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Observation of the three-body rare decay $B \rightarrow J/\psi\phi K$ at BABAR

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Abstract

We report the study of the B meson decays $B^{\pm} \to J/\psi \phi K^{\pm}$, $B^0 \to J/\psi \phi K^0$ using 433 million of $B\overline{B}$ events collected at the $\Upsilon(4S)$ resonance with the BABAR detector at the PEP-II e^+e^- asymmetric-energy collider. We obtain the branching fraction measurements:

$$\mathcal{B}(B^{\pm} \to J/\psi \phi K^{\pm}) = (5.6 \pm 0.9(stat) \pm 0.3(sys)) \times 10^{-5},$$
$$\mathcal{B}(B^0 \to J/\psi \phi K^0) = (5.4 \pm 1.2(stat) \pm 0.4(sys)) \times 10^{-5}$$

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1 INTRODUCTION

Several new charmonium-like states have been observed at BABAR revealing a spectrum too rich to be uniquely described from potential models[1]. Different hypotheses have been proposed from theorists to explain their nature, such as hybrid charmonium states, diquark-antidiquark states or $D^0\bar{D}^{0(*)}$ molecules[2]. A recent theoretical paper explores, for example, the possibility of hybrid $c\bar{c}g$ states, predicting mass splitting and decay rates of the lowest hybrid multiplet[3].

While resonant structures like X(3872) and Y(4260) have been seen in $B \to XK, X \to J/\psi\,\pi^+\pi^-$ [4, 5], no indication of new states has been observed in the $J/\psi\ K^+K^-$ channel.
The rare B decay $B \to J/\psi\phi K$, $\phi \to K^+K^-$, is a promising place to search for new resonances. It proceeds, at quark level, via the weak transition $b \to c\bar{c}s$ and the creation of an additional $s\bar{s}$ pair (Fig. 1). Since the $c\bar{c}$ pair is mainly formed in a color octet state, it could strongly couple to charmonium hybrids and enhance their production. The decay of such hybrids into $J/\psi\phi$ would be however observable below 4.3 GeV/c^2; above this threshold the DD^{**} branching ratio largely dominates other modes.

Using 56 million $B\bar{B}$ pairs, BABAR found 15.2 ± 4.8 $B^\pm \to J/\psi\phi K^\pm$ events and 9.7 ± 3.6 $B^0 \to J/\psi\phi K^0_S$ events[6], corresponding to the branching fractions listed in Table 1. CLEO-II first measured the charged B branching fraction using 9.6 million $B\bar{B}$ pairs and assumed the same branching fraction for neutral B[7]. This paper presents a new determination of the $B^\pm \to J/\psi\phi K^\pm$ and $B^0 \to J/\psi\phi K^0$ branching ratios, using eight times more data than the previous BABAR measurements.

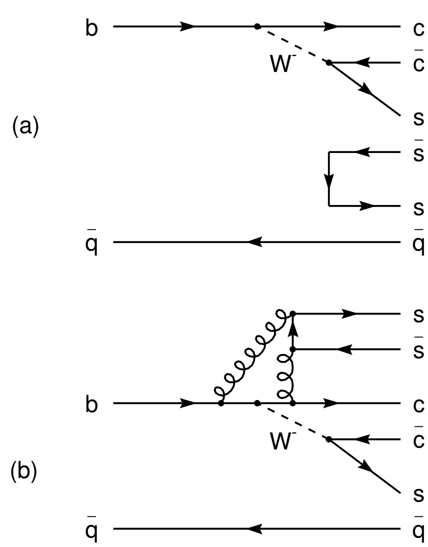


Figure 1: Quark diagrams for $B \to J/\psi\phi K$ via (a) strange sea quarks and (b) gluon coupling.

Experiment	Channel	B.R. (10^{-5})	PDG average (10^{-5})
BaBar	$B^{\pm} \to J/\psi\phi K^{\pm}$	$4.4 \pm 1.4 \pm 0.5$	5.2 ± 1.7
CLEO-II		$8.8^{+3.5}_{-3.0} \pm 1.3$	
BaBar	$B^{0} \to J/\psi\phi K^{0}$	$10.2 \pm 3.8 \pm 1.0$	9.4 ± 2.6
CLEO-II		$8.8^{+3.5}_{-3.0} \pm 1.3$	

Table 1: Previous branching fraction measurements in PDG08[8].

