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A method to measure ϕ_1 using $\bar{B}^0 \to D^{(*)}h^0$ with multibody D decay

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Abstract

We describe a new method to measure the angle ϕ_1 of the CKM Unitarity Triangle using amplitude analysis of the multibody decay of the neutral D meson produced via $\bar{B} \to D^{(*)}h^0$ colour-suppressed decays. The method employs the interference between D^0 and $\bar{D}^0$ to directly extract the value of $2\phi_1$, and thus resolve the ambiguity between $2\phi_1$ and $\pi - 2\phi_1$ in the measurement of $\sin(2\phi_1)$ using $\bar{B}^0 \to J/\psi K_S$. We present a feasibility study of this method using Monte Carlo simulation.

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1. Introduction

Precise determinations of the Cabibbo–Kobayashi–Maskawa (CKM) matrix elements [1] are important to check the consistency of the Standard Model and search for new physics. The value of $\sin(2\phi_1)$, where ϕ_1 is one of the angles of the Unitarity Triangle [2] is now measured with high precision: $\sin(2\phi_1) = 0.731 \pm 0.056$ [3]. However, this measurement contains an intrinsic ambiguity: $2\phi_1 \longleftrightarrow \pi - 2\phi_1$. Various methods to resolve this ambiguity have been introduced [4], but they require very large amounts of data (some impressive first results notwithstanding [5]).

We suggest a new technique based on the analysis of $\bar{B}^0 \to Dh^0$, followed by the multibody decay of the neutral D meson. Here we use h^0 to denote a light neutral meson, such as π^0, η, ρ^0, ω. The modes $\bar{B}^0 \to D_{CP}h^0$, utilizing the same B decay but requiring the D meson to be reconstructed via CP eigenstates, have previously been proposed as "gold-plated" modes to search for new physics effects [6]. Such effects may result in deviations from

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the Standard Model prediction that CP violation effects in $b \to c\bar{u}d$ transitions should be very similar to those observed in $b \to c\bar{c}s$ transitions, such as $\bar{B}^0 \to J/\psi K_S$. Detailed considerations have shown that the contributions from $b \to u\bar{c}d$ amplitudes, which are suppressed by a factor of approximately 0.02 [7], can be taken into account. Consequently, within the Standard Model, studies of $\bar{B}^0 \to D_{CP}h^0$ can give a measurement of $\sin(2\phi_1)$ that is more theoretically clean than that from $\bar{B}^0 \to J/\psi K_S$ [8]. However, these measurements still suffer from the ambiguity mentioned above.

In the case that the neutral D meson produced in $\bar{B}^0 \to Dh^0$ is reconstructed in a multibody decay mode, with known decay model, the interference between the contributing amplitudes allows direct sensitivity to the phases. Thus $2\phi_1$, rather than $\sin(2\phi_1)$ is extracted, and the ambiguity $2\phi_1 \longleftrightarrow \pi - 2\phi_1$ can be resolved. This method is similar to that used to extract ϕ_3, using $B^\pm \to DK^\pm$ followed by multibody D decay [9,10].

There are a large number of different final states to which this method can be applied. In addition to the possibilities for h^0, and the various different multibody D decays which can be used, the method can also be applied to $\bar{B}^0 \to D^*h^0$. In this case, the usual care must be taken to distinguish between the decays $D^* \to D\pi^0$ and $D^* \to D\gamma$ [11]. Also, if h^0 is not a spinless particle, angular analysis [12] will be required to resolve the contributing amplitudes to $\bar{B}^0 \to D^*h^0$.

We also note that this method can be applied to other neutral B meson decays with a neutral D meson in the final state. In particular, the decay $\bar{B}^0 \to D^{(*)}K_S$ has contributions from $b \to c\bar{u}s$ and $b \to u\bar{c}s$ amplitudes, which have a relative weak phase difference of ϕ_3. Therefore, analysis of $\bar{B}^0 \to D^{(*)}K_S$ can be used to measure not only ϕ_1, but also ϕ_3 [13]. The value of ϕ_1 obtained from such an analysis can be used to test the Standard Model prediction that CP violation effects in $b \to c\bar{u}s$ transitions should be, to a good approximation, the same as those in $b \to c\bar{c}s$ transitions. Furthermore, modes such as $B_s^0 \to D\phi$ can in principle be used to measure the weak phase in B_s^0–$\bar{B}_s^0$ mixing. However, our feasibility study is not relevant to B_s^0 decay modes, which cannot be studied at a B factory operating at the $\Upsilon(4S)$ resonance, and therefore we do not discuss this case further.

In this Letter we concentrate primarily on the decay $\bar{B}^0 \to D\pi^0$ with $D \to K_S\pi^+\pi^-$ (and denote the decay chain as $\bar{B}^0 \to (K_S\pi^+\pi^-)_D\pi^0$). This multibody D decay has been shown, in the ϕ_3 analysis, to be particularly suitable for Dalitz plot studies. In the remainder of the Letter, we first give an overview of the relevant formalism, and then turn our attention to Monte Carlo simulation studies of $\bar{B}^0 \to (K_S\pi^+\pi^-)_D\pi^0$. We attempt to include all experimental effects, such as background, resolution, flavour tagging, and so on, in order to test the feasibility of the method. Based on these studies, we estimate the precision with which ϕ_1 can be extracted with the current B factory statistics.

2. Description of the method

Consider a neutral B meson, which is known to be $\bar{B}^0$ at time $t_{\rm tag}$. For experiments operating at the $\Upsilon(4S)$ resonance, such knowledge is provided by tagging the flavour of the other B meson in the $\Upsilon(4S) \to B\bar{B}$ event. At another time $t_{\rm sig}$ the amplitude content of the B meson is given by[1]

$$\left|\bar{B}^0(\Delta t)\right\rangle = e^{-|\Delta t|/2\tau_{B^0}}\left(\left|\bar{B}^0\right\rangle \cos(\Delta m \Delta t/2) - i\frac{p}{q}\left|B^0\right\rangle \sin(\Delta m \Delta t/2)\right), \tag{1}$$

where $\Delta t = t_{\rm sig} - t_{\rm tag}$, τ_{B^0} is the average lifetime of the B^0 meson, Δm, p and q are parameters of B^0–$\bar{B}^0$ mixing (Δm gives the frequency of B^0–$\bar{B}^0$ oscillations, while the eigenstates of the effective Hamiltonian in the B^0–$\bar{B}^0$ system are $|B_\pm\rangle = p|B^0\rangle \pm q|\bar{B}^0\rangle$), and we have assumed CPT invariance and neglected terms related to the B^0–$\bar{B}^0$ lifetime difference.[2] In the following we drop the terms of $e^{-|\Delta t|/2\tau_{B^0}}$.

[1] Details of the time-evolution of the neutral B meson system can be found in many references, for example the BaBar Physics Book, [14].

[2] A full treatment of the B_s case must take the non-zero lifetime difference into account. We do not include this extension here, for brevity.