1 Mpix Adaptive Gain Integrating Pixel Detector (AGIPD) for the European XFEL – Installation, Commissioning and First User Operation at the SPB/SFX Instrument

Jola Sztuk-Dambietz

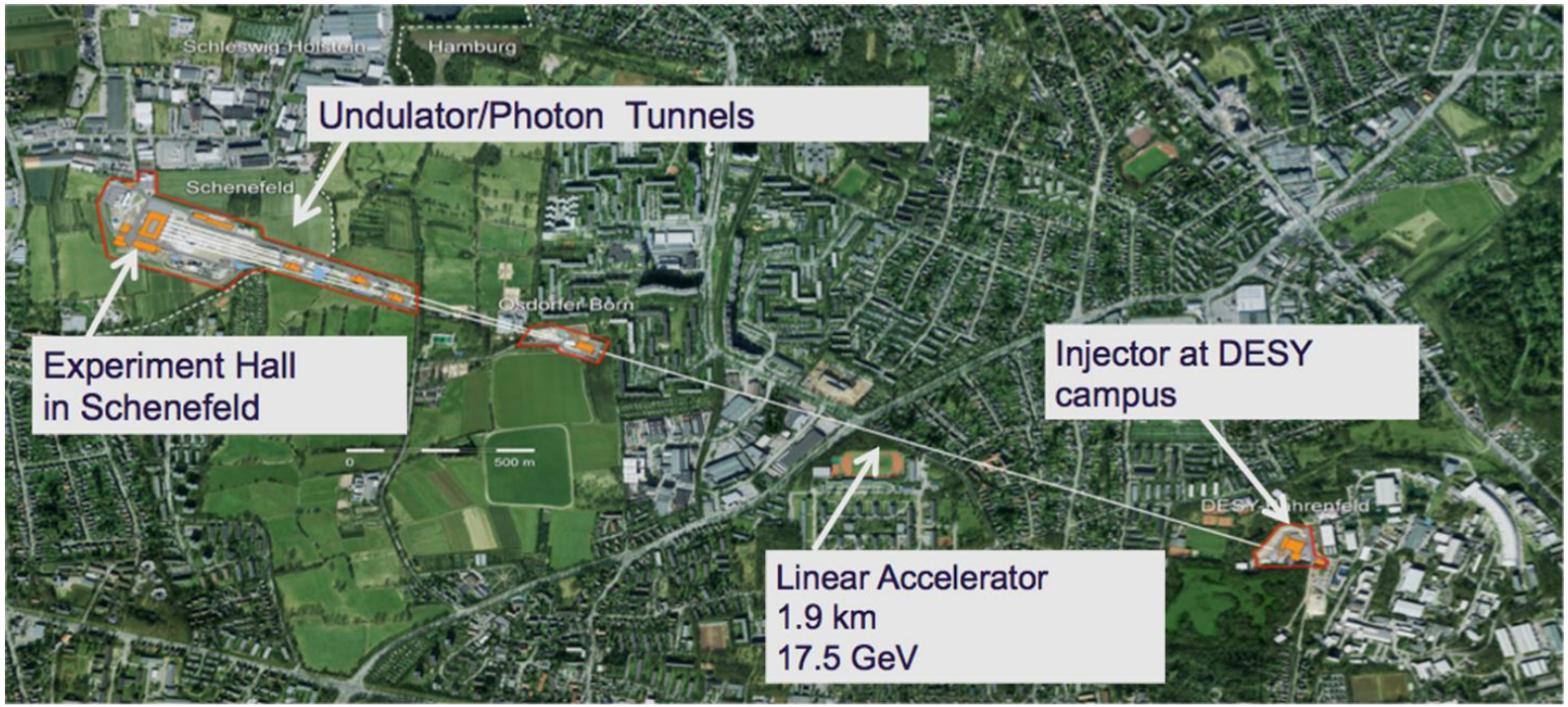
Outline

- **Introduction**
  - The European XFEL and SPB/SFX instrument
  - AGIPD Detector
- **1 Mpix AGIPD at XFEL**
  - Integration tests in Detector Laboratory at XFEL
  - Installation at the SPB/SFX instrument
  - First XFEL X-rays on the detector
  - First User Beam experience
- **Summary & Conclusion**

The European XFEL facility

The European XFEL Limited Liability Company

- Research institutes of different countries joined as shareholders → responsible for construction and operation of XFEL facility
- Staff XFEL about 370, Staff @ DESY about 250
- **Start of operation – July 2017**

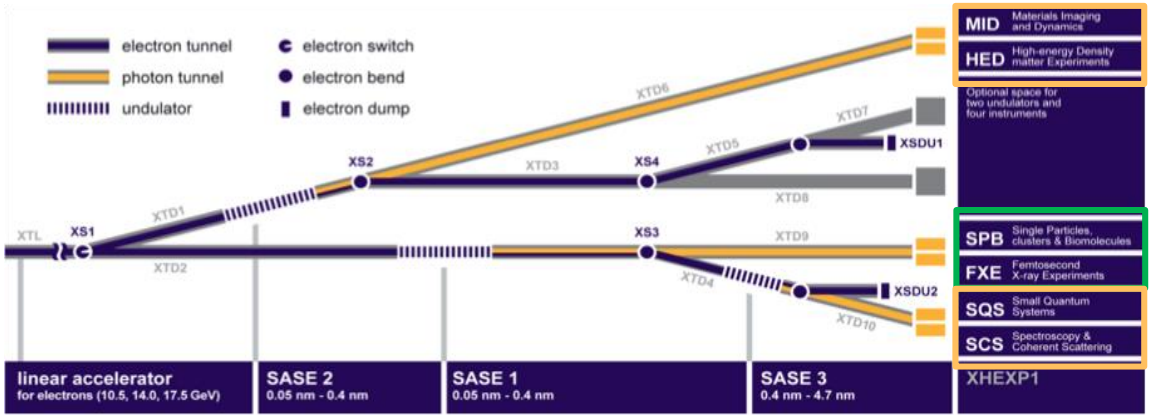


3.4 km long facility
1.2 billion Euro investment (2005 Euros)

The European XFEL – Parameters

	Beam parameters delivered 2017/18	Future beam parameters
Photon Energy	~ 9.3 keV	0.27 — 24+ keV
Repetition rate	1.1 MHz, 10 Hz - 2017 4.5 MHz , 10 Hz - 2018	4.5 MHz, 10 Hz
# of pulses/train	30	Up to 2700 delivered
Pulse duration	100 fs	100 fs
Pulse energy	300–1000µJ	> 1 mJ

Undulator Segment	FEL radiation energy [keV]
SASE 1	**3–24+ (Hard XR)**
SASE 2	**3–24+**
SASE 3	**0.27–3 (Soft XR)**



→ **SASE 1 instruments FXE and SPB/SFX stared operation in 2017**

→ **SASE 2 and 3 under commissioning → operational by the end of 2018**

SASE 1 Instrument - SPB/SFX

The scope of the SPB/SFX Instrument
Serial Crystallography and
single particle imaging of biological samples
including time resolved experiments

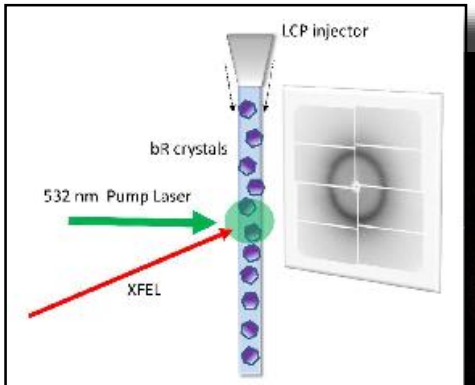
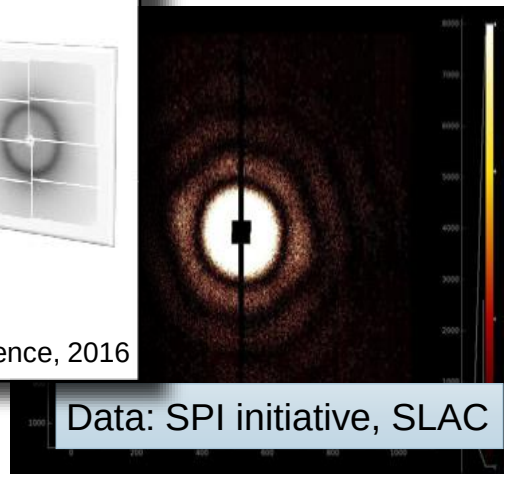
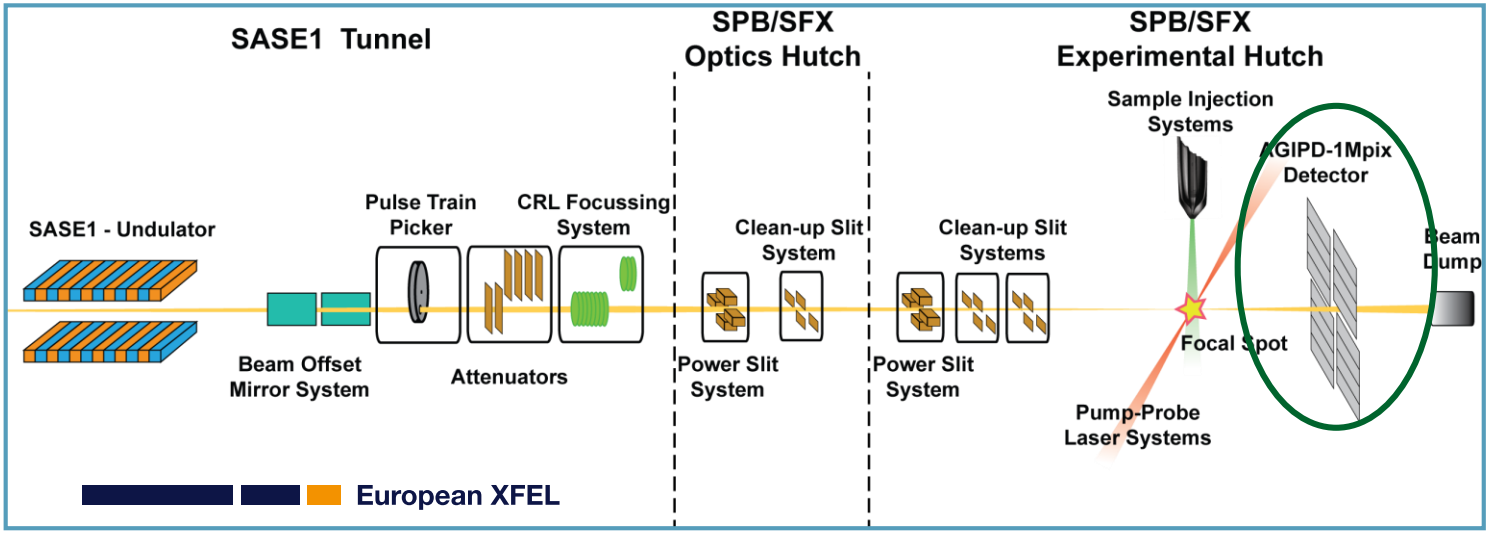


