

BaBar: $\sin(2\beta)$ with charmless and radiative decays

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We present new measurements of time-dependent CP -violation parameters in hadronic penguin decays: $B^0 \rightarrow K^+K^-K_L^0$, $K_S^0\pi^0\pi^0$, $K_S^0K_S^0K_S^0$, ωK_S^0 , $\eta'K_L^0$, and a radiative penguin decay $B^0 \rightarrow K_S^0\pi^0\gamma$ in a dataset of around $230 \cdot 10^6$ $B\bar{B}$ pairs collected by the *BABAR* detector at the asymmetric B Factory at SLAC. These CP asymmetry measurements probe for amplitudes beyond the Standard Model in loop-dominated decays of neutral B mesons. While we find a puzzling deviation of CP -asymmetry parameters from predicted values, a full confirmation still awaits more data.

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1. Introduction

In the standard model (SM), charged-current transitions among quarks are characterized by CKM [1] couplings that can have CP -violating phases and lead to large CP -asymmetry in B meson decays. The time-dependent CP -asymmetry is obtained by measuring the proper time difference Δt between a fully reconstructed neutral B meson and a partially reconstructed tagging B meson whose decay products are analyzed to determine its flavor. The decay rate f_{\pm} (f_{-}) when the flavor of the tagging meson is a B^0 (\bar{B}^0) is given by

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [1 \pm S \cdot \sin(\Delta m_d \Delta t) \mp C \cdot \cos(\Delta m_d \Delta t)], \quad (1.1)$$

where τ_{B^0} is the mean B^0 lifetime and Δm_d is the B^0 - \bar{B}^0 oscillation frequency [2], and S and C are CP -violation coefficients.

Decays of B mesons into charmless hadronic final states with the total strangeness of one are dominated by penguin-loop amplitudes. In the penguin decays to hadronic final states, we expect $S \approx -\eta_f \sin 2\beta$ and $C \approx 0$, where β is the B^0 - \bar{B}^0 mixing phase, and η_f is CP eigenvalue of the final state. Recently, there has been a progress in understanding hadronic uncertainties that can lead to deviations from these predictions. Studies based on the QCD factorization (QCDF) predict deviations of several percent that depend on the decay channel [3]. Another set of estimates based on the SU(3) symmetry of the quark flavor provides upper bounds on the absolute values of the deviations [4] which are consistent but less constraining than the QCDF calculations.

In the radiative decay $B^0(\bar{B}^0) \rightarrow K_s^0 \pi^0 \gamma$ the photon polarization is predominantly right (left) handed while decays to left (right) handed photons are suppressed by $2m_s/m_b$, where m_s , m_b are masses of s and b quarks, respectively. Interference between decay amplitudes is suppressed by the same factor and we expect to measure $S \approx -2m_s/m_b \sin 2\beta$ and $C \approx 0$. These predictions can be affected by hadronization uncertainties of order 0.1 [5].

Many models beyond the SM introduce new particles with CP -violating couplings that can appear in penguin decays and modify CP -violation observables. Therefore, any significant deviation in S and C from SM predictions beyond possible hadronization corrections would indicate new phenomena.

2. Summary of Results

The time-dependent CP -violation parameters are measured in a dataset of around $230 \cdot 10^6$ $B\bar{B}$ pairs collected by the BABAR detector [6] at the asymmetric B Factory at SLAC.

The CP eigenvalue of the final state is well defined when all final-state particles are also CP eigenstates [7]. However, the final state in $B^0 \rightarrow K^+ K^- K_L^0$ decays is a mixture of CP -even and -odd eigenstates. Assuming that K_L^0 is a pure CP eigenstate, the CP eigenvalue of the 3-body final state is given by the angular momentum between $K^+ K^-$ pair. Existence of non- CP final states can additionally complicate the measurement, but this has been disfavored by theory [8] and recent searches [9, 10]. We use results of angular-moment analysis that extracted fractions of S and P partial waves in $K^+ K^-$ mass bins from $B^0 \rightarrow K^+ K^- K_s^0$ decays [10] and scale them to the observed yield in $B^0 \rightarrow K^+ K^- K_L^0$ decays. When ϕK_L^0 decays are excluded, we find a dominance

Table 1: Summary of new measurements of CP asymmetry parameters in hadronic B meson decays that are dominated by penguin diagrams at $BABAR$. Results combined with decay modes that have K_S^0 instead of K_L^0 in the final state are shown in parentheses.

