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

Neckarzimmern Workshop,
6th March 2014

Michel De Cian, University of Heidelberg

Introduction

- This is mostly a walk-through of the $B^0 \to K^{*0}\mu^+\mu^-$ analysis like it was performed in 2012 & 2013 in LHCb.
- It should show how an angular analysis with $\mathcal{O}(1000)$ events might look like and where the problems are.

Vintage physics (I)

- The electroweak bosons W and Z^0 were proposed in the 60ies.
- They are quite heavy with 80 GeV/c^2 and 91 GeV/c^2 and were first seen directly at UA1.
- However, in principle, the Z^0 should also contribute to the process $e^+ e^- \to \mu^+ \mu^-$, even at lower energies than $\sqrt{s} \sim 91\,\mathrm{GeV}$
- Look at $\sqrt{s} = 34\,\mathrm{GeV}$. Simple calculation yields: Only very small effect of Z^0 in total cross-section.

VINTAGE PHYSICS (II)

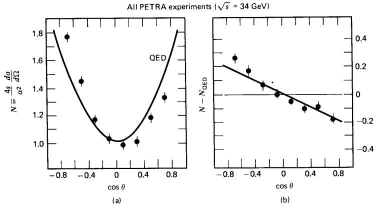
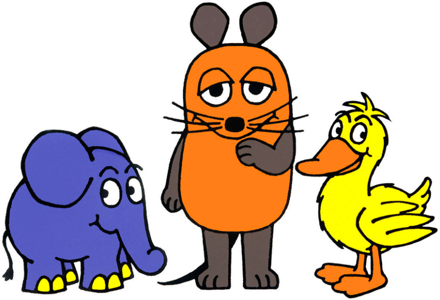


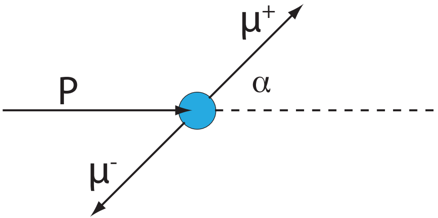
Fig. 13.7 (a) The cos θ distribution for the process $e^-e^+ \to \mu^-\mu^+$ does not follow the $1 + \cos^2\theta$ QED prediction. (b) The discrepancy is explained by the interference of the virtual Z and γ contributions. (Compilation by R. Marshall.)

- However, if you look at the differential cross-section, you clearly see the influence of the Z^0 due to interference terms.
- You have discovered a new particle/effect/... indirectly at a centre-of-mass energy lower than the mass of the particle.
- Even if your total cross-section is according to your prediction of the (standard) model, one might seen new effects when studying angular distributions.

Essentials of the $B^0 \to K^{*0}\mu^+\mu^-$ analysis
aka: The "Sendung-mit-der-Maus" version



ESSENTIALS OF THE $B^0 \to K^{*0}\mu^+\mu^-$ ANALYSIS



- A particle decays into two particles, with angle α.
- Suppose we can formulate the angular distribution as:

$$\frac{d\Gamma}{d\alpha} = \frac{1}{2\pi}\left[A\cos\alpha + B\sin\alpha + C\right] \quad \alpha \in [-\pi, \pi]$$

- The angular terms are given by kinematics / spin only.
- Remember: $\frac{d\sigma}{d\Omega}(e^+e^- \to \mu^+\mu^-) = \frac{\alpha^2}{4s}\left(1 + \cos^2\theta\right)$

Essentials of the $B^0 \to K^{*0}\mu^+\mu^-$ analysis

$$\frac{d\Gamma}{d\alpha} = \frac{1}{2\pi}\left[A\cos\alpha + B\sin\alpha + C\right] \quad \alpha \in [-\pi, \pi]$$

- The coefficients contain the physics-information we are interested in.
- Do: Run an experiment, collect data, select your decay, plot number of events as a function of α.
- Fit the angular distribution in collision data with the pdf and extract the coefficients.
- Ask a theorist and compare prediction with experimental result.

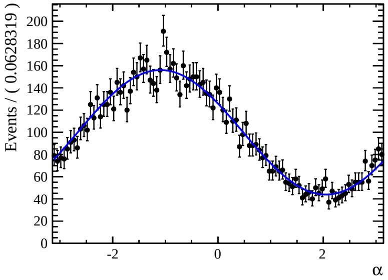
Folding technique (I)

- Suppose you don't have enough data to fit both terms.
- Solution: Use a variable transformation ("folding"). Example:

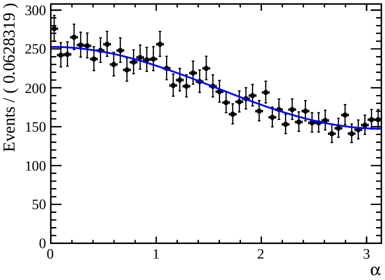
$$\begin{aligned}
\frac{\mathrm{d}\Gamma}{\mathrm{d}\alpha} &= \frac{1}{2\pi}\left[A\cos\alpha + B\sin\alpha + C\right] \qquad \alpha\in[-\pi,\pi] \\
\alpha\to-\alpha \quad &\text{if} \quad \alpha<0 \\
\frac{\mathrm{d}\Gamma}{\mathrm{d}\alpha} &= \frac{1}{\pi}\left[A\cos\alpha + C\right] \qquad \alpha\in[0,\pi]
\end{aligned}$$

- By folding we can use symmetries in the angular distribution to cancel observables without loosing sensitivity. Note: The angular terms are orthogonal.

