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Testing of a DSSSD detector for the stopped RISING project

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ABSTRACT

An active stopper for the RISING project at GSI has been developed for β-decay studies and conversion electron spectroscopy following projectile fragmentation/fission reactions. This system employs six double-sided silicon strip detectors in the final focal plane of the GSI FRagment Separator (FRS) to detect both the fragment implantations and their subsequent charged-particle (α, β, p) decays. The wide range of energy response required (150 keV up to several GeVs) was covered by the use of a logarithmic preamplifier. Measurements with a ^{207}Bi conversion electron source yielded an energy resolution of 20 keV at electron energies of ~1 MeV and a detection threshold of 150 keV. The response to the implantation of 400 AMeV ^{136}Xe ions in the active stopper is also discussed in the present paper.

1. Introduction

A new beta counting system has been developed for the RISING (Rare Isotope Spectroscopic INvestigation at GSI) project [1] to study the β-decay of exotic nuclei produced by projectile fragmentation and in-flight fission. The system employs up to six Micron Semiconductor Ltd. [2] Model W1(DS)-1000 DC coupled double-sided silicon strip detectors (DSSSD) with thickness of 1 mm to detect both fragment implantations and their subsequent β-decays. While this detector thickness provides an efficient implantation of heavy ions, the range of the β-particles emitted by the nuclear decays is usually significantly larger than 1 mm of silicon. This fact results in the probable escape of the particles from the DSSSD before they deposit their full kinetic energy. The deposited energy depends on the path of the electron in the silicon and therefore on the implantation depth. Fig. 1 (left) shows the simulated energy spectrum of the electrons emitted by the β-decay and detected by the DSSSD. A Fermi–Curie initial electron energy distribution with $Q_\beta = 5\,\text{MeV}$ was assumed. For different Q_β-values the simulated energy distribution only changes on the high-energetic side. The Monte-Carlo simulations were performed using the GEANT4 simulation toolkit [3] with the 'GEANT4 Low Energy Electromagnetic Physics' package [4]. Two cases of the implantation were considered: uniformly distributed and exact central implantation. In the later case the minimum distance to the surface is 0.5 mm, which corresponds to the minimum energy of 0.1 MeV that the electrons deposit in the crystal. This fact highlights the importance of achieving the low-energy threshold at 0.1 MeV as well as the importance of the accurate central implantation. Fig. 1 (right) shows the efficiency to detect β-particles in the 1 mm thick DSSSD as a function of the low-energy threshold for the two considered implantation scenarios. The efficiency is clearly high for a low detection threshold.

The array of six DSSSDs can be used in different configurations. The most common is to use three detectors positioned in two rows, one behind the other, at the final focal plane of the FRagment Separator (FRS) [5] which is used for the selection and identification of the radioactive nuclei. Each detector consists of 16 front strips and 16 back strips, each of width 3 mm, thus providing 256 $3 \times 3\,\text{mm}^2$ pixels on a $5\times5\,\text{cm}^2$ detector to encode x–y positions. A variable thickness aluminium degrader is used just in front of the DSSSD array to slow down the ions such that they are implanted in the active stopper at the centre of the stopped RISING germanium array [1]. Implantation and β-decay

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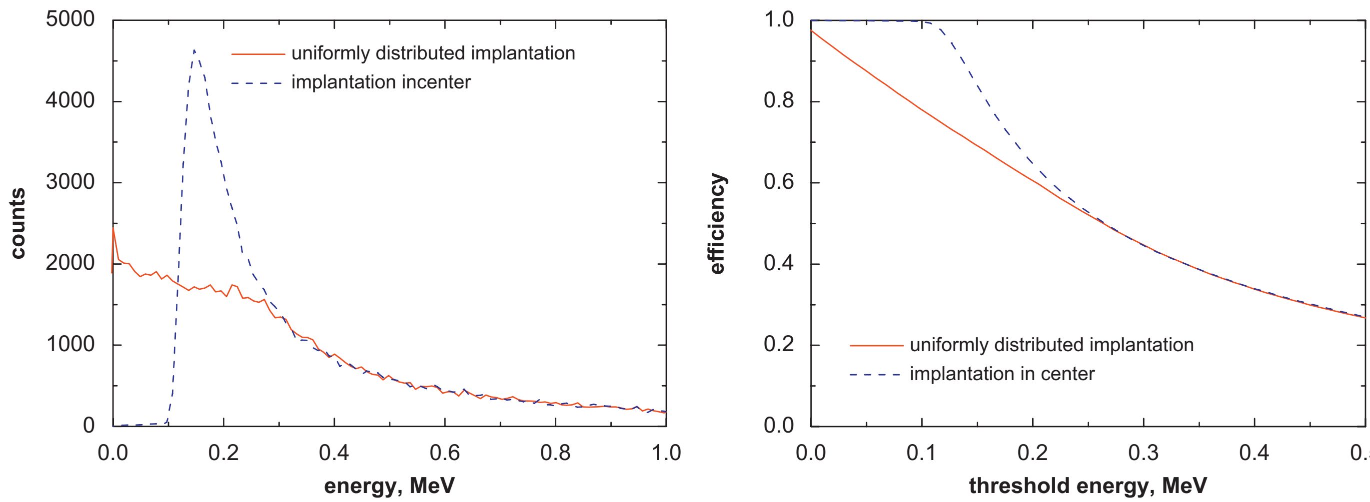

