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G. Goggi, G.C. Mantovani, A. Piazzoli and D. Scannicchio: SOME CONSIDERATIONS ON PHOTOPRODUCTION EVENTS WITH TWO PIONS OF THE SAME CHARGE IN ^{3}He AND ^{4}He. -

INTRODUCTION. -

In two experiments of pion photoproduction on ^{3}He and ^{4}He[1,2], carried out with the diffusion chamber technique on the bremsstrahlung beam of the Frascati Electronsynchrotron, some events were found, which can be assigned to double photoproduction reactions with two pions of the same charge.

Apart from some experimental uncertainty in the data, the very peculiar features of these processes suggested us to try a comparison between the results and some theoretical prevision. Because of the general scarcity of theoretical models, what follows has to be considered only as a preliminary approach to the study of these processes, which, however, could be interesting as to the method used, also in view of some further experimental investigation.

In the first section of this paper the theoretical and experimental results concerning double charge exchange reactions of pions on nuclei are considered. The presently available models for the description of these processes are discussed in view of a possible extrapolation to the photoproduction reactions. In the second section the statistical model is tentatively applied in detail in order to obtain a numerical prevision to be compared with the experimental data, which are presented and shortly discussed in the third section.

SECTION I. -

It is well known that the study of the interactions of elementary particles with nuclei may give useful informations both for particle physics and for nuclear physics. As to the first point, we only want to remind the coherent processes and the possibility of picking out a pure state from a state admixture by a suitable choice of a nucleus having such quantum numbers as to allow only the wanted state to survive. As concerns the second point, we will only quote the success of the ee'p experiments.

A very interesting interaction between a particle and the investigated nucleus is the so called "double charge exchange", i.e. the production of a π^+ on a nucleus by a π^-, or viceversa. Since whatever reaction mechanism must necessarily involve two nucleons, in these reactions the cross-section will strongly depend on the correlation among the nucleons within the nucleus. Indeed, the problem of nucleon correlations is one still open in modern nuclear physics. Very similar to the double charge exchange is the photoproduction on nuclei of two pions of the same charge, which obviously involves the same problems.

§ 1 - Since 1964 a certain interest arose for double charge exchange reactions of pions on nuclei of the type:

$$\pi^{\pm} + (A, Z) \rightarrow (A, Z \pm 2) + \pi^{\mp}$$

This interest was due mainly to the possibility of obtaining new information on the π^--nucleus interaction as well as to the possibility of exciting nuclear states with isospin T = 2.

The last fact is evident if one think that double charge exchange reactions require the change $\Delta T_3 = 2$ or, in other words, the change of two units in the number of protons or neutrons.

This fact seems to be of particular interest because of the possible formation of new isotopes of hydrogen and ^{4}He excited states (bound or unbound). A typical example is given by the reaction:

$$\pi^- + {}^9Be \rightarrow \pi^+ + {}^4H + {}^5H$$

Both these isotopes were experimentally found with other methods and were also much discussed(3).

The problematics of double charge exchange reactions may a priori show very different aspects according to the energy of the incoming pions:

A) $E_\pi \lesssim 150$ MeV

The reaction mechanisms a priori proposable are:

(1) $$\pi^{\pm} + (A,Z) \rightarrow \pi^{0} + (A, Z \pm 1) \rightarrow \pi^{\mp} + (A, Z \pm 2)$$

(2) $$\pi^{\pm} + \begin{matrix}(nn)\\(pp)\end{matrix} \rightarrow \begin{matrix}(pp)\\(nn)\end{matrix} + \pi^{\mp}$$

According to the first mechanism there are two consecutive charge exchange interactions, while in the second one a single, not better specified, elementary interaction occurs with a "cluster" of two equal nucleons.

B) $E_\pi \gtrsim 150$ MeV.

At these energies pion production by pions is possible and, therefore, also a two step mechanism, i.e. pion production followed by pion reabsorption:

(3) $$\pi^{\pm} + \binom{n}{p} \rightarrow \pi^{\mp} + \pi^{\pm} + \binom{p}{n}$$
$$\hookrightarrow \text{absorption}$$

At these energies, as it is well known, a non-negligible fraction of π-N states is resonant.

C) At sufficiently high energies a direct process is possible, as follows:

$$\pi^{-} + p \rightarrow X^{0} + n$$
$$\hookrightarrow \pi^{+} + \pi^{-}$$
$$\hookrightarrow \text{absorption}$$

where X^{0} is a boson decaying into $\pi^{+}\pi^{-}$.

§ 2 - We will now examine the experimental data at lower energy ($\lesssim 200$ MeV). Fig. 1 and 2 show the results due to π^{+} with energy 50-150 MeV in emulsion[4]. In Fig. 1 the cross-section vs. energy and in Fig. 2 the resulting π^{-} spectrum are shown.

The continuous curves are obtained with a cascade model, in which the cascade development is followed step by step by means of a Montecarlo calculation, assuming the validity of the mechanism

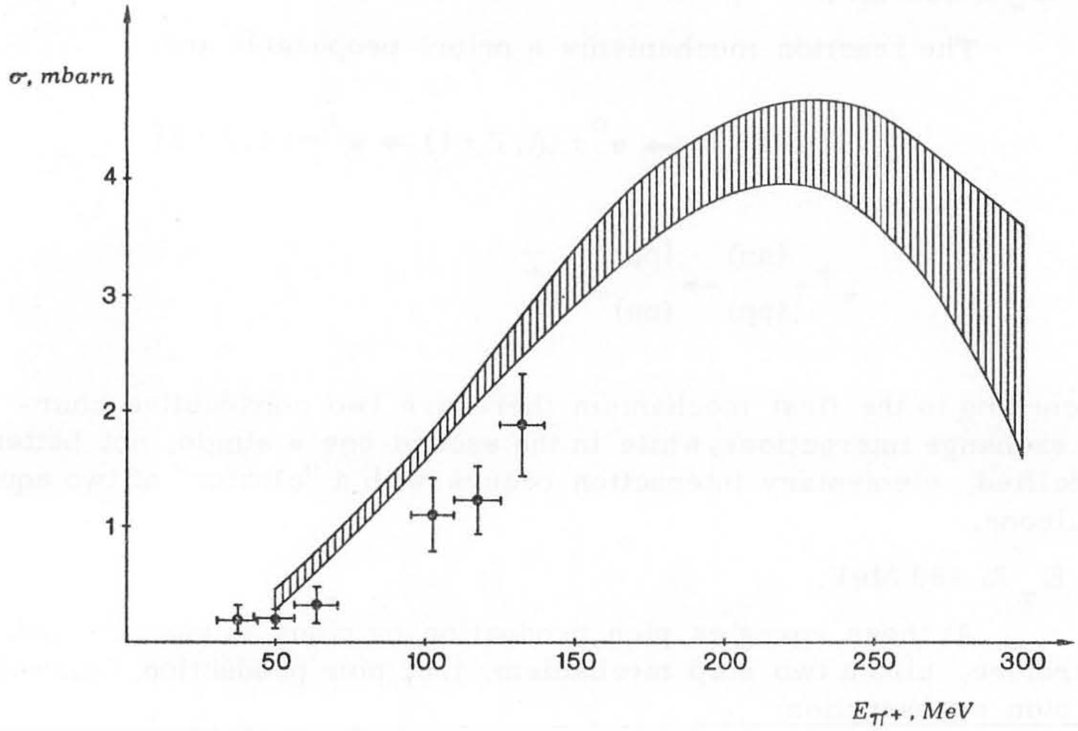


FIG. 1 - Energy dependence of the total cross section for double charge exchange of π^+ mesons on photoemulsion nuclei (the shaded area corresponds to a calculation by the Monte Carlo method).

