Characterization and Calibration of 2nd Gen AGIPD Electronics

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Abstract

The 2nd Gen Adaptive Gain Integrating Pixel Detector electronics is developed for European XFEL experimental stations and a 0.5 Mpix prototype is working in air and higher temperature. The high gain linear range is smaller than for the systems with old electronics operated at lower temperatures in vacuum. The dependence of this feature on the temperature was studied in this work.

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1 Introduction

The FS-DS DESY group in cooperation with other institutes have been developing a new version of the AGIPD detector for European XFEL experiments. The European XFEL is an extremely brilliant Free Electron Laser Source with a very demanding pulse structure and the Adaptive Gain Integrating Pixel Detector is developed to cope with these properties.
The new prototype of AGIPD is operated at a higher temperature (since it is operated in air and not vacuum) and the high gain linear range was observed to be smaller than for the 1M systems with old electronics operated at lower temperatures in vacuum. To understand if this is caused by temperature or new electronics, the task of this project is to study the temperature dependency of the new electronics.

2 The Adaptive Gain Integrating Pixel Detector

The Adaptive Gain Integrating Pixel Detector, is a hybrid pixel detector developed by DESY, PSI, and the Universities of Bonn and Hamburg to cope with the properties of European XFEL. The European XFEL is an extremely brilliant Free Electron Laser Source with a very demanding pulse structure: trains of 2700 X-ray pulses are repeated at 10 Hz. The pulses inside the train are spaced by 220 ns and each one contains up to 1012 photons of 12.4 keV, while being $\leq$ 100 fs in length. Two 1 Mpixel detector systems are in operation at the SPB and MID experimental stations and new AGIPD detector systems for SFX and HIBEF are under developed [1].

2.1 Front-end module

Front-end modules are constructed from Silicon p-on-n type sensor tiles. Two by eight AGIPD 1.2 readout ASICs[1] are bump-bonded to a sensor tile to form an assembly. These are glued and wire bonded to gold-plated pads on a Low Temperature Co-field Ceramics (LTCC). The front-end modules are attached to a copper cooling block. This cooling blocks allows to lower the temperature bellow 0 °C. The block is mounted in a vacuum vessel [1].

2.2 Adaptive gain switching

A charge-sensitive preamplifier forms the input of each pixel. The output of the preamplifier is connected to a discriminator as well as to a CDS[2] stage with two globally adjustable gain settings. Whenever the output of the preamplifier exceeds a selected threshold the discriminator triggers a gain change. Gain switching means additional feedback capacitors are added to the preamplifier feedback. The sensitivity of the preamplifier is adaptively decreased and the dynamic range is increased in two steps. The feedback

[1]Application Specific Integrated Circuits
[2]Correladed Double-Sampling

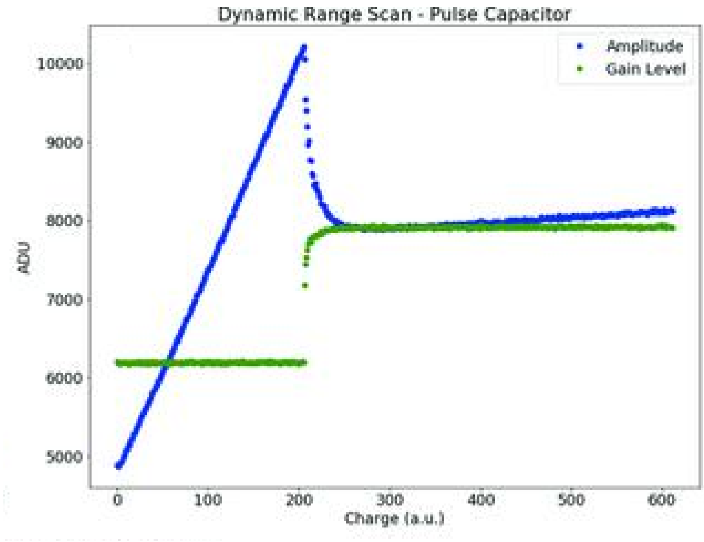

Figure 1: Example of dynamic range scan pulsed capacitor. Source: [2]

capacitances are 60 fF 30 pF, and 10 pF. The output of the CDS stage is stored in an analogue memory. The advantage of the adaptive gain switching it is that is possible achieve single photon resolution in the high gain and a higher dynamic range in the medium and the low gain in the same image. [2] [1].

