Highlights of Charm Physics at the BESIII

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In this talk, we present recent results on charm physics from the BESIII experiment. With 2.9 fb^{-1} integrated luminosity at the open-charm threshold, the leptonic and semileptonic decays of D mesons have been measured with high precision. The decay constant and transition form-factors are extracted to be used to test LQCD calculations. By using the Quantum correlation on the $\psi(3770)$ peak, the strong phase in neutral D decays is able to be accessed, and first results in the decay of $D^0 \to K\pi$ mode are presented, results in $D^0 \to K_S\pi^+\pi^-$ will apprear soon.

1 Introduction

BESIII will not be able to compete both BABAR and Belle in statistics on charm physics, especially on the rare and forbidden decays of charm mesons [1,2]. However, data taken at charm threshold still have powerful advantages over the data at $\Upsilon(4S)$, which we list here [3]: 1) Charm events produced at threshold are extremely clean; 2) The measurements of absolute branching fraction can be made by using double tag events; 3) Signal/Background is optimum at threshold; 4) Neutrino reconstruction is clean; 5) Quantum coherence allow simple [4] and complex [5] methods to measure the neutral D meson mixing parameters and strong phase difference [6], and to check for direct CP violation.

For charm physics at BESIII, the first physics results will be the measurements of the leptonic and semileptonic decays of charm mesons. Measurements of the leptonic decays at BESIII will benefit from the fully tagged D^+ and D_S^+ decays available at the $\psi(3770)$ and at $\sqrt{s} \sim 4170$ MeV or ~ 4017 MeV [7]. The leptonic decay rates for D^+ and D_S^+ has been measured with a precision of 4.3% and 2.0 % with the final data from CLEOc. It should be noted that the $D^+ \to \tau^+\nu$ decay is reported by CLEOc with upper limit of 1.2×10^{-3} at 90% C.L. [8]. At BESIII, with 3.5 times (about 3.0 fb^{-1}) of the CLEOc's luminosity, significant gains on these measurements will be made if the systematic errors remain the same. This will allow the validation of theoretical calculations of the decay constants at the 1-2% level. The neutral D mixing and CP violation in charm sector using quantum correlation are all statistics-starved at CLEOc, improvement will be made at BESIII experiment.

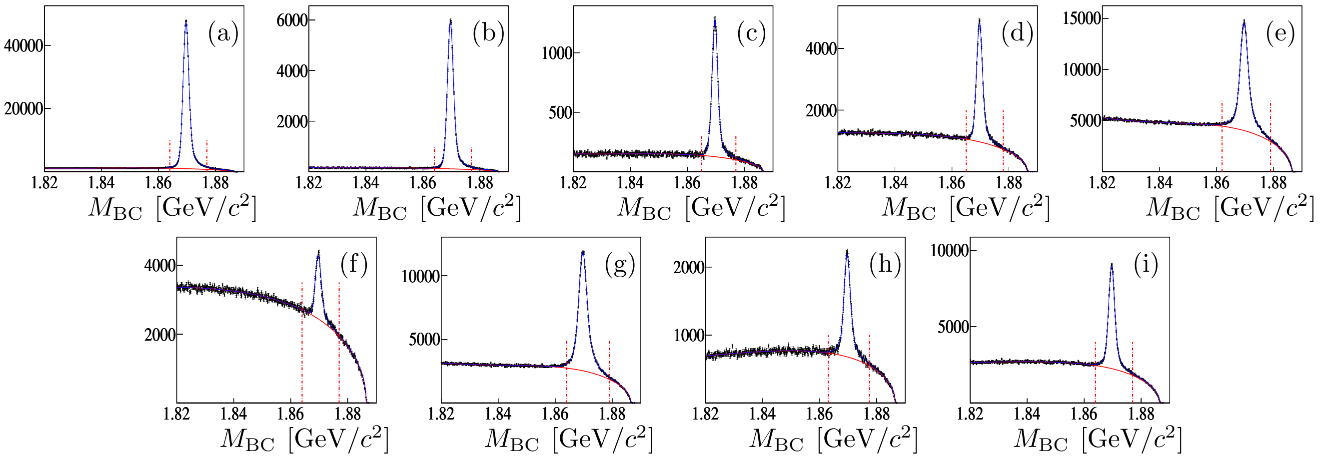

Figure 1 – The beam-energy-constrained mass distributions for the different tagged mode combinations, where (a), (b), (c), (d), (e), (f), (g), (h) and (i) are for the modes of $D^- \to K^+\pi^-\pi^-$, $K^0_S\pi^-$, $K^0_S K^-$,$K^+K^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $\pi^+\pi^-\pi^-$, $K^0_S\pi^-\pi^0$, $K^+\pi^-\pi^-\pi^-\pi^+$, and $K^0_S\pi^-\pi^-\pi^+$, respectively; the two vertical dashed red lines show the tagged D^- mass region[9].

