Timepix detector energy calibration using synchrotron light

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Resumo: O Timepix é um detector híbrido pixelizado. Ele é capaz de medir a energia de uma particula incidente sobre seu sensor e fornecer sua posição dentro de sua matriz de 256x256 pixels de 55 μm^2 simultaneamente. Possui aplicações diretas em física de altas energias e em física médica. A energia coletada pelo sensor é traduzida em um pulso elétrico analógico e então convertido em um sinal digital. Para se relacionar de uma forma precisa o sinal digital com os valores reais de energia, a calibração em energia é necessária. Nesse trabalho será apresentado um método de calibração e de análise para a calibração do detector.

Palavras-chave: LNLS, Timepix, Calibração em energia, luz sincrotron, raio-x.

Abstract: The Timepix is a hybrid pixelated detector. It is able to measure the energy of an incident particle on its sensor and provide the particle position within its matrix of 256x256 pixels 55 μm^2 simultaneously. It has direct applications in high energy physics and medical physics. The energy collected by the sensor is translated into an analog electrical pulse and then converted into a digital signal for the readout. To relate in a precise way the digital signal with the actual values of energy, an energy calibration is required. In this work a method of calibration and analysis for the calibration of the detector will be presented.

Keywords: LNLS, Timepix, Energy calibration, synchrotron light, X-ray.

1. INTRODUCTION

The Timepix detector is composed by a solid-state sensor brought in contact via bump-bonds with the front-end readout chip. The detector ASIC (Application Specific Integrated Circuit) is made of 256x256 pixels of 55x55 μm with individual analog and digital circuit to process the charge collected from the sensitive material when a particle interacts with the sensor.

The detector has three modes of operation: It can measure the time, with respect to a frame, that the interaction occurred in the sensor (Timepix mode); it is able to count how many signals above the threshold there was inside a time window (Medipix mode); and time over threshold (TOT) mode, providing the information proportional to the energy.

2. ENERGY MEASUREMENT

The energy is measured with a Wilkinson type ADC (Analog-to-Digital Converter). An integrator capacitor is allowed to charge until its voltage is equal to the amplitude of the input pulse from the sensor. When this condition is reached the capacitor is discharged linearly, producing a ramp voltage and if above a predefined threshold initiating a gate pulse, which remains turned on until the signal gets under the threshold. The duration of the gate pulse is directly proportional to the amplitude of the input pulse from the sensor. The gate pulse operates a linear gate that receives pulses from a high-frequency oscillator clock (from 9.6 to 96 MHz, what will affect the energy resolution). While the gate is open, a discrete number of clock pulses passes through the linear gate and are counted by the address register. Thus, the energy information (digital TOT) can be extracted once the number of clock cycles is proportional to the length of the gate pulse, which is proportional to the amplitude of the input pulse. A graphic visualization of the TOT value is shown on *figure 1*.

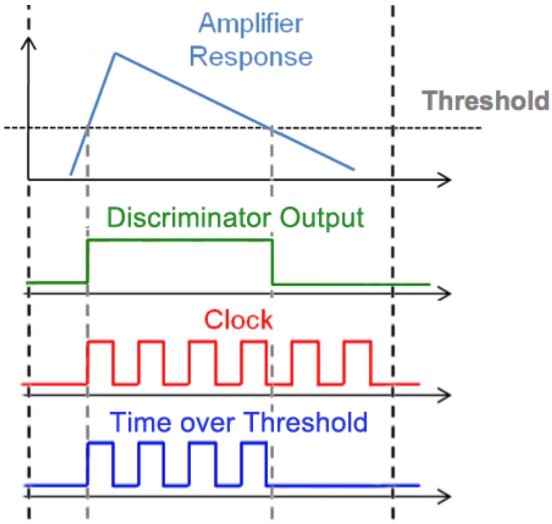

Figure 1: TOT measurement from amplified input pulse

To have the relationship between the TOT and the energy of the incident particle it is necessary to calibrate the detector with known energy depositions, at the sensor, of particles of known energies.

