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**Calibration procedure of hybrid pixel detectors with GaAs: Cr  
sensor and Timepix readout chip**

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## 1. Introduction

Hybrid pixel detectors are used in various fields of physics. In recent years they had shown great impact in the field of biology and geology. In biology they use hybrid pixel for computer tomography while in geology they use them for x-ray radiography in studies of the internal structure of different samples. In high energy physics these detectors are used for the registration of particle [1]. Si has been used as a sensor material in such detectors since it have good advantages in the field of semiconductor materials, however it have disadvantages as well, which had make GaAs:Cr to be introduced. Well GaAs:Cr has shown to be a good sensor material for X-rays detectors due to it high resistivity and other properties[2]. In this report we will discuss an iterative procedure of per pixel energy calibration of hybrid pixel detectors using GaAs:Cr as a sensor material.

## 2. Literature review

### 2.1 X-ray

X-ray photon photons were discovered by scientist Wilhelm Rontgen. Wilhelm discovered that in the experimental electrical discharge tube, with partial vacuum, there were unknown photons emanating, and he further gave them the name x-ray. Later on it was discovered that x-rays are higher energy photons and they are mainly used for imaging and material determination[3]. Figure 1.1 show the example of production of x-ray photons, they are produced by accelerating electrons with a high voltage and allowing them to collide with a metal target. X-rays are produced when the electrons are suddenly decelerated upon collision with the metal target.

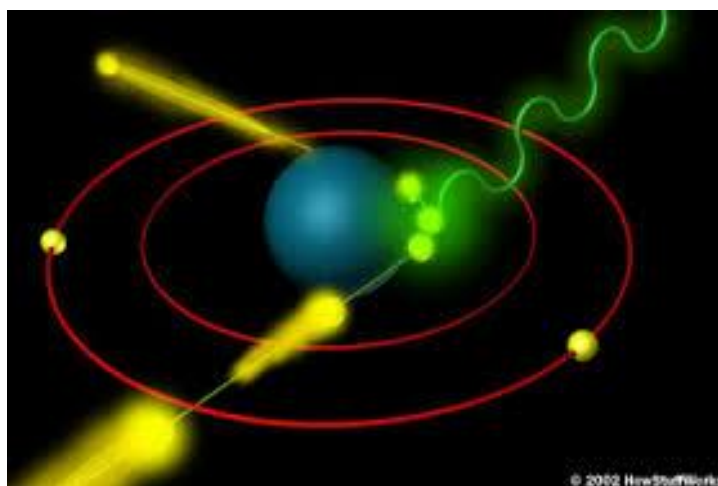


Figure 1. Production of x-ray photons

The most common use of x-ray is in the medical environment, the medical community uses x-rays to examine several parts of the body and to treat conditions[1]. Imaging with x-rays involves exposing a part of the body to a small dose of ionizing radiation to produce pictures of the inside of the body. There are many other fields as well where X-rays play a crucial role, fields like astronomy, where they use x-ray detectors to study objects in space, objects include neutron stars, black holes and binary star systems. Figure 2 shows these examples of the application of x-rays. One is the astronomy environment where a neutron star is detected and the other is in the medical field where x-ray is applied to view the inner part of a human foot.



**Figure 2. Application of X-ray in the astrophysics and medical fields**

### **3.2 x-ray source**

In the case of GaAs: Cr hybrid pixel detectors (current experiment), the x-ray source was micro-focus x-ray tubes which consist of features of x-ray units as follows:

- Small focal spot from 5 to 100 micron
- Adjustable voltage range from 20 to 150 kV
- Geometric magnification up to 100x

- Ability to inspect pipes with small diameter (down to 40 mm)

In Figure 3. the four x-ray sources are shown, and all these can be paired with x-ray tubes: rod anode, panoramic, thin (transparent) and thick (reflected) anodes. Rod anode length can be adjusted from 40 mm to 300 mm. The RAP-M x-ray units have a wide range of applications, such as microelectronic inspection systems [4].



**Figure 3. x-rays source setup**

### **3.3. GaAs**

Gallium Arsenide has become the most reliable and preferred semiconductor material for detectors and imaging system for x-rays. This happens due to its high atomic number with respect to silicon, and results in good efficiency of about 20% in detecting x-rays of about 12 keV. Moreover, gallium arsenide has a band-gap energy which is higher than for silicon and for germanium. Due to these properties, GaAs:Cr has been considered as a most preferable material in the development of detectors with potentially low thermal generated dark current, able to operate at room temperature and avoiding impractical cooling systems [5].

