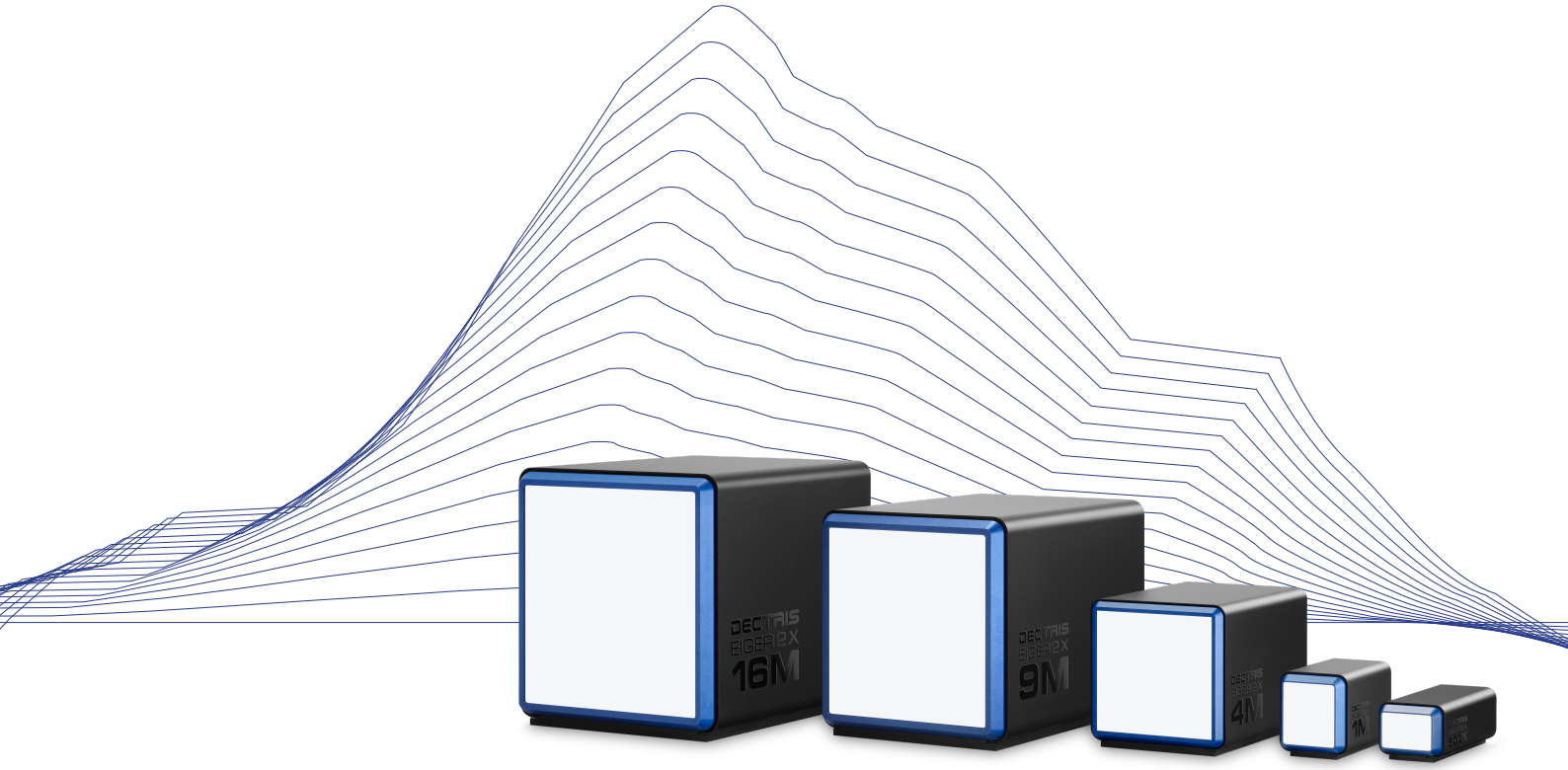
DECTRIS



User Manual
DECTRIS EIGER®2

Document Version v1.8.2

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CONTENT

DOCUMENT HISTORY

Current Document

Table 1: Current Version of this Document

Version	Date	Status	Prepared	Checked	Released
v1.8.2	2024-02-02	release	DanM	SasG	DanM

Changes

Table 2: Changes to this Document

Version	Date	Changes
v1.0.0	2017-04-09	First release.
v1.2.0	2017-09-04	EIGER2 R 500K integration.
v1.3.2	2017-09-04	PILATUS3 and EIGER2 R 500K API documentation integration.
v1.4.0	2018-06-19	EIGER2 Si detector series integration
v1.5.0	2020-03-02	New layout and rework of the technical specifications.
v1.5.1	2020-06-08	Fixed EIGER2 16M image of ground plate.
v1.6.0	2020-09-08	EIGER2 CdTe detector series integration.
v1.6.1	2020-11-27	EIGER2 S series integration.
v1.6.2	2021-01-14	EIGER2 XE 9M & 16M integration.
v1.7.0	2021-09-06	Introduced trademarks and general rework.
v1.7.1	2021-10-20	Update technical drawings.
v1.7.2	2022-02-24	Improve instructions on water cooling and cable handling.
v1.7.3	2022-02-24	Add manual for EIGER2 9M-V-RW.
v1.7.4	2022-04-14	Fixed EIGER2 vacuum operation and updated trademarks.
v1.8.0	2022-03-22	Documenting new features from release 2022.1
v1.8.1	2023-02-10	Updated frame rates and 8 bit mode for X and XE systems.
v1.8.2	2024-01-19	Implemented new CI/CD, added Lines-ROI, updated web interface info.

1. GENERAL INFORMATION

1.1. Contact and Support

Address:	**DECTRIS Ltd.** Taefernweg 1 5405 Baden-Daettwil Switzerland	**DECTRIS USA Inc.** 1500 Walnut Street, Suite 1630 Philadelphia, PA 19102 USA	**DECTRIS Japan K.K.** Mitsuwa Building 1F Minamimachi 63, Himeji-shi Hyogo 670-0912, Japan
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1.2. Explanation of Symbols

Warning #0

Warning blocks are used to indicate danger or risk to personnel or equipment.

Caution #0

Caution blocks are used to indicate danger or risk to equipment.

Information #0

Information blocks are used to highlight important information.

1.3. Warranty Information

Caution **#1**

Do not ship the system back before you receive the necessary transport and shipping information.

1.4. Disclaimer

DECTRIS® has carefully compiled the contents of this manual according to the current state of knowledge. Damage and warranty claims arising from missing or incorrect data are excluded.

DECTRIS® bears no responsibility or liability for damage of any kind, also for indirect or consequential damage resulting from the use of this system.

DECTRIS® is the sole owner of all user rights related to the contents of the manual (in particular information, images or materials), unless otherwise indicated. Without the written permission of DECTRIS® it is prohibited to integrate the protected contents in this publication into other programs or other websites or to use them by any other means.

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2. SAFETY INSTRUCTIONS

Caution **#2**

Please read these safety instructions before operating the detector system.

- Before turning the power supply on, check the supply voltage against the label on the power supply. Using an improper main voltage will destroy the power supply and damage the detector.
- Power down the detector system before connecting or disconnecting any cable.
- Make sure the cables are connected and properly secured.
- Avoid pressure or tension on the cables.
- The detector system should have enough space for proper ventilation. Operating the detector outside the specified ambient conditions could damage the system.
- The detector is not specified to withstand direct beam at a synchrotron. Such exposure will damage the exposed pixels.
- Place the protective cover on the detector when it is not in use to prevent the detector from accidental damage.
- Opening the detector or the power supply housing without explicit instructions from DECTRIS® will void the warranty.
- Do not install additional software or change the operating system.
- Do not touch the front window of the detector or the sensor modules.

3. SYSTEM DESCRIPTION

3.1. Components

The DECTRIS EIGER®2 detector system consists of the following components:

- EIGER2 detector
- Power supply unit (PSU) [1]
- Detector control unit (DCU)
- Thermal stabilization unit[2]
- Accessories
- Documentation

3.2. Hybrid Photon Counting (HPC) Technology

3.2.1. Basic Functionality

DECTRIS® X-ray detectors provide direct detection of X-rays with optimized solid-state sensors and CMOS readout ASICs in hybrid pixel technology. Well-proven standard technologies are employed independently for both the sensor and the CMOS readout ASIC. The EIGER2 hybrid pixel detector is composed of a sensor, a two-dimensional array of photodiodes or photoconductors processed in a high-resistivity semiconductor, connected to an array of readout channels designed in advanced CMOS technology. The X-ray detectors operate in single-photon counting mode and provide outstanding data quality. They feature very high dynamic range, zero dark signal and zero readout noise and hence achieve optimal signal-to-noise ratio at short readout time and high frame rates. Large-area detectors with dedicated active areas are built of multiple identical modules using a modular system concept.

Key Advantages

- Direct detection of X-rays
- Single-photon counting
- Excellent signal-to-noise ratio and very high dynamic range (zero dark signal, zero noise)
- Two energy discriminating thresholds
- Four 16 bit digital counters (two per energy discriminating threshold)
- Short readout time and high frame rates
- Shutterless operation
- Modular system enabling multi-module detectors with a large active area
- Full factory calibration in the specified energy range

[1] Some systems might be delivered without an external power supply unit. Please consult the Technical Specifications for more information.

[2] Also referred to as Chiller. Some systems might be delivered without a thermal stabilization unit. Please consult the Technical Specifications for more information.

3.2.2. Continuous Readout

A hallmark feature of EIGER2 is its continuous readout that enables high frame rates at high duty cycles with only 100 ns deadtime between frames. Every pixel of an EIGER2 ASIC features two digital counters for each of its two energy discriminating thresholds. After acquisition of a frame, the pixels switch from counting in one digital counter to the other. While one counter is being read out, data acquisition continues in the other counter.

