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HIGH ENERGY HADRON-NUCLEI COLLISIONS CAUSING INTENSIVE EMISSION OF FAST NUCLEONS NOT ACCOMPANIED BY THE MULTIPLE PION CREATION

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Объединенный институт
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БИБЛИОТЕКА

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Адрон-ядерные столкновения при высоких энергиях, приводящие к интенсивному испусканию быстрых нуклонов без сопровождения множественным образованием пионов

Обнаружены случаи столкновения пионов высоких энергий с ядрами ксенона, в которых интенсивной эмиссии быстрых протонов, с энергиями 20÷300 МэВ, не сопутствует множественное образование пионов. Проведен анализ таких событий. Из анализа следует: а/ испускание быстрых протонов во многих случаях происходит с опережением актов множественного образования пионов; б/ вероятно, что множественное образование пионов в пион-нуклонных столкновениях осуществляется через промежуточные системы; в/ ядро-мишень может быть использовано в качестве анализатора элементарных адрон-нуклонных столкновений; г/ указываются новые возможности исследования структуры атомных ядер адронами высоких энергий.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1979

Strugalski Z.

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High-Energy Hadron-Nuclei Collisions Causing Intensive Emission of Fast Nucleons not Accompanied by the Multiple Pion Creation

The events of high energy pion-xenon nuclei collisions accompanied by the intensive emission of fast protons, of the protons of energies 20 - 300 MeV, without multiple pion creation are discovered and analysed. From this analysis it follows that: a/ the fast proton emission in many cases goes on in advance of the pion creation acts; b/ the multiple pion creation acts in pion-nucleon collisions appear to be going on via some intermediate systems decaying outside the target nuclei; c/ the target nuclei may be used as analysers of the elementary hadron-nucleon collisions; d/ new possibilities are opened for the nuclei structure studies by means of the high energy hadrons.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1979

1. INTRODUCTION

The pion-xenon nuclei collision events at 3.5 GeV/c momentum have been observed in which "fast" protons, of kinetic energies from about 20 MeV to about 400 MeV, are intensively emitted without multiple secondary pion creation[1,2]. The analysis of these cases indicates that various characteristics of the fast protons observed contain important information being necessary for a more deep understanding how the fast hadrons penetrate into the atomic nuclei. These characteristics give us a clue to the direction in which we should try to explain the fast nucleon emission process as well.

During the past few months a great deal of our attention has been given to the detailed study of the events mentioned above[2-6]. In conclusion, it appears to be clear that the results of the analysis of such events hold the information which may be used in attempts to solve in experiments how are the various processes in the hadron-nuclei collisions interrelated: the particle creation, the fast nucleon emission, the nucleon evaporation, and the target nuclei fragmentation[4,6]. It appears, from this as well, to be clear how it is possible to apply the target nucleus as an analyser of the elementary hadron-nucleon collision processes, and to receive information concerning the particle production act in the elementary high energy hadron-nucleon collisions.

In this paper some more important results of these studies are presented in attempts to show shortly the more general properties of the mechanism of the hadron-nuclei collision process and of the particle creation process in the elementary hadron-nucleon collisions.

2. METHOD

The photographs of the xenon bubble chamber of the volume 100 x 40 x 40 cm^3, irradiated along its big axis in 3.5 GeV/c negative electric charged pion beam, were scanned in order to select the pion-xenon nuclei collisions with zero and one secondary pion and arbitrary number of fast protons. The event registered was accepted to be the beam pion collision with the xenon nucleus, if the track of this pion ends or breaks in some point within the fiducial volume inside the chamber, in accompaniament or not by the observable secondary particles outgoing from this reaction point. The minimal angle of the incident pion dispersion, detectable with the constant closed to 100% afficiency in the cases without any other observable secondaries, was 3°. This special scanning for the cases without multiple pion creation was the fragment of the general one being performed for the all pion-xenon nuclei interactions.

