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, we obtain the inclusive ϕ decay branching fractions of $BF(D^0 \to \phi X) = (1.1 \pm 0.8 \pm 0.1)\%$ and $BF(D^+ \to \phi X) = (2.0 \pm 1.9 \pm 0.2)\%$. For the combined $(75 \pm 5)\%$ neutral and $(25 \pm 3)\%$ charged D mixture, an average inclusive ϕ decay branching fraction $BF(D \to \phi X) = (1.3 \pm 0.5 \pm 0.1)\%$ is obtained. We have also searched for the decay $D^+ \to \phi e^+ \nu$, and place a 90% C.L. upper limit of $BF(D^+ \to \phi e^+ \nu) < 1.6\%$ based on nonobservation.

1 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 charm decays 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 better knowledge on charm decays and their branching fractions. In particular the inclusive decay $D \to \phi X$[a] has not been measured. Their branching fractions can serve as an independent check of existing exclusive decays of D mesons that contain a ϕ meson, and are important for studies of gluonic penguin ($b \to sg$) decay of B mesons[3], as well as for time-dependent $B_s^0 \overline{B}_s^0$ oscillation measurements[4] that use the $\phi \ell$ pair to tag the B_s^0 meson.

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 $D^+ \to \phi e^+ \overline{\nu}$ based on an analysis of the data collected with the Beijing Spectrometer (BES) in e^+e^- annihilation at $\sqrt{s} = 4.03$ GeV.

2 The Beijing Spectrometer and Data Sample

The BES detector has been described in details 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 event trigger. A forty-layer main drift chamber (MDC) located just outside the CDC provides measurements of charged tracks and ionization energy loss (dE/dx) with a solid angle coverage of 80% of 4π for a charged track. Momentum resolution of $1.7\%\sqrt{1+p^2}$ (p in GeV/c) and dE/dx 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 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, and has an energy resolution of $\sigma_E/E = 0.22/\sqrt{E}$(E in GeV), and spatial resolutions of $\sigma_\phi = 4.5$ mrad and $\sigma_Z = 2$ cm for 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). An end-cap time-of-flight and shower counters extend coverage to the forward and backward regions.

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

3 Charge determination of recoiling D mesons

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

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

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

[a]Throughout this letter, charge conjugation is implied.

3.1 *The D^0 and D^+ combinative double tag method (D^0 and D^+ CDTM)*

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

$$N^P_{D^0_{tag}} = \epsilon_1 N^{D^-}_{D^0_{tag}} BF(D^- \to PX) + \epsilon_2 N^{\overline{D}^0}_{D^0_{tag}} BF(\overline{D}^0 \to PX), \tag{1}$$

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

$$N^P_{D^+_{tag}} = \epsilon_1 N^{D^-}_{D^+_{tag}} BF(D^- \to PX) + \epsilon_2 N^{\overline{D}^0}_{D^+_{tag}} BF(\overline{D}^0 \to PX), \tag{2}$$

The $N^{D^-}_{D^+_{tag}}$ and $N^{\overline{D}^0}_{D^+_{tag}}$ are the numbers of D^- and $\overline{D}^0$ produced in the system recoiling against the tagged D^+. A Monte Carlo study shows that the detection efficiencies are nearly the same, which allow to take the $\epsilon \approx \epsilon_1 \approx \epsilon_2$. By using the numbers ($N_{D^0_{tag}}$ and $N_{D^+_{tag}}$) of the D^0 and D^+ single tags, the numbers of the $\overline{D}^0$ and D^- produced in the side recoiling against the single tags can be calculated as following

$$N^{\overline{D}^0}_{D^0_{tag}} = (1-\eta) N_{D^0_{tag}}, \qquad N^{D^-}_{D^0_{tag}} = \eta N_{D^0_{tag}},$$
$$N^{\overline{D}^0}_{D^+_{tag}} = \beta N_{D^+_{tag}}, \qquad N^{D^-}_{D^+_{tag}} = (1-\beta) N_{D^+_{tag}},$$

