Inclusive Charged D^* Production in e^+e^- Annihilations at $W = 10.4$ GeV

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A measurement is presented of inclusive charged $D^*(2010)$ production from nonresonant e^+e^- annihilation in the center-of-mass energy (W) range 10.2 GeV $< W <$ 10.6 GeV. Charged D^* mesons are identified by the decays $D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$ and the charge conjugate mode. It is found that $40 \pm 7 \pm 13\%$ of the charm quarks from the process $e^+e^- \to c\bar{c}$ result in D^* mesons with $z > 0.7$ ($z = 2E/W$, where E is the D^* energy).

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Since the discovery of charmed hadrons,[1] there has been considerable interest in the mechanism for their production. The extraction of production cross sections has been difficult because of large backgrounds and limited statistics.[2,3] We present the first data on charged D^* production far above the charm threshold in e^+e^- annihilation. At large D^* energies, the observed signal is relatively background free, providing direct information on the charm-quark fragmentation function.

The data reported here were taken with the CLEO detector at the Cornell Electron Storage Ring (CESR). The total data set consists of 87 272 hadronic events from an integrated luminosity of 23060 nb^{-1} taken on and near the $\Upsilon(4S)$. A description of the detector may be found elsewhere,[4] but we note that for these data the spectrometer magnet was operated at 1.0 T.

Charged D^* mesons are identified through the cascade $D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$ and the charge-conjugate mode. (For simplicity, we shall assume throughout the paper that when one mode is specified the charge-conjugate mode is also implied.)

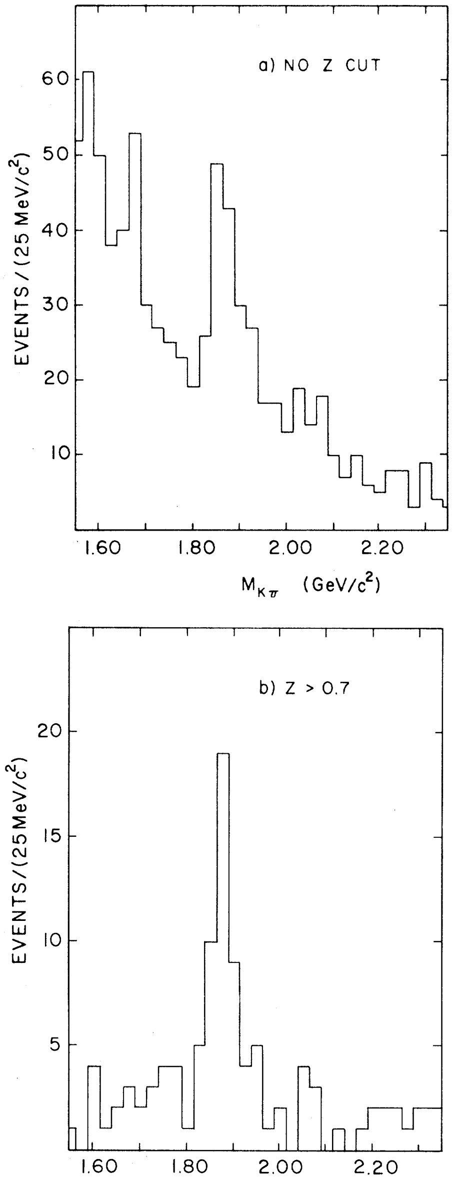

FIG. 1. Invariant mass of $K\pi$ combinations when the $K^-\pi^+\pi^+$-$K^-\pi^+$ or charge-conjugate mass difference, Δ, satisifes 143.8 MeV/$c^2 < \Delta <$ 146.8 MeV/c^2 for (a) no z cut, and (b) $z > 0.7$.

In this analysis, all $K\pi$ and $K\pi\pi$ mass combinations are formed; since pions and kaons are not individually identified, each detected charged particle enters under both K and π mass hypotheses. The geometrical acceptance for charged particles in the central detector is approximately 85% of 4π. Because of the small amount of energy available in the decay $D^{*+} \to D^0\pi^+$ (5.7 MeV in the rest frame of the D^{*+}),[5] the resolution in the $K\pi\pi$-$K\pi$ mass difference is excellent. Our rms momentum resolution measured from μ-pair and Bhabha events is $\Delta p/p = (0.012/\mathrm{GeV})p$.[6] The rms resolution of the $K^-\pi^+\pi^+$-$K^-\pi^+$ mass difference (Δ) is about 1 MeV/c^2.

