SoPhy

Software for Physics

Timepix control system

Timepix and Timepix3

User Manual

September 18, 2018

Contents

1 Introduction

1.1 SoPhy

SoPhy is an abbreviation for "Software for Physics". SoPhy is a data acquisition, visualization and processing software platform developed by Amsterdam Scientific Instruments. This manual describes SoPhy for Medipix/Timepix control and data acquisition.

1.2 SoPhy concept

SoPhy consists of multiple modules that can control each other and pass each other data for processing. Each module runs asynchronously from the rest of the program. The advantage of this approach is the maximization of utilization of modern multi core CPUs – each core can be processing a different task and therefore the data throughput is greatly increased. The modular structure is shown in figure 1.1.

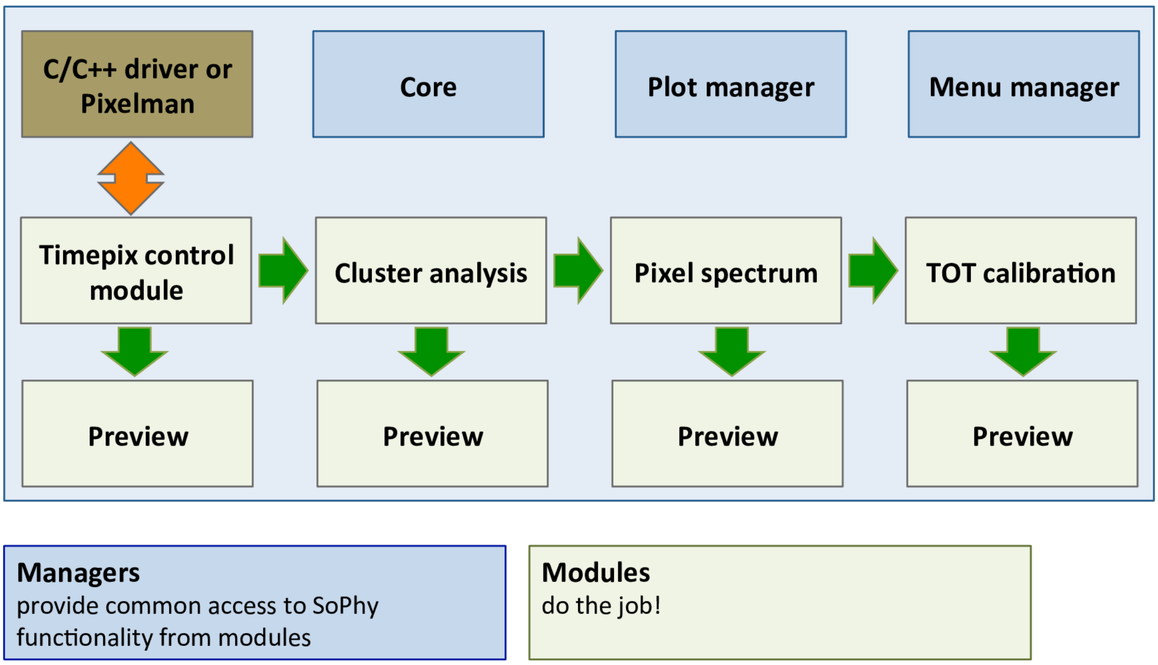


Figure 1.1: Schematics of SoPhy's modular structure

The data stream from the detector driver comes to the Timepix control module and then the data is distributed into other attached modules. Each module usually contains a preview to monitor the status and the progress of the measurement. SoPhy also provides numerous tools for users and programmers for easy data visualization (plots, images), processing (parallelized matrix operations, FFT, CT reconstructions, cluster analysis...) and data storage. Measured data are stored into zipped files containing and XML structure and the binary files with larger blocks of data. The data can be exported to different formats (ASCII and other).

1.3 Supported operating systems

SoPhy is written in Java. Therefore, SoPhy can be used on all major platforms: Windows (7, 10), Mac OS X (10.6 and up) and Linux (Debian, RedHat and other). Screenshots of SoPhy windows from all supported operating systems are used in this manual.

1.4 Connecting the detector

The detector to be used needs to be connected to the computer. The communication between the detector and the computer uses standard IPv4 Ethernet protocols, TCP/UDP. IPv6 is preferably disabled. The actual data are transmitted over UDP to minimise overhead, but this implies that dropped packets mean lost data. To avoid this, make sure the best available drivers are installed, do not use other software on the computer that is not necessary (for example mail programs or web browsers), and avoid having a firewall interfere with the network traffic on this connection.

For Timepix1/Medipix a Cat5e or Cat6 cable is used between the RJ45 socket of the detector and the corresponding connector on the computer. It is advisable to have a good quality network interface, we have good experiences with the Intel i350 series.

For Timepix3 a SPIDR readout board is used, which has both a double SFP+ cage and a RJ45 socket. To be used is the top part of the SFP+ cage, assuming the cooling ribs are on top of the housing. Typically a suitable fiber cable will be provided, with 2 transceivers, one of which is certified for use in the SPIDR board. The clip of the transceiver and cable will be on top.

The IP address of the computer network interface needs to be set manually, so the detector and computer are in the same segment.

- **For a Timepix1/Medipix detector, with IP address 192.168.33.175, the address of the computer is best set to 192.168.33.1, netmask 255.255.255.0.**
- **For a Timepix3 detector having IP address 192.168.100.10, the address of the computer is best set to 192.168.100.1, netmask 255.255.255.0.**
- **To use Timepix3 in the 1 Gb mode, the computer address has to be set to 192.168.1.1 with netmask 255.255.255.0.**

For the Timepix3 detector it is also essential to enable jumbo packets: these are up to 9000 bytes in size.

Some further parameter tuning:

- **For Linux:** `sysctl -w net.core.rmem_max=26214400` or rather add this setting to the `/etc/sysctl.conf`
- For Windows: increase the receive buffers under the adapter ⇒ configure ⇒ advanced ⇒ performance options

1.5 Installing and starting SoPhy

1.5.1 Windows

SoPhy is distributed as "all-in-one" package. It means that it does not require any installation. Unpacking the distribution package to selected directory is the only required installation step. SoPhy is started using "SoPhy.exe" executable.

1.5.2 Mac OS X

SoPhy is distributed as "all-in-one" application package. Installation requires only unzip the SoPhy.app and copying it into Application folder. Running it on Mac OS X 10.8 and up requires installation of Java version 1.8. If Java is not already installed a window will appear after starting SoPhy for the first time guiding you though the Java download and installation process. SoPhy can be then run as any other application on Mac.

1.5.3 Linux

SoPhy is distributed as "all-in-one" application package for Debian/Ubuntu or Red-Hat/Fedora.

1.6 Graphical User Interface

The main control window (figure 1.2a) and the toolbox (figure 1.2b) appear after starting SoPhy.