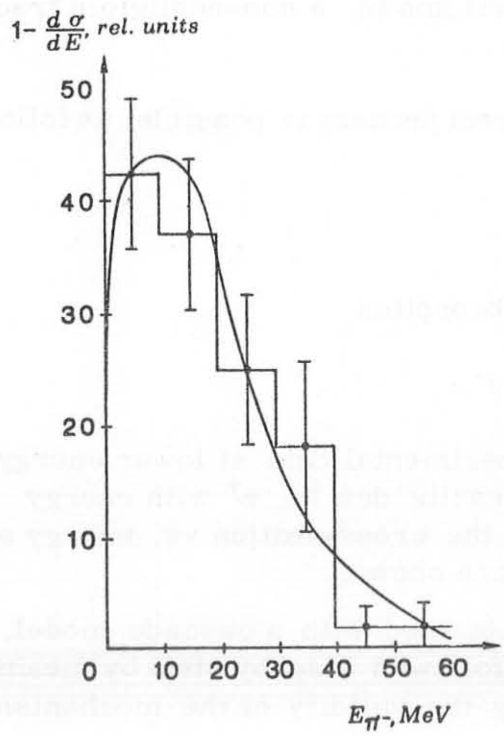


FIG. 2 - Energy distribution of secondary π^- mesons from the double charge exchange reaction for a primary π^+ meson energy of 60 - 100 MeV. The spectrum contains 100 events (the solid curve is based on a calculation by the Monte Carlo method).

(1) and considering the nucleus as a Fermi-gas spherical distribution with uniform density and radius $R = r_o A^{1/3}$ ($r_o = 1$ fm).

As one can see, the validity of the assumed mechanism seems to be well confirmed.

Later on the same authors[5, 6] extended their investigation to the absorption of π^+ and π^- by pure elements.

The results are summarized in Table I and in Fig. 3 and 4, where the continuous curves are derived with a Montecarlo calculation of the same type as above described.

A single measurement of $d\sigma / d\Omega$, at $\theta = 29^o$, exists for 31 MeV π^+ in ^{51}V[7], also quoted in Table I.

From all the above data the following conclusions can be drawn:

- a total cross-section amount of some millibarn, which is not so small as one could expect;
- the mechanism (1), which is in a certain sense the most natural one, seems to explain the experimental data in a satisfactory way in the limits of the unavoidable approximations of the model.

§ 3 - A third experiment by Batusov et al.[8] investigates the double charge exchange reactions on emulsion nuclei up to 375 MeV. 3289 events were found, due to the reaction:

(4) $$\pi^- + (A, Z) \rightarrow \pi^+ + (A, Z-2)$$

and 322 events due to the reaction:

(5) $$\pi^- + (A, Z) \rightarrow \pi^+ + \pi^- + (A, Z-1)$$

In Fig. 5, the total cross section of reaction (5) is shown, while the dashed points in Fig. 6 above the pion production threshold is the total cross section of reaction (4).

Obviously, above the threshold of reaction (5), the reaction (4) includes contributions from two different processes:

a) - pion production (reaction (5)) followed by π^- reabsorption;
b) - a "true" double exchange due, for instance, to the mechanism (1), which, as we have seen, can explain the low energy data.

The mentioned Montecarlo calculation was used by Batusov et al.[9] to determine the contribution b) for incident pion energy higher than 150 MeV (continuous line in Fig. 6); the effects due do the Coulomb barrier and to the Pauli principle were also taken into account.

TABLE I

Reference	Incident particle	Energy (MeV)	Angle θ^{o}	$d\sigma/d\Omega$ (μb) ^{7}Li	^{9}Be	^{23}Na	^{51}V	^{90}Zr
$\frac{d\sigma}{d\Omega}$ exp[12]	π^+	195	0^o	90 ± 10	10 ± 3	$1.4^{+1}_{-0.7}$	---	---
$\frac{d\sigma}{d\Omega}$ theor[18]	π^-	195	0^o	60 ± 10	17 ± 3	---	---	---
$\frac{d\sigma}{d\Omega}$ exp[10]	π^+	200	8.5^o	---	---	---	$60.2^{+9.2}_{-8.9}$	$49.0^{+7.5}_{-6.0}$
	π^+	200	16^o	51.3 ± 3.9	---	---	$36.8^{+4.3}_{-3.4}$	$35.0^{+6.0}_{-3.9}$
$\frac{d\sigma}{d\Omega}$ exp[7]	π^+	31	29^o	$0.165^{+0.225}_{-0.060}$	---	---	$0.52^{+0.71}_{-0.19}$	---

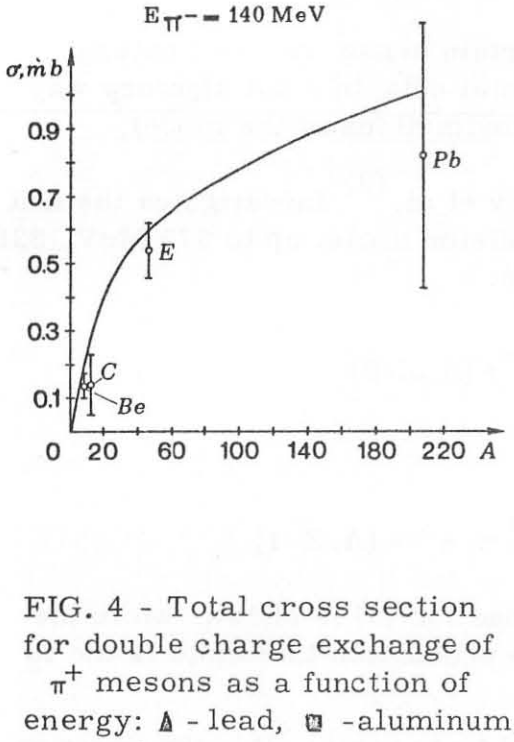


FIG. 3 - Total cross section for double charge exchange of 140 MeV π^- mesons as a function of atomic number of the nucleus; curve-result of calculations by the Monte Carlo method for the reactions $\pi^- + p \to \pi^0 + n$ and $\pi^0 + p \to \pi^+ + n$.

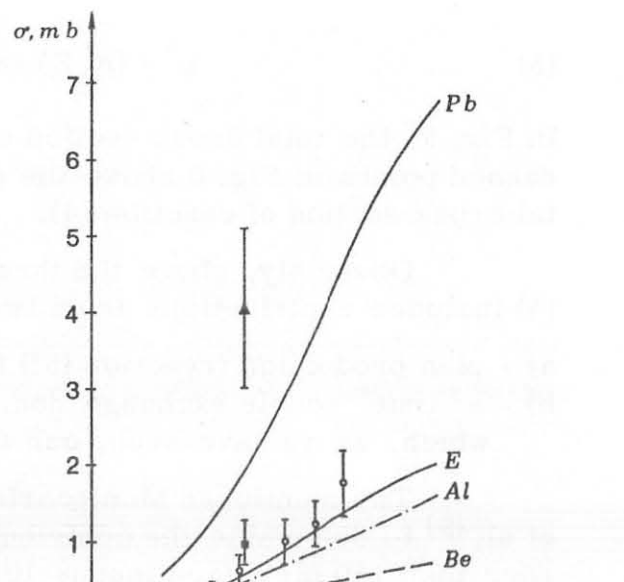


FIG. 4 - Total cross section for double charge exchange of π^+ mesons as a function of energy: ▲ - lead, ◘ -aluminum, O -emulsion ● -beryllium. The curves are the result of calculations made by the Monte Carlo method for the reactions $\pi^+ + n \to \pi^0 + p$ and $\pi^0 + n \to \pi^- + p$ for nuclei of lead, the effective nucleus of emulsion, aluminum, and beryllium.

