Production of charmed mesons in pion-proton collisions

É. A. Choban
M. I. Kalinin Polytechnic Institute

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The effect of the quasi-parton mechanism, which was proposed by É. A. Choban {Yad Fiz. **33**, 221 (1981) [Sov. J. Nucl. Phys. **33**, 115 (1981)]; Yad. Fiz. **33**, 1107 (1981) [Sov. J. Nucl. Phys. **33**, 585 (1981)]}, on the cross section for inclusive production of D, $\bar{D}$ mesons as a result of a collision between pions and protons has been analyzed. This effect is noticeably larger than the effect of the quantum-chromodynamic (QCD) mechanisms which are used in perturbation theory.

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The currently available experimental data[3,7] leave little doubt that hadron-hadron (specifically, pion-proton) collisions produced charmed mesons. It is important to know the channels through which they are produced. The QCD mechanisms have widely discussed within the context of perturbation theory (see, e.g., Refs. 8-11). The main point of these mechanisms is that a pair of c, $\bar{c}$ quarks is produced in the inelastic stage of the process as a result of fusion of two gluons in the original hadrons and as a result of quark and antiquark annihilation. The cross section determined by the QCD mechanisms depends quardratically on the effective quark-gluon interaction constant which can be written as follows in the case of three flavors

$$\alpha_S(Q^2) = \frac{12\pi}{27 \ln \dfrac{Q^2}{\Lambda^2}}, \tag{1}$$

where Q is the transferred momentum in the quark-gluon vertex, and Λ is a parameter associated with the confinement radius. The authors of Refs. 8-11 assumed that $\Lambda = 500$ MeV, yielding $\alpha_s \approx 0.38$ for $Q^2 = 4\,m_c^2$, where m_c is the mass of the c quark (m_c is assumed to be equal to 1.55 GeV). Recent experiments on e^-e^+ annihilation[12] and on deep inelastic scattering [13,14] showed that $\Lambda \approx 100$ MeV. According to Eq. (1), this value of Λ for Q^2 indicated above gives values $\alpha_s \approx 0.2$, for which the cross section for production of charmed mesons in hardon-hardon collisions occurring via QCD mechanism becomes appreciably smaller than the experimental cross sections. What additional mechanisms can therefore lead to the production of D, $\overline{D}$ mesons?

In this letter we analyze the effect of a quasi-parton mechanism, which was proposed by Choban,[1,2] on the $\sigma(\pi^{\pm}p\rightarrow D\overline{D}+\ldots)$. According to this mechanism, the systems $\overline{D}\,(\overline{D}^*)$, c and $D\,(D^*)$, $\overline{c}$ are produced in the inelastic stage of the process in the reactions

$$\pi^{\pm} + p \rightarrow \overline{D}(D) + c(\overline{c}) + \ldots, \tag{2}$$

$$\pi^{\pm} + p \rightarrow \overline{D}^*(D^*) + c(\overline{c}) + \ldots, \tag{3}$$

where $\overline{D}\,(D)$ and $\overline{D}^*(D^*)$ represent $\overline{D}^0, D^-$ (D^0, D^+) or $\overline{D}^{*0}, D^{*-}$ (D^{*0}, D^{*+}) mesons. The processes (2) and (3), which occur via two channels: quark (antiquark)-gluon channel and quark (antiquark)-quark (antiquark) channel, are illustrated in Fig. 1. In the diagrams in Fig. 1 $q(\overline{q})$ denotes a light (u or d) quark (antiquark), and the symbols $\overline{D}\,(D)$, $\overline{D}^*$ (D^*) are explained above. Separating α_s and the γ and β constants in the cross sections for the processes (2) and (3) from the vertices of the transitions $q(\overline{q})\rightarrow\overline{D}c(D\overline{c})$, $q(\overline{q})\rightarrow\overline{D}^*c(D^*\overline{c})$ of the virtual quarks (see Refs. 1 and 2), we represent the inclusive cross section $\sigma(\pi^{\pm}p\rightarrow D\overline{D}+\ldots)$ in the quark (antiquark)-gluon channel, which is denoted by $\sigma^{gq}_{D\overline{D}}$, as follows:

$$\sigma^{gq}_{D\overline{D}} = \alpha_S\,(A_1\gamma + B_1\beta), \tag{4}$$

and we represent this cross section in the quark (antiquark)-quark (antiquark) channel (we denote it by $\sigma^{qq}_{D\overline{D}}$) in the form

$$\sigma^{qq}_{D\overline{D}} = \alpha_S^2\,(A_2\gamma + B_2\beta). \tag{5}$$

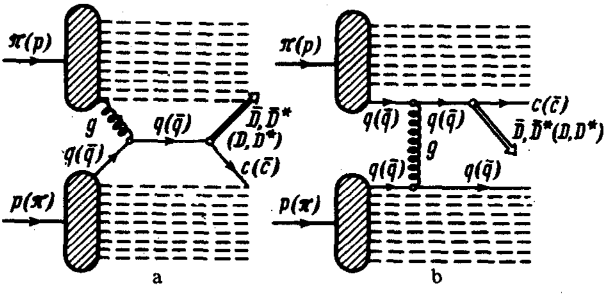

FIG. 1. Diagrams of processes (2) and (3). a—In a quark (antiquark)-gluon channel and b—in a quark (antiquark)-quark (antiquark) channel.

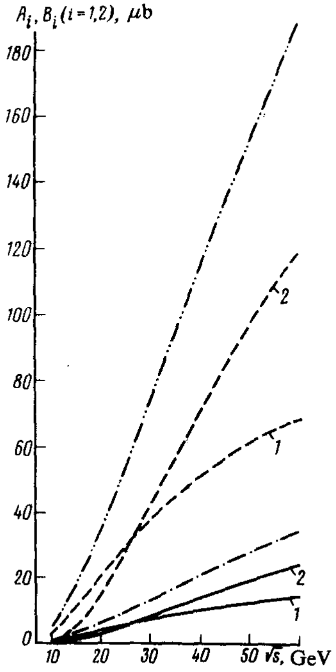

FIG. 2. Energy dependence of the quantities A_1(——), A_2(–·–·–) and B_1(- - - - -), B_2(—··—) appearing in Eqs. (4) and (5) for the distributions (6) and (7). The curves 1 and 2 represent the same for Eqs. (6) and (7)..

The quantities A_1, A_2,B_1, and B_2 in this expression are plotted in Fig. 2 as a function of the energy of the original particles in the reactions (2) and (3). In the numerical calculations of these values, the distributions of $u(\bar{u})$ and $d\,(\bar{d}\,)$ quarks in the proton and $\pi^{\pm}$ mesons were taken from the work of Feynman and Field,[15] and the gluon distributions, which are essential for the calculation of $\sigma_{D\bar{D}}^{gq}$, were taken from the two models of Babcock *et al.*[10]

$$G_g^{\pi}(x) = \frac{1.2}{x}\,(x\ln x + (1 - x^2));\ G_g^{p}(x) = 12.6\,(1 - x)^5 + \frac{1{,}6}{x}\,(1 - x)^7, \qquad (6)$$

$$G_g^{\pi}(x) = \frac{1}{x}\,[0.16\,(1 - x) + 3{,}2\ \exp\,(-(x/0{,}15)^2)];\ G_g^{p}(x) = \frac{1}{x}\,[\ 0{,}4(1 - x)^4 + 3.2\ \exp\,(-(x/0.15\ )^2)]. \qquad (7)$$

Taking into account the fact that the gluon distributions as well as the distributions of the valence and sea quarks and antiquarks in the π^+ and π^- mesons match, we can easily show that $\sigma(\pi^+p\to D\bar{D} + ...) = \sigma(\pi^-p\to D\bar{D} + ...)$ in the quasi-parton mechanism.

