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Paper Draft*
(BES Collaboration)

*This Paper draft is only for the use of BES Collaborators for the sole purpose of reviewing the analysis described in preparation for submission to Physical Letters B. Please send your comments to Rong Gang (rongg@bepc5.ihep.ac.cn) and Xinchou Lou (xinchou@utdallas.edu).

Measurement of Inclusive ϕ Decay Branching Fractions of the D^0 and D^+ Mesons and a Search for $D^+ \to \phi e^+ \nu$

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Using a data sample of 22.3 pb^{-1} collected at a center-of-mass energy of 4.03 GeV with the BES detector at the BEPC e^+e^- storage ring, we have measured the inclusive ϕ decay branching fractions of neutral and charged D mesons. Based on 10 $D^{+(0)} \to \phi X$ events, where X can be any unidentified particles, observed from $9054 \pm 313 \pm 88$ tagged D mesons, we obtain the inclusive ϕ decay branching fractions of $B(D^0 \to \phi X) = (1.17 \pm 0.79 \pm 0.10)\%$ and $B(D^+ \to \phi X) = (1.85 \pm 1.90 \pm 0.14)\%$. For a mixture of $(75 \pm 5)\%$ D^0 and $(25 \pm 3)\%$ D^+, an average inclusive ϕ decay branching fraction $B(D \to \phi X) = (1.29 \pm 0.51 \pm 0.10)\%$ is obtained. We have also searched for the decay $D^+ \to \phi e^+ \nu$, and place a 90% C.L. upper limit of $B(D^+ \to \phi e^+ \nu) < 1.6\%$ based on nonobservation.

I. INTRODUCTION

Much progress has been made in heavy flavor physics since the discoveries of open charm and bottom[1]. However, the experimental results on inclusive decays of charm mesons are limited[2,3]. In an era of high precision experiments such as B factories and LHC, accurate measurements of b-flavored particles can benefit from a better knowledge on charm decays and their branching fractions. In particular the inclusive decay $\mathrm{D} \to \phi \mathrm{X}^*$ has not been measured. These branching fractions can serve as an independent check on existing exclusive decays of D mesons that contain a ϕ meson, and are important for studies of gluonic penguin ($b \to sg$) decays of B mesons[3], as well as time-dependent $\mathrm{B_s^0}\overline{\mathrm{B_s^0}}$ oscillation measurements[4] that use the $\phi\ell$ pair to tag the $\mathrm{B_s^0}$ meson. In addition, these branching fractions would be helpful in understanding the charm meson decay machanisms.

In this letter we report on a first measurement of inclusive ϕ decay branching fractions of the charged and neutral D mesons and a new search for the exclusive semileptonic decay $\mathrm{D}^+ \to \phi \mathrm{e}^+ \bar{\nu}$ based on an analysis of the data collected with the Beijing Spectrometer (BES) in $\mathrm{e^+e^-}$ annihilations at $\sqrt{s} = 4.03$ GeV.

II. THE BEIJING SPECTROMETER AND DATA SAMPLE

The BES detector has been described in detail elsewhere[5]. Here we briefly describe detector elements crucial to this measurement.

BES is a conventional cylindrical magnetic detector operated at the Beijing Electron Positron Collider (BEPC)[6]. A four-layer central drift chamber (CDC) surrounding the beam pipe provides an event trigger. A forty-layer main drift chamber (MDC) located just outside the CDC provides measurements of charged tracks and ionization energy loss ($\mathrm{d}E/\mathrm{d}x$) with a solid angle coverage of 80% of 4π for charged tracks. Momentum resolution of $1.7\%\sqrt{1+p^2}$ (p in GeV/c) and $\mathrm{d}E/\mathrm{d}x$ resolution of 8.5% for Bhabha electrons are obtained for the data taken at $\sqrt{s} = 4.03$ GeV. An array of 48 scintillation counters surrounds the MDC and measures the time of flight (TOF) of charged tracks with a resolution of about 350 ps for Bhabha electrons. Surrounding the TOF is a 12-radiation-length, lead-gas barrel shower counter (BSC) operated in limited streamer mode, that measures the energy 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 resolution of $\sigma_\phi = 4.5$ mrad and $\sigma_Z = 2$ cm for the electrons. Outside the BSC is a solenoidal magnet providing a 0.4 T magnetic field for the central tracking region of the detector. Three double-layer muon counters instrument the magnet flux return, and serve to identify muons of momentum greater than 500 MeV/c. They cover 68% of the total solid angle with longitudinal (transverse) spatial resolution of 5 cm (3 cm). End-cap time-of-flight and shower counters extend coverage to the forward and backward regions.

This analysis is based on an integrated luminosity of 22.3 pb^{-1} data collected in $\mathrm{e^+e^-}$ annihilations at $\sqrt{s} = 4.03$ GeV at the BEPC during the years 1992-1994.

