

LHCb results on electroweak penguin decays

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CKM 2021, Melbourne (virtual), 22nd-26th Nov 2021

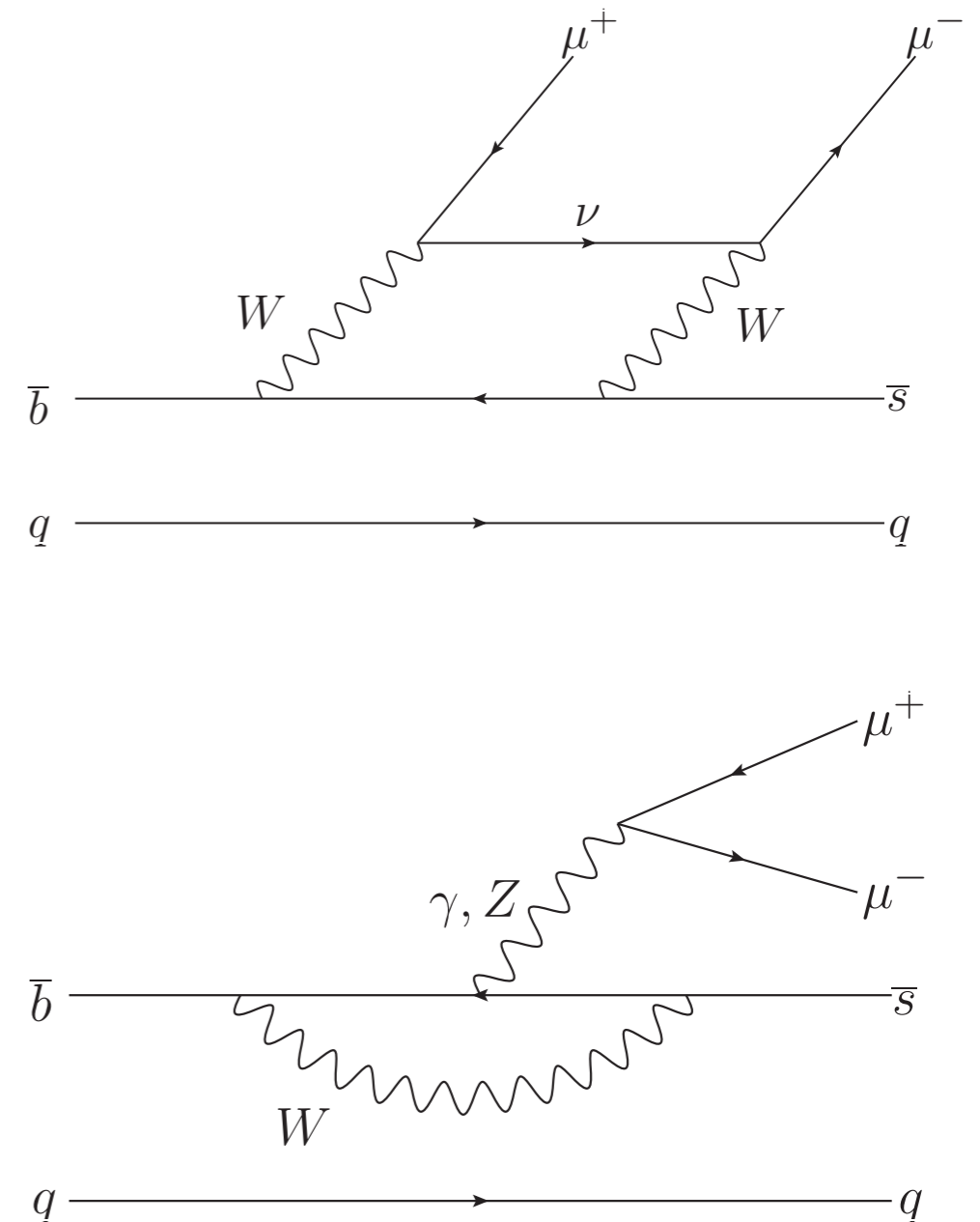
- See also other related talks:
 - Renato Quagliani: Lepton flavour violation in RD (Thu)
 - Francesco Dettori: Very rare B decays (Tue)
 - Carla Marin Benito: Radiative B decays (Wed)



WARWICK

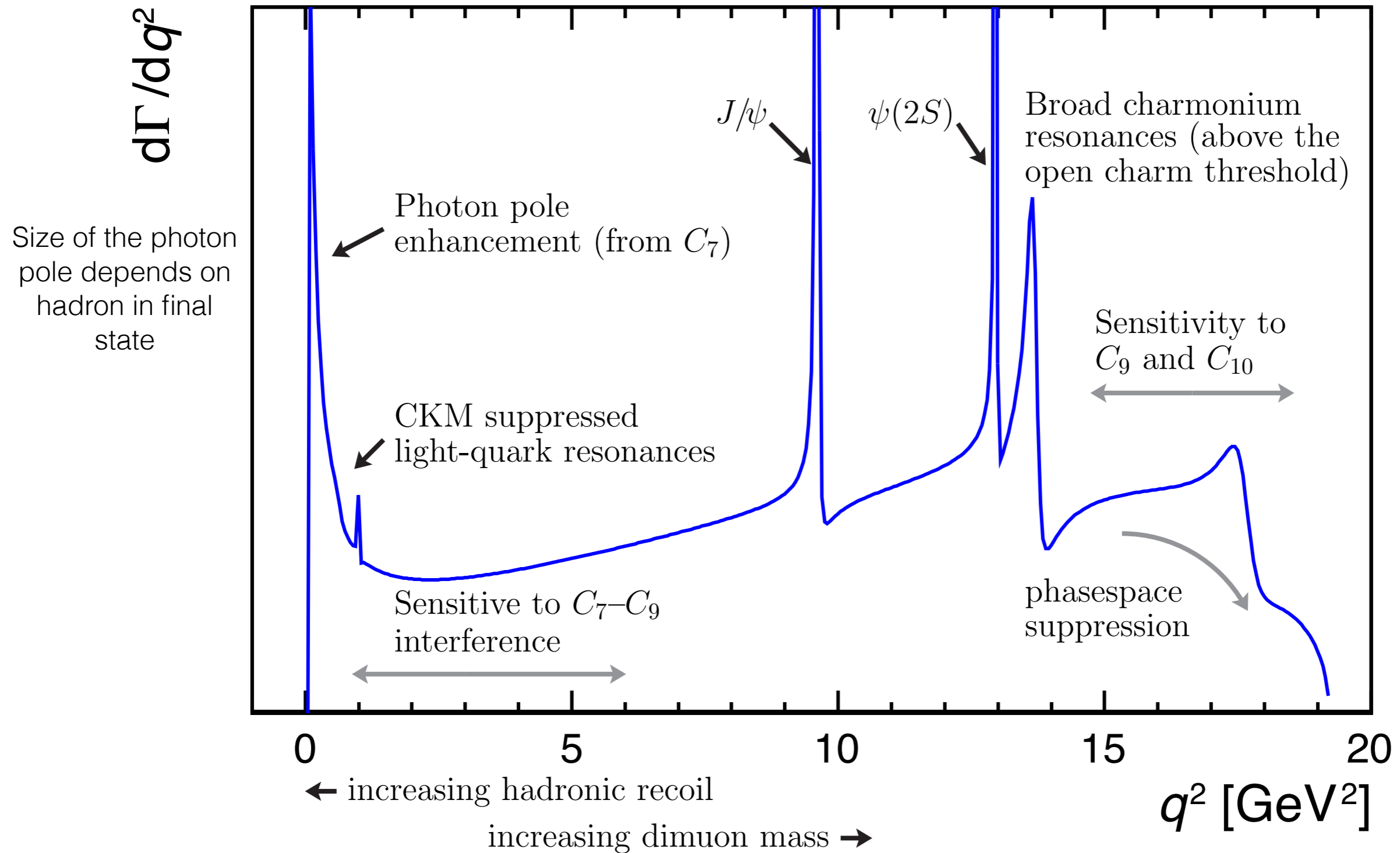


- In the SM, $b \rightarrow sll$ cannot happen at tree level
- FCNC decays through loop diagrams
- SM predicts BF of the order 10^{-6}
- Typically such decays have complex angular structure offering variety of observables
 - Precision of SM prediction varies depending on sensitivity to form factors
- Sensitive probe of NP contribution
- Many intriguing measurements in the past



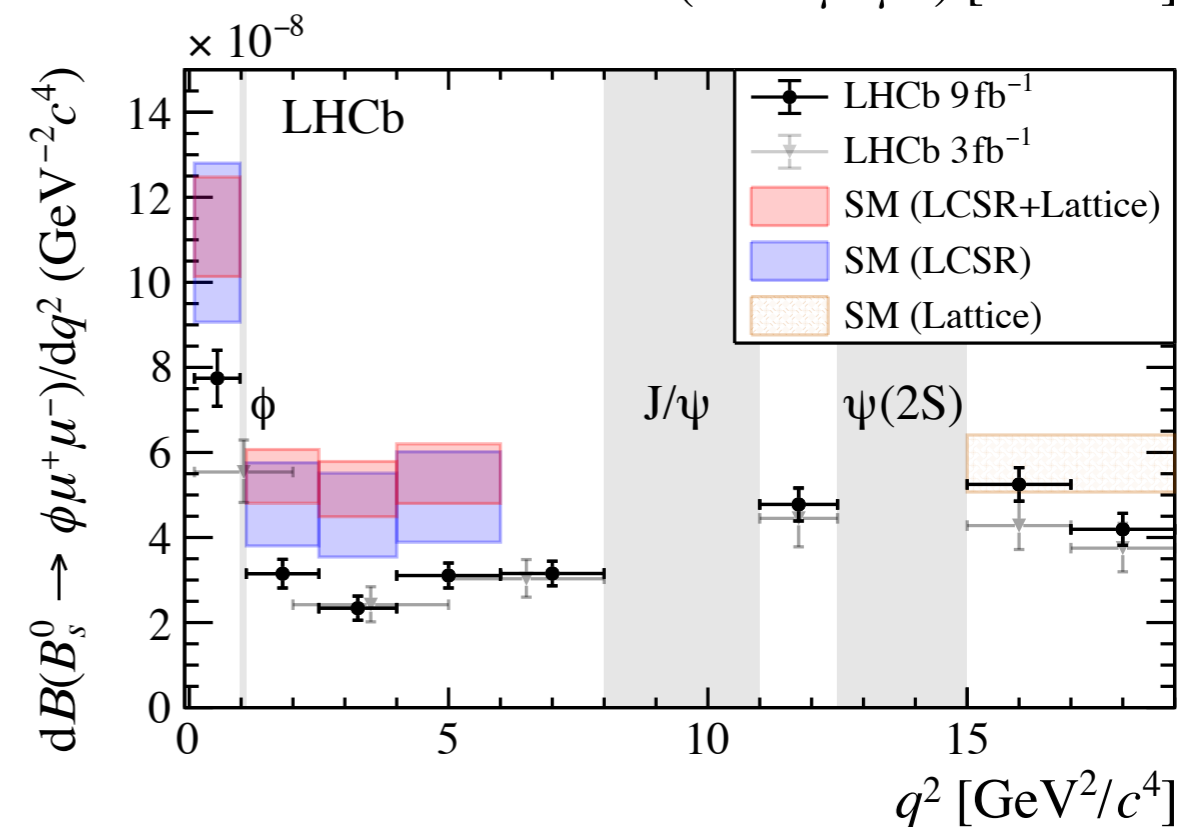
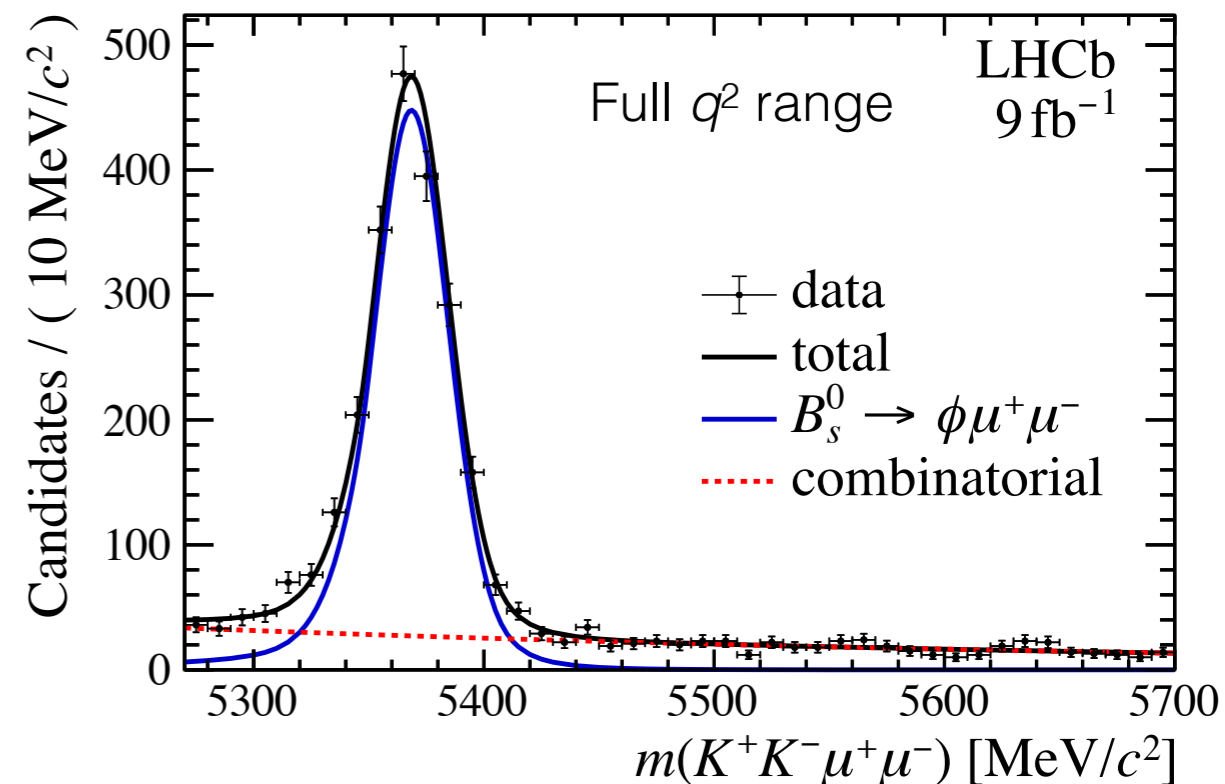
Typical q^2 spectrum

