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Tests of *CPT* symmetry in B^0-$\bar{B}^0$ mixing and in $B^0 \to c\bar{c}K^0$ decays

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Using the eight time dependences $e^{-\Gamma t}(1+C_i\cos\Delta mt+S_i\sin\Delta mt)$ for the decays $\Upsilon(4S)\to B^0\bar{B}^0\to f_jf_k$, with the decay into a flavor-specific state $f_j=\ell^\pm X$ before or after the decay into a *CP* eigenstate $f_k=c\bar{c}K_{S,L}$, as measured by the *BABAR* experiment, we determine the three *CPT*-sensitive parameters $\mathrm{Re}(\mathsf{z})$ and $\mathrm{Im}(\mathsf{z})$ in B^0-$\bar{B}^0$ mixing and $|\bar{A}/A|$ in $B^0\to c\bar{c}K^0$ decays. We find $\mathrm{Im}(\mathsf{z})=0.010\pm0.030\pm0.013$, $\mathrm{Re}(\mathsf{z})=-0.065\pm0.028\pm0.014$, and $|\bar{A}/A|=0.999\pm0.023\pm0.017$, in agreement with *CPT* symmetry.

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I. INTRODUCTION

The discovery of *CP* violation in 1964 [1] motivated searches for *T* and *CPT* violation. Since $CPT=CP\times T$, violation of *CP* means that *T* or *CPT* or both are also violated. For the K^0 system, the two contributions were first determined [2] in 1970, by using the Bell-Steinberger unitarity relation [3] for *CP* violation in K^0-$\bar{K}^0$ mixing: *T* was violated with about 5σ significance and no *CPT* violation was observed. Large *CP* violation in the B^0 system was discovered in 2001 [4,5] in the interplay of B^0-$\bar{B}^0$ mixing and $B^0\to c\bar{c}K^0$ decays, but an explicit demonstration of *T* violation was given only recently [6]. In the present analysis, we test *CPT* symmetry quantitatively in B^0-$\bar{B}^0$ mixing and in $B^0\to c\bar{c}K^0$ decays.

Transitions in the B^0-$\bar{B}^0$ system are well described by the quantum-mechanical evolution of a two-state wave function

$$\Psi=\psi_1|B^0\rangle+\psi_2|\bar{B}^0\rangle, \tag{1}$$

using the Schrödinger equation

$$\dot{\Psi}=-\mathrm{i}\mathcal{H}\Psi, \tag{2}$$

where the Hamiltonian $\mathcal{H}$ is given by two constant Hermitian matrices, $\mathcal{H}_{ij}=m_{ij}+\mathrm{i}\Gamma_{ij}/2$. In this evolution, *CP* violation is described by three parameters, $|q/p|$, $\mathrm{Re}(\mathsf{z})$, and $\mathrm{Im}(\mathsf{z})$, defined by

$$\begin{aligned}|q/p|&=1-\frac{2\mathrm{Im}(m_{12}^*\Gamma_{12})}{4|m_{12}|^2+|\Gamma_{12}|^2},\\ \mathsf{z}&=\frac{(m_{11}-m_{22})-\mathrm{i}(\Gamma_{11}-\Gamma_{22})/2}{\Delta m-\mathrm{i}\Delta\Gamma/2},\end{aligned} \tag{3}$$

where $\Delta m=m(B_H)-m(B_L)\approx2|m_{12}|$ and $\Delta\Gamma=\Gamma(B_H)-\Gamma(B_L)\approx+2|\Gamma_{12}|$ or $-2|\Gamma_{12}|$ are the mass and the width differences of the two mass eigenstates ($H=$ heavy, $L=$ light) of the Hamiltonian,

$$\begin{aligned}B_H&=(p\sqrt{1+\mathsf{z}}B^0-q\sqrt{1-\mathsf{z}}\bar{B}^0)/\sqrt{2},\\ B_L&=(p\sqrt{1-\mathsf{z}}B^0+q\sqrt{1+\mathsf{z}}\bar{B}^0)/\sqrt{2}.\end{aligned} \tag{4}$$

