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ЛАБОРАТОРИЯ ЯДЕРНЫХ ПРОБЛЕМ

EXPERIMENTAL STUDY OF MANY-BODY REACTIONS WITH ^{8}Li PRODUCTION IN SLOW NEGATIVE PION CAPTURE BY ^{12}C, ^{14}N, ^{16}O NUCLEI

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Abstract

Three- , four - and five-body reactions leading to lithium-8 production in negative pion capture by carbon, nitrogen and oxygen nuclei have been studied by using photoemulsion chambers. The relative probabilities of various reaction channels have been determined. The measurements have been made of the energy spectra and angular correlation of secondary particles for the reactions

$$\pi^- + {}^{12}C \rightarrow {}^{8}Li + {}^{2}H + {}^{1}H + n$$

$$\pi^- + {}^{14}N \rightarrow {}^{8}Li + {}^{3}He + {}^{2}H + n$$

$$\pi^- + {}^{14}N \rightarrow {}^{8}Li + {}^{4}He + {}^{1}H + n .$$

Our experiments show that four-nucleon clusters (^{4}Li) in the ^{12}C nucleus are of importance in the reactions with ^{8}Li - production in slow negative pion capture.

Experiments on negative pion capture by light nuclei are a source of information on the role of nucleon clusters in light nuclei.

The study of kinematic characteristics of secondary particles are of interest as far as the investigation of negative pion capture mechanism and light nuclei structure are concerned. The experimental study of negative pion capture allows to investigate various absorption mechanism by separating various reaction channels . In order to study some reactions with lithium-8 production in negative pion capture by light nuclei (C, N , O) the authors of the present paper have made an experiment using photoemulsion chambers at the Dubna synchrocyclotron. The experimental arrangement has been described in ref./1/. The reaction resulting in one- or two-prong σ -stars have been studied previously/1-3/.

Here the results of the kinematic analysis of three-prong σ -stars with hammer tracks in photoemulsion are reported. Fig.1 shows the distribution of σ -stars with hammer tracks according to the number of prongs. It is seen that three-prong events are most probable and they constitute 60% of the total number of σ -stars. Possible reactions on light nuclei resulting in three-prong σ -stars in photoemulsion are given in the Table.

As many as 1000 3-prong events have been measured in Dubna and Sofia and calculated according to the kinematic programme by using the CDC 3600 computer in Paris. The final treatment of the results obtained was performed at the Joint Institute for Nuclear Research in Dubna with the CDC 1604 A computer.

When separating reactions without neutrons or with one neutron only such events were taken for which energy conservation was valid within 8 MeV, whereas the momentum conservation law was valid to a 100 MeV/c accuracy. This corresponds to 1.5 -fold errors in measuring total energy and the total momentum of secondary particles. The total of 538 events of this type were separated. The number of events corresponding to various reactions is given in the Table. For the events which do not satisfy the kinematics of the reaction with one neutron or without it there are two possibilities: either they belong to reactions on heavy nuclei (Ag , Br) or on light nuclei (C, N, O) with the emission of two neutrons (reactions 4, 9, 15 of the Table). Fig.2b shows lithium-8 energy spectrum for not identified events. If they had occurred on heavy nuclei, the obtained spectrum should have differed greatly from the spectrum for reactions on light nuclei due to the Coulomb barrier ($\approx$ 15 MeV). As shows the comparison of Figs. 2a and 2b, there is no noticeable difference in the spectrum. This evidences that events not identified according to the kinematics programme mainly belong to reactions on light nuclei. In order to separate reaction channels the missing mass was calculated for all the not identified events under the assumption that they should correspond to reactions 4, 9, 15. For reaction 9 it was assumed that the second and third particles can be either ^{3}He or a proton. The results of calculations of the missing mass are shown in Fig. 3. It is seen that in the range of (1875-1900) MeV there is a considerable number of events near the two neutron mass value. By using these distributions one finds the proper number of events belonging to reactions 4, 9, 15 (see the Table).

The result of the analysis shows that the number of events corresponding to various reactions is equal to the total number of the analysed events within statistical accuracy. This confirms the conclusion that practically all σ -stars having hammer tracks belong to reactions on light nuclei in photoemulsion.

Similar to ref./1/ on the basis of the results obtained the relative probabilities of the reactions have been determined $W_i = \frac{n_i}{\eta_i N}$, where n_i is the number of events of the given reaction, η_i is the relative rate of pion capture by light nuclei of carbon, nitrogen and oxygen, N is the total number of negative pion capture by light nuclei. The obtained probability values are given in the Table.