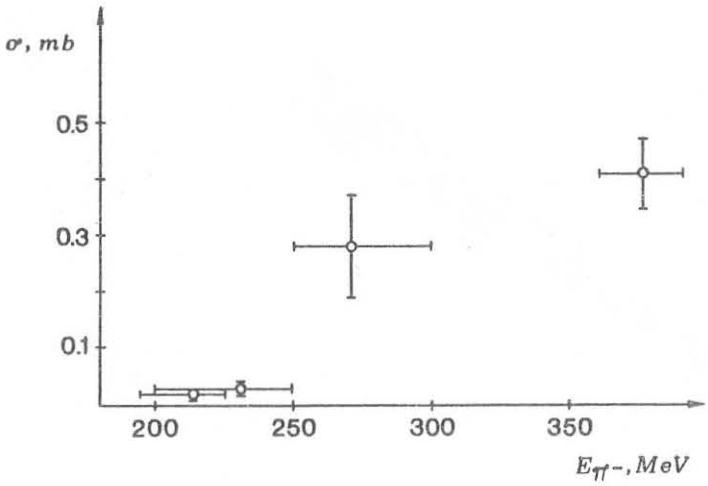


FIG. 5 - Total cross sections for the production of mesons by mesons mesons on emulsion nuclei in accordance with the reaction

$\pi^- + A \rightarrow \pi^+ + \pi^- + A' + \ldots$

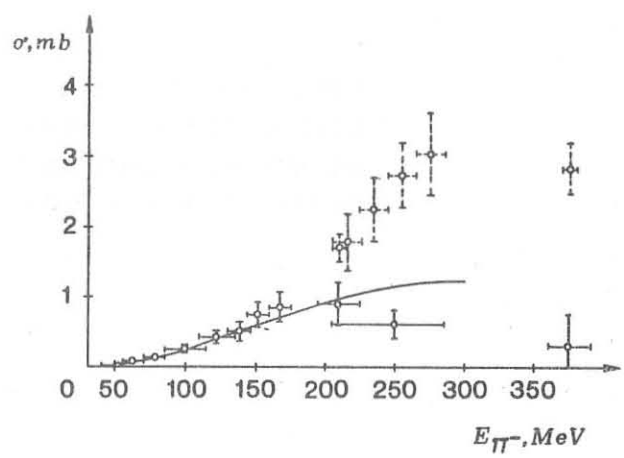


FIG. 6 - Total cross section for the production of π^+ mesons by π^- on emulsion nuclei in the reaction $\pi^- + A \rightarrow \pi^+ + A' + \ldots$ (dashed) and the cross sections for the charge exchange of π^- mesons. Curve calculation by the cascade model.

By comparing the distribution of the number of charged prongs for reaction (4) under pion production threshold and for reaction (5), Batusov et al. could estimate the contribution to the cross section (4) due to pion production with reabsorption. In this way in Fig. 6 the experimental points with full error lines represent the contribution from mechanism (b) only. As one can see, the previsions are in satisfactory agreement with the experimental data, although some discrepancy appears for $E_\pi \gtrsim 300$ MeV.

The analogous π^- production by π^+ should give different results because of the different features of π^+ and π^- absorption according to the properties of the target nucleus.

Fig. 7 and 8 show[9] the results of the described Montecarlo calculation concerning π^+ and π^- double charge exchange in emulsion vs. the energy of the incoming pion and the atomic number. As Fig. 7

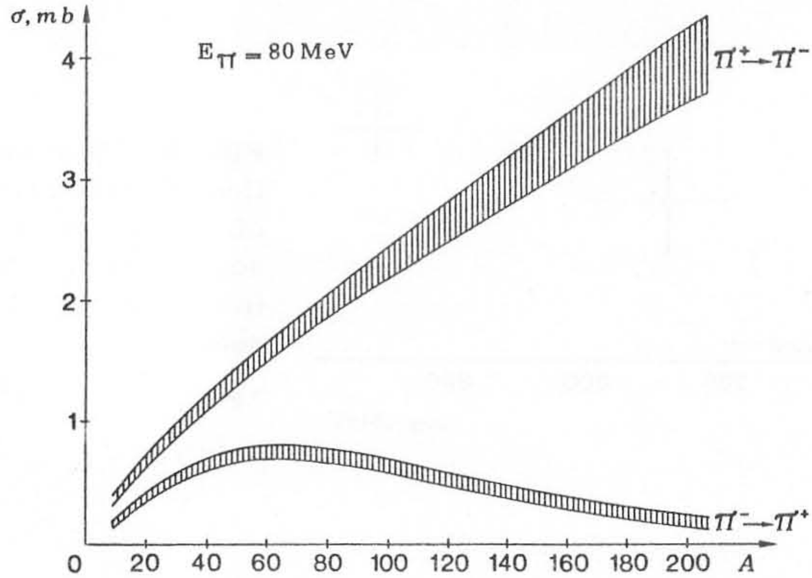


FIG. 7 - Calculated total cross sections for the double charge exchange of π^+ and π^- mesons on photoemulsion nuclei (the dashed regions indicate the error margin).

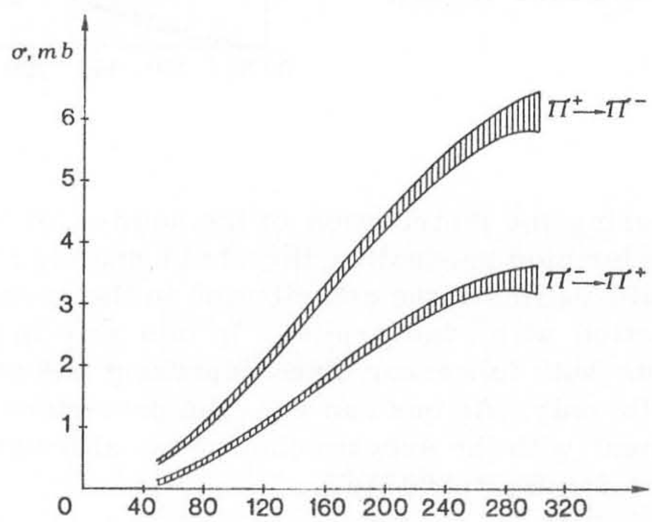


FIG. 8 - Calculated total cross sections for the double charge exchange of π^+ and π^- mesons at 80 MeV for different atomic numbers of the target nucleus (the dashed regions indicate the error margin).

shows, in the considered energy interval the total $\pi^- \to \pi^+$ cross-section is always lower than the $\pi^+ \to \pi^-$ one. The effect of the (3/2, 3/2) resonance is also evident.

As concerns the dependence of the total cross section on the atomic number A in the two cases (Fig. 8), one can see that the π^+ cross section increases monotonically unlike the π^- one which shows a broad maximum for intermediate A. These effects are due to the Coulomb interaction and to the different π^+ and π^- absorptions.

Interesting results are obtained in an experiment by Boyton et al. (10) on ^7Li, ^{51}V, ^{90}Zr targets with 200 MeV π^+ (see Table I). The differential cross sections at 8.5^o and 16^o were measured. The results essentially show that the cross-section for formation of "analogous states" (T = 2) is very small(7, 11): the upper limit results to be 1 ÷ 2 μb/sr and the decreasing of the angular cross-section with A is confirmed, as also found by Gilly et al. (12) with 120 ÷ 280 MeV π^- on ^4He, ^7Li and ^9Be targets.

The differential cross-sections for ^7Li, ^{51}V and ^{90}Zr obtained by Boyton et al. (10) with a Montecarlo calculation similar to those above described, are found to be a factor 2-3 higher than the measured values.

