Nuclear Instruments and Methods in Physics Research A 633 (2011) S262–S266

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Precise energy calibration of pixel detector working in time-over-threshold mode

Jan Jakubek*

Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, CZ 12800 Prague, Czech Republic

ARTICLE INFO

Available online 20 June 2010

Keywords:
Pixel detectors
X-ray radiography
Material recognition

ABSTRACT

The semiconductor pixel detector Timepix (256 × 256 pixels with pitch of 55 μm) is a successor of the Medipix2 device. Each Timepix pixel can be independently operated in one of three possible modes: (1) counting of the detected particles; (2) measurement of the particle energy; and (3) measurement of the time of interaction. The energy measurement in the second mode is performed via the determination of the "time-over-threshold" (TOT). The energy measurement with the Timepix detector in TOT mode requires knowledge of the energy calibration of each pixel of the matrix. Such calibration is very nonlinear in the low energy range and can be described by a surrogate function depending on four parameters. The determination of all these parameters can be performed by measurement and evaluation of the response of each pixel in at least four calibration points. The procedure is extremely demanding: it requires the analysis of at least 250 thousand spectra and the performance of 330 thousand least-squares fits. In this article, it is demonstrated that even better result can be achieved with only two or three calibration points halving the number of least-squares fits needed. The method is based on precise analysis of the shape of spectral peaks. The article also discusses the performance of energy calibrated device for spectrometry of heavy charged particles.

1. Introduction

Planar pixelated semiconductor detectors of the Medipix family are designed by Medipix consortium [1] primarily for X-ray radiography. Their ability to count ionizing particles from preselected energy range is targeted mainly at energy sensitive X-ray radiography allowing material recognition [2].

The new device Timepix [3] operating in time-over-threshold mode has the ability to measure the charge collected by each pixel, which allows substantial improvement of the quality of energy sensitive imaging [4] and opens access to many other fields [5].

2. The Timepix detector and its energy calibration

The hybrid silicon pixel device Timepix [3] consists of a pixelated semiconductor detector chip (256 × 256 square pixels with pitch of 55 μm) bump-bonded to a readout chip. Each element of the matrix (pixel) is connected to its respective preamplifier, discriminator and digital counter integrated on the readout chip. Each pixel can independently work in one of three modes: Medipix mode (the counter counts incoming particles), Timepix mode (the counter works as a timer and measures the time when the particle is detected) and time over threshold (TOT) mode (the counter is used as a Wilkinson type ADC allowing direct energy measurement in each pixel).

The Timepix detector running in TOT mode measures the charge collected in each pixel. As the device contains 65536 independent channels and as their response can be never identical it is necessary to perform an energy calibration for each of them.

The calibration procedure based on measurement of X-ray fluorescence (XRF) was already published in Ref. [6] and further improved in Ref. [4]. The device is irradiated by monoenergetic radiation recording a spectrum for each pixel using single pixel clusters[1] only. The spectral peaks are then fitted with Gaussians and four parameters of a surrogate function f describing the energy response of each pixel are computed by another fit (see Fig. 1). This procedure requires the measurement of at least 4 spectral lines and performance of at least five least-squares fits for each pixel.

---

* Tel.: +420 22435 9181; fax: +420 22435 9392.
E-mail address: jan.jakubek@utef.cvut.cz

[1] A single particle can create signal in several adjacent pixels due to various reasons: hitting the border between pixels (e.g. X-rays), having longer track (e.g. electrons), being blurred by charge diffusion in the sensor (all). Thus, the charge created by the particle is shared by multiple pixels forming a cluster.

0168-9002/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2010.06.183

The problem of such calibration procedure lies in the nonlinear response of pixels in the energy range close to the threshold (see Fig. 1). Fitting of spectral peaks with Gaussians in this region gives systematically shifted results as shown in Fig. 2.

3. Improved calibration procedure

The solution to the calibration problem of bad peak shape model is simple. The combination of a Gaussian $G_{\mu,\sigma,A}(e)$ with a surrogate function $f_{a,b,c,t}(e)$ has to be used for fitting instead of a plain Gaussian. Here, we use this notation: indices mark parameters, e is energy, the pixel calibration function $f_{a,b,c,t}(e)$ transforms energy to TOT signal s, Gaussian parameters are μ (mean energy), σ (energy noise) and A (spectral peak intensity or area). The new model M of the spectral peak is, therefore, a simple combination of G and inverse of f:

$$M_{a,b,c,t,\mu,\sigma,A}(s) = G_{\mu,\sigma,A}(f^{-1}_{a,b,c,t}(s)) \quad (1)$$

Although such model depends on 7 parameters, not all of them have to be searched by the fitting procedure. The parameter μ denotes the energy of the calibration peak and it is obviously known.

In principle it is possible to estimate all parameters of the calibration curve with single fit (see Fig. 3). Unfortunately, such a fit is very unstable due to the high number of free parameters requiring very good statistics. Moreover, the a and b parameters are rather correlated in the low energy range; therefore they are estimated with high uncertainty.

