Calibration of the AGIPD system at the European XFEL

Jennifer Poehlsen for the AGIPD Collaboration
PIXEL, Taipei 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Outline

01 Introduction
- The European XFEL
- The AGIPD system

02 The calibration challenge
- What needs to be calibrated
- Calibration concept
- Scaling to a Mpix detector
- Typical problems

03 Data storage & processing
- The DESY Maxwell cluster
- Typical volumes of a data set
- Processing times

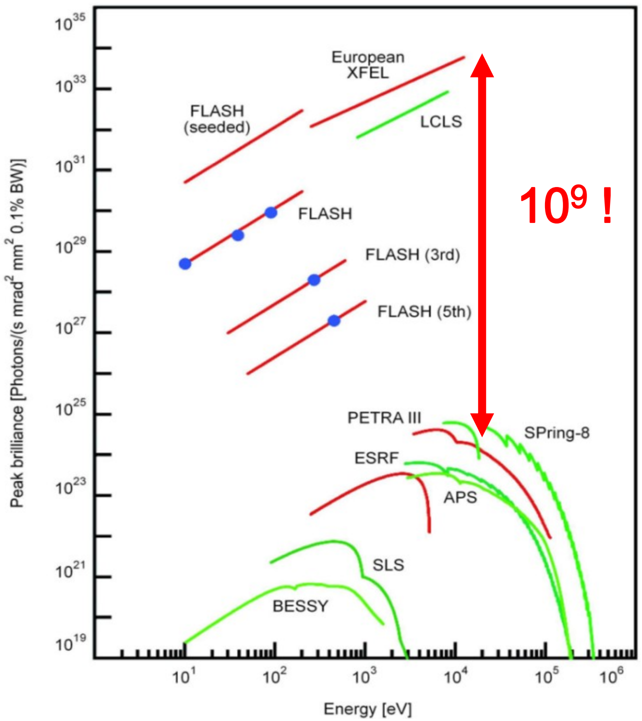
04 Open issues and future improvements
- Dependency on external parameters
- Non-linearities of the system
- Model assumptions

