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Measurement of D^0-$\overline{D}^0$ mixing using the ratio of lifetimes for the decays $D^0 \to K^-\pi^+$, K^-K^+, and $\pi^-\pi^+$

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We present a measurement of D^0-$\overline{D}^0$ mixing parameters using the ratios of lifetimes extracted from a sample of D^0 mesons produced through the process $D^{*+} \to D^0\pi^+$, which decay to $K^-\pi^+$, K^-K^+, or $\pi^-\pi^+$. The lifetimes of the CP-even, Cabibbo-suppressed modes K^-K^+ and $\pi^-\pi^+$ are compared with that of the CP-mixed, Cabibbo-favored mode $K^-\pi^+$ to obtain a measurement of y_{CP}, which in the limit of CP conservation corresponds to the mixing parameter y. The analysis is based on a data sample of 384 fb^{-1} collected by the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- collider. We obtain $y_{CP} = [1.24 \pm 0.39(\text{stat}) \pm 0.13(\text{syst})]\%$, which is evidence for D^0-$\overline{D}^0$ mixing at the 3σ level, and $\Delta Y = [-0.26 \pm 0.36(\text{stat}) \pm 0.08(\text{syst})]\%$, where ΔY constrains possible CP violation. Combining this result with a previous *BABAR* measurement of y_{CP} obtained from a separate sample of $D^0 \to K^-K^+$ events, we obtain $y_{CP} = [1.03 \pm 0.33(\text{stat}) \pm 0.19(\text{syst})]\%$.

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Several recent studies have shown evidence for mixing in the D^0-$\overline{D}^0$ system at the 1% level [1–3]. The measured values can be accommodated by the standard model (SM) [4], where the largest predictions for y are of $\mathcal{O}(10^{-2})$. These measurements provide strong constraints on new physics models [5]. One consequence of D^0-$\overline{D}^0$ mixing is that the D^0 decay-time distribution can be different for decays to different CP eigenstates [6]. An observation of CP violation in D^0-$\overline{D}^0$ mixing with the present experimental sensitivity would provide evidence for physics beyond the SM [7]. We present a measurement of this lifetime difference and the results of a search for CP violation in D^0-$\overline{D}^0$ mixing.

The two neutral D mass eigenstates $|D_1\rangle$ and $|D_2\rangle$ can be represented as

$$|D_1\rangle = p|D^0\rangle + q|\overline{D}^0\rangle,$$

$$|D_2\rangle = p|D^0\rangle - q|\overline{D}^0\rangle, \tag{1}$$

where $|p|^2 + |q|^2 = 1$. We characterize the rate of D^0-$\overline{D}^0$ mixing with the parameters $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/2\Gamma$, where $\Delta m = m_1 - m_2$ and $\Delta\Gamma = \Gamma_1 - \Gamma_2$ are the differences between the mass and width eigenvalues of the states in Eq. (1), respectively, and $\Gamma = (\Gamma_1 + \Gamma_2)/2$ is the average width. If either x or y is nonzero, mixing will occur.

The effects of CP violation in D^0-$\overline{D}^0$ mixing can be parameterized in terms of the quantities

$$r_m \equiv \left|\frac{q}{p}\right| \quad \text{and} \quad \varphi_f \equiv \arg\left(\frac{q}{p}\frac{\overline{A}_f}{A_f}\right), \tag{2}$$

where $A_f \equiv \langle f|\mathcal{H}_D|D^0\rangle$ ($\overline{A}_f \equiv \langle f|\mathcal{H}_D|\overline{D}^0\rangle$) is the amplitude for $D^0(\overline{D}^0)$ to decay into a final state f, and $\mathcal{H}_D$ is the Hamiltonian for the decay. A value of $r_m \neq 1$ would indicate CP violation in mixing. A nonzero value of φ_f would indicate CP violation in the interference between mixing and decay. Within the SM, CP violation in decay is expected to be small in the D^0-$\overline{D}^0$ system [7] and a search for this effect using these decay modes is considered elsewhere [8].

