



ELSEVIER

Available online at www.sciencedirect.com



Nuclear Physics B Proceedings Supplement 00 (2012) 1–6

**Nuclear Physics B
Proceedings
Supplement**

Searches for New Sources of CP and T Violation at $BABAR$

J. Albert, for the $BABAR$ Collaboration

Dept. of Physics and Astronomy, Univ. of Victoria, 3800 Finnerty Rd., Victoria, BC V8P 5C2 Canada

Abstract

We present recent results from searches for new sources of CP and T violation from the B , charm, and τ sectors from $BABAR$. From the B sector, we search for CP violation in B decays to three kaons, and to $K\ell^+\ell^-$, and present the first direct observation of T violation using $B^0 \rightarrow J/\psi K^0$. In the charm sector, we search for a T -odd correlation in D^+ decays to $K^+K^0\pi^+\pi^-$. And in the τ sector, we measure CP violation in τ^- decays to $K^0\pi^-\nu_\tau$. Highlights of these new results include the world's first observation of T violation that is fully experimentally independent of CP violation, and a 3.1σ deviation from the Standard Model predictions for CP violation in $\tau^- \rightarrow K^0\pi^-\nu_\tau$.

Keywords: CP violation, T violation, bottom mesons, charm mesons, tau leptons, B -factories

1. Introduction

The search for CP violation beyond the Standard Model (SM), as the primary goal of the B -factories, has a long and rich history with which most of the readers of these proceedings are very familiar. New sources of CP violation beyond the SM are expected, as that which occurs within the SM falls in the vicinity of 10 to 12 orders of magnitude short of that which is required to explain the baryon asymmetry of the Universe [1]. This additional CP violation might potentially occur in a very different sector or energy scale than that probed by modern experiments at the intensity frontier; nevertheless, hints might appear in the precision measurements performed by B -factories at any time.

CPT symmetry is a bulwark of the SM, as well as any other energy-conserving, Lorentz-invariant local quantum field theory; however it is of course critical to test each of its major predictions. T violation, as a firm consequence of the combination of CP violation and CPT symmetry, is one such prediction, for which tests that are fully experimentally independent of CP violation, and thus actually test the prediction of CPT symmetry itself, have been scant at best.

On behalf of the $BABAR$ Collaboration, in this talk I presented five very recent results on searches for new sources for CP and T violation. Three of the results are

from the most well-covered area of hadronic B decays, one is a search for T violation in the charm sector, and the last is a search for CP violation in τ decays. Our results use the full $BABAR$ dataset, containing 472 million $B\bar{B}$ events, 690 million $c\bar{c}$ pairs, and approximately 500 million $\tau^+\tau^-$ pairs.

2. Search for CP violation in B decays to three kaons

In the decay modes $B^0 \rightarrow K^+K^-K_s^0$, and $B^+ \rightarrow K^+K^-K^+$ and $B^+ \rightarrow K_s^0K_s^0K^+$, we search for both indirect and direct CP violation.¹ In $B^0 \rightarrow K^+K^-K_s^0$, we measure the time-dependent CP asymmetry $A_{CP}(\Delta t) \sim \eta_{CP} \sin(2\beta_{\text{eff}}) \sin(\Delta m_d \Delta t)$, however this analysis is complicated by the fact that $K^+K^-K_s^0$ is not a CP eigenstate; the CP content depends on the Dalitz plot (i.e. the spin structure) of the decay. In $B^+ \rightarrow K^+K^-K^+$ and $B^+ \rightarrow K_s^0K_s^0K^+$, we study the Dalitz structure in order both to help understand the CP content in $B^0 \rightarrow K^+K^-K_s^0$, and also to measure direct CP -violating charge asymmetries. Additionally, both the “ $f_X(1500)$ ” resonance, and large nonresonant contribution seen elsewhere in B decays to three kaons [2], are poorly-understood, thus we investigate these components in greater detail.

¹Throughout this contribution, charge-conjugate decay modes are implied, unless otherwise specified.

We fully reconstruct each decay mode; the event selection is performed using typical criteria for charged kaons and K_S^0 at BABAR [3], and we select B mesons using the typical variables $m_{ES} = \sqrt{\frac{1}{4}s - \mathbf{p}_B^{*2}}$ and $\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$, where $q_B^* = (E_B^*, \mathbf{p}_B^*)$ is the 4-momentum of the B candidate in the $\Upsilon(4S)$ frame, and s is the square of the invariant mass of the electron-positron system. Additional selection and separation from the dominant continuum background is performed using a neural net (NN)-based selection on event shape variables. The Dalitz structure is investigated by the usual technique of decomposing the amplitude as a function of the two Dalitz variables: $\mathcal{A} \equiv \mathcal{A}(B \rightarrow KKK; m_{12}, m_{23})$ as the sum of lineshapes $\sum_j a_j F_j(m_{12}, m_{23})$, where the F_j are resonant or nonresonant lineshapes, the amplitude factors are $a_j = c_j(1+b_j)e^{i(\phi_j+\delta_j)}$, the corresponding charge-conjugate amplitude factors are $\bar{a}_j = c_j(1-b_j)e^{i(\phi_j-\delta_j)}$, the direct CP asymmetries $A_{CP} = -2b/(1+b^2)$, the $\phi_j \equiv \beta$ are the weak phases, and δ_j are the strong phases. Figure 1 shows the measured Dalitz distributions for the three modes, with the signal enhanced via a tight constraint on the NN output.

