Measurements of time-dependent CP Asymmetries in $B \to D^{*\mp} \pi^\pm$ decays using a partial reconstruction technique

I. Adachi,10 H. Aihara,51 D. Anipko,1 K. Arinstein,1 T. Aso,55 V. Aulchenko,1 T. Aushev,26,16 H. Aziz,47 S. Bahinipati,3 A. M. Bakich,46 V. Balagura,16 Y. Ban,38 E. Barberio,25 A. Bay,22 I. Bedny,1 K. Belous,15 V. Bhardwaj,37 U. Bitenc,17 S. Blyth,29 A. Bondar,1 A. Bozek,31 M. Bracko,24,17 J. Brodzicka,10,31 T. E. Browder,9 M.-C. Chang,4 P. Chang,30 Y.-W. Chang,30 Y. Chao,30 A. Chen,28 K.-F. Chen,30 B. G. Cheon,8 C.-C. Chiang,30 R. Chistov,16 I.-S. Cho,57 S.-K. Choi,7 Y. Choi,45 Y. K. Choi,45 S. Cole,46 J. Dalseno,10 M. Danilov,16 A. Das,47 M. Dash,56 A. Drutskoy,3 W. Dungel,14 S. Eidelman,1 D. Epifanov,1 S. Esen,3 S. Fratina,17 H. Fujii,10 M. Fujikawa,27 N. Gabyshov,1 A. Garmash,39 P. Goldenzweig,3 B. Golob,23,17 M. Grosse Perdekamp,12,40 H. Guler,9 H. Guo,42 H. Ha,19 J. Haba,10 K. Hara,26 T. Hara,36 Y. Hasegawa,44 N. C. Hastings,51 K. Hayasaka,26 H. Hayashi,27 M. Hazumi,10 D. Heffernan,36 T. Higuchi,10 H. Hödlmoser,9 T. Hokue,26 Y. Horii,50 Y. Hoshi,49 K. Hoshina,54 W.-S. Hou,30 Y. B. Hsiung,30 H. J. Hyun,21 Y. Igarashi,10 T. Iijima,26 K. Ikado,26 K. Inami,26 A. Ishikawa,41 H. Ishino,52 R. Itoh,10 M. Iwabuchi,6 M. Iwasaki,51 Y. Iwasaki,10 C. Jacoby,22 N. J. Joshi,47 M. Kaga,26 D. H. Kah,21 H. Kaji,26 H. Kakuno,51 J. H. Kang,57 P. Kapusta,31 S. U. Kataoka,27 N. Katayama,10 H. Kawai,2 T. Kawasaki,33 A. Kibayashi,10 H. Kichimi,10 H. J. Kim,21 H. O. Kim,21 J. H. Kim,45 S. K. Kim,43 Y. I. Kim,21 Y. J. Kim,6 K. Kinoshita,3 S. Korpar,24,17 Y. Koizaki,26 P. Križan,23,17 P. Krokovny,10 R. Kumar,37 E. Kurilhara,2 Y. Kuroki,36 A. Kuzmin,1 Y.-J. Kwon,57 S.-H. Kyeong,57 J. S. Lange,5 G. Leder,14 J. Lee,43 J. S. Lee,45 M. J. Lee,43 S. E. Lee,43 T. Lesiak,31 J. Li,9 A. Limosino,25 S.-W. Lin,30 C. Liu,42 Y. Liu,6 D. Liventsev,16 J. MacNoughton,10 F. Mandl,14 D. Marlow,39 T. Matsumura,26 A. Matyja,31 S. McOnie,46 T. Medvedeva,10 Y. Mikami,50 K. Miyabayashi,27 H. Miyata,33 Y. Miyazaki,26 R. Mizuk,16 G. R. Moloney,25 T. Mori,26 T. Nagamine,50 Y. Nagasaka,11 Y. Nakahama,51 I. Nakamura,10 E. Nakano,35 M. Nakao,10 H. Nakayama,51 H. Nakazawa,28 Z. Natkaniec,31 K. Neichi,49 S. Nishida,10 K. Nishimura,9 Y. Nishio,26 I. Nishizawa,53 O. Nito,54 S. Noguchi,27 T. Nozaki,10 A. Ogawa,40 S. Ogawa,48 T. Ohshima,26 S. Okuno,18 S. L. Olsen,13 S. Ono,52 W. Ostrowicz,31 H. Ozaki,10 P. Pakhlov,16 G. Pakhlakh,16 H. Palka,31 C. W. Park,45 H. Park,21 H. K. Park,21 K. S. Park,45 N. Parslow,46 L. S. Peak,46 M. Pernicka,14 R. Pestotnik,17 M. Peters,9 L. E. Piilonen,56 A. Poluektov,1 J. Rorie,9 M. Rozanska,31 H. Sahoo,9 Y. Sakai,10 N. Sasao,20 K. Sayeed,3 T. Schietinger,22 O. Schneider,22 P. Schönmeier,50 J. Schümmp,10 C. Schwanda,14 A. J. Schwartz,3 R. Seidl,12,40 A. Sekiya,27 K. Senyo,26 M. E. Sevior,25 L. Shang,13 M. Shapkin,15 V. Shebalin,1 C. P. Shen,9 H. Shibuya,48 S. Shinomiya,36 J.-G. Shiu,30 B. Shwartz,1 V. Sidorov,1 J. B. Singh,37 A. Sokolov,15 A. Somov,3 S. Stančić,34 M. Starić,17 J. Stypula,31 A. Sugiyama,41 K. Sumisawa,10 T. Sumiyoshi,53 S. Suzuki,41 S. Y. Suzuki,10 O. Tajima,10 F. Takasaki,10 K. Tamai,10 N. Tamura,33 M. Tanaka,10 N. Taniguchi,20 G. N. Taylor,25 Y. Teramoto,35 I. Tikhomirov,16 K. Trabelsi,10 Y. F. Tse,25 T. Tsuboyama,10 Y. Uchida,6 S. Uehara,10 Y. Ueki,53 K. Ueno,30 T. Uglov,16 Y. Unno,8 S. Uno,10 P. Urquijo,25 Y. Ushiroya,10 Y. Usos,1 G. Varner,9
K. E. Varvell, K. Vervink, S. Villa, A. Vinokurova, C. C. Wang, C. H. Wang, J. Wang, M-Z. Wang, P. Wang, X. L. Wang, M. Watanabe, Y. Watanabe, R. Wedd, J.-T. Wei, J. Wicht, L. Widhalm, J. Wiechczynski, E. Won, B. D. Yabsley, A. Yamaguchi, H. Yamamoto, M. Yamaoka, Y. Yamashita, M. Yamauchi, C. Z. Yuan, Y. Yusa, C. C. Zhang, L. M. Zhang, Z. P. Zhang, V. Zhilich, V. Zhulanov, T. Zivko, A. Zupane, N. Zwahlen, and O. Zyukova

