Polarization amplitudes and CP asymmetries in $B^0 \to \Phi K^*(892)^0$ at LHCb

Anh-Duc Nguyen on behalf of the LHCb collaboration

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Overview

1. Motivation

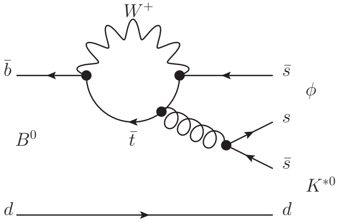
2. LHCb experiment

3. Angular analysis

4. Conclusion

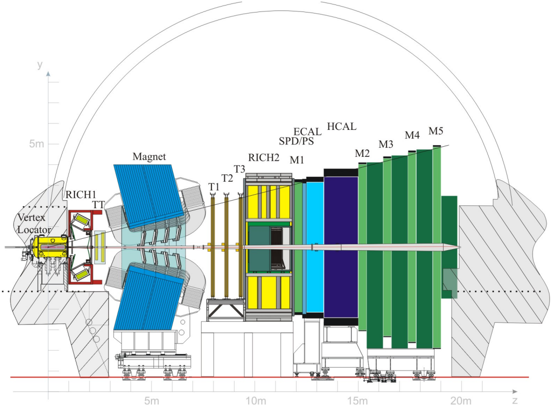
Motivation

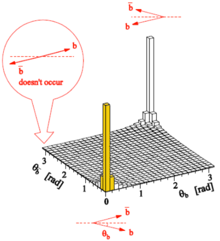
- The first evidence for the decay $B \to \phi K^*$ was provided by CLEO (*Phys.Rev.Lett.86,3718 (2001)*) and BABAR (*Phys.Rev.Lett.87, 151801 (2001)*) experiments
- In the SM, the decay $B_d^0 \to \phi K^*(892)^0$ proceeds mainly via the gluonic penguin diagram (b $\to$ s transition)
- This b $\to$ s transition is sensitive to contributions from physics beyond the SM.
- Previous measurements of $B_d^0 \to \phi K^*(892)^0$ show that $f_{longitudinal} \approx f_{transverse}$ which were not in agreement with theory (the longitudinal components dominates)
- The pseudoscalar to vector-vector decay $B_d^0 \to \phi K^*(892)^0$ also allows to study the CP violation in polarization parameters
- In this talk I present the measurements of the polarization amplitudes, phases and CP asymmetries (LHCb-PAPER-2014-005, JHEP 1405 (2014) 069)

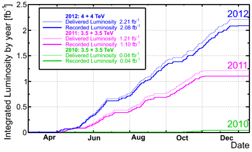


The LHCb detector

LHCb :dedicated to the study of CP violation and rare decays in b-quark and c-quark sectors
also indirect search for New Physics







- LHCb is a single-arm forward spectrometer at the LHC
- Optimized for measurements in heavy-flavour physics
- Recording pp collisions with $\sqrt{s} = 7$ TeV (in 2011) and 8 TeV (in 2012)
- The experiment has a large forward acceptance of $2 < \eta < 5$

Analysis Strategy

- B^0 is a pseudoscalar-meson with spin 0; ϕ and $K^*(892)^0$ are vector-mesons with spin 1 decayed into K^+K^- and $K^+\pi^-$ (P-wave) respectively.
- Angular momentum conservation allows three possible helicity configurations with amplitudes denoted H_{+1}, H_{-1} and H_0.
- In the transversity basis, we can write these in term of a longitudinal polarization, A_0, and two transverse polarizations, $A_\perp$ and $A_\parallel$

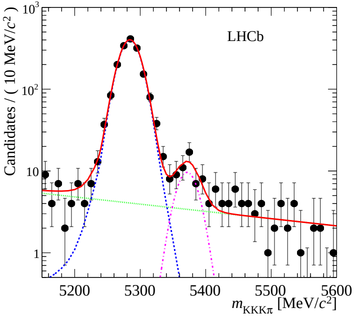
$$A_0 = H_0 \,, \qquad A_\perp = \frac{H_{+1} - H_{-1}}{\sqrt{2}} \qquad \text{and} \qquad A_\parallel = \frac{H_{+1} + H_{-1}}{\sqrt{2}} \,.$$

- There are also contributions from S-wave K^+K^- and S-wave $K^+\pi^-$ with spin 0. (amplitudes A_S^{KK} and $A_S^{K\pi}$)
- The amplitudes have magnitudes and relative phases defined as:

$$A_\parallel = |A_\parallel| e^{i\delta_\parallel} \,,\ A_\perp = |A_\perp| e^{i\delta_\perp} \,,\ A_S^{K\pi} = |A_S^{K\pi}| e^{i\delta_S^{K\pi}} \,,\ A_S^{KK} = |A_S^{KK}| e^{i\delta_S^{KK}} \,, \delta_0 = 0$$

- To determine these quantities, an analysis of the angular distribution and the invariant masses of the decay products is performed.