To determine $\sigma_{D\bar{D}}^{gq}$ and $\sigma_{D\bar{D}}^{qq}$, we must calculate the values of α_s, γ, and β. Since allowance for the Q^2 dependence of α_s [see Eq. (1)] changes the value of the cross section by an account not exceeding the accuracy of the calculations (5–6%), we set $\alpha_s = (m_D + m_c)^2$ for Q^2, where m_D is the average mass of the D of D^* doublet ($m_D = 1.866$ GeV and $m_{D^*} = 2.007$ GeV). Thus, for $\Lambda = 100$ MeV we obtain the value of $\alpha_s \approx 0.2$, a value which will be used by us below. The value $\gamma = 0.5 \pm 0.2$ was determined in Ref. 2 from the neutrino data for single-charged dimuons. The β constant was calculated in Ref. 1 from the experimental cross section for photoproduction of a $D^0\overline{D}^0$ pair in the reaction $\gamma N \rightarrow D^0\overline{D}^0X$. This constant turned out to be different for different values of the anomalous magnet moment of $D^{*\pm}$ mesons, which is denoted by λ. If the QCD cross section for the reaction $\gamma N \rightarrow c\bar{c} + \ldots$, which was used by Choban[1] for $\alpha_s = 0.35$, is scaled to $\alpha_s = 0.2$, we find that $\beta_{\lambda=0} = 1.9 \pm 1.2$ and $\beta_{\lambda=1} = +0.05 \pm 0.35$, respectively, for $\lambda = 0$ and $\lambda = 1$. The large errors of these values are mainly the result of the large uncertainty of the branching of the decay of a c quark into D, D^* mesons, rather than the result of the error of the experimental cross section of the process $\gamma N \rightarrow D^0\overline{D}^0X$ (see Ref. 1). Because of this, we consider it essential to add the value $\beta = 0.7 \pm 0.2$, which was determined from the ISR data for $\sigma(pp \rightarrow D\overline{D} + \ldots)$ at $\sqrt{s} = 53$ GeV (Ref. 3) and which has a smaller error than $\beta_{\lambda=0}$ and $\beta_{\lambda=1}$ from photoproduction.$^{1)}$ We chose these data because they do not have an indeterminate A-dependence, as is the case in the beam-dump experiment.[3,4] Thus we shall estimate $\sigma(\pi^{\pm}p \rightarrow D\overline{D} + \ldots)$ in the quasi-parton mechanism for the following values of the α_s, γ, and β coupling constants:

$$\alpha_S = 0.2;\ \gamma = 0.5 \pm 0.2;\ \beta_{\lambda=0} = 1.9 \pm 1.2;\ \beta_{\lambda+1} = 0.50 \pm 0.35;$$
$$\beta = 0.7 \pm 0.2. \tag{8}$$

The plots for the $\sigma_{D\overline{D}}^{\text{theor}} = \sigma_{D\overline{D}}^{gq} + \sigma_{D\overline{D}}^{qq} + \sigma_{D\overline{D}}^{\text{QCD}}$ vs the energy of the original particles in the process $\pi^+p \rightarrow DD + \ldots$ for the constants in (8) are shown in Fig. 3. The cross section $\sigma_{D\overline{D}}^{\text{QCD}}$ represents the effect of the QCD mechanisms on the cross section of the reaction $\pi^+p \rightarrow D\overline{D} + \ldots$, which was scaled from $\alpha_s(Q^2 = 4m_D^2) = 0.35$ (Ref. 10) to $\alpha_s = 0.2$. For comparison, we have plotted this effect separately in Fig. 3. We see that