2. EXPERIMENTAL SETUP

In this work it was used a synchrotron light source. X-rays with well-established and stable energies, ranging from 5 to 13 keV, were illuminating the detector. Since for energies below 50 KeV the photoelectric effect is the dominant mechanism of interaction between radiation and matter, X-rays (photons) fulfill the condition of total energy deposition on the sensor (differently from a charged particle that can deposit part of its energy and pass through the detector). In this way it is possible to know precisely the energy deposited on the detector's sensor.

3. DATA ANALYSIS

A dataset was recorded for each X-ray energy. The TOT spectra are shown in *figure 2*. It is possible to note that the 11 keV spectrum is wrongly located in the spectrum with all the energies. This is due to miscalibrated beam that was not noticed during data taking.

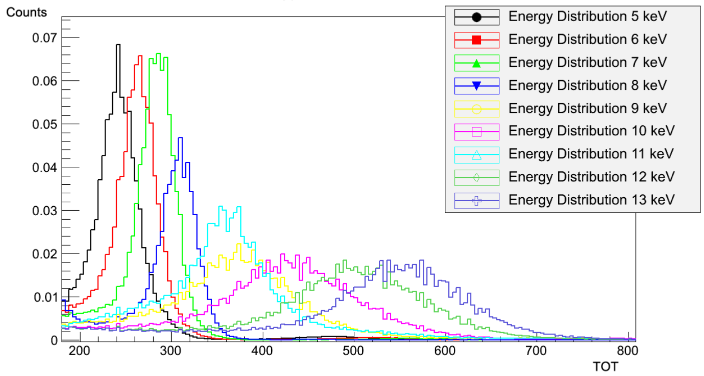

Figure 2: TOT normalized spectra for all X-ray energies

Figure 3 shows the energy spectrum analyzed for the whole pixel matrix in red, for clusters (combinations of more than one pixel that were hit by one photon) in blue, for single pixel hit (particle interactions without charge sharing between pixels) in green, and for one specific chosen pixel in brown. The spectrum is shown with logarithmic scale for visualization purpose.

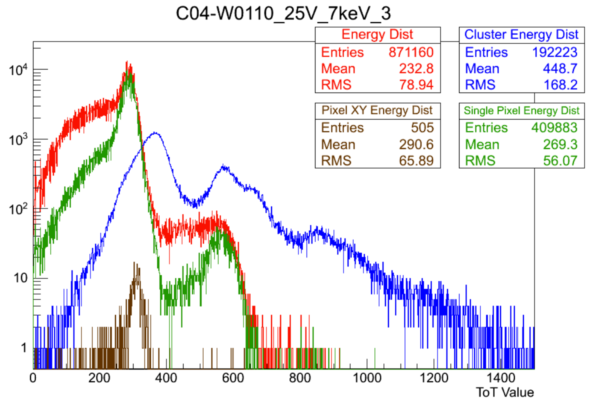

Figure 3: 7 KeV spectrum distribution of differents contibutions

It is possible to see that with the (single) cluster reconstruction secondary peaks are more evident at higher energies. The pixel response is not perfectly linear for low energy photons and therefore a 10 keV photon will give a different signal than two photons of 5 keV piled-up together. It is important to know if these secondary peaks are from pile-up or if they are the beam harmonics. It is also possible to see that with the cluster reconstruction, the first peak of the cluster energy distribution is shifted to higher TOT values with respect to the other distributions. This is because the clustering reconstruction recovers fractions of the charge that drift to neighboring pixel, if this charge is enough to generate a signal above the discriminating threshold. Single pixel hits with quiet neighboring pixels have a charge collection more approximate to the full energy deposited on the sensor. In this way it is expected that the clusterized energy reconstruction is almost the same as the single pixel hit, within random fluctuations.

A first check of the pile-up to second harmonics hypothesis is to plot the second peak versus two times the energy of the first peak. If the plot behaves as the same way as the first peak it is valid to assume it is due the photons pile-up on the detector. If it is different, it is reasonable to assume the second peak as the beam harmonics.