2.3 Pulsed capacitor

Calibration procedure requires to calibrate for each pixel any memory cell individually for all three gain settings. This means that there are more than 2.8 billion calibration parameters for a 1 million pixel detector system. The ASIC includes two internal calibration sources - pulsed capacitor and a current source. So an external stimulus is not necessary for dynamic range scans. Using the pulsed capacitor is possible cover the full high gain, and half of the medium gain range. The full dynamic range can be assessed using the current source, albeit with some drawbacks.
The pulsed capacitor scans the dynamic range by gradually increasing the amplitude of a voltage step applied to a small capacitor connected to the pixel input. On the contrary to the current source, this allows a constant integration time [2].

2.4 Memory

The pixel response is recorded by the in-pixel high speed memory, which records the pixel response. Due the in-pixel memory is area of each pixel bigger, but recording speed is higher, which is compatible with the 4.5 Mhz requirement of the European XFEL. Each memory address contains two separate pieces of information:

i the output voltage of the CDS stage, which is proportional to the detected signal is stored on a 200 pF capacitor

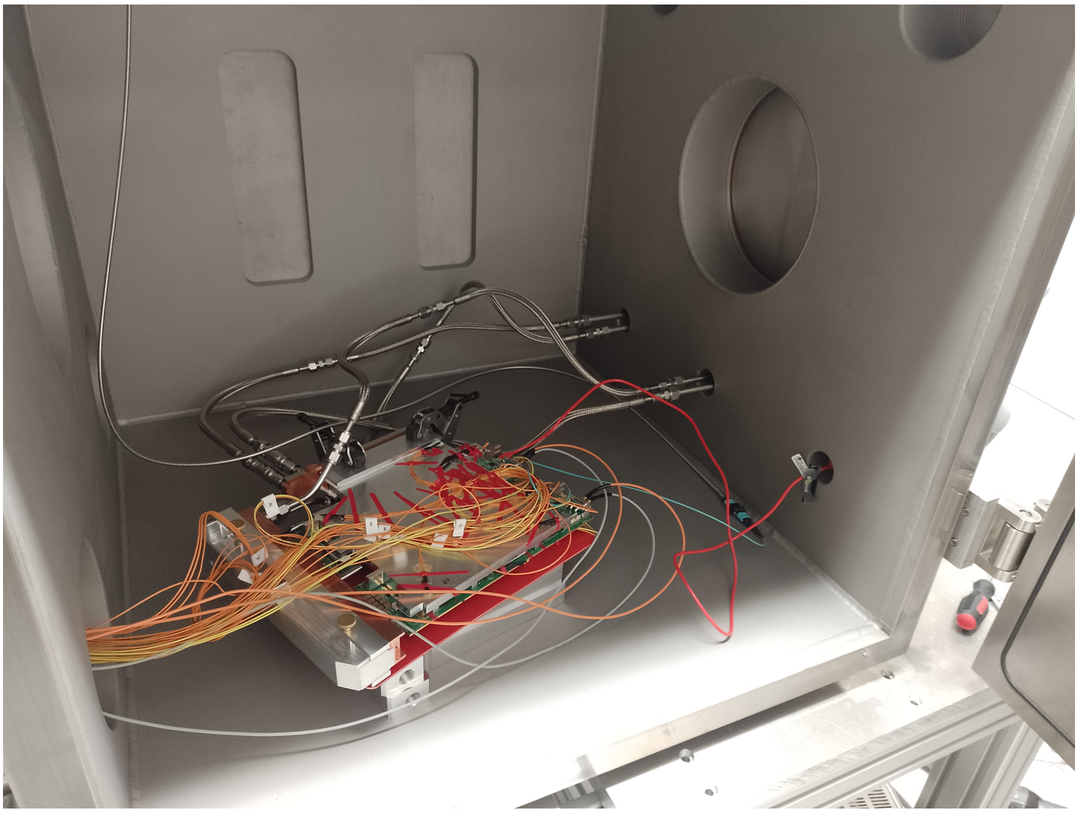

Figure 2: Front-end module, Read-out Board with cooling pipes inside a vacuum chamber

ii the gain state of the pixel, encoded as a voltage is stored on a 30 pF capacitor.

