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Penetrating heavy ion charge and velocity discrimination with a TimePix-based Si detector (for space radiation applications)

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ABSTRACT

Exposures were made with Medipix2 TimePix-based Si detectors at the HIMAC facility in Japan to explore the potential for discrimination between tracks with differing charges and energies, but with very similar dE/dx values. Data were taken at 15° increments for a number of different beams including 600 and 800 MeV/A Si, 180 MeV/A Ne and 100 MeV/A O. Data were also obtained for 400 MeV/A Si and 500 MeV/A Fe along with 290 and 180 MeV/A N. The TimePix chips have been calibrated to achieve the maximum resolution. Estimates for the angular resolution for these types of tracks are also possible from these data, which are essential in the development of a TimePix-based dosimetric device for use in a space radiation environment. One of the principal objectives of these data runs was to explore the resolution of TimePix-based Si detectors to discriminate between various ions with different energies and charges, but with similar dE/dx values in Si. Analysis of the images obtained shows the clear differences in the δ-ray halos for particles with similar dE/dx values but for differing charges and energies. These measurements are part of an ongoing program to explore the range of capabilities of the TimePix-based detector with respect to dosimetry uses in space.

1. Introduction

The TimePix version of the Medipix2 detector technology [1] is very attractive as a basis for development of a space radiation personal dosimeter or even as part of a general radiation area monitor for use in spacecraft or habitats on the lunar or planetary surfaces. Any such device must be capable of sampling a radiation field that is isotropic in the sense that the incident radiation can come from any direction, and that includes a wide range of energetic charged particles from singly charged through fully ionized Fe nuclei, with the potential to also have a substantial neutron component in some situations.

The general properties of a TimePix-based device with a bump-bonded silicon detector attached have been described previously in Ref. [2] and elsewhere in these proceedings in Ref. [3].

Briefly, the TimePix is a version of the technology developed by the Medipix2 Collaboration, which is based at CERN. It is a pixel-based ASIC wherein the electronics for each of the individual 55 μm square pixels is contained within the footprint of that pixel. The TimePix is distinguished from other Medipix2 versions in that after the charge-sensitive pre-amp and associated discriminator in the front end it possesses a logic unit capable of being employed in one of several different modes including as a simple counter for the number of times that the externally applied common threshold value has been exceeded (Medipix mode), as a time to digital convertor (TDC) or as in the application described here, as a Wilkinson-type analog to digital converter (ADC). Each pixel has its own 14-bit shift register for data storage and transfer.

The TimePix ASIC is agnostic in the sense that it accepts either positive or negative inputs and can be attached to any acceptable overlying detector input. For application to the problem of measuring the properties of the radiation field in a typical space radiation environment, a simple reverse-biased Si detector layer works fine. This is because, as noted, the dominant components of that environment are very energetic charged particles. The Si itself is not a very good neutron detector, but when coupled with converter materials such as Li for thermal neutrons or H for more energetic neutrons, the Si can detect the charged products. In general, the Si must be doped to provide the p–n junctions to

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allow reverse biasing. In the versions used for the measurements reported here the detector is generally bulk n-type Si, with embedded p-type Si pads arranged to correspond to the ASIC pick-up pad connection locations. The Si detector in this case was nominally 300 μm thick.

2. Measuring charged particle properties

As energetic charged particles pass through the Si detector layer, they lose energy due to their electromagnetic interactions with the medium. Occasionally, these traversing particles may become engaged in a nuclear interaction, but that occurrence is relatively rare, and is not the focus of the present investigation. Rather, due to the well known processes modeled by the Bethe–Bloch equation [4], the lineal energy loss rates are a function of both the charge-squared of the incident particle as well as that particle's velocity (or energy). Given that the fluences to be measured in the ultimate application are a mixed field, one must be prepared to distinguish between particles with differing charges and energies, but which deposit the same total amount of energy during their passage through the detector.

One common strategy is to use relatively thick detectors or layers of detectors to enable one to see the effects of the energy loss as the particles slow in passage through the detector system. However, for a useful personal dosimeter, one would like to have as compact and simple a detector system as possible, and in our case that means trying to use a single 300 μm Si layer as the entire active measurement region.

So, we are interested in determining the resolution possible for both charge and energy by examining the 'footprint' cluster images left by traversing particles.

