EPS HEP2023 HAMBURG

An overview of $b \to s\mu^+\mu^-$ decays at LHCb

Janina Nicolini

On behalf of the LHCb Collaboration

2023 European Physical Society Conference
for High Energy Physics

24th of August 2023

technische universität dortmund

université PARIS-SACLAY

cnrs

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

Supported by:

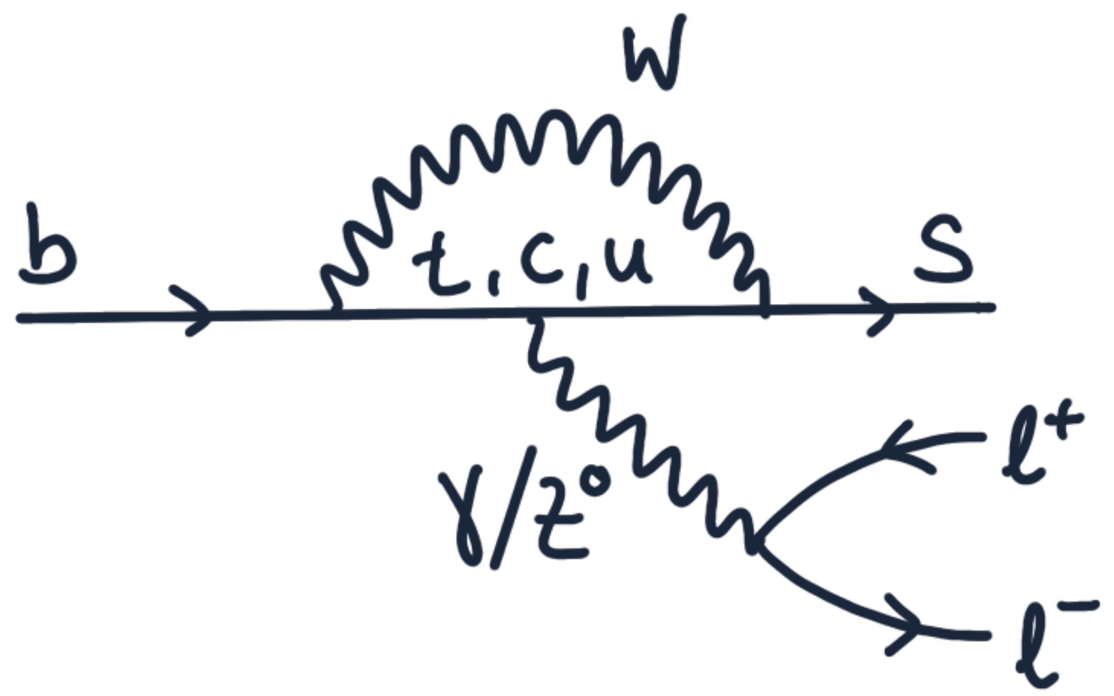
Studienstiftung des deutschen Volkes

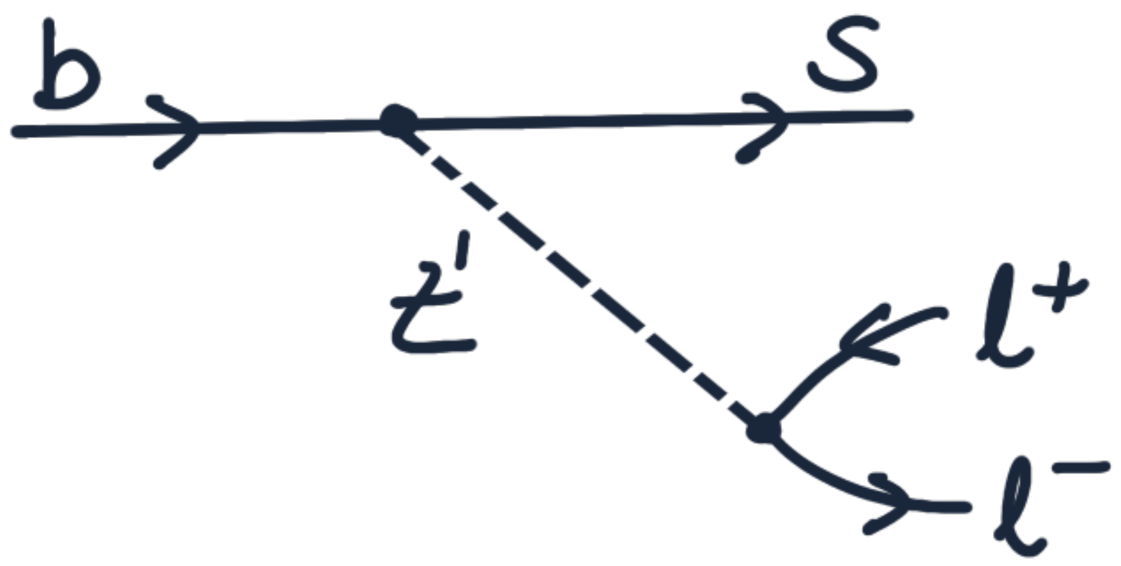
erc European Research Council Established by the European Commission

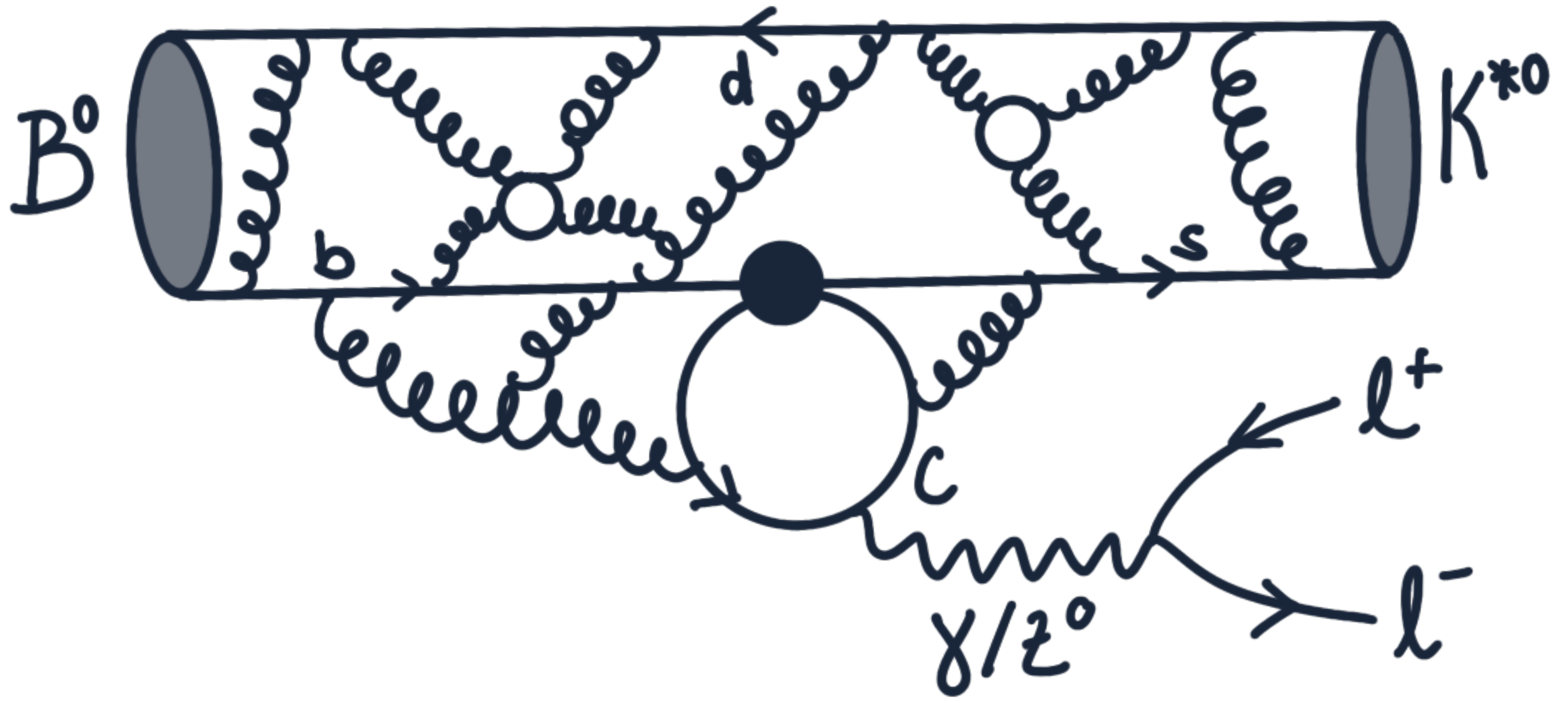
Electroweak Penguins

- Flavour-changing neutral currents at loop level
- Ideal for indirect searches $\mathrm{B}(b \to s\ell^+\ell^-) \sim 10^{-7} - 10^{-6}$
- New Physics (NP) can contribute :
  1. Enhance/suppress decay rates
  2. Modify angular distributions
  3. Introduce CP violation source
- Study in hadronised states
  1. Form Factor (FF) calculations
  2. Contributions of non-local uncertainties challenging
- Focus on muon decays

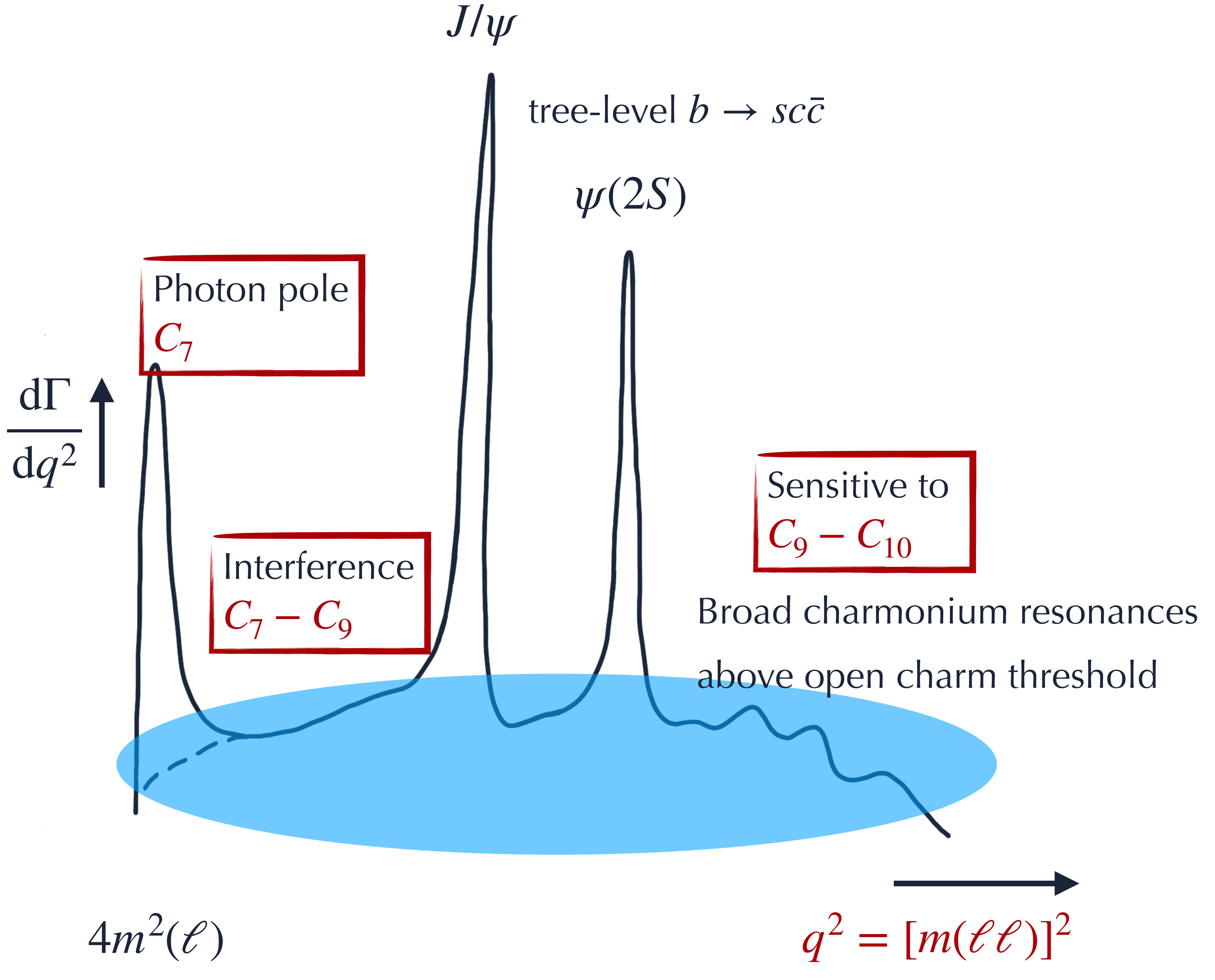
  → more results for LFU und LFV in A. López Huertas talk

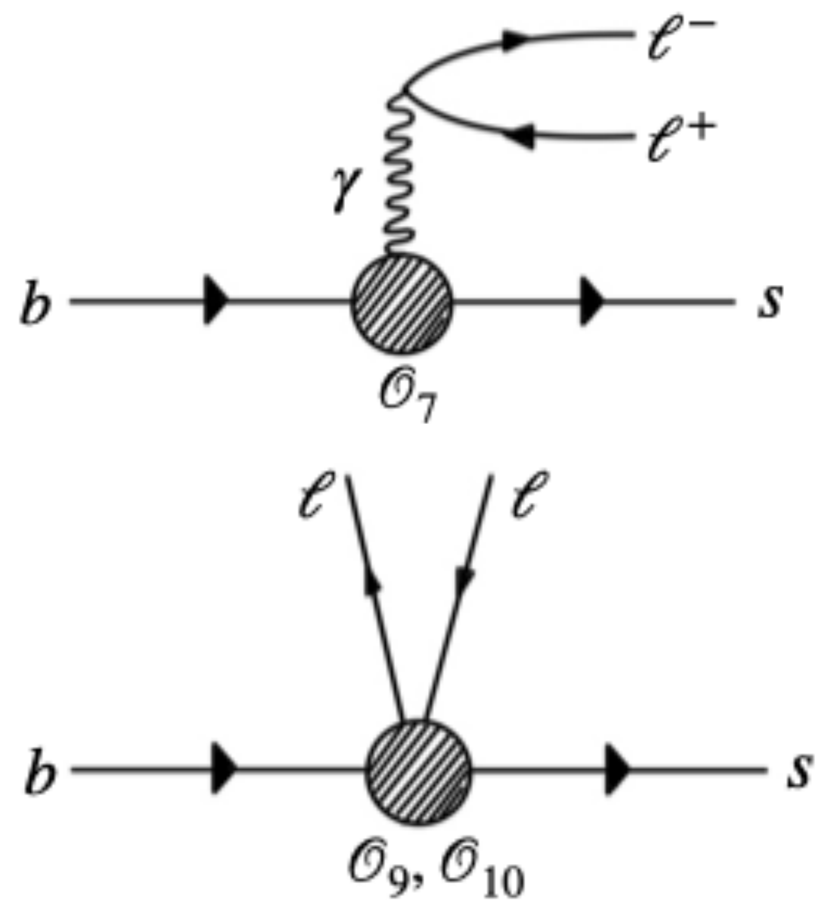






What to measure?



