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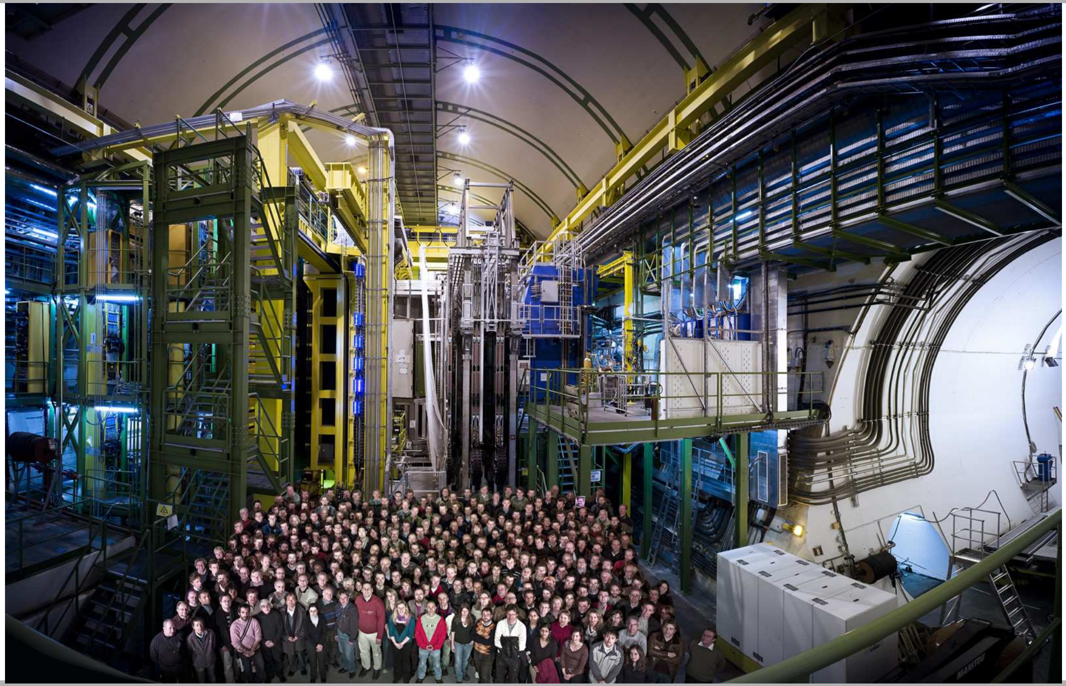
Electroweak penguins with di-leptons

M. Kreps on behalf of the LHCb Collaboration

Physics Department



Reminder of recent results

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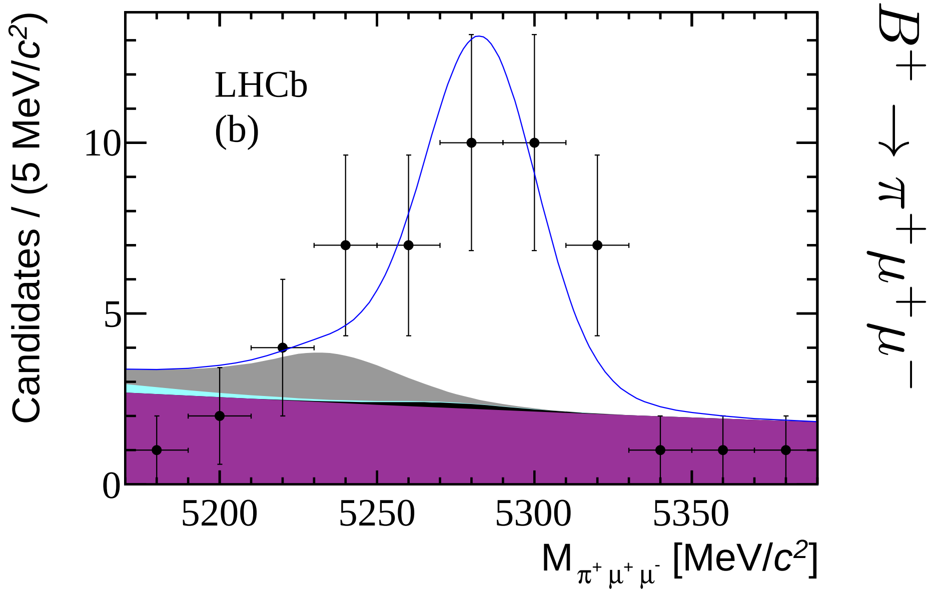

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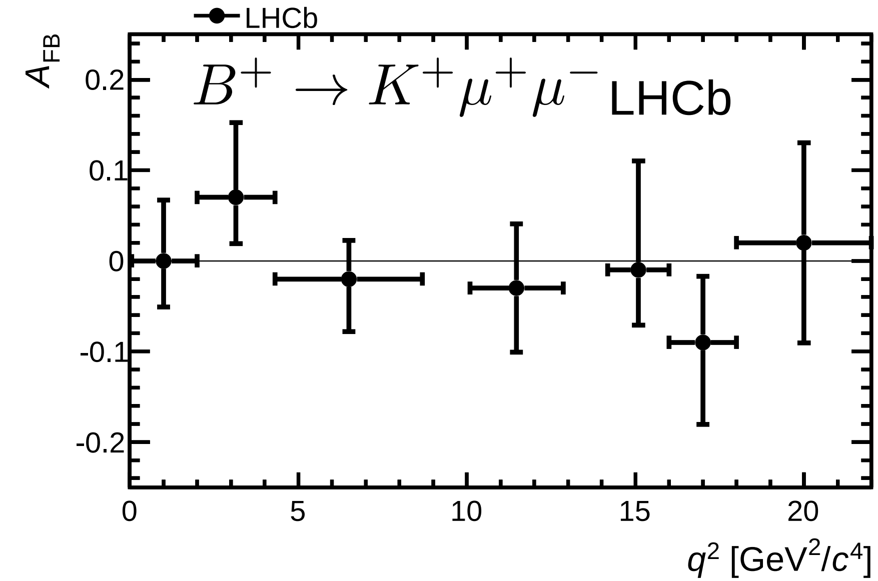

