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INVESTIGATIONS OF THE PARTICLE PRODUCTION PROCESS IN HADRON-NUCLEUS COLLISIONS:

Intensities of Particles

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1. INTRODUCTION

In this work, we analyse intensity distributions of the particles produced in hadron-nucleus collisions. As a measure of the intensity, the multiplicity n_π of the pions produced in the collisions is employed; with approximation well enough, the intensities of fast charged particles ejected in a collision may be used as well.

Many models of the particle production mechanism in hadron-nucleus collisions were proposed, but there is no one which could account for all hadron-nucleus collision data in a convincing manner in terms of our knowledge of hadron-nucleon collisions. Moreover, in the models many free parameters are involved.

In a series of articles, written by one of us, the purpose was to show how it is possible to reproduce the data on hadron-nucleus collisions in terms of: our knowledge of hadron-nucleon collisions, the target nucleus size and matter density distribution in nuclei[1-3]. Free-parameterless model of high energy particle collision with atomic nuclei was proposed[4].

First of all, we would like to present results of comparison of the experimental data on intensity distributions of the produced particles with corresponding distributions proposed by the free-parameterless model[4].

The paper is arranged as follows: after the introduction - in section 1 - we describe - in section 2 - the experimental data used, in section 3 we present shortly the predictions of the model and, in section 4, comparisons of the experimental data with the predictions are shown. Conclusions and remarks, section 5, close the article.

2. EXPERIMENTAL DATA USED FOR THE ANALYSIS

The data used here for the analysis of intensities of produced particles in hadron-nucleus collisions are from works of M.A.Faessler[5] and M.A.Faessler at al.[6] at 37.5 GeV, and from Z.Strugalski and T.Siemiarczuk[7], and E.Mulas[8] at

9 GeV. At 37.5 GeV the multiplicities of charged particles in Pi-C, Pi-Al, Pi-Cu, Pi-Ag, Pi-Pb collisions were determined; at 9 GeV the multiplicities of charged particles were measured in Pi-Xe collisions. For the analysis of experimental data, results for Pi-C, Pi-Cu, Pi-Pb and Pi-Xe were used.

In calculating corresponding distributions within the frames of the model[4], data on the particle intensity from hadron-nucleon collisions at various energies should be used. As such data the wealth of results were used from the work of Czyzewski and Rybicki[9]. In this work the description of data in pp and Pip collisions by simple formula has been done[9].

3. PREDICTIONS OF THE FREE-PARAMETERLESS MODEL

According to the model[4], particle production in hadron-nucleon collisions, in nucleon-nucleon collisions in particular, is mediated by intermediate objects created firstly in a $2 \to 2$ type endoergic reaction in the early stage of the collision [10,11]. The objects called generons[11] behave themselves as usual hadrons do it, in passing through intranuclear matter[11]. All what is seen as an outcome in the collision of hadrons with nuclei is a composition of some number $m = 1, 2, 3, \ldots$ of statistically independent outcomes which could be observed separately in elementary hadron-nucleon and nucleon-nucleon collisions at incident particle energy mean values of about E/m, where E is the energy of the incident hadron in hadron-nucleus collision reaction. The elementary or, better, quasielementary collisions occur when the incident hadron and the produced generons come into collisions with downstream nucleons inside the target nucleus. This way, the quasilinear unidimensional intranuclear cascade of generons develops. The quantity m depends on the intranuclear matter layer thickness[3] λ which incident hadron has to overcome in a collision. It is possible[3] to derive formulas for the mean value of m, $\langle m \rangle$, and for probability $P(m, t)$ that a value m will appear when a hadron is incident on intranuclear matter "slab" of a thickness $t = \lambda/\langle\lambda_0\rangle$, where $\langle\lambda_0\rangle$ is the mean free path of the hadron in intranuclear matter before to come into particle-producing collision; it is measurable quantity[12]. The quantity t may be related either to the average thickness of the intranuclear matter layer in a nucleus, when the value $\langle\lambda\rangle$ is used instead of λ, or to a thickness $\lambda(b)$ corresponding to any distance b from the target nucleus center; $\langle\lambda\rangle$ should be used when particle-production characteristics are related to the total sample of collision events, at all impact parameters.

Explicitly[3,4]:

$$P(m,\ t) = e^{-t}(1 - e^{-t})^{m-1} \tag{1}$$

with $\langle m\rangle = e^{t}$.

If $p_m(n)$ is the distribution of the n charged particle emission probability in an m-th act of the collision at $E_h^m = E_h/m$ the resulting distribution of the multiplicity n of produced particles can be written:

$$f(n) = \sum_m P(m,\ t)\cdot p_m(n), \tag{2}$$

where $p_m(n)$ is the composition of m statistically independent distributions p(u), p(v), p(w),..., p(z) of the charged particle multiplicities u, v, w,..., z in any of hadron interactions inside the target nucleus; u + v + w + ... + z = n. The distributions p(u), p(v),... may be taken directly from the experiments for hadron-nucleon collisions at E_h/m values of incident hadron energy.

