

Exploring the alpha cluster structure of nuclei using the thick target inverse kinematics technique for multiple alpha decays

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The alpha clustering properties of ^{24}Mg were investigated with the Thick Target Inverse Kinematics (TTIK) technique [1] using the reaction $^{20}\text{Ne}+\alpha$. This technique is particularly suited for this study because it allows the exploration of a large range of incident energies in the same experiment. Moreover, in the inverse kinematics, the reaction products are focused at forward angles and can be detected with detectors covering a relatively small portion of the solid angle in the forward direction.

^{20}Ne beams of energy 3.7 AMeV and 11 AMeV were delivered by the K150 cyclotron at Texas A&M University. The effective beam energies after the entrance window were 2.9 AMeV and 9.7 AMeV respectively. The reaction chamber was filled with ^4He gas at a pressure sufficient to stop the beam at 10 to 4 centimeters from the detectors (10.3 and 50 PSI respectively). In this way we could detect light particles emitted at zero degrees. The energy of the light reaction products was measured by three silicon detector telescopes placed at a radial distance of 48 cm from the entrance window. Each telescope consisted of two $5\times 5\text{ cm}^2$ Micron Semiconductors DC quadrant detectors (Design G). The time of flight of the detected particles was also measured relative to the cyclotron radiofrequency. A monitor detector was used to measure the intensity of the incident beam. A schematic picture of the experimental setup is given in Fig.1.

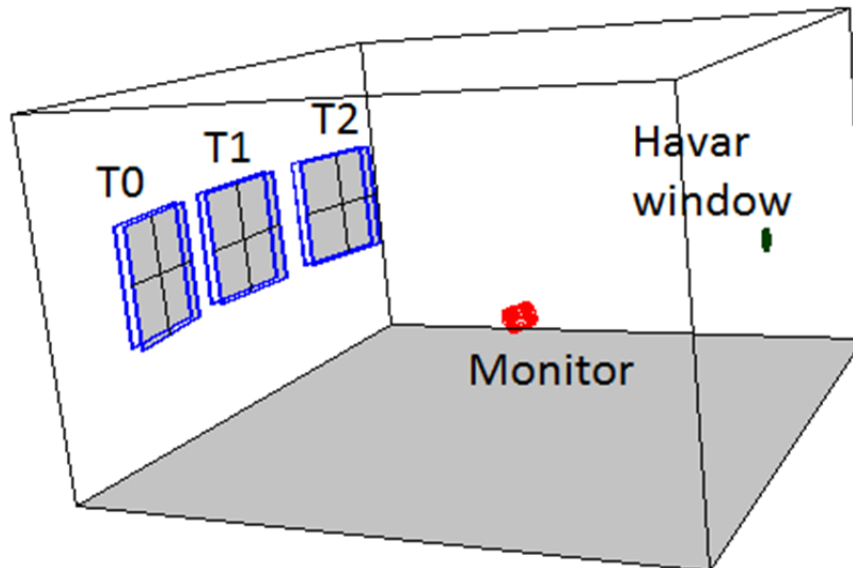


FIG. 1. Experimental setup. T0, T1 and T2 are the silicon detector telescopes.

After the energy and time calibration of the detectors, alpha particles were separated from protons and other light particles with proper gates on ΔE - E and E -Time plots. High Z reaction products are stopped in the gas before reaching the detectors.

According to the Ikeda picture [2] ^{24}Mg can be described as $^{20}\text{Ne} + \alpha$, $^{16}\text{O} + 2\alpha$, $^{12}\text{C} + 3\alpha$ or a cluster of 6 α particles. Each configuration is expected to be observable at excitation energies around the corresponding threshold values. In this experiment the TTIK method was used to study multiple α -particle decays as well as elastic scattering. We observed alpha particle multiplicities up to 3, when the ^{20}Ne beam energy was 2.9 AMeV, while at 9.7 AMeV we observed alpha particle multiplicities up to 6. The events with alpha particle multiplicity 1 and 2 are analyzed here.

The results obtained on the elastic resonant α scattering (alpha multiplicity 1) are shown in Fig. 2. The resonant elastic scattering differential cross-sections, in the center of mass frame, are plotted as a function of the ^{24}Mg excitation energy. Our differential cross-sections are compared with those measured in Ref. [3] at similar angles. New results are obtained at 180° up to ^{24}Mg excitation energies of about 35 MeV. We have an energy resolution of 30 keV at 180° , worsening with decreasing angles. It is interesting to note that 28.5 MeV is the threshold energy for the decomposition of ^{24}Mg into 6 alpha particles.

