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MEASUREMENT OF ϕ_3 IN $B^{\pm} \rightarrow D^{(*)}K^{\pm}$ DECAYS AT BELLE

T. Gershon*
IPNS, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305-0801, Japan

ABSTRACT

We present a measurement of the unitarity triangle angle ϕ_3 using a Dalitz plot analysis of $D \rightarrow K_S\pi^+\pi^-$, using neutral D mesons produced in $B^{\pm} \rightarrow D^{(*)}K^{\pm}$ decay. Using 140 fb^{-1} of data collected by the Belle experiment we obtain $\phi_3 = 81^\circ \pm 19^\circ \pm 13^\circ(\text{syst}) \pm 11^\circ(\text{model})$. The 95% confidence interval is $35^\circ < \phi_3 < 127^\circ$. Note that the results presented here have been superseded. [1]

1 Introduction

The determination of the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements [2] is important to check the consistency of the Standard Model and search for new physics. Various methods using $B \rightarrow DK$ decays have been

* On behalf of Belle Collaboration

introduced [3] to measure the unitarity triangle angle ϕ_3. Here we use a novel technique based on the analysis of the three-body decay of the D^0 meson. [4] This method is based on two key observations: neutral D^0 and $\bar{D}^0$ mesons can decay to a common final state $K_s\pi^+\pi^-$, and the decay $B^+ \to D^{(*)}K^+$ can produce neutral D mesons of both flavors via $\bar{b} \to \bar{c}u\bar{s}$ and $\bar{b} \to \bar{u}c\bar{s}$ transitions, where the relative phase θ_+ between the two interfering amplitudes is the sum, $\delta + \phi_3$, of strong and weak interaction phases. In the charge conjugate mode, the relative phase $\theta_- = \delta - \phi_3$, so both phases can be extracted from measurements of such B decays. The phase measurement is based on the analysis of the Dalitz distribution of the three body final state.

If the amplitude at each point in the Dalitz plot of $\bar{D}^0 \to K_s\pi^+\pi^-$ is defined as $f(m_+^2, m_-^2)$, where m_+^2 and m_-^2 are the squared invariant masses of the $K_s\pi^+$ and $K_s\pi^-$ combinations, respectively, then assuming no CP asymmetry in D decays, the amplitude of the B^+ decay is written as

$$M_+ = f(m_+^2, m_-^2) + re^{i(\delta+\phi_3)} f(m_-^2, m_+^2), \tag{1}$$

where r is the absolute value of the ratio between the two interfering amplitudes. Similarly, the amplitude of the charge conjugate B^- decay is

$$M_- = f(m_-^2, m_+^2) + re^{i(\delta-\phi_3)} f(m_+^2, m_-^2). \tag{2}$$

Once the functional form of f is fixed, the Dalitz distributions for B^+ and B^- decays can be fitted simultaneously using the above expressions with r, ϕ_3, and δ as free parameters. The method is therefore directly sensitive to the value of ϕ_3; moreover, the obtained value of r can be used in other ϕ_3 measurements. The method has only a single ambiguity ($\phi_3 \to \phi_3 + \pi$, $\delta \to \delta + \pi$).

To fit the $\tilde{D} \to K_s\pi^+\pi^-$ Dalitz plot distributions corresponding to B^+ and B^- decays, we use an unbinned maximum likelihood technique with a neutral D decay model determined from a flavor-tagged D sample. The drawback of this approach is that while the absolute value of the $\bar{D}^0$ decay amplitude f is determined directly, its complex form can be obtained only with certain assumptions, leading to substantial model uncertainties in the determination of ϕ_3. These uncertainties can be controlled in future using data from $c\tau$-factories. A sample of CP tagged neutral D mesons, which can be produced in the decay of the $\psi(3770)$ resonance, will provide information about the complex phase of f, allowing a model-independent measurement of ϕ_3.

2 Event selection

The analysis uses 140 fb^{-1} of data collected by the Belle detector. [5] From this data sample we select 146 $B^\pm \to DK^\pm$ candidates, with a background fraction of $25 \pm 4\%$, and 39 $B^\pm \to D^*K^\pm$ candidates, with a background fraction of

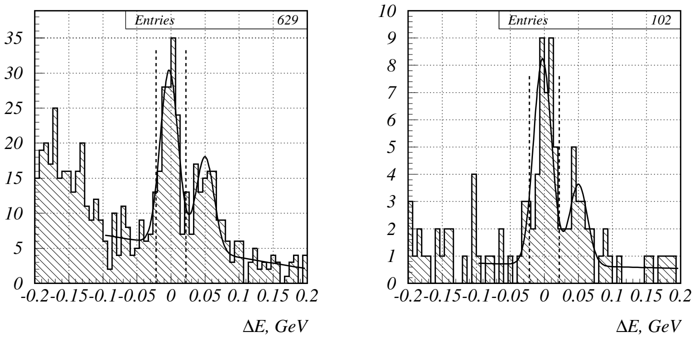

Figure 1: ΔE *distributions for (left)* $B^{\pm} \to DK^{\pm}$ *and (right)* $B^{\pm} \to D^{*}K^{\pm}$ *candidates. The signal region is shown by dotted lines.*

$12 \pm 4\%$. The ΔE distributions (the difference between the reconstructed and expected B candidate energies) are shown in Fig. 1. We also select 104204 $D^{*\pm} \to D\pi_s^{\pm}$ candidates, with a background fraction of $3.09 \pm 0.05\%$, which are used in the determination of the $\bar{D}^0$ decay model.

