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STUDY OF THE INCIDENT PION DEFLECTION IN PASSING THROUGH ATOMIC NUCLEUS

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1. INTRODUCTION

It was already pointed out some years ago[1-3] that when a high energy hadron, of energy much higher than the threshold for pion production, passes through an atomic nucleus it may undergo deflection only, without particle production. The passage through the layers of nuclear matter thick enough is always accompanied by the emission of fast protons[2], of kinetic energies from about a few MeV to about 400 MeV, observed in experiment; it is reasonable to think that the passage is accompanied by the emission of both nucleons - the observed protons and the neutrons usually not observed simply.

This kind of hadron-nucleus collision events could have been discovered[1] when all the secondary pions, charged and neutral, and the emitted protons were registered with an efficiency of about 100%; the 180 litre xenon bubble chamber[4] has been used at that time exposed to a beam of negatively charged pions of 3.5 GeV/c momentum.

During the last three years a special scanning for pion-xenon nucleus collisions of such a kind has been performed using the same chamber photographs, in order to obtain various characteristics of the pion deflection in its passage through nuclear matter. A description of the properties of the hadron deflection phenomenon observed in our experiments is the task of the present paper.

2. EXPERIMENT

The characteristics of the xenon bubble chamber[4] used as a detector of pions and protons, and an information in detail about the experimental procedure can be found in our previous works[1,5,6]; we limit ourselves here, therefore, to the presentation of the most important information about the experiment.

The photographs of the chamber exposed to negatively charged pions of 3.5 GeV/c momentum were carefully scanned and rescanned for pion-xenon nucleus collisions of the type

$$\pi^- + Xe \to \pi^- + kp + F \qquad (1)$$

(where F denotes residual nuclear fragments, $k=0,1,2,\ldots$) which could occur in the fiducial region of nearly $42\times10\times10$ cm^3 volume situated coaxially and centered inside the chamber of 104x40x40 cm^3 volume.

Any sharp change in the straight-line track of any beam pion was considered to be an indication that this pion underwent the interaction with the xenon nucleus; the end or deflection point of any beam pion track was accepted to be the point of impact. We were able to detect the collision events in which the incident pion track ends off or deflects at an angle of no less than 2 degrees, accompanied or not with any number of proton tracks outgoing from the interaction place.

In any of the events the deflection angle θ_{π^-} of the incident pion track, the number n_p of the protons emitted - called the proton multiplicity, the emission angle θ_p and the azimuth angle ϕ_p, the kinetic energy E_{kp}, the longitudinal momentum P_{Lp}, and the transverse momentum P_{Tp} of each of the protons were determined; the azimuth angle of the proton emission direction is defined as the angle between the pion deflection plane and the proton emission plane. The accuracy in measuring the pion deflection angle is about 1 degree; the accuracy in measuring the proton emission angle is about 3 degrees, on the average. Energies of the protons were measured, using the range-energy relation, with an accuracy of about 4%.

3. EXPERIMENTAL DATA

The data, set forth below in the table and in figs.1-6, are obtained in the analysis of 876 events of the kind in question (1) singled out in the scanning of about 150000 chamber stereophotographs.

The dependences of various quantities: $\langle n_p \rangle$, $\langle P_{Lp} \rangle$, $\langle P_{Tp} \rangle$, $\langle \cos\theta_p \rangle$ on the pion deflection angle θ_{π^-}, shown in figs.1,3,4, 5,6, are given for the total interval of the θ_{π^-} values. But, in an analysis of the experimental material, for the subject of the incident pion deflection process, the θ_{π^-} values of 0-100 degrees should be taken into account only; the data at θ_{π^-} over 100 degrees are biased because of large statistical fluctuations.

Before to start the presentation of conclusions from the experimental data, it should be taken into account that the number n_p of protons emitted when a hadron passed through an atomic nucleus is equal to the number of protons met [7] within the cylindrical volume of $\pi D_0^2 \lambda$, where λ is the path length of this hadron in the nucleus. The proton multiplicity n_p is, therefore, equivalent to the nuclear matter layer thickness λ traversed by this hadron [8], if λ is expressed in the number of protons per area $S = \pi D_0^2$, D_0 being equal to 1.81 f.

