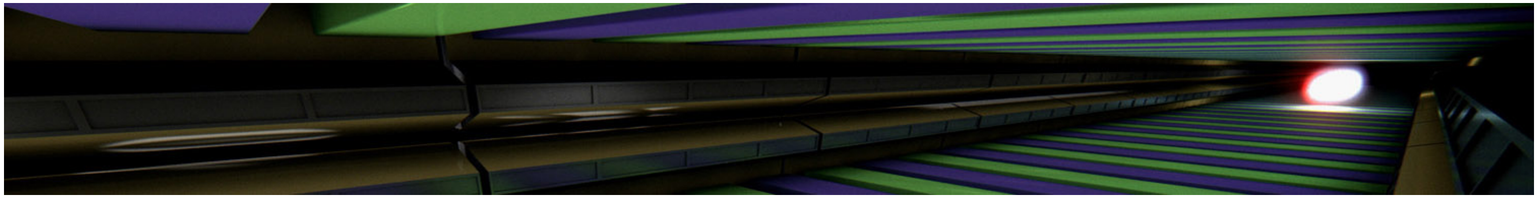


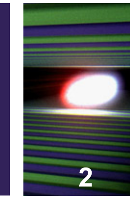
The Calibration Pipeline for the Large 2D Pixel Detectors with Mhz Readout at the European XFEL

S. Hauf, B. Heisen, A. Koch, M. Kuster, J. Sztuk-Dambietz, M. Turcato, C. Youngman

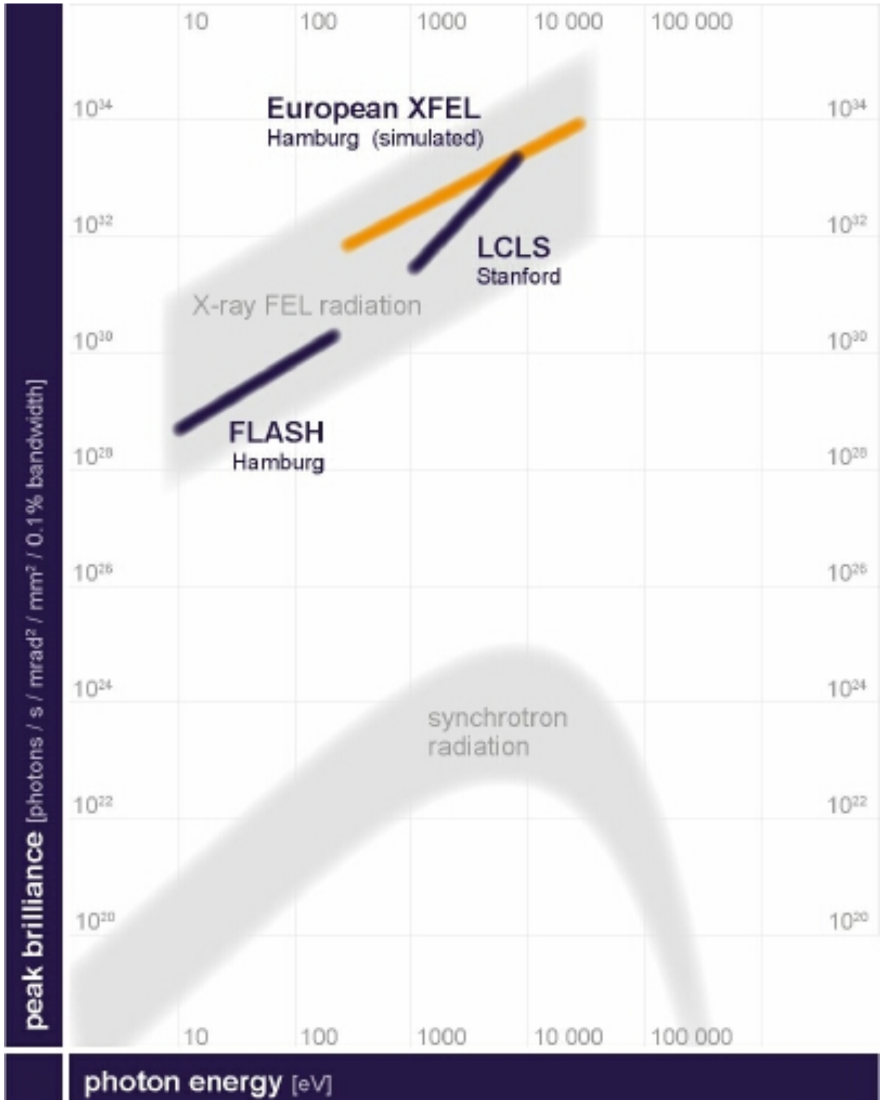
31.10.2013, IEEE NSS MIC 2013

Seoul, South Korea

European XFEL



The European XFEL – Facility Overview

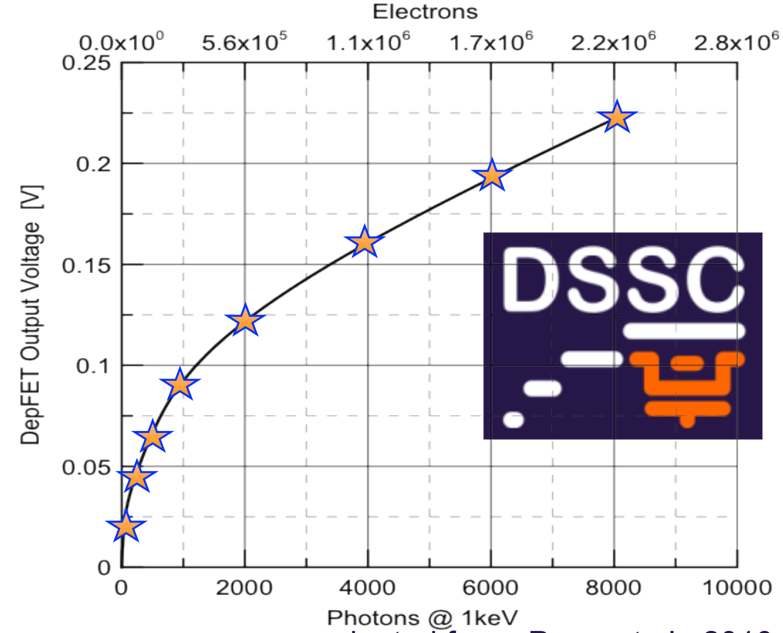


- A free electron laser facility which will produce coherent X-ray light
- High peak brilliance
- Photon energy: 0.4–20 keV
- Pulse duration: < 100 fs, 2700 pulse per train, 10 trains per second
- Pulse energy: a few mJ
- 5 beam lines for 10 experiments, initially 3 beam lines with 6 experiments
- Superconducting LINAC
- Start of operation: 2016

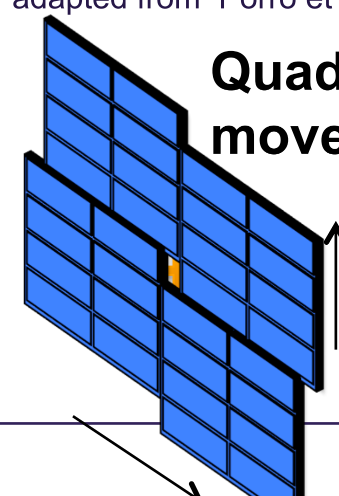
Calibration Pipeline Challenges – Number of Detector Parameters

- Large number of calibration constants, e.g. non-linear gain:
  100 memory cells/pixel x 1M pixel x 3 gains ≈ 10^9
- Diverse range of experiments, some single photon with low event rates, some with densely filled images.
  ➔effects calibration possibilities
- Long term change of detector properties due to irradiation
- Short term change of detector alignment due to movable quadrants

