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Measurement of the $^{18}O(\alpha,\gamma)^{22}Ne$ resonances at JUNA

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Abstract. $^{22}Ne(\alpha,n)^{25}Mg$ is one of the main neutron sources of the *s* process. ^{22}Ne is produced by the $^{14}N(\alpha,\gamma)^{18}F(\beta^{+})^{18}O(\alpha,\gamma)^{22}Ne$ reaction chain in the helium burning, thus, the production rate of ^{22}Ne is dominated by $^{14}N(\alpha,\gamma)^{18}F$ and $^{18}O(\alpha,\gamma)^{22}Ne$. At the astrophysical relevant temperatures, the $^{18}O(\alpha,\gamma)^{22}Ne$ reaction rates are determined by several low-energy resonances. In this work, the $^{18}O(\alpha,\gamma)^{22}Ne$ reaction was measured at the 400 kV accelerator of Jinping Underground Nuclear Astrophysics experiment (JUNA). The γ-ray yields of the resonances between 470 to 770 keV were obtained.

1 Introduction

About half of the heavy elements above Fe in our universe are synthesised by the slow neutron capture process (*s*-process) drove by the neutron from the $^{13}C(\alpha,n)^{16}O$ and $^{22}Ne(\alpha,n)^{25}Mg$ reactions [1, 2]. $^{22}Ne(\alpha,n)^{25}Mg$ is considered to be the main neutron source of the *s*-process during convective core helium burning and convective shell carbon burning in massive stars [2], in which the ^{22}Ne is produced through the $^{14}N(\alpha,\gamma)^{18}F(\beta^{+}\upsilon)^{18}O(\alpha,\gamma)^{22}Ne$ reaction chain in the early phase of core helium burning. Therefore, the $^{14}N(\alpha,\gamma)^{18}F$ and $^{18}O(\alpha,\gamma)^{22}Ne$ reaction rates are the key parameters in the calculation of ^{22}Ne abundance and the subsequent $^{22}Ne(\alpha,n)^{25}Mg$ neutron production rate, which need to be determined precisely.

Several direct measurements [3–5] of the $^{18}O(\alpha,\gamma)^{22}Ne$ resonances have been performed. Trautvetter et al. [3] obtained the resonance strengths of the 662 and 750 keV resonances. Vogelaar et al. [4] measured the precise resonance energies, the primary γ-ray branching ratios, and the resonance strengths of the 662, 750, and 770 keV resonances. And Dababneh et al. [5] investigated the 470 keV resonance by a coincidence method for the first time, however, in which the 470 keV resonance strength was derived by a presumptive branching ratio. The $^{18}O(\alpha,\gamma)^{22}Ne$ reaction needs to be further measured in an underground laboratory with low background to reduce the uncertainties of the low-energy resonance strengths and improve the precision of the reaction rates, which is of great significance to the nucleosynthesis study of *s* process.

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2 Experimental method

The experiment was performed at the 400 kV accelerator of Jinping Underground Nuclear Astrophysics experiment(JUNA) [6] in the China Jinping Underground Laboratory (CJPL) [7], the $^{4}He^{2+}$ beam was collimated by two apertures and then bombarded on the ^{18}O enriched isotopic target which was directly water cooling. The average beam current was 500 μA on the target. A cold trap cooled by liquid nitrogen was installed upstream of the target to minimize carbon build-up on the target surface, together with magnetic molecular pumps and dry scroll pumps. Target together with the chamber formed a Faraday cup for measuring the beam charge on the target. A ring electrode applied with a voltage of -300 V was installed between the target and cold trap to suppress secondary electrons emitted from both the target and the last aperture.

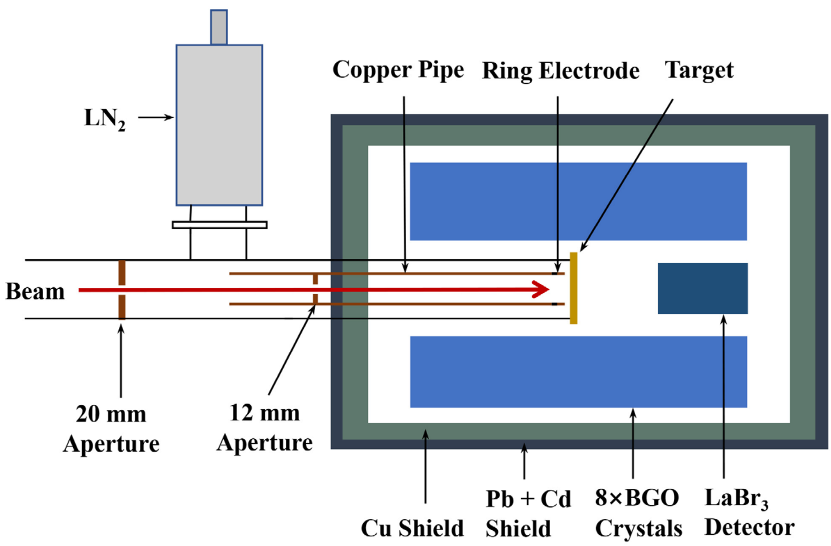

Figure 1: Schematic view of the experimental setup.

