Inclusive D and D^* Production in e^+e^- Annihilation at 29 GeV

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Inclusive production of $(D^0, \bar{D}^0)$ and $D^\pm$ mesons have been observed in e^+e^- annihilation at 29 GeV. The signals correspond to R values of $R(D^0+\bar{D}^0) = 3.25\pm1.2$ and $R(D^+ + D^-) = 1.35\pm 0.6$. $D^{*\pm}$ production is also observed via the process $D^{*+}\to D^0\pi^+$ and its charge conjugate. The D and D^* production rates are compared.

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Observation of charm production in e^+e^- annihilation[1,2] for $E_{\text{c.m.}} > 10$ GeV has been limited to the detection[3-5] of the D^0 as a decay product of the charged D^*:

$$D^{*+} \to D^0\pi^+, \quad D^0 \to K^-\pi^+. \qquad (1)$$

These results have provided measurements of the charm fragmentation function for $z_{D^*} \geq 0.4$, where $z_{D^*} \equiv 2E_{D^*}/E_{\text{c.m.}}$ They also indicated a surprisingly large D^* cross section, in the range of $R(D^*+\bar{D}^*) = 2.5-6.0$, where $R(D^*+\bar{D}^*)$ is the ratio of the inclusive cross section for D^* or $\bar{D}^*$ to the μ-pair cross section. These results suggest that D^* production alone may saturate the total charm cross section for c or $\bar{c}$ quarks which, when expressed as a similar ratio, is expected to be $R(c+\bar{c}) \simeq 3.53$.[6] It is interesting then to observe other modes of charm production at PEP and PETRA energies.

We report here the direct observation of neutral and charged D mesons reconstructed from the decay modes[7] $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$, respectively. With the simultaneous observation of the cascade pion in (1), we can measure the ratio of D^0 to D^* production without uncertainties from the D^0 decay branching fractions and minimal uncertainty in the acceptance calculation.

The data were obtained during the first year of operation of the high resolution spectrometer (HRS) at the PEP storage ring at the Stanford Linear Accelerator Center. The data sample corresponds to an integrated luminosity of 19.6 pb^{-1}. The HRS is a general purpose solenoidal detector that provides excellent measurements of charged-particle momenta. As shown in Fig. 1, the tracking is done by a 15-layer central drift chamber[8] extending to a radius of 1.03 m. A set of outer drift tubes[9] at 1.89 m radius provide two coordinate measurements for tracks that are within the central two thirds of the solid angle. The measured momentum resolution for high-momentum tracks at large angle is $\sigma_p/p = 1.0\times10^{-3}p$ (p in GeV/c). The drift-chamber system is surrounded by barrel and end-cap electromagnetic calorimeters. These calorimeters with 11 and 9.5 radiation lengths, respectively, of lead-scintillator sandwich measure electromagnetic energy with typical resolutions of $\sigma(E)/E = 0.18/\sqrt{E}$ (E in GeV). The position of a showering particle is determined by a set of proportional tubes. All of the detector elements are in a magnetic field of 1.62 T provided by a large solenoidal superconducting coil. One-photon annihilation events were triggered by the observation of ≥ 2 tracks in the central drift chamber or by the deposition of ≥ 4.8

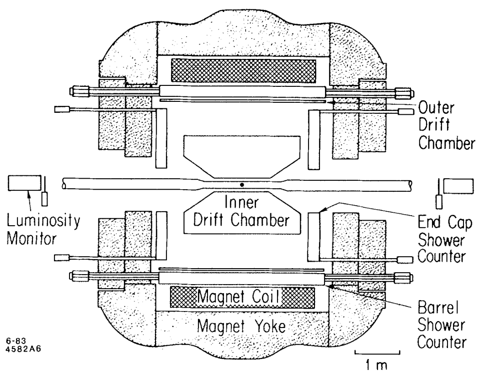

FIG. 1. The high resolution spectrometer (HRS).

GeV of neutral energy in the calorimeters.

To eliminate beam-gas and two-photon background, the events selected for this analysis had ≥ 5 charged prongs with a vertex constrained to the interaction point, a visible energy of $\sum|\vec{p}| \geq 8.7$ GeV, and ≥ 1.45 GeV of energy deposited in the shower calorimeters. No experimental particle identification was used.

Figure 2(a) shows the invariant mass of all $K^-\pi^+$ combinations with $z_D \geq 0.5$. A clear signal for D^0 production is observed which corresponds to 77 ± 15 events above a background of approximately 135 events. We measure a mass $m(D^0) = 1861 \pm 5$ MeV/c^2. The observed width of $\sigma = 17$ MeV/c^2 is consistent with the calculated resolution of the HRS. The invariant mass of all $K^-\pi^+\pi^+$ combinations with $z_D \geq 0.5$ is shown in Fig. 2(b). A signal for D^+ production is observed although the combinatorial background is larger. In this case 52 ± 16 events are observed over a background of approximately 180 events. Our measured D^+ mass is 1867 ± 4 MeV/c^2 with a width of 11 MeV/c^2 which is again consistent with calculated detector resolution. For $z_D < 0.5$, the combinatorial background in the D region increases rapidly, particularly for the $K\pi\pi$ channel. We do, however, observe a D^0 signal for $z_D \geq 0.4$ in the $K\pi$ channel shown as the upper curve of Fig. 2(a) with an observed signal of 114 ± 25 events.

