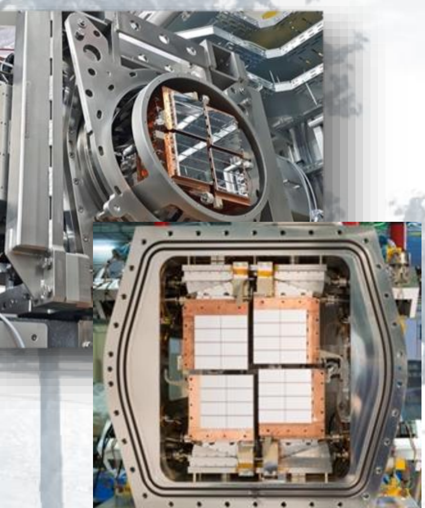
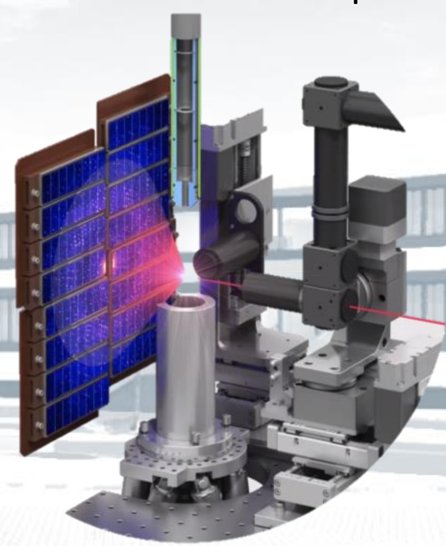
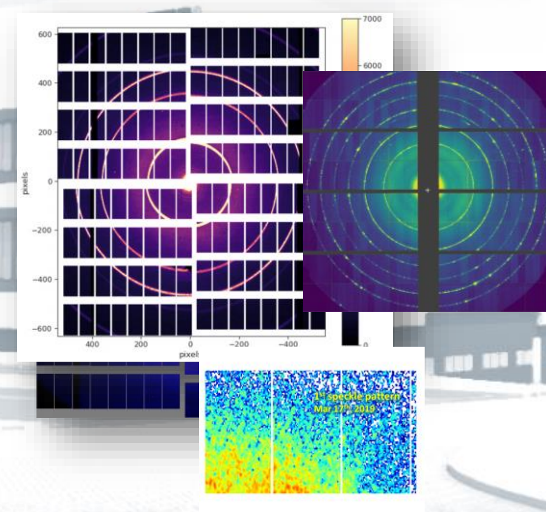
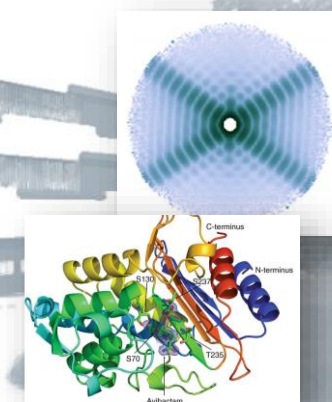
Operational Experience and Lessons Learned with Detectors at European XFEL
(mostly based on AGIPD)

Jola Sztuk-Dambietz
European XFEL









DESY Joint Instrumentation Seminar

Hamburg, 1st December 2023

Outline & Acknowledgment

Outline

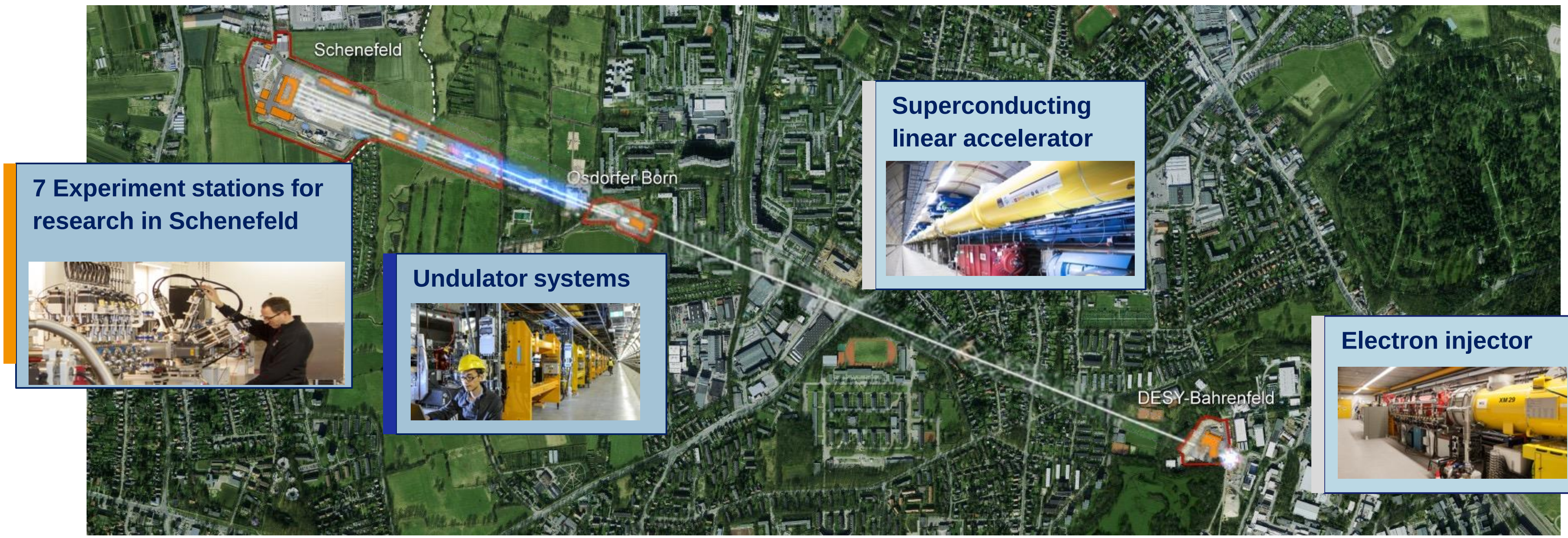
- Introduction
- First-Generation Detectors for EuXFEL: Navigating the Unique Time Structure
  - Our path to the current stage
- Operation and Lessons Learned
  - Insights gained from integration, commissioning and operations

People

- **AGIPD Consortium (H. Graafsma)**
  - DESY, PSI, Uni Bonn, Uni Hamburg
- **STFC UKRI (M. Hart)**
- **DSSC consortium (M. Porro)**
  - EuXFEL, DESY, PoliMi, Uni BG, Uni Heidelberg, pnSensor, MPG-HLL
- **European XFEL**
  - Data Department (S. Aplin)
    ► **DET Group**, Controls,ITDM, EEE, DA
  - SPB/SFX instrument (A. Mancuso/R. Bean)
  - MID instrument (A. Madsen)
  - FXE (Ch. Milne)
  - HED (U. Zastrau)
  - SCS (A. Scherz)
  - SQS (M. Meyer)

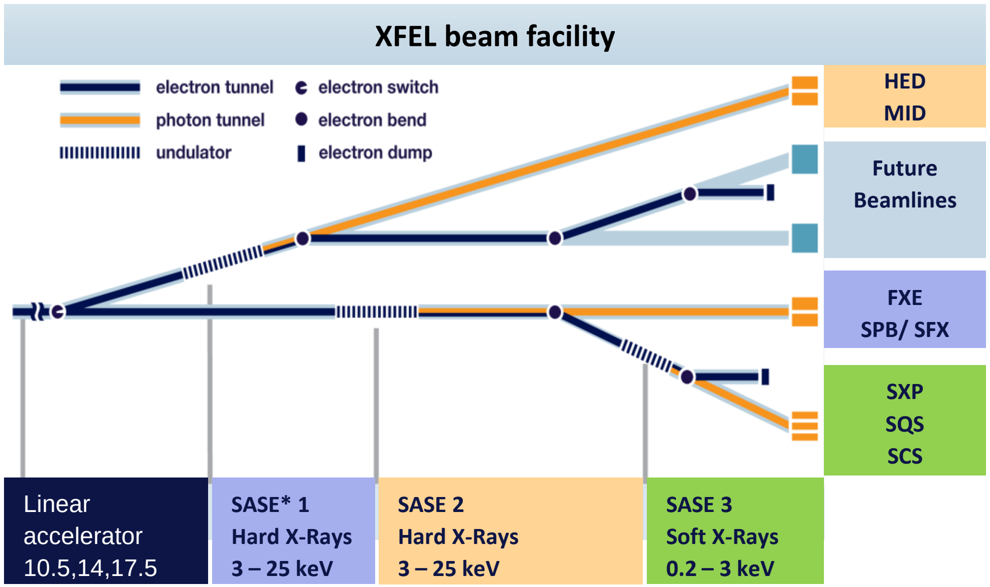
The European XFEL in Schenefeld, Germany

Total length: 3.4 km

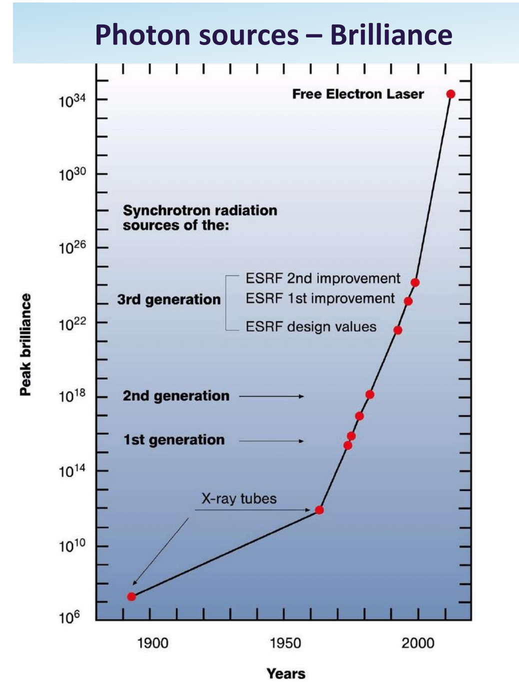


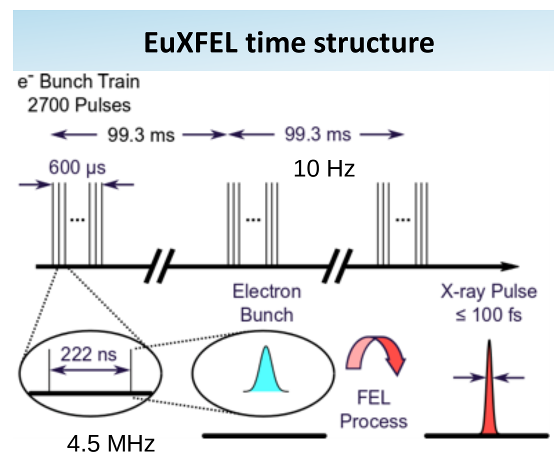
EuXFEL facility : 3 beamlines, 7 Instruments

Start of operation – July 2017



*Self-Amplified Spontaneous Emission





Challenges for Detectors → Demanding Intensity and Timing Constraints

- High dynamic range (10^4 ph/pixel/pulse) with single photon sensitivity for soft and hard X-ray instruments
- Radiation hardness
- MHz operation (in the burst mode)
- **No commercial imaging detectors available**

First Generation of EuXFEL detectors: A journey from concept to user operation

- **For the first-generation detectors, EuXFEL initiated a dedicated call for proposals from external development groups**
  - **2006:** Launched a Call for Expression of Interest
  - **Selected Proposals →** Three different projects adopting different solutions to solve the EuXFEL challenges
    - ▶ Adaptive Gain Integrating Pixel Detector
    - ▶ Large Pixel Detector
    - ▶ DEPFET Sensor with Signal Compression
  - **Goal:** Developing at least one MHz 2D Imaging Detector
  - Development started ca. 2009


European XFEL Project Team
c/o Deutsches Elektronen-Synchrotron DESY
in der Helmholtz-Gemeinschaft,
Notkestraße 85,
D-22607 Hamburg, Germany

XFEL
X-Ray Free-Electron Laser

Call by the:

European Project Team for the X-ray Free-Electron Laser

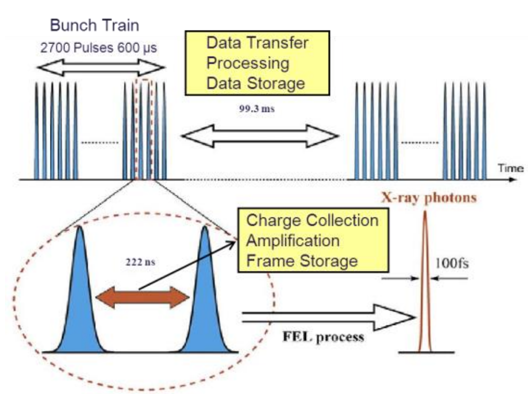
for:

Expressions of Interest

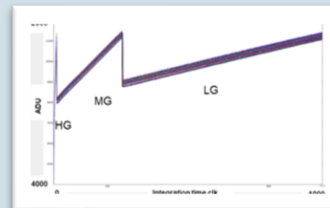
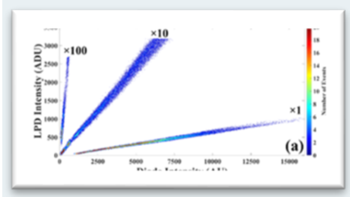
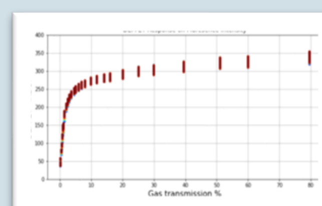
to:

Develop and Deliver Large Area Pixellated X-ray Detectors.

Deadline: 30 September 2006
http://xfel.desy.de/xfelhomepage



The first MHz detector generation at the EuXFEL

Detector	Specs	Gain Mechanism	Gain	Start of Operation
AGIPD 	352 memory cells (analog) 200µm x 200µm sq. pixels 1-10^4 12 keV ph 3-20 keV Modular: 16 (1MPix) or 8 (0.5MPix) modules	3 gains with automatic switching		AGIPD1M (SPB/SFX): 2017 AGIPD1M (MID): 2019 AGIPD500K: 2020 (new gen.) AGIPD4M (SPB/SFX): 2024 (new. gen) AGIPD1M (HED): 2024 (new gen)
LPD 	(3x)512 memory cells (analog) 500µm x 500µm sq. pixels 1-10^5 12 keV ph 7- 20 keV Modular: 16 module (1MPix)	3 parallel gain stages with on front-end selection		LPD (FXE): 2017
DSSC 	800 memory cells (digital) 204µm x 236µm hex. pixels N x 256 ph @ 4.5 Mhz N x 512 @ f≤2.2 MHz N ≤ 1 for single ph sensitivity 0.5 – 6 keV Modular: 16 modules (1MPix)	Linear response (miniSDD), non-linear signal compression in sensor (DEPFET)		DSSC1M (SCS): 2019 DSSC DEPFET: 2024

A Journey from Concept to User Operation <u>> 10 years</u>

Detectors at EuXFEL

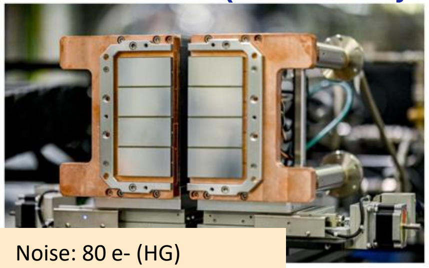
X-ray energy

Hard X-rays 6-25 keV

ePix100 (MID, HED)

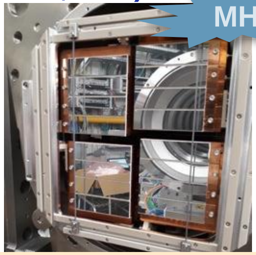
Noise: 50 e- (HG)
Dyn range: 100 8 keV ph

JUNGFRAU x 18 (all hard X-ray inst.)



