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Update of Time-Dependent CP Asymmetry Measurements in $b \to c\bar{c}s$ Decays

The BABAR Collaboration

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Abstract

We present updated measurements of time-dependent CP asymmetries in fully reconstructed neutral B decays containing a charmonium meson. The measurements reported here use a data sample of $(465 \pm 5) \times 10^6$ $\Upsilon(4S) \to B\overline{B}$ decays collected with the BABAR detector at the PEP-II B factory. The time-dependent CP asymmetry parameters measured from $J/\psi K^0_S$, $J/\psi K^0_L$, $\psi(2S)K^0_S$, $\chi_{c1}K^0_S$, $\eta_c K^0_S$, and $J/\psi K^{*0}$ decays are

$$C_f = 0.026 \pm 0.020(\text{stat}) \pm 0.016(\text{syst}),$$
$$S_f = 0.691 \pm 0.029(\text{stat}) \pm 0.014(\text{syst}).$$

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1 INTRODUCTION

The Standard Model (SM) of electroweak interactions describes *CP* violation as a consequence of an irreducible phase in the three-family Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix [1]. In the CKM framework, neutral B decays to *CP* eigenstates containing a charmonium and a $K^{(*)0}$ meson through tree-diagram dominated processes provide a direct measurement of $\sin 2\beta$ [2], where the angle β is defined in terms of the CKM matrix elements $V_{\rm ij}$ for quarks i, j as $\arg[-(V_{\rm cd}V_{\rm cb}^{*})/(V_{\rm td}V_{\rm tb}^{*})]$.

We identify (tag) the initial flavor of the reconstructed B candidate, $B_{\rm rec}$, using information from the other B meson, $B_{\rm tag}$, in the event. The decay rate g_{+} (g_{-}) for a neutral B meson decaying to a *CP* eigenstate accompanied by a B^0 ($\overline{B}^0$) tag can be expressed as

$$g_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left\{(1 \mp \Delta w) \pm (1-2w) \times \Big[-\eta_f S \sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)\Big]\right\} \quad (1)$$

where

$$S = -\eta_f \frac{2\,\mathcal{I}m\,\lambda}{1+|\lambda|^2},$$
$$C = \frac{1-|\lambda|^2}{1+|\lambda|^2},$$

the *CP* eigenvalue $\eta_f = +1$ (-1) for a *CP* even (odd) final state, $\Delta t \equiv t_{\rm rec} - t_{\rm tag}$ is the difference between the proper decay times of $B_{\rm rec}$ and $B_{\rm tag}$, τ_{B^0} is the neutral B lifetime, and Δm_d is the mass difference of the B meson mass eigenstates determined from B^0-$\overline{B}^0$ oscillations [3]. We assume that the corresponding decay-width difference $\Delta\Gamma_d$ is zero. Here, $\lambda = (q/p)(\overline{A}/A)$ [4], where q and p are complex constants that relate the B-meson flavor eigenstates to the mass eigenstates, and $\overline{A}/A$ is the ratio of amplitudes of the decay without mixing of a $\overline{B}^0$ or B^0 to the final state under study. The average mistag probability w describes the effect of incorrect tags, and Δw is the difference between the mistag probabilities for B^0 and $\overline{B}^0$ mesons. The sine term in Eq. 1 results from the interference between direct decay and decay after $B^0-\overline{B}^0$ oscillation. A non-zero cosine term arises from the interference between decay amplitudes with different weak and strong phases (direct *CP* violation $|\overline{A}/A| \neq 1$) or from *CP* violation in $B^0-\overline{B}^0$ mixing ($|q/p| \neq 1$). In the SM, *CP* violation in mixing and direct *CP* violation in $b \to c\overline{c}s$ decays are both negligible [4]. Under these assumptions, $\lambda = \eta_f e^{-2i\beta}$, and $C = 0$. Thus, the time-dependent *CP*-violating asymmetry is

$$A_{CP}(\Delta t) \equiv \frac{g_{+}(\Delta t) - g_{-}(\Delta t)}{g_{+}(\Delta t) + g_{-}(\Delta t)} = -(1-2w)\eta_f S \sin(\Delta m_d \, \Delta t), \quad (2)$$

and $S = \sin 2\beta$. If we relax the assumption that $C = 0$, then $S = \sqrt{1-C^2}\sin 2\beta$.