Since for some reactions there is sufficiently rich statistics one can obtain some information on the mechanism of these reactions from the characteristics of secondary particles. Fig.4 shows energy spectra of secondary particles for reaction 2. The curves corresponding to the phase space are also given there. It is seen that there is a considerable contribution of events with the emission of high energy neutrons. The difference between phase space curves and the experimental data in proton and deuteron spectra is less noticeable.

Figs. 5-8 show the distribution of the number of events according to the effective masses and angular correlations of various combinations of final particles for reaction 2. Figs. 5 and 6 show that there is a noticeable difference of experimental distribution from the curves corresponding to phase space. A great number of events having the large values of effective masses and obvious angular correlations show that the important contribution to reaction (2) is made by negative pion absorption on ^4Li and ^3He clusters in the ^{12}C nucleus. The role of four-nucleon ^4Li cluster in the ^{12}C nucleus for reaction 2 is most essential.

Figs. 9-10 show the energy spectra of secondary particles for reactions 7 and 8 on nitrogen. These distributions show that as well as in reaction 2 on carbon there is a considerable amount of events with high energy neutron emission. The difference between experimental spectra for other particles and curves for the phase space is less noticeable.

Thus, from the results obtained and from refs.[1,3] it is seen that the negative pion capture on four-nucleon (^{4}Li) -cluster on carbon nuclei is of importance for the reactions with ^{8}Li -production on carbon.

In order to give the quantitative evaluation of the significance of various nucleon clusters in negative pion capture by light nuclei a more detailed analysis of the experimental results obtained is being carried out.

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Table

number of channel	reaction	number of events	relative probabilities
1	$\pi^- + {}^{12}C \rightarrow {}^8Li + {}^2H + {}^2H$	21	$1.4 \cdot 10^{-4}$
2	$\rightarrow {}^8Li + {}^2H + {}^1H + n$	324	$2.1 \cdot 10^{-3}$
3	$\rightarrow {}^8Li + {}^3H + {}^1H$	24	$1.5 \cdot 10^{-4}$
4	$\rightarrow {}^8Li + {}^1H + {}^1H + 2n$	271	$1.7 \cdot 10^{-3}$
5	$\pi^- + {}^{14}N \rightarrow {}^8Li + {}^3He + {}^3H$	5	$1.1 \cdot 10^{-4}$
6	$\rightarrow {}^8Li + {}^4He + {}^2H$	7	$1.5 \cdot 10^{-4}$
7	$\rightarrow {}^8Li + {}^3He + {}^2H + n$	54	$1.2 \cdot 10^{-3}$
8	$\rightarrow {}^8Li + {}^4He + {}^1H + n$	66	$1.5 \cdot 10^{-3}$
9	$\rightarrow {}^8Li + {}^3He + {}^1H + 2n$	155	$3.4 \cdot 10^{-3}$
10	$\pi^- + {}^{16}O \rightarrow {}^8Li + {}^4He + {}^4He$	0	$\leq 2.3 \cdot 10^{-5}$
11	$\rightarrow {}^8Li + {}^6Li + {}^2H$	7	$6.2 \cdot 10^{-5}$
12	$\rightarrow {}^8Li + {}^7Li + {}^1H$	2	$\leq 3.5 \cdot 10^{-5}$
13	$\rightarrow {}^8Li + {}^6Li + {}^1H + n$	12	$1.2 \cdot 10^{-4}$
14	$\rightarrow {}^8Li + {}^4He + {}^3He + n$	16	$1.4 \cdot 10^{-4}$
15	$\rightarrow {}^8Li + {}^3He + {}^3He + 2n$	15	$1.3 \cdot 10^{-4}$