Prog. Part. Nucl. Phys. 92 (2017) 50



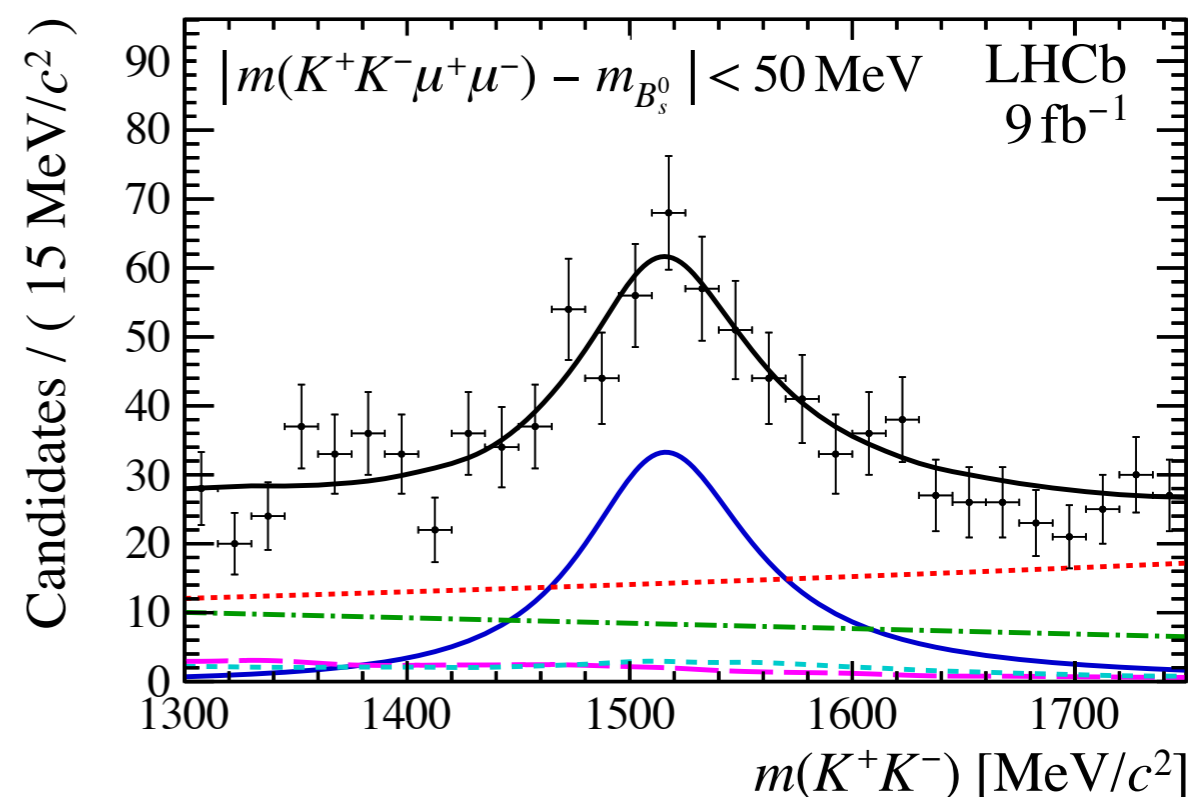
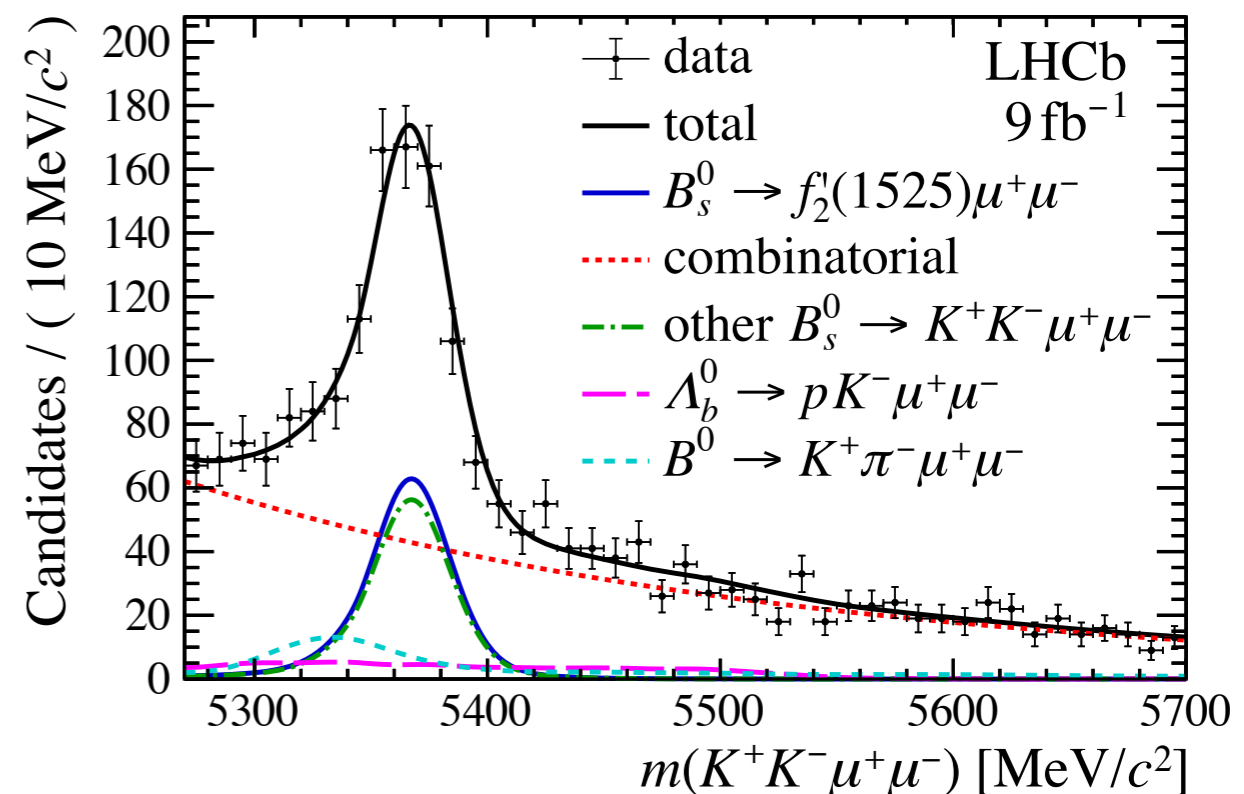
$B_s \rightarrow \phi\mu\mu$ differential BF

- Past measurements below SM
- Measured relative to $B_s \rightarrow J/\psi\phi$
- About 2000 signal events observed in the full q^2 range
 - Efficiency of q^2 veto is $(65.47 \pm 0.27)\%$
- Integrated BF is $(8.14 \pm 0.21 \pm 0.16 \pm 0.03 \pm 0.39) \times 10^{-7}$
- Dominant systematic uncertainties: physics model, simulation sample size and normalisation mode BF
- In q^2 between 1.1 and 6.0 GeV^2 measurement deviates by 3.6σ from the SM (LCSR+Lattice)



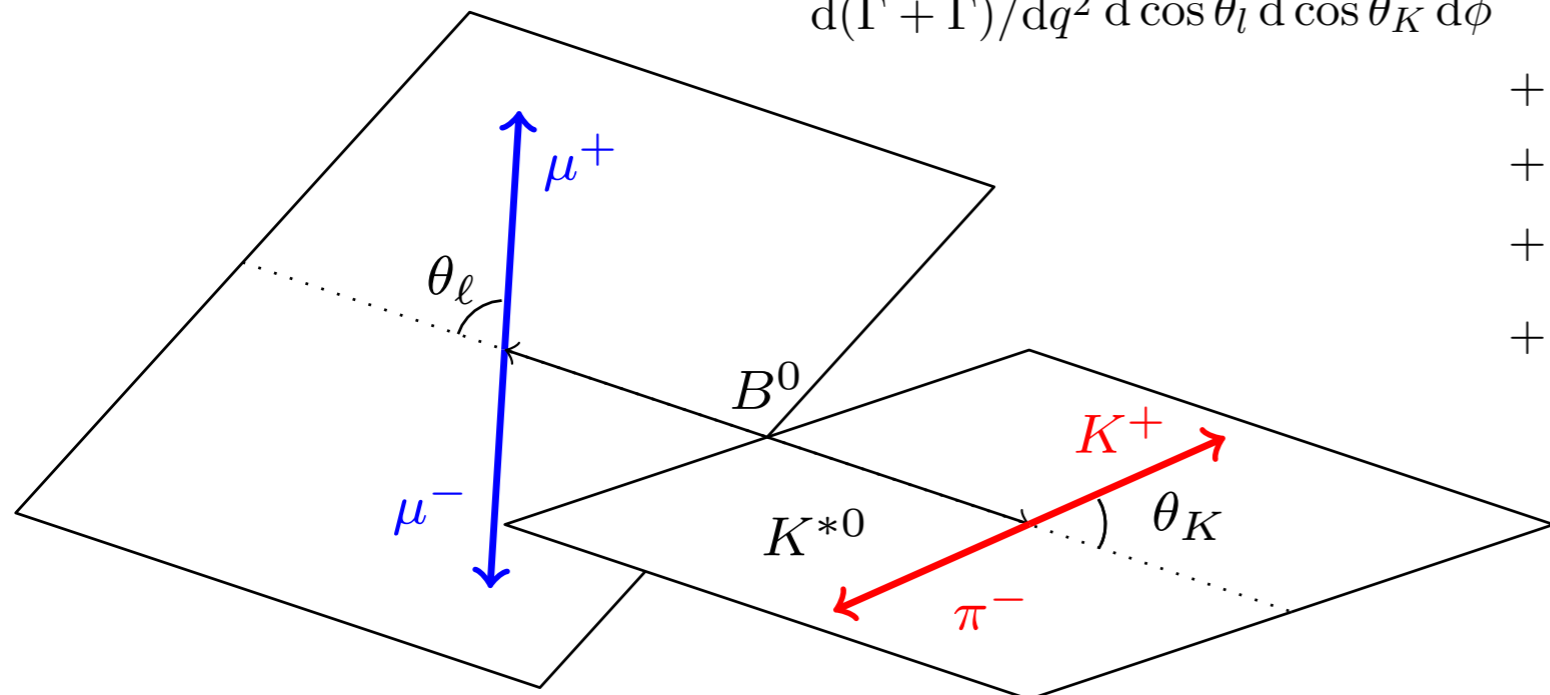
$B_s \rightarrow f_2'(1525)\mu\mu$ observation

- Lower statistics, so all q^2 combined
 - $[0.1, 0.98] \cup [1.1, 8.0] \cup [11.0, 12.5] \text{ GeV}^2$
- Two-dimensional fit to $m(KK\mu\mu)$ and $m(KK)$
- Signal yield 290 ± 23
- Statistical significance 9σ
 - Negligible effect from systematic
- Dominant systematic from external BF and modelling of $m(KK)$
- Measured BF
 $(1.57 \pm 0.19 \pm 0.06 \pm 0.06 \pm 0.08) \times 10^{-7}$
- Consistent with SM



$B \rightarrow Vll$ angular analysis

- Kinematics of $B \rightarrow Vll$ decays can be described by q^2 and 3 angles
- They typically have complex angular structure
- This gives access to different operators in effective Hamiltonian
- Self-tagging decays access CP average observables
- Self-conjugated decays access some CP average (S) and some CP asymmetry (A) observables