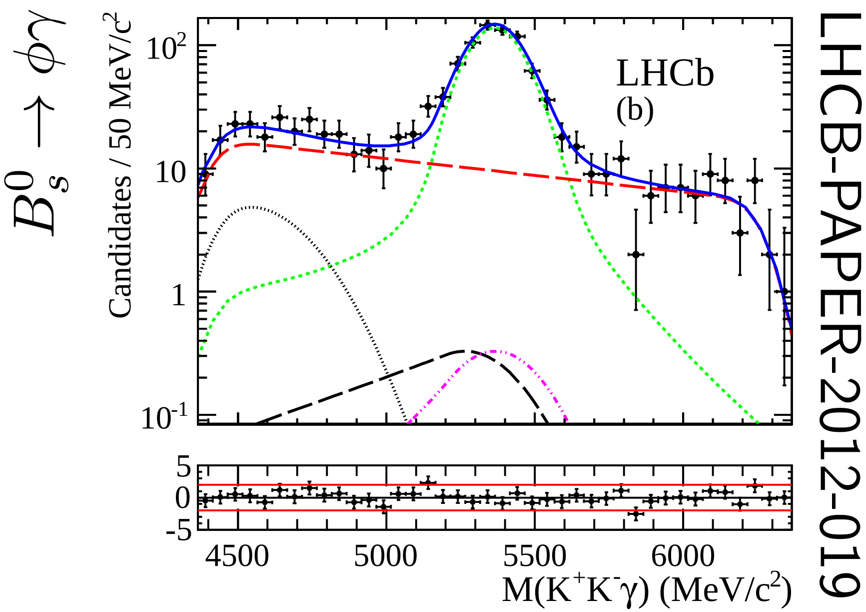

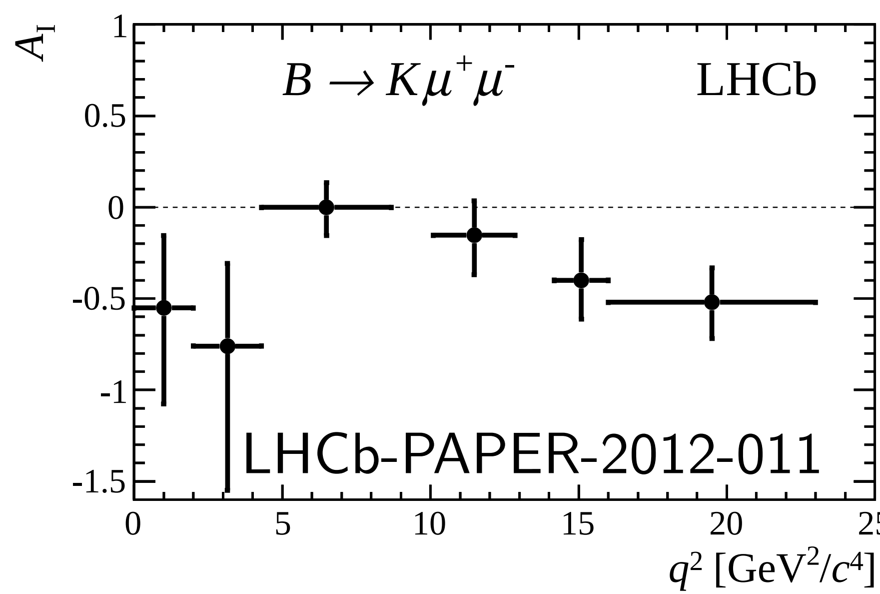

Motivation for EWK penguins

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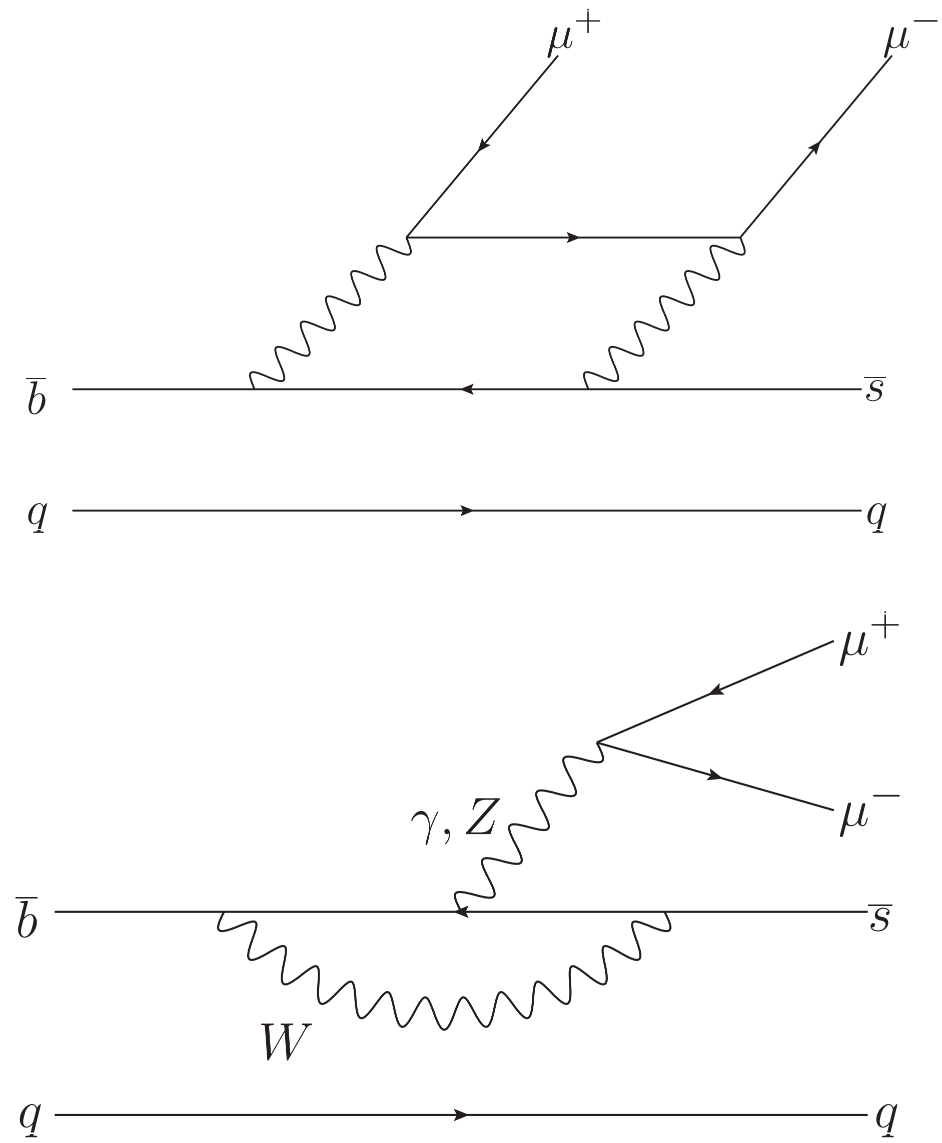
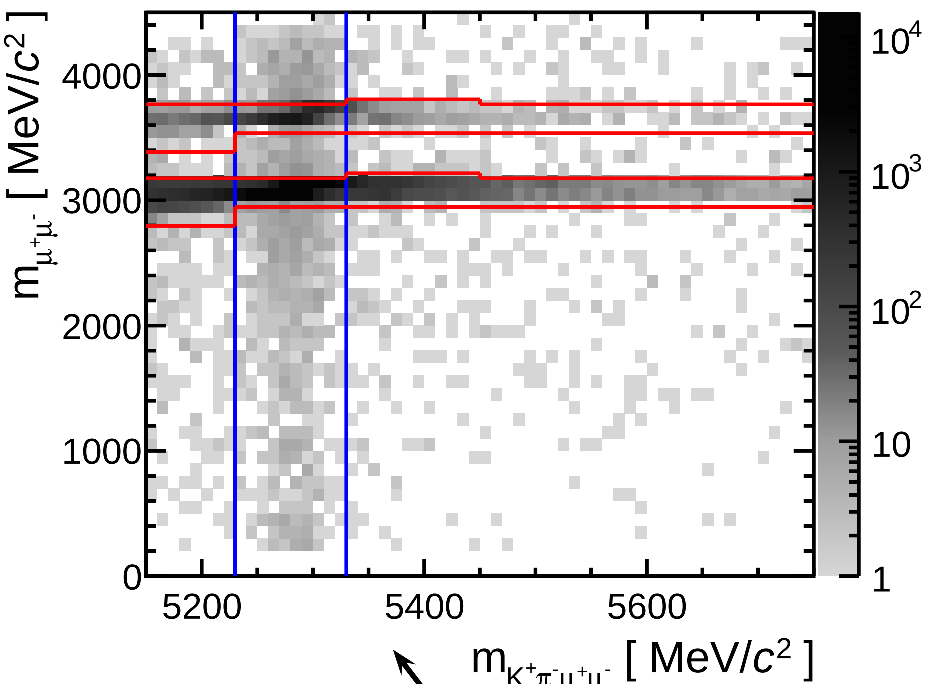
- In the SM, $b \to s$ FCNC decays
- SM BF of the order of 10^{-6}
- With angular analysis offers variety of observables
- Allows to test some underlying details of the NP
- Form factors make prediction of some observables less precise
- But many observables are free of form factor uncertainties
- Today, new results on
  - $B^0 \to K^{*0}\mu^+\mu^-$
  - $B^0 \to K^{*0}e^+e^-$
  - $B_s^0 \to \phi\mu^+\mu^-$
- All use 1 fb^{-1} of data from 2011
- All results preliminary



Selection with dimuons

- Uses BDT to combine kinematic, topological and PID inputs
- Trained on resonant (J/ψ) signal in data
- Relatively complicated removal of $c\bar{c}$ regions
- Decays via J/ψ used for normalization



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

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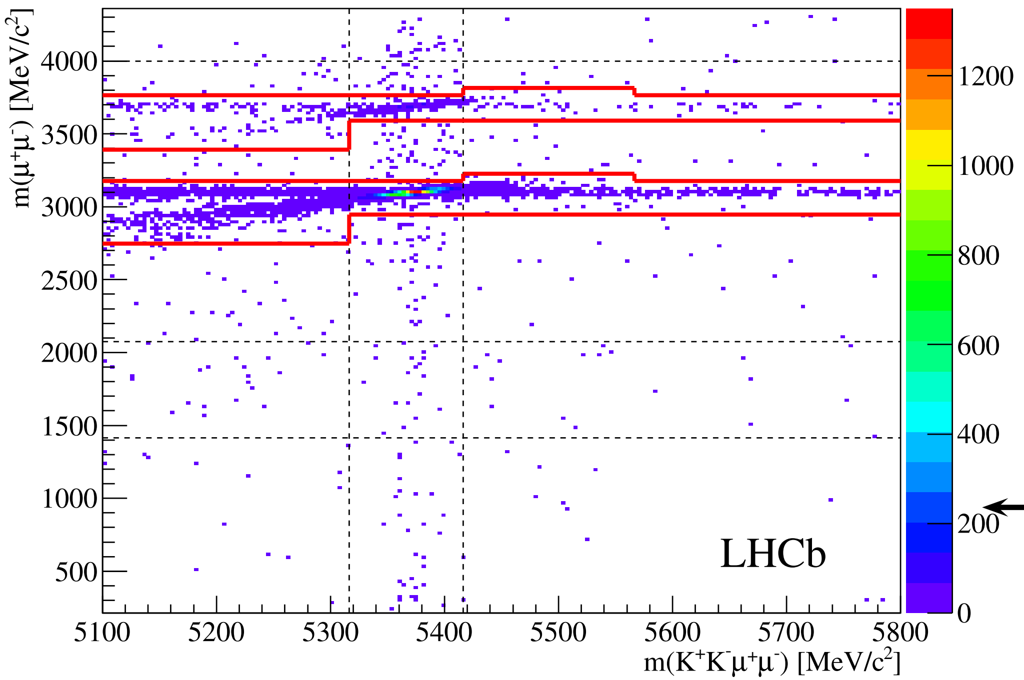

$B_s^0 \to \phi\mu^+\mu^-$

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$B^0 \to K^{*0}\mu^+\mu^-$ — q^2 bins

- Extended maximum likelihood fit
- Signal: double Crystal ball function fixed from J/ψ decays
- Bg: combinatorial (exponential), $B_s^0 \to K^{*0}\mu\mu$, $B_s^0 \to \phi\mu\mu$ and $B^0 \to J/\psi K^{*0}$ from MC

