High-mass test of the MDM mass-separation capabilities

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The Multipole Dipole Multipole (MDM) spectrometer is an integral component our study of astrophysical reactions here at the Texas A&M Cyclotron Institute. Currently it is used in conjunction with the TIARA (Transfer and Inelastic scattering All-angle Reaction Array) experimental setup to study nucleon transfer reactions like (d,p) and (6Li,d) in inverse kinematics. This type of reaction is useful for nuclear spectroscopy, cross section measurements, and reaction spin-transfer dynamics, whose measurements can inform models of nucleosynthesis in stars. So far, all TIARA for Texas (T4T) studies have been done with stable beams in the K150 and K500 cyclotrons, with reactions such as ^{19}F(d,p)^{20}F, ^{23}Na(d,p)^{24}Na and ^{22}Ne(^{6}Li,d)^{26}Mg. Soon, the Cyclotron Institute will be capable of producing rare isotope beams (RIBs). Transfer reaction experiments with RIBs are especially interesting as many astrophysical reactions occur away from stability. In this report we discuss a recent investigation of the mass separation abilities of the Multipole Dipole Multipole spectrometer in order to extend the mass range of possible experiments done with MDM.

The T4T setup uses a large slew of detectors to so that a nearly perfect reconstruction of each event can be done. TIARA itself consists of a target chamber surrounded by a barrel of resistive strip detectors. TIARA is capped at the end by a modular silicon detector HYBALL which can be placed up- or downstream of the target, depending on the kinematics of the reaction under study. In conjunction these detectors allow for large angular coverage of transfer reaction products and elastically scattered beam. A set of High Purity Germanium (HPGe) clovers used in the HYPERION experiment is also employed for prompt γ-ray detection. These detectors are coupled to the Si and barrel detectors to give coincidence measurements of the de-exciting states populated from transfer reactions. The HPGe's are integral in the PID test in this review. After passing through TIARA the beam moves through MDM for mass-separation before entering the new focal plane detector (FPD) array. The FPD array, utilizes a gas chamber of isobutane with avalanche wires and MicroMegas to measure beam position and energy deposition in the gas. The chamber is capped at the end with a CsI detector to measure energy of the reaction products in coincidence with proton energies in TIARA.

Experiment

In summer 2017 the T4T group ran a ^{63}Cu beam at 10 MeV/u into Cave 3 holding the MDM spectrometer. The beam was impinged on a 500µg/cm2 CD2 target to induce the ^{63}Cu(d,p)^{64}Cu reaction. Protons were measured in the HYBALL detector in correlation with the copper recoils, see Fig. 1a and 1d. The MDM was tuned to place the beam centrally in the FPD. The majority of unreacted beam throughput was removed by MDM. Some unreacted ^{63}Cu was observed in the CsI and MicroMegas with the daughter nucleus, see Fig. 1c. The two were further separated in the analysis. The ^{64}Cu nuclei created in this reaction are pushed into a slew of different excited states. We used the HPGe detectors around the reaction center to observe de-excitation of these states.