Some experimental data also exist at higher energies (≃ 500 MeV)(13, 14); in particular Carayannopulos et al. (13) obtain a total cross section of 1.2 ± .21 mb for the double charge exchange in ^4He with 470 MeV π^-.

Recently Becker and Schmit(16) have analyzed with some success the double exchange of π^- in ^4He according to a model in which the process takes place on a pair of target nucleons.

The results of the calculation reproduce, at least qualitatively, the main feactures of the reaction. At higher energy every contribution from inelastic processes, such as isobar intermediate state formation, has been neglected; nevertheless, the calculation results are twice as large as the experimental values(13), as also happens for the Montecarlo calculations (Fig. 6 and ref. (10)).

§ 4 - The quoted experimental results, although very scanty, may give some indication on the final state of the double exchange reactions. In effect, by comparing the energy dependence of the total cross section in emulsion nuclei and in ^{90}Zr(10) for $E_\pi \lesssim 180$ MeV with the phase-space, we can clearly argue the dominance of a 3 - particles final state in addition to the charge exchanging pion (Fig. 9 and 10)(4, 8, 10). Further confirmation of this fact is given by the corrcspondant momentum distributions of the outgoing pions (Fig. 11)(17).

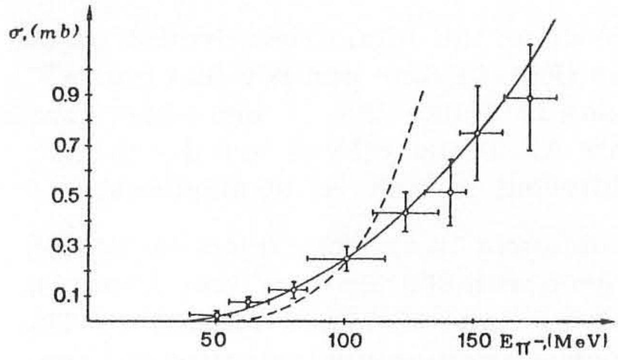
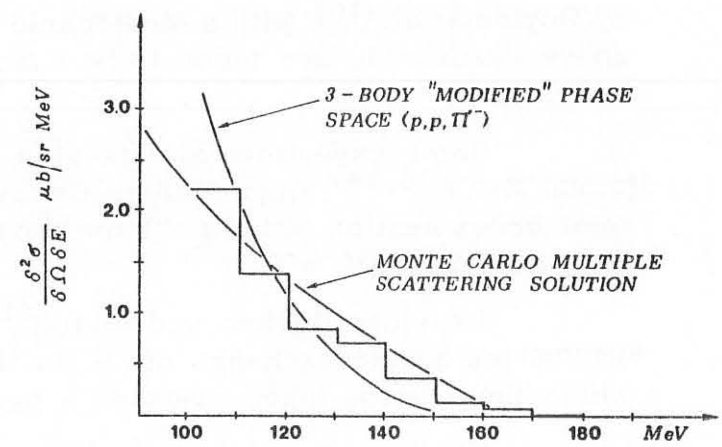


FIG. 9 - Energy behaviour of the cross section for double charge exchange of pions in emulsion nuclei. The curves represent the phase space behaviour of the reaction with the residual nucleus decaying in three particles (continous curve) and in four particles (dashed line). The curves are normalized to 100 MeV kinetic energy T of the incident pion.

FIG. 10 - Comparison of $(\partial^2\sigma/\partial\Omega\,\partial E)_{16^o}$ measured for zirconium (histogram) with Montecarlo results and three body phase space which includes effects of nucleon momentum and exclusion principle (ref. (10)).



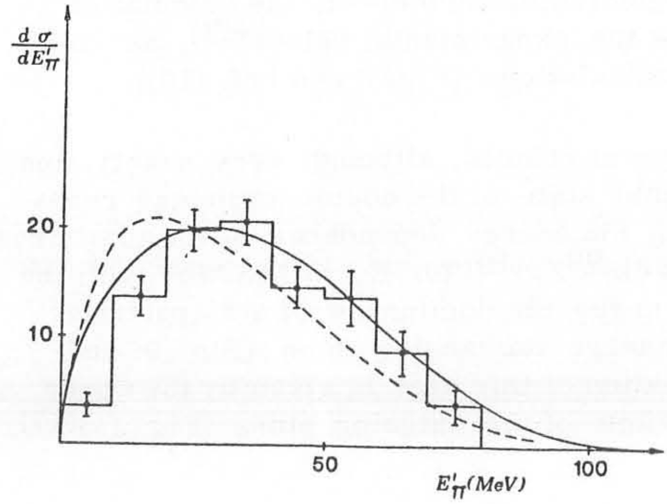


FIG. 11 - Energy distribution for secondary π meson. The curves represent the phase space behaviour of the reaction with the residual nucleus decaying in three particles (continous curve) and in four particles (dashed line).

From above considerations, which seem to indicate a rather small energy transfer to the nuclear system, one can reasonably argue that a process with low momentum transfer should considerably contribute to the double charge exchange, if one also remembers that, as shown in Fig. 6 the mechanism (1) alone cannot explain the data at higher energies.

Shapiro[18] proposed the process described by the diagram in Fig. 12; where A, B, N are the initial nucleus, the intermediate nucleus, the nucleon and a virtual nucleon isobar respectively. Such diagrams are called "triangular" and were calculated in the past for some reactions on light nuclei, such as $\pi^+ + D \rightarrow p + p$[19].

Their contribution can generally be put in evidence when the energy is so high as to excite the virtual isobar at small momentum transfer. As a main feature, they have a logaritmic singularity near the physical region (if the momentum transfer is small) and another singularity due to the mass of the exchanged isobar. The energy position of this one varies with the transferred momentum. Although no direct experimental evidence exists, the contribution of the triangular graphs seems very likely and represents an elegant way of explaining the resonant behaviour of many nuclear processes.

It seems reasonable that a triangular graph may also contribute to the photoproduction on nuclei of two pions with the same charge, if we merely substitute the incoming pion with a photon, as shown in Fig. 13.

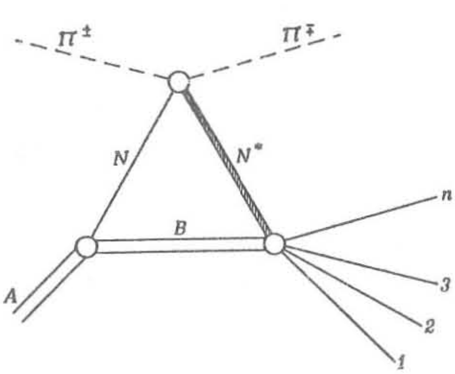


FIG. 12

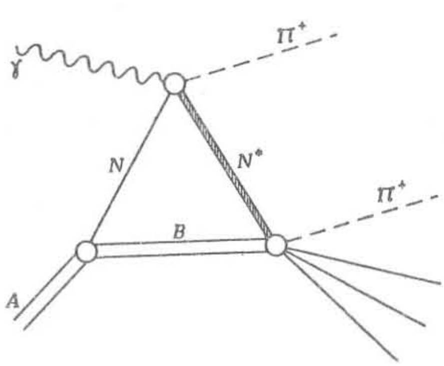


FIG. 13

However, such graphs seem very difficult to calculate and, in any case, their validity can be tested only on the basis of detailed theoretical previsions, which are not presently easily obtainable.

In the next section we want to try, therefore, a somewhat different approach to the photoproduction process of two pions with the same charge.

An eventual striking disagreement with experiment will make the contribution of particular reaction mechanisms, such as the triangular graphs, even more likely.

SECTION II. -

In this section we will try to deduce a threoretical prevision of the number of events to be found in our experiments[1], according to a statistical model similar to the one successfully used by Wilson[20] in order to explain high energy deuteron photodisintegration by reabsorption of the photoproduced pions.

