

Particle detection using a silicon pixel detector 2024

2nd School on Dark Matter and Neutrino Detection

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Particle detection using a hybrid silicon pixel detector

Abstract

This experiment is designed to introduce a state-of-the-art hybrid silicon pixel x-rays detection system developed at CERN as a spin-off from the Large Hadron Collider (LHC). A basic understanding of semiconductor pixel detectors will be given by calibrating the detector with known x-ray sources and measuring the spectrum from radioactive sources. A variety of software tools will be used for data acquisition, detector calibration and data analysis.

Objectives

- Understand x-ray detection mechanisms in silicon pixel detectors;
- Measure x-ray energy spectra from various x-ray sources;
- Gain practical skills in data acquisition using the specialised program Pixelman;
- Practice data mining skills.



Caution

This experiment involves the use of an x-ray source. Improper use could result in long-term health consequences. The source should be handled with care. The Timepix detection system is fragile and very expensive. Please handle with care.





Particle detection using a silicon pixel detector 2024

General recommendations

Use the folder “C:\Users\Lape\Desktop\YourName\” to store any files. There are questions in the script highlighted with a “?” sign. These are questions to guide the discussion.

Particle detection using a silicon pixel detector

2024

TimePix detectors

The hybrid pixel detector is one of several types of instrumentation currently available for x-ray precision measurements. [What other types of detectors do you know?](#) It comprises a detection medium and readout electronics manufactured in different fabrication processes. Both parts of the detection system have a matching matrix of electrodes that are brought into contact via a process called bump bonding (see [Figure 1](#)). [What other solid-state detectors apart from silicon are in use?](#)

The Timepix detector used in this experiment was developed by CERN and the Timepix Collaboration (see [Figure 2](#)). It contains 256x256 pixels of 55x55 μm^2 each that can operate in spectroscopic mode (Time-over-Threshold mode, known as ToT mode), where energy information is obtained at the same time as the position of the interactions. [What other modes can this device run in?](#) The data is read out by a plug & play USB interface using the Pixelman software. [How does the ToT mode work? Discuss with the demonstrator.](#)

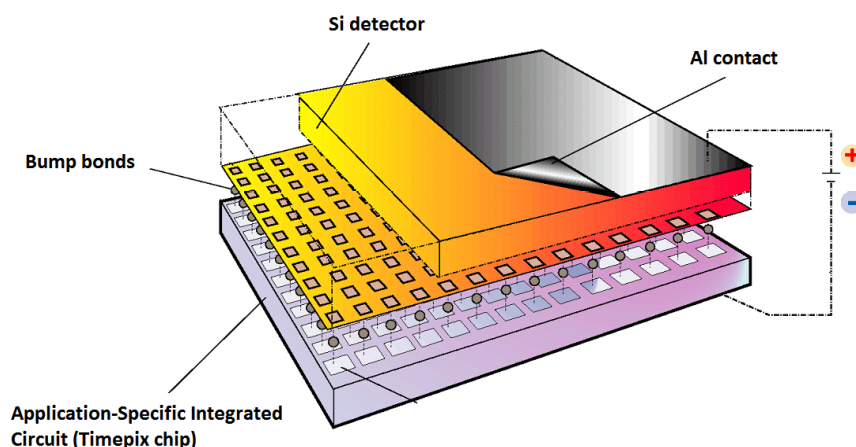


Figure 1. Hybrid pixel detector schematics.

Particle detection using a silicon pixel detector 2024

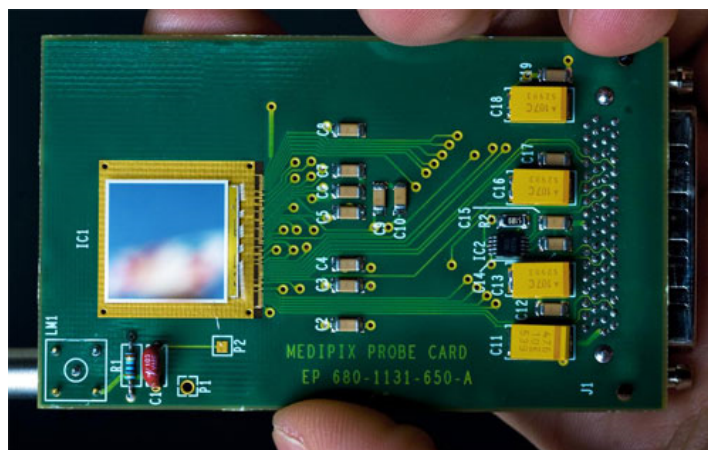


Figure 2. TimePix detector.

