PROCEEDINGS OF SCIENCE

Hadronic charm meson decays at BESIII

Yu-Lan Fan*

School of Physics and Technology,Wuhan University, Wuhan, P.R.China

E-mail: yulanf@whu.edu.cn

(On behalf of the BESIII Collaboration)

BESIII experiment has collected e^+e^- collision data samples corresponding to integrated lumonisities of 2.93 fb^{-1}, 3.19 fb^{-1} and 3.13 fb^{-1} at the center-of-mass (c.m.) energies of 3.773 GeV, 4.178 GeV, and 4.189-4.226 GeV, respectively. We report the measurements of strong phase differences in D^0 decays, including $K^0_{S/L}\pi^+\pi^-$, $K^0_{S/L}K^+K^-$, $K^+\pi^-\pi^-\pi^+$ and $K^-\pi^+\pi^0$, which can reduce the systematic uncertainty of γ/ϕ_3 measurement at LHCb and Belle II experiments. In addition, we report the amplitude analyses and measurements of the absolute branching fractions of D^0, D^+ and D_s decays.

10th International Workshop on Charm Physics (CHARM2020),
31 May - 4 June, 2021
Mexico City, Mexico - Online

*Speaker

PoS(CHARM2020)032

1. Introduction

BEPCII is a double-ring e^+e^- collider operating at c.m. energy between 2.0 GeV and 4.9 GeV, which has reached the design luminosity of 1×10^{33} cm^{-2}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 and 4.189-4.226 GeV) without accompanying particles, corresponding to integrated luminosity of 2.93 fb^{-1} (3.19 fb^{-1} and 3.13 fb^{-1}) [1]. Based on these data samples, hadronic D decays can be studies with low background. A double tag (DT) technique is used in most analyses expect 4.4, in which a single tag (ST) technique is used. DT is a method of fully reconstructing $D\bar{D}$ pair, which ST is a method of partially reconstructing a D meson. We report the recent results with precision 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 decays

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

BESIII has reported the determination of strong-phase parameters in $D^0 \to K^0_{S/L}\pi^+\pi^-$ decay [2, 3]. In model-independent GGSZ approach [4], 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 $\bar{D}^0 \to K^0_{S/L}\pi^+\pi^-$), 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^0_S.

The results of c_i and s_i (c_i and s_i shown in Fig. 1 are the average cosδ_D and sinδ_D in Dalitz plot bin i, respectively.) from $D^0 \to K^0_{S/L}\pi^+\pi^-$, 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 results is important input for γ/ϕ_3 measurement in B decay.

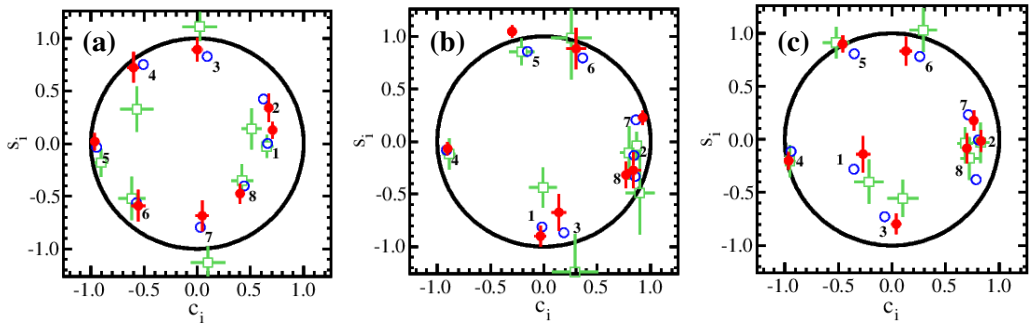

Figure 1: The c_i and s_i measured from this work, the predictions of Ref.[5] and the results of Ref. [6] corresponding to the red dots with error bars, the black open circles and green squares with error bars, respectively.

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

For the strong-phase parameters measured in $D^0 \to K^0_{S/L}K^+K^-$ decay [7], 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 measurement [6] in all bins and are the most precise measurement to date of strong-phase difference in these decays. For N=2, 3 and 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 search of CP violation.

