

Recent results from LHCb

11th May 2015

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Outline

- $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ angular analysis
 - Brief tour of features [LHCb-CONF-2015-002]
 - Future prospects
- Recent highlights of other EW-penguin measurements
 - $B^0 \rightarrow K^{*0} e^+ e^-$ [JHEP04 (2015) 064]
 - $B^0_{(s)} \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ [PLB 743 (2015) 46]
 - $\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$ [LHCb-PAPER-2015-009]

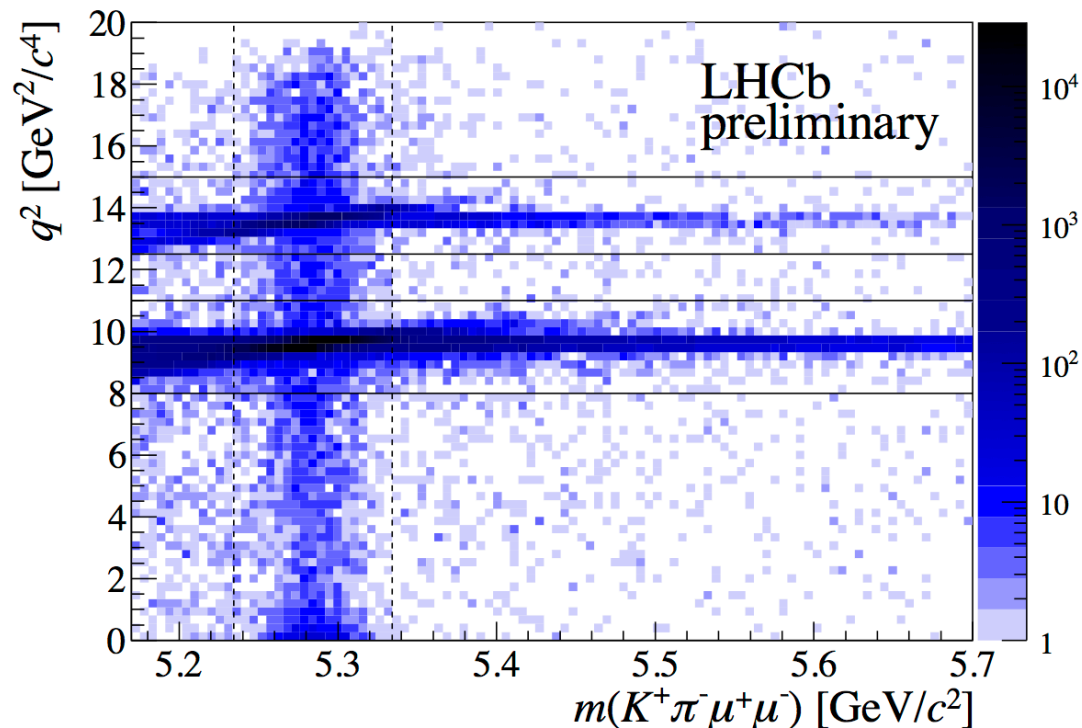
$B^0 \rightarrow K^{*0} \mu^+ \mu^-$ – Introduction

- [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 systs.)
- Make simultaneous determination of all eight CP-averaged observables in a single fit (→ provided correlation matrices)

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

- Selection uses range of Particle IDentification, kinematic and geometric quantities in a Boosted Decision Tree
- Veto $B^0 \rightarrow K^{*0} J/\psi$ and $B^0 \rightarrow K^{*0} \psi(2S)$ decays, as well as a number of peaking backgrounds (PID)



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

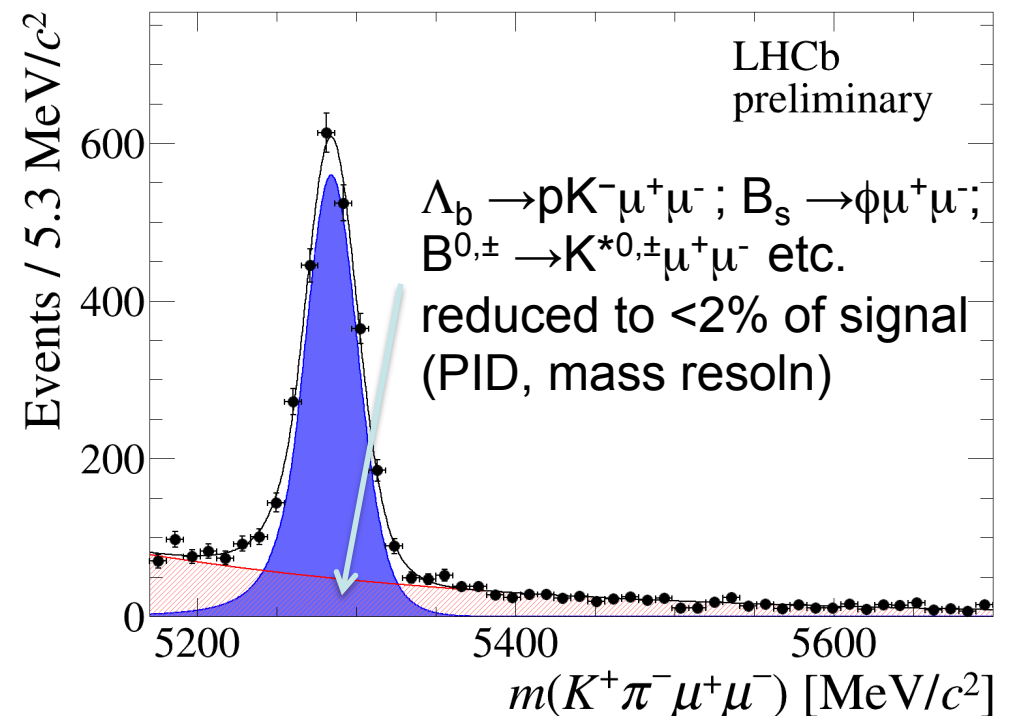
- Signal mass model defined using $B^0 \rightarrow K^{*0} J/\psi$ control channel (correct for q^2 dependence)
- Find 2398 ± 57 signal events in $0.1 < q^2 < 19.0 \text{ GeV}^2/c^4$ (~ 600 events in $1.1 < q^2 < 6.0 \text{ GeV}^2/c^4$)

- Cleanliness

- $\sigma_{m(K\pi\mu\mu)} \sim 19 \text{ MeV}/c^2$
cf. CMS $44 \text{ MeV}/c^2$, [PLB 727 (2013) 77]

