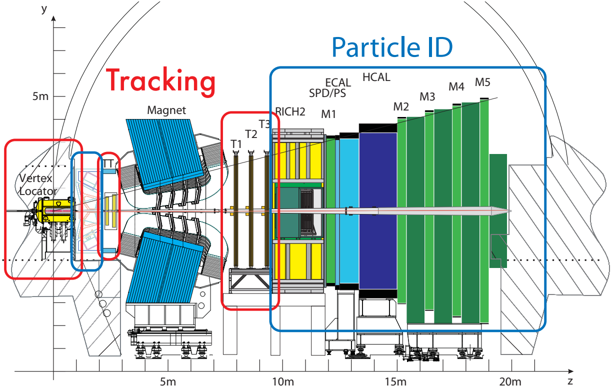
Physics with EW penguins at LHCb

7th International Workshop on the CKM Unitarity Triangle, Cincinnati, Ohio, USA

28. September - 2. October 2012

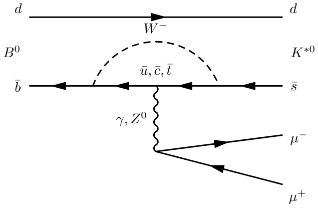
Michel De Cian
on behalf of the LHCb collaboration

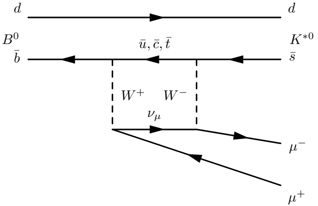
THE LHCb DETECTOR

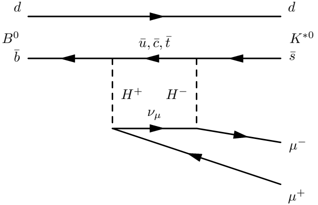


- LHCb covers a pseudorapidity $\eta = 2 - 5$.
- Excellent momentum resolution: $\Delta p/p = 0.4\% - 0.6\%$ in $5 - 140\,\mathrm{GeV}/c$.
- $K - \pi$ separation up to 100 GeV/c.
- All presented analyses with $\approx 1\ \mathrm{fb}^{-1}$ collected in 2011.

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

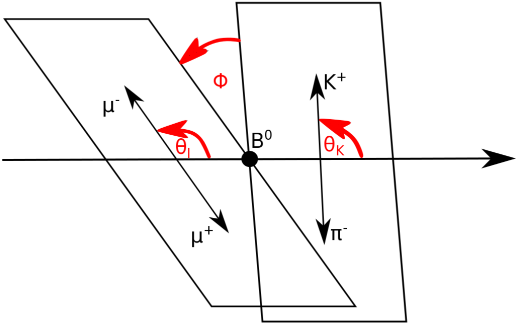






- Rare decay with $\mathcal{B} = (1.05^{+0.16}_{-0.13}) \times 10^{-6}$ [PDG]
- Decay only possible via penguin- or box diagrams, "new physics" can enter at the same level as SM physics.
- Four-particle final state: Plenty of observables in angular distributions.

$B^0 \to K^{*0}\mu^+\mu^-$: Angular distribution (I)



- Decay can be fully described by three angles ($\cos\theta_\ell, \cos\theta_K, \phi$) and the dimuon invariant mass (square) q^2.

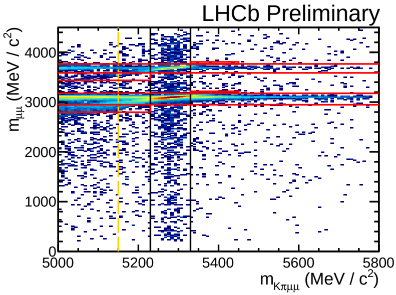
$B^0 \to K^{*0}\mu^+\mu^-$: Angular distribution (II)