D^0-$\overline{D}^0$ mixing will alter the decay-time distribution of D^0 and $\overline{D}^0$ mesons that decay into final states of specific CP. To a good approximation, these decay-time distributions can be treated as exponential with effective lifetimes τ^+_{hh} and τ^-_{hh}, given by [9]

$$\begin{aligned}\tau^+_{hh} &= \tau_{K\pi}[1 + r_m(y\cos\varphi_f - x\sin\varphi_f)]^{-1}\\ \tau^-_{hh} &= \tau_{K\pi}[1 + r_m^{-1}(y\cos\varphi_f + x\sin\varphi_f)]^{-1},\end{aligned} \tag{3}$$

where $\tau_{K\pi}$ is the lifetime for the Cabibbo-favored decays $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$, and $\tau^+_{hh}(\tau^-_{hh})$ is the lifetime for the Cabibbo-suppressed decays of the $D^0(\overline{D}^0)$ into CP-even final states (such as K^-K^+ and $\pi^-\pi^+$). These effective lifetimes can be combined into the quantities y_{CP} and ΔY

$$y_{CP} = \frac{\tau_{K\pi}}{\langle\tau_{hh}\rangle} - 1,$$

$$\Delta Y = \frac{\tau_{K\pi}}{\langle\tau_{hh}\rangle}A_\tau, \tag{4}$$

where $\langle\tau_{hh}\rangle = (\tau^+_{hh} + \tau^-_{hh})/2$ and $A_\tau = (\tau^+_{hh} - \tau^-_{hh})/(\tau^+_{hh} + \tau^-_{hh})$. Both y_{CP} and ΔY are zero if there is no D^0-$\overline{D}^0$ mixing. In the limit of CP conservation, $y_{CP} = y$ and $\Delta Y = 0$, with the convention that $\cos\varphi_f > 0$.

We measure the D^0 lifetime in the three different D^0 decay modes, $K^-\pi^+$, K^-K^+, and $\pi^-\pi^+$. We use D^0 mesons coming from $D^{*+} \to D^0\pi^+$ decays [10]; the requirement of a D^{*+} parent strongly suppresses the backgrounds. We use the charge of the $D^{*\pm}$ to split the K^-K^+ and $\pi^-\pi^+$ samples into those originating from D^0 and from $\overline{D}^0$ mesons for measuring the CP-violating parameters. To avoid potential bias, we finalize our data selection criteria, the procedures for fitting and for extracting the statistical limits, and determine the systematic errors, prior to examining the mixing results.

Most systematic errors related to signal events are expected to cancel in the lifetime ratios. Background events can contain effects that differ in each decay mode, making them difficult to characterize. Therefore, the event selection is chosen to produce very pure samples. The decay-time distribution of signal candidates is fit to an exponential convolved with a resolution function that uses event-by-event decay-time errors. The decay-time resolution parameters are allowed to vary in the fit. Residual background components are modeled using Monte Carlo (MC) simulated events and control samples obtained from the data.

