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Measurement of $sin(2\phi_1 + \phi_3)$ at Belle

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We report measurements of time dependent decay rates for $B^0(\overline{B}^0) \to D^{(*)\mp}\pi^{\pm}$ decays and extraction of CP violation parameters containing ϕ_3. Using fully reconstructed $D^{(*)}\pi$ events and partially reconstructed $D^*\pi$ events from a data sample containing 152 million $B\overline{B}$ pairs that was collected near the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric energy e^+e^- collider, we obtain the CP violation parameters $S^{\pm} \equiv 2R_{D^{(*)}\pi} \sin(2\phi_1 + \phi_3 \pm \delta_{D^{(*)}\pi})$, where $R_{D^{(*)}\pi}$ is the ratio of the magnitudes of the doubly-Cabibbo-suppressed and Cabibbo-favoured amplitudes, and $\delta_{D^{(*)}\pi}$ is the strong phase difference between them.

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1. Introduction

Within the Standard Model (SM), *CP* violation arises due to a single phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [1]. Precise measurements of CKM matrix parameters therefore constrain the SM, and may reveal new sources of *CP* violation. Measurements of the time-dependent decay rates of $B^0 \to D^{(*)\mp}\pi^{\pm}$ provide a theoretically clean method for extracting $\sin(2\phi_1+\phi_3)$ [2]. These decays can be mediated by both Cabibbo-favoured ($V_{cb}^* V_{ud}$) and Cabibbo-suppressed ($V_{ub}^* V_{cd}$) amplitudes, which have a relative weak phase ϕ_3.

The interference of the Cabibbo-favoured (CFD) and doubly Cabibbo-suppressed (DCSD) decays with mixing leads to time-dependent decay probabilities written:

$$\begin{aligned} P(B^0 \to D^{(*)\pm}\pi^{\mp}) &\approx \frac{1}{8\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} [1 \mp \cos(\Delta m \Delta t) - S^{\pm} \sin(\Delta m \Delta t)] \\ P(\overline{B}^0 \to D^{(*)\pm}\pi^{\mp}) &\approx \frac{1}{8\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} [1 \pm \cos(\Delta m \Delta t) - S^{\pm} \sin(\Delta m \Delta t)] \end{aligned} \tag{1.1}$$

where $S^{\pm} = (-1)^L 2R_{D^{(*)}\pi} \sin(2\phi_1 + \phi_3 \pm \delta_{D^{(*)}\pi})$. L is the angular momentum of the final state (1 for $D^*\pi$), $R_{D^{(*)}\pi}$ is the ratio of magnitudes of the suppressed and favoured amplitudes, and $\delta_{D^{(*)}\pi}$ is their strong phase difference. It is assumed that $R_{D^{(*)}\pi}$ is small and second order terms in $R_{D^{(*)}\pi}$ can be neglected.

The *CP*-violating parameters $\sin(2\phi_1+\phi_3)$ were measured with the Belle detector [3] using a full reconstruction of $B^0 \to D^{(*)}\pi$ decays and a partial reconstruction of $B^0 \to D^*\pi$ decays [4]. Both analyses are based on a sample of 140 fb^{-1}, corresponding to 152 million $B\overline{B}$ pairs.

2. Full reconstruction

For the full reconstruction of $\overline{B}^0 \to D^{*+}\pi^-$ events, we use the decay chain $D^{*+} \to D^0\pi^+$ and $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$. For the $\overline{B}^0 \to D^+\pi^-$ event selection, we use $D^+ \to K^-\pi^+\pi^+$ decays. We select B candidates using requirements on the energy difference $\Delta E \equiv \sum_i E_i - E_{\rm beam}$ and the beam-energy constrained mass $M_{\rm bc} \equiv \sqrt{E_{\rm beam}^2 - (\sum_i \vec{p}_i)^2}$, where $E_{\rm beam}$ is the beam energy, and $\vec{p}_i$ and E_i are the momenta and energies of the daughters of the reconstructed B meson candidate, all in the $\Upsilon(4S)$ rest frame. The signal yields are extracted by a 2D fit to the $(\Delta E, M_{\rm bc})$ plane (see Table 1).

