

Clustering in Hot Even-Even $N=Z$ nuclei. The ^{28}Si case.

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INTRODUCTION

The NUCL-EX collaboration is carrying on an experimental campaign devoted to a systematic study of the properties of highly excited light nuclei [1]. Both statistical decay of hot nuclei, produced in fusion-evaporation reactions, and α -clustering [2] were investigated in this framework. According to the Ikeda diagram [3], clustering effects are expected to appear at high excitation energies close to the multi-alpha decay threshold in even-even $N=Z$ nuclei. Our goal was to search for the nuclear structure signatures by means of exclusive channel selections and a comparison with a highly constrained Hauser-Feshbach statistical decay code (HF ℓ), which includes also discrete excited states of light nuclei [4].

We studied the reaction $^{16}\text{O} + ^{12}\text{C}$, at three different incident energies (90.5, 110 and 130 MeV) of the Oxygen beam delivered by the XTU Tandem accelerator of INFN Laboratori Nazionali di Legnaro (LNL), with the GARFIELD+RingCounter (RCo) apparatus [5]. With this experimental setup, one is able to measure charge, energy and emission angles of the charged reaction products and reaching an almost 4π coverage of the solid angle. The data sample has been analyzed with the aim of selecting the compound nucleus (CN) reactions in which a $^{28}\text{Si}^*$ nucleus is formed at three different excitation energies (55, 63 and 72 MeV). The subsequent decay channels of the CN are then studied and compared with the HF ℓ model.

RESULTS

The fusion-evaporation events have been selected by requiring the complete detection of the charge in the entrance channel ($Z_{tot}=14$) and conservation of the initial momentum. The shape of the charge distributions is typical of a fusion-evaporation reaction and it is reasonably well described by the statistical HF ℓ code. In Fig. 1 the energy spectra of protons (upper panels) and α -particles (lower panels), detected in coincidence with each residue, are shown for the 110 MeV beam energy. Overall, the proton distributions are well reproduced by the HF ℓ model whereas for the α -particles some differences can be noticed, as for example for the Neon and Magnesium residues.

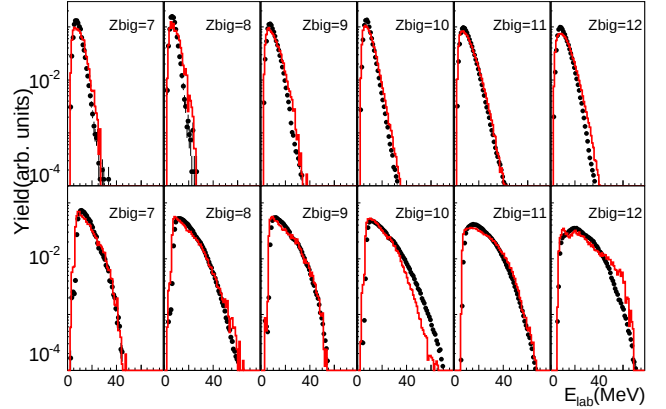


Fig. 1. Proton (upper panels) and α (lower panels) laboratory energy spectra detected in coincidence with a residue of charge Z_{big} , indicated in each panel, for $^{16}\text{O} + ^{12}\text{C}$ at 110 MeV incident energy. The data (black dots) is compared to the HF ℓ predictions (red line). All distributions are normalized to unitary area.

To try to evidence possible α -clustering effects, for each of the residues mentioned previously in Fig. 1, the Branching Ratio (BR) for the experimental most populated decay channel was calculated and compared to the HF ℓ predictions. The preliminary results obtained for 90.5 and 110 MeV are illustrated in table 1. The data sample at 130 MeV instead are still under investigation. The extra probability of α -emission is better revealed by introducing a new variable quantifying the experimental branching ratio excess with respect to the model predictions. The variable R_{clust} [1] is defined as follows:

$$R_{clust} = \frac{Y_{exp}(Z, n_Z \alpha)}{Y_{exp}(Z)} - \frac{Y_{HF\ell}(Z, n_Z \alpha)}{Y_{HF\ell}(Z)}$$

where $Y(Z, n_Z \alpha)$ and $Y(Z)$ indicate coincident and inclusive alpha particle yield; $n_Z \alpha$ represents the maximum number of α -particles emitted in coincidence with the Z charge residue. The “exp” and “HF ℓ ” subscripts are used for indicating the experimental data and the model predictions. In Fig. 2, the R_{clust} variable as a function of the charge Z_{big} of the evaporation residue is shown. The evaporation chains leading to Oxygen, Neon and Magnesium residues show a preferential α -decay as in the case for even residues in the $^{12}\text{C} + ^{12}\text{C}$ reaction [1].

Table 1. For the measured evaporation residues of the $^{16}\text{O} + ^{12}\text{C}$ reaction, the table below shows the experimental most probable channels and their experimental branching ratio alongside with the predicted HF ℓ value for the 90.5 and 110 MeV incident energy cases.

