

An Investigation of How Pixel Size Affects the Energy Resolution of a Photon Counting X-ray Imaging System by Gaussian curve fitting

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ABSTRACT

For a variety of applications, Radiation imaging sensors are being used and a similar kind of sensor, namely the “Timepix”, has been developed. An attempt has been made to discover the center peak position by removing the effect of charge sharing. With reference to the center peak detection, the Gaussian curve fitting technique has been applied to obtain a noise free peak. Different fluorescent materials were used as samples in order to generate test images and the analysis was conducted using MATLAB.

KEYWORDS: Radiation Imaging sensor, Timepix, Energy Spectrum, Gaussian curve fitting.

1. INTRODUCTION

The digital revolution within technology has been made possible because of the efficiency and minimization of electronic circuits. This technology is being used in imaging and particle physics experiments for the development of image sensors for pixel detection. Pixel detectors are now being used in medical imaging. Timepix is an excellent chip but, at present, it is still not ready to be used as a medical imaging sensor as it is still too small and only has the ability to handle low flux rates. At this point, more research is required to overcome these problems. In this paper we attempt to discover some better solution in order to enhance the features of the present Timepix. In order to achieve, analysis has been performed using different metals. The tests and the analysis have been conducted using MATLAB. The key point is to discover a method which will provide the best possible results. It is hoped that the results thus obtained can then be integrated into a future version of the Timepix chip and thus produce improved results.



Figure 1.1 TIMEPIX CHIP [1]

MEDIPIX2 was used in the previous work but, in this case, an alternative to this, namely Timepix, is to be used as the detector. Thus the main focus is on defining a pathway and then attempting to calibrate the Timepix sensor. In order to achieve this goal, observations must be made regarding the response of pixels against different energies in the x-ray imaging system, given that there are different photon energies for different fluorescent materials and to discover the real centre of the peak position of the curve by fitting a Gaussian curve.

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2. LITERATURE REVIEW

Radiation is defined as the energy that comes from a source and travels through space or a medium and the energy which travels through space or a medium absorbed in another body [2], [3]. Radiation can be categorized as given below

Charged Particulate Radiation

- Fast Electron (Beta Decay)
- Heavy charged Particles (Alpha Decay)

Uncharged Radiation

- Electromagnetic Radiation (Gamma Rays Following Beta Decay)
- Neutrons

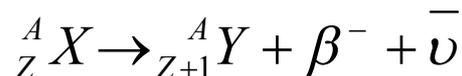
Radioactivity is the process through which unstable atomic nuclei spontaneously emit subatomic particles. During this process it emits alpha particles, beta particles, gamma rays or electromagnetic rays. The decay equation for radioactivity decay is defined as the rate of decay of the radioactive nuclei in a large sample that depends only on the number of decaying nuclei in the sample. A mathematical expression for the decay equation can be written as

$$\frac{dN}{dt} \Big|_{decay} = -\lambda N$$

Where dN is the number of radioactive nuclei in the time window dt and λ is the decay constant.

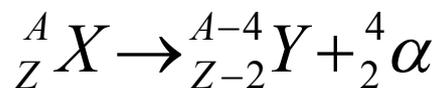
Fast Electron Source (Beta Decay) has two types of beta decay, the electron emission (β^-) and the positron emission (β^+).

The decay process can be written schematically as



in which X and Y are the initial and final nuclear species; β^- shows the electron emission and $\bar{\nu}$ is an antineutrino. The neutrino and antineutrino have very small interactions because they travel at the speed of light and are thus undetectable and are also invisible [2], [3].

Heavy Charged Particles (Alpha Decay) decay occurs in the heaviest nuclides. The decay process is written schematically as



The majority of the energy for the alpha particles remains between 4 and 6 Mev. However, because of the dependency with regards to the half-life of the energy process there are minor variations in the energy [2], [3].

Electromagnetic Radiation (Gamma Rays Following Beta Decay) Gamma rays are produced in alpha or beta rays because of their excitation or de-excitation. The example below in figure 2.1 shows the decay scheme for ${}^{60}\text{Co}$ for gamma rays sources. How do alpha or beta particles work in the excitation or de excitation states for gamma rays? When an alpha or beta ray is emitted from the nucleus the daughter nucleus goes into an excited state. On return to a lower energy state due to the de-excitation, then gamma rays are emitted.

