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Highlight of Charm Physics at BESIII

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Abstract. In this talk, we present the recent results of charm physics from the BESIII collaboration. This talk covers the studies of the leptonic and semi-leptonic decays of D mesons, and the measurement of the strong phase difference based on the quantum correlation.

1 Introduction

The BESIII [1] experiment at the BEPCII collider started data taking since 2008. For the study of charm meson decays, about 2.9 fb^{-1} data on the $\psi(3770)$ peak has been accumulated. $\psi(3770)$ dominantly decays into $D\bar{D}$, which provides an ideal place for studying the decays of D^0 and D^+ mesons.

2 Determination of $\mathcal{B}(D^+ \to \mu^+\nu)$ and the decay constant f_{D^+}

In the Standard Model of particle physics, the D^+ meson can decay into $l^+\nu_l$ via a virtual W^+ boson. The decay rate depends on the D^+ decay constant f_{D^+}, in which all of the strong interaction effects between the two initial-state quarks are absorbed. The decay width of $D^+ \to l^+\nu_l$ is given by [2]

$$\Gamma(D^+ \to l^+\nu_l) = \frac{G_F^2 f_{D^+}^2}{8\pi}|V_{cd}|^2 m_l^2 m_{D^+}(1 - \frac{m_l^2}{m_{D^+}^2})^2, \tag{1}$$

where G_F is the Fermi coupling constant. So by measuring the branching ratio of $D^+ \to l^+\nu_l$, the decay constant f_{D^+} can be determined to test the calculations from lattice QCD. In addition, $|V_{cd}|$ can be directly accessed. f_{D^+} is also helpful to constrain the CKM matrix element $|V_{td}|$ through its relation to the mixing parameter x_B and the ratio f_D/f_B [3, 4].

To determine the branching ratio of $D^+ \to \mu^+\nu_\mu$, the D tagging method is used. Firstly, D^- mesons are reconstructed with 9 hadronic decay modes ($D^- \to K^+\pi^-\pi^-$, $K_S^0\pi^-$, $K_S^0K^-$, $K^+K^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $\pi^+\pi^-\pi^-$, $K_S^0\pi^-\pi^0$, $K^+\pi^-\pi^-\pi^-\pi^+$ and $K_S^0\pi^-\pi^-\pi^+$), and then μ^+ is sought out in the remaining tracks. $M_{miss}^2 = (E_{beam} - E_{D^-} - E_{\mu^+})^2 - (-\overrightarrow{p}_{D^-} - \overrightarrow{p}_{\mu^+})^2$ is used to extract the signal events which peak

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around 0. Finally, with 2.9 fb^{-1} $\psi(3770)$ data, the branching fraction of $D^+ \to \mu^+\nu_\mu$ is measured to be [5]

$$\mathcal{B}(D^+ \to \mu^+\nu_\mu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}.$$

With combination of G_F, the mass of μ^+ and D^+, the lifetime of D^+ and $|V_{cd}|$ from the global fit in the SM [6], the decay constant f_{D^+} is obtained with the best precision in the world [5]

$$f_{D^+} = (203.2 \pm 5.3 \pm 1.8)\,\text{MeV}.$$

3 Measurement of $\mathcal{B}(D^0 \to K^-/\pi^- e^+\nu)$ and the Form-Factor $f_+(q^2)$

The differential decay rate of $D^0 \to K^-(\pi^-)e^+\nu$ is written as

$$\frac{\Delta\Gamma(D \to K(\pi)e\nu)}{dq^2} = \frac{G_F^2|V_{cs(d)}|^2}{24\pi^3} p^3 |f_+(q^2)|^2. \quad (2)$$

With the precisely determined $V_{cs(d)}$ from the unitarity of the CKM matrix, we can obtain the form-factor $f_+(q^2)$ to check the lattice QCD calculations.

