Measurement of the Absolute Inclusive Leptonic-Decay Branching Fraction of the D_s^+ Meson

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(Received 26 March 1990)

We have searched for the inclusive reaction $D_s^\pm \to e^\pm X$ using a tagged sample of 68 $D_s^\pm$ produced in the reaction $e^+e^- \to D_s^\pm D_s^\mp$ at a center-of-mass energy of 4.14 GeV. The tagged sample consists of the decays $D_s^+ \to \phi\pi^+$, $D_s^+ \to \bar{K}^{*0}K^+$, and $D_s^+ \to \bar{K}^0 K^+$. We determine $B(D_s^+ \to e^+X) = 0.05^{+0.05}_{-0.05} \pm 0.02$, which corresponds to a limit of $B(D_s^+ \to e^+X) < 0.20$, at the 90% confidence level.

PACS numbers: 13.20.Fc

Although the existence of the D_s^+ meson[1] is well established,[2-4] few of its decay modes have been observed; only hadronic decay modes have been seen, and the corresponding branching ratios have been measured[5-10] only relative to that of the $D_s^+ \to \phi\pi^+$ mode. The lifetime of the D_s^+ is measured[11] to be close to that of the D^0 and less than half that of the D^+. Semileptonic decays of charmed mesons, which do not suffer the theoretical complications of hadronic decays, can provide insight into the mechanism of the weak decay of charmed mesons. The inclusive electronic branching fractions of the D^+ $[B(D^+ \to e^+X) = 0.192]$ and D^0 $[B(D^0 \to e^+X) = 0.077]$ (Ref. 11) are found to have the same ratios as the lifetimes, indicating that the partial widths to leptons of the D^+ and D^0 are identical.[12] If the semileptonic decay of the D_s^+ occurs dominantly via the spectator mechanism as expected, the electronic width of the D_s^+ should be identical to that of the D^+ and D^0. As the D_s^+ lifetime is known, a measurement of the D_s^+ electronic branching ratio allows a test of this assumption, which predicts $B(D_s^+ \to e^+X) = 8\%$. We present herein the first candidates for the semileptonic decay of the D_s^+ and a measurement of $B(D_s^+ \to e^+X)$.

The Mark III experiment has collected a 6.3 pb^{-1} at a center-of-mass energy of 4.14 GeV at the SLAC e^+e^- storage ring SPEAR. At this energy, the D_s^+ is produced primarily in association with the vector D_s^{*-} meson,[9] through the reaction $e^+e^- \to D_s^\pm D_s^{\mp *} \to \gamma D_s^+ D_s^-$. For this analysis, a sample of *tagged* events is obtained by reconstructing hadronic $D_s^\pm$ decays; the charm of the recoil $D_s^\mp$ is therefore *a priori* determined. The reconstructed D_s^+ tag may arise from either production mechanism: $e^+e^- \to D_s^+ D_s^{*-}$ or $e^+e^- \to D_s^{*+} D_s^-$, $D_s^{*+} \to \gamma D_s^+$. We measure the inclusive electronic branching ratio $B(D_s^+ \to e^+X)$ by searching for electrons in the recoil system produced in semileptonic or purely leptonic decays.

The Mark III detector has been described in detail elsewhere.[13] Kaons are identified primarily by using the time-of-flight (TOF) system, which provides greater than 3σ separation of kaons and pions for $p < 800$ MeV/c. For momenta less than 650 MeV/c, specific ionization information from the drift chamber is used when TOF information is lacking. Electrons are identified by a lead-proportional-chamber gas-sampling calorimeter and TOF.

Three channels are used to tag the $D_s^+ D_s^{*-}$ sample: $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$; $D_s^+ \to \bar{K}^{*0}K^+$, $\bar{K}^{*0} \to K^-\pi^+$; and $D_s^+ \to \bar{K}^0 K^+$, $K_S^0 \to \pi^+\pi^-$. More detailed discussions of these decay modes may be found in Refs. 9, 14, and 15. The present analysis has minor differences in particle identification and other selection criteria, made to enhance the signal-to-noise ratio of the tagged sample.