2.3 $D^0 \to K^-\pi^+\pi^+\pi^-$ and $D^0 \to K^-\pi^+\pi^0$

Recently, BESIII reported a coherence factors and strong-phase differences study of $D \to K^\pm\pi^\mp\pi^+\pi^-$ and $D \to K^\pm\pi^\mp\pi^0$ decays [8]. Based on the global analysis and equal $\Delta\delta_D$ binning scheme which the phase space is partitioned into 4 pairs of irregularly bin, the coherence factor (R) and average strong-phase difference (δ) of each decay are measured. The region of parameter spaces ($R_{K3\pi}$, $\delta_D^{K3\pi}$) and ($R_{K\pi\pi^0}$, $\delta_D^{K\pi\pi^0}$) encompassed by 2-3 σ confidence intervals are significantly more constrained than the measurements of CLEO-c [9]. The phase space is re-performed in four bins of the $D \to K^\pm\pi^\mp\pi^+\pi^-$ to yield results, to which the γ/ϕ_3 is determined with the precision to be around 6°.

3. Amplitude analyses

3.1 $D_s^+ \to \pi^+\pi^0\eta$

BESIII has reported the first amplitude analysis of $D_s^+ \to \pi\pi^0\eta$ decay [10] which is a W-annihilation (WA) dominated channel. We retain a sample of 1239 $D_s^+ \to \pi^+\pi^0\eta$ candidates that has a purity of (97.7 ± 0.5)%. The WA dominant decays $D_s^+ \to a_0(980)^+\pi^0$ and $D_s^+ \to a_0(980)^0\pi^+$ are observed for the first time. The measured absolute branching fraction (BF) $\mathcal{B}(D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}, a_0(980)^{+(0)} \to \pi^{+(0)}\eta) = (1.46 \pm 0.15_{\text{stat.}} \pm 0.23_{\text{syst.}})$ is larger than the BFs of other measured pure WA decays by at least one order of magnitude. Furthermore, the BF of $D_s^+ \to \pi^+\pi^0\eta$ is measured with significantly improved precision.

3.2 $D_{(s)}^+ \to K_s^0\pi^+(K^+)\pi^0$

Using a data sample of 692 DT candidate events with a purity of 97.4%, we perform the first Dalitz plot (DP) analysis of the singly Cabibbo-suppressed (SCS) decay $D^+ \to K^0_S K^+\pi^0$ [11]. The DP analysis shows that the BF of dominated component $K^*(892)^+K^0_S$ is $(8.69 \pm 0.46_{\text{stat.}} \pm 0.68_{\text{syst.}} \pm 0.18_{\text{exet.}}) \times 10^{-3}$, which is consistent with the previous results [12] but with a precision improved by a factor of 4.6.

We perform an amplitude analysis of the $D_s^+ \to K^0_S\pi^+\pi^0$ decay [13] to better understand the vector-pesudoscalar channels of the SCS D_s^+ decay. We obtained 609 DT events with a purity of 83.1%. Amplitudes, fit fractions (FFs) and phases contributing to this final state are measured. The BF for the decay $D_s^+ \to K^0_S\pi^+\pi^0$ is measured to be $(5.43 \pm 0.30_{\text{stat.}} \pm 0.15_{\text{syst.}}) \times 10^{-3}$ with an improved precision by a factor of 3 compared to the previous measurement [14]. The decay BFs

with intermediate states like $K^*(892)^{0(+)}\pi^{+(0)}$ and $K^0_S\rho$ are consistent with the theoretical predictions in Ref. [13].

3.3 $D_s^+ \to K^+K^-\pi^+(\pi^0)$

BESIII perform an amplitude analysis of $D_s^+ \to K^+K^-\pi^+$ [16], this results provides important inputs for theory and refines theoretical models. Meanwhile, there are obvious difference between FFs of BaBar and CLEO results [17, 18]. We obtain 4399 DT events with a purity of 99.6% which means a background free. And a model-independent partial wave analysis in the low K^+K^- mass region is performed to determine the K^+K^- S-wave lineshape. The BF of $D_s^+ \to K^+K^-\pi^+$ is determined to be $(54.7 \pm 0.08_{\text{stat.}} \pm 0.13_{\text{syst.}})\%$ which is the most precise measurement up to know. The decay BFs with intermediate states like $\bar{K}^*(892)^0K^+$ and $\phi(1020)\pi^+$ are consistent with theoretical predictions [19].

