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EMISSION OF π° AND η° MESONS IN π^+ + Xe INTERACTIONS AT 2.34 GeV/c AND THE PROBLEM OF THE EXISTENCE OF π MESONS INSIDE THE NUCLEUS

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EMISSION OF π° AND η° MESONS IN π^{+} + Xe INTERACTIONS AT 2.34 GeV/c AND THE PROBLEM OF THE EXISTENCE OF π MESONS INSIDE THE NUCLEUS

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1. INTRODUCTION

The investigation of the collisions of relativistic particles with atomic nuclei provides a source of information on the mechanism of the interaction of particles with nuclei and on the structure of target nuclei. In particular, this concerns the reactions leading to the emission of a small number of secondary particles. From this point of view the simplest ones are two-body or quasi two-body reactions which are known in detail from the study of interactions with free protons as targets (cf. e.g., [1]).

In this paper we present the results of the investigation of $\pi^+ + \mathrm{Xe}$ interactions at 2.34 GeV/c which are accompanied by the emission of two gamma quanta and no more than four charged secondary particles. The angular and energetic characteristics of π^0 mesons decaying into these gamma quanta were analysed in order to determine the mass of the effective intranuclear target.

2. METHOD OF INVESTIGATION

Investigations were performed using the 25ℓ xenon bubble chamber of the Joint Institute for Nuclear Research at Dubna. The method of the analysis of events registered in this chamber was described in our earlier papers [2-6]. In this experiment about

550000 chamber stereophotographs were scanned which were obtained by exposure of the chamber in the π^+ meson beam of 2.34 GeV/c momentum. Out of the 50 000 photographs the events with the number of charged secondary particles $N_{ch} \leq 4$ and an arbitrary number k of accompanying gamma quanta were chosen: in the following these events will be denoted as $\pi^+ + Xe \to k\gamma + (N_{ch} \leq 4)$. Out of the following 500 000 photographs the events with no more than one track of charged secondary particles stopping in the chamber accompanied by the number $k = 2$ of gamma quanta were chosen; these events will be denoted in the following as $\pi^+ + Xe \to \gamma\gamma + (N_{ch} = 0{,}1\ \mathrm{stop})$. The total number of 2356 events with $N_{ch} \leq 4$ were singled out; their distribution over the N_{ch} and k is given in Table 1. The number of events with $N_{ch} = 0{,}1$ stopping in the chamber and $k = 2$ amounted to 701. In this research all the events with $N_{ch} \leq 4$ and $k = 2$ were analysed; their number amounted to 1497.

In these events the energies of gamma quanta and their emission angles were measured using the method worked out earlier /3/. The mean accuracy of the determination of the energies of gamma quanta was equal to 20 per cent. The mean accuracy of the measurement of gamma quanta emission angles was not worse than 5° /4,5/.

In each case of the chosen interaction the pairs of gamma quanta were correlated in the effective mass $m_{\gamma\gamma}$. The typical distribution over effective masses $m_{\gamma\gamma}$ of pairs of gamma quanta is presented in Fig.1. An analogical distribution was performed earlier /2/ for such events with $N_{ch} = 0{,}1$ in which the secondary charged particle

Table 1

Numbers of the $\pi^+ + Xe \to k\gamma + (N_{ch} \leq 4)$ events at 2.34 GeV/c; k - the number of gamma quanta, N_{ch} - the number of charged secondary particles

N_{ch} \ k	0	1	2	3	4	5	6	7	8	All
0	1	0	4	0	2	0	0	1	0	8
1	48ˣ	35	162	25	54	9	11	1	4	349
2	313	54	198	27	58	5	11	3	3	672
3	337	74	258	44	63	5	4	1	2	788
4	260	48	174	16	34	3	3	0	1	539
All	959	211	796	112	211	22	29	6	10	2356

ˣ Events in which the projection of the emission angle of secondary particle on the plane of the film is not smaller than 5°.

stops in the chamber. Further the corrections of the measured values of the energies of gamma quanta were performed for these cases in which these $m_{\gamma\gamma}$ values did not differ from the mass values of π^0 and η^0 mesons more than the three-fold error interval /6/.

