IL NUOVO CIMENTO VOL. 18 A, N. 1 1 Novembre 1973

Positive-Pion Absorption by C Nuclei at 130 MeV.

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(ricevuto il 9 Aprile 1973)

Summary. — About 1500 absorption events of π^+ in flight ($\sim$130 MeV of kinetic energy) have been studied in a propane bubble chamber. The corresponding cross-section is (189 ± 19) mb/C nucleus, about one half of the total inelastic cross-section. The absorption on two nucleons with low excitation of the residual nucleus seems to be responsible for 10% of the $\sigma_{\text{tot abs}}$ only, while the capture by an α-cluster seems to be more important ($\sim$40% of the total). The events have been analysed according to their charged-prong multiplicity. Data concerning two-prong events agree with the theoretical predictions calculated by assuming the dominance of the reaction $\pi^+(\text{np}) \to \text{pp}$ and by using the impulse approximation model; however a large fraction of them ($\sim$40%) is due to the absorption on an α-cluster: $\pi^+(\alpha) \to \text{ppd}$ with very-low-energy transfer to the deuteron. Three-prong events have been interpreted as due to the process $\pi^+(\alpha) \to \text{pppn}$ and qualitative agreement between data and theory has been found. Some data on many-prong events are also reported.

1. – Introduction.

Many experiments on π absorption on light nuclei have been carried out, either at rest or with $\pi^\pm$ in flight (*) [1-18], with a variety of techniques. It is generally thought that the absorption process at slow and medium energy

(*) An incomplete list of papers on π absorption is given here for different techniques: π^- at rest, counter technique [1-6]; π^+ in flight, counter technique [7,8]; $\pi^\pm$ in flight, bubble chamber technique [9-11]; emulsion technique [12-15]; other techniques [16,17]; more complete references can be found in the review article [18].

[1] S. OZAKI, R. WEINSTEIN, O. GLASS, E. LOCH, L. NEIMOLA and A. WATTENBERG:

($T < 500$ MeV) is mostly due to the capture by a correlated nucleon pair. It is also assumed that only the two nucleons participate to the process, the residual nucleus acting as a spectator (impulse approximation model). Nevertheless an emulsion experiment ([12]) and recent counter experiments ([4,6]) suggest that other processes are important.

In the present bubble chamber experiment, we try to show that the two-nucleon emission explains only a fraction of the absorption cross-section, as the multiparticle emission is predominant.

In the following Sections are described: Sect. **2**: some details about the bubble chamber and the beam; Sect. **3**: scanning and analysis method; Sect. **4**: total cross-section and charged-prong multiplicity distribution; Sects. **5**, **6** and **7**: results concerning events with two fast particles, three fast particles and more than three fast particles in the final state. Finally in Sect. **8** the results are discussed.

2. – The chamber and the beam.

The École Polytechnique heavy-liquid bubble chamber ($(100 \times 50 \times 50)$ cm^3) filled with propane (radiation length 110 cm) was exposed to different π^+ beams in Saclay. For the present experiment $\sim 11\,000$ pictures taken at

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Phys. Rev. Lett., **4**, 533 (1960).

([2]) H. DAVIES, H. MUIRHEAD and J. N. WOULDS: *Nucl. Phys.*, **78**, 663 (1966).

([3]) M. E. NORDBERG, K. F. KINSEY and R. L. BURMAN: *Phys. Rev.*, **165**, 1096 (1968).

([4]) F. CALLIGARIS, C. CERNIGOI, I. GABRIELLI and F. PELLEGRINI: *Nucl. Phys.*, **126** A, 209 (1969).

([5]) D. L. CHESHIRE and S. E. SOBOTKA: *Phys. Lett.*, **30** B, 244 (1969); *Nucl. Phys.*, **146** A, 129 (1970).

([6]) P. J. CASTLEBURRY, L. COULSON and R. C. MINEHART: *Phys. Lett.*, **34** B, 57 (1971).

([7]) K. GOTOW, T. R. WITTEN and M. BLECHER: *Phys. Rev.*, **174**, 1166 (1968).

([8]) J. FAVIER, T. BRESSANI, G. CHARPAK, L. MASSONNET, W. E. MEYERHOF and Č. ZUPANČIČ: *Phys. Lett.*, **25** B, 409 (1967); *Nucl. Phys.*, **169** A, 540 (1971).

([9]) R. SALUKVADZE and D. NEAGU: *Žurn. Èksp. Teor. Fiz.*, **14**, 59 (1962).

([10]) V. S. DEMIDOV, V. S. VEREBRYNSOV, V. G. KIRILLOV-UGRYMOV, A. K. PONOSOV and F. N. SERGEEV: *Žurn. Èksp. Teor. Fiz.*, **17**, 773 (1963); **19**, 826 (1964).

([11]) M. P. BALANDIN, O. IVANOV, V. MOISCENKO and G. SOKOLOV: *Žurn. Èksp. Teor. Fiz.*, **19**, 279 (1964).

([12]) P. I. FEDOTOV: *Journ. Nucl. Phys.*, **2**, 335 (1966).

([13]) V. G. KIRILLOV, F. M. SERGEEV and A. I. FESENKO: *Journ. Nucl. Phys.*, **5**, 604 (1967).

([14]) A. VAISENBERG and N. KOLGANOVA: *Journ. Nucl. Phys.*, **7**, 324 (1968).

([15]) V. F. KOSMACK, A. A. KOTOV and V. I. OSTROUMOV: *Journ. Nucl. Phys.*, **8**, 18 (1969).

([16]) L. M. LEDERMAN and P. AMMIRAJU: *Nuovo Cimento*, **4**, 283 (1956).

([17]) M. S. KOZODAEV and H. H. KOLINKIN: *Žurn. Èksp. Teor. Fiz.*, **11**, 300 (1960).

([18]) D. S. KOLTUN: *Adv. Nucl. Phys.*, Vol. **3** (New York and London, 1969), p. 71.

280 MeV/c have been used. The kinetic energy of the interacting pions ranges from 115 to 150 MeV, due to the energy loss in the liquid.

3. – Selection of the events.

