MEASUREMENT OF TIMEPIX DETECTOR PERFORMANCE

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ABSTRACT

Recent advances in semiconductor technology allow construction of highly efficient and low noise pixel detectors of ionizing radiation. Steadily improving quality of front end electronics enables fast digital signal processing in each pixel which offers recording of more complete information about each detected radiation. All these features improve an extend applicability of pixel technology in different fields. The TimePix pixel device was derived directly from the Medipix2 development. It shares many of the physical dimensions of the Medipix2 chip but has a different functionality at the level of the single pixel.

INTRODUCTION

CMOS (Complementary Metal-Oxide-Semiconductor) is a technology for constructing Integrated Circuits also known as IC, microchip, silicon chip, or chip. This technology is also used for analog circuits such as image sensors and data converters. The digital design with CMOS uses complementary and symmetrical pairs of p-type and n-type metal oxide semiconductor field effect transistors. The most important characteristics of CMOS devices are high noise immunity and low static power consumption.

The new generation of CMOS technology open new possibilities in particle detection and imaging. Nowadays, the Integrated Circuits have been used in a lot of particle physics experiments, particularly for tracking detectors. Pixel detectors have become important components in tracking systems because of its excellent spatial resolution and extremely high signal to noise ratios. Pixel detectors are very useful to scientists for finding traces of rare particle tracks in very complicated events.

The Medipix2 (Figure 1) detector is a photon-counting X-ray pixel detector that not only provides a high spatial resolution but also information about the energy of detected photons. It is an hybrid silicon pixel detector device Medipix2 consists of a sensor chip with 256 x 256 square pixels of 55 µm each and a read-out chip containing an amplifier, two discriminators and a 13-bit counter for each pixel. In addition, external power supplies were needed.

Figure 1. Medipix detector with the USB Interface

The Timepix chip (Figure 2), developed at CERN, is a device based on Medipix2 chip. It is an hybrid pixel device consisting of 300 μm thick silicon detector chip bump-bonded to a readout chip. The readout chip provides 256 × 256 square pixel of 55 μm size, the same as MediPix2.

Figure 2. Timepix Detector

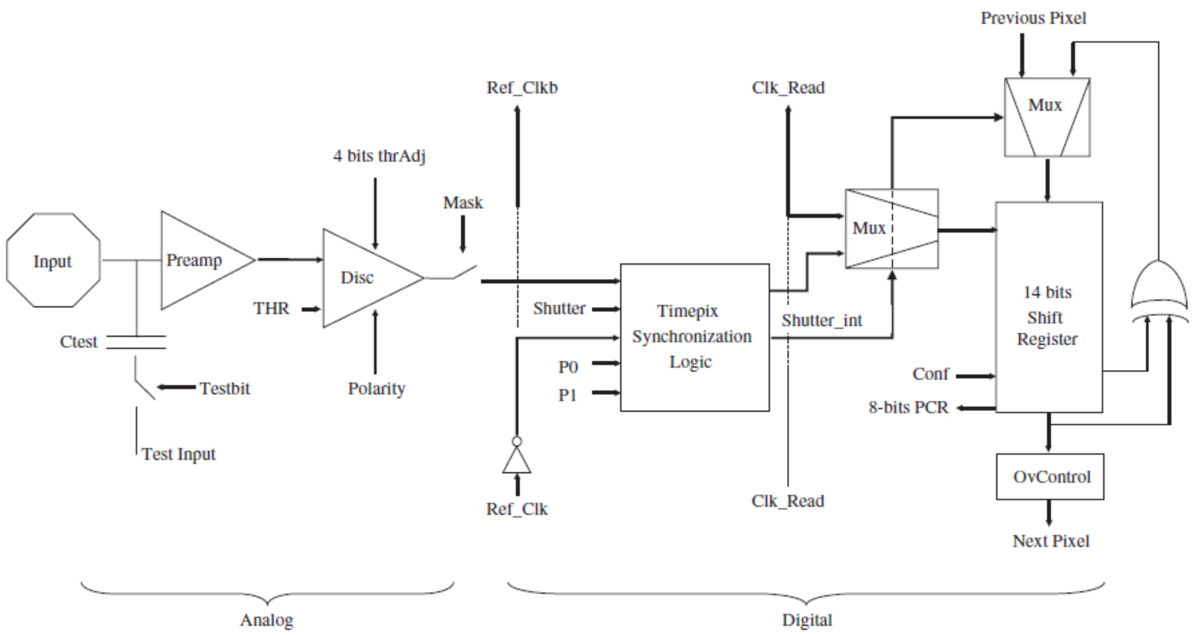

Figure 3. Schematic of Timepix cell

As it can be seen in Figure 3, the pixel is divided in two parts: the analog part and the digital part.

Analog part: Formed by the preamplifier, the discriminator and 4-bit threshold adjustment.

Digital Part: Formed by Timepix Synchronization Logic (TSL), the 14-bit shift register, the overflow control logic, the Ref_Clk pixel buffer and 8-bit Pixel Configuration Register (PRC).The PRC contains 4 bits for the pixel threshold equalization, 1 bit for Masking, 1 bit for changing the test pulse input and 2 bits for selecting the operation mode (P0 and P1).

The pixel cell contains approximately 550 transistors, its dimensions are 55 × 55 μm^2.

The input signal goes to the Preamplifier, where the electronic signal is prepared for processing. In the Discriminator it is set a threshold (the minimum voltage that must be applied to an electronic device to produce a particular operating characteristic) for the minimum energy needed to trigger a count. The discriminator can give two digital pulses, one if the signal pulse is over the threshold, and other if the signal pulse is lower than the threshold. After, if the signal is over the threshold and depending in which mode the pixel is working, the Shift register counts the digital signals (Medipix mode) or counts the time of the pulses over the threshold (ToT mode).

Although it is very similar to the Medipex2 chip, it has three main differences:

- There is a single threshold with 4-bits threshold adjustment.

- Each pixel can be configured in three different operation modes:
  MediPix Mode: The counter counts incoming particles
  TimePix Mode: The counter in this mode work as a timer and measures time of a particle detection.
  TOT (Time Over Threshold) Mode: The counter in this mode can record the duration of an event is above a threshold.

- The counting clock is synchronized with the external clock reference (Ref_Clk)

In this report it is showed the work with Medipix in two of the modes mentioned above. First it is explained the calibration for the MediPix Mode and the test results with radioactive source. The source constis of Am^{241} which produces α-particles, those particles impact with an Ag target and produces flourecense (X-rays). After, the Medipex chip in TOT mode it has been tried with the same source.

CALIBRATION OF TIMEPIX

First of all it must be said that before start running all the experiments two problems occur due to light and temperature.

IMPORTANCE OF LIGHT

When the detector is an atmosphere with a considerable amount of light, the pixels in the center of the detector counts hits, even if the threshold is so high. In the edge pixels no hits are counted even though the threshold is changed because of the leakage current is deposited in the edge of the detector.

