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

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Using the BES detector at BEPC we have measured the inclusive Cabbibo-Favoured $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} decay branching fractions of neutral and charged D mesons. We obtained the charged and neutral D mesons inclusive Cabbibo-Favoured $\bar{K}^{*0}$ decay branching fractions of $BF(D^+ \to \bar{K^{*0}}X) = (27.5 \pm 13.0 \pm 4.2)\%$, $BF(D^0 \to \bar{K^{*0}}X) = (12.1 \pm 4.3 \pm 2.8)\%$ and an average inclusive Cabbibo-Favoured $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} decay branching fractions of the combined neutral and charged D mesons together to be $BF(D \to \bar{K^{*0}}X) = (15.8 \pm 1.9 \pm 0.8)\%$ and $BF(D \to K^{*0}X) = (2.7 \pm 1.6 \pm 0.8)\%$, respectively.

During the last two decades a lot of progress in heavy flavour physics have been made. Up to now more and more precise measurements of exclusive decay branching fractions and inclusive semileptonic decay branching fractions of charmed and bottom measons have been performing. These make one understand the decay mechanism of heavy flavor mesons better and better. However, the measurement of inclusive $\bar{K}^{*0}$ (Through the paper, reference to a particular charge configuration implies reference to the charge conjugate configuration as well.) decay branching fractions of charmed mesons is not available[1]. These inclusive decay branching fractions may be served as an independent check for a sum of exclusive decay modes containing a $\bar{K}^{*0}$ meson in final states, which can be used to lead one to search for some new decay modes containing the $\bar{K}^{*0}$ in final states and help one understand the decay mechanism better. The values of the decay branching fractions may also be needed as inputs to more precisely simulate the charm decay in accurate measurements of B physics in experiments such as LEP, CDF and B factories, and could be useful for subtracting background in measurements of inclusive $\bar{K}^{*0}$ decay branching fractions of B mesons. Further more the values of inclusive Cabbibo-Favoured $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} decay branching fractions of charmed mesons can provide the valuable information in understanding the weak decay mechanism better.

This paper reports on a first measurement of the inclusive Cabbibo-Favoured $\bar{K}^{*0}$ decay branching fractions of the charged and neutral D mesons using a "method of combining the D^+ and D^0 double tags together", 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 during the 1992, 1993 and 1994 runs.

BES is a conventional cylindrical magnetic detector[2] operated at the Beijing Electron Positron Collider (BEPC)[3]. 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 performs charged track reconstruction and ionization energy loss (dE/dx) measurement 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 scattering electrons are obtained for the data taken at $\sqrt{s} = 4.03$ GeV. A array of 48 scintillation counters surrounds the MDC and measures the time of flight (TOF) of the charged track with a resolution of about 350 ps for the 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. Outsiding the BSC is a solenoidal magnet which 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.

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

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

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 recoiling side 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 values of the decay branching fractions independently.

In the 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 recoiling side 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 numbers of D^- and $\bar{D}^0$ produced in the recoiling system 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 detection efficiency for the K^{*0}, $BF(D^- \to K^{*0}\,X)$ and $BF(\bar D^0 \to K^{*0}X)$ are decay branching fractions to be measured. Similarly, for D^+ tags we have

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

The $N^{D^-}_{D^+_{tag}}$ and $N^{\bar D^0}_{D^+_{tag}}$ are the numbers of D^- and $\bar D^0$ produced in the recoiling system against the tagged D^+. By using the numbers, $N_{D^0_{tag}}$ and $N_{D^+_{tag}}$, of the D^0 and D^+ single tags and the probabilities, η and β, of D^- and $\bar D^0$ appeared respectively in the recoiling side against the tagged D^0 and D^+, we obtained

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

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 the $f = 1/(\epsilon(1-\beta-\eta))$. Where the $\eta = 0.1768 \pm 0.0175$ and $\beta = 0.5460 \pm 0.0622$ were obtained by using the values of $\bar D^* D^*$ and $\bar D^* D(\bar D D^*)$ production cross section measured by the BES experiment[4].

In the data analysis, 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 cadidate 2(or 3 or 4)-charged-track combination, each track must be well reconstructed and consistent with origin in the interaction region. In addition, in order to optimize the momentum resolution and charged particle identification, a geometry cut ($|\, cos\theta \,| \leq 0.8$, 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 (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 the track pass 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 weak 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 corrected momenta components for a small value of shift of magnetic field and ionization loss of the particle in the material interior to the Main Drift Chamber[2] gas. In order to reduce combinatorial background for accumulating the singly tagged D meson sample, a roughly 3σ cut on the momenta is used. In the analysis only the D mesons from the $e^+e^- \to \bar D D^*(D\bar D^*), D^*\bar D^*$ reactions are selected. Figure 1a, 1b and 1c show the invariant mass distributions for the events of which the combinations passed the momentum cuts for the three hadronic decay modes. The spectra were fitted with one Gaussian function and three order polynomial background. After correcting to double counting tags per event, the fit gives 6923 ± 252 neutral and 2234 ± 120 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. These yield 6919 ± 217 neutral and 2241 ± 70 charged D mesons appeared in the recoil.

