Measurements of Inclusive Cabbibo-Favored $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} Decay Branching Fractions of Charged and Neutral D Mesons

Gang Rong

Institute of High Energy Physics, Chinese Academy of Since, P.O. Box 918-1, Bijing 100039, China
E-mail: rongg@bepc5.ihep.ac.cn

Representing the BES Collaboration

Using the BES detector at BEPC with $\sqrt{s} = 4.03$ GeV, we have measured the inclusive Cabbibo-Favored $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} decay branching fractions of neutral and charged D mesons. We obtain the inclusive Cabbibo-Favored $\bar{K}^{*0}$ decay branching fractions of $BF(D^+ \to \bar{K}^{*0}X) = (27.7 \pm 14.1 \pm 4.4)\%$ and $BF(D^0 \to \bar{K}^{*0}X) = (11.1 \pm 5.1 \pm 3.2)\%$. For the combined neutral and charged D mesons, an average inclusive Cabbibo-Favored $\bar{K}^{*0}$ branching fraction of $BF(D \to \bar{K}^{*0}X) = (15.7 \pm 1.9 \pm 1.4)\%$ and a 90% C.L. upper limit for the Cabbibo-Suppressed K^{*0} decay branching fraction of $BF(D \to K^{*0}X) < 4.1\%$ are obtained. If we treat our K^{*0} candidates as a signal, we obtain a Cabbibo-Suppressed K^{*0} decay branching fraction of $BF(D \to K^{*0}X) = (2.6 \pm 1.1 \pm 0.2)\%$.

1 Introduction

Measurement of the inclusive decay branching fractions of D mesons provides general information about D decay properties. It may be used to determine characteristics of decay modes which have not been observed yet through measurements of exclusive decay modes. For instance, the measurement of the inclusive decay branching fractions could provide evidence for new decay modes. The measurement of the inclusive $\bar{K}^{*0}/K^{*0}$ decay branching fraction of the D^a mesons not only provides valuable information about the relative strength of Cabbibo-Favored and Cabbibo-Suppressed D decays, but it can also be used to indicate the existence of new decay modes containing $\bar{K}^{*0}/K^{*0}$ in their final states. At present the values of the inclusive $\bar{K}^{*0}/K^{*0}$ decay branching fractions of the D mesons are not available[1]. These inclusive measurements would be beneficial to more precise measurements of B meson decay properties in the experiments such as LEP, CDF and B factories, where the values of the inclusive $\bar{K}^{*0}/K^{*0}$ decay branching fractions may be needed as inputs to simulate the D decays and to subtract charm background in the measurements of inclusive B mesons decay properties.

This paper reports the first measurement of the inclusive Cabbibo-Favored $\bar{K}^{*0}$ decay branching fractions of the charged and the neutral D mesons using a double tag method described in section III and based on an analysis of the 22.3 pb^{-1} data collected with BES[2] in e^+e^- annihilation at $\sqrt{s} = 4.03$ GeV at BEPC[3].

2 The BES Detector

BES is a conventional cylindrical magnetic detector[2] operated at the Beijing Electron Positron Collider (BEPC).

[a]Throughout this paper, charged conjugation is implied.

A four-layer central drift chamber (CDC) surrounding the beam pipe provides trigger information. A forty-layer main drift chamber (MDC) just outside the CDC performs charged track reconstruction and ionization energy loss (dE/dx) measurements with a solid angle coverage of 80% of 4π. Momentum resolution of $1.7\%\sqrt{1+p^2}$ (p in GeV/c) and dE/dx resolution of 8.5% for Bhabha scattering electrons are obtained for 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, which measures the energies of electrons and photons over 80% of the total solid angle, and has energy resolution of $\sigma_E/E = 0.22/\sqrt{E}$(E in GeV), spatial resolutions of $\sigma_\phi = 4.5$ mrad and $\sigma_Z = 2$ cm for the electrons. A solenoidal magnet 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 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.

