

also astrophysical interests since these processes are important in the stellar evolution.

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THE CHIMERA DETECTOR AT LNS IN CATANIA: RECENT ACHIEVEMENTS AND PERSPECTIVES

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Since January 2003, the new 4π detector CHIMERA is operational at Laboratori Nazionali del Sud in Catania. The device was designed to study multifragmentation at Fermi energy ($10 \text{ MeV/nucleon} < E/A < 100 \text{ MeV/nucleon}$). Good identification of light charged particles and fragments allow to perform careful investigations of the reaction mechanism. During 2003 and 2004 different experiments were accomplished in the framework of an international collaboration. Triggered by recent increasing interest for isospin physics and future facilities with radioactive beams, in 2006-2007 CHIMERA will be upgraded by a suitable pulse shape analysis in silicon detectors, so that the present identification performance of the apparatus will be extended. CHIMERA fostered the interest of researchers for new developments in the field of particle identification and innovative signal processing methods. In this paper, a report of this activity is given and the experimental capability of the apparatus is illustrated.

1. Introduction

The field of Heavy Ion collisions at Fermi energies ($10 \text{ MeV/nucleon} < E/A < 100 \text{ MeV/nucleon}$) has attracted much interest by nuclear scientists during the last two decades. The reason is that, in this energy domain, the dissipative processes driven by the mean field, typical of the Coulomb-energies regime, are progressively replaced by nucleon-nucleon dynamics. Consequently, a transition in the reaction mechanism is expected¹. However, due to the complexity of the mechanism involved, it was necessary to develop sophisticated 4π experimental devices, to detect charged particles, neutrons or gamma rays². The Multifragmentation of a transient highly excited nuclear system into several massive clusters of intermediate mass (IMF) and light particles (LP) was the key - phenomenon to be studied. The process was linked to basic properties of the nuclear equation of state (EOS) and, consequently, much importance assumed the concept of Liquid-Gas Phase transition³. More recently, isoscaling⁴ and isospin degree of freedom⁵ have assumed a prominent role, also in view of the production of exotic secondary beams. This last perspective motivates efforts in the direction of improving the identification methods, in order to extend simultaneous mass and charge identification of IMFs in existing 4π detector systems⁶ or to plan new designs for future third generation experiments⁷. In this report the recent status of the CHIMERA detector is briefly described and some perspectives in the medium term are discussed. This paper is ideally linked with the early CHIMERA proposal published a few years ago in Ref.⁸.

2. The CHIMERA Detector

The CHIMERA (Charged Heavy Ion Mass and Energy Resolving Array) detector was designed in order to significantly contribute to Multifragmentation reaction studies in Heavy Ion collisions at Fermi energy. Basically, CHIMERA is made of 1192 detection cells, each consisting of a planar $300 \mu\text{m}$ -silicon detector ($200 \mu\text{m}$ for the most forward ring) followed by a CsI(Tl) scintillator of thickness ranging from 3 cm at backward angles to 12 cm at the most forward angles. In 1997 the first ring of the detector was coupled with the INDRA detector in GANIL for a full test of the experimental procedures involved⁹. In 1999, the forward part of the apparatus, made of 688 detection cells (CHIM688), arranged in nine rings covering the angular range from 1° to 30° , with full 2π azimuthal symmetry around the beam axis, was installed inside the reaction chamber CICLOPE at Lab-

oratori Nazionali del Sud in Catania (LNS). The nine rings were placed, by design, at variable distances from the target, ranging from 3.5 m (1°) to 1 m (30°). In April-June 2000 the experimental campaign REVERSE was able to study the reactions in reverse kinematics $^{112,124}\text{Sn} + ^{58,64}\text{Ni}$ and $^{124}\text{Sn} + ^{27}\text{Al}$ at the incident energy $E(^{112,124}\text{Sn}) = 35 \text{ MeV/nucleon}$ ¹⁰. Experimental results and performance of the forward part of the apparatus and the identification methods used for isotopic identification of light fragments, intermediate mass fragments (IMF) and light charged particles (LPC), have been described in detail in Refs.¹¹. Figure 1. shows a portion of the forward rings of the detector during its first mounting phase in year 2000.

