Direct Measurement of the Branching Fraction for the Decay of $D^+ \to \bar{K}^0 e^+\nu_e$ and Determination of $\Gamma(D^0 \to K^- e^+\nu_e)/\Gamma(D^+ \to \bar{K}^0 e^+\nu_e)$

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The absolute branching fraction for the decay $D^+ \to \bar{K}^0 e^+\nu_e$ is determined using $5321 \pm 149 \pm 160$ singly tagged $D^+$ event sample from the data collected around 3.773 GeV with the BES-II detector at the BEPC collider. In the system recolliding against the singly tagged $D^+$ mesons, $34.4 \pm 6.1$ events for $D^+ \to \bar{K}^0 e^+\nu_e$ are observed. Those yield the absolute branching fraction to be $BF(D^+ \to \bar{K}^0 e^+\nu_e) = (8.95 \pm 1.59 \pm 0.67)\%$. The ratio of the two partial widths for the decays of $D^0 \to K^- e^+\nu_e$ and $D^+ \to \bar{K}^0 e^+\nu_e$ is determined to be $\Gamma(D^0 \to K^- e^+\nu_e)/\Gamma(D^+ \to \bar{K}^0 e^+\nu_e) = 1.08 \pm 0.22 \pm 0.07$.

I. INTRODUCTION

Experimental study of the exclusive semileptonic decays of the charged and neutral $D$ mesons can provide important information on the decay mechanisms. Fig. 1(a) and Fig. 1(b) show the decay diagrams of the $D^0 \to K^- e^+\nu_e$ and the $D^+ \to \bar{K}^0 e^+\nu_e$, respectively. The isospin symmetry predicts that the partial widths of the two decay processes should be equal. However, the
studied the two decay modes of the fractions for the two decay processes and the lifetimes of which is determined based on the measured branching ratios of the two partial widths is

\[ \frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)} = 1.34 \pm 0.20, \]

which is determined based on the measured branching fractions for the two decay processes and the lifetimes of the $D^0$ and $D^+$ quoted from PDG [1]. It deviates by 1.7σ from the expected unit ratio.

To test the isospin symmetry in the exclusive semileptonic decays of the charged and neutral $D$ mesons, we studied the two decay modes of $D^0 \rightarrow K^- e^+ \nu_e$ and $D^+ \rightarrow \bar{K}^0 e^+ \nu_e$ with the same data sample of about 33 $\mathrm{pb}^{-1}$ collected at and around the center-of-mass energy of 3.773 GeV with the BES-II detector at the BEPC collider. In this Letter, we report the direct measurements of the branching fraction for the decay of $D^+ \rightarrow \bar{K}^0 e^+ \nu_e$ (Throughout this Letter, charged conjugation is implied) and the ratio of the two decay widths.

$\sqrt{s} = 3.773$ GeV. An array of 48 scintillation counters surrounding the MDC measures the time of flight (TOF) of charged particles with a resolution of about 180 ps for electrons. Outside the TOF, 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 $\sigma_E/E = 0.22/\sqrt{E}$ (E in GeV) and spatial resolutions of $\sigma_x = 7.9$ mrad and $\sigma_y = 2.3$ cm for electrons. A solenoidal magnet outside the BSC provides input to the event trigger, as well as coincidence measurements of charged particle trajectories with a solid angle coverage of 85% of $4\pi$.

III. DATA ANALYSIS

Around the center of mass energy 3.773 GeV, the $\psi(3770)$ resonance is produced in electron-positron ($e^+e^-$) annihilation. The $\psi(3770)$ decays predominantly into $D\bar{D}$ pairs. If a $D^-$ meson is fully reconstructed (This is called a singly tagged $D^-$ meson), the $D^+$ meson must exist in the system recoiling against the singly tagged $D^-$ meson. Using the singly tagged $D^-$ meson sample, the decay of $D^+ \rightarrow \bar{K}^0 e^+ \nu_e$ can be well selected in the recoiling system. Therefore, the absolute branching fraction for the decay of $D^+ \rightarrow \bar{K}^0 e^+ \nu_e$ can be well measured.