Previous *BABAR* measurements have reported time-dependent *CP* asymmetries in terms of the parameters $\sin 2\beta$ and $|\lambda|$. In this paper we report results in terms of $C_f = \eta_f C$ and $S_f = \eta_f S$ to be consistent with other time-dependent *CP* asymmetry measurements. We reconstruct B^0 decays to the final states $J/\psi K^0_S$, $J/\psi K^0_L$, $\psi(2S)K^0_S$, $\chi_{c1}K^0_S$, $\eta_c K^0_S$, and $J/\psi K^{*0}$ ($K^{*0} \to K^0_S\pi^0$) [5]. The $J/\psi K^0_L$ final state is *CP* even, and the $J/\psi K^{*0}$ final state is an admixture of *CP* even and *CP* odd amplitudes. Ignoring the angular information in $J/\psi K^{*0}$ results in a dilution of the measured *CP* asymmetry by a factor $1 - 2R_{\perp}$, where $R_{\perp}$ is the fraction of the L=1 contribution. In Ref. [6] we have measured $R_\perp = 0.233 \pm 0.010\,(\mathrm{stat}) \pm 0.005\,(\mathrm{syst})$, which gives an effective $\eta_f = 0.504 \pm 0.033$ for $f = J/\psi K^{*0}$, after acceptance corrections. In addition to measuring a combined S_f and C_f for the CP modes described above, we measure S_f and C_f for each mode individually, for the $J/\psi K^0_S$ mode where we split this into samples with $K^0_S \to \pi^+\pi^-$ and $\pi^0\pi^0$, and for the channel $J/\psi K^0$ (combining the K^0_S and K^0_L final states). Since our last published result [7], we have added 82×10^6 $B\overline{B}$ decays and applied improved event reconstruction algorithms to the entire dataset.

2 THE DATASET AND *BABAR* DETECTOR

The results presented in this paper are based on data collected with the *BABAR* detector at the PEP-II asymmetric energy e^+e^- storage rings [8] operating at the Stanford Linear Accelerator Center. At PEP-II, 9.0 GeV electrons and 3.1 GeV positrons collide at a center-of-mass energy of 10.58 GeV which corresponds to the $\Upsilon(4S)$ resonance. The asymmetric energies result in a boost from the laboratory to the center-of-mass (CM) frame of $\beta\gamma \approx 0.56$. The dataset analyzed has an integrated luminosity of 425.7 fb^{-1} corresponding to $(465 \pm 5) \times 10^6$ $B\overline{B}$ pairs recorded at the $\Upsilon(4S)$ resonance (on-peak).

The *BABAR* detector is described in detail elsewhere [9]. Surrounding the interaction point is a five-layer double-sided silicon vertex tracker (SVT) which measures the impact parameters of charged particle tracks in both the plane transverse to, and along the beam direction. A 40-layer drift chamber (DCH) surrounds the SVT and provides measurements of the momenta for charged particles. Charged hadron identification is achieved through measurements of particle energy-loss in the tracking system and the Cherenkov angle obtained from a detector of internally reflected Cherenkov light. A CsI(Tl) electromagnetic calorimeter (EMC) provides photon detection, electron identification, and π^0 reconstruction. The aforementioned components are surrounded by a solenoid magnet, that provides a 1.5 T magnetic field. Finally, the flux return of the magnet is instrumented in order to allow discrimination of muons from pions. For the most recent 211.7 fb^{-1} of data, a portion of the resistive plate chambers constituting the muon system has been replaced by limited streamer tubes [10, 11].

We use a right-handed coordinate system with the z axis along the electron beam direction and the y axis upward, with the origin at the nominal beam interaction point. Unless otherwise stated, kinematic quantities are calculated in the laboratory rest frame. The other reference frame which we commonly use is the CM frame of the colliding electrons and positrons.

We use Monte Carlo (MC) simulated events generated using the GEANT4 [12] and EvtGen [13] based *BABAR* simulation.

3 RECONSTRUCTION OF B CANDIDATES

We select two samples of events in order to measure the time-dependent CP asymmetry parameters S_f and C_f. These are a sample of fully reconstructed B meson decays to flavor eigenstates (B_{flav}) and a sample of signal events used in the extraction of the CP parameters (B_{CP}). The B_{flav} sample consists of B^0 decays to $D^{(*)-}(\pi^+, \rho^+, a_1^+)$ and $J/\psi K^{*0}$ (where $K^{*0} \to K^+\pi^-$) final states. We use the B_{flav} sample of events to determine dilution parameters (mistag probabilities). The B_{CP} sample of events consists of B^0 decays to $J/\psi K^0_S$, $J/\psi K^0_L$, $\psi(2S)K^0_S$, $\eta_c K^0_S$, $\chi_{c1}K^0_S$, and $J/\psi K^{*0}$. We assume the interference between the CP side and the tag side reconstruction is negligible and therefore the dilution parameters are assumed to be the same for the B_{flav} and B_{CP} samples. We also select a sample of fully reconstructed charged B meson decays to $J/\psi K^+$, $\psi(2S)K^+$, $\chi_{c1}K^+$, $\eta_c K^+$, and $J/\psi K^{*+}$ (where $K^{*+} \to K^+\pi^0$) final states to use as a control sample.

