

Jungfrau gain switching issue

H Lemke

Observations

...during Ovuka and Duncan Bernina experiments, September - October 2023

During the Duncan beamtime at Bernina, weird signals/correlations were seen in the high intensity pixels. For better investigation, we looked at the pump-delayed shots in run 346 where signals should be equal within the setup noise.

The data in this experiment were automatically transformed by `jungrau_utils` within the DAQ recording, the setting used were

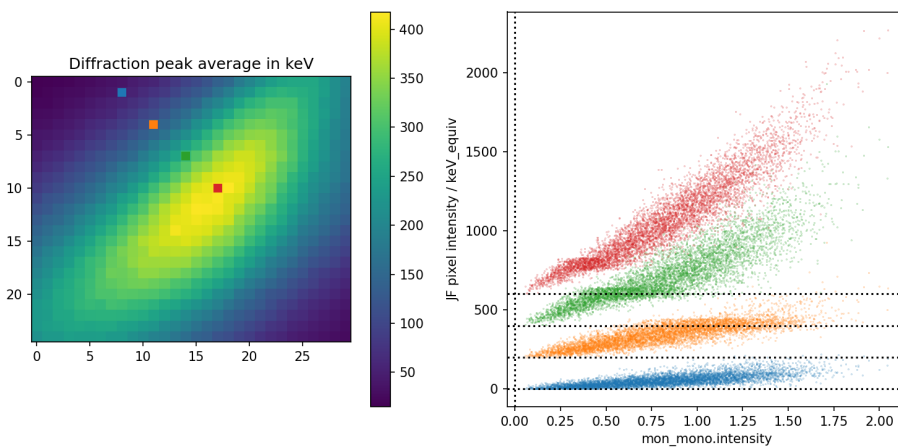
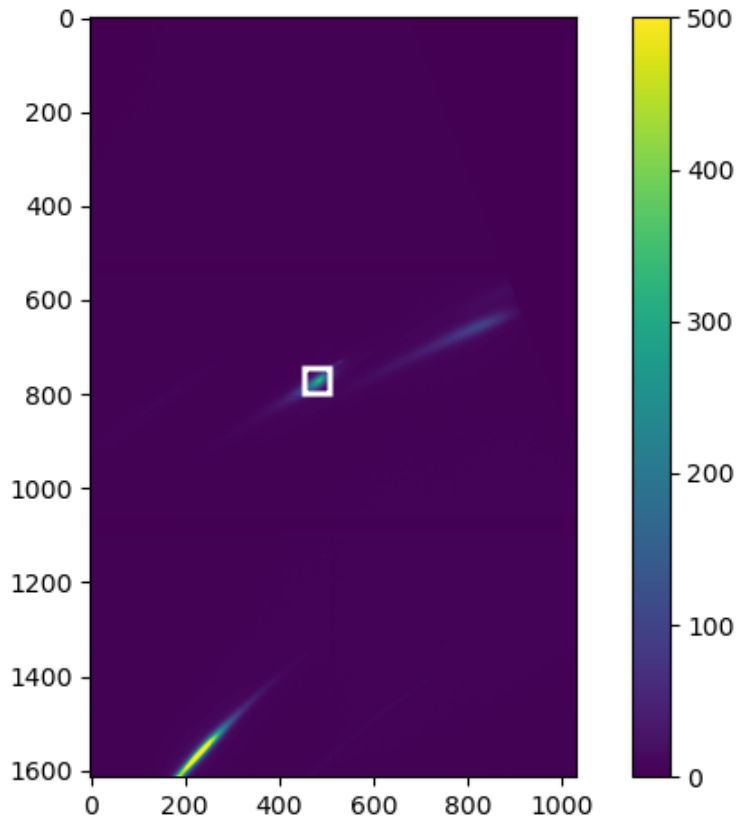
```
{'apply_tile_geometry': True,  
'compress_bitshuffle': True,  
'convert_adc_to_energy': True,  
'disabled_tiles': [],  
'keep_raw_data': True,  
'large_pixel_processing': 'keep',  
'rounding_factor_keV': 0.25}  
'gain_file': '/sf/jungfrau/config/gainMaps/JF01T03V01/gains.h5'  
'pedestal_file': '/sf/jungfrau/data/pedestal/JF01T03V01/20231007_153506.h5'
```

Other parameters

- Experiment at 10.6 keV
- measurements close to bragg peaks at high dynamic range

In order to understand the intensity developments, few pixels at different working point were regarded and plot against an external detector proportional to incoming Xray pulse energy. The region of interest used in the corrected data corresponds to (473,503,756,781), denoting (ymin, ymax, xmin, xmax).

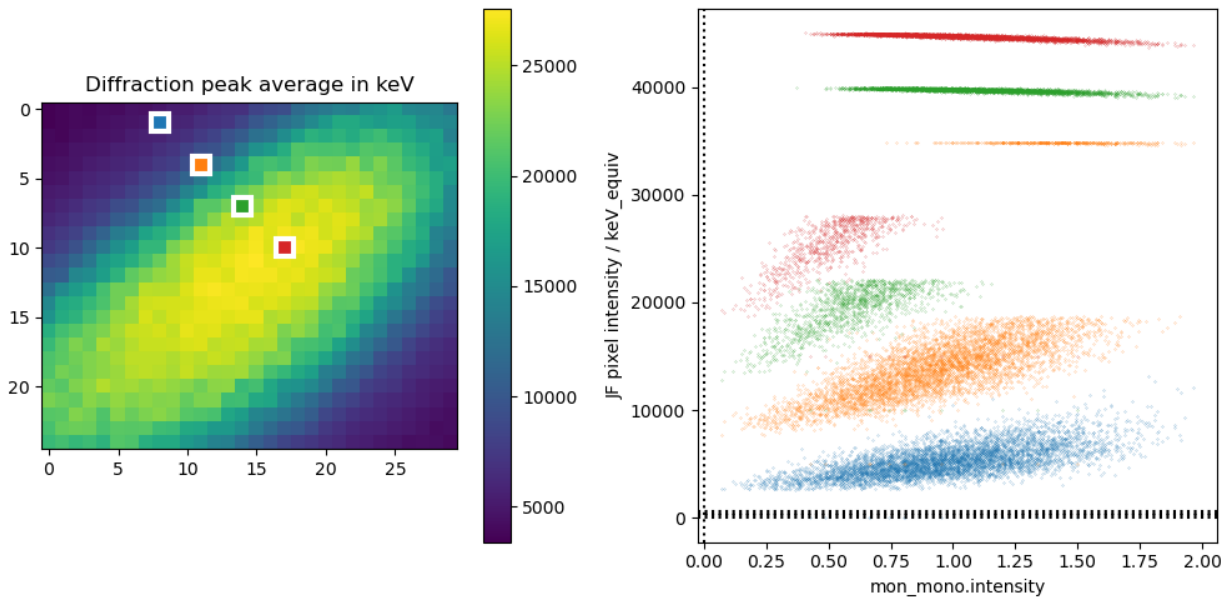
Full acquired pattern, the white square indicated the location of the region of interest used below.



