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Measurement of the ratio $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ and the time-integrated CP asymmetry in $D^0 \to \pi^+\pi^-\pi^0$

Belle Collaboration

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Abstract

We report a high-statistics measurement of the relative branching fraction $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ using a 532 fb^{-1} data sample collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. The measured value of the relative branching fraction is $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0) = (10.12 \pm 0.04(\text{stat}) \pm 0.18(\text{syst})) \times 10^{-2}$, which has an accuracy comparable to the world average. We also present a measurement of the time-integrated *CP* asymmetry in $D^0 \to \pi^+\pi^-\pi^0$ decay. The result, $A_{CP} = (0.43 \pm 1.30)\%$, shows no significant *CP* violation.

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Keywords: D^0; $\pi^+\pi^-\pi^0$; *CP*; Asymmetry

1. Introduction

Using a large data sample of D^0 decays accumulated with the Belle detector, we obtain a precise determination of the $D^0 \to \pi^+\pi^-\pi^0$ branching fraction using the $D^0 \to K^-\pi^+\pi^0$ decay mode for normalization.[1] This study is the first step towards a high-statistics Dalitz-plot analysis of the $D^0 \to \pi^+\pi^-\pi^0$ decay.

Since both $D^0 \to \pi^+\pi^-\pi^0$ and $D^0 \to K^-\pi^+\pi^0$ involve a neutral pion and the same number of charged tracks in the final state, several sources of systematic uncertainties nearly cancel in the determination of the relative branching fraction. The method used minimizes any dependence on the assumed decay model. The result obtained is compared to recent measurements by the CLEO [1] and BaBar [2] Collaborations.

In this study, we also subdivide the same data into D^0 and $\bar{D}^0$ subsamples to calculate the time-integrated *CP* asymmetry (A_{CP}) in the $D^0 \to \pi^+\pi^-\pi^0$ decay mode. The latter

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[1] Unless specified otherwise, both flavors of D^0 mesons are implied: $D^0 \to K^-\pi^+\pi^0$ and $\bar{D}^0 \to K^+\pi^-\pi^0$.

study is motivated by the recent measurements of mixing parameters in neutral D-meson system [3]. The rate of CP violation predicted by the Standard Model reaches $\sim 0.1\%$ in some Cabibbo-suppressed decays such as $D^0 \to \pi^+\pi^-\pi^0$ [4,5]. The value of A_{CP} in the $D^0 \to \pi^+\pi^-\pi^0$ decay obtained in the single existing measurement by the CLEO Collaboration is $(1^{+10}_{-9})\%$ [6]. We provide a significantly improved measurement of $A_{CP}(D^0 \to \pi^+\pi^-\pi^0)$. This measurement is complementary to other measurements of A_{CP} in singly-Cabibbo suppressed decay modes (the most sensitive statistically is one by the BaBar experiment in $D^0 \to K^+K^-, \pi^+\pi^-$ [7]).

2. Experiment

The Belle detector is a large-solid-angle magnetic spectrometer located at the KEKB e^+e^- storage rings, which collide 8.0 GeV electrons with 3.5 GeV positrons to produce $\Upsilon(4S)$ at the energy of 10.58 GeV [8]. Closest to the interaction point is a silicon vertex detector (SVD) surrounded by a 50-layer central drift chamber (CDC), an array of aerogel Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight (TOF) scintillation counters, and an electromagnetic calorimeter (ECL) comprised of CsI (Tl) crystals. These subdetectors are located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return yoke located outside the coil is instrumented to detect K^0_L mesons and identify muons. The detector is described in detail elsewhere [9,10].

3. Data selection

For this analysis, we used a data sample of 532 fb^{-1}. To reduce backgrounds and also tag the flavor of the D^0 or $\bar{D}^0$ decay, we require that the D^0's originate from $D^* \to D^0\pi$ decays. A $D^{*\pm}$ candidate is reconstructed from a D^0 and a low momentum π where the charge of the latter tags the D^0 flavor: $D^{*+} \to D^0\pi^+_{\text{tag}}$, $D^{*-} \to \bar{D}^0\pi^-_{\text{tag}}$.[2] D^0 candidates are reconstructed from combinations of two oppositely charged pions (a pion and a kaon in the case of $D^0 \to K^-\pi^+\pi^0$) and one neutral pion formed by two photons. In the case of multiple candidates, we choose the best candidate using a χ^2 value based on the vertex information of all charged particles, $M(D^*) - M(D^0)$, and $M(\pi^0)$ values. A fit in which the $\pi^\pm/K^\pm$, π^0 momenta are constrained to originate from a common vertex and have the nominal mass of the D^0 meson is also performed.