Figure: Nango, et al, Science, 2016



Data: SPI initiative, SLAC

Schematic of the "Day one" SPB/SFX Instrument
→ **1MPix AGIPD as a primary detector**

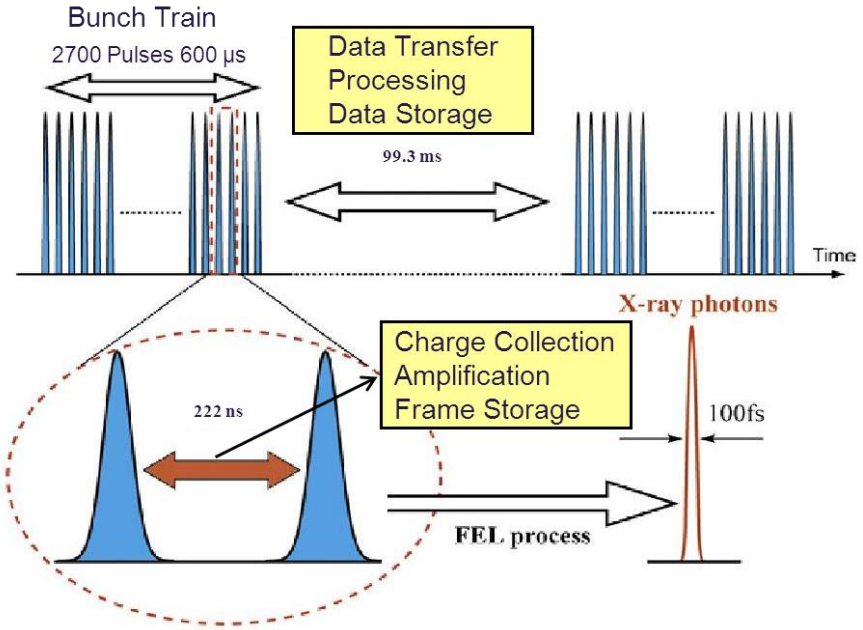


AGIPD Detector for SPB/SFX Instrument

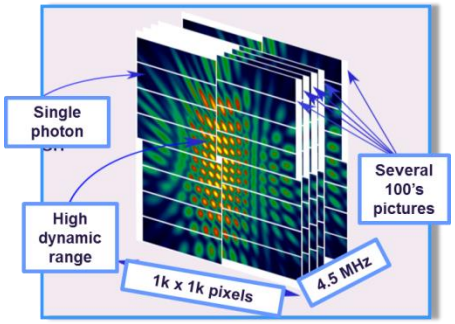
Detector specification based on scientific requirements

- Energy 3 – 16 keV
- Single photon sensitivity > 8.5 keV
  - High quantum efficiency (>0.8)
  - Noise < 350 e- r.m.s.
- High dynamic range 10^4 ph/pixel/pulse
- Vacuum compatible < 10^{-3} mbar
- Flexible central hole

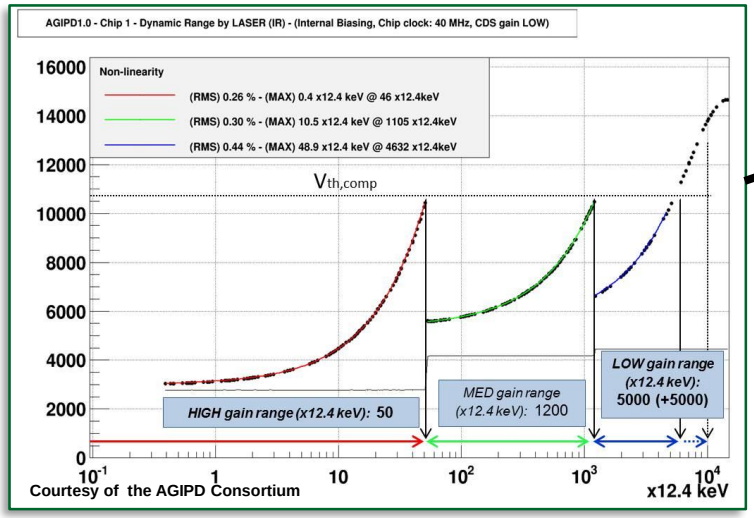
- Sufficiently rad. hard for operation at XFEL
- XFEL timing compliant

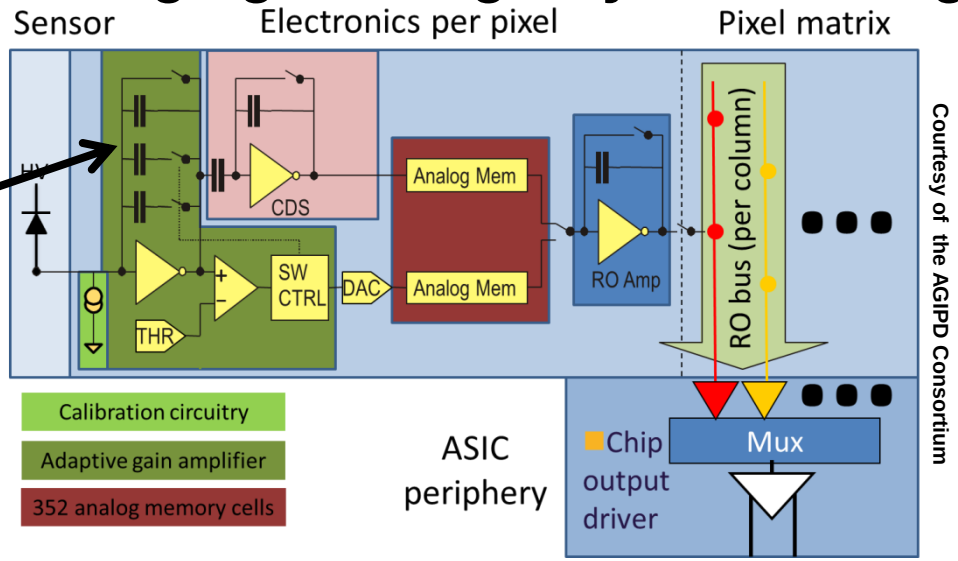


- Detector developed for XFEL.EU by AGIPD Consortium:
  - Participating institutes: DESY, PSI, Uni Bonn, Uni Hamburg
  - Project lead by DESY (Heinz Graafsma)
  - Project started (contract signed): 2010



AGIPD Pixel Design for Fast Imaging and High Dynamic Range

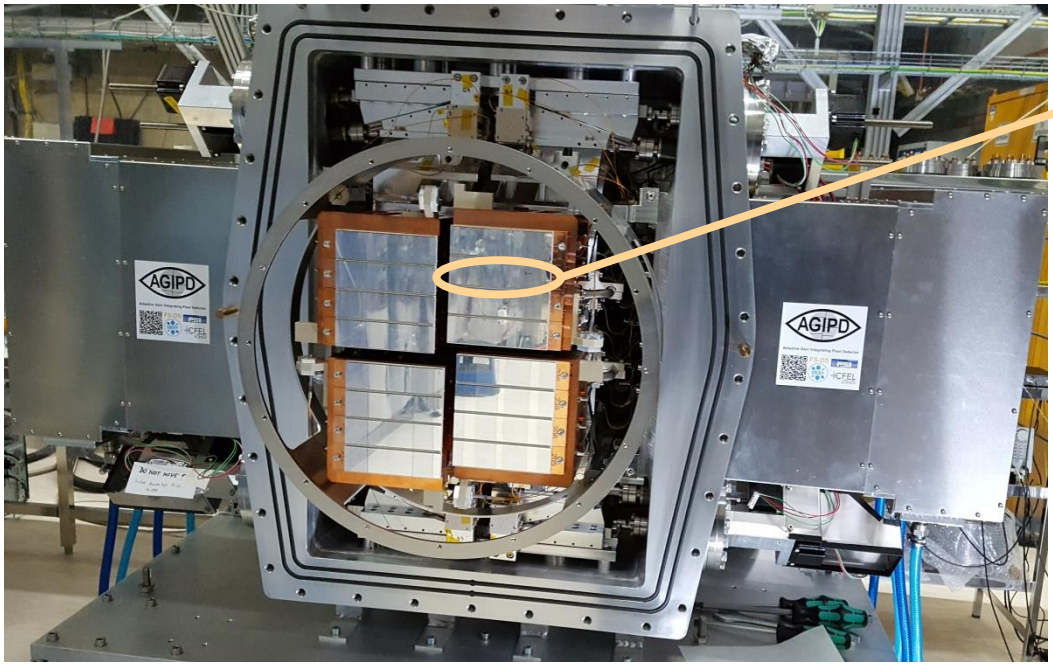




- 200 µm x 200 µm pixels
- 352 storage cells for 4.5 MHz frame rate
- Veto & trigger capabilities by overwriting unfit/obsolete images
- Dynamic range: from single photon to 10^4 @ 12 keV

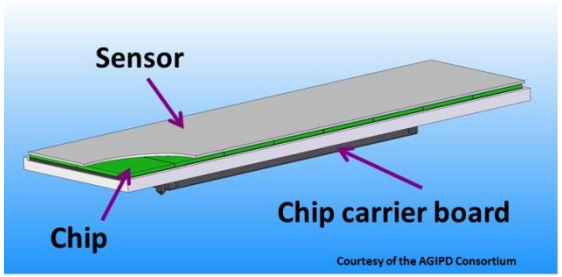
- Preamplifier with **adaptive gain** by insertion of additional feedback capacitors to lower sensitivity and increase dynamic range once a defined threshold is crossed
- Correlated Double Sampling (CDS) stage to remove reset noise and reduce low frequency noise
- Analogue memory, which can store 352 images
- Read out of stored signals are through the pixel buffer, column buffer and off-chip driver in between the bunch

