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Structure of ^{10}Be and ^{16}C nuclei via break-up reactions studied with the 4π Chimera array

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Abstract. The study of cluster states in neutron-rich Be and C isotopes is a subject of interest in Nuclear Physics. These states should be characterized by high deformation where α-clusters are bounded by valence neutrons. We performed a spectroscopic study of ^{10}Be and ^{16}C isotopes via projectile break-up reactions, by using radioactive beams produced at the INFN-LNS FRIBs facility and the Chimera 4π array. The possible evidence of a new ^{10}Be state at 13.5 MeV excitation energy was found in the ^{6}He+^{4}He disintegration channel. The spectroscopy of ^{16}C was studied via the ^{6}He+^{10}Be break-up channel; in this case we found the indication of a possible new state at about 20.6 MeV.

1. Introduction

The investigation of cluster structures in nuclei could be a powerful tool to explore the behaviour of nuclear forces in few body interacting systems [1]. These studies are important also in the astrophysical context; for example, the existence of the Hoyle state (0^+, 7.654 MeV) in ^{12}C makes possible the so called 3α process, justifying the observed carbon abundance in Universe.

In presence of extra neutrons, clustering phenomena could assume very different features from the self-conjugated nuclei, originating peculiar configurations, such as nuclear molecules. In the last case the extra-neutrons could act as covalent particles between the α-clusters [2, 3], increasing the stability of the whole configuration [3]. A typical example is the ^{9}Be nucleus that is weakly bound, while the self-conjugated ^{8}Be is unbound. An interesting neutron-rich Be isotope is the ^{10}Be, for which the spectroscopy is not well known and the possible existence of rotational and molecular bands is not definitively clarified [4]. For this nucleus, near the ^{4}He+^{6}He energy threshold the existence of a 0^{+} state was predicted by AMD calculations [5] and experimentally confirmed [6]. This state can be described as a α:2n:α linear dimer. The existence of the molecular 2^{+} and 4^{+} states at 7.54 and 10.15 MeV was recently reported [7], while the subsequent 6^{+} member is still missing. Other interesting examples are represented by carbon isotopes. A special attention is given to the ^{16}C isotope, for which various linear chain and triangular configurations have been recently predicted [8]. Unfortunately, the spectroscopy of ^{16}C is presently very poorly known [9, 10]. In this paper we report preliminary results of a new experimental investigation of ^{10}Be and ^{16}C spectroscopy via break-up reactions, that allows to explore the structure of these nuclei above the ^{4}He and ^{6}He decay thresholds.

2. The Experimental Technique

The experiment was carried out at the INFN-LNS by using beams provided by the FRIBs facility. A primary ^{18}O 55 MeV/u beam, impinging on a ^{9}Be production target, was used to produce neutron-rich fragments via the In Flight technique. A tagging system [11] made by a Micro Channel Plate and a Double Side Silicon Strip detector was also used to identify particle by particle the various components of the cocktail beam. We observed typical intensities of ^{16}C at 49.5 MeV/u ($\approx 10^{5}$ particles per second), ^{13}B ($\approx 5 \times 10^{4}$ particles per second) and ^{10}Be at 56 MeV/u ($\approx 4 \times 10^{4}$). These beams bombarded a CH_2 target. The subsequent break-up fragments were identified and tracked via the forward three rings of the CHIMERA 4π multi-detector array [12, 13], constituted by 144 ΔE-E Si-CsI(Tl) telescopes. To reconstruct the excitation energy E_x of the decaying nuclear states, we analyzed kinematical correlations between couples of break-up fragments identified by means of the ΔE-E technique and we reconstructed their relative energy (E_{rel}). The energy of decaying states is given by $E_x = E_{rel} + E_{thr}$, where E_{thr} is the energy emission threshold for the selected break-up channel.

