Measurement of D(0)-D# (0) Mixing from a Time-Dependent Amplitude Analysis of D(0) -->K(+)pi(-)pi(0) Decays

Measurement of D^0-$\bar{D}^0$ Mixing from a Time-Dependent Amplitude Analysis of $D^0 \to K^+\pi^-\pi^0$ Decays

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We present evidence of D^0-$\bar{D}^0$ mixing using a time-dependent amplitude analysis of the decay $D^0 \to K^+\pi^-\pi^0$ in a data sample of 384 fb^{-1} collected with the *BABAR* detector at the PEP-II e^+e^- collider at the Stanford Linear Accelerator Center. Assuming *CP* conservation, we measure the mixing parameters $x'_{K\pi\pi^0} = [2.61^{+0.57}_{-0.68}(\mathrm{stat}) \pm 0.39(\mathrm{syst})]\%$, $y'_{K\pi\pi^0} = [-0.06^{+0.55}_{-0.64}(\mathrm{stat}) \pm 0.34(\mathrm{syst})]\%$. This result is inconsistent with the no-mixing hypothesis with a significance of 3.2 standard deviations. We find no evidence of *CP* violation in mixing.

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D^0-$\bar{D}^0$ mixing is a transition between flavor eigenstates of neutral charmed mesons $|D^0\rangle$ and $|\bar{D}^0\rangle$, and it depends upon the mass and width differences of the mass eigenstates. If mixing occurs, the physical eigenstates $|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$ $(|p|^2 + |q|^2 = 1)$ must have different masses $M_{1,2}$ or widths $\Gamma_{1,2}$. The oscillation is parametrized by $x \equiv 2(M_1 - M_2)/(\Gamma_1 + \Gamma_2)$ and $y \equiv (\Gamma_1 - \Gamma_2)/(\Gamma_1 + \Gamma_2)$, where 1 (2) refers to the nearly *CP*-even (odd) eigenstate. If *CP* is conserved, then $|p/q| = 1$ and $\arg(q/p\bar{A}_f/A_f) = 0$. Here A_f ($\bar{A}_f$) is the amplitude of the transition of the D^0 ($\bar{D}^0$) to the final state f. In the standard model (SM), the D^0-$\bar{D}^0$ mixing contribution from loop diagrams is negligible [1]. This is due to Glashow-Iliopoulos-Maiani suppression of the first two quark generations and Cabibbo-Kobayashi-Maskawa suppression of the third. Contributions from intermediate physical states that couple to both D^0 and $\bar{D}^0$ are difficult to predict; they are estimated to be of the order 10^{-3}–10^{-2} [1]. Several recent studies report evidence for mixing parameters at the 1% level [2]. This is consistent with some SM expectations. As mixing is a rare process, it may be sensitive to particles and processes beyond the SM; existing measurements already pose constraints on a large number of new physics models [3]. *CP* violation in the charm sector is expected to be negligible in the SM; an observation would indicate contributions beyond SM.

We present the first time-dependent amplitude analysis of the $D^0 \to K^+\pi^-\pi^0$ Dalitz plot to extract the mixing parameters. Previously, we studied the time dependence of $D^0 \to K^+\pi^-\pi^0$ decays integrated over large regions of the Dalitz plot. We found no evidence for mixing [4]. However, since certain regions of the phase space are more sensitive to mixing than others, this analysis is more sensitive than our previous work. Two modes are reconstructed: (1) right-sign (RS) decays $D^0 \to K^-\pi^+\pi^0$ from a Cabibbo-favored (CF) amplitude and (2) wrong-sign (WS) decays $D^0 \to K^+\pi^-\pi^0$ from the coherent sum of a doubly Cabibbo-suppressed (DCS) amplitude and a CF amplitude produced by mixing. The interference of the two amplitudes gives rise to a linear dependence on the mixing parameters. We analyze events in which the flavor of the D^0 [5] is measured at production. We identify RS and WS decays by reconstructing the $D^{*+} \to D^0\pi_s^+$, $D^0 \to K\pi\pi^0$ decay chain. The flavor of the D^0 candidate is known by the charge of the low-momentum pion (π_s^+). The DCS and the CF amplitudes are described with isobar models [6].

