STUDY OF NEUTRON HALO STRUCTURE IN INTERACTION OF ^{6}He WITH NUCLEI OF PHOTOEMULSION

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Abstract

To investigate the structure of halo of Borromean nuclei, we propose an experimental method of studying quasi-free scattering of proton by the constituents of halo-nuclei in photo emulsion. The experimental study of ^{6}He+^{1}H interaction is performed using ^{6}He beam of Flerov Laboratory of Nuclear Reactions (JINR, Dubna) at energy of about 10 MeV/u and technique of nuclear photo emulsions. Searching for events of quasi-free scattering and their processing is performed using the PAVICOM-setup at P.N. Lebedev Physical institute.

Keywords: *Halo-nuclei, quasi-free scattering, dineutron*

1. INTRODUCTION

Investigation of reactions using beams of radioactive nuclei has extended the area of nuclear physics on nuclei far from the stability line. Many new phenomena characteristic for unstable nuclei, for example, nuclei with neutron halo were discovered. Especially interesting are so-called Borromean nuclei - nuclei with two-neutron halo (^{11}Li, ^{6}He, ^{14}Be) [1]. In these nuclei the two neutrons can be bound to the core only as a pair but not separately. The problem of more detailed study of such two-neutron halo structure and, in particular, - how these two neutrons exist in halo-nucleus as dineutron or as cigarlike configuration - is not solved so far.

To investigate the structure of two-neutron halo various reactions induced by beams of radioactive nucleus are used. One should mention here the one and two-neutron transfer reactions, reaction of quasi-free scattering and quasi-free capture.

It was shown in [2] that in the pole approximation differential cross section of $A+^{11}Li \rightarrow A+^{9}Li+2n \rightarrow B+^{9}Li$ reaction is determined by two factors: momentum distribution of ^{9}Li-core in ^{11}Li nucleus (i.e. by momentum distribution of dineutron in ^{11}Li) and absorption cross-section of two neutrons by A-nucleus. In fig.1 the pole diagram of transfer of two-neutron cluster in $A+a \rightarrow A+b+c \rightarrow B+b$ reaction is presented.

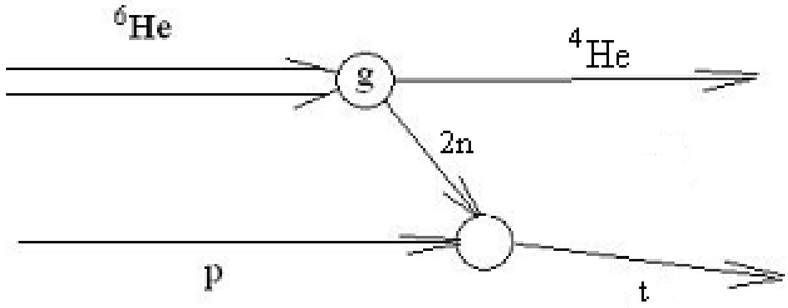

Fig.1. Pole diagram of transfer of two-neutron cluster in $A+a\rightarrow A+b+c\rightarrow B+b$ reaction.

Thus the information on the structure of neutron halo can be directly obtained from the analysis of differential cross section of two-neutron transfer. Similar diagram (fig.2) can be drawn for quasi-free scattering of proton by one constituent of halo-nucleus.

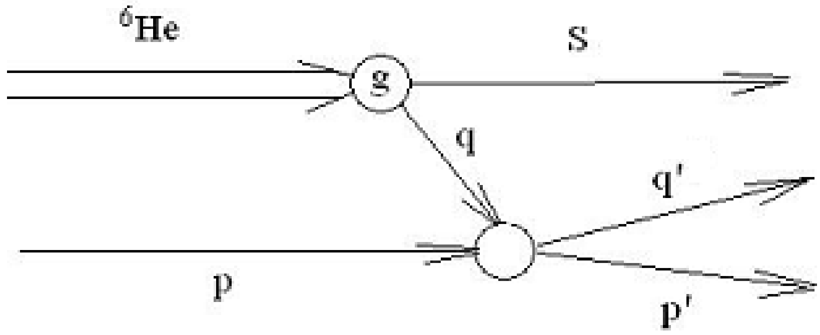

Fig.2. Pole diagram of transfer for quasi-free scattering of proton by one of constituents of halo-nucleus. Here q (cluster) and S (spectator) are constituents of halo-nucleus.