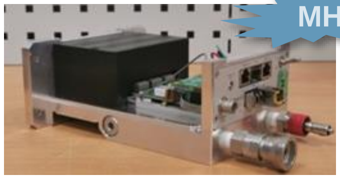
Noise: 80 e- (HG)
Dyn range: 10^4 12 keV ph

AGIPD (SPB/SFX, MID, HED) MHz



Noise: 350 e- (HG)
Dyn range: 10^4 12 keV ph

GOTTHARD-II MHz

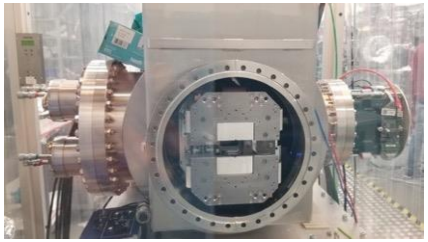


LPD (FXE) MHz

Noise: 2010 e- (HG)
Dyn range: 10^5 12 keV ph

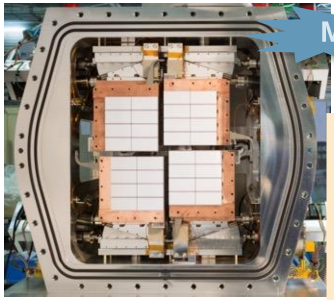
Soft X-rays 0.5-3 keV

pnCCD (SQS)



Noise: 3 e-
Dyn range: 1500-3000 1 keV ph

DSSC (SCS, SQS) MHz

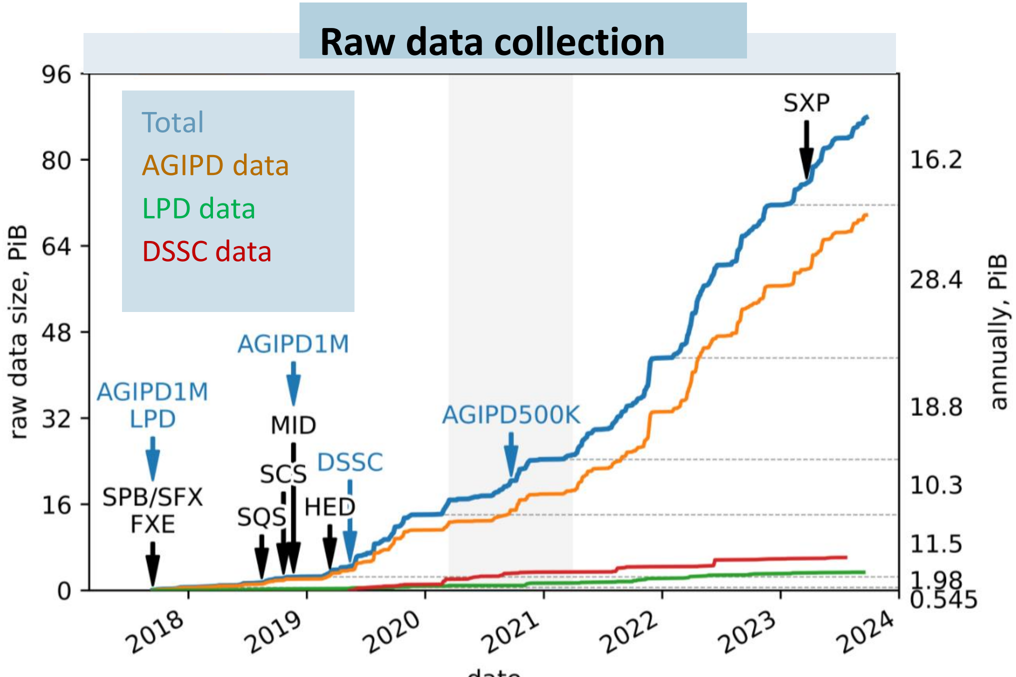


Noise: 60 e-
Dyn range:
N x 256 ph @ 4.5 Mhz
–
N x 512 @ f≤2.2 MHz
N ≤ 1 for single ph sens.

10 Hz 4.5 MHz *Rate*

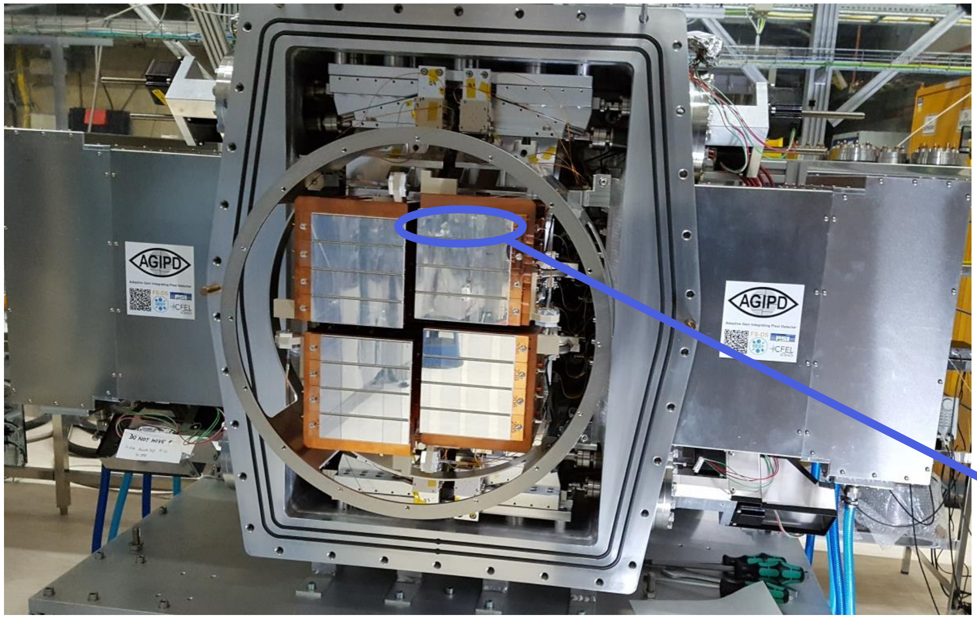
Why “mostly based on AGIPD” detectors?

- **Most Frequent Usage:**
  - AGIPD detectors are the most frequently used 2D MHz detectors at EuXFEL
  - Primary detectors at SPB/SFX and MID
- **Operational Demands:**
  - One of the most demanding detectors at EuXFEL in terms of infrastructure and operational requirements



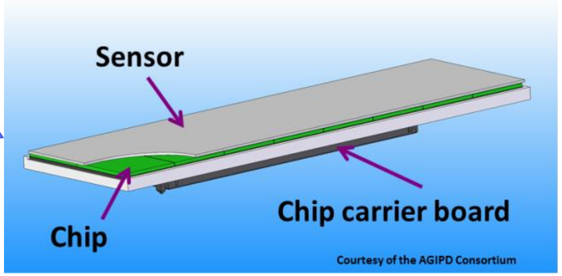
Courtesy of EuXFEL DA Group

AGIPD1M detector system for SPB/SFX and MID instruments



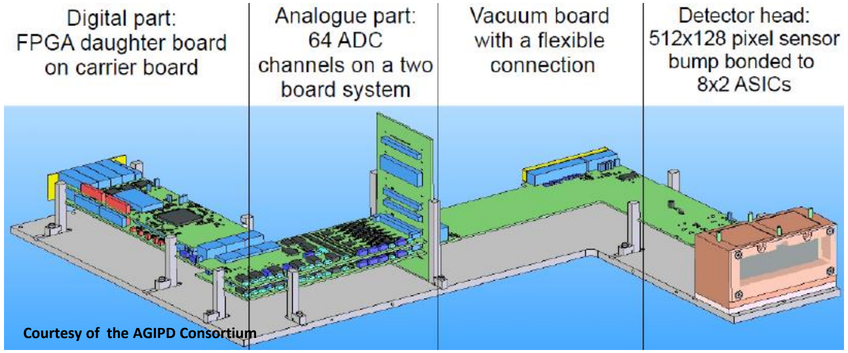
Hybrid detector module

- Sensor:
  - 128 x 512 pixels
  - 500 µm thick silicon
- 2 x 8 read-out chips connected to sensor via bump-bonding
- Size: ~26 x 105 mm^2



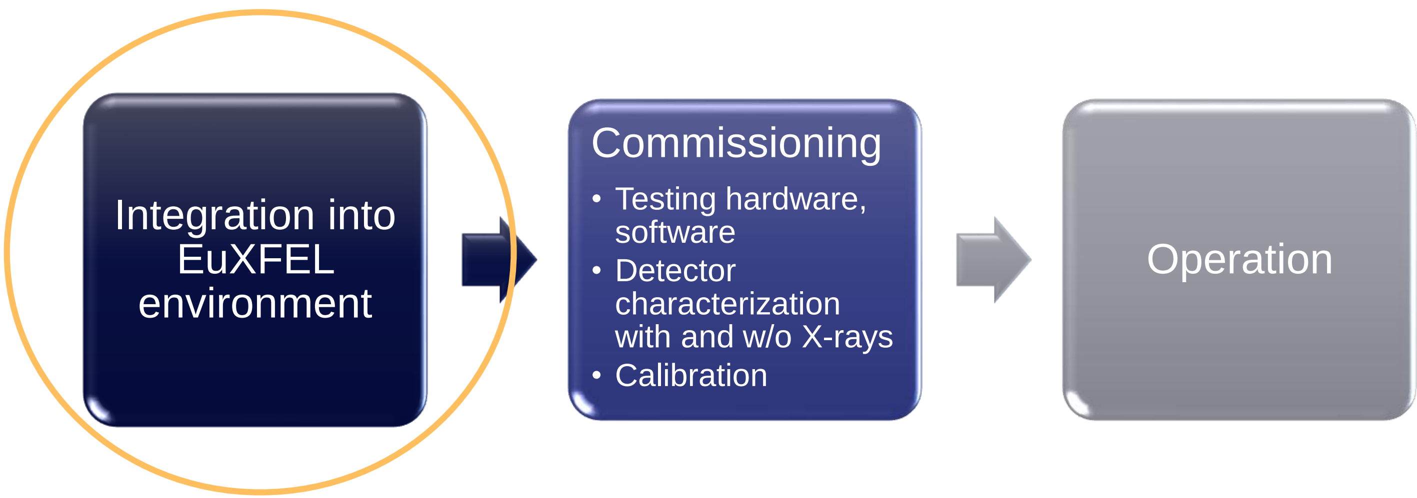
1M AGIPD system

- 16 modules are mounted on four independently movable quadrants
- Vacuum operation (P< 10^{-5} mbar)
- Electronics/Control: two independent detectors: 'half 1' and 'half 2'
- Readout: 16 independent detectors



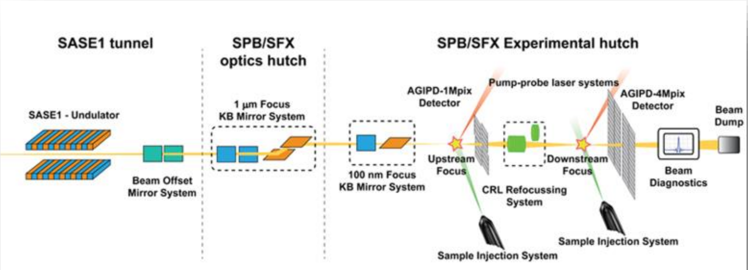
In ambient In vacuum

What have we learned from the first-generation detectors?



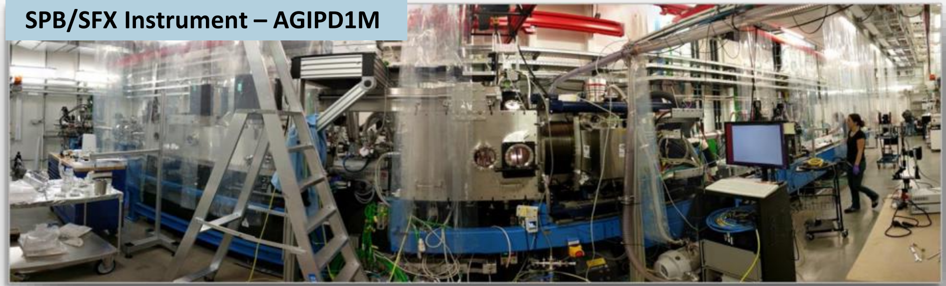
AGIPD1M detectors are integral part of the instruments

General layout of the SPB/SFX instrument.



Courtesy of SPB/SFX Instrument

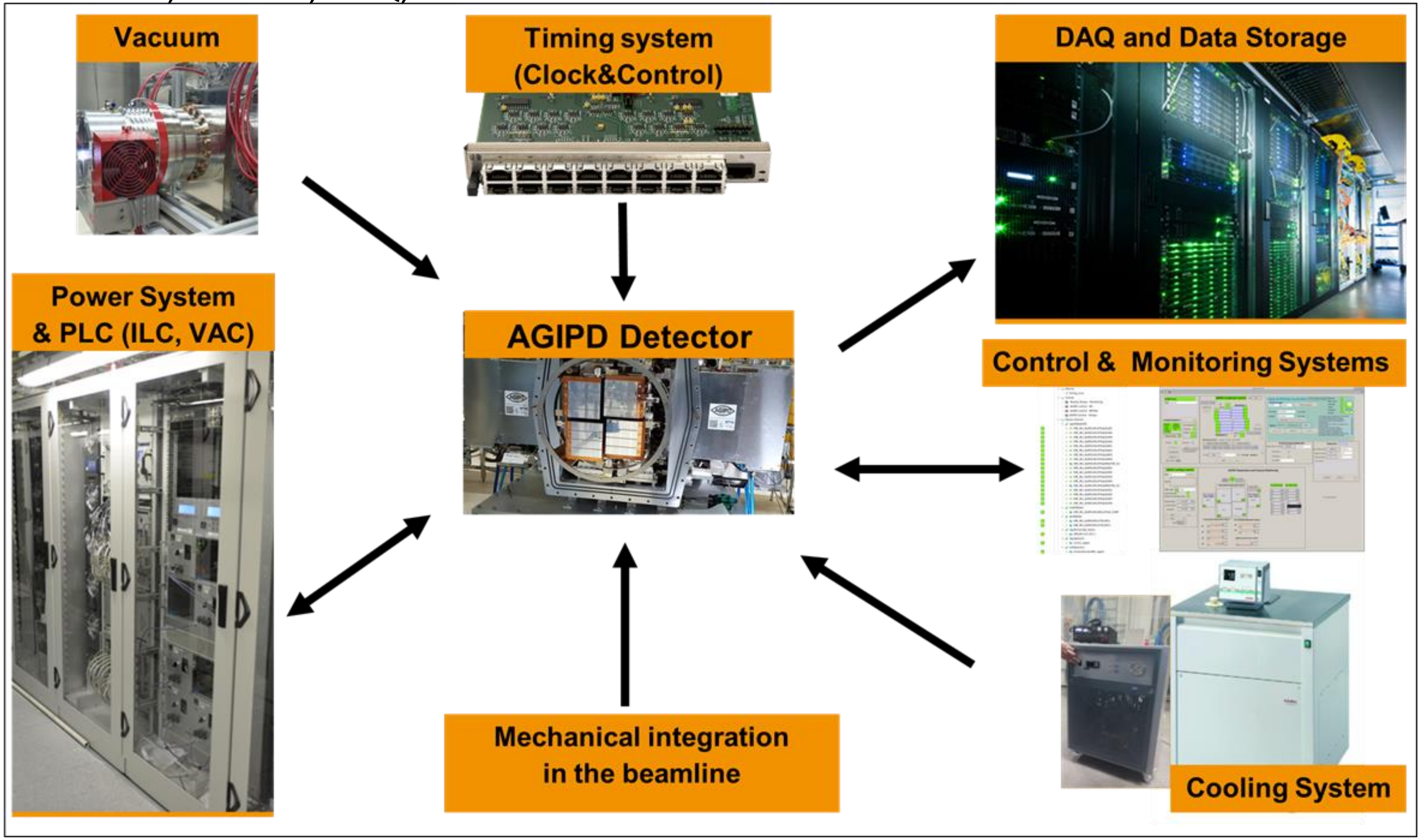
SPB/SFX Instrument – AGIPD1M



MID Instrument – AGIPD1M in WAXS configuration

Integration: A complex task

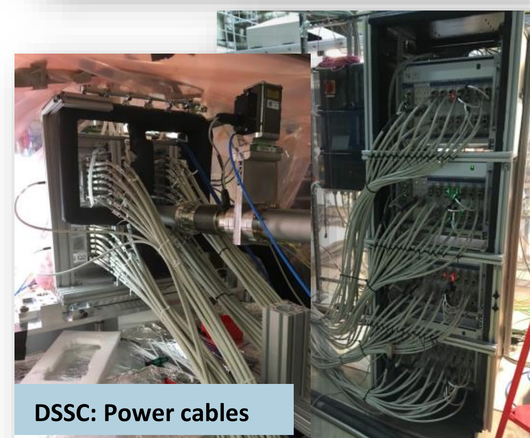
- EuXFEL detectors were fully integrated into our infrastructure: mechanics, cooling, power, interlock, vacuum, DAQ, Control