In order to solve the problem of light, the detector was tried with some different levels of darkness. The test results with total darkness have showed that center pixels do not count any hit with high threshold, but the problem remains in the edge pixels because they still count no hits.

In Figure 4 it can be seen the behaviour of the detector.

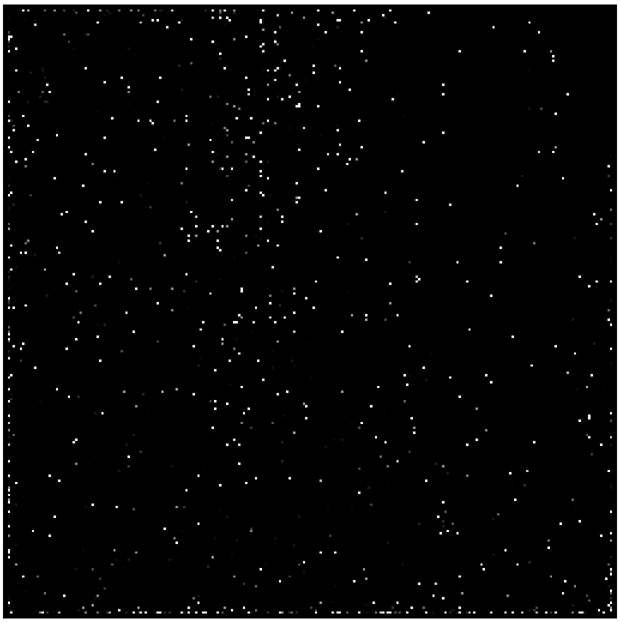

Figure 4. Caption of Timepix with no counts in the edge pixels

IMPORTANCE OF TEMPARUTE

To minimize the leakage current in the edge pixels, the detector has been tested in lower temperatures (5 ºC). It has been used a cooling chamber (Figure 5) to decrease the temperature.

Figure 5.Cooling chamber

Cooling the atmosphere of working, improves the situation, the leakage current is minimize and edge pixels are able to count hits.

Covering the detector and decreasing the temperature this is the result.

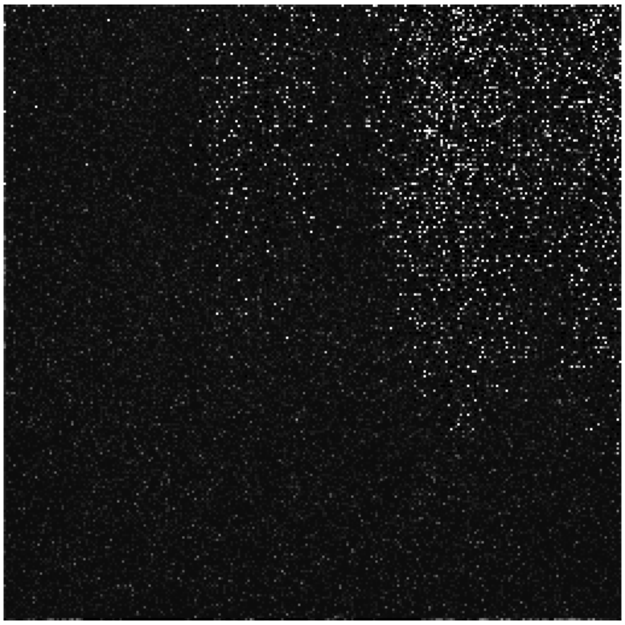

Figure 6. Caption of Timepix with counts all around the the detector.

IKRUM CURRENT

The I_{Krum} current is used to discharge the capacitor and compensate the leakage current. It has a nominal value of nA.

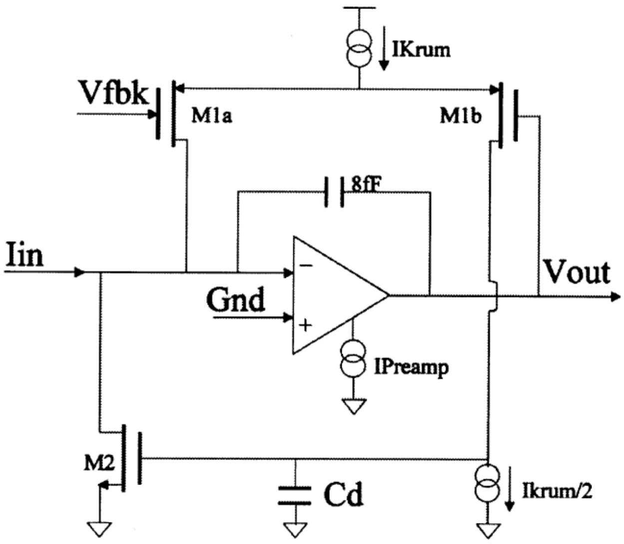

Figure 7. Schematic view of the preamplifier

As the Ikrum value is increased, the amount of leakage current tolerated is increased too, but the problem is that the capacitor is discharged more quickly and the signal pulse that is reduce.

The detector also it is tested in three temperatures for 2 Ikrum values to confirm the problem with the leakage current and the temperature. The graphics show the noise level for different temperatures and Ikrum values without any source. It can be seen that when the Ikrum and the temperature is reduced, the amount of noise counts is reduce. This is the main reason to start working with the detector in an atmosphere of 5 ºC, an Ikrum value of 5 and with any light.

