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Measurement of the branching fraction and decay rate asymmetry of $B^- \to D_{\pi^+\pi^-\pi^0} K^-$

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We report the observation of the decay $B^- \to D_{\pi^+\pi^-\pi^0} K^-$, where $D_{\pi^+\pi^-\pi^0}$ indicates a neutral D meson detected in the final state $\pi^+\pi^-\pi^0$, excluding $K^0_S\pi^0$. This doubly Cabibbo-suppressed decay chain can be used to measure the CKM phase γ. Using about 229×10^6 $e^+e^- \to B\overline{B}$ events recorded by the *BABAR* experiment at the PEP-II e^+e^- storage ring, we measure the branching fraction $\mathcal{B}(B^- \to D_{\pi^+\pi^-\pi^0} K^-) = (5.5 \pm 1.0(\text{stat.}) \pm 0.7(\text{syst.})) \times 10^{-6}$ and the decay rate asymmetry $A(B^- \to D_{\pi^+\pi^-\pi^0} K^-) = -0.02 \pm 0.16(\text{stat.}) \pm 0.03(\text{syst.})$ for the full decay chain.

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The Cabibbo-Kobayashi-Maskawa (CKM) matrix, whose element V_{ij} [1] describes the weak charged-current coupling between quark flavors i and j, provides an explanation for CP violation in the standard model. A crucial part of the program to study CP violation is the measurement of the angle $\gamma = \arg(-V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$ of the unitarity triangle related to the CKM matrix. The decays $B \to D^{(*)0}K^{(*)}$ can be used to measure γ with essentially no hadronic uncertainties, making use of interference between $b \to u\bar{c}s$ and $b \to c\bar{u}s$ decay amplitudes. A number of variations on the original method [2] have been developed, and some have been explored experimentally. Employing multiple methods helps to resolve discrete ambiguities and decrease the experimental error.

An important class of γ measurement methods involves $B \to D^{(*)0}K^{(*)}$ with multibody D decays.[1] In this technique, γ is extracted from an analysis of the D-decay Dalitz plot, and ambiguities are resolved through interference between several D decay amplitudes [3]. Both Belle [4] and *BABAR* [5] have used this method to obtain limits on γ with the Cabibbo-favored decay $D \to K^0_S\pi^+\pi^-$. The same approach can be carried out with multibody final states that are produced by singly Cabibbo-suppressed decay of both D^0 and $\overline{D}^0$ [6]. While these modes yield much smaller event samples, their interfering D^0 and $\overline{D}^0$ decay amplitudes have similar magnitudes. Therefore, their overall sensitivity to γ is *a priori* expected to be similar to that of Cabibbo-favored D decays, where the interfering amplitudes typically have very dissimilar magnitudes.

Among the singly Cabibbo-suppressed modes, the decay $D \to \pi^+\pi^-\pi^0$ has a relatively large branching fraction [7] and a simple Dalitz plot dominated by broad ρ resonances [8], making it attractive for the measurement of γ with this technique. Its major difficulty is the relatively small signal-to-background ratio, which results mainly from the high combinatorial background associated with π^0 reconstruction. In this article, we describe an analysis procedure with which to extract the $B^- \to D_{\pi^+\pi^-\pi^0} K^-$ signal for later use in a Dalitz plot analysis measurement of γ, and report the measured branching fraction and decay rate asymmetry of this decay chain. Our result excludes the decay mode $D \to K^0_S\pi^0$, which is a previously-studied CP-eigenstate not related to the method of Ref. [3].