3.2.3. Auto-Summation

EIGER2 auto-summation mode is a further benefit of continuous readout with high duty cycle. While a single frame is limited to the 16 or 8 bit of the digital counter, auto-summation extends the data depth up to 32 bit, or more than 4.2 billion counts per pixel, depending on the number of summed frames in an image. At short exposure times and high frame rates, all counts are captured in the digital counter of a pixel and directly read out as an image. If long exposure times are requested, frames are still acquired at high rates on the pixel level, effectively avoiding any overflows. The detector system sums the frames to images on the fly, extending the bit depth of the data by the number of summed frames.

3.2.4. Instant Retrigger

EIGER2 X-ray detectors feature the DECTRIS INSTANT RETRIGGER® technology for improved high-rate counting performance. The Instant Retrigger capability results in non-paralyzable counting and allows for enhanced count-rate correction.

DECTRIS INSTANT RETRIGGER® with adjustable dead time is a photon counting imaging method that results in non-paralyzable counting and achieves an improved high-rate counting performance. In a conventional single-photon counting X-ray detector, the charge pulses generated by impinging photons are counted by digital circuits. Simultaneously generated pulses can pile up and result in photon counts being lost. At high photon fluxes, pulse pile-up significantly affects the observed count rate and can lead to complete paralyzation of the counting circuit. In the first generations of EIGER and PILATUS photon counting detectors, even though a count rate correction was applied to compensate for the counting loss at high count rates, the maximum usable count rate was still limited by counter paralyzation. In EIGER2 detectors, the Instant Retrigger re-evaluates the pulse signal after a predetermined dead-time interval after each count and is able to retrigger the counting circuit should a pulse pile-up occur. The dead time interval is adjustable and is equivalent to the width of one single photon pulse. This results in non-paralyzable counting and allows for enhanced count-rate correction so as to achieve improved data quality at high count rates.

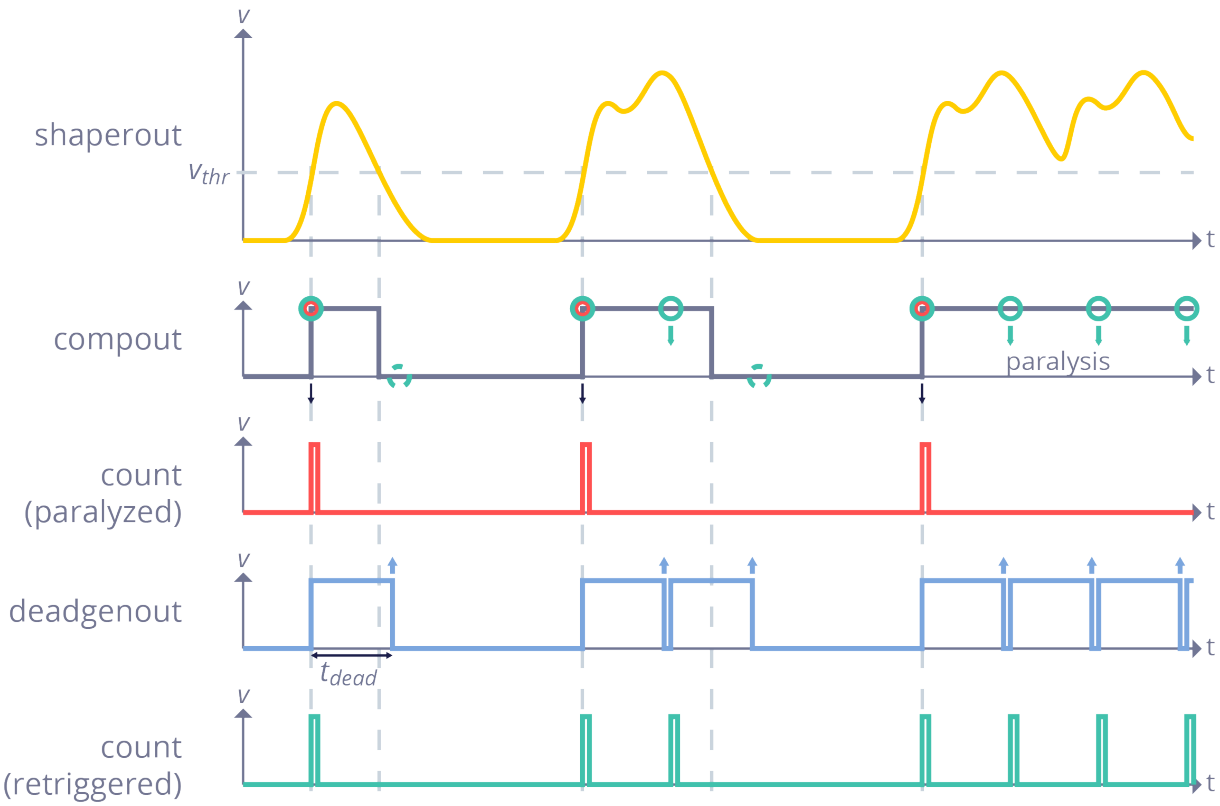

Figure 3.1: Signal Waveforms Illustrating the DECTRIS INSTANT RETRIGGER® technology

The Instant Retrigger principle is illustrated in figure 3.1. The first diagram shows the signal pulses generated by impinging photons and the effective discriminator threshold level for single photon counting. The pulse signal includes a series of one single pulse, a pile-up of two pulses and a pile-up of multiple pulses. The second diagram shows the corresponding digital discriminator output signal that triggers the counting circuit. The third diagram shows the corresponding counts being registered by a conventional single photon counting X-ray detector, clearly illustrating that counts are lost in the case of pulse pile-up and that this can lead to paralyzation. The fourth diagram shows the respective dead-time generator output signal provided by a single photon counting X-ray detector with Instant Retrigger. Here, a predefined dead time interval is started whenever a count has been registered. The fifth diagram shows the corresponding counts being registered, including potential retriggering of the counting circuit after the dead-time interval after each count. This clearly illustrates that pulses are counted more accurately in the case of pile-up and that counting is non-paralyzable.

3.2.5. 8-bit Readout

Information	#1

The 8-bit readout mode is only available with DECTRIS EIGER®2 X and XE detectors.

The EIGER2 ASIC allows the option to read out only the first 8 bits of every counter instead of the full 16 bits. This enables a higher maximum frame rate at the cost of a lower dynamic range. The 8-bit mode is automatically enabled as soon as the frame rate exceeds the maximum frame rate in 16-bit mode, as indicated in the Technical Specifications.
When using the 8-bit mode, it is important not to exceed the maximum flux per pixel, as there is no overflow protection and the counter will roll over if 255 counts are exceeded. This means the maximum flux per pixel is 255 × frame rate in 8-bit mode.

3.3. Software

3.3.1. Overview of SIMPLON

The EIGER2 detector system is controlled via the SIMPLON API, which relies on a http/REST interface. The API Reference is provided as a separate document ”SIMPLON API Reference”.
The detector’s web interface (chapter 6) gives access to fundamental settings and status parameters and also enables a first test to see if the detector system has been set up properly (after installation and startup as described in chapters 4 and 5).

3.3.2. HDF5 file format and ALBULA image viewer

The EIGER2 detector writes images in the HDF5 file format (chapter 10). DECTRIS® provides the image viewer ALBULA, which is able to handle the HDF5 images, with the primary aim to display them. ALBULA is available free of charge at www.dectris.com. The ALBULA Python API allows to handle HDF5 files and perform arithmetic operations on image data as well as basic analysis. Furthermore, the API enables seamless integration of the viewer into user-specific infrastructure. More information on HDF5 and ALBULA is given in chapter 10.

4. QUICK START GUIDE

4.1. Accessing the Detector Control Unit

The EIGER2 detector is controlled via the network interface of the detector control unit. Hence, the IP network address of the detector control unit has to be known to be able to connect to the API. Depending on the network structure, there are several ways of determining the IP network address, which are described below.

- See the Technical Specifications for the default network port configuration of your detector control unit.
- The default network port configuration may be changed through the detector's web interface (see section 6.2).

4.1.1. Using DHCP

If there is a DHCP server available on the network, plug the network cable into a port of the detector control unit pre-configured for DHCP. See the Technical Specifications for the default network port configuration of your detector control unit.

To determine the IP of your detector, plug in a keyboard and monitor to the detector control unit and power it up. Then follow the following steps:

- Once the detector control unit is fully booted, a command line login prompt will appear.
- Type `recovery` and press return.
- If a password prompt appears, leave it empty and press return. The login name was most likely misspelled, restart from point 1.
- Type `i` to select option `(i) show ip addresses`.
- The IP address will be displayed on the screen.
- If no IP is displayed, make sure that the DCU is properly connected to your network.

Alternatively, the IP network address can be retrieved by searching for the MAC address on the network. For network safety reasons, please ask the network administrator for assistance in obtaining the IP address. If you are the network administrator or have the required permission, the following Linux command can be used to retrieve the IP network address:

[]$_ Linux Command

```
sudo nmap -sP xxx.xxx.xxx.xxx/24 | awk '/^Nmap/{ip=$NF}/yy:yy:yy:yy:yy:zz/{print ip}'\\
```

where xxx.xxx.xxx.xxx/24 is the network address range to be scanned (e.g. 192.168.0.1/24) and yy:yy:yy:yy:yy:zz is the MAC address of the DHCP network port in the back of the detector control unit. You can find the MAC address of the port using the method described below.

Determining the MAC Address of a Port

The MAC address of the first network port can be found on the bottom of the service tag label (pull-out label in the front of the detector control unit, the correct address is the `EMBEDDED NIC 1 MAC ADDRESS`). The MAC addresses of the second, third and fourth ports are the same as the first one, but with the last two digits incremented by zz+2, zz+4 and zz+6, respectively. E.g. if the first port is 01:23:45:67:89:ab, then the second port is 01:23:45:67:89:ad (make sure to use the hexadecimal system).

