INCLUSIVE PRODUCTION OF D-MESONS IN e^+e^- ANNIHILATION AT 7 GeV ☆

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Inclusive momentum and energy spectra of neutral and charged D-mesons produced in e^+e^- annihilation at energies near 7 GeV are presented. The slope of the energy spectrum is similar to the charged pion spectrum at the same energy. The inclusive cross section $\sigma(e^+e^- \to D \text{ or } \bar{D} + \text{anything})$ at 7 GeV is 4.8 ± 1.3 nb.

Recently, there has been considerable interest in the dynamical mechanism for fragmentation of heavy quarks into hadrons. Many authors [1–4] have proposed a variety of forms for the quark fragmentation function for the charmed quark and have analyzed the recently available data on dilepton [5] and D-meson [6] production by neutrinos trying to obtain some information on its shape. The production of D-mesons in e^+e^- annihilation provides a particularly clean way for studying the charmed quark fragmentation function. In particular the shape of the differential cross section $d\sigma/dz$ for inclusive D-meson production (where $z = 2E_D/\sqrt{s}$) can be directly related to the fragmentation function. In this letter we present inclusive momentum spectra for charged and neutral D-meson production in e^+e^- annihilation at SPEAR for the energy range $\sqrt{s} = 6.0$ to 7.8 GeV.

The data presented here were collected with the Mark I magnetic detector [7,8] at SPEAR; they include all data obtained with this detector for which $\sqrt{s}$ is greater than 6.0 GeV. This sample corresponds to an integrated luminosity of 22.5 pb^{-1} at an average center-of-mass energy of 7.0 GeV. This analysis used events with three or more charged tracks. We searched for D-mesons in this sample of 222000 hadronic events by looking at the invariant mass distribution of $K^-\pi^+$ combinations for the D^0 and of $K^-\pi^+\pi^+$ combinations for the D^+. (To avoid unwieldy notation, reference to a state always implies the sum of that state and its charge conjugate state.)

The analysis techniques are substantially the same as those used previously [9]. Briefly, each particle in

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an event is assigned a weight proportional to the probability that it is a π, K, or p. These weights are determined from the measured momentum and time-of-flight over a 1.5 to 2.0 m flight path using a gaussian time distribution with a 0.4 ns standard deviation. The π–K–p weights are normalized so that their sum is unity for each track. All possible combinations of tracks and particle hypotheses are made with each combination weighted by the joint probability that the tracks satisfy the particular particle hypotheses assigned to them.

In order to determine the inclusive momentum spectrum the data were binned into different z or x bins, where $z = 2E_D/\sqrt{s}$ and $x = 2p_D/\sqrt{s}$. Since we are quite close to the charm threshold it is not clear which one of the two scaling variables is more appropriate to use. For the same reason these variables do not cover the complete range of 0 to 1. The kinematically allowed regions are $z > 0.54$ and $x < 0.84$. The invariant mass distribution for the four z bins are shown in fig. 1. The number of weighted D's in such plots was determined from a fit of a sum of a gaussian at the expected mass and width of the D and a simple polynomial background.

We estimated our detector efficiency from a Monte Carlo simulation as a product of two terms. We first determined the efficiency for detecting D-mesons of fixed momentum decaying into $K^-\pi^+$ (for the D^0) or $K^-\pi^+\pi^+$ (for the D^+). The D-mesons in this simulation were generated with an angular distribution of the form $d\sigma/d\Omega \propto 1 + \alpha \cos^2\theta$, where α is a momentum-dependent parameter determined from inclusive hadron production in e^+e^- annihilation [10] and varies from $\alpha = 0.0$ at $x = 0.0$ to $\alpha = 1.0$ at $x = 0.84$. This part of the efficiency, which incorporated the effects of the time-of-flight weighting and K decay in flight, shows significant variation as a function of the D momentum. Typical values for the D^0 are 0.17 at $z = 0.65$ and 0.10 at $z = 0.95$ (0.11 and 0.060 for the D^+). This variation is easily understood if one takes into account the fact that the decay products of a low-momentum D also have relatively low momenta which allow for a better identification by the time-of-flight system. The effect of the angular distribution is negligible at low z values, and at high z it reduces the efficiency by approximately 15%; the correction due to K decay in flight is of the order of 15% for all values of z. Systematic uncertainties to

