# Studying the $^{23}$Na($d,p$)$^{24}$Na reaction to constrain the astrophysical $^{23}$Mg($p,\gamma$)$^{24}$Al reaction rate


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In classical novae, the $^{23}$Mg($p,\gamma$)$^{24}$Al reaction provides an escape from the Ne-Na cycle and is therefore important in understanding nucleosynthesis in the $A$>20 mass range. A classical nova provides the increased temperatures necessary for the proton capture reaction on $^{23}$Mg to outpace the β decay reaction favored at lower temperatures [1,2]. The $^{24}$Al generated by this proton capture reaction quickly decays into $^{24}$Mg and allows entrance into the Mg-Al cycle [4].

Several resonances may be of astrophysical interest; however, at nova temperatures, the lowest resonance at ~475 keV appears to be the dominant contributor to the reaction rate [1]. Multiple experiments have investigated the excited states in $^{24}$Al that correspond to the resonances of astrophysical interest. A fusion-evaporation experiment at gammasphere found the first resonance energy to be 473 ± 3 keV [3] by performing in-beam γ-ray spectroscopy on the Al nucleus. While this is regarded as the most precise measurement to date, other particle spectroscopy experiments have placed the resonance energy between 456 ± 10 keV and 497 ± 5 keV [4]. Following these experiments, the first direct measurement of 23Mg(p,g)24Al was performed at DRAGON. Using a $^{23}$Mg beam a resonance energy of 485.7 keV and a resonant strength of 38 meV [3] were determined. However, an additional resonance strength higher than initially anticipated was noted upstream of the target position. This observation introduces some uncertainty into the veracity of the results produced.

We believe an indirect measurement of the resonant strength will either verify or throw into question the DRAGON measurement. Given the isobaric analogue of $^{24}$Al is $^{24}$Na, we have made a measurement of the $^{23}$Na($d,p$)$^{24}$Na reaction in inverse kinematics to measure the ejected proton and extract the spectroscopic factor. Since the spectroscopic factor for $^{24}$Na and $^{24}$Al should be the same, we can then use this to calculate the proton width and, utilizing the known gamma width, can extract the resonant strength. The experiment conducted here at the Cyclotron Institute was performed using TIARA, a compact silicon detector array designed to study direct reactions in inverse kinematics [5]. We impinged a 10 AMeV beam of Na on a 500 μg deuterated plastic target mounted in the center of the TIARA chamber. In conjunction with the MDM and Oxford Detector, we are able to look at protons from the $^{23}$Na($d,p$)$^{24}$Na reaction in the backward angle silicon array with relatively high precision. HPGe detectors mounted around the target position also allow for gamma-ray spectroscopy.

Significant progress has been made in the analysis of our experimental data. The calibration has been completed for the backward annular silicon detector and work continues towards calibrating the barrel silicon detectors and performing the beam position minimization. This progress has allowed us to generate the first excitation spectrum for our reaction, seen in Fig. 1. You can clearly make out the excited states of the $^{24}$Na nucleus and the values for these states fall within expected bounds. Previously, due to an issue we encountered while running, we had thought that few to none of the $^{24}$Na nuclei had made it through the MDM and into the Oxford Detector. Recent progress in the analysis has revealed that