3 The D^0 and D^+ combinative double tag method

At $\sqrt{s} = 4.03$ GeV charm mesons are produced as

$$\begin{aligned} e^+e^- \to\ & D_s^+D_s^-, D^+D^-, D^0\bar{D}^0, \\ & D^{\pm}D^{*\mp}, D^0\bar{D}^{*0}(\bar{D}^0D^{*0}), \\ & D^{*\pm}D^{*\mp}, D^{*0}\bar{D}^{*0}. \end{aligned}$$

Since the $D^{*\pm}$ can decay to $\pi^+D^0(\pi^-\bar{D}^0)$ and $\pi^0(\gamma)D^+(\pi^0(\gamma)D^-)$, it is impossible to know whether a $D^+(D^-)$ or $D^0(\bar{D}^0)$ appears in the side recoiling against a tagged $\bar{D}(D)$ meson. But if we combine single and double tags for the two mesons to measure their inclusive K^{*0} decay branching fractions together, we can obtain the values of the decay branching fractions separately.

In this analysis, we search for the K^{*0} and count its numbers $N^{K^{*0}}_{D^0_{tag}}$ and $N^{K^{*0}}_{D^+_{tag}}$ in the side recoiling against the tagged D^0 and D^+, respectively. The $N^{K^{*0}}_{D^0_{tag}}$ is related to $N^{D^-}_{D^0_{tag}}$ and $N^{\bar{D}^0}_{D^0_{tag}}$, which respectively are the numbers of D^- and $\bar{D}^0$ produced in the system recoiling against the tagged D^0 sample, by

$$N^{K^{*0}}_{D^0_{tag}} = \epsilon N^{D^-}_{D^0_{tag}} BF(D^- \to K^{*0}X) + \epsilon N^{\bar{D}^0}_{D^0_{tag}} BF(\bar{D}^0 \to K^{*0}X), \tag{1}$$

where ϵ is the detection efficiency for the K^{*0}, $BF(D^- \to K^{*0}\,X)$ and $BF(\bar{D}^0 \to K^{*0}X)$ are the decay branching fractions to be measured. Similarly, for D^+ tags we have

$$N^{K^{*0}}_{D^+_{tag}} = \epsilon N^{D^-}_{D^+_{tag}} BF(D^- \to K^{*0}X) + \epsilon N^{\bar{D}^0}_{D^+_{tag}} BF(\bar{D}^0 \to K^{*0}\,X). \tag{2}$$

$N^{D^-}_{D^+_{tag}}$ and $N^{\bar{D}^0}_{D^+_{tag}}$ are the numbers of D^- and $\bar{D}^0$ produced in the system recoiling against the tagged D^+. By using the numbers $N_{D^0_{tag}}$ and $N_{D^+_{tag}}$ of the D^0 and the D^+ single tags respectively, and the ratios η and β of the numbers of the D^- and the $\bar{D}^0$ produced respectively in the recoil to the numbers of the D^0 and the D^+ in the tagged sample, we obtain

$$BF(\bar{D}^0 \to K^{*0}X) = f((1-\beta)\frac{N^{K^{*0}X}_{D^0_{tag}}}{N_{D^0_{tag}}} - \eta\frac{N^{K^{*0}X}_{D^+_{tag}}}{N_{D^+_{tag}}}) \tag{3}$$

and

$$BF(D^- \to K^{*0}X) = f((1-\eta)\frac{N^{K^{*0}X}_{D^+_{tag}}}{N_{D^+_{tag}}} - \beta\frac{N^{K^{*0}X}_{D^0_{tag}}}{N_{D^0_{tag}}}) \tag{4}$$

with $f = 1/(\epsilon(1-\beta-\eta))$. The values $\eta = 0.2116$ and $\beta = 0.5235$ were calculated based on doubly tagged events (see below).

