The commissioning run for the Texas-Edinburgh-Catania silicon array (TECSA): Measurement of the d(^{14}C,p)^{15}C at 11.7 MeV/u

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The Texas A&M-Edinburgh-Catania Silicon detector Array (TECSA) is a collaborative effort to construct a silicon detector array with high efficiency and high granularity for use in experiments at the Texas A&M Cyclotron Institute (TAMU-CI). The array consists of up to 16 Micron Semiconductor Ltd. YY1-300 silicon detectors (MSL-YY1) [1] and up to 256 channels (16 Si detectors sectors × 16 strips per detector) of associated electronics [2]. TECSA will be used to study reactions to obtain information relevant for nuclear astrophysics by indirect methods such as the asymptotic normalization coefficient (ANC) and Trojan Horse Method THM). Details on the TECSA detector setup at TAMU-CI can be found in last-year's annual report [3] and in a recently published article [4].

In an experiment conducted in May 2010, TECSA was commissioned at TAMU-CI by measuring the d(^{14}C,p)^{15}C reaction in inverse kinematics as a precursor to future measurements with rare isotope beams. The ^{14}C beam for the experiment was obtained as a primary beam from the K500 cyclotron at 11.7 MeV/u and delivered to the MARS spectrometer. The beam was tuned through MARS with no primary production target in place. Then, the beam spot was tuned at the TECSA reaction target position on a position sensitive silicon detector. This target detector was a MSL type-MSPSD TL 20 position sensitive detector with four-corner readout [5]. A beam spot size of 3mm × 1mm (FWHM) was obtained.

Following the beam tuning, the ^{14}C impinged on a target of deuterated-polyethylene (CD$_2$) with areal density of 251 ± 5 μg/cm^2 and D:H ratio enriched to 98%. For this reaction, it was expected that the protons from the forward center-of-mass angles would be detected at the backward lab angles. Thus, TECSA was mounted upstream of the CD$_2$ target in the flat configuration. The detector thickness of≈ 300 μm was sufficient to stop the protons from the reaction at all angles measured. Also, the detector ring has a hole in middle to allow the ^{14}C beam to pass through it on its way to the target.

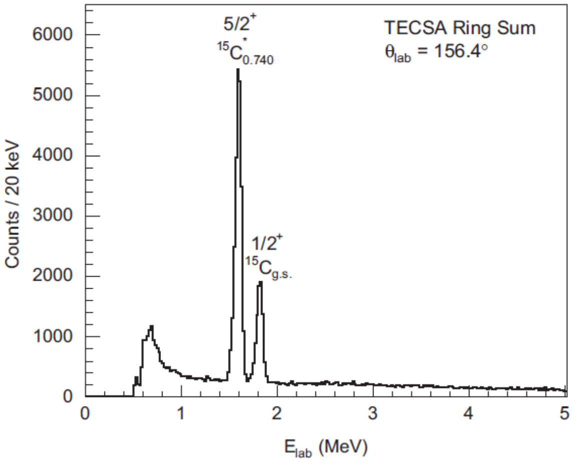

FIG. 1. Typical energy-matched spectrum from the d(^{14}C,p)^{15}C measurement.

A typical spectrum for the d(^{14}C,p)^{15}C reaction for the TECSA ring centered at θ_{lab} = 156.4° is shown in Fig. 1. In the figure, protons resulting from the population of the ground and first excited states of ^{15}C are observed. A peak resolution of ≈ 100 keV (FWHM) was obtained, which arose mainly from the thickness of the target and the kinematic resolution ($\Delta E/\Delta\theta$). The background under the peaks was due to reactions of the beam with the carbon in the CD_2 target (as observed from background measurements on a natural carbon target), and events uncorrelated with the ^{14}C beam such as cosmic rays and residue from the α-source used to calibrate the detectors.

The proton yields were measured for the ^{15}C ground and 0.740 MeV states over the angular range $102° < \theta_{lab} < 165°$. To cover this angular range, the CD_2 target was positioned at 20, 12, 5, and 2.8 cm from the center of TECSA along the beam axis. With this angular range, the differential cross sections for ^{15}C states were measured from $4° < \theta_{CM} < 34°$ in the center of mass system. These data were then compared with distorted-wave Born approximation (DWBA) calculations carried out with the program TWOFNR [6]. The calculations were performed assuming the orbital angular momentum and spin values found for the ^{15}C states in previous work. The results of these calculations are shown in Figure 2. The details of these calculations, including the optical potentials used, are given in Ref. [4]. While better descriptions of these data are likely possible, the general features of the angular distributions are reproduced, and the difference in the angular momenta of the two states is clearly seen.