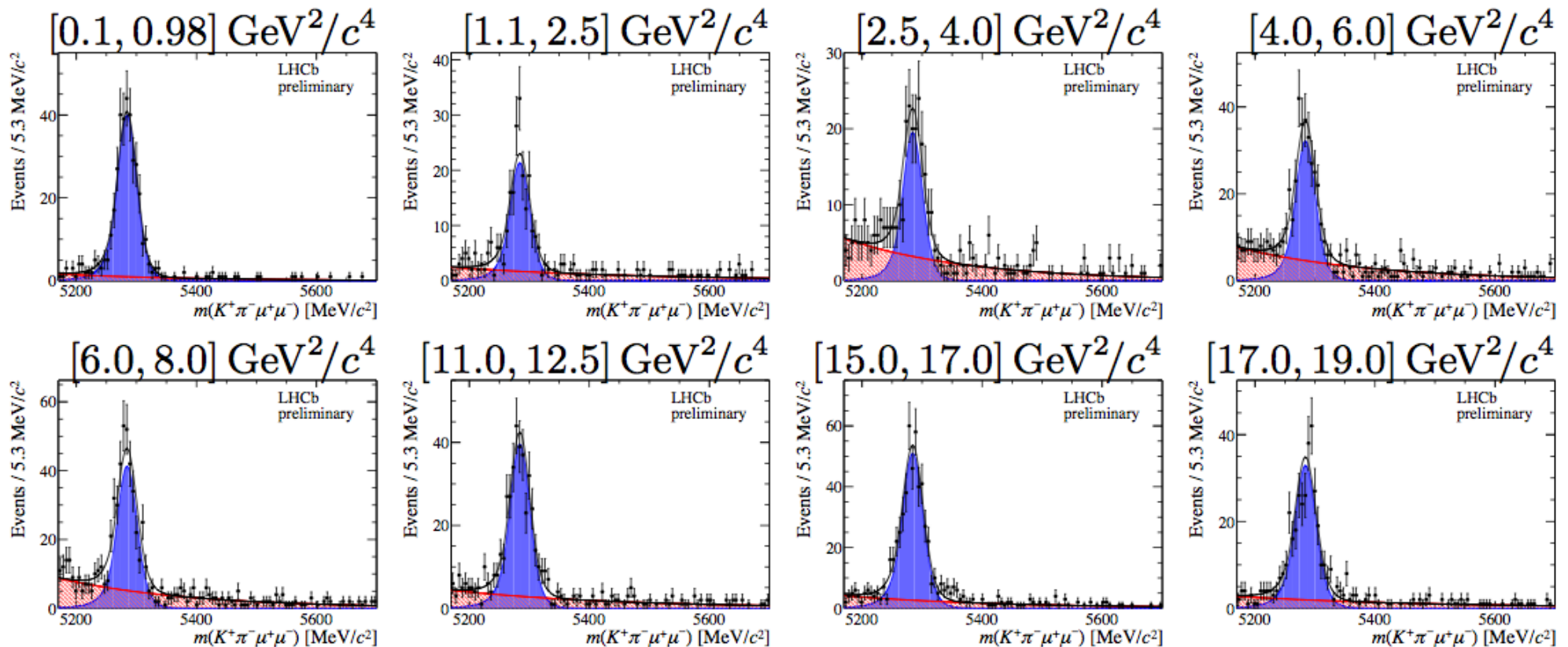
- Modified q^2 binning

- Avoid ϕ region
 - Finer than for 1fb^{-1}



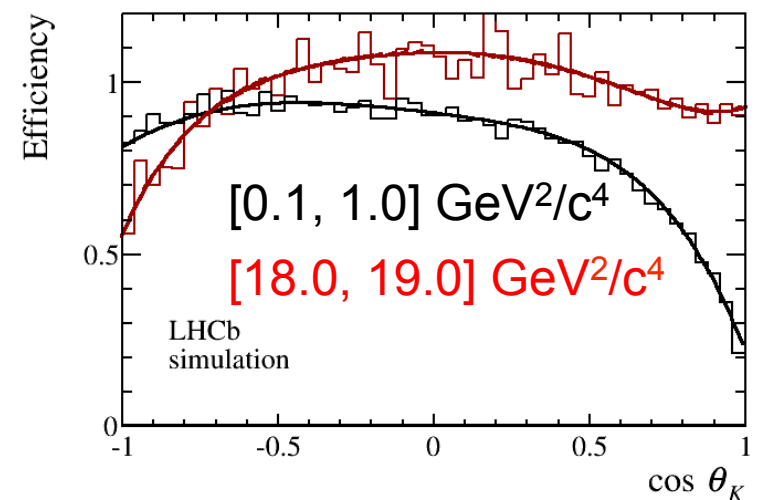
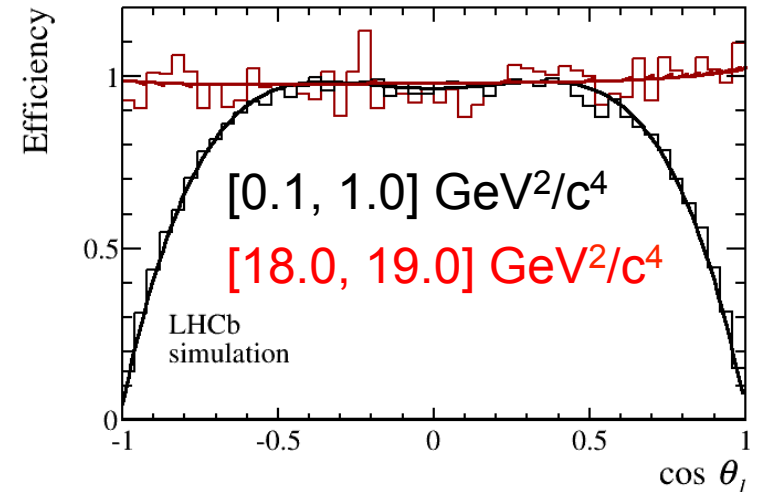
$B^0 \rightarrow K^{*0} \mu^+ \mu^-$ signal selection

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



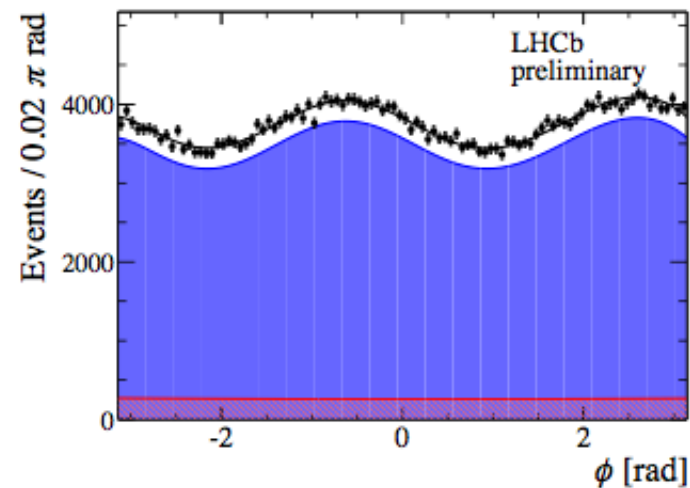
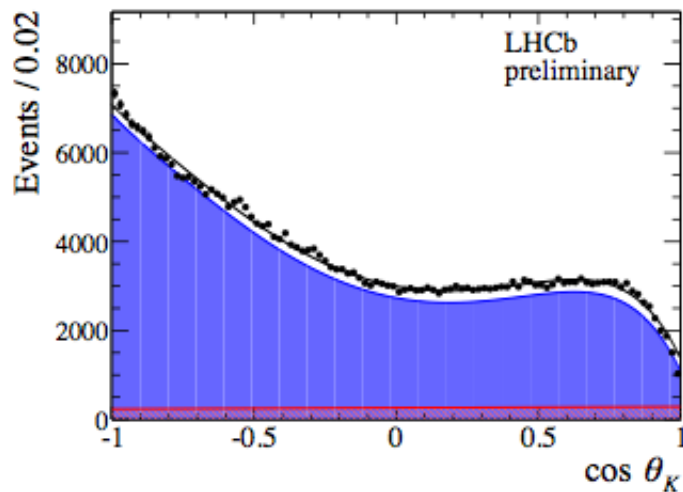
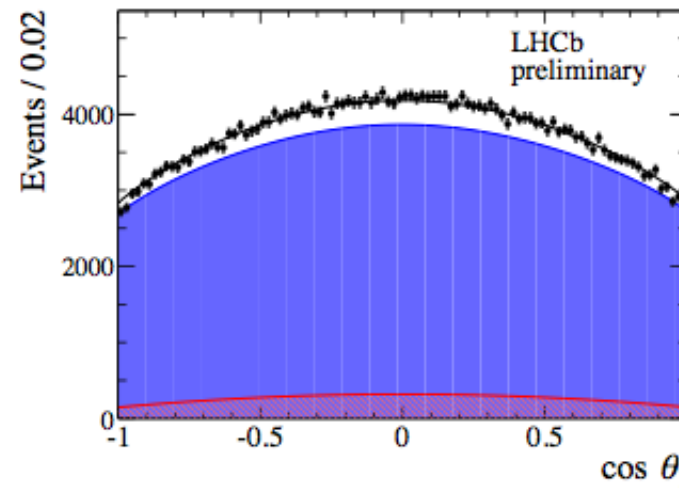
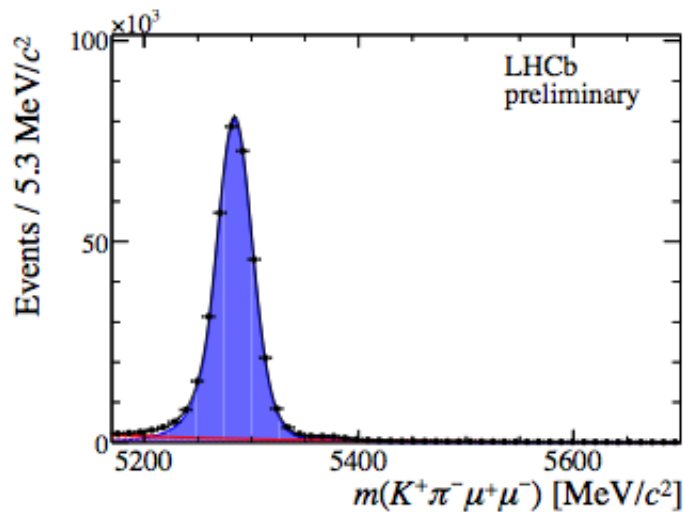
Correcting for the efficiency

