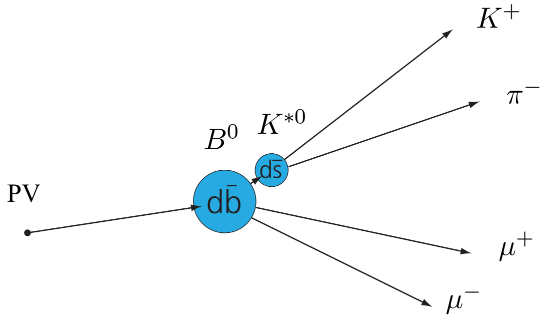
Analysis of $B^0 \to K^{*0}\mu^+\mu^-$ at the LHCb Experiment

Latsis Symposium 2013, Zurich,
4th June 2013

[arxiv:1304.6325]

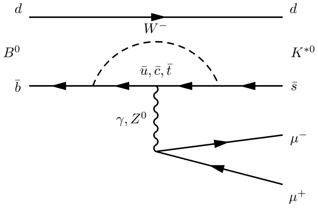
Michel De Cian, University of Heidelberg

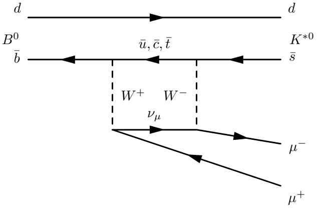
$B^0 \to K^{*0}\mu^+\mu^-$ DECAY TOPOLOGY



Particle	mass	lifetime ($c\tau$)
B^0	5279 MeV/c^2	491.1 μm
K^{*0}	892 MeV/c^2	$\approx 3 \cdot 10^{-12}$ μm

$B^0 \to K^{*0}\mu^+\mu^-$: Rare, but exciting

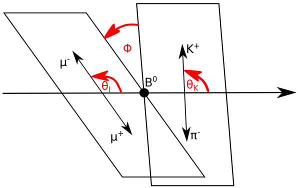




- Rare decay with $\mathcal{B}= (1.05^{+0.16}_{-0.13}) \times 10^{-6}$ [PDG]
- Decay only possible via penguin- or box diagrams, "new physics" can enter at the same level as SM physics.
- Pseudoscalar $\longrightarrow$ Vector-Vector decay: Plenty of observables in the angular distribution.

Angular distribution (I)

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



$$\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\ \mathrm{d}\cos\theta_K\ \mathrm{d}\phi\ \mathrm{d}q^2} = \frac{9}{32\pi}\sum_{i=1}^{9} I_i^{(s,c)} \cdot f(\cos\theta_i, \cos\theta_\ell, \phi).$$

- I_i are function of Wilson-coefficients $\mathcal{C}_7^{(\prime)}, \mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$ and hadronic form-factors.
- In an ideal world, we would fit this expression to the collision data and extract all I_i observables.
- Can construct $\mathcal{CP}$-symmetric and $\mathcal{CP}$-antisymmetric observables: $S_i = I_i + \bar{I}_i$, $A_i = I_i - \bar{I}_i$,

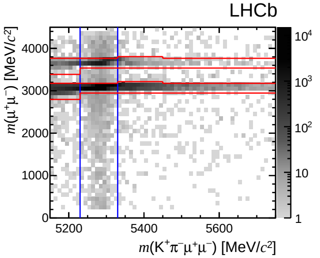
Angular distribution (II)

- In 2011, LHCb reconstructed ≈ 900 $B^0 \to K^{*0}\mu^+\mu^-$ events: Not enough for full angular fit.
- Apply "folding" technique: $\phi \to \phi + \pi$ for $\phi < 0$.
  This cancels four terms in the total angular distribution.
- And leaves (neglecting lepton masses and S-wave contributions)

$$\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} \propto F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) + F_L\cos^2\theta_K(2\cos^2\theta_\ell) + \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\phi + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell + A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\phi$$

- This expression was fitted to the 1 fb^{-1} of LHCb data at $\sqrt{s} = 7\,\mathrm{TeV}$ in 2011.