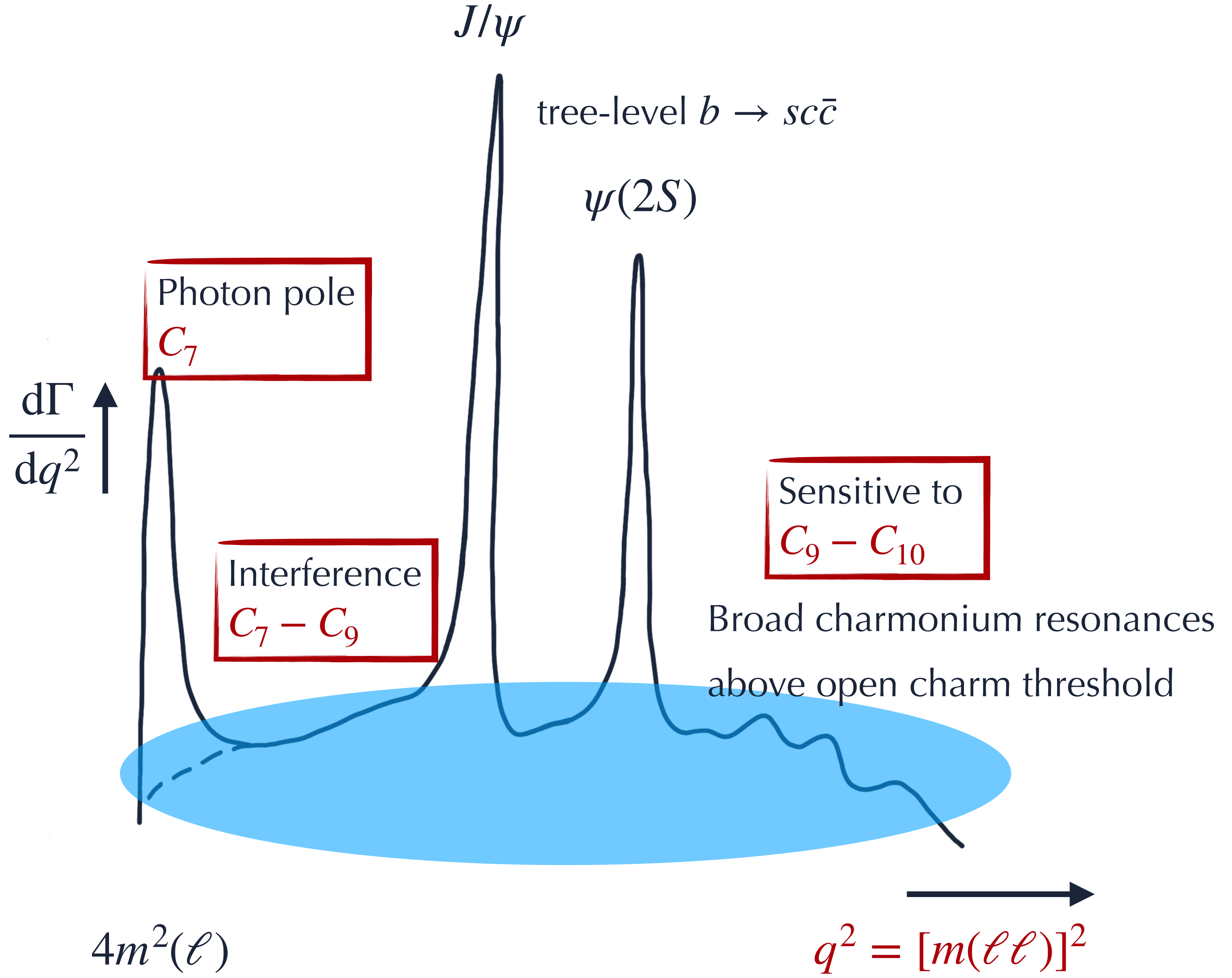


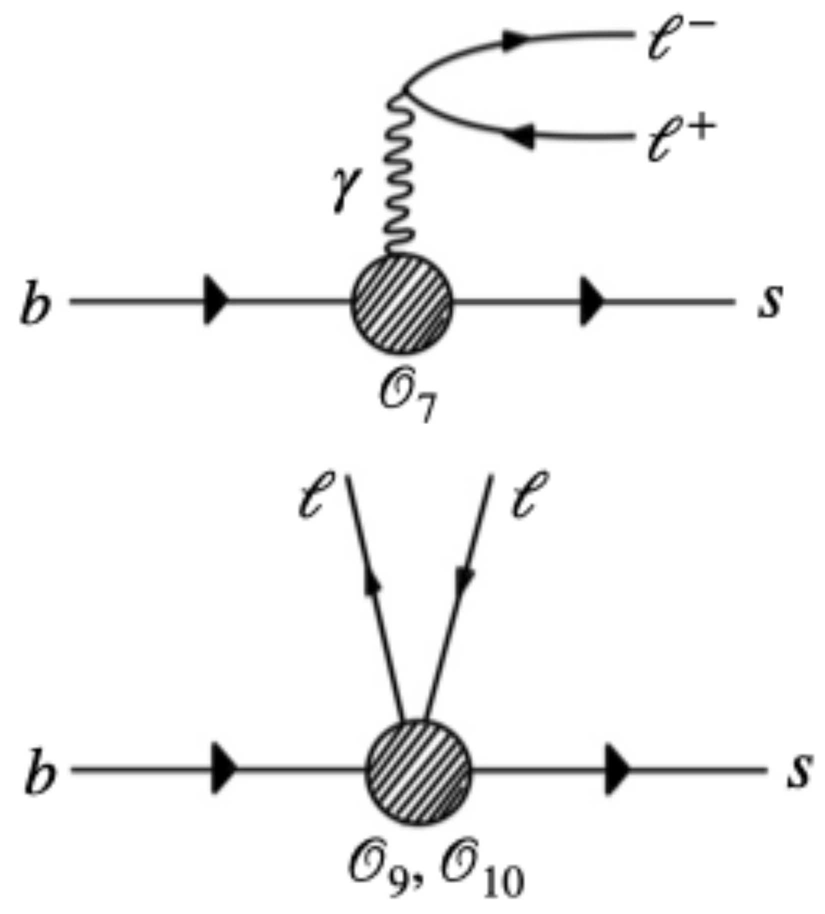
Weak effective Hamiltonian

$$H_{eff} = \frac{-4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_i C_i(q^2) O_i$$

- Wilson coefficients $C_i(q^2) = C_i^{SM} + C_i^{NP}$
- Additional NP operator O_i^{NP} (e.g JHEP 01(2015)155)

What to measure?





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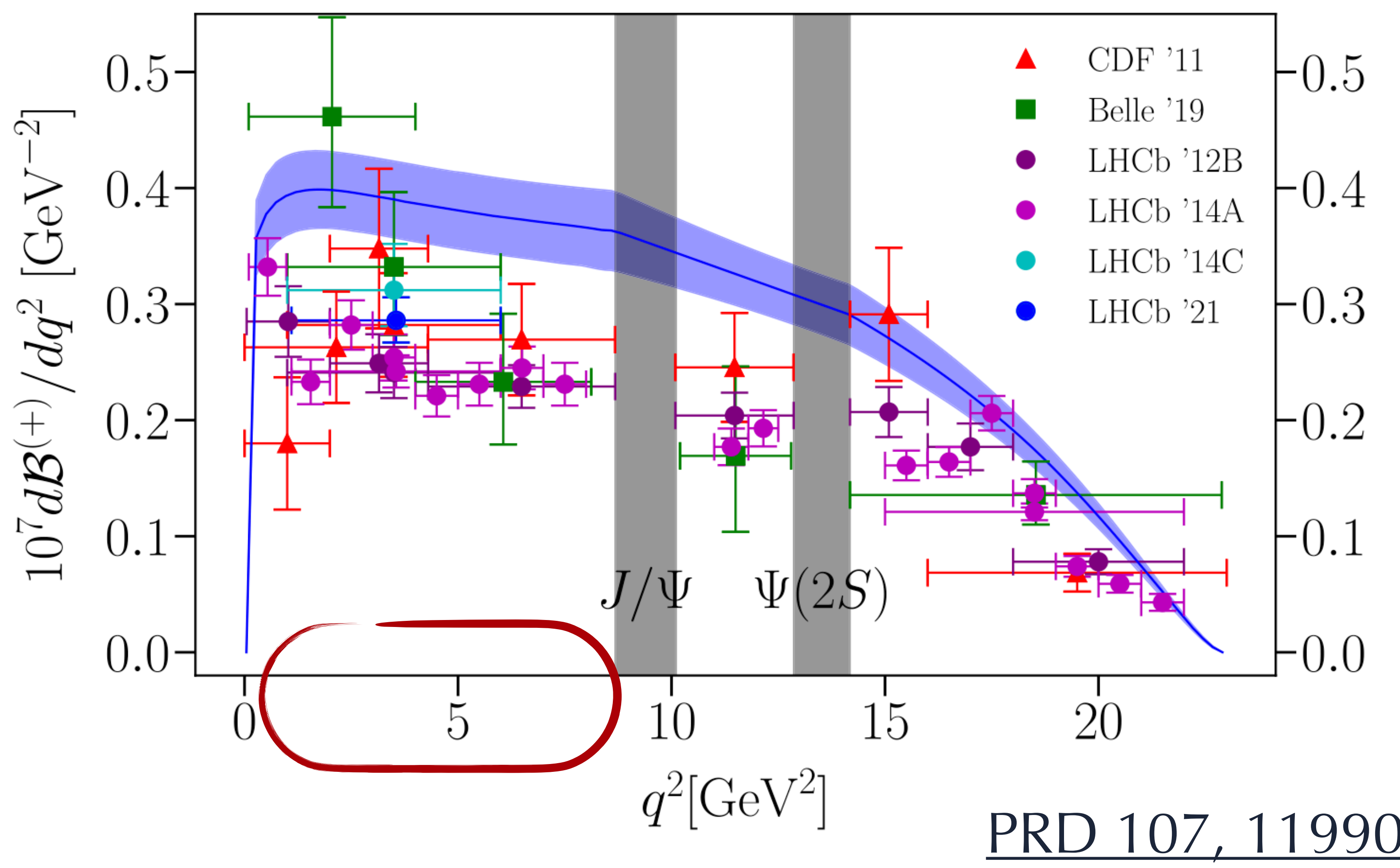
$B^+ \to K^+ \mu^+ \mu^-$

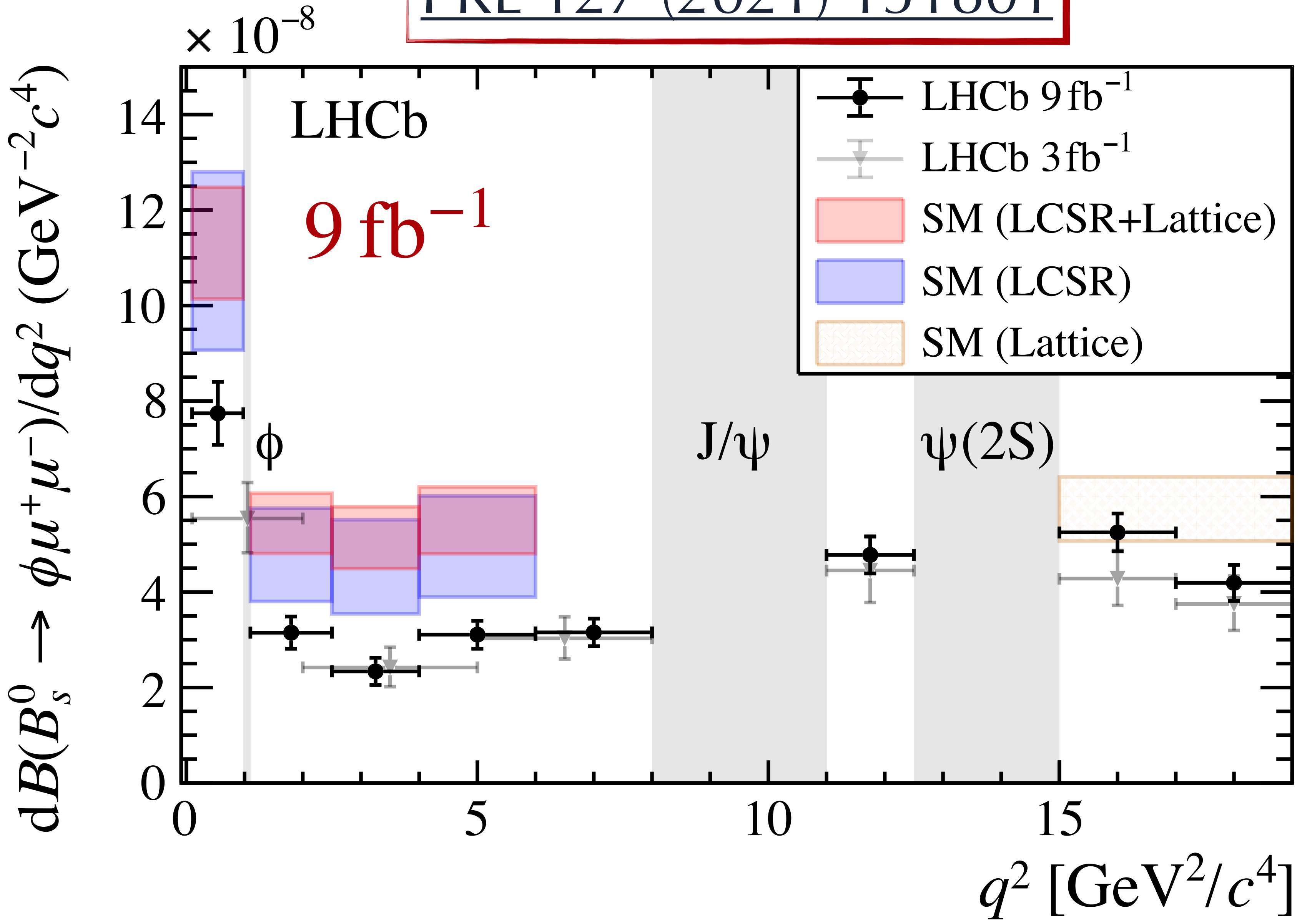


PRD 107, 119903 (2023)

- *B* anomalies: in differential BF & angular observables (CP-even S_i, CP-odd A_i)
- Angular analysis experimentally more challenging → disentangle Wilson coefficients
- Meson and baryon decays probe different spin configurations

