Statistical Decay of Light Hot Nuclei

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INTRODUCTION

The reaction $^{12}C+^{12}C$ at 95 MeV beam energy was measured using the GARFIELD + Ring Counter (RCo) [1, 2] apparatuses. This experiment is aimed at progressing in our understanding of the statistical properties of light nuclei at excitation energies above the particle emission thresholds.

Thanks to the very high efficiency of the experimental setup for the detection of all the charged reaction products, the reaction mechanism can be determined, and a discrimination between direct reactions and fusion-evaporation reactions leading to the formation of ^{24}Mg can be performed. Physics goals of the experiment include the determination of the level density in the $A \sim 20$ region, the interplay between continuum and discrete particle-unstable states, as well as the exploration of possible α-clustering at high excitation energy for the Mg isotopes.

The comparison of exclusive data with the prediction of the statistical model, which explicitly includes all the experimentally measured particle unstable levels for this mass region, will allow to make a step forward in this study.

PHYSICS CASES

Fusion - evaporation reactions are the only kind of study which makes a fundamental quantity, such as the nuclear level density, accessible for energies above the particle decay thresholds. Despite the fundamental interest of this issue, only inclusive experiments have been used up to now to constrain this quantity [3], and very few studies exist altogether concerning the evaporation of very light nuclei in the mass region $A \sim 20$ [4–6]. This is surprising if we think that both theoretical and experimental studies [7] point to a limiting temperature increasing with decreasing compound mass, making in this sense light nuclei better suited to high temperature nuclear thermodynamics studies.

Furthermore, hot light nuclei, in the mass region $A \sim 20$ and with excitation energies of the order of 3 MeV per nucleon, are massively produced in multifragmentation reactions and successively undergo secondary decays; their statistical behavior is thus essential to access the properties of heavy excited sources at break-up time [8].

Another reason to pursue this kind of study is that some excited states of different nuclei in this mass region are known to present pronounced cluster structures; these correlations may persist in the ground state along some selected isotopic chains [9]; according to the Ikeda diagrams [10] alpha-clustered excited states are massively expected at high excitation energies close to the multi-alpha decay threshold in all even-even $N = Z$ nuclei; such states should lead to exotic non-statistical decays which start to be identified in the recent literature [11].

These issues are clearly intercorrelated: a trustable modelization of highly correlated alpha-clustered states in the continuum is very difficult to achieve [12], however such effects might be experimentally seen as an excess of cluster production with respect to the prediction of the statistical model, provided that the ingredients of the latter are sufficiently constrained via experimental data and available information [13].

EXPERIMENTAL SETUP

The RCo coupled to the GARFIELD setup, now fully equipped with digital electronics [14], allows a nearly-4π coverage. These apparatuses have the capability to measure the charge, the energy and the emission angles of nearly all the charged reaction products, allowing an excellent discrimination of the different reaction mechanisms. They also provide information on the mass of the emitted charged products in a wide range of particle energy and type.

GARFIELD is a two detection stages device, made by a microstrip gaseous drift chamber (μSGC), filled with CF_4 gas at low pressure (53 mbar), and CsI(Tl) scintillation detectors, lodged in the same gas volume.

In some more detail the RCo detector is designed to be centered at 0° with respect to the beam direction. It is an array of three-stages telescopes realized in a truncated cone shape. The first stage is an ionization chamber (IC), the second a 300 μm reverse mounted Si(nTd)-detector, and the last a CsI(Tl) scintillator. It has an angular coverage $5^\circ \leq \theta \leq 18^\circ$, an angular resolution $\Delta\theta \approx 1^\circ$ and an energy resolution of silicon strips and CsI(Tl) detectors given by 0.3% and 2-3%, respectively. The identification of the charge of fragments stopped in the Silicon detector via pulse shape and digital electronics resulted feasible, as in previous tests at LNL of the FAZIA detectors [15]. In addition, the RCo has recently shown the possibility of A identification via pulse shape for fragments with charge up to $Z = 14$.