Up to 352 images consisting of signal and gain information can be stored in the memory matrix. Another charge-sensitive amplifier in each pixel is used to read the memory during readout of the chip, which happens in parallel for each row of pixels. Two interleaved column buses and four multiplexers, each serializing data from a block of 16 $\times$ 64 pixels are used for the further readout. This parallelizing onto four outputs reduces the power consumption of the readout circuitry by reducing its speed. Instrumentation amplifiers convert the signal to differential levels, which are driven off-chip for subsequent digitization.[2]

3 Experimental set up and measurements

3.1 Cooling system

The AGIPD detector will work in vacuum and at low temperatures. It is necessary to use a temperature-controlled chiller to find how linearity change depends on temperature. The temperature stability of the detector is also important. The most important part to be cooled is the front-end module.

When FEM and readout electronics were initially cooled with a Huber Unistat 620 in series, the following issue occurred: at a temperature of 0 °C the input pressure[3] of the cooling liquid dropped to atmospheric pressure and the temperature raised up to 10 °C. All components were removed and added back step by step to identify the cause. The conclusion is that the ROB[4] is cooled by an independent cooling circuit using a NESLAB MERINEM 25. It is necessary to use a booster pump to reach FEM temperatures below -12 $°C$. Around 0 $°C$ it is better to use small steps. The setup in vacuum chamber is shown in the figure 2.

3.2 Measurement

For different temperatures, a dynamic range scan was taken in 612 steps for 40 memory cells with pulsed capacitor. The ASIC was configured such that the pulsed capacitor injected charge into every 8th pixel line. We used 40 memory cells for data taking. The data was measured in a temperature range from 15 $°C$ to -5 $°C$ with 5 °C steps on the first day. The measurements started at -50 °C temperature to -10 °C with 5 °C steps on the second day.

4 Data analysis

In the data analysis, the size of the linear part of the dynamic range is to be determined for a large number of pixels and memory cells. The values for the pixels at the edge of each 64x64 matrix have been removed, because values there are doubled because of wider pixels. Still it is needed to analyse 14x496 pixels per 40 memory cells per 14 different temperatures. Therefore a algorithm was developed to analyse all of that data. The data was stored and analysed on DESY's Maxwell cluster [3].

4.1 Algorithm

In the beginning, the value of the first point of dynamic range scan was subtracted for all data to start at 0. Then data from 0 to n-th burst were linearly fitted. To achieve this n was swept from 150 to the point of gain switching. For each fit correlation coefficients were calculated and the fit with the highest correlation was used for the next analysis step.
However, this procedure takes 50 minutes to process 10 memory cells. Thus the procedure was divided into the following 3 steps to reduce the computing time:

1.) initial data processing in step 30 instead of 1

2.) 40 points midpoint [5] is deeply analyzed with a step size of 10

[3]The pressure which was measured by probe placed to input vacuum chamber pipe.

[4]Read-out Board - printed circuit board for reading data from memory cells designed for European XFEL fast reading requirements

[5]Set of points with the best correlation coefficient with own linear fit is used and a midpoint

3.) 20 points midpoint is deeply analyzed with a step size of 1

Using this three step procedure it takes around 16 minutes to analyze 10 memory cells per temperature. Furthermore, the process was parallelized (multiple CPUs), which further reduced the runtime: 3-4 minutes for the analysis of all dynamic range scans of 40 memory cells per temperature. The function polyfit() of the python NumPy package is used to find the linear fit of data and the function corrcoef() of the python NumPy package is used to find the correlation coefficient.
The last step of the algorithm consists in determining the end of the linear range of the dynamic range scan for each pixel. It was defined as the lowest point of the dynamic range scan, whose deviation from the is greater or equal to 2 %. The deviation error formula is defined as:

$$D_{err} = \frac{|B_0 - y|}{x} \tag{1}$$

Where B_0 is the relative value of point of dynamic range scan and y is y the value of the best linear fit curve.

4.2 Not properly working pixels

There were some not properly working pixels. And there are a lot of data to analyse for each pixel individually. Thus some conditions and parameters were created to analyse as many pixels as possible with the algorithm (see: 4.1) and remove not properly working pixels. The main condition was to remove less than 10% pixels. Only data sets that meet the following conditions were analysed:

- correlation coefficient must be higher than 0.997 (see: 3 b))
- deviation[6] must be less than 200 ADU in the fit range (see: 3 a)).
- the maximum amplitude of the dynamic range scan is larger than the amplitude of all pixels averaged over the scan for a fixed temperature - 2000 ADU (see: 4).

