Measurement of inelastic resonance scattering cross section of the ^{12}C(^{12}C,^{12}C[0_2^+])^{12}C[0_2^+] reaction to search for alpha condensation

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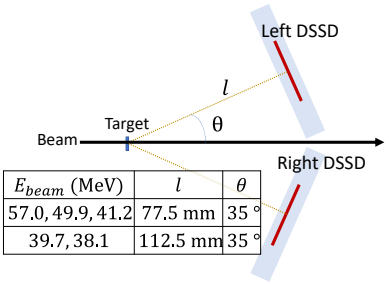
One of the theoretically predicted states at low nucleon density is a superfluid condensate of α particles. The 0_2^+ state at E_x =7.65 MeV in ^{12}C is well recognized as a 3α condensed state and called Hoyle state [1][2]. Although it is pointed that α condensed states emerge in self-conjugate $A = 4N(N \leq 10)$ nuclei [3], there are few experimental data concerning nuclei heavier than ^{12}C. In this work, we explored the 6α condensed state in ^{24}Mg by measuring the inelastic resonance scattering cross section of the ^{12}C(^{12}C,^{12}C[0_2^+])^{12}C[0_2^+] reaction.

According to the calculation by T. Yamada, the excitation energy of the 6α condensed state in ^{24}Mg is predicted 33.4 MeV [3], which corresponds to 39.0 MeV in the beam energy of the ^{12}C + ^{12}C collision. This 6α condensed state has a large decay width to the ^{24}Mg $\rightarrow$^{12}C[0_2^+] + ^{12}C[0_2^+] channel. We focused on this channel and detected 6α emitted from the two ^{12}C[0_2^+]s.

The experiment was performed at the Research Center for Nuclear Physics cyclotron facilities. A ^{12}C beam at 57.0 MeV extracted from the AVF cyclotron was transported to the EN course. The beam energy was degraded to 57.0, 49.9, 41.2, 39.7, and 38.1 MeV by using a gas degrader and aluminum degraders. Then the beams bombarded the ^{12}C target with a thickness of 0.5 mg/cm^2. Once the 6α condensed state is formed and decays into the ^{12}C[0_2^+] + ^{12}C[0_2^+] channel, the emitted two ^{12}C[0_2^+]s immediately decay into 3α+3α. In the present measurement, we detected 3α+3α by the two double-sided silicon strip detectors (DSSD) which were located at forward symmetric angles. The angles and distances from the target of the DSSDs are shown in Fig. 1.



E_{beam} (MeV)	l	θ
57.0, 49.9, 41.2	77.5 mm	35 °
39.7, 38.1	112.5 mm	35 °

Figure 1: Layout of DSSDs

The invariant mass of the ^{12}C* was calculated from energy and momentum of 3α, and the excitation energy of ^{12}C* was determined. The upper-right and lower-right panels in Fig. 2 show the excitation-energy spectra in ^{12}C obtained by the left and right DSSDs, respectively, when the beam energy is 57.0 MeV. We clearly observed the peak due to the 0_2^+ state in ^{12}C at E_x = 7.65 MeV. The left panel in Fig. 2 presents a correlation in the excitation energy between two ^{12}C*s. The ^{12}C(^{12}C,^{12}C[0_2^+])^{12}C[0_2^+] events are successfully identified as shown by the solid line. Finally, we counted the events in which the both two detectors detected 3α from ^{12}C[0_2^+] and determined cross sections to be 0.58 ± 0.04 μb/sr and 0.047 ± 0.004 μb/sr at E_{beam} = 57.0 and 49.9 MeV, respectively. At E_{beam} = 39.7 and 38.1 MeV, no ^{12}C[0_2^+] + ^{12}C[0_2^+] event was observed. The present result is compared with the previous results reported in Refs. [4] and [5] in Fig. 3.

In the present work, we successfully determined cross section of the ^{12}C(^{12}C,^{12}C[0_2^+])^{12}C[0_2^+] reaction at E_{beam} = 57.0 and 49.9 MeV which correspond to the excitation energies of E_x=42.5 and 38.9 MeV respectively. Although the 6α condensed state in ^{24}Mg is predicted at E_x = 33.4 MeV (E_{beam} =39.0 MeV), we could not determine the cross section at the energy region of interest. Further measurements with high statistics and sensitivity are strongly desired.

Reference

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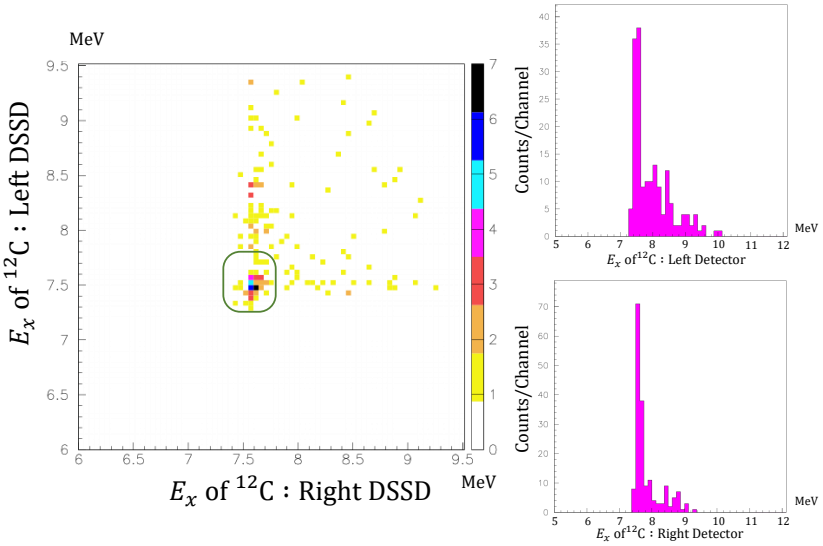

Figure 2: Excitation-energy spectra in ^{12}C when 3α were detected by the two DSSDs : (left) Correlation in excitation energies between two ^{12}C detected by the left and right DSSDs, (upper-right) excitation energy determined by the left DSSD, (lower-right) excitation energy determined by the right DSSD.

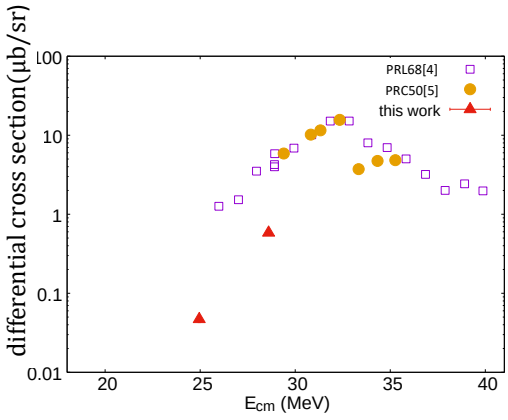

Figure 3: Measured differential cross section of ^{12}C(^{12}C,^{12}C[0_2^+])^{12}C[0_2^+] reaction averaged over $\theta_{cm} = 20^\circ - 105^\circ$ as a function of the center-of-mass energy $E_{cm}(= E_{beam}/2)$.