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ЦЕНТРАЛЬНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ ИНФОРМАЦИИ И ТЕХНИКО-ЭКОНОМИЧЕСКИХ ИССЛЕДОВАНИЙ ПО АТОМНОЙ НАУКЕ И ТЕХНИКЕ

S.R.GEVORKYAN, G.R.GULKANYAN, Ar.M.KOTZINIAN,
V.M.ZHAMKOCHYAN

INCLUSIVE SPECTRA OF HADRONS IN PROTON-NUCLEI COLLISIONS

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S.R.GEVORKYAN, G.R.GULKANYAN, Ar.M.KOTZINIAN,

V.M.ZHAMKOCHYAN

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A model is proposed, which allows one to describe all experimental data on inclusive spectra of different hadrons produced on nuclei. The model is based on the following assumptions:

i) After the first inelastic collision with nucleon in the nucleus the proton transforms into some excited system H, which collides with the other nucleons during its passage through the nucleus. Since in inelastic collisions the wee partons play the dominant role, the valence quarks of this system H coincide with those of proton.

ii) Fragmentation of H into hadrons (as well as into proton) is dilated in the lab system by the Lorentz factor $E/m \gg 1$ and so it takes place out of the nucleus.

Using the methods of multiple scattering theory one can receive the connection between inclusive spectra on nuclei and those on nucleons. The calculations of inclusive spectra of different hadrons (p, n , $\pi^{\pm}$, $k^{\pm}$) were done, and a satisfactory description of the experimental data was obtained. It should be noted that this description was done without introduction of any free parameters. Analogous models are discussed, and their difference from the method proposed is outlined.

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С.Р.ГЕВОРКЯН, Г.Р.ГУЛКАНЯН, В.М.ЖАМКОЧЯН,
А.М.КОЦИНЯН

ИНКЛЮЗИВНЫЕ СПЕКТРЫ АДРОНОВ В ПРОТОН-ЯДЕРНЫХ СОУДАРЕНИЯХ

Предложена модель, позволяющая описать всю совокупность экспериментальных данных по инклюзивным спектрам $pA \to hx(h \equiv p, \bar{p}, \pi^{\pm}, K^{\pm})$, полученных во FNAL [2]. В основе модели лежат следующие предположения: а) после первого акта взаимодействия налетающего протона с нуклоном ядра образуется возбужденное адронное состояние H, которое испытывает ряд многократных неупругих перерассеяний в ядре. Поскольку в неупругих соударениях принимают участие медленные моревые партоны, валентный состав состояния H совпадает с валентным составом протона; б) фрагментация H в адроны (в том числе, в протон) замедлена в лабораторной системе координат на лоренц-фактор $E/m \gg 1$ и происходит вне ядра. Используя аппарат теории многократного рассеяния, удается получить связь между инклюзивным спектром на ядре и спектрами на нуклоне. Проведены конкретные расчеты инклюзивных спектров различных адронов $(p, \bar{p}, \pi^{\pm}, K^{\pm})$ и получено удовлетворительное согласие с экспериментальными данными. Необходимо отметить, что описание получено фактически без введения свободных параметров. Кратко обсуждаются аналогичные модели и их отличие от предлагаемого метода.

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One of the urgent problems of the strong interaction physics is the establishment of the space-time picture of high-energy hadroproduction. From this viewpoint, of particular importance is the investigation of the hadroproduction processes on atomic nuclei, particularly of inclusive spectra in these processes, especially sensitive to the mechanisms of formation and interaction of hadrons and hadronic systems in the nuclear matter in the space-time ranges of the order of a few fermi. At present, there are pretty enough experimental data on the hadron inclusive spectra in the hadron-nuclei collisions [1] . Comparatively complete and statistically provided data in the region of highest energies available were recently obtained in Fermilab [2] . In these experiments there are measured the inclusive spectra of hadrons in the processes $pA \to hx (h = p^{\pm}, \pi^{\pm}, K^{\pm})$ in the incident hadron fragmentation region ($0.3 \leq x \leq 0.88$, where x is the Feynman variable) at two fixed values of the final hadron transverse momentum, $P_{\perp} = 0.3$ and 0.5 GeV/c, and initial momentum, $P_0 = 100$ GeV/c.