III. METHOD

At $\sqrt{s}$=4.03 GeV charm mesons D^0 and D^+ are produced via

$$\begin{aligned}\mathrm{e^+e^-} \to\ & \mathrm{D^+D^-}, \mathrm{D^0}\overline{\mathrm{D^0}}, \\ & \mathrm{D^+D^{*-}}, \mathrm{D^{*+}D^-}, \mathrm{D^0}\overline{\mathrm{D^{*0}}} \\ & \mathrm{D^{*+}D^{*-}}, \mathrm{D^{*0}}\overline{\mathrm{D^{*0}}}\end{aligned}$$

followed by the cascade decay of the D^* mesons. However, the D^{*-} can decay either to $\pi^-\overline{\mathrm{D^0}}$ or $\pi^0(\gamma)\mathrm{D}^-$, such that in these events the type of the D meson recoiling against a fully reconstructed $\overline{\mathrm{D}}$ can be neutral or charged. In order to measure separately $B(\mathrm{D}^0 \to \phi\mathrm{X})$, and $B(\mathrm{D}^+ \to \phi\mathrm{X})$, the exact numbers of recoiling neutral and charged D mesons, as well as the type of the D meson from which the ϕ mesons come, must be determined. To this end we have developed two independent methods. In this paper we used both of these two methods to measure the inclusive branching fractions of the D mesons.

A. The D^0 and D^+ combinative double tag method (CDTM)

To measure inclusive particle P decay branching fractions of the D^0 and D^+, particle P is searched for and the numbers ($\mathrm{N}^{\mathrm{P}}_{\mathrm{D}^0_{\mathrm{tag}}}$ and $\mathrm{N}^{\mathrm{P}}_{\mathrm{D}^+_{\mathrm{tag}}}$) of the particle P are counted that appear in the recoil side against the tagged D^0 and D^+,respectively. The $\mathrm{N}^{\mathrm{P}}_{\mathrm{D}^0_{\mathrm{tag}}}$ is related to $\mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^0_{\mathrm{tag}}}$ and $\mathrm{N}^{\overline{\mathrm{D^0}}}_{\mathrm{D}^0_{\mathrm{tag}}}$, which respectively are numbers of D^- and $\overline{\mathrm{D^0}}$ produced in the system recoiling against the tagged D^0 sample, by

$$\mathrm{N}^{\mathrm{P}}_{\mathrm{D}^0_{\mathrm{tag}}} = \epsilon_1 \mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^0_{\mathrm{tag}}} B(\mathrm{D}^- \to \mathrm{PX}) + \epsilon_2 \mathrm{N}^{\overline{\mathrm{D^0}}}_{\mathrm{D}^0_{\mathrm{tag}}} B(\overline{\mathrm{D^0}} \to \mathrm{PX}), \quad (1)$$

where ϵ_1 and ϵ_2 are detection efficiencies for the particle P, $B(\mathrm{D}^- \to \mathrm{P\ X})$ and $B(\overline{\mathrm{D^0}} \to \mathrm{PX})$ are decay branching fractions to be measured. Similarly, for D^+ tags one has

$$\mathrm{N}^{\mathrm{P}}_{\mathrm{D}^+_{\mathrm{tag}}} = \epsilon_1 \mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^+_{\mathrm{tag}}} B(\mathrm{D}^- \to \mathrm{PX}) + \epsilon_2 \mathrm{N}^{\overline{\mathrm{D^0}}}_{\mathrm{D}^+_{\mathrm{tag}}} B(\overline{\mathrm{D^0}} \to \mathrm{PX}), \quad (2)$$

the $\mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^+_{\mathrm{tag}}}$ and $\mathrm{N}^{\overline{\mathrm{D^0}}}_{\mathrm{D}^+_{\mathrm{tag}}}$ are the numbers of D^- and $\overline{\mathrm{D^0}}$ produced in the system recoiling against the tagged D^+. A Monte Carlo study shows that the detection efficiencies

*Throughout this letter, charge conjugation is implied.

ϵ_1 and ϵ_2 are the same within 5%, which allow us to take the $\epsilon \approx \epsilon_1 \approx \epsilon_2$. The effect of difference between the ϵ_1 and ϵ_2 on the branching farctions will be considered in the systematic uncertainties in values of the measured branching fractions. By using the numbers ($\mathrm{N}_{\mathrm{D}^0_{\mathrm{tag}}}$ and $\mathrm{N}_{\mathrm{D}^+_{\mathrm{tag}}}$) of the D^0 and D^+ single tags, the numbers of the $\overline{\mathrm{D}^0}$ and D^- produced in the side recoiling against the single tags can be calculated from

$$\mathrm{N}^{\overline{\mathrm{D}^0}}_{\mathrm{D}^0_{\mathrm{tag}}} = (1-\eta)\mathrm{N}_{\mathrm{D}^0_{\mathrm{tag}}} \tag{3}$$