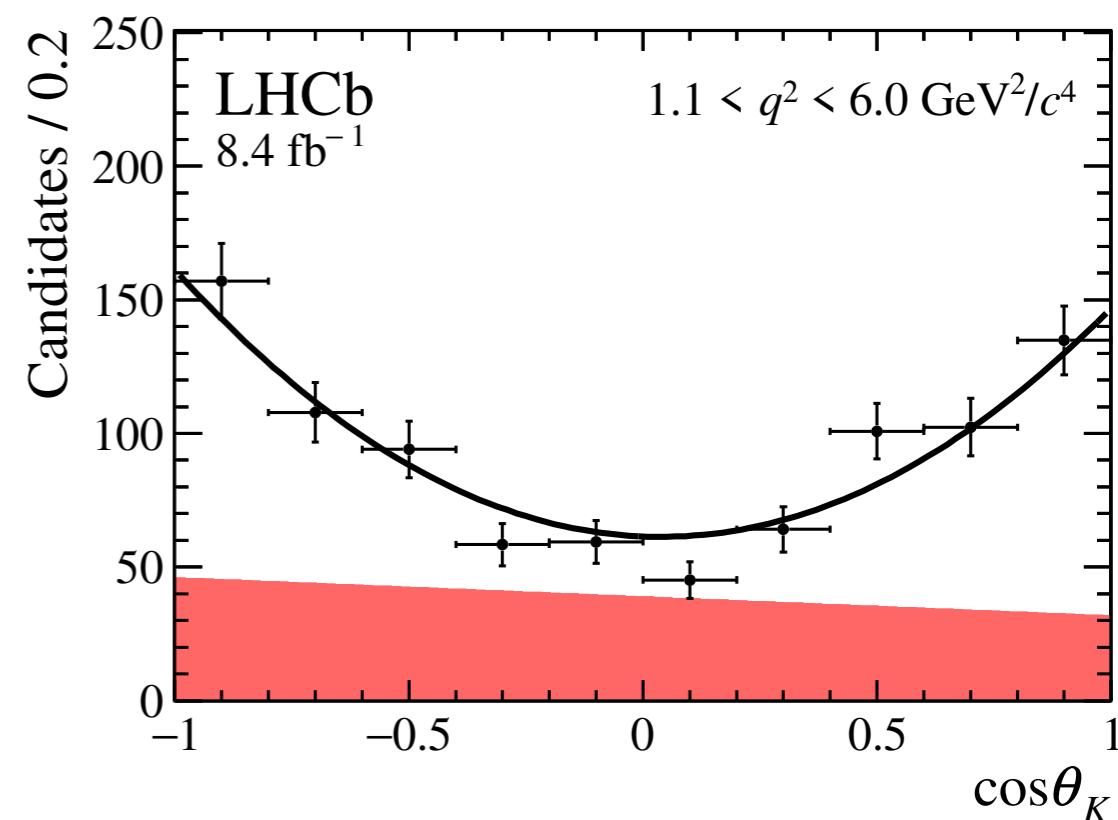
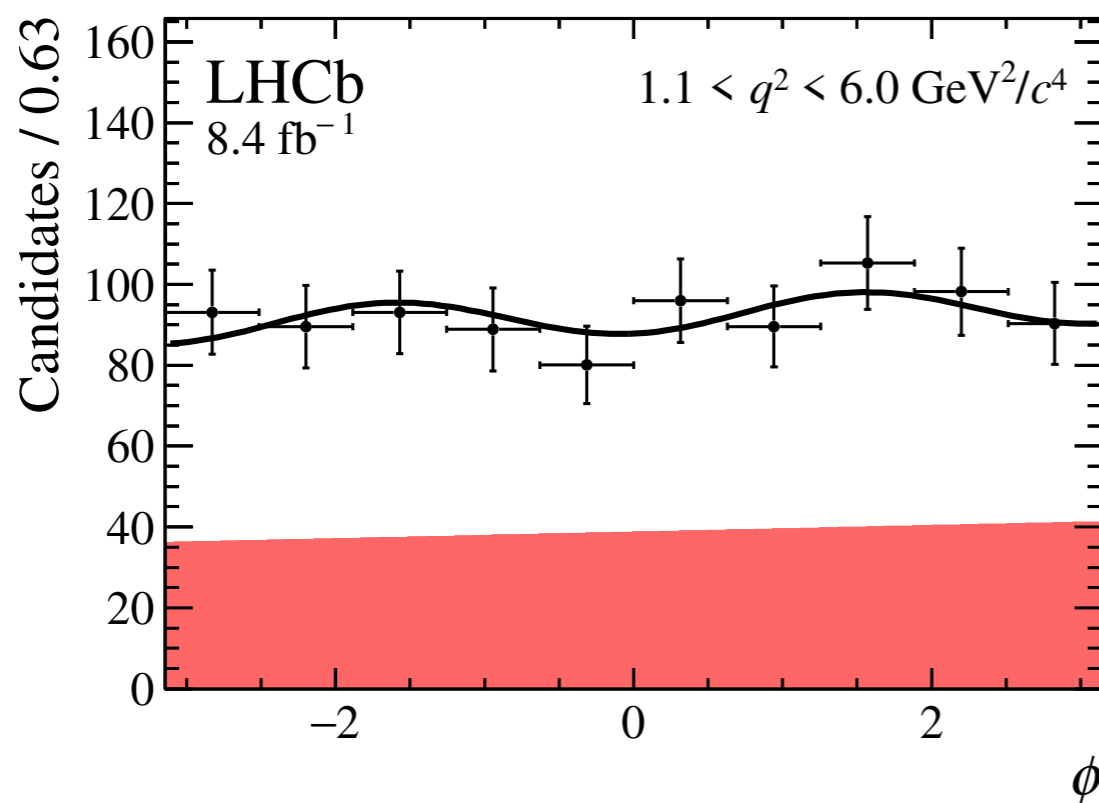
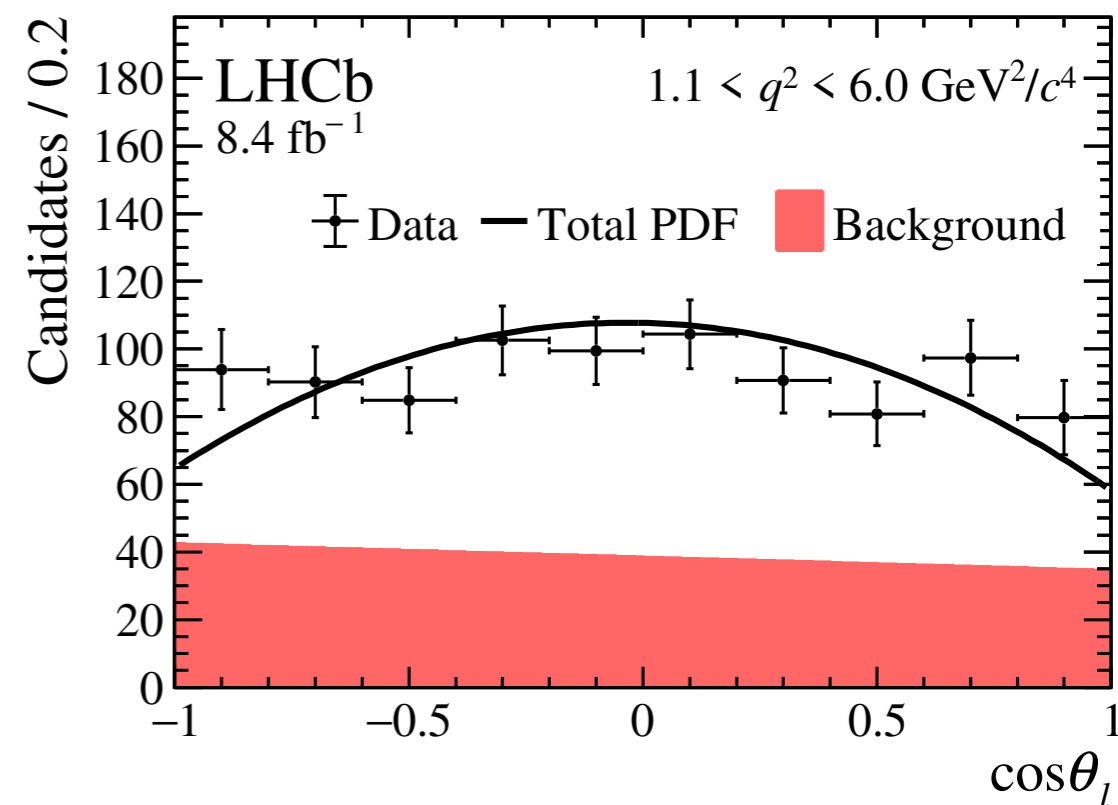


$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^3(\Gamma + \bar{\Gamma})}{d \cos \theta_l d \cos \theta_K d \phi} = \frac{9}{32\pi} \left[\frac{3}{4}(1 - F_L) \sin^2 \theta_K (1 + \frac{1}{3} \cos 2\theta_l) \right. \\ + F_L \cos^2 \theta_K (1 - \cos 2\theta_l) + S_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi \\ + S_4 \sin 2\theta_K \sin 2\theta_l \cos \phi + A_5 \sin 2\theta_K \sin \theta_l \cos \phi \\ + \frac{4}{3} A_{\text{FB}}^{CP} \sin^2 \theta_K \cos \theta_l + S_7 \sin 2\theta_K \sin \theta_l \sin \phi \\ \left. + A_8 \sin 2\theta_K \sin 2\theta_l \sin \phi + A_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi \right]$$



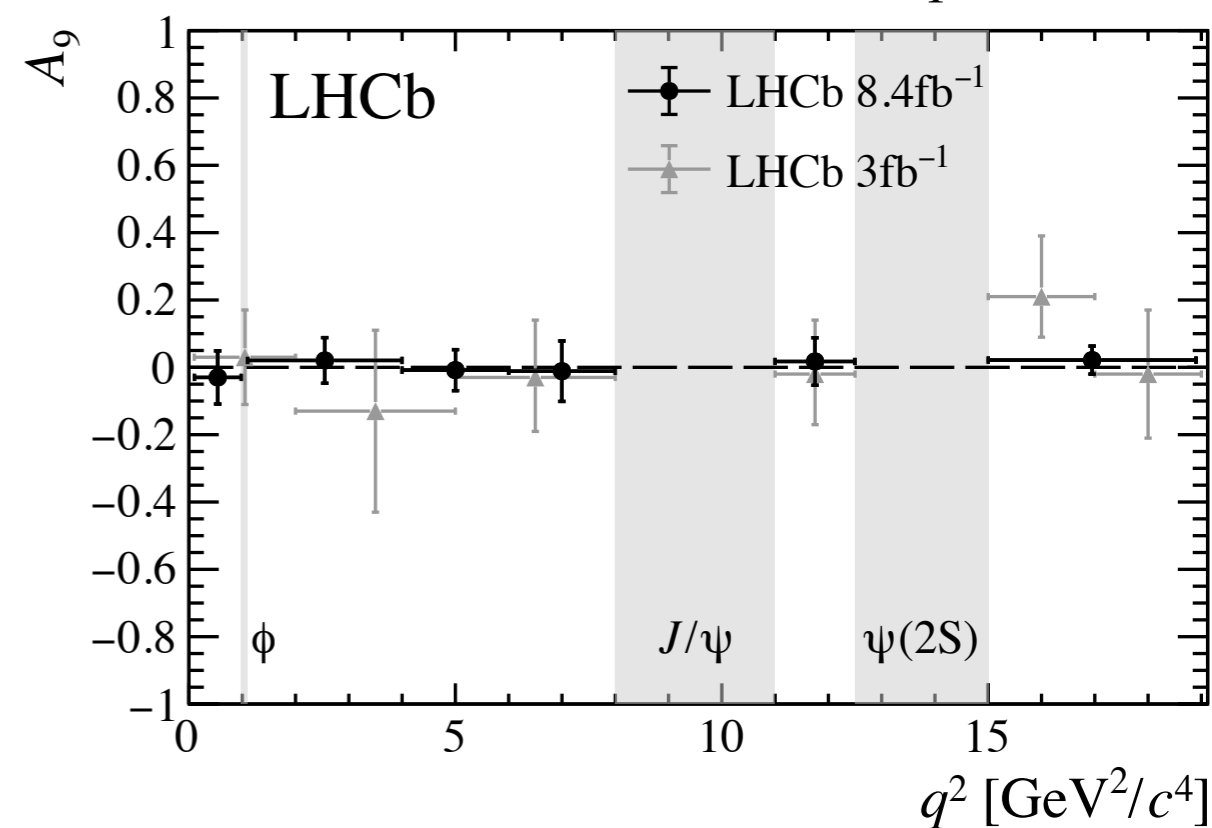
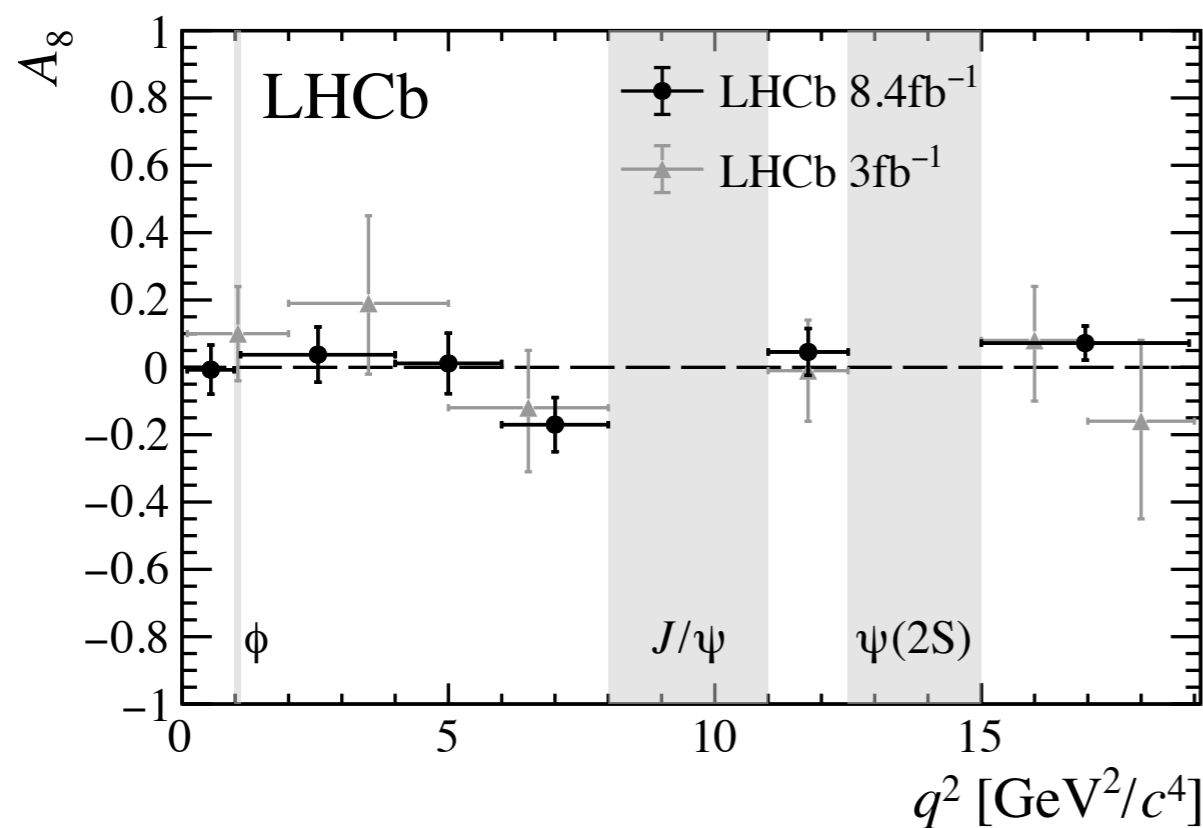
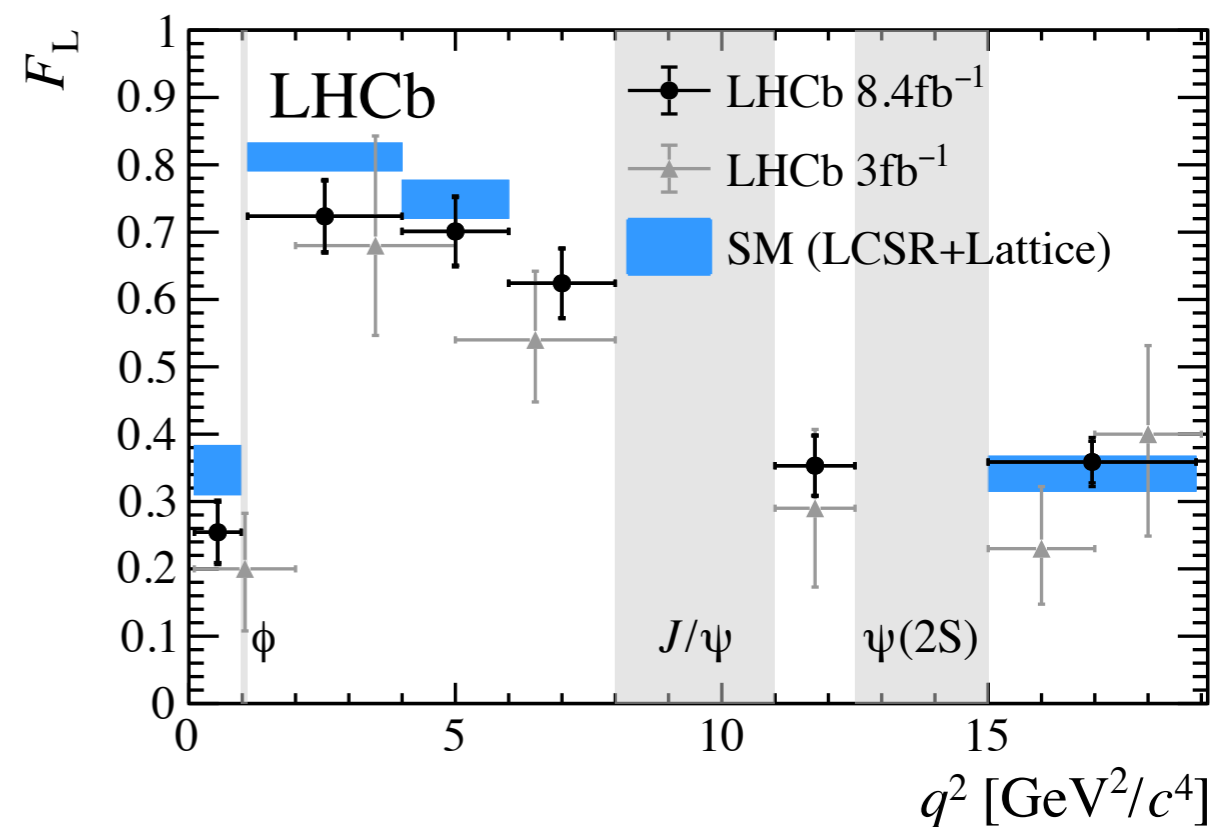
$B_s \rightarrow \phi\mu\mu$ angular analysis