We measure an indication, at 2.8σ significance, of direct CP violation in the component $B^+ \rightarrow \phi K^+$: $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$, with Standard Model expectations of this quantity being in the range $(0 - 4.7)\%$ [4]. We also measure the CP phase β in $B^0 \rightarrow \phi K_S^0$ to be $(21 \pm 6 \pm 2)^\circ$, which is in good agreement with the Standard Model expectation of equality with the β from charmonium world average of $(21 \pm 0.8)^\circ$. Additionally, we find that the “ $f_X(1500)$ ” is not a single resonance: we find that it is far better described by a combination of three well-established resonances: $f_0(1500)$, $f_2'(1525)$, and $f_0(1710)$.

3. Search for direct CP violation in $B \rightarrow K\ell^+\ell^-$

In $B \rightarrow K\ell^+\ell^-$, we measure CP -violating charge asymmetries in the six modes $B^+ \rightarrow K^+\ell^+\ell^-$, $B^+ \rightarrow K^{*+}\ell^+\ell^-$, and $B^0 \rightarrow K^{*0}\ell^+\ell^-$, where $\ell = e$ or μ . (we also measure the two modes $B^0 \rightarrow K^0\ell^+\ell^-$, but CP -violating asymmetries are not measured in those two modes in our recent results). In the SM, $B \rightarrow K^{(*)}\ell^+\ell^-$, is a combination of penguin and box diagrams, as shown in Fig. 2; however new physics (for example the supersymmetric diagrams shown in Fig. 3) can potentially enter at the same order as the SM processes. In the SM, these direct CP asymmetries are predicted to be of order 10^{-3} [5], however large enhancements (up to order 1) from new physics are possible [6].

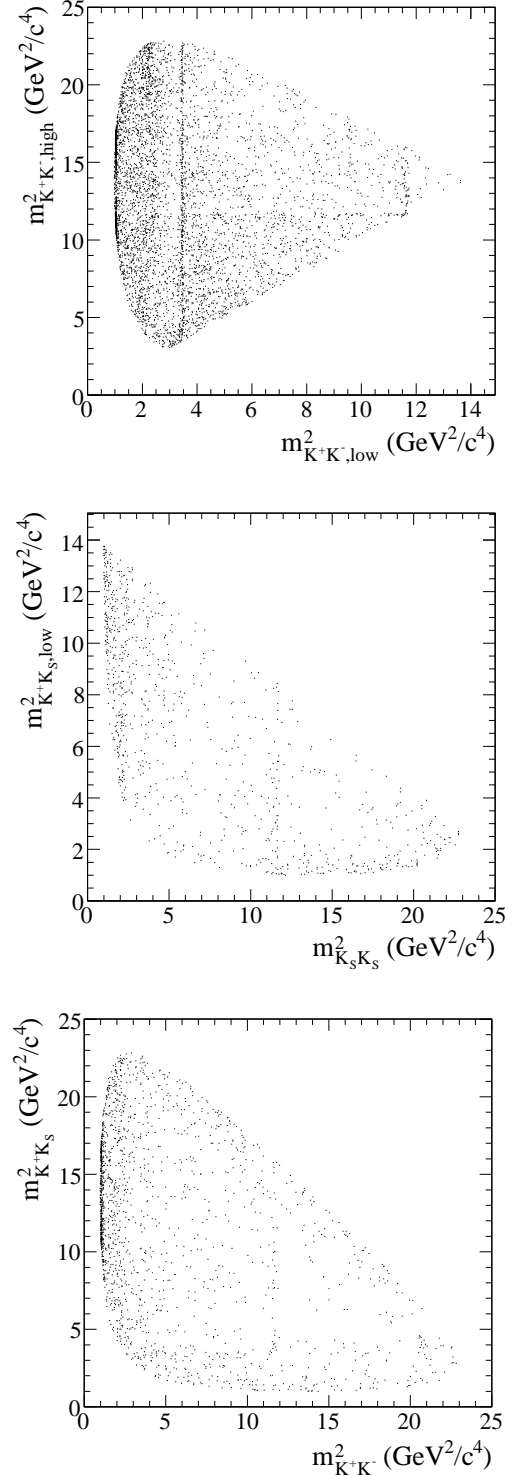
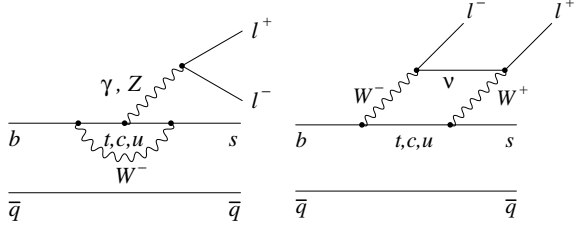
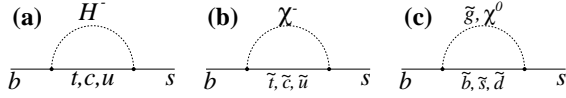