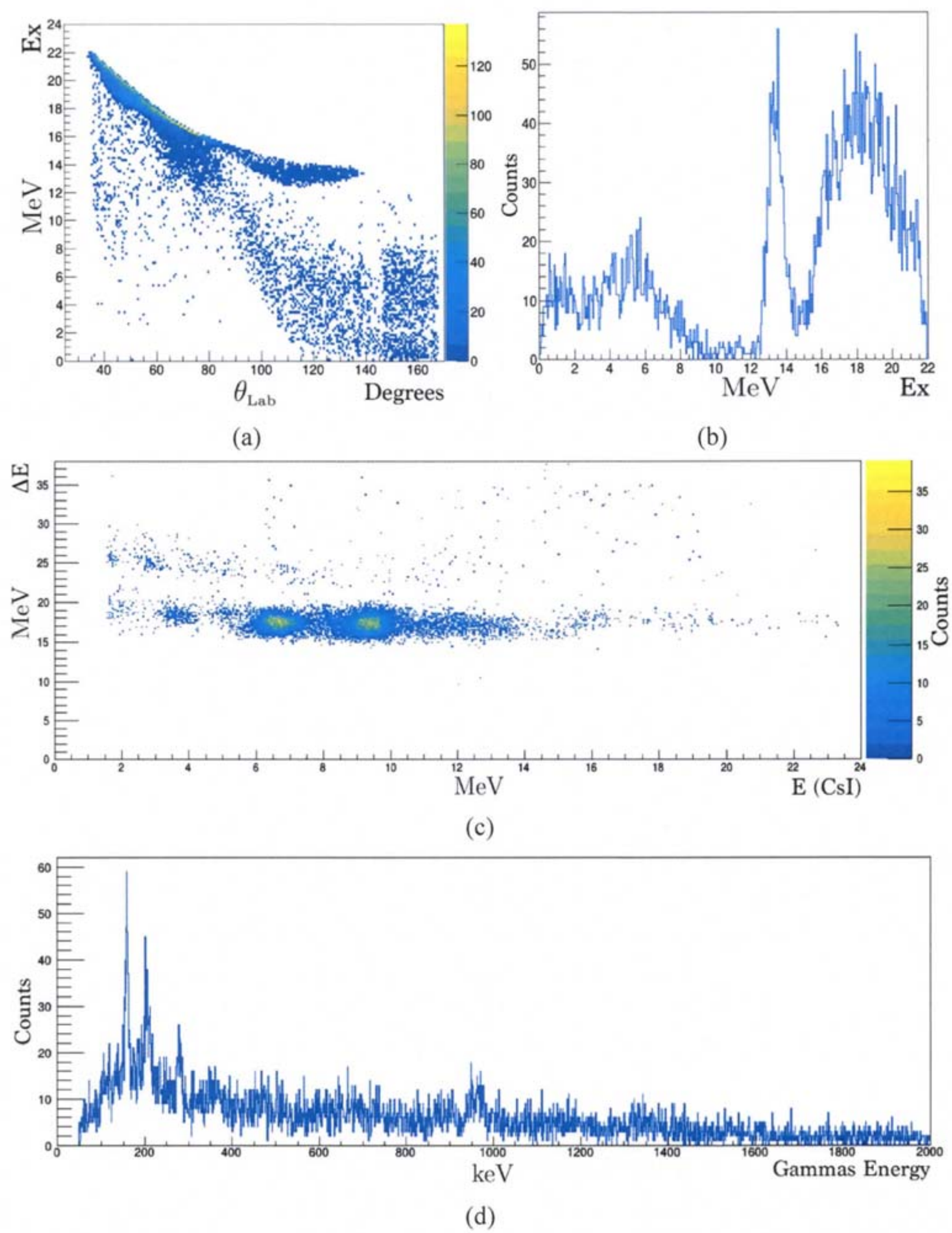

FIG. 1. Above, a) shows the proton impact energy, Ex measured from HYBAL L vs θLab. This gives us the angular distribution of recoiling protons. Plot b) shows ELab vs Ex. c) is the ECsI–ΔE that shows the separation of the two copper nuclei. The blob to the right side is identified to be ^{64}Cu. d) shows the gamma spectrum. We see some features which are shrouded partially by a continuum-like ban.

Analysis

Once our measurements were calibrated the first step in the analysis was to gate on the reaction peak of proton events which triggered the TAC (time-to-amplitude converter). Now gated, we can present the reaction measurements and do rudimentary particle ID. With the ECsI–ΔE plot we can assume that our particles are indeed separated here. However, to convince ourselves of which nuclei are which and that separation was actually achieved we look to the gamma-ray spectrum. Gating on each blob in ECsI–ΔE (Fig. 1c) individually we clearly see distinction in the two spectra. When gated on the suspected ^{64}Cu events a clearer spectrum with strong features is teased out. We compare these features to the NNDC adopted level scheme [1], and notice that each peak match with known levels in ^{64}Cu that have high spectroscopic factors [2, 3]. From this we're confident that the PID is accurate and separation is achieved.

Conclusion

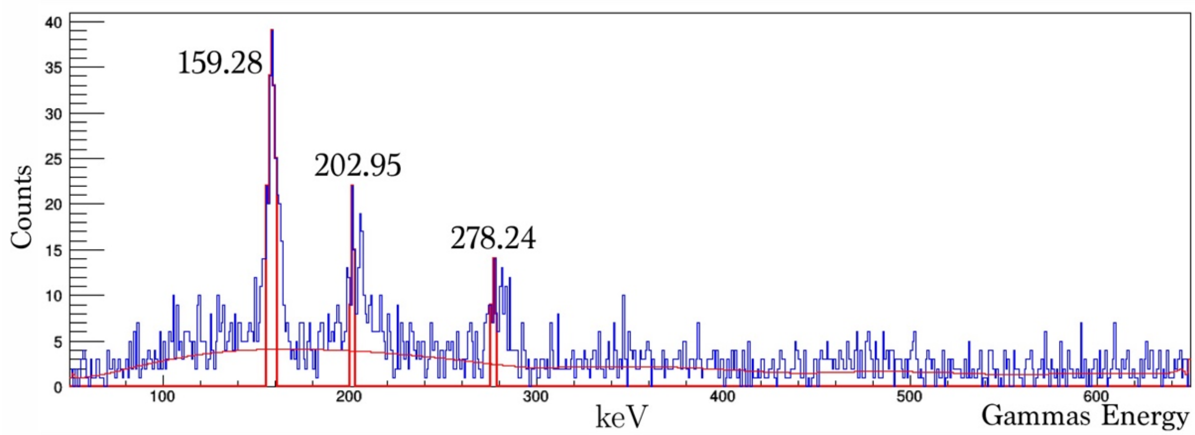

FIG. 2. Here we see the gamma spectrum resulting from gating on the suspected ^{64}Cu

In summary, this experiment has tested the ability of MDM to separate ions at a higher mass range than previously probed. Using the gamma excitation spectrum from HYPERION detectors we can be certain that separation was achieved. In the past the highest mass ranges used in MDM peaked in the A=30 mass range. Through this analysis we've found that MDM is capable of separating ions through the A=60 mass range, and perhaps higher. Coupled with our future RIBs this ability opens and extremely large range of new experiments and nuclei that can be probed at the Cyclotron Institute.

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