AGIPD detector system for SPB/SFX instrument

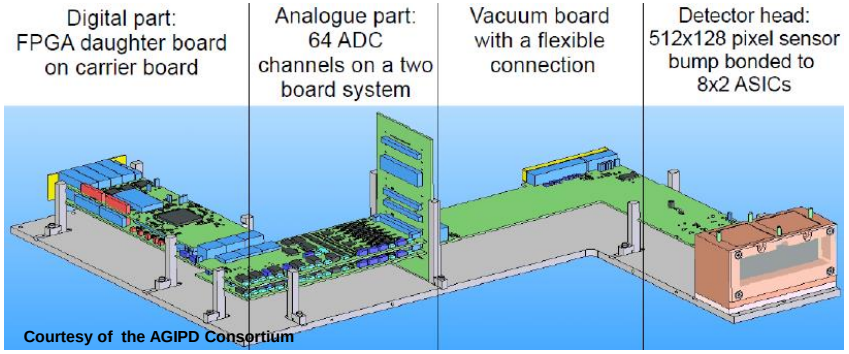


Module

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



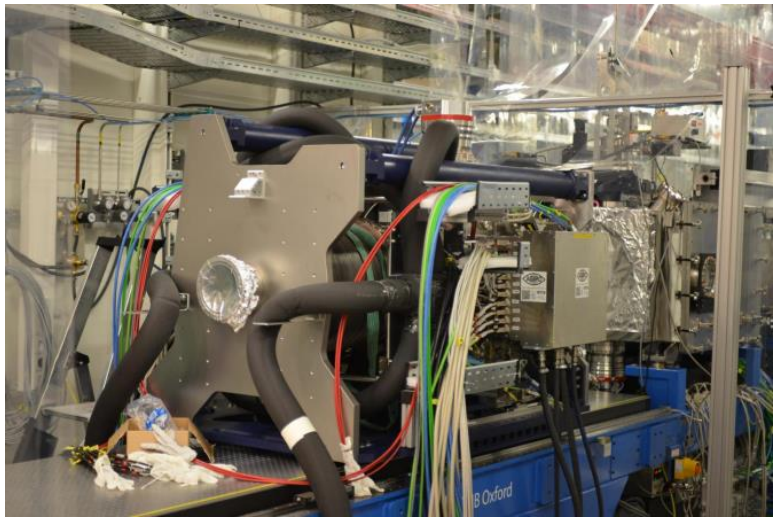
- 16 modules are mounted on four independently movable quadrants
- Electronics/control: two independent detectors ‘half 1’ and ‘half 2’
- Readout: 16 independent detectors



Installation and Commissioning of AGIPD detector at XFEL.EU – two steps approach

- Integration Tests in XFEL.EU Detector Laboratory
  - Demonstrate the functionality of the detector system including all subcomponents **before system integration at SPB/SFX beam line**.
  - Started: January 2017

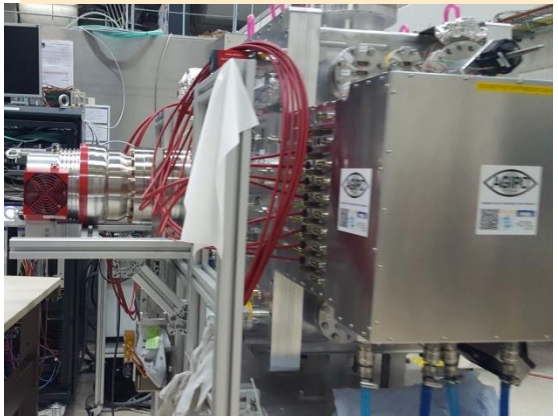
- Installation and Commissioning at SPB/SFX beamline
  - Started: 14.08.2017



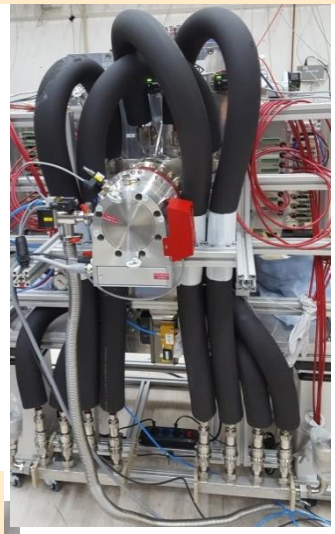
AGIPD installation steps in DET lab at XFEL.EU

Installation on the support

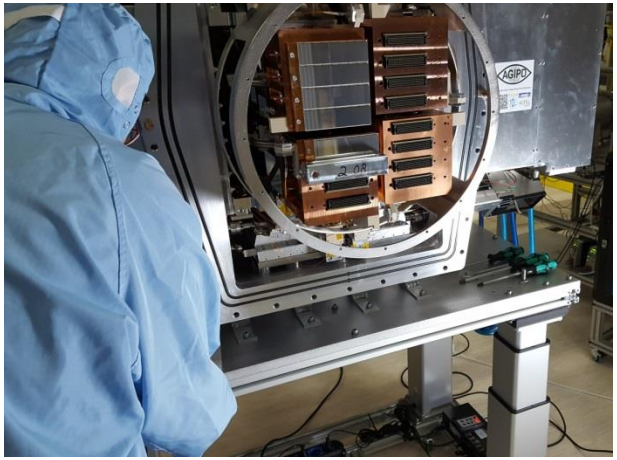
Vacuum components



Cooling pipes and isolation



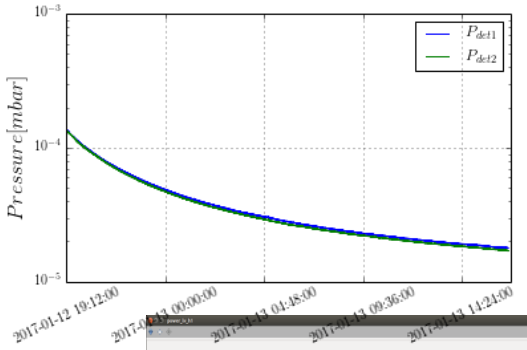
FEM installation (AGIPD1.0)

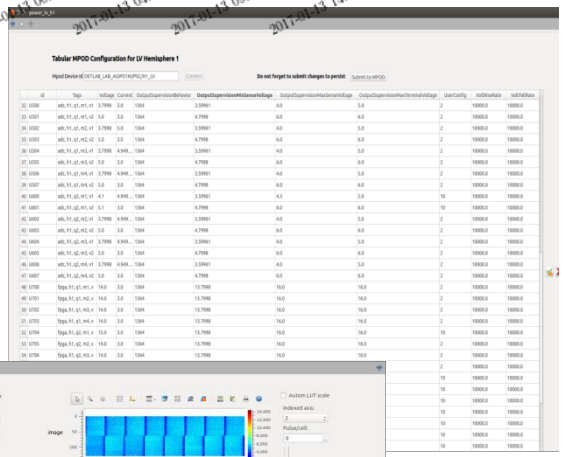


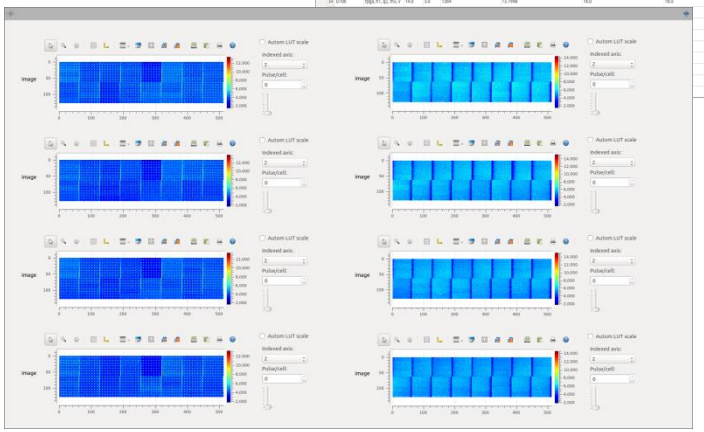
Cables (power and DAQ, PLC)

Integration Test of AGIPD in Detector Laboratory at XFEL

- Integrate the detector in XFEL.EU infrastructure
  - Power (150 channels, 52 cables)
  - Vacuum
  - Cooling – (500 W in-vacuum, 1000 W in ambient) → two cooling system
  - Interlocks (PLC)
  - Control and monitoring in Karabo
  - DAQ systems – ¼ Mpix
- Test and identify as many hardware, firmware, software issues as possible on both sides, XFEL and AGIPD, for different detector subsystems



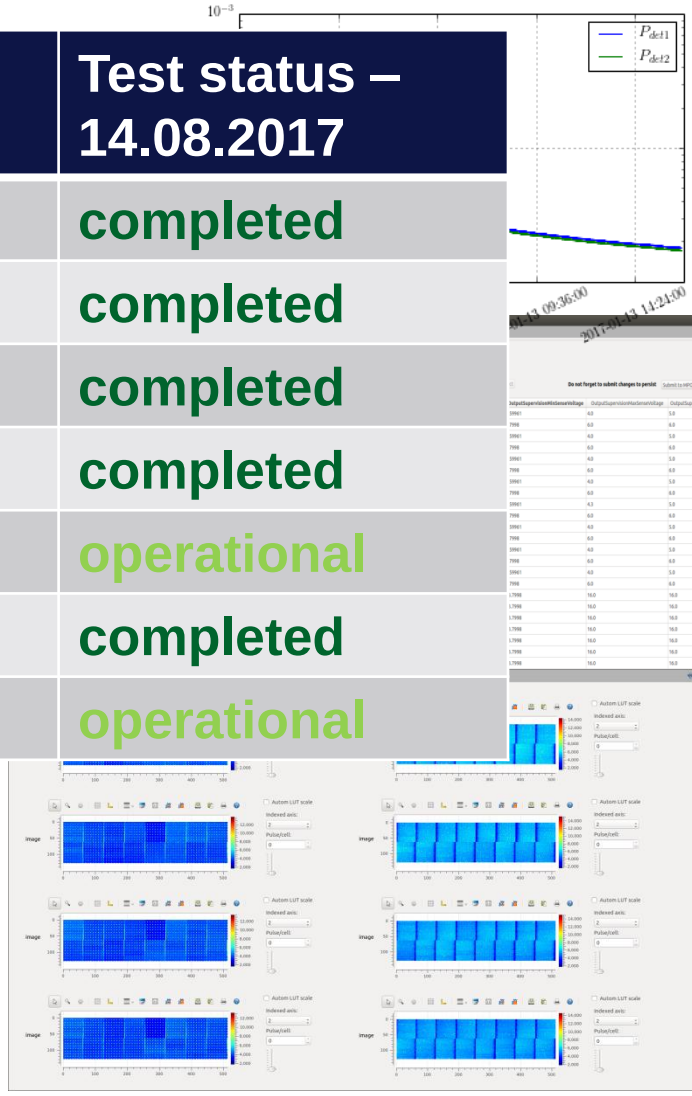




Integration Test of AGIPD in Detector Laboratory at XFEL

- Integrate the de
  infrastructure
  - Power (150
  - Vacuum
  - Cooling (two
  - Interlocks (P
  - Control and r
  - DAQ system
- Test and identify
  firmware, softwa
  both sides, XFEL and AGIPD, for different
  detector subsystems

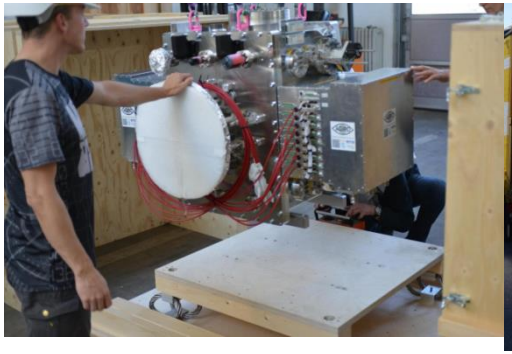
Tests	Test status – 14.08.2017
Cooling systems	completed
Vacuum system	completed
Power system	completed
Interlock system	completed
Control system	operational
C&C system	completed
DAQ and DM	operational