- 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 \rightarrow can determine with a phase-space simulation
- Cross-check with $B^0 \rightarrow K^{*0} J/\psi \dots$



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

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



Determining the S-wave pollution

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

$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^3(\Gamma + \bar{\Gamma})}{d\vec{\Omega}} \Big|_{S+P} = (1 - F_S) \frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^3(\Gamma + \bar{\Gamma})}{d\vec{\Omega}} \Big|_P + \frac{3}{16\pi} F_S \sin^2 \theta_\ell + \text{S-P interference}$$

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

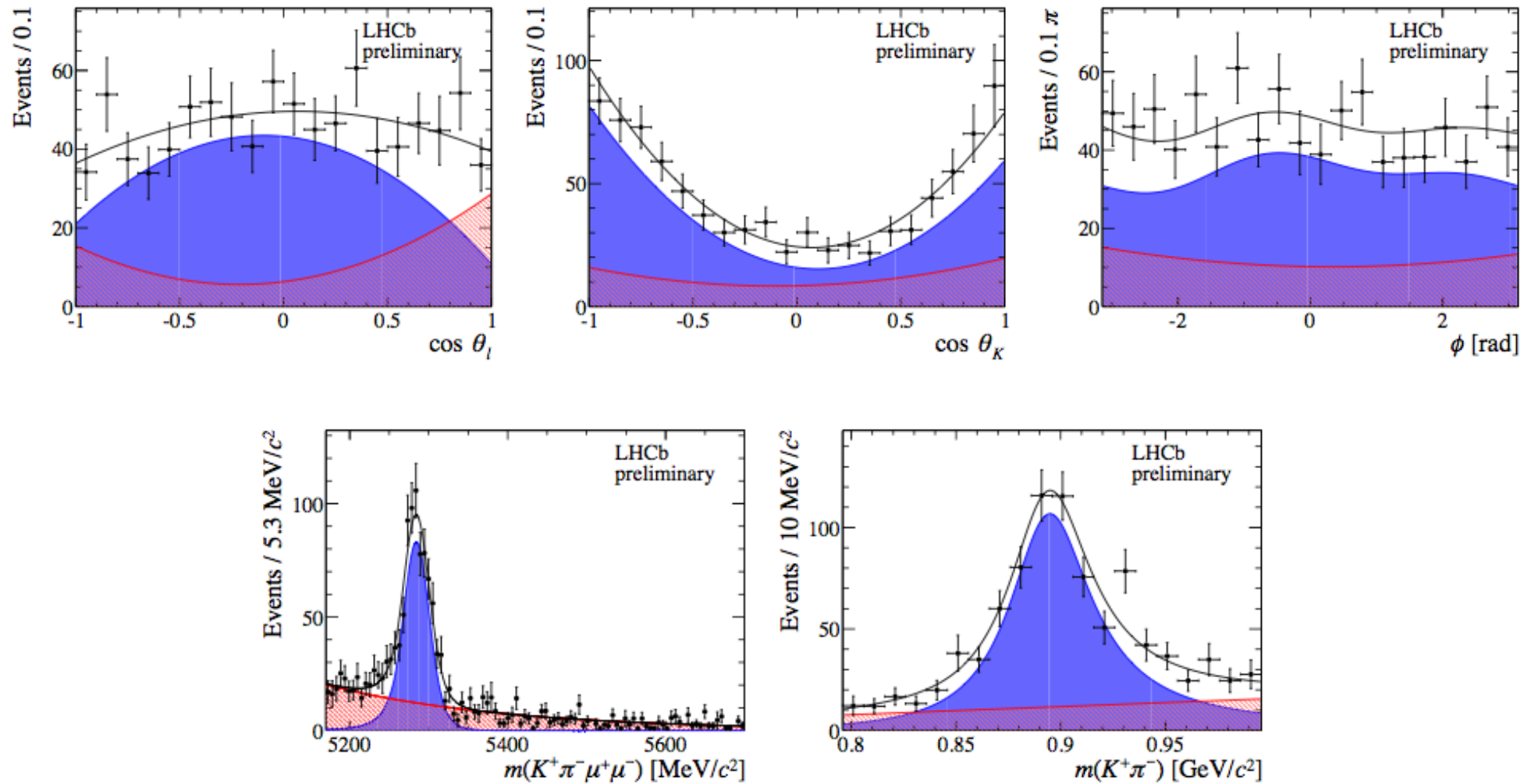
$B^0 \rightarrow K^{*0} \mu^+ \mu^-$ likelihood fit