Folding technique (II)



fit pdf: $\frac{1}{2\pi}\left[A\cos\alpha + B\sin\alpha + C\right]$

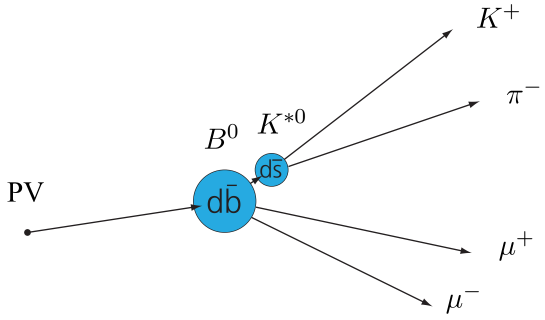


fit pdf: $\frac{1}{\pi}\left[A\cos\alpha + C\right]$

- Apply transformation to the pdf and to the dataset.
- Results:
  - $A = 1.03 \pm 0.05$ (without folding)
  - $A = 1.05 \pm 0.05$ (with folding)
- We have determined A!

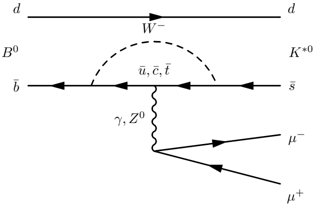
And now the real $B^0 \rightarrow K^{*0}\mu^+\mu^-$ analysis

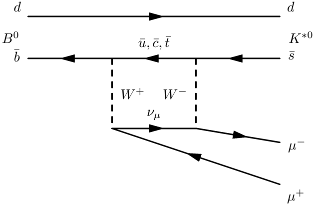
$B^0 \to K^{*0}\mu^+\mu^-$ DECAY TOPOLOGY

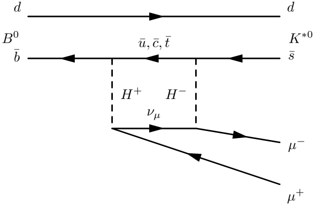


Particle	mass	lifetime ($c\tau$)
B^0	5279 MeV/c^2	491.1 µm
K^{*0}	892 MeV/c^2	$\approx 3 \cdot 10^{-12}$ µm

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

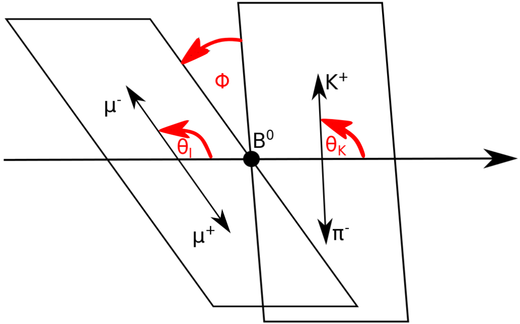






- $\mathcal{B}$= $(1.05^{+0.16}_{-0.13}) \times 10^{-6}$ [PDG]
- Pseudoscalar $\rightarrow$ Vector-Vector decay: Plenty of observables in the angular distribution.

$B^0 \to K^{*0}\mu^+\mu^-$ ANGULAR DISTRIBUTION (I)



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

$B^0 \to K^{*0}\mu^+\mu^-$ ANGULAR DISTRIBUTION (II)

$$
\begin{aligned}
\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[& \frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \\
& \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \\
& S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + \\
& S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + \\
& S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + \\
& S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]
\end{aligned}
$$

- The F_L, S_i depend on q^2 and contain the information we are interested in.
- The angular terms are... the angular terms.
- Note that this formula adds $B^0 \to K^{*0}\mu^+\mu^-$ and $\overline{B}^0 \to \overline{K}^{*0}\mu^+\mu^-$ i.e. it's a $\mathcal{CP}$ average.

$B^0 \to K^{*0}\mu^+\mu^-$ ANGULAR DISTRIBUTION (II)

- This is the full angular distribution of $B^0 \to K^{*0}\mu^+\mu^-$, neglecting lepton masses (and scalar and tensor contributions).
- There are 8 independent, $\mathcal{CP}$ averaged observables that all can be measured experimentally.
- Could in principle also measure $\mathcal{CP}$ asymmetric observables, but then could not profit from adding the datasets.

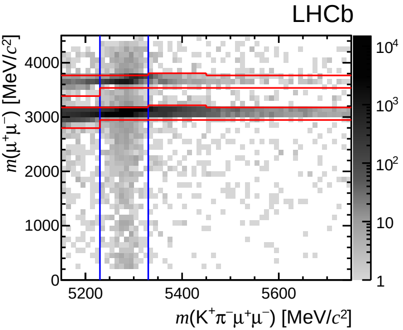
$B^0 \to K^{*0}\mu^+\mu^-$ angular distribution (III)

- In 2011, LHCb reconstructed $\approx$ 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:

$$\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell +$$
$$S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi +$$
$$S_6\sin^2\theta_K\cos\theta_\ell +$$
$$S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

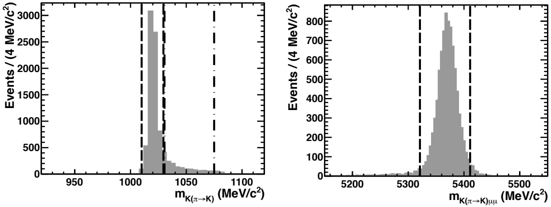
- This expression was fitted to the 1 fb^{-1} of LHCb data at $\sqrt{s} = 7\,\mathrm{TeV}$ in 2011.