Note that we use the convention with $+q$ for the light and $-q$ for the heavy eigenstate. If $|q/p|\neq1$, the evolution violates the discrete symmetries *CP* and *T*. If $\mathsf{z}\neq0$, it violates *CP* and *CPT*. The normalizations of the two eigenstates, as given in Eq. (4), are precise in the lowest order of r and z, where $r=|q/p|-1$. Throughout the following, we neglect contributions of orders r^2, z^2, $r\mathsf{z}$, and higher.

The *T*-sensitive mixing parameter $|q/p|$ has been determined in several experiments, the present world average [7] being $|q/p|=1+(0.8\pm0.8)\times10^{-3}$. The *CPT*-sensitive parameter $\mathrm{Im}(\mathsf{z})$ has been determined by analyzing the time dependence of dilepton events in the decay $\Upsilon(4S)\to B^0\bar{B}^0\to(\ell^+\nu X)(\ell^-\bar{\nu}X)$; the *BABAR* result [8] is $\mathrm{Im}(\mathsf{z})=(-13.9\pm7.3\pm3.2)\times10^{-3}$. Since $\Delta\Gamma$ is very small, dilepton events are only sensitive to the product $\mathrm{Re}(\mathsf{z})\Delta\Gamma$. Therefore, $\mathrm{Re}(\mathsf{z})$ has so far only been determined by analyzing the time dependence of the decays $\Upsilon(4S)\to B^0\bar{B}^0$ with one *B* meson decaying into $\ell\nu X$ and the other one into $c\bar{c}K$. With $88\times10^6 B\bar{B}$ events, *BABAR* measured $\mathrm{Re}(\mathsf{z})=(19\pm48\pm47)\times10^{-3}$ in 2004 [9], while Belle used $535\times10^6 B\bar{B}$ events to measure $\mathrm{Re}(\mathsf{z})=(19\pm37\pm33)\times10^{-3}$ in 2012 [10].

In our present analysis, we use the final data set of the *BABAR* experiment [11,12] with $470\times10^6 B\bar{B}$ events for a new determination of $\mathrm{Re}(\mathsf{z})$ and $\mathrm{Im}(\mathsf{z})$. As in Refs. [9,10], this is based on $c\bar{c}K$ decays with amplitudes A for $B^0\to c\bar{c}K^0$ and $\bar{A}$ for $\bar{B}^0\to c\bar{c}\bar{K}^0$, using the following two assumptions:

(1) $c\bar{c}K$ decays obey the $\Delta S=\Delta B$ rule, i.e., B^0 states do not decay into $c\bar{c}\bar{K}^0$, and $\bar{B}^0$ states do not decay into $c\bar{c}K^0$;

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(2) *CP* violation in K^0-$\bar{K}^0$ mixing is negligible, i.e., $K_S^0 = (K^0 + \bar{K}^0)/\sqrt{2}$, $K_L^0 = (K^0 - \bar{K}^0)/\sqrt{2}$.

The *CPT*-sensitive parameters are determined from the measured time dependences of the four decay rates $B^0, \bar{B}^0 \to c\bar{c}K_S^0, K_L^0$. In $\Upsilon(4S)$ decays, B^0 and $\bar{B}^0$ mesons are produced in the entangled state $(B^0\bar{B}^0 - \bar{B}^0B^0)/\sqrt{2}$. When the first meson decays into $f = f_1$ at time t_1, the state collapses into the two states f_1 and B_2. The later decay $B_2 \to f_2$ at time t_2 depends on the state B_2 and, because of B^0-$\bar{B}^0$ mixing, on the decay-time difference

$$t = t_2 - t_1 \geq 0. \tag{5}$$

Note that t is the only relevant time here; it is the evolution time of the single-meson state B_2 in its rest frame.

