

Study of the lowest states in ${}^9\text{He}$ as a test of unusual nuclear structure beyond nuclear stability

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Examining nuclear matter under extreme conditions makes the most demanding test of our understanding of nuclear structure. A well known opportunity is provided by the study of nuclei which are far from the valley of stability. Indeed, it looks like we encounter a case of very light neutron rich nuclei: ${}^9\text{He}$, ${}^{10}\text{He}$, and ${}^7\text{H}$ which challenges our current knowledge of nuclear structure. A controversy between different experimental results and predictions for ${}^7\text{H}$ and ${}^{10}\text{He}$ is broadly discussed (see [1,2] and references therein). However, the most evident contradiction between the theoretical predictions and experimental results is for ${}^9\text{He}$.

The structure of ${}^9\text{He}$, with its 2 protons and 7 neutrons could be expected to be simple: two protons fill the s shell, while six neutrons fill the $p_{3/2}$ sub shell and the extra neutron should be in $p_{1/2}$ state. The most sophisticated modern calculations ([3,4] and references therein) support this “naive” view on the ${}^9\text{He}$ structure. This means that the reduced neutron decay width for the $1/2^-$ state should be close to the Wigner limit and the state should be rather broad (all calculations predict the ${}^9\text{He}$ to be unstable to a neutron decay to ${}^8\text{He}$). However several high resolution measurements of spectra of products of complicated binary or quasi binary reactions induced by heavy ions by a group in the Hahn-Meitner Institute [5, 6] brought interesting data with rather small uncertainties. They found the $1/2^-$ state of ${}^9\text{He}$ at 1.27 ± 0.10 MeV above the ${}^8\text{He} + n$ threshold with $\Gamma = 0.10 \pm 0.06$ MeV. The width appeared to be more than ten times smaller than it can be expected [4]. The narrow width of the $1/2^-$ state could be considered as a direct evidence for its complicated, non shell model structure, and could be a sign of an unusual structure appearing at the neutron drip line. Several groups tried to obtain detailed information on the lowest states in ${}^9\text{He}$ (including using the ${}^8\text{He}(d,p)$ reaction[7]), but low counting statistics or inadequate energy resolution did not give a possibility to test results [5,6].

We began an experimental study of the lowest states in ${}^9\text{He}$ using the ${}^9\text{Be}({}^{18}\text{O}, {}^{18}\text{Ne}){}^9\text{He}$ reaction. Different to other similar investigations we used coincidence between ${}^{18}\text{Ne}$ and the products of the ${}^9\text{He}$ decay, ${}^8\text{He}$ and ${}^6\text{He}$. This should provide for the attribution of the correct excitation energy to the reaction products because there are excited states in ${}^{18}\text{Ne}$ which are stable to a nucleon decay, and improve the effect/background ratio. The first stage of study was to understand counting conditions in the MDM chamber and to test a possible time resolution in the experiment. The experiment was made using ${}^{18}\text{O}$ beam of 11.5 MeV/A energy of K150 cyclotron. Heavy ions were detected using MDM spectrometer [8] in the angular interval $5^\circ \pm 2^\circ$. Detection system of the MDM spectrometer [8] provided for the needed angular ($\pm 0.3^\circ$) and energy resolution (~ 200 keV). The charged products of ${}^9\text{He}$ decay: ${}^8\text{He}$, ${}^6\text{He}$ or ${}^4\text{He}$ should be detected by Si detectors placed in the scattering chamber of the MDM spectrometer (a scheme of the setup is given in Fig.1). As tests of the setup and the experimental parameters we used reactions of the ${}^{18}\text{O}+{}^9\text{Be}$ elastic scattering and the ${}^9\text{Be}({}^{18}\text{O}, {}^{20}\text{Ne}){}^7\text{He}$ reaction.