Table

The proton multiplicity distribution dependence on the incident pion deflection angle in the pion-xenon nucleus collision events without particle production, at 3.5 GeV/c momentum. n_p - proton multiplicity, θ_{π^-} - pion deflection angle

n_p \ ϑ_{π}	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-120	120-180
	263	53	6	1	1	0	4	2	0	0	0
1	81	52	6	6	3	5	1	2	1	2	2
2	17	28	12	9	3	5	3	4	1	4	1
3	8	8	7	4	2	3	1	1	2	5	2
4	7	9	7	6	8	1	1	2	4	3	0
5	0	7	7	8	4	6	3	3	2	3	0
6	4	5	5	9	5	4	9	1	1	2	1
7	0	6	3	3	1	3	7	2	3	4	0
8	1	1	3	4	4	6	5	3	0	2	0
9	0	1	2	7	1	2	2	2	4	6	0
10	0	1	1	1	5	1	0	2	2	1	2
11	0	1	3	1	3	2	1	2	2	2	1
12	0	0	0	2	1	1	1	1	0	1	0

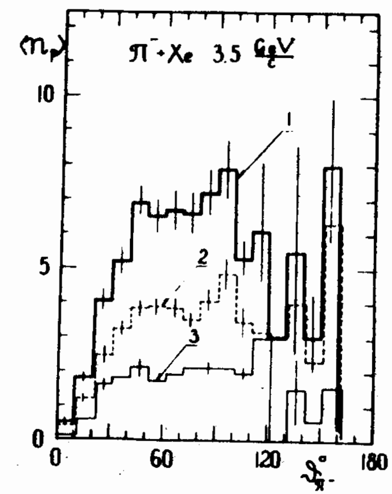


Fig.1. The dependence of the emitted proton average multiplicity $\langle n_p \rangle$ on the incident pion deflection angle θ_{π^-}: 1 - for protons emitted through any emission angle; 2 - for protons emitted into the forward hemisphere; 3 - for protons emitted into the backward hemisphere.

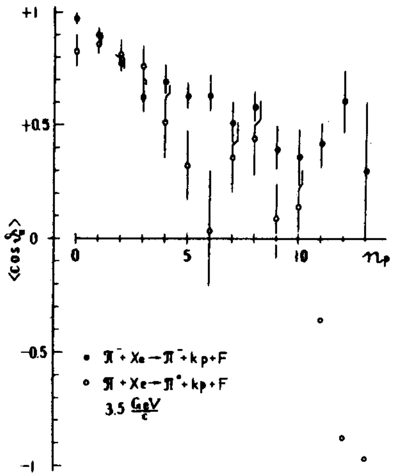
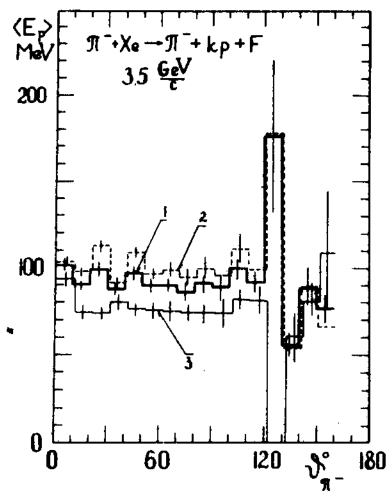


Fig.2. The dependence of the average cosine of the incident pion deflection angle, $\langle \cos\theta_{\pi^-} \rangle$, on the multiplicity n_p of the protons emitted.

Fig.3. The dependence of the proton average kinetic energy, $\langle E_{kp} \rangle$, on the incident pion deflection angle θ_{π^-} : 1 - for the protons emitted in any direction; 2 - for the protons emitted into the forward hemisphere; 3 - for the protons emitted into the backward hemisphere.