One can see that the both diagrams include the same vertex G, describing the virtual decay of halo-nuclei into clusters and containing information about the structure of neutron halo. When considering quasi-free scattering or quasi-free capture of proton by one constituent of halo-nucleus there exists additional condition that the other constituent (spectator) doesn't interact and stay at rest.

The most studied experimentally is the structure of halo of ^{6}He nucleus. So in the works performed in Dubna two-neutron transfer reaction was investigated using 6He beam with energy of 151 MeV [3]. The analysis of this reaction allows the authors to state that the "dineutron "configuration of the ^{6}He nucleus gives the dominant contribution to the two-neutron transfer cross-section" [4].

On the other hand Sauvan, Marques with co-authors [5] studied radiative capture of proton on ^{6}He nucleus. They found events which can be described as quasi-free radiative capture on a halo neutron, the α core and ^{5}He. However they did not observe the capture on a di-neutron" Authors stated: "This indicates… that ^{4}He-n-n (that is no compact dineutron component) is the dominant configuration present in $^{6}He_{gs}$." It should be noted that proton wavelength in this experiment was 0.7 fm at 40 MeV and authors stated that it would be of interest to search for larger distance correlations between the neutrons using lower-energy protons. So, even for the most studied ^{6}He-nucleus it is impossible to draw a final conclusion on the structure of neutron halo. New experiments for various reactions and at various energies are needed.

2. PROPOSED METHOD AND SCHEME OF THE EXPERIMENT

To investigate two-neutron configuration in Borromean nuclei we proposed an experimental method of studying neutron-neutron correlations by measuring reactions induced by halo projectile in nuclear photo emulsions. Irradiation of photo emulsion is performed by a beam of radioactive halo-nucleus. As halo - projectile we plan to use nuclei ^{6,8}He, ^{11}Li with energy about 3-15 MeV/nucleon. Thus, nuclei of photo emulsion (hydrogen, carbon, nitrogen and so on) are used as target nuclei. So, the photo emulsion (PE) is simultaneously the target and detector of secondary particles. Nuclear photo emulsion is an efficient instrument for nuclear reaction study. Especially it refers to stacks of photo emulsion or to so-called emulsion chambers, being a 4-pi detector of charged particles produced inside it, allowing simultaneously detect several charged particles. Studying trajectories of the reaction products, we can reconstruct the reaction kinematics and determine energies and emission angles of particles with sufficient resolution. Another advantage of the use of photo emulsion is a possibility to detect secondary particles at very small angles with respect to the direction of the beam particles. Thus, the detection of two or more secondary charged particles allows one to detect one of them even at zero angles. As a disadvantage of PE, the difficulty of tracks detection in PE using conventional microscopes is often considered. Situation was changed with appearance of complexes allowing high-speed automatic scanning of large amount of PE and software packages also allowing high-speed processing of this information.

