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Search for T, CP and CPT Violation in B^0-$\overline{B}^0$ Mixing with Inclusive Dilepton Events

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We report the results of a search for T, CP and CPT violation in B^0-$\overline{B}^0$ mixing using an inclusive dilepton sample collected by the *BABAR* experiment at the PEP-II B Factory. Using a sample of 232 million $B\overline{B}$ pairs, with a simultaneous likelihood fit of the same-sign and opposite-sign dileptons, we measure the T and CP violation parameter $|q/p| - 1 = (-0.8 \pm 2.7(\text{stat.}) \pm 1.9(\text{syst.})) \times 10^{-3}$, and the CPT and CP parameters $\text{Im}\,\mathsf{z} = (-13.9 \pm 7.3(\text{stat.}) \pm 3.2(\text{syst.})) \times 10^{-3}$ and $\Delta\Gamma \times \text{Re}\,\mathsf{z} = (-7.1 \pm 3.9(\text{stat.}) \pm 2.0(\text{syst.})) \times 10^{-3}\,\text{ps}^{-1}$. The statistical correlation between the measurements of $\text{Im}\,\mathsf{z}$ and $\Delta\Gamma \times \text{Re}\,\mathsf{z}$ is 76 %.

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Since the first observation of CP violation in 1964 [1], the neutral kaon system has provided many results probing the CPT and T discrete symmetries [2] in K^0-$\overline{K}^0$ mixing. Similarly, the *BABAR* experiment can investigate T, CP, and CPT violation in B^0-$\overline{B}^0$ mixing.

The physical states (solutions of the complex effective Hamiltonian for the B^0-$\overline{B}^0$ system) [3] can be written as

$$\begin{aligned}|B_L\rangle &= p\sqrt{1-\mathsf{z}}|B^0\rangle + q\sqrt{1+\mathsf{z}}|\overline{B}^0\rangle,\\ |B_H\rangle &= p\sqrt{1+\mathsf{z}}|B^0\rangle - q\sqrt{1-\mathsf{z}}|\overline{B}^0\rangle.\end{aligned}$$

where H and L stand for Heavy and Light. In the case of CPT invariance, the complex parameter z is equal to 0. Similarly, T invariance leads to $|q/p| = 1$. Finally, CP invariance requires both $|q/p| = 1$ and $\mathsf{z} = 0$.

Inclusive dilepton events, where both B mesons decay semileptonically $b \to X\ell\nu$ ($l = e$ or μ), represent 4% of all $\Upsilon(4S) \to B\overline{B}$ decays and provide a very large sample to study T, CPT and CP violation in mixing. In the direct $b \to \ell$ decay process, the flavor $B^0(\overline{B}^0)$ is tagged by the charge of the lepton $\ell^+(\ell^-)$.

At the $\Upsilon(4S)$ resonance, neutral B mesons are produced in a coherent p-wave state. At the instant that the first B meson decays, the second B meson has the opposite flavor. Then, the second B meson will continue to evolve in time. Defining the time difference as $\Delta \text{t} = t^+ - t^-$ where $t^+(t^-)$ is the decay time of the neutral B tagged by $\ell^+(\ell^-)$, and neglecting second order terms in z, the decay rates for the three configurations ($\ell^+\ell^+$, $\ell^-\ell^-$ and $\ell^+\ell^-$) are given by