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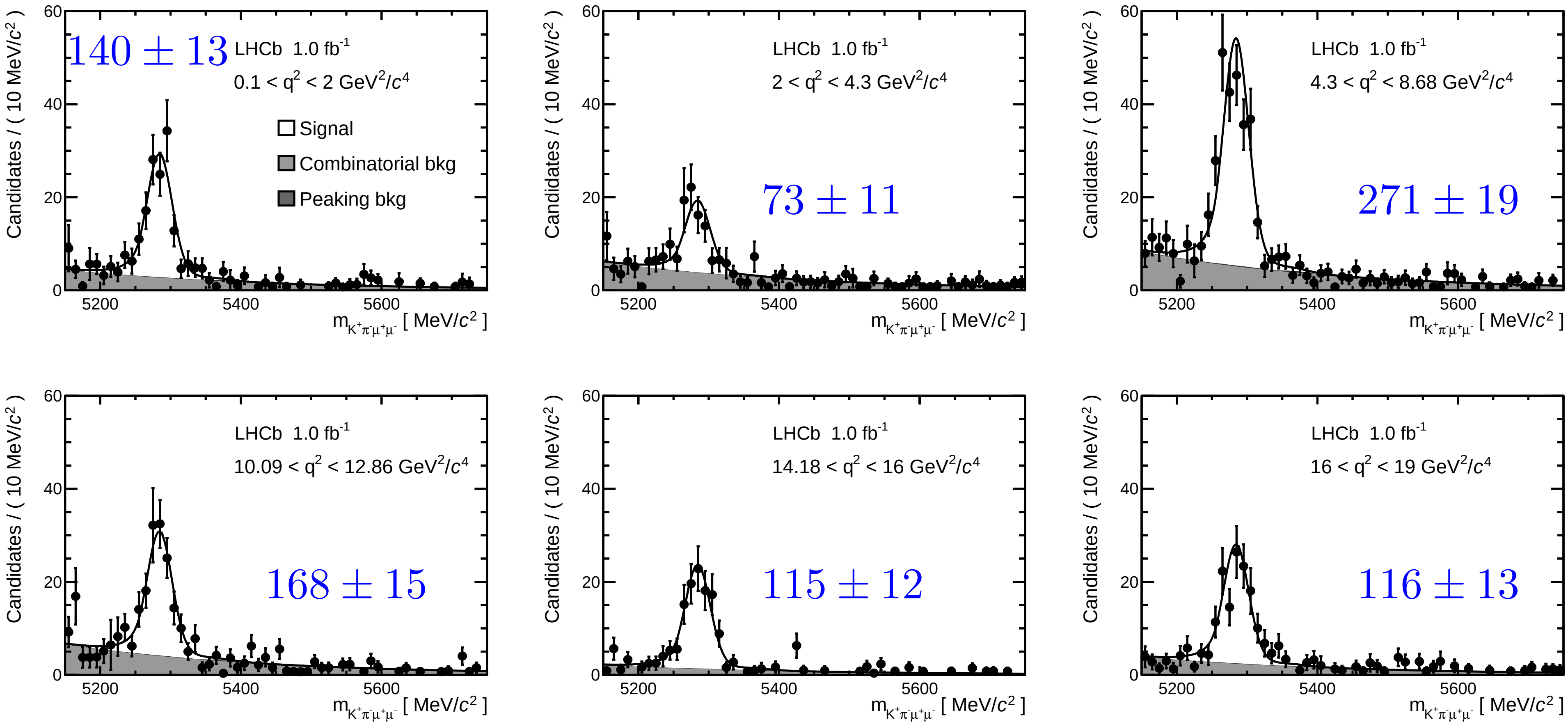

$B_s^0 \to \phi\mu^+\mu^-$ — q^2 bins

- Extended maximum likelihood fit
- Signal: double Gaussian function fixed from J/ψ decays
- Bg: combinatorial (exponential)
- Clear signal in all q^2 bins
- First time we see signal in all q^2 bins

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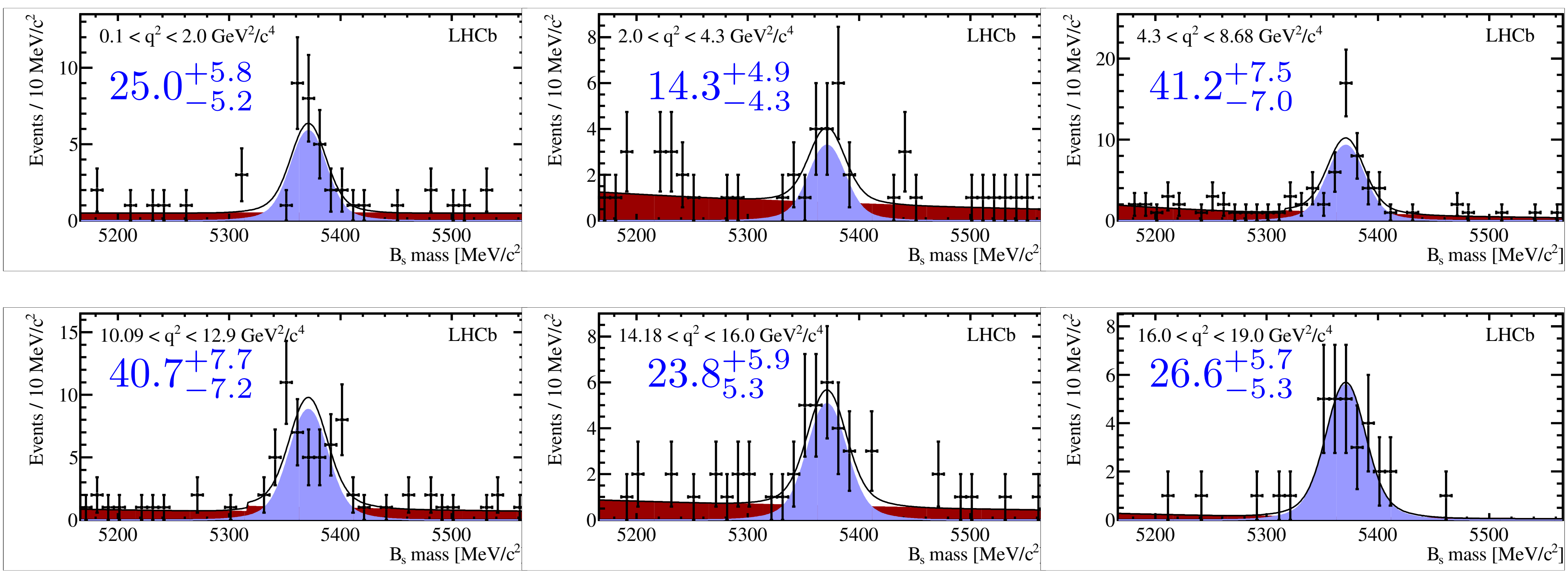
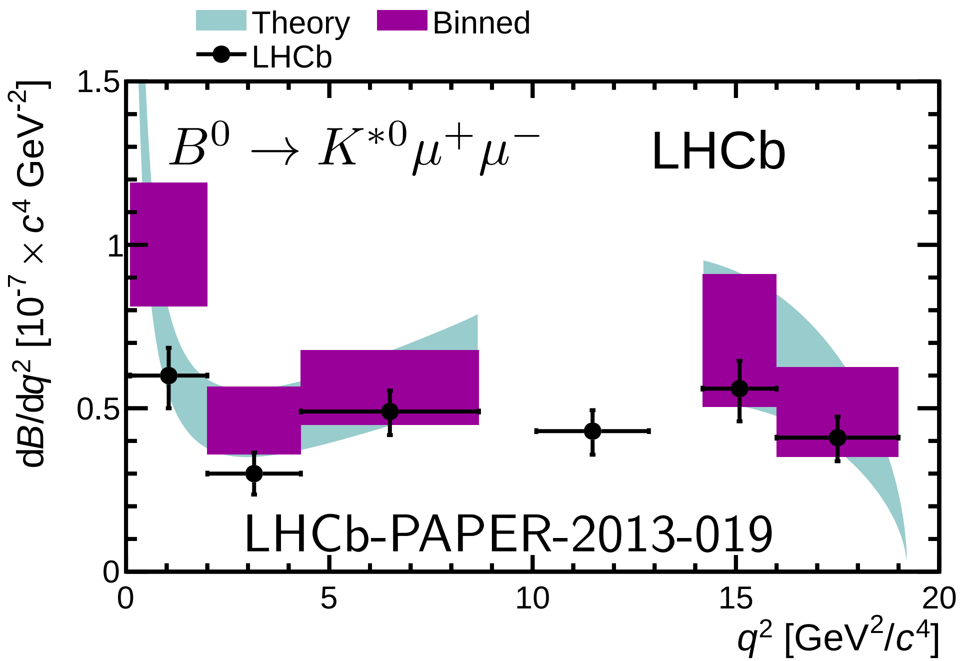
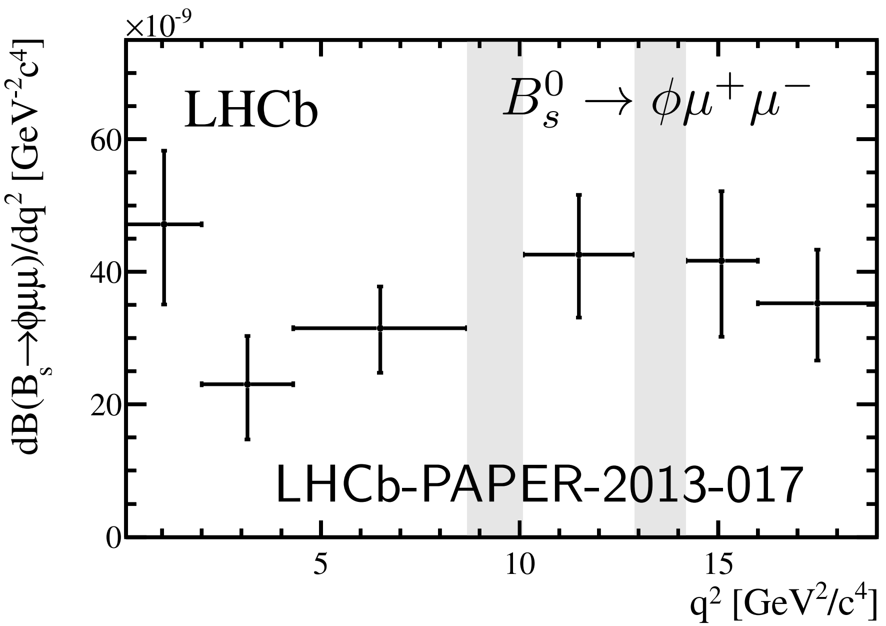