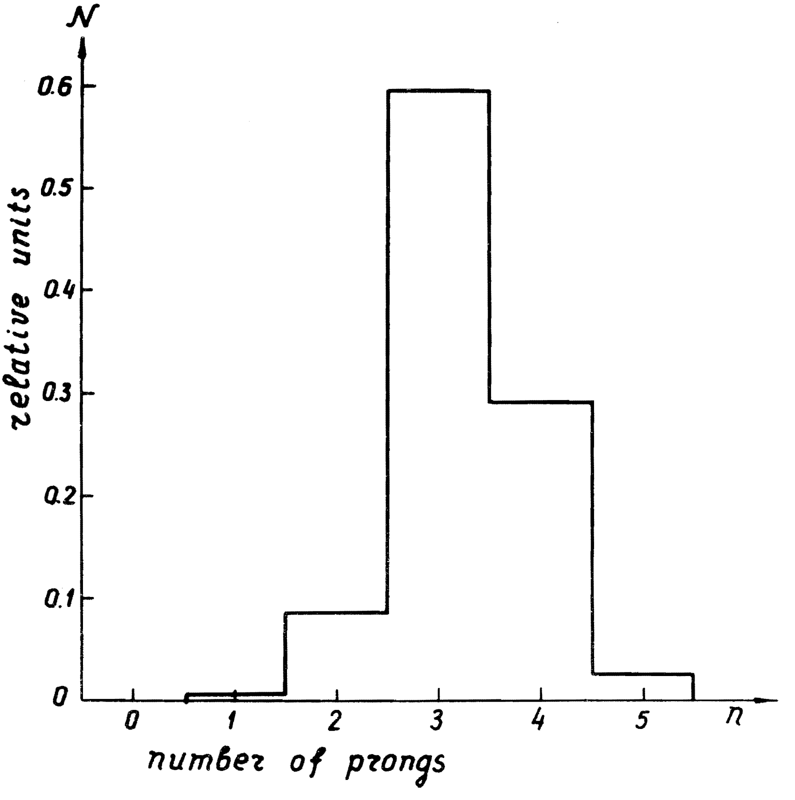

Fig.1. The distribution of σ-stars with hammer tracks according to the number of prongs.

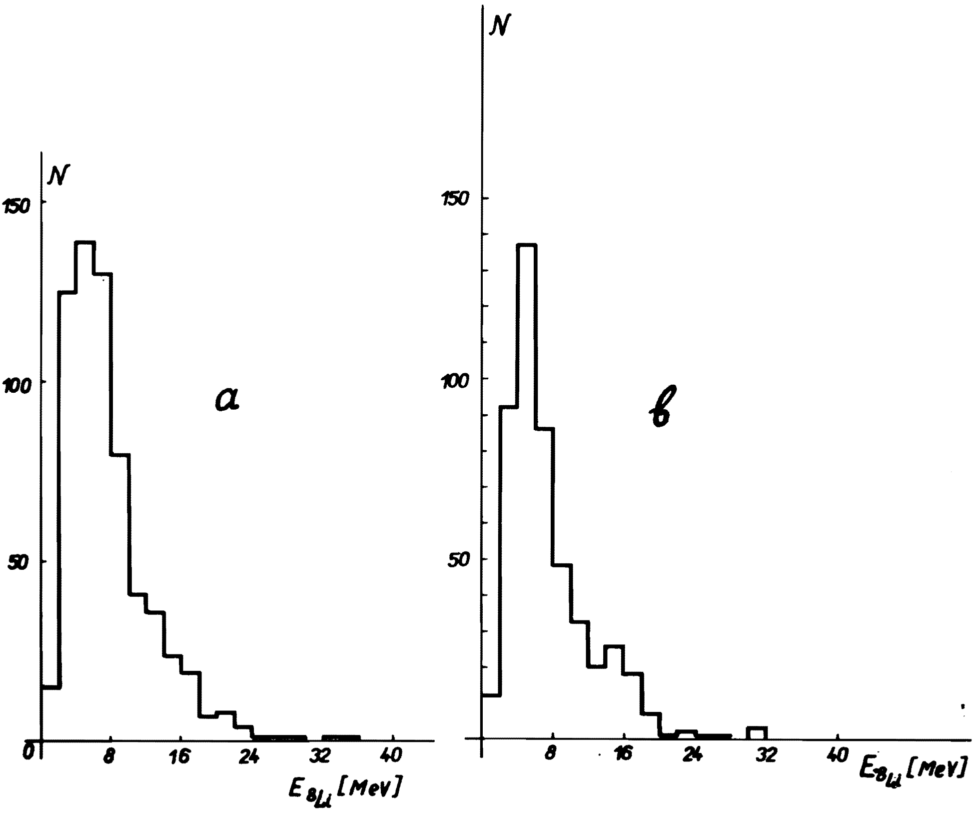

Fig.2. ^{8}Li energy spectrum for three-prong events
a) for events satisfying the kinematics of reactions without neutron emission and with the emission of one neutron,
b) for events not satisfying the kinematics of reactions without neutron emission or with the emission of one neutron.

