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

Anh-Duc Nguyen

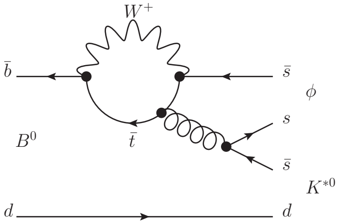
Ecole Polytechnique Fédérale de Lausanne
anhduc.nguyen@epfl.ch

CHIPP PhD Winter School
Grindelward, Switzerland 2015

Overview

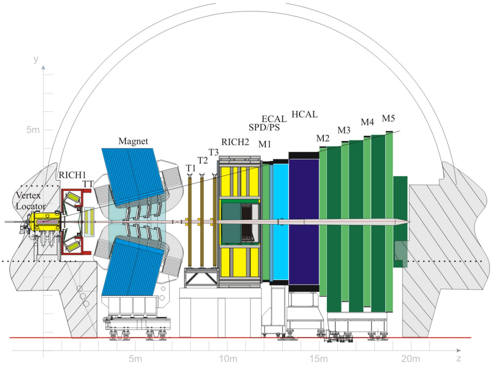
Motivation

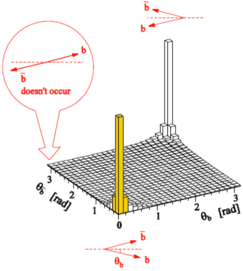
- The first evidence for the decay $B \rightarrow \phi K^*$ was provided by CLEO (*Phys.Rev.Lett.86,3718 (2001)*) and BABAR (*Phys.Rev.Lett.87, 151801 (2001)*) experiments
- In the SM, the decay $B_d^0 \rightarrow \phi K^*(892)^0$ proceeds mainly via the gluonic penguin diagram (b $\rightarrow$ s transition)
- This b $\rightarrow$ s transition is sensitive to contributions from physics beyond the SM.
- The pseudoscalar to vector-vector decay $B_d^0 \rightarrow \phi K^*(892)^0$ 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 using 2012 data, with an integrated luminosity of 2.0 fb^{-1}, collected at a centre-of-mass energy of $\sqrt{s} = 8$ TeV at the LHCb experiment.

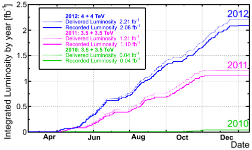


The LHCb detector

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 decaying 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 $A_\parallel$

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

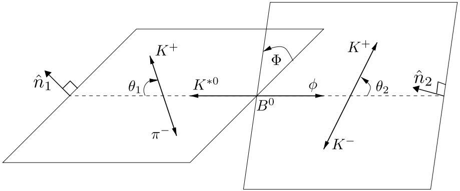
- There are also contributions from S-wave K^+K^- and S-wave $K^+\pi^-$ with spin 0. (amplitudes A_S^{KK} and $A_S^{K\pi}$)
- The amplitudes have magnitudes and relative to A_0 phases defined as:

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

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

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:

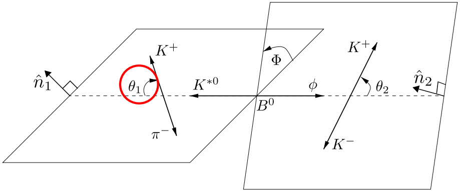
$$d^5\Gamma \propto |PWave \times M_1(m_1)M_1(m_2) + SWave(K\pi) \times M_0(m_1)M_1(m_2) + SWave(KK) \times M_1(m_1)M_0(m_2)|^2$$

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

which can be re-written as:

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:

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

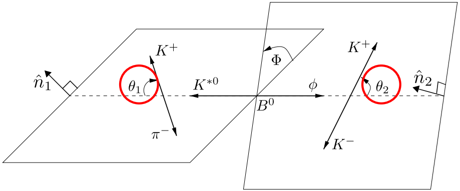
$$d^5\Gamma = \frac{9}{8\pi} \; | \; (\mathcal{A}_0 \cos\theta_1 \cos\theta_2 + \frac{\mathcal{A}_\parallel}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \cos\varphi + \frac{\mathcal{A}_\perp}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin\varphi) M_1(m_1)M_1(m_2)$$

$$+ \frac{\mathcal{A}_S}{\sqrt{3}} \cos\theta_1 M_0(m_1)M_1(m_2) + \frac{\mathcal{A}_S^{'}}{\sqrt{3}} \cos\theta_2 M_1(m_1)M_0(m_2) \; |^2 \; d\phi(K, K, K, \pi)$$

which can be re-written as:

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:

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

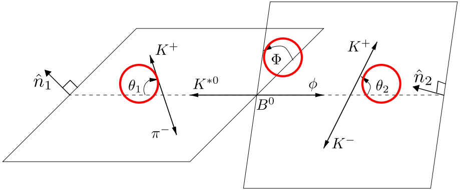
$$d^5\Gamma = \frac{9}{8\pi} \mid (\mathcal{A}_0 \cos\theta_1 \cos\theta_2 + \frac{\mathcal{A}_\parallel}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \cos\varphi + \frac{\mathcal{A}_\perp}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin\varphi) M_1(m_1)M_1(m_2)$$

$$+ \frac{\mathcal{A}_S}{\sqrt{3}} \cos\theta_1 M_0(m_1)M_1(m_2) + \frac{\mathcal{A}_S'}{\sqrt{3}} \cos\theta_2 M_1(m_1)M_0(m_2) \mid^2 \; d\phi(K, K, K, \pi)$$

which can be re-written as:

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:

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

Modelling the $K\pi$ P-wave and S-wave

- The $K\pi$ P-wave amplitude (the resonant mass) is parameterised with a relativistic Breit-Wigner spin-1

$$M_1^{K\pi}(m_{K\pi}) = N_1 \frac{m_{K\pi}}{q} \frac{m_0^{K^*}\Gamma_1^{K\pi}(m_{K\pi})}{(m_0^{K^*})^2 - m_{K\pi}^2 - i m_0^{K\pi}\Gamma_1^{K\pi}(m_{K\pi})}$$

The mass-dependent width is given by

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

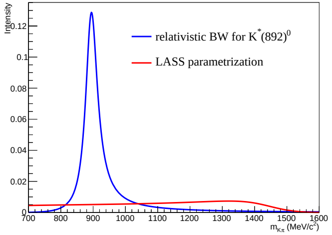
- The LASS parameterisation is used to describe the $K\pi$ S-wave (addition of a rel. BreitWigner spin-0 $K_0^*(1430)$ and a nonresonant amplitude):

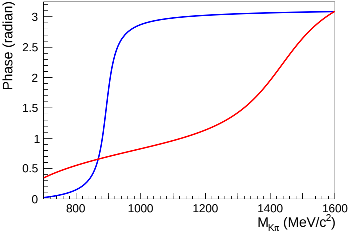
$$M_0^{K\pi}(m_{K\pi}) = N_2 \frac{m_{K\pi}}{q} \left[\frac{1}{\cot\delta_\beta - i} + e^{2i\delta_\beta} \frac{1}{\cot\delta_\alpha(m_{K\pi}) - i}\right]$$

Resonance: $\cot\delta_\alpha(m_{K\pi}) = \dfrac{(m_0^{K_0^*})^2 - m_{K\pi}^2}{m_0^{K_0^*}\Gamma_0(m_{K\pi})}$

Non-resonance: $\cot\delta_\beta = \dfrac{1}{aq} + \dfrac{1}{2} bq$

a is the scattering length; b is the effective range





Modelling the KK P-wave and S-wave

- For the decay $\phi \to K^+K^-$ (a vector meson decays in two pseudoscalars with equal masses), the P-wave can be parametrized with a rel. Breit-Wigner spin-1, given by:

$$M_1^{KK}(m_{KK}) = N_3\sqrt{\frac{m_{KK}}{q}}\,\frac{\sqrt{m_{KK}\Gamma_1^{KK}(m_{KK})}}{(m_0^{\phi})^2 - m_{KK}^2 - i m_0^{\phi}\Gamma_1^{KK}(m_{KK})}$$

where, $\Gamma_1^{KK}(m_{KK}) = \Gamma_0^{\phi}\,\frac{m_0^{\phi}}{m_{KK}}\,\frac{1+r^2q_0^2}{1+r^2q^2}\left(\frac{q}{q_0}\right)^3$