2 THE *BaBar* DETECTOR AND DATASET

This analysis is based on a data sample of 412 fb^{-1} collected by the BaBar detector[9] at the PEP-II asymmetric-energy e^+e^- collider. Charged tracks are reconstructed with a silicon-strip detector (SVT) and a drift chamber (DCH), both in a 1.5 T magnetic field. Particle identification (PID) is based on the energy loss dE/dx in the SVT and DCH together with measurements from a Cherenkov ring-imaging device. Photon energies are measured with a CsI calorimeter. The return yoke of superconducting coil is instrumented with resistive plate chambers and limited streamer tubes for the identification of muons and the detection of clusters produced by K_L and neutron interactions.

Several Monte Carlo data sets are generated to simulate the detector response and to validate the analysis technique, taking into account the conditions of all data taking periods. Their properties are listed in Table 2. A large sample of signal $B \to J/\psi\phi K$ events is generated to evaluate the efficiency of the signal. Background sources are studied using generic $e^+e^- \to B\bar{B}$ and $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) Monte Carlo samples. The branching fraction $B \to J/\psi\phi K$ is set to 9×10^{-5} for the generic $e^+e^- \to B\bar{B}$ sample.

Channel	Cross Section (nb)	Events (100k)	Eq. Lumi (fb^{-1})
$c\bar{c}$	1.3	772	786
$u\bar{u}, d\bar{d}, s\bar{s}$	2.09	679	414
$B^0\bar{B}^0$	0.53	317	1277
B^+B^-	0.53	368	1265

Table 2: Monte Carlo samples used in this analysis.

3 ANALYSIS METHOD

B meson candidates are first formed by taking the J/ψ and ϕ combination, and combining that with either a charged or neutral kaon. J/ψ, ϕ and K^0_S are reconstructed using the decays $J/\psi \to e^+e^-$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$ and $K^0_S \to \pi^+\pi^-$.

The B meson daughter candidates are selected in the mass range:

- $0.47267 < m_{K_S} < 0.52267$ GeV/c^2

- 1.004< $m_{\phi\to K^+K^-}$ <1.034 GeV/c^2
- 2.97 < $m_{J/\psi\to e^+e^-}$ < 3.14 GeV/c^2 and 3.056< $m_{J/\psi\to\mu^+\mu^-}$ <3.14 GeV/c^2

The asymmetric cut on $m_{J/\psi\to e^+e^-}$ is due to bremsstrahlung and is partially recovered by an algorithm that combines the energy of electrons with that of nearby photons. In addition, the polar angle of the neutral B meson, θ_B, must satisfy $\cos\theta_{\rm B} > 0.96$ to reduce the combinatorial background. The value of each cut has been separately optimized to maximize the signal significance, estimated from $S/\sqrt{S+B}$. S and B represent the numbers of signal and background events, respectively, after the selection is applied; they are estimated from Monte Carlo sample cocktails, and rescaled to 412 fb^{-1}.

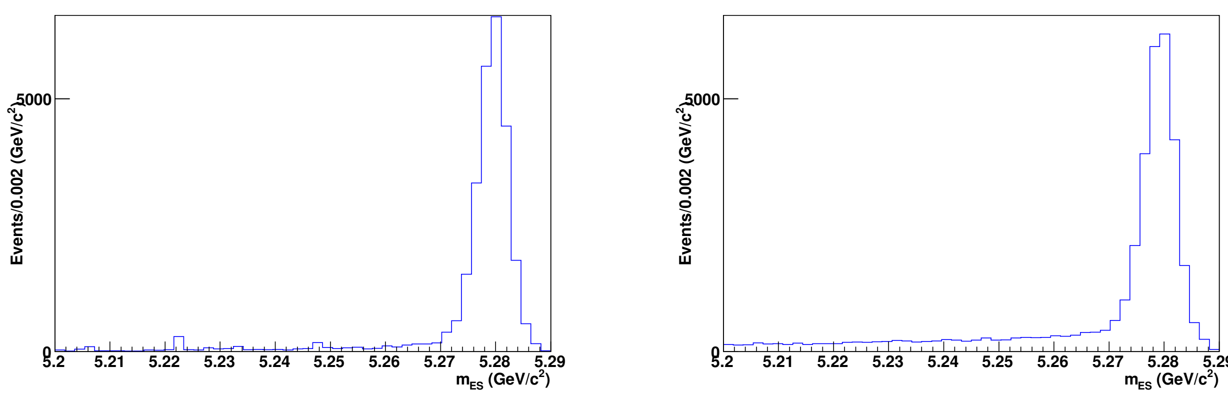
Signal decays can further be selected using the kinematic variables m_{ES} and ΔE, defined as

