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ON THE PRODUCTION OF CHARMED HADRONS IN NUCLEON-NUCLEI COLLISIONS

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ՆՈՒԿԼՈՆ-ՄԻՋՈՒԿ ՓՈԽԱԶԴԵՑՈՒԹՅՈՒՆՆԵՐՈՒՄ՝ ՀՄԱՅՎԱԾ ՀԱԴՐՈՆՆԵՐԻ ԾՆՄԱՆ ՄԱՍԻՆ

Առաջնորդող հադրոնի մոդելի [5] շրջանակներում դիտարկված է հմայված մասնիկների ծնումը միջուկների փոխազդեցություններում: A -կախվածության փորձարարական տվյալների նկարագրությունը՝ ստացված $NA \to h_c X$ գործընթացներում, ցույց է տալիս այն մոդելների ճշմարտացիությունը [8], որտեղ ծնված C -քվարկը տանում է ,,մայր,, հադրոնի իմպուլսի մեծ մասը:

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ON THE PRODUCTION OF CHARMED HADRONS IN NUCLEON-NUCLEI COLLISIONS

The process of charmed particle production on nuclei is considered in the framework of the leading hadron model [5]. The obtained description of experimental data on the A-dependence in the processes $NA \to h_c X$ points out the validity of the models [8] in which the produced c-quark carries away a larger portion of momentum of the "parental" hadron.

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В.М.ЖАМКОЧЯН

О РОЖДЕНИИ ОЧАРОВАННЫХ АДРОНОВ В НУКЛОН-ЯДЕРНЫХ ВЗАИМОДЕЙСТВИЯХ

В рамках модели лидирующего адрона [5] рассмотрен процесс рождения очарованных частиц на ядрах. Полученное описание экспериментальных данных по А-зависимости в процессах $NA \to h_c X$ служит указанием на справедливость моделей [8], в которых рожденный c - кварк уносит большую долю импульса "родительского" адрона.

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The study of the processes of the open-charm particle production $h_c(\Lambda_c, \mathcal{D}, \ldots)$ on nuclei seems to be highly important to clarify the mechanism of production of charmed hadrons in the elementary collisions as well as to analyze the interaction of the c-quark with the nucleus nucleons.

Existing at present experimental data on charmed particles hadroproduction on nuclei point out their curious distinctions from the processes of the production of the "ordinary" hadrons. If using the generally accepted approximation for the A-dependence of the inclusive spectra of the process $h_1 A \to h_2 X$

$$\frac{d\sigma^{h_1 A \to h_2 X}}{dx} = \sigma_0 A^{\alpha} \tag{1}$$

then the parameter α in the case of charmed hadrons production in the incident particle fragmentation region turns out to be [1] $\alpha \approx 0.75$, whereas for the "ordinary" hadrons (not containing the c-quark) $\alpha \simeq 0.4 - 0.5$ in the same kinematic region.

In Refs. [5] the leading hadron model was developed that made it possible to describe a large set of experimental data on inclusive spectra of hadrons produced on nuclei in the fragmentation region of incident particle. In the present work we have considered the process of charmed hadrons production on nuclei and carried out a comparison with experimental data.

In the experiment [4], there was studied the A-dependence in the processes $nA \to \Lambda^0 X$ and $nA \to \Lambda_c X$ at E_n = 58 GeV. Let us first apply the leading hadron model to the process $nA \to \Lambda^0 X$. In the mentioned model the incident neutron just in the first inelastic collision with the nucleus nucleon turns to the excited hadronic state H_n which then interacts with the nucleus nucleons (with a cross section equal to that of the "parental" hadron) and forms Λ^0 only beyond the nucleus (the Lorentz factor $E/m \gg 1$). In this case, the cross section $\frac{d\sigma}{dx}(H_n N \to \Lambda^0 X)$ corresponding to the last act of interaction within the nucleus and to the subsequent fragmentation coincides with the cross section $\frac{d\sigma}{dx}(nN \to \Lambda^0 X)$ (see Refs. [5]).

The inclusive cross section of the considered process can be presented as

$$\frac{d\sigma^{nA\to\Lambda^0 X}}{dx} = \sum_{n=1}^{\infty} \frac{N_n(\sigma)}{\sigma^{n-1}} \Phi_n^{n\Lambda_0}(x), \tag{2}$$

where

$$\Phi_n^{h_1 h_2} = \int \frac{d\sigma^{h_1 N\to H_{h_1} X}}{dx_1} \frac{d\sigma^{H_{h_1} N\to H_{h_1} X}}{dx_2} \cdots \frac{d\sigma^{H_{h_1} N\to h_2 X}}{dx_n} \times$$

$$\times\, \delta(x - x_1 \dots x_n)\, dx_1 \dots dx_n \qquad (h_1 = n;\ h_2 = \Lambda^0);$$

$N_n(\sigma) = \frac{1}{\sigma n!}\int (\sigma T)^n e^{-\sigma T} d^2 b$, $T(b) = \int \rho(b, z)\, dz$ is a projection of one-particle nuclear density on the impact parameter plane.

