Measurement of *CP* Violation Parameters with a Dalitz Plot Analysis of $B^{\pm} \to D_{\pi^+\pi^-\pi^0} K^{\pm}$

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We report the results of a *CP* violation analysis of the decay $B^{\pm} \to D_{\pi^+\pi^-\pi^0} K^{\pm}$, where $D_{\pi^+\pi^-\pi^0}$ indicates a neutral D meson detected in the final state $\pi^+\pi^-\pi^0$, excluding $K_S^0\pi^0$. The analysis makes use of 324×10^6 $e^+e^- \to B\bar{B}$ events recorded by the *BABAR* experiment at the PEP-II e^+e^- storage ring. Analyzing the $\pi^+\pi^-\pi^0$ Dalitz plot distribution and the $B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm$ branching fraction and decay rate asymmetry, we find the following one-standard-deviation constraints on the amplitude ratio and on the weak and strong phases: $0.06 < r_B < 0.78$, $-30° < \gamma < 76°$, $-27° < \delta < 78°$. We also measure the magnitudes and phases of the components of the $D^0 \to \pi^+\pi^-\pi^0$ decay amplitude.

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An important component 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 Cabibbo-Kobayashi-Maskawa quark mixing matrix [1]. The decays $B \to D^{(*)0}K^{(*)}$ can be used to measure γ with essentially no hadronic uncertainties, exploiting interference between $b \to u\bar{c}s$ and $b \to c\bar{u}s$ decay amplitudes [2]. In one of the measurement methods [3], γ is extracted by analyzing the D-decay Dalitz plot distribution in $B^\pm \to DK^\pm$ with multibody D decays [4]. This method has only been used with the Cabibbo-favored decay $D \to K_S^0\pi^+\pi^-$ [5,6], and Cabibbo-suppressed decays are expected to be similarly sensitive to γ [7]. We present here the first *CP*-violation study of $B^\pm \to DK^\pm$ with a multibody, Cabibbo-suppressed D decay, $D \to \pi^+\pi^-\pi^0$.

The data used in this analysis were collected with the *BABAR* detector at the PEP-II e^+e^- storage ring, and they include 288 fb^{-1} taken on the $\Upsilon(4S)$ resonance and 27 fb^{-1} collected 40 MeV below the resonance. Samples of simulated Monte Carlo (MC) events were analyzed with the same reconstruction and analysis procedures. These samples include an $e^+e^- \to B\bar{B}$ sample 5 times larger than the data, a continuum $e^+e^- \to q\bar{q}$ sample, where q is a u, d, s, or c quark, with luminosity equivalent to the data, and a signal sample 300 times larger than the data, with both phase space D decays and decays generated according to the amplitudes measured by CLEO [8]. The *BABAR* detector and the methods used for particle reconstruction and identification are described in Ref. [9].

We use event-shape variables [10] to suppress the continuum background, and we identify kaon and pion candidates using specific ionization and Cherenkov radiation. The invariant mass of D candidates must satisfy $1830 < M_D < 1895$ MeV$/c^2$. We require $5272 < m_{\rm ES} < 5300$ MeV$/c^2$, where $m_{\rm ES} \equiv \sqrt{E_{\rm c.m.}^2/4 - |\mathbf{p_B}|^2}$, $E_{\rm c.m.}$ is the total e^+e^- center of mass (c.m.) energy, and $\mathbf{p_B}$ is the B candidate c.m. momentum. Events must satisfy $-70 < \Delta E < 60$ MeV, where $\Delta E = E_B - E_{\rm c.m.}/2$ and E_B is the B candidate c.m. energy. We exclude the decay mode $D \to K_S^0\pi^0$, which is a previously studied *CP* eigenstate not related to the method of Ref. [3], by rejecting candidates with $489 < M(\pi^+\pi^-) < 508$ MeV$/c^2$ or for which the distance between the $\pi^+\pi^-$ vertex and the B^- candidate decay vertex is more than 1.5 cm. We reject $B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm$ candidates in which the $K^\pm\pi^\mp$ invariant mass satisfies $1840 < M(K^\pm\pi^\mp) < 1890$ MeV$/c^2$, to suppress $B^- \to D^0_{K^-\pi^+}\rho^-$ decays. We require $d > 0.25$, where d [10] is a neural net variable that separates signal candidates (which peak toward $d = 1$) from those with a misreconstructed D (peaking toward $d = 0$). In events with multiple candidates (9% of the sample), we keep the candidate whose $m_{\rm ES}$ value is closest to the nominal $B^\pm$ mass [11]. The final signal reconstruction efficiency is $\epsilon = 11.4\%$.