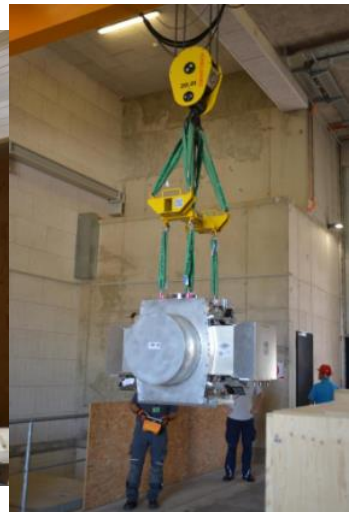
Move to XHQ

Main Goal:
Operational system before first User beam – 14.09
→ AGIPD should be integrated into beamline and see the first XFEL X-rays by the end of August 2017 (~ 2 weeks)

14.08.2017 at ~12a.m.: Bye bye DET Lab…

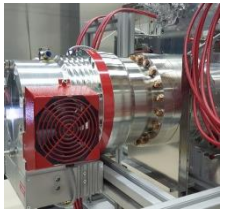


14.08.2017 at 1:00p.m.: …welcome to XHQ



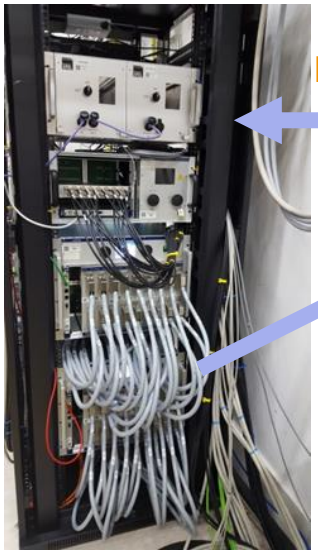
AGIPD (Standalone) Detector System at XFEL DET Lab

Vacuum

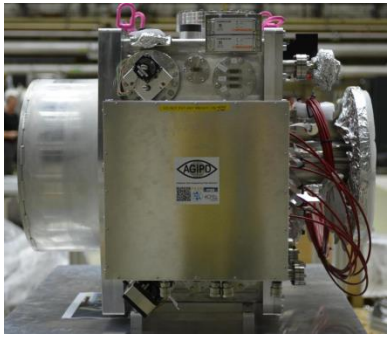


C&C system

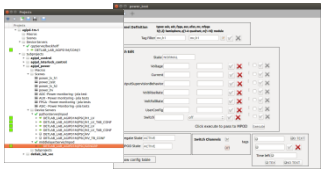
DAQ and Data Storage



VAC/ILC PLC



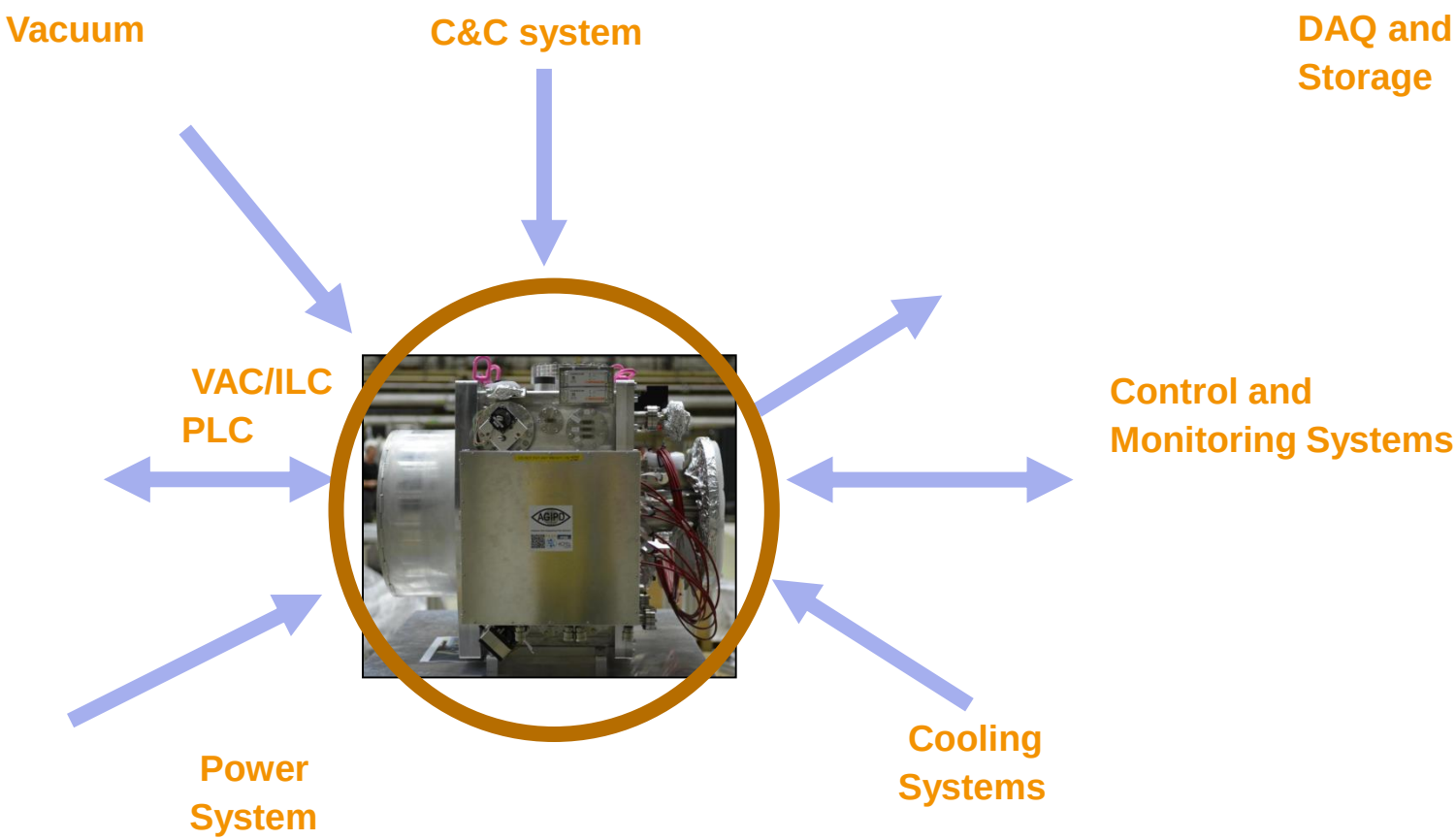
Control and Monitoring Systems



Power System

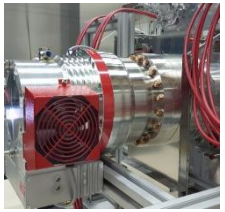
Cooling Systems

Transported from DET Lab to XHQ (SPB instrument)