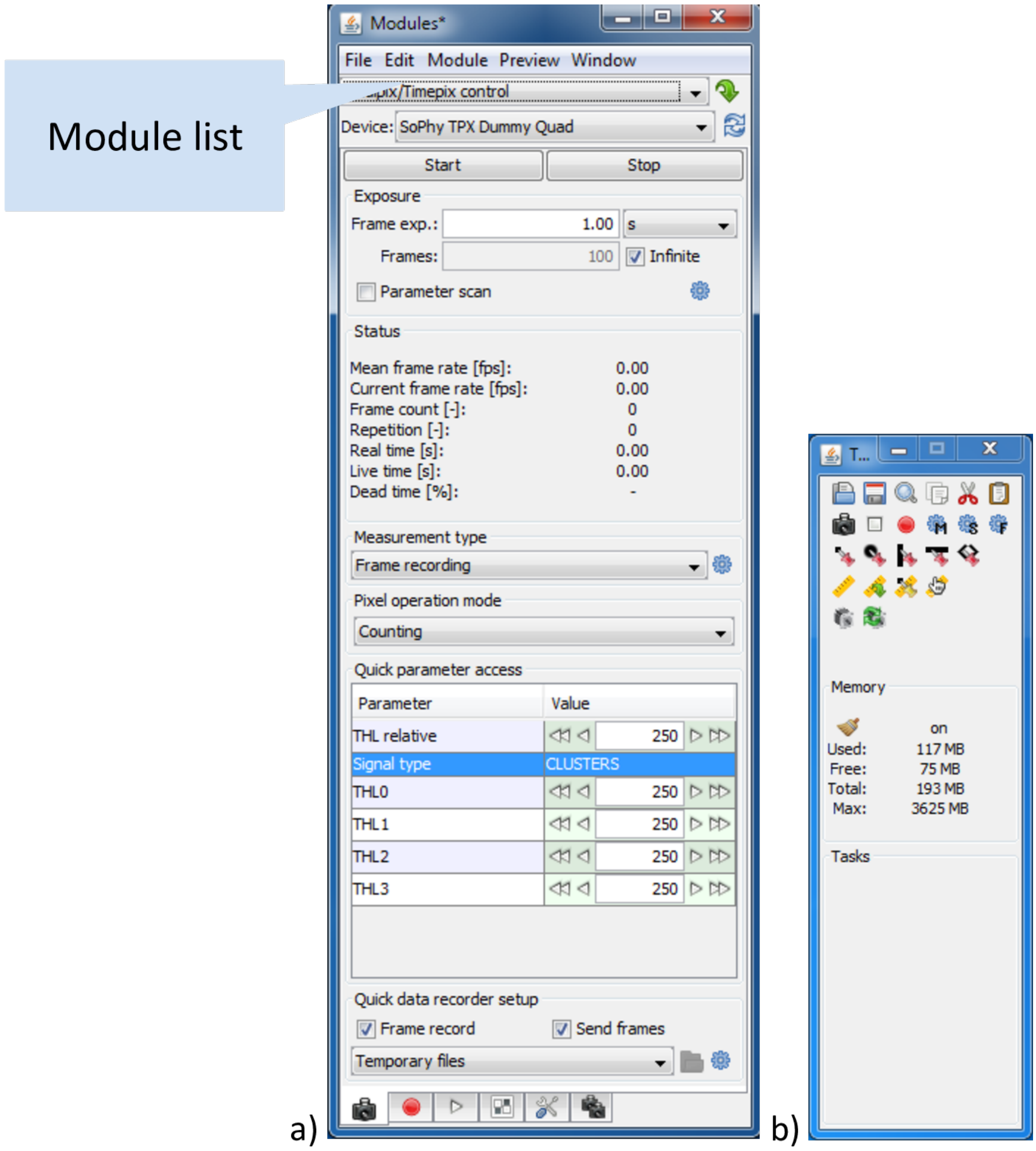


Figure 1.2: SoPhy main control window (a) and toolbox (b).

The main control window contains a list of modules that can be controlled by the user. Changing the selected module in the list will switch to the control panel of the selected module. The toolbox contains icons allowing direct switching to other modules too. For instance:

 Medipix/Timepix control.

 Beam hardening calibration.

 Stepper motor controller.

The detector configuration can be loaded through “Module ⇒ Medipix/Timepix control ⇒ Open settings...” or simply by dragging the file onto the toolbox or main panel window. A configuration file was delivered with the detector. SoPhy saves the location of this file in the user preferences, and loads the same file automatically next time you start it. The toolbox contains besides load/save, copy/cut/paste icons also tools for different modules. See description of the actual module for details.

2 Plot control and data import/export

The basic plot window (figure 2.1) contains the plot canvas and properties panel on right.

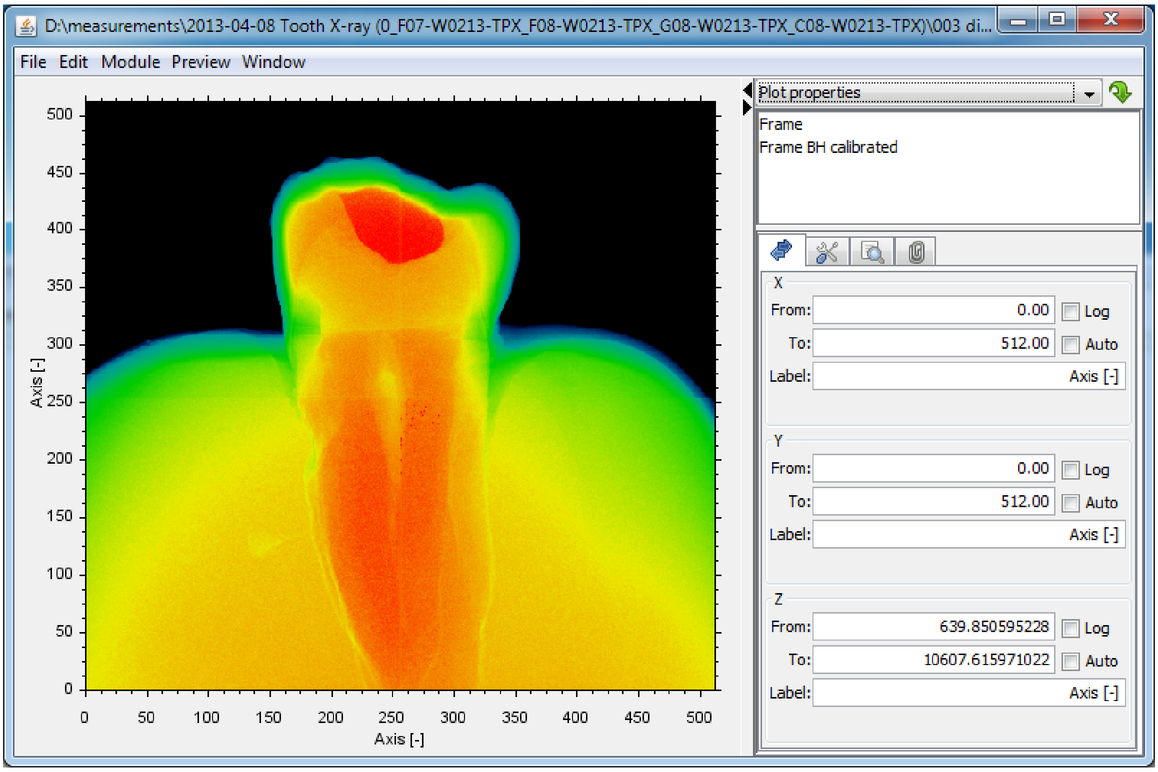
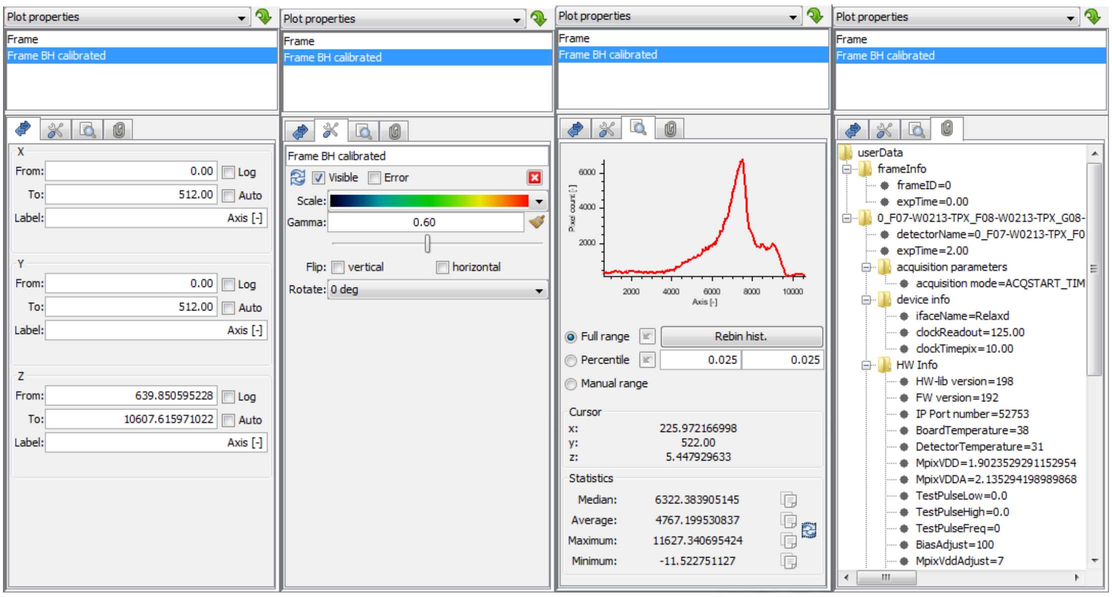


