Direct Measurements of the Branching Fractions for the Semileptonic Decays

\[ D^0 \rightarrow K^{-}\mu^+\nu_{\mu} \] and \[ D^0 \rightarrow \pi^{-}\mu^+\nu_{\mu} \]

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Based on the data sample of 33 pb⁻¹ collected at and around 3.773 GeV with the BES-II detector at the BPEC collider, the absolute branching fractions for the semileptonic decays \[ D^0 \rightarrow K^{-}\mu^+\nu_{\mu} \] and \[ D^0 \rightarrow \pi^{-}\mu^+\nu_{\mu} \] have been measured. In the system recoiling against \( 7584 \pm 198 \pm 341 \) singly tagged \( D^0 \) mesons, \( 87.2 \pm 13.6 \) events for \( D^0 \rightarrow K^{-}\mu^+\nu_{\mu} \) and \( 9.3 \pm 4.7 \) events for \( D^0 \rightarrow \pi^{-}\mu^+\nu_{\mu} \) are observed. These yield the absolute branching fractions to be \( BF(D^0 \rightarrow K^{-}\mu^+\nu_{\mu}) = (3.55 \pm 0.56 \pm 0.59)\% \) and \( BF(D^0 \rightarrow \pi^{-}\mu^+\nu_{\mu}) = (0.38 \pm 0.30 \pm 0.10)\% \). The measured branching fraction for \( D^0 \rightarrow K^{-}\mu^+\nu_{\mu} \) was previously used to determine the ratio \( \Gamma(D^0 \rightarrow K^{-}\mu^+\nu_{\mu})/\Gamma(D^+ \rightarrow K^+\mu^+\nu_{\mu}) \).
combining the previously measured branching fraction for $D^+ \rightarrow \bar{K}^0 \mu^+ \nu_\mu$ by the BES Collaboration.

I. INTRODUCTION

The pseudoscalar semileptonic decays $D^0 \rightarrow K^- \ell^+ \nu_\ell$ and $D^0 \rightarrow \pi^- \ell^+ \nu_\ell$ are the best understood in theory, since the effects of weak and strong interactions can be separated reasonably well. Their decay amplitudes are simply related to the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements $V_{cs}$ and $V_{cd}$, which parameterize the mixing between the quark mass eigenstates and the weak eigenstates, and the form factor describing the strong interaction between the final state quarks. As a result, measurements of the branching fractions for $D^0 \rightarrow K^- \ell^+ \nu_\ell$ and $D^0 \rightarrow \pi^- \ell^+ \nu_\ell$ play an important role in understanding of both the weak and strong interactions. In addition, measurements of the branching fractions for $D^0 \rightarrow K^- \mu^+ \nu_\mu$ and $D^+ \rightarrow \bar{K}^0 \mu^+ \nu_\mu$ can be used to test isospin symmetry in exclusive semileptonic decays of the charged and neutral $D$ mesons [1].

In this paper, we report direct measurements of the branching fractions for $D^0 \rightarrow K^- \mu^+ \nu_\mu$ and $D^0 \rightarrow \pi^- \mu^+ \nu_\mu$ (Throughout the paper, charged conjugations are implied). The measured branching fraction for $D^0 \rightarrow K^- \mu^+ \nu_\mu$ was previously used to determine the ratio of the partial widths $\Gamma(D^0 \rightarrow K^- \mu^+ \nu_\mu) / \Gamma(D^+ \rightarrow \bar{K}^0 \mu^+ \nu_\mu)$ [2]. This ratio can be used to test the isospin symmetry in the $D$ semileptonic decays [2].