4.1.2. Using a Fixed IP

If you want to access the detector control unit using a fixed IP network address, plug the network cable into the service port of your detector control unit pre-configured for a fixed IP. See the Technical Specifications for the network port configuration of your detector control unit and configure your network accordingly.

If you use e.g., a laptop to access the detector control unit directly for the initial configuration, you can use the following network settings on the laptop:

Table 4.1: Network Settings

IP Adress	169.254.254.100
Subnet Mask	255.255.0.0
Default Gateway	not required

5. GETTING STARTED

Information	#2

Instructions on properly mounting and preparing the detector system can be found in the Technical Specifications. Before operating the detector, read the complete documentation.

5.1. Startup Procedure

- Turn on the nitrogen or dry air flow at least 30 min before turning on the detector.[1]
- Turn on the thermal stabilization unit and set the operation temperature as specified in the Technical Specifications. Please read the thermal stabilization unit manual, as some models must be powered and additionally activated in order to operate properly.[2]
- Connect all the required cables for power, data, and trigger signals (if applicable) to the detector and the detector control unit.
- Turn on the detector.
- Turn on the detector control unit. Please allow 6 minutes for the BIOS test procedures and startup of software to complete.
- Access the web interface via the IP address of the detector control unit or start using the SIMPLON API to initialize and control the detector (see the API Reference documentation).
- For detectors with a CdTe sensor, it is necessary to wait up to 30 minutes after initializing the detector in order to get the best data quality.

[1] Some detectors do not require a dry air connection. Consult the Technical Specifications for more information.
[2] Some detectors do not require water cooling. Consult the Technical Specifications for more information.

6. WEB INTERFACE

6.1. Overview

The EIGER2 web interface (figure 6.1) provides simple access to basic functions and settings of the detector system for installation, debugging, and system updates. For productive operation of the detector, please refer to the API Reference.

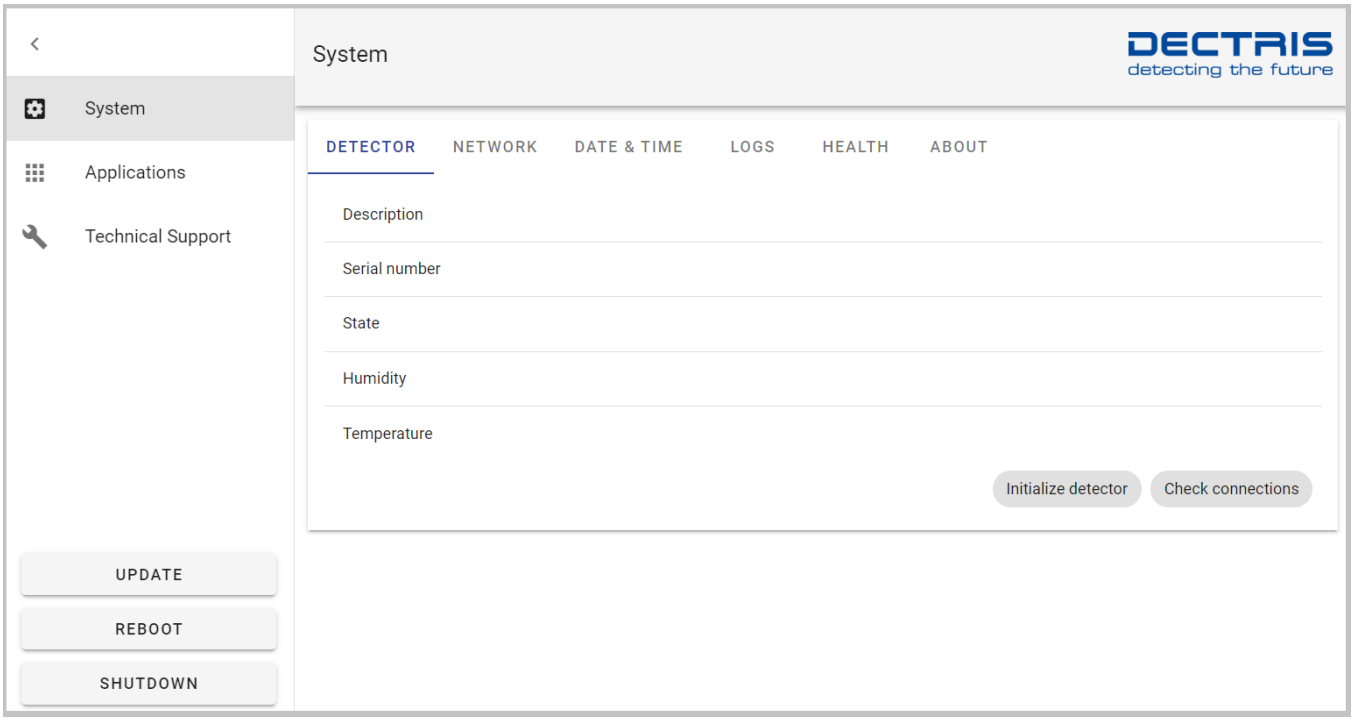

Figure 6.1: EIGER2 home page.

Table 6.1 summarizes the functions available through the left panel of the web system interface.

Table 6.1: Menu items of the EIGER2 web interface.

Menu Point	Content
System	View the system information and access the detector control unit system settings (see section 6.2)
Applications	Manage the detector and calibration applications. This tab provides functions to start and stop the detector software, change software versions and upgrade the detector software to a new version.
Technical Support	Simple interface to create a bug-report. The bug-report creates a tarball that can be downloaded and sent to DECTRIS® support at support@dectris.com. The bug report is not sent automatically.

6.2. System Settings and Administration

To access the EIGER2 system settings, click on the corresponding tab on the homepage. The system tab allows to configure the detector control unit network settings and get some status and system informations.

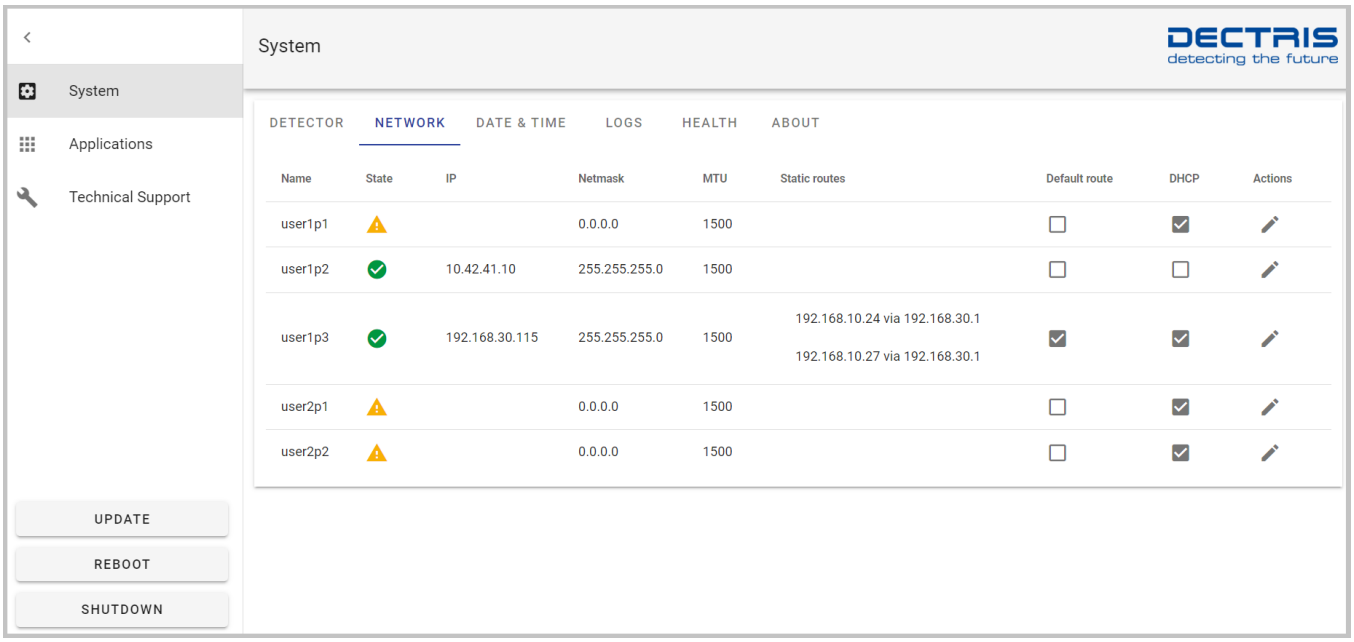

Figure 6.2: Screenshot of the system settings showing the network configuration page.

Table 6.2 summarises menu items available for configuration

Table 6.2: Menu Items for Configuration/Testing

Detector	See the detector status and initialize the detector. The detector status can only be read out when the detector is initialized and the detector application is running. This tab also provides a way to quickly check the quality of the detector connection using the ”Check connections” button. Typical values are above 0.15 mW for the TX power and above 0.3 mW for the RX power.
Network	Configure the user accessible network interfaces.
Date & Time	Configure date and time on the detector control unit. Provides the possibility to add an NTP server.
Logs	Select and view detector logs, including error, warning and debugging information.
Health	View system health information, such as temperature and humidity history, as well as board errors.
About	Display system details.

7. GENERAL USAGE OF THE DETECTOR SYSTEM

7.1. Detector Control and Output

The EIGER2 detector system is controlled through the SIMPLON API, an interface to the detector that is based on the http protocol and implemented on the detector control unit. The API Reference supplied with the system describes this interface in detail and allows for easy integration of the detector control into the user instrumentation independent of the operating system or programming language being used. Please refer to the API Reference for details.