Experimental aspects (I)



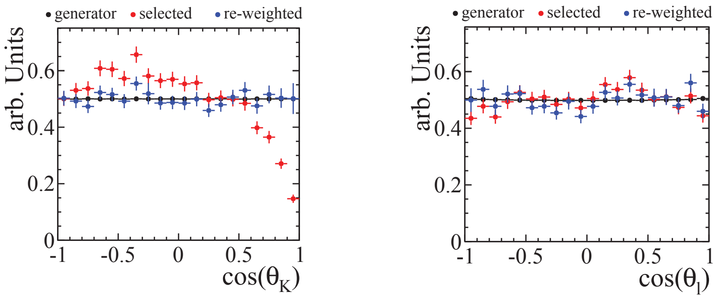
- Select signal events with a multivariate classifier (BDT): Based on kinematic quantities (IP, pointing angle, p_{T}) and particle identification for μ, π, K
- Dominated by $B^0 \to J/\psi\, K^{*0}$ and $B^0 \to \psi(2S) K^{*0}$ in two regions of q^2: Cut out.

Experimental aspects (II)



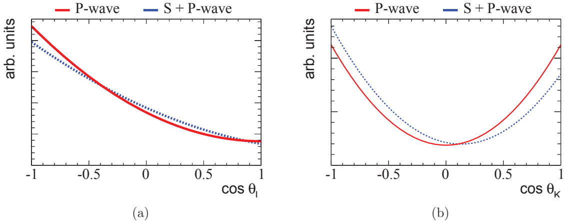
- Peaking background due to misidentification of particles. e.g. $B_s^0 \to \phi\mu^+\mu^-$, where $K \to \pi$.
- Evaluate $m_{K\pi}$ mass under hypothesis that the π is actually a K. Does it peak in the ϕ region?
- Other peaking backgrounds like $B^0 \to J/\psi K^{*0}$, where $\pi \to \mu$ and $\mu \to \pi$

Experimental aspects (III)



- Remember: We want to measure an angular distribution and extract physics parameters.
- We need to be sure, the angular distribution reflects the physics.
- Acceptance of detector distorts angular distribution. Need event-by-event correction, determined on simulation.
- Need to have a simulation describing collision data: Correct for particle ID and efficiency (tracking, trigger, ...)-differences in simulation and collision data.

S-wave / Background



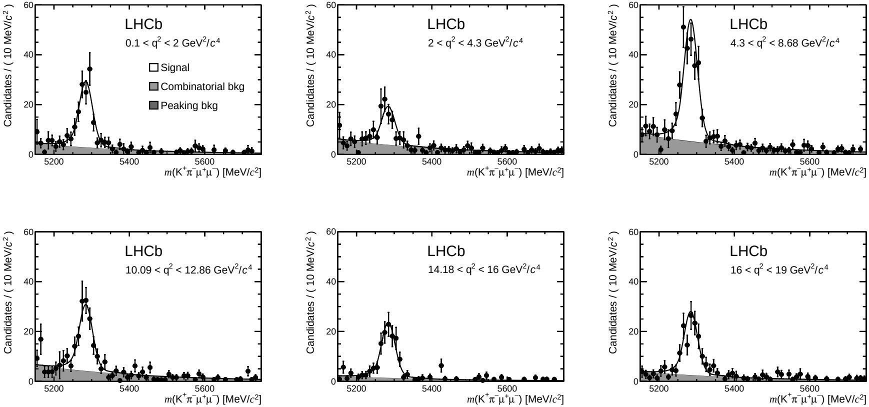
- $B^0 \to K^{*0}\mu^+\mu^-$ is contaminated with S-wave $K\pi$ contributions, stemming from non-resonant decays or higher $K^{(*)}_{(i)}$ states.
- Ideally one would fit for this contribution. However, this adds many terms in the angular distribution.
- Instead: Estimate the S-wave contribution and check with simulation how large the effect on the results is. Add to systematic uncertainty.

Distribution of events in q^2 (I)

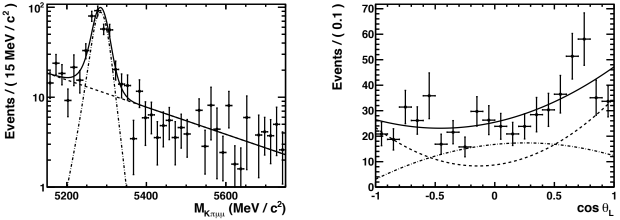
- Told you that F_L, S_i depend on q^2.
- Need to parametrize / bin in q^2 to understand dependence.
- This analysis uses 6 q^2 bins. The binning scheme was copied from the analysis of the Belle collaboration.
- See later for a possible unbinned way (in a slightly different context).

[JHEP 08 (2013) 131]

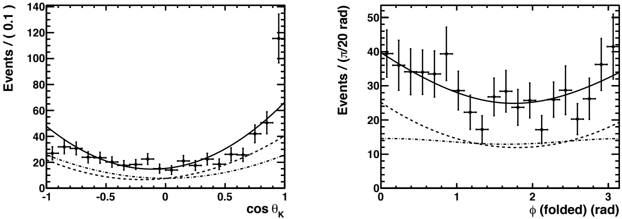
Distribution of events in q^2 (II)