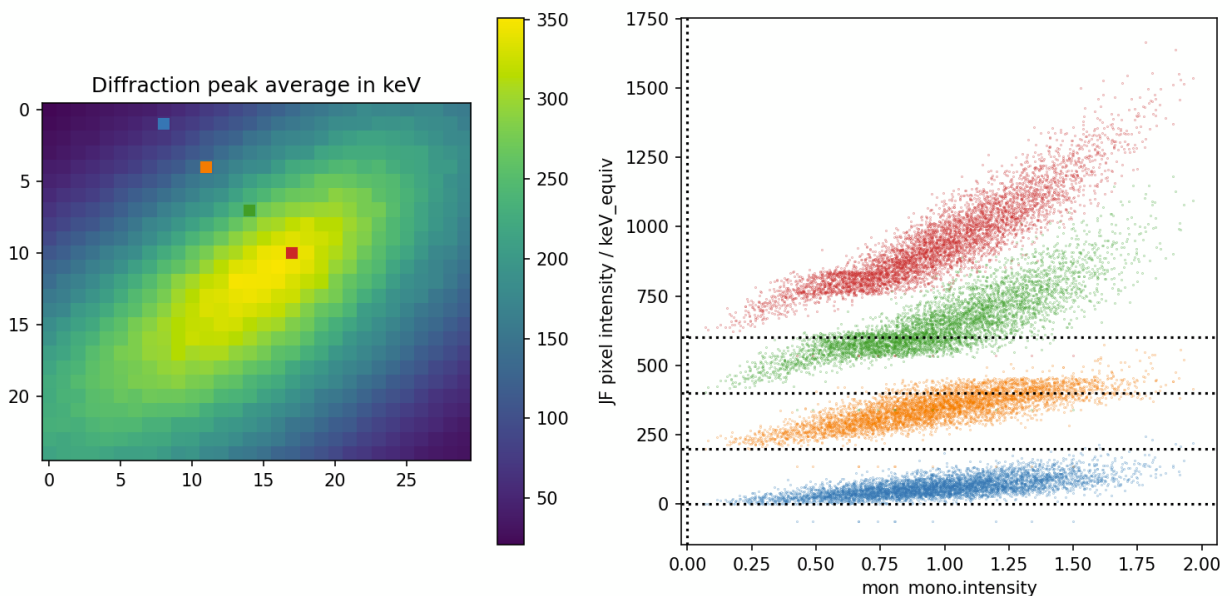
Left: regarded region of interest of JF01T03V01 spreading over quite different intensities, colored squares represent positions of pixels that were correlated in the plot to the right with a PBPS intensity monitor. Colors correspond to the positions and the JF pixel values were offset by each 200 keV equivalents for visibility.

The broad but clear correlations show a visible step in direction of JF detector intensity for those working points overcoming the expected gain switching point of ~ 250 keV equivalents at exactly that value. a second step well visible around 70 keV equivalents below.

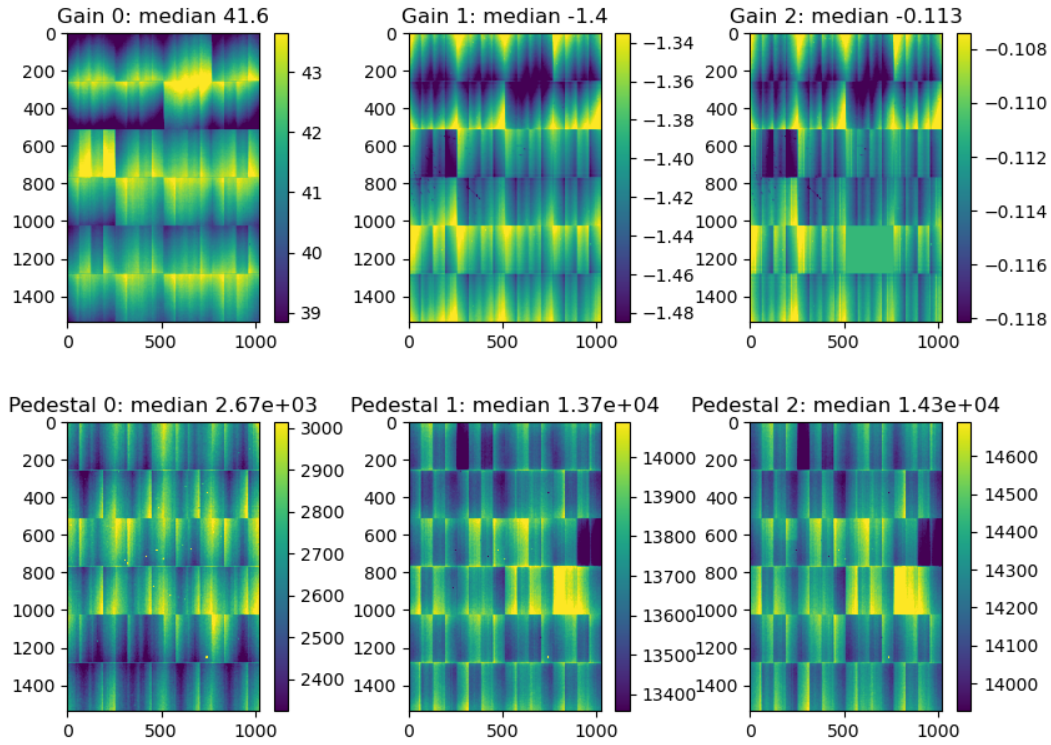
The obvious correlation to gain switching can also be seen drawing the same kind of correlation plots with the pure raw data, where the different gains are clearly offset (here the region of interest was shifted according to here missing geometrical correction to $(xmin, xmax, ymin, ymax) = (469, 499, 722, 747)$):i