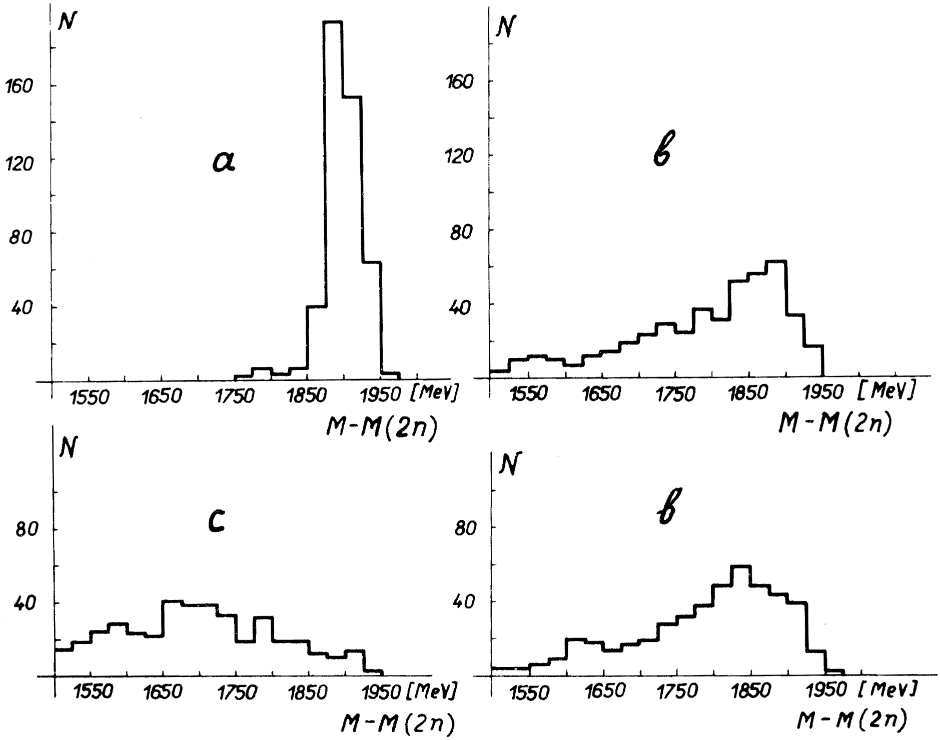

Fig. 3a,b,c. Distributions according to the missing mass for events not satisfying the kinematics of reactions without any neutron or with single neutron emission

a) for the reaction $\pi^- + {}^{12}C \rightarrow {}^{8}Li + {}^{1}H + {}^{1}H + 2n$ (4)

b) for the reaction $\pi^- + {}^{14}N \rightarrow {}^{8}Li + {}^{3}He + {}^{1}H + 2n$ (9)

c) for the reaction $\pi^- + {}^{16}O \rightarrow {}^{8}Li + {}^{3}He + {}^{3}He + 2n$ (15)