For each $B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm$ candidate, we compute the neural net variable q [10]. The q distribution of $B\bar{B}$ events peaks toward $q = 1$, while that of continuum peaks at $q = 0$. For $\nu \in \{q, d\}$, we define the variables $\nu' \equiv \tanh^{-1}\{[\nu - \frac{1}{2}(\nu_{\rm max} + \nu_{\rm min})]/\frac{1}{2}(\nu_{\rm max} + \nu_{\rm min})\}$, where $q_{\rm max} = d_{\rm max} = 1$, $q_{\rm min} = 0.1$, and $d_{\rm min} = 0.25$ are the allowed ranges for q and d. The ν' variables can be conveniently fit with Gaussians, as described later.

As in Ref. [10], we identify in the MC samples ten event types, one signal, and nine different backgrounds. We list them here with the labels used to refer to them throughout the Letter. $\boldsymbol{DK_{\rm sig}}$: $B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm$ events that are correctly reconstructed; these are the only events considered to be signal. $\boldsymbol{DK_{\rm bgd}}$: $B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm$ events that are misreconstructed; namely, some of the particles used to form the final state do not originate from the $B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm$ decay. $\boldsymbol{D\pi_D}$ ($\boldsymbol{D\pi_{\not D}}$): $B^- \to D^0\pi^-$, $D^0 \to \pi^+\pi^-\pi^0$ decays, where the decay $D^0 \to \pi^+\pi^-\pi^0$ is correctly reconstructed (misreconstructed). $\boldsymbol{DKX}$: $B \to D^{(*)}K^{(*)-}$ events not containing the decay $D \to \pi^+\pi^-\pi^0$. $\boldsymbol{D\pi X}$: $B \to D^{(*)}\pi^-$ and $B \to D^{(*)}\rho^-$ decays, excluding $D \to \pi^+\pi^-\pi^0$. $\boldsymbol{BBC_D}$ ($\boldsymbol{BBC_{\not D}}$): all other $B\bar{B}$ events with a correctly reconstructed (misreconstructed) D candidate. $\boldsymbol{qq_D}$ ($\boldsymbol{qq_{\not D}}$): continuum $e^+e^- \to q\bar{q}$ events with a correctly reconstructed (misreconstructed) D candidate.

The measurement of the *CP* parameters proceeds in three steps, each involving an unbinned maximum likelihood fit. In step 1, we measure the complex Dalitz plot amplitude $f(s_+, s_-)$ for the decay $D^0 \to \pi^+\pi^-\pi^0$, where $s_\pm = m^2(\pi^\pm\pi^0)$ are the squared invariant masses of the $\pi^\pm\pi^0$ pairs. In step 2, we extract the numbers of B^+ and B^- signal events and background yields. We obtain the *CP* parameters in step 3.

