Study of $B^{\pm,0} \rightarrow J/\psi K^+K^-K^{\pm,0}$ and search for $B^0 \rightarrow J/\psi \phi$ at $\text{BaBar}$

J. P. Lees, V. Poireau, and V. Tisserand

Laboratoire d’Annecy-le-Vieux de Physique des Particules (LAPP),
Université de Savoie, CNRS/IN2P3, F-74941 Annecy-Le-Vieux, France

E. Grauges

Universitat de Barcelona, Facultat de Fisica, Departament ECM, E-08028 Barcelona, Spain

A. Palano$^{ab}$

INFN Sezione di Bari$^a$; Dipartimento di Fisica, Università di Bari$^b$, I-70126 Bari, Italy

G. Eigen and B. Stugu

University of Bergen, Institute of Physics, N-5007 Bergen, Norway

D. N. Brown, L. T. Kerth, Yu. G. Kolomensky, M. J. Lee, and G. Lynch

Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA

H. Koch and T. Schroeder

Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

C. Hearty, T. S. Mattison, J. A. McKenna, and R. Y. So

University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1

A. Khan

Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom

V. E. Blinov$^{ac}$, A. R. Buzykaev$^a$, V. P. Druzhinin$^{ab}$, V. B. Golubev$^{ab}$, E. A. Kravchenko$^{ab}$, A. P. Omuchin$^{ac}$, S. I. Serednyakov$^{ab}$, Yu. I. Skovpen$^{ab}$, E. P. Solodov$^{ab}$, K. Yu. Todyshev$^{ab}$, and A. N. Yushkov$^a$

Budker Institute of Nuclear Physics SB RAS, Novosibirsk 630090$^a$,
Novosibirsk State University, Novosibirsk 630090$^b$,
Novosibirsk State Technical University, Novosibirsk 630092$^c$, Russia

A. J. Lankford and M. Mandelkern

University of California at Irvine, Irvine, California 92697, USA

B. Dey, J. W. Gary, and O. Long

University of California at Riverside, Riverside, California 92521, USA

C. Campagnari, M. Franco Sevilla, T. M. Hong, D. Kovalskyi, J. D. Richman, and C. A. West

University of California at Santa Barbara, Santa Barbara, California 93106, USA

A. M. Eisner, W. S. Lockman, W. Panduro Vazquez, B. A. Schumann, and A. Seiden

University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA

D. S. Chao, C. H. Cheng, B. Echenard, K. T. Flood, D. G. Hitlin, T. S. Miyashita, P. Ongmongkolkul, and F. C. Porter

California Institute of Technology, Pasadena, California 91125, USA

R. Andreassen, Z. Huard, B. T. Meadows, B. G. Pushpawela, M. D. Sokoloff, and L. Sun

University of Cincinnati, Cincinnati, Ohio 45221, USA

P. C. Bloom, W. T. Ford, A. Gaz, U. Nauenberg, J. G. Smith, and S. R. Wagner

University of Colorado, Boulder, Colorado 80309, USA

R. Ayad$^a$ and W. H. Toki
I. INTRODUCTION

Many charmonium-like resonances have been discovered in the past, revealing a spectrum too rich to interpret in terms of conventional mesons, expected from potential models [1]. In several cases, it has not been possible to assign a spin-parity value to the resonance. Some of them have been extensively investigated as possible candidates for non-conventional mesons, such as tetraquarks, glueballs, or hybrids [2].

In a search for exotic states, the CDF experiment studied the decay $B^+ \rightarrow J/\psi K^+ K^0$, where $J/\psi \rightarrow \mu^+ \mu^-$ and $\phi(1020) \rightarrow K^+ K^-$, claiming the observation of a resonance labeled as the $X(4140)$ decaying to $J/\psi \phi$ [3]. They found evidence in the same decay mode for another resonance, labeled as the $X(4270)$ [4]. Recently, the LHCb experiment studied the decay $B^+ \rightarrow J/\psi \phi K^+$ in $pp$ collisions at 7 TeV, with a data sample more than three times larger than that of CDF, and set an upper limit (UL) incompatible with the CDF result [6]. The D0 and the CMS experiments more recently made studies of the same decay channel, leading to different conclusions [6] than the LHCb experiment.

