Saturation Effects in the Response of Silicon Strip Detectors Exposed to Carbon, Calcium and Ruthenium Ion Beams

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Abstract

An amplifier with a very large dynamic range for charge measurement, from fractions of minimum ionizing particles (MIP) up to 16000 MIP's, has been developed and used for reading solid state detectors. The low power consumption of the amplifier makes it suitable for balloon-borne experiments. Measurements of signal amplitude from silicon detectors have been made at the GSI accelerator using ions with different atomic numbers in the energy interval from 0.3 up to 1.4 GeV/u. The results agree with the expected signal both in magnitude and width for carbon, but largely disagree for ruthenium ions. The average signal amplitude is about 50% lower than expected for ruthenium.

1 Introduction:

The detection of nuclides of the cosmic radiation using solid state detectors to determine the specific ionization (dE/dX) in restricted intervals of atomic numbers is routinely achieved in many experiments (Stone, 1977; Simpson, 1992). The detection of all the nuclides of the Periodic Table of the elements with a single solid state detector becomes possible and practical if the amplifier coupled to the detector has a very large charge dynamic range, matching the large excursions in the ionization generated by the nuclide traversing the detector. The number of electron-hole pairs produced by heavy and ultraheavy, mildly relativistic, ions for typical detector thicknesses is so high that a significant deviation from a linear response between the amount of ionization, $\Delta I(Z)$, and signal amplitude of the amplifier may occur.

In this paper test beam results of the response of silicon detectors exposed to heavy ions are presented. These results are part of a series of measurements with heavy ions made at the GSI accelerator in Darmstadt (Germany). The measurements have determined the distribution of the signal amplitude and signal width, $\Gamma(Z)$, for carbon, calcium and ruthenium ions.

A charge amplifier with unsurpassed performance characteristics (low noise, low power consumption, large charge dynamic and good linearity) has been constructed to read silicon strip detectors (Codino et al., 1996). The results of systematic tests of the response of the VENUS amplifier with electronic pulser and a calcium ion beam of 0.5 GeV/u have been reported elesewhere (Codino et al., 1997).

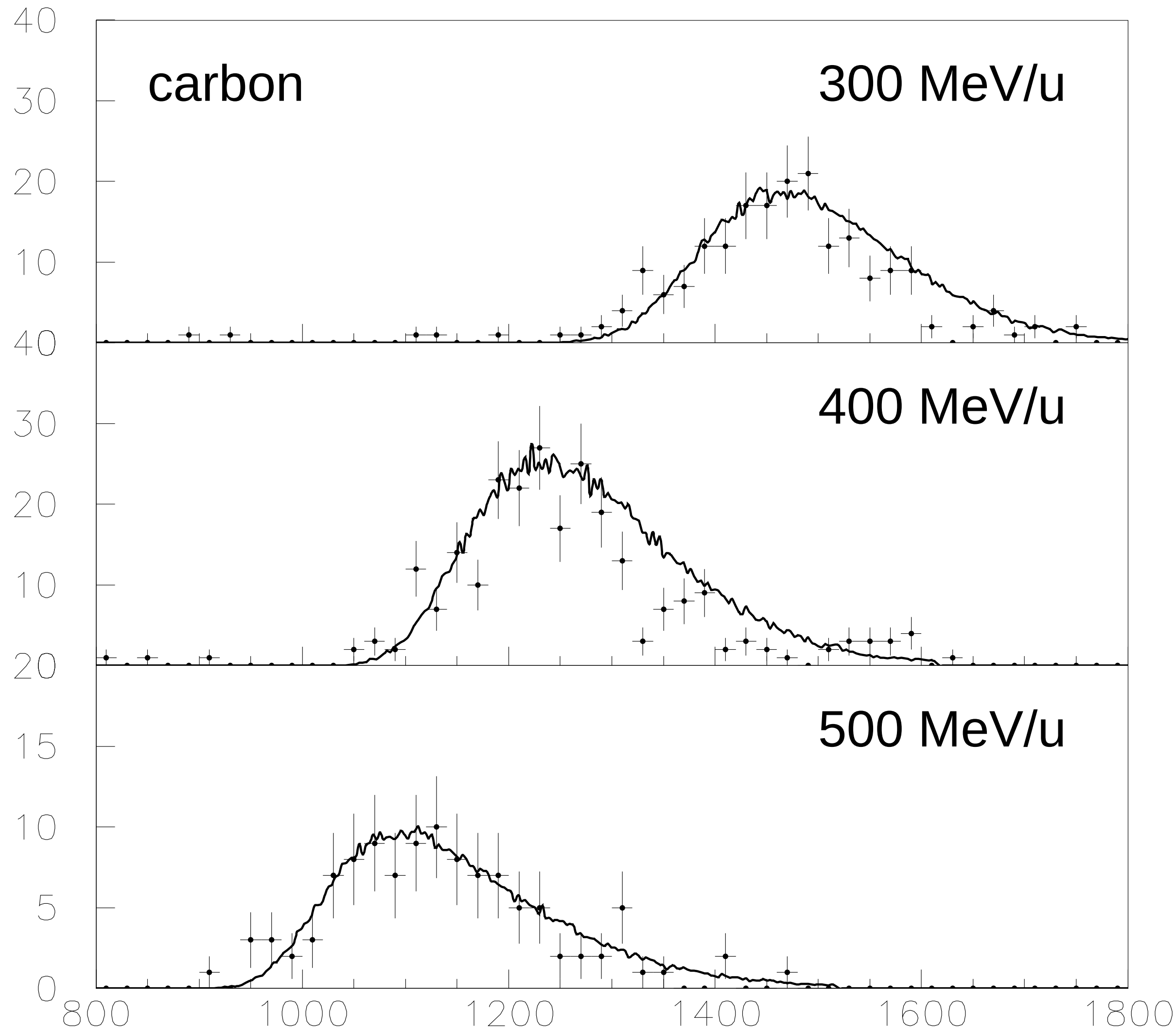
2 Description of the set-up:

The experimental set-up utilized in this beam test consists of two scintillator counters viewed by 4 photomultiplier tubes, 4 planes of silicon detectors and a caesium iodide scintillator (not used in this analysis). A copper box of external dimensions of $50 \times 50 \times 23$ cm^3 contains the silicon strip detectors connected to the VENUS amplifiers and two batteries to power the detectors. The copper box is light tight and shields the enviromental noise. Silicon wafers are fabricated by CANBERRA (Belgium) and have dimensions of 6×6 cm^2. Wafers are subdivided into 16 (aluminium) strips 3.75 mm wide. The average detector thickness is $380\,\mu$m. Heavy ions (ruthenium, Z=44 and A=96) traverse the detector in the beam location VP242 at the GSI accelerator after the fragment separator.

The calibration and noise measurements of the electronic readout have been previously reported (Codino et al., 1997). One should notice that the global noise level affecting the energy deposit resolution of heavy ions is completely negligible compared to the energy deposit fluctuations. Furthermore, the amplifier non-linearity ($< 0.5\%$) is negligible compared to the non-linearity in the observed detector response.

3 Response of the detector to carbon and calcium ions:

Tests with carbon ions have been made at kinetic energies of 300, 400 and 500 MeV/u, corresponding to



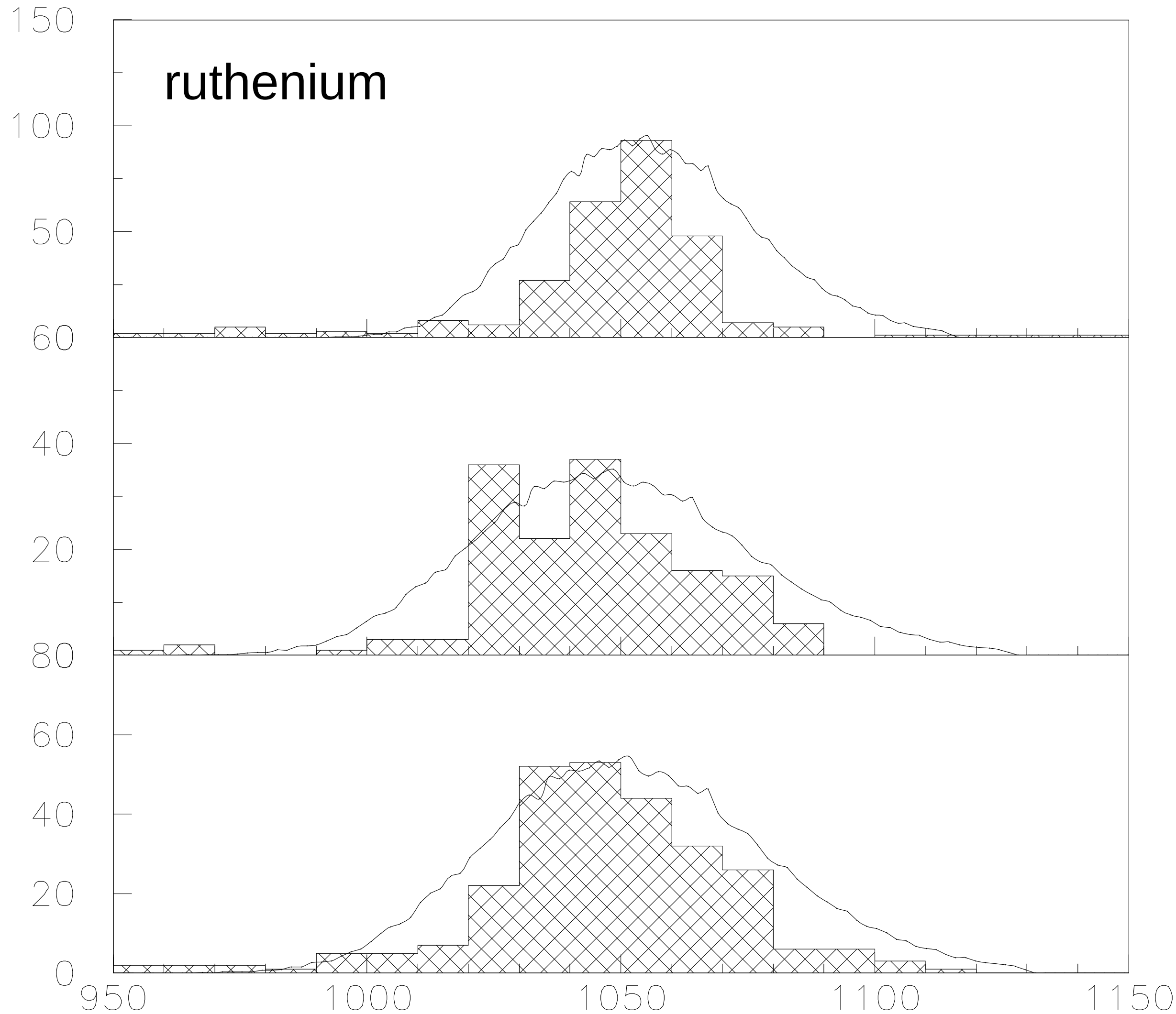
$\beta = 0.654$, 0.715 and 0.759. At these energies, dE/dX decreases as β increases. Fig. 1 shows typical amplitude distributions for carbon ions measured in the same strip.

In order to normalize ion signals all amplifier channels have been calibrated with cosmic muons prior to each data taking run. The normalization avoids the detector thickness uncertainty and the necessity of an absolute calibration of the readout system. Note that the limited number of muon events used for normalization, typically 100 events, is due to the very small area of the silicon detectors of 20 mm^2 which requires a relatively long acquisition time during the data taking.

Tests with calcium ions have been made at 0.5 GeV/u (Codino et al., 1997).

4 Response of the detector to ruthenium ions:

The experimental set-up has been also exposed to a ruthenium beam of 1.4 GeV/u corresponding to the