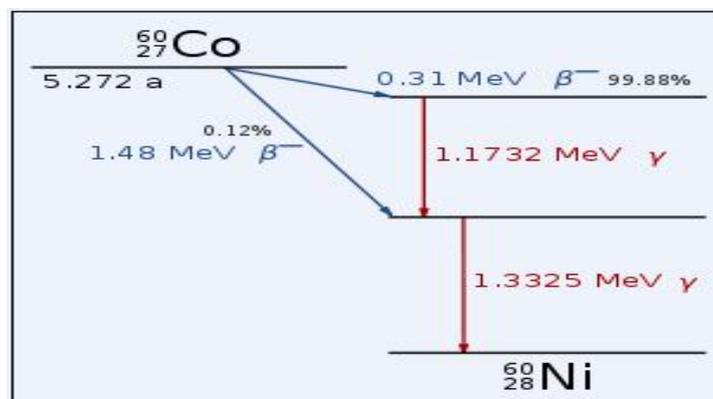


Figure 2.1 Decay Scheme of CO [2], [3]

Characteristics X-rays-When electrons receive some energy they go into the excitation state but this state will only exist for a short period of time. It is a natural characteristic of an electron that it returns to its ground state within a given timescale, which is based on the characteristics of the electron. The energy liberated in the transition from the excited to the ground state takes the form of a characteristic x-ray photon whose energy is given by the energy difference between the initial and final states. If the vacancy is created in the k shell then the outer shell falls into this and fill this vacancy. Vacancies created in the outer shells by the filling in of the k shell vacancies are filled by means of the emission of L-, M-,....series characteristic X-rays. When an electron is removed from an atom and thus leaving a vacancy, an electron from the outer energy level falls into the vacancy. The electron then falls from the outer level due to the release of energy or the emission of a photon. Energy can also be transferred to another electron, which is ejected from the atom. This ejected electron is called an auger electron. Figure 2.2 below shows a characteristic X-ray and auger electron.

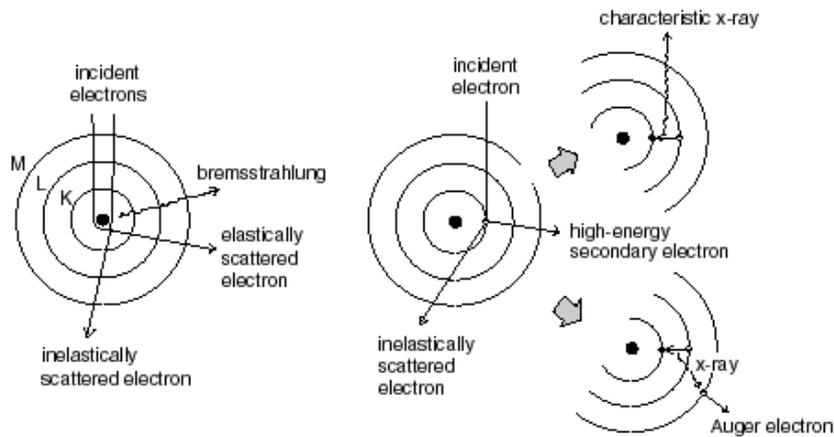


Figure 2.2 showing the production of bremsstrahlung, characteristic X-rays, and Auger electrons [4].

Neutron Sources are generally stated as the emission of neutrons. There are several kinds of neutron sources

- Small Size Devices
- Medium Size Devices
- Large Size Devices

Measurement setup consists of a hybrid silicon pixel device, the Timepix, is used. This device is the combination of two chips which are connected together by a bump-bonding method. One chip is a pixilated 300 μm thick silicon detector chip and other is a bottom read-out chip with matrix dimensions of 256x256. This chip was developed at CERN by the MEDIPIX collaboration [7]. In this setup, fluorescence materials are placed in front of an x-ray radiation source to create fluorescence radiation and a detector is placed behind the source at a certain angle. A schematic of this setup is shown in figure 2.3 while the actual setup is shown in figure 2.4 below.