The present analysis does not start from raw data but uses intermediate results from Ref. [6] where, as mentioned above, we used our final data set for the demonstration of large T violation. This was shown in four time-dependent transition-rate differences

$$R(B_j \to B_i) - R(B_i \to B_j), \tag{6}$$

where $B_i = B^0$ or $\bar{B}^0$, and $B_j = B_+$ or B_-. The two states B_i were defined by flavor-specific decays [13] denoted as $B^0 \to \ell^+X$, $\bar{B}^0 \to \ell^-X$. The state B_+ was defined as the remaining state B_2 after a $c\bar{c}K_S^0$ decay, and B_- as B_2 after a $c\bar{c}K_L^0$ decay. In order to use the two states for testing T symmetry in Eq. (6), they must be orthogonal; $\langle B_+|B_-\rangle = 0$, which requires the additional assumption

(3) $|\bar{A}/A| = 1$.

In the same 2012 analysis, we demonstrated that *CPT* symmetry is unbroken within uncertainties by measuring the four rate differences

$$R(B_j \to B_i) - R(\bar{B}_i \to B_j). \tag{7}$$

For both measurements in Eqs. (6) and (7), expressions

$$R_i(t) = N_i \mathrm{e}^{-\Gamma t}(1 + C_i \cos \Delta m t + S_i \sin \Delta m t), \tag{8}$$

$i = 1\ldots8$, were fitted to the four time-dependent rates where the ℓX decay precedes the $c\bar{c}K$ decay, and to the four rates where the order of the decays is inverted. The rate ansatz in Eq. (8) requires $\Delta\Gamma = 0$. The time $t \geq 0$ in these expressions is the time between the first and the second decay of the entangled $B^0\bar{B}^0$ pair as defined in Eq. (5). In our 2012 analysis, we named it $\Delta\tau$, equal to $t_{c\bar{c}K} - t_{\ell X}$ if the ℓX decay occurred first, and equal to $t_{\ell X} - t_{c\bar{c}K}$ with $c\bar{c}K$ as the first decay. After the fits, the T-violating and *CPT*-testing rate differences were evaluated from the obtained S_i and C_i results. The *CPT* test showed no *CPT* violation, i.e., it was compatible with $\mathsf{z} = 0$, but no results for $\mathrm{Re}(\mathsf{z})$ and $\mathrm{Im}(\mathsf{z})$ were given in 2012.

Our present analysis uses the eight measured time dependences in the 2012 analysis, i.e., the 16 results C_i and S_i, for determining z. This is possible without assumption (3) since we do not need to use the concept of states B_+ and B_-. We are therefore able to determine the decay parameter $|\bar{A}/A|$ in addition to the mixing parameters $\mathrm{Re}(\mathsf{z})$ and $\mathrm{Im}(\mathsf{z})$. As in 2012, we use $\Delta\Gamma = 0$, but we show at the end of this analysis that the final results are independent of this constraint. Accepting assumptions (1) and (2), and in addition

(4) that the amplitudes A and $\bar{A}$ have a single weak phase,

only two more parameters $|\bar{A}/A|$ and $\mathrm{Im}(q\bar{A}/pA)$ are required in addition to $|q/p|$ and z for a full description of *CP* violation in time-dependent $B^0 \to c\bar{c}K^0$ decays. In this framework, T symmetry requires $\mathrm{Im}(q\bar{A}/pA) = 0$ [14], and *CPT* symmetry requires $|\bar{A}/A| = 1$ [15].