3 Determination of $\bar{D}^0 \to K_s\pi^+\pi^-$ decay model

The amplitude f of the $\bar{D}^0 \to K_s\pi^+\pi^-$decay is represented by a coherent sum of two-body decay matrix elements, each having its own amplitude and phase, plus one non-resonant decay amplitude. To be consistent with the CLEO analysis, [6] we have chosen the $K_s\rho$ mode to have unit amplitude and zero relative phase, and use an established description of the matrix elements. [7]

We use a set of 15 two-body amplitudes, as shown in Table 1. These include four Cabibbo-allowed $K^*\pi$ amplitudes, their doubly Cabibbo-suppressed partners, and seven channels with K_s and a $\pi\pi$ resonance. The masses and Breit-Wigner widths of scalars σ_1 and σ_2 are left unconstrained, while the parameters of other resonances are the same as in the CLEO analysis. [6] The parameters of the σ resonances obtained in the fit are as follows: $M_{\sigma_1} = 539 \pm 9$ MeV/c^2, $\Gamma_{\sigma_1} = 453 \pm 16$ MeV/c^2, $M_{\sigma_2} = 1048 \pm 7$ MeV/c^2, $\Gamma_{\sigma_2} = 109 \pm 11$ MeV/c^2.

We perform an unbinned maximum likelihood fit to the Dalitz plot distribution. The fit function is represented by the sum of the squared absolute value of the decay amplitude $|f(m_+^2, m_-^2)|^2$ and the background distribution, with momentum resolution and detector efficiency taken into account. The amplitudes and phases obtained from the fit are presented in Table 1.

Table 1: *Fit results for $\bar{D^0} \to K_s\pi^+\pi^-$ decay. Errors are statistical only.*

Resonance	Amplitude	Phase ($^\circ$)
$K^*(892)^-\pi^+$	1.656 ± 0.012	137.6 ± 0.6
$K^*(892)^+\pi^-$	$(14.9 \pm 0.7) \times 10^{-2}$	325.2 ± 2.2
$K_0^*(1430)^-\pi^+$	1.96 ± 0.04	357.3 ± 1.5
$K_0^*(1430)^+\pi^-$	0.30 ± 0.05	128 ± 8
$K_2^*(1430)^-\pi^+$	1.32 ± 0.03	313.5 ± 1.8
$K_2^*(1430)^+\pi^-$	0.21 ± 0.03	281 ± 9
$K^*(1680)^-\pi^+$	2.56 ± 0.22	70 ± 6
$K^*(1680)^+\pi^-$	1.02 ± 0.2	103 ± 11
$K_s\rho^0$	1.0(fixed)	0(fixed)
$K_s\omega$	$(33.0 \pm 1.3) \times 10^{-3}$	114.3 ± 2.3
$K_sf_0(980)$	0.405 ± 0.008	212.9 ± 2.3
$K_sf_0(1370)$	0.82 ± 0.10	308 ± 8
$K_sf_2(1270)$	1.35 ± 0.06	352 ± 3
$K_s\sigma_1$	1.66 ± 0.11	218 ± 4
$K_s\sigma_2$	0.31 ± 0.05	236 ± 11
non-resonant	6.1 ± 0.3	146 ± 3

4 Dalitz plot analysis of $B^\pm \to D^{(*)}K^\pm$ decay

The Dalitz plots (shown for $B^\pm \to DK^\pm$ candidates in Fig. 2) are fitted by minimizing the combined logarithmic likelihood function for B^- and B^+ data sets. The corresponding Dalitz plot densities are based on decay amplitudes $M_\pm$ described by Eqs. 1 (B^+) and 2 (B^-). The $\bar{D^0}$ decay model f is fixed, and the free parameters of the fit are the amplitude ratio r and phases ϕ_3 and δ. Contributions from several background sources are taken into account; the largest background source is of combinatoric origin.