We have also isolated a sample of D^{*+} events by exploiting the low-Q value for process (1): All $K\pi$ pairs in the mass range $1.80 \leq m_{K\pi} \leq 1.93$ MeV/c^2 were kinematically constrained to the D^0 mass. Those $K\pi$ combinations with $\chi^2 \leq 6$ for that constraint were then combined with all other pions of the appropriate charge and the difference $\Delta \equiv m_{D\pi} - m_D$ was calculated. The χ^2 cut loses less than 1 event. Figure 2(c) shows that this procedure results in a clear peak at $\Delta = 145.8 \pm 1.5$ MeV/c^2 without requiring a $z_D{}^*$ cut. An inclusive D^* signal of 16 ± 4.5 events is measured.

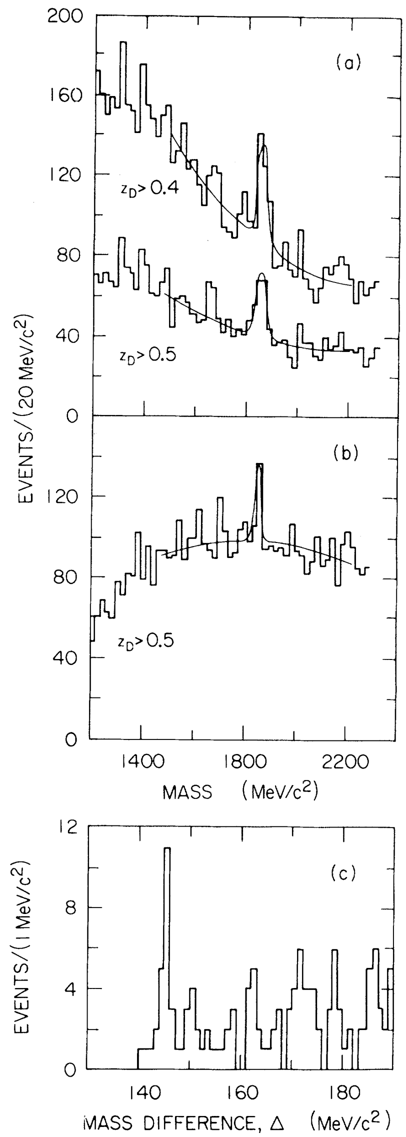

FIG. 2. (a) Invariant $K\pi$ mass distribution for $z_D \geq 0.4$ and $z_D \geq 0.5$. (b) Invariant $K\pi\pi$ mass distribution for $z_D \geq 0.5$. Fits used to extract cross sections are shown. (c) $D^* - D^0$ mass difference.

The determination of the cross sections and fragmentation functions for D and D^* mesons requires values for the apparatus acceptance and the appropriate branching fractions.[10] Our acceptances are estimated by Monte Carlo calculation based on the Lund model.[11] Efficiencies and cross sections for D and D^* production are summarized in Table I for the z regions where signals are actually observed. Cross sections are also given in Table I which have been extrapolated

TABLE I. D and D^* cross-section data for $\sqrt{s} = 29$ GeV.

Decay	z range	Numbers of events	Acceptance	Branching fraction[a]	Observed cross section in z range (nb)	Extrapolated cross section to all z (nb)
$D^0 \to K^- \pi^+$	> 0.4	114 ± 25	0.64 ± 0.07	0.030 ± 0.006	0.30 ± 0.11	0.36 ± 0.13
	> 0.5	77 ± 15			0.20 ± 0.07	
$D^+ \to K^- \pi^+ \pi^+$	> 0.5	52 ± 16	0.48 ± 0.08	0.063 ± 0.015	0.088 ± 0.037	0.15 ± 0.06
$D^{*+} \to D^0 \pi^+$	All z	16 ± 4.5	0.58 ± 0.11	0.44 ± 0.10	0.105 ± 0.035	

[a]Ref. 10.

to all z under the assumption of a z dependence which is discussed below.

If one assumes from isospin arguments that $\sigma(D^{*+}) = \sigma(D^{*0})$, the total D^* cross section is $\sigma(D^* + \bar{D}^*) = 0.20 \pm 0.07$ nb which, when divided by the μ-pair cross section and corrected for radiative effects,[12] yields an R value of $R(D^* + \bar{D}^*) = 1.9 \pm 0.7$. This is in good agreement with the value of $2.50 \pm 0.64 \pm 0.88$ from the TASSO collaboration.[4] Yelton *et al.* (Mark II detector) have reported,[3] for D^{*+} production alone, a cross section corresponding to $R(D^{*+} + D^{*-}) = 3.1 \pm 1.55$. This would represent substantially more D^* production than we observe, but the results are consistent within the quoted errors.