Fig. 1. Simulated energy spectrum of β-particles emitted from fragments implanted uniformly (solid line) and exactly in the centre (dashed line) of a DSSSD (left). The simulation assumes a Q_β-value of 5 MeV and a Fermi–Curie distribution for β-particles. The right figure shows the calculated β-detection efficiency as a function of the DSSSD threshold for the two considered implantation scenarios discussed in the text.

events are directly correlated within each pixel of the detector, which requires accurate knowledge of the implantation position. The half-life of the nucleus is deduced from the time correlation between the implantation time of the identified fragments in the active catcher and the subsequent β-decay. The time correlation is measured with a time stamping system providing a resolution of 25 ns.

One of the challenges in designing the electronics for the beta counting system is the range of charged particle energies that must be measured. A fast fragment implantation will deposit more than 1 GeV total energy when it is stopped in the centre of the DSSSD, while an emitted β-particle will deposit less than 1 MeV. Measurements with *Mesytec* [6] electronics are described in Section 2. The experimental results with a ^{207}Bi β-source are compared with the data taken with *Multi Channel Systems* [7] electronics in Section 3. Finally, a measurement with ^{136}Xe ions was performed in order to investigate the heavy-ion implantation response in the DSSSD. These results are presented in Section 4.

2. Measurements with *Mesytec* electronics

The *Mesytec* MPR-32 preamplifier is a 32-channel input preamplifier which was used for the 16 front and 16 back strips of a single DSSSD. It can accept positive or negative input polarities. The *Mesytec* MPR-32 multi-channel preamplifier is available in a linear or logarithmic mode. For the linear MPR-32 preamplifier an amplification range of 5 or 25 MeV can be chosen. For the 978 keV line seen from the ^{207}Bi conversion electron source the MPR-32 output signal has a pulse height of approximately 200 mV and its signal-to-noise ratio is 10:1 (5 MeV range). The logarithmic MPR-32 preamplifier provides a linear range of 2.5 or 10 MeV, which covers 70% of the total range. The last 30% covers the energy range from 10 MeV up to 3 GeV. Both MPR-32 units have a full voltage range of preamplifier output of 4 V. Fig. 2 shows the characteristics of the logarithmic MPR-32 preamplifier which was measured with a research pulser. It is worth mentioning that the pulse height cannot be directly related to the implantation energy because of the pulse height defect in solid state detectors.

The MPR-32 was combined with two *Mesytec* STM-16 shaping-/timing filter/discriminator modules when the differential input version is used. The STM-16 is a NIM-powered device which

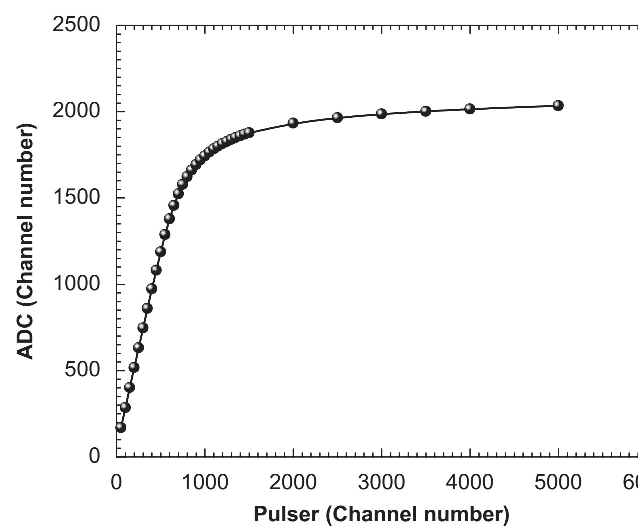

Fig. 2. The characteristics of the logarithmic MPR-32 preamplifier was measured with a 10 MeV linear range setting and STM-16 spectroscopy amplifiers.