2 Purely leptonic D decay

With a sample of 2.9 fb^{-1} taken at open-charm threshold, BESIII experiment measures the decay branching fraction for $D^+ \to \mu^+\nu_\mu$ and extracts decay constant f_{D^+}[9]. In a fully leptonic decay, the decay constant parameterizes all of the essential theoretical limitations. The leptonic decay of charm meson presents an opportunity to check LQCD results for decay constants against precision measurements.

We call an event a tagged one if it has a fully-reconstructed D hadronic decay. A sample of tagged events has greatly reduced background and constrained kinematics, both of which aid studies of how the other D in the event decays. One can infer neutrinos from energy and momentum conservation, allowing "full" reconstruction of (semi)leptonic D decays. The typical tag rates per D (not per pair) are roughly 15% and 10% for D^0 and D^+, respectively. For pure leptonic decay, the singly tagged D^- meson events are reconstructed in nine non-leptonic decay modes, and mass peaks for the nine hadronic tag modes are shown in Fig. 1. The total number of tagged D^- events are 170305 ± 3405[9].

The chosen signal variable for the $\mu^+\nu$ decay is the calculated square of the missing-mass of any undetected decay products, shown in Fig. 2; this should of course peak at $M^2_\nu = 0$ for signal events. After subtracting the number of background events, $409.0 \pm 21.2 \pm 2.3$ signal events ($N^{\rm net}_{\rm sig}$) for $D^+ \to \mu^+\nu_\mu$ remain, where the first error is statistical and the second is the systematic associated with the uncertainty of the background estimate. Thus we obtain the branching fraction to be $B(D^+ \to \mu^+\nu_\mu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$, which is consistent within error with world average of $\mathcal{B}(D^+ \to \mu^+\nu) = (3.82 \pm 0.33) \times 10^{-4}$, but has better precision. The decay constant f_{D^+} is then obtained by using 1040 ± 7 fs as the D^+ lifetime and 0.2252 as V_{cd}. Our result is $f_{D^+} = (203.2 \pm 5.3 \pm 1.8)$ MeV, where the first errors are statistical and the second systematic[9].

3 Semileptonic D decays: $D^0 \to K^-e^+\nu$ and $\pi^-e^+\nu$

One of the best ways to measure magnitudes of CKM elements is to use semileptonic decays. On the other hand, measurements using other techniques have obtained useful values for V_{cs} and V_{cd}[12], and thus semileptonic D decay measurements are a good laboratory for testing theories of QCD. For a D meson decaying into a single hadron (h), the decay rate can be written exactly in terms of the four-momentum transfer defined as $q^2 = (p^\mu_D - p^\mu_h)^2 = m^2_D + m^2_h - 2E_h m_D$. For

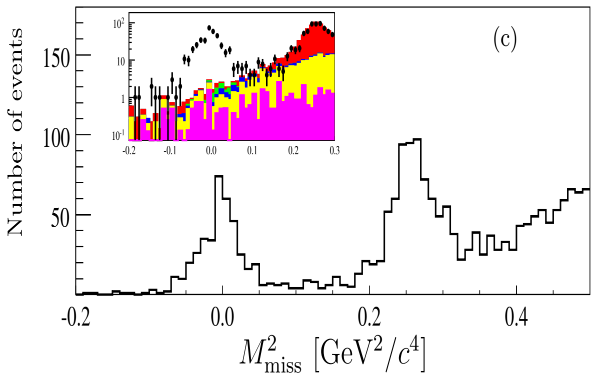

Figure 2 – BESIII missing-mass-squared plot for $D^+ \to \mu^+\nu$. The insert shows the signal region on a vertical log scale, where dots with error bars are for the data, histograms are sum for the simulated backgrounds from $D^+ \to K_L\pi^+$, $D^+ \to \pi^+\pi^0$, $D^+ \to \tau^+\nu$ and other decays of D mesons as well as from $e^+e^- \to$ non-$D\bar{D}$ decays.

decays to pseudoscalar mesons and "virtually massless" leptons, the decay width is given by:

$$\frac{d\Gamma(D \to Pe^+\nu)}{dq^2} = \frac{G_F^2|V_{cq}|^2 p_P^3}{24\pi^3}|f_+(q^2)|^2, \qquad (1)$$

where p_P is the three-momentum of pseudoscalar meson in the D rest frame, and $f_+(q^2)$ is a "form-factor" whose normalization must be calculated theoretically, although its shape can be measured.