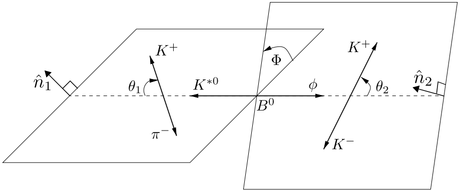
$K^+K^-K^+\pi^-$ mass model



- The selection of events is divided into two steps:
  - Apply a loose selection to retain majority of signal events and reduce a large fraction of background
  - Then, a geometric likelihood (GL) method is used to further reduce the background
- The signal invariant mass distribution is modelled as sum of a Crystal Ball and a Gaussian function.
- Included the contribution from $\bar{B}_s^0 \to \phi K^{*0}$ which has the same shape with B^0
- The background here is mainly combinatorial and is modelled by an exponential.
- A yield of 1655 ± 42 B^0 signal candidates is found

Angular Analysis

- The angular analysis is performed in term of the three helicity angles $(\theta_1, \theta_2, \Phi)$
- The flavour of the decaying the B^0 meson is determined by the charge of the pion from the K^{*0} decay
- B^0 and $\bar{B}^0$ decays are analysed separately



- Taking into account both the P- and S-wave contributions and their interference, the differential decay rate is given by:

$$d^5\Gamma \propto |PWave \times M_1(m_1)M_1(m_2) + SWave(K\pi) \times M_0(m_1)M_1(m_2) + SWave(KK) \times M_1(m_1)M_0(m_2)|^2$$

$$d^5\Gamma = \frac{9}{8\pi} \mid (\mathcal{A}_0 \cos\theta_1 \cos\theta_2 + \frac{\mathcal{A}_\parallel}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \cos\varphi + \frac{\mathcal{A}_\perp}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin\varphi) M_1(m_1)M_1(m_2)$$
$$+ \frac{\mathcal{A}_S}{\sqrt{3}} \cos\theta_1 M_0(m_1)M_1(m_2) + \frac{\mathcal{A}_S^{'}}{\sqrt{3}} \cos\theta_2 M_1(m_1)M_0(m_2) \mid^2 \, d\phi(K, K, K, \pi)$$

which can be re-written as:

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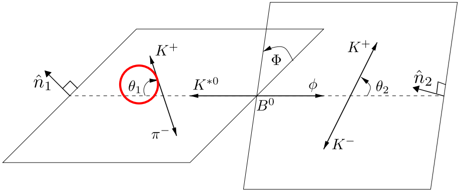

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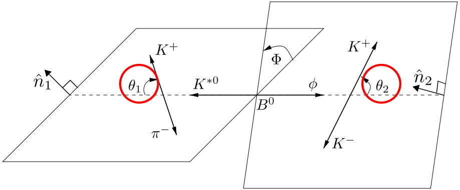

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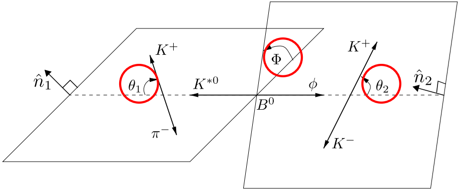

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$$d^5\Gamma = \frac{9}{8\pi} \mid (\mathcal{A}_0 \cos\theta_1 \cos\theta_2 + \frac{\mathcal{A}_\parallel}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \cos\varphi + \frac{\mathcal{A}_\perp}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin\varphi) M_1(m_1)M_1(m_2)$$
$$+ \frac{\mathcal{A}_S}{\sqrt{3}} \cos\theta_1 M_0(m_1)M_1(m_2) + \frac{\mathcal{A}'_S}{\sqrt{3}} \cos\theta_2 M_1(m_1)M_0(m_2) \mid^2 \ d\phi(K, K, K, \pi)$$

which can be re-written as:

Angular Analysis

$$d^5\Gamma = \frac{9}{8\pi}\sum_{i=1}^{15} h_i \; f_i(\theta_1,\theta_2,\Phi)\mathcal{M}_i(m_{K\pi},m_{KK})d\Omega(KKK\pi)\ .$$