4 Single Tags

In this analysis, the singly tagged neutral and charged D mesons were reconstructed in hadronic decay modes: $K^\mp\pi^\pm$, $K^\mp\pi^\pm\pi^\pm\pi^\mp$, and $K^\mp\pi^\pm\pi^\pm$. For a candidate 2(or 3 or 4)-charged-track combination, each track must be well reconstructed and consistent with coming from the interaction region. In addition, to optimize momentum resolution and charged particle identification, a geometry cut ($\mid cos\theta \mid \leq 0.8$, where the θ is polar angle of the track) is applied. For the charged particle mass assignment, one (or two) level(s) of particle identification is

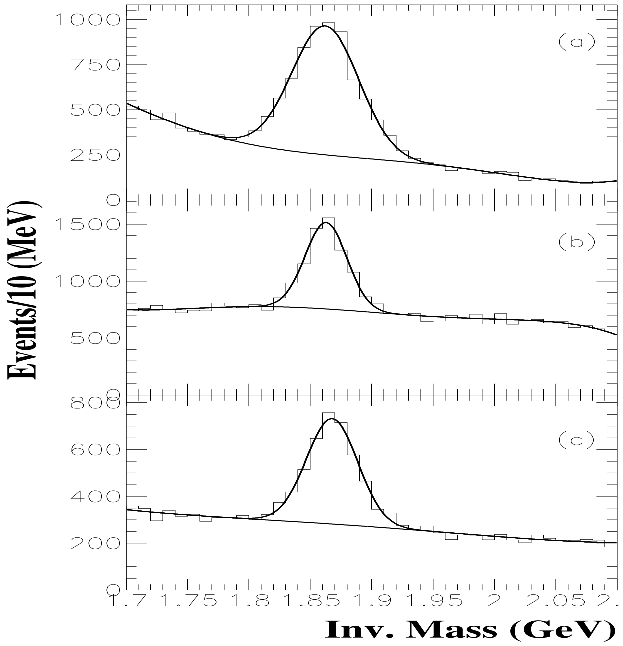

Figure 1: Distribution of invariant masses of the selected (a) $K^\mp\pi^\pm$, (b) $K^\mp\pi^\pm\pi^\pm\pi^\mp$, and (c) $K^\mp\pi^\pm\pi^\pm$ combinations.

(are) 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; then a normalized likelihood ratio $LR(K) > 50\%$ is required for the K hypothesis. If a track passes the particle identification cuts, the $\pi(K)$ mass is assigned to the track.

After the particle mass assignments, the invariant masses of different $Kn\pi$ (n=1 or 2 or 3) combinations for the three hadronic decay modes $\bar{D}^0(D^0) \to K^\pm\pi^\mp$, $K^\pm\pi^\mp\pi^\mp\pi^\pm$ and $D^\mp \to K^\pm\pi^\mp\pi^\mp$ are calculated using momenta components corrected for a small shift in the magnetic field and for ionization loss in the material of the Main Drift Chamber[2]. In order to reduce combinatorial background in the singly tagged D meson sample, a roughly 3σ cut on the momenta is used. In this analysis, only the D mesons from the $e^+e^- \to \bar{D}D^*(D\bar{D}^*), D^*\bar{D}^*$ reactions are selected by using the D momentum cut[4]. Figures 1(a), 1(b) and 1(c) show the invariant mass distributions for events in which the combinations passed the momentum cuts for the three hadronic decay modes. The spectra were fit with a Gaussian function and a third order polynomial background. After correcting for double counting[4], the fits give $4207\pm196\pm92$, $2716\pm158\pm88$ neutral and $2234 \pm 120 \pm 49$ charged D mesons for the $K^\mp\pi^\pm$, $K^\mp\pi^\pm\pi^\pm\pi^\mp$ and $K^\mp\pi^\pm\pi^\pm$ modes, respectively, where the first errors are statistical and the second are systematic due to variations in the mass fits.