(The Belle Collaboration)

1Budker Institute of Nuclear Physics, Novosibirsk
2Chiba University, Chiba
3University of Cincinnati, Cincinnati, Ohio 45221
4Department of Physics, Fu Jen Catholic University, Taipei
5Justus-Liebig-Universität Gießen, Gießen
6The Graduate University for Advanced Studies, Hayama
7Gyeongsang National University, Chinju
8Hanyang University, Seoul
9University of Hawaii, Honolulu, Hawaii 96822
10High Energy Accelerator Research Organization (KEK), Tsukuba
11Hiroshima Institute of Technology, Hiroshima
12University of Illinois at Urbana-Champaign, Urbana, Illinois 61801
13Institute of High Energy Physics, Chinese Academy of Sciences, Beijing
14Institute of High Energy Physics, Vienna
15Institute of High Energy Physics, Protvino
16Institute for Theoretical and Experimental Physics, Moscow
17J. Stefan Institute, Ljubljana
18Kanagawa University, Yokohama
19Korea University, Seoul
20Kyoto University, Kyoto
21Kyungpook National University, Taegu
22École Polytechnique Fédérale de Lausanne (EPFL), Lausanne
23Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana
24University of Maribor, Maribor
25University of Melbourne, School of Physics, Victoria 3010
26Nagoya University, Nagoya
27Nara Women's University, Nara
28National Central University, Chung-li
29National United University, Miao Li
30Department of Physics, National Taiwan University, Taipei
31H. Niewodniczanski Institute of Nuclear Physics, Krakow
32Nippon Dental University, Niigata
33Niigata University, Niigata
34University of Nova Gorica, Nova Gorica
35Osaka City University, Osaka
36Osaka University, Osaka
37Panjab University, Chandigarh
38Peking University, Beijing
Abstract