For further analysis corrected energy values were used. An analogical analysis performed by us with the use of non-corrected, experimentally determined, values of the

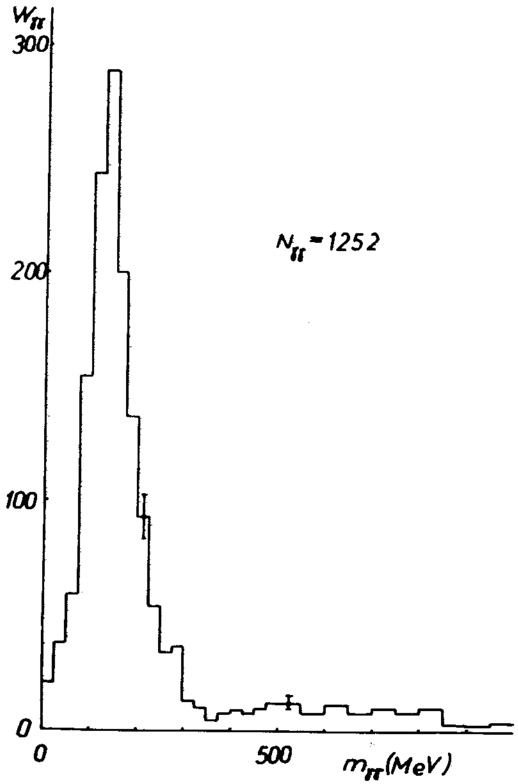

Fig. 1. Distribution of $\pi^{+} + Xe \to 2\gamma + (N_{ch} \leq 4)$ interactions at 2.34 GeV/c versus effective masses $m_{\gamma\gamma}$ of gamma quanta pairs.

energies of the gamma quanta did not lead to essential discrepancies with the results of our present analysis, but was, on the average, less exact.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Below the distributions of the investigated $\pi^{+} + Xe \to \gamma\gamma + (N_{ch} \leq 4)$ interactions at 2.34 GeV/c are given over energies, longitudinal and transverse momenta and over emission angles of the produced π° and η° mesons.

3.1. Energy and momentum distributions of π° and η° mesons

In Fig. 2 distributions of π° and η° mesons produced in such $\pi^{+} + Xe$ interactions are presented in which no more than one charged secondary particle stopping in the chamber is produced. In this Figure we also present distributions versus total energies of pairs of gamma from the events in which effective masses of gamma quanta do not obey the assumed condition of energy correction. Here, also, the energy distribution of π° mesons from the reaction $\pi^{+} + Xe \to \pi^{\circ} + (N_{ch} \leq 4)$ is presented. In the energy distribution of π° and η° mesons from $\pi^{+} + Xe$ interactions with $N_{ch} = 0$ or 1 stopping in the chamber there appears a conspicuous peak in the energy region of 2000-2200 MeV which could be expected in the cases of reactions of the type $\pi^{+} + n \to \pi^{\circ} + p$ or $\pi^{+} + n \to \eta^{\circ} + p$. The second peak in the energy distribution of π° mesons which appears in the region of 200-400 MeV, is caused by the processes in which a greater number of particles are produced. This is additionally indicated also by the energy distribution of π° mesons from the inclusive reaction $\pi^{+} + Xe \to \pi^{\circ} + (N_{ch} \leq 4)$ having also a conspicuous peak in this energy region. The distribution of events not

