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Measurement of the branching fraction for $B^{\pm}\to\chi_{c0}K^{\pm}$

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We present a measurement of the branching fraction of the decay $B^{\pm}\to\chi_{c0}K^{\pm}$ from a sample of 89×10^6 $B\overline{B}$ pairs collected by the *BABAR* detector at the SLAC PEP-II asymmetric-energy B factory. The χ_{c0} meson is reconstructed through its two-body decays to $\pi^+\pi^-$ and K^+K^-. We measure $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})\times\mathcal{B}(\chi_{c0}\to\pi^+\pi^-)=[1.32^{+0.28}_{-0.27}(\text{stat})\pm0.26(\text{syst})]\times10^{-6}$ and $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})\times\mathcal{B}(\chi_{c0}\to K^+K^-)=[1.49^{+0.36}_{-0.34}(\text{stat})\pm0.22(\text{syst})]\times10^{-6}$. Using the known values for the χ_{c0} decays branching fractions, we combine these results to obtain $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})=(2.7\pm0.7)\times10^{-4}$.

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In the simplest approximation, weak decays such as $B\to J/\psi K$ arise from the quark-level process $b\to c\overline{c}s$ through a current-current interaction that can be written as $[\overline{c}\gamma^{\mu}(1-\gamma_5)c][\overline{s}\gamma_{\mu}(1-\gamma_5)b]$. The colorless current $\overline{c}\gamma_{\mu}(1-\gamma_5)c$, which can create the J/ψ, can also create the P-wave state χ_{c1}. It cannot, however, create χ_{c0}, χ_{c2}, or h_c, so their appearance would have to be ascribed to more complex mechanisms. The $b\to c\overline{c}s$ process also occurs through the interaction of two color-octet currents $J_8^{\mu(\overline{cc})}J_{8\mu}^{(\overline{sb})}=[\overline{c}(\lambda_a/2)\gamma_{\mu}(1-\gamma_5)c]\,[\overline{s}(\lambda_a/2)\gamma^{\mu}(1-\gamma_5)b]$, where λ_a are color $SU(3)$ matrices. The current $J_8^{\mu(\overline{cc})}$ can create a color-octet $c\overline{c}$ pair in an S state, which can then radiate a soft gluon to produce a P-wave bound state [1,2].

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Alternatively, the χ_{c0}, χ_{c2}, h_c states might arise from final state interactions that mix the $(c\bar{c})K$ channel with channels like $D^{(*)}D_s^{(*)}$ [3].

The first evidence for the $B^{\pm}\to\chi_{c0}K^{\pm}$ decay was reported by the Belle Collaboration [4], who measured $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})=(6.0^{+2.1}_{-1.8}\pm1.1)\times10^{-4}$ on a sample of 31.3×10^6 $B\bar{B}$ events. Previously CLEO had reported an upper limit of $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})<4.8\times10^{-4}$ at 90% C.L. [5].

This work presents the study of the $B^{\pm}\to\chi_{c0}K^{\pm}$ decay using data collected by the *BABAR* detector operating at the SLAC PEP-II asymmetric energy e^+e^- collider. The data sample consists of 81.9 fb^{-1} collected at the $\Upsilon(4S)$ resonance containing 88.9×10^6 $B\bar{B}$ pairs.

The *BABAR* detector is fully described elsewhere [6]. It consists of a tracking system for the detection of charged particles, a Cherenkov detector (DIRC) for particle identification, an electromagnetic calorimeter, and a detector for muon and K_L^0 identification. The tracking system includes a five-layer, double-sided silicon vertex tracker and a 40-layer drift chamber filled with a mixture of helium and isobutane, both in a 1.5-T magnetic field supplied by a superconducting solenoidal magnet. The DIRC is a novel imaging Cherenkov detector relying on total internal reflection in the radiator. The electromagnetic calorimeter consists of 6580 CsI(Tl) crystals. The iron flux return is segmented and instrumented with resistive plate chambers for muon and K_L^0 identification.

Events with $B\bar{B}$ pairs are selected by requiring the presence of at least three charged tracks, the ratio of the second to the zeroth order Fox-Wolfram moment [7] to be less than 0.5 and the total energy of all the charged and neutral particles to be greater than 4.5 GeV. We consider only events where at least one track identified as a kaon has a momentum greater than 900 MeV/c in the e^+e^- center-of-mass frame.

