Measurement of Polarisation Amplitudes and Phases in the decay $B^0 \to \phi K^*(892)^0$ at LHCb

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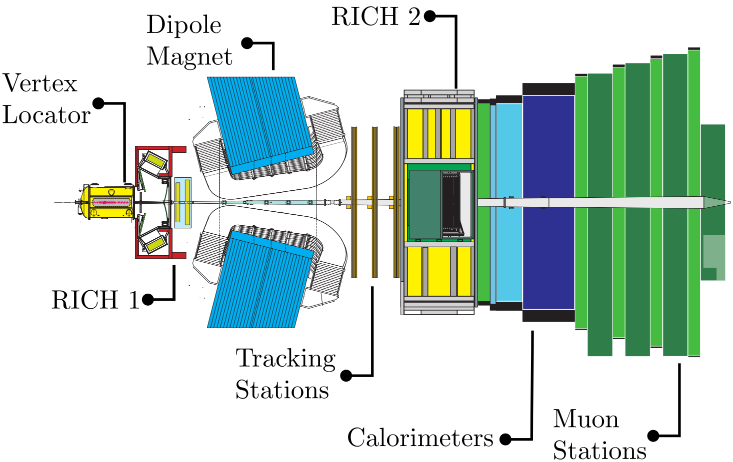
Outline

- The LHCb Detector
- Analysis Motivation
  - Why do we study $B^0 \to \phi K^*(892)^0$?
  - What do we measure?
  - How do we make these measurements?
- Experimental Challenges
- Expected Precision

The LHCb Detector

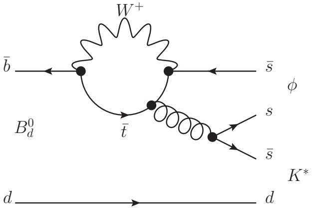


VELO and tracking stations allow excellent B vertex reconstruction.
Accurate particle identification from RICH detectors.

Analysis Motivation - Why

Why Study $B^0 \to \phi K^*(892)^0$

- This decay involves a **flavour-changing neutral-current**, which is forbidden at tree level in the Standard Model. Therefore it must proceed via a **penguin diagram**.
- Loops can hide particles from beyond the Standard Model.



"Polarisation Puzzle"

- Due to V-A nature of the weak interaction, naively expect $f_L \gg f_T$.
- Experimentally confirmed by the B-factories in tree dominated processes e.g. $B_d^0 \to \rho^+\rho^-$.
- However in decays such as $B_d^0 \to \phi K^*(892)^0$ it was found $f_L \approx f_T$.
- This is sometimes known as the "polarisation puzzle."

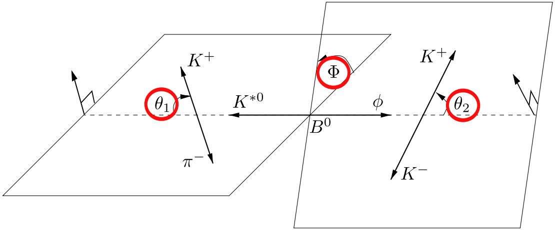
$$f_L = \frac{|A_0|^2}{|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}, f_T = \frac{|A_\perp|^2 + |A_\parallel|^2}{|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}.$$

These terms explained in the next slide!

Analysis Motivation - What

What We Measure

- The direct **CP asymmetry** in the polarisation amplitudes and strong phase differences.



- P→VV decay, spin 0 B-meson decays to two particles of spin 1.
- Therefore there are 3 possible **spin configurations** allowed by conservation of orbital angular momentum.
- These correspond to 3 linear **polarisation amplitudes**, $A_0, A_\perp, A_\parallel$.

Analysis Motivation - How

How

- Study decays of $B^0 \to \phi(\to K^+K^-)K^*(\to K^+\pi^-)$.
- Analysis of m_{KK}, $m_{K\pi}$ and decay angles $(\cos\theta_1, \cos\theta_2, \Phi)$ used to measure polarisation amplitudes and phases.

$$\Gamma(B^0 \to \phi K^*(892)^0) \simeq$$

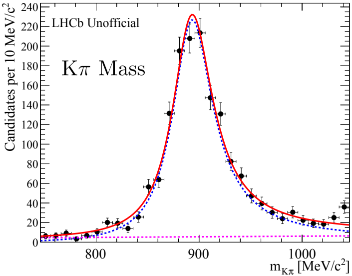
$$\int \sum_{i=1}^{15} F(m_{K\pi}, m_{KK}) K_i(t) f_i(\cos\theta_1, \cos\theta_2, \Phi) M_i(m_{K\pi}, m_{KK}) dt$$

- $F(m_{K\pi}, m_{KK})$ is 4-body phase space factor.
- K are the complex amplitudes.
- $f(\cos\theta_1, \cos\theta_2, \Phi)$ are the angular terms.
- $M(m_{K\pi}, m_{KK})$ are the mass terms.