DSSC non-linear Gain



adapted from Porro et al., 2010



Quadrant movement

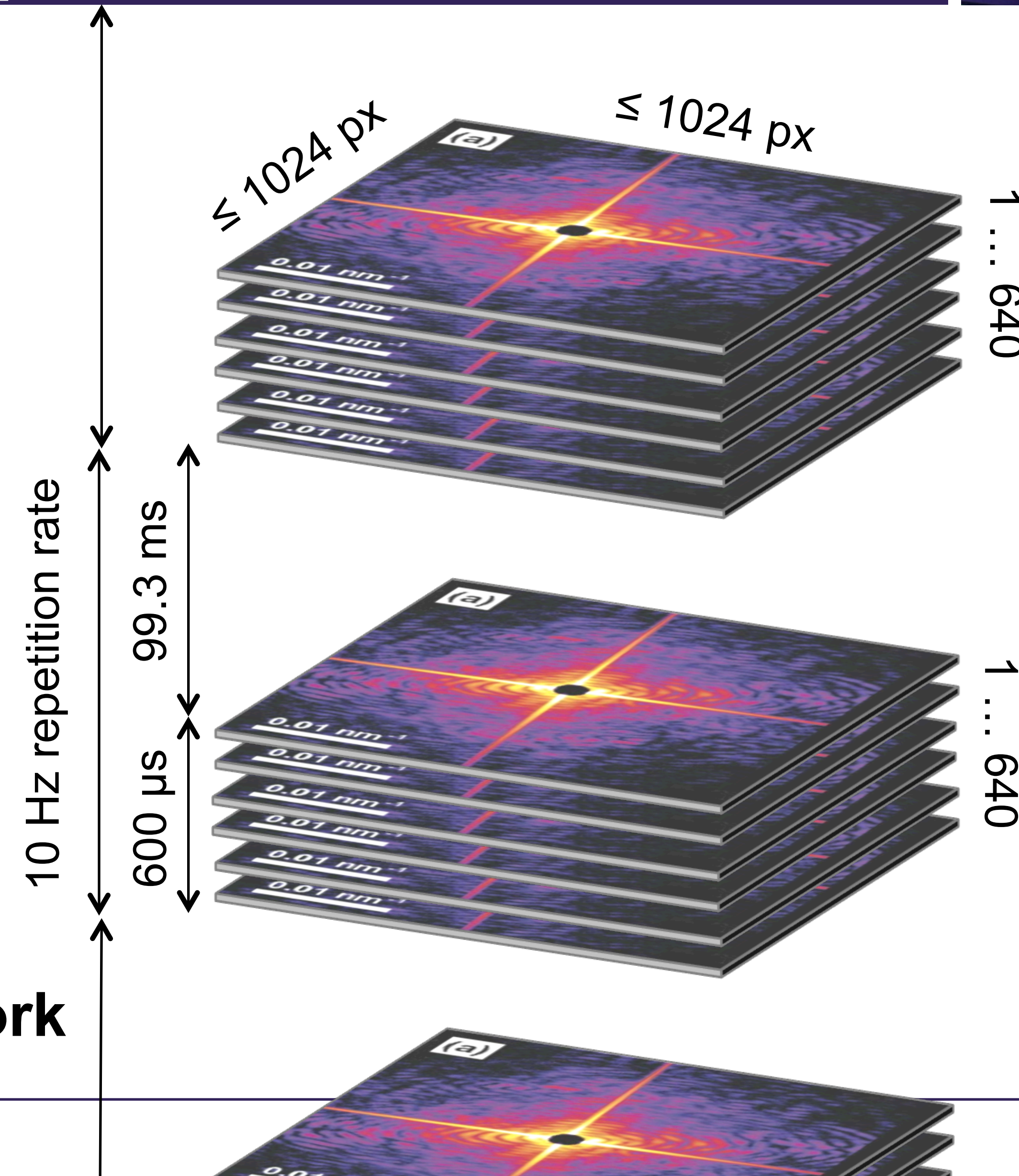
➔ **Need for powerful calibration database**
Easy access to current detector state

Calibration Pipeline Challenges – Near-Online Application to Data

Most challenging scenario

- Up to 1 Mpixel images
- Up to 640 frames per train (current DSSC detector buffering capability)
- 10 trains per second
- i.e. 6.4 kHz frame rate
- i.e. 6.4 Gpixel/s
- All pixels may have events
- Or sparse images with few events

→ **Efficient, scalable calibration framework**

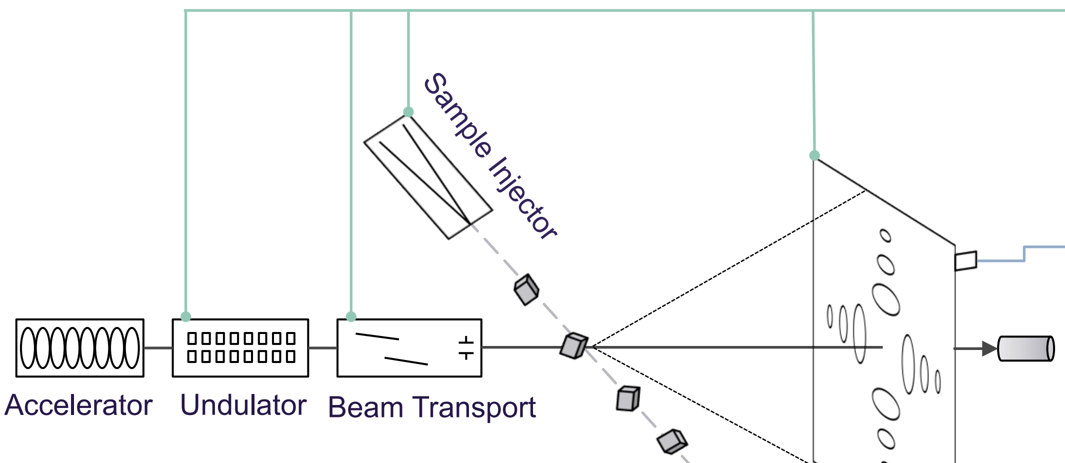


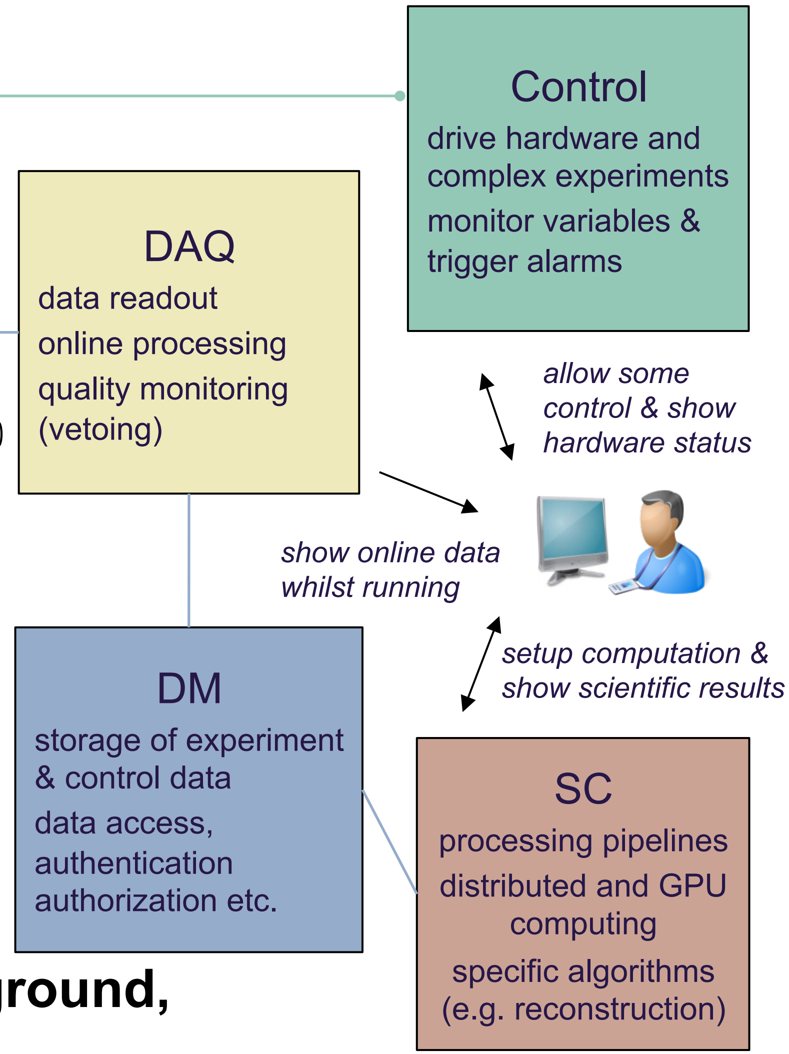
Calibration Pipeline Challenges – Flexibility

- **Calibration constants are obtained from:**
  - Dedicated calibration runs and lab measurements (recurring)
  - Calibration measurements before experiments (needs fast processing)
- **Calibration constants need to be applied to data for:**
  - Online monitoring (selected calibration steps)
  - Near-real time feedback during experiments for input into preliminary scientific analysis (selected data sets)
  - Post-experiment analysis on full data sets using standardized calibration (possibility of using updated calibration parameters)