Particle detection using a silicon pixel detector

2024

Experimental procedures

Experimental setup

Figure 3 shows the diagram of the detection system used for this experiment. It consists of various x-ray sources, ([Get the energy of the fluorescence light from the source datasheet](#)), a TimePix detector with USB interface and a PC used for data acquisition.

The USB interface has two connections. The LEMO cable provides DC bias to the silicon detector (+100V) from the USB interface. The USB cable powers the device and handles data acquisition.

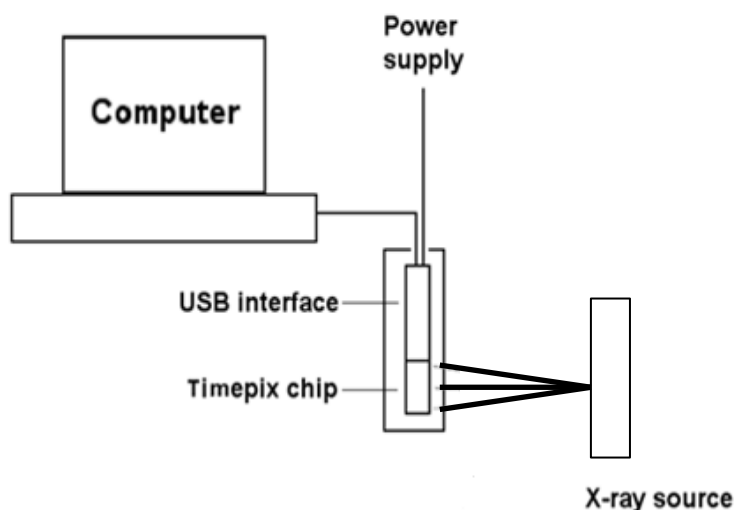


Figure 3. Characteristic x-ray spectra acquisition setup.

Setting up the detector

Run the Pixelman program from the Desktop. Two windows should pop up, Medipix Control and Preview. The first one is used to control the parameters of data acquisition and set up the sensor, while the latter displays the data recorded. The software is user friendly and most of the options are self-explanatory.

Check that the bias on the detector is set correctly on the panel (**Device Control** → **Options** → **Device Settings** → **Interface Specific Info** tab). Check, that bias voltage is about 90 V (usually 80-98 V). Otherwise consult your demonstrator. [Why do you need to bias a silicon detector?](#)

Check that the ToT clocking frequency is set to either 48 or 40 MHz (**Device Control** → **Options** → **Device Settings** → **Interface Specific Info** tab, set TimePix clock value to 48).

Particle detection using a silicon pixel detector 2024

Threshold equalisation

The Timepix sensor operates in a “noise-free” mode. The chip removes the electronic noise in the silicon detector system by setting an appropriate threshold (called THL in Pixelman), below which the signal induced in the pixel is disregarded. The threshold needs to be adjusted for each pixel with a per pixel threshold adjustment bit. [Why would one need to equalise thresholds in different pixels?](#)

Each pixel in the chip responds in a slightly different way to incident radiation due to transistor fabrication mismatches and non-uniformities of the detector. In order to obtain a better and more uniform response, the narrowest possible distribution of pixel threshold levels across the chip has to be found. The procedure for threshold equalisation is described below. [It is recommended to perform this once a day to ensure uniform response of the chip. What could happen on another day that affects the performance of the detector?](#)

Device Control → File → Set Mode → Medipix

Device Control → File → Reset Pixel Cfg. → All Bits

Device Control → Tools → Threshold Equalization

A window similar to the one in [Figure 4](#) will be displayed. Make sure that the parameter values on the left-hand side of the window are as indicated.

Press Start. The plot on the right hand side should look similar to the one in [Figure 4](#). If the distributions do not have Gaussian-like shapes, it could be due to too much ambient light incident on the detector. Cover it with black tape.

