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Response of the pixel detector Timepix to heavy ions

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ABSTRACT

The response of the pixel detector Timepix to ions in the 4–110 MeV kinetic energy range and $A=3$–136 mass range has been studied at the fission-fragment separator Lohengrin of the Institute Laue Langevin in Grenoble. Timepix detects single ions measuring their position, kinetic energy, and time of arrival. Heavy ions with energy above several tens of 10 MeV produce a distortion of the electronic pixel signal response which arises when the energy collected is, under conventional detector settings, of around $\sim$1 MeV per pixel. This effect can be suppressed, and the detector energy range extended, by suitable pixel signal baseline and threshold levels, together with optimally low sensor chip bias voltage. Reasonable results are achieved within the range of ion mass and energy studied extending the linearity level of per pixel measured energy up to $\sim$2 MeV.

1. Introduction

The position-sensitive quantum counting hybrid pixel detectors of the Medipix type present a number of advantages for sensitive studies of a broad range of particles including fission fragments [1]. The new Timepix device [2] adds the capability of directly measuring the particle energy and/or arrival time in each individual pixel as it has been demonstrated for X-rays and heavy charged particles in the MeV range [3]. In this paper, we investigate the response of Timepix to heavy ions in view of expanding the linearity and range of the detector operating in time-over-threshold (ToT) mode.

2. Experimental

For this work we employed the hybrid pixel detector Timepix [2], equipped with a 300 μm silicon sensor bump bonded to the Timepix readout chip, together with the USB-based interface [4]. Measurements were carried out at the high-flux reactor of the Institute Laue Langevin in Grenoble where fissible samples of ^{239}Pu and ^{235}U were placed in a neutron flux of 5×10^{14} n/cm^2/s. The fission fragment separator Lohengrin [5] extracts and separates fission fragments according to their mass over ionic charge and kinetic energy over ionic charge, respectively. For this study ions were selected in the mass $A=3$–136 and energy 4–110 MeV ranges. The mass- and energy-selected fragments were focused as an ion beam onto the Timepix sensor placed at the Lohengrin focal plane.

3. Single ion detection and charge sharing

The spatial distribution of ions along the mass- and energy-dispersive directions of the separator focal plane can be observed (see Fig. 1). In addition to individual ion events (the detection of four individual ions is shown in the bottom image of Fig. 1), signals from single electrons and X-rays can be registered as well. Long tracks and small blobs are produced by fast electrons while single- and few-pixel clusters are generally produced by soft, respectively hard, X-rays.

The charge created by a heavy charged particle in the semiconductor sensor spreads, due to charge diffusion, over adjacent pixels the signals of which form a *cluster* (see Fig. 2). The response of each pixel, when calibrated, records the energy measured which can be displayed on the vertical axis. In this work we use the calibration method based on the measurement of fluorescence X-rays [6]. The full energy of the ion is thus obtained as the sum of the energies of all the pixels in the cluster.

4. Distortion of pixel electronic signal

In the case of heavy charged particles in the MeV range, such as α particles from radioactive sources, the pixel signal response is linear and within the proportional range. The charge spread cluster follows a Gaussian shape [6]. However, for heavy ions with large energy (above ≈ 10 MeV), which can deposit in the sensor a

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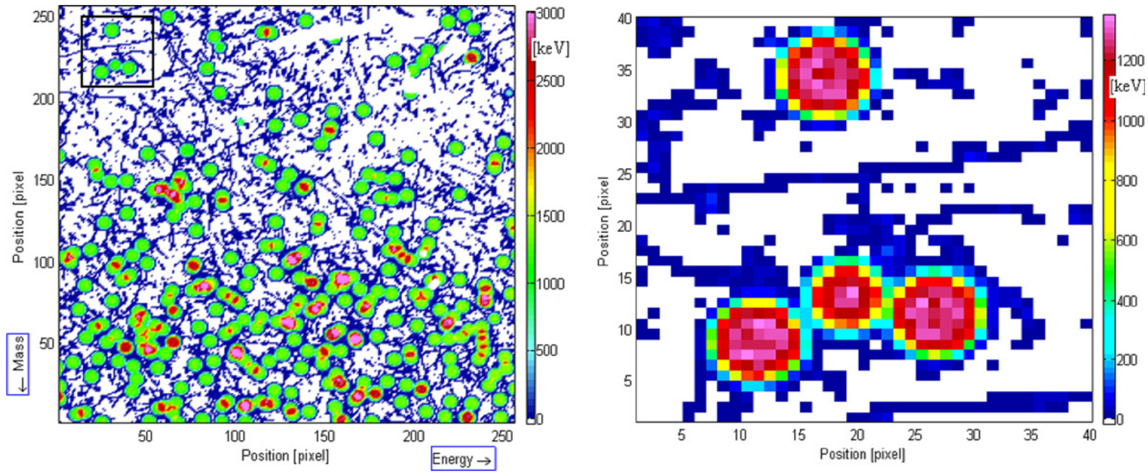

Fig. 1. Detection of $A=90$ ions (predominantly ^{90}Sr) with energy 110 MeV by Timepix in ToT mode and sensor bias 11 V. The energy collected per pixel is registered (displayed by the color bar in keV). The full display of the detector 256×256 pixels (left—displayed with per pixel energy threshold 8 keV and range 3 MeV) contains many single events (detail of square region shown at right—displayed with range 1.3 MeV) which pile up over the long (19 s) exposure time.

