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Mixing Induced T and CP Violation at BABAR

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While *CP* violation in the B-meson system has been well established by the B factories, there has been no direct observation of time-reversal violation in this system. Using 468 million $B^0\overline{B}^0$ pairs collected by the BABAR detector at SLAC, we measure T-violating parameters in the time evolution of neutral-B mesons by comparing the probabilities of definite flavour states B^0 or $\overline{B}^0$ transforming into definite *CP* final states and vice versa, yielding $\Delta S_T^+ = -1.37 \pm 0.14$ (stat.) $\pm$ 0.06 (syst.) and $\Delta S_T^- = 1.17 \pm 0.18$ (stat.) ± 0.11 (syst.). The results lead to the first direct observation of time reversal non-invariance through an observation which is independent of CP violation, and are consistent with current CP-violating measurements obtained invoking CPT invariance. We also report a new BABAR measurement of the time-dependent *CP*-asymmetry parameters S and C in the decay $B^0 \to D^{*+}D^{*-}$ decays using 471 million $B^0\overline{B}^0$ pairs. This new analysis makes use of the partial reconstruction technique, resulting in a high reconstruction efficiency and high statistics measurement. We measure the time-dependent *CP* asymmetry parameters $S = -0.34 \pm 0.12 \pm 0.05$ and $C = +0.15 \pm 0.09 \pm 0.04$ and, using the value for the *CP*-odd fraction $R_\perp = 0.158 \pm 0.028 \pm 0.006$, previously measured by BABAR with fully reconstructed $B^0 \to D^{*+}D^{*-}$ events, we extract the *CP*-even components $S_+ = -0.49 \pm 0.18 \pm 0.07 \pm 0.04$ and $C_+ = +0.15 \pm 0.09 \pm 0.04$. In each case, the first uncertainty is statistical and the second is systematic; the third uncertainty on S_+ is the contribution from the uncertainty on $R_\perp$. The measured value of the *CP*-even component S_+ is consistent with the value of $\sin 2\beta$ measured in $b \to (c\overline{c})s$ transitions, and with the Standard Model expectation of small penguin contributions.

36th International Conference on High Energy Physics,
July 4-11, 2012
Melbourne, Australia

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1. Observation of Time Reversal Violation in the B^0 Meson System

In the past decade the *BABAR* and Belle experiments have produced precise measurements of the *CP*-violating parameters in a large number of different *B* decay channels [1, 2] establishing first, then testing with unprecedented precision, the interpretation of *CP*-violation in terms of the Standard Model (SM) mechanism of a single *CP*-violating phase appearing in the three-generation Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix [3]. Within this framework, it is expected that the *CP*-violating weak interaction must also violate time reversal invariance because, as any local Lorentz invariant quantum field theory, the SM requires *CPT* invariance as a fundamental symmetry [4], as confirmed by all present experimental evidence [5].

To date, the only evidence related to T violation has been found in the neutral K system, where a difference between the probabilities of $K^0 \to \bar{K}^0$ and $\bar{K}^0 \to K^0$ transitions for a given elapsed time has been measured [6]. This flavor mixing asymmetry is both *CP*- and T-violating (the two transformations lead to the same observation), independent of time, and requires a nonzero decay width difference $\Delta\Gamma_K$ between the neutral K mass eigenstates to be observed [7, 8], which has aroused controversy in the interpretation of this observable [8, 9].

Experiments that could provide direct evidence of T non-invariance, without using an observation which also violates *CP*, involve either nonvanishing expectation values of T-odd observables like the electric dipole moments of the neutron and the electron, for which only experimental upper limits [10] exist today; or the exchange of initial and final states that are not *CP* conjugates to each other, in the time evolution of transition processes; these require neutrinos or unstable particles, and are therefore particularly difficult to implement and have never been done to date.

We present here the observation, made by *BABAR*, of T violation in the B meson system, through the exchange of initial and final states in transitions that can only be connected by a T-symmetry transformation.