$$\begin{aligned}N^{++} &\propto \frac{e^{-\Gamma|\Delta \text{t}|}}{2}\left|\frac{p}{q}\right|^2\Big\{\cosh\Big(\frac{\Delta\Gamma\Delta \text{t}}{2}\Big) - \cos(\Delta m\Delta \text{t})\Big\},\\ N^{--} &\propto \frac{e^{-\Gamma|\Delta \text{t}|}}{2}\left|\frac{q}{p}\right|^2\Big\{\cosh\Big(\frac{\Delta\Gamma\Delta \text{t}}{2}\Big) - \cos(\Delta m\Delta \text{t})\Big\},\\ N^{+-} &\propto \frac{e^{-\Gamma|\Delta \text{t}|}}{2}\Big\{\cosh\Big(\frac{\Delta\Gamma\Delta \text{t}}{2}\Big) - 2\,\text{Re}\,\mathsf{z}\,\sinh\Big(\frac{\Delta\Gamma\Delta \text{t}}{2}\Big)\\ &\qquad + \cos(\Delta m\Delta \text{t}) + 2\,\text{Im}\,\mathsf{z}\,\sin(\Delta \text{m}\Delta \text{t})\Big\}, \quad (1)\end{aligned}$$

where Δm is the B^0-$\overline{B}^0$ oscillation frequency, Γ is the average neutral B decay rate and $\Delta\Gamma$ is the decay rate difference between the two physical states.

The same-sign dilepton asymmetry $A_{T/CP}$, between the two oscillation probabilities $P(\overline{B}^0 \to B^0)$ and $P(B^0 \to \overline{B}^0)$ probes both T and CP symmetries and can be expressed in terms of $|q/p|$:

$$\begin{aligned}A_{T/CP} &= \frac{P(\overline{B}^0 \to B^0) - P(B^0 \to \overline{B}^0)}{P(\overline{B}^0 \to B^0) + P(B^0 \to \overline{B}^0)}\\ &= \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{1 - |q/p|^4}{1 + |q/p|^4}. \quad (2)\end{aligned}$$

Standard Model calculations [4] predict the size of this asymmetry to be at or below 10^{-3}. A large measured value would be an indication of new physics.

Similarly, the opposite-sign dilepton asymmetry, $A_{CPT/CP}$, between events with $\Delta \text{t} > 0$ and $\Delta \text{t} < 0$ compares the $B^0 \to B^0$ and $\overline{B}^0 \to \overline{B}^0$ probabilities and is sensitive to CPT and CP violation. This asymmetry is given by

$$\begin{aligned}A_{CPT/CP}(|\Delta \text{t}|) &= \frac{P(B^0 \to B^0) - P(\overline{B}^0 \to \overline{B}^0)}{P(B^0 \to B^0) + P(\overline{B}^0 \to \overline{B}^0)}\\ &= \frac{N^{+-}(\Delta \text{t} > 0) - N^{+-}(\Delta \text{t} < 0)}{N^{+-}(\Delta \text{t} > 0) + N^{+-}(\Delta \text{t} < 0)}\\ &\simeq 2\frac{\text{Im}\,\mathsf{z}\sin(\Delta \text{m}\Delta \text{t}) - \text{Re}\,\mathsf{z}\sinh(\frac{\Delta\Gamma\Delta \text{t}}{2})}{\cosh(\frac{\Delta\Gamma\Delta \text{t}}{2}) + \cos(\Delta m\Delta \text{t})}. \quad (3)\end{aligned}$$

As $|\Delta\Gamma|/\Gamma \ll 1$ [3], we have $\text{Re}\,\mathsf{z}\sinh(\Delta\Gamma\Delta \text{t}/2) \simeq \Delta\Gamma \times \text{Re}\,\mathsf{z} \times (\Delta \text{t}/2)$ and this asymmetry is not sensitive to the CPT-violating term $\text{Re}\,\mathsf{z}$ alone, but to the product $\Delta\Gamma \times \text{Re}\,\mathsf{z}$.

In this Letter, we present measurements of $|q/p|$, $\text{Im}\,\mathsf{z}$ and $\Delta\Gamma \times \text{Re}\,\mathsf{z}$ with a simultaneous likelihood fit of the same-sign and opposite-sign dilepton Δt distributions. In the $\cosh(\Delta\Gamma\Delta \text{t}/2)$ term, we fix $|\Delta\Gamma|$ to $0.005\,\text{ps}^{-1}$, the value reported in [3] with a 90% confidence-level limit of $0.055\,\text{ps}^{-1}$.