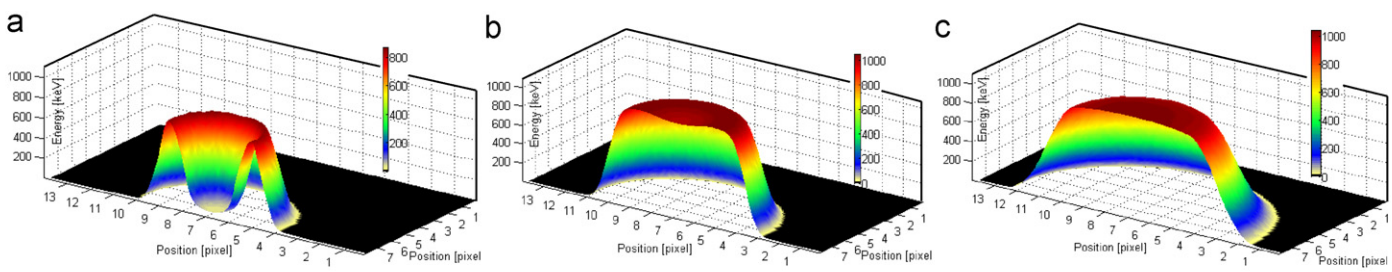

Fig. 2. Detection of 90 MeV ^{98}Zr ions as measured by Timepix in ToT mode under *standard* settings (baseline parameter $FBK=160$) for varying sensor bias voltage: (a) 95 V, (b) 21 V, and (c) 7 V. The per-pixel ToT signal registered is displayed in the vertical axis in keV in the form of a cluster only one half of which is displayed. Under these detector settings, the total registered signal would correspond to 14.0, 48.5, and 62.5 MeV, respectively. The cluster area is 50, 54 and 92 pixels, respectively.

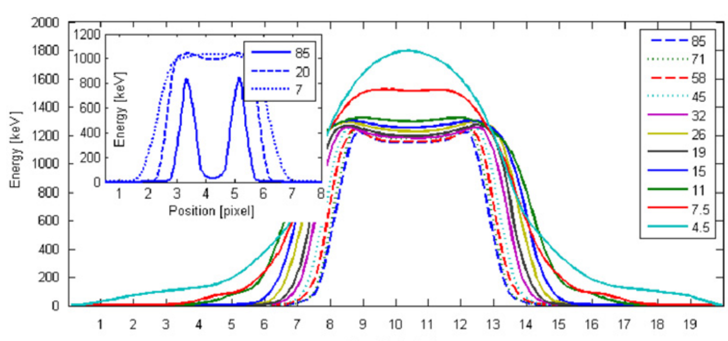

Fig. 3. Sectional view profile of cluster shape recorded by Timepix for 100 MeV ^{98}Zr ions at different sensor bias voltage (values given in the text inset). Curves are shown for fine-tuned detector baseline (FBK=128—main figure) and conventional baseline (FBK=160—inset).

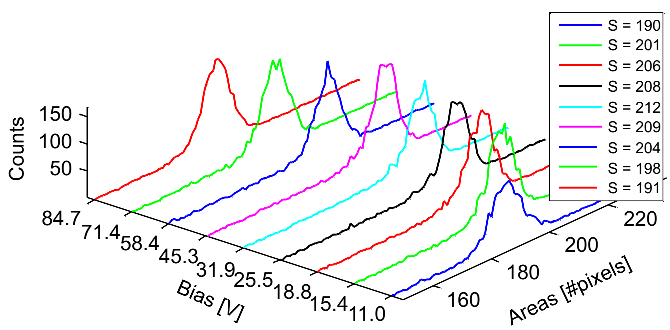

Fig. 4. Distribution of cluster areas of 100 MeV ^{98}Zr ions for different sensor bias voltage (same data from main image in Fig. 3). Curves shown for fine-tuned baseline (FBK=128).

large amount of charge along a short path ($\approx 10\ \mu$m), the charge spread cluster appears to deviate from the Gaussian shape (see Fig. 2). The magnitude of this distortion depends on the readout chip settings, namely pixel baseline and threshold, as well as on the sensor chip bias voltage (see Figs. 2 and 3). In this work we established that when the charge collected by a single pixel crosses a value of about 1 MeV (*distortion level*) the response of the pixel electronic chain (integrated in the Timepix chip) distorts and gradually saturates with increasing energy. At high ion energy and under high sensor bias voltage the charge cluster exhibit a dip in the central pixels, which get most of the charge, as shown in Figs. 2b, c and 3. When a very large amount of charge is created (e.g. for 100 MeV ions) and under high sensor bias, the signal of the central pixels appear as largely overridden becoming nearly zero (see Fig. 2a and the inset in Fig. 3).