We parametrize $f(s_+, s_-)$ using the isobar model, $f(s_+, s_-) = [a_{\rm NR}e^{i\phi_{\rm NR}} + \sum_r a_r e^{i\phi_r}A_r(s_+, s_-)]/N_f$, where the first term represents a nonresonant contribution, the sum is over all intermediate two-body resonances r, and N_f is such that $\int ds_+ds_-|f(s_+, s_-)|^2 = 1$. The amplitude for the decay chain $D^0 \to rC$, $r \to AB$ is $A_r(s_+, s_-) = F_rF_s[m_r^2 - M_{AB}^2 - im_r\Gamma_r(M_{AB})]^{-1}$, where m_r is the peak mass of the resonance [11], M_{AB}^2 is the squared invariant mass of the AB pair, F_r is a spin-dependent form factor [12], and $\Gamma_r(M_{AB})$ is the mass-dependent width for the resonance r [12]. The spin factors F_s are $F_0 = m_D^2$, $F_1 = M_{BC}^2 - M_{AC}^2 + (m_D^2 - m_C^2)(m_A^2 - m_B^2)M_{AB}^{-2}$, and $F_2 = (F_1^2 - \frac{1}{3}\mu_{CD}^2\mu_{AB}^2)m_D^{-2}$, where $\mu_{jk}^2 \equiv M_{AB}^2 - 2m_j^2 - 2m_k^2 + (m_j^2 - m_k^2)^2 M_{jk}^{-2}$, and m_i is the mass of particle i [11].

In step 1, we determine the parameters $a_{\rm NR}$, a_r, $\phi_{\rm NR}$, and ϕ_r by fitting a large sample of D^0 and $\bar{D}^0$ mesons, flavor tagged through their production in the decay $D^{*+} \to D^0\pi^+$ [13]. To select this sample, we require the c.m. momentum of the D^* candidate to be greater than 2770 MeV$/c$, and $|M_{D^*} - M_D - 145.4\ \text{MeV}/c^2| < 0.6\ \text{MeV}/c^2$, where M_{D^*} is the invariant mass of the D^* candidate. The signal and background yields are obtained from a fit to the M_D distribution, modeling the signal as a Gaussian and the background as an exponential. The signal Gaussian peaks at 1863.7 ± 0.4 MeV$/c^2$ and has a width of 17.4 ± 0.8 MeV$/c^2$.

Of the D^0 candidates in the signal region $1848 < M_D < 1880$ MeV$/c^2$, we obtain from the fit $N_S = 44\,780 \pm 250$ signal and $N_B = 830 \pm 70$ background events. To obtain the parameters of $f(s_\pm, s_\mp)$, we fit these candidates with the probability distribution function (PDF) $N_S|f(s_+, s_-)|^2\epsilon(s_+, s_-) + N_B|f_B(s_+, s_-)|^2$, where the background PDF $f_B(s_+, s_-)$ is a binned distribution obtained from events in the sideband $1930 < M_D < 1990$ MeV$/c^2$, and $\epsilon(s_+, s_-)$ is an efficiency function, parametrized as a two-dimensional third-order polynomial determined from MC. To within the MC-signal statistical uncertainty, $\epsilon(s_+, s_-) = \epsilon(s_-, s_+)$. The region $M_D < 1848$ MeV$/c^2$, which contains $D^0 \to K^-\pi^+\pi^0$ events that are absent from the signal region, is not used.

Table I summarizes the results of this fit, with systematic errors obtained by varying the masses and widths of the $\rho(1700)$ and σ resonances, setting $F_r = 1$, and varying $\epsilon(s_+, s_-)$ to account for uncertainties in reconstruction and particle identification. The Dalitz plot distribution of the data is shown in Fig. 1(a). The distribution is marked by three destructively interfering $\rho\pi$ amplitudes, suggesting an $I = 0$-dominated final state [14].

The fit for step $i \in \{2, 3\}$ uses the PDF

$$\mathcal{P}_i^C = \sum_t \frac{N_t}{2\eta}(1 - CA_t)\mathcal{P}_{i,t}^{(C)}(\xi_i) \Big/ \int \mathcal{P}_{i,t}^{(C)}(\xi_i')d^{n_i}\xi_i', \quad (1)$$

where ξ_i is the set of n_i event variables $\xi_2 = \{\Delta E, q', d'\}$, $\xi_3 = \{\Delta E, q', s_-, s_+\}$, t corresponds to one of the ten event types listed above, $N_t = N_t^+ + N_t^-$ is the number of events of type t, $A_t = (N_t^- - N_t^+)/N_t$ is their charge asymmetry, $C = \pm 1$ is the electric charge of the B candidate, and $\eta \equiv \sum_t N_t$. Using MC, we verify that the variables in each set ξ_i are uncorrelated for each event type. Therefore, the PDFs $\mathcal{P}_{i,t}^{(C)}$ are the products

