An Analysis Note on

Direct Measurement of $\mathrm{Br}(\mathrm{D_S^+} \to \overline{\mathrm{K^{*0}}}\mathrm{X})$ and $\mathrm{Br}(\mathrm{D_S^+} \to \mathrm{K^{*0}X})$

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Abstract

We report a first measurement of the absolutely inclusive $\overline{K^{*0}}$ and/or K^{*0} branching fractions of D_S^+ meson, using a data sample of 22.3 pb^{-1} collected with BES detector at BEPC e^+e^- Collider at $\sqrt{s} = 4.03$ GeV. At this energy, D_S^+ is produced in pair in $e^+e^- \to D_S^+D_S^-$. We reconstructed $183.6 \pm 24.0 \pm 6.5$ singly tagged D_S^- decay events in five hadronic decay modes. In the system recoiling against these tagged D_S^-, we observed 7.5 ± 4.4 candidates of $D_S^+ \to \overline{K^{*0}}$X events. We do not observed significant signal for $D_S^+ \to K^{*0}$X. These lead to the absolute branching fractions $Br(D_S^+ \to \overline{K^{*0}}\mathrm{X}) = (20.3 \pm 11.9 \pm 1.8)\%$, and $Br(D_S^+ \to K^{*0}\mathrm{X}) < 7.5\%$ at 90% confidence level.

I. INTRODUCTION

During the last two decades much progress in heavy flavor physics have been made. Up to now more and more precision measurements of exclusive decay branching fractions of charmed mesons have been done. However, experimental studies of inclusive decay properties of the charmed mesons are still limited. Previously, we reported the absolute inclusive branching fractions of $D_S^+ \to e^+X$[1], and $D_S^+ \to \phi X$[2]. Here we report the absolutely inclusive branching fractions of $D_S^+ \to \overline{K^{*0}}X$ (Throughout this paper, charge conjugation of all particles is implied.) and $D_S^+ \to K^{*0}X$. These inclusive decay branching fractions could be served as an independent check for a sum of exclusive decay modes containing a $\overline{K^{*0}}$ or a K^{*0} meson in final states, which can be used to lead one to search for some new decay modes containing $\overline{K^{*0}}$ or K^{*0} in final states. The values of the decay branching fractions may also be needed as inputs to more precisely simulate the charm decay in accurate measurements of branching fractions of B mesons in experiments such as LEP, CDF and B factories, and could be useful for subtracting background in experimental study of B meson decays.

In this paper, we report a direct measurement of the inclusive decay branching fractions of $D_S^+ \to \overline{K^{*0}}X$ and $D_S^+ \to K^{*0}X$ using the data collected with BES detector at BEPC e^+e^-Collider at $\sqrt{s} = 4.03$ GeV.

II. THE BEIJING SPECTROMETER AND DATA SAMPLE

The BES detector has been described in details elsewhere[3]. 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)[4]. 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 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), a 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). An end-cap time-of-flight and shower counters extend coverage to the forward and backward regions.

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

III. SINGLE D_S^- TAGS

At the center-of-mass energy of $\sqrt{s} = 4.03$ GeV, D_S^- mesons are produced only in pair in the process of $e^+e^- \to D_S^+ D_S^-$. The energy of D_S^- equals to the beam energy $E_{beam} = 2.015$ GeV. Hence the beam-energy-constraint can be imposed on the measured momenta of D_S daughter particles via a kinematic fit to improve the measured D_S mass resolution. This constraint is applied in the reconstruction of singly tagged D_S^- mesons.

D_S^- mesons are reconstructed in five hadronic decay modes $\phi\pi^-$, $K^{*0}K^-$, $K_S^0K^-$, $K_S^0K^+\pi^-\pi^-$, and $f_0\pi^-$ with subresonances decaying as $\phi \to K^+K^-$, $K^{*0} \to K^+\pi^-$, $K_S^0 \to \pi^+\pi^-$, and $f_0 \to \pi^+\pi^-$. Events used in the single tag are required to contain at least three reconstructed charged tracks with good helix fits. In order to ensure good momentum resolution and charged particle identification, the tracks are required to be within $|cos\theta| < 0.8$, where θ is the polar angle. All tracks, save those from K_S^0 decays, must originate from the interaction region. Pions and kaons are identified by means of TOF and dE/dx measurements. Identification requires consistency with the pion or kaon hypothesis at a confidence level greater than 0.1% (or 1%). In order to reduce misidentifications, kaon candidates are further required to have a larger confidence level for the kaon hypothesis than for the pion hypothesis. For the $f_0\pi^-$ mode, all pion candidates are required to have a larger confidence level for the pion hypothesis than for the kaon and electron hypothesis.

