Measurement of ^{14}O(α,p) at MARS/RIKEN with TexAT

S. Ahn,[1] C. Park,[1] M. Barbui,[2] J. Bishop,[2] E. Koshchiy,[2] C.E. Parker,[2] B. Roeder,[2] G. Rogachev,[2,3,4] M. Roosa,[3,4] A. Saastamoinen,[2] and CENS[1]/CNS[5] collaborators

[1]*Center for Exotic Nuclear Studies, Institute for Basic Science, 34126 Daejeon, Republic of Korea*

[2]*Cyclotron Institute, Texas A&M University, College Station, TX 77843, USA*

[3]*Department of Physics & Astronomy, Texas A&M University, College Station, TX 77843, USA*

4*Nuclear Solutions Institute, Texas A&M University, College Station, TX 77843, USA*

[5]*Center for Nuclear Study (CNS), University of Tokyo, Wako, Japan*

Sensitivity studies have shown that ^{14}O(α,p)^{17}F is one of the most important reactions affecting the light curve in multi-zone X-ray burst models [1]. Increases or decreases in the reaction rate can affect the peak brightness and time variation. In addition, the breakout path from the hot CNO cycle to the rp-process at T>0.5 GK is also determined by this reaction rate – mainly through a single resonance at E_x = 6.15 MeV. The previously measured cross sections for this reaction are shown in Fig. 1 where a large disagreement across the energy regime of interest is clearly observed.

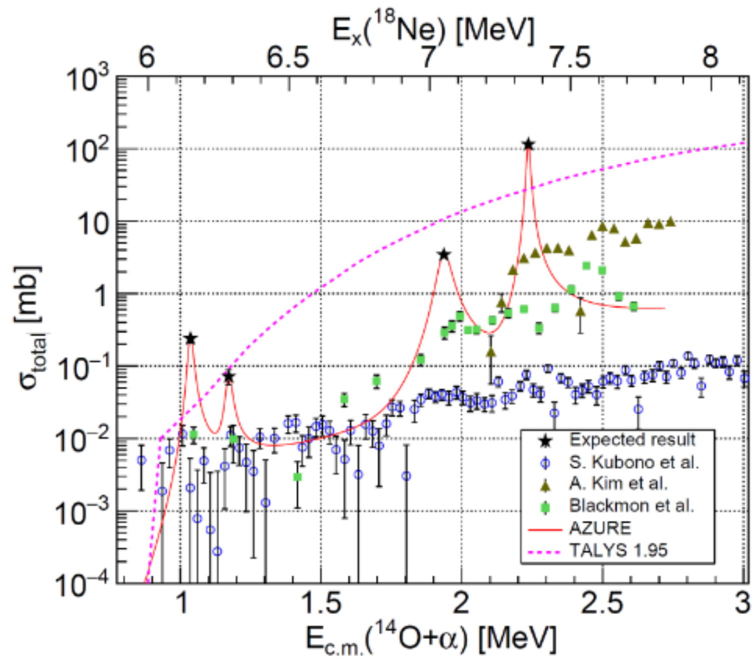

Fig. 1. Previously-measured data and the predicted AZURE cross section using the known resonances.

In order to better understand the importance of this reaction, a measurement was performed with the TexAT TPC [2] to measure the ^{14}O(α,p) reaction cross section across a range of energies using a ^{14}O beam impinging onto a He:CO2 gas mixture. Following a provisional measurement at the Cyclotron Institute where a high-purity MARS beam was delivered at around a peak intensity of 10^5 pps, the experiment was performed at the CRIB beamline in RIKEN, Japan in collaboration with the Center for Exotic Nuclear Studies, Republic of Korea who acted as the spokesperson.

The preliminary run at MARS yielded a multitude of insights into how to best measure this extremely challenging reaction. In particular, it was observed that at high beam intensities – the Micromegas of TexAT were approaching the Raether limit and this was causing an unintended consequence of triggers in the data acquisition that did not correspond to real events – so called "dark triggers". In addition, to increase the solid-angle coverage and therefore statistics, CENS modified TexAT to have a much larger number of silicon detectors (X6 type) of thickness 1 mm and also modified the field cage to be smaller so the detectors could be placed closer. These X6 detectors were then backed by a set of CsI crystals readout with a Si MPPC. Due to the higher thickness, the beta-decay of the stopped ^{14}O beam lead to a high real trigger rate in the Si detectors. In order to address this, a more complicated L0L1 trigger scheme was implemented where the first trigger comes from the MARS upstream scintillator and the L1 trigger is then validated by the Si detectors. This then ensured that the beta trigger rate was greatly suppressed and only random coincidences made it into this time window.

To address the issue of the high rate on the Micromegas, CENS produced a gating grid for the central beam region where the biases between parallel wires could be modified to restrict the transparency of electrons from the drift region to the avalanche region as shown in Fig. 2. This was first tested at CRIB and was shown to be highly-effective and was able to suppress the amplitude in the beam region by a factor of ~6.