- The K^+K^- S-wave is described by a coupled-channel Breit-Wigner (Flatté parameterization) describing the $f_0(980)$ meson close to K^+K threshold

$$M_0^{KK}(m_{KK}) = N_4\,\frac{1}{m_{f_0}^2 - m_{KK}^2 - i m_{f_0}(g_{\pi\pi}\rho_{\pi\pi} + g_{KK}\rho_{KK})}\ ,$$

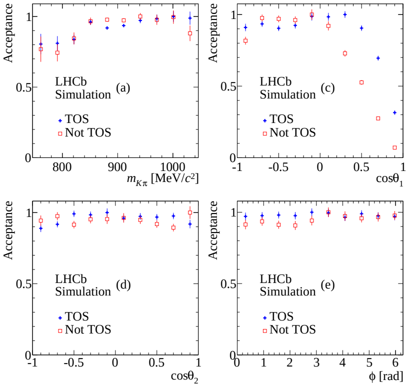
$g_{KK,\pi\pi}$ are partial decay widths and the $\rho_{KK,\pi\pi}$ are phase-space factors.

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

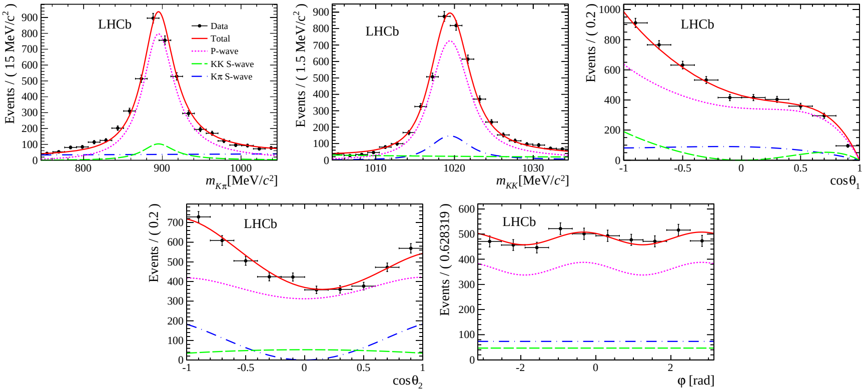
Angular Acceptance

- 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. We have to correct for it.

- 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 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

{TOS;B0}	1163
{TIS;B0}	1247
{TOS;B0bar}	1175
{TIS;B0bar}	1239

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	0.004	0.021	0.002	0.002	0.022
$f_\perp$	0.003	0.009	0.001	0.002	0.010
$f_S(K\pi)$	0.007	0.005	0.001	0.002	0.009
$f_S(KK)$	0.003	0.004	0.002	0.004	0.007
$\delta_\perp$	0.015	0.002	0.006	0.008	0.018
$\delta_\parallel$	0.015	0.004	0.004	0.006	0.017
$\delta_S(K\pi)$	0.011	0.020	0.004	0.055	0.060
$\delta_S(KK)$	0.013	0.002	0.004	0.018	0.023
A_0^{CP}	-	0.001	0.002	0.006	0.006
$A_\perp^{CP}$	-	0.005	0.006	0.004	0.009
$A_S(K\pi)^{CP}$	-	0.001	0.005	0.018	0.019
$A_S(KK)^{CP}$	-	0.006	0.009	0.046	0.047
$\delta_\perp^{CP}$	-	0.004	0.001	0.003	0.005
$\delta_\parallel^{CP}$	-	0.008	0.002	0.004	0.009
$\delta_S(K\pi)^{CP}$	-	0.002	0.003	0.027	0.027
$\delta_S(KK)^{CP}$	-	0.002	0.002	0.014	0.014