Using one-third of the data at the BESIII, a partially-blind analysis has been done with the $D^0 \to Ke\nu$ and $D^0 \to \pi e\nu$ decays. After hadronic D^0 tags are found by using $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^0\pi^0$ and $K^-\pi^+\pi^-\pi^+$, we reconstruct signal decay for the other $\bar{D}^0$. The signal events with a missing ν are inferred using the variable $U = E_{miss} - |P_{miss}|$, similar to missing mass square, where "miss" here refers to the missing energy or momentum. Figure. 3 shows the U distributions and fit projections for the decays of $\bar{D}^0 \to K^+e^-\nu$ and $\bar{D}^0 \to \pi^+e^-\nu$.

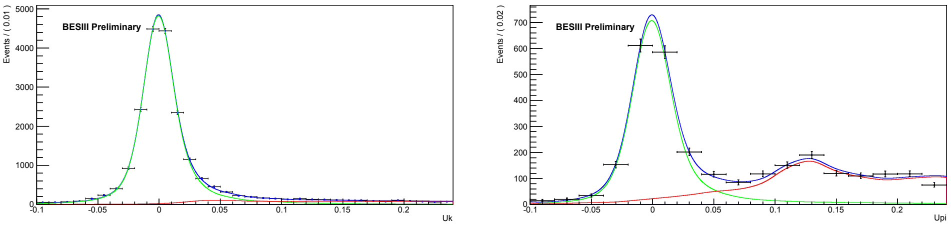

Figure 3 – U distributions of $\bar{D}^0 \to K^+e^-\nu$(left) and $\bar{D}^0 \to \pi^+e^-\nu$(right).

In order to measure form factor, partial decay rates are measured in different q^2 bins. $\bar{D}^0 \to K^+e^-\nu$ candidates are divided into nine q^2 bins, while $\bar{D}^0 \to \pi^+e^-\nu$ candidates are divided into seven q^2 bins. Signal yields in each q^2 bin are obtained by fitting U distributions in that q^2 range. Using an efficiency matrix *versus* q^2, obtained from Monte-Carlo simulation, and combining with tag yields and tag efficiencies, the partial decay rates are obtained, as shown in Fig. 4.

The values of q^2-dependent form factors in each q^2 bin can be extracted from the measured partial decay rates. These data can be fitted with different parameterizations of the form factors, and the fit can distinguish between form factor parameterizations. Three different parameterizations of the form factor $f_+(q^2)$ are considered. The first parameterization, known as the simple pole model, is dominated by a single pole[15]; the second parameterization is known as the modified pole model[15]; the third parameterization is known as the series expansion[14].

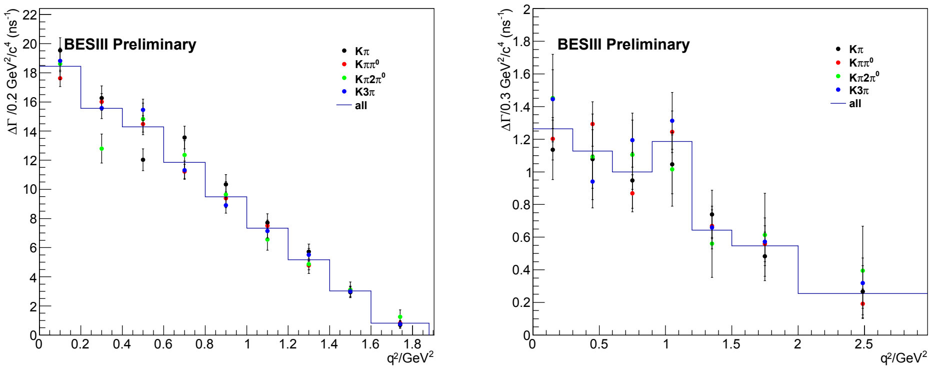

Figure 4 – Partial decay rates measurement using individual tag modes (points) and all tag modes combined (histogram) for decay of $\bar{D}^0 \to K^+e^-\nu$ (left) and $\bar{D}^0 \to \pi^+e^-\nu$ (right).

Thus minimized χ^2 fits are employed to extract the values of $f_+(0)|V_{cd(s)}|$ using each of the parameterizations. The preliminary results for $f_+(0)|V_{cd(s)}|$ are shown in Table 1 [16].

Table 1: Results of $f_+(0)|V_{cd(s)}|$ from individual form factor fits; statistical and systematic uncertainties on the least significant digits are shown in parentheses. Results from CLEO-c are compared.

