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Hadronic Charm Meson Decays at BESIII

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The BESIII experiment has collected e^+e^- collision data samples corresponding to integrated luminosities of 2.93 fb^{-1} and 3.19 fb^{-1} at center-of-mass energies of 3.773 GeV and 4.178 GeV, respectively. We report the measurements of strong phase differences in D^0 decays, including $K_{S/L}\pi^+\pi^-$ and $K_{S/L}K^+K^-$, which can reduce the systematic uncertainty of γ/ϕ_3 measurement at LHCb and Belle II. In addition, we report the amplitude analyses and the measurements of the absolute branching fractions of D^+, D^0, and D_s decays.

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1. Introduction

BEPCII is a double-ring e^+e^- collider operating at center-of-mass energy between 2.0 GeV and 4.9 GeV, which has reached the design luminosity of $1\times10^{33}\text{cm}^{-2}\text{s}^{-1}$ in April 2016. BESIII is a major spectrometer running at BEPCII for the studies of hadron physics and τ-charm physics. Charm meson pairs $D\bar{D}$ ($D_s\bar{D}_s^*$) are produced near energy threshold 3.773 GeV (4.178 GeV) without accompanying particles, corresponding to integrated luminosity of 2.93 fb^{-1} (3.19 fb^{-1}) [1]. Based on the data samples, hadronic D decays can be studied with low background. A double tag (DT) technique is used in most analyses except Sec. 4.1 and 4.2, in which a single tag (ST) technique is used. DT is a method of fully reconstructing $D\bar{D}$ pair, while ST is a method of partially reconstructing a D meson. ST technique can obtain more data yields for decay channels with few background, while DT technique provides clean samples for amplitude analysis and branching fraction (BF) measurements. We report the recent results with precisions significantly improved or observation for the first time. Charge-conjugate modes are implied throughout this paper.

2. Measurements of strong-phase parameters in D^0 decay

2.1 $D^0 \to K_{S/L}\pi^+\pi^-$

Recently, BESIII has reported the determination of strong-phase parameters in $D^0 \to K_{S/L}\pi^+\pi^-$ decay. In model-independent GGSZ approach [2], strong-phase parameters measured from quantum-correlated $D^0\bar{D}^0$ decays are the key input parameters for γ/ϕ_3 measurement. Three binning schemes are used in this work, equal $\Delta\delta_D$ ($\Delta\delta_D$ is the relative strong-phase between D^0 and $\bar{D}^0 \to K_{S/L}\pi^+\pi^-$), optimal and modified optimal. Two-dimensional fits are performed to extract signal events. In order to enlarge the amount of collected DT events, two partial-reconstruction methods are used by missing one π^+ from D and missing one π^0 from K_S.

Figure 1 shows the results of c_i and s_i (c_i and s_i are the average $\cos\delta_D$ and $\sin\delta_D$ in Dalitz plot bin i, respectively.) from $D^0 \to K_{S/L}\pi^+\pi^-$, which are the most precise measurements to date. The strong-phase parameters are still limited by statistical uncertainty. BESIII results are a factor of 1.9 to 2.8 more precise than previous results, and the associated uncertainty on γ/ϕ_3 is reduced from 4 degrees to 1 degree. The improved result is important input for γ measurement in B decay [3, 4].

2.2 $D^0 \to K_{S/L}K^+K^-$

For the strong-phase differences measured in $D^0 \to K_{S/L}K^+K^-$ decay, by using the equal $\Delta\delta_D$ binning scheme, the results of strong-phase parameters for N=2, 3 and 4 equal $\Delta\delta_D$ bins are obtained, which are consistent with the CLEO measurements in all bins and are the most precise measurement to date of strong-phase difference in these decays. For N=2, N=3, and N=4 equal $\Delta\delta_D$ binning, the estimated uncertainties caused by the uncertainty of the measured values of c_i and s_i is 2.3°, 1.3°, and 1.3°, respectively. The values are also important for the determination of charm-mixing parameters and the search of CP violation [7].

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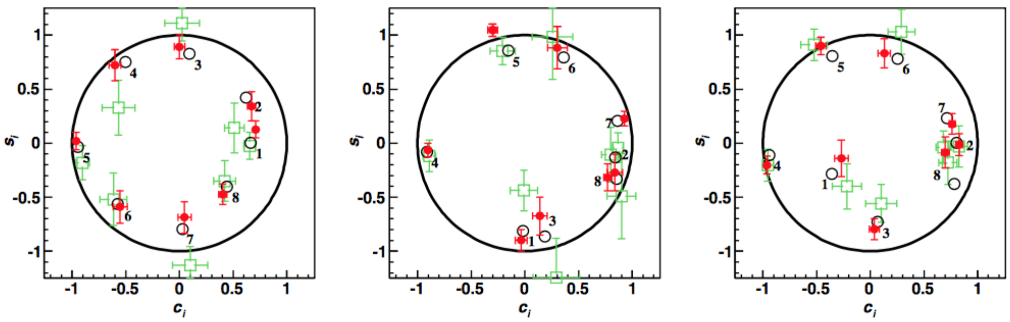

Figure 1: The c_i and s_i measured from this work, the predictions of Ref. [5] and the results of Ref. [6] correspond to the red dots with error bars, the black open circles and green open squares with error bars, respectively. The left, middle and right plots from the equal $\Delta\delta_D$, optimal and modified optimal binnings, respectively. The circle indicates the boundary of the physical region $c_i^2 + s_i^2 = 1$.