has 16 input channels allowing parallel processing. The gain was adjusted individually in 16 steps with a maximum gain of 30. A shaping time of 1 or 2.5 μs (FWHM) was chosen. For the following measurements a shaping time of 1 μs (FWHM) was selected as this would be needed for higher count rate experiments.

The STM-16 was controlled by a NIM-module MRC-1 which works as a bus master. One *Mesytec* MRC-1 can control 32 various *Mesytec* modules (not only STM-16). It is prepared for the remote control of (i) individual discriminator thresholds (0–40% of maximum range, 4 V) and (ii) gains (in 16 steps) for pairs of channels. Communication with a control PC is done via RS-232 serial interface. Each analogue signal was fed directly to a CAEN V785AF VME-ADC which has a maximum input voltage of 8 V. The trigger signal of STM-16 is a logical OR of the 16 discriminator channels and was used to produce the ADC gate. In Fig. 3 semi-logarithmic energy spectra of a ^{207}Bi β-source are shown for different discriminator thresholds of the *Mesytec* STM-16 module. As can be seen, the detection limit for electron measurements using this system was set as low as 150 keV with the present electronics and the detectors/electronics working at room temperature. This limit was defined at 50% of the logarithmic spectral curvature caused by the discriminator threshold.

3. Energy resolution measured with electrons of a ^{207}Bi source

First, a standard ^{241}Am source was used to verify the performance of the DSSSD and to measure the resolution of the system. The alpha source was placed 5 cm from the detector's surface in a vacuum vessel. Individual strips displayed energy resolutions of 0.48–0.52% (front) and 0.51–0.64% (back) FWHM for the 5.5 MeV peak. Then a ^{207}Bi source, which emits mono-energetic conversion electrons, was used to calibrate the DSSSD. The ^{207}Bi source was covered with 70 μg/cm^2 polypropylene foil and positioned at 5 cm from the front face of the detector. The measured electron spectrum for a front strip is shown in Fig. 4 (left). Four peaks (482, 555, 976 and 1049 keV) are clearly observed, due to K and L + M + N conversion electrons of the 570 keV (E2) and 1060 keV (M4) transition in ^{207}Pb. The energy resolution of the 976 keV line is 14.4 keV (FWHM) for this strip. Fig. 4 (right) shows an overview of the energy resolution as a function of the strip number. The front junction side of the detector has clearly got better resolution compared to the rear ohmic side. A comparison between the linear and logarithmic MPR-32 preamplifier reveals a slightly poorer energy resolution in the logarithmic one, 19.7 keV compared to 15.3 keV for a selected front strip of the DSSSD-2243-5. However, the logarithmic MPR-32 has the advantage of being able to measure both the heavy-ion implantation as well as the β-particle. All the data discussed so far were obtained for detector tests performed in vacuum. DSSSD tests were also carried out in dry nitrogen. The energy resolutions measured in vacuum and dry nitrogen were the same within the experimental uncertainties. Therefore, the RISING experiments with an active stopper can be performed in dry nitrogen, allowing the use of a detector vessel with thin walls, thereby minimizing the absorption of the emitted γ-rays.