### 3.4 Pixel detectors

Pixel detectors are used in high energy physics and radiation experiments, the known use for such devices is in a photo camera. MediPix is one of the families of device. There are four pixel devices under this family, namely Medipix1, Medipix2, Medipix3 and timepix, the latter is a device derived from the design of Medipix2, with some functions that differ from the Medipix ones.

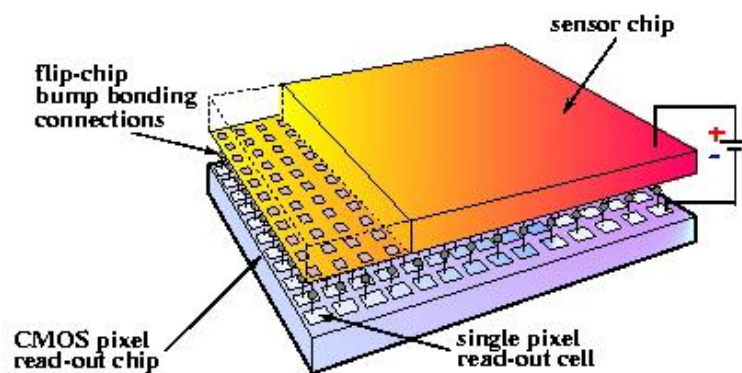


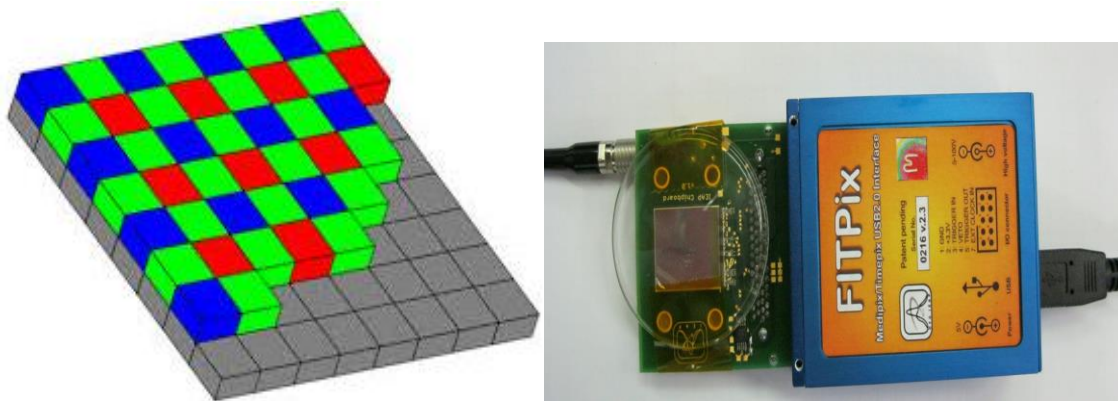
Figure 4. setup of pixel detector with sensor

Detectors in the Medipix family are single photon counting detectors, which means they detect single photons and count the total amount of photons during a measurement. Figure four show medipix detector with a sensor. This Pixel operate in one of the four ways.

1. Medipix mode: The chip count how many times during the open shutter the signal exceeds a certain threshold;
2. Time-over-Threshold (ToT) mode: the chip measures for how long the signal stays above the threshold;
3. Time-of-arrival (ToA) Mode: the chip measures time from the moment when the signal crosses the threshold until the shutter is closed.
4. OneHit mode: the chip checks if the signal exceeds the threshold at least once during the open shutter

### 3.5 Sensor

Single incident high energy photons such as X-rays are able to release photoelectrons in the sensor. Photoelectrons are electrons which are freed by photoelectric effect. The photoelectron has the same energy of the original photon. Once the electron is freed, it travels through the sensor material and produces secondary electrons along its track, emitted by ionization. Ionization is the separation of a bounded electron from its atom due to the energy releases of a particle, in this case the photoelectron.



