Experimental overview of b→sll decays

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LHCb

The Overview…

Branching Ratio

$B^{0,+} \to K^{0,+,*+}\mu^+\mu^-$ (LHCb, Mar 14)

$B^0 \to K^{*0}\mu^+\mu^-$ (CMS, Jul 15)

$B_s^0 \to \phi\, \mu^+\mu^-$ (LHCb, Jun 15)

$B^+ \to \pi^+\mu^+\mu^-$ (LHCb, Sep 15)

$\Lambda_b^0 \to \Lambda\, \mu^+\mu^-$ (LHCb, Mar 15)

$B_{(s)}^0 \to \mu^+\mu^-$ (CMS+LHCb, Jun 15)

CP asymmetry

$B^+ \to \pi^+\mu^+\mu^-$ (LHCb, Sep 15)

Isospin asymmetry

$B^{0,+} \to K^{0,+,*+}\mu^+\mu^-$ (LHCb, Mar 14)

Lepton universality

$B^+ \to K^+ l^+ l^-$ (LHCb, Jun 14)

$b \to (s/d)(\mu^+\mu^-/e^+e^-)$

Angular

$B^0 \to K^{*0} l^+ l^-$ (LHCb, Jan 15
LHCb, Mar 15
CMS, Jul 15
BaBar, Aug 15)

$B^+ \to K^{*+} l^+ l^-$ (BaBar, Aug 15)

$B_s^0 \to \phi\, \mu^+\mu^-$ (LHCb, Jun 15)

$\Lambda_b^0 \to \Lambda \mu^+\mu^-$ (LHCb, Mar 15)

The Overview…

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Lepton universality

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>2σ deviation from SM prediction

Angular

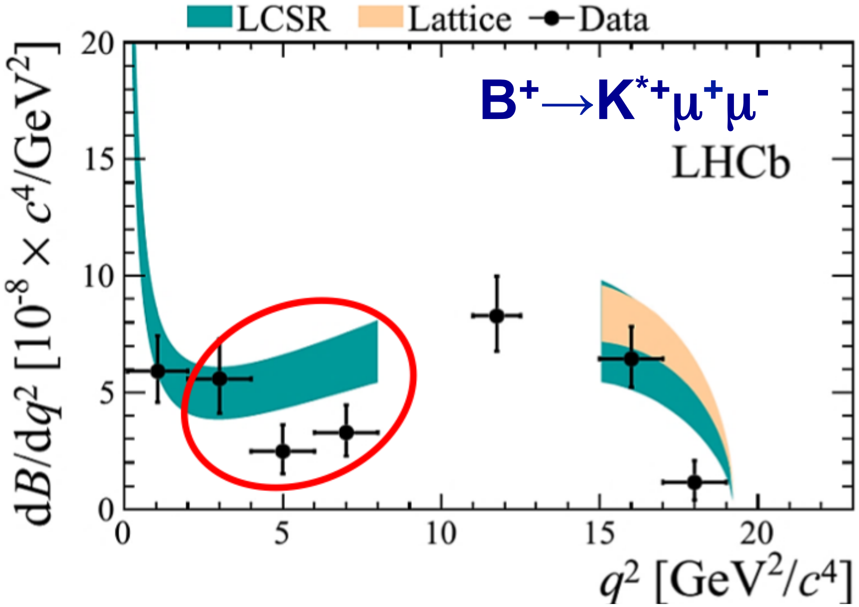
$B^0 \to K^{*0} l^+ l^-$	(LHCb, Jan 15 LHCb, Mar 15 CMS, Jul 15 BaBar, Aug 15)
$B^+ \to K^{*+} l^+ l^-$	(BaBar, Aug 15)
$B_s^0 \to \phi\,\mu^+\mu^-$	(LHCb, Jun 15)
$\Lambda_b^0 \to \Lambda\mu^+\mu^-$	(LHCb, Mar 15)

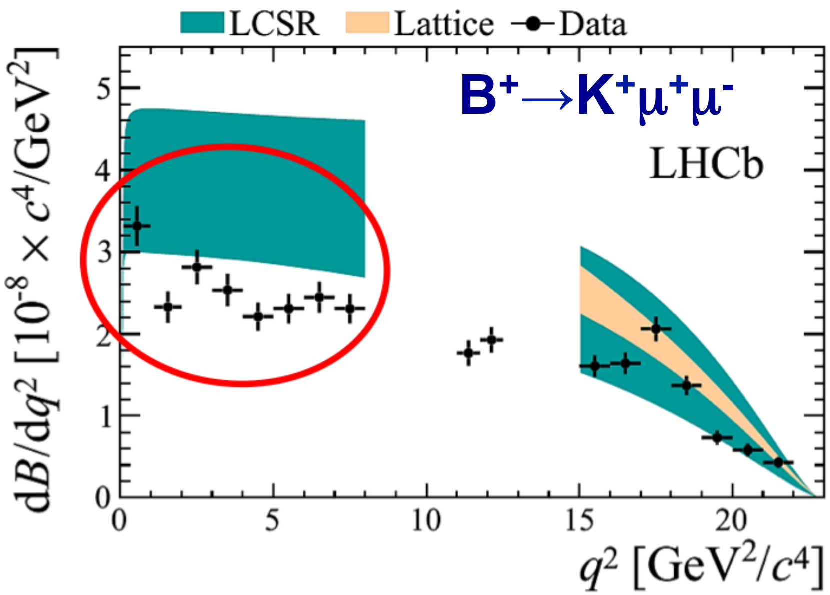
Branching fractions

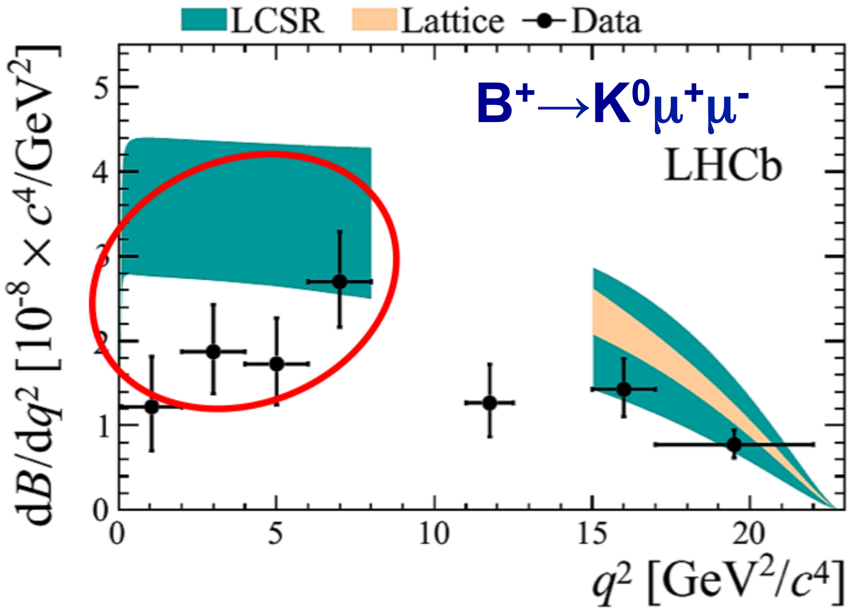
$B^{0,+} \to K^{0,+,*+}\mu^+\mu^-$

- Although larger theoretical uncertainties from form factors – previous measurements show some tension with SM predictions

[JHEP 06 (2014) 133]