The time-dependent decay rate depends on both the DCS amplitude $A_{\bar{f}}(s_{12}, s_{13}) = \langle \bar{f}|\mathcal{H}|D^0\rangle$ and the CF amplitude $\bar{A}_{\bar{f}}(s_{12}, s_{13}) = \langle \bar{f}|\mathcal{H}|\bar{D}^0\rangle$, where $s_{12} = m^2_{K^+\pi^-}$, $s_{13} = m^2_{K^+\pi^0}$, and $\bar{f} = K^+\pi^-\pi^0$. In the limit $|x|, |y| \ll 1$ and defining $\delta_{\bar{f}}(s_{12}, s_{13}) = \arg[A^*_{\bar{f}}(s_{12}, s_{13})\bar{A}_{\bar{f}}(s_{12}, s_{13})]$,

$$\frac{dN_{\bar{f}}(s_{12}, s_{13}, t)}{ds_{12}ds_{13}dt} = e^{-\Gamma t}\Big\{|A_{\bar{f}}|^2 + |A_{\bar{f}}||\bar{A}_{\bar{f}}|[y\cos\delta_{\bar{f}} - x\sin\delta_{\bar{f}}](\Gamma t) + \frac{x^2 + y^2}{4}|\bar{A}_{\bar{f}}|^2(\Gamma t)^2\Big\}. \quad (1)$$

The first term in Eq. (1) is the DCS contribution to the WS rate; the second term arises from the interference between DCS and mixing CF amplitudes; the third term is a pure mixing contribution. We determine the CF amplitude $\bar{A}_{\bar{f}}$ in a time-independent Dalitz plot analysis of the RS decay sample and use it in the analysis of the WS sample. The DCS amplitude $A_{\bar{f}}$ is extracted along with the mixing parameters using a fit to the WS data that separates the time dependence across the Dalitz plot from its overall rate. The time dependence is manifest in

$$\frac{dN_{\bar{f}}(s_{12}, s_{13}, t)}{ds_{12}ds_{13}dt} \propto e^{-\Gamma t}r_0^2\Big\{|A^{\mathrm{DCS}}_{\bar{f}}|^2 + |A^{\mathrm{DCS}}_{\bar{f}}||A^{\mathrm{CF}}_{\bar{f}}|[\tilde{y}\cos\delta_{\bar{f}} - \tilde{x}\sin\delta_{\bar{f}}](\Gamma t) + \frac{\tilde{x}^2 + \tilde{y}^2}{4}|A^{\mathrm{CF}}_{\bar{f}}|^2(\Gamma t)^2\Big\}, \quad (2)$$

where $A^{\mathrm{DCS}}_{\bar{f}} \equiv A_{\bar{f}}/\sqrt{\int |A_{\bar{f}}|^2 ds_{12}ds_{13}}$ and $A^{\mathrm{CF}}_{\bar{f}} \equiv \bar{A}_{\bar{f}}/\sqrt{\int |\bar{A}_{\bar{f}}|^2 ds_{12}ds_{13}}$ are normalized shapes, $r_0 \equiv \sqrt{\int |A_{\bar{f}}|^2 ds_{12}ds_{13}/\int |\bar{A}_{\bar{f}}|^2 ds_{12}ds_{13}}$, and $\tilde{x} \equiv x/r_0$ and $\tilde{y} \equiv y/r_0$ are normalized mixing parameters. In the isobar approach, $\bar{A}_{\bar{f}}$ and $A_{\bar{f}}$ are described as coherent sums of amplitudes, where each amplitude accounts for a resonance contribution. Previous studies [6] showed that the WS decays proceed primarily through the resonance $D^0 \to K^{*+}\pi^-$, while RS decays proceed primarily through $D^0 \to K^-\rho^+$ [Figs. 1(a) and 1(b)].