The pictures at our disposal have been scanned for every kind of events: elastic interactions on H and elastic and inelastic interactions on C. Part of the events has been used to study the quasi-elastic scattering and the charge exchange process on bound nucleon ([19]). For the present analysis only the events which do not have a π^+ in the final state or which do not have a γ-ray associated to the interaction point have been retained. Due to the chamber size and the low energy of the emitted particles, it is generally easy to distinguish pions from protons, for their different ionization and momentum values. Two possible sources of background are

a) charge exchange events,

b) events where the outgoing π^+ is absorbed in a secondary interaction very close to the primary one.

To estimate the importance of the background *a*) we have analysed all charge exchange events where at least one γ-ray, coming from the π^0 decay, is materialized in the fiducial volume of the chamber. So it has been possible to evaluate the background of *a*) for every final multiplicity (Fig. 1). This background is particularly important for the channel with no or one proton in the final state and prevented us from analysing these channels.

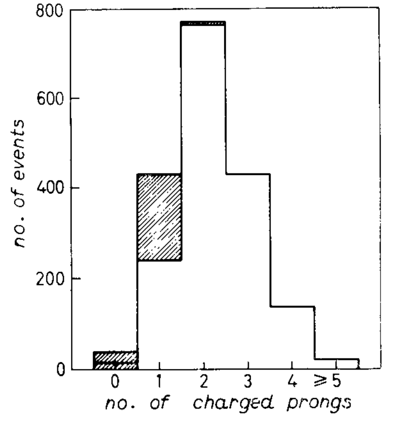

Fig. 1. – Multiplicity distribution; prongs shorter than 4 mm have not been considered. The shaded area corresponds to the estimated charge exchange background.

([19]) E. BELLOTTI, S. BONETTI, D. CAVALLI and C. MATTEUZZI: *Nuovo Cimento*, **14** A, 567 (1973).

In $\sim 3\%$ of the events, a secondary particle interacts near (track length < 5 cm) the primary vertex and it is hard to classify such a track from its ionization. If we take into account the *a priori* probabilities of having a secondary π^+ or p and their interaction length in propane, the background of *b*) has been evaluated to be $\leqslant 1\%$.

The sample of absorption candidates consists of 1814 events, 326 of which are supposed to be charge exchange reactions. All the events have been measured and processed with the standard CERN program chain.

The shortest track length one can measure is 4 mm, corresponding to 12 MeV of kinetic energy for a proton. It is not possible to distinguish a deuteron or a triton from a proton (α-particles are practically not detectable). In measuring and processing the events, all particles are treated as protons, but we will take into account this systematic error in comparing data and theoretical predictions.

4. – Cross-section and multiplicity.

a) *Cross-section.* The absorption cross-section has been calculated by comparing the number of absorption events with the number of elastic scatterings on H, selected and measured on one-third of the pictures. This procedure has been chosen to avoid systematical errors due to the μ^+ background in the beam. The cross-section results constant within the range $(115 \div 150)$ MeV;

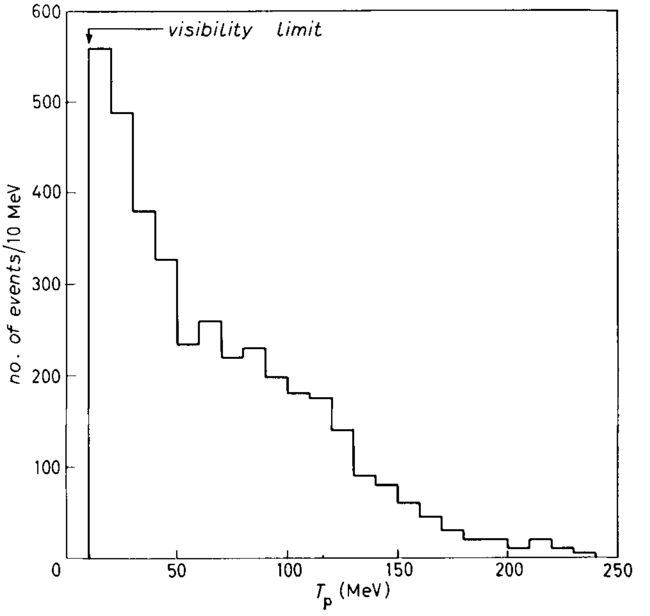

Fig. 2. – Kinetic energy of all prongs considered as protons.

its value is (189 ± 19) mb; the error takes into account the statistical errors as well as the incertitude in the charge exchange subtraction.

b) Multiplicity distribution. Figure 2 shows the energy distribution of all charged visible particles. Due to the large percentage of low-energy particles, the prong multiplicity strongly depends on the energy cut because of the visibility. If we assume a cut-off of 10 MeV, that is approximately the visibility limit for protons in this chamber, we obtain the distribution of Fig. 1, where the estimated background of charge exchange events is also shown. From this distribution it can immediately be noted that

processes with more than two nucleons in the final state are important,

emission of a n-p pair, obviously subsequent to a capture by an (n-n) pair, is much smaller than the emission of a p-p pair.

5. – Two-prong events.

Our sample of two-prong events consists of 771 events, 113 of them are associated with a short unmeasurable track (blob) and 36 are not measurable. Let us consider first the clear events: they are usually interpreted as due to the reaction

$$\pi^{+12}\mathrm{C} \to \mathrm{pp}^{10}\mathrm{B}\,. \tag{1}$$

It is supposed that the π interacts on a correlated n-p pair in the nucleus and that the process is dominated by the Feynman graph of Fig. 3. In this hypothesis it is expected that most of the total energy of the incident π^+ is

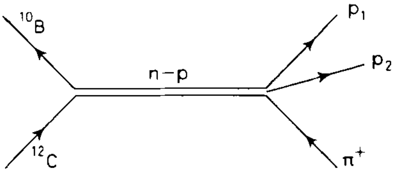

Fig. 3. – Feynman graph for the reaction $\pi^+\mathrm{C}\to\mathrm{ppB}$.

taken away by the two protons, the separation energy of a (n-p) pair being ~ 25 MeV (p-shell nucleons) or ~ 50 MeV (s-shell nucleons) as measured in [5]. In Fig. 4 the distribution of the missing energy, defined as

$$E_m = E_{\pi\,\mathrm{inc}} - T_{\mathrm{p}_1} - T_{\mathrm{p}_2} - T_{\mathrm{B}}\,,$$

where $T_{\mathrm{B}} = p_r^2/2m_{\mathrm{B}}$ and p_r momentum of the recoiling nucleus is assumed equal to the missing momentum:

$$\boldsymbol{p}_r = \boldsymbol{p}_{\pi_{\text{inc}}} - \boldsymbol{p}_{p_1} - \boldsymbol{p}_{p_2} ,$$

is shown. A large peak appears for $E_m < 60$ MeV and is followed by a long tail where it is not easy to single out any signal. Then we are induced to assign the low-E_m events only to process (1).

