ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Лаборатория ядерных проблем

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Abstract

The low-energy region of the H^3 -momentum spectra at 5.8° in the lab. system has been measured in (p + d) -collisions at the proton energy of 670 MeV. We have not got the confirmation of the resonance interaction between two pions in the states with the isotopic spin $T_{\pi\pi} = 1$ and the total energy from 275 up to 400 MeV in the center - mass of the $\pi\pi$ system. It has been found that the cross section for the two pion production in the state with $T_{\pi\pi} = 0$ is greater by an order of a magnitude than that with $T_{\pi\pi} = 0$, up to the total energy of 400 MeV in the c.m.s. of two pions.

Introduction

Recently the existence of the resonance $\pi\pi$ -interaction in the states with the isotopic spin $T_{\pi\pi} = 1$ has begun widely discussed /1,2/. Possible parameters of this resonance depend both upon the electromagnetic properties of a nucleon /3/, and on the nature of the strong interaction between nucleons /4,5/. In order to investigate such a resonance directly, some authors /6,7/ suggested the processes in the final state of which two pions are emitted. For instance, in order to observe the $\pi\pi$ resonance with the isotopic spin $T_{\pi\pi} = 1$ the authors /7/ suggested the study of the energy spectra of deuterons and He^4 nuclei in the reactions

$$\begin{aligned} &p+p \to d+\pi^+ + \pi^0 \\ &\pi^+ + He^4 \to He^4 + \pi^+ + \pi^0 \\ &\pi^+ + d \to d+\pi^+ + \pi^0 \end{aligned} \quad (1)$$

The idea of such experiments is as follows. It is well-known, that the resonance interaction between any two particles in the final state gives rise to a strong deformation in the spectrum of the third particle. Therefore, if the observed spectrum of heavy particles in reactions (1) is compared with the phase-space volume element, then a possible anomaly of the result will prove the existence of the resonance. Besides, it allows to determine its general parameters.

Such a method of investigation was employed in /9/, the authors of which measured the momentum spectra of He^3 and He^3 nuclei emitted in ($p+d$) -collisions. In this case the following reactions are possible:

$$p+d \to \begin{cases} He^3 + \pi^0 & (2a) \\ He^3 + \pi^0 + \pi^0 & (2b) \\ He^3 + \pi^+ + \pi^- & (2c) \\ He^3 + \omega^0 & (2d) \end{cases}$$

$$p + d \rightarrow \begin{cases} H^3 + \pi^+ & (3a) \\ H^3 + \pi^+ + \pi^0 & (3b) \\ H^3 + \omega^+ & (3c) \end{cases}$$

where ω is a hypothetical particle with a mass intermediate between those of a π -meson and a K -meson.

The momentum spectra of He^3 nuclei were measured at the proton energy of 743, 695, 648 and 624 MeV. The spectra obtained were compared with the statistically independent distribution. The authors of /9/ did not succeed in fitting this distribution with the observed spectra at either of the energies indicated. The spectra measured had a narrow peak which corresponded either to the total energy of the two pions, or to the mass of a hypothetical π^0-particle equal to (310 ± 10) MeV.

The momentum spectrum of H^3 nuclei at the proton energy of 743 MeV had not been measured with a sufficient accuracy. However, on the momentum spectrum of H^3 nuclei given in /9/ one can observe besides the peak, corresponding to the momentum of 1.55 BeV/c, from reaction (3a) also some increase of the yield of H^3 nuclei with the momentum 1.4 BeV/c.

All these results of the experiments /9/ were treated as an indication that these two pions have the resonance interaction in the state with $T_{\pi\pi} = 1$. However, this conclusion of the authors /9/ needs a further experimental check, inasmuch as the total energy of two pions at which this anomaly was observed is in essential contradiction with the resonance energy predicted theoretically /3/.

The aim of our experiments was to investigate the momentum spectrum of H^3 nuclei more precisely. This spectrum is very important since in this case the system consisting of π^+- and π^0-mesons may be in the state with the isotopic spin $T_{\pi\pi} = 1$ only. In the experiments performed the region of the momentum spectra of H^3 nuclei which is adjacent to the low-energy branch of reaction (3a) has been measured at the proton energy of 670 MeV. The region of the momentum spectrum of H^3 nuclei from 840 MeV/c up to 1100 MeV/c corresponds to the total energy of two pions in their c.m.s. from 275 up to 400 MeV, respectively. (Fig. 1).