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}	$0.5(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$0.503 \pm 0.011 \pm 0.022$
$f_{\perp}$	$0.5(\lvert A_{\perp}\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_{\perp}\rvert^2/\overline{F}_{\mathrm{P}})$	$0.221 \pm 0.009 \pm 0.010$
$f_{\mathrm{S}}(K\pi)$	$0.5(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$0.152 \pm 0.007 \pm 0.009$
$f_{\mathrm{S}}(KK)$	$0.5(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$0.097 \pm 0.007 \pm 0.007$
$\delta_{\perp}$	$0.5(\arg A_{\perp} + \arg \overline{A}_{\perp})$	$2.610 \pm 0.038 \pm 0.018$
$\delta_{\parallel}$	$0.5(\arg A_{\parallel} + \arg \overline{A}_{\parallel})$	$2.524 \pm 0.038 \pm 0.017$
$\delta_{\mathrm{S}}(K\pi)$	$0.5(\arg A_{\mathrm{S}}^{K\pi} + \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$2.200 \pm 0.033 \pm 0.060$
$\delta_{\mathrm{S}}(KK)$	$0.5(\arg A_{\mathrm{S}}^{KK} + \arg \overline{A}_{\mathrm{S}}^{KK})$	$2.536 \pm 0.045 \pm 0.023$

$$F_{\mathrm{P}} = \lvert A_0\rvert^2 + \lvert A_{\parallel}\rvert^2 + \lvert A_{\perp}\rvert^2 \,, F_{\mathrm{S}} = \lvert A_S^{K\pi}\rvert^2 + \lvert A_S^{KK}\rvert^2 \,, F_{\mathrm{P}} + F_{\mathrm{S}} = 1$$

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}	$0.5(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$0.503 \pm 0.011 \pm 0.022$
$f_\perp$	$0.5(\lvert A_\perp\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_\perp\rvert^2/\overline{F}_{\mathrm{P}})$	$0.221 \pm 0.009 \pm 0.010$
$f_{\mathrm{S}}(K\pi)$	$0.5(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$0.152 \pm 0.007 \pm 0.009$
$f_{\mathrm{S}}(KK)$	$0.5(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$0.097 \pm 0.007 \pm 0.007$
$\delta_\perp$	$0.5(\arg A_\perp + \arg \overline{A}_\perp)$	$2.610 \pm 0.038 \pm 0.018$
$\delta_\parallel$	$0.5(\arg A_\parallel + \arg \overline{A}_\parallel)$	$2.524 \pm 0.038 \pm 0.017$
$\delta_{\mathrm{S}}(K\pi)$	$0.5(\arg A_{\mathrm{S}}^{K\pi} + \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$2.200 \pm 0.033 \pm 0.060$
$\delta_{\mathrm{S}}(KK)$	$0.5(\arg A_{\mathrm{S}}^{KK} + \arg \overline{A}_{\mathrm{S}}^{KK})$	$2.536 \pm 0.045 \pm 0.023$

$$F_{\mathrm{P}} = \lvert A_0\rvert^2 + \lvert A_\parallel\rvert^2 + \lvert A_\perp\rvert^2 \,, F_{\mathrm{S}} = \lvert A_S^{K\pi}\rvert^2 + \lvert A_S^{KK}\rvert^2 \,, F_{\mathrm{P}} + F_{\mathrm{S}} = 1$$

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

Angular analysis results

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

Parameter	Definition	Fitted value
$f_{\rm L}$	$0.5(\|A_0\|^2/F_{\rm P} + \|\overline{A}_0\|^2/\overline{F}_{\rm P})$	$0.503 \pm 0.011 \pm 0.022$
$f_\perp$	$0.5(\|A_\perp\|^2/F_{\rm P} + \|\overline{A}_\perp\|^2/\overline{F}_{\rm P})$	$0.221 \pm 0.009 \pm 0.010$
$f_{\rm S}(K\pi)$	$0.5(\|A_{\rm S}^{K\pi}\|^2 + \|\overline{A}_{\rm S}^{K\pi}\|^2)$	$0.152 \pm 0.007 \pm 0.009$
$f_{\rm S}(KK)$	$0.5(\|A_{\rm S}^{KK}\|^2 + \|\overline{A}_{\rm S}^{KK}\|^2)$	$0.097 \pm 0.007 \pm 0.007$
$\delta_\perp$	$0.5(\arg A_\perp + \arg \overline{A}_\perp)$	$2.610 \pm 0.038 \pm 0.018$
$\delta_\parallel$	$0.5(\arg A_\parallel + \arg \overline{A}_\parallel)$	$2.524 \pm 0.038 \pm 0.017$
$\delta_{\rm S}(K\pi)$	$0.5(\arg A_{\rm S}^{K\pi} + \arg \overline{A}_{\rm S}^{K\pi})$	$2.200 \pm 0.033 \pm 0.060$
$\delta_{\rm S}(KK)$	$0.5(\arg A_{\rm S}^{KK} + \arg \overline{A}_{\rm S}^{KK})$	$2.536 \pm 0.045 \pm 0.023$