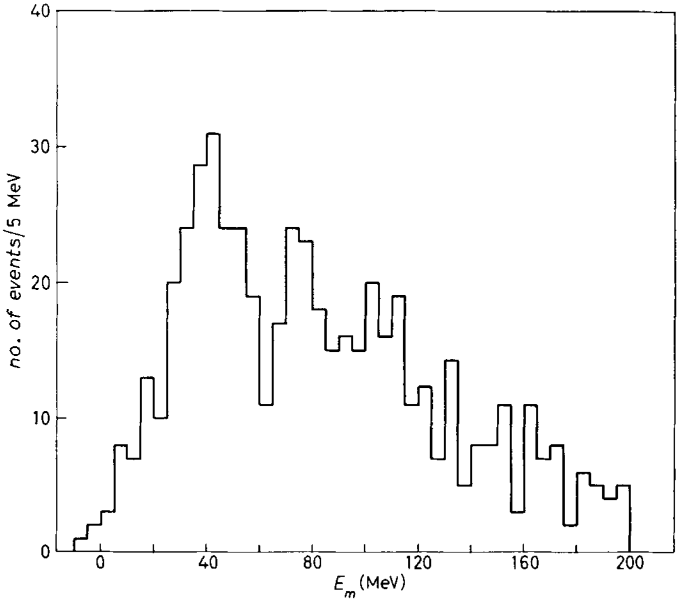

Fig. 4. – Missing-energy distribution for the 2-prong events, 616 events.

The interpretation is supported by the distribution of the opening angle between the two outgoing protons, shown in Fig. 5 for different values of E_m. The angular correlation is specially evident for the low-E_m events.

To check quantitatively our interpretation, various experimental distributions will be compared with the theoretical predictions calculated assuming the dominance of the pole graph of Fig. 3. In the usual approximations [20], the differential cross-section can be written

$$\frac{\mathrm{d}\sigma}{\mathrm{d}^3p_r\,\mathrm{d}^3p_1\,\mathrm{d}^3p_2} = |f(p_r)|^2 \frac{(2E^*_{p_1})^2}{(p_r^2+\varkappa^2)^2} \frac{(p^*_\pi/p^*_p)^2}{E_{p_1}E_{p_2}E_{(pn)}} \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)^* \cdot$$
$$\cdot\,\delta(E_c + E_{\pi_{\text{inc}}} - E_{p_1} - E_{p_2} - E_B)\,\delta(\boldsymbol{p}_{\pi_{\text{inc}}} + \boldsymbol{p}_C - \boldsymbol{p}_B - \boldsymbol{p}_{p_1} - \boldsymbol{p}_{p_2}) ,$$

[20] See, for instance, I. S. SHAPIRO: *Rendiconti S.I.F.*, Course XXXVII (New York, 1967), p. 210.

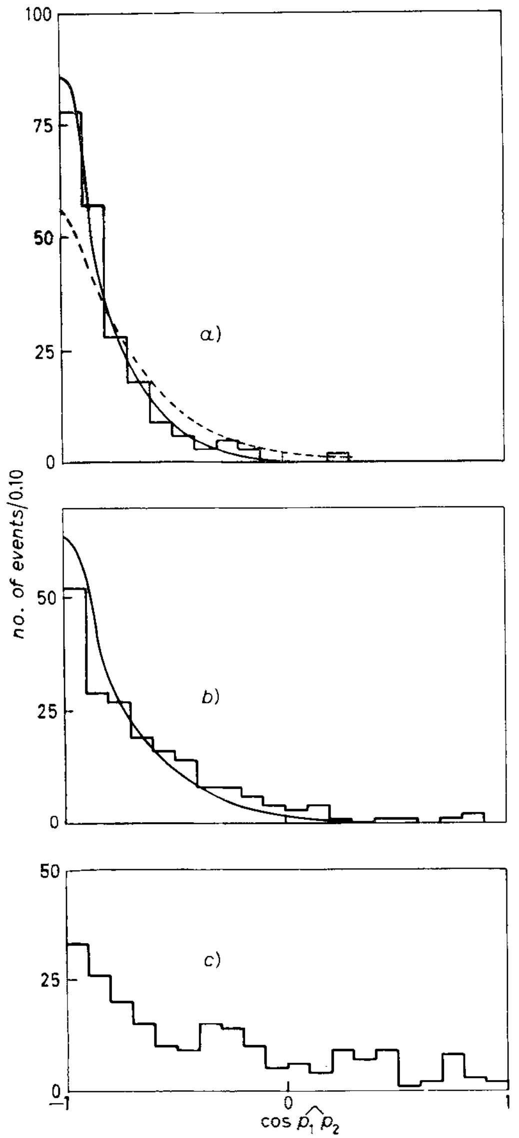

Fig. 5. – Opening angle between the two outgoing protons (laboratory system): *a*) for $E_m < 60$ MeV, 210 events —— prediction for reaction (1) $(\pi(\mathrm{d})\to\mathrm{pp})$, – – – prediction for reaction (2) $(\pi(\alpha)\to\mathrm{ppd})$; *b*) for $60 < E_m < 115$ MeV, 196 events —— prediction for reaction (1) with 60 MeV of excitation energy for the residual nucleus; *c*) for $E_m > 115$, 216 events.

where p_r is the momentum of the recoiling nucleus,

$|f(p_r)|^2$ is the form factor for the left vertex,

p^*_π, p^*_{p}, E^*_{p} are the momenta and the energy of the incoming π and outgoing protons in the system of the two final protons,

p_1, p_2, E_1, E_2 and E_{np} are the momenta and the energies of the outgoing protons and of the virtual n-p pair,

$\varkappa = \sqrt{2m_{B(n-p)}\,\varepsilon}$ where $m_{B(n-p)}$ is the reduced mass for the system B(n—p) and ε is the binding energy of the virtual n-p pair,

$(\mathrm{d}\sigma/\mathrm{d}\Omega)^*$ is the cross-section for the free process

$$\pi^+(\mathrm{np}) \to \mathrm{pp}\,.$$

A form factor of the shape

$$|f(p_r)|^2 \propto \exp\,[-(p_r/A)^2]$$

has been assumed.