$$\mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^0_{\mathrm{tag}}} = \eta\mathrm{N}_{\mathrm{D}^0_{\mathrm{tag}}} \tag{4}$$

$$\mathrm{N}^{\overline{\mathrm{D}^0}}_{\mathrm{D}^+_{\mathrm{tag}}} = \beta\mathrm{N}_{\mathrm{D}^+_{\mathrm{tag}}} \tag{5}$$

$$\mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^+_{\mathrm{tag}}} = (1-\beta)\mathrm{N}_{\mathrm{D}^+_{\mathrm{tag}}} \tag{6}$$

where the η and β are the probabilities of D^- and $\overline{\mathrm{D}^0}$ appeared in the side recoiling against the tagged D^0 and D^+, respectively. By using the values of $\mathrm{D}^*\mathrm{D}^*$ and $\mathrm{D}^*\mathrm{D}$ production cross section measured by the BES experiment[5], the probabilities are found to be $\eta = 0.1768 \pm 0.0175$ and $\beta = 0.5460 \pm 0.0622$.

Combining the equations (1) and (2) by inserting the $\mathrm{N}^{\overline{\mathrm{D}^0}}_{\mathrm{D}^0_{\mathrm{tag}}}$, $\mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^0_{\mathrm{tag}}}$, $\mathrm{N}^{\overline{\mathrm{D}^0}}_{\mathrm{D}^+_{\mathrm{tag}}}$, and $\mathrm{N}^{\mathrm{D}^-}_{\mathrm{D}^+_{\mathrm{tag}}}$ from equations (3), (4), (5) and (6) into them, the inclusive particle 'P' decay branching fractions of $\overline{\mathrm{D}^0}$ and D^- are given by

$$B(\overline{\mathrm{D}^0} \to \mathrm{PX}) = \frac{1}{\epsilon(1-\beta-\eta)}((1-\beta)\frac{\mathrm{N}^{\mathrm{PX}}_{\mathrm{D}^0_{\mathrm{tag}}}}{\mathrm{N}_{\mathrm{D}^0_{\mathrm{tag}}}} - \eta\frac{\mathrm{N}^{\mathrm{PX}}_{\mathrm{D}^+_{\mathrm{tag}}}}{\mathrm{N}_{\mathrm{D}^+_{\mathrm{tag}}}}) \tag{7}$$

and

$$B(\mathrm{D}^- \to \mathrm{PX}) = \frac{1}{\epsilon(1-\beta-\eta)}((1-\eta)\frac{\mathrm{N}^{\mathrm{PX}}_{\mathrm{D}^+_{\mathrm{tag}}}}{\mathrm{N}_{\mathrm{D}^+_{\mathrm{tag}}}} - \beta\frac{\mathrm{N}^{\mathrm{PX}}_{\mathrm{D}^0_{\mathrm{tag}}}}{\mathrm{N}_{\mathrm{D}^0_{\mathrm{tag}}}}). \tag{8}$$

B. The recoil charge method

At 4.03 GeV, $\mathrm{D}^*\overline{\mathrm{D}^*}$ and $\mathrm{D}^*\overline{\mathrm{D}}$ pairs are produced with no additional charged tracks. Charged pions arising from D^* decays are very slow, and are mostly undetected in the BES detector. As a result, only decay products of the D^+ and D^0 are visible to BES. Let Q_{D} be the charm flavor quantum number of the reconstructed D meson, and Q_{rec} be the total charge of tracks recoiling against this D meson. Ideally, Q_{rec} would be 0 for a recoiling neutral $\overline{\mathrm{D}}$, and -1e for a recoiling charged D^-. Furthermore, Q_{D} and Q_{rec} are anti-correlated for a charged $\overline{\mathrm{D}}$ in the recoil. In reality, limited acceptance of the detector results in loss of charged tracks, which smears the Q_{rec} distribution. The Q_{rec} distribution for D^0 centers at 0, and has a spread of about $\pm$1e. The Q_{rec} distribution for recoiling D^- centers at -1e with a similar spread. The recoil charge method selects neutral and charged D mesons according to

$$Q_{rec} = 0, \quad \text{or} \quad Q_{rec} = Q_{\mathrm{D}} = \pm 1 \text{ for } \mathrm{D}^0 \tag{9}$$

and

$$Q_{rec} \cdot Q_{\mathrm{D}} < 0 \text{ for } \mathrm{D}^+ \tag{10}$$

The efficiencies, and the misidentification rates of the D charge tag with the recoil charge method are obtained from Monte Carlo simulations. For inclusive D decays, the efficiency and the misidentification rate are 0.74$\pm$0.02 and 0.25$\pm$0.02, respectively, and are the same for the charged and neutral D mesons. These numbers are further checked with kinematically selected data events $\mathrm{e}^+\mathrm{e}^- \to \mathrm{D}^+\mathrm{D}^-$, and $\mathrm{e}^+\mathrm{e}^- \to \mathrm{D}^0\overline{\mathrm{D}^0}$ with excellent agreement between simulation and data.