The quantity σ in (2) represents the inelastic nucleon-nucleon cross section with the deduction of the cross section of the diffraction processes, so that

$$\sigma = \sigma^{in}(nN) - \sigma_{diff}(nN) = \int_{x_{min}}^{x_{max}} \frac{d\sigma}{dx}(nN \to H_n X)\,dx =$$

$$= \int_{x_{min}}^{x_{max}} \frac{d\sigma}{dx}(H_n N \to H_n X)\,dx, \tag{3}$$

where $X_{min} = \frac{m}{\sqrt{s}}$ is the minimum value of the variable X in the lab. system; X_{max} is the maximum value of X at which the non-diffraction inelastic processes take place.

For the inclusive cross sections of elementary acts of interaction the following equalities hold (see [5]):

$$\frac{d\sigma}{dx}(H_n N \to \Lambda^\circ X) = \frac{d\sigma}{dx}(nN \to \Lambda^\circ(X)),$$

$$\frac{d\sigma}{dx}(nN \to H_n X) = \frac{d\sigma}{dx}(H_n N \to H_n X). \tag{4}$$

Just like in [5] , for simplicity it was taken:

$$\frac{d\sigma}{dx}(nN \to H_n X) \equiv \sigma\,. \tag{5}$$

(At considered energies σ = 26 - 27 mb). The inclusive cross section $\frac{d\sigma}{dx}^{nN \to \Lambda^\circ X}$ was parametrized according to the results of [6] . The calculation of the effective nucleon numbers for different nuclei in (2) (as everywhere in the given work) was carried out with the use of the Fermi distribution for the one-particle nuclear density:

$$\rho(r) = \frac{\rho_0}{1 + \exp\left\{\frac{r-R}{c}\right\}} \tag{6}$$

with the parameters from [7] .

Finally, for the parameter α in the A-dependence (1) there was obtained the value $\alpha_{\Lambda^0} = 0.47$ (at $X_{\Lambda^0} = 0.6$) being in agreement with the value $\alpha_{\Lambda^0} = 0.49 \pm 0.05$ found in the experiment [4] .

Note, that the applied model with the intermediate hadronic state H_{h_1} allowed also to describe [5] the whole set of experimental data on the inclusive spectra $h_1 A \to h_2 X$ ($h_1 = p, \pi^+, K^+$; $h_2 = p, \bar{p}, \pi^\pm, K^\pm$) obtained at FNAL [3] .

What can be responsible for the transition to the A-dependence with $\alpha \simeq 0.75$ in the case of the Λ_c -baryon production [4] ? Such dependence seems to be natural in the models [8] , in which the charmed quark, produced in the elementary act, carries since the moment of its production a larger portion of momentum of the final charmed hadron. If here we assume that the cross section of the c-quark with nucleon is negligibly small, and the final charmed hadrons production occurs outside the nucleus ($E/m \gg 1$), then for the inclusive spectrum of the process $nA \to \Lambda_c X$ the following expression will hold:

$$\frac{d\sigma^{nA\to\Lambda_c X}}{dx} = \sum_{n=1}^{\infty} \frac{N_n^*(\sigma)}{\sigma^{n-1}} \Phi_n^{n\Lambda_c}(x), \tag{7}$$

where

$$N_n^*(\sigma) = N(0,\sigma) - \sum_{i=1}^{n-1} N_i(\sigma),$$

$$N(0,\sigma) = \frac{1}{\sigma}\int (1 - e^{-\sigma T})\, d^2 b.$$

The expression (7) describes the process $nA \to \Lambda_c X$ with account of the fact that the last act of interaction within the nucleus is the process $H_n N \to cX$. If the charmed hadrons h_c had been produced from the c-quarks carrying a small portion of momentum of h_c , then in the considered model the account of inelastic interactions of the system H_n right up to the escape from the nucleus would have been essential, which would have led to the A-dependence slightly different from the "standard" one ($\alpha \simeq 0.4$ at $x \to 1$).

The neglect in (7) of explicit energy dependence of the charmed hadrons production cross section determines the applicability region of expression (7) by the values of the variable $x \sim 1$. (In the experiment [4] $\bar{x}_{\Lambda_c} = 0.8$).