Example of angular distribution

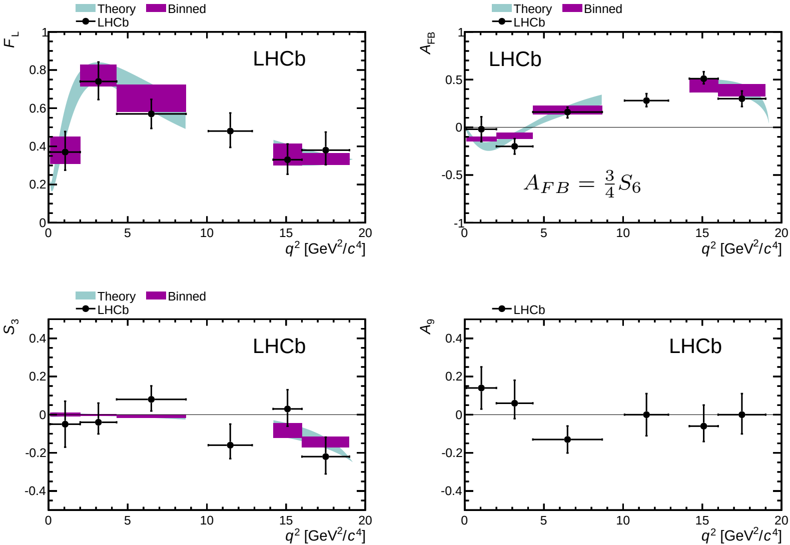


(a) $\mathrm{m}_{K\pi\mu\mu}$ (b) $\cos\theta_L$

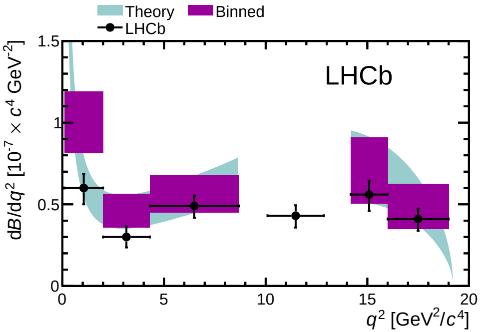


$$q^2 = 4.3 - 8.68\,\mathrm{GeV}^2/c^4$$

Results

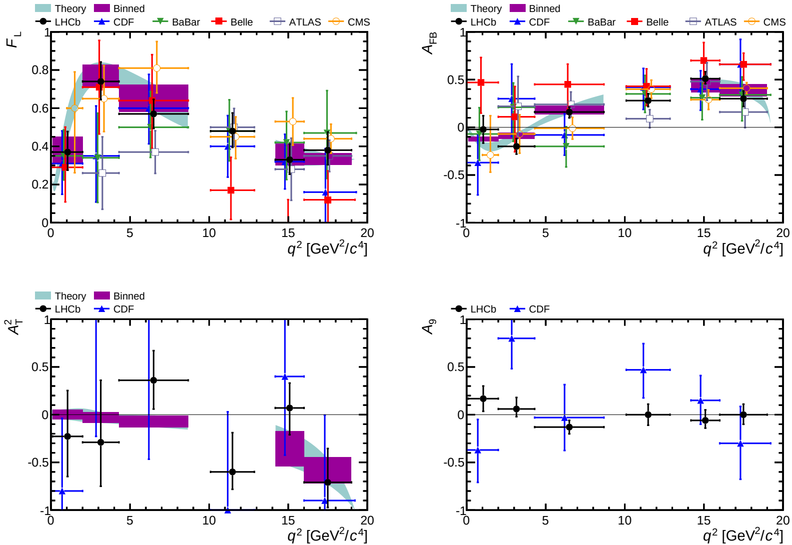

Theory
Binned
LHCb
F_L
A_{FB}
$A_{FB} = \frac{3}{4} S_6$
S_3
A_9
q^2 [GeV^2/c^4]
0
5
10
15
20
1
0.8
0.6
0.4
0.2
0.5
-0.5
-1
-0.2
-0.4

Differential branching fraction



- Note that the theoretical uncertainty is larger than the experimental one.
- This is / was a major showstopper for discovering smallish effects of new physics.
- However, new lattice results can reduce the uncertainty for high q^2.

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)]

More observables

- Angular distribution has 8 independent observables in total. Have only measured 4 of them due to folding. Want to measure the remaining ones as well.
- Could now go on and devise other foldings to extract the remaining S_4, S_6, S_7 and S_8.
- Or we can try something slightly different...

Esses and Pees

- While all S_i observables can be predicted theoretically, they have large theoretical uncertainties.
- We can do a basis-transformation:
  - Old basis: F_L, $S_3 - S_9$ (8 $\times$ large theo. uncertainty)
  - New basis: F_L, $\frac{d\mathcal{B}}{dq^2}$, $P_1, P_2, P_3, P_4', P_5', P_6'$ (2 $\times$ large theo. uncertainty, 6 $\times$ small theo. uncertainty)

$$P_4' = \frac{S_4}{\sqrt{F_L(1-F_L)}} \quad P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}} \quad P_6' = \frac{S_7}{\sqrt{F_L(1-F_L)}} \text{ [sic!]}$$

$$P_8' = \frac{S_8}{\sqrt{F_L(1-F_L)}} \text{ (not fully independent)}$$

- Replace the S_i observables with the $P_i^{(\prime)}$ observables and determine their values on collision data.

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

- The first folding gave us with one transformation 4 observables.
- To extract the other observables, more effort is needed.
- Example: Extracting P_5':

$$\begin{aligned} \phi &\to -\phi \quad \text{for} \quad \phi < 0 \\ \theta_\ell &\to \pi - \theta_\ell \quad \text{for} \quad \theta_\ell > \pi/2 \end{aligned}$$

- Similar foldings for P_4', P_6', P_8'.