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

Combining the equation (1) and (2) together by inserting the $N^{\overline{D}^0}_{D^0_{tag}}$, $N^{D^-}_{D^0_{tag}}$, $N^{\overline{D}^0}_{D^+_{tag}}$, and $N^{D^-}_{D^+_{tag}}$ into them, the inclusive particle 'P' decay branching fractions of $\overline{D}^0$ and D^- are given by

$$BF(\overline{D}^0 \to PX) = \frac{1}{\epsilon(1-\beta-\eta)}((1-\beta)\frac{N^{PX}_{D^0_{tag}}}{N_{D^0_{tag}}} - \eta \frac{N^{PX}_{D^+_{tag}}}{N_{D^+_{tag}}}) \tag{3}$$

and

$$BF(D^- \to PX) = \frac{1}{\epsilon(1-\beta-\eta)}((1-\eta)\frac{N^{PX}_{D^+_{tag}}}{N_{D^+_{tag}}} - \beta \frac{N^{PX}_{D^0_{tag}}}{N_{D^0_{tag}}}). \tag{4}$$

3.2 *The recoil charge method*

At 4.03 GeV, $D^*\overline{D}^*$ and $D^*\overline{D}$ 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 $D^0\overline{D}^0$, $D^+\overline{D}^0$, and D^+D^- pairs 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 the D meson. Ideally, Q$_{rec}$ would be 0 for a recoiling neutral D, and $\pm$1e for a recoiling charged D. Furthermore, Q$_D$ and Q$_{rec}$ are anti-correlated for a charged 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 +e or -e. The Q$_{rec}$ distribution for recoiling D$^+$ centers at +1 with a similar spread. The recoil charge method selects neutral and charged D mesons according to

$$Q_{rec} = 0, \quad or \quad Q_{rec} = Q_D = +1, \quad or \quad Q_{rec} = Q_D = -1 \; for \quad D^0 \tag{5}$$

and

$$Q_{rec} \cdot Q_D < 0 \quad for \quad D^+ \tag{6}$$

The selections allow for a maximum error of $\pm$1e in Q$_{rec}$. The efficiencies, and the misidentification rates of the D charge tag with the recoil charge method are obtained from Monte Carlo simulations to be 0.74$\pm$0.02, 0.25$\pm$0.02, respectively. They are further checked with kinematically selected data events $e^+e^- \to D^+D^-$, and $e^+e^- \to D^0\overline{D}^0$ with excellent agreements between the simulation and the data.

4 Monte Carlo Simulations

In the Monte Carlo simulation we generate physics interactions $e^+e^- \to D^*\overline{D}$ and $e^+e^- \to D^*\overline{D}^*$. Several combinations of $D^0\overline{D}^0$, $D^+\overline{D}^0$ and D^+D^- are selected from the intermedia states $D^*\overline{D}$ and $D^*\overline{D}^*$. The D^0 and D$^+$ mesons are decayed into final states $K^-(n\pi)^{0+}$, where n=1,3 for D^0 and n=2 for D$^+$, which are the modes through which we reconstruct charm mesons in this measurement. The $\overline{D^0}$ and D^- are decayed into ϕK, $\phi\pi$, $\phi\pi\pi$, and $\phi\mu^-\nu$. 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 $BF(D \to \phi X)$.

Table 1: D meson samples from fits to $Kn\pi$ mass distributions

decay Modes	mass MeV	σ_{M_D} MeV	number of observed D	single tag D events
$K^{\pm}\pi^{\mp}$	1862 ± 1	28 ± 1	4946 ± 287	4243 ± 247
$K^{\pm}\pi^{\mp}\pi^{\mp}\pi^{\pm}$	1863 ± 1	17 ± 1	3152 ± 178	2652 ± 148
$K^{\pm}\pi^{\mp}\pi^{\mp}$	1869 ± 1	21 ± 1	2273 ± 118	2159 ± 112
Sum			10371 ± 357	9054 ± 308

5 Data Analysis

5.1 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 is applied. First a combined particle confidence level calculated using the dE/dx and TOF measurements is required to be greater than 1% for $\pi(K)$ hypothesis; and secondly a normalized likelihood ratio $LR(K) > 50\%$ is required for the K hypothesis. If a track passes these particle identification requirements, the $\pi(K)$ mass is assigned to the track.

5.2 Analysis of Inclusive D meson events

Tracks passing the selections are assigned the appropriate masses, and the invariant mass is calculated for the $Kn\pi$ (n=1,2,3) combination if it matches one of the three modes of the D meson, $D^0 \to K^-\pi^+$, $K^-\pi^-\pi^+\pi^+$ and $D^+ \to K^-\pi^+\pi^+$. A correction to the momentum is made to compensate for a small shift in the BES B field, and momentum loss due to ionizations loss in the material of the Main Draft Chamber[5].