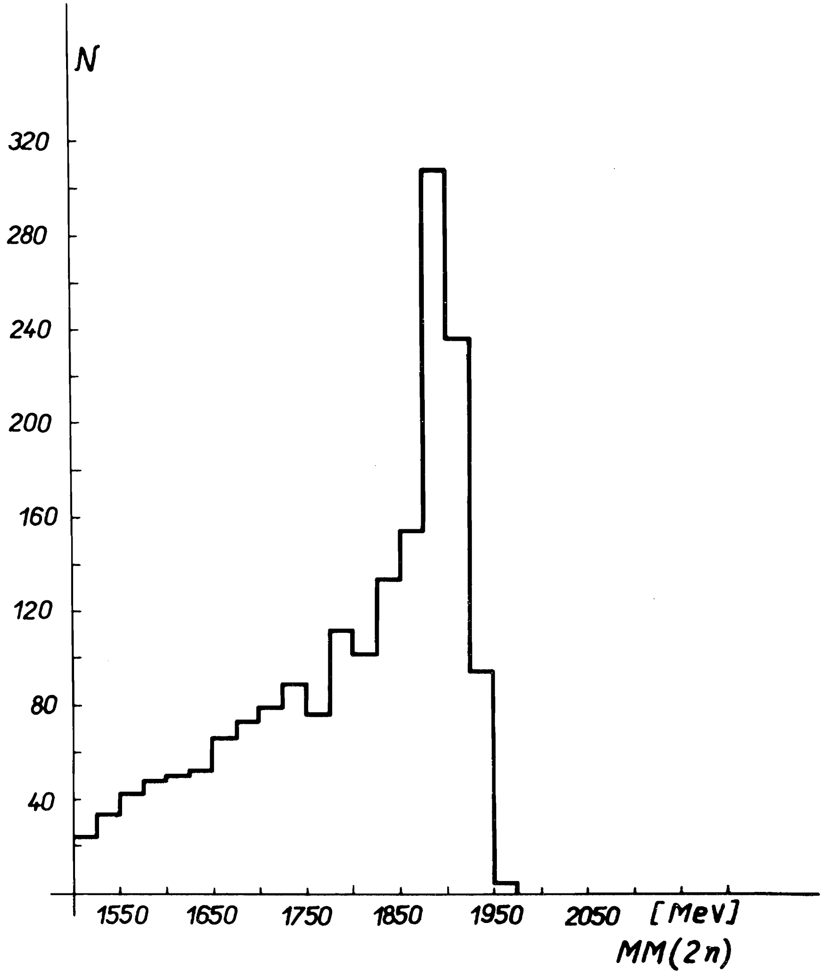

Fig.3d. Distributions according to the missing mass for events not satisfying the kinematics of reactions without any neutron or with single neutron emission
d) for reactions 4, 9, 15.

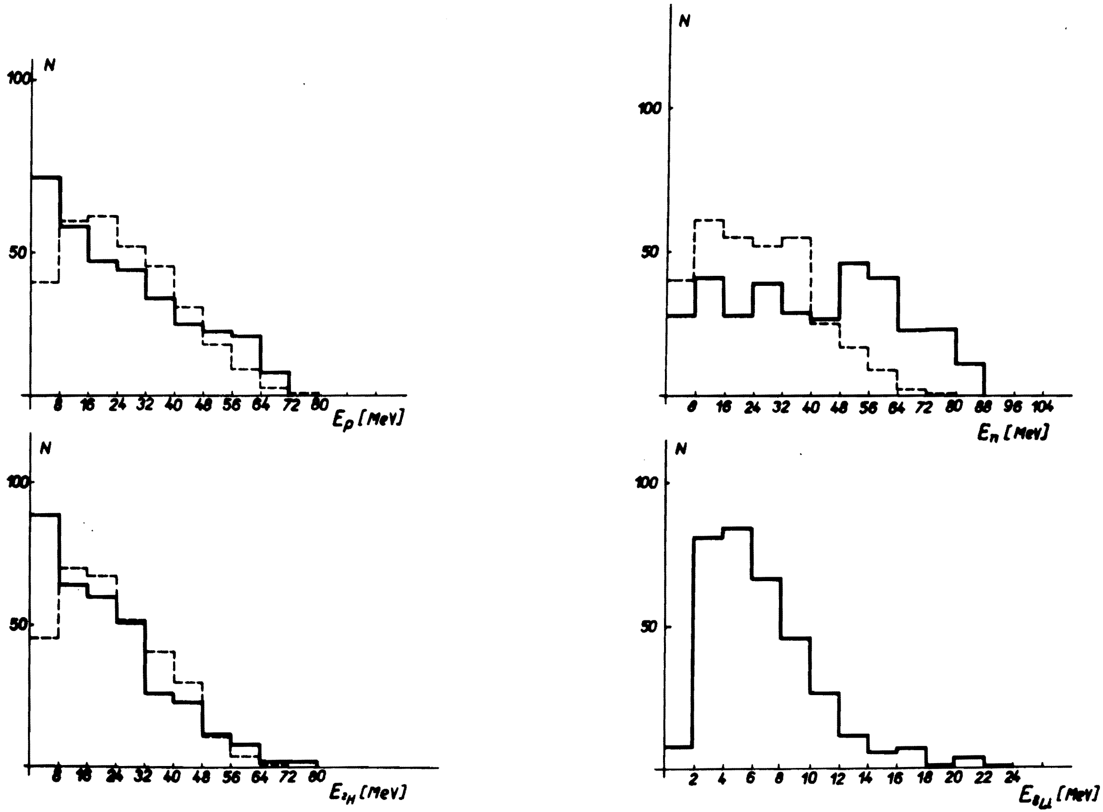

Fig.4. Energy spectra of secondary particles from reaction (2) $\pi^- + {}^{12}C \to {}^{8}Li + {}^{2}H + {}^{1}H + n$.