Then, the charged particle multiplicity n distribution in a collision of a hadron with an atomic nucleus A at the incident energy E_h is:

$$f(n,A,E_h) = e^{-\frac{\langle\lambda\rangle}{\langle\lambda_0\rangle}} \sum_m \left(1 - e^{-\frac{\langle\lambda\rangle}{\langle\lambda_0\rangle}}\right)^{m-1}\cdot p_m(n); \tag{3}$$

there are not any free parameters in this formula, it was prompted by experiment. The probabilities p(u), p(v), p(w), ..., p(z) could be taken directly from experiments in which hadron-nucleon collisions were studied at various energies.

In this work we use the functional approximation[9] of the experimentally obtained particle multiplicity distributions in hadron-nucleon collisions instead of the direct data, although. This approximation[9] is:

$$p_m(n) = \frac{d^2\left(d\frac{n}{D} - d\frac{\langle n\rangle}{D} + d^2\right)}{\Gamma\left(d\frac{n}{D} - d\frac{\langle n\rangle}{D} + d^2 + 1\right)}\cdot\frac{2d}{D}\cdot e^{-d^2} \tag{4}$$

within the energy interval $E_h \approx 4\div59$ GeV, where: $\langle n\rangle=\langle n(\frac{E_h}{m})\rangle$,

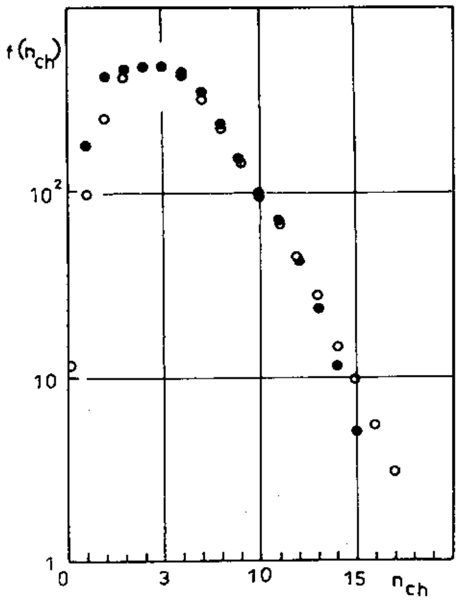

Fig.1. Charged secondaries multiplicity n_{ch} distribution $f(n_{ch})$ in pion-^{12}C collisions at 37.5 GeV/c momentum. o - experimental data [5,6], o - predictions of the model [4].

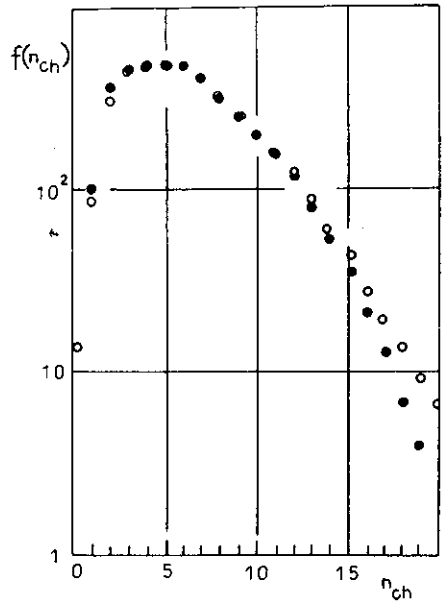

Fig.2. Charged secondaries multiplicity n_{ch} distribution $f(n_{ch})$ in pion-^{64}Cu collisions at 37.5 GeV/c momentum. o - experimental data [5,6], o - predictions of the model [4].

$D = D(\frac{E_h}{m})$, d = 1.7 for interactions pp, and d = 2.2 for interactions [15] Pi-p. For higher energies, 50÷300 GeV, the approximation is [14]:

$$P_m(n) = \frac{1}{<n>}\,\psi(z), \qquad (5)$$

where $z = n/<n>$ and

$$\psi(z) = (3.79z + 33.7z^3 - 6.64z^5 + 0.332z^7)\cdot e^{-3.04z}\,. \qquad (6)$$

for both the approximations (4) and (5), it can be taken [14]:

$$<n> = \alpha + \beta\cdot\left(1 - \frac{1.24}{\sqrt[4]{P_{lab}}}\right)\ln P_{lab} \qquad (7)$$

with $\alpha = 2.2$ and $\beta = 1.5$.