An amplitude analysis of decay $D_s^+ \to K^+K^-\pi^+\pi^0$, which BF has a large systematic uncertainty, has performed by BESIII [20]. This analysis allows to probe the substructures involving $K_1(1270)$, $K_1(1400)$ and $f_1(1420)$ mesons. Using a data sample of 3088 DT events with a purity of 97.5%, the magnitudes, FFs and phases of different components have been determined. For the BFs measurements, the BF of $D_s^+ \to K^+K^-\pi^+\pi^0$ is measured to be $(5.42 \pm 0.10_{\text{stat.}} \pm 0.17_{\text{syst.}})\%$ with the precision significantly improved. The BFs of intermediate processes like $(\phi\rho^+)$ and $\bar{K}^{*0}K^{*+}$ are obtained with a much better precision than previous measurements [21, 22]. The inconsistence exists between different experiments of the ratio of $K_1(1270)$ decay, $R_{K_1(1270)} = \frac{\mathcal{B}(K_1(1270)\to K^*\pi)}{\mathcal{B}(K_1(1270)\to K\rho)}$ [23]. This ratio is measured to be $(0.51 \pm 0.12_{\text{stat.}} \pm 0.09_{\text{syst.}})\%$ in this analysis, which is consistent with the results using CLEO's and Belle' data within uncertainties.

4. Absolute branching fractions

4.1 $D \to \eta X$

BESIII report the first measurements of the absolute BFs of 14 hadronic decays to exclusive final states with an η [24] which are key potential backgrounds in some lepton flavor universality (LFU) tests. The known exclusive $D^{0(+)} \to \eta X$ decays only account for 44% (16%) of their corresponding inclusive rates. Moreover, these decays are crucial to address the tensions found in LFU tests with semi-leptonic B decays, as well as searches for CP violation. In this analysis, two decay channels with largest BFs are $\mathcal{B}(D^0 \to K^-\pi^+\eta) = (1.853 \pm 0.025_{\text{stat.}} \pm 0.031_{\text{syst.}})\%$ and $\mathcal{B}(D^+ \to K^0_S\pi^+\eta) = (1.309 \pm 0.037_{\text{stat.}} \pm 0.031_{\text{syst.}})\%$. The charge-parity asymmetries for the six decays with highest event yields are determined, and so no evidence of CP violation is found.

4.2 $D \to \omega\pi\pi$

We measure the BFs of SCS decays $D \to \omega\pi\pi$ [25]. In this analysis, the BF of $D^0 \to \omega\pi^+\pi^-$ is determined to be $(1.33 \pm 0.16_{\text{stat.}} \pm 0.12_{\text{syst.}}) \times 10^{-3}$ with the statistical significance of 12.9 σ, and corresponding precision highly improved than CLEO measurement. We also measure the BF of $D^+ \to \omega\pi^+\pi^0$, which is $(3.87 \pm 0.83_{\text{stat.}} \pm 0.25_{\text{syst.}}) \times 10^{-3}$, for the first time with the statistical significance of 7.7σ. 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 $\mathcal{B}(D^0 \to \omega\pi^0\pi^0) < 1.10 \times 10^{-3}$ at 90% confidence level.

4.3 $D \to K\bar{K}\pi\pi$

We report the first direct measurements of the absolute BFs of nine $D^{0(+} \to K\bar{K}\pi\pi$ decays containing K^0_S or π^0 mesons. The $D^0 \to K^+K^-\pi^0\pi^0$, $D^0 \to K^0_SK^-\pi^+\pi^0$, $D^0 \to K^0_SK^+\pi^-\pi^0$, $D^+ \to K^0_SK^+\pi^0\pi^0$ and $D^+ \to K^0_SK^0_S\pi^+\pi^0$ decays are observed for the first time, while the BFs of the $D^0 \to K^0_SK^0_S\pi^+\pi^-$, $D^+ \to K^+K^-\pi^+\pi^0$, $D^+ \to K^0_SK^-\pi^+\pi^+$ and $D^+ \to K^0_SK^+\pi^+\pi^-$ 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.

4.4 $D^+_s \to PP$

The BFs D^+_s to two peseudo-scalar mesons ($K^+\eta'$, $\pi^+\eta'$, $K^+\eta$, $pi^+\eta$, $K^+K^0_S$, $\pi^+K^0_S$ and $K^+\pi^0$) are measured by analyzing data collected at $\sqrt{s}$ = 4.178-4.226 GeV with BESIII [27], 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 are significantly improved in comparison with current world average values.