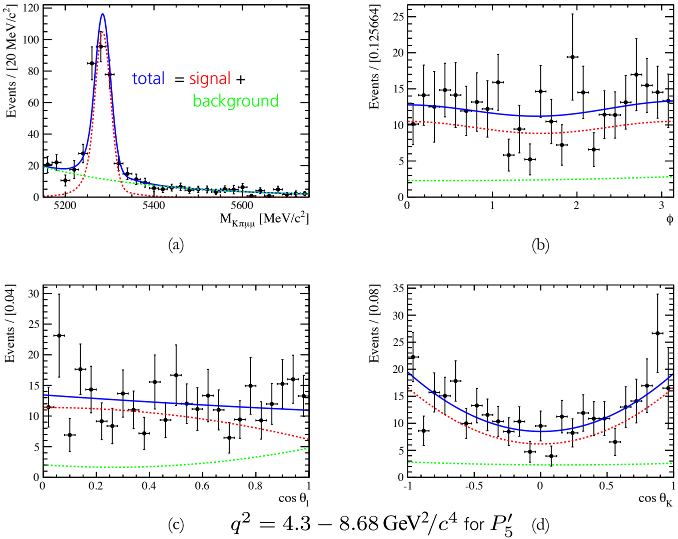
$B^0 \to K^{*0}\mu^+\mu^-$ FOLDED ANGULAR DISTRIBUTION

- The folding for P_5' leads to:

$$\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \right.$$
$$\frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell +$$
$$\frac{1}{2}S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi +$$
$$\left.\sqrt{F_L(1-F_L}P_5'\sin 2\theta_K\sin\theta_\ell\cos\phi\right]$$

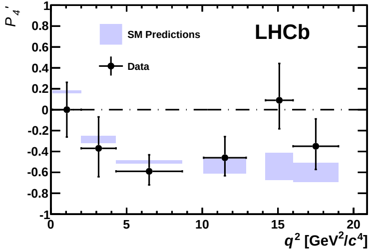
- Only three observables left after the folding. Now we can fit the distribution.
- Only one of them we are interested in, the other two are "nuisance parameters".
- Selection, corrections, etc. all are the same as for the "first" analysis.

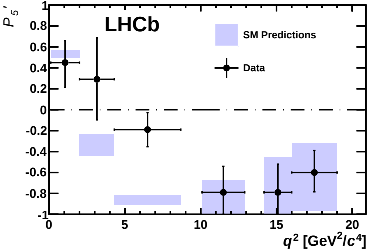
Example of angular distribution



$q^2 = 4.3 - 8.68\,\mathrm{GeV}^2/c^4$ for P_5'

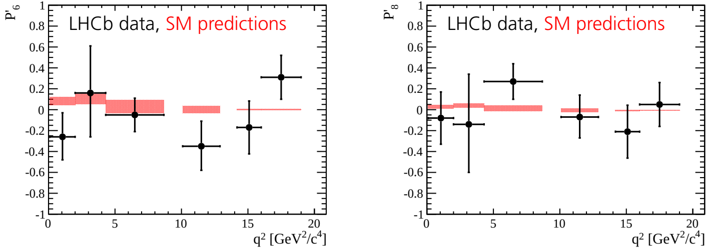
P_4' AND P_5'





- Analysis is performed in the same six bins of q^2 as the first analysis.
- Good agreement for P_4' for the full q^2 range.
- Disagreement for P_5' for low q^2.
- Discrepancy in third bin is about 4 standard deviations. The chance of this happening in one bin out of 24 is about 0.5%.

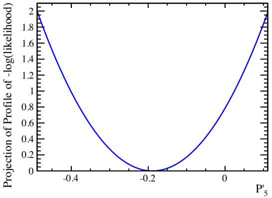
P'_6 AND P'_8



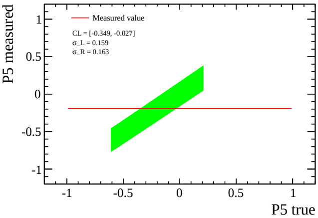
- Good agreement for P'_6 for the full q^2 range.
- Good agreement for P'_8 for the full q^2 range.

Theoretical predictions by J. Matias et al.

Statistical uncertainties

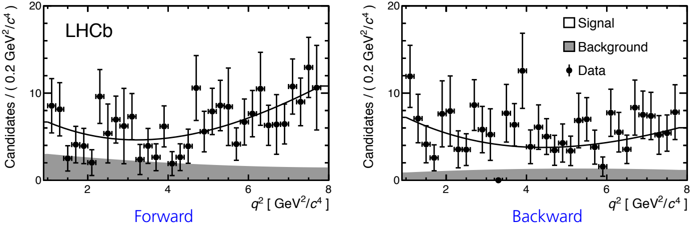


(b)



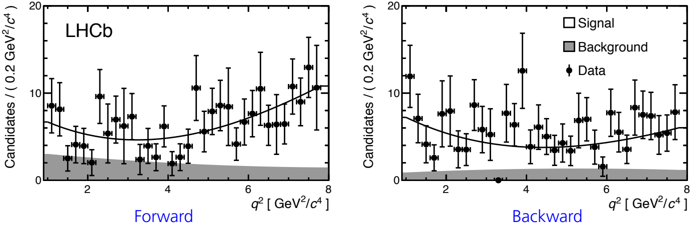
- For some bins the likelihood looked was perfectly parabolic, for some not. Evaluate statistical uncertainty using "Feldmann-Cousins".
- FC:
  - For each possible value of x, generate toys (with: removing events and correcting for acceptance).
  - Order them according to $R = \frac{\mathcal{L}(x|\mu)}{\mathcal{L}(x|\mu_{best})}$, where μ_{best} is the value of μ that maximises $\mathcal{L}(x|\mu)$.
  - Determine 68% CL.
  - Construct band and read off interval.

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).
- $A_{FB} = \frac{\text{Forward}-\text{Backward}}{\text{Forward}+\text{Backward}}$. "Forward" = $\cos\theta_\ell > 0$
- 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 $\cos\theta_\ell$).