For semiexclusive events in which a ϕ has been fully reconstructed, the efficiency of the recoil charge method is improved over that of the inclusive D events. A Monte Carlo study of various D decay modes into a ϕ containing final state has been performed and the variations among their efficiencies are included in the systematic errors. A set of efficiency and misidentification rates of 0.91$\pm$0.01$\pm$0.02 and 0.09$\pm$0.01$\pm$0.02 are obtained, where the first error is due to Monte Carlo statistics, and the second is systematic.

IV. MONTE CARLO SIMULATIONS

In the Monte Carlo simulation we generate the physics interactions $\mathrm{e}^+\mathrm{e}^- \to \mathrm{D}^*\overline{\mathrm{D}}$ and $\mathrm{e}^+\mathrm{e}^- \to \mathrm{D}^*\overline{\mathrm{D}^*}$. Several combinations of $\mathrm{D}^0\overline{\mathrm{D}^0}$, $\mathrm{D}^+\overline{\mathrm{D}^0}$ and $\mathrm{D}^+\mathrm{D}^-$ are selected from the intermediate states $\mathrm{D}^*\overline{\mathrm{D}}$ and $\mathrm{D}^*\overline{\mathrm{D}^*}$. The D^0 and D^+ mesons are decayed into final states $\mathrm{K}^-(\mathrm{n}\pi)^{0,+}$, where n=1,3 for D^0 and n=2 for D^+. These are the modes through which we reconstruct charm mesons in this measurement. The $\overline{\mathrm{D}^0}$ and D^- are decayed into ϕK, $\phi\pi$, $\phi\pi\pi$, and $\phi\mathrm{e}^-\overline{\nu_e}$. The generated physics events are processed by the BES detector simulation program, and are reconstructed using the BES offline reconstruction package. These simulated events are analyzed to guide the selection of cuts and to determine the detection efficiencies relevant to the measurement of $\mathrm{B}(\mathrm{D} \to \phi\mathrm{X})$.

V. DATA ANALYSIS

A. Event selection

In this measurement, charged tracks must be good helix fits which have a normalized chi-square of less than

9 per degree of freedom. These tracks need to be within $|cos\theta|$ <0.8, where θ is the polar angle, and be consistent with being from the primary event vertex. For the charged particle mass assignment, particle identification procedure is applied. A combined particle confidence level calculated using the $\mathrm{d}E/\mathrm{d}x$ and TOF measurements is required to be greater than 1% for π(K) hypothesis. In addition, a normalized likelihood ratio $LR(\mathrm{K}) > 50\%$ is required for the K hypothesis. If a track passes these particle identification requirements, the π(K) mass is assigned to the track.

B. Analysis of inclusive D meson events

Tracks passing the selection criteria are assigned the appropriate masses, and the invariant mass is calculated for the Knπ (n=1,2,3) combination if it matches one of the three modes of the D meson, $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$, $\mathrm{K}^-\pi^-\pi^+\pi^+$ and $\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+$. A correction to the momentum is made to compensate for a small shift in the BES magnetic field.

Figures 1a-c show the momentum distributions of the Knπ combinations whose invariant masses are within ± 2.5 standard deviations of the nominal D^0 and D^+ masses. The lowest momentum peak in each figure corresponds to D mesons from the $\mathrm{D}^*\overline{\mathrm{D}^*}$, the middle peak is due to $\mathrm{D}\overline{\mathrm{D}^*}$, and the highest momentum peak is from direct $\mathrm{D}\overline{\mathrm{D}}$ events.

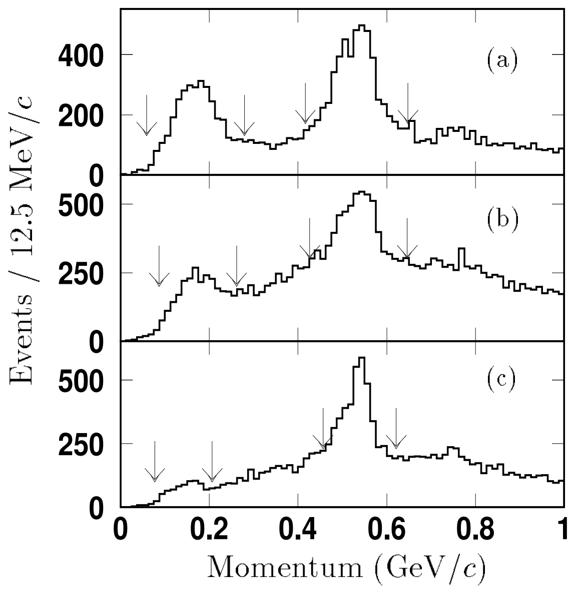

FIG. 1. Momentum distribution of (a) the $\mathrm{K}^-\pi^+$, (b) the $\mathrm{K}^-\pi^-\pi^+\pi^+$, and (c) the $\mathrm{K}^-\pi^+\pi^+$ combinations for events of which the charged tracks passed selection criteria and mass cuts mentioned in the text.

