PAPER • OPEN ACCESS

Active target MAIKo to investigate cluster structures in unstable nuclei

To cite this article: T Furuno *et al* 2017 *J. Phys.: Conf. Ser.* **863** 012076

IOP Conf. Series: Journal of Physics: Conf. Series **863** (2017) 012076 doi:10.1088/1742-6596/863/1/012076

Active target MAIKo to investigate cluster structures in unstable nuclei

T Furuno[1], T Kawabata[1], M Murata[1], S Adachi[2], Y Ayyad[3], H Baba[4], T Baba[1], M Cavallaro[5], T Hashimoto[6], Y Ishii[1], R Kobayakawa[1], Y Matsuda[7], Y Matsuoka[1], T Morimoto[1], T Nanamura[1], S Beceilo-Novo[3], H J Ong[2], A Sakaue[1], J Tanaka[8,2], I Tanihata[2], D T Trong[2], M Tsumura[1] and H D Watanabe[1]

[1] Department of Physics, Kyoto University, Kyoto 606-8502, Japan
[2] Research Center for Nuclear Physics, Osaka University, Osaka 567-0047, Japan
[3] National Superconducting Cyclotron Laboratory, Michigan State University, MI 48824, USA
[4] RIKEN Nishina Center, Saitama 351-0198, Japan
[5] INFN Laboratori Nazionali del Sud, Catania 95125, Italy
[6] Rare Isotope Science Project, Institute for Basic Science, Daejeon 305-811, Korea
[7] Cyclotron and Radioisotope Center, Tohoku University, Miyagi 980-8578, Japan
[8] Faculty of Science and Engineering, Konan University, Hyogo 658-8501, Japan

E-mail: `furuno@scphys.kyoto-u.ac.jp`

Abstract. Study on clustering of nucleons in nuclei is recently focusing on unstable nuclei where new kinds of structures, namely molecular structures with excess nucleons, are predicted. The Coulomb shift of energy in the mirror system is suggested to reflect the size of these structures. Although the missing mass spectroscopy is expected to give access to these structures even beyond particle decay thresholds without any biases in excitation energy spectra but the detection of very low energy particles is challenging. To satisfy the requirement, a new active target system MAIKo has been developed at RCNP. The detector was commissioned using a ^{13}C beam under the same kinematical condition as that of RI beam experiments.

1. Introduction

The clustering phenomena are observed in the various hierarchies from the subatomic scale to the cosmic scale. In order to understand the essential nature of each physics hierarchy, it is important to find out why the clustering structures appear. Investigation of the clustering of nucleons is thus necessary to understand many-body problems of nucleons. Especially the alpha clustering has been widely studied among self-conjugate $4n$ nuclei over the past fifty years. Recently, research interests in alpha clustering are extending from stable nuclei to unstable neutron-rich nuclei. In such nuclei, excess neutrons are speculated to occupy the particle orbits between alpha cores and exhibit a variety of new cluster structures, namely molecular structures. For example, rotational bands of alpha molecular structures in ^{10}Be were discussed by Freer *et al* [1].

It is a natural question whether proton-rich molecular structures with valence protons are also be formed. Moreover, it is recently pointed out that energy shifts between isobaric analogous states unveil the dynamics of the constituent clusters [2]. Usually, energy levels in proton-rich sides are higher than those in the mirror nuclei due to the repulsive Coulomb force. However, if the relative wave function between the clusters contains a large s-wave component, the energy shifts will become smaller because the wave functions of the clusters are spatially extended. In case of the ^{10}C-^{10}Be system, the 0_1^+ and 0_2^+ states are considered to be $2\alpha + 2N$ molecular structures where two valence nucleons move among two alpha cores. The 0_3^+ and 0_4^+ states are considered to be well-developed α+^{6}Be or α+^{6}He structures. The energy shift of the 0_2^+ and 0_3^+ states are expected to be smaller than those of the 0_1^+ and 0_4^+ states, respectively. This is because the 0_2^+ and 0_3^+ states mainly contain the s-wave components while the 0_1^+ and 0_4^+ states contain the p-wave and the d-wave components, respectively. This can be regarded as cluster Thomas-Ehrman shift. In order to confirm the cluster Thomas-Ehrman shift, it is mandatory to perform experiments on both of the mirror system. However, experimental information on ^{10}C is scarce. Therefore, we propose a novel experiment to search for alpha cluster states in ^{10}C to compare with ^{10}Be data.