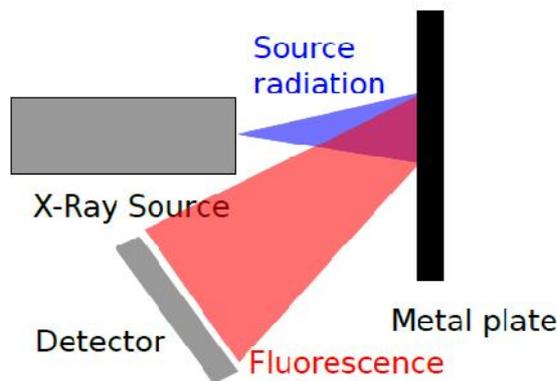


Figure 2.3 Measurement Setup[5]

Pixel cell although the architecture of MEDIPIX resembles that of the Timepix cell there are three features in the cell that differentiate the two. Every pixel can work in three different modes, and the counting Clk is synchronized with the external reference clock. The pixel is further divided into two parts, one of which digital and the other is analog. The analog part is a combination of a preamplifier, 4-bit threshold adjustment, and a discriminator. The digital part is a combination of a 14-bit shift register, Timepix Synchronization Logic, overflow control logic and an 8-bit Pixel Configuration Register. There are 550 transistors in the pixel cell. It consumes $13.5\mu\text{W}$ [9]. Figure 2.8 shows the schematics of the Timepix pixel cell and figure 2.9 shows the Timepix pixel cell layout.

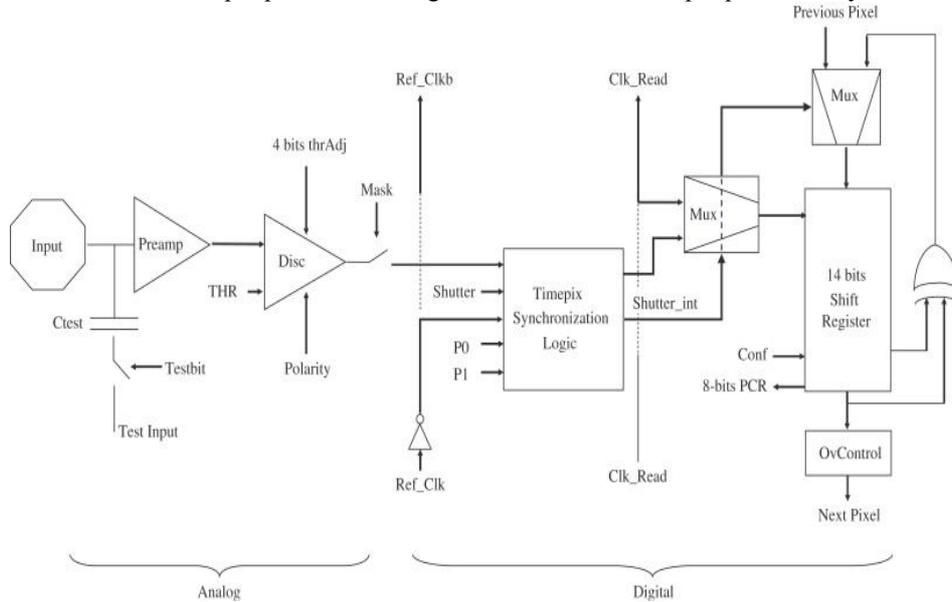


Figure 2.8 Timepix pixel cell schematic [9]

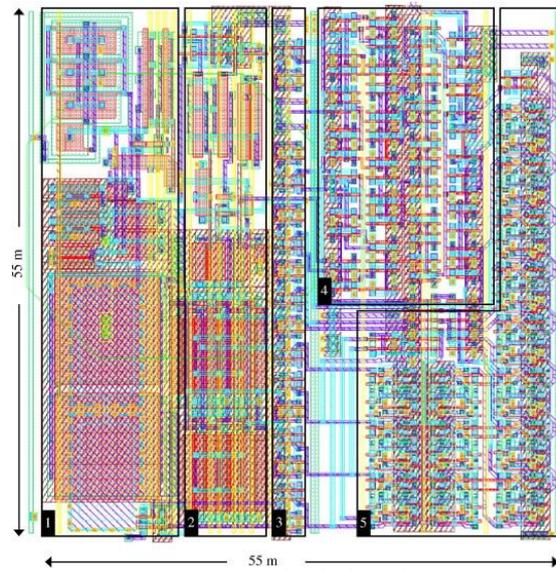


Figure 2.9 Timepix pixel cell layout

Charge sharing-ClusterThe charge collected by each pixel in the cluster can be measured using the Timepix device. The charge collection speed depends on the applied bias voltage and the cluster size (number of pixels in the cluster) also depends on that voltage. The number of pixels in one cluster is called the cluster size. If measurements are performed without removing the cluster then the resulting spectrum is distorted. Thus a calibration of the Timepix is required in order to produce a satisfactory spectrum [10].If the computation of a cluster volume is conducted without any pixel calibration then the resulting spectrum is distorted.