Integration is a highly complex task → Start early to define interfaces

It is all about the cables…

- The challenge of cables and cooling is often underestimated
- The "HEP approach" for powering the detector is not well-suited for XFEL applications, especially considering the number of cables that need to be managed when detectors must be moved (more than 100 cables for one AGIPD1M detector)
  - this approach significantly increases the risk of damaging the detector or other beamline instrumentation.
  - it limits access to the detector electronics in case of failure or routine maintenance



More compact design and optimization of the power/cooling system would make integration and operation easier

Interlock system for detector protection

- Relies on Programmable Logic Controllers (PLCs)
- Monitors:
  - Vacuum quality and cooling efficiency
  - Detector cooling block temperatures
  - Pressure values in detector vessel and sample chamber
  - Chiller conditions
  - Internal detector conditions (hardware and FEM temperatures)
- PLCs initiate appropriate actions when needed
  - Switching off power
  - Warming up detector
  - Close valves to protect vacuum

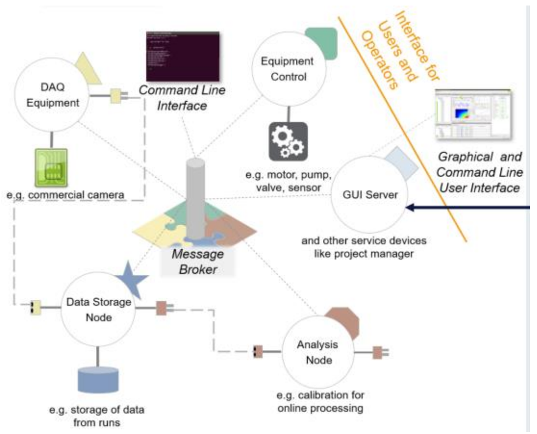
Input	**ILC Trigger**	**ILC Action**
Vacuum status	Pressure P > 10^{-3} mbar or pump failure	Warm up detector to RM, Switch off HV, Close relevant valves
Cooling blocks Temperature (in vacuum)	Temp. > 0ºC	Switch off power for components in vacuum (HV, ASICs, vacuum boards)
Electronics temperature (outside vacuum)	Temp. > 35ºC	Switch off power for all components (except MicroController)
µController signals (internal detector conditions)	FEM temp. not OK Electronics boards status not OK	Switch off power for all components (except MicroController)

Detector integration in Karabo

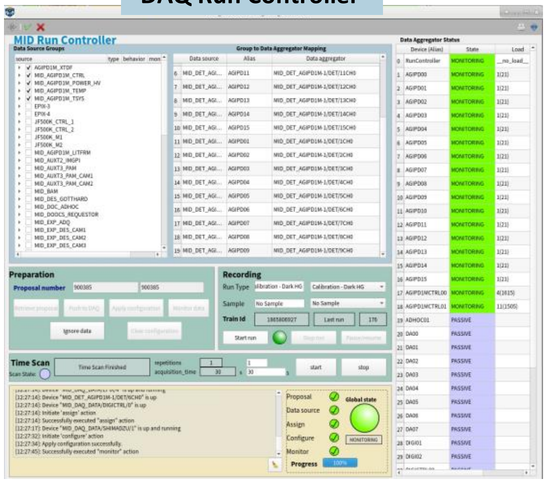
- Karabo - European XFEL’s Control System framework for control, DAQ and monitoring
  - Distributed system of devices (physical and ‘logical’) that communicate with each other through a message broker
  - Devices are aggregated in topics (one topic per instrument)
  - GUI Client facilitates interaction and control of devices

- Tight coupling of controls and DAQ
  - DAQ is generic for all data source (e.g. detector, motors, sensors, etc)
  - Data is stored centrally, ensuring easy accessibility

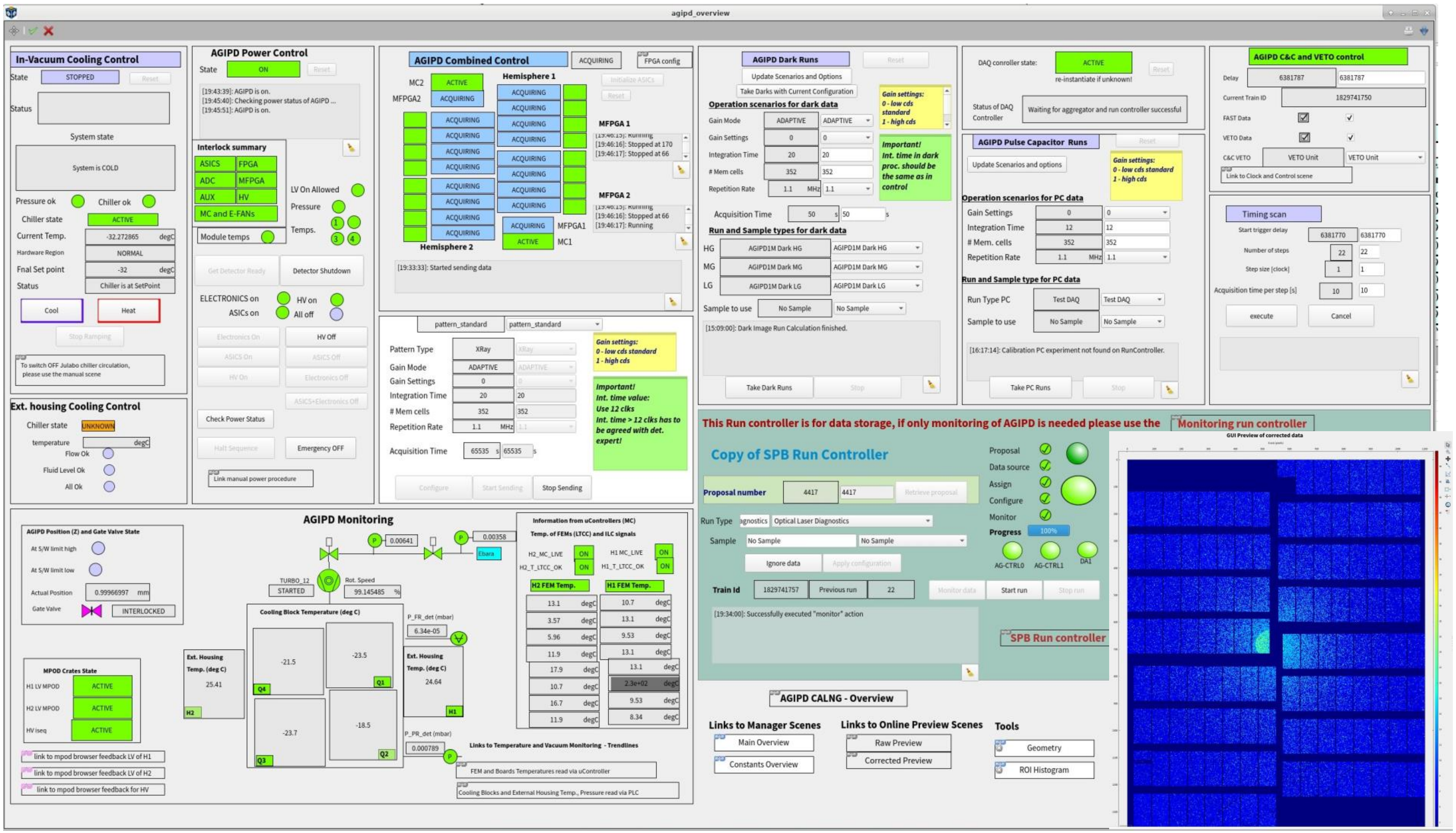
- Integration of detectors in Karabo
  - Enables control of the detector and its infrastructure
  - Supports complex procedures, including detector startup and calibration data collection
  - Provides monitoring capabilities (e.g., temperatures, power, detector status) and 2nd level detector protection
  - Data online viewers offer near real-time experiment feedback



DAQ Run Controller



Primary AGIPD1M control panel



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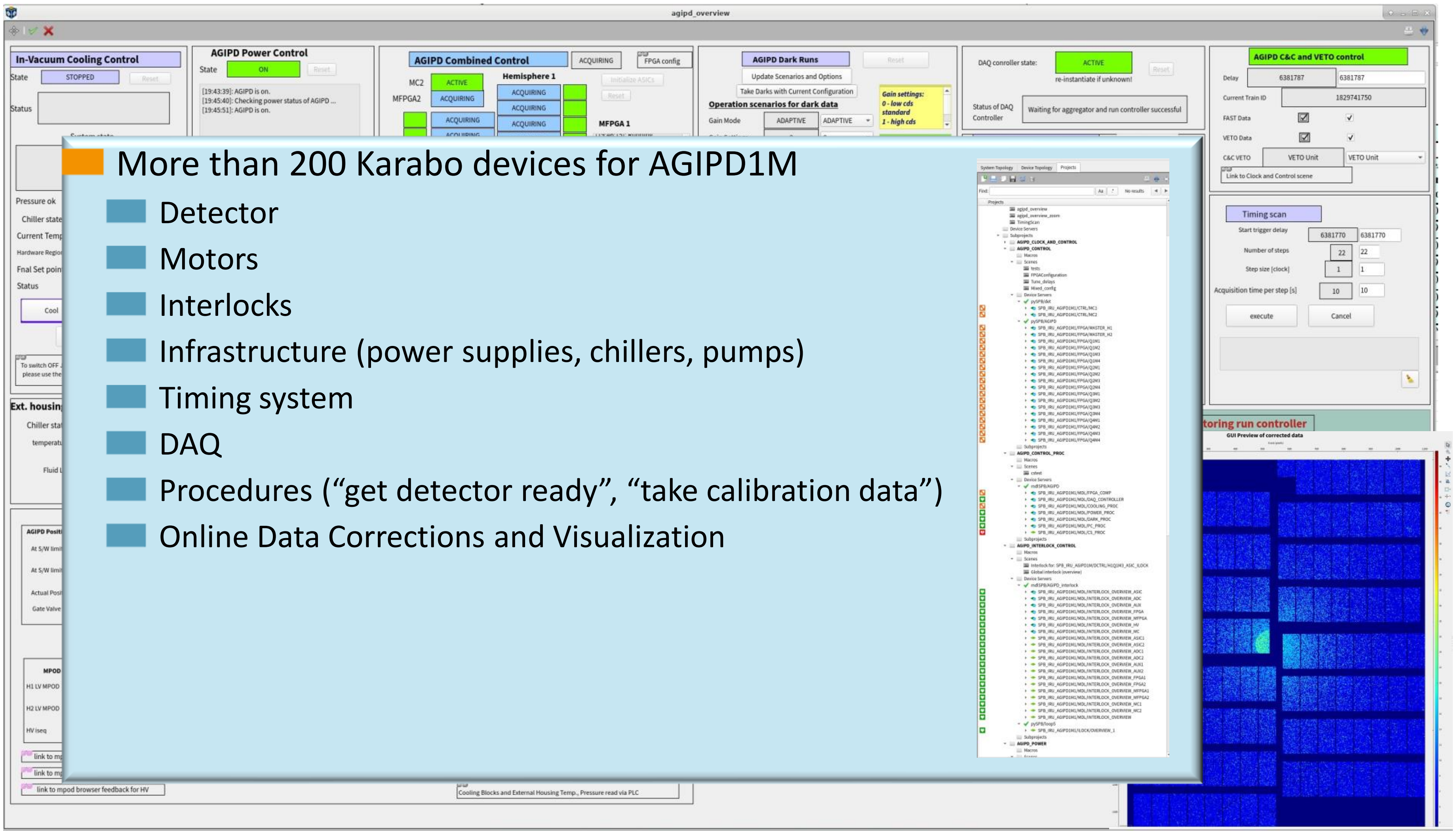
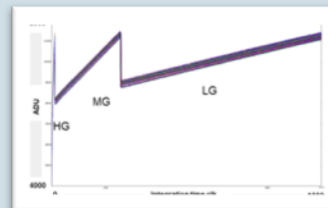
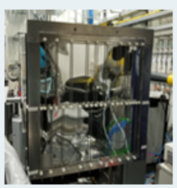
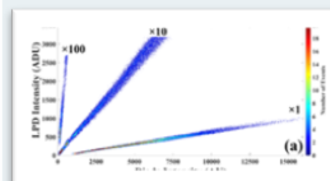
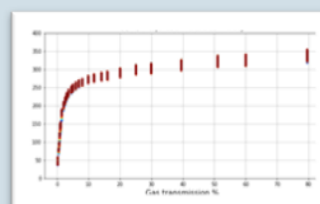


- More than 200 Karabo devices for AGIPD1M
  - Detector
  - Motors
  - Interlocks
  - Infrastructure (power supplies, chillers, pumps)
  - Timing system
  - DAQ
  - Procedures (“get detector ready”, “take calibration data”)
  - Online Data Corrections and Visualization

What have we learned from the first-generation detectors?

MHz, MPix & high dynamic range detectors – challenges for calibration

- Calibration needs to be performed whenever there are significant changes in detector hardware or performance
  - Routinely done after each maintenance period for the hard X-ray detectors
  - Calibrating the full dynamic range is a major challenge

Detector	Specs	Gain Mechanism	Gain
AGIPD 	352 memory cells (analog) 200µm x 200µm sq. pixels 1-10^4 12 keV ph 3-20 keV Modular: 16 (1MPix) or 8 (0.5MPix) modules	3 gains with automatic switching	
LPD 	(3x)512 memory cells (analog) 500µm x 500µm sq. pixels 1-10^5 12 keV ph 7- 20 keV Modular: 16 module (1MPix)	3 parallel gain stages with on front-end selection	
DSSC 	800 memory cells (digital) 204µm x 236µm hex. pixels N x 256 ph @ 4.5 Mhz N x 512 @ f≤2.2 MHz N ≤ 1 for single ph sensitivity 0.5 – 6 keV Modular: 16 modules (1MPix)	Linear response (miniSDD), non-linear signal compression in sensor (DEPFET)	

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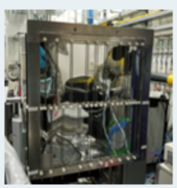
LPD 	(3x)512 memory cells (analog) 500µm x 500µm sq. pixels 1-10^5 12 keV ph 7- 20 keV Modular: 16 module (1MPix)	Three gain stages per pixel Analog memory cells Detector artefacts	
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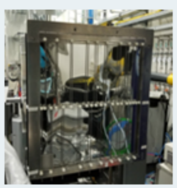
LPD 	(3x)512 memory cells (analog) 500µm x 500µm sq. pixels 1-10^5 12 keV ph 7- 20 keV Modular: 16 module (1MPix)	Three gain stages per pixel Analog memory cells Detector artefacts	
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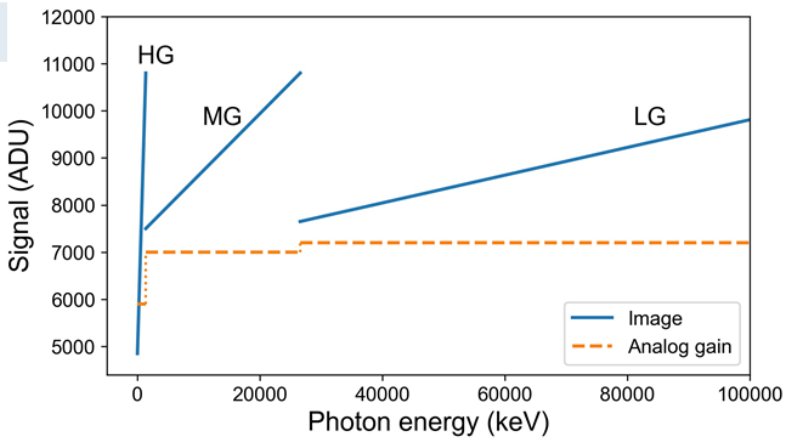
Example AGIPD (one operation scenario)
x 1 million pixels
x 352 memory cells
x 3 gain stages
x number of needed calibration constants
→ > 10^9 parameters

