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CP and Time Reversal Violation from BABAR

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Recent measurements of direct *CP* violation in τ and D decays, and the first direct observation of time reversal violation in the B^0 meson system, are reported. The analyses have been performed using the complete sample of 437×10^6 $\tau^+\tau^-$, 690×10^6 $c\bar{c}$, and 468×10^6 $B\bar{B}$ pairs collected by the BABAR detector at the SLAC PEP-II asymmetric-energy B factory.

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1. Introduction

In the standard model (SM) of particle physics, *CP* violation in the quark sector of weak interactions arises from a single irreducible phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix that describes the mixing of quarks [1]. The *CP*-symmetry breaking has been widely explored during the last decade, especially in B mesons, confirming the CKM mechanism as the dominant source of *CP* violation [2]. In the last years these studies have been extended to D mesons and τ leptons, where effects of SM *CP*-violating phases are expected to be small or negligible, thus providing a tool for searches of physics beyond the SM. On the other hand, while it is expected that the *CP*-violating weak interaction also violates time reversal invariance, as implied from the *CPT* theorem (in accordance with all experimental evidence [3]), there has been no direct observation of T violation, i.e., without being indirectly inferred from the observation of *CP* violation. In this talk, we first discuss recent direct *CP* violation searches in τ^- decays into $\pi^- K_S^0 \nu_\tau$ and $D^-_{(S)}$ decays into $\pi^- K_S^0$ and $K^- K_S^0$ final states. Then we shall report the new analysis probing directly, and for the first time, time reversal violation through the exchange of initial and final states in transitions that can only be connected by a T-symmetry transformation. Other recent *CP* violation results from *BABAR* in charmless B decays into three kaons, are not discussed here.

The *BABAR* experiment has been operating between 1999 and 2008 at a center-of-mass (c.m.) energy around 10.58 GeV with a c.m. boost $\beta\gamma = 0.58$, and has recorded about 530 fb^{-1} of data, most of which (426 fb^{-1}) taken at the $\Upsilon(4S)$ resonance, but also at the $\Upsilon(3S)$ and $\Upsilon(2S)$, and off-resonance data for background studies (45 fb^{-1}). In total, the $\Upsilon(4S)$ data sample has 468 million $B\bar{B}$ pairs, 437 million $\tau^+\tau^-$ pairs, and about 690 million $c\bar{c}$ pairs, and the samples of $\Upsilon(3S)$ and $\Upsilon(2S)$ decays contain approximately 120 and 100 millions each. The results discussed in this talk make use of the complete $\Upsilon(4S)$ data sample.

2. *CP* violation in $\tau^- \to \pi^- K_S^0 \nu_\tau$ decays

The decay of the τ^- lepton into $\pi^- K_S^0 \nu_\tau$ proceeds through gluon and W^- emission with no weak phase (see Fig. 1). Therefore, the SM predicts the decay amplitude for the τ^- to be the same as for the τ^+, and the direct *CP*-violating asymmetry

$$A_Q = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}, \tag{2.1}$$

is expected to vanish. However, as the final reconstructed final state contains a K_S^0, the net expected asymmetry is $A_Q^{\text{SM}} = (0.33 \pm 0.01)\%$ due to *CP* violation in $K^0 - \bar{K}^0$ mixing, for τ decay times of the order of the K_S^0 lifetime [5, 6]. The sign of the asymmetry is determined by the fact that the τ^- decay produces a $\bar{K}^0$ and the τ^+ a K^0. Moreover, since π^0s are produced via gluon emission, we can also consider final states containing π^0s without changing the expected asymmetry. Additional *CP*-violating phases arising from new physics, like exotic charged Higgs bosons, could change the SM expectation [7].

Since τ leptons in e^+e^- collisions are produced in pairs in a back-to-back topology, we first divide the event into two hemispheres in c.m., and apply kinematic cuts (event thrust) to remove background from Bhabha, $\mu^+\mu^-$ and $q\bar{q}$ events. One of the τ leptons is reconstructed in a leptonic

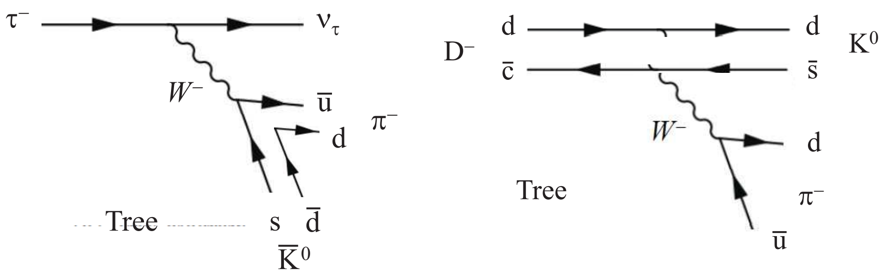

Figure 1: Feynman diagrams contributing to the $\tau^- \to \pi^- \overline{K}^0 \nu_\tau$ (left) and $D^- \to \pi^- K^0$ (right) decays.

