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D semi-leptonic and leptonic decays at BESIII

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During 2010 and 2011, a data sample of 2.92 fb^{-1} was accumulated at $\sqrt{s}$ = 3.773 GeV by the BESIII detector operating at the BEPCII e^+e^- collider. Based on analysis of this data sample, we report the studies of the purely leptonic decay $D^+ \to \mu^+\nu_\mu$, and the semileptonic decays $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$.

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1. Introduction

The BESIII/BEPCII [1] is an major upgrade of the BESII/BEPC[2]. The BEPCII collider operates in the energy range of $\sqrt{s} = $ (2-4.6) GeV. The main physics goals of the BESIII experiments are precision measurements of $\tau-$ charm physics and probing for new physics or new phenomena beyond conventional expectation in this energy region. The BESIII collected 2.92 fb^{-1} data at $\sqrt{s}$ = 3.773 GeV in 2010 and 2011 [3]. At $\sqrt{s}$ = 3.773 GeV, the $\psi(3770)$ is produced in e^+e^- collision. Since the $\psi(3770)$ lies above the production threshold of $D\bar{D}$ ($D^0\bar{D}^0$ and D^+D^-) pair but below the production threshold of $D\bar{D}^*$ pair, it predominately decays into $D\bar{D}$ ($D^0\bar{D}^0$ and D^+D^-) [4], thus providing ideal place to study the decays of D^0 and D^+ mesons. Herein, we report some recent results on the purely leptonic decay $D^+ \to \mu^+\nu_\mu$, and the semileptonic decays $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$ at BESIII. Throughout the proceeding, the charge conjugate is implied.

2. Improved measurements of $B(D^+ \to \mu^+\nu_\mu)$, decay constant f_{D^+} and CKM matrix element $|V_{cd}|$

In the Standard Model of particles physics, the D^+ mesons decay into $\ell\nu_\ell$ via a vitual W^+ boson. The decay rate can be parameterized by the D^+ decay constant f_{D^+}, in which, all strong interaction effects between the two quarks (c and $\bar{d}$) in initial state are absorbed. The decay width of $D^+ \to \ell^+\nu_\ell$ can be given by

$$\Gamma(D^+ \to \ell^+\nu_\ell) = \frac{G_F^2}{8\pi}|V_{\rm cd}|^2 m_\ell^2 m_{D^+}(1 - \frac{m_\ell^2}{m_{D^+}^2}), \tag{2.1}$$

where G_F is the Fermi coupling constant, $|V_{\rm cd}|$ is the CKM matrix element between the two quarks $c\bar{d}$, m_ℓ and m_{D^+} are the masses of the lepton and D^+. Using the precisely measured branching fraction for $D^+ \to \ell^+\nu_\ell$, we can accurately determine the decay constant f_{D^+} or the CKM matrix element $|V_{\rm cd}|$. By analyzing all the 2.92 fb^{-1} data, we studied the purely leptonic decay $D^+ \to \mu^+\nu_\mu$.

2.1 Singly tagged D^- mesons

We reconstruct singly tagged D^- mesons by using nine hadronic decay modes. Figure 1 (left side) shows the fits to the beam-energy-constrained mass spectra of the singly tagged D^- candidates reconstructed by the (a) $K^+\pi^-\pi^-$, (b) $K^0\pi^-$, (c) K^0K^-, (d) $K^+K^-\pi^-$, (e) $K^+\pi^-\pi^-\pi^0$, (f) $\pi^-\pi^-\pi^+$, (g) $K^0\pi^-\pi^0$, (h) $K^+\pi^-\pi^-\pi^-\pi^+\pi^+$ and (i) $K^0\pi^-\pi^-\pi^+$ combinations. We obtain $(1.566 \pm 0.002_{\rm stat.}) \times 10^6$ singly tagged D^- mesons [5]. For each mode, the signal region is marked by the pair of arrows in each sub-figure.

2.2 Determination of $B(D^+ \to \mu^+\nu_\mu)$, f_{D^+} and $|V_{cd}|$

Figure 1 (right side) shows the $M^2_{\rm miss}$ distribution of the selected candidates for $D^+ \to \mu^+\nu_\mu$. After subtracting backgrounds based on Monte Carlo simulation, we obtain $377.3 \pm 20.7_{\rm stat.}$ signal events of $D^+ \to \mu^+\nu_\mu$. Based on these, we determine the branching fraction for $D^+ \to \mu^+\nu_\mu$ to be

$$B(D^+ \to \mu^+\nu_\mu) = (3.74 \pm 0.21_{\rm stat.} \pm 0.06_{\rm sys.}) \times 10^{-4}.$$

Using the measured $B(D^+ \to \mu^+\nu_\mu)$ and the CKM matrix element $|V_{\rm cd}|$ value determined from a global Standard Model fit [4], we determine the decay constant of D^+ to be

$$f_{D+} = 203.91 \pm 5.72_{\rm stat.} \pm 1.97_{\rm sys.}\ {\rm MeV}.$$

The measured $B(D^+ \to \mu^+\nu_\mu)$ and f_{D^+} at the BESIII are consistent within errors with those measured at the BESI [6], BESII [7]and CLEO-c [8] experiments, but with the best precision.

