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# Decay competition for IMF produced in the collisions $^{78}$Kr+$^{40}$Ca and $^{86}$Kr+$^{48}$Ca at 10 A·MeV

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**Abstract.** Decay modes of excited compound systems $^{118}$Ba and $^{134}$Ba, produced respectively in the $^{78}$Kr+$^{40}$Ca and $^{86}$Kr+$^{48}$Ca collisions at 10 A·MeV, are investigated. In particular, the competition between the various disintegration path of medium mass compound nuclei, formed by fusion processes, the production of the so referred Intermediate Mass Fragments (IMF), and the isospin dependence of the decay process are studied. Data were taken at the INFN-Laboratori Nazionali del Sud (LNS) by using the CHIMERA array. Data analysis is in progress; a first indication on the average-energy angular distributions suggests pre-equilibrium effects affecting the data and the presence of isotopical effects.

## Introduction.

Since by-now several years the nuclear physicist community is devoting ever major efforts and time in investigating nuclei under extreme conditions, as high excitation energy and/or intrinsic angular momentum. 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

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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 modelled. 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 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 extremely interesting effects.

## Experimental aspects.

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* (with excitation energy ranging from 215 to 270 MeV) compound nuclei produced by bombarding a $^{40,48}$Ca target with $^{78,86}$Kr beams at 10 A· MeV delivered by the LNS superconducting cyclotron [5-8]. This allows the investigation of compound nuclei with a large variation of N/Z (1.11 – 1.39) and at very high angular momentum (above 100 $h/2\pi$). 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 experiment to some extent complements data taken at GANIL for the $^{78,82}$Kr + $^{40}$Ca reactions at 5.5 A·MeV [9], where it has been seen that the yields of the IMFs exhibit an even-odd staggering more pronounced for the neutron-poor system, showing such a behaviour the possible persistence of structural effects for dissipative processes. The key observables are the IMFs 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 $4\pi$ 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 [10] is operational since 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. In fact, the detector was conceived for measurements at intermediate energy and in particular at Fermi energy, to study multifragmentation mechanism and related topics. The implementation of Pulse Shape Discrimination technique on silicon detectors, allowed us the extension at low energy range. For details showing the exact configuration this array has been settled up for our experiment refer to [7,10]

## Results.

In fig. 1 the "isotopical effect" can be clearly seen: for the two reactions, different carbon isotopes are produced according to the N/Z ratio of the compound system, as one can see being the reciprocal abundances different from each other.

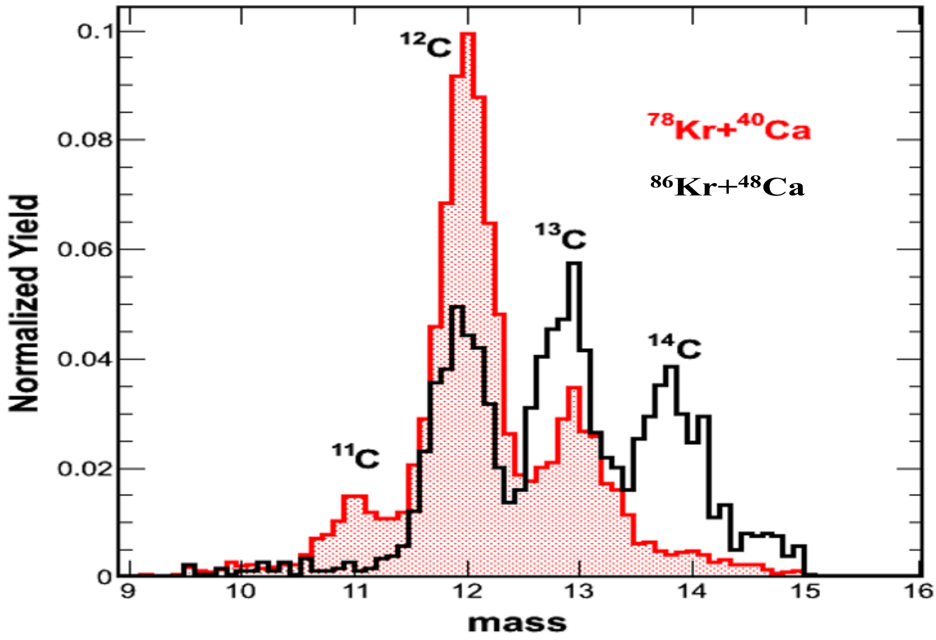


**Figure 1.** Yield of carbon nuclides emitted in the neutron poor reaction (red) and in the neutron rich one (black), as a function of the corresponding mass.