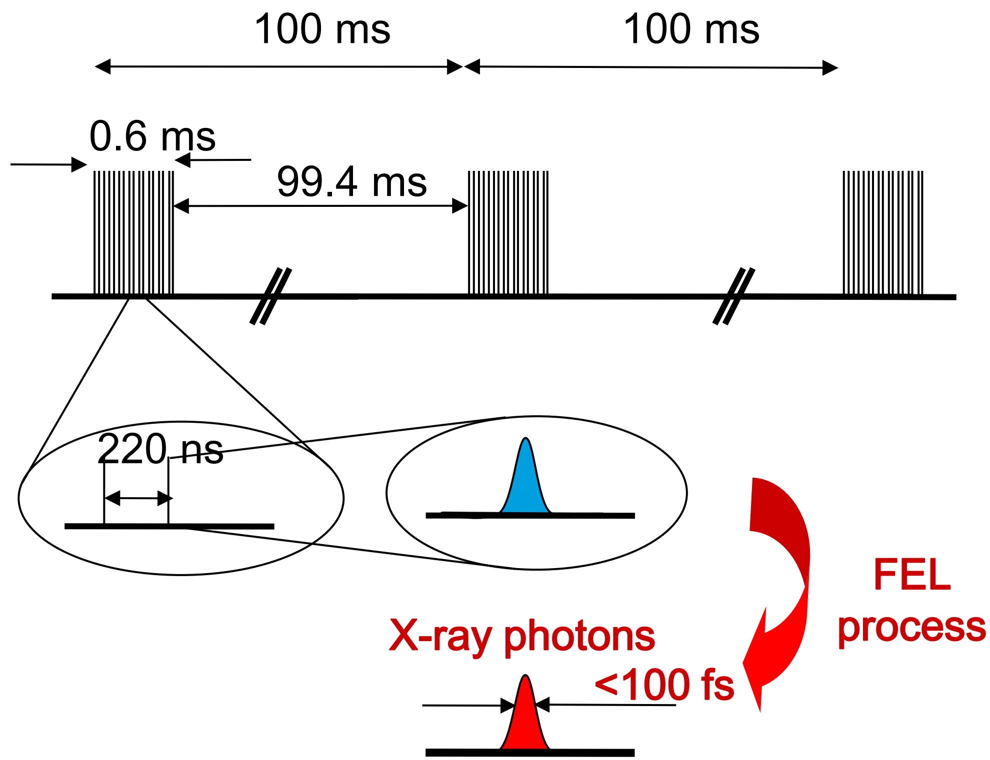
05 Summary

01
Introduction

The European XFEL

A challenging environment



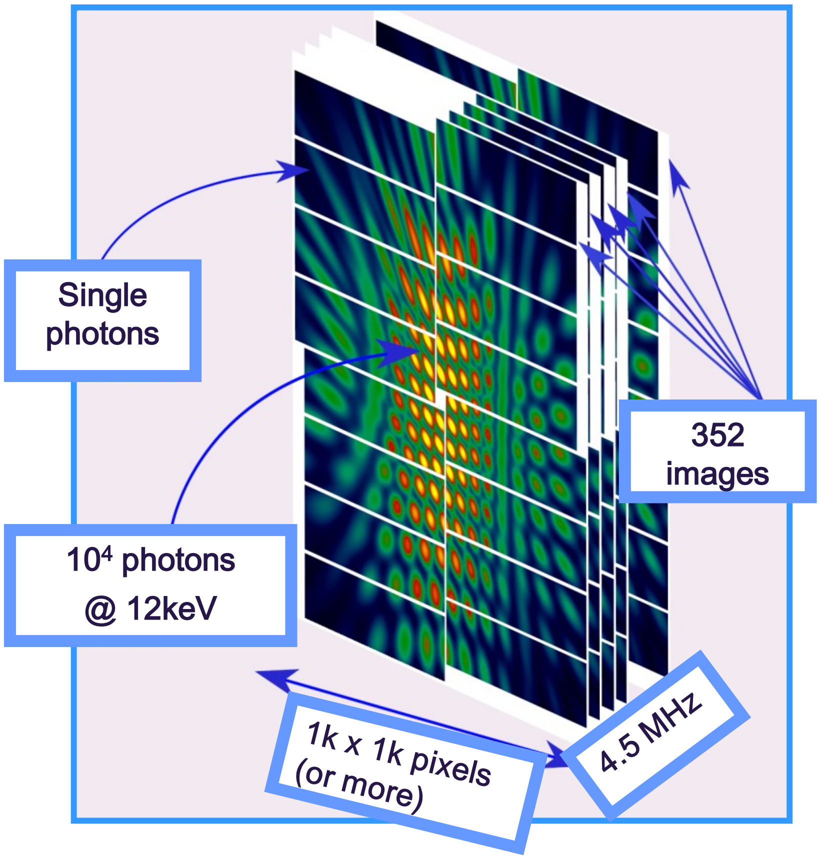


Detectors:

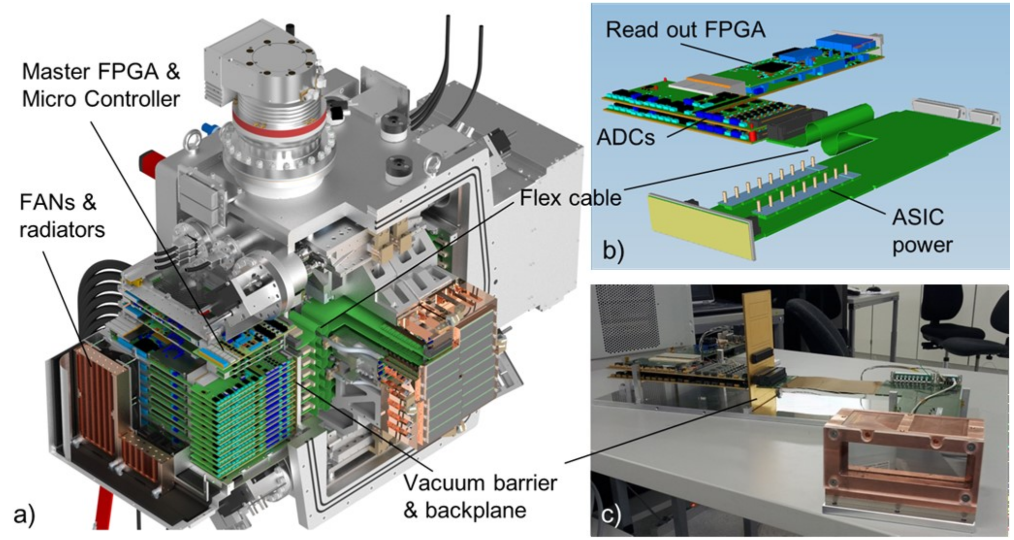
- LPD (500µm x 500µm) - 1Mpix installed
- AGIPD (200µm x 200µm) -1Mpix installed, 1Mpix commissioning, 4Mpix & 1Mpix under construction
- DSSC (230µm x 200µm) - 1Mpix under construction