We reconstruct the χ_{c0} meson in the decay modes $\chi_{c0}\to\pi^+\pi^-$ and $\chi_{c0}\to K^+K^-$ from an oppositely charged pair of tracks identified as both pions or both kaons, respectively. Candidates for the decay $B^{\pm}\to\chi_{c0}K^{\pm}$ are formed by combining a track identified as a charged kaon (referred to as the "bachelor" kaon in the following) with a χ_{c0} candidate and performing a geometrical vertex fit. The efficiency for the kaon selection used is between 70% and 90%, depending on momentum, while the probability for a pion to be misidentified as a kaon is below 5%. All the tracks are required to have polar angles in the region $0.35<\theta<2.54$ rad, to have at least 12 hits in the drift chamber and a transverse momentum with respect to the beam direction larger than 100 MeV/c. In addition, tracks consistent with being from $K_s^0\to\pi^+\pi^-$, $\eta\to\pi^+\pi^-\pi^0$, $\Lambda\to p\pi^-$ ($\bar{\Lambda}\to\bar{p}\pi^+$) decays and tracks from γ conversions are rejected. The χ_{c0} candidates are required to have invariant mass in the range $3.32<m_{\chi_{c0}}<3.50$ GeV/c^2.

To reject the large combinatorial background coming from continuum $q\bar{q}$ events, a Fisher discriminant $\mathcal{F}$ [8] is used, built from a linear combination of 11 quantities related to the event shape or the B kinematics. The coefficients are determined by maximizing the separation between signal and continuum background on simulated events.

The selection of B candidates relies on the kinematic constraints given by the $\Upsilon(4S)$ initial state. Two variables are defined: the beam-energy substituted mass, $m_{\rm ES}=\sqrt{(s/2+\mathbf{p}_0\cdot\mathbf{p})^2/E_0^2-|\mathbf{p}|^2}$, and $\Delta E=E^*-\sqrt{s}/2$, where $\mathbf{p}$ is the momentum of the B candidate and $(E_0,\mathbf{p}_0)$ is the four-momentum of the initial state in the laboratory frame, and E^* is the B candidate energy and $\sqrt{s}$ is the total energy in the center-of-mass frame. For the $B^{\pm}\to\chi_{c0}K^{\pm}$, $\chi_{c0}\to K^+K^-$ mode, when an ambiguity arises in cases with the same three final state kaons, we select as the bachelor kaon the one with the highest center-of-mass momentum.

The values of the cuts for $\mathcal{F}$, $m_{\rm ES}$, and ΔE are determined by an optimization procedure aimed at maximizing the value of $S/\sqrt{S+B}$. The number S of signal candidates and B of background events surviving the selection are estimated on samples of simulated events and data from the ΔE "sidebands" of the $m_{\rm ES}$-ΔE plane, respectively. The sidebands are defined by $5.2<m_{\rm ES}<5.3$ GeV/c^2, $0.1<|\Delta E|<0.2$ GeV. The relative normalization of the signal and background samples is determined by assuming the value measured by Belle for $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})$ and the world average for $\mathcal{B}(\chi_{c0}\to\pi^+\pi^-)$ and $\mathcal{B}(\chi_{c0}\to K^+K^-)$ [9]. The signal regions in ΔE and $m_{\rm ES}$ are defined by $-45<\Delta E<35$ MeV, $m_{\rm ES}>5.2750$ GeV/c^2 for the $\chi_{c0}\to\pi^+\pi^-$ mode and by $-70<\Delta E<60$ MeV, $m_{\rm ES}>5.2735$ GeV/c^2 for the $\chi_{c0}\to K^+K^-$ mode.

We apply a veto on fully reconstructed $B\to D^{(*)}h$ decays, where h denotes a π, K, or ρ meson. We reject B candidates if at least one of their decay products also contributes to the reconstruction of a $B\to D^{(*)}h$ decay, with $|\Delta E|<30$ MeV and $m_{\rm ES}>5.27$ GeV/c^2. To reduce the residual contamination from other B decays with charmed or charmless mesons in the final state, we require the invariant mass of the pair formed by the bachelor kaon with the oppositely charged track from the χ_{c0} decay to be greater than 2 GeV/c^2.

The main source of the noncombinatorial background remaining after the selection described comes from nonresonant B decays with the same final state as the signal, $B^{\pm}\to K^{\pm}\pi^+\pi^-$ and $B^{\pm}\to K^{\pm}K^+K^-$. A reliable evaluation of the expected contamination from these processes cannot be obtained based on the available measurements. These modes are expected to behave as a "peaking background," that is, to peak in $m_{\rm ES}$ and ΔE, while the distribution of $m_{\chi_{c0}}$ is expected to be flat: this is used to separate their contribution from the signal by means of a fit to the data, as described below.

