EXPERIMENT PROPOSAL

# Testing signal shapes of silicon and scintillation detectors with digital sampling electronics

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The NUCL-EX & FAZIA collaborations

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## Abstract

We propose some test-measurements on solid state detectors with Tandem-ALPI beams to charatectize their response to heavy-ions. This characterization is needed in order to fully exploit the powerful digital treatment of the signals which makes it feasible to push the pulse shape discrimination capability at the maximum level needed for next generation studies. We intend to study silicon and CsI(Tl) detectors and for this reason we propose in the following two different sections.

## General Motivation

Since several years the NUCL-EX collaboration performs experiments with heavy-ions to explore both the nuclear equation of state (EOS) [1] and fast processes developing at the early phases of the collisions [2, 3]. This program will continue in next years both with stable and unstable beams at GANIL and Legnaro laboratories.
Exotic beams will allow to better address the role of the isospin degree of freedom on the nuclear dynamics and thermodynamics. However, to reach this goal, it is mandatory to push at the maximum level the mass and charge identification capability of the detectors. Indeed, the predicted signals connected to isospin dynamics always require, in order to be determined and identified, a detailed information about charge and mass of detected particles over a wide range of energy, charge and mass. Moreover, since next generation exotic beams (SPIRAL, SPIRAL-2, SPES) will have rather low energies ($\leq 20 MeV/u$), very low thresholds will be necessary to detect the reaction products. Following these guidelines, an intense *R&D* program has been started by italian, french and other foreign groups aiming at the design of a dedicated new array. This international initiative, called FAZIA (Four Pi A and Z Identification Array), in its presently running first phase, aims at characterizing and understanding the physical processes at the basis of signal development in different types of detectors. Only once the physical processes are understood, it could be possible to optimize the discrimination procedures and algorithms. The present conceptual design of the FAZIA array is based

on a modular scheme where the basic telescope is made of two layers of silicon detectors followed by a CsI(Tl) crystal to stop the energetic and/or light fragments. In the following we briefly discuss with some details the measurements planned for these two types of detector.
More information on the FAZIA collaboration can be obtained at the URL [4].

## A) Physics case for Silicon Detectors

One of the most important goals of the FAZIA collaboration is to lower the particle identification thresholds. Generally speaking, the best Z-identification can be obtained with $\Delta E - E$ silicon telescopes but it is obvious that only ions which punch through the first layer can be identified. The effort of using thinner and thinner silicon layers is strongly hampered by the increasing capacitance, by the thickness non-homogeneities and cost. Alternatively, the thresholds can be lowered by exploiting the fact that ions with different charge generate signals with different shapes (Pulse Shape Analysis, PSA) and this feature is enhanced when ions enter the low-field ohmic side of the diode [5–7]. The PSA has been already exploited by experiments both with conventional analogic techniques [8] and with digital electronics, which is the most promising one for several reasons [9, 10]. Very encouraging results have recently been obtained on this issue; however there still exist some important limitations which must be addressed and investigated before the decision of building a large array is taken. In particular, we propose to study the effect of channeling on the pulse shape. It is well known that channeling can occur in crystalline materials (as silicon is) when ions enter the detector along directions close to crystallografic axes or planes (for instance see Ref.[11] for the case of stopped ions). For the channeled ions the average cross-section for Coulomb interaction with electrons (which mainly governs the slowing down process) is smaller than for non-channeled ions; therefore channeled ions are associated with smaller specific energy losses and electron-ion densities and, if stopped, with longer and fluctuating ranges. All these factors make the signal shape different for ions which channel inside the silicon with respect to the non-channeld ones. Some preliminary possible evidence of this effect has been discussed within a recent meeting at the SPIRAL2 Workshop 'Reactions' [12]. The fraction of channeled ions depends on several parameters like the ion charge, its velocity and the orientation of the ion direction with respect to the crystallografic axes/planes. Depending on the various combinations of these parameters this fraction may be as large as 50% percent or more [11]. This effect represents a possible important limitation for the PSA technique since channeled ions with a given charge and velocity may interact in the crystal like non-channeled ions of different charge and velocity.

### Experimental Details

We propose to acquire signal shapes for different ions stopped in silicon crystals. We will use Rutherford scattering of several ions on gold target (with thickness around 0.5 $mg\dot{c}m^{-2}$) to irradiate silicon detectors. These detectors will be mounted on a precise remote-controlled goniometer suited for in-vacuum operation (already available [11]) for finely selecting the orientations ($0.01^o$ precision) of the crystals with respect to the ions. The signal shapes will be studied via a full digital treatment by using the hardware and software solutions developed within our collaboration, already available [13, 14].

