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ϕ_1 from $b \to c$ decays at Belle

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We present preliminary measurements of the angle ϕ_1, which is one of the angle in the CKM Unitarity Triangle, in a 386×10^6 $B\overline{B}$ events collected at $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric energy B factory. One neutral B meson is fully reconstructed in one of the specified decay channels, and the flavor of the accompanying B meson is identified from its decay products. We perform an improved measurement of CP asymmetries in $B^0 \to J/\psi K^0$ decays. Obtained CP-violation parameters are $\sin 2\phi_1 = +0.652 \pm 0.039(\text{stat}) \pm 0.020(\text{syst})$ and $A = +0.010 \pm 0.026(\text{stat}) \pm 0.036(\text{syst})$. The ambiguity between $2\phi_1$ and $\pi - 2\phi_1$ is resolved by the time-dependent Dalitz plot analysis in neutral B meson decay to a neutral D meson with a light meson $B^0 \to D\left[K_S^0\pi^+\pi^-\right]h^0$ decays, where h^0 denotes a light neutral meson. We obtain $\phi_1 = (16 \pm 21(\text{stat}) \pm 11(\text{syst}))^\circ$. The 95 % CL region is -30° $< \phi_1 <$ 62°, thus the second solution for ϕ_1 is ruled out more than 2σ significance.

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1. Introduction

In the standard model (SM), *CP* violation arises from an irreducible phase in the weak interaction quark-mixing matrix (Cabibbo-Kobayashi-Maskawa (CKM) matrix) [1]. In particular, 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} [2]. In the decay chain $\Upsilon(4S) \to B^0\bar{B}^0 \to f_{CP} f_{tag}$, where on of the B mesons 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

$$P(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \Big\{ 1 + q\big[S\sin(\Delta m_d \Delta t) + A\cos(\Delta m_d \Delta t)\big] \Big\}. \tag{1.1}$$

Here S and A are *CP*-violation parameters, τ_{B^0} is the B^0 lifetime, Δm_d is the mass difference between the two B^0 mass eigenstates, $\Delta t = t_{CP} - t_{tag}$, and the b-flavor charge q = +1 (-1) when the tagging B meson is a B^0 ($\bar{B}^0$). For $b \to c\bar{c}s$ transition such as $B^0 \to J/\psi K^0$ decays, the SM predicts $S = -\xi_f \sin 2\phi_1$ and A = 0 with a good approximation, where ξ_f = +1 (-1) corresponds to *CP*-even (-odd) final states and ϕ_1 is one of the angle of the Unitarity Triangle.

The measured ϕ_1 with $b \to c\bar{c}s$ transition contains an intrinsic ambiguity: $2\phi_1 \leftrightarrow \pi - 2\phi_1$, whereas the accuracy of the $\sin 2\phi_1$ is already several percent [3]. A new technique, to solve this ambiguity, based on the analysis of $B^0 \to D\left[K_S^0\pi^+\pi^-\right] h^0$ has bean suggested recently [4], where we use h^0 to denote a light neutral meson, such as π^0, η or ω. The neutral D meson is reconstructed in the $K_S^0\pi^+\pi^-$ mode. Due to a interference between $B^0 \to \bar{D}^0 h^0$ and $\bar{B}^0 \to D^0 h^0$, the phase $2\phi_1$ can be extracted from a time-dependent Dalitz plot fitting.

All results are based on 386×10^6 $B\bar{B}$ pairs collected with the Belle detector [5] at the KEKB asymmetric energy e^+e^- (3.5 on 8 GeV) collider [6] operating at the $\Upsilon(4S)$ resonance.

2. $\sin 2\phi_1$ Measurement with $B^0 \to J/\psi K^0$ decays

We have two modes for K^0: K_S^0 and K_L^0. The reconstruction and selection criteria which are described in detail elsewhere [7]. We reconstruct J/ψ candidates via their decays to l^+l^- ($l = \mu, e$), and K_S^0 candidates via $K_S^0 \to \pi^+\pi^-$ decays. We identify B meson decays using the energy difference $\Delta E \equiv E_B^{cms} - E_{beam}^{cms}$ and the beam-energy constrained mass $M_{\rm bc} \equiv \sqrt{(E_{beam}^{cms})^2 - (p_B^{cms})^2}$, where E_{beam}^{cms} is the beam energy in the cms (rest frame of the $\Upsilon(4S)$ system), and E_B^{cms} and p_B^{mcs} are the cms energy and momentum of the reconstructed B candidate, respectively. The signal region for $B^0 \to J/\psi K_S^0$ decay is defined as $|\Delta E| < 0.04$ GeV and 5.27 GeV/$c^2 < M_{\rm bc} <$ 5.29 GeV/c^2. Since the energy of the K_L^0 is not measured, $M_{\rm bc}$ and ΔE cannot be calculated in the same way as other final states. Using the four-momentum of a reconstructed J/ψ candidate, the K_L^0 flight direction and the B meson mass, we calculate the momentum of the K_L^0 candidate from the four-momentum conservation in B decay, We then calculated p_B^{cms}, the momentum of the B candidate in the cms, and define the B meson signal region as 0.2 GeV/c $< p_B^{cms} <$ 0.45 GeV/c. Extracted number of signals are summarized in Table 1, it is 10,056 events in total. The detail description for the flavor identification of B meson and the decay vertex measurement are written in [8, 9].

We determine $\sin 2\phi_1$ and A for each mode by performing an unbinned maximum-likelihood fit to the observed Δt distribution. The distribution is convolved with the proper-time interval resolution function, which takes into account the finite vertex resolution. The resolution function is well calibrated with flavor-specific B decays.