Figure 2.1: Plot/image window

The properties panel allows setting axis ranges (figure 2.2a), hide/show and setup individual data sets (figure 2.2b), explore the image histogram (figure 2.2c), and explore user data associated with the data set[1] (figure 2.2d).

Windows for previews of measured/processed data in modules contain also frame rate control (figure 2.3).

Clicking and dragging in the image canvas allows zooming into a section of the image/plot. The mouse scroll wheel can be used as well and it can be combined with control, alt and shift keys to scroll and zoom vertically/horizontally. SoPhy on Mac supports also gestures (swipe to scroll and pinch to zoom).



(a) axis ranges (b) data sets and color scales (c) image histogram (d) meta data

Figure 2.2: Plot control sub-panels

TIP 1!

Gestures, mouse wheel and zooming works also on the histogram and other embedded plots.

TIP 2!

List of data sets allow copy, cut and paste operation. It is possible to select more than one data set

The plots can be opened, saved and exported from the File menu. Plots can be loaded by dragging and dropping the saved file onto SoPhy main panel or toolbox windows.

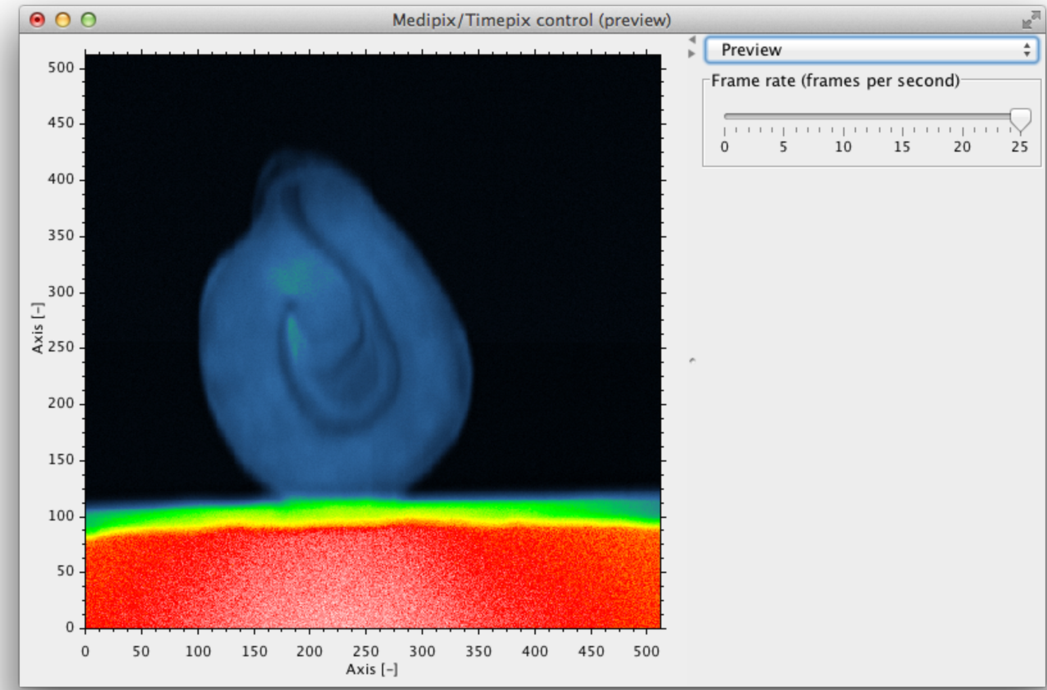


Figure 2.3: Frame rate control in module preview window.

3 Medipix/Timepix control

3.1 Description of Timepix/Medipix chip

The names Medipix and Timepix refer to Application Specific Integrated Circuits (ASICs) of pixelated single quantum counting detectors. Both Medipix and Timepix are chips with arrays of 256x256 pixels. Each pixel contains its own electronics for processing the signals delivered to it from a sensor. Individual pixels count the number of detected quanta (counting mode). Timepix has compared to Medipix also two additional modes: Time-Over-Threshold and Time-Of-Arrival. All three modes of operation are supported by SoPhy.

Counting mode
Every pixel contains an amplifier, pulse height discriminator and counter. The number of pulses above a pre-set threshold is recorded in the counter. The counting mode is suitable for X-ray imaging where intensity of the incoming radiation is measured. The energy of incoming radiation can be estimated by varying the energy discrimination level in the chip (see section 3.7).

Time-Over-Threshold mode
Timepix electronics is compared to Medipix extended also by a mode where the total amount of charge collected in an individual pixel can be recorded: Time-Over-Threshold mode (ToT). The pulse length from the amplifier depends on the amount of charge collected from the sensor. Larger signals will increase the ToT. The counter in the ToT mode then contains the number of clock signals elapsed while the detected signal was above the pulse discrimination level (threshold). The ToT mode is used in the spectral imaging measurement type described in section 3.6.

Time-Of-Arrival mode
An other mode of Timepix operation is Time-of-Arrival (ToA), where the pixel records time between opening the shutter and arrival of radiation into the sensor. This mode is suitable for Time-Of-Flight applications. The ToA mode can be used in combination with any of measurement types in SoPhy depending on the application.

3.2 Description of Timepix 3 chip

The Timepix 3 chip is a further development of the Timepix chip. The most distinguishing feature is the "Data driven" mode, where every detected hit produces an immediate response during the exposure, which can contain both the Time-Over-Threshold and Time-Of-Arrival information. While this raw data can be stored for later analysis, SoPhy will show a frame-based preview.

Counting mode
: Every pixel in the preview will show how many hits have been recorded.

Time-Over-Threshold mode
: Every pixel will show the sum of the ToT-values of the hits observed for the pixel.

Time-Of-Arrival mode
: Every pixel will show the latest ToA value.

3.3 Main control window

The Module control window and toolbox will appear (figure 3.1) after starting SoPhy.