- Same selection as BF analysis
- Analysis performed in q^2 intervals
- Self-conjugated, some terms measure CP asymmetry
- Angular projections well described



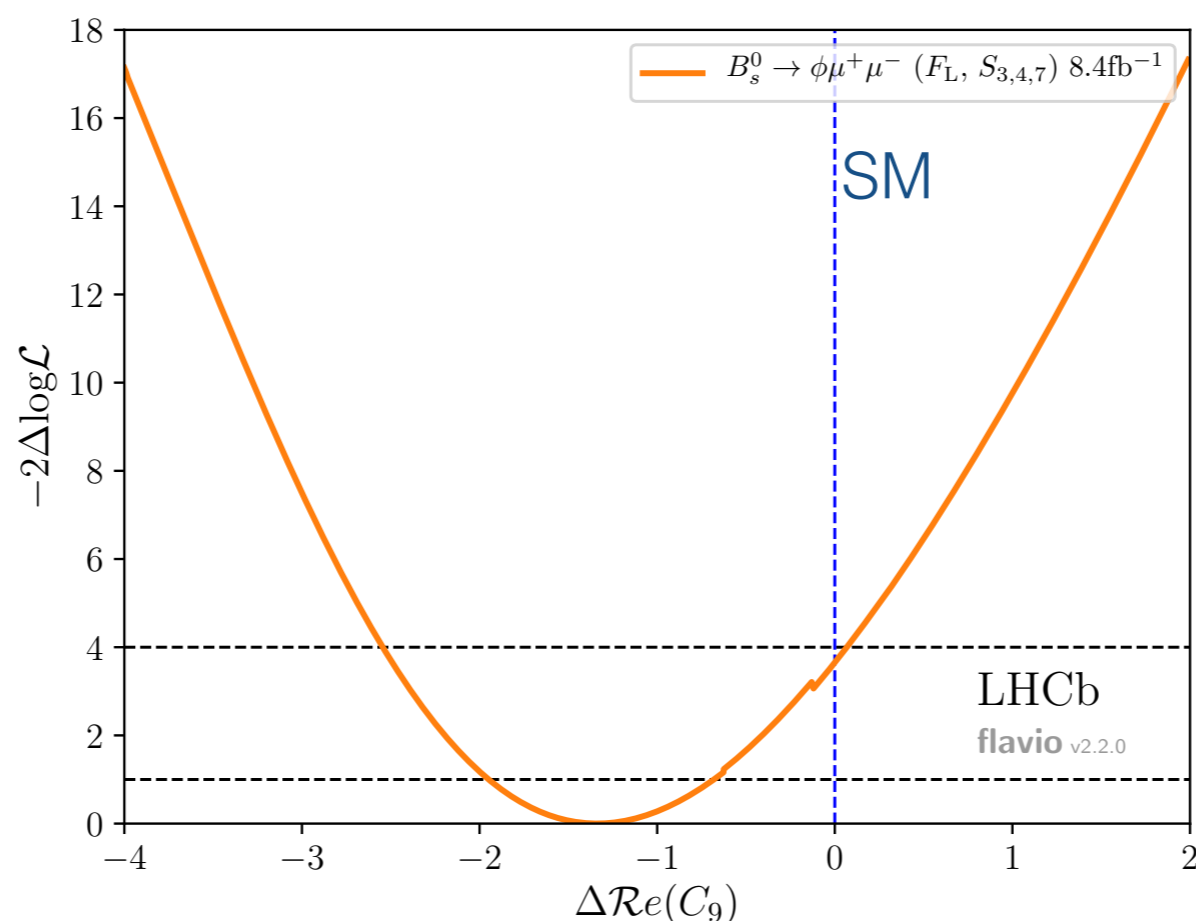
$B_s \rightarrow \phi \mu \mu$ angular analysis

- Full set of observables measured
- T -odd A_8 and A_9 particularly interesting
- Systematic uncertainties much smaller than statistical
 - Largest for F_L with about 30% of statistical uncertainty



$B_s \rightarrow \phi \mu \mu$ angular analysis

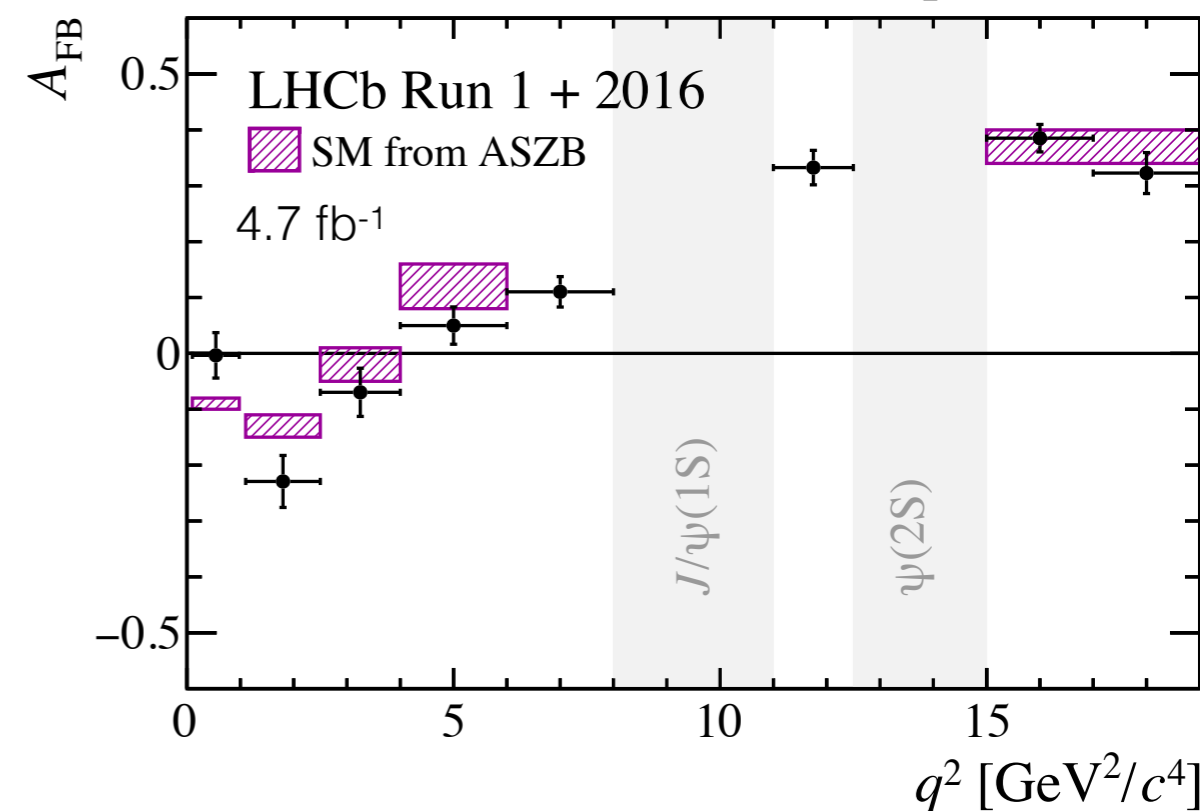
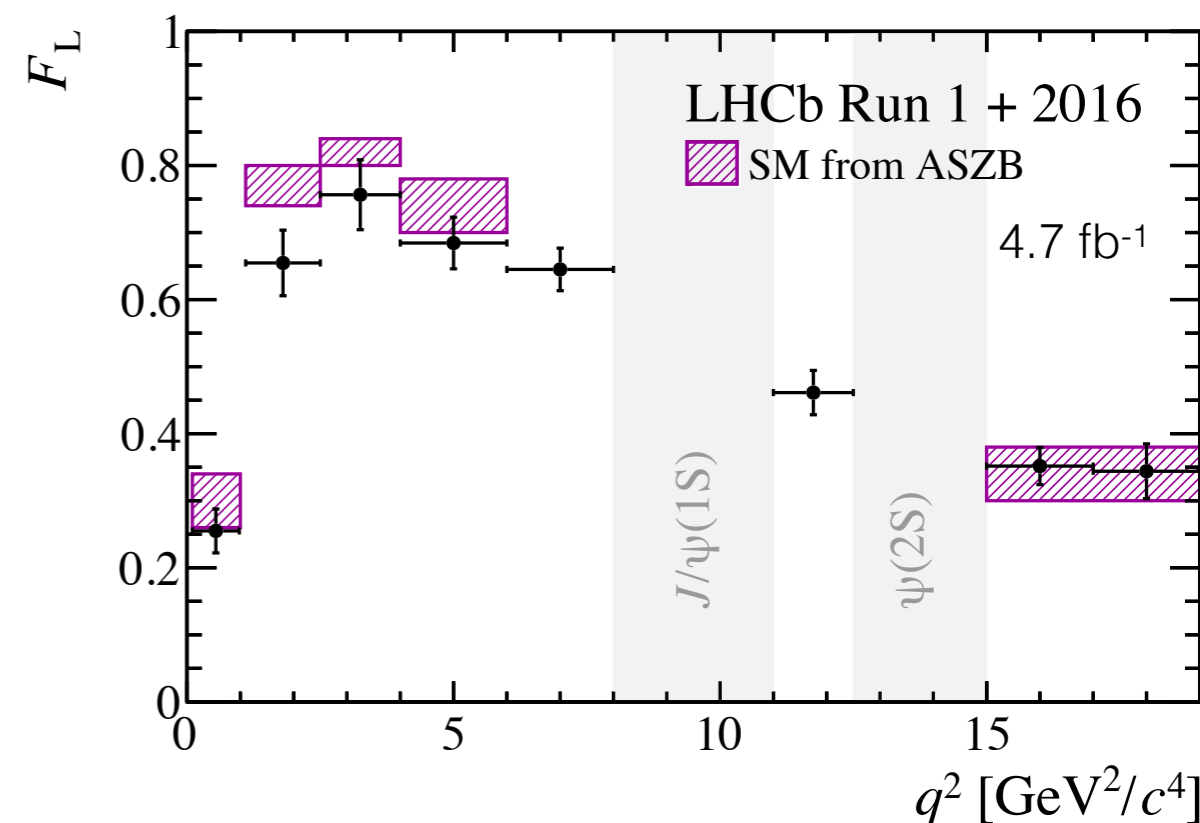
- Consistency evaluated using Flavio ([arXiv:1810.08132](https://arxiv.org/abs/1810.08132)) by testing consistency of $\text{Re}[C_9]$ with SM
- Uses observables F_L , S_3 , S_4 and S_7 in q^2 bins where long-distance effects expected small
- The best fit gives NP contribution $\Delta\text{Re}[C_9] = -1.3^{+0.7}_{-0.6}$
- Preferred by 1.9σ over SM value