The secondary neutral pions of kinetic energies $E_{\pi^0} \gtrsim 0$ were recorded with the efficiency larger than 99.9% within the total 4π solid angle; the secondary positive electric charged pions of energies $0 \le E_{\pi^+} \le 100$ MeV are simple detectable by the observable track sequence $\pi^+ \to \mu^+ \to e^+$ with the efficiency closed to 100% within the total 4π solid angle; the negative electric charged pions of energies $10 \le E_{\pi^-} \lesssim 100$ MeV are detectable with the efficiency closed to 96% within the total solid 4π angle. The protons of energies from 15 to 220 MeV were recorded with the efficiency closed to 100% within the total 4π solid angle. These registration efficiencies were estimated on the basis of the appropriate experimental data.

The kinetic energies of protons were estimated using the range-energy relation, with the accuracy 10% - at energies of nearly 15 MeV, and with the accuracy of 1% - at energies nearly 200 MeV; the average accuracy being almost 4%.

Then, the methodical possibilities allow one to discover and select the pion-xenon nuclei collision events accompanied by the fast proton emission without multiple meson creation.

3. EXPERIMENTAL DATA

About 20 000 frames were carefully scanned and rescanned for arbitrary pion-xenon nuclei collision events within the small central fiducial volume of 30 x 7 x 7 cm^3 inside the xenon bubble chamber. In result, 2800 pion-xenon nuclei collision events containing the sample of 318 events in which the emission of fast protons was not accompanied by the multiple meson creation were found. This sample contains 283

events with one secondary electric charged pion and 35 events without any secondary pion [1,2].

The fast protons, being not the commonly known evaporated protons, are emitted with an average multiplicity $\bar{n}_p = 7.8 \pm 0.8$ in the events without any secondary pion, and with an average multiplicity $n_p = 3.6 \pm 0.4$ in the events with single one secondary pion; it should be noted that the average fast proton multiplicities in the events with two, three, four and more secondary pions equal to $\bar{n}_p = 3.5 \pm 0.7$ being nearly constant [1].

The fast proton multiplicity distribution in the sample of the 35 events without any secondary pion is shown in fig. 1. A peak appears at $n_p = 8$: the events with $n_p > 8$ amount in this sample of events 12%. The fast proton multiplicity distribution in the sample of 283 events with single one secondary pion is shown in fig.2. The fast proton multiplicity distribution in the total sample of the 318 events without multiple pion creation is presented in fig.3. Two last distributions are evidently inmonotonous; irregularity is seen at the proton multiplicity $n_p = 6$. We do not observe any irregularities in the fast proton multiplicity distribution of all the 2800 pion-xenon nuclei collision events, (fig.4a). These experimental data are the result of the work performed together with my co-authors [1,2].

The ratio k of the number N_f of the fast protons emitted in the forward direction to the number N_b of these in the backward direction equals

$$k_0 = \frac{N_f}{N_b} = 1.69 \pm 0.20 \qquad (1)$$

in the sample of the 35 events without secondary pion, and

$$k_1 = \frac{N_f}{N_b} = 1.78 \pm 0.11 \qquad (2)$$

in the sample of all the 318 events without multiple pion creation [2], in all the 2800 pion-xenon nuclei collision events this ratio is

$$k_t = \frac{N_f}{N_b} = 2.00 \pm 0.07 . \qquad (3)$$

The distribution of azimuth angles of the proton emission directions - of the angles between the proton track projection on the plane perpendicular to the primary pion track

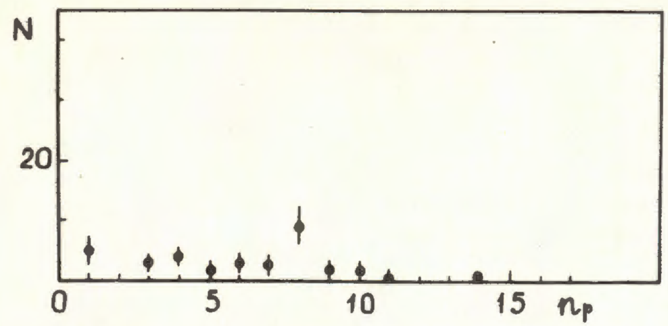


Fig.1. Distribution of fast proton multiplicities in pion-xenon nuclei collisions without secondary pions[2]. N - the numbers of events with the proton multiplicities n_p .