i	h_i	$f_i(\theta_1,\theta_2,\Phi)$	$\mathcal{M}_i(m_{K\pi},m_{KK})$
1	$\|A_0\|^2$	$\cos\theta_1^2\cos\theta_2^2$	$\|M_1^{K\pi}(m_{K\pi})\|^2\|M_1^{KK}(m_{KK})\|^2$
2	$\|A_\parallel\|^2$	$\frac{1}{4}\sin\theta_1^2\sin\theta_2^2(1+\cos(2\Phi))$	$\|M_1^{K\pi}(m_{K\pi})\|^2\|M_1^{KK}(m_{KK})\|^2$
3	$\|A_\perp\|^2$	$\frac{1}{4}\sin\theta_1^2\sin\theta_2^2(1-\cos(2\Phi))$	$\|M_1^{K\pi}(m_{K\pi})\|^2\|M_1^{KK}(m_{KK})\|^2$
4	$\|A_\perp\|\|A_\parallel^*\|e^{i(\delta_\perp-\delta_\parallel)}$	$-\frac{1}{2}\sin\theta_1^2\sin\theta_2^2\sin(2\Phi)$	$\|M_1^{K\pi}(m_{K\pi})\|^2\|M_1^{KK}(m_{KK})\|^2$
5	$\|A_\parallel\|\|A_0^*\|e^{i\delta_\parallel}$	$\sqrt{2}\cos\theta_1\sin\theta_1\cos\theta_2\sin\theta_2\cos\Phi$	$\|M_1^{K\pi}(m_{K\pi})\|^2\|M_1^{KK}(m_{KK})\|^2$
6	$\|A_\perp\|\|A_0^*\|e^{i\delta_\perp}$	$-\sqrt{2}\cos\theta_1\sin\theta_1\cos\theta_2\sin\theta_2\sin\Phi$	$\|M_1^{K\pi}(m_{K\pi})\|^2\|M_1^{KK}(m_{KK})\|^2$
7	$\|A_S^{K\pi}\|^2$	$\frac{1}{3}\cos\theta_2^2$	$\|M_0^{K\pi}(m_{K\pi})\|^2\|M_1^{KK}(m_{KK})\|^2$
8	$\|A_\parallel\|\|A_S^{*K\pi}\|e^{i(\delta_\parallel-\delta_S^{K\pi})}$	$\frac{\sqrt{6}}{3}\sin\theta_1\cos\theta_2\sin\theta_2\cos\Phi$	$\|M_1^{KK}(m_{KK})\|^2 M_1^{K\pi}(m_{K\pi})M_0^{*K\pi}(m_{K\pi})$
9	$\|A_\perp\|\|A_S^{*K\pi}\|e^{i(\delta_\perp-\delta_S^{K\pi})}$	$-\frac{\sqrt{6}}{3}\sin\theta_1\cos\theta_2\sin\theta_2\sin\Phi$	$\|M_1^{KK}(m_{KK})\|^2 M_1^{K\pi}(m_{K\pi})M_0^{*K\pi}(m_{K\pi})$
10	$\|A_0\|\|A_S^{*K\pi}\|e^{-i\delta_S^{K\pi}}$	$\frac{2}{\sqrt{3}}\cos\theta_1\cos\theta_2^2$	$\|M_1^{KK}(m_{KK})\|^2 M_1^{K\pi}(m_{K\pi})M_0^{*K\pi}(m_{K\pi})$
11	$\|A_S^{KK}\|^2$	$\frac{1}{3}\cos\theta_1^2$	$\|M_0^{KK}(m_{KK})\|^2\|M_1^{K\pi}(m_{K\pi})\|^2$
12	$\|A_\parallel\|\|A_S^{*KK}\|e^{i(\delta_\parallel-\delta_S^{KK})}$	$\frac{\sqrt{6}}{3}\sin\theta_1\cos\theta_1\sin\theta_2\cos\Phi$	$\|M_1^{K\pi}(m_{K\pi})\|^2 M_1^{KK}(m_{KK})M_0^{*KK}(m_{KK})$
13	$\|A_\perp\|\|A_S^{*KK}\|e^{i(\delta_\perp-\delta_S^{KK})}$	$-\frac{\sqrt{6}}{3}\sin\theta_1\cos\theta_1\sin\theta_2\sin\Phi$	$\|M_1^{K\pi}(m_{K\pi})\|^2 M_1^{KK}(m_{KK})M_0^{*KK}(m_{KK})$
14	$\|A_0\|\|A_S^{*KK}\|e^{-i\delta_S^{KK}}$	$\frac{2}{\sqrt{3}}\cos\theta_1^2\cos\theta_2$	$\|M_1^{K\pi}(m_{K\pi})\|^2 M_1^{KK}(m_{KK})M_0^{*KK}(m_{KK})$
15	$\|A_S^{K\pi}\|\|A_S^{*KK}\|e^{i(\delta_S^{K\pi}-\delta_S^{KK})}$	$\frac{2}{3}\cos\theta_1\cos\theta_2$	$M_1^{KK}(m_{KK})M_0^{K\pi}(m_{K\pi})M_0^{*KK}(m_{KK})M_1^{*K\pi}(m_{K\pi})$

Modelling the resonances P-wave

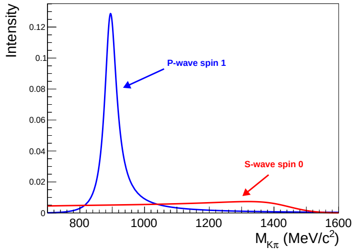
- The resonances ($K\pi$, KK) can be modelled by a relativistic Breit-Wigner spin-1