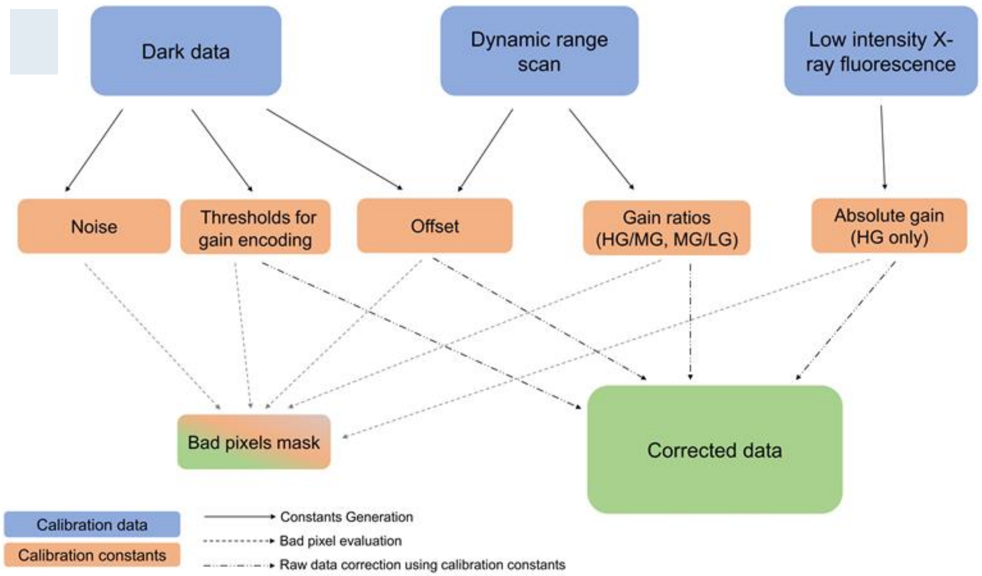
The constants have to be generated for different operation modes:
→ rep. rate
→ Number of mem. cells
→ Integration time

For the next detector generation, prioritize a design that is calibration-friendly and supports reliable in-situ calibration sources

AGIPD Calibration Process - Overview



AGIPD Calibration Strategy – Flowchart



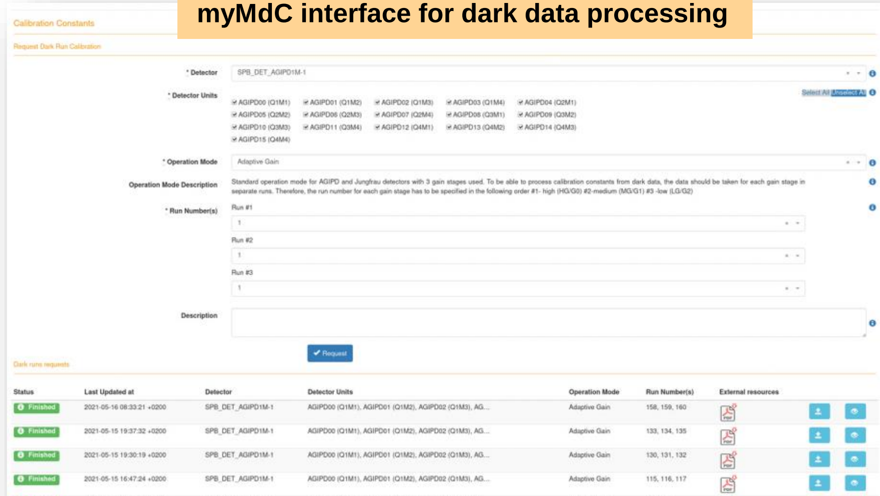
AGIPD Calibration for one operation mode

Data Type	Data Size	Measurement Time	Data Processing Time	Frequency
Dark Data	2.2 TB	5 mins	~ 10 mins	at least once per shift
Dynamic Range Scan - Pulsed Capacitor	8.2 TB	20 mins	~ 100 mins	6 months
Dynamic Range Scan - Current Source	21 TB	65 mins	~ 180 mins	6 months
Fluorescence Data	15-20 TB	25-30 mins	up to 720 mins	6-12 months

- Generated calibration constants is centrally stored and indexed in the Calibration Catalogue (CalCat)
  - CalCat allows easy retrieval based on detector identifier, creation time, and specific conditions (e.g. bias voltage, integration time, etc.)

Characterization of the detectors – Calibration constants

- Characterization with dark data → Offset, Noise and Bad Pixels
  - Generation of the constants for **all detectors** in use is a **part of the experiment routine** → performed **at least once per shift**
  - Automatic procedure for data taking and interface via myMdC web interface to start dark data processing → do not requires expert level to generate new set of calibration constants
  - Automatically generated reports available to monitor the performance of the detector:
    - ► Configuration information, status of the processing
    - ► Control plots including comparison to the previous version of the calib. constants
  - Time: below 30 mins
    - ► Data collection < 5 mins
    - ► Migration to offline < 5 min
    - ► Processing and generation of reports < 10 min

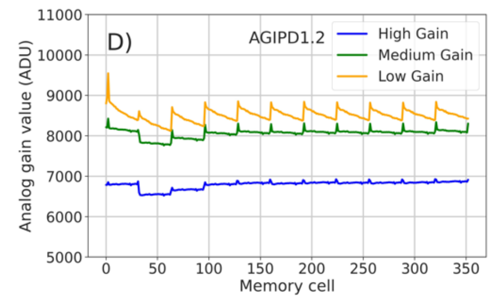


myMdC interface for dark data processing

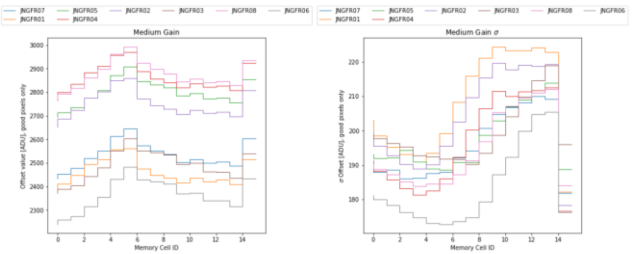
Data Quality: Analog memory cells

- Analog memory cells are used to temporarily store signals before they can be read out → this storage technique is employed in several detectors, including AGIPD, LPD, and JUNGFRAU
  - Analog memory cells impact data quality with offset and gain variations
  - Cross-talk observed between adjacent memory cells
  - Extensive calibration required to mitigate the issues

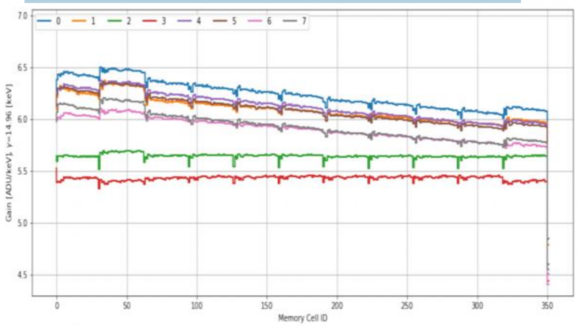
AGIPD: Analog gain value vs. mem. cell



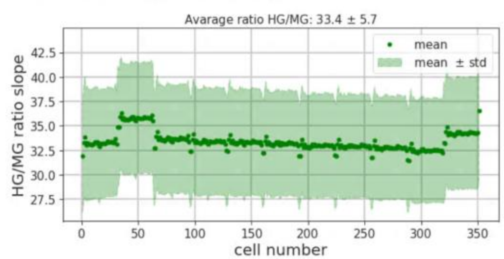
JNGF4M: Average Offset MG vs. mem. cell



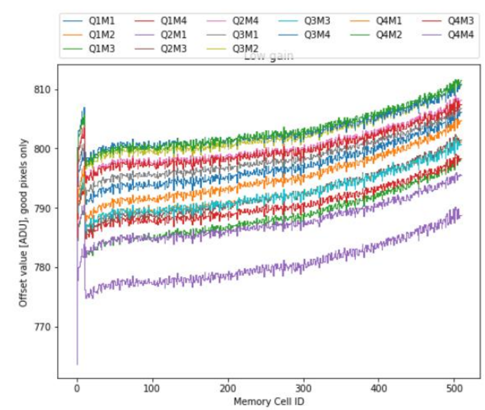
AGIPD: Average Gain (HG) vs. mem. cell



AGIPD: Average HG/MG ratio vs. mem. cell



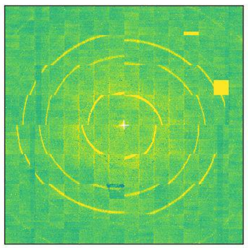
LPD1M: Average Offset LG vs. mem. cell



Move away from analog memory cells for the next generation of the detectors

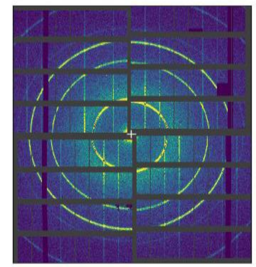
Detectors data correction

- Corrected data proposed for each detector



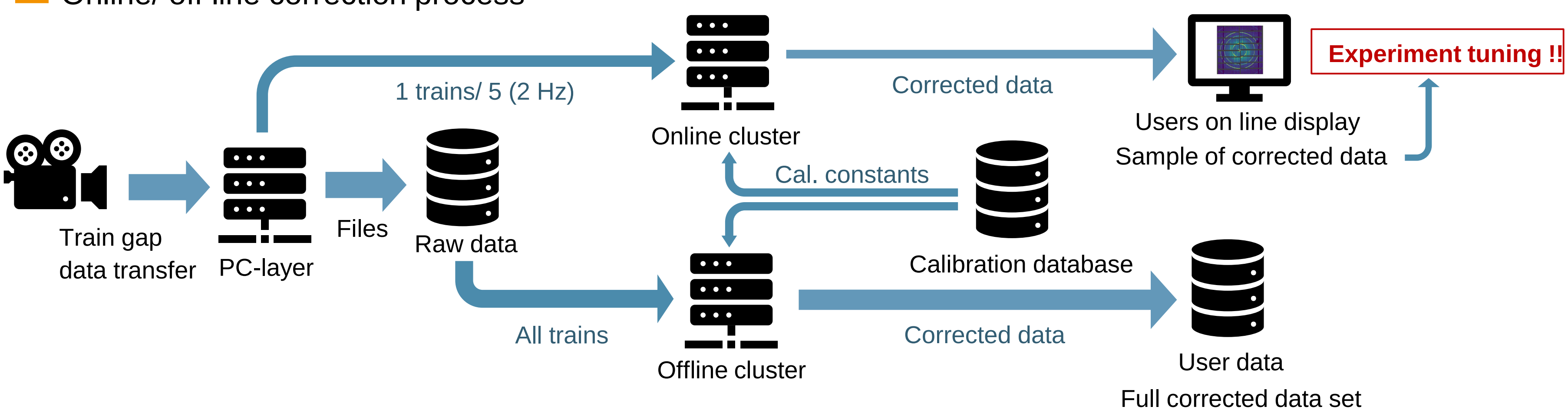
Raw data

- Offset Correction
- Gain corrections
- Bad Pixel Maps
- Detector specific corrections

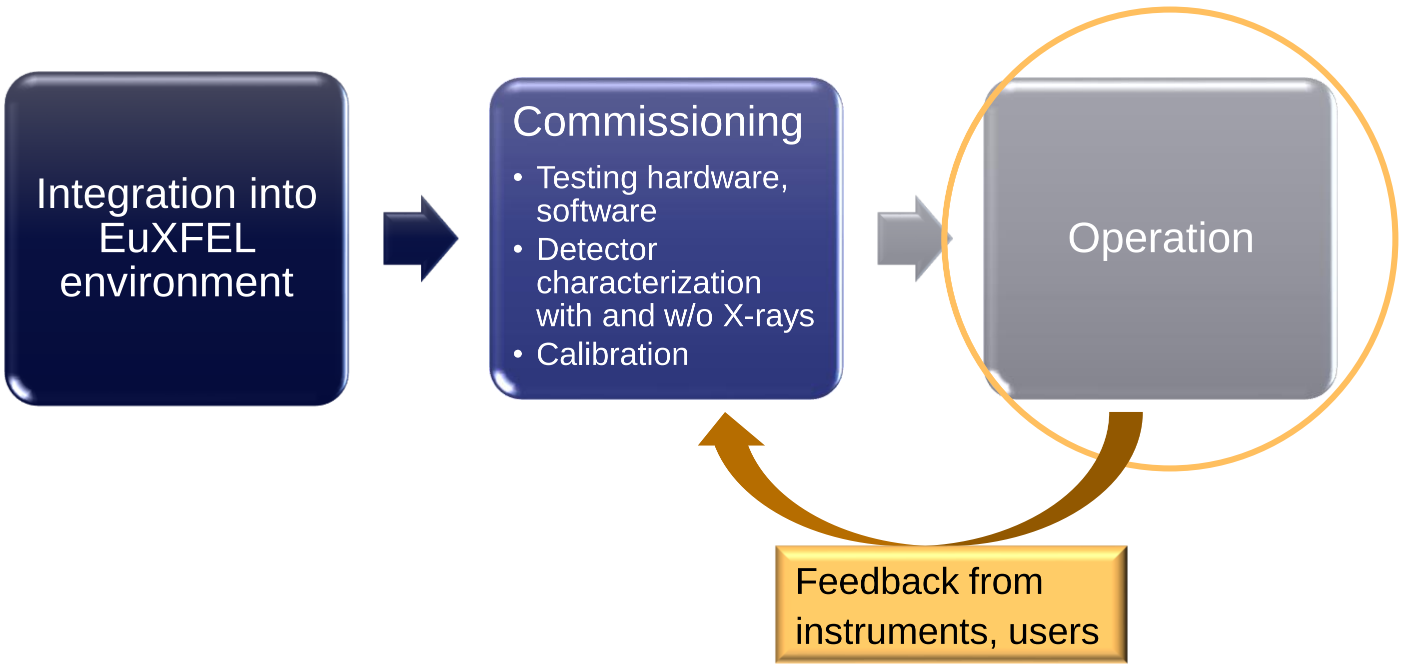


Corrected data

- Online/ off line correction process

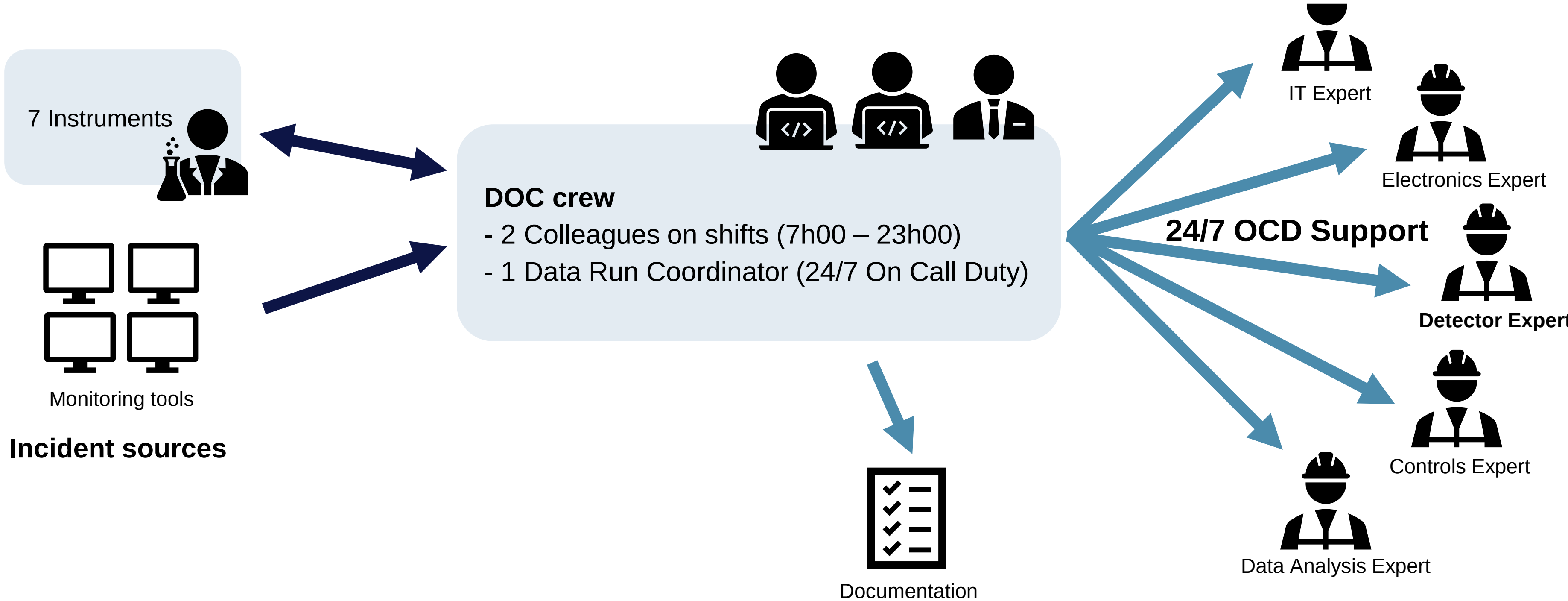


What have we learned from the first-generation detectors?