AGIPD Integration in SPB instrument

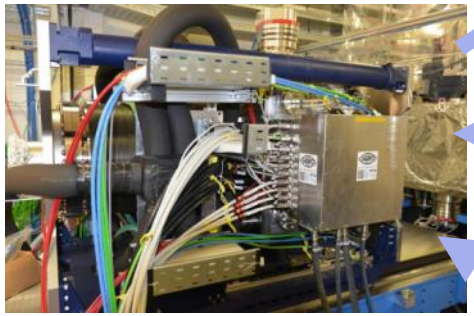
Vacuum



C&C system

DAQ and Data Storage

VAC/ILC PLC



Control and Monitoring Systems

Power System

Cooling Systems

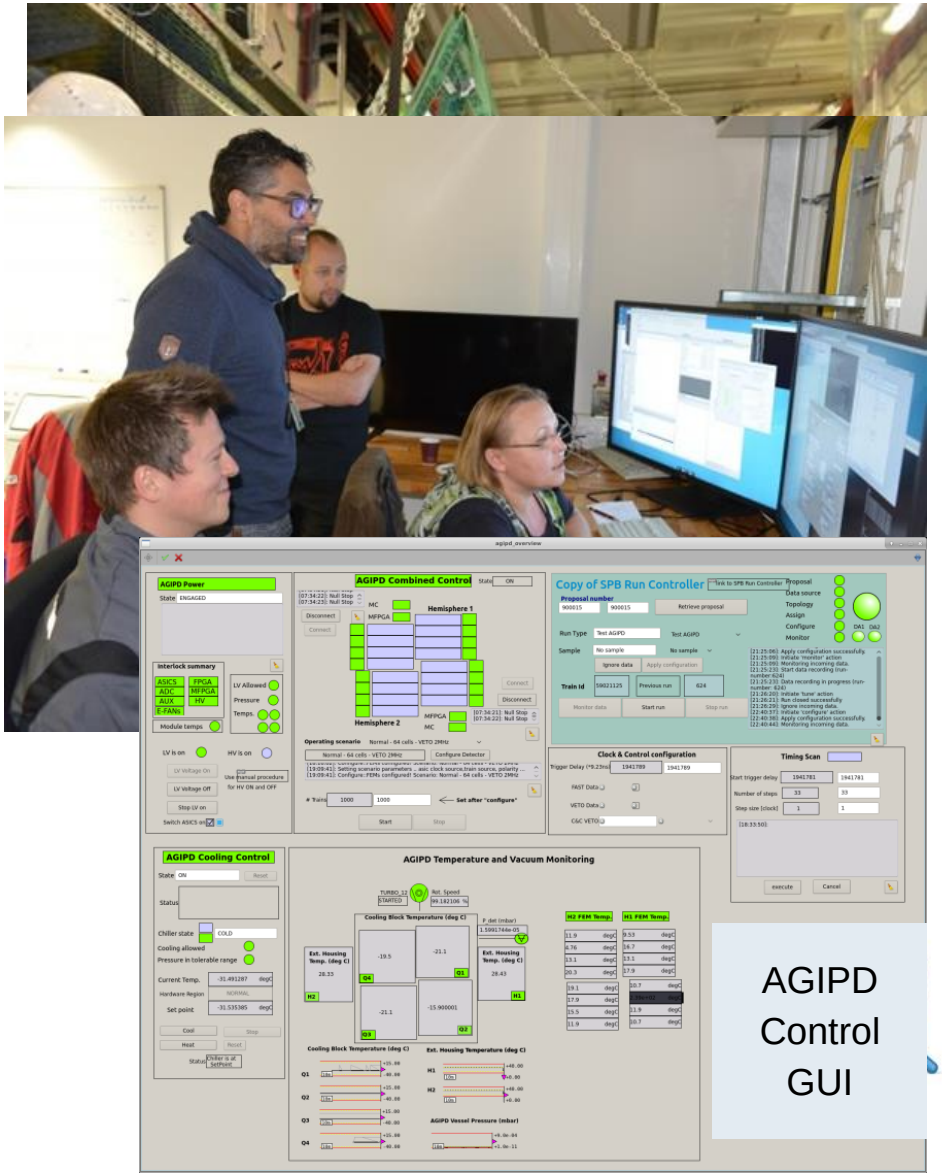
Mechanical integration in the beamline

AGIPD at SPB/SFX – Integration steps

- **Installation of AGIPD detector on CSS support (14.08)**

AGIPD at SPB/SFX – Integration steps

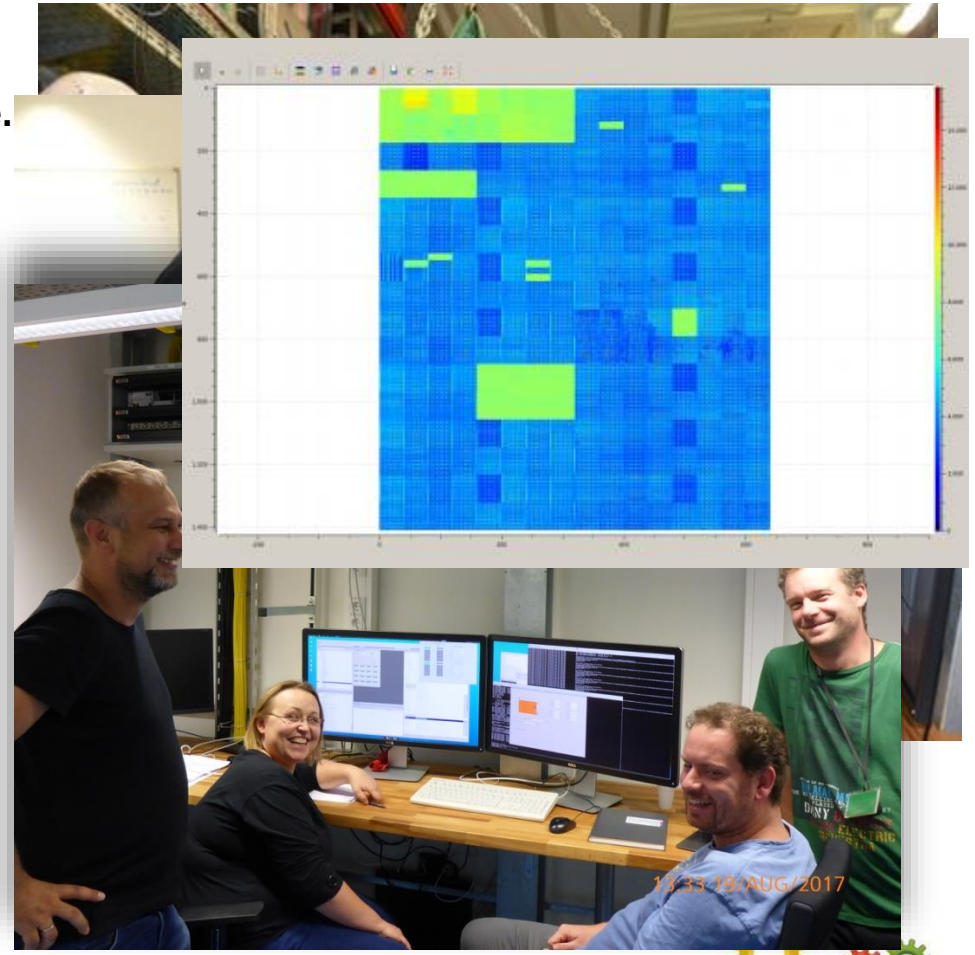
- Installation of AGIPD detector on CSS support (14.08)
- Integration in SPB/SFX infrastructure (i.e. vacuum, cooling, power, interlock control, DAQ) – (14-18.08)



AGIPD Control GUI

AGIPD at SPB/SFX – Integration steps

- Installation of AGIPD detector on CSS support (14.08)
- Integration in SPB/SFX infrastructure (i.e. vacuum, cooling, power, interlock control, DAQ)
- First test and dark images at (19.08)



AGIPD at SPB/SFX – Integration steps

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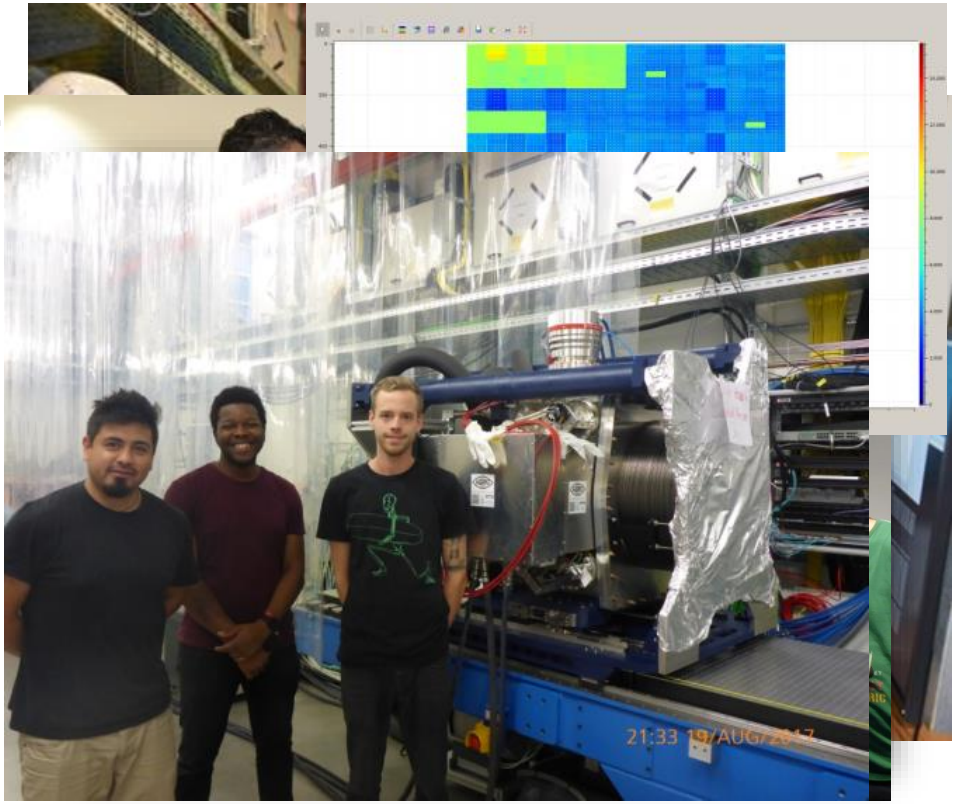
- Integration in SPB/SFX infrastructure (i.e. vacuum, cooling, power, interlock control, DAQ) – (14-18.08)
- First test and dark images at (19.08)
- Installation of the detector in the SPB “cage “(19-20.08)



AGIPD at SPB/SFX – Integration steps

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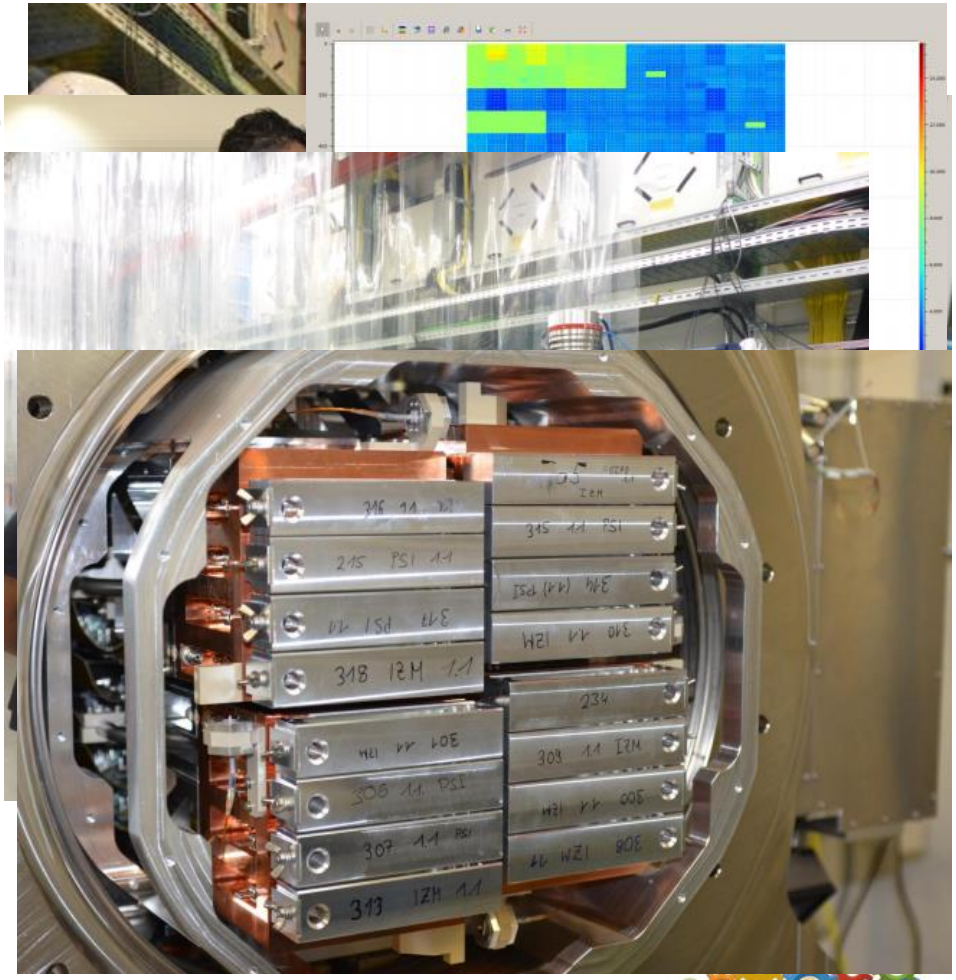
- Integration in SPB/SFX infrastructure (i.e. vacuum, cooling, power, interlock control, DAQ) – (14-18.08)
- First test and dark images at (19.08)
- Installation of the detector in the SPB cage (19-20.08)
- Exchange FEMs to AGIPD 1.1, adjust and test the system (21-22.08)



