Clustering in ^{11,12,13}C

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In the light nuclei both single-particle dynamics and nucleon correlations, which result in clustering, are well manifested. The correlations and formation of α-clusters are closely related to fine details of the nuclear force as well as to spatial and quantum symmetries within the nuclei [1]. Modern nuclear theories are able to model structure and trace the origin of α-clustering in $A < 20$ nuclei from first principles, starting from individual nucleons [2,3]. Calculated nuclear properties should be compared with experimental data and therefore high-precision experimental results on the key nuclei are of prime importance to benchmark these models.

Key nuclei to understand α-clustering are C isotopes [2,4]. Low excitation level scheme of the ^{12}C nucleus corresponds to one for an assembly of three α-particles [1] and a correct description of its structure is a way to improve understanding of the nuclear interaction [3] and develop a theory able to model nuclei in a broad range of nuclear masses. Understanding the ^{12}C structure is a research breakthrough, because prominent α-clustering of its second 0^+ state, the Hoyle state, enables nucleosynthesis of all elements heavier than Li in the Universe [5]. For understanding the effects of additional nucleons on developed α-cluster structure essential are C isotopes [4]: the ^{13}C, with one extra neutron, and ^{11}C, which corresponds to the $2\alpha+^3He$ structure, or a neutron-hole system. For these reasons, the $^{11,12,13}C$ have been subject of extensive theoretical and experimental studies. The calculations have suggested analogs of the Hoyle state in $^{11,13}C$, an important result which has to be experimentally confirmed.

With the aim to study clustering in Carbon isotopes, experiment was carried out at the INFN Laboratori Nazionali di Legnaro, using the 95 MeV ^{14}N beam and ^{10}B target. Reaction products were detected with the setup of six highly segmented silicon telescope detectors, each consisting of 20 μm thick single sided strip detector ΔE and 1000 μm thick double sided strip detector E, covering polar angels from 15 to 70 degrees, allowing for clear identification of the reaction products using the standard ΔE-E approach. Many interesting decay channels were populated in this reaction. Here will be presented results on the observed decays of the excited states of ^{11}C to the $^7Be+^4He$, ^{12}C to the $^8Be+^4He$, and ^{13}C to the $^9Be+^4He$. There are also observed ^{11}C states decaying into $^{10}B+^1H$. Obtained results will be discussed in the context of their cluster structure and their possible effect on nuclear astrophysics.

[1] M. Freer, Rep. Prog. Phys. **70** (2007) 2149.
[2] M. Freer, H. Horiuchi, Y. Kanada-En'yo, D. Lee, U.G. Meissner, Rev. Mod. Phys. **90** (2018) 035004.
[3] T. Otsuka, T. Abe, T. Yoshida, Y. Tsunoda, N. Shimizu, N. Itagaki, Y. Utsuno, J. Vary, P. Maris, and H. Ueno, Nature Communications **13** (2022) 2234.
[4] W. von Oertzen, M. Freer, and Y. Kanada-En'yo, Physics Reports **432(2)** (2006) 43.
[5] M. Freer, H.O.U. Fynbo, Prog. Part. Nucl. Phys. **78** (2014) 1.