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HADRON DEFLECTION IN ITS PASSAGE THROUGH NUCLEAR MATTER

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1. INTRODUCTION

Almost 75 years ago H.Geiger and E.Marsden, two of Rutherford's students, directed a beam of alpha particles onto a thin foil of gold. With a screen of fluorescent material they then counted the number of particles scattered at various angles as a result of encounters with the gold atoms[1]. Most of the particles passed straight through the foil or were deflected by only a small angle - the average deflection was less than a degree; surprisingly, however, a few, about one in tens thousands, were deflected sharply.

It was E.Rutherford who supplied the interpretation of these findings: both the surprising violence of the collisions and their rarity could be explained by assuming that the atom has an impenetrable, dense core - an atomic nucleus - where all its positive electric charge is concentrated in a small volume [2].

In the interpretation of the experimental results, E.Rutherford had also introduced a method for investigating the constitution of matter, a method whose importance is indiminished today. The metallic foil was many atom thick. In traversing it most of the bombarding particles never approached one of the atomic nuclei close enough to be strongly influenced by it, but when a collision did take place, the projectile-particle could be scattered in any direction, even straight back along its original path.

I would like to communicate, in this paper, that it is possible now to perform similar experiments in which instead of the metallic foil the"foil" of nuclear matter of definite thickness will be used, and the projectiles employed will be, instead of the alpha particles, the strongly interacting particles - pions or protons for example, raised to high energy by an accelerator; obviously, alpha particles and various other nuclei can be used for the bombardment of these "foils" as well. (A definition of the nuclear matter "foil" is given in section 2).

The term "nuclear matter" we apply for the many-nucleon conglomerate existing in the nature in its natural form - as the atomic nucleus. We call "high" the kinetic energies of the bombarding hadrons if larger than the energy threshold for the pion production.

In contrast to Rutherford's experiment, where the scattered alpha particles have been observed only, in the experiments with nuclear matter "foils", exposed to beams of high energy strongly interacting particles, an emission of nucleons from the "foil" in majority of cases is observed and two general kinds of events occur against the background of this emission: a) events in which the projectile is deflected only, without causing the particle production[3]; b) events in which particles are produced. The emitted nucleons accompanying collisions are "fast", of kinetic energy from a few MeV to about 400 MeV. In many cases the nucleon emission may be very intensive - of some tens nucleons per event, when a nuclear matter "foil" of the thickness large enough is bombarded.

Such a kind of experiments may provide new and original data on the structure of atomic nuclei, on the structure of the nucleons, and on the particle creation process in its early stage. The new experimental information is complementary to that obtained usually in experiments when two beams of accelerated particles are made to collide head on; it is complementary as well to that information about the internal structure of the nucleon as illuminated by high energy electrons, which is obtained in R.Hofstadter's experiments[4] and in the successive SLAC experiments[5].

The new information about the particle production process[6], obtained in this way, should be necessary information, additional to that obtained about the nucleon structure in electron-nucleon collisions[5], which must be used in attempts to interpret the large transverse momentum phenomena in colliding beam experiments[7], for example, and in attempts to use the information about the jet structure of the outcome in nucleon-nucleon collisions for the nucleon internal structure studies[8]. In my opinion, both the two informations - about the internal structure of the nucleon as illumunated by electrons and about the particle production process as analysed by the nuclear matter "foils" should be taken into account simultaneously when one wants to draw the diagram of the large transverse momentum production of hadrons in hadronic reactions, in the nucleon-nucleon collision for example; it is insufficiently to use one of these informations only for the study of the nucleon structure as well. In experiments with the nuclear matter "foils" it can be experimentally proved[6] whether the particle-producing nucleon-nucleon collision is a two particle final state endoergic reaction, of the type 2 → 2, in an early stage of the collision or not.

The subject matter in this work is to show how it is possible to perform experiments with nuclear matter "foils". Because investigations of the particle production process by this way have been performed in our former works[6], we limit ourselves here to present main results of the investigation of high energy hadron passage through a "foil" of nuclear matter when the projectile is deflected from its original direction only, without causing particle production.

2. NUCLEAR MATTER "FOILS"

The term "foil" expresses usually a very thin sheet of metal, such as is used to protect packaged cigaretes or food against moisture, for example. It is impossible to product such a foil of nuclear matter, but, as it was shown[9,10], atomic nuclei can be used successfully as "foils" in experiments similar to those made first by E. Rutherford, H.Geiger and E.Marsden[1,2]. The nuclear matter is met with in the form of the atomic nuclei. Any of the nuclei massive enough can be regarded as the lens-shaped "foil" or "slab" of nuclear matter, if the thickness of the nuclear matter layer is measured in units of the number of nucleons per some area S, like the atmosphere thickness is expressed usually in cosmic ray physics, for example[11], in units of grams per cm², fig.1.