The decay rate asymmetry $A(B^- \to D_{\pi^+\pi^-\pi^0} K^-) = (N^- - N^+)/(N^- + N^+)$, where N^- (N^+) is the number of signal B^- (B^+) decays, depends on the weak and strong phases of the B decay, as well as the D^0 and $\overline{D}^0$ decay rate and phase variation over the Dalitz plot. Its magnitude is at most of order $2r_B$, where r_B, estimated to be about 0.1 [3], is the ratio between the magnitudes of the interfering $b \to u\bar{c}s$ and $b \to c\bar{u}s$ amplitudes. Because of interference, the branching fraction $\mathcal{B}(B^- \to D_{\pi^+\pi^-\pi^0} K^-)$ may differ from the product $\mathcal{B}_{\text{prod}} \equiv \mathcal{B}(B^- \to D^0K^-) \times \mathcal{B}(D^0 \to \pi^+\pi^-\pi^0) = (4.1 \pm 1.6) \times 10^{-6}$ [7] by up to about $2r_B\mathcal{B}_{\text{prod}}$.

The data used in this analysis were collected with the *BABAR* detector at the PEP-II energy-asymmetric e^+e^- storage ring. The data consist of 207 fb^{-1} collected on the $\Upsilon(4S)$ resonance (on-resonance sample), and 21 fb^{-1} collected at an e^+e^- center-of-mass (CM) energy approximately 40 MeV below the resonance peak (off-resonance sample). Samples of simulated events were analyzed with the same reconstruction and analysis procedure. These include an $e^+e^- \to B\overline{B}$ sample about 3 times larger than the data; a continuum $e^+e^- \to q\bar{q}$ sample, where q represents a u, d, s, or c quark, with equivalent luminosity similar to that of the data; and a signal sample about 200 times larger than what is expected in the data. Both phase space D decays and decays according to Ref. [8] were used in the signal sample. The *BABAR* detector and the methods used for particle reconstruction and identification are described in detail in Ref. [9].

We select events using criteria designed to maximize the signal branching fraction sensitivity and the reliability of the maximum likelihood fit procedure described below. To suppress the continuum background, we require the ratio H_2/H_0 of the 2nd to the 0th Fox-Wolfram moments [10], computed from the momenta of all charged particles and photon candidates not matched to tracks, to be less than 0.50. Charged kaon candidates are required to have a high quality particle identification measurement and be identified using kaon selection criteria that reduce the pion background to less than 3%. The measured energy of photon candidates is required to be at least 30 MeV. Photon candidate pairs whose invariant mass is within

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[1]We use the symbol D to indicate any linear combination of a D^0 and a $\overline{D}^0$ meson state.

25 MeV/c^2 of the nominal π^0 mass [7] are combined to make π^0 candidates, to which we perform a constrained-mass fit in order to improve the π^0 energy and momentum resolutions. Throughout this article, we use the symbol γ_h to refer to the harder (higher-energy) of the two photons constituting a π^0 candidate, and γ_s to denote the softer (lower-energy) photon.

We select $D \to \pi^+\pi^-\pi^0$ candidate decays by requiring the $\pi^+\pi^-\pi^0$ invariant mass m_D to be between 1.830 GeV/c^2 and 1.895 GeV/c^2. The m_D resolution is about 14 MeV/c^2. The D candidate energy and momentum resolutions are then improved by performing a constrained-mass fit. The charged pion candidates are required to fail kaon selection criteria. The decay $D \to K^0_S\pi^0$ is rejected by excluding $\pi^+\pi^-$ candidate pairs whose invariant mass is between 0.489 GeV/c^2 and 0.508 GeV/c^2. We note that this last requirement will not be needed when measuring γ with an analysis of the $\pi^+\pi^-\pi^0$ Dalitz plot, where the $K^0_S\pi^0$ final state can be included as an incoherent term, as done in Ref. [8].