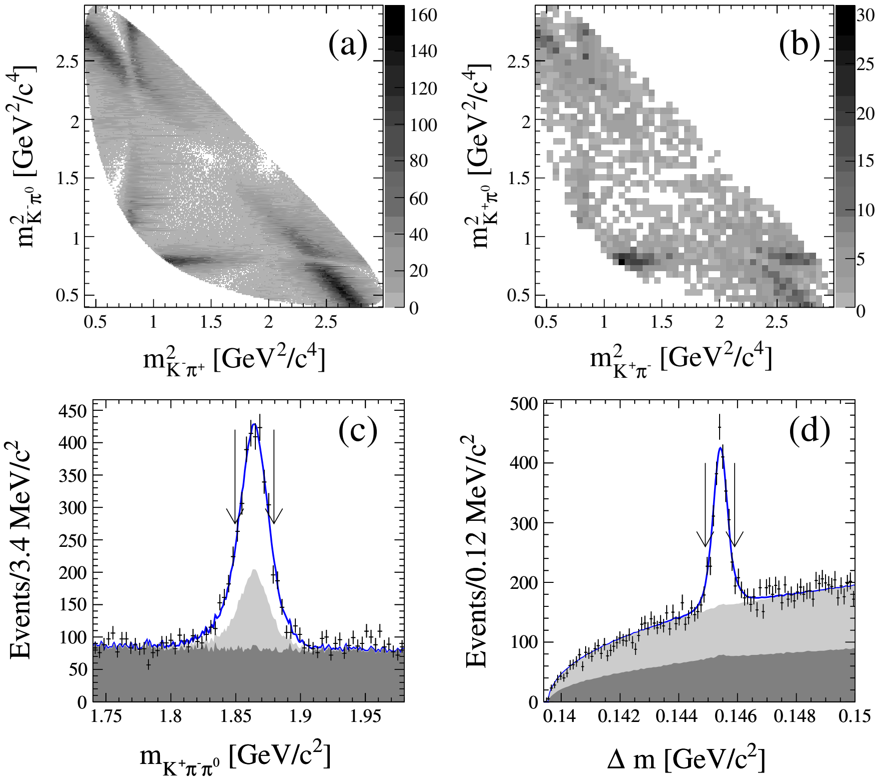

FIG. 1 (color online). Dalitz plots for the (a) RS and (b) WS D^0 samples. The reconstructed (c) D^0 mass and (d) Δm distributions for the WS sample requiring, respectively, (c) $0.1449 < \Delta m < 0.1459$ GeV$/c^2$ and (d) $1.8495 < m_{K\pi\pi^0} < 1.8795$ GeV$/c^2$. The fit results are shown by the superimposed curves. The light histogram represents the mistag background, while the dark histogram shows the combinatorial background.

The interference terms in Eqs. (1) and (2) produce a variation in average decay time as a function of position in the WS Dalitz plot that is sensitive to the complex amplitudes of the resonant isobars as well as the mixing parameters. The change in the average decay time and the interference between the $D^0 \to K^{*+}\pi^-$ and $D^0 \to \rho^- K^+$ amplitudes are the origin of our sensitivity to mixing. For both $\bar{A}_{\bar{f}}$ ($A_{\bar{f}}^{\mathrm{CF}}$) and $A_{\bar{f}}$ ($A_{\bar{f}}^{\mathrm{DCS}}$), one complex amplitude must be fixed arbitrarily; the strong interaction phase difference $\delta_{K\pi\pi^0}$ between the DCS $D^0 \to \rho^- K^+$ and the CF $\bar{D}^0 \to K^+\rho^-$ cannot be determined in this analysis. As a result, we are sensitive to x and y in the form

$$\begin{aligned} x'_{K\pi\pi^0} &\equiv x\cos\delta_{K\pi\pi^0} + y\sin\delta_{K\pi\pi^0}, \\ y'_{K\pi\pi^0} &\equiv y\cos\delta_{K\pi\pi^0} - x\sin\delta_{K\pi\pi^0}. \end{aligned} \qquad (3)$$

A nonzero value of $x'_{K\pi\pi^0}$ or $y'_{K\pi\pi^0}$ would signify mixing. In general, δ differs among decay modes.

The amplitudes entering the WS analysis are described as a sum of isobar components A_j that are parametrized with Breit-Wigner functions, $A_{\bar{f}}^{\mathrm{CF/DCS}} = \sum_{j=1}^{n_{\mathrm{CF/DCS}}} a_j e^{i\delta_j} A_j(m^2_{K^+\pi^-}, m^2_{K^+\pi^0})$, where a_j and δ_j are the strong interaction amplitudes and phases of the jth resonant amplitude [6]. For the $K\pi$ S-wave component, we use a parametrization derived from $K-\pi$ scattering data [7], which has a $K_0^*(1430)$ resonance plus an effective nonresonant component. The mass and width of the resonances are taken from the world average [8].

