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SEARCH FOR EFFECTS OF THE PARTICLE PRODUCTION PROCESS ON THE NUCLEON EMISSION AND TARGET FRAGMENT EVAPORATION IN COLLISIONS OF HADRONS WITH ATOMIC NUCLEI

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1. INTRODUCTION

When high energy hadrons - with energies larger than the pion production threshold - collide with atomic nuclei, nucleons and target fragments are always emitted and particles may be generated, as it has been stated experimentally.

The emission of nucleons and target fragment evaporation may occur without particle production. The question arises therefore: "How does effect the particle production process on the nucleon emission and target fragment evaporation?"

In this paper, the results obtained in our searches for the effects in question are presented.

2. METHOD

In our investigations, we have used the 26 and 180 litre xenon bubble chambers [1,2] exposed to pion beams at energies from about 2 up to about 9 GeV. Main results are based on the data from the 180 litre chamber which is practically 4Pi detector for all emitted protons and for all secondary pions. This chamber was exposed to 3.5 GeV/c momentum negatively charged pion beam. The 26 litre chamber was exposed to 2.34 GeV/c momentum positively charged pion beam, and to 5 and 9 GeV/c momentum negatively charged pion beams.

General information about pion-xenon nucleus collisions at projectile kinetic energy 2-9 CeV was published in a set of our papers [3]; we use for the analysis in this work the DST used in them. Additional appropriate information at higher energies we have found in various emulsion works [4-11]. The accelerator data there are up to 400 GeV of incident protons. Some data from cosmic rays investigations [12] are up to about 3500 GeV.

Firstly, we used to prepare a set of various dependences of the characteristics of the emitted protons of kinetic energy from about 20 up to about 300 MeV on the multiplicities n_π of secondary pions, in pion-xenon nucleus collisions at 3.5GeV/c momentum, and we discovered general features of these dependences.

Secondly, we compared available characteristics of the proton emission process at high energies, up to 3500 GeV, with corresponding characteristics in pion-xenon nucleus collisions at energy 3.5 GeV. Results of such a comparison allow to con-