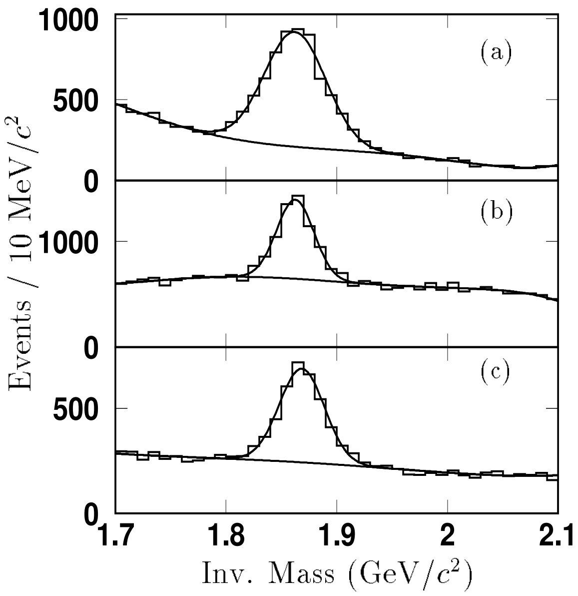

FIG. 2. Invariant mass distribution of selected (a) $K^-\pi^+$, (b) $K^-\pi^+\pi^+\pi^-$, and (c) $K^-\pi^+\pi^+$ combinations.

To reduce combinatorial backgrounds in these singly tagged D meson samples, momentum cuts of $\pm 2.5\sigma$ are used. In the analysis only the D mesons from the $\mathrm{e}^+\mathrm{e}^- \to \overline{\mathrm{D}}\mathrm{D}^*, \mathrm{D}^*\overline{\mathrm{D}^*}$ reactions are used. Figures 2a-c show the invariant mass distributions for events which pass the momentum cuts. Using a binned maximum-likelihood fit to those mass distributions with one Gaussian signal function and third order polynomial background we obtain the fitted masses and observed numbers of D mesons in Figures 2a-c, as listed in Table 1. The fitted masses are consistent with the Particle Data Book masses for D^0 and D^+. A total of 10371 ± 357 observed singly tagged events is obtained. Due to K-π interchange and random combinations some D events enter the D signal region more than once, which are doubly counted in the fit. We evaluate this rate of double counting using the D side band as defined in section V.C. After subtracting the doubly counted D mesons, a net sample of 9054 ± 308 singly tagged events containing neutral and charged D mesons is selected.

TABLE I. Fitted masses and numbers of the D meson samples from fits to Knπ mass distributions

decay modes	mass MeV	number of observed D	single tag D events
$\mathrm{K}^-\pi^+$	1862 ± 1	4946 ± 287	4243 ± 247
$\mathrm{K}^-\pi^-\pi^+\pi^+$	1863 ± 1	3152 ± 178	2652 ± 148
$\mathrm{K}^-\pi^+\pi^+$	1869 ± 1	2273 ± 118	2159 ± 112
Sum		10371 ± 357	9054 ± 308

Table 2 summarizes the numbers of neutral and charged D mesons in the recoil against the reconstructed D tags. The average from the D^0 and D^+ combinative double tag method and the recoil charge method, calculated assuming a full correlation between their statistical errors, are 6803±303±77 and 2251±77±43 for D^0 and D^+, respectively, where the first errors are statistical and the second are systematic due to variations in the mass fits and between the two D identification methods. These numbers of recoiling D^0 and D^+ mesons are used as the denominators in the branching fraction measurements.

TABLE II. Determination of number of recoiling neutral ($N_{REC}^{D^0}$) and charged ($N_{REC}^{D^+}$) D mesons

method	number of D^0 events	numbers of D^+ events
CDTM	6839±308	2215±70
recoil charge	6767±297	2287±83
Average	6803±303	2251±77

C. Reconstruction of $D \to \phi X$ events

1. *Reconstruction of* $\phi \to K^+K^-$ *events*

The ϕ meson is reconstructed in its decay to K^+K^-, using criteria described in section V.A. Figure 3 shows the invariant mass distribution of the K^+K^- pairs selected. Using a convoluted Breit-Wigner and Gaussian functions plus a third order polynomial background to fit the mass spectrum, we obtain a fitted mass of 1.0194 ± 0.0002 GeV/c^2 and a total of 1108±70 ϕ events. In this measurement, a ϕ signal window is defined as the region 1.00-1.04 GeV/c^2, as indicated by the arrows in Figure 3.