Due to space limitation, we give here only a sketchy summary of the measurement method which is described in details elsewere [12]. This analysis uses the same reconstruction algorithms, selection criteria, calibration techniques, and B meson samples as our most recent time-dependent *CP* asymmetry measurement in $B \to c\bar{c}K^{(*)0}$ decays [13], where the composition of the final sample is obtained from fits to the $m_{\rm ES}$ (for $c\bar{c}K^0_S$) and ΔE (for $J/\psi K^0_L$) distributions, using parametric forms and distributions extracted from MC simulation and dilepton mass sidebands in data to describe the signal and background components. However in the present analysis, to determine the T-violating parameters and their significance, we use for the first time the concept [14] of "*CP* tagging", which is used in combination with the usual "flavor tagging" to construct T-transformed processes and, to get access to the T-violating parameters, we treat the signal data differently, as described below.

In the decay of the $\Upsilon(4S)$, the two B mesons are in an entangled, antisymmetric state, as required by angular momentum conservation for a P-wave particle system. This two-body state is usually written in terms of flavor eigenstates, such as B^0 and $\bar{B}^0$, but can be expressed in terms of any linear combinations of B^0 and $\bar{B}^0$, such as the B_+ and B_- states introduced in Ref. [12]. They are defined as the neutral B states filtered by their decay to *CP*-eigenstates: $J/\psi K^0_L$ (*CP*-even, B_+) and $J/\psi K^0_S$, $\Psi(2S)K^0_S$ or $\chi_{c1}K^0_S$, with $K^0_S \to \pi\pi$ (*CP*-odd, B_-). The B_+ and B_- states are orthogonal to each other when there is only one weak phase involved in the B decay amplitude, as it occurs in B decays to $J/\psi K^0$ final states [15], and *CP* violation in neutral kaons is neglected.

We select events in which one B candidate is reconstructed in a B_+ or B_- state at time t_1, and the flavor of the other B is identified (flavor ID) at a later time $t_2 > t_1$, or vice versa. Flavor ID is made on the basis of the charges of selected prompt leptons, kaons, pions from D^* mesons, and high-momentum charged particles. Denoting generically with $\ell^- X$ ($\ell^+ X$) reconstructed final states that identify the flavor of the B as $\bar{B}^0$ (B^0), we can thus have, for example, an event reconstructed in the time-ordered (t_1, t_2) final states $(\ell^+ X, J/\psi K_S^0)$ identifying the transition $\bar{B}^0 \to B_-$. We compare the rate for this transition to its T-reversed $B_- \to \bar{B}^0$ (exchange of initial and final states) by reconstructing the final states $(J/\psi K_L^0, \ell^- X)$. Any difference in these two rates is direct evidence for T-symmetry violation.

Assuming $\Delta\Gamma_d = 0$ and defining $\Delta\tau = t_2 - t_1 > 0$, each of the eight transitions $\bar{B}^0 \to B_-$, $B_+ \to B^0$, $\bar{B}^0 \to B_+$, $B_- \to B^0$ and their T-symmetry transformed, has a general time-dependent decay rate given by:

$$g^{\pm}_{\alpha,\beta}(\Delta\tau) \propto e^{-\Gamma_d \Delta\tau}\left\{1 + S^{\pm}_{\alpha,\beta}\sin(\Delta m_d \Delta\tau) + C^{\pm}_{\alpha,\beta}\cos(\Delta m_d \Delta\tau)\right\}, \tag{1.1}$$

where indices $\alpha = \ell^+, \ell^-$ and $\beta = K_S^0, K_L^0$ stand for $\ell^+ X, \ell^- X$ and $c\bar{c}K_S^0, J/\psi K_L^0$ final states, respectively, and the symbol $+$ or $-$ indicates whether the decay to the flavor final state α occurs before or after the decay to the CP final state β. Here, Γ_d is the average decay width, Δm_d is the mass difference between the neutral B mass eigenstates, and $C^{\pm}_{\alpha,\beta}$ and $S^{\pm}_{\alpha,\beta}$ are model independent coefficients. T violation would manifest itself through differences between the $S^{\pm}_{\alpha,\beta}$ or $C^{\pm}_{\alpha,\beta}$ values for T-conjugated processes, for example between $S^{+}_{\ell^+, K_S^0}$ and $S^{-}_{\ell^-, K_L^0}$.

We perform a simultaneous, unbinned maximum likelihood fit to the Δt distributions for flavor identified $c\bar{c}K_S^0$ and $J/\psi K_L^0$ events, split by flavor category.

