IL NUOVO CIMENTO **48 C** (2025) 35
DOI 10.1393/ncc/i2025-25035-0

Colloquia: WPCF-Resonance 2023

# The pixelation technique applied to FARCOS correlator in the CHIFAR experiment

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received 23 July 2024

**Summary.** — The CHIFAR experiment, carried out at Laboratori Nazionali del Sud-INFN (INFN-LNS), was proposed to investigate the emission probability of Intermediate Mass Fragments (IMFs) in non-central Heavy Ion (HI) collisions. The aim was the study of the features of the Equation of State of the nuclear matter, focusing also on the role of the isospin degree of freedom of the colliding nuclei. The CHIMERA Collaboration has investigated at the incident beam energy of 20 AMeV some nuclear reactions including: $^{124}\mathrm{Sn} + ^{64}\mathrm{Ni}$, $^{112}\mathrm{Sn} + ^{58}\mathrm{Ni}$ and $^{124}\mathrm{Xe} + ^{64}\mathrm{Zn}$. The experimental setup was equipped with ten telescopes of the FARCOS (Femtoscope ARray for COrrelation and Spectroscopy) correlator in its final configuration, coupled with the $4\pi$ CHIMERA multi-detector allowing the study of correlations among IMFs and light charged particles produced in a nuclear reaction. The results on the energy calibration, on the energy resolution and on the particle identification phase of the FARCOS correlator used in the CHIFAR experiment are reported. The so-called "pixelation technique" is the last step of the analysis explained here.

 

## 1. – Introduction

The CHIFAR experiment [1], carried out at INFN-LNS in 2019, was proposed to investigate the emission probability of Intermediate Mass Fragments (IMFs) in non-central collisions. The initial properties of the colliding nuclei are expected to play an important role in the final outcomes of the reaction; this triggered the realization of the CHIFAR experiment, aimed at studying the role both of the isospin degree of freedom and of the size of the colliding systems in a nuclear reaction. The CHIMERA detection system [2], operating at INFN-LNS, aimed to detect simultaneously all charged particles emitted in the final state of a nuclear reaction, *e.g.*, in semi-peripheral collisions, the classes of the emission products, Projectile-Like Fragment (PLF), Target-Like Fragment (TLF) and Intermediate Mass Fragment (IMF) and the associated Light Charged Particle (LCP). In previous experiments, the CHIMERA collaboration investigated some reaction systems, such as the "neutron rich" $^{124}\mathrm{Sn} +^{64}\mathrm{Ni}$ and the "neutron poor" $^{112}\mathrm{Sn} +^{58}\mathrm{Ni}$ at 35 AMeV beam energy, in the REVERSE experiment [3]. In particular, the data analysis highlighted that the fast dynamical emission is favoured for the neutron rich system. Then, the InKiIsSy experiment studied other two nuclear reactions: $^{124}\mathrm{Xe} +^{64}\mathrm{Zn}$, that is an isobaric combination of the neutron rich one with isospin contribution similar to the neutron poor one, and the $^{124}\mathrm{Xe} +^{64}\mathrm{Ni}$ [4]. Data analysis of the REVERSE and of the InKiIsSy experiments showed that the IMFs emission probability grows with the isospin content of both projectile and target. The enhanced IMFs emission in the neutron rich systems originates from an enhancement of the dynamical emission. Thus, the influence of the isospin content is relevant in triggering the dynamical emission mechanism, while it can be excluded that the mass difference plays a significant role in the dynamical IMFs emission.

The CHIFAR experiment was proposed to study the above-mentioned physics cases at a lower energy. In particular, the "neutron rich" system $^{124}\mathrm{Sn} +^{64}\mathrm{Ni}$, the "neutron poor" system $^{112}\mathrm{Sn} +^{58}\mathrm{Ni}$ and the "isobaric" one $^{124}\mathrm{Xe} +^{64}\mathrm{Zn}$ were investigated at 20 AMeV incident beam energy, so at lower energy with respect to the Fermi energy regime. The experimental goals were the study of the emission mechanism (dynamical or statistical), the IMFs production and the investigation of the isospin role in HI collisions.

