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Calibration and first operation of the JUNGFRAU detector in 16-memory cells mode at European XFEL

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Introduction

The JUNGFRAU detector is a now established hybrid pixel detector developed at Paul Scherrer Institute (PSI) [1], featuring 75 µm pixel pitch with a charge integrating dynamic gain switching (DGS) architecture designed for FEL applications. Optionally, the dynamic gain switching mechanism can be bypassed, and the detector can operate with a fixed feedback capacitor in the pre-amplifier.
Originally designed to cope with the SwissFEL 10 Hz pulse rate, it is however endowed with an array of 16 analog storage cells per pixel, which makes it possible to store more than one image per pulse train at a 'burst' repetition rate greater than 100 kfps.

The possibility to tap into the so-called 'burst' operation mode, would allow the scientific instruments to exploit more efficiently the European XFEL (EuXFEL) pulse train structure.

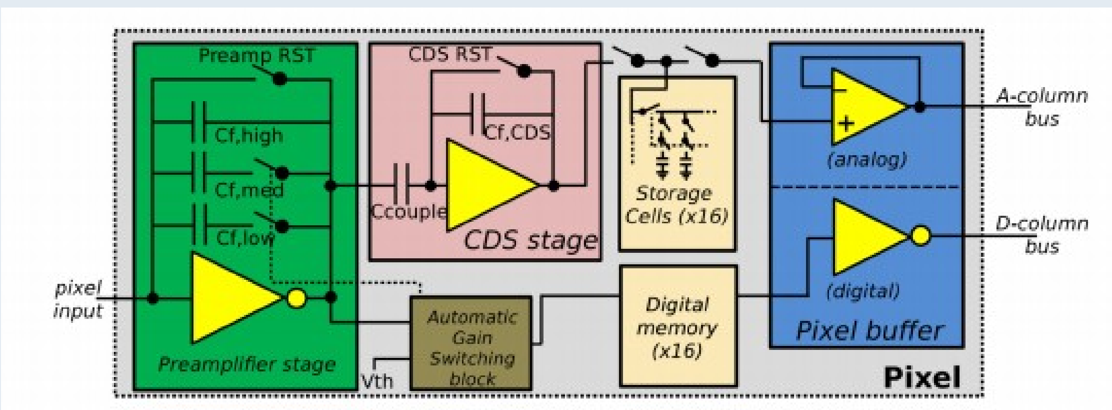
However, due to the uniqueness of the bunch structure within the train at EuXFEL, the 16-memory cell operation mode has never been fully tested before and characterized in conditions comparable to the ones available at our facility.
Therefore, we will present the current status of the implementation of the 16-memory cell operation mode at the European XFEL and the issues we have encountered, focusing on the detector characterization, and the consequent path towards the establishment of a validated calibration procedure.

Motivation

There are several operational advantages in enabling the 16-memory cell operation ('burst') mode, for example:

- Correlate of pulse-resolved measurements with other detectors
- Increasing the data throughput:
  - e.g.: serial femtosecond protein crystallography experiments would require less data taking time and use less valuable sample
- Better suited for 'slow' (~kHz rate) samples than MHz-capable detectors currently employed

Methods



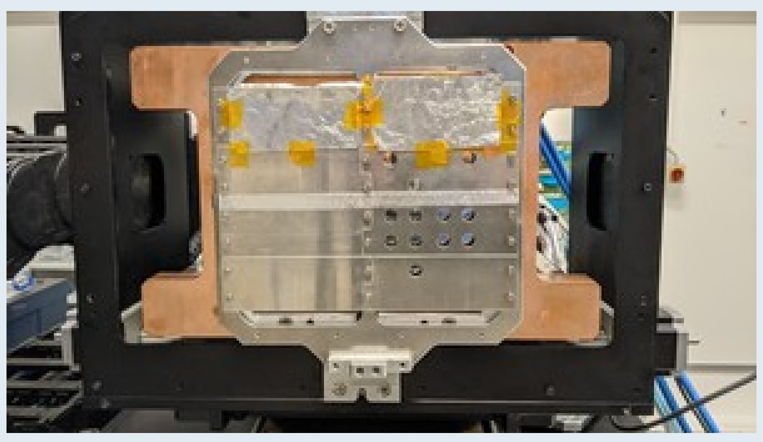
Schematics of the JUNGFRAU detector pixel architecture

While the calibration procedure is fully established for 10 Hz, 'single cell' operation mode[2], there is at the moment no validated equivalent for the 'burst' operation.
The initially proposed strategy consisted in:

- Offset evaluation:
  - Use dark runs to estimate the constant for high gain
  - Use the built-in firmware 'forceswitch' option for medium and low gain
- Gain conversion factors:
  - calculate intercalibration factors (e.g. from single photon flat fields) to re-scale the constants obtained for 'single cell' operation

The approach chosen to validate such procedure is to perform intensity scans of the detector response

- The JUNGFRAU 4M (JF4M) at the SPB/SFX has been used for these studies:
  - The detector has been exposed to Cu fluorescence
  - Intensity has been changed by using different combinations of the beamline filters



The detector used for the tests:

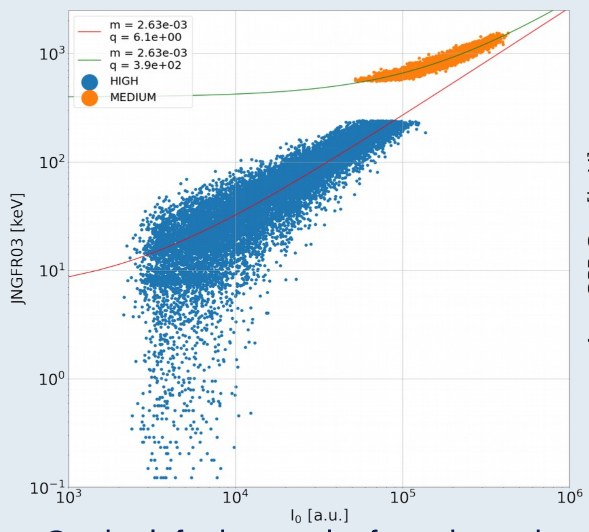
Top two modules are masked with Al to serve as intensity monitors.

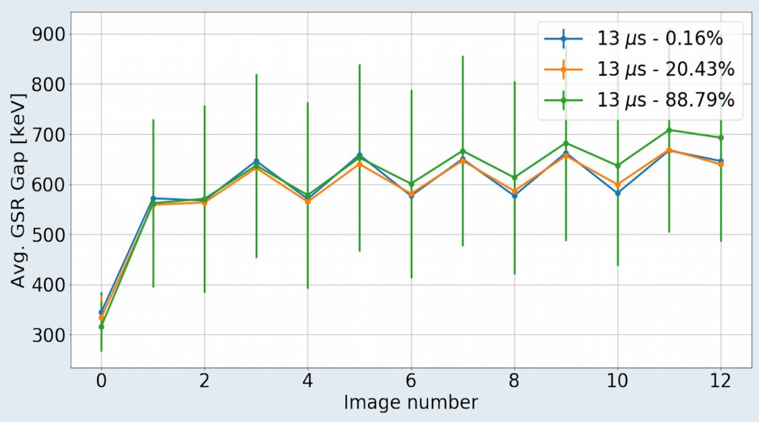
The other six have been masked to expose different fractions of the front end modules (FEM) surface to the fluorescence photons, in order to study possible effects due to the total intensity.

Results

- Calibration is not fully validated for the DGS 'burst' operation mode
- Pedestal evaluation for medium and low gain is non-predictive of the correct offset
  - This results in a 'gap' artifact around the gain switching region in the intensity scan
  - 'gap' value does not depend on occupancy of the FEM

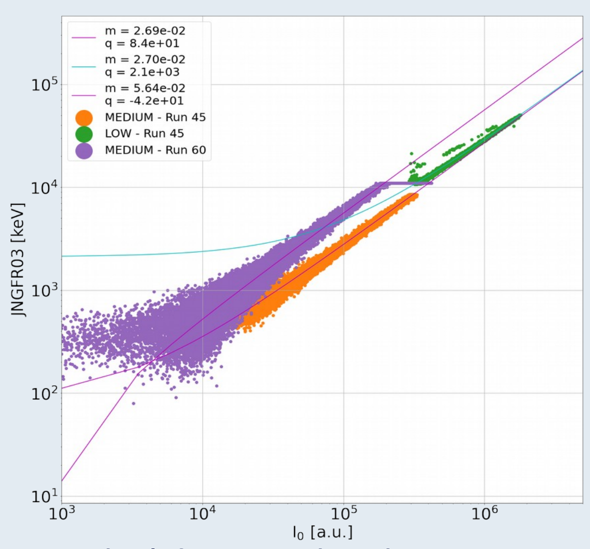
Note: although acquired in 'burst' mode, the intensity scan plots presented from here on depict the results for an individual pixel, for the default cell used in 'single cell' operation.

