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Preparations for the study on the cluster structure of ^{16}C*

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Abstract In order to look for a proposed cluster structure of ^{16}C, simulation work was made. The simulation of the reaction dynamics give the resolution of the excitation energy on ^{16}C which was reconstructed prior to breakup. The excitation energy resolution is typically ~200 keV at 2 MeV above the two body decay threshold for $^{16}\mathrm{C}\rightarrow{}^{12}\mathrm{Be}+{}^{4}\mathrm{He}$. Moreover,some performances of detectors tested using ^{241}Am α source are also reported.

Key words simulation, excitation energy resolution, cluster structure, the performance of detector

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1 Introduction

Clustering has long been known to play an important role in the structure and properties of light nuclei. For example, the deformation of the ground state rotational band in ^{8}Be is consistent with an α-α structure. The two center nature has a marked impact on the structure of nuclei which are formed by the addition of nucleons to the double-α core[1, 2]. The natural progression from these idea is to consider whether more complex structures exist. The 7.65 MeV 0_2^+ level in ^{12}C has long been considered to three particles arranged in a chain-like or slightly bent linear configuration[3, 4]. Levels with similar properties are predicted may exit in nuclei such as ^{14}C and ^{16}C at higher degrees of excitation energy. Recent theoretical calculations on ^{16}C have indicated that it is one of the most promising candidate of the carbon isotopes which process the $3\alpha+x$n structure[5].

In classical terms the structure of ^{16}C resembles 3α+4n, with the neutrons providing additional binding to stabilize its structure. These structural consideration suggest that the dominant two-body decay mode of these states of ^{16}C might be the $^{10}\mathrm{Be}+{}^{6}\mathrm{He}$ or $^{12}\mathrm{Be}+{}^{4}\mathrm{He}$ channels[6, 7]. In this paper, we will report the simulant results of the excitation energy resolution on ^{16}C which was reconstructed prior to breakup. The simulation based on the kinematics of the charged reaction products, which included the angular distributions and energy distributions of the particles. The work is also based on the performance of detectors such as the detector energy and position resolution, which made up of telescopes used in our beam experiment. Furthermore, as such the present work should also provide the performances of the detectors were tested using ^{241}Am α source. The simulation work and the result are reported in Sect. 2. The performance of detectors are give in Sect. 3. We reserve our summary and concluding remarks for Sect. 4.

2 Simulation and results

In beam experiment, the determination of the energy, mass, charge, and emission angles for breakup fragment and thus the momenta of the charged reac-

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tion products allowed the kinematics of the reactions to be reconstructed[8, 9]. For the two-body cluster decay of the projectile ^{16}C nucleus, in which the two charged particles are known, it is possible to reconstruct the excitation energy of the projectile prior to breakup. This is achieved by knowing the relative energy between the breakup particles and where the excitation energy E_x[10]is given by

$$E_x = E_{\text{thresh}} + E_{\text{rel}} \ . \tag{1}$$

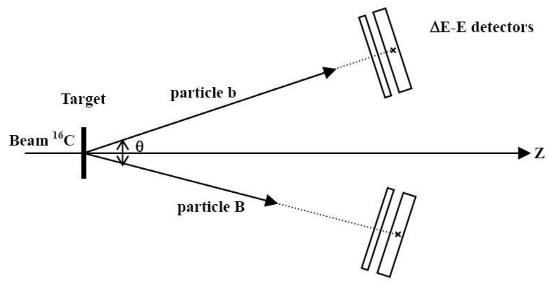

Fig. 1. A diagram for sequential two-body cluster decays of the excited ^{16}C nucleus.