Pixelman-The Institute of Experimental and Applied Physics (IEAP) at the Czech Technical University (CTU) in Prague have developed software for the MEDIPIX2 acquisition control and have named it Pixelman [17]. This software supports all the MEDIPIX family devices including the MEDIPIX 2, 2.1, MXR, MEDIPIX2 MXR Quad, Timepix and Timepix Quad. All of this is achieved based on their internal flexibility. In order for these to operate for different options, it is necessary to use custom made plug-ins.**Threshold equalization**is used in order to compensate for the pixel to pixel threshold variations. The adjustment code is then selected for each pixel in order to make its threshold as near as possible to the average of the threshold distribution mean values. In other words it can be stated that threshold equalization is a procedure in which THL/THH adjustment is performed so as to make all the thresholds as homogenous as possible.Figure 2.10 below shows the threshold equalization of the TIMEPIX detector.

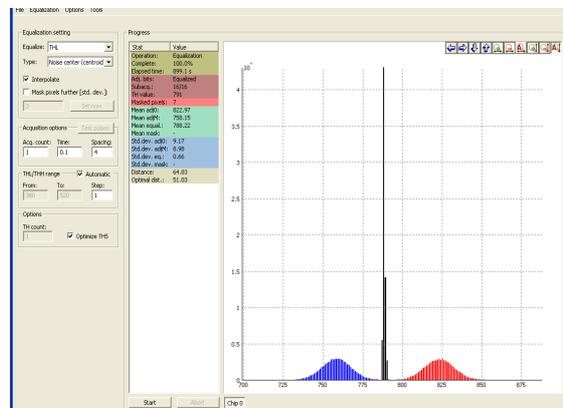


Figure 2.10 Threshold Equalization of Timepix Detector

Time over Threshold calibration-Before it is possible to make any measurements of metals, the TIMEPIX detector must be calibrated. For this purpose the TIMEPIX will be used in Time-over-Threshold (TOT) mode in which a single pixel is used for the calibration. The time –over-threshold will calibrate the energy.The calibration technique used in this case is different to that of the technique given in the TIMEPIX home page [5]. In this case, the maximum peaks of the fluorescence materials are used and these are then used for the calibration. A Gaussian curve fitting method is used in order to determine the maximum peak of the fluorescence materials. Figure 2.11 below displays the TOT calibration curve

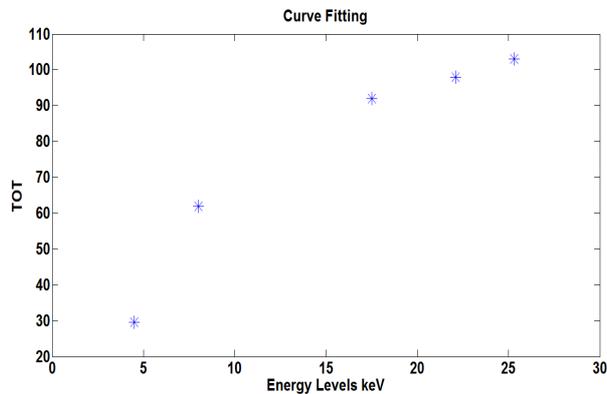


Figure 2.11 TOT Calibration measurement

The mathematical equation below is used in order to verify the calibration

$$y = ax + b - \frac{c}{x-t}$$

$$y(x-t) = ax(x-t) + b(x-t) - c$$

$$yx - yt = ax^2 - axt + bx - bt - c$$

$$ax^2 + bx - axt - yx - bt + yt - c = 0$$

$$ax^2 + (b - at - y)x - bt + yt - c = 0$$

It is known that the general form of a quadratic equation is

$$ax^2 + bx + c = 0$$

And that the quadratic Formula is

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

By placing the values of a, b and c into the quadratic formula

$$x = \frac{-(b - at - y) \pm \sqrt{(b - at - y)^2 - 4a(-bt + yt - c)}}{2a}$$

the equation thus becomes

$$x = \frac{-(b - at - y) \pm \sqrt{b^2 + a^2 t^2 + y^2 - 2bat - 2by + 2aty + 4abt - 4aty - 4ac}}{2a}$$

and finally

$$x = \frac{ta + y - b + \sqrt{(b + ta - y)^2 + 4ac}}{2a}$$

which thus verifies the calibration.

Fluorescence-In medical science, different fluorescence materials are used in order to detect and visualize the structure and process of biological samples. The reason why these are used is because the fluorescence molecule has extraordinary selectivity and sensitivity. How is it possible for fluorescence material to emit different colors of light?