II. BES-II DETECTOR

The BES-II is a conventional cylindrical magnetic detector that is described in detail in Ref. [3]. A 12-layer Vertex Chamber (VC) surrounding a beryllium beam pipe provides input to event trigger, as well as coordinate information. A forty-layer main drift chamber (MDC) located just outside the VC yields precise measurements of charged particle trajectories with a solid angle coverage of 85% of $4\pi$; it also provides ionization energy loss ($dE/dx$) measurements for particle identification. Momentum resolution of 1.7% $\sqrt{1 + p^2}$ (in GeV/c) and $dE/dx$ resolution of 8.5% for Bhabha scattering electrons are obtained for the data taken at $\sqrt{s} = 3.773$ GeV. An array of 48 scintillation counters surrounding the MDC measures time of flight (TOF) of charged particles with a resolution of about 180 ps for electrons. Outside the TOF counters, a 12 radiation length, lead-gas barrel shower counter (BSC), operating in limited streamer mode, measures the energies of electrons and photons over 80% of the total solid angle with an energy resolution of $\sigma_E / E = 0.22 / \sqrt{E}$ (in GeV) and spatial resolutions of $\sigma_x = 7.9$ mm and $\sigma_z = 2.3$ cm for electrons. A solenoidal magnet outside the BSC provides a 0.4 T magnetic field in the central tracking region of the detector. Three double-layer muon counters instrument the magnet flux return and serve to identify muons with momentum greater than 500 MeV/c. They cover 68% of the total solid angle.

III. DATA ANALYSIS

The data used in the analysis were collected with the BES-II detector at the BEPC collider. A total integrated luminosity of about 33 pb$^{-1}$ was taken at and around the c.m. (center-of-mass) energy of $\sqrt{s} = 3.773$ GeV. Around the c.m. energy, the $\psi(3770)$ resonance is produced in electron-positron ($e^+e^-$) annihilation. It decays to $D\bar{D}$ pairs ($D^0\bar{D}^0$ and $D^+D^-$) with a large branching fraction of about (85 ± 6)% [4]. If a $D^0$ meson is fully reconstructed (this is called a singly tagged $D^0$ meson) from this data sample, the $D^0$ meson must exist in the system recoiling against the singly tagged $D^0$ meson. In the system recoiling against the singly tagged $D^0$ mesons, we can select the semileptonic decays $D^0 \rightarrow K^- \mu^+ \nu_\mu$ and $D^0 \rightarrow \pi^- \mu^+ \nu_\mu$ based on the kinematic signature of the singly tagged $D^0$ event, and measure branching fractions for these decays directly.

A. Event selection

In order to ensure the well-measured 3-momentum vectors and the reliability of the charged-particle identification, all charged tracks are required to be well reconstructed in the MDC with good helix fits, and to satisfy a geometry cut $|\cos \theta| < 0.85$, where $\theta$ is the polar angle of the charged track. Each track, except for those from $K^0_S$ decays, must originate from the interaction region, which is defined by $V_{xy} < 2.0$ cm and $|V_z| < 20.0$ cm, where $V_{xy}$ and $|V_z|$ are the closest approach of the charged track in the $xy$-plane and $z$ direction.

Muons, pions and kaons are identified using the $dE/dx$ and TOF measurements, with which the combined confidence levels ($CL_{\mu}$, $CL_{\pi}$, or $CL_K$) for a muon, a pion or a kaon hypotheses are calculated. A pion candidate is required to have $CL_{\pi} > 0.001$. In order to reduce misidentification, a kaon candidate is required to satisfy $CL_K > CL_{\pi}$. A muon candidate is required to have $CL_{\mu} > 0.001$ and satisfy the relation $CL_{\mu} / (CL_{\mu} + CL_{\pi} + CL_K) > 0.8$.

Neutral kaons are reconstructed through the decay $K^0_S \rightarrow \pi^+\pi^-$. We require that the $\pi^+$ and the $\pi^-$ must originate from a secondary vertex which is displaced from the event vertex by 4 mm. Moreover, the difference between the $\pi^+\pi^-$ invariant mass and the $K^0_S$ nominal mass should be less than 20 MeV/$c^2$.

Neutral pions are reconstructed through the decay $\pi^0 \rightarrow \gamma\gamma$. A good photon candidate must satisfy the following criteria: (1) the energy deposited in the BSC is greater than 70 MeV; (2) the electromagnetic shower starts in the first 5 readout layers; (3) the angle between the photon and the nearest charged track is greater than
The opening angle between the direction of the cluster development and the direction of the photon emission is less than 37°.