We report preliminary results on time-dependent CP asymmetries in $B \to D^{*\pm}\pi^\mp$ decays. The CP asymmetry in these decays is proportional to $2R_{D^{*}\pi}\sin(2\phi_1 + \phi_3 \pm \delta_{D^{*}\pi})$, where $R_{D^{*}\pi}$ is the ratio of the magnitudes of the doubly-Cabibbo-suppressed and Cabibbo-favoured amplitudes, $\delta_{D^{*}\pi}$ is the strong phase difference between them, and $\phi_1$ and $\phi_3$ are two angles of the CKM Unitarity Triangle. This study is based on a large data sample that contains 657 million $B\overline{B}$ pairs collected with the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider at the $\Upsilon(4S)$ resonance. We use a partial reconstruction technique, wherein signal $B \to D^{*\mp}\pi^\pm$ events are identified using information only from the $\pi^\pm$ from the $B$ decay and the charged slow pion from the subsequent decay of the $D^{*-}$. We obtain $S^+(D^{*}\pi) = +0.057 \pm 0.019(\text{stat}) \pm 0.012(\text{sys})$ and $S^-(D^{*}\pi) = +0.038 \pm 0.020(\text{stat}) \pm 0.010(\text{sys})$.

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INTRODUCTION

In the Standard Model (SM), quark flavour mixing occurs via the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1]. CP violation in the SM occurs due to the presence of a complex phase in the CKM matrix. Precision measurements of the parameters of CKM matrix are of utmost importance to constrain the SM and measure the amount of CP violation. The study of the time-dependent decay rates of $B^0(\overline{B}^0) \to D^{*\mp}\pi^\pm$ provide a theoretically clean method for extracting $\sin(2\phi_1 + \phi_3)$ [2], where $\phi_1$ and $\phi_3$ are angles of the CKM Unitarity Triangle. As shown in Fig. 1, this decay can be mediated by both Cabibbo-favoured (CFD) and doubly-Cabibbo-suppressed (DCSD) processes, whose amplitudes are proportional to $V^*_cbV^*_ud$ and $V^*_ubV^*_cd$ respectively, which have a relative weak phase $\phi_3$.

FIG. 1: Diagrams for $B^0 \to D^{*+}\pi^-$ (left) and $\overline{B}^0 \to D^{*-}\pi^+$ (right). Those for $B^0 \to D^{*-}\pi^+$ and $B^0 \to D^{*+}\pi^-$ can be obtained by charge conjugation.

The time-dependent decay rates are given by [3]

$$P(B^0 \to D^{(*)\pm}\pi^\mp) = \frac{1}{8\tau_{B^0}}e^{-|\Delta t|/\tau_{B^0}} \times \left[ 1 \mp C \cos(\Delta m \Delta t) - S^\pm \sin(\Delta m \Delta t) \right],$$

$$P(\overline{B}^0 \to D^{(*)\pm}\pi^\mp) = \frac{1}{8\tau_{B^0}}e^{-|\Delta t|/\tau_{B^0}} \times \left[ 1 \pm C \cos(\Delta m \Delta t) + S^\pm \sin(\Delta m \Delta t) \right].$$

(1)

Here $\Delta t$ is the difference between the time of the decay and the time that the flavour of the $B$ meson is tagged, $\tau_{B^0}$ is the average neutral $B$ meson lifetime, $\Delta m$ is the $B^0$-$\overline{B}^0$ mixing parameter, and $C = (1 - R^2) / (1 + R^2)$, where $R$ is the ratio of the magnitudes between the DCSD and CFD (we assume the magnitudes of both the CFD and DCSD amplitudes are the same for $B^0$ and $\overline{B}^0$ decays). The CP violation parameters are given by

$$S^\pm = \frac{2(-1)^L R \sin(2\phi_1 + \phi_3 \pm \delta)}{(1 + R^2)},$$

(2)

where $L$ is the orbital angular momentum of the final state (1 for $D^*\pi$), and $\delta$ is the strong phase difference between CFD and DCSD. Since the predicted value of $R$ is small, ~0.02 [4], we neglect terms of $O(R^2)$ (and hence take $C = 1$). The strong phase $\delta$ for $D^*\pi$ is predicted to be small [3, 5]. Since $R$ is expected to be suppressed, the amount of CP violation in $D^*\pi$ decays, which is proportional to $R$, is expected to be small and a large data sample is needed in order to obtain sufficient sensitivity. We employ a partial reconstruction technique [6] for the $D^*\pi$ analysis, wherein the signal is distinguished from background on the basis of kinematics of the ‘fast’ pion ($\pi_f$) from the decay $B \to D^*\pi_f$, and the ‘slow’ pion ($\pi_s$) from the subsequent decay of $D^* \to D\pi_s$; the $D$ meson is not reconstructed at all.
Previous analyses have been reported by Belle [7, 8] as well as by Babar [9]. This study uses a data sample of 605 fb$^{-1}$ containing 657 million $B\overline{B}$ events, which is about two times the size of the dataset used in the previous Belle analysis [8] and supersedes the previous Belle result.