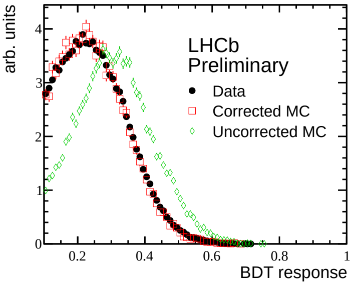
- Apply "folding": $\phi \to \phi + \pi$ for $\phi < 0$: Cancels four terms.
- And leaves...

$$\frac{\mathrm{d}^4(\Gamma + \bar{\Gamma})}{\mathrm{d}\cos\theta_\ell \,\mathrm{d}\cos\theta_K \,\mathrm{d}\phi \,\mathrm{d}q^2} \propto F_L \cos^2\theta_K + \frac{3}{4}(1 - F_L)(1 - \cos^2\theta_K) + F_L \cos^2\theta_K (2\cos^2\theta_\ell) + \frac{1}{4}(1 - F_L)(1 - \cos^2\theta_K)(2\cos^2\theta_\ell - 1) + S_3(1 - \cos^2\theta_K)(1 - \cos^2\theta_\ell)\cos 2\phi + \frac{4}{3}A_{FB}(1 - \cos^2\theta_K)\cos\theta_\ell + S_9(1 - \cos^2\theta_K)(1 - \cos^2\theta_\ell)\sin 2\phi$$

- This expression was simultaneously fitted to the angles and the invariant mass in 2011 dataset.
- The S_i expressions are the $\mathcal{CP}$ averaged I_i expressions.
- Neglect lepton masses and S-wave contribution ($\to$ systematics).

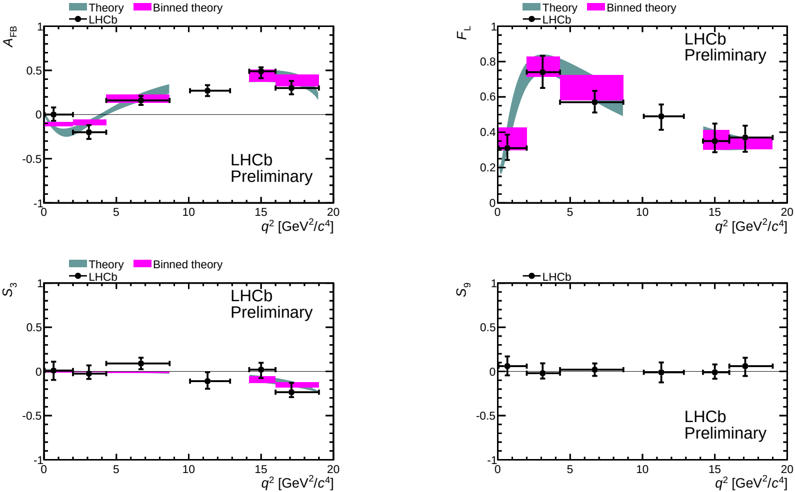
$B^0 \to K^{*0}\mu^+\mu^-$: Experimental aspects





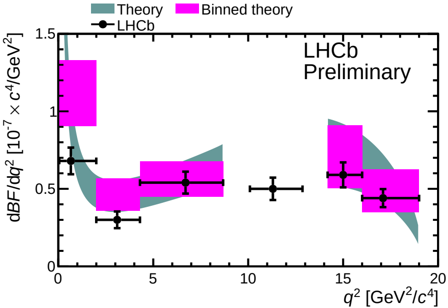
- Some experimental details:
  - Cut out $B^0 \to J/\psi K^{*0}$ and $B^0 \to \psi(2S)K^{*0}$, veto peaking background, e.g. $B_s^0 \to \phi\mu^+\mu^-$.
  - Select signal events with a BDT.
  - Correct for acceptance effects with event-by-event correction using simulation.
  - Correct for simulation $\leftrightarrow$ data differences with control channels (e.g. $J/\psi \to \mu^+\mu^-$ for particle identification)

