PROCEEDINGS OF SCIENCE

CP Violation, Mixing and non-Leptonic Decays at BESIII

Minggang Zhao[*†]
on behalf of BESIII Collaboration
Nankai University, Tianjin, China
E-mail: zhaomg@nankai.edu.cn

The BESIII detector at Beijing Electron-Positron Collider has collected the world's largest charm threshold data (2.93 fb^{-1}), which provide a good laboratory for quantum correlation measurement as well as testing QCD in charm meson decays. This work focuses on the recent measurement of CP asymmetry, mixing parameter, strong phase difference and branching fractions of $D^0 \to K^-\pi^+\pi^+\pi^-$, $D^0 \to K_S^0 K^+K^-$, $D^{0,\pm} \to PP'$ ($P = Pseudoscalar$), $D^{0,\pm} \to \omega\pi^{0,\pm}$, $D_S^+ \to \eta'\rho$ and $D_S^+ \to \eta' + anything$ at the BESIII experiment.

VIII International Workshop On Charm Physics
5-9 September, 2016
Bologna, Italy

*Speaker.

†I would like to thank for the support of the National Natural Science Foundation of China (NSFC) under Contracts No. 11475090 and No. 11005061, Natural Science Foundation of Shandong Province under Contract No. ZR2009AQ002 and the Ministry of Science and Technology of China (973 by MOST) under Contracts No. 2009CB825200 and No. 2015CB856700

PoS(CHARM2016)023

1. $D^+ \to K^0_S/K^0_L K^+(\pi^0)$ and CP asymmetry

In the Standard Model (SM), the singly Cabibbo suppressed (SCS) D meson hadronic decays are predicted to exhibit CP asymmetries at the order of 10^{-3} [1]. Direct CP violation in SCS decays could arise from the interference between tree-level and penguin decay processes. However, Cabibbo-suppressed (DCS) and Cabibbo-favored (CF) decays are expected to be CP invariant in the SM because they are dominated by a single weak amplitude. So, measurements of CP asymmetries in SCS processes greater than $O(10^{-3})$ would be evidence of physics beyond the SM [2]. CP asymmetry can be tested by using SCS decays $D^+ \to K^0_S/K^0_L K^+(\pi^0)$ based on a charge-dependent measurement. This work reports the measurements of the absolute branching factions and the CP asymmetries of the SCS decays of $D^+ \to K^0_S K^+$, $K^0_S K^+\pi^0$, $K^0_L K^+$ and $K^0_L K^+\pi^0$. The measurement of the branching fraction of the two body decay $D^+ \to \bar{K}^0 K^+$ is also helpful for better understanding SU(3)-violating effects in D meson decays [3].

In this analysis, we employ the double tag (DT) technique to measure the absolute branching fractions. First, we select the single tag (ST) events in which either a D or $\bar{D}$ is fully reconstructed by hadronic decays. Then we look for the D decays of interest in the presence of the ST $\bar{D}$ mesons; these are the DT events in which both the D and $\bar{D}$ mesons are fully reconstructed. The ST and DT yields (NST and $N_{\rm DT}$) can be described by

$$N_{\rm ST} = 2\cdot N_{D^+D^-}\cdot \mathscr{B}_{\rm tag}\cdot \varepsilon_{\rm ST}, N_{\rm DT} = 2\cdot N_{D^+D^-}\cdot \mathscr{B}_{\rm tag}\cdot \mathscr{B}_{\rm sig}\varepsilon_{\rm DT}, \tag{1.1}$$

where $N_{D^+D^-}$ is the total number of D^+D^- pairs produced in data, $\varepsilon_{\rm ST}$ and $\varepsilon_{\rm DT}$ are the efficiencies of reconstructing the ST and DT candidate events, $\mathscr{B}_{\rm tag}$ and $\mathscr{B}_{\rm sig}$ are the branching fractions for the ST mode and the signal mode. The absolute branching fraction for the signal decay is extracted by

$$\mathscr{B}_{\rm sig} = \frac{N_{\rm DT}/\varepsilon_{\rm DT}}{N_{\rm ST}/\varepsilon_{\rm ST}} = \frac{N_{\rm DT}/\varepsilon}{N_{\rm ST}}, \tag{1.2}$$

where $\varepsilon = \varepsilon_{\rm ST}/\varepsilon_{\rm DT}$ is the efficiency of reconstructing the signal decay. With the measured absolute branching fractions of D^+ and D^- decays, the CP asymmetry for the decay of interest can be determined by

$$\mathscr{A}_{CP} = \frac{\mathscr{B}(D^+ \to K^0_{S,L}K^+(\pi^0)) - \mathscr{B}(D^- \to K^0_{S,L}K^-(\pi^0))}{\mathscr{B}(D^+ \to K^0_{S,L}K^+(\pi^0)) + \mathscr{B}(D^- \to K^0_{S,L}K^-(\pi^0))}. \tag{1.3}$$

