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Status of the FAZIASYM experiment

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Summary. — In this paper, the status of the FAZIASYM experiment is reported. This FAZIASYM experiment was performed at the LNS cyclotron using four blocks of the future FAZIA apparatus. The goal of this experiment is to measure the absolute cross section of projectile-like fragments produced in the ^{40,48}Ca+^{40,48}Ca binary dissipative reactions at a beam energy of 35 MeV/A. The second step is to trace back the isospin effect on fragment isotopic distributions in order to extract information on the symmetry energy near the saturation density. Identification in mass and charge of fragments is almost complete and calibration of the different detection layers is ongoing. The first results show the very promising capabilities of the FAZIA telescope.

1. – Introduction

Since a decade, the FAZIA project [1] is focused on the development of a new generation of multi-layer telescopes dedicated to the detection and identification of charged particles produced in Heavy-Ion reactions at the Fermi energy domain. During the R&D phase [2], major improvements have been made in the design and fabrication of Silicon and Cesium Iodide detectors to reach identification capabilities comparable to those of a magnetic spectrometer. At the same time, an in-board dedicated full digitalized electronic has been developed by the laboratories involved in the FAZIA project [3]. Since 2012, construction of blocks for the FAZIA demonstrator has been developing. The demonstrator should be coupled to the INDRA multidetector to perform a physics campaign at GANIL in the next years. To prepare this campaign, the FAZIA collaboration starts physics measurements with a limited number of available blocks to validate FAZIA telescope capabilities, to test the data acquisition system, the slow-control and

(*) Present address: SUBATECH, Nantes, France the data analysis softwares. In this spirit, two experiments have been performed in 2015: ISOFAZIA [4] and FAZIASYM. In the following, we briefly recall the physics goals of this FAZIASYM experiment, the set-up and then some preliminary results concerning calibration and identification are displayed.

2. – Physics goals

In a previous experiment done at GANIL, reactions of ^{40,48}Ca beams at 35 MeV/A on ^{40,48}Ca targets have been measured with the magnetic spectrometer VAMOS coupled with the charged particle detection array INDRA. Projectile-like fragments (PLF) and light charged particles (LCP) produced in binary dissipative collisions have been detected in coincidence. The powerful capabilities of VAMOS give the full $A\&Z$ identification of the PLF in the polar range between 2 and 7 degrees while the remainder of the solid angle was covered by INDRA which gives access to LCP properties like for example their multiplicity which is a good dissipation estimator. By combining information coming from both devices, analyses on the symmetry energy term of the nuclear equation of state have been done near the saturation density [5] and a new signal linked with Bose-Einstein condensate in nuclei has been proposed [6]. Nevertheless, absolute cross sections of the PLF production have not been measured and events with PLF and LPCs located both in the VAMOS acceptance cannot be resolved. The FAZIASYM experiment has been proposed in order to bring complementary information with respect to this measurement but also to use this latter as a guideline.

On top of that, the use of neutron-rich ^{48}Ca beam allows us to address the limit of the identification techniques by means of the ΔE-E_{res} method. Actually, by construction, looking at the simplified relation $\Delta E \propto Z^2 A/E_{res}$, overlaps between elements are expected leading to ambiguities of mass attribution: for a given E_{res}, two neighbouring elements will have the same ΔE in the map if their masses verify the relation: $A_1 \sim (1 + Z^{-1})^2 A_2$. These conditions are easily fullfilled in reactions with neutron-rich systems where a larger mass exploration is possible for produced nuclei. Therefore, one goal of this measurement is to see if identification through existing or new PSA technics in a single detector can help to increase the number of possible solved isotopes per element.

3. – Description of the experimental set-up

The experimental set-up is made of four FAZIA blocks put inside a mechanical dedicated structure located at 80 cm from the target point. Each block, made of 4×4 Si(300 μm)-Si(500 μm)-CsI(10 cm) telescopes, are localized around the beam axis in the polar angular range between 2 and 10 degrees (same as the VAMOS spectrometer location). The angular coverage of the set-up is displayed on fig. 1. The integrated geometrical efficiency in the considered angular range is around 70%. In addition a Si-Si telescope, called "Rutherford" telescope, is located at 1.8 degree (under the grazing angle) and 2.2 meters from the target. It is devoted to a continuous monitoring of the counting rate of the Rutherford elastic scattering during the beam time. As mentioned in the introduction, one goal of the experiment is to extract cross section production of PLF. From this telescope we can select the elastic scattering spot in the identification map, then, knowing the Rutherford cross section and extracting the number of counts in the spot, we get directly the absolute cross section of a given reaction detected in the FAZIA blocks by using the following relation: $X_{sec}(reaction) = N_{reaction} \times \frac{X_{sec}(ruth)}{N(ruth)}$,