Temperature 25 ºC Ikrum 5

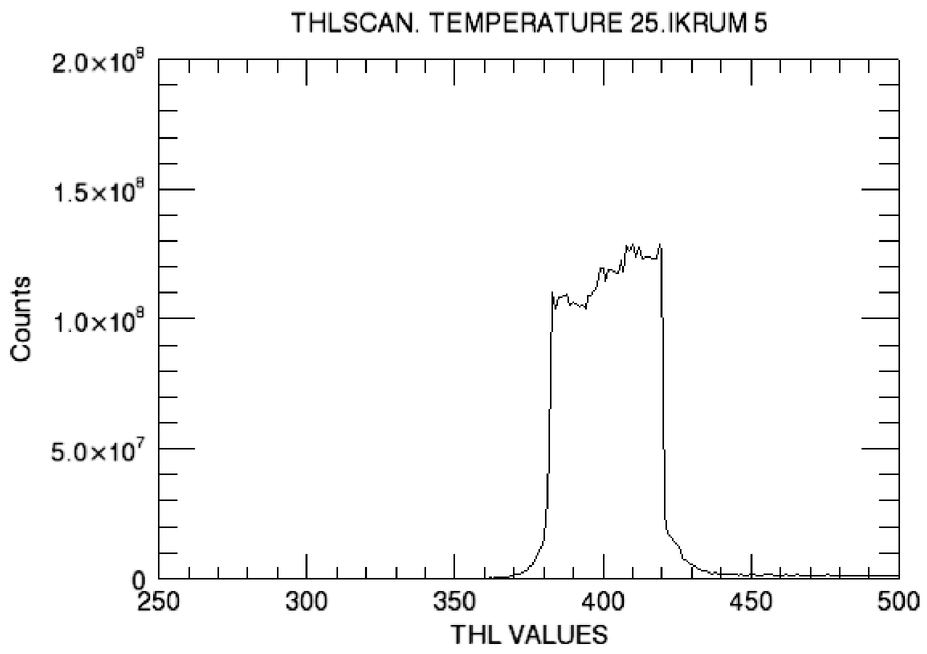

Figure 8. Threshold Scan. Temperature 25. Ikrum 5

Noise edge: 372

<u>Temperature 25 ºC Ikrum 20</u>

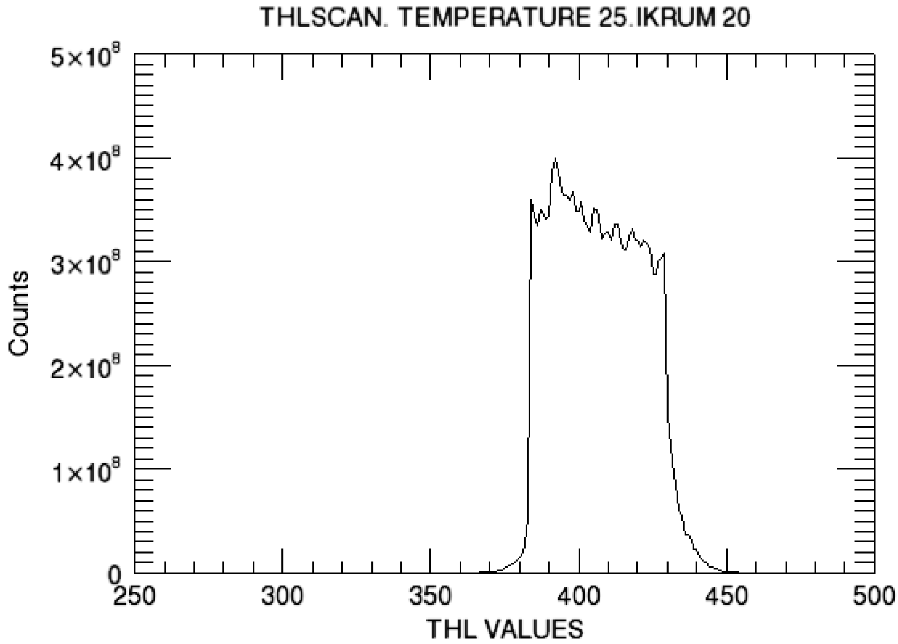

Figure 9. Threshold Scan. Temperature 25. Ikrum 20.

Noise edge: 372

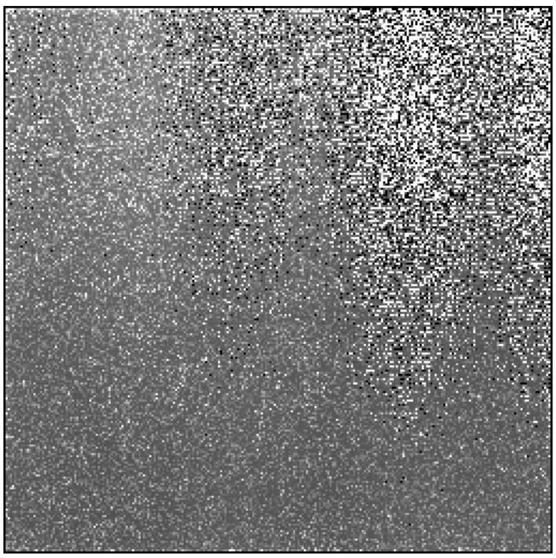

Figure 10. Timepix Screen. THL 394. Temperature 25. Ikrum 20.

Temperature 15 ºC Ikrum 5

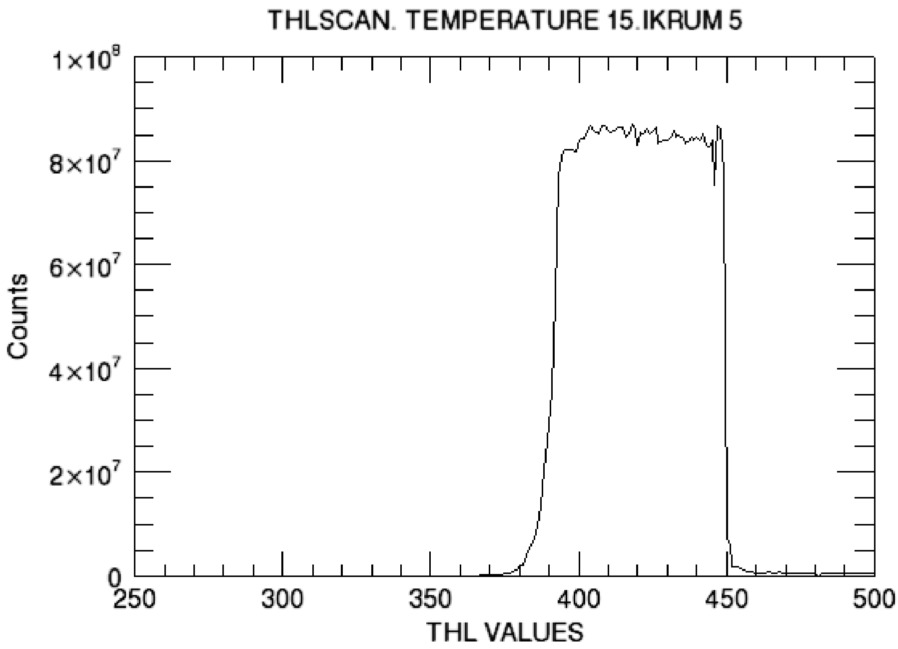

Figure 11. Threshold Scan. Temperature 15. Ikrum 5

Noise edge: 374

Temperature 15 ºC Ikrum 20

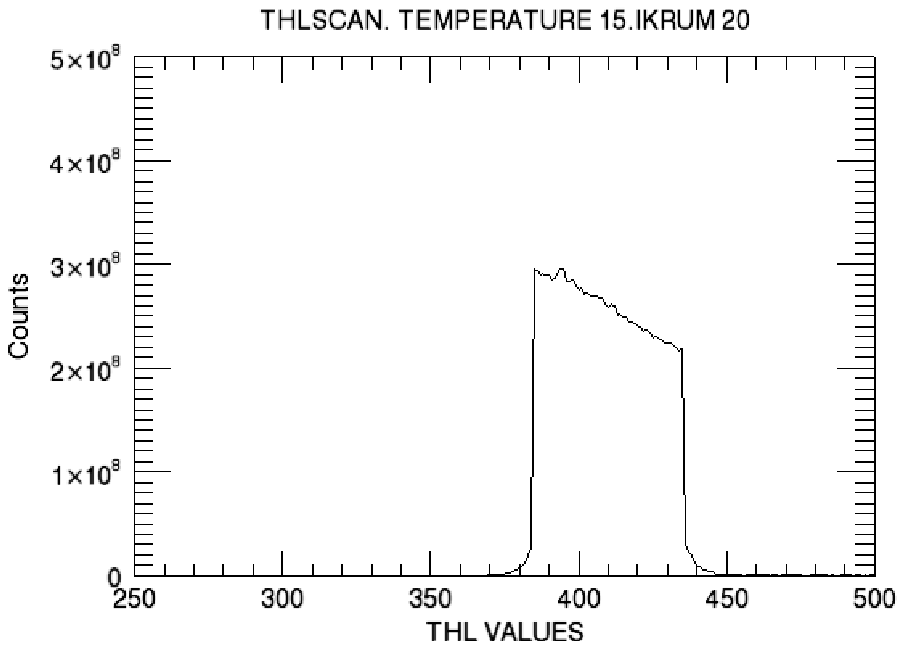

Figure 12. Threshold Scan. Temperature 15. Ikrum 20.