decay, containing either an identified electron or a muon ("tagging side”). In order to reduce background from non-τ pairs we require a momentum for the electron or muon higher than 4 GeV/c in c.m. The opposite τ ("signal side”) is then reconstructed into a $K^0_S \to \pi^+\pi^-$, plus one charged pion, and up to 3 π^0s. After all these selection criteria we obtain about 200k e-tagged and 150k μ-tagged events [8].

Backgrounds from $q\overline{q}$ events are further reduced by rejecting events in which the invariant mass $M_{\rm rec}$ of the hadronic system in the signal side is greater than 1.8 GeV/c^2 (see Fig. 2). Residual discrepancies between data and Monte Carlo (MC) simulation are due to imperfect simulation of strange resonances, causing very small effects in the analysis, which are anyway taken into account in the systematic uncertainties. The remaining $q\overline{q}$ and K^0_S background is further reduced using a likelihood ratio technique with a number of variables involving kinematic and lifetime information, like the visible energy and displaced vertices. The sample contains events from two τ decay modes containing K^0_S mesons in the final state: $\tau^- \to K^- K^0_S (\geq 0\pi^0)\nu_\tau$, where the charged kaon has been misidentified as a pion, and $\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau$. The latter satisfies the selection criteria if one neutral kaon decays into $\pi^+\pi^-$ and the other neutral kaon decays into $\pi^0\pi^0$ or appears as a K^0_L meson. The composition of the final sample is given in Table 1. From this sample, after the subtraction of remaining background composed of $q\overline{q}$ and non-K^0_S τ decays, the measured raw asymmetries for e-tag and μ-tag are $A^{\rm RAW}_{Q,e-{\rm tag}} = (-0.32 \pm 0.23)\%$ and $A^{\rm RAW}_{Q,\mu-{\rm tag}} = (-0.05 \pm 0.27)\%$, respectively, where the errors are statistical. We have verified with a control sample of $\tau^- \to h^- h^- h^+ (\geq 0\pi^0)\nu_\tau$ decays that there is no detector charge asymmetry in the measurement.

Source	Fractions (%)	
	e-tag	μ-tag
$\tau^- \to \pi^- K^0_S (\geq 0\pi^0)\nu_\tau$	78.7 ± 4.0	78.4 ± 4.0
$\tau^- \to K^- K^0_S (\geq 0\pi^0)\nu_\tau$	4.2 ± 0.3	4.1 ± 0.3
$\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau$	15.7 ± 3.7	15.9 ± 3.7
Other background	1.40 ± 0.06	1.55 ± 0.07

Table 1: The composition of the $\tau^- \to \pi^- K^0_S (\geq 0\pi^0)\nu_\tau$ signal side sample after all selection criteria [8].

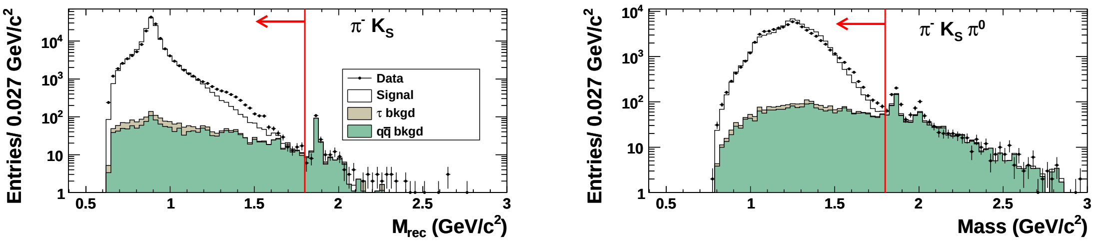

Figure 2: Invariant-mass distributions for the combined e-tag and μ-tag samples, for $\pi^- K_S^0$ (left) and $\pi^- K_S^0 \pi^0$ (right) final states [8]. Points with error bars represent the data, while the histograms represent the simulated sample. The histogram labeled as "Signal" includes the $\tau^- \to \pi^- K_S^0 (\geq 0\pi^0)\nu_\tau$, residual $\tau^- \to K^- K_S^0 (\geq 0\pi^0)\nu_\tau$, and $\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau$ modes. These distributions have been produced applying all selection criteria, except the $M_{\rm rec}$ criterion. The vertical lines and arrows indicate the $M_{\rm rec} < 1.8$ GeV/c^2 selection criterion.