AGIPD at SPB/SFX – Integration steps

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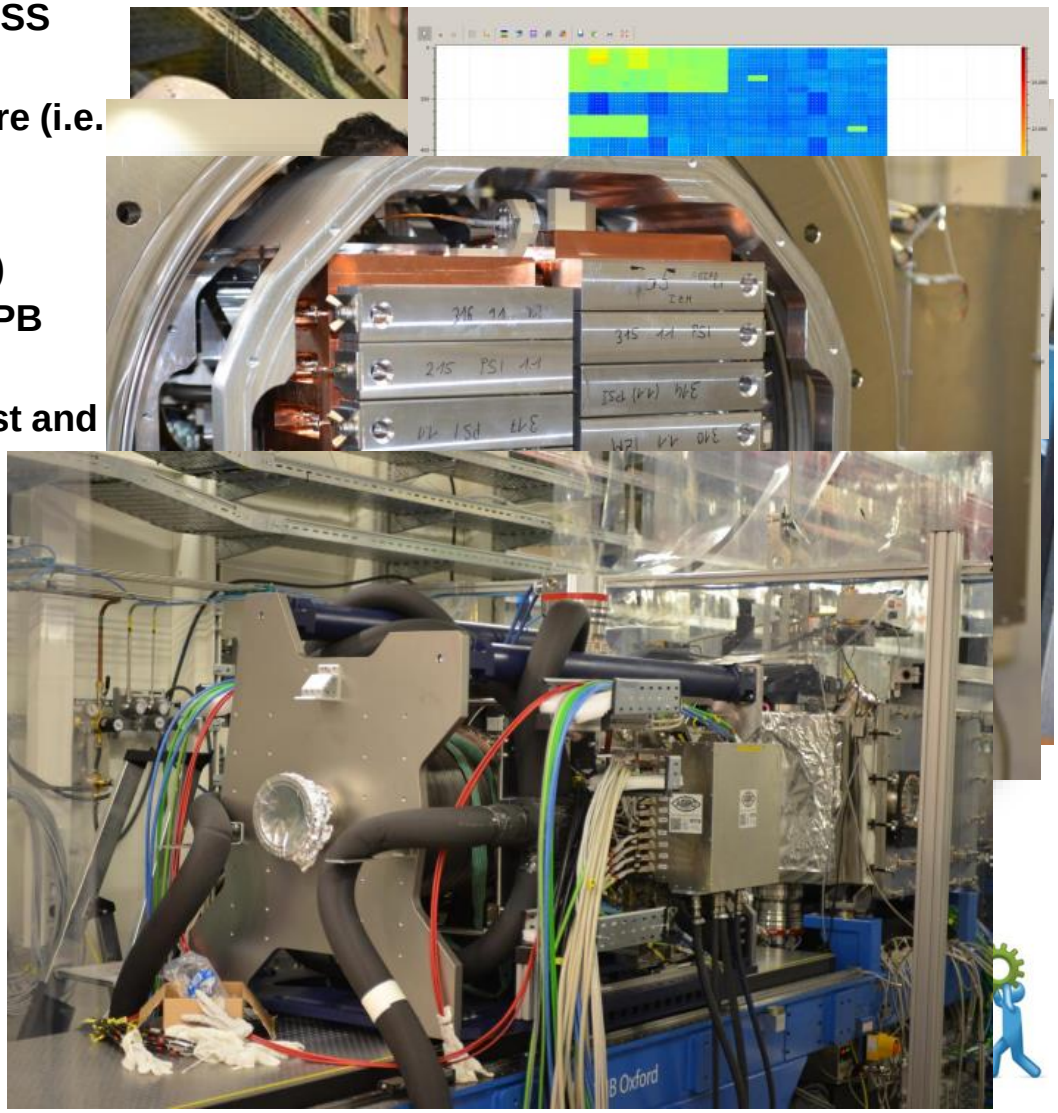
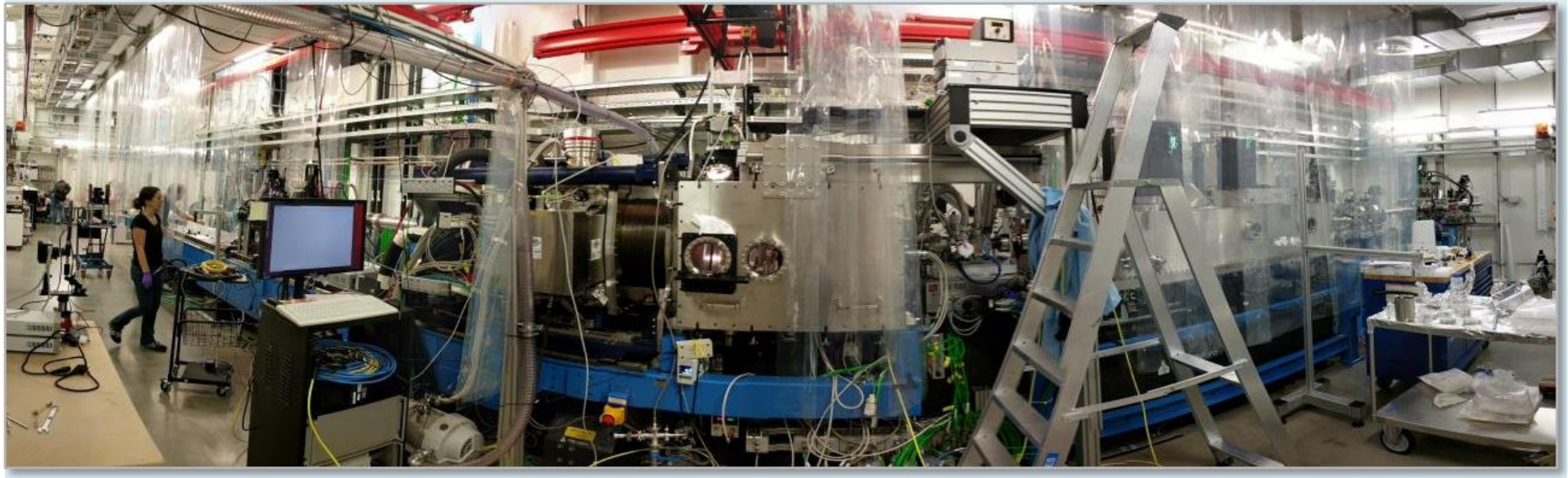
- First test and dark images at (19.08)
- Installation of the detector in the SPB cage (19-20.08)
- Exchange FEMs to AGIPD 1.1, adjust and test the system (21-22.08)
- Connect the detector to the sample chamber (23.08)



AGIPD at SPB/SFX – Integration steps

- Installation of AGIPD detector on CSS

AGIPD operational for XFEL beam – 24.08

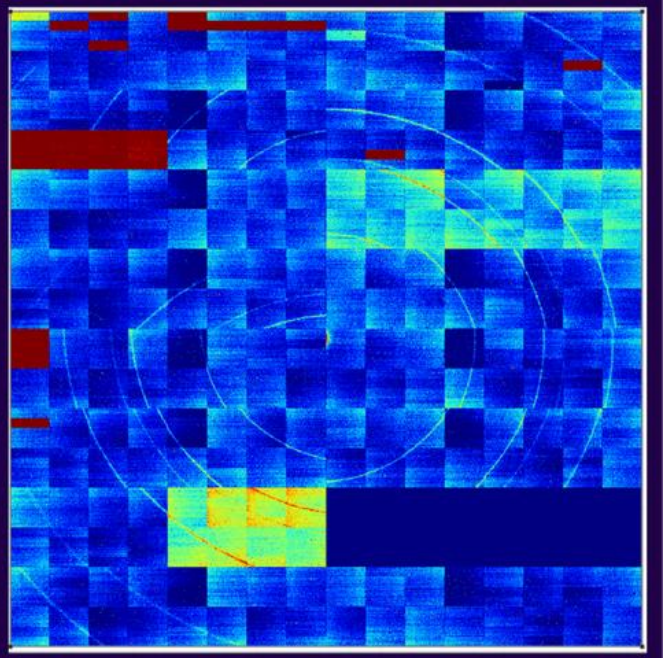


European XFEL

Live demonstration experiment on the occasion of the European XFEL inauguration, including AGIPD data.

SPB/SFX Scientific Instrument

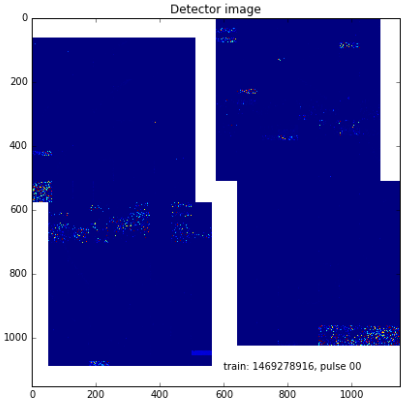
September 1st, 2017



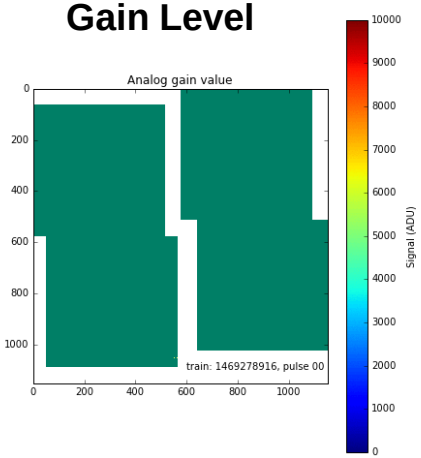
First X-ray images taken with AGIPD at SPB/SFX instrument

- Data set
  - E=9.2 keV, 30 pulses @ 1.1 MHz
  - LiTi sample
  - Frame rate 4.5 MHz, no veto, X-rays expected in every 4th frame starting from cell index 4
  - Preliminary corrections applied

Image

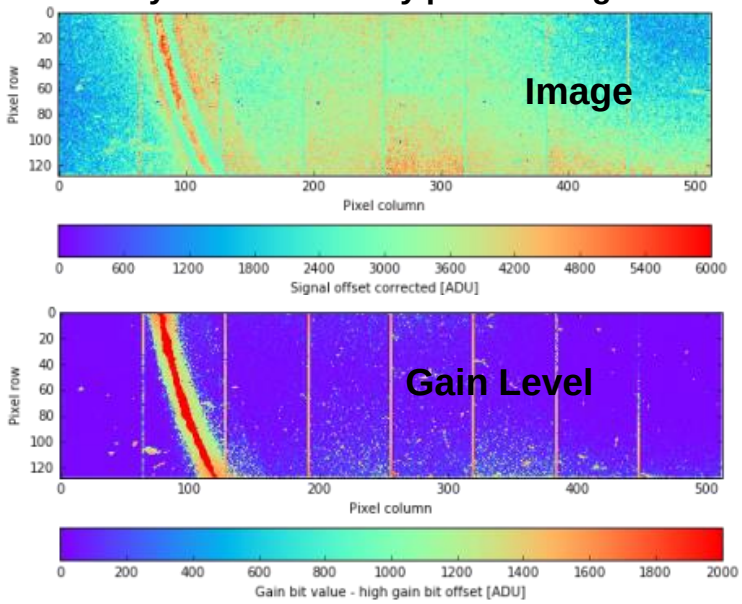


Gain Level



- Data set
  - E=9.2 keV, 30 pulses @ 1.1 MHz
  - CVD sample (strong scattering!)
  - Frame rate 4.5 MHz, internal veto, X-rays expected in every 2nd frame starting from cell index 2
  - Raw image offset corrected