Wilson's assumptions can be summarized as follows: a pion photoproduced in the deuteron enters a statistical equilibrium state with the two nucleons, if at the interaction moment these are sufficiently close (the limit distance was assumed to be $0.7\hbar/\mu c = 1$ fm). The equilibrium state so formed can decay into two nucleons + n pions (where n varies from zero to the maximum allowed by kinematics) with probabilities which are exactly evaluable with the Fermi model[21]. These are functions of the total energy of the decaying system, that is of the energy of the incoming photon.

The cross section for deuteron photodisintegration was well reproduced by the probability that the two nucleons be closer than 1 fm, calculated with the Hulthèn wave function, and by setting $n = 0$ in the Fermi model.

In the following we would like to generalize the described model and

a) - we determine the probability that two protons (or two neutrons) be closer than $\hbar/\mu c$ in ^3He and ^4He, assuming the Gunn - Irving wave functions[22];

b) - by using the known single and double pion photoproduction cross sections on free nucleons, we calculate the formation probability of the equilibrium state (we neglect triple photoproduction, since we had a $\sim$800 MeV bremsstrahlung beam);

c) - with the Fermi model we determine the probability that the equilibrium state, formed by two nucleons plus one or two pions in whatever charge state, decay into $2n + 2\pi^+$ (or $2p + 2\pi^-$);

d) - for completness, we also calculate the probability for equilibrium states with three nucleons, which results to be negligible.

Let us consider the reaction

$$\gamma + {}^3He \rightarrow 3n + 2\pi^+ \tag{6}$$

In our model the total cross section as a function of the photon energy can be written:

(8) $$\sigma^{^3He}_{2\pi^+}(E_\gamma) = N_{2p}\, \Omega^{^3He}\, \sigma^{\pi}_{2p}(E_\gamma)\, p_f^{(2N,2\pi)}(E_\gamma)\, N_2\, \varepsilon(^3He)$$

where:

$N_{2p} = 1/3$ is a factor due to selection of (pp) pairs among all possible nucleon pairs in ^3He;

$\Omega^{^3He}$ = is the probability that two nucleons be closer than 1 fm in ^3He;

$\sigma^{\pi}_{2p}(E_\gamma)$ is the sum of the following cross sections:

(9)

a) $\gamma + p \rightarrow \pi^+ + n$

b) $\gamma + p \rightarrow \pi^o + p$

c) $\gamma + p \rightarrow \pi^+ + \pi^- + p$

d) $\gamma + p \rightarrow \pi^+ + \pi^o + n$

e) $\gamma + p \rightarrow \pi^o + \pi^o + p$

$P_f^{(2N,2\pi)}(E_\gamma)$ is the probability that the equilibrium state decay in $2N+2\pi$ in the Fermi model;

$N_{2\pi^+}$ is the probability that the final state be $2n + 2\pi^+$. We can set $N_{2\pi^+} = 1/4$, since in a statistical model the final state cannot remember the initial one.

$\varepsilon(^3He)$ is the Pauli exclusion factor and it is difficult to evaluate. As an order of magnitude we quote the one calculated for the reaction:

$$\gamma + {}^3He \rightarrow 3n + \pi^- : \ \varepsilon = 0.27^{(1)}.$$

Calculation of $\Omega^{^3He}$. We developed a Montecarlo calculation by using the Gunn-Irving wave function. The result is $\Omega^{^3He} = 0.257$. As a control we also determined the r.m.s. radius of ^3He (1.98 fm).

Cross section $\sigma^{\pi}_{2p}(E_\gamma)$. The cross sections (9 a, b, c) were taken from ref. (23). As concerns the reactions (9 d, e), only approximative experimental evaluations exist[24, 25] for the ratios:

$$\sigma(p, \pi^+\pi^o)/\sigma(p, \pi^+\pi^-) \simeq 1;\ \sigma(p, \pi^o\pi^o)/\sigma(p, \pi^+\pi^-) \simeq 0.15$$

in the interesting energy range.

Calculation of P_f. The formula[21]

$$(10) \qquad S(s,n) = \frac{6.31}{s^{3/2}\, w^{1/3}} \left(\frac{98.8}{w}\right)^{\frac{s-1}{2}} \frac{\left(6.31\,(w-S)/w^{1/3}\right)^{3n+\frac{3}{2}s-1}}{(3n+\frac{3}{2}s-1)\,!}$$

was used, where s is the nucleon number, n the pion number and $w = E_\gamma + 2$ (in unit of m_p). We get:

$$P_f^{(2,2)} = \frac{S(2,2)}{S(2,0)+S(2,1)+S(2,2)}$$

In Figs. 14 and 16 the values of

$P_f^{(2,2)}(E_\gamma)$, $P_f^{(2,0)}(E_\gamma)$, $P_f^{(2,1)}(E_\gamma)$ are shown.

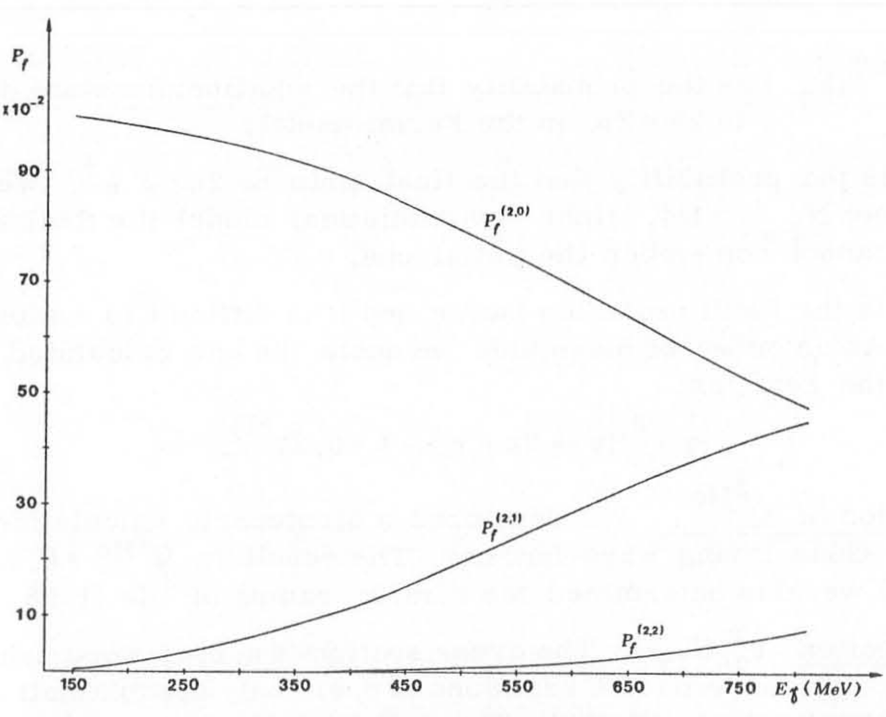


FIG. 14 - Behaviours of the Fermi factors $P_f^{(2,0)}$, $P_f^{(2,1)}$, $P_f^{(2,2)}$, giving the probability that the statistical system decays in two nucleons and 0, 1, 2 pions.

From eq. (8) we obtain at last:

$$\sigma^{^3He}_{2\pi^+}(E_\gamma) = 2.14 \times 10^{-2} \quad \sigma^{\pi}_{2p}(E_\gamma)\, P_f^{(2,2)} \; \varepsilon(^3He) \tag{11}$$

which behaves as shown in Fig. 15.