1.4 GeV/u.

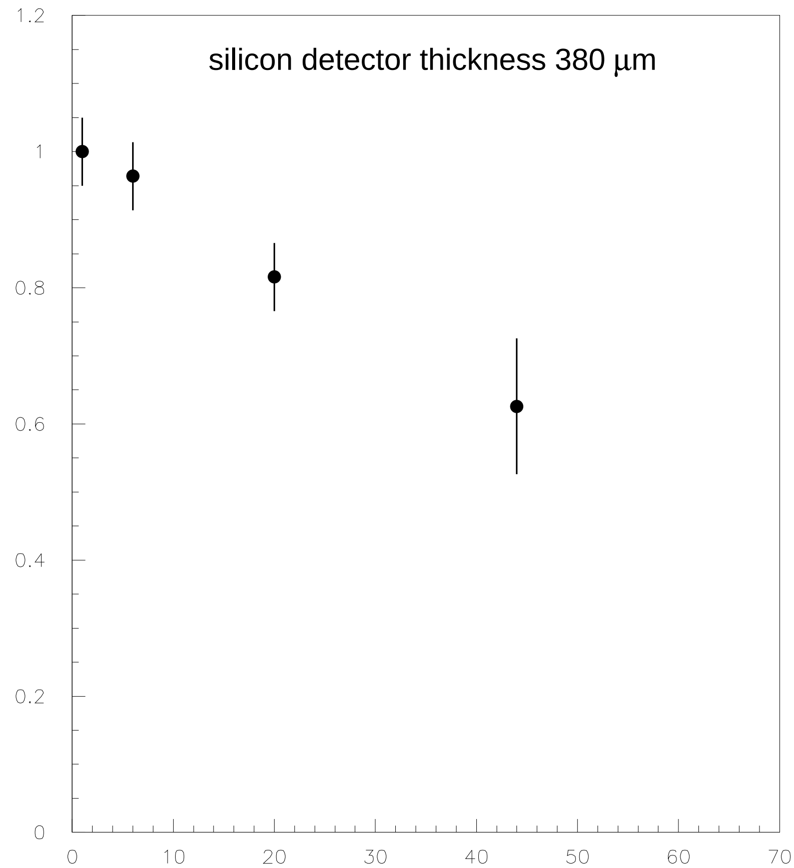
velocity $\beta = 0.918$ which is close to the minimum of ionization. The expected mean energy deposit in the silicon detectors is about 2500 MIPs which is located in the high range of the preamplifier scale corresponding to the interval of $195 - 16000$ MIPs. Fig. 2 shows amplitude distributions in different strips of the silicon detectors traversed by the ruthenium beam.

The energy deposit distributions have been compared to Vavilov distributions obtained using the GEANT program from CERN Library. The solid lines in Fig. 1 and 2 are Vavilov distributions calculated using the appropriate Landau parameters, 0.746 (300 MeV/u), 0.448 (400 MeV/u) and 0.304 (500 MeV/u) for carbon and 2.901 (1400 MeV/u) for ruthenium. For calcium ions of 500 MeV/u the Landau parameter is 3.377.

The carbon data (Fig. 1) closely follow a Vavilov distribution. On the contrary, the width of the energy deposit distributions of ruthenium (Fig. 2) is significantly smaller than that computed by the Vavilov distribution.

5 Conclusions:

The mean energy deposits and widths (FWHM) of the carbon data satisfactorily conform to the expected energy deposit distributions in all hodoscopes of the instrument. The width of the energy deposit distribution of calcium ions has a small deviation from the computed width while that for ruthenium has a quite large deviation.
The ratio of the energy deposit resolution $\Gamma(Z)\,/\,\Delta I(Z)$ determined in this measurement and that computed by the Vavilov distribution, $\Gamma_c(Z)\,/\,\Delta I_c(Z)$, is shown in Fig. 3 as a function of the atomic number.
Additional beam tests should assess whether or not the saturation effect observed in this particular series of measurements is reproducible and, possibly, becomes even more pronounced for ions with higher Z. It is desirable that additional measurements clarify:
(1) the deviation of the average value of the energy deposit, $\Delta I(Z)$, and width, $\Gamma(Z)$, from the computed values, $\Delta I_c(Z)$ and $\Gamma_c(Z)$.



$\Gamma(Z)$ and $\Delta I(Z)$. It is not unlikely that the over-bias may affect the electron-hole recombination along the track of the ionizing particle traversing the silicon detector.
A similar analysis regarding the signal amplitude for the three nuclides shows that ruthenium ions have average amplitudes about half of those computed by the appropriate Vavilov distribution. This saturation effect is not observed for carbon ions.
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References

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