The measured raw asymmetry has to be corrected for distorsions introduced by the differences in K^0 and $\bar{K}^0$ cross-sections with the detector material [9]. The correction is found to be $(0.07 \pm 0.01)\%$ for both the e-tag and the μ-tag samples. The error includes the statistical uncertainty in the MC simulation, the uncertainties in the kaon-nucleon cross-sections, nuclear screening, and an uncertainty due to the assumption of isospin invariance. The asymmetry at this stage is still affected by the dilution from background modes containing a K_S^0: $\tau^- \to K^- K_S^0 (\geq 0\pi^0)\nu_\tau$ decays represent $f_2 \approx 4\%$ of the selected sample (Table 1) and have a *CP* asymmetry with opposite sign to that of the signal ($A_2 = -A_1$), and $\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau$ decays, which have no net *CP* asymmetry ($A_3 = 0$) and amount for about $f_3 \approx 15\%$ of the sample. The measured raw asymmetry $A_Q^{\rm RAW}$ is therefore related to the signal asymmetry $A_1 \equiv A_Q$ by $A_Q^{\rm RAW} = (f_1 - f_2)A_Q/(f_1 + f_2 + f_3)$. The overall dilution factor is 0.75 ± 0.04. The systematic uncertainties are evaluated using MC and data control samples, and account for the detector and selection bias, and all the corrections performed to the raw asymmetries (background subtraction, $K^0/\bar{K}^0$ nuclear cross sections), and are 0.13% and 0.10% for e- and μ-tag, well below the statistical uncertainties.

The final result for the *CP* asymmetry is $A_Q = (-0.36 \pm 0.23 \pm 0.11)\%$ [8]. This result has to be compared to the SM expectation corrected by the decay time dependence of the selection efficiency, as recently pointed out in Ref. [6]. This correction is required because the reconstructed state in $\pi^+\pi^-$ is not a pure K_S^0, but an overlap of K_S^0 and K_L^0, strongly dominated by the K_S^0 for decay times close to the K_S^0 lifetime. However, the interference is important and since the K_S^0 selection effienciency is decay-time dependent, introduces a time-dependence of the asymmetry. Figure 3 shows the selection efficiency, normalized to unity in the range $0.25 < t/\tau_{K_S^0} < 1.0$: for very short times increases rapidly, then is flat and about 100% up to one lifetime, and then drops for large decay times. Taking into account this dependence, the expected SM decay-rate asymmetry is $A_Q^{\rm SM} = (0.36 \pm 0.01)\%$, 2.8$\sigma$ above the measured A_Q value.

3. *CP* violation in $D^-_{(S)} \to h^- K_S^0$, $h = \pi, K$ decays

With this tension, it is fundamental to search for similar effects in other related decay channels,

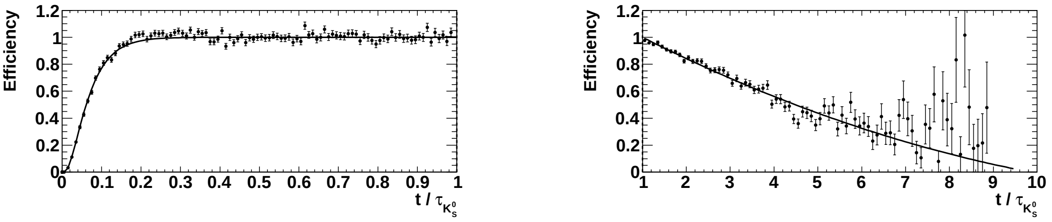

Figure 3: The selection efficiency as a function of $t/\tau_{K^0_S}$, in the region $0 < t/\tau_{K^0_S} < 1$ (left) and in the region $1 < t/\tau_{K^0_S} < 8$ (right), normalized to unity for the region $0.25 < t/\tau_{K^0_S} < 1.0$.

like Cabibbo-favored $D^\pm$ and $D^\pm_S$ decays into $\pi^\pm K^0_S$ or $K^\pm K^0_S$ final states. Here again the decay proceeds via W^- emission with no weak phase (see Fig. 1), thus the time-integrated direct *CP*-violating asymmetry

$$A_{CP} = \frac{\Gamma(D^+_{(S)} \to h^+ K^0_S) - \Gamma(D^-_{(S)} \to h^- K^0_S)}{\Gamma(D^+_{(S)} \to h^+ K^0_S) + \Gamma(D^-_{(S)} \to h^- K^0_S)}, \tag{3.1}$$

is CKM suppressed at 10^{-3} level or less, but since we have a final reconstructed final state containing a K^0_S, the SM expected value is $A^{\rm SM}_{CP} \approx (-0.33 \pm 0.01)\%$ [11, 6], opposite in sign to the case of the τ^-, given that the $D^-_{(S)}$ decay produces a K^0 instead of a $\bar{K}^0$ (see Fig. 1). The effect of the K^0_S/K^0_L interference in this case is significantly smaller, $\sim 0.01\%$.

