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ENERGY- AND A-DEPENDENCES OF THE NUCLEON EMISSION INTENSITY IN HADRON-NUCLEUS COLLISIONS

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1. INTRODUCTION

When a hadron of high energy - of the kinetic energy higher than the energy threshold for the pion production - collides with an atomic nucleus, various phenomena occur, mainly: nucleon emission, pion production, target fragmentation. The frequency of an appearance of these phenomena depends on the sort of incident hadron h, on its energy E_h, and on the mass number A of the target nucleus. It is known from experiments performed at various incident hadron energy, from about 2 up to about a few thousands GeV, that any high energy hadron-nucleus collision is accompanied by an emission of nucleons from the target nucleus. The emitted nucleons are "fast" - of kinetic energy higher than the kinetic energy of the so-called "evaporated" nucleons; as it is known from experiments, these nucleons are of kinetic energy from about 20 to about 400 MeV. In emulsion experiments the fast protons are identified as the charged particles leaving "gray" tracks, or "g-tracks".

The nucleon emission accompanying a hadron-nucleus collision process may be characterized simply by the multiplicity n_N of emitted nucleons, used as a measure of the emission intensity, the emission intensity distribution, energy spectra, momentum distribution, and angular distributions of the emitted nucleons.

Any experimental information about the nucleon emission is obtained usually from the proton emission study only, because in almost all experiments performed now neutrons are unobserved. But, the similarity of the shapes of the dependences of average number $\langle n_p \rangle$ of emitted fast protons and of average number $\langle n_n \rangle$ of observed neutral "stars" on the number n_π of observed produced pions, in pion-xenon nucleus collisions, indicates that the data on the fast proton emission can be generalized to the fast nucleon emission process at all. Then the proton multiplicity, the proton emission intensity distribution, proton energy and momentum spectra, and proton angular distributions characterize the nucleon emission. These characteristics are, of course, main characteristics and other additional characteristics may be used as well.

We limit ourselves, in this paper, to considerations about the nucleon or, correctly, proton emission intensity; energy and momentum spectra, and angular distributions were considered in my previous works [1,2].

Following parameters describing the multiplicity distribution are usually of interest: a) Mean proton multiplicity $<n_n>$ used as a measure of mean proton emission intensity; b) The width of the distribution defined by the square root of the second central moment, or the dispersion $D = (<n_p^2> - <n_p>^2)^{1/2}$; c) The asymmetry of the distribution as measured by the skewness $\gamma_1 = (<(n_p - <n_p>)^3>)/D^3$; d) The kurtosis of the distribution $\gamma_2 = (<(n_p - <n_p>)^4>)/D^4$.

In my previous works, it was shown that fast proton emission intensity distribution in high energy hadron-nucleus collisions is determined by the target nucleus geometry - its size and nucleon density distribution inside it /3,4/. But, what is observed in experiments depends as well on various hadron-nucleon collision cross-sections. The purpose of this paper is to show that the energy E_h- and the mass number A-dependence of mean proton intensity $<n_p>$ observed in experiments can be reproduced simply by mean thickness $<\lambda>$ of target nuclei, measured in nucleons per some area S, and the total hadron-nucleon cross-section σ_t, measured in S per nucleon.

We start our consideration with a short review of properties of the fast nucleon emission in hadron-nucleus collisions, found experimentally.

2. SHORT REVIEW OF EXPERIMENTAL DATA ON FAST NUCLEON EMISSION IN HADRON-NUCLEUS COLLISIONS

Distributions of the multiplicities n_p, or n_g, of the fast protons emitted in proton-emulsion nuclei collisions, at the incident proton momentum over some GeVs, are energy-independent, fig.1. It was shown that $<n_g>$ distribution at 17-200 GeV in pion-nucleus collisions is energy-independent as well /7/, but the n_g distributions are different for primary protons and pions /7/. The proton multiplicity n_g in pion-nucleus collisions at 37.5 GeV/c momentum changes with the mass number A of the target nucleus /9/. It is reasonable to generalize these facts and to state that the nucleon multiplicity n_N distribution is the same for collisions of definite hadron h with definite target nucleus A at energies over a few GeV; the n_N distribution changes when h or A, or both h and A, change.