A possible origin of the issue could be a incorrect assignment of pedestal or gain values in the correction. Reanalysis of the raw data shows the same effect though without visible difference:



In order to understand the variations in gains and pedestal the values used for corrections are visualized over the entire detector:

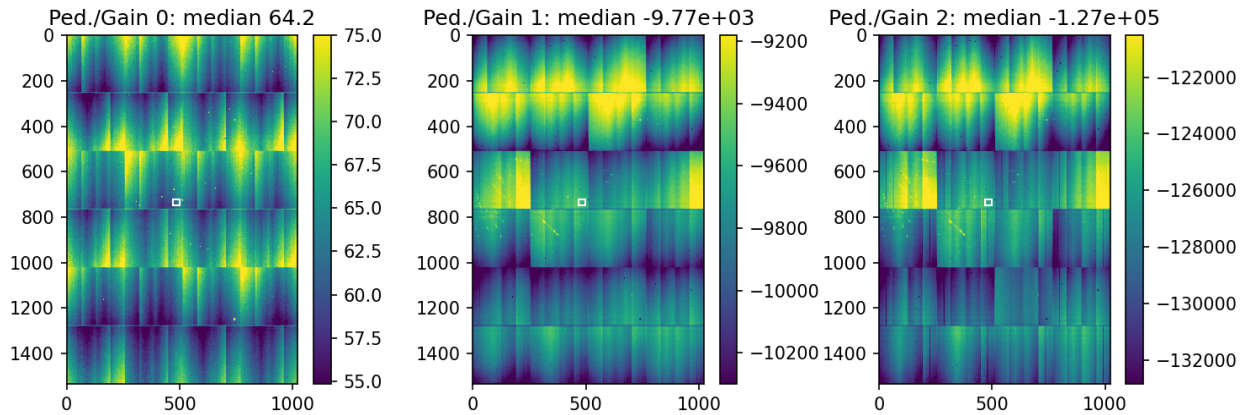


The gains and pedestal are applied in the correction algorithms as

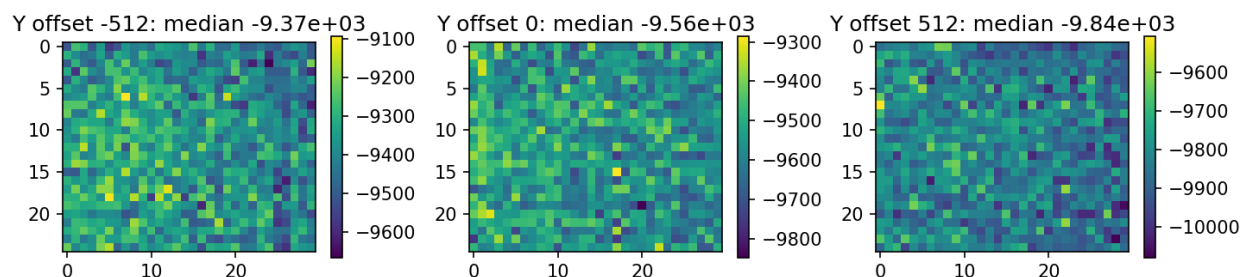
$$I_{corr} = (I_{raw} - P) / G$$

Where P and G represent the pedestal and gain fields.

The pedestal values therefore need to be rescaled to represent keV equivalent intervals. The above used region of interest is depicted as white rectangle:

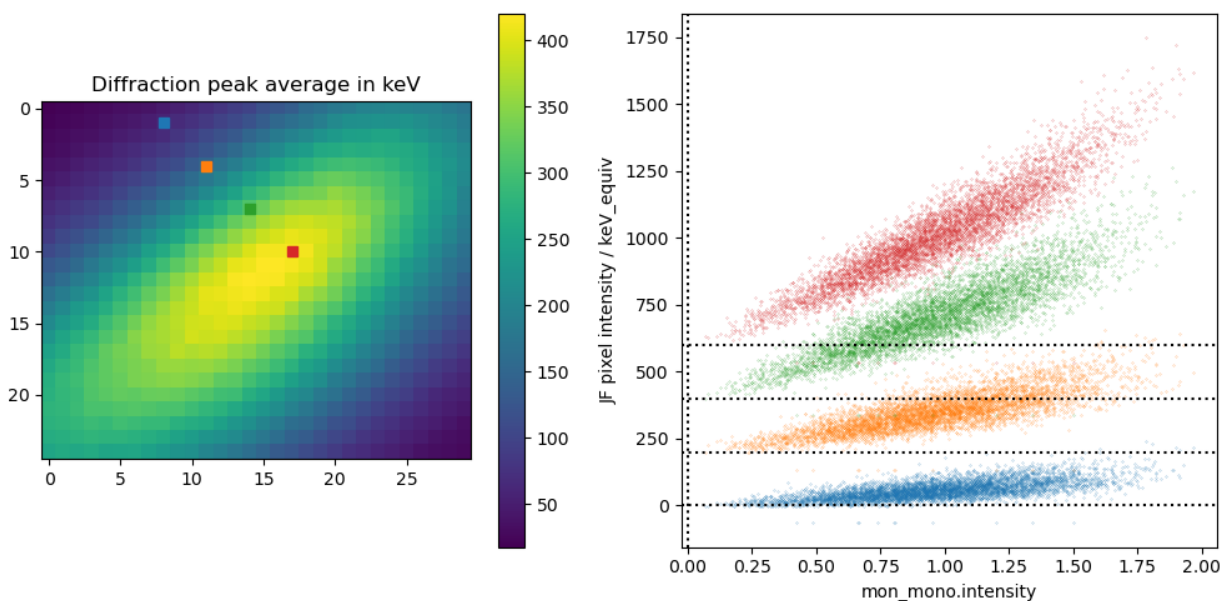


Within the gain 1, an offset by ~100 through incorrect assignment seems plausible regarding the variations over the entire detector. A potential tile misassignment can be evaluated regarding by 512 pixel shifted regions of interest in the y direction:



Correction by gain pedestal shift

In order to understand the approximate expected shift, the data with standard tile assignment was manually modified in pedestal of gain 1.



