Cross Section Measurements of the ^{12}C$(\alpha, \gamma)^{16}$O Reaction at $E_{\mathbf{c.m.}} = 3.7$, 4.0, and 4.2 MeV

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Introduction

The $3\alpha \rightarrow {}^{12}$C and ^{12}C$(\alpha, \gamma)^{16}$O reactions occur during the helium burning stage in massive stars. The rate of these reactions greatly affects the C/O abundance ratio. Changes in this abundances have significant effects on the subsequent stellar evolution, structure, and nucleosynthesis [1, 2]. The $3\alpha \rightarrow {}^{12}$C rate is well understood (uncertainty <10%) but the uncertainty in the ^{12}C$(\alpha, \gamma)^{16}$O reaction cross section continues to be an obstacle. In fact, the results obtained from inverse kinematics measurement at DRAGON [3], and a subsequent measurement using the ERNA [4] recoil separator revealed discrepancies regarding the ^{12}C$(\alpha, \gamma)^{16}$O reaction cross section.

To resolve this problem, and also provide information on how higher-energy resonances interfere with each other, a new experiment was carried out in inverse kinematics at the DRAGON recoil separator, located at the TRIUMF-ISAC facility, at energies $E_{c.m.} =$ 3.7, 4.0, and 4.2 MeV. The experiment utilized 30 BGO detectors and a Double-Sided Silicon Strip Detector (DSSSD) to detect γ-rays and ^{16}O recoils respectively. Fig. 1 shows the energy level diagram of ^{16}O, and the astrophysical S-factor.

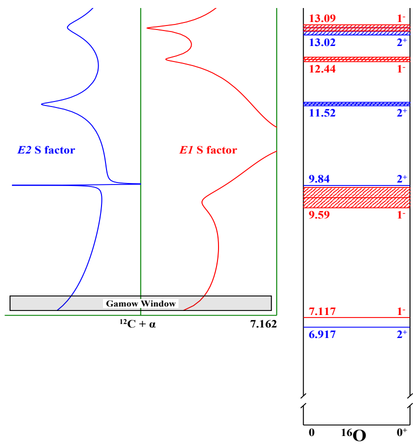

FIG. 1: Left: S-factor; right:Energy levels of ^{16}O (credit: C.R. Brune).

Experimental Procedure

High intensity ^{12}C^{2+} beam was produced using TRIUMF's Offline Laser Ion Source (OLIS) and delivered in bunches to the windowless He gas target at DRAGON. The γ-rays from the de-excitation of the ^{16}O compound nucleus were detected with 30 BGO detectors assembled in a close-packed configuration around the target. The ^{12}C beam and ^{16}O recoils left the gas target with almost similar momentum and range of charge states and entered into the DRAGON electromagnetic separator.

The beam size and position were monitored by CCD camera in line with the tar-

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get located behind the first magnetic dipole (MD1). The beam current was periodically monitored by Faraday cups located upstream and downstream of the target. The magnetic dipole (MD1) and electric dipole ED1 in the DRAGON separator select the desired charge state and mass, respectively, leading to separation of recoils of particular charge state with negligible background. The $^{16}O^{6+}$ recoils resulting from He capture were transmitted to the end of DRAGON where they were detected in a DSSSD.

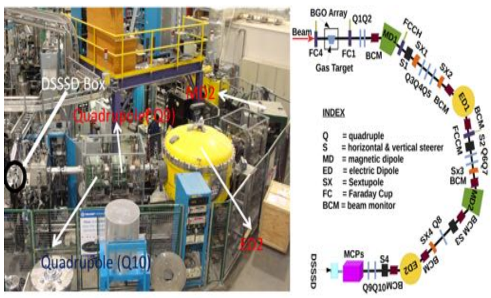

FIG. 2: Photograph and schematic diagram of the DRAGON facility.

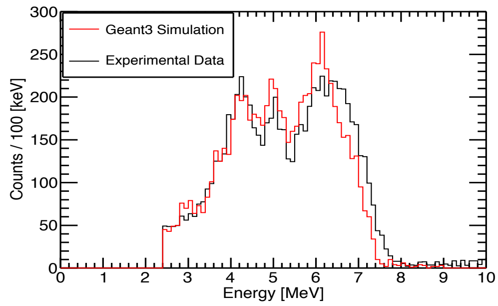

FIG. 3: Comparison of simulated and experimental BGO γ-spectra for $E_{c.m.} = 3.935$ MeV.

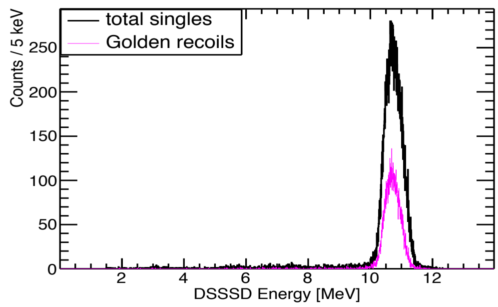

FIG. 4: DSSSD singles and coincidence events for the yield measurement at resonance energy of $E_{c.m.} = 3.935$ MeV.

Results And Discussion

Data analysis to extract the reaction cross section is currently ongoing, whereby priority is given to the analysis of the center-of-mass energies at $E_{c.m.} = 3.7$, 4.0, and 4.2 MeV. We will extend our experiment to more energies including on and off resonance measurements, to understand the nature of interference effects at higher energies, which is not known with high precsion. These measurements will constrain global R-Matrix fits by providing information on higher energy levels, aiding the extrapolation to helium burning energies of 300 keV.

Fig. 3 shows simulated and experimental γ-ray spectrum, and Fig. 4 shows DSSSD recoils spectrum at resonance energy $E_{c.m.} = 3.935$ MeV.

Acknowledgments

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