Detectors at European XFEL

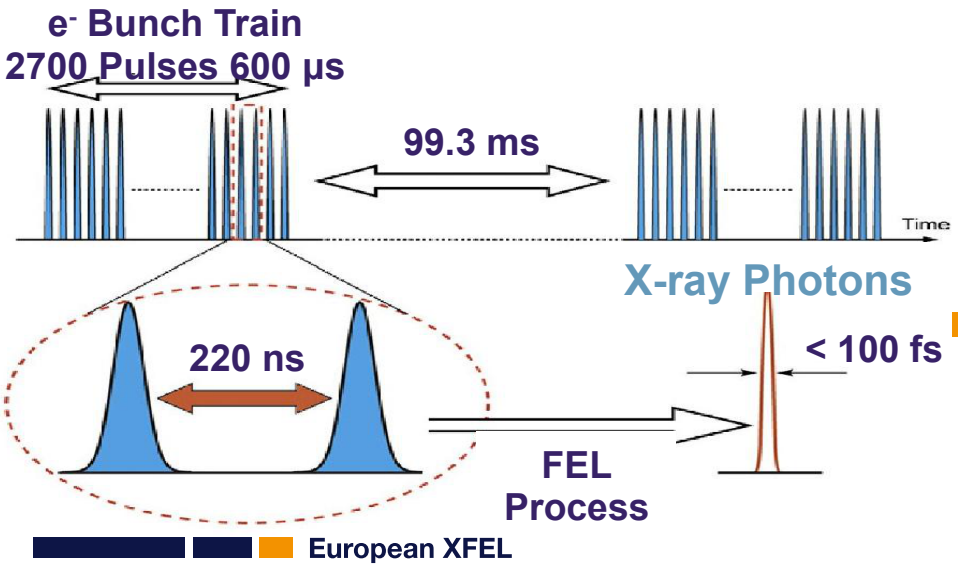
Markus Kuster
for the European XFEL Detector Group (WP75)
Group Head

Schenefeld, January 25th 2017

From First Ideas to User Operation – 2006 till 2017

- The European XFEL pulse structure poses strict constraints on detectors (e.g. intensity and time structure)
- No commercial imaging detectors available
- Call for expression of interest launched in 2006
- 3 project proposals were selected with the goal to finally have at least one fast 2D imaging detector

e^- Bunch and X-ray Pulse Structure



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:

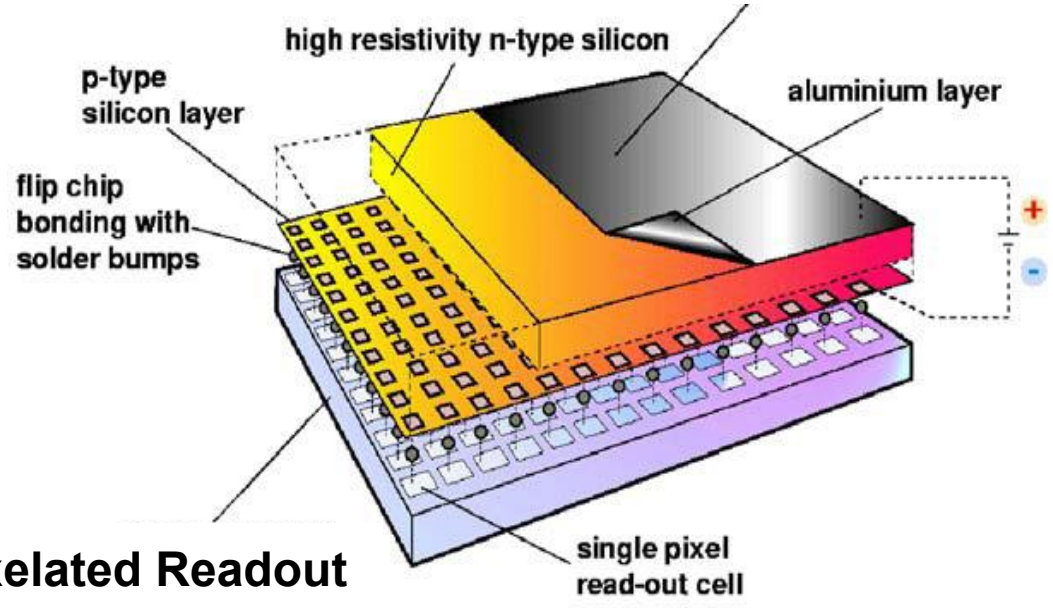
Develop and Deliver Large Area Pixellated X-ray Detectors.