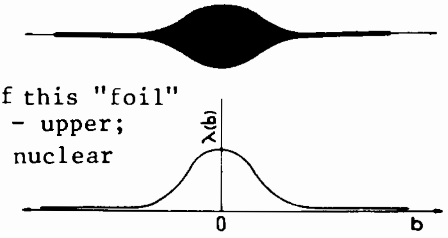

Fig.1. The atomic nucleus as the nuclear matter "foil"[10]. The cross-section, if the thickness of this "foil" is expressed in nucleons per fm² - upper; typical radial dependence of the nuclear matter layer thickness λ(b) on the impact parameter b - lower.

Such a "slab" should be characterized generally by the maximum thickness of the nuclear matter layer - λ_{max}, its average thiskness - <λ>, and the potential thickness corresponding to a given impact parameter b - λ(b) expressed in numbers of nucleons per some area[9,10]. The values of the quantities λ(b), <λ> and λ_{max} can be found in our works[9,10] for many atomic nuclei.

Because the thickness λ [nucl/S] of the natural nuclear matter "slab" is not constant but varies with the distance b from the centre of the atomic nucleus, λ = λ(b), important question arises then: how can be determined the thickness λ of the nuclear matter layer which an incident hadron has to interact with in any case of the hadron-nucleus collision?

Results of experimental studies of the nucleon emission process in hadron-nucleus collisions[9,10,12-14] prompt to us the procedure by which we can determine the quantity λ. It has been concluded, in result of the data analysis, that any high energy hadron traversing nuclear matter causes monotonously along its course the "fast" nucleon emission from the target-nucleus[18]. Usually the emitted protons are observed only. We have shown[12-15] that the number n_p of emitted "fast" protons, or the proton multiplicity n_p in a collision event, equals the number of protons contained inside cylindrical volume through which, along the path λ lying on the cylinder axis, the hadron passes:

$$n_p = \pi D_0^2 \lambda \bar{\rho} \frac{Z}{A}, \qquad (1)$$

when $n_p \le n_p(D)$; in this formula D is the target-nucleus diameter, $D_0 = 1.81$ fm is defined by the relation $D_0^3\rho = 1/A$ between the nucleon density ρ [nucl/fm^3] in the nucleus region, where ρ is saturated, and the mass number A of the target-nucleus of the atomic number Z, $\bar{\rho}$ [nucl/fm^3] is the average nucleon density along the hadron path λ. If the thickness λ of nuclear matter layer is expressed as $\lambda\bar{\rho}$, in nucleons per $S = \pi D_0^2$ fm^2 then λ [nucl/S] equals the number n_N of emitted fast nucleons.

Because the ratio N_p/N_n, between the number N_p of protons and the number N_n of neutrons, is almost radially independent within atomic nuclei[16,17] and $N_p/N_n \approx Z/A$, then λ can be expressed as well in units of [protons/S] by multiplying λ [nucl/S] by Z/A:

$$\lambda\left[\frac{\text{protons}}{S}\right] = n_p\left[\frac{\text{protons}}{S}\right], \qquad (2)$$

where $S = \pi 1.81^2$ fm^2.

Relations (1) and (2) give an answer to the question.

3. EXPERIMENTAL ARRANGEMENTS

Any of the heavy liquid bubble chambers, of volume large enough for effective registration of electrically charged and neutral particles, can serve as almost ideal arrangement for hadron deflection study in its passage through nuclear matter. As an example we show how the 180 litre xenon bubble chamber[18] can be used.

Various electronic arrangements of the type as used in the Faessler. Powh et al. experiment[19]. for example, can be used as well.

Let us consider a general plan view of an electronic arrangement. Any of such arrangements should consist of: a set of detectors for selection of pure incident hadron deflection events without particle production, a set of detectors for the measurement of the deflection angle of the incident hadron, and a set of detectors for determination of the "fast" proton multiplicity n_p[prot/S] $\equiv \lambda$[pro/S] in any of events singled out. Schematic plan view of a proposed apparatus is shown in fig.2.

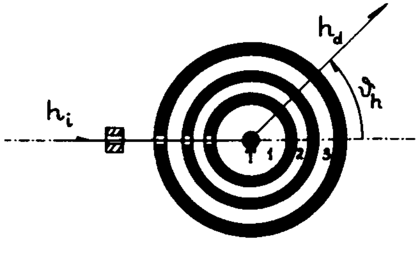

Fig.2. Schematic plan view of an electronic arrangement for hadron deflection study in its passage through nuclear matter. h_i - an incident hadron, h_d - the deflected hadron, θ_h - the deflection angle of the hadron, T - nuclear target or nuclear matter "foil", 1 - proton counter, 2 - gamma quanta anticoincidence counter, 3 - produced particle anticoincidence counter.

