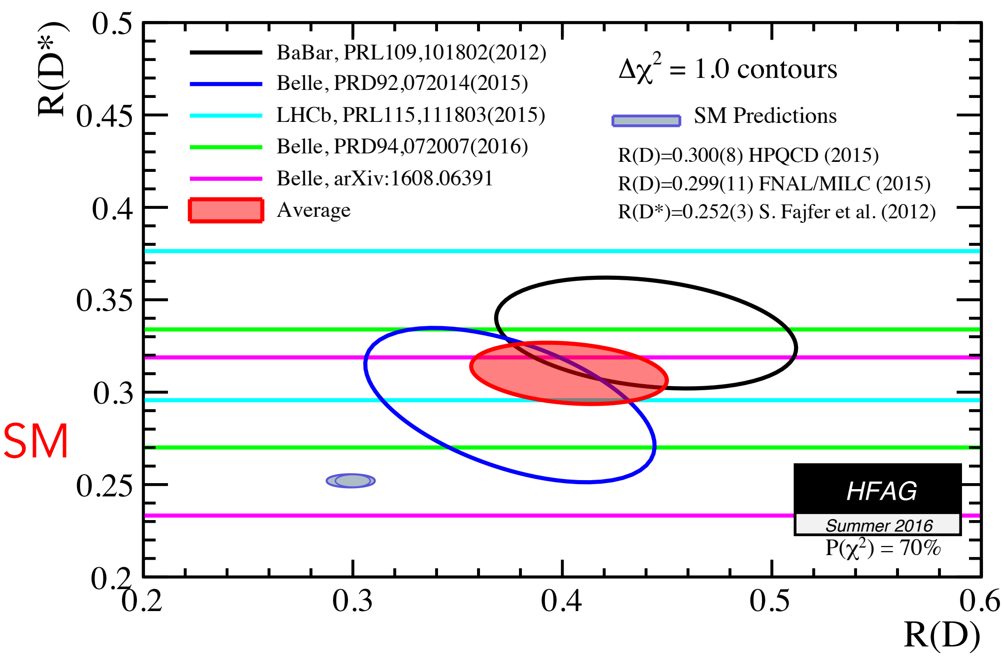
Phys. Rev. Lett. 115 (2015) 111803



$$\mathcal{R}(D^*) = 0.336 \pm 0.027\,(\mathrm{stat}) \pm 0.030\,(\mathrm{syst})$$

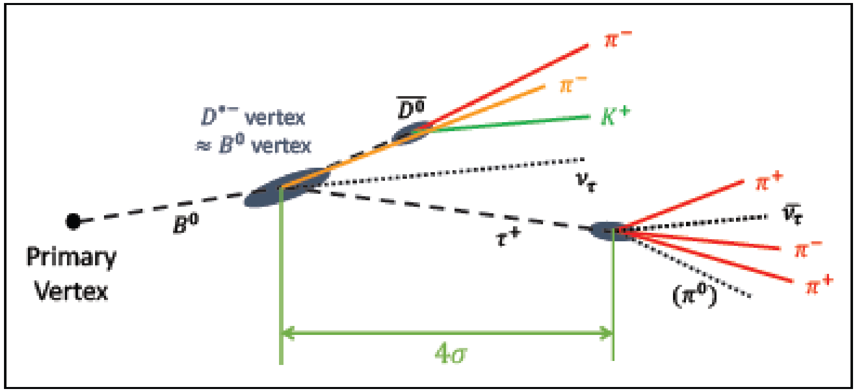
In agreement with other measurements and 2.1 σ away from the SM

In total ~ 3.9 σ away from the SM



R(D*) : what's next ?

Increase the statistics by using hadronic tau decays (BR(τ→ 3 prongs ~ 15 %))