➔ **A modular pipeline is needed**

Karabo Framework – Addressing the Challenges



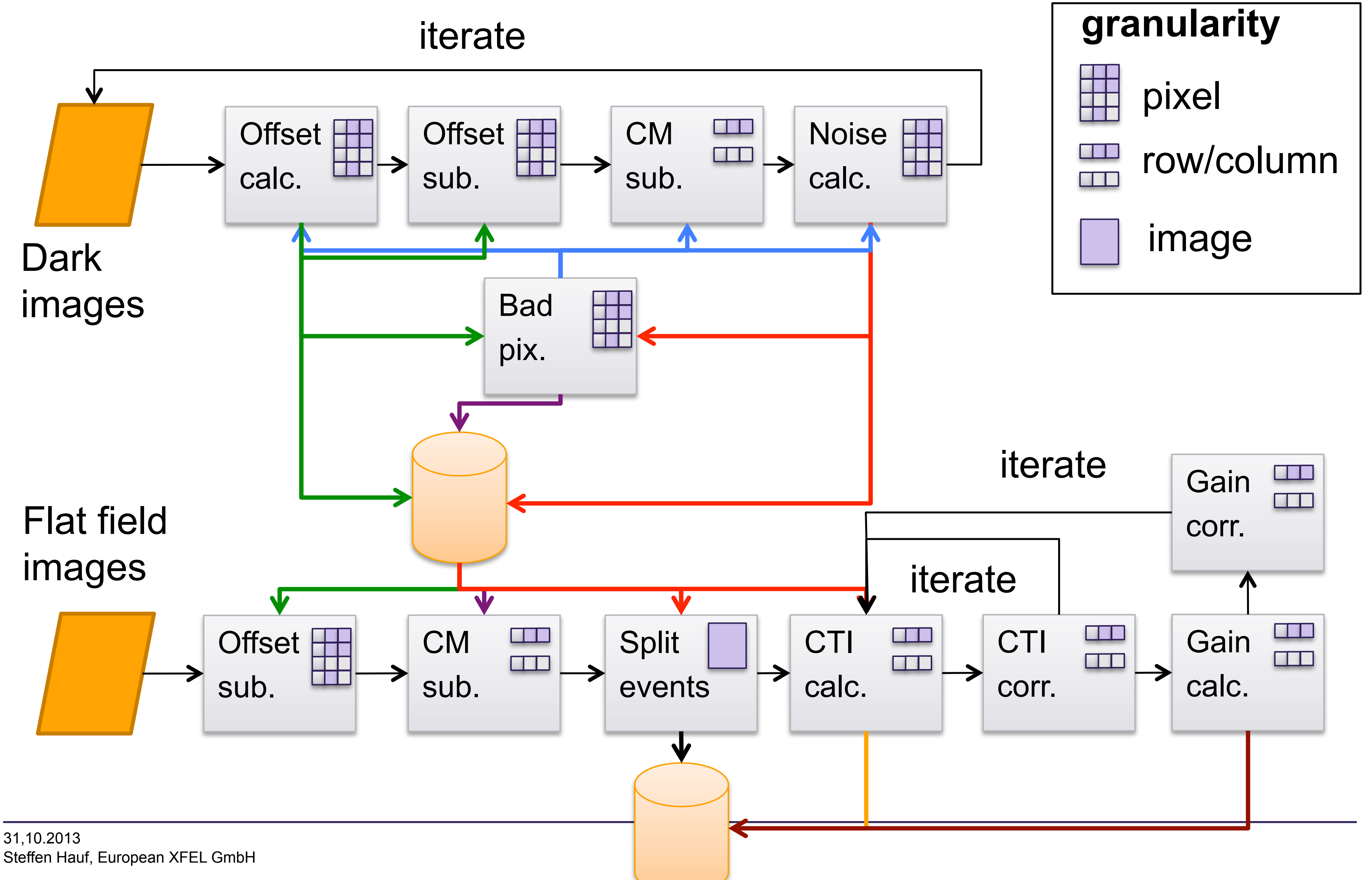


No need to worry about:

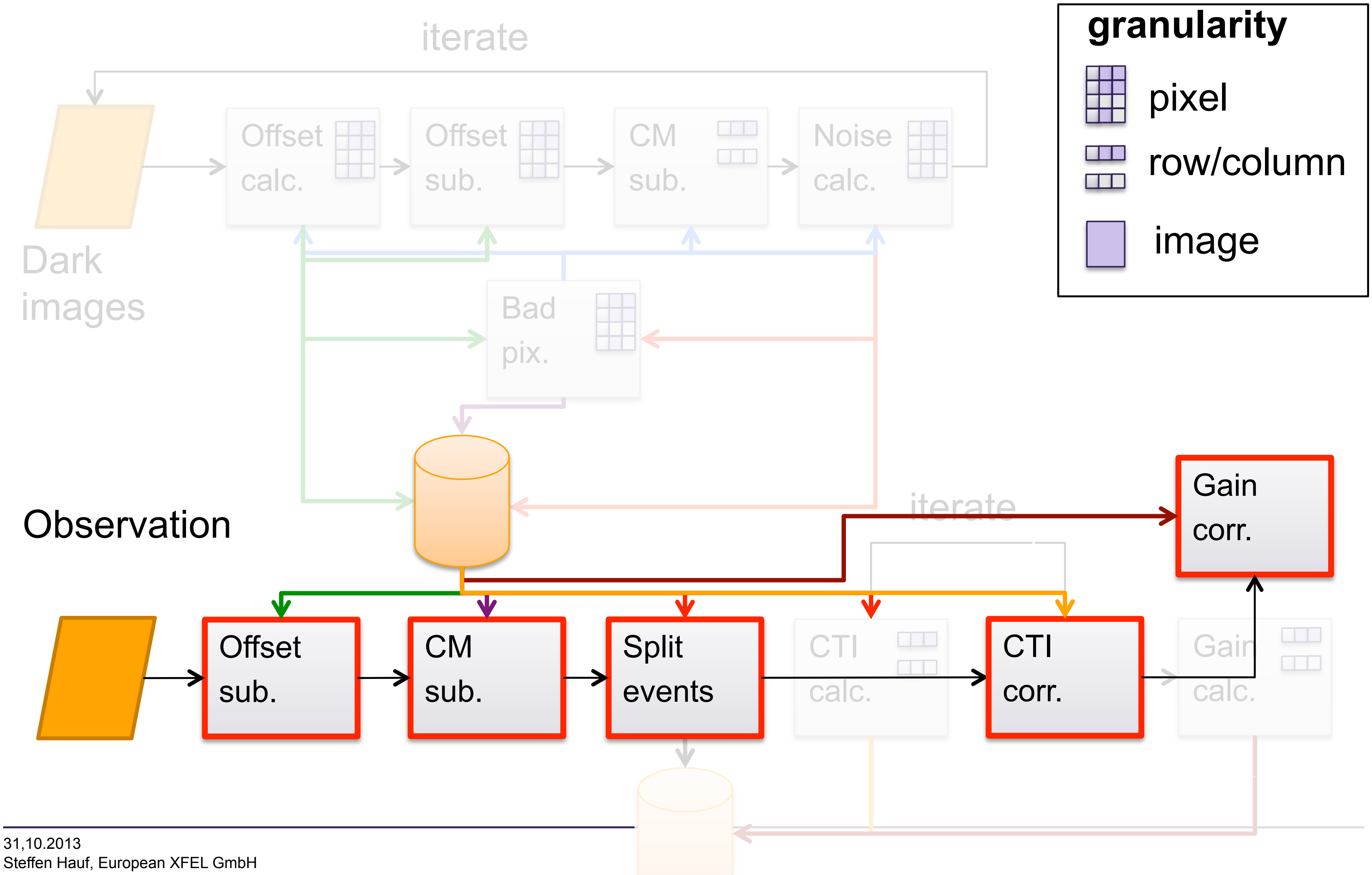
- Concurrency/Scheduling
- Persisting data (HDF5, DB)
- State-awareness (FSM)
- GUI & CLI

… the framework handles this in the background, while allowing a large degree of flexibility

The pn-CCD Pipeline as a Reference Implementation



The pn-CCD Pipeline as a Reference Implementation

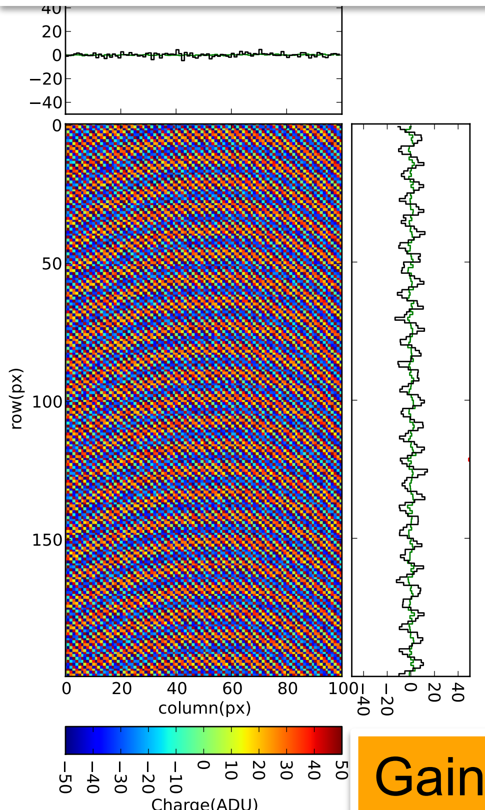


From Concepts to “Software in Action”

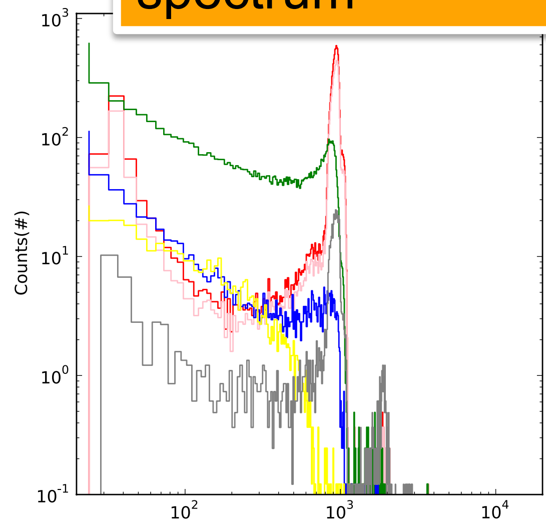
- Initial stand-alone (i.e. non-Karabo) pipeline as reference
  - Implements calibration routines as shown on previous slides
  - Concurrency on a per-pixel and per-image level
  - Mixed image-based/event-based data-layout
  - FITS and HDF5 I/O
  - iPython/matplotlib auto-report generation in conjunction with iPython-notebook based layout tool
- Core fully implemented into Karabo by now (manager device still missing)
- Both are being benchmarked against data from the pn-CCD of the CAST experiment and its well-tested calibration pipeline

