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 \(\mathcal{B}(D^+ \rightarrow \mu^+\nu)\) 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 \(D^+ \rightarrow l^+\nu_l\) is given by [2]

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

where \(G_F\) is the Fermi coupling constant. So by measuring the branching ratio of \(D^+ \rightarrow l^+\nu_l\), 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 \(D^+ \rightarrow \mu^+\nu_{\mu}\), the \(D\) tagging method is used. Firstly, \(D^-\) mesons are reconstructed with 9 hadronic decay modes (\(D^- \rightarrow K^+\pi^-\pi^-, K_S\pi^-, K_S^0K^-, K^-K^+\pi^-, K^+\pi^0\pi^0, \pi^+\pi^-\pi^-, K_S^0\pi^-\pi^0, K^+\pi^-\pi^0\pi^+\) and \(K^0\pi^+\pi^-\pi^+)\), and then \(\mu^+\) is sought out in the remaining tracks. \(M_{miss}^2 = (E_{beam} - E_{D^-} - E_{\mu^+})^2 - (\vec{p}_{D^-} - \vec{p}_{\mu^+})^2\) 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 \(D^+ \rightarrow \mu^+\nu_\mu\) is measured to be [5]

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

With combination of \(G_F\), the mass of \(\mu^+\) 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 \(\mathcal{B}(D^0 \rightarrow K^-/\pi^- e^+\nu)\) and the Form-Factor \(f_+(q^2)\)

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

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

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 (\(\bar{D}^0 \rightarrow K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^0\pi^0\) and \(K^+\pi^-\pi^-\pi^+\)). The signal candidates are searched by reconstructing two opposite charged tracks (\(K^+/\pi^+ e^-\)) left in the event, and \(U_{\text{miss}} = E_{\text{miss}} - p_{\text{miss}}\) is used to extract the signal events which peak around 0. Here, \(E_{\text{miss}} = E_{\text{beam}} - E_{\text{hadron}} - E_{\text{electron}}\) and \(p_{\text{miss}} = |-\vec{p}_{\text{hadron}} - \vec{p}_{\text{electron}}|\). The branching fractions are measured to be

\[ \mathcal{B}(D^0 \rightarrow K^- e^+\nu) = (3.542 \pm 0.030 \pm 0.067)\% \]
\[ \mathcal{B}(D^0 \rightarrow \pi^- e^+\nu) = (0.288 \pm 0.008 \pm 0.005)\%. \]

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](image-url)  

**Figure 1.** \(f_+(q^2)\) distributions for the decay of \(D^0 \rightarrow K^- e^+\nu\) (left) and \(D^0 \rightarrow \pi^- e^+\nu\) (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 $\delta$ between the doubly Cabibbo-suppressed (DCS) decay $D^0 \rightarrow K^-\pi^+$ and the corresponding Cabibbo-favored (CF) $D^0 \rightarrow K^-\pi^+$, 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 $\delta$ helps the $\gamma/\phi_3$ angle measurement in CKM matrix according to the so-called ADS method [6].

Using the quantum-correlated technique, $\delta$ can be accessed using the following formula

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

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

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

By quoting the external inputs of $R_D = r^2 = (3.50 \pm 0.04)\%e$, $y = (6.7 \pm 0.9)\%e$ from HFAG 2013 [11] and $R_{WS} = (3.80 \pm 0.05)\%e$ 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 $K_S^0\pi^+\pi^-$

The CKM angle $\gamma/\phi_3$ can be measured from the decay $B^+ \rightarrow D(K_S^0\pi^+\pi^-)K^\pm$ 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 $i'$, and these square bins are symmetric under exchange of $x$ and $y$ ($x \equiv m_{K_S^0\pi^+\pi^-}^2$, $y \equiv m_{K_S^0\pi^+\pi^-}^2$). 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 $D^0 \rightarrow K_S^0\pi^+\pi^-$ and the corresponding CF decay $D^0 \rightarrow K_S^0\pi^+\pi^-$. The number of events in the $i^{th}$ bin of a Dalitz plot originating from the $B^\pm$ decay is

$$N_i^\pm = \frac{a_B}{a_D} [K_i + r_B^2 K_i \pm 2r_B \sqrt{K_i K_i} (\cos(\delta_B + \gamma)c_i + \sin(\delta_B + \gamma)s_i)].$$

The normalization factors, $r_B$ and $\delta_B$ could be determined at $B$ factories. Using $\psi(3770)$, $K_i$ can be obtained by flavor tagged $D \rightarrow K_S^0\pi^+\pi^-$ decays, $c_i$ can be obtained from CP tagged $D \rightarrow K_S^0\pi^+\pi^-$ decays, and $s_i$ is obtained from double Dalitz decays $D^0 \rightarrow K_S^0\pi^+\pi^-$ and $\bar{D}^0 \rightarrow K_S^0\pi^+\pi^-$. The Dalitz plot is split into 8 bins as shown in figure 2(b), which have been optimized, to get the highest sensitivity of $\gamma$. 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 $\gamma/\phi_3$.  

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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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References