At the present paper these data are described quantitatively within the simple model of the leading hadron multiple interactions. The model is based on the following assumptions.

The first act of interaction of the incident proton with the nucleus nucleon produces the excited hadronic state H which undergoes in the nucleus multiple inelastic interactions with the cross section equal to the inelastic cross section in the proton-nucleon interactions.

In the inelastic interactions there participate the slow sea partons, therefore the valent composition of the hadronic state H coincides [3] with that of the incident hadron (proton) and does not vary at multiple inelastic interactions. The fragmentation of the excited hadronic state H into hadrons $H \to h$ (as well as into protons) is slowed down in the lab system by the Lorentz factor $E/m \gg 1$ and occurs outside the nucleus.

In these assumptions the multiple scattering theory yields the following form for the inclusive spectra integrated over transverse momentum:

$$\frac{d\sigma}{dx}(pA \to hX) = \sum_{n=1}^{A} N_n(\sigma)\Phi_n(x) \qquad (1)$$

where

$$N_n(\sigma) = \frac{1}{\sigma n!}\int (\sigma T)^n e^{-\sigma T} d^2 b \qquad (2)$$

are the so-called "effective nucleon numbers", $T(\vec{b}) = \int \rho(\vec{b}, z)\, dz$ is a projection of one-particle nuclear density $\rho(\vec{r})$ on the impact parameter plane. $\Phi_n(x)$ is the inclusive spectrum of the final particle h provided that the leading hadron in nucleus underwent n inelastic collisions.

$$\Phi_n(x) = \int_x^{x_{max}} \cdots \int_{x/x_1 \cdots x_{n-1}}^{x_{max}} \frac{1}{\sigma}\frac{d\sigma}{dx_1}(pN \to HX)\frac{1}{\sigma}\frac{d\sigma}{dx_2}(HN \to HX) \cdots \qquad (3)$$

$$\frac{d\sigma}{dx_n}(HN \to hx)\,\delta(x - x_1 \cdots x_n)\, dx_1 \cdots dx_n$$

In this expression the factor $\frac{d\sigma}{dx_n}(HN \to hX)$ is the inclusive cross section of the production of hadron h in inelastic interaction of the excited hadronic state H with the nucleon.

Since the inclusive spectrum of an hadron of the given type h in the fragmentation region is determined practically only by its valent composition [4], one may expect that $\frac{d\sigma}{dx}(HN \to hX) = \frac{d\sigma}{dx}(pN \to hX)$ in virtue of the above assumption about identity of valent compositions of proton and state H.

As inclusive spectra of the elementary acts $pN \to hX (h = p^{\pm}, \pi^{\pm}, K^{\pm})$ the experimental data from Ref. [5] are used.

Turn now to the choice of the form for the inclusive spectra $\frac{d\sigma}{dx}(pN \to HX)$ and $\frac{d\sigma}{dx}(HN \to HX)$. Note first of all that in the considered experiment [2] the inclusive spectra are measured in the region $x \leqslant 0.88$, where the processes of the diffraction dissociation type contribute insignificantly. Since the calculation of spectra on nuclei with small losses (i.e. in the region $x < 0.9$) is beyond the scope of our consideration, we neglect the contribution of the diffraction dissociation processes at which the energy losses of the leading hadron (or excited state H) do not exceed a few per cent [6].

Following from the stated above the elementary spectra satisfy the following sum rule:

$$\int_{x_{min}}^{x_{max}} \frac{d\sigma}{dx}(pN \to HX)dx = \int_{x_{min}}^{x_{max}} \frac{d\sigma}{dx}(HN \to HX)dx = \sigma^{in}(pN) - \sigma_{diff} \equiv \sigma \quad (4)$$

where $x_{min} = \frac{m}{\sqrt{s}}$ is a minimum value of variable x in the lab system; x_{max} is a maximum value of variable x at which the non-diffractive inelastic interactions take place; $\sigma_{diff} \approx 5$ mb is the cross section of the diffractive dissociation σ at energies in the region of 100 GeV; $\sigma^{in}(pN) = 31.4$ mb.

