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EXPERIMENTAL STUDY OF THE PION-XENON NUCLEUS COLLISIONS WITHOUT PARTICLE PRODUCTION AT 3.5 GeV/c MOMENTUM: General Data

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1. INTRODUCTION

It was already communicated some years ago that we have observed such collisions of pions with xenon nuclei, at 3.5 GeV/c momentum, in which fast protons, of kinetic energy from about 20 to about 400 MeV, are intensively emitted without particle production[1,2]. In the events the protons are recorded simply with an efficiency of about 100%, neutrons of any kinetic energy are not observed practically. It is reasonable to think that fast neutrons, of similar energy spectrum, are intensively emitted in such kind of events as well.

Among the pion-xenon nucleus collisions without particle production two classes of events can be distinguished: a) The class of events in which none of secondary pions is emerged[1]; the incident pion is absorbed in the target-nucleus accompanied by fast nucleon emission. b) The class of events in which the incident pion underwent a deflection only in its passage through the target-nucleus accompanied by fast nucleon emission. Additional investigations of the hadron-nucleus collision events without particle production [3,4] allow one to conclude that the ratio between the number of events in which incident hadrons are absorbed in the target-nucleus and the number of events in which incident hadrons are deflected decreases to zero with the incident hadron momentum increase and with the target-nucleus mass number A decrease; at small-mass-number-targets, $A \lesssim 6$, the events belonging to the class a) do not occur practically at any incident hadron momentum over the pion production threshold; at incident pion momentum larger than about 4 GeV/c the projectile absorption in the target-nucleus does not occur practically in collisions with the most heavy target-nuclei. But, events without particle production in which incident hadron underwent a deflection only, accompanied by fast nucleon emission, should occur in collisions of hadrons of any kinetic energy over the particle production threshold with any target-nuclei.

Investigations of such a type of events without particle production may provide new and original data on the nucleon emission process in hadron-nucleus collisions[5], on the target-nucleus structure [6] and on the structure of the nucleon[7]. During the last three years a special additional investigation of the events in question has been performed using photographs from the 180 litre xenon bubble chamber[8] exposed to 3.5 GeV/c momentum negatively charged pion beams. A description of various characteristics of these events is the task of the present paper.

2. EXPERIMENT

The hadron-nucleus collision events without particle production could have been discovered when all the secondary pions, charged and neutral, all other produced particles, and the emitted protons were registered with an efficiency of about 100%. The 180 litre xenon bubble chamber satisfies these requirements practically. In our experiment this chamber was exposed to a beam of negatively charged pions of 3.5 GeV/c momentum.

The characteristics of the xenon bubble chamber used in this experiment and detailed information about the experimental procedure can be found in our previous works /1,4,9/ ; we limit ourselves here, therefore, to the presentation of the most important information about the experiment.

The photographs of the chamber were scanned and rescanned for pion-xenon nucleus collisions of the type:

$$\pi^- + Xe \to n_p + f \qquad (1a)$$

and

$$\pi^- + Xe \to n_p + \pi^- + f \qquad (1b)$$

which could occur in the fiducial region of nearly 42x10x10 cm^3 volume situated coaxially and centered inside the chamber of 104x40x40 cm^3 volume; n_p=0, 1, 2, ... denotes the number of emitted fast protons and f denotes residual nuclear fragments.

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 by any number of the 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 emitted 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 /10/, with an accuracy of about 4%. The number n_p of the proton tracks, corresponding to the proton kinetic energy larger than 20 MeV, was determined with a constant detection efficiency close to 100%.

3. EXPERIMENTAL DATA

The data, set forth below, are obtained in the analysis of 972 events of the kind in question (1a) and (1b) singled out in the scanning of about 150 000 chamber stereophotographs. A systematical scanning of some part of photographs for any type collision events, with and without particle production, shows that a sample of 6 301 such any-type pion-xenon nucleus events at 3.5 GeV/c momentum contains 848 events without particle production; 78 of them are such in which incident pion is absorbed in the target-nucleus, in 588 events incident pion deflection is observed, and in 182 events pion charge exchange is registered. Thus, the pion-xenon collision events without particle production occur, at 3.5 GeV/c momentum, in about (10.6±0.5)% of all pion-xenon nucleus collision events.