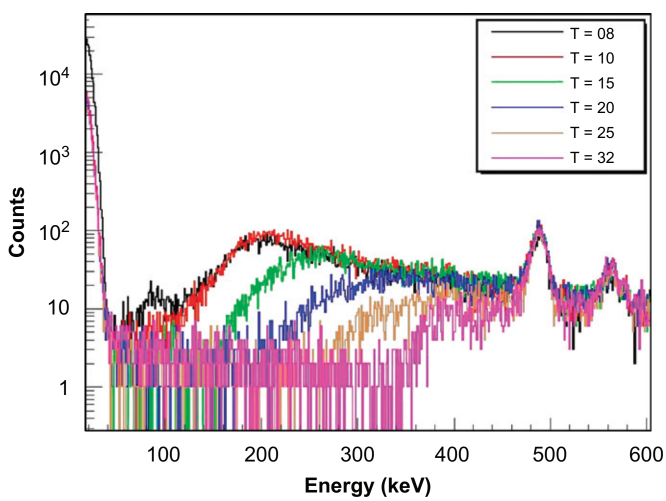

Fig. 3. Energy spectra of a ^{207}Bi β-source measured for different discriminator thresholds labelled $T = 8-32$ of the *Mesytec* STM-16 module.

At the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU), a beta counting system [8] has been developed with different electronics which yields reliable energy information for both implants and decays. The DSSSD signals are first processed by two 16-channel charge sensitive preamplifier modules CPA-16 supplied by *Multi Channel Systems* [7]. These modules contain precision pre- and shaping amplifier electronics and provide both high gain (2 V/pC) and low gain (0.1 V/pC) analogue outputs. They have a full voltage range of preamplifier output of 5 V. The high gain signals carry information from low-energy β-decay events, and they require further amplification. This is accomplished at MSU using *Pico Systems* [9] 16-channel shaper/discriminator modules in CAMAC. The shaper output of the Pico Systems module is sent directly to an ADC. For the present DSSSD tests two 16-channel charge sensitive preamplifier modules CPA-16 were also tested at GSI. For a ^{207}Bi β-source the CPA-16 output signals have a pulse height of approximately 200 mV and a signal-to-noise ratio of 7:1. At GSI *ORTEC* 572 and 16-channel *CAEN* N568BC amplifiers were used for