[This procedure takes about 10 minutes. Discuss with each other and the demonstrator what is happening during this procedure. Look at the results window and try and understand what it is showing you.](#)

Particle detection using a silicon pixel detector 2024

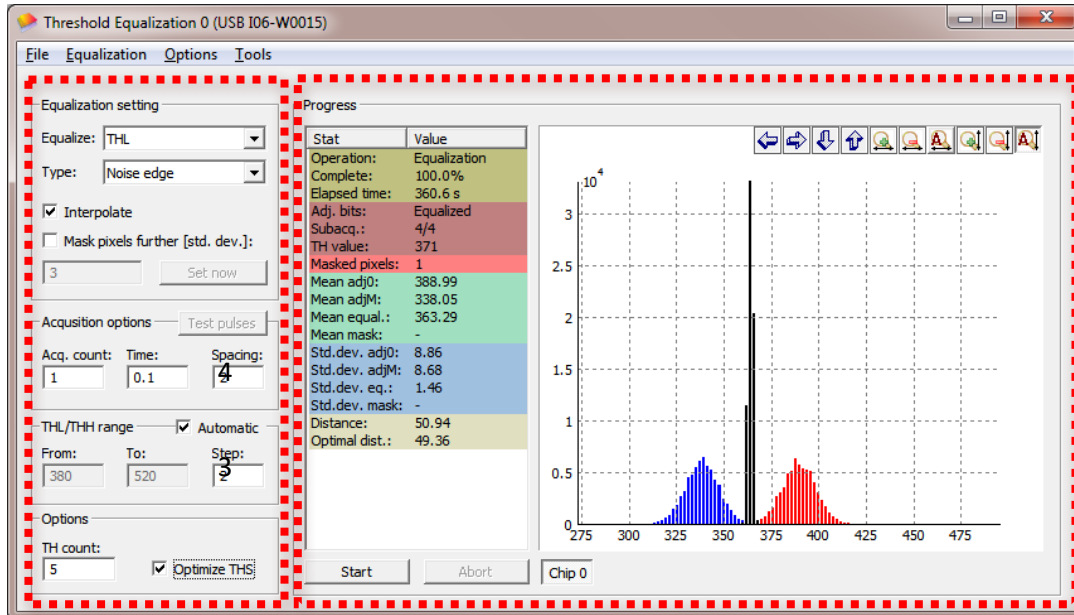


Figure 4. Threshold Equalization of the chip.

Device Control → Tools → DAC Control Panel (see Figure 5)

The THL (threshold) value is ambient-temperature-dependent, but should be around 350-380 ADC. *What do ADC and DAC stand for?* Set THL to about 20-25 units below the indicated value (see Figure 5), e.g. if the displayed value is 385 ADC, set ~360-365 ADC. Note that a lower THL value here implies a higher threshold value.

Close the Threshold Equalization window.

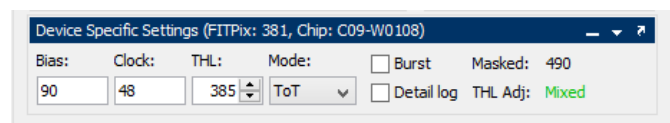


Figure 5. Device Specific Settings control panel.

In the Device Control window set

Acquisition type Integral

Acquisition count 10

Acquisition time 1 s

Press Start to acquire data. In the Device Specific Settings panel set Max Level 1. Some pixels will be shown in red, indicating an excessive (> 100) number of counts. These are to be excluded from further data acquisition.

If there is an excessive number of red pixels set the THL DAC level 5 lower.

Particle detection using a silicon pixel detector

2024

Right click on the image area and select **Mask...** from the menu, enter 1 and press OK. These pixels should now be displayed in blue.

The setup is now ready for data acquisition. [Can noisy pixels appear in the future? Why?](#)

Time over Threshold (ToT) x-ray energy spectra

Data acquisition

A photon of specific energy generates a certain number of electron-hole pairs in the detector. [What energy required to generate an electron-hole pair in silicon for ionisation from high-energy photons/particles?](#) These are collected by the pixels and converted into digital units. There is a relation between incident photon energy and corresponding ADC value for a given detector.

In order to establish this relation, spectra of known x-ray sources must be recorded. In this experiment characteristic photons from [he different sources available](#). [What are the different characteristics for alpha/beta/gamma energy depositions?](#)

There is limited time for this laboratory and it is not expected that a full energy calibration be possible. Data will be collected over the session to build a more detailed graph. Your results of x-ray energy and ToT value should be added to the Calibration Graph spread sheet on the desktop.

It is important to look at the images collected in the Pixelman Preview window and at the spectra produced in the analysis section.