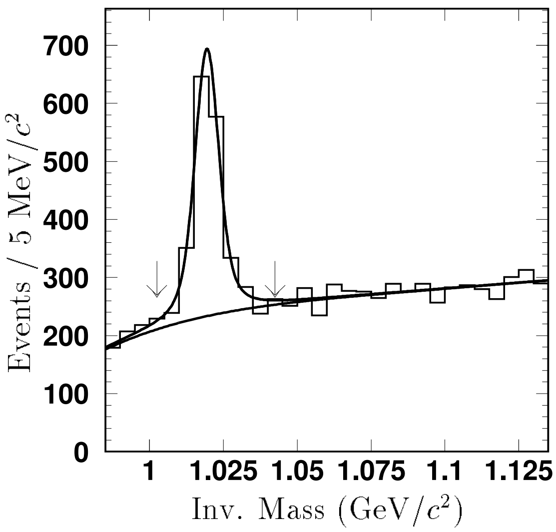

FIG. 3. Invariant mass distribution of inclusive K^+K^- pairs.

2. *Inclusive* $D \to \phi X$

Figure 4c shows the invariant mass distributions of the K^+K^- pairs selected for the events whose $Kn\pi$ invariant masses are within $\pm 2.5\sigma_{M_D}$ of the D masses. Breaking down the events in the figure 4c into the singly tagged neutral and charged D events separately, we obtained figures 4a and 4b. In our measurement, the K^+K^- mass region 1.00-1.04 GeV/c^2 is chosen as the signal region which is within ±2.5 standard deviation of the nominal ϕ mass, and the intervals 0.98-1.00 GeV/c^2 and 1.04-1.15 GeV/c^2 are considered as background regions for the ϕ. The $Kn\pi$ mass regions from 1.7 to 2.1 GeV/c^2, excluding regions within $\pm 3\sigma_{M_D}$ of the fitted D masses, are defined as sideband background control regions for the D mesons. As shown in Figure 4c, 15 events are found as $D\phi$ candidates, and 14 events are selected as D-'ϕ side band' events. Using the D side band events, a total of 0.5±0.5 background events has been estimated as the background among the D candidates. Subtracting the background contributions to both the D and the ϕ, we obtain 10.2±4.0 inclusive $\mathrm{D} \to \phi\mathrm{X}$ events, 6.6±3.5 $\mathrm{D}^{0(+)} \to \phi\mathrm{X}$ events in the recoil of D^0 tags, and 3.6±2.0 $\mathrm{D}^{0(+)} \to \phi\mathrm{X}$ events in the system recoiling against D^+ tags. Figures 5a and 5b show the invariant mass distributions of the $\mathrm{K}^+\mathrm{K}^-$ pairs from D^+ and D^0, repectively, as identified by the recoil charge selection criteria.

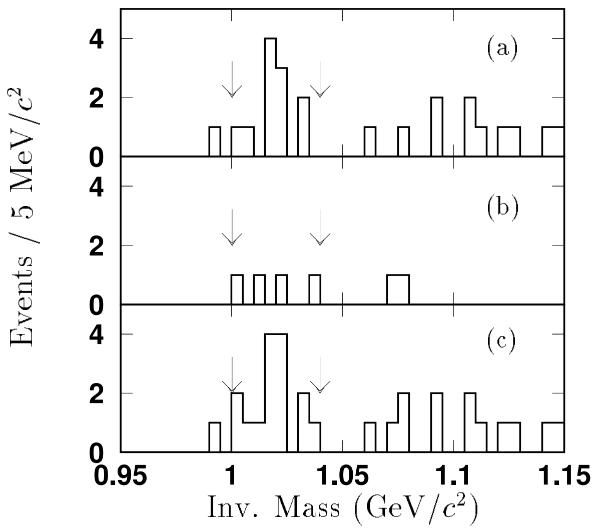

FIG. 4. Invariant mass dstributions of $\mathrm{K}^+\mathrm{K}^-$ pairs recoiling against fully reconstructed (a) neutral D, (b) charged D, and (c) all D events.