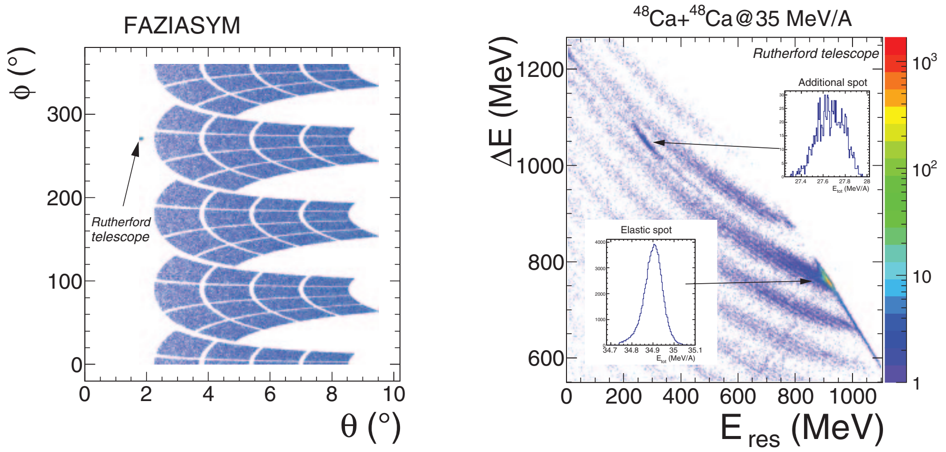

Fig. 1. – Left: angular coverage of the FAZIASYM set-up. The "Ruth-Tel" indicated the position of the Si-Si telescope dedicated to a continuous monitoring of the Rutherford elastic scaterring during beam time. Right: ΔE-E_{res} identification map of the "Rutherford" telescope around the elastic scattering region. The two insets show the total energy per nucleon of the two main spots: the expected one localized close to the initial beam energy (34.9 MeV/A) and a second one at 27.6 MeV/A.

where $X_{sec}(ruth)$ is the Rutherford cross section integrated on the solid angle of the Rutherford telescope.

Beams of ^{40,48}Ca beams with an incident energy of 35 MeV/A and a mean intensity between 10^6 and 10^7 pps were delivered by the LNS cyclotron. 500 μg/cm^2 thick ^{40,48}Ca targets were used with a backing of 20 μg/cm^2 of Carbon material to ensure their stability against oxydation. On the right panel of fig. 1, the ΔE-E_{res} identification map of the Rutherford telescope is drawn. A zoom around the elastic scattering region ($E_{Si2} \sim$ 900 MeV) is made. Additional spot is visible for E_{Si2} around 300 MeV, which could be due to some issues in the extraction of the beam from the cyclotron. We observe also, and not only on this card, a continuous line of ^{48}Ca coming from slight scaterring of the beam all along its transportation. These additional contributions have to be carefully taken into account before extracting the fragment cross sections from FAZIA.

4. – Ongoing identification and calibration

In the following, all data presented are coming from the ^{48}Ca+^{48}Ca@35 MeV/A reaction.

Identification maps built from Si-Si and Si-CsI telescope charge signals show clear separation between isotopes up to the Ca (see typical map in the top left panel of fig. 2). For Si-Si telescopes, the choosen method to perform identification and calibration is based on the AMI method [7]. This method proposes a coherent treatment of nuclei identification and the calibration of the detectors used to build experimental identification map. This method is based on the reproduction of the observed ΔE-E_{res} isotopic (Z&A) lines by a formula which describes explicitly the different contributions to the energy loss process when a nucleus goes through a material [8]. First, several isotopic (Z&A) lines, well defined on the experimental identification map, are drawn. Then these lines are