Support for User Operation

- Each week: 3 instruments run Tuesday-Sunday 24h/day
  - Data Operation Center (DOC): single contact point for support



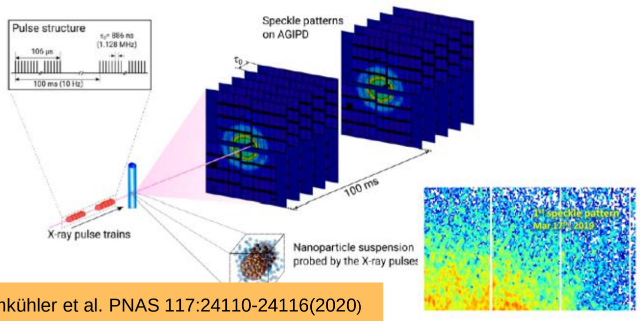
User Operation

- User experiments at EuXFEL:
  - Mostly performed with a beam at repetition rate 2.25 MHz, 1.125 MHz and lower
  - Experiments performed at 4.5MHz <<10% (~ 1-2 weeks per year)
- Detectors run stable and provide high quality data for scientific publications
- An example: Functionality of SPB/SFX Instrument with liquid jet and AGIPD1M detector

User Operation

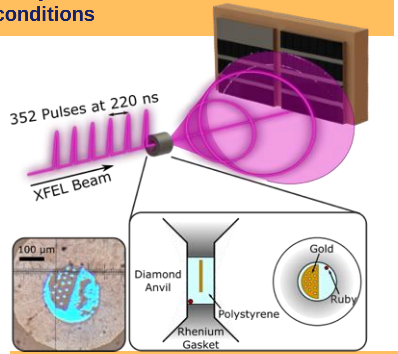
European XFEL Detectors: enabling scientific excellence

MHz XPCS to look at system dynamics

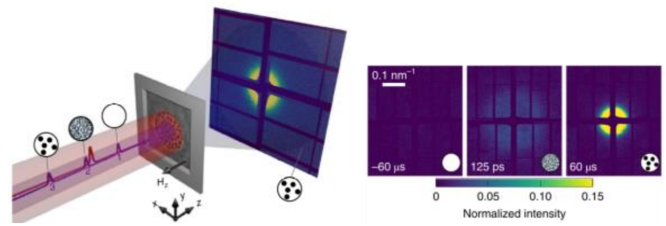


Lehmkühler et al. PNAS 117:24110-24116(2020)

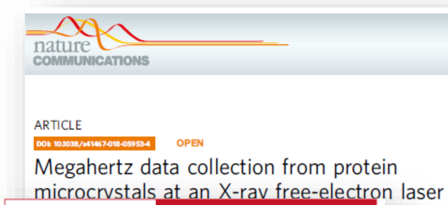
Study of materials in extreme conditions



M. Frost et al., accepted by Nature Astronomy (2023)



F. Büttner et al., Nat. Mater., 20, 30-37 (2021)


nature COMMUNICATIONS

ARTICLE
DOI: 10.1038/s41467-018-05953-4 OPEN

Megahertz data collection from protein microcrystals at an X-ray free-electron laser


nature methods ARTICLES

Time-resolved serial femtosecond crystallography at the European XFEL

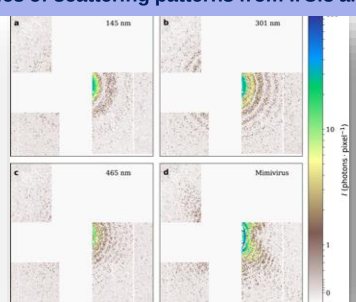
Suraj Pandey, Richard Bean, Tokushi Sato, Ishwor Poudyal, Johan Bielecki, Jorvani Cruz Villarreal, Oleksandr Yefanov, Valerio Mariani, Thomas A. White, Christopher Kupitz, Mark Hunter, Mohamed H. Abdellatif, Saša Bajt, Valerii Bondar, Austin Echelmeier, Diandra Doppler, Moritz Emons, Matthias Frank, Raimund Fromme, Yaroslav Gevorkov, Gabriele Giovanetti, Man Jiang, Daihyun Kim, Yoonhee Kim, Henry Kirkwood, Anna Klimovskaia, Juraj Knoska, Faisal H. M. Koua, Romain Letrun, Stella Lisova, Luis Maia, Victoria Mazalova, Domingo Meza, Thomas Michelat, Abbas Ourmazd, Guido Palmer, Marco Ramilli, Robin Schubert, Peter Schwander, Alessandro Silenzi, Jolanta Sztuk-Dambietz, Alexandra Tolstikova, Henry N. Chapman, Alexandra Ros, Anton Barty, Petra Fromme, Adrian P. Mancuso and Marius Schmidt


ARTICLES nature materials

Observation of fluctuation-mediated picosecond nucleation of a topological phase

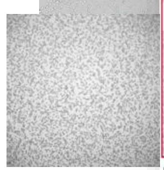
Felix Büttner, Bastian Pfau, Marie Böttcher, Michael Schneider, Giuseppe Mercurio, Christian M. Günther, Piet Hessing, Christopher Klose, Angela Wittmann, Kathinka Gerlinger, Lisa-Marie Kern, Christian Strüber, Clemens von Korff Schmising, Josefin Fuchs, Dieter Engel

Examples of scattering patterns from IrCl3 and Mimivirus.

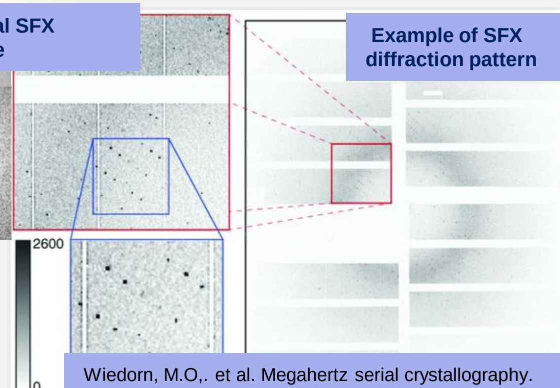


Sobolev, E. et al. Megahertz single-particle imaging at the European XFEL Commun Phys 3, 97 (2020)

Typical SFX sample



Example of SFX diffraction pattern

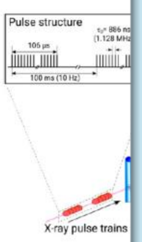


Wiedorn, M.O,. et al. Megahertz serial crystallography. Nat Commun 9, 4025 (2018)

European XFEL Detectors: enabling scientific excellence

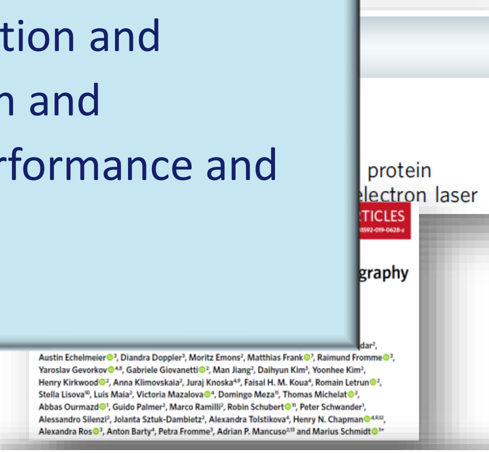
Study of materials in extreme conditions

MHz XPCS to look at system dynamics



Lehmkühl

Examples of s



- Significant role of EuXFEL detectors in facilitating high-quality scientific outcomes → the data provided by the detectors allows production of high-quality scientific results
- Integration, commissioning, operation, data collection and dedicated studies have also led to the identification and quantification of challenges related to detector performance and operation

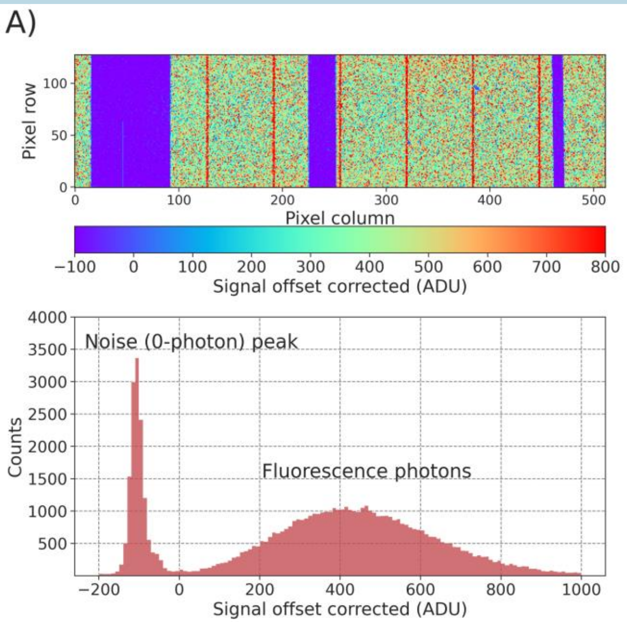
Sobolev, E. et al. Megahertz single-particle imaging at the European XFEL. Commun Phys 3, 97 (2020)

Wiedorn, M.O,. et al. Megahertz serial crystallography. Nat Commun 9, 4025 (2018)

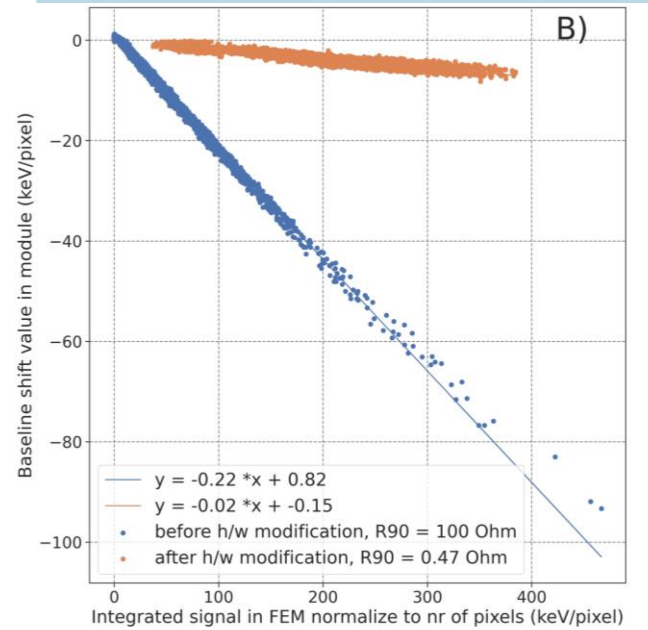
Testing under real experimental conditions

- We can test at the same time all detector properties only with the EuXFEL beam
  - Identifying features related to high intensity at high speed can be challenging
  - Dedicated beam time for detector characterization is essential to optimize detector performance
  - Characterizing the detectors requires a joint effort between EuXFEL and DET developers

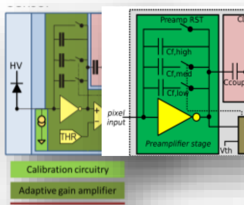
Baseline shift - effect in offset corrected image (Cu fluorescence)



AGIPD: Baseline shift as a function of X-ray intensity

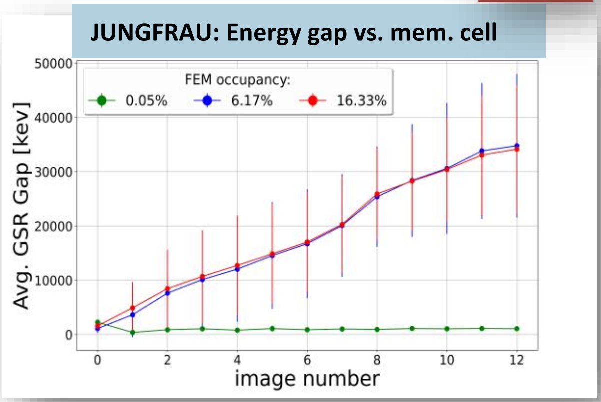


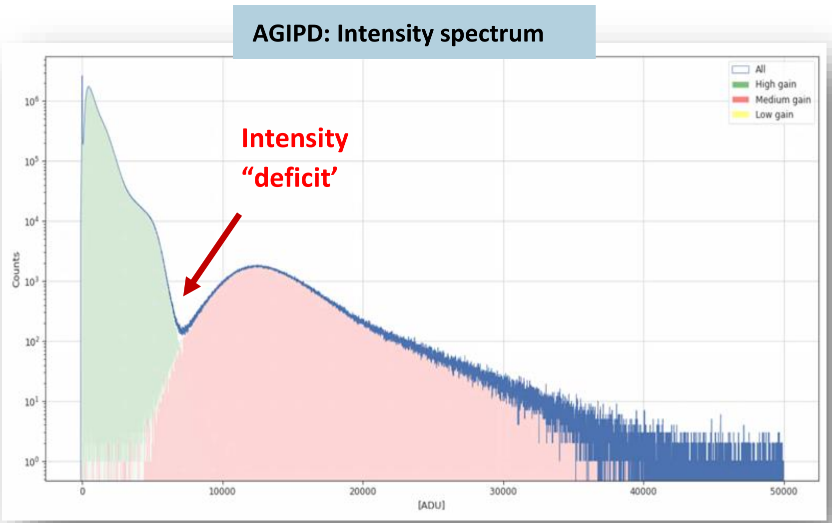
Effective detector optimization requires the XFEL beam and is a continuous processes that necessitates collaboration and feedback from DET developers, instrument scientists and users

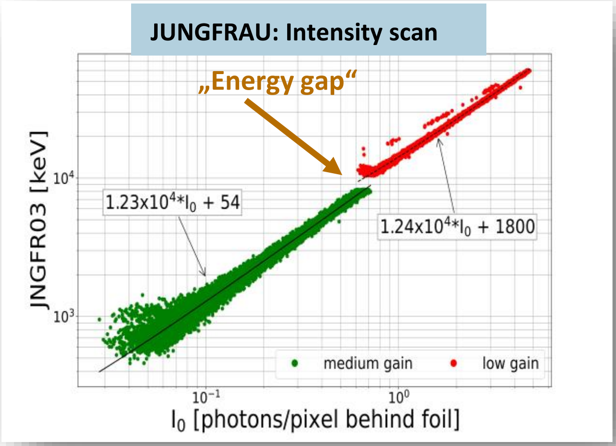


Data Quality: Adaptive gain and its transition region

- Adaptive gain, an elegant method to achieve a high dynamic range, faces challenges in the transition region
  - Issue with proper determination of “baseline’ for lower gain stages
  - Both AGIPD and JUNGFRAU affected
  - Preliminary findings indicate an issue in that region with GOTTHARD-II as well