Candidate $B^- \to D_{\pi^+\pi^-\pi^0}K^-$ decays are constructed by combining a $D \to \pi^+\pi^-\pi^0$ candidate with a charged kaon candidate. Additional continuum suppression is obtained by requiring $|\cos\theta_T| < 0.8$, where θ_T is the angle between the thrust axis calculated in the CM frame with the daughters of the B candidate and the thrust axis of the rest of the event (ROE). For each B candidate we calculate the beam-energy substituted mass $m_{ES} \equiv \sqrt{E^2_{\rm CM}/4 - |\mathbf{p_B}|^2}$, where the total CM energy $E_{\rm CM}$ is continuously determined from the measured PEP-II beam energies, and $\mathbf{p_B}$ is the momentum of the B candidate in the CM frame. Signal events have a Gaussian m_{ES} distribution that peaks at the nominal B^- mass with a width of about 2.7 MeV/c^2, while background is distributed more broadly than signal. We require $5.272 < m_{ES} < 5.300$ GeV/c^2. The energy difference $\Delta E = E_B - E_{\rm CM}/2$, where E_B is the CM energy of the B candidate, is required to be between -70MeV and 60 MeV. The ΔE distribution of signal events peaks around 0 MeV with a width of 21 MeV.

About 25% of the events selected have more than one B candidate. In these events, we select one B candidate at random. Random selection allows consistent studies of background suppression variables, and degrades the signal sensitivity by only a few percent relative to the best possible selection method.

Studying the simulated event sample selected by the above criteria, we identify ten event types, one signal and nine background. We list these types with the labels used to refer to them throughout the article:

(i) DK_D : $B^- \to D_{\pi^+\pi^-\pi^0}K^-$ events that were correctly reconstructed. These are the only events considered to be signal.

(ii) DK_D : $B^- \to D_{\pi^+\pi^-\pi^0}K^-$ events in which the D candidate is misreconstructed, namely, some of the particles used to form the final state $\pi^+\pi^-\pi^0$ do not originate in the decay of the D meson.

(iii) $D\pi_{\not D}$: $B^- \to D^0\pi^-$, $D^0 \to \pi^+\pi^-\pi^0$ decays, where the decay $D^0 \to \pi^+\pi^-\pi^0$ is correctly reconstructed and the remaining π^- is mistaken to be the kaon.

(iv) $D\pi_{\not D}$: $B^- \to D^0\pi^-$, $D^0 \to \pi^+\pi^-\pi^0$ decays, where the D candidate is misreconstructed. The kaon candidate may be either the remaining π^- or a particle from the other B meson in the event.

(v) DKX : $B \to D^{(*)}K^{(*)-}$, excluding $D \to \pi^+\pi^-\pi^0$ decays, with a misreconstructed D candidate.

(vi) $D\pi X$: $B \to D^{(*)}\pi^-$ and $B \to D^{(*)}\rho^-$, excluding $D^0 \to \pi^+\pi^-\pi^0$ decays, with a misreconstructed D candidate.

(vii) $BBC_{\not D}$: All other $B\overline{B}$ events with a misreconstructed D candidate.

(viii) BBC_D : Other $B\overline{B}$ events with a correctly reconstructed $D \to \pi^+\pi^-\pi^0$ decay.

(ix) $qq_{\not D}$: Continuum $e^+e^- \to q\overline{q}$ events with a misreconstructed D candidate.

(x) qq_D : Continuum $e^+e^- \to q\overline{q}$ events with a correctly reconstructed $D \to \pi^+\pi^-\pi^0$ decay.

The Cabibbo-favored decay chain $B^- \to D^0\pi^-$, $D^0 \to K^-\pi^+\pi^0$, which has the same final state particles as our signal decay, does not contribute significantly to the background, since it is suppressed by the particle identification and m_D cuts

The majority of background events are of the $qq_{\not D}$ type. The combination of $D\pi X$, DKX, and $BBC_{\not D}$ events constitutes the second largest background. In order to suppress these backgrounds, we have developed two neural networks, each of which combines several input variables that provide separation between signal and background. The first neural network variable q is computed from input variables that provide separation between continuum and $B\overline{B}$ events. The second variable d combines input variables that separate correctly reconstructed π^0 and D candidates from misreconstructed ones. It provides separation between signal and all misreconstructed-D background.