The event selection is unchanged from that described in Ref [7]. Events that pass the selection requirements are refined using kinematic variables. The $J/\psi K_L^0$ mode has the requirement that the difference ΔE between the candidate CM energy and the beam energy $E^*_{\rm beam}$ in the CM satisfies $|\Delta E| < 80\,{\rm MeV}$. We require that the beam-energy substituted mass $m_{ES} = \sqrt{(E^*_{\rm beam})^2 - (p^*_B)^2}$ is greater than $5.2\,{\rm GeV}/c^2$ for all other categories of events, where p^*_B is the B momentum in the e^+e^- CM frame.

We calculate the proper time difference Δt between the two B decays from the measured separation Δz between the decay vertices of $B_{\rm rec}$ and $B_{\rm tag}$ along the collision (z) axis [14]. The z position of the $B_{\rm rec}$ vertex is determined from the charged daughter tracks. The $B_{\rm tag}$ decay vertex is determined by fitting tracks not belonging to the $B_{\rm rec}$ candidate to a common vertex, and including constraints from the beam spot location and the $B_{\rm rec}$ momentum [14]. Events are accepted if the calculated Δt uncertainty is less than 2.5 ps and $|\Delta t|$ is less than 20 ps. The fraction of signal MC events satisfying these requirements is 95 %.

4 *B* MESON FLAVOR TAGGING

A key ingredient in the measurement of time-dependent CP asymmetries is to determine whether at the time of the $B_{\rm tag}$ decay the $B_{\rm rec}$ was a B^0 or a $\overline{B}^0$. This 'flavor tagging' is achieved with the analysis of the decay products of the recoiling B meson $B_{\rm tag}$. The overwhelming majority of B mesons decay to a final state that is flavor-specific, i.e. only accessible from either a B^0 or a $\overline{B}^0$, but not from both. The purpose of the flavor tagging algorithm is to determine the flavor of $B_{\rm tag}$ with the highest possible efficiency $\epsilon_{\rm tag}$ and lowest possible probability w of assigning the wrong flavor to $B_{\rm tag}$. It is not necessary to fully reconstruct $B_{\rm tag}$ in order to estimate its flavor. The figure of merit for the performance of the tagging algorithm is the effective tagging efficiency

$$Q = \epsilon_{\rm tag}(1 - 2w)^2, \tag{3}$$

which is related to the statistical uncertainty σ_S and σ_C in the coefficients S and C through

$$\sigma_{S,C} \propto \frac{1}{\sqrt{Q}}. \tag{4}$$

We use a neural network based technique [14, 7] that isolates primary leptons, kaons and pions from B decays to final states containing D^* mesons, and high momentum charged particles from B decays, to determine the flavor of the $B_{\rm tag}$. The output of this algorithm is divided into seven mutually-exclusive categories. These are (in order of decreasing signal purity) Lepton, Kaon I, Kaon II, Kaon-Pion, Pion, Other and Untagged. The performance of this algorithm is determined using the $B_{\rm flav}$ sample. The Untagged category of events contain no flavor information, so carry no weight in the time-dependent analysis, and are not used here.

5 LIKELIHOOD FIT METHOD

We determine the composition of our final sample by performing simultaneous fits to the m_{ES} distributions for the full B_{CP} and $B_{\rm flav}$ samples, except for the $J/\psi K_L^0$ sample for which we fit the ΔE distribution.

We define a signal region $5.27 < m_{ES} < 5.29\,\mathrm{GeV}/c^2$ ($|\Delta E| < 10\,\mathrm{MeV}$ for $J/\psi\,K^0_L$), which contains 15481 CP candidate events that satisfy the tagging and vertexing requirements (see Table 1). For all modes except $\eta_c K^0_S$ and $J/\psi\,K^0_L$, we use simulated events to estimate the fractions of events that peak in the m_{ES} signal region due to cross-feed from other decay modes (peaking background). For the $\eta_c K^0_S$ mode, the cross-feed fraction is determined from a fit to the $m_{KK\pi}$ and m_{ES} distributions in data. For the $J/\psi\,K^0_L$ decay mode, the sample composition, effective η_f, and ΔE distribution of the individual background sources are determined either from simulation (for $B \to J/\psi\,X$) or from the $m_{\ell^+\ell^-}$ sidebands in data (for non-J/ψ background). Figure 1 shows the distributions of m_{ES} obtained for the B_{CP} and B_{flav} events, and ΔE obtained for the $J/\psi\,K^0_L$ events.