**BELLE DETECTOR**

The data were collected with the Belle detector [10] at the KEKB asymmetric energy electron-positron ($e^-e^+$) collider [11] operating at the $\Upsilon(4S)$ resonance. The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) comprised of CsI(Tl) crystals located inside a superconducting solenoidal coil that provides a 1.5 T magnetic field. An iron flux-return located outside of the coil is instrumented to detect $K^0_L$ mesons and to identify muons (KLM).

A sample containing 152 million $B\overline{B}$ pairs was collected with a 2.0 cm radius beampipe and a 3-layer silicon vertex detector (SVD1), while a sample of 505 million $B\overline{B}$ pairs was collected with a 1.5 cm radius beampipe, a 4-layer silicon vertex detector (SVD2), and a small-cell inner drift chamber [12].

**ANALYSIS PROCEDURE**

**Partial Reconstruction of $B \rightarrow D^{*\mp}\pi^\pm$ decays**

To reconstruct the $CP$-side tags, we use: $\overline{B} \rightarrow D^{*\pm}\pi^\mp; D^{*\pm} \rightarrow D^0\pi^\pm$. Candidate events are selected by requiring the presence of oppositely charged ‘f’ and ‘s’ candidates. We estimate the $D^*$ frame using energy-momentum conservation:

$$E_{D^*} = E_{\overline{B}^0} - E_f,$$

$$\vec{p}_f + \vec{p}_{D^*} = \vec{p}_B.$$  \hspace{1cm} (3)

Here, $E$ and $p$ stand for energy and momentum respectively. $E_{\overline{B}^0}$ is half the total centre-of-mass energy ($E_{CM}$) of the incoming $e^+e^-$ beams and $p_B = \sqrt{E_{CM}^2/4 - m_{B^0}^2}$, where $m_{B^0}$ is the nominal $B^0$ mass [14]. Using $E_{D^*}$, the momentum of $D^*$ can be obtained in the $e^+e^-$ centre-of-mass (cms) as: $p_{D^*} = \sqrt{E_{D^*}^2 - m_{D^*}^2}$. We construct a partially reconstructed $D^{*+}$ frame, using $p_{D^*}$ and $E_{D^*}$ and taking the direction of $\vec{p}_{D^*}$ opposite to $\vec{p}_f$.

We define a variable, $p_\delta$, which is strongly correlated with the fast pion momentum, $p_f$. $p_\delta$ is defined as: $||p_f| - |p_{D^*}||$ and from Eq. (3), it follows: $|p_\delta| \lesssim |\vec{p}_B|$ ($\approx 0.3$ GeV/c). We boost the charged slow pion into the partially reconstructed $D^*$ frame. In the true $D^*$ frame, the slow pion is mono-energetic. However, in the partially reconstructed $D^{*+}$ frame, the slow pion momentum will have a limited spread. We study the parallel and the transverse components of the momentum of the slow pion, $\pi_s$ along the direction opposite to $f$, which are denoted as $p_\parallel$ and $p_\perp$, respectively. In the true $D^*$ frame, the $p_\parallel$ variable has a distribution proportional to $\cos \theta^2$ for signal events, as the $B$ decay is a pseudoscalar to pseudo-scalar vector transition.
**CP side selection**

Fast pion ($f$) candidates are required to have a radial (longitudinal) impact parameter $dr < 0.1 \text{ cm}$ ($|dz| < 2.0 \text{ cm}$) and to have associated hits in the SVD. We reject leptons and kaons based on information from the CDC, TOF and ACC from the fast pion candidate list. A requirement is made on the fast pion cms momentum, $1.93 \text{ GeV}/c < p_f < 2.50 \text{ GeV}/c$. Slow pion ($s$) candidates are required to have cms momentum in the range $0.05 \text{ GeV}/c < p_s < 0.30 \text{ GeV}/c$. Since slow pions are not used for vertexing, no particle identification requirement is applied; we impose only a loose requirement that they originate from the IP. We select candidates that satisfy $+0.00 \text{ GeV}/c < p_\perp < +0.06 \text{ GeV}/c$, $-0.10 \text{ GeV}/c < p_\parallel < 0.07 \text{ GeV}/c$ and $-0.60 \text{ GeV}/c < p_\delta < 0.50 \text{ GeV}/c$.