We fix τ_{B^0} and Δm_d at their world average values [10]. The only free parameters in the final fits are S and A. Table 1 summarizes the fit results of $\sin 2\phi_1$ and A. The detail for the systematic errors is described in elsewhere [11]. We measure $\sin 2\phi_1$ very precisely, whereas we have two solution for ϕ_1; $\sim 20^\circ$ or $\sim 70^\circ$.

Table 1: Number of signal events (N_{sig}), signal purities and fit results to the Δt distributions for each modes. The first error is statical and the second error is systematic.

	ξ_f	purity	N_{sig}	$\sin 2\phi_1 (\equiv -\xi_f S)$	A
$J/\psi K^0_S$	-1	0.98	5264 ± 73	$+0.668 \pm 0.0047$	-0.021 ± 0.034
$J/\psi K^0_L$	+1	0.60	4792 ± 105	$+0.619 \pm 0.0069$	$+0.049 \pm 0.039$
$J/\psi K^0$	—	—	10056 ± 128	$+0.652 \pm 0.0039 \pm 0.020$	$+0.010 \pm 0.026 \pm 0.036$

3. Solution for Ambiguity $2\phi_1$ and $\pi - 2\phi_1$

We reconstruct the decays $\bar{B}^0 \to D[K^0_S\pi^+\pi^-]h^0$ for $h^0 = \pi^0, \eta$ and ω, and $\bar{B}^0 \to D^{*0}h^0$ for $h^0 = \pi^0$ and η. We use the sub-decays $D^{*0} \to D^0\pi^0$, $D^0 \to K^0_S\pi^+\pi^-$, $K^0_S \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$ and $\omega \to \pi^+\pi^-\pi^0$ [12]. The signal B meson decay vertex is reconstructed using the D trajectory and an IP constraint.

To suppress the large combinatorial background dominated by the two-jet-like $e^+e^- \to q\bar{q}$ ($q = u, d, s$ light mesons) continuum process, variables that characterize the event topology are used. The signal yield is obtained from the fit to the ΔE distribution, the results are summarized in Table 2. Total number of signals is 309 ± 31 events with 63 % average purity.

We perform an unbinned time-dependent Dalitz plot fit for each events. The fit function for Dalitz plot is calibrated with real data, $D^{*-} \to D^0(K^0_S\pi^+\pi^-)\pi^-_{\rm slow}$ decay, we can distinguish D^0 or $\bar{D}^0$ from the charge information of $\pi_{\rm slow}$ [13]. Measured ϕ_1 results are given Table 2 for each of the three final states separately and for combined fit. The combined result is $\phi_1 = (16 \pm 21 \pm 11)^\circ$, the first error is statistical and the second is systematic. The model used for the Dalitz distribution is the main sources of systematic error [12].

With 95 % C.L. we can constrain -30° $< \phi_1 <$ 62°. One of the two solutions for $\phi_1 \sim 70^\circ$ shown in previous section can be ruled out more than 2σ significance.

Table 2: Signal purities, number of signal events (N_{sig}) and Time-dependent Dalitz plot fit results for ϕ_1.

	purity	N_{sig}	ϕ_1 (°)
$D\pi^0$	0.59	157 ± 24	11 ± 26
$D\omega$, $D\eta$	0.74	125 ± 16	28 ± 32
$D^*\pi^0, D^*\eta$	0.52	27 ± 11	25 ± 35
combined	—	309 ± 31	16 ± 21

4. Conclusion

We measure the ϕ_1 using 386×10^6 $B\bar{B}$ events collected with the Belle detector. Using the time-dependent analysis for $B^0 \to J/\psi K^0$ decays, the $\sin 2\phi_1$ is measured about 7 % accuracy whereas an intrinsic ambiguity: $2\phi_1 \leftrightarrow \pi - 2\phi_1$. Due to the new technique based on the time-dependent Dalitz plot analysis, this ambiguity is solved more than 2σ significance. Thus, we have one solution for $\phi_1 = (20.3 \pm 1.8)^\circ$ based on the Belle results. This is the most precise parameter for the Unitarity Triangle.

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References

[1] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[2] A. B. Carter and A. I. Sanda, Phys. Rev. D **23**, 1567 (1981); I. I. Bigi and A. I. Sanda, Nucl. Phys **B193**, 85 (1981).

[3] Heavy Flavor Average Group (HFAG), winter 2005 averages, hep-ex/0505100.

[4] A. Bondar, T. Gershon and P. Krokovny, hep-ph/0503174.

[5] A. Abashian *et al.* (Belle Collaboration), Nucl. Instr. and Math. A **479**, 117 (2002).

[6] S. Kurokawa and E. Kikutani, Nucl. Instr. and Math. A **499**, 1 (2003).

[7] K. Abe *et al.*, (Belle Collaboration), Phys. Rev. Lett. **87**, 091802 (2001); Phys. Rev. D **66**, 032007 (2002); K. Abe *et al.*, (Belle Collaboration), hep-ex/0507037.

[8] H. Kakuno *et al.*, Nucl. Instr. and Math. A **533**, 516 (2004).

[9] H. Tajima *et al.*, Nucl. Instr. and Math. A **533**, 370 (2004).

[10] S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).

[11] K. Abe *et al.*, (Belle Collaboration), hep-ex/0507037.

[12] K. Abe *et al.*, (Belle Collaboration), hep-ex/0507065.

[13] A. Poluektov *et al.*, (Belle Collaboration), Phys. Rev. D **70**, 072003 (2004).