4. RESULTS OBTAINED

First experimental information about pion deflection in its passage through nuclear matter was obtained by us[20] using 180 litre xenon bubble chamber exposed to a beam of negatively charged pions of 3.5 GeV/c momentum; the xenon nucleus served as the nuclear matter "slab"[10]. The subject matter in this section is an additional and more accurate analysis of the experimental material used in that paper[20].

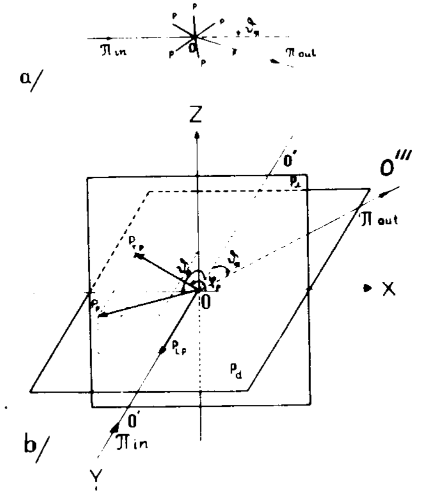

Fig.3. The scheme of typical pion deflection event: a) As shown in a track detector; 0 - the centre of an observed "star"; π_{in} - 0 and π_{out} - 0 the tracks of the incident and deflected pions correspondingly; 0 - p the emitted proton tracks. b) The pion deflection event in the XYZ coordinate system; 0 - the location of the point of impact; 0''-0' incident pion course; 0 - 0''' the course of the pion after deflection by a deflection angle θ_π; P_d - the deflection plane, $P_\perp$ - the plane perpendicular to it; P_p - the momentum of one of the emitted protons, P_{Tp} - its transverse component, P_{Lp} - its longitudinal component; the azimuth angle of the proton emission direction is denoted by ϕ_p, the zenith angle by θ_p.

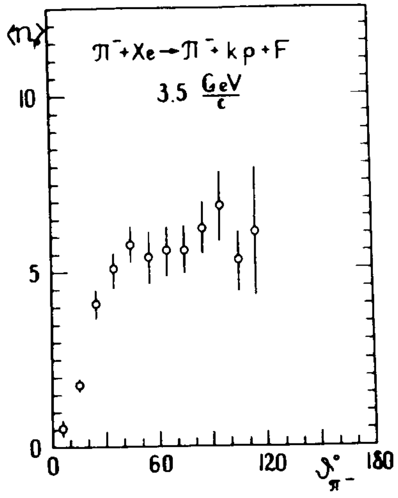

Fig.4. The dependence of the emitted proton average multiplicity $\langle n_p \rangle$ on the incident pion deflection angle θ°_π - in pion-xenon nucleus collision events of the type $\pi^- + Xe \to \pi^- + kp + F$ at 3.5 GeV/c momentum; k = 0,1,2,... number of emitted protons; F - target fragments.

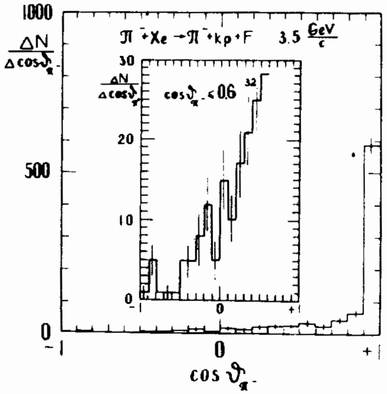

Fig.5. Pion deflection angle distribution, in $\cos\theta_\pi$, in the pion-xenon nucleus collisions of the type $\pi^- + Xe \to \pi^- + kp + F$ at 3.5 GeV/c momentum; k =0,1, 2,3,... proton multiplicity, F - target fragments.

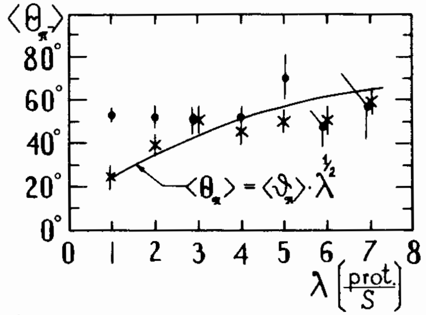

Fig.6. The dependence of the average pion deflection angle $<\Theta_{\pi^-}>$ on the nuclear matter layer thickness λ [prot/S]: x - experiment, ● - intranuclear cascade model[21,22], ——— - formula (3); in pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum. $<\Theta_{\pi^-}>$ is estimated as $\arccos <\cos\Theta_{\pi^-}>$.

