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TEST OF FAZIA PROTOTYPES AT LNS

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Abstract

The response of a few silicon-silicon-CsI(Tl) and silicon-silicon telescopes with high quality detectors developed within the FAZIA collaboration [1] is tested in this work. The silicon detectors were manufactured from "random cut" wafers to avoid channeling effects and are characterized by a high dopant homogeneity. One silicon-silicon telescope was mounted on a rotating platform to compare its response in case of front and rear injection. Another silicon detector was mounted on a motorized support, sliding to angles very close to the beam (~0.5°), in order to measure the effects of radiation damage on energy resolution and PSA.

Beams of ^{84}Kr and ^{129}Xe at 35A MeV, impinging on targets of ^{nat}Ni, ^{93}Nb, ^{120}Sn and Au, produced fragments over a large range of charge, mass and energy. The aim was to explore the capabilities of various solutions exploiting the digital techniques of Pulse Shape Analisys (PSA) for the Z and A identification of stopped ions.

It has been found that PSA is able to fully discriminate the charge of stopped ions up to the maximum available Z (that of the beam, Z=54). The ΔE-E correlations of the first two silicon detectors can separate all the nuclides up to Z~25 and no difference in resolution between front and rear injection is observed. The experimental data also provide some preliminary information about the effects of radiation damage on energy resolution and PSA for high fluences of heavy ions.

INTRODUCTION

For the next generation of nuclear physics experiments it is important to optimize the isotopic resolution of reaction fragments with the lowest possible thresholds. Pulse Shape Analysis techniques coupled to digital signal processing are very useful to this aim.

In the last years the FAZIA collaboration and other groups [1,2,3] have investigated the behaviour of silicon detectors for pulse shape applications. It was found [4] that, for stopped ions, the discrimination capability with PSA strongly depends on the homogeneity of the detector resistivity and on a careful control of channeling-related effects.

Previous studies [5] of the FAZIA collaboration demonstrated the importance of using silicon detectors from wafers cut along the so called "random" directions, namely those which make the crystal appear like an amorphous material to impinging particles.

The silicons of the FAZIA telescopes were built adopting such type of cut. Moreover only detectors with doping inhomogeneities of about 1% or better were used. This last selection was done with a laser-based nondestructive method [6] developed by the collaboration, that allows building a map of the resistivity as a function of the position on the silicon.

The aim of the experiment was to test the capabilities of these well-controlled detectors for the identification of heavy ions over a large energy span.

EXPERIMENTAL DETAILS

The silicon detectors are all ion-implanted and of the nTD type, with bulk resistivity values around 3200 Ωcm. They are reverse mounted, i.e. particles enter from the low field side. In this way the risetime differences of the charge signals for different ions are maximized and this is of fundamental importance for PSA applications.

Eight different telescopes (Table 1) with their Front End Electronics (FEE) were mounted in the "Ciclope" scattering chamber of the Laboratori Nazionali del Sud (LNS Catania). They were irradiated by the reaction products of ^{129}Xe and ^{84}Kr beams accelerated at 35A MeV by the "Ciclotrone Superconduttore" (CS) impinging on targets of ^{nat}Ni, ^{93}Nb, ^{120}Sn and Au.

Table 1: Telescopes characteristics

Telescope	Silicon 1	Silicon 2	CsI(Tl) readout
Tele A	300 μm	500 μm	4 cm + PhD
Tele B	300 μm	500 μm	4 cm + PhD
Tele C (SCT)	300 μm	300 μm	4 cm
Tele D	300 μm	300 μm	4 cm + PhD
Tele E	500 μm	-	4 cm + PhD
Tele L	300 μm	-	4 cm + PhD
Tele FR	300 μm	300 μm	-
Tele RD	300 μm	-	-

Three telescopes (Tele A, B, D) consisted of three elements: a first (300 μm) silicon, a second (300 or 500 μm) silicon and a 4 cm thick CsI(Tl) scintillator with photodiode (PhD) readout. Two other telescopes (Tele E, L) consisted of a single silicon (500 μm or 300 μm thick), followed by a 4 cm CsI(Tl), read out again by a photodiode.

There was also a three-element telescope (C) of the Single Chip type (SCT) [7], namely a configuration in which the second 300 μm silicon acts at the same time as a detector and as a photodiode for the following CsI(Tl).

A silicon-silicon telescope (Tele FR) with both elements of 300 μm was mounted on a 180°-rotating platform, in order to compare its energy resolution, ΔE-E and PSA discrimination in the front- and the rear-injection configurations.