The analysis of $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$ requires no kinematic fitting. Figure 1(a) shows the $\phi\pi^\pm$ invariant

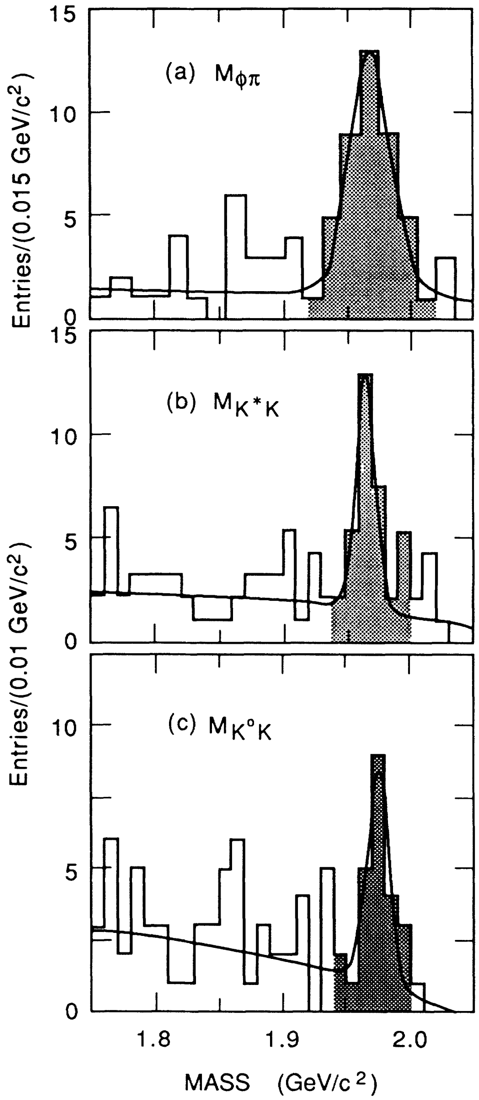

FIG. 1. (a) $M_{\phi\pi}$ when M_{recoil} is required to lie in the range 2.04–2.18 GeV/c^2. (b) M_{K^*K} following a one-constraint fit and the selection criteria described in the text. (c) M_{K^0K} following a two-constraint fit and the selection criteria described in the text. The shaded regions denote events used in the tagged sample. The curves show the results of fits of Gaussian distributions to the signal and polynomial fits to the background.

mass when the recoil mass, calculated using the constraint on the total energy (4.14 GeV), is required to be within 70 MeV/c^2 of the nominal D_s^* mass. Events which satisfy $1.92 < M_{\phi\pi} < 2.02$ GeV/c^2 and $2.04 < M_{\text{recoil}} < 2.18$ GeV/c^2 are selected for the tagged sample. There are 41 such events. The number of signal tagged events, determined by fitting a Gaussian distribution to the data of Fig. 1(a), is $33 \pm 3 \pm 3$. The first error is the statistical error on the number of background events and the second, the uncertainty in the background estimation. The latter is obtained by studying the number of events found under a Gaussian peak with different polynomials used to parametrize the background shape in the signal region. Below the D_s^+ mass region, there are structures due to genuine Cabibbo-suppressed decay modes of the D^+ or misidentified decay products of the D^0 and the D^+, both of which are produced copiously relative to the D_s^+. No enhancement in the D_s^+ signal region for any of the three tagged modes is predicted to arise from D-meson decays or from other D_s^+ decay modes.[16]

In the $D_s^+ \to \bar{K}^{*0} K^+$, $\bar{K}^{*0} \to K^- \pi^+$ analysis, a one-constraint fit is performed with the recoil mass constrained to the D_s^* mass. Figure 1(b) shows the $\bar{K}^{*0} K^+$ invariant-mass distribution. Events for which M_{K^*K} is within 30 MeV/c^2 of the nominal D_s^+ mass are selected for the tagged sample. This yields 31 events, of which $19 \pm 4 \pm 3$ are estimated to be signal, where again the errors are statistical and systematic errors in the background estimation.

For $D_s^+ \to \bar{K}^0 K^+$, $K_S^0 \to \pi^+ \pi^-$, a two-constraint kinematic fit (using the recoil and K^0 masses constraints) is performed. Figure 1(c) shows M_{K^0K} after selection criteria are applied. For the tagged sample, events for which M_{K^0K} is within 30 MeV/c^2 of the nominal D_s^+ mass are selected. There are 24 events which satisfy these criteria; the estimated number of signal events is $16 \pm 3 \pm 2$.

The tracks recoiling against a tag are then examined for electron candidates. Tracks are required to pass within 0.03 m transverse to the beam direction of the event vertex and to enter the central electromagnetic calorimeter ($|\cos\theta| < 0.76$). For tracks with momenta less than 300 MeV/c, the identification is made using TOF. For tracks with momenta greater than 300 MeV/c, a recursive partitioning algorithm,[17] which uses information from the TOF and the shower shape and energy in the electromagnetic calorimeter, is employed to separate electrons from pions. Recoil tracks which satisfy the electron requirements are classified as electrons. All other tracks, including those lacking TOF or shower-counter information, are called pions. Electrons originating from photon conversions in the beam pipe are rejected. A recoil track is classified as right sign (wrong sign) if its charge is opposite (equal to) that of the D_s tag.