The measured raw *CP* asymmetry $A^{\rm RAW}_{CP}$ is not directly the physical A_{CP} asymmetry, since it has to be corrected by forward-backward (A_{FB}) and charge (A_ε) asymmetries [10]. The charge asymmetry A_ε is due to the different cross-sections between particles of different charge and the detector material. We use a data-driven method that uses tracks from B decays (which are produced isotropically in the detector) to map the ratio of π^-/π^- or K^+/K^- detection efficiencies as a function of momentum and polar angle. This charge asymmetry changes the *CP* asymmetry by about 0.05%. The forward-backward asymmetry A_{FB} arises from the interference between the weak and electromagnetic currents (as well as higher order QED corrections) in the $e^+e \to c\bar{c}$ process, combined with the asymmetric acceptance of the detector. Again, we use a data-driven approach to extract this asymmetry together with the *CP* asymmetry. The idea to unfold A_{CP} and A_{FB} relies on the fact that A_{FB} is an odd function of the cosine of the polar angle in c.m., $\cos\theta^*_D$, while A_{CP} is independent (i.e., an even function) of $\cos\theta^*_D$, thus we can construct two combinations of the raw asymmetry in bins of $x \equiv |\cos\theta^*_D|$ to disentangle the two contributions, $A_{FB}(x) = \left[A^{\rm RAW}_{CP}(x) - A^{\rm RAW}_{CP}(-x)\right]/2$, $A_{CP}(x) = \left[A^{\rm RAW}_{CP}(x) + A^{\rm RAW}_{CP}(-x)\right]/2$.

The A_{CP} and A_{FB} distributions in bins of $|\cos\theta^*_D|$ for the most precise D decay channel, $D^\pm \to \pi^\pm K^0_S$, are shown in Fig. 4. Since A_{CP} does not depend upon $\cos\theta^*_D$, we compute an average value of this parameter, $A_{CP} = (-0.44 \pm 0.13 \pm 0.10)\%$ [10]. The preliminary A_{CP} average values for the other D decay modes are $(0.13 \pm 0.36 \pm 0.35)\%$, $(-0.05 \pm 0.23 \pm 0.25)\%$, and $(0.55 \pm 1.97 \pm 0.29)\%$, for $D^\pm \to K^\pm K^0_S$, $D^\pm_S \to K^\pm K^0_S$, and $D^\pm_S \to \pi^\pm K^0_S$, respectively. The systematic uncertainties are dominated by the charge asymmetry correction, which is basically related to statistics and the use of MC to extrapolate the efficiency map from tracks from B to D decays.

All results are consistent with the SM expectation. Note that the most precise one, $D^{\pm} \to \pi^{\pm} K_S^0$, has the same sign as the τ *CP* asymmetry, while the SM predicts opposite sign.

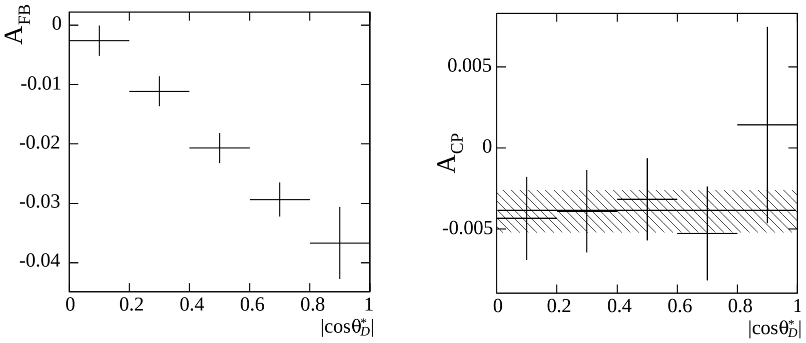

Figure 4: A_{FB} (left) and A_{CP} (right) asymmetries for $D^{\pm} \to \pi^{\pm} K_S^0$ candidates as a function of $|\cos\theta_D^*|$ in the data sample [10]. The solid line and the hatched region represent the central value and the 1σ region of A_{CP}, obtained assuming no dependence on $|\cos\theta_D^*|$.