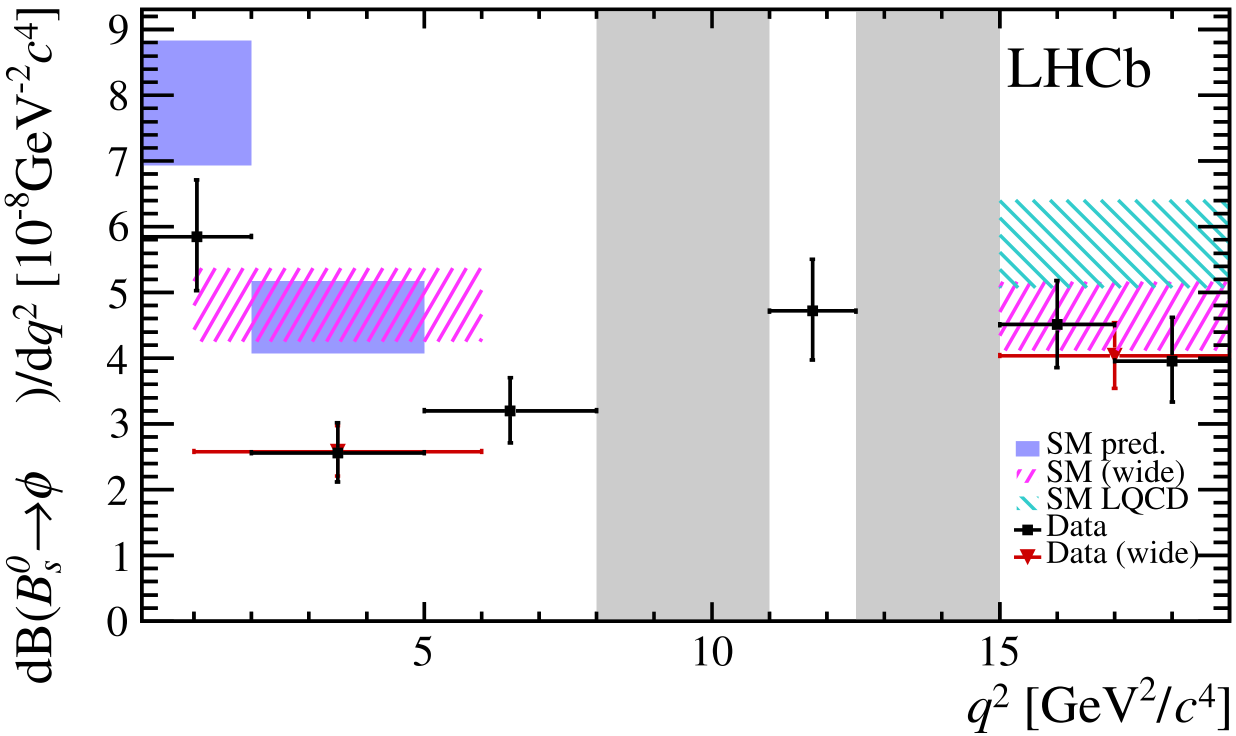




$B^0_s \to \phi\mu^+\mu^-$

- Recent LHCb measurements of $B^0_s \to \phi\mu^+\mu^-$ show similar trend in low q^2 region
  - Narrow ϕ resonance gives clean signal
  - 3.3σ from SM prediction in $1<q^2<6$ GeV^2

[JHEP09 (2015) 179]

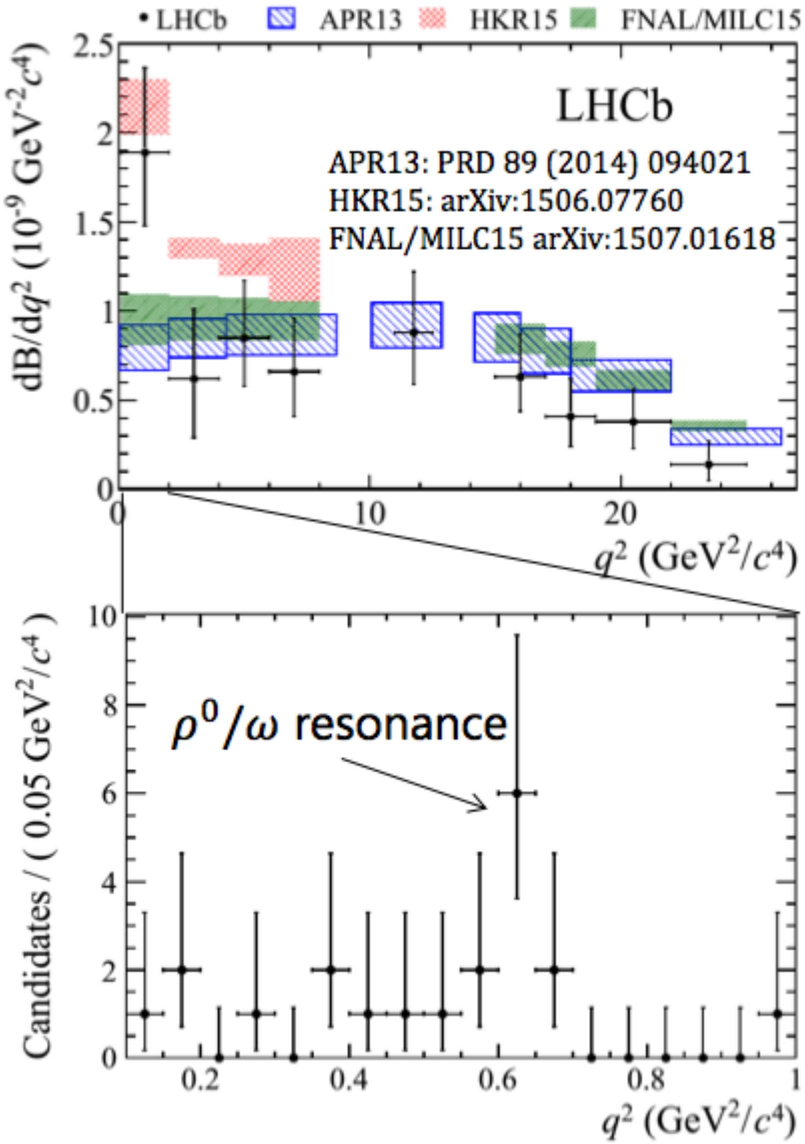


$B^+ \to \pi^+ \mu^+ \mu^-$

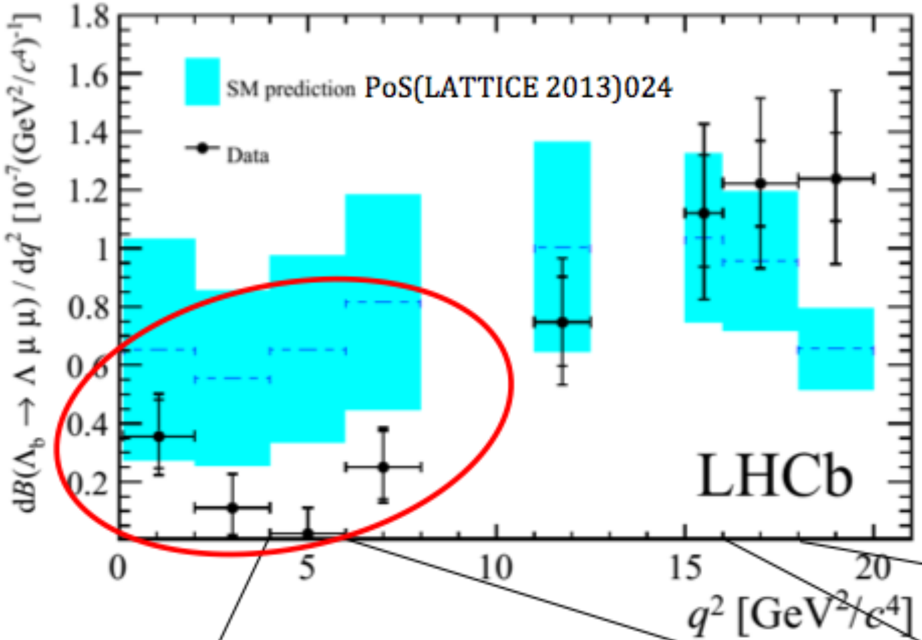
[arXiv:1509.00414]

- Have also now added diff. BF and A_{CP} measurements of $b \to d$ transition, $B^+ \to \pi^+ \mu^+ \mu^-$
  - Agree with SM but on low side
- HKR15 calcn takes into account low q^2 resonances for which we see a hint
- Determine $|V_{td}/V_{ts}|^2$
- Find,

$A_{CP} = -0.11 \pm 0.12\ (\text{stat}) \pm 0.01(\text{syst})$

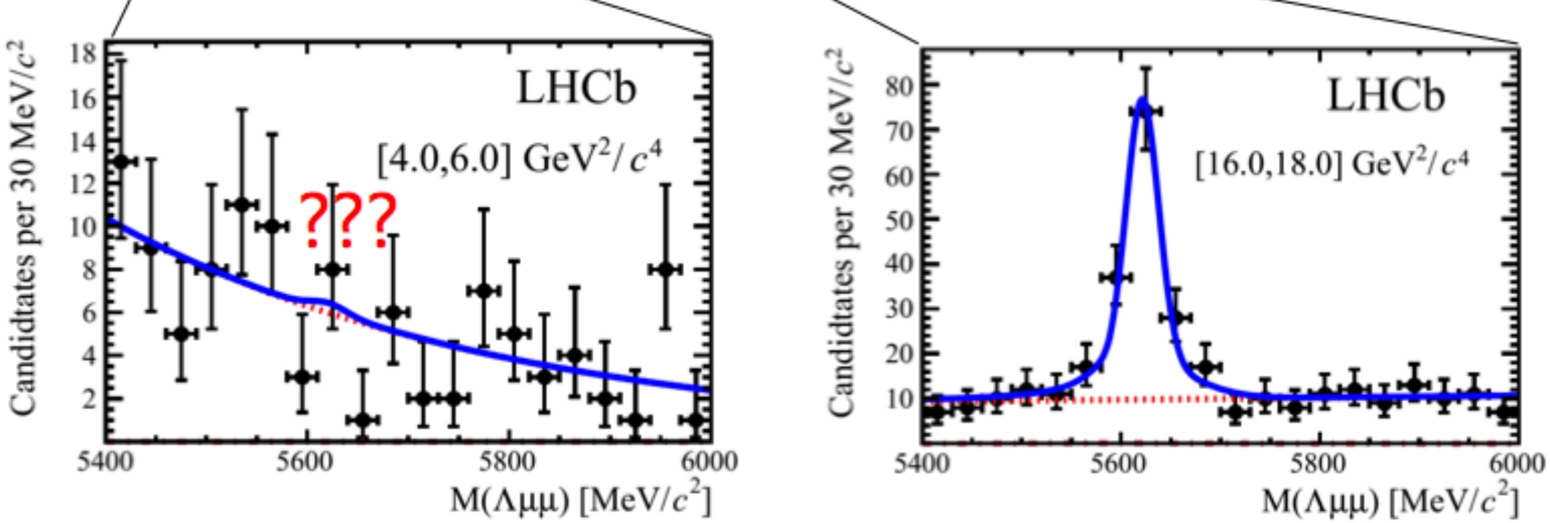


$\Lambda_b \rightarrow \Lambda^0\mu^+\mu^-$



- Have ~300 $\Lambda_b \rightarrow \Lambda^0\mu^+\mu^-$ candidates at LHCb
- Establish evidence for signal $0.1<q^2<2.0$ GeV^2/c^4 for 1st time, no significant signal in $1.1<q^2<6.0$ GeV^2/c^4

