Study of CP Violating Effects in Time Dependent 

\[ B^0(\bar{B}^0) \rightarrow D^{(*)\mp} \pi^\pm \] 

decays

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Abstract

We report measurements of time dependent decay rates for \(B^0(B^0) \to D^{(*)\pm}\pi^\pm\) decays and extraction of CP violation parameters containing \(\phi_3\). Using fully reconstructed \(D^{(*)}\pi\) events from a 140 fb\(^{-1}\) data sample collected at the \(\Upsilon(4S)\) resonance, we obtain the CP violation parameters for \(D^*\pi\) and \(D\pi\) decays, 

\[
2R_{D^{(*)}\pi}\sin(2\phi_1 + \phi_3 \pm \delta_{D^{(*)}\pi}),
\]

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. Under the assumption of \(\delta_{D^{(*)}\pi}\) being close to either 0 or 180\(^\circ\), we obtain 

\[
|2R_{D^*\pi}\sin(2\phi_1 + \phi_3)| = 0.060 \pm 0.040\text{(stat)} \pm 0.019\text{(sys)}
\]

and

\[
|2R_{D\pi}\sin(2\phi_1 + \phi_3)| = 0.061 \pm 0.037\text{(stat)} \pm 0.018\text{(sys)}.
\]

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The good agreement between direct measurements of $\sin 2\phi_1$ \[1\] \[2\] and the outcome of global fits to the CKM quark mixing matrix elements \[3\] strongly supports the standard model explanation of CP violation. To determine whether it is the complete description or whether additional factors come into play, further measurements of other CKM parameters are required. Among these parameters $\phi_3$ is of particular importance. The measurements of time-dependent decay rates of $B^0(\bar{B}^0) \rightarrow D^{(*)\mp}\pi^\pm$ provide a theoretically clean method for extracting $\sin(2\phi_1 + \phi_3)$, since loop diagrams do not contribute to these decays \[4\].

There are two ways for a state which is initially $B^0$ to be found as $D^{(*)-}\pi^+$ at a later time $t$. It can occur either directly through a Cabibbo-favoured decay (CFD) or through mixing followed by doubly-Cabibbo-suppressed decay (DCSD), as shown in Fig. 1. Interference of the two processes introduces the term containing $\phi_3$ to the time dependent decay rates, which are given by \[5\] \[6\]

\[
P(B^0 \rightarrow D^{(*)+}\pi^-) = c[1 - \cos \Delta mt - 2\Im \rho \sin \Delta mt]
\]
\[
P(B^0 \rightarrow D^{(*)-}\pi^+) = c[1 + \cos \Delta mt + 2\Im \rho \sin \Delta mt]
\]
\[
P(\bar{B}^0 \rightarrow D^{(*)+}\pi^-) = c[1 + \cos \Delta mt + 2\Im \rho \sin \Delta mt]
\]
\[
P(B^0 \rightarrow D^{(*)-}\pi^+) = c[1 - \cos \Delta mt - 2\Im \rho \sin \Delta mt]
\]

(1)

where $c = (e^{-t/\tau_{B^0}})/2\tau_{B^0}$ with $\tau_{B^0}$ denoting the lifetime of the neutral $B$ meson and $\Delta m$ is the $B^0-\bar{B}^0$ mixing parameter. The $\rho$ and $\bar{\rho}$ are defined as $\rho = (q/p)(|A(\bar{B}^0 \rightarrow D^{(*)-}\pi^+)|/|A(B^0 \rightarrow D^{(*)-}\pi^+)|)$ and $\bar{\rho} = (p/q)(|A(B^0 \rightarrow D^{(*)+}\pi^-)|/|A(\bar{B}^0 \rightarrow D^{(*)+}\pi^-)|)$, where $p$ and $q$ relate the mass eigenstates to the flavour eigenstates in the neutral $B$ meson system \[7\]. They lead to CP violating terms $\Im \rho = -(1)^L R \sin(2\phi_1 + \phi_3 - \delta)$ and $\Im \bar{\rho} = -(1)^L R \sin(2\phi_1 + \phi_3 + \delta)$, where $R$ is the ratio of the magnitudes of the DCSD and CFD amplitudes (here the magnitudes of both the CFD and DCSD amplitudes are assumed to be same for $B^0$ and $\bar{B}^0$ decays), $\delta$ is the strong phase difference between DCSD and CFD, and $L$ is the angular momentum of the final state (1 for $D^*\pi$ and 0 for $D\pi$). $R$ and $\delta$ are not necessarily the same for $D^*\pi$ and $D\pi$ final states, and are denoted with subscripts, $D^*\pi$ and $D\pi$, in what follows.

