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Measurement of *CP* Asymmetry in $B^0 \to f_0 K^0_S$, $B^0 \to \phi K^0$ and $B^0 \to K^+K^-K^0_S$ Decays

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We present results on time-dependent *CP* asymmetries in $f_0(980)(\to \pi^+\pi^-)K^0_S$ and $B^0 \to K^+K^-K^0$. The measurements use a data sample consisting of approximately $209(f_0(980)(\to \pi^+\pi^-)K^0_S)$ and $227(B^0 \to K^+K^-K^0)$ million B-meson pairs recorded at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the PEP-II B-meson Factory at SLAC. From a time-dependent maximum likelihood fit, we measure for $B^0 \to f_0(980)(\to \pi^+\pi^-)K^0_S$: the mixing-induced *CP* violation parameter $S_{f_0K} = -0.95^{+0.32}_{-0.23}\,(\text{stat}) \pm 0.10(\text{syst})$ and the direct *CP* violation parameter $C_{f_0K} = -0.24 \pm 0.31\,(\text{stat}) \pm 0.15\,(\text{syst})$. From a simultaneous fit to $B^0 \to \phi K^0_S$ and $B^0 \to \phi K^0_L$ decays, we find: $S_{\phi K^0_S} = -S_{\phi K^0_L} = +0.50 \pm 0.25\,(\text{stat})^{+0.07}_{-0.04}(\text{syst})$ and $C_{\phi K} = 0.00 \pm 0.23\,(\text{stat}) \pm 0.05\,(\text{syst})$. For $B^0 \to K^+K^-K^0_S$ decays with $B^0 \to \phi K^0_S$ decays excluded, we find: $S_{KKK(\text{no }\phi K^0_S)} = -0.42 \pm 0.17\,(\text{stat}) \pm 0.04\,(\text{syst})$ and $C_{KKK(\text{no }\phi K^0_S)} = +0.10 \pm 0.14\,(\text{stat}) \pm 0.06\,(\text{syst})$. From the $B^0 \to K^+K^-K^0_S$ decays with $B^0 \to \phi K^0_S$ decays excluded, we extract the fraction of *CP*-even final states from angular moments $f_{even} = 0.89 \pm 0.08 \pm 0.06$.

1. INTRODUCTION

In the Standard Model (SM), *CP* violation arises from a single phase in the three-generation Cabibbo-Kobayashi-Maskawa quark-mixing matrix [1]. Possible indications of physics beyond the SM may be observed in the time-dependent *CP* asymmetries of B decays dominated by penguin-type diagrams to states such as f_0K^0[a], ϕK^0 and $K^+K^-K^0$ [2]. Neglecting CKM-suppressed amplitudes, these decays carry the same weak phase as the decay $B^0 \to J/\psi\, K^0$ [3]. As a consequence, their mixing-induced *CP*-violation parameter is expected to be $-\eta_f \times \sin 2\beta = -\eta_f \times 0.725 \pm 0.037$ [4] in the SM, where η_f is the *CP* eigenvalue of the final state f, which is +1 for $f_0K^0_S$, -1 for ϕK^0_S and +1 for ϕK^0_L. If $K^+K^-K^0_S$ decays proceed through a P(S)-

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[a]Throughout the paper f_0 refer to the $f_0(980)$ and its decay to $\pi^+\pi^-$. In addition, charge conjugate decay modes are assumed unless explicity stated.