This study is performed with events collected by the *BABAR* detector [5] at the PEP-II asymmetric-energy B Factory between October 1999 and July 2004. The integrated luminosity of this sample is about 211 fb^{-1} recorded at the $\Upsilon(4S)$ resonance ("on-resonance") (232 million $B\overline{B}$ pairs) and about 16 fb^{-1} recorded about 40 MeV below the $\Upsilon(4S)$ resonance ("off-resonance").

The event selection is identical to that described in [6]. Non-$B\overline{B}$ events are suppressed by applying requirements on the ratio of second to zeroth order Fox-Wolfram moments [7], the squared invariant mass, the aplanarity and the number of charged tracks of the event.

Lepton candidate tracks must have at least 12 hits in the drift chamber, at least one z-coordinate hit in the silicon vertex tracker (SVT), and a momentum in the $\Upsilon(4S)$ center-of-mass system between 0.8 and 2.3 GeV/c. Electrons are selected by requirements on the ratio of the energy deposited in the electromagnetic calorimeter and the momentum measured in the drift chamber. Muons are identified through the energy released in the calorimeter, as well as the strip multiplicity, track continuity, and penetration depth in the instrumented flux return. Lepton candidates are rejected if their signal in the detector of internally reflected Cherenkov light is consistent with that of a kaon or a proton. The electron and muon selection efficiencies are about 85% and 55%, with pion misidentification probabilities around 0.2% and 3%, respectively.

Electrons from photon conversions are identified and rejected with a negligible loss of efficiency for signal events. Leptons from J/ψ and $\psi(2S)$ decays are identified by pairing them with other oppositely-charged candidates of the same lepton species, selected with looser criteria.

The separation between *direct* leptons ($b \rightarrow \ell$) and background from the $b \rightarrow c \rightarrow \ell$ decay chain (*cascade decays*) is achieved with a neural network that combines five discriminating variables: the momenta and opening angles of the two lepton candidates, and the total visible energy and missing momentum of the event, all computed in the $\Upsilon(4S)$ rest frame.

Of the original sample of 232 million $B\overline{B}$ pairs, 1.4 million pass this dilepton selection.

Since the asymmetry $A_{T/CP}$ is expected to be small, we have determined the possible charge asymmetries induced by the detection and reconstruction of electrons and muons. The charge asymmetries are defined by $a \equiv (\varepsilon^+ - \varepsilon^-)/(\varepsilon^+ + \varepsilon^-)$ where $\varepsilon^+(\varepsilon^-)$ is the efficiency for positive and negative particles. As the lepton efficiencies and purities depend on their allowed phase space, we consider separately the asymmetry for the higher and lower momentum lepton, respectively, a_1 and a_2.

The charge asymmetry of track reconstruction is measured in the data by comparing tracks reconstructed using only the SVT with those passing the dilepton track selection, obtaining $a_{trk} = (0.8 \pm 0.2) \times 10^{-3}$.

The lepton identification efficiencies are measured as a function of total momentum and polar and azimuthal angles, with a control sample of radiative Bhabha events for electrons, and with a $ee \rightarrow \mu\mu\gamma$ control sample for muons. The misidentification probabilities are determined with control samples of kaons produced in $D^{*+} \rightarrow \pi^+ D^0 \rightarrow \pi^+ K^- \pi^+$ (and charge conjugate) decays, pions produced in $K_S \rightarrow \pi^+\pi^-$ decays, one-prong and three-prong τ decays, and protons produced in Λ decays.

The control samples show that the muon track reconstruction efficiency has a charge asymmetry reaching $\sim 5 \times 10^{-3}$ and that the positive kaons are more likely than negative kaons to be misidentified as muons at the 20-30% level. As a consequence, in the likelihood fit (described below), we float the charge asymmetries a_μ^{dir} and a_μ^{casc} for direct and cascade muons.