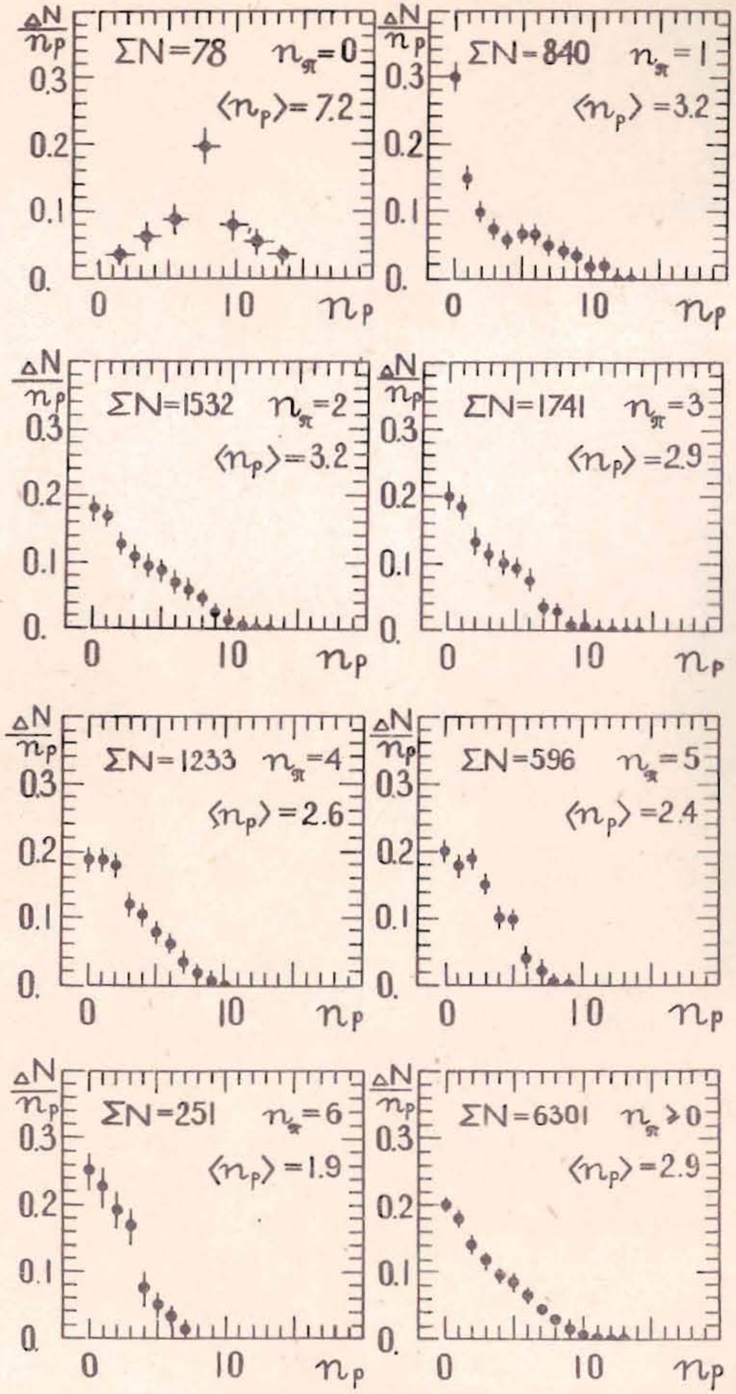

Fig.1. Proton multiplicity n_p *distributions* $f(n_p) = \Delta N/n_p$ *in pion-xenon nucleus collision events with various multiplicities* $n_\pi = 0, 1, 2, \ldots, \geq 0$ *of secondary pions, at 3.5 GeV/c momentum.* ΣN *- number of collision events in a histogram,* $\langle n_p \rangle$ *- the mean proton multiplicity.*

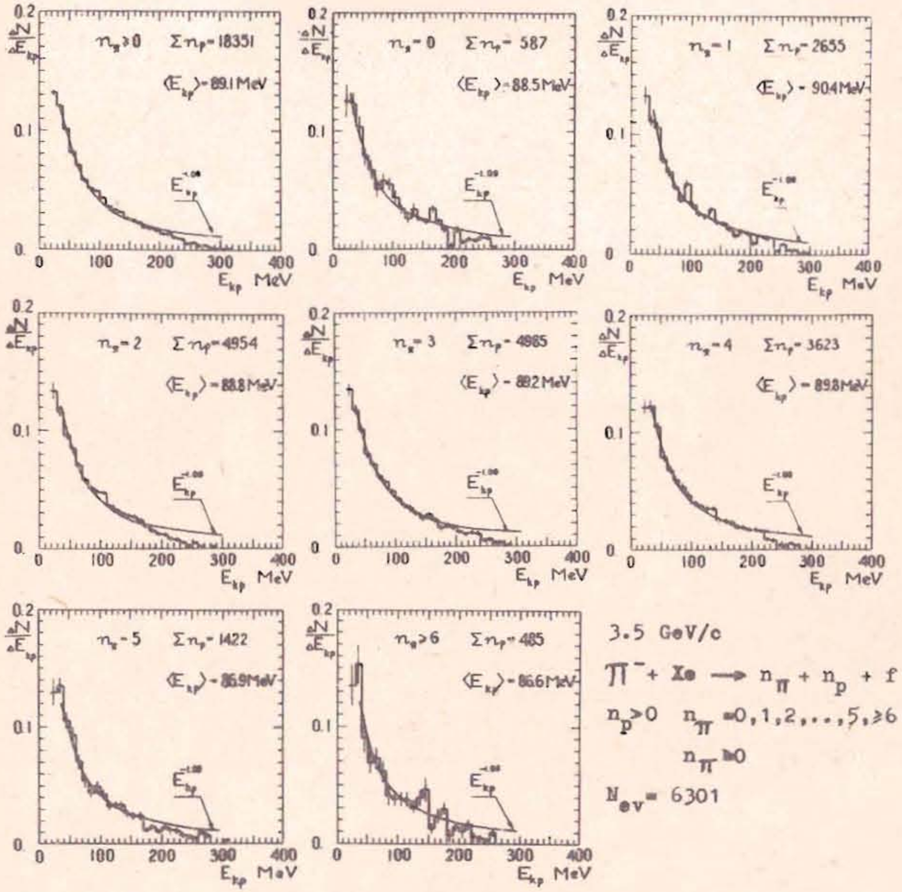

Fig.2. Energy spectra of protons emitted in pion-xenon nucleus collisions with various multiplicities $n_\pi = 0, 1, \ldots, \geq 6; \geq 0$*, at 3.5 GeV/c momentum.* Σn_p *- total number of protons in a histogram,* $\langle E_{kp} \rangle$ *- the mean kinetic energy of the protons; solid line - proton spectra in proton-nucleus collisions in emulsion at 4 and 400 GeV energy* [7].