The scheme of typical pion deflection event is shown in fig.3.

It was found that[20]: a) A definite simple relation exists between the pion deflection angle θ_π° and the average number $<n_p>$ of emitted fast protons, fig.4. b) The average value of the deflection angle $<\Theta_\pi>$ of the incident pion increases in a definite manner with increasing the thickness λ [prot/S] of the nuclear matter layer traversed by the pion.

In order to supply the interpretation of these findings, we found necessary to obtain more information about the hadron deflection phenomenon. Therefore, using the same experimental material as used in our work with Pawlak and J.Pluta[20], new set of characteristics, more adequate to the problem, was prepared: the distribution of incident pion deflection angles θ_π°, in $\cos\theta_\pi$, fig.5; the dependence of the incident pion average deflection angle $<\Theta_\pi>$, in $\arccos<\cos\theta_\pi>$, on the nuclear matter layer thickness λ[prot/S], fig.6; the dependence of the incident pion deflection angle θ_π distribution on the multiplicity n_p of emitted fast protons, fig.7; the distribution of the emitted fast proton multiplicity n_p in dependence on the incident pion deflection angle θ_π, fig.8. I wish to thank Mr. T.Pawlak for assistance with the computations.

5. DISCUSSION OF THE RESULTS

Let us try to supply at first an interpretation of the pion deflection average angle $<\Theta_\pi>$ dependence on the emitted proton multiplicity n_p, or on the nuclear matter layer thickness $\lambda\,[prot/S] = n_p\,[prot/S]$.

Imagine please that strongly interacting particles fall on atomic nuclei. Each particle comes into interaction with nucleons in nuclear matter as it passes through it and is deflected. The deflection will vary even if the thickness of the nuclear matter layer the particle strikes is constant; there will, however, be a measurable mean value $<\Theta_\pi>$ for the deflection produced by nuclear matter. When we are considering the effects produced on a large collection of incident hadrons, we may suppose that the course of each hadron suffers the mean deflection. Such mean deflection $<\Theta_\pi>$ corresponds to any definite nuclear matter layer thickness λ[nucl/S] or λ[prot/S] and, according to formula (1) the nucleons inside the cylindrical volume $\pi D_0^2 \lambda$ are involved in interactions. There will be, therefore, a mean value $<\theta>$ for the deflection θ produced per one nucleon on the direction of motion of strongly interacting particles passing through the sphere of action of the nucleon. In fact, the deflection will vary with the way the hadron strikes the sphere of action of the nucleon; there will be, however, a mean value for the deflection produced by a nucleon on the direction of motion of a hadron passing through the sphere of action, and when we are considering only the effects produced by large collection of particles we may suppose that the course of each particle suffers the mean deflection per one nucleon. The direction of this deflection is quite arbitrary.

Let us consider now the case when a large number of strongly interacting particles pass through a large number of spheres of action of nucleons and discuss what will be the average deflection of the particles after they have passed through n_N nucleon spheres of action. Similar problem was originally considered by J.J.Thomson[23] in 1910, for the case when electrified particles pass through atoms in metallic foils. Since the directions of the deflections are quite arbitrary, it is evident that the problem is the same as that of finding the average value of the resultant of n_N displacements of arbitrary phase and of constant amplitude $<\theta>$. This average value is well known[23,24] to be

$$<\Theta> = \sqrt{n_N}\,<\theta> = <\theta> \cdot \lambda^{1/2}, \qquad (3)$$

where the nuclear matter layer thickness λ is in [nucl/S]. In Thomson's considerations it was supposed that the particle is not bent so much in passing through the plate that the length of its path is materially different from λ. In our case we use the lens-shaped and very thin "slabs" of nuclear matter and this condition is naturally almost always fulfilled.

Because the forces acting between strongly interacting particles are not known now adequately, the correct average value $<\theta>$ should be determined experimentally. This value for the mean deflection angle per one [proton/S] is defined by the first experimental point in fig.6, it equals $<\theta> = 25.5 \pm 3$ degrees per one [proton/S]; this value is estimated when all events, in which $\theta_\pi \leq 180°$ are taken into account. The relation $<\Theta> = 25.5\lambda^{1/2}$ is shown in fig.6 by the solid line. For comparison, the $<\Theta> - \lambda$ dependence, or $<\Theta> - n_p$ dependence, evaluated using the intranuclear cascade model /21,22/ adopted for the registration conditions in our chamber /22/ is shown.

