Production of Charmed Mesons in e^+e^- Annihilation at 10.5 GeV

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A measurement is presented of the inclusive production of charged D^* and neutral D mesons from nonresonant e^+e^- annihilation in the energy region near the $\Upsilon(4S)$ resonance. The momentum distribution shows a large contribution at high momenta as expected for heavy quark production. Comparison of the spectrum with several phenomenological models is made. The relative yields of the D^* and D mesons indicate that the charm cross section is dominated by the D^* contribution.

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The nonresonant annihilation of e^+e^- into hadrons is described in a simple quark model by the formation of $q\bar{q}$ pairs which subsequently fragment into two hadron jets. The possibility of understanding the behavior of the primary quark and antiquark in the jets is limited in the case of the light quarks (u,d,s), since the hadron carrying the primary quark is not distinguishable from other light hadrons. In contrast, a heavy primary quark may be readily identified because the production of additional heavy quarks is suppressed by phase space. The momentum distribution of charmed hadrons therefore gives insight into the mechanism of quark hadronization.

In an earlier publication[1] we reported the cross section for the production of charged D^* mesons in nonresonant e^+e^- annihilation in the Υ energy region. Several groups have reported D^* production at substantially higher energies.[2] At our energy there is a larger cross section and no contribution from b quarks, which decay primarily to c quarks.[3] In this paper we present an improved measurement of the charged D^* inclusive cross section and a new measurement of the D^0 production cross section. Combining these results, we estimate the direct production of D^0 mesons.

Data were collected with the CLEO detector[4] at the Cornell Electron Storage Ring (CESR), running at energies on the $\Upsilon(4S)$ resonance (10.568 to 10.588 GeV) and below (10.378 to 10.558 GeV). The total data sample consisted of 150 000 nonresonant hadronic events, corresponding to an integrated luminosity of 59 pb^{-1} at an average center-of-mass energy of 10.5 GeV. The detection of both $D^{*\pm}$ and D^0 for this work was accomplished with use of only information supplied by the CLEO central drift chamber[4] $\{\delta p/p = [0.012\ (\text{GeV}/c)^{-1}]p \text{ rms}\}$, with no supplementary particle identification.

Charged D^*'s were observed via the decay sequence $D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$ (when referring to a given state, we imply both the state and its charge conjugate). The analysis procedure takes advantage of the 1.2-MeV resolution (rms) in the mass difference $\Delta M = M_{K\pi\pi} - M_{K\pi}$ to enhance the D^* signal relative to the background.[1,2] We require $|\Delta M - 145.4\ \text{MeV}/c^2| < 1.5\ \text{MeV}/c^2$. The resulting K-π mass distribution for $p_{K\pi\pi} > 3$ GeV/c is shown in Fig. 1.

For the D^0 inclusive analysis the D^0 was identified through the decay $D^0 \to K^-\pi^+$. In each event all pairs of oppositely charged tracks were given the two assignments (K,π) and (π,K), which were treated independently. To be considered further an assignment was required to have $|\cos\theta_K| < 0.75$, where θ_K is the angle in the K-π rest frame between the K direction and the boost axis. Thus a given pair of tracks could contribute zero, one, or two D^0 candidates. Since the D^0 is spinless the signal has a flat $\cos\theta_K$ distribution. In contrast we found the background strongly peaked at $\cos\theta_K = \pm 1$. The θ_K requirement reduces the background by a factor of 3. The resulting distribution of invariant masses for $p_{K\pi} > 2.5$ GeV/c is shown in Fig. 2.

To obtain the charm fragmentation functions the data were divided according to the momentum of the D^* or D^0 candidate. For momenta less than 2.4 GeV/c we included only data collected on the continuum (17 pb^{-1}) to avoid a contribution to the charmed mesons from the decay of B mesons at the $\Upsilon(4S)$ resonance. The D^{*+} and D^0 yields in each momentum interval were obtained by fitting the relevant K-π mass distribution with a

