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# ISODEC Experiment: study and comparison of the decay mode of $^{78}$Kr+$^{40}$Ca and $^{86}$Kr+$^{48}$Ca systems at 10 AMeV

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**Abstract.** We present the first results of the ISODEC experiment, performed at the INFN-LNS with the CHIMERA device, in order to study the competition between the various disintegration modes of $^{118,134}$Ba compound nuclei produced by bombarding $^{40,48}$Ca targets with beams of $^{78,86}$Kr at 10 AMeV. This work aims thus to explore the isospin dependence of the decay modes of medium mass compound nuclei formed by fusion processes. The experiment complements data already obtained at 5.5 MeV/A for $^{78,82}$Kr+$^{40}$Ca reactions, studied by Ademard et al. with beams delivered by GANIL facility and by using the INDRA detector.

## 1 Introduction

Recently, the ISODEC experiment was performed at the INFN-Laboratori Nazionali del Sud (LNS) by using the CHIMERA detector, in order to study the competition between the various disintegration modes of $^{118,134}$Ba compound nuclei produced in the reactions $^{78}$Kr+$^{40}$Ca and $^{86}$Kr+$^{48}$Ca at 10 AMeV.
This experiment is part of a project that aims to explore the isospin 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, providing crucial information on fundamental nuclear quantities as level density, fission barrier or viscosity. In fact, for example, the level density parameter plays a key role in the thermal properties of excited nuclei, and it is 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 strongly upon the symmetry energy that is weakly constraining by existing data. Last, the viscosity reflects the coupling between collectives modes and intrinsic degree of freedom that is related to the Fermi energy level, an thus depends on the neutron-proton ratio. Thus the chemical composition

influences the fission dynamics and a program of systematic measurements of fission cross-section for a large isotopic chain of compound nuclei, from neutron-rich to neutron-poor systems, careful information.
The studied systems allow to produce compound nuclei with a large variation of N/Z, at very high angular momentum, and with similar excitation energy. Such a set of data also will provide new constraint on sophisticated models attempting to describe statistical and/or dynamical properties [2] of excited nuclei.
The experiment complements the data already obtained at 5.5 MeV/A for $^{78,82}$Kr+$^{40}$Ca reactions [1], realized with beams delivered by GANIL facility and by using the INDRA detector.

## 2 Experimental Methods and Results

In this experiment the principal observables are the cross-sections, multiplicities, angular and kinetic energy distributions of the various emitted species (Intermediate Mass Fragments, IMFs, Light Charge Particles, LCPs, and Fission Fragments, FF). The measurement of these observables with sufficient accuracy requires good isotopic resolution and low energy thresholds for LCPs and IMFs, high granularity and broad angular acceptance, and the 4π CHIMERA multi detector [3] was a very suitable device to achieve this goal.

### 2.1 CHIMERA device

The CHIMERA array is operational since a long time 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 that populate a broad energy range.
CHIMERA is formed by 1192 detector telescopes, distributed on 9 rings, in the forward part , and 17 rings, in spherical configuration, in the backward part, covering the 94% of the total solid angle.
In figure 1 a sketch of the detector is reported. The target is placed in the centre of the sphere and the direction of the beam is from the right part of the figure.

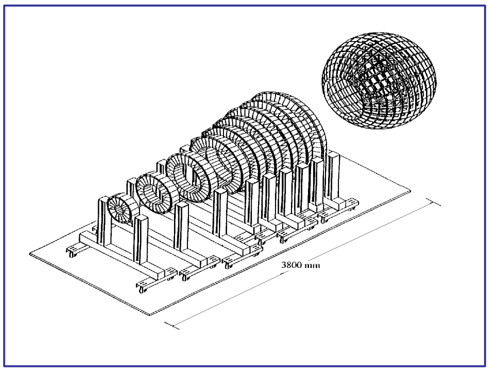


**Fig. 1**. Sketch of the CHIMERA detector

The single detection cell consists of a silicon detector (Si, thickness about 300 μm) followed by a Caesium Iodine, Thallium doped crystal, CsI(T1), (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) and mass identification for particles with Z≤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 (Pulse Shape Discrimination) in Si detector, for charge identification of the particles stopped in the Silicon detector.
This last method [4,5] was recently implemented in CHIMERA, allowing to work for the first time in a low energy range, with this device.
In figure 2 is reported a ΔE - Rise Time plot, obtained by the PSD methods in silicon detector, for the n-poor system $^{78}$Kr+$^{40}$Ca at 10 AMeV at θ =34°.

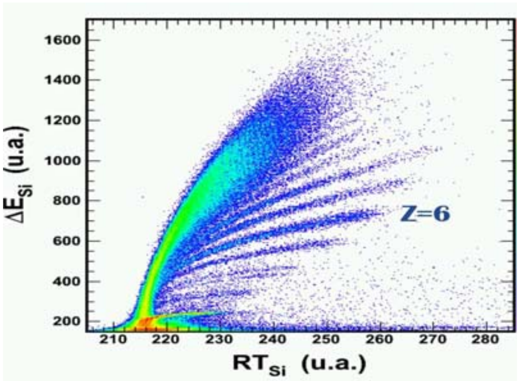


**Fig. 2.** ΔE - Rise Time plot for $^{78}$Kr+$^{40}$Ca , at θ =34°.

Besides, the CHIMERA multidetector is characterized by a low energetic detection threshold, that is less of 0,5 MeV/A for heavy ions and 1 MeV/A for light particles.
These characteristics permitted the complete identification of LCP in a wide energy range, the complete identification in charge and mass of the IMF (3<Z<12) products, the charge identification for products stopped in the Silicon up to Z =14-16, and up to about Z = 30 for the most energetic particles stopped in CsI.