$B_s^0 \to \phi\mu\mu$ BF measurement

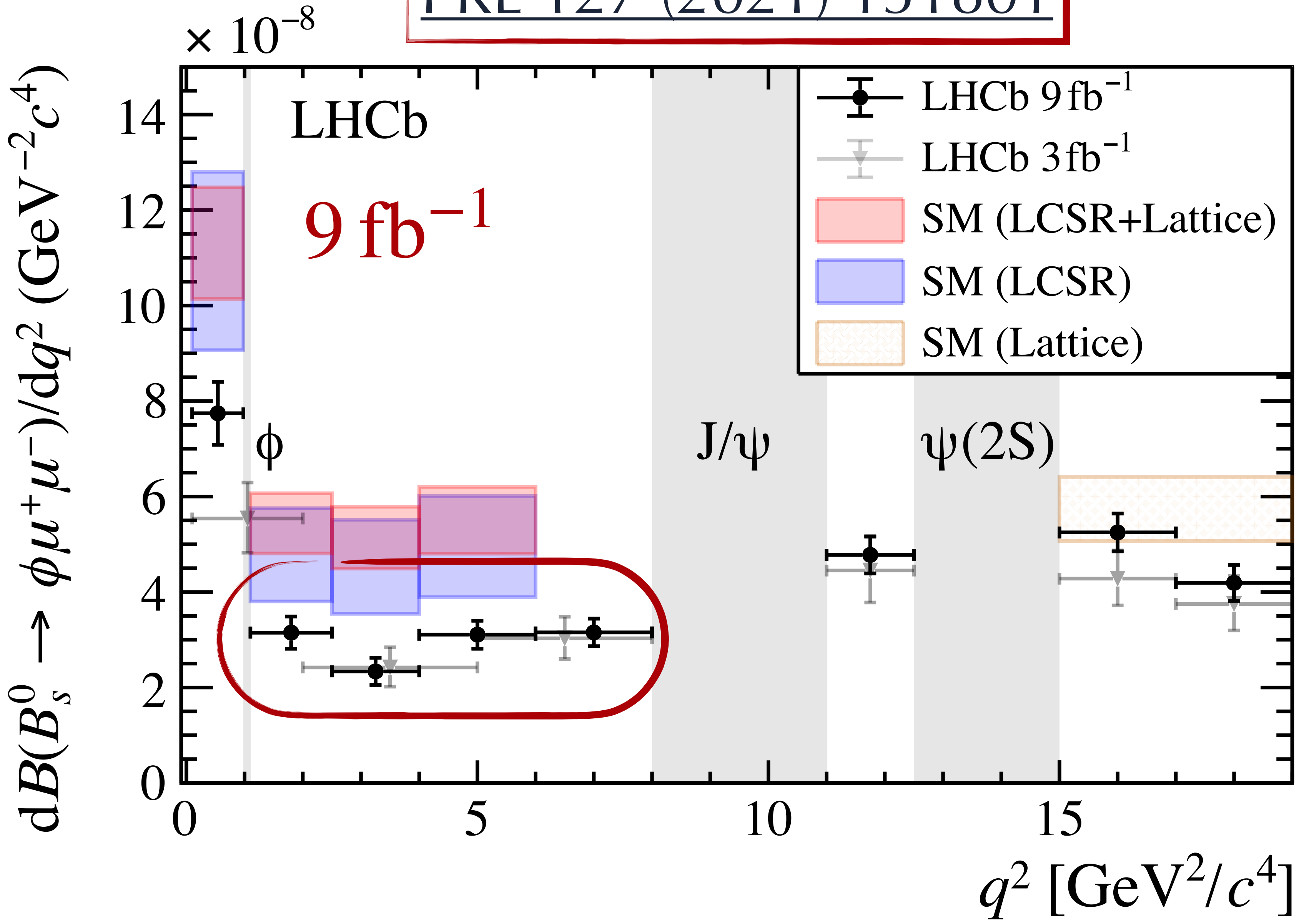
PRL 127 (2021) 151801

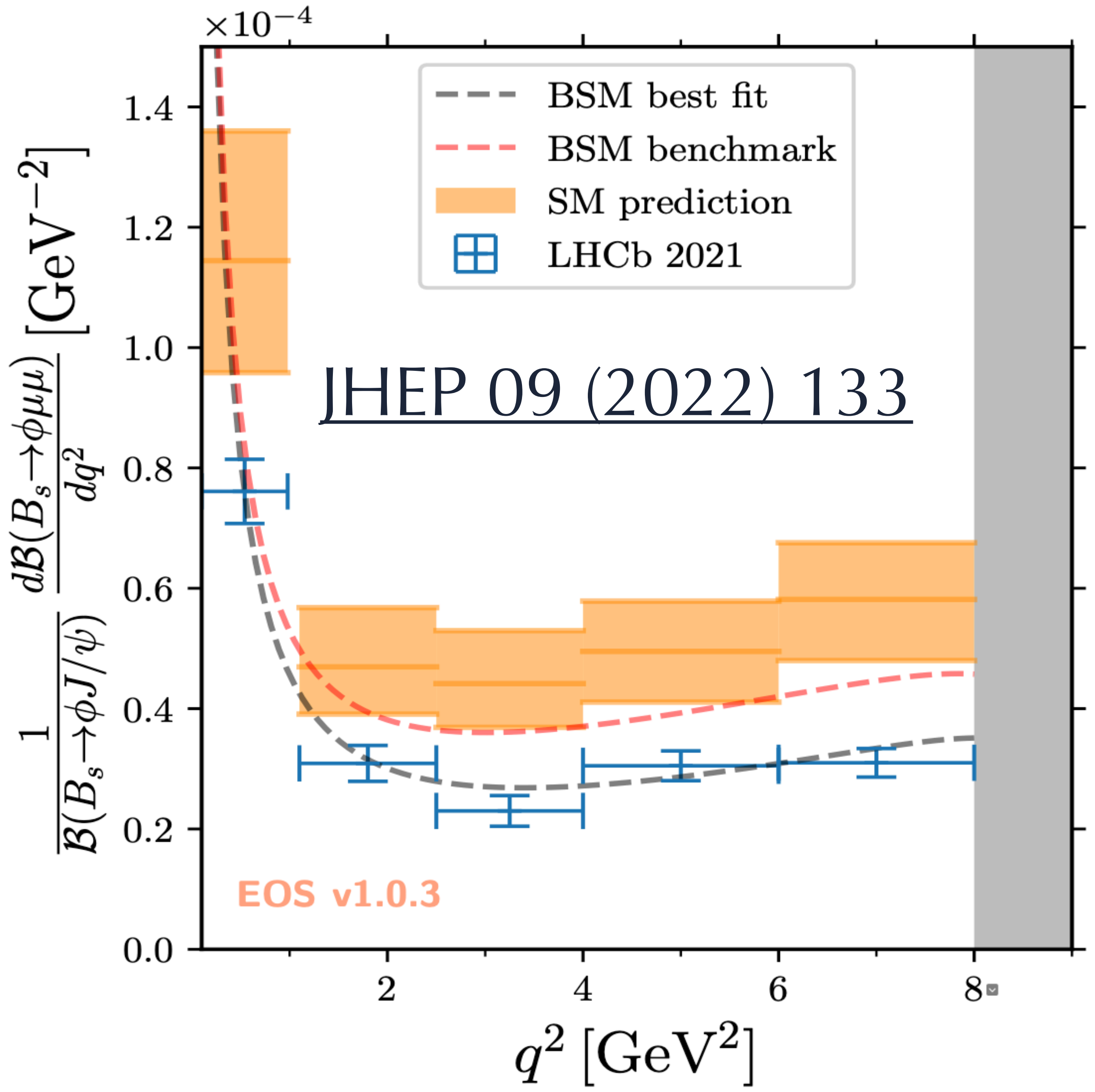


- Factor 4 more B_s^0 compared to JHEP 09 (2015) 179
- Reconstructed via displaced $K^+K^-\mu^+\mu^-$ vertex
- Veto q^2 for $B_s^0 \to \phi(\to \mu^+\mu^-)\phi$, $B_s^0 \to \phi J/\psi$ and $B_s^0 \to \phi\psi(2S)$
- Normalised to $B_s^0 \to \phi J/\psi$
- Simultaneous fit to different q^2 bins

$B_s^0 \to \phi\mu\mu$ BF measurement

PRL 127 (2021) 151801





JHEP 09 (2022) 133

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Most precise BF measurement

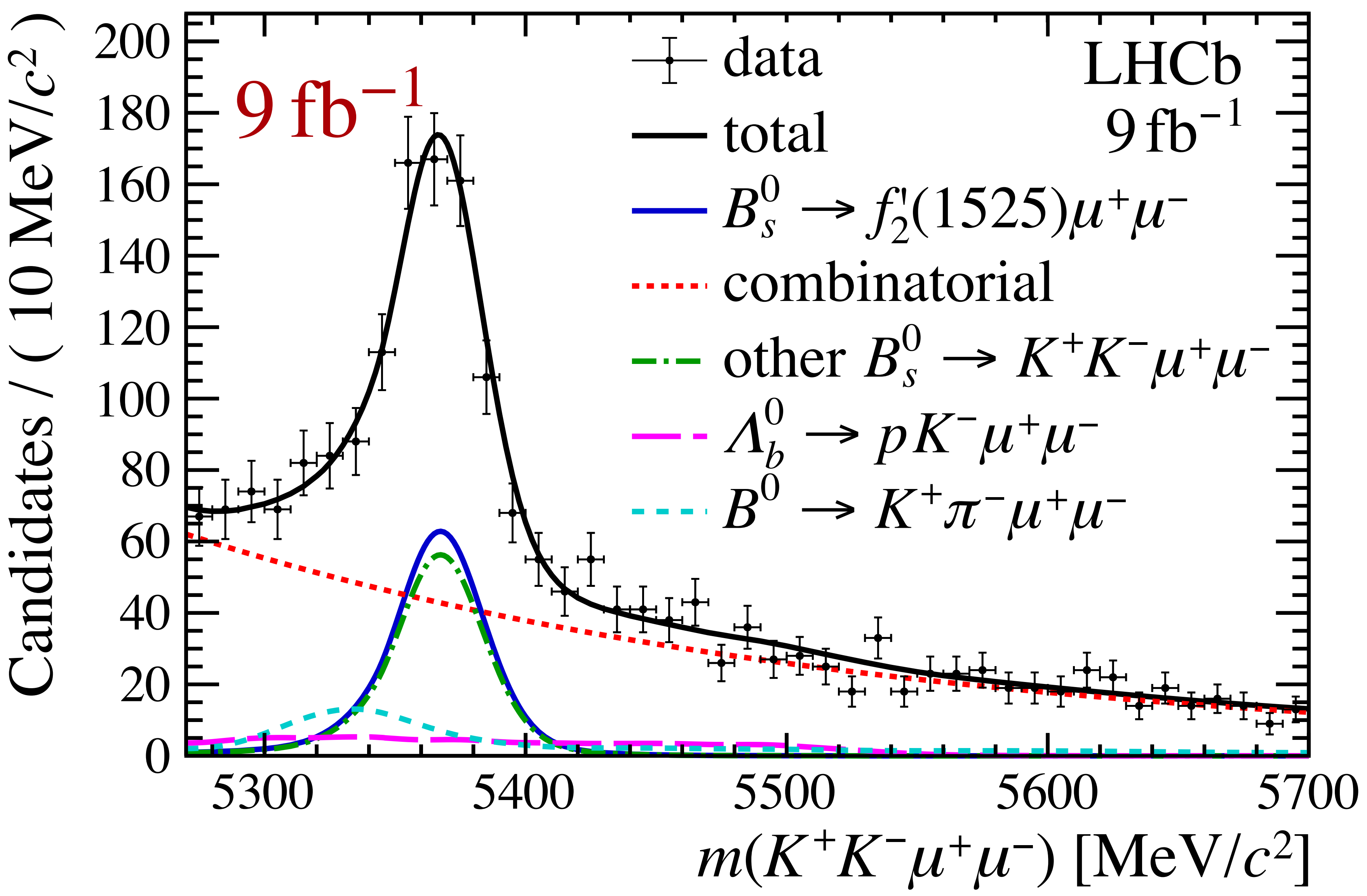
$$\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-) = (8.14 \pm 0.22 \pm 0.16 \pm 0.39 \pm 0.03) \times 10^{-7}$$

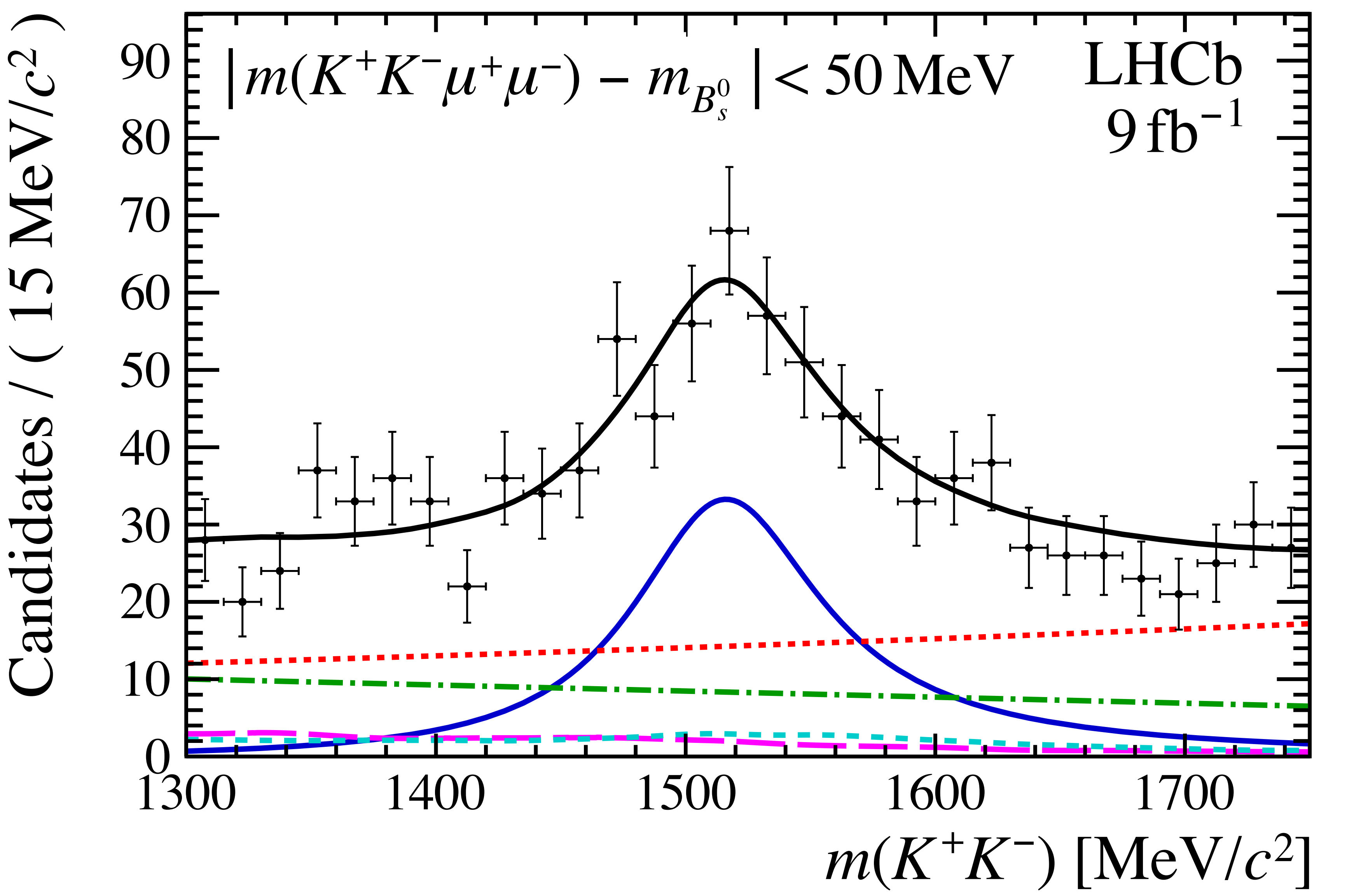
stat. syst. abs. BF q2 extrapol.

In $q^2[1.1,6.0]$ GeV$^2/c^4$: 3.6σ (LCSR+Lattice) and 1.8σ (LCSR)

