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ANGULAR DISTRIBUTIONS OF NUCLEONS EMITTED IN HIGH ENERGY HADRON-NUCLEUS COLLISIONS

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1. INTRODUCTION

Collisions of high energy hadrons, of kinetic energy higher than the energy threshold for pion production, can be collected in two samples: a) the sample containing events in which particle production does not occur, but incident hadron is absorbed inside the target nucleus or deflected in passage through the target nucleus [1,2]; b) the sample of the any-type collisions including events with particle production and without particle production. In all events belonging to any of the samples the collision is accompanied by emission of "fast" nucleons - of kinetic energy from about 20 to about 400 MeV; the emission is intensive enough - events occur in which tens nucleons are emitted, when the target nucleus is massive enough.

There are impressive features of energy spectra and momentum distributions of the emitted protons, discovered experimentally [3-5] in studying pion-xenon nucleus collisions at 3.5 GeV/c momentum. It was found that the energy spectra and momentum distributions of the fast protons are identical in both the samples of events a) and b) or, in other words, they are independent of the particle production process. Moreover, the energy spectra and momentum distributions are independent of the multiplicity n_p, or of the intensity, of emitted protons. Simple comparison of the energy spectra of protons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum [4] with energy spectra of protons emitted in proton-emulsion collisions at 300-400 GeV/c momentum [6] shows that these spectra can be regarded as identical, as energy independent.

It was argued [5] that it is reasonable to think these features to be proper to both the nucleons, not to protons only, and to nucleons emitted in any hadron-nucleus collisions at any high energy.

The following questions arose: "Are the angular characteristics of nucleon emission process independent as well of the occurrence of the particle production process and of the nucleon emission intensity ?" Are the angular distributions independent of the incident hadron energy ?" The answer to these questions should be based on the results of careful experimental studies. Appropriate investigations were performed on the samples of events used in studies of the energy and momentum spectra of the emitted protons. The description of our experiment and the experimental procedure applied can be found in our previous works [1,2,4,6,7,8] and it is found not necessary to repeat it here.

The subject matter in this paper is a presentation of experimental results obtained in studying angular distributions of the fast protons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum; the comparison of angular distributions in the samples a) and b) of events is accentuated here, as giving new experimental facts.

2. EXPERIMENTAL DATA

Experimental data on proton angular distributions presented here are based on the sample of 6301 any-type pion-xenon nucleus collision events at 3.5 GeV/c momentum and 972 pion-xenon nucleus collision events without particle production at the same incident pion momentum [3,4,7,8] ; the pion-xenon nucleus collision events without particle production occur in $(10.6 \pm 0.5)\%$ of the any-type collisions, the enlarged number of the events in question used here is from additional scanning and selection of these collisions registered in the chamber.

Experimental data are presented in figs. 1-5 and in the table characterizing angular distributions in dependence on the proton emission multiplicity n_p.

Let us sum up the most impressive features of the angular distributions of the fast protons, discovered experimentally; we can conclude in reviewing the data presented that:

1) The proton emission angles θ_p lie within the value interval from 0 to 180 degrees, in both samples of events a) and b) - in the sample of events without particle production and in the sample of the any-type events, fig. 1.

2) Angular distributions are practically the same in both samples of collision events - a) and b), figs. 1 and fig. 2, and the table.

3) The average proton emission angle $\langle\theta_p\rangle$ does not depend practically on the proton emission intensity n_p, when $n_p \geq 2$; the n_p - dependences of the $\langle\theta_p\rangle$ are practically the same in both two samples of events a) and b), figs.3 and 4.

4) Distributions of the proton emission angles are practically identical in pion-xenon nucleus collisions belonging to any of the samples a) and b), independently of the proton emission intensity n_p, fig.3 and the table.

5) Angular distributions of protons of kinetic energy from about 30 to about 400 MeV emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum are the same as angular distributions of protons of kinetic energy from about 30 to about 400 MeV emitted in proton-emulsion collisions at 300-400 GeV/c momentum, fig.5.