II. B-MESON DECAY RATES

The time-dependent rates of the decays $B^0, \bar{B}^0 \to c\bar{c}K$ are sensitive to both symmetries *CPT* and T in B^0-$\bar{B}^0$ mixing and in B^0 decays. For decays into final states f with amplitudes $A_f = A(B^0 \to f)$ and $\bar{A}_f = A(\bar{B}^0 \to f)$, using $\lambda_f = q\bar{A}_f/(pA_f)$ and approximating $\sqrt{1 - \mathsf{z}^2} = 1$, the rates are given by

$$\begin{aligned} R(B^0 \to f) &= \frac{|A_f|^2\mathrm{e}^{-\Gamma t}}{4}|(1 - \mathsf{z} + \lambda_f)\mathrm{e}^{\mathrm{i}\Delta m t}\mathrm{e}^{\Delta\Gamma t/4} + (1 + \mathsf{z} - \lambda_f)\mathrm{e}^{-\Delta\Gamma t/4}|^2, \\ R(\bar{B}^0 \to f) &= \frac{|\bar{A}_f|^2\mathrm{e}^{-\Gamma t}}{4}|(1 + \mathsf{z} + 1/\lambda_f)\mathrm{e}^{\mathrm{i}\Delta m t}\mathrm{e}^{\Delta\Gamma t/4} + (1 - \mathsf{z} - 1/\lambda_f)\mathrm{e}^{-\Delta\Gamma t/4}|^2. \end{aligned} \tag{9}$$

For the *CP* eigenstates $c\bar{c}K_L^0(CP = +1)$ and $c\bar{c}K_S^0(CP = -1)$ with $A_{S(L)} = A[B^0 \to c\bar{c}K_{S(L)}^0]$ and $\bar{A}_{S(L)} = A[\bar{B}^0 \to c\bar{c}K_{S(L)}^0]$, assumptions (1) and (2) give $A_S = A_L = A/\sqrt{2}$ and $\bar{A}_S = -\bar{A}_L = \bar{A}/\sqrt{2}$. In the following, we only need to use $\lambda_S = -\lambda_L = \lambda$. Setting $\Delta\Gamma = 0$ and keeping only first-order terms in the small quantities $|\lambda| - 1$, z, and $r = |q/p| - 1$, this leads to rate expressions as given in Eq. (8) with coefficients

$$\begin{aligned}
S_1 &= S(\ell^- X, c\bar{c}K_L) \\
&= \frac{2\mathrm{Im}(\lambda)}{1+|\lambda|^2} - \mathrm{Re}(\mathsf{z})\mathrm{Re}(\lambda)\mathrm{Im}(\lambda) + \mathrm{Im}(\mathsf{z})[\mathrm{Re}(\lambda)]^2, \\
C_1 &= +\frac{1-|\lambda|^2}{2} - \mathrm{Re}(\lambda)\mathrm{Re}(\mathsf{z}) - \mathrm{Im}(\lambda)\mathrm{Im}(\mathsf{z}), \\
S_2 &= S(\ell^+ X, c\bar{c}K_L) \\
&= -\frac{2\mathrm{Im}(\lambda)}{1+|\lambda|^2} - \mathrm{Re}(\mathsf{z})\mathrm{Re}(\lambda)\mathrm{Im}(\lambda) - \mathrm{Im}(\mathsf{z})[\mathrm{Re}(\lambda)]^2, \\
C_2 &= -\frac{1-|\lambda|^2}{2} + \mathrm{Re}(\lambda)\mathrm{Re}(\mathsf{z}) - \mathrm{Im}(\lambda)\mathrm{Im}(\mathsf{z}), \\
S_3 &= S(\ell^- X, c\bar{c}K_S) \\
&= -\frac{2\mathrm{Im}(\lambda)}{1+|\lambda|^2} - \mathrm{Re}(\mathsf{z})\mathrm{Re}(\lambda)\mathrm{Im}(\lambda) + \mathrm{Im}(\mathsf{z})[\mathrm{Re}(\lambda)]^2, \\
C_3 &= +\frac{1-|\lambda|^2}{2} + \mathrm{Re}(\lambda)\mathrm{Re}(\mathsf{z}) + \mathrm{Im}(\lambda)\mathrm{Im}(\mathsf{z}), \\
S_4 &= S(\ell^+ X, c\bar{c}K_S) \\
&= \frac{2\mathrm{Im}(\lambda)}{1+|\lambda|^2} - \mathrm{Re}(\mathsf{z})\mathrm{Re}(\lambda)\mathrm{Im}(\lambda) - \mathrm{Im}(\mathsf{z})[\mathrm{Re}(\lambda)]^2, \\
C_4 &= -\frac{1-|\lambda|^2}{2} - \mathrm{Re}(\lambda)\mathrm{Re}(\mathsf{z}) + \mathrm{Im}(\lambda)\mathrm{Im}(\mathsf{z}).
\end{aligned} \tag{10}$$

