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Measurements of time-dependent *CP* violation in charmless B meson decays

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We report measurements of time-dependent *CP* violation in charmless B meson decays that are sensitive to physics beyond the Standard model or Kobayashi-Maskawa *CP* violation angle ϕ_2 in b to s penguin or b to u tree transitions, respectively. The analyses use Belle final entire data sample collected at the Upsilon(4S) resonance containing 772 mullion B meson pairs.

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1. Introduction

In the Standard Model (SM), *CP* violation in the quark sector is induced by a complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [1]. In the decay sequences $\Upsilon(4S) \to B^0\bar{B}^0 \to f_{CP}f_{tag}$, where one of the B mesons decays at time t_{CP} to a *CP* eigenstate f_{CP} and the other decays at a 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[2, 3]

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

where S and A are time-dependent and direct *CP* violation parameters, respectively. Δt is the decay time difference of the B mesons, τ_{B^0} is the B^0 lifetime, Δm_d is the mass difference between the mass eigenstates of the B meson and q is the flavor of the B meson decays in *CP* eigenstate: +1 for B^0 and -1 for $\bar{B}^0$. Since B^0 and $\bar{B}^0$ measons are approximately at rest in the $\Upsilon(4S)$ center-of-mass system (CM), the Δt can be determined from the distance between f_{tag} and f_{CP} decay vertices along flight direction of $\Upsilon(4S)$, $\Delta t \simeq \Delta z/(\beta\gamma c)$. Since most of the *CP* eigenstates are not flavor specific, q is determined using the information of f_{tag} such as flavor for charged lepton, high momentum kaon and low momentum pion. Here we present the recent measurements of time-dependent *CP* violation in charmless B meson decays, $B^0 \to K_S\eta\gamma$ and $B^0 \to \pi^0\pi^0 K_S$ using the full data sample of 711 fb^{-1} containing $772 \times 10^6 B\bar{B}$ pairs recorded at the $\Upsilon(4S)$ resonance with the Belle detector [4] at the KEKB e^+e^- collider[5].

2. Measurement of Time-dependent *CP* Asymmetries in $B^0 \to K_S\eta\gamma$ Decays

The radiative $b \to s\gamma$ decay proceeds dominantly via one-loop electromagnetic penguin diagrams at lowest order in the standard model (SM). Since heavy unobserved particles might enter in the loop, such decay are sensitive to new physics (NP). The BF($B^0 \to X_S\gamma$) is a sensitive probe for new physics [6] and measured precisely [7, 8, 9, 10, 11, 12]. Another important is the photon polarization the $b \to s\gamma$ process. Within the SM, the photon is mostly produced with left-handed polarization; the right-handed contribution is suppressed by m_s/m_b at leading order, where $m_s(m_b)$ is the strange (bottom) quark mass. Thus, it can be an important evidence, if we observe right-handed photon in $b \to s\gamma$ process. At Belle and BaBar , the *CP* violation parameters for the $b \to s\gamma$ transition were measured in the decays of $B^0 \to K^0_S\pi^0\gamma$ including $K^{*0} \to K^0_S\pi^0$ [13, 14], $B^0 \to K^0_S\eta\gamma$ [15], $B^0 \to K^0_S\rho^0\gamma$ [16, 17], and $B^0 \to K^0_S\phi\gamma$[18]. We report the first measurement of time-dependent *CP* violation in $B^0 \to K_S\eta\gamma$ at Belle.

K^0_S candidates are reconstructed from pairs of oppositely-charged tracks, treated as pions. We reconstruct η candidates from the $\gamma\gamma$ ($\eta_{\gamma\gamma}$)and $\pi^+\pi^-\pi^0$ ($\eta_{3\pi}$) final states. Candidate gamma is required no to associated with any charged tracks. We extract the signal yield with a three-dimensional extended unbinned maximum-likelihood fit. We obtain $69^{+13.4}_{-12.4}$ and $22^{+7.3}_{-6.4}$ signal events for the $\eta_{\gamma\gamma}$ and $\eta_{3\pi}$ decays, respectively, with purities in the signal region of 28.4% and 22.5%. Using Eq. 1 as signal probability function, we obtain

$$S = -1.32 \pm 0.77(stat.) \pm 0,36(syst.),$$
$$A = -0.48 \pm 0.41(stat.) \pm 0.07(syst.)$$

with unbined maximum likelihood fit to Δt. The obtained parameters are consistent with the SM predictions within 2σ[19, 20, 21, 22, 23, 24].

3. Measurement of Time-dependent *CP* Asymmetries in $B^0 \to \pi^0\pi^0 K_S$ decay

$B^0 \to \pi^0\pi^0 K_S$ is a decay to a *CP*-even eigenstate predominantly induced by a $b \to sd\bar{d}$ penguin diagram [25] so that is expected that $S \sim -\sin\phi_1$ and $S \sim 0$, where the ϕ_1 is an angle of the CKM unitarity triangle, defined using CKM quark mixing matrix elements, $\phi_1 \equiv arg\left[-V_{cd}V_{cb}^*/V_{td}V_{tb}^*\right]$. The transition $b \to sq\bar{q}$ is sensitive to new physics beyond the SM which is expected to contribute to a time-dependence *CP* violation phase [26]. Although the effective *CP* violation parameter, $\sin 2\phi_1^{\rm eff}$, contains a small deviation due to the presence of $b \to u$ tree diagram in the SM [27], it is good probe to search for the physics beyond the SM by comparing the $\sin 2\phi_1$ from $b \to c\bar{c}s$ transitions [28, 29]. In the past analysis by the BaBar experiment, they obtain $\sin 2\phi_1^{\rm eff} = -0.72 \pm 0.71 \pm 0.08$ from 227 million $B\bar{B}$ sample [30]. We report the first result of the *CP* violation measurement in $B^0 \to \pi^0\pi^0 K_S$ decay at Belle. pi^0 candidates are reconstructed from the decay of $\pi^0 \to \gamma\gamma$. Candidate K_S^0 decays are reconstructed two opposite charged pion and selected using multi-variable analysis based on a neural-network technique[31]. Using a three-dimensional extended unbinned maximum-likelihood fit, we extract the signals as 335.4 ± 37.1. From the Δt fit to those events, we obtain the *CP* violation parameters,

$$\sin 2\phi_1^{\rm eff} = 0.92^{+0.27}_{-0.11}(stat.)^{+0.10}_{-0.11}(syst.),$$
$$A = 0.28 \pm 0.21(stat.) \pm 0.04(syst.).$$

These results are consistent with $\sin 2\phi_1$ from the decays induced by $b \to c\bar{c}s$ transition [28, 29] and no direct *CP* violation as expected from the SM.

4. Summary

In summary, we review the recent result of time-dependent *CP* violation measurements in charmless *B* decay using full data set in Belle experiments. *CP* violation parameters from $B^0 \to K_S\eta\gamma$ and $B^0 \to \pi^0\pi^0 K_S$ are consistent with SM prediction. Both measurement for two modes are dominated by statistical uncertainty. Therefore , the forthcoming Belle II experiment should significantly improve upon the precision of this measurement. Both results from

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