Figures 1a-c show the momentum distributions of the $Kn\pi$ combinations whose invariant masses are within ± 2.5 standard deviations of the D^0 and D^+ nominal masses. The lowest peaks correspond to D mesons from the $D^*\overline{D}^*$; the mid peaks are due to $D\overline{D}^*$ and the peaks at high momentum position reflect the D mesons from direct $D\overline{D}$. In order to reduce combinatorial backgrounds in these singly tagged D meson samples, a $\sim 2.5\sigma$ cut on the momenta is used. In the analysis only the D mesons from the $e^+e^- \to \overline{D}D^*, D^*\overline{D}^*$ reactions are used. Figures 2a-c show the invariant mass distributions for these events which pass the momentum cuts. Using a binned maximum-likelihood fit to those three mass distributions with a Gaussian function and three order polynomial background we obtain the masses, widths and observed numbers of D mesons in Figures 2a-c. Table 1 lists the fit results. A total of 10371 ± 357 singly tagged events is

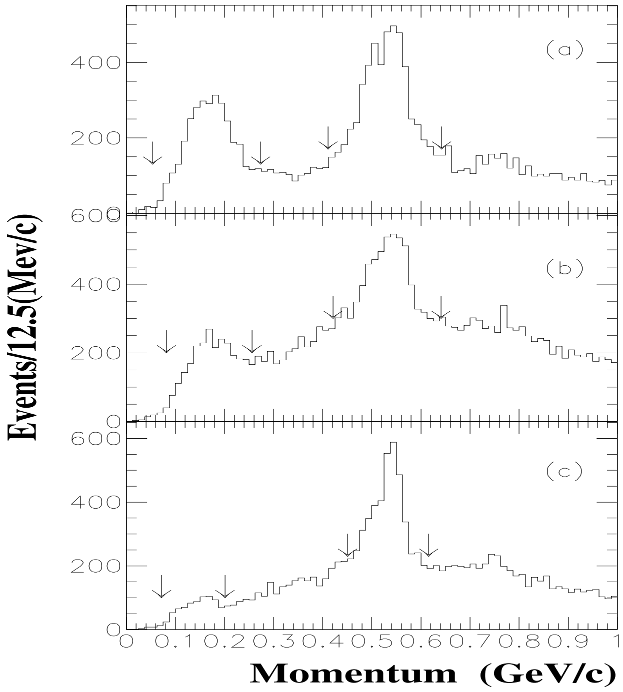

Figure 1: Momentum distribution of (a) the $K^{\mp}\pi^{\pm}$, (b) the $K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\mp}$, and (c) the $K^{\mp}\pi^{\pm}\pi^{\pm}$ combinations for events of which the charged tracks passed selection criteria and mass cuts mentioned in the text.

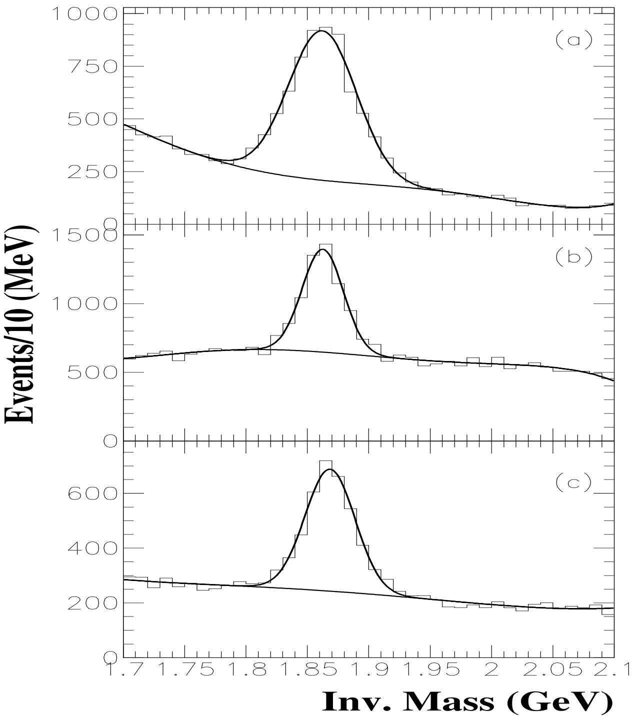

Figure 2: Invariant mass distribution of selected (a) $K^-\pi^+$, (b) $K^-\pi^+\pi^+\pi^-$, and (c) $K^-\pi^+\pi^+$ combinations.

obtained. Due to K π interchange 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 5. After subtracting the doubly counted D mesons, a net sample of 9054 ± 308 events containing neutral and charged D mesons is selected.