**Vertexing and Flavour Tagging**

The determination of the flavour of the $B$ meson opposite to the CP-side $B$ is essential for the $\Delta t$ measurement. In order to tag the flavour of the associated $B$ meson, we require the presence of a high-momentum lepton ($l$) in the event. This helps reduce background from continuum $e^+e^- \rightarrow q\overline{q}$ ($q = u, d, s, c$) processes. Tagging lepton candidates are required to be positively identified either as electrons, on the basis of information from the CDC, ECL and ACC, or as muons, on the basis of information from the CDC and the KLM. They are required to have momenta in the range $1.1 \text{ GeV}/c < p_l < 2.3 \text{ GeV}/c$, and to have an angle with the fast pion candidate that satisfies $-0.75 < \cos\delta_{\pi l}$ in the cms. The lower bound on the momentum and the requirement on the angle also reduce, to a negligible level (0.7%), the contribution of leptons produced from semi-leptonic decays of the unreconstructed $D$ mesons in the $B^0 \rightarrow D^{*\pm}\pi^\pm$ decay chain.

Identical vertexing requirements to those for fast pion candidates are made in order to obtain an accurate $z_{\text{tag}}$ position. To further suppress the small remaining continuum background, we impose a loose requirement on the ratio of the second to zeroth Fox-Wolfram [13] moments, $R_2 < 0.6$.

At the KEKB asymmetric-energy $e^+e^-$ (3.5 GeV on 8 GeV) collider, operating at the $\Upsilon(4S)$ resonance ($\sqrt{s} = 10.58 \text{ GeV}$), the $\Upsilon(4S)$ is produced with a Lorentz boost of $\beta\gamma = 0.425$, almost along the electron beamline ($z$) at KEKB. In the cms, $B^0$ and $\overline{B}^0$ mesons are approximately at rest. Hence the proper time-difference ($\Delta t$) between the $z_{\text{CP}}$ and $z_{\text{tag}}$ vertices is obtained from fast pion on the CP-side and the tagging lepton. The variable $\Delta t$ is defined as:

$$\Delta t \approx (z_{\text{CP}} - z_{\text{tag}})/\beta\gamma c. \tag{4}$$

The CP-side ($z_{\text{CP}}$) vertex is obtained from the fast pion on the CP-side and the run-dependent interaction point profile (IP). The tag-side ($z_{\text{tag}}$) vertex is obtained from tagging lepton and the run-dependent IP.

**Yield Fit**

We use the three kinematic variables, $p_\delta$, $p_\parallel$ and $p_\perp$ to distinguish between signal and background on the CP side. Background events are separated into three categories: $D^{*\pm}\rho^\pm$, which is kinematically similar to the signal; correlated background, in which the slow pion
originates from the decay of a $D^*$ that originates from the decay of the same $B$ as the fast pion candidate (e.g., $D^{**}\pi$); and uncorrelated background, which includes everything else (e.g., continuum processes, $D\pi$). The kinematic distributions of the signal and background categories are determined from a large MC sample, corresponding to three times the integrated luminosity of our data sample.

We select candidates that satisfy $-0.10 \text{ GeV/c} < p_\parallel < +0.07 \text{ GeV/c}$ and $-0.60 \text{ GeV/c} < p_\delta < +0.50 \text{ GeV/c}$. In the cases where more than one candidate satisfies these criteria, we select the one with the largest value of $\delta_{\pi f\pi s}$, where $\delta_{\pi f\pi s}$ is the angle between the fast pion direction and the slow pion direction in the cms frame. The signal region is defined as: $-0.40 \text{ GeV/c} < p_\delta < +0.40 \text{ GeV/c}$ and two regions in $p_\parallel$: $-0.05 \text{ GeV/c} < p_\parallel < -0.01 \text{ GeV/c}$ and $+0.01 \text{ GeV/c} < p_\parallel < +0.04 \text{ GeV/c}$.

Event-by-event signal and background fractions are determined from binned maximum likelihood fits to the two-dimensional kinematic distributions ($p_\delta$ and $p_\parallel$). The results of these fits, projected onto each of the two variables, are shown in Fig. 2, and summarized in Table I. We obtain a signal purity of $59.0 \pm 0.4\%$, where purity is defined as ratio of the signal and total yield.

![Figure 2](image-url)

**FIG. 2:** Results of the yield fits to $D^*\pi$ candidates projected onto the $p_\parallel$ (left) and $p_\delta$ (right) axes in the signal region of the kinematic variables. The contributions are: $D^*\pi$ (yellow), $D^*\rho$ (magenta), correlated background (blue) and uncorrelated background (red).

