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Decay modes of the systems formed in the reactions ^{78}Kr+^{40}Ca and ^{86}Kr+^{48}Ca

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Abstract

Preliminary outcome of ISODEC experiment, performed at INFN-LNS with the CHIMERA array, are presented. Disintegration path dependence on the entrance-channel N/Z ratios (isospin asymmetries) for the reactions ^{78}Kr+^{40}Ca and ^{86}Kr+^{48}Ca at 10 A·MeV, which give origin to the intermediate systems ^{118}Ba and ^{134}Ba, is being investigated. Staggering effects seem to be present as it was the case of a complementary measurement performed at GANIL at lower energy, i.e. ^{78,82}Kr+^{40}Ca at 5.5 A·MeV.

Nuclei under extreme conditions as high spin and temperature and/or large isotopic-spin represent a relevant issue of modern nuclear physics and therefore are object of many and deeply driven investigations by great part of nuclear-physicist scientific community . The measurement we performed aims to explore the isospin (N/Z) dependence of medium-mass compound nuclei decay formed by fusion process. Indeed, the neutron enrichment of the compound nuclei is expected to play an important role on the various emission mechanisms that provide crucial information on fundamental nuclear quantities such as fission barrier, viscosity or level density; this latter plays a key role in the thermal properties of excited nuclei, being related to the effective mass a property of the effective interaction that is sensitive to the neutron-proton composition of nuclei. The fission barriers depend clearly on the symmetry energy that is weakly constrained by existing data [1]. A better accuracy is expected by means of a systematic measurement of fission cross-sections for a large isotopic chain of compound nuclei, from neutron-rich to neutron-poor compound nuclei, formed in the same conditions in terms of excitation energy and angular momentum. Furthermore, the nuclear viscosity reflects the coupling between collective modes and intrinsic degrees of freedom and it is related to the Fermi energy level, thus being dependent on the neutron-proton ratio, and then letting the chemical composition influencing the fission dynamics. Eventually, the characterization of intermediate mass fragment (IMF) emission in heavy-ion collisions at low and medium bombarding energies (from 5 to 100 A MeV) has been an important ingredient in the study of heavy-ion nuclear reaction mechanisms [2]. All in all, by studying those themes several questions could be answered to, as: (i) how is the N/Z degree of freedom coupled to thermal and centrifugal degrees of freedom; (ii) which new nuclear properties result from such coupling; (iii) how the N/Z content of the emitter plays a role in the competition among the various decay channels; (iv) is there a transition in decay processes from neutron rich to neutron deficient nuclei; and (v) how can be hot exotic-nuclei modeled. Last but not least, as far as nuclear structure aspects are concerned, the results can shed further light on the very particular topic of the usefulness of IMF emission as a spectroscopic tool. It is well established, indeed, that not only does IMF emission populate the high-spin states, but it also shows a very strong exit-channel selectivity, for example it may provide a unique tool to reach nuclei in the vicinity of ^{100}Sn nuclide-chart region [3], [4]; then further studies would us lead towards a better understanding of the mechanisms and of the reaction dynamics underlying those extreme interesting effects.

We aim to study the intermediate mass region by using Kr projectiles since they will allow to span a wide region of neutron-proton ratio and we started the program by studying the competition between the various decay modes of excited ^{118,134}Ba* compound nuclei produced by bombarding a ^{40,48}Ca target with ^{78,86}Kr beams at 10 A$\cdot$ MeV delivered by the LNS superconducting cyclotron [5], [6], [7]. This allows the investigation of compound nuclei with a large variation of N/Z and at very high angular momentum. The bombarding energy has been chosen in order to ensure the formation of excited nuclei in a controlled way in terms of excitation energy and angular momentum since at high excitation energy, the influence of the initial neutron enrichment could be blurred by a long de-excitation cascade. This experiments to some extent complements data taken at GANIL for the ^{78,82}Kr + ^{40}Ca reactions at 5.5 A$\cdot$MeV [8], where it has been seen that the yields of the IMF exhibit an even-odd staggering more pronounced for the neutron-poor system, showing such a behavior the possible persistence of structural effects for dissipative processes.