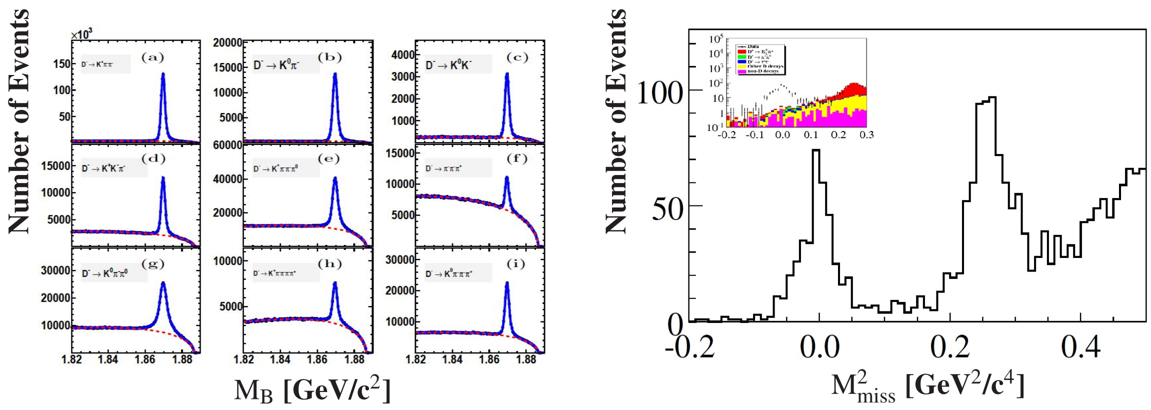

Figure 1: (left side) The fits to the beam-energy-constrained mass spectra for singly tagged D^- modes. (right side) The $M^2_{\rm miss}$ distribution for $D^+ \to \mu^+\nu_\mu$ candidates.

So far, the CKM matrix element $|V_{\rm cd}|$ was usually measured though experimental studies of the semileptonic decay $D \to \pi\ell^+\nu_\ell$ or measurement of charm production cross section of $\nu\bar{\nu}$ interaction, among which the best measurement precision is 4.8% [4]. By using the measured $B(D^+ \to \mu^+\nu_\mu)$ and the Lattice QCD prediction for f_{D^+} [9], we determine the CKM matrix element $|V_{\rm cd}|$ to be

$$|V_{\rm cd}| = 0.222 \pm 0.006_{\rm stat.} \pm 0.005_{\rm sys.},$$

which has the best precision in the world to data.

2.3 Measurements of $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$

The semileptonic decays of D mesons can be well interpreted because the effects of the weak and strong interaction can be well separated. In theory, their decay amplitudes are parameterized by the CKM matrix element describing the mixing between the quark mass eigenstates and the weak eigenstates, and the form factor describing the strong interaction between the final state quarks. For the semileptonic decays $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$, their differential decay rates can be given by

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{\rm cs/d}|^2 p^3_{K/\pi}|f_+^{K/\pi}(q^2)|^2, \tag{2.2}$$

where G_F is the Fermi coupling constant, $|V_{\rm cs/d}|$ is the CKM matrix element between the two quarks $c\bar{s}/\bar{d}$, $p_{K/\pi}$ is the momentum of the kaon/pion in the rest frame of D meson, $f_+^{K/\pi}(q^2)$ is the form factor of hadronic weak current depending on the square of the four momentum transfer $q = p_D - p_{K/\pi}$. Based on experimental studies of the semileptonic decays of $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$, we can precisely determine their decay branching fractions, as well as the form factors which will accurately test or calibrate the theoretical expectations on these form factors [10, 11, 12] at higher precision. By analyzing 0.928 fb^{-1} data taken in 2010, we studied the semileptonic decays $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$.

2.4 Singly tagged $\bar{D}^0$ mesons

We reconstruct singly tagged $\bar{D}^0$ mesons by using four hadronic decay modes. Figure 2 shows the fits to the beam-energy-constrained mass spectra of the singly tagged $\bar{D}^0$ candidates reconstructed by the (up-left) $\bar{D}^0 \to K^+\pi^-$, (up-right) $\bar{D}^0 \to K^+\pi^-\pi^0$, (down-left) $\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$ and (down-right) $\bar{D}^0 \to K^+\pi^-\pi^0\pi^0$ combinations. From the fits, we obtain $(0.774 \pm 0.001_{\rm stat.}) \times 10^6$ singly tagged $\bar{D}^0$ mesons.