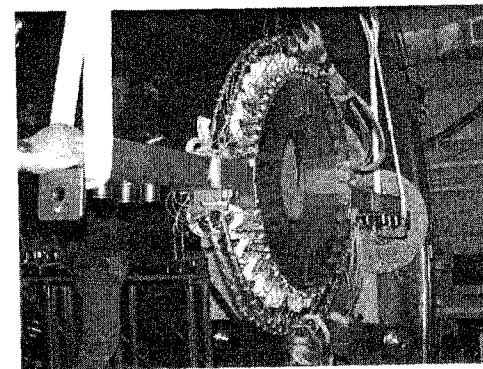


Figure 1. Forward part of CHIMERA installed inside the CICLOPE reaction chamber at Laboratori Nazionali del Sud in Catania, during its mounting phase

Finally, in January 2003, the apparatus was completed by adding the spherical structure of 40 cm radius housing 504 detection cells and covering the detection angles between 30° and 176° . Figure 2. shows a portion of the spherical configuration with the target framework position. In figure 3. the final configuration of the complete apparatus is shown. During years 2003 and 2004 two separate experimental campaigns were performed. The experiments were performed with the aim to extend the REVERSE campaign by studying the reactions $^{112}\text{Sn} + ^{64}\text{Ni}$ and $^{124}\text{Sn} + ^{58}\text{Ni}$ at the Sn beam energies of 25 and 35 MeV/nucleon, and to further explore the evolution of reaction mechanism. In collaboration with different international institutions several different experiments in the field of energy dissipation, dynamical production of fragments, phase transition, isospin degree of freedom, isoscaling, cluster condensation, and limiting temperature were performed.

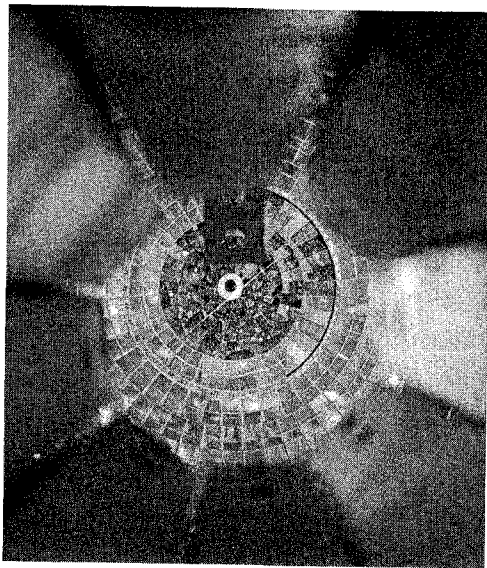


Figure 2. Portion of the spherical configuration of the CHIMERA apparatus. The position of the target framework is visible

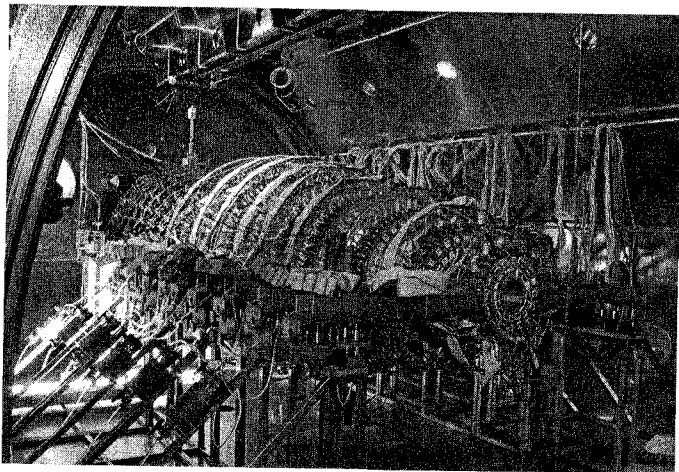


Figure 3. Recent picture of the CHIMERA multidetector

Three different detection techniques are simultaneously used in CHIMERA. First, the ΔE - E technique is employed for charge identification of heavy ions and for isotopic identification of IMF's with atomic number

$Z < 10$. Second, mass identification is performed with signals from silicon detectors generating the time-of-flight signal (TOF), obtained by comparing the timing of the detector signal and the timing of the high frequency signal (HF) from the cyclotron. Third, energetic light charged particles (LCP), which are stopped in the scintillator crystal, are identified by applying the pulse-shape discrimination method using well shaped amplified signals generated by a $18 \text{ mm} \times 18 \text{ mm}$ photodiode, optically coupled to the crystal.

