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PRODUCTION OF DEUTERONS IN A ^{4}He-p INTERACTION AT 8.6 GeV/c

B. S. ALADASHVILI,[1] M. BÁNÓ,[2] H. BRAUN,[3] J. P. GERBER,[3] V. V. GLAGOLEV,[4] A. N. GORBUNOV,[5] J. HLAVÁČOVÁ,[6] P. JUILLOT,[3] K. U. KHAIRETDINOV,[5] R. M. LEBEDEV,[4] G. MARTINSKÁ,[6] Z. R. MENTESHASHVILI,[1] A. MICHALON,[3] D. G. MIRIANASHVILI,[1] M. S. NIORADZE,[1] J. PATOČKA,[6] M. SEMAN,[2] T. SOBSZAK,[7] J. STEPANIAK,[7] V. N. STRELTSOV,[4] L. ŠÁNDOR,[2] J. URBAN,[6] L. I. ZHURAVLEVA,[4] A. FUTÓ[2]

The present paper is devoted to an analysis of deuteron production in a ^{4}He-p reaction at the momentum 8.6 GeV/c. Cross section of individual channels are obtained and the possibility of dividing the deuterons into two groups — the slow ones and the fast ones — is shown.

An attempt has been made to explain the existence of slow deuterons by means of a pick-up reaction. It is shown that the treating the fast deuterons as fragments of ^{4}He nuclei, those are mostly spectators. An analysis of $\alpha + p \rightarrow d + p + p + n$ indicates that the probability of d-d association in the ^{4}He nuclei is small.

РОЖДЕНИЕ ДЕЙТРОНОВ ПРИ ВЗАИМОДЕЙСТВИИ ^{4}He-p

Настоящая статья посвящена анализу рождения дейтронов в реакциях ^{4}He-p с импульсом 8,6 Гэв/с. Получены поперечные сечения отдельных каналов и показана возможность разделения дейтронов на две группы: на медленные и быстрые. Сделана также попытка объяснить существование медленных дейтронов на основе реакции подхвата. Показано, что быстрые дейтроны представляют собой осколки ядер ^{4}He, которые в большинстве случаев имеют спектаторный характер. Анализ реакции $\alpha + p \rightarrow d + p + p + n$ показывает, что вероятность образования d-d ассоциации в ядре ^{4}He мала.

[1] Tbilisi State University, SU — TBILISI
[2] Inst. of Experimental Physics SASc, CS — 041 54 KOŠICE
[3] Centre de Recherches Nucléaires, F — STRASBOURG
[4] Joint Inst. for Nuclear Research, SU — DUBNA
[5] Lebedev Physical Institute, SU — MOSCOW
[6] University of P. J. Šafárik, CS — KOŠICE
[7] Institute of Nuclear Research, PL — WARSAW

I. INTRODUCTION

Several experiments have recently been performed to observe interactions of a nucleon with ^{4}He nuclei at relativistic energies (see, for example [1—3]). Most of them has been performed on a ^{4}He nucleus at rest with an experimental set-up unable to detect slow reaction products.

In our experiment, using the ^{4}He beam and a 1 m hydrogen bubble chamber as a detector (the 4π geometry), we had the possibility to identify all events with no more than one outgoing neutral particle, and to study momenta of nuclei fragments in the ^{4}He system with an accuracy of ~40 MeV/c. 10 688 events were used altogether for the present analysis (12.22 μb/event). Normalization was obtained by means of the topological cross section of three-prong events from [4]. The main point of interest in this paper is the production of deuterons with spectator characteristics, which allows to analyse the possibility of the d-d association in ^{4}He nuclei.