[JHEP 06 (2015) 115]

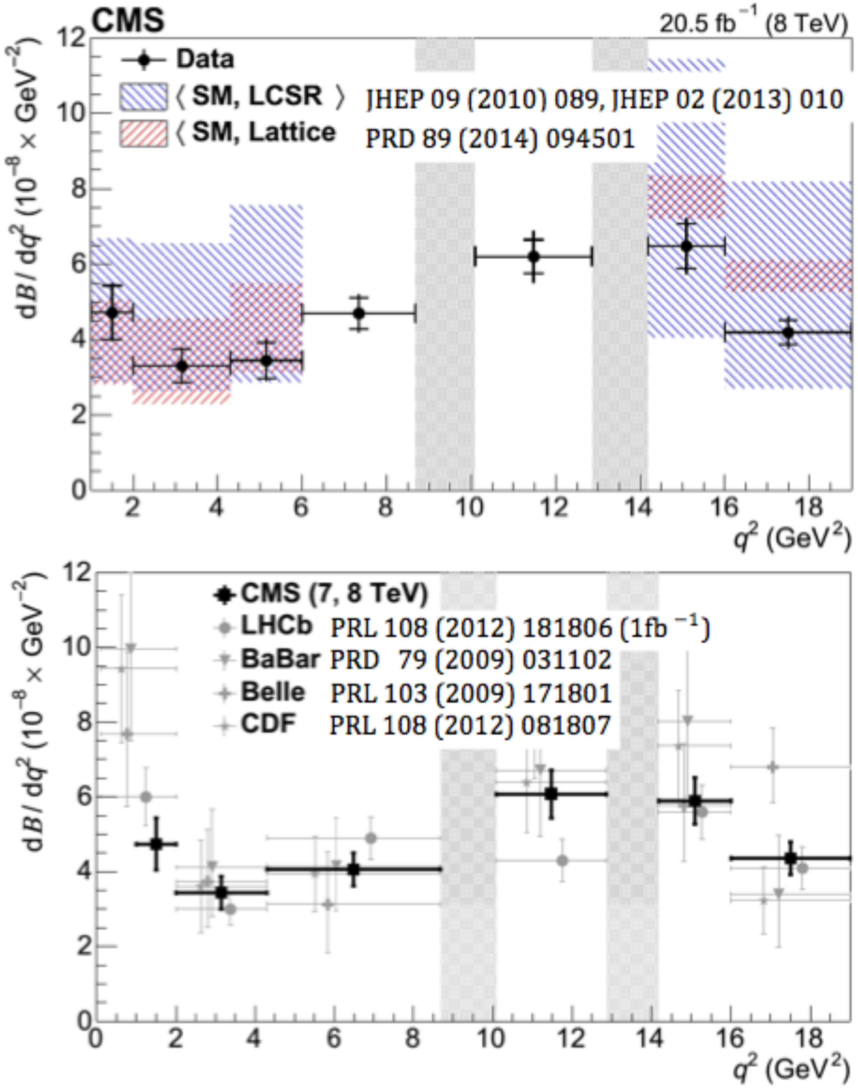


$B^0 \to K^{*0}\mu^+\mu^-$

[arXiv:1507.08126]

- Recent CMS measurements of $B^0 \to K^{*0}\mu^+\mu^-$ BF

- Compatible with both SM prediction and previous measurements



Upcoming LHCb measurements

Angular analyses

$B^0 \to K^{*0}\mu^+\mu^-$ – Introduction

- [LHCb-CONF-2015-002]

- $1fb^{-1}$ angular analysis statistically dominated, have added $2fb^{-1}$ data
  - Allows us to refine q^2 binning scheme, selection procedure
  - Previously had systematic uncertainties from efficiency correction, S-wave contamination – have established better control of both

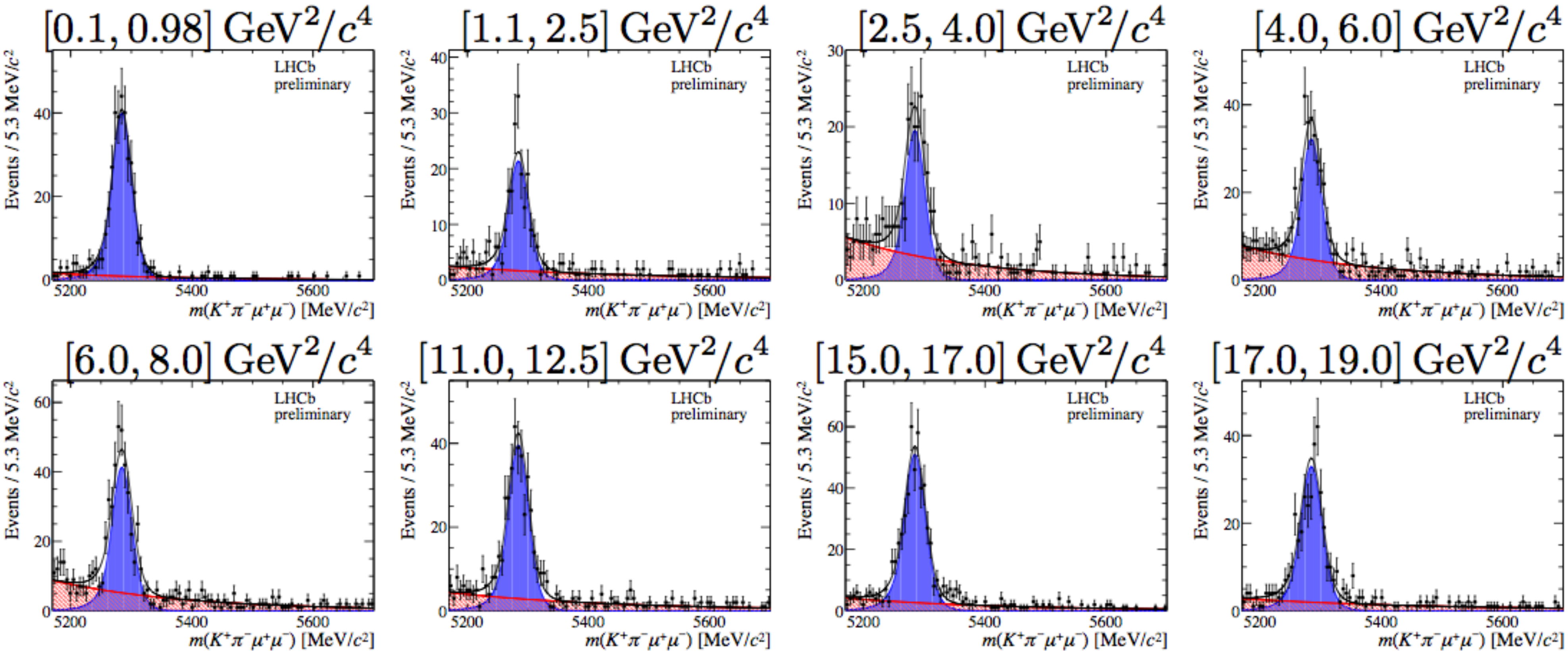
  → $3fb^{-1}$ still completely statistically dominated

  (will not discuss details of analysis or systs etc.)

- Make simultaneous determination of all eight CP-averaged observables in a single fit (→ provide correlation matrices)

$B^0 \rightarrow K^{*0}\mu^+\mu^-$ signal selection

- Even in finer q^2 binning scheme, signal well-established in every q^2 bin :