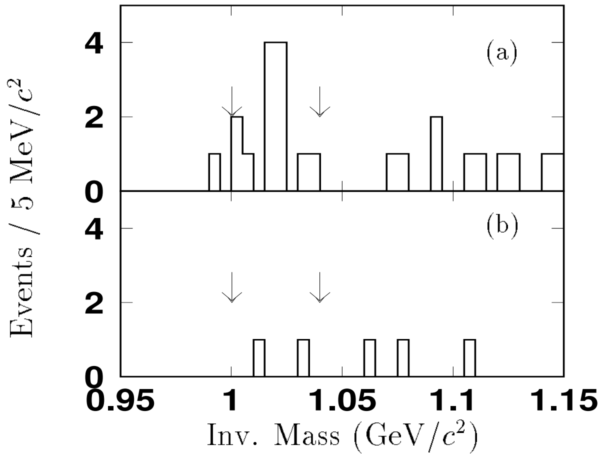

FIG. 5. Invariant mass dstributions of $\mathrm{K}^+\mathrm{K}^-$ pairs recoiling against fully reconstructed D decays for which the side recoiling has been identified by the recoil charged method as (a) D^0, and (b) D^+.

The two D type identification methods, CDTM and the recoil charge method, are applied to these events to extract the numbers of ϕ from specific D^0 and D^+ decays. Subtracting backgrounds estimated using the ϕ and D side bands, the two methods determine 3.7±4.7 (CDTM applied) and 9.7±4.2 (recoil charge applied) $\mathrm{D}^0 \to \phi\mathrm{X}$ events, and 6.5±5.5 (CDTM applied), and 0.5±1.7 (recoil charge applied) $\mathrm{D}^+ \to \phi\mathrm{X}$ events, respectively. Averaging over the two methods and assuming a complete correlation in their statistical errors, the number of $\mathrm{D}^0 \to \phi\mathrm{X}$ and $\mathrm{D}^+ \to \phi\mathrm{X}$ events are set to be 6.7±4.5, 3.5±3.6, respectively, and are used to determine their branching fractions.

3. Search for the decay $\mathrm{D}^+ \to \phi\mathrm{e}^+\nu$

Among the 15 ϕ candidates observed in the recoil side of the events, 4 are accompanied by at least one charged track which has $|cos\theta| < 0.85$. Each of these tracks is checked against the electron identification procedure by using information from the $\mathrm{d}E/\mathrm{d}x$ measurement. The electron identification requires consistency with the electron hypothesis at a confidence level greater than 1% and it requires the electron confidence level to be greater than the confidence level for pion hypothesis. None of the accompanying tracks are identified as an electron.

VI. RESULTS

A. Inclusive ϕ decay branching fractions of the charged and neutral D mesons

The measurement of $B(\mathrm{D}^{0(+)} \to \phi\mathrm{X})$ is obtained from the number of neutral or charged D events ($\mathrm{N}_{\mathrm{REC}}^{\mathrm{D}^{0(+)}}$) appearing in the recoils of the tagged D sample, number of inclusive ϕ events ($\mathrm{N}_{\mathrm{REC}}^{\mathrm{D}^{0(+)}\to\phi\mathrm{X}}$), and the inclusive efficiency ($\epsilon_{\mathrm{D}\to\phi\mathrm{X}}$) as follows

$$B(\mathrm{D}^{0(+)} \to \phi\mathrm{X}) = \frac{\mathrm{N}_{\mathrm{REC}}^{\mathrm{D}^{0(+)}\to\phi\mathrm{X}}}{\mathrm{N}_{\mathrm{REC}}^{\mathrm{D}^{0(+)}} \times \epsilon_{\mathrm{D}\to\phi\mathrm{X}}}. \tag{11}$$

Inserting the number of the inclusive ϕ events, the number of the neutral or the charged D events appearing in the recoils as shown in the Table 2, the inclusive efficiency $\epsilon_{\mathrm{D}\to\phi\mathrm{X}} = 0.084 \pm 0.006$, including the branching fraction for $\phi \to \mathrm{K}^+\mathrm{K}^-$ and uncertainties of about 3% in the $\epsilon_{\mathrm{D}^0\to\phi\mathrm{X}}$ and $\epsilon_{\mathrm{D}^+\to\phi\mathrm{X}}$, as estimated by Monte Carlo simulations, into the equation (11), we obtained the inclusive ϕ decay branching fractions for the neutral, charged, and the mixture of (75±5)% D^0 and (25±3)% D^+ as in the data sample to be

$$B(\mathrm{D}^0 \to \phi\mathrm{X}) = (1.17 \pm 0.79 \pm 0.10)\%,$$

$$B(\mathrm{D}^+ \to \phi\mathrm{X}) = (1.85 \pm 1.90 \pm 0.14)\%,$$

and

$$B(\mathrm{D} \to \phi\mathrm{X}) = (1.29 \pm 0.51 \pm 0.10)\%,$$

where the first errors are statistical and second systematic. The systematic errors arise from uncertainties ($\pm 0.05\%$, $\pm 0.06\%$ and $\pm 0.04\%$) in the numbers of singly tagged D mesons due to the choice of a background function and fit interval for the single tag sample, uncertainties ($\pm 0.08\%$, $\pm 0.13\%$ and $\pm 0.09\%$) in the inclusive ϕ efficiency. The combined effect of these sources is obtained by adding in the uncertainties in quadrature, which yields total systematic errors of $\pm 0.10\%$, $\pm 0.14\%$ and $\pm 0.10\%$ for the D^0, D^+ and the total of the D^0 and D^+, respectively.