The best match was obtained with a +120 change in pedestal of mid gain ("gain 1"), which after division by the median gain value becomes -85 keV equivalent, which is (abs. change) close to the ~70 keV equiv. observed above.

A switch of tile assignment was tried but with significantly worse results (all pedestals got swapped).

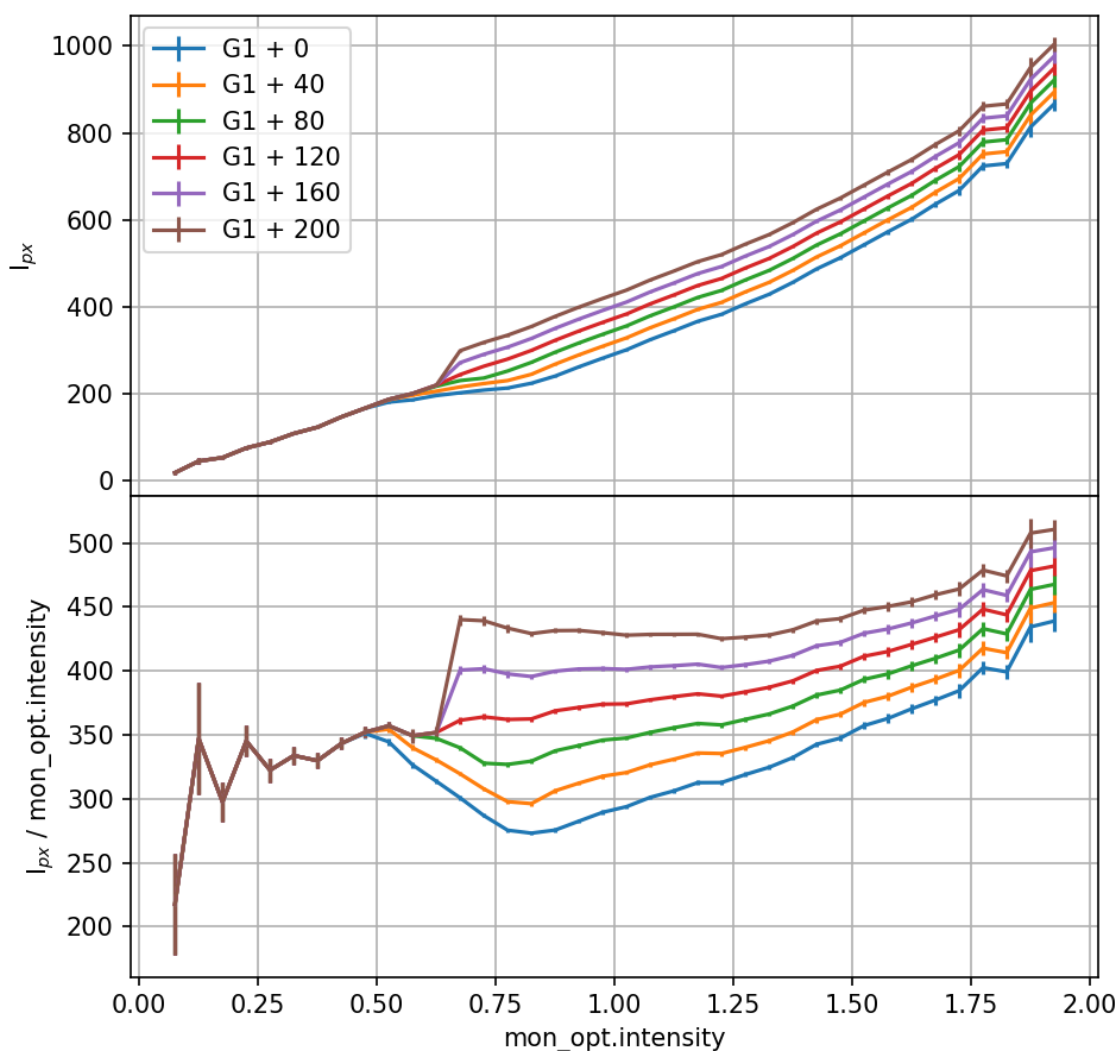
Increased sensitivity by intensity binning

The quite broad correlation in the pixels above is partially explained by systematic fluctuations in the scattering geometry, but to large extent also by poisson counting statistics noise.

In order to visualize smaller deviations from a smooth straight (not necessarily only linear) dependency, the data of multiple pulses may be binned into intensity intervals, the size of which only depends on the available statistics and the expected features to be seen.

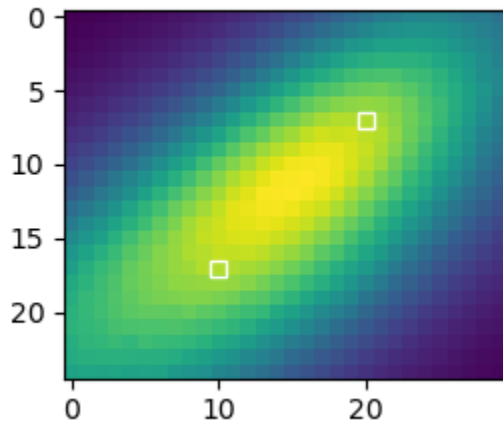
In the following the data from the single jungfrau regarded above was corrected for gain and pedestal, using different offsets for Gain1 pedestal. Then the was sorted into 0.05 intensity bins of the intensity monitor `mon_mono.intensity`, and statistically analyzed (average and standarddeviation, number of events corrected).

The results are shown below as curve and errorbars, once as direct data against the binning array of `mon_mono.intensity`, and once as ration to the `mon_mono.intensity`, in order to evaluate deviations from purely linear behavior.