From Concepts to “Software in Action” – Visualization

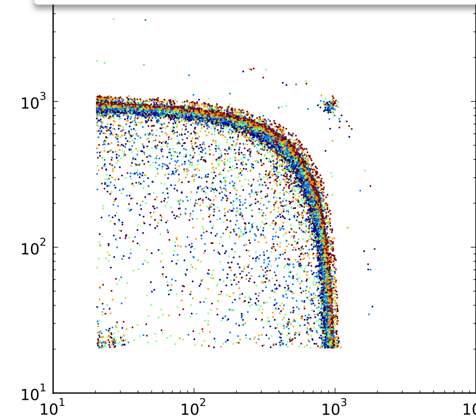
Frame dependent common mode



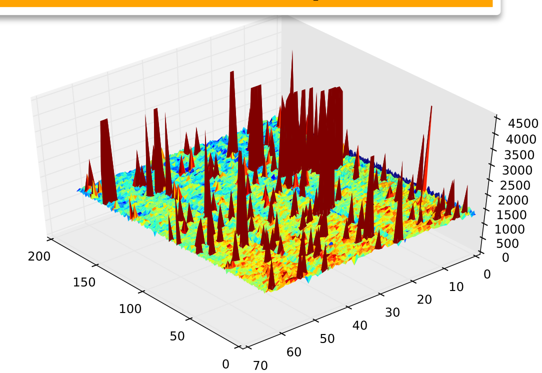
Split event spectrum



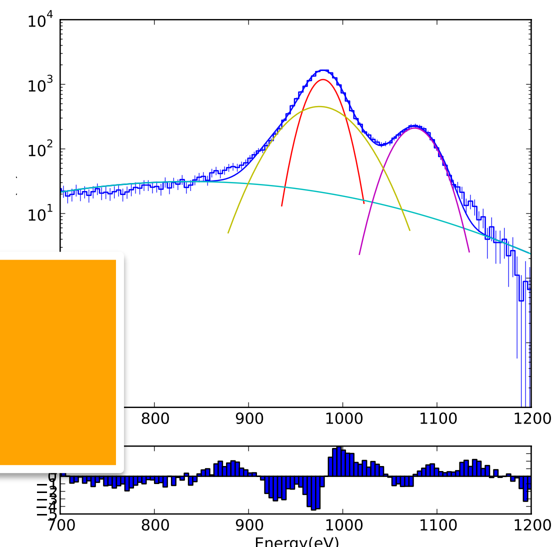
Double split-ratios



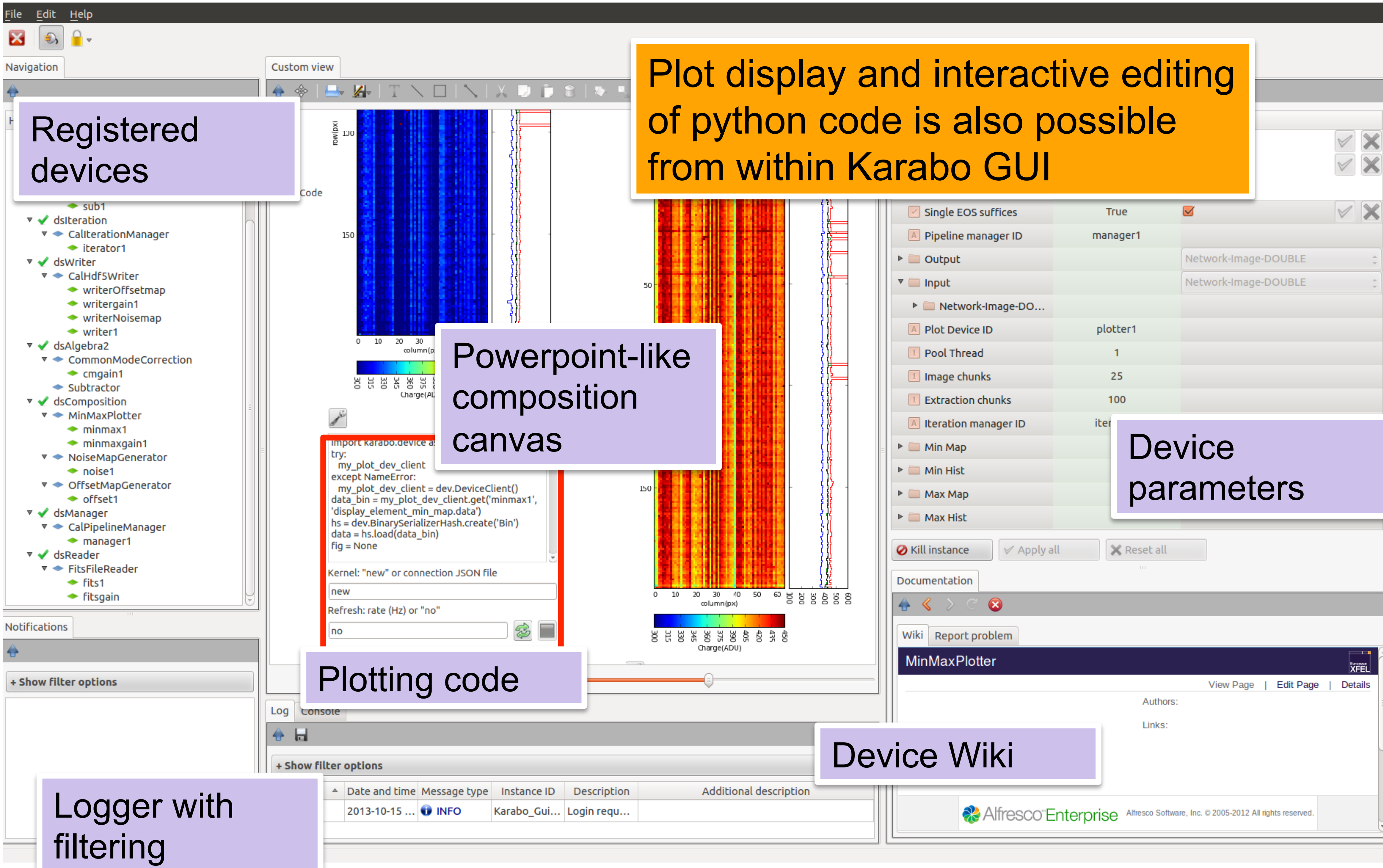
Max PHA map



Gain calibration after full event reconstruction

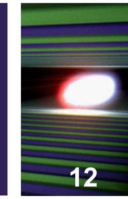


From Concepts to "Software in Action" – Karabo Pipeline



European XFEL

From Concepts to "Software in Action" – Report Generation



127.0.0.1:8890/6a4be3c1-8e0c-432d-907a-f351000ab377

IP[y]: Notebook structure Last Checkpoint: Oct 15 09:52 (autosaved)

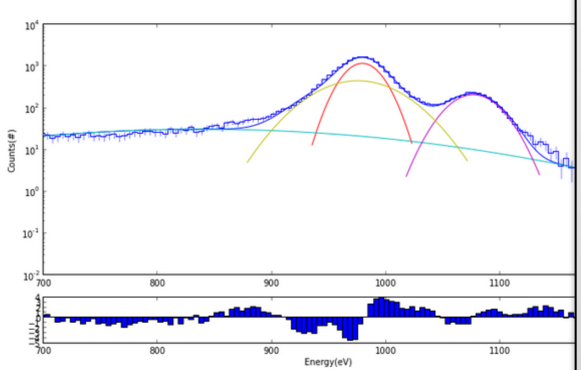
File Edit View Insert Cell Kernel Help

Code Cell Toolbar: None

Data source: file /home/haufs/NetBeansProjects/Ima spectrum_raw_frames

Page layout

<h1>Gain Corrected Spectrum</h1>

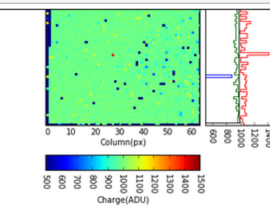


0	Peak position (ADU)	979.05 +- 0.0404502
1	Peak FWHM (ADU)	34.4453 +- 0.0807869
2	Peak position (eV)	5895.1 +- 0.24356
3	Peak FWHM (eV)	207.404 +- 0.486437
4	ADU/eV	0.1660786
5	Reduced Chi2	5.800319
6	Goodness of Fit	0

- The iPython notebook based layout tool allows for WYSIWG report layouting.
- By using matplotlib as a backend flexible, publication-quality plotting is possible.
- LaTeX syntax is fully supported for equations and plot labels.
- Model and view are separated, layouts can be reused for new data.
- Final product is a standardized PDF report

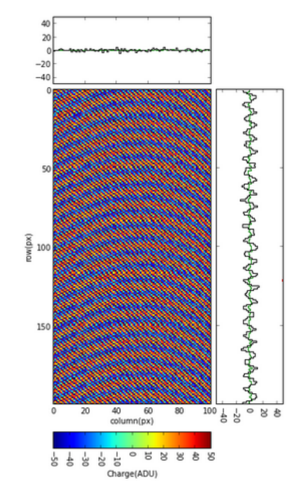
Insert page above

Delete this page



Minimum KeV of all Frames

Out[20]: <matplotlib.text.Text at 0x3bdfa90>



Maximum ADU off All Frames (Raw Data) excluding bad pixels.

