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P. Ottanelli, G. Pasquali, S. Piantelli, et al.

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## FAZIA: a new performing detector for charged particles

S Barlini\*<sup>1,2</sup>, M Bini<sup>1,2</sup>, A Buccola<sup>1,2</sup>, A Camaiani<sup>1,2</sup>, G Casini<sup>2</sup>, C Ciampi<sup>1,2</sup>, C Frosin<sup>1,2</sup>, P Ottanelli<sup>1,2</sup>, G Pasquali<sup>1,2</sup>, S Piantelli<sup>2</sup>, G Poggi<sup>1,2</sup>, A A Stefanini<sup>1,2</sup>, S Valdré<sup>2</sup>, E Bonnet<sup>3</sup>, B Borderie<sup>4</sup>, R Bougault<sup>5</sup>, A Chibli<sup>6</sup>, M Cicerchia<sup>7,8</sup>, M Cinausero<sup>9</sup>, J A Dueñas<sup>10</sup>, D Fabris<sup>8</sup>, J Frankland<sup>6</sup>, D Gruyer<sup>5</sup>, M Henri<sup>5</sup>, A Kordyasz<sup>11</sup>, T Kozik<sup>12</sup>, N LeNeindre<sup>5</sup>, I Lombardo<sup>13</sup>, O Lopez<sup>5</sup>, G Mantovani<sup>7,8</sup>, T Marchi<sup>9</sup>, J Quicray<sup>5</sup>, S Upadhyaya<sup>12</sup>, G Verde<sup>13</sup>, E Vient<sup>5</sup>, M Vigilante<sup>14,15</sup>

<sup>1</sup>Dipartimento di Fisica, Università di Firenze, I-50019 Sesto Fiorentino, Italy

<sup>2</sup>INFN-Sezione di Firenze, I-50019 Sesto Fiorentino, Italy

<sup>3</sup>IPNO, CNRS-IN2P3, Univ. Paris-Sud, Université Paris-Saclay, 91406 Orsay, France

<sup>4</sup>Subatech, EMN-IN2P3/CNRS-Université de Nantes, Nantes, France

<sup>5</sup>LPC Caen, Normandie Univ, ENSICAEN, UNICAEN, CNRS/IN2P3, LPC Caen, 1400 Caen, France

<sup>6</sup>GANIL, CEA/DRF-CNRS/IN2P3, 14076 Caen, France

<sup>7</sup>Dipartimento di Fisica, Università di Padova, 35131 Padova, Italy

<sup>8</sup>INFN –Sezione di Padova, 35131 Padova, Italy

<sup>9</sup>INFN –Laboratori Nazionali di Legnaro, 35020 Legnaro, Italy

<sup>10</sup>Depto. de Ingeniería Eléctrica y Centro de Estudios Avanzados en Física, Matemáticas y Computación, Universidad de Huelva, 21071 Huelva, Spain

<sup>11</sup>Heavy Ion Laboratory, University of Warsaw, 02-093 Warszawa, Poland

<sup>12</sup>Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Cracow, Poland

<sup>13</sup>INFN-Laboratori Nazionali del Sud, 95123 Catania, Italy

<sup>14</sup>Dipartimento di Fisica, Università di Napoli, 80126 Napoli, Italy

<sup>15</sup>INFN-Sezione di Napoli, 80126 Napoli, Italy

\*barlini@fi.infn.it

**Abstract.** The FAZIA apparatus is a new detector designed for the Fermi energy domain for charged particles based on three stages telescopes: Silicon detector (300  $\mu\text{m}$  thick), Silicon detector (500  $\mu\text{m}$  thick) and CsI(Tl) (10 cm). Using the  $\Delta E$ -E technique and the Pulse Shape Analysis (PSA) it permits the charge and mass discrimination up to more than  $Z=20$ . In the following, some details about the FAZIA detectors and electronics, their performance and the first experimental campaigns already performed will be discussed.



## 1. FAZIA: a first introduction

The FAZIA apparatus has been built within an international collaboration [1] with the aim to obtain the best as possible charged particles identification in nuclear reaction studies in the domain of the Fermi energy. For this reason, an intense R&D phase has been carried out in order to study the best solutions in terms of silicon detectors and electronics.