The background from misreconstructed χ_{c0} decays to other modes is studied on simulated events and found to be negligible with respect to the other background sources for both the $\pi^+\pi^-$ and the K^+K^- modes.

The number of signal events is extracted by a simultaneous unbinned maximum likelihood fit to the $m_{\rm ES}$ and $m_{\chi_{c0}}$ distributions for the events in the ΔE signal band. Three components are assumed to contribute to the selected sample: a signal component, modeled with a nonrelativistic Breit-Wigner function convolved with a Gaussian distribution in $m_{\chi_{c0}}$ and a Gaussian distribution in $m_{\rm ES}$; a combinatorial background component, modeled with a flat distribu-

TABLE I. Number of signal ($N_{\rm sig}$), combinatorial background ($N_{\rm comb}$), and peaking background ($N_{\rm pkg}$) events obtained by the fit described in the text (with statistical errors only).

Mode	$N_{\rm sig}$	$N_{\rm comb}$	$N_{\rm pkg}$
$\chi_{c0}\to\pi^+\pi^-$	$33.0^{+7.0}_{-6.7}$	111^{+12}_{-11}	$12.3^{+7.3}_{-6.3}$
$\chi_{c0}\to K^+K^-$	$30.4^{+7.3}_{-6.9}$	102^{+12}_{-11}	$22.2^{+8.5}_{-7.6}$

tion in $m_{\chi_{c0}}$ and an Argus threshold function [10] in $m_{\rm ES}$; and a peaking background component, modeled with a flat distribution in $m_{\chi_{c0}}$ and a Gaussian distribution in $m_{\rm ES}$, assuming the same resolution as for the signal.

In the fit the $B^{\pm}$ and χ_{c0} masses are fixed to their Particle Data Group (PDG) values [9]; the χ_{c0} width is fixed to the value recently measured by E835 [11], $\Gamma(\chi_{c0})=(9.8\pm1.0\pm0.1)$ MeV/c^2. The width of the Gaussian peak in $m_{\rm ES}$ and the $m_{\chi_{c0}}$ resolution are determined from Monte Carlo samples. The Argus shape parameter and the relative weight of the three components are left as free parameters in the fit.

We verify the goodness of the fit with the three-component model using a Monte Carlo technique. For each of the two χ_{c0} decay modes, we simulate a number of experiments by randomly generating samples of events distributed in $m_{\rm ES}$ and $m_{\chi_{c0}}$ according to the distributions used in the fit. The number of events generated for each sample is equal to the number of events in the corresponding real data sample; the parameters of the distributions are set to their fixed or fitted values. For each sample, the fit is repeated in the same conditions as on real data. The pulls for the number of signal and background events are distributed as expected. The probability of having a worse fit than the one to the data is found to be about 65% and 27% for $\chi_{c0}\to\pi^+\pi^-$ and $\chi_{c0}\to K^+K^-$, respectively.

We check the reliability of the yield extraction on a sample containing known amounts of combinatorial background, peaking background, and signal events. We also verify the stability of the fit results against variations of the parameters fixed in the fit by floating them one at a time.

The signal and background yields resulting from the fit to the data are reported in Table I. The maximum correlation we observe is about -40%, between the number of signal and peaking background events for both the $\pi^+\pi^-$ and the K^+K^- modes.

Figure 1 shows the $m_{\rm ES}$ and the $m_{\chi_{c0}}$ distributions for events in the ΔE signal region for the two modes considered. The results of the fit are superimposed.

We evaluate the systematic uncertainty to be attributed to the choice of the parameter values fixed in the yield extraction by varying each of them, one at a time, by its error, and repeating the fit. This results in a 2.4% (3.3%) fractional uncertainty for the $\chi_{c0}\to\pi^+\pi^-$ ($\chi_{c0}\to K^+K^-$) mode.