B. Singly tagged $D^0$ sample

The singly tagged $D^0$ sample used in this analysis was selected in the previous work [3, 5]. The singly tagged $D^0$ mesons are reconstructed in four hadronic decay modes of $K^+\pi^-$, $K^+\pi^-\pi^+$, $K^0\pi^+\pi^-$ and $K^+\pi^-\pi^0$. The total number of the singly tagged $D^0$ mesons is 7584±198±341 [3, 5], where the first error is statistical and the second systematic.

C. Candidates for $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$

Candidates for the semileptonic decays $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$ are selected from surviving tracks in the system recoiling against the singly tagged $D^0$. It is required that there are only two oppositely charged tracks, one of which is identified as muon and the other as kaon or pion. Muon should have its charge opposite to the charm of the singly tagged $D^0$ meson, except for the mode $K^0\pi^+\pi^-$. In addition, it is required that there should be no isolated photon, which has not been used in the reconstruction of the singly tagged $D^0$. The isolated photon should have its energy deposited in the BSC greater than 100 MeV [1, 3, 5, 7] and satisfy the photon selection criteria described earlier.

In order to obtain the information about the missing neutrino, a kinematic quantity $U_{\text{miss}} \equiv E_{\text{miss}} - p_{\text{miss}}$ is defined, following the previous BES works [1, 3, 5, 7], where $E_{\text{miss}}$ and $p_{\text{miss}}$ are the total energy and momentum of all the missing particles. Figures 1a and b show the distributions of the $U_{\text{miss}}$ for the Monte Carlo events of $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$. The values of $\sigma_{U_{\text{miss},1}}$ are ~50 MeV for $D^0 \to K^-\mu^+\nu_\mu$ versus $D^0 \to K^+\pi^-\pi^0$, and ~40 MeV for $D^0 \to K^-\pi^+\pi^-\nu_\mu$ versus the other singly tagged $D^0$ modes. To select the candidates for $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$, it is required that each event should have its $|U_{\text{miss},1}| < 2\sigma_{U_{\text{miss},1}}$. Here, $\sigma_{U_{\text{miss},1}}$ is the standard deviation of the $U_{\text{miss},1}$ distribution, obtained by analyzing the Monte Carlo events of $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$ versus the ith singly tagged $D^0$ mode. Because kaon can be misidentified as pion, the Cabibbo favored decay $D^0 \to K^-\mu^+\nu_\mu$ can satisfy the selection criteria for the Cabibbo suppressed decay $D^0 \to \pi^-\mu^+\nu_\mu$. In the selection of $D^0 \to \pi^-\mu^+\nu_\mu$, these background events are suppressed by requiring that $|U_{\text{miss}}| < |U_{\pi^-\mu^+\nu_\mu}|$, where $U_{\pi^-\mu^+\nu_\mu}$ is calculated by replacing pion mass with kaon mass. Figure 1c shows the distribution of the $U_{\text{miss}}$ calculated by replacing kaon mass by pion mass for the Monte Carlo events of $D^0 \to K^-\mu^+\nu_\mu$, while Fig. 1d shows the distribution of the $U_{\text{miss}}$ calculated by replacing pion mass by kaon mass for the Monte Carlo events of $D^0 \to \pi^-\mu^+\nu_\mu$. The quantity $U_{\text{miss}}$ is expected to be closer to zero for the correct particle assignment.