- 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

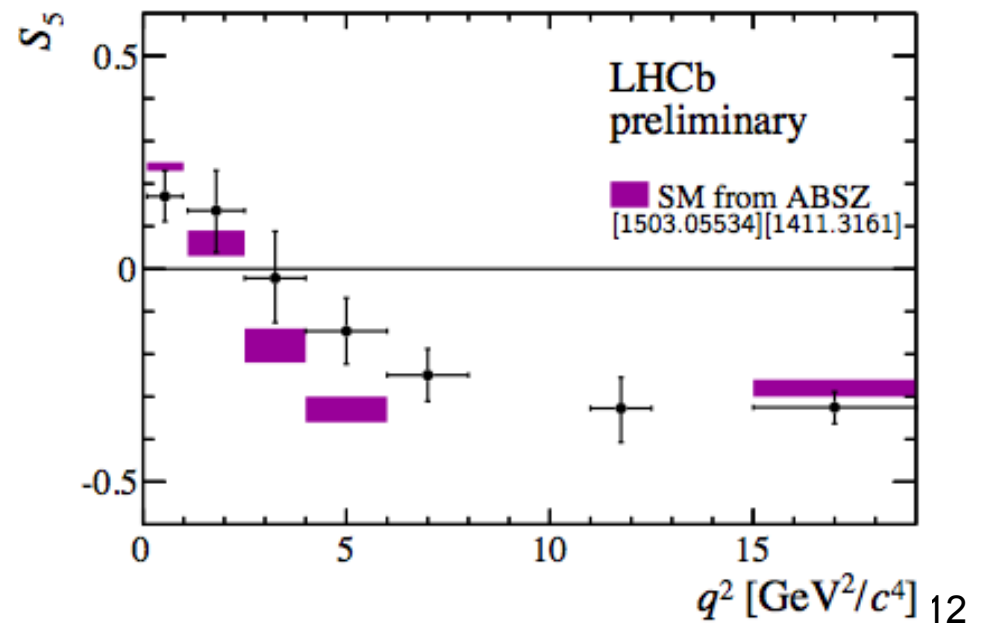
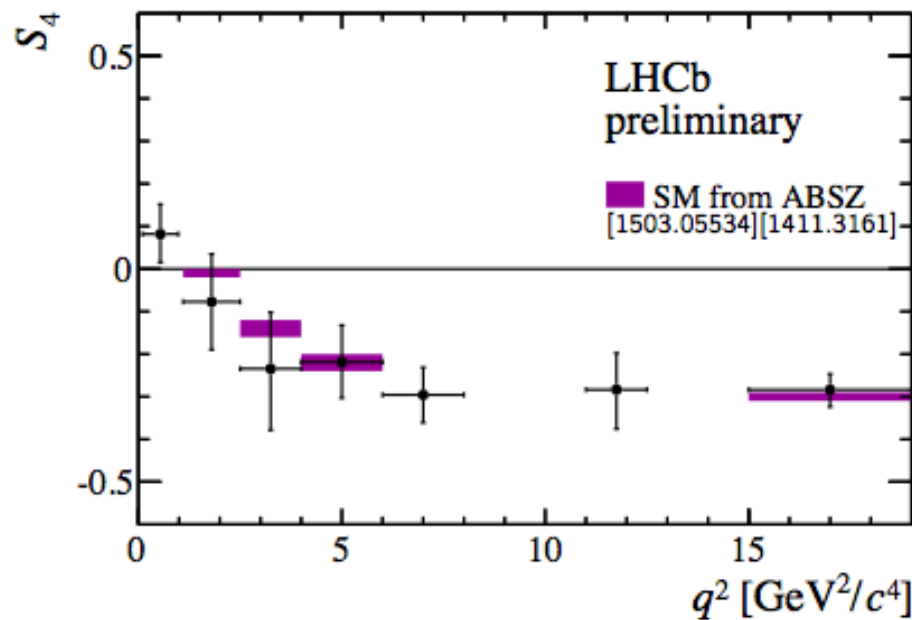
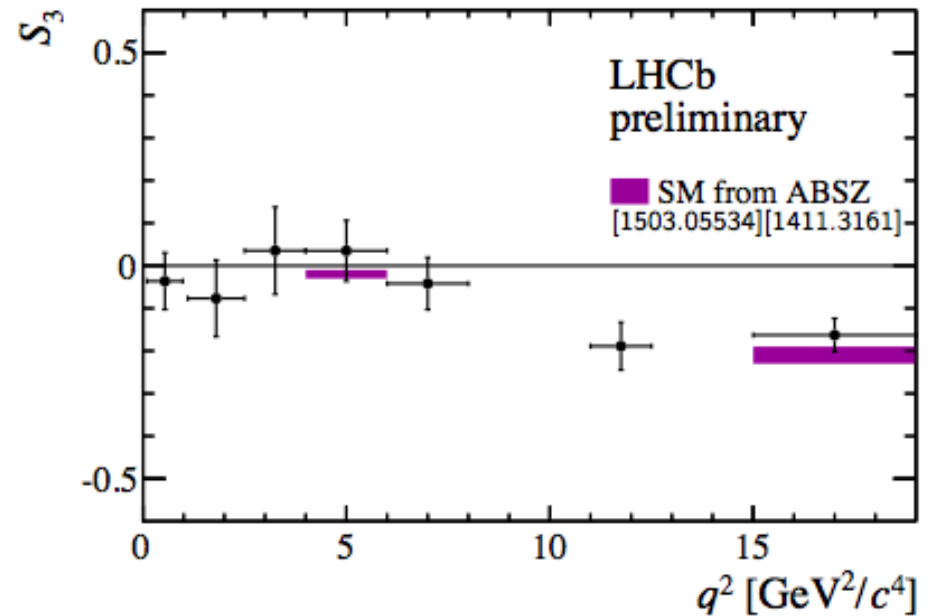
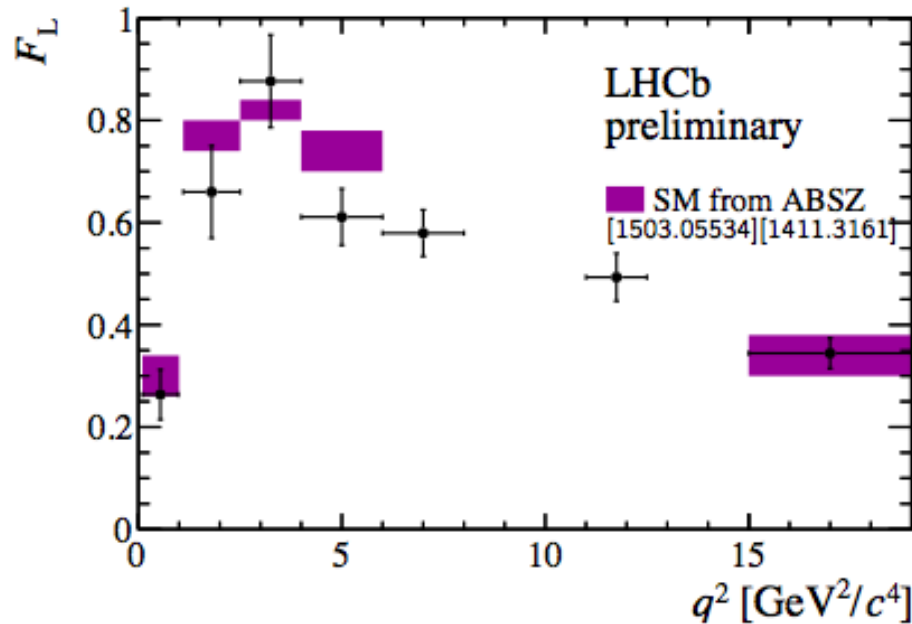
$$\log \mathcal{L} = \sum_i \log \left[\epsilon(\vec{\Omega}, q^2) f_{\text{sig}} \mathcal{P}_{\text{sig}}(\vec{\Omega}) \mathcal{P}_{\text{sig}}(m_{K\pi\mu\mu}) \right. \\ \left. + (1 - f_{\text{sig}}) \mathcal{P}_{\text{bkg}}(\vec{\Omega}) \mathcal{P}_{\text{bkg}}(m_{K\pi\mu\mu}) \right] \\ + \sum_i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

- where, $\mathcal{P}_{\text{sig}}(\Omega) = \frac{1}{d(\Gamma+\bar{\Gamma})/dq^2} \frac{d^3(\Gamma+\bar{\Gamma})}{d\vec{\Omega}} \Big|_{S+P}$
 $\mathcal{P}_{\text{bkg}}(\Omega) = 2^{\text{nd}}$ order (chebychev) polynomial
 $\mathcal{P}_{\text{sig}}(m_{K\pi}) = \text{Breit-Wigner} + \text{LASS parameterisation}$