4. Observation of Time Reversal violation in the B^0 meson system

Time reversal transforms time t into $-t$, leaving positions unchanged but modifying the sign of momenta (reversal of motion) [12]. Microscopic T non-invariance means an asymmetry not only under the reversal of the sign of time in the equations of motion, but also under the exchange of *in* and *out* states, if *out*, which arises as a final state in the original process, is arranged identically as the initial state for the T-mirror process. For stable systems, T violation is implied by a non-zero expectation value of a T-odd observable, as for example the electric dipole moment of the neutron or the electron, which also violates P. To date, no signal has been found, as inferred from the best current measurements, $d_n < 2.9 \times 10^{-26}$ e-cm and $d_e = (0.7 \times 0.7) \times 10^{-26}$ e-cm [13]. In these systems, in general, one has to account for final state interaction (FSI) effects, which could mimic T violation [14]. One might also consider differences in probabilities for transitions *in* $\to$ *out* to *out* $\to$ *in*, for example $\nu_e \to \nu_\mu$ to $\nu_\mu \to \nu_e$ at a future muon storage ring facility. For unstable systems, the exchange of *in* and *out* states turns out impossible in most (or all) practical cases.

The difficulties to arrange the T-mirror process under the same initial conditions are manifest in searches for T violation in decay processes. Let us take the B^0 decay into $K^+\pi^-$, with rate R_1 [15]. The *CP* symmetry is known to be broken in this decay [16], thus we have a $\bar{B}^0$ decay to $K^-\pi^+$ with rate $R_2 \neq R_1$. By *CPT* invariance, the time reversed processes, $K^+\pi^- \to B^0$ and $K^-\pi^+ \to \bar{B}^0$, have expected rates R_1 and R_2, respectively. However, we are unable to perform the T experiment due to the practical impossibility to prepare the initial states of the T-transformed transitions, and even if we could do it, the strong interaction would swamp the feeble weak interaction that dominates the original processes.

Searches for T violation in mixing have been done in kaons at CPLEAR [17] and in B mesons [2] by comparing particle-antiparticle oscillation probabilities. In this case the T-transformed process is identical to the *CP*-conjugated one, thus the effect here is both *CP* and T violating. Moreover, this flavor oscillation asymmetry is independent of time, and requires a nonzero decay width difference $\Delta\Gamma$ between the neutral K or B mass eigenstates to be observed [18, 14], which has aroused some controversy [14, 19]. In the kaon system a nonzero asymmetry has been found, which is, up to now, the only evidence related to T violation [13], while in the neutral B and B_s systems, where $\Delta\Gamma$ is negligible and significantly smaller, it is much more difficult to detect.

Finally, we could also consider searches for T violation arising from the interference between mixing and decay in neutral B mesons. This is the place where we expect the largest T violation effect, since here we known from the time-dependent *CP*-violating studies at B factories that *CP* is largely violated. However, these *CP* violation results cannot be directly interpreted as T violation since those results are obtained invoking *CPT* invariance and $\Delta\Gamma = 0$, and not the reversal of time and the exchange of *in* and *out* states, as required for a direct probe of T non-invariance [20].

Therefore, a goal in particle physics has been to demonstrate directly T violation without any experimental connection to *CP*, and without invoking *CPT* invariance. This requires genuine and pure T-violating observables obtained through the exchange of initial and final states in transitions that can only be connected by a T-symmetry transformation. At B factories this can be done because the $\Upsilon(4S)$ decay yields an entangled, antisymmetric system of orthogonal states. These can be either flavor eigenstates B^0 or $\bar{B}^0$, $|i\rangle = 1/\sqrt{2}[B^0(t_1)\bar{B}^0(t_2) - \bar{B}^0(t_1)B^0(t_2)]$, as used extensively in time-dependent *CP* violation studies at B factories [21], or states projected by *CP*-odd and *CP*-even final states, like $J/\psi K^0_S$ and $J/\psi K^0_L$, denoted as B_- and B_+, respectively, $|i\rangle = 1/\sqrt{2}[B_+(t_1)B_-(t_2) - B_-(t_1)B_+(t_2)]$ [22].