In order to reduce background a difference between the measured energy of the D_S^- candidates and the beam energy $|E_{diff}|$ is required to be less than 50 MeV for $\phi\pi^+$ and $\overline{K}^{*0}K^+$ modes, 30 MeV for $f_0\pi^+$ mode. For the modes containing a K^0 an asymmetric cut $-50 < E_{diff} < 20$ MeV is imposed. Candidate D_S^- decays are subject to beam energy constrained kinematic fit and required to have the fit confidence level greater than 1% for $\phi\pi^+$ and $\overline{K}^{*0}K^+$ modes, greater than 6% for $K_S^0K^-$ and $K_S^0K^-\pi^+\pi^+$ modes, and greater than 10% for $f_0\pi^+$ mode. Backgrounds can be further reduced by applying a mass cut on the subresonances which are defined as follows: $|M_{K^+K^-} - M_\phi| < 18$ MeV/c^2, $|M_{K^+\pi^-} - M_{K^{*0}}| <$ 70 MeV/c^2, $|M_{\pi^+\pi^-} - M_{K_S^0}| < 22$ MeV/c^2, and $|M_{\pi^+\pi^-} - M_{f_0}| < 30$ MeV/c^2. The cosine of the polar angle in the K^{*0} helicity frame is required to be $|\cos\theta_h| > 0.35$ to reduce background in the $K^{*0}K^-$ mode. For the $f_0\pi^-$ mode, the cosine of the D_S^- production angle relative to beam direction is required to be $|cos\theta| < 0.6$. For the K_S^0 reconstruction, we require the momentum vector of the two oppositely charged pions to be aligned with the position vector of the secondary vertex in the xy plane with a confidence level greater than 10%. The secondary vertex is required to be greater than 0.4 cm away from the collision point in xy plane, and the z coordinates of the two pion tracks to be within 4 cm of the secondary vertex.

After applying the above cuts, signals for D_S^- are clearly evident in the invariant mass spectra for each decay mode as shown in Figure 1(a-g). The figure 1(f) shows the combined invariant masses of the five tagged modes. In the figure the lower peak beside D_S^- is mainly due to $D^- \to K_S^0\pi^-$ and $D^- \to K_S^0K^-\pi^+\pi^+$ produced via $e^+e^- \to DD^*$, where the pion is misidentified as a kaon. A fit to the mass spectra with a Gaussian function for the D_S^- signal and a quadratic function for combinatorial background and another Gaussian function for the $D^- \to \overline{K_S^0}\pi^-$ and $D^- \to K_S^0K^-\pi^+\pi^+$ background yields a total number of $183.6\pm24\pm6.5$ singly tagged D_S^- mesons. The first error is statistical, the second systematic evaluated by varying the parameterization of the background.

IV. CANDIDATES OF $D_S^+ \to \overline{K^{*0}}$X AND $D_S^+ \to K^{*0}$X

To measure the inclusive $\overline{K^{*0}}$ and/or K^{*0} decay branching fractions of D_S^+ meson, the $\overline{K^{*0}}$ and/or K^{*0} mesons are need to be searched for in the system recoiling against the tagged D_S^-. The $\overline{K^{*0}}$ (K^{*0}) meson is reconstructed through its decay to $K^-\pi^+$ ($K^+\pi^-$).

