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Study of the cluster structure of ^{10}Be and ^{16}C neutron-rich isotopes by means of intermediate energies breakup reactions

D Dell'Aquila[4], L Acosta[8], L Auditore[5], G Cardella[1], E De Filippo[1], S De Luca[5], L Francalanza[4], B Gnoffo[1], G Lanzalone[2,6], I Lombardo[4], N S Martorana[3,2], A Pagano[1], E V Pagano[2,3], M Papa[1], S Pirrone[1], G Politi[1,3], L Quattrocchi[2], F Rizzo[2,3], E Rosato[4,†], P Russotto[1], A Trifirò[5], M Trimarchi[5], G Verde[1,7] and M Vigilante[4]

[1] INFN-Sezione di Catania, Catania, Italy
[2] INFN-Laboratori Nazionali del Sud, Catania, Italy
[3] Dipartimento di Fisica e Astronomia, Università di Catania, Catania, Italy
[4] Dipartimento di Fisica, Università di Napoli Federico II and INFN Sezione di Napoli, Italy
[5] INFN Gruppo Collegato di Messina and Dipartimento di Fisica e Scienze della Terra, Università di Messina, Italy
[6] Facoltà di Ingegneria e Architettura, Università Kore, Enna, Italy
[7] Institute de Physique Nucléaire d'Orsay, Orsay, France
[8] National Autonomous University of Mexico, Mexico City, Mexico
[†] deceased;

E-mail: dellaquila@na.infn.it

Abstract. We describe the results of a new experiment aimed to investigate the possible existence of cluster structures in ^{10}Be and ^{16}C isotopes. They have been investigated at the FRIBs facility of INFN-LNS by means of an invariant mass analysis on correlated projectile breakup fragments carried out with the CHIMERA 4π detector. From the analysis of the ^{6}He+^{4}He channel we found evidence of a new state in ^{10}Be at 13.5MeV excitation energy. Concerning ^{16}C, we investigated ^{6}He+^{10}Be correlated fragments and we found a non-vanishing yield at about 20.5MeV in the corresponding excitation energy spectrum. Finally, we describe few details of a new experiment performed at the FRIBs facility where the CHIMERA detector was coupled to the FARCOS hodoscope, with the aim to improve the presently obtained results.

1. Introduction

The clusterization of light nuclei into α particles usually characterizes the structure of self-conjugated nuclei [1]. It can be imagined as the tendency of nucleons to create bounded sub-units made of quartet of nucleons, due to the stability of α particles. These phenomena are governed by the residual interaction inside nuclei and, for this reason, they are important to understand the properties of nuclear forces [2]. α clustering in nuclei can gain an important role also in Nuclear Astrophysics; for example the existence of cluster states in light nuclei can determine different scenarios in the nucleosynthesis of elements in stars (see for example the case of Hoyle state in ^{12}C [3] or the ^{20}Ne [4, 5, 6]).

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Cluster structures can also occur in neutron-rich nuclei. These states are generally characterized by large deformation and therefore they can give rise to rotational bands. The extra neutrons can act as sort of covalent particles between α-cluster centres, increasing the stability of the structure and, for this reason, they are usually called *valence neutrons* [7]. Important examples are Be and C isotopes, giving rise respectively to possible dimeric or chain structures [7].

A very interesting beryllium isotope is the ^{10}Be. For this nucleus, theoretical calculations based on the Antisymmetrized Molecular Dynamics model (AMD) predicted the existence of a state close to the helium emission threshold at 6.18MeV (0^+) with a pronounced dimeric structure [8]. The existence of this state has been confirmed by several experiments and a rotational excitation of this highly deformed state has been pointed out at 7.54MeV (2^+), indicating its molecular nature. Recently the existence of a state at about 10.2MeV (4+) has been reported [9], indicating the continuation of this band but, to date, no further members of this band have been suggested in the literature. Ambiguities in the determination of the ground state band are also present in the literature [10].

The carbon isotopic chain has been the subject of several experiments aimed to the study of possible cluster configuration. A study of cluster states in the proton-rich ^{11}C nucleus has been recently published [11]. Resonant elastic experiments have been reported on ^{13}C [12, 13, 14, 15] and ^{14}C [16] nuclei. Anyway, despite the recent theoretical predictions of ref. [17] on the existence of molecular states, very few experimental information are reported for the ^{16}C isotope, for which data at low statistics are published [18, 19].

2. Experimental results

To investigate ^{10}Be and ^{16}C structure we have carried out an experiment at the FRIBs facility of the INFN-Laboratori Nazionali del Sud. A fragmentation cocktail beam (mainly constituted by 10^5 pps ^{16}C at 49.5MeV/u and 4×10^4 pps ^{10}Be at 56MeV/u), characterized by a particle-by-particle tagging system [20], was used to induce sequential breakup reactions on polyethylene

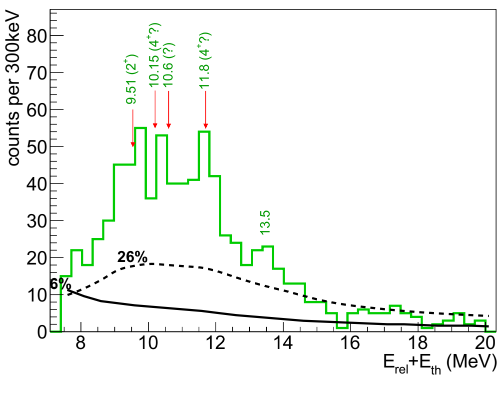

Figure 1. ^{10}Be invariant mass spectrum ($E_{rel}+E_{thr}$) for the ^{4}He+^{6}He break-up channel. The dashed and solid lines represent, respectively, the simulated detection efficiency for inelastic scattering on proton, peaking at 26%, or carbon, peaking at 6%. Arrows indicate the position of known states in the literature.