This analysis has been done using one-third of the 2.9 fb^{-1} $\psi(3770)$ data, with a partial-blind method. Firstly, the singly tagged $\bar{D}^0$ is reconstructed with four hadronic modes ($\bar{D}^0 \to K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^0\pi^0$ and $K^+\pi^-\pi^-\pi^+$). The signal candidates are searched by reconstructing two opposite charged tracks ($K^+/\pi^+\ e^-$) left in the event, and $U_{miss} = E_{miss} - p_{miss}$ is used to extract the signal events which peak around 0. Here, $E_{miss} = E_{beam} - E_{hadron} - E_{electron}$, and $p_{miss} = |-\vec{p}_{hadron} - \vec{p}_{electron}|$. The branching fractions are measured to be

$$\mathcal{B}(D^0 \to K^- e^+\nu) = (3.542 \pm 0.030 \pm 0.067)\%$$

$$\mathcal{B}(D^0 \to \pi^- e^+\nu) = (0.288 \pm 0.008 \pm 0.005)\%.$$

These two results are consistent with the world averages [6].

To measure the form factor, the partial decay rates are measured in different q^2 bins, where q^2 is the squared invariant mass of $e^+\nu$ system. The $f_+(q^2)$ distributions are shown in figure 1 with theoretical curves overlaid [7].

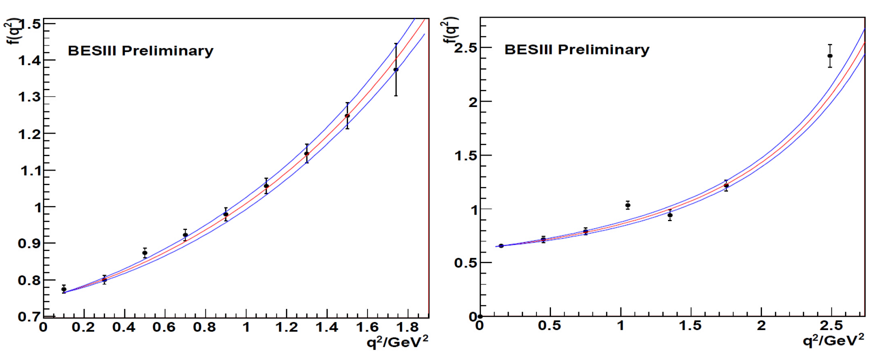


Figure 1. $f_+(q^2)$ distributions for the decay of $D^0 \to K^-e^+\nu$ (left) and $D^0 \to \pi^-e^+\nu$ (right). Points are measured from data, curves are the theoretical predictions varying within one statistical standard sigma.

4 Measurement of the strong phase difference $\delta_{K\pi}$

Studying the D^0-$\bar{D}^0$ mixing is important for identifying the size of the long distance effect and searching for new physics [8], and also helpful for studying CP violation in charm physics. Charm mixing is described by two dimensionless parameters x and y. The measurement of the strong phase difference δ between the doubly Cabibbo-suppressed (DCS) decay $\bar{D}^0 \to K^-\pi^+$ and the corresponding Cabibbo-favored (CF) $D^0 \to K^-\pi^+$, allows x and y to be extracted from $x' \equiv x\cos\delta + y\sin\delta$ and $y' \equiv y\cos\delta - x\sin\delta$ [9]. Furthermore, finer precision of δ helps the γ/ϕ_3 angle measurement in CKM matrix according to the so-called ADS method [6].

Using the quantum-correlated technique, δ can be accessed using the following formula

$$2r\cos\delta + y = (1 + R_{\rm WS}) \cdot \mathcal{A}_{CP\to K\pi}, \tag{3}$$

where $\mathcal{A}_{CP\to K\pi}$ is the asymmetry between the branching fractions of CP-odd and CP-even states decaying to $K^-\pi^+$. $\mathcal{B}(D^{CP^\pm} \to K^-\pi^+)$ are measured with D tagging method using 5 CP-even D^0 decay modes ($K^+K^-, \pi^+\pi^-, K^0_S\pi^0\pi^0, \pi^0\pi^0$ and $\rho^0\pi^0$) and 3 CP-odd modes ($K^0_S\pi^0$, $K^0_S\eta$ and $K^0_S\omega$). With $2.9\,\text{fb}^{-1}$ $\psi(3770)$ data, we obtain the asymmetry to be [10]

$$\mathcal{A}_{CP\to K\pi} = (12.7 \pm 1.3 \pm 0.7)\%.$$

By quoting the external inputs of $R_{\rm D} = r^2 = (3.50 \pm 0.04)‰$, $y = (6.7 \pm 0.9)‰$ from HFAG 2013 [11] and $R_{\rm WS} = (3.80 \pm 0.05)‰$ from PDG [6], we obtain [10]

$$\cos\delta_{K\pi} = 1.02 \pm 0.11 \pm 0.06 \pm 0.01,$$

where the third uncertainty is due to the errors introduced by the external input parameters. This result provides the world best constrain to $\delta_{K\pi}$.