The AGIPD system

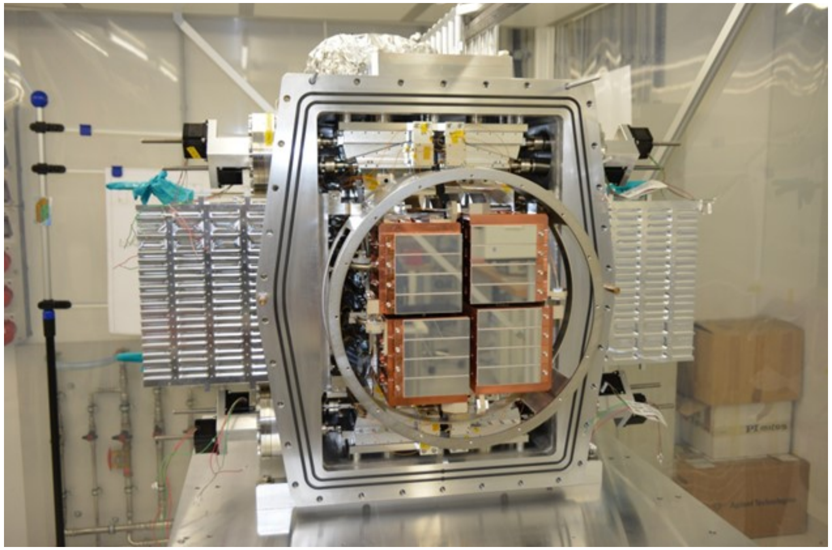
Adaptive Gain Integrating Pixel Detector



- 500 µm silicon sensor
- 200 µm square pixels
- Vacuum compatibility
- Detector with central hole



Allahgholi et al. arXiv:1808.00256



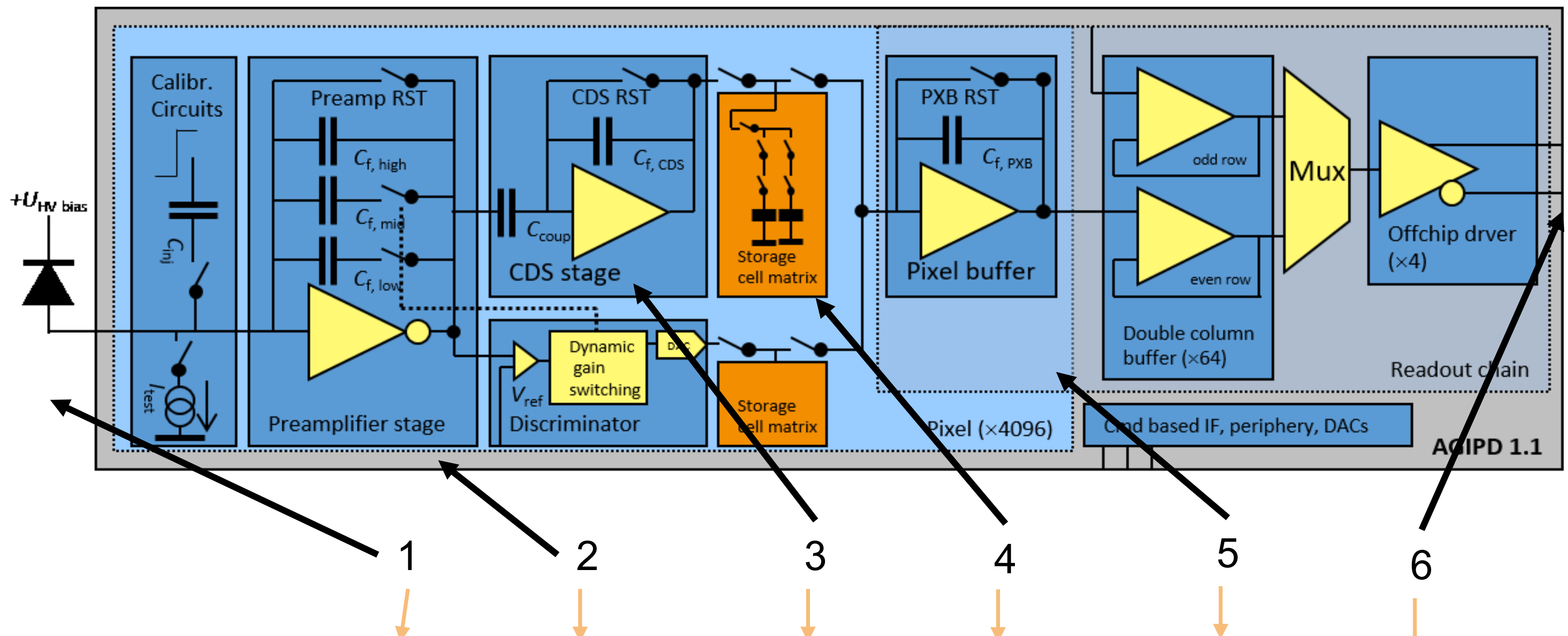
02

The calibration challenge

What needs to be calibrated

Active Parts:

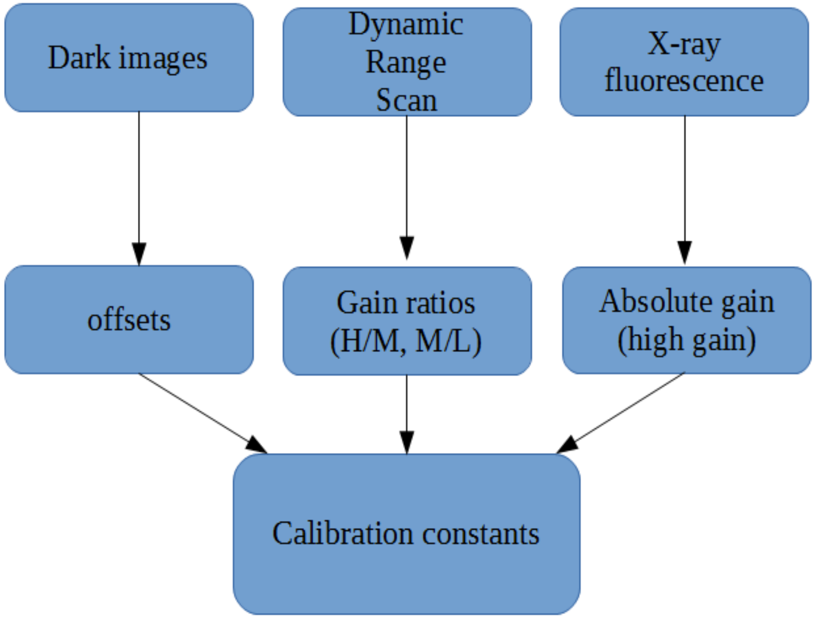
1. Sensor
2. Gain stage with 3 automatically adjusting states
3. CDS stage with 2 user-selectable states
4. Memory cell matrix
5. Pixel buffer & Offchip driver
6. ADCs



$$Signal\ [ADU] \propto \frac{N_\gamma E_\gamma}{3.6}\ g_{CSA}(N_\gamma E_\gamma)\left[\frac{mV}{eV}\right]\ g_{CDS}\ C_{mem}(pix, mem)\ C_{pix}\ C_{ADC}(output)\left[\frac{ADU}{mV}\right]$$

Calibration concept

Why we do what we do



General approach

- Treat every mem cell of every pixel as independent.
- Assume gains within a pixel are correlated and ratios are constant
- Use on-chip calibration sources for relative cross-calibration
- Pin calibration with 1 absolute measurement per pixel using x-ray fluorescence
- Merge data from different sources into one unified set of calibration constants