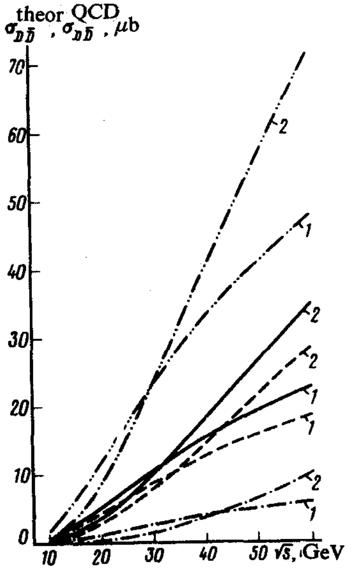

FIG. 3. Energy dependence of the cross sections $\sigma_{D\overline{D}}^{\text{theor}}$(—··—, for $\beta_{\lambda=0} = 1.9$; ----, for $\beta_{\lambda=1} = 0.5$; —, for $\beta = 0.7$) and $\sigma_{D\overline{D}}^{\text{QCD}}$ (—·—·—) for the values of α_s and γ in (8); the curves 1 and 2 correspond to Eqs. (6) and (7).

the effect of the quasi-parton mechanism is noticeably greater than that of $\sigma_{D\bar{D}}^{\rm QCD}$. In the case of the process $\pi^- p \to D\bar{D} + \ldots$, it would be useful to compare $\sigma_{D\bar{D}}^{\rm theor}$ with the experimental cross sections $\sigma_{D\bar{D}}^{\rm exp}$ obtained in Refs. 5–7 at the energies of π^- mesons $E_\pi = 70$ GeV, $E_\pi = 225$ GeV, and $E_\pi = 340$ GeV, respectively, as well as with $\sigma_{D\bar{D}}^{\rm QCD}$, which coincide almost exactly with their counterpart for the reaction $\pi^+ p \to D\bar{D} + \ldots$ mentioned above, because the effect of the QCD mechanism on $q\bar{q} \to c\bar{c}$, in which there is a difference, is $\leqslant 1\%$ of $\sigma_{D\bar{D}}^{\rm theor}$. We shall use $\sigma_{D\bar{D}}^{\rm theor}$, for example, for $\beta_{\lambda=0} = 1.9 \pm 1.2$ and for the gluon distributions in the model (6). Thus, for $E_\pi = 70$ GeV we find that $\sigma_{D\bar{D}}^{\rm exp} = 19 \pm 11\,\mu$b (Ref. 5), $\sigma_{D\bar{D}}^{\rm QCD} = 0.21\,\mu$b (Ref. 10), and $\sigma_{D\bar{D}}^{\rm theor} = 2.9 \pm 1.6\,\mu$b. The upper limits on $\sigma_{D\bar{D}}^{\rm exp}$ at $E_\pi = 225$ GeV for different models for identification of D mesons were determined in Ref. 6: $\sigma_{D\bar{D}}^{\rm exp} < 10.4\,\mu$b and $\sigma_{D\bar{D}}^{\rm exp} < 6.2\,\mu$b. The QCD mechanism yield $\sigma_{D\bar{D}}^{\rm QCD} = 1.2\,\mu$b (Ref. 10) at this energy, and our results correspond to $\sigma_{D\bar{D}}^{\rm theor} = 13 + 7\,\mu$b. Finally, for $E_\pi = 340$ GeV we have $\sigma_{D\bar{D}}^{\rm exp} = 35\text{-}40\,\mu$b (Ref. 7), $\sigma_{D\bar{D}}^{\rm QCD} = 1.9\,\mu$b (Ref. 10), and $\sigma_{D\bar{D}}^{\rm theor} = 18 \pm 10\,\mu$b. We conclude from a comparison of the cross sections indicated above that for the reaction $\pi^- p \to D\bar{D} + \ldots$ the QCD mechanisms yield $\sigma_{D\bar{D}}^{\rm QCD}$, which are noticeably smaller than the experimental values, and allowance for the effect of quasi-parton mechanism on $\sigma(\pi^- p \to D\bar{D} + \ldots)$ improves substantially the agreement between theory and experiment.

[1]The contribution of the quasi-parton mechanism to $\sigma(pp \to D\bar{D} + \ldots)$ will be analyzed in another paper.

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