The signal probability density function (PDF) is [12]:

$$\mathscr{H}_{\alpha,\beta}(\Delta t) \propto g^{+}_{\alpha,\beta}(\Delta t_{\rm true})H(\Delta t_{\rm true}) \otimes \mathscr{R}(\delta t; \sigma_{\Delta t}) + g^{-}_{\alpha,\beta}(-\Delta t_{\rm true})H(-\Delta t_{\rm true}) \otimes \mathscr{R}(\delta t; \sigma_{\Delta t}),$$

where $\Delta t_{\rm true}$ is the signed difference of proper time between the two B decays in the limit of perfect Δt reconstruction, H is the Heaviside step function, $\mathscr{R}(\delta t; \sigma_{\Delta t})$ with $\delta t = \Delta t - \Delta t_{\rm true}$ is the resolution function, and $g^{\pm}_{\alpha,\beta}$ are given by Eq. (1.1). Note that $\Delta t_{\rm true}$is equivalent to $\Delta\tau$ ($-\Delta\tau$) when a true flavor (CP) tag occurs. However, due to finite time resolution, a contamination of true CP tags in the flavour ID sample and vice versa is possible and leads to a dilution of the T-violating asymmetry. Flavor ID misidentification, occurring with probability ω, also introduces an additional dilution by a factor of approximately $(1 - 2\omega)$.

From the 16 signal coefficients ($C^{\pm}_{\alpha,\beta}$, $S^{\pm}_{\alpha,\beta}$) we form 6 independent asymmetry parameters ($\Delta C^{\pm}_T$, $\Delta S^{\pm}_T$), ($\Delta C^{\pm}_{CP}$, $\Delta S^{\pm}_{CP}$), ($\Delta C^{\pm}_{CPT}$, $\Delta S^{\pm}_{CPT}$) as shown in Table 1, which also lists the experimental results obtained from the fits. T-symmetry breaking manifests itself as a non zero value of $\Delta S^{\pm}_T$.

We evaluate the significance of the T-violation signal based on the change in log-likelihood with respect to the maximum ($-2\Delta\ln\mathscr{L}$), reducing it by a factor $1 + \max\{m_i^2\} = 1.61$ to account for systematic errors in the evaluation of the significance. Figure 1 shows CL contours calculated from the change $-2\Delta\ln\mathscr{L}$ in two dimensions for the T-asymmetry parameters $(\Delta S^{+}_T, \Delta C^{+}_T)$ and $(\Delta S^{-}_T, \Delta C^{-}_T)$.

Assuming Gaussian errors, and including systematic uncertainties, the significance is equivalent to 14 standard deviations (σ), and thus constitutes direct observation of T violation. The

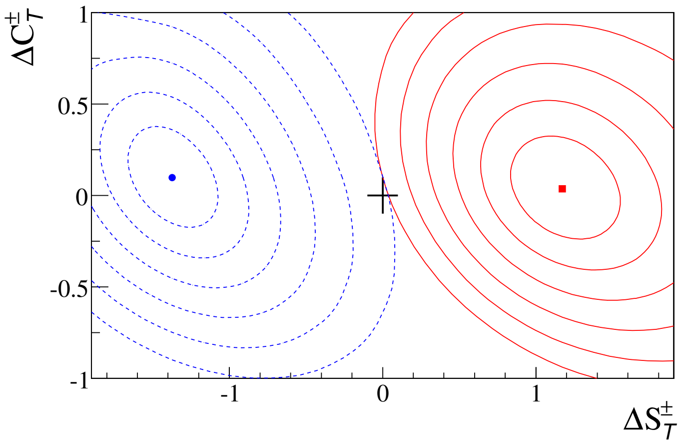

Figure 1: The central values (blue point and red square) and two-dimensional CL contours for $1-\mathrm{CL} = 0.317, 4.55\times10^{-2}, 2.70\times10^{-3}, 6.33\times10^{-5}, 5.73\times10^{-7}$, and 1.97×10^{-9}, calculated from the change in the value of $-2\Delta\ln\mathscr{L}$ compared with its value at maximum ($-2\Delta\ln\mathscr{L} = 2.3, 6.2, 11.8, 19.3, 28.7, 40.1$), for the pairs of T-asymmetry parameters $(\Delta S_T^+, \Delta C_T^+)$ (blue dashed curves) and $(\Delta S_T^-, \Delta C_T^-)$ (red solid curves). Systematic uncertainties are included. The T-invariance point is shown as a $+$ sign.

significance of *CP* and *CPT* violation is determined analogously, obtaining respectively, 17σ and 0.3σ, consistent with *CP* violation and *CPT* invariance.