Memory cell 2 with X-ray pulse – singe frame



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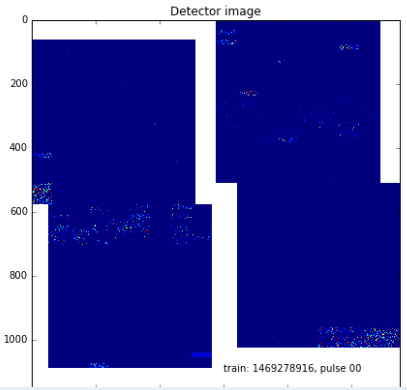
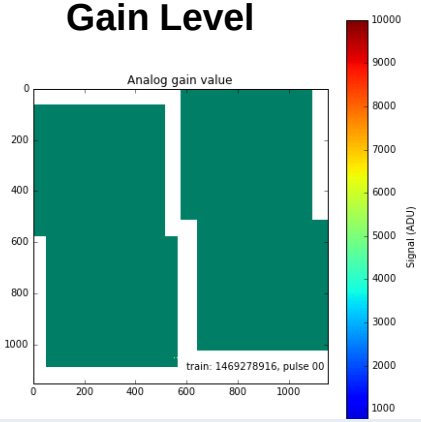
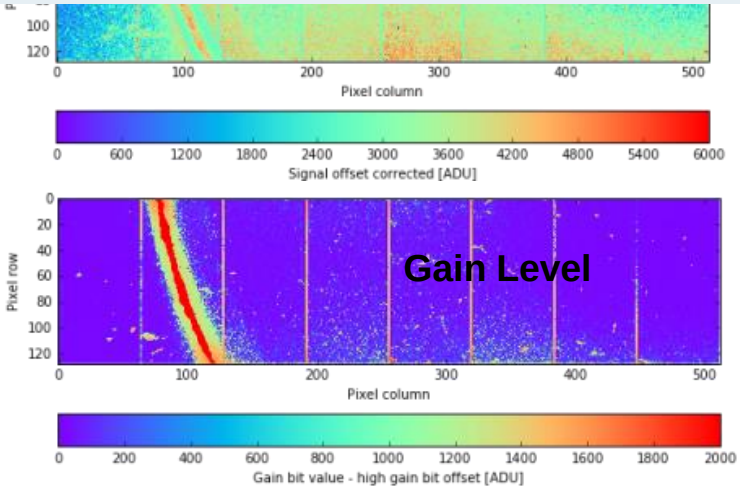


Gain Level



- AGIPD operation @ 4.5 MHz in XFEL burst mode
- Dynamic gain switching demonstrated

- Data se
  - E=9.
  - CVD sample (strong scattering!)
  - Frame rate 4.5 MHz, internal veto, X-rays expected in every 2nd frame starting from cell index 2
  - Raw image offset corrected



Calibration of the AGIPD detector

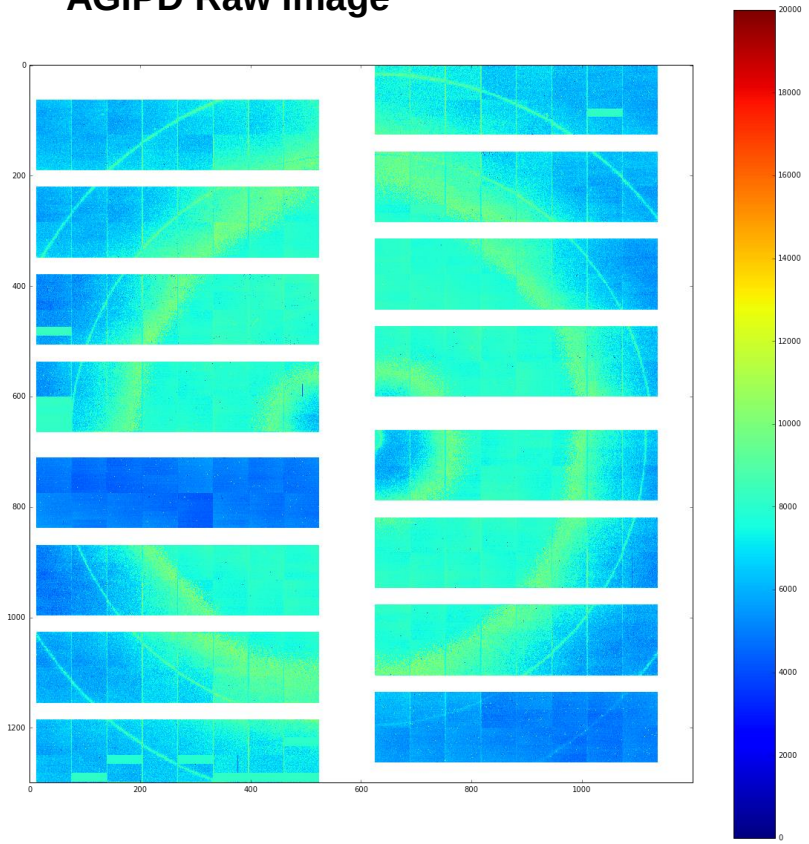
- Joint effort from XFEL, AGIPD consortium
- First calibration data set for high and medium gains exist → work on optimization ongoing
- First calibration procedures at the experiment are established

Data set	Frequency	Collection time	Parameters	Time for processing
Dark data sets High medium and low gains	At least at the beginning and the end of shift, Always after detector has to be restarted	300 sec	Offset, Noise Bad pixels	< 5 min
Pulse capacitor data	After change of detector parameters (i.e. HV, LV, number of cells, int. time)	< 15 min	Relative gain for high and medium	1 hours/ module*
Flat fields, different intensities	After change of detector parameters (i.e. HV, LV, number of cells, int. time)	300 sec per intensity + preparation in sample chamber	Relative gain, bad pixels	1 hours/ module*