The key observables are the IMF production cross-sections, the multiplicity and the various emitted nuclei angular and kinetic energy distributions. Good isotopic resolution for the IMF's, high granularity, low energy thresholds and large angular acceptance are required to measure these observables with optimum accuracy. The latter features call for the use of a very powerful 4π array for charged reaction products. The choice of the reverse kinematics permits to boost and to concentrate the fragments in the forward direction. However, a key technique is the measurement of the correlation of the light charged particles (LCP) emitted in coincidence with charged products and this requires an angular coverage as large as possible. Considering these requirements, the CHIMERA array has been utilized for the measurement of the charged products. This multidetector [9] is operational for a long time at INFN-LNS (Catania, Italy) and has proven its capabilities to provide accurate results in the intermediate energy regime characterized by final states with a large number of charged products in a broad energy range. In this experiment CHIMERA worked for the first time in a low energy regime.

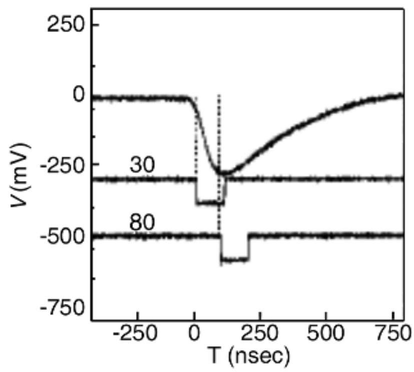

Figure 1: Signal rise-time as deduced by time difference between CFD's output at 30% and 80% of original signal.

The device consist of 1192 detector telescopes, distributed on 9 rings in the forward part and 17 rings in spherical configuration in the backward part, for a geometrical efficiency of 94%. The single detection cell consists of a silicon detector (Si, thickness about 300 μm) followed by a Caesium Iodine Thallium activated crystal (CsI(Tl), thickness ranges from 3 cm to 12 cm), coupled to a photodiode. The identification methods employed are: - ΔE-E, for charge identification of the particles punching through the Si detector and stopped in the CsI(Tl), with also mass identification for particles with Z$\leq$9; - E-TOF (Time of Flight), for mass identification, velocity and energy measurement of the particles stopped in the Si detector; - PSD (Pulse Shape Discrimination) in CsI(Tl), for isotopic identification of light charge particles; - PSD in Si detector, for charge identification of the particles stopped in the Silicon detector.

This last method was recently upgraded in CHIMERA [10], and it allowed to work for the first time in a low energy regime, where most of the particles are stopped in the first stage of the telescope. In Figure 1 a schematic view of a charge pre-amplifier utilized in order to perform such discrimination is reported. We managed to obtain a very good charge identification by using the PSD method for particles stopped in silicon detector, as it can be verified by looking at Figure 2, where a E-RiseTime plot is presented for the n-poor system ^{78}Kr+^{40}Ca at 10 A·MeV at θ=34°.

Preliminary results of the experiment referred qualitative mass distribution for lighter fragments, showing a different neutron enrichment according to the entrance channel ratio N/Z [5]. By looking at Figure 3, showing the yields for intermediate mass fragment for both systems, one can see

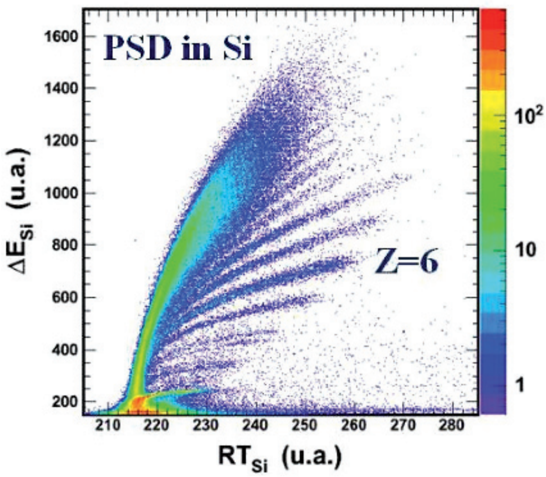

Figure 2: E-RiseTime plot for ^{78}Kr+^{40}Ca, at $\theta = 34°$.