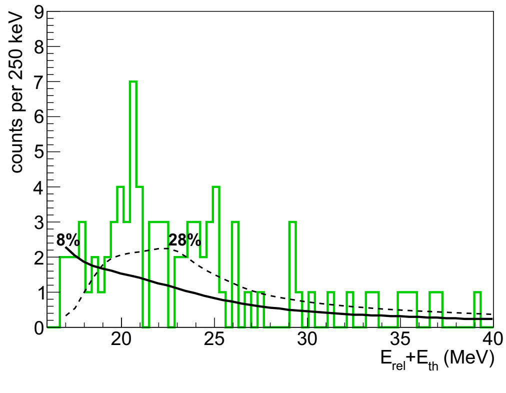

Figure 2. ^{16}C invariant mass spectrum ($E_{rel}+E_{thr}$) for the ^{10}Be+^{6}He break-up channel. The dashed and solid lines represent, respectively, the simulated detection efficiency for inelastic scattering on proton, peaking at 28%, or carbon, peaking at 8%.

target (CH_2). Correlation between couples of breakup fragments are used to provide information on the excitation energy of the projectile prior to decay by means of the invariant mass technique [21]. To identify and track particles and fragments we used the CHIMERA 4π multi-detector; detailed information about the functioning and the capabilities of this device can be found in Refs. [22, 23, 24, 25, 26, 27, 28].

The structure of ^{10}Be has been studied by inspecting the ^{4}He+^{6}He invariant mass spectrum ($E_{rel} + E_{thr}$), as described in [29]. The corresponding excitation energy spectrum is reported in the Fig. 1, where arrows are used to indicate the positions of known states in the literature. Peaks, even with poor statistics, are visible in figure, compatible with the presence of states already established in the literature. A further peak is present at about 13.5MeV. This peak is not compatible with detection efficiency effects, as confirmed by the solid and dashed lines (which represent the efficiency curves for excitation induced, respectively, by carbon or hydrogen inside the target), and therefore could be attributed to the existence of a new state in ^{10}Be, as discussed in more details in [30, 31].

A non-vanishing yield is also reported in the ^{6}He+^{10}Be excitation energy spectrum, as shown on Fig. 2, at about 20.5MeV. In analogy to the previous case we could attribute this peak to the population of a new state in ^{16}C. Anyway, in this case the statistics is very limited and this enhancement could be also compatible with a non resonant phase space component.

3. Preliminary results from the CLIR experiment and perspectives

Following the suggestions previously reported, we have recently carried out a new experiment at the FRIBs facility. In this case we used the FARCOS correlator [32, 33] covering the most forward part of the CHIMERA device. FARCOS is based on 3-stages high granularity telescopes made of a 300μm DSSSD, a 1500μm DSSSD and a CsI scintillator based layer. In order to obtain the particle tracking we have firstly developed specific algorithms for the track recognition in the DSSSD detectors. To benchmark the developed algorithms and the data reduction procedure we have studied α-α correlations for two different nuclear systems: ^{16}O+^{11}B and ^{16}O+^{12}C at 55MeV/u. The corresponding correlation functions are reported in the Fig. 2, respectively with the blue and red lines. The result is very nice, indicating the presence of a narrow peak at $\approx$ 92keV relative energy related to the ground state of ^{8}Be, and a broad bump at about 3MeV, evidence of the first excited state in ^{8}Be. Finally, a further small peak is present at $\approx$ 600keV, compatible with the ghost peak due to the ^{9}Be decays, as described for example in [34].

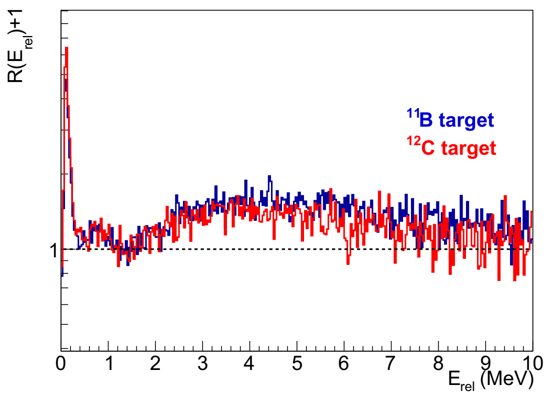

Figure 3. α-α correlation function ($R(E_{rel} + 1)$) in logarithmic scale for two different nuclear collisions ^{16}O+^{11}B (blue line) and ^{16}O+^{12}C (red line) at 55MeV/u. The dashed line represents the line $R(E_{rel}) = 1$.

In the near future we plan to extend the data analysis to the part of the experiment carried out with in-flight beams. We will benefit of the 4π coverage of CHIMERA and the very high granularity given by FARCOS, with the aim of improving the present spectroscopic information especially for the case of ^{16}C, for which no definitive conclusions can currently be drawn.

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