Experimental Conditions

A general experimental scheme is shown in Fig. 2. The external proton beam with an intensity of about 10^{11} sec^{-1} was focused by magnetic quadrupole lenses at the gaseous deuterium or hydrogen target filled up to the pressure of 3 atm. Secondary charged particles generated in the gaseous target were selected by a collimator placed at 5.8^0 to the proton beam axis. After the deflection in the analysing magnet at the angle of 27^0 the particles with a definite effective momentum passed through the collimator in the shielding concrete wall and were detected by a telescope consisting of seven scintillation counters. H^3 nuclei were selected by the time of flight, by the range and by the ionization losses in four scintillation counters. This made it possible to select reliably the particles with high ionization against the high level of the background of outside particles with lower ionization /10/.

The pulses from counters '14' were fed to the coincidence circuit with the resolving time of about 6 nsec, the pulses from the first counter were delayed for a time necessary for H^3 nuclei to cover the distance of 3.2m between these counters. One of the counters '11' selecting by the magnitude of the ionization was placed in front of the first counter which selected the particles by the time of flight, i.e., at a large distance from the rest counters '11'. This was done in order to decrease the background from the stars which the particles having smaller ionization than H^3 nuclei formed inside the counters and the absorber.

In Fig.3 the counting characteristics of the telescope are plotted against the thickness of the slowing down filter /I/, the discriminator threshold /II/ and the voltage of one of the counters which selected the particles by the time of flight /III/. A similar characteristic has been also obtained of the voltage-dependence at another counter.

Results of Measurements and Their Discussion

Fig. 4 shows the results of the measurements of the momentum spectrum of H^3 nuclei. The abscissa axis is the current of the deflecting magnet in the relative units, the ordinate axis is the counting difference from the deuterium and hydrogen target filled up to the same pressure. The background of the hydrogen target was 20-30% of the maximum counting rate of H^3 nuclei in reaction (3a). Arrow N1 indicates the minimum value of the current corresponding to the lower limit of the spectrum of H^3 nuclei. Arrow N2 indicates the value of the current corresponding to the energy of two pions in their own c.m.s. equal to 310 MeV and to the momentum of H^3 nuclei equal to 875 MeV/c.

The statistical analysis of the results of measurements shows that the yield of H^3 nuclei with the momentum 875 MeV/c at 5.8^0 in the lab. system does not exceed 6% of that in reaction (3a) at the same angle with the confidence of 90%.

The absolute cross section for reaction (3a) has been measured by comparing it with the known cross section for the reaction $p+p \to d+\pi^+$ /11/. Calculated in the c.m.s. and reffered to the angle of π^+-meson emission the cross section for reaction (3a) is

$$\frac{d\sigma}{d\Omega}\,(\Theta_{\pi^+}=12^{\circ}) = (9.1 \pm 0.5)\ 10^{-30} cm^2/sterad. \qquad (4)$$

The cross section for reactions (3b), (3c) reffered either to the angle between the velocity vector of the mass-system of the light particles and the beam axis, or to the angle of α -particle emission is

$$\frac{d\sigma}{d\Omega} \; (\vartheta_\alpha - 12^o) < 0.2 \; 10^{-30} cm^2 \, sterad. \qquad (5)$$

with the confidence of 30%.

As is seen from Fig. 4, obvious anomalies in the spectrum of H^3 nuclei are not observed in the range of the total energies of light particles in their c.m.s. from 275 MeV up to 400 MeV.

The cross section for reaction (2a) (Fig. 5) has been also measured for the high-energy branch of this reaction. It has been found that in the c.m.s.

$$\frac{d\sigma}{d\Omega} \; (\vartheta_{\pi^o} = 154^\circ) = (0.295 \pm 0.032) \; 10^{-32} cm^2 / sterad. \qquad (6)$$

Besides, the yield of He^3 nuclei from reactions (2b, 2c) has been measured for three values of the momenta in the region adjacent to the high-energy branch of reaction (2a). The results of these measurements plotted in Fig. 5 show that the cross section for reactions (2b) (2c) can be compared by a magnitude with that for reaction (2a).

We did not succeed in making direct measurements in the region of the spectrum of H^3 nuclei which is adjacent to the high-energy branch of reaction (3a) because of the large background and high level of the counting rates due to the protons elastically scattered on deuterium.

When striking at the corresponding currents the collimator in the shielding concrete wall through the deflecting magnet, the protons produce secondary particles on the internal walls of this collimator. These secondaries may be detected by a telescope tuned to H^3 nuclei with little but a noticeable probability.

Yet, we make an attempt to compare quantitatively our results with the data of paper /9/. With this aim the angular distributions of reactions (3a) and (3c) have been calculated in the impulse approximation like it was done in papers /12, 13/ for reaction (3a). In the calculations the wave function of Hulthen was used for a deuteron, and for the tritium nucleus -- the wave function of an exponental form

$$\Psi_t = N_t \exp \{ -a_t \sqrt{\textstyle\sum_{ij} r_{ij}^2} \}, \qquad (7)$$

where $\vec{r}_{ij} = \vec{r}_i - \vec{r}_j$ is the distance between the nucleons i and j. The parameter a_t is found from the energy of the Coulomb interaction in a He^3 nucleus, which is 771 KeV. The radius of the repulsive core of the nucleon was assumed to be zero.