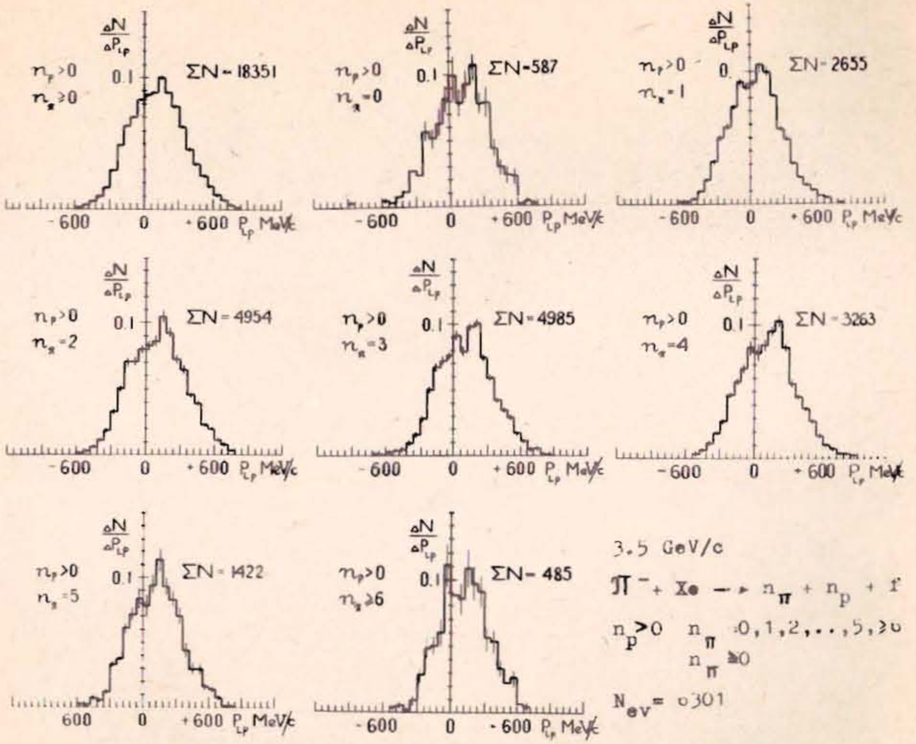

Fig.3. Longitudinal momentum P_{Lp} *spectra* $\Delta N/\Delta P_{Lp}$ *of protons emitted in pion-xenon nucleus collisions with various multiplicities* $n_\pi = 0,1,2,\ldots,\geq 6$; ≥ 0 *of secondary pions, at 3.5 GeV/c momentum.* ΣN *- number of protons in a histogram,* n_p *- the multiplicity of emitted protons.*

clude about the behaviour of the nucleon emission process with incident hadron energy increase, in other words - with increase of the multiplicity of produced particles.

This way, the effect of the particle production process on the nucleon emission process may be discovered.

3. RESULTS

Following results of experimental investigations performed by us and by other groups of physicists are important here, for the considerations in question:

I. The proton multiplicity distribution changes with the incident hadron energy increase - up to about 4 GeV for inci-

dent pions [13] and up to about 8 GeV for incident protons [14,15], in collisions with relatively heavy nuclei - as xenon, silver. At higher energies the distribution is energy-independent [14,16,17]. The mean multiplicity of the emitted protons is energy-dependent [15] up to about 4 GeV for the pion-nucleus collisions and up to about 8 GeV for proton-nucleus collisions, for collisions with heavy nuclei, at larger energies it is energy-independent [18-21] and almost equal to the mean thickness $\langle\lambda\rangle$ of the target nucleus [21] measured in protons/S, where $S = \pi D_0^2 \doteq$ $\doteq 10$ fm^2 and D_0 is the nucleon diameter.