→ LHCb precise vertex reconstruction

→ Measurement of the background levels on data

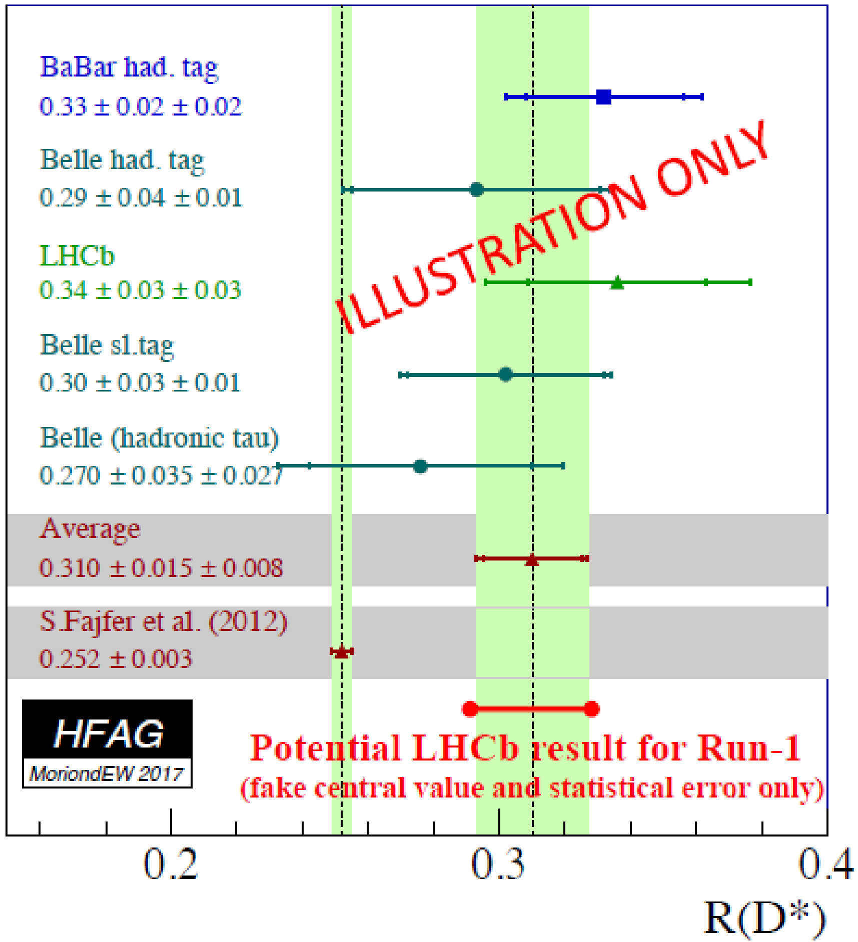
→ Use D* $D_s(3\pi)$ control channel to monitor the background

as well as R(D), R(Λ_c)

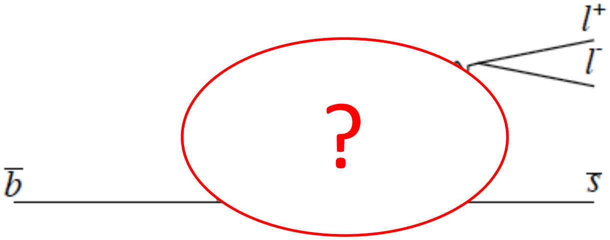
Very different backgrounds :

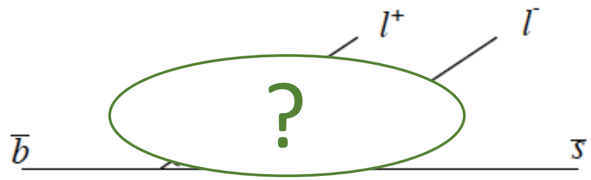
D*3πX

Double charm decays



R(K)





[PRL 113 (2014) 151601](PRL 113 (2014) 151601)

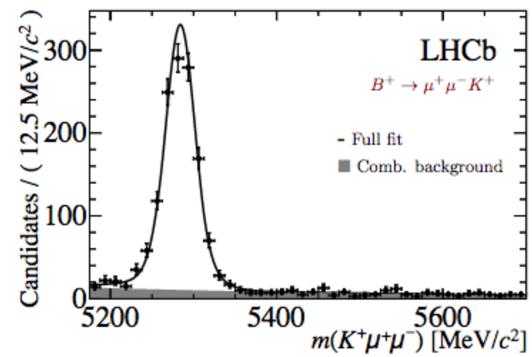
$1 < q^2 < 6\ \mathrm{GeV}^2/c^4$

$$R_K = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{\mathrm{d}\Gamma[B^+ \to K^+\mu^+\mu^-]}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{\mathrm{d}\Gamma[B^+ \to K^+e^+e^-]}{\mathrm{d}q^2}\mathrm{d}q^2}$$