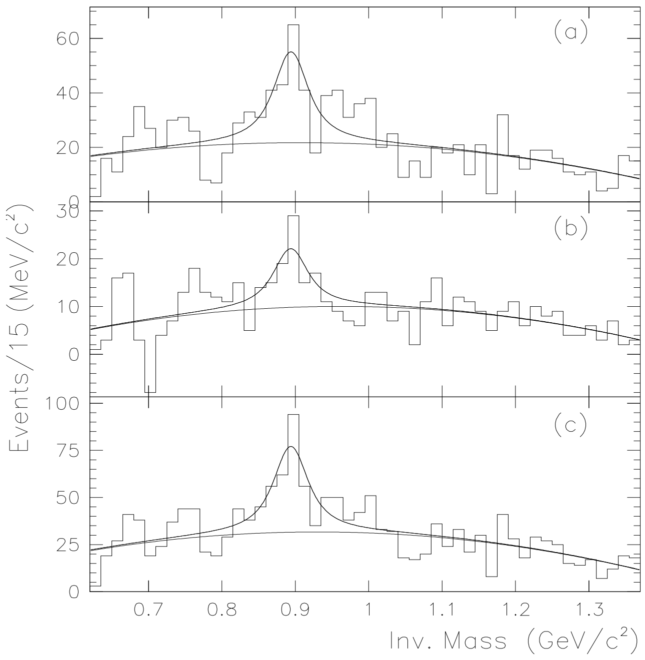

Figure 2: Distribution of the invariant masses of $K^-\pi^+$ combinations for Cabbibo-Favored decay modes of D mesons in the system recoiling against the tagged (a) neutral $\bar{D}$, (b) charged $\bar{D}$, and (c) combined the neutral and charged $\bar{D}$ mesons together.

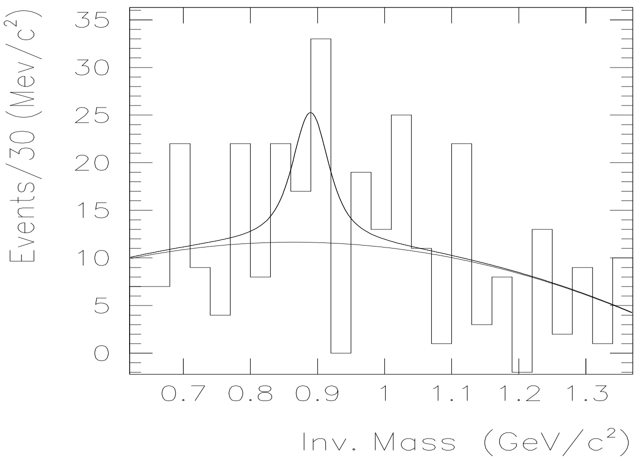

Figure 3: Distributions of the invariant masses of $K^+\pi^-$ combinations for Cabbibo-Suppressed decay modes of the D mesons from the system recoiling against the tagged neutral and charged $\bar{D}$ mesons together.

5 Double Tags

The inclusive $\bar{K}^{*0}$ meson is reconstructed in its $\bar{K}^{*0} \to K^-\pi^+$ mode in the system recoiling against both the $\bar{D}$ tagged region and $\bar{D}$ sideband. Regions of $\sim \pm 1.5\sigma_{m_D}$ both above and below the tag regions for each of the three modes are defined as sideband control regions to be used to estimate the numbers of background events in the tag regions. Figure 2(c) shows the distribution of the subtracted-sideband-background invariant masses of the $K^-\pi^+$ pairs selected in the recoils. The mass distribution reflects the net events from the recoils of the tagged $\bar{D}$. Breaking down the events in figure 2(c) into two groups for the tagged neutral and the charged $\bar{D}$ events separately, we obtained figures 2(a) and 2(b). After correcting for double counting, we obtained 224 ± 27 inclusive Cabbibo-Favored $\bar{K}^{*0}$ events from the total $\bar{D}$ tags, 158 ± 22 inclusive Cabbibo-Favored $\bar{K}^{*0}$ events from the neutral $\bar{D}$ tags and 66 ± 16 inclusive Cabbibo-Favored $\bar{K}^{*0}$ events from the charged $\bar{D}$ tags. Figure 3 shows the distribution of the subtracted-sideband-background invariant masses of the $K^+\pi^-$ pairs selected in the recoils. It reflects the net events from the recoils of the tagged $\bar{D}$. After correcting for double counting, we obtain 37.1 ± 15.7 inclusive Cabbibo-Suppressed K^{*0} candidate events in total.