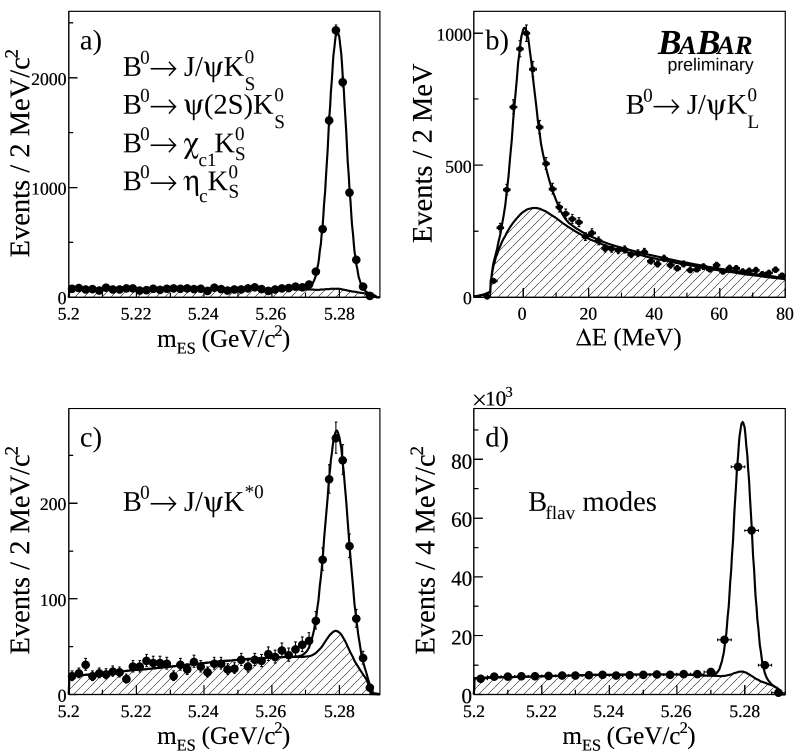

Figure 1: Distributions for B_{CP} and B_{flav} candidates satisfying the tagging and vertexing requirements: a) m_{ES} for the final states $J/\psi\,K^0_S$, $\psi(2S)K^0_S$, $\chi_{c1}K^0_S$, and $\eta_c K^0_S$, b) ΔE for the final state $J/\psi\,K^0_L$, c) m_{ES} for $J/\psi\,K^{*0}(K^{*0} \to K^0_S\pi^0)$, and d) m_{ES} for the B_{flav} sample. In each plot, the shaded region is the estimated background contribution.

We determine S_f and C_f from a simultaneous maximum likelihood fit to the Δt distribution of the tagged B_{CP} and B_{flav} samples. The Δt distributions of the B_{CP} sample are modeled by Eq. 1. Those of the B_{flav} sample evolve according to Eq. 1 with $S_f = C_f = 0$. The observed amplitudes for the CP asymmetry in the B_{CP} sample and for flavor oscillation in the B_{flav} sample are reduced by the same factor, $1-2w$, due to flavor mistags. The Δt distributions for the signal are convolved with a resolution function common to both the B_{flav} and B_{CP} samples, modeled by the sum of three Gaussian functions [14]. The combinatorial background is incorporated with an empirical description of its Δt spectra, containing zero and non-zero lifetime components convolved with a resolution function [14] distinct from that of the signal. The peaking background is assigned the same Δt distribution as the signal but with $S_f = C_f = 0$, and uses the same Δt resolution function as the signal. As the non-zero lifetime component of the combinatorial background contains both events that are mixed and un-mixed, we allow the value of Δm_d for this component to float in the fit.

In addition to S_f and C_f, there are 69 free parameters in the *CP* fit. For the signal, these are

- 7 parameters for the Δt resolution,
- 12 parameters for the average mistag fractions w and the differences Δw between B^0 and $\overline{B}^0$ mistag fractions for each tagging category,
- 7 parameters for the difference between B^0 and $\overline{B}^0$ reconstruction and tagging efficiencies.

The background is described by

- 24 mistag fraction parameters,
- 3 parameters for the Δt resolution,
- 4 parameters for the $B_{\rm flav}$ time dependence,
- 8 parameters for possible *CP* violation in the background, including the apparent *CP* asymmetry of non-peaking events in each tagging category,
- 1 parameter for possible direct *CP* violation in the $\chi_{c1} K^0_S$ background to $J/\psi\, K^{*0}$, and
- 3 parameters for possible direct *CP* violation in the $J/\psi\, K^0_L$ mode, coming from $J/\psi\, K^0_S$, $J/\psi\, K^{*0}$, and the remaining J/ψ backgrounds.