For electrons, the charge asymmetry averaged over the signal phase space is $a_e = (0.4 \pm 0.2) \times 10^{-3}$ and we find that antiprotons with momentum $\sim 1\,\mathrm{GeV}/c$ are significantly more likely than protons to be misidentified, due to annihilation with nucleons in the calorimeter material. Based on the charge asymmetry in tracking and in identification, we fix the charge asymmetry for the direct electrons with the higher momentum to $a_{e_1}^{dir} = 1.2 \times 10^{-3}$. For the lower momentum direct electrons and the cascade electrons, for which antiprotons contamination is more important, we correct the initial charge asymmetry by the fraction of antiprotons estimated with generic $B\overline{B}$ Monte Carlo samples and the proton control sample, this gives the following charge asymmetries: $a_{e_2}^{dir} = 0.8 \times 10^{-3}$, $a_{e_1}^{casc} = 0.5 \times 10^{-3}$, and $a_{e_2}^{casc} = 0.2 \times 10^{-3}$.

In the inclusive approach used here, the z coordinate of the B decay point is approximated by the z position of the point of closest approach between the lepton candidate and an estimate of the $\Upsilon(4S)$ decay point in the transverse plane. The $\Upsilon(4S)$ decay point is obtained by fitting the two lepton tracks to a common vertex in the transverse plane that is constrained to be consistent with the beam-spot position. The proper time difference Δt between the two B meson decays is determined from $\Delta z = z^+ - z^-$, the difference in z between the leptons ℓ^+ and ℓ^-, by $\Delta \mathrm{t} = \Delta z / \langle \beta\gamma \rangle c$ with a nominal Lorentz boost $\langle \beta\gamma \rangle = 0.55$. In case of same-sign dileptons, the sign of Δt is chosen randomly.

We model the contributions to our sample from $B\overline{B}$ decays using five categories of events, i, each represented by a probability density function (PDF) in Δt, $\mathcal{P}_i^{n,c}$. Their shapes are determined using the $B^0\overline{B}^0$ (n) and B^+B^- (c) Monte Carlo simulation separately, with the approach described in [8].

The five categories are the following. First, the pure signal events with two direct leptons (*sig*) represent 81% of the $B\overline{B}$ events and give information on the T, *CPT* and *CP* parameters. Then, we consider two categories of cascade decays: those with a direct lepton and cascade lepton from the opposite B decays (*obc*), and those with direct lepton and cascade lepton from the same B decay (*sbc*). According to generic $B\overline{B}$ Monte Carlo simulation, their contributions are around 9% and 4% respectively. In addition, 3% of the dilepton events originate from the decay chain $b \rightarrow \tau^- \rightarrow \ell^-$ ($1d1\tau$) which tags the B flavor correctly. Finally, the remaining events (*other*) consist mainly of one direct lepton and one lepton from charmonium resonances in the B decays.

The *sig* event PDF, $\mathcal{P}_{sig}^{n,c}$, is obtained by the convolution of an oscillatory term containing the T, *CPT* and *CP* parameters (Eq. 1) for neutral B decays or an exponential function for charged B decays, with a resolution function which is the sum of three Gaussians. The widths of the core and tail Gaussians and the fractions of core and outlier Gaussians are free parameters in the fit. The width of the outlier Gaussian is fixed to 8 ps. The means of the Gaussians are fixed to zero [9].

The *obc* event PDF, $\mathcal{P}^{n,c}_{obc}$, is modeled by the convolution of Δt-dependent terms of a form similar to those of the signal with a resolution function which takes into account the effect of the charmed meson lifetimes. Since both short-lived D^0 and D_S, and long-lived D^+ mesons are involved in cascade decays, the resolution function for the long-lived and short-lived components is a sum of three Gaussians, which are convoluted with double-sided exponentials. To correct the effect of possible outliers not observed with the Monte Carlo simulation, the fraction of the third Gaussian is free in the fit. Similarly, we take the effect of the charmed mesons into account in the *sbc* event PDF, $\mathcal{P}^{n,c}_{sbc}$.