Decay mode	Candidates	Selected	Purity
$B \to D\pi$	9711	9351	91%
$B \to D^*\pi$	8140	7763	96%

Table 1: Number of reconstructed candidates, selected candidates (after tagging and vertexing) and purity, extracted from the fit to $(\Delta E, M_{\rm bc})$

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The standard Belle tagging algorithm [5] is used to identify the flavour of the accompanying B meson. It returns the flavour and a tagging quality r used to classify events in six bins. The standard Belle vertexing algorithm [6] is then used to obtain the proper-time difference Δt.

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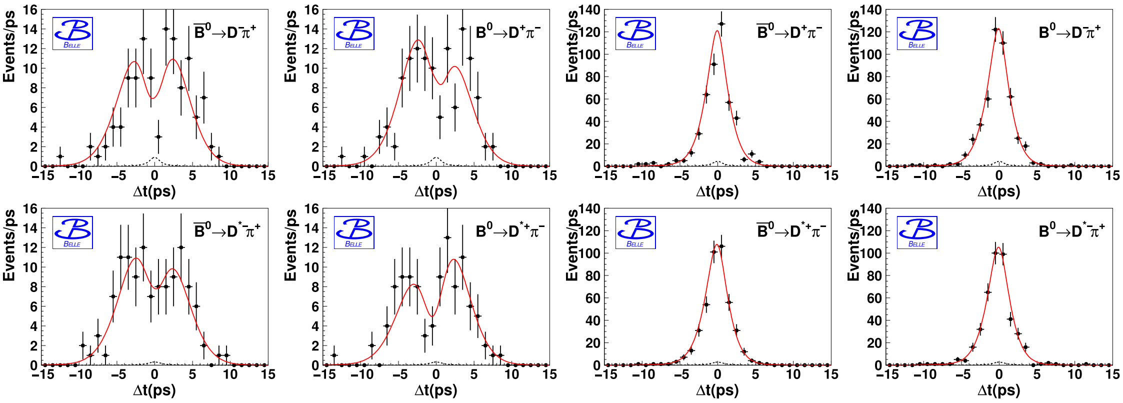

Figure 1: Δt distributions for the events with the best quality flavour tagging.

The $S^{\pm}$ have to be corrected to take into account possible tag-side interference due to tagging on $B^0 \to DX$ decays [7]. Effective corrections $\{S^{\pm}_{\text{tag}}\}^{\text{eff}}$ are determined for each r bin by a fit to fully reconstructed $D^*\ell\nu$ events, where the reconstructed side asymmetry is known to be zero.

Finally, a fit is performed to determine $S^{\pm}$, with Δm and τ_{B^0} fixed to the world average, and the wrong-tag fractions and $\{S^{\pm}_{\text{tag}}\}$ for each r bin fixed to the values determined previously. We obtain:

$$\begin{aligned} 2R_{D\pi}\sin(2\phi_1+\phi_3+\delta_{D\pi}) &= 0.087\pm 0.054\pm 0.018 \\ 2R_{D\pi}\sin(2\phi_1+\phi_3-\delta_{D\pi}) &= 0.037\pm 0.052\pm 0.018 \\ 2R_{D^*\pi}\sin(2\phi_1+\phi_3+\delta_{D^*\pi}) &= 0.109\pm 0.057\pm 0.019 \\ 2R_{D^*\pi}\sin(2\phi_1+\phi_3-\delta_{D^*\pi}) &= 0.011\pm 0.057\pm 0.019 \end{aligned} \tag{2.1}$$

The systematic errors come from the uncertainties of parameters that are constrained in the fit and uncertainties on the tagging side asymmetry. The result of the fit for the subsamples having the best quality flavour tagging is shown on Figure 1.