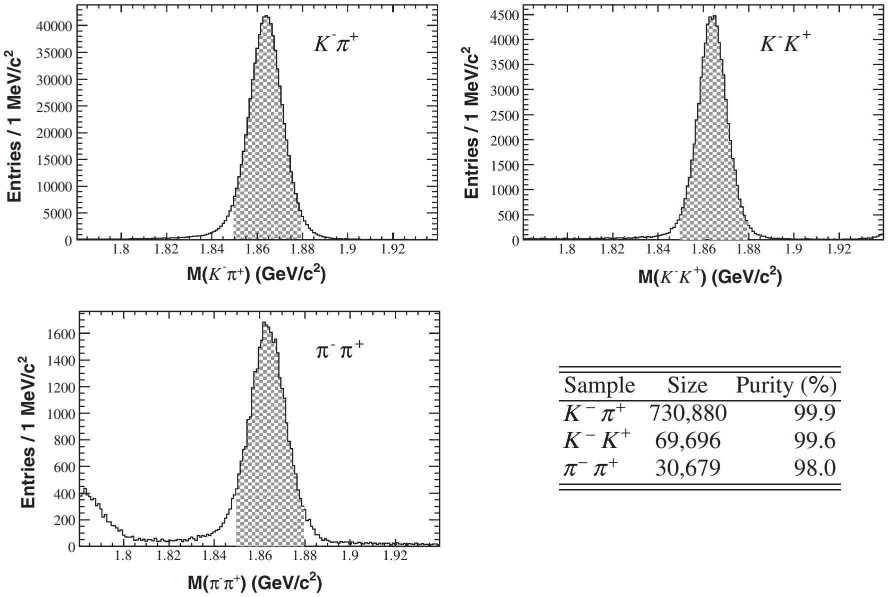
We use 384 fb^{-1} of e^+e^- colliding-beam data recorded near $\sqrt{s} = 10.6$ GeV with the *BABAR* detector [11] at the PEP-II asymmetric-energy storage rings. We begin by reconstructing candidate D^0 decays into the final states $K^-\pi^+$, $\pi^-\pi^+$, and K^-K^+. We require tracks to satisfy particle identification criteria based upon $\mathrm{d}E/\mathrm{d}x$ ionization energy loss and Cherenkov angle measurements. We fit pairs of tracks with the appropriate mass hypotheses to a common vertex. We require the invariant mass of a candidate track pair to be within the range 1.78–1.94 GeV/c^2. To further reduce backgrounds, we require the helicity angle θ_H, defined as the angle between the positively charged track in the D^0 rest frame and the D^0 direction in the lab frame, to satisfy $|\cos\theta_H| < 0.7$. This is particularly helpful for rejecting combinatorial background, especially in the $\pi^-\pi^+$ mode.

We reconstruct D^{*+} candidates by combining a D^0 candidate with a slow pion track (denoted π_s^+), requiring them to originate from a common vertex constrained to the e^+e^- interaction region. We require the π_s^+ momentum to be greater than 0.1 GeV/c in the laboratory frame and less than 0.45 GeV/c in the e^+e^- center-of-mass frame. We perform a vertex-constrained combined fit to the D^0 production and decay vertices, requiring the χ^2-based probability $P(\chi^2)$ to be at least 0.1%. The decay time t and its estimated uncertainty σ_t for each D^0 candidate are determined by this fit. We reject slow electrons that fake π_s^+ candidates using $\mathrm{d}E/\mathrm{d}x$ measurements in the tracking volume and further veto any π_s^+ candidate that may have originated from a reconstructed gamma conversion or π^0 Dalitz decay.

To reduce contributions from D^0's produced via B-meson decay to a negligible amount, we require each D^0 to have a momentum in the center-of-mass frame greater than 2.5 GeV/c. We also require $-2 < t < 4$ ps and $\sigma_t < 0.5$ ps. The most probable value of σ_t for signal events is 0.16 ps. For cases where multiple $D^{*\pm}$ candidates in an event share one or more tracks, we retain only the candidate with the highest $P(\chi^2)$.

The distribution of the difference in the reconstructed D^{*+} and D^0 masses (δm) peaks near 0.1455 GeV/c^2. Backgrounds are suppressed by retaining only those D^{*+} candidates within the interval $0.1447 < \delta m < 0.1463$ GeV/c^2. The reconstructed invariant mass (M_{hh}) distributions for the selected D^0 candidates are shown in Fig. 1. When determining the D^0 lifetime, we only use D^0 candidates with M_{hh} within the interval $1.8495 < M_{hh} < 1.8795$ GeV/c^2 around the D^0 signal peak (shaded regions in Fig. 1); the sample yields and purities within this signal region are also given.

