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Measurements of Time-Dependent *CP* Asymmetries in $b \to s$ Penguin Dominated Hadronic *B* Decays at BABAR

Pietro Biassoni
(On behalf of the BABAR Collaboration)

Università degli Studi and INFN Milano, via Celoria 16, I-20133 Milano, Italy

Abstract. We report measurements of Time-Dependent *CP* asymmetries in several $b \to s$ penguin dominated hadronic *B* decays, where New Physics contributions may appear. We find no significant discrepancies with respect to the Standard Model expectations.

Keywords: Charmless Hadronic *B* decays, Time-Dependent *CP* Violation, sin2β Measurement.
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INTRODUCTION

The measurement of *CP* violation in *B* meson decays provides crucial tests of the Standard Model (SM) and of the Cabibbo-Kobayashi-Maskawa (CKM) mechanism [1].

CKM-suppressed $b \to q\bar{q}\, s$ ($q = u, d, s$) processes are dominated by a single loop (penguin) amplitude, that, assuming penguin dominance and neglecting higher order contributions, is expected to have the same phase β of the CKM-favored $b \to c\bar{c}s$ transition [2]. In many extensions of the SM new heavy particles may appear in the loop [3], giving rise to deviations from this expectation. These deviations are expected to be channel dependent. The measurement of the phase difference between $B^0 \to K^*(892)^+\pi^-$ and $\overline{B}^0 \to K^*(892)^-\pi^+$ can be used to constrain the CKM parameters in the $(\bar{\rho}, \bar{\eta})$ plane [4].

TIME-DEPENDENT DECAY RATES

The CKM phase β is accessible experimentally through the interference between the decay of mixed and unmixed *B* meson into a *CP* eigenstate. This interference is observable through the time evolution of the decay.

In the studies reported in this presentation, one B^0 from $\Upsilon(4S) \to B^0\overline{B}^0$ is reconstructed in $\eta' K^0_S$, $\eta' K^0_L$, ωK^0_S, or $K^0_S K^0_S K^0_S$ *CP* eigenstate, or in $\pi^+\pi^- K^0_S$ or $K^+K^- K^0_S$ non-*CP* eigenstate final state (B_{sig}), and its vertex fitted using all charged daughter tracks. In K^0_S K^0_S K^0_S mode, where no charged track is present at B^0 meson decay vertex, B_{sig} vertex is identified using the K^0_S reconstructed flight directions and the knowledge of the average interaction point [5]. From the remaining particles in the event we reconstruct the decay vertex of the other *B* meson ($B_{\rm tag}$) and identify its flavor, through the analysis of the decay product of $B_{\rm tag}$ [6].

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The distribution of the difference $\Delta t \equiv t_{CP} - t_{\rm tag}$ of the proper decay times of B mesons into CP-eigenstate final states is given by

$$f(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\{1 \pm \left[-\eta_f S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t)\right]\} \quad (1)$$

where η_f is the CP eigenvalue of the final state f and τ is the B^0 meson lifetime. The upper (lower) sign denotes a decay accompanied by a $B^0(\overline{B}^0)$ tag, and Δm_d is the mixing frequency.

For three body non-CP-eigenstate final state, the CP-violating parameters are a function of the position over the Dalitz Plot (DP). In this case Eq. (1) is written as

$$f(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left\{|A|^2 + |\overline{A}|^2 \pm \left[\eta_f 2Im[\overline{A}A^*]\sin(\Delta m_d \Delta t) - (|A|^2 - |\overline{A}|^2)\cos(\Delta m_d \Delta t)\right]\right\}. \quad (2)$$