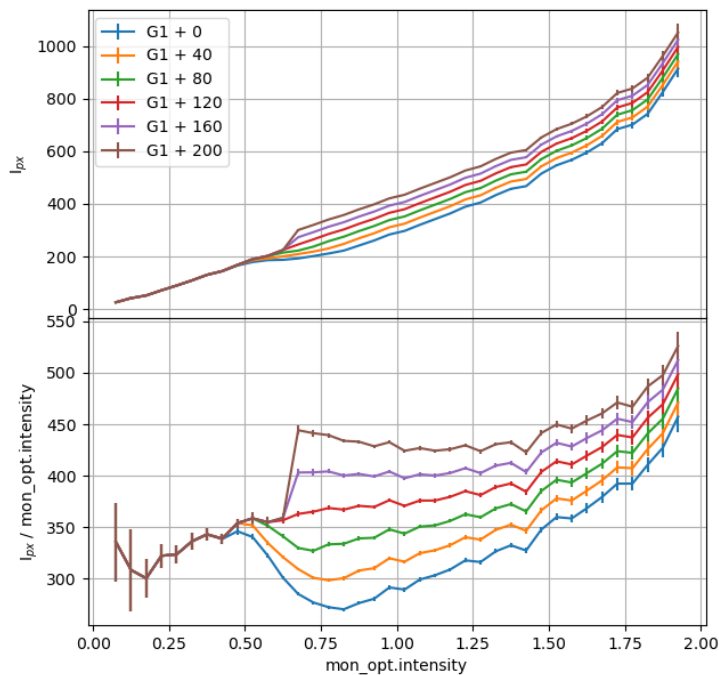
Such visualization, *especially in the ratio-representation on the bottom*, clearly shows a wiggle at the non-adjusted measured gain level (blue G1+0 curves). As determined on the noisy curve above, an offset value of **120 in raw Gain1 pedestal** (red G1+120 curves) makes up closest to the expected straight correlation. Deviations from the expected horizontal line in the lower ration plot indicate quadratic and cubic terms in the correlation. These could originate quite possibly also from the diode characteristic of the mon_opt Hamamatsu diodes.

Spatial dependency



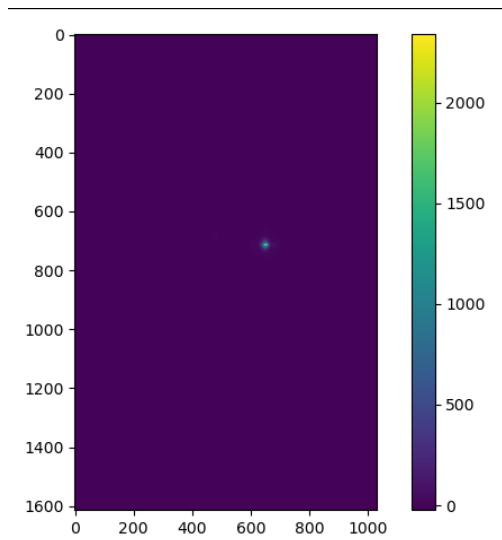
Above analysis (done on pixel marked by white square bottom left))was done at the opposite location of the peak feature (top right white square).

The result is very similar in behavior and the required offset in G1 is identical:

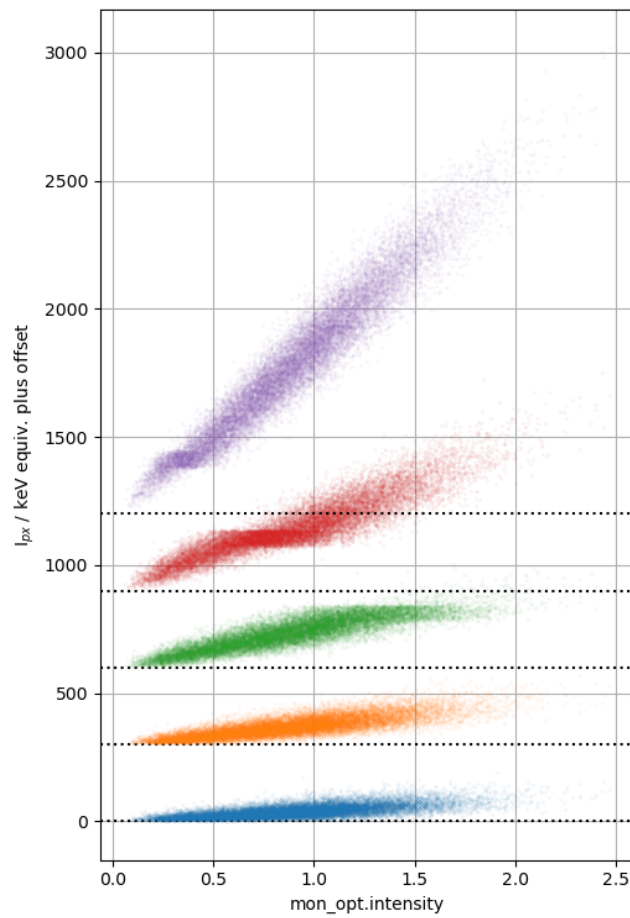
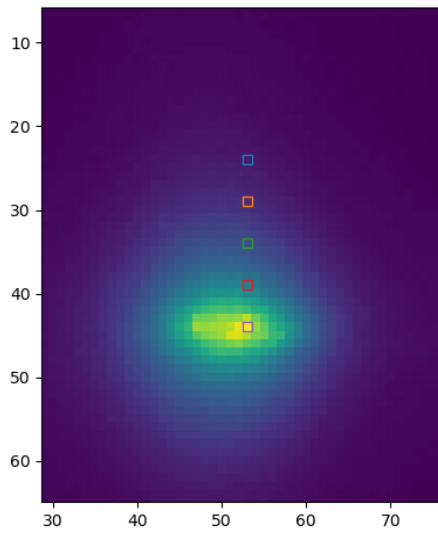


Time dependency over ~ 1 month

Data from another experiment about 1 month before in September was investigated for the same behavior. The data consists of a single stronger peak at $x=650$, $y=713$, also on the middle/center Tile of JF1, same as the data regarded above.