The D^0 lifetime is determined from an unbinned maximum likelihood fit to the reconstructed decay time and its estimated error for events in the signal region. The fit has 18 free parameters and is performed simultaneously to all five decay samples ($D^0 \to K^-K^+$; $\overline{D}^0 \to K^+K^-$; $D^0 \to \pi^-\pi^+$; $\overline{D}^0 \to \pi^+\pi^-$; $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$ combined). The D^0 candidates in the signal region can be divided into three components: D^0 signal events, combi-



Sample	Size	Purity (%)
$K^-\pi^+$	730,880	99.9
K^-K^+	69,696	99.6
$\pi^-\pi^+$	30,679	98.0

FIG. 1. The reconstructed D^0 mass distributions for the three D^0 samples, within ± 0.0008 GeV/c^2 of the peak of δm. The shaded regions indicate the mass distributions of the D^0 candidates used in the lifetime fit. (The structures appearing above 1.92 GeV/c^2 in the K^-K^+ decay mode, and below 1.81 GeV/c^2 in the $\pi^-\pi^+$ decay mode, are mainly due to candidates with misidentified kaons or pions.) Also shown are the yield and purity for each of the three D^0 samples as determined in the D^0 lifetime fit.

natorial background, and mis-reconstructed charm events. Each component is described by its own probability density function (PDF), which also depends upon the D^0 or $\overline{D}^0$ decay mode. Approximately 0.4% of the D^0 signal events consists of a correctly reconstructed D^0 candidate combined with an unrelated π_s; this yield is estimated from MC and verified in data. These candidates have the same resolution and lifetime behavior as those from correctly reconstructed D^{*+} decays, but about half of them will be tagged as the wrong flavor. We therefore include a 0.2% component in the signal PDF that uses the lifetime of the opposite flavor state. These events are included in the signal sample in Fig. 1.

The measured decay-time distribution of signal events is described by an exponential convolved with a resolution function. The resolution function is the sum of three Gaussian functions with widths proportional to σ_t. The three Gaussian functions share a common mean, which is allowed to be offset from zero in order to take detector misalignment effects into account. The effect of the offset is studied as part of the cross-checks and taken into account as a systematic uncertainty. The resolution function parameters are all permitted to vary in the fit. Up to an overall scale factor in the width, the resolution function is observed to have the same shape for all modes, including the offset. To account for the small (1.5%) differences in width, we introduce two parameters $S_{K^-K^+}$ and $S_{\pi^-\pi^+}$ to scale the overall width of the K^-K^+ and $\pi^-\pi^+$ resolution functions relative to the width of the $K^-\pi^+$ resolution function. All other resolution function parameters are shared among the different modes and are determined by a simultaneous fit to all modes together.

The decay-time distribution of the combinatorial background is described by a sum of a Gaussian and a modified Gaussian with a power-law tail to account for a small number of events with large reconstructed lifetimes. The means of these functions are allowed to vary in the fit. Each of the three decay modes has its own shape for the combinatorial background. These shapes are determined from fits to the events in the sideband region defined by $1.89 < M_{hh} < 1.92$ GeV/c^2 and $0.151 < \delta m < 0.159$ GeV/c^2. We determine the amount of combinatorial background using MC samples scaled to the same luminosity as the data, modeling all known, relevant physics processes. The fraction of combinatorial background in the $K^-\pi^+$ mode is estimated to be $(0.032 \pm 0.003)\%$, in the K^-K^+ mode $(0.16 \pm 0.02)\%$, and in the $\pi^-\pi^+$ mode $(1.8 \pm 0.2)\%$. The uncertainties are determined by comparing data and MC events in the $(M_{hh}, \delta m)$ sideband where the combinatorial background is dominant.