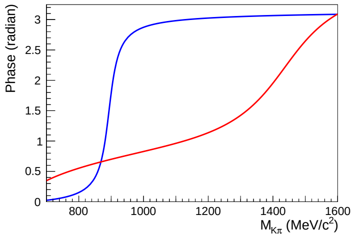
$$M_1(m) = \frac{m_0\Gamma_1(m)}{(m_0^2 - m^2) - im_0\Gamma_1(m)}$$

- The mass-dependent width is given by

$$\Gamma_1(m) = \Gamma_0 \frac{m_0}{m} \frac{1+r^2q_0^2}{1+r^2q^2} \left(\frac{q}{q_0}\right)^3$$

- The value of resonance mass (m_0) and the natural width (Γ_0) are taken from PDG.
- r is the interaction radius ($r = 3.4\ \hbar c/\mathrm{GeV}$ is taken from Nucl. Phys. B296 (1988) 493)
- q is the momentum of the decay products in the rest frame of the mother particle





Modelling the $K\pi$ S-wave

- The LASS collaboration (*Nucl.Phys. B296, 493. 1988*) has studied $K^-\pi^+$ scattering in the reaction $K^-p \to K^-\pi^+n$. They found that the S-wave can be parameterized as:

$$M_0(m) = \sin\delta_0 e^{i\delta_0}$$
$$\delta_0 = \Delta R + \Delta B$$

- ΔR represents the resonance $K^*(1430)^0$ contribution (relativistic BW spin-0)

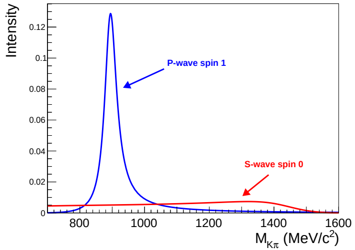
$$\cot\Delta R = \frac{m_0^2 - m^2}{m_0\Gamma_0(m)}$$
$$\Gamma_0(m) = \Gamma_0\frac{m_0}{m}\left(\frac{q}{q_0}\right)$$

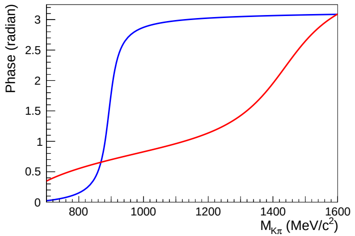
- ΔB represents a non-resonance contribution given by an effective range parameterization

$$\cot\Delta B = \frac{1}{aq} + \frac{1}{2}bq$$

  a is the scattering length; b is the effective range

- The values for the parameterization are taken from the BaBar's paper: Phys. Rev. D78 (2008) 092008





Modelling the KK S-wave

- S-wave in the K^+K^- system is described by the Flatté parameterization of the $f_0(980)$ resonance

$$M_0^{KK}(m_{KK}) = \frac{1}{m_{f_0}^2 - m_{KK}^2 - i m_{f_0}(g_{\pi\pi}\rho_{\pi\pi} + g_{KK}\rho_{KK})} ,$$

- m_{f_0} is the resonance mass
- $g_{KK,\pi\pi}$ are partial decay widths
- and the $\rho_{KK,\pi\pi}$ are phase-space factors.

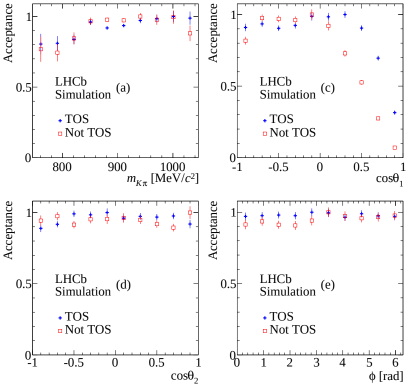
$$\rho_{KK} = \begin{cases} (1 - 4m_K^2/m^2)^{1/2} & \text{above } KK \text{ threshold} \\ i(4m_K^2/m^2 - 1)^{1/2} & \text{below } KK \text{ threshold} \end{cases}$$

- The values $m_{f_0} = 939\,\mathrm{MeV}/c^2$, $g_{\pi\pi} = 199\,\mathrm{MeV}/c^2$ and $g_{KK}/g_{\pi\pi} = 3.0$ are taken from LHCb paper (Phys. Rev. D87 (2013) 052001)

Angular Acceptance

- Due to detector geometry and kinematic cuts, the acceptance of the detector is not uniform as a function of the decay angles and invariant mass

- TOS (Trigger On Signal)
- TIS (Trigger Independent of Signal)
- 17% overlap between TOS and TIS are treated as TOS. The remaining TIS are labelled "Not TOS"



Angular Acceptance weights

- Instead of parameterizing the acceptance, we use the normalization weights proposed by T. du Pree (CERN-THESIS-2010-124)
- An unbinned log likelihood fit is used to determine the polarization amplitudes and phases:

