

η -nuclei in the SCAN experiment

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Abstract. η -mesic nucleus or the quasibound nuclear state of an η -meson in a nucleus is caused by the strong-interaction force alone. The project SCAN2 is aimed at searching and studying the η -meson nuclei production. The experiment is based on two-arms spectrometer using internal target at the Nuclotron. The setup was designed to study products from η -meson nucleus decay in the reaction $d + {}^{12}\text{C} \rightarrow (A)_\eta + X \rightarrow \pi + p + (A - 2)$ at deuteron energies from 0.5 to 2.5 GeV/nucleon. The energy spectrum of secondary protons has been measured. The dependence of the yields of protons and pions on the beam energy has been obtained. This dependence can show us the minimum energy for the S_{11} resonance formation. The first prototype of the neutron detector, which will be used in a new modified experimental setup SCAN3 for recording of neutrons from η -nucleus decays in the πn and pn channels, has been tested. The time-of-flight method to obtain the neutron spectrum was used. The time resolution and efficiency of the neutron detector have been obtained.

1 Introduction

The study of the in-medium properties of hadrons has attracted continuous attention and is one of the most interesting topics of nuclear physics. The existence of an η -meson nuclei was postulated in 1986 by Liu and Haider and since then a search for such states was conducted in many experiments [1]. However, up to now no confirmed experimental evidence for the η -meson nuclei was found. It has been considered that a meson-nucleus system may exist as a quasi-bound state, caused by the strong interaction. In nuclear reactions the η -meson interacts with recoiling nucleon and in the low momentum region the interaction is dominated by the broad nucleon $S_{11}(1535)$ resonance, which is very close to the η production threshold (49 MeV above the ηN threshold). The decay of this state through the $S_{11}(1535)$ resonance would lead to a $p\pi$ - pair emitted in opposite directions. The experiment SCAN at the Nuclotron in Joint Institute for Nuclear Research studies these exotic nuclei [2].

2 Data analysis of the SCAN2 experiment

The project SCAN2 is aimed at searching and studying η -meson nuclei production. The experiment is based on the two-arms spectrometer using the internal target at the Nuclotron.

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The setup was designed to study products of the η -meson nucleus decay in the reaction $d + {}^{12}\text{C} \rightarrow (A)_\eta + X \rightarrow \pi + p + (A - 2)$ at deuteron energies from 0.5 to 2.5 GeV/nucl. The experiment was carried out on "the rise of the magnetic field". The dependence of the magnetic field induction on time is shown in Fig. 1.

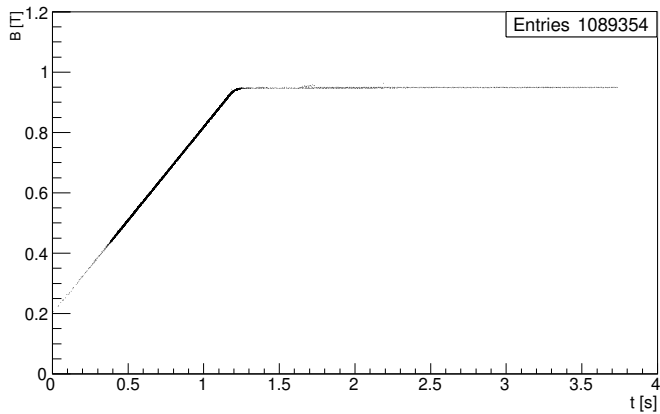


Figure 1. Dependence of the magnetic field induction on time of deuteron beam

Expression (1) transfers the magnetic field induction to the kinetic energy of initial particles:

$$T = \sqrt{m_d^2 + (0.3BZR)^2} - m_d, \quad (1)$$

where m_d is the mass of deuteron, B is the magnetic field induction and R is the effective radius. The maximum energy of the deuteron beam was 2.3 GeV/nucl (Fig. 2).

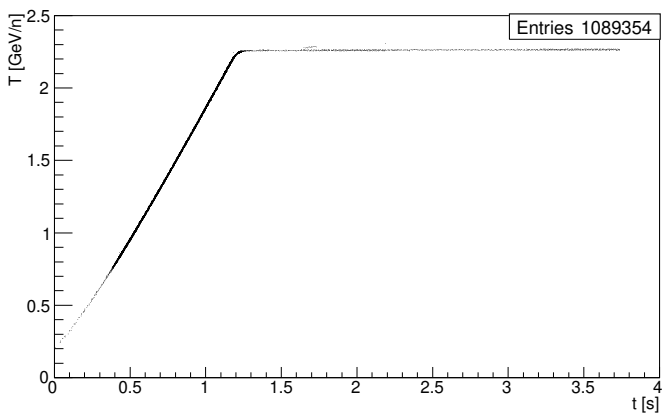


Figure 2. Dependence of the deuteron beam kinetic energy on time

The energy spectra of secondary protons for the different energies of primary deuterons T_d were calculated. An example of these spectra is shown in Fig. 3. The proton from the

η -nuclei decay should have the kinetic energy about 90 MeV. If the η -nuclei was formed than two peaks would be observed. One can see that the minimal energy of the deuteron beam for η -nuclei production is 0.8 GeV/nucleon. Since the observed peak was not at 90 MeV, the corrections need to be made.