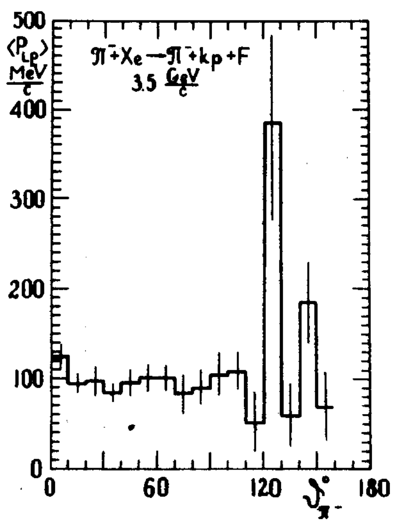


Fig.4. The dependence of the proton average longitudinal momentum $\langle P_{Lp} \rangle$ on the incident pion deflection angle θ_{π^-} .

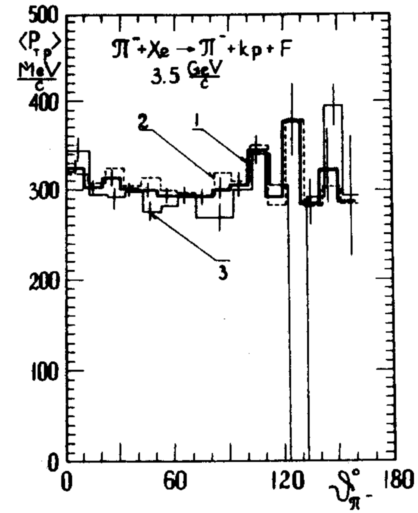
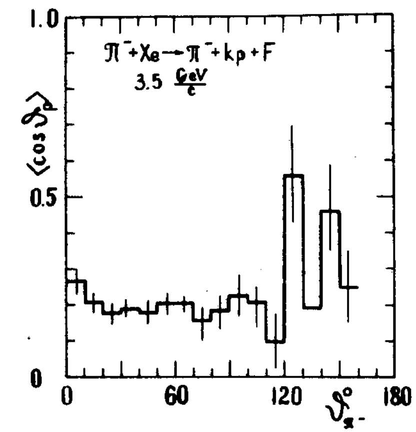


Fig.5. The dependence of the proton average transverse momentum $\langle P_{Tp} \rangle$ on the incident pion deflection angle θ_{π^-} : 1 - for the protons emitted in any direction; 2 - for the protons emitted into the forward hemisphere; 3 - for the protons emitted into the backward hemisphere.

Fig.6. The dependence of the proton emission angle average cosine, $\langle \cos\theta_p \rangle$, on the incident pion deflection angle θ_{π^-}.



4. CONCLUSIONS

From the analysis of the characteristics of the incident pion deflection in traversing a nuclear matter layer of the thickness λ protons/S $\equiv n_p$ protons/S, it can be concluded that:

a) A definite simple relation exists between the incident pion deflection angle θ_{π^-} and the average multiplicity $\langle n_p \rangle$ of emitted protons, fig.1. In other words, a definite simple relation exists between the pion deflection angle θ_{π^-} and the thickness λ of the nuclear matter layer traversed by this pion.

b) The average value of the cosine of the pion deflection angle, $\langle \cos\theta_{\pi^-} \rangle$, depends definitely and simply on the number n_p of emitted protons, fig.2. In other words, the deflection angle θ_{π^-} of the incident pion increases in a definite manner with increasing the thickness λ of the nuclear matter layer traversed by the pion.

The data on the proton emission accompanying the incident pion deflection, shown in figs.3-5, allow one to state that: The average kinetic energy $\langle E_{kp} \rangle$, average longitudinal momentum $\langle P_{Lp} \rangle$ and average transverse momentum $\langle P_{Tp} \rangle$ of the protons emitted do not depend on the pion deflection angle θ_{π^-}. The average value of the cosine of the proton emission angle, $\langle \cos\theta_p \rangle$, is almost independent of the incident pion deflection angle θ_{π^-}, fig.6; some weak dependence may be probably observed at $\theta_{\pi^-} \lesssim 10$ degrees, when a more accurate investigation will be done, however.

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