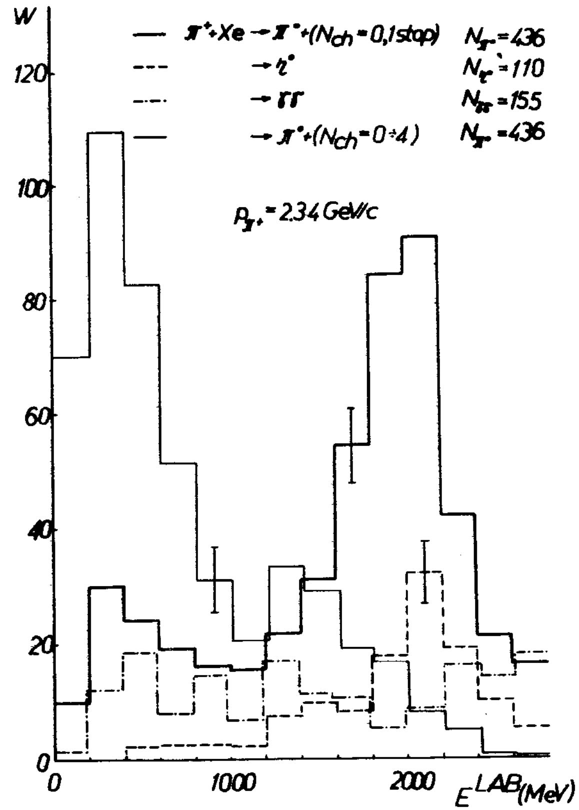

Fig. 2. Distribution of $\pi^+ + Xe \to 2\gamma + (N_{ch} = 0,1 \, stop)$ interactions at 2.34 GeV/c versus total energies: ▬▬ of π° mesons, - - - of η° mesons and -.-.-.-of gamma quanta pairs not satisfying the correlation condition; —— the energy distribution of π° mesons from the reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} \le 4)$ at 2.34 GeV/c.

obeing the correction condition over total energies of the pair of gamma quanta does not differ within the limits of error from the uniform distribution over the whole energy range.

Information analogical to that quoted above is contained also in the distribution of the considered events over longitudinal momenta $p_{||}$ of π° and η° mesons in the laboratory system of coordinates (LAB); the corresponding distribution is presented in Fig. 3.

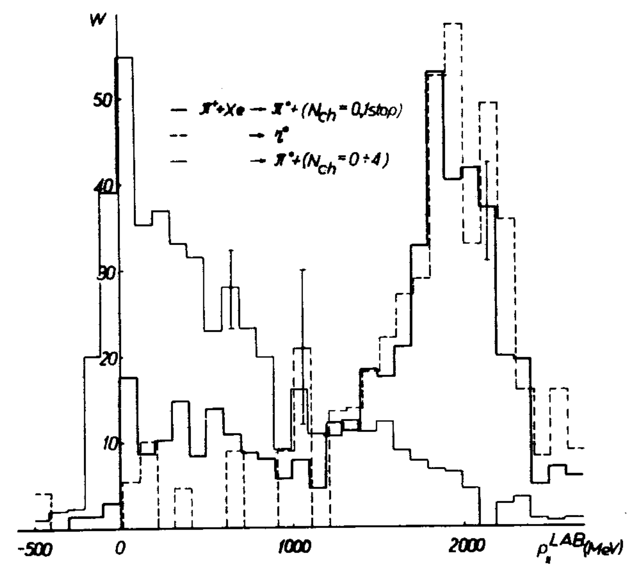

Fig. 3. Distribution of π° and η° mesons versus longitudinal momenta $p_{||}$ in LAB. Distributions are mutually normalized.

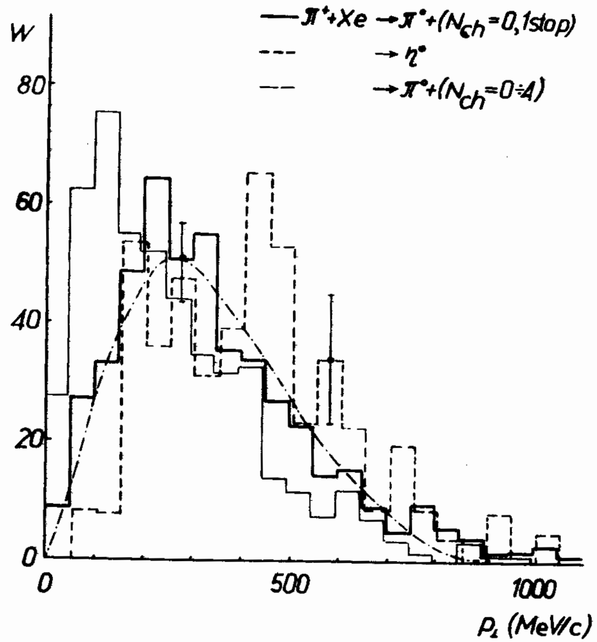

Fig. 4. Distribution of π° and η° mesons in LAB versus transverse momenta $p_\perp$. The curve -·-·- represents the function (1). Distributions are mutually normalized.