Dashed line is phase space.

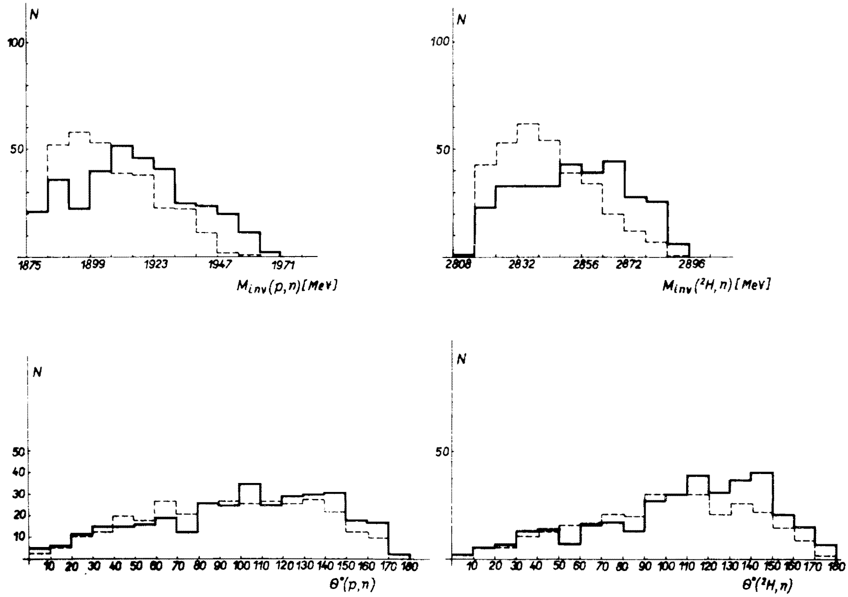

Fig.5 Distributions according to the effective masses and angular correlation for various combinations of final particles for reaction (2)

$\pi^- + {}^{12}C \rightarrow {}^8Li + {}^2H + {}^1H + n$.

Dashed line is phase space.

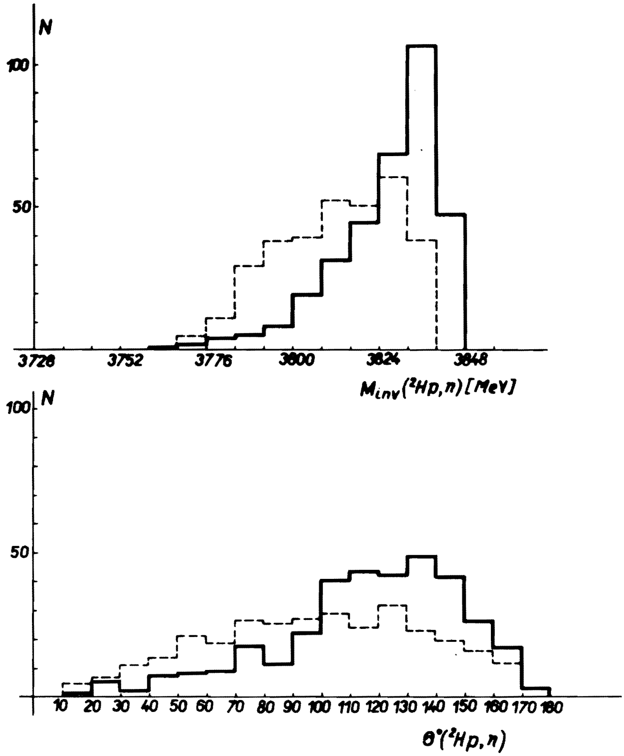

Fig.6. Distributions according to the effective masses and angular correlation for $(^2Hp,n)$ combination of final particles for reaction (2)

$$\pi^- + {}^{12}C \rightarrow {}^8Li + {}^2H + {}^1H + n .$$

Dashed line is phase space.

