



**Thermodynamical coordinates of excited nuclear systems  
NUCL-EX collaboration**

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*Abstract*

*The measurement of thermodynamical coordinates ( $T, \rho, N/Z$ ) of excited sources formed in  $^{58,62}\text{Ni}+^{40,48}\text{Ca}, ^{48}\text{Ti}$  at 35 AMeV incident energies is proposed. This detailed experimental information is an important experimental step for a deeper understanding of finite nuclear systems at the phase transition.*

We propose here to complete the measurements proposed in 2002 (experiment C57) on the determination of the thermodynamical characteristics of sources formed in central collisions for the reactions  $^{62,58}\text{Ni}+^{40,48}\text{Ca}$  at 25 and 35 AMeV incident energy. The first part of the experiment (Ni beams on Ca targets at 25 AMeV incident energy) was performed in July 2003 using the full configuration of the CHIMERA apparatus. The experiment C57 was successful, thanks to the good preparation of the complex experimental apparatus, its electronic and acquisition system and the high efficiency of the CHIMERA-ISOSPIN collaboration during the running of the experimental device and the data acquisition system. We have to thank also the accelerator staff for the very good quality of the beams, especially as far as stability and timing are concerned.

About  $40 \times 10^6$  events were accumulated on tapes for each combination of projectile and target. The calibrations started on September 2003. One year later, for two of the measured reactions, the charged products punching through the Silicon detectors were calibrated in Z, A and energy for the 1200 Chimera telescopes. The remaining reactions are under check, as far as the stability of the calibration parameters are concerned, and we plan to complete these calibrations within the end of this year. The number of measured events, corresponding to the estimates made for the C57 proposal, will allow for isospin studies, even by selecting the most central collisions by refined statistical methods (see [1]).

For the thermodynamical characterization of the hot and excited systems produced in central reactions, several open questions remain, even if some advances have been recently made (compare, for instance, Ref.s [2] and [3]) on the existence of different phases for finite nuclear matter[4]. The

measurements we are planning to perform are in the framework of a systematic study of the coexistence region planned by the NUCL-EX collaboration, starting from the liquid side up to some AMeV of available energy.

We propose to investigate the multifragmentation of sources formed in central collisions, by changing the isospin ratio of the entrance channel. In particular with the Chimera apparatus we propose to measure the reactions:

- i)  $^{58}\text{Ni} + ^{40}\text{Ca}$
- ii)  $^{58}\text{Ni} + ^{48}\text{Ca}$
- iii)  $^{62}\text{Ni} + ^{48}\text{Ca}$
- iv)  $^{58}\text{Ni} + ^{48}\text{Ti}$

at 35 AMeV incident energy.

The  $^{58}\text{Ni} + ^{48}\text{Ti}$  reaction, not measured in the C57 experiment, compared with the  $^{58}\text{Ni} + ^{48}\text{Ca}$  one, could allow to investigate the role of p-n shells closures in the fusion process and N/Z equilibration. In all the reactions it is expected that incomplete fusion of projectile and target gives sources of mass about 100, charge about 40, N/Z from 1.02 to 1.28 and excitation energies about 6–7 AMeV. Due to the different N/Z values of the sources, the limiting temperature [5], i.e. the maximal temperature for a nucleus in a liquid phase at normal density, results 6.7, 7.8, 8.3, 7 for reactions from i) to iv), respectively. These values correspond to level density parameters 7.5, 10, 11.5, 8.2 in a low temperature approximation of a Fermionic system. Non-negligible changes of thermodynamical characteristics of the nearly fused systems are also predicted by multifragmentation statistical models [6]. Microcanonical temperatures for the neutron-poor systems lower than those of neutron-rich ones, for sources at the same excitation energy, should give different charge partitions at the phase coexistence.

These theoretical predictions can be experimentally checked by measuring, together with the charge partition of the systems, also the isotopic composition of the emitted products. The isotope double ratio temperatures can be calculated from data. The yield of the isotopes need to be corrected for secondary decay: the corrections to extract the microcanonical temperature of the system can be deduced not only via model comparisons, but also by estimating the excitation energy of primary fragments from the correlation functions between asymptotically detected fragments and light particles. We plan also to apply to the data measured with Chimera, the same analysis we are setting for the data measured at Laboratori Nazionali di Legnaro with the Garfield device. This analysis evaluates the probability of the decay of primary IMFs, by looking at their discrete levels, identified through the correlation functions of the relative momentum of their isotopically resolved decay products.

The temperature evaluation, together with the estimate of the average volume from Coulomb trajectory calculations and of the isospin from the N/Z ratio of the decay products, allow to identify the position of the measured excited sources in the 3-dimensional Equation of State (T,  $\rho$ , and isospin).

Another interesting aspect, which has to be theoretically and experimentally studied [7], is related to the preequilibrium stage. A considerable emission of nucleons, light particles and even larger mass fragments can occur before producing thermally equilibrated nuclear systems. These emissions not only reduce the excitation energy provided to the equilibrated sources, but may also change the isotopic composition of the intermediate system created when the projectile and the target nucleus overlap. Another important feature is that nuclei produced at the end of the preequilibrium phase have a distribution in A, Z and E; thus one would expect fluctuations of the quantities that characterize the equilibrated nucleus. To estimate the extent and the importance of these fluctuations is a significant aim of present experiment. This may be done by correctly estimating the multiplicity and the spectra of particles emitted during the pre-equilibrium phase with methods which provide not only information about average observables, but also on high order

correlations. An approach, based on the Boltzmann Master Equation theory [8] resulted very suitable, for a wide range of projectile and target combinations at many incident energies, to reproduce accurately the double differential spectra of nucleons [9,10], light particles [11], and intermediate mass fragments [12] emitted in the first stage of the reaction.

We estimate that the beam time needed to collect at least  $10^5$  complete central events, with a cross section of the order of 100 mb, a beam intensity of 0.02 pnA and a thickness of the target about 500 microg/cm<sup>2</sup>, is 6 BTU for each combination of projectile/target.

Due to the maintenance of the apparatus and some modifications planned for the Chimera Silicon and CsI(Tl) detectors we ask in addition 2 BTUs in order to set and check with the beam the settings (gains, thresholds,...) in order to be compatible with our previous experiment (C57).

For energy calibration we plan to use some of the required beam time by measuring elastically scattered beams on a Au target. In addition we strongly support the beam request of the Isospin collaboration for calibration purposes of Silicon and CsI detectors. As in the C57 experiment, Carbon and Oxygen beams at Tandem energies (40-100 MeV), as well as proton beams at 10-60 MeV, will be analysed in order to have energy calibrations.

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