II. ANALYSIS OF EXPERIMENTAL DATA

Cuts of momenta given in Table 1 were used in the analysis of experimental data and for the determination of reaction channels. Momentum cuts of pions and

Table 1

Cuts of Momenta Used in the Present Paper

$P_\pi < 1.2$ GeV/c
$P_N < 3.2$ GeV/c
$P_d < 5.2$ GeV/c
$P_t > 5.2$ GeV/c
$P_{^3He} < 7.2$ GeV/c
$P_{^4He} > 7.2$ GeV/c

nucleons were introduced to reduce a misidentification of slow deuterons. Values of momentum thresholds were taken from momentum distributions of pions and nucleons shown in Figs. 1 and 2. The mentioned cuts decrease estimations of the total cross section of deuteron production by 5.6 % and of the cross sections of reaction channels with deuteron production (Table 2) by at most 9 %. The experimentally obtained ratios between the following cross sections

$$\sigma(ddp\pi^0)/\sigma(ddn\pi^+) = 0.63 \pm 0.14$$
$$\sigma(^3\text{He}d\pi^0)/\sigma(td\pi^+) = 0.65 \pm 0.22$$

are in good correspondence to the isospin predictions (0.5), giving evidence of the correctness of our data processing.

The total cross section for reactions with deuteron production is (28.06 ± 0.59)mb and the inclusive cross section for deuteron production is (30.64 ± 0.62)mb.

Fig. 3 shows the momentum distribution for deuterons in channels with no more than one neutral particle (the so called FIT channels). One can see that the deuterons can be divided into two groups: the fast ones and the slow ones. The mean value of momentum for fast deuterons is close to $m_d/m_{^4He} \times P_{^4He}$. This fact indicates their fragmentational origin.

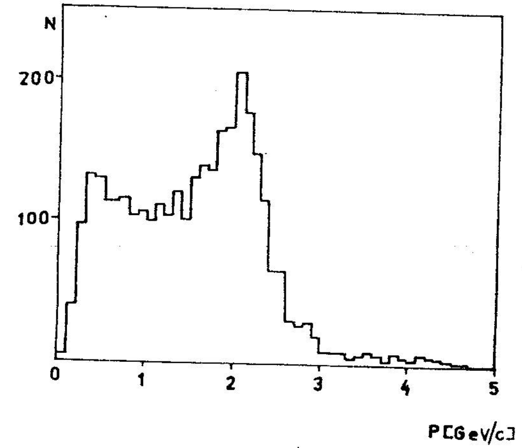

Fig. 1. Momentum distribution of nucleons in channels with deuteron production.

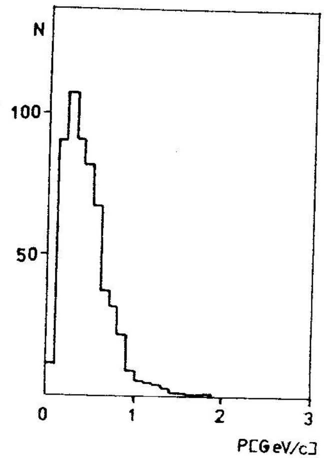

Fig. 2. Momentum distribution of pions in channels with deuteron production.

The momentum distribution for deuterons in channels where a ^3He or ^3H nuclei are observed together with a deuteron, as shown in Fig. 4, suggests an explanation of the origin of the slow deuterons. Since all deuterons here are slow, they can be considered to originate in the pick-up reaction. Let us assume that slow deuterons