The comparison between data and theoretical predictions is shown in:

Figure 5 *a*). For the opening angle of the two protons.

Figure 6 *a*). For p_r; the recoil momentum assumes generally low values, while the kinematical limit is $\geqslant 1$ GeV.

Figure 7 *a*). For the cosine of the angle between p_r and $p_{\pi_{\mathrm{inc}}}$. This distribution is practically uniform (in the laboratory system) and confirms that the recoil nucleus acts as a spectator in the reaction.

Figure 8 *a*). For the kinetic energy of the outgoing protons. This distribution gives information on the right vertex of the diagram of Fig. 3, as discussed below. (All distributions are in the laboratory system.)

The theoretical curves (continuous lines on figures) have been computed for $A = 360$ MeV/c and for $(\mathrm{d}\sigma/\mathrm{d}\Omega)^* \propto \text{const}$.

The value of A has been determined by fitting the p_r distribution. The choice of the $(\mathrm{d}\sigma/\mathrm{d}\Omega)^*$ shape has been made looking at the T_p distribution: in fact, if we use the free π^+-d absorption cross-section ([21])

$$(\mathrm{d}\sigma/\mathrm{d}\Omega)^* \propto a + \cos^2\theta^*$$

(where typically $a = 0.20$), it is impossible to reproduce the data (Fig. 8 *a*)).

In the above assumptions, the agreement between data and theory is fairly good, but it must be noted that an alternative interpretation of the two-prong events can be put forward: they could be due to the reaction on an α-cluster

$$\pi^+ + {}^{12}\mathrm{C} \to \mathrm{ppd}\,\underbrace{{}^{8}\mathrm{Be}}_{\to\,\alpha\alpha}\,. \tag{2}$$

([21]) C. Richard-Serre: *Étude de la réaction* $\pi^+\mathrm{d}\to\mathrm{pp}$ *pour des pions d'énergie comprise entre* 143 *et* 264 MeV, CERN 68-40.

KOSMACH *et al.* ([15]) measured the cross-section for the reaction (2) and found 19 mb at 117 MeV (*i.e.* practically at our energy) and observed a kinetic-energy distribution of the deuteron peaked toward low values ($\leqslant 20$ MeV). According

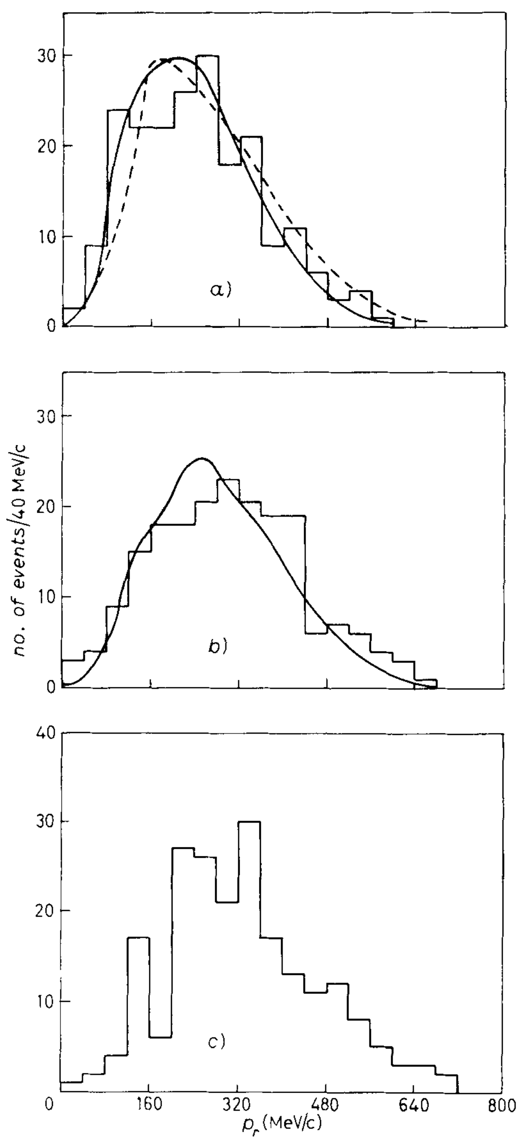

Fig. 6. – Recoil-momentum distribution (laboratory system); *a*), *b*) and *c*) as for Fig. 5.

their results, in 60 % of the cases the deuteron leaves a nondetectable track in propane and then the events with very low T_d are classified as two-prong events.

Furthermore the value of the separation energy for the reaction (2) is ~ 35 MeV and, also if the deuteron is not measured, the missing energy remains small. In the E_m distribution the events due to reaction (2) lie in the same position as those due to the separation of a (n-p) pair from the s-shell. On the other hand reactions (1) and (2) give similar distributions for the kinematical