The following kinematic and topological criteria are applied to the charged track candidates: the distance from the nominal interaction point to the point of closest approach of the track is required to be within 0.2 cm in the radial direction and 2.0 cm along the beam direction. We also require the transverse momentum of the track to be greater than 0.050 GeV$/c$, to suppress beam background. Kaons and pions are separated by combining the responses of the ACC and the TOF with the dE/dx measurement from the CDC to form a likelihood $\mathcal{L}(h)$, where h is a pion or a kaon. Charged particles are identified as pions or kaons using the likelihood ratio $\mathcal{R} = \mathcal{L}(K)/(\mathcal{L}(K) + \mathcal{L}(\pi))$. For the identification of a charged pion, we require $\mathcal{R} < 0.4$; this requirement selects pions with an efficiency of 93% and a kaon misidentification probability of 9%. For the identification of charged kaons, the requirement is $\mathcal{R} > 0.6$; in this case, the efficiency for kaon identification is 86% and the probability to misidentify a pion is 4%. We require $\theta_{\text{lab}}(\pi^\pm/K^\pm) < 2.2$ rad to improve K/π separation,[3] where θ_{lab} is the angle between the particle momentum and the z-axis, defined as the direction opposite to that of the positron beam. To suppress random combinations of two photons, we impose conditions on the energies of the photons constituting the π^0 candidate ($E_\gamma(\pi^0) > 0.070$ GeV), the two-photon invariant mass (0.120 GeV$/c^2 < M(\gamma\gamma) < 0.150$ GeV$/c^2$, which corresponds to 2.8 standard deviations (σ) in reconstructed $M(\gamma\gamma)$) and the π^0 momentum in the laboratory frame ($p_{\text{lab}}(\pi^0) > 0.35$ GeV$/c$). The mass difference of D^* and D^0 candidates must satisfy the restriction 0.1449 GeV$/c^2 < M(\pi_{\text{tag}}\pi^+\pi^-\pi^0) - M(\pi^+\pi^-\pi^0) <$ 0.1461 GeV$/c^2$ (2σ in reconstructed $M(D^*) - M(D^0)$). The momentum of the D^* in the center-of-mass (cms) frame of the $\Upsilon(4S)$ must be in the range 3.0 GeV$/c < p_{\text{cms}}(D^*) <$ 4.5 GeV$/c$. The lower cut is applied to reject D^*'s originating from B mesons. The upper cut excludes the region of $p_{\text{cms}}(D^*)$ with the largest discrepancy between Monte Carlo (MC) simulation and data (the difference is taken into account in the systematic error). To eliminate background from $D^0 \to K_S\pi^0 \to (\pi^+\pi^-)\pi^0$ decays, the following veto on $M(\pi^+\pi^-)$ is applied: 0.455 GeV$/c^2 < M(\pi^+\pi^-) < 0.537$ GeV$/c^2$ (6.5σ in the reconstructed K_S invariant mass resolution). We also require that the $\pi^+\pi^-\pi^0/K^-\pi^+\pi^0$ invariant mass be in the range 1.79–1.91 GeV$/c^2$, which corresponds to 5.5σ in the $M(D^0)$ resolution. For events passing this requirement, the momenta of the final state particles are refitted using the nominal D^0 mass as a constraint. These refitted momenta are used to calculate Dalitz plot variables as described below. After applying all selection criteria, we find $123.2 \times 10^3 D^0 \to \pi^+\pi^-\pi^0$ and 1221.0×10^3 $D^0 \to K^-\pi^+\pi^0$ events in our data sample.

4. Efficiency calculation

To obtain reconstruction efficiencies, 22×10^6 MC events, uniformly distributed over the Dalitz plane (DP), were generated for each of the two modes. They were processed using the GEANT detector simulation package [11] and reconstructed with the same selection criteria as for data. To take into account the radiative tail in the D^0 invariant mass distribution (Fig. 1) due to final state radiation (FSR), the PHOTOS package [12] was used for $D^0 \to \pi^+\pi^-\pi^0/D^0 \to K^-\pi^+\pi^0$ at the generator level.

[2] D^*'s originate mainly from continuum. Although we do not apply any topological cuts, the yield of D^*'s coming from B mesons is negligible: they are rejected by kinematic cuts, mainly by the stringent $p_{\text{cms}}(D^*)$ requirement.

[3] The backward end of the ACC corresponds to $\theta_{\text{lab}} \sim 2.2$ rad, and as a result, kaon–pion separation is less efficient for $\theta_{\text{lab}} > 2.2$ rad.

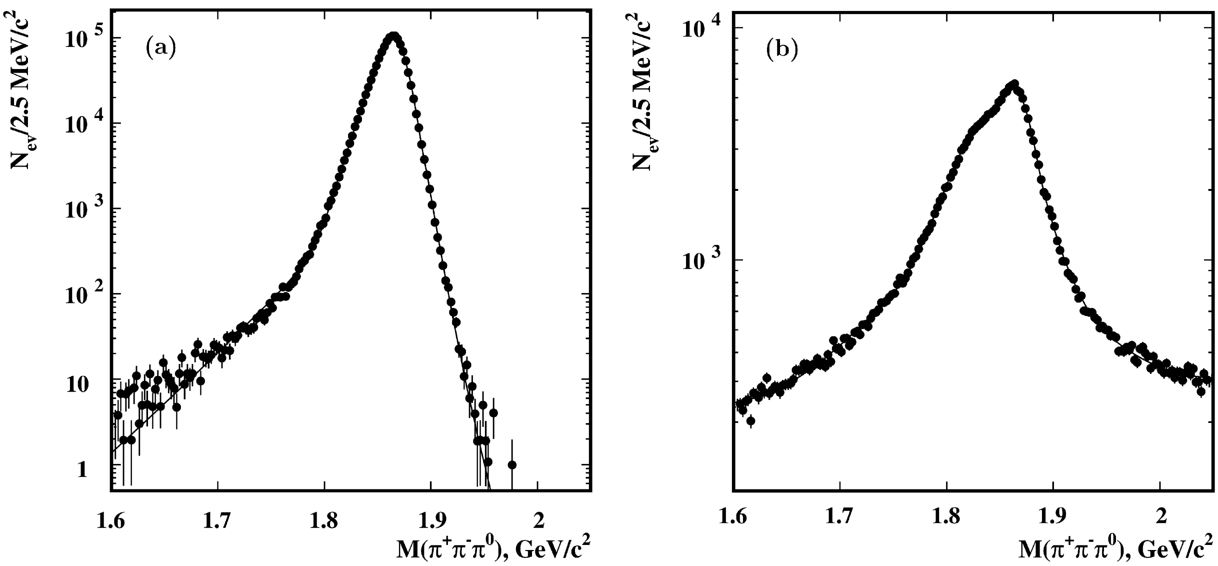

Fig. 1. (a) Correctly reconstructed (χ^2/n.d.f. = 1.7, n.d.f. = 132) and (b) misreconstructed (χ^2/n.d.f. = 1.0, n.d.f. = 169) signal MC distributions.