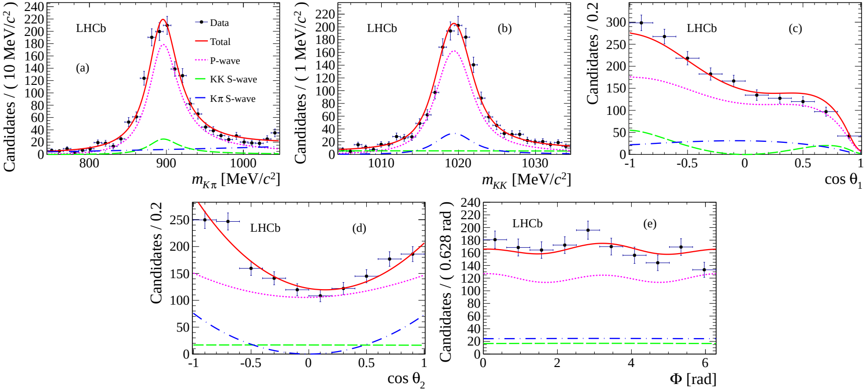
$$\frac{d}{d_{\lambda_k}}\ln\mathcal{L}(\vec{\lambda}) = \frac{d}{d_{\lambda_k}}\sum_e \ln\frac{\sum_{i=1}^{15} K_i(t_e|\vec{\lambda}) f_i(\vec{\Omega_e})}{\int \sum_{j=1}^{15} K_j(t|\vec{\lambda})\xi_j(t)dt}$$

  where the index e denotes the event, $f_i(\vec{\Omega_e})$ is the angular function and the physics parameters dependent amplitude terms is $K_i(t_e|\vec{\lambda})$ ($\vec{\lambda}$: the set of parameters).
- The normalization weights ξ_j is obtained from the simulated data:

$$\xi_j = \frac{1}{N_{gen}}\sum_e^{accepted}\frac{f_j(\vec{\Omega}_e)}{S(\vec{\Omega_e}|\vec{\lambda})}\ ,$$ S is the signal PDF.

- This method is independent of the shape of the acceptance, and the acceptance does not need to be parameterized.

Angular analysis results



- Data are separated in four categories, depending on the flavour of the B meson and the trigger category TOS and TIS.
- A simultaneous fit is performed to the four subsets

Angular analysis results

- Parameters measured in the angular analysis. The first and second uncertainties are statistical and systematic, respectively.

Parameter	Definition	Fitted value
f_{L}	$0.5(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$0.497 \pm 0.019 \pm 0.015$
$f_\perp$	$0.5(\lvert A_\perp\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_\perp\rvert^2/\overline{F}_{\mathrm{P}})$	$0.221 \pm 0.016 \pm 0.013$
$f_{\mathrm{S}}(K\pi)$	$0.5(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$0.143 \pm 0.013 \pm 0.012$
$f_{\mathrm{S}}(KK)$	$0.5(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$0.122 \pm 0.013 \pm 0.008$
$\delta_\perp$	$0.5(\arg A_\perp + \arg \overline{A}_\perp)$	$2.633 \pm 0.062 \pm 0.037$
$\delta_\parallel$	$0.5(\arg A_\parallel + \arg \overline{A}_\parallel)$	$2.562 \pm 0.069 \pm 0.040$
$\delta_{\mathrm{S}}(K\pi)$	$0.5(\arg A_{\mathrm{S}}^{K\pi} + \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$2.222 \pm 0.063 \pm 0.081$
$\delta_{\mathrm{S}}(KK)$	$0.5(\arg A_{\mathrm{S}}^{KK} + \arg \overline{A}_{\mathrm{S}}^{KK})$	$2.481 \pm 0.072 \pm 0.048$

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- The value of f_L is close to 0.5, indicating that the longitudinal and transverse polarizations have similar size

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Parameter	Definition	Fitted value
f_{L}	$0.5(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$0.497 \pm 0.019 \pm 0.015$
$f_{\perp}$	$0.5(\lvert A_\perp\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_\perp\rvert^2/\overline{F}_{\mathrm{P}})$	$0.221 \pm 0.016 \pm 0.013$
$f_{\mathrm{S}}(K\pi)$	$0.5(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$0.143 \pm 0.013 \pm 0.012$
$f_{\mathrm{S}}(KK)$	$0.5(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$0.122 \pm 0.013 \pm 0.008$
$\delta_\perp$	$0.5(\arg A_\perp + \arg \overline{A}_\perp)$	$2.633 \pm 0.062 \pm 0.037$
$\delta_\parallel$	$0.5(\arg A_\parallel + \arg \overline{A}_\parallel)$	$2.562 \pm 0.069 \pm 0.040$
$\delta_{\mathrm{S}}(K\pi)$	$0.5(\arg A_{\mathrm{S}}^{K\pi} + \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$2.222 \pm 0.063 \pm 0.081$
$\delta_{\mathrm{S}}(KK)$	$0.5(\arg A_{\mathrm{S}}^{KK} + \arg \overline{A}_{\mathrm{S}}^{KK})$	$2.481 \pm 0.072 \pm 0.048$