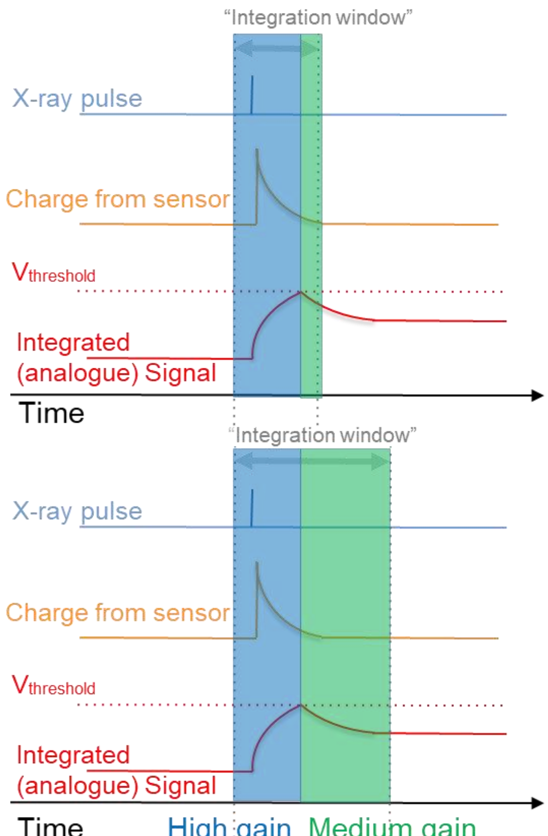






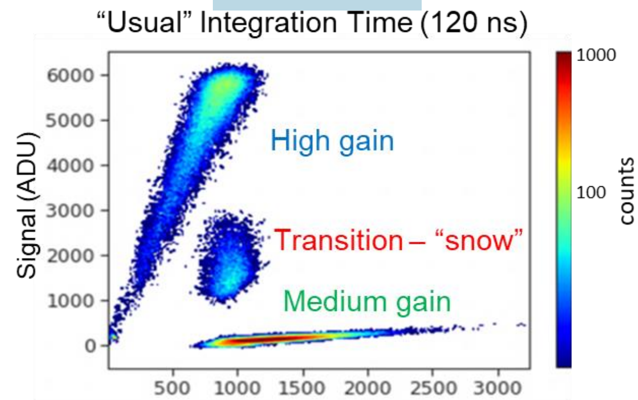
Data Quality: Adaptive gain and its transition region

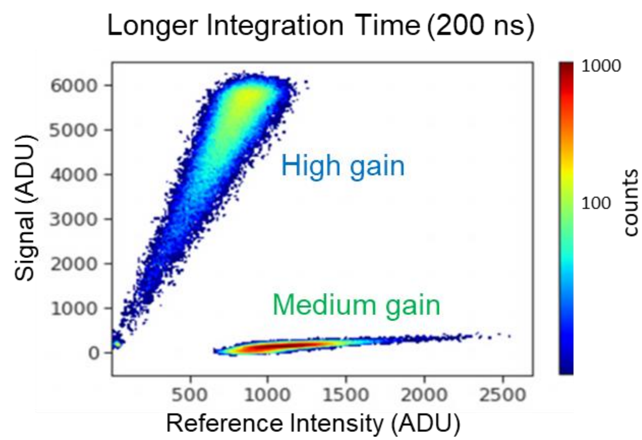
- Fast (4.5MHz) operation → ‘late gain switching’ (“snowy pixels”)



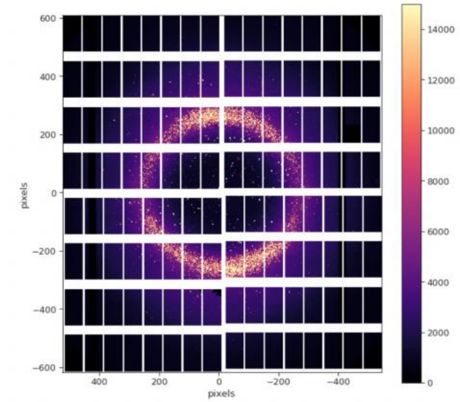
Courtesy of Ulrich Trunk (DESY FS-DS)

Intensity scan

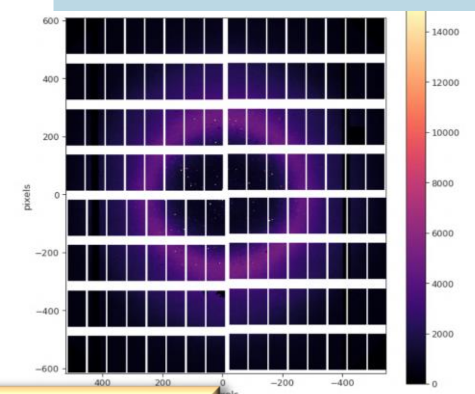




Lysozyme data – 120 ns int. time



Lysozyme data – 200 ns int. time



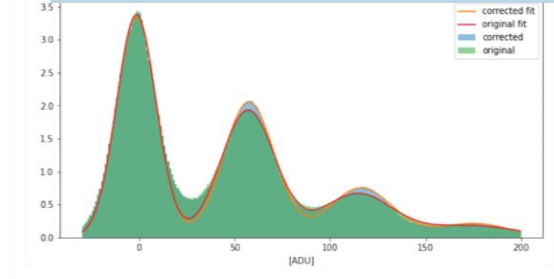
For the next generation of detectors, addressing the observed issue with the adaptive gain mechanism is crucial, and alternatives should be explored

Data Quality: Addressing issues with dedicated operation modes

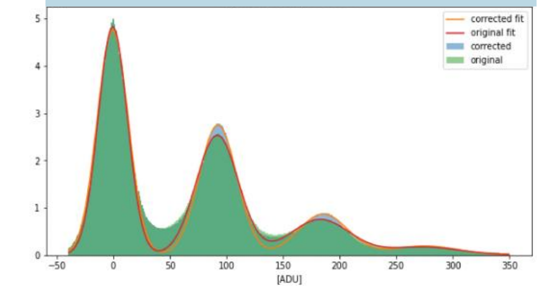
- Enable "experiment-specific" operation modes (detector configurations)
  - "**Very High Gain mode**" with improved noise performance
    - ► low intensity data (i.e. no dynamic range required)
  - **Fixed (medium) Gain mode**
    - ► solution for experiments which does not required single ph. sensitivity
  - **Operation with longer int. time** (for acq < 4.5MHz) to avoid snowy pixels

- Implement **image-topology dependent corrections**
    - ► Low intensity data: Common mode corrections (across ASIC and memory cell rows) for very low intensity data

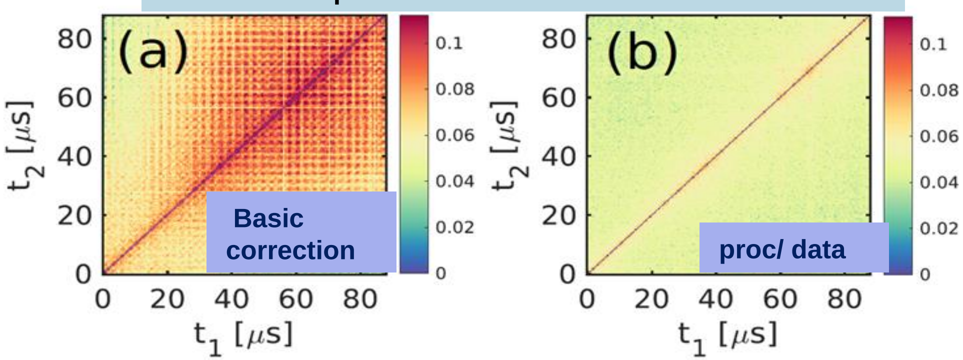
Cu fluorescence in 'default' High Gain



Cu fluorescence in Very High Gain

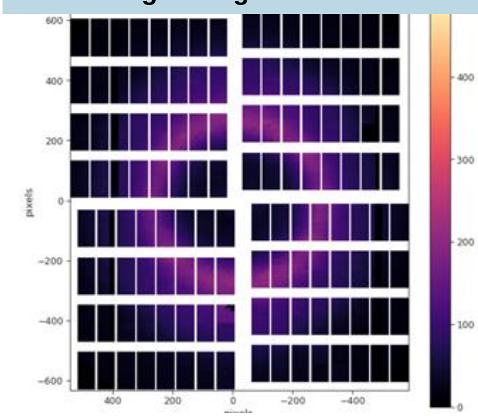


XPCS – Example of Double correlation function – MID



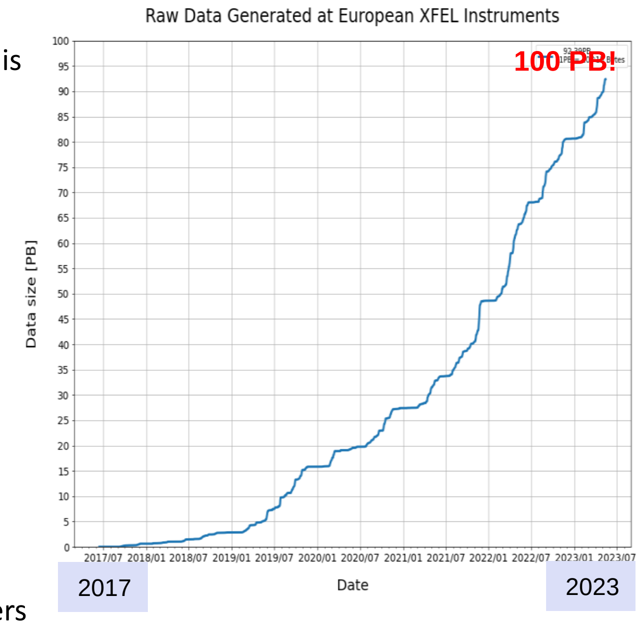
Francesco Dallari et. al., Applied Sciences, vol. 11, no. 17, p. 8037, 2021.

SFX – single image in fixed MG mode



Data volume challenge

- The amount of collected data is huge (> 100 PB of raw data)
- The initial strategy of indefinitely storing all data beyond the embargo period is no longer sustainable
- Data reduction addressed starting from policy down to specific online and offline data reduction implementations:
  - **Data management plan (DMP)** to include data reduction early and throughout the proposal process
  - **Operation-specific**, e.g.: automatic detection of non-illuminated frames
  - **Technique-specific,** e.g. event reconstruction, hit finding (*SFX*, *SPI*), $g^{(2)}$ correlation functions (*XPCS*, *XCCA*)
- First attempts with real-time reduction before saving to disk
- Currently preparing to apply techniques to past data in collaboration with users

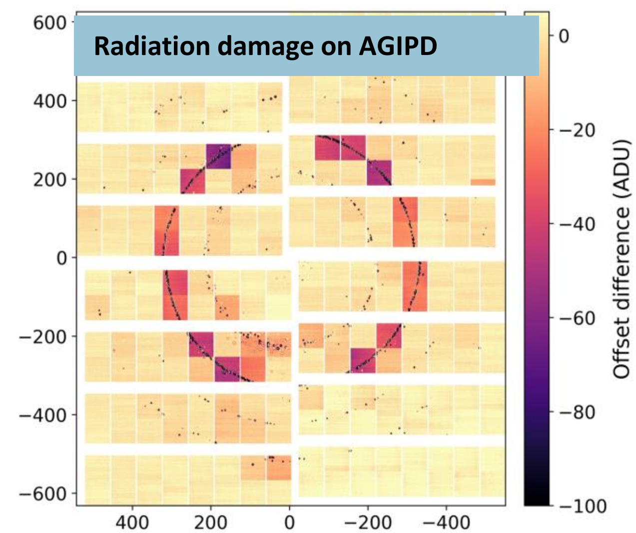


In the next detector generation, consider implementing data reduction as near to the detector head as possible

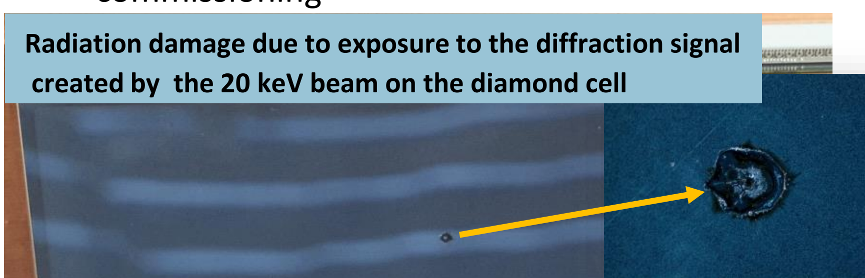
The significance of ease of operation and interlocks

- Incidents happen → Interlock system has saved detectors from severe damage on several occasions:
  - Chillers, cooling water failures
  - Vacuum quality during liquid jet injection, pump failure
  - Power cuts
  - Human error
- Radiation damage and hardware failure happens
  - An online monitoring and alarm system is a necessity
  - Easy access and the ability to quickly exchange modules
  - Fast access to electronics is crucial
  - Protection against e.g. ice formation would help, under commissioning

Deformed DSSC cooling pipes



Radiation damage on AGIPD

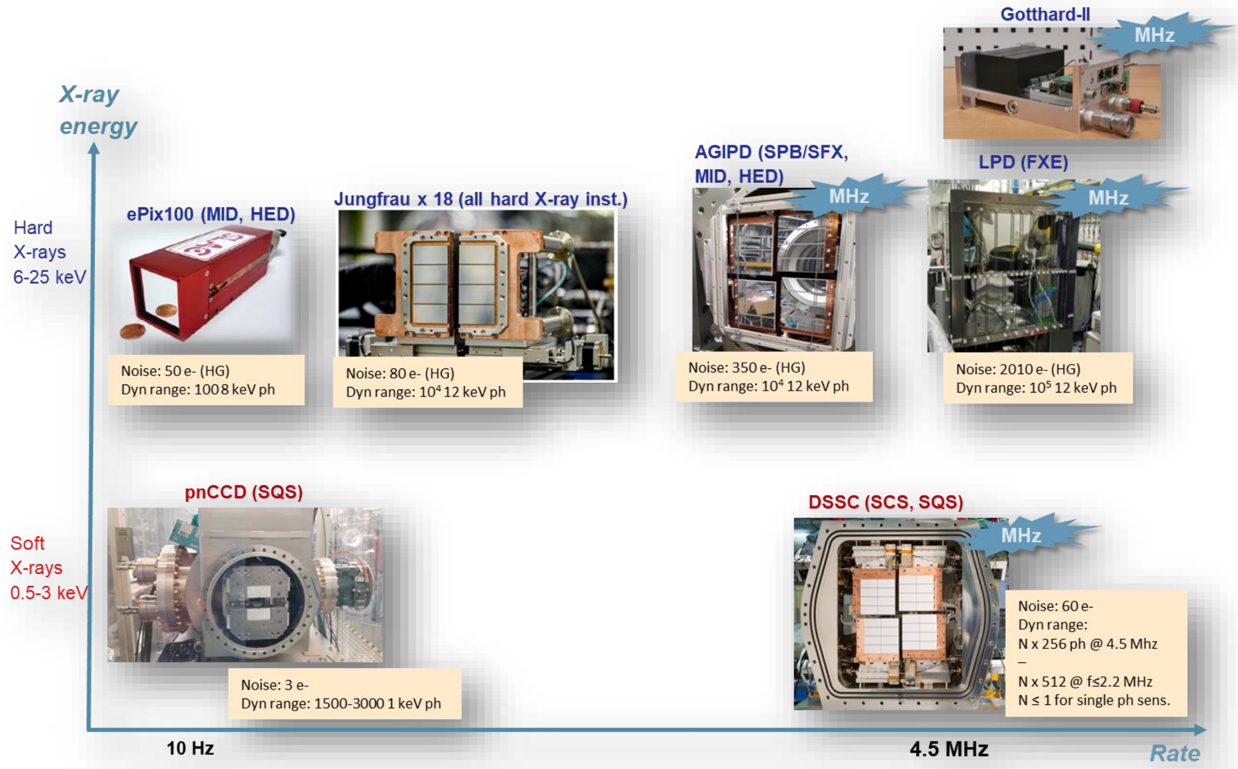


Radiation damage due to exposure to the diffraction signal created by the 20 keV beam on the diamond cell

Courtesy of DESY FS-DS

A self-protecting, robust system with easy access to electronics components in the detector vessel and the availability of spare parts is essential

The impact of having a detector ‘zoo’



- Different technologies require different experts
- Standardization in controls, interlocks, and calibration is challenging, if not impossible
- We heavily rely on developers for tasks like firmware updates.