3.1. Dependences of Various Characteristics of the Emitted Protons on the Proton Multiplicity

It has been pointed out /3,11 that the proton multiplicity n_p of emitted protons is a measure of the nuclear matter layer thickness, measured in units of the proton number per some area S, the incident hadron interacted with in a collision event, when $n_p \leq n_p(D)$, where $n_p(D)$ is the proton multiplicity corresponding to the nuclear matter layer as thick as the diameter D of the target-nucleus is. It is reasonable, therefore, to present various characteristics of the secondaries, of the emitted protons in the case, as a function of the proton multiplicity n_p.

3.1.1. Proton Multiplicity Distributions

Proton multiplicity distributions $N(n_p)$ in the classes of events of the type (1a) and (1b) are characterized by the data contained in tables 1 and 2, and in fig.1; in table 1 the proton multiplicity distribution in collision events without particle production, in which incident pion charge exchange takes place, is presented as well.

Table 1

Proton multiplicity, n_p, distribution, $N(n_p)$, in pion-xenon nucleus collision events without particle production, with the number of secondary pions n_π =0 or 1, at 3.5 GeV/c momentum

n_p	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	≥ 0
$N(n_p)$, n_{π^-} = 0,1	323	165	90	50	52	48	57	44	45	31	27	27	4	4	3	1	0	1	972
$N(n_p)$, n_{π^-} = 0	3	4	3	8	4	5	11	12	16	4	11	9	1	1	3	0	0	1	96
$N(n_p)$, n_{π^-} = 1	320	161	87	42	48	43	46	32	29	27	16	18	3	3	0	1	0	0	876
$N(n_p)$, n_{π^0} = 1	47	30	21	25	20	19	14	22	15	13	5	6	1	1	0	0	0	0	239

Table 2

Characteristics of the proton multiplicity distributions $N(n_p)$ in various classes of pion-xenon nucleus collision events without particle production at 3.5 GeV/c momentum; samples of events distinguished as n_π =0 and $n_\pi \leq 1$ contain events of the type (1a) and of the types (1a) and (1b) together, correspondingly. Denotations of the quantities are as usual/13/

Quantity	Samples of the pion-xenon nucleus collision events	
	$n_{\pi^-}=0$	$n_{\pi^-} \leq 1$
$\langle n_p \rangle$	7.10	3.23
r.m.s.	3.45	3.48
skewness	-0.0013	1.05
kurtosis	-0.13	0.11

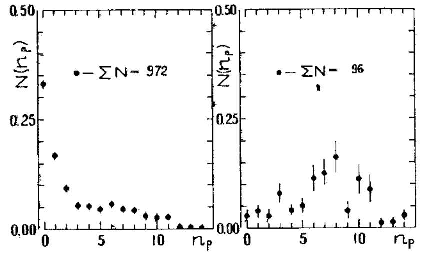

Fig.1. Proton multiplicity, n_p, distribution, $N(n_p)$, in pion-xenon nucleus collision events at 3.5 GeV/c momentum; left - in the sample of events of the type (1a) and (1b) together, right - in the sample of events of the type (1a); N - total number of events in the sample.

3.1.2. Dependences of the Average Value of the $\cos\theta_p$ on the Proton Multiplicity n_p

The dependences of the proton emission angle θ_p, in $\cos\theta_p$, on the proton multiplicity n_p are presented in fig.2. In this figure the normalized dispersion $D/\langle\cos\theta_p\rangle$ in dependence on n_p is given as well.

3.1.3. Dependences of the Average Proton Energy on the Proton Multiplicity

The average kinetic energy $\langle E_{kp} \rangle$ of the emitted protons in dependence on the proton multiplicity is shown in fig.3. In this figure the normalized dispersion $D/\langle E_{kp} \rangle$ in dependence on n_p is presented as well.

3.1.4. Average Values of the Longitudinal Component of the Emitted Proton Momentum $\langle P_{Lp} \rangle$ in Dependence on the Proton Multiplicity n_p

The $\langle P_{Lp} \rangle - n_p$ dependences are characterized in fig.4, where the normalized dispersions $D/\langle P_{Lp} \rangle$ are presented in dependence on n_p as well.