Here, E_{thresh} is the threshold for the two-body decay process, for example in $^{16}\text{C}\rightarrow{}^{12}\text{Be}+{}^{4}\text{He}$, $E_{\text{thresh}} = 13.81$ MeV and $^{16}\text{C}\rightarrow{}^{10}\text{Be}+{}^{6}\text{He}$ $E_{\text{thresh}} = 16.51$ MeV. where,

$$E_{\text{rel}} = \frac{1}{2}\mu v_{\text{rel}}^2 \ , \tag{2}$$

where μ is the reduced mass of the system and v_{rel} is the relative velocity of the two breakup particles. This is related via the cosine rule to the mass and energy of two particles and the opening angle between the two fragments. In principle, it is possible to reconstruct the excitation energy of the projectile ^{16}C nucleus which is populated above the cluster breakup threshold. However, the excitation energy may be described by the velocity and the spanned angular of breakup fragments as:

$$\begin{aligned} E_x \ = \ & E_{\text{thresh}} + \frac{1}{2}\frac{m_{\text{b}}m_{\text{B}}}{m_{\text{b}}+m_{\text{B}}}\big[v_{\text{b}}^2 + v_{\text{B}}^2 - \\ & 2v_{\text{b}}v_{\text{B}}\cos(\theta)\big]. \end{aligned} \tag{3}$$

Here m_{b}, m_{B} and v_{b}, v_{B} are nuclear mass and velocity of particles b and B, respectively. A diagram for sequential two-body cluster decays of the excited ^{16}C nucleus is shown in Fig. 1. Where θ indicates the opening angle of the two particles. It also can be given by following expression:

$$\begin{aligned} E_x \ = \ & E_{\text{thresh}} + \frac{1}{m_{\text{b}}+m_{\text{B}}}\big[m_{\text{B}}E_{\text{b}} + m_{\text{b}}E_{\text{B}} - \\ & 2\sqrt{m_{\text{b}}m_{\text{B}}E_{\text{b}}E_{\text{B}}}\cos\theta\big]. \end{aligned} \tag{4}$$

Furthermore, in term of the error transfer formula we may derived the standard error for excitation energy, which written as the following:

$$\begin{aligned} \sigma_{E_x^2} \ = \ & \left[\left(\frac{m_{\text{B}}}{m_{\text{b}}+m_{\text{B}}}\right) - \right. \\ & \left.\left(\frac{1}{m_{\text{b}}+m_{\text{B}}}\sqrt{\frac{m_{\text{b}}m_{\text{B}}E_{\text{B}}}{E_{\text{b}}}}\cdot\cos\theta\right)\right]^2\cdot\sigma_{E_{\text{b}}}^2 + \\ & \left[\left(\frac{m_{\text{b}}}{m_{\text{b}}+m_{\text{B}}}\right) - \right. \\ & \left.\left(\frac{1}{m_{\text{b}}+m_{\text{B}}}\sqrt{\frac{m_{\text{b}}m_{\text{B}}E_{\text{b}}}{E_{\text{B}}}}\cdot\cos\theta\right)\right]^2\cdot\sigma_{E_{\text{B}}}^2 + \\ & \left(\frac{\sqrt{4m_{\text{b}}m_{\text{B}}E_{\text{b}}E_{\text{B}}}}{m_{\text{b}}+m_{\text{B}}}\cdot\sin\theta\right)^2\cdot\sigma_{\theta}^2 \ . \end{aligned} \tag{5}$$

Where $\sigma_{E_{\text{b}}}$ and $\sigma_{E_{\text{B}}}$ indicate the standard error of the kinetic energy for the two charged particles b and B respectively, which are decided by energy resolution of the ΔE-E telescopes. Here σ_{θ} is the standard error of the opening angle of two fragments. It also is determined by position resolution of the position sensitive detectors.

The present work we give the simulation result about a two-body decay reaction channel $^{16}\text{C}\rightarrow{}^{12}\text{Be}+{}^{4}\text{He}$. When the energy of the ^{16}C beam is 50 MeV/nucleon and was incident on a 225.3 mg cm^{-2} carbon reaction target. The energy of a state in the intermediate nucleus, $^{16}\text{C}^*$, for sequential binary decay reaction, is given a certain value ~15.81 MeV in simulant calculation. Energy resolution of telescope is ~ 3% and the angle resolution is less than 1%. Then the simulation suggests the reconstructed excitation energy resolution is typically ~200 keV at 2 MeV above the decay threshold, as shown in Fig. 2. Simulation also give the result at 10 MeV above the decay threshold and it increases to ~600 keV. The performances of detectors make up of telescopes are described in Sect. 3.