Due to a very compact mounting of the telescopes, the total (nominal) geometrical efficiency of the apparatus is about 95% of the total solid angles (including holes at the forward ($\theta \leq 1^\circ$) and backward direction ($\theta \geq 176^\circ$). However, during the experiments, about 70 telescopes, on average, showed partial or total inefficiency; so, the effective average geometrical efficiency was somewhat reduced to a value around 90% of 4π .

Detectors, preamplifiers and switching system for pulser signals are operated in vacuum and are connected to the main spectroscopic amplifiers located out of the reaction chamber by multiple pin to pin flanges especially developed to reduce electronics cross talk. In figure 4., a portion of the detector array with the electronics connecting detectors and preamplifiers in vacuum and a detail of the cooling system is shown. In figure 5., one of the 600 main motherboards allocating two preamplifiers for silicon detectors (left) and two preamplifiers for photodiodes (right) are shown.

The front-end electronics was integrated in a remote controlled NIM or CAMAC architecture allocating about 300 16-channel compact analogical electronics. The acquisition system was based on a FDL (Fast Data Link) read out VME connection of a 9U VME DAQ system ¹².

Chimera benefits of the unique opportunity of the LNS Super-Conducting Cyclotron to deliver beams of suitable intensities for the 4π detector ($\sim 5 \cdot 10^7$ particles/s), high efficiency for physics runs and with good time resolution ($\Delta T \leq 1 \text{ ns}$) during most of the operation time.

The identification characteristics recently achieved for the forward part of the apparatus (CHIM688) in the recent 2003 and 2004 campaigns were very similar to the ones already described for the 2000 REVERSE experiment ^{10,11}; so, those results are not shown in this paper. All the basic experimental performances of the spherical backward part of the apparatus such as timing and energy resolution are also very similar to those observed for the forward part. Evidently, as expected, the mass by mass identification properties of the sphere are limited to a value of the atomic mass $A \approx 7$ (a factor 4 lower than the one observed in the forward part) according to

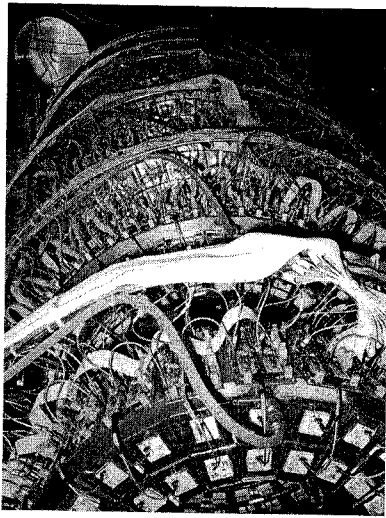


Figure 4. Front-end electronics in vacuum. Photodiodes coupled with the rear of the CsI(Tl) crystals are clearly visible



Figure 5. Example of main motherboard of the CHIMERA detector allocating four charge preamplifiers

the reduced flight distance of the detected particles from the target (40cm).

3. Physics with CHIMERA

The physics addressed with CHIMERA is mainly fragment productions in multifragmentation reactions and isospin physics related with phase transition. In these fields, most of the physics results already published are related to the 2000 year campaign where the forward part of the detector was used for the first time in the framework of the REVERSE collaboration. The analysis of the reactions $^{112,124}\text{Sn} + ^{58,64}\text{Ni}$ at the beam energy, $E(^{112,124}\text{Sn}) = 35 \text{ MeV/nucleon}$ have revealed very interesting results for

