Inclusive production of D-mesons in e^+e^- annihilation

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It is shown that the D-meson c-quark fragmentation function computed in V.G. Kartvelishvili, A.K. Likhoded, and V.A. Petrov, Phys. Lett. **78B**, 615 (1978) is in good agreement with new experimental data on the inclusive production of D-mesons in e^+e^- annihilation.
nb·GeV^2

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In recent years the fragmentation function $D_H^Q(x)$ of heavy quarks ($Q = c,b,...$) to hadrons has become the subject of intensive study.[3-5] The representations of $D_H^Q(x)$ obtained by different techniques have a maximum near $x = |\mathbf{p}_H|/|\mathbf{p}_Q| \simeq 1$ at which there is a characteristic difference of $D_H^Q(x)$ from the fragmentation functions $D_H^q(x)$[6] of light quarks ($q = u,d,s$) concentrated mainly in regions of small $x : x = |\mathbf{p}_h|/|\mathbf{p}_q| \simeq 0$. Thus, it is expected that the heavy quark $Q(\bar{Q})$ will fragment into a hadron $H = (Q\bar{q})$, $(\bar{Q}q)$ with momentum $\mathbf{p}_H$ close to the momentum of the quark $\mathbf{p}_Q$.

One of the representations for $D_H^Q(x)$ obtained by us earlier[3] on the basis of a "reciprocity relation" between $D_H^Q(x)$ and the distribution function of quark Q in hadron H, $f_Q^H(x)$, is significantly related to the trajectory parameters of the Regge $Q\bar{Q}$-system and has the following form:

$$D_H^Q(x) = \frac{\Gamma(2 + \gamma_H - a_Q - a_{\bar{u}})}{\Gamma(1 - a_Q)\,\Gamma(1 + \gamma_H - a_{\bar{u}})}\, x^{-a_Q}(1 - x)^{\gamma_H - a_{\bar{u}}}, \tag{1}$$

where $a_u = \frac{1}{2}$ are the intersections of the $f - A_2$ trajectories, a_Q is the intersection of the leading trajectory of the $Q\bar{Q}$ system, and γ_H is a parameter determining the behavior of the distribution function $f_Q^H(x)$ (and, consequently, of $D_H^Q(x)$) for $x \to 1$ and is related to the analogous parameter γ_π for $f_q^\pi(x)$ by the equation[7]

$$\gamma_H = \frac{1}{4}\gamma_\pi\left(\frac{1}{1 - a_Q} + \frac{1}{1 - a_{\bar{u}}}\right), \tag{2}$$

where $\gamma_\pi = \frac{3}{2}$.

Thus, the heavy quark fragmentation function [Eq. (1)] contains one unknown parameter, the intersection of the $(Q\bar{Q})$ trajectory. It is possible to express a_Q by the masses of the vector m_V and tensor m_T $(Q\bar{Q})$-meson, assuming exchange degeneracy of the $(Q\bar{Q})$ vector and tensor trajectories[8]:

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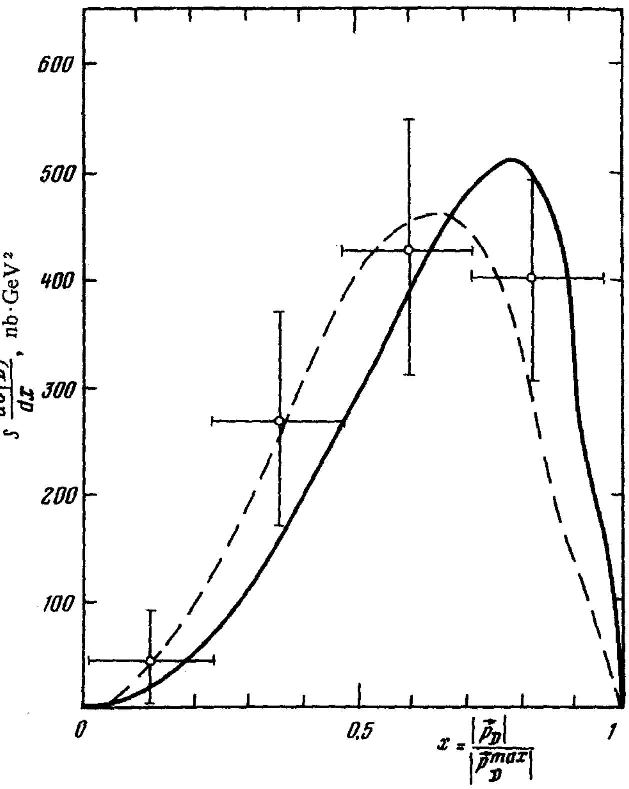