$B_s^0 \to f_2' \mu\mu$ BF measurement

PRL 127 (2021) 151801



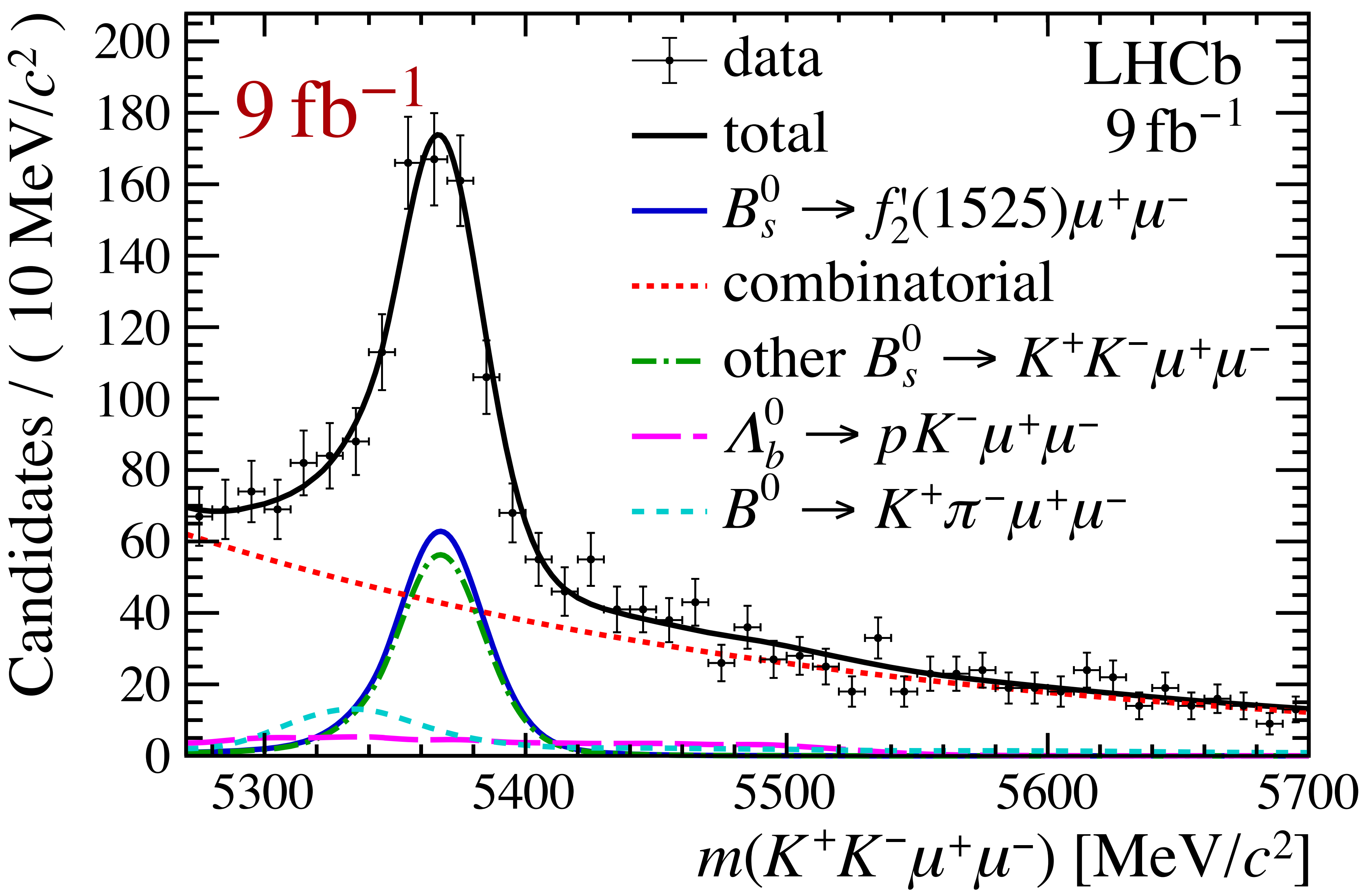


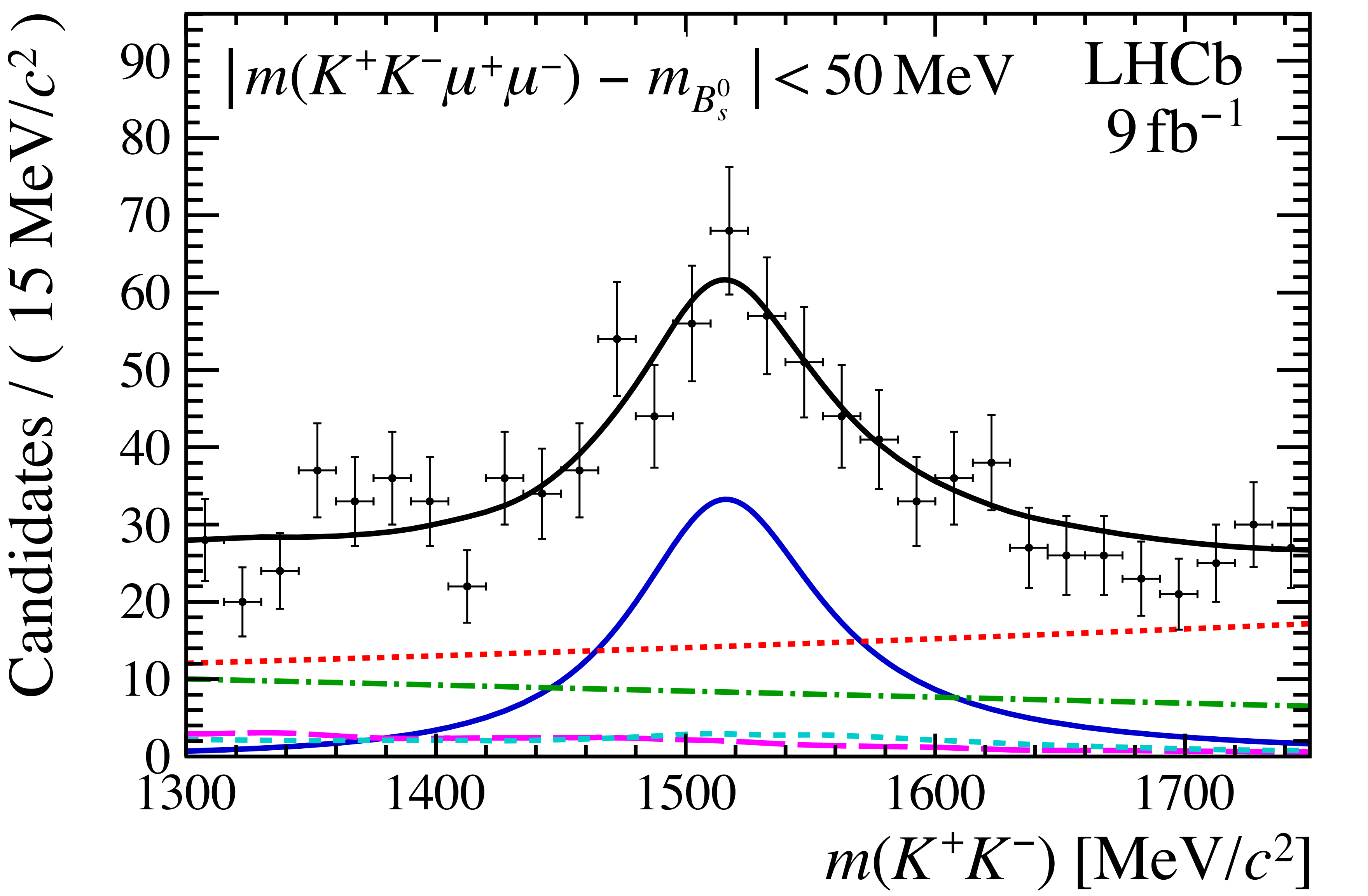
- Measurement with spin-2 meson in final state
- Similar selection to $B_s^0 \to \phi\mu^+\mu^-$ and normalised to $B_s^0 \to \phi J/\psi$
- Combined in q^2 $[0.1,0.98] \cup [1.1,8.0] \cup [11.0,12.5]$ GeV$^2/c^4$
- 2D fit to $m(K^+K^-\mu^+\mu^-)$ and $m(K^+K^-)$

  with $|m(f_2'(1525)) - m_{PDG}| < 225$ MeV/c^2
- S- and P-wave contributions from ϕ, $\phi(1680)$, … resonances

$B_s^0 \to f_2'\mu\mu$ BF measurement

PRL 127 (2021) 151801





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9σ observation

BF same order of magnitude as SM

$$\mathcal{B}(B_s^0 \to f_2'\mu^+\mu^-) = (1.57 \pm 0.19 \pm 0.06 \pm 0.08 \pm 0.06) \times 10^{-7}$$

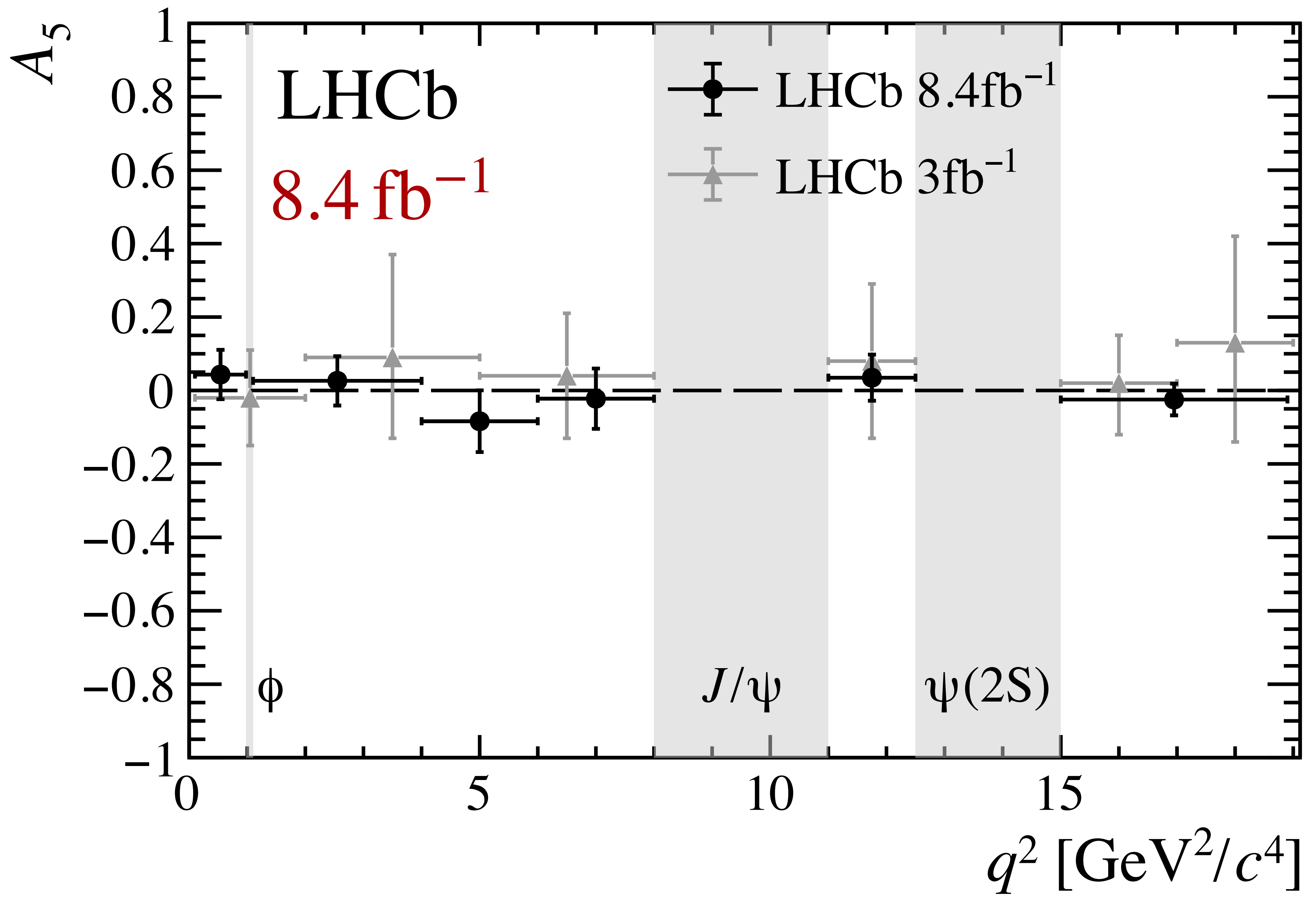
stat. syst. abs. BF q2 extrapol.

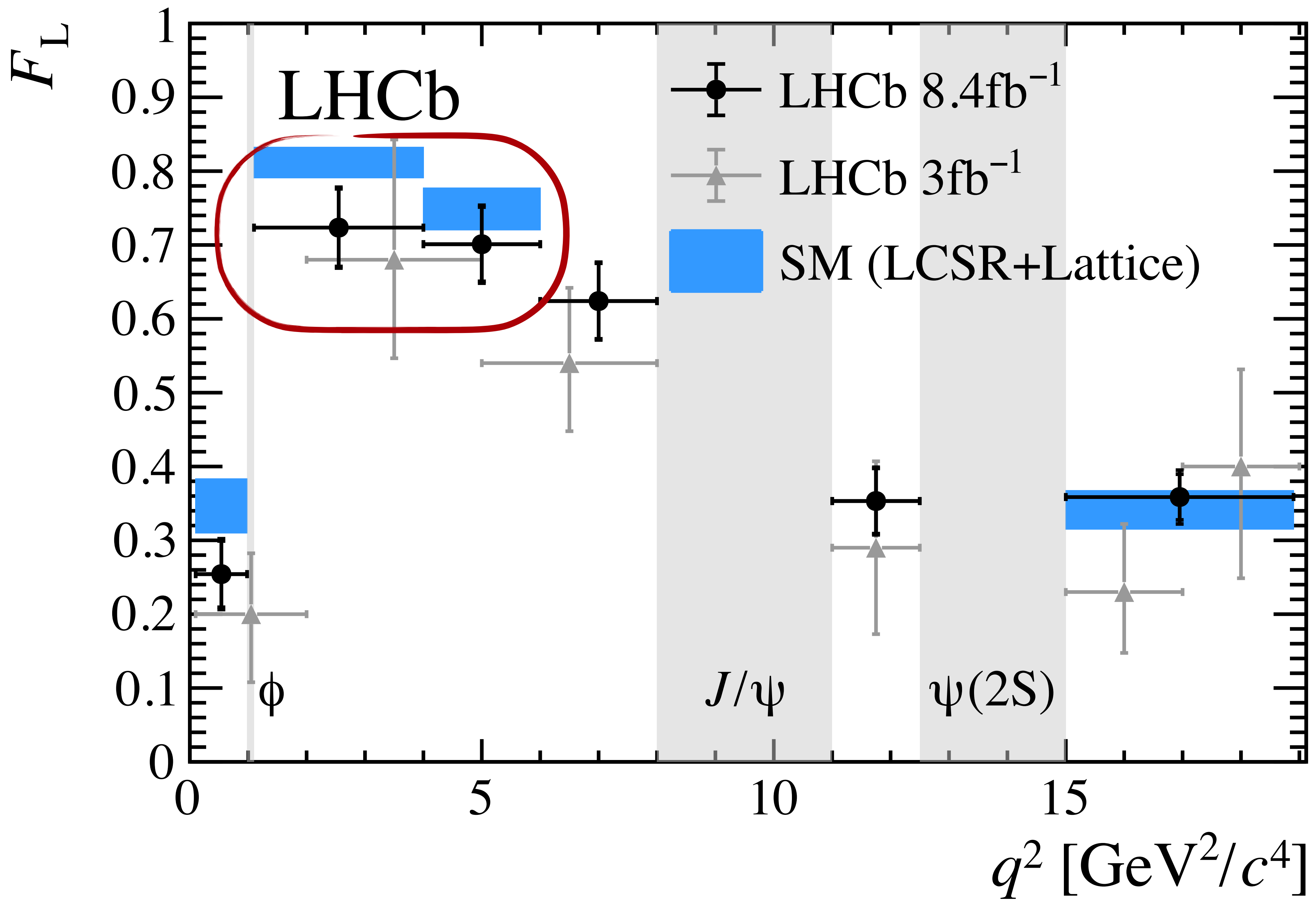
$B_s^0 \to \phi\mu\mu$ Angular analysis

- Same selection as BF measurement, flavour-untagged ($\phi \to K^+K^-$)
- Update of JHEP 09 (2015) 179
- Simultaneous fit to $[\theta_h, \theta_l, \phi, m(K^+K^-\mu^+\mu^-)]$
- S-wave only systematic uncertainty
- Agreement with SM, CP-Asymmetries ~0
- Mild trend in F_L