A. Events selection

The $D^-$ meson is reconstructed in non-leptonic decay modes of $K^+ \pi^- \pi^+$, $K^0 \pi^-$, $K^0 K^-$, $K^+ K^- \pi^0$, $K^0 \pi^- \pi^- \pi^+$, $K^0 \pi^- \pi^0$, $K^+ \pi^- \pi^- \pi^0$, $K^+ \pi^- \pi^- \pi^+ \pi^0$, $K^+ \pi^- \pi^- \pi^- \pi^0$, $K^+ \pi^- \pi^- \pi^- \pi^+ \pi^0$ and $\pi^+ \pi^- \pi^- \pi^0$. Events which contain at least three reconstructed charged tracks with good helix fits are selected. In order to ensure well-measured 3-momentum vectors and reliably charged particle identification, the charged tracks used in the single tag analysis are required to be within $|\cos\theta| < 0.85$, where $\theta$ is the polar angle. All tracks, save those from $K_2^0$ decays, must originate from the interaction region, which require that the closest approach of a charged track in the $xy$ plane is less than 2.0 cm and the $z$ position of the charged track is less than 20.0 cm. Pions and kaons are identified by means of TOF and $dE/dx$ measurements. Pion identification requires a consistency with the pion hypothesis at a confidence level ($CL_\pi$) greater than 0.1%. In order to reduce misidentification, a kaon candidate is required to have a larger confidence level ($CL_K$) for a kaon hypothesis than that for a pion hypothesis. For electron identification, the combined confidence level ($CL_e$), calculated for the $e$ hypothesis using the $dE/dx$, TOF and BSC measurements, is required to be greater than 0.1%, and the ratio $CL_e/(CL_\pi + CL_K)$ is required to be greater than 0.05.
0.8. The $\pi^0$ is reconstructed in the decay of $\pi^0 \rightarrow \gamma\gamma$. To select good photons from the decay of $\pi^0$, the energy of a photon deposited in the BSC is required to be greater than $0.07 \text{ GeV}$, and the electromagnetic shower is required to start in the first 5 readout layers. In order to reduce backgrounds, the angle between the photon and the nearest charged track is required to be greater than $22^\circ$, and the angle between the direction of the cluster development and the direction of the photon emission to be less than $37^\circ$.

For the single tag modes of $D^- \rightarrow K^+\pi^+\pi^-\pi^-\pi^-$ and $D^- \rightarrow \pi^+\pi^-\pi^-$, backgrounds are further reduced by requiring the difference between the measured energy of the $D^-$ candidate and the beam energy to be less than 70 and 60 MeV, respectively. In addition, the cosine of the $D^-$ production angle relative to the beam direction is required to be $|\cos \theta_{D^-}| < 0.8$.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{The distributions of the fitted masses of (a) $K^+\pi^-\pi^-$, (b) $K^0\pi^-$, (c) $K^0K^-$, (d) $K^+K^-\pi^-$, (e) $K^0\pi^-\pi^+\pi^-$, (f) $K^0\pi^-\pi^0$, (g) $K^+\pi^-\pi^-\pi^0$, (h) $K^+\pi^-\pi^-\pi^-$, and (i) $\pi^-\pi^+\pi^+$ combinations; (j) is the fitted masses of the $mKn\pi$ combinations for the 9 modes combined together.}
\end{figure}

B. Singly tagged $D^-$ sample

For each event, there may be several different charged track (or charged and neutral track) combinations for each of the nine single tag modes. Each combination is subject to a one-constraint (1C) kinematic fit requiring overall event energy conservation and that the unmeasured recoil system has the same invariant mass as the track combinations. Candidates with a fit probability $P(\chi^2)$ greater than 0.1% are retained. If more than one combination satisfies $P(\chi^2) > 0.1\%$, the combination with the largest fit probability is retained. For the single tag modes with a neutral kaon and/or neutral pion, one additional constraint kinematic fit for the $K_S^0 \rightarrow \pi^+\pi^-$ and/or $\pi^0 \rightarrow \gamma\gamma$ hypothesis is performed, separately.