		$f_+(0)\lvert V_{cd(s)}\rvert$	
		BESIII	CLEO-c
3 par. Series	$\bar{D}^0 \to K^+e^-\nu$	0.729(8)(7)	0.726(8)(4)
	$\bar{D}^0 \to \pi^+e^-\nu$	0.144(5)(2)	0.152(5)(1)
2 par. Series	$\bar{D}^0 \to K^+e^-\nu$	0.726(6)(7)	0.717(6)(4)
	$\bar{D}^0 \to \pi^+e^-\nu$	0.140(4)(2)	0.145(4)(1)
Modified pole	$\bar{D}^0 \to K^+e^-\nu$	0.725(6)(7)	0.716(6)(4)
	$\bar{D}^0 \to \pi^+e^-\nu$	0.140(3)(2)	0.145(4)(1)
Simple pole	$\bar{D}^0 \to K^+e^-\nu$	0.729(5)(7)	0.720(5)(4)
	$\bar{D}^0 \to \pi^+e^-\nu$	0.142(3)(1)	0.146(3)(1)

4 Measurements of the strong phase difference $\delta_{K\pi}$ and y_{CP}

Using the Quantum-correlation in the mass-threshold production process $e^+e^- \to D^0\overline{D}^0$, $\delta_{K\pi}$ and y_{CP} can be measured [6 18]. In this process, the initial system has $J^{PC} = 1^{--}$; as a result, the D^0 and $\overline{D}^0$ pair are in a CP-odd Quantum-coherent state, namely, the D^0 and $\overline{D}^0$ mesons are in opposite CP-eigenstates, until one of them decays [19]. This provides an unique way to probe D^0-$\overline{D}^0$ mixing as well as the strong phases difference between D^0 and $\overline{D}^0$ decay amplitudes. The strong phase difference $\delta_{K\pi}$ can be accessed using the following formula

$$2r\cos\delta_{K\pi} + y \quad = \quad (1 + R_{\mathrm{WS}}) \cdot \mathcal{A}_{CP\to K\pi}, \tag{2}$$

where R_{WS} is the decay rate ratio of the wrong sign process $\overline{D}^0 \to K^-\pi^+$ and the right sign process $D^0 \to K^-\pi^+$ [20] and $\mathcal{A}_{CP\to K\pi}$ is the asymmetry between CP-odd and CP-even states decaying to $K^-\pi^+$

$$\mathcal{A}_{CP\to K\pi} = \frac{\mathcal{B}_{D_2\to K^-\pi^+} - \mathcal{B}_{D_1\to K^-\pi^+}}{\mathcal{B}_{D_2\to K^-\pi^+} + \mathcal{B}_{D_1\to K^-\pi^+}}. \tag{3}$$

Using D tagging method in the quantum-coherent D^0 pair production, we can calculate the branching fractions with

$$\mathcal{B}_{D^{CP\pm}\to K\pi} = \frac{n_{K\pi,CP\pm}}{n_{CP\pm}} \cdot \frac{\varepsilon_{CP\pm}}{\varepsilon_{K\pi,CP\pm}}. \tag{4}$$

Here, $n_{CP\pm}$ ($n_{K\pi,CP\pm}$) and $\varepsilon_{CP\pm}$ ($\varepsilon_{K\pi,CP\pm}$) are yields and detection efficiencies of single tags (ST) of $D \to CP\pm$ (double tags (DT) of $D \to CP\pm$, $\bar{D} \to K\pi$), respectively. With external inputs of the parameters of r, y and R_{WS}, we can extract $\delta_{K\pi}$ from $\mathcal{A}_{CP\to K\pi}$. Based on a dataset of 818 pb^{-1} data collected with the CLEO-c detector at $\sqrt{s} = 3.77$ GeV, they measured $\cos\delta_{K\pi} = 0.81^{+0.22+0.07}_{-0.18-0.05}$ [21]. Using a global fit method with inclusion of the external mixing parameters, CLEO obtained $\cos\delta_{K\pi} = 1.15^{+0.19+0.00}_{-0.17-0.08}$ [21].

We choose 5 CP-even D^0 decay modes and 3 CP-odd modes to identify the CP ST signals. In the events of the CP ST modes, we reconstruct the $K\pi$ combinations using the remaining charged tracks with respect to the ST D candidates. Similar fits are implemented to the distributions of $M_{\mathrm{BC}}(D \to CP\pm)$ in the survived DT events to estimate yields of DT signals. The fits are shown in Fig. 5.