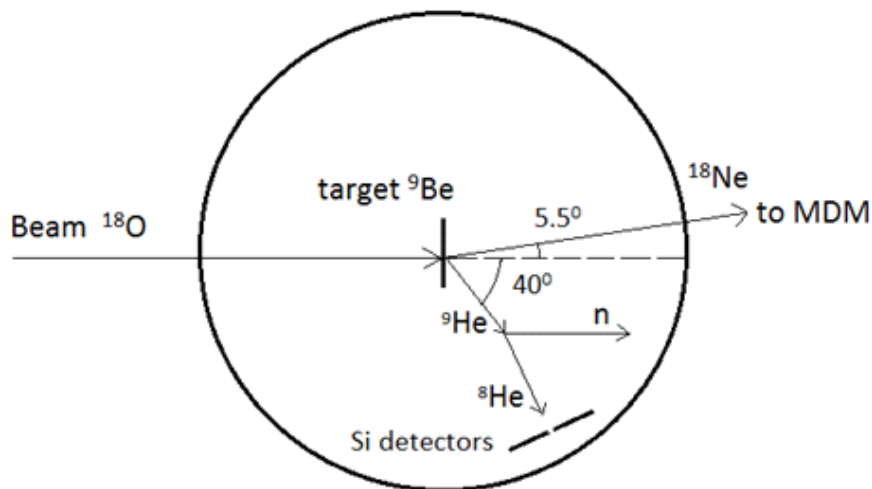


FIG. 1. Scheme of setup of the experiment.

In the first part of the data analysis we looked at the coincidences between ^{18}O and ^9Be in the process of elastic scattering. ^{18}O was registered in the Oxford detector and ^9Be in the silicon detectors. Coincidence scheme did prove to work fine in the case of elastic scattering with the best time resolution 5 ns for the energy 3 MeV in the silicon detector (Fig. 2).

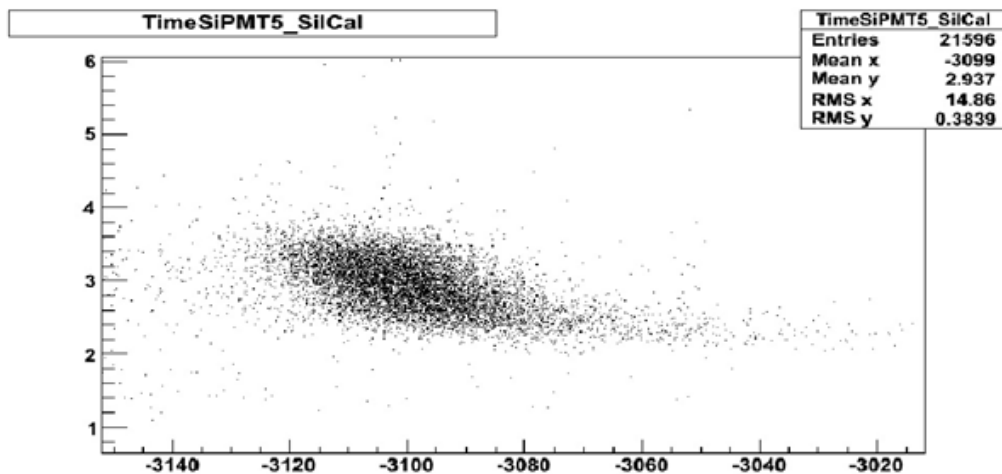


FIG. 2. Energy in the silicon in MeV (y-axis) versus time between the silicon detector and PMT in the Oxford (x-axis) 200ps/channel.

The following Fig.3 presents two dimensional dE-E spectrum for the reaction ${}^9\text{Be}({}^{18}\text{O}, {}^{20}\text{Ne}){}^7\text{He}$. The magnetic field of the MDM was tuned to detect ${}^{20}\text{Ne}$ in the Oxford detector. It can be seen that Oxygen and Carbon isotopes produced relatively narrow stripes which we assume are related to ${}^{12}\text{C}$ and ${}^{16}\text{O}$. In the Ne region we observed a broad distribution which we think includes isotopes of Ne (and probably F) with comparable intensities. We could not select ${}^{20}\text{Ne}$ using coincidences with Si detectors placed in the MDM target chamber.