In particular, the collaboration decided to build a modular and versatile apparatus, based on 3 stages telescopes with the dimension of 2x2 cm, read by a fully digital electronics integrated on board. The structure of the telescope is Silicon (300  $\mu\text{m}$  – Si1 in the following) + Silicon (500  $\mu\text{m}$  – Si2) + CsI(Tl) (10 cm). In this way, at Fermi energy (20-80 AMeV) the less energetic or the heaviest charged fragments can be identified using the Si1 vs Si2 correlation, while the most energetic and the lightest ones with the Si2 vs CsI correlation and even, in limiting cases, only using the intrinsic fast-slow method for CsI(Tl) scintillators. The 10 cm thickness of the CsI crystals guarantees to stop into the detector also the most energetic protons (up to 195 MeV) produced in the reaction. To decrease the identification threshold, the Pulse Shape Analysis is applied to the silicon detectors.

## 2. The FAZIA block: detectors and electronics.

The first part of the FAZIA R&D has been devoted to the tests of the single pad silicon detectors, in order to study the effect of the channeling phenomena with respect to the identification capability, the effect of the detector mounting (rear or front mounting), the type of the Pulse Shape (using the maximum of the current signal or the rise-time of the charge signal) and the effect of the doping homogeneity on the Pulse Shape Analysis. All those different aspects have been studied with dedicated experiments, mainly at LNS (Laboratori Nazionali del Sud, Catania, Italy) using different setups and configurations.

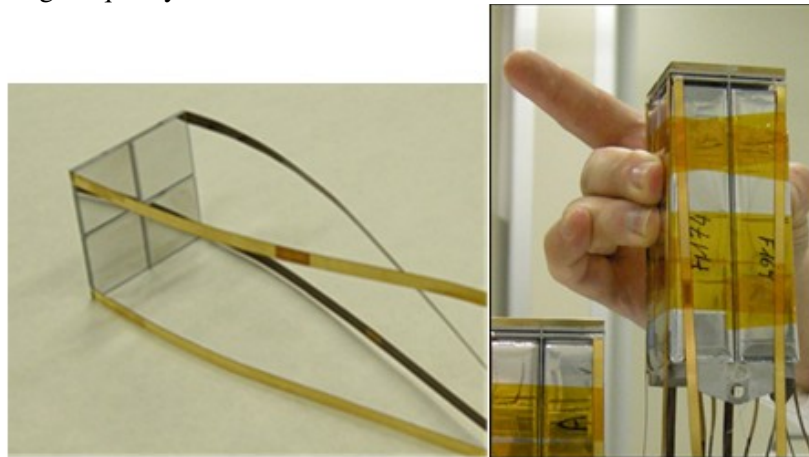
The result is the so called “FAZIA recipe”, which consists in a list of features that the silicon detectors of the FAZIA apparatus have to respect:

- "Random" cut of the Silicon wafers which are tilted with respect to the major crystal direction in order to avoid as much as possible the channeling effect [2];
- Usage of nTD (neutron Transmutation Doped) Silicon detectors (or High Purity Silicon) with good dopant homogeneity (1-3%) to preserve as much as possible the PSA [3];
- Reverse mounting configuration of Silicon detectors: the particles enter from the low-field side, permitting a better PSA performance without losing any identification capability in the  $\Delta E$ -E correlation [4];
- An Aluminum layer of about 30 nm on both sides of detectors: negligible sheet resistance to avoid position-dependence of the signal shapes, that would degrade the PSA considering that the FAZIA silicon are single pad 2x2 cm detectors;
- High thickness uniformity and planarity (around 1 $\mu\text{m}$ ) to preserve the  $\Delta E$ -E correlation on the full size of the detector.

It is important to stress that the reverse current on the silicon detectors must be controlled. In fact, its variation during the experiment will change the effective applied voltage on the silicon junction, producing a varying electric field into the detector and consequently a different Pulse Shape during the experiment for the same impinging particles. For such a reason, a monitoring of the reverse current is

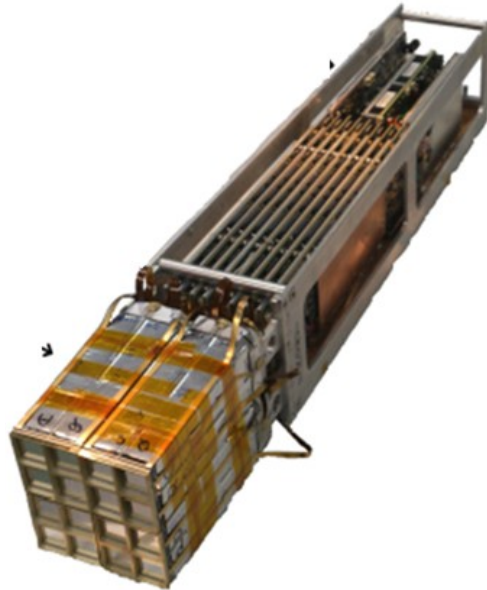
needed in order to compensate the voltage drop on the bias resistance keeping the voltage on the silicon junction constant during the whole experiment.