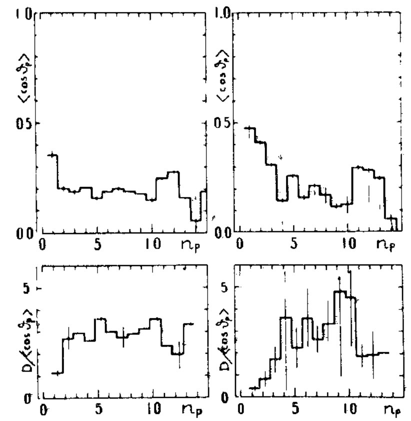

Fig.2. Dependences of the average values $\langle\cos\theta_p\rangle$, where θ_p is the proton emission angle, on the proton multiplicity in pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum - upper; n_p - dependences of the normalized dispersion $D/\langle\cos\theta_p\rangle$ - lower. Lef - in the sample of events of the type (1a) and (1b) together, right - in the sample of events of the type (1a).

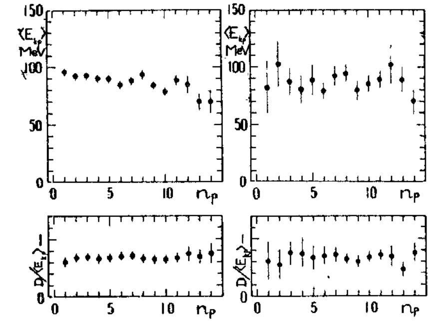

Fig.3. The dependences of the average kinetic energy $<E_{kp}>$ of the emitted protons on the proton multiplicity n_p, in pion-xenon nucleus collision events without particle production at 3.5 GeV/c momentum. Left upper - in the sample of events of the types (1a) and (1b) together; right upper - in the sample of events of the type (1a). Lower - n_p-dependences of corresponding normalized dispersions $D/<E_{kp}>$.

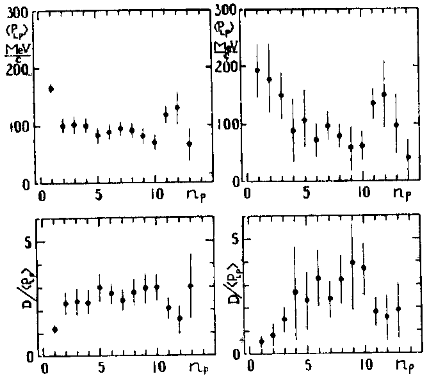

Fig.4. Average values of the longitudinal momentum of the emitted protons, $<P_{Lp}>$, in dependence on the proton multiplicity n_p - upper; corresponding normalized dispersions, $D/<P_{Lp}>$, in dependence on n_p - lower. Left - in the sample of events of the types (1a) and (1b) together; right - in the sample of events of the type (1a).

3.1.5. Average Values of the Proton Momentum Transverse Component in Dependence on the Proton Multiplicity

The $<P_{Tp}> - n_p$ dependences are characterized in fig.5; in this figure the normalized distributions $D/<P_{Tp}>$ in dependence on n_p are shown as well.

3.2. Proton Kinetic Energy Distributions

Distributions of the kinetic energy, E_{kp}, of the emitted protons in various samples of events are presented in figs.6 and 7; the characteristics of these distributions are given in table 3.

3.3. Distributions of the Proton Longitudinal Momentum

Distributions of the longitudinal component of the emitted proton momentum P_{Lp}, in the samples of events of the types (1a) and (1b) together, and of the type (1a) are presented in fig.8; the characteristics of these distributions are given in table 4.

Table 3

Characteristics of the energy spectra of protons emitted in pion-xenon nucleus collisions without particle production, at 3.5 GeV/c momentum. The quantities are defined and denoted as usual [13]; F and B is for "forward" and "backward" correspondingly.