If we also wish to consider the formation of an equilibrium state with three nucleons, we have to set s = 3 in (10) and we get $P_f^{(3,2)} \simeq 1/8\, P_f^{(2,2)}$ (Fig. 16), while the probability that three nucleons be closer than 1 fm is Ω^2 and the total cross section for single and double pion photoproduction is $\sigma^{\pi}_{3He} = 3/2 \; \sigma^{\pi}_{2p}$, if we assume that neutron cross sections are equal to proton ones. Moreover, a further charge configuration appears among the possible final states: $\pi^- \pi^o$. Therefore, $N^{3N}_{2\pi^+} = 4/5 \; N^{2N}_{2\pi^+}$. We get finally:

$$\sigma^{3N}_{2\pi^+} \simeq 3 \; \frac{3}{2} \; 0.257 \; \frac{1}{8} \; \frac{4}{5} \; \sigma^{2N}_{2\pi^+} \simeq \frac{1}{9} \; \sigma^{2N}_{2\pi^+}$$

Hence, the three nucleon contribution is negligible.

We consider now the reactions:

(7) a) $\gamma + {}^4He \rightarrow 4n + 2\pi^+$, b) $\gamma + {}^4He \rightarrow 4p + 2\pi^-$

In a completely analogous way we obtain:

$$\sigma^{^4He}_{2\pi^\pm}(E_\gamma) = N_{2p}\; \Omega^{^4He} \; \sigma^{\pi}_{2p}(E_\gamma)\; P_f^{(2,2)}(E_\gamma)\, N_{2\pi^\pm} \; \varepsilon(^4He)$$

where $N_{2p} = 1/6$, while $\sigma^{\pi}_{2p}(E_\gamma)$, $P_f^{(2,2)}$, $N_{2\pi^+}$ have the same values as for ^3He. The same Montecarlo calculation gives $\Omega^{^4He} = 0.272$.

Therefore, we have:

$$\sigma^{^4He}_{2\pi^\pm} \simeq 0.6 \;\; \sigma^{^3He}_{2\pi^+} \; \frac{\varepsilon(^4He)}{\varepsilon(^3He)} \tag{12}$$

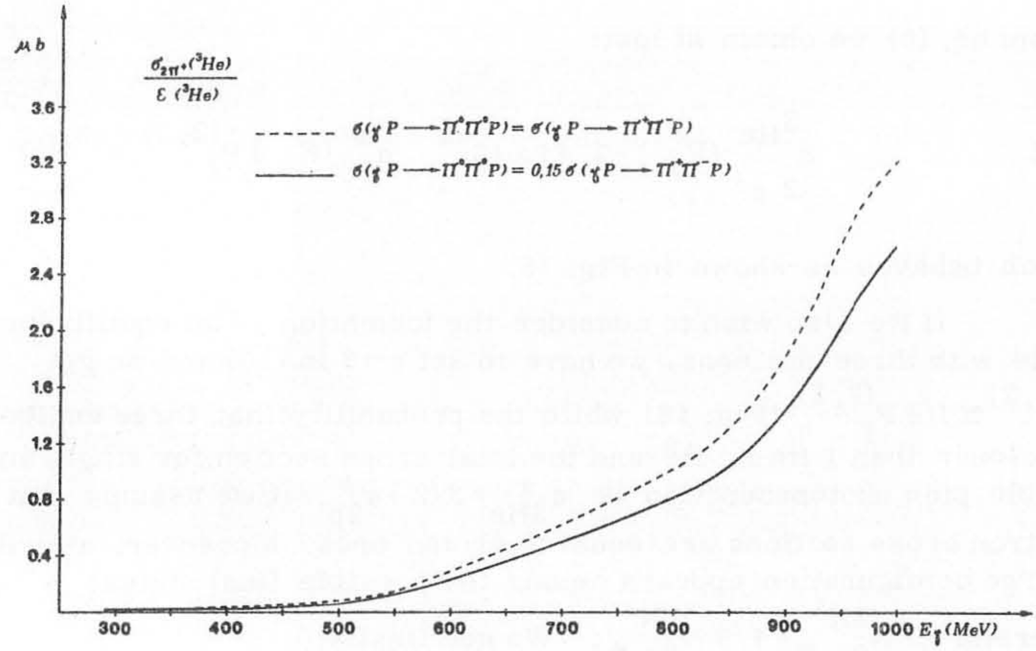


FIG. 15 - Behaviour of the function $\sigma_{2\pi^+}/\varepsilon(^3He) = 2.14 \times 10^{-2}$ x x $\sigma^{\pi}_{2p}(E_\gamma)\, P_f^{(2,2)}(E_\gamma)$.

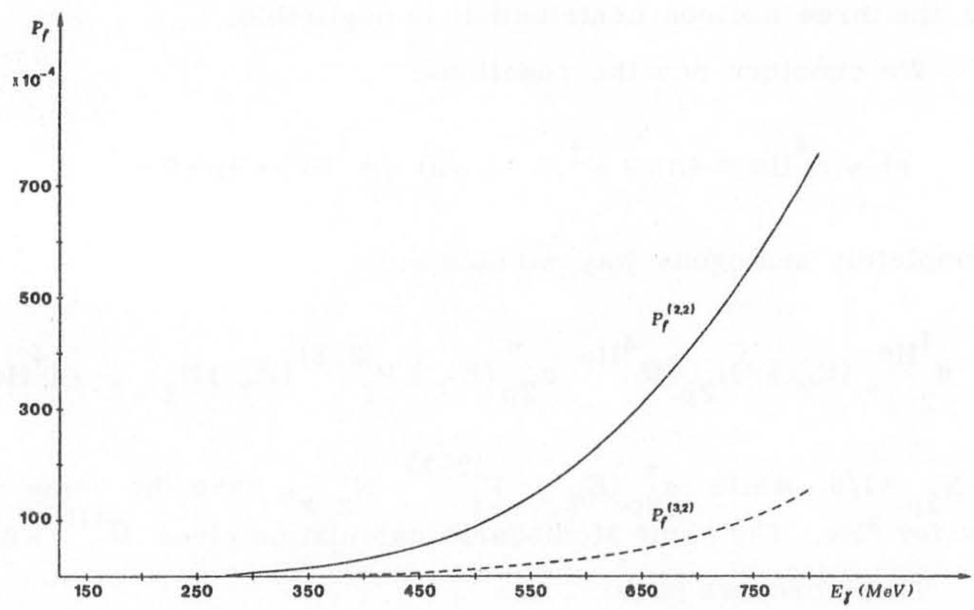


FIG. 16 - Behaviours of the Fermi factors $P_f^{(2,2)}$, $P_f^{(3,2)}$ giving the probability that the statistical system decays in two pions and two or three nucleons.

Evaluation of ε .

The Pauli factor ε is the probability that the final state nucleons of the reactions (6) and (7), exceeding the s state nucleon pair, be in a $L \neq 0$ state.

The calculation is complicated due to the multiplicity of the reacting particles. However, a first estimation is possible if we consider the value calculated for the reaction $\gamma + {}^3He \rightarrow \pi^- + 3n^{(1)}$, already mentioned: $\varepsilon = 0.27$. In effect, for reaction (6) $({}^3He)$ should be about the same, while for the reactions on ${}^4He$, the s - state being totally forbidden for a nucleon pair, one should expect

$$\varepsilon({}^4He) \simeq (0.27)^2, \qquad \text{i.e.,} \quad \varepsilon({}^4He)/\varepsilon({}^3He) \simeq 0.27$$

We will assume these values in the approximative evaluations obtained in Sect. III.