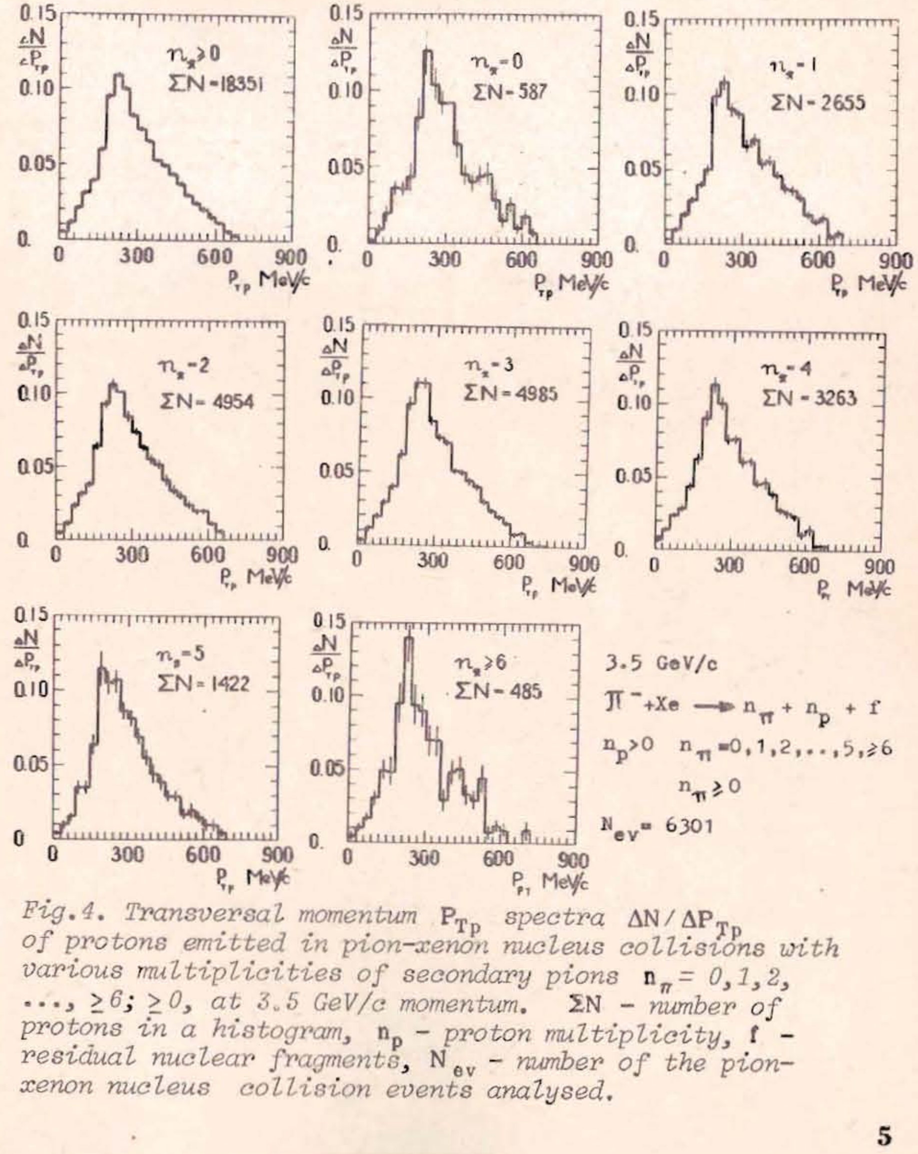

Fig.4. Transversal momentum P_{Tp} *spectra* $\Delta N/\Delta P_{Tp}$ *of protons emitted in pion-xenon nucleus collisions with various multiplicities of secondary pions* $n_\pi = 0,1,2,\ldots,\geq 6$; ≥ 0, *at 3.5 GeV/c momentum.* ΣN *- number of protons in a histogram,* n_p *- proton multiplicity,* f *- residual nuclear fragments,* N_{ev} *- number of the pion-xenon nucleus collision events analysed.*