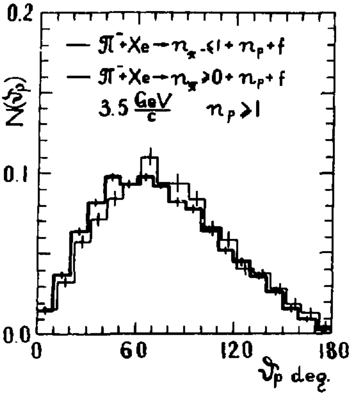


Fig.1. Distributions $N(\theta_p)$ of the emission angles θ_p of fast protons, of kinetic energy from about 20 to about 400 MeV, emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum: ——— - in the sample of events without particle production, when incident pion is absorbed inside the target nucleus or deflected in traversing it; ▬▬ in the sample containing any-type collision events, with particle production and without particle production. n_π - multiplicity of secondary pions, n_p - multiplicity of emitted protons, f - residual nuclear fragments.

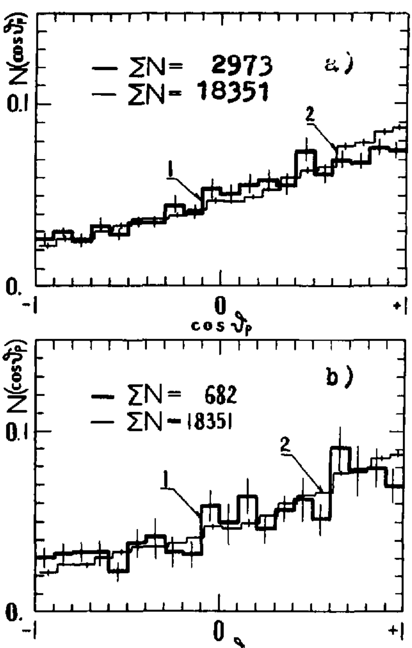


Fig.2. Distributions $N(\cos\theta_p)$ of cosine of the emission angle θ_p of fast protons, of kinetic energy from about 20 to about 400 MeV, in various samples of pion-xenon nucleus collisions at 3.5 GeV/c momentum [4,7]: a) in the sample containing collision events without particle production, when incident pion is absorbed inside the target nucleus or deflected in traversing it, histogram 1, and in the sample of any-type collision events, histogram 2; b) in the sample of collision events without particle production when incident pion is absorbed inside the target nucleus, histogram 1, and in the sample of any-type collision events, histogram 2. ΣN - number of protons in the histogram.

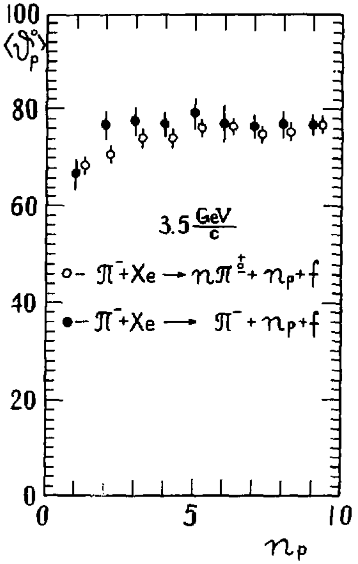


Fig.3. Proton emission average angle $<\theta_p>$ in dependence on the multiplicity n_p of fast protons, of kinetic energy from about 20 to about 400 MeV, emitted in two samples of pion-xenon nucleus collision events at 3.5 GeV/c momentum: full circles - in the sample of collisions without particle production, when incident pion is absorbed inside the target nucleus or deflected in passage through it; empty circles - in the sample of any-type collisions, n - number of secondary pions, f - residual nuclear fragments.

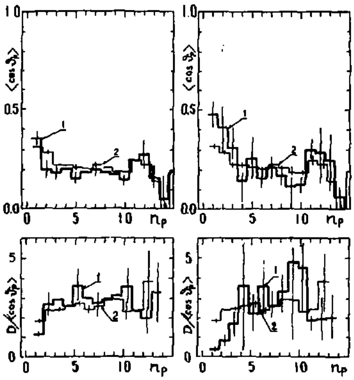
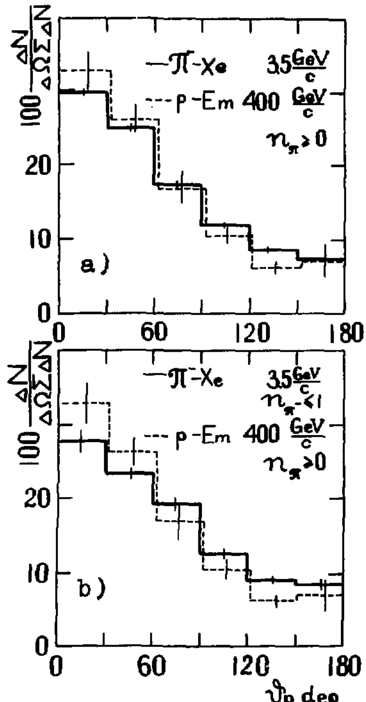