To address these challenges for the next generation of detectors, standardization efforts is required

Key Takeaways

- EuXFEL producing excellent scientific results based on data collected by the present detector generation
- Integration, commissioning, operation and dedicated studies have also led to the identification and quantification of challenges related to detectors performance and operation
- Integrating the first detector generation into EuXFEL was a complex task
  - The required infrastructure poses challenges for integration and operation
  - More compact, efficient power and cooling design with standardized interfaces are needed

- EuXFEL provided around 8000 hours of user beamtime this year:
  - Ease operation and reliability are essential
  - Accessible detector components for maintenance and replacement
  - Hardware interlocks are crucial (consider self-protecting detectors)
- Data quality is the primary measure of detector performance
  - Testing detectors under real XFEL conditions already on prototype level is essential
  - Methods for achieving high dynamic range need evaluation
  - A design that is calibration-friendly and supports reliable in-situ calibration sources is necessary
  - Optimization is a continues process → Collaborative efforts involving experts with diverse backgrounds and investment in “In-House Expertise” are vital for optimizing detector performance and addressing observed issues
- Managing the enormous volume of generated data requires early design-level reduction strategies

Lessons learned today shape the detectors of tomorrow

European XFEL

Thank you

Backup slides

XFEL Science: 7 Instruments

SASE 1 (Hard X-Rays)

SPB/SFX (start Sep 2017)
Single Particles, Clusters and Biomolecules /
Serial Femtosecond Crystallography

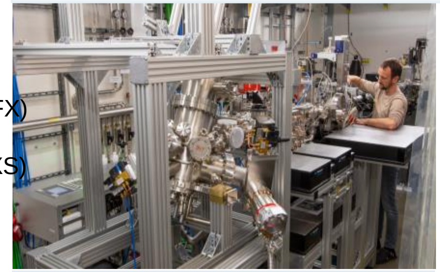
FXE (start Sep 2017)
Femtosecond X-Ray Experiment

SASE 2 (Hard X-Rays)

MID (start Apr 2019)
Materials Imaging & Dynamics

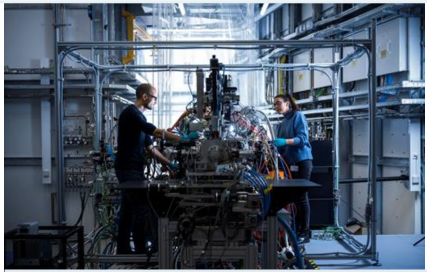
HED (start May 2019)
High Energy Density Matter

SASE 3 (Soft X-Rays)



SXP (start summer 2023)
Soft Xray Port

SCS (start Nov 2018)
Soft X-Ray Coherent Scattering / Spectroscopy



SQS (start Nov 2018)
Small Quantum Systems

Main Technics:

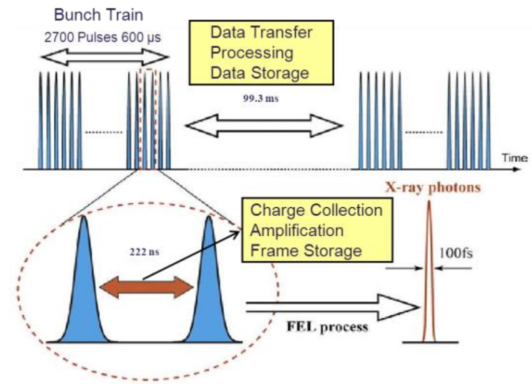
- Single Particle Imaging (SPI)
- X-ray scattering (WAXS/ SAXS)
- Serial Femtosecond Crystallography (SFX)
- X-ray Spectroscopies (XES/ XAS)
- Resonant Inelastic X-ray Scattering (RIXS)
- ….

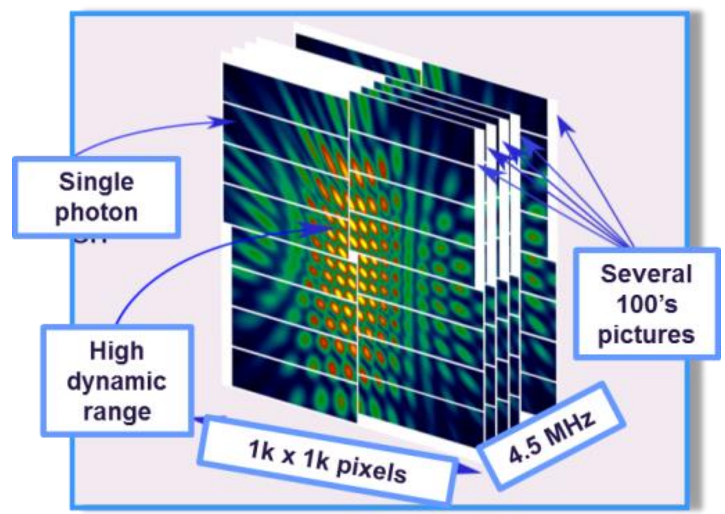
→ **More constraints on detectors**

First Generation Detectors for EuXFEL

Detector requirements from < 2010

- Energy range 0.2 – ~25 keV
- Single photon sensitivity
  - High quantum efficiency (>0.8)
  - Low noise
- High dynamic range 10^4 ph/pixel/pulse
- Vacuum compatible (< 10-6 bar)
- Flexible central hole
- Sufficiently rad. hard for operation at XFEL
- EuXFEL timing compliant

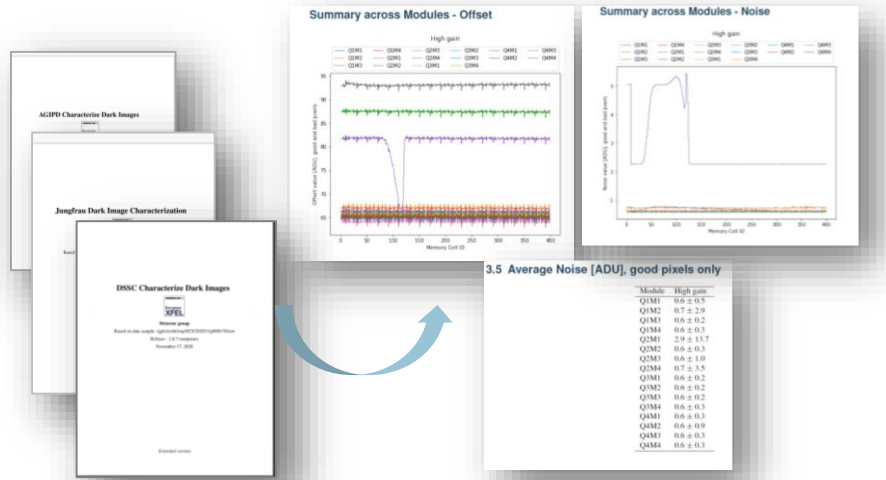


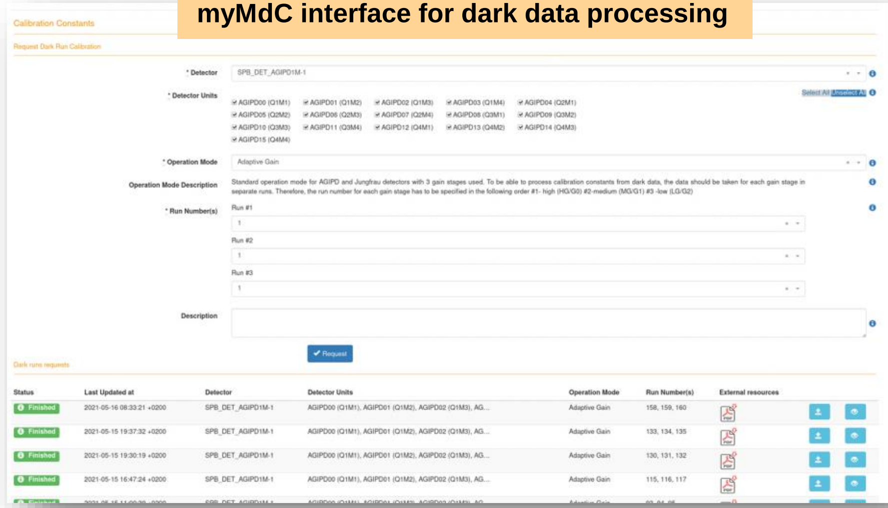


Characterization of the detectors – Calibration constants

Overview – current status

- Characterization with dark data → Offset, Noise and Bad Pixels
  - Generation of the constants for **all detectors** in use is a **part of the experiment routine** → performed **at least twice during the shift**
  - Automatic procedure for data taking and interface via myMdC to start dark data processing → do not requires expert level to create constants
  - Calibration constants are produced and injected to calibration data base
  - Automatically generated reports available to monitor the performance of the detector:
    - ▶ Configuration information, status of the processing
    - ▶ Control plots including comparison to the previous version of the calib. constants
  - Time: below 30 mins
    - ▶ Data collection < 5 mins
    - ▶ Migration to offline < 5 min
    - ▶ Processing and generation of reports < 15 min





myMdC interface for dark data processing

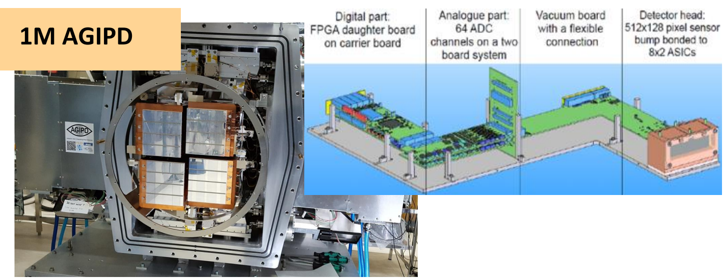
Background information - AGIPD detectors @ EuXFEL

- Detectors developed for EuXFEL by AGIPD Consortium (DESY, PSI, Uni Bonn, Uni Hamburg)
- Design for fast imaging and high dynamic range
- Hybrid detector – module:
  - 128 x 512 pixels, Pixel size: **200x200 um, 500 um** thick Si, 2x8 chips
  - Module size: **~26 x 105 mm^2**

Noise (HG)	**350 e r.m.s.**
Dynamic range	**Upto 10^4 10 keV ph/pix/pulse**
# images/train	**Upto 352**

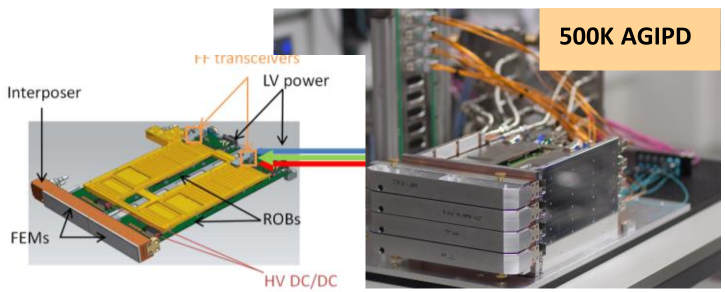
- Available detectors:

Instrument	#Pixels/ modules	In-vacuum operation	AGIPD (ASIC) version	Electronics	First User experiment
SPB/SFX	1MPix / 16	yes	AGIPD1.1	1st generation	2017
MID	1MPix / 16	yes	AGIPD1.1	1st generation	2019
HED/HiBEF	0.5MPix / 8	no	AGIPD1.2/1.1	2nd generation	2021



1M AGIPD

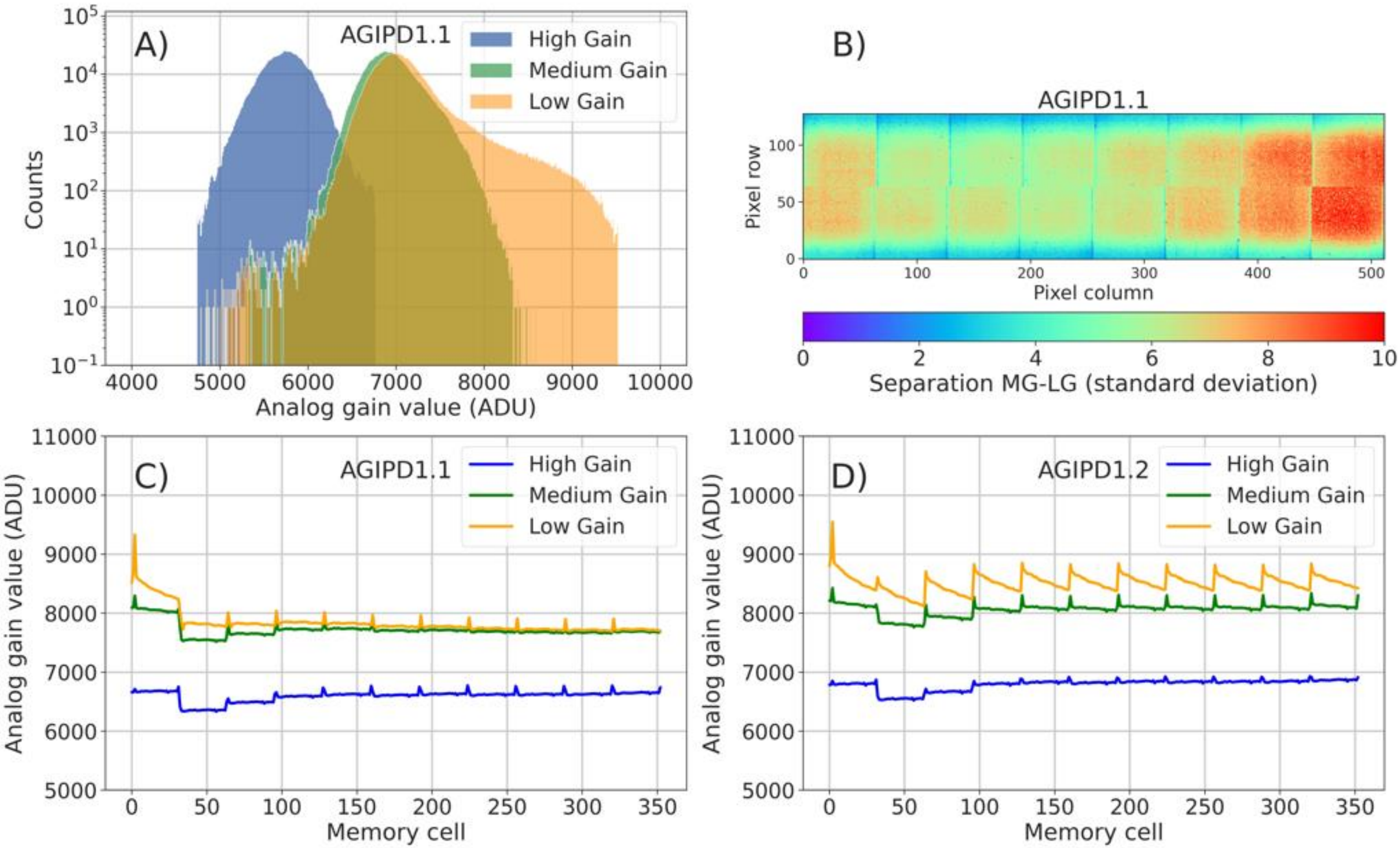
- 1st generation of electronics and AGIPD1.1 ASIC
- 16 modules are mounted on **four independently movable quadrants**
- **Vacuum operation (P< 10^{-5} mbar)**



500K AGIPD system

- 8 modules
- **New version of electronics (compact system)**
- **Operation in ambient**

New generation AGIPD detectors to come next year :
1M AGIPD @ HED/HiBEF
4M AGIPD @ SPB/SFX


