CP violation in $b \rightarrow c\bar{c}d$ decays at Belle

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Abstract

We report a measurement of the CP violation parameters in $b \rightarrow c\bar{c}d$ decays. Mixing-induced CP violation involving this transition is studied using a sample of $B^0 \rightarrow J/\psi\pi^0, D^{*+}D^{*-}$ and $D^{*\pm}D^{\mp}$ decays with a data set accumulated at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB energy-asymmetric $e^+e^-$ collider. CP violation parameters are extracted from a fit to the distributions of time intervals between two $B^0$ meson decay vertexes.

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INTRODUCTION

In the Standard Model (SM), $CP$ violation arises from the Kobayashi-Maskawa (KM) phase in the weak interaction quark-mixing matrix. The SM predicts $CP$ asymmetries in the time-dependent rates for $B^0$ and $\bar{B}^0$ decays to a common $CP$ eigenstate $f_{CP}$. Recent measurements of the $CP$ violation parameter $\sin 2\phi_1$ by Belle[1] and BaBar[2] collaborations established $CP$ violation in $B^0 \to J/\psi K_S$ and related decay modes at a level consistent with KM expectations. Comparisons between SM expectations and measurements in various modes are important to test the KM model. In particular, the $CP$ violation in the decays, dominated by the tree $b \to c\bar{c}d$ transition, is sensitive to the same angle $\phi_1$ as in the $b \to c\bar{c}s$. If other contributions to the same final state are substantial, a precision measurement of the time-dependent $CP$ asymmetry in $b \to c\bar{c}d$ may reveal a phase that differs from $\phi_1$. One of the contribution leading to a different weak phase, is a penguin diagram, which is expected to be small in the SM. Thus, the measurements of $CP$ asymmetries in $b \to c\bar{c}d$ transitions play an important role to probe the SM.

The analyses described here are based on 140 fb$^{-1}$ of data, corresponding to 152 million $BB$ pairs, collected with the Belle detector at the KEKB asymmetric energy storage rings.

STUDY OF THE $B^0 \to J/\psi\pi^0$

The details of the analysis are described in Ref.[4]. $B$ meson candidates are identified using the beam constrained mass $M_{bc} \equiv \sqrt{E_{beam}^2 - P_B^2}$ and the energy difference $\Delta E \equiv E_B - E_{beam}$, where $E_B(P_B)$ is the energy(momentum) of the $B$ candidate and $E_{beam}$ is the center-of-mass (CM) beam energy. For extracting the $CP$ asymmetry, the standard Belle tagging and vertexing procedures[1] are used. After flavor tagging and vertex reconstruction, 91 $B^0 \to J/\psi\pi^0$ candidates with $(84 \pm 11)\%$ purity are selected. $\Delta E$ and $M_{bc}$ distributions for the candidate events are shown in Fig. 1.

In the decay chain $\Upsilon(4S) \to B^0\bar{B}^0 \to f_{CP}f_{tag}$, where one of the $B$ meson decays at time $t_{CP}$ to a final state $f_{CP}$ and the other decays at time $t_{tag}$ to a final state $f_{tag}$ that distinguishes between $B^0$ and $\bar{B}^0$, the decay rate has a time dependence given by[3]

$$P(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 + q[S_{fCP} \sin(\Delta m_d\Delta t) + C_{fCP} \cos(\Delta m_d\Delta t)]\}, \quad (1)$$

where $\tau_{B^0}$ is the $B^0$ lifetime, $\Delta m_d$ is the mass difference between the two $B^0$ mass eigenstates,
FIG. 1: $\Delta E$ and $M_{bc}$ distributions for $B^0 \to J/\psi \pi^0$ candidates. The superimposed curves show fitted contribution from signal (dot-dashed line), $B \to J/\psi X$ background (dotted line), combinatorial background (dashed line) and the sum of all the contributions (solid line).

$\Delta t \equiv t_{CP} - t_{tag}$, and the $b$-flavor $q = +1(-1)$ when the tagging $B$ meson is a $B^0(\bar{B}^0)$. In $b \to c\bar{c}d$ transition the SM predicts $S_{f_{CP}} = -\xi_f \sin 2\phi_1$ and $C_{f_{CP}} = 0$, where $\xi_f = +1(-1)$ corresponds to $CP$-even (-odd) final state ($\xi_f = +1$ in case of $J/\psi \pi^0$).