In calculations the cross section $\frac{d\sigma^{nN\to\Lambda_c X}}{dx}$ was parametrized in the form [9] :

$$\frac{d\sigma^{nN\to\Lambda_c X}}{dx} \sim \frac{(1-x)^{1,5}}{x} \qquad (x > 0,5)$$

With the use of the distribution (6), for the parameter α corresponding to the process $nA \to \Lambda_c X$ at $E_n = 58$ GeV and $x_{\Lambda_c} = 0.8$, there was found the value $\alpha_{\Lambda_c} = 0.78$ which agrees with experimental value [4] .

The account of energy dependence in the act of charm hadroproduction can be carried out in the expression of the type of (7) through the replacement:

$$\Phi_n^{h_1h_2}(x) \to \Phi_n^{h_1h_2}(x,E) = \int \frac{d\sigma^{h_1N\to H_{h_1}X}}{dx_1}(x_1) \frac{d\sigma^{H_{h_1}N\to H_{h_1}X}}{dx_2}(x_2) \quad \dots \times$$

$$\times \frac{d\sigma^{H_{h_1}N\to h_2X}}{dx_n}(x_n; x_1 \dots x_{n-1} E)\, \delta(x - x_1 \dots x_n)\, dx_1 \dots dx_n \qquad (8)$$

where E is the energy of incident hadron h_1 .

Now we use the expressions (7) and (8) to calculate the effective nucleon numbers

$$N_{eff}(X) = \frac{\frac{d\sigma}{dx}^{pA\to\Lambda_c(D)X}}{\frac{d\sigma}{dx}^{pp\to\Lambda_c(D)X}} \qquad (9)$$

for the processes $pA\to\Lambda_c X$ and $pA\to DX$ at E = 400 GeV. Using the data [10] on the X-dependence of the cross sections $\frac{d\sigma}{dx}^{pp\to\Lambda_c(D)X}(x,E)$ and the dependence [11] on the incident proton energy E, we'll obtain the curves for the quantities α and β in the approximation of the form of (1) for (9), as shown in Figs. 1 and 2 . $\left(N_{eff}(x) = \beta(x)\cdot A^{\alpha(x)}\right)$

As one can see from Figs. 1 and 2, the parameters of the A-dependence of the effective nucleon numbers (9) slightly depend on the shape of the elementary spectrum (the spectra $pp\to\Lambda_c X$ and $pp\to DX$ depend substantially differently on the variable X [10]).

For the comparison with experimental data [1] on the A-dependence in the processes $pA\to h_c X$, $h_c \to \nu_e(\bar\nu_e)$, an appropriate recalculation of quantities $N_{eff}^{pA\to\Lambda_c(D)X}(x)$ is necessary, which was carried out according to the method used in [12] . The values obtained for the parameter $\alpha_{\nu_e\bar\nu_e}$ are given as a curve in Fig. 3, being in complete agreement with experiment [1]

In experiments [2] there was measured the ratio:

$$R = \frac{\frac{d\sigma}{dx_{\mu^+}}^{pA\to\Lambda_c(D)X,\ \to\mu^+} + \frac{d\sigma}{dx_{\mu^-}}^{pA\to\Lambda_c(D)X,\ \to\mu^-}}{\frac{d\sigma}{dx_{\pi^+}}^{pA\to\pi^+X} + \frac{d\sigma}{dx_{\pi^-}}^{pA\to\pi^-X}} \qquad (10)$$

at $X_\pi = X_\mu$. The results of the relevant calculation for R in the used model (for the ^{64}Cu nucleus) are presented as a curve in Fig. 4.

For the normalization of the cross sections $\frac{d\sigma}{dx}^{pA\to\Lambda_c(D)X}$ the data of [13] were used; the values of the inclusive cross sections $\frac{d\sigma}{dx_\pi}^{pA\to\pi^+(\pi^-)X}$ were calculated in the model [5] which was applied above to describe the process $nA \to \Lambda^{\circ} X$.

Thus, the above-performed study of the A-dependence of the processes of charmed hadrons production on nuclei serves as an argument in favour of the models [8] in which the presence of states with prompt charmed quarks in the incident hadron wave function is assumed.

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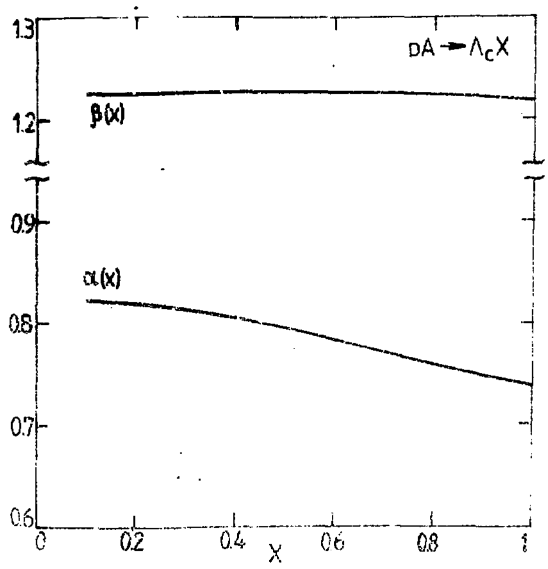