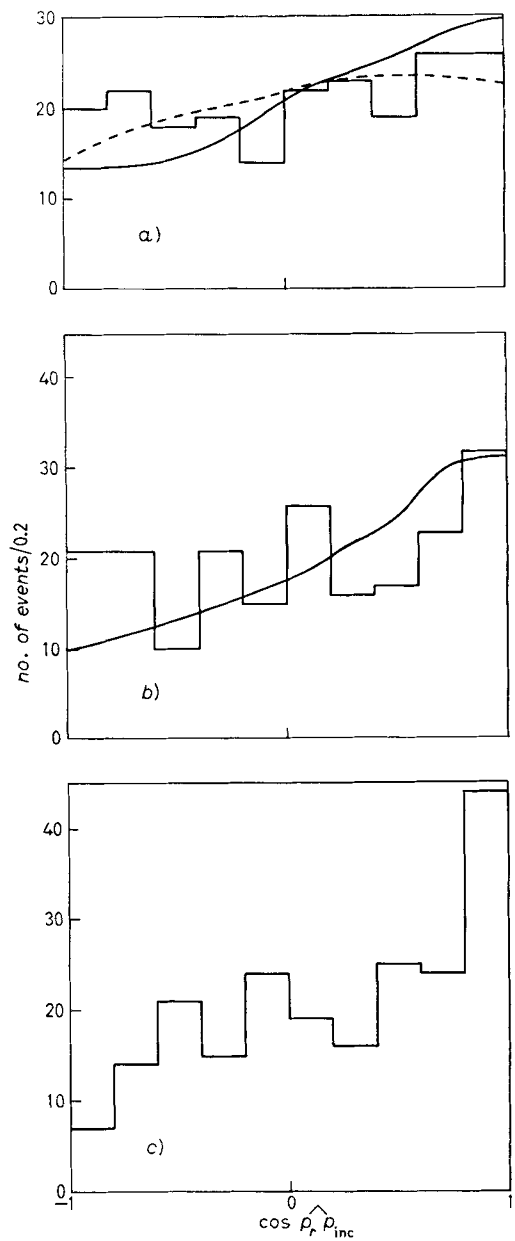

Fig. 7. – $\cos \widehat{\boldsymbol{p}_r \boldsymbol{p}_{\text{inc}}}$ distribution (laboratory system); *a*), *b*) and *c*) as for Fig. 5.

variables above considered. In fact a calculation carried out in the same way as for the reaction (1), if one imposes the deuteron experimental energy distribution [15], gives the curves shown in Fig. 5 *a*) to 8 *a*). Then it is not possible

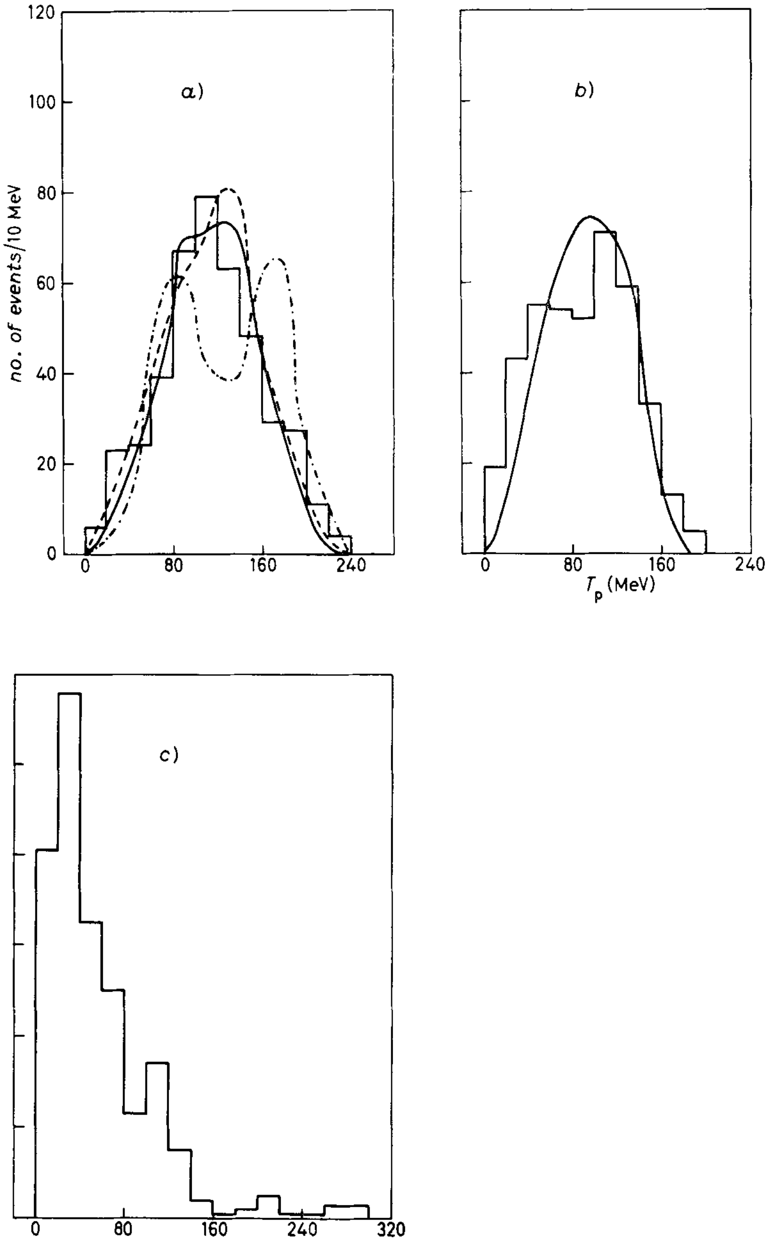

Fig. 8. – Kinetic energy of the outgoing protons (laboratory system) *a*) for $E_m < 60$ MeV, —— prediction for reaction (1) with $(d\sigma/d\Omega)^* \propto$ const, —·—·— with $(d\sigma/d\Omega)^* \propto a + \cos^2\theta^*$, — — — for reaction (2); *b*) and *c*) as in Fig. 5.

to distinguish the events due to reaction (2) from those where two nucleons only are separated from the s-shell, without detecting the deuteron.

If we assume a cross-section of 19 mb for reaction (2) also at our energy, from the values of the two-prong event percentage (14 %, see Sect. 7) and of the total cross-section, the percentage of events due to reaction (2) in our sample of two-prong events is found to be $(40 \pm 5)\,\%$ (the error is statistical only).

From the data of ([15]), we expect ~ 35 events due to process (2), where the d leaves a detectable but unmeasurable track ($1 < 4$ mm). In fact, in our sample of 113 2-prong events accompanied by a blob, 30 events have a missing energy < 60 MeV. Also these events have been compared with the predictions calculated for the reaction (2) and the agreement between data and theory is, in the limit of the poor statistics, good.

Let us consider now the events with large E_m. It can be noted (Fig. 5 b)) that the angular correlation exists also for these events. The graph of Fig. 3 has been computed by assuming a high excitation energy (60 MeV) of the residual nucleus. The results are compared with the experimental data in Fig. 5 b) to 8b). The qualitative agreement suggests that in these events other fast nucleons are not emitted, but probably the residual nucleus breaks up in heavy fragments.