Table 2 summarizes the numbers of neutral and charged D mesons in the recoil against the reconstructed D events. 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 measurement.

5.3 *Reconstruction of $D \to \phi X$*

Reconstruction of $\phi \to K^+K^-$ events

The ϕ meson is reconstructed in its decay to K^+K^-, using criteria described in section 5. Figure 3 shows the

Table 2: Determination of number of recoiling neutral ($N^{D^0}_{REC}$) and charged ($N^{D^+}_{REC}$) D mesons

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

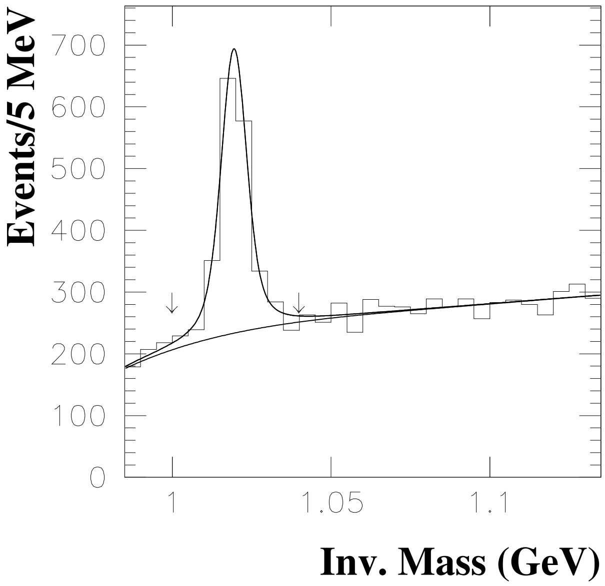

Figure 3: Invariant mass distribution of inclusive K^+K^- pairs.

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 fit 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, as marked in Figure 3.

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 neutral and charged D events separately, we obtained figure 4a and 4b. The K^+K^- mass region 1.00-1.04 GeV is chosen as the signal region, and the intervals 0.98 - 1.00 GeV and 1.04 - 1.15 GeV are considered as background regions for the ϕ. The $Kn\pi$ mass regions from 1.7 to 2.1 GeV , except for regions within $\pm 3\sigma_{M_D}$ of the fitted D masses,

Table 3: $D^{0(+)} \to \phi X$ candidates in the recoil side

double tag mode or D meson type	method	$D\phi$ candidates	ϕ sideband background	D sideband background	D_{tag} VS ϕX events	$N_{REC}^{D^{0(+)}\to\phi X}$ events observed	$N_{REC}^{D^{0(+)}\to\phi X}$ events unfolded
D^0_{tag} VS ϕX D^0	D^0 and D^+ CDTM	11	3.7±1.0	0.7±0.4	6.6±3.5		3.7±4.7
D^0	recoil charge	13	3.4±1.0	0.7±0.4		8.9± 3.	9.3±4.0
D^0	average						6.5±4.4
D^+_{tag} VS ϕX D^+	D^0 and D^+ CDTM	4	0.6±0.4	-0.2±0.2	3.6±2.0		6.5±5.5
D^+	recoil charge	2	0.9±0.5	-0.2±0.2		1.3±1.5	0.9±1.6
	average						3.7±3.6
all D					10.2±4.0	10.2±4.0	10.2±5.7

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 $D \to \phi X$ events. Figure 5a and 5b show the invariant mass distributions of the K^+K^- pairs from D^+ and D^0, respectively. These events are selected based on the recoil charge selection criteria. Combining the events in the two plots together we obtain the invariant mass distributions of the K^+K^- pairs from the D^+ and D^0 as shown in figure 5c. Applying the two D type identification methods to these events, numbers of events for $D^0 \to \phi X$ and $D^+ \to \phi X$ are found, as summarized in Table 3, where for the recoil charge method, the efficiency of 0.95 and the misidentification rate of 0.05 for D type identification have been used to unfold the tagged $D^{0,+} \to \phi X$ candidates to obtain the exact $D^{0,+} \to \phi X$ events. The averages from the two methods are 6.5 ± 4.4 and 3.7 ± 3.6 events, for $D^0 \to \phi X$ and $D^+ \to \phi X$, respectively, and are used to determine their branching fractions.