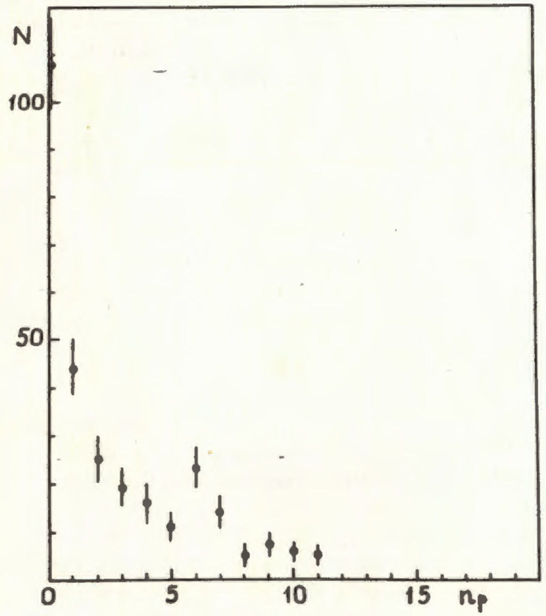


Fig.2. Distribution of fast proton multiplicities in the pion-xenon nuclei collisions with single one secondary pion[2]. N - the numbers of events with the proton multiplicities n_p .

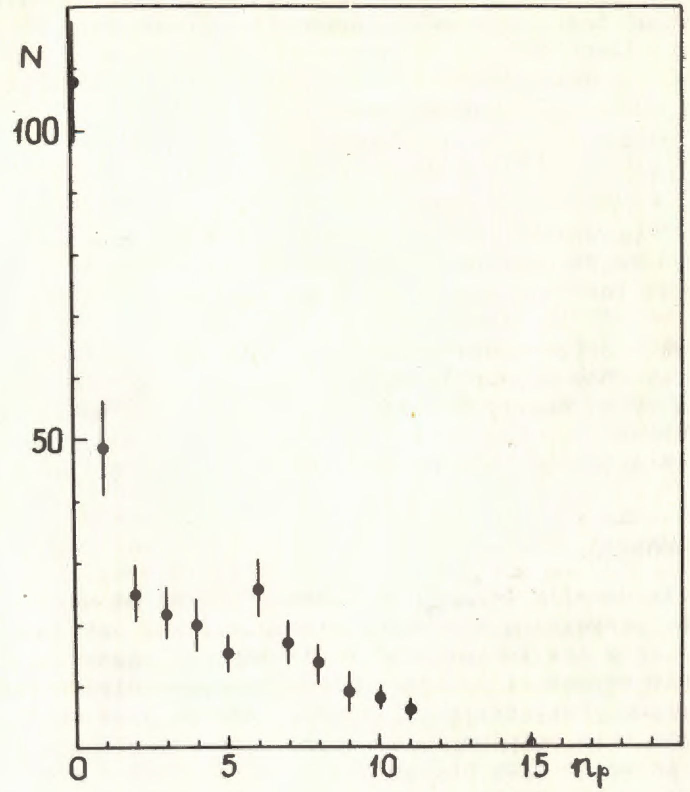


Fig.3. Distribution of fast proton multiplicities in 318 pion-xenon nuclei collision events without multiple pion creation[2]. N - the numbers of events with the proton multiplicities n_p.

and the reaction plane containing the tracks of the primary and secondary pions, fig.5, were prepared in the sample of the 283 events with single one secondary pion and arbitrary number of fast protons [2]. Asymmetry is observed in this azimuth distribution. It is evidently visible in the interval of the azimuth angle values $\Delta\phi_1 = 0 \pm 11.25$ degrees and $\Delta\phi_2 = 180 \pm 11.25$ degrees, being [2]

$$a = \frac{N_{\Delta\phi_2}}{N_{\Delta\phi_1}} = 1.66 \pm 0.15 , \qquad (4)$$

where $N_{\Delta\phi_2}$ and $N_{\Delta\phi_1}$ are the numbers of protons within the azimuth angle diapasons $\Delta\phi_2$ and $\Delta\phi_1$; at larger $\Delta\phi$ this asymmetry is less visible being almost constant [2], $a = 1.20 \pm 0.10$.