For the events with $E_m > 115$, the angular correlation is weaker than the foregoing (Fig. 5 c)) and probably fast neutrons are emitted.

6. – Three-prong events.

In our sample of absorption events, 360 (19 not measurable) are clean three-prong events; this noticeable percentage ($\sim 24\,\%$ of the total) suggests that an absorption mechanism is important according to the reactions (2) and

$$\pi\,^{12}\mathrm{C} \to \mathrm{pppn}\,^{8}\mathrm{Be} \quad \llcorner\!\!\to \alpha\alpha \tag{3}$$

described by the dominant graph ([22]) of Fig. 9.

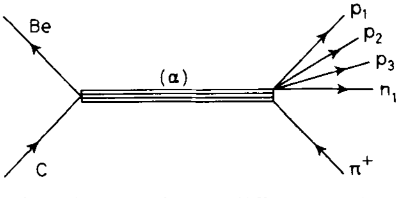

Fig. 9. – Feynman graph for the reaction $\pi^{+}\,^{12}\mathrm{C} \to \mathrm{pppn}\,^{8}\mathrm{Be}$.

([22]) V. M. KOLYBASOV: *Yad. Fiz.*, **3**, 535 (1966).

Our sample of 3-prong events contains a small percentage ($\sim 3\%$) of events due to reaction (2), but in the following we will neglect this contribution and test the assumption of the dominance of reaction (3).

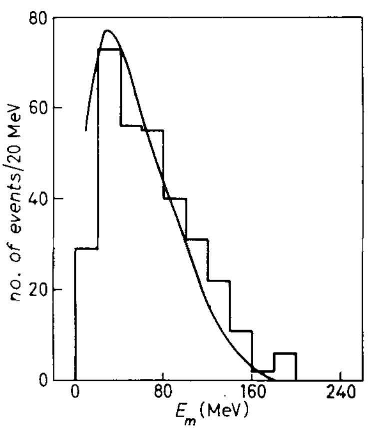

Fig. 10. – Missing-energy distribution for 3-prong events (laboratory system); ——— for reaction (3) $(\pi(\alpha) \to \text{pppn})$.

The theoretical differential cross-section has been calculated with formulae similar to those used for the quasi-deuteron capture, by assuming a constant matrix element for the right vertex describing the process $\pi^+(\alpha) \to \text{pppn}$ and no excitation energy for the residual nucleus.

Figure 10 shows the E_m distribution; in the present case E_m is practically

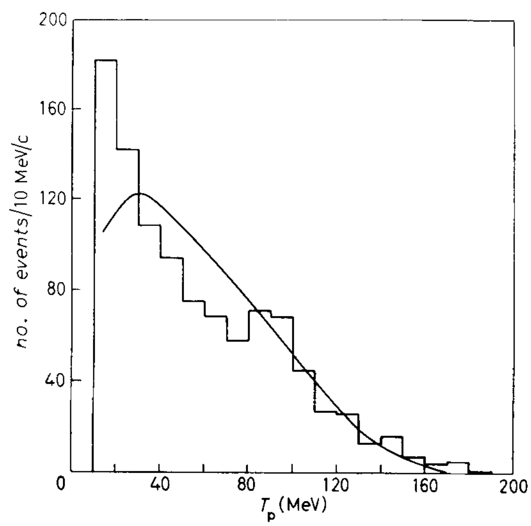

Fig. 11. – Proton kinetic-energy distribution for 3-prong events (laboratory system); ——— prediction for reaction (3), 341 events.

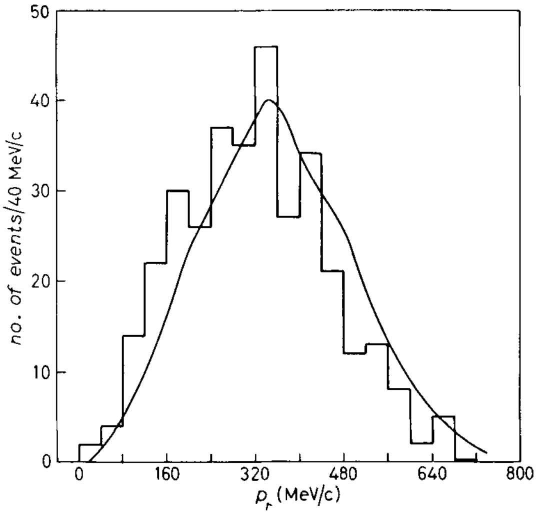

Fig. 12. – Missing-momentum distribution for 3-prong events (laboratory system); ——— prediction for reaction (3), 341 events.

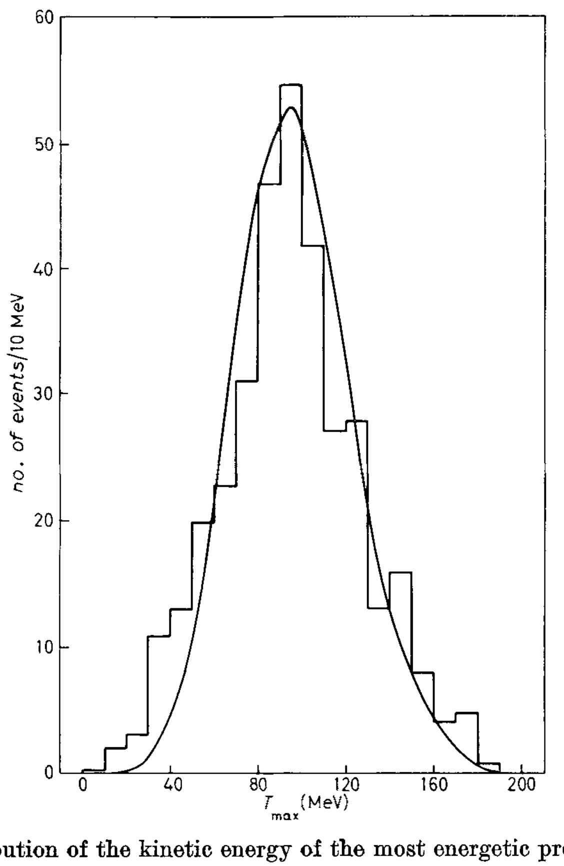

Fig. 13. – Distribution of the kinetic energy of the most energetic proton in the event (laboratory system); - prediction for reaction (3), 3-prong events, 341 events.

equal to the separation energy plus the neutron kinetic energy, the kinetic energy taken away by the residual Be nucleus being negligible. The proton kinetic energy distribution is shown in Fig. 11 and the distribution of the missing momentum, which would be equal to the sum of the n and the Be momenta, is shown in Fig. 12. A further check of our assumption is given by the distribution of the fastest proton in the events (Fig. 13).