The data recorded by the detector can be accessed in different ways. Images can be stored by the filewriter on the detector control unit as HDF5 files (see chapter 10). HDF5 files include metadata in a NeXus-compatible format. Buffered files have to be regularly fetched and subsequently deleted on the detector control unit as buffer space is limited[1]). Support for reading out multiple thresholds has been introduced in filewriter2. See the API Reference for further details.
Data can also be fetched through the stream interface, which relies on the ZeroMQ[2] distributed messaging protocol. The stream has a low latency and offers utmost flexibility. The metadata is transferred as part of the header. Streamed data is not buffered and will be lost if not fetched or incompletely fetched. With the introduction of stream2 it is possible to retrieve the images from multiple thresholds simultaneously at full frame rates.
Lastly, the monitor interface provides images as raw tiff files with minimal metadata. This is a low performance and low bandwidth interface, which allows to retrieve the latest recorded image for monitoring purposes during acquisitions. The monitor offers a relatively small buffer. In case of buffer overflow, the oldest images will be overwritten. The monitor also allows to retrieve the images from multiple thresholds.

7.2. Recording an Image or an Image Series

Caution **#3**

Data might have to be fetched concurrently to a running image series. The lifespan of the data on the detector control unit is dependent on the configuration of your system as well as the interface used for collecting data. Data not fetched within this lifespan is permanently lost.

To record images or image series, the following steps need to be performed through the SIMPLON API (see the API Reference for details).

1. Make sure the detector has been set up according to the steps described in chapter 5.
2. Initialize the detector if this has not yet been done. The detector does not need to be reinitialized unless the detector entered an error status.
3. Set the detector parameters for data acquisition and specify and configure the desired output interface (file writer and/or stream interface). A list of essential configuration parameters can be found in section 7.3.1.
4. Arm the detector
5. Record the image or image series.
   - Send trigger(s) to record the image or image series as previously configured.
   - Fetch data through the data interface(s).
6. Disarm the detector (to ensure files are finalized and closed).
7. Repeat from step 2 for further data acquisition with different settings or to step 3 for identical settings.

[1] Buffer space varies dependent on the configuration of your system, buffer overflow will cause loss of data. See API Reference for further details.
[2] ZeroMQ distributed messaging (http://zeromq.org/)

7.3. Control of the Detector from a Specific Environment

Integrating the detector into a specific environment requires understanding of the necessary detector functions. The API reference will list all possible commands and features, but it does not give an explanation of the required functionality. Sections 7.3.1 and 7.3.2 cover a selection of essential and situational parameters respectively.

7.3.1. Main Configuration Parameters

The parameters described in this section allow control of the detector and data acquisition. Data will be acquired, however further configuration of the interface for data retrieval might be necessary depending on your set up. For starting a data acquisition, only the following parameters need to be adjusted:

- detector | config | count_time
- detector | config | frame_time
- detector | config | photon_energy

The parameter count_time refers to the actual time the detector counts photons, while frame_time is the interval between acquisitions of subsequent frames (i.e. period).
The detector configuration parameter photon_energy has to be set to the X-ray energy used for the experiment.
There is a convenience function for setting the photon_energy, called element.

- detector | config | element

The parameter element accepts the chemical symbols for elements, e.g., "Cu", "Mo", as argument and sets photon_energy to the K_{α_1} emission line for that element.

- detector | config | ntrigger
- detector | config | nimages

The ntrigger parameter configures the number of expected triggers for one acquisition series. Setting values greater than 1 for ntrigger allows several trigger commands or external trigger pulses per arm/disarm sequence. This mode allows recording several series of nimages with the same parameters.
The parameter nimages configures the number of images that will be acquired for one trigger. In internally and externally triggered series ("ints" and "exts", respectively), the detector considers a trigger as the start of a series of n images. For example a single image is considered as a series of images containing 1 image. Once the detector has been armed a series can be started by issuing a trigger command or triggering the detector using an electronic pulse on the external trigger input. In "inte" and "exte" trigger modes the parameter nimages should be set to one, as every trigger will always trigger a single image. To switch between the trigger modes (see chapter 9) one can use the configuration parameter trigger_mode.

- detector | config | trigger_mode

Information #3

Please note that the acquired data can be retrieved via different interfaces. For details, please see the API Reference.

With the filewriter mode set to "enabled", the acquired data is written to HDF5 files. The filewriter has the following important configuration parameters:

- filewriter | config | mode
- filewriter | config | name_pattern
- filewriter | config | nimages_per_file
- filewriter | config | compression_enabled

The filewriter name_pattern sets the name for the HDF5 files. When using the pattern "$id", it will be replaced with a sequence identification number and can be used to differentiate between subsequent series. The sequence identification number is reset after initializing the detector. The parameter nimages_per_file sets the number of images stored per data file. A value of 1000 (default) means that for every 1000th image, a data file is created. If for example, 1800 images are expected to be recorded, the arm, trigger, disarm sequence means that a master file is created in the data directory after arming the detector. The trigger starts the image series and after 1000 recorded images one data container is made available on the buffer of the detector control unit. No further files will made available until the series is finished either by completing the nth image (nimages) of the nth trigger (ntrigger) or by ending the series using the detector command disarm. As soon as either criteria is met the second data container is closed and made available for fetching.

7.3.2. Additional Configuration Parameters

Information **#4**

The following parameters are for special conditions and should be set with care and with understanding of the consequences. Changing these parameters to non-default values can have a substantial negative impact on data quality!

- detector | config | threshold/n/energy
- detector | config | threshold/n/mode
- detector | config | threshold/difference/mode

The EIGER2 detectors provide two independent thresholds and it is possible to read out either one threshold, all of them at once or the difference of the thresholds. Reading out more than one threshold at a time is possible with the stream2, filewriter2 or monitor interfaces. The thresholds can be enabled or disabled using the threshold/n/mode configuration parameter, where n is the threshold number. The difference mode is enabled with the threshold/difference/mode parameter. Enabling the difference mode will automatically disable the threshold/n/mode parameters.

The threshold energy of the lower threshold (n=1) is set automatically to 50 % of the photon_energy. Threshold/1/energy should only be changed in cases where the suppression of fluorescence is a necessity in the experiment. The threshold/1/energy must be kept within 50 % to 80 % of the incoming photon_energy. The API incorporates no sanity check on the threshold/n/energy.

Corrections are enabled by default, but can be turned off using the following detector configuration parameters. In the vast majority of experiments data quality benefits from the data corrections. Therefore, disabling either correction will likely result in inferior data quality.

- detector | config | countrate_correction_applied
- detector | config | flatfield_correction_applied
- detector | config | pixel_mask_applied

Further parameters, represented by the following selection, allow to enrich the meta-data of the image (series) with experimental data.

- beam_center_x
- beam_center_y
- detector_distance
- detector_orientation
- detector_translation
- wavelength (see section 7.4.1 for dependency with photon_energy)

Further parameters and their function are described in the API Reference.

7.4. Interdependency of Configuration Parameters

7.4.1. Interdependency of Calibration Parameters

The following calibration parameters have an implied or direct dependency. Changing either of the parameters might influence other parameters in the list.

- detector | config | photon_energy

Changing photon_energy sets element to an empty string and sets wavelength to its corresponding value. The threshold/1/energy is set to half of photon_energy, which is the optimal threshold energy in most cases. The threshold/2/energy is set to $1.3 \times$ photon_energy, which can be used to suppress higher energy photons and cosmic radiation. In order to use values different from the defaults, the threshold/n/energy should be explicitly set after setting photon_energy. The flatfield is recalculated whenever a calibration relevant parameter is changed.

- detector | config | element

Setting the element is equivalent to setting photon_energy to the energy of the K_{α_1} emission line of the element. Hence, photon_energy, wavelength and all parameters that depend on photon_energy are changed accordingly.

- detector | config | wavelength

Setting the wavelength is equivalent to setting photon_energy to the equivalent energy of the wavelength. Hence, photon_energy, element and all parameters that depend on photon_energy are changed accordingly.

- detector | config | threshold/n/energy

Changing threshold_energy for a threshold causes the flatfield for this threshold to be recalculated.

- detector | config | flatfield

The flatfield applied for a given photon_energy and threshold_energy is a result of the detector calibration. During the factory calibration a multitude of flatfields at different settings have been recorded to ensure optimal data quality of the flatfield for all common settings.

7.4.2. Interdependency of Timing Parameters

The following parameters are essential for exposure timing. Changing either values might influence other values in the list.

- detector | config | frame_time

If frame_time conflicts with the current count_time, then count_time is set to the difference of frame_time and detector_readout_time.

- detector | config | count_time

If count_time conflicts with frame_time, then frame_time is set to the sum of count_time and detector_readout_time. To acquire images with a certain frame rate and best possible duty cycle, a simple procedure is to first set count_time to the inverse of the frame rate and subsequently frame_time to the inverse of the frame rate.

8. REGION OF INTEREST (ROI)

8.1. 4M ROI mode

The Region Of Interest (ROI) feature enables the user to read out a reduced area of an EIGER2 X/XE 16M or EIGER2 X/XE 9M detector at higher frame rates. The ROI mode is also available on the EIGER2 S 16M or EIGER2 S 9M without the increase in frame rate. Refer to the corresponding Technical Specifications document for the ROI frame rate specifications.

Information	#5
Please consult the API reference for further details concerning the usage of the region of interest detector configuration parameter (roi_mode).	

Information	#6
Please consult the Technical Specifications for further details about the ROI capability of your detector.	