This study uses a 140 fb$^{-1}$ data sample, which contains 152 million $B\bar{B}$ events, collected with the Belle detector \[8\] at the KEKB collider \[9\]. The selection of hadronic events is described elsewhere \[10\].

For the $\bar{B}^0 \rightarrow D^{(*)+}\pi^-$ event selection, we use the decay chain $D^{*+} \rightarrow D^0\pi^+$, and $D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^0$ or $K^-\pi^+\pi^+\pi^-$ (charge conjugate modes are implied throughout this paper). For the $B^0 \rightarrow D^{+}\pi^-$ event selection, we use $D^+ \rightarrow K^-\pi^+\pi^+$ decays. Charged tracks except the slow $\pi^+$ in the $D^{+}\rightarrow D^0\pi^+$ decay are required to have a minimum of one hit (two hits) in the $r-$ $\phi$ (z) plane of the vertex detector in order to allow precise vertex determination. To separate kaons from pions, we form a likelihood for each track, $L_{K(\pi)}$. The kaon likelihood

\[
L_{K} = \frac{1}{1 + e^{-(x - \mu)}}
\]

where $x$ is the drift chamber hit parameter for each track, $\mu$ is the mean of the distribution parameter for pions, and $\sigma$ is the standard deviation of the distribution parameter for pions. The pion likelihood

\[
L_{\pi} = 1 - L_{K}
\]

where $L_{\pi}$ is the probability of a pion being detected. The likelihood for each track is calculated using the parameters $\mu$ and $\sigma$ for pions. The final likelihood for each track is calculated by combining the likelihoods for each track using the weights $w_{K}$ and $w_{\pi}$, which are the weights for kaons and pions, respectively.

\[
L_{K(\pi)} = w_{K} L_{K} + w_{\pi} L_{\pi}
\]

where $w_{K}$ and $w_{\pi}$ are the weights for kaons and pions, respectively.

\[
E_{K(\pi)} = \frac{1}{1 + e^{-(x - \mu)}}
\]

where $E_{K(\pi)}$ is the energy of the track, $x$ is the drift chamber hit parameter for each track, $\mu$ is the mean of the distribution parameter for pions, and $\sigma$ is the standard deviation of the distribution parameter for pions. The energy for each track is calculated using the parameters $\mu$ and $\sigma$ for pions. The final energy for each track is calculated by combining the energies for each track using the weights $w_{K}$ and $w_{\pi}$, which are the weights for kaons and pions, respectively.

\[
E_{K(\pi)} = w_{K} E_{K} + w_{\pi} E_{\pi}
\]

where $E_{K(\pi)}$ is the energy of the track, $E_{K}$ is the energy of the kaon, $E_{\pi}$ is the energy of the pion, $w_{K}$ is the weight for kaons, and $w_{\pi}$ is the weight for pions.

\[
E_{K(\pi)} = \frac{1}{1 + e^{-(x - \mu)}}
\]

where $E_{K(\pi)}$ is the energy of the track, $x$ is the drift chamber hit parameter for each track, $\mu$ is the mean of the distribution parameter for pions, and $\sigma$ is the standard deviation of the distribution parameter for pions. The energy for each track is calculated using the parameters $\mu$ and $\sigma$ for pions. The final energy for each track is calculated by combining the energies for each track using the weights $w_{K}$ and $w_{\pi}$, which are the weights for kaons and pions, respectively.

\[
E_{K(\pi)} = w_{K} E_{K} + w_{\pi} E_{\pi}
\]

where $E_{K(\pi)}$ is the energy of the track, $E_{K}$ is the energy of the kaon, $E_{\pi}$ is the energy of the pion, $w_{K}$ is the weight for kaons, and $w_{\pi}$ is the weight for pions.

\[
E_{K(\pi)} = \frac{1}{1 + e^{-(x - \mu)}}
\]

where $E_{K(\pi)}$ is the energy of the track, $x$ is the drift chamber hit parameter for each track, $\mu$ is the mean of the distribution parameter for pions, and $\sigma$ is the standard deviation of the distribution parameter for pions. The energy for each track is calculated using the parameters $\mu$ and $\sigma$ for pions. The final energy for each track is calculated by combining the energies for each track using the weights $w_{K}$ and $w_{\pi}$, which are the weights for kaons and pions, respectively.
ratio, \( P(K/\pi) = \mathcal{L}_K/(\mathcal{L}_K + \mathcal{L}_\pi) \), has values between 0 (likely to be a pion) and 1 (likely to be a kaon). We require charged kaons to satisfy \( P(K/\pi) > 0.3 \). No such requirement is imposed to select charged pions coming from \( D \) decays.