**Fit Procedure to obtain $CP$ violation parameters**

We perform a simultaneous unbinned fit to the same-flavour (SF) events, in which the fast pion and the tagging lepton have the same charge, and opposite-flavour (OF) events, in which the fast pion ($f$) and the tagging lepton ($l$) have the opposite charge, to measure the $CP$ violation parameters in the $D^*\pi$ sample. We minimize the quantity $-2 \ln \mathcal{L} = -2 \sum_i \ln \mathcal{L}_i$, where

$$
\mathcal{L}_i = f_{D^*\pi}P_{D^*\pi} + f_{D^*\rho}P_{D^*\rho} + f_{\text{unco}}P_{\text{unco}} + f_{\text{corr}}P_{\text{corr}}.
$$

(5)
TABLE I: Summary of the yields in the signal region

| Candidates       |         |
|------------------|---------|
| $D^*\pi$         | 50196 ± 286 |
| $D^*\rho$        | 10232 ± 150 |
| Correlated background | 10425 ± 135 |
| Uncorrelated background | 14193 ± 128 |

Here, $f$ stands for the event-by-event signal and background fractions and are obtained from the fits to the kinematic variables and $P$ stands for the probability density functions (PDF) for signal and backgrounds, which contain a physics PDF and experimental effects. For $D^*\pi$ and $D^*\rho$, the PDF is given by Eq. (1), where for $D^*\rho$ the terms $S^\pm$ are effective parameters averaged over the helicity states [15] and are constrained to be zero. The PDF for correlated background contains a term for neutral $B$ decays (given by Eq. (1) with $S^\pm = 0$), and a term for charged $B$ decays (for which the PDF is $\frac{1}{2\tau_B} e^{-|\Delta t|/\tau_B}$, where $\tau_B$ is the lifetime of the charged $B$ meson). The PDF for uncorrelated background also contains neutral and charged $B$ components, with the remainder from continuum $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s, c$) processes. The continuum PDF is modelled with two components: one with negligible lifetime, and the other with a finite lifetime.

The parameters in $P_{\text{uncorr}}$ and $P_{\text{corr}}$ are obtained from separate simultaneous fits to OF and SF candidates in the respective sideband regions. In these fits, the $CP$ violation parameters are fixed to 0 since there is no $CP$ in background. The fit is further simplified by fixing the biases in $\Delta z$ to zero (discussed later in detail). Monte-Carlo simulation studies demonstrate that floating or fixing these biases to 0 does not affect the background parameters.

To measure the uncorrelated background shape, we use events in a sideband region, $-0.10 \text{ GeV}/c < p_{\parallel} < 0.07 \text{ GeV}/c$, $0.01 \text{ GeV}/c < p_{\parallel} < 0.04 \text{ GeV}/c$, $-0.60 \text{ GeV}/c < p_{\parallel} < 0.50 \text{ GeV}/c$ and $0.08 \text{ GeV}/c < p_{\perp} < 0.10 \text{ GeV}/c$, which is populated mostly by uncorrelated background. To determine the correlated background parameters, we use events in a sideband region, $-0.10 \text{ GeV}/c < p_{\parallel} < 0.07 \text{ GeV}/c$, $-0.60 \text{ GeV}/c < p_{\parallel} < 0.00 \text{ GeV}/c$ and $0.00 \text{ GeV}/c < p_{\perp} < 0.05 \text{ GeV}/c$. This sideband region is dominated by correlated and uncorrelated backgrounds and has very small amount of $D^*\pi$ signal and $D^*\rho$ background. The uncorrelated background parameters are fixed to the values obtained in the previous fit.

The PDF for the signal and background in Eq. (5) must be convolved with corresponding $\Delta z$ resolution functions related to kinematic smearing ($R_k$), detector resolution ($R_{\text{det}}$), and asymmetry in $\Delta z$ due to non-primary tracks ($R_{\text{np}}$). The resolution function related to kinematic smearing is due to the fact that we use the approximation of Eq. (4). The detector resolution function parameters are obtained using $J/\psi \rightarrow \mu^+\mu^-$ candidates. Since both the fast pion and the tagging lepton originate directly from $B$ meson decays for correctly tagged signal events, we do not include any additional smearing due to non-primary tracks in such events. However, for incorrectly tagged events, almost exclusively originating from secondary leptons or pions, the PDF is convolved with an additional resolution component whose parameters are determined from MC simulations. The detector resolution and smearing due to asymmetry in $\Delta z$ due to non-primary tracks are described in detail elsewhere [8].
Mistagging is taken into account using
\[
P(l^\mp_{\text{tag}}, \pi_f^\pm) = (1 - w_\mp)P(B^0/\overline{B}^0 \rightarrow D^{*\mp}\pi^\pm) + w_\pm P(\overline{B}^0/B^0 \rightarrow D^{*\mp}\pi^\pm)
\]
where \(\pi_f\) is fast pion in CP-side, \(l\) is tag-side lepton, \(w^+\) and \(w^-\) are the wrong-tag fractions, defined as the probabilities to incorrectly measure the flavour of tagging \(B^0\) and \(\overline{B}^0\) mesons respectively and are determined from the data as free parameters in the fit for \(S^\pm\).