The four other rates $R_5(t)\cdots R_8(t)$ with $c\bar{c}K$ as the first decay and $t_{\ell X} - t_{c\bar{c}K} = t$ follow from the same two-decay-time expression [16,17] as the rates $R_1 \ldots R_4$ with $t_{c\bar{c}K} - t_{\ell X} = t$. Therefore, the rates $R_5(c\bar{c}K_L, \ell^- X)$, $R_6(c\bar{c}K_L, \ell^+ X)$, $R_7(c\bar{c}K_S, \ell^- X)$, and $R_8(c\bar{c}K_S, \ell^+ X)$ are given by Eq. (8) with the coefficients

$$S_i = -S_{i-4}, C_i = +C_{i-4} \quad \text{for } i = 5, 6, 7, \text{ and } 8. \tag{11}$$

The S_i and C_i results from our 2012 analysis, including uncertainties and correlation matrices, have been published as Supplemental Material [18] of Ref. [6] in Tables II–IV. For completeness, we include in Table I the results and the uncertainties.

TABLE I. Input values from the Supplemental Material [18] of Ref. [6]. The second column gives the two decays with their sequence in decay time.

i	decay pairs	S_i	σ_{stat}	σ_{sys}	C_i	σ_{stat}	σ_{sys}
1	$\ell^- X, c\bar{c}K_L$	0.51	0.17	0.11	−0.01	0.13	0.08
2	$\ell^+ X, c\bar{c}K_L$	−0.69	0.11	0.04	−0.02	0.11	0.08
3	$\ell^- X, c\bar{c}K_S$	−0.76	0.06	0.04	0.08	0.06	0.06
4	$\ell^+ X, c\bar{c}K_S$	0.55	0.09	0.06	0.01	0.07	0.05
5	$c\bar{c}K_L, \ell^- X$	−0.83	0.11	0.06	0.11	0.12	0.08
6	$c\bar{c}K_L, \ell^+ X$	0.70	0.19	0.12	0.16	0.13	0.06
7	$c\bar{c}K_S, \ell^- X$	0.67	0.10	0.08	0.03	0.07	0.04
8	$c\bar{c}K_S, \ell^+ X$	−0.66	0.06	0.04	−0.05	0.06	0.03

III. FIT RESULTS

The relations between the 16 observables $y_i = S_1 \cdots C_8$ in Eqs. (10) and (11) and the four parameters $p_1 = (1 - |\lambda|^2)/2$, $p_2 = 2\mathrm{Im}(\lambda)/(1 + |\lambda|^2)$, $p_3 = \mathrm{Im}(\mathsf{z})$, and $p_4 = \mathrm{Re}(\mathsf{z})$ are approximately linear. Therefore, the four parameters can be determined in a two-step linear χ^2 fit using matrix algebra. The first-step fit determines p_1 and p_2 by fixing $\mathrm{Re}(\lambda)$ and $\mathrm{Im}(\lambda)$ in the products $\mathrm{Re}(\mathsf{z})\mathrm{Re}(\lambda)$, $\mathrm{Im}(\mathsf{z})\mathrm{Im}(\lambda)$, $\mathrm{Im}(\mathsf{z})[\mathrm{Re}(\lambda)]^2$, and $\mathrm{Re}(\mathsf{z})\mathrm{Re}(\lambda)\mathrm{Im}(\lambda)$. After fixing these terms, the relation between the vectors y and p is strictly linear,