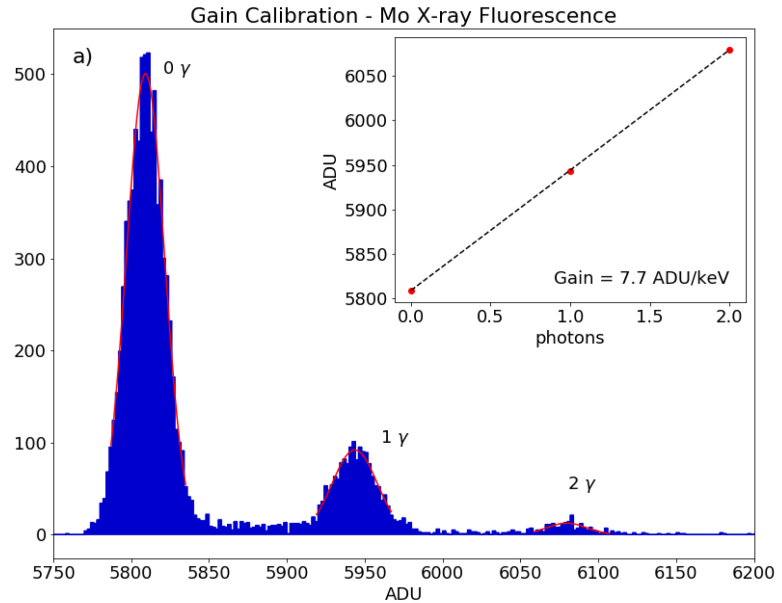
Scaling to a Mpix detector

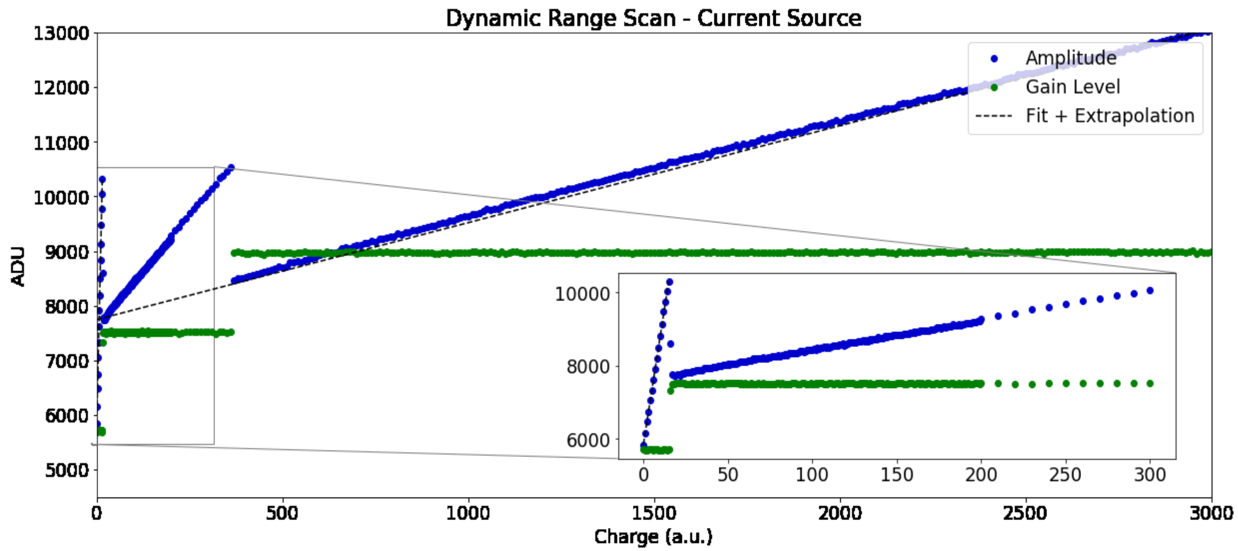
From 1 fit to ~ 3 billion constants

Inventory:

- 1 Offset + 1 Slope
- Per gain setting (x3)
- Plus discrimination thresholds (+2)
- Per pixel (x 1024^2)
- Per storage cell (x352)

= 2952790016 ~ 3 x 10^9 constants



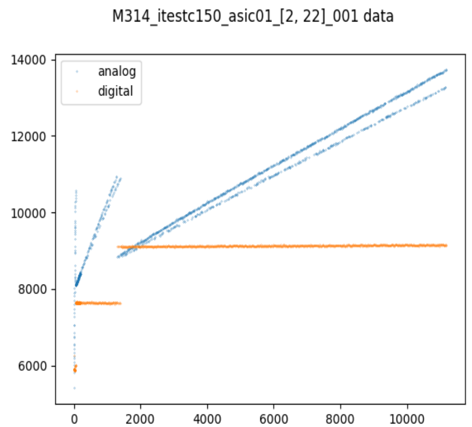


Typical problems

When it rains, it pours

Pixel related

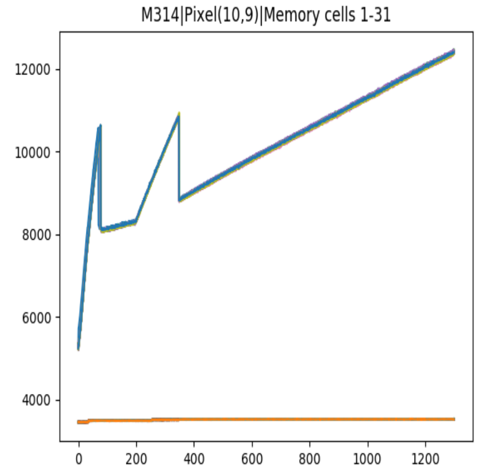
- Failed bump bonding
- Preamp not working properly
- Calibration circuitry not responsive
- Pixel buffer unresponsive



Affects: all mem cells in pixel

Storage cell related

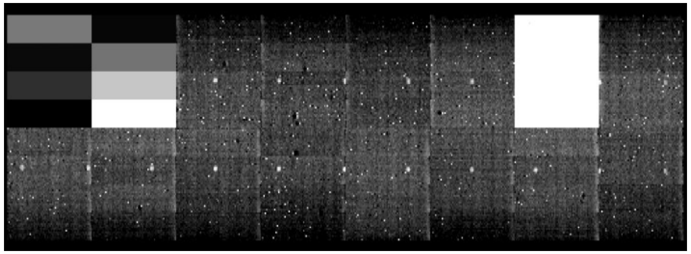
- Defects in addressing switches
- 'leaky' memory cells