Differences in the efficiency of particle identification (PID) selection criteria between MC and data events are taken into account as correction weights to each signal event. They are obtained using a large sample of $D^* \to D^0\pi_{\text{tag}}$, $D^0 \to K^-\pi^+$ decays, as a function of the momentum and polar angle of the decay products. The uncertainties of these corrections contribute to the systematic uncertainty of the result. We apply these weights only to the kaon in $D^0 \to K^-\pi^+\pi^0$ and to the corresponding pion (of the same charge) in $D^0 \to \pi^+\pi^-\pi^0$, since the corrections to the PID efficiency for the remaining decay pion and the tagging pion (π_{tag}) cancel in the ratio.

A certain portion of signal MC events ($\sim 15\%$) is reconstructed with one or more random particles (γ's, π^0's, $\pi^\pm$ or $K^\pm$) combined with true signal daughters. We distinguish correctly reconstructed and misreconstructed signal MC events by comparing the reconstructed momenta of all the final state particles to the corresponding generator information. The correctly reconstructed MC events are used to calculate the reconstruction efficiency, and the misreconstructed decays are treated as an additional source of background.

The $M(D^0)$ distributions for correctly reconstructed signal MC events (Fig. 1(a)) are fitted with a double hyperbolic Gaussian[4] and one regular Gaussian. The $M(D^0)$ distributions for the misreconstructed signal MC events (Fig. 1(b)) are fitted with a triple Gaussian. The results of the $M(D^0)$ fits are used to fix the shape of the signal and misreconstructed signal events for the data $M(D^0)$ fit.

The fraction of correctly reconstructed events in a certain bin depends on its position on the DP, i.e. $M^2(h\pi)$ vs. $M^2(\pi\pi^0)$ (h is K or π). To determine the reconstruction efficiency we divide the DP into bins of size 0.1 GeV$^2/c^4$ × 0.1 GeV$^2/c^4$, accumulate signal MC events from the $M(D^0)$ signal region, and then normalize by the number of generated events in each bin. The calculated values are later used as reciprocal weights for the corresponding data distribution. This method takes into account variations of the DP data density and minimizes D^0 decay model dependence.

[4] $f = e^{-(y-\alpha)} \cdot \frac{\alpha\cdot|(x-x_0)/\sigma|}{2\sqrt{2\sigma}\cdot y\cdot\sqrt{y-\alpha}}$, where $y = \sqrt{\alpha^2 + \alpha\cdot((x-x_0)/\sigma)^2}$. The function tends to a Gaussian for $|x-x_0| \ll \sqrt{\alpha}\cdot\sigma$ and has exponential behaviour for $|x-x_0| \gg \sqrt{\alpha}\cdot\sigma$.

5. Background study

To describe the shape of background in the $M(D^0)$ signal region for $D^0 \to \pi^+\pi^-\pi^0$ and $D^0 \to K^-\pi^+\pi^0$, a sample of generic MC events (including all significant processes in e^+e^- production of $\Upsilon(4S)$, $u\bar{u}$, $d\bar{d}$, $s\bar{s}$ and $c\bar{c}$ at the given $\sqrt{s}$), equivalent to ~ 600 fb^{-1}, was processed with the same selection criteria as data. All generic MC events reconstructed as $D^0 \to \pi^+\pi^-\pi^0$ were separated into three types: contributions from $u\bar{u}$, $d\bar{d}$, and $s\bar{s}$ fragmentation, and $\Upsilon(4S) \to B\bar{B}$ events; a contribution from $D^* \to D^0(K^-\pi^+\pi^0)\pi_{\text{tag}}$ ($c\bar{c}$ events) where the charged kaon is misidentified as a pion (the largest source of background); and a contribution from $c\bar{c}$ background that does not involve particle misidentification and from which the signal is excluded (Fig. 2(a)–2(c)). For the $D^0 \to K^-\pi^+\pi^0$ case, there are contributions from $u\bar{u}$, $d\bar{d}$, $s\bar{s}$ and $\Upsilon(4S) \to B\bar{B}$ events, a contribution from $D^* \to D^0(K^-\pi^+\pi^0\pi^0)\pi_{\text{tag}}$ via $D^0 \to K^*\rho$ and $D^0 \to a_1K$, as well as a small residual $e^+e^- \to c\bar{c}$ background (Fig. 2(d)–2(f)). The small peak in the signal region of the latter (Fig. 2(f)) is mainly due to combinations of a D^0 and a random π_{tag} and has to be taken into account. This background is also present in $D^0 \to \pi^+\pi^-\pi^0$. As described previously, the contributions of misreconstructed signal MC events are treated as separate sources of background for both decay modes.