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



Theory predictions from [C. Bobeth et al., JHEP 07 (2011) 067] and references therein

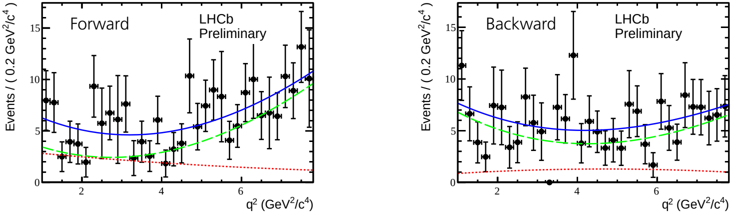
$B^0 \to K^{*0}\mu^+\mu^-$: Differential branching fraction



- Differential branching fraction determined with normalisation to $B^0 \to J/\psi\, K^{*0}$.

Theory prediction from [C. Bobeth et al., JHEP 07 (2011) 067] and references therein

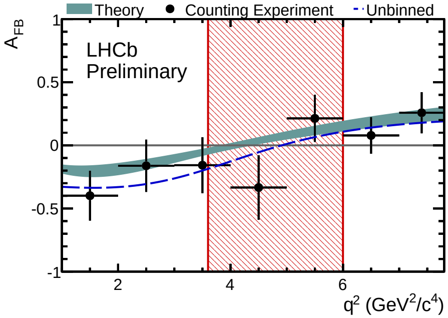
Measuring the zero-crossing point in A_{FB} of $B^0 \to K^{*0}\mu^+\mu^-$ (I)



- Zero-crossing point of A_{FB} has a very clean prediction, as the form factors cancel (to first order).
- Zero-crossing point was extracted using "unbinned counting" technique:
  - Split dataset in "forward" and "backward" events (with respect to $\cos\theta_\ell$).
  - Perform a 2D unbinned extended maximum likelihood fit to (q^2, mass) for forward and backward.
- Extract $A_{FB} = \frac{N_F \cdot PDF_F(q^2) - N_B \cdot PDF_B(q^2)}{N_F \cdot PDF_F(q^2) + N_B \cdot PDF_B(q^2)}$

19

Measuring the zero-crossing point in A_{FB} of $B^0 \to K^{*0}\mu^+\mu^-$ (II)

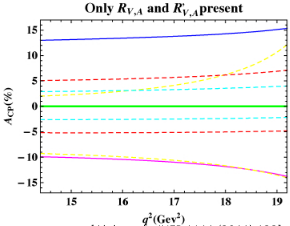


- Standard Model theory predicts zero-crossing in 4.0 - 4.3 GeV^2/c^4 (central values)

  e.g. [C. Bobeth et al., JHEP 1201 (2012) 107][M. Beneke et al., Eur. Phys. J. C41 (2005), 173][A. Ali et al., Eur. Phys. J. C47 (2006) 625]

- LHCb preliminary result: $4.9^{+1.1}_{-1.3}$ GeV^2/c^4

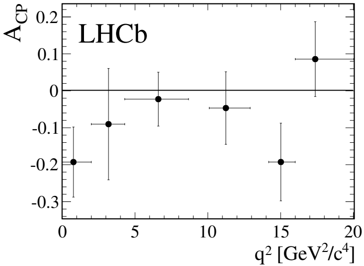
$\mathcal{CP}$-Asymmetry in $B^0 \to K^{*0}\mu^+\mu^-$ (I)



[Alok et al., JHEP 1111 (2011) 122]

