PROCEEDINGS OF SCIENCE

Hadronic decays of charmed hadrons at BESIII

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Based on the large and unique quantum-coherent (QC) data samples taken with the BESIII detector at the BEPCII collider, hadronic decays of charmed hadrons is always one of the main topics at BESIII . We review the recent highlight measurements in this field. These include the world best measurement of strong-phase difference and hadronic parameters of neutral D meson, amplitude analysis of charmed meson with newly observed decay modes and branching fraction measurements of charmed hadron with high precision.

**** Particles and Nuclei International Conference - PANIC2021 ****
**** 5 - 10 September, 2021 ****
**** Online ****

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PoS(PANIC2021)157

1. Introduction

BEPCII/BESIII produces charmed hadrons near their mass threshold, this allows exclusive reconstruction of their decay products with well-determined kinematics. Up to now, BESIII has collected data corresponding to the integrated luminosity over 14 fb^{-1} at 5 main charmed hadron production energy regions, respectively. In this paper, we report several highlight hadronic decay results of charmed hadrons measurements, including the most accurate measurements of the strong-phase difference between $D^0\bar{D}^0$ decays, the amplitudes measurements of charm meson decays, and the most precise branching fraction measurements with new observed decays of charm hadrons. The charge conjugation is always implied.

2. Strong-phase difference of neutral D meson

Considering the QC effect between $D^0\bar{D}^0$ produced from $\psi(3770)$, the decay rate of a double-tag event (one D decays to final state F and the other decays to final state G) can be described as:

$$\Gamma(F|G) \propto |A_F\bar{A}_G - A_G\bar{A}_F|^2 \tag{1}$$

here $A_{F(G)}$ and $\bar{A}_{F(G)}$ are the amplitude of $D^0 \to F(G)$ and $\bar{D}^0 \to F(G)$, respectively. The interference term in eq.1 is sensitive to strong-phase difference, which is indispensable parameter in model-independent γ measurements.

2.1 $c_i^{(\prime)}, s_i^{(i)}$ of $D^0 \to K_{S/L}\pi^+\pi^-$[1, 2]

The self-conjugate multi-body decay of $D^0 \to K_{S,L}\pi^+\pi^-$ can be used to improve the sensitivity of γ measurement in BPGGSZ method[3, 4] by binning the phase space of D^0 into 8 pairs of bins. The amplitude-weighted average of $\cos\delta_D$ in the ith $K_S\pi^+\pi^-$ Dalitz bin (D_i) is given by

$$c_i = \frac{\int_{D_i} |A||\bar{A}|\cos\delta_D dD}{\sqrt{\int_{D_i} |A|^2 dD \int_{D_i} |\bar{A}| dD}} \tag{2}$$

The term s_i is defined analogously with $\cos\delta_D$ replaced by $\sin\delta_D$ and $c_i'(s_i')$ is defined similarly with $K_L\pi^+\pi^-$ Dalitz bin. Combining eq.1 and considering CP eigenstates and flavour specific states as tag channel, c_i and s_i can be well constrained and extracted. To further improve the precision, bin migration effect caused by resolution of momentum reconstruction is corrected by efficiency matrix. In addition, $\Delta c_i \equiv c_i - c_i'$ and $\Delta s_i \equiv s_i - s_i'$ are constrained by the amplitude model of $K_{S/L}\pi^+\pi^-$ to decrease the statistical uncertainty.

As shown in fig. 1, the measured c_i and s_i have improved the precision by a factor of 3. The associated uncertainty on γ is studied by toy Monte Carlo (MC) sample, which is reduced to around 1° in $B^- \to D(K_S\pi^+\pi^-)K^-$ mode.

