сообщения
объединенного
института
ядерных
исследований
дубна

E1-93-31

Z.Strugalski[1], A.E.Dessoky[2]

THE RELATION BETWEEN INTRANUCLEAR MATTER DENSITY DISTRIBUTION AND THE MULTIPLICITY DISTRIBUTION OF NUCLEONS EMITTED FROM NUCLEI BOMBARDED BY HIGH ENERGY HADRONS

[1]Permanent address: Institute of Physics, Warsaw University of Technology «Politechnika», ul.Koszykowa 75, PL 00-662 Warsaw, Poland
[2]Warsaw University of Technology, Institute of Physics; on leave from Tanta University, Faculty of Science, Tanta, Egypt

1993

1. INTRODUCTION

The aim of this work is: a) to propose a model-independent method of nucleon density distribution determination in nuclei by means of high energy hadronic projectiles — used as hadronic probes; b) to show how it is possible to perform appropriate experiments; c) to discuss the physical analysis of the experimental data about.

The application of high energy hadrons as probes for the intranuclear matter distribution studies has been long a difficult problem [1—4]. After considerations, one is led to the conclusion, although, that the only probes of the intranuclear matter distribution must be strongly interacting [1,2,4,5].

But, many methods which have been used in determining the nuclear structure by means of such probes necessarily involved some model-dependences of the obtained results.

Thus, some model-independent method should be worked out and more experimental investigations are desired using the method which, in a direct way, will tell about both nucleons — protons and neutrons — distributions in nuclei.

Our first attempts to work out some model-independent method have been made before about 25 years [5] and were continued up to last a few years [4,6].

2. SEARCH FOR A PHYSICAL PHENOMENON WHICH MIGHT BE USED AS A PHYSICAL BASIS FOR A WORKING PRINCIPLE OF THE METHOD

The only way was to look for appropriate nuclear phenomenon in which the outcome in high energy hadron-nucleus collision reaction depends simply and definitely on the nucleon distribution in the target nucleus; this phenomenon should be connected with hadron passage through intranuclear matter accompanied by clearly observable and identificable effects. For example, it should be a nuclear process something like the well-known electromagnetic process — like the passage of electrons or muons through layers of a material. Intuitively, a nuclear analogue of the electromagnetic process should exist in nature, we should observe it sometimes in its pure form — as the passage of high energy hadron through a massive nucleus. Such nuclear process — the passage of hadrons through intranuclear matter could be applied as a physical principle of the method for nucleon density distribution determination, if characteristics of the secondary effect, of the nucleon emission — for example, are definitely and clearly dependent on the intranuclear matter layer thickness involved in the hadron-nucleus collisions; the thickness should be expressed in nucleons/fm^2.

The hadron passage through intranuclear matter, the nuclear analogue of the electromagnetic process — of the passage of electrically charged particle through layers of the matter — has been found in our experiments and studied in detail [7—11]. The passage is accompanied by nucleon emission from the target nucleus, and the nucleon emission intensity is related simply to the thickness of the intranuclear matter layer covered by the hadronic projectile [12].

This nuclear process has been employed as a physical basis of our method [4] — of the method of the matter density distribution determination by means of hadronic probes.

3. THE METHOD

The method is based on very simple relation revealed experimentally [8,9,12,13]: the number n_N, or the intensity n_N, of the nucleons emitted from a target nucleus, when a high energy hadron collided with it, depends simply on the thickness λ of the intranuclear matter layer involved in the collision. Quantitative relation is:

$$n_N = \lambda \cdot S \cdot \left(1 - e^{-\frac{\lambda}{\lambda_t}}\right), \qquad (1)$$

where λ in nucleons/S, $S = \pi D_0^2 \approx 10\ \ \mathrm{fm}^2$, $D_0 \approx R_s$ is the strong interaction range, D_0 is the diameter of the nucleon, $\lambda_t = 1/\sigma_t$ is the hadron mean free path in intranuclear matter in nucleons/S, σ_t is the hadron-nucleon total cross-section in S/nucleon.

The formula (1) was tested experimentally within 2 to 3500 GeV/c momentum of the hadronic probes. This formula is valid for the sample of the pure incident hadron passage through the target nucleus — when produced mesons do not appear, and for the sample of any-type hadron-nucleus collisions — when pions are produced as well [13]; the independence of the relation of the kind of the incident pion characterizes it.

On the basis of the formula (1), and the results of its testing, it might be stated that:

1. At energies high enough — over about 2 GeV of the hadronic probe, the thickness λ in nucleons/S involved in a hadron-nucleus collision may be taken along the projectile initial course.

2. The number of nucleons n_N emitted in any hadron-nucleus collision event, at an incident energy high enough, provides the information about the thickness λ in nucleons/S of the intranuclear layer covered by the projectile hadron in the target nucleus.