$$F_{\rm P} = |A_0|^2 + |A_\parallel|^2 + |A_\perp|^2\ , F_{\rm S} = |A_S^{K\pi}|^2 + |A_S^{KK}|^2\ , F_{\rm P} + F_{\rm S} = 1$$

- 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}	$0.5(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$0.503 \pm 0.011 \pm 0.022$
$f_{\perp}$	$0.5(\lvert A_{\perp}\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_{\perp}\rvert^2/\overline{F}_{\mathrm{P}})$	$0.221 \pm 0.009 \pm 0.010$
$f_{\mathrm{S}}(K\pi)$	$0.5(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$0.152 \pm 0.007 \pm 0.009$
$f_{\mathrm{S}}(KK)$	$0.5(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$0.097 \pm 0.007 \pm 0.007$
$\delta_{\perp}$	$0.5(\arg A_{\perp} + \arg \overline{A}_{\perp})$	$2.610 \pm 0.038 \pm 0.018$
$\delta_{\parallel}$	$0.5(\arg A_{\parallel} + \arg \overline{A}_{\parallel})$	$2.524 \pm 0.038 \pm 0.017$
$\delta_{\mathrm{S}}(K\pi)$	$0.5(\arg A_{\mathrm{S}}^{K\pi} + \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$2.200 \pm 0.033 \pm 0.060$
$\delta_{\mathrm{S}}(KK)$	$0.5(\arg A_{\mathrm{S}}^{KK} + \arg \overline{A}_{\mathrm{S}}^{KK})$	$2.536 \pm 0.045 \pm 0.023$
$\mathcal{A}_0^{CP}$	$(\lvert A_0\rvert^2/F_{\mathrm{P}} - \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})/(\lvert A_0\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_0\rvert^2/\overline{F}_{\mathrm{P}})$	$-0.020 \pm 0.022 \pm 0.006$
$\mathcal{A}_{\perp}^{CP}$	$(\lvert A_{\perp}\rvert^2/F_{\mathrm{P}} - \lvert\overline{A}_{\perp}\rvert^2/\overline{F}_{\mathrm{P}})/(\lvert A_{\perp}\rvert^2/F_{\mathrm{P}} + \lvert\overline{A}_{\perp}\rvert^2/\overline{F}_{\mathrm{P}})$	$-0.035 \pm 0.042 \pm 0.009$
$\delta_{\perp}^{CP}$	$0.5(\arg A_{\perp} - \arg \overline{A}_{\perp})$	$+0.031 \pm 0.038 \pm 0.005$
$\delta_{\parallel}^{CP}$	$0.5(\arg A_{\parallel} - \arg \overline{A}_{\parallel})$	$+0.020 \pm 0.038 \pm 0.009$
$\mathcal{A}_S(K\pi)^{CP}$	$(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 - \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)/(\lvert A_{\mathrm{S}}^{K\pi}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{K\pi}\rvert^2)$	$+0.119 \pm 0.049 \pm 0.019$
$\mathcal{A}_S(KK)^{CP}$	$(\lvert A_{\mathrm{S}}^{KK}\rvert^2 - \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)/(\lvert A_{\mathrm{S}}^{KK}\rvert^2 + \lvert\overline{A}_{\mathrm{S}}^{KK}\rvert^2)$	$+0.002 \pm 0.072 \pm 0.047$
$\delta_S(K\pi)^{CP}$	$0.5(\arg A_{\mathrm{S}}^{K\pi} - \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$+0.027 \pm 0.033 \pm 0.027$
$\delta_S(KK)^{CP}$	$0.5(\arg A_{\mathrm{S}}^{KK} - \arg \overline{A}_{\mathrm{S}}^{KK})$	$+0.085 \pm 0.045 \pm 0.014$