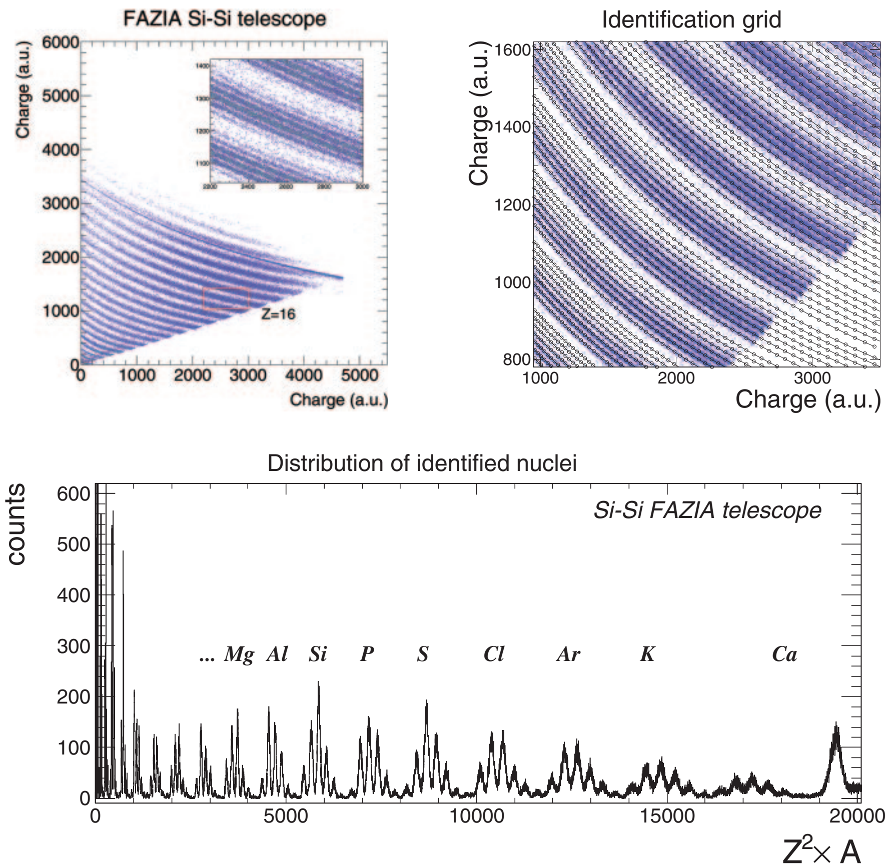

Fig. 2. – Top panel: left, typical ΔE-E_{res} identification map built from Si-Si telescope on the whole dynamics, the insert is a zoom around the $Z = 16$ region; right, example of the generated $Z\&A$ lines from parameters obtained after the AMI fit procedure. Bottom panel: Distribution of identified nuclei after linearization. The X-axis is the product between the squared charge and the real mass (distance to the closest identification line) in order to put on the same scale all nuclei.

used as inputs for the fit procedure which give output parameters. From these output parameters, we generate all needed isotopic lines to cover the whole range populated in the experimental identification map (top right panel of fig. 2). In the same time, both detectors are calibrated. In the bottom panel of fig. 2, an example of the identification results after linearization is shown. We clearly see the discrimination between each isotope up to the Ca beam. We also see the continuous filling from one element to the others with a possible overlap between them. As mentionned in the introduction, this overlap was expected and the next step is the identification cross check between ΔE-E_{res} and PSA identification techniques. However, for the present reaction, masses attributed to each element are coherent with those obtained with the INDRA-VAMOS experiment [5].

The same procedure will be applied to the Si-CsI telescope. But, at this stage of the analysis, only Z-lines have been drawn using the semi-automatic algorithm proposed

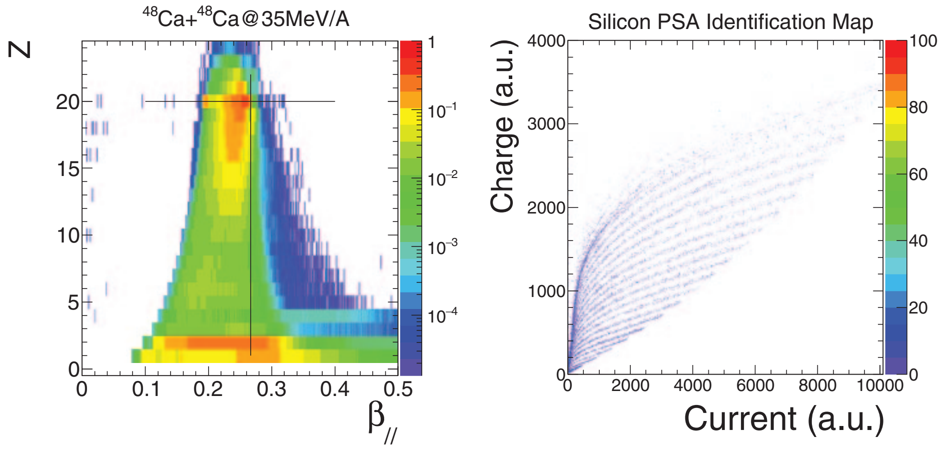

Fig. 3. – Left: two-dimensional plot of the correlation between the charge (Z) and the parallel velocity ($\beta_{//}$ in c units) of fragments identified in Si-Si and Si-CsI telescopes. Right: typical identification map obtained using the correlation between the maximum of charge signal and the maximum of current signal for nuclei stopped in the first silicon detector.

in [9]. After Z-identification, for each element, the mean mass obtained from the previous Si-Si Z&A identification is given. As the CsI detectors are not yet calibrated, we use energy loss tables to extrapolate from the energy measured in Si2 detector, the residual energy in CsI detector. The two dimensional plot where the charge of the nucleus is correlated to its parallel velocity is shown on fig. 3. We see one drawback of this preliminary method for fragments with charge lower than five: some over-estimated velocities can be due to possible pile-up in the telescope and the mean mass attributed to these fragments. Anyhow, after the proper calibration of CsI detectors, high-energy light charged particles identified in the CsI detectors using Pulse Shape Analysis (PSA) will be available for analysis. Finally, the contribution of particles stopped in the first Silicon stage of the telescope will be recovered by the mean of Pulse Shape Analysis (see right panel of fig. 3 for typical PSA identification map).

5. – Conclusion

Current status of the FAZIASYM experiment has been presented in this paper. Projectile-like fragments produced in the reactions of ^{40,48}Ca beams at 35 MeV/A on ^{40,48}Ca targets have been successfully collected with the FAZIA blocks. Identification of all charged products is almost finished and calibration of the different detection layers is ongoing. Due to some additional contributions to the beam (slight scattering during the transportation and other not well established processes), the extraction of absolute cross section is not straightforward and needs more detailed analysis. Anyhow, FAZIA telescopes allow a powerful identification even better than those reached during the R&D phase. It is very promising for the FAZIA physics program at GANIL.

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