$$m_{\rm ES} = \sqrt{E^2_{\rm beam} - |\vec{p_B}|^2} \quad (1)$$

and

$$\Delta E = E_B - E_{\rm beam} \quad (2)$$

where $\vec{p_B}$ and E_B are the momentum and energy of the B candidate in the e^+e^- center-of-mass (CM) frame and $E_{\rm beam}$ is the beam energy in the CM frame. The distributions of these variables for the signal Monte Carlo samples are shown in Fig. 2 and Fig. 3, for events with $|\Delta E| < 0.2$ GeV.

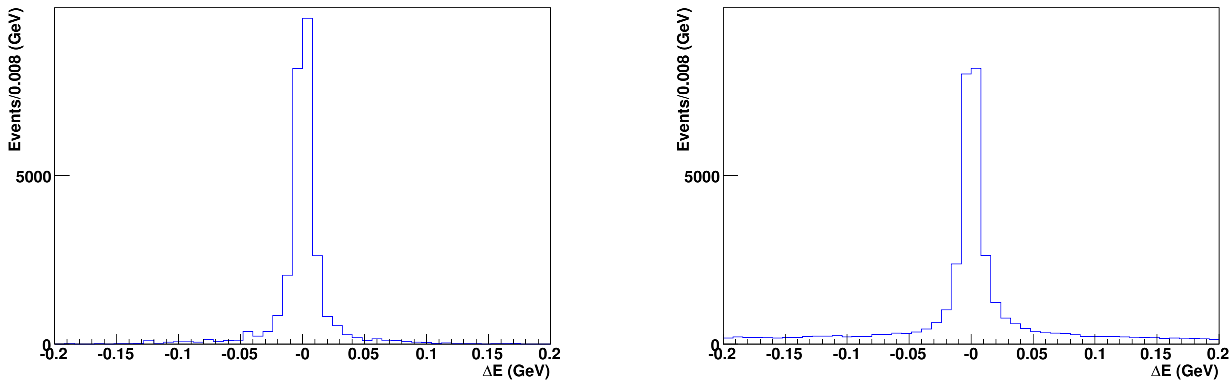


(a) m_{ES} for $B^\pm \to J/\psi\phi K^\pm$

(b) m_{ES} for $B^0 \to J/\psi\phi K^0_S$

Figure 2: m_{ES} plots obtained with signal Monte Carlo samples.

The B meson candidates with -0.05 GeV $< \Delta E < 0.1$ GeV are further selected (an asymmetric cut is used to take bremsstrahlung into account). An average of 1.013 $B^\pm \to J/\psi\phi K^\pm$ and 1.089 $B^0 \to J/\psi\phi K^0_S$ candidates per event are found analyzing the Monte Carlo sample cocktails. The combination that minimizes $|\Delta E|$ is chosen when multiple B mesons are reconstructed. The B candidate with the smallest $|\Delta E|$ is chosen. The selection criteria are listed in Table 3 together with the selected number of events of each cut for different Monte Carlo samples. The $m_{\rm ES}$ distributions for the Monte Carlo sample cocktail *udscb* are shown in Fig. 6. For charged and neutral B mesons a clear peak is observed around $m_{\rm ES} = 5.28$ GeV/c^2. The distribution obtained by removing the signal events from the *udscb* Monte Carlo cocktail is displayed in Fig. 4 and clearly demonstrates that no other peaking background is present.



(a) ΔE for $B^{\pm} \to J/\psi\phi K^{\pm}$ (b) ΔE for $B^0 \to J/\psi\phi K^0_S$

Figure 3: ΔE distributions obtained using signal Monte Carlo samples.

The effect of loosening the requirements on the selection of the B meson daughters has been carefully investigated. It was proved that the statistical and systematic uncertainties of the results are larger than the ones obtained using tighter cuts. This justifies the choice of our analysis procedure.