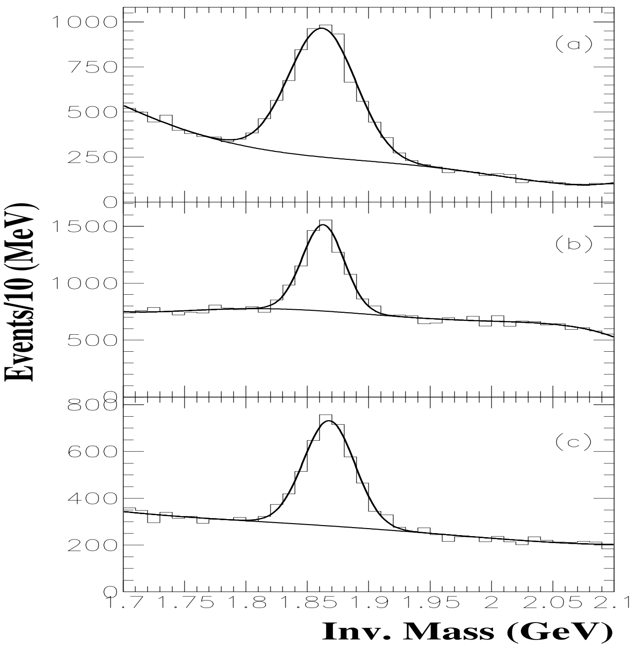

FIG. 1. Distribution of invariant masses of selected (a) $K^\mp\pi^\pm$, (b) $K^\mp\pi^\pm\pi^\pm\pi^\mp$, and (c) $K^\mp\pi^\pm\pi^\pm$ combinations.

The mass regions from 1.7 to 2.1 GeV, but outside $\pm3\sigma_{M_D}$ of the fitted D^0 and D^+ masses for each of the three tag modes as shown in figure 1, are defined as sideband background control regions. The inclusive $\bar K^{*0}$ meson is reconstructed in its $\bar K^{*0} \to K^-\pi^+$ mode in the recoil system against both the $\bar D$ tags and the $\bar D$ sidebands. Figure 2c shows distribution of the subtracted-sideband-backgroud 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 the figure 2c into two groups and histograming them for the neutral and charged $\bar D$ tagged events separately, we obtained figure 2a and 2b. After correcting to double counting tags per event, we obtained 226.3 ± 26.6 inclusive Cabbibo-Favoured $\bar K^{*0}$ events from the total $\bar D$ tags, 159.7 ± 21.7 inclusive Cabbibo-Favoured

$\bar{K}^{*0}$ events from the neutral $\bar{D}$ tags and 66.6 ± 15.4 inclusive Cabbibo-Favoured $\bar{K}^{*0}$ events from the charged $\bar{D}$ tags.

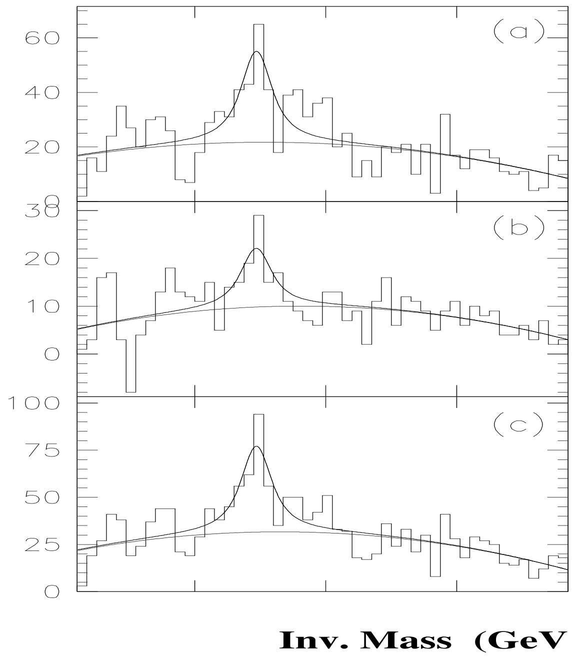

FIG. 2. Distributions of the invariant masses of $K^-\pi^+$ combinations for Cabbibo-Favoured decay modes of the D mesons from the recoiling system against the tagged (a) neutral $\bar{D}$, (b) charged $\bar{D}$, and (c) combined the neutral and charged $\bar{D}$ mesons together.

Figure 3a shows the inclusive $K^+\pi^-$ invariant mass distributions for the events of which the tagged $\bar{D}$ mesons observed in the tag side. We totaly observed 100.9 ± 18.7 inclusive K^{*0} events. Figure 3b shows the inclusive $K^+\pi^-$ invariant mass distributions for the events of which the $Kn\pi$ invariant mass within the $\bar{D}$ sideband were observed in the tag side. There are 58.0 ± 14.6 inclusive K^{*0} events. After substracting these sideband background and correcting to double counting tags per event, we obtained 39.0 ± 22.2 inclusive Cabbibo-Suppressed K^{*0} signal events in total.