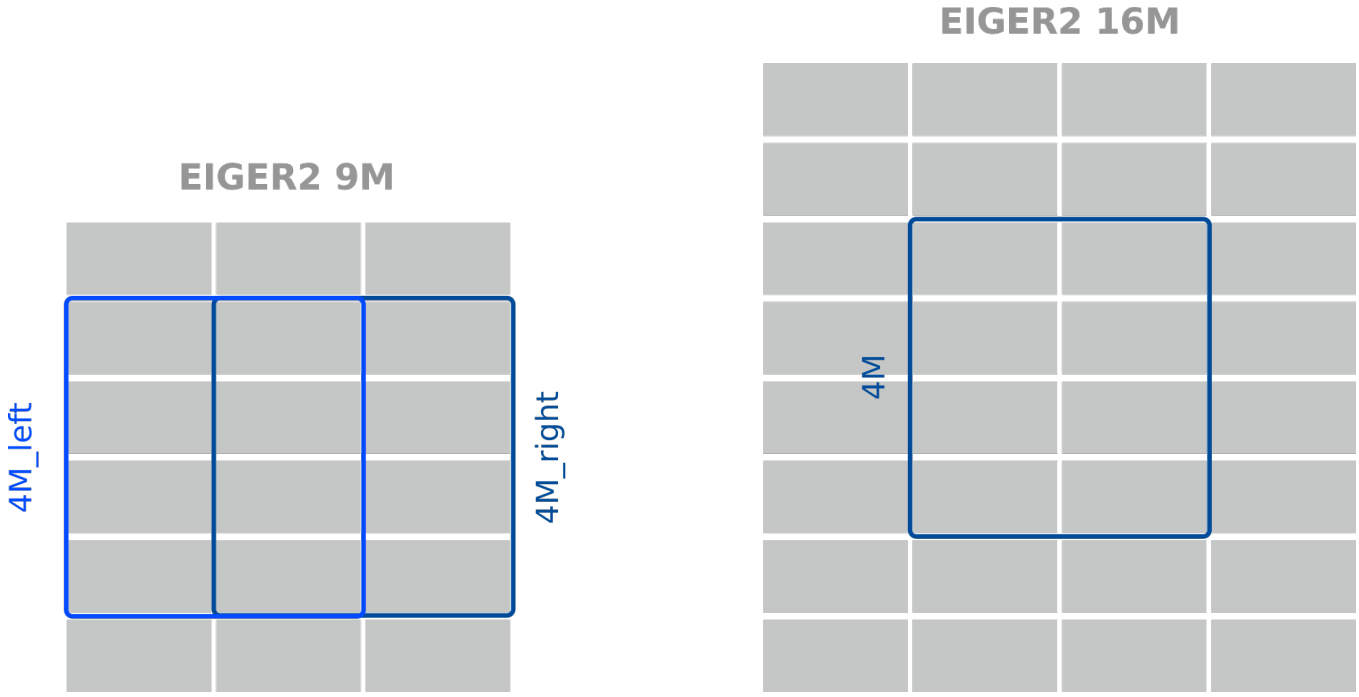

Figure 8.1: The different ROI modes for EIGER2 X 9M (left) and EIGER2 X 16M (right) as seen from the front of the detector.

The ROI mode is disabled by default and the full active area is read out (figure 8.1, grey and blue areas). Changing the ROI mode to another value (eg. "4M", "4M_left", "4M_right", figure 8.1, blue frame) from the list of allowed values will cause the detector to only read out the selected modules. In the EIGER2 X/XE detectors the selected ROI can be read out using an increased frame rate compared to a full detector read out.

8.2. Lines-ROI

The Lines-ROI® functionality is available in EIGER2 X and XE detectors with 1 module in height (500K, 1M-W, 2M-W). This feature allows to read out a user-defined area of the sensor equivalent to a selected number of lines (pixel rows) counted along the y axis, extending over the full horizontal length of the detector. This can be used to increase the acquisition frame rate with a reduced area selection.

In order to activate this modality, the roi_mode should be set to "lines" via the API. The ROI area is configured via the parameter roi_y_size, which defines the total number of pixel rows to be read out and should be a multiple of two. The Lines-ROI is centred around the horizontal axis of the detector.

Information #7

Please consult the API reference for further details concerning the usage of the Lines-ROI® configuration parameters (roi_mode and roi_y_size).

Information #8

Please consult the Technical Specifications for further details about the Lines-ROI® capability of your detector.

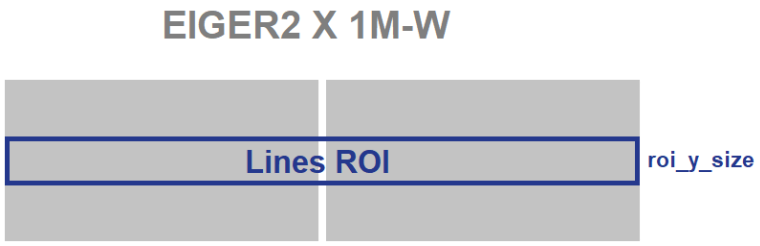

Figure 8.2: Lines-ROI area selection example for EIGER2 X 1M-W as seen from the front of the detector.

9. TRIGGER AND GATING

9.1. Introduction

Information	#9

Depending on the type of EIGER2 system, the valid ranges for the trigger parameter differ. Please consult the Technical Specifications for your system. The values presented in the examples below should work on every EIGER2 system. If the settings or the external trigger/enable pulses applied are out of specification, acquisitions will not be performed and the measurement obtained with the detector might be incomplete.
All values used in the example are for demonstrational purposes only and should be adapted to meet the requirements of your application.

In order to record an image or a series of images, the EIGER2 detector has to be initialized, configured, armed, and triggered or gated. The steps necessary to record an image series are comprehensively described in chapter 5 and section 7.2. The detector can be triggered through software (internal trigger) or by an externally applied trigger signal (external trigger). Various different trigger and gating modes are available and described in the following sections.

9.2. INTS - Internal (Software) Triggering

An exposure (series) can be triggered by using a software trigger. This is the default mode of operation.

Example detector configuration for internally triggered exposure series:

detector | config | trigger_mode	{"value": "ints"}
detector | config | nimages	{"value": 10}
detector | config | ntrigger	{"value": 3}
detector | config | frame_time	{"value": 1}
detector | config | count_time	{"value": 0.7}

The detector starts the first exposure after the trigger command has been received and processed[1]. All subsequent frames are triggered according to the configuration of the frame_time and count_time parameters. The detector records nimages frames per trigger and stays armed until ntrigger are received. Figure 9.1 depicts an internally triggered series defined by frame_time, count_time and nimages.

[1] As the trigger command is sent over an TCP/IP connection the exact latency of the start of the exposure is hard to predict.

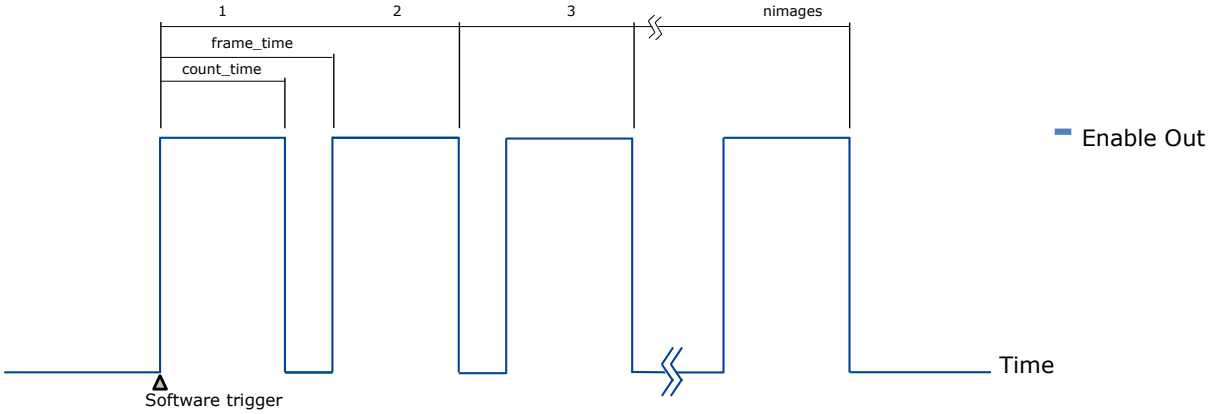

Figure 9.1: Series of exposures, defined by frame_time, count_time and nimages, triggered by a software trigger.

9.3. INTE – Internal (Software) Enable

In the trigger_mode 'inte' a single image or series of images with varying exposure times can be started by issuing a number ntrigger of trigger commands. Unlike the trigger_mode 'ints', the 'inte' trigger commands take an (optional) argument containing the count_time for the subsequent frame. In all enable modes the detector configuration parameter nimages is implied to be 1. The number of frames in a series therefore is solely based on the value of the parameter ntrigger.

Information	#10

The configured count_time and frame_time should be close to the count time and frame time of the shortest expected exposure in the configured series. The set count_time will be used to calculate internal auto-summation configuration values (section 3.2.3). In most situations a reasonable estimate of these values is sufficient.

Example detector configuration for an internally enabled exposure series:

detector | config | trigger_mode	{"value": "inte"}
detector | config | nimages	{"value": 1}
detector | config | ntrigger	{"value": 3}
detector | config | frame_time	{"value": 1.0} (see , 10)
detector | config | count_time	{"value": 0.7} (see , 10)

The detector starts the first exposure after a trigger command has been received and processed[2]. All subsequent frames have to be triggered by individual trigger commands with an (optional) argument containing the count_time of the triggered frame. The detector stays armed until ntrigger are issued or the detector is disarmed. Figure 9.2 depicts an internally enabled exposure series defined by count_time (payload of the trigger command) and ntrigger. Table 9.3 summarises the commands issued to record the same series.

[2] As the trigger command is sent over an TCP/IP connection the exact latency of the start of the exposure is hard to predict.

Table 9.3: Command sequence for an internally enabled (inte) series.