$$\begin{aligned} \mathcal{P}_{2,t}(\Delta E, q', d') &= \mathcal{E}_t(\Delta E)\mathcal{Q}_t(q')\mathcal{C}_t(d'), \\ \mathcal{P}_{3,t}^C(\Delta E, q', s_+, s_-) &= \mathcal{E}_t(\Delta E)\mathcal{Q}_t(q')\mathcal{D}'^C_t(s_+, s_-). \end{aligned} \quad (2)$$

The parameters of the Dalitz plot PDF $\mathcal{D}'^C_{DK_{\rm sig}}(s_+, s_-)$ are obtained from the data as described below. Those of all other functions in Eq. (2) are obtained from the MC samples. The functions $\mathcal{E}_t(\Delta E)$ are parametrized as the

TABLE I. Result of the fit to the $D^{*+} \to D^0\pi^+$ sample, showing the amplitudes ratios $R_r \equiv a_r/a_{\rho^+(770)}$, phase differences $\Delta\phi_r \equiv \phi_r - \phi_{\rho^+(770)}$, and fit fractions $f_r \equiv \int |a_r A_r(s_+, s_-)|^2 ds_- ds_+$. The first (second) errors are statistical (systematic). We take the mass (width) of the σ meson to be 400(600) MeV$/c^2$.

State	R_r (%)	$\Delta\phi_r$ (°)	f_r (%)
$\rho^+(770)$	100	0	$67.8 \pm 0.0 \pm 0.6$
$\rho^0(770)$	$58.8 \pm 0.6 \pm 0.2$	$16.2 \pm 0.6 \pm 0.4$	$26.2 \pm 0.5 \pm 1.1$
$\rho^-(770)$	$71.4 \pm 0.8 \pm 0.3$	$-2.0 \pm 0.6 \pm 0.6$	$34.6 \pm 0.8 \pm 0.3$
$\rho^+(1450)$	$21 \pm 6 \pm 13$	$-146 \pm 18 \pm 24$	$0.11 \pm 0.07 \pm 0.12$
$\rho^0(1450)$	$33 \pm 6 \pm 4$	$10 \pm 8 \pm 13$	$0.30 \pm 0.11 \pm 0.07$
$\rho^-(1450)$	$82 \pm 5 \pm 4$	$16 \pm 3 \pm 3$	$1.79 \pm 0.22 \pm 0.12$
$\rho^+(1700)$	$225 \pm 18 \pm 14$	$-17 \pm 2 \pm 3$	$4.1 \pm 0.7 \pm 0.7$
$\rho^0(1700)$	$251 \pm 15 \pm 13$	$-17 \pm 2 \pm 2$	$5.0 \pm 0.6 \pm 1.0$
$\rho^-(1700)$	$200 \pm 11 \pm 7$	$-50 \pm 3 \pm 3$	$3.2 \pm 0.4 \pm 0.6$
$f_0(980)$	$1.50 \pm 0.12 \pm 0.17$	$-59 \pm 5 \pm 4$	$0.25 \pm 0.04 \pm 0.04$
$f_0(1370)$	$6.3 \pm 0.9 \pm 0.9$	$156 \pm 9 \pm 6$	$0.37 \pm 0.11 \pm 0.09$
$f_0(1500)$	$5.8 \pm 0.6 \pm 0.6$	$12 \pm 9 \pm 4$	$0.39 \pm 0.08 \pm 0.07$
$f_0(1710)$	$11.2 \pm 1.4 \pm 1.7$	$51 \pm 8 \pm 7$	$0.31 \pm 0.07 \pm 0.08$
$f_2(1270)$	$104 \pm 3 \pm 21$	$-171 \pm 3 \pm 4$	$1.32 \pm 0.08 \pm 0.10$
$\sigma(400)$	$6.9 \pm 0.6 \pm 1.2$	$8 \pm 4 \pm 8$	$0.82 \pm 0.10 \pm 0.10$
Nonresonant	$57 \pm 7 \pm 8$	$-11 \pm 4 \pm 2$	$0.84 \pm 0.21 \pm 0.12$