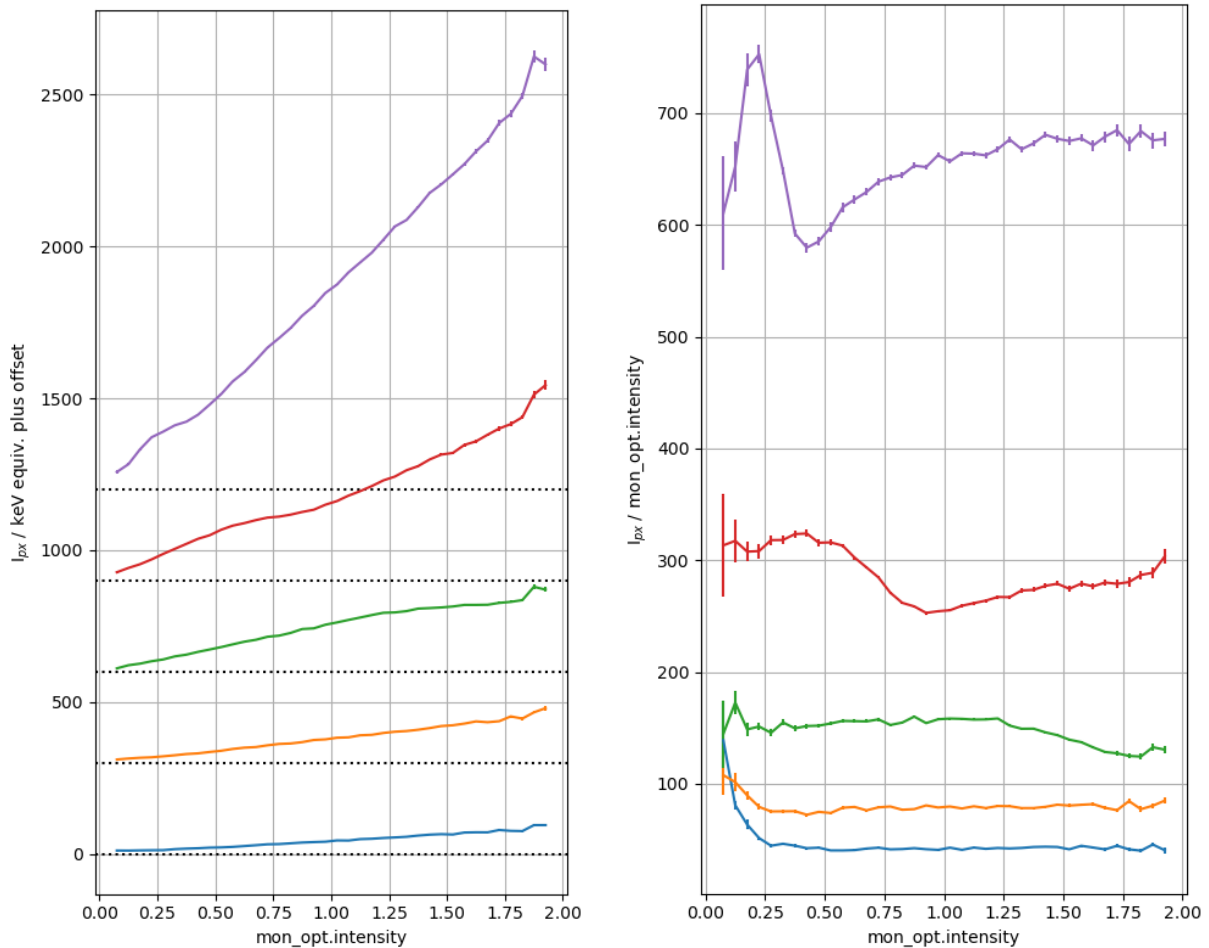


A ramp of different pixel intensities was extracted and correlated to the mon_opt.intensity signal:



The same phenomena tracked back to the G1 pedestal issue as described above is observed. The amount of the pedestal offset appears to be the same of ~ 80 keV.

The issue can here not be corrected as accidentally no raw data had been recorded. The binned result, however can be regarded .



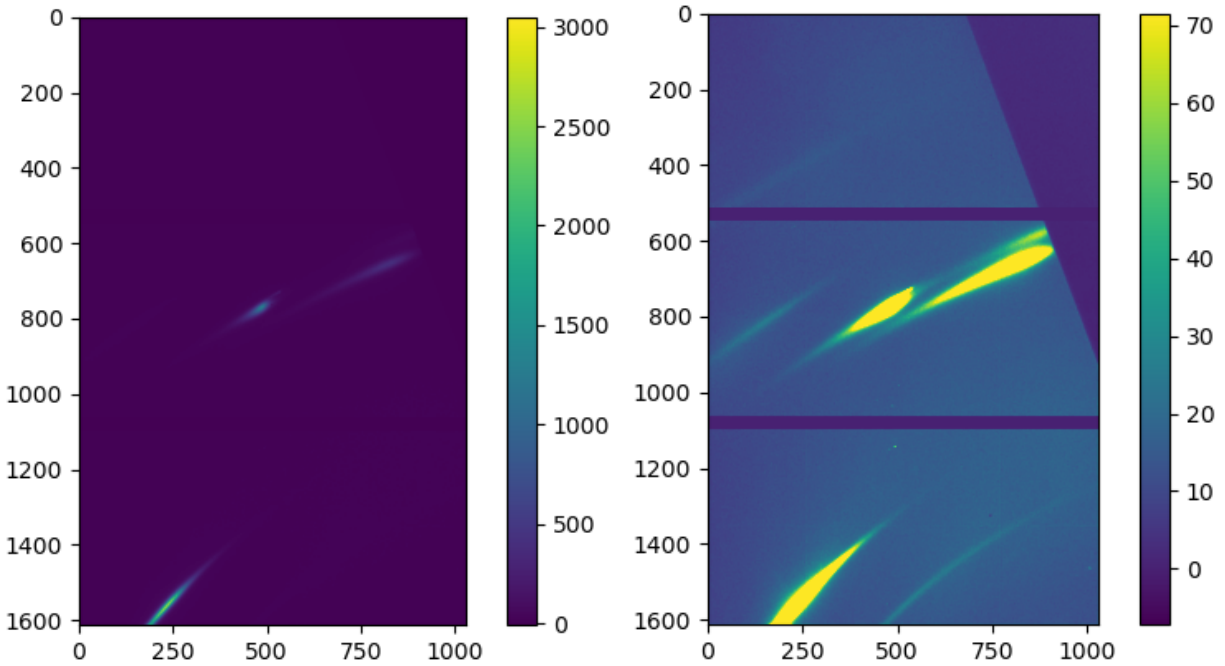
Except for the gain offset issue, these data show a more linear behavior, likely due to the better setup and electronics used in mon_opt.

The nonlinearity is still monotonic and could be corrected for by some per-pixel non-linearity correction. Even though the origin is different here, the methods described in <https://doi.org/10.1107/S1600577515005536> should be applicable here with minor adjustments.