FIG. 1. Total distribution of charged and neutral D-mesons for e^+e^--annihilation at 7 GeV in terms of the variable $x = |\mathbf{p}_D|/|\mathbf{p}_D^{\max}|$. The curves have been calculated from Eqs. (1) and (7) with the following parameter values: $a_c = -2.2$; $\gamma_D = 0.9$ ($D_D^c(x) = 6.22x^{2.2}(1-x)^{0.1}$, solid line) and $\gamma_D = 1.5$ ($D_D^c(x) = 13.44x^{2.2}(1-x)$, dashed line). Experimental data have been taken from Ref. 9.

$$a_Q = 1 - \frac{m_V^2}{m_T^2 - m_V^2}. \tag{3}$$

Thus, for a c-quark $m_V = m_\psi = 3.1$ GeV, $m_T = m_{\chi_2} = 3.55$ GeV, and $a_c \approx -2.2$. The experimental measurement of inclusive hadron spectra $H = (Q\bar{q})$ in e^+e^--annihilation to hadrons, where[2)]

$$D_H^Q(x) = \frac{1}{\sigma(H)}\,\frac{d\sigma(H)}{dx}, \tag{4}$$

$$x = \frac{|\mathbf{p}_H|}{|\mathbf{p}_Q|} \approx \frac{|\mathbf{p}_H|}{|\mathbf{p}_H^{max}|}; \tag{5}$$

is a direct test of Eq. (1) and our assumptions. Here $\sigma(H)$ is the cross section for the $e^+e^- \to H + \ldots$ process, $|\mathbf{p}_Q| = \frac{1}{2}(S - 4m_Q^2)^{1/2}$, and for the case of a heavy quark Q, $m_Q \approx m_H$.

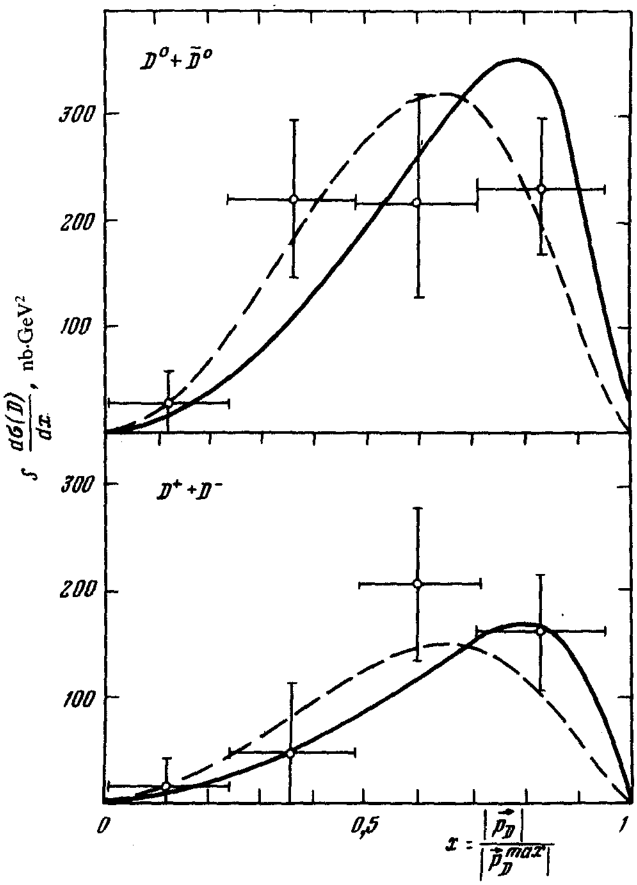

FIG. 2. Same as Fig. 1 for neutral (above) and charged (below) D mesons singly.

Recent experimental data on inclusive D-meson spectra for e^+e^--annihilation at an energy of $S^{1/2} = 7$ GeV [9] allow us to carry out this test for a c-quark ($Q = c$).