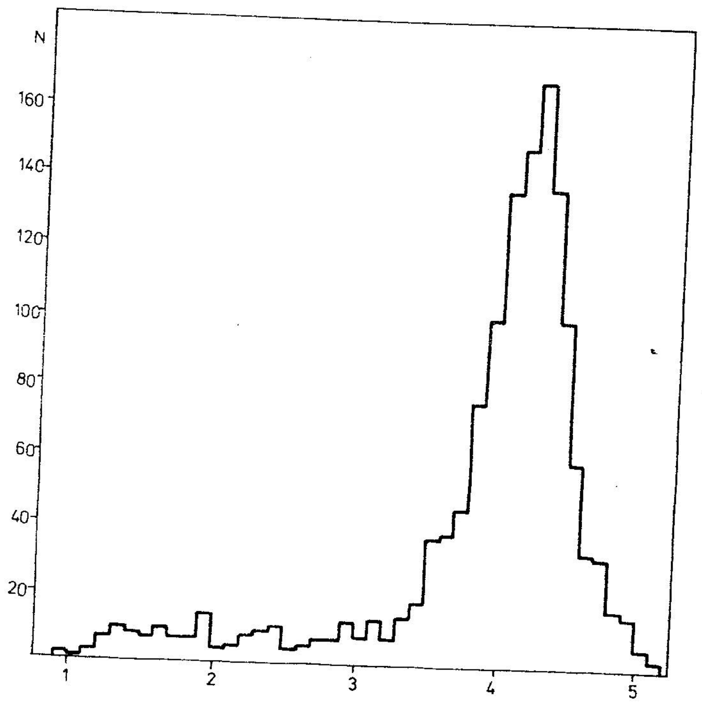

Fig. 3. Momentum distribution of deuterons in FIT channels (the laboratory system)

in all channels are produced in the pick-up reaction involving elementary processes of the following type

$$p+p\to d+\pi^+;\quad p+n\to d+\pi^0 \qquad (4)$$

$$p+p\to d+\pi^+ +\pi^0;\quad p+n\to d+2\pi^0;\quad p+n\to d+\pi^+ +\pi^+. \qquad (5)$$

Thus one should observe a slight deuteron production in channels without π^0 or π^+ mesons. This hypothesis is supported also by the fact that in channels with π^0 and π^+ production

$$\sigma_{slow}/\sigma_{tot}=0.132+0.010, \qquad (6)$$

while in channels without π^0 and π^+ production

$$\sigma_{slow}/\sigma_{tot}=0.017+0.004 \qquad (7)$$

and in $dpp\pi^-$ channel

$$\sigma_{slow}/\sigma_{tot}=0.041\pm0.020 \qquad (8)$$

(σ_{slow} — cross section of the produced deuterons at the momentum $p<2.5$ GeV/c, σ_{tot} — total cross section of a chosen set of channels).

The inclusive cross section of slow deuteron production is (2.37±0.17)mb, while the cross section for FIT channels is (1.40±0.13)mb and for channels with a production of no more than one pion is (0.81±0.1)mb.

We have compared the last value with the prediction of a simple model. The assumption of elementary actions (4) on quasi-free nucleons with an account of the Fermi motion gives an estimate of (0.57±0.09)mb which does not contradict our hypothesis. However, in channels where more than one neutral particle are produced, the value of this cross section is higher than the model estimate. It can be explained by the absence of the kinematic fit and the impossibility of using momentum cuts for neutrons and neutral pions.

We have analyzed the fast deuterons within the framework of the spectator model. We consider as a spectator the particle with the smallest momentum in the ^4He rest system.

The ratio of the cross section for channels with spectator deuterons to the cross

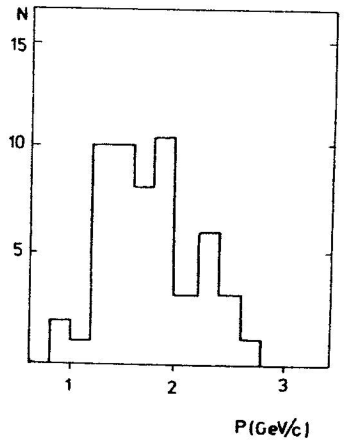

Fig. 4. Momentum distribution of deuterons in channels $^3Hed\pi^0$, $^3Hed\pi^0\pi^0$, $^3Hed\pi^+\pi^-$, $td\pi^+$, $td\pi^+\pi^0$.

