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ABSTRACT

The differential cross section of the D(n,np) reaction was measured at $\vartheta_n = 0^{\circ}$. Due to the applied special geometry the experimental data extend over a large fraction of the phase space, including several final state interaction regions as well as regions far from the dominance of the quasi-two body processes. This offers possibility to extract the neutron-neutron scattering parameters and to get simultaneously additional knowledge on the N-N potentials and on three-body forces in the frame of an exact three-body calculation.

KIVONAT

A D(n,np) reakció differenciális hatáskeresztmetszetét mértük $\vartheta_n = 0^{\circ}$-nál. Az alkalmazott speciális geometria következtében a kisérleti adatok a fázistérnek több végállapotkölcsönhatási, valamint a kvázi-kétrészecske folyamatokból nem dominált tartományát fedik le.
Exakt háromtest-számitások felhasználásával ez lehetővé teszi a n-n szórási paraméterek meghatározását és egyidejüleg további információk nyerését a N-N potenciálokra és a háromtesterőkre vonatkozóan.

РЕЗЮМЕ

Дифференциальное сечение для реакции D/n,np/ было измерено при $\vartheta_n = 0^{\circ}$. В силу использованной специальлной геометрии, экспериментальные данные распределяются в большой части фазового пространства, заключающей в себе несколько областей взаимодействия двух нуклонов в конечном состоянии, а также области, где квази-двухчастичные процессы не доминируют. Это дает возможность определить параметры n-n рассеяния при низких энергиях и одновременно получить дополнительную информацию о нуклон-нуклонных и трехчастичных силах путем сравнения экспериментальных данных с точным решением проблем трех тел.

INTRODUCTION

In order to determine the low-energy neutron-neutron scattering parameters a large number of experiments on the n + D→n+n+p reaction were performed during the last years. The method to extract these data was based on comparison of experimental results with theoretical calculations mainly in regions where the n-n final state interaction (FSI) is dominant, consequently, efforts were made to use a geometry which allows to detect events with small relative kinetic energy of the two neutrons.

Since the numerous kinematically incomplete measurements[1] didn't give unique results, mainly because of the insensitiveness of the various integrated theoretical differential cross sections to the parameters to be determined, it was necessary to perform measurements with uniquely defined kinematics. In a relatively small number of experiments[2,3,4] this requirement was met by measuring the coincident energy spectrum of two neutrons with two fixed detectors. In order to detect events dominated by the n-n FSI the two neutron detectors were placed close together in forward direction. Zeitnitz et.al[4] used a third detector too, which enabled them to measure the effect of the n-p FSI simultaneously. In their work the low-energy n-n scattering parameters were extracted by comparison with an exact three-body calculation.

The arrangement mentioned above, however, has a serious disadvantage. The kinematics being overdetermined, the kinematically allowed region degenerates into a line in the E_{n1}-E_{n2} plane, severely reducing the accessible phase space in one arrangement. It was, however, pointed out by D.H.Wilkinson[5], that it would be worthwhile to make measurements over a wide range of kinematical conditions, in order to check the interpretation method of Ref.4. It is also clear, that regions far from the FSI dominance might give information on the off-shell properties of the nucleon-nucleon interaction, and on the importance of the three-body forces.

Using the above mentioned geometry the extension of the measured phase space is time consuming because it would involve repeated experiments with different arrangements[6]. It is possible, however, to avoid this difficulty by choosing a special geometry, making the measurement kinematically determined, but not overdetermined, and thus allowing to measure in a much greater part of the phase space, including several FSI regions.