There was no gain switching in some pixels, mostly at lower temperatures. But the high gain was analysed, thus that was no problem. I If gain no gain switching was observed, the last point of the dynamic range scan (see: 4.1) was assumed..
Some pixels did not work during the measurement on the second day. It was pixel in row 80 and column 499 at the beginning (between temperatures -50 °C and -20 °C). Then also a pixel in row 96 and column 498 stopped working.
The number of pixels that needed to be processed for each temperature was 277760. The smallest allowed values for the maximum amplitude of the dynamic range scan (min) and the numbers of rejected pixel (rejected sets) per temperature are summarised in table 1.

[6] absolute value of difference between y values of the best linear fit and the points of dynamic range scan

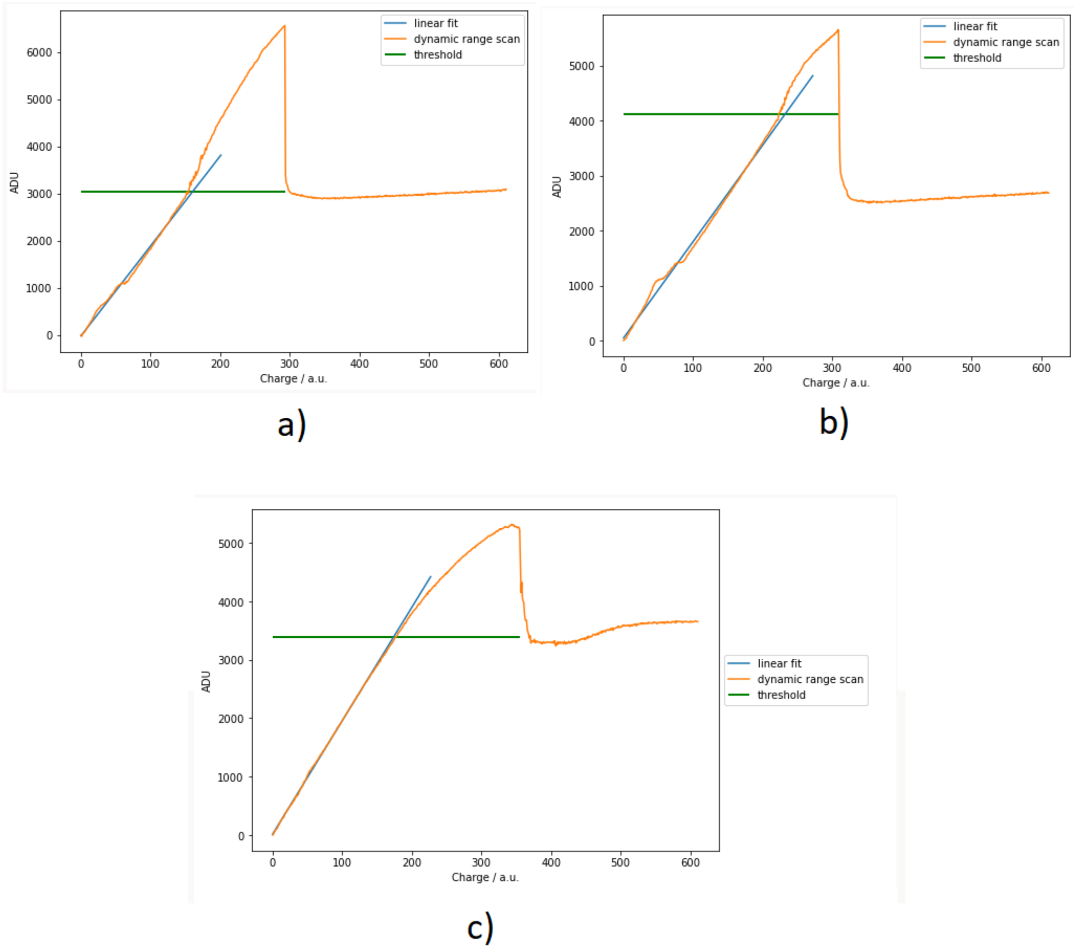

Figure 3: Example of pixels: a) deviation higher than 200, b) correlation coefficient lower than 0.997, c) analysed pixel.