To amplify channeling effects it would be preferable to use heavy beams as gold. However, we will focus on studying the shapes of somewhat lighter ions, which represent the most important ones for the physics that we want to pursue. Considering the beam palette and the available energies we ask for beams of S, Fe, and Ni at energies from 5 to 15 MeV/u with current intensity around several nA (about 1pnA). No time structure is needed for the beams. The rationale for asking two values for the energy is that of probing the response of the crystals for two different penetration depths (a few tens of $\mu m$ and about $100 - 200$ $\mu m$), well within the thickness of the used Silicon detectors (300 $\mu m$). We plan to run the tests using detectors made of nTD Silicon because of their expected better doping homogeneity. Comparison with standard Silicon detectors is also foreseen.
The goniometer with a few silicon detectors mounted on it will be placed inside the large vacuum

chamber of the Nucl-ex collaboration placed in the Third Experimental Room. A large chamber is needed because the Silicon detectors are to be placed sufficiently far from the target (at least 1 $m$) to carefully define the orientation of impinging particles, given the finite dimension of the beam spot. To better define the incident angle, the silicons will be narrow collimated (about 16 mm$^2$). For each bombarding energy-target combination a final angular scanning in the two directions (about $0.1^o$ step to cover a range of $+-10^o$) is needed in order to identify the channel direction. With the goniometer placed 1 m far from the target at polar angles around $10^o$, assuming a 1 pnA current, the elastic counting rates in the various cases vary from about 15 $s^{-1}$ (at 13-15 AMeV) to over 300 $s^{-1}$ (at 5 AMeV). This justifies the different requested beam-times necessary to accumulate enough statistics at the examined energies.
Summarizing, we ask (the values listed in the last column obviously refers to "beam -on-target" time):

| Beam | Energy (MeV/u) | Requested time (days) |
|---|---|---|
| $^{58}$Ni | 13 | 1 |
| $^{58}$Ni | 5 | 1/2 |
| $^{56}$Fe | 13 | 1 |
| $^{32}$S | 15 | 1 |
| $^{32}$S | 5 | 1/2 |

## B) Physics case for CsI(Tl) Scintillators

The luminescence of CsI(Tl), as for other inorganic crystals, strongly depends on the adsorbed ion (charge and mass) and on its energy. This non-linear dependence has been widely investigated in the years mainly because the light-energy response of these scintillators is necessary for energy-calibration purposes. As far of the crystal is concerned, the light production is critically governed by the doping density. For CsI(Tl) to be used for heavy-ion studies, most manufacturers grow crystals with Tl doping concentration around $700 - 1100\,ppm$ on the basis of the observation that for these concentrations the $\alpha/\gamma$ amplitude ratio saturates. In other words, at these concentration one should have reached the highest light production (i.e. the minimum quenching) for "heavy" species. However, the response of CsI(Tl) to ions heavier than $\alpha$ is not very well known and there are rather indications that for heavy ions the light is more efficiently produced at higher Tl concentrations. Since the FAZIA project foresees a large use of such scintillators, it is mandatory to study the light emission for heavy ions as a function of the doping concentration, keeping all the other features as constant as possible (crystal shape, surface treatment and wrapping, electronics).

### Experimental Details

We propose to study the fluorescence of several small crystals (20x20x40mm$^3$ following the present FAZIA prototype scheme) with Tl concentrations ranging from $200\,ppm$ to $3000\,ppm$ or higher. The light is collected by optically glued photodiodes which nicely match the emission band of the CsI regardless of the Tl concentration [15] at least in the considered range. As a minimal program, we will measure and compare the peak amplitude of the signal produced by stopped ions of known energy in different crystals. These can be made using standard electronics chains (preamp/shaper/peak-sensing ADC). Alternatively we can also acquire the entire signal shape by means of the ADC-DSP boards developed within the Nucl-ex collaborations [13], to better pin down the shape of the signal for various ions and Tl concentration. For this experiment we will use the same beams as for the previously illustrated test on Silicon crystals. In fact, the CsI(Tl) detectors will be mounted inside the large vacuum chamber of the Nucl-ex collaboration placed in the Third Experimental Room, using a set-up compatible with the other measurements with Silicon detectors; in this way the same beams will be used for studying both the presented topics.

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