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FAZIA applications

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Abstract

The present status and the perspectives of the FAZIA project are presented. The main achievements in terms of identification thresholds and isotopic resolution are discussed, together with the adopted technical solutions. The detector is particularly well suited for the investigation of isospin transport phenomena at intermediate beam energies; perspectives to reduce the identification thresholds to cope with lower energy ISOL beams are briefly introduced. Some experimental results concerning isospin transport effects obtained with a test telescope are presented. The study of isospin transport phenomena can give information on the symmetry energy term of the nuclear equation of state by comparing the experimental results on isospin related observables with the predictions of transport codes.

1 Introduction

The aim of the FAZIA (Four-π A and Z Identification Array) project [1] is the design and construction of a 4π detector with high resolution and low thresholds, which should be used both with stable beams (at GANIL (Caen, France), INFN-LNL (Legnaro, Italy), INFN-LNS (Catania, Italy)) and with radioactive beams (at SPIRAL2, SPES, EURISOL) in the range 10-50AMeV. Several European institutions are involved in the project and the R&D phase (concerning detectors, electronics and identification techniques) started in 2006.

The detector consists of blocks, each one comprising 16 three-layer telescopes. Each telescope, with an active area of 20x20mm^2, includes a first 300μm-thick Silicon (Si) layer, a second 500μm-thick Si layer, followed by a 10cm-thick CsI(Tl) crystal read out by a photodiode. Each telescope is fully equipped with digital electronics and the Si detectors are reverse mounted in order to improve the Pulse Shape Analysis (PSA). Concerning identification techniques, the Collaboration uses the standard ΔE-E method for particles punching through the first Si layer, obtaining isotopic resolution up to $Z \sim 23$. Particles stopped in the first layer are, on the contrary, identified by means of the PSA, exploiting either the "Energy (E) vs. Rise time of the Charge signal (Q_{trise})" correlation or the "E vs. Maximum of the Current signal (I_{max})" correlation; if the range of the particles in Si is greater than a given threshold, with a minimum value of 30μm and increasing with the charge of the ion, they can be identified in charge, up to that of the projectile. Concerning isotopic resolution, this is possible up to $Z \sim 15$ if the range of the particles in Si is greater than a certain threshold, starting from a minimum value of 150μm and increasing with Z.

During the R&D phase in the period 2007-2012 many tests of prototypes of the telescope were performed under beam at LNL-INFN , LNS-INFN and GANIL, obtaining very good performances in terms of identification capabilities (mass and charge) and thresholds. In December 2014 there was the commissioning of the first complete block and in June 2015 there was the first physics experiment with 4 blocks; data analysis is in progress. In December 2015 the second physics experiment will take place and, starting from 2016, 12 blocks of FAZIA (the so-called FAZIETTO) will be moved to GANIL, to be coupled with INDRA [2]. After 2020 FAZIETTO will be probably moved to LNL in order to exploit the first beams of SPES.

2 The FAZIA recipe

The main results obtained during the R&D phase are described in many technical papers (see [1] and references therein, with ref [41] now substituted by [3]).

Among the main prescriptions used by the Collaboration we can cite that:

- n-Transmutation Doped Si detectors with good doping uniformity ($< 3\%$) are used. Detector uniformity has strong influence on the identification capability: for example, in fig. 5 of [4] $E - Q_{trise}$ correlations for detectors with different homogeneity are presented, clearly showing the improvement on the charge resolution when detectors have homogeneities below 1%.

- The thickness uniformity of Si is within $\sim 1\mu m$; this is important to improve the quality of the $\Delta E - E$ correlation.

- Si detectors are obtained from wafers cut at 7° off the $< 100 >$ axis, in order to minimize channeling; this prescription improves significantly the isotopic resolution both on the $\Delta E - E$ correlation and in PSA, as it is shown in fig. 2 and fig. 3 of [4]: when particles enter along a crystallographic axis or plane, the isotopic resolution considerably worsens.

- Si detectors are reverse mounted; this is fundamental for the PSA. In fact the differences of signal shapes for light and heavy ions is maximized for rear injection (i.e. entrance from the low electric field side), as shown in fig. 2 of [5]; as a consequence, for the same detector used both in rear and in front configuration, the charge identification threshold significantly decreases for the reverse mounting, as it is clearly shown in fig. 10 of [5].