The effective $|\lambda|$ of the non-J/ψ background is fixed from a fit to the J/ψ-candidate sidebands in $J/\psi\, K^0_L$. We fix $\tau_{B^0} = 1.530\,\text{ps}$ and $\Delta m_d = 0.507\,\text{ps}$ [3]. The determination of the mistag fractions and Δt resolution function parameters for the signal is dominated by the $B_{\rm flav}$ sample, which is about 10 times more abundant than the *CP* sample.

6 LIKELIHOOD FIT VALIDATION

Before fitting the data in order to extract *CP* asymmetry parameters, we validate the integrity of the likelihood. We perform three sets of tests in order to validate the fit. The first of these tests consists of generating ensembles of simulated experiments from the PDFs and fitting each simulated experiment. The distribution of fitted S_f and C_f parameters are required to be unbiased, and we verify that the uncertainties are extracted correctly from the fit by requiring that the distribution of the pull $\mathcal{P}$ on a parameter $\mathcal{O}$, given by $\mathcal{P} = (\mathcal{O}_{\rm fit} - \mathcal{O}_{\rm gen})/\sigma(\mathcal{O}_{\rm fit})$, is a Gaussian centered about zero with a width of one. The quantity $\mathcal{O}_{\rm fit}$ is the fitted value, with a fitted error of $\sigma(\mathcal{O}_{\rm fit})$, and $\mathcal{O}_{\rm gen}$ is the generated value.

The second test involves fitting simulated *CP* events with the full *BABAR* detector simulation. We require that the $\mathcal{P}$ distributions for these signal-only simulated experiments are centered about zero with a width of one. We assign an systematic uncertainty corresponding to any deviations and the statistical uncertainties of the mean values of the fitted S_f and C_f distributions from the generated values.

The third test on our ability to extract S_f and C_f correctly is to perform null tests on control samples of neutral and charged B events where S_f and C_f should equal zero. We use charged B decays to $J/\psi K^{\pm}$, $\psi(2S)K^{\pm}$, $\chi_{c1}K^{\pm}$, $J/\psi K^{*\pm}$ with $K^{*\pm} \to K^{\pm}\pi^0$ and $K^0_S\pi^{\pm}$, and neutral $B_{\rm flav}$ decays for this purpose. The parameters S_f and C_f are zero for these modes within the SM.

7 RESULTS

The fit to the B_{CP} and $B_{\rm flav}$ samples yields $S_f = 0.691 \pm 0.029$ and $C_f = 0.026 \pm 0.020$, where the errors are statistical only. The correlation between these two parameters is +0.3 %. We also perform a separate fit in which we allow different S_f and C_f values for each charmonium decay mode, a fit to the $J/\psi K^0_S\,(\pi^+\pi^- + \pi^0\pi^0)$ mode, and a fit to the $J/\psi K^0\,(K^0_S + K^0_L)$ sample. We split the data sample by run period and by tagging category. We perform the *CP* measurements on control samples with no expected *CP* asymmetry. The results of these fits are summarized in Table 1. Figure 2 shows the Δt distributions and asymmetries in yields between events with B^0 tags and $\overline{B}^0$ tags for the $\eta_f = -1$ and $\eta_f = +1$ samples as a function of Δt, overlaid with the projection of the likelihood fit result. Figure 3 shows the Δt distributions and asymmetry for $J/\psi K^0_S$ events only. We also performed the *CP* fit using the sin2β and $|\lambda|$ parameters, which yields $\sin 2\beta = 0.691 \pm 0.029$ and $|\lambda| = 0.974 \pm 0.020$.

The dominant systematic errors on S_f are due to limited knowledge of various background properties, including possible differences between the $B_{\rm flav}$ and B_{CP} tagging performances, to the description of the Δt resolution functions, uncertainties in $J/\psi K^0_L$-specific backgrounds and in the amounts of peaking backgrounds and their *CP* asymmetries, and to the uncertainties in the values of the physics parameters $\Delta m_d, \tau_B, \Delta\Gamma_d/\Gamma_d$. The only sizable systematic uncertainties on C_f are due to the *CP* content of the peaking backgrounds and to the possible interference between the suppressed $\bar{b} \to \bar{u}c\bar{d}$ amplitude with the favored $b \to c\bar{u}d$ amplitude for some tag-side B decays [18]. The total systematic error on S_f (C_f) is 0.014 (0.016). The main systematic uncertainties on both S_f and C_f for the full sample, for the seven individual modes, and for the fits to the $J/\psi K^0$ and $J/\psi K^0_S$ samples are summarized in Tables 2 and 3.