In this work we study the rare decays $B^\pm \rightarrow J/\psi K^\pm K^\mp$, $B^0 \rightarrow J/\psi \phi$, and search for possible resonant states in the $J/\psi \phi$ mass spectrum. We also search for the decay $B^0 \rightarrow J/\psi \phi$, which can result only from rescattering $b \bar{d}$ to $c \bar{c} dd$ with rescattering of $d \bar{d}$ to $s \bar{s}$, therefore no signal is expected.

This paper is organized as follows. In Sec. II we describe the detector and data selection and in Sec. III we report the branching fractions (BF) measurements. Section IV is devoted to the resonance search, while Sec. V summarizes the results.

II. THE BAbAR DETECTOR AND DATA SELECTION

We make use of the data set collected by the BAbar detector at the PEP-II $e^+ e^-$ storage rings operating at the $\Upsilon(4S)$ resonance. The integrated luminosity for this
analysis is 422.5 fb$^{-1}$, which corresponds to the production of 469 million $B\bar{B}$ pairs.

The $\text{BABAR}$ detector is described in detail elsewhere. We mention here only the components of the detector that are used in the present analysis. Charged particles are detected and their momenta measured with a combination of a cylindrical drift chamber (DCH) and a silicon vertex tracker (SVT), both operating within the 1.5 T magnetic field of a superconducting solenoid. Information from a ring-imaging Cherenkov detector (DIRC) is combined with specific ionization measurements from the SVT and DCH to identify charged kaon and pion candidates. The efficiency for kaon identification is 90% while the rate for a pion being misidentified as a kaon is 2%. For low transverse momentum kaon candidates that do not reach the DIRC, particle identification relies only on the energy loss measurement, so that the transverse momentum spectrum of identified kaons extends down to 150 MeV/c. Electrons are identified using information provided by a CsI(Tl) electromagnetic calorimeter (EMC), in combination with that from the SVT and DCH, while muons are identified in the Instrumented Flux Return (IFR). This is the outermost subdetector, in which muon/pion discrimination is performed. Photons are detected, and their energies measured with the EMC.

For each signal event candidate, we first reconstruct the $J/\psi$ by geometrically constraining to a common vertex a pair of oppositely charged tracks, identified as either electrons or muons, and requiring a $\chi^2$ fit probability larger than 0.1%. For $J/\psi \to e^+e^-$ we use bremsstrahlung energy-loss recovery: if an electron-associated photon cluster is found in the EMC, its three-momentum vector is incorporated into the calculation of the invariant mass $m_{e^+e^-}$. The vertex fit for a $J/\psi$ candidate includes a constraint to the nominal $J/\psi$ mass value.

For $B^+ \to J/\psi K^+ K^- K^+$ candidates, we combine the $J/\psi$ candidate with three loosely identified kaons and require a vertex probability larger than 0.1%. Similarly, for $B^0 \to J/\psi K^- K^+ K^0_s$ candidates, we combine the $J/\psi$ and $K^0_s$ with two loosely identified kaons and require a vertex probability larger than 0.1%.

A $K^0_s$ candidate is formed by geometrically constraining a pair of oppositely charged tracks to a common vertex, with $\chi^2$ fit probability larger than 0.1%. The pion mass is assigned to the tracks without particle-identification (PID) requirements. The three-momenta of the two pions are then added and the $K^0_s$ energy is computed using the nominal $K^0_s$ mass. We require the $K^0_s$ flight length significance with respect to the $B^0$ vertex to be larger than 3σ.

We further select $B$ mesons candidates using the energy difference $\Delta E \equiv E^i_B - \sqrt{s}/2$ in the center-of-mass frame and the beam-energy-substituted mass defined as $m_{ES} \equiv \sqrt{(s)/2 + p_i \cdot \vec{p}_B}/E_i^2 - \vec{p}_B^2$, where $(E_i, \vec{p}_i)$ is the initial state $e^+e^-$ four-momentum vector in the laboratory frame and $\sqrt{s}$ is the center-of-mass energy. In the above expressions $E^i_B$ is the $B$ meson candidate energy in the center-of-mass frame, and $\vec{p}_B$ is its laboratory frame momentum.