A much better approach combines the usage of both models: Gaussian for energies in the linear range and M in the nonlinear energy range close to the threshold. One or (better) two spectral lines (e_1 and e_2) are measured in the linear energy range and their peaks are fitted with Gaussians. From the fit we determine the mean TOT values s_1 and s_2 registered by pixel. Knowledge of these two points allows the determination of a and b for each c and t from the following equations:

$$f_{a,b,c,t}(e_1) = s_1 \quad \text{and} \quad f_{a,b,c,t}(e_2) = s_2 \quad (2)$$

Thus, the calibration function f can be now rewritten as $f_{[e_1,s_1],[e_2,s_2],c,t}(e)$ having just two free parameters c and t because both pairs $[e_1,s_1]$ and $[e_2,s_2]$ are known from Gaussian fits to high energy peaks. Now we can perform fit to one peak in the nonlinear region with the model $M_{[e_1,s_1],[e_2,s_2],c,t,\sigma,A}(e)$ searching for 4 parameters only (c, t, σ and A). The a and b parameters are then computed from Eq. (2).

The obvious effect of the described calibration technique is reliable shape restoration of spectral peaks in the nonlinear region (see Fig. 4).

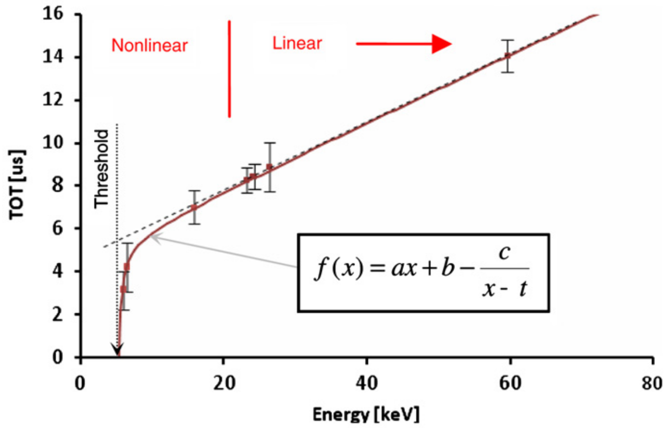

Fig. 1. Dependence on particle energy of the time-over-threshold signal measured by a single Timepix pixel. The dependence is modeled by a surrogate function f depending on four parameters.

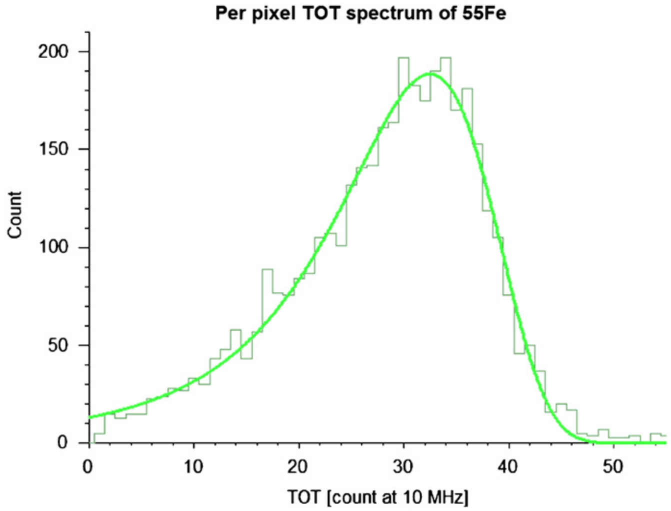

Fig. 3. The TOT spectrum of ^{55}Fe (the same spectrum as shown in Fig. 2) fitted with the model M. The model describes the data very well.

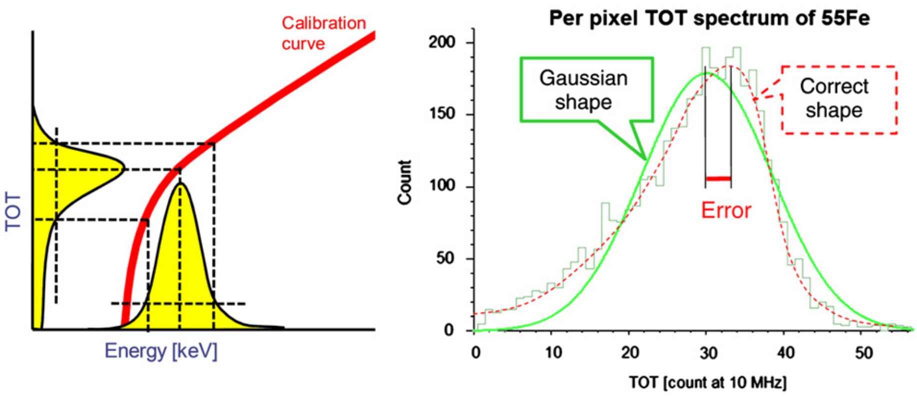

Fig. 2. The nonlinear calibration curve of a Timepix pixel device in TOT mode deforms shapes of peaks (left). Fitting of the ^{55}Fe spectrum (5.9 keV) with a Gaussian gives systematic error (right).