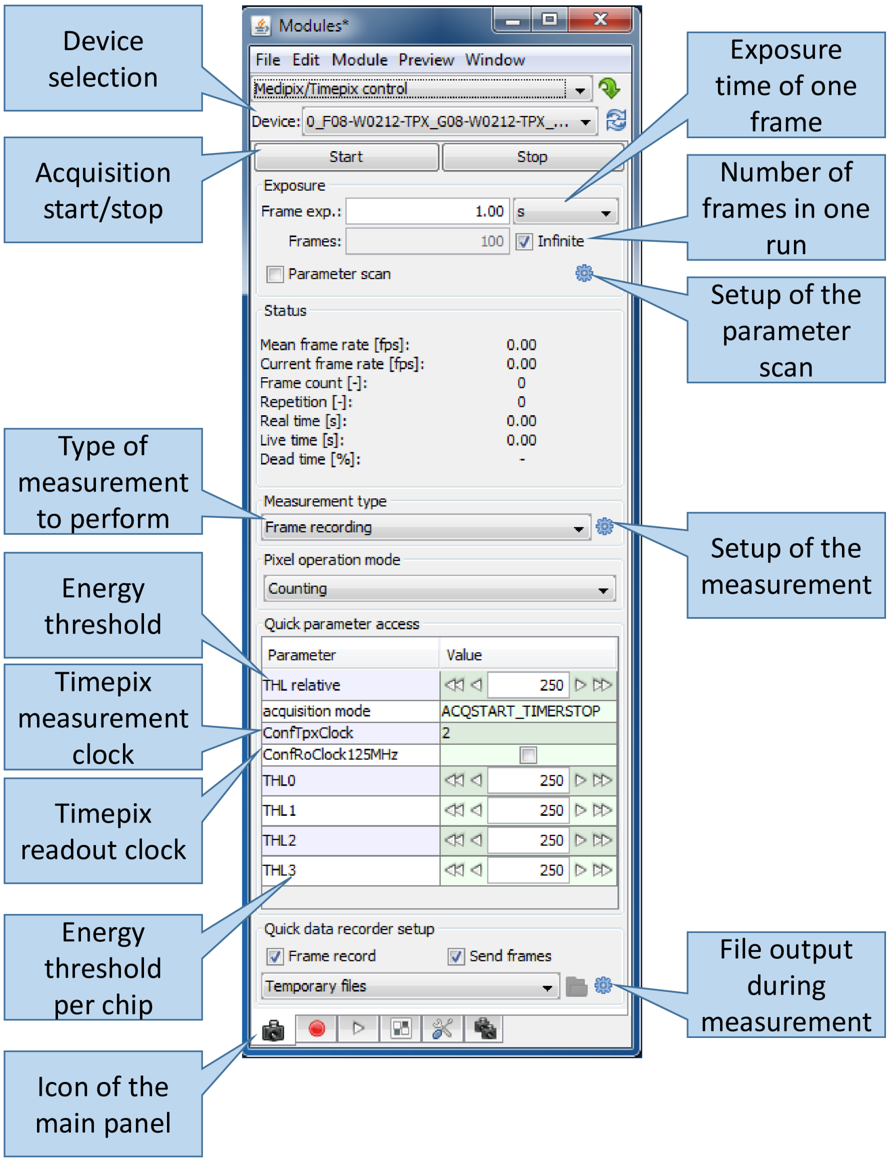


Figure 3.1: Medipix/Timepix detector main panel.

The first tab of the main panel allows selecting the connected device, setting the frame exposure time, number of frames to measure, type of measurements, location of data storage and access to the most important detector settings. For the Timepix chip these are

- energy thresholds: the average, and per chip;
- acquisition mode;
- measurement clock (0 = 100 MHz, 1 = 50 Mhz, 2 = 10 Mhz, 3 = Ext.);

- readout clock (default 62.5 MHz, optionally 150 MHz[1]);

Other tabs are switched using the icons on the bottom and contain the additional advanced settings of the detector and the data acquisition.

3.4 Detector settings

The detector parameters are accessible though the DAC settings panel under tab and the Advanded detector settings tab in figure 3.2.

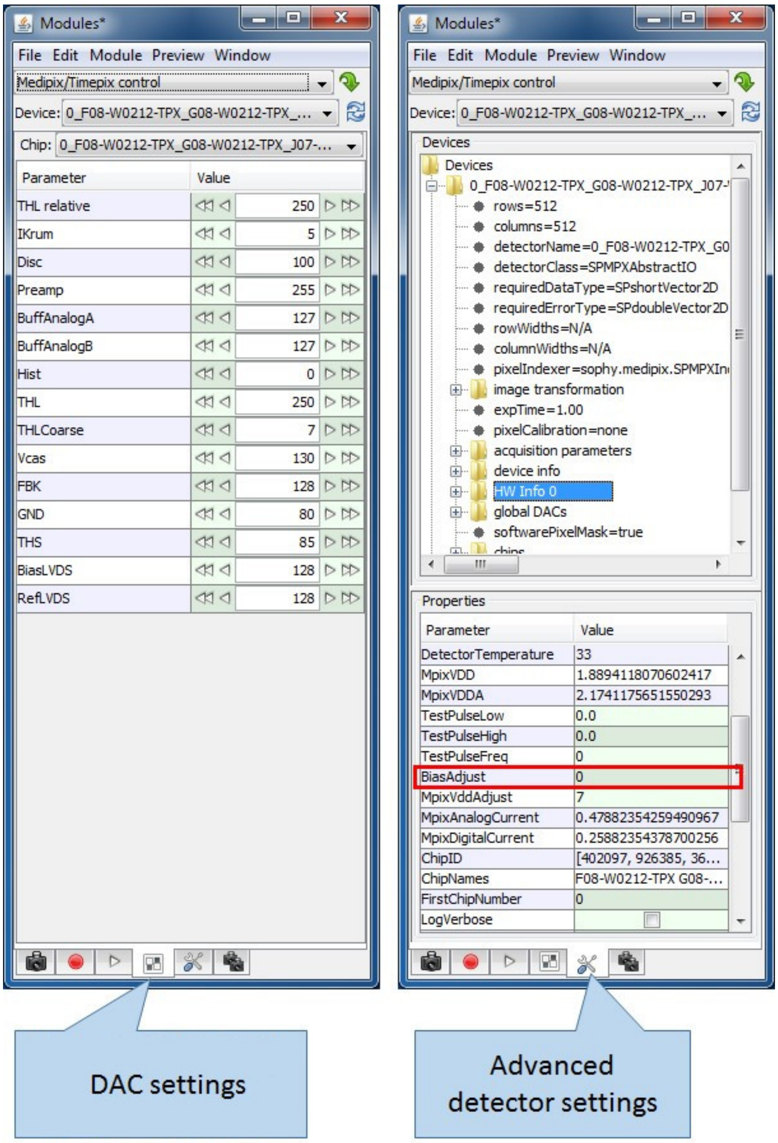


Figure 3.2: DAC settings panel and advanced detector/readout settings.