Let us take the case when one of the neutral B mesons from the $\Upsilon(4S)$ decays first producing a negative lepton from a $\bar{B}^0$ decaying semileptonically or a negative kaon from an hadronic cascade decay like $\bar{B}^0 \to D^0X$, $D^0 \to K^-X$. We generically denote reconstructed final states that identify the flavor of the B as ℓ^-X for $\bar{B}^0$ and ℓ^+X for B^0. The entanglement insures that at that time the other B meson was a B^0, thus we have prepared the initial state of the second B to decay as a B^0. We call this preparation of the initial state as "$\bar{B}^0$ tag". The second neutral B meson to decay then evolutes in time and is reconstructed into a $J/\psi K^0_L$ final state, in other words, a *CP*-even state. We have then a transition $B^0 \to B_+$, which is identified by reconstructing the time-ordered final states $(\ell^-X, J/\psi K^0_L)$. The time-reversed transition $B_+ \to B^0$ requires the neutral B meson decaying first to a final state $J/\psi K^0_S$ ("*CP*-odd" tag), and a positive lepton or kaon from the B meson decaying second, $(J/\psi K^0_S, \ell^+X)$. For this procedure to work we have to neglect *CP* violation in $K^0 - \bar{K}^0$ mixing, an effect at 10^{-3} level, and possible *CP* violation in the B decay. Both effects are well below the expected statistical sensitivity [22]. We have three other independent transitions, $B^0 \to B_-$ $(\ell^-X, J/\psi K^0_S)$, $\bar{B}^0 \to B_+$ $(\ell^+X, J/\psi K^0_L)$, $\bar{B}^0 \to B_-$ $(\ell^+X, J/\psi K^0_S)$, and their T-transformed versions, $B_- \to B^0$ $(J/\psi K^0_L, \ell^+X)$, $B_+ \to \bar{B}^0$ $(J/\psi K^0_S, \ell^-X)$, $B_- \to \bar{B}^0$ $(J/\psi K^0_L, \ell^-X)$. In all cases the T transformation implies comparison of $J/\psi K^0_S$ and $J/\psi K^0_L$ states, and of B^0 and $\bar{B}^0$ states, with the exchange of proper decay times, i.e., $\Delta t \to -\Delta t$, where $\Delta t = t_{B_+/B_-} - t_{B^0/\bar{B}^0}$ is the signed difference of proper time between the two B decays. This experimental requirement is different from that needed for *CP* violation experiments, where only B^0 and $\bar{B}^0$ comparisons are needed. Similarly, four different *CP* (*CPT*) comparisons can be made between the same eight independent transitions, e.g., between the $B^0 \to B_+$ transition and its *CP*- (*CPT*-)transformed $\bar{B}^0 \to B_+$ $(B_+ \to \bar{B}^0)$.

B_- states are reconstructed into the $J/\psi K^0_S$, $\Psi(2S)K^0_S$, $\chi_{c1}K^0_S$ final states (denoted generically as $c\bar{c}K^0_S$), while B_+ are into $J/\psi K^0_L$. We also reconstruct a large sample of self-flavor tagging neutral B decays into open charm and charmonium final states, $B^0 \to D^{(*)-}[\pi^+, \rho(770)^+, a_1(1260)^+)$ and

$B^0 \to J/\psi K^{*0}(\to K^+\pi^-)$, which are used for calibration of the Δt resolution function and the performance of the inclusive B flavor (B^0 or $\bar{B}^0$) identification. Finally we reconstruct a large sample of charged B decays into charmonium, $B^\pm \to J/\psi K^\pm, \Psi(2S)K^\pm, J/\psi K^{*\pm}$, which are used as control sample. We use the standard kinematic constraints available at B factories from the beam energies to reconstruct the mass and the energy difference of the B mesons, $m_{\rm ES} = \sqrt{(E^*_{\rm beam})^2 - (p^*_B)^2}$ and $\Delta E = E^*_B - E^*_{\rm beam}$, where E^*_B, p^*_B are the energy and momentum of the B in c.m. We also exploit the different topology of signal and $q\bar{q}$ events to reject continuum background. The final sample contains 7796 B_- signal events with purities ranging from 87 to 96%, and 5813 B_+ signal events with purity about 56%.

We perform an unbinned, maximum likelihood fit to the (signed) Δt dependence of all flavor- and *CP*-tagged events (4 samples in total), with a general, model-independent signal probability density function (p.d.f.) of the form

$$\Gamma^\pm_{\alpha,\beta} \propto \exp(-\Gamma|\Delta t|)\left\{1 + S^\pm_{\alpha,\beta}\sin(\Delta m|\Delta t| + C^\pm_{\alpha,\beta}\cos(\Delta m|\Delta t|)\right\}, \tag{4.1}$$