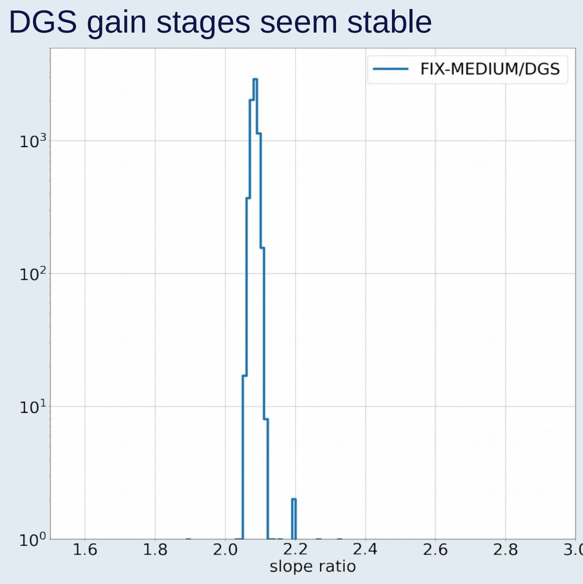




On the left, the result of one intensity scan. On the right, it is shown how the average 'gap' increases for subsequent images in the train without strong dependence on the FEM occupancy

- No major issues have been identified during the 'burst' operation in fixed gain
  - Minor baseline shifts effects < 1% of the signal
  - Shift amplitude depends on module occupancy
- Intercalibration constants between fixed and DGS gain stages seem stable

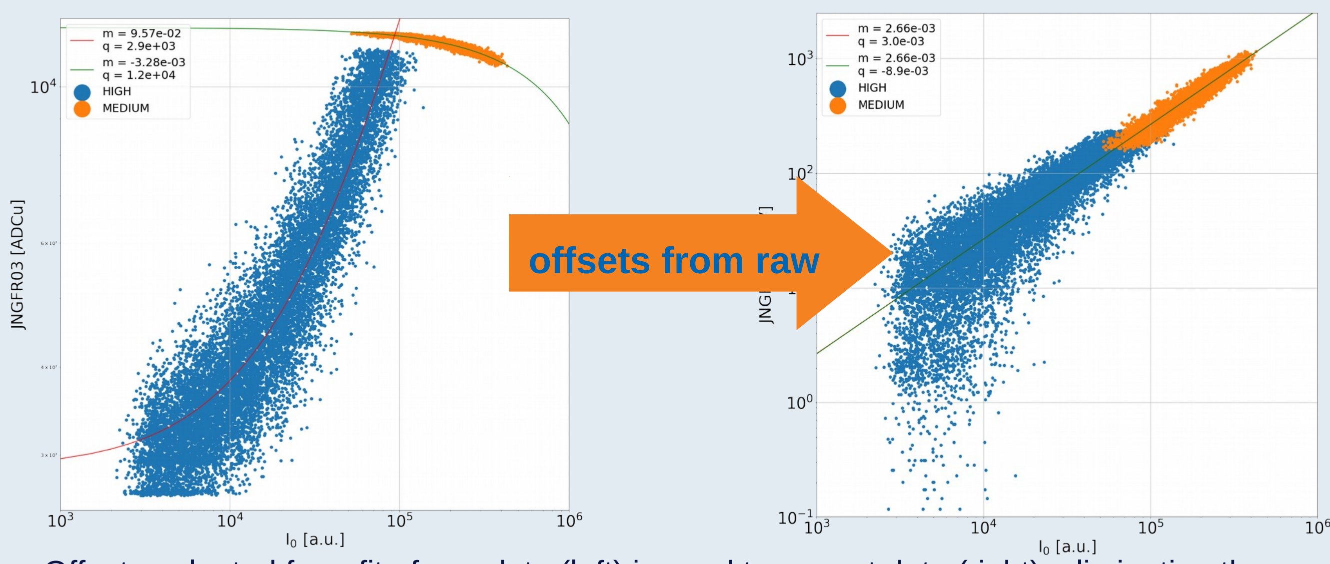




On the left, comparison between DGS and fixed gain intensity scan. On the right, intercalibration constants distribution between fixed and DGS for medium gain for illuminated pixels.

Summary and Outlook

- DGS 'burst' operation needs a new calibration strategy to estimate the offset
  - Use dynamic range scans with external charge injection
  - Portability and robustness of this calibration needs to be validated
- Fixed 'burst' operation shows no show-stopping issues
  - First user assisted commissioning in September 2022



Offset evaluated from fit of raw data (left) is used to correct data (right), eliminating the discontinuity around the gain switching region

References

[1] Mozzanica A. et al., Synchrotron Radiation News 31, 16 (2018)
[2] Redford S. et al., JINST 13 C01027 (2018)

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