1 historically this was 125 MHz, hence the name of the parameter

3.4.1 DACs and energy threshold settings for Timepix

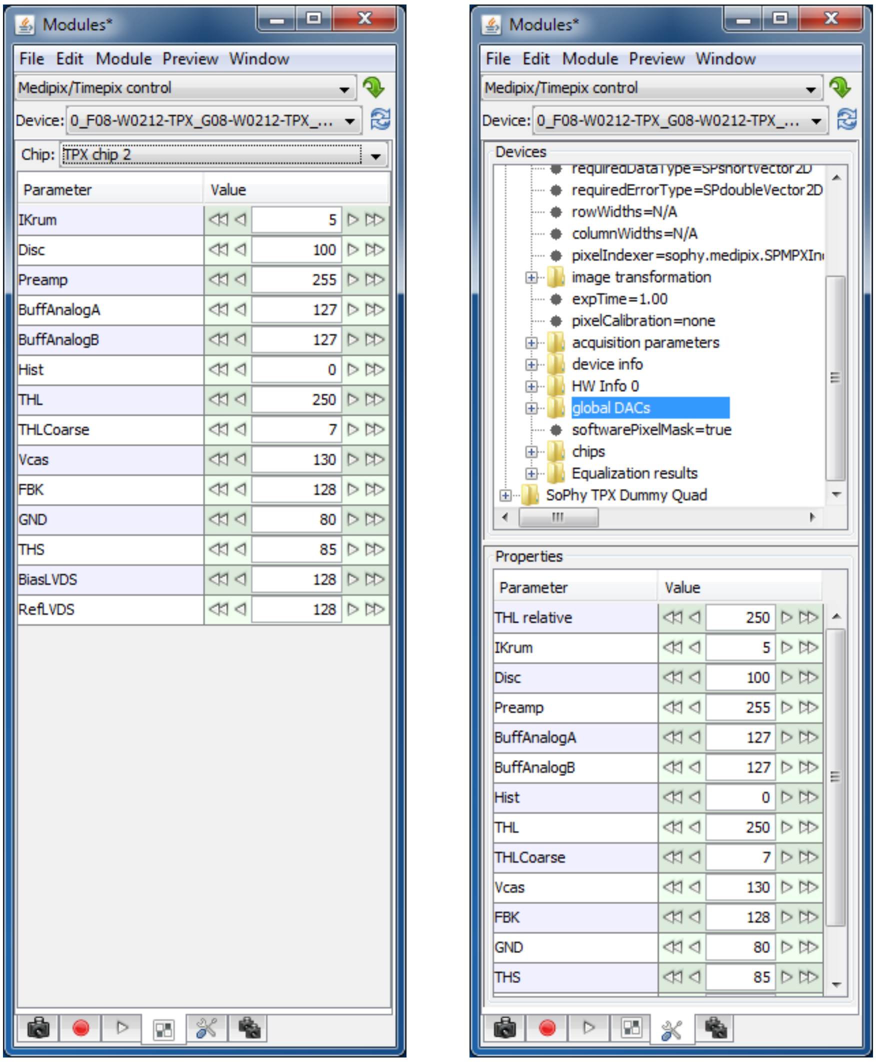
A subgroup of the detector parameters are the Timepix/Medipix Digital-to-Analog converters (DAC). DACs are settings of the Timepix/Medipix ASIC chip itself and table 3.1 contains the list of all DACs including a short description.

Table 3.1: DAC parameters

		DAC	Type	Description
Global biasing DACs	CSA	Preamp	Current	Controls the gain of the charge sensitive amplifier (CSA) and has effect on the equivalent noise charge - the lower the Peamp current, the higher the noise.
		IKrum	Current	Bias current, affects the pulse shaping and has effect on gain. The higher the current, the shorter shaping, but lower gain.
		GND	Voltage	DC voltage for CSA.
		FBK	Voltage	Baseline gate voltage. If V_TH=V_FBK then the discriminator is just in the noise.
	Discriminator	Disc	Current	Controls gain of the OTA amplifier in the discriminator.
		DelayN	Current	Delay in the Double Discriminator Logic (DDL) controlling pulse width.
		THS	Current	Current for pixel equalization.
		THL	Voltage	Fine lower threshold.
		THLCoarse	Voltage	Coarse lower threshold.
		THH	Voltage	Fine upper threshold.
Logic		THHCoarse	Voltage	Coarse upper threshold.
		BiasLVDS		Bias current in the LVDS drivers.
		RefLVDS		LVDS output common mode.
		Ext DAC		External DAC. Any internal DAC can be switched off and provided from outside.
Test pulse		BuffAnalogA		Gain of injection test pulse buffers. Limit of the test pulse charge.
		BuffAnalogB		Gain of injection test pulse buffers. Limit of the test pulse charge.
TPX[2]		IHist	Current	Hysteresis in the discriminator. Setting IHist to 00h switches off the hysteresis

The majority of DACs can be used with default settings. Exception are the DAC THL and THL coarse, which control the energy discrimination threshold in pixels. **For sensors with positive polarity (most of Si sensors) applies that the lower the value of the threshold, the higher the actually energy discrimination level.** The THL Coarse DAC and control the threshold in large steps. The default value is 7 and it is sufficient for most applications. The noise floor of the chip with Si sensor is typically at THL value between 300 and 500. Value within this range is within manufacturing tolerances.

The DAC values listed in table 3.1 are individual settings for one Timepix chip. I.e. the STPX device has one set of these parameters. The QTPX device consists of four chips and therefore has four sets of these DACs. The DACs can be changed either in the DAC panel (figure 3.3a) or in the detector settings tree (figure 3.3b).



(a) using the DAC pane, per chip

(b) using the settings tree, global

Figure 3.3: DAC settings

Select the chip in the combo box above and the table below is filled with the appropriate DACs panel (figure 3.3). The chip selection combo box contains also the detector ID that represents DACs of all chips combined. This allows changing the DAC value for all attached chips at the same time. In case that the DAC value is different for each chip the Value box right to the DAC name shows “multiple”. The only exception is the parameter “THL relative” which cannot be found in the individual chips. This is a virtual DAC parameter with value that is average value of all chips in the detector. Changing THL relative will cause all THL values to be changed by the same delta, i.e. if the THL relative is increased by 10 then all THL values in chips will be changed by 10 steps.

3.4.2 Readout parameters

The detector readout parameters can be set in the panel . The tree contains both read only and read/write type of parameters. Clicking on the tree node or parameter will fill up the table under the tree. Parameters that are green can be changed.

The most important are

Acquisition parameters defines how measurements are performed:
  - polarityPositive sets if electrons or holes are collected;
  - acquisition mode sets how the detector is triggered;

HW Info 0 status and adjustments for the readout electronics:
  - BiasAdjust sets the bias voltage on the detector;
  - ConfTpxClock sets the Timepix clock frequency;
  - ConfRoClock125MHz sets the readout clock frequency for Relaxd;
  - TriggerType (for Relaxd) defines the signal type for the shutter control.

3.5 Measurement types

The main SoPhy Medipix/Timepix control panel contains selection “Measurement type” (figure 3.4). It serves as pre-set configurations of SoPhy for different measurement tasks.

Currently these measurement types are supported:

- Frame recording: the basic mode where images are just recorded,
- Spectral imaging: (cluster analysis): per-pixel energy spectra and cluster analysis,
- Mass spectrometry: using the Time-of-Arrival,
- MPX Equalization: a pixel threshold fine tuning tool.

All the four measurement types are covered in following sections.

3.6 Frame recording

Select measurement type “Frame recording”, setup the desired number of frames and per-frame exposure time. Then press the “start” button on the control panel and the detector will start acquiring data. The acquisition will stop either after the

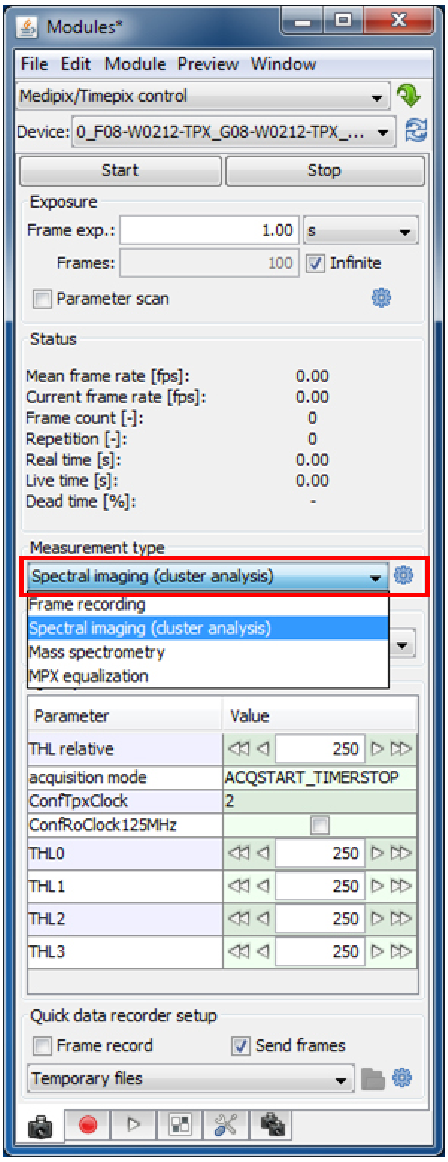


Figure 3.4: Measurement type selection.

pre-set number of frames is reached or when “stop” button is pressed. Open the preview window from “Preview ⇒ Medipix/Timepix control” or using the icon in the toolbox.