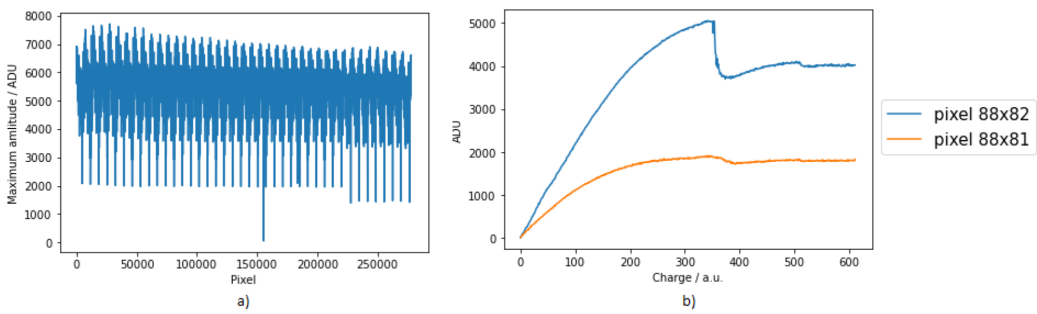

Figure 4: Comparison: a) of the maximum amplitude of the dynamic range scan for the temperature of -45 °C b) of the dynamic range scan for two neighbouring pixels at memory cell 2 for the temperature of -45 °C

T /°C	min	rejected sets
15	1900	25700
10	2100	19426
5	2200	13419
0	2300	8558
-5	2400	3879
-10	2500	3356
-15	2600	1512
-20	2900	794
-25	3000	612
-30	3100	583
-35	3200	627
-40	3300	687
-45	3400	988
-50	3500	1412

Table 1: The smallest allowed values for the maximum amplitude of dynamic range scan (min) and the numbers of rejected pixel (remote data) per temperature

5 Results and Discussion

The dependence of the high gain's linear range for 40 memory cells on temperature was determined. An inverse proportionality between the linearity threshold (i.e. the end of the linear dynamic range) and temperature was found (see: 5). By cooling from 10 °C to -50 °C the linear range increases by more than 1500 ADU.
Analysed data plotted in figure 6 shows, that there is a dependence of the linear range on the geometry of memory - for each measured temperature. The linear range is decreasing with increasing number of memory cell, until memory cell 32 where there is a local maximum. Memory cells from 0 to 31 are in the same row, and the linear range shrinks with increasing memory cell number within a row. The next row starts with memory cell number 32, and we find a local maximum at that point.
Pixel analysis shows that some pixel do not work as expected. Mainly there is a dependence of the linear range on the geometry. In addition points of dynamic range scan oscillate, there is a non-linear part in the first 50-70 points for some few pixels the scan range forms two linear parts of different slope.
There is a noticeably decreased linear range for memory cells 32 to 39 (compared to 0 to 31) at temperatures of -40 °C and -35 °C. here is an unexpected local maximum with memory cell number 7 at a temperature of -25 °C too, probably caused by removing pixel due to the selection criteria given in sec 4.2. The number of removed pixels (see: 4.1) decreases with lower temperature to reach a minimum at -30 °C and then increasing. It was expected that the number of removed pixels by temperature will be somehow stable. But the minimum number of removed pixels is about 50-times lower than the maximum. It is necessary to analyse dynamic range dependency on pixel geometry