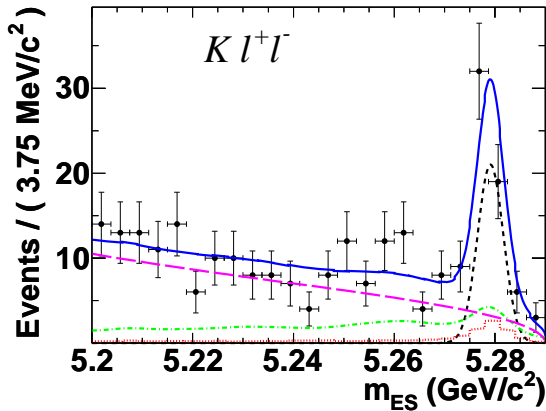
Figure 1: Dalitz plots for $B^+ \rightarrow K^+ K^- K^+$ (top), $B^+ \rightarrow K_S^0 K_S^0 K^+$ (middle), and $B^0 \rightarrow K^+ K^- K_S^0$ (bottom). Points correspond to candidates in data that pass the event selection, with an additional requirement on NN output, in order to enhance the signal.

Figure 2: Lowest-order Feynman diagrams for $b \rightarrow s \ell^+ \ell^-$.Figure 3: Examples of new physics loop contributions to $b \rightarrow s \ell^+ \ell^-$: (a) charged Higgs (H^-); (b) squark ($\tilde{t}, \tilde{c}, \tilde{u}$) and chargino (χ^-); (c) squark ($\tilde{b}, \tilde{s}, \tilde{d}$) and gluino (\tilde{g}) / neutralino (χ^0).

We fully reconstruct each mode, and select events using typical criteria [7]. We additionally reconstruct the pure background (lepton-number-violating) modes $K^{(*)} h \mu$ to aid in studying hadronic background sources. We exclude the J/ψ and $\psi(2S)$ mass regions, and use those regions as control samples. Signal yield is extracted in the m_{ES} variable. Figure 4 shows the m_{ES} distribution for all $K \ell^+ \ell^-$ modes combined.

We measure the CP -violating charge asymmetries

$$\mathcal{A}_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\bar{B} \rightarrow \bar{K}^{(*)} \ell^+ \ell^-) - \mathcal{B}(B \rightarrow K^{(*)} \ell^+ \ell^-)}{\mathcal{B}(\bar{B} \rightarrow \bar{K}^{(*)} \ell^+ \ell^-) + \mathcal{B}(B \rightarrow K^{(*)} \ell^+ \ell^-)} \quad (1)$$

Figure 4: The m_{ES} spectrum for all $K \ell^+ \ell^-$ modes combined, showing data (points with error bars), the total fit (solid line), signal component (short-dashed line), combinatorial background (long-dashed line), hadrons misidentified as muons (dash-dotted line), and the sum of cross-feed and peaking components (dotted line).

in bins of $s \equiv m_{\ell^+ \ell^-}^2$. Our measurements are in the following table:

s (GeV^2/c^4)	$\mathcal{A}_{CP}(B^+ \rightarrow K^+ \ell^+ \ell^-)$	$\mathcal{A}_{CP}(B \rightarrow K^* \ell^+ \ell^-)$
All	$-0.03 \pm 0.14 \pm 0.01$	$0.03 \pm 0.13 \pm 0.01$
0.10–8.12	$0.02 \pm 0.18 \pm 0.01$	$-0.13^{+0.18}_{-0.19} \pm 0.01$
>10.11	$-0.06^{+0.22}_{-0.21} \pm 0.01$	$0.16^{+0.18}_{-0.19} \pm 0.01$