The branching fractions of $D^+ \to K^0_S K^+(\pi^0)$ and $D^+ \to K^0_L K^+(\pi^0)$ are extracted according to Eq. 1.2. With the numbers of $N_{\rm ST}$, $N_{\rm DT}$, and ε, we obtain the $D^+ \to K_{S,L}K^+(\pi^0)$ branching fractions for different ST modes. They are averaged using the standard weighted least-squares method for D^+ and D^- decays, respectively. Based on these, we also determine the average branching fraction after considering charge conjugation, as well as the CP asymmetry for each decay with Eq. 1.3, as summarized in Table 1. No evidence for CP asymmetry is found.

2. $D^+ \to K^0_S/K^0_L\pi^0(\pi^0)$ and mixing parameter y_{CP}

As first pointed out by I.I.Bigi and H.Yamamoto [4], the decay rates of $D \to K^0_S\pi's$ and $D \to K^0_L\pi's$ are not the same because of the interference of the Cabibbo favored (CF) component $D \to$

Table 1: Summary of the measured branching fractions and CP asymmetries, where the first and second uncertainties are statistical and systematic, respectively, and a comparison with the world average value [15].

Signal mode	$\mathscr{B}(D^+)(\times 10^{-3})$	$\mathscr{B}(D^-)(\times 10^{-3})$	$\overline{\mathscr{B}}(\times 10^{-3})$	$\mathscr{A}_{CP}$ (%)
$K_S^0 K^\pm$	$3.01 \pm 0.12 \pm 0.10$	$3.10 \pm 0.12 \pm 0.10$	$3.06 \pm 0.09 \pm 0.10$	$-1.5 \pm 2.8 \pm 1.6$
$K_S^0 K^\pm \pi^0$	$5.23 \pm 0.28 \pm 0.24$	$5.09 \pm 0.29 \pm 0.22$	$5.16 \pm 0.21 \pm 0.23$	$1.4 \pm 4.0 \pm 2.4$
$K_L^0 K^\pm$	$3.13 \pm 0.14 \pm 0.13$	$3.32 \pm 0.15 \pm 0.13$	$3.23 \pm 0.11 \pm 0.13$	$-3.0 \pm 3.2 \pm 1.2$
$K_L^0 K^\pm \pi^0$	$5.17 \pm 0.30 \pm 0.21$	$5.26 \pm 0.30 \pm 0.20$	$5.22 \pm 0.22 \pm 0.21$	$-0.9 \pm 4.1 \pm 1.6$

$K^0\pi's$ with the doubly Cabibbo suppressed (DCS) component $D \to \bar{K}^0\pi's$. Scale of the asymmetry is set by the doubly Cabibbo suppression factor $\tan^2\theta_C$ 0.05, where θ_C is the Cabibbo angle. The exact asymmetry is difficult to predict theoretically. A possible theory interpretation is based on flavor SU(3) with an estimate of symmetry-breaking effects [5].

In this analysis, we employ the double tag (DT) technique to measure the absolute branching fractions. With the measured $\mathscr{B}(D \to K^0_{S,L}\pi^0)$ and $\mathscr{B}(D \to K^0_{S,L}\pi^0\pi^0)$, the $K^0_{S,L}\pi^0$, $K^0_{S,L}\pi^0\pi^0$ decay branching fraction asymmetries, as shown in Tab. 2, can be determined by

$$\mathscr{R}(D \to K^0_{S,L}\pi^0(\pi^0)) = \frac{\mathscr{B}(D \to K^0_S\pi^0(\pi^0)) - \mathscr{B}(D \to K^0_L\pi^0(\pi^0))}{\mathscr{B}(D \to K^0_S\pi^0(\pi^0)) + \mathscr{B}(D \to K^0_L\pi^0(\pi^0))}. \quad (2.1)$$

Table 2: Branching fractions and asymmetries of $D \to K^0_{S,L}\pi^0$ and $D \to K^0_{S,L}\pi^0\pi^0$, where the uncertainties are statistical only.