Just in the same manner the angular dependence of H^3 nuclei emission in reactions (3b) (3c) has been calculated. At the same time we assumed that the process occurs at two stages: first, two π-mesons or a ω^{+}-particle are produced in the reactions

$$p+p \left\{ \begin{array}{l} d+\pi^{+}+\pi^{0} \\ d+\omega^{+} \end{array} \right. \quad (8)$$

and, then a neutron and a deuteron form a T^{3} neucleus. The calculation has been made under two extreme assumptions about the angular distribution of deuterons in reactions (8): a) isotropic and b) - $\cos^{2}\Theta$. The normalization factor was determined from a possible relationship between reactions (3a) and (3b) which, according to the estimate of /9/ is 1.9 : 1 in the lab. system and depends weakly on the proton energy.

Under these two extreme assumptions the angular distributions calculated for reactions (3c), (3b) are only little different at the angles close to 0^{o} and 180^{o} in the c.m.s. This allows to estimate rather definitely an expectation value of the cross section for reactions (3b), (3c) in its low-energy branch for the angle of 5.8^{o} in the lab. system. The yield of T^{3} nuclei calculated by such a method, (in Fig. 4 it is shown by a dotted line), exceeds approximately by an order of a magnitude the upper limit of the cross section for reactions (3b); (3c) measured in the course of this investigation.

Thus, the results we have obtained and the given estimates of possible angular distributions of reaction (3c) indicate that the $\pi\pi$-resonance interaction in the state with the isotopic spin $T_{\pi\pi}=1$ and the total energy of 310 MeV is absent.

As far as at present there are quite definite indications to the absence of the vector meson with $T=0$ /16/ and the mass of 300-400 MeV, then it is also unlikely to account for the anomalies in reaction (2d) by assuming the existence of such a meson.

A possible explanation of the non-monotony observed in the spectrum of He^{3} nuclei /9/ may be threshold effects /17, 18/ in reactions (2b), (2c) which are due to the endothermic process

$$\pi^{0}+\pi^{0}\rightarrow\pi^{+}+\pi^{-} \, {}^{*} \quad (9)$$

As the analysis of the threshold effects by the method of dispersion relations /19/ shows the energy non-monotonies in the reactions involving three particles in the final states may extend far enough from the threshold of the corresponding endothermic process.

The authors express their gratitude to L.I. Lapidus for the interest in the investigations and discussions, as well as to B.M. Pontecorvo for fruitful remarks.

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* A possibility of such an interpretation has been pointed out by L.I. Lapidus.

Conclusions

1. The results obtained in these experiments do not confirm the existence of the $\pi\pi$ resonance in the states with the isotopic spin $T_{\pi\pi}=1$ for the interval of the total energy in the c.m.s. of two mesons from 275 up to 400 MeV. They allow also to conclude that there exists no ω particle with the isotopic spin $T=1$ and the mass of 310 MeV.

2. The comparison of the cross sections for the reactions $p+d\to H^3+\pi^++\pi^0$ and $p+d\to He^3+\pi+\pi$ shows that the cross section for the two pions production in the state with the isotopic spin $T_{\pi\pi}=0$ exceeds approximately by an order of a magnitude that with $T_{\pi\pi}=1$ up to the total energy of two pion equal tp 400 MeV (c.m.s.).

Such a ratio between the cross sections is likely to change at higher energies. What the data on the process $\pi N\to\pi\pi N$, obtained at energies of pions of 500 MeV, point to /20/.

3. An alternative explanation of the anomalies in the spectrum of He^3 nuclei emitted in the reactions $p+d\to He^3+\pi^0+\pi^0$ $p+d\to He^3+\pi^++\pi^-$ should be looked for in the threshold effects due to the endothermic process $\pi^0+\pi^0\to\pi^++\pi^-$.