Figure 1(a) shows the observed $K^-\pi^+$ mass distribution when we require 143.8 MeV/$c^2 < \Delta$ $<$146.8 MeV/c^2. The number of background combinations decreases rapidly with increasing momentum of the $K\pi\pi$ system. This is demonstrated in Fig. 1(b) where we demand the fraction of energy carried by the $K\pi\pi$ to be $z > 0.7$ ($z = 2E/W$, where E is the D^* energy). Figure 2 shows the measured mass difference, Δ, when the $K\pi$ mass is within ±45 MeV/c^2 of the D^0 mass (see Fig. 1),

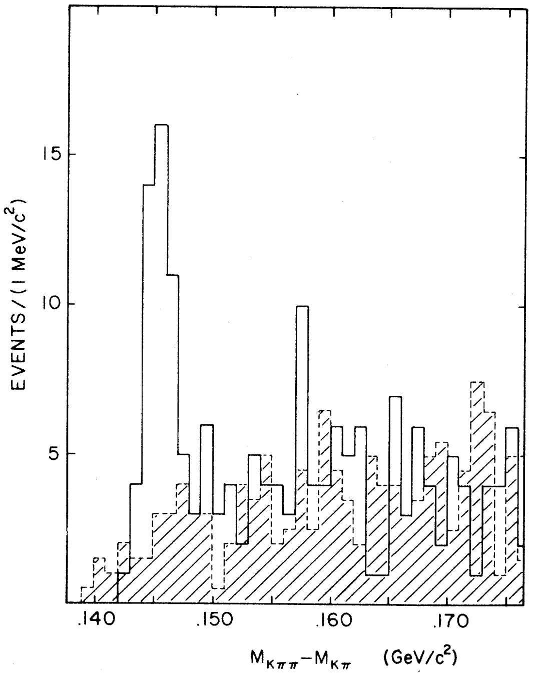

FIG. 2. Distribution of the measured $K^-\pi^+\pi^+$-$K^-\pi^+$ plus charge-conjugate mass difference for $z > 0.7$ when the $K\pi$ mass is within ± 45 MeV/c^2 of the D^0 mass. The shaded histogram is the average of two ± 45 MeV/c^2 intervals of $K\pi$ mass centered 160 MeV/c^2 above and below the D^0 mass.

and when the $K\pi$ mass is just above or below the D^0 mass (shaded).[7] No signal is seen in the non-exotic channel $K^+\pi^-\pi^+$ and the observed Δ distribution is in agreement with the shaded background of Fig. 2.

About 18% of the hadronic events come from $\Upsilon(4S)$ resonant decays. However, since the $\Upsilon(4S)$ decays strongly into $B\bar{B}$ mesons,[8] it cannot contribute any particles with $z > 0.6$ and a negligible amount for $0.5 < z < 0.6$ and therefore does not contaminate our measurement of continuum D^* production.

To identify a D^{*+}, we require that the $K^-\pi^+$ mass be within ±45 MeV/c^2 of the D^0 mass (see Fig. 1), and that Δ be within ±1.5 MeV/c^2 of the D^{*+}-D^0 mass difference (see Fig. 2). The background is determined by using events where the $K\pi$ mass is just above or just below the D^0 mass (see Fig. 2).[9] Figure 3 shows the charged D^* differential cross section $W^2d\sigma/dz$ (circles). The data are corrected for background from random combinations, the branching ratios of $D^{*+} \to D^0\pi^+$ ($44 \pm 10\%$) and $D^0 \to K^-\pi^+$ ($3.0 \pm 0.6\%$),[10] the D^* reconstruction efficiency (18–30%),[11] and the hadronic event selection efficiency ($71 \pm 5\%$). The errors shown in Fig. 3 are statistical only. There is an additional systematic error of 30% primarily due to the lack of a precise measurement of the branching ratios.

The charged D^* cross section is $1.1 \pm 0.3 \pm 0.4$ nb for $z > 0.5$, and $0.6 \pm 0.1 \pm 0.2$ nb for $z > 0.7$, where the errors are statistical and systematic, respectively. At $W = 10.4$ GeV, the simple quark model would imply that $\frac{4}{10}$ of the continuum cross section, 1.5 nb,[12] is due to the process $e^+e^- \to c\bar{c}$ (or equivalently, the charm particle cross section is 3.0 nb). If we assume that the neutral D^* cross section is the same as the charged D^* cross section (isospin invariance), then $40 \pm 7 \pm 13\%$ of the charm quarks from the process $e^+e^- \to c\bar{c}$ result in D^* mesons with $z > 0.7$. The remaining charm particle cross section is $1.8 \pm 0.2 \pm 0.4$ nb. For the case where every charm quark results in a D^* meson, the charged D^* cross section is $0.9 \pm 0.1 \pm 0.2$ nb for $z < 0.7$. In the other extreme where we have equal amounts of direct D and D^* meson production, the charged D^* cross section would be $0.15 \pm 0.1 \pm 0.2$ nb for $z < 0.7$.