JHEP 11 (2021) 043

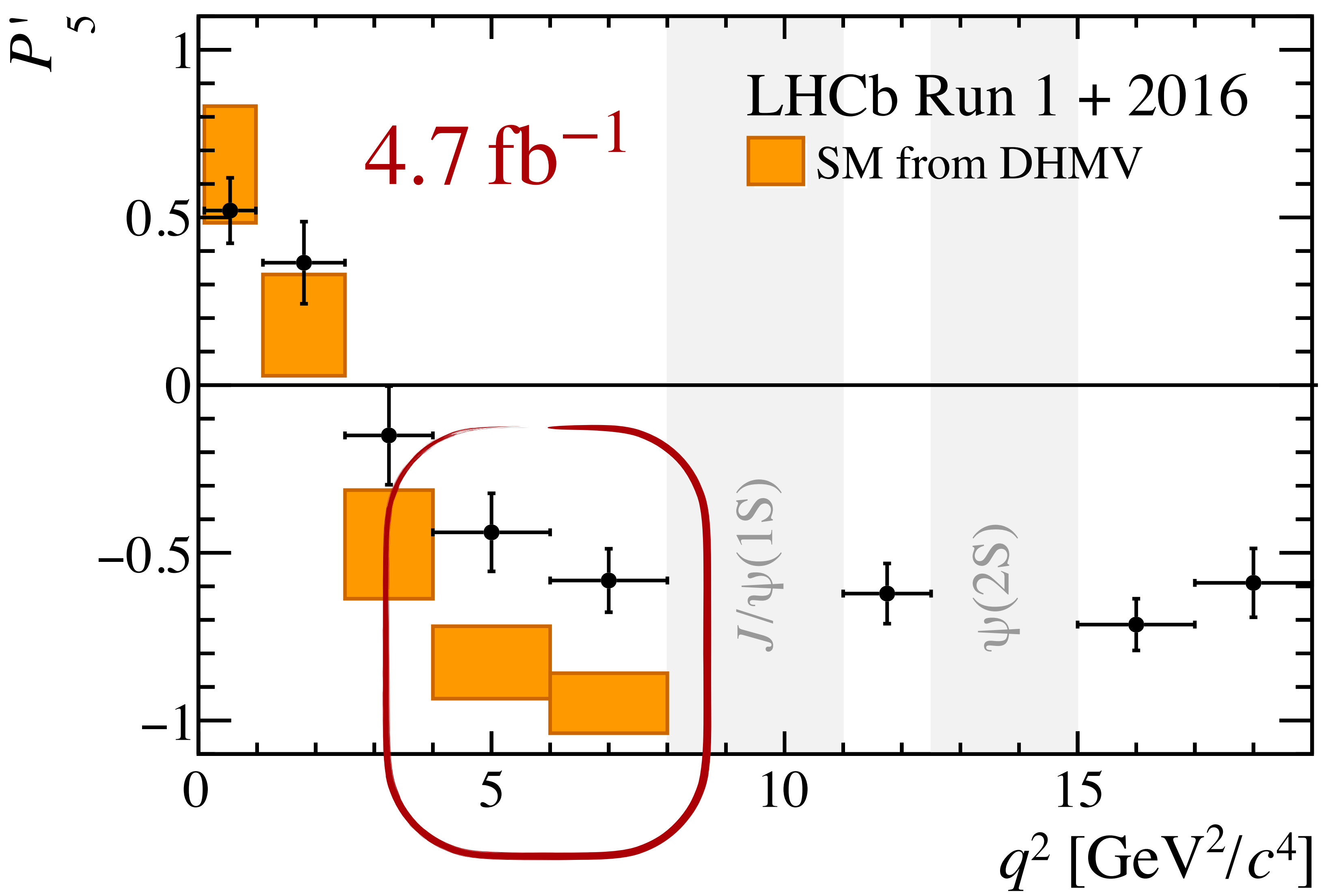
F_L : fraction of longitudinal polarisation of hadron

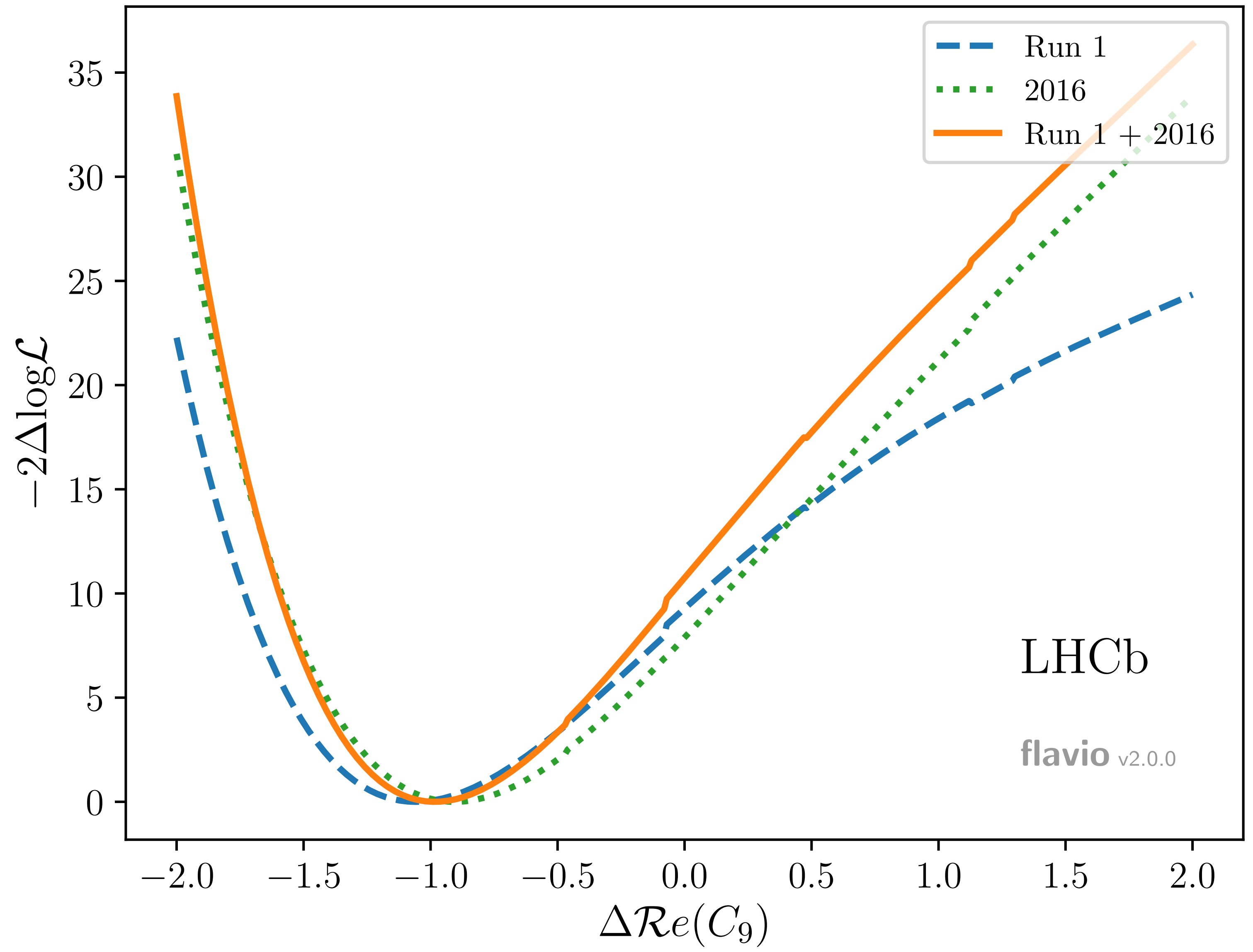




$B^0 \to K^{*0}\mu\mu$ Angular analysis

PRL 125, 011802 (2020)





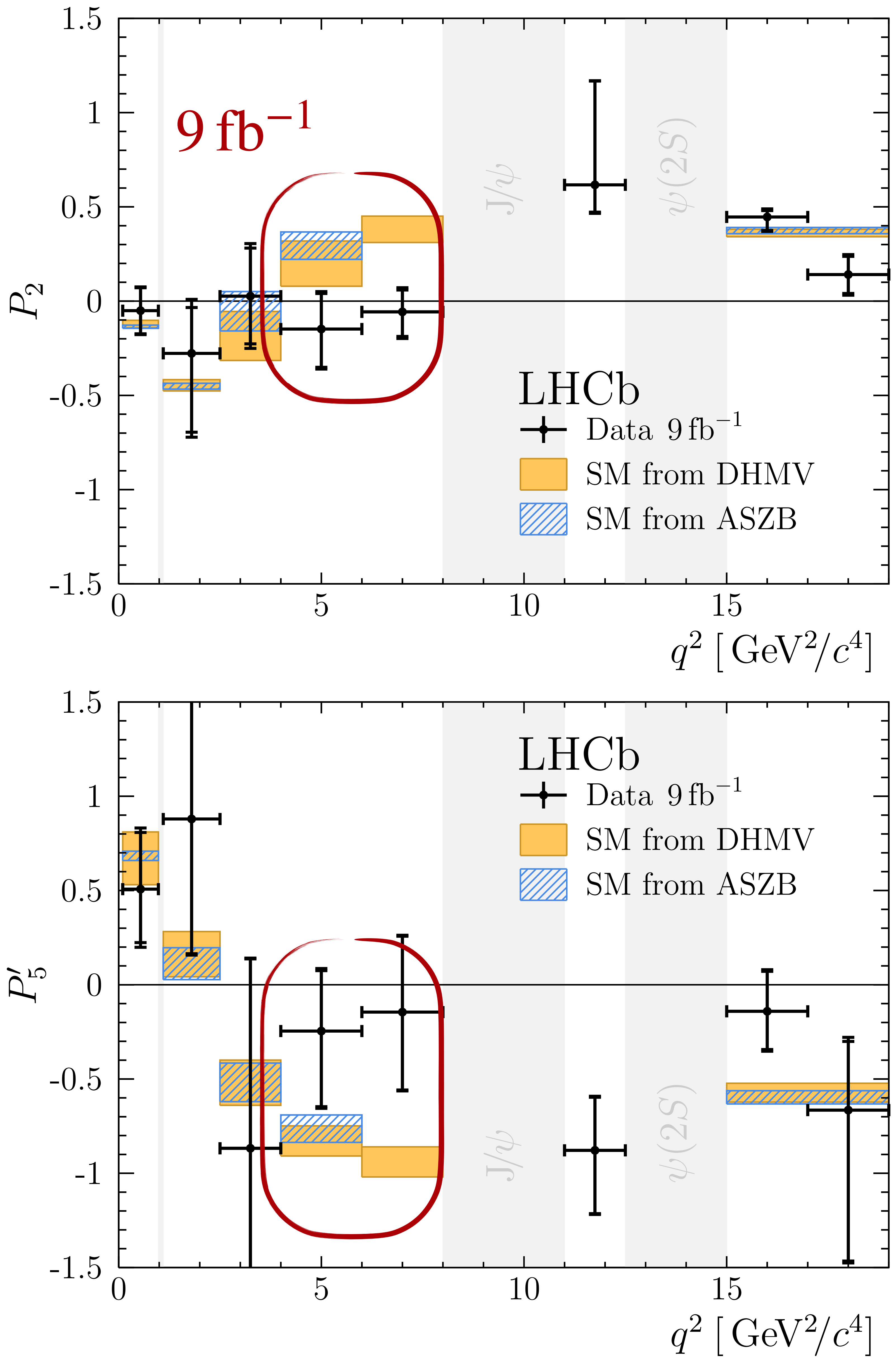
- Update of JHEP 02 (2016) 104
- Same selection as Run1 result, minor changes for 2016
- $P'_i = \dfrac{S_i}{\sqrt{F_L(1-F_L)}}$ observables to reduce FF uncertainties

  $\rightarrow$ non-local uncertainties ($c\bar{c}$ loop) remain
- Simultaneous fit to $[\theta_h, \theta_l, \phi, m(K^+\pi^-\mu^+\mu^-)]$
- S-wave contribution determined with $m(K^+\pi^-)$
- S- and P-wave interference treated as nuisance parameters
- Tension with SM e.g. P'_5

preferred over SM at 3.3σ

$$\Delta\mathrm{Re}(C_9) = -0.99^{+0.25}_{-0.21}$$

$B^+ \to K^{*+}\mu\mu$ Angular analysis

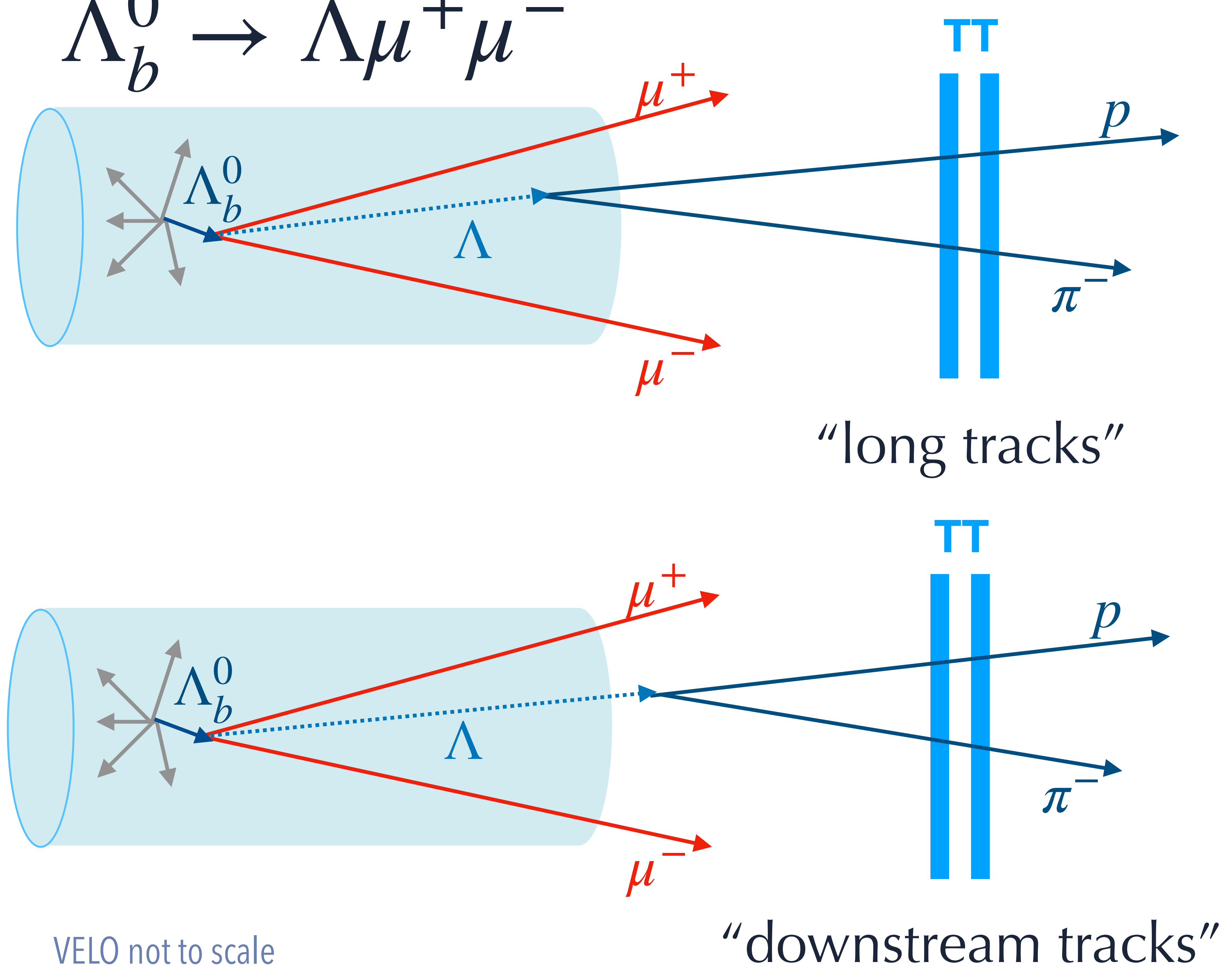


PRL 126, 161802 (2021)

- First measurement of full set of P-wave observables
- S-wave treated as nuisance parameters
- Reconstructed via $B^+ \to K^{*+}(\to K_s^0\pi^+)\mu^+\mu^-$ with $K_s^0 \to \pi^+\pi^-$
  $\to$ lower statistics due to reconstruction of K_s^0
- General good agreement with SM predictions
- P_2 and P_5' show same deviations as in $B^0 \to K^{*0}\mu^+\mu^-$