Fig.4. Average cosine $<\cos\theta_p>$ and corresponding normalized dispersion $D/<\cos\theta_p>$ in dependence on multiplicity n_p of fast protons, of kinetic energy from about 20 to about 400 MeV, emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum through emission angles θ_p: left side - in the sample of any-type collision events, histogram 2, and in the sample of collision events without particle production when incident pion is absorbed inside the target nucleus or deflected in passage through it, histogram 1, right side - in the sample of any-type collision events, histogram 2, and in the sample of collision events without particle production when insident pion is absorbed inside the target nucleus, histogram 1.

3. RESULTS AND DISCUSSION

Some years ago an argumentation was presented [9,10] that the number n_p of emitted protons in any hadron-nucleus collision

Fig.5. Angular distributions $100\,\Delta N/\Delta\Omega(\Sigma\Omega N)$ of protons of kinetic energy from 30 to about 400 MeV emitted in pion-xenon nucleus collisions and in proton-nucleus collisions, with nuclei in nuclear emulsion Em: a) Any-type pion-xenon nucleus collisions at 3.5 GeV/c momentum and any-type proton-Em collision at 300-400 GeV/c momentum /6/ ; b) Pion-xenon nucleus collisions at 3.5 GeV/c momentum without particle production and any-type proton-Em collisions at 300-400 GeV/c momentum /6/. θ_p - proton emission angle, ΔN - number of protons emitted within the interval $\Delta\theta_p$ of emission angles, $\Delta\Omega$ - solid angle corresponding to the $\Delta\theta_p$ interval, $\Sigma\Delta N$ - total number of emitted protons used in histogram.



is a measure of the nuclear matter layer thickness λ, expressed in number of protons n_p per some area πD_0^2, where $n_p = n_p(\lambda)$ and $n_p(\lambda)$ is the number of protons contained within the cylindrical volume $\pi D_0^2\lambda$; D_0 is for the nucleon diameter. Thus, the proton emission intensity n_p is a measure how much is the target nucleus involved in a hadron-nucleus collision event or, in other words, how thick is the nuclear matter layer the incident hadron is collided with.

Taking into account this remark, it can be stated in reviewing experimental data presented above that:

1) The average value of the proton emission angle $\langle\theta_p\rangle$ and the proton angular distributions do not depend practically on the nuclear matter layer thickness the incident hadron interacted with.

2) The fast protons emitted from the target nucleus seem do not interact inside the parent nucleus; we note that the features of the energy and momentum spectra /5/ of the emitted fast protons lead to the same conclusion.

Table

Characteristics of angular distributions $N(\theta_p)$ of fast protons, of kinetic energy from about 20 to about 400 MeV, in pion-xenon nucleus collisions at 3.5 GeV/c momentum with $n_p \geq 1$, $n_p = 1,2,\ldots,8,\geq 9$ emitted protons, for two samples of events: sample a) containing events in which particle production does not occur, but incident pion is absorbed inside the target nucleus or deflected in passage through it; sample b) containing any-type collision events. θ_p-proton emission angle in degrees, Σn_p- number of protons at a given n_p.