**Figure 5 . a) a view of sensor with readout chip,**

**b) Timepix pixel detector with USB interface FITPix**

When ionization occurs in a semiconductor, the electron leaves a vacancy (called hole) which behaves like a positive charge carrier. The minimum energy required to free an electron-hole pair is equal to the ionization energy. Figure (5) show an example of such sensor readout with chip [6]. To measure energy deposited in the sensor by a particle the ToT mode of the Timepix chip is used. In this mode, when the signal in a pixel crosses some threshold level THL the pixel counter starts counting pulses from the oscillator. It stops when the amplitude of the input signal falls below the threshold. The number of counted pulses depends on the amount of absorbed energy. More details on ToT are given on the experimental details.

The detector consists of two parts , the first is the sensor and the second is chip, The Timepix readout chip consists of 65,536 independent channels (pixels) assembled in a matrix of 256x256 elements. The single pixel size is  $55 \times 55 \text{ m}^2$ . Each pixel has an amplifier, a discriminator with adjustable threshold, and a counter. The first results of the studies of hybrid pixel detectors with GaAs:Cr sensors and the Timepix readout chips are given in [7].

In Fig. 5b one of the first GaAs:Cr Timepix detectors assembled in 2008 for the LNP is depicted, along with the FITPix [8] USB interface that connects the detector to a PC.

### 3.6 Pixel man software

The software package used to read the output of the chip is called Pixelman2. Pixelman is a program made by the Medipix group of the Czech Technical University (CTU) in Prague. The software is specially made to operate Medipix2 and Timepix based devices. The GUI allows to visualize the acquired frames and to write data in text files [9].

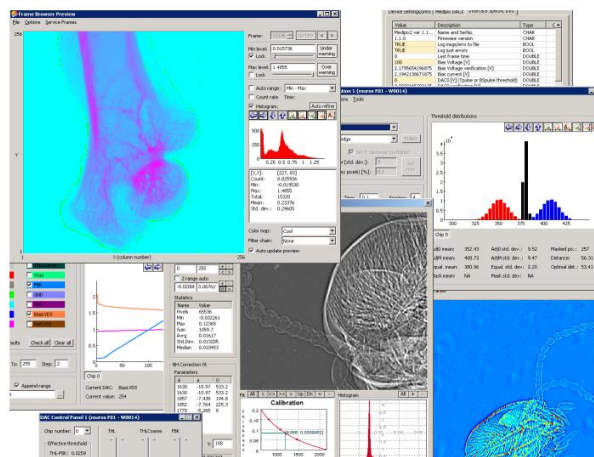


Figure 6”Pixelman program.”

Pixels in Medipix devices are designed to be identical to one another. However, due to natural mismatches that occur during the processing, some parameters may vary from pixel to pixel. In particular, the global value of threshold may translate to a local value which is different from pixel to pixel, more details about threshold equalizer are discussed on the next section(experimental details).

## 4. Experimental details

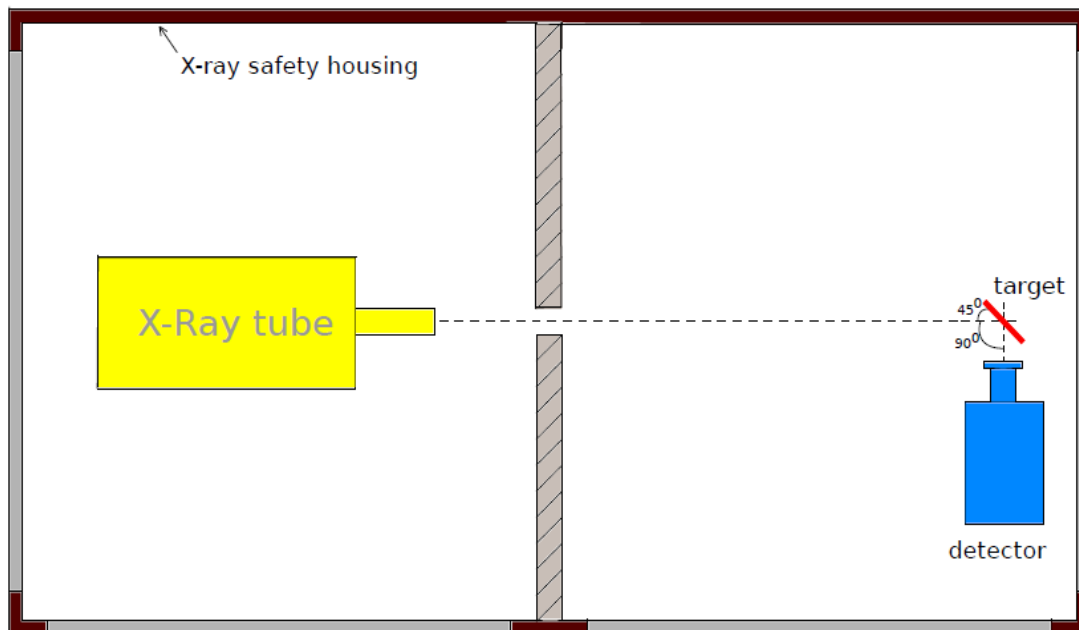
Table (1) shows different target foiles that were used for the expereriment, the measurments for each foil take time between (2 up to 4 hours) depending on the target efficiency of emitting x-rays.