The resulting distributions in the fitted invariant masses of $mKn\pi$ ($m = 0$ or 1 or 2 and $n = 1$ or 2 or 3 or 4) combinations, which are calculated using the fitted momentum vectors from the kinematic fit, are shown in Fig. 2. The signals for the singly tagged $D^-$ mesons are clearly observed in the fitted mass spectra. A maximum likelihood fit to the mass spectrum with a Gaussian function for the $D^-$ signal and a special background function to describe backgrounds yields the number of the singly tagged $D^-$ events for each of the nine modes and the total number of 5321 $\pm$ 149 $\pm$ 160 reconstructed $D^-$ mesons, where the first error is statistical and the second systematic obtained by varying the parameterization of the background. The curves of Fig. 2 give the best fits to the invariant mass spectra. In the fits to the mass spectra, the standard deviations of the Gaussian signal functions for the Fig. 2(g) and Fig. 2(h) are fixed at 4.27 MeV and 2.16 MeV, respectively. These standard deviations are obtained from Monte Carlo sample. All other parameters are left free in the fit.

C. Candidates of $D^+ \rightarrow \overline{K^0}e^+\nu_e$

Candidate events of the decay $D^+ \rightarrow \overline{K^0}e^+\nu_e$ are selected from the surviving tracks in the system recoiling against the tagged $D^-$. To select the $D^+ \rightarrow \overline{K^0}e^+\nu_e$, it is required that there are three charged tracks, one of which is identified as an electron with charge opposite to the charge of the tagged $D^-$ and the other two as $\pi^+$ and $\pi^-$. The difference between the invariant masses of the $\pi^+\pi^-$ combinations and the mass of $K_S^0$ should be less than 20 MeV/$c^2$. The neutrino is undetected, therefore the kinematic quantity $U_{\text{miss}} \equiv E_{\text{miss}} - p_{\text{miss}}$ is used to obtain the information about the missing neutrino, where $E_{\text{miss}}$ and $p_{\text{miss}}$ are the total energy and the total momentum of all missing particles respectively, which are carried by the undetected particles. The backgrounds from the decays such as $D^+ \rightarrow \overline{K^0}\pi^+\pi^0$ and $D^+ \rightarrow \overline{K^0}\pi^0e^+\nu_e$ are suppressed by rejecting the events with extra isolated photons which are not used in the reconstruction of the singly tagged $D^-$ meson. The isolated
and satisfy photon selection criteria as mentioned earlier. From the distribution, most of the events can be identified as the candidates of \( D^+ \to K^0 e^+\nu_e \) versus the tagged \( D^- \) mesons. Those can be further confirmed as follows. If we select the events which satisfy the signal regions; where the signal regions, while there are 4 events in the outside of and (b) \( D^+ \to K^0 e^+\nu_e \) versus \( D^- \to K^+\pi^-\pi^- \) and \( i = 9 \) is for \( \pi^+\pi^-\pi^- \) modes), and plot the fitted masses of the \( mK\pi \) combinations, we observe a clear signal of \( D^+ \to K^0 e^+\nu_e \) versus the single tag mode(i) (i = 1 is for \( K^+\pi^-\pi^- \); i = 2 is for \( K^0\pi^- \) and \( i = 9 \) is for \( \pi^+\pi^-\pi^- \) modes), and plot the fitted masses of the \( mK\pi \) combinations, we observe a clear signal of \( D^+ \to K^0 e^+\nu_e \) versus the single tag mode(i). By assuming that the background distribution is flat, \( 0.8 \pm 0.4 \) background events are estimated in the signal region. There may also be the \( \pi^+\pi^- \) combinatorial background. By selecting the events in which the invariant masses of the \( \pi^+\pi^- \) combinations in the recoil side of the tags are outside of the \( K_S^0 \) mass window, we estimate that there are \( 0.3 \pm 0.2 \) background events in the candidate events. After subtracting these numbers of background events, 35.9 \pm 6.1 \) candidate events are retained.