- The value of f_L is close to 0.5, indicating that the longitudinal and transverse polarizations have similar size
- Significant S-wave contributions are found in both the K^+K^- and $K^+\pi^-$ systems

Angular analysis results

Parameter	Definition	Fitted value
f_{L}	$0.5(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$0.497 \pm 0.019 \pm 0.015$
$f_{\perp}$	$0.5(\lvert A_{\perp}\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_{\perp}\rvert^2/\overline{F}_{\mathrm{P}})$	$0.221 \pm 0.016 \pm 0.013$
$f_{\mathrm{S}}(K\pi)$	$0.5(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$0.143 \pm 0.013 \pm 0.012$
$f_{\mathrm{S}}(KK)$	$0.5(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$0.122 \pm 0.013 \pm 0.008$
$\delta_{\perp}$	$0.5(\arg A_{\perp} + \arg \overline{A}_{\perp})$	$2.633 \pm 0.062 \pm 0.037$
$\delta_{\parallel}$	$0.5(\arg A_{\parallel} + \arg \overline{A}_{\parallel})$	$2.562 \pm 0.069 \pm 0.040$
$\delta_{\mathrm{S}}(K\pi)$	$0.5(\arg A_{\mathrm{S}}^{K\pi} + \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$2.222 \pm 0.063 \pm 0.081$
$\delta_{\mathrm{S}}(KK)$	$0.5(\arg A_{\mathrm{S}}^{KK} + \arg \overline{A}_{\mathrm{S}}^{KK})$	$2.481 \pm 0.072 \pm 0.048$
$\mathcal{A}_0^{CP}$	$(\lvert A_0\rvert^2/F_{\mathrm{P}} - \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})/(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$-0.003 \pm 0.038 \pm 0.005$
$\mathcal{A}_{\perp}^{CP}$	$(\lvert A_{\perp}\rvert^2/F_{\mathrm{P}} - \lvert\overline{A}_{\perp}\rvert^2/\overline{F}_{\mathrm{P}})/(\lvert A_{\perp}\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_{\perp}\rvert^2/\overline{F}_{\mathrm{P}})$	$+0.047 \pm 0.074 \pm 0.009$
$\delta_{\perp}^{CP}$	$0.5(\arg A_{\perp} - \arg \overline{A}_{\perp})$	$+0.062 \pm 0.062 \pm 0.005$
$\delta_{\parallel}^{CP}$	$0.5(\arg A_{\parallel} - \arg \overline{A}_{\parallel})$	$+0.045 \pm 0.069 \pm 0.015$
$\mathcal{A}_S(K\pi)^{CP}$	$(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 - \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)/(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$+0.073 \pm 0.091 \pm 0.035$
$\mathcal{A}_S(KK)^{CP}$	$(\lvert A_{\mathrm{S}}^{KK}\rvert^2 - \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)/(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$-0.209 \pm 0.105 \pm 0.012$
$\delta_S(K\pi)^{CP}$	$0.5(\arg A_{\mathrm{S}}^{K\pi} - \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$+0.062 \pm 0.062 \pm 0.022$
$\delta_S(KK)^{CP}$	$0.5(\arg A_{\mathrm{S}}^{KK} - \arg \overline{A}_{\mathrm{S}}^{KK})$	$+0.022 \pm 0.072 \pm 0.004$