The time difference \(\Delta t\) is related to the measured quantity \(\Delta z\) as described in Eq. (4), with an additional term due to possible offsets in the mean value of \(\Delta z\),
\[
\Delta t \longrightarrow \Delta t + \epsilon_{\Delta t} \simeq (\Delta z + \epsilon_{\Delta z})/\beta\gamma c.
\]
It is essential to allow non-zero values of \(\epsilon_{\Delta t}\) since a small bias can mimic the effect of CP violation:
\[
\cos(\Delta m \Delta t) \rightarrow \cos(\Delta m \Delta t) - \Delta m \epsilon_{\Delta t} \sin(\Delta m \Delta t)
\]
A bias as small as \(\epsilon_{\Delta z} \sim 1 \mu m\) can lead to sine-like terms as large as 0.01, comparable to the expected size of the CP violation effect. Because both vertex positions are obtained from single tracks, the partial reconstruction analysis is more susceptible than other Belle CP analyses to such biases.

In order to correct for a known bias due to the relative misalignment of the SVD and CDC in SVD1 data, a small correction is applied to each measured vertex position. This correction is dependent on the track charge, momentum and polar angle, measured in the laboratory frame and is obtained by comparing the vertex positions calculated with the alignment constants used in the data, to those obtained with an improved set of alignment constants [16], which removes the observed bias. Since the alignment in SVD2 data was found to be comparable to that of the corrected SVD1 data, no additional correction was applied to SVD2 data.

**Fit Result**

In order to test our fit procedure, we first constrain \(S^+\) and \(S^-\) to be zero and perform a fit in which \(\tau_{B^0}\) and \(\Delta m\) (as well as two wrong tag fractions and eight offsets) are free parameters. We obtain \(\tau_{B^0} = 1.538 \pm 0.008\) ps and \(\Delta m = 0.482 \pm 0.004\) ps\(^{-1}\), where the errors are statistical only. These values are compatible with their world average values [14]. Reasonable agreement with the input values is also obtained in MC. Furthermore, fits to the MC with \(S^\pm\) floated give results consistent with zero, as expected.

To extract the CP violation parameters we fix \(\tau_{B^0}\) and \(\Delta m\) at their world average values, and fit with \(S^+\), \(S^-\), two wrong tag fractions, and eight offsets as free parameters. We obtain \(S^+ = 0.057 \pm 0.019\) and \(S^- = 0.038 \pm 0.020\) where the errors are statistical only. The wrong tag fractions are \(w_- = (6.8 \pm 0.3)\%\) and \(w_+ = (6.6 \pm 0.3)\%\). All floating offsets are consistent with zero except for one of the OF combinations (\(h = \pi^-, l = \ell^+\)) in the SVD1 sample. The results are shown in Fig. 3. To further illustrate the CP violation effect, we define asymmetries in the same flavour events (\(A^{\text{SF}}\)) and in the opposite flavour events (\(A^{\text{OF}}\)), as
\[
A^{\text{SF}} = \frac{N_{\pi^- l^-}(\Delta z) - N_{\pi^+ l^+}(\Delta z)}{N_{\pi^- l^-}(\Delta z) + N_{\pi^+ l^+}(\Delta z)}
\]
\[
A^{\text{OF}} = \frac{N_{\pi^+ l^-}(\Delta z) - N_{\pi^- l^+}(\Delta z)}{N_{\pi^+ l^-}(\Delta z) + N_{\pi^- l^+}(\Delta z)} \quad (9)
\]
where the $N$ values indicate the number of events for each combination of $h$ and $l$ charge. These are shown in Fig. 4.

FIG. 3: $\Delta z$ distributions for 4 flavour-charge combinations: $\pi^- l^-$ (top left), $\pi^- l^+$ (top right), $\pi^+ l^-$ (bottom left), $\pi^+ l^+$ (bottom right). The fit result is superimposed on the data (blue line). The signal and background components are shown as the red and dotted black curves, respectively.

FIG. 4: Results of the fit to obtain $S^+$ and $S^-$, shown as asymmetries in the same flavour events (left) and opposite flavour events (right). The fit result (red curve) is superimposed on the data.
**Systematic Error**

This analysis is very sensitive to the vertexing bias. Hence, we have use $\Delta z$ offsets in the fits to take care of this bias. In order to estimate the error due to these offsets, we use the difference of the mean of $S^\pm$ obtained using an ensemble of 300 generated $D^*\pi$ signal samples with $CP$ ($S^\pm = -0.04$) and the generated $CP$ value.

