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THE FAST CHARMED QUARK AND LEADING D^--MESONS IN $\pi^- p$-COLLISIONS

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1. Leading effect is a characteristic property of inclusive production of charmed hadrons[1,2]. If one considers the reaction $a + b \rightarrow h + ...$, it is the charmed hadron h carrying the largest portion of the momentum $p_h = O(\sqrt{s}/2)$ that is regarded as a leader. The differential momentum spectrum dN/dx_F usually parametrised in the form $(1-x_F)^n$ at large $x_F = \frac{2}{\sqrt{s}} p_{\parallel}$ is "hard" for leading hadrons $(0 < n \lesssim 3)$ and "soft" for non-leading ones $(n \gtrsim 5)$.

The quark-parton approach interprets the leading particle effect in the following way: the valence quark q_V of an incident hadron undergoes recombination with the C-quark, a charmed meson h being the result. Owing to the large momentum of the valence quark x_V the meson h turns to be a leader, its momentum is large $x_h = x_V + x_c > x_V$. The same is true for baryons. Thus the charmed hadrons h with valence quarks q_V of the incident hadron are regarded as leaders[2].

From this point of view $D^-(d\bar{c})$ - and $D^0(\bar{u}c)$ - mesons must be leaders, i.e. have a large momentum (say, $x_F \gtrsim 0.5$), in the reaction $\pi^-(d\bar{u})+p \rightarrow D+X$. However, analysis of Ref.[2] which contains results of investigation of the process $\pi^- p \rightarrow DX$ at $\sqrt{s} = 26$ GeV shows that only $D^-(d\bar{c})$ mesons are fast. In fact, all neutral and half of charged D-mesons are produced in decay of D^*-mesons which were not found at $x_F \geq 0.5$[2]. Consequently, D^0-mesons were not found at $x_F \geq 0.5$ as well. That is why all detected mesons with $x_F \gtrsim 0.5$ can only be D^--mesons.

The data on asymmetrical yields of prompt muons $(\mu^-/\mu^+ \approx 2)$ in π^-Fe-interactions[3] are a less explicit indication of leading character of D^--mesons.

It is highly improbable that the significant difference in yields of D^- and D^0 mesons at $x_F \gtrsim 0.5$ can be explained by allegedly different distribution of d and $\bar{u}$ - valence quarks in the π^--meson. It is quite likely that the role of the charmed quark in the leading effect mechanism is underestimated.

Let us assume that hadrons only consist of valence quarks. In this case $D^0(\bar{u}c)$-mesons can by no means appear as a results of the reaction $\pi^-(d\bar{u})+p(uud) \rightarrow D+X$ since there is no C-quark. On the other hand, the $\bar{C}$-quark neede for $D^-(d\bar{c})$-meson is produced as a result of annihilation $\bar{u}_V^{\pi} u_V^{p} \rightarrow c\bar{c}$.

We note in advance that a more adequate approach retains the indicated difference in production of D^- and D^0-mesons (existence of the valence component $\bar u^{\pi}_v u^p_v \to c\bar c$) which fully describes the experimental situation.

2. We make quantitative estimations in the quark-quark recombination model[4,5]. It is easy to represent dynamics of the process $\pi^- p \to DX$ in a graphic way (Fig.1).

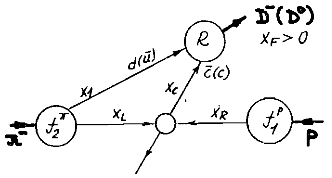

Fig.1. Production of $D^-(D^0)$-mesons through quark-quark recombination in π^-p-collisions.

The invariant differential cross section for the process $\pi^- p \to DX$ in the centre-of-mass system at the energy $\sqrt{S}$ and $x_F > 0$ is written down in the form[4,5]:

$$x^* \frac{d\sigma}{dx\,dp_T^2} = e^{-p_T^2}\int R(x_1,x_c,x)\frac{dx_1}{x_1}\frac{dx_c}{x_c^*}\left\{\frac{x_c^* x_1\, d\sigma}{dx_1\, dx_c\, dp_T^2}\right\}. \qquad (1)$$

Here $X \equiv X_F$, X_1, X_c are the Feynman variables of $D^-(D^0)$-meson, $d(u)$- and $\bar c(c)$-quark; $x^* = 2/\sqrt{S}\, E_D$, $x_c^* = 2/\sqrt{S}\, E_c$.

The recombination function $R(x_1,x_c,x)\sim \exp(-\gamma(x_c-x_1)^2)\,\delta(x-x_1-x_c)$[5,6] provides a probability of producing a $D^-(D^0)$-meson (with the momentum X) by means of a $d(\bar u)$-quark (X_1) and a $\bar c(c)$-quark (X_c).