Noise edge: 374

Temperature 5 ºC Ikrum 5

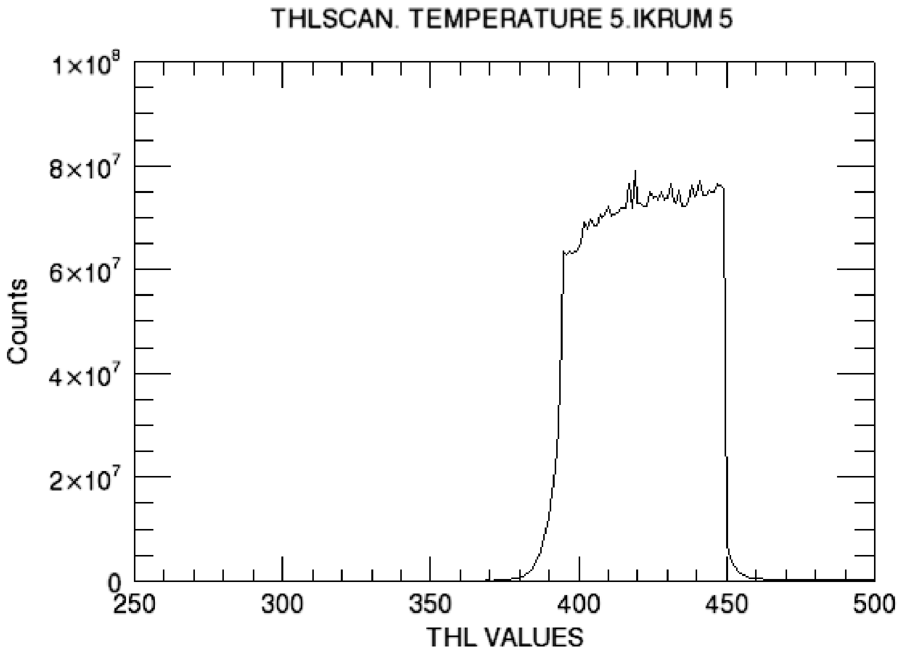

Figure 13. Threshold Scan. Temperature 5. Ikrum 5.

Noise edge: 378

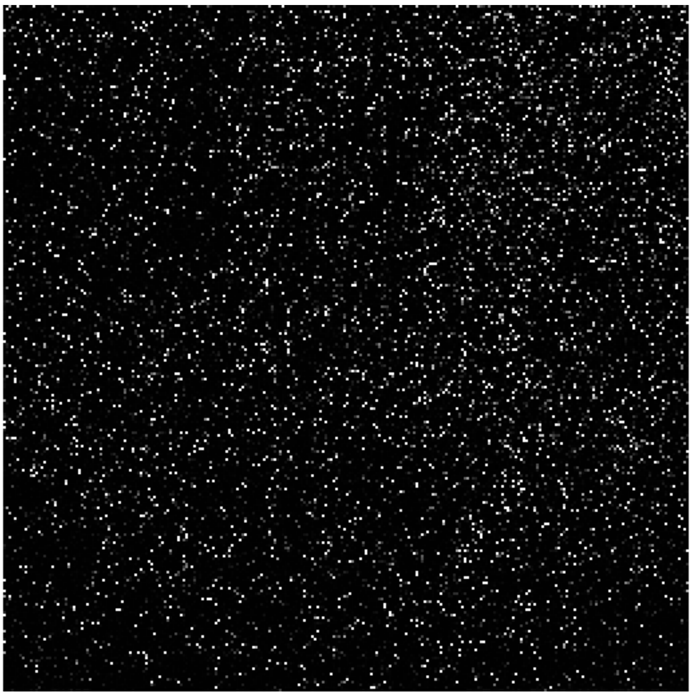

Figure 14. Timepix screen. Threshold 394. Temperature 5. Ikrum 5

Temperature 5 ºC Ikrum 20

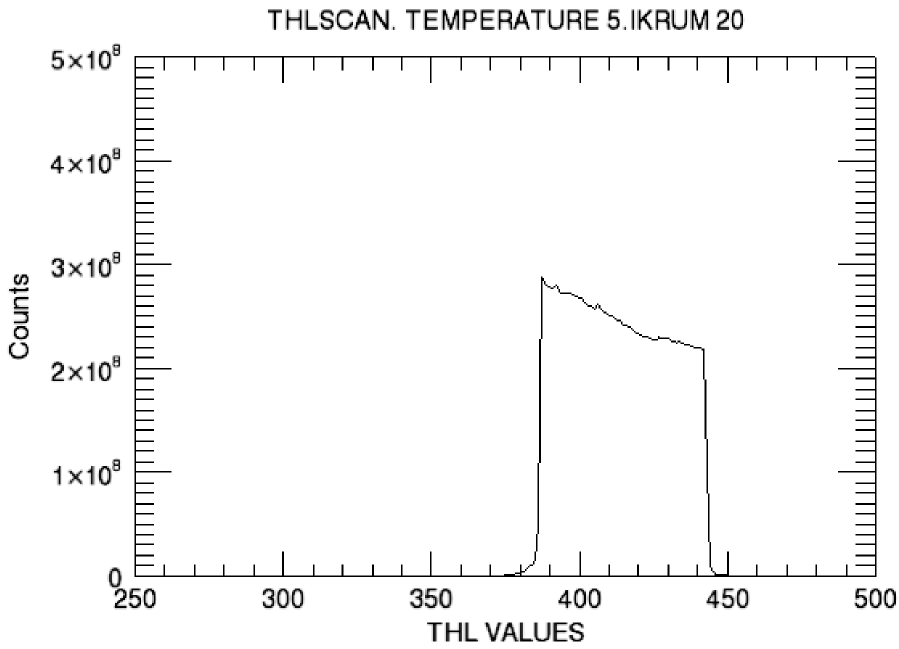

Figure 15. Threshold Scan. Temperature 5. Ikrum 20.

Noise edge: 378

The results of the graphics shows that when the Ikrum is increased the amount of counts is increased, when the temperature decreases the amount of counts is decrease. The position of the edge do not change with the Ikrum current, it only change with temperature, as the temperature is decrease, the noise edge moves to higher values.