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

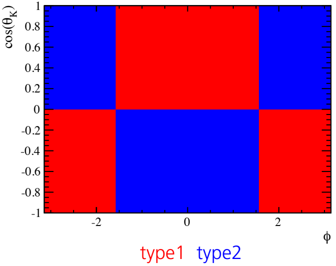


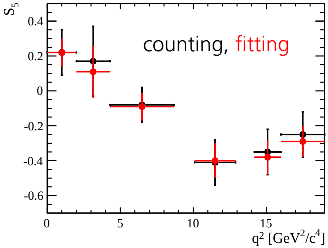
- Extract $A_{FB} = \frac{N_F \cdot PDF_F(q^2) - N_B \cdot PDF_B(q^2)}{N_F \cdot PDF_F(q^2) + N_B \cdot PDF_B(q^2)}$
- Standard Model theory predicts zero-crossing in 4.0 - 4.3 GeV^2/c^4 (central values)

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

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

Yes, we did some crosschecks





- Surely, if there is a discrepancy in P_5', there is also one in S_5.
- Measure S_5 with a "counting" experiment (similar to zero-crossing point) and with an angular fit and compare results.
- Can define S_5 as an asymmetry between two type of events:
  $S_5 = \frac{\text{\#type1 - \#type2}}{\text{\#type1 + \#type2}}$
- There is excellent agreement between fitting and counting.

Yes, we did more crosschecks...

- Cut very hard in selection until essentially no background is left. No effect.
- Apply selection, data-simulation corrections, acceptance correction to $B^0 \to J/\psi\, K^{*0}$. The values come out as predicted.
- Evaluate many systematic effects: Background angular distribution, signal mass distribution, removing events at large angles, neglecting acceptance correction, ...
- None had a seizable effect.

What is it? Possible answers:

- A statistical fluctuation. The chance of one bin fluctuating that much (assuming all bins independent) is 0.5%.
- A peaking background nobody could think of. Something else, nobody could think of...
- An underestimation of the theoretical uncertainty.
- If you dare to believe: New physics.

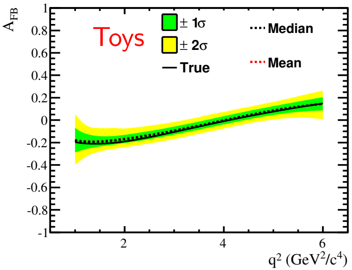
The future!

- Everything I showed so far was performed on data from 2011.
- We have 2 fb^{-1} more to analyse, giving in total $\approx$ 3000 events.
- What can we do with them?
- Goal would be to do a full angular analysis without folding.
- None of these studies is public yet, cannot show too much...

Full angular analysis

- In principle would like to fit all observables at once to get the values and the correlation matrix.
- Would also like to have a different (finer) binning scheme, to take steep shapes better into account.
- And would like to disentangle B^0 and $\overline{B}^0$.
- Would also like to have sunny weather every day.
- Realistic seems a full angular analysis with the same binning scheme - or again folding with a finer binning scheme. But not both.
- It might also be possible to gain back the correlation matrix from toy studies. This would allow folding (=more stable) fits and provide the same information as the full analysis.

Amplitude analysis

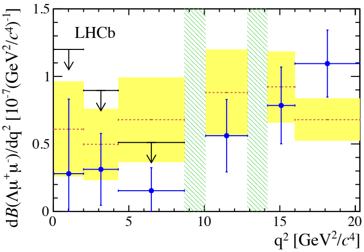


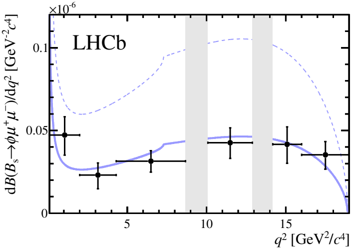
- $S_i = f_i(A_\perp^L, A_\parallel^L, A_0^L, A_\perp^R, A_\parallel^R, A_0^R)$. Can we measure the amplitudes directly?
- Need to parametrize q^2 dependence: $\alpha + \beta q^2 + \frac{\gamma}{q^2}$.
- Can in the end still build observables out of the amplitudes.
- Looks quite promising at the moment, but will be restricted to $q^2 = 1 - 6\,\mathrm{GeV}^2/c^4$ (as q^2 parametrisation does not hold anywhere else).

Moment analysis

- All angular terms are orthonormal.
- Basic linear algebra tells you: $g = \sum_i c_i g_i$ with $\langle g_i || g_j \rangle = \delta_{ij}$
- $\Rightarrow c_i = \langle g || g_i \rangle$
- $\Rightarrow$ To extract the angular coefficients, one can multiply distributions with each other.
- Looks quite promising at the moment, but study is only in an early stage.
- A nice thing about the moment analysis: The S-wave terms are orthogonal to all other (P-wave) terms, so they don't need special treatment.
- However, still need to care about acceptance correction.

Other EW penguins





dashed - SM prediction, solid - normalised to measured BR

- There are other electroweak penguin decays which are sensitive to the same underlying physics: $B_s^0 \to \phi\mu^+\mu^-$, $\Lambda_b^0 \to \Lambda\mu^+\mu^-$, ...
- Less events than for $B^0 \to K^{*0}\mu^+\mu^-$, angular analysis difficult.
- Isn't it fascinating that all branching fractions we measure are at the low end of the prediction?

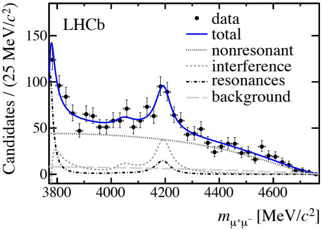
Summary

- Presented the 2012 & 2013 analyses of $B^0 \to K^{*0}\mu^+\mu^-$.
- Have seen some "interesting" effects in the 2011 data.
- Looking forward to analysing the 2011+2012 data.
- Atlas & CMS can analyse this decay as well...