The probability of existence of $d(\bar u)$ and $\bar c(c)$-quarks is determined by the differential cross section (see Fig.1):

$$\frac{x_c^* x_1\, d\sigma}{dx_1\, dx_c\, dp_T^2} = x_1\int dx_L\, dx_R \sum_{i=q,\bar q,g} f^{\pi}_{d(\bar u)i}(x_1,x_L)\, f^{p}_{\bar i}(x_R)\,\frac{x_c^*\, d\sigma}{dx_c\, dp_T^2}. \qquad (2)$$

Here $\frac{x_c^* d\sigma}{dx_c\, dp_T^2}$ is the quantum-chromodynamic cross section for the subprocess $i\bar i \to c\bar c$, where $i(\bar i)=q,g(\bar q,g)$[7]. Single-particle proton distribution functions (DF) are taken from Ref.[8]. The analytical form of two-particle pion DF $f^{\pi}_{Vi}(x_1,x_L)$ is given in the statistical parton

model[4,9]. Free parameters of these DF are fixed by comparision with the data[2].

The differential momentum spectrum is calculated by the formula

$$\frac{d\sigma}{dx} = \int \frac{dp_T^2}{x^*}\left\{x^*\frac{d\sigma}{dx\,dp_T^2}\right\}. \qquad (3)$$

It follows from relation (2) that difference in production of D^- and D^0-mesons on valence $d(\bar u)$-quarks mainly lies in contributions of DF: $\sum_{i=q,\bar q} f^{\pi}_{Vi}\cdot f^{p}_{\bar i}$.

For a D^0-meson we have

$$\Sigma'_{D^0} = f^{\pi}_{VV}\cdot f^{p}_{S} + f^{\pi}_{VS}\left(3f^{p}_{V}+6f^{p}_{S}\right). \qquad (4)$$

For a D^--meson

$$\Sigma'_{D^-} = f^{\pi}_{VV}\cdot f^{p}_{S} + f^{\pi}_{VS}\left(3f^{p}_{V}+6f^{p}_{S}\right)+2f^{\pi}_{VV}\cdot f^{p}_{V} = \Sigma_{D^0} + 2f^{\pi}_{VV}\,f^{p}_{V}. \qquad (5)$$

Here the index V corresponds to the valence quark and S to the see quark. The total spectrum of D^- and D^0-mesons, according to (4) and (5), can be put down in the form

$$\frac{d\sigma}{dx}(D^-+D^0) = 2\frac{d\sigma}{dx}(D^0) + \frac{d\sigma}{dx}(V). \qquad (6)$$

Fig.2 compares the (solid) curve calculated by formula (6)

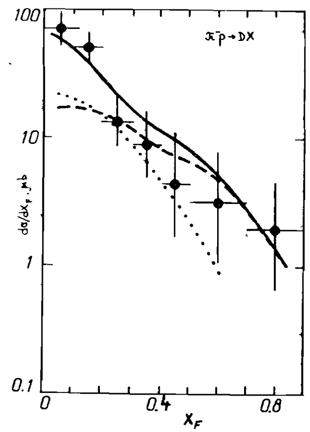

Fig.2. Momentum spectrum of D-mesons in $\pi^-p \to DX$ at $\sqrt{S}$ = 26 GeV. Data are taken from Ref.[2]. The dashed line is the contribution of the valence component. Points are the contribution of D^0-mesons. The solid line is the total spectrum calculated by formula (6).

with the experimental data on D-meson production in π^-p-collisions at $\sqrt{S}$ =26 Gev. The dashed line is the contribution of $\frac{d\sigma}{dx}(V)$; the dotted line is for $\frac{d\sigma}{dx}(D^0)$.

It is evidently due to the valence component $\frac{d\sigma}{dx}(V)$ that the spectrum differs from zero at $X_F \gtrsim 0.5$. As it makes no contribution to the spectrum of D^0-mesons (see formula (4)), absence of neutral D^0-mesons at large X_F gets natural explanation in the approach[4,5].

One can judge about quantitative proportion of D^0 and D^- yields at different X_F by Fig.3 which shows the ratio:

$$R(x_F) = \frac{\frac{d\sigma}{dx}(\pi^- p \to D^0 X)}{\frac{d\sigma}{dx}(\pi^- p \to D^- X)}. \qquad (7)$$

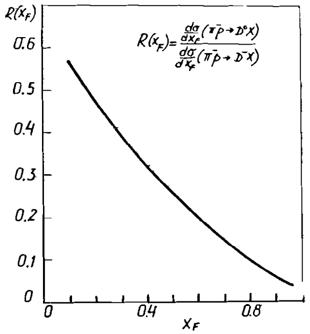

Fig.3.
D^0-to-D^- yield ratio for π^-p-collisions at $\sqrt{S}$ = 26 GeV.
The curve is calculated by formulae (3)-(5).

