The angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ at LHCb

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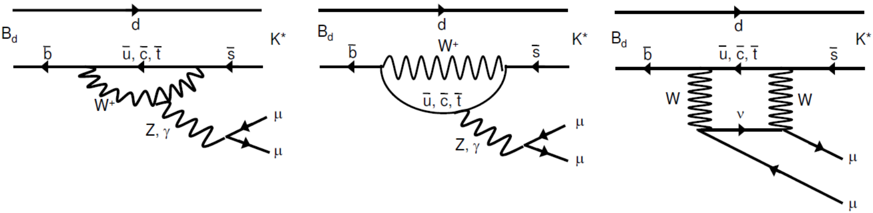
Outline

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

- $B^0 \to K^{*0}\mu^+\mu^-$ is a flavour-changing neutral current decay
- The $b \to s$ transition proceeds via a loop diagram.
- New physics can enter inside the loop.
- Branching fraction is well measured at $1.05^{+0.16}_{-0.13}$x10^{-6}, close to the SM value.
- However, smaller effects subtly affect the angular distribution of the decay products.

Figure: Dominant standard model Feynman diagrams for $B^0 \to K^{*0}\mu^+\mu^-$

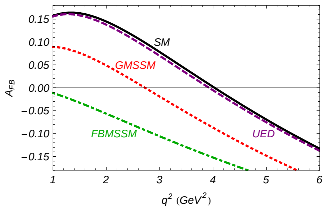


$B^0 \to K^{*0}\mu^+\mu^-$: angular distribution

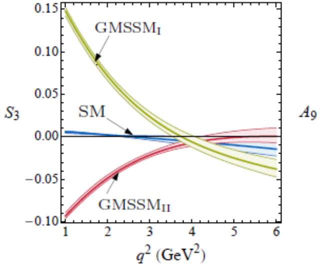
- The decay $B^0 \to K^{*0}\mu^+\mu^-$ can be described by four kinematic variables: θ_ℓ, θ_K,ϕ and q^2.
- The angles are defined with respect to the daughter kinematics in the B^0 rest frame and form the basis for the angular distribution.
- The angular distribution can expressed in terms of theoretically clean observables (for example A_{FB}, F_{L}, $\mathcal{S}_3$).
- These observables consist of combinations of the transversity (or heliticty) amplitudes which are sums of the Wilson coefficients $\mathcal{C}_{7,}^{(\mathrm{eff})}$ $\mathcal{C}_9^{(\mathrm{eff})}$ and $\mathcal{C}_{10.}$
- These Wilson coefficients parameterise the contributions from the penguin diagrams.

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

- $b \to s$ transitions have been explored to determine the effects of new physics models.
- Contributions from the effects of new physics can be encoded in the Wilson coefficients (Altmannshofer et al: 0811.1214)
- This leads to calculations made of the observables for different scenarios:



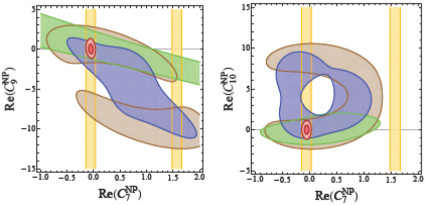
(a)



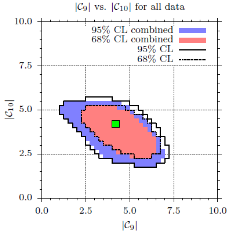
(b)

Current theoretical constraints

- The LHCb result in 2011 along with other $b \to s$ transition measurements have been used to provide experimental input on model independant fits to the Wilson coefficients: (a) & (b).
- The results from (a) give a 95% best fit compatibility with the standard model and the subsequent constraints give the scale of new physics in this system (Λ_{NP}) from 5 to 40 TeV.



(c) Altmannshofer et al: 1111.1257



(d) Bobeth et al: 1111.2558

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

- Cut based preselection with an MVA (BDT) offline selection.
- Select on daughter impact parameter, B vertex, particle identification, track quality
- There are minimal cuts on p_T to retain angular sensitivity.
- Packing backgrounds and mis-identified candidates vetoed.
  - $B_s^0 \to \phi\mu^+\mu^-$,
  - $B_s^0 \to \overline{K}^{*0}\ \mu^+\mu^-$,
  - $\pi \to \mu$ swaps etc.

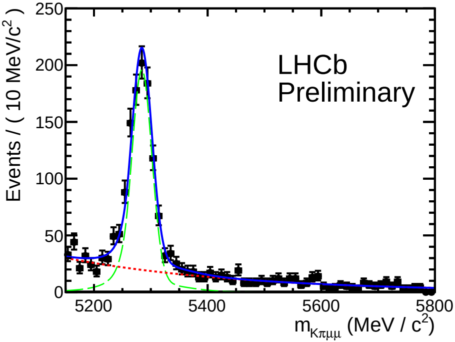


Figure: 900 ± 34 $B^0 \to K^{*0}\mu^+\mu^-$ candidates.

Acceptance correction

- The effects of the detector acceptance can bias the angular distributions.
- Correct on an event by event basis.
- Efficiency calculated using phase space simulated events - model independant
- Simulation corrected for known differences with data
- Assume efficiency factorises in phase space :
  $\epsilon(\cos\theta_l, \cos\theta_K, \phi, q^2) = \epsilon_{\cos\theta_l}(q^2)\epsilon_{\cos\theta_K}(q^2)\epsilon_{\phi}(q^2)$

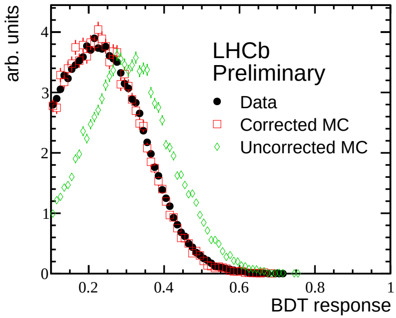


Figure: MVA distribution of $B^0 \to J/\psi K^{*0}$ events showing the impact of data/MC corrections.