- a thin Al layer is deposited on both sides of the Si in order to reduce sheet resistance to few Ω; this prescription allows to get better timing properties, thus improving the quality of the signal rise time measurement and -as a consequence- of the PSA.
- The Front End Electronics (FEE) and the preamplifiers, all purposely developed by the collaboration, are located inside the vacuum scattering chamber, in order to reduce the noise pickup; the connection between the vacuum chamber and the external world takes place only through a 3Gb/s optical fiber.
- The collaboration has also developed proper algorithms for digital signal shaping, whose implementation is mandatory to improve the quality of the charge and mass resolution. For example, we can cite the use of a cubic interpolation on four consecutive samples to extract the maximum of the current signal (left side of fig. 1), to be compared with the result obtained taking directly the sample with the maximum value of the current (right side of fig. 1): the isotopic resolution associated with the former technique is significantly better than in the latter case.
- Finally, the voltage drop across the detector is kept constant, by online monitoring the reverse current and consequently adjusting the applied voltage.

The quality of the obtained identification is very good: as an example, fig. 2 presents the Particle Identification (PI) spectrum obtained from the $\Delta E - E$ correlation for particles punching through the first Si layer and stopped in the second Si layer (from [6]). Only the regions with Z=11-14 and Z=22-27 are shown. Isotopic resolution is clearly seen up to $Z \sim 23$. Concerning PSA, the results obtained for the charge identification are shown in fig. 10, 11, 13, 15 of [6], while Ref. [3] shows the extremely good performances of a not completely depleted detector.

3 FAZIA applications and results

The physics which should best exploit the very good capabilities of FAZIA in terms of isotopic resolution and low thresholds concerns the study of the

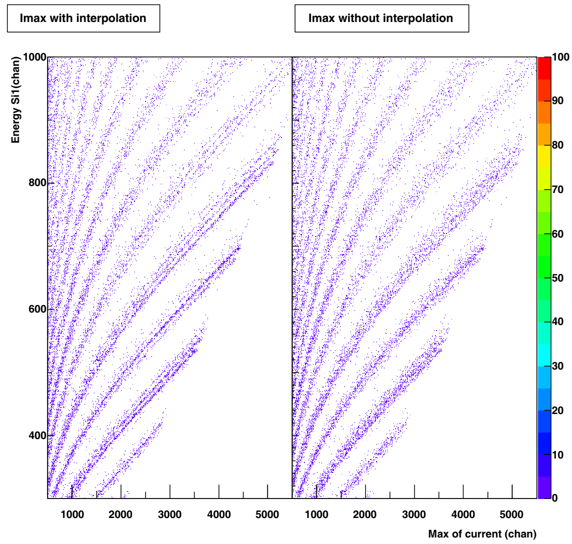

Figure 1: E vs. I_{max}. Left side: I_{max} obtained via cubic interpolation on four consecutive samples. Right side: I_{max} without interpolation.

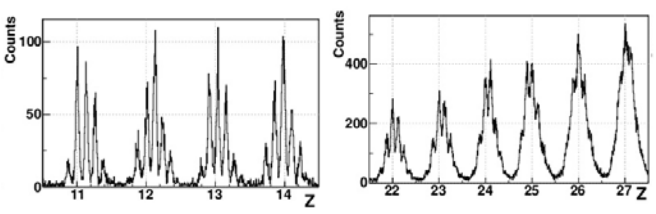

Figure 2: PI spectrum from $\Delta E - E$ correlation for particles punching through the first Si layer and stopped in the second Si layer (with Z=11-14 and Z=22-27) (from [6])

isospin of the ejectiles at medium-low beam energies; this kind of study is important because it can give information on isospin transport phenomena, which are strictly connected to the density dependence of the symmetry energy term of the nuclear equation of state, not well known far from normal conditions. In particular, we expect effects of isospin diffusion, sensitive to the symmetry energy itself, driven by the isospin gradient between target and projectile, and effects of isospin drift, sensitive to the derivative of the symmetry energy and driven by the density gradient between regions at normal density (QuasiTarget (QT) and QuasiProjectile (QP) zone) and the more diluted neck zone [7, 8]. Information on the symmetry energy behaviour can be obtained comparing experimental results on isospin related observables to the prediction of theoretical model, such as for example transport models like SMF [9] or AMD [10], including different recipes for the density dependence of the symmetry energy.