Experimentally, use a double ratio to cancel systematics

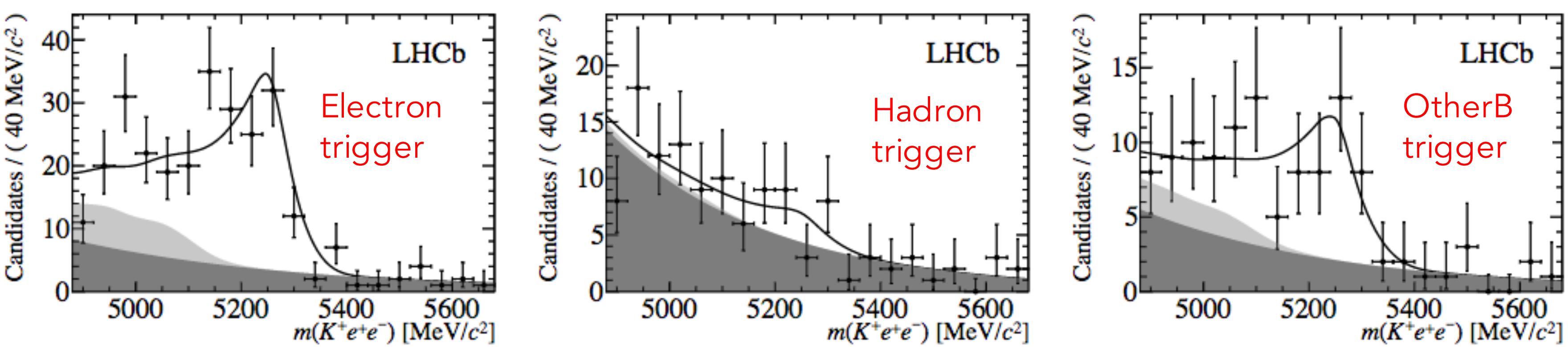
$q = M(ll)$

B→ K μμ
~1200 signal events



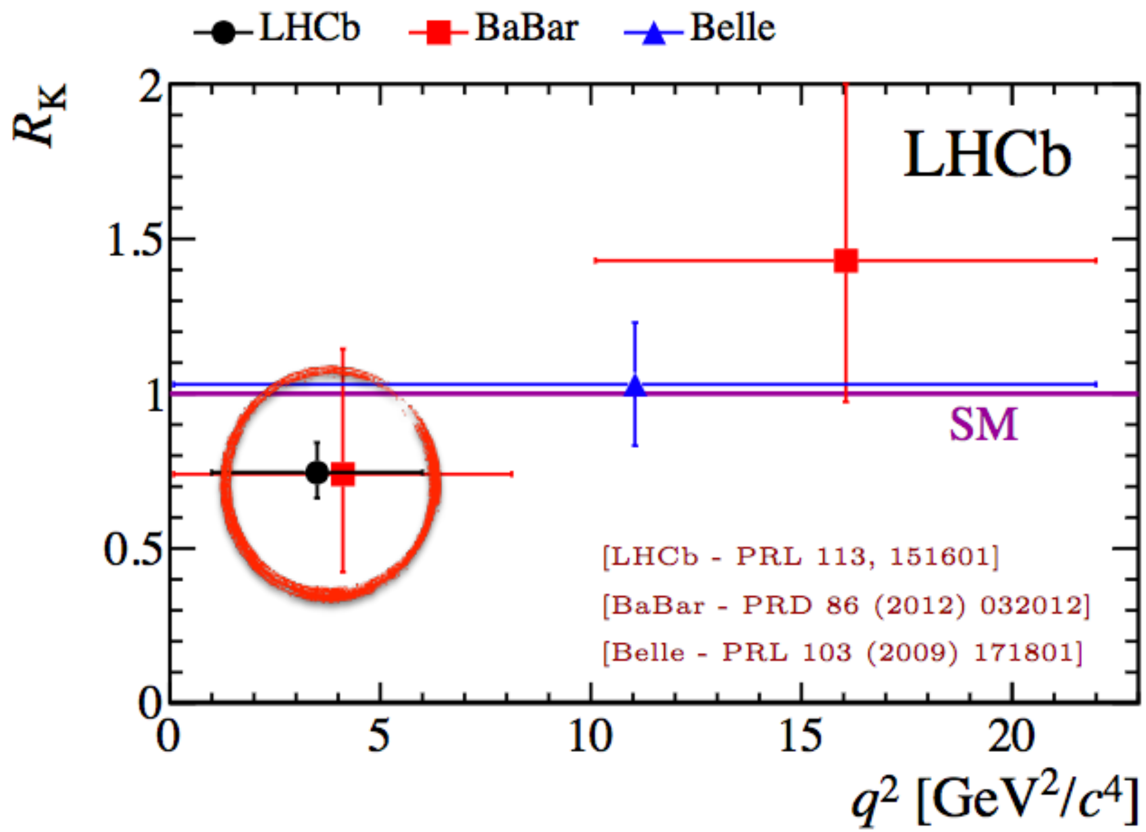
$$R_K = \left(\frac{\mathcal{N}_{K^+\mu^+\mu^-}}{\mathcal{N}_{K^+e^+e^-}}\right)\left(\frac{\mathcal{N}_{J/\psi\,(e^+e^-)K^+}}{\mathcal{N}_{J/\psi\,(\mu^+\mu^-)K^+}}\right)\left(\frac{\epsilon_{K^+e^+e^-}}{\epsilon_{K^+\mu^+\mu^-}}\right)\left(\frac{\epsilon_{J/\psi\,(\mu^+\mu^-)K^+}}{\epsilon_{J/\psi\,(e^+e^-)K^+}}\right)$$