Let us consider the geometry shown on Fig.1. The D(n,np) reaction takes place in a deuterated scintillator, which measures the proton energy at the same time. A neutrons detector is placed in the direction of the incident neutron beam ($\vartheta_n=0^o$), fixing the direction of the detected particle and measuring its energy by time-of-flight method, as well. It can be seen easily, that the events detected in this geometry are necessarily coplanar, and the measured quantities enable us to determine the kinematics uniquely, except for the azimuthal angle of the reaction plane. In case of unpolarized incident beam and target, however, the differential cross-section is independent of this undetermined azimuthal angle, therefore the geometry of Fig. 1 enables us to make kinematically complete measurements. We notice that a similar symmetry exists for $\vartheta_n=180^o$. Our method seems to be very similar to that of Arai[7], but in his arrangement ϑ_n was not equal to zero, and thus the advantages of the above mentioned symmetry were lost.

The kinematically allowed events cover an area of quasi-triangle form in the E_n-E_p plane (Fig.2). On the contour of this area we marked the points, where any two of the three break-up particles move together with zero relative kinetic energy. Two events, which in vertical direction are equally far spaced from the dashed line are symmetryc in the variables of the proton and of the undetected neutron.

The advantages of our geometry over that of the previous kinematically complete measurements are: i/ the possibility to measure in several FSI regions in one measurement with the same detectors. ii/ the region covered in phase space is some part of the E_n-E_p plane, while in the other case it was only a curve in the corresponding $E_{n_1}-E_{n_2}$ plane. This involves more complete covering of the FSI regions as well as making measurements far from them. iii/ in our method one of the particles (proton) is detected in 4π solid angle with 100 % efficiency strongly reducing the necessary measuring time.

To try this method in practice we made a measurement at E_0=14.1 MeV bombarding neutron energy. The neutron beam was provided by T(d,n)α reaction. The D(n,np) reaction took place in an 1.5"x1.5" NE 230 deuterated scintillator, which served at the same time as a detector for the protons. The energy of the neutron was measured by time-of-flight technique using the associated α particle method. The start signal was given by the neutron detector (Ne 213, 3.5" long, 2" in diameter), while the stop signal was given by the α detector (NE 102A, 0.1 mm thick). The angular resolution determined by the detector sizes was about 2.5°.

The experiment was performed on-line, using a small computer (TPA 1001). A triple coincidence between the above mentioned three detectors gave the gating signal to three analog-to-digital converters, which analysed the scintillation amplitude of the proton in the D target, the time of flight of the forward going neutron and the scintillation amplitude of the recoiled proton in the neutron detector. This latter was used for the purpose of a rise time correction of the time of flight[8]. All the events were stored on tape and afterwards analysed into a matrix of the neutron time of flight versus the proton amplitude. The dimension of the matrix was 256 x 256 channels. During 230 hours of measuring time some 13600 events were collected with $E_n > 1.7$ MeV over the kinematically allowed region for the D(n,np) break-up. A two-dimensional representation of the $E_n > 2.9$ MeV part of the data is shown on Fig. 3.

The background was determined in a separate measurement by replacing the D target NE 230 scintillator with its non-deuterated variant of NE 231. It had a smooth structure (see Fig. 4) except for the peak at E_n=4.2 MeV caused by the $^{12}C(n,n'3\alpha)$ reaction. This is, however, mainly outside of the kinematically allowed region for the deuteron break-up.

The distribution of the deuteron break-up events shows a definite structure, namely, the events are concentrated mainly in three regions where the effect of the final state interactions is expected to be dominant, corresponding to Fig. 2. The n-n and n-p peaks at E_n=5.5 MeV are relatively broad along the contour of Fig. 2 because the relative kinetic energy of the two nucleons varies very slowly in this direction. An additional enhancement is caused by the strong increase of the phase space density with increasing E_n.

The absolute value of the cross section can be determined by a comparison to that of the $^{12}C(n,n'3\alpha)$ peak at E_n=4.2 MeV. Using a value of 9 mb/sr[9] for the peak cross section some differential cross section values (uncorrected for experimental resolution) at E_n=5.5 MeV (see Fig. 4) are as follows:

$\sigma = 17.4 \pm 1.7$ mb/sr·MeV^2 at $E_{nn} = 0$ MeV

$\sigma = 4.6 \pm 0.7$ mb/sr·MeV^2 at $E_{np} = 0$ MeV

$\sigma = 1.5 \pm 0.4$ mb/sr·MeV^2 in the intermediate region.