Single mem cells or mem row/column

Electronics or sensor related

- Dead/noisy ADC channel
- Non working sensor
- 'Dead' ASIC



Group of pixels up to entire module

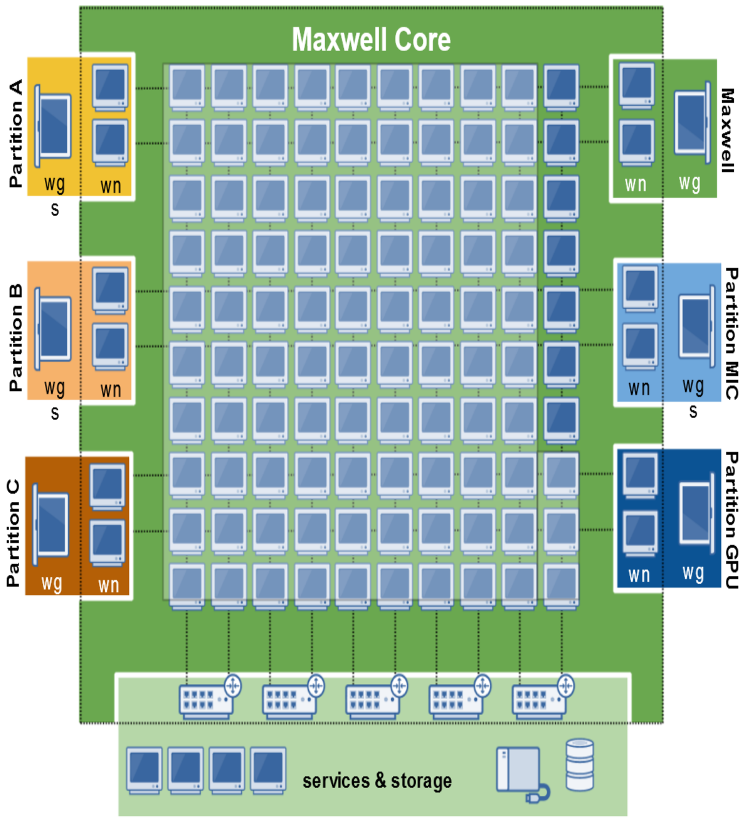
03
Data storage & processing

The DESY Maxwell cluster

At the heart of all processing

Essential for parallel processing

- High-Performance-Cluster, intended for parallel tasks
  - Multi-core architecture
  - Infiniband low-latency network
  - Fast storage
  - Large memory
  - GPU available
- Access to DESY GPFS file system infrastructure
- Cores can be allocated on demand (SLURM scheduling)
- Available for use for DESY employees and selected others (academic only)



Typical volumes of a data set

Type of data	Volume	Acquisition time	Comment
Dark frames	2.5 TB	20 min	Sensitive on operation mode and temperature
X-ray illumination	0.4 TB	1 min	Only for one memory cell
Pulsed capacitor	4 TB	15 min	Covers only high and part of the medium gain (partly redundant with current source)
Current Source	4.5 TB * 5 = 23 TB	15 hours	Covers all gain states
Sum	**~ 30 TB**	**16 hours**	

Processing times

Using the Maxwell cluster

Type of data	Time	Output	Comment
Dark frames	5 min	Offsets constants	Sensitive on operation mode and temperature
X-ray illumination	10 min	Absolute gain for high gain state	Only for one memory cell
Pulsed capacitor	15 min	Relative gain High/Medium	Partly redundant with current source
Current Source	20 min / current = 1.5 hours (5 currents)	All relative gains	Covers all gain states
Total	**2 hours**		