Method	Parameter	Payload
PUT	detector | command | arm	
PUT	detector | command | trigger	{"value": 0.7}
PUT	detector | command | trigger	{"value": 2.1}
...		
PUT	detector | command | trigger	{"value": 0.7}

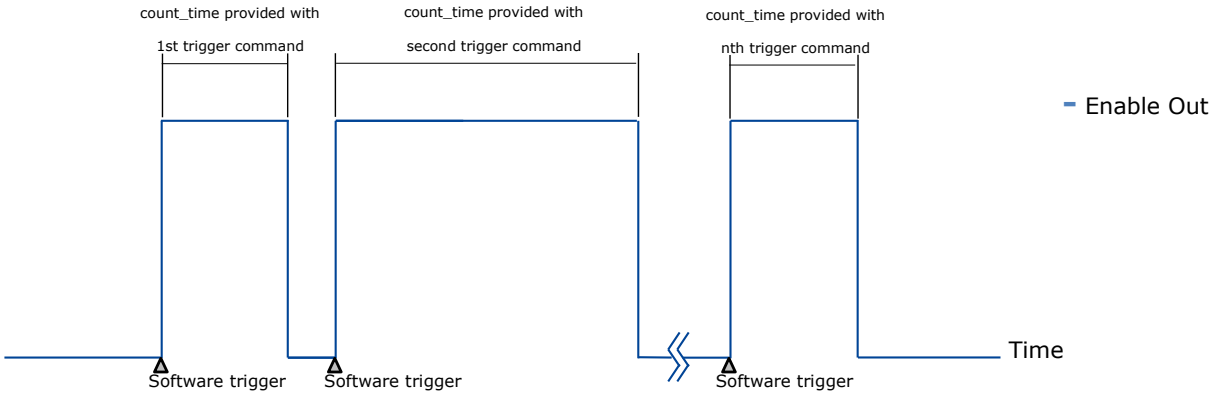

Figure 9.2: Series of exposures, defined by count_time (payload of the trigger command) and ntrigger, triggered by a software trigger.

9.4. EXTS - Externally Triggered Exposure Series

Caution **#4**

Consult the Technical Specifications for details about the required electrical characteristics of the trigger signal.

The EIGER2 detector systems also support external triggering. In the trigger_mode 'exts', nimages are recorded per trigger until ntrigger are received. Both count_time as well as frame_time are defined by the configuration. Example detector configuration for externally triggered exposure series:

detector | config | trigger_mode	{"value": "exts"}
detector | config | nimages	{"value": 10}
detector | config | ntrigger	{"value": 1}
detector | config | frame_time	{"value": 1.0}
detector | config | count_time	{"value": 0.7}

After the detector has been initialized, configured, and armed the acquisition can be triggered by a single external trigger pulse. The detector starts exposing after the (electrical) trigger signal has been issued. All subsequent frames are internally triggered according to the information previously configured by the frame_time and count_time parameters. The detector records nimages frames and stays armed until ntrigger are received. Figure 9.3 depicts an externally triggered series defined by frame_time, count_time and nimages.

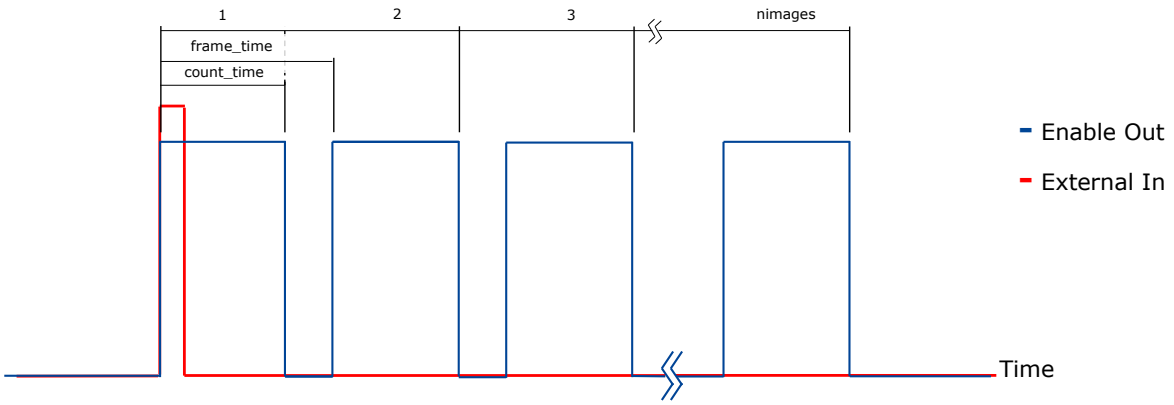

Figure 9.3: Exposure series defined by frame_time, count_time and nimages, triggered by a single external trigger pulse. Note that the periods are not drawn true to scale.

9.5. EXTE - Externally Enabled Exposure Series

Caution **#5**

Consult the Technical Specifications for details about the required electrical characteristics of the trigger signal.

The EIGER2 detector systems also support external enabling. In the external enable mode 'exte' a series of ntrigger frames can be recorded. The count time as well as the period of individual frames of a series are defined by the duration of the high state of the external enable signal. In all enable modes the detector configuration parameter nimages is implied to be 1. The number of frames in a series therefore is solely based on the value of the parameter ntriggger.

Information **#11**

The configured count_time and frame_time should be close to the count time and frame time of the shortest expected exposure in the configured series. The set count_time will be used to calculate internal auto-summation configuration values (section 3.2.3). In most situations a reasonable estimate of these values is sufficient.

Example detector configuration for externally enabled exposure series:

detector | config | trigger_mode	{"value": "exte"}
detector | config | nimages	{"value": 1}
detector | config | ntrigger	{"value": 10}
detector | config | frame_time	{"value": 1.0} (see . 11)
detector | config | count_time	{"value": 0.7} (see . 11)

After arming the detector, the acquisition can be enabled by an external signal. The value ntrigger defines how often this can be repeated. The detector starts exposing the first image after the rising edge and stops after the falling edge of the external trigger signal. In the same manner, all subsequent frames are externally enabled. The count time and period are therefore solely determined by the external enable signal and the limitations of your detector system. The detector records as many frames as valid (according to the specifications) enable pulses are received until the value set for ntrigger is reached. Figure 9.4 illustrates a externally enabled series.

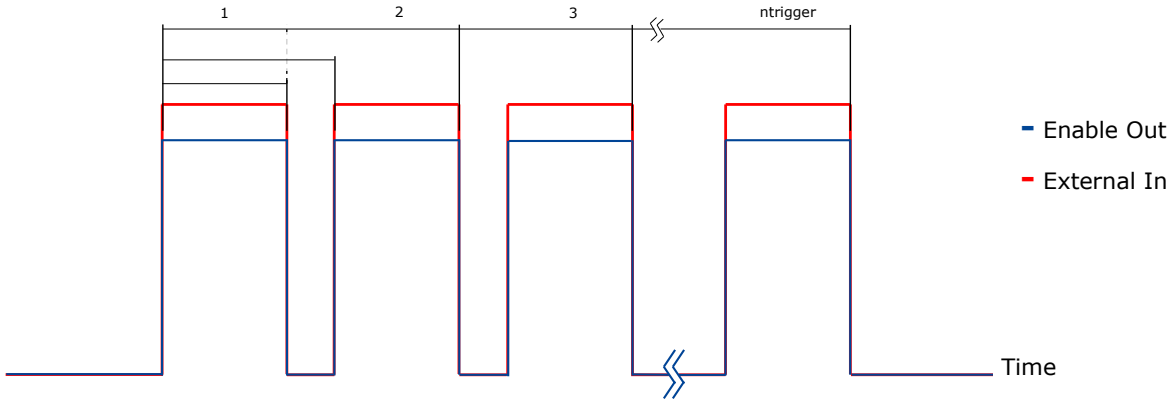

Figure 9.4: Exposures defined by external enable

9.6. EIES - Externally Interrupted Exposure Series

Information #12

The externally interrupted trigger series is not available on the EIGER2 R 250K and EIGER2 R 500K detector systems.

In the externally interrupted trigger series (”eies”) mode, the first trigger pulse will start the exposure and subsequent triggers will stop the running exposure and start the next exposure with the smallest possible delay. The last trigger, as configured in ntrigger will stop the running exposure and end the series. This mode is useful when the exact length of an exposure is unknown and no gating signal is available.

It is possible to configure a number of skipped triggers which will be ignored. E.g. if {ntriggers_skipped: 2}, the first trigger will start the exposure, the next two triggers will be ignored and the 4th trigger will stop the running exposure and immediately start the next one and so forth. This cycle will continue until ntrigger has been reached, where the skipped triggers are not counted. The number of trigger pulses to be sent for a full series is $(\text{ntriggers\_skipped}+1)*(\text{ntrigger}-1)+1$. The number of images acquired is always equal to $\text{ntrigger}-1$. Setting the count_time and frame_time as close to the expected real value is recommended to ensure the detector count rate correction works optimally.

Information #13

To use this mode, the number of images nimages has to be set to 1 and the number of triggers ntrigger has to be greater than 1. This has to be configured before changing to the eies mode. If either of these conditions is not met, an error will be returned and the mode cannot be enabled.

Example detector configuration for externally interrupted exposure series:

detector | config | nimages	{”value”: 1}

detector | config | ntrigger	{"value": 11}
detector | config | trigger_mode	{"value": "eies"}
detector | config | frame_time	{"value": 1.0} (see 11)
detector | config | count_time	{"value": 0.9999999} (see 11)
detector | config | ntriggers_skipped	{"value": 0}

This exposure configured in the example above will expect 11 trigger input signals and create 10 images.

9.7. EXTG - Externally Gated Exposure

Information **#14**

The trigger mode "extg" is only available with DECTRIS EIGER®2 X and XE detectors.

Caution **#6**

Consult the Technical Specifications for details about the required electrical characteristics of the gate signal.

The EIGER2 X and XE detector systems are fully gateable, allowing for measurements down to a few tens of nanoseconds. In the external gating mode, the detector counts only when the external input signal is high. This mode allows multiple short exposures to be summed in one image. This functionality is useful to capture data from rapidly repeating events with a high temporal resolution, such as in pump-probe experiments.

In this documentation a "gated window" describes the operation, time, and behavior of the detector between the transition from low to high and back to low of the signal on the external trigger input. Typical times for "gate windows" are a few tens of ns to a few 100 ns. The delay and jitter of the external gating is well below 100 ns.