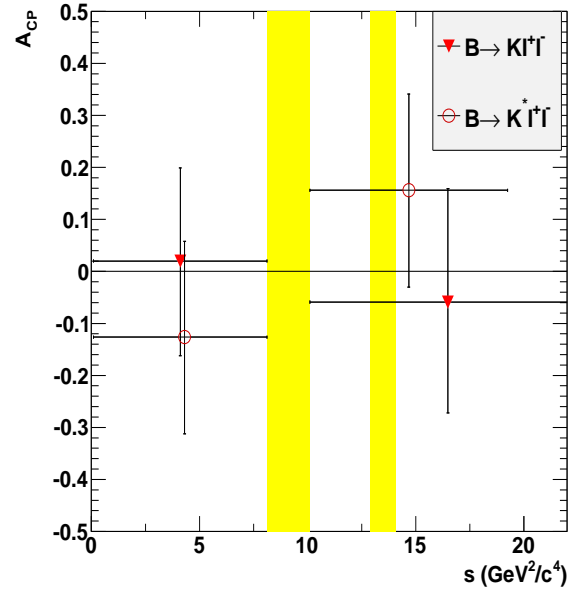
The values are consistent with SM expectations, within the measured uncertainties. A plot of the measured CP asymmetries as a function of s can be seen in Figure 5.

4. Observation of T violation using $B^0 \rightarrow J/\psi K^0$

A primary characteristic of B -factories is the production of $B^0 \bar{B}^0$ in an entangled state:

$$\begin{aligned} |\psi\rangle &= \frac{1}{\sqrt{2}} [B^0(t_1) \bar{B}^0(t_2) - \bar{B}^0(t_1) B^0(t_2)] \\ &= \frac{1}{\sqrt{2}} [B_+(t_1) \bar{B}_-(t_2) - \bar{B}_-(t_1) B_+(t_2)], \end{aligned} \quad (2)$$

where B_+ is a CP -even neutral B eigenstate and B_- is the corresponding CP -odd eigenstate. As the $\Upsilon(4S)$ has spin $J = 1$ and the B mesons have spin 0, we know that $L = 1$, thus the B mesons must always remain in opposite states (i.e. when one oscillates, the other must as

Figure 5: CP asymmetries \mathcal{A}_{CP} for $K \ell^+ \ell^-$ modes (red solid triangles) and $K^* \ell^+ \ell^-$ modes (red open circles) as a function of s . The vertical shaded bands show the vetoed s regions around the J/ψ and $\psi(2S)$.

well, unless it has already decayed). Thus, to examine T violation and CP violation independently, we can look at the eight different possible transformations:

	Reference	T -transformed
1a,b)	$B^0 \rightarrow B_+$	$B_+ \rightarrow B^0$
2a,b)	$B^0 \rightarrow B_-$	$B_- \rightarrow B^0$
3a,b)	$\bar{B}^0 \rightarrow B_+$	$B_+ \rightarrow \bar{B}^0$
4a,b)	$\bar{B}^0 \rightarrow B_-$	$B_- \rightarrow \bar{B}^0$

Process 1a) experimentally corresponds to a measurement of, for example, an ℓ^- tag, corresponding to a \bar{B}^0 , on the “tag”-side (non- CP -eigenstate-decaying) neutral B (implying that, at that time, the “signal” side is/was a B^0), and then afterwards, the signal-side neutral B decaying to, for example, $J/\psi K_L^0$, a CP -even final state; thus we could refer to 1a) as $(\ell^-, J/\psi K_L^0)$. Process 1b) corresponds to the CP -even state being measured first; thus, for example, we could measure the signal-side neutral B decaying to $J/\psi K_S^0$, implying that, at that instant, the tag side was CP -even, and then the tag side decaying to an ℓ^+ tag, corresponding to a B^0 ; thus we could refer to 1b) as $(J/\psi K_S^0, \ell^+)$. Similarly, 2a,b) could be referred to as $(\ell^-, J/\psi K_S^0)$ and $(J/\psi K_L^0, \ell^+)$ respectively; 3a,b) as $(\ell^+, J/\psi K_L^0)$ and $(J/\psi K_S^0, \ell^-)$; and 4a,b) as $(\ell^+, J/\psi K_S^0)$ and $(J/\psi K_L^0, \ell^-)$. Note that the CP -transform of, for example, 1a) is not 1b), but rather 4a) (and 2a)–3a), 1b)–4b), and 2b)–3b) are the other CP -transform pairs).