These results [17] constitute the first observation of T violation in any system through the exchange of initial and final states in transitions that can only be connected by a T-symmetry transformation.

2. Measurement of the Time-Dependent *CP* Asymmetry of Partially Reconstructed $B^0 \to D^{*+}D^{*-}$ Decays

The BABAR and Belle collaborations have performed the most accurate measurements [13, 18] of the *CP* parameter $\sin2\beta$, where $\beta \equiv \arg\left[-V_{cd}V_{cb}^*/V_{td}V_{tb}^*\right]$, via the time-dependent *CP* violation asymmetry in $b \to (c\bar{c})s$ transitions, in which the B^0 decays to charmonium final states. Similar measurements in Cabibbo suppressed $b \to c\bar{c}d$ transitions, such as $B^0 \to D^{(*)+}D^{(*)-}$, are predicted in the SM to yield the same value of $\sin2\beta$, if contributions from penguin processes can be neglected. Models based on factorization and heavy quark symmetry have found these to be only a few percent of the total amplitude, but they could be greatly enhanced by loop diagrams involving non-SM particles (e.g., charged Higgs) introducing additional phases [19]. A large deviation of the measured parameter S_η of Eq. 2.1 from the value of $\sin2\beta$ measured in $b \to (c\bar{c})s$ transitions, or a non-zero value of direct *CP* violation, would thus be strong evidence of new physics [20].

In $\Upsilon(4S) \to B^0\bar{B}^0$ events the time-dependent decay rate for $B^0 \to D^{*+}D^{*-}$, taking into account

Table 1: Measured values of the T-, CP-, and CPT-asymmetry parameters, defined as the differences in $S^{\pm}_{\alpha,\beta}$ and $C^{\pm}_{\alpha,\beta}$ between symmetry-transformed transitions. The values of reference coefficients are also given at the bottom. The first uncertainty is statistical and the second systematic. The indices ℓ^-, ℓ^+, K^0_S, and K^0_L stand for reconstructed final states that identify the B meson as $\bar{B}^0$, B^0, B_-, and B_+, respectively.

Parameter	Result
$\Delta S^+_T = S^-_{\ell^-,K^0_L} - S^+_{\ell^+,K^0_S}$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S^-_T = S^+_{\ell^-,K^0_L} - S^-_{\ell^+,K^0_S}$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C^+_T = C^-_{\ell^-,K^0_L} - C^+_{\ell^+,K^0_S}$	$0.10 \pm 0.14 \pm 0.08$
$\Delta C^-_T = C^+_{\ell^-,K^0_L} - C^-_{\ell^+,K^0_S}$	$0.04 \pm 0.14 \pm 0.08$
$\Delta S^+_{CP} = S^+_{\ell^-,K^0_S} - S^+_{\ell^+,K^0_S}$	$-1.30 \pm 0.11 \pm 0.07$
$\Delta S^-_{CP} = S^-_{\ell^-,K^0_S} - S^-_{\ell^+,K^0_S}$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C^+_{CP} = C^+_{\ell^-,K^0_S} - C^+_{\ell^+,K^0_S}$	$0.07 \pm 0.09 \pm 0.03$
$\Delta C^-_{CP} = C^-_{\ell^-,K^0_S} - C^-_{\ell^+,K^0_S}$	$0.08 \pm 0.10 \pm 0.04$
$\Delta S^+_{CPT} = S^-_{\ell^+,K^0_L} - S^+_{\ell^+,K^0_S}$	$0.16 \pm 0.21 \pm 0.09$
$\Delta S^-_{CPT} = S^+_{\ell^+,K^0_L} - S^-_{\ell^+,K^0_S}$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C^+_{CPT} = C^-_{\ell^+,K^0_L} - C^+_{\ell^+,K^0_S}$	$0.14 \pm 0.15 \pm 0.07$
$\Delta C^-_{CPT} = C^+_{\ell^+,K^0_L} - C^-_{\ell^+,K^0_S}$	$0.03 \pm 0.12 \pm 0.08$
$S^+_{\ell^+,K^0_S}$	$0.55 \pm 0.09 \pm 0.06$
$S^-_{\ell^+,K^0_S}$	$-0.66 \pm 0.06 \pm 0.04$
$C^+_{\ell^+,K^0_S}$	$0.01 \pm 0.07 \pm 0.05$
$C^-_{\ell^+,K^0_S}$	$-0.05 \pm 0.06 \pm 0.03$