Differential BF

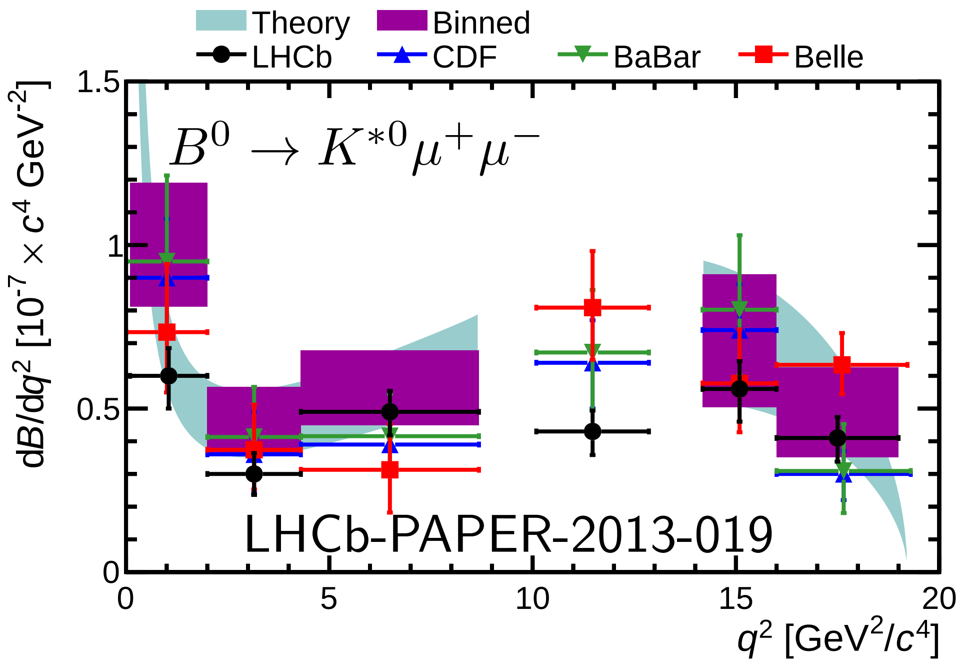


- Syst. uncertainties dominated by normalization BF
- Other contributions from Bg PDFs and data-MC differences
- Large fraction of systematic uncertainty correlated across q^2 bins



- $dB/dq^2 = \frac{1}{\Delta q^2}\frac{N_{sig}}{N_{norm}}\epsilon_{rel}B_{norm}$
- $B^0 \to K^{*0}\mu^+\mu^-$ agrees with SM
- Two decays have simular shape
- For $B_s^0 \to \phi\mu\mu$ we measure integrated rate $(7.07^{+0.64}_{-0.59} \pm 0.17 \pm 0.71) \times 10^{-7}$

Differential BF



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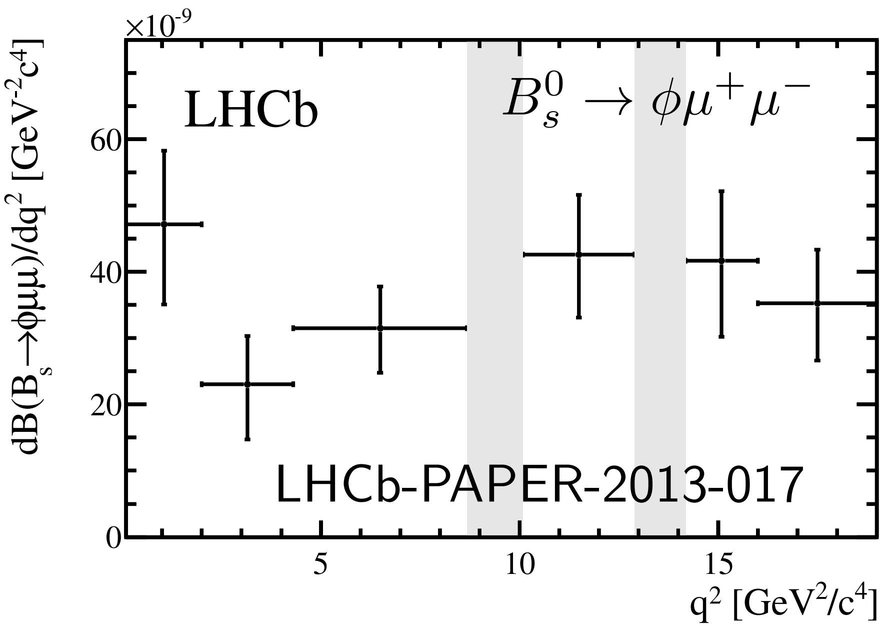

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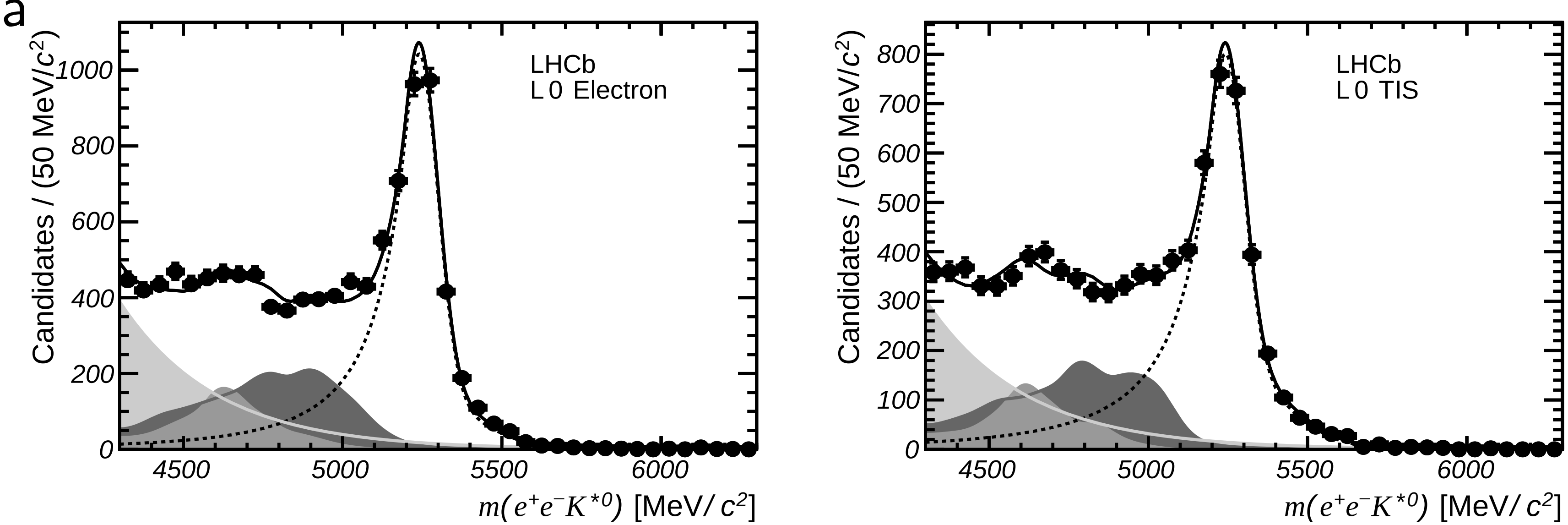
Low q^2 region

- Low q^2 region particularly sensitive to γ polarization
- Decay $B^0 \to K^{*0} e^+ e^-$ can reach lower q^2 as decay with dimuons
- Never observed on its own at low q^2
- Before moving to angular analysis, measure differential BF in $30 < m(\ell^+\ell^-) < 1000$ MeV
- Below 30 MeV angles hard to measure
- Analysis more challenging by significantly larger brehmstralung

$\Rightarrow$ Try to recover radiated photons

- Use of BDT for selection, trained on simulated signal and bg from data



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$B^0 \to K^{*0} e^+ e^-$ at low q^2