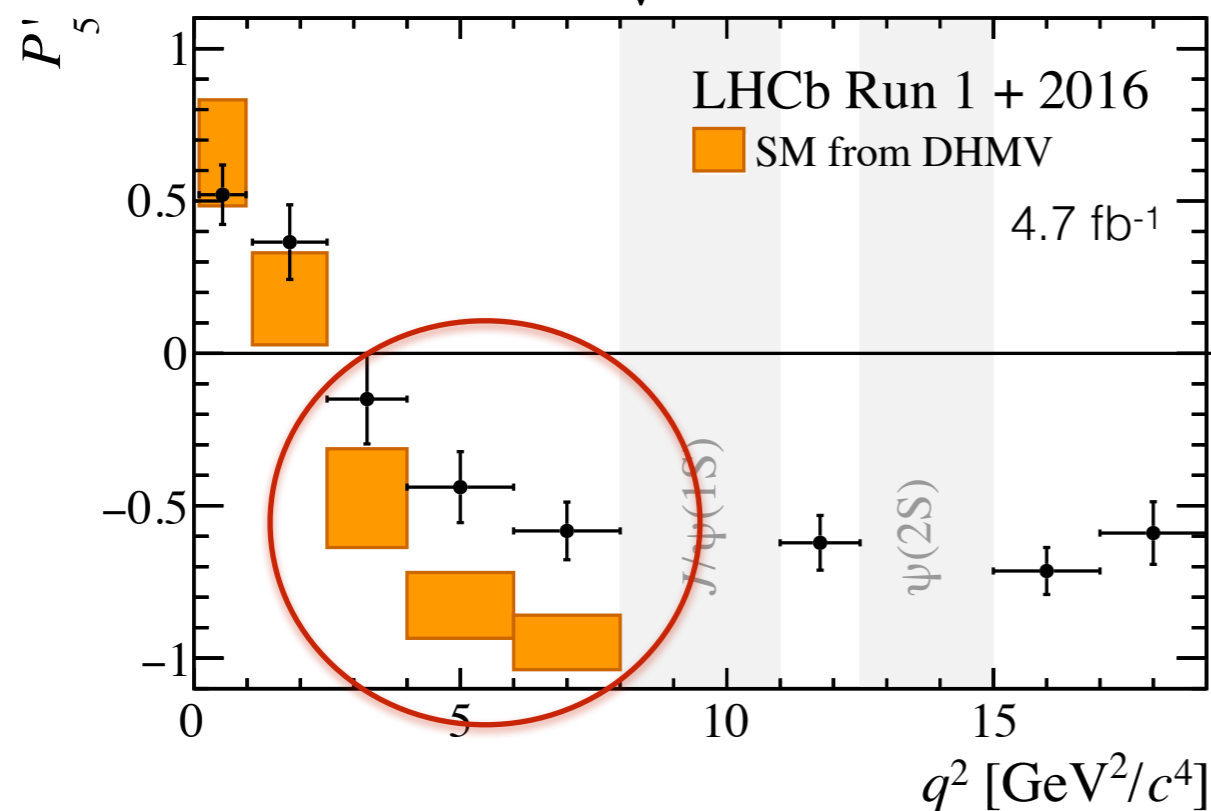
Recap of $B^0 \rightarrow K^{*0} \mu \mu$ angular analysis



- Lot of excitement from $B^0 \rightarrow K^{*0} \mu \mu$ over time
- Some tension with SM
- Last update in 2020
 - Expect further improvement with 2017 and 2018 data

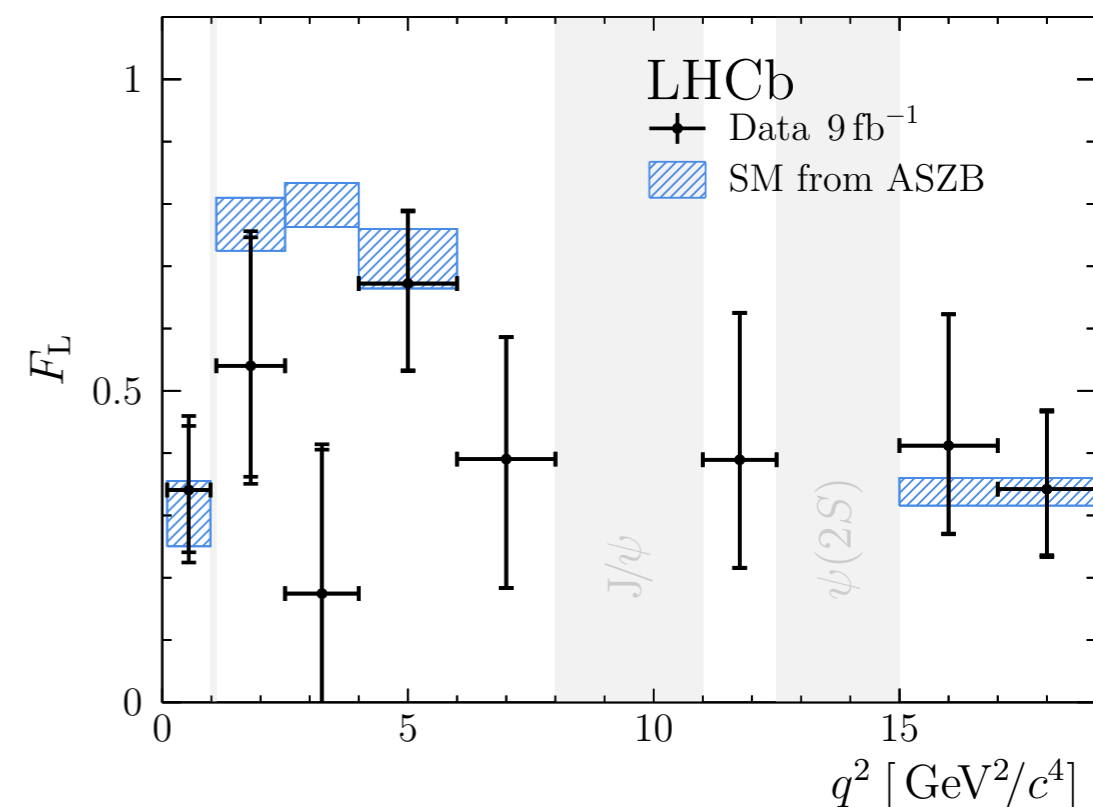
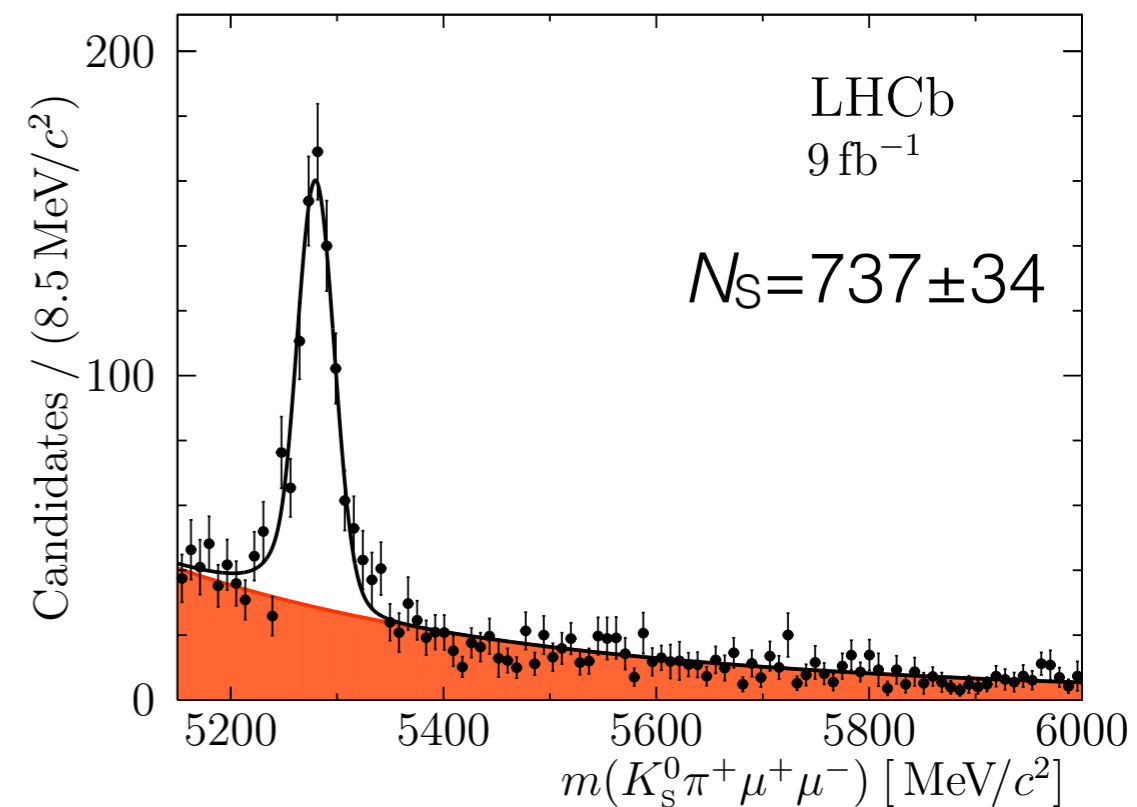


$$P'_i = S_i / \sqrt{F_L(1 - F_L)}$$



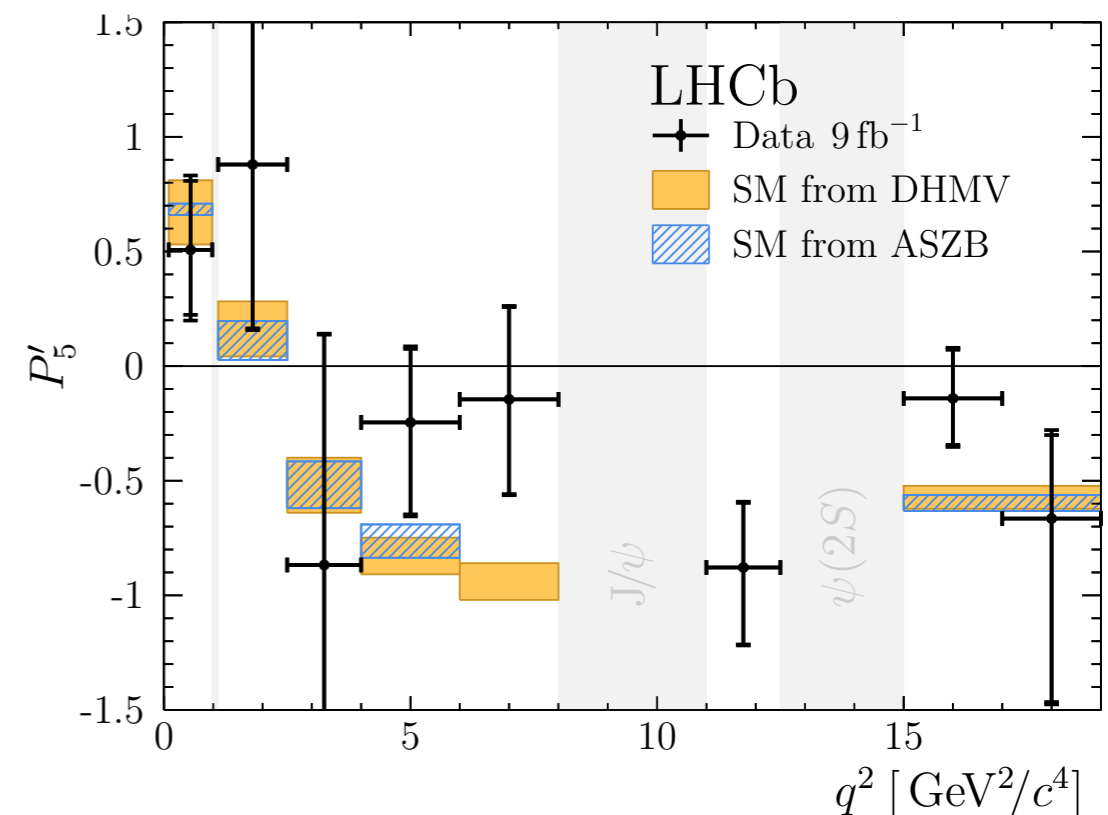
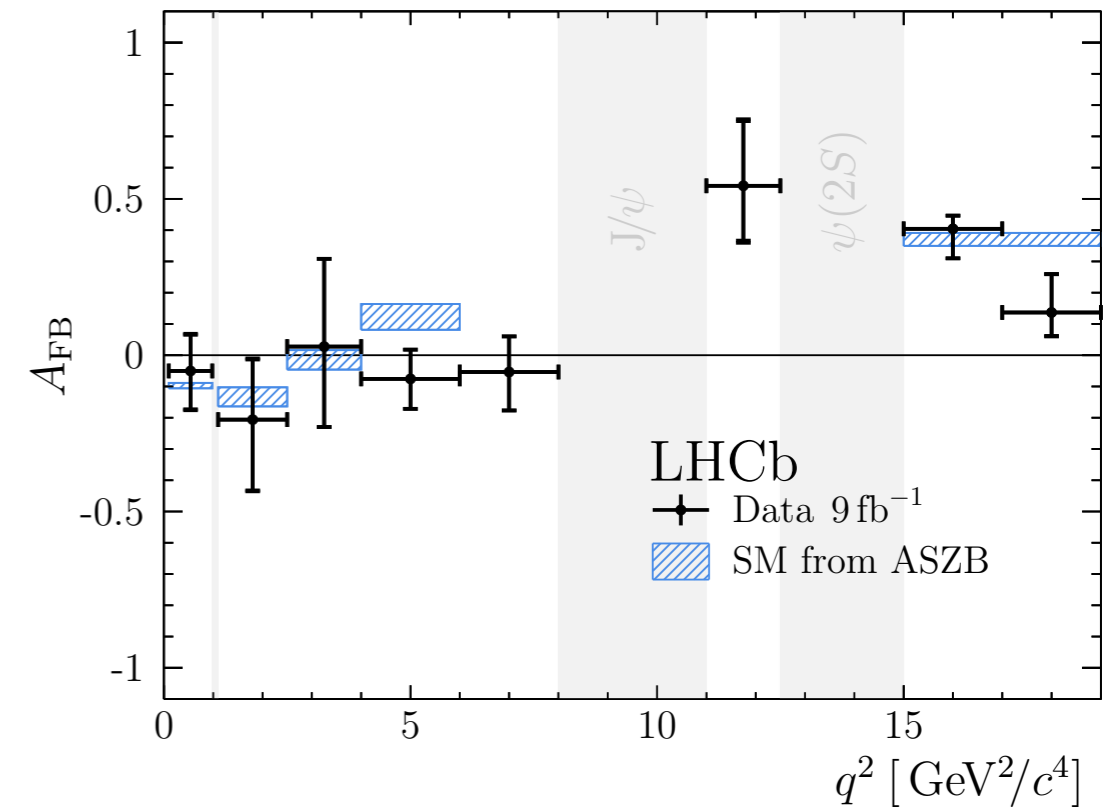
$B^+ \rightarrow K^{*+} \mu \mu$ angular analysis