There are possible hadronic backgrounds for the semileptonic decays due to misidentifying a pion as a muon and due to missing $\pi^0$s. For example, the hadronic decays $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^0\pi^0$ can be misidentified as the semileptonic decay $D^0 \to K^-\mu^+\nu_\mu$. Figure 2a shows the distribution of the invariant masses of $K^-\mu^+$ combinations from the candidates for $D^0 \to K^-\mu^+\nu_\mu$ which satisfy the selection criteria as mentioned above. In the figure the point with errors shows the events from the data and the hatched histogram represents the expected backgrounds which are misidentified from other $D^0$ decay modes as $D^0 \to K^-\pi^+\nu_\mu$. This background shape is estimated by analyzing the Monte Carlo events for $e^+e^- \to DD$, where the $D$ and $\bar{D}$ are set to decay into all possible channels with the branching fractions quoted from PDG [8]. To examine the mass spectrum of the $K^-\mu^+$ combinations from the decay $D^0 \to K^-\mu^+\nu_\mu$, we subtract the expected background shape from the mass spectrum of the $K^-\mu^+$ combinations from the candidates for $D^0 \to K^-\mu^+\nu_\mu$ selected from the data. In Fig. 2b, the point with errors shows the resulting spectrum of the $K^-\mu^+$ combinations and the histogram shows the mass spectrum of the $K^-\mu^+$ combinations from the Monte Carlo events of $D^0 \to K^-\mu^+\nu_\mu$. The mass spectra of $K^-\mu^+$ combinations from both the data and the Monte Carlo events matching well indicates that we can correctly count the number of the signal.
events for the decay $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$ from the data after subtracting the number of the background events from other decay modes of the $D^0$ mesons. Monte Carlo study shows that the dominant background events are from the hadronic decays $D^0 \rightarrow K^{-}\pi^{+}$ and $D^0 \rightarrow K^{-}\pi^{+}\pi^{0}$. To effectively remove these background events, we require that the invariant masses of the $K^{-}\mu^{+}$ combinations from the selected candidates to be less than 1.60 GeV/$c^2$. Similarly, in the selection of $D^0 \rightarrow \pi^{-}\mu^{+}\nu_{\mu}$, the invariant masses of the $\pi^{-}\mu^{+}$ combinations are also required to be less than 1.60 GeV/$c^2$.

For further check the selected candidates for the decay $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$, we examine the distributions of the quantity $U_{\text{miss}}$. We open the criterion $|U_{\text{miss,i}}| < 2\sigma U_{\text{miss,i}}$ in the criteria for selection of the events for the decay $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$. Figure 4 shows the distribution of the $U_{\text{miss}}$ calculated for the candidates for $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$ versus the singly tagged $D^0$ mesons selected from the data (point with errors), and from other decay modes of the Monte Carlo events (the hatched histogram) for $e^{+}e^{-}\rightarrow D\bar{D}$. Subtracting the background (hatched histogram) from the distribution of the $U_{\text{miss}}$ of the candidates for $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$ selected from the data yields the expected distribution of the $U_{\text{miss}}$ for the decay $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$ (point with errors) as shown in Fig. 4a. In Fig. 4b, the histogram shows the distribution of the $U_{\text{miss}}$ calculated for the Monte Carlo events of $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$ versus the singly tagged $D^0$.

Figures 5 and 6 show, respectively, the distributions of the invariant masses of the $Kn\pi$ (i.e. $K^{+}\pi^{-}$ or $K^{+}\pi^{+}\pi^{-}$ or $K^{0}\pi^{+}\pi^{-}$ or $K^{+}\pi^{+}\pi^{-}$) combinations from the events in which the candidates for $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$ and $D^0 \rightarrow \pi^{-}\mu^{+}\nu_{\mu}$ are observed in the system recoiling against the $D^0$ tags. Fitting to the mass spectra as shown in Fig. 5 with a Gaussian function for the $D^0$ signal and a special background function \[ \text{Fig. 2} \] to describe background yields $152.5 \pm 13.6$ candidates for $D^0 \rightarrow K^{-}\mu^{+}\nu_{\mu}$. In Fig. 6 there are 45 events in the $\pm 3\sigma_{M_{D_{s}}}$ mass window.
around the fitted $\bar{D}^0$ meson mass $M_{D_s}$, and 74 events in the outside of the signal regions, where $\sigma_{M_{D_s}}$ is the standard deviation of the distribution of the $K\pi\nu$ combinations for the $i$th mode. By assuming that the background distribution is flat except the one described in subsection IIID, 25.8 ± 3.1 background events are estimated in the signal regions. Subtracting the number of background events, we obtain 19.2 ± 7.4 candidates for $D^0 \to \pi^- \mu^+ \nu_\mu$.