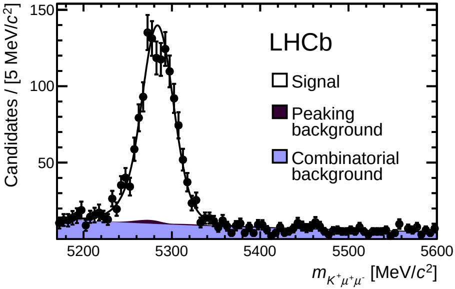
- Form $\mathcal{A}_{\mathcal{CP}} = \frac{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\mu^+\mu^-) - \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\mu^+\mu^-) + \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}$
- Predicted to be $\mathcal{O}(10^{-3})$ in SM, very clean prediction due to form factor suppression.
- Asymmetry up to 15% in certain models.
- Use the same corrections / selection / binning-scheme as for the $B^0 \to K^{*0}\mu^+\mu^-$ angular analysis.
- Additional difficulty: Measured is $\mathcal{A}_{raw} = \mathcal{A}_{\mathcal{CP}} + \mathcal{A}_{\text{Detector}} + \kappa\mathcal{A}_{\text{Production}}$
- $\kappa = \frac{\int_0^\infty \epsilon(t) e^{-\Gamma t} \cos \Delta m t \, \mathrm{d}t}{\int_0^\infty \epsilon(t) e^{-\Gamma t} \cosh \frac{\Delta m t}{2} \, \mathrm{d}t}$

$\mathcal{CP}$-Asymmetry in $B^0 \to K^{*0}\mu^+\mu^-$ (II)



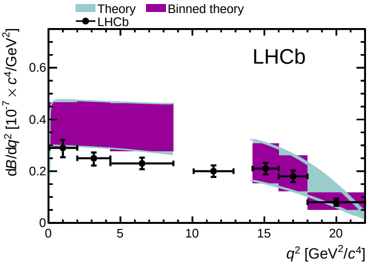
- $\mathcal{A}_{\text{Detector}}$: Detector asymmetries cancel when taking the average between the two magnet polarities.
- $\mathcal{A}_{\text{Detector}}/\mathcal{A}_{\text{Production}}$: Use $B^0 \to J/\psi\, K^{*0}$ as a control channel.
- $\mathcal{A}_{\mathcal{CP}} \approx \mathcal{A}_{\text{raw}}(B^0 \to K^{*0}\mu^+\mu^-) - \mathcal{A}_{\text{raw}}(B^0 \to J/\psi\, K^{*0})$
- Residual differences due to kinematical differences are accounted for in the systematic uncertainty.
- $\mathcal{A}_{\mathcal{CP}} = -0.072 \pm 0.040$ (stat) $\pm\, 0.005$ (sys)

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



- Rare decay, $\mathcal{B}$= $(4.36 \pm 0.15 \pm 0.18) \times 10^{-7}$ [arXiv:1209.4284]
- Use a loose preselection and a BDT for the final selection. Training on $B^+ \to J/\psi K^+$ (signal) and $B^+ \to K^+\mu^+\mu^-$ sidebands (background).
- Cut out resonant regions of $B^+ \to J/\psi K^+$ and $B^+ \to \psi(2S)K^+$.
- Remaining peaking background accounted for in the fit.

Measurement of $B^+ \to K^+\mu^+\mu^-$: Branching fraction

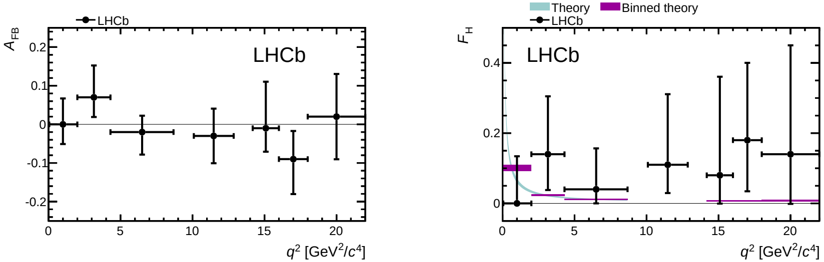


Theory predictions from [C. Bobeth et al., JHEP 07 (2011) 067] and [C. Bobeth et al., JHEP 01 (2012) 107]

- Determine branching fraction in 7 bins of q^2, using $B^+ \to J/\psi\, K^+$ as a normalisation channel and accounting for differences in the efficiencies.
- $\mathcal{B}$= $(4.36 \pm 0.15 \pm 0.18) \times 10^{-7}$, taking excluded charmonium resonance regions into account.
- World's best measurement of $\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$.