8 CONCLUSIONS

We report improved measurements of the time-dependent *CP* asymmetry parameters that supersede our previous results [7]. These measurements are given in terms of C_f and S_f for the first time with our data sample. We measure

$$\begin{aligned} C_f &= 0.026 \pm 0.020(\text{stat}) \pm 0.016(\text{syst}), \\ S_f &= 0.691 \pm 0.029(\text{stat}) \pm 0.014(\text{syst}), \end{aligned}$$

providing a model independent constraint on the position of the apex of the Unitarity Triangle [15]. Our measurements agree with previous published results [7, 19] and with the theoretical estimates of the magnitudes of CKM matrix elements within the context of the SM [20]. We also report measurements of C_f and S_f for each of the decay modes within our *CP* sample and of the $J/\psi K^0(K^0_S + K^0_L)$ sample.

Table 1: Number of events $N_{\rm tag}$ and signal purity P in the signal region after tagging and vertexing requirements, and results of fitting for *CP* asymmetries in the B_{CP} sample and various subsamples. In addition, fit results for the $B_{\rm flav}$ and B^+ control samples demonstrate that no artificial *CP* asymmetry is found where we expect no *CP* violation ($S_f = 0$, $C_f = 0$). Errors are statistical only.

Sample	N_{tag}	$P(\%)$	S_f	C_f
Full *CP* sample	15481	76	0.691 ± 0.029	0.026 ± 0.020
$J/\psi\, K^0_S(\pi^+\pi^-)$	5426	96	0.666 ± 0.039	0.019 ± 0.028
$J/\psi\, K^0_S(\pi^0\pi^0)$	1324	87	0.629 ± 0.092	0.093 ± 0.063
$\psi(2S) K^0_S$	861	87	0.905 ± 0.101	0.092 ± 0.077
$\chi_{c1} K^0_S$	385	88	0.619 ± 0.161	0.133 ± 0.109
$\eta_c K^0_S$	381	79	0.930 ± 0.160	0.082 ± 0.125
$J/\psi\, K^0_L$	5813	56	0.698 ± 0.062	-0.030 ± 0.050
$J/\psi\, K^{*0}$	1291	67	0.608 ± 0.241	0.028 ± 0.084
$J/\psi\, K^0$	12563	77	0.670 ± 0.031	0.019 ± 0.023
$J/\psi\, K^0_S$	6750	95	0.660 ± 0.036	0.029 ± 0.026
$\eta_f = -1$	8377	93	0.688 ± 0.032	0.041 ± 0.023
1999-2002 data	3079	78	0.736 ± 0.061	0.013 ± 0.045
2003-2004 data	4916	77	0.721 ± 0.050	0.047 ± 0.037
2005-2006 data	4721	76	0.634 ± 0.051	0.046 ± 0.035
2007 data	2765	75	0.666 ± 0.071	-0.017 ± 0.049
Lepton	1740	83	0.734 ± 0.052	0.079 ± 0.038
Kaon I	2187	78	0.617 ± 0.054	-0.045 ± 0.039
Kaon II	3630	76	0.695 ± 0.057	0.073 ± 0.039
Kaon-Pion	2882	74	0.746 ± 0.087	0.006 ± 0.061
Pion	3053	76	0.726 ± 0.135	0.018 ± 0.092
Other	1989	74	0.767 ± 0.349	-0.168 ± 0.238
$B_{\rm flav}$ sample	166276	83	0.021 ± 0.009	0.012 ± 0.006
B^+ sample	36082	94	0.021 ± 0.015	0.013 ± 0.011

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Table 2: Main systematic uncertainties on S_f and C_f for the full CP sample, and for the $J/\psi K^0$, $J/\psi K^0_S$, and $J/\psi K^0_L$ samples. For each source of systematic uncertainty, the first line gives the error on S_f and the second line the error on C_f. The total systematic error (last row) also includes smaller effects not explicitly mentioned in the table.