Quantity	The sample of the pion-xenon nucleus collisons	
	$n_{\pi^-} \leqslant 1$	$n_{\pi^-} = 0$
$\langle E_{kp} \rangle$	87.5 MeV	89.9 MeV
$\langle E_{kp} \rangle_F$	96.3 MeV	97.1 MeV
$\langle E_{kp} \rangle_B$	70.9 MeV	76.3 MeV
r.m.s.	59.7 MeV	60.5 MeV
$r.m.s._F$	63.4 MeV	61.9 MeV
$r.m.s._B$	47.8 MeV	55.3 MeV
skewness	1.11	1.14
$skewness_F$	0.92	0.91
$skewness_B$	1.45	1.76
kurtosis	0.69	0.86
$kurtosis_F$	0.08	-0.09
$kurtosis_B$	2.60	4.23

Table 4

Characteristics of the proton longitudinal momentum distributions in pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum. $<P_{Lp}>$ - average value of the proton momentum longitudinal component.

Quantity	The sample of the pion-xenon nucleus collisions	
	$n_{\pi^-} \leq 1$	$n_{\pi^-} = 0$
$<p_{Lp}>$	96.0 MeV/c	89.7 MeV/c
r.m.s.	237.0 MeV/c	242.0 MeV/c
skewness	0.04	-0.17
kurtosis	0.04	0.23

Table 5

Characteristics of the transverse momentum P_{Tp} distributions of the protons emitted in pion-xenon nucleus collision events without particle production at 3.5 GeV/c momentum. The quantities are defined and denoted as usually /13/; F is for "forward", B is for "backward".

Quantity	The sample of the pion-xenon nucleus collisions	
	$n_{\pi^-} \leqslant 1$	$n_{\pi^-} = 0$
$\langle P_{Tp} \rangle$	303.1 MeV/c	299.0 MeV/c
$\langle P_{Tp} \rangle_F$	309.4 MeV/c	306.5 MeV/c
$\langle P_{Tp} \rangle_B$	291.4 MeV/c	285.2 MeV/c
r.m.s.	134.7 MeV/c	132.6 MeV/c
r.m.s.$_F$	138.9 MeV/c	134.8 MeV/c
r.m.s.$_B$	125.6 MeV/c	127.2 MeV/c
skewness	0.46	0.53
skewness$_F$	0.39	0.41
skewness$_B$	0.59	0.78
kurtosis	-0.25	-0.26
kurtosis$_F$	-0.40	-0.49
kurtosis$_B$	0.10	0.36

Table 6

Characteristics of the angular distributions of the protons emitted in pion-xenon nucleus collisions without particle production, at 3.5 GeV/c momentum. θ_p - the proton emission angle; the quantities are defined and denoted as usual /13/.

Quantity	Type of the pion-xenon nucleus collisions	
	$n_{\pi^-} \leqslant 1$	$n_{\pi^-} = 0$
$\langle \cos \vartheta_p \rangle$	0.1976	0.1898
r.m.s.	0.5457	0.5578
skewness	-0.4311	-0.4456
kurtosis	-0.8689	-0.9300

3.4. Proton Transverse Momentum Distributions

The distributions of the proton transverse momenta are presented in figs.9 and 10; the characteristics of these distributions are presented in table 5.

3.5. Angular Distributions of the Protons Emitted

The characteristics of the proton emission angles, θ_p, and the proton emission azimuth angles, ϕ_p, are presented in figs.11, 12, and in table 6.

4. CONCLUSIONS AND REMARKS

From the analysis of the general characteristics of the pion-xenon nucleus collisions without particle production, at 3.5 GeV/c momentum, presented in this work, it can be concluded that:

1) The proton multiplicity distributions in the classes of events of type (1a) and (1b), in which the incident pion is absorbed and in which the incident pion is deflected, differ by much, fig.1. and tables 1 and 2; the distribution in the class of events of the type (1a) is practically normal, but the distribution in the class of events of the type (1b) is not.

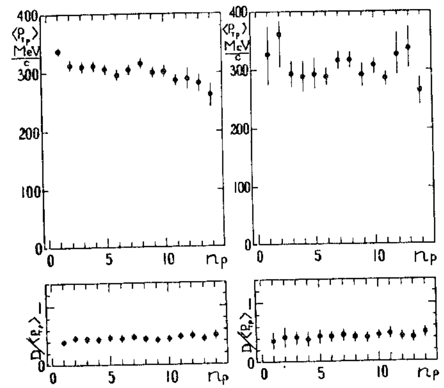

Fig.5. Pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum. Dependences of the proton transverse momentum average value, $\langle P_{Tp} \rangle$, on the proton multiplicity n_p - upper; corresponding dependences on n_p of the normalized dispersion $D/\langle P_{Tp} \rangle$ - lower. Left - in the samples of events of the type (1a) and (1b) together; right - in the sample of events of the type (1a).