The proton energy integrated cross section is 21.7±1.2 mb/sr·MeV, which is in quite a good agreement with the value measured by Brüllmann et al.[10] at $\vartheta_n = 7.5^{\circ}$. The errors given are only the statistical ones, the reference cross section has an uncertainty of approximately 15 %.

We conclude that the present method can be used in practice. Since the experimental results contain several FSI regions as well as regions between FSI peaks, where no approximate method of calculation is known to work well, an exact three-body calculation is needed to extract the information contained in them.

The evaluation of the data is in progress at the University of Hamburg, using the method of Ref.4.

We wish to thank Professor I. Lovas for his stimulating interest and helpful conversations and Professor B. Zeitnitz and Dr. I. Borbély for valuable discussions.

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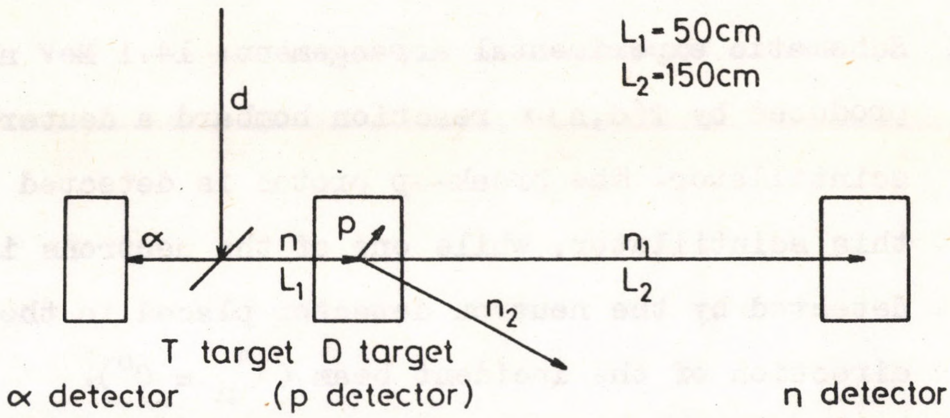
Figure captions

Fig. 1 Schematic experimental arrangement: 14.1 MeV neutrons produced by $T(d,n)\alpha$ reaction bombard a deuterated scintillator. The break-up proton is detected inside this scintillator, while one of the neutrons is detected by the neutron detector placed in the direction of the incident beam ($\vartheta_n = 0^o$).

Fig. 2 The kinematically allowed area in the E_n-E_p plane (lab system) for $\vartheta_n = 0^o$. The two contour lines correspond to the collinear events. At the marked points the denoted pairs of nucleons have zero relative energy. The dashed line is a symmetry axis: two events, which in vertical direction are equally far spaced from it are symmetric in the variables of the proton and of the undetected neutron.