Finally, a single 300 μm silicon detector was devoted to studying the effects of radiation damage (Tele RD). It was mounted on a motorized support that could slide to angular positions very close to the beam direction (~0.5°).

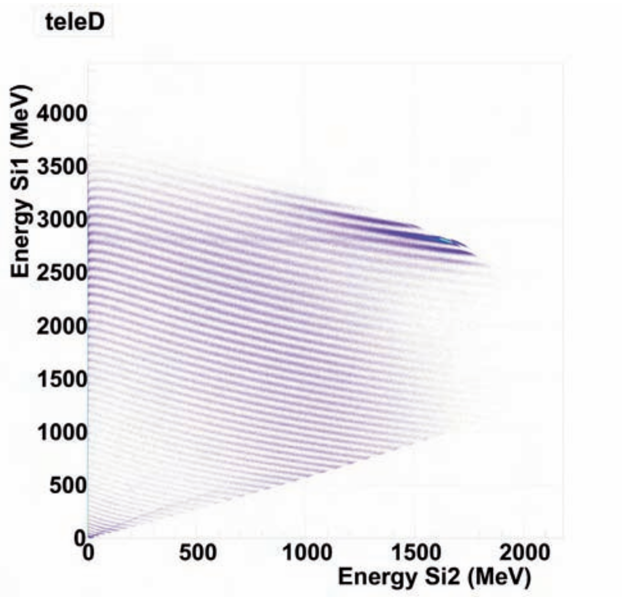

Figure 1: ΔE-E correlation for a Si(300μm) – Si (300μm), obtained with the ^{129}Xe beam.

By means of masks, three different small regions named "no damage", "transmission damage" and "implantation damage" were defined for Tele RD. The first one (to be used just as a reference) is an area of the detector never exposed to a high fluence of elastically scattered ions. The "transmission damage" and the "implantation damage" regions, on the contrary, were periodically exposed to the largest fluences of elastically scattered ions: in the first case the ions had enough energy to punch through the silicon, in the second case they were degraded by an absorber, so that they were stopped inside the detector. From time to time, Tele RD was moved to larger angles with "normal" fluences, so that its performances in terms of energy resolution and PSA in the damaged areas could be compared with those of the "no damage" area, as a function of the cumulated irradiation dose.

All the 300 μm thick detectors were manufactured by FBK (Trento), while the 500 μm thick ones were from Canberra (Belgium). All the silicon wafers were cut from an nTD silicon ingot produced by TOPSIL (Denmark). All elements of the FAZIA telescopes were coupled to dedicated Front End Electronics: current and charge preamplifiers (PaCI) [8] with different gains and custom-built digitizers. The digitizers were either 125 MS/s 12bit cards ("Florence" cards [9], developed by INFN-Sezione di Firenze) or 100 MS/s 14 bit cards developed in the framework of the FAZIA collaboration. Not all the current outputs of the PaCI were exploited. In a few cases, the current signal was derived, just before sampling it, on the FEE board via an analog differentiating circuit. For those cases, just the charge output of the PACI was needed.

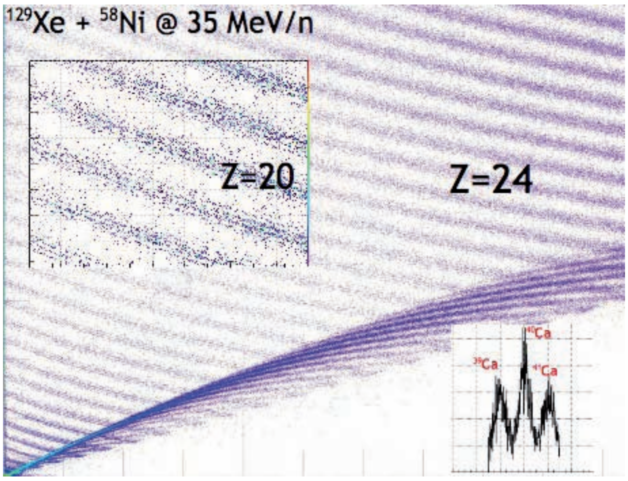

Figure 2: ΔE-E correlation for a Si(300µm)-Si (300µm), obtained with the ^{129}Xe beam. Isotopic separation is visible until Z~24. The top inset shows a detail around the Z=20 lines and the bottom one the isotopic discrimination for Ca ions.