The PDF for $1d1\tau$ events, $\mathcal{P}^{n,c}_{1d1\tau}$ is similar to that of the *sig* events. The resolution function used takes into account the τ lifetime effect and is chosen to be two Gaussians convoluted with two double-sided exponentials. Finally, the PDF for the remaining events, $\mathcal{P}^{n,c}_{other}$, is the convolution of an exponential function with an effective lifetime and two Gaussians.

The fractions ($f^{n,c}_{sbc}$,$f^{n,c}_{1d1\tau}$ and $f^{n,c}_{other}$) of *sbc*, $1d1\tau$ and *other* events, are determined directly with the $B^0\overline{B}^0$ and B^+B^- Monte Carlo simulation. The fractions $f^{n,c}_{obc}$ of *obc* events are fitted to the data, constraining the ratio f^n_{obc}/f^c_{obc} to the estimate obtained with Monte Carlo samples. The fraction f_{+-} of B^+B^- events is determined from the data themselves.

The last component of the dilepton sample originates from non-$B\overline{B}$ events, mainly continuum events, and has been estimated using off-resonance events to represent a fraction $f_{cont} = (3.1 \pm 0.1)\%$ of the data set. To model its PDF we use off-resonance events with looser cuts and on-resonance events that fail the continuum-rejection cut on the Fox-Wolfram moment ratio. The charge asymmetries $a^{cont}_{e,\mu}$ obtained with the two samples are consistent with zero at the 1% level and thus are fixed to zero in the likelihood.

The T/CP and CPT/CP violation parameters are extracted from a binned maximum likelihood fit of the events that pass the dilepton selection. The likelihood $\mathcal{L}$ combines the charge asymmetries in detection and the time-dependent PDFs described previously. As the charge asymmetries are significantly different for electrons and muons, we split the sample into four lepton combinations: ee, $e\mu$, μe and $\mu\mu$, in which the first lepton has the higher momentum.

The likelihood is given by

$$\begin{aligned}
\mathcal{L}(\Delta\mathrm{t}) &= (1+q_1 a^{cont}_{\mathrm{f}_1})(1+q_2 a^{cont}_{\mathrm{f}_2}) f_{cont}\mathcal{P}_{cont} \\
&\quad +(1-f_{cont})\{f_{+-}\mathcal{P}_{B^+B^-} + (1-f_{+-})\mathcal{P}_{B^0\overline{B}^0}\} \\
\mathcal{P}_{B^0\overline{B}^0} &= (1-f^n_{sig})(1+q_1 a^{casc}_{\mathrm{f}_1})(1+q_2 a^{casc}_{\mathrm{f}_2})\mathcal{P}^n_{casc} \\
&\quad +f^n_{sig}(1+q_1 a^{dir}_{\mathrm{f}_1})(1+q_2 a^{dir}_{\mathrm{f}_2})\mathcal{P}^n_{sig} \\
\mathcal{P}_{B^+B^-} &= (1-f^c_{sig})(1+q_1 a^{casc}_{\mathrm{f}_1})(1+q_2 a^{casc}_{\mathrm{f}_2})\mathcal{P}^c_{casc} \\
&\quad +f^c_{sig}(1+q_1 a^{dir}_{\mathrm{f}_1})(1+q_2 a^{dir}_{\mathrm{f}_2})\mathcal{P}^c_{sig} \\
\mathcal{P}^{n,c}_{casc} &= f^{n,c}_{other}\mathcal{P}^{n,c}_{other} + f^{n,c}_{1d1\tau}\mathcal{P}^{n,c}_{1d1\tau} + f^{n,c}_{sbc}\mathcal{P}^{n,c}_{sbc} + f^{n,c}_{obc}\mathcal{P}^{n,c}_{obc},
\end{aligned}$$

where q_1, q_2, f_1 and f_2 are the charges and the flavors (e,μ) of the two leptons.