It can be concluded that: a) The relation expressed by formula (3) describes roughly the experimental $<\Theta> - \lambda$ dependence. b) The $<\Theta> - \lambda$ relation obtained experimentally is not reproduced by intranuclear cascade model; the predicted relation is quite different. c) The maximum value for the pion deflection average angle in their passage through xenon nucleus is about $<\Theta> \approx 60°$ at 3.5 GeV/c momentum.

Formula (3) is valid for the description of the multiple scattering only and, therefore, it is reasonable to compare its predictions with appropriate experimental data. But, in corresponding relation shown in Fig.6 many events with large deflection angle of the projectile are included as well. We should construct, therefore, an experimental $<\Theta> - \lambda$ relation using the sample of events in which the pion deflection angles are smaller than some $\theta_{\pi c}$.

In order to obtain a correct value of the quantity $<\theta>$, the $<\theta_\pi> - n_p$ dependences were determined in four various samples of the pion-xenon nucleus collisions in question at 3.5 GeV/c momentum; when $\theta_\pi \leq 30°$, when $\theta_\pi \leq 60°$, when $\theta_\pi \leq 90°$, and $\theta_\pi \leq 180°$. It was found that the average deflection $<\theta_\pi>$ does not change by much in the classes of events with small values of the emitted fast proton multiplicity n_p. At $n_p = 0$ it equals: $<\theta_\pi> = (7.1 \pm 0.3)°$, when $\theta_\pi \leq 30$; $<\theta_\pi> = (7.3 \pm 0.3)°$, when $\theta_\pi \leq 60°$; $<\theta_\pi> = (8.5 \pm 0.5)°$, when $\theta_\pi \leq 90°$; $<\theta_\pi> = (8.5 \pm 0.5)°$, when $\theta_\pi \leq 180°$. As an example, we show in fig.9 the θ_π-distributions at $n_p = 1$ and $2 \leq n_p \leq 4$ for events with $\theta_\pi \leq 30°$. We think to be reasonable to use as the $\theta_{\pi c}$ the value $\theta_{\pi c} \lesssim 60°$ and as the $<\theta> \equiv <\theta_\pi> = (8.5 \pm 0.5)°$.

If this value $<\theta_\pi>$ is correctly determined and our picture of the hadron deflection in its passage through nuclear matter is true, the λ-dependence of the average deflection angle $<\Theta>$ provided by formula (3) should agree with that λ-dependence obtained in experiment. Using experimental materials as in our work with T.Pawlak and J.Pluta /20/, the λ-dependence of the average pion deflection angle $<\Theta_\pi>$ in the class of events with $\theta_\pi \leq 60°$ was prepared, fig.10, and compared with the predictions given by formula (3) in which $<\theta_\pi> = 8.5°$ is used.

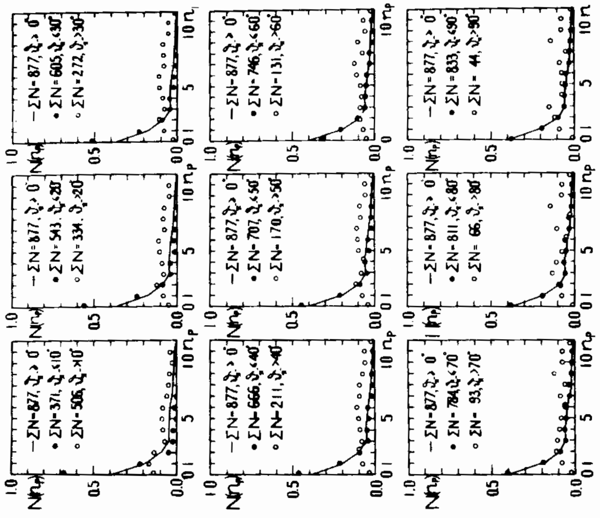

Fig.8. Proton multiplicity n_p distributions in pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum in classes of events with various pion deflection angles θ_π. ΣN denotes the numbers of events in a class.

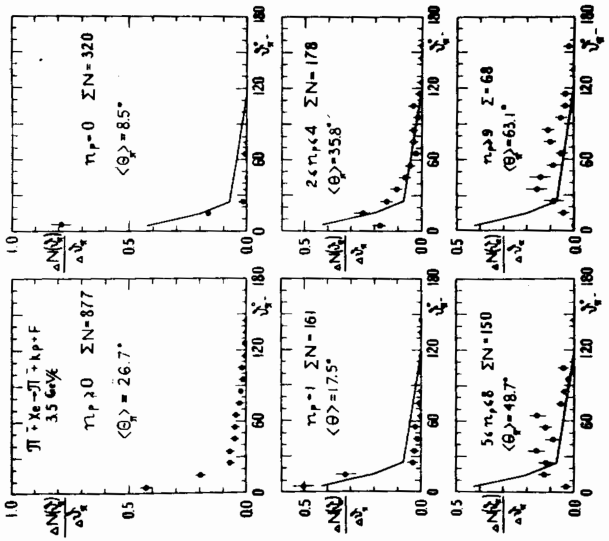

Fig.7. Distributions of the incident pion deflection angles θ_π in pion-xenon nucleus collisions $\pi^- + Xe \to \pi^- + kp + F$ at 3.5 GeV/c momentum with various number k=0,1,2,...=n_p of the protons emitted. ΣN - numbers of events in a class, $<\Theta_\pi>$-average pion deflection angle in a class.