The ^{18}O enriched oxygen (98% abundance) gas was used to produce the $Ti^{18}O_x$ (x is the atoms ratio of oxygen to titanium) targets by Filter cathodic vacuum arc (FCVA) technology [8, 9], in which Ta substrates with a diameter of 47.3 mm and a thickness of 0.7 mm was adopted. The targets were able to withstand the high beam loads for several coulombs without noticeable deterioration. The γ rays emitted from $^{18}O(\alpha,\gamma)^{22}Ne$ were detected by a near 4π BGO detector and a $3'' \times 4''$ $LaBr_3$ detector, as shown in Fig. 1. All of the detectors were shielded by 5 mm Cu, 100 mm Pb, and 1 mm Cd materials to further suppress the natural γ-ray background emitted from the rocks and induced by the neutron radioactive capture reactions.

3 Preliminary results

Fig. 2 shows the sum spectra obtained by the BGO detector array of the 470, 662, 750, and 770 keV resonances, respectively, in which the $E_{\rm sum}$ represents the sum of the energies

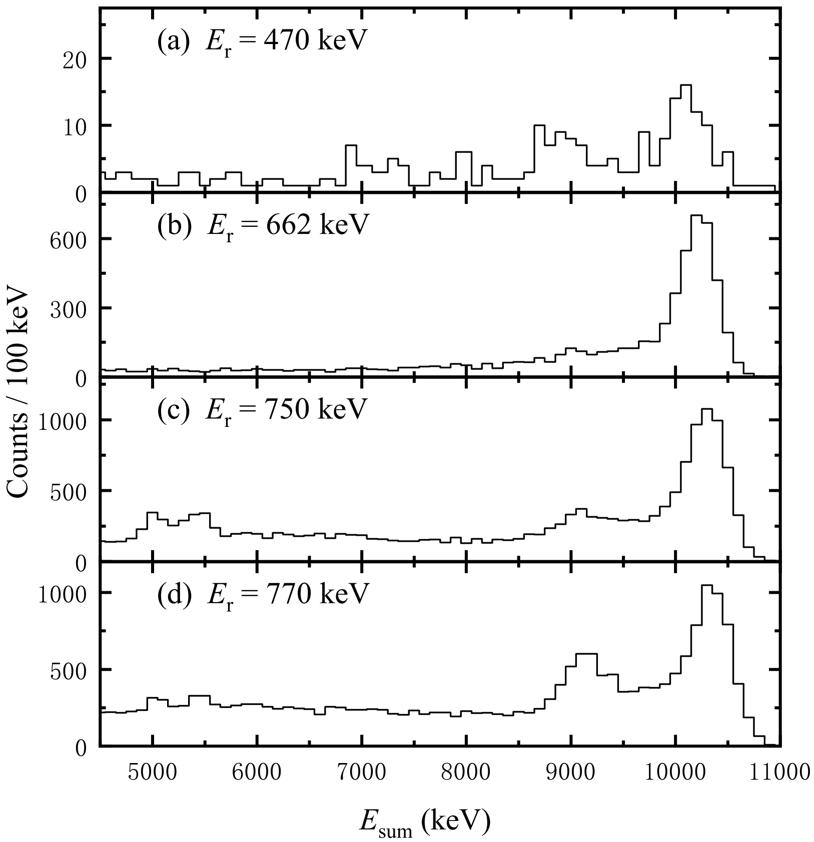

Figure 2: The sum spectra of the $^{18}O(\alpha,\gamma)^{22}Ne$ resonances: (a) at E_r = 470 keV, (b) at E_r = 662 keV, (c) at E_r = 750 keV, (d) at E_r = 770 keV, respectively.

of all eight BGO segments. It can be seen that the sum peaks ($E_{sum} = 9500 - 10500$ keV) of these resonances are clearly visible in the spectrum.

Based on the counts of the sum peak and the efficiency simulated with GEANT4 program [10], the yield curves of $^{18}O(\alpha,\gamma)^{22}Ne$ were derived, as shown in Fig. 3. In the GEANT4 simulation, the primary γ-ray branching ratios were extracted by fitting the single spectrum obtained of the BGO detector array. The uncertainty of the yields mostly arises from the statistic error, the change of the sum peak range, and the GEANT4 simulation. These yields will be used to extract the resonance strength. Further data analysis is in process and the results will soon be published.

4 Acknowledgments

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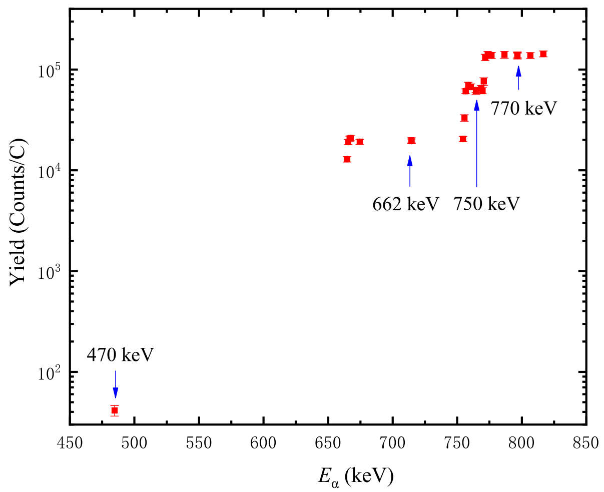

Figure 3: Yield of the 470, 662, 750 and 770 keV resonances of $^{18}O(\alpha, \gamma)^{22}Ne$.

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