	$D \to K^0_{S,L}\pi^0$		
	$\mathscr{B}_{K^0_S\pi^0}(\%)$	$\mathscr{B}_{K^0_L\pi^0}(\%)$	$\mathscr{R}_{D^0\to K^0_{S,L}\pi^0}$
$K\pi$	1.208 ± 0.041	1.061 ± 0.038	0.0646 ± 0.0245
$K3\pi$	1.212 ± 0.037	0.985 ± 0.036	0.1035 ± 0.0237
$K\pi\pi^0$	1.251 ± 0.028	0.953 ± 0.029	0.1351 ± 0.0186
All	1.230 ± 0.020	0.991 ± 0.019	0.1077 ± 0.0125
	$D \to K^0_{S,L}\pi^0\pi^0$		
	$\mathscr{B}_{K^0_S\pi^0\pi^0}(\%)$	$\mathscr{B}_{K^0_L\pi^0\pi^0}(\%)$	$\mathscr{R}_{D^0\to K^0_{S,L}\pi^0\pi^0}$
$K\pi$	1.024 ± 0.049	1.299 ± 0.080	-0.1183 ± 0.0385
$K3\pi$	0.887 ± 0.043	1.097 ± 0.073	-0.1060 ± 0.0409
$K\pi\pi^0$	1.010 ± 0.036	1.158 ± 0.060	-0.0681 ± 0.0313
All	0.975 ± 0.024	1.175 ± 0.040	-0.0929 ± 0.0209

Mixing in D^0 decays to CP eigenstates gives rise to an effective lifetime that differs from that in decays to flavor eigenstates. The difference can be parameterized by y_{CP}. In the absence of CPV, one has $y_{CP} = y$. To measure Y_{CP}, we use the DT technique. We partly reconstruct the D or $\bar{D}$ which decays to $Ke\nu$ and fully reconstruct the other $\bar{D}$ or D which decays to $K^0\pi^0$. When considering

$D^0\bar{D}^0$ mixing without CPV, the yields of the $CP\pm$ ($K^0_S\pi^0, K^0_L\pi^0$) ST events and the $Ke\nu$ vs $CP\pm$ ($K^0_S\pi^0, K^0_L\pi^0$) DT events can be denoted by Here $\varepsilon_{\mathrm{DT}(CP\pm,Ke\nu)}$ and $\varepsilon_{\mathrm{ST}(CP\pm)}$ are the efficiencies of reconstructing the ST and DT candidate events, and $N_{\mathrm{DT}(CP\pm,Ke\nu)}$ and $N_{\mathrm{ST}(CP\pm)}$ are the DT and ST yields, $\mathscr{B}_{Ke\nu}$ and $\mathscr{B}_{CP\pm}$ are the branching fractions for $Ke\nu$ and $CP\pm$ decays. y_{CP} then can be determined by

$$y_{CP} = \frac{\frac{N_{K^0_L\pi^0,Ke\nu}/\varepsilon_{K^0_L\pi^0,Ke\nu}}{N_{K^0_L\pi^0}/\varepsilon_{K^0_L\pi^0}} - \frac{N_{K^0_S\pi^0,Ke\nu}/\varepsilon_{K^0_S\pi^0,Ke\nu}}{N_{K^0_S\pi^0}/\varepsilon_{K^0_S\pi^0}}}{\frac{N_{K^0_L\pi^0,Ke\nu}/\varepsilon_{K^0_L\pi^0,Ke\nu}}{N_{K^0_L\pi^0}/\varepsilon_{K^0_L\pi^0}} + \frac{N_{K^0_S\pi^0,Ke\nu}/\varepsilon_{K^0_S\pi^0,Ke\nu}}{N_{K^0_S\pi^0}/\varepsilon_{K^0_S\pi^0}}} = \frac{\alpha-\beta}{\alpha+\beta}, \tag{2.2}$$

where $\alpha = \frac{N_{K^0_L\pi^0,Ke\nu}/\varepsilon_{K^0_L\pi^0,Ke\nu}}{N_{K^0_L\pi^0}/\varepsilon_{K^0_L\pi^0}}$, $\beta = \frac{N_{K^0_S\pi^0,Ke\nu}/\varepsilon_{K^0_S\pi^0,Ke\nu}}{N_{K^0_S\pi^0}/\varepsilon_{K^0_S\pi^0}}$. Table 3 shows the results of α, β and y_{CP}.

Table 3: Parameters in y_{CP} determination.

α	β	$y_{CP} = \frac{\alpha-\beta}{\alpha+\beta}$
3.603 ± 0.142	3.533 ± 0.100	$0.98 \pm 2.43\%$

3. $D^0 \to K^0_S\pi^+\pi^-$ and strong phase difference

We report the results on the measurement of the relative strong-phase difference parameters, c_i and s_i, from a binned Dalitz analysis for $D^0 \to K^0_S\pi^+\pi^-$ [6]. These parameters are measured by counting the number of $D^0 \to K^0_S\pi^+\pi^-$ events which fall into bins of similar phase in Dalitz plots when $D^0 \to K^0_S\pi^+\pi^-$ has been selected for a specified CP or flavor eigenstate. The results are given in terms of three previously used binning designs for ease of comparison to previous results and application for $B^\pm \to D(K^0_S\pi^+\pi^-)K^\pm$ GGSZ method analysis.