In order to obtain the reconstruction efficiencies for the two reaction channels we performed unbinned maximum likelihood (UML) fits on the signal Monte Carlo samples, allowing all parameters to be free to attain the values that maximize the likelihood (Fig. 5 and Table 4).
We obtained the following recontruction efficiencies:

$$\epsilon(B^{\pm} \to J/\psi\ \phi K^{\pm}) = (11.19 \pm 0.08)\%, \quad (3)$$

$$\epsilon(B^0 \to J/\psi\ \phi K^0_S) = (8.91 \pm 0.07)\% \quad (4)$$

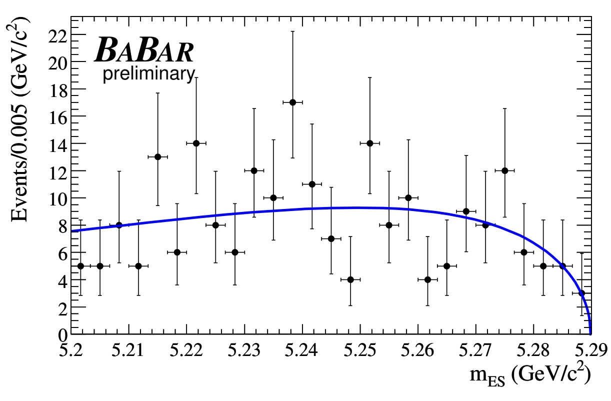


Figure 4: Background characterisation: $u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c} + B\bar{B}$ background fit with an Argus function[10], after the signal was removed.

$B^{\pm} \to J/\psi\ \phi\ K^{\pm}$	*udsc* events	$B\bar{B}$ events	signal events
tight pre-selection cuts	340	3495	31769
2.97< $m_{J/\psi \to e^+e^-}$ <3.14 GeV/c^2 3.056< $m_{J/\psi \to \mu^+\mu^-}$ <3.14 GeV/c^2	11	1352	26397
1.004< $m_{\phi \to K^+K^-}$ <1.034 GeV/c^2	7	1026	23254
$-0.05 < \Delta E < 0.1$ GeV	4	483	21023
$B^0 \to J/\psi\ \phi\ K^0_S$	*udsc*	$B\bar{B}$	signal
tight pre-selection cuts	220	853	25557
2.97< $m_{J/\psi \to e^+e^-}$ <3.14 GeV/c^2 3.056< $m_{J/\psi \to \mu^+\mu^-}$ <3.14 GeV/c^2	470	599	21067
1.004< $m_{\phi \to K^+K^-}$ <1.034 GeV/c^2	57	340	19116
0.493< $m_{K^0_S \to \pi^+\pi^-}$ <0.505 GeV/c^2	43	286	18172
cos θ >0.96	29	211	16042
$-0.05 < \Delta E < 0.1$ GeV	20	130	15776

Table 3: Cuts applied to the Monte Carlo samples, rescaled to 412 fb^{-1}.

The UML fit was also performed on the *udscb* Monte Carlo sample cocktails, fitting the $m_{\rm ES}$ distributions (charged and neutral decay modes, respectively) with a composite function: gaussian + Argus function[11] (Fig. 6 and Table 5). All the fit parameters were free to float again.
The fit results, listed in Table 6, on the Monte Carlo samples, are consistent with the expected values: 127 events for the charged channel, and 70 for the neutral channel, on 412 fb^{-1}.

The Monte Carlo studies confirm that the $m_{\rm ES}$ fits are stable and reproduce the expected values.

Decay mode	PDF	Parameters
$B^{\pm} \to J/\psi\phi K^{\pm}$	gaussian	$\bar{x} = 5.27910 \pm 0.00021$ $\sigma = (2.8610 \pm 0.0017) \times 10^{-3}$ $N_{peak} = 19585 \pm 151$ $\chi^2 = 0.78$
$B^0 \to J/\psi\phi K^0_S$	gaussian	$\bar{x} = 5.27942 \pm 0.00023$ $\sigma = (2.5801 \pm 0.0021) \times 10^{-3}$ $N_{peak} = 15599 \pm 124$ $\chi^2 = 0.67$

Table 4: *PDF* parameters of the $m_{\rm ES}$ fit performed on signal Monte Carlo samples of 175 000 events to calculate the reconstruction efficiencies.

We fit the data sample with the same PDFs like we used for the Monte Carlo samples. The projection plots of the fit are shown in Fig. 6 and Fig. 7, and the results are reported in Table 5, 6 for the Monte Carlo samples, and Table 7, 8 for data.