Element	$K_{\alpha_2}$ , keV	$K_{\alpha_1}$ , keV	$K_{\beta_1}$ , keV	$K_{\beta_2}$ , keV	$K_{\beta_3}$ , keV	$K_{\beta_4}$ , keV	$K_{\beta_5}$ , keV
$^{28}\text{Ni}$	7.46	7.48	8.27	–	8.27	–	8.33
$^{30}\text{Zn}$	8.62	8.64	9.57	–	9.57	–	9.65
$^{40}\text{Zr}$	15.69	15.78	17.68	17.97	17.65	17.97	17.82
$^{42}\text{Mo}$	17.38	17.48	19.61	19.97	19.59	19.97	19.77
$^{45}\text{Rh}$	20.07	20.22	22.72	23.17	22.70	23.17	22.91
$^{48}\text{Cd}$	22.98	23.17	26.10	26.64	26.06	26.64	26.30
$^{49}\text{In}$	22.98	23.17	26.10	26.64	26.06	26.64	26.30
$^{50}\text{Sn}$	25.04	25.27	28.49	29.11	28.44	29.11	28.71
$^{73}\text{Ta}$	56.28	57.54	65.22	67.01	64.95	66.95	65.24
$^{74}\text{W}$	57.98	59.32	67.24	69.10	66.95	69.03	67.65
$^{82}\text{Pb}$	72.81	74.97	84.94	87.36	84.45	87.24	85.42

**Table 1. table of target foils**

Figure. (8) show a layout for the experimental details, the lead collimator is placed in front of the detector window to prevent overlanding in measurements of direct spectra, it had (5) mm thickness and hole about (0.8) mm diameter in the middle.



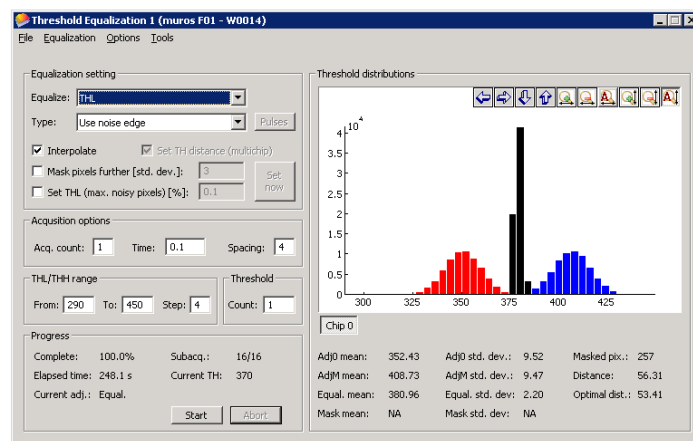
**Figure 8. experimental setup**

The per-pixel calibrations of Timepix detectors with GaAs:Cr sensors includes measurement of the energy resolution [1], the special properties of GaAs:Cr as a material and particularities of detector prototypes based on it require some changes in the calibration procedure.



In the current experiment a hybrid Timepix detector with a GaAs:Cr sensor of 500 micron thickness was used . The bias voltage applied to the sensor was  $V_{bias} = -500$  V. To exclude the effects of temperature the sensor was thermally stabilized (at 20<sup>0</sup>C) . Calibration of the pixel detector is carried out in two stages. The first stage is the pixels threshold equalization. For this purpose we used Pixelman software [9].

The threshold level THL is set the same for all pixels of the readout chip. But the electrical properties of each pixel are somewhat different due to technological features that lead to each pixel having its own noise level. Therefore, an additional corrective bias voltage is introduced into the amplifier channel of each pixel in order to equalize noise levels of all pixels at the set threshold level THL.