Place the source on top of the detector. In the Pixelman software follow this procedure.

Device Control → **File** → **Set Mode** → **Time Over Threshold**

Set the Acquisition Control parameters as shown in Figure 6.

Acq. type Frames

Acq. count 1000

Acq. time 0.05

Binary matrix

Single file

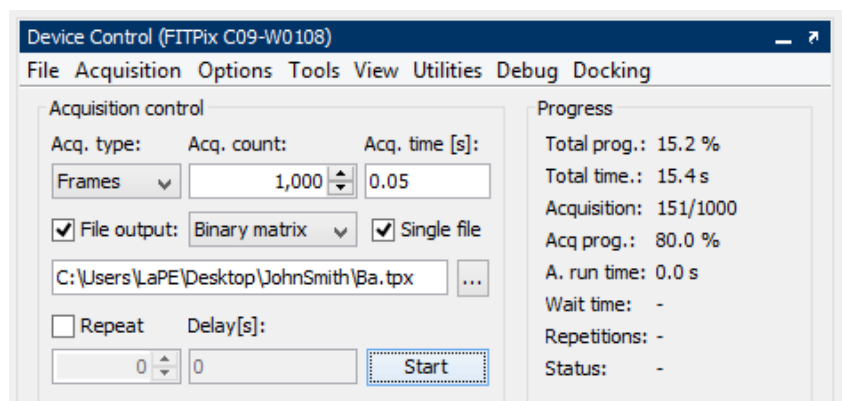


Figure 6. Device Control panel.

Particle detection using a silicon pixel detector 2024

✓ File output

The output file should correspond to each target element to be recorded, e.g. for a Ba target the path should be

```
"C:\Users\Lape\Desktop\YourName\Ba.tpx"
```

Press start. In the Preview window interactions of X-rays with the silicon sensor will be displayed and recorded. There are several options in the window available for better output data representation. Play around and figure out what they do.

Acquire data for **at least three** of the following targets: (Cu, Mo, Ag, Rb, Ba, Tb); and also for Sr-90.

Why does the image on the Preview screen look so different for the Sr-90 source?



Data analysis

Interaction of x-ray photons in the sensor is recorded in the form of digital units (ADC). These are converted into the incident photon energy using a *calibration curve*. Moreover, since the generated electron-hole cloud has a finite size, sometimes interactions are recorded by several pixels simultaneously. The spread of charge between adjacent pixels has to be corrected in order to obtain the correct spectrum (this is called *clustering*).

A ROOT script will be used to perform the analysis of the data from Pixelman. Execute root by opening a **cmd** terminal from the program menu, and typing **root**. Then load the cluster analysis code on the ROOT terminal:

```
.L C:\Macros\clusterAna.cpp
```

Executing the code reads TimePix data with the following input variables: data file, number of events, debug:

```
readTimePix("../Desktop/YourName/Ba.tpx", 1000, false)
```

The code returns to screen the number of clusters found per frame.



What is a cluster? Why does the size distribution change with the energy of the x-ray?

Why is there a different number of clusters for each target? Does that correspond to what you expect? Is the efficiency the same for all energies?



When the analysis is finished a canvas appears that contains three graphs, the ToT (energy) spectra obtained for single pixel clusters, the energy spectra obtained for multi-pixel clusters and the cluster size distribution.

Think about the shape of the different spectra. Make a note of the peak(s) from the spectra and record this against the x-ray energy to form a calibration graph (excel macro on the desktop).

Particle detection using a silicon pixel detector 2024

Are there any peaks present in the multi-pixel clusters that are absent from the single pixel clusters, if so why?

Why does the spectrum from the Sr-90 look so different to those from the other sources? Discuss your results among each other and with the demonstrator.



Additional literature

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8. G. P. Harnwell and J. J. Livingood (1933), *Experimental Atomic Physics*, 1st ed., McGraw-Hill Book company, 363-365.
9. J. C. Willmott (1975), *Atomic Physics*, John Wiley & Sons Ltd., 324-328.

Other relevant sources of information

1. Timepix chip <http://www.cern.ch/MEDIPIX>
2. Pixelman software <http://aladdin.utef.cvut.cz/ofat/others/Pixelman/Pixelman.html>
3. Periodic table elements fluorescence X-ray energies <http://xdb.lbl.gov/>
4. ROOT Data Analysis Framework <https://root.cern.ch>