After the definition of the elementary telescope, the collaboration focused on the electronics and on the mechanics needed to group a significant number of single telescopes. The idea was to build something versatile, easy to mount in different configurations and easy to transport in the different laboratories where the FAZIA group aimed measuring. This is possible exploiting the enormous potentiality of the fast digital electronics which is mounted as much as possible near to the detectors to preserve as best the signal quality for the PSA.



*Figure 1. Left panel: a matrix of 2x2 silicon detectors glued in the supporting frame with connection flexible strips. Right panel: a FAZIA quartet made of 4 telescopes.*

The final result of the work is the FAZIA block, which consists in 4 quartets formed by 4 Si+Si+CsI telescopes with all the electronics directly coupled under vacuum in the scattering chamber. The mechanics is designed to minimize as much as possible the dead zone between the telescopes. A quartet is built using two frames made by Ergal (a light and robust Aluminum alloy) with the electro-erosion method on which 4 silicon detectors are directly glued. Particular care has been dedicated to the silicon contact which has been realized using kapton strips directly bounded to the silicon chips (see Fig.1, left panel). The two frames are piled and fixed on a cross supporting structure hosting also the corresponding four CsI(Tl) crystals (see Fig1, right panel). On top of the structure, a collimator is placed to avoid border effects on the detectors. Finally, 4 quartets are mounted together on a specific holder which also gives the telescope orientation considering a target distance of 100 cm.



*Figure 2. A FAZIA block: detectors, FEE and service cards can be easily distinguished.*

Directly fixed to the same frame of the quartets, there is the digital homemade electronics which consists in 8 Front-End Cards (each of them is developed to serve two complete FAZIA telescopes) and three service cards (Block card for the I/O, Half Bridge and High Voltage to create the low voltages needed in the FEE and the HV for the photodiodes of the CsI(Tl) crystals). In Fig.2, a block of the FAZIA apparatus is shown. The total dimensions are around 80 cm of length. The detectors, the FEE and the service cards are visible.

More details about the electronics can be found in [5], here we only report some of the main characteristics. In each FEE card, we have a first pre-amplification stage with six channels (2 telescopes), then we have 6 ADCs at 14 bits for each telescope and an FPGA to perform on-board calculation and trigger. Then, the FEE card hosts also the circuits to produce the HV for silicon detectors, which include the monitoring of the reverse current with an automatic check in order to keep constant the HV on the silicon junction. The 6 ADCs are needed because we have 3 different electronic channels for Si1 (charge output with 4 GeV range sampled at 100 MHz, charge output with 250 MeV range sampled at 250 MHz, current signal sampled at 250 MHz derived analogically from the charge output), 2 channels for Si2 (charge at 4 GeV and current signals) and finally a channel for the CsI (only charge signal). The use of the current signal is needed to perform the maximum of the current signal which is used in the PSA. The FEE contains also a pulse generator useful to test the electronics stability during the experiment.

All the blocks are connected by optical fiber to a Regional Board (RB) which is located out of the scattering chamber. In the RB the main trigger is generated starting from the local triggers created in the various FEE with a fast shaping. Each local trigger is an OR-combination of logic signals from each detector of the telescopes, while the global trigger is a trigger of multiplicity of the previous ones. A different scaling factor can be introduced in the RB for each multiplicity trigger. The acquisition is connected to the RG by mean of an Ethernet link.