Everything is convolved with a Gaussian resolution.

Full differential decay rate is in backup slides.

Experimental Considerations - S-wave Contribution



Left: Background subtracted $K\pi$ invariant mass. Right: Background subtracted KK invariant mass. Blue is the p-wave, green is the s-wave and red is the total.

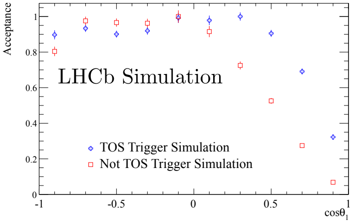
S-wave

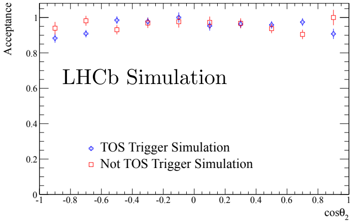
It is possible for the decays $B^0 \rightarrow \phi K\pi$ or $B^0 \rightarrow K^*(892)KK$ to occur.
In these cases the KK or $K\pi$ are **not** spin-1 states.
These states **do not** help us to measure the polarisation amplitudes $A_0, A_\perp, A_\parallel$.
They are accounted for in the fit and have their own amplitudes A_s^{KK} and $A_s^{K\pi}$.

Experimental Considerations - Angular Acceptance

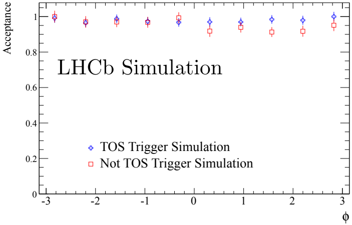
Angular Acceptance

Due to slow pion, acceptance drops off as $\cos\theta_1 \to 1$. Corrections are applied to the fit to account for this effect.



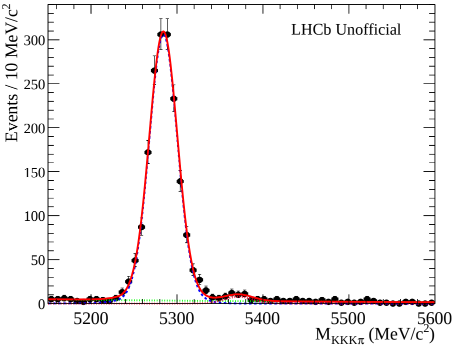


Acceptance is significantly different if the event is triggered by one of the particles in the $B^0 \to \phi K^*(892)^0$ final state (TOS) than if it is triggered by something else (Not TOS).
We apply separate corrections to each of these cases.



Data Sample - Mass Distribution

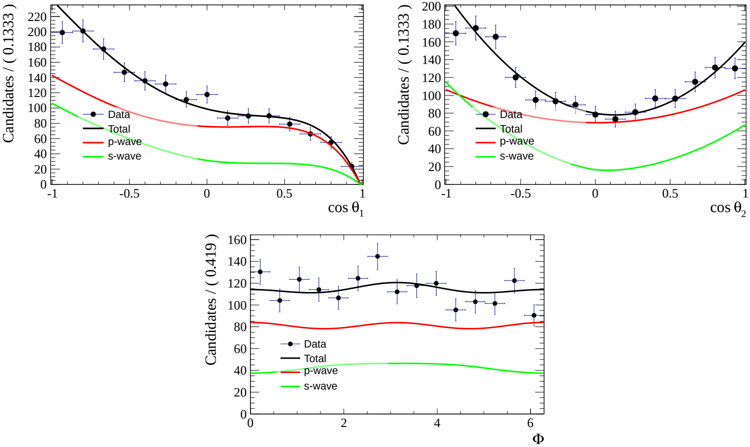
Analysis uses 1fb^{-1} of data collected in 2011 by LHCb.



- $N_{sig} = 1710 \pm 43$
- $N_{bkg} = 176 \pm 18$
- $N_{Bs} = 43 \pm 9$
- $\sigma = 16.1 \pm 0.4$ MeV

Signal shape is modelled by a Crystal Ball function and a Gaussian function, the B_s^0 is also fitted with this shape. The combinatorial background is modelled by an exponential function.