The form of the spectrum $\frac{d\sigma}{dx}(pN \to HX)$ can, in principle, be determined experimentally by measuring over summary limiting momentum (in the lab system) the distribution of all particles produced in the target pionization and fragmentation regions. Such experimental data are not available so far. Therefore, to simplify the calculations we shall consider the spectrum constant, i.e. with account of (4): $\frac{d\sigma}{dx}(pN \to HX) = \sigma = 26.4$ mb (5). The spectra $\frac{d\sigma}{dx}(HN \to HX)$ in all subsequent acts of inelastic collision of the excited hadronic state H with the nucleus nucleons are chosen in the same way, i.e. the validity of scaling in elementary acts is assumed.

The calculations of the nucleon numbers (3) were carried out in the

Fermi model for one-particle nuclear density using the parameters from Ref. [7].

To compare the calculated spectra (integrated over $P_\perp$) with the experimental ones (at fixed $P_\perp = 0.3$ GeV/c) we present the inclusive spectrum on nucleus in the following form: $\frac{d\sigma}{dx d^2 P_\perp} = \frac{\beta}{\pi} e^{-\beta P_\perp^2} \frac{d\sigma}{dx}$. For the $\langle P_\perp^2 \rangle$ we adopt the following values: 0,23 $(GeV/c)^2$ for protons; 0,14 $(GeV/c)^2$ for pions; 0,16 $(GeV/c)^2$ for kaons; 0,23 $(GeV/c)^2$ for antiprotons. These values are close to the experimental values of mean transverse momentum for the corresponding particles [8].

Figs 1-5 present the results of calculation of the inclusive spectra on nuclei calculated according to the expressions (1), (2), (3) in the abovementioned assumptions, and also their comparison with the experimental data [2] at $P_\perp = 0.3$ GeV/c is given.

As one can see, the calculated curves and experimental data are in satisfactory quantitative agreement for all the nuclei and various hadrons.

The other, different from our suggested, versions of the model of the leading hadron multiple scattering, by means of which the experimental data are described only on the proton inclusive spectra in the reaction $pA \to pX$, are considered in Refs [9-12]. In Ref. [9] the form $\frac{d\sigma}{dx} = \sigma^{in}(pN) = 31.3$ mb is chosen for the differential cross section of the inelastic interactions of the leading baryon. This leads to the artificial excess of energy losses, since a part of the inelastic cross section (~ 5 mb) corresponds to inelastic processes of the diffraction type for which the energy losses are insignificant; there is not achieved a satisfactory agreement with the experiment, especially in the region of small x, where the calculated curves lie noticeably lower than the experimental points.

In Refs [10-11] a satisfactory agreement is achieved by introducing a free parameter which has a sense of mean energy losses by nucleon in the elementary nucleon-nucleon interaction. It turned out unusually low (0.1 ± 0.26); note also that in Refs [10-11] the calculations are carried out in the constant nuclear density approximation, this leading to considerable discrepancies in the calculations of the "effective nucleon numbers" with realistic nuclear density (Fermi-type distribution) used in the presen work, especially for $N_1(\sigma)$. This discrepancy is illustrated in Fig.6, where the A-dependence of the effective nucleon number $N_1(\sigma)$ is given in the Fermi model (curve 1) and in the model with constant density (curve 2).

In Ref. [12] it is assumed, just like in the present work, that in the first act of the inelastic interaction of the incident proton with the nucleus nucleon there is produced an excited baryon state which undergoes multiple inelastic interactions inside the nucleus and decays into proton outside the nucleus; as a decay function the quantity $W_p \delta(1-x)$ is chosen, where $W_p \approx 0.5$, i.e. the decay into proton takes place in half of the cases, the whole momentum being transferred - the assumption which must not be considered well-grounded. The description of the experimental data is achieved by fitting as a free parameter the value of the leading system elasticity coefficient, the data in the region of small $x = 0.3$ being failed to describe (the experimental data are systematically higher for all the nuclei). It should be emphasized that the mentioned models can be applied only to the processes of $pA \to pX$ type (i.e. when the initial and final hadrons are identical), while the model suggested in the present work describes also the data for $pA \to hX\ (h = \pi^{\pm}, K^{\pm}, \bar{p})$. Note, however, that in our model also a set of approximations is applied, which in the presence of more detailed experimental data on nucleons and nuclei can be specified (the spectra of the excited hadron production in the process $pN \to HX$, dependence of the inclusive spectra on transverse momentum).