45

fin

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

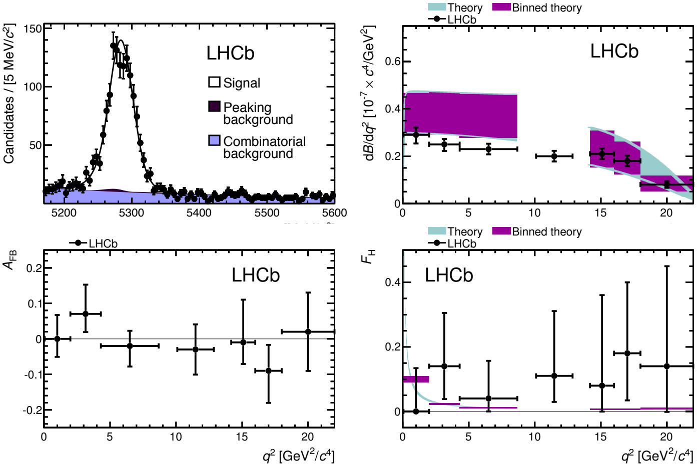


- Only angle θ_ℓ and q^2 for description of decay:

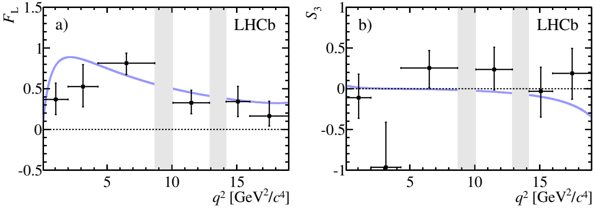
$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_\ell} = \frac{3}{4}(1 - F_H)\sin^2\theta_\ell + \frac{1}{2}F_H + A_{FB}\cos\theta_\ell \qquad (1)$$

- Branching fraction smaller than for $B^0 \to K^{*0}\mu^+\mu^-$, but cleaner. About 1200 events to analyse in 1 fb^{-1}.
- Good agreement with Standard Model, including resonance at high-q^2 (compatible with $\psi(4160)$).

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

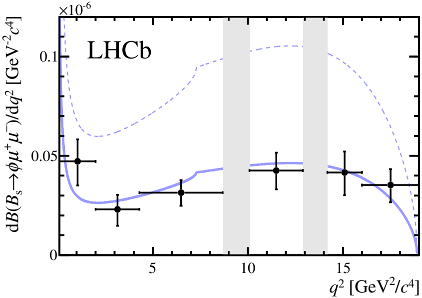

Candidates / [5 MeV/c^2]
LHCb
Signal
Peaking background
Combinatorial background
dB/dq^2 [10^{-7} × c^4/GeV^2]
Theory
Binned theory
LHCb
A_{FB}
F_H
q^2 [GeV^2/c^4]

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



- Very similar to $B^0 \to K^{*0}\mu^+\mu^-$, however, less B_s^0 produced than B^0. Only $\sim$ 175 signal events in 1 fb^{-1}.
- Decay is not self-tagging, as $\phi \to K^+K^-$.
- Need to restrict to observables invariant under $B_s^0 \leftrightarrow \overline{B}_s^0$: F_L, $S_{3,4,7}$, $A_{5,6,8,9}$.
- Only projections in one angles fitted, not full 3D-fit.
- Angular observables show good agreement with SM.

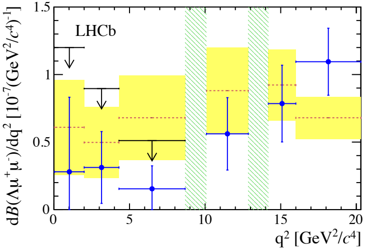
$B_s^0 \to \phi\mu^+\mu^-$



dashed - SM prediction, solid - normalised to measured BR

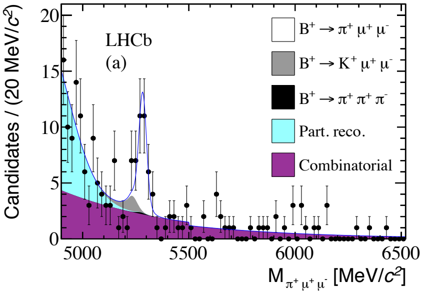
- However the branching fraction is significantly lower than the SM prediction.

$\Lambda_b^0 \to \Lambda\mu^+\mu^-$



- Even less signal than for $B_s^0 \to \phi\mu^+\mu^-$, $\sim$ 80 events in 1 fb^{-1}.
- Still most precise measurement of branching fraction.
- Basically no events at low q^2 (but very large uncertainties).

$B^+ \to \pi^+\mu^+\mu^-$



- $b \to d$ process, suppressed by $|V_{td}/V_{ts}|^2$ compared to $b \to s$
- LHCb observed $\sim$ 25 signal candidates in 1 fb^{-1}..
- Measured branching fraction of: $(2.3 \pm 0.6 \pm 0.1) \cdot 10^{-8}$, in good agreement with Standard Model.