Decay mode	PDF	Parameters
$B^{\pm} \rightarrow J/\psi\phi K^{\pm}$	gaussian + Argus	$\xi = -25 \pm 10$ $\bar{x} = 5.27921 \pm 0.0028$ $\sigma = (2.718 \pm 0.022) \times 10^{-3}$ $N_{peak} = 130 \pm 12$ $N_{bkg} = 127 \pm 13$ $\chi^2 = 0.66$
$B^0 \rightarrow J/\psi\phi K^0_S$	gaussian + Argus	$\xi = -44 \pm 10$ $\bar{x} = 5.28014 \pm 0.0070$ $\sigma = (3.08 \pm 0.022) \times 10^{-3}$ $N_{peak} = 69 \pm 9$ $N_{bkg} = 141 \pm 14$ $\chi^2 = 0.62$

Table 5: PDF parameters of the m_{ES} fit performed on Monte Carlo sample cocktails, rescaled to 412 fb^{-1}. Both fits were performed with gaussian + Argus function (ξ represents the Argus function free parameter).

Channel	Expected events	Measured events	Efficiency	Expected B.R.	Measured B.R.
$B^{\pm} \rightarrow J/\psi\phi K^{\pm}$	127	130 ± 12	$(11.19 \pm 0.08)\%$	9×10^{-5}	$(9.23 \pm 0.85) \times 10^{-5}$
$B^0 \rightarrow J/\psi\phi K^0_S$	70	69 ± 9	$(8.91 \pm 0.07)\%$	4.5×10^{-5}	$(4.42 \pm 0.58) \times 10^{-5}$

Table 6: Validation results on Monte Carlo sample cocktails, 412 fb^{-1}. The efficiency was evaluated by using signal Monte Carlo samples.

Decay mode	PDF	Parameters
$B^{\pm} \rightarrow J/\psi\phi K^{\pm}$	gaussian + Argus	$\xi = -33 \pm 11$ $\bar{x} = 5.2784 \pm 0.0042$ $\sigma = (2.880 \pm 0.040) \times 10^{-3}$ $N_{peak} = 79 \pm 12$ $N_{bkg} = 178 \pm 16$ $\chi^2 = 0.77$
$B^0 \rightarrow J/\psi\phi K^0_S$	gaussian + Argus	$\xi = -42 \pm 10$ $\bar{x} = 5.27805 \pm 0.0053$ $\sigma = (2.532 \pm 0.063) \times 10^{-3}$ $N_{peak} = 42 \pm 10$ $N_{bkg} = 166 \pm 14$ $\chi^2 = 0.82$

Table 7: PDF parameters of the m_{ES} fit performed on data, 412 fb^{-1}.

4 SYSTEMATIC STUDIES

In addition to the statistical error extracted from the fit, it is possible to distinguish six main types of uncertainties classified as systematic errors. They are due to:

Channel	Measured events	Efficiency	B.R. (10^{-5})
$B^{\pm} \to J/\psi\phi K^{\pm}$	79 ± 12	$(11.19 \pm 0.08)\%$	(5.57 ± 0.85)
$B^0 \to J/\psi\phi K^0_S$	42 ± 10	$(8.91 \pm 0.07)\%$	(2.69 ± 0.61)

Table 8: Final results on the data sample, 412 fb^{-1}. The efficiencies were evaluated by using signal Monte Carlo samples.

- $B\bar{B}$ pair number count.
  The systematic uncertainty quoted on the total number of $B\bar{B}$ events is standard evaluated equal to 1.1%.

- signal reconstruction efficiency.
  This systematic error contribution is due to the limited Monte Carlo statistics. It is estimated using the equation below:

$$\Delta(\epsilon) = \sqrt{\frac{\epsilon(1-\epsilon)}{N_{MC}}}, \tag{5}$$

  where N_{MC} is the number of the Monte Carlo events, ϵ represents the efficiency. The uncertainty is evaluated fractional equal to 5.0% for the charged channel and 4.7% for neutral channel.

- K^0_S correction efficiency and charged particle tracking.
  This systematic uncertainty contribution is evaluated by means of tables built by using data control samples, generated by matching data and Monte Carlo samples, for the specific selector chosen for this analysis. These uncertainties were evaluated equal to 2.0% and 6.0% for the charged and the neutral modes, respectively.