The resolution of the kinetic energy and angular position have a large effect on the excitation energy resolution. The simulation results suggest the angle resolution contributed to the excitation energy resolution is significant as the opening angle increased. Moreover, the error of total energy measurement for two decay reaction fragments have a large contribution to the excitation energy resolution. Then improving the energy resolution of the detectors for total energy measurement is necessary.

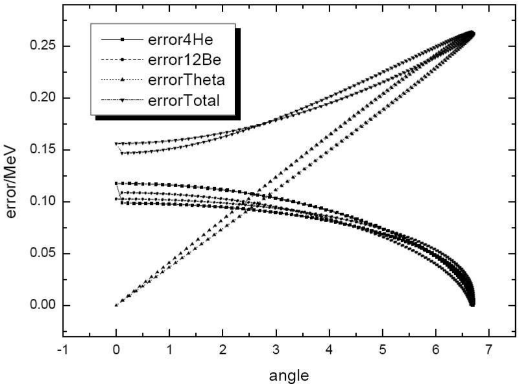

Fig. 2. Plot of the standard error versus the opening angle of two charged particles. The solid curve shows the energy resolution of the charged particle ^{4}He. The energy resolution of the particle ^{12}Be is indicated by the dashed curve and the dotted curve represent the angle resolution. The dash-dotted curve give the excitation energy resolution.

3 Performance of detectors

The ΔE-E telescopes, position sensitive in the reaction plane, are used to determine the kinetic energy, angular position, and nuclear mass and charge of particles b and B, which are detected in coincidence. Here, angle resolution is given by two orthogonal strip detectors which provide a measurement of the incident ions to 1 mm in both the x and y directions. To improve the energy resolution of the fragments b and B, a closed packed array of 4, 2.5-cm-thick, 2.6×2.6 cm^2, CsI scintillators is used to give the measurements of the total energy for two charged particles. The energy resolution of the telescope is determined by those of the detectors make up of telescope. As such here we also provide the energy resolution of the strip detector and CsI scintillation detector which was tested using 5.486 MeV ^{241}Am α source, as shown in Fig. 3 and Fig. 4.

The test results indicate the energy resolution of the strip detector is up to 0.5% and that of the CsI scintillation detector is about 3%. Then the energy resolution of the telescope consist of these detectors may meet request.

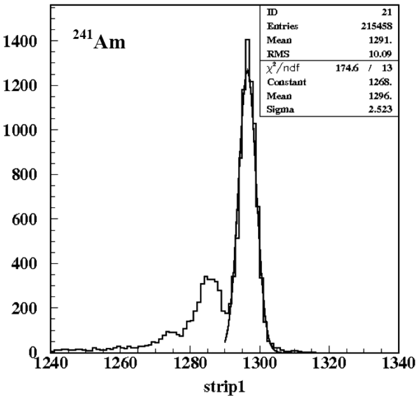

Fig. 3. The energy resolution (full width at half maximum) of strip detector by using ^{241}Am α source.

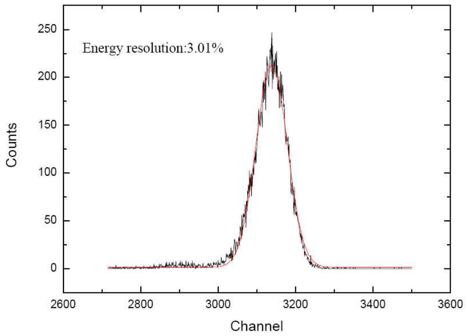

Fig. 4. The energy resolution (full width at half maximum) of the CsI scintillation detector by using ^{241}Am α source.

4 Summary

The excitation energy resolution in the decaying nucleus improves as the excitation energy decreases approaching threshold. We have given the simulation result of the excitation energy resolution at the location of the 15.81 and 23.81 MeV states for two body decay reaction channel ^{16}C→^{12}Be+^{4}He, and it yields about 200 and 600 keV, respectively. Moreover, we also provide the energy resolutions of the detectors make up of the telescope, which were tested using ^{241}Am α source. They are 0.5% for strip detector and 3% for CsI scintillation detector, respectively.

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