Figure 2 shows a scatter plot of the invariant masses of the $K^-\pi^+$ combinations VS the invariant masses of the $nKm\pi$ (where the n=0, 1 or 2 and the m=1, 2, 3 or 4) of the tags. There is a concentration around the cross bands of D_S^- and $\overline{K^{*0}}$ signal regions. This concentration corresponds to the $D_S^+ \to \overline{K^{*0}}$X signal events. By selecting the events for which the tagged masses are required to be within the D_S^- mass region ($1.958 - 1.982$ GeV/c^2) and projecting them onto the vertical scale of the figure 1, we obtained a invariant mass distribution (unshaded histogram) of the $K^-\pi^+$ combinations as shown in figure 3. A fit to the $K^-\pi^+$ mass spectra (unshaded histogram) with a Breit Wigner function involved a Gaussian resolution function plus a 1 order porlynomail gives 8.5 ± 4.2 candidate events. In order to estimate the number of background due to non D_S^+ decay, the invariant masses of $K^-\pi^+$ combinations for the events for which the tagged masses are outside the D_S^- mass region ($1.85 - 1.95$ GeV/c^2) are also projected onto the vertical scale of the figure 1 (shaded histogram). Here in the figure, the number of the events has been normalized to the number of the background events in the tagged D_S^- mass region. Fitting to this mass spectra with the same functions, we obtained 1.04 ± 1.10 $\overline{K^{*0}}$ events which are not due to D_S^+ decay. After subtracting this sideband background, a number of 7.5 ± 4.3 $D_S^+ \rightarrow \overline{K^{*0}}$X signal events are obtained.

Similarly, figure 4 shows the distribution of invariant masses of the $K^+\pi^-$ combinations for the events for which the tagged masses are within (unshaded histogram) and outside (shaded histogram) the D_S^- mass region as defined above. There is no significant signal found. Fitting to this unshaded histogram (shaded histogram) with the functions as mentioned before and fixed the peak at 0.892 and the standard deviation of 8.7 MeV/c^2 as obtained from Monte Carlo data, we obtained 1.2 ± 2.3 (1.1 ± 0.8) events for the $D_S^+ \rightarrow K^{*0}$X (for the non $D_S^+ \rightarrow K^{*0}$X) decay. After subtracting the D_S^- sideband background, we obtained 0.1 ± 2.4 $D_S^+ \rightarrow K^{*0}$X candidate events.

V. RESULT

The inclusive branching fraction is obtained based on the number $N(D_S^+ \rightarrow \overline{K^{*0}}/K^{*0}\mathrm{X})$ of $D_S^+ \rightarrow \overline{K^{*0}}/K^{*0}$X events, the number $N_{D_S^-}$ of the singly tagged D_S^-, and the efficiency $\epsilon_{D_S^+ \rightarrow \overline{K^{*0}}\mathrm{X}}$ by

$$Br(D_S^+ \rightarrow \overline{K^{*0}}/K^{*0}\mathrm{X}) = \frac{N(D_S^+ \rightarrow \overline{K^{*0}}/K^{*0}\mathrm{X})}{\epsilon_{D_S^+ \rightarrow \overline{K^{*0}}\mathrm{X}} \times N_{D_S^-}}.$$

The inclusive $\overline{K^{*0}}$ or K^{*0} double tag efficiency, $\epsilon_{D_S^+ \rightarrow \overline{K^{*0}}\mathrm{X}}$ was determined by using Monte Carlo simulation. The efficiency was found to be $\epsilon_{D_S^+ \rightarrow \overline{K^{*0}}\mathrm{X}} = 0.2014 \pm 0.009$.

Based on 7.5 ± 4.4 $D_S^+ \rightarrow \overline{K^{*0}}$X events, and assuming 0.1 ± 2.4 $D_S^+ \rightarrow K^{*0}$X events, the inclusive branching fractions

$$Br(D_S^+ \rightarrow \overline{K^{*0}}\mathrm{X}) = (20.3 \pm 11.9 \pm 1.8)\%,$$

and

$$Br(D_S^+ \rightarrow K^{*0}\mathrm{X}) < 7.5\% \text{ at } 90\% \text{ C.L.}$$

are obtained. Where the first error is statistical and the second systematic, mainly estimated on the basis of the changes of $Br(D_S^+ \rightarrow \overline{K^{*0}}\mathrm{X})$ due to uncertainty in MC inclusive $\overline{K^{*0}}$ efficiency and uncertainty in the number of the tagged D_S^- mesons. The combined effect of these sources is obtained by adding in the uncertainties in quadrature. The upper limit of $Br(D_S^+ \rightarrow K^{*0}\mathrm{X}) < 7.5\%$ at 90% C.L. includes the systematic uncertainties.