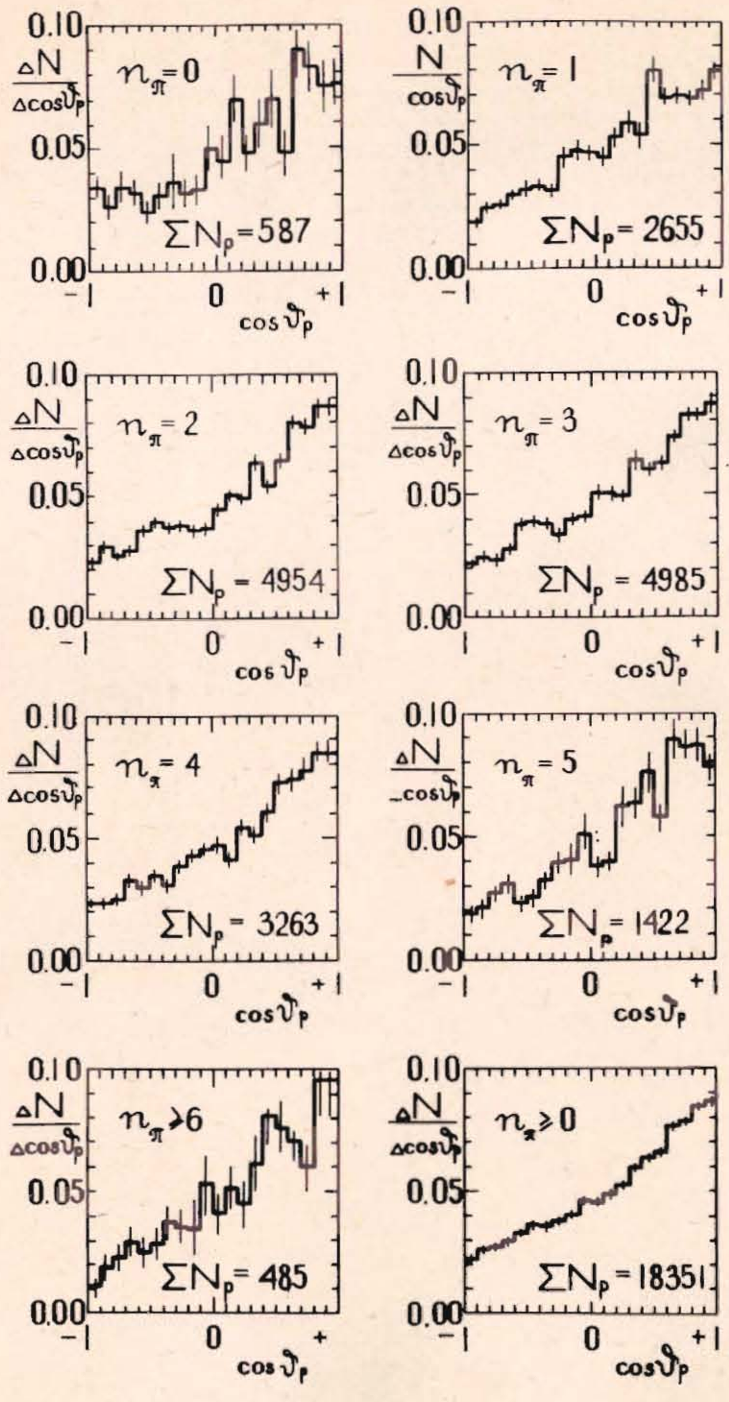

Fig.5. Distribution $\Delta N/\Delta\cos\theta_p$ of the proton emission angles θ_p in pion-xenon nucleus collision events with various multiplicities $n_\pi = 0, 1, 2, \dots, \geq 6; \geq 0$, at 3.5 GeV/c momentum. ΣN_p - number of protons in a histogram.

It is commonly known that the multiplicity of produced particles, of produced pions in particular, increases with increase of the incident hadron energy. The above described behaviour of the proton multiplicity distribution with incident hadron energy increase allows one to conclude that at energies above a few GeV the particle production process does not effect on the nucleon emission process.

II. At smaller energies of the incident hadrons, when the proton multiplicity distribution depends on the projectile energy, collision events occur in which incident hadron is completely stopped inside the target nucleus accompanied by intensive emission of observed protons from the target nucleus but without particle production[22,23]. It indicates that nucleon emission process can proceed without particle production process.