### 2.2 Results

Self-supporting 1 mg/cm$^2$ thick $^{40}$Ca and $^{48}$Ca targets were bombarded with 10 AMeV $^{78,86}$Kr beams delivered by the Superconductive Cyclotron at the INFN-LNS facility.
Inclusive and coincidence measurement were realized. Energy and time calibration measurements were performed by using $^{12}$C, $^{16}$O and p beams, delivered by the TANDEM SPM of the LNS, at incident energy ranging from 10 to 100 MeV.
This experiment is complementary to that in which were studied the $^{78,82}$Kr+$^{40}$Ca reactions [1] at 5.5 MeV/A, realized with beams delivered by GANIL facility and by using the INDRA detector. There, it was studied the

cross-sections $\sigma_Z$, for fragments with atomic number 6<Z<28 and the results for the n-poor $^{78}$Kr+$^{40}$Ca and for the n-rich $^{82}$Kr+$^{40}$Ca, systems were compared.
The present first results compare the inclusive data at θ =12°, for the two studied systems $^{78}$Kr+$^{40}$Ca, n-poor, and $^{86}$Kr+$^{48}$Ca, n-rich, at 10 AMeV.
In figure 3 are reported the charge distributions for the two systems.

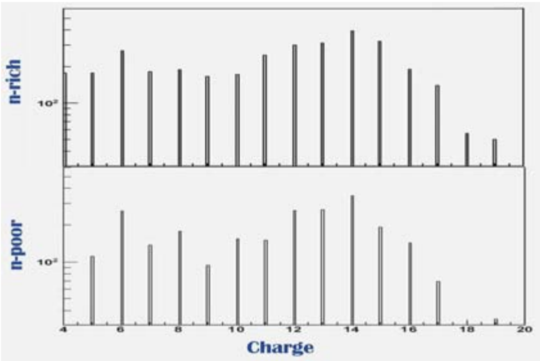


**Fig. 3.** Charge distributions for the two studied systems at 10 AMeV and θ = 12°: $^{78}$Kr+$^{40}$Ca (lower panel) and $^{86}$Kr+$^{48}$Ca (upper panel).

Note that these distributions are obtained by using DE-E and PSD in Si, identification methods: in this way, we identified all LCP and IMF detected at 12° and reaction products up to Z= 14 stopped in the Silicon. The next development of the data analysis will improve these preliminary results.
We can see that detected fragments show a strong odd-even staggering of the Z yield for Z<10 , and this effect persists for higher Z with a smaller amplitude.
Besides we note that in the comparison between the two systems with different isospin, the yields of the Intermediate Mass Fragments (IMF, 3<Z<12) exhibited an even-odd staggering that was more pronounced for the neutron-poor system. It seems also that the neutron excess affects the yields of the light fragments, but we have to wait the extraction of the absolute cross section of the reaction products to confirm this. The analysis is in progress.

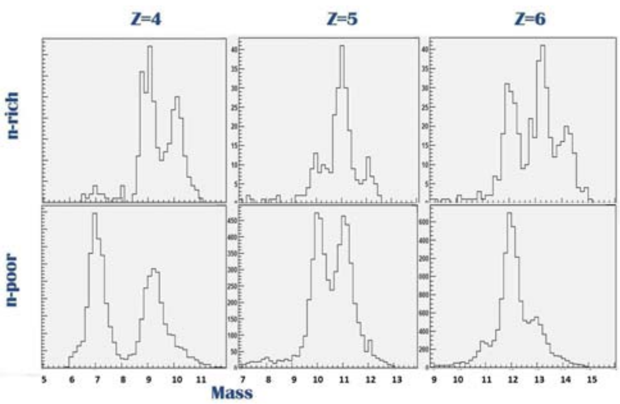


**Fig. 4.** Mass distributions for Z = 4, 5, 6 and for the two studied systems at 10 AMeV and θ = 12°: $^{78}$Kr+$^{40}$Ca (lower panel) and $^{86}$Kr+$^{48}$Ca (upper panel).

In figure 4 are reported the mass distributions for the IMF with Z = 4, 5, 6, and for the two systems.
We can see the different isotopic composition and relative enrichment in correspondence of the same Z, for the compared systems. In particular this effect is evident for the Be element, in which the isotopic composition goes from A=7,9, in the n-poor system, to A=9,10, in the n-rich system.

## 3 Conclusion

The influence of the neutron richness on binary decays was investigated in $^{78,86}$Kr+$^{40,48}$Ca reactions at 10 AMeV incident energy.
First results on the experimental features of the fragments were shown, in particular charge and mass distributions at θ=12° 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 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.
Absolute cross sections calculations of the reaction products are in progress, and these could provide important 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 separation phase in asymmetric fission.

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