B. Exclusive semielectronic decay branching fraction

A 90% C.L. Possion upper limit, $\mathrm{N}^{90\%\mathrm{C.L.}}_{\mathrm{D}^+ \to \phi\mathrm{e}^+\nu} = 2.3$, is obtained for $\mathrm{D}^+ \to \phi\mathrm{e}^+\nu$ based on zero candidate events. Using the total number, $\mathrm{N}^{\mathrm{D}^+}_{\mathrm{REC}}$, of the D^+ in the recoil side of the tagged D mesons, and the detection efficiency $\epsilon^{\mathrm{MC}}_{\mathrm{D}^+ \to \phi\mathrm{e}^+\nu}$, we have

$$B(\mathrm{D}^+ \to \phi e^+\nu) < \frac{\mathrm{N}^{90\%\mathrm{C.L.}}_{\mathrm{D}^+ \to \phi\mathrm{e}^+\nu}}{\epsilon^{\mathrm{MC}}_{\mathrm{D}^+ \to \phi\mathrm{e}^+\nu} \times \mathrm{N}^{\mathrm{D}^+}_{\mathrm{REC}}}.$$

The detection efficiency $\epsilon^{\mathrm{MC}}_{\mathrm{D}^+ \to \phi\mathrm{e}^+\nu}$ is estimated to be $\epsilon^{\mathrm{MC}}_{\mathrm{D}^+ \to \phi\mathrm{e}^+\nu} = 0.0652$ by Monte Carlo simulation. A 90% C. L. upper limit that includes a 1σ systematic error is set at

$$B(\mathrm{D}^+ \to \phi\mathrm{e}^+\nu) < 1.6\%.$$

C. Discussions

Table 3 summarizes the sums of all decay branching fractions, quoted from PDG98[3], for the exclusive decay modes containing a ϕ in the final states. The sums of decay branching fractions are $(2.92 \pm 1.00)\%$ for D^+ and $(0.97 \pm 0.14)\%$ for the D^0. Our measured values of inclusive ϕ branching fractions are consistent with the sums.

The sums in Table 3 are taken to calculate a weighted average of 1.44% for the BES data sample mixture of D^0 and D^+, which compares well with our measurement of $B(\mathrm{D} \to \phi X) = (1.29 \pm 0.51 \pm 0.10)\%$.

Our upper limit $B(\mathrm{D}^+ \to \phi e^+\nu) < 1.6\%$ is an improvement over the PDG98[3] value of $B(\mathrm{D}^+ \to \phi e^+\nu) < 2.09\%$.

TABLE III. Decay branching fractions of the D to final states containing a ϕ meson. The upper limits are set at 90% CL.

Decay Mode	Branching Fraction (%)	Sum (%)
$\phi\pi^+$	0.61 ± 0.06	
$\phi\pi^+\pi^0$	2.3 ± 1.0	2.92 ± 1.00
ϕK^+	$0.013^{+0.022}_{-0.019}$	
$\phi e^+\nu$	< 2.09	
$\phi\mu^+\nu$	< 3.72	< 6.01
$\phi\pi^+\pi^+\pi^-$	< 0.2	
$\phi\bar{K}^0$	0.86 ± 0.10	
$\phi\pi^+\pi^-$	0.108 ± 0.029	0.97 ± 0.14
$\phi\pi^0$	< 0.14	
$\phi\eta$	< 0.28	< 0.63
$\phi\omega$	< 0.21	

VII. CONCLUSION

In summary, the inclusive ϕ decay branching fractions of the charged and neutral D mesons have directly been measured. From singly tagged sample of 9054 ± 308 D^0 and D^+ events, 10.2±4.0 $D \rightarrow \phi X$ events are observed, leading to the first measurement of

$$B(D^0 \rightarrow \phi X) = (1.17 \pm 0.79 \pm 0.10)\%,$$

$$B(D^+ \rightarrow \phi X) = (1.85 \pm 1.90 \pm 0.14)\%,$$

and

$$B(D \rightarrow \phi X) = (1.29 \pm 0.51 \pm 0.10)\%.$$

No $D^+ \rightarrow \phi e^+ \nu$ events are observed in our sample of 2251 D^+ decays. A 90% C.L. upper limit is set at

$$B(D^+ \rightarrow \phi e^+ \nu) < 1.6\%.$$

Comparing with the sums of the existing measurements on the exclusive D^0 and D^+ decays containing a ϕ in the final states, our measured values of the inclusive ϕ decay branching fractions of the charged and neutral D mesons indicate that there is little room for additional ϕ containing decay modes of the D^0 and D^+ mesons.

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