Some molecules are capable of becoming excited by the absorption of light energy which results in a higher energy state which is called the excited state. This excitation cannot be sustained for any length of time and the result of this is the emission of light energy. This process is called fluorescence [11]. Fluorescence means to emit light and this process from absorption to emission is shown in Figure 2.12

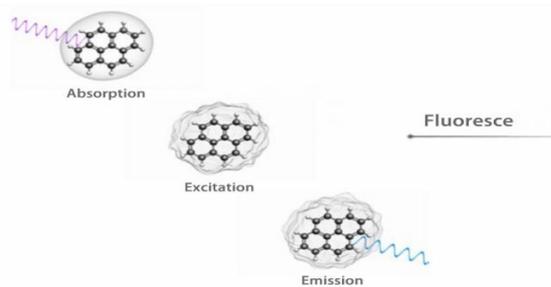


Figure 2.12 Fluorescence Procedure [11]

Fluorescence has many applications including dyes, biological detectors, chemical sensor and the very common fluorescence lamps. Materials used as fluorescence are given in the table below.

Sr.No	Materials	Energy	TOT
1	Copper(cu)	8.0KeV	62
2	Molybdenum(mo)	17.5KeV	92
3	Silver(Ag)	22.1KeV	98
4	Tin(Sn)	25.3KeV	103

Some characteristic of the materials are described in figures 2.13, 2.14, 2.15 and 2.16 below. As disused above copper, molybdenum, silver and tin are used as X-ray fluorescence. X-ray fluorescence is a processes related to x-ray absorption. The energy of generated X-ray photon typically corresponds to the binding energy of K-shell electron. The energy of fluorescent photons increases with atomic number in figures 2.13 and 2.14. Fluorescent X-

rays are emitted in any direction and can be absorbed again. X-ray fluorescence process is clearer in section 2.6 above.

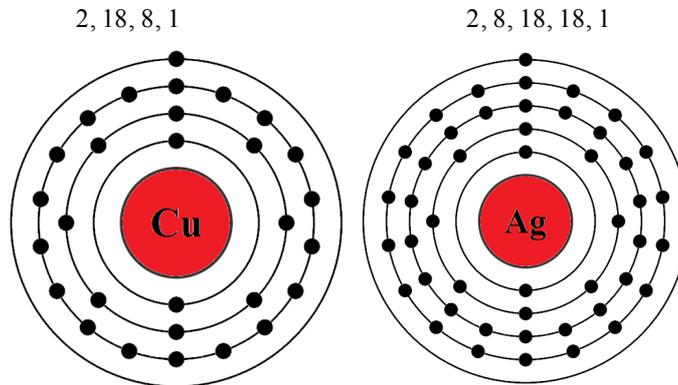


Figure 2.13 Copper

Figure 2.14 Silver

3. METHODOLOGY

In this section the different methods and techniques adopted in order to achieve the goals defined previously in chapter 1, will be discussed. Thus this section describes the entire design model in relation to the whole system. Since the problem has already been stated in the above section, it is unnecessary to provide any further explanation. However, a step wise explanation of the design model for every problem that has been already mentioned is now provided.

Curve Fitting-The idea of curve fitting is to discover a mathematical model that fits the given data. The curve fit discovers the specific coefficients or parameters which make that function match this data as closely as possible. Fitted curves can be used as an aid for data visualization and to summarize the relationships for two or more variables. It can also be stated that curve fitting is the process of constructing a curve, or mathematical function which offers the best fit to a series of data points, which are possibly subject to constraints. A Gaussian fit is used to determine the center of the peak. The reason behind the use of the Gaussian fit is that it is possible to easily view the real center of the peak because there is some noise at this peak and by using the Gaussian curve fitting technique it is easier to determine this position. It has been found that the Gaussian curve fitting is better than other models at determining the correct position of the peak.

In this work curve fitting is used to view the real center of the peak for different fluorescence materials. By using the Gaussian curve fitting technique, the real center of the peaks of different fluorescence (Cu, Mo, Ag and Sn) materials can be easily found. To implement this technique, the data will be processed in the developed MATLAB code.

RESULTS

To see the response of pixels at certain energy levels take example of copper and tin. Curve fitting is used to find the real center of the peak. Curve fitting plot in relation to the Copper sample in figure 4.13 below shows that the real central position of that curve is at 62 KeV.