Results of many works /5-7, 10-12/ performed using nuclear emulsions show that the mean multiplicity $<n_g>$ of the gray tracks does not depend on the energy of the incident proton within wide energy interval, from a few GeV up to about 3500 GeV, and on the energy of incident pions, within the energy interval from a few GeV up to about 200 GeV. But, it is known from proton-tungsten collision investigations at 2-10 GeV/c momentum that the mean number $<n_p>$ of emitted fast protons increases

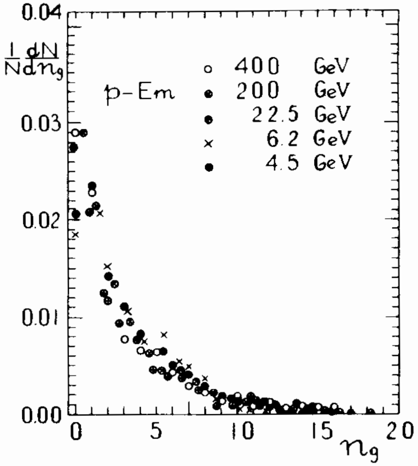

Fig.1. Distributions $\frac{1}{N}\frac{dN}{dn_g}$ of the multiplicities n_g of gray tracks in proton-emulsion nuclei collisions at 4.5, 6.2, 22.5, 200, and 400 GeV kinetic energy /5-8/; N - the total number of events in a distribution.

with the increase of the incident proton momentum /13/. It is known /9/ as well that the mean number $<n_p>$ of fast protons emitted in hadron-nucleus collisions at a definite energy increases with the increase of the target mass number A. It is a reason to generalize it and to state that the mean number $<n_N>$ of fast nucleons emitted in hadron-nucleus collisions increases firstly with the increase of the incident hadron energy up to a few GeV and becomes to be almost constant, being almost energy-independent, at higher projectile energy.

As can be concluded from experimental investigations /2,10,14,15/, the fast nucleons are emitted at relatively large angles, up to about 180 degrees. From our experimental investigations /2/, it is reasonable to conclude and generalize as well that angular distributions of nucleons emitted in hadron-nucleus collisions are energy- and h-independent; the average nucleon emission angle $<\theta_N>$ does not depend on the nucleon emission intensity n_N, when $n_N > 2$.

From experimental investigations of the fast proton energy spectra /1,6,10,14/, it is reasonable to conclude and generalize that nucleon energy spectra do not depend neither on the sort of the incident hadron h and the target nucleus A nor on the projectile hadron energy E_h. These experimental facts allow one to conclude as well that the particle production process does not influence the nucleon emission process.

Of course, it should be emphasized that the correctness of these generalizations must find its further support in future experiments.

In our studies of pion-xenon nucleus collisions at 2.34 and 3.5 GeV/c momentum we were able to identify events in which the incident pion is completely stopped and deposited its energy in the target nucleus, without particle production /14,15-22/. It was discovered /17/ that in such events at 3.5 GeV/c momentum

The width, the skewness and the kurtosis can be derived without difficulty from the λ distributions[30] for various target nuclei as well. But, we omit here this derivation, because we will discuss later only experimental data on the mean nucleon emission intensity.

Formula (2) is valid for hadron energies E_h higher than the hadron energy loss when it traverses the target nucleus along the nucleus diameter. When the hadron energy is smaller, the energy loss should be taken into account. At smaller energy a hadron can penetrate thinner layers of nuclear matter and the target mean thickness $\langle\lambda\rangle$ protons/S should be replaced by some effective target thickness $\langle\lambda_{ef}\rangle$ protons/S which is energy-dependent and determined by formula:

$$\langle\lambda_{ef}(E_h)\rangle_A = \sum_{n_p=\lambda_a}^{n_p=n_p(D)} W(A,n_p)\cdot\lambda_a + \sum_{n_p=1}^{n_p=\lambda_a-1} W(A,n_p)\,n_p\,, \qquad (3)$$

where λ_a protons/S $=\frac{E_h}{\epsilon_h}$ GeV/GeV/(protons/S), and ϵ_h is the measurable quantity - energy loss of the incident hadron on the path length as large as one proton per S; $W(A,n_p)$ is a given function[30] - distribution of the nuclear matter layer thicknesses λ protons/S in atomic nuclei with the mass number A. The value of ϵ_h was determined experimentally: $\epsilon_\pi = 0.18$ for pions and $\epsilon_p = 0.36$ for protons.

4. DESCRIPTION OF THE MEAN MULTIPLICITY OF EMITTED FAST PROTONS

Using formula (2) with $\langle\lambda_A\rangle$ determined in our previous work[30] and with $\langle\lambda_{ef}(E_h)\rangle_A$ determined by formula (3), the energy- and A-dependences of the mean multiplicities n_p were calculated. Results of calculations we confronted to corresponding experimental data, figs.3-5.

5. DISCUSSION AND RESULTS

From figs.3-5, it can be concluded that simple formula (2) reproduces available experimental data within wide energy region - from a few GeV up to 3500 GeV, and within wide range of the target mass numbers A - from 12 up to 206. It allows one to conclude that:

1. The mean intensity $\langle n_N\rangle$ of the nucleon emission is determined by the mean target nucleus thickness $\langle\lambda\rangle$ nucleons/S and by the total cross-section σ_t for hadron-nucleon collisions.