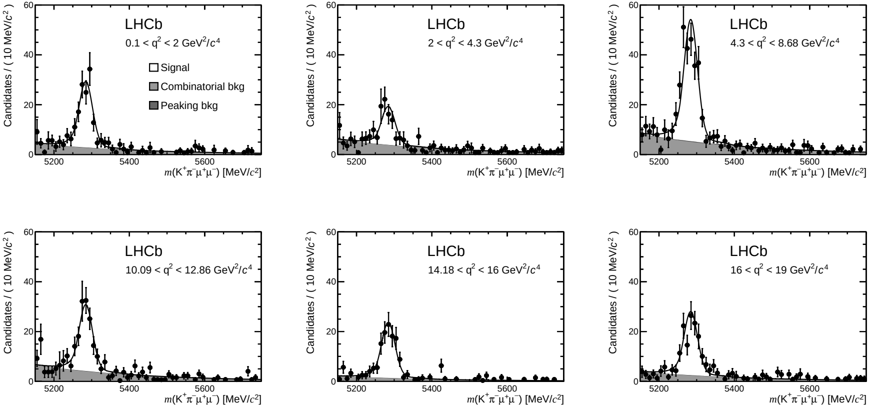
Experimental aspects



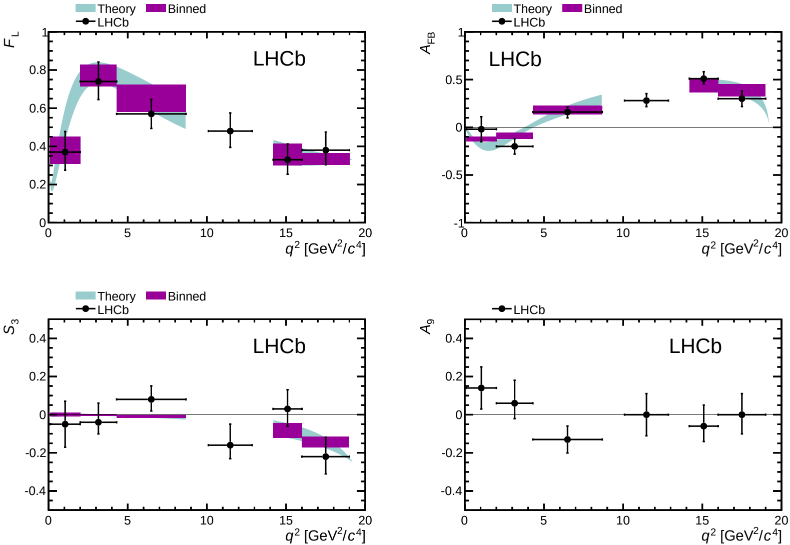
- Some experimental details:
  - Dominated by $B^0 \to J/\psi\, K^{*0}$ and $B^0 \to \psi(2S) K^{*0}$ in two regions: Cut out.
  - Peaking background due to misidentification of particles: Apply vetoes.
  - Select signal events with a BDT.
  - Acceptance of detector distorts angular distribution: Apply event-by-event correction, determined on simulation.
  - Correct for particle ID and efficiency (tracking, trigger, ...)-differences in simulation and collision data.

- Perform a unbinned maximum-likelihood fit to the mass distribution and to $(\theta_\ell, \theta_K, \phi)$ in 6 bins of q^2.