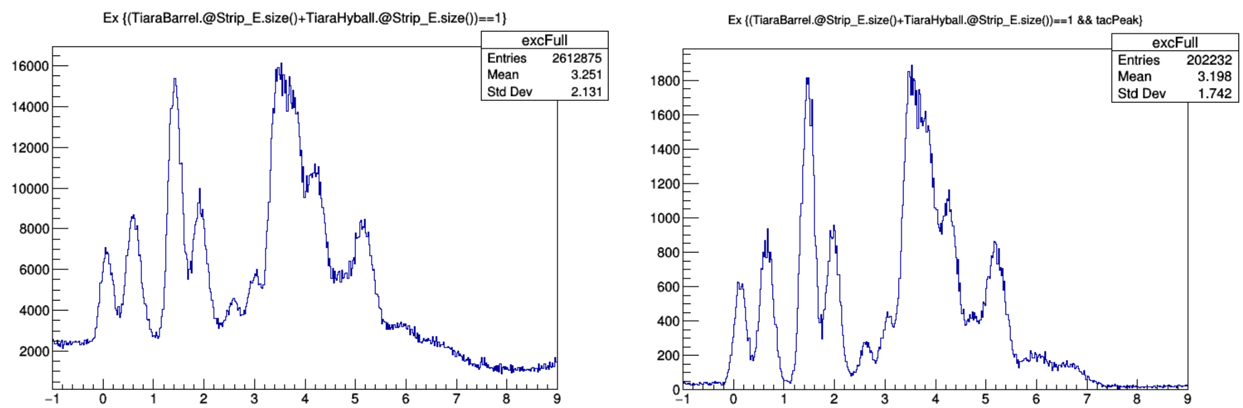


**FIG. 1.** Current excitation spectrums generated from the 23Na(d,p)24Na experiment. The plot on the left has full statistics and the plot on the right shows only events that made it through to the focal plane.

an appreciable fraction of the beam did in fact make it into the focal plane. Using this data we have managed to almost completely remove the background from our excitation spectrum without too significant a loss in efficiency. Fig. 2 illustrates the most recent particle identification plot generated from this data. More work remains to be done, but these developments mark a meaningful advance towards completing the analysis

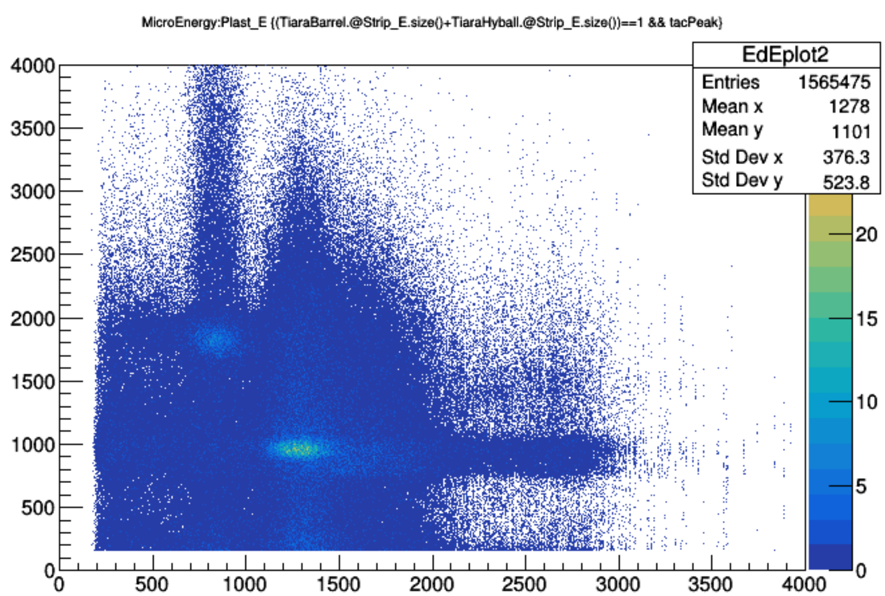


**FIG. 2.** Particle identification plot generated from events that were accepted into the focal plane. Work is continuing to improve the quality of this data.

In addition, we have been approved to repeat the $^{23}$Mg($p,\gamma$)$^{24}$Al direct measurement at TRIUMF. This experiment will take advantage of DRAGON's newly upgraded Lanthanum Bromide array, which will decrease systematic uncertainties relative to the previous experiment. Repeating the direct measurement should remove the aforementioned uncertainty from the previous run and will further constrain the resonant strength of the reaction. We hope to schedule beam time for this experiment at some point in 2019.


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