Irregularities are observed in the fast proton energy spectra; they appear as wide peaks mainly at the energy values lying nearly 40, 140, and 220 MeV [4]. We do not discuss these energy spectra here, the wide discussion concerning this problem has been given in one of our previous works [4].

4. DISCUSSION

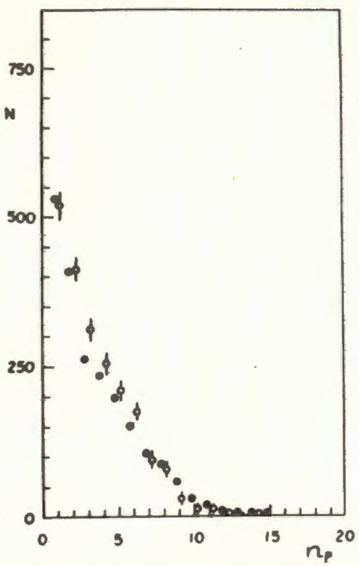
It is usually belived that every hadron of energy high enough, traversing a massive atomic nucleus at small distances from its center - at small impact parameter, causes multiple secondary particle production, mainly multiple pion production. But, the experimental results presented here indicate this opinion to be wrong - the events are discovered in which high energy pions, of 3.5 GeV/c momentum, traversing the xenon nuclei, cause the fast nucleon emission only, without multiparticle creation; the incident pions being absorbed inside the target nuclei or scattered at some angles [1,2]. This phenomenon appears to be very strange and we are met with the question: what is the fast proton emission process going on, how are the fast proton emission and the incident pion scattering interconnected, and how are the fast proton emission and the multiple pion creation process interrelated?

Let us try to give answers to these questions.

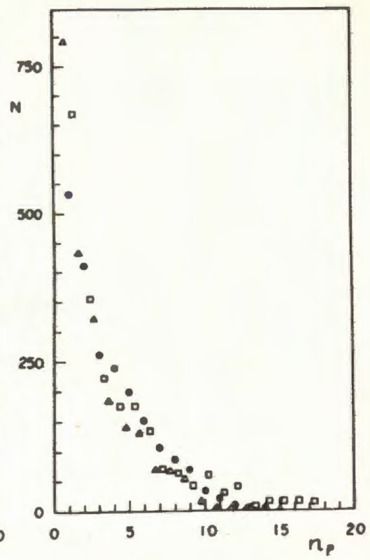
The energy spectra and angular characteristics of the fast protons in both the classes of collision events - in the 35 events without any secondary pion and in the 283 events with single one secondary pion - are almost the same. The shapes of the angular distributions and energy spectra of the fast protons emitted in all the pion-xenon nuclei collisions do not depend neither on the proton multiplicities nor on the secondary pion numbers [1]. Then, we may suppose the fast proton emission mechanism to be the same in all the cases registered: in the 35 events in which the incident pions were absorbed inside the target nuclei, in the 283 events in which the incident pions scatter at various angles, and in the rest of the cases in which the multiple pion creation takes place. The experimentally observed azimuth asymmetry of the fast proton emission directions [2] indicate the proton emission process to be localized in some space region inside the target nucleus; the above-mentioned similarity of the energy spectra and angular characteristics of the fast protons in both types of cases without the multiple meson creation prompts the idea that the protons may be emitted along the incident pion path inside the target nucleus. It appears this opinion to be supported by the existence of the inmonotony in the fast proton multiplicity distribution in the sample of the events without multiple pion creation as well.