B→ Kee (~ 250 signal events)



R(K)

$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$



Tension with the SM at 2.6 σ

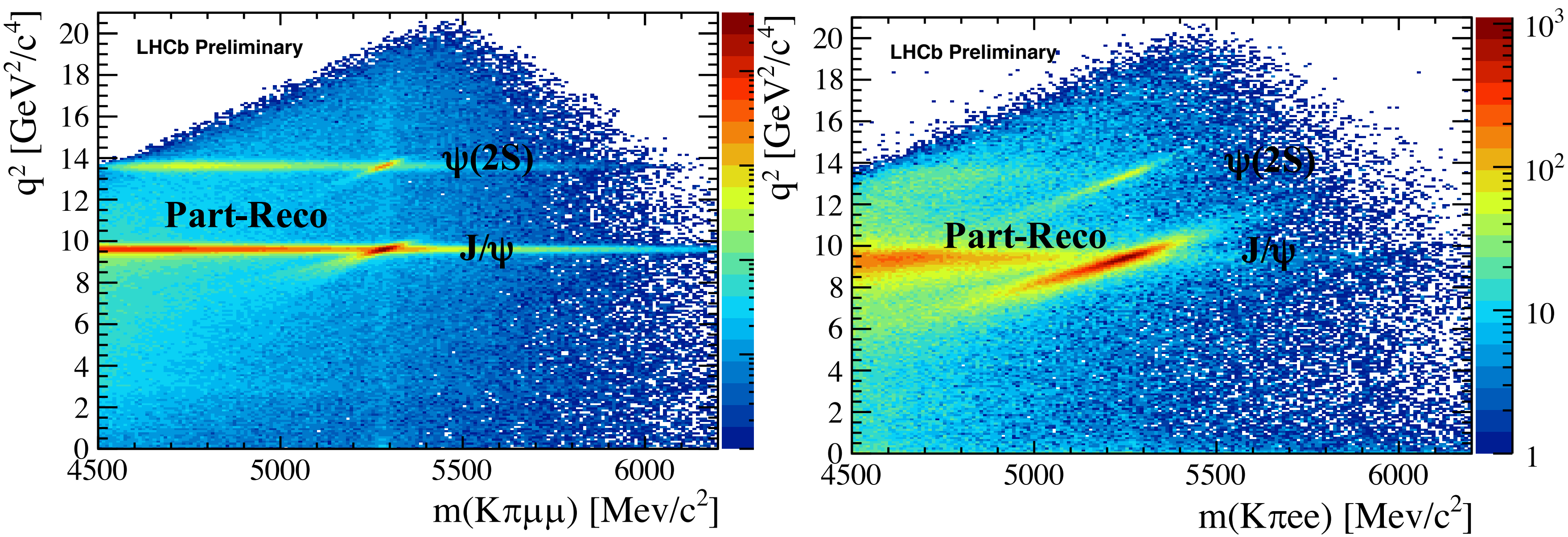
LFU tests in b→sll : what's next ?

Test more :

$$R(K^*) = \frac{B \to K^* \mu\mu}{B \to K^* ee} \qquad R(\phi) = \frac{B_s \to \phi\mu\mu}{B_s \to \phi ee}$$