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- Main physics background from $B^0 \to K^{*0}\gamma$ with γ conversion
- Extended maximum likelihood fit
  - Signal: double Crystal ball
  - Combinatorial bg: exponential
  - Partially reconstructed bg from simulation
- Significance 4.6σ
- Systematic uncertainties well bellow statistical
- Dominant contributions from normalization BF and fit procedure
- Resulting $B^0 \to K^{*0} e^+ e^-$ BF $(3.1^{+0.9}_{-0.8}{}^{+0.2}_{-0.3} \pm 0.3) \times 10^{-7}$ in $m(\ell^+\ell^-)$ within 30–1000 MeV

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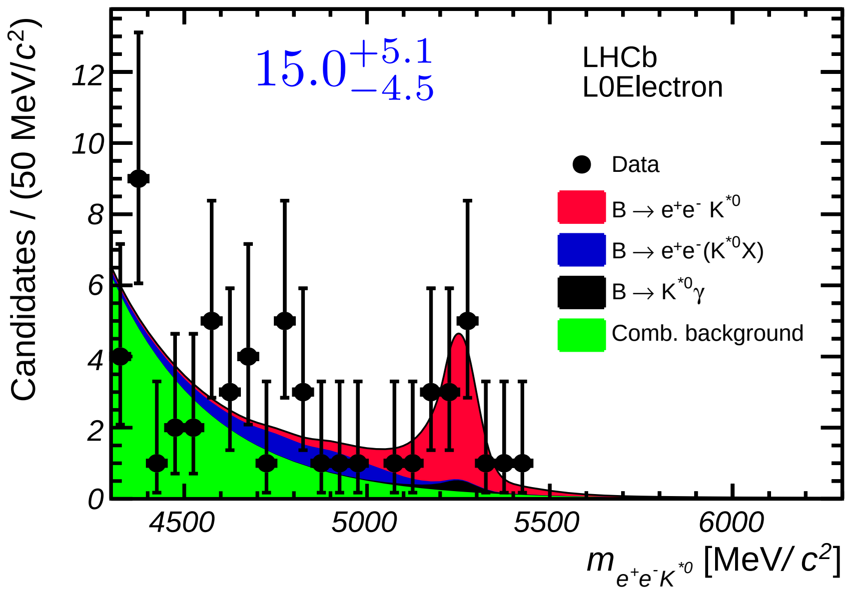

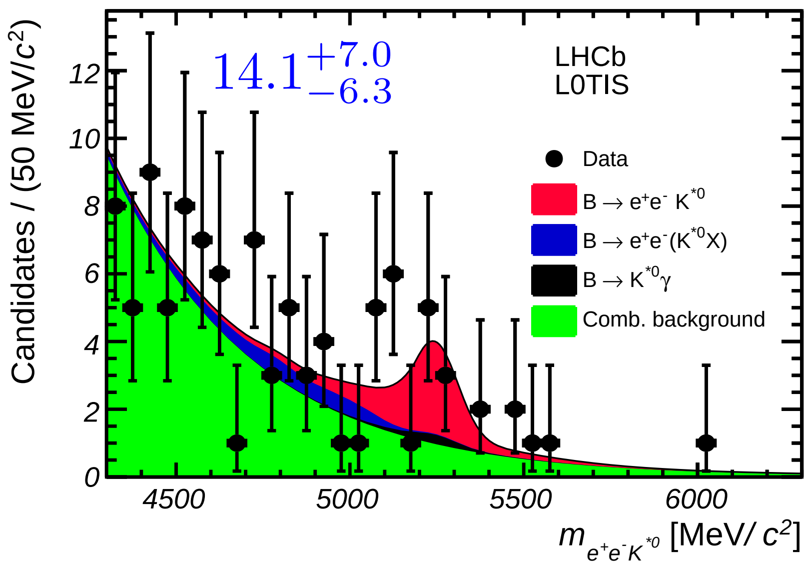

Angular analysis

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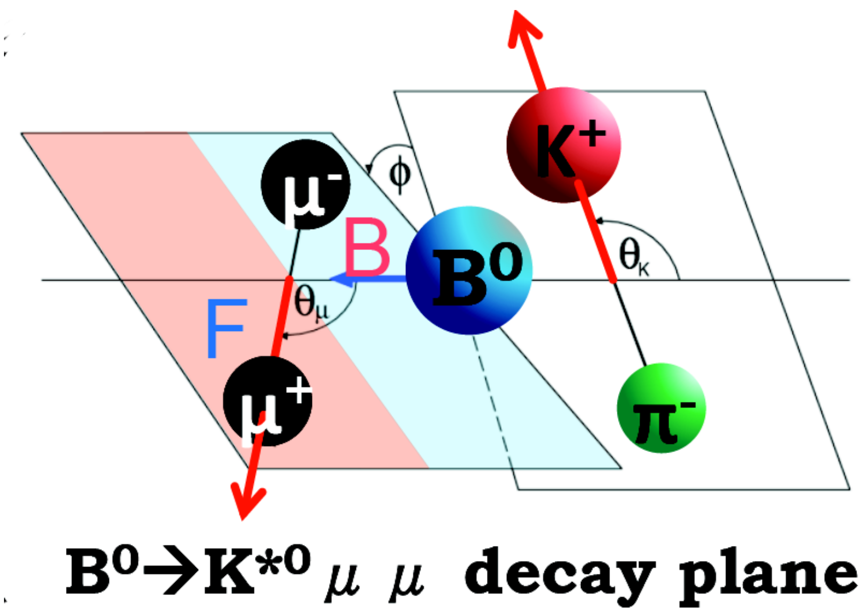
- Angular distribution

$$S_1^s \sin^2\theta_K + S_1^c \cos^2\theta_K +$$
$$S_2^s \sin^2\theta_K \cos 2\theta_\ell + S_2^c \cos^2\theta_K \cos 2\theta_\ell +$$
$$S_3 \sin^2\theta_K \sin^2\theta_\ell \cos 2\phi + S_4 \sin 2\theta_K \sin 2\theta_\ell \cos\phi +$$
$$S_5 \sin 2\theta_K \sin\theta_\ell \cos\phi + S_6 \cos^2\theta_K \cos\theta_\ell +$$
$$A_7 \sin 2\theta_K \sin\theta_\ell \sin\phi + A_8 \sin 2\theta_K \sin 2\theta_\ell \sin\phi +$$
$$A_9 \sin^2\theta_K \sin^2\theta_\ell \sin 2\phi$$

- Helicity angles θ_l and θ_K defined by μ^+ (μ^-) and K for B^0 ($\bar{B}^0$)
- Angle ϕ is given by
  $\sin\phi = (\hat{p}_{\mu^+} \times \hat{p}_{\mu^-}).\hat{p}_{K^{*0}}$
  $\sin\phi = (\hat{p}_{\mu^-} \times \hat{p}_{\mu^+}).\hat{p}_{\overline{K}^{*0}}$



Angular analysis

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- Assuming $q^2 >> 4m_\mu^2$ and transforming ϕ as $\phi+\pi$ if $\phi<0$ one can write

$$F_L \cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) \;-\; F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) \;+$$
$$\frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell-1) \;+$$
$$S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} \;+\; \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell \;+$$
$$A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}$$

- The observables have to satisfy:
  $|A_{FB}| \leq \frac{3}{4}(1-F_L)$, $\quad |A_9| \leq \frac{1}{2}(1-F_L)$, $\quad |S_3| \leq \frac{1}{2}(1-F_L)$
- Those boundary conditions introduce non-trivial effects
- The statistical uncertainties estimated using Feldman-Cousins technique
- At lowest q^2 bin one needs also correction from breakdown of $q^2 >> 4m_\mu^2$ assumption

B_s^0 angular analysis

- After adding decay rate for B_s and $\bar{B}_s$ it looks very similar to B^0 angular distribution
- Main difference is that $B_s \to \phi\mu^+\mu^-$ is not self-tagging

→ No sensitivity to A_{FB} unless production flavour is tagged

- Due to small statistics, flavour tagging not really possible
- Also full angular analysis difficult with current statistics

→ Look to 1D distributions instead

$$\theta_K : \frac{3}{4}(1 - F_\mathrm{L})(1 - \cos^2\theta_K) + \frac{3}{2}F_\mathrm{L}\cos^2\theta_K,$$

$$\theta_\ell : \frac{3}{8}(1 - F_\mathrm{L})(1 + \cos^2\theta_\ell) + \frac{3}{4}F_\mathrm{L}(1 - \cos^2\theta_\ell) + \frac{3}{4}A_6^s\cos\theta_\ell,$$

$$\mathrm{d}\phi : \frac{1}{2\pi} + \frac{1}{2\pi}S_3\cos 2\phi + \frac{1}{2\pi}A_9\sin 2\phi$$

- Subsequently fit all three distributions

Systematic uncertainties

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- Several sources investigated (not all for B_s due to small statistics)
  - Angular acceptance (dominant for B_s)
  - Data-MC differences
  - Mass model
  - Peaking backgrounds
  - S-wave (spin-0 $K\pi$)
  - $B^0 \leftrightarrow \bar{B}^0$ mis-id from $K \leftrightarrow \pi$ mis-id
  - B^0, $\bar{B}^0$ production and detection asymmetries
- Generally no single dominant contribution across all angular observables
- Many of the sources investigated are negligible
- Typicall size for B_s of order 20% – 40% of statistical uncertainty
- For B^0 typically of order 5% – 20% of statistical uncertainty