Each of the eight transitions has a time-dependent decay rate:

$$g_{\alpha,\beta}^{\pm}(\tau) \propto e^{-\Gamma|\tau|} \left\{ 1 + S_{\alpha,\beta}^{\pm} \sin(\Delta m_d \tau) + C_{\alpha,\beta}^{\pm} \cos(\Delta m_d \tau) \right\} \quad (3)$$

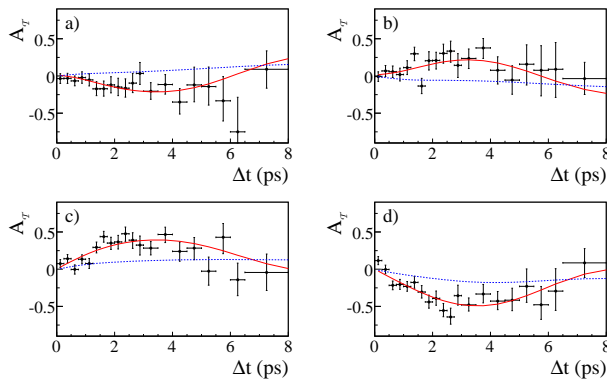


Figure 6: The four independent T -violating asymmetries for transition a) $\bar{B}^0 \rightarrow B_- (\ell^+ X, c\bar{c}K_S^0)$, b) $B_+ \rightarrow B^0 (c\bar{c}K_S^0, \ell^+ X)$, c) $\bar{B}^0 \rightarrow B_+ (\ell^+ X, J/\psi K_L^0)$, d) $B_- \rightarrow B^0 (J/\psi K_L^0, \ell^+ X)$. The points with error bars represent the data, the solid and dashed curves represent the projections of the best fit results with and without T violation, respectively.

with α being the tag flavor decay $\in \{\ell^+ X, \ell^- X\}$, β being the negative or positive CP eigenstate decay $\in \{c\bar{c}K_S^0, J/\psi K_L^0\}$, and the $+$ or $-$ indicating if the decay to the flavor final state α occurred before or after the decay to the CP final state β . Other parameters are the average decay width Γ , the mass difference between the B mass eigenstates Δm_d , and the measured C and S coefficients. The decay rate above is then convolved by the measured resolution function on the decay time difference $\Delta t = \tau_\alpha - \tau_\beta$ between the decays to the flavor and CP eigenstates, and then fitted to the data.

We measure the values [8]:

Parameter	Result
$\Delta S_T^+ = S_{\ell^-, K_L^0}^- - S_{\ell^+, K_S^0}^+$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S_T^- = S_{\ell^-, K_L^0}^+ - S_{\ell^+, K_S^0}^-$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C_T^+ = C_{\ell^-, K_L^0}^- - C_{\ell^+, K_S^0}^+$	$0.10 \pm 0.14 \pm 0.08$
$\Delta C_T^- = C_{\ell^-, K_L^0}^+ - C_{\ell^+, K_S^0}^-$	$0.04 \pm 0.14 \pm 0.08$
$\Delta S_{CP}^+ = S_{\ell^-, K_S^0}^- - S_{\ell^+, K_S^0}^+$	$-1.30 \pm 0.11 \pm 0.07$
$\Delta S_{CP}^- = S_{\ell^-, K_S^0}^+ - S_{\ell^+, K_S^0}^-$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C_{CP}^+ = C_{\ell^-, K_S^0}^- - C_{\ell^+, K_S^0}^+$	$0.07 \pm 0.09 \pm 0.03$
$\Delta C_{CP}^- = C_{\ell^-, K_S^0}^+ - C_{\ell^+, K_S^0}^-$	$0.08 \pm 0.10 \pm 0.04$
$\Delta S_{CPT}^+ = S_{\ell^+, K_L^0}^- - S_{\ell^-, K_S^0}^+$	$0.16 \pm 0.21 \pm 0.09$
$\Delta S_{CPT}^- = S_{\ell^+, K_L^0}^+ - S_{\ell^-, K_S^0}^-$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C_{CPT}^+ = C_{\ell^+, K_L^0}^- - C_{\ell^-, K_S^0}^+$	$0.14 \pm 0.15 \pm 0.07$
$\Delta C_{CPT}^- = C_{\ell^+, K_L^0}^+ - C_{\ell^-, K_S^0}^-$	$0.03 \pm 0.12 \pm 0.08$

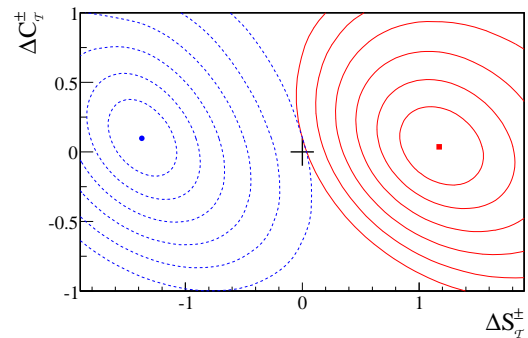


Figure 7: The central values (dot and square) and 2-dimensional contours representing $1\sigma - 6\sigma$ confidence intervals for the pairs of T -asymmetry parameters $(\Delta S_T^+, \Delta C_T^+)$ (dashed curves) and $(\Delta S_T^-, \Delta C_T^-)$ (solid curves). Systematic uncertainties are included. The T -invariance point is shown as a plus sign (+).

where in each case the first uncertainty is statistical and the second systematic. In the SM, we expect $\Delta S_T^- = -\Delta S_T^+ = \Delta S_{CP}^- = -\Delta S_{CP}^+ = 2 \sin(2\beta) = 1.35 \pm 0.04$ (twice the world average for $\sin(2\beta)$), and $\Delta C_T^\pm = \Delta C_{CP}^\pm = \Delta S_{CP T}^\pm = \Delta C_{CP T}^\pm = 0$ (up to corrections of, at maximum, order 10^{-2}); our measurements are all consistent with these expectations. As noted in the Di Domenico contribution to these proceedings [9], this is the first observation of T violation which is fully experimentally independent of CP violation, in any system.