Let the decay $B^0 \to X_1 X_2 X_3$ proceed through N intermediate states: the amplitude A depends only on the Mandelstam invariants s_{12} and s_{23}, and in the isobar approximation is

$$A(s_{12}, s_{23}) = \sum_{j=1}^{N} |c_j| e^{-i\phi_j} R_j(m_j) X_L(|\vec{p}*|r') X_L(|\vec{q}|r) T_j(L, \vec{p}, \vec{q}) \quad (3)$$

where c_j and ϕ_j are the relative magnitude and phase of the decay mode j, $R_j(m)$ is the lineshape term, X_L are Blatt-Weisskopf barrier factors [7], T_j is the angular distribution, $\vec{p}$ ($\vec{q}$) is the momentum of the prompt particle (one of the resonance daughters), L is the orbital angular momentum between $\vec{p}$ and the resonance momentum, and asterisk denotes B rest frame. For a decay into a quasi-two-body CP eigenstate, one can extract the parameters $\beta_{eff} = \frac{1}{2}\arg(c_k \bar{c}_k^*)$ and $\mathscr{A}_{ch}(k) = [|\bar{c}_k|^2 - |c_k|^2]/[|\bar{c}_k|^2 + |c_k|^2]$. For a decay into quasi-two-body non-CP eigenstate, we measure the charge asymmetry and the phase between the two conjugate states $\Delta\Phi(k) = \arg(c_k \bar{c}_k^*)$.

A nonzero value of the parameter C_f or $\mathscr{A}_{ch}$ would indicate direct CP violation. In these modes we expect $-\eta_f S_f \equiv -\eta_f \sin 2\beta_{eff} \approx \sin 2\beta$. Deviations $\Delta S_f = S_f - \sin 2\beta$ from this expectation may appear even within the SM [8, 9], and are estimated in several theoretical approaches [8, 10].

ANALYSIS TECHNIQUE

Analyses presented here are based on a sample of 465×10^6 $B\overline{B}$ pairs (383×10^6 for $B^0 \to K_S^0 \pi^+ \pi^-$), collected at a center-of-mass energy equal to the mass of the $\Upsilon(4S)$ resonance at the PEP-II asymmetric e^+e^- collider, at the SLAC National Accelerator Laboratory, and recorded by the *BABAR* detector [11]. The B meson is reconstructed into the above-mentioned CP eigenstates. The B meson is kinematically characterized by the variables $\Delta E \equiv E_B - \frac{1}{2}\sqrt{s}$ and $m_{\rm ES} \equiv \sqrt{s/4 - |\vec{p}_B|^2}$, where $(E_B, \vec{p}_B)$ is the B four-momentum vector expressed in $\Upsilon(4S)$ rest frame.

Background arises primarily from random combinations of particles in $e^+e^-\to q\bar{q}$ events ($q = u,d,s,c$). We suppress this background with requirements on the event shape variables and on the energy, invariant mass and particle identification signature of the decay products. All events are required to have $|\Delta t| < 20$ ps and $\sigma_{\Delta t} < 2.5$ ps.

For each mode, results are obtained from an extended maximum likelihood fit with input variables ΔE, $m_{\rm ES}$, Δt, and the output of a multivariate discriminant combining different event shape variables. In ωK^0_S decay we also use ω mass and angular variables into the fit. K^0_L momentum is determined using a B mass constraint, hence $m_{\rm ES}$ is fully correlated to ΔE, and is not used into the fit in $\eta' K^0_L$ modes. The likelihood for a given event is the sum of the signal, continuum and the B-background components, weighted by their respective event yields. In $K^0_S\pi^+\pi^-$ and $K^0_S K^+K^-$ modes, a time-dependent DP analysis is performed. The DP model includes $f_0(980)$, $\rho^0(770)$, $K^{*\pm}(892)$, $(K\pi)^{*\pm}_0$, $f_2(1240)$, $f_x(1300)$, χ_{c0} ($f_0(980)$, $\phi(1020)$, $X(1550)$, $f_2(1270)$, χ_{c0}, $D^\pm$, $D^\pm_s$) and non resonant component for $K^0_S\pi^+\pi^-$ ($K^0_S K^+K^-$) decay mode. In $K^0_S K^+K^-$ analysis, the fit is first performed on the whole DP, and then in the low (high) mass region $m_{K^+K^-} < 1.1$ GeV$/c^2$ ($m_{K^+K^-} > 1.1$ GeV$/c^2$), fixing all the parameters to the values found in the whole DP fit, except the ones involving the $f_0(980)$ ($\phi(1020)$) resonance.