6. Data $M(D^0)$ fit

The $M(D^0)$ distribution in data is fitted using fixed MC shapes for the various background components, and a signal

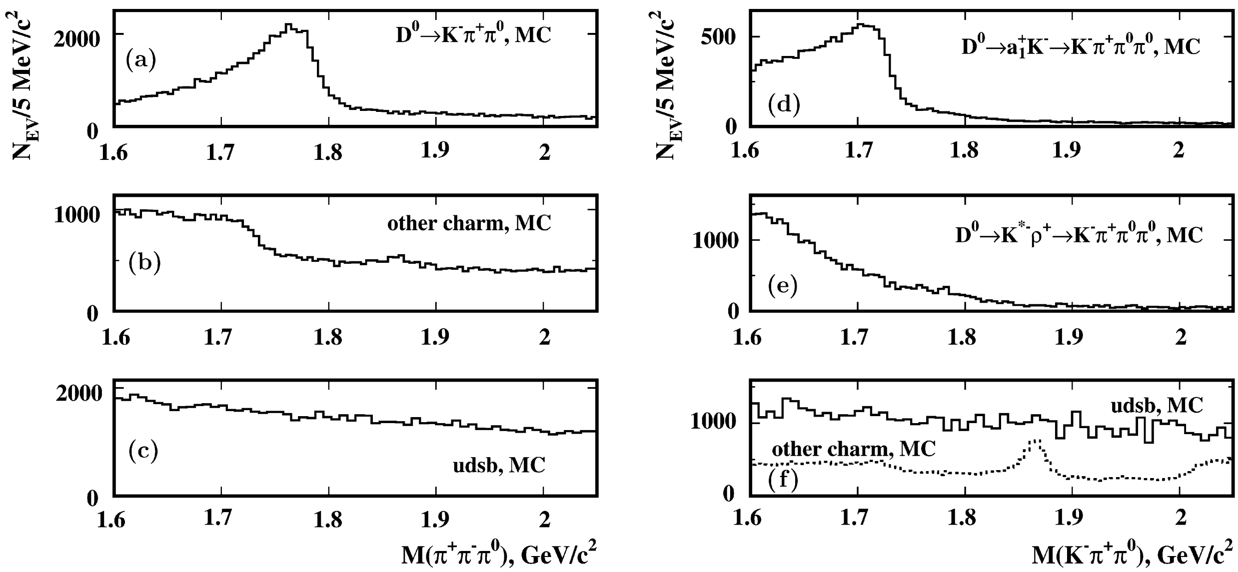

Fig. 2. $M(D^0)$ distributions for MC background events in (a)–(c) the $D^0 \to \pi^+\pi^-\pi^0$ and (d)–(f) the $D^0 \to K^-\pi^+\pi^0$ sample: (a) $D^0 \to K^-\pi^+\pi^0$ events, (b) other $e^+e^- \to c\bar{c}$ contributions, (c) contributions from light quark and $B\bar{B}$ decays, (d) $D^0 \to a_1 K \to K^-\pi^+\pi^0\pi^0$ events, (e) $D^0 \to K^*\rho \to K^-\pi^+\pi^0\pi^0$ events, (f) other $e^+e^- \to c\bar{c}$ contributions and contributions from light quark and $B\bar{B}$ decays. Events from the $M(D^0)$ signal region (1.79 to 1.91 GeV) are selected for the branching fraction calculation.

shape that allows for data-MC differences. The fit function for $D^0 \to \pi^+\pi^-\pi^0$ is

$$F_1 = N_{\text{sig}} \times P_{\text{sig}}(\sigma_{\text{add}}, \Delta x) + N_{\text{misrec}} \times P_{\text{misrec}} + N_{udsb} \times P_{udsb} + N_{\text{misid}} \times P_{\text{misid}} + N_c \times P_c, \quad (1)$$

where P_{sig} and P_{misrec} are the shapes of the $M(D^0)$ distributions for correctly reconstructed and misreconstructed signal MC events obtained from the corresponding MC distributions. The $M(D^0)$ shapes of u, d, s-quark and $B\bar{B}$ decays, misidentified $D^0 \to K^-\pi^+\pi^0$ decays and other c-quark contributions are denoted as P_{udsb}, P_{misid} and P_c, respectively; N_{sig}, N_{misrec}, N_{udsb}, N_{misid} and N_c are the normalizations of all the event types and are free parameters in the fit. The additional free parameter Δx represents a common shift in the central value of the Gaussians describing the signal. Similarly, σ_{add} is a free parameter added in quadrature to all the widths of the Gaussian functions (0.3 MeV for $M(D^0 \to \pi^+\pi^-\pi^0)$ and 0.1 MeV for $M(D^0 \to K^-\pi^+\pi^0)$). The $M(D^0 \to K^-\pi^+\pi^0)$ fit function has a similar form:

$$F_2 = N_{\text{sig}} \times P_{\text{sig}}(\sigma_{\text{add}}, \Delta x) + N_{\text{misrec}} \times P_{\text{misrec}} + N_{udsb} \times P_{udsb} + N_{K^*\rho} \times P_{K^*\rho} + N_{a_1 K} \times P_{a_1 K} + N_c \times P_c, \quad (2)$$

where $P_{K^*\rho}$ and $P_{a_1 K}$ are the shapes of the contributions of the $D^0 \to K^*\rho$ and $D^0 \to a_1 K$ decays to the $M(D^0)$ distribution, respectively, and $N_{K^*\rho}$, $N_{a_1 K}$ are their floating normalizations. All other variables are the same as in Eq. (1). Fig. 3(a) shows the fit for $M(D^0 \to \pi^+\pi^-\pi^0)$ described above, while Fig. 3(b) shows that for $M(D^0 \to K^-\pi^+\pi^0)$. The low fit quality ($\chi^2/\text{n.d.f.} = 3.2$, n.d.f. $= 350$) of the latter is due to the large statistics of the signal as well as the poor agreement of data and MC simulation for the $D^0 \to K\pi\pi^0\pi^0$ background. This discrepancy is taken into account as a systematic error due to the fit uncertainty.