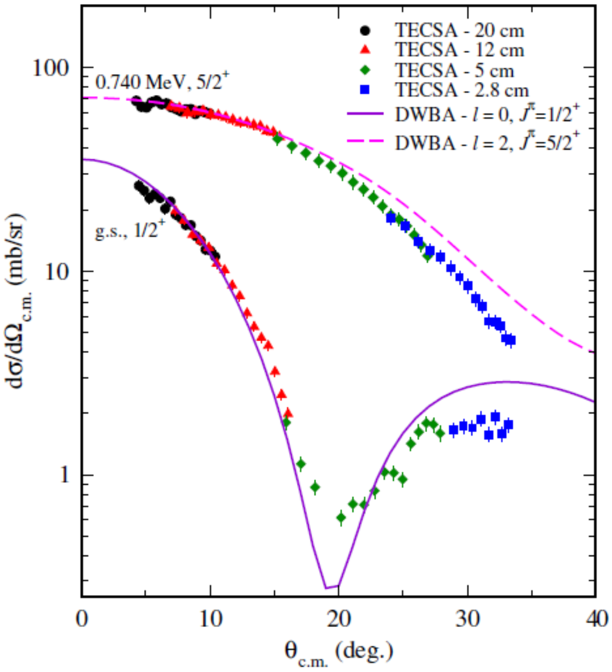

FIG. 2. Angular distributions obtained from the $d(^{14}C,p)^{15}C$ experiment.

Following this successful measurement, we tried to investigate the utility of the TECSA detector for measuring reactions with genuine rare isotope beams produced as secondary beams with MARS. Using the available ^{14}C primary beam at 11.7 MeV/u and deuterium gas in the MARS production target, secondary beams of $^{12,13}B$ were produced using the reactions $d(^{14}C,^{13}B)^3He$ and $d(^{14}C,^{12}B)^4He$. The goal of these measurements was to investigate the $d(^{12}B,p)^{13}B$ and $d(^{13}B,p)^{14}B$ reactions with TECSA. These reactions were expected to have cross sections similar in magnitude to those observed in the $d(^{14}C,p)^{15}C$ experiment. A production rate of 130 eV/nC was obtained for the ^{13}B, but the low primary beam current of 16 enA limited the total secondary beam rate to $\sim 2 \times 10^3$ pps. Similarly, the production rate for the ^{12}B beam was 154 eV/nC, but even with the higher beam current available at this point in the experiment of 120 enA, the maximum secondary beam rate available was around 2×10^4 pps. Thus, the reaction signals from $d(^{12}B,p)^{13}B$ and $d(^{13}B,p)^{14}B$ were not observable due to the combination of ~x 10^4 less beam current (than was used in the ^{14}C experiment) and background that arose from the presence of the ^{14}C primary beam in the experimental hall (likely from secondary neutrons produced when the ^{14}C primary beam impinged on the D_2 gas production target). Some of this background was able to be removed by adding a plastic scintillator/PMT system to the setup such that events not in coincidence with the beam could be excluded. However, the rate of available secondary beam was still too low to observe a signal from the reactions. At the end of the experiment, a signal was obtained with this system from the d(^{14}C,p)^{15}C reaction from the $^{15}C_{0.740\ MeV}$ state in the situation that the ^{14}C primary beam rate was reduced to ~ 1 × 10^5 pps. Improvements to the chamber mechanics and better treatment of the timing signals are expected to make future measurements with secondary rare isotope beams more feasible.

In conclusion, we have successfully constructed and commissioned TECSA in an experiment that measured d(^{14}C,p)^{15}C in inverse kinematics at 11.7 MeV/u. TECSA will be available for experiments at TAMU-CI for the next few years. In the near future, TECSA will be used for further experiments with rare isotope beams prepared with MARS. However, as was shown in the attempt to measure with ^{12,13}B secondary beams from MARS, beam production rates of > 10^5 pps are necessary for good measurements. After the TAMU-CI T-Rex upgrade, it will be possible to use TECSA, (or similar Si detector arrays) to conduct experiments similar to the d(^{14}C,p)^{15}C measurement with rare isotope beams reaccelerated by the K500 cyclotron.

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