SECTION III. -

By taking into account the photon spectrum in our ${}^3He$ experiment(1) (see Fig. 17) and the relation (11) and by integrating from the double photoproduction threshold up to 800 MeV, we obtain for reaction (6) the expected event number:

$$N_{2\pi^+}({}^3He) = 0.167 \quad \varepsilon({}^3He)$$

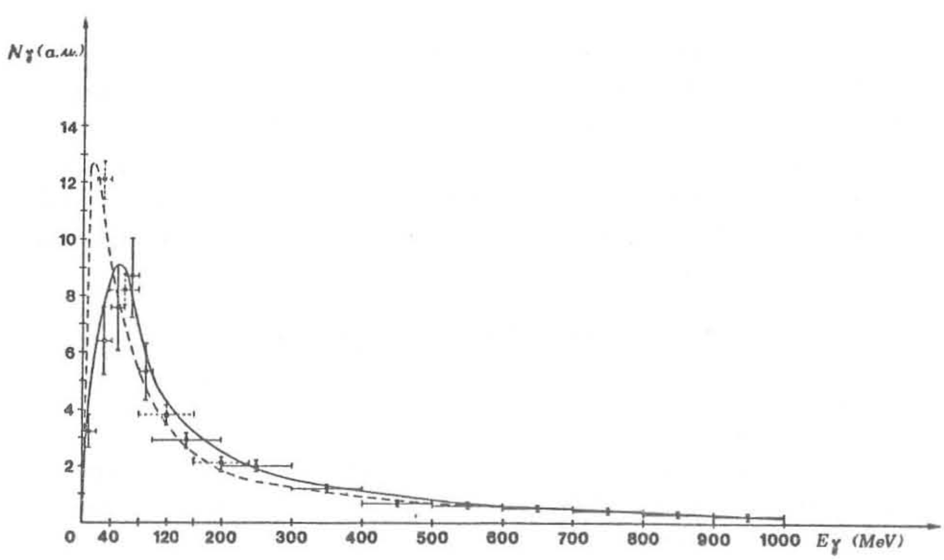


FIG. 17 - Photon spectra from the experiment on ${}^3He^{(1)}$ (full line and points) and on ${}^4He^{(2)}$ (dashed line and points).

If we assume, on the contrary, in contradiction with the uncertain experimental results above mentioned,

(13) $$\sigma(p, 2\pi^{o}) \cong (p, \pi^{+}\pi^{-})$$

we should obtain

$$N_{2\pi^{+}}(^{3}He) = 0.20 \ \varepsilon(^{3}He)$$

For the ^{4}He processes (7) we obtain in an analogous way, by integrating on the photon spectrum up to 1000 MeV (Fig. 17) and by using (12):

$$N_{2\pi^{\pm}}(^{4}He) = 0.114 \ \varepsilon(^{4}He)/\varepsilon(^{3}He)$$

or, alternatively,

$$N'_{2\pi^{\pm}}(^{4}He) = 0.137 \ \varepsilon(^{4}He)/\varepsilon(^{3}He)$$

in the limit (13).

With the mentioned estimates for ε we should obtain, finally:

$$N_{2\pi^{+}}(^{3}He) = 4.5 \times 10^{-2} \quad N'_{2\pi^{+}}(^{3}He) = 5.4 \times 10^{-2}$$

$$N_{2\pi^{\pm}}(^{4}He) = 0.8 \times 10^{-2} \quad N'_{2\pi^{\pm}}(^{4}He) = 1.0 \times 10^{-2}$$

Among the 3006 two prong events of our ^{3}He experiment[(1)] we have selected the non - coplanar ones with the two prongs at minimum ionization by comparison with the electron tracks in the event neighbourhood or, in same cases, by measuring the curvature of the tracks and comparing with completely reconstructed proton or π^{+} tracks from reactions $^{3}He(\gamma, p)d$ and $^{3}He(\gamma, \pi^{+})T$ respectively, with the same curvature.

Some comparisons are shown in Fig. 18. In this way only 5 events were selected as attributable to the reaction (6) with a reasonable confidence level.

As concerns ^{4}He[(2)], only 2 six prong events were identified with two negative track at minimum ionization. These events can only belong to the process (7b), because the total number of six prong events due to ^{12}C or ^{16}O photodisintegration in the methil alcohol of the diffusion chamber calculated for the experiment (2) is some 10^{-2}, i.e. negligible.

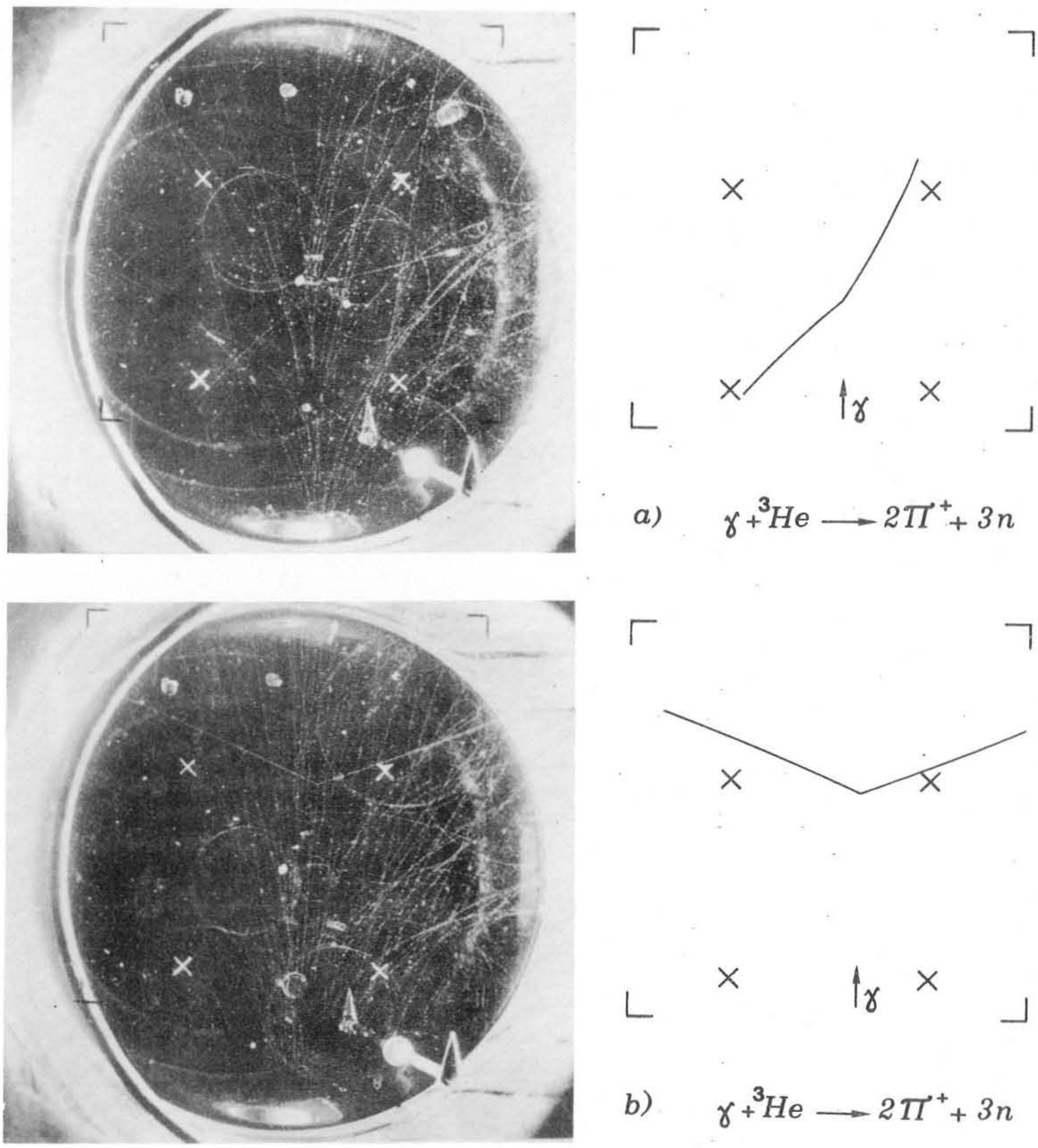


FIG. 18 - Photograms on ^{3}He :

a) and b) - events ascribed to reaction $\gamma(^3\mathrm{He}, 2\pi^+)\,4n$.