The cross section of Fig. 3 is a direct measurement of the charm quark fragmentation function. Also shown in Fig. 3 are charged and neutral D cross sections at $W = 7$ GeV.[2] Our data are consistent with a flat z distribution except near $z = 1.0$. Although details of the shape at low z require further measurements, the observed hard z distribution is in qualitative agreement with the theoretical expectations for heavy-quark fragmentation.[13]

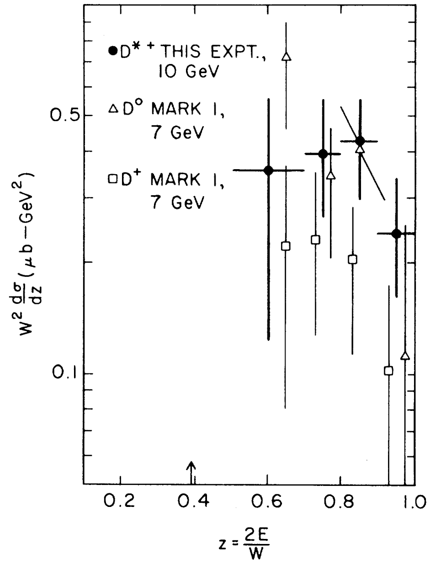

FIG. 3. Measured differential cross section $W^2d\sigma/dz$ for charged D^* mesons from this experiment for 10.2 GeV$< W <$10.6 GeV (circles), and for charged and neutral D mesons from Ref. 2 for 6.0 GeV$< W <$7.8 GeV (triangles and squares). The arrow denotes the minimum possible value of z for this experiment, 0.39. For Ref. 2, the minimum value of z is 0.54.

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[6] The momentum resolution of the spectrometer is given by $(\Delta p/p)^2 = (0.012p/\text{GeV})^2 + (0.006/\beta)^2$, where β is the particle velocity, v/c.

[7] With the same technique of cutting on the D^{*+}-D^0 mass difference, we also see a signal in the mode $D^0 \to K^-\pi^+\pi^+\pi^-$. However, the signal-to-background ratio is much worse than the case $D^0 \to K^-\pi^+$ due to the increased number of random combinations.

[8] D. Andrews *et al.*, Phys. Rev. Lett. 45, 219 (1980).

[9] Fits to a Gaussian plus smooth background were also done to the $K\pi$ mass spectra for each z bin with the D^0 mass and width fixed at their measured values (see Fig. 1). The fits gave excellent agreement with results of direct subtraction of Δ mass spectra like that of Fig. 2.

[10] R. H. Schindler *et al.*, Phys. Rev. D 24, 78 (1981); M. W. Coles *et al.*, Phys. Rev. D 24, 78 (1981); M. W. Coles *et al.*, Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory Report No. SLAC PUB-2196, LBL 14402, 1982 (to be published).

[11] The charged D^* acceptance was calculated using Monte Carlo events of the type $e^+e^- \to D^*X$, with the D^* decaying into $K\pi\pi$. The acceptance is small (about 3%) for $z < 0.5$ because the soft pion from the decay $D^{*+} \to D^0\pi^+$ does not penetrate the tracking chamber. The acceptance is 18% for $0.5 < z < 0.6$, and is 30% for $0.6 < z < 1.0$. The systematic uncertainty in these acceptance calculations is about 15%.

[12] The continuum hadronic cross section at $W = 10.4$ GeV is 3.76 ± 0.07, where the error is statistical only and we have not made any radiative corrections.

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Microcanonical Ensemble Formulation of Lattice Gauge Theory

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A new formulation of lattice gauge theory without explicit path integrals or sums is obtained by using the microcanonical ensemble of statistical mechanics. Expectation values in the new formalism are calculated by solving a large set of coupled, nonlinear, ordinary differential equations. The average plaquette for compact electrodynamics calculated in this fashion agrees with standard Monte Carlo results. Possible advantages of the microcanonical method in applications to fermionic systems are discussed.

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The formulation of gauge theories on a lattice has led to great progress in understanding relativistic quantum field theory. The use of the lattice spacing as an ultraviolet cutoff allows the calculation of relevant physical quantities without resorting to perturbation theory, which by itself is severely limited in computational possibilities.

In the usual approach[1] to lattice gauge theory the central assumption is that expectation values of functionals $\mathcal{O}$ of fields $\{\varphi\}$ on a finite Euclidean lattice can give physically meaningful results without having to go to the continuum limit. With use of an action $S\{\varphi\}$, with a finite number N of fields $\{\varphi\}$ and suitable boundary conditions, such expectation values are defined by

$$\begin{aligned}
&\langle \mathcal{O}\rangle_{\text{lattice}} \equiv Z^{-1}\int \mathfrak{D}\varphi\, \mathcal{O}\{\varphi\}e^{-S\{\varphi\}},\\
&Z \equiv \int \mathfrak{D}\varphi\, e^{-S\{\varphi\}}, \qquad\qquad (1)\\
&\int \mathfrak{D}\varphi \equiv \int d\varphi_1 \int d\varphi_2 \cdots \int d\varphi_N.
\end{aligned}$$

The continuum limit is obtained as N increases without bound and the lattice spacing approaches zero. As discussed below, the standard lattice path-integral formalism, Eqs. (1), is isomorphic to a *canonical ensemble*, familiar from classical statistical mechanics.

We propose an alternative formulation for lattice gauge theory. In this new formalism (hereafter referred to as the *microcanonical ensemble*)