5. Search for a T -odd correlation in D decays to $K^+ K^0 \pi^+ \pi^-$

In the SM, charm physics is approximately CP -conserving, as CP -violating effects are only at order 4 and higher in the Cabibbo angle; CP -violating effects are expected to be of order 10^{-3} at maximum. These always-small effects are expected to be at their largest in singly-Cabibbo-suppressed (SCS) modes; the effects should be even smaller in Cabibbo-favored (CF) and doubly-Cabibbo-suppressed channels [10]. The LHCb experiment has recently found evidence for a direct CP -violating asymmetry in time-integrated D^0 decays: $A_{CP}(K^+ K^-) - A_{CP}(\pi^+ \pi^-) = (-8.2 \pm 2.1 \pm 1.1) \times 10^{-3}$ [11], suggesting the possibility that new physics could potentially be enhancing CP violation via loop diagrams [12]. We thus investigate the related SCS mode $D^+ \rightarrow K^+ K^0 \pi^+ \pi^-$ and CF mode $D_s^+ \rightarrow K^+ K^0 \pi^+ \pi^-$.

We select $D_{(s)}^+ \rightarrow K^+ K_s^0 \pi^+ \pi^-$ in on- and off-peak data via fully reconstructing each decay. Figure 8 shows the invariant mass peak for the two decays; we reconstruct 21210 ± 392 D decays and 29791 ± 337 D_s^+ decays to this channel. The primary background is combinatorial background from $D^+ \rightarrow K_s^0 \pi^+ \pi^-$.

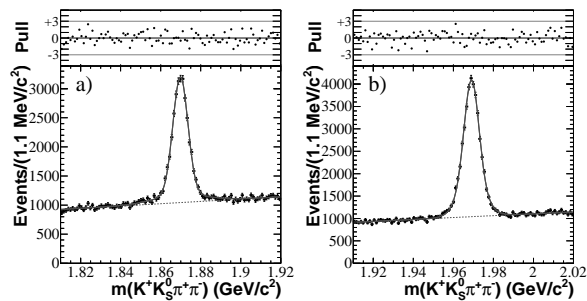


Figure 8: The $K^+ K_s^0 \pi^+ \pi^-$ mass spectrum in the (a) D^+ and (b) D_s^+ mass regions. The distributions of the pull values are also shown.

The T -odd correlation observable is built from the final state momenta: we can define $C_T \equiv \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$, and then define the asymmetry observable

$$A_T \equiv \frac{\Gamma(C_T > 0) - \Gamma(C_T < 0)}{\Gamma(C_T > 0) + \Gamma(C_T < 0)}. \quad (4)$$

Final state interactions could, however, produce $A_T \neq 0$ due to strong phases [13]; such effects can be removed by defining and measuring $\mathcal{A}_T \equiv \frac{1}{2}(A_T - \bar{A}_T)$, where \bar{A}_T is defined on the CP -conjugate process [14].

We thus measure the values $\mathcal{A}_T(D) = (-12.0 \pm 10.0 \pm 4.6) \times 10^{-3}$ and $\mathcal{A}_T(D_s^+) = (-13.6 \pm 7.7 \pm 3.4) \times 10^{-3}$ [15]. These values are consistent with the SM expectation of $O(10^{-3})$, and also consistent with previous (less precise) results from other experiments [16].

6. Search for CP violation in τ decays to $K^0 \pi^- \nu_\tau$

Little CP violation is expected in τ decays in the SM; in final states containing K_s^0 , a small $O(10^{-3})$ A_{CP} is expected due to CP violation in the kaon sector [17]. Interference between K_s^0 and K_L^0 thus plays an important role in measurements of CP -violating asymmetries in such final states. Assuming a $K_s^0 \rightarrow \pi^+ \pi^-$ section efficiency that is independent of decay times that are long compared with the K_s^0 lifetime, one expects the CP asymmetry

