Emission of fast protons in high-energy hadron-emulsion interactions

S. Drndarević, D. Krpić, and O. Adamović
Faculty of Physics, University of Beograd, 11000 Beograd, Yugoslavia
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The model-independent method for evaluating the intensity of the emission of fast nucleons in hadron-nucleus reactions as formulated by Strugalski is applied to the multiplicity distribution of fast protons in collisions of protons at 300 and 400 GeV/c and negative pions at 300 GeV/c with emulsion nuclei. It is shown that the production of pions does not influence significantly the emission of protons.

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I. INTRODUCTION

The model-independent method for the determination of the nuclear density distribution by means of fast hadron interactions was recently proposed by Pawlak *et al.* [1] and Strugalski and Dessoky [2,3]. The method is based on the statement that the probes of nuclear matter must be strongly interacting [4–6], as well as on certain relevant experimental results [7–9].

The number n_N of nucleons emitted from a target nucleus when a high-energy hadron traverses it through a thickness λ is

$$n_N = \lambda S[1 - e^{\lambda/\lambda_t}], \tag{1}$$

where λ is expressed in nucleons/S, $S = \pi D_0^2 \approx 10$ fm^2, D_0 is the nucleon diameter, and λ_t is the hadron mean free path in intranuclear matter. Since λ_t is connected with the hadron-nucleon total cross section σ_t as $\lambda_t = 1/\sigma_t$, if we express λ_t in nucleons/S, σ_t is in S/nucleon. Equation (1) shows the following:

(1) The number of nucleons, n_N, emitted in a high-energy hadron-nucleus collision (with or without pion production) provides information about the thickness λ of nucleon matter layer traversed by the projectile in the target nucleus.

(2) The mean $\langle n_N \rangle$ and the maximum number $n_{N_{\max}}$ of emitted nucleons are related to the mean $\langle \lambda \rangle$ and maximum thickness $\lambda_{\max}$ of the target nucleus, respectively.

(3) The normalized multiplicity distribution $N(n_N)$ presents actually the distribution $W(\lambda)$ of the thickness λ of the target nucleus at various impact parameters b. The distribution $W(\lambda)$ depends on the radial distribution $\rho(r)$ of the nuclear density.

The normalized multiplicity distribution of emitted nucleons, $N(n_N)$, is

$$N(n_N) = W(n_N)[1 - e^{\lambda S/\lambda_t S}] = W(n_N)[1 - e^{n_N/n_t}] \ , \tag{2}$$

where $\lambda_t S \equiv n_t$ and $\lambda S \equiv n_N$. The $W(n_N)$ distribution can thus be evaluated from the system of equations (2) using the $N(n_N)$ from the experiment.

In experiments where only the charged particles are detected, the $N(n_N)$ distribution has to be replaced by the multiplicity distribution of protons:

$$N(n_p) = k \sum_{n_N = n_p}^{n_{N_{\max}}} W(n_N)[1 - e^{n_N/n_t}] P_{n_N}(n_p) \ . \tag{3}$$

$P_{n_N}(n_p)$ in Eqs. (3) is the probability for n_p fast protons to be emitted when a hadron has traversed a nuclear matter thickness λ and met n_N nucleons within the volume λS centered on its course. This probability depends on Z/A of a target nucleus and is equal to

$$P_{n_N}(n_p) = C_{n_N}^{n_p} \left[\frac{Z}{A}\right]^{n_p} \left[1 - \frac{Z}{A}\right]^{n_N - n_p} \ , \tag{4}$$

with the binomial coefficient

$$C_i^j = \frac{i!}{j!(i-j)!} \tag{5}$$

and k is Eqs. (3) being the normalization factor.

There are two different possible approaches to using Eqs. (3).

(1) The multiplicity distribution of hadrons can be predicted by Eqs. (3) using some hypothetical distribution of $W(n_N)$ following, for example, from the Fermi distribution of nuclear density, and then comparised with the experiment.

(2) The system of $n_{N_{\max}}$ linear equations can be solved for $n_{N_{\max}}$ unknowns $W(n_N)$, using the experimental results on the left side of the equations. Relevant characteristics of the target nucleus and of the region from which the nucleons are emitted can than be estimated.

We choose to check the possible practical uses of the second of the two possibilities.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The nuclear emulsion was exposed to beams of protons at 300 and 400 GeV/c and to a beam of negative pions at 300 GeV/c. The experimental procedure is explained in our earlier work [10]. In the present work we use the multiplicity distributions of fast protons (gray tracks).