Note in conclusion that the experimental data [2] on $pA \to hX$ reactions are described (approximately at the same level of quantitative agreement) also in the framework of the other approaches - in the quark additive model [13] and in the dual-topological unitarization model [14] . Thus the further experimental and theoretical researches are necessary to finally establish the mechanism of hadron fragmentation on the atomic nuclei.

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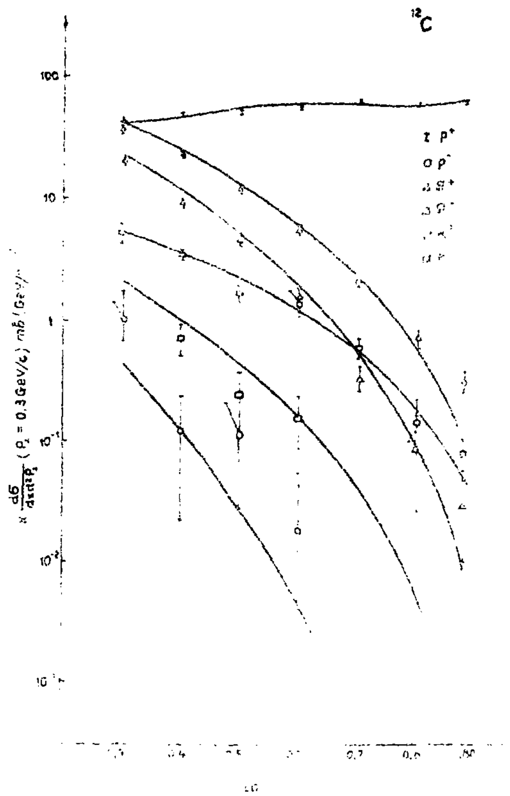

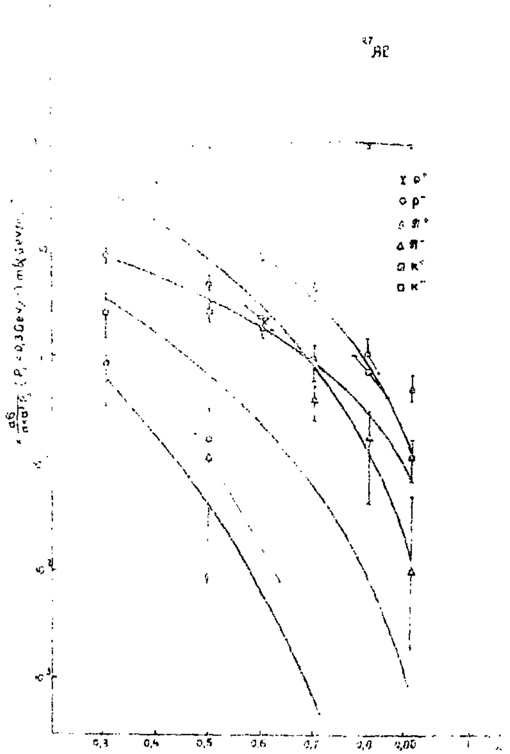
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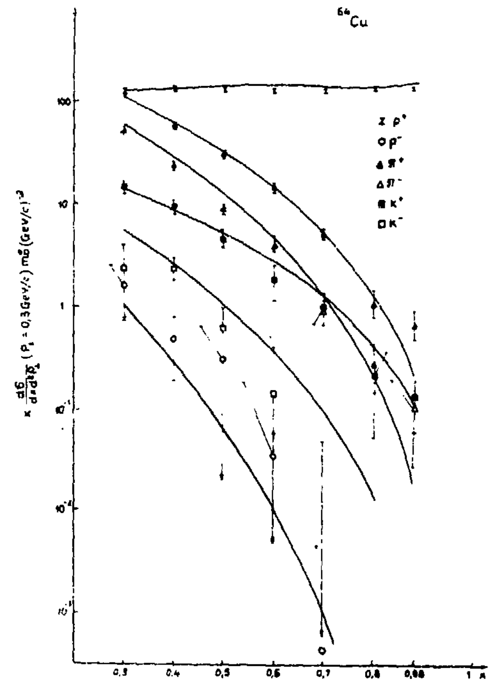
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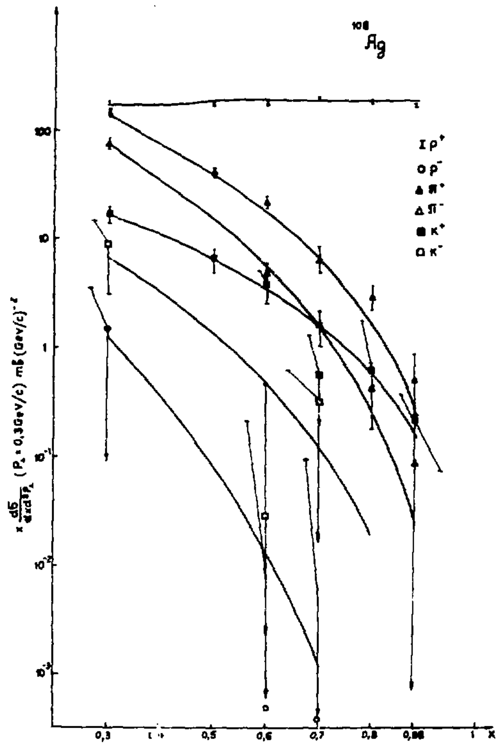