unfolding the true positive (symbol $+$) and negative ($-$) proper decay time differences for $\alpha = \ell^+, \ell^-$ (for ℓ^+X, ℓ^-X) and $\beta = K^0_S, K^0_L$ (for $c\bar{c}K^0_S, J/\psi K^0_L$) events. From this fit we obtain a total of eight independent pairs of $(S^\pm_{\alpha,\beta}, C^\pm_{\alpha,\beta})$ parameters. In the standard *CP* violation studies there is only one set of (S,C) parameters, which within the SM and CKM formalism are expected to be $(-\eta_{CP}\sin 2\beta, 0)$ [21], with $\eta_{CP} = -1(+1)$ for $B_-(B_+)$ events. From these eight pairs of signal coefficients, we construct six pairs of independent asymmetry parameters $(\Delta S^\pm_T, \Delta C^\pm_T)$, $(\Delta S^\pm_{CP}, \Delta C^\pm_{CP})$, and $(\Delta S^\pm_{CPT}, \Delta C^\pm_{CPT})$, as shown in Table 2.

Parameter	T-transformed transition	Transition	Result
$\Delta S^+_T = S^-_{\ell^-,K^0_L} - S^+_{\ell^+,K^0_S}$	$B_- \to \bar{B}^0\ (J/\psi K^0_L, \ell^-X)$	$\bar{B}^0 \to B_-\ (\ell^+X, c\bar{c}K^0_S)$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta C^+_T = C^-_{\ell^-,K^0_L} - C^+_{\ell^+,K^0_S}$			$0.10 \pm 0.14 \pm 0.08$
$\Delta S^-_T = S^+_{\ell^-,K^0_L} - S^-_{\ell^+,K^0_S}$	$B^0 \to B_+\ (\ell^-X, J/\psi K^0_L)$	$B_+ \to B^0\ (c\bar{c}K^0_S, \ell^+X)$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C^-_T = C^+_{\ell^-,K^0_L} - C^-_{\ell^+,K^0_S}$			$0.04 \pm 0.14 \pm 0.08$
$\Delta S^+_{CP} = S^+_{\ell^-,K^0_S} - S^+_{\ell^+,K^0_S}$	$B^0 \to B_-\ (\ell^-X, c\bar{c}K^0_S)$	$\bar{B}^0 \to B_-\ (\ell^+X, c\bar{c}K^0_S)$	$-1.30 \pm 0.11 \pm 0.07$
$\Delta C^+_{CP} = C^+_{\ell^-,K^0_S} - C^+_{\ell^+,K^0_S}$			$0.07 \pm 0.09 \pm 0.03$
$\Delta S^-_{CP} = S^-_{\ell^-,K^0_S} - S^-_{\ell^+,K^0_S}$	$B_+ \to \bar{B}^0\ (c\bar{c}K^0_S, \ell^-X)$	$B_+ \to B^0\ (c\bar{c}K^0_S, \ell^+X)$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C^-_{CP} = C^-_{\ell^-,K^0_S} - C^-_{\ell^+,K^0_S}$			$0.08 \pm 0.10 \pm 0.04$
$\Delta S^+_{CPT} = S^-_{\ell^+,K^0_L} - S^+_{\ell^+,K^0_S}$	$B_- \to B^0\ (J/\psi K^0_L, \ell^+X)$	$\bar{B}^0 \to B_-\ (\ell^+X, c\bar{c}K^0_S)$	$0.16 \pm 0.21 \pm 0.09$
$\Delta C^+_{CPT} = C^-_{\ell^+,K^0_L} - C^+_{\ell^+,K^0_S}$			$0.14 \pm 0.15 \pm 0.07$
$\Delta S^-_{CPT} = S^+_{\ell^+,K^0_L} - S^-_{\ell^+,K^0_S}$	$\bar{B}^0 \to B_+\ (\ell^+X, J/\psi K^0_L)$	$B_+ \to B^0\ (c\bar{c}K^0_S, \ell^+X)$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C^-_{CPT} = C^+_{\ell^+,K^0_L} - C^-_{\ell^+,K^0_S}$			$0.03 \pm 0.12 \pm 0.08$

Table 2: Definition and measured values of the T-, *CP*-, and *CPT*-asymmetry parameters. The first uncertainty is statistical and the second systematic.

The results for the asymmetry parameters are given in Table 2. Two of them, ΔS^+_T and ΔS^-_T, associated to T violation arising from the interference between mixing and decay, clearly deviate from zero, while ΔC^+_T and ΔC^-_T, associated to T violation in decay, are consistent with zero.