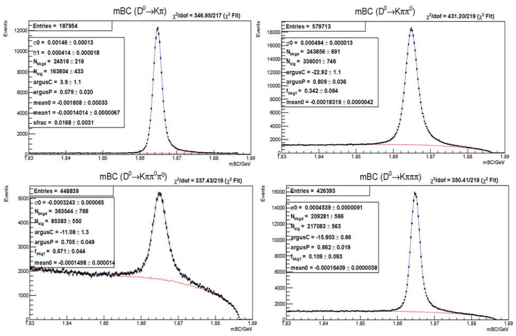

Figure 2: The fits to the beam-energy-constrained mass spectra for singly tagged $\bar{D}^0$ modes.

2.5 Determination of $B(D^0 \to K^- e^+ \nu_e)$ and $B(D^0 \to \pi^- e^+ \nu_e)$

Figure 3 shows the $U_{\rm miss}$ fits for $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$ candidates. From the fits, we obtain $18460 \pm 143_{\rm stat.}$ and $1677 \pm 45_{\rm stat.}$ signal events of $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$. Based on these, we determine the branching fractions for $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$ to be

$$B(D^0 \to K^- e^+ \nu_e) = (3.542 \pm 0.030_{\rm stat.} \pm 0.067_{\rm sys.})\%$$

and

$$B(D^0 \to \pi^- e^+ \nu_e) = (0.288 \pm 0.008_{\rm stat.} \pm 0.005_{\rm sys.})\%,$$

respectively. The measured $B(D^0 \to K^- e^+ \nu_e)$ and $B(D^0 \to \pi^- e^+ \nu_e)$ at the BESIII are consistent within errors with those measured at the BESII [13], CLEO-c [14], BELLE [15] and BABAR [16] experiments, and the averaged values by PDG [4].

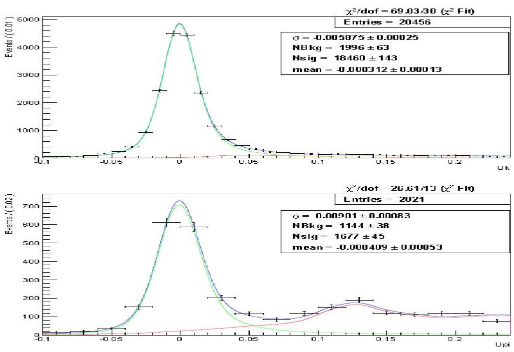

Figure 3: The $U_{\rm miss}$ fits for $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$ candidates.

2.6 Form factor fits

Figures 4 and 5 show the form factor fits for $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$ using the simple pole model (up-left) [10], the modified pole model (up-right) [10], the two-parameter series expansion (down-left) [12] and the three-parameter series expansion (down-right) [12].

3. Summary

During 2010 and 2011, the BESIII collected 2.92 fb^{-1} data at $\sqrt{s} = 3.773$ GeV. Based on analyzing this data sample, we present improved measurements of $B(D^+ \to \mu^+ \nu_\mu)$, the decay constant f_{D^+} and the CKM martix element $|V_{\rm cd}|$. Also, we present measurements of the semileptonic decays $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$.

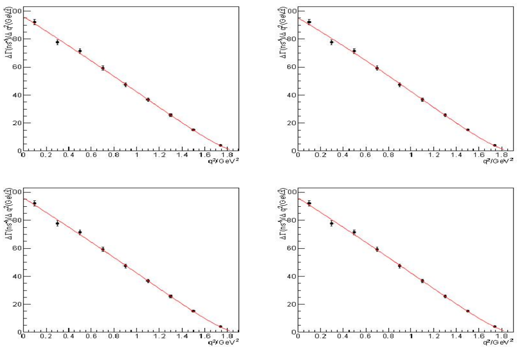

Figure 4: Form factor fits for $D^0 \to K^- e^+ \nu_e$.

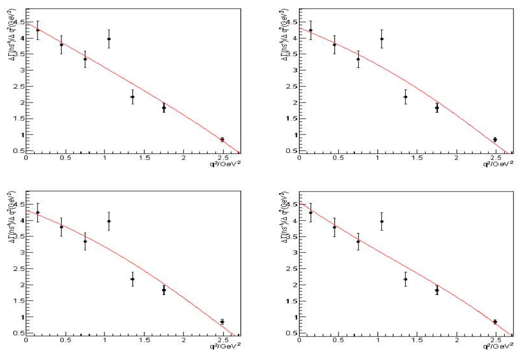

Figure 5: Form factor fits for $D^0 \to \pi^- e^+ \nu_e$.

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