Electroweak Penguins with Λ_b^0

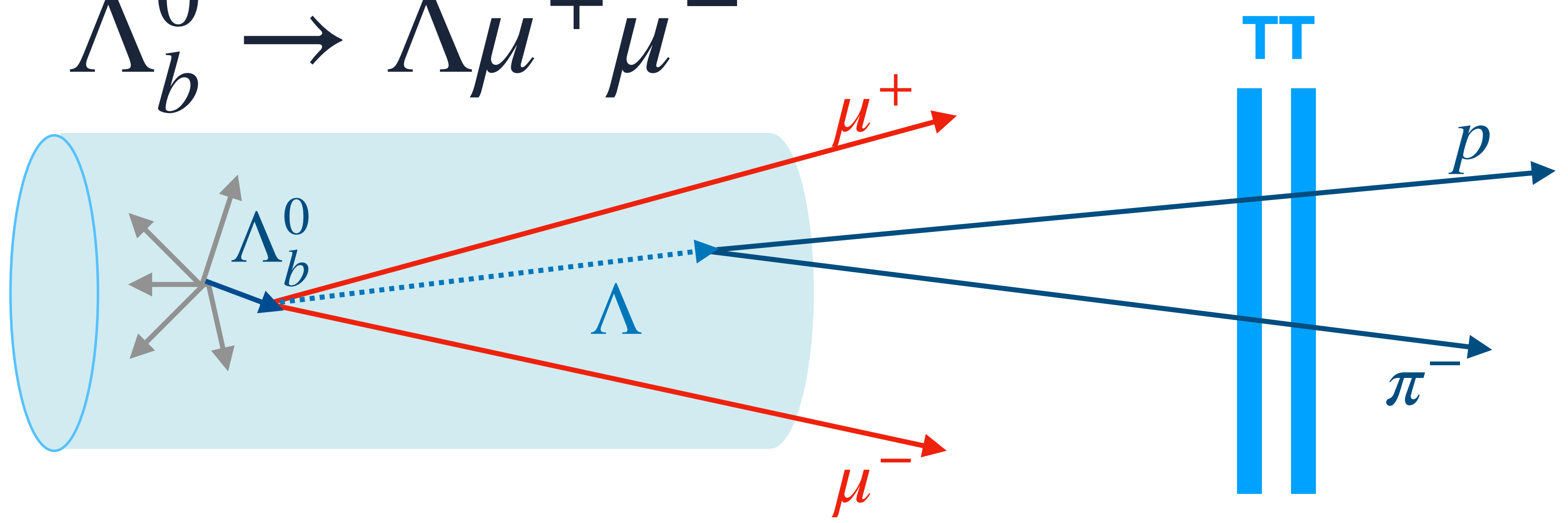
$\Lambda_b^0 \to \Lambda\mu^+\mu^-$



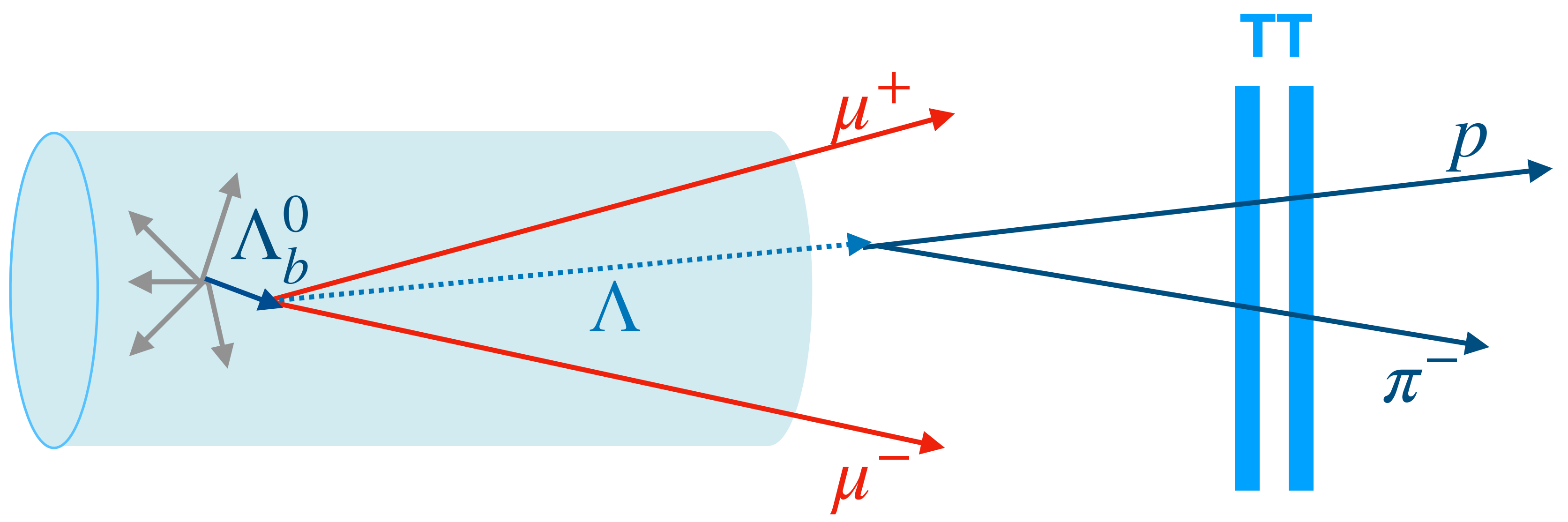
- ✓ Λ weakly-decaying hyperon
- ✗ lower efficiency to detect in acceptance
- ✗ lower efficiency to reconstruct vertex
- ✓ easier theoretical predictions

Electroweak Penguins with Λ_b^0

$\Lambda_b^0 \to \Lambda\mu^+\mu^-$



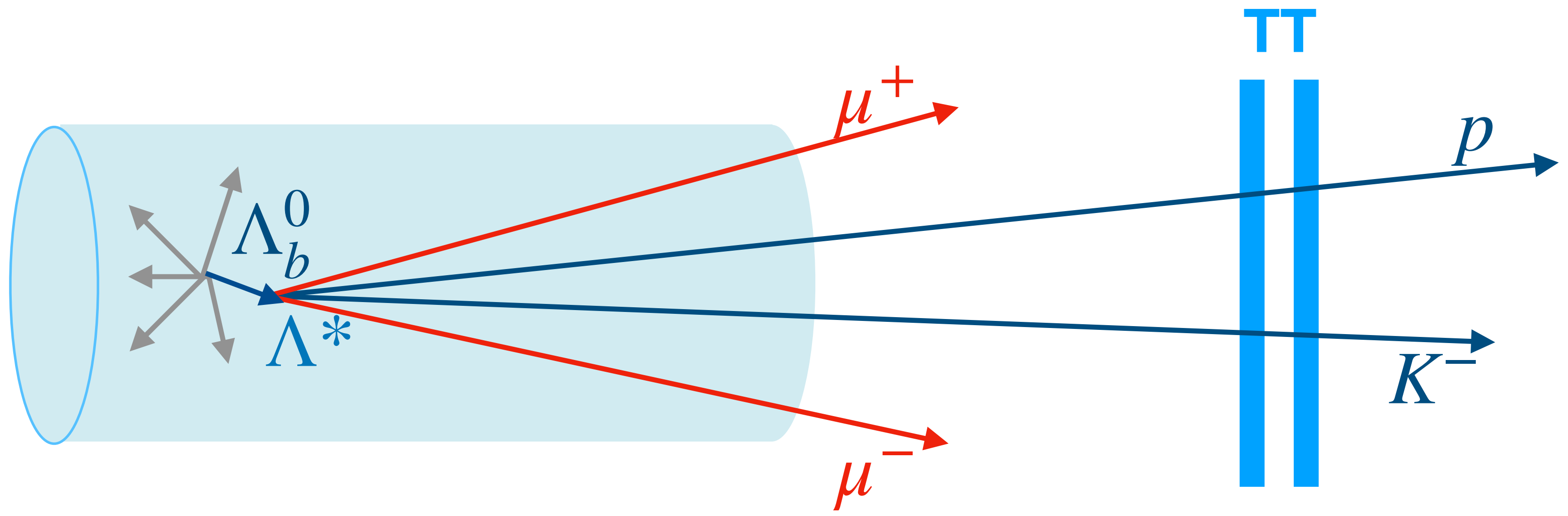
"long tracks"



VELO not to scale

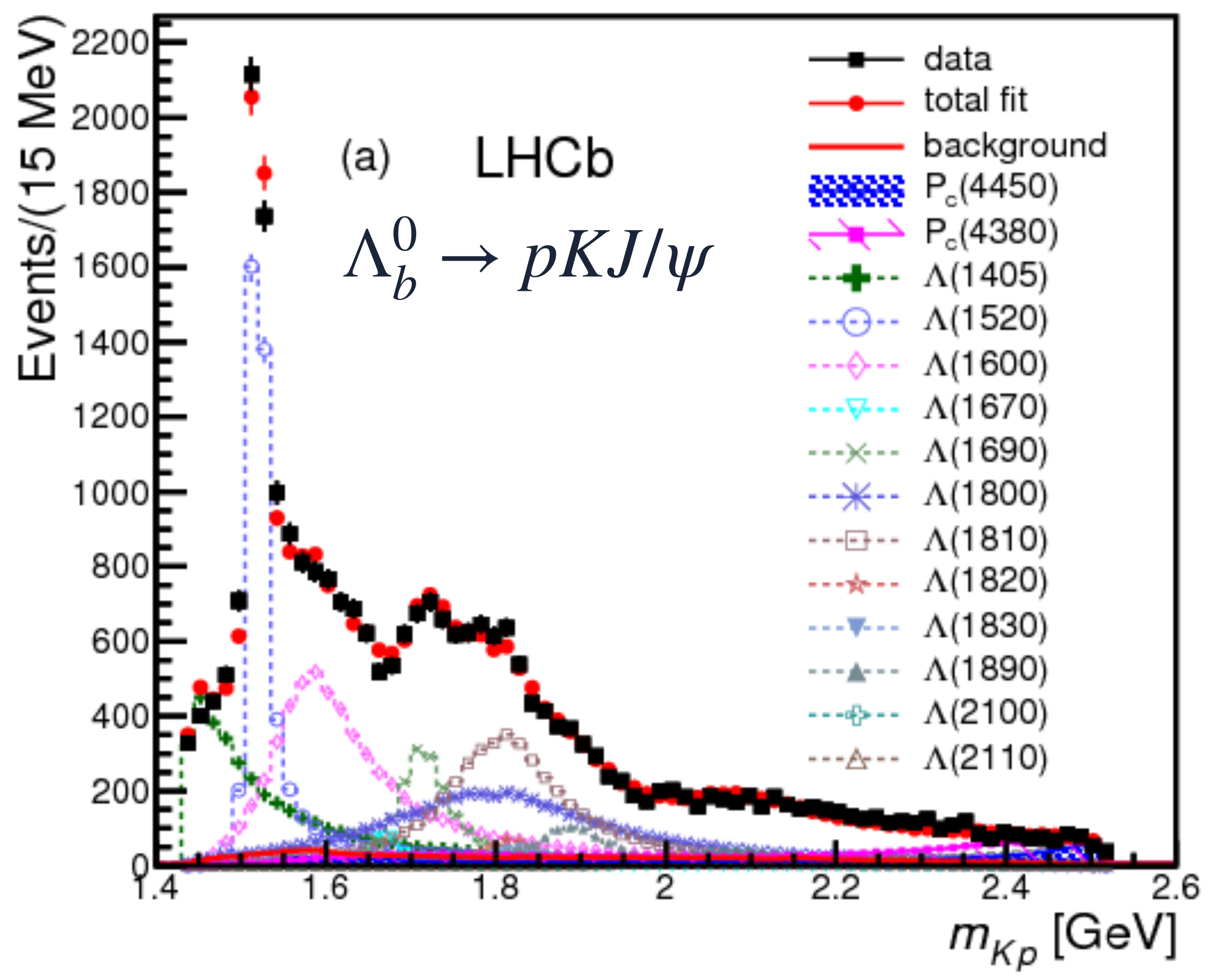
"downstream tracks"

$\Lambda_b^0 \to \Lambda^*\mu^+\mu^-$
$\equiv \Lambda_b^0 \to pK^-\mu^+\mu^-$



"long tracks"

Phys. Rev. Lett. 115, 072001

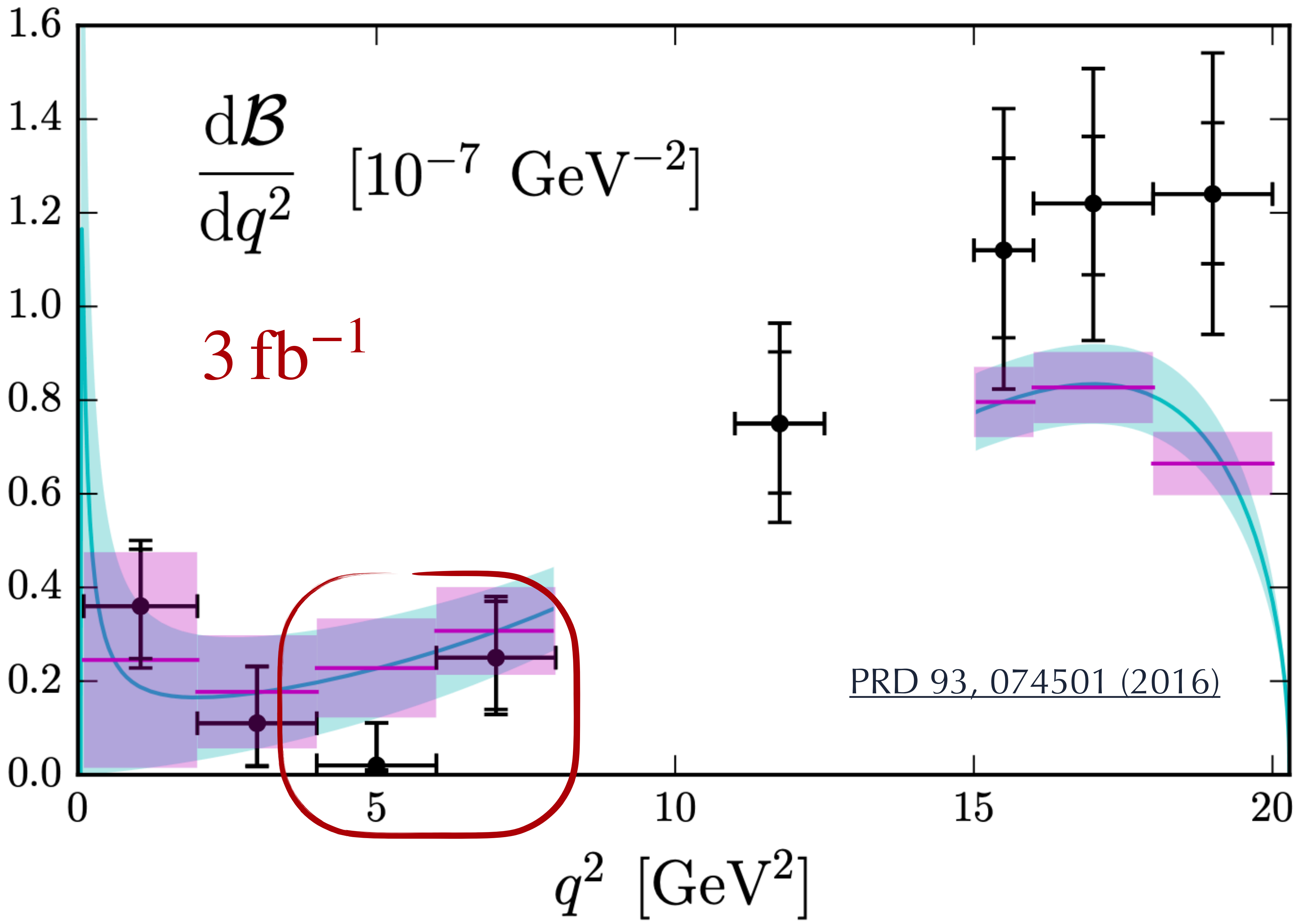


Λ^*: excited states, decay strongly

- ✓ Λ weakly-decaying hyperon
- ✗ lower efficiency to detect in acceptance
- ✗ lower efficiency to reconstruct vertex
- ✓ easier theoretical predictions

- ✗ interferences with other resonances
- ✓ Λ^* always decays in acceptance
- ✓ easy to reconstruct vertex
- ✗ more difficult theoretical interpretation