A data set can be used as a flat field. To do this, use the gear icon next to the measurement type. This will open a new menu where the current data set can used for the flat field correction. Also on this menu a previous flat field correction can be removed.

Medipix/Timepix is a single photon counting detector and therefore the error of the pixel value is $\sigma = \sqrt{n}$ where n is the number of counts in the pixel. An arbitrarily small relative error

$$\sigma_r = \frac{\sigma}{n} = \frac{1}{\sqrt{n}}$$

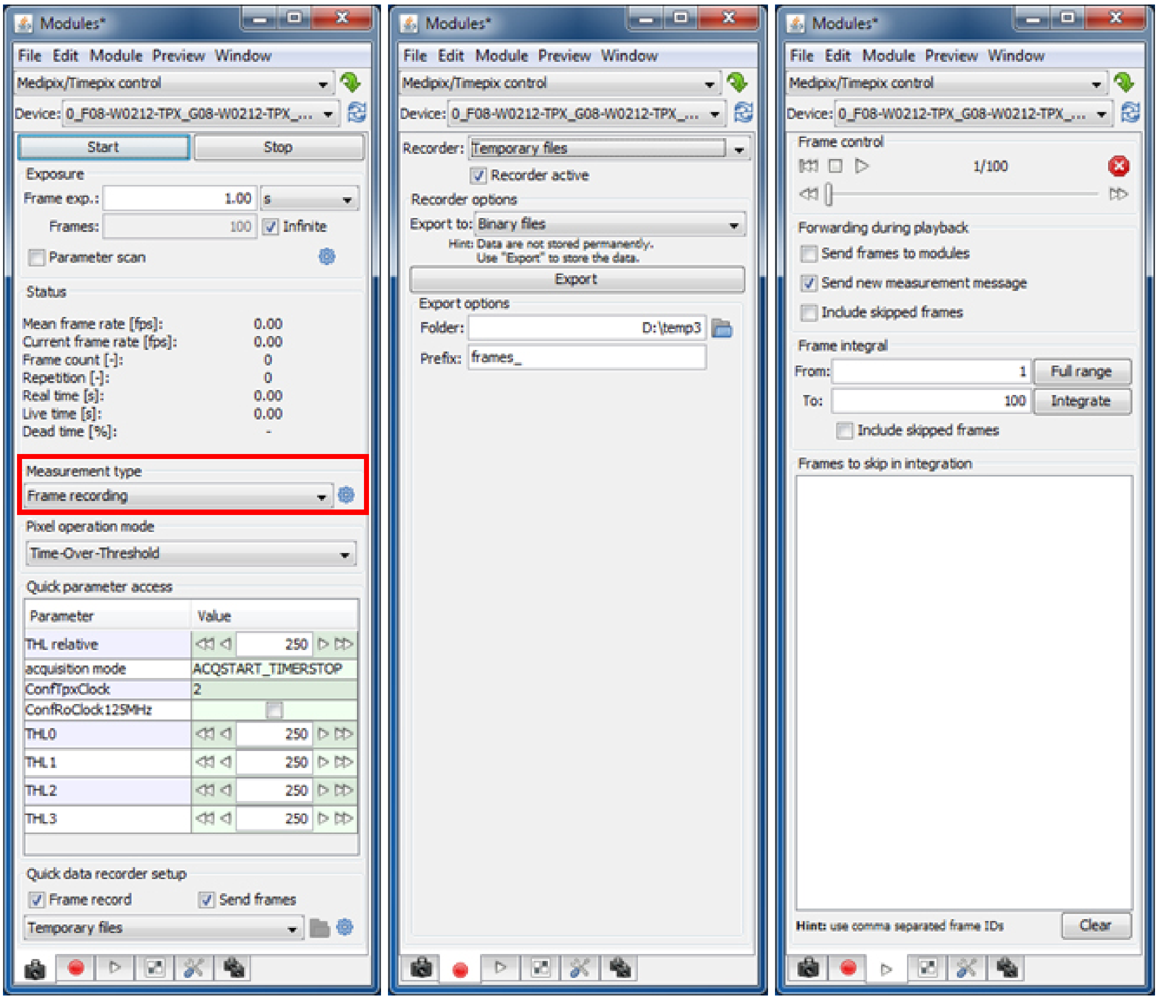


Figure 3.5: Frame recording and replay: a) frame recording measurement type, b) frame saving setup, c) frame replay and re-integration

can be achieved by measuring and summing number of images. A typical imaging measurement consists of integration of multiple frames at shorter exposure time. The frame exposure is set so that no pixels are in saturation (value of 11810 for Timepix1, 32767 for Timepix3[2]). The total number of collected frames corresponds to the desired overall statistics/error in the image. SoPhy automatically integrates the measured individual frames in the frame recording measurement type. The final measured image (integrated image) and last measured individual frame can be saved or export from the preview window. By default the individual frames are recorded to temporary files in the standard system temporary folder. The individual frames can be right after measurement exported into ASCII or binary file formats from the recording settings panel ● (figure 3.5b).

The frame recording panel also allows setting up direct storage of frames during the measurement in a number of formats:

- the default temporary data type;
- TIFF files;

- NetCDF;
- zipped binary files;
- zipped ascii files;
- raw pixel data.

The zipped files contain 100 frames as ASCII or binary files. They contain also an XML file containing parameters of the detector and setup. Only one full XML record is saved with the first frame in the batch of 100. Then only differences are stored to subsequent XML files. There might be no further XML file if there were no parameters changed. Frames measured in the last run can be replayed and re-integrated using the frame playback panel; however this is currently only supported while using the temporary files, or the zipped file types ▷ (figure 3.5c).

TIP 1!
Use the frame recording on the main panel to record all individual frames in the measurement.

TIP 2!
Parameters of the acquisition and measurement are recorded with frames. Those can be explored under “user objects” tab of a plot window.

TIP 3!
Frame recording can be used with any other measurement type (e.g. the spectral imaging). However, it may slow down the data processing.

3.7 Spectral imaging and cluster analysis

Timepix detector can be operated in the Time-over-Threshold mode (ToT). A spectrum of detected radiation energies can be recorded in each individual pixel. To initiate this type of measurement, select Measurement type "Spectral imaging (cluster analysis)", (figure 3.6); Pixels are then switched automatically to ToT mode.