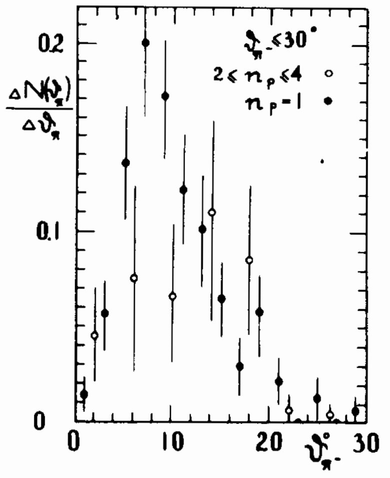

Fig.9. Distributions of the incident pion deflection angles θ_π in the pion-xenon nucleus collisions without particle production at 3.5 GeV/c, in the classes of events with the proton multiplicity $n_p = 1$ and $2 \leq n_p \leq 4$, when $\theta_\pi \leq 30°$.

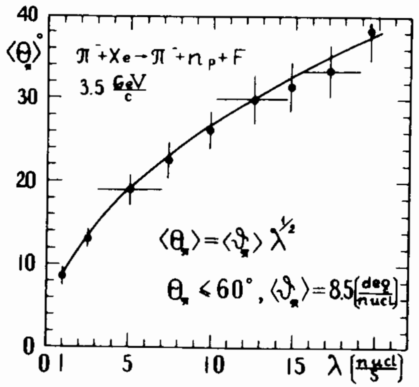

Fig.10. The dependence of the average incident pion deflection angle $\langle\theta_\pi\rangle$ on the nuclear matter layer thickness λ [nucl/S] in the pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum, when pions are deflected by an angle no larger than 60°. Solid line - prediction given by formula (3) in which $\langle\theta\rangle = 8.5$ degrees per nucleon is used.

The λ-dependences in the classes of events with $\theta_\pi \leq 90°$ and $\theta_\pi \leq 180°$ are given in table 1.

It can be concluded, from fig.10 and table 1, that formula (3) reproduced quantitatively the experimentally obtained λ-dependence when the incident pion deflection angles are relatively small, $\theta_\pi < 60°$.

This result provides an additional independent information that a strongly interacting particle in its passage through nuclear matter interacts only with the nucleons contained within the cylindrical volume $\pi D_0^2 \lambda$ situated coaxially with the particle course.

Let us try now to supply an interpretation of the data shown in fig.7 and fig.8. What can be concluded, when pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum are analysed, is : 1) In the class of the events in question with any multiplicity n_p of the emitted fast protons the distribution of the pion deflection angles, when deflection angle interval is $\Delta\theta_\pi = 10°$, can be approximately expressed by two straight lines $N(\theta_\pi) = A\theta_\pi + B$ with negative-sign slopes A, fig.7. 2) The distribution of the pion deflection angles θ_π- changes markedly when the nuclear matter layer thickness, λ[prot/S] = n_p[prot/S], changes from $\lambda = 0$ [prot/S] to $\lambda = 8$[prot/S]; starting from $\lambda \geq 3$ [prot/S] the shape of the distribution changes evidently as well, fig.7. 3) In the events in question with enlarged nucleon emission intensity, $n_p \geq 9$, the pion deflection angle distribution consists of two almost Gaussian distributions the peaks of which are at $\theta_\pi \approx 40°$ and $\theta_\pi \approx 90°$, fig.7. Let us remember here that the pion deflection angle distribution at "small" values of the angles, when $\theta_\pi < 60°$ and $\langle\theta_\pi\rangle \lesssim 40$, can be ragarded as being predominantly a result of multiple scattering of the projectile in its passage through nuclear matter.