Mis-reconstructed charm background events have one or more of the charm decay products either not reconstructed or reconstructed with the wrong particle hypothesis. Most are D^0 mesons from a $D^{*+} \to D^0\pi_s$ decay with a correctly reconstructed π_s. For the $K^-\pi^+$ mode, most of the charm background arises from semi-leptonic decays $D^0 \to K^-\ell^+\nu$, where the charged lepton is misidentified as a pion. The semi-leptonic decays also contribute to the K^-K^+ final state, but the dominant contribution is from $D^0 \to K^-\pi^+\pi^0$ in which the π^0 is not reconstructed and the π^+ is misidentified as a kaon. There is also a small contribution from $D^+ \to K^-\pi^+\pi^+$ decays. In the $\pi^-\pi^+$ mode, the charm background is almost exclusively due to mis-reconstructed $D^0 \to K^-\pi^+$ decays in which the kaon has been misidentified as a pion. The decay-time distributions of the charm backgrounds are described by an exponential convolved with a Gaussian. The parameters are fixed to values obtained in a fit to MC events. The fraction of charm background events in the signal region is estimated from MC simulation and cross-checked by comparing data and MC events in a $(M_{hh}, \delta m)$ sideband region defined by $1.78 < M_{hh} < 1.80$ GeV/c^2 and $0.14 < \delta m < 0.16$ GeV/c^2, where the charm background is the dominant contribution. We estimate the charm background to be $(0.009 \pm 0.002)\%$ of events in the signal region for $K^-\pi^+$, $(0.2 \pm 0.1)\%$ for K^-K^+, and $(0.15 \pm 0.15)\%$ for $\pi^-\pi^+$.

The results of the lifetime fits are shown in Fig. 2. The fitted D^0 lifetime $\tau_{K\pi}$ is found to be 409.33 ± 0.70 (stat) fs, consistent with the world-average lifetime [12]. From the fit results we calculate y_{CP} and ΔY for the K^-K^+ mode, the $\pi^-\pi^+$ mode, and the two modes combined, taking into account any correlations between the fitted lifetimes. The dominant correlation between lifetimes, 11%, arises because the decay-time resolution offset is shared between the decay modes. The y_{CP} and ΔY results are listed in Table I. The combined result is obtained by fitting the data with common lifetimes for the K^-K^+ and $\pi^-\pi^+$ modes, and assuming the same value of φ_f for the K^-K^+ and $\pi^-\pi^+$ decay modes.

Various cross-checks have been performed to ensure that the fit is unbiased and the assumptions in the fit model are well-founded. An offset in the resolution function is measured in the fit to be -4.75 ± 0.51 fs. This offset was seen in our recent $K^-\pi^+$ mixing analysis [1] and has also been observed in other *BABAR* measurements of charm decays. Because we measure ratios of lifetimes, the presence of a common offset has minimal impact on the values y_{CP} and ΔY. However, differences in the offset between the three decay modes, or between the D^0 and $\overline{D}^0$, could introduce a bias. No resolution offset is found in the MC samples. However, we are able to introduce offsets in the fits to the MC sample of up to twice the size of the offset in data by misaligning the silicon vertex tracker (SVT). In all cases, the offsets are found to be consistent between all modes.

The fitting procedure has been validated with generic MC samples weighted to the luminosity of the data sample and with dedicated signal MC samples. The signal efficiency is found to be independent of the true decay time, and the fitted lifetimes are consistent with the generated value.