The presence of a nonresonant contribution in both modes can give rise to interference effects, resulting in a departure of the $m_{\chi_{c0}}$ distribution from the shape that we use in the fit. In order to estimate how much this can affect the extracted

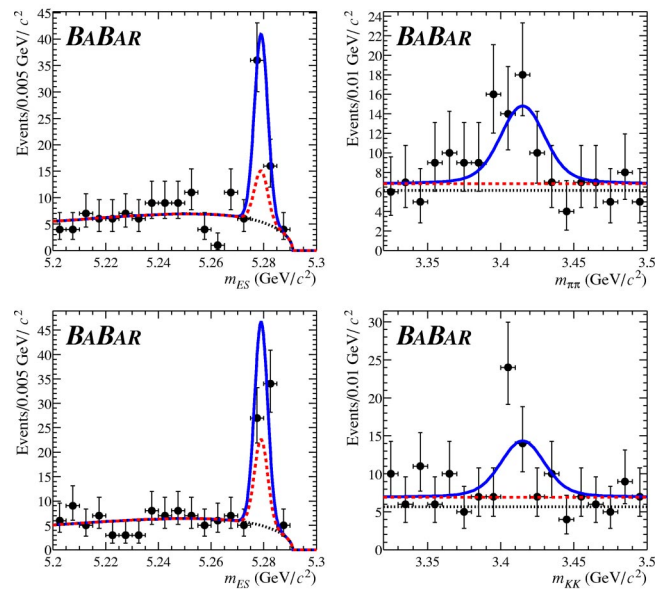

FIG. 1. (Color online) Extraction of the signal yield for $\chi_{c0}\to\pi^+\pi^-$ (top) and $\chi_{c0}\to K^+K^-$ (bottom). Left: $m_{\rm ES}$ distribution; right: $m_{\chi_{c0}}$ distribution. Dots with error bars represent the data; lines represent the projection of the fitted functions for the three contributions: combinatorial background (dotted), peaking + combinatorial background (dashed), and signal + backgrounds (solid).

yields, the fit is repeated with the inclusion of an interference term, under the assumption that all peaking background behaves as nonresonant three-body B decays. In this case two contributions are considered: a combinatorial background component, modeled as in the nominal fit, and a B-decay component, modeled with a Gaussian distribution in $m_{\rm ES}$ and the convolution of a Gaussian resolution function with a (resonant + nonresonant) shape containing an interference term in $m_{\chi_{c0}}$. The latter shape consists of the squared modulus of the sum of a Breit-Wigner amplitude and a constant amplitude, carrying an arbitrary phase difference. The relative weight of these two components and their phase difference are left floating in the fit, as well as the total number of combinatorial and B-decay events; all other parameters are kept fixed as in the nominal fit. The signal yields derived from this fit are larger than those in Table I by 18% and 13% for the $\chi_{c0}\to\pi^+\pi^-$ and $\chi_{c0}\to K^+K^-$ mode, respectively: we use this difference as an estimate of the systematic error due to neglecting interference effects.

The statistical significance of the signal, defined as $\sqrt{2\log(\mathcal{L}_{\rm max}/\mathcal{L}_0)}$, where $\mathcal{L}_{\rm max}/\mathcal{L}_0$ is the likelihood ratio for the fit with respect to the null signal hypothesis, is 8.1 (6.8) standard deviations (σ) for the $\chi_{c0}\to\pi^+\pi^-$ ($\chi_{c0}\to K^+K^-$) mode. When the systematic uncertainties are taken into account, the significances of the signals become 7.7σ and 6.4σ, respectively.

An alternative fitting method is employed to cross-check the results. An unbinned maximum likelihood fit to the $m_{\chi_{c0}}$ distribution only is used to extract the yield for the events selected in the $m_{\rm ES}$-ΔE signal region. The signal component is modeled with a Breit-Wigner shape convolved with a

TABLE II. Summary of the relative contributions to the systematic error on $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})\times\mathcal{B}(\chi_{c0}\to h^{+}h^{-})$ $(h=\pi,K)$.

	$\sigma_{\mathcal{B}}/\mathcal{B}(\%)$	
	$\chi_{c0}\to\pi^{+}\pi^{-}$	$\chi_{c0}\to K^{+}K^{-}$
Fit parameters	2.4	3.3
No interference	18	13
MC statistics	1.5	2.4
PID efficiency	0.7	4.1
Tracking efficiency	3.5	3.5
Fisher cut	0.7	0.4
ΔE resolution	3.7	
$N_{B^{\pm}}$	1.1	1.1
$\mathcal{B}(\Upsilon(4S)\to B^{+}B^{-})$	2.5	2.5
All	19	15

Gaussian resolution function, while the background component is modeled with a linear function. This fit yields $N_{\rm sig}(\chi_{c0}\to\pi^{+}\pi^{-})=32.9^{+5.7}_{-6.1}$ and $N_{\rm sig}(\chi_{c0}\to K^{+}K^{-})=29.7^{+6.5}_{-6.6}$. Both values are compatible with the results obtained with the primary fitting method.