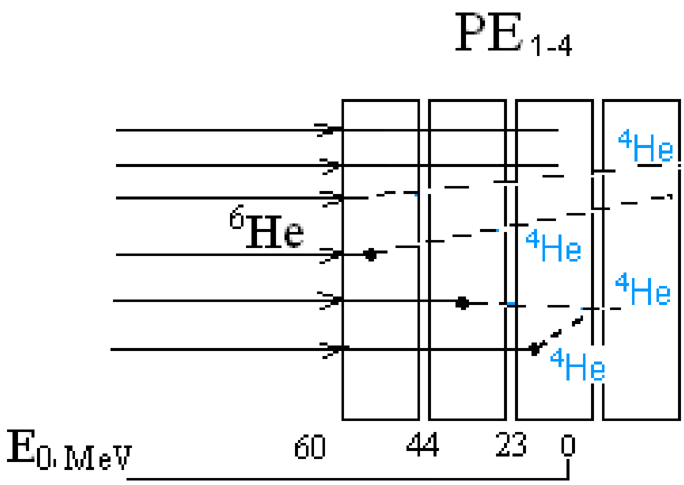

Fig.3. Layout of experiment

Irradiation of stacks of nuclear photo emulsion was performed at Flerov Laboratory of Nuclear Reactions (JINR, Dubna). The layout of the experiment (Fig.3) is very simple: ^{6}He beam with energy of 60 MeV was incident perpendicularly to the plane of the stack of photo emulsions. Total thickness of the stack (1600 μm) is greater than the range of ^{6}He-projectile with such energy and is sufficient to stop secondary particles produced in each photo emulsion of the stack. Thus, use of a stack of photo emulsions allows one to simultaneously study reactions at various energies in the energy range 15 -- 60 MeV, as penetrating into the photo emulsion the beam particles loose their energy due to ionization loss, and interaction with target nucleus occurs at smaller energies. The angular resolution in our experiment is about 1°, the energy resolution for secondary hellions with energy of 15 MeV is about 2-3%. Search of events of ^{6}He interaction with PE and further processing was performed using automated measuring setup PAVIKOM at P.N. Lebedev Physical Institute, Moscow [6]. In this setup the images of consecutive (with step of several μm) NPE layers were obtained and transferred to computer. At further processing of these images, we select darkening areas (globes) with darkening degree, shape, and size inherent for tracks of given charged particle (^{4,6}He). Coordinates (x, y) of centers of mass of all globes in each layer (z-coordinate) are determined and stored. Then, particle trajectories $X_i(z)$ and $Y_i(z)$ are determined by center-of-mass coordinates in consecutive layers of NPE. Further the trajectories obtained are processed to determine their parameters. The characteristic trajectory corresponding to the given reaction consists of the track of primary particle (^{6}He), interaction point (IP), and the trajectories of secondary particles emitting from the interaction point. Then the program determines range (energy) of the primary particle at the interaction point, angles of emission of secondary particles, and ranges (energies) of the secondary particles. Separation of events from different reactions (or on different targets) may be performed using the difference in kinematics: different Q-values, ratios of ranges and emitting angles.

3. PRELIMINARY EXPERIMENTAL DATA

The most simple problem is a separation of tracks from interaction of ^{6}He with hydrogen at energy of 15-22 MeV (third PE in the stack). In this case the tracks of products of transfer reaction and QFS (^{4}He, p, d, and t) are comparable in length so we can easily recognize the tracks of He-p interaction as a three-pronged star. For reliable separation of tracks in the photo emulsion, the length of the track of secondary particle must be greater than fixed value (about 15-20 micrometer). Thus the corresponding energy of secondary particles should be greater than 3 MeV for ^{4}He and greater than 1 MeV for a proton. Now we begin processing of experimental data and searching for three-pronged stars corresponding to interaction of ^{6}He with hydrogen at energy of 15-22 MeV.