In Fig. 4 distributions of π° and η° mesons versus the transverse momentum are presented. The mean values of longitudinal and transverse momenta and also the corresponding dispersion values for π° and η° mesons are given in Table 2. There also total cross sections for the investigated channels of $\pi^+ + \mathbf{Xe}$ interactions are written. The distributions of π° mesons from the reaction $\pi^+ + \mathbf{Xe} \to \pi^\circ + (\mathbf{N_{ch} = 0,1\ stop})$ versus transverse momentum $p_\perp$ are satisfactorily described by the function

Table 2

Numbers **N** of $\pi^+ + \mathbf{Xe}$ interaction events at 2.34 GeV/c and the corresponding cross sections σ. $\langle p_{||} \rangle$, $\langle p_\perp \rangle$ are mean values of longitudinal and transverse momenta, and $\langle \Delta p_{||}^2 \rangle^{1/2}$ and $\langle \Delta p_\perp^2 \rangle^{1/2}$ are the corresponding dispersion values for π° and η° mesons. **M** is the mass of the effective target defined by formula (2)

Reaction	N	σ (mb)	$\langle p_\perp \rangle$ (MeV/c)	$\langle p_{\parallel} \rangle$ (MeV/c)	$\langle \Delta p_\perp^2 \rangle^{1/2}$ (MeV/c)	$\langle \Delta p_\parallel^2 \rangle^{1/2}$ (MeV/c)	M(MeV)
$\pi^+ + Xe \to \gamma\gamma + (N_{ch} = 0,1\ stop)$	701	5.95±1.30	-	-	-	-	-
$\to \pi^\circ$	436	3.70±0.83	326 ± 11	1462 ± 34	237	737	59
$\to \eta^\circ$	110	0.94±0.21	388 ± 21	1573 ±56	238	625	85
$\pi^+ + Xe \to \gamma\gamma + (N_{ch} \leq 4)$	551	519 ± 51	-	-	-	-	-
$\to \pi^\circ$	436	410 ± 25	191 ± 12	438 ± 35	215	610	75
$\to \eta^\circ$	9	8.4 ± 2.8	300 ± 150	525 ± 300	435	755	60

$$f(p_\perp) = A\, p_\perp \exp(-B p_\perp^2), \qquad (1)$$

where $A = (316.7 \pm 24.2)(\text{MeV}/c)^{-1}$, $B = (7.2 \pm 0.4)\ (\text{MeV}/c)^{-2}$, at $\chi^2 = 11$; the number of degrees of freedom is equal to 20.

3.2. Angular distributions of π° and η° mesons

In Fig. 5 angular distributions of π° mesons from the reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0,1 stop)$ at 2.34 GeV/c are compared in the CMS of the π-nucleon system with the corresponding distributions of mesons from the reaction $\pi^- + p \to \pi^\circ + n$ at 2.39 GeV/c [7].

In Fig. 5 also the supplementary angular distributions of mesons of total energy $E \geq 1000$ MeV from the reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0,1 stop)$ at 2.34GeV/c is presented. Both the distributions are mutually normalized in the interval $0.9 \leq \cos\theta_{\pi^\circ}^{(CMS)} \leq 1$. Angular distributions of η° mesons in the π-nuclear distributions of η° mesons in the π-nucleon CMS are also given in this figure.

Let us remark that in the interval $-1 \leq \cos\theta_{\pi^\circ}^{(CMS)} \leq 0.6$ the distribution of π° mesons from the charge exchange reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0,1 stop)$ at 2.34 GeV/c essentially differs from the angular distribution of π° mesons from the charge exchange reaction $\pi^\circ + p \to \pi^\circ + n$ at 2.39 GeV/c. This discrepancy can be assigned to the processes of intranuclear absorption, if one assumes that the analysed events of $\pi^+ + Xe$ interactions occur on quasifree neutrons of the Xe nucleus. The value of the total cross section $\sigma = (3.70 \pm 0.83)$ mb of the reaction channel $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0,1 stop)$ at 2.34GeV/c which is about 5 times larger than the total