The input variables for q are (1) the cosine of the CM angle between $\mathbf{p_B}$ and the beams; (2) $|\cos\theta_T|$; (3-4) the zeroth and second Legendre moments of the momentum flow of the ROE about the CM thrust axis of the B candidate daughters; (5) log of the distance along the beam direction between the reconstructed B vertex and the vertex of the ROE, computed as in Ref. [11]; (6) log of the distance of closest approach between the kaon track and the D decay vertex, which is calculated from the π^+ and π^- track parameters; (7) an integer variable calculated from the probability that the ROE contains a B^0, determined using the lepton flavor tagging algorithm of Ref. [11].

The input variables for d are (1) the invariant mass of the π^0 candidate; (2) the π^0 momentum in the lab frame; (3) cosine of the π^0 decay angle θ_{π^0}, defined as the angle between the γ_h momentum and the momentum of the CM frame, calculated in the π^0 rest frame; (4) the invariant mass m_h of π_h^0, where π_h^0 is the π^0 candidate reconstructed from the γ_h and any additional photon in the event except γ_s, chosen such that m_h is closest to the nominal π^0 mass; (5) m_s, calculated analogously to m_h, but with γ_s instead of γ_h; (6-7) cosines of the decay angles of the π_h^0 and the π_s^0, calculated analogously to θ_{π^0}; (8) cosine of the angle between $\mathbf{p_B}$ and the thrust axis of the $\pi^+\pi^-\pi^0$ final state, calculated in the $\pi^+\pi^-\pi^0$ rest frame; (9) cosine of the angle between the D candidate momentum and the line connecting the B and D decay vertices.

The q and d distributions of simulated signal and background events are shown in Fig. 1. All events are required to satisfy the conditions $q > 0.1$, $d > 0.1$, in order to reduce the background and suppress correlations between the variables used in the fit described below. The final signal reconstruction efficiency is 10.5%.

We perform a maximum likelihood fit to measure the number and the decay rate asymmetry of signal events in the on-resonance data sample, using the variables ΔE, q, and d. The variable m_{ES}, which is commonly used as a fit variable in B decay analyses, is not included in the fit. Studies with simulated events indicate that correlations of m_{ES} with other fit variables in the distributions of $D\pi X$, DKX, and $BBC_{\not{D}}$ background events lead to a bias in the measured signal yield, unless the correlations are modeled correctly. Such modeling complicates the analysis procedure, increases the dependence on the simulation, and incurs additional systematic errors. By excluding m_{ES} from the fit, we give up some statistical precision in order to make the analysis more robust. Correlations between the ΔE, q, and d distributions for the different event types are at the few percent level in the worst cases, and ignoring them in fits to simulated events does not result in significant biases.

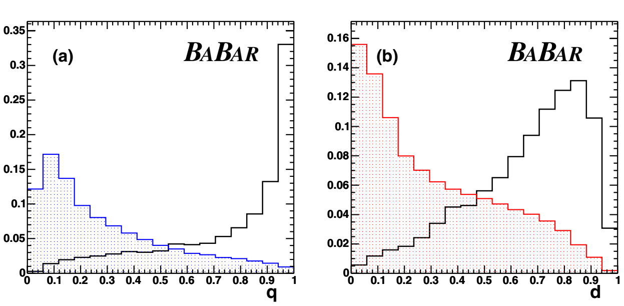

FIG. 1 (color online). (a) Distribution of the neural network variable q for continuum (hatched) and signal simulated events. The $B\overline{B}$ background distribution is similar to that of signal. (b) Distribution of the neural network variable d for $B\overline{B}$ background (hatched) and signal simulated events. The continuum background distribution is similar to that of the $B\overline{B}$ background. All histograms are normalized to unit area.