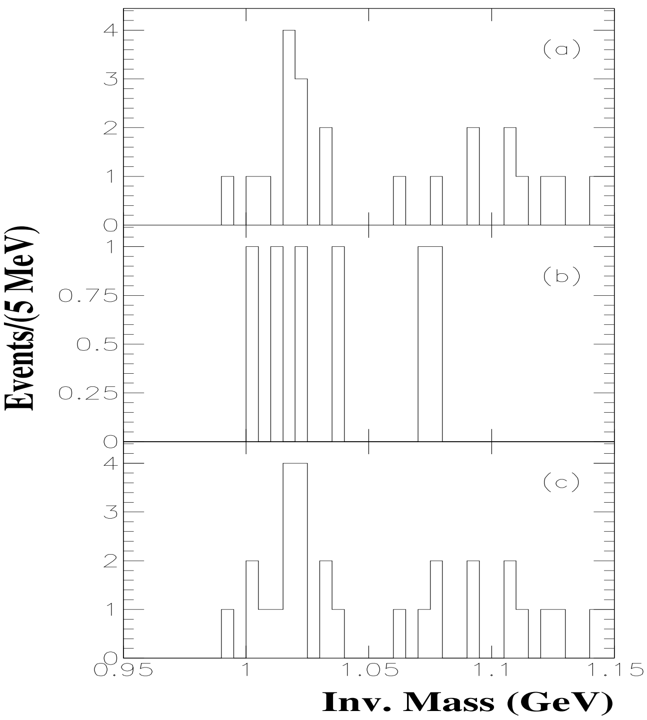

Figure 4: Invariant mass distributions of K^+K^- pairs recoiling against fully reconstructed (a) neutral D, (b) charged D, and (c) all D events.

Search for the decay $D^+ \to \phi e^+\nu$

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 dE/dx 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 tracks is identified as an electron. From the sample of 2251±77 charged D mesons in the recoil, a limit on the branching fraction for $D^+ \to \phi e^+ \nu$ will be set.

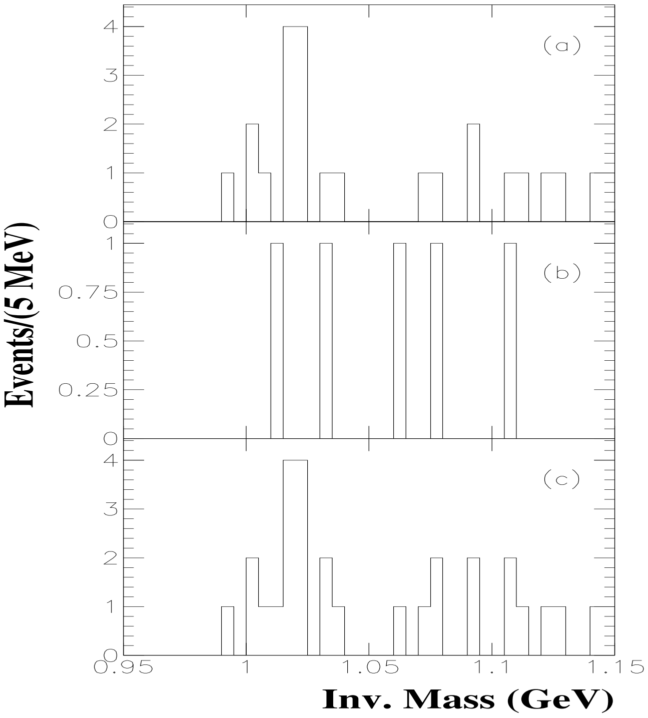

Figure 5: Invariant mass distributions of K^+K^- pairs recoiling against fully reconstructed D decays for which the recoiling side has been identified by the recoil charged method as (a) D^0, (b) D^+, and (c) D^0 or D^+.

6 Results

6.1 *Inclusive ϕ decay branching fractions of the charged and neutral D mesons*

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

$$BF(D^{0(+)} \to \phi X) = \frac{N_{REC}^{D^{0(+)}\to\phi X}}{N_{REC}^{D^{0(+)}} \times \epsilon_{D\to\phi X}}. \qquad (7)$$