Available plots and tables

From Concepts to "Software in Action" – Benchmarking against CAST Gain Calibration

- Implementations differ slightly, a few parameters still need to be adapted
- **Generally good agreement**

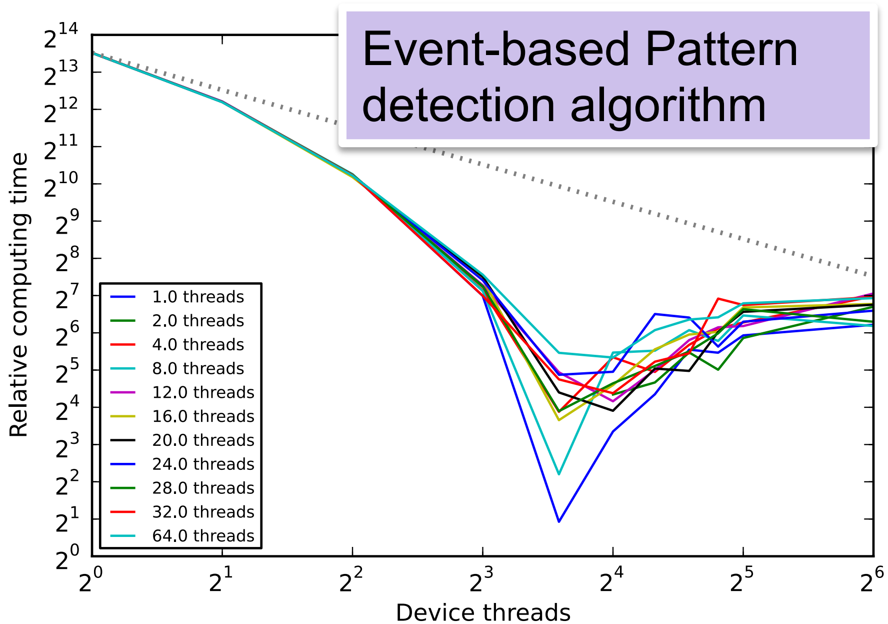
Parameter	CAST	XFEL	Diff. (%)
Min (median)	296.0	296.0	0
Max (median)	1372.0	1372.0	0
Noise (median)	5.3	5.5	3.6%
Peak pos (ADU)	986.3	979.1	0.7%
Peak FWHM (eV)	198.6	207.0	4.1%
ADU/eV	0.17	0.17	0%

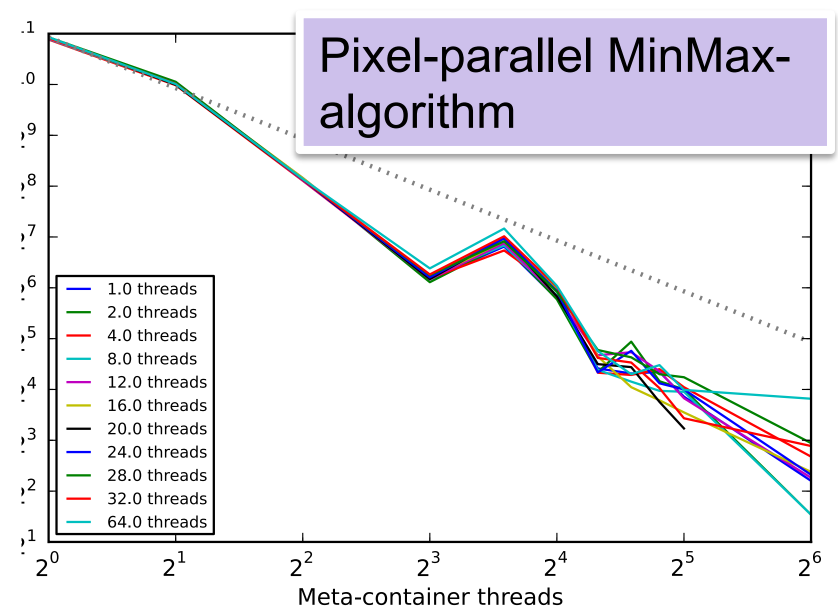
CAST pn-CCD
200x64 pixels
150 µm x 150 µm pixel size
300 µm sensor thickness
71.775 ms cycle time

Multiplicity	CAST	XFEL
Singles	60.9 %	56.7 %
– First singles	74.3 %	77.9 %
Double	35.9 %	39.3%
Triples	2.2 %	2.6 %
Quadruples	1.0 %	1.3 %

From Concepts to “Software in Action” – A few Words on Performance

- Preliminary performance tests on stand-alone pipeline
- Scales better than linear:
  - more threads: less pipeline stages lie dormant
  - CPU affinity
- Karabo-based pipeline not performance-optimized yet





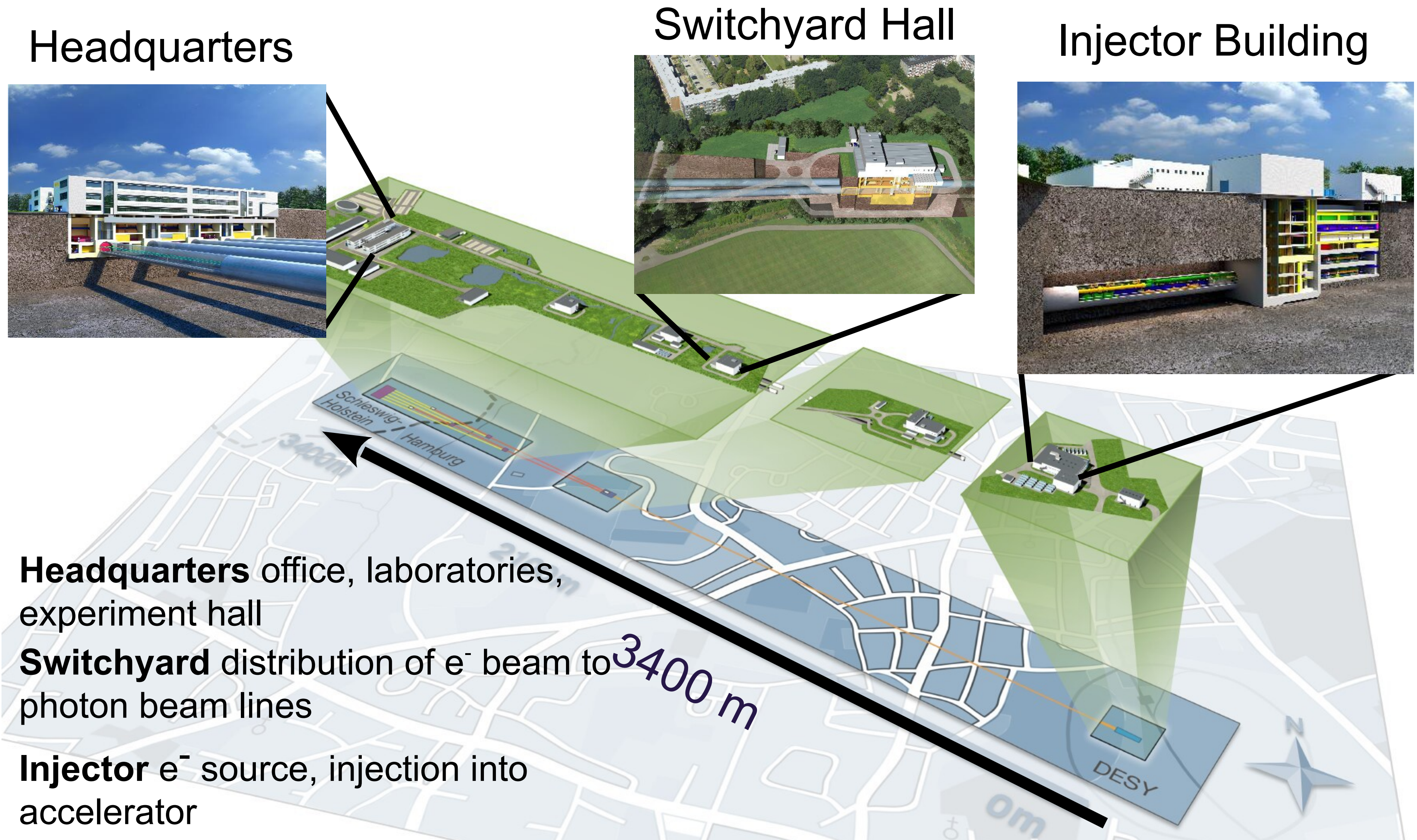
European XFEL

Conclusion

- Stand-alone pipeline is implemented and being used for analysis. It has been tested against the existing CAST CCD calibration analysis and matches results.
- Modular pipeline approach allows for reuse of components in diverse scenarios:
  - Monitoring
  - Near-online calibration application for rapid-feedback
  - Processing from archive after experiment
- The calibration concept for European XFEL foresees a Karabo-framework based pipeline for calibration constant analysis and application
- Powerful auxiliary packages provide a flexible, interactive report generator, which utilizes the full power of iPython and is deemed to be useful for non-calibration tasks as well