5 Measurement of the Relative Strong-phase Difference between D^0 and $\bar{D}^0$ decay to $K^0_S\pi^+\pi^-$

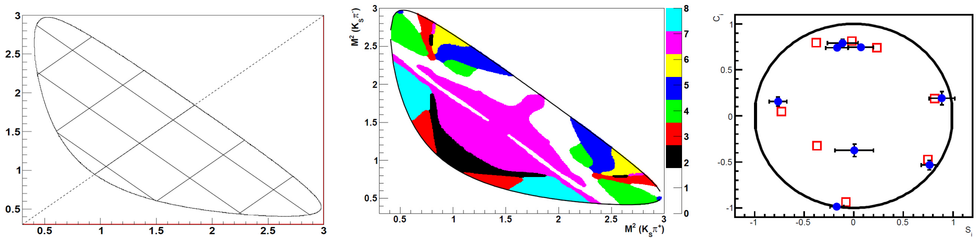
The CKM angle $\gamma/\phi3$ can be measured from the decay $B^+ \to D(K^0_S\pi^+\pi^-)K^\pm$ through the GGSZ method [12, 13]. The Dalitz plot can be separated into $2N$ bins as shown in figure 2(a). The N bins lying below the symmetry axis are denoted by the index i, while the remaining bins are indexed with $\bar{i}$, and these square bins are symmetric under exchange of x and y ($x \equiv m^2_{K^0_s\pi^-}$, $y \equiv m^2_{K^0_s\pi^+}$). The two parameters c_i and s_i denote the weighted average of $\cos(\Delta\delta_D)$ and $\sin(\Delta\delta_D)$ in the i^{th} bin, respectively. And $\Delta\delta_D$ is the strong phase difference between the DCS decay $\bar{D}^0 \to K^0_S\pi^+\pi^-$ and the corresponding CF decay $D^0 \to K^0_S\pi^+\pi^-$.

The number of events in the i^{th} bin of a Dalitz plot originating from the $B^\pm$ decay is

$$N_i^\pm = \frac{a_B}{a_D}[K_i + r_B^2 K_{\bar{i}} \pm 2r_B\sqrt{K_i K_{\bar{i}}}(\cos(\delta_{\rm B} + \gamma){\rm c_i} + \sin(\delta_{\rm B} + \gamma){\rm s_i})]. \tag{4}$$

The normalization factors, r_B and δ_B could be determined at B factories. Using $\psi(3770)$, K_i can be obtained by flavor tagged $D \to K^0_S\pi^+\pi^-$ decays, c_i can be obtained from CP tagged $D \to K^0_S\pi^+\pi^-$ decays, and s_i is obtained from double Dalitz decays $D^0 \to K^0_S\pi^+\pi^-$ and $\bar{D}^0 \to K^0_S\pi^+\pi^-$.

The Dalitz plot is split into 8 bins as shown in figure 2(b), which have been optimized, to get the highest sensitivity of γ. The results of c_i and s_i in each bin are given in figure 2(c). Our results will allow for increased precision in the measurement of $\gamma/\phi3$.



(a) (b) (c)

Figure 2. (a): Squared binned Dalitz plot with symmetric bins over an exchange of x and y. (b): Modified optimal binning. (c): Red squares mark the model predicted value of c_i and s_i [14], and the blue dot mark fitted value from data with statistical error.

6 Summary

Based on the 2.9 fb^{-1} data taken at the $\psi(3770)$ peak, the recent results on the study of charm physics are presented. The BESIII experiment aims at getting 20 fb^{-1} $\psi(3770)$, and more promising results are expected.

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