Angular analysis results

Parameter	Definition	Fitted value
f_{L}	$0.5(\|A_0\|^2/F_{\mathrm{P}} + \|\overline{A}_0\|^2/\overline{F}_{\mathrm{P}})$	$0.503 \pm 0.011 \pm 0.022$
$f_{\perp}$	$0.5(\|A_{\perp}\|^2/F_{\mathrm{P}} + \|\overline{A}_{\perp}\|^2/\overline{F}_{\mathrm{P}})$	$0.221 \pm 0.009 \pm 0.010$
$f_{\mathrm{S}}(K\pi)$	$0.5(\|A_{\mathrm{S}}^{K\pi}\|^2 + \|\overline{A}_{\mathrm{S}}^{K\pi}\|^2)$	$0.152 \pm 0.007 \pm 0.009$
$f_{\mathrm{S}}(KK)$	$0.5(\|A_{\mathrm{S}}^{KK}\|^2 + \|\overline{A}_{\mathrm{S}}^{KK}\|^2)$	$0.097 \pm 0.007 \pm 0.007$
$\delta_{\perp}$	$0.5(\arg A_{\perp} + \arg \overline{A}_{\perp})$	$2.610 \pm 0.038 \pm 0.018$
$\delta_{\parallel}$	$0.5(\arg A_{\parallel} + \arg \overline{A}_{\parallel})$	$2.524 \pm 0.038 \pm 0.017$
$\delta_{\mathrm{S}}(K\pi)$	$0.5(\arg A_{\mathrm{S}}^{K\pi} + \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$2.200 \pm 0.033 \pm 0.060$
$\delta_{\mathrm{S}}(KK)$	$0.5(\arg A_{\mathrm{S}}^{KK} + \arg \overline{A}_{\mathrm{S}}^{KK})$	$2.536 \pm 0.045 \pm 0.023$
$\mathcal{A}_0^{CP}$	$(\|A_0\|^2/F_{\mathrm{P}} - \|\overline{A}_0\|^2/\overline{F}_{\mathrm{P}})/(\|A_0\|^2/F_{\mathrm{P}} + \|\overline{A}_0\|^2/\overline{F}_{\mathrm{P}})$	$-0.020 \pm 0.022 \pm 0.006$
$\mathcal{A}_{\perp}^{CP}$	$(\|A_{\perp}\|^2/F_{\mathrm{P}} - \|\overline{A}_{\perp}\|^2/\overline{F}_{\mathrm{P}})/(\|A_{\perp}\|^2/F_{\mathrm{P}} + \|\overline{A}_{\perp}\|^2/\overline{F}_{\mathrm{P}})$	$-0.035 \pm 0.042 \pm 0.009$
$\delta_{\perp}^{CP}$	$0.5(\arg A_{\perp} - \arg \overline{A}_{\perp})$	$+0.031 \pm 0.038 \pm 0.005$
$\delta_{\parallel}^{CP}$	$0.5(\arg A_{\parallel} - \arg \overline{A}_{\parallel})$	$+0.020 \pm 0.038 \pm 0.009$
$\mathcal{A}_S(K\pi)^{CP}$	$(\|A_{\mathrm{S}}^{K\pi}\|^2 - \|\overline{A}_{\mathrm{S}}^{K\pi}\|^2)/(\|A_{\mathrm{S}}^{K\pi}\|^2 + \|\overline{A}_{\mathrm{S}}^{K\pi}\|^2)$	$+0.119 \pm 0.049 \pm 0.019$
$\mathcal{A}_S(KK)^{CP}$	$(\|A_{\mathrm{S}}^{KK}\|^2 - \|\overline{A}_{\mathrm{S}}^{KK}\|^2)/(\|A_{\mathrm{S}}^{KK}\|^2 + \|\overline{A}_{\mathrm{S}}^{KK}\|^2)$	$+0.002 \pm 0.072 \pm 0.047$
$\delta_S(K\pi)^{CP}$	$0.5(\arg A_{\mathrm{S}}^{K\pi} - \arg \overline{A}_{\mathrm{S}}^{K\pi})$	$+0.027 \pm 0.033 \pm 0.027$
$\delta_S(KK)^{CP}$	$0.5(\arg A_{\mathrm{S}}^{KK} - \arg \overline{A}_{\mathrm{S}}^{KK})$	$+0.085 \pm 0.045 \pm 0.014$