7. Calculation of the signal yields

After the parameters of the data $M(D^0)$ distributions are obtained from the fit, we fill separate $M^2(h\pi)$ vs. $M^2(\pi\pi^0)$ Dalitz histograms with events from the signal $M(D^0)$ region for data and simulated background with the normalizations fixed from the fit (Fig. 4). The bin size is $0.1\ \text{GeV}^2/c^4 \times 0.1\ \text{GeV}^2/c^4$, the same as for signal MC events.

The number of $D^0 \to \pi^+\pi^-\pi^0$ signal events in each bin is calculated as follows:

$$Y^i = D^i - N_{\text{misrec}} \times S^i_{\text{misrec}} - N_{udsb} \times B^i_{udsb} - N_{\text{misid}} \times B^i_{\text{misid}} - N_c \times B^i_c, \quad (3)$$

where D^i is the number of data events, and $N_{\text{misrec}} \times S^i_{\text{misrec}}$, $N_{udsb} \times B^i_{udsb}$, $N_c \times B^i_c$ are the numbers of different background events in the ith bin. The procedure for the $D^0 \to K^-\pi^+\pi^0$ case is similar.

The total number of signal events for both decays is obtained by summing the number Y^i of events over all bins: $S = \sum Y^i/\varepsilon^i$, where the reconstruction efficiency in each bin $\varepsilon^i = n^i_{\text{rec}}/n^i_{\text{gen}}$ is used as a reciprocal weight (n^i_{rec} and n^i_{gen} are the numbers of reconstructed and generated events in the ith bin).

At this point, we return to the stage of obtaining the $M(D^0)$ distributions from signal MC simulation and perform another iteration of the same procedure using the Dalitz histogram for data as an approximation of the D^0 decay model (for each of the two decay modes). As mentioned above, signal MC events, used at the first step of our calculations (the entire procedure described above), are distributed uniformly over the DP. At

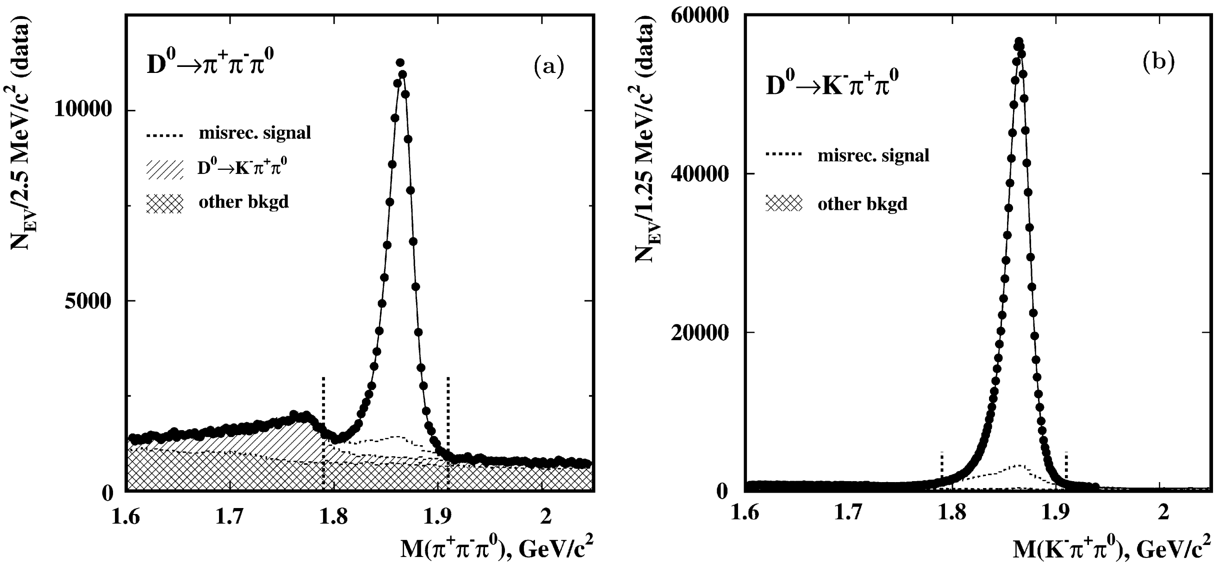

Fig. 3. (a) $M(D^0 \to \pi^+\pi^-\pi^0)$ data fit (χ^2/n.d.f. = 1.5, n.d.f. = 174). Data is represented by the points and the curve is the fitted sum of all the contributions (simulated signal and background). The vertical dashed lines indicate the $M(D^0)$ signal region. Background: misreconstructed signal (dashed line), $D^0 \to K^-\pi^+\pi^0$ with a misidentified kaon (shaded histogram) and other sources, i.e. other $c\bar{c}$ and light quark contributions (hatched histogram). (b) $M(D^0 \to K^-\pi^+\pi^0)$ data fit. Background: misreconstructed signal (dashed) and other sources (hatched). The fit results shown correspond to the second step of the $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ calculation, which takes into account the D^0 decay model (see text).