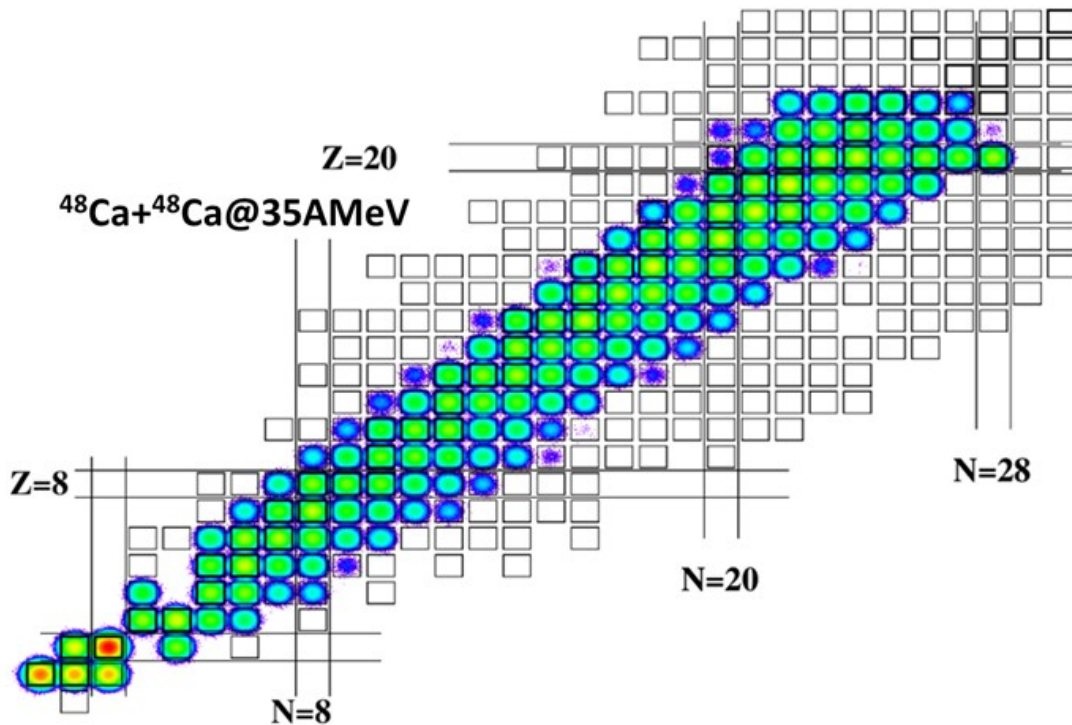


Figure 3. A chart of Nuclides built with particles coming from the reaction  $^{48}\text{Ca}+^{48}\text{Ca}@35\text{AMeV}$  fully identified by FAZIA.

Each single FAZIA block can work alone, and the only connections needed are two optical fibers (one for input and one for output) and a power 48 V link from which all the low voltages needed by the FEE and the HV for CsI(Tl) photodiodes are created in the service cards. Of course, considering that a part from the RB all the FAZIA electronics is under vacuum, the cooling is a very important issue taking into account that the power consumption of each FEE is around 25 W. For this reason, the electronic cards are mounted on a cold copper plate with particular attention in order to guarantee the best thermal contact. In the copper plate, a mixture of water and alcohol is circulating and kept at fixed temperature using an external chiller to dissipate the heat created in the electronics. At regime, the temperature of the FEE controlled in various hot spots, stays normally below 50-60°C.

With a single RB up to 36 FAZIA blocks could be connected. The installation of the blocks and their connection is quite easy: for each block (it means 16 telescopes), three connections are needed, i.e 2 optical fibers, a 48 V cable and the cooling system. In this sense the purpose to have a versatile and easy movable set-up is fully accomplished by the FAZIA apparatus.

Thanks to the big effort of the collaboration to have the best performance from the detectors and the electronics, the identification capability in terms of charge and mass identification of the charged fragments reached by the FAZIA apparatus fears no rivals: a complete identification (mass and charge) up to more than Calcium ions for all the fragments that punch-through the first silicon layer, as one can see in Fig.3. Some identification in charge and mass is moreover achievable using the PSA applied to the first layer. A global evaluation of the identification threshold and capability is given in the Fig.4 taken from [6] using the system  $^{40,48}\text{Ca}+^{40,48}\text{Ca}@35\text{ AMeV}$ . One should consider that there are some fluctuations between the detectors due to a different noise level or aging, and that for this particular

experiment the statistics of particles detected with charge more than 20 is lower. Using heavier projectiles (as Kr and Xe), better results have been reached for some telescopes in terms of mass separation (up to charge around 24-25) [7].

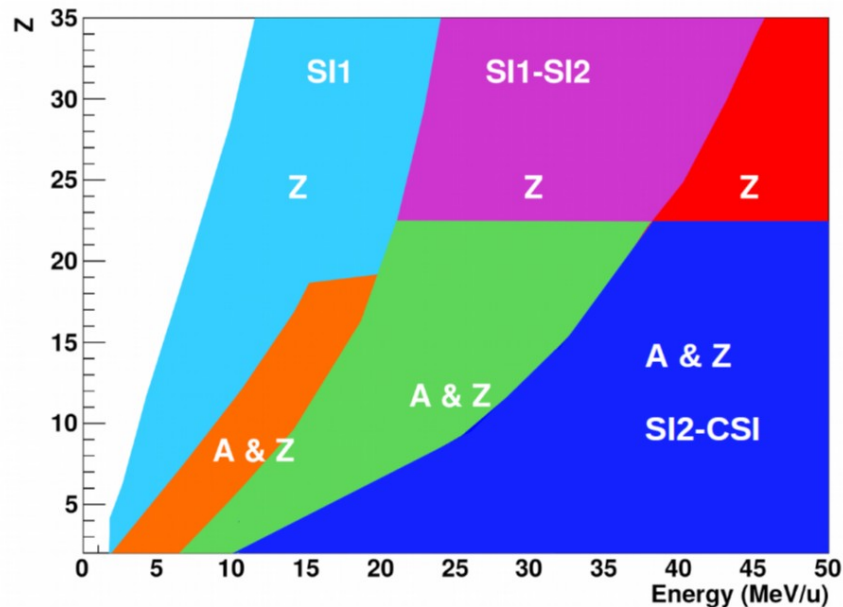


Figure 4. Performances and identification regions for the  $^{40,48}\text{Ca}+^{40,48}\text{Ca}@35\text{ AMeV}$  reactions.