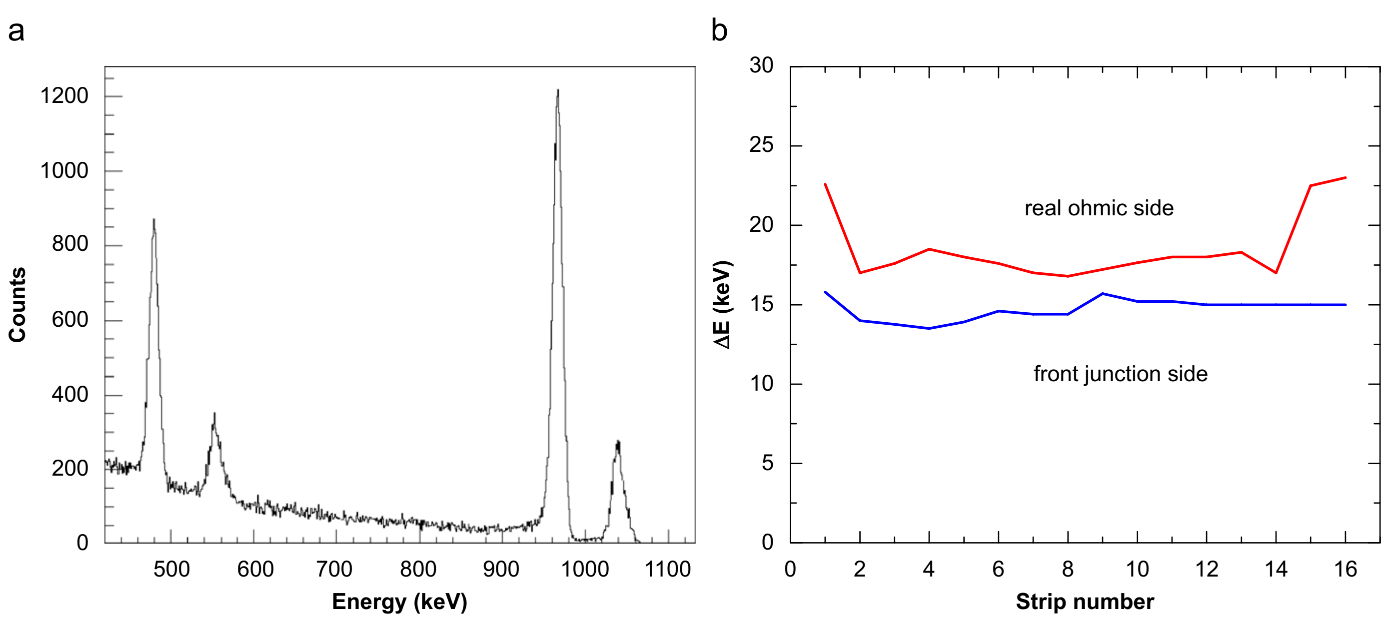

Fig. 4. The conversion electron spectrum of ^{207}Bi measured with a linear MPR-32 preamplifier for a front strip of DSSSD-2512-17. The four peaks at 482, 555, 976 and 1049 keV result from mono-energetic electrons—see text for details (left). The energy resolution for the front junction and the rear ohmic side versus the strip number is plotted on the right side.

shaping the high gain CPA-16 output signals. Three different measurements were performed: (i) the high gain output signal of the CPA-16 preamplifier was sent directly to the CAEN V785AF VME-ADC, (ii) it was additionally amplified using an *ORTEC* 572 amplifier with shaping times of 0.5, 1.0 and 2.0 μs, respectively, and (iii) using a *CAEN* N568BC module with a shaping time 2.0 μs before sending it to the same ADC. Fig. 5 shows the conversion electron spectrum of ^{207}Bi without further amplification. Only two peaks (482 and 976 keV) were clearly seen in the energy spectrum, due to K conversion electrons of the 570 and 1060 keV transitions in ^{207}Pb. The energy resolution of the 976 keV line varied between 100 and 120 keV depending on the different measurements. The detection limit for electrons was found to be approximately 300 keV.

In summary, with a ^{207}Bi source an energy resolution of 15–20 keV and an energy threshold of 150 keV were obtained for the *Mesytec* electronic, compared to a FWHM of 100 keV and a threshold of 300 keV for *Multi Channel Systems* electronics. Since conversion electron spectroscopy studies are also part of the RISING stopped beam campaign the *Mesytec* electronic was selected for the readout of the DSSSDs.

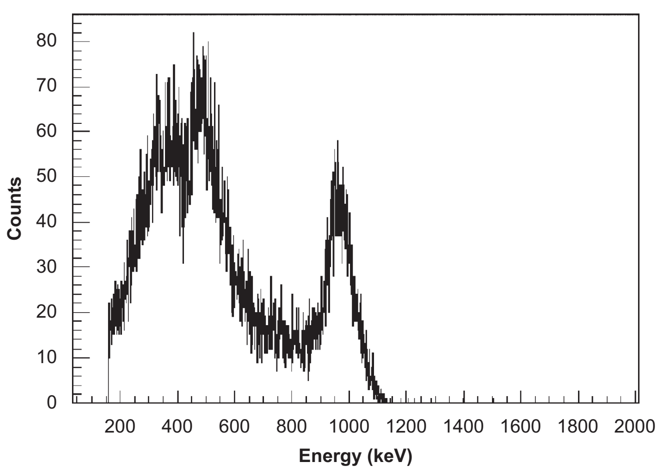

Fig. 5. The conversion electron spectrum of ^{207}Bi measured with the multi-channels electronics for the same strip of DSSSD-2243-5. The two peaks at 482 and 976 keV result from mono-energetic electrons.

4. Implantation measurement with a ^{136}Xe beam

A test measurement has been performed with the RISING set-up to investigate the heavy-ion implantation in the DSSSD. A primary beam of ^{136}Xe with an initial energy of 400 AMeV was slowed down in the aluminium degrader and implanted in the Si-detector. The active stopper vessel for the DSSSD was made out of Pertinax (phenolic–formaldehyde cellulose-paper PF CP 2061) with an entrance and exit window covered by a thin black Pocalon C foil of thickness 20 μm. The Pertinax wall was 2 mm thick, corresponding to an aluminium equivalent for γ-transmission of 0.7 mm.