Such a behaviour of the projectile deflection angle distribution can indicate that the mechanism of the hadron deflection at small angles, smaller than ~60°, differs from the mechanism

Table

Dependences of the average deflection angle of the incident pion in its passage through nuclear matter on nuclear matter layer thickness in classes of events with various deflection angles

$\lambda = n_p$ prot/S	$\langle\theta\rangle$					
	exp	calc	exp	calc	exp	calc
0	7.3±0.3	-	8.5±0.5	-	8.5±0.5	-
1	13.1±0.9	13.1	14.6±1.2	14.6	17.4±1.8	17.4
2	21.0±1.7	18.5	25.9±2.2	20.6	31.0±3.1	24.6
3	22.5±2.7	22.7	28.6±3.9	25.3	42.6±5.9	34.8
4	26.2±2.3	26.2	34.4±3.5	29.2	38.3±3.9	34.8
5	33.5±2.4	29.3	41.2±3.2	32.6	45.8±3.9	38.9
6	31.3±2.6	32.1	40.8±3.2	35.8	45.8±4.1	42.6
7	29.8±3.9	34.6	47.8±4.7	36.6	54.4±5.1	46.0
8	34.8±3.3	37.1	47.3±3.6	41.3	51.4±4.3	49.2
ϑ_π	≤ 60°		≤ 90°		≤ 180°	

Denotations: $\lambda = n_p$ [prot/S] - nuclear matter layer thickness; $\langle\Theta\rangle$ - average value of the pion deflection angle; θ_π - pion deflection angle; "exp" - experimental data, "calc" - calculated using formula (3).

of the deflection at larger angles. We have emphasized it in studying the proton multiplicity distributions /8,13/: the large-angle deflections are a result of the single hadron-nucleon collisions in nuclear matter; in such collisions the recoil nucleons appear of kinetic energy large enough them to be possible to cause monotonous nucleon emission from the target in ones turn. The existence of two peaks in the distribution at $n_p \gtrsim 9$ can be explained as a result of two such single collisions taking part in turn along the hadron path long enough in nuclear matter, when the mean free path for the single collision is long enough and does not fluctuate by much. Because the change in the deflection angle distribution appears evidently at $\lambda \approx 4$ [prot/S], we conclude that this mean free path is about 4 [prot/S] and the average deflection angle for the single pion-nucleon collision $\langle\Theta_\pi\rangle_s$ is about 40 [deg/nucl]. It is reasonable to conclude that the incident pion can undergo, in average, twice such a single collision with massive constituents in its passage through nuclear matter layers as thick as the diameter of the xenon nucleus, i.e. as $\lambda \approx 8$ [prot/S].

In support of this above-presented picture of the hadron deflection phenomenon, the dependence of the proton multiplicity distribution on the pion deflection angle can be adduced, fig.8. We see that when the incident pion deflection angles θ_π are larger than about $\theta_\pi^\ell \gtrsim 10°$ the proton multiplicity n_p distributions differ by much in the classes of events with the pion deflection $\theta_\pi \lesssim \theta_\pi^\ell$ and $\theta_\pi > \theta_\pi^\ell$, fig.8.

Obviously, this picture of the hadron deflection process is influenced by the structure of the constituents of the nuclear matter "foil" - of the nucleons. We would like to present our preliminary model of the nucleon as illuminated by the pions; we limit ourselves now here to the qualitative considerations only. This qualitative model we treate as a basis for our deeper quantitative analysis of the nucleon structure as illuminated by strongly interacting probes.

In passing through nuclear matter the incident pion, and a hadron in general, undergoes a quasielastic collision with something to which a definite rest mass can be ascribed. In order to determine this mass we can use the well known kinematical relations between the projectile deflection angle and the kinetic energy of this projectile after the 2 → 2 elastic collision. For the collisions of pions of the kinetic energy about 3.5 GeV with nucleons the values of the deflection angles are from $\theta_\pi \approx 0°$, when the kinetic energy E_{ki} of the incident pion is comparable with the kinetic energy of the deflected pion E_{kd}, and $\theta_\pi \approx 40°$ when the kinetic energy of deflected pion is about a half of the incident pion. If collisions are with objects of the rest mass as large as the pion rest mass, then the values are correspondingly $\theta_\pi \approx 0°$ and $\theta_\pi \approx 15°$; when the kinetic energy of deflected pions is about 1/4 of the kinetic energy of the incident pion, these angles are $\theta_\pi \approx 90°$ in collisions with nucleons and $\theta_\pi \approx 35°$ in collisions with pions. The analysis of the $\Theta_\pi - E_{kd}$ dependences in events with $n_p = 0$ and $n_p = 1$ shows that in about 90% of events the deflection corresponds kinematically to collisions of incident pions with objects of the rest mass approximately as large as the rest mass of the pion; in the rest 10% of the events the collisions can be regarded as occurring with objects of the rest mass as large as the rest mass of the nucleon.