Experimental evidence of isospin transport phenomena have been already obtained also by the FAZIA Collaboration thanks to inclusive data taken in 2011 during a test experiment performed at LNS-INFN with one prototype of the FAZIA telescope [11]. In particular, we investigated the reactions $^{84}Kr+^{112,124}Sn$ at 35AMeV and the angular coverage of the detector was such that it mainly detected ejectiles coming from the QP phase space and the neck zone. We found evidence of isospin diffusion by comparing the average isospin ($< N/Z >$) of the ejectiles as a function of their charge for the two different reactions: the $< N/Z >$ is sistematically higher when the target is the n-rich ^{124}Sn, thus indicating a isospin transport from target to projectile (see fig. 5 of [11]). Moreover, we found evidence of isospin drift looking at $< N/Z >$ as a function of the lab velocity for light products: light fragments emitted closer to the centre of mass (i.e. possibly coming from the neck source, a dilute zone) show a neutron enrichment with respect to those emitted closer to the QP velocity (i.e. coming from a zone at normal density), see, for example, fig. 3, adapted from fig. 6 of [11].

On the same set of data, the N and Z staggering was investigated too [12]. This phenomenon might affect the comparison of experimental data and theoretical models if not properly taken into account by the afterburner codes.

In June 2015 a first physics experiment with 4 complete block was done at INFN-LNS (see left part of fig. 4), on the system $^{80}Kr +^{48,40} Ca$ at 35AMeV; at present data analysis is in progress. The experimental counts in polar representation are shown in fig. 4 right part. Note that this was the first time that more than one block was acquired in coincidence. The main goal of the experiment is to extend the study of the isospin transport

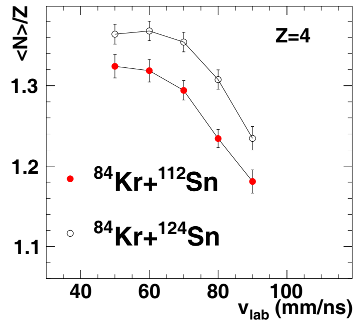

Figure 3: Average isospin as a function of the lab velocity for Z=4. Adapted from fig. 6 of [11]

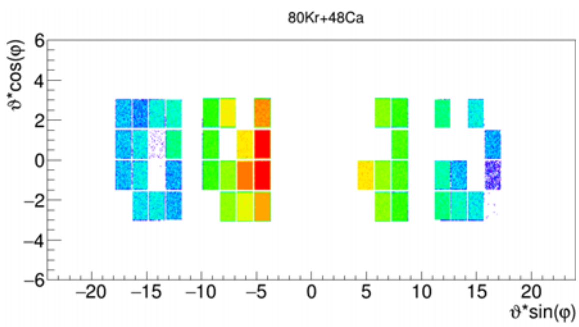

Figure 4: Left part: Four complete blocks of FAZIA inside the Ciclope scattering chamber of INFN-LNS during the first physics measurement in June 2015. Right part: Experimental raw counts in polar representation

process already undertaken in the test experiment of 2011. In particular, it will be possible to classify the events in different bins of centrality. Moreover the isotopic composition of both fission fragments coming from the QP will be measured in coincidence.

Starting from the end of 2016, 12 blocks of FAZIA will be moved to GANIL, in order to be coupled to INDRA after removing the first rings. This composite setup will have innovative characteristics; in fact in the forward direction it will provide performances comparable to a spectrometer for medium-light nuclei, but it will also allow the simultaneous measurement of more fragments in coincidence (for example, this point is extremely important for fission events), togheter with a 4π coverage.

In 2020 low energy ($\leq 10AMeV$) radioactive beams from SPES will become available and FAZIETTO will be moved back to LNL. This opportunity represents a challenge from the point of view of the identification thresholds. Among the possible solutions we can cite the use of the time of flight (strongly dependent on the available flight path) and the use of very thin Si detectors as first identification layer. Concerning this latter possibility, in 2012 the FAZIA Collaboration performed a test under beam using a standard FAZIA telescope in which the first Si layer was $21\mu m$ thick. The obtained results were very encouraging [13] from the point of view of the charge identification by means of the $\Delta E - E$ technique; some hints on the mass reconstruction might be obtained by means of energy loss calculations. PSA was of course not possible because the Si thickness was smaller than the minimum threshold for the charge resolution ($30\mu m$ for light ions).

All these results demonstrate the very good capabilities of FAZIA in terms of charge and mass identification with low thresholds; as a consequence we can expect that this detector will contribute in a substantial way to the study of isospin related phenomena.

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