4.5 $D^+ \to \eta\eta\pi^+$ 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 $(2.96 \pm 0.24_{\text{stat.}} \pm 0.10_{\text{syst.}}) \times 10^{-3}$, $(2.23 \pm 0.15_{\text{stat.}} \pm 0.10_{\text{syst.}}) \times 10^{-3}$, and $(1.20 \pm 0.07_{\text{stat.}} \pm 0.04_{\text{syst.}}) \times 10^{-3}$, 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'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 [28].

5. Summary

We report the measurements of the strong-phase parameters in D^0 decays with best precision, which can reduce the systematic uncertainty for γ/ϕ_3 measurements at LHCb and Belle II. In excess of five amplitude analyses of D decays are performed. In addition, more than 20 D meson decays are reported for the first time and exceeding 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 c.m. energy $\sqrt{s}$ = 3.773 GeV, BESIII plans to take another 17 fb^{-1} data [26]. More results in hadronic charm meson decays can be expected.

References

[1] M. Ablikim *et al.* (BESIII Collaboration), Chin. Phys. C **44** (2020), 040001.

[2] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. Lett. **124** (2020), 241802.

[3] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **101** (2020), 112002

[4] A. Giri, Y. Grossman, A. Soffer and J. Zupan, Phys. Rev. D **68** (2003), 054018.

[5] I. Adachi *et al.* (BaBar and Belle Collaboration), Phys. Rev. D **98** (2018), 112012.

[6] J. Libby *et al.* (CLEO Collaboration), Phys. Rev. D **82** (2010), 112006.

[7] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **102** (2020), 052008.

[8] M. Ablikim *et al.* (BESIII Collaboration), JHEP **05** (2021), 164.

[9] T. Evans, S. Harnew, J. Libby, S. Malde, J. Rademacker and G. Wilkinson,Phys. Lett. B **757** (2016), 520; Phys. Lett. B **765** (2017), 402 (erratum).

[10] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. Lett. **123** (2019), 112001.

[11] M. Ablikim *et al.* (BESIII Collaboration), arXiv:2104.09131 [hep-ex].

[12] P. L. Frabetti *et al.* (E678 Collaboration), Phys. Lett. B **346** (1995), 199.

[13] M. Ablikim *et al.* (BESIII Collaboration), arXiv:2103.15098 [hep-ex].

[14] . P. Naik *et al.* (CLEO Collaboration), Phys. Rev. D **80** (2009), 112004.

[15] Y. Fu-Sheng, X. X. Wang and C. D. Lu, Phys. Rev. D **84** (2011), 074019.

[16] M. Ablikim *et al.* (BESIII Collaboration), arXiv:2011.08041 [hep-ex].

[17] P. del Amo Sanchez *et al.* (BaBar Collaboration), Phys. Rev. D **83** (2011), 052001.

[18] R. E. Mitchell *et al.* (CLEO Collaboration), Phys. Rev. D **79** (2009), 072008.

[19] P. del Amo Sanchez *et al.* (BaBar Collaboration), Phys. Rev. D **83** (2011), 052001.

[20] M. Ablikim *et al.* (BESIII Collaboration), arXiv:2103,02482 [hep-ex].

[21] P. Avery *et al.* (CLEO Collaboration), Phys. Rev. Lett. **68** (1992), 1279.

[22] H. Albrecht *et al.* (ARGUS Collaboration), Z. Phys. C **53** (1992), 361.

[23] M. Artuso *et al.* (CLEO Collaboration), Phys. Rev. D **85** (2012), 122002; M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **95** (2017), 072010; R. Aaij *et al.* (LHCb Collaboration), Eur. Phys. J. C **78** (2018), 443; H. Guler *et al.* (Belle Collaboration), Phys. Rev. D **83** (2011), 032005; C. Daum *et al.* (ACCMOR Collaboration), Nucl. Phys. B **187** (1981), 1; P. dArgent *et al.* JHEP **05** (2017), 143.

[24] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. Lett. **124** (2020), 241803.

[25] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **102** (2020), 052003

[26] M. Ablikim *et al.* (BESIII Collaboration), Chinese Phys. C **44** (2020), 040001.

[27] M. Ablikim *et al.* (BESIII Collaboration), JHEP **08** (2020), 146.

[28] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **101** (2020), 052009.