The EIGER2 application specific integrated circuit (ASIC) offers two 16 bit counters for each threshold. To allow maximum flexibility, two different gating modes ("extg_mode") are provided: "single" and "double".

The "double" mode allows to acquire two images with two different delay times to be recorded during the same acquisition by alternating the two counters. For example, this can be used in pump-probe experiments to acquire an image of the ground state and one of the excited state for each pump-probe cycle in the same acquisition. This mode is explained in more detail in section 9.7.3.

The "single" mode connects the two 16 bit counters to form one 32 bit counter (for each threshold). This makes it possible to take gated acquisitions with a 32 bit dynamic range at the cost of a longer dead time. This mode is useful if short gating times are needed. All other trigger modes use a feature called auto-summation to achieve the 32 bit dynamic range while keeping a duty cycle above 99.9% (see section 3.2.3). More information on the single external gating mode can be found in section 9.7.4.

9.7.1. General Usage

To use the external gating feature, the trigger_mode "extg" needs to be set. If this mode is set, the behavior of the detector is controlled by a signal applied to the trigger input. In this mode, the enable out signal only mirrors the trigger input signal and does not give feedback on the internal status of the detector.

For the best results, the count rate correction and retrigger should be turned off in gating mode:

detector | config | countrate_correction_applied	{value: "false"}
detector | config | counting_mode	{value: "normal"}

9.7.2. Second threshold

Both thresholds can be used simultaneously if required. The second threshold needs to be activated by setting the parameter threshold/2/mode to enabled.

9.7.3. Gating Mode "double"

In gating mode "double", the EIGER2 system will write the counts detected during the first gated window into counter A and the value of the second gated window into counter B (see figure 9.5). The next gated window will be added again to counter A and so on. The minimal time between two gate signals is 100 ns. After the number of gate windows reaches the configured number of images per exposure nexpi for both counters A and B, a readout will happen (e.g. if nexpi=4, the readout will happen after 8 gated windows have passed, meaning 4 gated windows will have been summed up in each counter). The readout takes less than 2 ms after which the exposure of the next image can be started. This will be repeated until the set number of nimages is reached, where every measurement produces 2 images (nimages=6 would correspond to 3 measurements). Due to this, the configured number of images nimages has to be an even number.

Until the actual readout happens, the input line will continue to alternate the counters for every window received (typically derived from a continuous overall timing clock, such as e.g. the synchrotron ring clock). This way, the synchronization of the gates is maintained and the counters A and B will always be associated with the same gate delay in every readout.

In this mode, it is very important to avoid missed trigger signals. Check the quality of the trigger signal and avoid any ringing of the signal or other unwanted interference. Refer to the Technical Specifications for details on the trigger input signal level and impedance.

The images of the two counters can be read out using the stream2, filewriter2 or the monitor interfaces. The counter corresponding to each image can be figured out using the image_id, passed as stream2 header or tiff metadata. Counter A will always have an even image_id, while counter B will always be uneven.

This feature can be used for example in a pump-and-probe experiment to capture the state before and after the pump simultaneously in a single measurement.

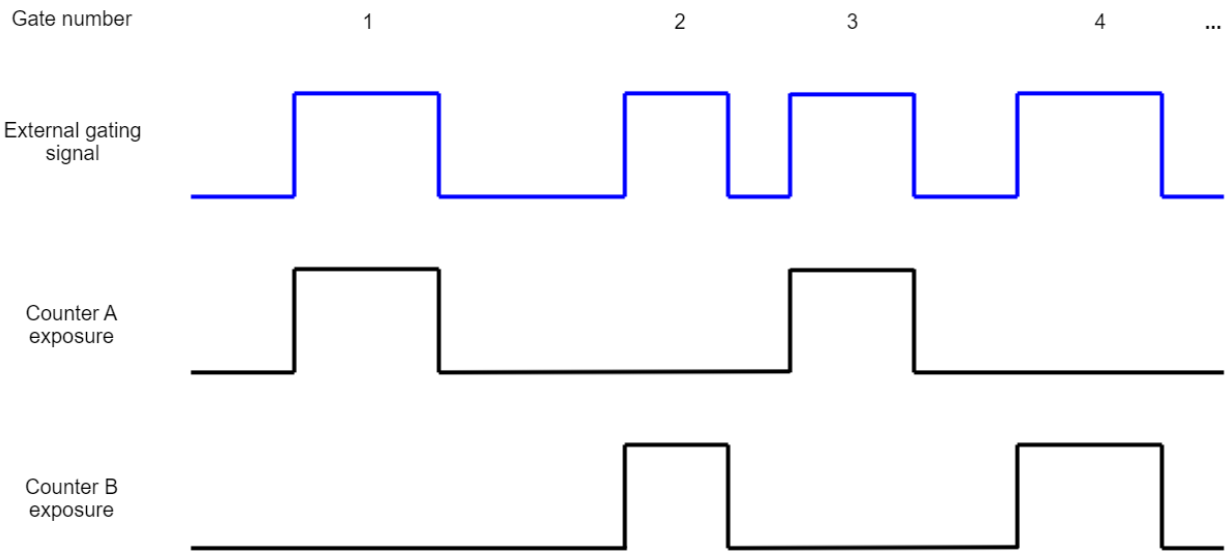

Figure 9.5: Scheme illustrating the gating mode ”double”.

Warning **#1**

In the extg_mode ”double”, nimages has to be an even number and ntrigger has to be set to 1. If these parameters are not configured correctly, an error will be returned and the mode cannot be enabled.

Example detector configuration for externally gated exposure series:

detector | config | trigger_mode	{”value”: ”extg”}
detector | config | extg_mode	{value: ”double”}
detector | config | ntrigger	{”value”: 1}
detector | config | nimages	{”value”: 10}
detector | config | nexpi	{”value”: 10000}
detector | config | countrate_correction_applied	{value: ”false”}

9.7.4. Gating Mode "single"

For gating measurements using gating mode ”single”, the two 16-bit counters of each threshold will be connected to form a single 32 bit counter. In ”single” mode the system adds up the signals in the combined counter. The advantage is a very large dynamic range, as each threshold gets one 32 bit counter. Photons arriving during each gated window will be integrated in the counter. After the desired number of gated windows is reached, as defined in nexpi, a readout will happen and produce a 32 bit image for each threshold enabled. The readout will take less than 2 ms. This will be repeated until the configured number of images nimages has been reached.

Please note, that it is not necessary to use the mode ”single” gating mode to achieve a 32-bit dynamic range. The other trigger modes offer auto-summation, also achieving 32 bit depth, and which are generally recommended unless you need very short gating windows and minimal jitter.

Warning **#2**

In the extg_mode ”single”, ntrigger has to be set to 1. If ntrigger is not configured correctly, an error will be returned and the mode cannot be enabled.

detector | config | trigger_mode	{value: ”extg”}
detector | config | extg_mode	{value: ”single”}
detector | config | nexpi	{value: 123456}
detector | config | nimages	{value: 20}
detector | config | ntrigger	{value: 1}
detector | config | countrate_correction_applied	{value: ”false”}

10. HDF5 AND ALBULA

10.1. ALBULA Overview

ALBULA is a cross-platform image viewer developed and maintained by DECTRIS®. It is a fast and easy-to-use program that allows optimal visualization of the data collected with DECTRIS detectors. The ALBULA API provides a Python interface for image display and for data processing and analysis. The API also enables easy integration of viewer functionality with the user infrastructure and experimental setups.

ALBULA can be downloaded for free[1] at www.dectris.com. Scripts written in Python using ALBULA can be used to read, display and store data taken by the EIGER2 detectors.