The general agreement is only qualitative, an excess of low energy protons being evident (Fig. 11). A better agreement could be obtained by assuming many contributions: from reactions (2) and (3) and from a background of many-particle events; statistics prevents us from doing such a mixture.

7. – Many-particle events.

The interpretation of the many-prong events is extremely difficult because of the large variety of reactions that could be responsible for them; moreover the emission of a large number of neutrons does not allow a complete kinematical analysis.

Two extreme hypothesis can be put forward:

a) the nucleus is completely broken, according to the reaction

$$\pi^{+12}C \rightarrow 7p + 5n \; ; \tag{4}$$

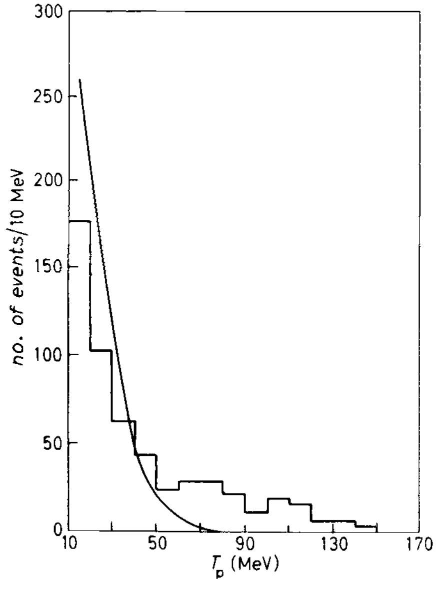

Fig. 14. – 4-prong events; proton kinetic-energy distribution (laboratory system); —— prediction for reaction (4), 138 events.

b) the capture is a two-step process: the π is first absorbed by a light cluster (d or α) and, in a second step, the nucleus is broken by secondary interactions of the protons.

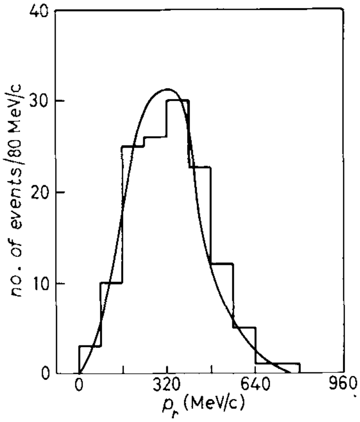

Fig. 15. – 4-prong events; missing-momentum distribution (laboratory system); ——— prediction for reaction (4), 138 events.

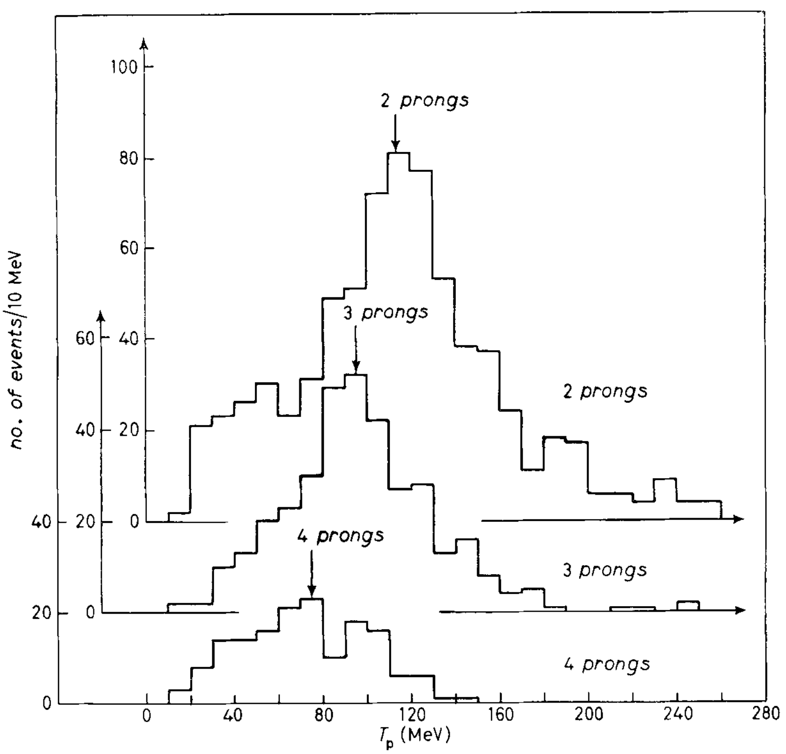

Fig. 16. – Distribution of the most energetic proton in 2-, 3- and 4-prong events (laboratory system).

To estimate the predictions of reaction (4), a simple phase-space calculation has been carried out.

The p kinetic energy and the missing-momentum distributions for the 4-prong events are compared in Fig. 14 and 15 with the results of the calculation. A quite strong disagreement in the T distribution appears in Fig. 14. Also the multiplicities, computed by taking into account the visibility limit, are in disagreement with the data, the high-multiplicity channels being less populated than predicted.

No theoretical calculation has been carried out for hypothesis *b*), but we can do the following qualitative consideration. Suppose the first step of the capture is an absorption on a correlated n-p pair; one of the two outgoing protons leaves undisturbed the nucleus, while the other one interacts deeply with the residual nucleus and causes its complete break-up. So we expect that the distribution of the energy of the fastest proton of each event T_{max} does not strongly depend on the multiplicity. The distribution of T_{max} for 2-, 3- and 4-prong events is shown in Fig. 16; it can be seen that T_{max} decreases slowly with the multiplicity, not in disagreement with hypothesis *b*).