3. Amplitude analysis of D decay

3.1 $D^0 \to K_{S/L}K^+K^-$

Using a sample of 1845 ± 45 flavor-tagged signal decays with a purity of 96%, we find that the Dalitz plot (DP) of this decay is well described by a set of six resonances: $a_0(980)^0$, $a_0(980)^+$, $\phi(1020)$, $a_2(1320)^+$, $a_2(1320)^-$ and $a_0(1450)^-$. The coupling of $a_0(980)^0$ to $K\bar{K}$ is determined to be $g_{K\bar{K}} = (3.77 \pm 0.24_{\text{stat.}} \pm 0.35_{\text{sys.}})$ GeV, and BF of $D^0 \to K_{S/L}K^+K^-$ decay is measured to be $(4.51 \pm 0.05_{\text{stat.}} \pm 0.16_{\text{sys.}}) \times 10^{-3}$ by using 11660 ± 118 untagged signal decays. Both measurements are systematically limited [8].

3.2 $D_s^+ \to K^+K^-\pi^+$

The preliminary result of amplitude analysis of $D_s^+ \to K^+K^-\pi^+$ provides important inputs for theory and refine theoretical models. Meanwhile, there is obvious difference of BFs of $S(980)\pi^+$ between CLEO and BABAR [9, 10]. We obtain 4397 DT events with a purity of 99.6% which means background free. BESIII results are closer to those of BABAR.

For the BF measurement of $D_s^+ \to K^+K^-\pi^+$, we obtain 5148 DT signal events from the fit of D_s mass from signal side and the fit of mass difference of D_s from signal side and tag side. The BF is measured to be $(5.47 \pm 0.08_{\text{stat.}} \pm 0.13_{\text{sys.}})\%$, which is the best precision up to now. The decay BFs with intermediate states like $\bar{K}^*(892)^0K^+$ and $\phi(1020)\pi^+$ are consistent with theoretical predictions [11].

3.3 $D_s^+ \to \pi^+\pi^-\pi^+$

We perform a DP analysis of the $D_s \to \pi^+\pi^-\pi^+$ decay to better understand intermediate scalars such as $f^0(980)$ or $f^0(1370)$ and to obtain important input for the global study of D_s decay. We obtained 13.8 thousand events with a purity of 80%. The unbinned maximum likelihood fit to data is performed with likelihood function depending on DP position for each event. Amplitudes and phases contributing to this final state are measured. The DP analysis shows that the decay is dominated by the $\pi^+\pi^-$ S-wave. The decay fraction result of $\Gamma(D_s \to \rho^0\pi^+)/\Gamma(D_s \to$

$\pi^+\pi^-\pi^+) = (0.9 \pm 0.4_{\text{stat.}} \pm 0.5_{\text{sys.}})\%$ shows a central value considerably lower than that of the BABAR result [12], although large uncertainties make both results still compatible within one standard deviation.

4. Measurements of branching fractions of D decay

4.1 $D_s^+ \to PP$

The BFs of D_s^+ to two pseudo-scalar mesons ($K^+\eta^{'}$, $\pi^+\eta^{'}$, $K^+\eta$, $\pi^+\eta$, $K^+K_S^0$, $\pi^+K_S^0$ and $K^+\pi^0$) are measured by analyzing data collected at $\sqrt{s} = 4.178 \sim 4.226$ GeV with BESIII, which can be used to explore SU(3) asymmetries and provide crucial calibrations to different theoretical models. The signal yields are extracted by fitting the invariant mass of D_s^+ with ST events, and the normalization mode $D_s^+ \to K^+K^-\pi^+$ is used in this work. Precision of our measurements is significantly improved in comparison with the current world average value [13].

4.2 $D \to \phi P$

The BFs of four $D \to \phi P$ decay modes are measured to be $\mathscr{B}(D^0 \to \phi\pi^0) = (1.168 \pm 0.028_{\text{stat.}} \pm 0.028_{\text{sys.}}) \times 10^{-3}$, $\mathscr{B}(D^0 \to \phi\eta) = (1.81 \pm 0.46_{\text{stat.}} \pm 0.06_{\text{sys.}}) \times 10^{-4}$, $\mathscr{B}(D^+ \to \phi\pi^+) = (5.70 \pm 0.05_{\text{stat.}} \pm 0.13_{\text{sys.}}) \times 10^{-3}$, and $\mathscr{B}(D^+ \to \phi K^+) < 2.1 \times 10^{-5}$ (at 90% confidence level), respectively. The ratio of $\mathscr{B}(D^0 \to \phi\pi^0)$ to $\mathscr{B}(D^+ \to \phi\pi^+)$ is calculated to be $(20.49 \pm 0.50_{\text{stat.}} \pm 0.045_{\text{sys.}})\%$, which shows better agreement with theoretical prediction than the previous measurement. Therefore, our results support the isospin symmetry between these two decay modes [14].