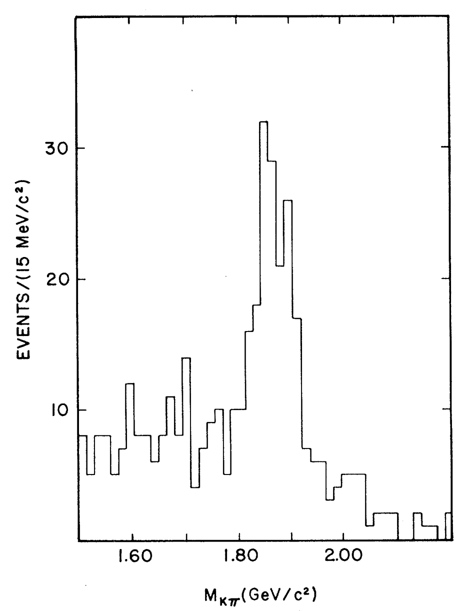

FIG. 1. The $K^-\pi^+$ invariant-mass spectrum, where the three-particle combination $K^-\pi^+\pi^+$ was required to satisfy 143.9 MeV/$c^2 < \Delta M <$ 146.9 MeV/c^2 and $p_{K\pi\pi} > 3$ GeV/c.

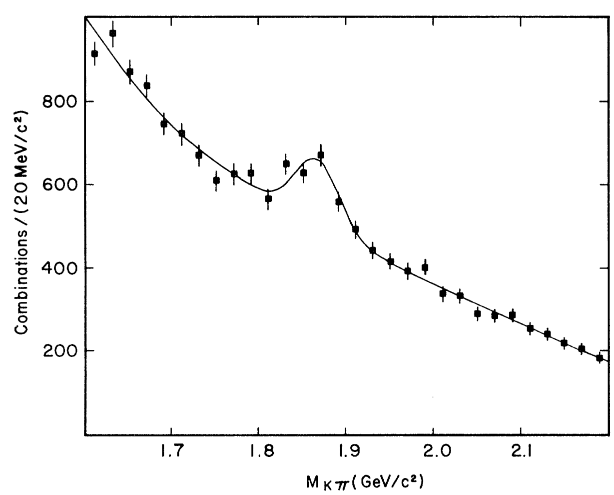

FIG. 2. The $K^-\pi^+$ invariant mass spectrum, where the two-particle system was required to satisfy $|\cos\theta_K| < 0.75$ and $p_{K\pi} > 2.5$ GeV/c. The curve is the result of a fit described in the text.

function consisting of a Gaussian plus a smooth background. After implementing all selection criteria we obtain 268± 21 D^*'s and 644± 80 D^0's.

The event reconstruction efficiencies were estimated with use of a Monte Carlo simulation in which we incorporated the effect of initial-state radiation. We calculate[5] that the probability for an event containing the above low-multiplicity D^0 and D^* decays to pass our criteria for a hadronic event is 89± 5%. The efficiency for detecting the decay chain $D^{*+}\to D^0\pi^+\to K^-\pi^+\pi^+$ is zero at momenta below 0.8 GeV/c, due to the failure of the soft pion resulting from the D^* decay to traverse the central drift chamber, and about 35% for momenta above 2.4 GeV/c. For $D^0\to K^-\pi^+$ the efficiency was 30–45% for all momenta. The branching fraction for the decay $D^0\to K^-\pi^+$ was taken to be 0.030± 0.006.[6] For the decay $D^{*+}\to D^0\pi^+$ we used the value 0.60± 0.15.[7,8]

The resulting charmed-particle cross sections $s\,d\sigma/dx$ as a function of the scaling variable $x=p/p_{\max}$ [$p_{\max}=(E_{\text{beam}}^2-M^2)^{1/2}$, where M is the mass of the meson] are shown in Fig. 3. We have chosen x, rather than the more widely used $z=E/E_{\max}$, because its range [0,1] is the same for all experiments. From a theoretical standpoint x is equivalent to z, since scaling is an asymptotic property. Although one might expect to observe threshold effects in the data collected at low s, we find good agreement between all the experiments plotted in Fig. 3. A similar shape is observed for the charm fragmentation functions extracted from neutrino experiments.[9] We have compared our data to several phenomenological models. One suggested fragmentation function,[10]

$$\frac{d\sigma}{dv}\propto\frac{1}{v[1-1/v-\epsilon_v/(1-v)]^2},$$

can accommodate our D^* data for both $v=x$ and $v=z$. The results of the fits are $\epsilon_x=0.14\pm0.03$ [solid curve in Fig. 3(a)] and $\epsilon_z=0.10\pm0.02$. The same is true for the form[11]

$$\frac{d\sigma}{dv}\propto v^{\alpha}(1-v)$$

for which we find $\alpha_x=1.7\pm0.4$ [dashed curve in Fig. 3(a)] and $\alpha_z=1.7\pm0.5$. The form advocated by Gottschalk[12] cannot be reconciled with our data. Its most striking feature, a peak at $z=1$, is not apparent in our results.