- more q^2 bins

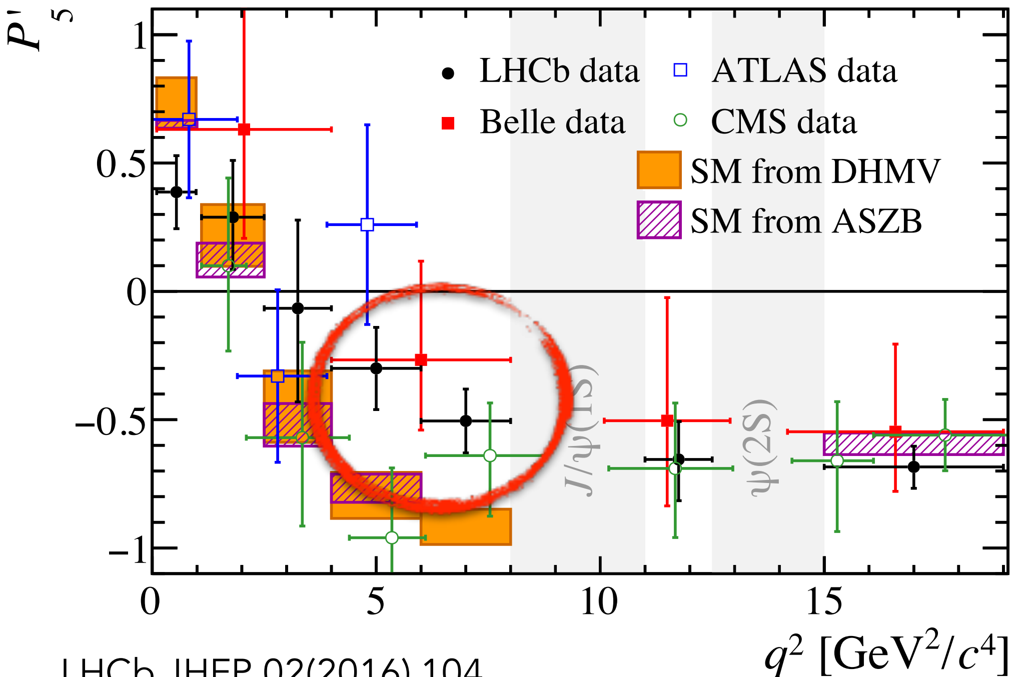
Test of LFU with $B^0 \to K^{*0}\mu\mu$ and $B^0 \to K^{*0}ee$

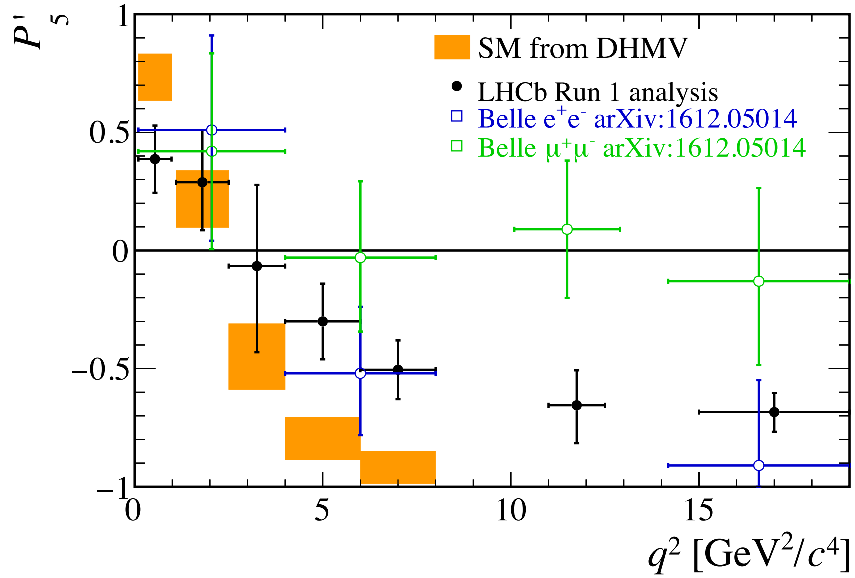


LFU tests in b→ sll transtions : what's next ?

LHCb : 2.8 and 3.0 σ from SM

B^0 → K*μμ angular analysis





LHCb JHEP 02(2016) 104

Belle PRL118, 111801 (2017)