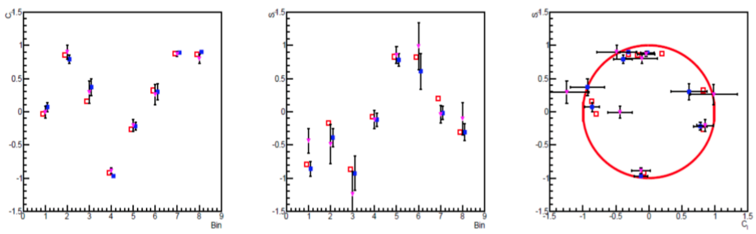

Figure 1: Fit results distributions, where red hollow squares represent the model predicted value, the blue solid squares mark the fitted value from data, the pink triangles indicate the results from CLEO-c experiment [7].

This analysis was performed on data from the 2.92 fb^{-1} of BESIII $\psi(3770)$ dataset. Our results, as shown in Fig. 1, represent a significant statistical and systematic improvement over previous measurements, which will allow for increased precision in the measurement of the unitarity triangle angle γ/ϕ_3 using the decay $B^\pm \to D(K^0_S\pi^+\pi^-)K^\pm$ through the GGSZ method. This result is intended to be used by BABAR, Belle, LHCb, as well as future Super-B factories in pursuit of improving the determination of γ/ϕ_3. The reduction in uncertainty should make the uncertainty on

c_i and s_i no longer the dominant systematic in the analysis. Toy MC studies have shown that there is still significant room for reduction of uncertainty with more statistics at BESIII. Steady gains can be obtained up to 50 fb^{-1} luminosity, with the an average ratio of predicted bin uncertainty to current bin uncertainty of 0.852, 0.6495, 0.5018, 0.4506 for 5 fb^{-1}, 10 fb^{-1}, 20 fb^{-1}, and 30 fb^{-1}, respectively.

4. Branching fraction measurements

4.1 Amplitude analysis of $D^0 \to K^-\pi^+\pi^+\pi^-$

The decay $D^0 \to K^-\pi^+\pi^+\pi^-$ is one of the three golden decay modes of the neutral D meson. Due to a large branching fraction and low background it is well suited as a reference channel. An accurate knowledge of its substructure and relative amplitudes and phases are important to reduce systematic uncertainties in analyses that use this channel for reference. In particular, the lack of the substructure knowledge leads to one of the largest systematic uncertainties in the measurement of the absolute branching fractions of the D hadronic decays [8]. The knowledge of the decay substructure in combination with a precise measurement of strong phase can also help to improve the measurement of the CKM angle γ [9]. In the γ measurement, the parameterization model is an important input information in a model dependent method and also can be used to generate Monte Carlo (MC) to check the sensitive in a model independent method [10]. Furthermore, the branching fractions of intermediate processes can be used to understand the $D^0\bar{D}^0$ mixing in theory [11].

We perform an amplitude analysis of the decay $D^0 \to K^-\pi^+\pi^+\pi^-$ (with charge conjugate process) with double tag technique to study the substructure in this decay. To suppress possible backgrounds, only the decay $\bar{D}^0 \to K^+\pi^-$ is used to tag the $D^0\bar{D}^0$ pair. The amplitude model is constructed using the covariant tensor formalism [12]. As shown in Fig. 2, our nominal fit yields a goodness of fit value of $\chi/\nu = 843.445/748 = 1.128$. To calculate the statistical significance of a process, we repeat the fit process without the corresponding process included, and the changes of log likelihood value and the number of free degree are taking into consideration. All of the components and fit fractions are listed in Table 4.

Table 4: Fitted branching fractions, where the first and second uncertainties are statistical and systematic uncertainties from the fit fractions, the third errors is the uncertainties related to $\mathscr{B}(D^0 \to K^-\pi^+\pi^+\pi^-)$ in PDG.