3. Partial reconstruction

The partial reconstruction of $B^0 \to D^*(\to D^0\pi_s)\pi_f$ is performed by requiring a fast pion π_f and a slow pion π_s, without any requirement on the D^0. The candidate selection exploits the 2-body kinematics of the decay using 3 variables: the fast pion CM momentum; the cosine of the angle between the fast pion direction and the opposite of the slow pion direction in the CM; the angle between the slow pion direction and the opposite of the B direction in the D^* rest frame. Yields are extracted from a 3D fit to these variables (see Table 2). The flavour of the accompanying B meson is identified by a fast lepton, ℓ_{tag}. The proper time Δt is obtained from the z coordinate of π_f and ℓ_{tag} constrained to the B-lifetime smeared beam profile.

The resolution function is modeled by a convolution of three gaussians whose parameters are determined by a fit to a $J/\psi \to \mu^+\mu^-$ sample selected the same way as the signal sample. In order to correct for possible biases due to tiny misalignements in the tracking devices that would mimic *CP* violation, the mean of the gaussian resolution is allowed to be slightly offset.

A fit for Δm and τ_{B^0} is performed to check the fit procedure. A fit to a $D*\ell\nu$ sample selected similarly to the signal sample is performed to check the bias correction.

Mode	Data	Signal	$D^*\rho$	Corr. bkg	Uncorr. bkg
SF	2823	1908	311	—	637
OF	10078	6414	777	928	1836

Table 2: Fit yield for the signal and the various types of background in same-flavour (SF) and opposite-flavour (OF) events.

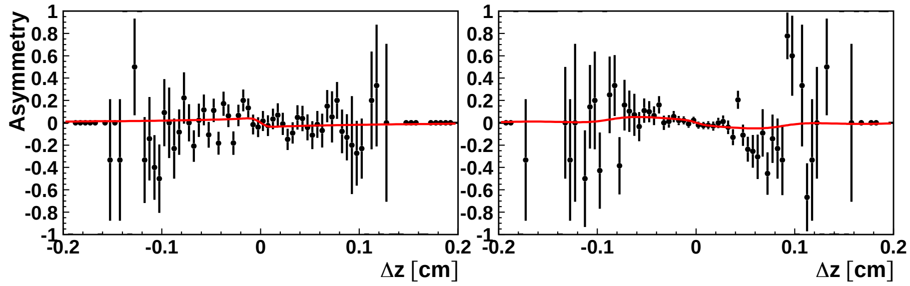

Figure 2: SF and OF partial reconstruction asymmetries and projection of the fit result.

An unbinned maximum likelihood fit with Δm and τ_{B^0} fixed to the world average, and $S^{\pm}$, Δt offsets and wrong-tag fractions floated, yields:

$$2R_{D^*\pi}\sin(2\phi_1+\phi_3+\delta_{D^*\pi}) = -0.035\pm0.041\pm0.018$$
$$2R_{D^*\pi}\sin(2\phi_1+\phi_3-\delta_{D^*\pi}) = -0.025\pm0.041\pm0.018 \qquad (3.1)$$

The main systematic errors come from the background fractions, the background shapes, the resolution function and the offsets. Figure 2 shows the fit result projected on the *CP* asymmetries $\mathscr{A}^{\rm SF} = (N_{\pi^-\ell^-}-N_{\pi^+\ell^+})/(N_{\pi^-\ell^-}+N_{\pi^+\ell^+})$ and $\mathscr{A}^{\rm OF} = (N_{\pi^+\ell^-}-N_{\pi^-\ell^+})/(N_{\pi^+\ell^-}+N_{\pi^-\ell^+})$.

4. Outlook

Increase of the available data and addition of more modes in the full reconstruction, as well as tuning of the selection and vertexing on more Monte Carlo and data, will help reduce both statistical and systematic errors in a very near future. A reduction by a factor 0.3 for the former and 0.5 for the latter is expected with 1 ab^{-1}.

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