$$y = M_1 p, \tag{12}$$

where M_1 uses $\mathrm{Im}(\lambda) = 0.67$ and $\mathrm{Re}(\lambda) = -0.74$, motivated by the results of analyses assuming *CPT* symmetry [7]. With this ansatz, χ^2 is given by

$$\chi^2 = (M_1 p - \hat{y})^T G (M_1 p - \hat{y}), \tag{13}$$

where $\hat{y}$ is the measured vector of observables, and the weight matrix G is taken to be

$$G = [C_{\mathrm{stat}}(y) + C_{\mathrm{sys}}(y)]^{-1}, \tag{14}$$

where $C_{\mathrm{stat}}(y)$ and $C_{\mathrm{sys}}(y)$ are the statistical and systematic covariance matrices, respectively. The minimum of χ^2 is reached for

$$\hat{p} = \mathcal{M}_1 \hat{y} \quad \text{with} \quad \mathcal{M}_1 = (M_1^T G M_1)^{-1} M_1^T G, \tag{15}$$

and the uncertainties of $\hat{p}$ are given by the covariance matrices

$$\begin{aligned}
C_{\mathrm{stat}}(p) &= \mathcal{M}_1 C_{\mathrm{stat}}(y) \mathcal{M}_1^T, \\
C_{\mathrm{sys}}(p) &= \mathcal{M}_1 C_{\mathrm{sys}}(y) \mathcal{M}_1^T,
\end{aligned} \tag{16}$$

with the property

$$C_{\mathrm{stat}}(p) + C_{\mathrm{sys}}(p) = (M_1^T G M_1)^{-1}. \tag{17}$$

This first-step fit yields

$$\begin{aligned}
p_1 &= 0.001 \pm 0.023 \pm 0.017, \\
p_2 &= 0.689 \pm 0.030 \pm 0.015.
\end{aligned} \tag{18}$$

This leads to

$$\begin{aligned}
|\lambda| &= 1 - p_1 = 0.999 \pm 0.023 \pm 0.017, \\
\mathrm{Im}(\lambda) &= (1 - p_1) p_2 = 0.689 \pm 0.034 \pm 0.019, \\
\mathrm{Re}(\lambda) &= -(1 - p_1)\sqrt{1 - p_2^2} \\
&= -0.723 \pm 0.043 \pm 0.028,
\end{aligned} \tag{19}$$

where the negative sign of $\mathrm{Re}(\lambda)$ is motivated by four measurements [19–22]. The results of all four favor $\cos 2\beta > 0$, and in Ref. [22] $\cos 2\beta < 0$ is excluded with 4.5σ significance.

In the second step, we fix the two λ values according to the p_1 and p_2 results of the first step, i.e. to the central values in Eqs. (19). Equations (12) to (17) are then applied again, replacing M_1 with the new relations matrix M_2. This gives the same results for p_1 and p_2 as in Eq. (18), and

$$\begin{aligned} p_3 &= \mathrm{Im}(\mathsf{z}) = 0.010 \pm 0.030 \pm 0.013, \\ p_4 &= \mathrm{Re}(\mathsf{z}) = -0.065 \pm 0.028 \pm 0.014, \end{aligned} \tag{20}$$

with a χ^2 value of 6.9 for 12 degrees of freedom.