The numbers of electrons and pions found for each of the tagged channels are shown in Table I. Electrons are correctly identified with a momentum-dependent probability of 0.76–0.95, as determined using a sample of radiative Bhabha events from the same data set. The radiative Bhabha events provide a clean sample of known electrons, with momenta between 0.1 and 1.5 GeV/c. The momentum-dependent probability to misidentify a pion as an electron ranges from 0.02 to 0.09, as obtained from a study of pions from K_S^0 decays.

The number of *observed* right-sign electrons n_{eR} has two components: electrons which are correctly identified and pions which are misidentified. This also holds for

TABLE I. The tagged D_s^+ channels and the total numbers of observed right- and wrong-sign electrons and pions found in the recoil.

Tag mode	Tagged events	Signal events	Observed electrons n_{eR}	Observed electrons n_{eW}	Observed pions $n_{\pi R}$	Observed pions $n_{\pi W}$
$\phi\pi^+$	41	$33\pm3\pm3$	2	0	39	14
$\bar{K}^{*0}K^+$	31	$19\pm4\pm3$	3	0	35	23
$\bar{K}^0K^+$	24	$16\pm3\pm2$	1	1	21	6
Totals	96	$68\pm6\pm5$	6	1	95	43

the number of observed wrong-sign electrons n_{eW}. Given the identification probabilities, the numbers of *produced* electrons can be unfolded and the branching ratio determined. The number of produced wrong-sign electrons N_{eW} is due solely to charge-symmetric background, such as charged-kaon decays, and to photon conversions and Dalitz decays, in which one of the charged tracks has been missed. The total number of produced right-sign electrons N_{eR} is due to semileptonic D_s decay, to charge-symmetric background, and to excess right-sign electrons resulting from D^0 and D^+ decays.

The branching ratio is expressed as

$$B(D_s^+ \to e^+X) = \frac{N_{eR} - N_{eW} - N_b}{\epsilon N_{\text{tags}}}, \qquad (1)$$

where the efficiency ϵ reflects the geometric acceptance (0.73), N_{tags} is the produced number of tagged signal events, and N_b is the expected number of background electrons due to semileptonic D^+ and D^0 decays. The value of N_b is determined to be 0.32 ± 0.20, by using events found in the sidebands of the D_s^+ mass region for the decay $D_s^+ \to \bar{K}^{*0}K^+$, the only tagged channel which suffers from significant D contamination. A joint likelihood function $\mathcal{L}$, the product of five likelihood functions,[18] is used to unfold the numbers of produced right- and wrong-sign electrons, the number of produced right- and wrong-sign pions, and the number of produced tagged events, and to thus best estimate the branching ratio and the statistical errors. Poisson statistics are used for the numbers of electrons and Gaussian statistics are used for the numbers of pions and the number of tags, where the error on the number of tags is due to statistical fluctuations of the background. The probability distribution for the number of right-sign electrons, one of five factors of $\mathcal{L}$, is given by

$$F = \frac{\{\exp[-(P_{ee}^R N_{eR} + P_{\pi e}^R N_{\pi R})]\}(P_{ee}^R N_{eR} + P_{\pi e}^R N_{\pi R})^{n_{eR}}}{n_{eR}!}, \qquad (2)$$

where n_{eR} is the number of observed right-sign electrons (equal to 6), N_{eR} is the number of produced right-sign electrons, and $N_{\pi R}$ is the number of produced right-sign pions. The overall probability to identify an electron, P_{ee}^R, determined using the observed momentum spectrum of the right-sign electrons opposite the tags, is equal to 0.85. The overall probability to misidentify a pion as an electron, $P_{\pi e}^R$, determined using the observed momentum spectrum of right-sign recoil pions, is 0.039. The wrong-sign electrons obey a similar Poisson distribution, in which the number of observed wrong-sign electrons $n_{eW}=1$. The wrong-sign identification probabilities, obtained in the same manner, are $P_{ee}^W=0.91$ and $P_{\pi e}^W=0.035$.

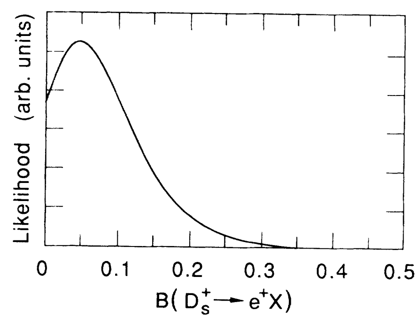

FIG. 2. The likelihood function $\mathcal{L}$ vs the branching ratio $B(D_s^+ \to e^+X)$.