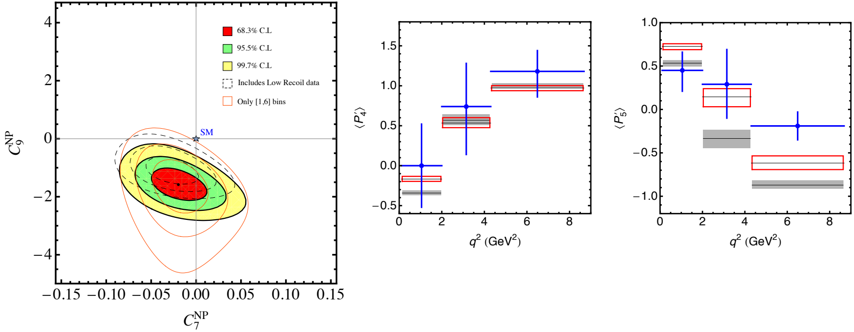
More penguins

- $B^0 \to K^{*0} e^+ e^-$: Interesting at low q^2, where muon mass cannot be neglected anymore.
- More EW penguin measurements: $\mathcal{CP}$ asymmetry and isospin asymmetry in $B^0 \to K^{*0}\mu^+\mu^-$, $B^+ \to K^+\mu^+\mu^-$.
- None of the other modes (except isospin asymmetry) shows such a large deviation.
- However, none of the other modes has the same sensitivity to "P_5'-physics" as $B^0 \to K^{*0}\mu^+\mu^-$.

BDT input variables

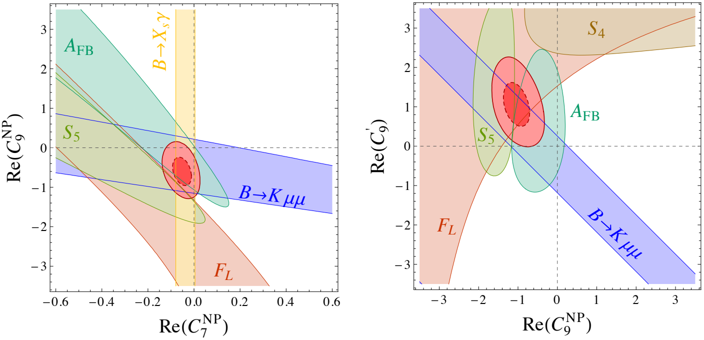
- the B^0 pointing to the primary vertex, flight-distance and IP χ^2 with respect to the primary vertex, p_T and vertex quality (χ^2);
- the K^{*0} and dimuon flight-distance and IP χ^2 with respect to the primary vertex (associated to the B^0), p_T and vertex quality (χ^2);
- the impact parameter χ^2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

Possible interpretations (I)



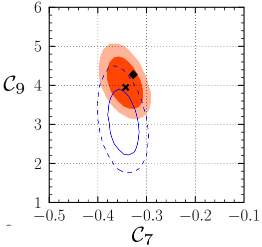
- Matias et al. did a combined fit of observables of $B^0 \to K^{*0}\mu^+\mu^-$, $B_s^0 \to \mu^+\mu^-$, $B^0 \to K^{*0}\gamma$ to extract the Wilson coefficients.
- Split Wilson coefficients in $\mathcal{C}_i^{(\prime)} = \mathcal{C}_{i,SM}^{(\prime)} + \mathcal{C}_{i,NP}^{(\prime)}$
- Determine best fit point and confidence intervals.
- Looks like a clear case for NP...

Possible interpretations (II)



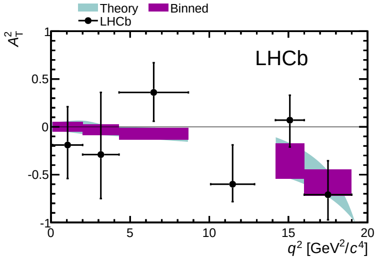
- Straub et al. did a combined fit of observables of $B^0 \to K^{*0}\mu^+\mu^-$, $B^+ \to K^+\mu^+\mu^-$, $B_s^0 \to \mu^+\mu^-$, $B^0 \to K^{*0}\gamma$. They also included results from other experiments besides LHCb.
- The trend is the same as for Matias et al., however the picture is a bit less clear.

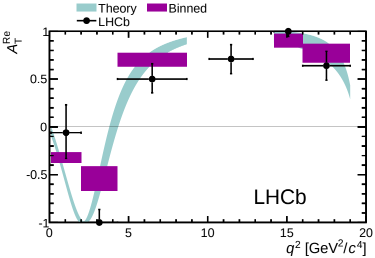
Possible interpretations (III)



- Van Dyk et al. did a Bayesian analysis using observables of $B^0 \to K^{*0}\mu^+\mu^-$, $B^+ \to K^+\mu^+\mu^-$, $B_s^0 \to \mu^+\mu^-$, $B^0 \to K^{*0}\gamma$ (and other information) where the QCD-uncertainties were allowed to float (using a prior).
- They conclude: "In the absence of substantial improvements in the handling of subleading contributions to the $B^0 \to K^{*0}\mu^+\mu^-$ amplitudes and given the statistical evaluation, we are therefore forced to conclude that the SM interpretation of the data is more economical than a New Physics hypothesis."

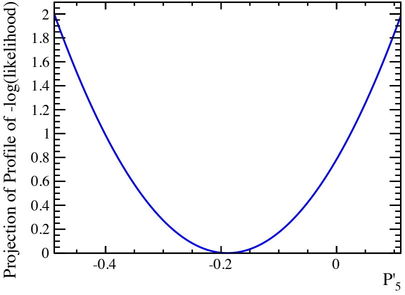
$A_T^{(2)}$ AND $A_T^{(Re)}$





- $S_3 = \frac{1}{2}(1 - F_L)A_T^{(2)}$
- $A_{FB} = \frac{3}{4}(1 - F_L)A_T^{(Re)}$

LIKELIHOOD FOR P'_5, BIN 3



(b)

- (Profile) likelihood for P'_5 in bin 3.