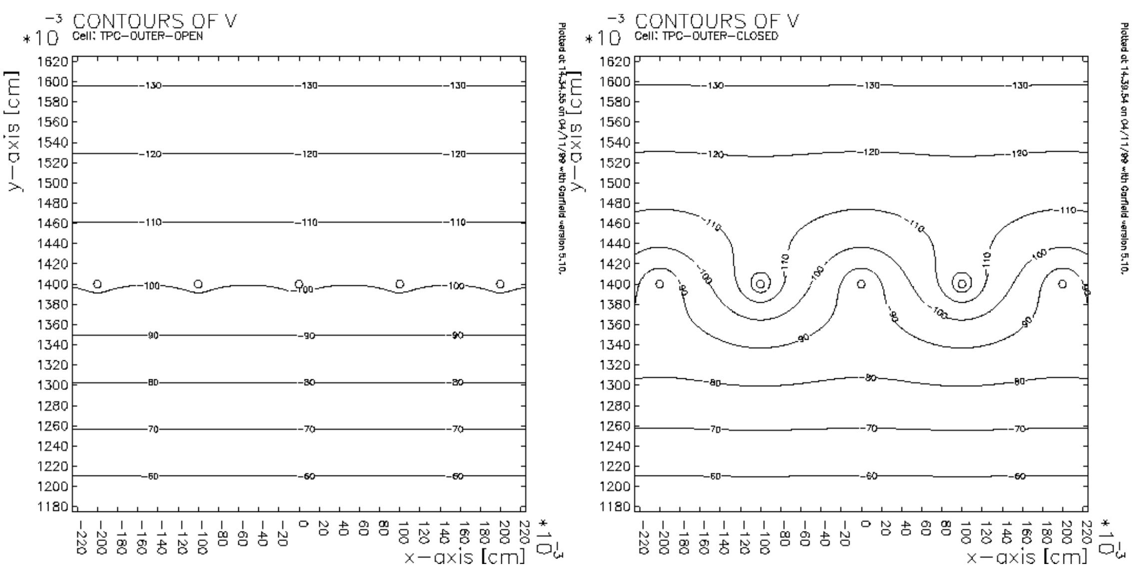

Fig. 2. Left: Electric field contours of a gating grid when set to be transparent (from [3]). Right: Electric field contours when adjacent wires are set to have a different voltage and the transparency of the gating grid to electrons is reduced (from [3]).

Following the successes of adapting to the challenges encountered at MARS – the production experiment at CRIB occurred in March 2023 with the implementation of the gating grid, additional field wires being added to the field cage to increase field uniformity, a further increase in X6 detector number to 30, and the MARS scintillator being replaced by a scintillator placed internally to the TexAT chamber which was readout by two MPPCs that then become the new L0 trigger. The gas pressure of the He:CO_2 used to stop the beam at the end of the Micromegas was 300 Torr. A schematic and photograph of the experimental setup with the new silicon detectors can be seen in Fig. 3.

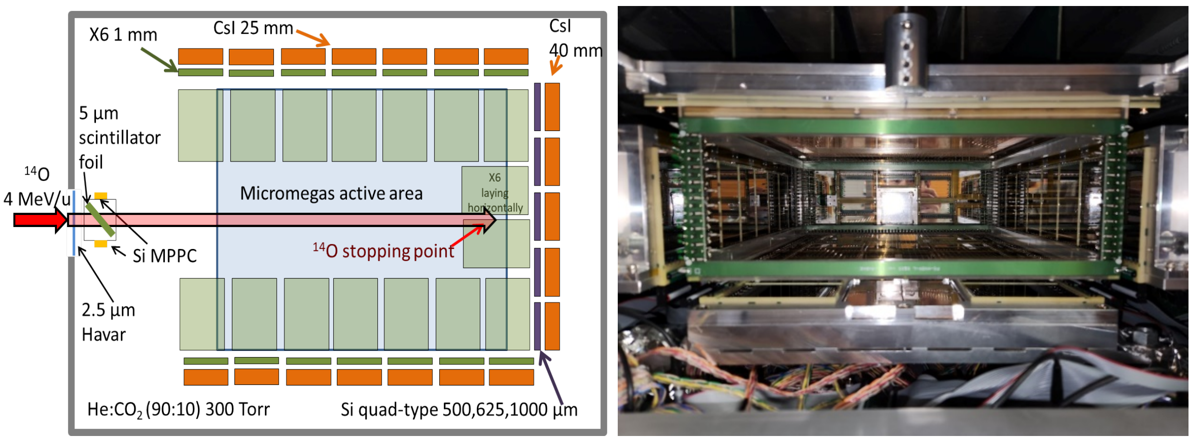

Fig. 3. (Left) Schematic of the experimental setup at CRIB-RIKEN. (Right) Photo of the inside of the chamber showing the arrangement of silicon detectors when looking down the beamline.

The purity of the CRIB beam was around 90% with 10% admixture of the primary ^{14}N beam which was differentiated by the amplitude of the signal measured in the scintillator. Additionally, an independent data acquisition system used multiple PPACs along the beamline to measure the purity of the beam run-by-run.

Given the short time since the run, data analysis is currently ongoing but there were hints of promising (α,p) events seen via the online event viewer that signify the gain in the Micromegas was sufficient to see protons above the threshold while maintaining a high beam rate. The effort as part of this work has also proved extremely useful to be able to understand how to better measure reactions with high beam rates with TexAT more generally.

[1] R.H. Cyburt *et al.*, Astrophys. J. **830**, 55 (2016).

[2] E. Koshchiy *et al*., Nucl. Instrum. Methods. Phys. Res. **A957**, 163398 (2020).

[3] https://www.star.bnl.gov/public/tpc/hard/tpcrings/page11.html