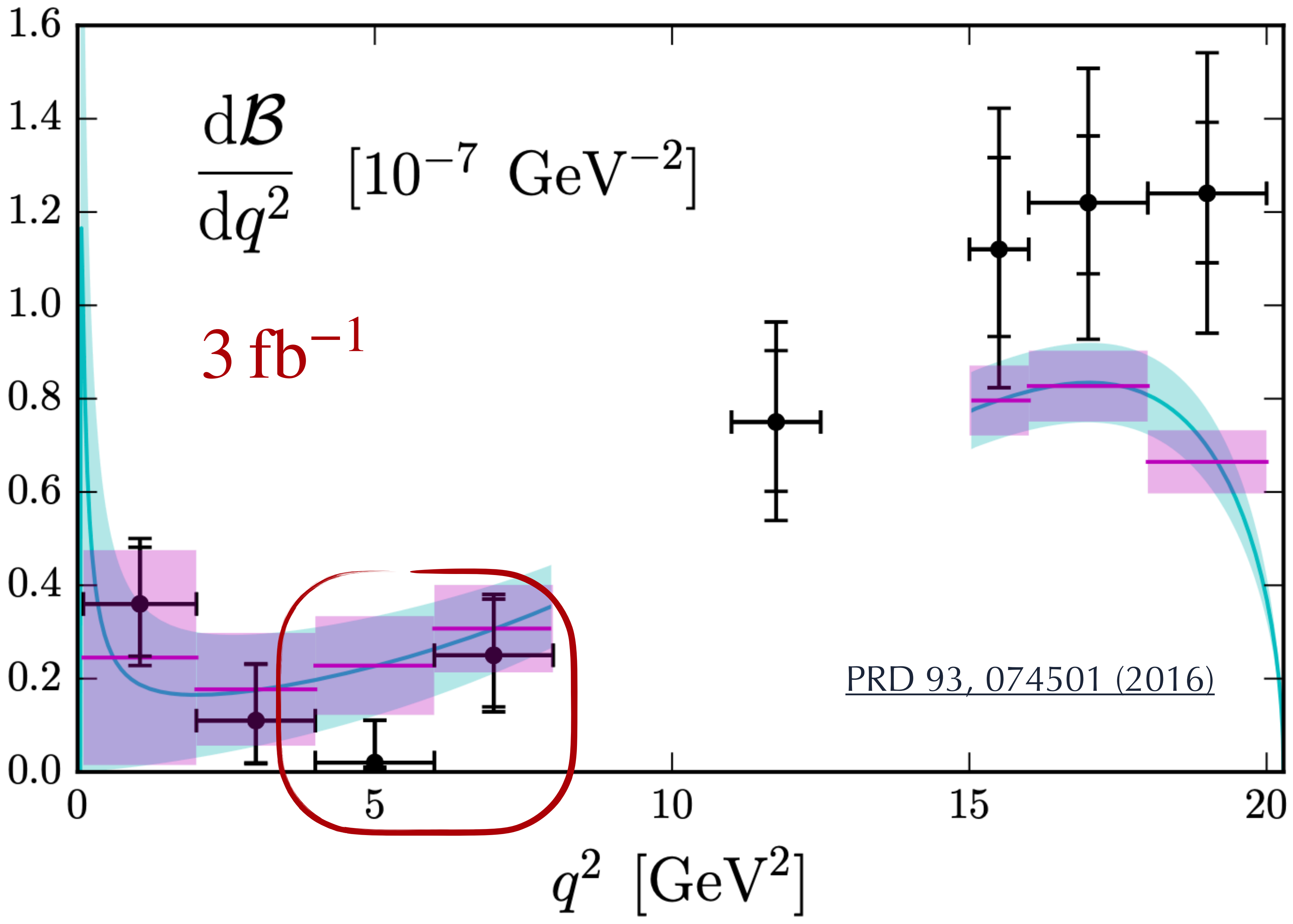
JHEP 06 (2015) 115



- Run 1 analysis with $\Lambda_b^0 \to \Lambda(\to p\pi^-)\mu^+\mu^-$
- Normalised to J/ψ decay
- again deviation in low q2 region
- Dominant syst. uncertainty $B(\Lambda_b^0 \to J/\psi\Lambda)$

Measurements of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$

JHEP 06 (2015) 115



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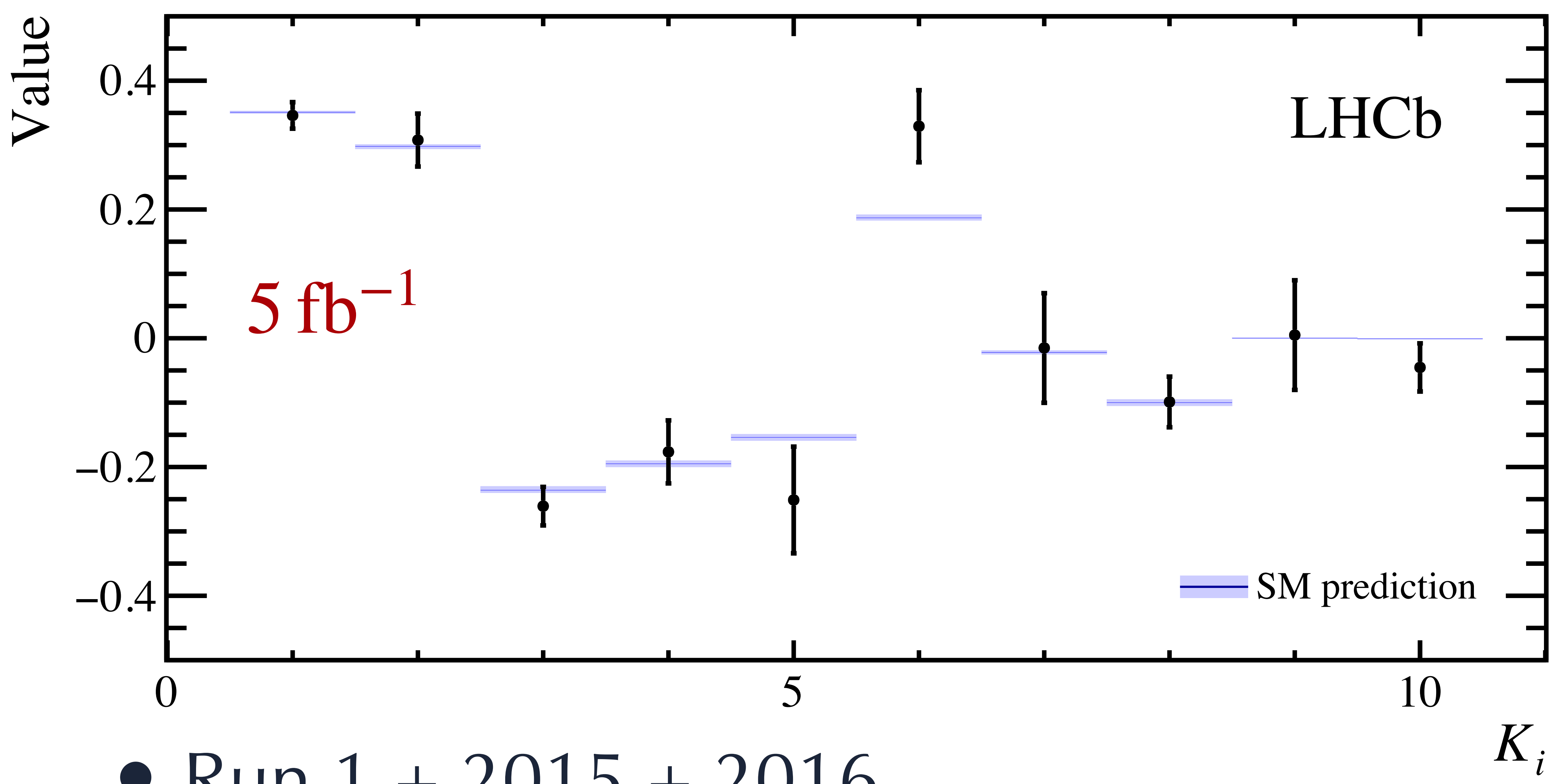
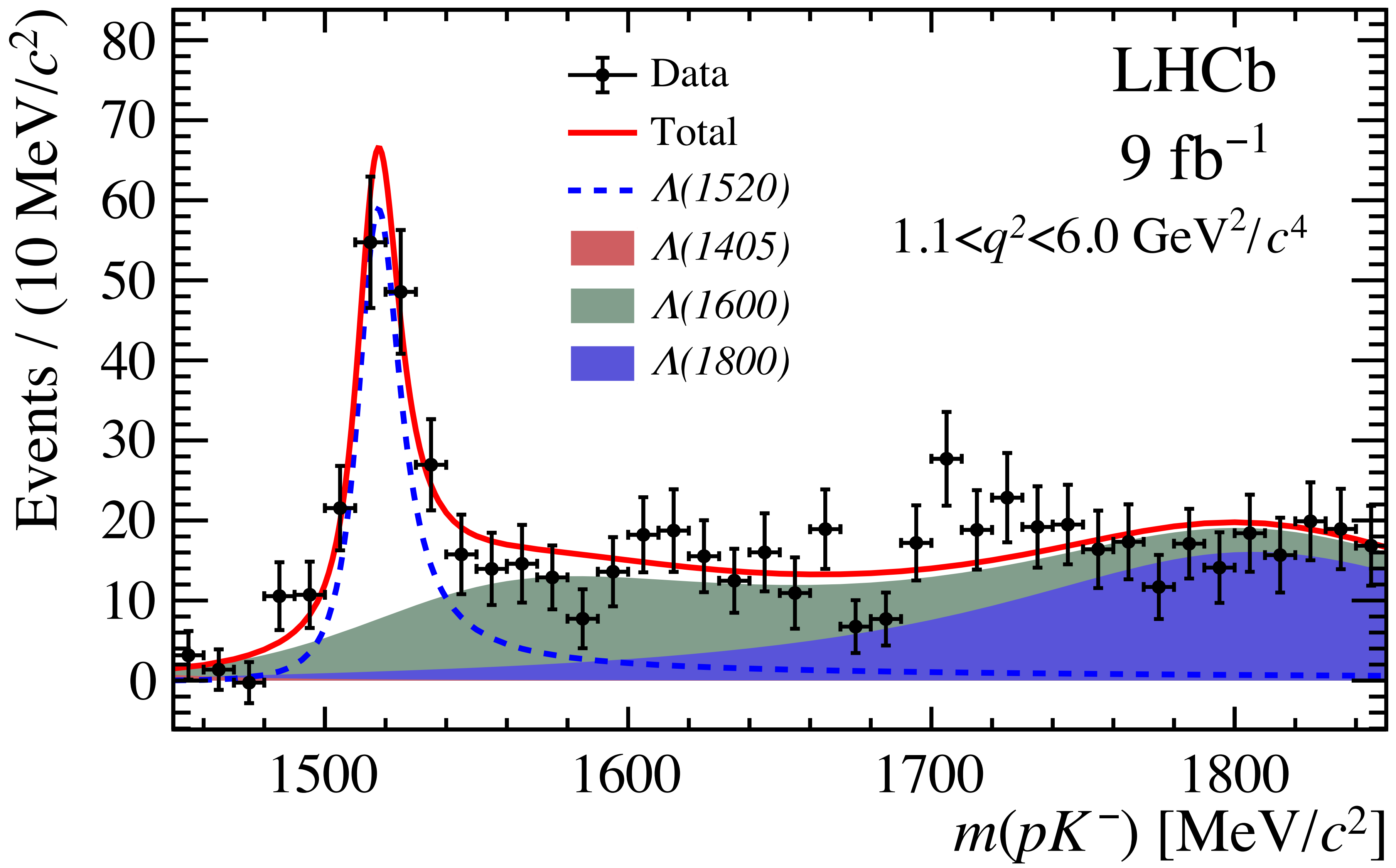
JHEP 09 (2018) 146

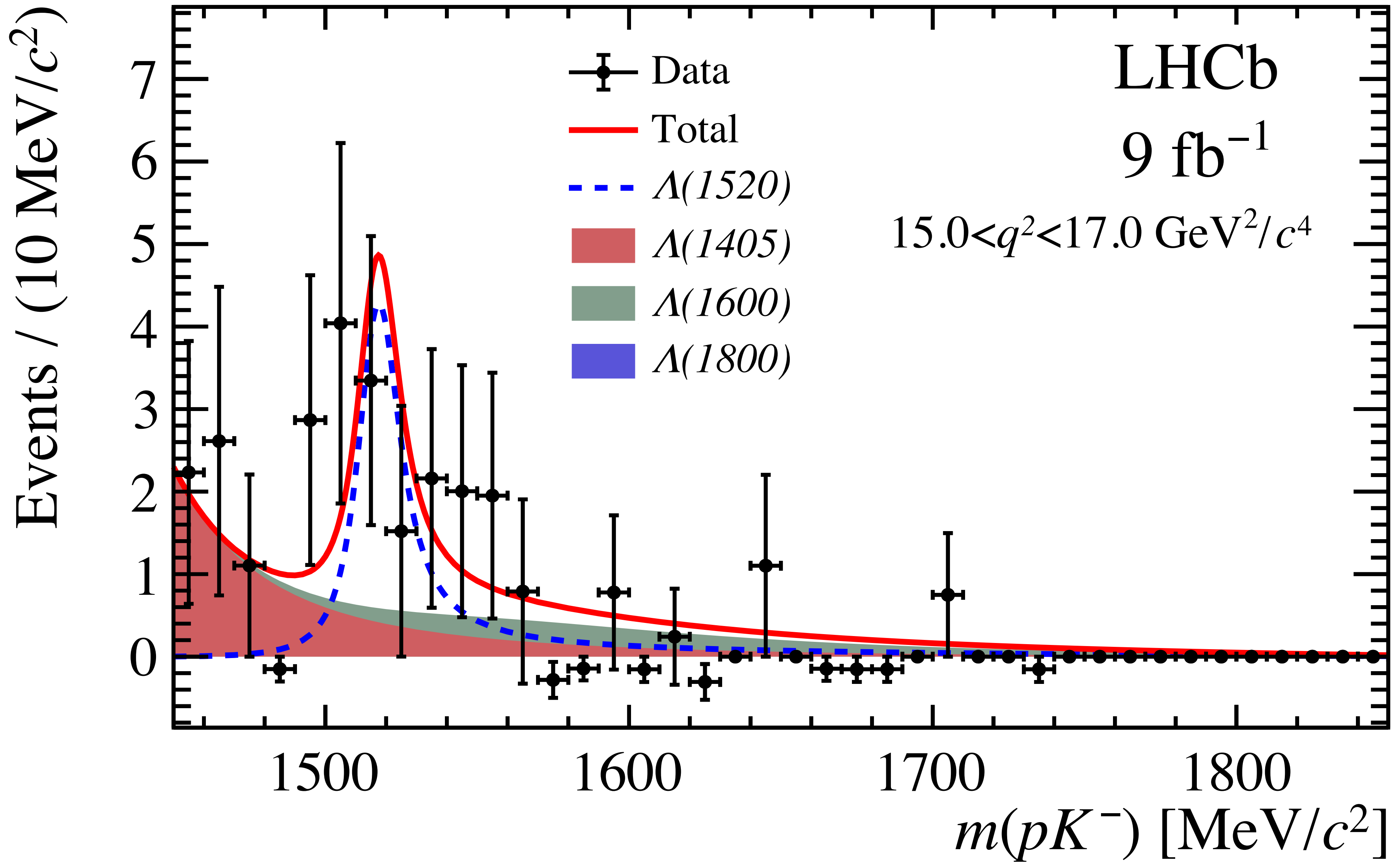


- Run 1 + 2015 + 2016
- Accounting for possible polarised of Λ_b^0
  $\to$ 5 angles: $\theta, \theta_l, \theta_b, \phi_l, \phi_b$
- Method of Moments angular analysis
  $\to$ extracting full basis for first time
- Extracted from high q^2[15,20] GeV$^2/c^4$
- Consistent with SM