The probability density function (PDF) for the fit is

$$\mathcal{P} = \frac{1}{\eta}\sum_t \frac{N_t}{2}(1 - CA_t)\mathcal{P}_t(\Delta E, q, d), \quad (1)$$

where the subscript t corresponds to one of the ten event types listed above, N_t is the number of events of type t, A_t is their decay rate asymmetry, C is the charge of the B candidate, and $\eta \equiv \sum_t N_t$. The PDF $\mathcal{P}_t$ for events of type t is a product of the form

$$\mathcal{P}_t(\Delta E, q, d) = \mathcal{E}_t(\Delta E)\mathcal{Q}_t(q)\mathcal{D}_t(d). \quad (2)$$

The functions $\mathcal{E}_{BBC_{\not{D}}}(\Delta E)$, $\mathcal{E}_{qq_D}(\Delta E)$, and $\mathcal{E}_{qq_{\not{D}}}(\Delta E)$ are parametrized as second order polynomials, and all other $\mathcal{E}_t(\Delta E)$ functions are the sum of a Gaussian and a second order polynomial. The parameters of these functions are obtained from fits to simulated events. The PDFs $\mathcal{Q}_t(q)$ and $\mathcal{D}_t(d)$ are 15-bin histograms obtained from simulated events.

To extract the signal yield and asymmetry, we minimize the log of the extended likelihood

$$\mathcal{L} = \frac{\eta^N e^{-\eta}}{N!}\prod_{i=1}^{N}\mathcal{P}(i). \quad (3)$$

Six parameters are floating in the fit. These are the event yields N_{DK_D}, $N_{D\pi_D}$, $N_{qq_{\not{D}}}$, and $N_{BB_{\not{D}}} \equiv N_{DKX} + N_{D\pi X} + N_{BBC_{\not{D}}}$, the ratio $R_{D\pi X} \equiv N_{D\pi X}/N_{BB_{\not{D}}}$, and the decay rate asymmetry A_{DK_D}. All other decay rate asymmetries are fixed to 0 in the fit. Five ratios of event yields are obtained from the simulation and are not varied in the fit. From these ratios we obtain the five parameters $N_{DKX} = 0.21N_{D\pi X}$, $N_{D\pi_{\not{D}}} = 0.171N_{D\pi_D}$, $N_{BBC_D} = 0.0089N_{BB_{\not{D}}}$, $N_{qq_D} = 0.0136N_{qq_{\not{D}}}$, and $N_{DK_{\not{D}}} = 0.1614N_{DK_D}$. All fixed parameters are later varied to evaluate systematic errors, as described below.

The results of the fit are summarized in Table I. We measure $N_{DK_D} = 133 \pm 23$ signal events and the decay rate asymmetry $A_{DK_D} = -0.02 \pm 0.16$, where the errors are statistical only. The corresponding branching fraction is $\mathcal{B}(B^- \to D_{\pi^+\pi^-\pi^0}K^-) = (5.5 \pm 1.0) \times 10^{-6}$, assuming equal production of B^+B^- and $B^0\overline{B}^0$.

The fit parameter most correlated with the signal yield is $N_{BB_{\not{D}}}$, with correlation matrix element $\rho(N_{DK_D}, N_{BB_{\not{D}}}) = -0.33$. The largest correlation matrix element for the

TABLE I. Results of the data fit. Errors are statistical only.

Parameter	Value
N_{DK_D}	133 ± 23
A_{DK_D}	-0.02 ± 0.16
$N_{D\pi_D}$	43 ± 16
$N_{qq_{\not{D}}}$	1454 ± 53
$N_{BB_{\not{D}}}$	806 ± 54
$R_{D\pi X}$	0.82 ± 0.11