We analyze a data sample of 384 fb^{-1} collected with the *BABAR* detector [9] at the PEP-II e^+e^- collider at the Stanford Linear Accelerator Center near a center-of-mass energy of 10.58 GeV. Charged tracks are reconstructed with a silicon-strip detector (SVT) and a drift chamber (DCH), both in a 1.5 T magnetic field. Particle identification is based on measurements of ionization energy loss (dE/dx) in the SVT and DCH together with measurements from a Cherenkov ring-imaging device. Photon energies are measured with a CsI(Tl) calorimeter. All selection criteria, the fit procedure, and the systematic error analysis are finalized before we search for evidence of mixing in the data.

Selection criteria, identical for the RS and WS samples, are based partly on Ref. [4]. The π_s^+ candidates must have a transverse momentum $p_t^{\mathrm{LAB}} > 0.12$ GeV$/c$, where LAB indicates the laboratory frame, and reject electrons using dE/dx measurements. We use kinematic selection criteria to eliminate electrons from pair conversions. The energies of photon candidates used to form π^0 are required to be greater than 0.1 GeV; the invariant mass of photon pairs must be in the range $0.09 < m_{\pi^0} < 0.16\ \mathrm{GeV}/c^2$. We require the π^0 momentum $p_{\pi^0}^{\mathrm{LAB}}$ to be greater than $0.35\ \mathrm{GeV}/c$. The reconstructed invariant mass for the D^0 candidates must have $1.74 < m_{K\pi\pi^0} < 1.98\ \mathrm{GeV}/c^2$. The π^0 and D^0 masses are then set equal to their nominal values [8], and the D^* is refitted [10] with the constraint that its production point lies within the beam spot region. The D^{*+} invariant mass and D^0 measured decay time $t_{K\pi\pi^0}$ are derived from this fit. We require $0.139 < \Delta m < 0.155\ \mathrm{GeV}/c^2$, where $\Delta m \equiv m_{K\pi\pi^0\pi_s} - m_{K\pi\pi^0}$. To reject D^* candidates from B decays, we require the D^0 center-of-mass momentum to be greater than $2.4\ \mathrm{GeV}/c$. For events containing multiple D^* candidates with shared tracks, the candidate that yields the most probable fit for the decay chain is used. The three-dimensional flight path determines $t_{K\pi\pi^0}$ and its uncertainty σ_t. For signal events, the typical value of σ_t is 0.23 ps; we accept D^* candidates with $\sigma_t < 0.50$ ps. The K^+ and π^- tracks dominate the decay-vertex resolution.

We extract the signal and background yields from a binned extended maximum likelihood fit to the $m_{K\pi\pi^0}$ and Δm distributions [Figs. 1(c) and 1(d)]. For subsequent analysis, we retain D^* candidates in the signal region, $0.1449 < \Delta m < 0.1459\ \mathrm{GeV}/c^2$ and $1.8495 < m_{K\pi\pi^0} < 1.8795\ \mathrm{GeV}/c^2$. Our final RS (WS) sample is composed of 658 986 (3009) events with a purity of 99% (50%). The efficiency of the signal region selection is 54.6%.

The RS sample is used to determine the CF isobar model parameters a_j^{CF} and δ_j^{CF}, as well as the decay time resolution function, which is parametrized as a sum of three Gaussian functions with a common mean, with widths given by the per event σ_t times a different scale factor for each Gaussian. We account for the reconstruction efficiency in the determination of the a_j^{CF} and δ_j^{CF}. The reconstructed RS signal decay time distribution [Fig. 2(a)] is described by a probability density function (PDF) consisting of an exponential function convolved with the resolution. The resolution function parameters and D^0 lifetime are determined in an unbinned maximum likelihood fit. The mean value of the resolution function is found to be 4.2 ± 0.7 fs, and it is consistent with the magnitude expected from instrumental effects. The associated systematic uncertainty is determined by setting the value to zero. We determine the D^0 mean lifetime to be $[409.9 \pm 0.8(\mathrm{stat\,only})]$ fs, in agreement with the world average $[410.1 \pm 1.5(\mathrm{stat} + \mathrm{syst})]$ fs [8].