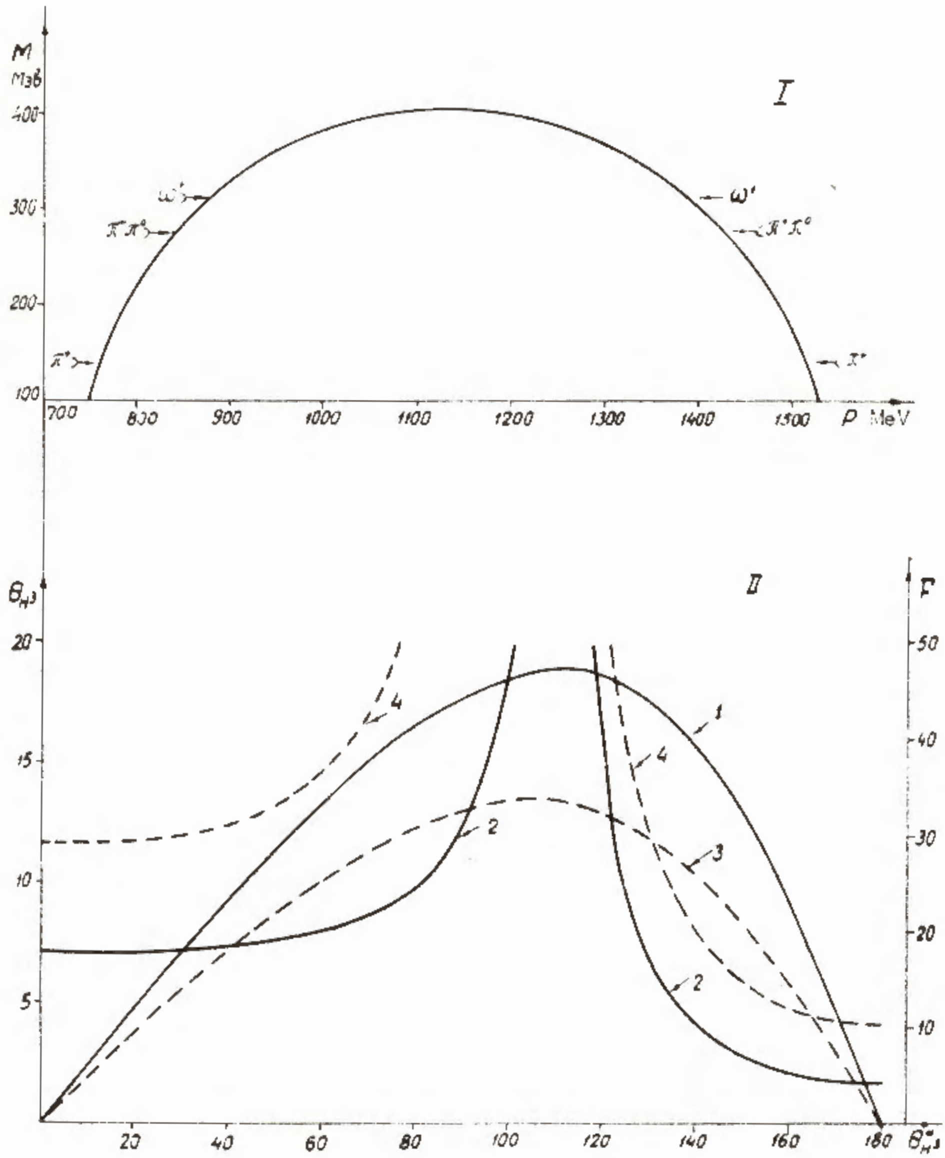

Fig. 1.

Kinematic characteristics of the reactions $p+d \to H^3+\pi^+$ and $p+d \to H^3+\omega^+$ at the proton energies of 670 MeV.

I. The abscissa axis is the momentum of H^3 nuclei emitted at 5.8° in the lab. system. The ordinate axis is the total energy of light particles produced in the reactions $p+d \to H^3+\pi^3$, $p+d \to H^3+\omega^+$, $p+d \to H^3+\pi^++\pi^0$ in their own c.m.s.

II. Curve 1 (or 3) shows the relationship between the angle of the emitted H nuclei in the lab. system and the angle for the reaction $p+d \to H^3+\pi^+$ (or $p+d \to H^3+\omega^+$) in the c.m.s. Curve 2 (or 4) – the kinematic coefficient of the transition from the cross section in the c.m.s. to those in the lab. system for the reaction $p+d \to H^3+\pi^+$ (or $p+d \to H^3+\omega^+$) depending upon the angle of H^3 nuclei emission in the c.m.s.