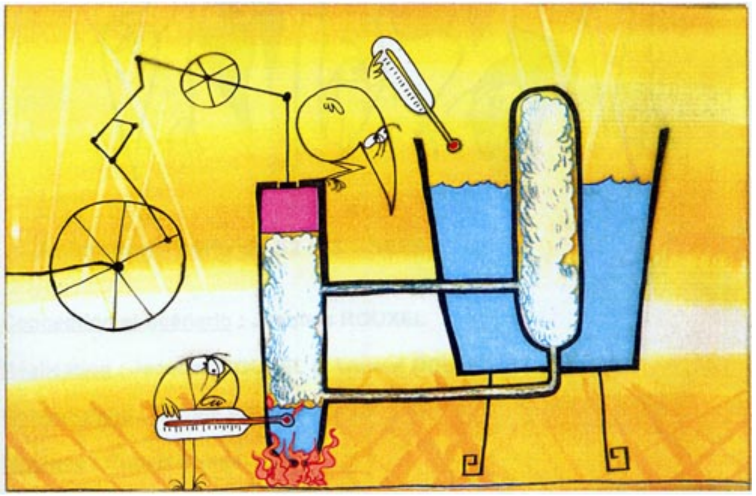
ATLAS, preliminary Moriond EW

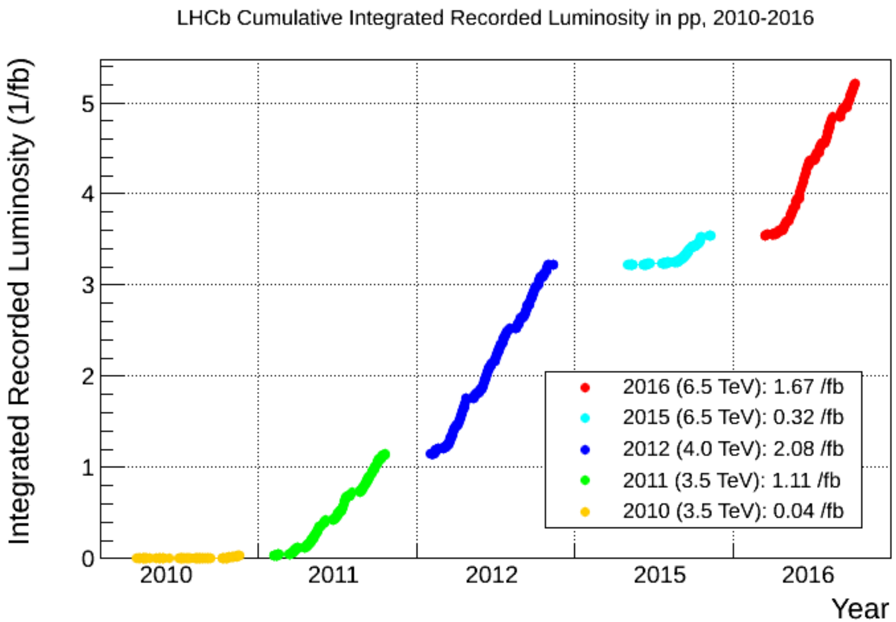
CMS, preliminary Moriond EW

→ $K^{(*)}$ ee angular analyses in the same q^2 region 1-6 GeV^2/c^4 ?

Summary

- In the SM observables to test Lepton Flavour Universality can be precisely predicted
- Experimentally challenging
- Stay tuned !



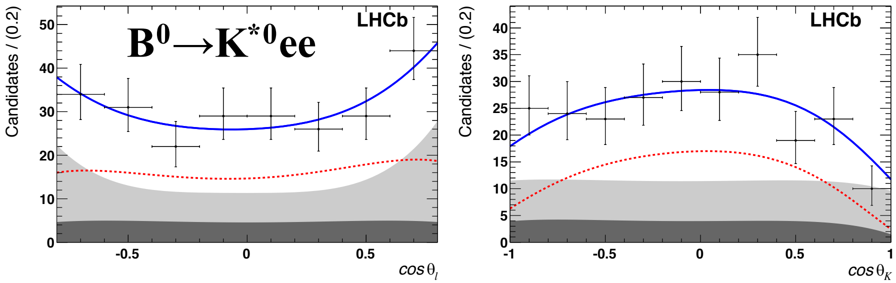


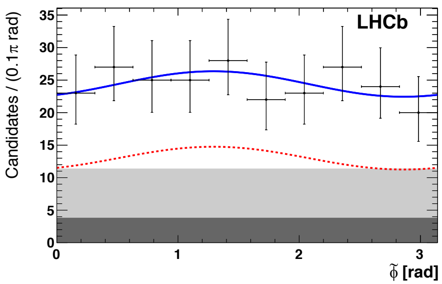
Increase of energy (cross-section) and collected data (~5 fb^{-1} expected in LHCb) in Run 2

Backup slides

Angular Analyses

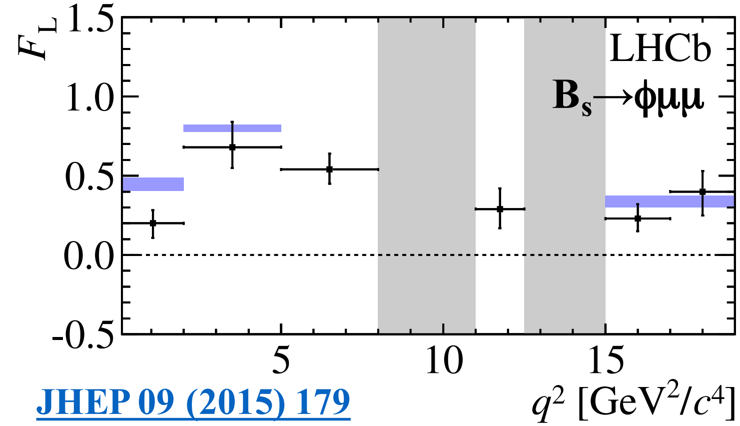
- Results **consistent with SM predictions**