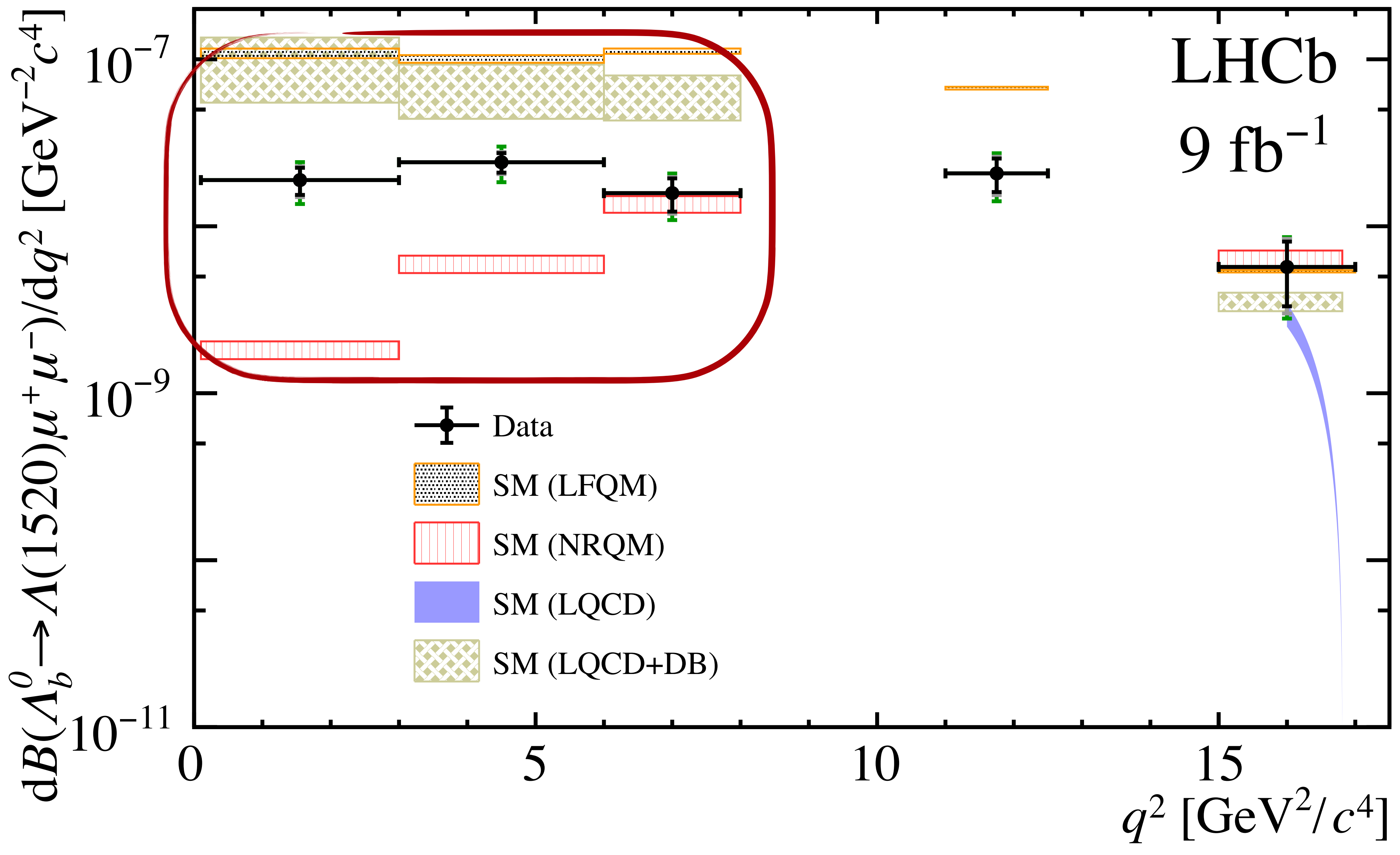
Differential $B(\Lambda_b^0 \to \Lambda(1520)\mu^+\mu^-)$

arXiv:2302.08262 Accepted by PRL





- First measurement of rare decay with $\Lambda(1520) \to pK^-$ resonance
- Normalised to $\Lambda_b^0 \to pK^- J/\psi$
- Narrow $\Lambda(1520)$ width ~16 MeV
- High-q^2 consistent with SM, low-q^2 inconclusive



Electroweak Penguins

- Several results in semi-leptonic $b \to s\mu^+\mu^-$ constraining NP
- Tensions with SM persist in decay rates and angular observables
- More results for LFU und LFV in A. López Huertas talk
- Also measurements with $b \to d\mu^+\mu^-$ decays

  e.g. $B^\pm \to \pi^\pm\mu^+\mu^-$ JHEP 10 (2015) 034, $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ JHEP 04 (2017) 029
- New measurement and more results updating to full Run 1+2 on the way

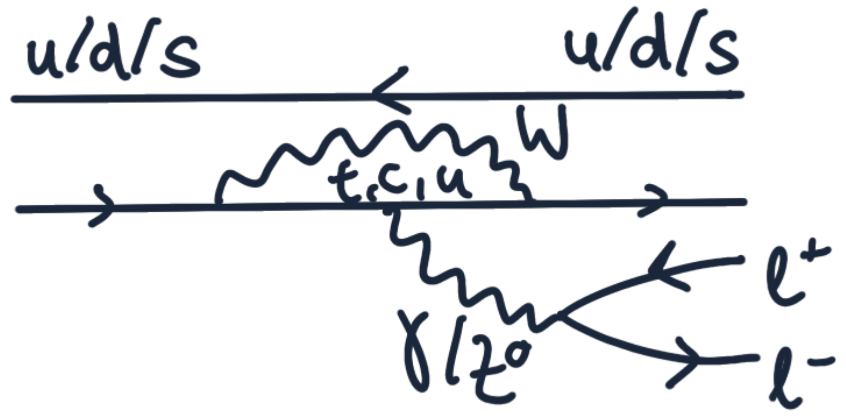
More data will become available with Run 3. Still statistically dominated, so stay tuned!

Backup

Which decays to study

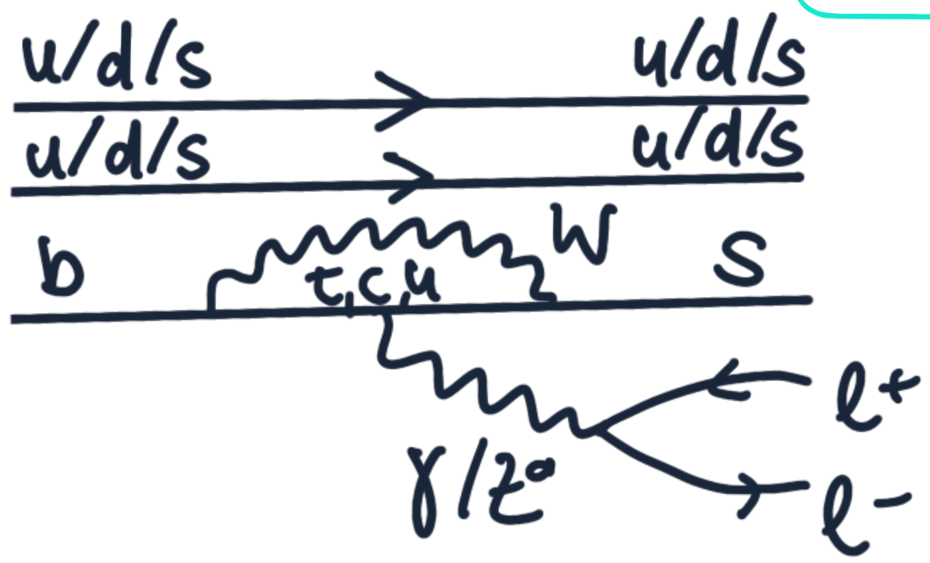
Mesons

$0 \to 0$	$0 \to 1$	$0 \to 2$
$B \to K\ell^+\ell^-$	$B \to K^*\ell^+\ell^-$	$B \to K_2^*(1430)\ell^+\ell^-$
$B_s \to f_0(980)\ell^+\ell^-$	$B_s \to \phi\ell^+\ell^-$	$B_s \to f_2(1525)\ell^+\ell^-$



Baryons

$1/2 \to 1/2$	$1/2 \to 3/2$	$1/2 \to 5/2$
$\Lambda_b^0 \to \Lambda\ell^+\ell^-$	$\Lambda_b^0 \to \Lambda^*(1520)\ell^+\ell^-$	$\Lambda_b^0 \to \Lambda^*(1820)\ell^+\ell^-$
$\Xi_b \to \Xi\ell^+\ell^-$	$\Xi_b \to \Xi^*(1820)\ell^+\ell^-$	
	$\Omega_b^- \to \Omega^-\ell^+\ell^-$	



'narrow' final state hadron

→ easy to select

'broad' final state hadron

→ interferences of overlapping states

weakly-decaying final state

→ easier theoretical interpretation

Testing different spin configurations

Weekly-decaying hadrons rich angular structure

Angle definition

Example for $B_s^0 \to \phi\mu^+\mu^-$

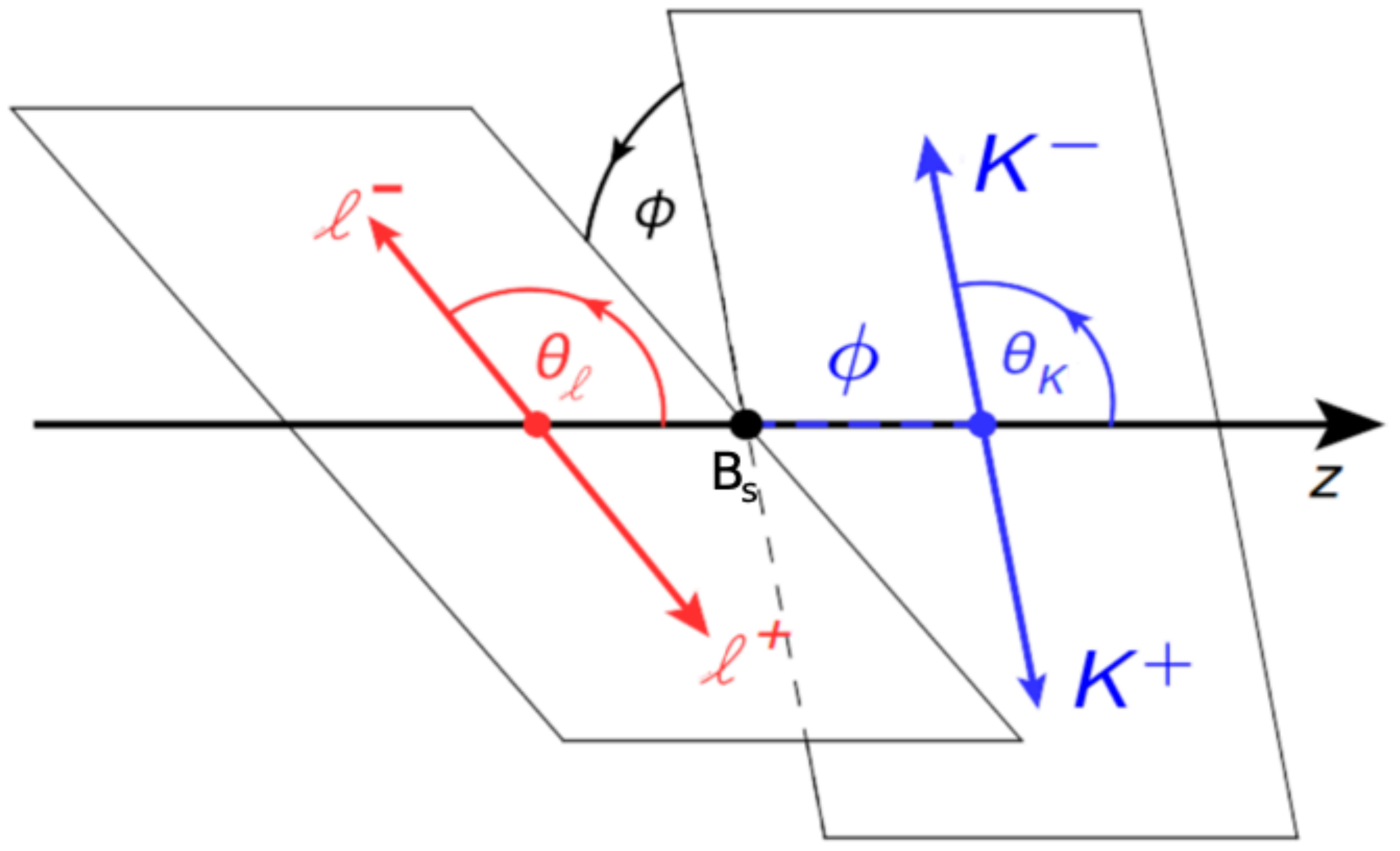


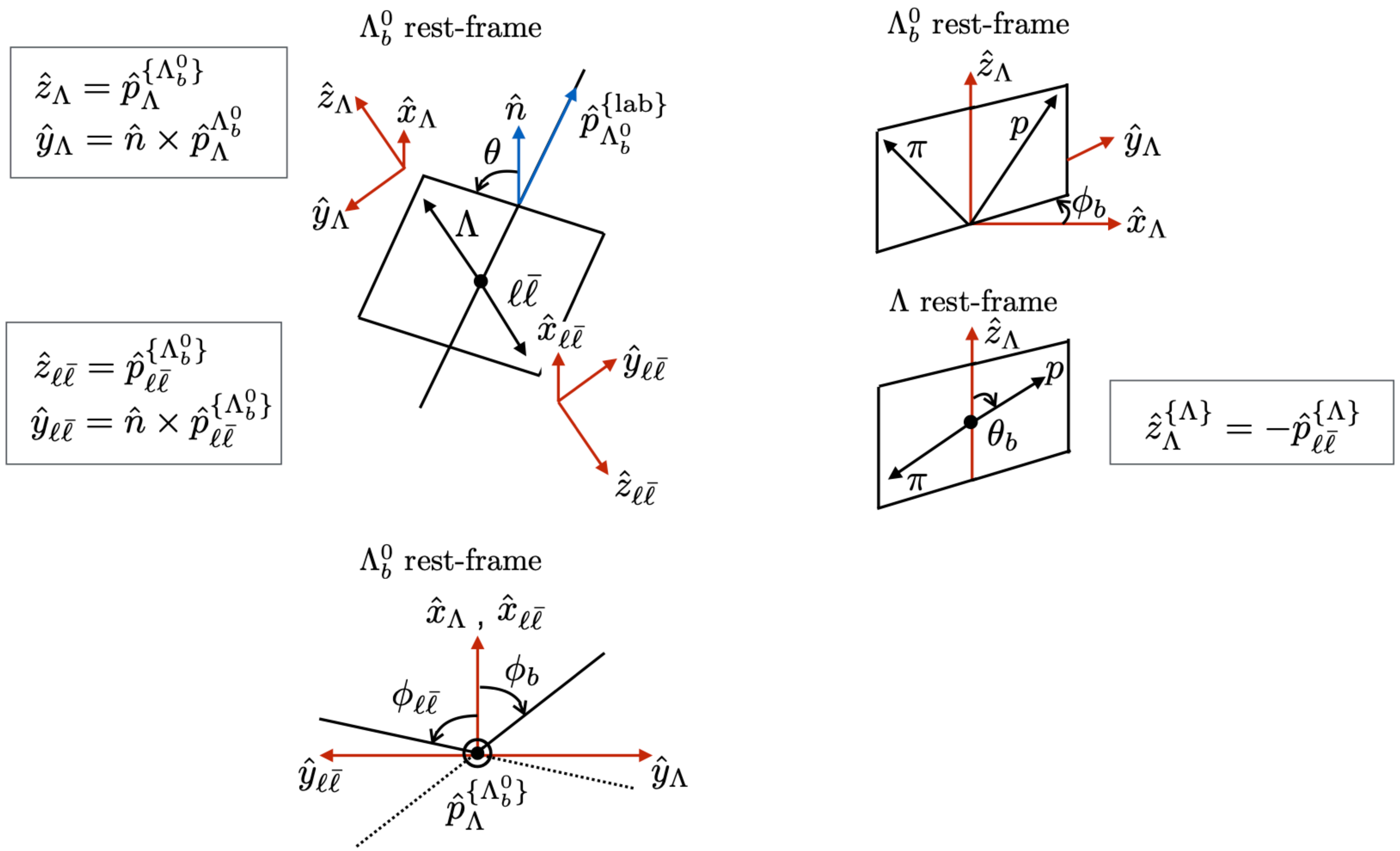
Figure 2: Schematic of the three decay angles, θ_K, θ_l and ϕ.

θ_K: angle between the daughter particles of the strange hadron

θ_l: angle between the two leptons

ϕ: angle between lepton and hadron plane

Example for $\Lambda_b^0 \to \Lambda\mu^+\mu^-$



5 angles reduce to 3 again for unpolarised Λ_b^0.
No polarisation supported by LHCb, CMS and ATLAS measurements