Correcting for the efficiency

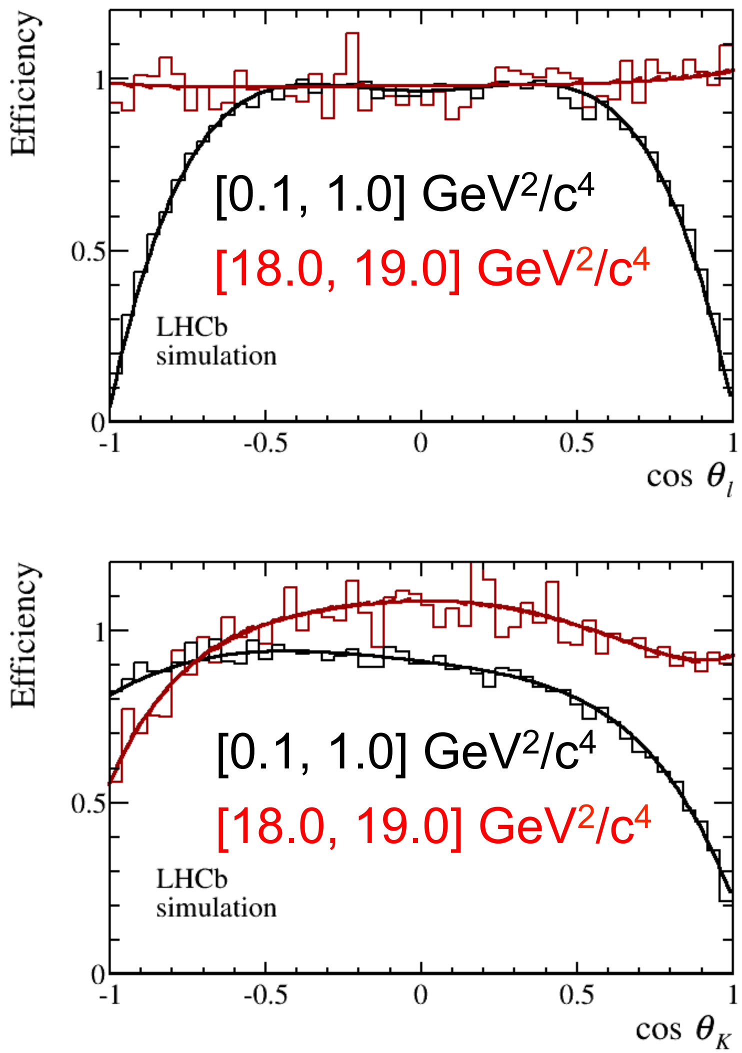
- Detector and selection distort the angular and q^2 distribution
  - Momentum/IP requirements

- Fit signal distribution modified by 4D efficiency function, ε,

  $\varepsilon(\cos\theta_l, \cos\theta_K, \phi, q^2)$

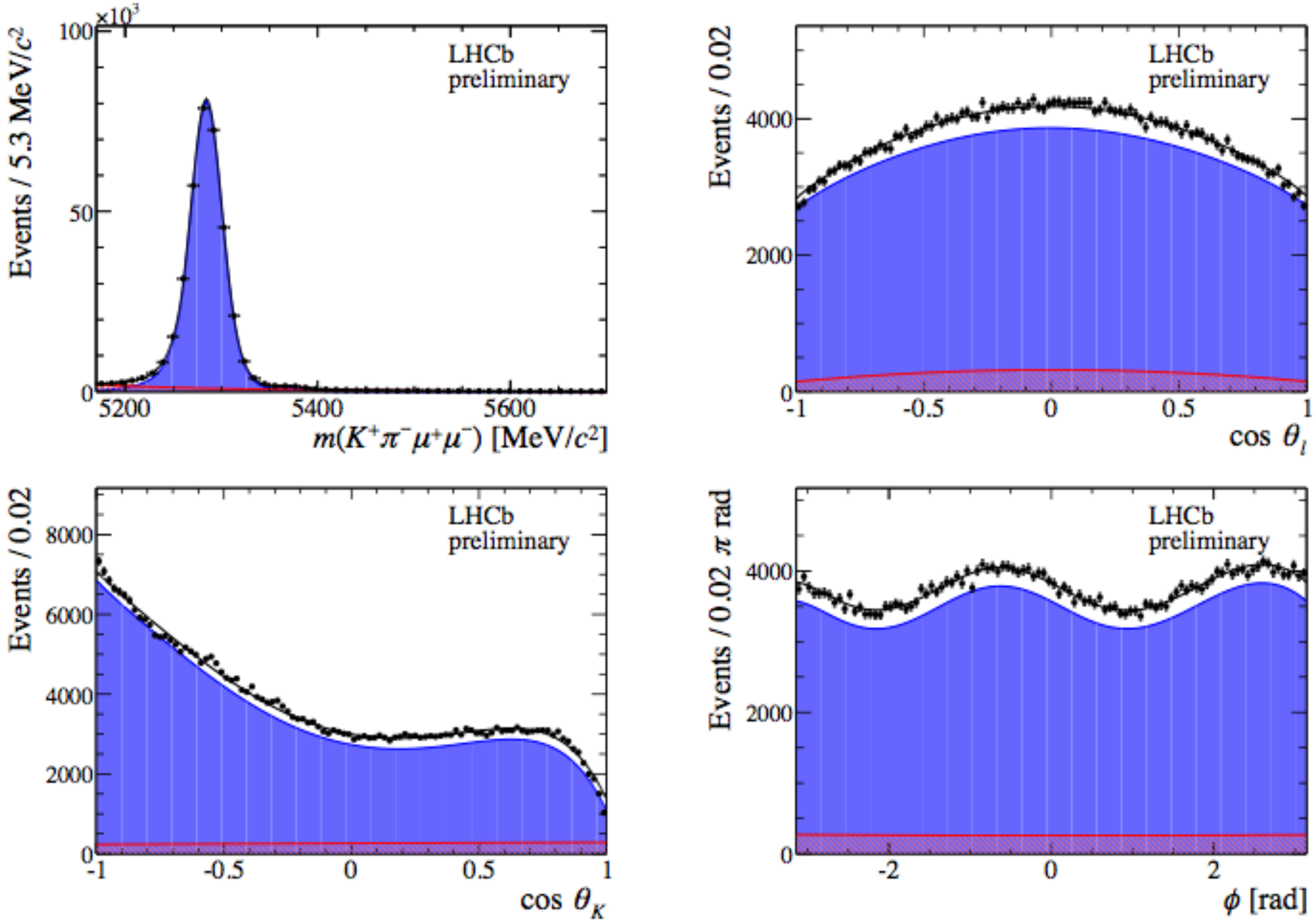
- Function of all underlying variables → can determine with a phase-space simulation

- Cross-check with $B^0 \to K^{*0} J/\psi$ …



$B^0 \to K^{*0} J/\psi$ angular fit

- Reproduce angular observables measured elsewhere
  [PRD 88 (2013) 052002]



Determining the S-wave

- Select $K\pi$ in a mass window $795.9 < m_{K\pi} < 995.9$ MeV/c^2
  - PID → no ambiguity πK vs $K\pi$ [cf CMS: 8% wrong assignments]
- Get contribution from S-wave confign., as well as P-wave → fraction of S-wave, F_S, dilutes P-wave observables

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\bigg|_{\mathrm{P}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K$$
$$+\tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_l$$
$$-F_{\mathrm{L}}\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi$$
$$+\tfrac{4}{3}A_{\mathrm{FB}}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]$$

- Introduces two new amplitudes and six new observables
- Make simultaneous fit of $m_{K\pi}$ distribution to constrain F_S

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$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\Bigg|_{\mathrm{S+P}} = (1-F_{\mathrm{S}})\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\Bigg|_{\mathrm{P}} + \frac{3}{16\pi}F_{\mathrm{S}}\sin^2\theta_\ell + \frac{9}{32\pi}(S_{11}+S_{13}\cos 2\theta_\ell)\cos\theta_K + \frac{9}{32\pi}(S_{14}\sin 2\theta_\ell + S_{15}\sin\theta_\ell)\sin\theta_K\cos\phi + \frac{9}{32\pi}(S_{16}\sin\theta_\ell + S_{17}\sin 2\theta_\ell)\sin\theta_K\sin\phi$$

- Introduces two new amplitudes and six new observables
- Make simultaneous fit of $m_{K\pi}$ distribution to constrain F_S

$B^0 \to K^{*0}\mu^+\mu^-$ likelihood fit

- Maximum likelihood fit to decay angles and $m_{K\pi\mu\mu}$ in q^2 bins, simultaneously fitting $m_{K\pi}$ to constrain F_S