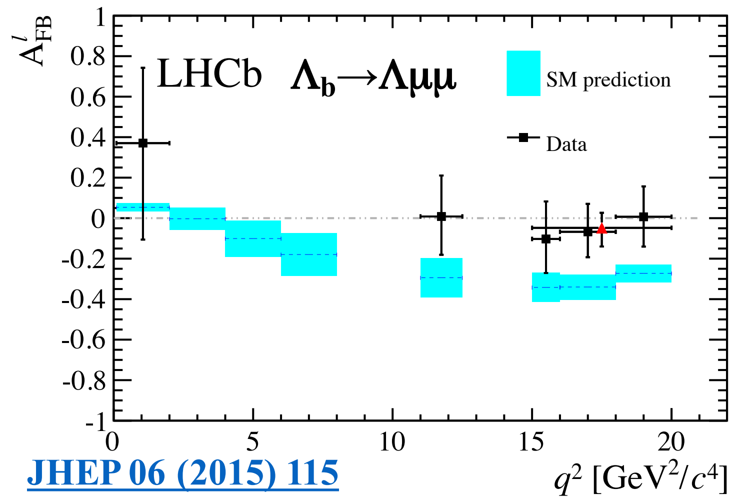


$$F_L = 0.16 \pm 0.06 \pm 0.03$$
$$A_T^{Re} = 0.10 \pm 0.18 \pm 0.05$$
$$A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05$$
$$A_T^{Im} = 0.14 \pm 0.22 \pm 0.05$$

JHEP 04 (2105) 064



JHEP 09 (2015) 179



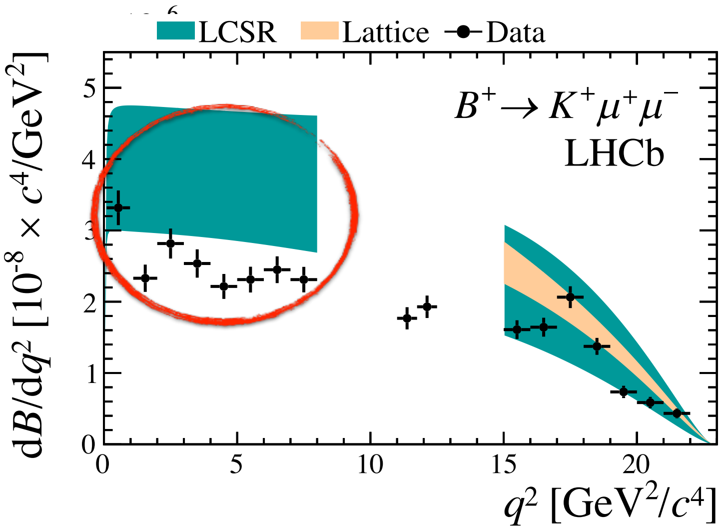
JHEP 06 (2015) 115

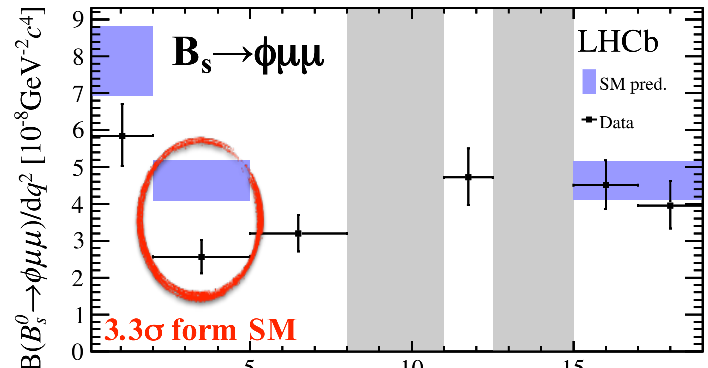
- **Low-q²**: 0.0004–1 GeV²
- Challenging due to Bremsstrahlung
- Sensitive to photon polarisation