2.2 $c_i^{(\prime)}, s_i^{(i)}$ of $D^0 \to K_{S/L}K^+K^-$[5]

Similarly with $K_{S/L}\pi^+\pi^-$, $K_{S/L}K^+K^-$ can also be used to constrain γ by BPGGSZ method. Due to the lack of statistics, we measure the c_i and s_i in equal $\Delta\delta_D$ binning scheme under N_{bin}(number of Dalitz bins) $= 2, 3, 4$. The result of $c_i^{(\prime)}$ and $s_i^{(\prime)}$ when $N_{\text{bin}} = 2$ is shown in

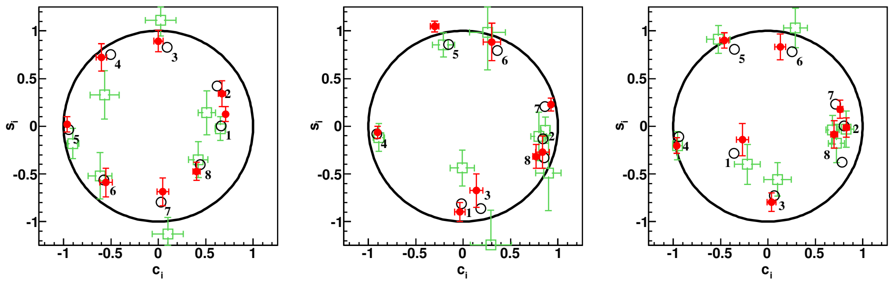

Figure 1: The c_i and s_i measured in this work (red dots with error bars), the prediction of amplitude model (black open circles) and the results of previous measurement (green open squares with error bars). The left, middle and right plots are from the equal $\Delta\delta_D$, optimal and modified optimal binnings, respectively.

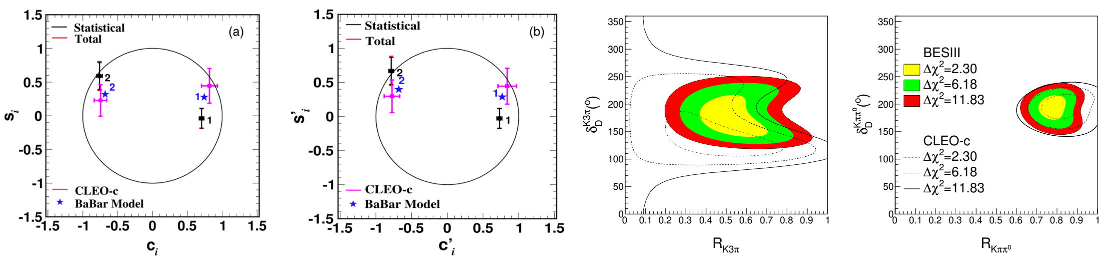

Figure 2: (Left two) Comparison between model predicted (blue stars) and measured (black dots with error bars are from this work, pink dots with error bars are from previous measurement) $c_i^{(\prime)}$, $s_i^{(i)}$ of $D^0 \to K_{S/L}K^+K^-$ when $N_{\text{bin}} = 2$. (Right two) Scans of $\Delta\chi^2$ in the global $(R_{K3\pi},\ \delta_D^{K3\pi})$ and $(R_{K\pi\pi^0},\ \delta_D^{K\pi\pi^0})$ parameter space. Also shown are the equivalent contours determined from the CLEO-c data.

the left two figures in fig. 2, which has higher precision and is consistent well with previous result. The least associated uncertainty on γ is 1.3° when $N_{\text{bin}} > 2$.

2.3 Hadronic parameters (δ_D, R) of $D \to K^-\pi^+\pi^+\pi^-$and $K^-\pi^+\pi^0$[6]

For final states including Cabibbo favored (CF) and doubly Cabibbo suppressed (DCS) processes, like $K^-\pi^+\pi^+\pi^-$and $K^-\pi^+\pi^0$, they have good sensitivity of γ in ADS method [7]. The hadronic parameters are given by

$$\Gamma(F|G) \propto A_F^2\bar{A}_G^2 + \bar{A}_F^2 A_G^2 - 2R_F R_G A_F \bar{A}_F A_G \bar{A}_G (\cos(\delta_D^F - \delta_D^G)) \tag{3}$$

The hadronic parameters are extracted by global fit on double-tagged $K^-\pi^+\pi^+\pi^-$and $K^-\pi^+\pi^0$ event. The right two figures in Fig. 2 shows the fit results. To further improve the precision with $K^-\pi^+\pi^+\pi^-$, its phase space are split into 4 bins and hadronic parameters in each bin are measured. The associated uncertainty on γ is around 6°.