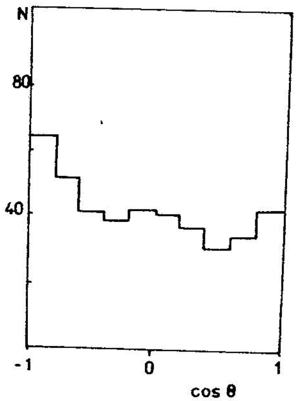

Fig. 5. Angular distribution of spectator deuterons in ^4He rest frame.

section for those with non-spectator deuterons is

$$\sigma_{spect.}/\sigma_{nonsp.} = 1.93 \pm 0.14 \tag{9}$$

and for the reaction

$$^4\text{He} + p \rightarrow d + p + p + n \tag{10}$$

$$\sigma_{spect.}/\sigma_{nonsp.} = 1.44 \pm 0.11\,. \tag{11}$$

Fig. 5 shows the angular distribution of spectator deuterons in the ^{4}He rest system for channel (10). The angular distribution is nearly isotropic, the coefficient of asymmetry being $A = 0.13 \pm 0.05$. In channel

$$^4\text{He} + p \rightarrow d + d + p \tag{12}$$

the angular distribution of spectators is also nearly isotropic and $A = 0.15 \pm 0.09$.

Fig. 6 shows the momentum distribution od spectator deuterons for all FIT channels. The theoretical curve was calculated in Ref. [5] on the basis of the direct reaction theory by the Monte-Carlo method from Sick's experimental data [6] on the charge density distribution in the ^{4}He nucleus. It is in reasonable agreement with the momenta distributions of spectator deuterons in individual channels as well as with the summary distribution. From the above one can conclude that deuterons which are slower than the other reaction products in ^{4}He rest system are

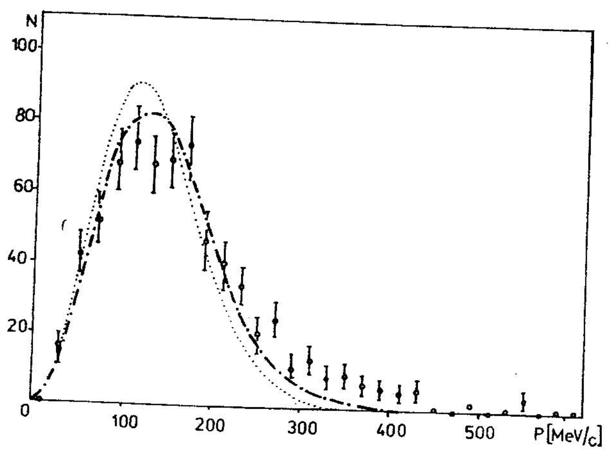

Fig. 6. Momentum distribution of spectator deuterons in FIT channels (dotted is theoretical curve, dash-dotted is theoretical curve deformed by the estimated errors in Monte-Carlo procedure).

spectators. This brings up the question as to what kind of interaction there is between the other nucleons from the nucleus and the target proton?

Let us consider two possibilities: either the nucleons interact as a virtual deuteron — Fig. 7a, or there exists a strong interaction between the target proton and two non-associated nucleons from the nucleus — Fig. 7b. We would be able to observe the difference between these mechanisms in the $d_s ppn$ reaction, since if

Fig. 7. Diagrams of the $d_s ppn$ channel: a) for existence of the d-d association; b) for two individually interacting nucleons.

a virtual deuteron exists, we should have a similar behaviour in the upper vertex of the diagram in Fig. 7a as in the experiments on the $dp \rightarrow ppn$ break-up reaction. As shown in [7], the dominant mechanism of the reaction is the direct reaction producing one spectator nucleon. To search for the contribution of diagram 7a, the nucleon momentum distribution is plotted for spectator nucleons in the virtual