Source/sample		Full	$J/\psi K^0$	$J/\psi K^0_S$	$J/\psi K^0_L$
Beamspot	S_f	0.0013	0.0021	0.0027	0.0000
	C_f	0.0006	0.0010	0.0021	0.0001
Mistag differences	S_f	0.0077	0.0057	0.0059	0.0083
	C_f	0.0047	0.0069	0.0053	0.0052
Δt resolution	S_f	0.0067	0.0068	0.0069	0.0071
	C_f	0.0027	0.0029	0.0034	0.0070
$J/\psi K^0_L$ background	S_f	0.0057	0.0063	0.0000	0.0271
	C_f	0.0007	0.0008	0.0000	0.0036
Background fraction	S_f	0.0046	0.0034	0.0036	0.0044
and CP content	C_f	0.0029	0.0021	0.0009	0.0107
m_{ES} parameterization	S_f	0.0022	0.0020	0.0026	0.0006
	C_f	0.0004	0.0005	0.0008	0.0002
$\Delta m_d, \tau_B, \Delta\Gamma_d/\Gamma_d$	S_f	0.0030	0.0033	0.0036	0.0040
	C_f	0.0013	0.0012	0.0011	0.0013
Tag-side interference	S_f	0.0014	0.0014	0.0014	0.0014
	C_f	0.0143	0.0143	0.0143	0.0143
Fit bias	S_f	0.0023	0.0044	0.0041	0.0063
(MC statistics)	C_f	0.0026	0.0044	0.0041	0.0060
Total	S_f	0.0135	0.0131	0.0119	0.0311
	C_f	0.0164	0.0187	0.0167	0.0270

Table 3: Main systematic uncertainties on S_f and C_f for the $J/\psi K^0_S(\pi^+\pi^-)$, $J/\psi K^0_S(\pi^0\pi^0)$, $\psi(2S)K^0_S$, $\chi_{c1}K^0_S$, $\eta_c K^0_S$, and $J/\psi K^{*0}(K^{*0} \to K^0_S\pi^0)$ decay modes. For each source of systematic uncertainty, the first line gives the error on S_f and the second line the error on C_f. The total systematic error (last row) also includes smaller effects not explicitly mentioned in the table.

Source/sample		$J/\psi K^0_S(\pi^+\pi^-)$	$J/\psi K^0_S(\pi^0\pi^0)$	$\psi(2S)K^0_S$	$\chi_{c1}K^0_S$	$\eta_c K^0_S$	$J/\psi K^{*0}$
Beamspot	S_f	0.0027	0.0020	0.0078	0.0284	0.0010	0.0058
	C_f	0.0017	0.0032	0.0084	0.0115	0.0001	0.0001
Mistag differences	S_f	0.0075	0.0074	0.0089	0.0065	0.0064	0.0117
	C_f	0.0039	0.0046	0.0052	0.0067	0.0047	0.0019
Δt resolution	S_f	0.0072	0.0074	0.0072	0.0099	0.0163	0.0259
	C_f	0.0030	0.0043	0.0070	0.0039	0.0036	0.0062
$J/\psi K^0_L$ background	S_f	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001
	C_f	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Background fraction	S_f	0.0032	0.0073	0.0156	0.0174	0.0506	0.0564
and CP content	C_f	0.0012	0.0034	0.0056	0.0098	0.0187	0.0256
m_{ES}	S_f	0.0021	0.0089	0.0238	0.0061	0.0023	0.0372
parameterization	C_f	0.0007	0.0063	0.0008	0.0017	0.0005	0.0080
$\Delta m_d, \tau_B, \Delta\Gamma_d/\Gamma_d$	S_f	0.0031	0.0073	0.0157	0.0025	0.0158	0.0140
	C_f	0.0014	0.0013	0.0010	0.0009	0.0020	0.0013
Tag-side interference	S_f	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014
	C_f	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143
Fit bias	S_f	0.0048	0.0040	0.0079	0.0072	0.0073	0.0271
(MC statistics)	C_f	0.0042	0.0030	0.0019	0.0042	0.0070	0.0389
Total	S_f	0.0129	0.0179	0.0365	0.0398	0.0566	0.0876
	C_f	0.0160	0.0187	0.0209	0.0257	0.0271	0.0540