The spectrum for the single pixel cluster was analyzed for the calibration. The value of the first peak of the spectrum was extracted fitting a Gaussian curve on top of it and getting its mean. It was not possible to get the second peak (harmonic) for the single pixel cluster because as the energy increased, the peak started to vanish. The result for the calibration is shown in *figure 4*.

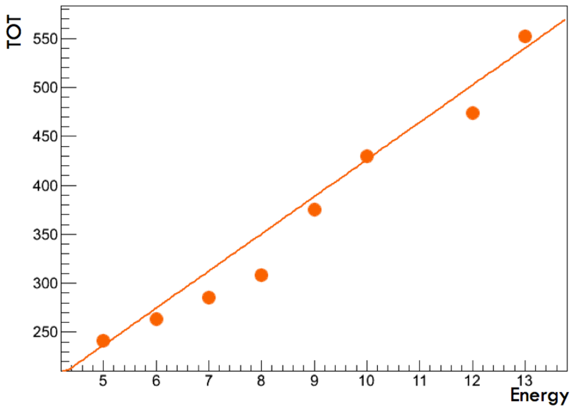

Figure 4: ToT vs Energy for single pixel clusters

In order to try to get a better calibration, we decided to analyze the spectrum for one specific pixel, choosen looking the beam profile, and picking the pixel with the higher number of hits.

The result is shown on *figure 5.* As it is possible to see, the single pixel clusters behave just as the pixel chosen. It validates the previous hypothesis but does not completely proves it.

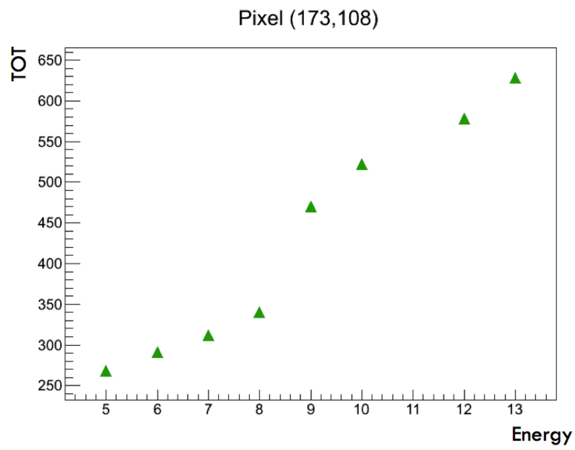

Figure 5: Relationship between energy and TOT for fixed pixel

The result of the cluster TOT versus the energy is shown in *figure 6*.

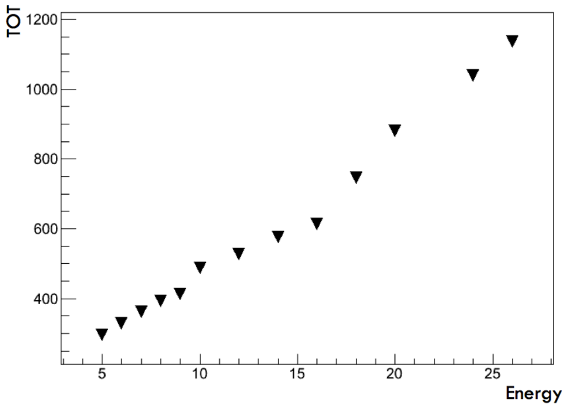

Figure 6: Cluster TOT versus X-ray beam energy

The multiple pixel TOT sum distributions were analysed and the results are shown on *figure*

4. DISCUSSION

Trying to understand better the calibration curve that should be nearly linear by design of the front-end chip, we noted a source problem with the filters in our X-ray. The beam energy was diverging from the expected values. The callibration is not successful on absolute values but a methodology was created as here presented.

5. CONCLUSIONS

A calibration method using a synchrotron X-ray light source was performed. Systematic error on the energy provided did not make the result agree with the expectations.

A method to distinguish pile-up interactions from beam harmonics is proposed. Promising results are expected on future data taking opportunities.

6. ACKNOWLEDGMENTS

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