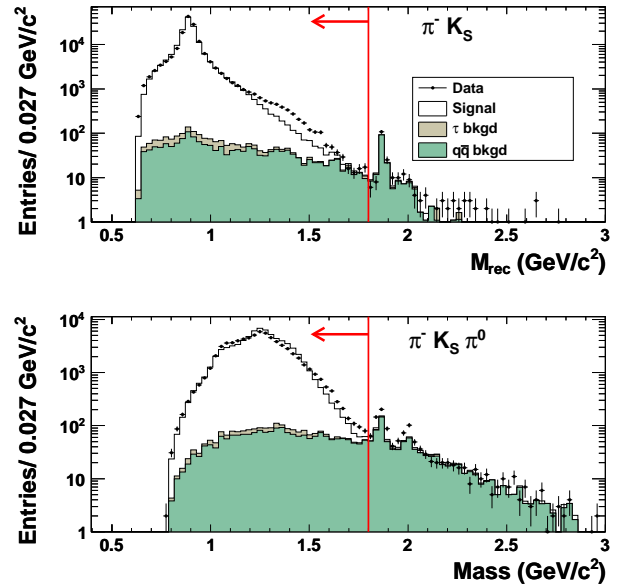


Figure 9: Invariant mass distributions for (top) $K^0 \pi^-$ and (bottom) $K^0 \pi^- \pi^0$ for τ to $K^0 \pi^- \nu_\tau$ and $K^0 \pi^- \pi^0 \nu_\tau$ respectively.

$$A_Q \equiv \frac{\Gamma(\tau^+ \rightarrow \pi^+ K_s^0 \bar{\nu}_\tau) - \Gamma(\tau^- \rightarrow \pi^- K_s^0 \nu_\tau)}{\Gamma(\tau^+ \rightarrow \pi^+ K_s^0 \bar{\nu}_\tau) + \Gamma(\tau^- \rightarrow \pi^- K_s^0 \nu_\tau)} \quad (5)$$

to equal $(0.33 \pm 0.1)\%$ for decay times that are of order $\tau_{K_s^0}$ [18]. New physics, however, could significantly modify the measured asymmetry [19].

We select $\tau^+\tau^-$ events via event shape criteria such as thrust and p_{prompt} ; $\tau^+\tau^-$ events are cleanly divided into two hemispheres via their thrust. We select events in which there is a single prompt track plus a K_s^0 in one hemisphere, and one prompt tag lepton (e/μ) with opposite charge in the other hemisphere. The dominant background is due to τ decays to $KK_s^0(N\pi^0)\nu_\tau$ and $\pi K^0 \bar{K}^0 \nu_\tau$; this is estimated from Monte Carlo and corrected using data sidebands. Figure 9 shows the reconstructed invariant mass distributions and the signal selection cuts. We reconstruct approximately 170000 events of each of $\tau^- \rightarrow K_s^0 \pi^- \nu_\tau$ and $\tau^+ \rightarrow K_s^0 \pi^+ \bar{\nu}_\tau$ decays.

We measure the raw charge asymmetries $A_Q(e\text{-tag}) = (-0.32 \pm 0.23)\%$ and $A_Q(\mu\text{-tag}) = (-0.05 \pm 0.27)\%$. However, the decay-rate asymmetries will be modified by the different K^0 and \bar{K}^0 nuclear interaction cross-sections with detector material [20]. We thus must compute corrections on an event-by-event basis in terms of the p and θ of the K_s^0 : $A_{K_s^0}^{\text{corr}}(e\text{-tag}) = (0.14 \pm 0.03)\%$ and $A_{K_s^0}^{\text{corr}}(\mu\text{-tag}) = (0.14 \pm 0.02)\%$; these corrections must be subtracted from the raw asymmetries. We thus measure the final asymmetry $A_Q = (-0.45 \pm 0.24 \pm 0.11)\%$; this is the first measurement of this quantity [21]. The measurement is 3.1σ from the SM prediction.

7. Conclusion

In B decays to three kaons, we measure an indication of direct CP violation in the process $B^\pm \rightarrow \phi K^\pm$ at 2.8σ significance: $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$, with Standard Model expectations of this quantity being in the range $(0\text{--}4.7)\%$; and we measure the CP phase β in $B^0 \rightarrow \phi K_s^0$ to be $(21 \pm 6 \pm 2)^\circ$, which is in good agreement with the Standard Model expectation of equality with the β from charmonium world average of $(21 \pm 0.8)^\circ$ [3]. We have searched for direct CP violation in $B \rightarrow K \ell^+ \ell^-$, and measure overall direct CP asymmetries $A_{CP}(B^\pm \rightarrow K^\pm \ell^+ \ell^-) = -0.03 \pm 0.14 \pm 0.01$ and $A_{CP}(B \rightarrow K^* \ell^+ \ell^-) = 0.03 \pm 0.13 \pm 0.01$ [7]. We present the first observation of T violation that is truly experimentally independent of CP violation [9], and we measure the parameters $\Delta S_T^+ = -1.37 \pm 0.14 \pm 0.06$ and $\Delta S_T^- = 1.17 \pm 0.18 \pm 0.11$, which constitute an observation of T violation at 14σ significance, and which are consistent with the expectations of $\Delta S_T^- = -\Delta S_T^+ = 2 \sin(2\beta)$ when assuming