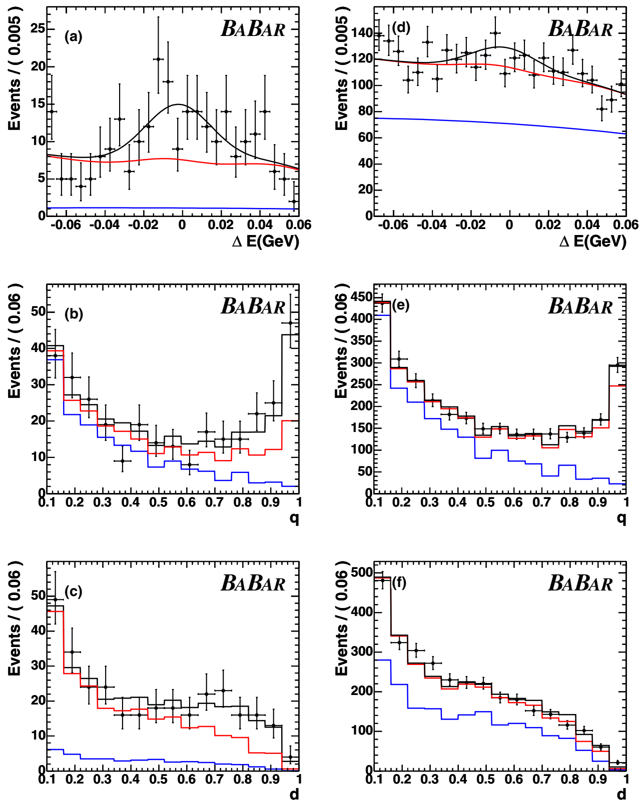

FIG. 2 (color online). Projections of the data (data points) and fit function onto the (a) ΔE, (b) q, and (c) d axes. The curves or histograms in each plot show, from bottom to top, the cumulative contributions of the continuum, $B\overline{B}$ background, and signal components of the fit function. For each of the variables plotted, a tight event selection is applied on the other two variables with a signal efficiency of about 50%, in order to increase the signal-to-background ratio in these plots. Figures (d), (e), and (f) show the same projections for the entire data sample.

asymmetry is $\rho(A_{DK_D}, N_{DK_D}) = 0.036$. Projections of the data and the fit function onto the fit variables are shown in Fig. 2 for events with a high likelihood of being signal and for the entire data sample.

The systematic uncertainties in the signal branching fraction and asymmetry measurements are summarized in Table II. We describe briefly the procedures used for their evaluation: (1) The statistical errors in the simulated samples used to obtain the shapes of $\mathcal{E}_t(\Delta E)$, $\mathcal{Q}_t(q)$, and $\mathcal{D}_t(d)$ are propagated to the final fit. (2) The value of N_{DKX} is varied by $\pm 25\%$, determined from the uncertainties on the decay modes contributing to the DKX background [7]. The parameters $N_{D\pi_{\not{D}}}$, N_{BBC_D}, N_{qq_D}, and $N_{DK_{\not{D}}}$ are varied by $\pm 50\%$, which is estimated to be very conservative, given the level of data-simulation agreement. (3) We evaluate the effect of possible differences between the event distributions in the data and the simulation by studying events in the m_{ES} sideband $5.23 < m_{ES} < 5.26$ GeV$/c^2$, as well as events produced in the copious decay mode $B^- \to D^0\pi^-$, $D^0 \to K^-\pi^+\pi^0$. (4) The ΔE and d distributions of

TABLE II. Fractional systematic error in the signal branching fraction $\mathcal{B}$ and absolute error in the asymmetry A_{DK_D}.

No. source	Error (%) $\sigma_{\mathcal{B}}/\mathcal{B}$	$\sigma_{A_{DK_D}}$
(1) Simulated sample statistics	7.9	1.8
(2) Variation of fixed yields	6.2	0.25
(3) Data-simulation shape comparison	5.8	1.6
(4) $\Delta E - d$ correlations in $\mathcal{P}_{DK_D}$	1.9	0.39
(5) Charmless branching fraction	0.85	0.09
(6) Dalitz plot distribution	0.33	···
(7) Detector asymmetry	···	1.0
(8) DKX and $DK_{\not{D}}$ asymmetry	···	0.9
(9) Track reconstruction efficiency	4.2	···
(10) π^0 efficiency	3.5	···
(11) Number of $B\overline{B}$ events produced	1.1	···
(12) Particle ID efficiency	1.0	···
Total	13	2.8