F_L

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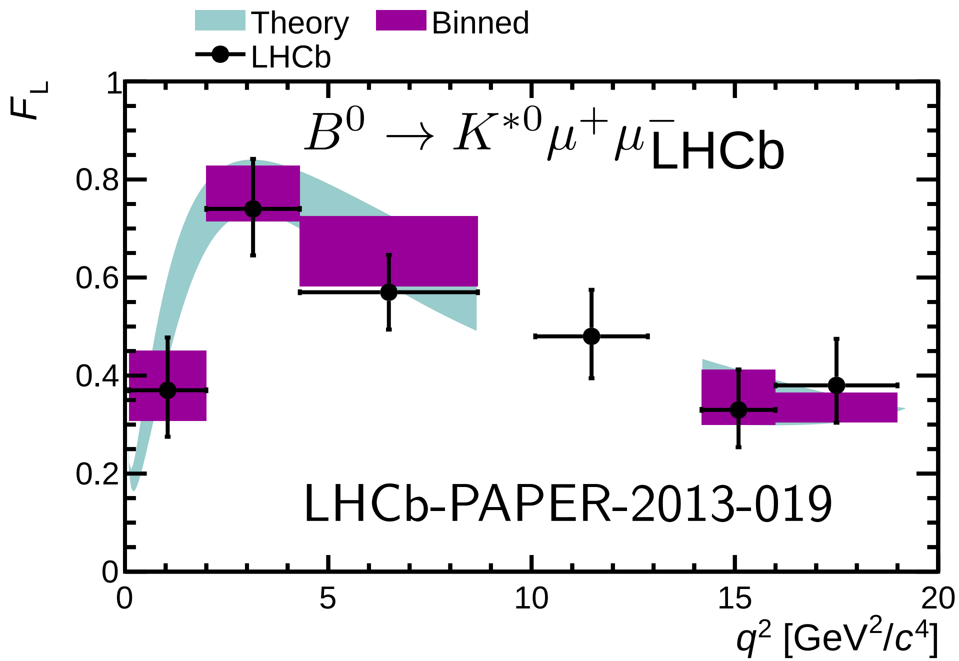
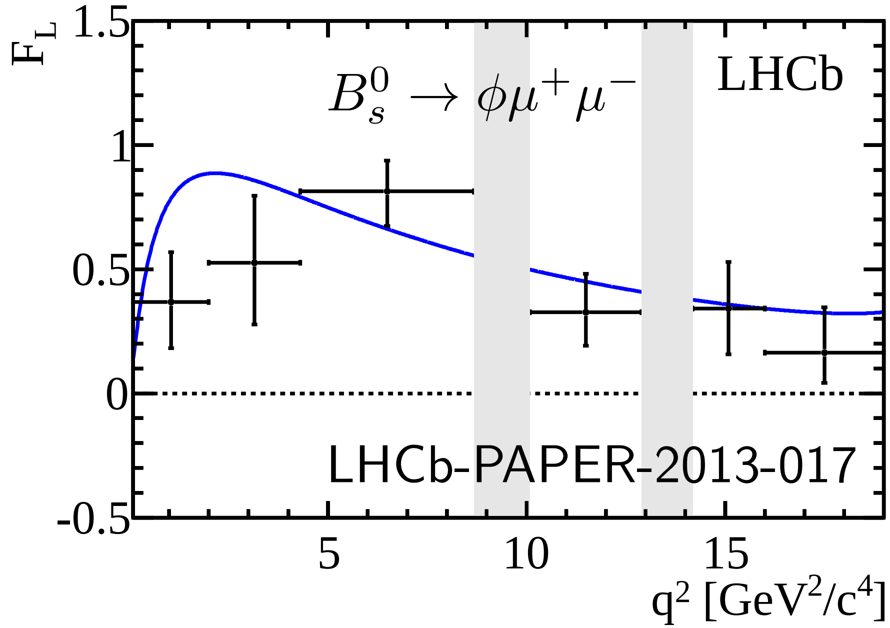
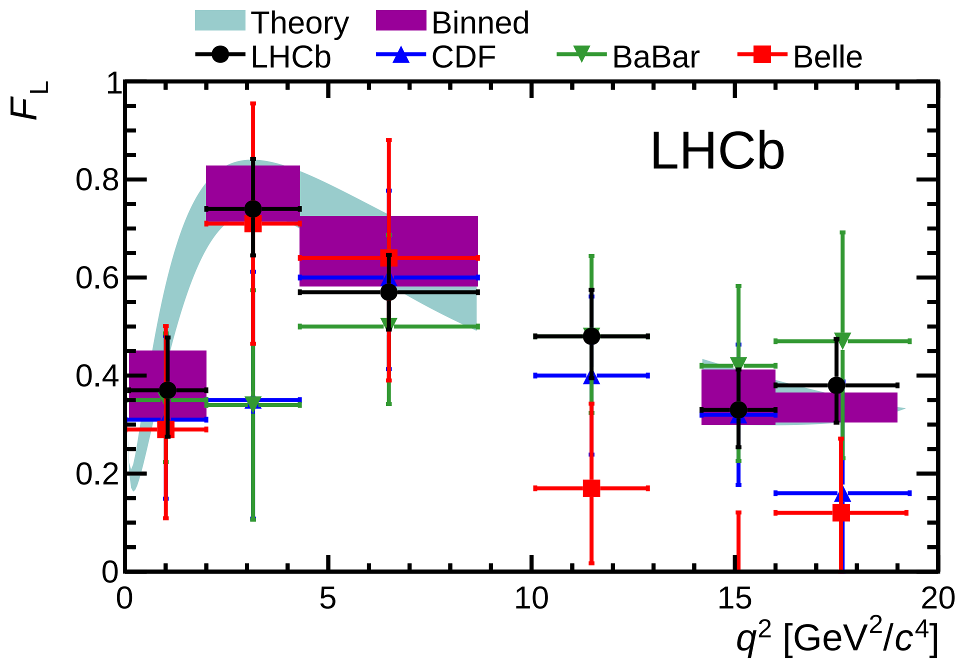


- F_L is fraction of longitudinal K^{*0}/ϕ
- Theory affected by form factors
- Good agreement between experiment and SM

- First angular analysis of $B_s^0 \to \phi\mu^+\mu^-$
- Within limited statistics consistent with SM
- I would also say that B^0 and B_s look consistent



F_L



- F_L is fraction of longitudinal K^{*0}/ϕ
- Theory affected by form factors
- Good agreement between experiment and SM
- Consistent but more precise than previous measurments

- First angular analysis of $B_s^0 \to \phi\mu^+\mu^-$
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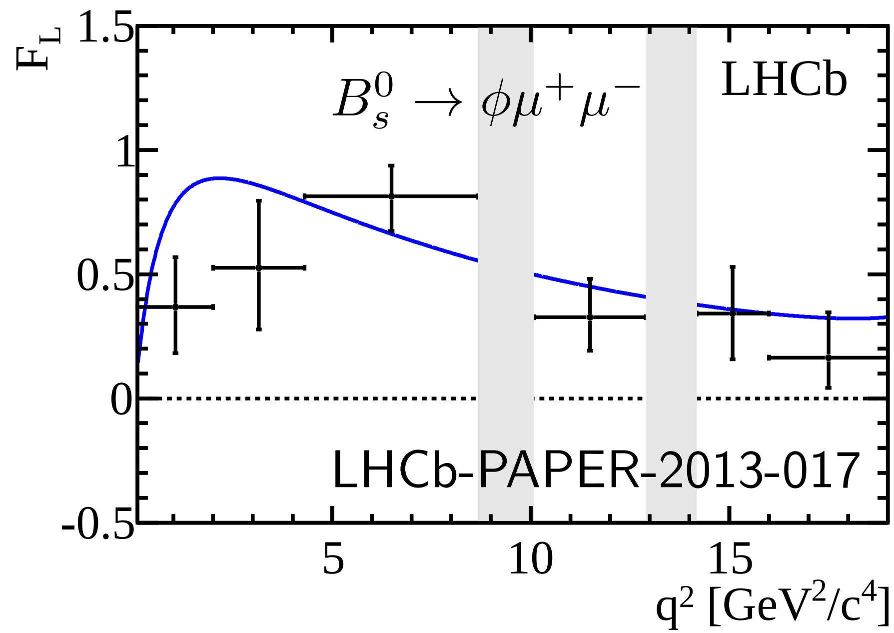