Data Sample - Angular Distributions



Background subtracted angular distributions.
Red is p-wave, green is s-wave and black is total.
The large acceptance effect can be seen in the $\cos\theta_1$ angle.

Comparision of Sensitivity

P-wave Parameters	LHCb Result	BaBar Result*
$\lvert A_\perp\rvert^2$	xxx $\pm$ 0.017	0.212 $\pm$ 0.032
$\lvert A_0\rvert^2$	xxx $\pm$ 0.019	0.494 $\pm$ 0.034
$\delta_\parallel$	xxx $\pm$ 0.065	2.40 $\pm$ 0.13
$\delta_\perp$	xxx $\pm$ 0.060	2.35 $\pm$ 0.13
S-wave Parameters		
$\lvert A_{s(K\pi)}\rvert^2$	xxx $\pm$ 0.013	-
$\lvert A_{s(KK)}\rvert^2$	xxx $\pm$ 0.012	-
$\delta_{s(K\pi)}$	xxx $\pm$ 0.057	2.82 $\pm$ 0.15
$\delta_{s(KK)}$	xxx $\pm$ 0.073	-

Comparison of **statistical** uncertainty on fit parameters between LHCb and BaBar results.

*Time-dependent and time-integrated angular analysis of $B \to \phi K_s^0 \pi^0 and \phi K^\pm \pi^\mp$.

PRD 78, 092008 (2008). http://arxiv.org/abs/0808.3586.

Systematics

Systematics on Angular Fit

- Uncertainty on angular acceptance correction.
- S-wave parameterisation in mass fit.
- Vary lineshapes for $M_{KKK\pi}$ fit, which is used to background subtract fit.
- Difference in shape of kinematic variables in data and MC.

Conclusion

Conclusion

- Selection allows good background rejection, signal to background ratio $\sim$10.
- Roughly four times as many signal events as previous largest single sample.
  - Expect to half statistical uncertainty on measurements of amplitudes.
- Includes s-wave under ϕ meson, not done in previous measurements.
- Good understanding of LHCb detector geometry and signal selection.
- Two times more data has been collected during 2012, could improve precision more!

END.

Angle and Mass dependent PDF

$$\frac{d^5\Gamma}{d\cos\theta_1 d\cos\theta_2 d\Phi dm_{KK} dm_{K\pi}} = \frac{9}{8\pi}(q_B q_{K*} q_\phi)^2 \Bigg| \Bigg(A_0 \cos\theta_1 \cos\theta_2 + \frac{A_\parallel}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \cos\Phi + i\frac{A_\perp}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin\Phi \Bigg) M_1(K\pi) M_1(KK) + \frac{A_s^{K\pi}}{\sqrt{3}} \cos\theta_1 M_1(KK) M_0(K\pi) + \frac{A_s^{KK}}{\sqrt{3}} \cos\theta_2 M_1(K\pi) M_0(KK) \Bigg|^2 . \quad (1)$$

$$q_A = \frac{\sqrt{(m_A^2 - (m_a + m_b)^2)(m_A^2 - (m_a - m_b)^2)}}{2m_A}$$

Where m_A is the mass of 'A' and $m_{a,b}$ are the masses of the daughters of 'A'.
M_1 is described by a spin-1 relativistic Breit-Wigner.
$M_0(KK)$ is a Flatté distribution and $M_0(K\pi)$ is the LASS parameterisation of non-resonant $K\pi$ and $K^*(1430)^0$.

This entire PDF is then convolved with a Gaussian function.

Fitter Validation

Parameter	Edinburgh Fit	Santiago Fit
$\|A_\perp\|^2$	0.251 ± 0.016	0.251 ± 0.016
$\|A_0\|^2$	0.457 ± 0.018	0.457 ± 0.018
$\|A_{s(K\pi)}\|^2$	0.148 ± 0.013	0.148 ± 0.013
$\|A_{s(KK)}\|^2$	0.113 ± 0.011	0.113 ± 0.011
$\delta_\parallel$	2.600 ± 0.061	2.600 ± 0.061
$\delta_\perp$	2.668 ± 0.058	2.667 ± 0.058
$\delta_{s(K\pi)}$	2.227 ± 0.059	2.227 ± 0.059
$\delta_{s(KK)}$	2.519 ± 0.068	2.518 ± 0.068

Table: Comparison of Edinburgh and Santiago fit results using the same nTuple. **Not** a definitive fit, just for comparison.