The independence of the shapes of the fast proton energy spectra and of the angular distributions either on the numbers of these protons emitted nor on the numbers of secondary pions produced in all pion-xenon nuclei collisions [1] indicates both the processes, the fast proton emission and the multiple pion creation, to be independent. Then, the existence of the fast proton emission without multiple pion creation and the absence of the multiple pion creation events without nucleon emission, in traversing the atomic nuclei by high energy hadrons, indicate the fast proton emission process in hadron-nuclei collisions may go on in many cases in advance of the multiple pion creation process. Then, the high energy hadron traversing an atomic nucleus may come into particle creation interaction with one of the nucleons inside the target nucleus after being braked in the fast nucleon emission process. These questions have been discussed widely in my previous papers [3,5,6].

Taking into account these conclusions - the localization of the fast proton emission process along the high energy hadron path inside the target nucleus, and the possible outstripping of the multiple pion creation act by the fast proton emission - a simple working hypothesis has been used for the explanation of the existence of the intensive fast proton emission without particle creation [3,4,6] ; The number n_p of the fast protons emitted by the passage of high energy pion



a)



b)

Fig.4. Comparison of the experimental fast proton multiplicity distributions of hadron-nuclei collisions with the derived one; • - calculated by the formula which has been derived in one of previous papers /6/ ; o - experimental for the pion-xenon nuclei collisions at 3.5 GeV/c /1/; Δ- experimental for the pion-AgBr collisions at 200 GeV /7,8/ ; □ experimental for the proton-AgBr collisions at 400 GeV /7,8/.

through an atomic nucleus of the radius R, at the distance d from its center, is equal to the number of protons met in the neighbourhood of close to the pion path ℓ inside the nucleus

$$n_p = \pi \cdot D_0^2 \cdot \frac{Z}{A} \cdot \rho \cdot \ell = 2\pi D_0^2 \frac{Z}{A} \cdot \rho \sqrt{R^2 - d^2}, \qquad (5)$$

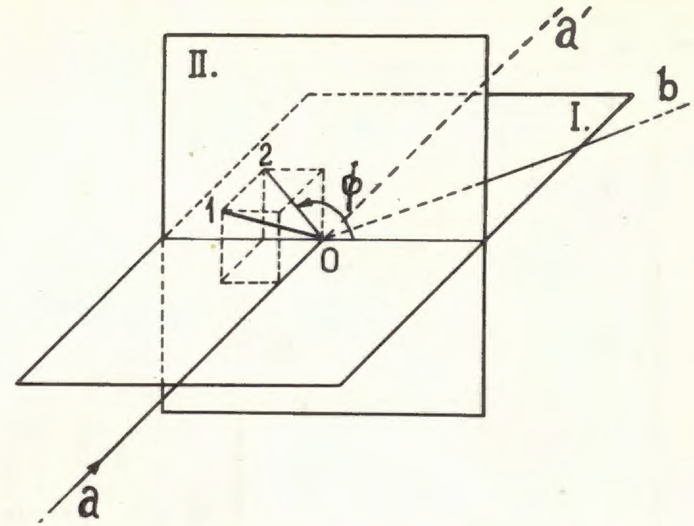


Fig.5. The scheme for the explanation of the fast proton azimuth distribution: I - the reaction plane, II - the plane perpendicular to it; a - a'- track direction of the incident pion; b - the track of the secondary pion; 1 -proton track; 2 - projection of the proton track on the plane II; ϕ - azimuth angle.

where D_0 is the diameter of a nucleon; Z - is the atomic number; A is the mass number; ρ the nucleon density along the pion path ℓ; we suppose the ratio $\frac{Z}{A-Z}$ is constant inside the target nucleus. For convenience , the distances inside the target nucleus we propose to express in the length units being as long as D_0 is.

Accepting this hypothesis, the fast proton multiplicity distribution has been derived for the cases with single one secondary pion which agrees well with the experimental one, and the peak in the fast proton distribution in the sample of events without any secondary pion, at $n_p = 8$, has been explained - qualitatively and quantitatively /3/.