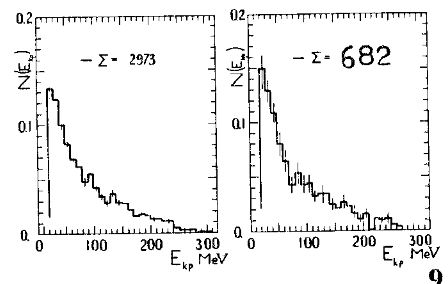

Fig.6. Kinetic energy spectra of the protons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum in which particle production does not occur; left - in the sample of events of the type (1a) and (1b) together, right - in the sample of events of the type (1a). Σ - number - of protons in the sample.

2) Average kinetic energy $<E_{kp}>$ and average transverse momentum $<P_{Tp}>$ of the emitted fast protons, of kinetic energy from about 20 to about 400 MeV, do not depend practically on the multiplicity n_p, at $n_p \leq n(D)=8$; the E_{kp} and P_{Tp} distributions in events with various n_p are practically identical, fig.3 and fig.5.

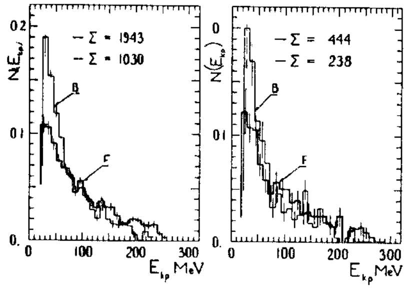

Fig.7. Kinetic energy spectra of the protons emitted into forward F and backward B hemisphere, in pion-xenon nucleus collision events at 3.5 GeV/c momentum in which particle production does not occur. Left – in the sample of events of the type (1a) and (1b) together; right – in the sample of events of the type (1a). Σ – number of the protons in the sample.

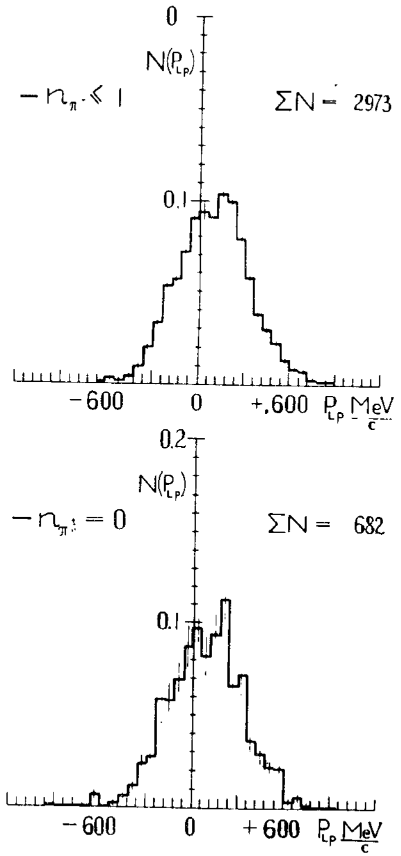

Fig.8. Distributions $N(P_{Lp})$ of the longitudinal momentum P_{Lp} of the protons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum in which particle production does not take place. Upper – in the sample of events of the type (1a) and (1b) together; lower – in the sample of events of the type (1a). ΣN – number of the protons in the sample.

3) The energy spectra of the emitted fast protons are almost identical in both types of events, (1a) and (1b), fig.6 and table 3; the energy spectra of the protons emitted into forward and backward hemispheres differ evidently in both the types of events, but the spectra of the protons emitted into forward hemisphere are identical in events of the type (1a) and (1b) and the spectra of the protons emitted into backward hemisphere are identical in events of the type (1a) and (1b), fig.7 and table 3.