wave leading to a *CP*-odd (even) final state, we expect $\eta_f = (-)1$. There is no direct *CP* violation expected in these decays since they are dominated by a single amplitude in the SM. Due to the large virtual mass scales occurring in the penguin loops, additional diagrams with non-SM heavy particles in the loops and new *CP*-violating phases may contribute. Measurements of *CP* violation in these channels and their comparisons with the SM expectation are therefore sensitive probes for physics beyond the SM. The time-dependent *CP* asymmetry is obtained by measuring the proper time difference Δt between a fully reconstructed neutral B meson (B_{CP}) decaying into $f_0 K^0_S$ or $K^+K^-K^0$, and the partially reconstructed recoil B meson ($B_{\rm tag}$). The asymmetry in the decay rate $\mathrm{f}_+(\mathrm{f}_-)$ when the tagging meson is a B^0 ($\overline{B}^0$) is given as

$$\mathrm{f}_\pm(\,\Delta t) = \frac{\mathrm{e}^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\,[\;1 \pm S_f \sin(\Delta m_d \Delta t) \mp C_f \cos(\Delta m_d \Delta t)],$$

where τ_{B^0} is the B^0 lifetime and Δm_d is the B^0–$\overline{B}^0$ mixing frequency. The parameter S is non-zero if there is mixing induced *CP* violation, while a non-zero value for C would indicate direct *CP* violation. We present an update of measurements of the *CP* asymmetry parameters in $f0K^0_S$, in ϕK^0, and in $K^+K^-K^0_S$ decays with ϕK^0_S events removed, with almost twice the statistics of the previous *BABAR* results [5,6,7]. For $K^+K^-K^0_S$ decays with ϕK^0_S decays excluded, we find the fraction of P-wave decays using an angular-moment analysis and cross-check it with an isospin analysis [8]; we then extract the SM parameter $\sin 2\beta$.

2. Analysis Method

This analysis is based on about 209 ($f0K^0_S$) and 227(ϕK^0_S and $K^+K^-K^0_S$) million $B\overline{B}$ pairs collected with the *BABAR* detector [9] at the PEP-II asymmetric-energy e^+e^- storage rings at SLAC, operating on the $\Upsilon(4S)$ resonance. We reconstruct B^0 candidates from combinations of two tracks and either a K^0_S decaying to $\pi^+\pi^-$ or a K^0_L. The K^+K^- candidates are considered a ϕ if they satisfy $1.005 < m(K^+K^-) < 1.035\,\mathrm{GeV}/c^2$. Reconstruction is described in more detail in [10,11,12]. See Table 1 for the signal efficiencies and number of events that pass all selection criteria. The time

Table 1. *CP* asymmetry parameters and yields from final 3 extended maximum likelihood fits, as well as the approximate signal efficiency as determined from simulation, and the number of events entering the fits. ϕK^0_S and ϕK^0_L are fitted simultaneously, and share common absolute values for S and C. The first errors are statistical, and the second are systematic.

	S	C	Yield	$\epsilon(\%)$	Fit Sample Size
$f_0 K^0_S$	$-0.95^{+0.32}_{-0.23} \pm 0.10$	$-0.24 \pm 0.31 \pm 0.15$	152 ± 19	39	12,586
ϕK^0_S	$+0.50 \pm 0.25^{+0.07}_{-0.04}$	$0.00 \pm 0.23 \pm 0.05$	114 ± 12	40	4,300
ϕK^0_L	$-0.50 \pm 0.25^{+0.04}_{-0.07}$		98 ± 18	20	8,238
$K^+K^-K^0_S$(no ϕ)	$-0.42 \pm 0.17 \pm 0.04$	$+0.10 \pm 0.14 \pm 0.06$	452 ± 28	26	27,368

difference Δt is obtained from the measured distance between the z positions (along the beam direction) of the B_{CP} and $B^0_{\rm tag}$ decay vertices, and the boost $\beta\gamma = 0.56$ of the e^+e^- system [2,13]. A multivariate tagging algorithm determines the flavor of the $B^0_{\rm tag}$ [14]. We use unbinned extended maximum likelihoods fit to extract the event yields and the *CP* parameters; this is described in detail in [10,11,12]. The ϕK^0_S and ϕK^0_L events are fitted with a single simultaneous maximum likelihood fit; they share the same absolute value for S and C.