In order to measure the inclusive decay branching fractions, the ratios $R^{\bar{D}^0}_{D^0_{tag}}$ and $R^{\bar{D}^0}_{D^+_{tag}}$ of the numbers of the $\bar{D}^0$ produced separately in the recoils to the numbers of D^0 and the D^+ in the singly tagged sample must be determined. To obtain them, a search for the doubly tagged events $\bar{D}^0 \to K^+\pi^-, K^+\pi^-\pi^-\pi^+$ in the recoil side of the tagged D^0 and D^+ was performed. Figure 4 shows the invariant mass distribution of the combined $K^+\pi^-$ and $K^+\pi^-\pi^-\pi^+$ combinations together observed in the recoils against the (a) D^0 and the (b) D^+ tags. The mass spectra were fit with a Gaussian plus a first-order polynomial to parameterize the background. The standard deviation of the Gaussian distribution was fixed at 23.8 MeV/c^2. The resolution was determined by using a weight factor of $\frac{4207}{4207+2716}$ for the standard deviation of the Gaussian distribution in Figure 1(a) and $\frac{2716}{4207+2716}$ for the standard deviation in Figure 1(b). The fit gives $N^{\bar{D}^0}_{D^0_{tag}} = 140 \pm 12$, and $N^{D^-}_{D^+_{tag}} = 30 \pm 6$. A Monte Carlo study shows that the efficiencies to observe the doubly tagged events are $\epsilon_{\bar{D}^0 \to K^+\pi^-} = 0.4234$ and $\epsilon_{\bar{D}^0 \to K^+\pi^-\pi^-\pi^+} = 0.1258$. These lead to $R^{\bar{D}^0}_{D^+_{tag}} = 0.5235 \pm 0.1047$ and $R^{\bar{D}^0}_{D^0_{tag}} = 0.7884 \pm 0.0732$, giving $\beta = R^{\bar{D}^0}_{D^+_{tag}}$ and $\eta = 1 - R^{\bar{D}^0}_{D^0_{tag}}$.

6 Results

Inserting the numbers of the inclusive $\bar{K}^{*0}$ events observed in the recoil, the numbers of charged and neutral $\bar{D}$ tags, the efficiency $\epsilon = 0.156 \pm 0.0078$ estimated by Monte Carlo simulation, and the ratios β and η into

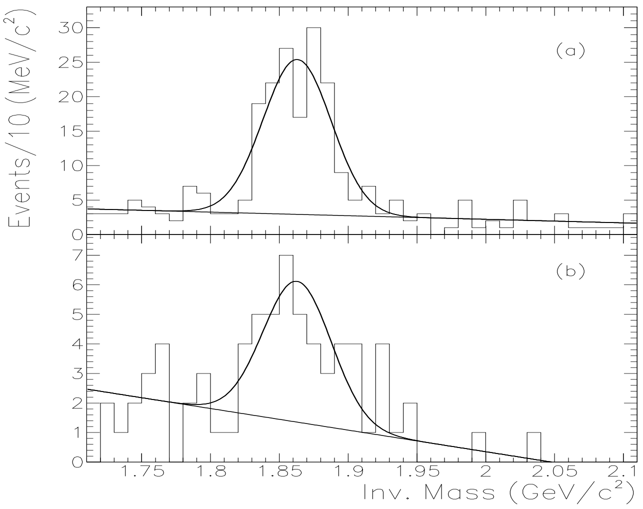

Figure 4: Invariant mass distributions of the combined $K^+\pi^-$ and $K^+\pi^-\pi^-\pi^+$ combinations together observed in the recoils against the D^0 (a) and the D^+ (b) tags.