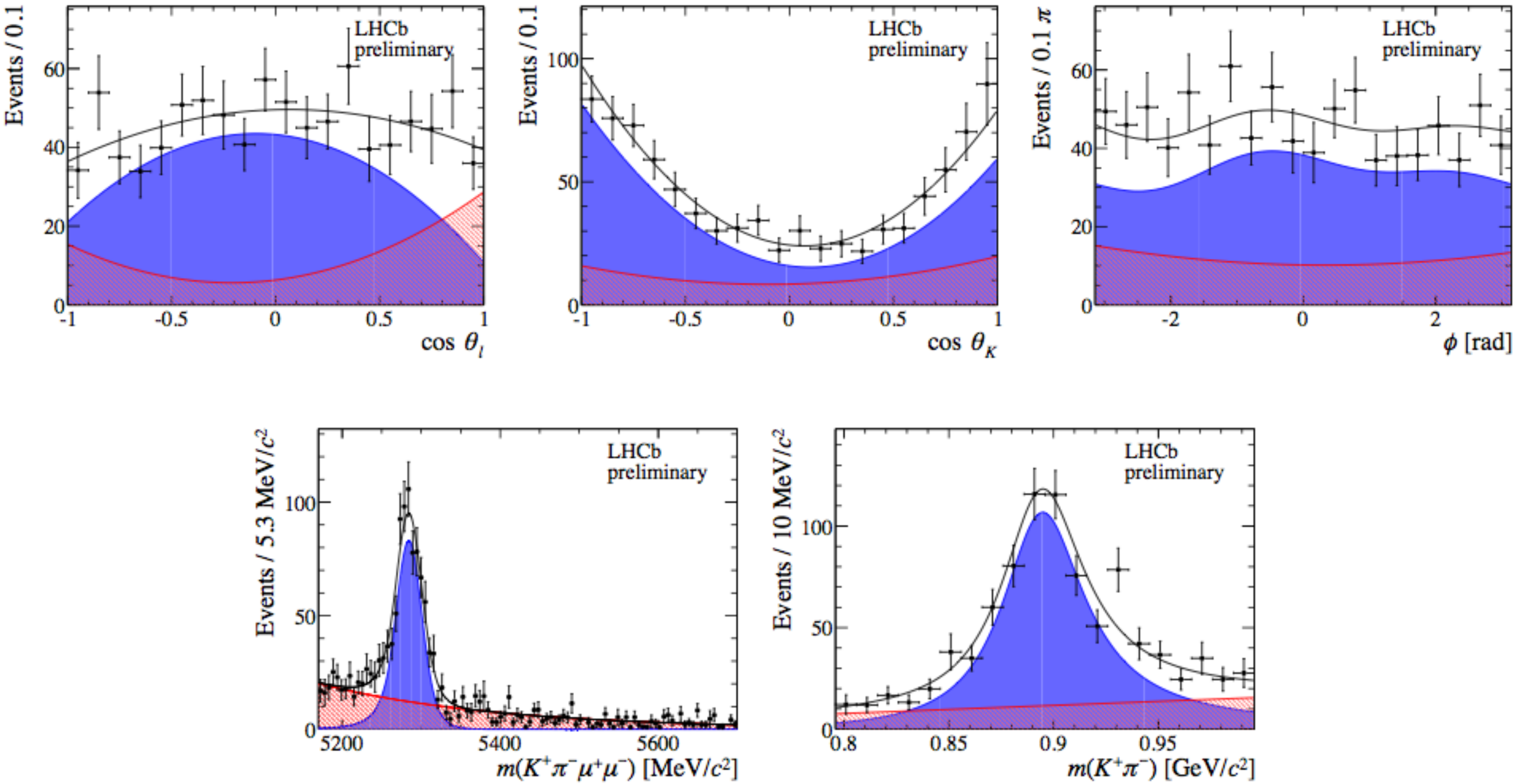
$$\log \mathcal{L} = \sum_i \log \left[\epsilon(\vec{\Omega}, q^2) f_{\rm sig} \mathcal{P}_{\rm sig}(\vec{\Omega}) \mathcal{P}_{\rm sig}(m_{K\pi\mu\mu}) + (1 - f_{\rm sig}) \mathcal{P}_{\rm bkg}(\vec{\Omega}) \mathcal{P}_{\rm bkg}(m_{K\pi\mu\mu}) \right] + \sum_i \log \left[f_{\rm sig} \mathcal{P}_{\rm sig}(m_{K\pi}) + (1 - f_{\rm sig}) \mathcal{P}_{\rm bkg}(m_{K\pi}) \right]$$

- where, $\mathcal{P}_{\rm sig}(\Omega) = \frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2} \frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\Big|_{\rm S+P}$

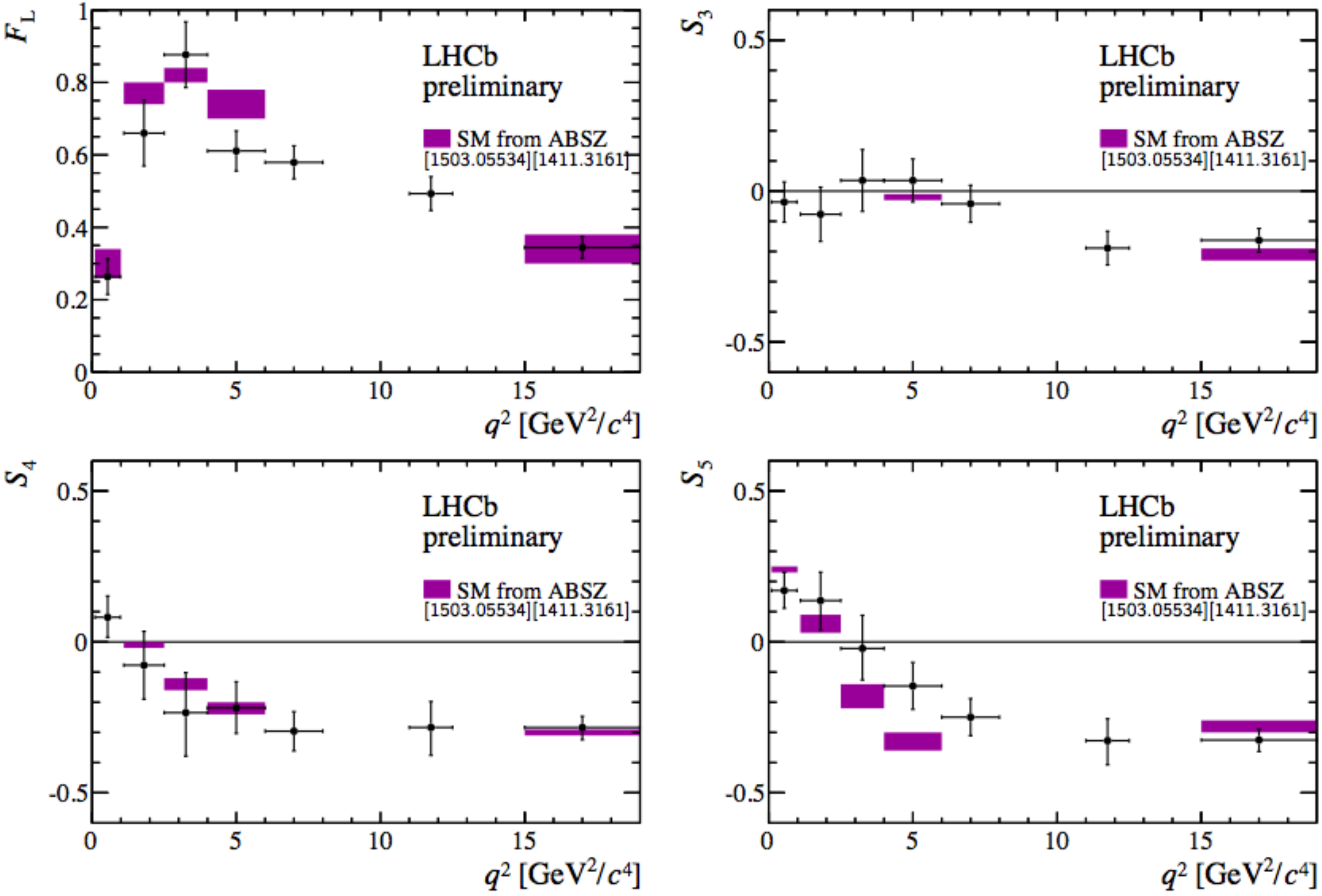
  $\mathcal{P}_{\rm bkg}(\Omega)$ = 2nd order (chebychev) polynominal