3. Systematics

The following contributes to systematic error: uncertainties in the Δt resolution, the beam spot position, and detector alignment; the effect of doubly CKM-suppressed decays [15]; bias due to the fit procedure;errors for the *CP* content of the background; uncertainties in the PDF parameterization; and the uncertainties on the lifetime and mixing frequency of the B. For the ϕK^0 analysis, the error due to S-wave contamination is estimated to be less than 6.6%. For the KKK^0_S analysis, we estimate the error due to possible intermediate D-wave decays into $K^+\ K^-$ or decays proceeding through an $I = 1$ resonance into $K^\pm K^0_S$ to be 4%. We estimate the uncertainty due to potential contributions from decays proceeding through isovector resonances into $K^+K^0_S$ to be 4.6%. Systematic errors are described in more detail in [10,11,12].

4. Results

Table 1 shows results of the extended maximum likelihood fits. All yields are consistent with the previously measured branching fractions [5,16,7]. The time-dependent asymmetry distributions are presented in Fig. 1.

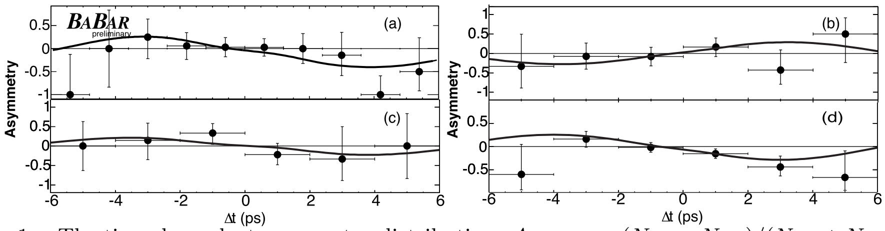

Fig. 1. The time-dependent asymmetry distributions $A_{B^0/\overline{B}^0} = (N_{B^0} - N_{\overline{B}^0})/(N_{B^0} + N_{\overline{B}^0})$ for $f_0K^0_S$ (a), ϕK^0_S (b), ϕK^0_L(c) and $K^+K^-K^0_S$ with no ϕK^0_S decays (d). The signal-to-background ratio is enhanced with a cut on the signal probability.

The fraction of P-wave decays of $K^+K^-K^0_S$ is extracted using an angular moment analysis [17] which examines the distribution of the cosine of the helicity angle θ_H between the K^+ and B^0 directions in the K^+K^- center of mass frame. We use a comparison of event rates of two isospin-equivalent channels [8]: $B^+ \to K^+K^0_SK^0_S$ and $B^0 \to K^+K^-K^0_S$ to verify this measurement [12]. More information on the moment analysis may be found in [12]. Using this estimate and setting $C = 0$ in the fit, we find a value for $\sin 2\beta$:

$$f_{even} = 0.89 \pm 0.08 \pm 0.06, \qquad (1)$$

$$(\sin 2\beta)_{KKK(\text{no }\phi)} = S_{KKK(\text{no }\phi)}/(1-2f_{even}) = 0.55 \pm 0.22 \pm 0.04 \pm 0.11, \quad (2)$$

where the first errors are statistical, the second systematic, and the last error on $(\sin 2\beta)_{KKK(\text{no }\phi)}$ is due to uncertainty on the *CP* content.

5. Summary

In a sample of $209(f_0 K^0_S)$ and $227(K^+K^-K^0)$ million $B\overline{B}$ mesons, we have obtained measurements of the *CP* content and *CP* parameters in decays to $f_0 K^0_S$, to ϕK^0 and to $K^+K^-K^0_S$ excluding ϕK^0_S decays. All of our results for S and C are consistent with the Standard Model, and are in agreement with our previously published values [5,6,7]; we see no evidence for mixing-induced *CP* violation. For $K^+K^-K^0_S$, from the distribution of the helicity angle in the K^+K^- frame, we extract the fraction of P-wave decays. The result is consistent with our cross-check and previous measurements based on isospin symmetry [7,18], and confirms the dominance of *CP*-even final states.The obtained value for $(\sin 2\beta)_{KKK(\text{no }\phi)}$ is consistent with the SM expectation and previous measurements [7,18].

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