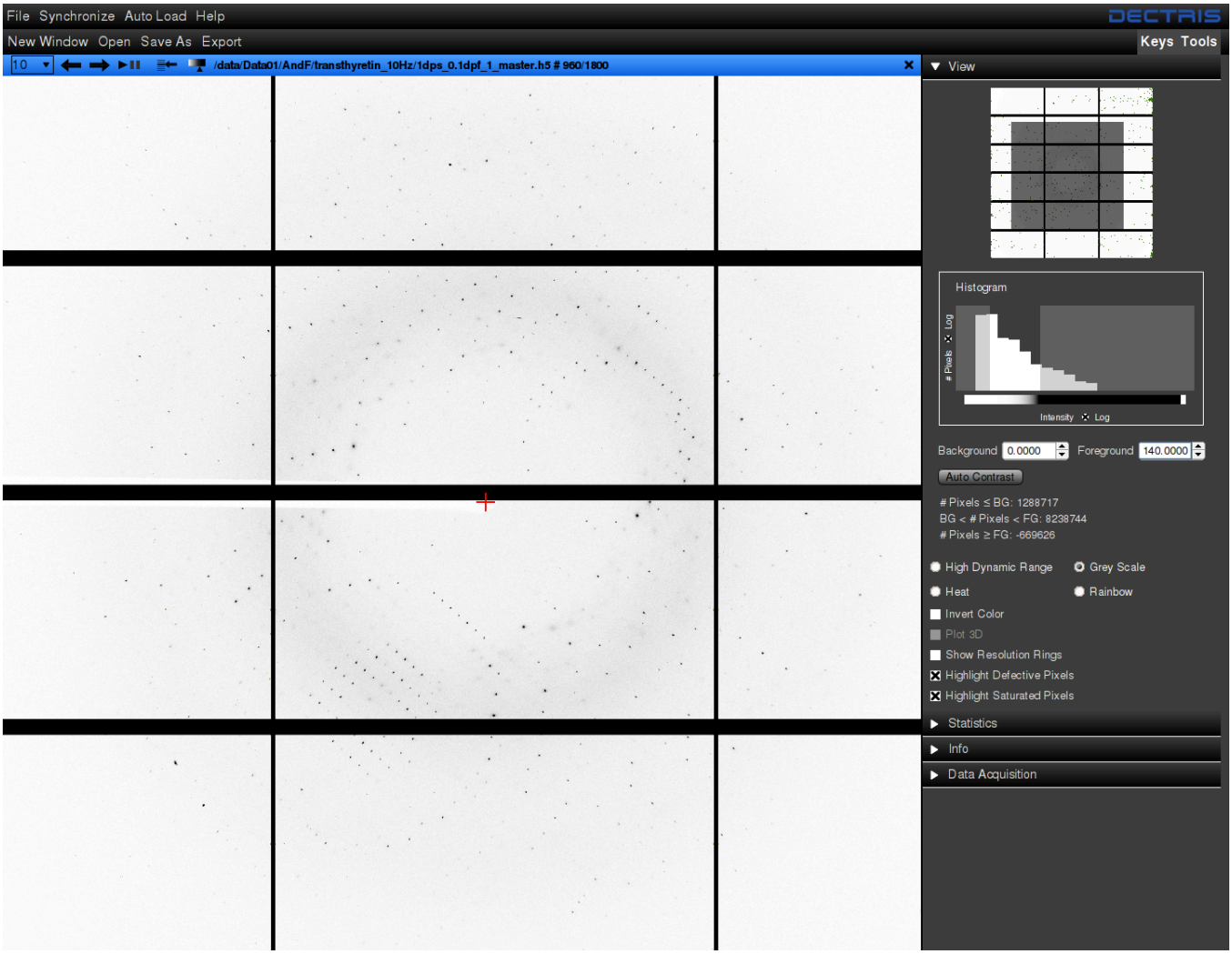

Figure 10.1: Screenshot ALBULA showing crystallographic data acquired by an EIGER X 9M

[1] Registration required

10.2. ALBULA HDF5 Python Library

The following examples illustrate how the data stored in HDF5 files by the EIGER2 detector can be manipulated with ALBULA.

10.2.1. Getting Started

[]$_ Example ALBULA

```
#!/usr/bin/python

### import the dectris.albula image library ###
import sys
sys.path.insert(0,"/usr/local/dectris/python")
import dectris.albula as albula
def iterateChildren(node,nodeList=[]):
    """ iterates over the children of a neXus node """
    if node.type() == albula.GROUP:
        for kid in node.children():
            nodeList = iterateChildren(kid,nodeList)
    else:
        nodeList.append(node)
    return nodeList
### open the albula viewer ###
m = albula.openMainFrame()
s = m.openSubFrame()
```

10.2.2. Reading data

[]$_ Example ALBULA

```
### read the compressed (or uncompressed) container through the master file ###
h5cont = albula.DImageSeries("series_16_master.h5")

### loop over the frames and read out optional data ###
for i in range(h5cont.first(), h5cont.last() + 1):
    img = h5cont[i]
    ### read header items using convenience functions ###
    optData = img.optionalData()
    ## e.g. wavelength ##
    wavelength = optData.wavelength()
    ## threshold energy ##
    threshold_energy = optData.threshold_energy()

### Read the header item directly without convenience functions ###
neXusHeader = h5cont.neXus()
### print all header item names with path ###
neXusRoot = neXusHeader.root()

def iterateChildren(parent):
    if not hasattr(parent, 'children'):
        return set([parent.path()])
    else:
        paths = set()
        for child in parent.children():
            paths.update(iterateChildren(child))
        return paths

for kid in iterateChildren(neXusRoot):
    print kid.neXusPath()

## extract wavelength ##
wavelength = neXusRoot.childElement('/entry/instrument/monochromator/wavelength')
## print value ##
print "wavelength value: ",wavelength.value()
## extract threshold ##
threshold_energy = neXusRoot.childElement('/entry/instrument/detector/threshold_energy')
## print value ##
print "threshold_energy value: ",threshold_energy.value()
```

10.2.3. Writing Data

[]$_ Example ALBULA

```
### write the (uncompressed) images and the neXus header to a new HDF5 file ###
HDF5Writer = albula.DHdf5Writer("testContainer.h5",1000, neXusHeader)
for i in range(h5cont.first(), h5cont.last() + 1):
    img = h5cont[i]
    HDF5Writer.write(img)
### flushing closes the master and the data files ###
HDF5Writer.flush()

### write the images in the cbf format. Careful: Information from the header will be lost!
    ###
for i in range(h5cont.first(), h5cont.last() + 1):
    img = h5cont[i]
    albula.DImageWriter.write(img, "testImage_{0:05d}.cbf".format(i))

### write the images in the tif format. Careful: Information from the header will be lost!
    ###
for i in range(h5cont.first(), h5cont.last() + 1):
    img = h5cont[i]
    albula.DImageWriter.write(img, "testImage_{0:05d}.tif".format(i))
```

10.3. Third Party HDF5 Libraries

The EIGER2 HDF5 data can also be directly read with programs using the HDF5 library. By default the EIGER2 data is compressed using the BSLZ4[2] algorithm. In order to decompress the data, the HDF5 plug-in filter[3] can be used, see github.com/nexusformat/HDF5-External-Filter-Plugins. By setting the environment variable HDF5_PLUGIN_PATH to the path where the compiled plug-in filter can be found, the HDF5 library will decompress the data compressed with LZ4 by itself. If you want to use proprietary software like Matlab, IDL or similar, make sure that the HDF5 library version used by this software is at least v1.8.11 in order for the plug-in mechanism to work.

For developers using C++, example code can be found on the DECTRIS® website, after registration and login.

[2] See: https://code.google.com/p/lz4/, https://github.com/kiyo-masui/bitshuffle

[3] In order to use the filter plug-in mechanism, HDF5 v1.8.11 or greater must be used. See also http://www.hdfgroup.org/HDF5/doc/Advanced/DynamicallyLoadedFilters/HDF5DynamicallyLoadedFilters.pdf

11. PIXEL MASK

11.1. Applying the pixel mask

The detector configuration parameter pixel_mask_applied enables (True) or disables (False) applying the pixel mask on the acquired data. Every threshold has its own pixel mask. These masks may differ from one another. If true (default), pixels which have any bit set in the pixel_mask are flagged with $(2^{\text{image bit depth}} - 1)$. Please consult the API Reference for details on the detector configuration parameter pixel_mask.

11.2. Updating the pixel mask

11.2.1. Overview

Updating the pixel mask of an EIGER2 detector system involves four basic steps:

1. Retrieving the current pixel mask from the detector system via the SIMPLON API.
2. Manipulating the pixel mask to add or update pixels.
3. Uploading the updated pixel mask to the detector system via the SIMPLON API.
4. Persistently storing the updated pixel mask on the detector system by sending the detector command arm.

11.2.2. Retrieving the current mask from the detector system

The pixel mask can be retrieved from the detector system by a GET request on the detector configuration parameter threshold/n/pixel_mask where n is the threshold number. The data of the pixel mask is retrieved either as tiff or in JSON serialization by choosing application/tiff or application/json in the get request accordingly.

11.2.3. Manipulating the pixel mask

Information #15

For details about the pixel values in the pixel mask and their meaning, consult the API Reference.

TIFF

If the pixel mask is retrieved and stored as tiff, the uint32 data in the tiff file can be manipulated with ALBULA API.

JSON

If the pixel mask is retrieved as JSON, the HTTP reply has to be parsed correctly into an array. Please see the example below and the API Reference for details. The values in this array can then be manipulated to reflect the required updates of the pixel mask. After updating the array, it has to be serialized again in JSON according to the specifications in the API Reference.

11.2.4. Uploading and storing the pixel mask

The pixel mask is uploaded by sending a PUT request on the detector configuration parameter pixel_mask with the new mask as data. After sending the detector command arm, the updated pixel mask is permanently stored on the detector system.

11.2.5. Python Example

The following Python code using common libraries provides a simple example for updating the pixel mask:

[]$_ Python Code

```
import json
import numpy
import requests

from base64 import b64encode, b64decode

IP = '169.254.254.1'
PORT = '80'

def get_mask(ip, port):
    """
    Return the pixel mask of host EIGER system as numpy.ndarray
    """
    url = 'http://{}:{}/detector/api/1.8.0/config/pixel_mask'.format(ip, port)
    reply = requests.get(url)
    darray = reply.json()['value']
    return numpy.frombuffer(b64decode(darray['data']),
        dtype=numpy.dtype(str(darray['type']))).reshape(darray['shape'])

def set_mask(ndarray, ip, port):
    """
    Put a pixel mask as ndarray on host EIGER system and return its reply
    """
    url = 'http://%s:%s/detector/api/1.8.0/config/pixel_mask' % (ip, port)
    data_json = json.dumps({'value': {
                            '__darray__': (1,0,0),
                            'type': ndarray.dtype.str,
                            'shape': ndarray.shape,
                            'filters': ['base64'],
                            'data': b64encode(ndarray.data).decode('ascii') }
                        })
    headers = {'Content-Type': 'application/json'}
    return requests.put(url, data= data_json, headers=headers)

if __name__ == '__main__':
        # initialize the detector
        url = 'http://{}:{}/detector/api/1.8.0/command/initialize'.format(IP, PORT)
        assert (requests.put(url).status_code == 200), 'Detector could not be initialized'
    # get the mask
    mask = get_mask(ip=IP, port=PORT)
    # copy the mask to writeable buffer, necessary for numpy>=1.16.0
    mask = numpy.copy(mask)
    # set a new dead pixel [y,x]
    mask[123, 234] = 2
    # set a new noisy pixel [y,x]
    mask[234, 123] = 8
    # upload the new mask
    reply = set_mask(mask, ip=IP, port=PORT)
    # reply.status_code should be 200, then arm and disarm to test the system
    if reply.status_code == 200:
        for command in ('arm', 'disarm'):
            url = 'http://{}:{}/detector/api/1.8.0/command/%s'.format(IP, PORT, command)
            requests.put(url)
    else:
        print reply.content
```

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