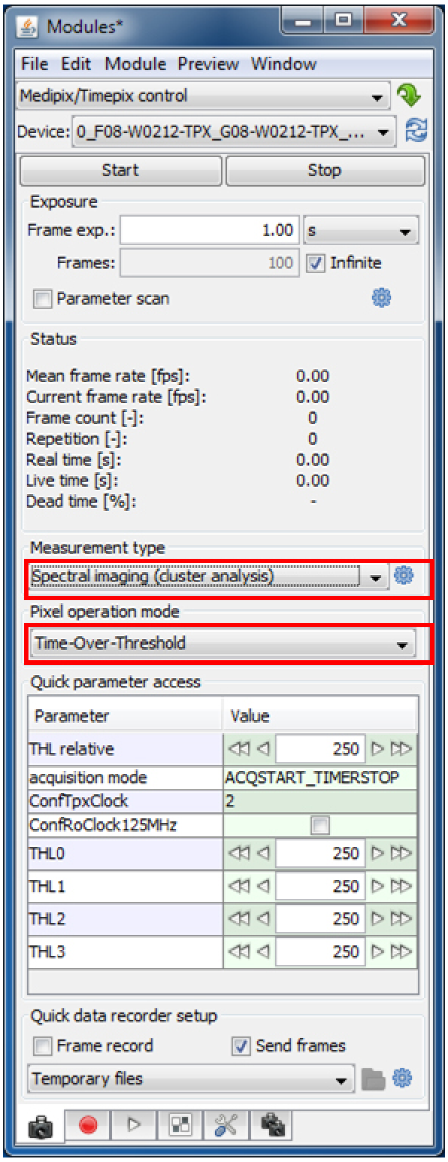


Figure 3.6: Setup of the detector for the ToT (spectrometric) measurement: switch pixels to the ToT mode and select the "Spectral imaging (cluster analysis)" type of measurement.

A long series of short exposure frames is collected and pattern recognition techniques are used to find hits (clusters) in each frame and filter out those that are not desired (i.e. long tracks of electron background). The filtering type can be selected on the first page of the ToT spectrum measurement control panel (figure 3.7). Select the desired type of radiation you wish to measure and then switch to “Spectrum” tab. Set an appropriate number of bins and maximum range of the spectrum (in arbitrary units of the ToT conversion ADC).

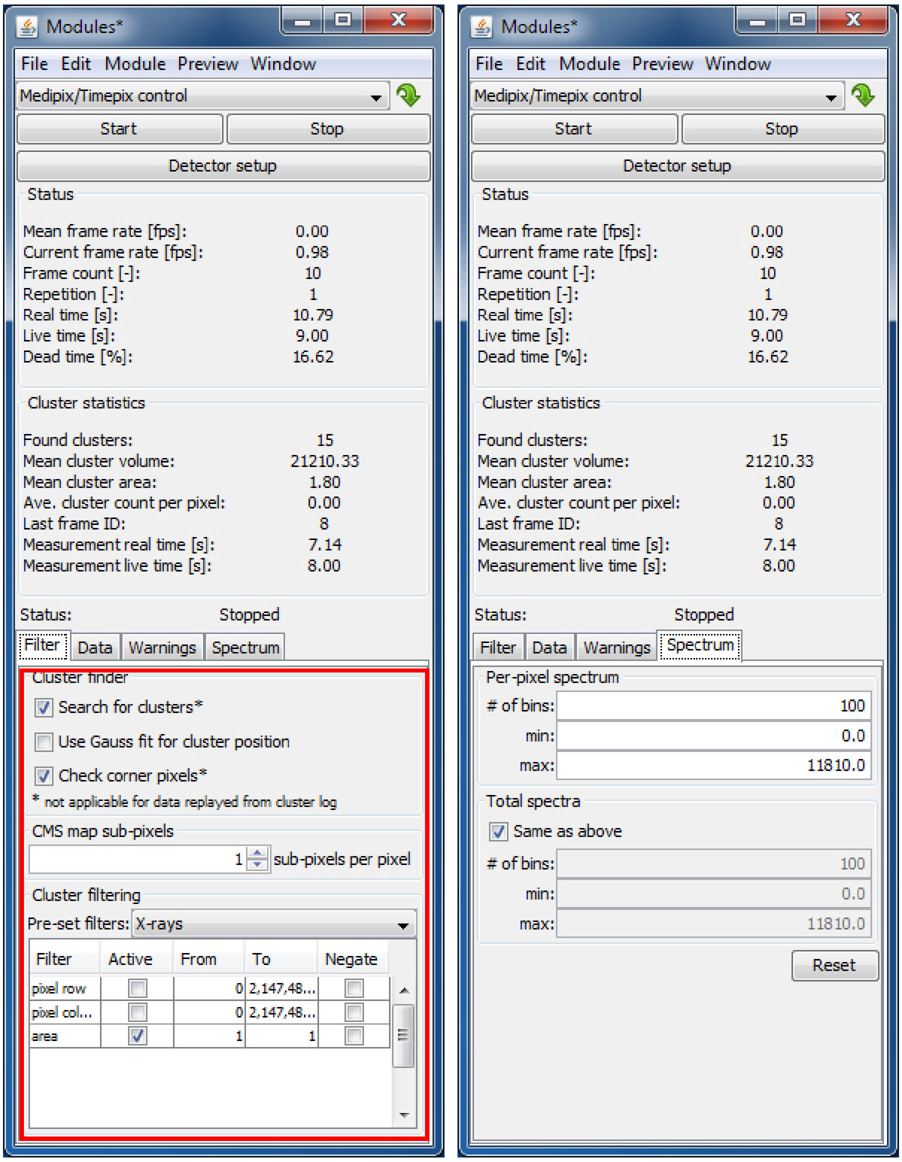


Figure 3.7: Setup of the cluster filtering (left) and spectrum binning (right).

NOTE 1!

Set a short frame exposure time in order to make the ToT spectrum measurement working. The frame exposure time must be short enough to see individual hits of radiation. The hits must not overlap. Too many overlaps leads to distorted spectrum or to rejection of valid hits.

Start/Stop the measurement using buttons on the top of the panel. Individual spectra (total spectrum of accepted hits, rejected hits, individual pixel spectra etc.) can be view using “Preview ⇒ Spectra (cluster analysis)”. Integrated images including images at each energy bin of the spectrum can be viewed using “Preview ⇒ Spectral images" menu item. Recorded data can be saved or exported either from the preview windows or from "File ⇒ Spectral imaging ⇒ Save As.../Export Spectrum..." menu. The "Data" panel on the Spectral imaging control window can be used to record and replay/re-filter raw data of the measurement.

3.8 Mass spectrometry

Mass spectrometry is similar to Spectral analysis, but typically uses ToA measurements.

3.9 Parameter scans

Parameters scan serves as a tool to collect data at various detector settings (e.g. energy threshold) or parameters of the setup (e.g. position or rotation of sample). Nearly all detector parameters and parameters of other attached devices such as stepper motors can varied in parameters scans. SoPhy allows also multi-dimensional scans, i.e. combinations of variations of samples. For example: sample position can be changed by the scan and for each position of the sample can be acquired a set of images at different energy thresholds. The parameter scans can be combined with any measurement type except the equalization. Hence, even the spectral imaging can be combined with rotating the sample – a spectral CT data is easy to collect this way. The parameter to be scanned is selected in the left tree. A range of values is controlled in the bottom right part of the window. Lines in the scan can be edited manually or together when selected. The scan settings can be saved for later use.

3.10 Equalization

The energy discrimination threshold is set the same for all pixels. However, there are some pixel-to-pixel variations in the actual threshold level due to tolerances in the ASIC manufacturing process. Each individual pixel contains threshold equalization Digital-To-Analog converter that can be used to correct the threshold pixel-to-pixel variations. The process of finding the values of the threshold equalization parameters is implemented in SoPhy as one of the measurement types (figure 3.8).