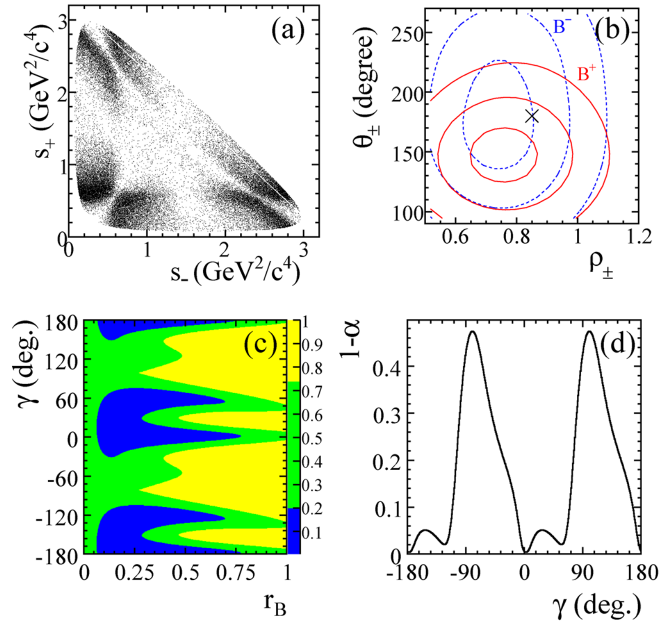

FIG. 1 (color online). (a) The two-dimensional (s_+, s_-) distribution of the $D^{*+} \to D^0\pi^+$ data. Charge conjugation is implied. (b) One-, two-, and three-standard-deviation contours of $\mathcal{L}$ as functions of $\theta_\pm$ vs $\rho_\pm$. The solid (dashed) curves correspond to B^+ (B^-) results. The no-interference point ($\rho_\pm = x_0$, $\theta_\pm = 180°$) is marked with an $\times$. (c) Projection of the three-dimensional confidence level $1 - \alpha$ onto r_B and γ. (d) $1 - \alpha$ vs γ.

sum of a Gaussian and a second-order polynomial. The PDFs $\mathcal{Q}_t(q')$ and $\mathcal{C}_t(d')$ are the sum of a Gaussian and an asymmetric Gaussian. The PDF parameters are different for each event type. Assuming no CP violation in the background, we take $\mathcal{D}'^+_t(s_+, s_-) = \mathcal{D}'^-_t(s_-, s_+)$ and $A_t = 0$ for $t \neq DK_{\rm sig}$. The functions $\mathcal{D}'^C_{D\pi X}(s_+, s_-)$ and $\mathcal{D}'^C_{DK_{\rm bgd}}(s_+, s_-)$ are binned histograms obtained from the MC. For other event types, $\mathcal{D}'^C_t(s_+, s_-) = \epsilon(s_+, s_-)\mathcal{D}^C_t(s_+, s_-)$, where the efficiency function $\epsilon(s_+, s_-)$ has different parameters for well-reconstructed and misreconstructed D candidates.