Our measurement of both D^* and D^0 in the same experiment allows us to determine the D^0/D^* ratio directly without problems of overall normalization between experiments. This ratio also is independent of the large uncertainty in the D branching fractions[10] and is much less dependent on the acceptance calculation although it still depends on the $D^{*+} \to D^0\pi^+$ branching fraction. With 13.5 ± 4 $D^{*+} \to D^0\pi^+$ events observed for $z_D^* \geqslant 0.4$, we obtain a D^0/D^* ratio of 1.7 ± 0.7 in this z range. We note that if all D^0's resulted from the production and decays of D^*'s, a D^0/D^* ratio of 0.7 would be expected. For $z_D \geqslant 0.5$ the results in Table I give a D^0/D^+ ratio of 2.3 ± 1.2.

We have studied the z dependence of the D^* production and of the D^0 production. Figure 3(a) shows the fragmentation functions $D(z)$,

$$D(z) = (1/\sigma)\, d\sigma/dz \qquad (2)$$

for both the D^0 and D^* data. The upper limit for D^0 production in the z range $0.2 < z_D < 0.4$ is also indicated and the D^* cross section in that bin has been corrected for a small drop in the calculated efficiency there. Using the parametrization of Petersen *et al.*,[13] we find that both sets of data are consistent with a value of the parameter $\epsilon = 0.36 \pm 0.12$, as shown by the curve. Our measurement of the mean z value of the D mesons is $\langle z_D \rangle = 0.56 \pm 0.02$. In Fig. 3(b) we compare our D^{*+} data with other measurements of $s\, d\sigma/dz(D^{*+} + D^{*-})$ at similar energies. The overall agreement in shape is reasonable. These results also agree with the charmed-quark fragmentation functions which are less directly measured by neutrino[14] and muon[15] interactions.

We have studied the extrapolation of the cross sections to the full range in z_D using a variety of forms for the fragmentation functions. The corrections are 1.25 ± 0.1 for $z_D > 0.5$, where the errors reflect the uncertainty in this extrapolation. The resulting total cross sections are given in

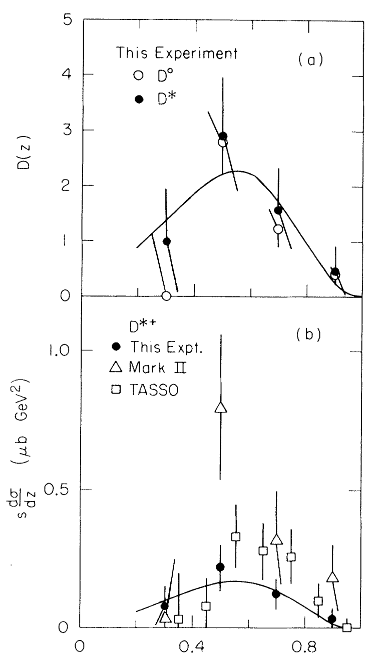

FIG. 3. (a) Fragmentation function obtained from D^0 and D^*. (b) Comparison of $s\,d\sigma/dz$ for D^{*+} with other experiments (Mark II, Ref. 3; TASSO, Ref. 4).

Table I. Dividing by the μ-pair cross section, they correspond to radiatively corrected R values of 3.25 ± 1.2 and 1.35 ± 0.6 for neutral and charged D's, respectively. The summed R value of 4.6 ± 1.4 for D production is consistent with the expectation of 3.53 units of total charm production.[6]

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[6]This estimate of the number of c or $\bar{c}$ quarks produced relative to μ pairs includes $\frac{4}{3}$ units from c and $\frac{1}{3}$ from b quarks, if one assumes all $b \to c$. A value of $\alpha_s = 0.17$ is assumed for the QCD correction.

[7]Reference to particle states is taken to include their charge conjugates as well.

[8]D. Rubin *et al.*, Nucl. Instrum. Methods 203, 119 (1982).

[9]G. Baranko *et al.*, Nucl. Instrum. Methods 169, 413 (1980).

[10]We use the D branching fractions $B(D^0 \to K^- \pi^+) = 0.030 \pm 0.006$ and $B(D^+ \to K^- \pi^+ \pi^+) = 0.063 \pm 0.011$ from R. Schindler *et al.*, Phys. Rev. D 24, 78 (1981). These D branching fractions, together with the D^* branching fraction $B(D^{*+} \to D^0 \pi^+) = 0.44 \pm 0.10$, provide a self-consistent fit to the SPEAR data of Ref. 2.

[11]J. Andersson, G. Gustafson, and T. Sjoestrand, Phys. Lett. 94B, 211 (1980).

[12]The size of the correction for initial-state radiation is 0.93, which corresponds to an average $\langle s \rangle \simeq (28\ \mathrm{GeV})^2$.

[13]C. Petersen *et al.*, Phys. Rev. D 27, 105 (1983), suggest

$$D(z) = \frac{A}{z}\left[1 - \frac{1}{z} - \frac{\epsilon}{1-z}\right]^{-2},$$

where the parameter ϵ is a function of the charmed-quark mass.

[14]For example, N. Ushida *et al.*, Phys. Lett. 121B, 292 (1983).

[15]J. J. Aubert *et al.*, Nucl. Phys. 213B, 31 (1983).