For \( D^0 \) selection, the invariant mass of the daughter particles is required to be within \( \pm 16.5 \text{ MeV}/c^2 \), \( \pm 24.0 \text{ MeV}/c^2 \), and \( \pm 13.5 \text{ MeV}/c^2 \) of the nominal \( D^0 \) mass, for \( K^{-}\pi^+ \), \( K^{-}\pi^+\pi^0 \), and \( K^{-}\pi^+\pi^+\pi^- \) modes, respectively. These intervals correspond to \( \pm 3\sigma \), where \( \sigma \) is the Monte Carlo determined invariant mass resolution. For the \( D^+ \), the invariant mass is required to be within \( \pm 12.5 \text{ MeV}/c^2 \) of the nominal \( D^+ \) mass. For the \( D^0 \to K^{-}\pi^+\pi^0 \) reconstruction, we further require the \( \pi^0 \) momentum to be greater than 200 MeV/c in the \( \Upsilon(4S) \) rest frame, and the ratio of the second to zeroth Fox-Wolfram moments \[^{10} R_2 \] to be less than 0.55. We require \( R_2 < 0.5 \) for \( D^+ \to K^{-}\pi^+\pi^+ \). We use a mass- and vertex-constrained fit for \( D^0 \) and a vertex-constrained fit for \( D^+ \).

The \( D^{*+} \) is reconstructed by combining \( D^0 \) candidates with a slow \( \pi^+ \). Here, slow pions are required to have momentum less than 300 MeV/c in the \( \Upsilon(4S) \) rest frame. The \( D^* \) candidates are required to have a mass difference \( \Delta M \equiv M_{D^0\pi} - M_{D^0} \) within \( \pm 7 \text{ MeV}/c^2 \), \( \pm 2 \text{ MeV}/c^2 \), or \( \pm 4 \text{ MeV}/c^2 \) of the nominal value, for the \( K^{-}\pi^+ \), \( K^{-}\pi^+\pi^0 \), and \( K^{-}\pi^+\pi^+\pi^- \) modes respectively.

We reconstruct \( B \) candidates by combining the \( D^{(*)+} \) candidate with a \( \pi^- \) candidate satisfying \( P(K/\pi) < 0.8 \). We identify \( B \) decays based on requirements on the energy difference \( \Delta E \equiv \sum_i E_i - E_{\text{beam}} \) and the beam-energy constrained mass \( M_{bc} \equiv \sqrt{E_{\text{beam}}^2 - (\sum_i \vec{p}_i)^2} \), where \( E_{\text{beam}} \) is the beam energy, \( \vec{p}_i \) and \( E_i \) are the momenta and energies of the daughters of the reconstructed \( B \) meson candidate, all in the \( \Upsilon(4S) \) rest frame. If more than one \( B \) candidate is found in the same event, we select the one with best \( D \) vertex quality. We define a signal region in the \( \Delta E-M_{bc} \) plane of 5.27 GeV/c\(^2\) < \( M_{bc} < 5.29 \text{ GeV}/c^2 \) and \( |\Delta E| < 0.045 \text{ GeV} \), corresponding to about \( \pm 3\sigma \) of both quantities. For the determination of background parameters, we use events in a sideband region defined by \( M_{bc} > 5.2 \text{ GeV}/c^2 \) and \( -0.14 \text{ GeV} < \Delta E < 0.20 \text{ GeV} \), excluding the signal region.

Charged leptons, pions, and kaons that are not associated with the reconstructed \( D^{(*)+} \) decays are used to identify the flavour of the accompanying \( B \) meson. The algorithm \[^{[1]} \] leads to two parameters, \( q \) and \( r \), where \( q = +1 \) indicates \( \bar{B}^0 \) and \( q = -1 \) indicates \( B \) hence \( B^0 \). The parameter \( r \) is an event-by-event dilution factor ranging from \( r = 0 \) for no flavour discrimination to \( r = 1 \) for unambiguous flavour assignment. More than 99.5\% of the events are assigned non-zero values of \( r \).