- PID selectors.
  It is evaluatd equal to 0.5% for both decay modes.

- secondary branching fractions.
  The systematic uncertainty due to the secondary branching fractions (0.6%) is calculated by summing in quadrature the statistical errors of:

  - $\mathcal{B}(\phi \to K^+K^-) = (49.3 \pm 0.6) \times 10^{-2}$
  - $\mathcal{B}(J/\psi \to l^+l^-) = (11.87 \pm 0.17) \times 10^{-2}$
  - $\mathcal{B}(K^0_S \to \pi^+\pi^-) = (69.20 \pm 0.05) \times 10^{-2}$

  We considered that B.R.$(B^0 \to J/\psi\phi K^0) = 2 \times B.R.(B^0 \to J/\psi\phi K^0_S)$.

- decay model.
  The $B \to J/\psi\phi K$ Monte Carlo data set was generated with the three-body phase space model. However, there can be more complicated decay dynamics which give different decay amplitudes and angular distributions. Thus the efficiencies are subject to variations in the Dalitz plot. So we generated 2 samples of $B \to J/\psi\phi$: one with 100% transversely polarized J/ψ and ϕ vector mesons, another with 100% longitudinally polarized J/ψ and ϕ. The

angular distribution is known for this decay mode (see Tab. 9). The difference between the two extreme cases for each mode was divided by $\sqrt{12}$, then taken as systematic uncertainty. The systematic error was evaluated equal to 0.4% for the charged and 0.9% for the neutral $B \to J/\psi\phi K$.

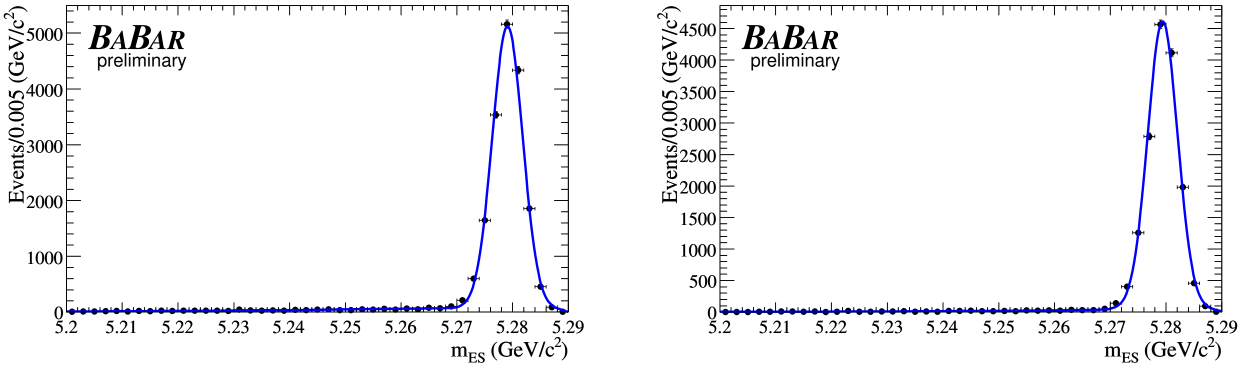
Polarization	$\mathcal{D}_{\mathcal{L}}$	$\mathcal{D}_{\mathcal{K}}$	Efficiency	$\Delta\epsilon/\epsilon$
$\lambda_{J/\psi} = 0$ $\lambda_\phi = 0$	$(d^1_{0,\pm1})^2 = \sin^2\theta/2$	$(d^1_{0,0})^2 = \cos^2\theta/2$	$B^\pm \to J/\psi\phi K^\pm$: 13.86% $B^0 \to J/\psi\phi K^0_S$: 10.14%	0.4% 1.6%
$\lambda_{J/\psi} = \pm1$	$(d^1_{\pm1},\pm1)^2 = (1+\cos^2\theta)/4$	$(d^1_{\pm1,0})^2 = \sin^2\theta/2$	$B^\pm \to J/\psi\phi K^\pm$: 13.91% $B^0 \to J/\psi\phi K^0_S$: 10.84%	0.1% 5.2%
$\lambda_\phi = \pm1$	$(d^1_{\pm1},\pm1)^2 = (1-\cos^2\theta)/4$	$(d^1_{\pm1,0})^2 = \sin^2\theta/2$	$B^\pm \to J/\psi\phi K^\pm$: 14.14% $B^0 \to J/\psi\phi K^0_S$: 10.07%	1.6% 2.2%