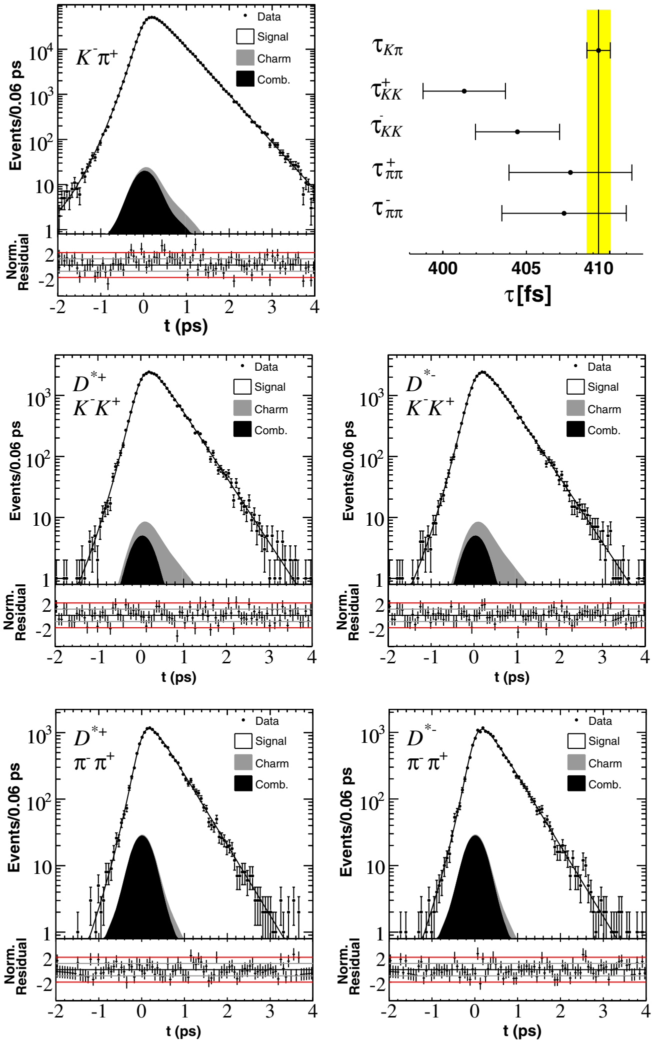


FIG. 2 (color online). Decay-time distribution in the data samples with the combined fit overlaid. The top left plot is the tagged $K^-\pi^+$ sample, the middle plots are the D^{*+} (left) and D^{*-} (right) tagged K^-K^+ samples, and the bottom plots are the tagged $\pi^-\pi^+$ samples. The shaded and black distributions represent the charm and combinatorial background in the fit, respectively. The normalized residuals for each fit are shown as a separate histogram for each sample. The top right plot shows a summary of the measured lifetimes.

The assumption that the resolution function is the same for all decay modes except for a scale factor is tested by fitting each sample independently. This gives mixing parameters and resolution offsets consistent with the nominal fit, but with significantly larger statistical uncertainties. The lifetime has also been extracted in independent fits to the flavor-separated samples of $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$ decays. The fitted lifetimes and resolution functions in these two samples are consistent with each other.

To cross-check the effect of the resolution offset, we performed further studies by dividing the data sample into subsamples with different sensitivities to detector effects and fitting each subsample independently. Besides the D^* tagged samples used for this mixing measurement, we also use a control sample of $D^0 \to K^-\pi^+$ decays, where the D^0 is not required to come from a D^* decay. This untagged sample has about 5 times as many D^0 decays as the D^* tagged samples combined, allowing us to divide the sample

TABLE I. The mixing parameters extracted from the fit to data, where the first error is statistical and the second is systematic.

Sample	y_{CP}	ΔY
K^-K^+	$(1.60 \pm 0.46 \pm 0.17)\%$	$(-0.40 \pm 0.44 \pm 0.12)\%$
$\pi^-\pi^+$	$(0.46 \pm 0.65 \pm 0.25)\%$	$(0.05 \pm 0.64 \pm 0.32)\%$
Combined	$(1.24 \pm 0.39 \pm 0.13)\%$	$(-0.26 \pm 0.36 \pm 0.08)\%$

more finely. The quantities used to divide the data into subsamples for these tests include the run period, the azimuthal and polar angle of the D^0 meson, the opening angle between the D^0 daughter tracks, and the orientation of the D^0 decay plane with respect to the X-Y (bending) plane of the detector. In all of the variables mentioned, the resolution offset is observed to have a large variation (typically between -10 fs and 0 fs), but the fitted lifetimes are consistent among samples. Furthermore, the weighted average of the mixing parameters from the subdivided data samples is in almost all cases nearly identical to that obtained by fitting the full data sample with one common lifetime and resolution function as described previously. We find no evidence of variation in the fitted lifetime between the five *BABAR* running periods (χ^2 probability for consistency of 57%). The largest variation is observed with the polar angle of the D^0 meson in the laboratory frame, where decays perpendicular to the beam line are found to have almost no resolution offset, while decays into the forward region of the detector have a large offset. Since the acceptance for $D^0 \to K^- K^+$ decays is lower in the forward region than for $D^0 \to K^- \pi^+$ or $D^0 \to \pi^- \pi^+$ decays, the polar angle dependence in the offset could potentially introduce a different average offset for each of the three modes. This is accounted for in the systematic errors.