When multiple candidates are present, the combination with the smallest $\Delta E$ is chosen. The final selection requires $|\Delta E| < 30$ MeV and $|\Delta E| < 25$ MeV for $B^+$ and $B^0$ decays, respectively; the additional selection criterion $m_{ES} > 5.2$ GeV/c$^2$ is required for the calculation of the BF's, while $m_{ES} > 5.27$ GeV/c$^2$ is applied to select the signal region for the analysis of the invariant mass systems.

### III. BRANCHING FRACTIONS

Fig. 1 shows the $m_{ES}$ distributions for (a) $B^+ \to J/\psi K^+ K^- K^+$ and (b) $B^0 \to J/\psi K^- K^+ K^0_s$ candidates after having applied the $\Delta E$ selections described in Sec. II, while the corresponding $\Delta E$ distributions are shown in Fig. 2(c) and Fig. 2(d), respectively, for $m_{ES} > 5.27$ GeV/c$^2$. Fig. 2 shows the $K^+ K^-$ invariant mass distributions in the region $m_{K^+ K^-} < 1.1$ GeV/c$^2$ for (a) $B^+$ and (b) $B^0$ candidates. A $\phi(1020)$ signal is present in both mass spectra. The background contributions, estimated from the $\Delta E$ sidebands in the range $40 < |\Delta E| < 70$ MeV are shown as shaded histograms in Fig. 2(a) and Fig. 2(b), and they are small.

We select the $\phi(1020)$ signal region to be in the mass range $[1.004; 1.034]$ GeV/c$^2$. Fig. 2 shows the $m_{ES}$ distributions for (c) $B^+ \to J/\psi K^+ K^+$ and (d) $B^0 \to J/\psi K^0_s$ candidates, respectively, for events in the $\phi$ mass region, which satisfy the $\Delta E$ selection criteria. Fig. 2(e) and Fig. 2(f) show the $\Delta E$ distributions for $m_{ES} > 5.27$ GeV/c$^2$, when requiring the $K^+ K^-$ invariant mass to be in the $\phi(1020)$ signal region. The distributions of Fig. 2(c) and Fig. 2(e) contain 212 events in the $\phi$ signal region, with an estimated background of 23 events; those of Fig. 2(d) and Fig. 2(f) contain 50 events in the $\phi$ signal region, with an estimated background of 9 events.

We search for the decay $B^0 \to J/\psi$ by constraining to a common vertex a fitted $J/\psi$ with two loosely identified kaon candidates. Possible backgrounds originating from the decay $B^0 \to J/\psi K^{0*}(892), K^{0*}(892) \to K^- \pi^+$, and from the channel $B^0 \to J/\psi K_1(1270), K_1(1270) \to K^- \pi^+ \pi^0$ are found consistent with zero, after applying a dedicated selection as described in Sec. II and III. Fig. 3 shows the corresponding $m_{ES}$ and $\Delta E$ distributions. We do not observe a significant signal for this decay mode.

An unbinned maximum likelihood fit to each $m_{ES}$ distribution is performed to determine the yield and obtain a BF measurement. We use the sum of two functions to parametrize the $m_{ES}$ distribution: a Gaussian function describes the signal, and an ARGUS function the background. The study of the $\Delta E$ sidebands does not show the presence of peaking backgrounds. Table I summarizes the fitted yields obtained.

As a validation test we fit, for the $B^+ \to J/\psi K^+$ and the $B^0 \to J/\psi K^0_s$ decays, the $\Delta E$ distributions...
shown in Fig. 2(e) and Fig. 2(f) respectively, using a double Gaussian model for the signal and a linear function for the background, and we obtain yields consistent with those from the $m_{ES}$ fits.
FIG. 2: (a) $K^+K^-$ mass spectrum, (c) $m_{ES}$, and (e) $\Delta E$ distributions for $B^+ \rightarrow J/\psi K^+$. (b) $K^+K^-$ mass spectrum, (d) $m_{ES}$, and (f) $\Delta E$ distributions for $B^0 \rightarrow J/\psi K^0_S$. The dots are the data points, the shaded (yellow) distributions are obtained from the $\Delta E$ sidebands. Vertical (blue) lines indicate the selected signal region. In (a) and (b) the $m_{ES}$ and $\Delta E$ selection criteria described in Sec. II have been applied.