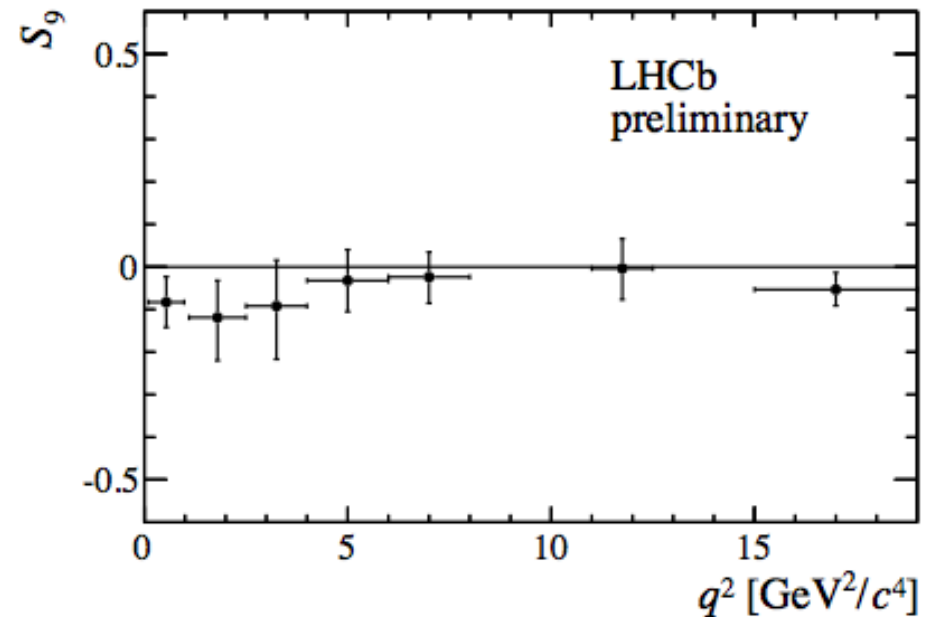
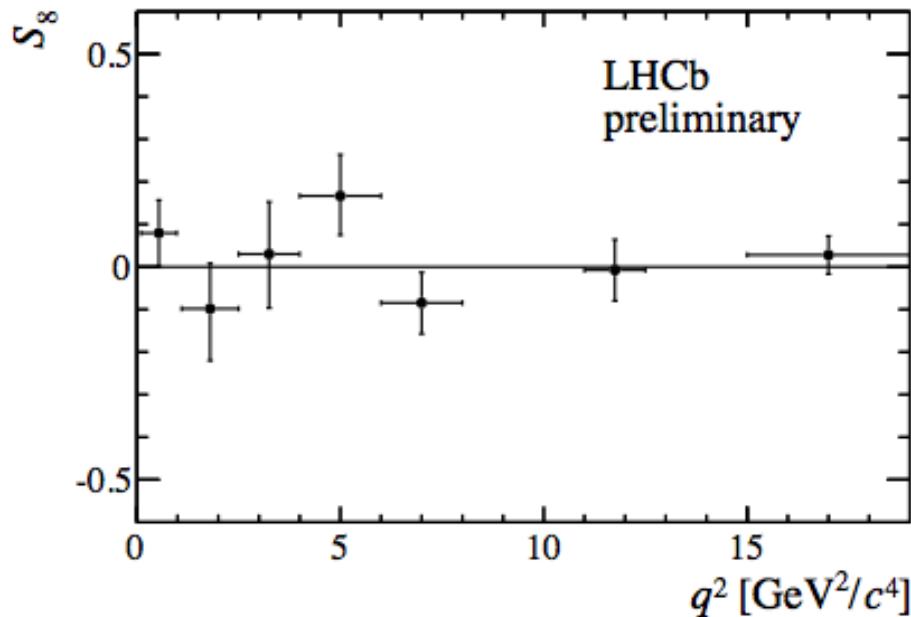
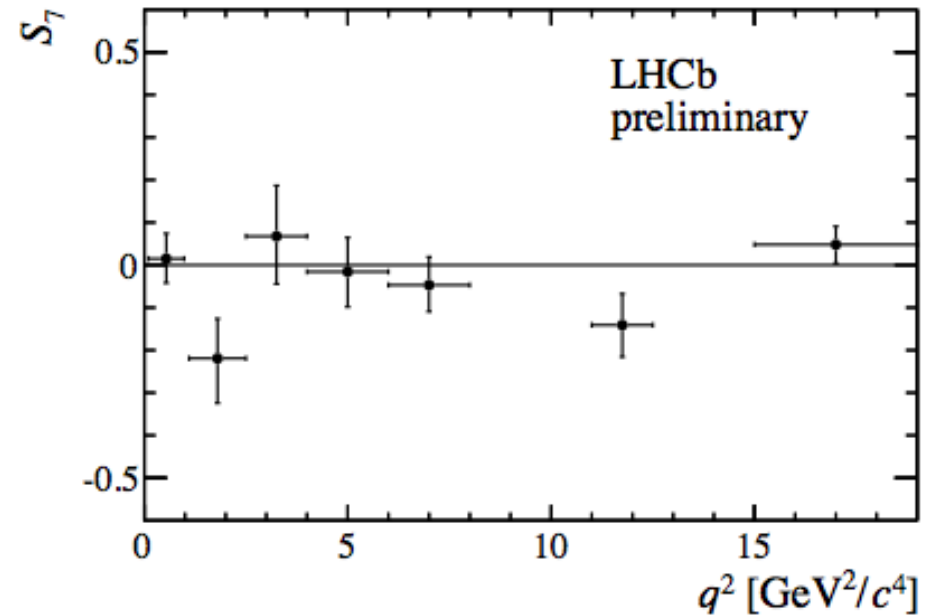
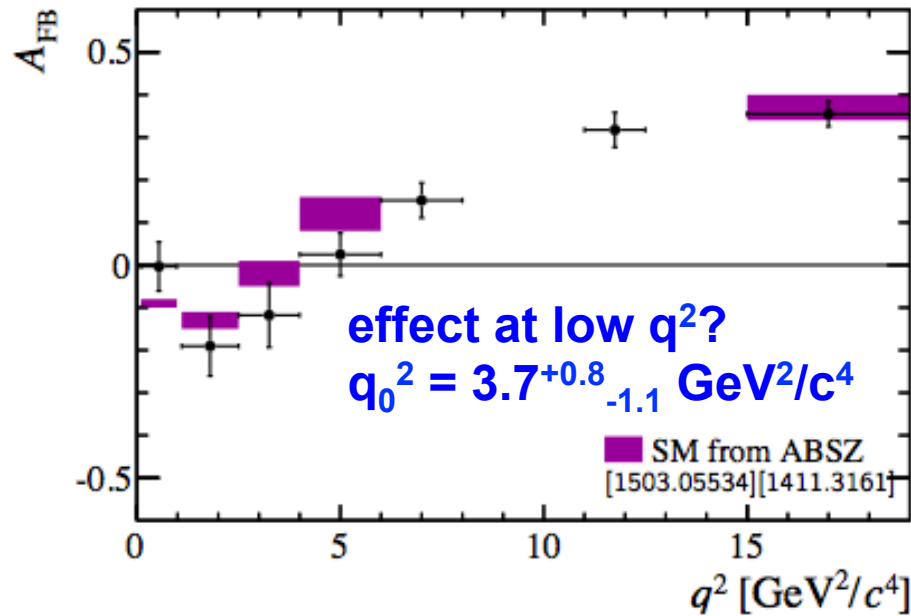
Fit projection $1.1 < q^2 < 6.0 \text{ GeV}^2/c^4$



Fit results: F_L , S_3 , S_4 , S_5

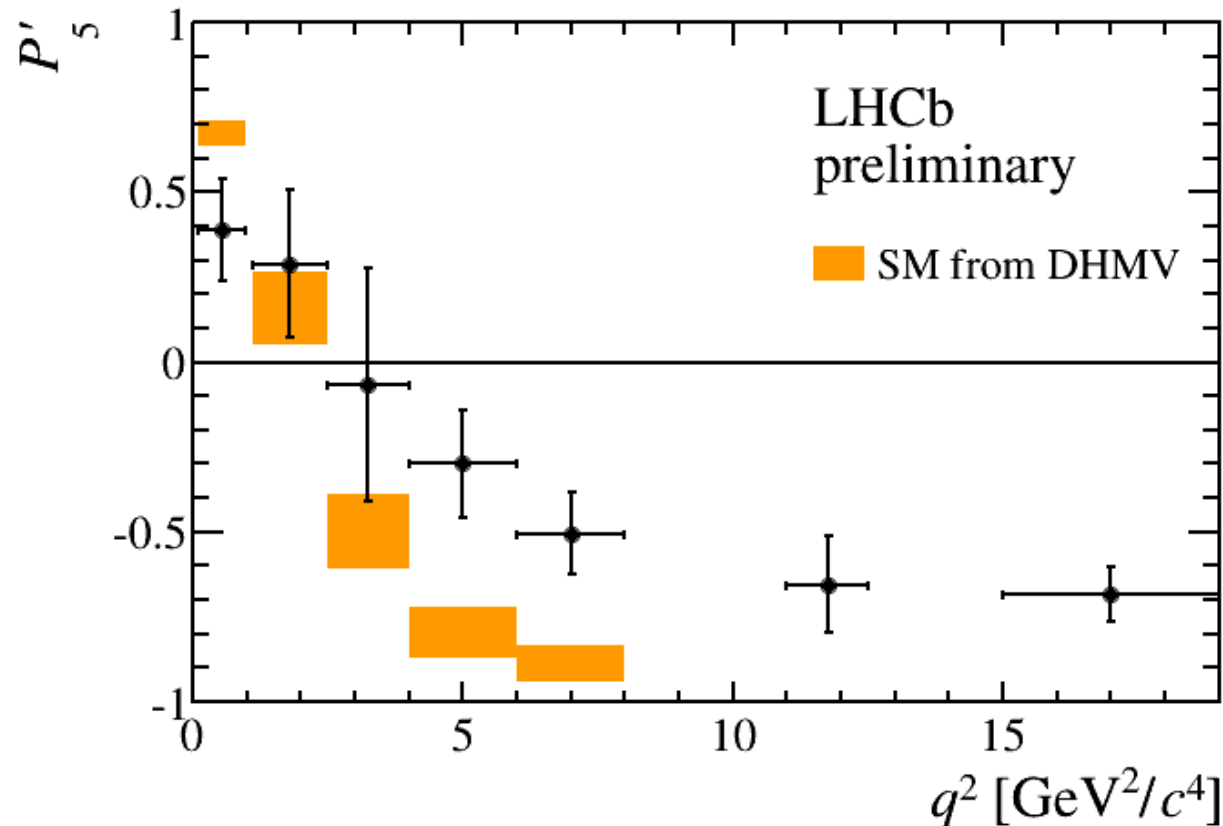


Fit results: A_{FB} , S_7 , S_8 , S_9



The tension in P_5'