Alpha inelastic scattering is the best probe to systematically search for the 0^+ states discussed above because it has a selectivity to excite the natural parity states and the reaction is described by a simple mechanism. The 0_3^+ and 0_4^+ states in ^{10}C will decay into the 2α+2p channels. Invariant mass spectroscopy on such states is difficult because all of the decay fragments must be detected. On the other hand, missing mass spectroscopy is useful because only the recoil alpha particle needs to be detected. The differential cross sections calculated by the distorted-wave Born approximation (DWBA) with different transferred angular momenta are shown in Fig. 1. The measurement should cover $\theta_{\rm CM} \sim 3°$ to search for the 0^+ states because the cross section for the monopole transition becomes dominant. As shown in Fig. 2, the recoil alpha particles are emitted from the target with very small energy ($\sim$ 500 keV) at $\theta_{\rm CM} \sim 3°$. If one tries to perform a measurement with a conventional setup using a external detectors, the He gas target should be extraordinary thin which makes the luminosity irredeemable.

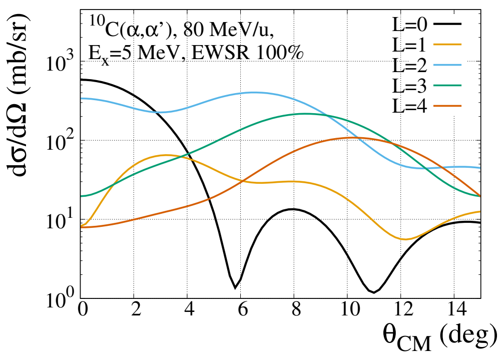

Figure 1. Angular distribution of cross sections calculated by DWBA.

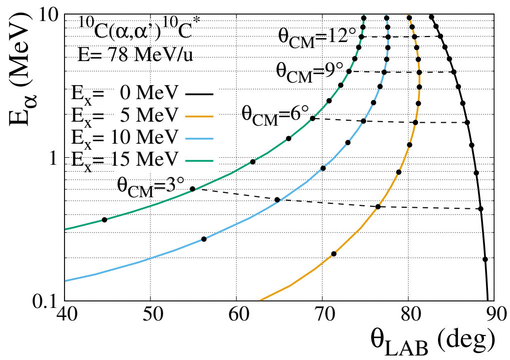

Figure 2. Recoil alpha energy as a function of recoil angle.

2. Design of MAIKo

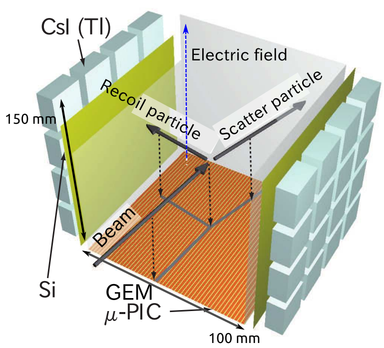

Figure 3. Schematic view of MAIKo.

To overcome the problem stem from the low momentum transfer kinematics, a new active target system MAIKo (μ-PIC based Active target for Inverse Kinematics.) has been recently developed at Research Center for Nuclear Physics (RCNP), Osaka University.