The overall selection efficiency, estimated by using simulated data, is $(27.4\pm1.5)\%$ for the $\chi_{c0}\to\pi^{+}\pi^{-}$ mode and $(22.3\pm1.3)\%$ for the $\chi_{c0}\to K^{+}K^{-}$ mode. The quoted uncertainty is mostly due to observed inaccuracies in the Monte Carlo (MC) simulation, evaluated by comparison with control samples obtained from real data. Several effects have been taken into account: they are detailed in Table II, together with the other sources of systematic error. The largest contributions arise from differences in the track reconstruction efficiency, in the ΔE resolution (for the $\chi_{c0}\to\pi^{+}\pi^{-}$ mode) and in the particle identification (PID) efficiency (for the $\chi_{c0}\to K^{+}K^{-}$ mode).

We derive the branching fractions as $\mathcal{B}=N_{\rm sig}/(\epsilon N_{B^{\pm}})$, where ϵ denotes the overall signal efficiency and $N_{B^{\pm}}$ is the total number of $B^{\pm}$ mesons produced in the data sample considered. The value of $N_{B^{\pm}}$ is determined from the measured number of $B\overline{B}$ pairs, $N_{B\overline{B}}=(88.9\pm1.0)\times10^{6}$, and using $\mathcal{B}(\Upsilon(4S)\to B^{+}B^{-})=(0.513\pm0.013)$ [9]. We obtain

$$\mathcal{B}(B^{\pm}\to\chi_{c0}(\pi^{+}\pi^{-})K^{\pm})=1.32^{+0.28}_{-0.27}(\text{stat})\pm0.26(\text{syst}),$$

$$\mathcal{B}(B^{\pm}\to\chi_{c0}(K^{+}K^{-})K^{\pm})=1.49^{+0.36}_{-0.34}(\text{stat})\pm0.22(\text{syst}),$$

expressed in units of 10^{-6}. The systematic error combines the uncertainties from the determination of the number of $B\overline{B}$ pairs, from the branching fraction for $\Upsilon(4S)\to B^{+}B^{-}$, from the yield extraction, and from the signal efficiency.

TABLE III. Branching fraction for $B^{\pm}\to\chi_{c0}K^{\pm}$ with the two χ_{c0} decay modes. The meaning of the quoted errors and of the combined measurement is explained in the text.

Mode	$\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})$ $(\times10^{-4})$
$\chi_{c0}\to\pi^{+}\pi^{-}$	$2.83^{+0.60}_{-0.58}\pm0.55\pm0.52$
$\chi_{c0}\to K^{+}K^{-}$	$2.63^{+0.63}_{-0.60}\pm0.39\pm0.43$
Combined	2.7 ± 0.7

The ratio of the branching fractions for the χ_{c0} into the two modes is

$$\frac{\mathcal{B}(\chi_{c0}\to\pi^{+}\pi^{-})}{\mathcal{B}(\chi_{c0}\to K^{+}K^{-})}=0.88^{+0.28}_{-0.27}(\text{stat})\pm0.21(\text{syst})$$

which is compatible within the quoted errors with the world average [9].

Using $\mathcal{B}(\chi_{c0}\to\pi^{+}\pi^{-})=(4.68\pm0.26\pm0.65)\times10^{-3}$ and $\mathcal{B}(\chi_{c0}\to K^{+}K^{-})=(5.68\pm0.35\pm0.85)\times10^{-3}$, as reported by the BES Collaboration [12], we measure the values of $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})$ reported in Table III. There the first quoted error is statistical, the second is systematic, and the third accounts for the uncertainty on the χ_{c0} decay branching fractions. The measurements of $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})$ obtained with the two χ_{c0} decay modes are compatible. Taking into account the correlated errors, we have combined them and derived the value reported in Table III.

In summary, we have studied the process $B^{\pm}\to\chi_{c0}K^{\pm}$, reconstructing the χ_{c0} meson through its decay modes $\chi_{c0}\to K^{+}K^{-}$ and $\chi_{c0}\to\pi^{+}\pi^{-}$; the measured branching fraction is $\mathcal{B}(B^{\pm}\to\chi_{c0}K^{\pm})=(2.7\pm0.7)\times10^{-4}$. The result is significantly different from the zero value expected from the color-singlet current-current contribution alone.

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