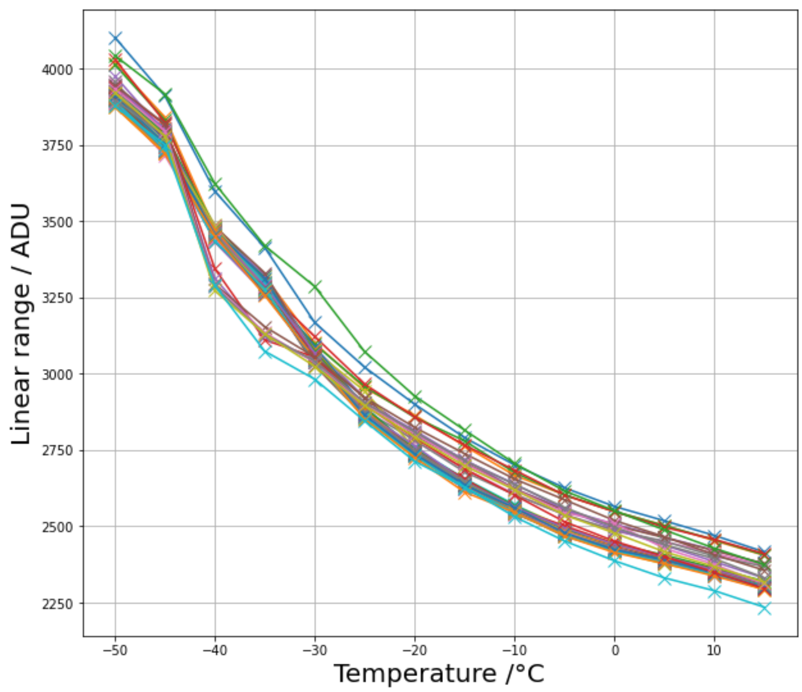

Figure 5: Dependency of the linear range on temperature for all used memory cells

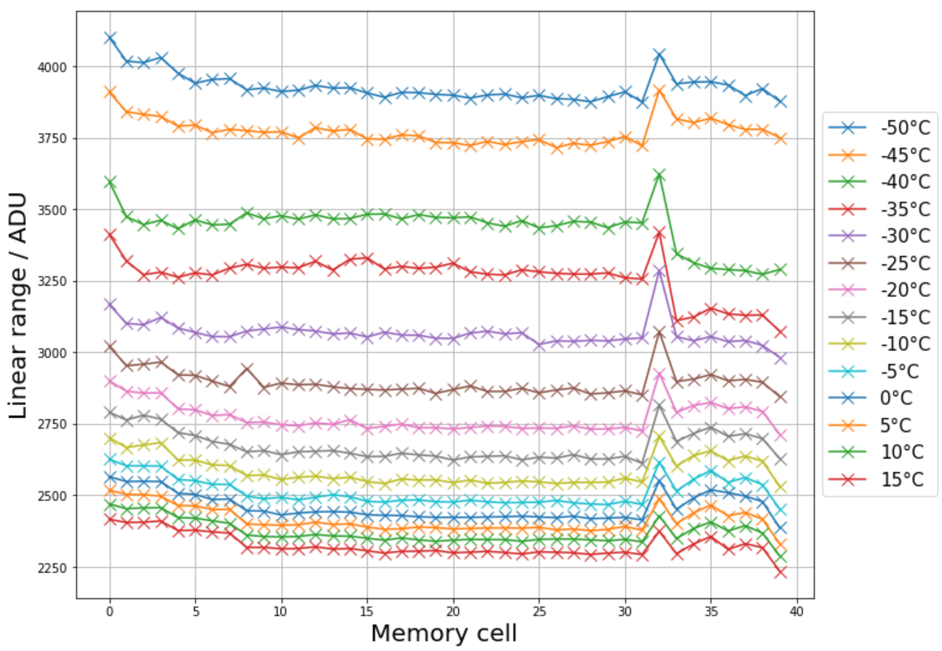

Figure 6: Linear range dependency on memory cell for all of the measured temperatures

and on temperature for better understanding that. All kinds of unexpected values are probably caused by the algorithm of removing pixels. It is important to do further analyses to prove this.

6 Summary and outlooks

The problem with the cooling system was solved before measurement. Dynamic range scan were taken in 612 steps for 40 memory cells with pulsed capacitor for 14 different temperatures. The algorithm was developed to analyse data. There is a dependence of the mean value of the set of points at which the dynamic range scan is linear on the temperature, the lower temperature, the higher mean value. For each measured temperature, there is a dependence of the mean value of the set of points at which the dynamic range scan is linear on the geometry of the memory cells.

Next step would be to analyse dynamic range scan of all pixels to study geometry and/or read-out effects. Data already available for most of the temperatures. It was possible to use only 40 memory cells (due restriction of data receiver software) and analyse more memory cells could be useful for better understanding the dependence on geometry. Another option is change other ASIC parameters/settings and analyse data of that. Regarding the algorithm used remove pixels: For better analysis is desirable to consistently remove the same pixels for all temperatures.

References

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[2] Aschkan Allahgholi, Julian Becker, Annette Delfs, Roberto Dinapoli, Peter Goettlicher, Dominic Greiffenberg, Beat Henrich, Helmut Hirsemann, Manuela Kuhn, Robert Klanner, et al. The adaptive gain integrating pixel detector at the European XFEL. *Journal of synchrotron radiation*, 26(1):74–82, 2019.

[3] Desy's maxwell cluster. `https://confluence.desy.de/display/MXW/Maxwell+Cluster`. Accessed: 2022-09-01.