a strong odd-even staggering of the Z yield for Z<10, and this effect persists for higher Z with a smaller amplitude. Moreover, in the comparison between the two systems with different isospin, the even-odd staggering is more pronounced for the neutron-poor system. There are indications that the influence of the neutron excess affects the light-fragment yields, but a confirmation of such statement has to wait the evaluations of the production

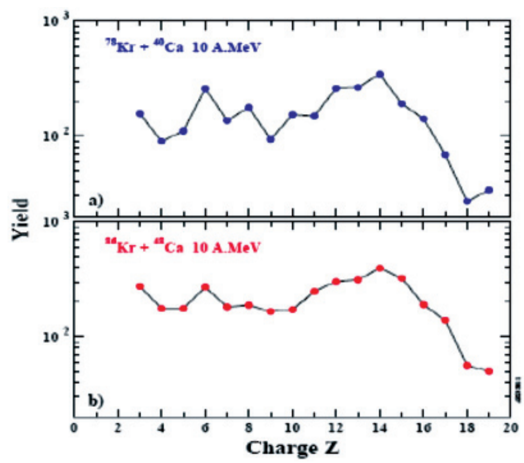

Figure 3: Charge yield of IMF for the n-poor system and the n-rich one, $\theta =$ 10°-13°.

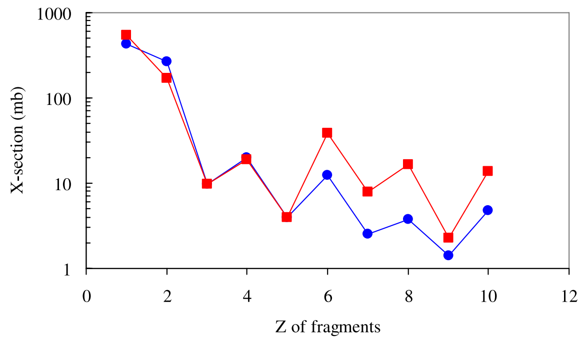

Figure 4: (Color Online) DNS calculation for fragments with atomic number Z such that 1≤Z≤10. The red squares refer to the n-poor system (reaction ^{78}Kr+^{40}Ca), whereas the blue circles refer to the n-rich one (reaction ^{82}Kr+^{40}Ca).

absolute cross-section. These absolute values will then be compared with different theoretical models in order to infer information about composite system propereties. As an example, in Figure 4 production cross-sections for different charge are shown, as calculated with the code DNS (dinuclear system model) [11] are showed: it seems that there could be a certain agreement for the n-poor system, whereas it falls down for the n-rich one.

The influence of the neutron richness on composite decays was investigated in ^{78,86}Kr+^{40,48}Ca reactions at 10 A·MeV. Preliminary results on the experimental features of the fragments were shown, in particular energy in the center of mass frame and charge and mass distributions at θ=11°-13° were reported and compared for the two system with different isospin degree. Staggering effects are evident in the Z distributions, as well as different isotopic composition and enrichment for the reaction products in the two systems. Since both the excitation energy and the maximum angular momentum stored in the intermediate system are similar in both reactions, the observed effects are probably due to the role of the N/Z degree of freedom on the decay channels. The reaction product absolute cross-sections are being evaluated; the outcome could provide relevant indication on the isospin influence on the reaction mechanism and fragments production. Comparisons with theoretical models are in progress and from these we could estimate the influence of structural effects during the disintegration path of compound nucleus.

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