FIG. 3: (a) $m_{ES}$ and (b) $\Delta E$ distributions for $B^0 \rightarrow J/\psi \phi$ event candidates. The curves in (a) and (b) are the result of the fit described in the text.

The signals in Fig. 1 corresponding to the $B^+ \rightarrow J/\psi K^+K^-K^+$ and the $B^0 \rightarrow J/\psi K^+K^-K^0_S$ decays, yield 14.4$\sigma$ and 5.5$\sigma$ significance, respectively; while those in Fig. 2 which restrict the invariant mass $m_{K^+K^-}$ to the signal area of the $\phi(1020)$ meson, are observed with significance 16.1$\sigma$ and 5.6$\sigma$, respectively. In this paper the statistical significance of the peaks is evaluated as $\sqrt{-2\ln(L_0/L_{\text{max}})}$, where $L_{\text{max}}$ and $L_0$ represent the maximum likelihood with the fitted signal yield and with yield fixed to zero, respectively.

We estimate the efficiency for the different channels using Monte Carlo (MC) simulations. For each channel we perform full detector simulations where $B$ mesons decay uniformly over the available phase space (PHSP). These simulated events are then reconstructed and analyzed as are the real data. These MC simulations are also used to
validate the analysis procedure and the BF extractions.

Table I reports the resulting integrated efficiencies for the different channels, and the efficiency-corrected yields. The yields are computed with two different approaches to determining the efficiency. In the first approach, the averaged efficiency based on PHSP distributions is used. In the second approach, the efficiency is allowed to vary over the Dalitz plot. The difference between the two approaches shows that in the low-mass region of the invariant mass \( m_{K^+K^-} \) more events are seen than would be on the basis of PHSP expectations. This effect is visible in Fig. 4 where lower efficiency is seen at low \( K^+K^- \) mass (\( \phi \) mass region). The impact on the BFs may be observed in Table 1. The charged B channels are affected more than the neutral B channels.

Systematic uncertainties affecting the BF measurements are listed in Table II. The evaluation of the integrated luminosity is performed using the method of \( BB \) counting [10], and we assign a uniform 0.6% uncertainty to all the final states. The uncertainty on the efficiency evaluation related to the size of the MC simulations is negligible with respect to the other contributions. The systematic uncertainty on the charged particle track reconstruction efficiency is estimated from the comparison of data samples and full detector simulations for well-chosen decay modes. In a similar way we obtain a 1.7% systematic uncertainty in the reconstruction of \( B_s^0 \) meson decays. In the case of the \( B^0 \to J/\psi \phi K_s^0 \) and \( B^+ \to J/\psi \phi K^+ \) final states, since the \( J/\psi \) and the \( \phi \) are vector states, we compute the efficiency also under the assumption that the two vectors are transversely or longitudinally polarized. We also consider the uncertainties related to the choice of the probability density functions (pdf) in the fit procedure, by varying fixed parameters by \( \pm \sigma \) in their uncertainties, and we evaluate the variations in the efficiency of PID for the charged particle tracks. All uncertainties are added in quadrature. We note that the BF of \( B^+ \to J/\psi \phi K^+ \) is in agreement with the previous published \( BABAR \) measurement [14], which dominates the world average [11], but now we obtain more than 4 times better precision. BFs of the decays \( B^+ \to J/\psi K^+ K^- K^+ \) and \( B^0 \to J/\psi K^+ K^- K_s^0 \) are first observations.

We estimate an upper limit (UL) at 90% confidence level (c.l.) for the BF of the decay \( B^0 \to J/\psi \phi \). The signal yield obtained from the fit to the \( m_{ES} \) distribution is 6±4 events (Fig. 3(a)), corresponding to an UL at 90% c.l. of 14 events. The Feldman-Cousins method [15] is used to evaluate ULs on BFs. Ensembles of pseudo-experiments are generated according to the pdfs for a given signal yield (10000 sets of signal and background events), and fits are performed. We obtain an UL on the \( B^0 \to J/\psi \phi \) BF of 1.01×10^{-6}. The Belle Collaboration reported a limit of 0.94×10^{-6} [16], while a recent analysis from the LHCb Collaboration lowers this limit to 1.9×10^{-7} [17].