- Mediated by the same underlying physics as $B^0 \rightarrow K^{*0} \mu \mu$
- Potentially interesting in view of isospin asymmetry in $B \rightarrow K^* \gamma$
- Angular analysis in several q^2 intervals
 - As statistics is low, several maximum likelihood fits with transformed angular distributions
 - Each fit contains only limited number of observables
- Measurement statistically limited, systematic uncertainties much smaller



$B^+ \rightarrow K^{*+} \mu \mu$ angular analysis

- General pattern observed similar to $B^0 \rightarrow K^{*0} \mu \mu$
- Largest local deviation from SM has significance of 3.0σ
- To evaluate consistency with SM, fit for $\text{Re}[C_9]$ from measured observables using Flavio
 - Uses subset of q^2 intervals
- Best fit value $\text{Re}[C_9] = -1.9$
- Consistency with SM at 3.1σ



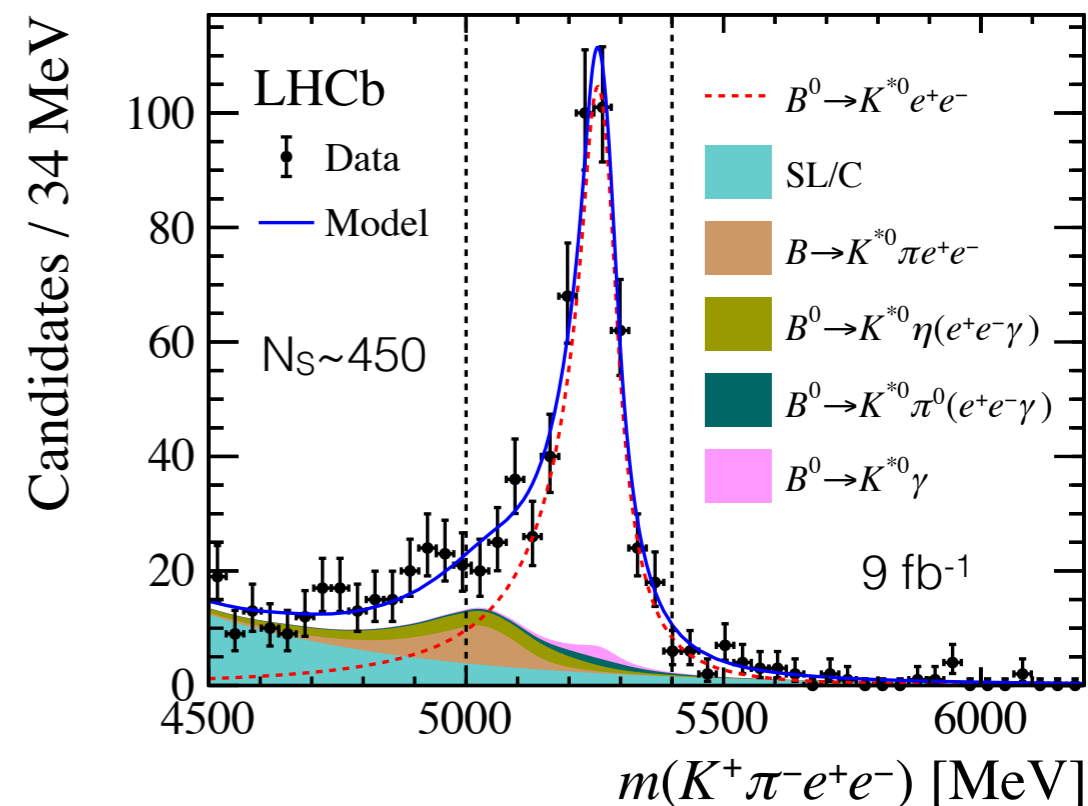
Photon polarisation in $B^0 \rightarrow K^{*0}ee$

- In the SM $b \rightarrow s\gamma$ transition, real photon is dominantly left handed
- Right handed contribution would be clear sign of NP
- Same holds also in $B^0 \rightarrow K^{*0}ee$ at low q^2
- Angular analysis is sensitive to photon polarisation
- Measurement in $q^2 \in [0.0008, 0.257] \text{ GeV}^2$
 - Lower bound to remove real $B \rightarrow K^*\gamma$, upper optimises sensitivity to photon polarisation
- Same angular distribution as before, just reparametrised

$$\tan \chi \equiv |A_R/A_L|,$$

$$A_T^{(2)} = \sin(2\chi) \cos(\phi_L - \phi_R),$$

$$A_T^{\text{Im}} = \sin(2\chi) \sin(\phi_L - \phi_R),$$



Photon polarisation in $B^0 \rightarrow K^{*0}ee$

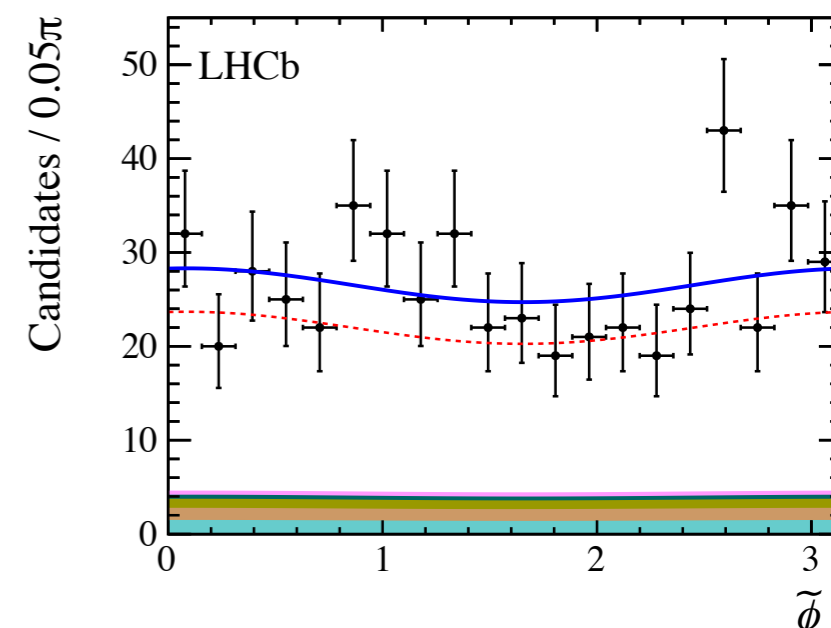
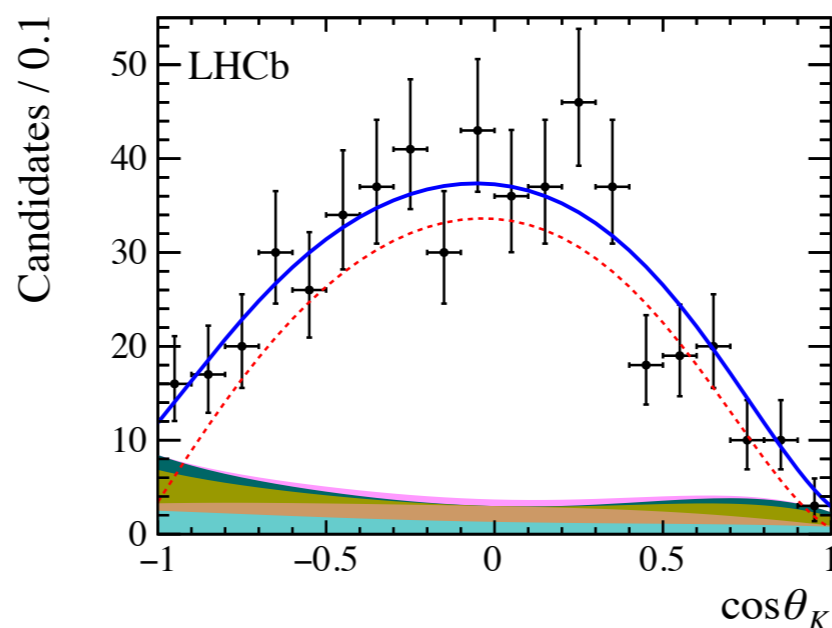
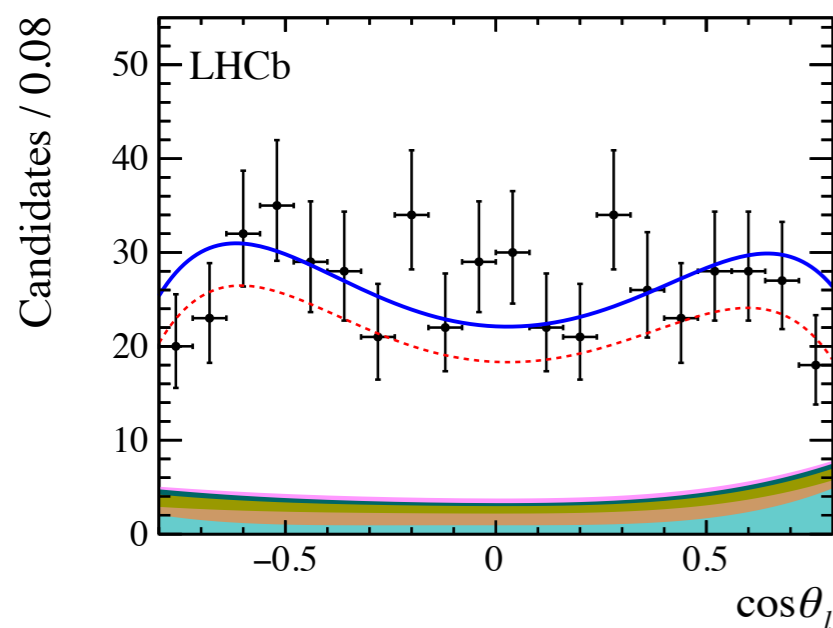
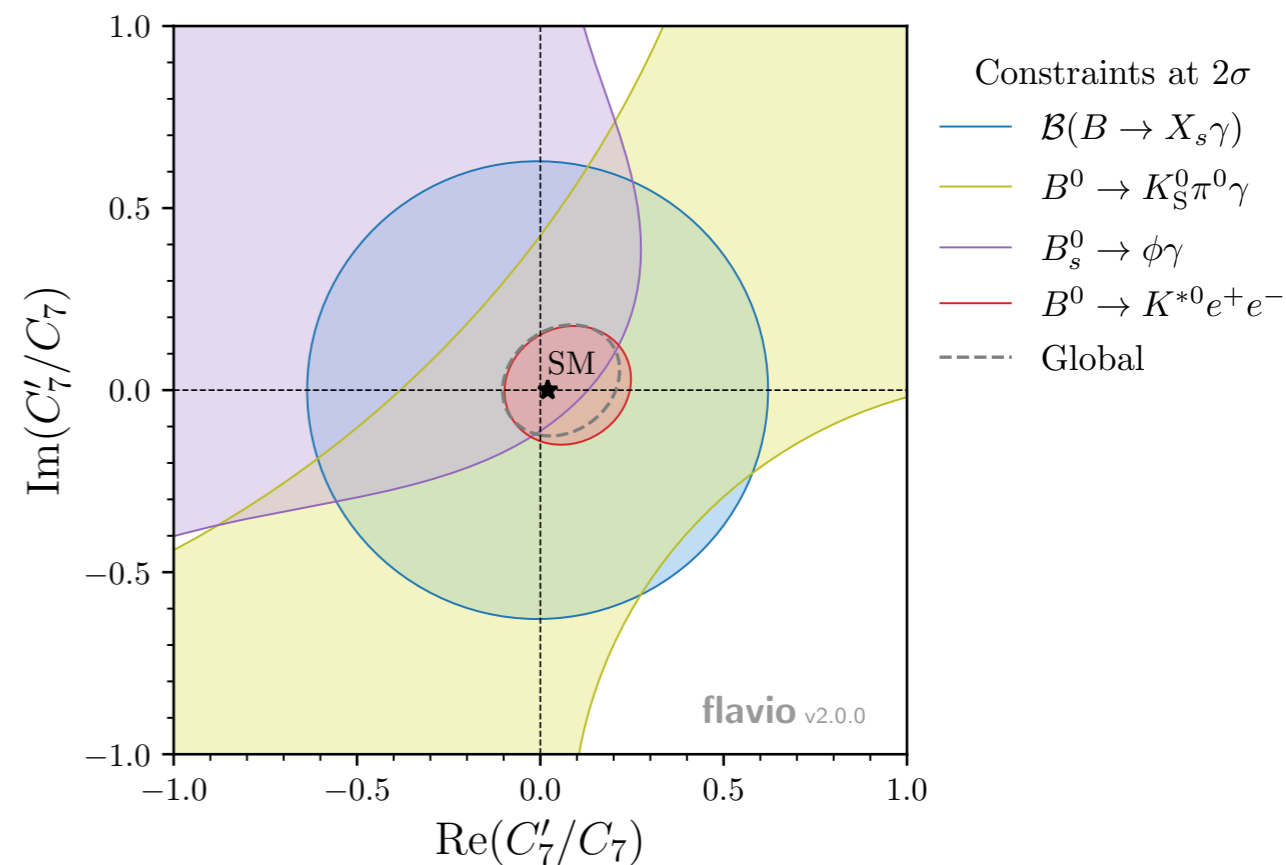
Measured observables