Fig.1

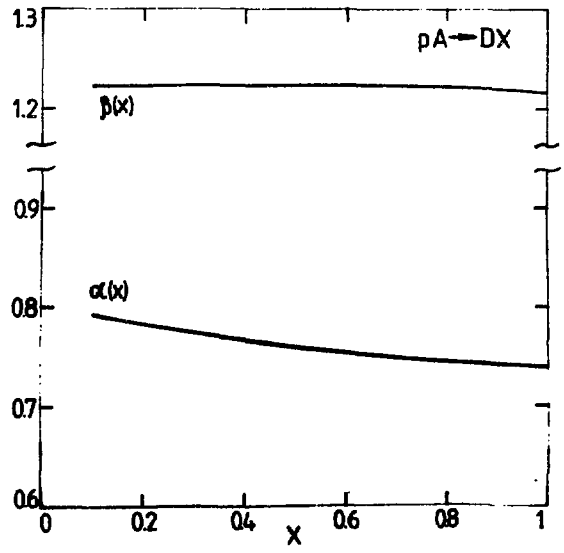

Fig.2

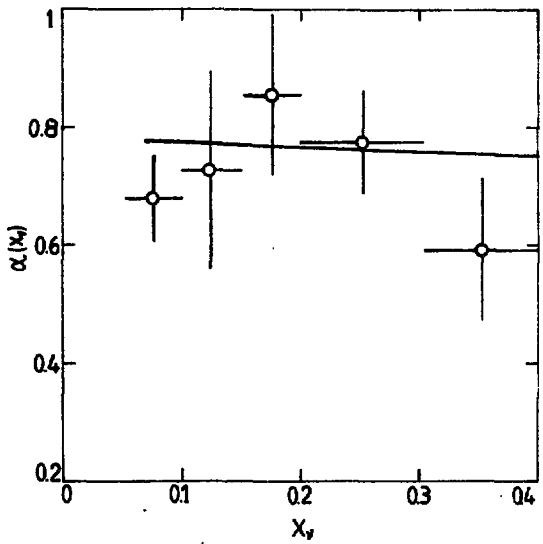

Fig.3

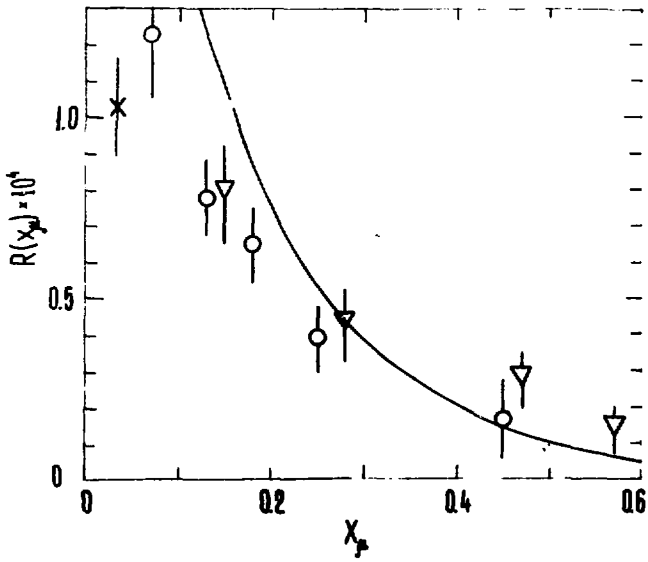

Fig.4

Figure Captions

Fig.1. Parameters α and β in the A-dependence of the inclusive cross sections of the process $pA \to \Lambda_c X$ at E = 400 GeV at different values of variable X .

Fig.2. Parameters α and β in the A-dependence of the inclusive cross sections of the process $pA \to DX$ at E = 400 GeV at different values of variable X .

Fig.3. The index α in the A-dependence of the process $pA \to h_c X$, $h_c \to \nu_e(\bar{\nu}_e)$ at different values of X_ν . Experimental data are taken from Ref. [1] .

Fig.4. The ratio $R\left(\mu^+ + \mu^- / \pi^+ + \pi^-\right)$ as a function of the portion of longitudinal momentum $X = \frac{2P_\parallel}{\sqrt{S}}$ at $\sqrt{S}$ = 28 GeV given in comparison with experimental data [2] on the processes $pCu \to \mu + \ldots$ (▽), $pFe \to \mu + \ldots$ (○), $pFe \to \mu + \ldots$ (×).

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