Table 9: Systematics from decay model. For leptons coming from J/ψ decays, the angular distribution is called $d^{J_{J/\psi}}_{\lambda_{J/\psi},\lambda_{l^+}-\lambda_{l^-}}$. Similarly for kaons: $d^{J_{J/\psi}}_{\lambda_{J/\psi},\lambda_{K^+}-\lambda_{K^-}}$. The vector mesons J/ψ and ϕ have $J_{J/\psi}$ =1 and $J_\phi = 1$. For 100% transverse polarization they have helicity 0, while for 100% longitudinal polarization they have helicity ±1. The helicity relation of the decay daughters are $\lambda_{l^+} - \lambda_{l^-} = \pm1$ and $\lambda_{K^+} - \lambda_{K^-} = 0$. $\Delta\epsilon$ was calculated with respect the efficiency of $B^0 \to J/\psi\phi$, that was estimated from a gaussian fit to (12.10 ± 0.09)% on a signal Monte Carlo sample of 175 000 events, generated for this study. With $\mathcal{D}_{\mathcal{L}}$ we mean the angular distribution function of leptons; with $\mathcal{D}_{\mathcal{K}}$ we mean the angular distribution function of kaons.

We evaluated the systematic uncertainties as reported in Table 10 and calculated the total systematic error by summing them in quadrature.

Systematics	B$^\pm$ (10^{-2})	B^0 (10^{-2})
$B\bar{B}$	1.1	1.1
Efficiency	5.0	4.7
Tracking	2.0	6.0
PID	0.5	0.5
Secondary B.R.	0.6	0.6
Polarization	0.4	0.9
Total Fractional Contribution	5.9	7.1

Table 10: Systematic error contributions.



(a) $B^{\pm} \to J/\psi\ \phi\ K^{\pm}$ (b) $B^0 \to J/\psi\ \phi\ K^0_S$

Figure 5: Fits to the signal Monte Carlo samples.

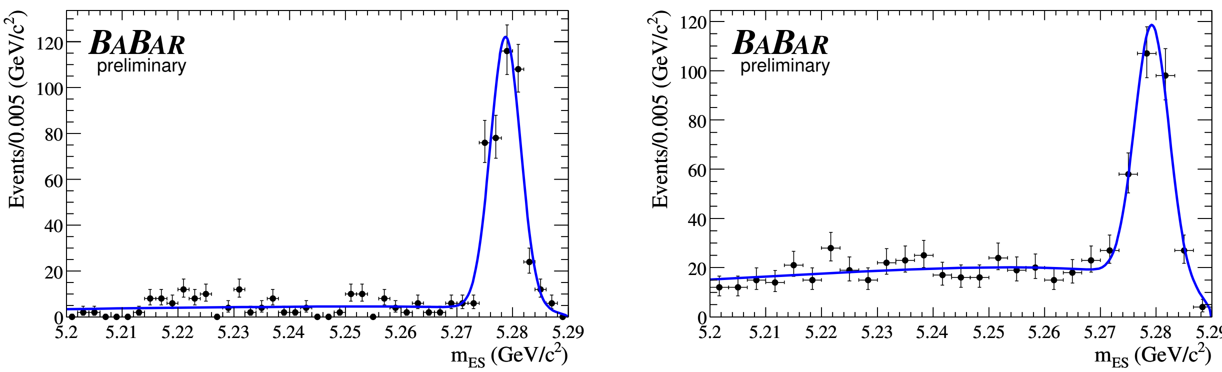
5 RESULTS

We calculated the branching fractions with statistical and systematic errors summarized in Table 11.

$$\mathcal{B}(B^{\pm} \to J/\psi\phi K^{\pm}) = (5.6 \pm 0.9(stat) \pm 0.3(sys)) \times 10^{-5}$$