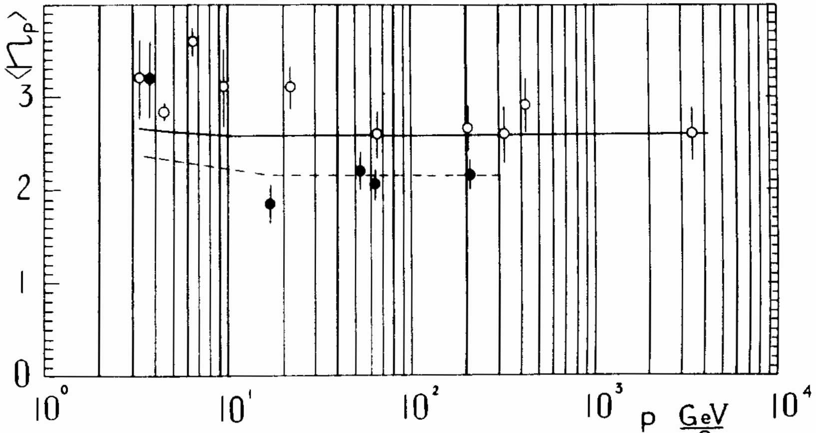

Fig.3. Dependence of the mean proton multiplicity $\langle n_g\rangle$, of fast protons emitted in proton-emulsion o and pion-emulsion ● nuclei collisions, on the incident hadron momentum. Results of calculations performed using formula (2) are for proton-emulsion ——— and for pion-emulsion - - - - nuclei collisions. Experimental data are from various works[5-11].

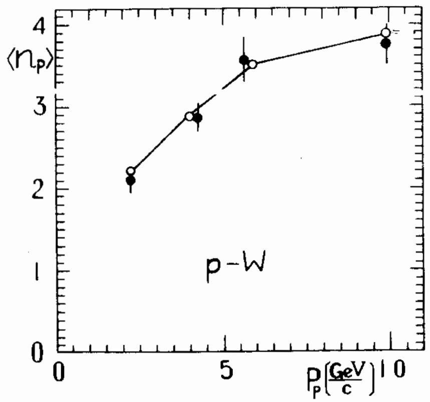

Fig.4. Dependence of the mean proton multiplicity $\langle n_p\rangle$, in proton-tungsten nucleus collisions at 2-10 GeV/c, on incident proton momentum P_p. Experimental data[13] ●, calculations by means of formulas (2) and (3) —o— .

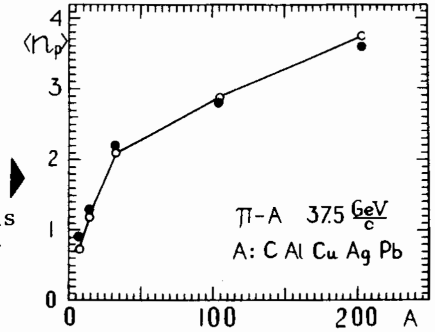

Fig.5. A-dependence of the mean multiplicity $\langle n_p\rangle$ of fast protons emitted in pion-nucleus collisions at 36.5 GeV/c momentum. ● - experimental data[9], -o- - calculations using formula (2).

2. Observed energy-independence of the mean proton multiplicity $\langle n_p\rangle$ at energies higher than a few GeV appears due to very weak energy-dependence of the total cross-section for had-

ron-nucleon collisions; the energy-dependence of $<n_p>$ at smaller energies reflects the energy loss of incident hadron in nuclear matter, and energy-dependence of σ_t at this energy region.

3. Observed A-dependence of the mean intensity of proton emission $<n_p>$ is determined by the target nucleus size and nucleon density distribution in it.

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Стругальский З. E1-83-851
Зависимость от энергии и от массового числа A
интенсивности испускания нуклонов в столкновениях адрон-ядро

Анализируется интенсивность испускания нуклонов в столкновениях адронов высоких энергий с ядрами. Энергетическую и A-зависимости средней интенсивности испускания протонов, измеряемой средней кратностью испускания протонов, наблюдаемые на опыте, можно просто воспроизвести в терминах средних толщин ядер-мишеней, выраженных в числах протонов на Фм², и полного эффективного сечения столкновений адрон-нуклон. Выведены соответствующие формулы, которые проверены на опыте в пределах энергий адронов от 2 до 3500 ГэВ и в пределах значений массового числа ядер-мишеней от 12 до 206.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Strugalski Z. E1-83-851
Energy- and A-Dependences of the Nucleon Emission Intensity
in Hadron-Nucleus Collisions

The intensity of nucleon emission in high energy hadron-nucleus collisions is considered. Energy- and A-dependences of the mean proton intensity, measured by the mean proton multiplicity, observed in experiments, can be reproduced simply by the mean thicknesses of target nuclei, expressed in protons per some fm², and by the total cross section for hadron-nucleon collisions. Formulas are derived and tested experimentally within incident hadron energy region from 2 up to 3500 GeV, and within target nucleus mass numbers 12-206.

The investigation has been performed at the Laboratory of High Energies, JINR.

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