Z_{big}	Channel	$BR_{exp}(90.5 \text{ MeV})$	$BR_{HF\ell}(90.5 \text{ MeV})$	$BR_{exp}(110 \text{ MeV})$	$BR_{HF\ell}(110 \text{ MeV})$
6	$^{12-xn}\text{C}+xn+4 \alpha$	100 ± 5	100 ± 5	100 ± 5	100 ± 5
7	$^{15-xn}\text{N}+xn+p+3\alpha$	99 ± 5	99 ± 5	98 ± 5	99 ± 5
8	$^{16-xn}\text{O}+xn+3\alpha$	99 ± 5	99 ± 5	99 ± 5	90 ± 5
9	$^{19-xn}\text{F}+xn+p+2\alpha$	99 ± 5	99 ± 5	93 ± 5	95 ± 5
10	$^{20-xn}\text{Ne}+xn+2\alpha$	74 ± 4	18 ± 1	45 ± 2	4 ± 1
11	$^{23-xn}\text{Na}+xn+p+\alpha$	95 ± 5	95 ± 5	92 ± 5	88 ± 4
12	$^{24-xn}\text{Mg}+xn+\alpha$	52 ± 3	10 ± 1	35 ± 2	4 ± 1

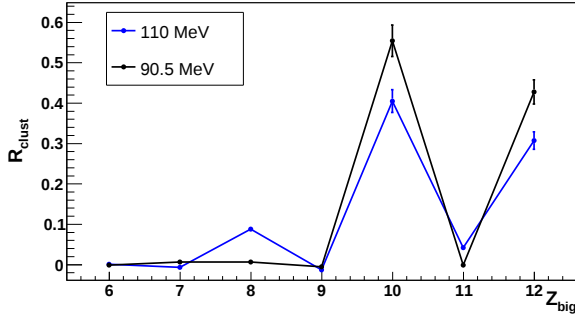


Fig. 2. Branching ratio excess for the α -particle decay channels of table 1, as a function of the charge Z_{big} of the final residue. The different colored lines represent the two energies of the $^{16}\text{O} + ^{12}\text{C}$ reaction, as illustrated in the legend.

Since the experimental apparatus allows a complete reconstruction of the events, a Q-value distribution can be built to further investigate each channel at the various energies:

$$Q_{val} = E_{kin} - E_{beam} = \sum_{i=1}^N E_i - E_{beam}$$

where E_i represents the energy of the particles in the laboratory frame and E_{beam} is the initial energy of the projectile nucleus. The summation extends to the N particles and fragments that are detected in coincidence, and exhausts the total charge $Z_{tot}=14$. In Fig. 3, the Q-value distribution for the $^{16-xn}\text{O} + xn + 3\alpha$ decay channel is illustrated as an example. One can clearly distinguish the ground state of ^{16}O experimentally located at -8.1 MeV and a second peak distant about 6.3 MeV from the first, which represents the superposition of the excited 0^+ , 3^- and 2^+ states, as reported in the NUDAT2 database [6]. The Q-value spectrum presents also a continuous part, with a predicted Q_{val} threshold of -22.9 MeV, which corresponds to opening of channels with neutron emission. The energy of neutron(s) is not measured with the current apparatus. As one can notice from the Q-value distribution, the HF ℓ model overestimates the population of the neutron decay channels

with respect to the observed data which on the other hand

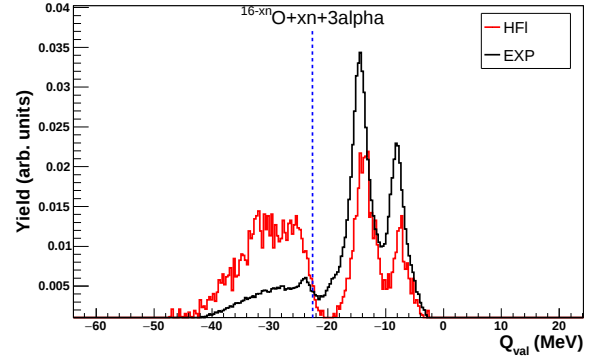


Fig. 3. Q-value distribution for the $^{16-xn}\text{O} + xn + 3\alpha$ decay channel of the $^{16}\text{O} + ^{12}\text{C}$ reaction at 130 MeV. The black line corresponds to the distribution obtained for the experimental data while the red one shows the HF ℓ predictions. The blu dashed line indicates the energy threshold for the neutron emission channels. The Q-value distribution is normalized to unitary area.

indicate a dominance of the less dissipative channels (decay channels without neutron emission).

In summary, these preliminary results for the $^{16}\text{O} + ^{12}\text{C}$ reaction indicate the persistence of cluster structures. This is highlighted by the excess of branching ratio in the experimental α -decay channels shown in table 1, in the fused ^{28}Si system and/or its daughter nuclei at energies above the threshold energy for alpha-particle disintegration. The data analysis is still in progress.

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