4) The longitudinal momentum spectra $N(P_{Lp})$ of the fast protons emitted are practically identical in both the samples of events – of the type (1a) and (1b), fig.8 and table 4.,

5) The transverse momentum spectra $N(P_{Tp})$ of the protons emitted in events of the type (1a) and (1b) are identical, fig.9 and table 5; there are some small differences between the spectra of protons emitted into backward and forward hemispheres, but these differences are almost identical in both the types of events (1a) and (1b), fig. 10 and table 5.

6) Practically, there are no differences between $\cos\theta_p$ distributions of the proton emission angles θ_p, in the two samples of events of the type (1a) and of the type (1b), fig.11 and table 6.

7) An anisotropy is observed in the proton emission azimuth angle distribution, fig. 12;

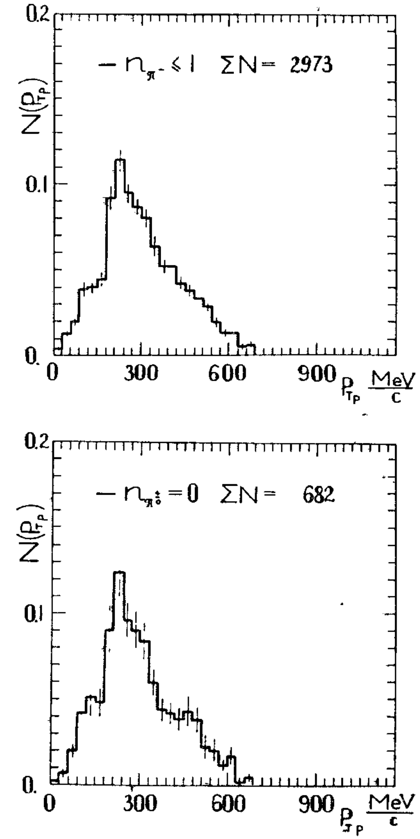

Fig.9. Transverse momenta P_{Tp} of the protons emitted in pion-xenon nucleus collision events without particle production at 3.5 GeV/c momentum. Upper – in the sample of events of the type (1a) and (1b) together; lower – in the sample of events of the type (1a). ΣN – number of the protons in the sample.

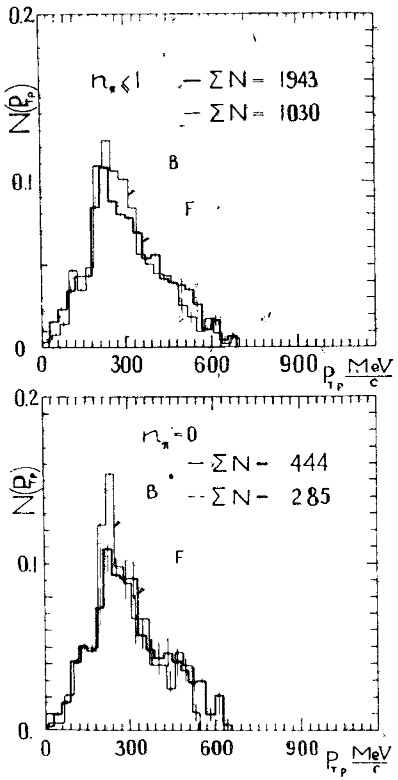

Fig.10. Transverse momenta P_{Tp} of the protons emitted into forward F and backward B hemisphere in the pion-xenon nucleus collision events without particle production at 3.5 GeV/c momentum. Upper - in the sample of events of the type (1a) and of the type (1b) together; lower - in the sample of events of the type (1a). ΣN - number of the protonsin the sample.

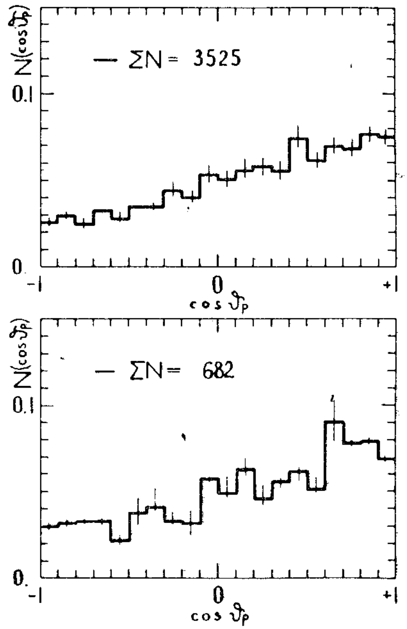

Fig.11. Angular distributions, in $\cos\theta_p$, of the protons emitted in pion-xenon nucleus collisions without particle production at 3.5 GeV/c momentum. Upper - in the sample of events of the type (1a) and (1b) together; lower - in the sample of events of the type (1a). ΣN - numbers of the protons in the sample.

this anisotropy decreases with increase of the incident pion deflection angle θ_π. fig.12.