the mistag probability [1] and the effect of tags due to the unreconstructed D^0, is given by

$$
\begin{aligned}
T_{D^{*+}D^{*-}} = \; & \tfrac{\Gamma_d}{4}\, e^{-\Gamma_d|\Delta t|} \cdot \Big\{ 1 - S_{\rm tag}\, \Delta\omega (1-\alpha) + \\
& + S_{\rm tag}\,(1-2\omega)\,(1-\alpha) \cdot [C\cos(\Delta m_d \Delta t) + S_\eta \,\sin(\Delta m_d \Delta t)] \Big\},
\end{aligned}
\tag{2.1}
$$

where α, the fraction of events in which the tagging track is from the unreconstructed D^0, is determined combining Monte Carlo and data information to be $\alpha = 0.12 \pm 0.04$ (0.0 ± 0.02) for kaon (lepton) tags, after a cut has been applied on the cosine of the CM opening angle $\theta_{\rm tag}$ between the tagging track and the direction of the unreconstructed D^0 equal to $\cos\theta_{\rm tag} \leq 0.75$ (0.50) for the kaon (lepton) tagged sample. Γ_d is the B^0 width averaged over the two mass eigenstates, Δm_d is the $B^0\bar{B}^0$ mixing frequency and Δt is the resolution-convolved time interval between the $B^0 \to D^{*+}D^{*-}$ decay ($B_{\rm rec}$) and the decay of the other B ($B_{\rm tag}$) in the event; the parameter $S_{\rm tag} = +1$ (-1) indicates the flavor of the $B_{\rm tag}$ as a B^0 ($\bar{B}^0$). Possible detector effects leading to a small difference between the

[1] In this analysis we only use flavor tagging, so here and in the following we refer to it simply as tag (or mistag).

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mistag probability of B^0 tags (ω^+) and that of $\bar{B}^0$ tags (ω^-), are parametrized in the PDF by using the average mistag rate $\omega \equiv (\omega^+ + \omega^-)/2$ and the mistag rate difference $\Delta\omega \equiv \omega^+ - \omega^-$. We obtain their values of $\omega = 0.201 \pm 0.002$ (0.104 ± 0.002) and $\Delta\omega = -0.011 \pm 0.003$ (0.001 ± 0.005) for the kaon (lepton) tags from Monte Carlo. The time-dependent *CP* asymmetry parameters S_η and C are given by

$$C = \frac{1-|\lambda|^2}{1+|\lambda|^2}; \quad S_\eta = -\eta \frac{2\Im m(\lambda)}{1+|\lambda|^2}; \quad \lambda = \frac{q}{p}\frac{\overline{A}}{A}; \quad \sin 2\beta = \Im m(\lambda). \tag{2.2}$$

We present here a new measurement based on the technique of partial reconstruction, which allows us to gain a factor of $\simeq 5$ in the number of selected signal events with respect to the most recent BABAR full reconstruction analysis [21].

In the partial reconstruction of a $B^0 \to D^{*+}D^{*-}$ candidate, we reconstruct fully only one of the two $D^{*\pm}$ mesons in the decay chain $D^* \to D^0\pi$ [2], by identifying D^0 candidates in one of four final states: $K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$, $K^0_s\pi\pi$. Since the kinetic energy available in the decay $D^* \to D^0\pi$ is small, we combine one reconstructed $D^{*\pm}$ with an oppositely charged low-momentum pion, assumed to originate from the decay of the unreconstructed $D^{*\mp}$, and evaluate the mass $m_{\rm rec}$ of the recoiling D^0 meson by using the momenta of the two particles. For signal events, $m_{\rm rec}$ peaks at the nominal D^0 mass [16] with a r.m.s. width of about 3 MeV$/c^2$, while for background events no such peak is visible, which makes $m_{\rm rec}$ the primary variable to discriminate signal from background.

Backgrounds to the $B^0 \to D^{*+}D^{*-}$ process include combinatorial $B\bar{B}$ events, reduced by using kinematical and vertex constraints, and non-$b\bar{b}$ (continuum) backgrounds, reduced with a constraint on the second Fox-Wolfram moment ratio R_2 and by combining several event-shape variables into a Fisher discriminant variable F used in the fits.