Figure 5(left) shows the two-dimensional confidence regions in the $(\Delta S_T^+, \Delta C_T^+)$ and $(\Delta S_T^-, \Delta C_T^-)$ planes. In both cases we observed that the T invariance point is excluded with $1-CL$ close to 10^{-9}, corresponding to about 6σ, including systematic uncertainties. Combining all the information from the data, the global significance for T violation is 14σ, assuming Gaussian errors. The results for the *CP* and *CPT*-violating parameters are also shown in Table 2. There is no sign of *CPT* violation at 0.3σ level, and for *CP* we observe a similar behavior as for T, thus compensating the observed T violation, with largest significance (17σ), since in this case B_- and B_+ states, and positive and negative Δt regions sum up statistically to the final precision. The classical way to illustrate the T-violating effect is through the raw T asymmetries we can build from the four possible and independent comparisons. Figure 5(right) shows the raw T asymmetry for transition $\bar{B}^0 \to B_-$ $(\ell^+ X, c\bar{c}K_S^0)$. Here, the asymmetry from data is overlaid with the projection of the best fit results with and without T violation: the solution with T violation is clearly favored. The three other T asymmetries reveal a similar behavior.

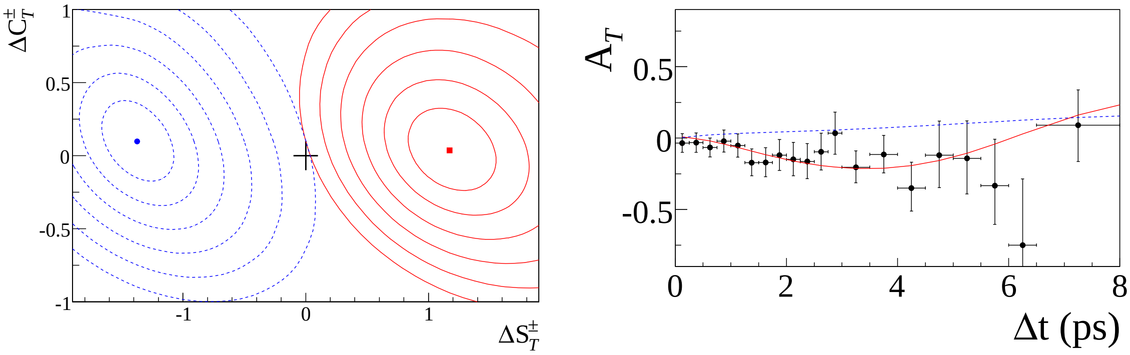

Figure 5: (Left) The central values and two-dimensional confidence level (CL) contours for $1-\mathrm{CL} = 0.317$, 4.55×10^{-2}, 2.70×10^{-3}, 6.33×10^{-5}, 5.73×10^{-7}, and 1.97×10^{-9}, for the pairs of T-asymmetry parameters $(\Delta S_T^+, \Delta C_T^+)$ (blue dashed curves) and $(\Delta S_T^-, \Delta C_T^-)$ (red solid curves). Systematic uncertainties are included. The T-invariance point is shown as a plus sign (+). (Right) The T-violating asymmetry for transition $\bar{B}^0 \to B_-$ $(\ell^+ X, c\bar{c}K_S^0)$, defined as $A_T(\Delta t) = \frac{\Gamma_{B_-\to\bar{B}^0}(\Delta t) - \Gamma_{\bar{B}^0\to B_-}(\Delta t)}{\Gamma_{B_-\to\bar{B}^0}(\Delta t) + \Gamma_{\bar{B}^0\to B_-}(\Delta t)}$, in a signal enriched region. The points with error bars represent the data, the red solid and dashed blue curves represent the projections of the best fit results with and without T violation, respectively. $A_T(\Delta t)$ is constructed so that is defined only for positive Δt [23]. Neglecting reconstruction effects, $A_T(\Delta t) \approx \frac{\Delta C_T^+}{2}\cos(\Delta m \Delta t) + \frac{\Delta S_T^+}{2}\sin(\Delta m \Delta t)$.

5. Summary

In summary, *BABAR* ended data taking in 2008 but continues to produce physics results on *CP* violation in τ and D decays, in addition to B decays. In this talk we have reported a tension with the SM expectation (at 2.7σ level) in the direct *CP*-violating asymmetry from $\tau^- \to \pi^- K_S^0 \nu_\tau$ decays. However, the direct *CP* asymmetries from the related, Cabibbo-favored $D^-_{(S)} \to h^- K_S^0$, $h = \pi, K$ decays are consistent with expectations. We have also reported the measurement of T-violating parameters in the time evolution of neutral B mesons, leading to a large (at 14σ level), direct observation of time reversal violation. The results are consistent with *CP*-violating measurements performed at B factories assuming *CPT* invariance, and represent the first direct observation of time reversal violation in any system without being indirectly inferred from the observation of *CP* violation, through the exchange of initial and final states in transitions that can only be connected by a T-symmetry transformation.

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