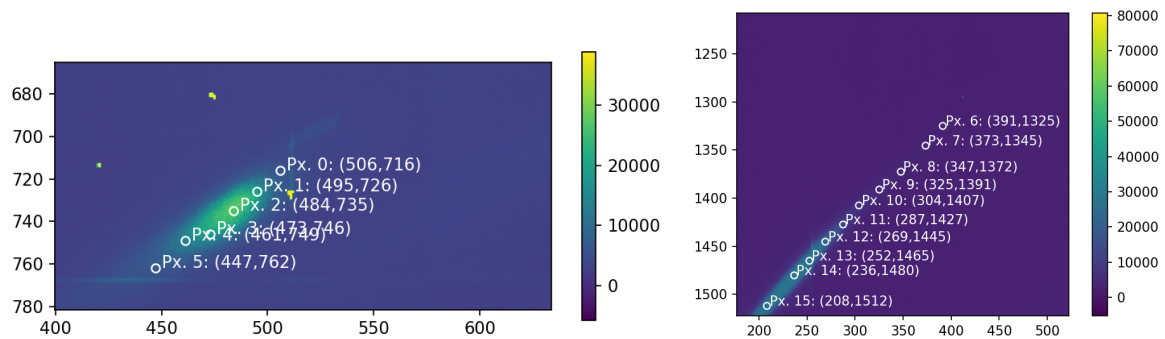
Differences over asics and tiles

The duncan dataset 376 was analyzed at different detector positions in order to investigate potential differences in gain1 pedestal offset.

The raw image looks like the following (same data, two different color scales):



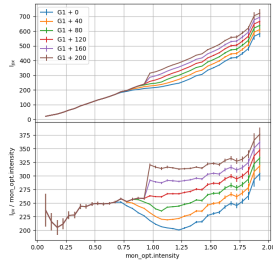
Selected pixels in the strongest features in the mid and bottom tile were selected (see selected pixels in raw data below).



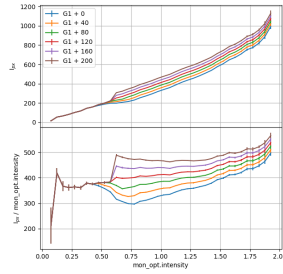
In the feature shown left all selected pixels (in center of round circles), originate from the same asic in the middle tile of the JF1 detector. the feature show to the right spans over two asics on the lower tile, namely pixels 13/14/15 are on one asic while the pixels 6 to 15 belong to the neighbor asic.

Pixels 1 to 4 of the center tile span intensities over to Gain1:

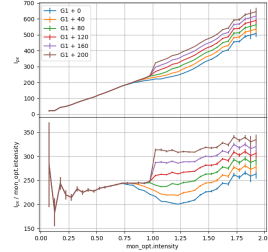
px1



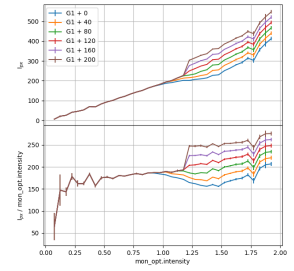
px2



px3



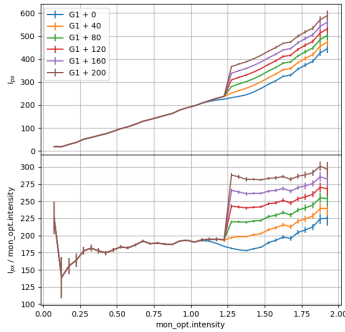
px4



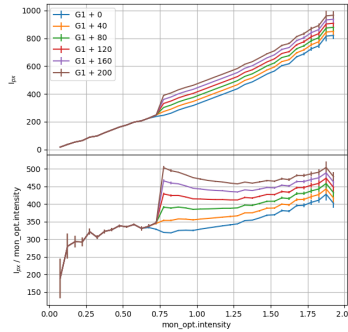
As found already above, the spatial difference of the gaon1 pedestal offset is very small, between 80 and 120.

Pixels 11 to 15 of the lower tile feature go into the medium gain. Here pixel 11 is on a different asic than pixel 12 to 15:

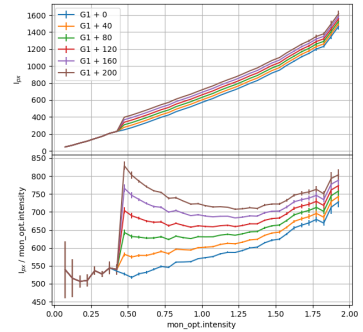
px11



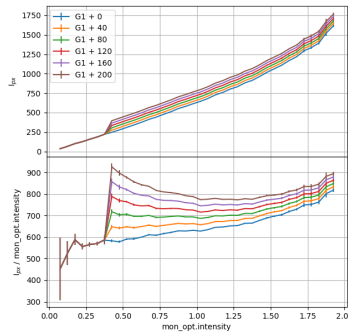
px12



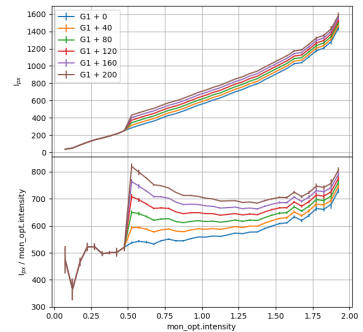
px13



px14



px15



Overall, the gain offset on the lower tile is much smaller than on the center tile. While pixels 11 to 13 indicate best offset between 0 and 40, pixels 14 and 15 show most continuous correlations around gain1 pedestal offset 0.

Summary

The frequently observed nonlinear behavior at Jungfrau gain switching points can be mainly attributed to differences in the pedestal of lower gain steps between the forced measurement and the dynamic switching.

The data analyzed here show that this difference/offset can be refined by optimizing the continuity of the correlation to a secondary intensity measurement which is continuous over the gain switching region. A broad intensity distribution over different pulses and significantly more than the gain switching region can be obtained using the large intensity fluctuations of monochromatic SASE beams.

The broadened single pulse correlation (due to poisson statistics) can effectively be averaged over by binning the data into small intensity intervals of the secondary intensity scalar, so that the sensitivity of continuity condition can be scaled up by high statistics.

The significant differences of actual and dynamic low gain pedestals can be very high as seen here, up to 40% difference between actual and measured intensity has been observed here at maximum. The effects may therefore be the origin of significant systematic signal distortions.

The regarded data show quite a significant difference of the effect as function of the Jungfrau detector tile/element, which for a large deviation will be the primary source of error that may be mitigated by a common offset for all pixels in one detector tile.