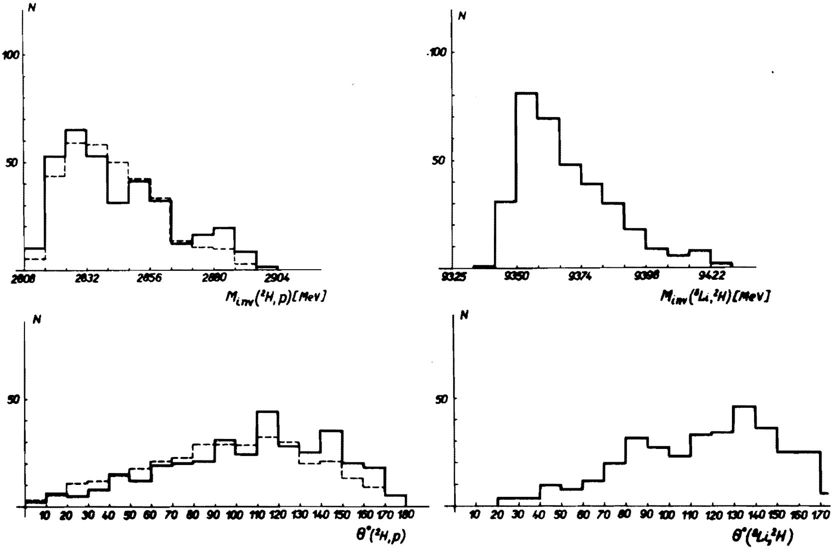

Fig.7. Distributions according to the effective masses and angular correlation for various combinations of final particles for reaction (2)

$\pi^- + {}^{12}C \rightarrow {}^8Li + {}^2H + {}^1H + n$

Dashed line is phase space.

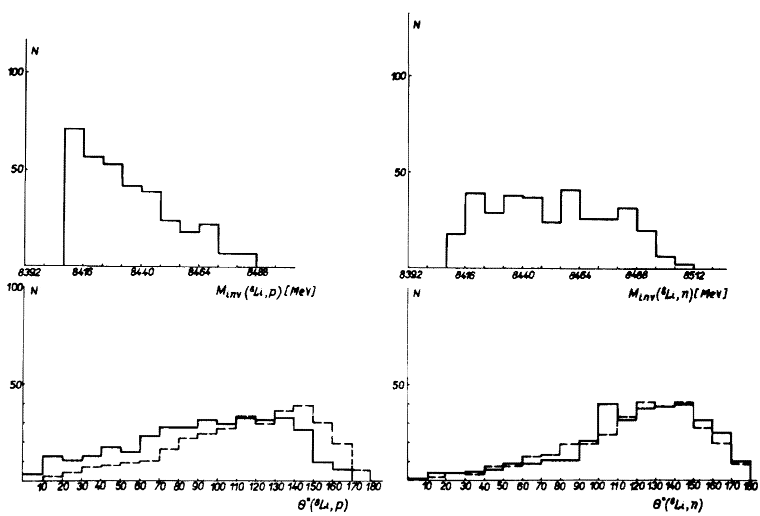

Fig.8. Distributions according to the effective masses and angular correlation for various combinations of final particles for reaction (2)

$\pi^- + {}^{12}C \rightarrow {}^{8}Li + {}^{2}H + {}^{1}H + n$.

Dashed line is phase space.