The likelihood function $\mathcal{L}$ is maximized for given values of the branching ratio by varying the five parameters N_{eR}, N_{eW}, $N_{\pi R}$, $N_{\pi W}$, and N_{tags}, subject to the constraint given by Eq. (1). Figure 2 shows $\mathcal{L}$ vs $B(D_s^+ \to e^+X)$. The maximum of $\mathcal{L}$ occurs at a branching ratio of $B(D_s^+ \to e^+X) = 0.05$. The statistical errors, determined by integrating $\mathcal{L}$ from 0 to 1, are those values on either side of the most likely value, such that the integral between the value and the most likely value is 34% of the total area. The systematic error arises from uncertainties in the classification probabilities (up to 15%), the systematic error on the number of tags (7%), the uncertainty in the geometric acceptance and detector efficiency (5%), and the error due to track quality criteria (1%). We obtain

$$B(D_s^+ \to e^+X) = 0.05^{+0.05}_{-0.05} \pm 0.02, \qquad (3)$$

where the first error is statistical[19] and the second is systematic. This corresponds to a limit of $B(D_s^+ \to e^+X) < 0.20$ at the 90% confidence level, including the systematic error, obtained by integrating $\mathcal{L}$. The probability that the expected background due to pion misidentification of 3.7 right-sign electrons and 1.5 wrong-sign electrons has fluctuated to produce the observed difference in the numbers of right- and wrong-sign electrons is less than 0.17.

We have presented the first candidates for the semileptonic decay of the D_s^+ meson, finding an absolute branching fraction which is in agreement with the value of 0.08 which is predicted by the spectator model of semileptonic charmed quark decay. This represents the first measurement of an absolute branching ratio in D_s^+

decay. Using this branching ratio and the measured D_s^+ lifetime, we obtain a semileptonic width $\Gamma(D_s^+ \to e^+X) = (1.1 \pm 1.2) \times 10^{11}\ \mathrm{s}^{-1}$, in agreement with the semileptonic widths $\Gamma(D^0 \to e^+X) = (1.80 \pm 0.26) \times 10^{11}\ \mathrm{s}^{-1}$ and $\Gamma(D^+ \to e^+X) = (1.80 \pm 0.20) \times 10^{11}\ \mathrm{s}^{-1}$. While limits on the branching ratios of specific semileptonic modes relative to hadronic modes may be obtained,[20] theoretical assumptions must be made to extract the absolute branching ratio. In contrast, our measurement provides an absolute scale for the magnitude of all semileptonic decays.

We gratefully acknowledge the dedicated efforts of the SPEAR staff. This work was supported by the Department of Energy, under Contracts No. DE-AC03-76SF00515, No. DE-AC02-76ER01195, No. DE-AC03-81ER40050, No. DE-AC02-87ER40318, and No. DE-AM03-76SF00034, and the National Science Foundation.

[1]Throughout this paper, reference to a charged state implies the charge-conjugate state as well.

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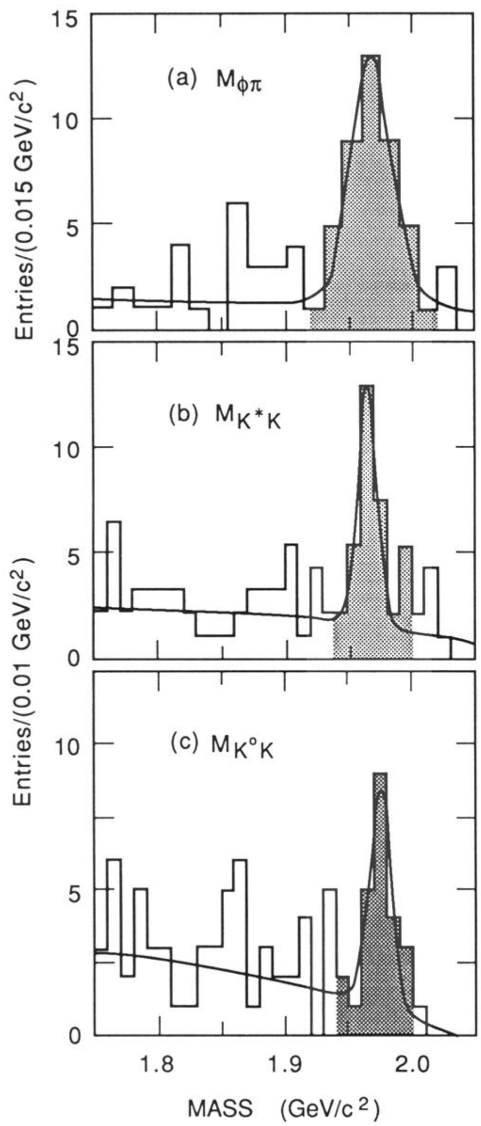

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