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ϕ_1/β Determination

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Measurements of time-dependent CP asymmetries in $B^0 \to J/\psi K^0$ and related $b \to c$ transitions provide precise measurements of $\sin 2\phi_1$. Time-dependent CP asymmetries in $B^0 \to \phi K^0$ and related $b \to s$ FCNC transitions also give $\sin 2\phi_1$ to a good approximation within the Standard Model. Deviations from the Standard Model expectations would indicate a new source of CP violation. In this article, the present experimental results, as well as prospects for discoveries at LHC experiments and at SuperKEKB are summarized. In the end, several questions for discussions are raised.

1. Introduction

The purpose of this article is to summarize the status of ϕ_1/β measurements at two B factories Belle and BaBar, and raise some questions for discussions.

In the Standard Model (SM), CP violation arises only from an irreducible phase, the Kobayashi-Maskawa phase [1], in the weak-interaction quark-mixing matrix. In the decay chain $\Upsilon(4S) \to B^0\overline{B}^0 \to f_{CP} f_{\rm tag}$, where one of the B mesons decays at time t_{CP} to a final state f_{CP} and the other decays at time $t_{\rm tag}$ to a final state $f_{\rm tag}$ that distinguishes between B^0 and $\overline{B}^0$, the decay rate has a time dependence [2] given by

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

Here $\mathcal{S}_f$ and $\mathcal{A}_f$ 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, $\Delta t = t_{CP} - t_{\rm tag}$, and the b-flavor charge $q = +1$ (-1) when the tagging B meson is a B^0 $(\overline{B}^0)$.

To a good approximation, the SM predicts $\mathcal{S}_f = -\xi_f \sin 2\phi_1$ and $\mathcal{A}_f = 0$ for both tree transitions (e.g. $b \to c\bar{c}s$) and penguin transitions (e.g. $b \to s\bar{s}s$) unless V_{ub} or V_{td} is involved in the decay amplitude. Here $\xi_f = +1(-1)$ corresponds to CP-even (-odd) final states.

Why were/are the $\sin 2\phi_1$ measurements so interesting ? There are three major reasons:

1. The $\sin 2\phi_1$ measurements clearly tell us what the dominant source of CP violation is. This question has already been answered by two B factories; the Kobayashi-Maskawa phase (KM phase) IS the dominant source.

2. The direct $\sin 2\phi_1$ measurements can be compared with indirect determination from a global CKM fit. This provides a stringent test of the SM.

3. By comparing $\sin 2\phi_1$ measurements from tree-dominated decays with those from penguin-dominated decays, we can search for a new source of CP violation. In particular, the $b \to s$ penguin is a very natural place to accommodate such a new phase in many extensions of the SM. A discovery of a new CP-violating phase would lead to reconsideration of the origin of the matter-dominated universe.

2. $\sin 2\phi_1$ with tree-dominated modes

Figure 1 summarizes $\sin 2\phi_1$ measurements as of May 2006. They are obtained from $B^0 \to J/\psi K^0_S$ and other decays that are governed by $b \to c\bar{c}s$ transitions. The world average value is $\sin 2\phi_1 = 0.69 \pm 0.03$, which is essentially determined by two B factories, BaBar and Belle. The value is consistent with the result of the

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global CKM fit where direct measurements of $\sin 2\phi_1$ are excluded. Figure 2 shows background-

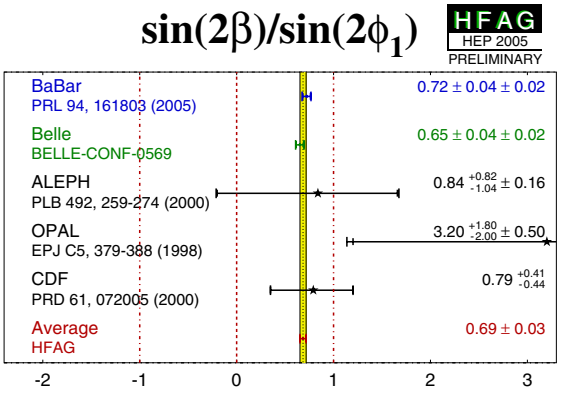

Figure 1. Compilation of results for $\mathcal{S}_f$ from time-dependent $b \to c\bar{c}s$ analyses [3].

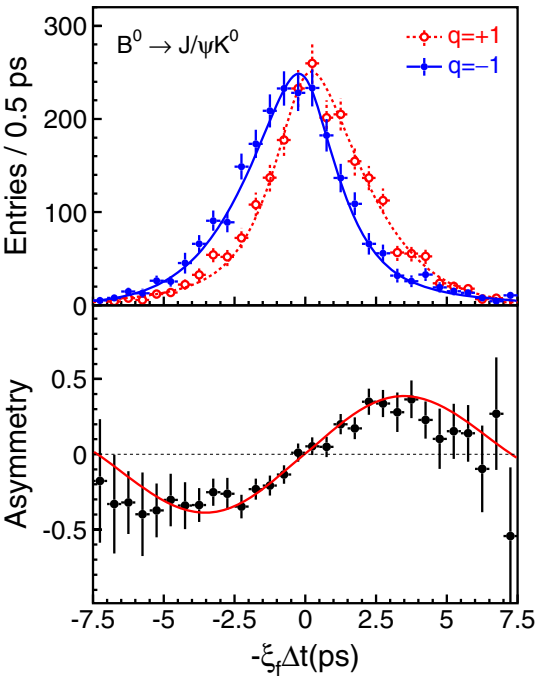

Figure 2. Background-subtracted Δt distributions and asymmetry in each Δt bin for $B^0 \to J/\psi K^0$ from the Belle experiment. The result of the unbinned maximum-likelihood fit is also shown [4].

subtracted Δt distributions and asymmetry for $B^0 \to J/\psi K^0$ decays from the Belle experiment. Large CP violation is clearly seen. The direct CP-violation parameter $\mathcal{A}_f$ is also consistent with the SM expectation; the world average value is $\mathcal{A}_f = -0.027 \pm 0.028$.

Another type of tree-dominated (but theoretically less clean) transition is $b \to c\bar{c}d$. The present measurements are summarized in Fig. 3. Measurements for $B^0 \to J/\psi\pi^0$, $D^{*+}D^{*-}$ and $D^{*+}D^-$ are available. Because of an additional Cabibbo suppression, experimental errors on CP parameters are larger than those for $\sin 2\phi_1$ from $b \to c\bar{c}s$ transitions by a factor of λ^{-1}, where $\lambda \simeq 0.22$. There are no sizable deviations from the SM expectations at the moment.

3. $\sin 2\phi_1$ with penguin-dominated modes

Recent theoretical studies within the SM framework [5] find that the effective $\sin 2\phi_1$ values, $\sin 2\phi_1^{\rm eff}$, obtained from $B^0 \to \phi K^0$, $\eta' K^0$ and $K^0_S K^0_S K^0_S$ are expected to agree within the level of $\mathcal{O}(0.01)$ with $\sin 2\phi_1$ from the $B^0 \to J/\psi K^0$ decay, which is governed by the $b \to c\bar{c}s$ transition. A comparison of CP-violation parameters between these theoretically clean $b \to s\bar{q}q$ modes and $b \to c\bar{c}s$ decays is an important test of the SM.

Figure 4 summarizes the experimental results as of May 2006. As shown in the figure, an average of the three cleanest decay modes differs from the average of $b \to c\bar{c}s$ modes by 2.2 standard deviations. An average of all available modes in the figure is 0.50 ± 0.06, which differs from the SM expectation by 2.6 standard deviations. Although the results hint at a new CP-violating