Mode		$\sin 2\beta$	C
$K^+K^-K_L^0$	[12]	$0.09 \pm 0.33^{+0.13}_{-0.14} \pm 0.10$	$0.54 \pm 0.22^{+0.08}_{-0.09}$
		$(0.41 \pm 0.18 \pm 0.07 \pm 0.11)$	$0.23 \pm 0.12 \pm 0.07$
$K_S^0K_S^0K_S^0$	[14]	$0.63^{+0.28}_{-0.32} \pm 0.04$	$-0.10 \pm 0.25 \pm 0.05$
$K_S^0\pi^0\pi^0$	[16]	$-0.84 \pm 0.71 \pm 0.08$	$0.27 \pm 0.52 \pm 0.13$
$\eta'K_L^0$	[17]	$0.60 \pm 0.31 \pm 0.04$	$0.10 \pm 0.21 \pm 0.03$
		$(0.36 \pm 0.13 \pm 0.03)$	$(-0.16 \pm 0.09 \pm 0.02)$
ωK_S^0	[18]	$0.50^{+0.34}_{-0.38} \pm 0.02$	$-0.56^{+0.29}_{-0.27} \pm 0.03$

Table 2: Summary of new measurements of CP asymmetry parameters in radiative B meson decays that are dominated by penguin diagrams at $BABAR$. † $K^{*0} \rightarrow K_S^0\pi^0$. ‡ $1.1 < M(K_S^0\pi^0) < 1.8 \text{ GeV}/c^2$.

Mode		S	C
$K^{*0}\gamma$ †	[19]	$-0.21 \pm 0.40 \pm 0.05$	$-0.40 \pm 0.23 \pm 0.03$
$K_S^0\pi^0\gamma$ ‡	[19]	$0.9 \pm 1.0 \pm 0.2$	$-1.0 \pm 0.5 \pm 0.2$

of S -waves and CP -odd final states with a fraction of $f_{CP\text{-odd}} = 0.92 \pm 0.07 \pm 0.06$. This result is consistent with an analysis using isospin symmetry [11] and a time-integrated Dalitz plot analysis of $B^0 \rightarrow K^+K^-K_S^0$ decays which describes the decay rate over the Dalitz plot as a function of two invariant masses and the flavor tag and assumes nonexistence of direct CP violation in decay amplitudes [15].

The decay $B^0 \rightarrow K^+K^-K_L^0$ is reconstructed from combination of charged kaons and K_L^0 candidates and we find 777 ± 80 signal events. The final state $\eta'K_L^0$ is reconstructed from $K_S^0 \rightarrow \pi^+\pi^-$ and $\eta' \rightarrow \rho\gamma$, $\eta(\gamma\gamma)\pi^+\pi^-$ candidates and we get 137 ± 22 and 303 ± 49 signal events, respectively. In both $B^0 \rightarrow K^+K^-K_L^0$ and $K_L^0\eta'$, the K_L^0 is identified by the shape of the energy cluster deposited in the electromagnetic calorimeter, or as a set of hits in two or more layers of the muon detector that cannot be associated with any charged track in the event. Since the K_L^0 energy is not measured, it is calculated from a constraint that the momentum sum of all decay products equal the B^0 meson mass.

The final state for decay $B^0 \rightarrow K_S^0K_S^0K_S^0$ is reconstructed from combination of three K_S^0 candidates. When all K_S^0 's decay to a $\pi^+\pi^-$ pair we find 88 ± 10 signal events, and if we allow at most one K_S^0 to decay to $\pi^0\pi^0$ we find additional $41.0^{+9.2}_{-8.3}$ signal events. The final state $K_S^0\pi^0\pi^0$ is reconstructed from $K_S^0 \rightarrow \pi^+\pi^-$ and $\pi^0 \rightarrow \gamma\gamma$ candidates, and we find 117 ± 27 signal events. We reconstruct $B^0 \rightarrow K_S^0\pi^0\gamma$ decays from $K_S^0 \rightarrow \pi^+\pi^-$ and $\pi^0 \rightarrow \gamma\gamma$ and find 157 ± 16 signal events consistent with $K^{*0} \rightarrow K_S^0\pi^0$ and 59 ± 13 signal events when $1.1 < M(K_S^0\pi^0) < 1.8 \text{ GeV}/c^2$. Since there are no charged tracks coming from the neutral B vertex, the decay point for $B^0 \rightarrow K_S^0K_S^0K_S^0$, $B^0 \rightarrow K_S^0\pi^0\pi^0$ and $B^0 \rightarrow K_S^0\pi^0\gamma$ is found by constraining momenta of the decay products to originate from the interaction point [13].

The final state $K_S^0 \omega$ is reconstructed from $K_S^0 \rightarrow \pi^+ \pi^-$ and $\omega \rightarrow \pi^+ \pi^- \pi^0$ candidates, and we find a total of 92 ± 13 signal events.

New results of CP asymmetry measurements from *BABAR* are given in Table 1 for hadronic and Table 2 for radiative decays. The $\sin 2\beta$ parameter in Table 1 is extracted from S coefficient after taking into account the CP content of the final state.

3. Conclusion

Measurements of CP asymmetry in penguin-dominated decays probe for possible CP -violating phases in addition to SM phase β . New *BABAR* measurements are listed in Tables 1,2 while a summary of all existing measurements is given in [2]. There is a hint that the value of the $\sin 2\beta$ parameter extracted from penguin decays can be smaller than predicted by the SM, but a confirmation awaits more data. Future prospects for such measurements at the *BABAR* depend on the available luminosity and the character of new physics amplitudes.

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