D. Background subtraction

The events from other hadronic or semileptonic decays may also satisfy the selection criteria for the semileptonic decays and are misidentified as the $D^0 \to K^- \mu^+ \nu_\mu$ and $D^0 \to \pi^- \mu^+ \nu_\mu$ decay events. The peak-like background due to these misidentified events can not be illustrated by the background shape as mentioned earlier. The numbers of these background events have to be subtracted by the background shape as mentioned earlier. The numbers of the backgrounds are estimated by analyzing a Monte Carlo sample which is about fourteen times larger than the data. The Monte Carlo events are generated as $e^+e^- \to DD$, where the $D$ and $\bar{D}$ mesons are set to decay into all possible final states with the branching fractions quoted from PDG [8] excluding the two decay modes under study. The numbers of the events satisfying the selection criteria are then normalized to the corresponding data set. Monte Carlo study shows that the dominant background for $D^0 \to K^- \mu^+ \nu_\mu$ is from the hadronic decay $D^0 \to K^- \pi^+ \pi^0$, and the main backgrounds for $D^0 \to \pi^- \mu^+ \nu_\mu$ are from $D^0 \to \pi^+ \pi^0$, $D^0 \to K^- \pi^+ \pi^0$, $D^0 \to K^- \pi^+$, $D^0 \to K^0 \pi^+ \pi^-$ and $D^0 \to K^- \mu^+ \nu_\mu$. Totally 65.3 ± 2.5 and 9.9 ± 1.2 background events are obtained for $D^0 \to K^- \mu^+ \nu_\mu$ and $D^0 \to \pi^- \mu^+ \nu_\mu$, respectively. After subtracting these numbers of background events, 87.2 ± 13.6 and 9.3 ± 7.4 signal events for $D^0 \to K^- \mu^+ \nu_\mu$ and $D^0 \to \pi^- \mu^+ \nu_\mu$ decays are retained, respectively.

FIG. 4: The distributions of the $U_{\text{miss}}$ of the candidates for $D^0 \to K^- \mu^+ \nu_\mu$, (a) the point with errors show the events selected from the data, while the hatched histogram represents the expected background from $DD$ Monte Carlo events; and (b) comparison of the data (point with errors) after subtracting the background and the Monte Carlo events of $D^0 \to K^- \mu^+ \nu_\mu$ (histogram).

FIG. 5: The distributions of the fitted $K\pi\nu$ invariant masses for the events, selected from the data, in which the candidates for $D^0 \to K^- \mu^+ \nu_\mu$ are observed in the system recoiling against the singly tagged $D^0$ in decay modes of (a) $K^+ \pi^-$, (b) $K^+ \pi^- \pi^+$, (c) $K^0 \pi^+ \pi^-$ and (d) $K^+ \pi^- \pi^0$.

FIG. 6: The distribution of the fitted $K\pi\nu$ invariant masses for the events, selected from the data, in which the candidates for $D^0 \to \pi^- \mu^+ \nu_\mu$ are observed in the system recoiling against the singly tagged $D^0$. 

Events/(0.002 GeV/²)

Invariant Mass(GeV/²)

Events/(0.002 GeV/²)

Invariant Mass(GeV/²)
IV. RESULTS

The measured branching fractions for the semileptonic decays are obtained by dividing the observed numbers of the semileptonic decay events $N[D^0 \to K^-(\pi^-)\mu^+\nu_\mu]$ by the number $N_{tag}$ of the singly tagged $D^0$ mesons and the reconstruction efficiencies $\epsilon_{K^-(\pi^-)\mu^+\nu_\mu}$,

$$BF(D^0 \to K^-(\pi^-)\mu^+\nu_\mu) = \frac{N[D^0 \to K^-(\pi^-)\mu^+\nu_\mu]}{\epsilon_{K^-(\pi^-)\mu^+\nu_\mu} N_{tag}}.$$  \hspace{1cm} (1)