The likelihood fit gives $|q/p|-1 = (-0.8 \pm 2.7)\times 10^{-3}$, $\mathrm{Im}\,\mathsf{z} = (-13.9 \pm 7.3)\times 10^{-3}$, and $\Delta\Gamma \times \mathrm{Re}\,\mathsf{z} = (-7.1 \pm 3.9)\times 10^{-3}\,\mathrm{ps}^{-1}$. The correlation between the measurements of $\mathrm{Im}\,\mathsf{z}$ and $\Delta\Gamma \times \mathrm{Re}\,\mathsf{z}$ is 76 %. If we fix $\Delta\Gamma = 0$, we obtain $\mathrm{Im}\,\mathsf{z} = (-3.7 \pm 4.6)\times 10^{-3}$. Figure 1 shows the $A_{T/CP}$ asymmetry between (ℓ^+,ℓ^+) and (ℓ^-,ℓ^-) dileptons defined in Eq. 2 and the $A_{CPT/CP}$ asymmetry between (ℓ^+,ℓ^-) dileptons with $\Delta\mathrm{t} > 0$ and $\Delta\mathrm{t} < 0$ defined in Eq. 3.

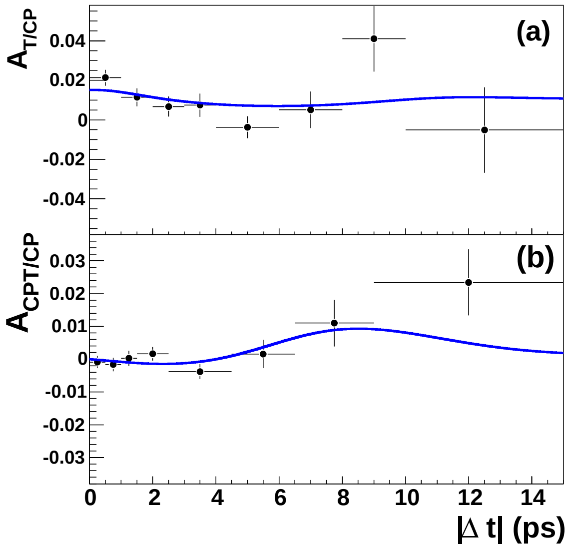

FIG. 1: (a) $A_{T/CP}$ asymmetry between (ℓ^+,ℓ^+) and (ℓ^-,ℓ^-). A larger charge asymmetry for cascade muons, dominant at small $|\Delta\mathrm{t}|$, explains the non-flatness of the curve. (b) $A_{CPT/CP}$ asymmetry between (ℓ^+,ℓ^-) dileptons with $\Delta\mathrm{t} > 0$ and $\Delta\mathrm{t} < 0$.

There are several sources of systematic uncertainty in these measurements. To determine their effect, we vary each source of systematic uncertainty by its known or estimated uncertainty, and take the resulting deviation in the CP parameter as its systematic uncertainty.

For $|q/p|$, the most important systematic errors are due to uncertainties on electron charge asymmetries. A 1.4×10^{-3} deviation of $|q/p|$ is observed by shifting simultaneously the electron charge asymmetries by 1.0×10^{-3}

which corresponds to the uncertainty estimated with Monte Carlo and control samples. The systematic uncertainty related to the charge asymmetry due to the tracking is estimated by randomly removing a fraction equal to 1.6×10^{-3} of the negative tracks from our data sample. This fraction has been determined from an independent data control sample. A 1.0×10^{-3} deviation of $|q/p|$ is observed. Similarly, the 1% uncertainty on charge asymmetry for non-$B\overline{B}$ backgrounds induces a systematic error of 0.6×10^{-3}.