Backup Slides

The European XFEL – Facility Overview



Headquarters office, laboratories, experiment hall

Switchyard distribution of e^- beam to photon beam lines

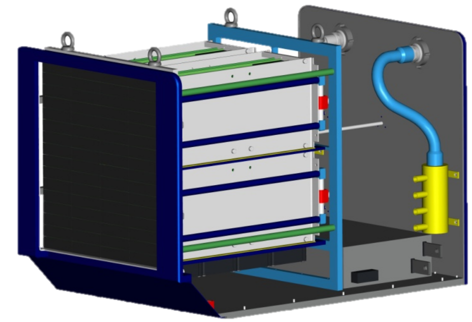
Injector e^- source, injection into accelerator

Calibration Challenges – Detector Parameters

LPD

Energy range: 5(1)–20(25) keV
Dynamic range: 10^5 ph. @ 12 keV
Pixel size: 500 x 500 µm^2
Storage cells: 512
Single photon sens.: ✓

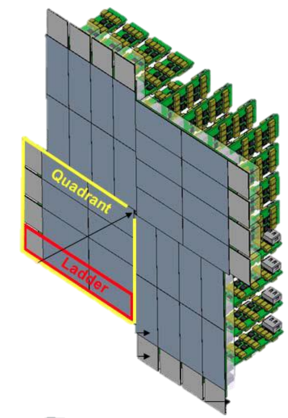
Rutherford Appleton Labs/STFC, University of Glasgow



DSSC

Energy range: 0.5–6 keV
Dynamic range: 6000 ph. @ 1 keV
Pixel size: 236 x 236 µm^2
Storage cells: 640
Single photon sens.: ✓

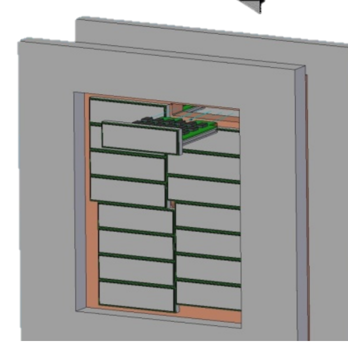
Max-Planck-Halbleiterlabor, Universität Heidelberg, Universität Siegen, Politecnico di Milano, Università di Bergamo, DESY



AGIPD

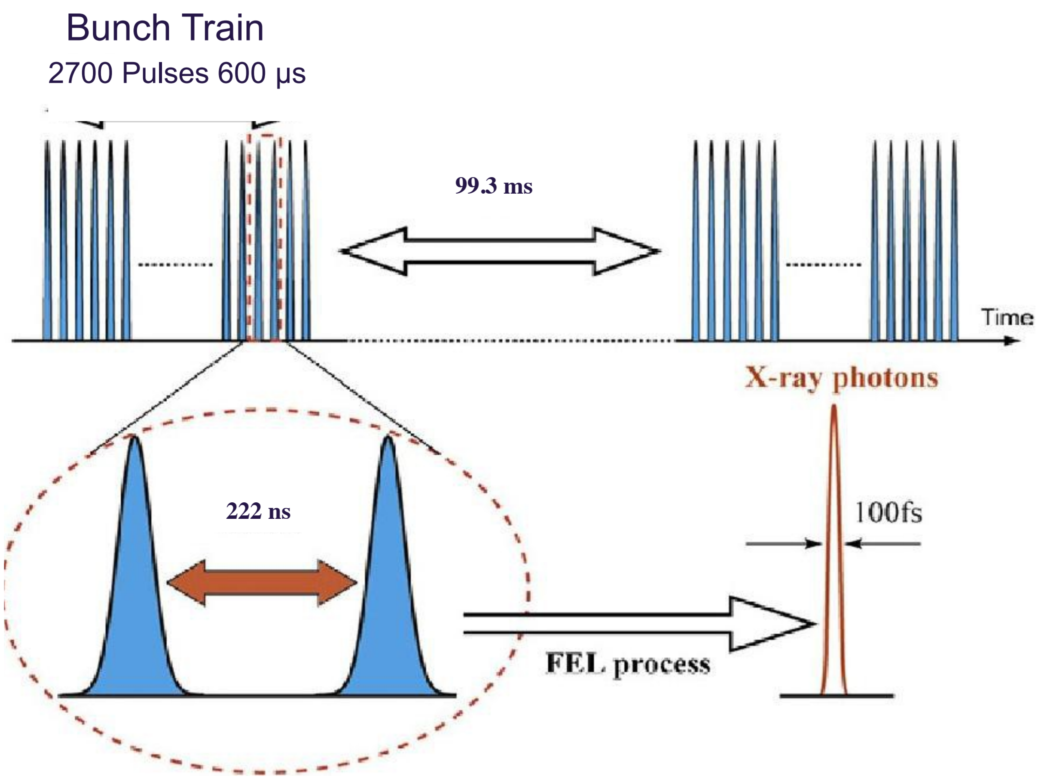
Energy range: 3–13 keV
Dynamic range: 10^4 ph. @ 1 keV
Pixel size: 200x 200µm^2
Storage cells: 300
Single photon sens.: ✓

DESY, PSI/SLS Villingen, Universität Bonn, Universität Hamburg,

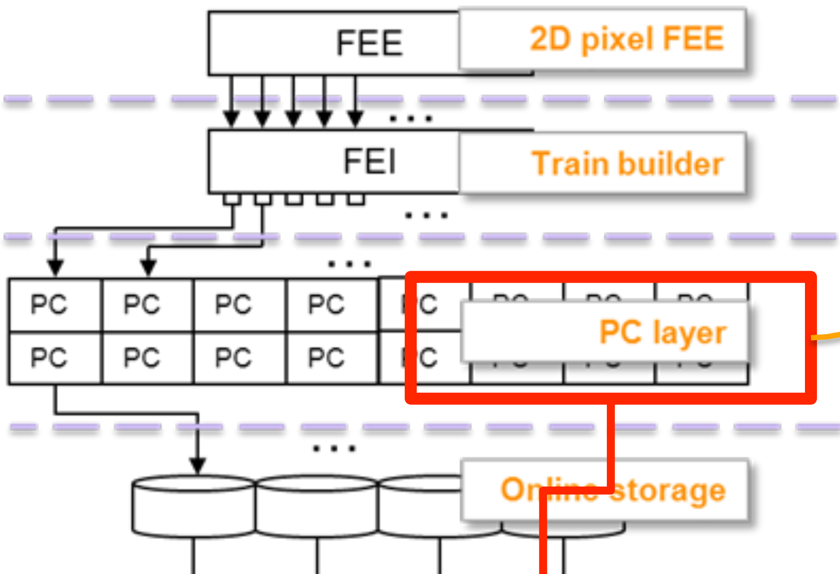


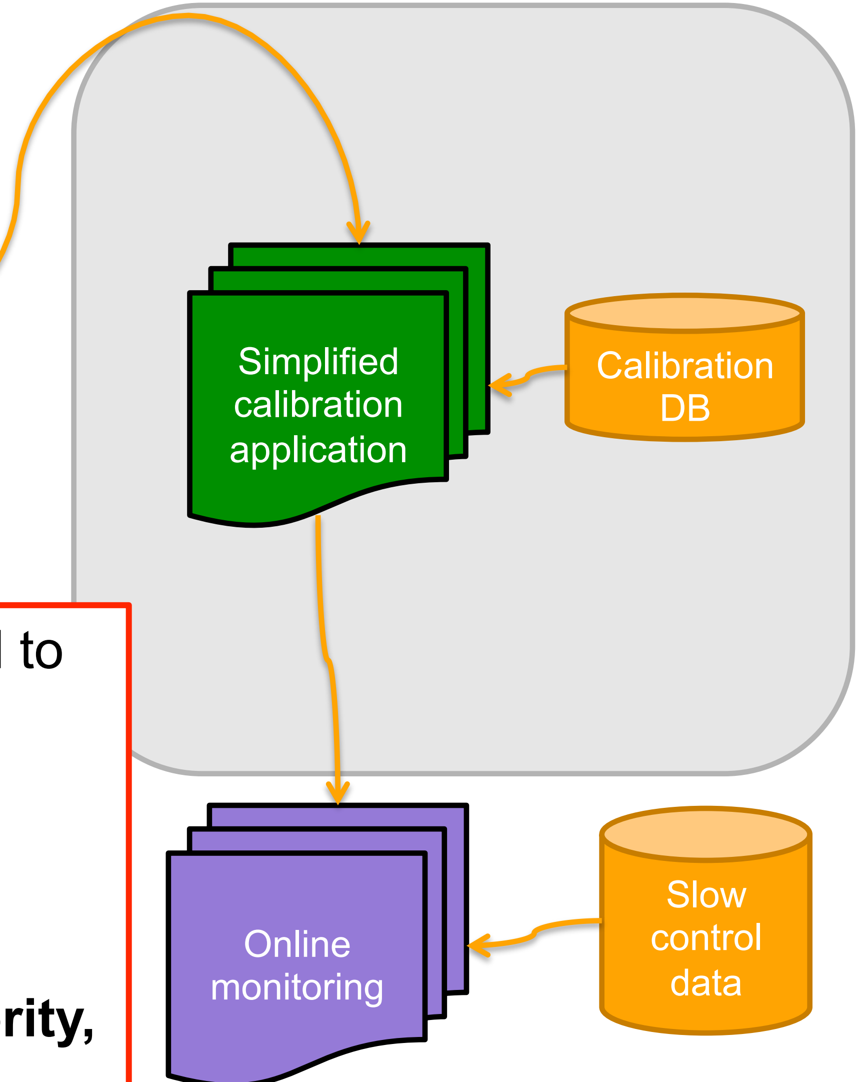
Calibration Challenges – Near-Online Application