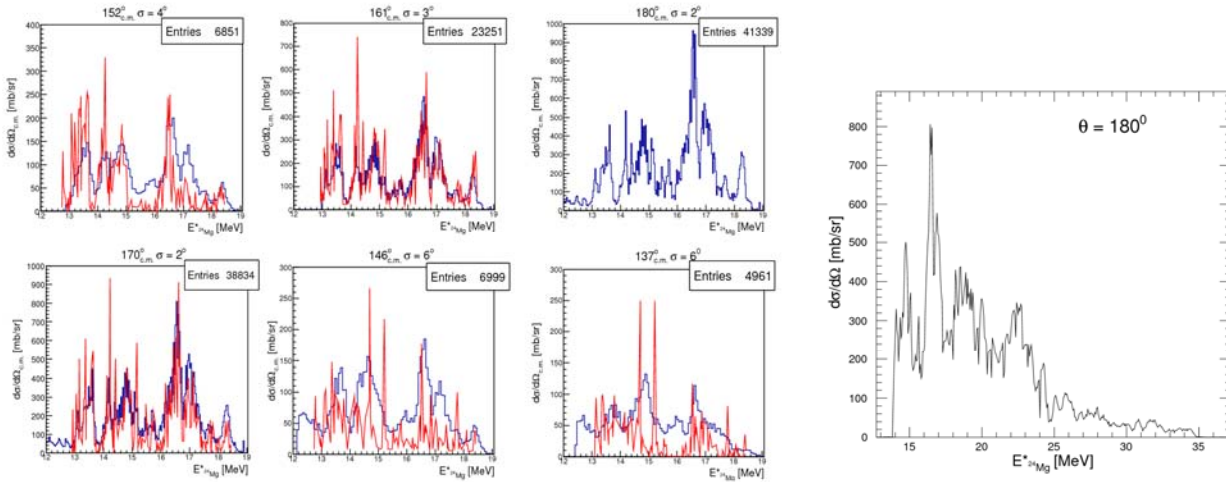


FIG. 2. Resonant elastic scattering cross-sections. Left panel: obtained at 2.9 AMeV ^{20}Ne ; Right panel: obtained with the 9.7 AMeV ^{20}Ne . The red lines show the cross-sections measured in Ref. [3] at 156° , 164° , 168° , 143° and 139° .

Fig. 3 shows the energies of the two alpha particles detected in events with alpha multiplicity 2. Uncorrelated events have been estimated by randomly mixing two alpha particles from the experimental distribution of multiplicity one events. The subtracted two dimensional plots are shown in Fig. 3.

A reconstruction code developed to analyze this experiment was used to derive the interaction point inside the gas volume. This code uses the kinematics, the alpha particle energies and a double check with the measured times of flight.

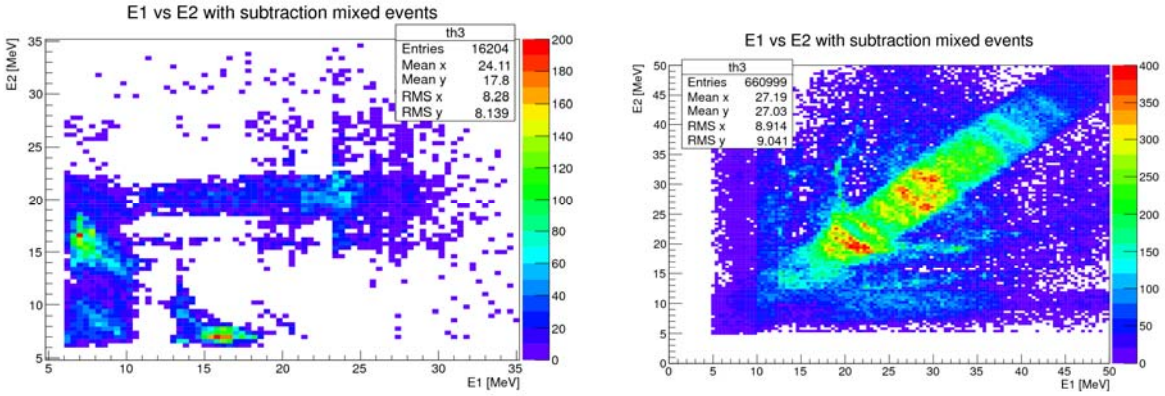


FIG. 3. Energy of the two detected alpha particles in case of 2.9 AMeV (left panel) and 9.7 AMeV beam (right panel).

At the incident energy of 2.9 AMeV we observed 2 alpha particles with quite different energies. We hypothesize that a resonant alpha scattering populates a ^{24}Mg excited state that has enough energy to emit one alpha particle and leave the ^{20}Ne in an excited state that alpha decays to the ground state of ^{16}O . Using this assumption in the reconstruction code we obtained the excitation energy of the ^{24}Mg (from the reconstructed interaction point and the beam energy loss) and the excitation energy of the ^{20}Ne (using the energy of the second alpha particle). The result is shown in Fig.4. It is interesting to note that the excitation energy of ^{24}Mg is in this case very close to the energy threshold to observe the decay in ^{16}O and two alphas.