Table 1 summarizes the sums of all decay branching fractions, quoted from PDG98[5], for the exclusive decay modes containing a $\overline{K^{*0}}$ and/or a K^{*0} in the final states. The sums of the exclusive branching fractions are $Br(D_S^+ \rightarrow \overline{K^{*0}}\mathrm{X}) = (9.1 \pm 2.7)\%$ and $Br(D_S^+ \rightarrow K^{*0}\mathrm{X}) = (0.7 \pm 0.29)\%$. Our measured most probable value of inclusive $\overline{K^{*0}}$ branching fraction of D_S^+ is larger than the sum.

TABLES

TABLE I. Decay branching fractions of D_S^+ to final states containing a $\overline{K^{*0}}$ or a K^{*0} meson.

Decay Mode	Branching Fraction (%)
$K^+\overline{K^{*0}}$	3.3 ± 0.9
$K^{*+}\overline{K^{*0}}$	5.8 ± 2.5
Sum	9.1 ± 2.7
$\overline{K^{*0}}\pi^+$	0.65 ± 0.28

VI. CONCLUSION

In summary, the absolutely inclusive $\overline{K^{*0}}$ and K^{*0} decay branching fractions of the D_S^+ meson have directly been measured. From singly tagged sample of $183.6 \pm 24 \pm 6.5$ $D_S^+D_S^-$ pairs, 7.5 ± 4.4 $D_S^+ \to \overline{K^{*0}}$X events are observed, leading to the first measurement of $Br(D_S^+ \to \overline{K^{*0}}\mathrm{X}) = (20.2 \pm 11.9 \pm 1.8)\%$. From this data sample, no $D_S^+ \to K^{*0}$X signal is observed. This leads to $Br(D_S^+ \to K^{*0}\mathrm{X}) < 7.5\%$ at 90% C.L.%.

Comparing with the sum of the existing measurements on the exclusive D_S^+ decays containing a $\overline{K^{*0}}$ in the final states, our measured most probable value of the inclusive $\overline{K^{*0}}$ decay branching fraction of D_S^+ meson may indicate that some decays of D_S^+ to $\overline{K^{*0}}$ remain unmeasured.