The inclusive production cross sections are 0.87± 0.10± 0.28 nb for charged D^* with $x>0.35$ and 1.6 ± 0.3± 0.3 nb for D^0 with $x>0.3$, where the errors are statistical and systematic, respectively. The systematic error is dominated by the uncertainties in the D^{*+} and D^0 branching ratios. Assuming that charged and neutral D^*'s are produced equally and that the charm cross section comprises $\frac{4}{10}$ of the continuum hadronic cross section (3.3± 0.2 nb at $\sqrt{s}=10.5$ GeV), we calculate that (65± 7± 21)% of charmed quarks produced fragment into D^*'s with $x>0.35$.

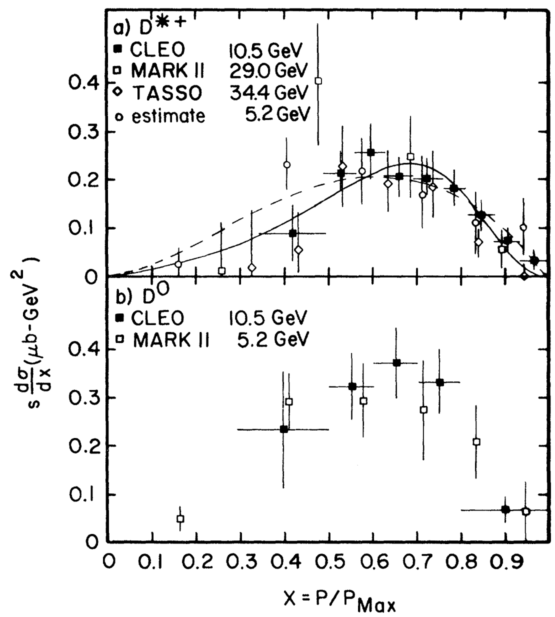

FIG. 3. The cross sections $s\,d\sigma/dx$ for (a) charged D^* and (b) neutral D mesons from various experiments. The $D^{*+}\to D^0\pi^+$ branching ratio is taken (Refs. 7 and 8) to be (60± 15)% for all experiments. D^* data are taken from this experiment, Ref. 2, and Ref. 7. We computed the 5.2-GeV D^* estimate from the average of the D^+ and D^0 Mark II measurements (Ref. 7), assuming that all D mesons come from D^* decays. D^0 data come from this experiment and Ref. 7. The curves are the results of fits to fragmentation models described in the the text.

Our results can be used to estimate how often the fragmentation of a c quark produces a D^0 directly. At 10.5 GeV center-of-mass energy a D^* produced with $x=0.6$ decays to a D with $x=0.55\pm0.01$. We therefore subtract from the cross section for production of D^0's with $x>0.55$ the contribution of D^*'s with $x>0.6$. Since the D^0 is identified by the same decay mode in both analyses, there is a partial cancellation of systematic errors due to the uncertainty in the branching ratio of the D^0 decay. The principal systematic error is thus the uncertainty in the measurement of the branching ratio for the decay $D^{*+}\to D^0\pi^+$. Assuming that all neutral D^*'s decay to D^0 and that neutral D^* production is equal to

TABLE I. Quantities used to calculate the D^0/D^* production ratio.

		Cross section (nb)
(a) $D^{*\pm}$ $(x > 0.6)$	Measured	$0.54 \pm 0.05 \pm 0.17$
(b) $D^0(x > 0.55)$ from $D^*(x > 0.6)$	Calculated from (a)	$0.87 \pm 0.08 \pm 0.28$
(c) $D^0(x > 0.55)$	Measured	$0.98 \pm 0.13 \pm 0.20$
(d) Direct $D^0(x > 0.55)$	Calculated from (b), (c)	$0.12 \pm 0.15 \pm 0.14$
(e) $D^{*\pm}$ $(x > 0.55)$	Measured	$0.65 \pm 0.06 \pm 0.21$

that of charged D^*'s, we obtain a cross section for direct production of D^0's with $x > 0.55$ of $0.12 \pm 0.15 \pm 0.14$ nb. This corresponds to a ratio $0.18 \pm 0.24 \pm 0.25$ for D^0/D^{*+} production with $x > 0.55$. Our results are summarized in Table I. This ratio is consistent both with zero and with $\frac{1}{3}$, the naive prediction of spin counting. From our measurement it seems unlikely that D's and D^*'s are produced equally.

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