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

Angular analysis results

- Comparison with previous LHCb result using 2011 data (JHEP 1405 (2014) 069)

Parameter	2011 data 1.0 fb^{-1} at $\sqrt{s} = 7$ TeV	2012 data (not yet approved) 2.0 fb^{-1} at $\sqrt{s} = 8$ TeV
$f_{\rm L}$	$0.497 \pm 0.019 \pm 0.015$	$0.503 \pm 0.011 \pm 0.022$
$f_{\perp}$	$0.221 \pm 0.016 \pm 0.013$	$0.221 \pm 0.009 \pm 0.010$
$f_{\rm S}(K\pi)$	$0.143 \pm 0.013 \pm 0.012$	$0.152 \pm 0.007 \pm 0.009$
$f_{\rm S}(KK)$	$0.122 \pm 0.013 \pm 0.008$	$0.097 \pm 0.007 \pm 0.007$
$\delta_{\perp}$	$2.633 \pm 0.062 \pm 0.037$	$2.610 \pm 0.038 \pm 0.018$
$\delta_{\parallel}$	$2.562 \pm 0.069 \pm 0.040$	$2.524 \pm 0.038 \pm 0.017$
$\delta_{\rm S}(K\pi)$	$2.222 \pm 0.063 \pm 0.081$	$2.200 \pm 0.033 \pm 0.060$
$\delta_{\rm S}(KK)$	$2.481 \pm 0.072 \pm 0.048$	$2.536 \pm 0.045 \pm 0.023$
$\mathcal{A}_0^{CP}$	$-0.003 \pm 0.038 \pm 0.005$	$-0.020 \pm 0.022 \pm 0.006$
$\mathcal{A}_{\perp}^{CP}$	$+0.047 \pm 0.074 \pm 0.009$	$-0.035 \pm 0.042 \pm 0.009$
$\mathcal{A}_S(K\pi)^{CP}$	$+0.073 \pm 0.091 \pm 0.035$	$+0.119 \pm 0.049 \pm 0.019$
$\mathcal{A}_S(KK)^{CP}$	$-0.209 \pm 0.105 \pm 0.012$	$+0.002 \pm 0.072 \pm 0.047$
$\delta_{\perp}^{CP}$	$+0.062 \pm 0.062 \pm 0.005$	$+0.031 \pm 0.038 \pm 0.005$
$\delta_{\parallel}^{CP}$	$+0.045 \pm 0.069 \pm 0.015$	$+0.020 \pm 0.038 \pm 0.009$
$\delta_S(K\pi)^{CP}$	$+0.062 \pm 0.062 \pm 0.022$	$+0.027 \pm 0.033 \pm 0.027$
$\delta_S(KK)^{CP}$	$+0.022 \pm 0.072 \pm 0.004$	$+0.085 \pm 0.045 \pm 0.014$

- The results with 2012 data are consistent with and more precise than the results with 2011 data.

Conclusion

- We have studied the decay $B^0 \to \phi K^{*0}$ with the S-wave included in the $K\pi$ and KK decays.
- We have obtained:
  - The polarization amplitudes and strong phase differences in the decay mode $B^0 \to \phi K^{*0}$.
  - The results are consistent with, but more precise than previous measurements
  - The CP asymmetries which are consistent with no direct CP violation.

Thank you for your attention !

Backup