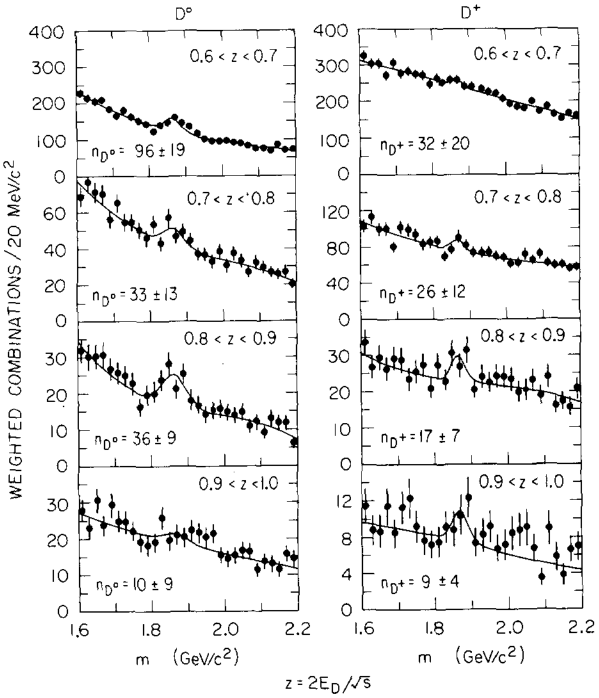

Fig. 1. Weighted invariant mass spectrum for $K^\pm\pi^\mp$ and $K^\mp\pi^\pm\pi^\pm$ combinations for four regions of $z = 2E_D/\sqrt{s}$. The fitted curves are described in the text. The weighted number of observed D's is indicated in the lower left side of each graph.

this part of the efficiency may be as high as 15%, but the point to point uncertainty is less than half as much.

We then determined the probability for an event with a detected D-meson to trigger our apparatus by simulating a final state of two D's or D^*'s together with a few pions. This part of the efficiency is model dependent, but this dependence is small. Typical values are 0.95 ± 0.05 for the D^0 and 0.99 ± 0.02 for the D^+. The quoted error is more than the observed variation for a wide variety of choices for the final state.

After these efficiency corrections, and taking into account the known branching ratios for the decays $D^0 \to K^-\pi^+$ ($2.2 \pm 0.6\%$) and $D^+ \to K^-\pi^+\pi^+$ ($3.9 \pm 1.0\%$) [11] the inclusive momentum spectra shown in fig. 2 were obtained. For comparison the same spectra are shown again in fig. 3 together with the charged π and K_s inclusive spectra observed in e^+e^- annihilation over a comparable range of energies

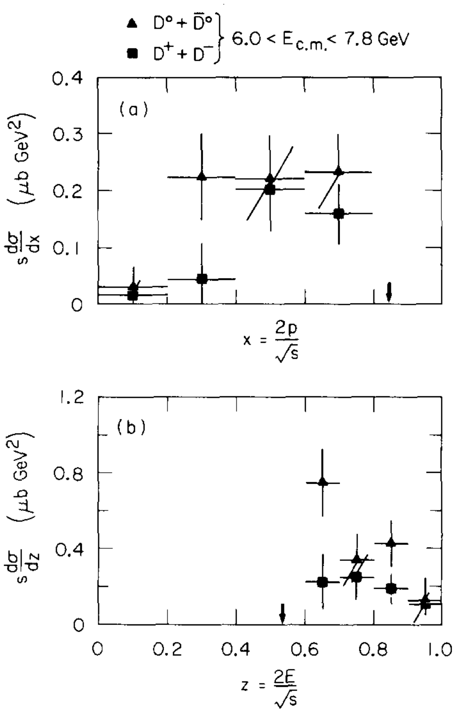

Fig. 2. Inclusive production spectra for charged and neutral D-mesons as a function of z or x. The indicated error bars include statistical errors and the expected systematic variation from point to point. An overall normalization uncertainty of approximately 10% as well as the uncertainty in the D decay branching ratios have *not* been included. The arrows indicate the kinematic limits.