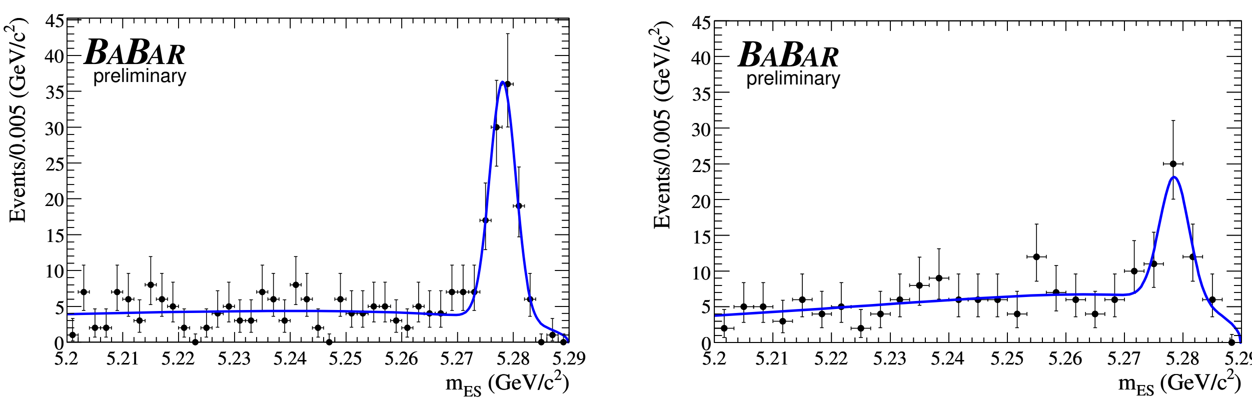
$$\mathcal{B}(B^0 \to J/\psi\phi K^0) = (5.4 \pm 1.2(stat) \pm 0.4(sys)) \times 10^{-5}$$

Table 11: Final branching fraction measurements.



(a) $B^{\pm} \rightarrow J/\psi\phi K^{\pm}$. (b) $B^{0} \rightarrow J/\psi\phi K^{0}_{S}$

Figure 6: m_{ES} fits to the Monte Carlo sample cocktails.



(a) $B^{\pm} \rightarrow J/\psi\phi K^{\pm}$. (b) $B^{0} \rightarrow J/\psi\phi K^{0}_{S}$

Figure 7: m_{ES} fits to the data sample, 412 fb^{-1}.

6 CONCLUSIONS

In summary, we observed the three-body decay $B \to J/\psi\phi K$ and we performed the branching fraction measurements listed in Table 11 with a significance corresponding to 9.9 and 4.9 standard deviations for the charged and the neutral B decay modes, respectively. The significance was evaluated as $\sqrt{(2 \times \Delta(ln\ \mathcal{L}))}$, $\mathcal{L}$ = likelihood.
The measured ratio R = $\mathcal{B}(B^0 \to J/\psi\phi K^0_S)/\mathcal{B}(B^\pm \to J/\psi\phi K^\pm) = (0.48 \pm 0.13)$ is consistent with the expectation of the spectator model (R = 0.5) shown in Fig. 1.

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References

[1] N. Brambilla *et al.*, *Yellow Report*, hep-ph/0412188 (2005);

[2] Barnes and Godfrey, PRD 69, 054008 (2004);
Eichten, Lane and Quigg, PRD 69, 094019 (2004);
Swanson, PLB 588, 189 (2004);
Tornqvist, PLB 590, 209 (2004);
Suzuki, PRD 72, 114013 (2005);
Maiani, et. al., PRD 71, 014028 (2005).

[3] Y.S. Kalashnikova, A.V. Nefediev, Phys. Rev. D. **77**, (2008) 054025.

[4] The *BABAR* collaboration, B. Aubert *et al.*, hep-ex/0803.2838; Phys. Rev. D. **71**, (2005) 071103; Phys. Rev. D. **77** (2007) 011102; Phys. Rev. D. **77** (2008) 111101;

[5] The *BABAR* Collaboration, B.Aubert *et al.*, Phys. Rev. Lett. **91**, 262001 (2003); Phys. Rev. D. **75** (2005) 142001; Phys. Rev. D. **73** (2006) 011101.

[6] The *BABAR* Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **91** 071801 (2003).

[7] The CLEO Collaboration, A. Anastassov *et al.* Phys. Lett. **B369**, 186 (1996) 360.

[8] C. Amsler *et al.* [Particle Data Group], Phys. Lett. B667, 1 (2008).

[9] The *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instrum. Methods **A479**, 1-116 (2002).

[10] The ARGUS Collaboration, H. Albrecht *et al.*, **B241** (1990) 278.

[11] RooFit User Manual v2.07, V. Verkerke, D. Kirkby. arXiv/physics/0306116