We define $z_\pm \equiv r_B e^{i(\delta \pm \gamma)}$, where δ is a CP-even phase and r_B is the ratio of the magnitudes of the $b \to u\bar{c}s$ and $b \to c\bar{u}s$ amplitudes. Ignoring negligible D^0-$\bar{D}^0$ mixing effects [15], the signal Dalitz PDF is

$$\mathcal{D}^\pm_{DK_{\rm sig}}(s_+, s_-) = |f(s_\mp, s_\pm) + z_\pm f(s_\pm, s_\mp)|^2. \quad (3)$$

In the step-2 fit, we extract the $B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm$ signal yield and asymmetry, as well as some background yields, as described in Ref. [10]. From this fit we find $N_{DK_{\rm sig}} = 170 \pm 29$ signal events, corresponding to the branching fraction $\mathcal{B}(B^\pm \to D_{\pi^+\pi^-\pi^0}K^\pm) = (4.6 \pm 0.8 \pm 0.4) \times 10^{-6}$, and the decay rate asymmetry $A_{DK_{\rm sig}} = -0.02 \pm 0.15 \pm 0.03$. The first errors are statistical and the second are systematic, due to sources described below.

Only the complex parameters $z_\pm$ are free in the step-3 fit. This fit minimizes the function

$$\mathcal{L} = -\sum_{e=1}^{N_{\rm ev}} \log \mathcal{P}_3^{C_e}(\xi_3^e) + \frac{1}{2}\chi^2, \quad (4)$$

where $N_{\rm ev}$ is the number of events in the data sample. The term $\chi^2 = \sum_{u,v=1}^{2} X_u V_{uv}^{-1} X_v$ increases the sensitivity of the fit by using the results of the step-2 fit via $X_1 = N_{DK_{\rm sig}} - (n_- + n_+)$ and $X_2 = A_{DK_{\rm sig}} - (n_- - n_+)/(n_- + n_+)$, where

$$n_\pm = N^0 \frac{\int \mathcal{D}'^\pm_{DK_{\rm sig}}(s_+, s_-) ds_+ ds_-}{\int |f(s_\mp, s_\pm)|^2 \epsilon(s_+, s_-) ds_+ ds_-} \quad (5)$$

are the expected numbers of $B^\pm$ signal events. In Eq. (5), N^0 is the product of the number $N_{B^+B^-}$ of charged B^+B^- pairs in the data set, the branching fractions $\mathcal{B}(B^- \to D^0K^-)$ [11] and $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)$ [13], and the reconstruction efficiency ϵ. The error matrix V_{uv} is the sum of two components: the step-2 fit error matrix $V_{uv}^{\rm stat}$, which is almost diagonal (the correlation coefficient is -2.8%), and the N^0 systematic error matrix $V_{uv}^{\rm syst}$. Here $V_{12}^{\rm syst} = V_{22}^{\rm syst} = 0$, and $V_{11}^{\rm syst} = \sum_{c=1}^{4}(N^0\sigma_c^{\rm rel})^2$, where $\sigma_c^{\rm rel}$ are the relative errors on the four components $N_{B^+B^-}$ (1.1%), ϵ (3.3%), $\mathcal{B}(D \to \pi^+\pi^-\pi^0)$ (3.8%) [13], and $\mathcal{B}(B^- \to D^0K^-)$ (5.9%) [11].

We parametrize $z_\pm$ with the polar coordinates

$$\rho_\pm \equiv |z_\pm - x_0|, \qquad \theta_\pm \equiv \tan^{-1}\left(\frac{{\rm Im}[z_\pm]}{{\rm Re}[z_\pm] - x_0}\right), \quad (6)$$

where the parameter $x_0 = 0.85$ is obtained from

$$x_0 \equiv -\int {\rm Re}[f(s_+, s_-)f^*(s_-, s_+)]\epsilon(s_+, s_-) ds_+ ds_-. \quad (7)$$

This parametrization is optimal due to the polar symmetry of $n_\pm = N^0(1 + \rho_\pm^2 - x_0^2)$, and avoids nonlinear correlations and biases that occur with the parametrizations (r_B, γ, δ) or (${\rm Re}[z_\pm]$, ${\rm Im}[z_\pm]$). The step-3 fit yields

$$\begin{aligned} \rho_- &= 0.72 \pm 0.11 \pm 0.04 \pm 0.05, \\ \theta_- &= (173 \pm 42 \pm 2 \pm 19)°, \\ \rho_+ &= 0.75 \pm 0.11 \pm 0.04 \pm 0.05, \\ \theta_+ &= (147 \pm 23 \pm 1 \pm 13)°, \end{aligned} \quad (8)$$

where the first errors are statistical, the second are due to $V_{11}^{\rm syst}$, and the third are due to additional systematic errors, described below. The largest correlation coefficient is $c_{\rho_-\rho_+} = 14\%$, originating from $V_{11}^{\rm syst}$. All others are 1% or less. Contours of constant $\mathcal{L}$ values are shown in Fig. 1(b).