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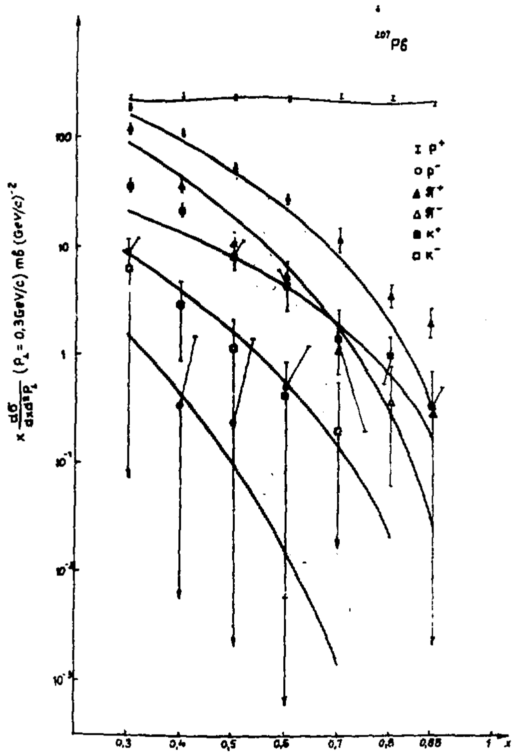

Fig. 5

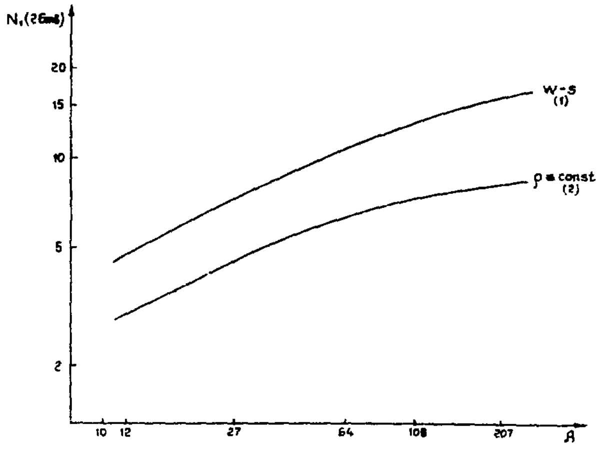

Fig. 6

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