The distribution of the momentum of the electrons from the selected candidate events of \( D^+ \to K^0 e^+\nu_e \) is shown in Fig. 4, where the error bars are for the events from the data and the histogram is for the events of \( D^+ \to K^0 e^+\nu_e \) from Monte Carlo sample. The measured electron momentum is in good agreement with the electron momentum from the Monte Carlo events of \( D^+ \to K^0 e^+\nu_e \).

**D. Background Subtraction**

There are still some background contaminations in the observed candidate events due to other semileptonic or hadronic decays. These background events must be subtracted from the candidate events. The numbers of background events are estimated by analyzing the Monte Carlo events of \( D^+ \to K^0 e^+\nu_e \).
Carlo sample which is 13 times larger than the data. The
Monte Carlo events are generated as \( e^+e^- \rightarrow D\bar{D} \)
and the \( D \) and \( \bar{D} \) mesons are set to decay to all possible final
states according to the decay modes and branching frac-
tions quoted from PDG \[1\] excluding the decay mode un-
der study. The number of events satisfying the selection
criteria is then renormalized to the corresponding data
set. Totally 1.5 \( \pm \) 0.4 background events are obtained for
\( D^+ \rightarrow K^0 e^+\nu_e \). After subtracting the number of back-
ground events, 34 \( \pm \) 6.1 signal events for \( D^+ \rightarrow K^0 e^+\nu_e \)
decay are retained.

![Momentum of electron (GeV/c)](image)

**FIG. 6:** The distribution of the momentum of the electrons
from the selected candidate events of \( D^+ \rightarrow K^0 e^+\nu_e \),
where the error bars are for the events from the data and the
histogram is for the events of \( D^+ \rightarrow K^0 e^+\nu_e \) from the Monte
Carlo sample.

### IV. RESULTS

#### A. Monte Carlo Efficiency

The efficiency for reconstruction of the semileptonic
decay events of \( D^+ \rightarrow K^0 e^+\nu_e \) is estimated by Monte
Carlo simulation. A detailed Monte Carlo study gives
the efficiency to be \( \epsilon_{K^0 e^+\nu_e} = (7.22 \pm 0.06)\% \),
where the error is statistical.

#### B. Branching Fraction

The measured branching fraction is obtained by di-
viding the observed number of the semileptonic decay
events \( N(D^+ \rightarrow K^0 e^+\nu_e) \) by the number of the singly
tagged \( D^- \) mesons \( N_{D^-} \) and the reconstruction effici-
cy \( \epsilon_{K^0 e^+\nu_e} \),

\[
Br(D^+ \rightarrow K^0 e^+\nu_e) = \frac{N(D^+ \rightarrow K^0 e^+\nu_e)}{\epsilon_{K^0 e^+\nu_e} \times N_{D^-}}.
\]

Inserting these numbers into the equation (1), the
branching fraction for \( D^+ \rightarrow K^0 e^+\nu_e \) decay is obtained to be

\[
BF(D^+ \rightarrow K^0 e^+\nu_e) = (8.95 \pm 1.59 \pm 0.67)\%,
\]

where the first error is statistical and the second system-
atic. The systematic uncertainty in the measured branch-
ing fraction arises from the particle identification (1.5%),
tracking efficiency (2\% per track), photon reconstruc-
tion (2.0%), \( U_{miss} \) selection (0.6%), the number of the
singly tagged \( D^- \) mesons (3.0%), background subtraction (1.6%),
Monte Carlo statistics (0.7\%) and \( K_S^0 \) selection (1.1%).
These uncertainties are added in quadrature to obtain the
total systematic error, which is 7.5%.