A)
AGIPD1.1
High Gain
Medium Gain
Low Gain
Counts
Analog gain value (ADU)
B)
AGIPD1.1
Pixel row
Pixel column
Separation MG-LG (standard deviation)
C)
AGIPD1.1
High Gain
Medium Gain
Low Gain
Analog gain value (ADU)
Memory cell
D)
AGIPD1.2
High Gain
Medium Gain
Low Gain
Analog gain value (ADU)
Memory cell

the bunch

Radiation hardness sensor design

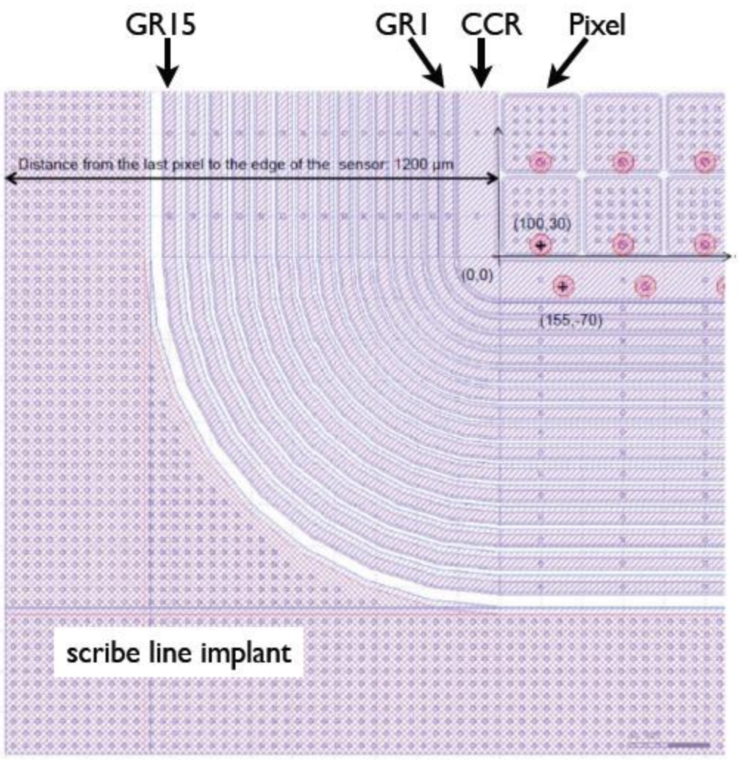
- **No bulk damage expected for E < 300 keV**

  BUT
- **Surface and interface damage:**
  - Higher leakage current
  - Higher depletion voltage
  - Lower breakdown voltage
  - Charge losses at interface
  - Increased inter-pixel capacitance

➔ **Special high voltage design with 15 guard rings:**

- radiation tolerant up to 1GGy ☺

- introduced additional non-sensitive area between detector modules ☹



Distance from the last pixel to the edge of the sensor 1200 µm

JINST (2013) 8 C12015,
DOI: 10.1088/1748-0221/8/01/C01015,
e-Print: arXiv:1210.0430 [physics.ins-det]

Calibration constants – Gain

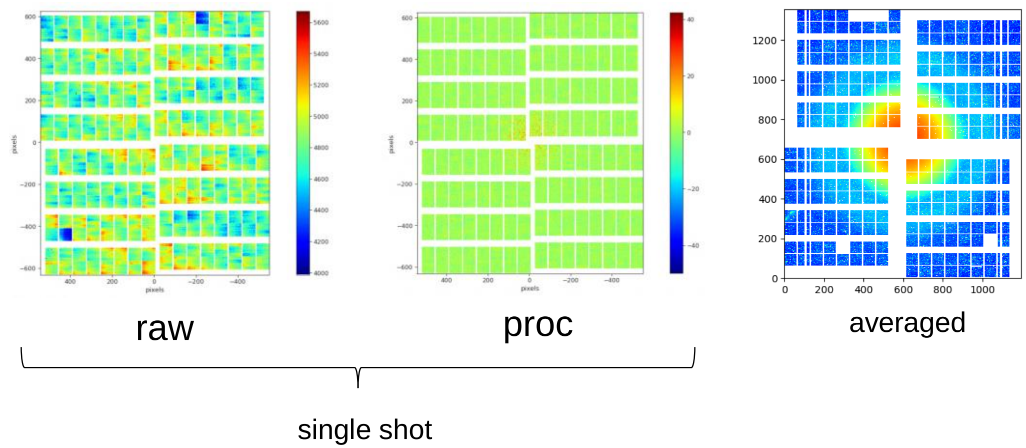
- Characterization with X-rays and internal calibration sources → det. response (gain, linearity)
  - Characterization is done by detector experts
  - Frequency: every 4-6 months, dedicated calibration beamtime or calibration campaign
  - Source requirements and techniques depends on the detector type: X-rays or combination of X-ray data and dedicated charge injection calibration sources
  - Charge injection calibration sources validated and cross-calibrated with X-rays are very useful (if not mandatory)

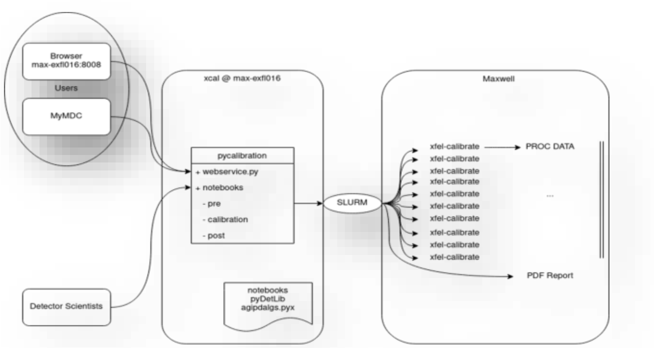
- All detectors - final validation of calibration should always be done under real conditions with the real scientific data!

Source	AGIPD	LPD	DSSC	pnCCD	Jungfrau	Epix100
XFEL beamlines (where the detectors belongs)	- Cu flat-fields – single photon intensity Other: - Cu flat-fields Intensity scan - Water ring - Powder diffraction - SFX data	- Cu flat-fields intensity scan - Single ph. with E> 16keV (scattering) Other: - PP water scattering	(DSSC DEPFET will need FEL beam)	Al flat-fields	Cu flat-fields – intensity scan including single photons	Cu, Fe flat-fields – single ph. intensity
Laboratory X-ray sources			PulXar with different targets and filter (Cu and higher energies)	PulXar with different targets and filters at higher energies		
Charge injection calibration circuits	Yes, dynamic range scan for HG and MG with Pulse Capacitor (MG and LG with Current Source)		Yes, DAC injection sweep		Yes, dynamic range scan G0 and G1 (backplane pulsing), G1 and G2 – current source	

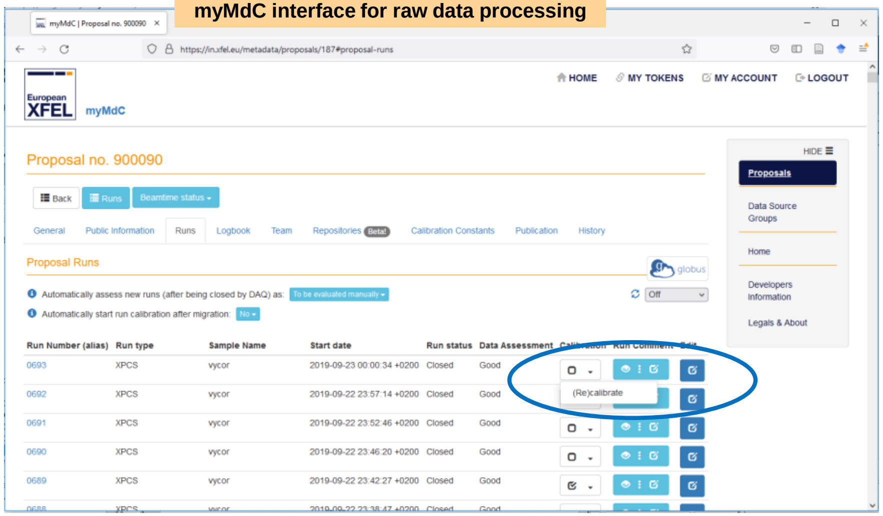
Offline Calibration Pipeline

- Many 2D detectors require corrections to process "raw" detector data into analysis-ready "proc"
- Raw data processing (calibration request through myMdC (metadata catalogue, in.xfel.eu/metadata)
- XFEL offline calibration (xfel-calibrate) runs on DESY HPC cluster (Maxwell), jobs are distributed across nodes using SLURM





myMdC interface for raw data processing



European XFEL Storage Overview (

Schenefeld

Online GPFS

Cache

- Extremly high performance
- Data available immediately
- Optimised for concurrency
- High redundancy
- Dedicated storage for each SASE
- Very high cost per PB
- Capacity for a few days

DESY Data Center

Offline GPFS

Performance

- High performance
- Large scale data analysis
- High redundancy
- High cost per PB
- Shared within XFEL
- Large capacity

dCache

Capacity

- Lower performance
- Lower cost
- Scalability
- Shared within XFEL
- High capacity

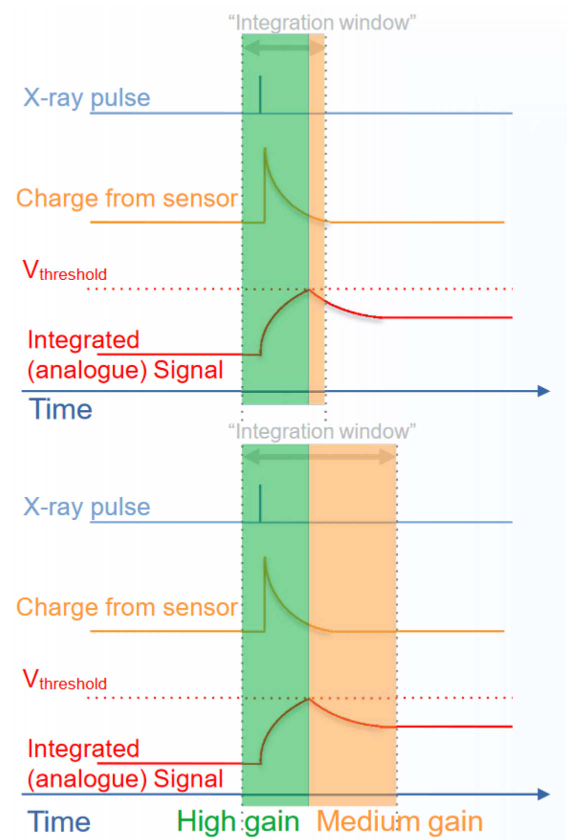
Tape Archive

Safety

- Very slow
- Even lower cost
- Very high capacity
- Safety (second copy)
- Shared within DESY campus
- Long term

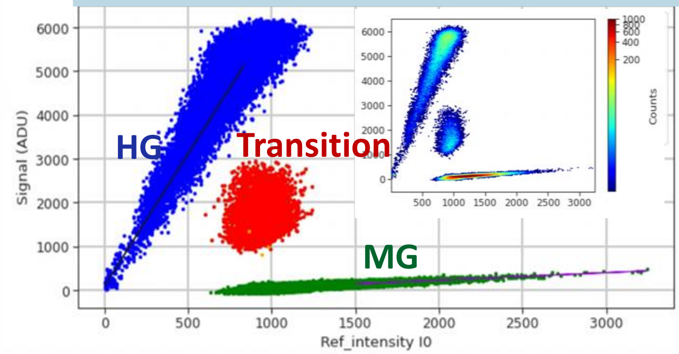
Data Quality: Adaptive gain and its transition region

- Fast (4.5MHz) operation → ‘late gain switching’ (“snowy pixels”)

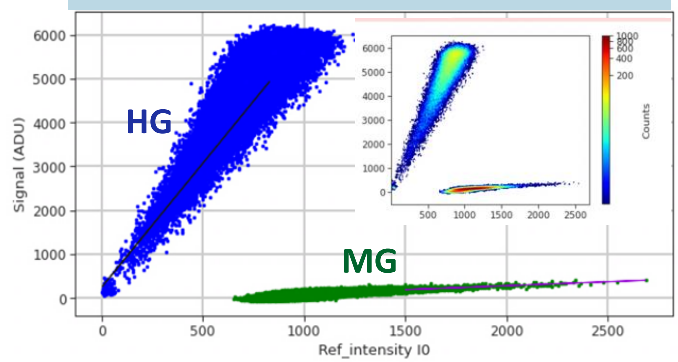


Courtesy of Ulrich Trunk (DESY FS-DS)

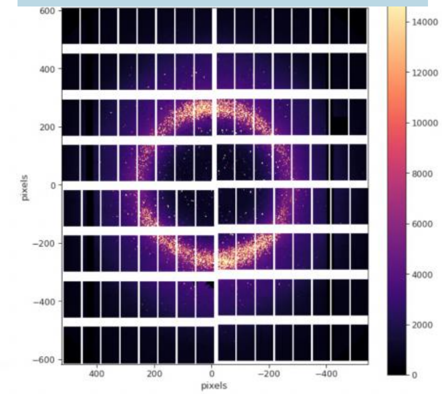
Intensity scan (single pixel, all mem. cells) – 120 ns



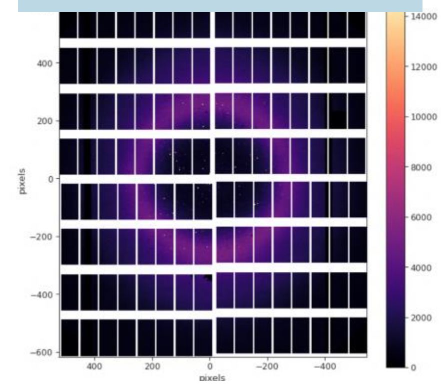
Intensity scan (single pixel, all mem. cells) – 200 ns



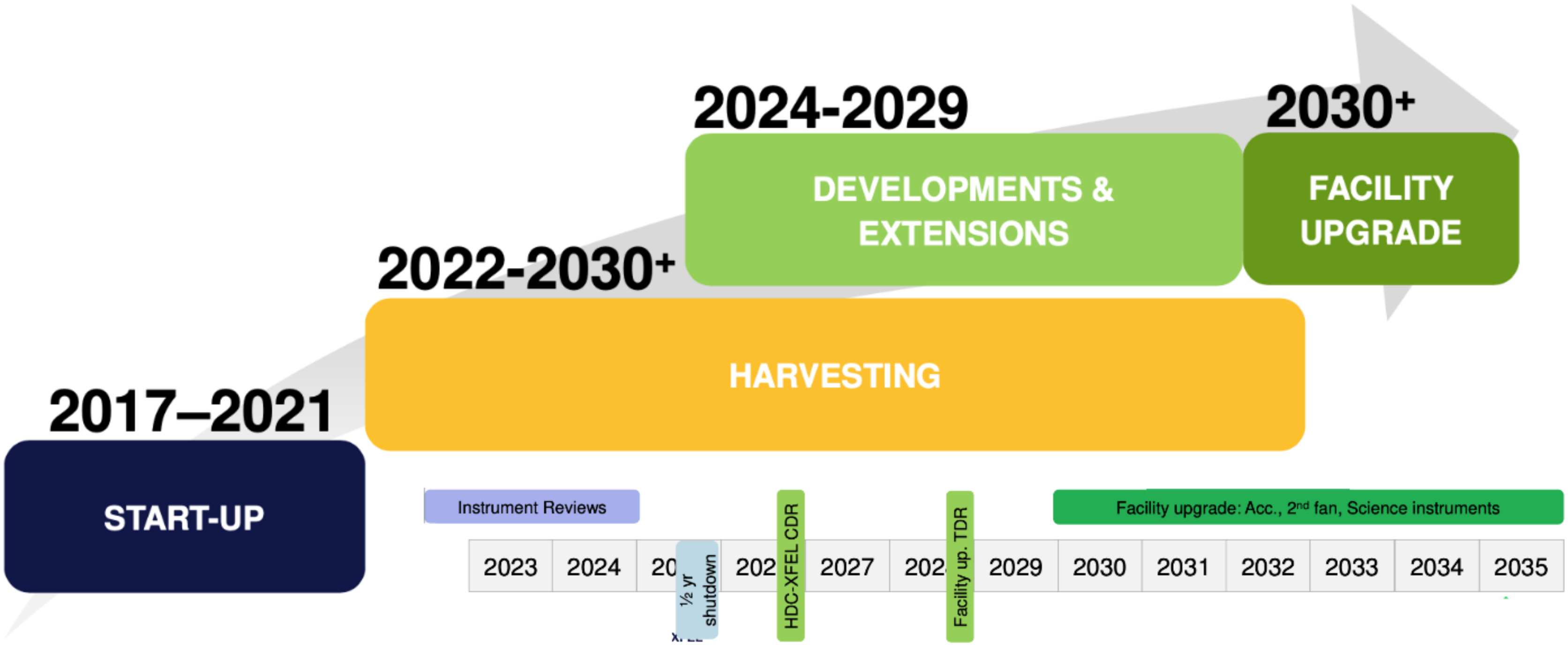
Lysozyme data – 120 ns int. time



Lysozyme data – 200 ns int. time



Where are we now?



European XFEL plan for the next decade+