DK_D events are slightly correlated, and this correlation is ignored in the PDF. To evaluate the uncertainty due to this, we repeat the fit with $\mathcal{D}_{DK_D}(d)$ taken from simulated DK_D events in different ΔE bins. (5) We consider the effect of a possible contribution of charmless $B^- \to K^-\pi^+\pi^-\pi^0$ events, assuming a branching fraction of 6×10^{-5}. (6) The uncertainty in the contribution of a nonresonant component to the $D \to \pi^+\pi^-\pi^0$ decay [8] is propagated to the signal efficiency. (7) We account for the possibility of charge-dependence in the track reconstruction efficiency for both kaons and pions. (8) We conservatively vary A_{DKX} by ± 0.022 and take $A_{DK_{\not{D}}} = A_{DK_D}$ to evaluate the effect of possible asymmetries in the DKX and $DK_{\not{D}}$ backgrounds. (9-10) We assign a reconstruction efficiency uncertainty of 1.4% per charged track and 3.5% for the π^0. (11) We account for the uncertainty in the number of $B\overline{B}$ events produced by PEP-II and (12) the uncertainty in the efficiency of the particle identification requirements applied to the data sample.

Additional cross checks are performed to verify the validity of our results. We compare the fit variable distributions of the data with those of simulated events in the ΔE sideband $90 < \Delta E < 140$ MeV. The fit variable distributions of simulated continuum events are validated against the off-resonance data. The simulated distributions of $B^- \to D^0\pi^-$, $D^0 \to \pi^+\pi^-\pi^0$ events are compared with their distributions in the data. We verify the signal efficiency by measuring the branching fraction $\mathcal{B}(B^- \to D^0\pi^-)$ using D^0 decays to $D^0 \to K^-\pi^+\pi^0$ and $D^0 \to \pi^+\pi^-\pi^0$. The simulated distributions of the q and d input variables are compared with the distributions in the data. In all cases, good agreement between simulation and data is observed. No significant excess of signal events is found in a fit to data events in the m_D sidebands $1.775 < m_D < 1.800$ GeV$/c^2$ and $1.920 < m_D < 1.955$ GeV$/c^2$. We conduct fits to event samples containing simulated signal and background events and find no significant biases in any of the fit parameters. Fits to parametrized experiments generated with the parameter values obtained in the data fit are unbiased, and their distributions of fit parameter errors and maximum likelihood are consistent with those of the data fit.

In summary, using a sample of $229 \pm 2.5 \times 10^6$ $e^+e^- \rightarrow B\overline{B}$ events we observe 133 ± 23 events in the decay chain $B^- \rightarrow D_{\pi^+\pi^-\pi^0}K^-$, where the $\pi^+\pi^-\pi^0$ final state excludes the CP-eigenstate $K_S^0\pi^0$. We extract the branching fraction and decay rate asymmetry

$$\mathcal{B}(B^- \rightarrow D_{\pi^+\pi^-\pi^0}K^-) = (5.5 \pm 1.0 \pm 0.7) \times 10^{-6},$$
$$A(B^- \rightarrow D_{\pi^+\pi^-\pi^0}K^-) = -0.02 \pm 0.16 \pm 0.03, \qquad (4)$$

where the first errors are statistical and the second are systematic. The level of background suppression we achieve is critical for using this mode to measure γ. The remaining background doubles the statistical error on γ with respect to the no-background case.

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by the US Department of Energy and National Science Foundation, the Natural Sciences and Engineering Research Council (Canada), Institute of High Energy Physics (China), the Commissariat à l'Energie Atomique and Institut National de Physique Nucléaire et de Physique des Particules (France), the Bundesministerium für Bildung und Forschung and Deutsche Forschungsgemeinschaft (Germany), the Istituto Nazionale di Fisica Nucleare (Italy), the Foundation for Fundamental Research on Matter (The Netherlands), the Research Council of Norway, the Ministry of Science and Technology of the Russian Federation, and the Particle Physics and Astronomy Research Council (United Kingdom). Individuals have received support from CONACyT (Mexico), the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

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