Two measurements, triggered by a scintillation detector for beam particles in the FRS, were carried out with the linear and logarithmic MPR-32 preamplifiers. The linear MPR-32 preamplifier is well suited for the electron measurement (MeV range), however, for the implantation of heavy ions (GeV range) the output signals saturate. The energy spectra (see e.g. Fig. 7) show the low-energetic part of the implantation caused by light charged particles and atomic X-rays. In most cases all the strips of the DSSSD fire (see Fig. 6, left), since no condition is set on the implantation of the heavy ions. If only the overflow data of the energy spectra ($>$10 MeV) are considered (see Fig. 6, right), the multiplicity spectrum is localized at small values, which is expected for the implantation. For multiplicity one on each side of the DSSSD the position is uniquely determined, while for higher multiplicities the centroid has to be determined. When using the linear MPR-32 preamplifier each saturated strip has the same weight for this calculation, since the individual strip energies above 10 MeV are not measured. Therefore, the overflow data of the DSSSD only allow a zero order position determination of the heavy-ion implantation. Based on the multiplicity distribution (Fig. 6, right) one obtains an average shift of 2.3 mm (0.75*strip width) for each event.

The logarithmic MPR-32 preamplifier is well suited for both electron measurement (MeV range) and heavy-ion implantation (GeV range). The measured energy spectrum (10 MeV range

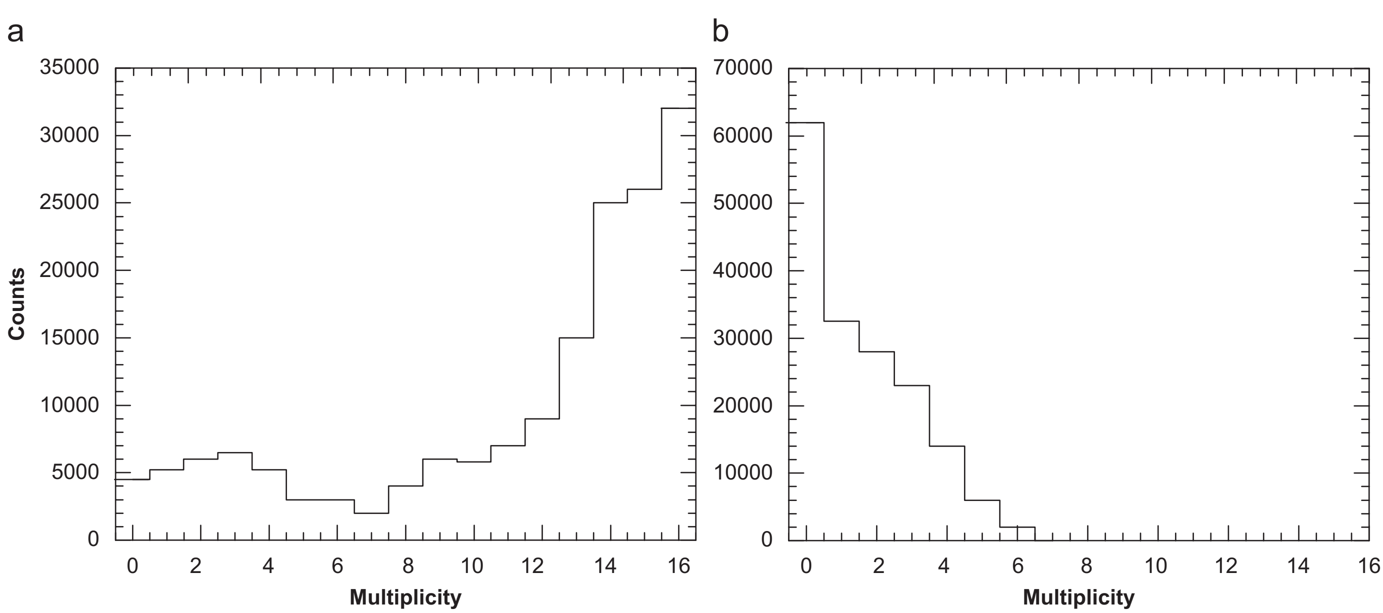

Fig. 6. Multiplicity distributions measured by x-strips for different energy thresholds. For a very low-energy threshold almost all x-strips are firing (left), while for the overflow ($>$10 MeV) data the hit probability is very low (right), as expected for the implantation of ^{136}Xe ions.