4.3 $D \to \omega\pi\pi$

We measure the BFs of singly Cabibbo-suppressed decays $D \to \omega\pi\pi$ to be $\mathscr{B}(D^0 \to \omega\pi^+\pi^-) = (1.33 \pm 0.16_{\text{stat.}} \pm 0.12_{\text{sys.}}) \times 10^{-3}$ and $\mathscr{B}(D^+ \to \omega\pi^+\pi^0) = (3.87 \pm 0.83_{\text{stat.}} \pm 0.25_{\text{sys.}}) \times 10^{-3}$, corresponding to the statistical significances of 12.9σ and 7.7σ, respectively. $\mathscr{B}(D^+ \to \omega\pi^+\pi^0)$ is measured for the first time and the precision of $\mathscr{B}(D^0 \to \omega\pi^+\pi^-)$ is significantly improved than CLEO measurement. In addition, no significant signal of $D^0 \to \omega\pi^0\pi^0$ is observed, and the upper limit on the BF is set to be $\mathscr{B}(D^0 \to \omega\pi^0\pi^0) < 1.10 \times 10^{-3}$ at 90% confidence level [15].

4.4 $D \to K\bar{K}\pi\pi$

We report the first direct measurements of the absolute BFs of nine $D^{0(+)} \to K\bar{K}\pi\pi$ decays containing K_S^0 or π^0 mesons. The $D^0 \to K^+K^-\pi^0\pi^0$, $D^0 \to K_S^0K^-\pi^+\pi^0$, $D^0 \to K_S^0K^+\pi^-\pi^0$, $D^+ \to K_S^0K^+\pi^0\pi^0$, and $D^+ \to K_S^0K_S^0\pi^+\pi^0$ decays are observed for the first time, while the BFs of the $D^0 \to K_S^0K_S^0\pi^+\pi^-$, $D^+ \to K^+K^-\pi^+\pi^0$, $D^+ \to K_S^0K^-\pi^+\pi^+$, and $D^+ \to K_S^0K^+\pi^+\pi^-$ decays are measured with improved precision in comparison with the world-average values. Our results can be use to explore $D\bar{D}$ mixing or CP violation and to understand quark SU(3)-flavor symmetry [16].

4.5 $D \to \eta X$

The known $D^{0(+)} \to \eta X$ decays only account for 44% (16%), while they are the key potential backgrounds in some lepton flavor universality (LFU) tests. These decays are crucial to address the tensions found in LFU tests with semi-leptonic B decays, as well as searches for CP violation. We report the first measurements of the absolute BFs of 14 hadronic $D^{0(+)}$ decays to exclusive final states with an η. The two decay channels with the largest BFs are $\mathscr{B}(D^0 \to K^-\pi^+\eta) = (1.853 \pm 0.025_{\rm stat.} \pm 0.031_{\rm sys.})\%$ and $\mathscr{B}(D^+ \to K^0_S\pi^+\eta) = (1.309 \pm 0.037_{\rm stat.} \pm 0.031_{\rm sys.})\%$, respectively. The charge-parity asymmetries for the six decays with highest event yields are determined, and no evidence of CP violation is found [17].

4.6 $D^+ \to \eta\eta\pi^+$ and $D^{0(+)} \to \eta\pi^+\pi^{-(0)}$

We measure the absolute BFs of $D^+ \to \eta\eta\pi^+$, $D^+ \to \eta\pi^+\pi^0$, and $D^0 \to \eta\pi^+\pi^-$ to be $(2.96 \pm 0.24_{\rm stat.} \pm 0.10_{\rm sys.}) \times 10^{-3}$, $(2.23 \pm 0.15_{\rm stat.} \pm 0.10_{\rm sys.}) \times 10^{-3}$, and $(1.20 \pm 0.07_{\rm stat.} \pm 0.04_{\rm sys.}) \times 10^{-3}$, respectively. The BF of $D^+ \to \eta\eta\pi^+$ is measured for the first time. The BFs of $D^{0(+)} \to \eta\pi^+\pi^{-(0)}$ are consistent with the CLEO-c's results with improved precision. We also test CP asymmetries of the BFs of D and $\bar{D}$ decays, but no evidence of CP violation is found [18].

5. Conclusions

We report the measurements of strong-phase parameters in D^0 decays with best precision, which can reduce the systematic uncertainty of γ measurements at LHCb and Belle II. Three amplitude analysis of D decays are performed. In addition, 21 D meson decays are reported for the first time, and 20 D decays are measured with best precision. These results have been used to check SU(3) asymmetry and to support isospin symmetry, but no CP violation is found. At the center-of-mass energy $\sqrt{s} = 3.773$ GeV, 17 fb^{-1} $\psi(3770)$ data is scheduled to be collected in the next two years. More results in hadronic charm meson decays can be expected.

6. Acknowledgments

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