Inserting the number of the inclusive ϕ events as shown in Table 3, the number of the neutral or the charged D events appeared in the recoils as shown in Table 2, the inclusive efficiency $\epsilon_{D\to\phi X} = 0.084 \pm 0.004$, including the branching fraction for $\phi \to K^+K^-$, as estimated by Monte Carlo simulations, into the equation (7), we obtained the inclusive ϕ decay branching fractions for the neutral, charged and for the (75±5)% neutral and (25±3)% charged D mixture to be

$$BF(D^0 \to \phi X) = (1.1 \pm 0.8 \pm 0.1)\%,$$

$$BF(D^+ \to \phi X) = (2.0 \pm 1.9 \pm 0.2)\%$$

and

$$BF(D \to \phi X) = (1.3 \pm 0.5 \pm 0.1)\%.$$

Where the first errors are statistical and second systematic. The systematic errors arise from uncertainties (±0.05%, ±0.08% and ±0.05%) in the numbers of singly tagged D mesons due to the choice of a background functional form and fit interval for the single tag sample, uncertainties (±0.1%, ±0.2% and ±0.1%) in the inclusive ϕ efficiency. The combined effect of these sources is obtained by adding in the uncertainties in quadrature, which yields a total systematic errors of ±0.1%, ±0.2% and ±0.1% for the D^0, D^+ and the total of the D^0 and D^+, respectively.

6.2 *Exclusive semileptonic decay branching fraction*

No $D^+ \to \phi e^+ \nu$ candidates have been selected, and a 90% C.L. Possion upper limit, $N_{D^+\to\phi e^+\nu}^{90\%C.L.} = 2.3$, is obtained for $D^+ \to \phi e^+ \nu$. Using the total number, $N_{REC}^{D^+}$, of the D^+ in the recoil side of the tagged D mesons and the detection efficiency $\epsilon_{D^+\to\phi e^+\nu}^{MC}$, we have

Table 4: 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	2.91 ± 1.00
$\phi\pi^+\pi^0$	2.3 ± 1.0	
ϕK^+	$0.013^{+0.022}_{-0.019}$	
$\phi e^+\nu$	< 2.09	< 6.01
$\phi\mu^+\nu$	< 3.72	
$\phi\pi^+\pi^+\pi^-$	< 0.2	
$\phi\overline{K}^0$	0.85 ± 0.10	0.96 ± 0.14
$\phi\pi^+\pi^-$	0.107 ± 0.029	
$\phi\pi^0$	< 0.14	< 0.63
$\phi\eta$	< 0.28	
$\phi\omega$	< 0.21	

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

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

$$BF(D^+ \to \phi e^+\nu) < 1.6\%.$$

6.3 *Discussion of the results and comparison with that measured by other experiments*

Table 4 summarizes the sums of all decay branching fractions, quoted from PDG96[3], for the exclusive decay modes containing a ϕ in the final states, yielding two sums of decay branching fractions to be $(2.91 \pm 1.00)\%$ for D^+ and $(0.96 \pm 0.14)\%$ for the D^0. Our measured most probable values of inclusive ϕ branching fractions are all consistent within the errors with the sums well.

If we take the summed decay branching fractions of D^+ and D^0 to calculate an average-weighted decay branching fractions weighted in $\frac{2251}{9054}$ for D^+ and in $\frac{6803}{9054}$ for D^0, respectively, we obtain the average-weighted decay branching fraction to be 1.44%. Our measured value of the averaged inclusive ϕ decay branching fraction, $BF(D \to \phi X) = (1.4 \pm 0.5 \pm 0.2)\%$ is in good agreement with the average-weighted decay branching fraction of the D^+ and D^0.

Our upper limit of the exclusive semileptonic decay branching fraction $BF(D^+ \to \phi e^+\nu) < 1.6\%$ is a bit tighter than the value listed in PDG96[3] in which the upper limit is $BF(D^+ \to \phi e^+\nu) < 2.09\%$.

7 Conclusion

In summary, the inclusive ϕ decay branching fractions of the charged and neutral D mesons have been presented. From singly tagged sample of 9054 ± 308 D^0 and D^+ events, 10 $D \to \phi X$ events are observed. These lead to the first measurement of

$$BF(D^0 \to \phi X) = (1.1 \pm 0.8 \pm 0.1)\%,$$

$$BF(D^+ \to \phi X) = (2.0 \pm 1.9 \pm 0.2)\%,$$

and

$$BF(D \to \phi X) = (1.3 \pm 0.5 \pm 0.1)\%.$$

No exclusive semileptonic decay process of $D^+ \to \phi e^+\nu$ is observed from the 2251 D^+ events. This leads to a new C.L.=90% upper limit of

$$BF(D^+ \to \phi e^+\nu) < 1.6\%.$$

Comparing with the sums of the existing measurements on the exclusive 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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