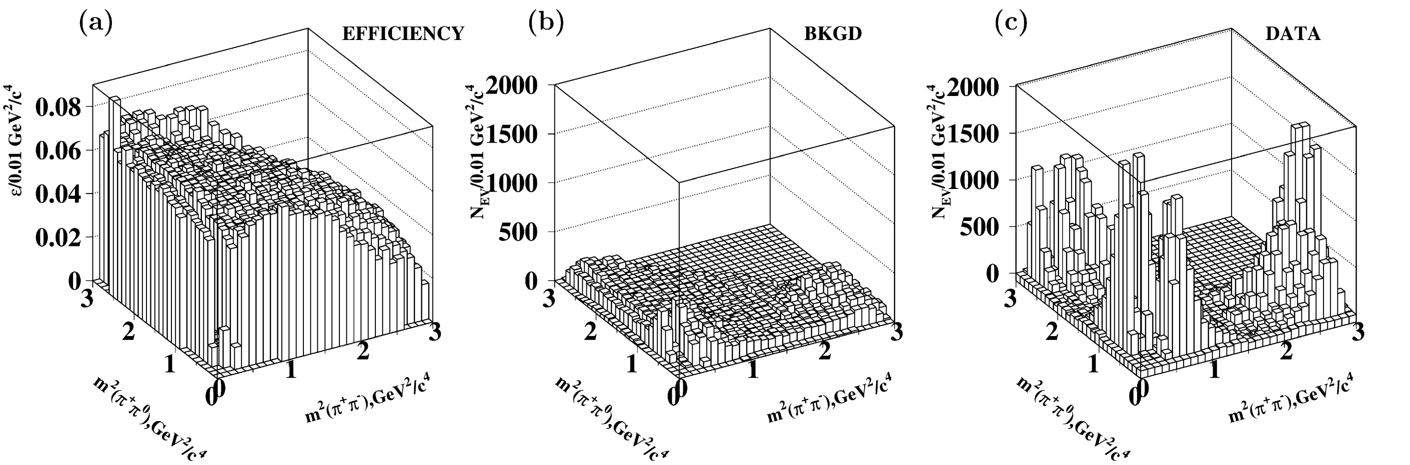

Fig. 4. $D^0 \to \pi^+\pi^-\pi^0$: Dalitz ($M^2(\pi^+\pi^-)$ vs. $M^2(\pi^+\pi^0)$) distributions for (a) efficiency, (b) simulated background and (c) data.

the second step, the D^0 decay model is taken into account by weighting entries in a histogram according to their positions on the DP. This is done to obtain a more exact $M(D^0)$ distribution for the signal and misreconstructed signal MC events. The distributions are refitted and the resulting background normalizations in Eq. (2) are used to recalculate the signal yields Y^i in Eq. (3). This results in $S(D^0 \to \pi^+\pi^-\pi^0) = (2403.6 \pm 9.2) \times 10^3$ and $S(D^0 \to K^-\pi^+\pi^0) = (23751 \pm 24) \times 10^3$.

8. Systematic uncertainties

The sources of systematic uncertainty are as follows; the values quoted are relative fractions. The estimate of the error due to the tracking efficiency uncertainty is based on a large sample of partially reconstructed $D^* \to D^0\pi_{\text{tag}}$, $D^0 \to K_S\pi^+\pi^-$ decays. The uncertainty for the two charged tracks – $\pi^+\pi^-$ or $K^-\pi^+$ – cancels to a large extent in the ratio of the $D^0 \to \pi^+\pi^-\pi^0$ and $D^0 \to K^-\pi^+\pi^0$ branching fractions. It contributes only 0.01% to the overall systematic uncertainty. We assume that the π^0 and the tagging pion (from the D^*) reconstruction efficiencies fully cancel in the ratio of the branching fractions.

The uncertainties of the corrections to the efficiency of PID selection criteria contribute ±0.91% to the systematic uncertainty of the result. The statistical error of the signal MC sample contributes ±0.30% to the total systematic uncertainty. The systematic uncertainty due to the fractions of signal and various backgrounds, which are fixed from the $M(D^0 \to \pi^+\pi^-\pi^0)$ fit results, was determined by varying the fractions within their errors (±0.61%). The correlations between the fit parameters were accounted for using the covariance matrix obtained from the fit. The uncertainty due to the $M(D^0 \to K^-\pi^+\pi^0)$ fit

Table 1
Contributions to the relative systematic error on $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$

Source	Error, %	Source	Error, %
PID corrections	0.91	*Selection criteria*:	
MC statistics	0.30	K_S veto	0.50
Fit($D^0 \to \pi^+\pi^-\pi^0$)	0.61	$p_{\rm cms}(D^*)$	0.77
Fit($D^0 \to K^-\pi^+\pi^0$)	0.30	$M(K^-\pi^+\pi^0/3\pi)$	0.36
$D^0 \to \pi^+\pi^-\pi^0$ backgr. model	0.48	ΔM	0.30
Binning	0.54	E_γ	0.40
MC misreconstruction	0.10	$M(\pi^0)$	0.20
Tracking	0.01	$p_{\rm lab}(\pi^0)$	0.16
Total			1.79

(±0.30%) was estimated by relaxing or fixing relative normalizations of some of the background types.

Our method for calculating $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ minimizes the uncertainty due to modelling the $D^0 \to \pi^+\pi^-\pi^0$ and $D^0 \to K^-\pi^+\pi^0$ decays. However, the model dependence of the background is included in the total systematics. The level of background in the $D^0 \to K^-\pi^+\pi^0$ decay is small and its effect on the ratio of $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ is negligible. The dominant source of background for the $D^0 \to \pi^+\pi^-\pi^0$ mode is the $D^0 \to K^-\pi^+\pi^0$ decay with the kaon misidentified as a pion. The normalizations of the $D^0 \to K^-\pi^+\pi^0$ submodes ($D^0 \to \rho K$, $D^0 \to K^*\pi$, $D^0 \to K^{*0}\pi^0$ and non-resonant $D^0 \to K^-\pi^+\pi^0$) are varied within the uncertainties of their branching fractions [13] and the resulting differences from the central value of $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$, summed in quadrature, are treated as the background model uncertainty (±0.48%).