THRESHOLD EQUALIZATION

Threshold equalization is used to compensate the pixel to pixel threshold variations. Then the adjustment code is selected for each pixel to make its threshold as near as possible to the average of the threshold distribution mean values. Picture 5 shows an example of a threshold equalization of Timepix.

A 100 V bias is applied to the sensor. The current version of Pixelman automatically changed this to 94.3 V. Bias voltage and current verification are 2.307 and 2.329, which are typical values.

The results show, the centroid is at 438.14, and std dev goes from 9.09 to 1.02 with adjustment. Then, started threshold equalization, using the noise centroid and a spacing of 3, with the detector covered.

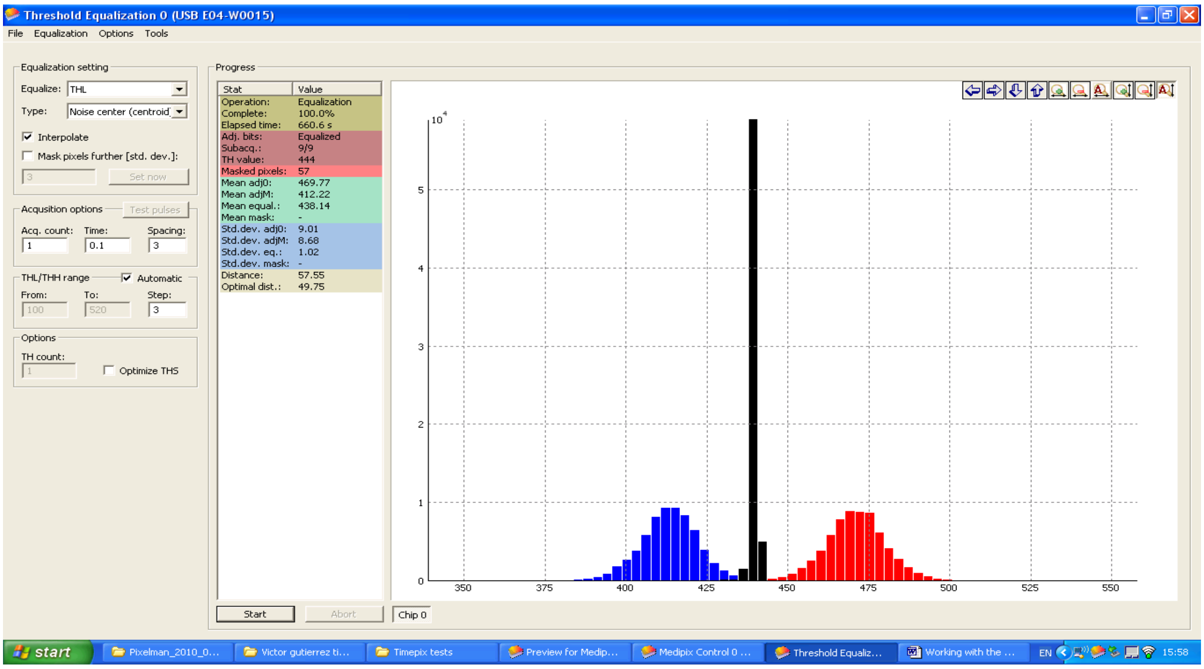

Figure 16. Threshold Equalization of the Timepix.

Threshold Equalization (Noise Centroid)	
Time (s)	660
Threshold Value	444
Masked Pixels	57
Meam Adj0	469.77
Meam AdjM	422.22
Meam Equalization	438.14
Standard deviation Adj0	9.01
Standard deviation AdjM	8.68
Standard deviation Equalization	1.02

Table 1. Threshold Equalization Values.

TEST RESULTS. MEDIPEX MODE. SILVER RADIOACTIVE SOURCE

In the next picture shows the set up of the experiment inside the cooling chamber.

Figure 17. Medipix Set up.

Covering half of the detector, it can be seen the pictures of the photons impacts in only one part of the screen. It has been tested for 1,10 and 60 seconds. Logically when the amount of time is it increased, more impacts arrived in the the detector.

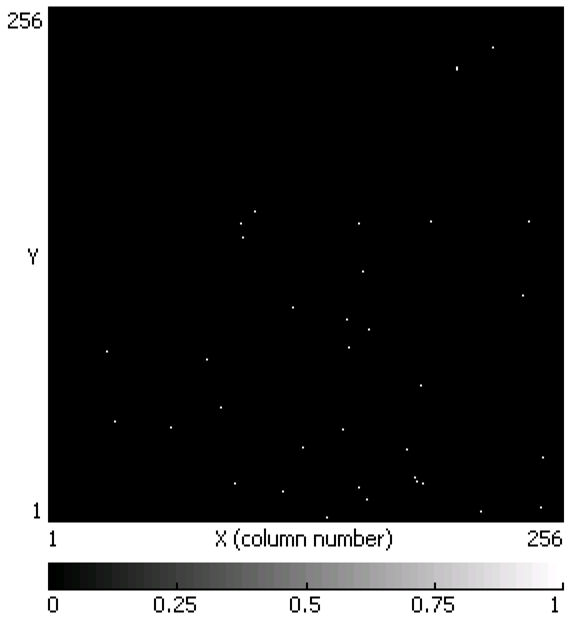

Figure 18. Timepix Screen. Medipix Mode. Counts 1 second.

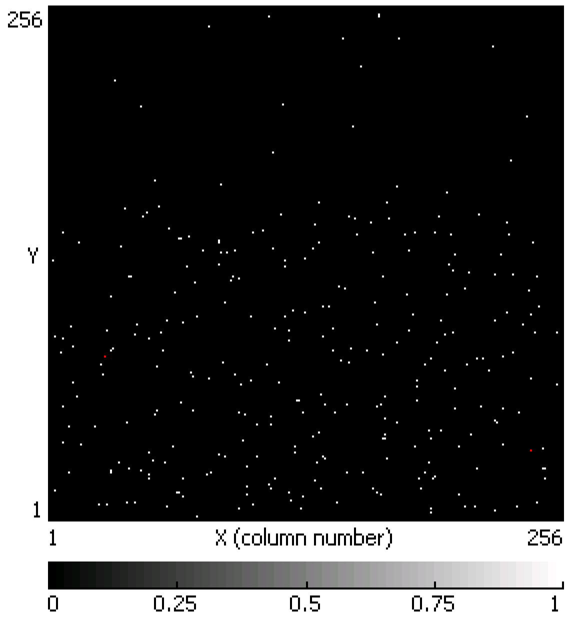

Figure 19. Timepix Screen. Medipix Mode. Counts 10 seconds.