The different reciprocal isotope-abundances between the n-poor system and the n-rich one can be certainly ascribed to different intermediate dinuclei barrier-energies as well as slightly different energy threshold emission for the various isotopes. A relevant achievement that we got from a first glance at data consisted in an evident staggering, often referred as "even-odd effect", in the light Z production cross-sections as already showed elsewhere [5, 9].

Data analysis is very complex and articulated and at present only preliminary results can be showed and no definite outcome can be inferred on the physics of the decay mechanisms. Nevertheless we would like to underline that the dependence of the average energy of the fragments as a function of the emission angle reflects an expected behaviour of an equilibrated-system emission with the possible presence of pre-equilibrium reactions, as can be inferred looking at fig.2.

However we are very much aware of the fact that no conclusion can be stated for the time being since it will be very enlightening the analysis of the relevant observable, cross-sections and their angular distributions above all, in the CM frame.
For those reasons a very detailed and careful data elaboration is being performed taking into account any possible effect in order to avoid any possible contamination on the decay mechanism.

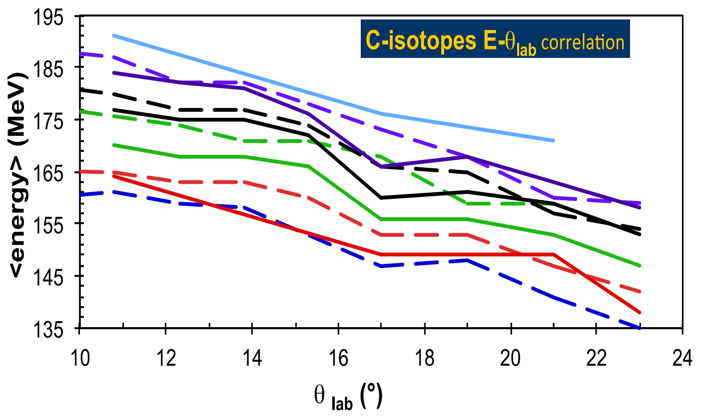


**Figure 2.** C-isotopes E-θ correlation. Dashed lines: neutron poor reactions, from A=10 till A=14. Solid lines: neutron rich reactions, from A=11 till A=15. Mass are growing from bottom toward top.

## References

1. A. Sierk et al., Phys. Rev.**C 33** (1986) 2039, Phys. Rev. Lett. **55** (1985) 582.
2. L. G. Moretto and G. J.Wozniack, Ann. Rev. Nucl. Part. Sci. **43** (1993) 379.
3. J. Gómez del Campo et al., Phys. Rev. **C 57** (1998) R457.
4. M. La Commara et al., Nucl. Phys. **A 669** (2000) 43.
5. S. Pirrone et al., Proc. of the FUSION11 Int. Conf., Saint-Malo 2011, Eur. Phys. Journal, EPJ Web Conf. **17** 16010 (2011).
6. G. Politi et al., Proc. of the CNR11 Int. Conf., Praga 2011, EPJ Web of Conf. **21** 02003 (2012).
7. M. La Commara et al., EPJ Web of Conf. **31** 00022 (2012).
8. S. Pirrone et al., Proc. of ICRTNP2012, AIP Conf. Proc. **1524,** 7-10 (2013).
9. G. Ademard et al., Phys. Rev. **C 83** (2011) 054619.
10. A. Pagano, Nucl. Phys. News 22, 28 (2012) and references therein