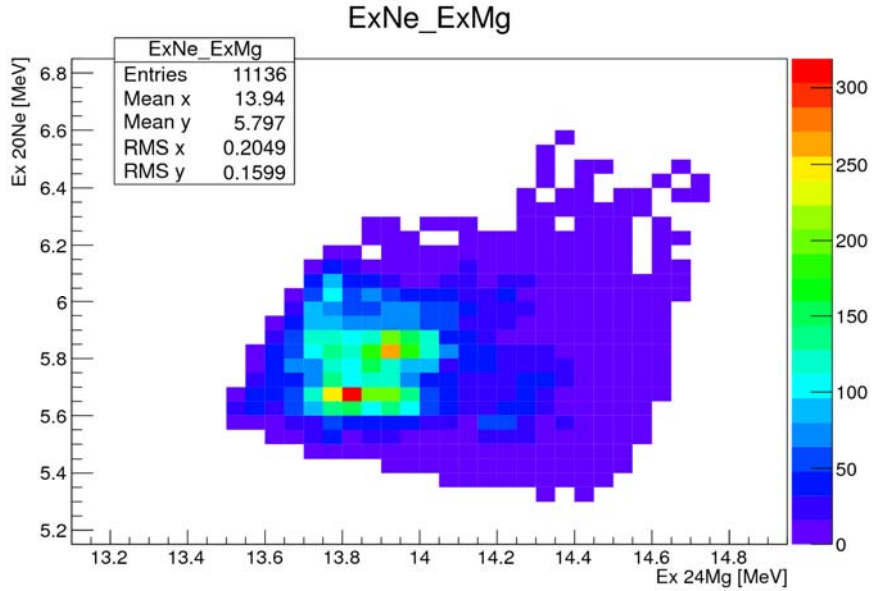


FIG. 4. Reconstructed excitation energies for ^{24}Mg (x-axis) and ^{20}Ne (y-axis). The initial energy of the ^{20}Ne energy was 2.9 AMeV.

At the incident energy of 9.7 AMeV we observed several groups of 2 alpha particles with similar energy emitted mostly at angles close to 0° in the laboratory frame. We explain these, as alpha particles coming from the splitting of a ^8Be . Therefore, the hypothesis in the reconstruction of the events is that the resonant scattering populates a $^{24}\text{Mg}^*$ state with enough energy to decay in $^8\text{Be} + ^{16}\text{O}$. The reconstructed excitation energies of the ^{24}Mg are presented in Fig. 5.

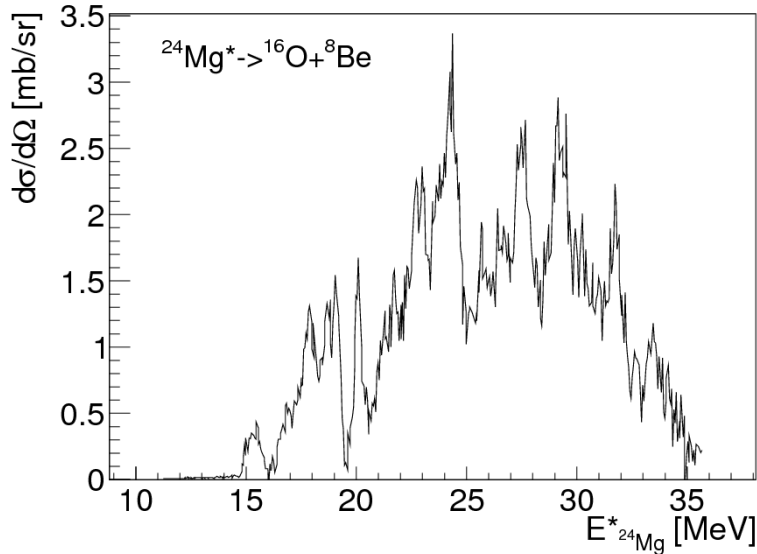


FIG. 5. Reconstructed excitation energy of the ^{24}Mg , measured with a ^{20}Ne 9.7 AMeV at 180° in the center of mass. Very preliminary.

Fig.5 shows a surprisingly high number of resonance peaks in the ^{24}Mg excitation function. These structures might be related with the multiple alpha cluster structure in ^{24}Mg . The broad peaks at about 28 and 32 MeV are particularly interesting because they lie very close to the energy threshold for the splitting of ^{24}Mg into 6 alphas. Further analysis of the data is necessary to get a final answer.

Another experiment with an improved experimental setup is planned for the near future. A better time resolution is necessary in order to have a better reconstruction of the events. Moreover a larger angular coverage at forward angles is necessary to increase the detection efficiency if we want to be able to improve detection of the events in which the ^{24}Mg decays in 6 alphas.

[1] K. Artemov *et al.*, Sov. J. Nucl. Phys. **52**, 406 (1990);

[2] K. Ikeda, N. Takigawa, and H. Horiuchi, Prog. Theor. Phys. Suppl. Extra Number, 464 (1968);

[3] Abegg *et al.*, Phys. Rev C **43**, 2523 (1990).