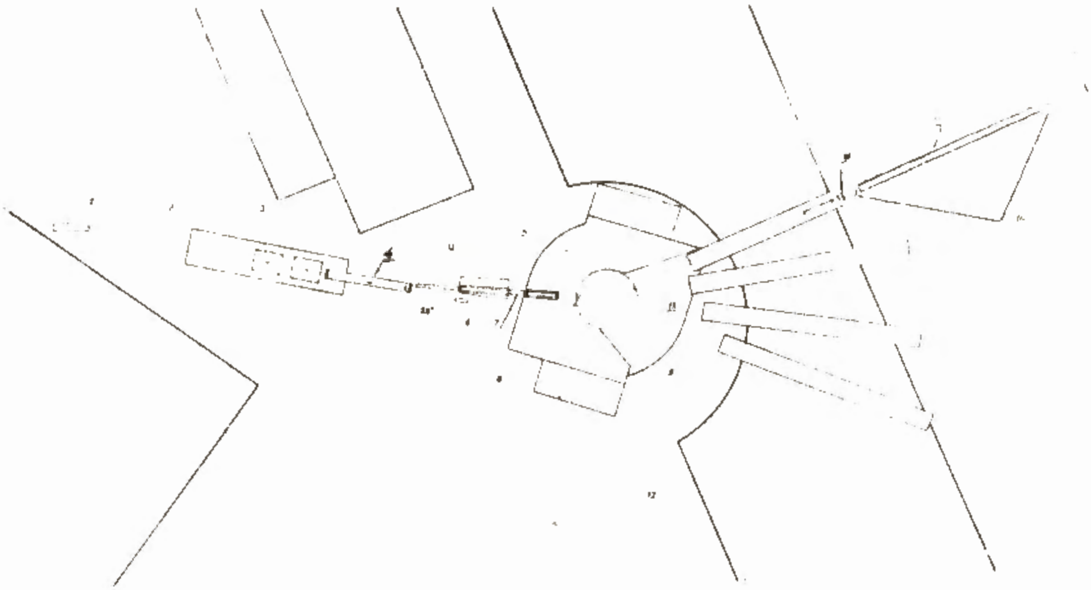

Fig. 2.

Experimental set-up

1. – deflection pieces
2. – external proton beam
3. – magnetic quadrupole lenses
4. – gaseous target
5. – lead shilding
6. – monitor
7. – the trajectory of secondary charged particles
8. – deflecting electromagnet
9. – focusing shimms
10. – concrete shielding
11. – telescope consisting of five scintillation counters
12. – shielding wall
13. – vacuum pipe
14. – scintillation counters selecting by the time of flight

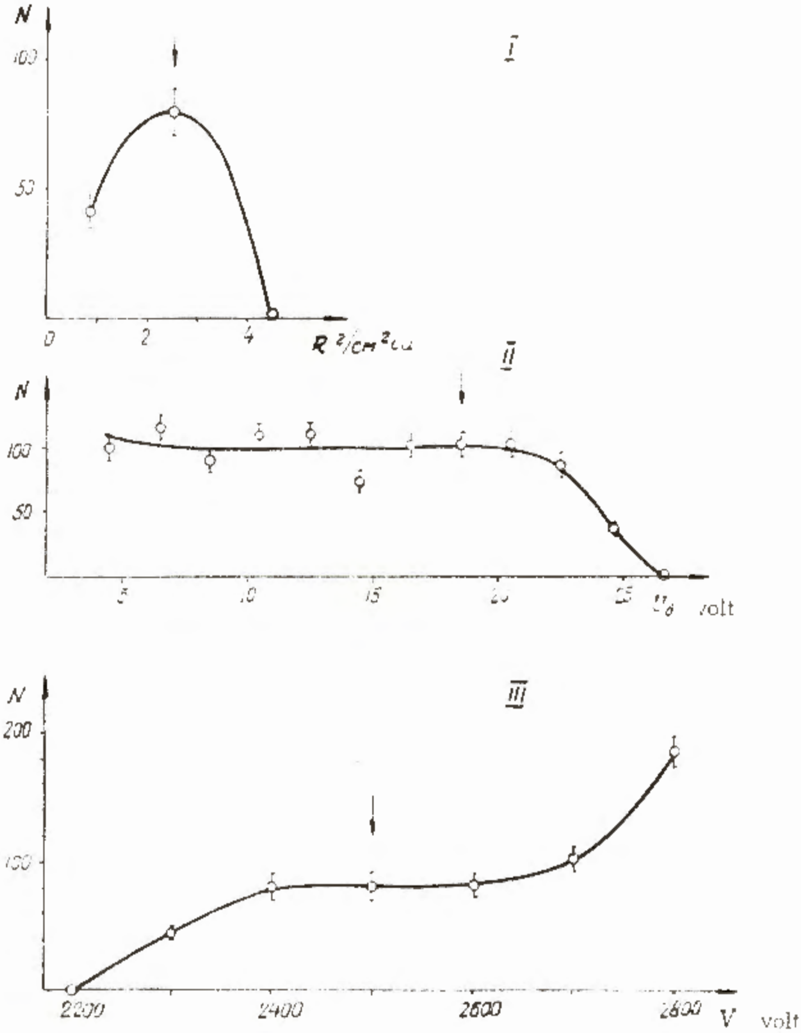

Fig. 3.