The efficiencies for reconstruction of the semileptonic decay events of $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$ are estimated by Monte Carlo simulation. A detail Monte Carlo study gives that the efficiencies are $\epsilon_{K^-\mu^+\nu_\mu} = (32.39 \pm 0.24)\%$ and $\epsilon_{\pi^-\mu^+\nu_\mu} = (32.04 \pm 0.25)\%$. Inserting these numbers in (1), we obtain the branching fractions for the semileptonic decays

$$BF(D^0 \to K^-\mu^+\nu_\mu) = (3.55 \pm 0.56 \pm 0.59)\%$$

and

$$BF(D^0 \to \pi^-\mu^+\nu_\mu) = (0.38 \pm 0.30 \pm 0.10)\%,$$

where the first error is statistical and the second systematic. In the measurements of the branching fractions, the systematic error arises mainly from the uncertainties in tracking efficiency ($\sim 2.0\%$ per track), in particle identification ($\sim 0.5\%$ per charged kaon or pion, $\sim 1.5\%$ per muon), in photon selection ($\sim 2.0\%$), in $U_{miss}$ selection ($\sim 0.6\%$ for $D^0 \to K^-\mu^+\nu_\mu$ and $\sim 1.2\%$ for $\pi^-\mu^+\nu_\mu$), in the number of the singly tagged $D^0$ mesons ($\sim 1.5\%$), in Monte Carlo statistics ($\sim 0.7\%$ for $D^0 \to K^-\mu^+\nu_\mu$ and $\sim 0.8\%$ for $D^0 \to \pi^-\mu^+\nu_\mu$), in background fluctuation ($\sim 2.9\%$ for $D^0 \to K^-\mu^+\nu_\mu$, $\sim 12.9\%$ for $D^0 \to \pi^-\mu^+\nu_\mu$) and in background estimation ($\sim 15.0\%$ for $D^0 \to K^-\mu^+\nu_\mu$, $\sim 21.3\%$ for $D^0 \to \pi^-\mu^+\nu_\mu$) due to unknown branching fractions of some background channels. Adding these uncertainties in quadrature yields the total systematic errors of $\sim 16.7\%$ for $D^0 \to K^-\mu^+\nu_\mu$ and $\sim 25.8\%$ for $D^0 \to \pi^-\mu^+\nu_\mu$.

Table I gives a comparison of the measured branching fractions for $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$ by the BES Collaboration in this work, along with those measured by other Collaborations [10, 11, 12, 13]. For the measurements from other experiments, the branching fraction for $D^0 \to K^-\mu^+\nu_\mu$ (or $D^0 \to \pi^-\mu^+\nu_\mu$) was measured relative to the decay $D^0 \to K^-\pi^+$ or $D^0 \to \mu^+X$ (or $D^0 \to K^-\mu^+\nu_\mu$). The branching fraction for $D^0 \to K^-\mu^+\nu_\mu$ (or $D^0 \to \pi^-\mu^+\nu_\mu$) is calculated by multiplying the measured ratio $\Gamma(D^0 \to K^-\mu^+\nu_\mu)/\Gamma(D^0 \to K^-\pi^+)$ or $\Gamma(D^0 \to K^-\mu^+\nu_\mu)/\Gamma(D^0 \to K^-\mu^+\nu_\mu)$ (or $\Gamma(D^0 \to \pi^-\mu^+\nu_\mu)/\Gamma(D^0 \to K^-\mu^+\nu_\mu)$) by the branching fraction for $D^0 \to K^-\pi^+$ or $D^0 \to \mu^+X$ (or $D^0 \to K^-\mu^+\nu_\mu$) from PDG [8]. The directly measured branching fractions reported in this paper agree within error with those measured by the CLEO, E687, E653 and FOCUS Collaborations [9, 10, 11, 12, 13].