We compute the ratios:

\[
R_+ = \frac{B(B^+ \to J/\psi K^+ K^- K^+)}{B(B^+ \to J/\psi \phi K^+)} = 1.39 \pm 0.15 \pm 0.07
\]
and
\[ R_0 = \frac{B(B^0 \to J/\psi K^+ K^- K^0_S)}{B(B^0 \to J/\psi K^+ K^-)} = 1.54 \pm 0.40 \pm 0.08, \]
and they are consistent with being equal within the uncertainties. For the ratios:
\[ R_\phi = \frac{B(B^0 \to J/\psi K_S^0)}{B(B^0 \to J/\psi K^+)} = 0.48 \pm 0.09 \pm 0.02 \]
and
\[ R_{2K} = \frac{B(B^0 \to J/\psi K^+ K^- K^0_S)}{B(B^0 \to J/\psi K^+ K^-)} = 0.52 \pm 0.09 \pm 0.03, \]
we find values in agreement with the expectation of the spectator quark model \cite{18,19} \((R_\phi \sim R_{2K} \sim 0.5)\).

IV. SEARCH FOR RESONANCE PRODUCTION

We plot in Fig. 4(a) the \(J/\psi K^+ K^-\) mass distributions for \(B^+ \to J/\psi K^+ K^- K^0_S\) and in Fig. 4(b) that for \(B^0 \to J/\psi K^- K^+ K^0_S\), the signal regions are defined by the \(\Delta E\) selections indicated in Sec. II and \(m_{ES} > 5.27\) GeV/c^2. No prominent structure is observed in either of the mass spectra.

We search for the resonant states reported by the CDF Collaboration in the \(J/\psi\phi\) mass spectrum \cite{5}. The masses and the widths are fixed to \(m=4143.4\) MeV/c^2 and \(\Gamma=15.3\) MeV for the \(X(4140)\), and \(m=4274.4\) MeV/c^2 and \(\Gamma=32.3\) MeV for the \(X(4270)\) resonance. We evaluate the mass resolution using MC simulations and we obtain 2 MeV/c^2 resolution in the mass region between 4100 MeV/c^2 and 4300 MeV/c^2. Therefore resolution effects can be ignored because they are much smaller than the widths of the resonances under consideration.

We estimate the efficiency on the Dalitz plot as the ratio between the reconstructed and generated distributions, where the values are generated according to PHSP. Fig. 5 shows the resulting distributions evaluated over the \(m_{J/\psi\phi}^2, m_{K^0_S}^2\) plane for the charged and neutral (b) \(B\) decay, respectively. The lower efficiency at low \(J/\psi\phi\) mass is due to the lower reconstruction of low kaon momentum in the laboratory frame, as a result of energy loss in the beampipe and SVT material.

To search for these two resonances, we perform an unbinned maximum likelihood fit to the \(B \to J/\psi K\) decays. We model the resonances using S-wave relativistic Breit-Wigner (BW) functions with parameters fixed to the CDF values. The non-resonant contributions are represented by a constant term and no interference is allowed between the fit components. We estimate the background contributions from the \(\Delta E\) sidebands and find them to be small and consistent with a PHSP behavior, so in the fits they are incorporated into the non-resonant PHSP term. The decay of a pseudoscalar meson to two vector states contains high spin contributions which could generate non-uniform angular distributions. However, due to the limited data sample we do not include such angular terms, and assume that the resonances decay isotropically. The amplitudes are normalized using PHSP MC generated events with \(B\) parameters obtained from the fit to the data. The fit functions are weighted by the the two-dimensional efficiency computed on the Dalitz plots.

We perform fits separately for the charged \(B^-\) sample and the combined \(B^+\) and \(B^0\) samples. Due to the very limited statistics of the \(B^0\) sample we do not perform a separate fit, but we subtract the fit to the \(B^-\) sample from the fit to the combined \(B^+\) and \(B^0\) sample. In this case we make use of the two different efficiencies for the two channels. In the MC simulation performed, we make use of a weighted mean of the two efficiencies evaluated on the respective Dalitz plots.