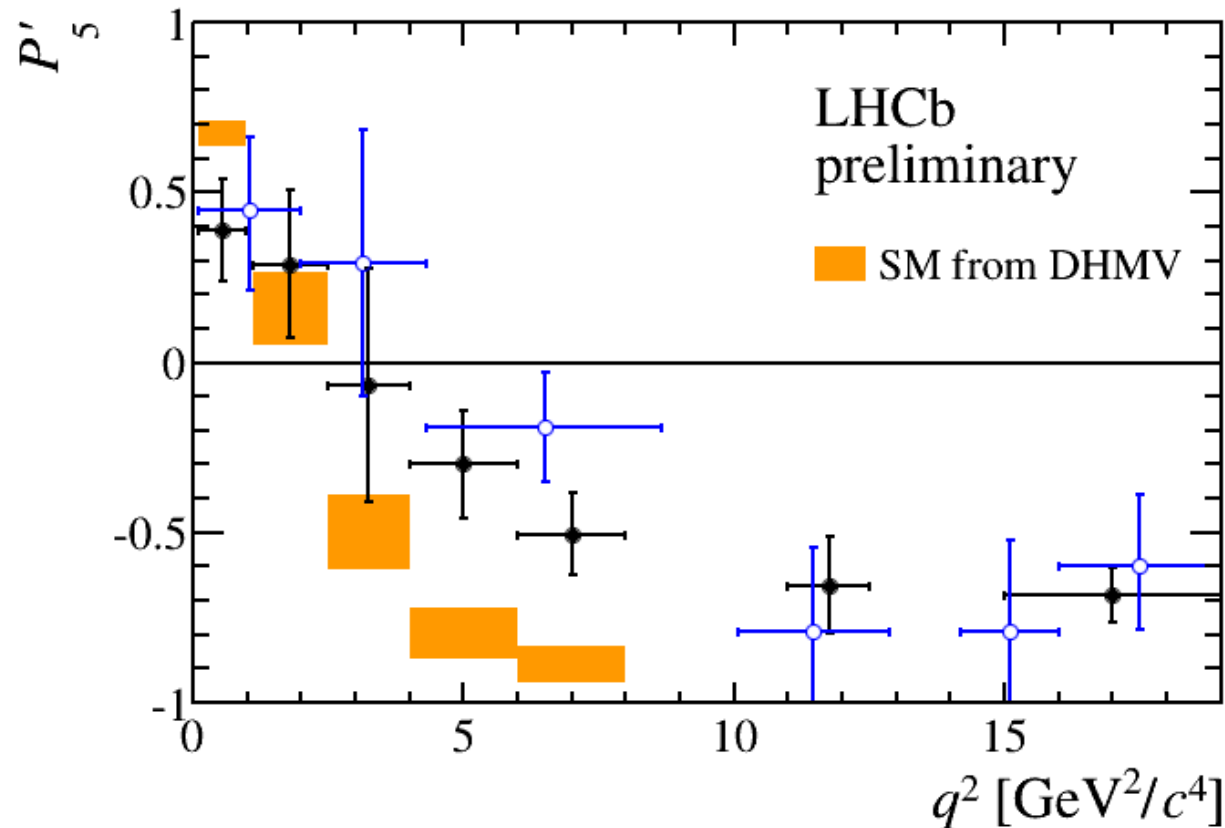
- Tension seen in P_5' in 1fb^{-1} data confirmed with 3fb^{-1} :



- $4.0 < q^2 < 6.0$ and $6.0 < q^2 < 8.0$ GeV²/c⁴ 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

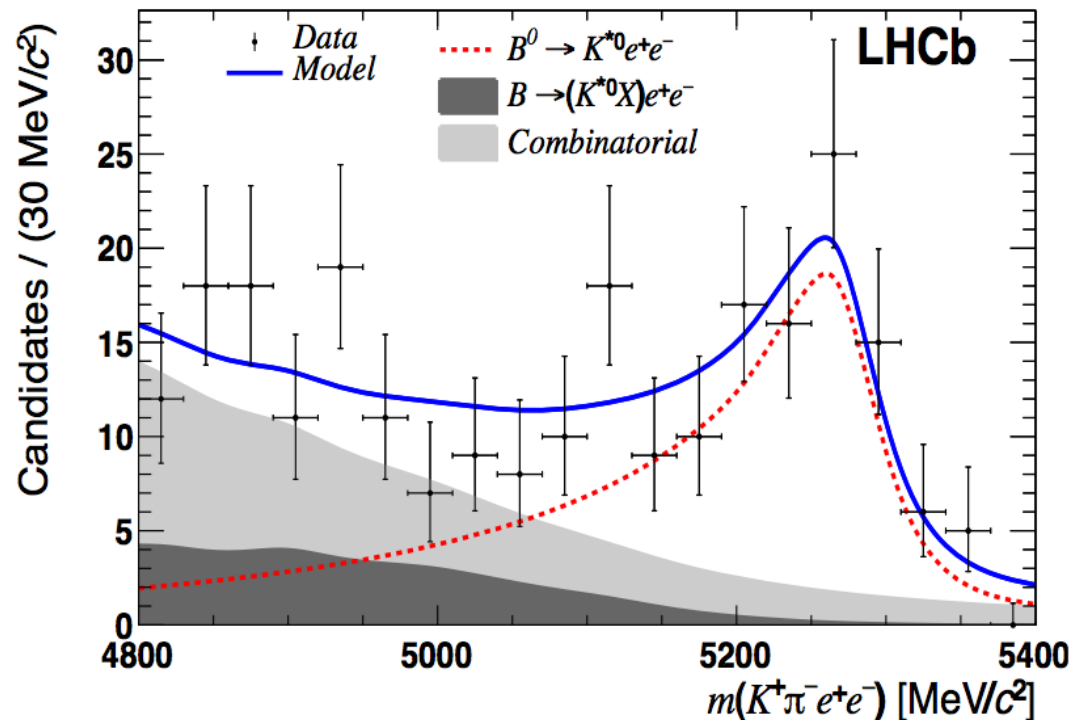
The future

- What can you expect from LHCb in the near future?

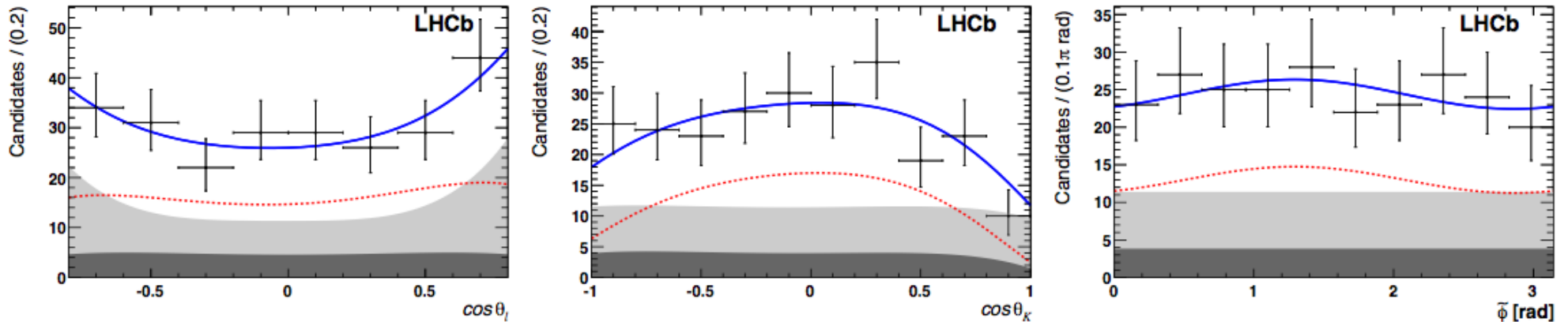
Other EW-penguin measurements

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

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



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



[arxiv:1501.03038]

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

[JHEP 05 (2013) 043]