$B^0 \to K^{*0}\mu^+\mu^-$ A_{FB}

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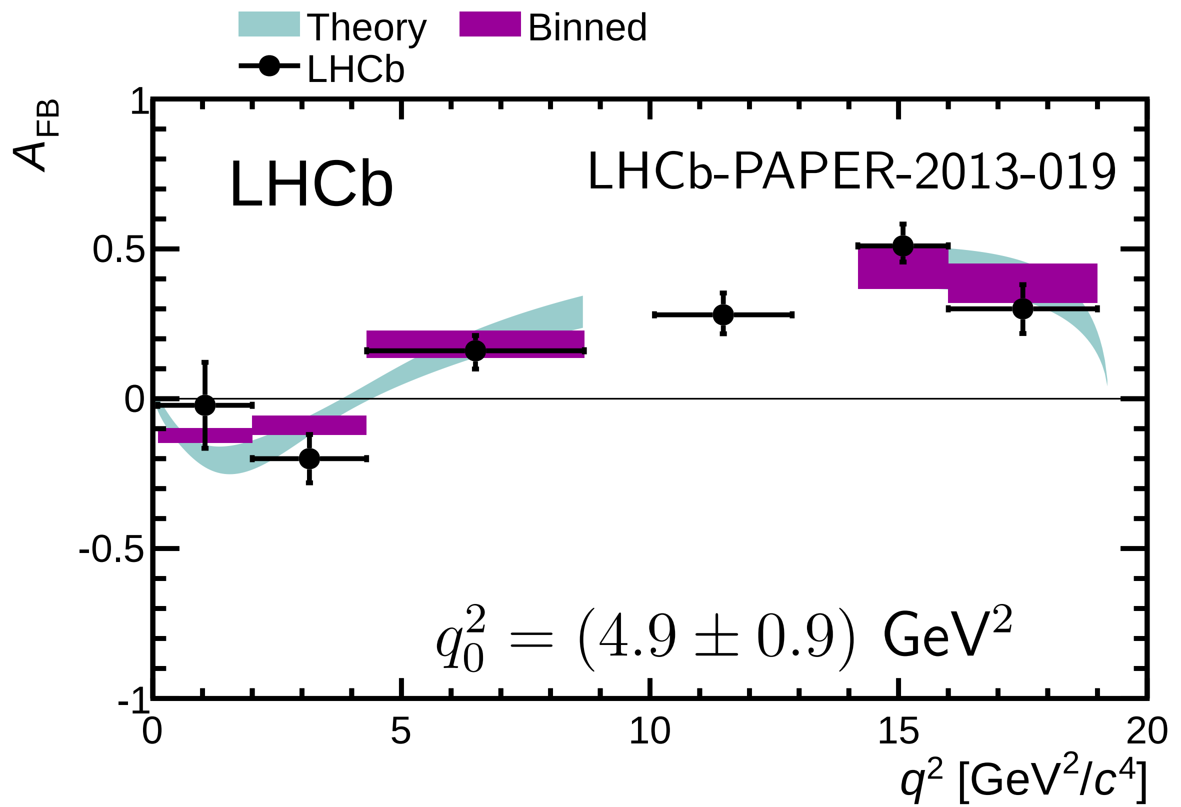
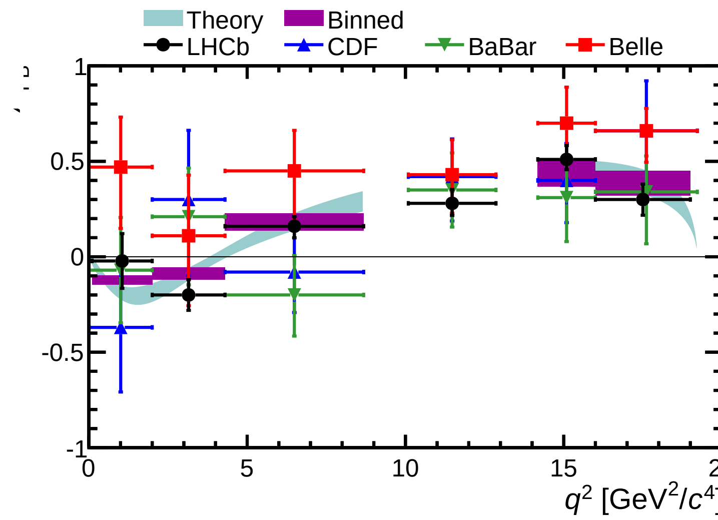


For $B_s^0 \to \phi\mu\mu$ no sensitivity without flavour tagging

- Probably best known of angular observables
- Early measurements caused some excitements
- With increased statistical power of LHCb, fully consistent with SM



S_3 and A_6

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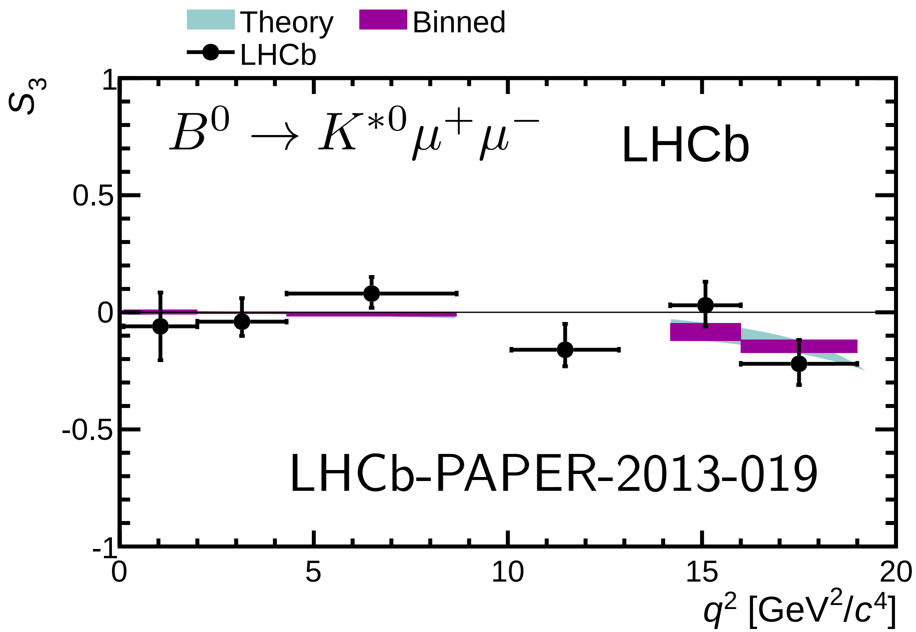
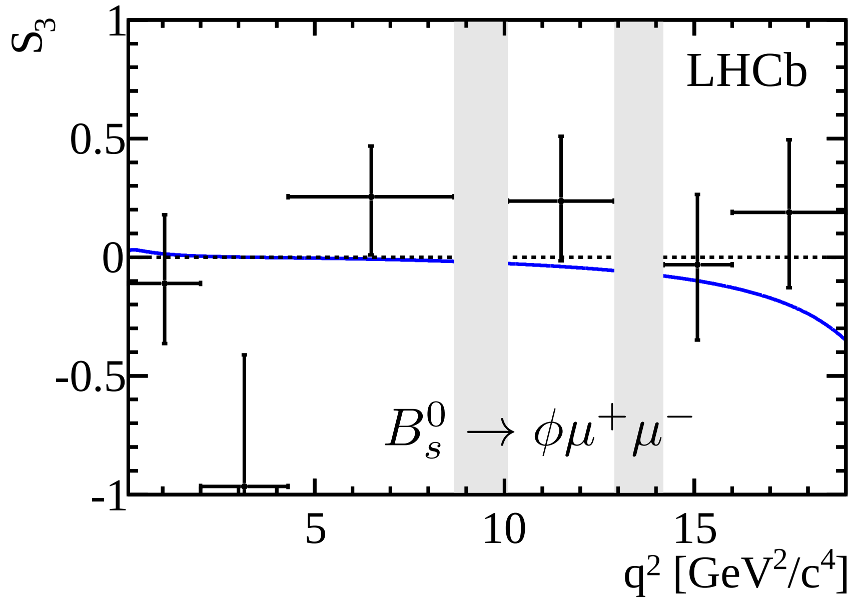
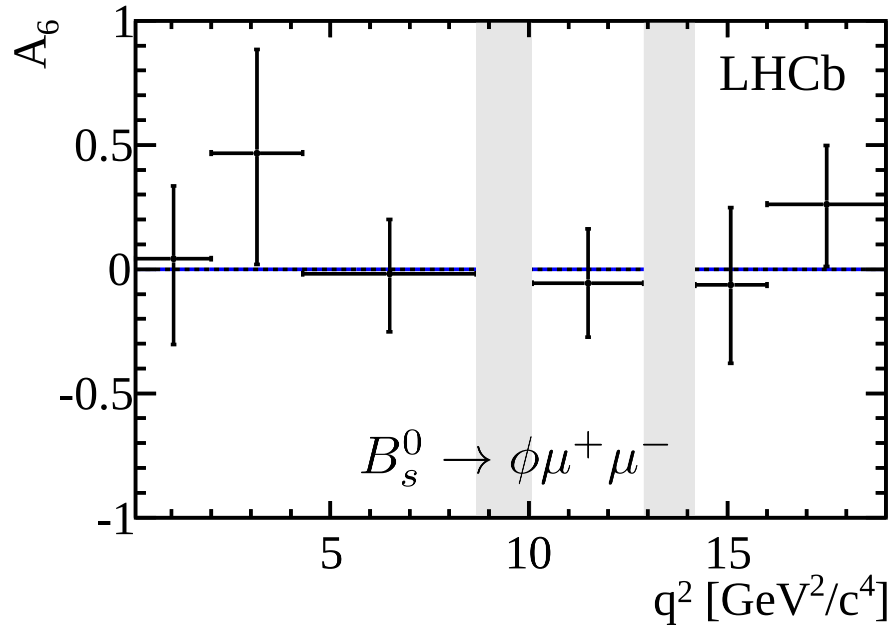
- S_3 is asymmetry between two transverse K^{*0} amplitudes (averaged B^0 and $\bar{B}^0$)
- A_6 is asymmetry between B_s^0 and $\bar{B}_s^0$ of real part of transverse amplitudes interference
- Both agree with SM