With the measured branching fractions for $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$, we determine the ratio of the two branching fractions

$$\frac{BF(D^0 \to \pi^-\mu^+\nu_\mu)}{BF(D^0 \to K^-\mu^+\nu_\mu)} = 0.11 \pm 0.09 \pm 0.03,$$  \hspace{1cm} (2)

where the first error is statistical and the second systematic, which arises mainly from the uncertainties including $\epsilon_{K^-\mu^+\nu_\mu}$ selection ($\sim 1.3\%$), Monte Carlo statistics ($\sim 1.1\%$), and background subtraction ($\sim 29.1\%$).

Our measured branching fraction for $D^0 \to K^-\mu^+\nu_\mu$ was previously used to determine the ratio of the partial widths $\Gamma(D^0 \to K^-\mu^+\nu_\mu)/\Gamma(D^0 \to K^-\mu^+\nu_\mu) = 0.87 \pm 0.24 \pm 0.15$ [2]. Combining the ratio with the one obtained by analyzing the semielectronic modes yields the ratio $\Gamma(D^0 \to K^-\ell^+\nu_\ell)/\Gamma(D^+ \to K^0\ell^+\nu_\ell) = 1.00 \pm 0.17 \pm 0.06$ [2], which is in good agreement with $\Gamma(D^0 \to K^-\ell^+\nu_\ell)/\Gamma(D^+ \to K^0\ell^+\nu_\ell) = 1$ predicted by the isospin symmetry in the exclusive semileptonic decays of the charged and neutral $D$ mesons.

V. SUMMARY

In summary, using the data sample of about 33 pb$^{-1}$ collected at and around 3.773 GeV with the BES-II detector at the BEPC collider, the absolute branching fractions for the decays $D^0 \to K^-\mu^+\nu_\mu$ and $D^0 \to \pi^-\mu^+\nu_\mu$ have been measured. These are $BF(D^0 \to K^-\mu^+\nu_\mu) = (3.55 \pm 0.56 \pm 0.59)\%$ and $BF(D^0 \to \pi^-\mu^+\nu_\mu) = (0.38 \pm 0.30 \pm 0.10)\%$. The ratio of the branching fractions for the two decays is determined to be $BF(D^0 \to \pi^-\mu^+\nu_\mu)/BF(D^0 \to K^-\mu^+\nu_\mu) = 0.11 \pm 0.09 \pm 0.03$. The measured branching fraction for $D^0 \to K^-\mu^+\nu_\mu$ was previously used to determine the ratio $\Gamma(D^0 \to K^-\mu^+\nu_\mu)/\Gamma(D^+ \to K^0\mu^+\nu_\mu)$ combining the previously measured branching fraction for $D^+ \to K^0\mu^+\nu_\mu$ [2] by the BES Collaboration.

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TABLE I: Summary of the measured branching fractions for $D^0 \rightarrow K^- \mu^+ \nu_\mu$ and $D^0 \rightarrow \pi^- \mu^+ \nu_\mu$ from different experiments.

| Collab. | BF($D^0 \rightarrow K^- \mu^+ \nu_\mu$)(%) | BF($D^0 \rightarrow \pi^- \mu^+ \nu_\mu$)(%) |
|---------|----------------------------------------|----------------------------------------|
| BES     | 3.55 $\pm$ 0.56 $\pm$ 0.59             | 0.38 $\pm$ 0.30 $\pm$ 0.10             |
| CLEO[9] | 3.00 $\pm$ 0.30 $\pm$ 0.34 $\pm$ 0.06  |                                         |
| E687[10]| 3.12 $\pm$ 0.49 $\pm$ 0.49 $\pm$ 0.06  |                                         |
| E687[11]| 3.24 $\pm$ 0.13 $\pm$ 0.11 $\pm$ 0.06  |                                         |
| E653[12]| 3.07 $\pm$ 0.33 $\pm$ 0.26 $\pm$ 0.33  |                                         |
| FOCUS[13]| 0.24 $\pm$ 0.03 $\pm$ 0.02 $\pm$ 0.01 |                                         |

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