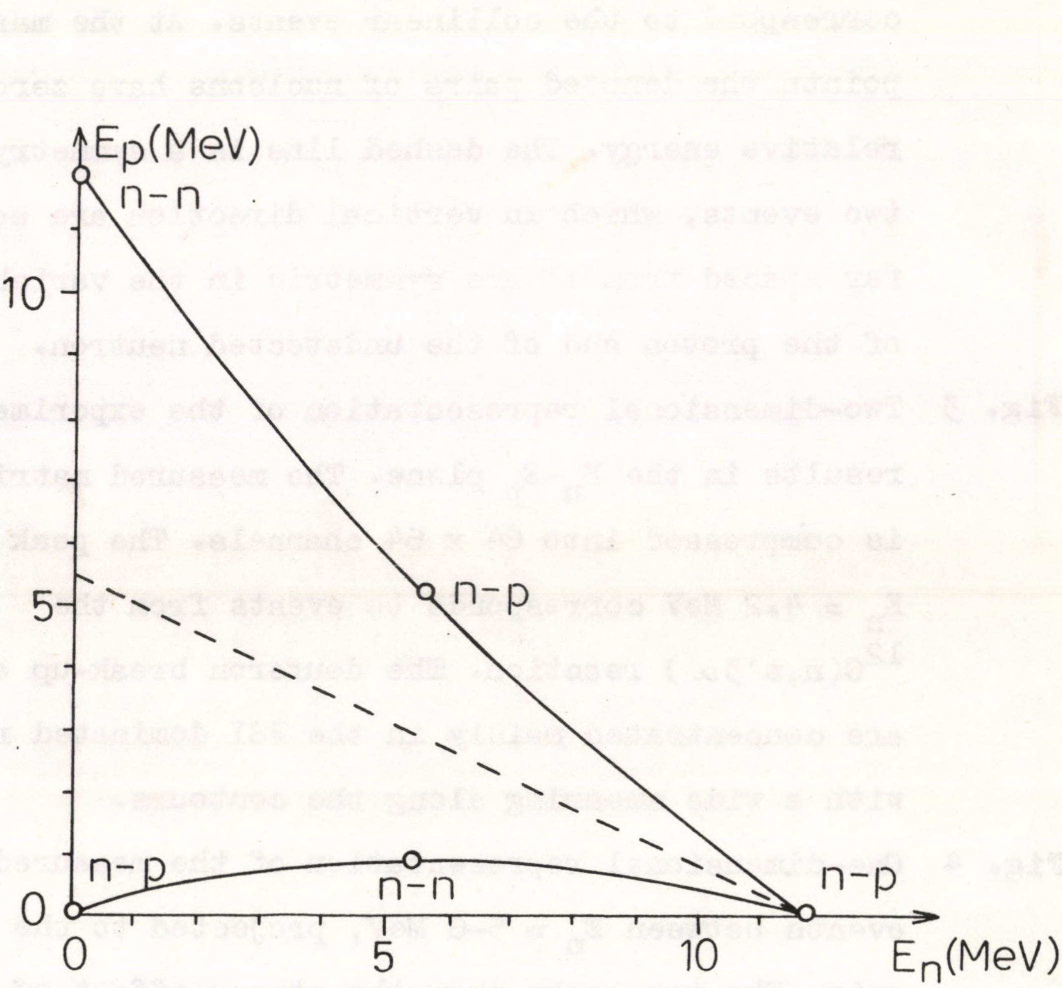
Fig. 3 Two-dimensional representation of the experimental results in the E_n-E_p plane. The measured matrix is compressed into 64 x 64 channels. The peak at $E_n = 4.2$ MeV corresponds to events from the $^{12}C(n,n'3\alpha)$ reaction. The deuteron break-up events are concentrated mainly in the FSI dominated regions with a wide smearing along the contours.

Fig. 4 One-dimensional representation of the measured events between $E_n = 5$-6 MeV, projected to the E_p axis. The two peaks show the strong effect of the n-n and n-p FSI, respectively. The dashed line represents the background.



L_1=50cm
L_2=150cm
d
∝
n
p
n_1
L_1
L_2
n_2
T target
D target
∝ detector
(p detector)
n detector

Fig. 1



E_p(MeV)
n-n
10
n-p
5
n-p
n-n
n-p
0
0
5
10
E_n(MeV)