- The European XFEL will have a unique time structure:
  - Ultra-short pulses < 100 fs
  - 1300 pulses in a train
  - 99.3 ms between bunches ⇨ 10 Hz bunch rate
  - 27.000 pulses/s at a maximum pulse rate of 4.5 MHz
  - Pulse patterns may differ from 1…n pulse per train, with variable spacing
- Up to 10^{12} photons/bunch



Where is Centralized Calibration Involved? – Monitoring



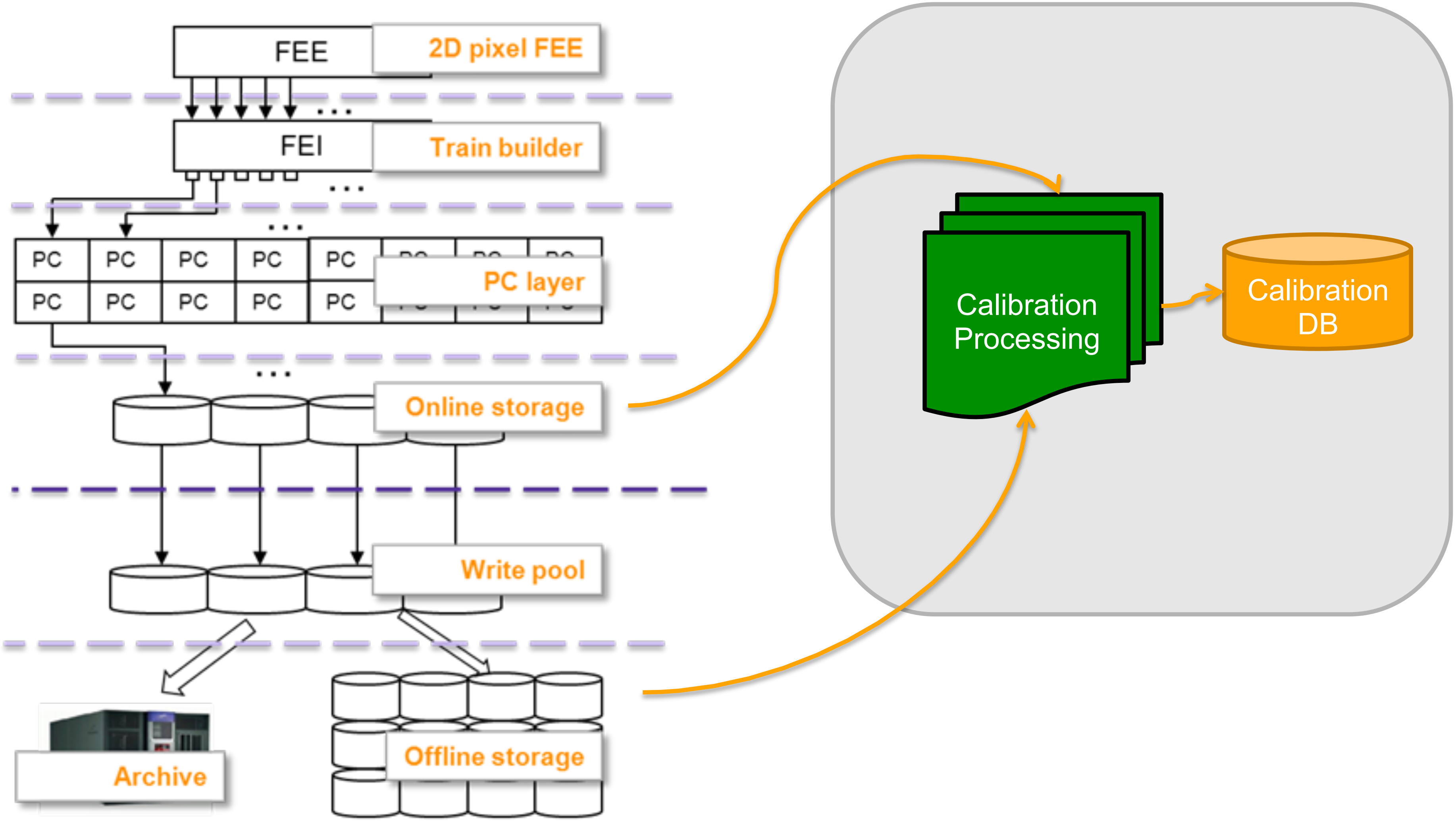


Unused PC layer resources can be used to apply simple calibration to **online monitoring data:**

- Typically: every nth frame
- Algorithms run in constant time
- **Output of raw data always has priority, i.e. monitor rate is not guaranteed.**

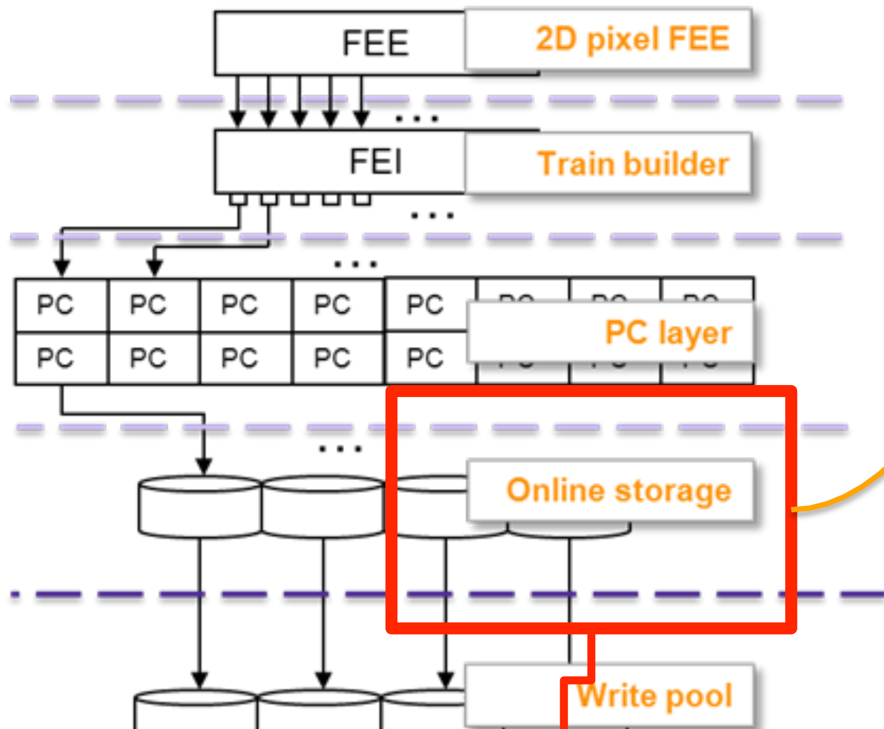
Sources: Djelloul Boukhelf, Janusz Szuba, 13th XDAC Meeting, European XFEL GmbH, 2012