3. Data Analysis

In the present work we reconstructed the relative energy spectra of the impinging ^{10}Be and ^{16}C nuclei respectively via the ^{4}He+^{6}He and ^{10}Be+^{6}He cluster break-up channels, as presented in Figs. 1 and 2.

3.1. $^{10}Be^{*} \rightarrow {}^{4}He + {}^{6}He$ *channel*

The relative energy ($E_{rel} + E_{thr}$) spectrum for the ^{4}He+^{6}He break-up channel is shown on Fig. 1 with the green histogram. The vertical arrows indicate the energies of ^{10}Be excited states known from literature. Despite the low statistics, it is very interesting to observe the appearance of a bump at $E_x \simeq 13.5$ MeV that could be the suggestion of a possible new state in ^{10}Be. To check the nature of this bump we evaluated the efficiency of our detection device via a MonteCarlo simulation. The behaviour of the estimated efficiency, respectively for the case of inelastic excitation on proton or carbon of the target, is represented by the blue (peaking at 26%) and purple (peaking at 6%) dashed lines. The efficiency curves are very smooth and differences between them can be attributed to the different kinematics. Also the calculated combinatorial background due to spurious coincidences does not show peaks in the region of interest where the 13.5 MeV signal is observed. For these reasons we suggest to attribute the 13.5 MeV bump to the decay from an excited state in ^{10}Be.

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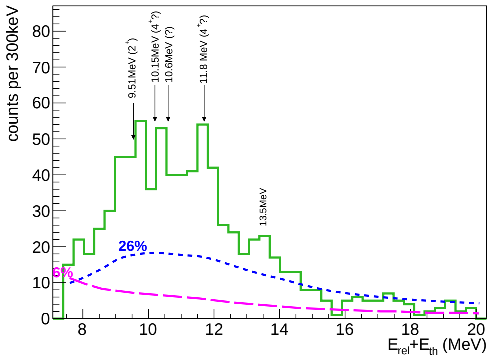

Figure 1. (color online) ^{10}Be relative energy spectrum ($E_{rel} + E_{thr}$) for the ^{4}He+^{6}He break-up channel. The blue and the purple dashed lines represent, respectively, the simulated detection efficiency for inelastic scattering on proton or carbon.

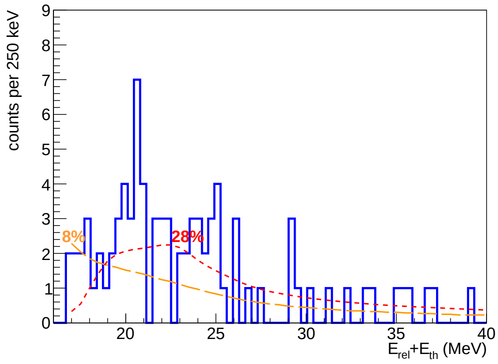

Figure 2. (color online) ^{16}C relative energy spectrum ($E_{rel} + E_{thr}$) for the ^{10}Be+^{6}He break-up channel. The red and the orange dashed lines represent, respectively, the simulated detection efficiency for inelastic scattering on proton or carbon.

3.2. $^{16}C^{*} \rightarrow {}^{10}He + {}^{6}He$ *channel*

The spectroscopy of ^{16}C was studied by using the ^{10}Be-^{6}He kinematical correlations. The corresponding relative energy ($E_{rel} + E_{thr}$) spectrum is shown, as the blue histogram, in Fig. 2. In this case the accumulated statistic is extremely low; anyway, we can find an yield enhancement at ≈20.6 MeV excitation energy. As in the case of ^{10}Be, it seems that this peak should not be due to an efficiency effect (red and orange lines). Another interesting point is that also previous works [9, 10] show a yield enhancement at about 21 MeV of ^{16}C excitation energy. This evidence, even with poor statistics, could be an indication of the possible existence of exotic ^{16}C shape configurations, theoretically predicted by [8] in this energy region; but a new experiment with improved statistic and energy resolution is needed to definitely confirm this hypothesis.

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