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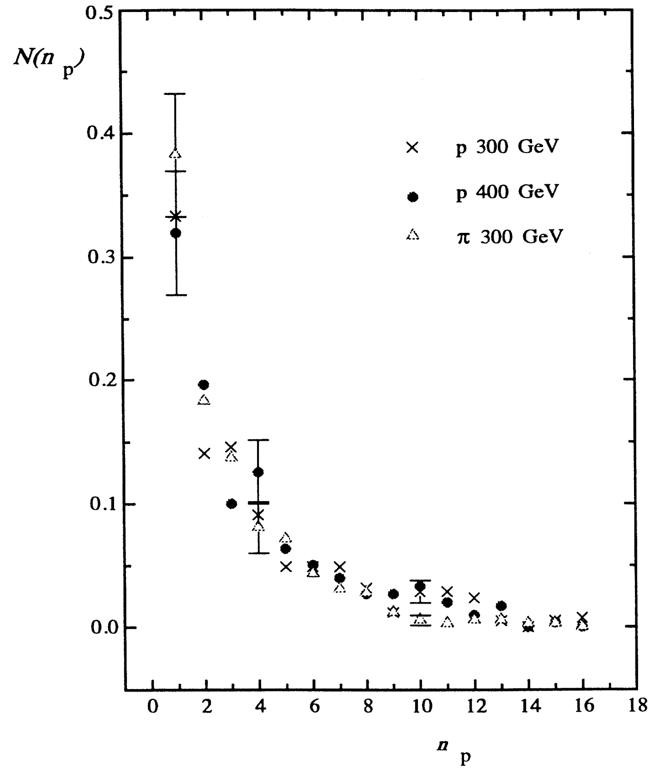

FIG. 1. Normalized multiplicity distributions of fast protons emitted in interactions of protons at 300 and 400 GeV/c and π^- mesons at 300 GeV/c with emulsion nuclei.

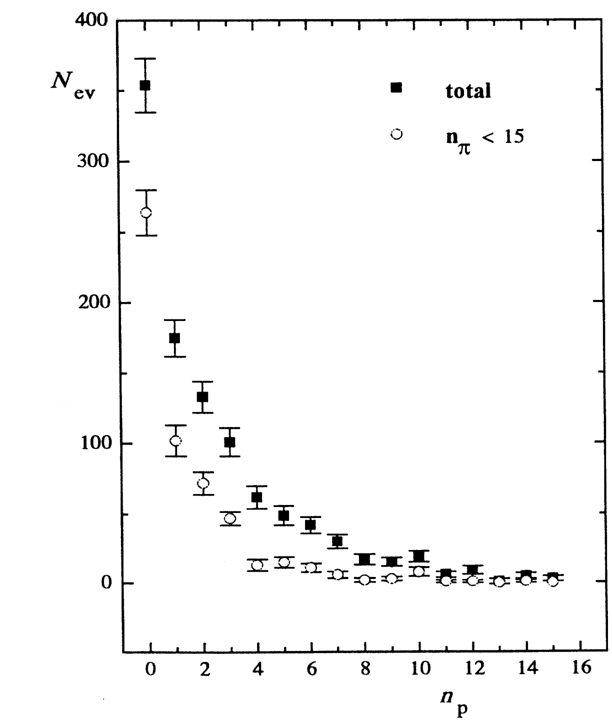

FIG. 2. Non-normalized multiplicity distribution for the total sample of 1028 hadron-emulsion interactions (rectangles) and for the subsample with the "small" number of created pions (circles).

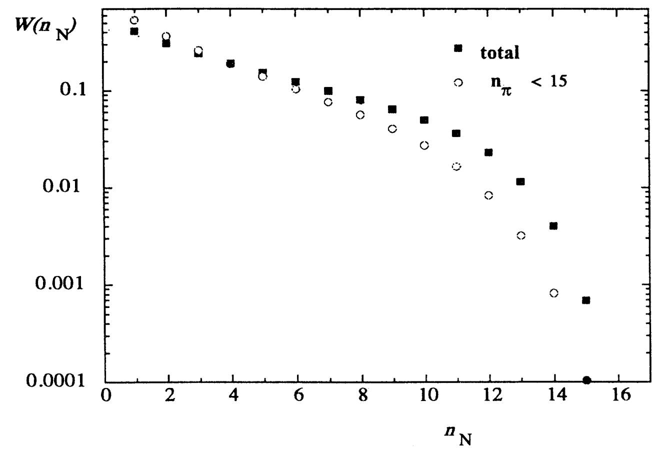

FIG. 3. Solutions of the system of linear equations, $W(n_N)$, for the total sample (rectangles) and for the subsample with $n_\pi < 15$ (circles).