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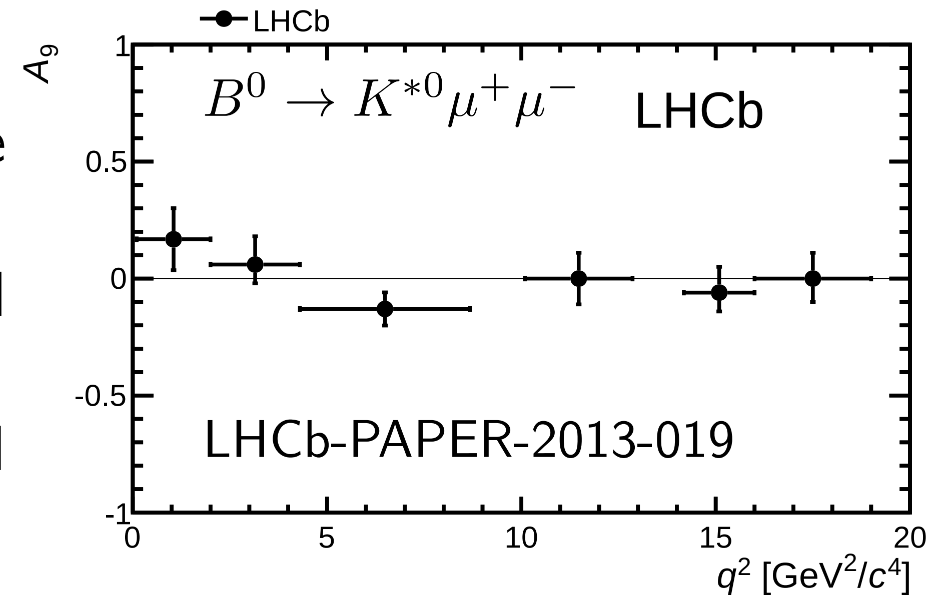
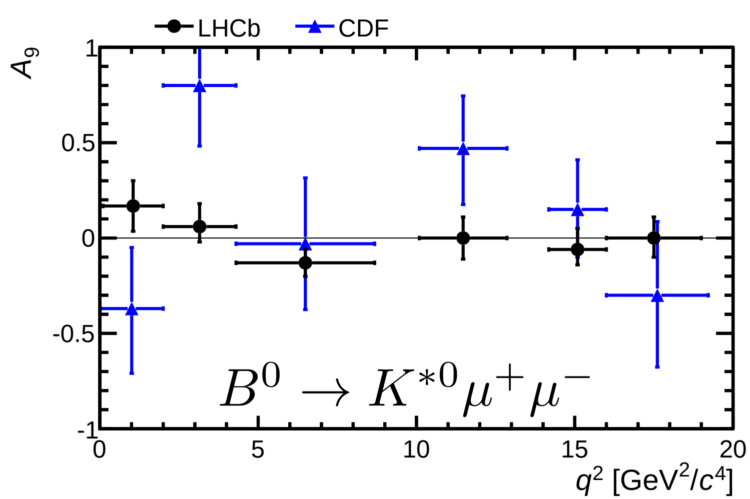
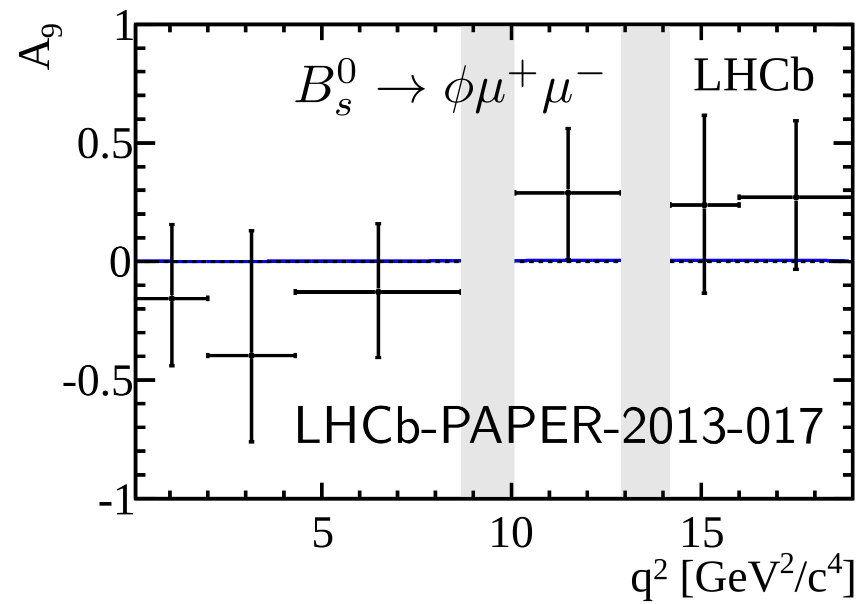
A_9

- T-odd asymmetry from interference of transverse K^{*0} amplitudes
- Sensitive when strong phase would make CP violation zero
- High sensitivity to right handed currents







B^0 reparametrisation

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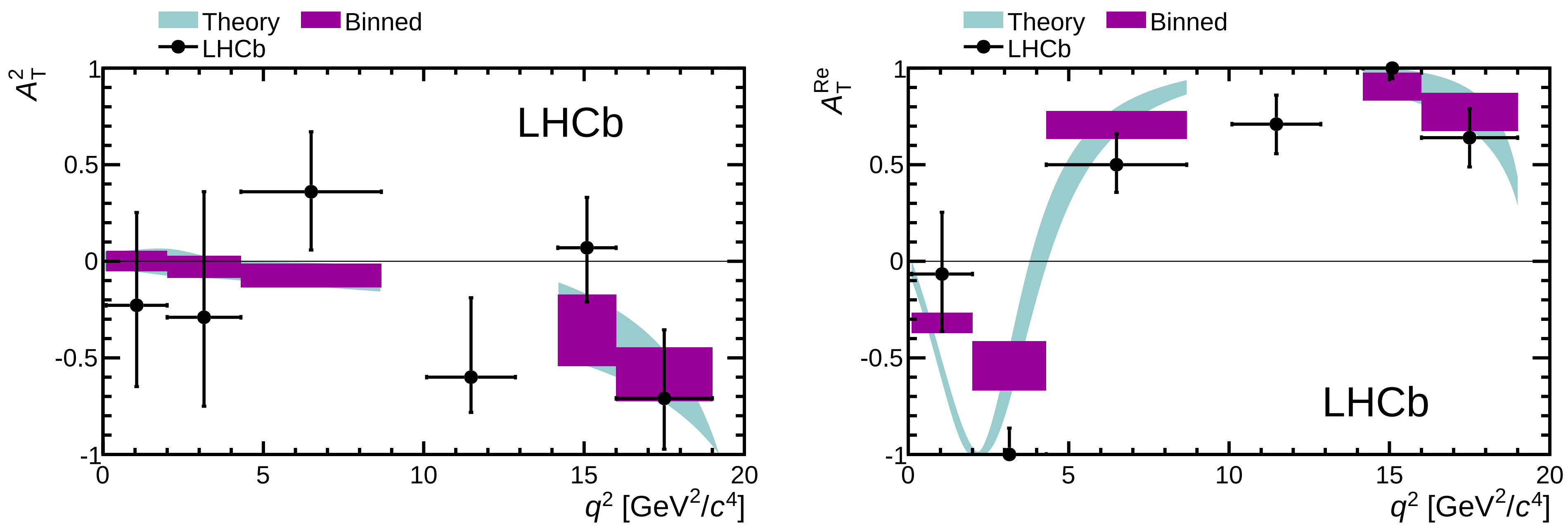
- One can define alternative set of observables by $S_3 = \frac{1}{2}(1-F_L)A_T^2$ and $A_{FB} = \frac{3}{4}(1-F_L)A_T^{Re}$
- In large recoil limit the observables A_T^2 and A_T^{Re} have reduced form-factor uncertainties
- It is not easy to handle correlations while maintaining solid meaning of uncertainties

$\rightarrow$ Extract also A_T^2 and A_T^{Re}



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Conclusions

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- Presented three new analyses of rare EWK decays
- First time we did multidimensional angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ (LHCb-PAPER-2013-019)
- First convincing signal for $B^0 \to K^{*0}e^+e^-$ at low q^2 (LHCb-PAPER-2013-005)
- First angular analysis of $B_s \to \phi\mu^+\mu^-$ (LHCb-PAPER-2013-017)
- All results are worlds best
- All consistent with SM

$\to$ But placing strong constraints on new physics

- Papers to be submitted soon

- B^0 theory based on JHEP 07 (2011) 067, NP B612 (2001) 25, PR D70 (2004) 114005, EPJ C71 (2011) 1635, PR D71 (2005) 014029, JHEP 11 (2008) 032
- B_s^0 prediction from JHEP 01 (2009) 019, JHEP 0807 (2008) 106, PR D71 (2005) 014029