The D^0 candidates in the WS signal region can be divided into three categories: signal events, combinatorial

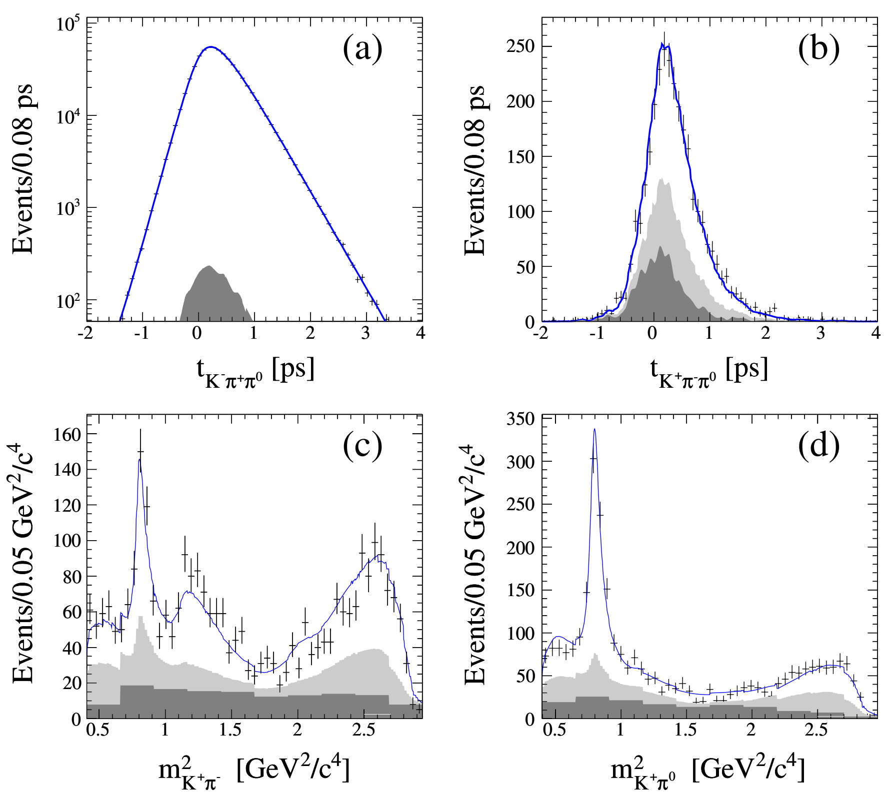

FIG. 2 (color online). (a) Proper time distribution for RS events with the fit result superimposed. The distribution of background events is shown by the shaded histogram. (b) Proper time distribution for WS events. (c), (d) $m^2_{K^+\pi^-}$ and $m^2_{K^+\pi^0}$ projections with superimposed fit results (line). The light histogram represents the mistag background, while the dark histogram shows the combinatoric background.

background, and incorrectly tagged RS events (mistag), each one described by its own PDF whose parameters are determined in an unbinned maximum likelihood fit. During the fit procedure, the number of events in each category is fixed to the value obtained from the fit to the $m_{K\pi\pi^0}$ and Δm distributions.

The PDF describing the WS decay rate as a function of the Dalitz plot variables is convolved with the $t_{K\pi\pi^0}$ resolution function. The DCS amplitudes and phases for each resonance, along with the mixing parameters, are determined in the fit. The CF Dalitz plot amplitudes arising from mixing are taken from the fit to the RS sample previously described. The mistag events contain correctly reconstructed RS D^0 decays; as the π_s^+ has no influence in the decay chain fit, the D^0 lifetime of those events is also correct. Therefore, the mistag events are parametrized using an empirical PDF obtained from the RS data for both the lifetime and the Dalitz plot variables. The PDF describing the combinatorial background is constructed by averaging the (s_{12}, s_{13}, $t_{K\pi\pi^0}$) distributions obtained from the WS $m_{K\pi\pi^0}$ sidebands: this accounts for correlations between those three variables that might be present in the data. We describe the σ_t distribution for signal and background using an empirical PDF from the RS data.

The results of the time-dependent fit of the WS data, the $a_j^{\rm DCS}$, $\delta_j^{\rm DCS}$ and fit fractions f_j [6], are given in Table I. The fit fraction of the nonresonant contribution to the $K\pi$ S wave is absorbed into the $K_0^{*+}(1430)$ and $K_0^{*0}(1430)$ fit fractions. Projections of the fit results are shown in Figs. 2(b)–2(d). The change in log-likelihood ($-2\Delta\ln\mathcal{L}$) between the fit with mixing and with no mixing ($x'_{K\pi\pi^0}/r_0 = y'_{K\pi\pi^0}/r_0 = 0$) is 13.5 units, including systematic uncertainties. For 2 degrees of freedom, the confidence level for the no-mixing hypothesis is 0.1%. Equivalently, this constitutes evidence for D^0-$\bar{D}^0$ at the 3.2 standard deviation level.