8. – Conclusions.

a) *Total cross-section.* The absorption cross-section is quite important at the resonance energy. The total cross-section, measured on the same pictures, is in good agreement with the figure obtained for π^- by BINON *et al.* [23]; the ratio between absorption and total cross-sections is

$$\sigma_{abs}/\sigma_{tot\ in} = 0.5 \pm 0.05$$

in the energy interval $(115 \div 150)$ MeV.

b) *Two-prong events.* Two-prong events are $\sim 40\%$ of the total, but the E_m distribution (Fig. 4) is extremely broadened; then only a fraction of them can be interpreted as due to the capture by a quasi-deuteron with low energy transfer to the residual nucleus.

A similar E_m distribution has been obtained by FAVIER *et al.* [8] in a counter experiment where an *a priori* selection favoured large opening angles between the two protons. In fact the opening angle distribution is peaked towards 180° (Fig. 5) both for events with low and high E_m. Furthermore different reactions give similar configuration for the two final protons as discussed in Sect. **5**: only a quantitative comparisons with a definite model is meaningful.

([23]) F. BINON, P. DUTEIL, J. P. GAMOV, J. GOZLER, L. HUGON, J. PEJGNEUX, C. SCHMIT, M. SPIGHEL and J. P. STROOT: *Nucl. Phys.*, **17** B, 168 (1970).

It must be noted the disagreement of the T_p distribution with the prediction computed using the π^+-d absorption cross-section. The choice among different shapes for $(d\sigma/d\Omega)^*_{\pi(pn)\to pp}$ must be made on the basis of the T_p distribution because the distributions of other variable as p_r, $\cos \widehat{p_{inc} p_r}$ etc. are weakly affected by it (*). To our knowledge no other experimental information exists on this point. Theoretically GUY *et al.* [24] obtained for ^{16}O a prediction for the T_p distribution similar to our experimental one.

c) *Three-prong events.* Our data suggest that the capture on an α-cluster could explain most of the three-prong events. An upper limit for the cross-section of reaction (3) can be obtained by assuming that all the 3-prong events are due to reactions (2) or (3); taking into account the contribution of reaction (2) and the loss of low-energy protons, we get

$$\frac{\sigma_{\pi^+(\alpha)\to pppn}}{\sigma_{tot\ abs}} \approx 0.29 \,.$$

d) *Branching ratios.* Finally we try a gross classification of the absorption reactions. In Table I the extimated percentages for different channels are reported.

TABLE I.

Final state or reaction	Percentage
1p+neutrals	12
$\pi^+(d)\to pp$ (low E_m)	9.5
$\pi^+(d)\to pp$ high residual excitation ($60 < E_m < 115$ MeV)	13
2p+fast neutrals ($E_m > 115$ MeV)	12
$\pi^+(\alpha)\to ppd$ (*)	10
$\pi^+(\alpha)\to pppn$	29
multiparticles ($n_{prongs} \geqslant 4$)	15

(*) Computed from the data of KOSMACH *et al.* [15].

It is evident the difficulty of even a rough interpretation of the events on the basis of the fast protons only; anyway the capture by a correlated pair does not seem to be the most important process, but the capture by an α-cluster seems predominant. Also the multiparticle emission gives a nonnegligible contribution to the absorption cross-section.

(*) An equivalent variable to T_p is $\cos\theta^*$, where θ^* is the angle between an outgoing proton and the direction of the c.m. of the two protons, in that system.

[24] R. GUY, J. M. EISENBERG and J. LETOURNEUX: *Nucl. Phys.*, **112** A, 689 (1968).

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We are indebted to Prof. E. FIORINI for his continuous interest and encouragement and to Dr. S. BONETTI for her contribution in the early stage of the experiment.

We would also like to thank Mr. CIGHETTI who supervised the scanning and measuring operations.

● RIASSUNTO

Si sono studiati circa 1500 eventi di assorbimento di π^+ in volo (di $\sim$130 MeV di energia cinetica) in camera a bolle a propano. La sezione d'urto corrispondente è (189 ± 19) mb per nucleo di carbonio, che è circa la metà della sezione di urto totale anelastica. L'assorbimento su due nucleoni con bassa eccitazione del nucleo residuo sembra essere responsabile soltanto del 10% della $\sigma_{\text{tot ass}}$, mentre la cattura da parte di una sottostruttura α sembra essere più importante ($\sim$40% del totale). Gli eventi sono stati analizzati secondo la molteplicità dei loro rami carichi. I dati concernenti gli eventi a due rami sono in accordo con le predizioni teoriche calcolate adottando il predominio della reazione $\pi^+(\text{np})\to\text{pp}$ e usando il modello dell'approssimazione degli impulsi; comunque un'alta percentuale di essi ($\sim$40%) è dovuta all'assorbimento su una sottostruttura α secondo la reazione $\pi^+(\alpha)\to\text{ppd}$ con un trasferimento molto basso di energia al deuterone. Gli eventi a tre rami sono stati interpretati come dovuti al processo $\pi^+(\alpha)\to\text{pppn}$ ed è stato trovato un accordo qualitativo tra i dati e la teoria. Sono riportati anche alcuni dati sugli eventi a molti rami.

Поглощение положителных пионов ядрами углерода при 130 МэВ.

Резюме (*). — В пропановой пузырьковой камере были исследованы около 1500 случаев поглощения π^+ на лету (с кинетической энергией $\sim$130 МэВ). Соответствующее поперечное сечение составляет $(189\pm19)\,\mu$б на ядро C, то есть около половины полного неупругого поперечного сечения. Поглощение на двух нуклонах с малым возбуждением остаточного ядра, по-видимому, ответственно только за 10% от полного сечения поглощения, тогда как захват α-кластером является, по-видимому, более важным ($\sim$40% от полного сечения). Был проведен анализ событий в соответствии с множественностью их заряженных лучевых следов. Данные, относящиеся к двухлучевым событиям, согласуются с теоретическими предсказаниями, вычисленными в предположении доминантности реакции $\pi^+(\text{np})\to\text{pp}$ и, используя модель импульсного приближения. Однако большая часть событий ($\sim$40%) обусловлена поглощением на α-кластере: $\pi^+\alpha\to\text{ppd}$ с очень малой передачей энергии дейтрону. Трехлучевые события были интерпретированы, как процессы $\pi^+\alpha\to\text{pppn}$, и получено качественное согласие между экспериментальными данными и теорией. Также приводятся некоторые данные по многолучевым событиям.

(*) *Переведено редакцией.*