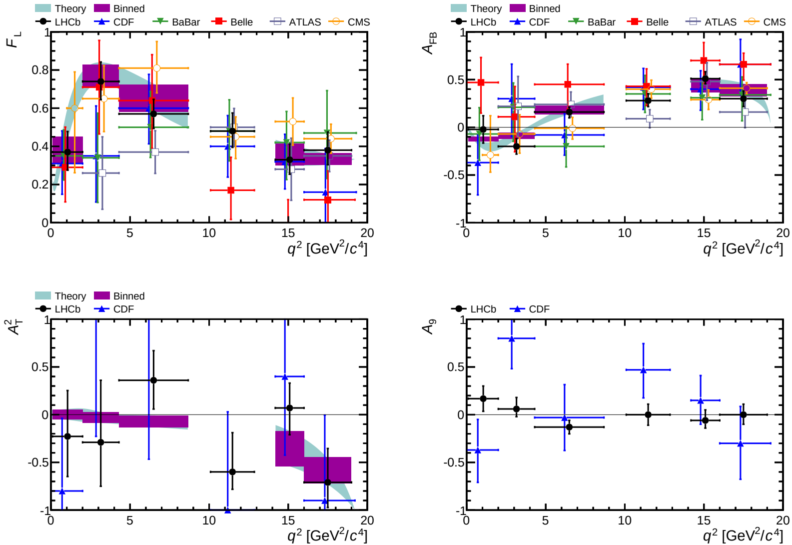
Distribution of events in q^2



Results


Theory
Binned
LHCb
F_L
LHCb
q^2 [GeV^2/c^4]
Theory
Binned
LHCb
A_{FB}
LHCb
q^2 [GeV^2/c^4]
Theory
Binned
LHCb
S_3
LHCb
q^2 [GeV^2/c^4]
LHCb
A_9
LHCb
q^2 [GeV^2/c^4]

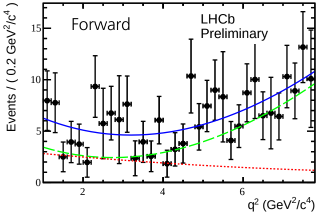
Comparison with other experiments

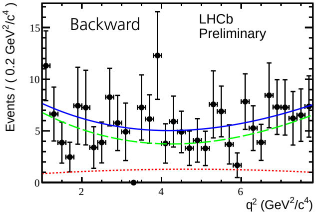


ATLAS: [ATLAS-CONF-2013-038] CMS: [CMS-BPH-11-009] CDF: [PRL 108 (2012)]

Belle: [PRL 103 (2009)] BaBar: [PRD 86 (2012)]

Measuring the zero-crossing point of A_{FB}(I)





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

MEASURING THE ZERO-CROSSING POINT OF A_{FB} (II)

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

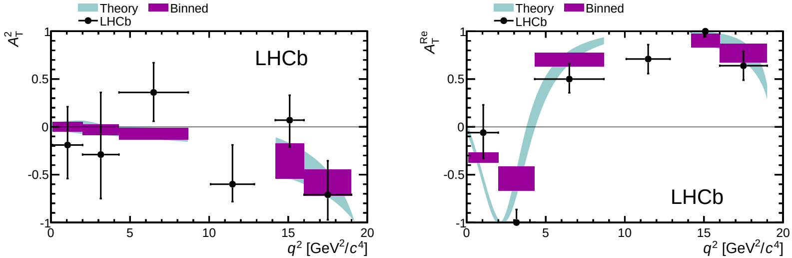
  [JHEP 1201 (2012) 107][Eur. Phys. J. C41 (2005), 173][Eur. Phys. J. C47 (2006) 625]

- LHCb result: $4.9 \pm 0.9\,\mathrm{GeV}^2/c^4$

Clean observables

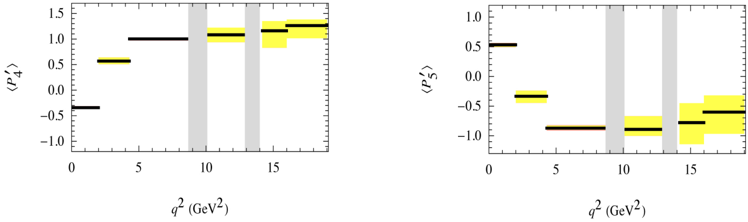
- Goal is to measure (more) observables which have a "clean" prediction, i.e. are not affected by form-factor uncertainties.
- Two examples:
  - $S_3 = \frac{1}{2}(1 - F_L)A_T^{(2)}$
  - $A_{FB} = \frac{3}{4}(1 - F_L)A_T^{(Re)}$
- Can re-express the angular distribution using these replacements and determine $A_T^{(2)}$ and $A_T^{(Re)}$.
- Caveat: F_L and $A_T^{(2)}/A_T^{(Re)}$ both vary with q^2. Result presented is a weighted average of the transverse observables.