The systematic uncertainties on the mixing parameters are small, since most uncertainties in the lifetimes cancel in the ratios. We have considered variations in the signal and background fit models, changes to the event selection and detector effects that could introduce biases in the lifetime. Table II summarizes the various systematic uncertainties. The evaluation of each of these is described below. The systematic uncertainty on y_{CP} and ΔY averaged over the two *CP* modes is occasionally smaller than the individual uncertainties because of anti-correlations.

We vary the signal PDF shape, and the size and position of the signal region. As part of the PDF shape variations, we perform a fit without a resolution offset. The effect of the polar angle dependence in the resolution offset is evaluated by performing the fit with separate, floating offsets in seven bins of polar angle, but sharing all other resolution parameters and lifetimes across all polar angle bins. The difference in the mixing parameters between this fit and the nominal fit is found to be small ($< 0.02\%$). The largest systematic contribution to y_{CP}^{KK} (0.12%) is due to changing the M_{hh} requirement to $1.8395 < M_{hh} < 1.8895\ \mathrm{GeV}/c^2$. The choice of signal region determines the level of mis-reconstructed signal events included in the fit.

The mis-reconstructed charm background is a very small component in the lifetime fit and is determined using MC events. Varying the charm background fraction (depending on the mode) and the effective lifetime, both within their associated uncertainties, yields a minor contribution to the systematic uncertainty.

Because of the high purity, the results have little sensitivity to the modeling of the combinatorial background, except in the $\pi^- \pi^+$ mode where varying the fraction of combinatorial background by 10% yields a systematic uncertainty in $y_{CP}^{\pi\pi}$ of 0.14%. We also alter the fit procedure by using a different sideband region and by substituting the MC decay-time distribution for that obtained from fitting the data. Neither variation contributes a large systematic uncertainty.

We have studied the effect of varying the event selection criteria, which could potentially affect the lifetime measurement. Changing the treatment of events where multiple D^{*+} candidates share one or more tracks (either keeping all of them or throwing them all out) has little effect, while changing the upper bound on the decay-time uncertainty from 0.5 to 0.4 ps yields the largest individual systematic uncertainty on $y_{CP}^{\pi\pi}$ of 0.172%. As with the D^0 mass window, the choice of the σ_t range affects the level of mis-reconstructed events.

To evaluate the effect of possible misalignments in the SVT on the mixing parameters, signal MC events are reconstructed with different alignment parameters, and the analysis is repeated. The misalignments introduce resolution offsets in the MC of up to 10 fs, and the corresponding fitted lifetimes change by up to 3 fs. Since the same MC sample is reconstructed for each set of alignment parameters, the variations are dominated by systematic effects. We therefore assign 100% of each variation as a systematic uncertainty, combining them in quadrature. Since the lifetimes of all decay modes change by similar

TABLE II. Summary of systematic uncertainties on y_{CP} and ΔY, separately for $K^- K^+$ and $\pi^- \pi^+$ and averaged over the two *CP* modes, in percent.

Systematic	$\sigma_{y_{CP}}$ (%) $K^- K^+$	$\sigma_{y_{CP}}$ (%) $\pi^- \pi^+$	$\sigma_{y_{CP}}$ (%) Av.	$\sigma_{\Delta Y}$ (%) $K^- K^+$	$\sigma_{\Delta Y}$ (%) $\pi^- \pi^+$	$\sigma_{\Delta Y}$ (%) Av.
Signal model	0.130	0.059	0.085	0.072	0.265	0.062
Charm bkg.	0.062	0.037	0.043	0.001	0.002	0.001
Combinatoric bkg.	0.019	0.142	0.045	0.001	0.005	0.002
Selection criteria	0.068	0.178	0.046	0.083	0.172	0.011
Detector model	0.064	0.080	0.064	0.054	0.040	0.054
Quadrature sum	0.172	0.251	0.132	0.122	0.318	0.083

amounts, the effect on y_{CP} and ΔY is small. We also changed the energy loss correction applied in the tracking by 20%, since a previous analysis has shown that the energy loss is underestimated in the reconstruction of data events [13]. This changes the fitted lifetimes by about 0.5 fs but has little effect on the mixing parameters.