Table III summarizes the results from the fits. We report the fit fractions for the two resonances, \(f_X(4140)\) and \(f_X(4270)\), the two-dimensional (2D) \(\chi^2\) computed on the Dalitz plot and the one-dimensional (1D) \(\chi^2\) computed on the \(J/\psi\phi\) mass projection. For this purpose, using an adaptive binning method, we divide the Dalitz plot into a number of cells in such a way that the minimum expected population per cell is not smaller than \(7\). We then compute the \(\chi^2 = \sum_i (N_{obs}^i - N_{exp}^i)^2 / N_{exp}^i\) where \(N_{obs}^i\) and \(N_{exp}^i\) are the data and MC simulation event yields, respectively. Indicating with \(n\) the number of free parameters, corresponding to the number of resonances included in the fit, the number of degrees of freedom is \(\nu = N_{cells} - n\). For computing the 1D \(\chi^2\) we rebin the \(J/\psi\phi\) mass projection into 25 bins, again with at least \(7\) entries per bin.

We perform the fits using models with two resonances (labeled as model A), one resonance (models B and C), and no resonances (model D). The fit projections for fit A are displayed in Fig. 6 showing enhancements with a statistical significance smaller than \(3.2\sigma\) for all fit models. All models provide a reasonably good description of the data, with \(\chi^2\) probability larger than \(1\%\).

We estimate systematic uncertainties on the fractions by varying the masses and the widths of both resonances within their parameters uncertainties. The results shown in Table III are corrected by the fraction of background estimated in the sample, which corresponds to a correction factor of \(1.12\) and \(1.21\) for the \(B^-\) and the \(B^0\) channels, respectively. We obtain the following background-corrected fractions for \(B^+\):

\[ f_X(4140) = (9.2 \pm 3.3 \pm 4.7)\%, \quad f_X(4270) = (10.6 \pm 4.8 \pm 7.1)\%. \]

Combining statistical and systematic uncertainties in quadrature, we obtain significances of \(1.6\) and \(1.2\sigma\) for \(X(4140)\) and \(X(4270)\), respectively.

Using the Feldman-Cousins method \cite{15}, we obtain the ULs at 90\% c.l.:

\[
\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi \phi) / \mathcal{B}(B^+ \to J/\psi \phi K^+) < 0.135
\]
TABLE III: Fits to the $B \rightarrow J/\psi \phi K$ Dalitz plot. For each fit, the table gives the fit fraction for each resonance, and the 2D and 1D $\chi^2$ values. The fractions are corrected for the background component.

| Channel | Fit | $f_{X(4140)}(\%)$ | $f_{X(4270)}(\%)$ | 2D $\chi^2/\nu$ | 1D $\chi^2/\nu$ |
|---------|-----|---------------------|---------------------|-----------------|-----------------|
| $B^+$   | A   | 9.2 ± 3.3           | 10.6 ± 4.8          | 12.7/12         | 6.5/20          |
|         | B   | 9.2 ± 2.9           | 0.0                 | 17.4/13         | 15.0/17         |
|         | C   | 0.0                 | 10.0 ± 4.8          | 20.7/13         | 19.3/19         |
|         | D   | 0.0                 | 0.0                 | 26.4/14         | 34.2/18         |

$B^0 + B^+$ A 7.3 ± 3.8 12.0 ± 4.9 8.5/12 15.9/19

FIG. 6: Dalitz plot projections for $B^+ \rightarrow J/\psi \phi K^+$ on (a) $m_{J/\psi \phi}$, (b) $m_{J/\psi \phi}^2$, and (c) $m_{J/\psi \phi}^2$. The continuous (red) curves are the results from fit model A performed including the $X(4140)$ and $X(4270)$ resonances. The dashed (blue) curve in (a) indicates the projection for fit model D, with no resonances. The shaded (yellow) histograms indicate the background estimated from the $\Delta E$ sidebands.

$$B(B^+ \rightarrow X(4270)K^+) \times B(X(4270) \rightarrow J/\psi \phi) / B(B^+ \rightarrow J/\psi \phi K^+) < 0.184.$$ (7)

The Feldman-Cousin intervals are evaluated as explained in Ref. 15 and in Sec. III. The $X(4140)$ limit may be compared with the CDF measurement of $0.149 \pm 0.039 \pm 0.024$ Ref. 4 and the LHCb limit of 0.07 Ref. 6. The $X(4270)$ limit may be compared with the LHCb limit of 0.08.