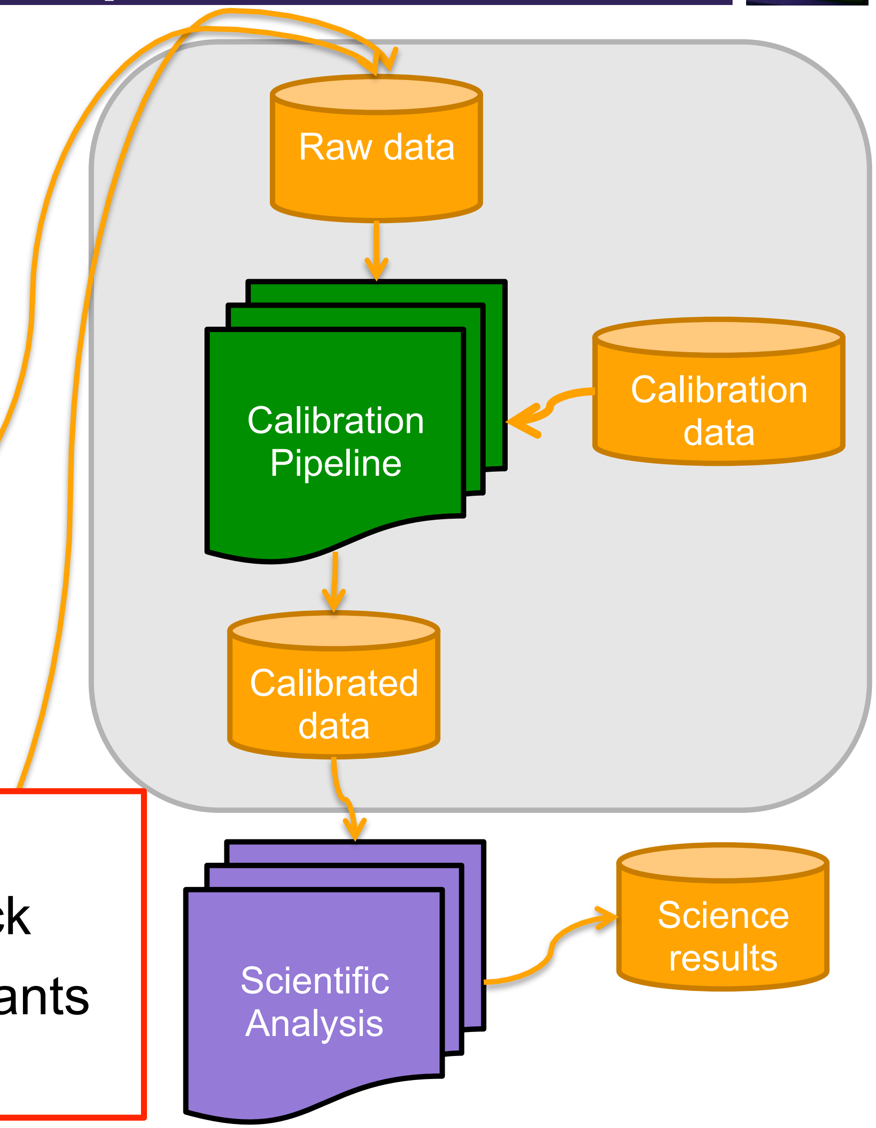
Where is Centralized Calibration Involved? – Acquiration of Calibration Constants



Sources: Djelloul Boukhelf, Janusz Szuba, 13th XDAC Meeting, European XFEL GmbH, 2012

Where is Centralized Calibration Involved? – Applying Calibration for Rapid Feedback





Processing "in parallel" to experiment:

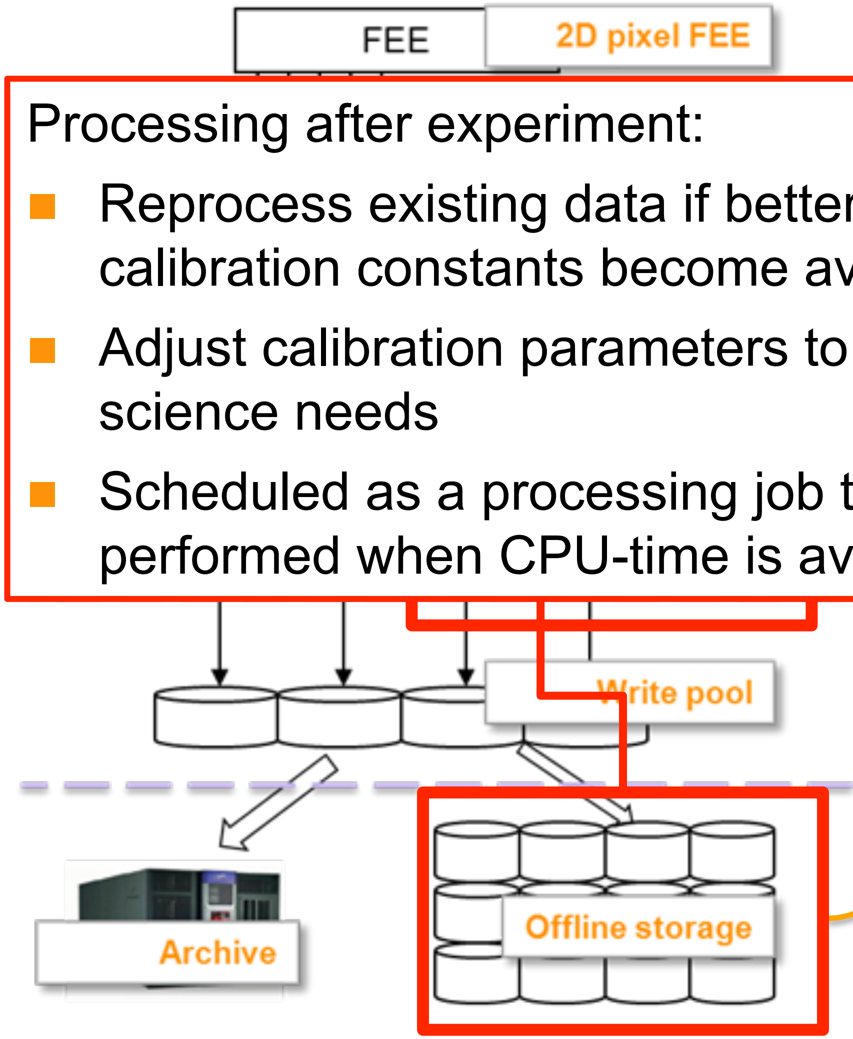
- Provide scientist with rapid feedback
- Use current set of calibration constants
- near online

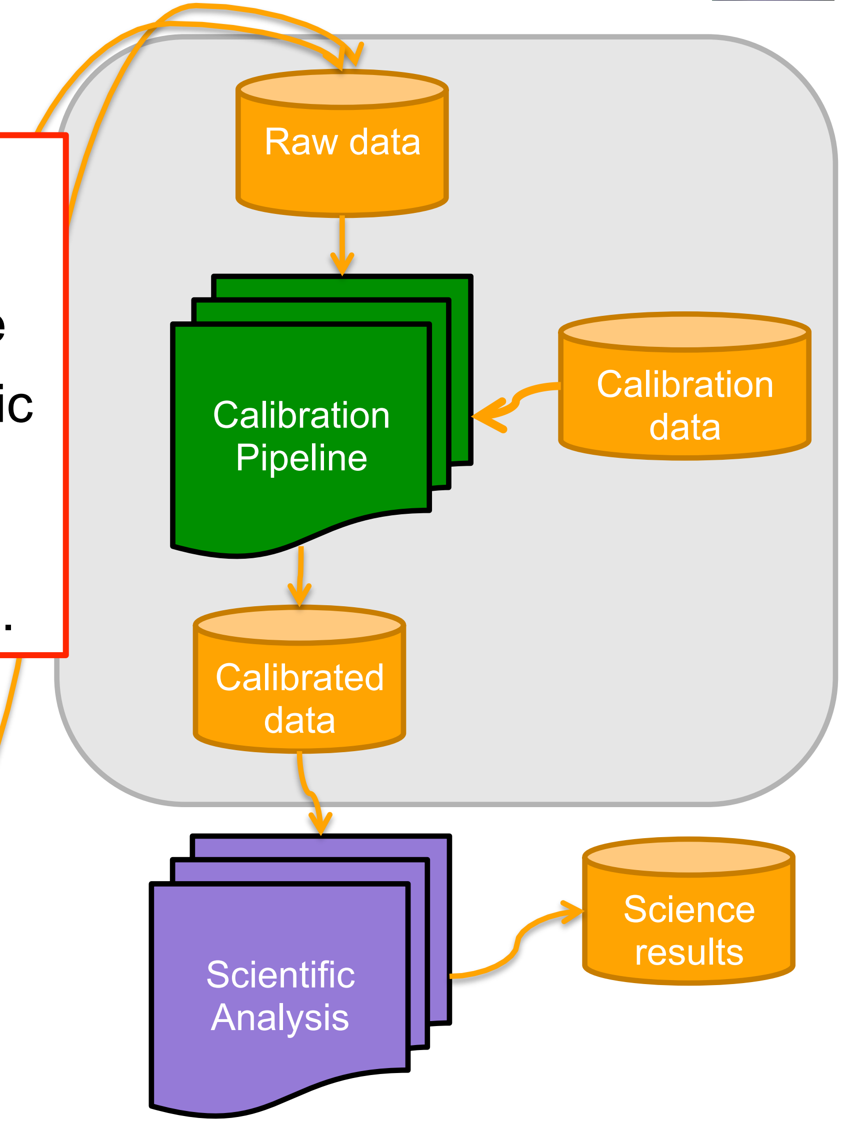
Sources: Djelloul Boukhelf, Janusz Szuba, 13th XDAC Meeting, European XFEL GmbH, 2012

Where is Centralized Calibration Involved? – (Re)processing Data after Experiment

Processing after experiment:

- Reprocess existing data if better calibration constants become available
- Adjust calibration parameters to specific science needs
- Scheduled as a processing job to be performed when CPU-time is available.





Sources: Djelloul Boukhelf, Janusz Szuba, 13th XDAC Meeting, European XFEL GmbH, 2012