We combine the results shown in Table I, with those from a previous *BABAR* study [14], based on 91 fb^{-1} of data, that does not require a D^{*+} parent to identify the D^0 decays. In this earlier analysis, tagged D^0 decays have been removed. Therefore, the data sample of the earlier analysis is essentially disjoint from the present sample and its results statistically independent. The systematic uncertainties in the previous analysis were dominated by the limited number of simulated events. Since the MC samples in the present study are entirely independent, these uncertainties are not correlated with those of the new results. Conservatively assuming the remaining systematic uncertainties to be 100% correlated, we combine the two results using the BLUE method [15] and obtain $y_{CP} = [1.03 \pm 0.33\ (\text{stat}) \pm 0.19\ (\text{syst}))]\%$.

In summary, we have obtained a value of $y_{CP} = [1.24 \pm 0.39\ (\text{stat}) \pm 0.13\ (\text{syst}))]\%$, which is evidence of D^0-$\overline{D}^0$ mixing at the 3σ level. It is compatible with our previous result [14] and the recent lifetime ratio measurement from Belle of $y_{CP} = [1.31 \pm 0.32\ (\text{stat}) \pm 0.25\ (\text{syst})]\%$ [2]. We find no evidence for *CP* violation and determine ΔY to be $[-0.26 \pm 0.36\ (\text{stat}) \pm 0.08\ (\text{syst})]\%$. The result is consistent with SM estimates for mixing.

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[1] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **98**, 211802 (2007).
[2] M. Staric *et al.* (BELLE Collaboration), Phys. Rev. Lett. **98**, 211803 (2007).
[3] L.M. Zhang *et al.* (BELLE Collaboration), Phys. Rev. Lett. **99**, 131803 (2007).
[4] L. Wolfenstein, Phys. Lett. **164B**, 170 (1985); J.F. Donoghue, E. Golowich, B.R. Holstein, and J. Trampetic, Phys. Rev. D **33**, 179 (1986); I. I. Y. Bigi and N. G. Uraltsev, Nucl. Phys. **B592**, 92 (2001); A. F. Falk, Y. Grossman, Z. Ligeti, and A. A. Petrov, Phys. Rev. D **65**, 054034 (2002); A. F. Falk, Y. Grossman, Z. Ligeti, Y. Nir, and A. A. Petrov, Phys. Rev. D **69**, 114021 (2004).
[5] 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).
[6] T. Liu, in Batavia 1994, The Future of High-Sensitivity Charm Experiments, Proceedings of the CHARM 2000 Workshop, edited by D. Kaplan and S. Kwan, FERMILAB-Conf-94/190 (1994).
[7] G. Blaylock, A. Seiden, and Y. Nir, Phys. Lett. B **355**, 555 (1995); I. I. Bigi and A. I. Sanda, *CP Violation* (Cambridge University Press, Cambridge, England, 2000), p. 257; G. Burdman and I. Shipsey, Annu. Rev. Nucl. Part. Sci. **53**, 431 (2003); Y. Grossman, A. L. Kagan, and Y. Nir, Phys. Rev. D **75**, 036008 (2007).
[8] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **94**, 122001 (2005); X. C. Tian *et al.* (BELLE Collaboration), Phys. Rev. Lett. **95**, 231801 (2005); B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **100**, 061803 (2008).
[9] S. Bergmann, Y. Grossman, Z. Ligeti, Y. Nir, and A. A. Petrov, Phys. Lett. B **486**, 418 (2000).
[10] The use of charge-conjugate modes is implied unless otherwise noted.
[11] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).
[12] W. M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006).
[13] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **72**, 052006 (2005).
[14] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **91**, 121801 (2003).
[15] L. Lyons, D. Gibaut, and P. Clifford, Nucl. Instrum. Methods Phys. Res., Sect. A **270**, 110 (1988).