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Measurement of CP Asymmetry in B0 ---> F0 K0(S), B0 ---> Phi K0 And B0 ---> K+ K- K0(S) Decays

by P. E. Kutter

on behalf of the BaBar Collaboration

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Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

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MEASUREMENT OF CP ASYMMETRY IN $B^0 \rightarrow f_0 K_s^0$, $B^0 \rightarrow \phi K^0$ AND $B^0 \rightarrow K^+K^-K_s^0$ DECAYS

PAUL E. KUTTER[*]

The Department of Physics, University of Wisconsin at Madison, Madison, Wisconsin 53706-1390 USA[†]

We present results on time-dependent CP asymmetries in $f_0(980)(\rightarrow \pi^+\pi^-)K_S^0$ and $B^0 \rightarrow K^+K^-K^0$. The measurements use a data sample consisting of approximately $209(f_0(980)(\rightarrow \pi^+\pi^-)K_S^0)$ and $227(B^0 \rightarrow K^+K^-K^0)$ 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 $B^0 \rightarrow f_0(980)(\rightarrow \pi^+\pi^-)K_s^0$: the mixing-induced CP violation parameter $S_{f_0K} = -0.95^{+0.32}_{-0.23}$ (stat) $\pm$ 0.10(syst) and the direct CP violation parameter $C_{f_0K} = -0.24 \pm 0.31$ (stat) $\pm$ 0.15 (syst). From a simultaneous fit to $B^0 \rightarrow \phi K_S^0$ and $B^0 \rightarrow \phi K_L^0$ decays, we find: $S_{\phi K_S^0} = -S_{\phi K_L^0} = +0.50 \pm 0.25$ (stat)$^{+0.07}_{-0.04}$(syst) and $C_{\phi K} = 0.00 \pm 0.23$ (stat) $\pm$ 0.05 (syst). For $B^0 \rightarrow K^+K^-K_S^0$ decays with $B^0 \rightarrow \phi K_S^0$ decays excluded, we find: $S_{KKK(\text{no } \phi K_S^0)} = -0.42 \pm 0.17$ (stat) $\pm$ 0.04 (syst) and $C_{KKK(\text{no } \phi K_S^0)} = +0.10 \pm 0.14$ (stat) $\pm$ 0.06 (syst). From the $B^0 \rightarrow K^+K^-K_S^0$ decays with $B^0 \rightarrow \phi K_S^0$ 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 $B^0 \rightarrow J/\psi K^0$ [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 $f_0K_s^0$, -1 for ϕK_S^0 and $+1$ for ϕK_L^0. If $K^+K^-K_S^0$ decays proceed through a P(S)-

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* On behalf of the BaBar Collaboration

† Department of Physics, 1150 University Ave., Madison, WI 53706, USA

[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 $f_0 K_s^0$ or $K^+K^-K^0$, and the partially reconstructed recoil B meson (B_{tag}). The asymmetry in the decay rate f_+ (f_-) when the tagging meson is a B^0 ($\bar{B}^0$) is given **as**

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

where τ_{B^0} is the B^0 lifetime and Δm_d is the B^0–$\bar{B}^0$ 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 $f0K_s^0$, in ϕK^0, and in $K^+K^-K_s^0$ decays with ϕK_s^0 events removed, with almost twice the statistics of the previous *BABAR* results [5,6,7]. For $K^+K^-K_s^0$ decays with ϕK_s^0 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 ($f0K_s^0$) and 227(ϕK_s^0 and $K^+K^-K_s^0$) million $B\bar{B}$ pairs collected with the *BABAR* detector [9] at the PEP-I1 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_s^0 decaying to $\pi^+\pi^-$ or a K_L^0. The K^+K^- candidates are considered a ϕ if they satisfy $1.005 < m(K^+K^-) < 1.035 \text{GeV}/c^2$. 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 difference Δt is obtained from the measured distance between the z positions (along

Table 1. CP asymmetry parameters and yields from find **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_S^0 and ϕK_L^0 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
$f_0K_S^0$	$-0.95^{+0.32}_{-0.23} \pm 0.10$	$-0.24 \pm 0.31 \pm 0.15$	152 ± 19	**39**	12,586
ϕK_S^0	$+0.50 \pm 0.25^{+0.07}_{-0.04}$	$0.00 \pm 0.23 \pm 0.05$	114 ± 12	40	4,300
ϕK_L^0	$-0.50 \pm 0.25^{+0.04}_{-0.07}$		98 ± 18	20	**8,238**
$K^+K^-K_S^0$(no ϕ)	$-0.42 \pm 0.17 \pm 0.04$	$+0.10 \pm 0.14 \pm 0.06$	452 ± 28	26	27.368

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 At 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.

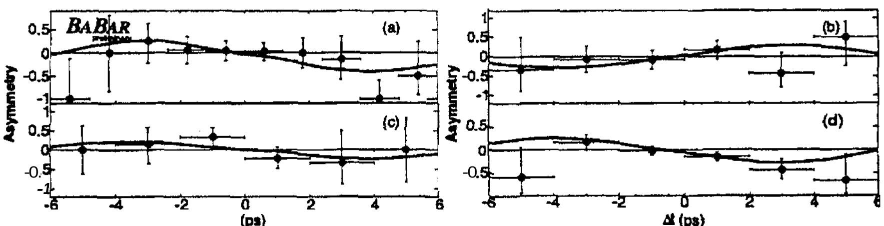

Fig. 1. The time-dependent asymmetry distributions $A_{B^0/\bar{B}^0} = (N_{B^0} - N_{\bar{B}^0})/(N_{B^0} + N_{\bar{B}^0})$ for $f_0K^0_S$ (a), ϕK^0_S (b), ϕK^0_L(c) and $K^+K^-K^0_S$ with no ϕK^0_S decays (d). The signal-to-background ratio is enhanced with a cut on the signal probability.

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 $\sin 2\beta$:

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

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

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 $209(f_0K^0_s)$ 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 $f_0K^0_s$, 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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