The third errors in Eq. (8) and the systematic errors on $\mathcal{B}(B^{\pm} \to D_{\pi^+\pi^-\pi^0} K^{\pm})$ and $A_{DK_{\rm sig}}$ are obtained as follows. The uncertainty in the model used for $f(s_+, s_-)$ is the largest source of error on the *CP* parameters: $\sigma^{\rm model}_{\rho_\pm} = 0.03$, $\sigma^{\rm model}_{\theta_-} = 14°$, $\sigma^{\rm model}_{\theta_+} = 11°$. This error is evaluated by removing all but the $\rho(770)$, $\rho(1450)$, $f_0(980)$, and nonresonant terms in $f(s_+, s_-)$, adding an $f_2'(1525)$, an ω, and a nonresonant *P*-wave contribution, varying the meson "radius" parameter in F_r [12], and propagating the errors from Table I. Uncertainties due to the masses and widths of the $\rho(1700)$ and σ resonances are small by comparison. Other errors are due to uncertainties on background yields that are fixed in the fits [10], the finite MC sample size, a possible reconstruction efficiency charge asymmetry, and uncertainties in the background PDF shapes, evaluated by comparing MC and data in signal-free sidebands of the variables M_D, ΔE, and $m_{\rm ES}$. We also evaluate errors due to possible charge asymmetries in DKX and $DK_{\rm bgd}$ events, uncertainties in particle identification and the efficiency functions, the finite $s_\pm$ measurement resolution, the background PDF f_B in the D^* sample, D-flavor mistagging in the D^* sample, and correlations between the D flavor and the kaon charge in qq_D events.

The analysis procedure is validated in several ways. Conducting the analysis on the MC sample yields results consistent with the generated values. We carry out the step-3 fit on a sample of 1800 ± 70 $B^- \to D^0_{\pi^+\pi^-\pi^0}\pi^-$ events, obtaining the background Dalitz plot distribution from the ΔE sideband. The fit yields $\rho_- = 0.815 \pm 0.034$, $\theta_- = (186 \pm 7)°$, $\rho_+ = 0.854 \pm 0.035$, $\theta_+ = (192 \pm 7)°$, consistent with $\rho_\pm = x_0$, $\theta_\pm = 180°$, which corresponds to $z_\pm = 0$. We verify the signal efficiency by measuring the branching fraction $\mathcal{B}(B^- \to D^0\pi^-)$ with $D^0 \to K^-\pi^+\pi^0$ and $D^0 \to \pi^+\pi^-\pi^0$. We compare the fit variable distributions of data and MC events in signal-free sidebands. Good agreement is found in all cases.

We use the frequentist approach outlined in Ref. [6] to extract confidence regions of $\mathbf{p} = (r_B, \gamma, \delta)$, accounting for the dependence of the experimental errors on the values of $z_\pm$ and for small non-Gaussian effects in the likelihood function. Two-dimensional projections onto r_B and γ of regions of one, two, and three standard deviations (σ) are shown in Fig. 1(c). These regions are defined as containing the $\mathbf{p}$ values with three-dimensional significance α smaller than 19.9%, 73.9%, and 97.1%, respectively. Figure 1(d) shows the projected γ dependence of the confidence level $1 - \alpha$. We find the one-σ regions

$$0.06 < r_B < 0.78, \qquad -30° < \gamma < 76°, \qquad -27° < \delta < 78°, \tag{9}$$

including both statistical and systematic errors. Sensitivity to r_B, γ, and δ arises from both the Dalitz plot distribution and the signal branching fraction and asymmetry.

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