The decay vertices of the \( B \to D^{(*)+} \pi \) are fitted using the momentum vectors of the \( D \) and \( \pi \) (except the slow \( \pi \) from \( D^* \) decay) and a requirement that they are consistent with the interaction region profile. For the decay vertices of the tagging \( B \) meson, the remaining well reconstructed tracks in the event are used. Tracks that are consistent with \( K_d^0 \) decay are rejected. The proper-time difference between the fully reconstructed and the associated \( B \) decay is calculated as \( \Delta t = (z_{\text{rec}} - z_{\text{tag}})/c\beta\gamma \), where \( z_{\text{rec}} \) and \( z_{\text{tag}} \) are the \( z \) coordinates of the two \( B \) decay vertices and \( \beta\gamma = 0.425 \) is the Lorentz boost factor at KEKB. After application of the event selection criteria and the requirement that both \( B \)'s have well defined vertices and \( |\Delta t| < 70 \text{ ps} \) \((\sim 45 \tau_{B^0})\), 7763 and 9351 events remain as the \( D^*\pi \) and \( D\pi \) candidates, respectively. The signal fractions of the samples, which vary for different \( r \) bins, are 96\% for \( D^*\pi \) and 91\% for \( D\pi \).

Unbinned maximum likelihood fits to the four time dependent decay rates are performed to extract \( 3\rho \) and \( 3\bar{\rho} \). We minimize \( -2 \sum_i \ln L_i \) where the likelihood for the \( i \)-th event is
given by

\[ L_i = (1 - f_{ol}) [f_{sig} P_{sig} \otimes R_{sig} + (1 - f_{sig}) P_{bkg} \otimes R_{bkg}] + f_{ol} P_{ol}. \]

The signal fraction \( f_{sig} \) is determined from the \((\Delta E, M_{bc})\) value of each event. The signal distribution is the product of the sum of two Gaussian in \( \Delta E \) and a Gaussian in \( M_{bc} \); that for the background is the product of a first order polynomial in \( \Delta E \) and an ARGUS function \([11]\) in \( M_{bc} \).

The \( \Delta t \) distribution is modeled by a core distribution convolved with resolutions. A small number of events have poorly reconstructed vertices resulting in a very broad distribution \( \Delta t \). We account for the contributions from these “outliers” by adding a Gaussian component \( P_{ol} \) with a width and fraction determined from the \( B \) lifetime analysis \([12]\). The \( \Delta t \) resolution, denoted by \( R_{sig} \) and \( R_{bkg} \) for the signal and background, is determined on an event-by-event basis, using the estimated uncertainties on the \( z \) vertex positions \([13]\).

The signal \( \Delta t \) distributions are given by

\[
P_{sig}(q = -1, D^{(*)\pm\pi^\mp}) = (1 - w_-) P(B^0 \rightarrow D^{(*)\pm\pi^\mp}) + w_+ P(\bar{B}^0 \rightarrow D^{(*)\pm\pi^\mp}) \]

\[
P_{sig}(q = +1, D^{(*)\pm\pi^\pm}) = (1 - w_+) P(\bar{B}^0 \rightarrow D^{(*)\pm\pi^\pm}) + w_- P(B^0 \rightarrow D^{(*)\pm\pi^\mp})
\]

(2)

where \( w_- \) and \( w_+ \) are wrong tag fractions for the \( q = -1 \) and \( q = +1 \) samples, respectively. \( P \)'s are given by Eq. [1] with \( t \) and \( c \) replaced by \( \Delta t \) and \((e^{-|\Delta t|/\tau_{B^0}})/4\tau_{B^0}\), respectively.

The background \( \Delta t \) distribution is parameterized as a sum of a \( \delta \)-function component and an exponential component with a lifetime \( \tau_{bkg} \)

\[
P_{bkg} = f_{bkg}^\delta \delta(|\Delta t - \mu_{bkg}^\delta|) + \frac{(1 - f_{bkg}^\delta)}{2\tau_{bkg}} e^{-|\Delta t - \mu_{bkg}^\delta|/\tau_{bkg}}
\]

(3)

where \( f_{bkg}^\delta \) is the fraction of events contained in the \( \delta \)-function, and \( \mu_{bkg}^\delta \) and \( \mu_{bkg}^\tau \) are the mean values of \(|\Delta t|\) in the \( \delta \)-function and exponential components, respectively.