Changing the DP bin size from 0.1 $\mathrm{GeV}^2/c^4 \times 0.1\ \mathrm{GeV}^2/c^4$ to 0.05 $\mathrm{GeV}^2/c^4 \times 0.05\ \mathrm{GeV}^2/c^4$ yields a ±0.54% difference in the value of $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$. We study the effect of the selection criteria upon the fraction of correctly reconstructed signal MC events and obtain a corresponding error of ±0.10%. We varied the event selection criteria in order to estimate the systematic error due to any inadequacies in the background description. Varying the K_S veto yields a ±0.50% systematic uncertainty. The change of $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ due to the variation of the $p_{\rm cms}(D^*)$ upper cut is negligible. Varying the $p_{\rm cms}(D^*)$ lower cut yields a relatively large uncertainty of ±0.77%. Uncertainties due to the variation of other selection requirements are listed in Table 1. The total uncertainty is obtained by adding all contributions in quadrature.

9. Results for $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$

Summarizing the discussion above, we obtain the following ratio of the branching fractions:

$$\frac{\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)} = \frac{S(D^0 \to \pi^+\pi^-\pi^0)}{S(D^0 \to K^-\pi^+\pi^0)} = 0.10120 \pm 0.00040(\mathrm{stat}) \pm 0.00181(\mathrm{syst}) = 0.1012 \pm 0.0019. \quad (4)$$

We can compare our measurement of the ratio with a recent result obtained by BaBar [2]. There is a 2σ difference between the central values; the accuracies of the measurements are comparable. To compare results from different experiments, we multiply the obtained value of Eq. (4) by the 2007 world average of $\mathcal{B}(D^0 \to K^-\pi^+\pi^0) = (13.5 \pm 0.6)\%$ [13] to calculate the absolute branching fraction for the $D^0 \to \pi^+\pi^-\pi^0$ decay (Table 2). In a recent study by CLEO [1], the relative branching fraction $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+)$ is measured to be $0.344 \pm 0.005(\mathrm{stat}) \pm 0.012(\mathrm{syst})$. Using the world average value of $\mathcal{B}(D^0 \to K^-\pi^+) = (3.82 \pm 0.07)\%$ from [13], one can calculate the absolute branching fraction of $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)$ from CLEO data as shown in Table 2. A comparison of the corresponding values for the absolute branching fraction $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)$ shows that the results are in good agreement.[5]

10. Measurement of A_{CP}

We subdivide the $\pi^+\pi^-\pi^0$ sample into $D^0 \to \pi^+\pi^-\pi^0$ and $\bar{D}^0 \to \pi^+\pi^-\pi^0$ subsamples to calculate the value of the time-integrated *CP* asymmetry using the same method for calculating the signal yield that was used for the relative branching fraction. The fitted $M(D^0)$ distributions of the data are shown in Fig. 5. The resulting values of $S = \sum Y^i/\varepsilon^i$ are

$$S_{D^0} = (1154.7 \pm 6.7) \times 10^3,$$
$$S_{\bar{D}^0} = (1144.7 \pm 6.6) \times 10^3. \quad (5)$$

Their sum differs from the value used to calculate the branching fraction, because the corrections for the PID efficiency of the pions originating from the D^0 cancel out in the case of the A_{CP} calculation and thus are not applied.

A detector bias may exist that leads to different efficiencies for reconstructing positively and negatively charged tracks. This may be due to charge-dependent effects such as opposite signs of the Lorentz angle with respect to the curvature of tracks in the CDC, and a difference in nuclear interactions with the detector material for positive and negative tracks. The former is partially taken into account by generating signal MC samples for $D^{*+} \to D^0\pi^+_{\rm tag}$ and $D^{*-} \to \bar{D}^0\pi^-_{\rm tag}$ separately. However, nuclear interactions of charged tracks with the detector material are imperfectly simulated. This fact also causes a systematic difference between tracking efficiencies for positive and negative particles and has to be taken into account.

Since D^0 and $\bar{D}^0$ are distinguished only by $\pi^\pm_{\rm tag}$, and the neutral D meson decays are charge and particle-type balanced, the uncertainties of the reconstruction efficiencies of the pions originating from D^0 do not affect the result. We consider the uncertainties in the tracking and PID efficiencies of the tagging pions as the main source of systematic errors for A_{CP}.

The uncertainty of the tracking efficiency was obtained using the same method used for the systematics of the $D^0 \to$

[5] Our conclusions do not change if instead of the world average value of $\mathcal{B}(D^0 \to K^-\pi^+)$ we use the value of this branching fraction from the recent high precision measurement of CLEO [14].

Table 2
$\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)$ by Belle, BaBar [2] and CLEO [1]. The first two errors are statistical and systematic, respectively, and the third one (the fourth column) is the normalization uncertainty. The latter is common in the Belle and BaBar results

Group	N_{ev}, 10^3	$\frac{\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)}$	$\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)$, 10^{-3}
Belle	123.19 ± 0.49	$0.1012 \pm 0.0004 \pm 0.0018$	$13.66 \pm 0.05 \pm 0.24 \pm 0.61$
BaBar	60.43 ± 0.34	$0.1059 \pm 0.0006 \pm 0.0013$	$14.30 \pm 0.08 \pm 0.18 \pm 0.64$
CLEO	10.83 ± 0.16	–	$13.14 \pm 0.19 \pm 0.46 \pm 0.24$

Table 3
Systematic uncertainties for A_{CP}

Source	MC stat.	Tracking	Fit	K_S veto	PID	Binning	A_{fb}	Total
σ, %	0.24	1.01	0.58	0.23	0.15	0.05	0.15	1.23