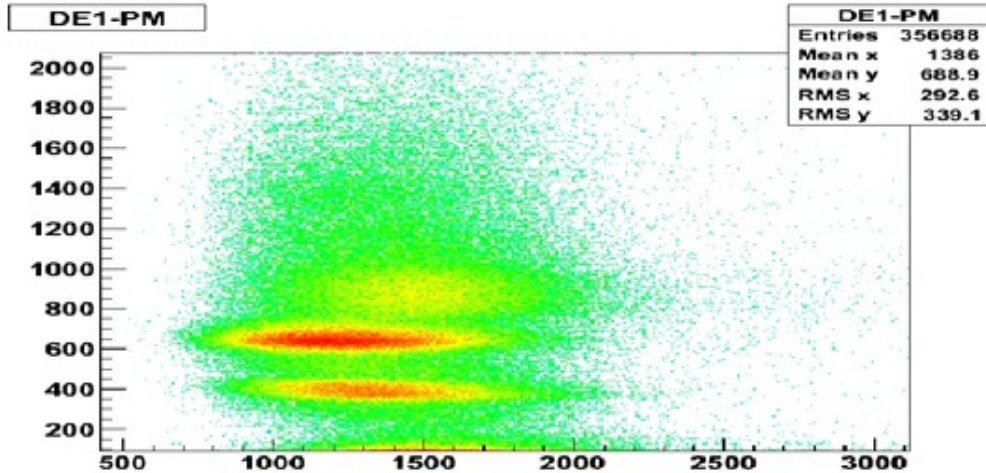


FIG. 3. In y-axis energy loss in dE1 plate of the Oxford detector versus energy in the PMT x-axis.

Time resolution of coincidence scheme in this case was 16 ns. It can be seen in the Fig.4 as the time-width of the most intense spot in the picture.

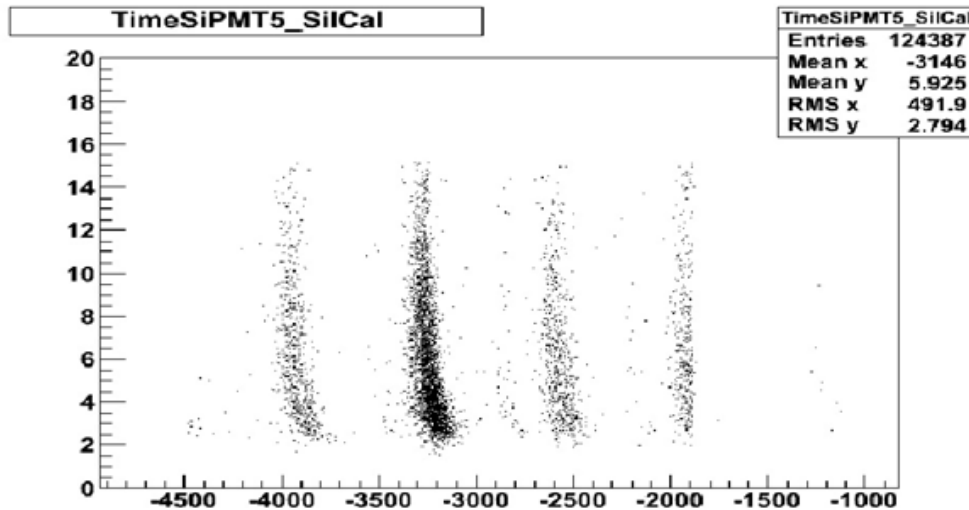


FIG. 4. Energy in the silicon detector in MeV (y-axis) versus time between the silicon detector and PMT in the Oxford (x-axis) 200ps/channel.

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