While the tagging side should have no asymmetry if the flavour is tagged by primary leptons, it is possible to introduce a small asymmetry when daughter particles of hadronic decays such as \( D^{(*)}\pi \) are used for the flavour tagging, due to the same CP violating effect, which is the subject of this paper \([14]\). This effect is taken into account by replacing the coefficients of \( \sin \Delta m t \) in Eqs. [1] by \( 3\rho - 3\rho^* \), \( 3\rho - 3\rho' \), \( 3\rho - 3\rho^* \), and \( 3\rho - 3\rho' \), respectively. Here the \( 3\rho' \) and \( 3\rho^* \) represent the CP violating effect due to the presence of \( B^0 \rightarrow DX \) and \( \bar{B}^0 \rightarrow DX \) amplitudes in the flavour tagging side. Note that unlike the \( 3\rho \) and \( 3\rho' \), which are rigorously defined in terms of \( B^0 \rightarrow D^{(*)\mp}\pi^\pm \) and \( B^0 \rightarrow D^{(*)\pm}\pi^\mp \) amplitudes, \( 3\rho' \) and \( 3\rho^* \) are effective quantities that include effects of the fraction of \( B \rightarrow DX \) components in the tagging \( B \) decays and all experimental effects of subsequent behaviour of \( D \) mesons. Therefore, these quantities must be determined experimentally.

The values of \( 3\rho' \) and \( 3\rho^* \) are determined in each of six \( r \) bins by fitting the \( \Delta t \) distributions of a \( D^*\ell\nu \) control sample \([13]\) using the signal distributions of Eq. [2] and setting \( 3\rho \) and \( 3\rho^* \) to zero. Since the \( D^*\ell\nu \) final states have specific flavour, any observable
asymmetry must originate from the tagging side. The results for the combined $r$ bins are $2\Delta \rho' = 0.038 \pm 0.014(\text{stat}) \pm 0.005(\text{sys})$ and $2\Delta \bar{\rho}' = 0.002 \pm 0.014(\text{stat}) \pm 0.009(\text{sys})$.

The procedures for $\Delta t$ determination and flavour tagging are tested by extracting $\tau_{B^0}$ and $\Delta m$. When all four signal categories in Eq. 1 are combined, the signal $\Delta t$ distribution reduces to an exponential lifetime distribution. We obtain $\tau_{B^0} = 1.583 \pm 0.029$ ps ($1.575 \pm 0.032$ ps) for the $D^*\pi$ ($D\pi$) samples, in good agreement with the world average ($1.542 \pm 0.016$ ps) [3]. Combining the two CFD-dominant modes and the two mixing-dominant modes and ignoring the CP violating terms, the asymmetry behaves as $\cos \Delta m_t$. We then perform fits to determine the $\Delta m$ and $\tau$ for the $D^*\pi$ ($D\pi$) samples, also in good agreement with the world average ($0.489 \pm 0.008$ ps$^{-1}$) [3]. The same fits also provide wrong tag fractions $w_-$ and $w_+$ in each $r$ bin for both $D^*\pi$ and $D\pi$ data samples. The errors of our results are statistical only.

We then perform fits to determine the $3\rho$ and $3\bar{\rho}$ by fixing $\tau_{B^0}$ and $\Delta m_d$ to the world average values and using $w_-$, $w_+$, $3\rho'$, and $3\bar{\rho}'$ for each $r$ bin, as obtained from the above fits. The results are $2\Delta \rho_{D^*\pi} = 0.011 \pm 0.057$, $2\Delta \bar{\rho}_{D^*\pi} = -0.109 \pm 0.057$, $2\Delta \rho_{D\pi} = -0.037 \pm 0.052$, and $2\Delta \bar{\rho}_{D\pi} = 0.087 \pm 0.054$. The errors are statistical only. The $\Delta t$ distributions for the subsamples having the best quality flavour tagging ($0.875 < r < 1.000$) are shown in Fig. 2 for the $D^*\pi$ and in Fig. 3 for the $D\pi$ samples, respectively.

The systematic errors come from i) the uncertainties of parameters which are constrained in the fit, including $\Delta t$ resolution parameters, background parameters, wrong tag fractions, and physics parameters; ii) uncertainties of the tagging side asymmetries; iii) fit biases induced by the vertexing and other unknown factors. For item i), we repeat the fits varying each parameter value by $\pm 1\sigma$. To estimate item ii), we repeat the fits by varying the $3\rho'$ and $3\bar{\rho}'$ by their errors. Errors are not explicitly assigned for item iii), since they are included in the errors of $3\rho'$ and $3\bar{\rho}'$ from the $D^*l\nu$ control sample fit (item ii). Table I summarizes the systematic errors.