To test the consistency of the fit, we use $B^\pm \to D^{(*)}\pi^\pm$ and $\bar{B^0}(B^0) \to D^{*\pm}\pi^\mp$ control samples. For the control sample fits, we consider B^+ and B^- data separately, to check for the absence of CP violation. In the fit of $B^\pm \to D\pi^\pm$ data, we obtain $r \sim 0.06$, more than two standard deviations from zero; however, no CP asymmetry is found. (Note that a non-zero amplitude ratio is expected - $r \sim |V_{ub}V_{cd}^*|/|V_{cb}V_{ud}^*| \sim 0.02$). This bias is considered as a systematic effect. The other control samples do not show any significant deviation from $r = 0$.

The combined unbinned maximum likelihood fit of B^+ and B^- samples with free parameters r, ϕ_3 and δ yields the following values: $r = 0.31 \pm 0.11$, $\phi_3 = 86^\circ \pm 17^\circ$, $\delta = 168^\circ \pm 17^\circ$ for $B^\pm \to DK^\pm$ and $r = 0.34 \pm 0.14$, $\phi_3 = 51^\circ \pm 25^\circ$, $\delta = 302^\circ \pm 25^\circ$ for $B^\pm \to D^*K^\pm$.

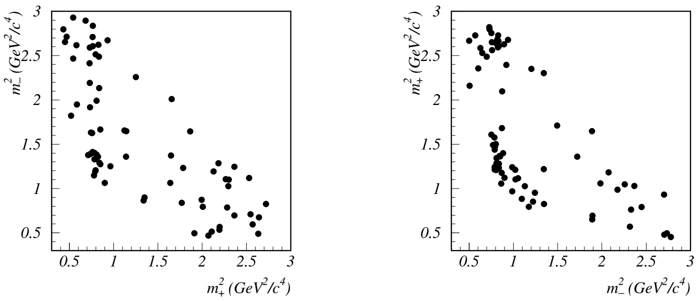

Figure 2: *Dalitz plots for (left) $B^+ \to DK^+$ and (right) $B^- \to DK^-$ candidates. CP violation would appear as a difference between these two plots.*

To estimate the statistical errors we do not use the values obtained from the likelihood fit given above, but follow a Bayesian approach in which a large number of MC pseudo-experiments are used to obtain a probability density function (PDF) of the fitted parameters for any set of true parameters.

The results for ϕ_3 from the "toy" MC are: $\phi_3 = 86 \pm 20^\circ(49^\circ)$ for $B^\pm \to DK^\pm$ and $\phi_3 = 51 \pm 47^\circ(82^\circ)$ for $B^\pm \to D^*K^\pm$; where the errors are 68% (95%) confidence limits. We obtain a combined result from $B^\pm \to DK^\pm$ and $B^\pm \to D^*K^\pm$ by multiplying the ϕ_3 PDFs; the result is $\phi_3 = 81 \pm 19^\circ(46^\circ)$.

The model used for the $\bar{D}^0 \to K_s\pi^+\pi^-$ decay is one of the main sources of uncertainty in our analysis. To estimate the model uncertainties, a MC simulation is performed. Event samples are generated according to the amplitude described by Eqs. 1 and 2 with resonance parameters as in Table. 1, and then fit these samples with different models for $f(m_+, m_-)$. Since the Breit-Wigner amplitude only describes narrow resonances well, we scan for the maximum deviation of the fit parameters using a fit model containing only narrow resonances, with wide ones approximated by a constant complex term. The estimated value of the systematic uncertainty on ϕ_3 is 11°.

Other sources of systematic errors include the uncertainties of the knowledge of the detector response, background estimation and possible fit biases. The non-zero amplitude ratio observed in the $B^\pm \to D\pi^\pm$ control sample may be due to a statistical fluctuation or may indicate some systematic effect such as background structure or a deficiency of the decay model; we conservatively treat it as an additional systematic effect. The corresponding bias of the weak and strong phases is 11°; this contribution dominates the systematic error.

5 Conclusion

We have studied a new method to measure the unitarity triangle angle ϕ_3 using Dalitz plot analysis of the three-body D^0 decay in the process $B^\pm \to$

$D^{(*)}K^{\pm}$. The first measurement of ϕ_3 using this technique was performed based on 140 fb^{-1} statistics collected by the Belle detector. From the combined fit of $B^{\pm} \to DK^{\pm}$ and $B^{\pm} \to D^{*}K^{\pm}$ modes, we obtain the value of $\phi_3 = 81^{\circ} \pm 19^{\circ} \pm 13^{\circ} \pm 11^{\circ}$. The first error is statistical, the second is experimental systematics and the third is model uncertainty. The 95% confidence interval is $35^{\circ} < \phi_3 < 127^{\circ}$ The statistical significance of the CP violation is 94% for $B^{\pm} \to DK^{\pm}$ mode and 38% for $B^{\pm} \to D^{*}K^{\pm}$ mode.

The method has a number of advantages over other methods to measure ϕ_3. [3] It is directly sensitive to the value of ϕ_3 and has only one discrete ambiguity. Note that the results presented here have been superseded. [1]

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