The efficiency of the registration of protons is near 100% within the 4π emission solid angle.

The proton multiplicity distributions $N(n_p)$ for $405p$(300 GeV)-, $301p$(400 GeV)-, and $322\pi^-$(300 GeV)-emulsion interactions, normalized to 1, are presented in Fig. 1. Statistical errors are shown only on some experimental points. Since it is seen that there is no significant dependence on the incident particle, we conclude that the data can safely be united. The total sample of 1028 events contains 3582 fast protons. Rectangles in Fig. 2 represent the total number of events, N_{ev}, with a given multiplicity.

For the emulsion, $\langle Z \rangle = 29.3$ and $\langle A \rangle = 66.6$. We estimate that $n_{N_{max}} = 15$, which is in agreement with the experimental finding that events with more than 15 emitted protons are extremely rare. Using this value as the limit in the sums (3) and the total multiplicity distribution normalized to 1, we calculated the solutions of the given system of linear equations. The solutions, $W(n_N)$, are presented as rectangles in Fig. 3.

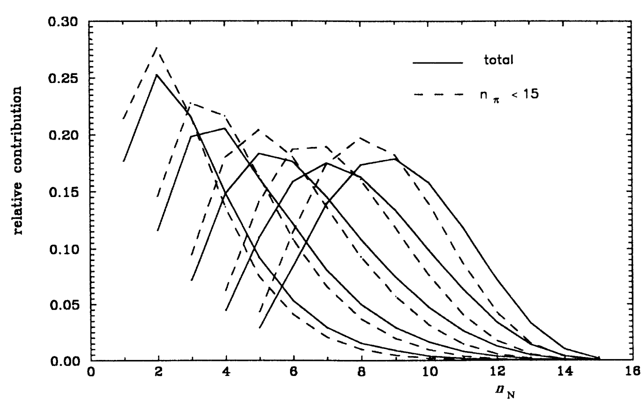

FIG. 4. Relative contributions of the members of sums in Eqs. (3), comparison of the total sample (solid line) and the subsample with $n_\pi < 15$ (dashed line). Beginning from the left, the pairs of curves present the first five of Eqs. (3) each normalized to 1 and corresponding to events with one to five emitted protons.

The emulsion is a composite target, and it is impossible to ascertain which nucleus has interacted with a projectile. Estimating the parameters of the target nuclei from the $W(n_N)$ distribution is not an easy task. Instead, we aim at checking the important statement of Strugalsky that in this energy region the production of pions should not influence the emission of protons significantly.

The mean multiplicity of pions produced in this experiment is about 15 as had been found in our earlier works [11,12]. From the total sample we extracted events with $n_\pi < 15$ ("small" number of pions), and the multiplicity distribution of fast protons for this subsample is shown in Fig. 2 by circles. In Fig. 3 the corresponding $W(n_N)$ distribution is also presented by circles. It is seen that both $W(n_N)$ distributions have basically the same shape.

In order to make some comparison of the subsample with a low pion production with the whole set of data, we calculated the relative contributions of members of the sums (3) using the values of $W(n_N)$. We present only a few sets of our results in Fig. 4. The solid line corresponds to the total sample, while the dashed line corresponds to events with $n_\pi < 15$. Beginning from the left, the first pair of curves presents the first of Eqs. (3), i.e., events with $n_\pi = 1$, the second presents the events with $n_\pi = 2$, etc. We can see that the distributions for the subsample are slightly shifted to the left. When the production of pions is poor, we are led to conclude that the impact parameter is large, i.e., that the projectile meets a small number of nucleons on its way through the target. The emission of protons is thus expected to be less intensive. But, generally, as Strugalsky states, pion production in this energy region indeed does not influence very much the total process.

Finally, we have some comments on the method itself. First, the solving of Eqs. (3) starts from the tail of the multiplicity distribution where the experimental data are the least reliable. The method is thus very sensitive to the shape of the experimental distributions, and a large relative fluctuation in the distribution easily leads to meaningless values of $W(n_N)$. Those properties indicate that the method requires very large statistics for a confident estimation of nuclear parameters.

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