Starting from 1975 we have performed special experimental investigations of the rest mass of the targets the charge-exchange collisions occur with /25/. In result we concluded that the collisions in almost 100% of events are with the objects of the rest mass kinematically corresponding to the rest mass of the pion; the experimentally determined values of the deflection angles θ_{π^0} of the neutral pions are /25/ $\theta_{\pi^0} = (5-15)°$.

As a first approximation, in result of our attempts to supply a deep physical meaning to the hadron deflection phenomenon occurring when hadrons pass through nuclear matter, it can be concluded: the multiple scattering, described by formula (3), occurs predominantly in collisions with downstream objects in nuclear matter of the rest mass as large as about the rest mass of the pion; the single scattering occurs predominantly in collisions with objects in nuclear matter of the rest mass as approximately the rest mass of the nucleon.

Taking into account the relation between frequencies of the multiple scattering events and the single scattering events, we can conclude preliminarily that the cross-sections for both the types of scatterings are $\sigma_s : \sigma_m \approx 0.2$, where σ_s and σ_m are for the single and multiple scatterings, correspondingly, in nuclear matter.

6. CONCLUSIONS AND REMARKS

From the analysis of the pion deflection phenomenon occurring in pion passage through nuclear matter, it can be concluded that: 1) The observed deflection angle distribution is a result of two sorts of deflections - one is due to a multiple scattering from objects of the rest mass as large approximately as the pion rest mass, the second is due to a single scattering from massive objects in nuclear matter of the rest mass approximately as large as the nucleon rest mass. 2) The result of the multiple scattering $\langle\Theta_\pi\rangle$ is described by simple formula (3), $\langle\Theta_\pi\rangle = \langle\theta_\pi\rangle \cdot \lambda^{1/2}$, where $\langle\theta_\pi\rangle$ is the value of the mean deflection angle per one nucleon and λ [nucl/S] is the path length of the pion in nuclear matter; the value of the $\langle\theta_\pi\rangle$ corresponds kinematically to the $\pi-\pi$ collision[25].

In this paper the data on the pion deflection have been analysed only, but it is reasonable to think such a phenomenon is occurring if any hadron passes through nuclear matter; similar interpretation should be applied therefore for any hadron deflection in its passage through nuclear matter.

This picture of the phenomenon is certainly influenced by the size and structure of nucleons as well. The nucleon structure as illuminated by pions can be draw at yet in a preliminary qualitative version. The nucleon consists of at least two sorts of objects: a massive hard object of the rest mass approximately as large as nucleon rest mass, it forms probably a core of the nucleon which may consist of the hard constituents discovered in the SLAC experiments, called either partons or quarks[5,26,27]; surrounding lighter constituents, like pions or, may be, their combinations, bound strongly with this core with a large binding energy - approximately as large as the rest mass of these constituents. The nucleon may be an object which can absorp lighter objects, as pions, bind them and to be again the object of the same rest mass - the nucleon; the nucleon can as well emit lighter objects, if appropriate energy is transferred to it, and be again the same object - the nucleon.

A preliminary and very inprecise estimation, from the relation between the cross-sections for the single and multiple scatterings, indicates that the radius of the core may be about five times smaller as the radius of the nucleon.

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Стругальский З. Отклонение направления движения адрона при прохождении через ядерную материю E1-82-455

Приводятся аргументы в пользу того, что атомные ядра могут применяться как "фольги" из ядерной материи, по аналогии с тем, как металлические фольги применялись в эксперименте Резерфорда.

Из анализа соответствующих экспериментальных данных можно заключить, что: а/ наблюдаемое на опыте распределение углов отклонения является результатом двоякого рода рассеяния адрона в ядерной материи - одно рассеяние происходит от многократных столкновений с объектами с массой покоя порядка массы покоя пиона, второе рассеяние происходит от однократного столкновения с объектом с массой покоя порядка массы покоя нуклона; б/ результат многократного рассеяния описывается количественно с помощью простой формулы.

Проводится предварительная дискуссия касающаяся структуры нуклона, отраженной в столкновениях с сильно взаимодействующими частицами.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1982

Strugalski Z. Hadron Deflection in Its Passage through Nuclear Matter E1-82-455

It is shown that atomic nuclei can be applied as nuclear matter "foils" in study of hadron deflections in their passage through nuclear matter, similarly as metallic foils were used in Rutherford's experiment.

From the analysis of appropriate experimental data it can be concluded that: a) The observed deflection angle distribution is a result of two sorts of projectile deflections in nuclear matter - one is due to a multiple scattering from objects of the rest mass as large approximately as the pion rest mass, the second is due to a single scattering from massive objects of the rest mass as large approximately as the rest mass of the nucleon. b) The result of the multiple scattering is described quantitatively by simple formula.

Nucleon structure is discussed preliminarily as illuminated by strongly interacting probes.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1982