Conditions of H^3 nuclei detection from reaction $p + d \to H^3 + \pi^+$

I. The counting rate of the telescope *vs* the thickness of the slowing down filters.

II. The counting rate of the telescope *vs* the discriminator threshold.

III. The counting characteristic of the telescope *vs* the voltage at one of the counters selecting by the time of flight.

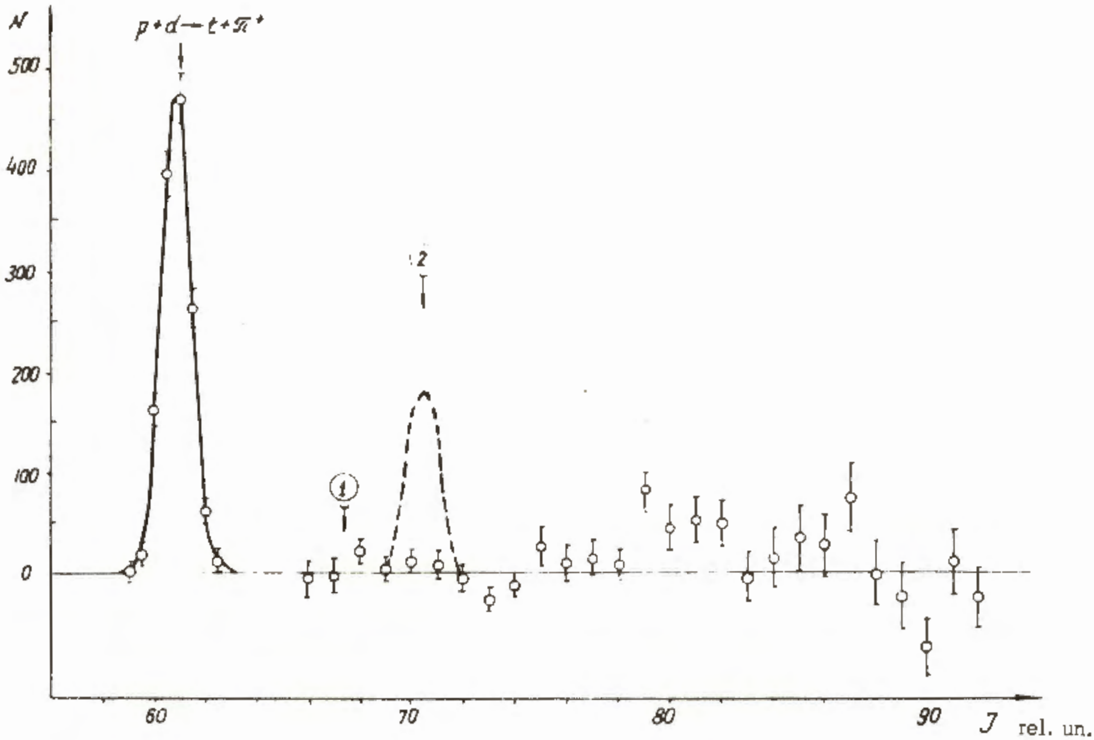

Fig. 4.

Momentum spectrum of H^3 nuclei detected at 5.8° in the lab. system. The abscissa axis is the current of the deflecting magnet, the ordinate axis is the counting difference of the deuterium and hydrogen target which is reduced to the unit interval of momenta. The arrow N 1 indicates the value of the current corresponding to the lower limit of the spectrum of H^3 nuclei from the reaction $p + d \to H^3 + \pi^+ + \pi^0$. Arrow N 2 indicates the value of the current corresponding to the total energy of two pions in their own c.m.s. equal to 310 MeV and to the momentum of H^3 nuclei equal to 875 MeV/c.