We determine $S_{f_{CP}}$ and $C_{f_{CP}}$ by performing an unbinned maximum-likelihood fit to the observed $\Delta t$ distribution. The probability density function expected for the signal distribution is given by Eq. 1 taking into account the effect of incorrect flavor assignment and the finite vertex resolution. The fit yields $CP$ violating parameters presented in Table I. Fig. 2 shows $\Delta t$ distributions for $B \to J/\psi \pi^0$ decays tagged as $B^0$ and $\bar{B}^0$ and $CP$ violation asymmetry.

STUDY OF THE $B^0 \to D^{*+}D^{*-}$

$B^0 \to D^{*+}D^{*-}$ meson candidates are identified using $\Delta E$ and $M_{bc}$ variables. These distributions for the selected events are shown in Fig. 3. The fit yields $130 \pm 13$ signal events and the branching fraction is calculated to be $[0.81 \pm 0.08(stat) \pm 0.11(syst)] \times 10^{-3}$.

In the $B^0 \to D^{*+}D^{*-}$ decay, the final state consists of S, P and D waves, corresponding to different $CP$ eigenvalues, thus the $CP$ violation parameters are diluted. Corresponding fractions of these final states $R_0$, $R_\parallel$ ($CP$-even) and $R_\perp$ ($CP$-odd) are extracted from the transversity basis\cite{5} angular analysis using $\cos \theta_1$ and $\cos \theta_{tr}$ distributions (Fig. 4). The fit
FIG. 2: The $\Delta t$ distributions for a) $B^0 \to J/\psi \pi^0$ ($q = +1$) and b) $B^0 \to J/\psi \pi^0$ ($q = -1$) and the raw asymmetry c) for the good tag region. The curves show the result of the fit, and dashed curves show the background distributions.

yields $R_\perp = 0.19 \pm 0.08$(stat) $\pm 0.01$(syst) and $R_\parallel = 0.57 \pm 0.08$(stat) $\pm 0.02$(syst).

We perform a simultaneous unbinned maximum likelihood fit to the $\Delta t$, $\cos \theta_{tr}$ and $\cos \theta_1$ distributions for $B^0 \to D^{*\pm}D^{*-}$ candidates to measure $CP$ violation parameters. The signal $B^0$ decay vertex is reconstructed by fitting $D$ mesons momentum vectors with the constraint of the interaction region profile. The tagging probability and the $B$ vertices determination are identical to our others $CP$ violation analysis[1]. The fit results are presented in Table I. Fig. 5 shows the $\Delta t$ distributions for $B^0 \to D^{*\pm}D^{*\mp}$ candidates and $CP$ violation asymmetry.

**STUDY OF THE $B^0 \to D^{*\pm}D^{\mp}$**

Although the $D^{*\pm}D^{\mp}$ final states are not $CP$ eigenstates, they can be produced in the decays of both $B^0$ and $\bar{B}^0$ with comparable amplitudes; the interference between amplitudes
FIG. 3: a) $\Delta E$ and b) $M_{bc}$ distributions for $B^0 \rightarrow J/\psi \pi^0$ candidates. Solid curves show the fit to signal plus background distributions, and dashed curves show the background contributions.

FIG. 4: The angular distributions of $B^0 \rightarrow D^{*+}D^{-}$ candidates projected onto (left) $\cos \theta_{tr}$ and (right) $\cos \theta_1$. The solid curves show the background, the dashed-dotted lines show $R_0$ polarization, the dotted lines show $R_\parallel$, the dashed lines show $R_\perp$ polarization.

of the direct transition and those via $B\bar{B}$ mixing results in $CP$ violation[6]. The probability for a $B$ meson to decay to $D^{*\pm}D^{\mp}$ at time $\Delta t$ can be expressed in terms of five parameters, $A$, $S_{\pm}$ and $C_{\pm}$:

$$P_{D^{*}D}(\Delta t) = (1 \pm A)e^{-|\Delta t|/\tau_{B^0}}\{1 + q[S_{\pm} \sin(\Delta m_d \Delta t) - C_{\pm} \cos(\Delta m_d \Delta t)]\}. \quad (2)$$