## 2. – Experimental setup

In the CHIFAR experiment, the FARCOS correlator was coupled with the $4\pi$ CHIMERA detector. The configuration CHIMERA+FARCOS is thought to permit the study of nuclear reactions at the Fermi energies, with CHIMERA able to provide a complete characterization of the reaction events, and FARCOS acting as a high-resolution detector able to give a very precise identification of the fragments detected in its limited solid angle coverage.

The CHIMERA detector is made of 1192 telescopes: a Si detector (300 $\mu$m thick) is coupled with a CsI(Tl) scintillator detector (3-12 cm of thickness). In the $4\pi$ configuration, the angular polar range covered is between 1∘ and 176∘. The typical energy resolution (FWHM), evaluated by elastic scattering, is around $\Delta$E/E<1% for the Si detectors and about 2% for the CsI(Tl) scintillators [5, 6]. This $4\pi$ detector has permitted to study different phenomena, such as the neck fragmentation in ternary events (PLF + TLF + IMFs) or the dynamical fission of the PLF related to the reaction dynamics, and such as Pygmy Dipole Resonance [7] or Hoyle state [8, 9] with reference to the nuclear structure and the nuclear astrophysics.

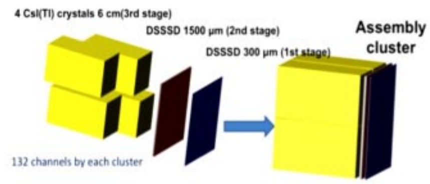


Fig. 1. – Schematic representation of a cluster of FARCOS (taken from [10])

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The experimental setup also included ten telescopes of the FARCOS (Femtoscope ARray for COrrelation and Spectrocopy) correlator in its final configuration. FARCOS [10] is a new generation correlator for reaction dynamics and nuclear structure studies. The basic idea in the design of FARCOS was to construct an array of detectors for charged particles, featuring high energy and angular resolution. The array, coupled with $4\pi$ detectors, like the CHIMERA multidetector, allows measures of the particle properties with high precision, such as the relative linear momentum (≈1 MeV/c) and the relative energy (≈1%) of the detected particles. Each FARCOS telescope is made of three stages, as schematically shown in fig. 1. Two Double Sided Silicon Strip Detectors (DSSSDs) 300 $\mu$m and 1500 $\mu$m thick respectively and having 32 vertical strips in the front side and 32 horizontal strips in the back side, and an active area of 6.4×6.4 cm$^2$, are in front of four CsI(Tl) crystals 6 cm thick, each one with an active area of 3.2×3.2 cm$^2$. The CsI(Tl) light signal is read by a photodiode. During the CHIFAR experiment, FARCOS telescopes covered the polar angle in the laboratory frame between 13○ and 30○. The signals were processed by ASIC preamplifiers [11] and digitized with the GET electronics [12].

## 3. – Data analysis and preliminary results

**3**˙1. *Energy calibration and resolution of the DSSSDs.* – The first step of the data analysis is related to the energy calibration of the two DSSSDs of FARCOS. The so-called "punching through" technique was applied to the ΔE-E identification matrices related to the two Si detectors, as schematically shown in fig. 2.

In the ΔE-E identification matrix, the snap backs at the end of each hyperbolic curve are generated by the particles that are in transmission also in the second Si stage and

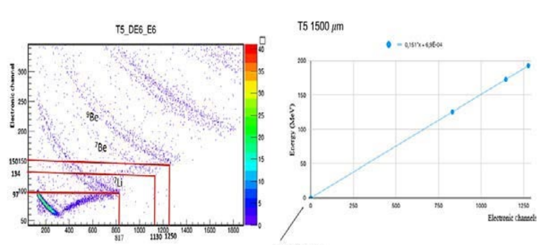


Fig. 2. – Punching-through points are indicated in the ΔE-E identification matrix of the front side of one of Si-detectors (left panel). Energy calibration of the module assuming linear dependence (right panel).

lose completely their energy in the CsI(Tl) stage. Choosing the initial point (where the particles are assumed to have stopped in 1800 $\mu$m of Si) of the tails of $^7$Li $--$ $^7$Be $--$ $^9$Be and using LISE++ software, the initial energy was reconstructed, by setting the final energy equal to zero at the end of the path; the energy lost in each of the two DSSSDs was obtained by the difference.