04
Open issues and future improvements

Dependency on external parameters

What changes calibration constants

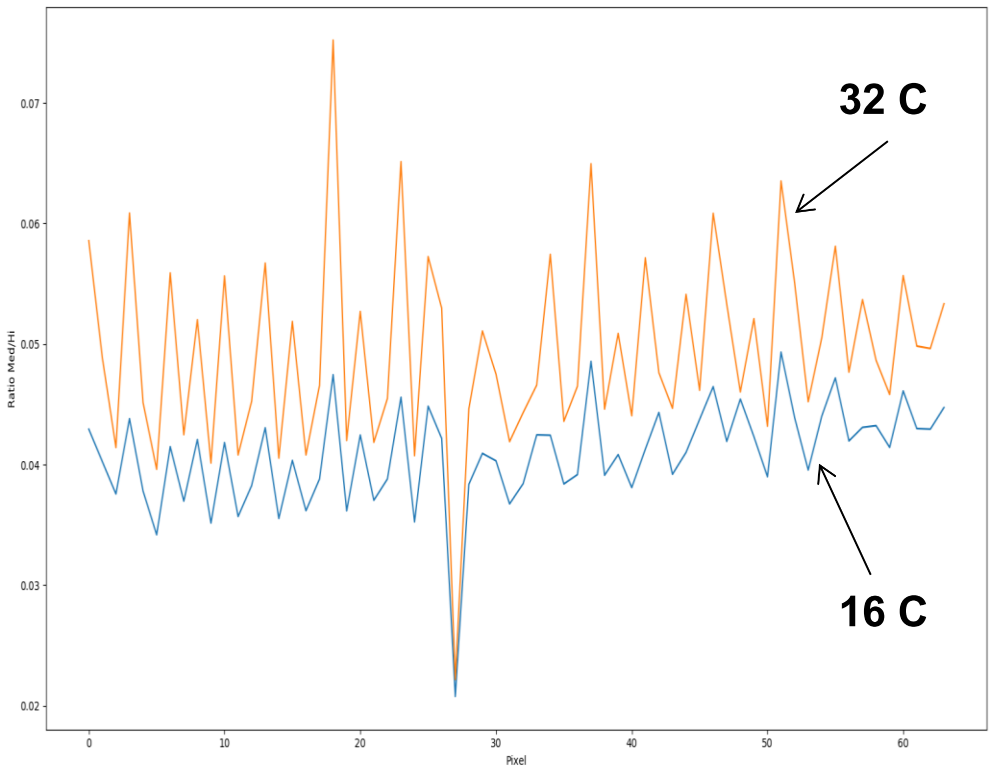
Known influence

- Temperature
- Operation mode
  - rep. rate
  - vetoing
  - number of used mem cells
- Synchronization w.r.t photon pulses

Suspected influence

- Total accumulated dose
- Sensor bias voltage

Gain ratio Medium/High for a column of pixels



Non-linearity of the system

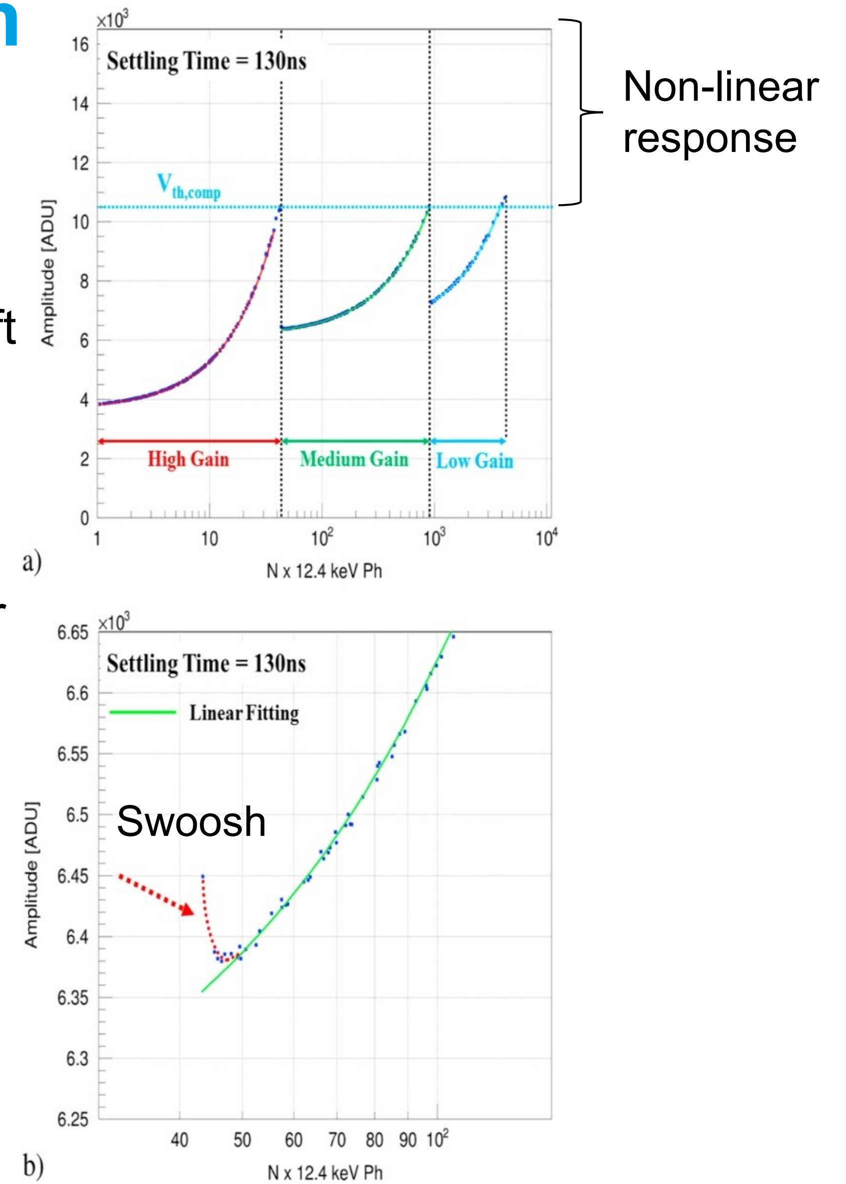
After all, what is ever truly linear?