The existence of the pion-xenon nucleus collision events without particle production, in which intensive emission of fast protons occurs, forces us to think that the proton emission process in hadron-nucleus collisions proceeds independently of the particle creation process, as it was pointed out in our works many years ago /12/.

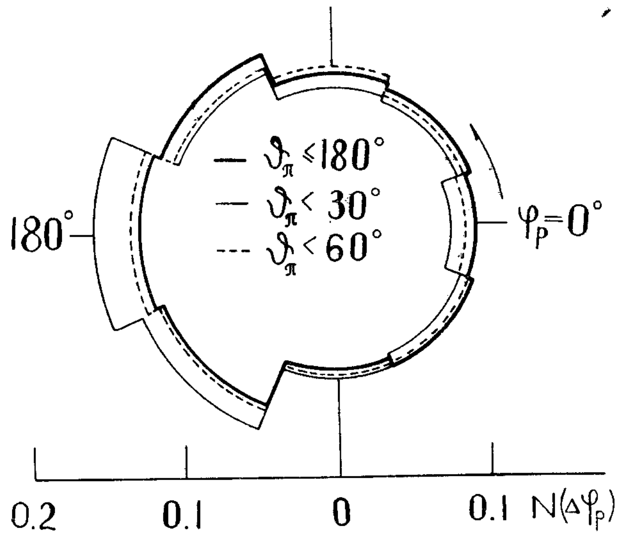

Fig.12. Distributions $N(\Delta\phi_p)$ of the azimuth angles ϕ_p of the emitted protons in pion-xenon nucleus collision events at 3.5 GeV/c momentum in which particle production does not occur, in classes of events of the type (1b) with various deflection angles θ_π of the incident pion. The proton emission azimuth angle ϕ_p is defined as the angle between the point deflection plane and the proton emission plane.

The characteristics of the proton emission process, presented in this paper, show that the observed proton emission is not a result of a simple knocking out of the protons from the target-nucleus by the incident hadron. The independences of the $\langle E_{kp} \rangle$ and the $\langle P_{Tp} \rangle$ of the proton multiplicity n_p indicate that the protons may be emitted in result of decay of some many-nucleon systems formed in the target-nucleus when an incident hadron passes through it.

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Стругальский З., Павляк Т., Плюта Я. E1-82-718
Экспериментальные исследования столкновений пион-ксенон без рождения частиц при 3,5 ГэВ/с: общие характеристики

Существуют случаи пион-ксенон столкновений, в которых интенсивное испускание быстрых протонов с кинетическими энергиями около 20-400 МэВ происходит без рождения частиц. Приводятся распределения протонов по энергиям, импульсам и углам испускания. Эти распределения анализируются в классах событий с разными интенсивностями испускания протонов. Анализ экспериментальных характеристик приводит к заключению что: а/ испускание нуклонов протекает независимо от процесса рождения частиц; б/ наблюдаемое интенсивное испускание "быстрых" протонов нельзя считать результатом прямого выбивания нуклонов из ядра-мишени налетающим адроном.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1982

Strugalski Z., Pawlak T., Pluta J. E1-82-718
Experimental Study of the Pion-Xenon Nucleus Collisions without Particle Production at 3.5 GeV/c Momentum: General Data

There exist pion-xenon nucleus collision events in which intensive emission of fast protons, of kinetic energy of about 20-400 MeV, is observed only without particle production. Energy, momentum and angular distributions of the emitted protons are presented and analysed in classes of events with various proton emission intensity. It is concluded that: a) The nucleon emission proceeds independently of the particle production process; b) The observed intensive emission of the "fast" protons cannot be treated as a result of a simple knocking-out of the nucleons from the target by the incident hadron.

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

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