A schematic view of MAIKo system is shown in Fig. 3. The system consists of a time projection chamber (TPC) which can provide the three-dimensional information of charged particle trajectories. The main feature of the active target is to employ the detection gas of the TPC as the target gas. In particular, He gas is filled in the TPC chamber to perform alpha inelastic

IOP Conf. Series: Journal of Physics: Conf. Series **863** (2017) 012076 doi:10.1088/1742-6596/863/1/012076

scattering. Since the scattering is measured inside the sensitive volume of the TPC, the detection threshold for the recoil particle is lowered. Moreover, the thick gas target and large solid angle of the TPC increase the statistics.

The TPC has a sensitive volume of $100 \times 100 \times 150$ mm^3. For the amplification of the ionized electron, Gas Electron Multiplier (GEM) and Micro-PIxel Chamber (μ-PIC) [3] are utilized. The drift electrons are first amplified by GEM and then further multiplied around the anode pixels of μ-PIC. The electron drift time and position are recorded through anode and cathode strips of μ-PIC with a pitch of 400 μm. The anode and cathode strips are arranged orthogonally and they provide two-dimensional projections of the particle trajectories (Fig. 4). The two-stage amplification achieves larger total gas gain than the single amplification. It suppresses the breakdown and enables the stable operation of the TPC. This also helps to reduce the amount of quench gas which can be a background source. The structure and the readout system of the TPC are described in detail in Refs. [4][5].

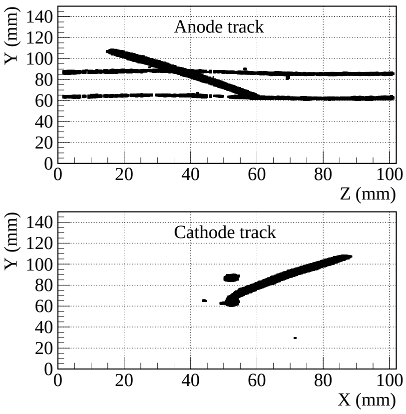

Figure 4. Track example of a scattering event.

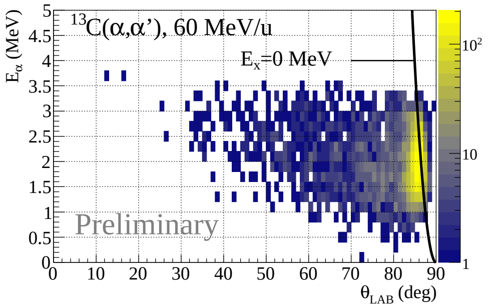

Figure 5. Reconstructed energy versus angle of recoil alpha particle.

3. Test experiment

A test experiment was carried out at RCNP EN beam line using a 60-MeV/u ^{13}C beam. The kinematic condition of the experiment was almost same as that of the ^{10}C experiment. The TPC chamber was filled with He(98%)+CF_4(2%) at 100 kPa to measure alpha inelastic scattering. A typical track of a scattering event is shown in Fig. 4. Each trajectory in the anode and cathode images was identified by an algorithm based on Hough transform method [6]. The track of the recoil alpha particle was fitted by a straight line to reconstruct the scattering event. Energy of the recoil alpha particle was calculated from the range in the TPC gas. Figure 5 shows the correlation between the reconstructed energy and angle of the recoil alpha particle. A clear locus corresponding to the elastic scattering was observed. The detection threshold was successfully lowered to less than 1 MeV. A further test experiment on ^{10}C will be performed in November 2016. The detection threshold will be further lowered to less than 500 keV by reducing the gas pressure to 50 kPa.

References

[1] Freer M *et al* 2001 *Phys. Rev.* C **63** 034301
[2] Ito M 2016 *EPJ Web Conf.* **117** 06014
[3] Ochi A *et al* 2001 *Nucl. Inst. Meth. Phys. Res.* A **471** 264
[4] Furuno T *et al* 2014 *Jour. Phys.: Conf. Series* **569** 012042
[5] Mizumoto T *et al* 2015 *Nucl. Inst. Meth. Phys. Res.* A **800** 40
[6] Furuno T *et al* 2016 *RCNP annual report*