IL NUOVO CIMENTO **47 C** (2024) 43
DOI 10.1393/ncc/i2024-24043-x

Colloquia: COMEX7

^{10}Be clustering states investigation at LNS

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received 31 October 2023

Summary. — The study of the formation of cluster structures in light nuclei plays an important role in the understanding of nuclear forces and nucleon-nucleon correlations. Clustering states can be investigated via break-up reactions showing, especially in radioactive neutron-rich nuclei, molecular structures of α clusters held together by *valence neutrons*. The CLIR experiment, carried out at Laboratori Nazionali del Sud of INFN, fits into this context to investigate the cluster structure of various light neutron-rich nuclei. This paper will report some recent results on the analysis, still ongoing, for the ^{10}Be case, obtained by means of the FARCOS array.

1. – Introduction

The study of clustering in nuclear physics is a fascinating subject, which is acquiring more and more importance at an international level. This is mainly due to the fact that it constitutes a powerful tool to investigate the nuclear force and the potentials that arise from it. It is well known in literature that due to the nuclear potential, nucleons

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(*) Email: `farisitano@unime.it`, `fabio.risitano@ct.infn.it` can rearrange themselves into group structures, such as α particles, characterized by large deformations [1-3]. Other than even self-conjugated nuclei (*i.e.*, nuclei with even $A = 2Z$, like ^{8}Be, ^{12}C, ^{16}O, ^{20}Ne, etc.), cluster structure phenomena can also occur in neutron-richer isotopes, in which the additional *valence* neutrons act as a "glue" among the α clusters. A typical case is that of the neutron-rich isotopes of beryllium: while ^{8}Be is unstable at its ground state, decaying into 2 α particles, ^{9}Be and ^{10}Be are much more stable and can present molecular structures. In particular for ^{10}Be, while theoretical studies have suggested the existence of molecular structures [4-6], experimentally the situation is not entirely clear, especially for high excitation energy states.

One of the research lines of the CHIRONE collaboration [7,8] at LNS concerns the study of cluster states in neutron-rich isotopes of light nuclei. In particular, prominent results precisely in the case of ^{10}Be, have showed the presence of a possible new high spin state belonging to the molecular rotational band, at 13.5 MeV (6^{+}) [9]. In this context, the *CLIR* (Cluster in Light Ion Reactions) experiment was carried out [10], in the footsteps of previous results, investigating on the break-up decay channels of light neutron-rich nuclei such as ^{10}Be, ^{13}B or ^{16}C.

2. – Experimental details

The experiment was performed at INFN-LNS, in Catania (Italy), using the FRIBs@LNS (in-Flight Radioactive Ions Beams at LNS) facility [11,12]: a radioactive beam (RIB) was produced with the *In-Flight* technique, fragmenting a ^{18}O^{7+} (55 MeV/u) primary beam on a ≈ 1.5 mm thick beryllium target. The isotopes of the *cocktail beam* produced were selected with a rigidity $B\rho \approx 2.8$ Tm and then sent to the CHIMERA experimental hall. A *tagging* system, employing the ΔE-Time-of-Flight (ToF) technique, was used to identify the ions of the RIB produced [13]. It consisted of a Micro-Channel Plate (MCP) detector, measuring the *start* of the ToF, and a Double Sided Silicon Strip Detector (DSSSD, 156 μm), measuring the energy loss ΔE and *stop* of the ToF, with a flight path of ≈ 12.9 m. The reaction products have been detected by four FARCOS telescopes [14], coupled with the CHIMERA multidetector [15]. To induce break-up reactions, a polyethylene target (CH$_2$, 50 μm thick) was employed, placed in the centre of CHIMERA's sphere. The FARCOS telescopes, placed at about 75 cm from the reaction target, covered polar angles around the beam axis in the range $1.6^\circ \leq \theta \leq 8.2^\circ$. These are made up of 3 different stages, expanding the basic concept of a 2 stage *telescope* detector: the first two are made up of DSSSD, 300 μm and 1500 μm respectively, 32×32 strips front-back, 2 mm wide (6.4×6.4 cm^2 total area); the third stage consists of four CsI(Tl) detectors, 6 cm thick and 3.2×3.2 cm^2 front area. Since the break-up products are forward focused, and thanks to the presence of narrow strips, the FARCOS array proves to be an excellent tool, capable of greatly increasing the angular and energetic resolution achievable.