Angular analysis results

Parameter	Definition	Fitted value
$f_{\rm L}$	$0.5(\lvert A_0\rvert^2/F_{\rm P} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\rm P})$	$0.497 \pm 0.019 \pm 0.015$
$f_{\perp}$	$0.5(\lvert A_\perp\rvert^2/F_{\rm P} + \lvert\overline{A}_\perp\rvert^2/\overline{F}_{\rm P})$	$0.221 \pm 0.016 \pm 0.013$
$f_{\rm S}(K\pi)$	$0.5(\lvert A_{\rm S}^{K\pi}\rvert^2 + \lvert\overline{A}_{\rm S}^{K\pi}\rvert^2)$	$0.143 \pm 0.013 \pm 0.012$
$f_{\rm S}(KK)$	$0.5(\lvert A_{\rm S}^{KK}\rvert^2 + \lvert\overline{A}_{\rm S}^{KK}\rvert^2)$	$0.122 \pm 0.013 \pm 0.008$
$\delta_\perp$	$0.5(\arg A_\perp + \arg \overline{A}_\perp)$	$2.633 \pm 0.062 \pm 0.037$
$\delta_\parallel$	$0.5(\arg A_\parallel + \arg \overline{A}_\parallel)$	$2.562 \pm 0.069 \pm 0.040$
$\delta_{\rm S}(K\pi)$	$0.5(\arg A_{\rm S}^{K\pi} + \arg \overline{A}_{\rm S}^{K\pi})$	$2.222 \pm 0.063 \pm 0.081$
$\delta_{\rm S}(KK)$	$0.5(\arg A_{\rm S}^{KK} + \arg \overline{A}_{\rm S}^{KK})$	$2.481 \pm 0.072 \pm 0.048$
$\mathcal{A}_0^{CP}$	$(\lvert A_0\rvert^2/F_{\rm P} - \lvert\overline{A}_0\rvert^2/\overline{F}_{\rm P})/(\lvert A_0\rvert^2/F_{\rm P} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\rm P})$	$-0.003 \pm 0.038 \pm 0.005$
$\mathcal{A}_\perp^{CP}$	$(\lvert A_\perp\rvert^2/F_{\rm P} - \lvert\overline{A}_\perp\rvert^2/\overline{F}_{\rm P})/(\lvert A_\perp\rvert^2/F_{\rm P} + \lvert\overline{A}_\perp\rvert^2/\overline{F}_{\rm P})$	$+0.047 \pm 0.074 \pm 0.009$
$\delta_\perp^{CP}$	$0.5(\arg A_\perp - \arg \overline{A}_\perp)$	$+0.062 \pm 0.062 \pm 0.005$
$\delta_\parallel^{CP}$	$0.5(\arg A_\parallel - \arg \overline{A}_\parallel)$	$+0.045 \pm 0.069 \pm 0.015$
$\mathcal{A}_S(K\pi)^{CP}$	$(\lvert A_{\rm S}^{K\pi}\rvert^2 - \lvert\overline{A}_{\rm S}^{K\pi}\rvert^2)/(\lvert A_{\rm S}^{K\pi}\rvert^2 + \lvert\overline{A}_{\rm S}^{K\pi}\rvert^2)$	$+0.073 \pm 0.091 \pm 0.035$
$\mathcal{A}_S(KK)^{CP}$	$(\lvert A_{\rm S}^{KK}\rvert^2 - \lvert\overline{A}_{\rm S}^{KK}\rvert^2)/(\lvert A_{\rm S}^{KK}\rvert^2 + \lvert\overline{A}_{\rm S}^{KK}\rvert^2)$	$-0.209 \pm 0.105 \pm 0.012$
$\delta_S(K\pi)^{CP}$	$0.5(\arg A_{\rm S}^{K\pi} - \arg \overline{A}_{\rm S}^{K\pi})$	$+0.062 \pm 0.062 \pm 0.022$
$\delta_S(KK)^{CP}$	$0.5(\arg A_{\rm S}^{KK} - \arg \overline{A}_{\rm S}^{KK})$	$+0.022 \pm 0.072 \pm 0.004$

- The *CP* asymmetries in both amplitudes and phases are consistent with zero

Angular analysis results

- Comparison of measurements made by the LHCb, BaBar (Phys. Rev. D78 (2008) 092008) and Belle (Phys. Rev. D88 (2013) 072004) collaborations.

Parameter	LHCb	BaBar	Belle
f_{L}	$0.497 \pm 0.019 \pm 0.015$	$0.494 \pm 0.034 \pm 0.013$	$0.499 \pm 0.030 \pm 0.018$
$f_{\perp}$	$0.221 \pm 0.016 \pm 0.013$	$0.212 \pm 0.032 \pm 0.013$	$0.238 \pm 0.026 \pm 0.008$
$\delta_{\perp}$	$2.633 \pm 0.062 \pm 0.037$	$2.35 \pm 0.13 \pm 0.09$	$2.37 \pm 0.10 \pm 0.04$
$\delta_{\parallel}$	$2.562 \pm 0.069 \pm 0.040$	$2.40 \pm 0.13 \pm 0.08$	$2.23 \pm 0.10 \pm 0.02$
A_0^{CP}	$-0.003 \pm 0.038 \pm 0.005$	$+0.01 \pm 0.07 \pm 0.02$	$-0.030 \pm 0.061 \pm 0.007$
$A_{\perp}^{CP}$	$+0.047 \pm 0.072 \pm 0.009$	$-0.04 \pm 0.15 \pm 0.06$	$-0.14 \pm 0.11 \pm 0.01$
$\delta_{\perp}^{CP}$	$+0.062 \pm 0.062 \pm 0.006$	$+0.21 \pm 0.13 \pm 0.08$	$+0.05 \pm 0.10 \pm 0.02$
$\delta_{\parallel}^{CP}$	$+0.045 \pm 0.068 \pm 0.015$	$+0.22 \pm 0.12 \pm 0.08$	$-0.02 \pm 0.10 \pm 0.01$

- The results for the P-wave parameters are consistent with and more precise than BaBar and Belle measurements

Systematic uncertanties

- Various sources of systematic uncertainty are studied
  - Uncertainty on acceptance correction
  - Difference in kinematic variables between Data and MC
  - The $K^+K^-K^+\pi^-$ mass model used to determine the signal weights for the angular analysis.
  - The models of the S-wave in the K^+K^- and $K^+\pi^-$ system.