Other sources of systematic error are the parameters of resolution functions, $R_k$, $R_{det}$ and $R_{np}$, the parameters of uncorrelated and correlated background and physics parameters, $\Delta m$, $\tau_{B^0}$, $\tau_{B^+}$, $S_{D^\pm \rho}^\pm$ and $S_{corr}^\pm$ that are fixed in the $CP$ fit, where $S_{corr}^\pm$ are the $CP$ violation parameters for the correlated background component ($S_{corr}^\pm = \pm 0.05$ in the $CP$ fit). Additional systematic errors can result from varying the number of bins for the kinematic variables, $p_\delta$ and $p_{||}$ in the yield fit.

We use a triple Gaussian as the detector resolution ($R_{det}$) function model. We consider the systematic uncertainty due to lack of knowledge of the exact functional form of the resolution model. Hence, we change the resolution models and obtain shifts as large as 0.008 for $S^+$. This is conservatively assigned as the systematic error due to lack of knowledge of the resolution model.

We also performed a linearity test to check for possible fit bias by generating a number of large samples of signal MC simulations with different input values of $S^+$ and $S^-$. All results are consistent with the input values, without evidence of any bias. In addition, we checked the pull for $S^+$ and $S^-$ using two types of ensembles, one set generated with no $CP$ ($S^\pm = 0$) and the other with $CP$ ($S^\pm = -0.04$) and obtained mean ($m$) and rms ($\sigma$) of the pull distributions fitted to a single Gaussian. For the no $CP$ case, $m_{S^+} = +0.10 \pm 0.06$, $\sigma_{S^+} = +0.94 \pm 0.05$; $m_{S^-} = -0.10 \pm 0.06$, $\sigma_{S^-} = +0.96 \pm 0.05$ and for the case with $CP$, $m_{S^+} = +0.14 \pm 0.07$, $\sigma_{S^+} = +1.10 \pm 0.06$; $m_{S^-} = -0.29 \pm 0.06$, $\sigma_{S^-} = +0.98 \pm 0.05$. Both cases yield $m$ and $\sigma$ for the pull distributions close to 0 and 1, respectively. This shows that our fit routine does not have any significant bias.

The systematic errors are summarized in Table II. The total systematic error is obtained by adding the above terms in quadrature.

| Systematic error source                  | $S^+$  | $S^-$  |
|----------------------------------------|--------|--------|
| $\Delta z$ offset                      | 0.002  | 0.003  |
| $R_k$ parameters                       | 0.002  | 0.003  |
| $R_{det}$ parameters                   | 0.002  | 0.002  |
| $R_{np}$ parameters                    | 0.008  | 0.007  |
| Background parameters                  | 0.002  | 0.003  |
| Physics parameters                     | 0.004  | 0.004  |
| Yield fit                              | 0.003  | 0.003  |
| Resolution model                       | 0.006  | 0.002  |
| $\Delta z$ floated in background PDF  | 0.000  | 0.000  |
| Total systematic error                 | 0.012  | 0.010  |

**Table II**: Summary of possible sources of systematic error.
The results using the partial reconstruction method are

\[
S^+ = +0.057 \pm 0.019 \pm 0.012, \\
S^- = +0.038 \pm 0.020 \pm 0.010,
\]

where the first error is statistical and the second error is systematic.

**SUMMARY**

We have measured CP violation parameters that depend on \( \phi_3 \) using the time-dependent decay rates of the decay \( B^0 \to D^{\ast\pm} \pi^\mp \) using a data sample containing 657 million \( B\bar{B} \) events. We obtain the CP violation parameters expressed in terms of \( S^+ \) and \( S^- \), which are related to the CKM angles \( \phi_1 \) and \( \phi_3 \), the ratio of suppressed to favoured amplitudes, and the strong phase difference between them, as

\[
S^\pm = -R_{D^\ast \pi} \sin(2\phi_1 + \phi_3 \pm \delta_{D^\ast \pi})/(1 + R_{D^\ast \pi}^2)
\]

for \( D^\ast \pi \) as

\[
S^+ = +0.057 \pm 0.019 \pm 0.012, \\
S^- = +0.038 \pm 0.020 \pm 0.010,
\]

where the first errors are statistical and the second errors are systematic.

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[16] A small amount of data is reprocessed using a set of constants which is corrected for the small relative misalignment of the SVD and CDC. The correction function is calculated from comparisons of the vertex positions for tracks between the two reprocessings.