Here the $+$(-) sign represents the $D^{*+}D^- (D^{*-}D^+)$ final state.
Two reconstruction techniques, full and partial, are used to increase the reconstruction efficiency[7]. In case of the full reconstruction, a fit to the $M_{bc}$ distribution finds a signal yield to be $161 \pm 16$ events. In the partial reconstruction method the angle $\alpha$ between the $D^-$ and $\pi^+_\text{slow}$ CMS momenta is used to identify the studied decay. In this case, we require the high momentum lepton in the event to suppress the background and provide the vertex and flavor of tagging $B$, while in the full reconstruction method we use the standard tagging procedures[1]. In both cases, the signal $B^0$ vertex is reconstructed as in $B^0 \to D^{*+}D^{*-}$ analysis. The fit to $\cos \alpha$ distribution yields $137 \pm 39$ signal events, in good agreement with those expected from the full reconstruction analysis. Fig. 6 shows the signal distributions for selected candidates.

The $\Delta t$ distributions after background subtraction are shown in Fig. 7 a) and b) for the full and partial reconstruction methods, respectively. The fit results are summarized in the Table I.
FIG. 6: a) $M_{bc}$ and b) $\cos\alpha$ distributions of $B^0 \to D^{*\pm}D^{\mp}$ candidates for the full and partial reconstruction methods, respectively.

FIG. 7: Background subtracted $\Delta t$ distributions in the full and partial reconstruction methods. The curves show the result of the fits.

SUMMARY

We measured $CP$ violation parameters in the $B^0 \to J/\psi\pi^0, D^{*+}D^{*-}$ and $D^{*\pm}D^{\mp}$ decays. The results of these measurements are presented in the Table I, which are consistent with the expectations from the SM. We also report the measurement of the branching fraction
and the polarization parameters for the $B^0 \to D^{*+}D^{*-}$ decay mode.

**TABLE I:** The summary for the $CP$ violating parameters measurement.

|                  | $B^0 \to J/\psi\pi^0$ | $B^0 \to D^{*+}D^{*-}$ | $B^0 \to D^{*\pm}D^{\mp}$ |
|------------------|------------------------|-------------------------|-----------------------------|
| $S_{f_{CP}}$     | $-0.72 \pm 0.42 \pm 0.09$ | $-0.75 \pm 0.56 \pm 0.12$ | $-0.96 \pm 0.43 \pm 0.12$ |
| $S_{\pm}$       | $-0.55 \pm 0.39 \pm 0.12$ | $-0.26 \pm 0.26 \pm 0.04$ | $-0.37 \pm 0.22 \pm 0.07$ |
| $C_{f_{CP}}$     | $-0.01 \pm 0.29 \pm 0.03$ | $-0.26 \pm 0.26 \pm 0.04$ | $+0.23 \pm 0.25 \pm 0.07$ |
| $C_{\pm}$       | $+0.23 \pm 0.25 \pm 0.07$ | $-0.37 \pm 0.22 \pm 0.07$ | $+0.07 \pm 0.08 \pm 0.04$ |

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[1] K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **87**, 091802 (2001); Phys. Rev. **D66**, 032007 (2002); Phys. Rev. **D66**, 071102 (2002).

[2] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **87**, 091801 (2001); Phys. Rev. **D66**, 032003 (2002); Phys. Rev. Lett. **89**, 201802 (2002).

[3] I.I. Bigi, V.A. Khoze, N.G. Uraltsev, and A.I. Sanda, “$CP$ Violation”, 175 (1989).

[4] S.U. Kataoka *et al.* (Belle Collaboration), submitted to PRL, hep-ex/0408105.

[5] I. Dunietz, H.R. Quinn, A. Snyder, W. Toki and H.J. Lipkin, Phys. Rev. **D43**, 2193 (1991).

[6] R. Aleksan *et al.*, Phys. Lett. B**317**, 173 (1993).

[7] T. Aushev *et al.* (Belle Collaboration), submitted to PRL, hep-ex/0408051.