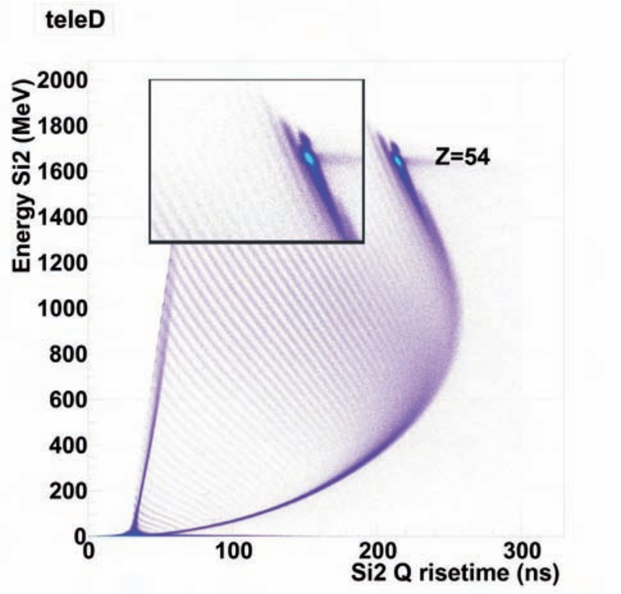

Figure 3: Identification obtained by plotting the measured energy versus the rise-time of the charge signals for ions stopped in a 300 µm silicon detector. The inset shows a detail of the element separation around the elastically scattered ^{129}Xe beam at 35A MeV.

EXPERIMENTAL RESULTS

Ions identification with ΔE-E (Si-Si) technique

As anticipated, the used Silicon material, which strongly reduces crystal-orientation-related effects and minimizes those due to the dopant inhomogeneity, allowed us to obtain unprecedented results in the particle identification with the ΔE-E technique. An example is presented in Figure 1, showing the ΔE-E correlation for a Si(300µm)-Si(300µm) telescope, with the ^{129}Xe beam on a ^{nat}Ni target. Clear isotopic separation is present up to Z=23-24, as can be seen from Figure 2, where the top inset shows the isotopic resolution around Z=20 and the bottom one the corresponding mass discrimination for Ca isotopes. Equally good performances have been obtained for all telescopes. We remind that this result is based not only on the selected Silicon material (doping uniformity at the 1% level) and on the special wafer cut (to avoid channelling), but also on the optimized Digital Signal Processing and on the very well performing FEE developed by the collaboration.

Ions identification via PSA in silicon

All detectors performed extremely well, as shown in the following correlations. In Figure 3, the identification obtained by plotting the energy versus the rise-time of the charge signals is shown for ions stopped in a 300 µm Silicon detector (the high-intensity spot corresponds to elastically scattered ^{129}Xe ions of ~35A MeV).

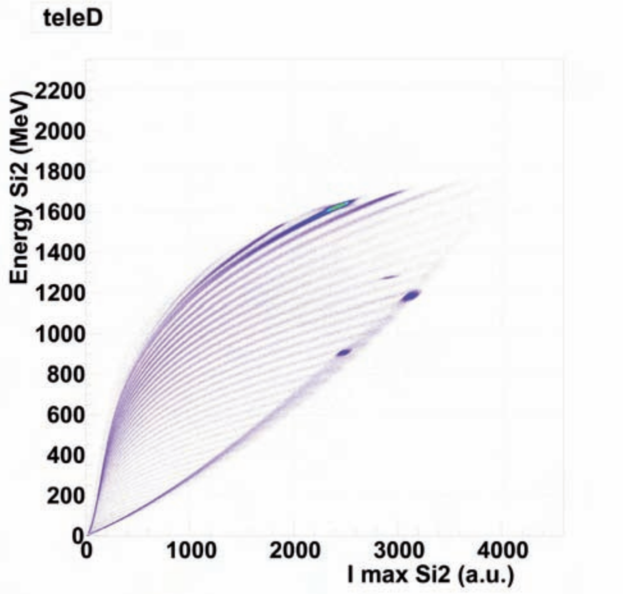

Figure 4: Identification obtained by plotting the measured energy versus the maximum of the current signals for the products of the ^{84}Kr on ^{nat}Ni reaction at 35A MeV, stopped in a 500 µm Silicon detector.