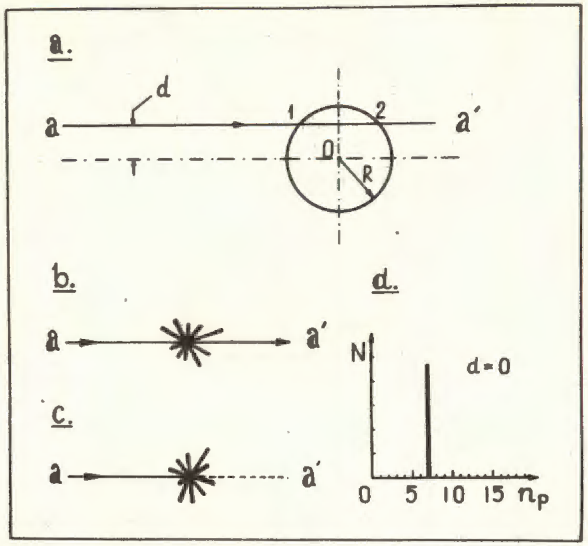


Fig.6. The scheme explaining the penetration of hadrons into the target nucleus. a/ the incident hadron moving along the line a - a'at the impact parameter d enters an atomic nucleus of the radius R at the point 1 and goes out from it at the point 2; b/ the incoming hadron traverses the target nucleus along the line a - a'causing the fast proton emission; c/ the incoming hadron is absorbed inside the target nucleus causing the fast proton emission; d/ the observed picture in the case in which the incident pions of constant initial kinetic energies are absorbed inside the target nuclei in traversing they along the diameters.

For example, suppose the pions traverse the target nuclei of the radius R along the path corresponding to the impact parameter d, fig.6, being smaller than some minimal value d_0, $d < d_0$. This value d_0 corresponds to the appropriate minimal thickness x_0 of the nuclear matter layer inside the target nucleus. If the energy of the incident pions, being constant, is as high as it is needed for their stoping in this layer, we shall observe, according to our working hypothesis and owing to the fact that the fast proton emission

process may go in advance of the multiple pion creation act, the pion-nuclei collision cases in which incident pions shall be absorbed with the accompaniament of the constant fast proton multiplicity. In fact we have same background in the proton multiplicity distribution, and instead of the constant value of the proton number n_p we have the peak in the proton multiplicity distribution. In the case observed in our experiment this peak appears at $n_p = 8$. It has been shown that this peak corresponds to the stopping of the incident pions inside target xenon nuclei in traversing of their total diameter length [2] . Really, the number of protons met in this situation equals $n_p = 8$, if $A = 131$, $\rho = 1$, $Z = 54$, and $R = 3.1\, D_0$ is used.

On the basis of this hypothesis the formula for the proton multiplicity distribution of all the pion-xenon nuclei collisions has been derived [6]. It agrees well with the experimental data, fig.4 at 3.5 GeV/c; the same formula describes well the fast proton multiplicity distribution of the pion-AgBr collisions at 200 GeV/c and that of the proton-AgBr collisions at 400 GeV/c, fig.4b.

In derivation of this formula an assumption has been used: the multiplė pion creation process goes on via some intermediate states decaying outside of the target nucleus; these states are generated in elementary hadron-nucleon collisions. The agreement of the fast proton multiplicity distribution derived with the experimental one indicates this assumptions may be truthful. It appears to be supported by the experimentally observed independence of the average proton multiplicity of the number of secondary pions in all the pion-xenon collisions events [1].

5. CONCLUSION

As results of the discussion being done above, we may state the following more important assertions:

a/ The emission process of the fast protons is localized along the high energy hadron path inside the target nucleus; we do not discuss at yet this emission to be direct or it is going on via some intermediate systems.

b/ The number of the fast protons emitted along the path of the hadron traversing the target nucleus equals to the number of the protons met in the neighbourhood of close to this path.

c/ The fast proton emission process in hadron-nuclei collisions goes on in many cases in advance of the multiple meson creation act.

d/ It is very probable, the multiple pion creation acts go via some intermediate states decaying outside of the target nucleus.

e/ From the conclusions a/ and b/ it follows the indication of important methodical significance: the target nucleus may be used as an analyser of the elementary hadron-nucleon collision process, and new possibilities are appeared for the investigation of the target nuclei structure applying high energy pions or other various hadrons.

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