$A_T^{(2)}$ AND $A_T^{(Re)}$



Theory
Binned
LHCb
A_T^2
LHCb
q^2 [GeV^2/c^4]
Theory
Binned
LHCb
A_T^{Re}
LHCb
q^2 [GeV^2/c^4]

More (clean) variables



- Angular distribution has 8 independent observables in total. Have only measured 4 of them due to folding, measure the remaining ones as well.
- Instead of measuring the S_i observables one can choose basis: $\left\{ \frac{d\Gamma}{dq^2}, F_L, P_1, ..., P_6 \right\}$, with $P_1, ..., P_6$ clean observables.
- $P_1 = A_T^{(2)}, P_2 = A_T^{(Re)}$
- Goal is to measure all observables of this basis.
- From an experimental point it's advantageous to replace: P_4, P_5, P_6 with: P'_4, P'_5, P'_6

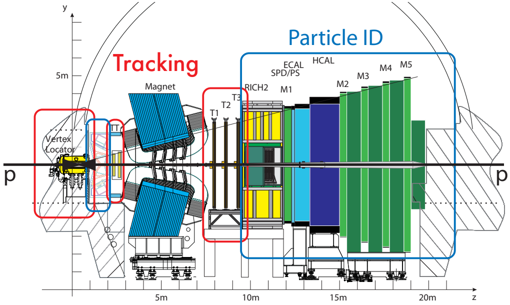
Summary

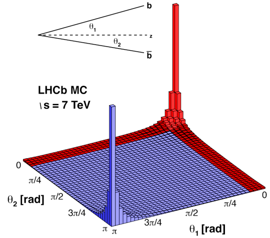
- Performed an angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ and measured the observables F_L, S_3, A_{FB} and A_9 (and $A_T^{(2)}$ and $A_T^{(Re)}$). All agree with SM predictions.
- Measured the zero-crossing point of A_{FB}.
- The future is the determination of the "remaining" information, using observables which are less affected by form-factor uncertainties.

15

fin

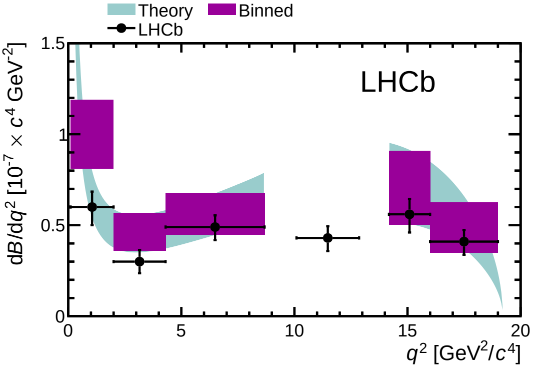
The LHCb detector





- b-quarks are produced in pairs, mostly in the forward- and backward region.
- LHCb has excellent tracking capabilities ($\Delta p/p \approx 0.4 - 0.6\%$)...
- ... and very good particle identification: K and π can be separated up to $p \approx 100\,\mathrm{GeV}/c$.
- Collected $\approx 1\,\mathrm{fb}^{-1}$ in 2011 and $\approx 2.2\,\mathrm{fb}^{-1}$ in 2012

Differential branching fraction



BDT INPUT VARIABLES

- the B^0 pointing to the primary vertex, flight-distance and IP χ^2 with respect to the primary vertex, p_T and vertex quality (χ^2);
- the K^{*0} and dimuon flight-distance and IP χ^2 with respect to the primary vertex (associated to the B^0), p_T and vertex quality (χ^2);
- the impact parameter χ^2 and the $\Delta LL(K-\pi)$ and $\Delta LL(\mu-\pi)$ of the four final state particles.