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

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In classical novae, the ^{23}Mg(p,γ)^{24}Al reaction provides an escape from the Ne-Na cycle and is therefore important in understanding nucleosynthesis in the A>20 mass range. Classical novae occur in binary star systems where one of the two main sequence stars has regressed to a white dwarf. When the white dwarf's companion star sheds its matter, the white dwarf begins to accrete hydrogen-rich materials on its surface. The burning of the materials raises the white dwarf's temperature and runaway nuclear reactions begin. It is at these increased temperatures that the proton capture reaction on ^{23}Mg outpaces 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 [3].

Several resonances may be of astrophysical interest; however, at novae temperatures, the resonance at ~475 keV is thought to be the dominant contributor to the reaction rate [2]. 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 energy of this resonance to be 473 ± 3 keV [4], by performing in-beam γ-ray spectroscopy on the ^{24}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 [3]. A direct measurement of the ^{23}Mg(p,γ)^{24}Al reaction was performed at DRAGON, using a ^{23}Mg beam impinging on a windowless H_2 gas target. This experiment determined a resonance energy of 485.7 keV and a resonance strength of 38 meV [4]. However, the authors were only able to weakly exclude the possibility of a stronger resonance lying at the edge of their gas target, in the region where the gas pressure has not reached equilibrium. These uncertainties motivate additional experiments constraining the strength of the ~475 keV resonance.

We believe an indirect measurement of the resonance strength will either verify or throw into question the DRAGON measurement. Since ^{24}Na is the isobaric analogue of ^{24}Al, we can easily make an indirect measurement using the stable beams available to us at the Cyclotron Institute. Specifically, we use the ^{23}Na(d,p)^{24}Na reaction in inverse kinematics to extract the spectroscopic factor for the mirror of the ~475 keV resonance in ^{23}Mg + p. Given the spectroscopic factor for ^{24}Na and ^{24}Al is the same, we can then use this to calculate the proton width and, utilizing the known gamma width, can extract the resonance 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 10A MeV beam of ^{23}Na on a 500 μg/cm^2 CD_2 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.

Fig. 1 shows a sample online proton spectrum we observed during one of our runs. The spectrum clearly shows several excited states in the ^{24}Na nucleus, including the mirror of the astrophysical state of interest, which lies at 2514 keV. We are currently in the process of performing the offline analysis to extract the differential cross section for population of this state in ^{23}Na(d,p)^{24}Na. Analysis continues on the data set and we hope to use our final results to determine if another run at DRAGON is warranted to repeat the direct measurement of the ^{23}Mg(p,γ)^{24}Al reaction.

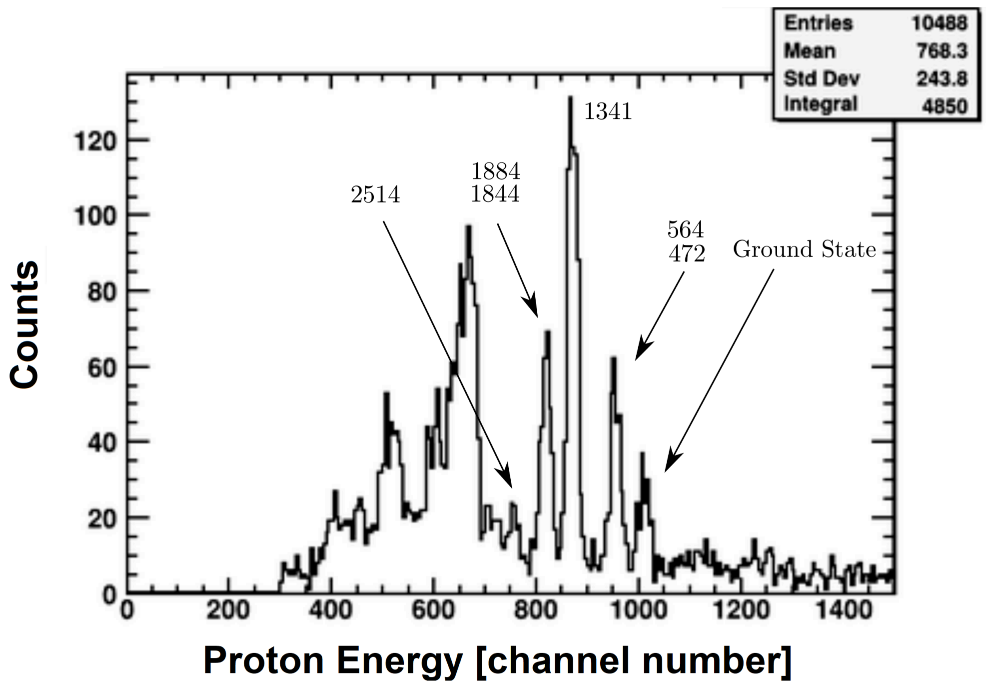

FIG. 1. A sample proton spectrum seen during our experiment. This spectrum includes labels for several suspected resonance energies in the ^{24}Na nucleus.

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