ASIC related

- Gain is slightly non-linear towards large signal part of the response
- When switching gain, the preamp does not settle fully in time for the sampling ('Swoosh')
- Larger than usual crosstalk between neighboring pixels due to low effective input capacitance

Sensor related

- Large signals shift offsets for entire module
- Persistence of large signals over multiple pulses



D. Mezza et al. 10.1016/j.nima.2016.09.007

Model assumptions

Results will only be as good as your model

Totally independent

- Treat every mem cell and gain state of every pixel as independent
- Requires absolute calibration sources for medium and low gain
- Minimum of model assumptions
- Practically impossible due to lack of time and calibration sources

Some correlation

- Treat every mem cell of every pixel as independent, gains within a pixel as correlated
- Use on-chip calibration sources for relative cross-calibration
- Pin calibration with 1 absolute measurement per pixel using x-ray fluorescence
- Robust against broken pixels and mem cells
- Currently employed model

Minimum parameters

- Calibrate gain states per pixel and treat mem cells as correction
- Potential to reduce required constants to ~380 million (factor 7.8)
- Potential to reduce data volume by a factor ~ 350 by merging cell data (remapping)
- Danger of systematic errors due to propagation of damaged cells to gain state determination and propagation of the result to all mem cells

05
Summary

Summary

and where we go from here

Challenge

- Complex system which requires good calibration to produce the best possible scientific data
- ~3 billion parameters per Mpix to calibrate due to storage cell architecture
- Reasonable time & data volume requirements to collect and process calibration data
- Evolving detector integration and data formats as expected at a new facility

Approach

- Use ‘fast’ methods for relative cross-calibration, and reduce time required with external source
- Prioritize robust, deployable code and tools over ultimate precision

Future

- Include code and tools into XFEL environment (ongoing)
- Quantify deviations due to non-linearity for large signals and ‘Swoosh’
- Compare results for current models and minimum parameter approaches
- Develop robust algorithm using minimum parameter approach to reduce time and date volume requirements for system calibration (important as systems grow, e.g., 4 MPix SFX)

Thank you!

The AGIPD collaboration

Aschkan Allahgholi[a], Julian Becker[a], Annette Delfs[a], Roberto Dinapoli[b], Peter Goettlicher[a], Dominic Greiffenberg[b], Beat Henrich[b], Helmut Hirsemann[a], Manuela Kuhn[a], Robert Klanner[d], Alexander Klyuev[a], Hans Krueger[e], Sabine Lange[a], Torsten Laurus[a], Alessandro Marras[a], Davide Mezza[b], Aldo Mozzanica[b], Magdalena Niemann[a], Jennifer Poehlsen[a], Joern Schwandt[d], Igor Sheviakov[a], Xintian Shi[b], Sergej Smoljanin[a], Lothar Steffen[a], Jolanta Sztuk-Dambietz[c], Ulrich Trunk[a], Qingqing Xia, Mourad Zeribi[a], Jiaguo Zhang[b], Manfred Zimmer[a], Bernd Schmidt[b], and Heinz Graafsma[a,f]

[a] Deutsches Elektronen Synchrotron, Notkestrasse 85, 22607 Hamburg, Germany,
[b] Paul Scherrer Institut, Forschungsstrasse 111, 5232 Villigen, Switzerland,
[c] European XFEL, Holzkoppel 4, 22869 Schenefeld, Germany,
[d] University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany,
[e] University of Bonn, Nussallee 12, 53115 Bonn, Germany, and
[f] Mid Sweden University, Holmgatan 10, S-85170 Sundsvall, Sweden.