[arXiv:1209.4284]

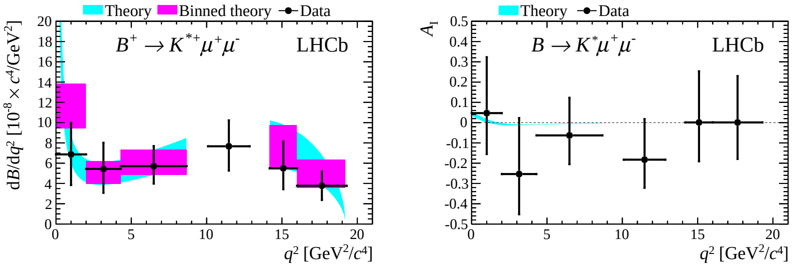
Measurement of $B^+ \to K^+\mu^+\mu^-$: Angular analysis



Theory predictions from [C. Bobeth et al., JHEP 07 (2011) 067] and [C. Bobeth et al., JHEP 01 (2012) 107]

- $\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma(B^+\to K^+\mu^+\mu^-)}{\mathrm{d}\cos\theta_\ell} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_\ell)+\frac{1}{2}F_H + A_{FB}\cos\theta_\ell$
- Acceptance correction using simulation in q^2 and $\cos\theta_\ell$.
- Simultaneous fit to mass and $\cos\theta_\ell$. Background modeled with second-order polynomial in angles.

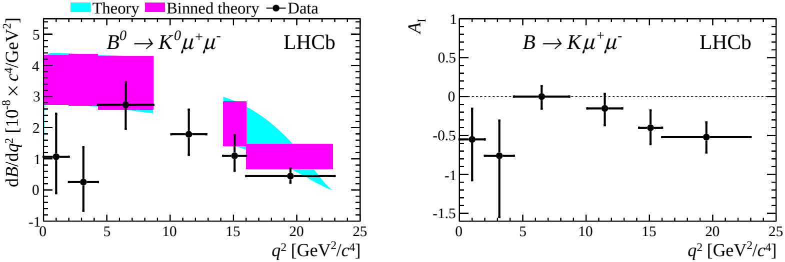
Isospin asymmetry (I)



Theory predictions from [C. Bobeth et al., JHEP 01 (2012) 107] and [M. Beneke et al., Nucl. Phys. B612 (2001) 25-58]

- Measure "Isospin asymmetry": $\frac{\Gamma(B^0\to K^{*0}\mu^+\mu^-)-\Gamma(B^+\to K^{*+}\mu^+\mu^-)}{\Gamma(B^0\to K^{*0}\mu^+\mu^-)+\Gamma(B^+\to K^{*+}\mu^+\mu^-)}$
- Predicted to be very small.
- Use $B \to J/\psi K^*$ as a normalisation channel.
- $B^+ \to K^{*+}\mu^+\mu^-$ is challenging due to K^0_S reconstruction from $K^{*+} \to K^0_S\pi^+$.
- Results for $B \to K^*\mu^+\mu^-$ agree well with prediction.

Isospin asymmetry (II)

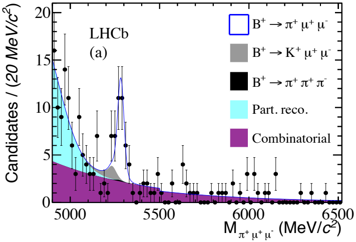


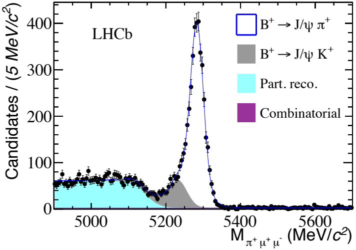
Theory predictions from [C. Bobeth et al., JHEP 01 (2012) 107] and [M. Beneke et al., Nucl. Phys. B612 (2001) 25-58]