**Figure:7. Threshold equalizer in pixel man**

The second step is the establishment of a one-to-one correspondence between the time length of the signal in ToT counts and the absorbed energy. The procedure for obtaining  $E(\text{ToT})$  dependence is called ToT-calibration. It can be done individually for each pixel (per-pixel calibration) and for the entire matrix as a whole (generalized calibration). ToT-calibration comprises of the following steps[1]:

- Measurements of X-ray spectra of known radioactive  $\gamma$ -sources and spectra of characteristic emission of selected materials in units ToT.
- Identification of peaks in the recorded ToT-spectra with corresponding X-ray emission lines.
- Fitting of the peaks and constructing of a ToT (E) .

## 5. Results.

Figure (8) shows the obtained result for the Mo foil . The accuracy in Timepix detector is not good since it does not take into account the differences between the pixel caused by non uniformity of the sensor material and quality of the detector assembly. As can be seen from these figure.

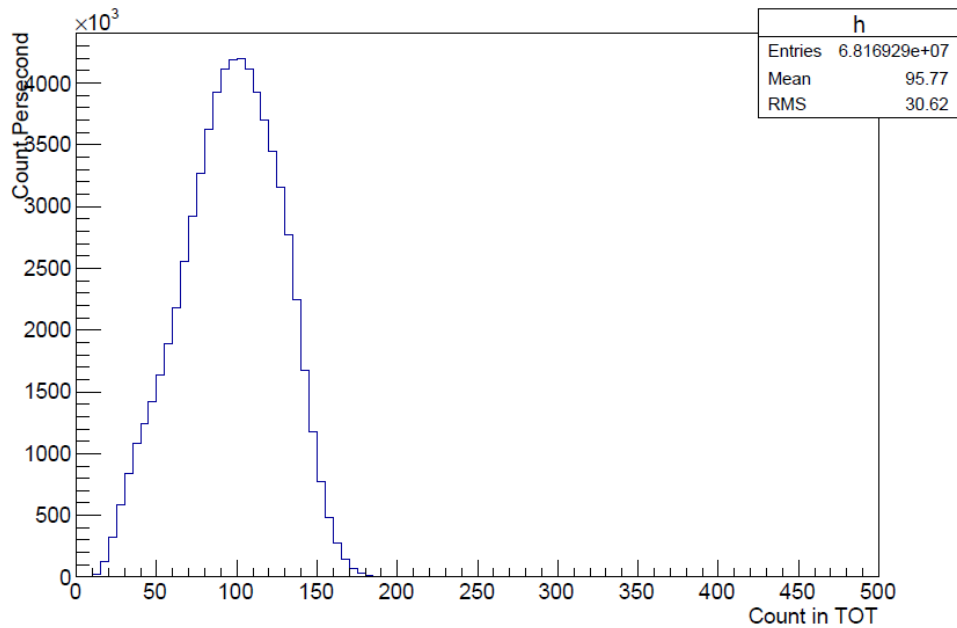


Figure (8) spectrum of Mo foil

Figure (9) shows the fitting for the obined spectra for Cd foil .