3. The mean number n_N and the maximum number $n_{N\max}$ of the emitted nucleons in a sample of hadron-nucleus collisions are simply related to the mean thickness $<\lambda>$ in nucleons/S and maximum thickness $\lambda_{\max}$ in nucleons/S of the intranuclear matter layers in the target nucleus.

4. The multiplicity n_N, or intensity n_N, distribution $N(n_N)$ of the nucleons emitted in a numerous samples of collisions of a definite hadron with a definite nucleus is in fact the distribution $W(\lambda)$ of the thicknesses λ in nucleons/S of the target nucleus involved in the collisions; $W(\lambda \cdot S) \equiv W(n_N)$.

5. On the basis of experimental findings [14], the relation between the distribution $N(n_n)$ obtained experimentally and the distribution $W(\lambda \cdot S) \equiv W(n_N)$ of the matter layer thicknesses λ in nucleons/S, can be expressed as follows:

$$N(n_N) = W(n_N) \cdot \left(1 - e^{-\frac{\lambda \cdot S}{\lambda_t \cdot S}}\right) = W(n_N) \cdot \left(1 - e^{-\frac{n_N}{n_t}}\right), \qquad (2)$$

where $\lambda_t = 1/\sigma_t$, σ_t are the above-determined quantities, $S\,\lambda_t \equiv n_t$, $S\,\lambda = n_N$; formula (2) is related simply to the observed distribution $N(n_N)$ of the nucleon emission intensities n_N.

In the formula (2), the values $N(n_N)$ at $n_N = 1,2,3,\dots,n_{N\max}$ are given from experiment, σ_t and S are known as well.

In fact, the formula (2) represents $n_{N\max}$ equations with $n_{N\max}$ unknown quantites $W(n_N)$; the values of the $W(\lambda \cdot S) = W(n_N)$ which should be evaluated characterize the unknown distribution of the intranuclear matter layer thicknesses expressed in nucleons/S.

From the distribution $W(n_N) \equiv W(\lambda \cdot S)$ one can evaluate [15,16] the radial distribution $\rho(r)$ of the intranuclear matter density, in nucleons/fm^3, for the target nucleus.

The mean intensity $<n_N>$, or the mean multiplicity $<n_N>$, is [14]:

$$<n_N> = S \cdot <\lambda> \left(1 - e^{-\frac{<\lambda>}{\lambda_t}}\right), \qquad (3)$$

where $<\lambda>$ is the mean thickness in nucleons/S of the spherical target nucleus.

The maximum intensity $n_{N\max}$, or maximum multiplicity $n_{N\max}$, of the nucleon emission is:

$$n_{N\max} = S \cdot D \cdot \left(1 - e^{-\frac{D}{\lambda_t}}\right), \tag{4}$$

where D in nucleons/S is the diameter of the target nucleus.

It was shown [16] how it is possible to transform known data on radial distribution of the matter layer thicknesses in a spherical nucleus to unknown radial distribution of the matter densities in this nucleus.

4. RESULTS AND REMARKS

It can be stated that the simply measurable distributions $N(n_N)$ of the nucleon emission intensities n_N contain information about the matter density distribution in atomic nuclei. The method of the matter density distribution determination by means of hadronic probes consists, therefore, in:

1. Experimental determination of the nucleon multiplicity n_N distribution $N(n_N)$;

2. Solution of a set of equations (2) for $n_N = 1,2,3,...,n_{N\max}$ unknown values $W(n_N) \equiv W\{\lambda(n_N)\cdot S\}$, in order to obtain the data on radial distribution of the matter layer thicknesses in the target nucleus;

3. Evaluation of the radial distribution of the matter densities $\rho(r)$ in the nucleus, using relations [16] between the matter density and layer thicknesses radial distributions in spherically symmetric objects.

The experimental procedure which allows one to obtain the nucleon multiplicity n_N distribution $N(n_N)$ is very simple. For the protons only, corresponding characteristic $N(n_p)$ is measured in any of hadron-nucleus collision reaction studies. But, when one would like to measure the nucleon multiplicity n_N in any of hadron-nucleus collision reactions, the experimental arrangement should register all the nucleons — both the protons and neutrons — with practically 100% efficiency, within the kinetic energy range of the emitted nucleons from a few up to about 500 MeV. Such experimental conditions might be provided with electronic arrangements like the SFERA or Crystall Ball detectors, when additional parts for effective detection of neutrons will be added to them.

The second variant of the method proposed here could be used as well — the method consisting in the solution of equations for the distribution $N(n_p)$ of the proton multiplicites $n_p = 0,1,2,...,n_{p\max}$. The system of corresponding equations for $N(n_p)$ is similar to (2) but more complicated [4]. In this variant, the distributions $N(n_p)$ should be obtained experimentally only — by means of heavy liquid bubble chambers [4] or corresponding electronic arrangements [17].

The matter density distribution in atomic nuclei, based on the proton multiplicity n_p distribution $N(n_p)$, has been successfully determined for Xenon nuclei in our previous work [4].

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Received by Publishing Department
on February 3, 1993.