Component	Branching fraction (%)	PDG value (%)
$D^0 \to \bar{K}^{\star 0}\rho^0$	$0.99 \pm 0.04 \pm 0.04 \pm 0.03$	1.05 ± 0.23
$D^0 \to K^- a_1^+(1260)(\rho^0\pi^+)$	$4.41 \pm 0.22 \pm 0.30 \pm 0.13$	3.6 ± 0.6
$D^0 \to K_1^-(1270)(\bar{K}^{\star 0}\pi^-)\pi^+$	$0.07 \pm 0.01 \pm 0.02 \pm 0.00$	0.29 ± 0.03
$D^0 \to K_1^-(1270)(K^-\rho^0)\pi^+$	$0.27 \pm 0.02 \pm 0.02 \pm 0.01$	
$D^0 \to K^-\pi^+\rho^0$	$0.68 \pm 0.09 \pm 0.18 \pm 0.02$	0.51 ± 0.23
$D^0 \to \bar{K}^{\star 0}\pi^+\pi^-$	$0.57 \pm 0.03 \pm 0.03 \pm 0.02$	0.99 ± 0.23
$D^0 \to K^-\pi^+\pi^+\pi^-$	$1.77 \pm 0.05 \pm 0.04 \pm 0.05$	1.88 ± 0.26

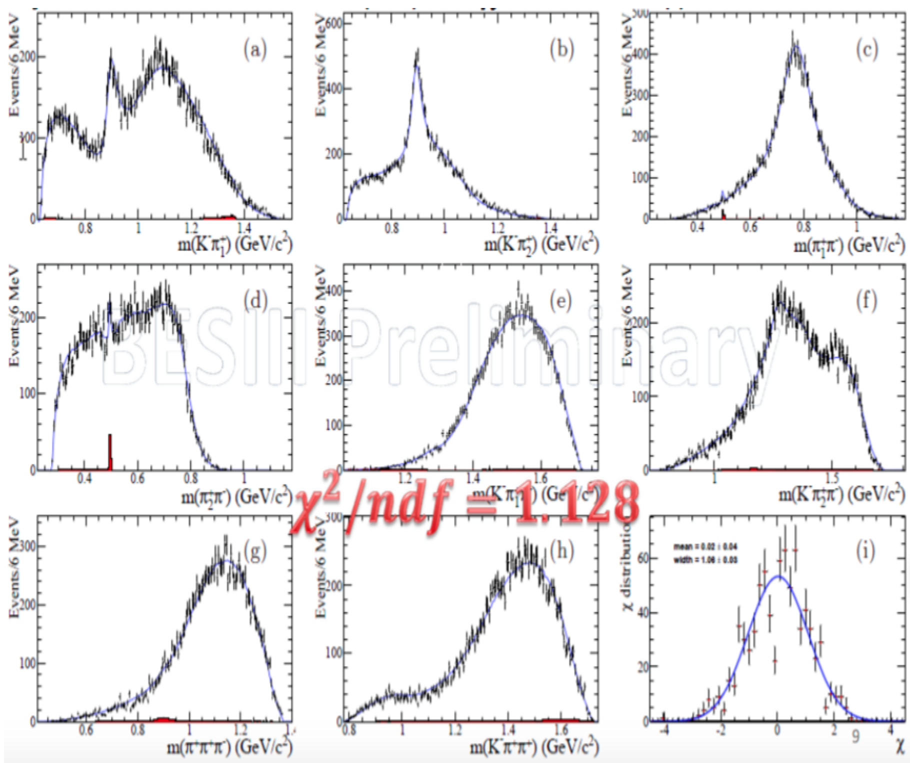

Figure 2: Projections of invariant mass (a) $m_{K^-\pi_1^+}$, (b) $m_{K^-\pi_2^+}$, (c) $m_{\pi_1^+\pi^-}$, (d) $m_{\pi_2^+\pi^-}$, (e) $m_{K^-\pi_1^+\pi^-}$, (f) $m_{K^-\pi_2^+\pi^-}$, (g) $m_{\pi_1^+\pi_2^+\pi^-}$, (h) $m_{K^-\pi_1^+\pi_2^+}$, and the fit (curve) to the distribution of χ (points with error bars) with a Gaussian function and the fitted values of the parameters (mean and width of Gaussian).

4.2 Branching fraction of $D^0 \to K_S^0 K^+ K^-$

The analysis of the Dalitz plot of the weak decay $K_S^0 K^+ K^-$ gives access to the intermediate resonances and in particular, the KK S-wave can be studied. On the other hand, the accurate measurement of the branching fraction can help to improve theoretical predictions for the D^0 meson. Therefore, this work is intended to contribute to the fields of light meson and charm physics. At BESIII experiment, $D\bar{D}$ are produced in a quantum entangled state which allows to conclude quantum numbers (e. g. CP or flavor) of one decay from the opposite decay. We reconstruct one $\bar{D}^0$ meson in a flavor tag channel or a CP eigenstate and then we are able to study the D^0 with known flavor or CP quantum number. The possibility of D tagging and the clean environment makes BESIII an excellent laboratory for the study of charm decays.