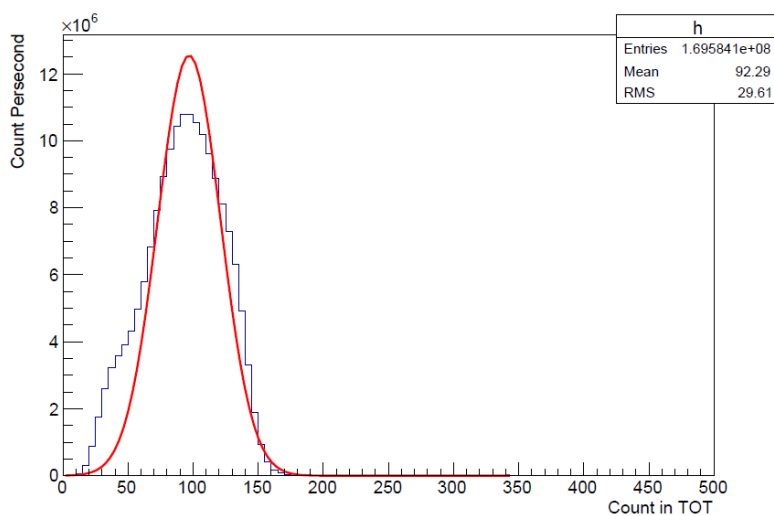


figure 9. Spectrum for Cd target foil fitted with gaussian

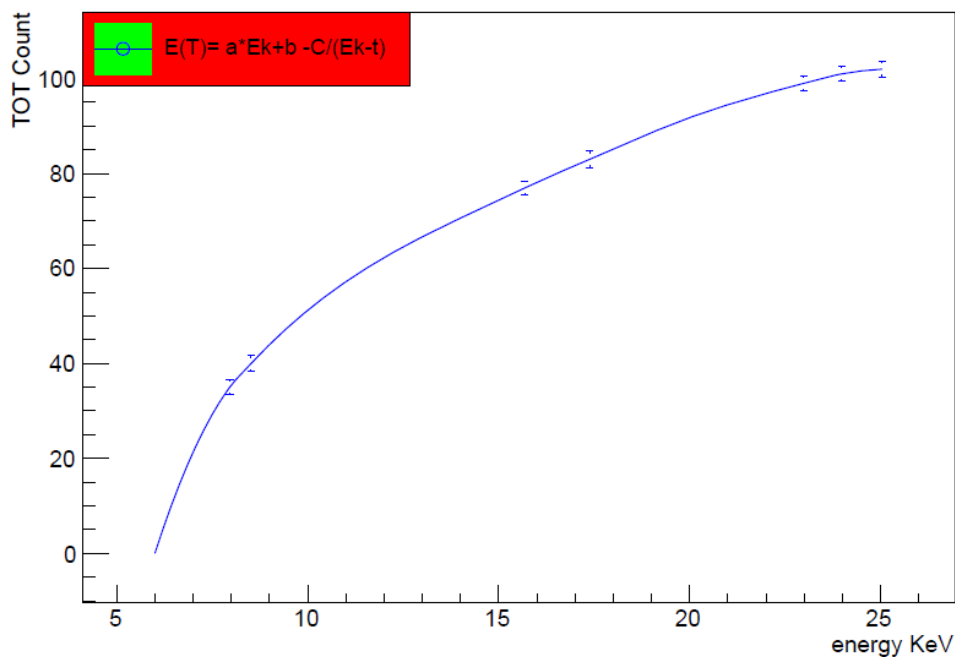
Table (2) shows The obtaine peak from all spetrum were used to for the relation between the energy in Tot and energy in keV. Knowing the ToT values of the peak positions and the mean energies of their corresponding characteristic emission lines ( $K_{\alpha}$  and  $K_{\beta}$ ), we can construct a relation between  $E_{TOT}$  and  $E_{KeV}$ .

**Table (2)  $K_{\alpha}$  in TOT with its error bars**

Element	$K_{\alpha}$ in TOT	Error bars
Ni	35	1.04
Zn	40	2.343
Zr	75	1.36
Mo	83	1.036
Cd	94	1.023
Rh	99	1.30
In	100	1.25
Sn	101	1.05

the following equation were used for best fit of the relation:

$$E(ToT) = aE_{kev} + b - \frac{c}{E_{kev} - t}$$



**Figure.10 Calibration curve**

From the above equation, the constants  $a, b, c$  and  $t$  can be obtained from the best fit in gaussian fitting. The fit to this graph is performed in two steps. Firstly, in the energy range [10; 25] keV a straight line  $a \cdot E + b$  is used as the fitting function and the values of the parameters  $a$  and  $b$  are determined as well as their errors. These errors define the range of variation for the parameters  $a$  and  $b$  in the second step when all data points in the energy range [8; 25] keV are fitted with the function (1). As a result, all four parameters  $a, b, c, t$  are determined. The result of the calibration Timepix detector in the energy range [8; 25] keV is shown in Fig. (10) with the obtained parameter values:  $a = 2:18, b = 55:4, c = 196, t = 2:3$ .

## 6. Conclusions

In this paper, a brief description of the calibration procedure of Timepix pixel detectors is given. The procedure uses different materials (foil) with different X-ray emission spectrum to have a relation between energy in TOT and Energy in KeV. The use of pixel calibration allows to achieve a good energy resolution of the Timepix detector with GaAs:Cr sensor, To improve the quality of these calibration in the calibration curve, it is required the increasing number of energy points.

## 7. References

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