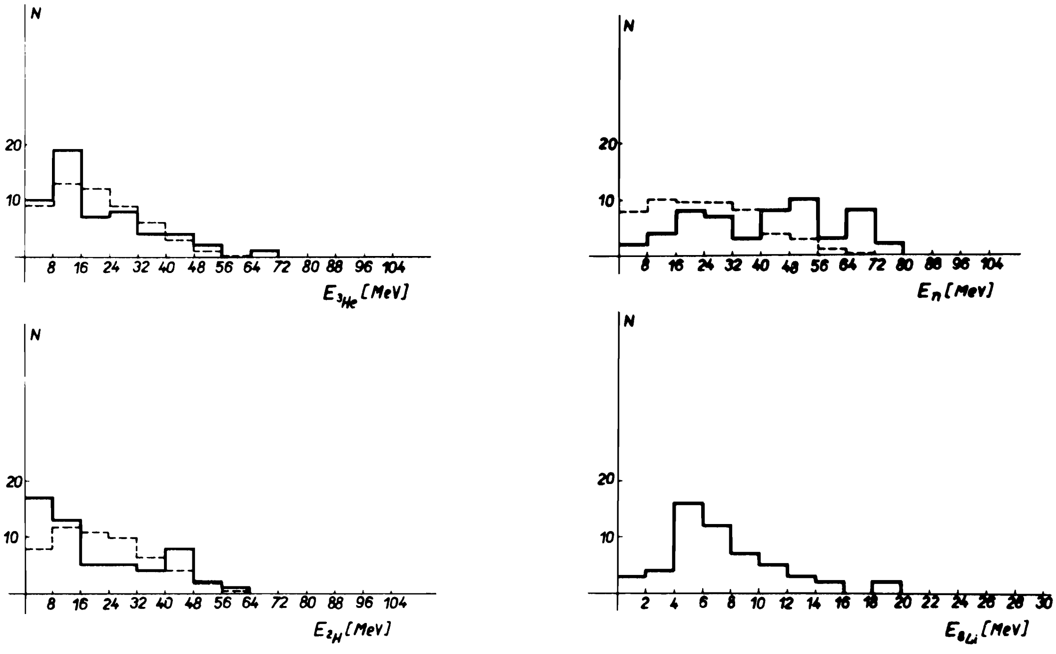

Fig.9. Energy spectra of secondary particles for reaction (7)
$\pi^- + {}^{14}N \to {}^{8}Li + {}^{3}He + {}^{2}H + n$.

Dashed line is phase space.

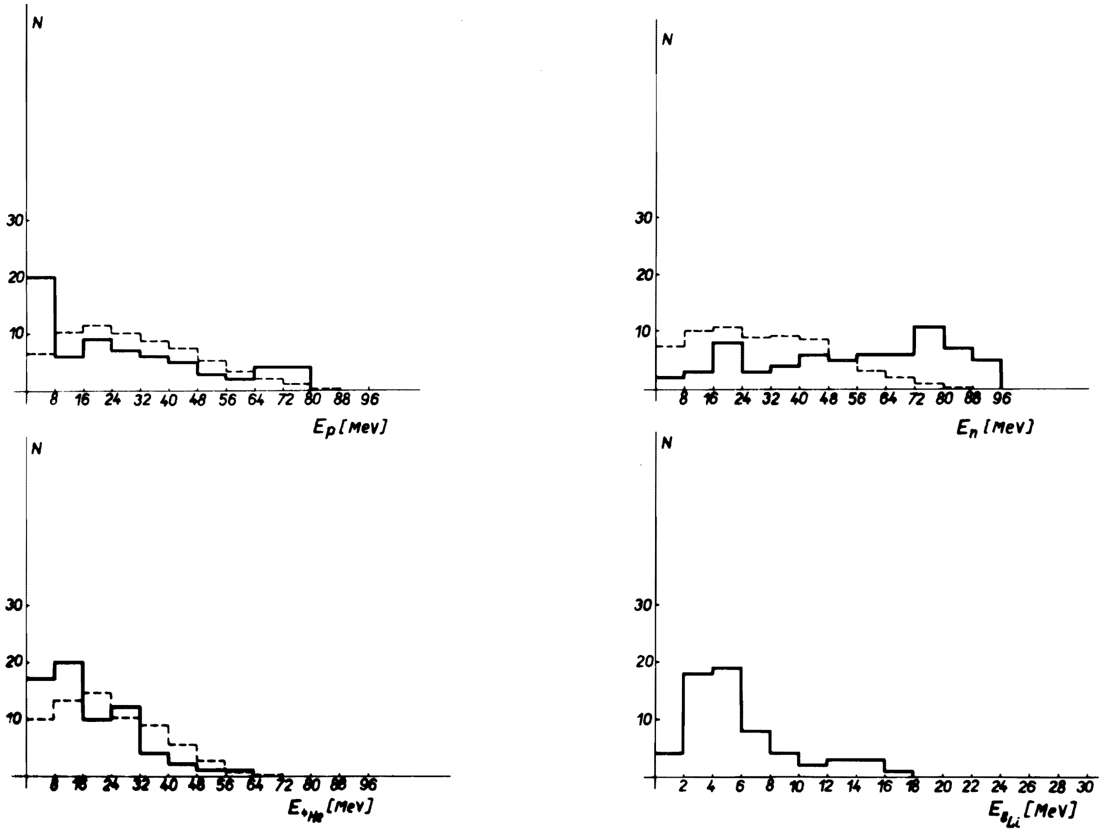

Fig.10. Energy spectra of secondary particles for reaction (8)
$\pi^- + {}^{14}N \to {}^{8}Li + {}^{4}He + {}^{1}H + n.$
Dashed line is phase space.