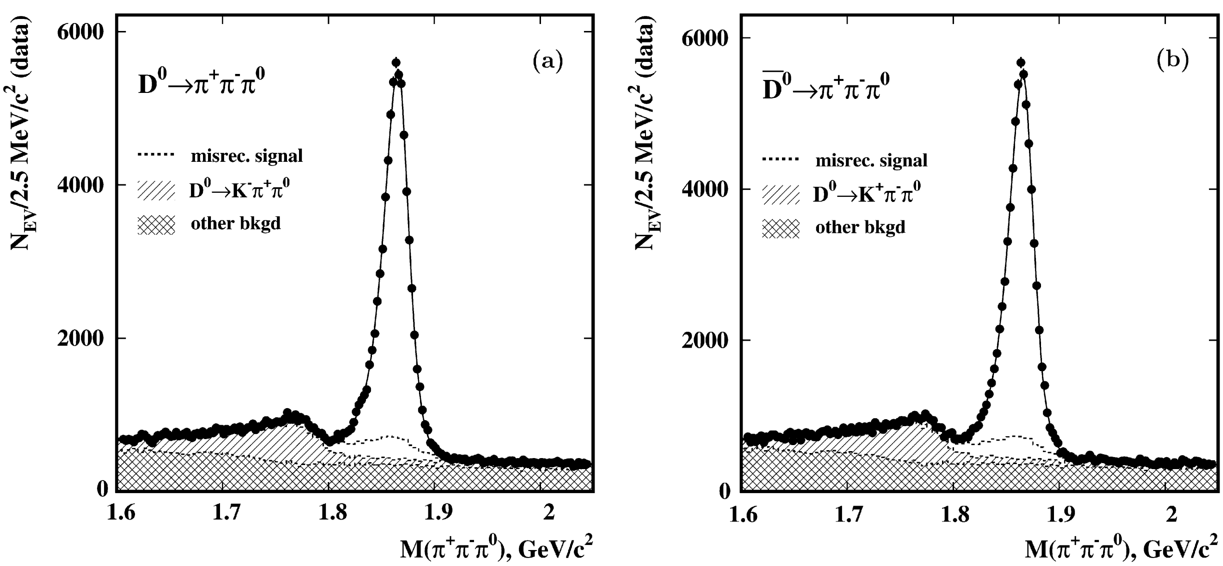

Fig. 5. (a) $M(D^0 \to \pi^+\pi^-\pi^0)$ and (b) $M(\bar{D}^0 \to \pi^+\pi^-\pi^0)$ data. Background: misreconstructed signal (dashed line), $D^0 \to K^-\pi^+\pi^0$ with misidentified kaon (shaded histogram) and other sources (hatched histogram). Events from the $M(D^0)$ signal region (1.79 to 1.91 GeV/c^2) are selected.

$\pi^+\pi^-\pi^0/D^0 \to K^-\pi^+\pi^0$ ratio, but in this case, positive and negative π_{tag}'s were treated separately. The calculation of the systematic error takes into account the momentum dependence. The errors for π^+_{tag} and π^-_{tag} were propagated to A_{CP} assuming them to be uncorrelated. The charge-dependent data/MC PID corrections for π_{tag} were obtained using independent $D^* \to D^0(K_S\pi^0)\pi_{tag}$ data and MC samples.

In general, the D-meson distribution is an asymmetric function of $\cos(\theta)$ (where θ is the polar angle) due to the interference of virtual γ and Z^0 in the process of c-quark pair production. If the detector acceptance in the center-of-mass frame were perfectly symmetric, the $\cos(\theta)$ dependent asymmetry of D^0 and $\bar{D}^0$ (D^+ and D^-, etc.) production would cancel out in the integral over $\cos(\theta)$ in a symmetric interval. However, the detector acceptance is not symmetric and a possible forward–backward asymmetry (A_{fb}) should be taken into account. A data sample of $D^0 \to K^+K^-, \pi^+\pi^-$ decay events was used to calculate $A_{fb}(\cos(\theta))$. This function was then used to weight the MC $D^0 \to \pi^+\pi^-\pi^0$ distribution, which was then normalized to the total number of MC $D^0 \to \pi^+\pi^-\pi^0$ events. The calculated value equals 0.15% and is treated as the systematic uncertainty related to the forward–backward asymmetry. Other individual sources of systematic uncertainties are listed in Table 3. Systematic errors for each D^0 flavor are calculated similarly to those for $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$, propagated to A_{CP}, and then added in quadrature.

The resulting value of the asymmetry is

$$\begin{aligned} A_{CP} &= (S_{D^0} - S_{\bar{D}^0})/(S_{D^0} + S_{\bar{D}^0}) \\ &= \big(0.43 \pm 0.41(\text{stat}) \pm 1.01(\text{track}) \pm 0.70(\text{other syst})\big)\% \\ &= (0.43 \pm 1.30)\%. \end{aligned} \tag{6}$$

This result is consistent with CP conservation in this decay mode; its sensitivity is a significant improvement over that of the previous measurement, $(1^{+10}_{-9})\%$ [6].

11. Summary

Using 532 fb^{-1} of data collected with the Belle detector, a high-precision measurement of the relative branching fraction $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0) = 0.1012 \pm 0.0004 \pm 0.0018$ has been performed. The method applied minimizes possible systematic uncertainties due to the D^0 decay model. The mode $D^0 \to K^-\pi^+\pi^0$ is chosen for normalization to avoid most of the tracking and particle identification uncertainties. We also calculate the value of the time-integrated CP asymmetry to be $A_{CP}(D^0 \to \pi^+\pi^-\pi^0) = (0.43 \pm 1.30)\%$, which is consistent with zero. The sensitivity is significantly better than that of the previous measurement [6].

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