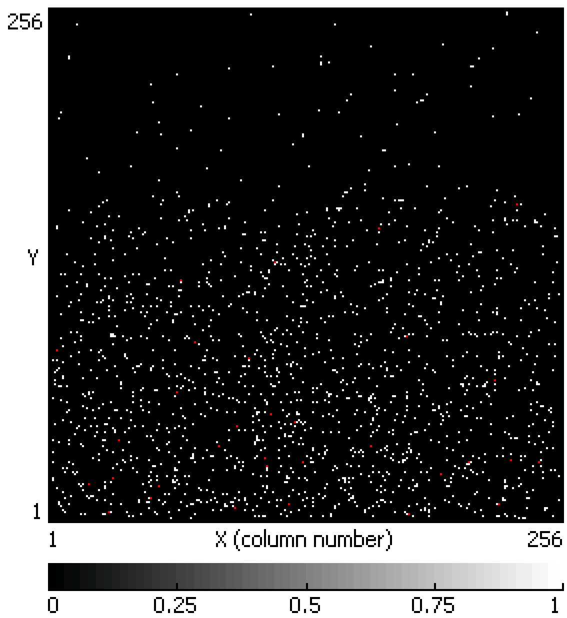

Figure 20. Timepix Screen. Medipix Mode. Counts 60 seconds.

A Threshold Scan is done with the silver source (Figure 20). As the threshold is changed it can be seen the number of counts in all the pixels. The threshold value of the graphic is a digital conversion of the signal obtained, it do not corresponds to the real threshold value. The silver florescence emits X-rays of 22.10 KeV and the Americum emits its own γ-particles of 59.60 KeV . In the end of the section will be demonstrate approximately that $\Delta 10$ THL = 1 KeV, this is why at the begging of the graphic there are counts, because of the γ-particles.

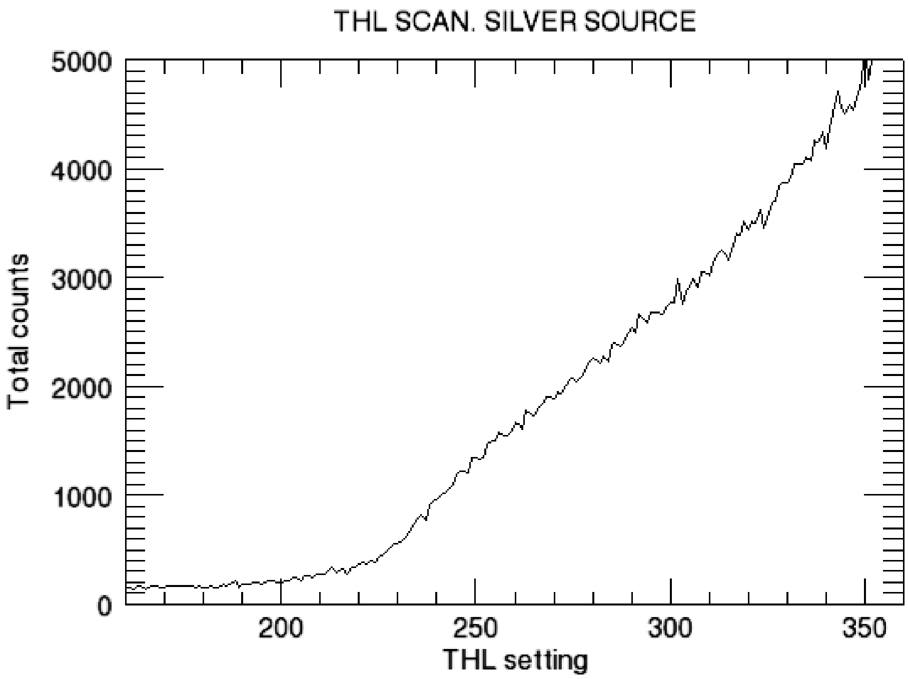

Figure 20. Threshold Scan. Silver source.

It is expected to have a 'S' shape line, the reason of having this variations is the charge sharing effect, some pixels can be hit by one photon. After being absorbed by a silicon atom, the photon become a cloud of carriers (holes and electrons). This cloud of carriers can hit neighborings pixels. In the next simulations, is explained the charge sharing effect.

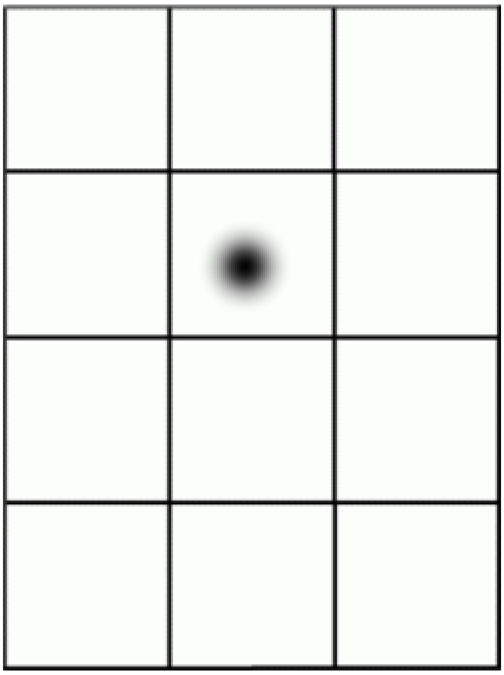

Figure 21. Simulation 1 photon in 1 pixel.

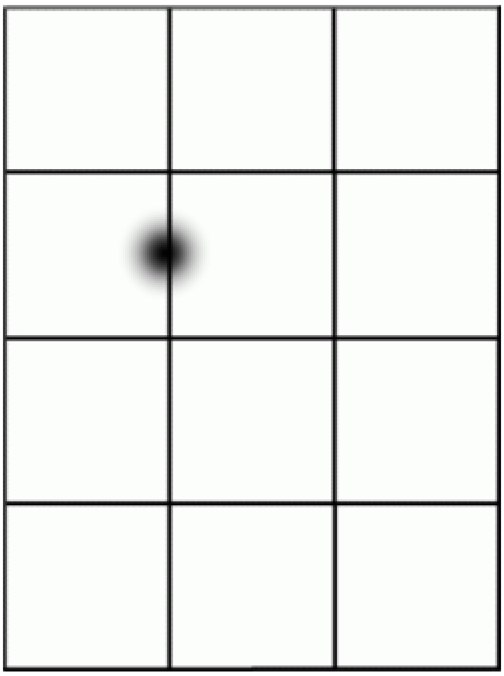

Figure 22. Simulation 1 photon in 2 pixels.

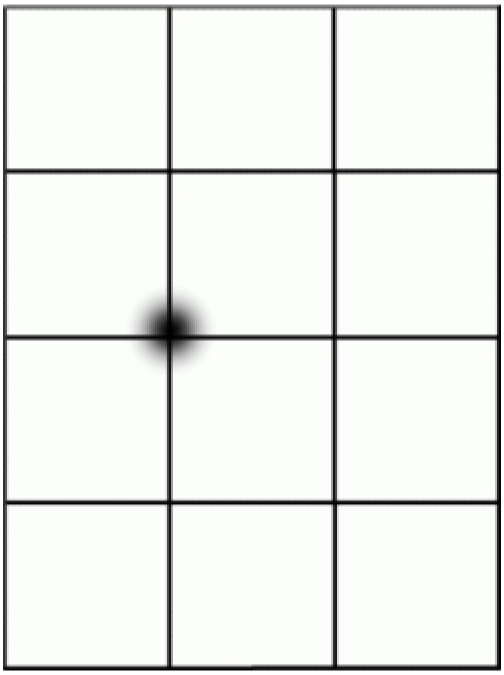

Figure 23. Simulation 1 photon in 4 pixels.