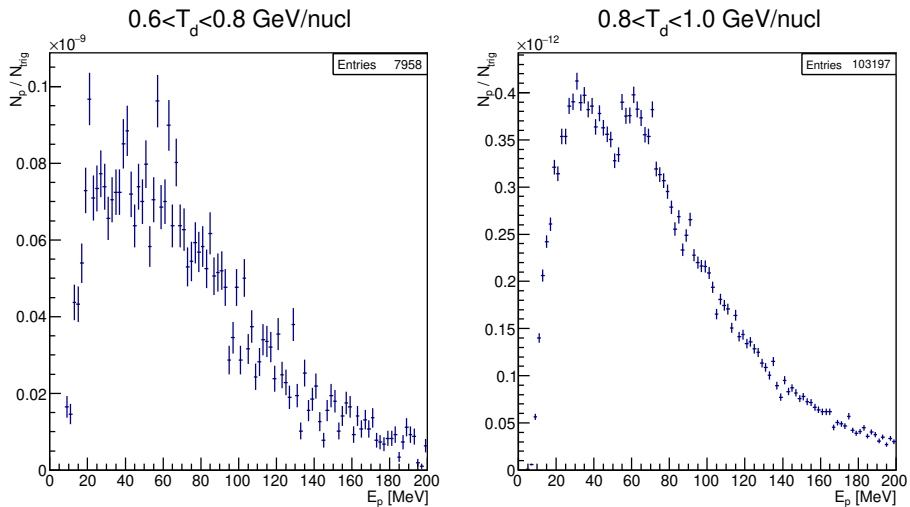


Figure 3. Energy spectrum of secondary protons. The minimal energy of deuteron beam for η -nuclei production is 0.8 GeV/nucleon

3 Neutron detector for the SCAN3 experiment

The experimental setup SCAN2 will be modified to the experimental setup SCAN3. The new setup is planned as the three-arms spectrometer. The one arm is a magnetic arm for charged particles and another two are the time-of-flight spectrometers for the registration of neutrons and protons [3].

One of the tasks of the spectrometer SCAN3 is the detection of neutrons from the η -meson nucleus decay in πn and pn channels. Theoretical predictions impose requirements on the accuracy in determining the energy of the pion-nucleon and nucleon-nucleon pairs $\delta E \leq 10$ MeV. The only way to ensure the neutron spectrometry is to use the time-of-flight method. In the SCAN-3 geometry, this leads to a limitation on the neutron transit time measurement accuracy $\delta t = 2.2$ ns for the pion-nucleon channel and $\delta t = 0.4$ ns for the nucleon-nucleon channel.

To test the neutron detector, a deuteron stripping reaction on the fixed target to obtain the neutron beam was used. The geometry of the neutron detector is shown in Fig. 4. The prototype of the neutron detector consist of 4 scintillation layers with 8 photomultipliers (8ND) on two opposite ends of the counter. The size of each scintillation layer is: $50\text{ cm} \times 14\text{ cm} \times 5\text{ cm}$. A1 and A3 are the anticoincidence counters for detecting the charged particles and 4-SP-12 is the magnet. The target S1 is the thin fiber with two photomultipliers.

The idea of the experiment is based on the "time-of-flight" method. The neutron flying through the layers of the detector, at some point hits a proton in plastic and knocks it out from the material. As soon as the charged particle starts to move in the scintillator, the counter is

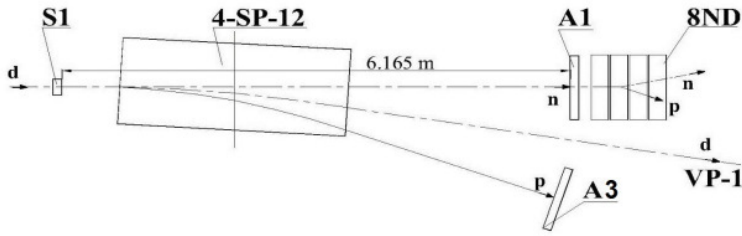


Figure 4. Scheme of the neutron detector

running. Depending on the length of the flight and the arrival time of the signal from the interaction to the counter, it is possible to estimate the velocity and the energy of the neutron.

The energy distribution of neutrons in each layer of the detector is shown in Fig. 5. The neutrons interact continuously in all layers. The number of events in each layer depends on the position of layer. Each next layer detects the products of neutron interaction in all previous layers. It can be seen that the probability of interaction increase from layer to layer and after interaction the neutron with the proton of material these secondary protons have forward direction.