Table I gives the comparison of our measured value of
the branching fraction for the decay of \( D^+ \rightarrow K^0 e^+\nu_e \)
with that measured by MARK-III \[2\]. Our measured
branching fraction is consistent within the error with that
measured by MARK-III.

| Branching fraction [%] | Branching fraction [%] |
|------------------------|------------------------|
| (This experiment)       | (MARK-III)             |
| 8.95 \( \pm \) 1.59 \( \pm \) 0.67 | 6.0\% \( \pm \) 0.7\% |

**TABLE I:** Comparison of our measured branching fraction for
the decay of \( D^+ \rightarrow K^0 e^+\nu_e \) with that measured by MARK-
III.

#### C. The ratio of \( \Gamma(D^0 \rightarrow K^- e^+\nu_e)/\Gamma(D^+ \rightarrow K^0 e^+\nu_e) \)

With the same data sample, BES-II measured the ab-
olute branching fraction for \( D^0 \rightarrow K^- e^+\nu_e \) decay to be

\[
BF(D^0 \rightarrow K^- e^+\nu_e) = (3.82 \pm 0.40 \pm 0.27)\% \[2\].
\]

Using the measured branching fractions for the decays of
\( D^0 \rightarrow K^- e^+\nu_e \) and \( D^+ \rightarrow K^0 e^+\nu_e \) and the lifetimes of
the \( D^0 \) and \( D^+ \) quoted from the PDG \[1\], the ratio of the
decay widths is obtained to be

\[
\frac{\Gamma(D^0 \rightarrow K^- e^+\nu_e)}{\Gamma(D^+ \rightarrow K^0 e^+\nu_e)} = 1.08 \pm 0.22 \pm 0.07,
\]

where the first error is statistical and the second system-
atic which arises from some uncanceled systematic uncer-
tainty (6.8\%) in the measured ratio of the branching frac-
tions for the two decay modes and the uncertainty (0.8\%)
in the measured ratio of the \( D^0 \) and \( D^+ \) lifetimes \[1\].

### V. SUMMARY

In summary, by analyzing the data sample of about 33 pb\(^{-1}\) collected at and around 3.773 GeV with the

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\[1\] PDG

\[2\] MARK-III

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BES-II detector at the BEPC collider, the branching fraction for the decay of $D^+ \rightarrow K^0 e^+ \nu_e$ has been measured. From a total of $5321 \pm 149 \pm 160$ singly tagged $D^-$ event sample, $34.4 \pm 6.1 \ D^+ \rightarrow K^0 e^+ \nu_e$ signal events are observed in the system recoiling against the singly tagged $D^-$ mesons. Those yield the decay branching fraction to be $BF(D^+ \rightarrow K^0 e^+ \nu_e) = (8.95 \pm 1.59 \pm 0.67)^\%$. Using the values of the measured branching fractions for the decays of $D^0 \rightarrow K^- e^+ \nu_e$ and $D^+ \rightarrow K^0 e^+ \nu_e$, the ratio of the two partial decay widths is determined to be
\[
\frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow K^0 e^+ \nu_e)} = 1.08 \pm 0.22 \pm 0.07,
\]
which is consistent within the errors with the theoretical prediction of the spectator model and supports that isospin conservation holds in the exclusive semileptonic decays of the $D^+ \rightarrow K^0 e^+ \nu_e$ and the $D^0 \rightarrow K^- e^+ \nu_e$.

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\[
(1.0 + p_1 y + p_2 y^2) N \sqrt{1 - \left(\frac{x}{E_b}\right)^2} e^{-f(1 - \frac{x}{E_b})^2} + c,
\]
where $N \sqrt{1 - \left(\frac{x}{E_b}\right)^2} e^{-f(1 - \frac{x}{E_b})^2}$ is the ARGUS background shape, $x$ is the fitted mass, $E_b$ is the beam energy, $y = (E_b - x)/(E_b - 1.8)$, $N$, $f$, $p_1$, $p_2$ and $c$ are the fit parameters. The parameter $c$ accounts for the varying of the beam energy. The ARGUS background shape was used by the ARGUS experiment to parameterize the background for fitting $B$ mass peaks. For details, see [4].