In the next graphic is represented the difference of counts between two consecutive threshold values in order to see how is the variation of the counts when the threshold is changed. In order to fitting the results, it is made an smoothing of 2 points, 5 points and 10 points.

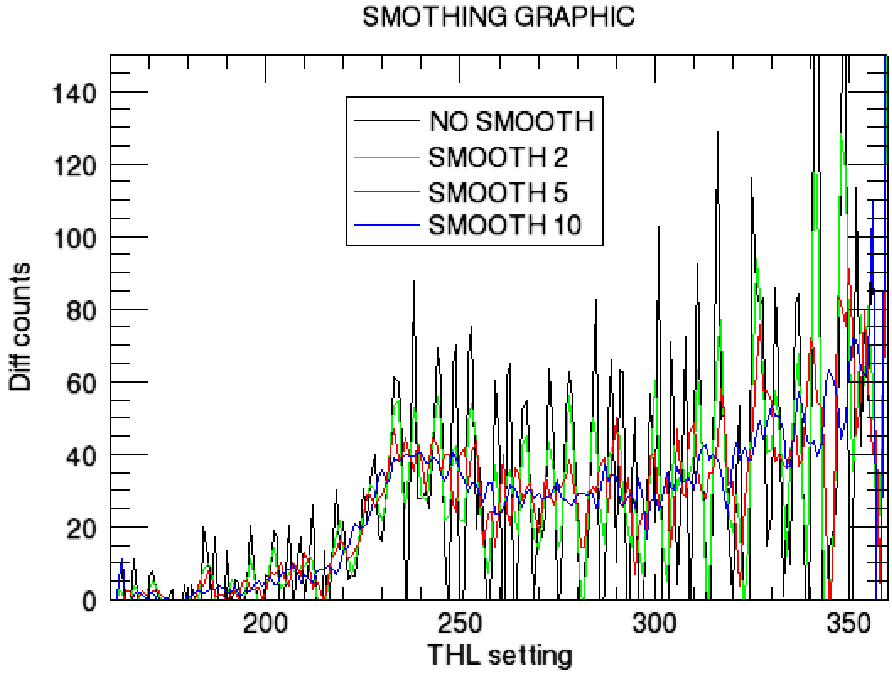

Figure 24. Smoothing graphic of differential counts between two consecutive THL values.

Although the most easy result to fit are the results of the smoothing 10 points (the most flat one), the error that cover is two times higher than the results of smoothing 5 points and the difference between 5 and 10 points smoothing is not that big. This is why, the decision to fit the smoothing of 5 points.

To fit the smoothing mentioned before, it is chosen a function call 'Gauss + Integral'. This function is the sum of the Gaussian function plus the integral of Gaussian.

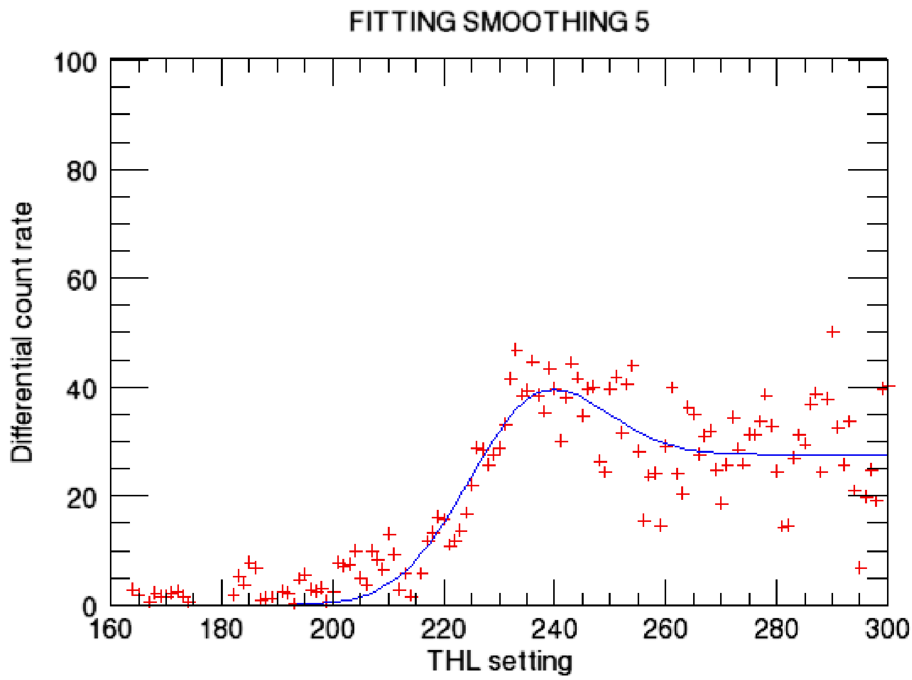

Figure 25. Fitting function of Smoothing 5.

In this graphic the peak is THL = 240.In our previous Threshold equalization, the noise centroid is THL = 438.19.That means the 22.10 KeV is the difference between the peak of the graphic and noise centroid.

$$\Delta\ 8.96\ \text{THL} = 1\ \text{KeV}$$

First the detector is tested with a Fe-55 source, it emits 5,985 KeV α-particles wich is Δ 53,74 THL . Our noise centroid is in 438.19 THL value, so the its X-rays it is expected in 384 THL value, this value is very near to noise level. The graphic shown before with different Ikrum currents and temperatures shows us that the noise level is around 375 THL. This is why it was very difficult to see the results of this source and another source with more energy it was needed.

TEST RESULTS. TIMEPIX MODE. SILVER RADIOACTIVE SOURCE

In this mode every pixel provides total time (in clock counts) over threshold for all hits in a readout cycle. To explain how the detector works in this mode, three pictures were made. It can be seen in this pictures that the half of the detector is cover, and there is almost no count in the superior part of the detector. It is tested in 1, 10 and 60 seconds. The lightness in the pictures means the time that the hit pixel is over the threshold. If the pixel is dark, it has no time over the threshold. If a pixel is hit twice during one acquisition time, then the detector measure the total time over the threshold.

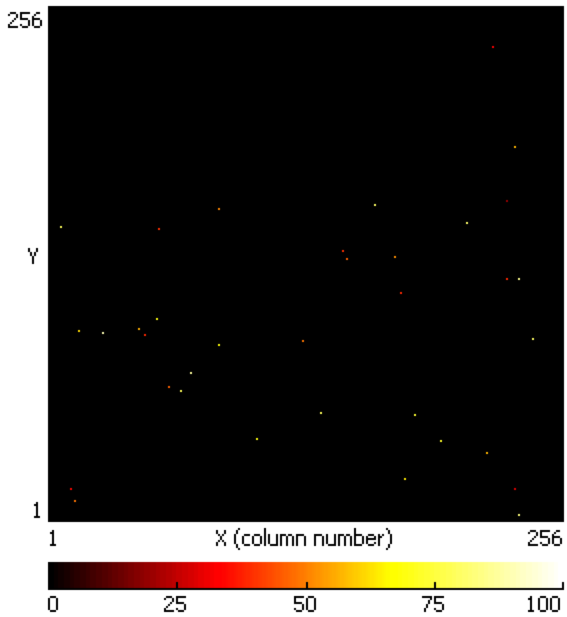

Figure 26. Timepix Screen. TOT Mode. 1 second.