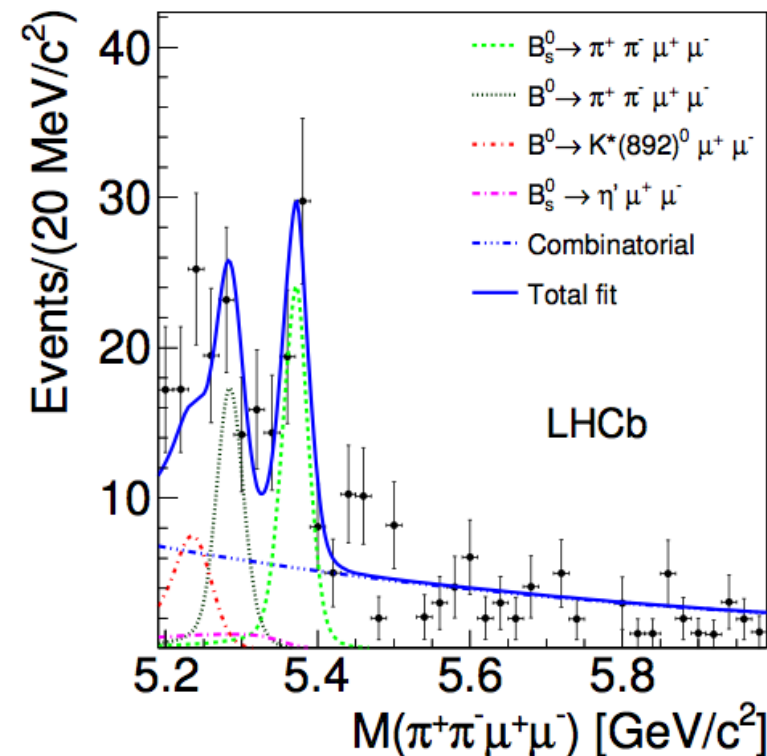
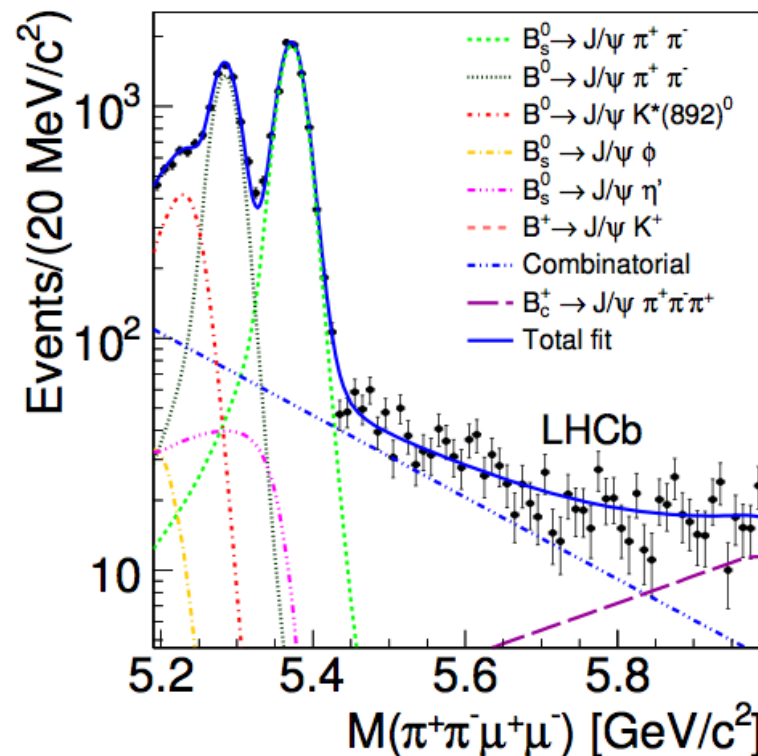
obs.	SM prediction
F_L	$+0.10^{+0.11}_{-0.05}$
$A_T^{(2)}$	$+0.03^{+0.05}_{-0.04}$
A_T^{Re}	$-0.15^{+0.04}_{-0.03}$
A_T^{Im}	$(-0.2^{+1.2}_{-1.2}) \times 10^{-4}$

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

Other EW-penguin measurements

- $B^0_{(s)} \rightarrow \pi^+ \pi^- \mu^+ \mu^-$: get contributions from f^0 ($b \rightarrow s$ transition) and ρ^0 ($b \rightarrow d$ transition)

[PLB 743 (2015) 46]

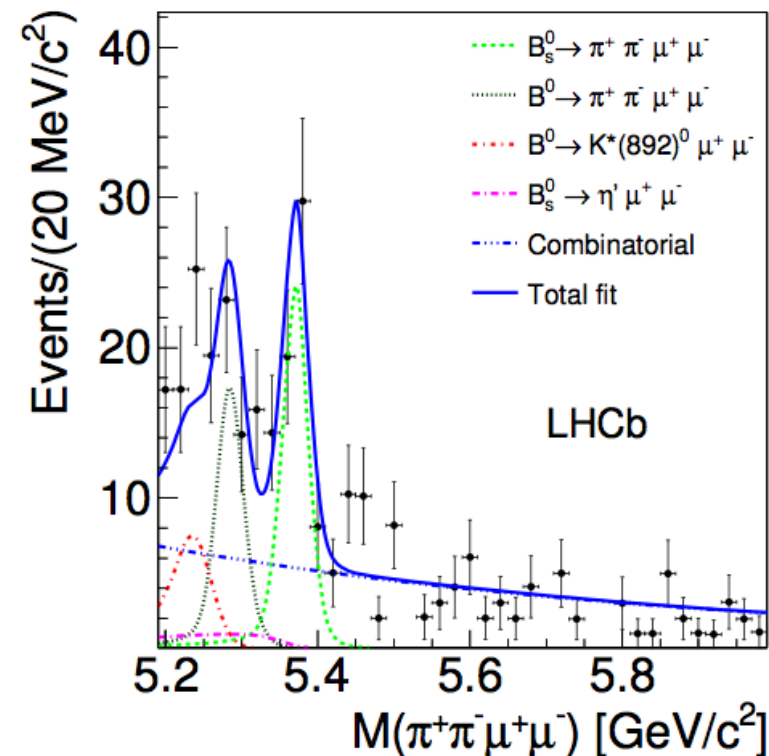
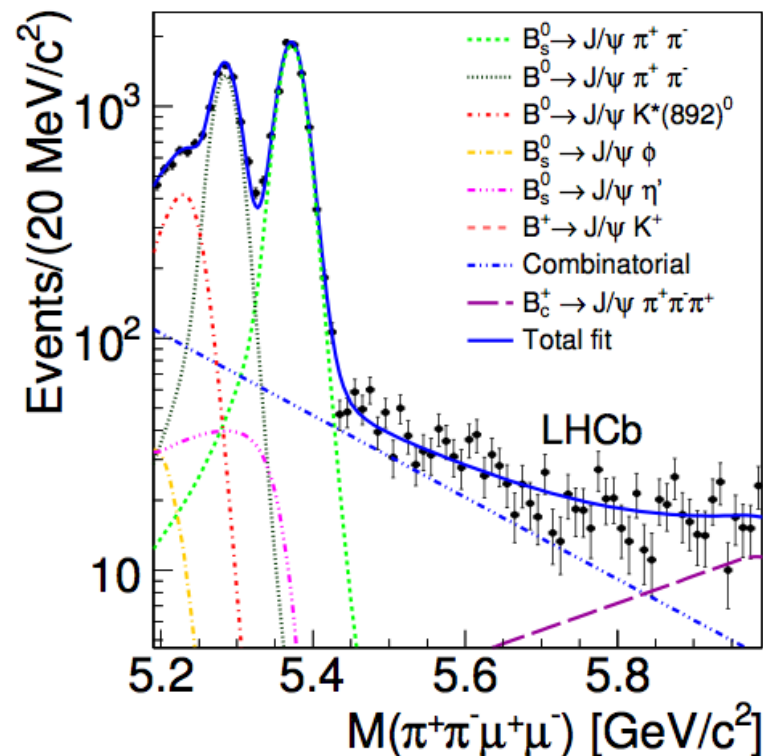


- Observed $B_s \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ @ 7.6σ ; Evidence $B^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ @ 4.8σ
- Branching fractions compatible with SM predictions...