The $\mathrm{Re}(\mathsf{z})$ result deviates from 0 by 2.1σ. The result for $|\lambda|$ can be easily converted into $|\bar{A}/A|$ by using the world average of measurements for $|q/p|$. With $|q/p| = 1.0008 \pm 0.0008$ [7], we obtain

$$|\bar{A}/A| = 0.999 \pm 0.023 \pm 0.017, \tag{21}$$

in agreement with *CPT* symmetry. Using the matrix algebra in Eqs. (12) to (17) allows us to determine the separate statistical and systematic covariance matrices of the final results, in agreement with the condition $C_{\mathrm{stat}}(p) + C_{\mathrm{sys}}(p) = (M^T G M)^{-1}$, where M relates y and p after convergence of the fit. The statistical correlation coefficients are $\rho[|\bar{A}/A|, \mathrm{Im}(\mathsf{z})] = 0.03$, $\rho[|\bar{A}/A|, \mathrm{Re}(\mathsf{z})] = 0.44$, and $\rho[\mathrm{Re}(\mathsf{z}), \mathrm{Im}(\mathsf{z})] = 0.03$. The systematic correlation coefficients are $\rho[|\bar{A}/A|, \mathrm{Im}(\mathsf{z})] = 0.03$, $\rho[|\bar{A}/A|, \mathrm{Re}(\mathsf{z})] = 0.48$, and $\rho[\mathrm{Re}(\mathsf{z}), \mathrm{Im}(\mathsf{z})] = -0.15$.

IV. ESTIMATING THE INFLUENCE OF $\Delta\Gamma$

Using an accept/reject algorithm, we have performed two "toy simulations," each with ~2×10^6 events, i.e. t values sampled from the distributions

$$\mathrm{e}^{-\Gamma t}[1 + \mathrm{Re}(\lambda)\sinh(\Delta\Gamma t/2) + \mathrm{Im}(\lambda)\sin(\Delta m t)], \tag{22}$$

with $\Delta\Gamma = 0$ for one simulation and $\Delta\Gamma = 0.01\Gamma$ for the other one, corresponding to one standard deviation from the present world average [7]. For both simulations we use $\mathrm{Im}(\lambda) = 0.67$ and $\mathrm{Re}(\lambda) = -0.74$ and sample t values between 0 and $+5/\Gamma$. We then fit the two samples, binned in intervals of $\Delta t = 0.25/\Gamma$, to the expressions

$$N\mathrm{e}^{-\Gamma t}[1 + C\cos(\Delta m t) + S\sin(\Delta m t)], \tag{23}$$

with three free parameters N, C and S. The fit results agree between the two simulations within 0.002 for C and 0.008 for S. We, therefore, conclude that omission of the sinh term in Ref. [6] has a negligible influence on the three final results of this analysis.

V. CONCLUSION

Using $470 \times 10^6 B\bar{B}$ events from *BABAR*, we determine

$$\begin{aligned} \mathrm{Im}(\mathsf{z}) &= 0.010 \pm 0.030 \pm 0.013, \\ \mathrm{Re}(\mathsf{z}) &= -0.065 \pm 0.028 \pm 0.014, \\ |\bar{A}/A| &= 0.999 \pm 0.023 \pm 0.017, \end{aligned}$$

where the first uncertainties are statistical and the second uncertainties are systematic. All three results are compatible with *CPT* symmetry in B^0-$\bar{B}^0$ mixing and in $B \to c\bar{c}K$ decays. The uncertainties on $\mathrm{Re}(\mathsf{z})$ are comparable with those obtained by Belle in 2012 [10] with $535 \times 10^6 B\bar{B}$ events, $\mathrm{Re}(\mathsf{z}) = -0.019 \pm 0.037 \pm 0.033$. The uncertainties on $\mathrm{Im}(\mathsf{z})$ are considerably larger, as expected, than those obtained by *BABAR* in 2006 [8] with dilepton decays from $232 \times 10^6 B\bar{B}$ events, $\mathrm{Im}(\mathsf{z}) = -0.014 \pm 0.007 \pm 0.003$. The result of the present analysis for $\mathrm{Re}(\mathsf{z})$, $-0.065 \pm 0.028 \pm 0.014$, supersedes the *BABAR* result of 2004 [9].

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