Results of calculations for $Pi^- + C \to n_{ch}$, $Pi^- + Cu \to n_{ch}$, $Pi^- + Pb \to n_{ch}$ at 37.5 GeV are presented in figs.1÷3, the re-

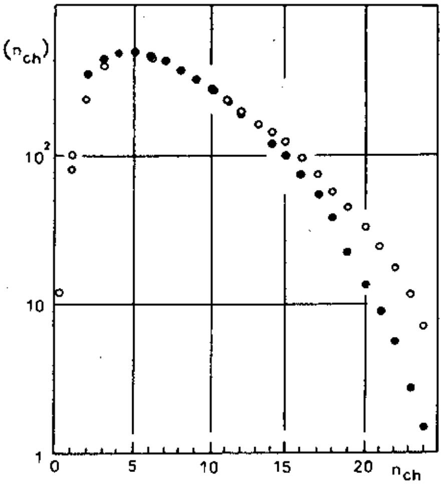

Fig.3. Charged secondaries multiplicity n_{ch} distribution $f(n_{ch})$ in pion-^{207}Pb collisions at 37.5 GeV/c momentum. o - experimental data [5,6], predictions of the model [4].

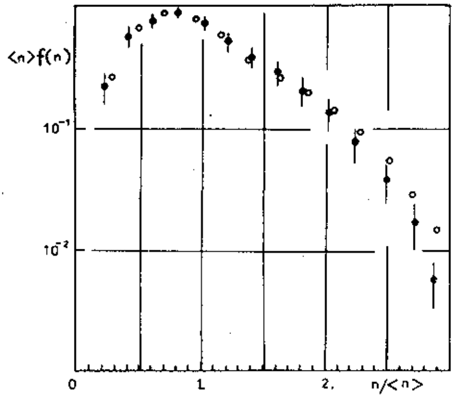

Fig.4. The distribution $\langle n \rangle f(n)$ of the charged secondaries n multiplicity expressed in $n/\langle n \rangle$ in pion-^{131}Xe collisions at 9 GeV/c momentum. • - experimental data [7,8], o - predictions of the model [4].

sults for $Pi^- + Xe \to n_{ch}$ at 9 GeV are shown in fig.4.The results of calculation and the experimental data have been put together for comparison in figs. 1÷4.

4. RESULTS AND DISCUSSION

The above presented set of experimental data on the produced charged particles multiplicities distributions[5-8] in pion-^{12}C, -^{64}Cu, -^{207}Pb collisions at 37.5 GeV/c and in pion-^{131}Xe collisions at 9 GeV/c has been employed in order to assess the correctness of the free-parameterless model[4], in this work.

In putting together the experimental data and corresponding predictions of the model for comparison, it was found that: a) The shapes of the confronted distributions are almost identical. b) At the multiplicity values n_{ch} near to the mean multiplicity $\langle n_{ch} \rangle$, both the multiplicity distributions - the experimental and the predicted one - are practically the same. c) Outside the "mean" region, especially for large n_{ch} values - at $n_{ch} \gtrsim 10$, disagreement is observed of the order of 1÷2 standard deviations. The higher are the values of n_{ch} the larger is the disagreement; mostly evident, it increases for the target nuclei with larger mass numbers A, fig.1÷3. d) At smaller values of n_{ch}, $n_{ch} \lesssim 3$, there are observed differences between the experimental distributions and the predicted ones, but the disagreement is evidently smaller. e) At $n_{ch} \lesssim 3$, the experimental values for the distributions are higher than the predicted ones; at $n_{ch} \gtrsim 10$ the experimental distributions are situated lower than the corresponding predicted distributions, fig.1÷4.

In order to express some conclusive opinion about a usefulness of the free-parameterless model for a description of the experimental data on the distributions of the particle ejection intensities in hadron-nucleus collisions, one should take into account that: a) The predictions of the model are based on the data on all charged particles emitted in hadron-nucleon collisions; the data are practically for all charged secondaries ejected in elementary hadron-nucleon collisions. b) The experimental data, from the hadron-nucleus collisions, are obtained for the relativistic secondary charged particles and should be of smaller values as corresponding values based on the data from elementary hadron-nucleon collisions reactions; it may cause the observed differences at $n_{ch} \gtrsim 10$. c) The experimental data on n_{ch} distributions in hadron-nucleus collisions contain the target protons accounted for produced particles as well, what leads to small increase of the production intensity at small values of n_{ch}; protons are emitted from the target nucleus, not produced. And so, the small differences between corresponding distributions - the obtained experimentally and the predicted ones by the model - may be explained simply; in principle the differences can be evaluated accurately.

The most important result from the investigations performed in this work is that the free-parameterless model/4/ reproduces the intensity n_{ch} distributions of the produced charged particles quantitatively well enough, without any free parameters in terms of corresponding data on hadron-nucleon collisions and known data/16/ on target nucleus size and matter density distribution in it. Within the frames of this model, the distributions of particle production intensities in hadron-nucleus collisions are represented by simple formulas derived/4,17/ on the basis of the picture of the collision process; the picture was prompted experimentally/1-3/.

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