### 3. The physics items investigated with the FAZIA blocks.

The excellent identification capability of the FAZIA apparatus can be used to investigate different physics items. It has been designed mainly to approach the study of the isospin transport in nuclear reactions, which is connected to the study of the Nuclear Equation of State for the Asymmetric matter, but it can be used as particle correlator and in general in all the experiments where an isotopic identification is important.

Starting from 2015, at least 4 blocks up to a maximum of 6 blocks of the FAZIA apparatus have been used for different experiments all performed at the LNS with a “wall” or “belt” configuration, depending on the cases. In particular, the following experiments have been performed:

- $^{80}\text{Kr}+^{40,48}\text{Ca}@35\text{ AMeV}$  and  $^{40,48}\text{Ca}+^{40,48}\text{Ca}@35\text{ AMeV}$  focusing on the exited Quasi-Projectile decay and the Isospin transport mechanism. It is important to note that using the Ca beam the fission fragments from the Quasi-Projectile breakup are fully identifiable in terms of charge and mass by the FAZIA apparatus, if they are inside the geometrical acceptance. The same occurs also for the great part of the Kr\* fissions. This is not usual in such type of studies, where usually only one of the two fragments is fully identified by a magnetic spectrometer (no coincidences), while for most other multi-detectors there are limitations in mass separation typically beyond oxygen.
- $^{20}\text{Ne},^{32}\text{S}+^{12}\text{C}@25,45\text{ AMeV}$  where the particle correlation technique is applied to study the in-medium effects in the decay of fragments created in the nuclear reactions. Note that thanks to the identification capability of FAZIA, also correlation between Light Charged Particles ( $Z=1,2$ ) and Intermediate Mass Fragments ( $Z$  between 6 and 10) can be detected and analysed.



- $^{40,48}\text{Ca}+^{12}\text{Ca}@20,40$  AMeV where the question of the Isospin mechanism versus the beam energy is approached to study how the possible appearance of a preferential neutron pre-equilibrium emission can decrease the initial isospin difference between projectile and target
- $^{12}\text{C}+^{12}\text{C}@62$  AMeV (in collaboration with the Beihang University) to test the FAZIA blocks for cross section measurements at zero degrees with very low current beams. The test was performed on a rather well known system, but the final goal concerns cross sections of reactions with exotic ions, using selected fragmentation beams at cyclotron facilities.

The analysis of those experiments is in some cases still in progress, while results from the first two experiments are near to be published.

Presently, 12 blocks of FAZIA are coupled to the INDRA  $4\pi$  detector [8] at GANIL; they cover the angular range between  $1.5^\circ \leq \theta \leq 14^\circ$  to detect with precision mainly the QP decay products, while the INDRA detector covers a large part of the rest of the solid angle thus allowing for a good characterization of the reaction mechanism. A big effort has been devoted to couple together those two detectors, a task complicated by the fact that INDRA is based on old analog electronics. During the 2019, an experimental campaign about the isospin transport mechanism has been performed measuring the systems  $^{58,64}\text{Ni}+^{58,64}\text{Ni}@32,52$  AMeV. About 30 Million of events for each combination of projectile, target and energy have been collected and the analysis is now in progress.

#### 4. Conclusions

The FAZIA apparatus represents one of the best detectors for charged particles in the range between 20-60 MeV/n in term of identification capability with reasonable energy threshold. It can be used for different purposes, mainly connected to isospin transport in nuclear collisions by accurately detecting Quasi-Projectile and their emission particles for which a complete isotopic characterization is crucial, but not only. At present, 12 blocks are coupled to the INDRA detector at GANIL, while 4 blocks will be available for different experiments also in other laboratories.

#### Acknowledgments

Authors wish to remember here the colleague Prof. Mauro Bruno from the University of Bologna (Italy) deceased in 2019. He dedicated his carrier to study heavy-ion reactions with passion and competence, becoming a point of reference for all the students of the Bologna University interested in the nuclear physics and for his colleagues during his entire professional life.

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