Fig. 2

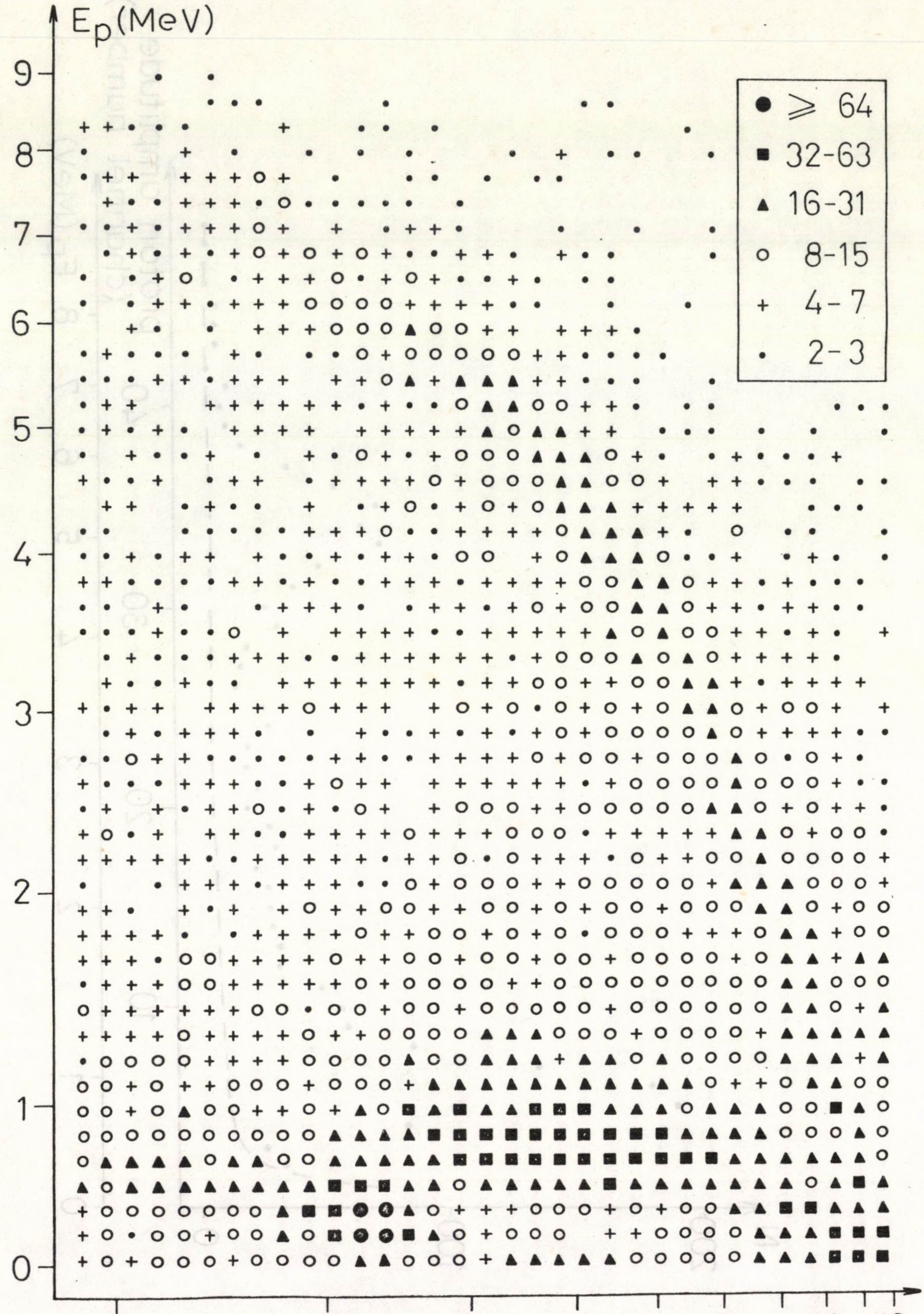


Fig. 3

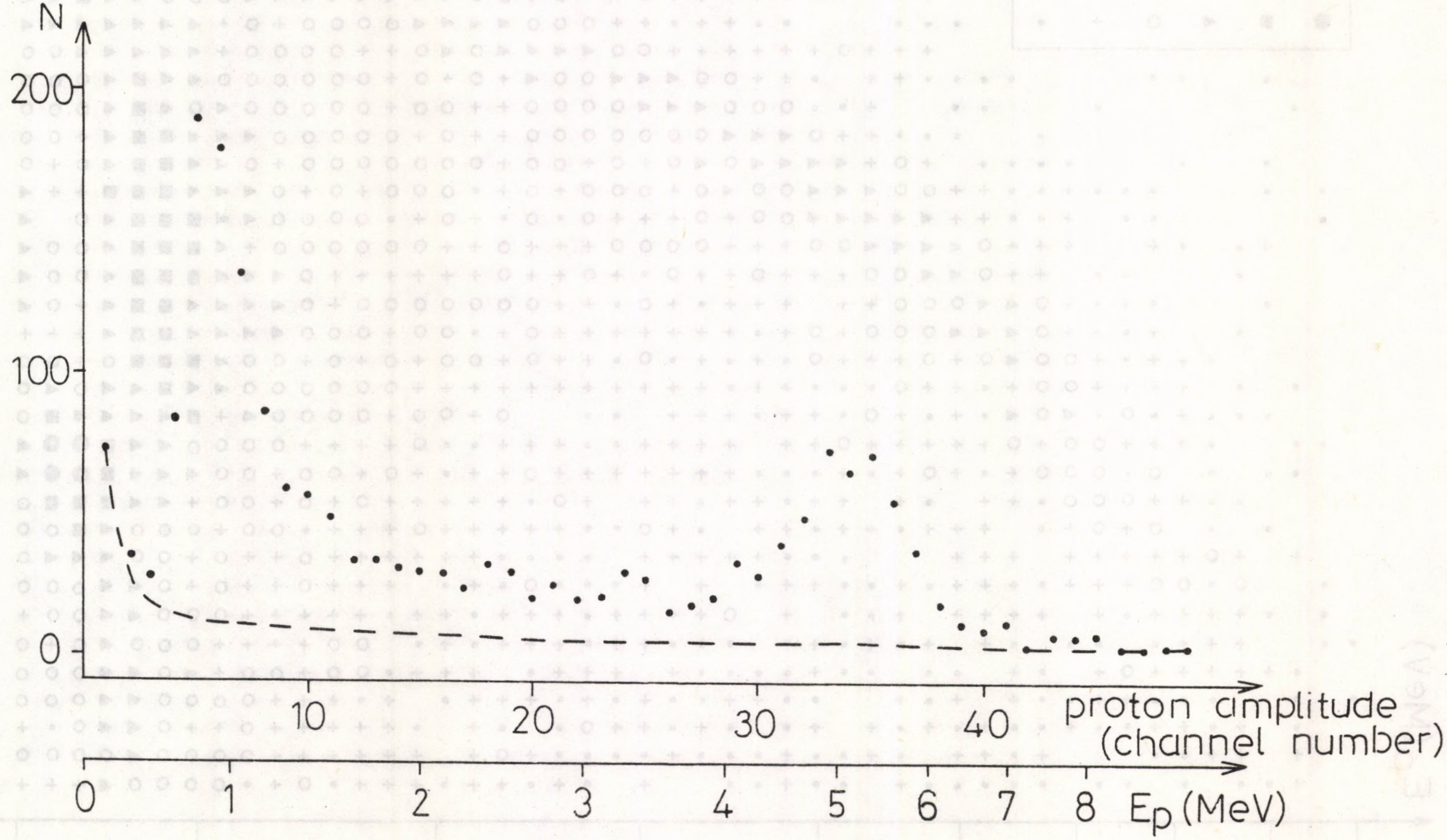

N
200
100
0
10
20
30
40
proton amplitude
(channel number)
0
1
2
3
4
5
6
7
8
E_p (MeV)

Fig. 4

62.046

Kiadja a Központi Fizikai Kutató Intézet
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