The flavor tagging algorithm is based on selected quality tracks identified as electrons, muons (lepton tags) or kaons.

The time difference Δt is calculated using $\Delta t = \Delta z/\gamma\beta c$, where $\Delta z = z_{\rm rec} - z_{\rm tag}$ is the difference between the z-coordinates of the partially reconstructed $B_{\rm rec}$ and $B_{\rm tag}$ vertices and the boost parameters are calculated using the measured beam energies. We define the $B_{\rm rec}$ vertex as the decay point of the fully reconstructed $D^{*\pm}$.

The $B_{\rm tag}$ vertex reconstruction depends on the tagging category. For kaon-tagged events, we obtain $z_{\rm tag}$ from a beam spot constrained vertex fit of all charged tracks in the event, excluding those from the $B_{\rm rec}$ meson and those within 1 rad of the unreconstructed D^0 momentum in the CM frame, which presumably originate from the D^0 decay. For lepton-tagged events, we use the lepton track parameters and errors, and the measured beam spot position and size in the plane perpendicular to the beams.

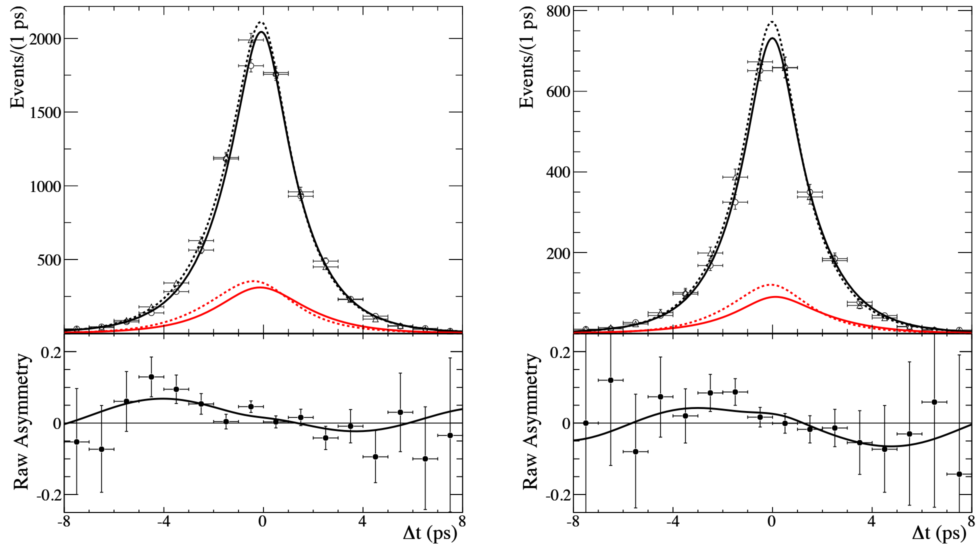
After the event selection is complete, the rest of the analysis proceeds with a series of unbinned maximum-likelihood fits, performed simultaneously on the on- and off-resonance data samples and independently for the lepton-tagged and kaon-tagged events.

The final results of the Δt fits for the kaon- and lepton-tagged sample are shown in Fig. 2, where we plot the Δt distributions separately for B^0 and $\bar{B}^0$ tags, together with the time-dependent

[2] Charge conjugate decay modes are implied.

raw *CP* asymmetry defined as:

$$A(\Delta t) = \frac{N_{S_{\rm tag}=1}(\Delta t) - N_{S_{\rm tag}=-1}(\Delta t)}{N_{S_{\rm tag}=1}(\Delta t) + N_{S_{\rm tag}=-1}(\Delta t)}. \quad (2.3)$$



(a) Kaon tags (b) Lepton tags

Figure 2: Top: Δt distribution for B^0 (dashed) and $\bar{B}^0$ (solid) kaon and lepton tags; the lower curves in red are the corresponding signal PDFs. Bottom: raw time-dependent *CP* asymmetry. Only data in the restricted signal region $m_{\rm rec} > 1.860$ GeV$/c^2$ are shown.