The branching fraction of $D^0 \to K_S^0 K^+ K^-$ is $\mathscr{B}(D^0 \to K_S^0 K^+ K^-) = (4.622 \pm 0.045 \pm 0.181) \times 10^{-3}$, where the first error is statistical and the second systematic. The relative uncertainty is 4.0%. Our result improve the precision of the branching fraction $D^0 \to K_S^0 K^+ K^-$ significantly and is in good agreement with the world average result of $(4.51 \pm 0.34) \times 10^{-3}$ [13], whose relative uncertainty is 7.5%.

4.3 Measurement of $D^{0,\pm} \to$ Pseudoscalar Pair

The two-body hadronic decays of $D \to P_1 P_2$ serve as an ideal testbed to improve the understanding of the weak and strong interactions in the decays of charmed mesons. They proceed via external and internal W-emssion as well as W-exchange diagrams. Due to relatively simple topology, the amplitude of each $D \to P_1P_2$ decay can be theoretically simplified as sum of different diagrams based on flavor SU(3) symmetry [14]. Thus, comprehensive and improved measurements of the branching fractions for these decays in experiment will help to better validate the theoretical calculations. Moreover, these measurements will also provide complementary and important data to explore SU(3)-flavor symmetry breaking effects in the hadronic decays of the D mesons [15].

Table 5: Summary of the measured branching fractions. The first and second uncertainties are statistical and systematic, respectively.

Mode	$N^{\rm net}_{\rm signal}$	ε (%)	$\mathscr{B} \pm$ (stat) $\pm$ (sys)	$\mathscr{B}_{\rm PDG}$
$\pi^+\pi^-$	21105 ± 249	66.03 ± 0.25	$(1.505 \pm 0.018 \pm 0.031) \times 10^{-3}$	$(1.421 \pm 0.025) \times 10^{-3}$
K^+K^-	56438 ± 273	62.82 ± 0.32	$(4.229 \pm 0.020 \pm 0.087) \times 10^{-3}$	$(4.01 \pm 0.07) \times 10^{-3}$
$K^-\pi^+$	537745 ± 767	64.98 ± 0.09	$(3.896 \pm 0.006 \pm 0.073)$ %	(3.93 ± 0.04) %
$K^0_S\pi^0$	66539 ± 302	38.06 ± 0.17	$(1.236 \pm 0.006 \pm 0.032)$ %	(1.20 ± 0.04) %
$K^0_S\eta$	9532 ± 126	31.96 ± 0.14	$(5.149 \pm 0.068 \pm 0.134) \times 10^{-3}$	$(4.85 \pm 0.30) \times 10^{-3}$
$K^0_S\eta'$	3007 ± 67	12.66 ± 0.08	$(9.562 \pm 0.197 \pm 0.379) \times 10^{-3}$	$(9.5 \pm 0.5) \times 10^{-3}$
$\pi^0\pi^+$	10108 ± 267	48.98 ± 0.34	$(1.259 \pm 0.033 \pm 0.025) \times 10^{-3}$	$(1.24 \pm 0.06) \times 10^{-3}$
π^0K^+	1834 ± 168	51.52 ± 0.42	$(2.171 \pm 0.198 \pm 0.060) \times 10^{-4}$	$(1.89 \pm 0.25) \times 10^{-4}$
$\eta\pi^+$	11636 ± 215	46.96 ± 0.25	$(3.790 \pm 0.070 \pm 0.075) \times 10^{-3}$	$(3.66 \pm 0.22) \times 10^{-3}$
ηK^+	439 ± 72	48.21 ± 0.31	$(1.393 \pm 0.228 \pm 0.124) \times 10^{-4}$	$(1.12 \pm 0.18) \times 10^{-4}$
$\eta'\pi^+$	3088 ± 83	21.49 ± 0.18	$(5.122 \pm 0.140 \pm 0.210) \times 10^{-3}$	$(4.84 \pm 0.31) \times 10^{-3}$
$\eta'K^+$	87 ± 25	22.39 ± 0.22	$(1.377 \pm 0.428 \pm 0.202) \times 10^{-4}$	$(1.83 \pm 0.23) \times 10^{-4}$
$K^0_S\pi^+$	93884 ± 352	51.38 ± 0.18	$(1.591 \pm 0.006 \pm 0.033) \times 10^{-2}$	$(1.53 \pm 0.06) \times 10^{-2}$
$K^0_SK^+$	17704 ± 151	48.45 ± 0.14	$(3.183 \pm 0.028 \pm 0.065) \times 10^{-3}$	$(2.95 \pm 0.15) \times 10^{-3}$