| TABLE I: Systematic errors in the $2R \sin(2\phi_1 + \phi_3 \pm \delta)$ extractions. |
|-------------------------------------------------|
| Sources                                        | $D^*\pi$ | $D\pi$ |
|------------------------------------------------|
| Signal $\Delta t$ resolution                   | 0.014    | 0.013  |
| Background $\Delta t$ shape                    | 0.001    | 0.003  |
| Background fraction                            | 0.002    | 0.001  |
| Wrong tag fraction                             | 0.006    | 0.006  |
| Vertexing                                      | 0.005    | 0.005  |
| Physics parameters ($\Delta m, \tau_{B^0}$)    | 0.001    | 0.002  |
| Tagging side asymmetry                         | 0.009    | 0.009  |
| Combined                                       | 0.019    | 0.018  |

We obtain

\[
2R_{D^*\pi} \sin(2\phi_1 + \phi_3 + \delta_{D^*\pi}) = 0.109 \pm 0.057 \pm 0.019,
\]
\[
2R_{D^*\pi} \sin(2\phi_1 + \phi_3 - \delta_{D^*\pi}) = 0.011 \pm 0.057 \pm 0.019,
\]
\[
2R_{D\pi} \sin(2\phi_1 + \phi_3 + \delta_{D\pi}) = 0.087 \pm 0.054 \pm 0.018,
\]
\[
2R_{D\pi} \sin(2\phi_1 + \phi_3 - \delta_{D\pi}) = 0.037 \pm 0.052 \pm 0.018.
\]
The first and second errors are statistical and systematic. At present, the statistical errors are too large to allow any meaningful conclusion to be drawn. However, it is interesting to consider how the four results can be combined using knowledge of $R$ and $\delta$ to improve the precision of $\sin(2\phi_1 + \phi_3)$. Several methods have been proposed to measure $R$ \cite{4}. A method that compares the branching fractions of $B^0 \to D_s^{(*)}+\pi^-$ and $B^0 \to D_s^{(*)}-\pi^+$ and uses factorization relation gives $R_{D\pi} = 0.0237 \pm 0.0050$ and $R_{D^*\pi} = 0.0180 \pm 0.0067$ \cite{16}. The present errors are too large to conclude that the two $R$ values are equal. On the other hand, there are solid theoretical grounds for assuming $\delta_{D^{(*)}\pi}$ and $\delta_{D\pi}$ to be very small and therefore equal \cite{17}. However, some argue that there is an ambiguity of 180° between $\delta_{D^*\pi}$ and $\delta_{D\pi}$ \cite{6}. Assuming $\delta_{D^{(*)}\pi}$ is close to either 0° or 180°, we obtain $|2R_{D^*\pi}\sin(2\phi_1 + \phi_3)| = 0.060 \pm 0.040(\text{stat}) \pm 0.019(\text{sys})$ and $|2R_{D^{(*)}\pi}\sin(2\phi_1 + \phi_3)| = 0.061 \pm 0.037(\text{stat}) \pm 0.018(\text{sys})$. 

FIG. 2: $\Delta t$ distributions for the $D^*\pi$ data in the $0.875 < r < 1.000$ flavour tagging quality bin. (a) $B^0 \to D^+\pi^-$, (b) $B^0 \to D^+\pi^+$, (c) $\bar{B}^0 \to D^+\pi^-$, (d) $\bar{B}^0 \to D^+\pi^+$. Curves show the fit results with the entire event sample, hatched regions indicate the backgrounds.

FIG. 3: $\Delta t$ distributions for the $D\pi$ events in the $0.875 < r < 1.000$ flavour tagging quality bin. (a) $B^0 \to D^+\pi^-$, (b) $B^0 \to D^-\pi^+$, (c) $\bar{B}^0 \to D^+\pi^-$, (d) $\bar{B}^0 \to D^-\pi^+$. Curves show the fit results with the entire event sample, hatched regions indicate the backgrounds.
In summary, we measure the time dependent CP violation parameter $2R \sin(2\phi_1 + \phi_3 \pm \delta)$ for the $B^0(B^0) \to D^{(*)\pm}\pi^\pm$ decays using 152 million $B\bar{B}$ events. Under the assumption of $\delta_{D^{(*)}\pi}$ being close to either 0° or 180°, we obtain $|2R_{D^+\pi}\sin(2\phi_1 + \phi_3)| = 0.060 \pm 0.040 \text{(stat)} \pm 0.019 \text{(sys)}$ and $|2R_{D^0\pi}\sin(2\phi_1 + \phi_3)| = 0.061 \pm 0.037 \text{(stat)} \pm 0.018 \text{(sys)}$.

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