Calibrations were performed on the tagging system through simulations of the fragmentation beam production. This allowed to identify the components of the cocktail beam (fig. 1 left), with ^{10}Be, ^{16}C, ^{8}Li and ^{13}B being the most produced components. The FARCOS stages were also calibrated to allow us to reconstruct the total kinetic energy of the impinging ion. Therefore, the excitation energy of the original nucleus can be reconstructed knowing the emission angle and the total kinetic energy of the fragments deriving from the decay channel studied. The 1500 μm thick stage was calibrated, for each strip of the front side, by calculating for each ion of the cocktail beam, the energy loss of the beam undergoing elastic scattering on carbon ions. Figure 1 (right) shows an

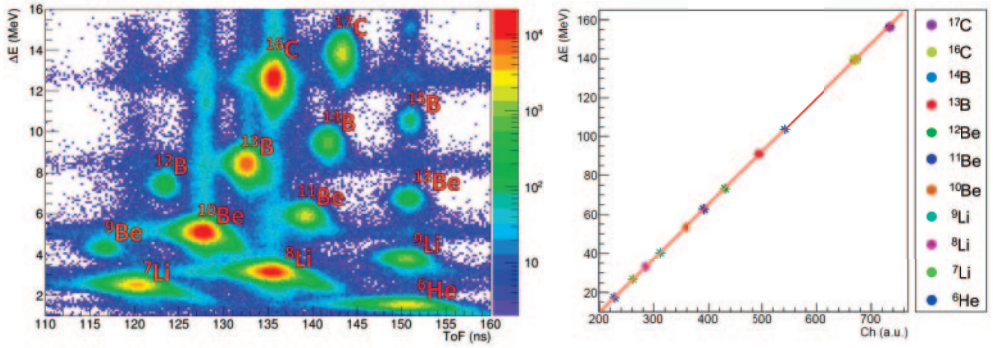

Fig. 1. – Left: tagging ΔE-ToF calibrated plot. Several isotopic species can be identified through simulations. Figure taken from ref. [10]. Right: linear calibration relative to a single strip of a 1500 μm stage of a FARCOS detector [16].

example of a calibration for a single strip. Very much attention was also given to the CsI(Tl) calibrations, which response depends from the charge, mass and energy of the impinging ion, by a non-linear relation, following the method described in [16, 17].

3. – Preliminary results on ^{10}Be

The cluster structure of ^{10}Be was investigated by analysing the ^{4}He + ^{6}He decay channel. Events with the two reaction products in coincidence were identified through ΔE-E matrices after the selection from the cocktail beam of the ^{10}Be beam of interest, through cut graphs on the tagging matrix of fig. 1 (left). The energies and emission angles of the decay products were then reconstructed, allowing us to calculate the invariant mass of the reacting ^{10}Be. The excitation spectrum was then reconstructed (fig. 2) by adding the energy threshold for the decay channel under study $-Q_{gg} = 7.409$ MeV. The arrows in the figure show the position of peaks known in the literature [4, 18]. Among these, the 7.5 (0^+) MeV and 9.5 (2^+) MeV peaks stand out, as well as possible evidence of the states at 11.8 (4^+) MeV and 13.5 (6^+) MeV, belonging to the molecular band. The last one in particular would be a further confirmation of the state already identified at LNS during previous experiments [9]. Further improvements will consist especially in including the CHIMERA multidetector in the analysis, evaluating the background through event-mixing procedures, calculating the simulated detection efficiency, to observe whether structures within the spectrum are attributable to the geometry of the detector.

4. – Conclusions

This paper shows the progress of the analysis of the CLIR experiment performed at INFN-LNS. In particular, details were given for the analysis on ^{10}Be. The ^{4}He + ^{6}He break-up decay channel was studied. An excitation spectrum was therefore obtained, showing the presence of peaks, some of which could be related to molecular states of the α:2n:α configuration. The analysis is still in progress and the next updates will contribute to increase the statistics, to evaluate the background and to calculate the detection efficiency of FARCOS. Furthermore, the research topic on cluster states will continue in the next years at the LNS [3], with the completion of the new FRAISE facility

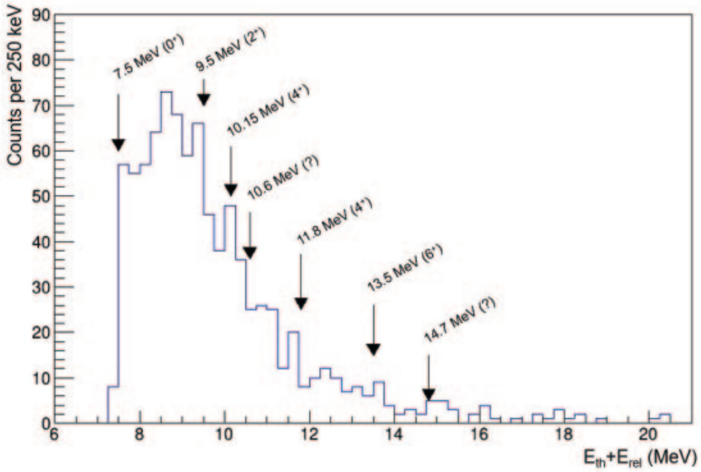

Fig. 2. – ^{10}Be relative energy spectrum reconstructed for the ^{4}He + ^{6}He decay channel. Positions of various peaks known in literature are marked. In the brackets the J^π spin parity is shown.

[19-21], currently under construction. Moreover, the construction of new detectors, such as the NARCOS neutron detector [22-24], currently under development, will provide information on neutron emission allowing the reconstruction of complete events in cluster decay reactions.

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