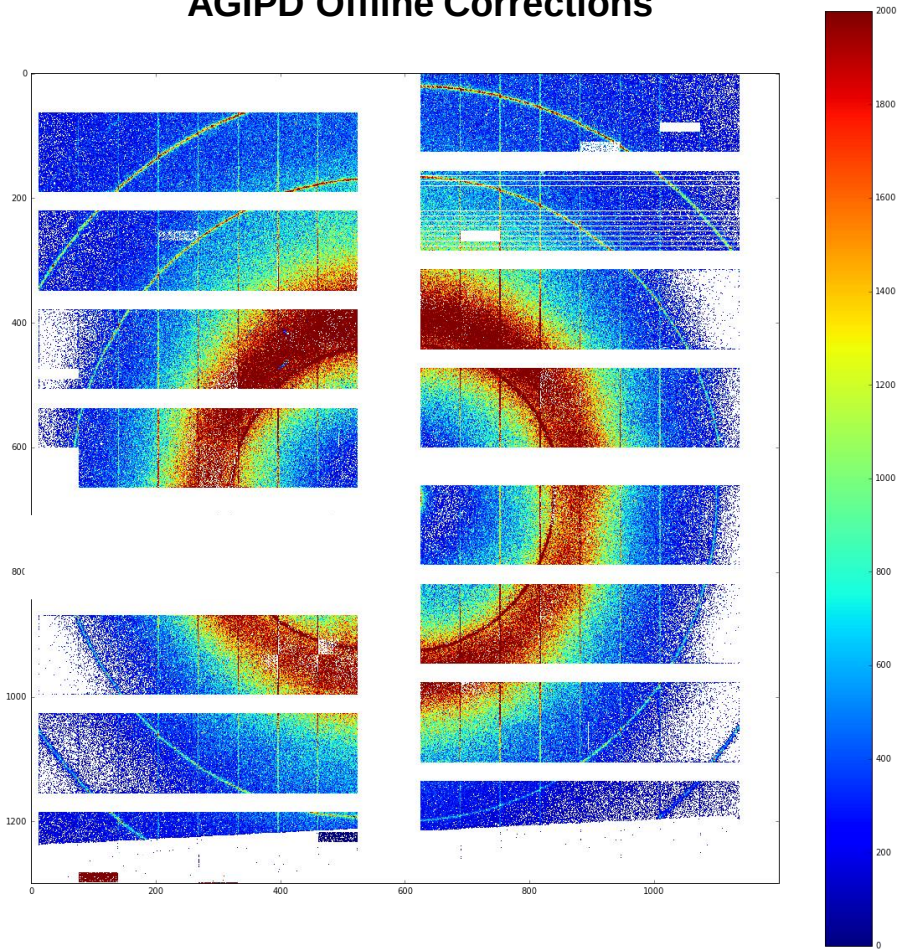
* run in parallel on Maxwell cluster

Offline Calibration - Example

AGIPD Raw Image

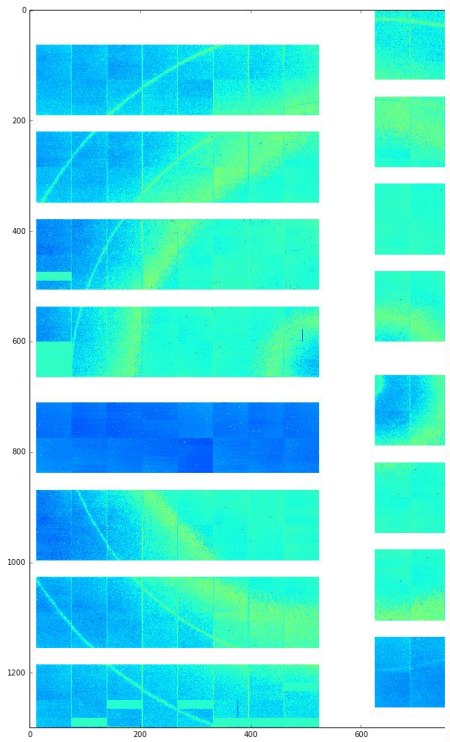


AGIPD Offline Corrections

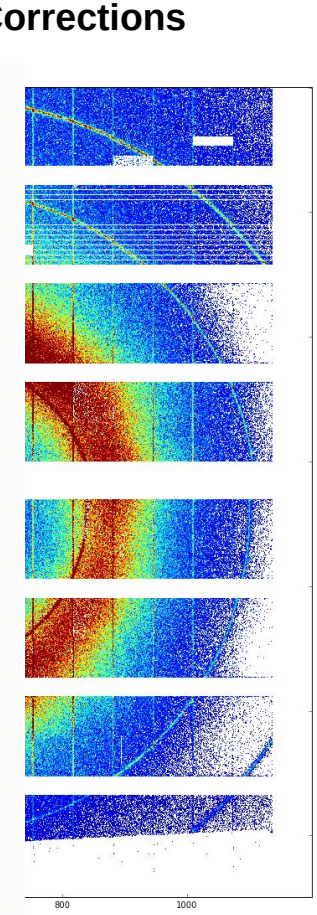


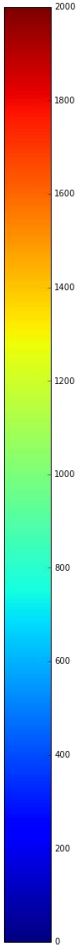
Offline Calibration - Example

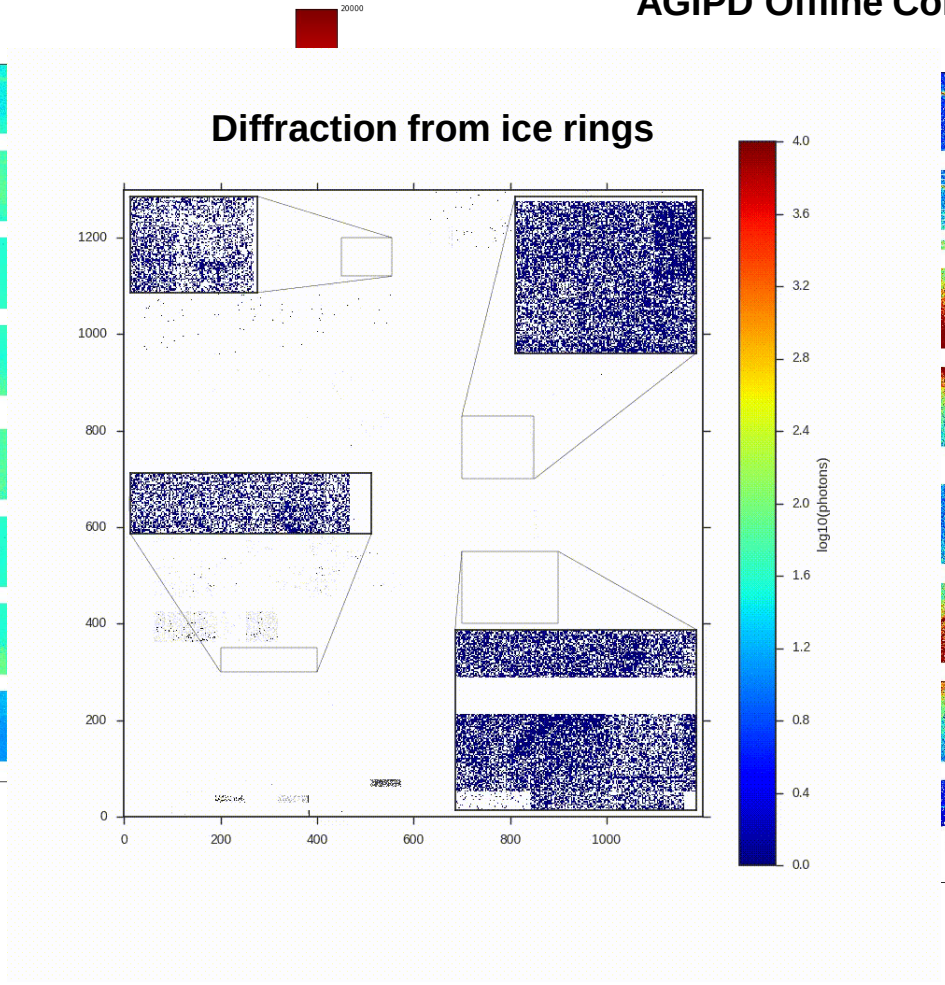
AGIPD Raw Image



AGIPD Offline Corrections







The first experiment at SPB/SFX instrument was an open collaboration with over 100 participants – 14.09.2017

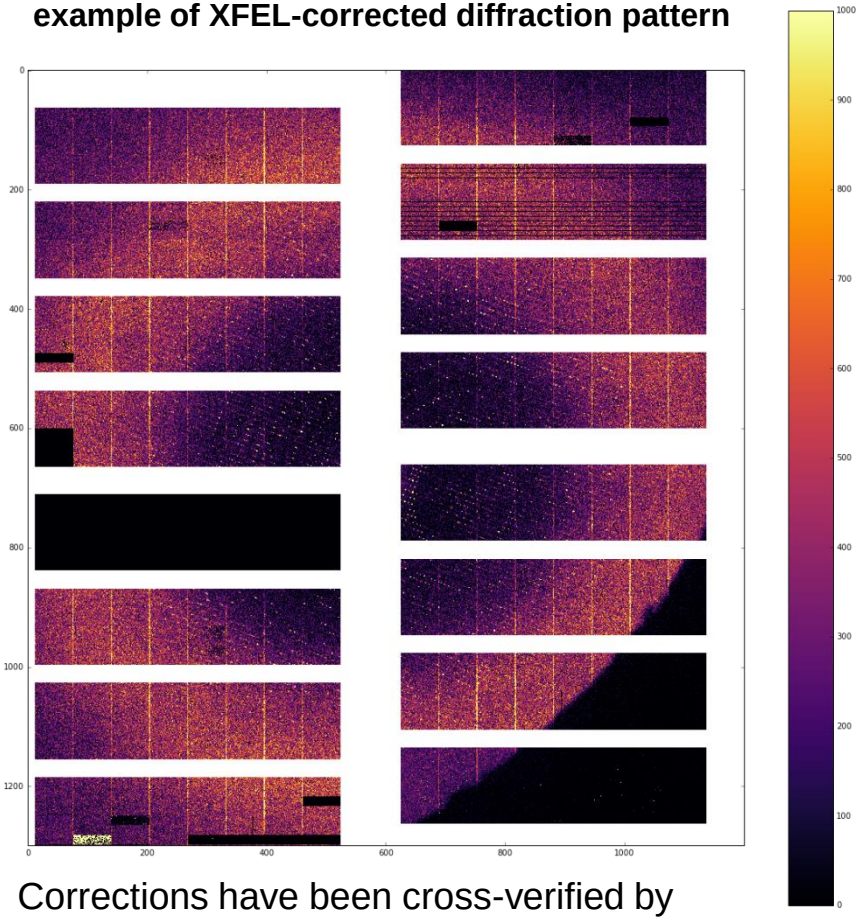
AGIPD at SPB – User Operation with AGIPD

- User Operation SPB started 14th September 2017
  - 5 experiments
  - AGIPD stable operation ~90% of the time

Experiment/ proposal	Number of hours	Raw data size [TB]
p2012	60	57
p2042	60	87
p2017	60	49
p2066	48	80
p2013	60	116
Total	**288 h**	**389 TB***

*** Double size images, X-rays in every 2nd image**

Time resolved fs crystallography – example of XFEL-corrected diffraction pattern

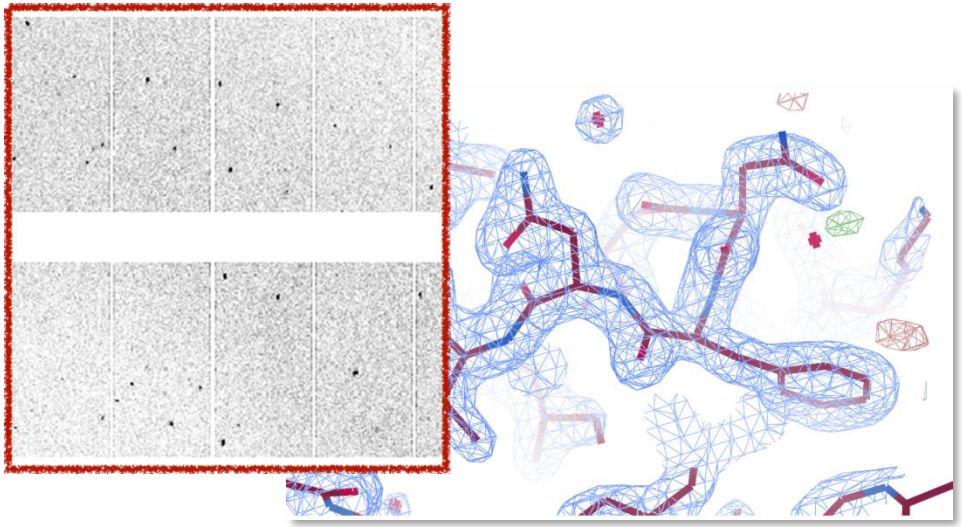


Corrections have been cross-verified by Barty et al. group

Feedback from Users

A.Barty:

- AGIPD exhibits an excellent dynamic range
- First round of reflection intensities from XFEL2012 data are accurate enough to produce a structure

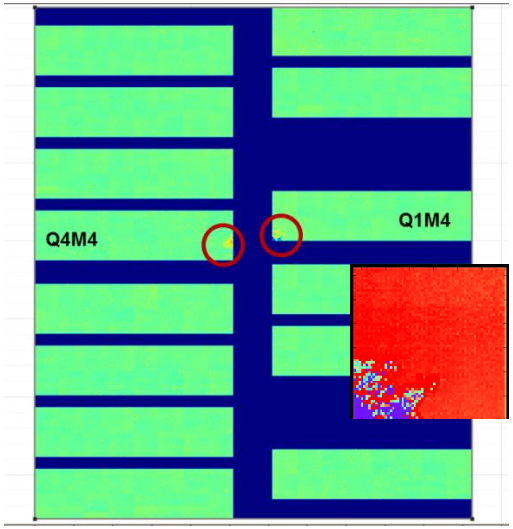


P. Fromme:

- this is **the first time EVER that time-resolved X-ray diffraction data were collected on Photosystem I crystals** with the goal to study the light-driven electron transfer process in Photosynthesis by **use of the unique pulse train structure of the XFEL.**

AGIPD at SPB/SFX – User Operation with AGIPD

- **Detector support September-October 2017:** experts from XFEL and AGIPD Consortium present during beam-times
- **Detector support November 2017-March 2018** trained personnel from XFEL DET and SPB
  - System still in the shape that requires expert support for operation
- Incidents happen → interlock is a must:
  - accidentally unplugged chiller
  - vacuum quality during liquid jet injection
  - accidentally unplugged vacuum pump
  - strong scattering of the primary beam on the sample chamber components
  - cooling water failure



- Hardware failure happens (in the worst moment) :
  - Access to Spare Parts
  - Relatively easy access to the electronics is required → electronics boxes were opened 5 times for hardware repair or firmware/hardware upgrade
  - FE modules can be relatively easily installed (~day)
  - Opening the back of the system is time consuming and complicated (~ week)

Conclusions

- Integration of AGIPD detector at SPB/SFX instrument went well → we learnt a lot from the integration tests of the detector
- AGIPD detector operation at 4.5 MHz, dynamic gain switching with XFEL beam demonstrated
- **First User experiments were successful**
- A lot of work has been done, there is still a lot of work ahead:
  - Optimization of control systems and DAQ
  - Improvement of the detector firmware
  - Calibration/characterization work by AGIPD team and at the European XFEL
    - Preliminary calibration exists
    - Work on calibration optimization ongoing
    - Work on characterization ongoing → tuning of the detector parameters with X-ray beam

Last but not least…

This success would not have been possible without the excellent cooperation and commitments of all involved parties (SPB/SFX instrument, AGIPD Consortium, ITDM, AE, CAS and DET).

It was a great example of what teamwork can achieve

People

AGIPD Consortium:

Lead by DESY (H. Graafsma): PSI/SLS Villingen, Universität Bonn, Universität Hamburg, DESY

Responsibilities: Detector development, provide first calibration data

XFEL.EU Groups:

Detector development(M. Kuster):: Coordination of the project at XFEL.EU, coordination of AGIPD integration in XFEL infrastructure, coordination of calibration activity, calibration software development)

SPB/SFX (A.P. Mancuso): Define the scientific requirements, mechanical integration of the detector in the beamline

Advance Electronics (P. Gessler): PLC control system, Clock & Control system

Control and Analysis Software (S. Brockhauser): Control integration in XFEL.EU framework, development of scientific analysis and computing framework

IT and Data Management (K. Wrona): DAQ, Data Management and IT integration

Thank you