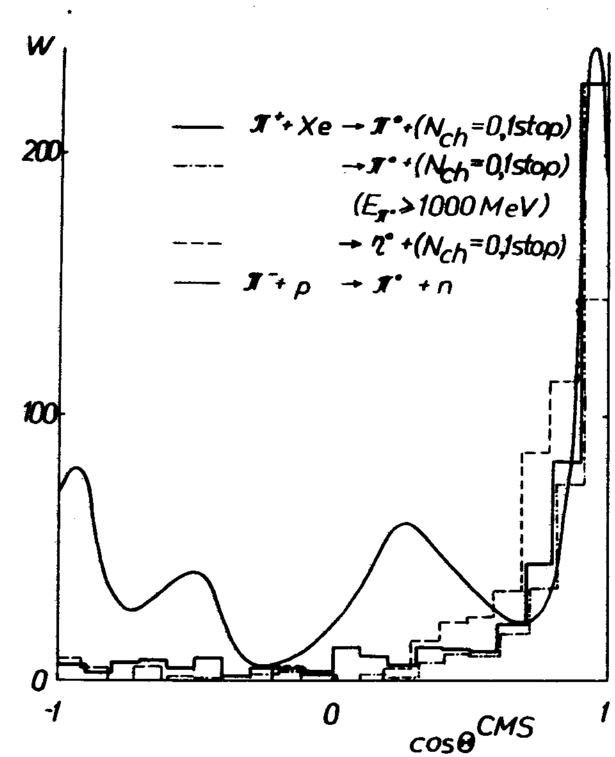

Fig. 5. Angular distribution of π° mesons from the reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0,1 stop)$ at 2.34 GeV/c in the postulated π-nucleon CMS: ——; —·—· the same but for π° mesons with total energy $E \geq 1000$ MeV. The solid curve corresponds to the π° meson angular distribution from the reaction $\pi^- + p \to \pi^\circ + n$ at 2.39 GeV/c [7]. All these distributions are mutually normalized in the interval $0.9 \leq \cos\theta_{\pi^\circ}^{(CMS)} \leq 1$; - - - angular distribution in the CMS of η°-mesons from $\pi^+ + Xe \to \eta^\circ + (N_{ch} = 0,1 stop)$ interactions at 2.34 GeV/c. The η° meson distribution is normalized to the total number of π° mesons.

cross section $\sigma(\pi^- + p \to \pi^\circ + n) = (0.60 \pm 0.03)$ mb for the reaction of charge exchange at the same energy, does not contradict the above assumption when one takes into account that the isotopically conjugated processes can be considered as these having equal cross sections and occuring on quasifree neutrons. When we confine ourselves to the energy interval of π° mesons $E \geq 1000$ MeV, correspon-ding to the right-hand part in energy dis-tribution of π° mesons (Fig. 2), then the total cross section will be equal to $(3.05 \pm \pm 0.75)$ mb. These estimations sufficiently agree with the earlier obtained estimation of the effective numbers in nuclei taking part in the reaction /8/.

3.3. The dependence of emission angles of the produced π° and η° mesons on their total energy

In Fig. 6 the two-dimensional distribu-tion of π° mesons from the reaction $\pi^+ + Xe \to \to \pi^\circ + (N_{ch} = 0{,}1 stop)$ at 2.34 GeV/c versus their emission angle and total energy in LAB is presented. Here also kinematical curves corresponding to collisions of 2.34 GeV/c π^+ mesons with targets composed of two, three and four nucleons and also with π me-son target and with the hypothetical targets of masses $m_{\pi'} = 100$ MeV, $m_{\pi''} = 80$ MeV and $m_{\pi'''} = = 40$ MeV are drawn. Dashed curves in this Figure represent the limits of the region of allowed energy values and the values of emission angles of π° mesons from the reac-tion $\pi^+ + n \to \pi^\circ + p$ at 2.34 GeV/c when the Fermi motion of the quasifree neutron inside of the Xe nucleus is taken into ac-