  $\mathcal{P}_{\rm sig}(m_{K\pi})$ = Breit-Wigner + LASS parameterisation

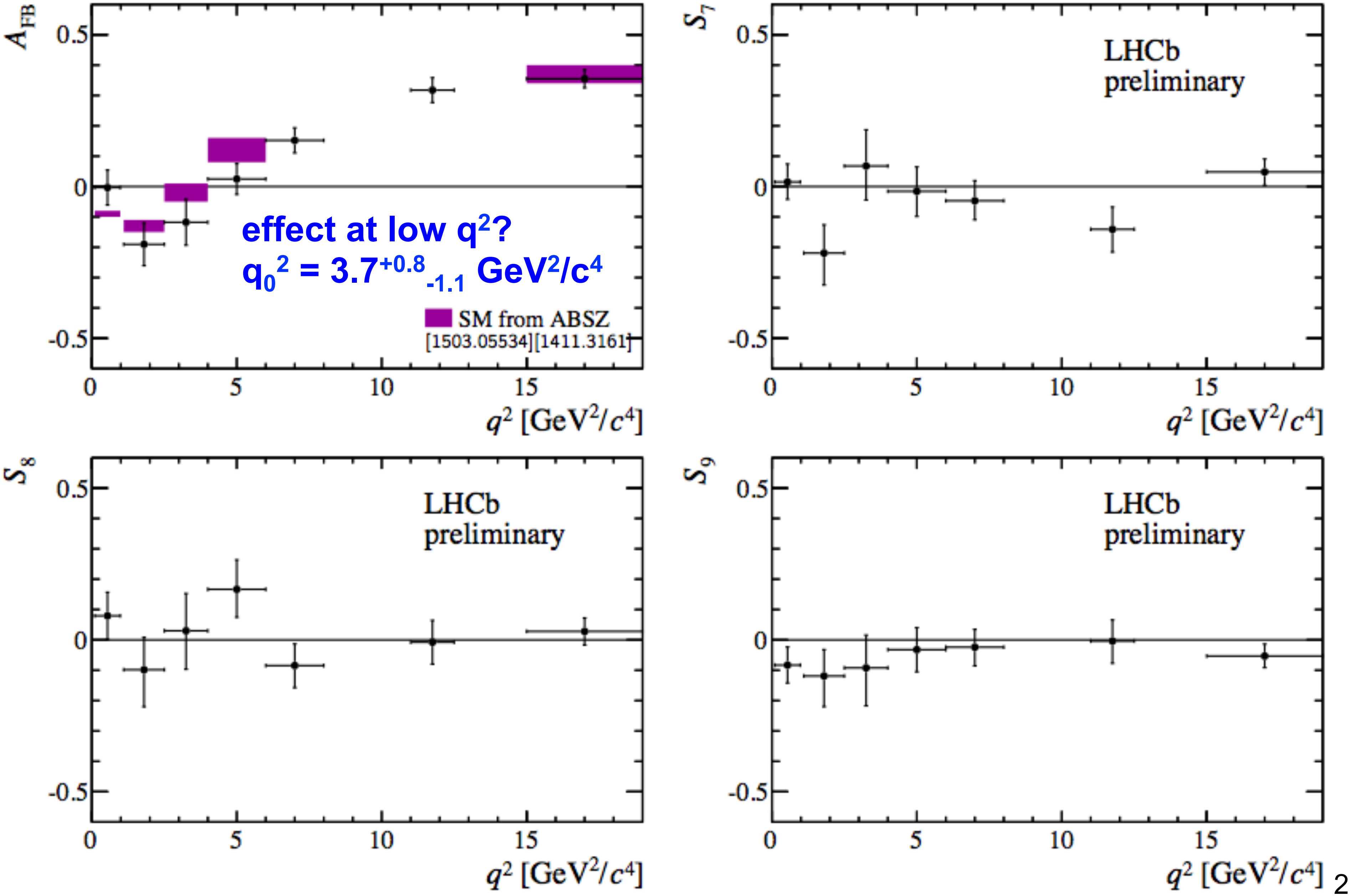
Fit projection $1.1<q^2<6.0$ GeV^2



Fit results: F_L, S_3, S_4, S_5

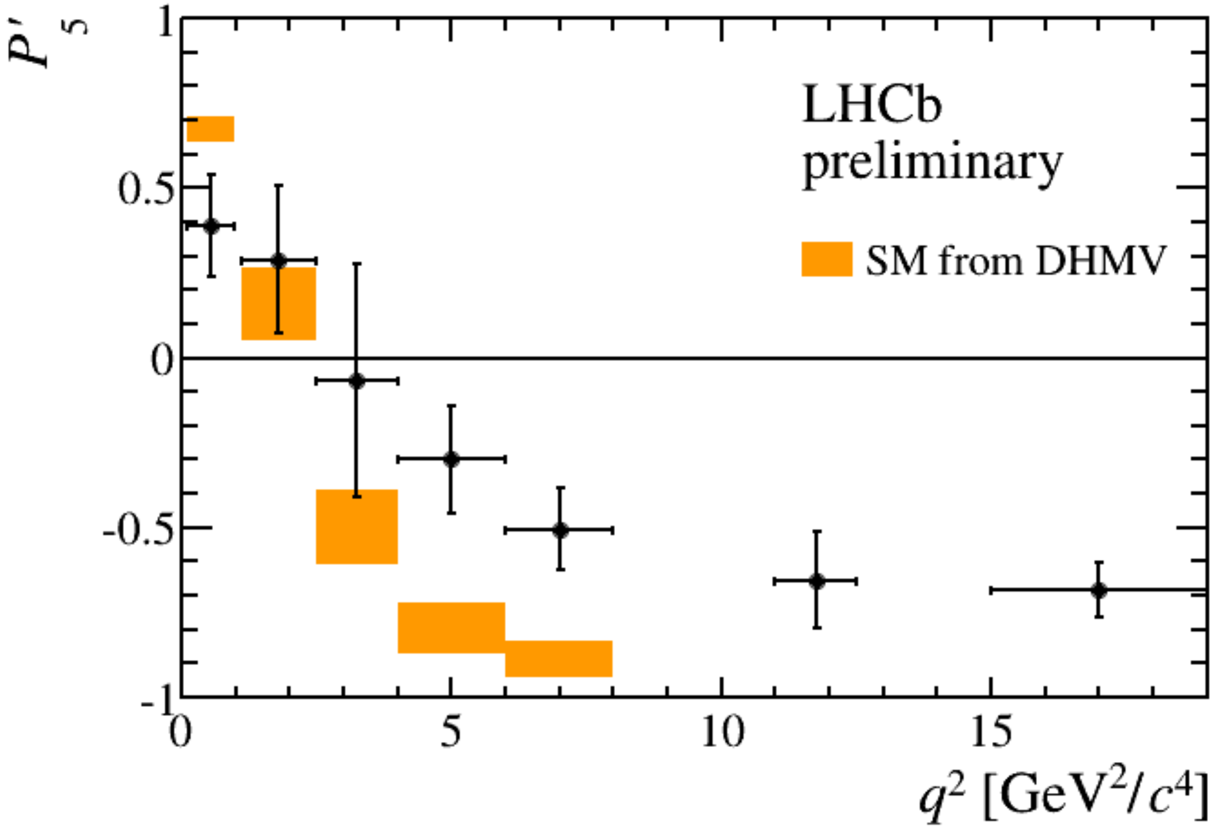


Fit results: A_{FB}, S_7, S_8, S_9



The tension in P_5'

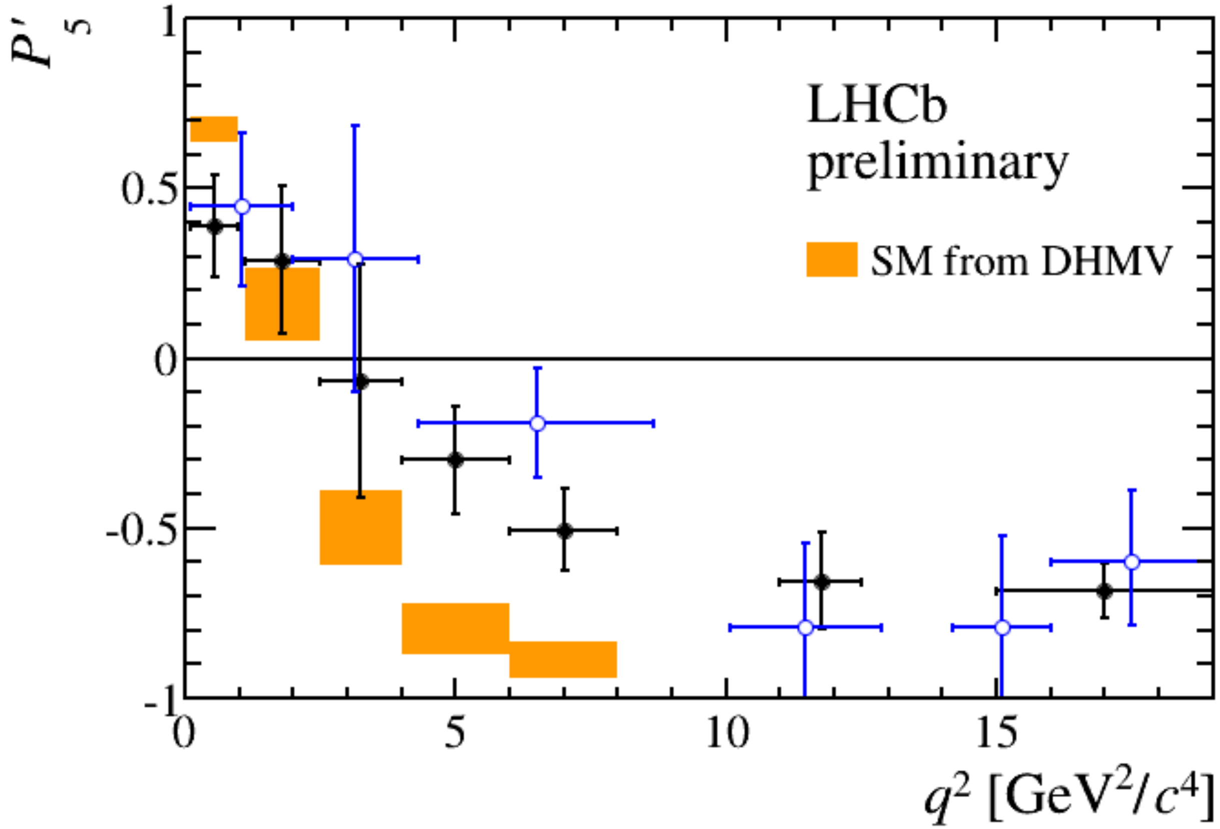
- Tension seen in P_5' in 1fb^{-1} data confirmed with 3fb^{-1}:



- 4.0<q^2<6.0 and 6.0<q^2<8.0 GeV^2/c^4 bins each show deviations of 2.9σ

The tension in P_5'

- Tension seen in P_5' in $1fb^{-1}$ data confirmed with $3fb^{-1}$:

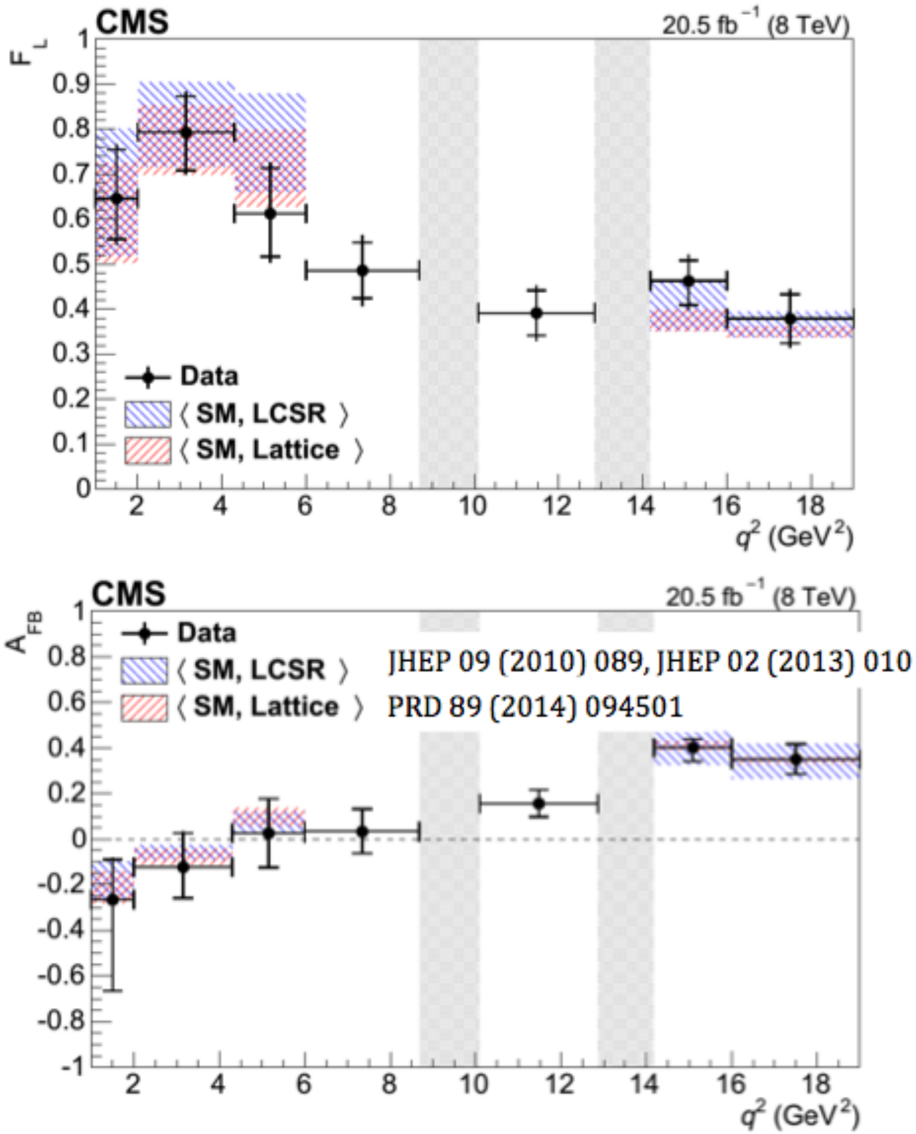


- $4.0<q^2<6.0$ and $6.0<q^2<8.0$ GeV^2/c^4 bins each show deviations of 2.9σ

$B^0 \rightarrow K^{*0}\mu^+\mu^-$

[arXiv:1507.08126]

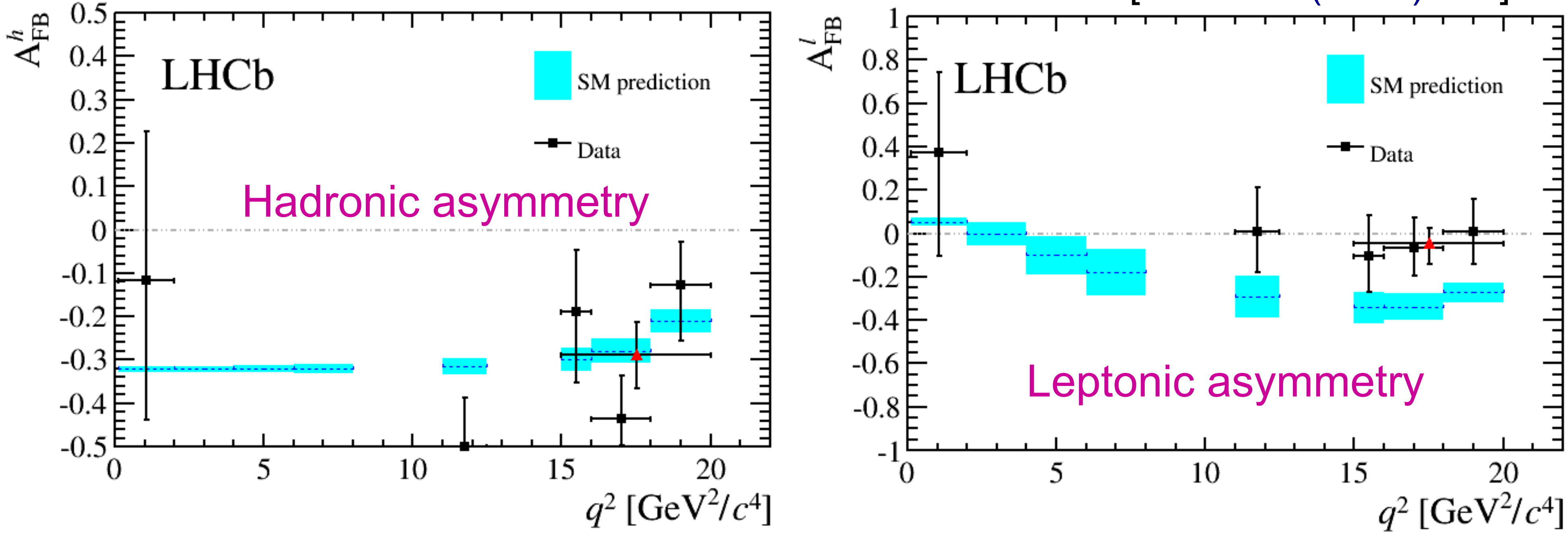
- CMS make 2d angular fit to θ_L and θ_K
- Measurements in good agreement with SM and with LHCb data



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

- Where signal significance is >3σ, use angular analysis to determine A_{FB} in both hadronic and leptonic systems

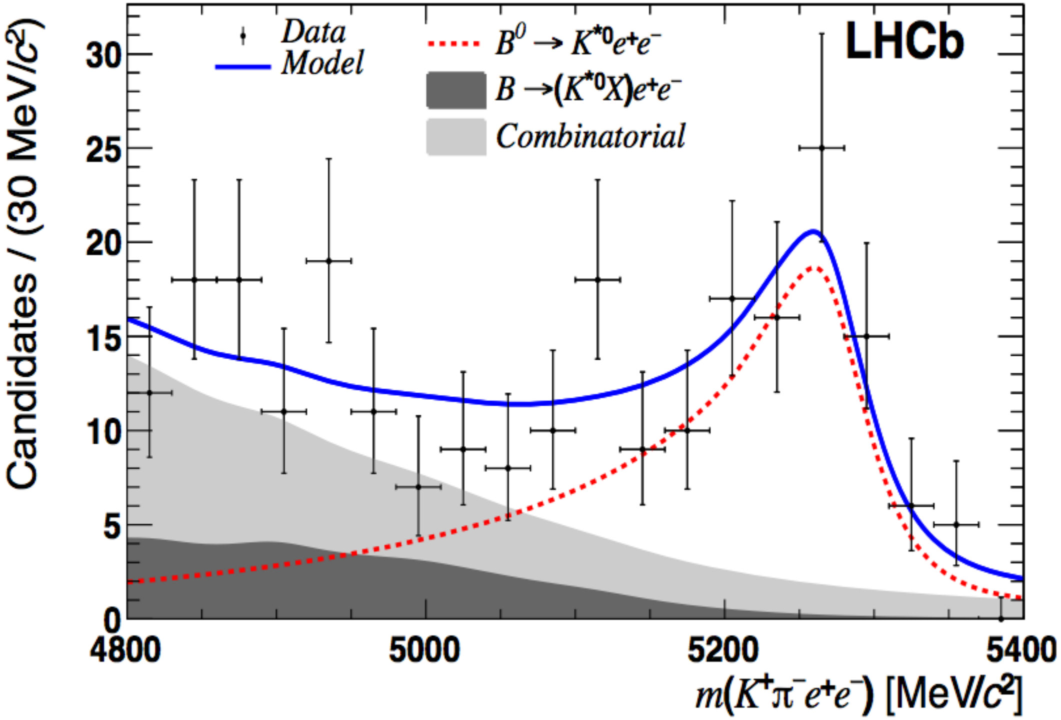
[JHEP 06 (2015) 115]



- A^h_{FB} is in good agreement with SM prediction [PRD 87 (2013) 074502]
- A^l_{FB} is consistently above the SM prediction (large $c\bar{c}$?)