CPT conservation (i.e. the Standard Model) [8]. In D decays to $K^+ K_s^0 \pi^+ \pi^-$, we measure the T -odd correlations $\mathcal{A}_T(D) = (-12.0 \pm 10.0 \pm 4.6) \times 10^{-3}$ and $\mathcal{A}_T(D_s^+) = (-13.6 \pm 7.7 \pm 3.4) \times 10^{-3}$, which are consistent with SM expectations of $\mathcal{O}(10^{-3})$ [15]. And we measure the CP -violating asymmetry A_Q in τ decays to $K^0 \pi^- \nu_\tau$ to be $(-0.45 \pm 0.24 \pm 0.11)\%$, a value 3.1σ from the SM prediction [21]. These new measurements show that *BABAR* continues to produce important new results in multiple sectors on violations of fundamental symmetries in nature, which are largely still statistics-limited, and B physics has a very long and fruitful future ahead of it.

References

- [1] For example, A. Riotto and M. Trodden, *Ann. Rev. Nucl. Part. Sci.* **49**, 46 (1999) [arXiv:hep-ph/9901362].
- [2] *BABAR* Collaboration, B. Aubert *et al.*, *Phys. Rev. D* **74**, 032003 (2006) and *Phys. Rev. Lett.* **99**, 161802 (2007); Belle Collaboration, A. Garmash *et al.*, *Phys. Rev. D* **71**, 092003 (2005) and Y. Nakahama *et al.*, *Phys. Rev. D* **82**, 073011 (2010).
- [3] *BABAR* Collaboration, J. P. Lees *et al.*, *Phys. Rev. D* **85**, 112010 (2012) [arXiv:1201.5897].
- [4] M. Beneke and M. Neubert, *Nucl. Phys. B* **675**, 333 (2003); H. Li and S. Mishima, *Phys. Rev. D* **74**, 094020 (2006).
- [5] W. Altmannshofer *et al.*, *JHEP* **0901**, 019 (2009).
- [6] F. Krüger, L. Sehgal, N. Sinha, and R. Sinha, *Phys. Rev. D* **61**, 114028 (2000) [Erratum-ibid *D* **63**, 019901 (2001)].
- [7] *BABAR* Collaboration, J. P. Lees *et al.*, *Phys. Rev. D* **86**, 032012 (2012) [arXiv:1204.3933].
- [8] *BABAR* Collaboration, J. P. Lees *et al.*, arXiv:1207.5832 (submitted to *Phys. Rev. Lett.*).
- [9] A. Di Domenico and J. Albert, these proceedings.
- [10] F. Bucella *et al.*, *Phys. Rev. D* **51**, 3478 (1995); S. Bergmann and Y. Nir, *JHEP* **09**, 031 (1999).
- [11] LHCb Collaboration, R. Aaij *et al.*, *Phys. Rev. Lett.* **108**, 111602 (2012) [arXiv:1112.0938].
- [12] Y. Grossman, A. Kagan, and Y. Nir, *Phys. Rev. D* **75**, 036008 (2007); I. I. Bigi, arXiv:0907.2950.
- [13] I. I. Bigi and H.-B. Li, *Int. J. Mod. Phys. A* **24S1**, 657 (2009).
- [14] W. Bensalem, A. Datta, and D. London, *Phys. Rev. D* **66**, 094004 (2002); *Phys. Lett. B* **538**, 309 (2002); *Phys. Rev. D* **64**, 116003 (2001).
- [15] *BABAR* Collaboration, J. P. Lees *et al.*, *Phys. Rev. D* **84**, 031103 (2011) [arXiv:1105.4410].
- [16] FOCUS Collaboration, J. M. Link *et al.*, *Phys. Lett. B* **622**, 239 (2005).
- [17] I. I. Bigi and A. I. Sanda, *Phys. Lett. B* **625**, 47 (2005); G. Calderon, D. Delepine, and G. Lopez Castro, *Phys. Rev. D* **75**, 076001 (2007).
- [18] Y. Grossman and Y. Nir, arXiv:1110.3790.
- [19] J. H. Kühn and E. Mirkes, *Phys. Lett. B* **398**, 407 (1997).
- [20] B. R. Ko *et al.*, *Phys. Rev. D* **84**, 111501 (2011) [arXiv:1006.1938].
- [21] *BABAR* Collaboration, J. P. Lees *et al.*, *Phys. Rev. D* **85**, 031102 (2012) [arXiv:1109.1527].