The fit projections on the $J/\psi \phi$ mass spectrum using the fit model A with two resonances are shown in Fig. 6(a) for $B^+$, in Fig. 6(b) for $B^0$, and in Fig. 6(c) for the combined $B^+$ and $B^0$ sample. The fit results are summarized in Table III.

The central values of mass and width of the two resonances are also fixed to the values recently published from CMS Ref. 8. In this case we obtain, for the $B^+$ data, the following background-corrected fractions:

$$f_{X(4140)} = (13.2 \pm 3.8 \pm 6.8)\%, f_{X(4270)} = (10.9 \pm 5.2 \pm 7.3)\%.$$ (8)

These values are consistent within the uncertainties with those obtained in Eq. 5. For comparison, CMS reported a fraction of $0.10 \pm 0.03$ for the $X(4140)$, compatible with CDF, LHCb and our values within the uncertainties. CMS could not determine reliably the significance of the second structure $X(4270)$ due to possible reflections of two-body decays.

Fig. 7(a) shows the efficiency as a function of the $J/\psi \phi$ mass, obtained from a PHSP simulation of the $B^+ \rightarrow J/\psi \phi K^+$ Dalitz plot. We observe a decrease of the efficiency in the $J/\psi \phi$ threshold region, already observed in Fig. 4. Fig. 7(b) shows the efficiency corrected $J/\psi \phi$ mass spectrum for the combined $B^+$ and $B^0$ samples. To obtain this spectrum, we weight each event by the inverse of the efficiency evaluated on the respective $B^+$ and $B^0$ Dalitz plots. The curve is the result from fit model A. The background contribution (shown shaded) is estimated from the $\Delta E$ sidebands and has also been corrected for efficiency. However, since part of the background events fall outside the efficiency Dalitz plots, we assume the same efficiency as for $B$ signal events.

Finally, Fig. 7(c) shows the efficiency corrected and background subtracted $J/\psi \phi$ mass spectrum for the combined $B^+$ and $B^0$ samples.

V. SUMMARY

In summary, we perform a study of the decays $B^{+}\rightarrow J/\psi K^{0}K^{-}K^{+}$ and $B^{+} \rightarrow J/\psi K^{0}K^{+}$, obtaining currently the most precise BF measurements. We search for resonance production in the $J/\psi \phi$ mass spectrum and obtain significances below 2\sigma for both the $X(4140)$ and the $X(4270)$ resonances, within systematic uncertainties. Limits on the BF of these resonances are obtained. We find that the hypothesis that the events are distributed uniformly on the Dalitz plot gives a poorer description of the data. We also search for $B^0 \rightarrow J/\psi \phi$ and derive an UL on the BF for this decay mode, which is in agreement with theoretical expectations.
FIG. 7: Projections on the $J/\psi \phi$ mass spectrum from the Dalitz plot fit with the $X(4140)$ and the $X(4270)$ resonances for the (a) $B^+$, (b) $B^0$, and (c) combined $B^+$ and $B^0$ data samples. The continuous (red) curves result from the fit; the dashed (blue) curve in (a) indicates the projection for fit model D, with no resonances. The shaded (yellow) histograms show the background contributions estimated from the $\Delta E$ sidebands.

FIG. 8: (a) Average efficiency distribution as a function of the $J/\psi \phi$ mass for $B^+ \rightarrow J/\psi \phi K^+$. (b) Efficiency corrected $J/\psi \phi$ mass spectrum for the combined $B^+$ and $B^0$ samples. The curve is the result from the fit model A described in the text. The shaded (yellow) histogram represents the efficiency corrected background contribution. (c) Efficiency corrected and background subtracted $J/\psi \phi$ mass spectrum for the combined $B^+$ and $B^0$ samples.

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