Thus, presence of a valence quark from the initial pion (so-called leading quark state) in the charmed meson is a necessary but insufficient condition for the meson to be a leader.

Actually, those D-mesons are leaders whose light quarks are valence quarks of the pion and charmed quarks are produced in annihilation of valence quarks and carry a large momentum X_c.

So it is quite natural that the search for charm in K^+p-collisions at $|X_F| \gtrsim 0.5$ was unsuccessful[10]. As it is, charmed quarks cannot be produced on the valence component in reactions $K^+(\bar{s}u)+p \to D+X$ and $K^+ + n \to D+X$. Consequently, there are no fast C-quarks, and the D_s-meson yield is suppressed at large X_F. Therefore $K^-(s\bar{u})$-mesons are more preferable for searching for charm: their valence $\bar{u}$-quarks may produce fast $C(\bar{C})$-quarks in annihilation with valence nucleon u-quarks.

It is easy to point out leading mesons in a developed approach

and construct relations like (7) for reactions similar to $\pi^- p \to DX$. Thus we have for $X_F \gtrsim 0.5$ (denominators show the leading mesons):

$$\frac{\sigma(\pi^- n \to D^+ X)}{\sigma(\pi^- n \to \bar{D}^0 X)} = \frac{\sigma(\pi^+ \bar{p} \to \bar{D}^0 X)}{\sigma(\pi^+ \bar{p} \to D^+ X)} = \frac{\sigma(\pi^- \bar{n} \to D^- X)}{\sigma(\pi^- \bar{n} \to D^0 X)} = R(x_F);$$

$$\frac{\sigma(K^- p \to \bar{D}^0 X)}{\sigma(K^- p \to D_s^- X)} = \frac{\sigma(K^+ \bar{p} \to D^0 X)}{\sigma(K^+ \bar{p} \to D_s^+ X)} = R(x_F);$$

$$\frac{\sigma(\pi^+ p \to D^+ X)}{\sigma(\pi^+ p \to \bar{D}^0 X)} = \frac{\sigma(\pi^- n \to D^0 X)}{\sigma(\pi^- n \to D^- X)} = 2R(x_F);$$

$$\frac{\sigma(\pi^- \bar{p} \to D^- X)}{\sigma(\pi^- \bar{p} \to D^0 X)} = \frac{\sigma(\pi^+ \bar{n} \to \bar{D}^0 X)}{\sigma(\pi^+ \bar{n} \to D^+ X)} = 2R(x_F);$$

$$\frac{\sigma(K^- n \to \bar{D}^0 X)}{\sigma(K^- n \to D_s^- X)} = \frac{\sigma(K^+ \bar{n} \to \bar{D}^0 X)}{\sigma(K^+ \bar{n} \to D_s^+ X)} = 2R(x_F).$$

CONCLUSION

Inclusive momentum spectra of charmed mesons produced in π^-p-collisions at $\sqrt{S}$ = 26 GeV are calculated in the quark-quark recombination model.

It is shown that only D^--mesons must be leaders in the reaction $\pi^- p \to DX$. This completely agrees with the experimental data[2,3].

Relations between cross sections are formulated and composition of leading charmed mesons is shown for processes $\pi^\pm p \to DX$; $\pi^\pm n \to DX$; $K^+ p \to DX$, etc. at $\sqrt{S} \gtrsim 26$ GeV.

The analysis has shown that having a valence quark of the initial pion is not enough for the charmed meson to be a leader.

It is stated that only those D-mesons are leaders in reactions like $\pi^- p \to DX$ whose light quarks are valence quarks of pions, and charmed quarks are produced in annihilation of valence quarks and carry a large momentum. If annihilation of valence quarks is impossible there must be no distinct leading effect.

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Быстрый очарованный кварк и лидирование D^--мезонов
в $\pi^- p$-столкновениях

На основе модели кварк-кварковой рекомбинации показано, что в реакциях типа $\pi^- p \to DX$ лидирует (т.е. уносит большую долю импульса) только такой D-мезон, легкий кварк которого есть валентный кварк пиона, а очарованный кварк рожден путем аннигиляции валентных кварков и имеет большой импульс.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Перевод М.И.Потапова

Bednyakov V.A. E2-86-789

The Fast Charmed Quark and Leading D^--Mesons
in π^-p-Collisions

It is shown on the basis of the quark-quark recombination model that only the D-meson, whose light quark is the pion valence quark and whose charmed quark is produced in annihilation of valence quarks and has a large momentum, is a leading meson in reactions like $\pi^- p \to DX$.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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