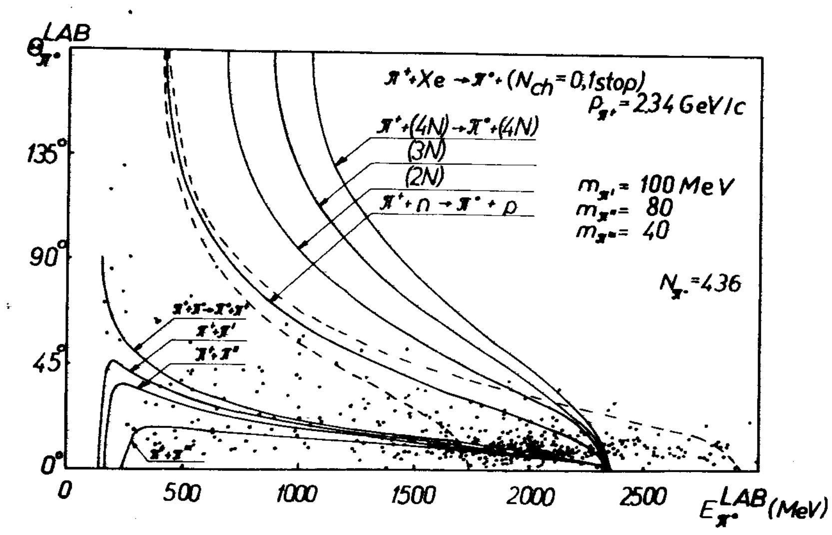

Fig. 6. The distribution of π° mesons from the reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0{,}1$ stop$)$ at 2.34 GeV/c versus the emission angle and total energy in LAB. Kinematical curves corresponding to reactions marked in the Figure are represented by solid lines. Dashed curves represent the limits of the region of allowed total energy values and emission angles of π° mesons when the Fermi motion of the quasifree neutron is taken into account.

count. Inside this region no less than 90 per cent of such π° mesons should be contained if we disregard their scattering and absorption inside the nucleus.

It should be stressed that a conside-rable collimation of mesons from the reac-tion $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0{,}1$ stop$)$ at 2.34 GeV/c occurs in the region of small emission angles, that would not appear in the case of the collisions of π° mesons with intranuclear nucleons. The above mentioned collimation corresponds to the effective mass of the hypothetical intranuclear target possessing the mass of the order of the π meson mass.

It is interesting that an analogical distribution of π° mesons from the inclusive reaction $\pi^+ + \mathbf{Xe} \to \pi^\circ + (\mathbf{N_{ch}} \le 4)$ at 2.34 GeV/c reveals the same tendency (cf. Fig. 7).

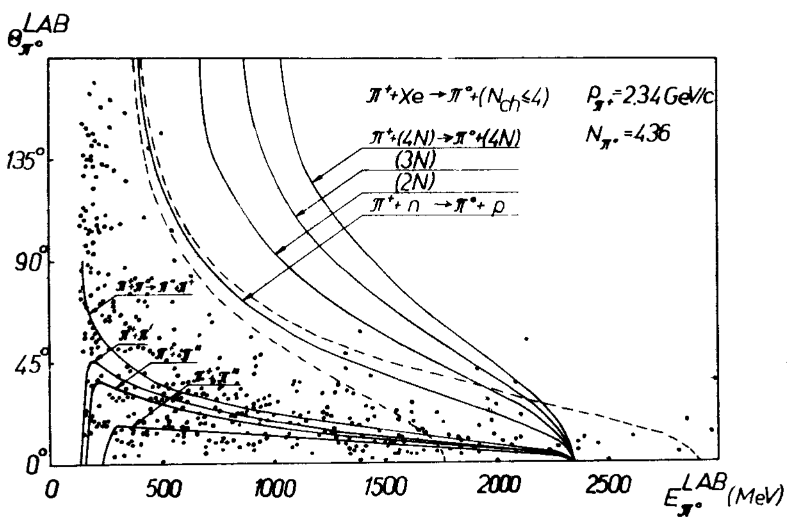

Fig. 7. The same as in Fig. 6 but for π° mesons from $\pi^+ + \mathbf{Xe} \to \pi^\circ + (\mathbf{N_{ch}} \le 4)$ interactions at 2.34 GeV/c.