equations (3) and (4), we determine the inclusive $\bar{K}^{*0}$ decay branching fractions of the charged and the neutral D mesons to be

$$BF(D^+ \to \bar{K}^{*0}X) = (27.7 \pm 14.1 \pm 4.4)\%,$$

and

$$BF(D^0 \to \bar{K}^{*0}X) = (11.1 \pm 5.1 \pm 3.2)\%.$$

To obtain the average inclusive Cabbibo-Favored $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} decay branching fractions of the neutral and the charged D mesons combined together, the 210.5 ± 24.9 and 37.1 ± 15.7 events from the $9157 \pm 279 \pm 136$ D decays have to be corrected with the efficiency ϵ. We obtain the average inclusive Cabbibo-Favored $\bar{K}^{*0}$ decay branching fraction of

$$BF(D \to \bar{K}^{*0}X) = (15.7 \pm 1.9 \pm 1.4)\%,$$

and we place a 90% C.L. upper limit including systematic uncertainty for the Cabbibo-Suppressed K^{*0} decay branching fraction at

$$BF(D \to K^{*0}X) < 4.1\%.$$

Treating our K^{*0} candidates as a signal we obtained the Cabbibo-Suppressed K^{*0} decay branching fraction of

$$BF(D \to K^{*0}X) = (2.6 \pm 1.1 \pm 0.2)\%.$$

In the values of the decay branching fractions, the first errors are statistical and the second systematic. The systematic errors arise from uncertainties ($\pm 0.1\%$, $\pm 1.2\%$, $\pm 0.06\%$ and $\pm 0.06\%$) in the numbers of singly tagged D mesons due to uncertainty in background, uncertainties ($\pm 1.3\%$, $\pm 2.9\%$, $\pm 0.8\%$ and $\pm 0.1\%$) in the efficiency and uncertainties ($\pm 2.5\%$, $\pm 3.0\%$, $\pm 0.0\%$ and $\pm 0.0\%$) in η and β, uncertainties ($\pm 1.6\%$, $\pm 0.9\%$, $\pm 1.2\%$ and $\pm 0.2\%$) in variation in the sidebands (for the neutral, the charged, the total of the neutral and the charged D mesons for Cabbibo-Favored, and for Cabbibo-Suppressed decays, respectively.) The combined effect of these sources is obtained by adding the uncertainties in quadrature, which yield total systematic errors of $\pm 3.2\%$, $\pm 4.4\%$, $\pm 1.4\%$, and $\pm 0.2\%$ for each of the cases.

7 Summary

By using a double tag method, we have measured the inclusive Cabbibo-Favored $\bar{K}^{*0}$ decay branching fractions of the charged and the neutral D mesons of

$$BF(D^+ \to \bar{K}^{*0}X) = (27.7 \pm 14.1 \pm 4.4)\%,$$

and

$$BF(D^0 \to \bar{K}^{*0}X) = (11.1 \pm 5.1 \pm 3.2)\%.$$

We have measured an average Cabbibo-Favored $\bar{K}^{*0}$ decay branching fraction of the D mesons to be

$$BF(D \to \bar{K}^{*0}X) = (15.7 \pm 1.9 \pm 1.4)\%,$$

and placed a 90% C.L. upper limit for the Cabbibo-Suppressed K^{*0} decay branching fraction at

$$BF(D \to K^{*0}X) < 4.1\%$$

for combined signal of the charged and the neutral D mesons produced at $\sqrt{s} = 4.03\ GeV$, respectively. If we treat our K^{*0} candidates as a signal, we obtain a Cabbibo-Suppressed K^{*0} decay branching fraction of $BF(D \to K^{*0}X) = (2.6 \pm 1.1 \pm 0.2)\%$.

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