Inter-tile differences still can be observed but are much smaller. The regarded data did not allow yet a conclusion if remaining offsets may be common per asic or pixel-individual.

Next steps

Even though the low gain deviations between measured and dynamic pedestal mitigate significantly the linearity or even continuity of the Jungfrau detectors, the origin appears rather identified. The procedure shown here may well be used to identify the issue pixel by pixel and determine correction offset. As a direct action it is therefore important to

- 1) Save raw image data in case single pixel intensities may reach into medium or low gain steps.**

The detector group has worked on firmware based procedures that would be suited to reduce the offset in the measured lower gain pedestals.

- 2) Apply and test firmware update reducing the difference between measured from dynamic lower gain pedestal.**

In case of the Bernina JF1 detector, the plan is to apply the new firmware in January and use startup time end of January 2024 to test the fix.

In order to determine pedestal offsets in the lower gains for all Jungfrau detectors at SwissFEL we suggest

- 3) development of optimized analysis routines that automatically analyze the offset for each gain switching pixel in selected pulses of a dataset**

Such routine would be able to

- a. select a subset of the data in one dataset (boolean information per pulse e.g. generated for signal stability by external data)
- b. find all gain-switching pixels in a dataset that span the gain switching regions
- c. correlate the gain switching pixels to a secondary intensity information, allowing binning definition to improve sensitivity
 - i. external data source
 - ii. internal data from e.g. a region of interest (might be all) in the same detector.
- d. Find the low gain pedestal offsets by e.g. optimizing continuity over the gain switching intensity steps.

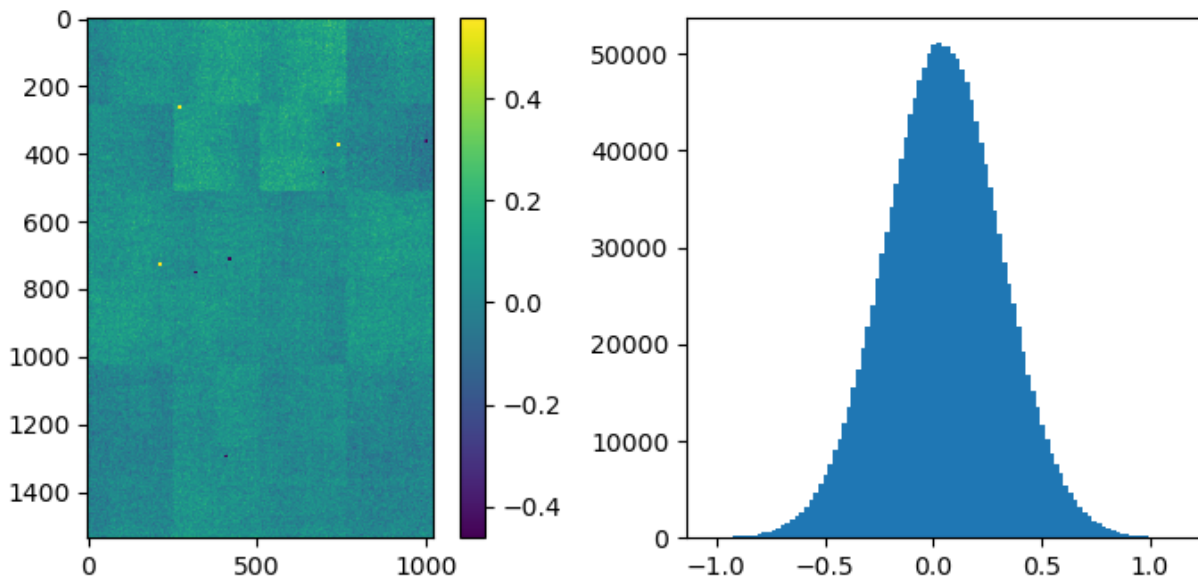
Once the effect is better understood also for different JF detectors and generations, further strategies for potentially required reference measurements or analysis steps in detector data correction need to be developed.

Appendix

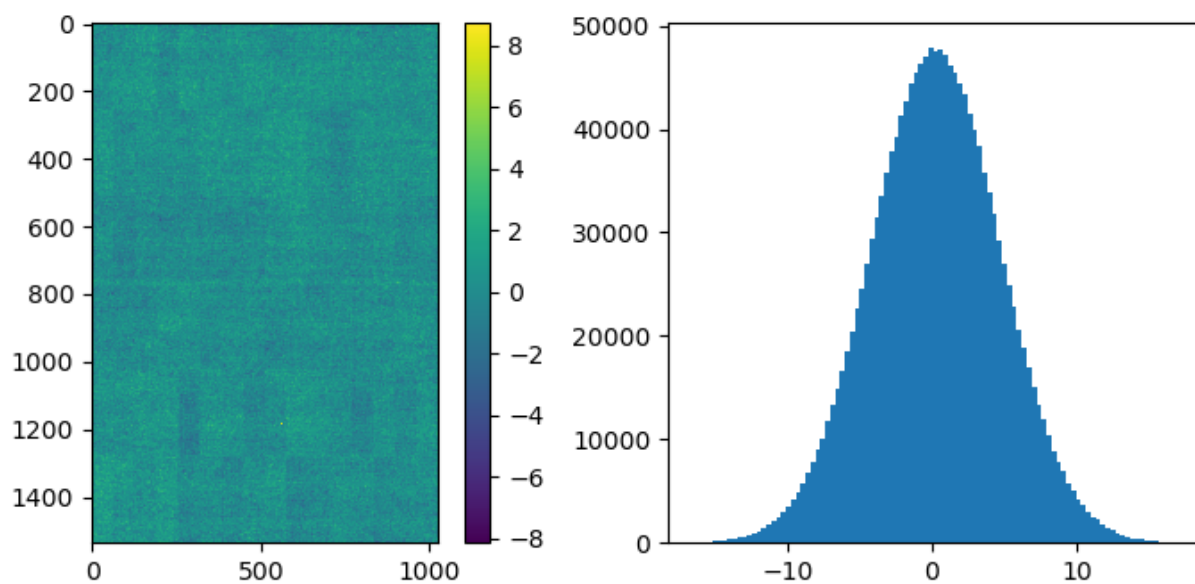
Test on raw pedestal data

The pedestal raw data were corrected by the pedestal data with the numpy algorithm used above as sanity check:

Gain0



Gain1



Gain2