By analyzing 2.93 fb^{-1} data taken at $\sqrt{s} = 3.773$ GeV, we measure the branching fractions of the two-body hadronic decays $D^+ \to \pi^0\pi^+$, π^0K^+, $\eta\pi^+$, ηK^+, $\eta'\pi^+$, $\eta'K^+$, $K^0_S\pi^+$, $K^0_SK^+$, and $D^0 \to \pi^+\pi^-$, K^+K^-, $K^-\pi^+$, $K^0_S\pi^0$, $K^0_S\eta$, $K^0_S\eta'$ with single tag technique. Our results are consistent with the world average values within uncertainties and the branching fractions for $D^+ \to \pi^0\pi^+$, $\eta\pi^+$, $\eta'\pi^+$, $K^0_S\pi^+$, $K^0_SK^+$, and $D^0 \to K^0_S\eta$ are determined with improved precisions. The measured branching fractions of $D^0 \to K^0_S\pi^0$ and $D^+ \to K^0_SK^+$ are consistent with those measured using double tag techniques in our previous works [16, 17]. These will benefit the testing of theoretical calculations and a better understanding of SU(3)-flavor symmetry breaking effects in the hadronic decays of the $D^{+(0)}$ mesons [15].

4.4 Cabibbo suppressed decay $D^{0,\pm} \to \omega\pi^{0,\pm}$

With the double tag technique, we firstly observe the singly Cabibbo-suppressed (SCS) decay $D^+ \to \omega\pi^+$ with the statistical significance of 5.5σ and find the first evidence of $D^0 \to \omega\pi^0$ with 4.1σ based on 2.93 fb^{-1} data taken at $\sqrt{s} = 3.773$ GeV, at the same time, the branching fractions of $D^{+,0} \to \eta\pi^{+,0}$ are also reported which are consistent with the previous measurements. Figure 3 shows the fits to the data. Table 6 summarize the branching fractions of this work and previous measurement. Our results can help to improve the understanding of U-spin and SU(3) flavor symmetry breaking effects in D decays and benefit theoretical prediction of CP violation in D decays. This work has been published at Phys. Rev. Lett. [18].

Table 6: Comparison of branching fractions between this work and previous measurement.

Branching fraction	This work	Previous measurement
$\mathscr{B}(D^+ \to \omega\pi^+)$ (10^{-4})	$2.79 \pm 0.57 \pm 0.16$	< 3.4 at 90% C.L.
$\mathscr{B}(D^0 \to \omega\pi^0)$ (10^{-4})	$1.17 \pm 0.34 \pm 0.07$	< 2.6 at 90% C.L.
$\mathscr{B}(D^+ \to \eta\pi^+)$ (10^{-3})	$3.07 \pm 0.22 \pm 0.13$	3.53 ± 0.21
$\mathscr{B}(D^0 \to \eta\pi^0)$ (10^{-3})	$0.65 \pm 0.09 \pm 0.04$	0.68 ± 0.07

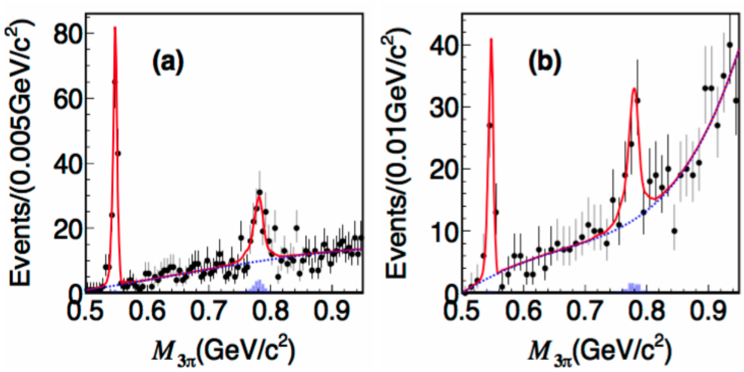

Figure 3: Fits to the 3π mass spectra for (a) $D^+ \to \pi^+\pi^-\pi^0\pi^+$ and (b) $D^0 \to \pi^+\pi^-\pi^0\pi^0$, where points are data; the (red) solid lines are the total fits, the (blue) dashed lines are the background shapes, and the hatched histograms 25 are peaking background estimated from $2D$ MBC sidebands.