An estimation of the DSSSDs front side energy resolution was evaluated from gaussian fits of the elastic peaks for the reactions O+Au@85 MeV, C+Au@75 MeV, C+Au@65MeV (Tandem beam energy). An energy resolution around 0.5% RMS (corresponding to 1.5 MeV at 300 MeV of peak) was achieved, better for higher energies. The DSSSDs back side strips were calibrated by using the front side ones, and concerning their energy resolution, the ratio ($\Delta E_{front}$-$\Delta E_{back}$)/$\Delta E_{front}$ was evaluated for each front strip in coincidence with all 32 back strips: an energy resolution around 1.6% RMS (corresponding to 4.8 MeV at 300 MeV of peak) was obtained. The intrinsic component of the resolution and the electronic one were estimated using the proportionality between the FWHM and the square root of the energy released, typically of the Si-detectors. The electronic error contribution was estimated around (0.5–1) MeV $\pm$ 0.2 MeV in a dynamical range of 500 MeV, and the total error of energy measured in the DSSSD was assumed to be less than 1.5 MeV. This is an upper limit of the error estimation, which is not only related to the preamplifier: it also includes the contribution of the digitizer and any errors coming from the entire experimental setup.

**3**˙2. *Particle identification.* – The particle identification was performed by applying the $\Delta$E-E technique to the first and the second DSSSDs, for each telescope. An automatic algorithm developed by the CHIMERA collaboration, based on the Bethe-Bloch formula, was applied to the $\Delta$E-E matrices of the DSSSDs. Considering that FARCOS was placed between 13◦–30◦ in the laboratory frame system, an unambiguous charge identification of fragments up to Z≈16 and an isotopic identification for IMFs with atomic number up to Z≈9 and atomic mass up to A≈20 were achieved (see fig. 3).

**3**˙3. *The pixelation technique.* – The so called "pixelation technique" is a method that permits to assign the correct position to each particle detected by the FARCOS correlator [13]. The aim of this technique is the assignment of the coordinate, the polar angle $\theta$ and the azimuthal angle $\phi$ for each detected particle from the analysis of the fired strip of the front side and the one of the back side of the DSSSDs.

The procedure works step by step. In the first one some experimental constraints were imposed to select particles having multiplicity equal to 1 in both sides of the first

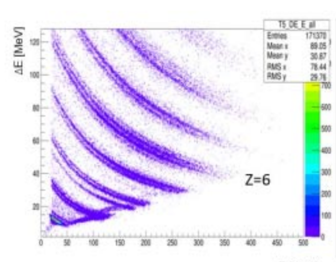


Fig. 3. – $\Delta$E-E matrix identification related to the telescope n. 5; the zoom highlights the good separation in charge and mass for the IMFs up to atomic number Z=7 and mass number A=15.

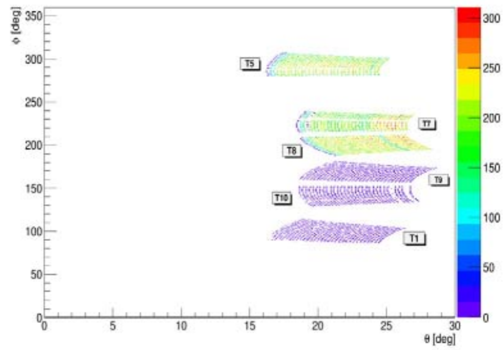


Fig. 4. – Assignment of the positions of the detected particles in the plane $\phi$-$\theta$ for the six telescopes analyzed.

DSSSD and in the front side of the second DSSSD, but multiplicity less than 4 in its back side; it was required that the particles stopped in the Si detectors, so the multiplicity of the CsI(Tl) crystals is zero. Furthermore, ideally the energy released in the front side must be approximately the same as that one released in the back side of the first DSSSD, since the two sides belong to the same detector; it was required to be of the same range within $\pm 15\%$: this range was selected in order to maintain a good statistic of the events. Finally, it was also required that the strips hit by the particle were the same or neighboring between the first and the second DSSSDs front stages. For the events selected this way, a good assignment of the position of the particles detected without ambiguity was obtained, as shown in fig. 4.

In the next step of the analysis, the imposed constraints will be partly modified to also include the events that have multiplicity equal to 2; the requirements concerning the energy released and the hit strips will remain the same. The comparison among only the energies released will not be enough to classify all observed events, such as interstrip, electronic induction or spurious events. The time variable will be very useful to complete the pixelation procedure [13, 14].

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