It should be pointed out that the Bethe–Bloch equation gives the energy 'lost' or 'stopping power' of a material, which is not the same thing as the energy deposited directly in that same medium. This is crucial in our case because we see only the effects of the energy actually deposited. As the δ-ray (knock-on electron) spectrum increases in energy as the energy of the incident particle increases, there is likelihood that some of the electrons produced in the detector Si will escape from that volume and thus not deposit that energy within the volume. Likewise, any δ-rays produced in the media preceding the detector Si may also carry energy into that Si that was not from energy lost by the traversing particle in the medium itself. If that preceding medium was air, for instance as in our measurements, then the asymmetry in the energy loss rates between the Si and air leads to the case where one must calculate the detailed effect in order to know what energy beams to request in order to have multiple examples of particles with the same net lineal energy deposit rates in the Si detector layer employed.

Fig. 1 presents the predictions from the FLUKA Monte Carlo code [5] for the species and energies explored in the measurements reported here. Those include 100 MeV/A O, 180 MeV/A Ne and both 600 and 800 MeV/A Si beams. Note that the 800 MeV/A Si has approximately the same (Bethe–Bloch) lineal energy *loss* rate as either the 100 MeV/A O or 180 MeV/A Ne. Note also that the 600 MeV/A Si beam lineal energy *deposit* rate falls very close to those for 100 MeV/A O and 180 MeV/A Ne at a total value of about 0.0265 GeV, or 26,500 KeV.

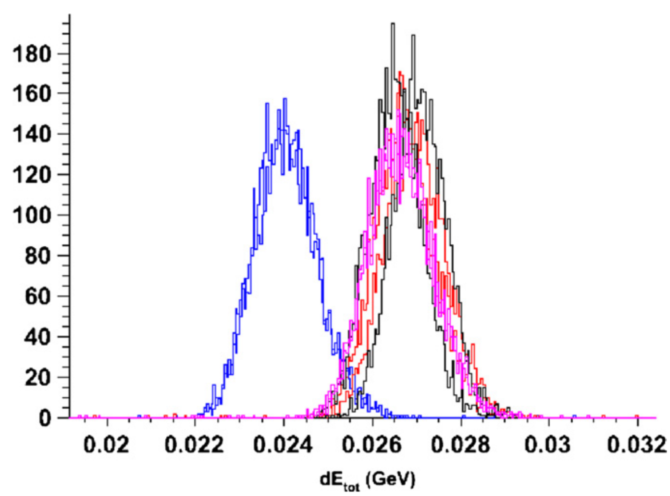

Fig. 1. Total energy deposited by normally incident ions in 300 μm of Si for 100 MeV/A O (black), 180 MeV/A Ne (red), 600 MeV/A Si (magenta), and 800 MeV/A Si (blue). Note that the 800 MeV/A Si has the same Bethe–Bloch stopping power as the O and Ne beams. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. HIMAC measurements

A sequence of measurements were made at the HIMAC facility at the National Institute for Radiological Sciences in Chiba, Japan with a TimePix-based device in order to explore its response to several different beams all of which possessed approximately the same expected value for total energy loss in the Si detector layer. As noted, the beams used were 100 MeV/A O, 180 MeV/A Ne and 600 MeV/A Si. Data were taken at normal incidence and at 15° intervals out to and including runs with the plane of the Si detector layer parallel to the beam direction. Due to a change in the interface hardware and an oversight in updating the DAQ software, the bias voltage applied to the detector layer was much lower than originally planned. The intended bias voltage for the 300 mm Si layer was supposed to be on the order of 35 V, but the actual voltage across the Si during the runs reported here was only about 3.8 V, which was insufficient to fully deplete the Si layer. However, the detector performed exceptionally well in this

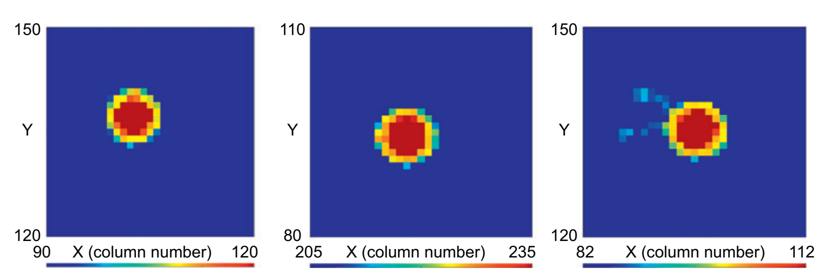

Fig. 2. From left to right the images are of the pixel clusters resulting from typical normally incident beams of 100 MeV/A O, 180 MeV/A Ne, and 600 MeV/A Si. The color scales are the same and are arbitrarily set to allow visualization of the δ-rays as seen in the Si beam cluster.