n_p	Σn_p		$\langle\theta_p\rangle$		r.m.s.		skewness		kurtosis	
	a)	b)	a)	b)	a)	b)	a)	b)	a)	b)
≥1	2973	18351	76.7	74.7	37.3	37.5	0.32	0.36	-0.51	-0.59
1	165	1120	67.0	68.6	27.1	36.5	0.51	0.53	0.15	-0.28
2	180	1804	76.6	70.4	37.2	37.0	0.37	0.42	-0.53	-0.50
3	150	2193	77.8	74.6	37.8	37.1	0.42	0.31	-0.53	-0.70
4	208	2392	76.4	74.9	35.5	37.5	0.32	0.37	-0.31	-0.55
5	240	2689	79.2	76.0	38.6	37.8	0.13	0.35	-0.62	-0.59
6	342	2502	77.4	76.3	37.4	37.8	0.23	0.33	-0.72	-0.64
7	308	1890	76.3	74.6	36.8	36.8	0.18	0.29	-0.77	-0.64
8	360	1600	77.4	75.7	37.5	37.8	0.30	0.35	-0.44	-0.59
≥9	1020	2161	77.4	77.1	38.5	37.7	0.35	0.34	-0.51	-0.62

3) The observed properties of the angular distribution may be ascribed to any high energy hadron-nucleus collision, at least to proton-nucleus and pion-nucleus collisions at any energy - at least within the energy value interval from some GeV to some hunderds GeV, fig.5.

It is known, from our experiments, that the dependences on the multiplicity n_π of produced pions of the average number $\langle n_p \rangle$ of emitted fast protons and of the average number $\langle n_n \rangle$ of neutral "stars" registered are of almost identical shapes. It enables us to think that our data on the fast proton angular distributions are informative about the neutron angular distributions as well.

The analysis of properties of the fast protons assumed as knocked-out from target nuclei by energetic hadrons, performed within the frames of the intranuclear cascade model[11], allows to conclude that the mechanism of observed fast proton emission cannot be of this simple nature - the observed fast protons cannot be regarded as knocked out. One possible mechanism was proposed in one of may earlier works[12]: along the hadron course in nuclear matter mesons appear of kinetic energy small enough at which they are absorbed simply by two or more nucleons; the systems formed in such a way, of relatively small kinetic energy, might move inside the target nucleus without causing nucleon emission in ones turn and decay after having left it into nucleons.

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Угловые распределения нуклонов, испущенных в столкновениях адрон-ядро при высоких энергиях

Угловые распределения "быстрых"протонов с кинетическими энергиями от ~20 до ~400 МэВ, испущенных в столкновениях пион-ксенон при импульсе 3,5 ГэВ/с,исследовались в двух группах событий - когда происходит рождение частиц и когда рождение частиц отсутствует. Распределения практически одинаковы в обеих группах событий и в подгруппах с разными кратностями испущенных протонов. Проведено сравнение угловых распределений протонов, испущенных в столкновениях пион-ксенон при импульсе 3,5 ГэВ/с, с соответствующими распределениями протонов, испущенных в столкновениях протон-ядро эмульсии при импульсах от 300 до 400 ГэВ/с. Полученные результаты позволяют заключить, что: 1/ среднее значение угла испускания нуклонов и угловые распределения испущенных нуклонов практически не зависят от толщины слоя ядерной материи, с которым произошло столкновение первичного адрона; 2/ быстрые нуклоны,испущенные из ядра-мишени,ведут себя так,как будто не подвергались взаимодействию внутри этого ядра; 3/ угловые распределения не зависят от энергии налетающего адрона и практически одинаковы для столкновений пион-ядро и протон-ядро.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Angular Distributions of Nucleons Emitted in High Energy Hadron-Nucleus Collisions

Angular distributions of "fast" protons, of kinetic energy from about 20 to about 400 MeV, emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum were studied in two samples of events - when particles are produced and when particle production does not occur. The distributions are practically the same in both the samples of events and in subsamples of events with various multiplicities of emitted protons. Comparison of angular distributions of protons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum with corresponding angular distributions of protons emitted in proton-emulsion collisions at 300-400 GeV/c momentum is performed. Results obtained allow to conclude that: 1) Average value of the nucleon emission angle and the nucleon angular distributions do not depend practically on the nuclear matter layer thickness the incident hadron collided with; 2) Fast nucleons emitted from the target nucleus seem did not interact inside the parent nucleus: 3) Fast nucleon angular distributions do not depend on the energy of incident hadron, they are the same for pion-nucleus and for proton-nucleus collisions as well.

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

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