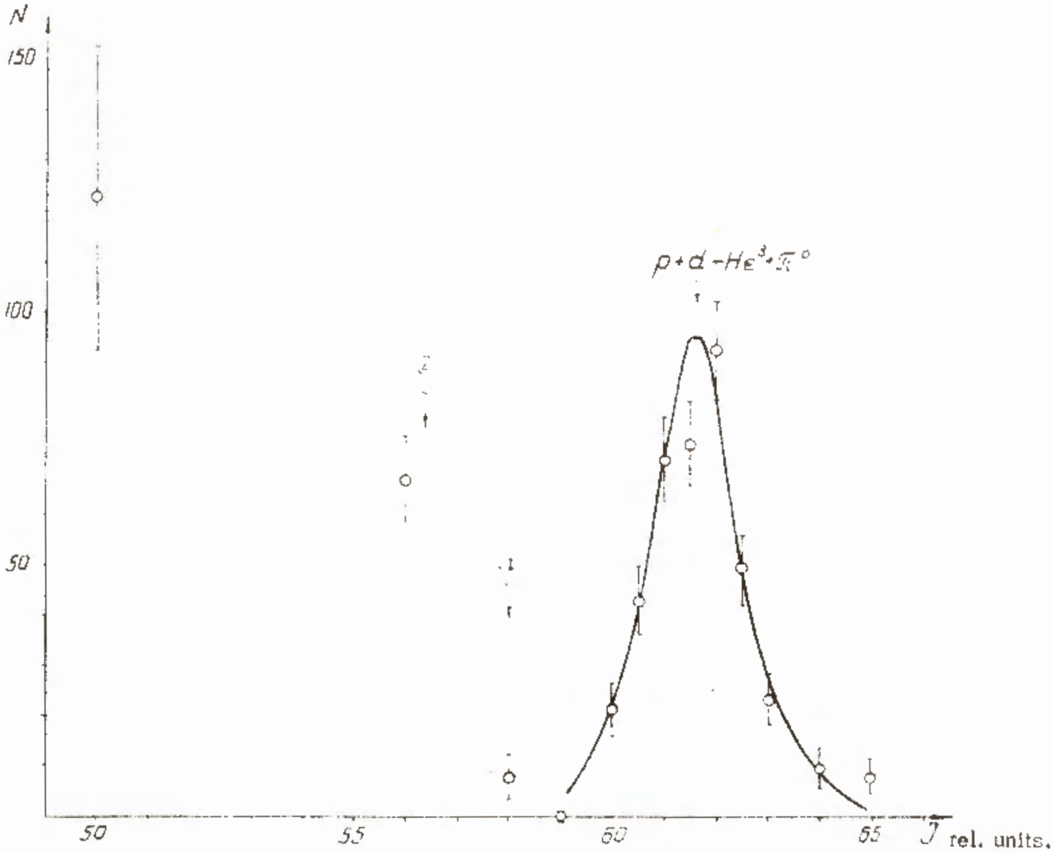

Fig. 5.

The momentum of He^3 nuclei detected at 5.8° in the lab. system. Arrow N 1 indicates the value of the current corresponding to the upper limit of He^3 nuclei from the reactions $p+d \to He^3+\pi+\pi$. Arrow N 2 indicates the value of the current corresponding to the total energy of the two pions in their c.m.s. equal to 310 MeV.