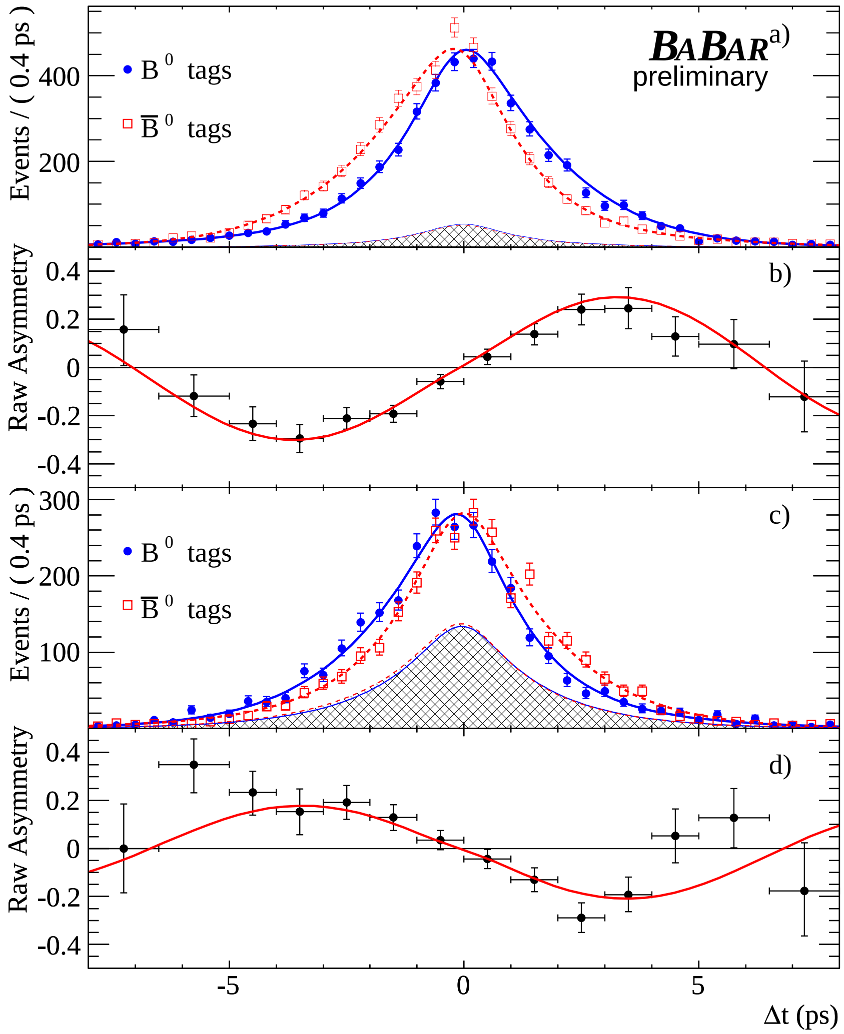

Figure 2: a) Number of $\eta_f = -1$ candidates ($J/\psi K^0_S$, $\psi(2S)K^0_S$, $\chi_{c1}K^0_S$, and $\eta_c K^0_S$) in the signal region with a B^0 tag (N_{B^0}) and with a $\overline{B}^0$ tag ($N_{\overline{B}^0}$), and b) the raw asymmetry, $(N_{B^0} - N_{\overline{B}^0})/(N_{B^0} + N_{\overline{B}^0})$, as functions of Δt; c) and d) are the corresponding distributions for the $\eta_f = +1$ mode $J/\psi K^0_L$. The solid (dashed) curves represent the fit projections in Δt for B^0 ($\overline{B}^0$) tags. The shaded regions represent the estimated background contributions.

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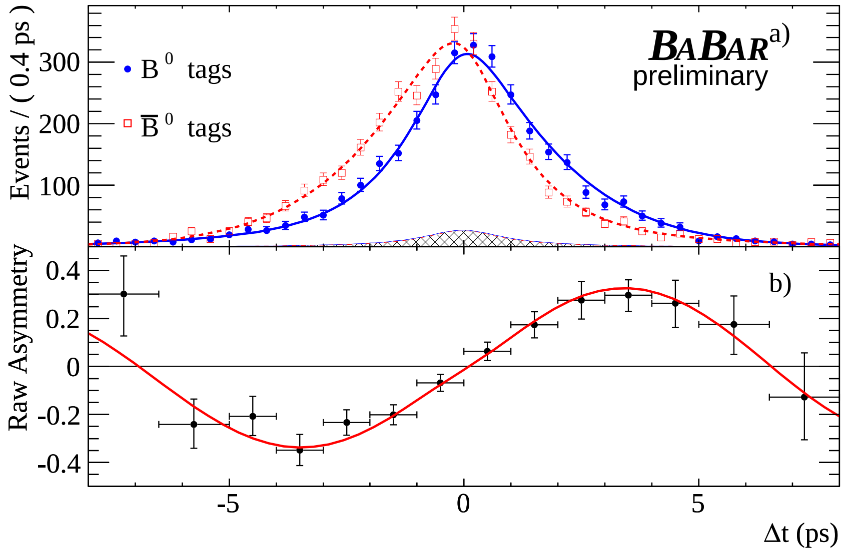

Figure 3: a) Number of $J/\psi\, K_S^0$ candidates in the signal region with a B^0 tag (N_{B^0}) and with a $\overline{B}^0$ tag ($N_{\overline{B}^0}$), and b) the raw asymmetry, $(N_{B^0} - N_{\overline{B}^0})/(N_{B^0} + N_{\overline{B}^0})$, as functions of Δt. The solid (dashed) curves represent the fit projections in Δt for B^0 ($\overline{B}^0$) tags. The shaded regions represent the estimated background contributions.

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