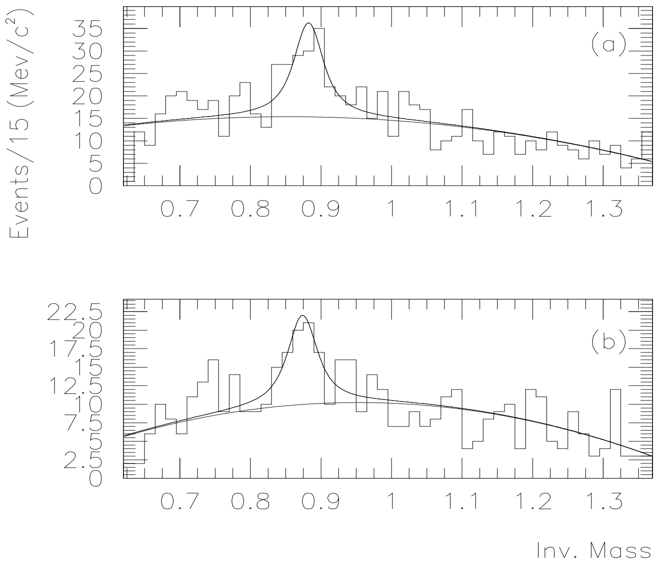

FIG. 3. Distributions of the invariant masses of $K^+\pi^-$ combinations for Cabbibo-Suppressed decay modes of the D mesons from the recoiling system against the tagged neutral and charged $\bar{D}$ mesons together.

Using the relations of decay branching fraction (3) and (4), the numbers of the inclusive $\bar{K}^{*0}$ events observed in the recoil side, the number of the charged and neutral $\bar{D}$ tags, the efficiency $\epsilon = 0.156 \pm 0.0078$ estimated by Monte Carlo simulation, and the probabilities η and β, we obtained the inclusive decay branching fractions of charged and neutral D mesons to be

$$BF(D^+ \to \bar{K}^{*0}X) = (27.5 \pm 13.7 \pm 4.2)\%,$$

and

$$BF(D^0 \to \bar{K}^{*0}X) = (12.1 \pm 4.3 \pm 2.8)\%.$$

In order to obtain the average inclusive Cabbibo-Favoured $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} decay branching fraction of the neutral and charged D mesons combined together, the 226.3 ± 26.6 and 39.0 ± 22.2 events from the 9160 D decays have to be corrected with the efficiency ϵ. We obtained the average inclusive Cabbibo-Favoured $\bar{K}^{*0}$ decay branching fraction of

$$BF(D \to \bar{K}^{*0}X) = (15.8 \pm 1.9 \pm 0.8)\%,$$

and Cabbibo-Suppressed K^{*0} decay branching fraction of

$$BF(D \to K^{*0}X) = (2.7 \pm 1.6 \pm 0.8)\%.$$

In the values of the decay branching fractions, the first errors are statistical and 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 $\pm 0.8\%$) in the efficiency and uncertainties ($\pm 2.5\%$, $\pm 3.0\%$, $\pm 0.0\%$ and $\pm 0.0\%$) of η and β which are due to uncertainties in values of production cross section measured (for neutral, charged, the total neutral and charged D mesons for Cabbibo-Favoured, and Cabbibo-Suppressed decays, respectviely.). The combined effect of these sources is obtained by adding in the uncertainties in quadrature, which yields a total systematic errors of $\pm 2.8\%$, $\pm 4.2\%$, $\pm 0.8\%$ and $\pm 0.8\%$ for the each case. For estimate of the systematic errors, the uncertainty in luminosity is also taken into account (in η and β).

In summary, by using the "method of combining D^+ and D^0 double tags together", we have measured the inclusive Cabbibo-Favoured $\bar{K}^{*0}$ decay branching fractions of the charged and the neutral D mesons of

$$BF(D^+ \to \bar{K}^{*0}X) = (27.5 \pm 13.0 \pm 4.2)\%,$$

and

$$BF(D^0 \to \bar{K}^{*0}X) = (12.1 \pm 4.3 \pm 2.8)\%.$$

We have measured an average Cabbibo-Favoured $\bar{K}^{*0}$ and Cabbibo-Suppressed K^{*0} decay branching fractions of the combined the neutral and the charged D mesons of

$$BF(D \to \bar{K}^{*0}X) = (15.8 \pm 1.9 \pm 0.8)\%,$$

and

$$BF(D \to K^{*0}X) = (2.7 \pm 1.6 \pm 0.8)\%.$$

[1] R.M Barnett et al. (Particle Data Group), Review of particle properties, Phys. Rev. D54(1996)445, 455.

[2] J.Z. Bai et al, Nucl. Instr. and Methods A 344(1994)319.

[3] M. H. Ye and Z.P. Zheng, Proceeding of the XIV International Symposium on Lepton and Photon Interaction, Stanford, California, 1989 (World Scientific, Singapore, 1990)

[4] H.W. Zhao "$D^{\pm}$, D^0, $\bar{D}^0$ Single Tag and the Measurement of Production Cross Section at Ecm=4.03 GeV in e^+e^- Annihilation", Oct, 1995