We note that in the reaction

$$e^+e^- \to D + \bar{D} + \ldots \tag{6}$$

pseudoscalar and vector D^* mesons may arise, which subsequently decay through the $D^* \to D + \pi(\gamma)$ channel. Actually, the enhancement of the cross section for the production of neutral D-mesons observed in experiment ($\sigma(D^\circ) + \sigma(\bar{D}^\circ) = 3.2 \pm 0.9$ nbarn) in comparison with the cross section for the formation of charged D-mesons ($\sigma(D^+) + \sigma(D^-) = 1.7 \pm 0.7$ nbarn) may be explained by a substantial contribution of D^* mesons. Thus, the inclusive spectrum of the pseudoscalar D mesons should be written as the sum of two terms

$$\frac{1}{\sigma(D)}\,\frac{d\sigma(D)}{dx} = (1-\beta)\,D_D^c(x) + \beta\,\frac{1}{2\kappa}\int_{x_-}^{A}\frac{dy}{y}\,D_D^c(y), \tag{7}$$

where the first term corresponds to direct D formation, and the second term describes the production of D^* and the decay $D^* \to D + \pi(\gamma)$. The parameter β describes the probability for the fragmentation of a c-quark to a vector meson, and κ, x_-, and A determine the kinematic decay of $D^* \to D + \pi(\gamma)$:

$$\kappa = \frac{q}{m_{D^*}}, \quad \kappa_0 = \frac{q_0}{m_{D^*}}, \quad q_0 = \sqrt{m_D^2 + q^2},$$

$$x_\pm = \frac{x}{\kappa_0 \mp \kappa}, \quad A = \theta(1 - x_+)x_+ + \theta(x_+ - 1)\cdot 1,$$

where q is the momentum of the D-meson in the rest system of the decaying D^*, and m_{D^*} and m_D are the masses of the vector and pseudoscalar D-mesons, respectively.

It may be thought that sufficiently far from the $D\bar{D}$ formation threshold the vector states of D^* occur three times as often as the pseudoscalar (proportional to the statistical weight $2J+1$), i.e., $\beta = \frac{3}{4}$.

The inclusive spectrum of pseudoscalar D-mesons calculated for this value of β taking into account the decay kinematics according to Eq. (7) is given in Fig. 1 in comparison with the experimental data.[9]

The theoretical curve is normalized such that

$$\sigma(D) + \sigma(\bar{D}) = 2\sigma(e^+e^- \to c\bar{c}) = 2\cdot 3\cdot\left(\frac{2}{3}\right)^2 \frac{4\pi\alpha^2}{3S}. \qquad (8)$$

The 5.0-nbarn cross section obtained by averaging over the energy interval $S^{1/2} = 6$–7.8 GeV is in good agreement with the experimental value of 4.8 ± 1.3 nbarn (this agreement indicates that the cross section for the production of F-mesons and charmed baryons at this energy is small in comparison with the D-meson production cross section).

As can be seen in Fig. 1, there is good agreement between our predictions and experiment.

The asymmetry in the yield of charged and neutral D-mesons arises because of the fact that the D^{*+} meson decays through the $D^{*+} \to D^+ + \pi^\circ(\gamma)$ and $D^{**} \to D^\circ + \pi^+$ channels with approximately the same probability. While the neutral $D^{*\circ}$ decays exclusively through the $D^{*\circ} \to D^\circ + \pi^\circ(\gamma)$ channel. Taking this fact into account, it is easy using Eq. (7) to calculate the inclusive spectra of charged and neutral D-mesons, which are shown in Fig. 2. Thus,

$$\sigma(D^\circ) + \sigma(\bar{D}^\circ) = 3.44 \text{ nbarn},$$

$$\sigma(D^+) + \sigma(D^-) = 1.56 \text{ nbarn}$$

which should be compared with the experimental values 3.2 ± 0.9 nbarn and 1.7 ± 0.7 nbarn, respectively.

Proceeding from standard assumptions about the suppresion of the strange sea,[8] we expect the production cross section for F-mesons to be $\sim 20\%$ of the production cross section for D-mesons.

In conlcusion, we note that the parameter γ_H in Eq. (1) was computed under the assumption of tensor dominance for the coupling between the Pomeron trajectory and hadron H [10] [see Eq. (2)]. Under this assumption the heaviness of the quark Q leads to a reduction in the cross section a_Q and a decrease in the parameter γ_H which, in turn, leads to a decrease in the total cross section for the interaction of particles containing heavy quarks. In the quark-patron model this corresponds to a reduction in the normalization of the sea of quark-antiquark pairs.[7] However, if Eq. (2) is not satisfied, we have two independent parameters a_Q and γ_H in the fragmentation function (1). As an example, Figs. 1 and 2 contain dashed lines representing the D-meson distributions computed under the assumption $\gamma_D = \gamma_\pi = \frac{3}{2}$. As can be seen from the figures, the existing experimental data do not permit us to give preference to either of these two possibilities ($\gamma_D = 0.9$ or $\gamma_D = 1.5$).

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[2)]For small energies there is an ambiguity in selecting a scaling variable, which vanishes in the limit of infinite energy. The variable x defined by Eq. (5) is, in our view, the most suitable one at finite energies.

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