RESULTS

In Table 1 and 2 we report the results for *CP*-violating parameters in analyses of the decay of a B^0 meson into a *CP* eigenstates and a three body non-*CP* eigenstates final state (DP analyses), respectively [12]. Results for $K^0_S K^+K^-$ and K^0_S K^0_S K^0_S are preliminary.

TABLE 1. Results of analyses of $b\to s$ decays into *CP* eigenstates. For each decay mode we report $-\eta_f S_f$ and C_f. The first error is statistical, the second systematic.

Decay Mode	$-\eta_f S_f$	C_f
$\eta' K^0$	$0.57 \pm 0.08 \pm 0.02$	$-0.08 \pm 0.06 \pm 0.02$
ωK^0_S	$0.55^{+0.26}_{-0.29} \pm 0.02$	$-0.52^{+0.22}_{-0.20} \pm 0.03$
$K^0_S K^0_S K^0_S$	$0.90^{+0.20}_{-0.18}{}^{+0.04}_{-0.03}$	$-0.16 \pm 0.17 \pm 0.03$

In K^0_S $\pi^+\pi^-$and $K^0_S K^+K^-$ low mass region, the likelihood function has two minima. In $B^0\to f_0(980)K^0_S$ with $f_0(980)\to K^+K^-$, the second solution is disfavored by the result from $f_0(980)\to\pi^+\pi^-$. In K^0_S $\pi^+\pi^-$ analysis we measure $\mathscr{A}_{ch}(K^*(892)^+\pi^-) = 0.20 \pm 0.10 \pm 0.02$, where the first (second) error is statistical (systematic). We also exclude $-137^\circ < \Delta\Phi(K^*(892)^+\pi^-) < -5^\circ$ at 95% confidence level.

CONCLUSIONS

We have reported the results of measurements of *CP*-violating parameters in several $b\to s$ hadronic B meson decays. All the results are consistent with the SM. Results are in agreement with and supersede previous *BABAR* measurements.

TABLE 2. Results of DP $b \rightarrow s$ analyses. For each decay mode we report β_{eff}, and $\mathscr{A}_{ch}$, for both solutions. The first error is statistical, the second systematic.

Decay Mode	Solution I		Solution II	
	β_{eff} (°)	$\mathscr{A}_{ch}$	β_{eff} (°)	$\mathscr{A}_{ch}$
$K^0_S\,\pi^+\pi^-$				
$f_0(980)K^0_S$	$36.0 \pm 9.8 \pm 3.0$	$-0.08 \pm 0.19 \pm 0.05$	$56.2 \pm 10.4 \pm 3.0$	$-0.23 \pm 0.19 \pm 0.05$
$\rho^0(770)K^0_S$	$10.2 \pm 8.9 \pm 3.6$	$0.05 \pm 0.26 \pm 0.10$	$33.4 \pm 10.4 \pm 3.6$	$0.14 \pm 0.26 \pm 0.10$
$K^0_S K^+K^-$				
Whole DP	$25.2 \pm 4.0 \pm 1.1$	$0.03 \pm 0.07 \pm 0.02$	–	–
High Mass	$29.8 \pm 4.6 \pm 1.7$	$0.05 \pm 0.09 \pm 0.04$	–	–
ϕK^0_S	$7.4 \pm 7.4 \pm 1.1$	$0.14 \pm 0.19 \pm 0.02$	$8.0 \pm 8.0 \pm 1.1$	$0.13 \pm 0.18 \pm 0.02$
$f_0(980)K^0_S$	$8.6 \pm 7.4 \pm 1.7$	$0.01 \pm 0.26 \pm 0.07$	$197.1 \pm 10.9 \pm 1.7$	$-0.49 \pm 0.25 \pm 0.07$

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