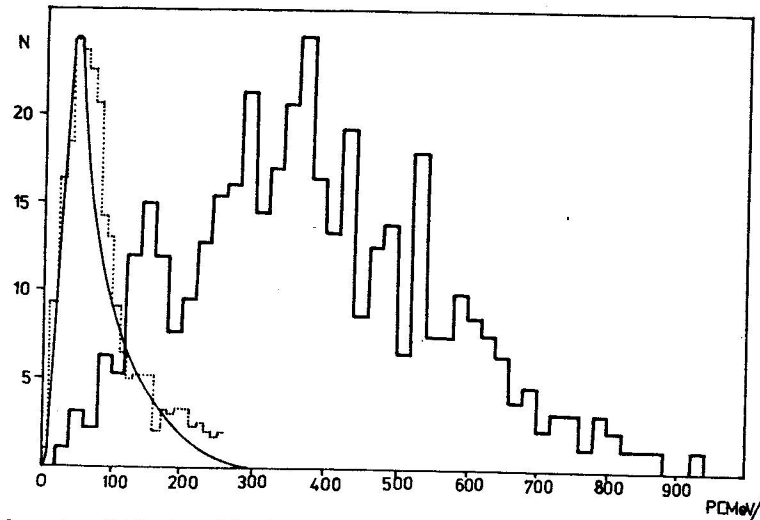

Fig. 8. Momentum distribution of the slowest nucleon in the virtual deuteron rest system for diagram 7a in contrast to the spectator momentum distribution for the $dp \rightarrow ppn$ reaction (dotted line). The theoretical prediction.

Table 2

Cross Sections of Channels with Production of Deuterons

Channel	σ [mb]
^{3}He$d\pi^0$	0.15±0.04
^{3}He$d\pi^0\pi^0+\ldots$	0.06±0.03
^{3}He$d\pi^+\pi^-$	0.19±0.05
^{3}He$d\pi^+\pi^-\pi^0$	0.01±0.01
$td\pi^+$	0.23±0.05
$td\pi^+\pi^0$	0.15±0.04
ddp	1.42±0.13
$ddp\pi^0$	0.30±0.06
$ddp\pi^0\pi^0+\ldots$	0.02±0.02
$ddn\pi^+$	0.48±0.08
$ddn\pi^+\pi^0$	0.19±0.05
$ddp\pi^+\pi^-+\ldots$	0.19±0.05
$ddp\pi^+\pi^-\pi^0$	0.02±0.02
$dppp\pi^-$	0.89±0.10
$dppp\pi^-\pi^0$	0.25±0.05
$dppn$	9.32±0.33
$dppn\pi^0+\ldots$	4.50±0.23
$dppn\pi^+\pi^-$	1.76±0.15
$dppn\pi^+\pi^-\pi^0+\ldots$	0.13±0.04
$dpnn\pi^++\ldots$	7.52±0.30
$dpnn\pi^+\pi^+\pi^-+\ldots$	0.05±0.03
$dnnn\pi^+\pi^++\ldots$	0.21±0.05

deuteron rest system. Comparison of results is presented in Fig. 8. Here the momentum distribution of the slowest nucleon in the virtual deuteron rest system is shown in contrast to the spectator momentum distribution for the $dp\rightarrow ppn$ reaction at 3.3 GeV/c (dotted line). The solid curve shows the theoretical prediction [7]. We summarize that in our experiment an existence of d-d association in the ^{4}He nucleus is not observable and the diagram 7b represents the dominant mechanism of the reaction ^{4}He$p\rightarrow d_s ppn$.

III. CONCLUSIONS

An analysis of the deuteron production in a ^{4}Hep reaction at 8.6 GeV/c gas been performed. The cross sections for channels with deuteron production have been measured. The separation of the outgoing deuterons into groups (slow and fast ones) was observed. Experimental data support the hypothesis that slow deuterons are produced in pick-up reactions with the associated production of the π^+ and π^0 mesons. Considering the resonance energy dependence of the cross reaction for

processes (4) (with a maximum at a kinetic energy $T=615$ MeV and a steep decrease at our energy), we expect the probability of slow deuteron production in reactions with no more than one produced pion tó decrease with the increasing energy for ^{4}Hep collisions.

If we treat the deuterons as fragments of ^{4}He nuclei, most of them have spectator characteristics.

The analysis of the $d_s ppn$ channel showed that the probability of the d-d association in the ^{4}He nucleus is small and the two nonspectator nucleons interact individually.

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