Result extraction

- Fit angular distribution :

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}\,\mathrm{d}q^2} = \frac{9}{16\pi}\Big[F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) + F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell + A_{Im}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big]$$

- This is a distribution is simplified using the symmetry : $\phi \to \phi + \pi$
- 3D phase space ($\cos\theta_K$,$\cos\theta_K$,ϕ) with 4 free parameters (A_{FB}, F_{L}, $\mathcal{S}_{3}$, A_{Im})
- Observables are correlated non-trivially via the K^{*0} polarisation amplitudes

The zero crossing point of A_{FB}

- A_{FB} changes sign at a well defined point in the SM.
- Uncertainty on form factors roughly cancels when $A_{\mathrm{FB}}(q^2) = 0$ and the SM prediction is between 4 and 4.3.
- Zero-crossing point extracted using 'unbinned-counting' technique
- Fit 'forward-going' and 'backward-going' events seperately,

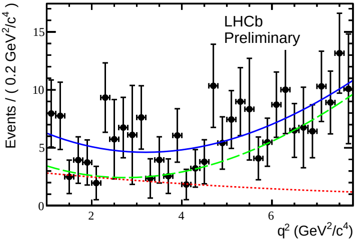


Figure: Forward-going events

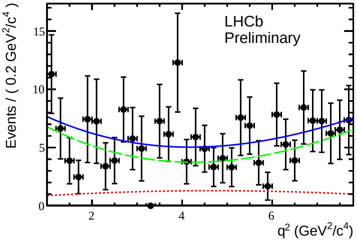


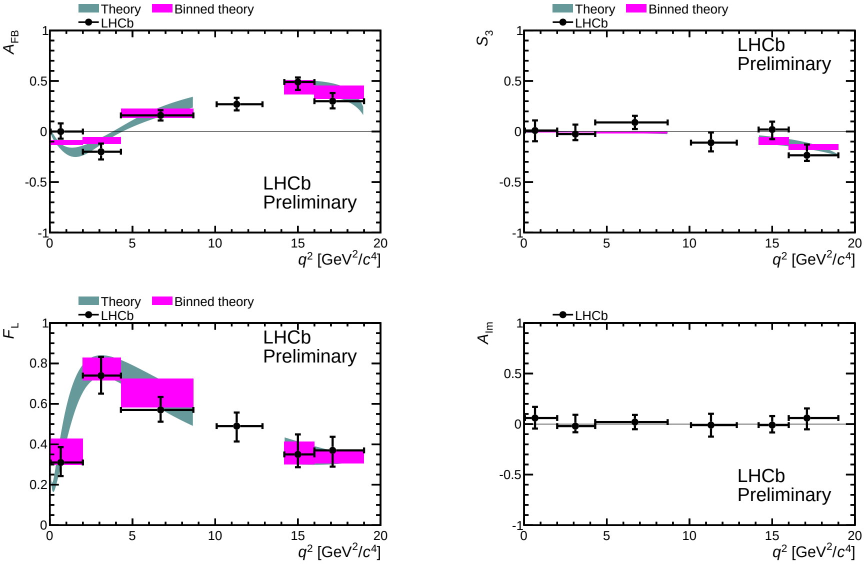
Figure: Backward-going events

Systematics

For the determination of A_{FB}, F_{L}, $\mathcal{S}_3$ and A_{Im} the dominant sources of systematic uncertainty are

- uncertainty on the acceptance correction
- contains uncertainties from the data-simulation corrections: tracking, trigger, PID correction
  - This is explored by varying event weights coherently and refitting the angular distribution
- Second main source of systematic is dependance on the signal and background model
- Additional systematic uncertainties:
  - S-wave : Fit with values taken from from $B^0 \rightarrow J/\psi\ K^{*0}$ at BABAR and LHCb (8%)
  - B^0 mis ID fraction.

Results



Theory
Binned theory
LHCb
A_{FB}
LHCb Preliminary
q^2 [GeV^2/c^4]
S_3
F_L
A_{Im}

Results

- The zero crossing point is measured to be $q_0^2 = 4.9^{+1.1}_{-1.3}\,\mathrm{GeV}^2$
- The measured range of the crossing point is shown in red below.

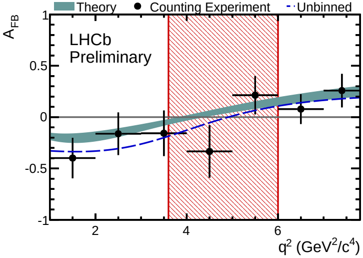


Figure: The zero crossing point showing a comparison of a counting experiment and the unbinned analysis

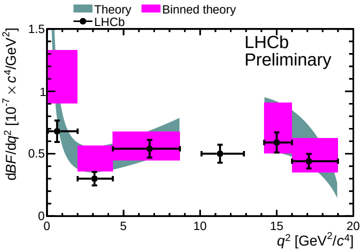


Figure: The differential branching ratio of $B^0 \to K^{*0}\mu^+\mu^-$

Summary

- $B^0 \to K^{*0}\mu^+\mu^-$ is a promising channel to discover new physics in the flavour sector.
- However, the analysis of 341 pb^{-1} of LHCb data in 2011 set significant constraints on the scale of new physics
- Angular analysis of 1 fb^{-1} of LHCb data is the most precise measurement of A_{FB}, F_{L}, A_{Im} and $\mathcal{S}_3$ yet.
- First measurement of the zero-crossing point of A_{FB}.
- LHCB-CONF-2012-008