both central ^{13,14} and peripheral collisions ^{15,16}. Other important analyses, such as isoscaling, source reconstruction, angular correlations concerning ^{112,124}Sn induced reactions are in progress and they will be discussed in separate publications. Obviously, the relevant conclusions achieved by the REVERSE and ISOSPIN collaborations, and recently published or communicated in numerous proceedings of conferences ¹⁷ are not repeated in the present contribution. However it is useful to discuss some global experimental features underlying these reaction studies in order to illustrate the typical reaction pattern of the Fermi energy domain. In figure 6., a typical global variable event by event analysis is shown. In the left panel, for each of the detected particles, the atomic number is plotted (event by event) as a function of the experimental parallel velocity (i.e., velocity vector projected on the beam direction). The typical classification of fragments in three main groups is easily recognized by distinguishing: a) projectile-like fragments (PLF) having both charge and velocity close the beam ones, b) target-like fragments (TLF), slowly moving in the laboratory rest framework, and having atomic number close to the target one, and c) fragments of intermediate mass (IMF) having also a velocity intermediate between the PLF's and the TLF's velocities. The different plots (from the top to the bottom) correspond to three different selections of the centrality, as roughly evaluated by three different cuts in the charged particle multiplicity. From peripheral (top, $M \leq 6$) to central collisions (bottom, $M \geq 13$) the corresponding Dalitz plots (on the right panel) clearly illustrate the characteristic evolution of the reactions from binary gentle reactions (top) to the most dissipative multifragmentation ones (bottom).

Several different nuclear systems were investigated with the CHIMERA apparatus during 2003 and 2004. For all these systems, an important work of calibration, made in collaboration with all the international groups which have proposed new experiments, is still in progress ¹⁷.

Another aspect of the CHIMERA activity is represented by an important work in the field of R&D and detector upgrading. This activity is mainly devoted to pulse shape analysis for both silicon and CsI(Tl) detectors. Important progress was achieved in the field of the pulse shape analysis for the large capacitance planar n-type silicon detectors of CHIMERA mounted in direct - mode configuration ¹⁸. The obtained good results have motivated an upgrading of the apparatus, to be accomplished in 2006-2007. The pulse shape analysis was also performed by a digital sample analysis (DSA). Also in this field, recent important progress of DSA has been successful applied to the signals delivered by a fast charge preamplifier,

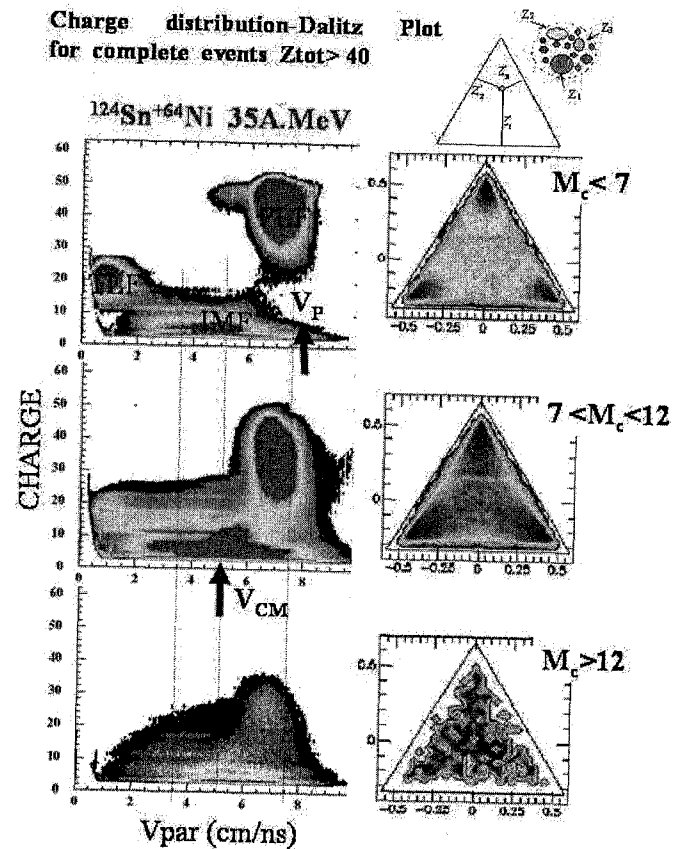


Figure 6. Charge vs parallel velocity scatter plots (left) and Dalitz plots of the three biggest fragments detected event by event (right). The analysis is performed as a function of the particle multiplicity .

especially developed for this purpose. All optimization and filtering procedures of the signals, typical in nuclear spectroscopy, have been performed by software analysis. Very good results have been obtained for energy measurement and charge identification¹⁹. The digital methods are also very promising for timing applications. Progress of this latter application is crucial in order to design third generation detectors for nuclear reaction studies.

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