- Λ_b: gives access to different combinations of Wilson coefficients

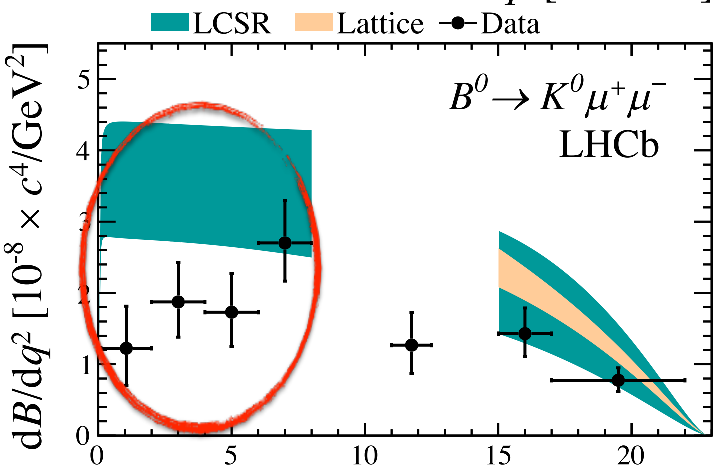
Differential Branching Fractions

- Results **consistently lower than SM predictions** despite large theory uncertainties from form-factors

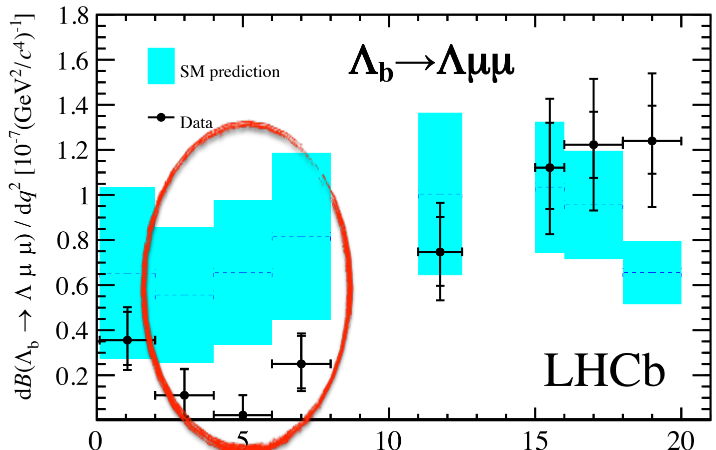




JHEP 09 (2015) 179



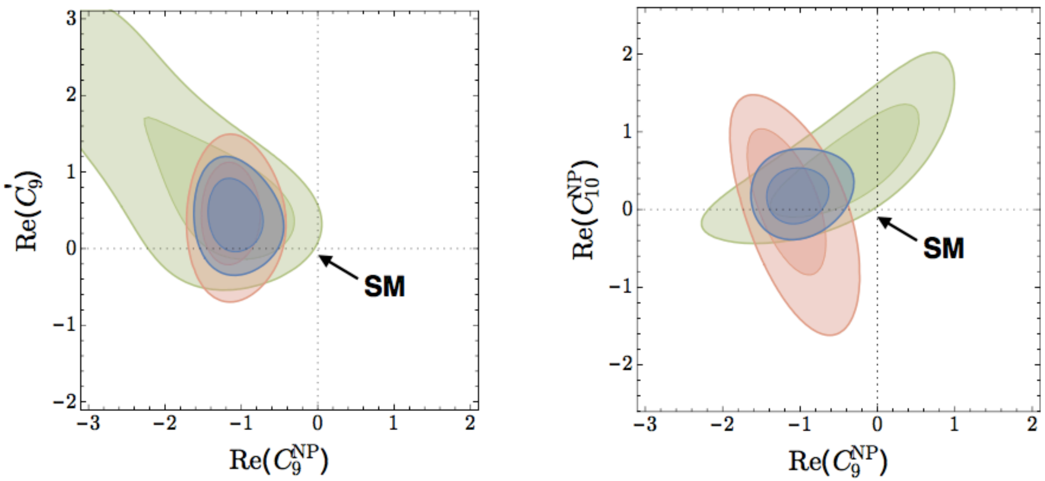
JHEP 06 (2014) 133



JHEP 06 (2015) 115

Global Fits

- Several attempts to interpret results by performing **global fits to b⟶s data** (e.g. arXiv:1503.06199, arXiv:1510.04239 and arXiv:1512.07157)
- Take into account ~80 observables from 6 experiments including b⟶μμ, b⟶sll and b⟶sγ transitions
- All global fits require an **additional contribution with respect to the SM to accommodate the data, with a preference for NP in C_9 at ~4σ**



arXiv:1503.06199

branching fractions, angular observables and combination

- **Or is this a problem with our understanding of QCD?** (e.g. are we correctly estimating the contribution for charm loops?)