The combined kaon and lepton tag results for the *CP* violating parameters are:

$$C = +0.15 \pm 0.09 \pm 0.04$$
$$S = -0.34 \pm 0.12 \pm 0.05.$$

Since the $B^0 \to D^{*+}D^{*-}$ is the decay of a scalar to two vector mesons, the final state is a mixture of *CP*-even and *CP*-odd eigenstates. If penguin amplitudes can be neglected then $S_+ = -S_-$, $C_+ = -C_-$ and the value of the *CP*-even components S_+ and C_+ can be obtained using the *CP*-odd fraction measured by BABAR [21] of $R_\perp = 0.158 \pm 0.029$ to give

$$C_+ = +0.15 \pm 0.09 \pm 0.04$$
$$S_+ = -0.49 \pm 0.18 \pm 0.07 \pm 0.04,$$

where the uncertainties shown are statistical and systematic. The third uncertainty is the contribution from the error on $R_\perp$, which is obtained by varying the value of $R_\perp$ by $\pm 1\sigma$. The systematic uncertainties are dominated by the imperfect knowledge of the shape of the background, of the mistag parameters and for kaon tags by interference effects from doubly Cabibbo-suppressed decay amplitudes on the tagging side of the event.

This result [22] is an independent determination of the *CP*-violating parameters of $b \to (c\bar{c})d$ transitions, is compatible with previous measurements [21] from *BABAR* and Belle using fully reconstructed decays, and leads to a significant improvement in the total overall errors on these parameters. It agrees well with the Standard Model expectation of negligible contributions to the decay amplitude from penguin diagrams and thence with $S_+ = -\sin 2\beta$.

References

[1] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **87**, 091801 (2001); K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **87**, 091802 (2001).

[2] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **93**, 131801 (2004); Y. Chao *et al.* (Belle Collaboration), Phys. Rev. Lett. **93**, 191802 (2004).

[3] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[4] G. Lüders, Math. Fysik. Medd. Kgl. Danske Akad. Ved. Volume 28, 1954, p. 5; J.S. Bell, Birmingham University thesis (1954); W. Pauli, in W. Pauli, ed., Niels Bohr and the Development of Physics (McGraw-Hill, NY, 1955).

[5] R. Carosi *et al.*, Phys. Lett. B **237**, 303 (1990); A. Alavi-Harati *et al.*, Phys. Rev. D **67**, 012005 (2003); B. Schwingenheuer *et al.*, Phys. Rev. Lett. **74**, 4376 (1995).

[6] A. Angelopoulus *et al.* (CPLEAR Collaboration), Phys. Lett. B **444**, 43 (1998).

[7] P. K. Kabir, Phys. Rev. D **2**, 540 (1970). Phys. Rev. D 86, 112006 (2012)

[8] L. Wolfenstein, Int. Jour. Mod. Phys. **8**, 501 (1999).

[9] H.J. Gerber, Eur. Phys. Jour. C **35**, 195 (2004), and references therein.

[10] J.J. Hudson *et al.*, Nature **473**, 493-496 (2011); C.A. Baker *et al.*, Phys. Rev. Lett. **97**, 131801 (2006).

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

[12] J. Bernabeu, F. Martinez-Vidal, P. Villanueva-Perez, JHEP **1208**, 064 (2012).

[13] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **79**, 072009 (2009).

[14] M. C. Banuls and J. Bernabeu, Phys. Lett. B 464, 117(1999); Nucl. Phys. B 590, 19(2000)

[15] See "*CP* violation in meson decays" review in [16].

[16] K. Nakamura *et al.* (Particle Data Group), J. Phys. **G37**, 075021 (2010).

[17] J.P. Lees *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **109**, 211801 (2012).

[18] K. F. Chen et al. (Belle collaboration), Phys. Rev. Lett. **98**, 031802 (2007).

[19] Z. Xing, Phys. Lett. B **443**, 365 (1998); Z. Xing, Phys. Rev. D **61**, 014010 (1999).

[20] Y. Grossman and M. P. Worah, Phys. Lett. B **395**, 241 (1997); M. Gronau, J. L. Rosner and D. Pirjol, Phys. Rev. D **78**, 033011 (2008); R. Zwicky, Phys. Rev. D **77**, 036004 (2008).

[21] B. Aubert et al. (*BABAR* collaboration), Phys. Rev. D **79**, 032002 (2009b); B. Vervink et al. (Belle collaboration), Phys. Rev. D **80**, 111104 (2009b).

[22] J.P. Lees *et al.* (*BABAR* Collaboration), Phys. Rev. D **86**, 112006 (2012).

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