To derive the values of $x'_{K\pi\pi^0}$ and $y'_{K\pi\pi^0}$, we first determine $r_0^2 = [5.25^{+0.25}_{-0.31}({\rm stat}) \pm 0.12({\rm syst})] \times 10^{-3}$ using

$$r_0^2 = N_{\rm WS} \Big/ \left[N_{\rm RS}\left(1 + \tilde{y}A^2 - \tilde{x}B^2 + \frac{\tilde{x}^2 + \tilde{y}^2}{2}\right)\right] \quad (4)$$

with $A^2(B^2) \equiv \int {\rm Re(Im)}[A_{\bar{f}}^{\rm DCS*}A_{\bar{f}}^{\rm CF}]ds_{12}ds_{13}$. $N_{\rm WS}$ ($N_{\rm RS}$) is the number of WS (RS) signal events in the sample. We then generate 10^6 ($x'_{K\pi\pi^0}/r_0$, $y'_{K\pi\pi^0}/r_0$) points in accordance with the fit covariance matrix, assuming Gaussian errors (width given by the total uncertainty including systematics). For each point, we compute r_0 using Eq. (4) and determine values for $x'_{K\pi\pi^0}$ and $y'_{K\pi\pi^0}$. Using a Bayesian approach, by integrating the likelihood function with respect to $x'_{K\pi\pi^0}$ and $y'_{K\pi\pi^0}$, assuming a flat prior distribution, we obtain $x'_{K\pi\pi^0} = [2.61^{+0.57}_{-0.68}({\rm stat}) \pm 0.39({\rm syst})]\%$ and $y'_{K\pi\pi^0} = [-0.06^{+0.55}_{-0.64}({\rm stat}) \pm 0.34({\rm syst})]\%$ with a correlation of -0.75.

TABLE I. Fit results for the WS D^0 data sample. The total fit fraction is 102% and the χ^2/ndof is 188/215. The results for $x'_{K\pi\pi^0}/r_0$ and $y'_{K\pi\pi^0}/r_0$ include statistical and systematic errors; their total linear correlation is -0.34.

Resonance	$a_j^{\rm DCS}$	$\delta_j^{\rm DCS}$ (°)	f_j (%)
$\rho(770)$	1 (fixed)	0 (fixed)	39.8 ± 6.5
$K_2^{*0}(1430)$	0.088 ± 0.017	−17.2 ± 12.9	2.0 ± 0.7
$K_0^{*+}(1430)$	6.78 ± 1.00	69.1 ± 10.9	13.1 ± 3.3
$K^{*+}(892)$	0.899 ± 0.005	−171.0 ± 5.9	35.6 ± 5.5
$K_0^{*0}(1430)$	1.65 ± 0.59	−44.4 ± 18.5	2.8 ± 1.5
$K^{*0}(892)$	0.398 ± 0.038	24.1 ± 9.8	6.5 ± 1.4
$\rho(1700)$	5.4 ± 1.6	157.4 ± 20.3	2.0 ± 1.1
$x'_{K\pi\pi^0}/r_0 = 0.353 \pm 0.091 \pm 0.066$			
$y'_{K\pi\pi^0}/r_0 = -0.002 \pm 0.090 \pm 0.057$			

Extensive validation of this fitting procedure is performed using Monte Carlo (MC) experiments based on the PDF shapes and DCS amplitudes extracted from data. The validation studies are performed over the range $\{-0.6, 0.6\}$ for both $x'_{K\pi\pi^0}/r_0$ and $y'_{K\pi\pi^0}/r_0$. These studies demonstrate that the fit correctly determines the mixing parameters to within a small offset of 0.2–0.3σ, where σ is the statistical uncertainty. These small biases are a consequence of the relatively small size of our data sample and become negligible if MC samples with higher statistics are used. We correct the final result for this offset.