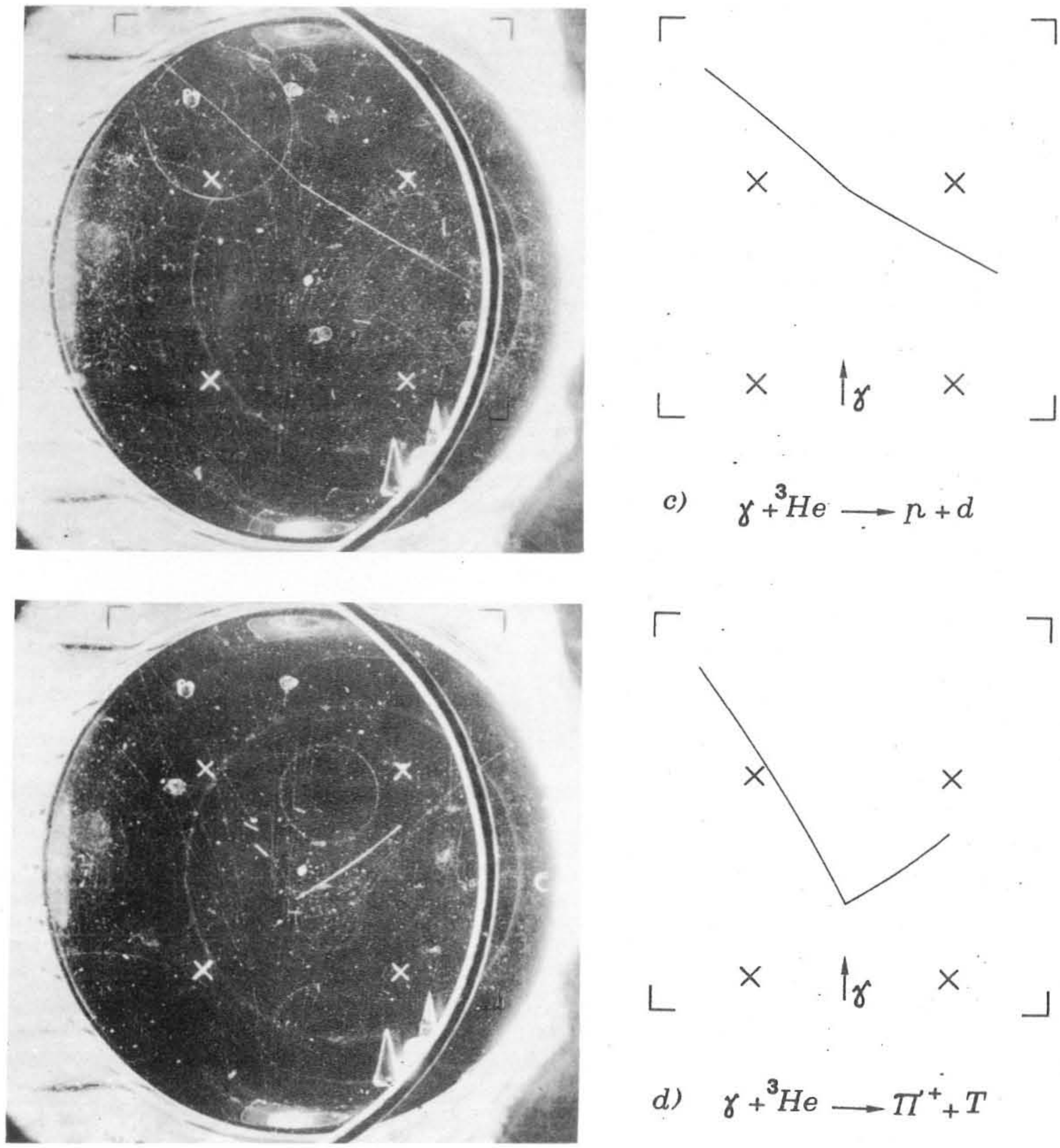


FIG. 18 - Photograms on ^{3}He :
c) reaction $\gamma({}^3\mathrm{He}, \mathrm{p})\mathrm{d}$;
d) reaction $\gamma({}^3\mathrm{He}, \pi^+)\mathrm{T}$.

In the same experiment we also found 10 possible candidates for the reaction (7a). However, because of the worse quality of the pictures containing the events, this number will not to be considered. In Tablé II the calculations are compared with the experimental data.

TABLE II

events / nuclei		calculated values				experimental data	
		$N_{2\pi^+}$	$N_{2\pi^-}$	$N_{2\pi^+}$	$N_{2\pi^-}$	$N_{2\pi^+}$	$N_{2\pi^-}$
^{3}He	(a)	$0.167\ \varepsilon(^3He)$	---	0.045	---	5 ± 2.3	---
	(b)	$0.20\ \varepsilon(^3He)$	---	0.054	---		
^{4}He	(a)	$0.134\ \varepsilon(^4He)/\varepsilon(^3He)$	$0.114\ \varepsilon(^4He)/\varepsilon(^3He)$	0.008	0.008	10 (?)	2 ± 1.4
	(b)	$0.137\ \varepsilon(^4He)/\varepsilon(^3He)$	$0.137\ \varepsilon(^4He)/\varepsilon(^3He)$	0.010	0.010		

(a) $\sigma(\gamma p \rightarrow \pi^o \pi^o p) = 0.15\ \sigma(\gamma p \rightarrow \pi^+ \pi^- p)$

(b) $\sigma(\gamma p \rightarrow \pi^o \pi^o p) = \sigma(\gamma p \rightarrow \pi^+ \pi^- p)$

$\varepsilon(^3He) = 0.27$

$\varepsilon(^4He) = \left[\varepsilon(^3He)\right]^2$

It is interesting to remark that, if we assume the mentioned estimates for the Pauli factors ε :

$$\varepsilon(^3He) = 0.27 \qquad \varepsilon(^4He) = (0.27)^2$$

the ratio of 2 π^+ photoproduction on ^{4}He and ^{3}He respectively in the two experiments, depends on a factor $\varepsilon = 0.27$, on a factor 0.6 due to the different properties of the two nuclei (relation (12)) and, finally, on a factor 1.2 due to the somewhat different bremsstrahlung spectra.

Hence, indipendently from the assumption of the statistical model, one should have:

$$(14) \qquad N_{2\pi^\pm}(^4He) = 0.27 \,.\, 0.6 \,.\, 1.2\ N_{2\pi^+}(^3He) = \frac{1}{5} N_{2\pi^+}(^3He)$$

As mentioned, we have found two 2 π^- events in ^{4}He and five 2 π^+ events in ^{3}He: the ratio of the two numbers agrees with prevision (14) within statistics.

However, we want to remark the big discrepance between the single values and the prevision of the statistical model (Table II). Evidently, the simple statistical approach used cannot describe such type of reactions and, as for the double charge exchange processes, one has to look for new detailed mechanisms with could give a remar-kable contribution to the total cross section in the explored energy interval.

Unfortunately, such reactions are somewhat difficult to investigate experimentally due to both their very small cross sections and their particular features, so that, in spite of the great interest, we cannot expect a great amount of new data in the future.

In any case, photoproduction of two pions with the same charge represents an important alternative to the double charge exchange reactions for testing any theory or model of nuclear processes, in which the nuclear correlations come into play.

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