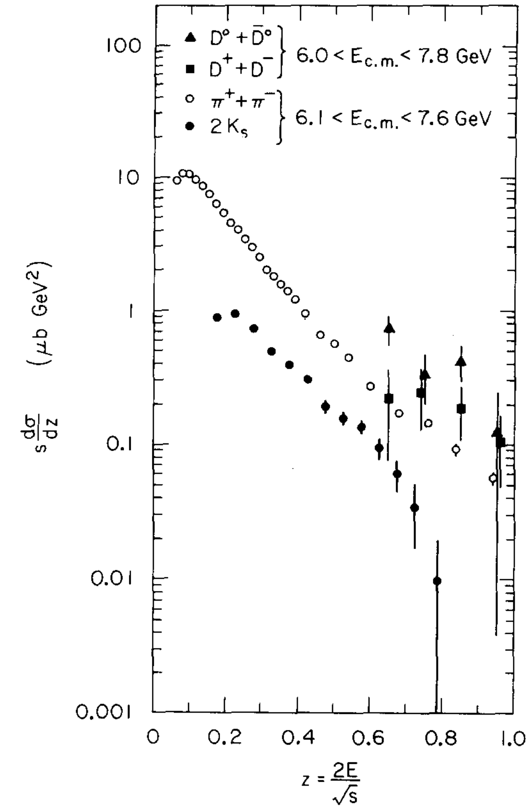

Fig. 3. Inclusive spectra for charged and neutral D-mesons and for charged π-mesons and K_S. The charged π and K_S spectra are from refs. [12] and [13]. The error bars for the D spectra are the same as in fig. 2.

[12,13] ‡1. We observe that the D-meson production is similar to the π production and significantly higher than the K_s production over the range of $z = 0.6$ to 1.0. All three of the displayed spectra are decreasing functions of z and have approximately the same slope.

We fit the averaged D-meson production spectrum with three of the forms proposed for the quark fragmentation function. For the form $D(z)=(a/z)(1-z)^{\alpha}$ [1] we obtain $\alpha = 0.42 \pm ^{0.28}_{0.23}$, for $D(z) = b(1-z)^{\beta}$ [2] we obtain $\beta = 0.63 \pm ^{0.30}_{0.24}$, and for $D(z) = ce^{\gamma z}$ [3] we obtain $\gamma = -3.6 \pm ^{1.3}_{1.4}$. All of these forms give a reasonable representation of the data. Even though our statistical error is quite large and even though charm threshold effects could be significant at this energy range, our results, fig. 2b and fig. 3, are in disagreement with the idea that the fragmentation function for heavy quarks should be an increasing function of z. A similar conclusion can be drawn from the D-meson spectrum observed in neutrino reactions [6].

Finally, the total number of D^0's and D^+'s observed ‡2 allows us to determine the cross section for inclusive D-meson production in e^+e^- annihilation for the energy range $\sqrt{s} = 6$ to 7.8 GeV. We find $\sigma(e^+e^- \to D^0$ or $\bar{D}^0$ + anything$) = 3.2 \pm 0.9$ nb and $\sigma(e^+e^- \to D^+$ or D^- + anything$) = 1.7 \pm 0.7$ nb. Their sum corresponds to $R_D = 2.7 \pm 0.7$, where R_D is the

‡1 The inclusive pion spectrum is obtained from the single-particle inclusive spectrum of ref. [13] by subtracting the charged kaon contribution which is assumed to be equal to twice the K^0_S measurements of ref. [12].

‡2 This measurement covers the full kinematically allowed range from $z = 0.54$ to $z = 1.0$.

ratio of the charged and neutral D- and $\bar{D}$-meson production to the rate of $\mu^+\mu^-$-pair production.

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