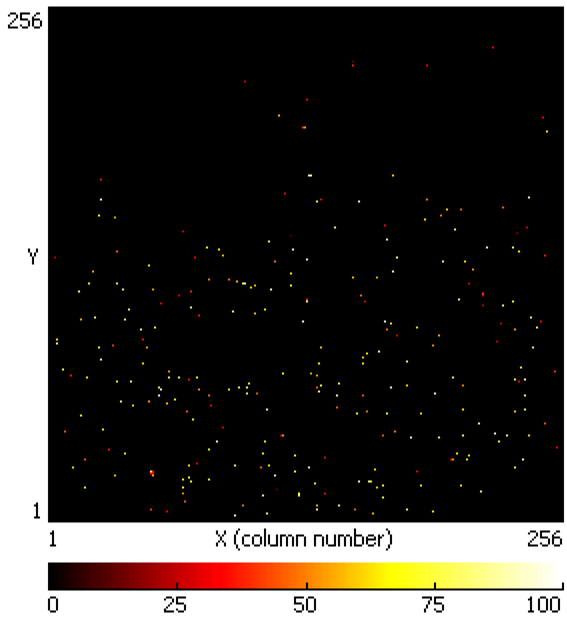

Figure 27. Timepix Screen. TOT Mode. 10 seconds.

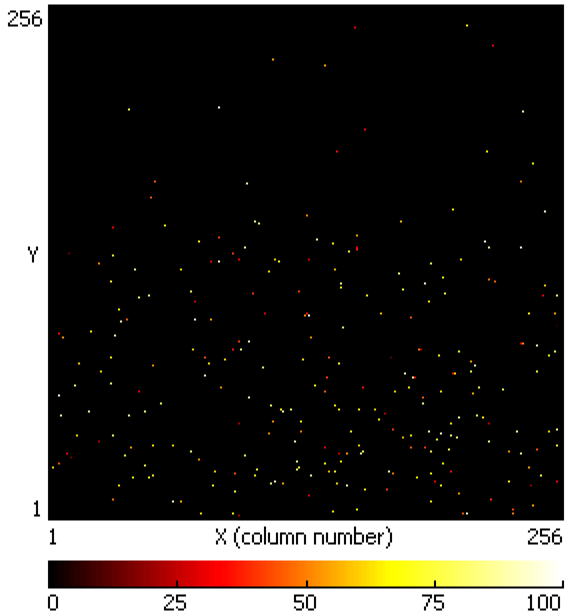

Figure 28. Timepix Screen. TOT Mode. 60 seconds.

In order to test the detector in this mode, the set up is the same of the Midipex mode. The temperature is 5 ºC, the Ikrum value is 5 and also the source is the silver. In the next graphic it is showed the number of pixels with different Time over Threshold values.

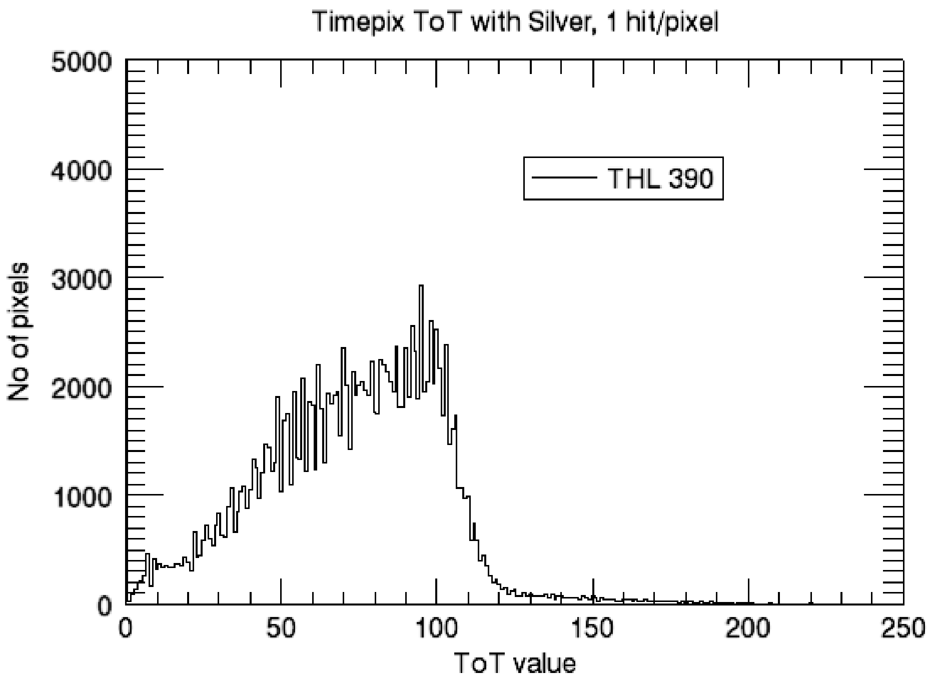

Figure 29. Timepix TOT. Silver source. 1 hit per pixel.

The Time Over Threshold graphic is not linear, beacuase of the pulse shaping
The THL value of 390 is an energy of 5,37 KeV. To start counting the energy has to be up than 5,37 KeV. The peak in this graphic is a TOT value of 90, it is supposed X-rays with an energy of 22.10 KeV. So the difference of energy between the α-particles and the energy of the THL value divided by 90 is the TOT step.

TOT step = 0.185 KeV/step

The Time Over Threshold graphic is not linear, because of the pulse shaping, this is why the TOT calculated before is approximated.

CONCLUSIONS

It is foun an important change in the behaviour of the detector in darkness and its behaviour in lightness, the detector works better when there is as less as possible light in the room. Surprisingly, the behaviour of the detector is much better when the detector works in low temperatures. The Ikrum value is a relevant factor to tolerate the leakage current in the edge pixels. In counting mode the behaviour for the variations of the counts by the the threshold can be fit by sum of the Gaussian function and its integral. In the Medipex mode is try a different and useful way to measure the photon’s hits.

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2- “Medipix2: a 64-k Pixel Readout Chip With 55-_m Square Elements Working in Single Photon Counting Mode.” *X. Llopart, M. Campbell, R. Dinapoli, D. San Segundo, and E. Pernigotti.*

3- “Pixel detectors for imaging with heavy charged particles” *Jan Jakubek, Andrea Cejnarova, Tomas Holy, Stanislav Pospisil, Josef Uher, Zdenek Vykydal.*