$$\begin{aligned}
 F_L &= 0.044 \pm 0.026 \pm 0.014, \\
 A_T^{\text{Re}} &= -0.06 \pm 0.08 \pm 0.02, \\
 A_T^{(2)} &= +0.11 \pm 0.10 \pm 0.02, \\
 A_T^{\text{Im}} &= +0.02 \pm 0.10 \pm 0.01,
 \end{aligned}$$

The ratio of right- and left-handed amplitudes

$$\begin{aligned}
 \text{Re}(A_R/A_L) &= 0.05 \pm 0.05 \\
 \text{Im}(A_R/A_L) &= 0.01 \pm 0.05.
 \end{aligned}$$

World's best constraint



See further discussion by Carla Benito



- Several new results on $b \rightarrow sll$ transitions
- Tensions seen in the past continue to be present
- Individually measurements are generally in agreement with SM
- They are all consistent with each other and together do point towards same NP
- New measurement constraining photon polarisation
 - $B^0 \rightarrow K^{*0}ee$
 - Consistent with negligible right-handed polarisation
 - Provides best constraint
- Work continues and many new measurements expected
- Upgraded detector is coming together to give us another large step in sensitivity

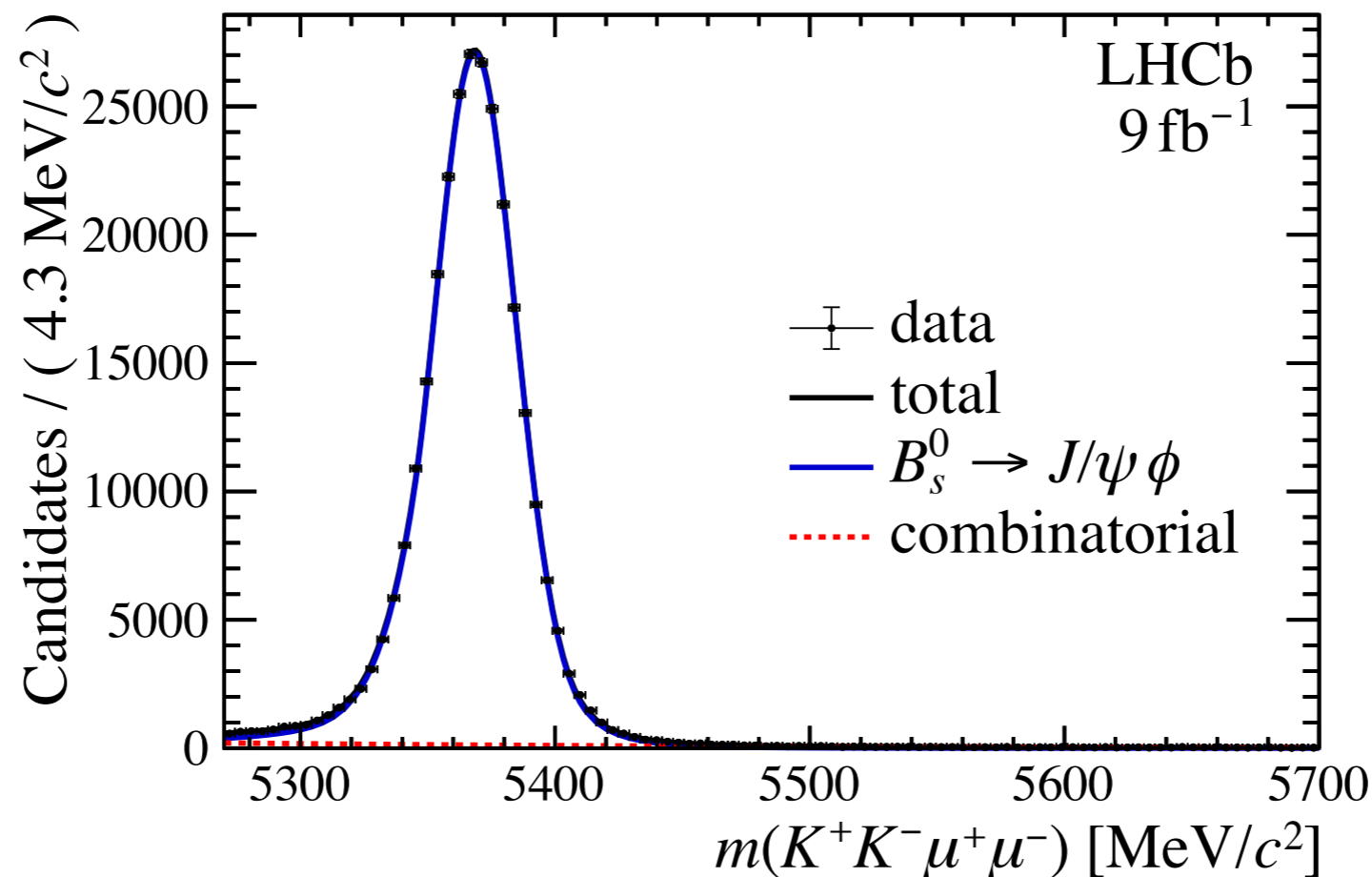


Backup

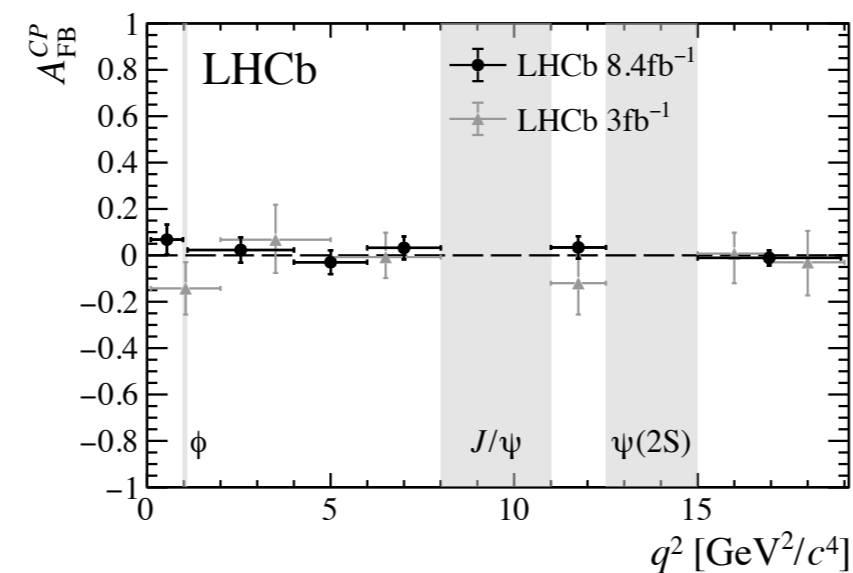
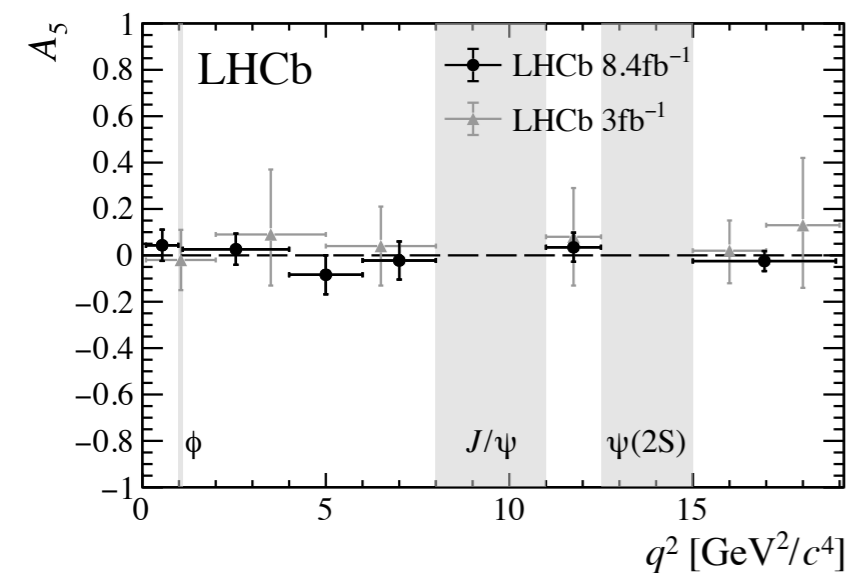
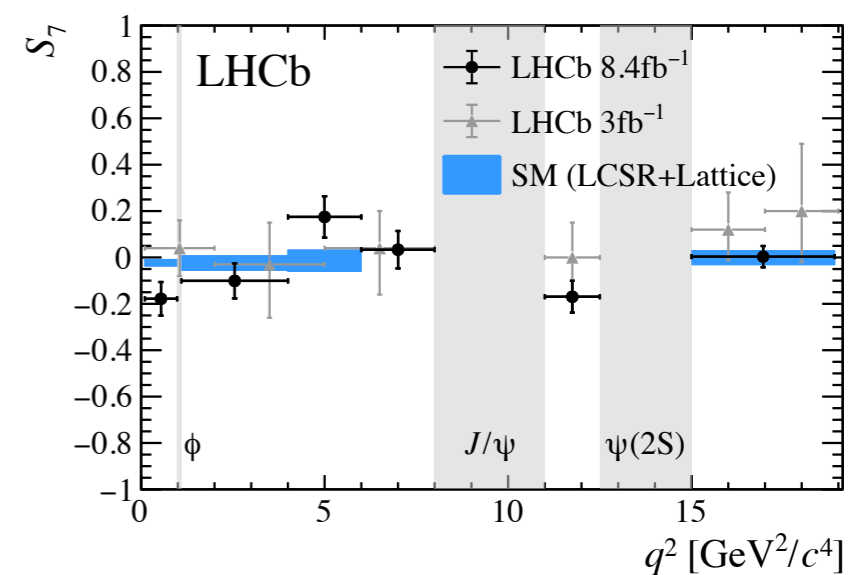
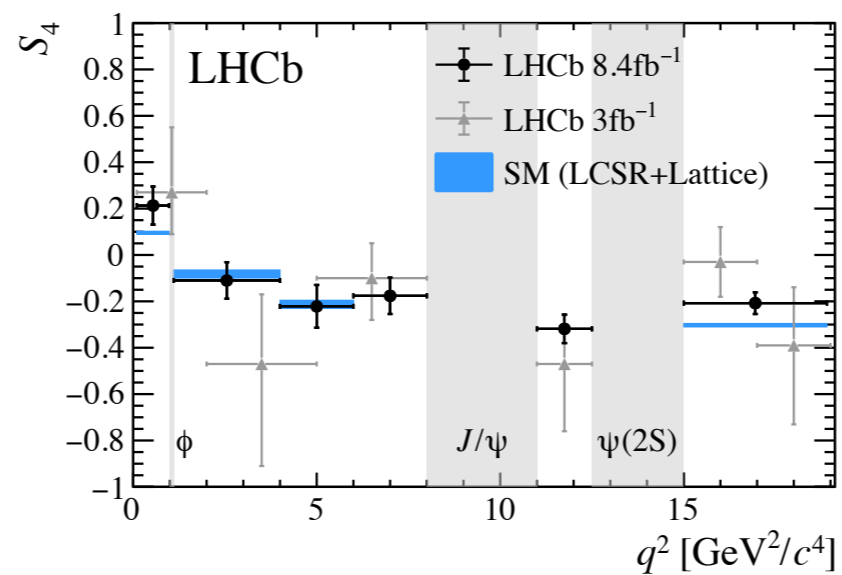
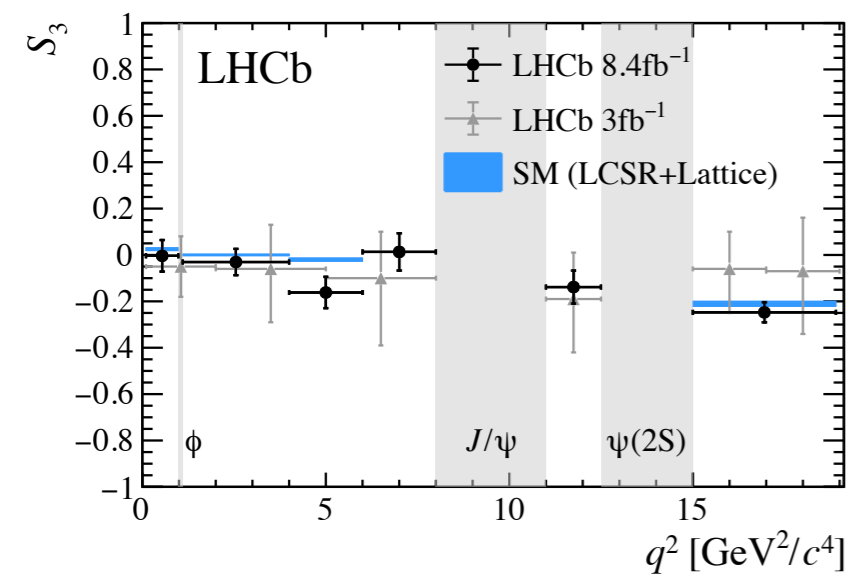