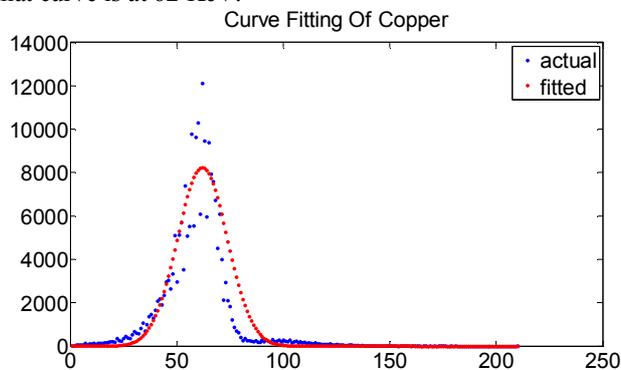


Figure 4.13 Curve Fitting of Copper

Curve fitting plot for the Molybdenum sample in figure 4.14 below shows that the real central position of that curve is at 92 KeV.

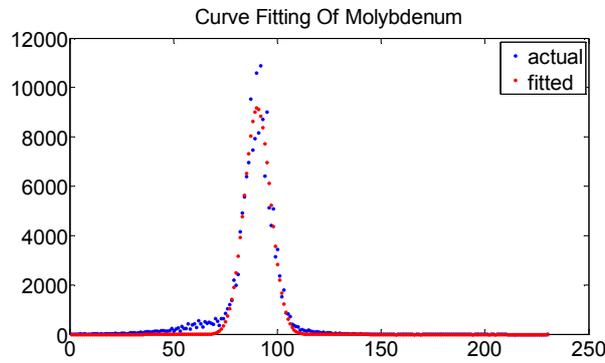


Figure 4.14 Curve Fitting of Molybdenum

Curve fitting plot of the Silver sample in figure 4.15 below shows that the real central position of that curve is at 98 KeV.

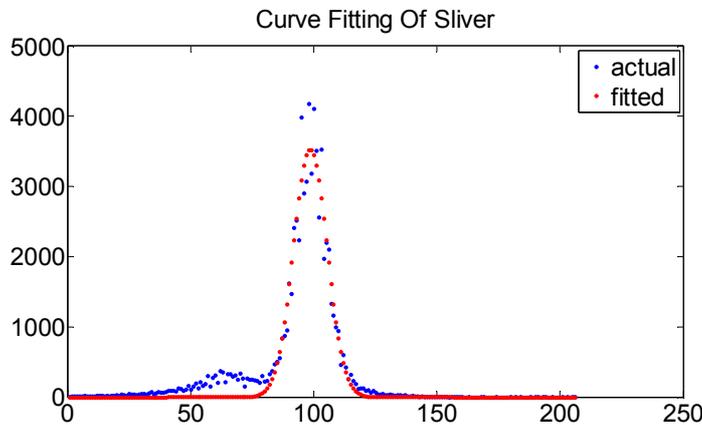


Figure 4.15 Curve Fitting of Silver

Curve fitting plot of the Tin sample in figure 4.16 below shows that the real central position of that curve is at 103 keV.

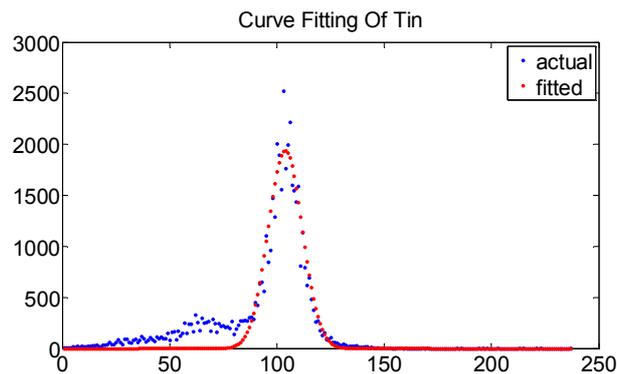


Figure 4.16 Curve Fitting of Tin

4. CONCLUSION AND DISCUSSION

System was successfully calibrated so that the response of the system could be observed for different metals at different energy levels. The analysis and the results thus generated during this paper shows that the charge summing strategy implemented in MEDIPIX3 will successful for applications in this energy ranges. Timepix is used as tool to

predict how MEDIPIX3 work and also test if sum over large area what will happen than. MEDIPIX3 and Timepix are similar but they are completely different. Spectrum of MEDIPIX3 is different from Timepix. Timepix can get the energy from every interaction in TOT mode but in MEDIPIX we get only count.

5. REFERENCES

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