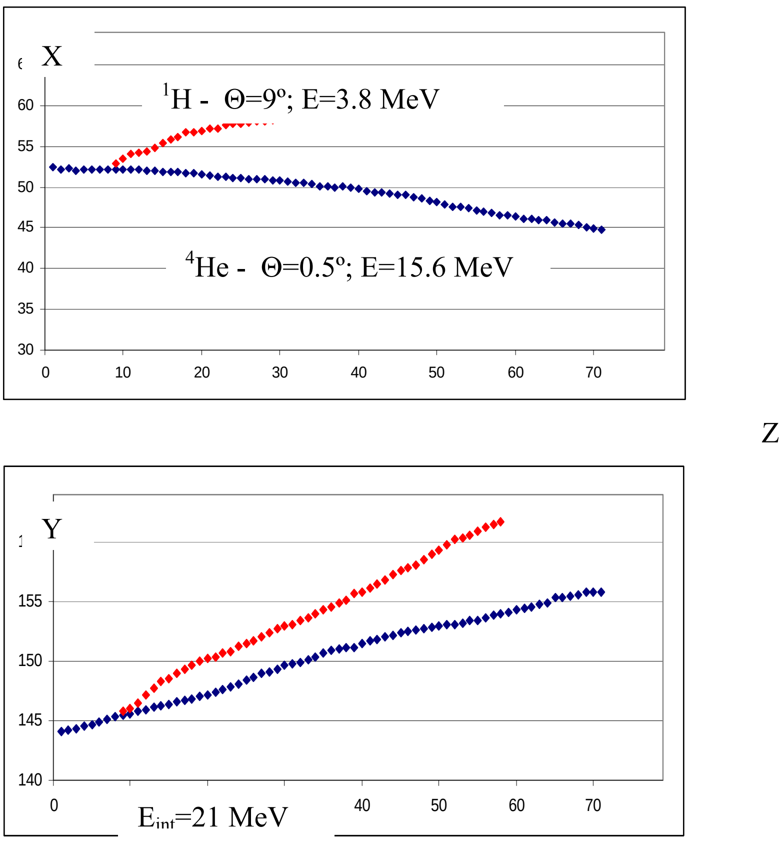

Fig.4. Trajectories in XZ и YZ planes of photo emulsion obtained at interaction of incident halo-nucleus ^{6}He with hydrogen. As secondary particles ^{4}He, ^{1}H are detected.

The example of such a trajectory is shown in fig.4 in two planes XZ and YZ where Z is the coordinate perpendicular to the plane of photo emulsion XY. One can see that ^{4}He is emitting at angle close to zero and ranges of two particles are comparable.

Now the preliminary data for three-pronged stars in photo emulsion irradiated by a beam of ^{6}He are obtained. Data are obtained for interaction energy of 15-22 MeV. Events with tracks of ^{4}He and ^{1}H stopped in PE were selected under conditions that ^{4}He emitting angle is close to zero and that of proton is less than 10 degree. The preliminary experimental data are presented in fig.4 as a two-dimensional plot (Dalitz diagram) where X-axis is ratio of energies of secondary ^{4}He and primary ^{6}He, and Y-axis is that of secondary proton and primary ^{6}He.

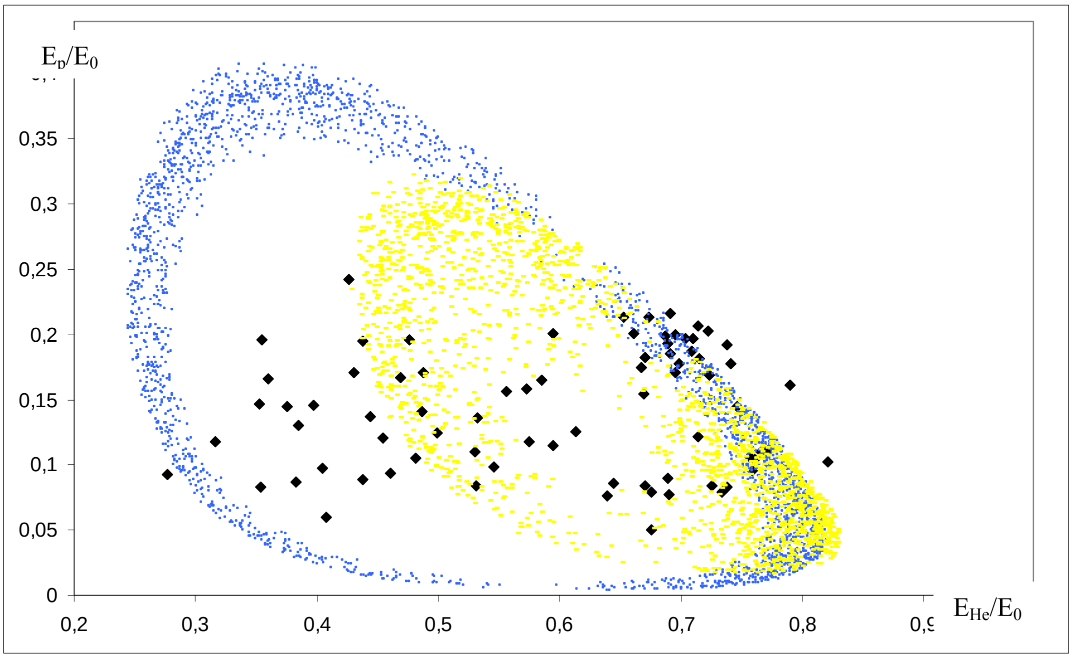

Fig.5. Dalitz plot for reduced energies of secondary ^{4}He and proton. Solid rhombs – experimental data, yellow and blue points show areas allowed for scattering of proton by halo neutron and dineutron under condition that spectator is not scattered and moves in the direction of incident halo-nucleus ^{6}He.