4.5 Measurement of $D_S^+ \to \eta'\rho$ and $D_S^+ \to \eta' + anything$

In 2013, the CLEO Collaboration reported an updated measurement of $\mathscr{B}(D_S^+ \to \eta'\pi^+\pi^0)$, their result is $(5.6 \pm 0.5 \pm 0.6)\%$ [19]. This value is much smaller than the previous result [20]. We make use of double tag method to measure the concerned branching fractions with 9 singly tagged D_S^- modes, they are $K_S^0K^-$, $K^+K^-\pi^-$, $K^+K^-\pi^-\pi^0$, $K_S^0K^+\pi^-\pi^-$, $\pi+\pi^-\pi^-$, $\pi^-\eta$, $\pi^-\eta'$ $(\eta' \to \pi^+\pi^-\eta)$, $\pi^-\eta'$ $(\eta' \to \gamma\rho^0, \rho^0 \to \pi^+\pi^-)$, and $\pi^-\pi^0\eta$. The branching fraction $\mathscr{B}(D_S^+ \to \eta'X) = (8.8 \pm 1.8 \pm 0.5)\%$, which is consistent with previous measurement. $\mathscr{B}(D^+ \to \eta'\rho^+)$ is obtained to be $(5.8 \pm 1.4 \pm 0.4)\%$, which is compatible with CLEO's latest measurement [19]. This work has been publish at Phys. Lett. B [21].

5. Summary

To summarize, by analysing 2.93 fb^{-1} data taken at $\sqrt{s} = 3.773$ and 4.009 GeV with the BESIII detector, the charmed meson hadronic decays are widely studied for the first time or with significant improved precision. All these results can improve our knowledge about non-perturbative QCD. We are pleased to mention that more BESIII charm analyses are under internal review, and

BESIII has finished data taken at 4.180 GeV with about 3 fb^{-1} data, this will benefit the understanding of physics related to Ds decay.

References

[1] F. Buccella et al. (CLEO Collaboration), Phys. Lett. B. **302**, 319 (1993); F. Buccella et al. Phys. Rev. D **51**, 3478 (1995); M. Golden and B. Grinstein, Phys. Lett. B **222**, 501 (1989).

[2] S. Bianco et al. Riv. Nuovo. Cim. **26N7-8**, 1 (2003); A. Le Yaouanc et al. Phys. Lett. B. **292**, 353 (1992).

[3] K. Arms et al. (CLEO Collaboration), Phys. Rev. D. 69, 071102 (2004).

[4] I.I. Bigi and H. Yamamoto, Phys. Lett. B**349**, 363 (1995).

[5] D. N. Gao, Phys. Lett. B **645**, 59 (2007).

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

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

[8] S. Dobbs et al. (CLEO Collaboration), Phys. Rev. D **76**, 112001 (2007); G. Bonvicini et al. (CLEO Collaboration), Phys. Rev. D **89**, 072002 (2014).

[9] D. Atwood, I. Dunietz and A. Soni, Phys. Rev. Lett. **78**, 3257 (1997).

[10] Samuel Harnew and Jonas Rademacker, JHEP **03**, 169 (2015).

[11] A. F. Falk, Y. Grossman, Z. Ligeti and A. A. Petrov, Phys. Rev. D **65**, 054034 (2002); H. Y. Cheng and C. W. Chiang, Phys. Rev. D **81**, 114020 (2010).

[12] B. S. Zou and D. V. Bugg, Eur. Phys. J. A **16**, 537 (2003).

[13] K.A. Olive et al. (Particle Data Group), Chin. Phys. C **38**, 090001 (2014) and 2015 update.

[14] L.-L. Chau and H.-Y. Cheng, Phys. Rev. D **36**, 137 (1987); H.-Y. Cheng and C.-W. Chiang, Phys. Rev. D **81**, 074021 (2010).

[15] K. Waikwok and S. Rosen, Phys. Lett. B **298**, 413 (1993); Y. Grossman and D. J. Robinson, J. High Energy Phys. **2013**, 67 (2013).

[16] M. Ablikim et al. (BESIII Collaboration), $D^0 \to K^0_{S/L}\pi^0(\pi^0)$ decay rates and y_{CP} measurement (publication in preparation) (2016).

[17] M. Ablikim et al. (BESIII Collaboration), Branching fraction measurements and related CP violation in $D^+ \to K^0_{S/L}K^+(\pi^0)$ (publication in preparation) (2016).

[18] M. Ablikim et al. (BESIII Collaboration) Phys. Rev. Lett. **116**, 082001 (2016).

[19] P. U. E. Onyisi et al. (CLEO Collaboration),Phys. Rev. D **88**, 032009 (2013).

[20] C. Jessop et al. (CLEO Collaboration), Phys. Rev. D **58**, 052002 (1998).

[21] M. Ablikim et al. (BESIII Collaboration) Phys. Lett. B **750**, 466 (2015).