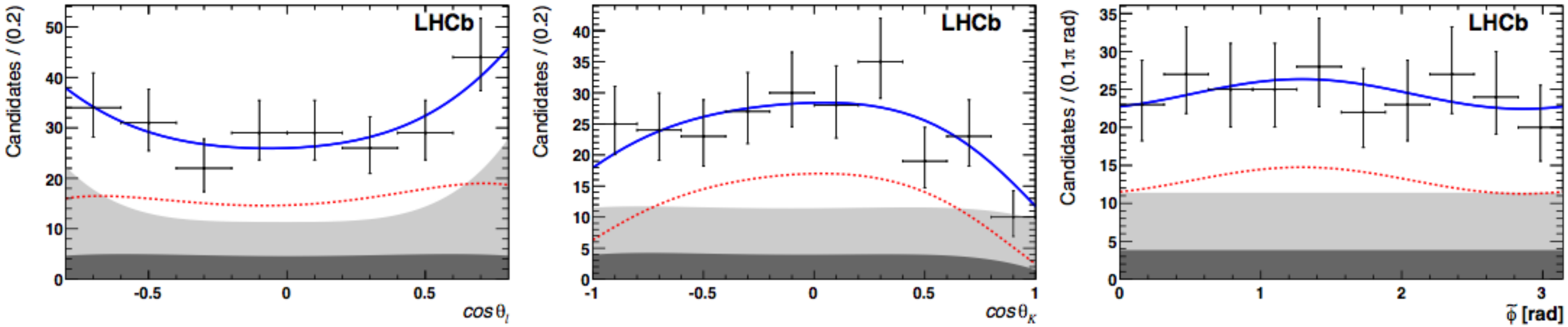
$B^0 \rightarrow K^{*0}e^+e^-$ angular analysis

- Have made $3fb^{-1}$ $B^0 \rightarrow K^{*0}e^+e^-$ angular analysis for $0.0004<q^2<1.0\ GeV^2/c^4$
- Very different experimental challenges: trigger and brem.
- Determine angular observables F_L, A_T^2, A_T^{Re}, A_T^{Im}



(See Arantza's talk, tomorrow morning…)

$B^0 \rightarrow K^{*0} e^+ e^-$ angular analysis



[arxiv:1501.03038]

obs.	result
F_{L}	$+0.16 \pm 0.06 \pm 0.03$
$A_{\mathrm{T}}^{(2)}$	$-0.23 \pm 0.23 \pm 0.05$
$A_{\mathrm{T}}^{\mathrm{Re}}$	$+0.10 \pm 0.18 \pm 0.05$
$A_{\mathrm{T}}^{\mathrm{Im}}$	$+0.14 \pm 0.22 \pm 0.05$

[JHEP 05 (2013) 043]

obs.	SM prediction
F_{L}	$+0.10^{+0.11}_{-0.05}$
$A_{\mathrm{T}}^{(2)}$	$+0.03^{+0.05}_{-0.04}$
$A_{\mathrm{T}}^{\mathrm{Re}}$	$-0.15^{+0.04}_{-0.03}$
$A_{\mathrm{T}}^{\mathrm{Im}}$	$(-0.2^{+1.2}_{-1.2}) \times 10^{-4}$

- Results are in good agreement with SM predictions
- Constraints on $C_7^{(')}$ competitive with radiative decays

Upcoming LHCb measurements

Ratio measurements

R_K

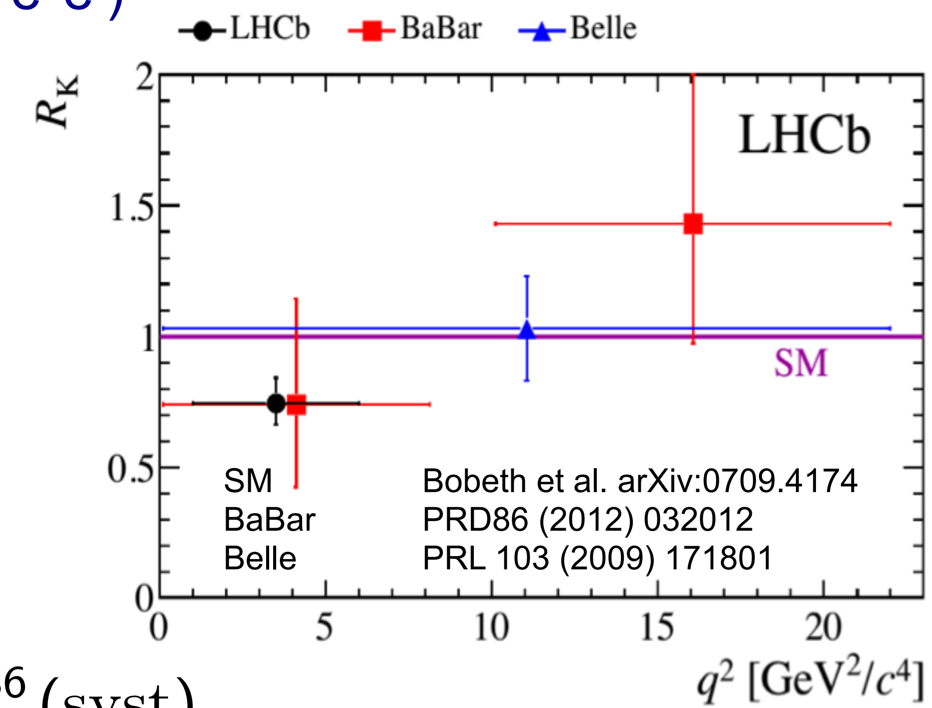
- The ratio of branching fractions,

  $R_K = B(B^+ \to K^+\mu^+\mu^-) / B(B^+ \to K^+e^+e^-)$

- Precisely predicted in SM,

  $R_K = 1.00030^{+0.00010}_{-0.00007}$

- But LHCb measurement in $1<q^2<6$ GeV^2



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

→ 2.6σ from SM prediction

(See Francesco's talk, this afternoon…)

Upcoming LHCb measurements

Conclusions

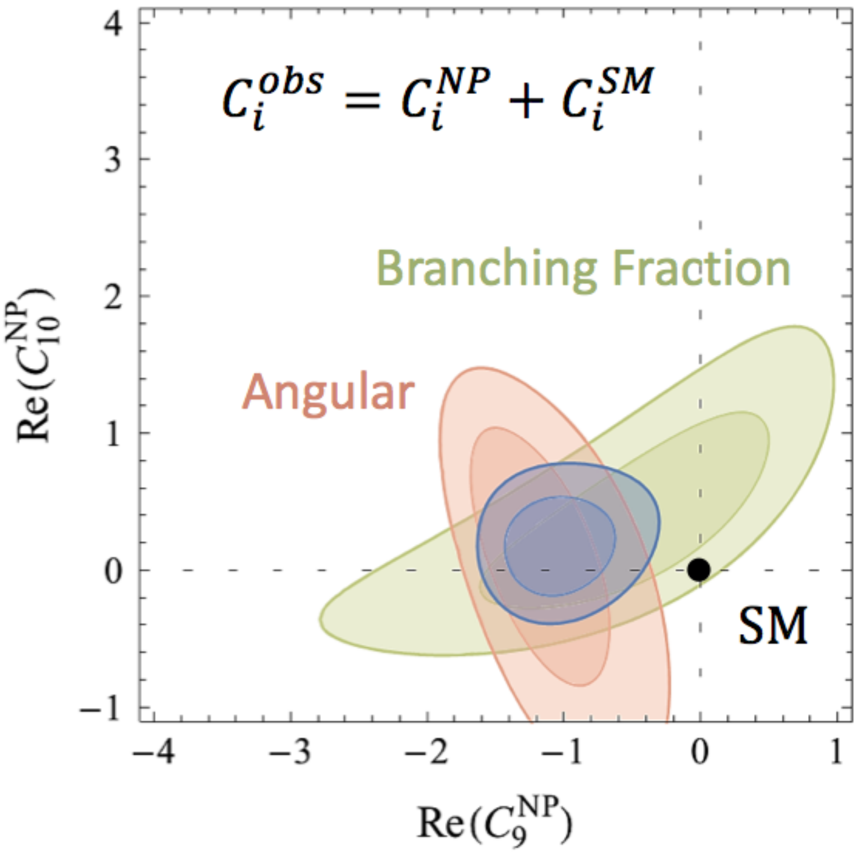
- Branching fraction measurements continue to show mild tension with SM in low q^2 region

- $B^0 \rightarrow K^{*0}\mu^+\mu^-$ angular analysis
  - New benchmark for the experimental measurement
    - Simultaneous determination of all eight CP-averaged observables in a single fit (correlation matrices)
    - Background suppression; Handling s-wave; Model independent determination of experimental effects
  - P_5' deviation confirmed: Two q^2 bins with significance of 2.9σ each; effect in A_{FB}?

- Lepton-universality challenged by R_K measurement – would like to see effect in other channels

Conclusions

- Are the measurements compatible with a consistent underlying effect?



[Altmannshofer, Straub, EPJC (2015) 75: 382]

Backup

$B^0 \to K^{*0}\mu^+\mu^-$

ATLAS NOTE

ATLAS-CONF-2013-038

April 5, 2013

Withdrawn: June 17, 2015

Angular Analysis of $B_d^0 \to K^{*0}\mu^+\mu^-$ with the ATLAS Experiment

The ATLAS Collaboration

Abstract

A measurement of the forward-backward asymmetry A_{FB} and the fraction of the K^{*0} longitudinal polarisation F_L in the decay $B_d^0 \to K^{*0}\mu^+\mu^-$ as a function of the di-muon invariant mass is presented. A data sample of 4.9 fb^{-1} of integrated luminosity collected with the ATLAS detector at the LHC at CERN taken in the year 2011 is used. The measurement is compared to the expectations from the Standard Model.

A bug has been found in the analysis in the calculation of the kinematic angles (Figure 1 in the conference note; the definition was correct, but the implementation not). This invalidates the presented analysis result.