Measurement	Acceptance	Data/MC	Mass model	S-wave	Total
f_{L}	0.014	0.005	0.002	0.001	0.015
$f_{\perp}$	0.013	0.002	0.001	0.001	0.013
$f_{\mathrm{S}}(K\pi)$	0.012	-	0.001	0.002	0.012
$f_{\mathrm{S}}(KK)$	0.007	-	0.002	0.003	0.008
$\delta_{\perp}$	0.023	0.010	0.006	0.026	0.037
$\delta_{\parallel}$	0.029	0.013	0.004	0.024	0.040
$\delta_{\mathrm{S}}(K\pi)$	0.045	0.026	0.004	0.062	0.081
$\delta_{\mathrm{S}}(KK)$	0.045	0.005	0.004	0.016	0.048
A_0^{CP}	-	0.002	0.002	0.004	0.005
$A_{\perp}^{CP}$	-	0.001	0.006	0.007	0.009
$A_{\mathrm{S}}(K\pi)^{CP}$	-	0.007	0.005	0.034	0.035
$A_{\mathrm{S}}(KK)^{CP}$	-	0.007	0.009	0.003	0.012
$\delta_{\perp}^{CP}$	-	0.003	0.001	0.004	0.005
$\delta_{\parallel}^{CP}$	-	0.005	0.002	0.014	0.015
$\delta_{\mathrm{S}}(K\pi)^{CP}$	-	0.005	0.003	0.021	0.022
$\delta_{\mathrm{S}}(KK)^{CP}$	-	0.002	0.002	0.003	0.004

Conclusion

- The results for the P-wave parameters for the decay mode $B^0 \to \phi K^{*0}$ are consistent with, but more precise than previous measurements
- The CP asymmetries are consistent with no direct CP violation.
- The difference in direct CP asymmetries between the $B^0 \to \phi K^{*0}$ and $B^0 \to J/\psi K^{*0}$ where CP violation is predicted to be very small ($\sim 10^{-3}$) is also measured,

$$\Delta A_{CP} = (+1.5 \pm 3.2 \pm 0.5)\,\%\ ,$$

This is a factor of two more precise than previous values reported by BaBar and Belle and is found to be consistent with zero

Conclusion

- This analysis was done with 2011 data ($1.0\,\text{fb}^{-1}$ at $\sqrt{s} = 7$ TeV)
  New results and measurements with full 2011 and 2012 data ($2.0\,\text{fb}^{-1}$ at $\sqrt{s} = 8$ TeV) will come soon

Parameter	Fitted value 2011 data	Lausanne (not yet approved) 2012 data
$f_{\rm L}$	$0.497 \pm 0.019 \pm 0.015$	0.498 ± 0.011
$f_{\perp}$	$0.221 \pm 0.016 \pm 0.013$	0.214 ± 0.009
$f_{\rm S}(K\pi)$	$0.143 \pm 0.013 \pm 0.012$	0.129 ± 0.007
$f_{\rm S}(KK)$	$0.122 \pm 0.013 \pm 0.008$	0.090 ± 0.007
$\delta_{\perp}$	$2.633 \pm 0.062 \pm 0.037$	2.557 ± 0.036
$\delta_{\parallel}$	$2.562 \pm 0.069 \pm 0.040$	2.456 ± 0.036
$\delta_{\rm S}(K\pi)$	$2.222 \pm 0.063 \pm 0.081$	2.971 ± 0.037
$\delta_{\rm S}(KK)$	$2.481 \pm 0.072 \pm 0.048$	2.131 ± 0.045
$\mathcal{A}_0^{CP}$	$-0.003 \pm 0.038 \pm 0.005$	-0.034 ± 0.022
$\mathcal{A}_{\perp}^{CP}$	$+0.047 \pm 0.074 \pm 0.009$	-0.053 ± 0.042
$\mathcal{A}_S(K\pi)^{CP}$	$+0.073 \pm 0.091 \pm 0.035$	$+0.124 \pm 0.052$
$\mathcal{A}_S(KK)^{CP}$	$-0.209 \pm 0.105 \pm 0.012$	$+0.005 \pm 0.074$
$\delta_{\perp}^{CP}$	$+0.062 \pm 0.062 \pm 0.005$	$+0.045 \pm 0.036$
$\delta_{\parallel}^{CP}$	$+0.045 \pm 0.069 \pm 0.015$	$+0.017 \pm 0.036$
$\delta_S(K\pi)^{CP}$	$+0.062 \pm 0.062 \pm 0.022$	$+0.056 \pm 0.036$
$\delta_S(KK)^{CP}$	$+0.022 \pm 0.072 \pm 0.004$	$+0.031 \pm 0.045$

Thank you for your attention !

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