Investigation of ground state alpha cluster structure using the NIMROD detector array

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Alpha clusterization is the phenomenon where a certain number of ^{4}He particles can make up the structure of nuclei. At certain excitation energies, these alpha cluster structures tend to dominate as a result of the large binding energy and high excitation energy of ^{4}He. At such excitation energies, the nucleus can be described as a low density, gas-like state consisting of a discrete number of alpha clusters. An example of such a state is the Hoyle state in ^{12}C, which can decay into three alpha particles. However, this type of cluster structure does not exclusively exist in excited states of nuclei. Models calculating the density distributions of alpha conjugate nuclei indicate that some degree of alpha cluster structure coexists with a dominate mean-field type structure at the ground state level and other low-lying states [1-3]. Such models also suggest that the energy levels of the alpha conjugate nuclei are sensitive to the degree of mixing between the mean-field structure and cluster structure at these states.

In order to measure the degree of clusterization at the ground state level, we examined quasifree knockout reactions with a 60 MeV/u ^{4}He beam on various light alpha-conjugate targets. This experiment was performed using the NIMROD 4π detector array (Fig. 1) so that the detection coverage of quasifree, energy conversing angle pairs is maximized. In other words, NIMROD provides good coverage for the detection of the knocked-out particle and scattered projectile at angles where the energies sum to the original projectile energy.

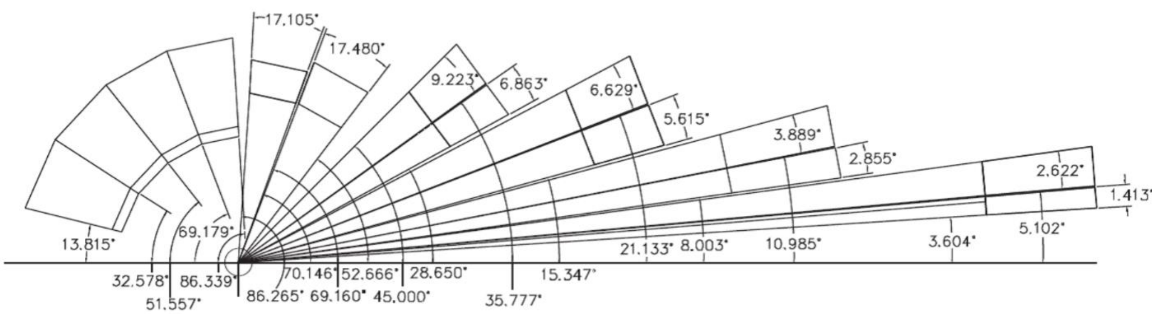

Fig. 1. Schematic of the detector module locations in the NIMROD detector array. NIMROD contains 156 detector modules consisting of Si-CsI and Si-Si-CsI telescopes.

This experiment was rerun in late March of 2022 for the purpose of enhancing the statistics of the knockout yield. This was done using the multi-event capabilities of the Struck Flash 3316 waveform digitizers. In the previous run of 2020, we were running with a live time of approximately 20-50%. This severely limited the amount of data we were capable of recording. With the multi-event mode, we were able to collect 20-40 times more data than the previous experiment.

Additionally, we were better able to quantify and correct for a detector anomaly observed in the data analysis of the 2020 run. The gain of approximately half of the CsI(Tl) detectors appears to be unstable with the rate of incident ions. As presented in Fig. 2, the measured energy increases with increasing rate. This is inconsistent with conventional gain drifts observed with voltage sagging in PMTs at high rates. Oddly, the largest change in gain typically occurs at relatively low rates (~20-60 ev/s). There appears to be no detector location dependence to this effect. The severity of the gain drifts also varies across detector from approximately 2-9%. It also has been reproduced in several experiments after the 2020 run with proton and alpha beams. From those experiments, it was concluded that this effect is likely an issue with the detector, not with the electronics. More work needs to be done in order to better understand the issues with these detectors.

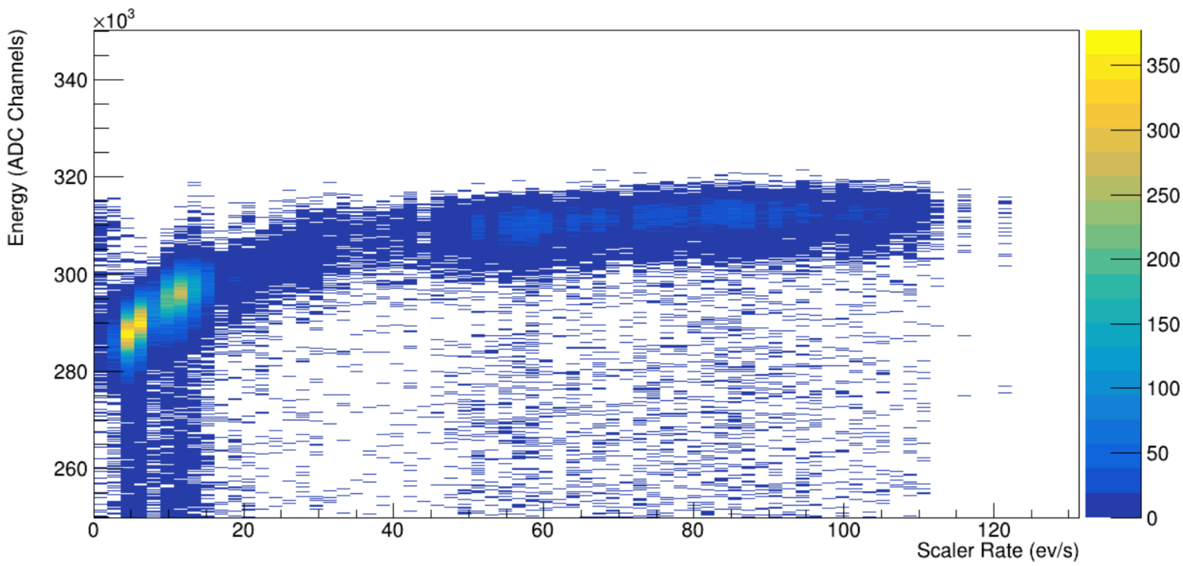

Fig. 2. Measured energy in a CsI(Tl) detector correlated with the rate of incident ions on the detector. Shown in this plot is the gain drift of 60 MeV/u alpha projectiles elastically scattered off of a Th target.

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