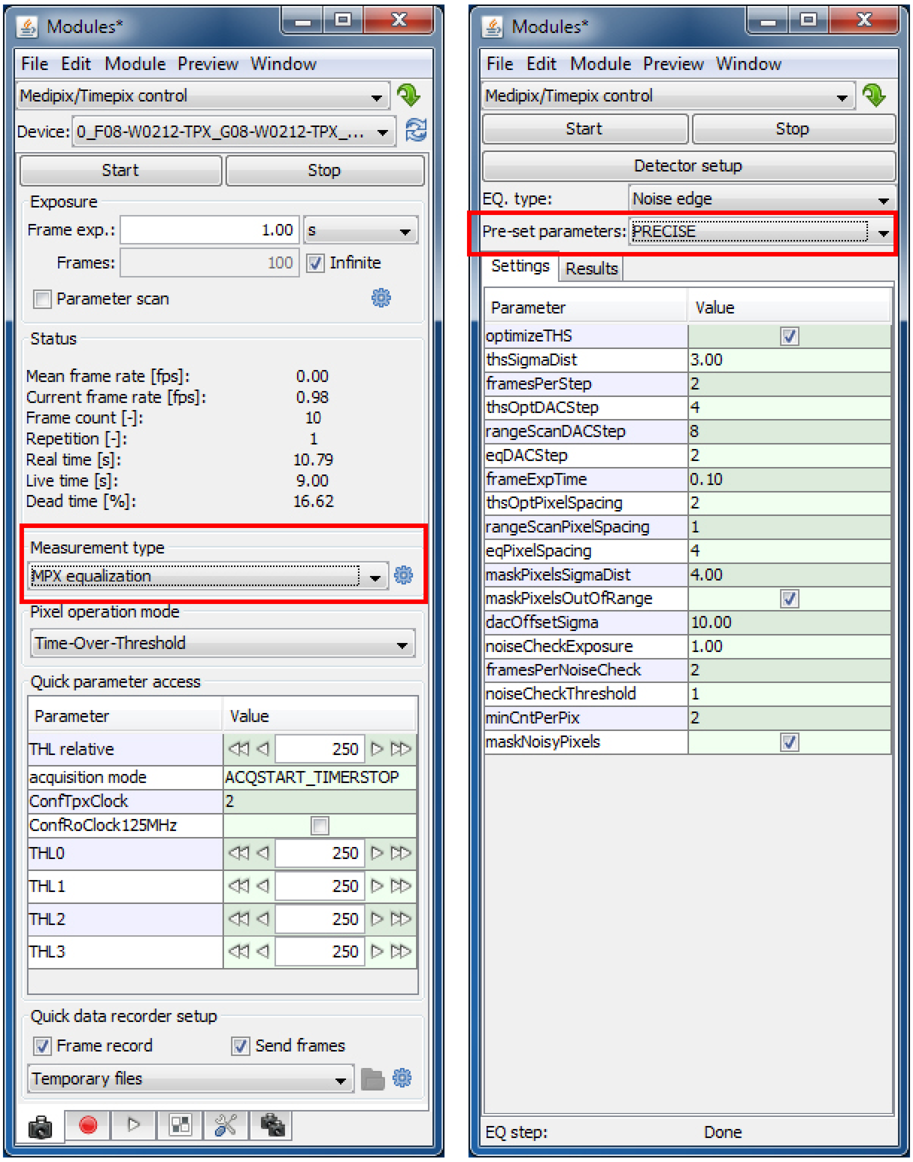


Figure 3.8: The threshold equalization process is implemented as one of measurement types.

Typically the equalization will determine settings for all pixels to be just below the noise, i.e. a noise edge equalization. The equalization procedure will (optionally) first determine the spread of the thread of the variations, the THS, then find the range of threshold levels to use, then perform the actual equalization. For each of these phases a number of scans is made over the THL range with a certain step size, the thsOptDACStep, the rangeScanDACStep and the eqDACStop respectively. When the ASIC is driven deep into the noise, it may draw too much current, causing the supply voltage to drop, leading to an unreliable threshold voltage. To reduce this problem, the equalization procedure can use a pixel spacing, where only one in n pixel rows/columns is enabled at a time. This does imply that the scan over the THL values needs to be repeated n*n times for shifted pixel enabling patterns. At the end one can either mask all pixels that are found to have an equalization adjustment out of range, or simply are noisy. There are a number of sets of parameters for these options that one can select.

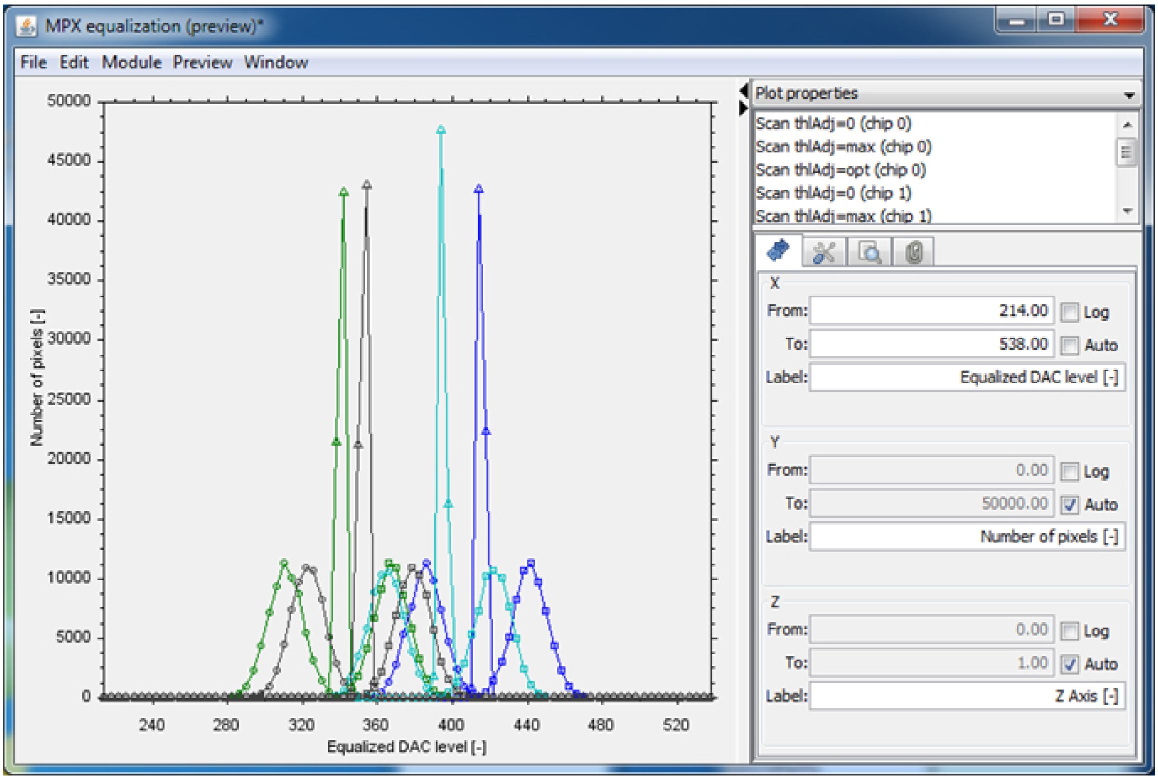


Figure 3.9: Distributions of equalized DACs during and after the equalization.

1. User data typically contain settings of the detector during measurement, parameter scan value, positions of stepper motors, etc.
2. As the hits for Timepix3 are collected by SoPhy, the saturation value is determined by software; this might change in the future

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