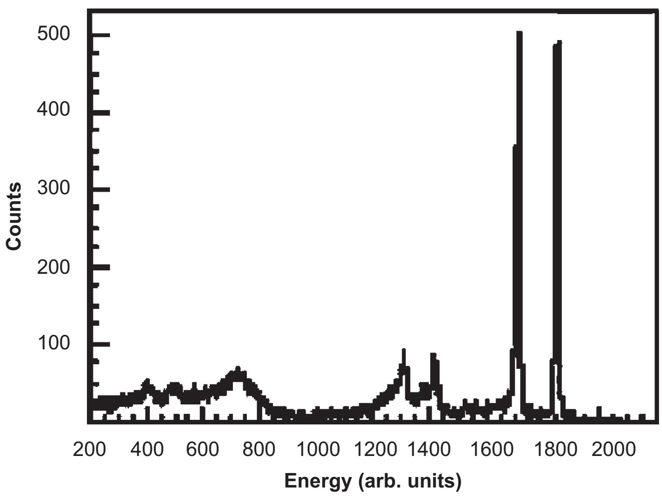

Fig. 7. Measured energy spectrum (10 MeV range for the linear part of the logarithmic MPR-32 preamplifier) obtained by a x-strip (front junction) for the implantation of ^{136}Xe ions. The double hump structure around 1600 and 1800 is related to the stopping of the heavy ions.

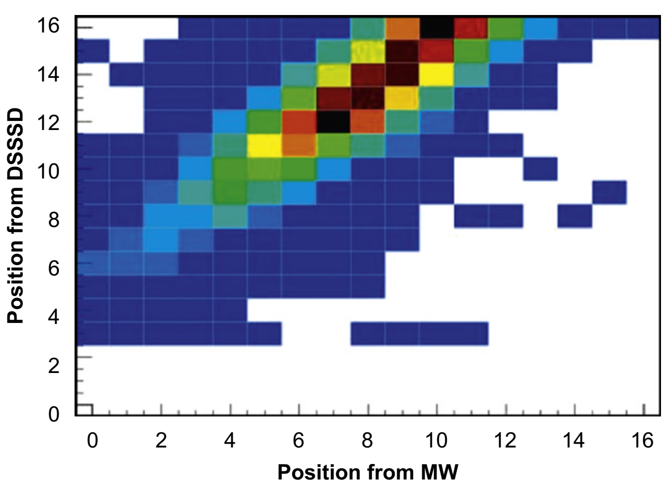

Fig. 8. Position correlation in x direction between the DSSSD and the multi-wire (MW) detector of the FRS. For the DSSSD the position of the implanted ^{136}Xe ion was determined from the mean of highest energy peaks, when a logarithmic MPR-32 preamplifier was used. The position of the MW was projected on the strip number of the DSSSD.

setting for the linear part of the logarithmic preamplifier) obtained from a x-strip (front junction) is shown in Fig. 7 for the implantation of ^{136}Xe ions. It shows a similar distribution to that obtained from the linear MPR-32, and a pronounced double hump structure in the logarithmic part of the spectrum. The double hump structure (see Fig. 7) is related to the implantation of the ^{136}Xe ions. A detailed analysis of the implantation events showed that in most cases only one (88%) or two (11%) strips on the x- and y-side of DSSSD were activated, which is quite different to the result with the linear MPR-32 (see Fig. 6, right) The highest energy peak could always be related to the implantation, while the second highest peak is due to the cross talk with the neighbouring strip. In 90% of all multiplicity two events the second highest peak was observed in the neighbouring strip. For the logarithmic MPR-32 preamplifier the mean of the highest peak of the double hump structure was used for the position determination. In summary, the measurement with the logarithmic preamplifier yields in 98% of all events an implantation within one strip, while the analysis with linear preamplifier determines, on average, a false shift of the implantation by 2.3 mm. Since no decay electrons were measured in this part of the study (^{136}Xe is a β-stable beam), a position correlation in x-direction between the DSSSD and a multi-wire (MW) detector of the FRS (in front of the active stopper) was determined. This is displayed in Fig. 8. It shows a strong correlation but also an offset since the DSSSD was not accurately centred in the frame of the FRS.

In conclusion, the logarithmic MPR-32 preamplifier is well suited for the active stopper of the RISING project. It covers a large energy range from fragment implantation down to β-decay. After the implantation of the exotic nuclei, the β-particles will be measured with high efficiency due to the low detection threshold of 150 keV. Since the DSSSDs are operated in dry nitrogen, a detector vessel with thin walls can be used to minimize the absorption of the emitted γ-rays. The excellent energy resolution of 20 keV also allows conversion electron spectroscopy to be performed as part of the stopped beam RISING campaign. Such an electron conversion measurement on ^{205}Au [10] was successfully performed with the present setup.

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