In the fig.5 are also shown the results of simple kinematical calculation of ^{6}He+p→p'+C+S reaction, where C (cluster) and S (spectator) are constituents of halo-nucleus ^{6}He. In the case of QFS of proton by dineutron (cluster) ^{4}He acts as spectator. If proton is scattered by a single neutron then ^{5}He acts as spectator. In fig.3 blue points show the area of Dalitz plot allowed for the scattering of proton by dineutron and yellow points show the area allowed for scattering by a single neutron under condition that spectator is not scattered and moves in the direction of incident halo-nucleus ^{6}He. One can see that there is an area of some concentration of points which is close to the both areas allowed for the scattering of proton by dineutron and single neutron.

It should be noted that presented above kinematical calculations were performed ignoring the requirements of conservation of momentum distribution of spectator in the projectile nucleus. Satisfying this requirement we considerably restrict the areas of possible values of energies in the Dalitz plot for QFS of proton by a neutron and dineutron.

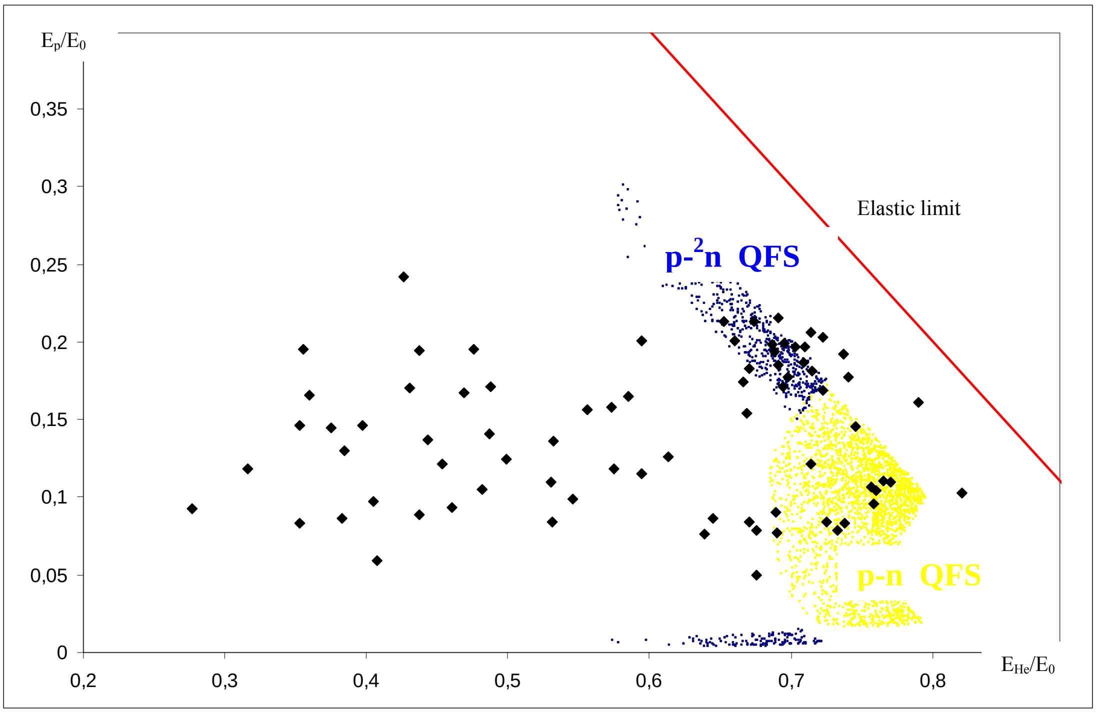

Fig.6. Dalitz plot for reduced energies of secondary ^{4}He and proton. Solid rhombs – experimental data, yellow and blue points show areas allowed for scattering of proton by halo neutron and dineutron under additional requirement of conservation of momentum distribution of spectator in the projectile nucleus.

In fig.6 we can see these restricted areas and the experimental data. Here the red line corresponds to the elastic limit for two-body kinematics. Though in our opinion the area of experimental data concentration is closer to the calculated area of QFS of proton by dineutron, we don't draw any conclusions about the structure of neutron halo in ^{6}He. It is necessary to obtain more experimental data, especially at different energies and perform more accurate calculation of QFS.

The work was supported by the Russian Foundation for Basic Research, Project N 05-02-16865a.

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