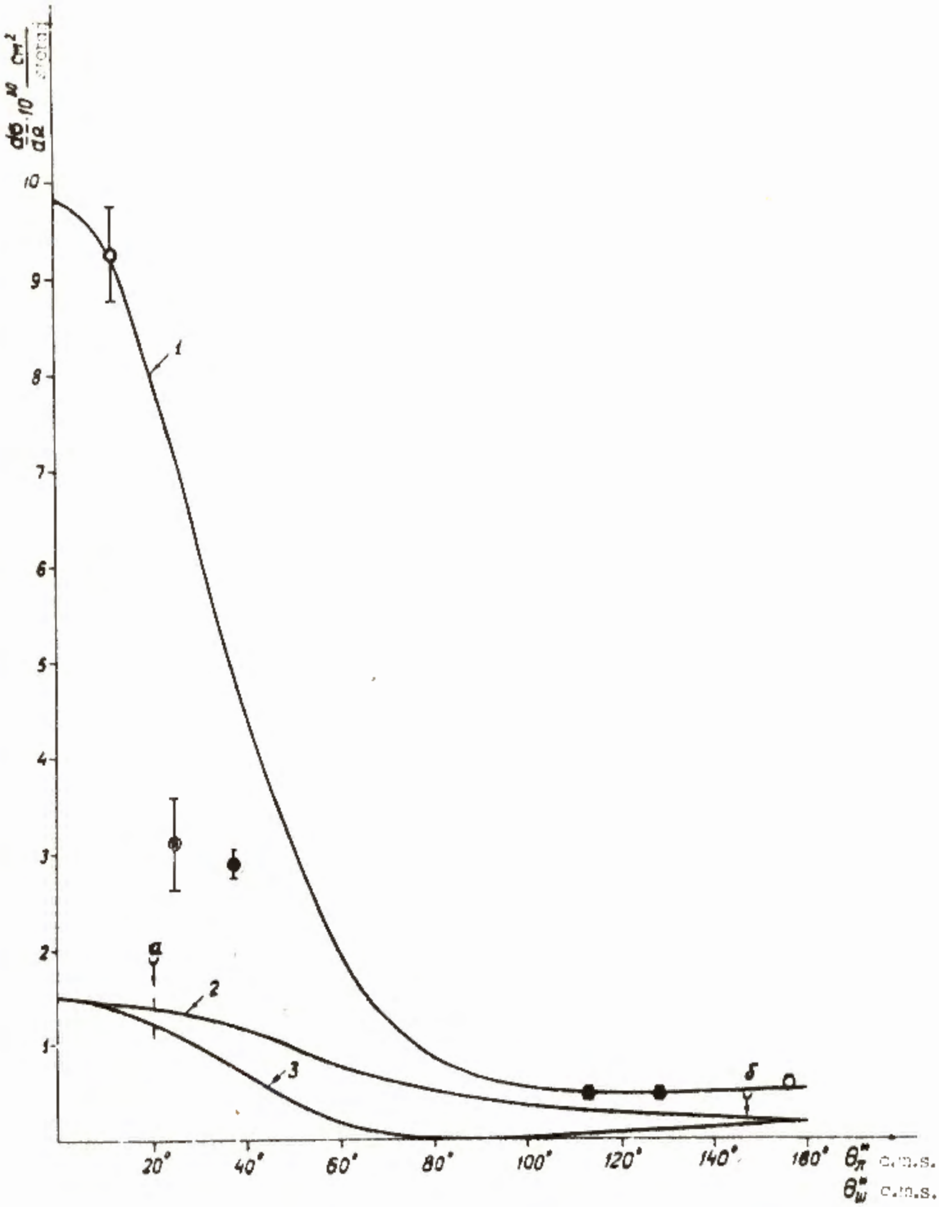

Fig. 6.

The angular dependence of the cross sections for the reactions $p + d \to H^3 + \pi^+$ (cuve 1) and the reaction $p + d \to H^3 + \omega^+$ (curves 2 and 3) calculated in the impulse approximation. Curve 2 (or 3) corresponds to the isotropic distribution (or $\sim \cos^2\vartheta$) of deuterons in the reactions $p + p \to d + \omega^+$ and $p + p \to d + \pi^+ + \pi^0$. The differential cross sections for the reaction $p + d \to H^3 + \pi^+$ were measured at the proton energies: 591 MeV/15/, 670 MeV (this work), 670 MeV/14/. The arrows indicate the angles of observation: (a) – this work, (b) – paper/9/.

References

1. S.D.Drell. Proc.Ann.Intern.Confer. on High Energy Physics, CERN (1958).
2. G.F.Chew. Proc.Ann. Intern.Confer. on High Energy Physics, Rochester (1960).
3. W.R.Frazer, J.R.Fulco. Phys.Rev.Lett., 2, 365 (1959). Phys.Rev.,177, 1609 (1960).
4. J.Bowcock, W.Cottingham, D.Lurie. Phys.Rev.Lett., 5, 386 (1960).
5. F.Cerulus. Nuovo Cim., XIV, 4, 3731 (1959).
6. G.F.Chew. Препринт 1960; N.Cabibbo, R.Gatto. Phys.Rev.Lett., 4, 313 (1960). L.M.Brown, F.Calogero. Phys.Rev.Lett., 4, 315 (1960).
7. Хэ Цзо-сю, Чжоу Гуан-чжао. ЖЭТФ, 39, 1485 (1960).
8. А.Б.Мигдал. ЖЭТФ, 28, 10 (1955).
9. A.Abashian, N.E.Booth, K.M.Crowe. Phys.Rev.Lett., 5, 258 (1960).
10. Ю.К.Акимов, В.И.Комаров, О.В.Савченко, Л.М.Сороко. ПТЭ, №4 (1960).
11. М.Г.Мещеряков, Б.С.Неганов. ДАН СССР, 100, 677 (1955).
12. S.Bludman. Phys.Rev., 94, 1722 (1954).
13. M.Ruderman. Phys.Rev., 87, 383 (1952).
14. Ю.К.Акимов, О.В.Савченко, Л.М.Сороко. ЖЭТФ, 38, 643 (1960).
15. D.Harting, J.Kluyver, A.Kusumegi, R.Rigopoulas, A.Sachs, G.Tibell, G.Vanderhaeghe, G.Weber. Phys.Rev., 119, 1716 (1960).
16. R.Gomez, H.Burkhardt, M.Daybell, H.Ruderman, M.Sands, R.Talman. Phys.Rev. Lett., 5,170 (1960).
17. Л.И.Лапидус, Чжоу Гуан-чжао. ЖЭТФ, 39, 364 (1960).
18. L.Fanda, G.Newton. Phys.Rev., 199, 1394 (1960).
19. Л.И.Лапидус, Чжоу Гуан-чжао. ЖЭТФ, 39, 112 (1960).
20. W.J.Willis. Phys.Rev., 116, 753 (1959).

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