ONGOING ANALYSIS

Data taking lasted approximately 70 hours with a ^{12}C beam of intensity ≈ 0.05 pnA and beam energy 95 MeV on a ^{12}C target 200 μg/cm^2 thick. We also measured the reaction ^{12}C+^{179}Au at the same beam energy in order to have a reference point for the energy calibration of the detectors given by the elastically scattered ^{12}C ions. From a preliminary analysis we have estimated $\approx 8 \cdot 10^6$ measured fusion evaporation residues.

The analysis has been focused up to now on the necessary preliminary checks on the good quality of collected data. Charge (and mass, where the information is available) identification and energy calibration are in progress for the different kinds of matrices: $\Delta E(\mu\text{SGC}) - E(\text{CsI})$ for GARFIELD, $\Delta E(\text{IC}) - E(\text{Si})$, $\Delta E(\text{Si}) - E(\text{CsI})$ (figure 1) for the RCo. We plan to intensively use the semi-automatic procedure developed in the framework of the NUCL-EX collaboration for (A,Z) identification and energy calibration of the fast versus slow matrices with signals from the CsI scintillators [16], both for GARFIELD and for the RCo. Semi-automatic identification procedures for the Si energy versus signal rise-time matrices (pulse shape, see figure 2) are currently under study, and Si energy calibration is in progress.

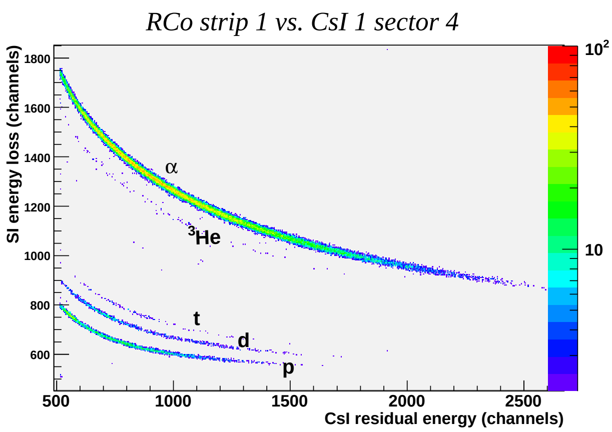

Fig. 1. Typical Si energy loss versus CsI residual energy ($\Delta E - E$) matrix. Light particles are isotopically resolved, a dominant production of α-particles can be observed.

Once the identification and energy calibration of all the measured reaction products is achieved, an event by event reconstruction has to be performed. The multiplicity of the event and the kinetic variables associated with the produced fragments will give us information on the reaction mechanism. In the case of fusion evaporation reaction we plan to achieve a quasi-complete reconstruction of the evaporation chain. Another interesting observable will be the α particle multiplicity distribution: for this

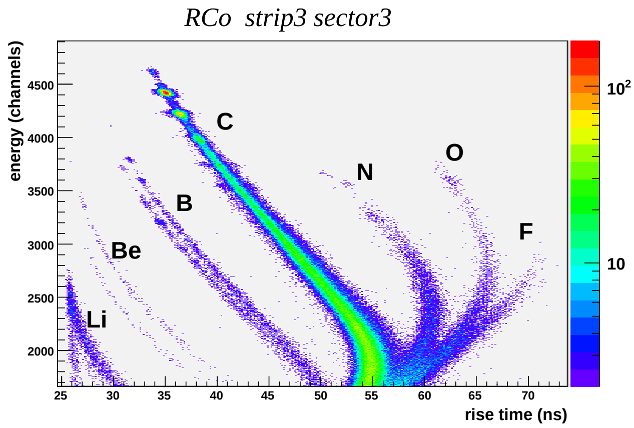

Fig. 2. Typical Si energy versus signal rise-time matrix. Different isotopic ridges are clearly visible. Besides the elastically scattered ^{12}C ions, one can also see the contribution of different direct reactions proceeding through discrete states of the involved nuclei.

reaction we expect indeed an important contribution of multiple α-decays even in the framework of standard Hauser-Feshbach theory for the evaporation of the compound nucleus.

We will finally compare the measured data with the predictions of the statistical model, in order to constrain the ingredients of the latter (level density, deformation, etc.) with exclusive data, and to get information on clustering effects in hot nuclei.

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