FIGURES

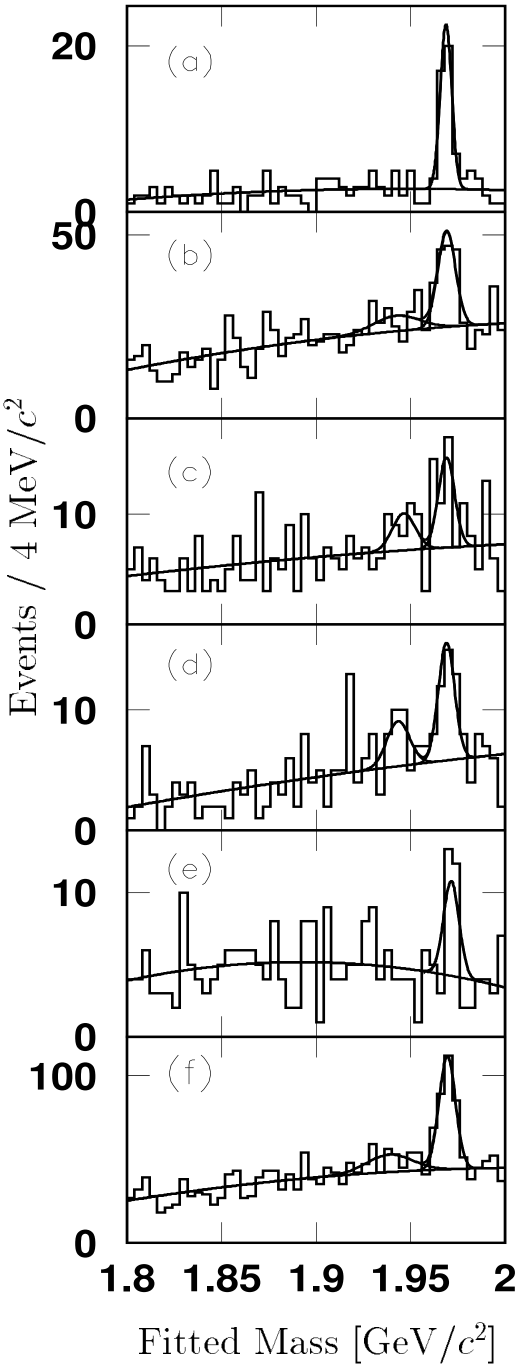

FIG. 1. Distributions of invariant masses of (a) $\phi\pi^+$, (b) $K^{*0}K^-$, (c) $K_S^0K^-$, (d) $K_S^0K^+\pi^-\pi^-$, (e) $f_0\pi^-$ and (f) combined the $\phi\pi^+$, $K^{*0}K^-$, $K_S^0K^-$, $K_S^0K^+\pi^-\pi^-$ and $f_0\pi^-$ together.

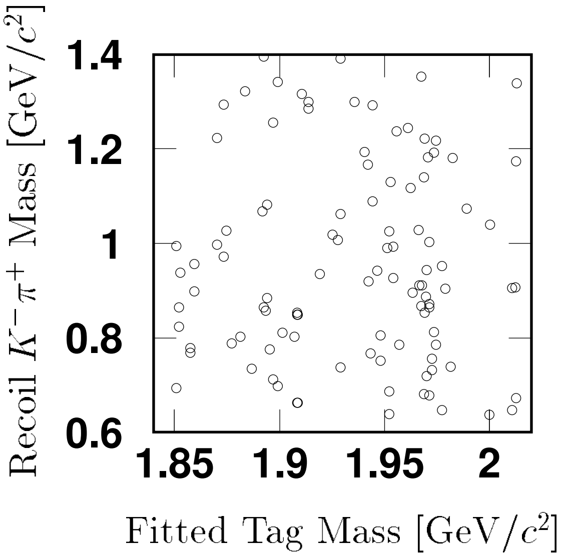

FIG. 2. Scatter plot of the $K^-\pi^+$ Mass VS the fitted tag mass of $mKn\pi$ combinations (D_S^+ tags). See text.

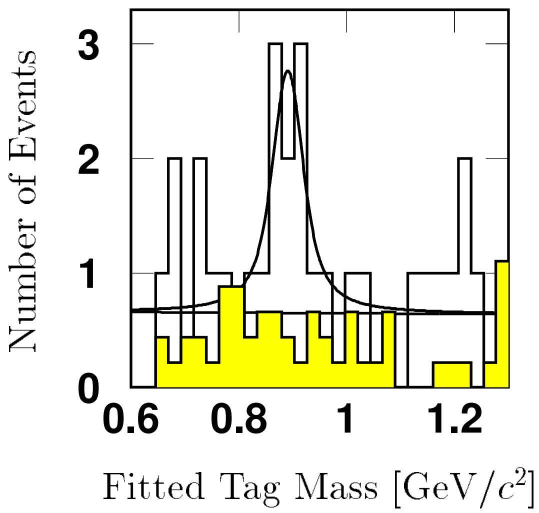

FIG. 3. Distribution of the invariant masses of $K^-\pi^+$ combinations reconstructed in the system recoiling against the tagged D_S^+. See text.

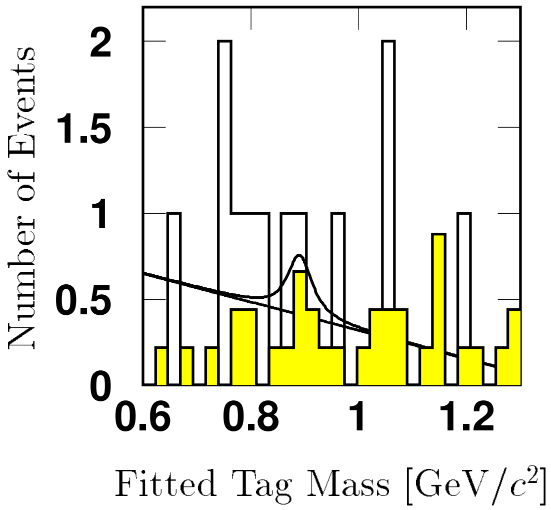

FIG. 4. Distribution of the invariant masses of $K^+\pi^-$ combinations reconstructed in the system recoiling against the tagged D_S^+. See text.

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