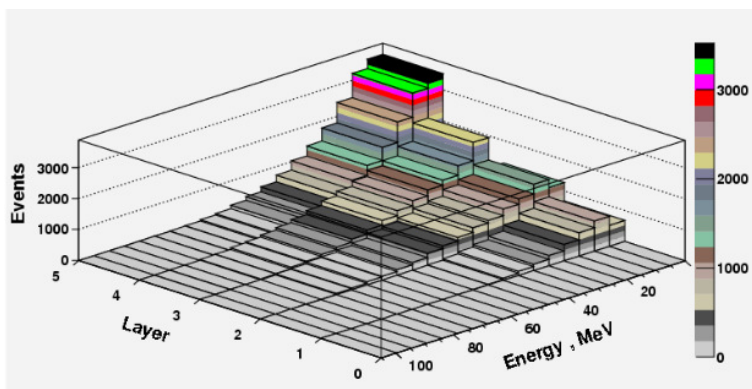


Figure 5. Energy distribution of the number of signals in each layer

In the case of incoming charged particles in the first layer, we have the signal and practically constant occupancy in all layers. This case is shown in Fig. 6.

We have obtained the time resolution for the two closest layers at the deuteron beam energy 3 GeV/nucleon. This time resolution is shown in Tab. 1.

Table 1. Time resolution for the two closest layers at deuteron energy beam 3 GeV/nucleon

$N_i - N_k$	$N_1 - N_3$	$N_3 - N_5$	$N_5 - N_7$	$N_2 - N_4$	$N_4 - N_6$	$N_6 - N_8$
σ [ns]	0.27	0.27	0.30	0.44	0.30	0.20

The efficiency of the neutron detector depends on the number of scintillation layers used. If we use four layers, the efficiency of the detector is about 27% (Fig. 7).

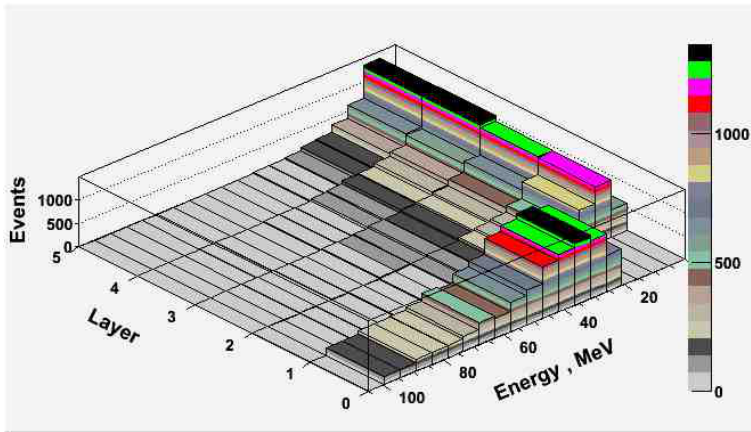


Figure 6. Energy distribution of the number of signals for charged particles in each layer

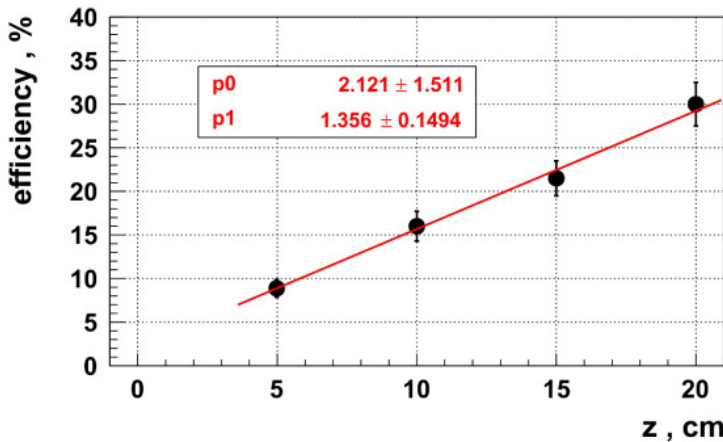


Figure 7. The efficiency of the neutron detector depends on the number of scintillation layers used

4 Conclusions

We have made the analysis of $d + C$ reaction using the regime of increasing the primary energy of the beam. The maximum energy of deuteron beam was 2.3 GeV/nucleon. The minimum energy for the η -nuclei formation is 0.8 GeV/nucleon. Corrections are needed to obtain more correct results. It has been shown that we can use increasing the magnetic field of the Nuclotron for study of the energy dependence. At the first time the experiment with the increasing magnetic field has been carried out. The first prototype of the neutron detector has been investigated. The detection efficiency of neutrons using four layers is 27%. This detector can be used for the time resolution in the experimental setup SCAN3 for recording neutrons in the πn and pn decay channels of the η -nucleus.

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References

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