III. The proton multiplicity distributions, in pion-xenon nucleus collisions with $n_\pi = 0, 1, 2, \dots$ produced pions, do not vary strongly at $n_\pi > 3$ and are similar to the distribution for events with $n_\pi \geq 0$, fig.1 and table 1. The distribution for the events without particle production, when $n_\pi = 0$, is of principally different shape, and the mean proton multiplicity $\langle n_p \rangle$ exceeds markedly the means in other cases - when $n_\pi = 1, 2, \dots$, fig.1. The rate of the stopped events in hadron-nucleus collisions decreases with incident hadron energy increase[24]. It was shown that such a behaviour is caused by energy losses of incident hadron in passing through nuclear matter[21,24].

IV. Energy spectra, longitudinal and transverse momentum distributions, and angular distributions of the emitted protons do not depend on the number n_π of priduced pions in pion-xenon nucleus collisions at 3.5 GeV/c momentum, figs.2-5 and tables II-V. It was shown that the energy spectrum and angular distribution of protons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum and the energy spectrum and angular distribution in proton-nucleus collisions in nuclear emulsions at 400 GeV/c momentum are correspondingly the same[14,25,26].

Table 1

Characteristics of the proton multiplicity n_p distributions $f(n_p) = \Delta N / n_p$ in pion-xenon nucleus collisions with multiplicities of secondary pions $n_\pi = 0, 1, 2, \ldots; \geq 0$, at 3.5 GeV/c momentum. N_0 – number of events

n	$\langle n_p \rangle$	r.m.s.	skewness	kurtosis	N_o
0	7.2	3.5	0.0064	-0.646	78
1	3.3	3.2	0.8978	-0.146	840
2	3.2	2.8	0.7000	-0.326	1532
3	2.9	2.5	0.7822	0.103	1741
4	2.6	2.2	0.8086	0.083	1253
5	2.4	2.0	0.6403	-0.259	596
6	1.9	1.7	0.8468	0.145	251
≥0	2.9	2.6	0.9236	0.411	6301

Table 2

Characteristics of the kinetic energy E_{kp} MeV spectra of protons emitted in pion-xenon nucleus collisions with various multiplicity n_π of secondary pions of any electric charge, at 3.5 GeV/c momentum. N_p – number of protons in a spectrum

n_π	N_p	$\langle E_{kp} \rangle$	r.m.s.	skewness	kurtosis
0	587	88.5 ± 2.6	60.2	1.16	1.02
1	2655	90.4 ± 1.3	62.6	1.11	0.60
2	4954	88.8 ± 1.0	61.3	1.17	0.92
3	4895	89.2 ± 0.9	62.4	1.20	0.98
4	3263	89.8 ± 1.1	61.8	1.17	0.97
5	1422	86.9 ± 1.8	61.5	1.23	0.93
≥6	485	86.6 ± 2.8	60.0	1.17	1.03
≥0	18351	89.1 ± 0.5	61.8	1.18	0.91

Table 3

Characteristics of the longitudinal momentum P_{lp} distributions $f(P_{lp}) = \Delta N / \Delta P_{lp}$ of protons emitted in pion-xenon nucleus collisions with various multiplicities n_π of secondary pions with any electric charge, at 3.5 GeV/c momentum. N_p – number of protons in a distribution, P_{lp} in MeV/c

n_π	N_p	$\langle P_{lp} \rangle$	r.m.s.	skewness	kurtosis
0	587	98.2 ± 10.6	245.1	-0.2540	0.2140
1	2655	104.4 ± 4.9	237.1	0.1127	-0.0843
2	4954	106.7 ± 3.7	243.5	0.0641	-0.2550
3	4985	109.0 ± 3.7	243.8	0.0769	-0.0703
4	3263	119.2 ± 4.6	247.3	0.1191	-0.1162
5	1422	120.9 ± 6.7	233.8	0.0225	-0.0661
≥6	485	120.9 ± 10.6	224.6	-0.0050	-0.2798
≥0	18351	110.4 ± 1.2	242.2	0.0697	-0.1194