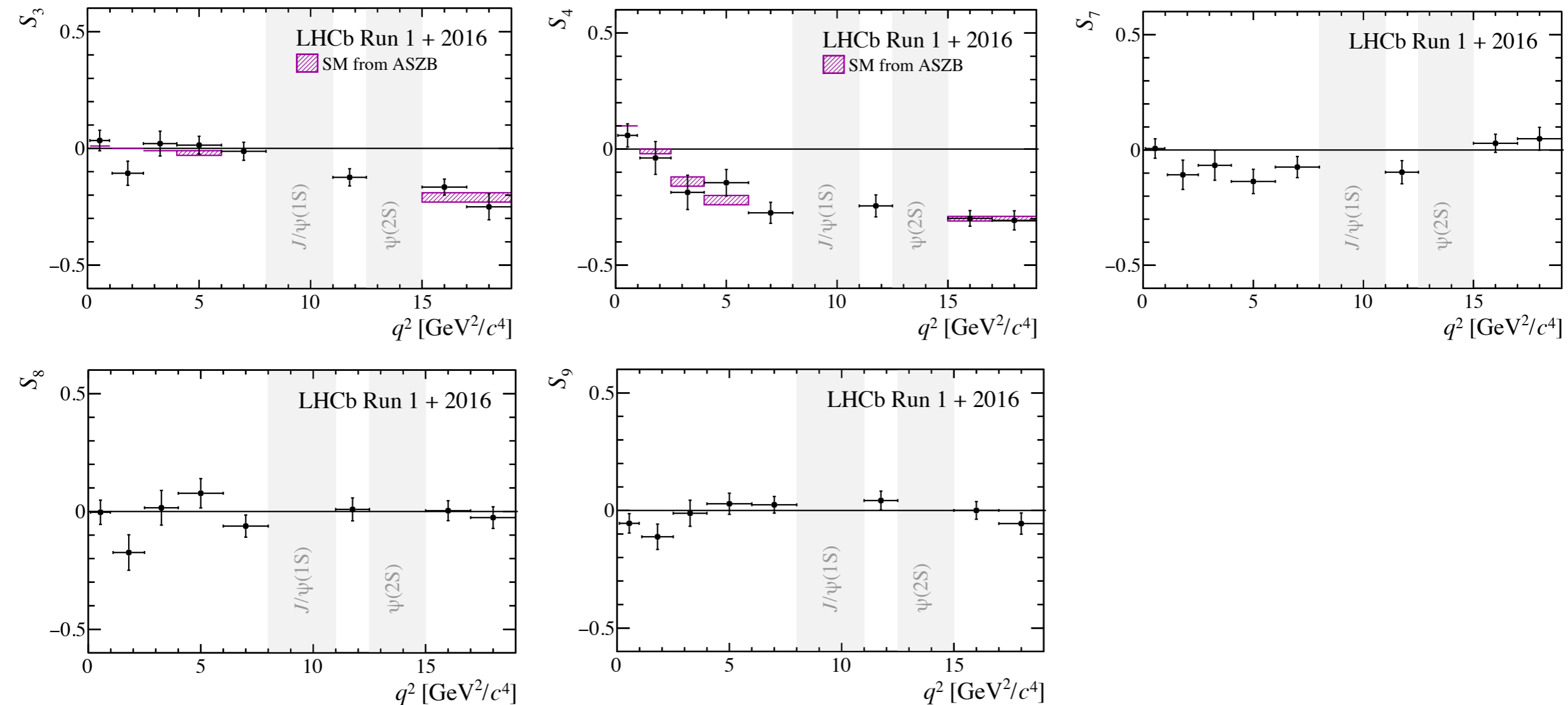
$B_s \rightarrow \phi \mu \mu$ differential BF normalisation

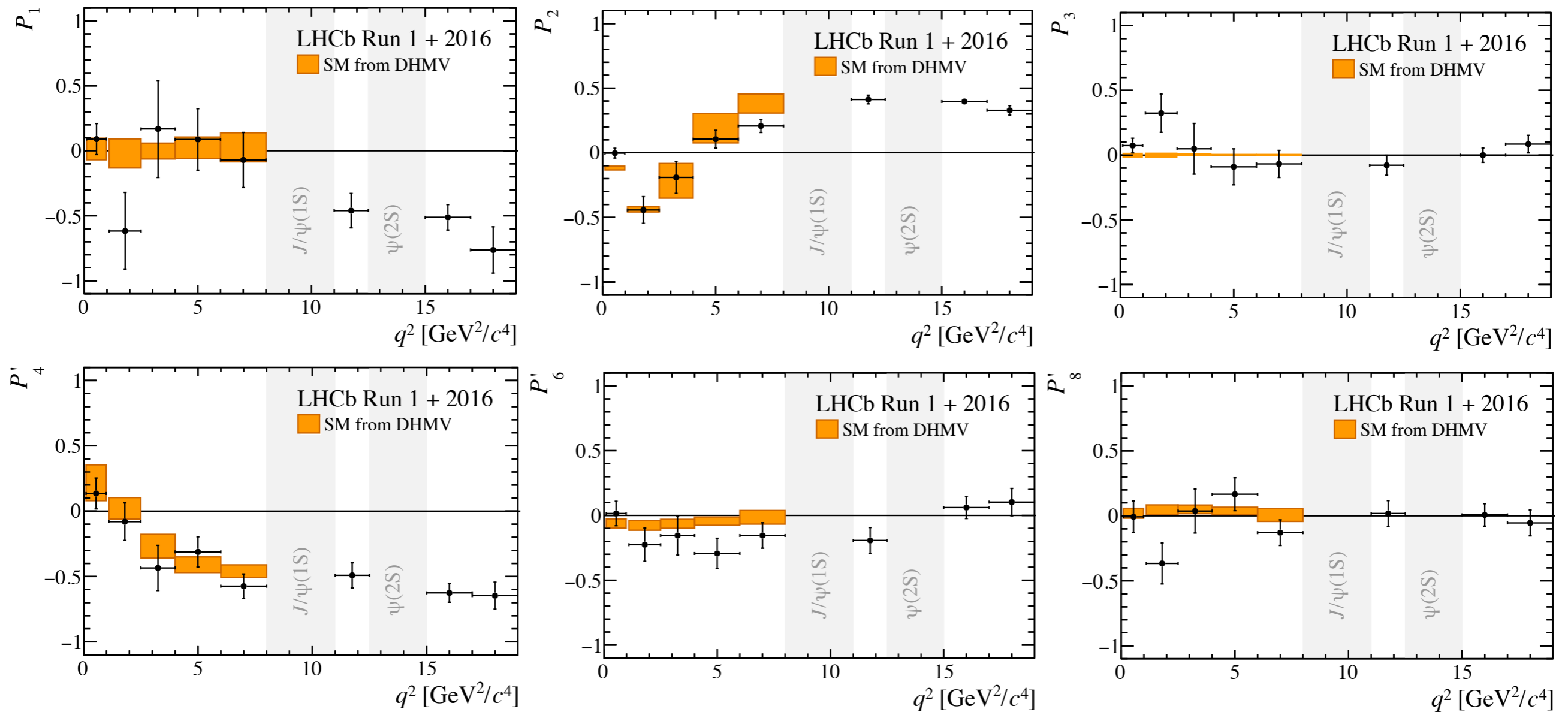
- Normalisation mode (PRD 104, 032005 (2021))
 $BF(B_s^0 \rightarrow J/\psi \phi) = (1.018 \pm 0.032 \pm 0.037) \times 10^{-3}$
- $BF(J/\psi \rightarrow \mu \mu) = (5.961 \pm 0.033) \%$ (PDG)



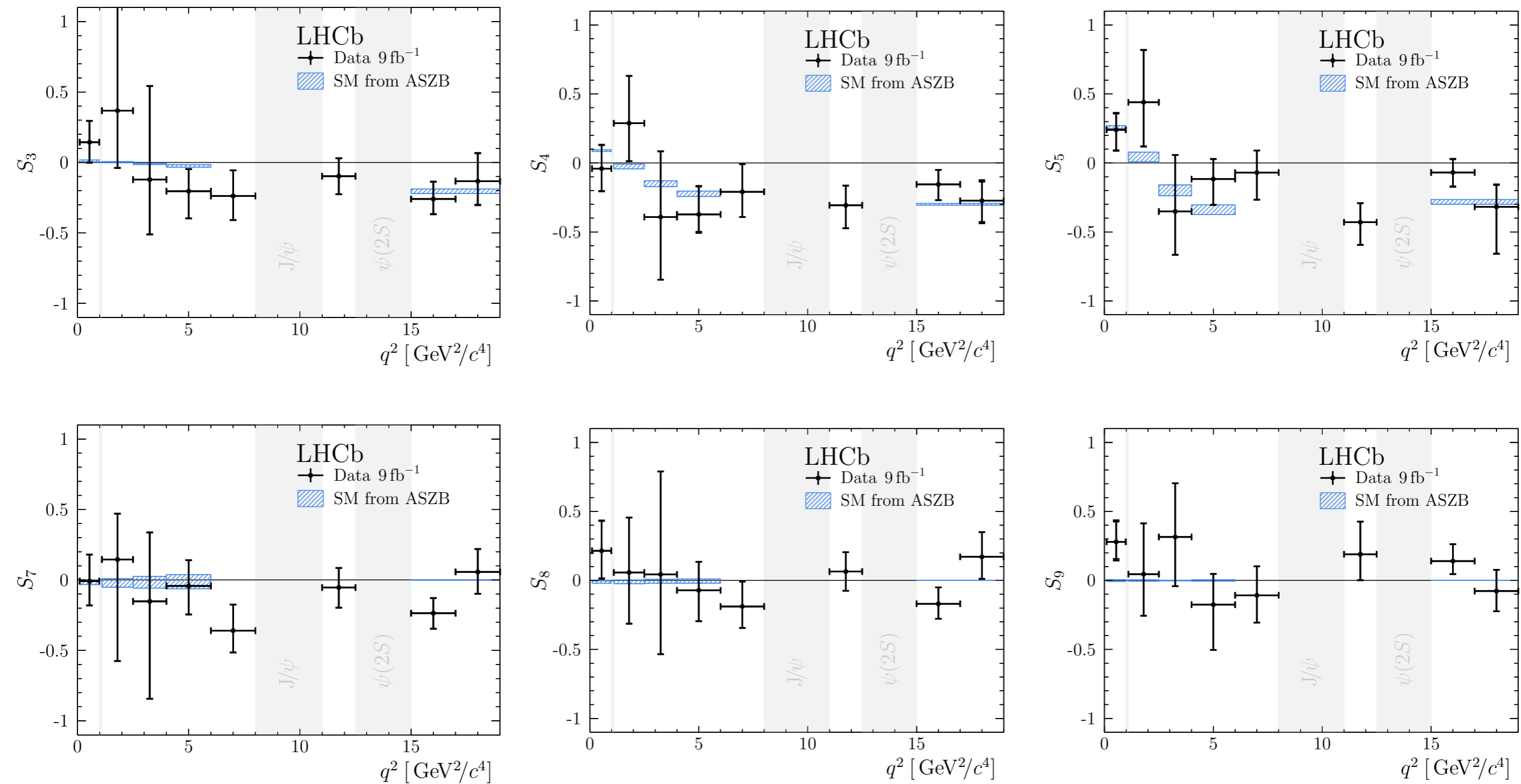
$B_s \rightarrow \phi \mu \mu$ angular analysis



Recap of $B^0 \rightarrow K^{*0} \mu \mu$ angular analysis

Recap of $B^0 \rightarrow K^{*0} \mu \mu$ angular analysis

$B^+ \rightarrow K^{*+} \mu \mu$ angular analysis



$B^+ \rightarrow K^{*+} \mu \mu$ angular analysis