Other EW-penguin measurements

- $B^0_{(s)} \rightarrow \pi^+ \pi^- \mu^+ \mu^-$: get contributions from f^0 ($b \rightarrow s$ transition) and ρ^0 ($b \rightarrow d$ transition)

[PLB 743 (2015) 46]



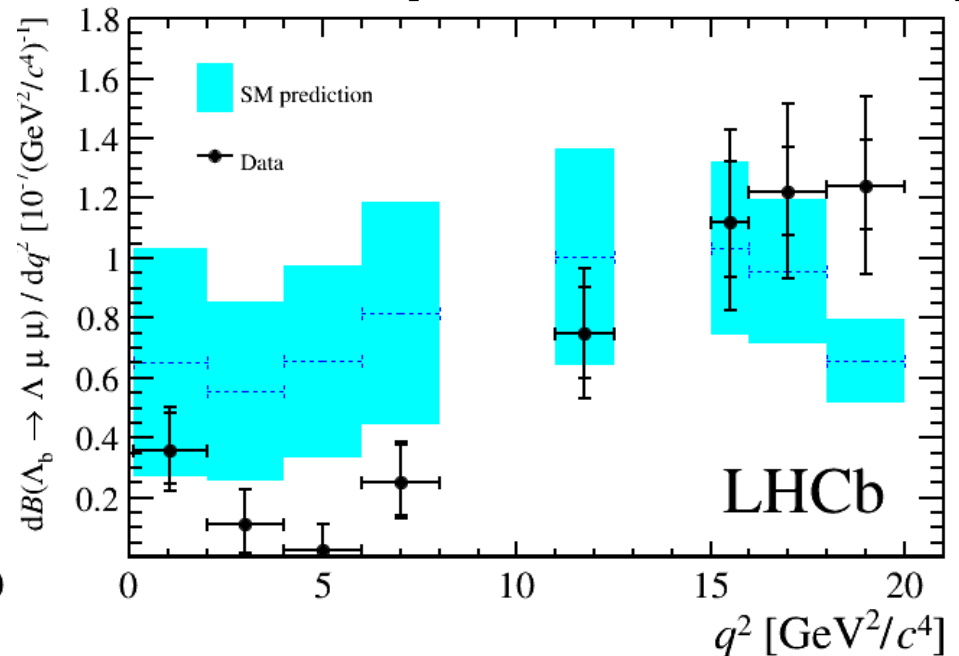
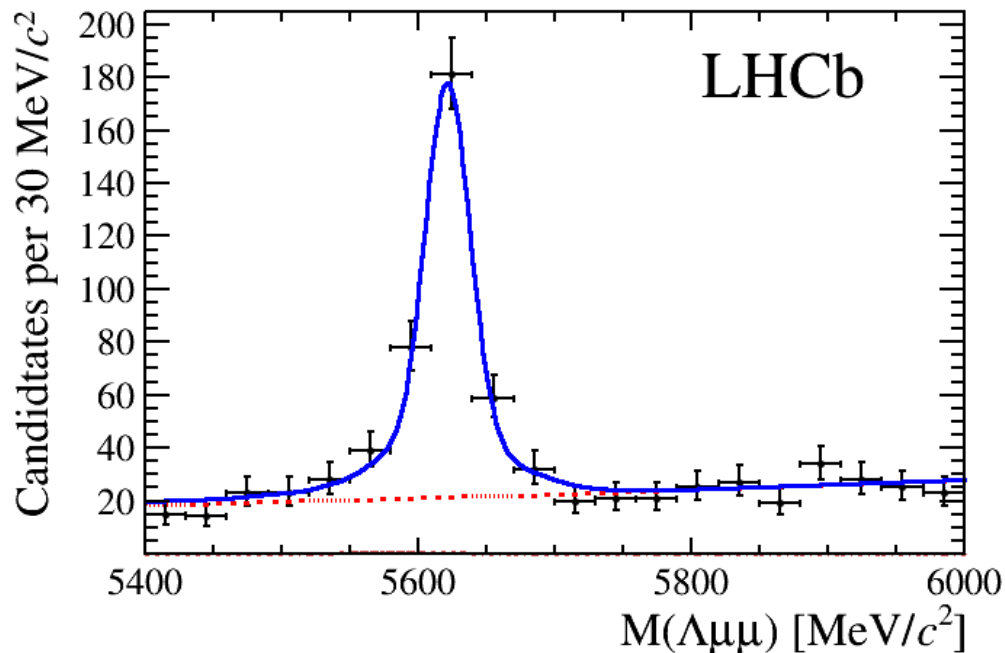
$$\mathcal{B}(B_s^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-) = (8.6 \pm 1.5_{\text{stat.}} \pm 0.7_{\text{syst.}} \pm 0.7_{\text{norm.}}) \times 10^{-8}$$

$$\mathcal{B}(B^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-) = (2.11 \pm 0.51_{\text{stat.}} \pm 0.15_{\text{syst.}} \pm 0.16_{\text{norm.}}) \times 10^{-8}$$

Other EW-penguin measurements

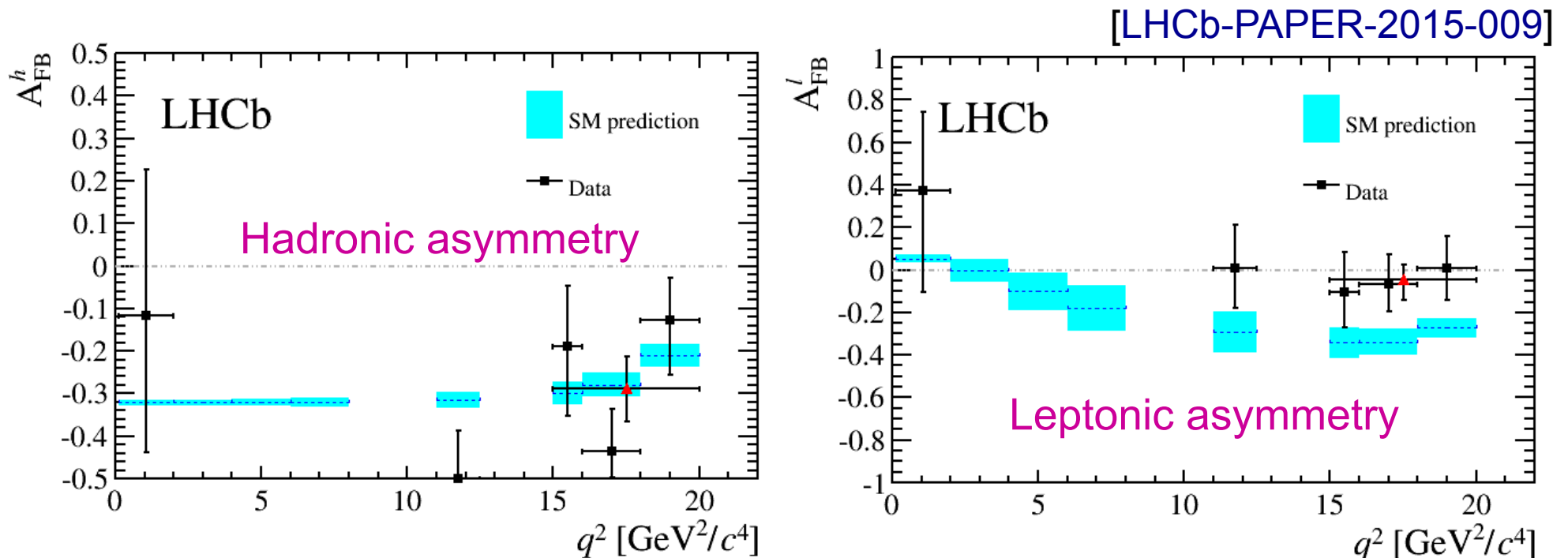
- $\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$ process of interest owing to half-integer spin, heavy quark + light di-quark system
- Reconstruct ~ 300 $\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$ candidates
- Establish evidence for signal $0.1 < q^2 < 2.0 \text{ GeV}^2/c^4$ for 1st time, no significant signal in $1.1 < q^2 < 6.0 \text{ GeV}^2/c^4$

[LHCb-PAPER-2015-009]



Other EW-penguin measurements

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



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

Conclusions

- $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ 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} ?
 - More to come – see T.Blake, tues AM

Conclusions

- $B^0 \rightarrow K^{*0} e^+ e^-$ angular analysis – constraints on $C_7^{(')}$ competitive with radiative decays
- $B_{(s)}^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ – observation of B_s decay and evidence for B^0 decay, BFs in agreement with SM predictions
- $\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$ – A_{FB}^h consistent with SM, A_{FB}^l consistently above the SM prediction

Backup

$\pi\pi$ spectra from $B^0_{(s)} \rightarrow \pi^+\pi^-\mu^+\mu^-$