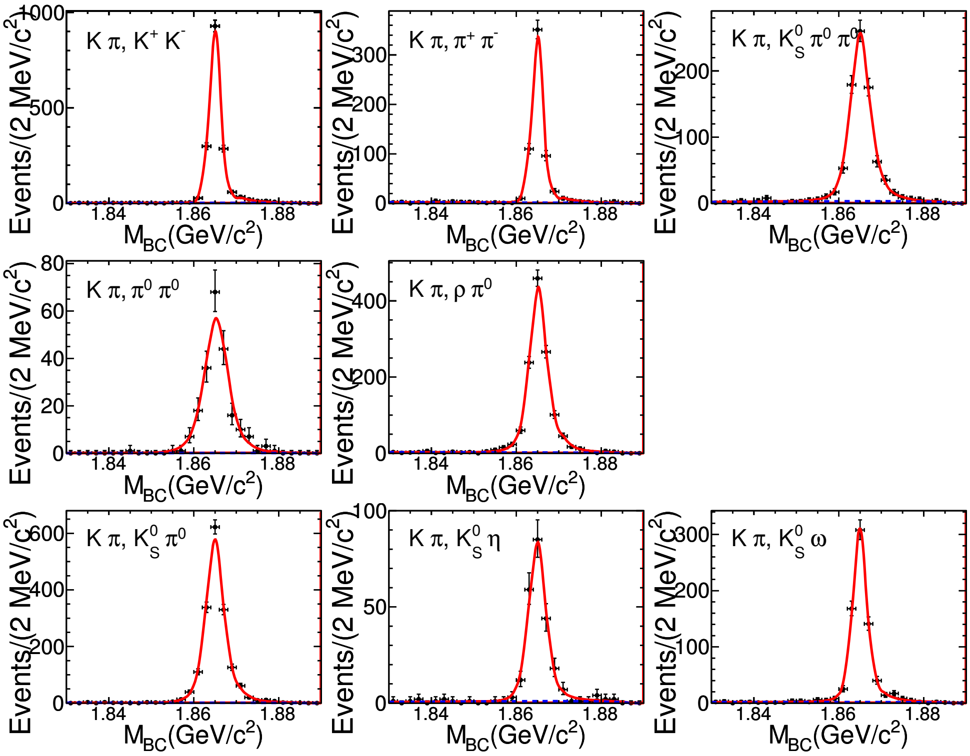

Figure 5 – DT M_{BC} distributions and the corresponding fits. Data are shown in points with error bars. The solid lines show the total fits and the dashed lines show the background shapes.

We get the asymmetry to be $\mathcal{A}_{CP\to K\pi} = (12.77 \pm 1.31^{+0.33}_{-0.31})\%$. To measure the strong phase $\delta_{K\pi}$, we quote the external inputs of $R_{\mathrm{D}} = r^2 = (3.47 \pm 0.06) \times 10^{-3}$, $y = (6.6 \pm 0.9) \times 10^{-3}$, and $R_{\mathrm{WS}} = (3.80 \pm 0.05) \times 10^{-3}$ from HFAG 2013 [22] and PDG [23]. Hence, we obtain $\cos\delta_{K\pi} = 1.03 \pm 0.12 \pm 0.04 \pm 0.01$, where the first uncertainty is statistical, the second uncertainty is systematic, and the third uncertainty is due to the errors introduced by the external input parameters. This result is more precise than CLEO's measurement and provides the world best constrain to $\delta_{K\pi}$.

As proposed in Ref. [24], the CP tagged $D \to Ke\nu$ and $D \to K\mu\nu$ decays can be used to extract y_{CP}. For the detail of experimental technique, one can find in Ref. [17]. With 2.9fb^{-1} data at the BESIII, we obtained the preliminary rsults as [17]

$$y_{CP} = -1.6\% \pm 1.3\%(\mathrm{stat.}) \pm 0.6\%(\mathrm{syst.}).$$

The result is compatible with the previous measurements [22]. This is the most precise measurement of $y_{\rm CP}$ based on $D^0\overline{D}^0$ threshold productions. However, its precision is still statistically limited.

5 Summary

More analyses on the $D \to h_1h_2h_3$ Dalitz decays and $D \to h_1h_2h_3h_4$ four-body decays are under going at the BESIII, from which one will extract amplitudes from qusi-two-body contributions. Therefore the strong phase difference, neutral D mixing parameters and CP violation asymmetries can be studied. For the rare charm decays, many decay modes including photons and π^0 in the final states can be probed with high sensitivities (with relative smaller integrated luminosity than that at the B factories). More promising results are expected to be coming soon.

Acknowledgments

This work is supported in part by the National Natural Science Foundation of China (NSFC) under Contract No. 11125525.

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