Sources of systematic uncertainty for $x'_{K\pi\pi^0}/r_0$ ($y'_{K\pi\pi^0}/r_0$), related to the choice of the isobar model and the experimental assumptions, are considered. For each effect we refit the data with an alternative assumption and extract the overall correlated uncertainty for the fitted parameters. We estimate the Dalitz model uncertainties [0.38σ (0.35σ)], where σ is the statistical uncertainty, by varying the mass and the width of each resonance within their error and by using alternative parametrizations for the isobar components A_j in the fit: the largest error arises from uncertainties in the K^* and ρ parameters and from uncertainties in the parametrization of the $K\pi$ S wave. Systematic uncertainties related to the number of signal and background events [0.15σ (0.22σ)] are evaluated by varying them according to their statistical uncertainties. Similarly, the definition of the signal region, the σ_t requirement, and the selection of the best D^* candidate are varied. The effect on the mixing parameters is 0.50σ (0.37σ). Variations in efficiency across the Dalitz plot contribute systematic uncertainties of 0.09σ (0.10σ). The $t_{K\pi\pi^0}$ resolution function parameters are varied within their errors. The offset is also set to zero. The systematic effect is 0.11σ (0.09σ). The total systematic error on $x'_{K\pi\pi^0}/r_0$ ($y'_{K\pi\pi^0}/r_0$) is 0.66σ (0.57σ).

The same procedure is applied separately to the WS D^0-tagged (+) and $\bar{D}^0$-tagged (−) events to search for

CP violation in mixing or interference. We find $x'^{+}_{K\pi\pi^0} = (2.53^{+0.54}_{-0.63} \pm 0.39)\%$, $y'^{+}_{K\pi\pi^0} = (-0.05^{+0.63}_{-0.67} \pm 0.50)\%$, $x'^{-}_{K\pi\pi^0} = (3.55^{+0.73}_{-0.83} \pm 0.65)\%$, and $y'^{-}_{K\pi\pi^0} = (-0.54^{+0.40}_{-1.16} \pm 0.41)\%$, respectively, and thus observe no evidence for CP violation. The correlation between $x'^{+}_{K\pi\pi^0}$ ($x'^{-}_{K\pi\pi^0}$) and $y'^{+}_{K\pi\pi^0}$ ($y'^{-}_{K\pi\pi^0}$) is -0.69 (-0.66).

Our data are inconsistent with the no-mixing hypothesis with a significance of 3.2 standard deviations including systematic uncertainties and thus present evidence of mixing. For the rotated mixing parameters, we find $x'_{K\pi\pi^0} = (2.61^{+0.57}_{-0.68} \pm 0.39)\%$ and $y'_{K\pi\pi^0} = (-0.06^{+0.55}_{-0.64} \pm 0.34)\%$ with a correlation of -0.75. These values are consistent with our previous result [4] and with some SM estimates. No evidence for CP violation is found.

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[1] L. Wolfenstein, Phys. Lett. **164B**, 170 (1985); A. F. Falk, Y. Grossman, Z. Ligeti, Y. Nir, and A. A. Petrov, Phys. Rev. D **69**, 114021 (2004).

[2] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **98**, 211802 (2007); M. Staric *et al.* (Belle Collaboration), Phys. Rev. Lett. **98**, 211803 (2007); L. M. Zang *et al.* (Belle Collaboration), Phys. Rev. Lett. **99**, 131803 (2007); B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **78**, 011105 (2008); T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **100**, 121802 (2008).

[3] G. Burdman and I. Shipsey, Annu. Rev. Nucl. Part. Sci. **53**, 431 (2003); A. A. Petrov, Int. J. Mod. Phys. A **21**, 5686 (2006); E. Golowich, J. Hewett, S. Pakvasa, and A. A. Petrov, Phys. Rev. D **76**, 095009 (2007); S. Bergmann, Y. Grossman, Z. Ligeti, Y. Nir, and A. A. Petrov, Phys. Lett. B **486**, 418 (2000).

[4] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **97**, 221803 (2006).

[5] The use of charge-conjugate modes is implied unless otherwise noted.

[6] S. Kopp *et al.* (CLEO Collaboration), Phys. Rev. D **63**, 092001 (2001).

[7] D. Aston *et al.*, (LASS Collaboration), Nucl. Phys. **B296**, 493 (1988).

[8] W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006).

[9] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).

[10] W. D. Hulsbergen, Nucl. Instrum. Methods Phys. Res., Sect. A **552**, 566 (2005).