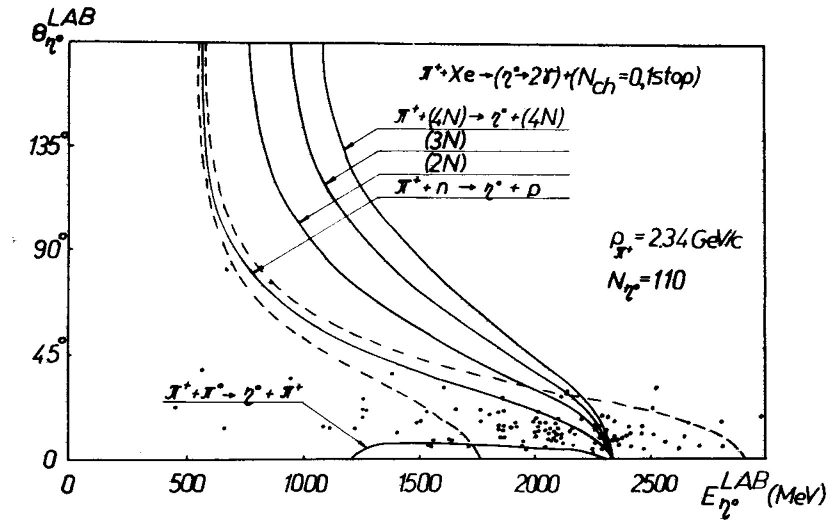

Fig. 8. The same as in Fig. 7 but for η° mesons from $\pi^+ + \mathbf{Xe} \to \eta^\circ + (\mathbf{N_{ch}} = 0{,}1\ \mathbf{stop})$ at 2.34 GeV/c.

In Fig. 8 the two-dimensional distribution of η° mesons from the reaction $\pi^+ + \mathbf{Xe} \to \eta^\circ + (\mathbf{N_{ch}} = 0{,}1\ \mathbf{stop})$ at 2.34 GeV/c is represented versus the emission angles and total energy in LAB.

The value of the mass of the effective target can be also estimated as a function of the ratio of the dispersions of the distributions over longitudinal and transverse momenta of mesons. Then [9]

$$M = \frac{p_{\pi^+}}{\sqrt{1 - \frac{\langle \Delta p_\perp^2 \rangle}{2 \langle \Delta p_{\parallel}^2 \rangle}}} - E_{\pi^+} , \qquad (2)$$

where p_{π^+} and E_{π^+} are the momentum and the total energy of the incident π^+ meson. Numerical values of the masses, being rather qualitative estimations, are given in Table 2. Kinematical curves corresponding to these mass values of the effective target do not contradict the experimental data presented in Figs. 6 and 7.

4. CONCLUSIONS

The analysis of the characteristics of π° and η° mesons generated in $\pi^+ + Xe$ interactions at 2.34 GeV/c with the emission of no more than one charged secondary particles stopping in the chamber, and also of $\pi^+ + Xe$ interactions with the emission of no more than four charged secondary particles, leads to the following conclusions:

1. Mean values of longitudinal and transverse momenta of π° and η° mesons and also the dispersion of these distributions over longitudinal and transverse momenta of π° and η° mesons produced in the interactions with $N_{ch}=0,1$ stopping in the chamber are equal within the limits of experimental errors.

2. The distributions over transverse momenta of π° mesons from the reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0,1 \text{ stop})$ are satisfactorily described by the function (1).

3. Angular distribution of π° mesons from the reaction $\pi^+ + Xe \to \pi^\circ + (N_{ch} = 0,1 \text{ stop})$ at 2.34 GeV/c in the π-nucleon CMS essentially differs from the corresponding distribution of π° mesons from the reaction $\pi^- + p \to \pi^\circ + n$ at 2.39 GeV/c.

4. The emission of π° mesons shows a strong collimation in the region of small values of emission engles which cannot be explained neither by the Fermi motion of intranuclear nucleons nor by the production of other kinds of particles absorbed inside the nucleus, if one assumes that the interaction occurs on quasifree nucleons of Xe nucleus.

5. The observed collimation of the emission of π° mesons corresponds kinematically to the emission of π° mesons in collisions with the hypothetical intranuclear target possessing the mass of the order of 100 MeV. A possibility of the existence of intranuclear particles having the mass of this order might be connected with the real existence of pions as the quanta of nuclear field inside nuclei. Recently also the meson condensate in heavy nuclei is theoretically discussed (cf. e.g. /10/).

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