The widths of the first and second Gaussian of the resolution function for the *obc* and *sbc* categories as well as the pseudo-lifetime for the $1d1\tau$ and *other* categories are varied separately by 10%. This variation is motivated by the comparison of the fitted parameters of the signal resolution function obtained on generic $B\overline{B}$ Monte Carlo samples and on data being in agreement at 10% level. The fractions of the short-lived and long-lived charmed meson components for *obc* and *sbc* are varied by 10 %.

We have also varied the parameters Δm, τ_{B^0} and $\tau_{B^\pm}$ independently within their known uncertainties [10] and $\Delta\Gamma$ from 10^{-5} to 0.1. Finally, one of the dominant systematic errors on $\Delta\Gamma \times \mathrm{Re}\,\mathsf{z}$ is imperfect knowledge of the absolute z scale of the detector and the residual uncertainties in the SVT local alignment, giving an error of $1.2 \times 10^{-3}\,\mathrm{ps}^{-1}$.

TABLE I: Summary of systematic errors for $|q/p|$, $\mathrm{Im}\,\mathsf{z}$, and $\Delta\Gamma \times \mathrm{Re}\,\mathsf{z}$ measurements.

Systematic Effects	$\sigma(\lvert q/p\rvert)$ $(\times 10^{-3})$	$\sigma(\mathrm{Im}\,\mathsf{z})$ $(\times 10^{-3})$	$\sigma(\Delta\Gamma\times\mathrm{Re}\,\mathsf{z})$ $(\times 10^{-3}\,\mathrm{ps}^{-1})$
Ch. asym. of non-$B\overline{B}$ bkg	0.6	0.0	0.0
Ch. asym. in tracking	1.0	0.0	0.0
Ch. asym. of electrons	1.4	0.0	0.0
PDF modeling	0.3	2.5	1.2
Fraction of bkg components	0.2	0.4	0.1
Δm, τ_{B^0}, $\tau_{B^\pm}$ and $\Delta\Gamma$	0.2	1.9	1.1
SVT alignment	0.5	0.6	1.2
Total	1.9	3.2	2.0

For each parameter, the total systematic error is the sum in quadrature of the estimated systematic errors from each source, as summarized in Table I. When we assume $\Delta\Gamma = 0$, the systematic error for $\mathrm{Im}\,\mathsf{z}$ is 2.9×10^{-3}.

If we compare our results to $\Delta\Gamma \times \mathrm{Re}\,\mathsf{z} = 0.0$ and $\mathrm{Im}\,\mathsf{z} = 0.0$ (no *CPT* violation case), the χ^2 is 3.25 for 2 degrees of freedom, which gives a confidence level of 19.7%. Finally, assuming $\Delta\Gamma = 0$, we obtain $\mathrm{Im}\,\mathsf{z} = (-3.7 \pm 4.6(\mathrm{stat.}) \pm 2.9(\mathrm{syst.})) \times 10^{-3}$.

In summary with the 1999-2004 data (232×10^6 $B\overline{B}$ pairs), we have performed a simultaneous likelihood fit of the same-sign and opposite-sign dileptons. We measure the independent parameters governing *CP* and *T* violation, and the *CPT* and *CP* violation parameters. The results are

$$\begin{aligned}
|q/p| - 1 &= (-0.8 \pm 2.7(\mathrm{stat.}) \pm 1.9(\mathrm{syst.})) \times 10^{-3}, \\
\mathrm{Im}\,\mathsf{z} &= (-13.9 \pm 7.3(\mathrm{stat.}) \pm 3.2(\mathrm{syst.})) \times 10^{-3}, \\
\Delta\Gamma \times \mathrm{Re}\,\mathsf{z} &= (-7.1 \pm 3.9(\mathrm{stat.}) \pm 2.0(\mathrm{syst.})) \times 10^{-3}\,\mathrm{ps}^{-1}.
\end{aligned}$$

These measurements are a clear improvement over the most precise results previously published [3, 11]. The new measurement of $|q/p|$ is consistent with the Standard Model predictions [4].

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