A similar result is obtained by plotting the energy versus the maximum of the current signal [10], as displayed in Figure 4, again for the fragments from the ^{84}Kr + ^{nat}Ni reaction at 35A MeV. An unprecedented identification performance is obtained, with full Z separation up to the highest detected charge (Z=54). There is no evidence, yet, of any appreciable degradation of the Z-identification, so that full charge identification may be expected for all elements with the adopted FAZIA approach. For lower Z, mass identification was already demonstrated during an LNL-experiment [4].

The Single Chip Telescope

In the SCT, the use of digital signal processing is fundamental for disentangling the scintillation and the ionization signals. This can be done by exploiting a PSA-based method developed by the collaboration [11,12]. Once separated, the silicon and CsI(Tl) components are used to build the usual ΔE-E correlation: an example is shown in Figure 5. A good separation in Z is observed, together with a clear mass discrimination for light elements. This kind of telescope reduces the electronics needed for read out and could be employed in the future FAZIA 4π-setup for covering the most backward angles.

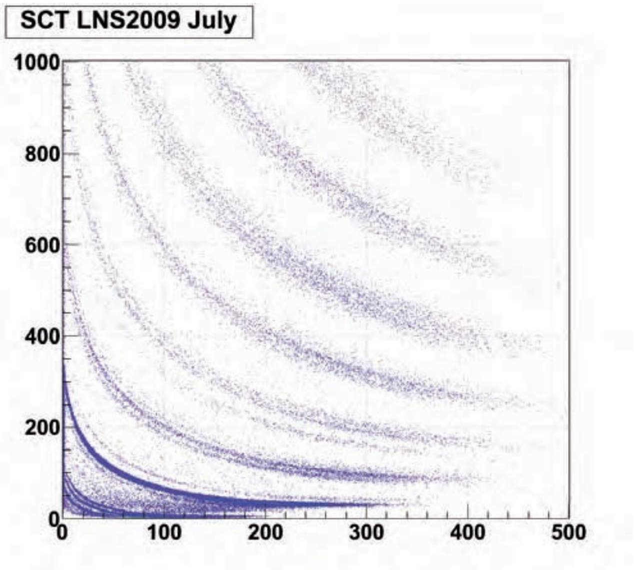

Figure 5: Digitally reconstructed (ΔE-E)-like correlation from the SCT. A good separation in Z is observable and a clear mass discrimination for the light elements.

The Radiation damage

Preliminary results on radiation damage show that for fluences of the order of 10^9 ions/cm^2 a significant increase of pulse-height defect and a decrease of rise-time is observed in case of implanted ions. Appreciably smaller damage is present, on the contrary, in case of punching-through ions, while practically no damage effects are visible in the area irradiated with the fluence of a “regular experiment”. Analysis of these data is still in progress.

CONCLUSIONS

In the present work the response of eight silicon-silicon-CsI(Tl) and silicon-silicon telescopes with purposely developed high quality silicon detectors has been tested. In particular the silicon detectors were manufactured with stringent requirements for what concerns doping homogeneity, thickness uniformity and crystal orientation, to avoid channeling effects. All these features are obtained by proper choice of the silicon material and cutting geometry, without significantly affecting the cost of the detectors. Custom-developed digital electronics and original digital signal processing techniques [5,6,11] have been extensively used.

The results of the digital PSA technique for identifying stopped ions are very satisfactory: full charge separation is obtained up to the maximum observed Z=54. For mass identification (which was presently limited by the large dynamic-range in energy of ~5 GeV) a higher energy gain would have been necessary, as it was done in [4].

The ΔE-E (Si-Si) correlations allow isotopic separation up to Z=23-24, not far from the physical limit imposed by the energy straggling, as suggested by simulations.

Preliminary results on the radiation damage show that an increase of the pulse-height defect and a decrease of the rise-time is observed for fluences of the order of 10^9 ions/cm^2, while practically no damage is found for the fluences typical of a “regular experiment”. The analysis of these aspects is still in progress.

The detectors used in this experiment, although very well performing in terms of Pulse Shape Analysis and ΔE-E discrimination, still require improvements in order to obtain also excellent timing performances. In fact the manufacturing process was not optimized for what concerns the sheet resistance of the electrodes. As a matter of fact, bench tests with a pulsed laser showed a position dependence of the time response (of the order of 1-2 ns), for both rear and front injection. Next production of silicon detectors by FBK-Trento is expected to solve this problem by a proper metallization of junction and ohmic sides. Once these detectors are available, new experimental data will be necessary to test their timing performance, with the aim of extending the present mass identification by means of the Time-of-Flight technique.

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