- Measure "Isospin asymmetry": $\frac{\Gamma(B^0 \to K^0\mu^+\mu^-) - \Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^0 \to K^0\mu^+\mu^-) + \Gamma(B^+ \to K^+\mu^+\mu^-)}$
- Predicted to be very small.
- Use $B \to J/\psi\, K$ as a normalisation channel.
- $B^0 \to K^0\mu^+\mu^-$ is challenging due to K^0_S reconstruction.
- A_I shows a 4.4σ deviation from 0, driven by low $\mathcal{B}(B^0 \to K^0\mu^+\mu^-)$.

[LHCb-PAPER-2012-020]

Branching Fraction Measurement of $B^+ \to \pi^+\mu^+\mu^-$





- Fit four distributions simultaneously: $B^+ \to J/\psi\, K^+$, misidentified $B^+ \to J/\psi\, K^+$, $B^+ \to K^+\mu^+\mu^-$, $B^+ \to \pi^+\mu^+\mu^-$
- Measured branching fraction: $\mathcal{B} = (2.3 \pm 0.6(\text{stat}) \pm 0.1(\text{sys})) \times 10^{-8}$
- In good agreement with SM expectation: $(1.96 \pm 0.21) \times 10^{-8}$.

  [S. Hai-Zen et al., 2008 Commun. Theor. Phys. 50 696]
- Also determine: $R = \frac{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)} = f^2 \frac{|V_{td}|^2}{|V_{ts}|^2}$
- Which leads to: $\frac{|V_{td}|}{|V_{ts}|} = 0.266 \pm 0.035$ (stat) $\pm\, 0.007$ (sys)

SUMMARY

- EW penguins are a very active area in LHCb.
- $B^0 \to K^{*0}\mu^+\mu^-$ is a "golden-channel" and allows measurment of many observables: angular analysis, zero-crossing point of A_{FB}, differential branching fraction, Isospin asymmetry, $\mathcal{CP}$ asymmetry.
- $B^+ \to K^+\mu^+\mu^-$: Angular analysis, differential branching fraction and Isospin asymmetry.
- Discovery of $B^+ \to \pi^+\mu^+\mu^-$, rarest B decay ever observed.
- 2011+2012 ($\approx$ 3.2 fb^{-1}) data will allow more precision, more observables and (hopefully) conclusions on discrepancies.

19

Васкир

$B^0 \to K^{*0}\mu^+\mu^-$: Full angular distribution

- If we neglect lepton masses and S-wave component, the angular distribution of $B^0 \to K^{*0}\mu^+\mu^-$ is:

$$
\begin{aligned}
\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} \quad \propto \quad & I_1^s \sin^2\theta_K + I_1^c \cos^2\theta_K \\
& + \left(I_2^s \sin^2\theta_K + I_2^c \cos^2\theta_K\right)\cos 2\theta_\ell \\
& + I_3 \sin^2\theta_K \sin^2\theta_\ell \cos 2\phi \\
& + I_4 \sin 2\theta_K \sin 2\theta_\ell \cos\phi \\
& + I_5 \sin 2\theta_K \sin\theta_\ell \cos\phi \\
& + \left(I_6^s \sin^2\theta_K + I_6^c \cos^2\theta_K\right)\cos\theta_\ell \\
& + I_7 \sin 2\theta_K \sin\theta_\ell \sin\phi \\
& + I_8 \sin 2\theta_K \sin 2\theta_\ell \sin\phi + \\
& + I_9 \sin^2\theta_K \sin^2\theta_\ell \sin 2\phi
\end{aligned}
$$

- The I_i depend on q^2 and contain the (transversity) amplitudes of the K^{*0}.
- All I_i are observables, 8 of them are independent.