3. Amplitude analysis

3.1 Amplitude analysis of $D_s^+ \to \pi^+\pi^0\eta$[8]

$D_s^+ \to \pi^+\pi^0\eta$ is one of the perfect modes to study W-annihilation (WA) process that help understand weak decay of charm mesons. In this work, the pure WA decays $D_s^+ \to a_0(980)^+\pi^0$

and $D_s^+ \to a_0(980)^0\pi^+$ are observed for the first time, with absolute branching fractions $B(D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}, a_0(980)^{0(+)} \to \pi^{0(+)}\eta) = (1.46 \pm 0.15 \pm 0.23)\%$, which is larger than the branching fractions of other measured pure WA decays by at least one order of magnitude. In addition, the branching fraction of $D_s^+ \to \pi^+\pi^0\eta$ is measured as $(9.50 \pm 0.28 \pm 0.41)\%$ with significantly improved precision.

3.2 Amplitude analysis of $D_s^+ \to \eta\pi^+\pi^+\pi^-$[9]

$D_s^+ \to \eta\pi^+\pi^+\pi^-$ decay is expected to have a large branching fraction among the possible missing hadronic decays of D_s^+ with η in the final state. Besides, this decay is one of the main background in $R(D^*)$ measurements. We observed this decay for the first time by using all data sample between 4.178 GeV and 4.226 GeV, with absolute branching fraction of $(3.12 \pm 0.13 \pm 0.09)\%$. The amplitude analysis reveals the sub-structures in $D_s^+ \to \pi^+\pi^+\pi^-\eta$. The $D_s^+ \to a_1(1260)^+\eta, a_1(1260)^+ \to \rho(770)^0\pi^+$ and $D_s^+ \to a_0(980)^+\rho(770)^0, a_0(980)^+ \to \pi^+\eta$ are observed with branching fractions of $(1.73 \pm 0.14 \pm 0.08)\%$ and $(0.21 \pm 0.08 \pm 0.05)\%$, respectively. The branching fraction of the later decay is larger than the branching fractions of other measured pure WA decays by one order of magnitude. These indicate that long-distance WA may play an essential role in this decay.

4. Branching fractions of charmed hadrons

Finding the missing decay modes of charmed hadrons is one of the main topics in charm physics and BESIII always plays an important role in this field.

We observed a new DCS decay $D^+ \to K^+\pi^+\pi^-\pi^0$ [10], the branching fraction is measured to be $(1.13 \pm 0.08 \pm 0.03) \times 10^{-3}$. The asymmetry of the branching fraction is also determined, and no evidence for CP violation is found. In addition, the first evidence for $D^+ \to K^+\omega$ is presented with a statistical significance of 3.3σ.

To probe the space of missing decay mode with η in final state, the absolute branching fractions of 14 exclusive hadronic D decays to η are determined with high precision [11] . The total branching fractions of exclusive D^0 and D^+ decays to η are consistent with the corresponding inclusive rates within 0.9σ and 2.5σ, respectively, leaving little room for other exclusive decays involving η.

Besides, the branching fractions of D_s^+ two body decays are measured with higher precision [12] and a new decay mode of Λ_c^+ is observed [13], which may have rich resonances and provide more information with higher statistics.

5. Outlook

After two-years data taking above 4.6 GeV, BESIII has accumulated a large amount of coherent $\Lambda_c^+\bar{\Lambda}_c^-$ data, the hadronic decays of charmed baryon are under going recently and the results will be released soon. Meanwhile, BESIII plans to collect more data at 3.773 GeV in the next two years, which will give more opportunities and possibilities in charmed meson measurements.

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