Table 4

Characteristics of the transverse momentum P_{Tp} distributions $f(P_{Tp}) = \Delta N / \Delta P_{Tp}$ of protons emitted in pion-xenon nucleus collisions with various multiplicities n_π of secondary pions, at 3.5 GeV/c momentum. N_p – number of protons in a distribution, P_{Tp} in MeV/c

n_π	N_p	$\langle P_{Tp} \rangle$	r.m.s.	skewness	kurtosis
0	587	301.1 ± 5.7	130.3	0.4809	-0.2313
1	2655	309.4 ± 2.8	137.1	0.4666	-0.3271
2	4954	299.4 ± 2.0	133.8	0.4652	-0.2745
3	4985	300.6 ± 2.0	131.8	0.5050	-0.1802
4	3263	298.1 ± 2.5	133.7	0.4342	-0.3099
5	1422	295.9 ± 3.7	130.0	0.6082	0.0506
≥6	485	300.4 ± 6.3	135.1	0.7938	0.8315
≥0	18351	300.8 ± 1.0	133.4	0.4916	-0.2067

Table 5

Characteristics of the cosine of the proton emission angle θ distributions $N(\cos\theta_p) = \Delta N / \Delta \cos\theta_p$ *in pion-xenon nucleus collisions with various multiplicities* n_π *of secondary pions with any electric charge, at 3.5 GeV/c momentum.* N_p *- number of protons in a distribution*

n_π	N_p	$\langle \cos\vartheta_p \rangle$	r.m.s.	skewness	kurtosis
0	587	0.2020 ± 0.0024	0.5574	-0.4964	-0.8687
1	2655	0.2115 ± 0.0011	0.5374	-0.4422	-0.8659
2	4954	0.2168 ± 0.0008	0.5570	-0.4579	-0.9455
3	4985	0.2229 ± 0.0008	0.5499	-0.4617	-0.9205
4	3263	0.2432 ± 0.0010	0.5551	-0.5131	-0.8726
5	1422	0.2544 ± 0.0015	0.5363	-0.5690	-0.7514
≥ 6	485	0.2638 ± 0.0025	0.5225	-0.5001	-0.7781
≥0	18351	0.2260	0.5497	-0.4774	-0.8940

4. CONCLUSIONS

The experimentally stated facts presented in foregoing section 3 allow one to conclude in general that: The particle production process in hadron-nucleus collisions does not effect on the nucleon emission process in them at any energy of incident hadron. The observed energy-dependences of the proton multiplicity distributions at smaller energies - smaller than a few GeV - are caused by the monotonic energy loss of the incident hadron in nuclear matter. The particle production process at the smaller energies causes a decrease of the mean number of the emitted nucleons as well, due to the loss of a part of the projectile energy used for the particle production; the nature of the nucleon emission process is not effected at the time.

We can state, therefore: The particle production process in hadron-nucleus collisions does not influence the nucleon emission process at any projectile energy.

Because relation exists between the mean multiplicity $\langle n_b \rangle$ of the target nucleus charged fragments evaporated in hadron-nucleus collisions and the multiplicity n_p of protons emitted in these collisions[20]

$$\langle n_b \rangle = 1.25\,(n_p + \frac{A-Z}{Z}), \qquad (1)$$

we can conclude as well that: The evaporation process of the fragments from target nuclei in hadron-nucleus collisions is not influenced by the particle production process at any projectile energy.

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Стругальский З. E1-84-854

Поиски влияния процесса рождения частиц на испускание нуклонов и испарение ядерных фрагментов в столкновениях адронов с атомными ядрами

Исследуются возможные эффекты влияния процесса рождения частиц на испускание нуклонов и испарение ядерных фрагментов в адрон-ядерных столкновениях. Обнаружено, что процесс рождения частиц не влияет ни на процесс испускания нуклонов, ни на процесс испарения ядерных фрагментов.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Strugalski Z. E1-84-854

Search for Effects of the Particle Production Process on the Nucleon Emission and Target Fragment Evaporation in Collisions of Hadrons with Atomic Nuclei

Possible effects of the particle production process on the nucleon emission and target fragment evaporation in hadron-nucleus collisions are investigated. It was found that the particle production process does not influence the nucleon emission and fragment evaporation processes.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1984