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

- Selected proposals
  - Adaptive Gain Integrating Pixel Detector
  - Large Pixel Detector
  - DEPFET Sensor with Signal Compression

European XFEL Fast 2D Imagers – Hybrid Pixel Detectors

Pixelated Silicon Sensor



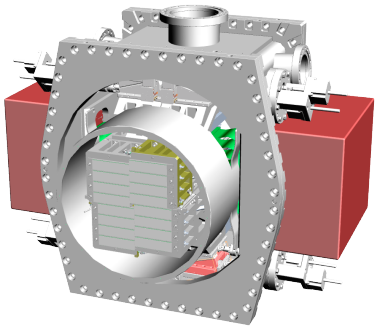
Pixelated Readout Chip (ASIC)

- Analog or digital memory
  - Capacity up to 800 cells/pixel
- Veto and trigger capability
  - Overwrite empty images

- Direct photon detection with Silicon sensor
  - High quantum efficiency
- Signal processing by read-out chip in each pixel
  - Amplification, AD con-version, storage in memory
- Fast read out up to sever-al MHz and low power consumption
- Al entrance window
  - Optical/IR light blocking

European XFEL Fast 2D Imagers

Adaptive Gain Integrating Pixel Detector (AGIPD)



4.5 MHz

Energy Range 3 – 13 (25) keV

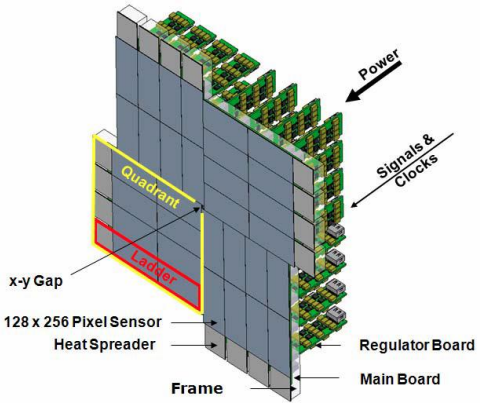
Dynamic Range 10^4 ph/px/pulse@12 keV

Single Photon Sens. Yes

Memory ≈380 images

Pixel Size 200×200 µm²

MiniSDD Sensor with Signal Compression (DSSC)



4.5 MHz

Energy Range 0.5 – 6 (25) keV

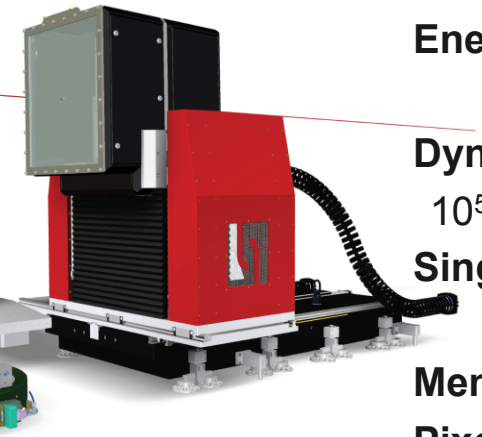
Dynamic Range ≈100 ph/px/pulse@1 keV

Single Photon Sens. No

Memory ≈800 images

Pixel Size 236×236 µm²

Large Pixel Detector (LPD)



4.5 MHz

Energy Range 3 – 13 (25) keV

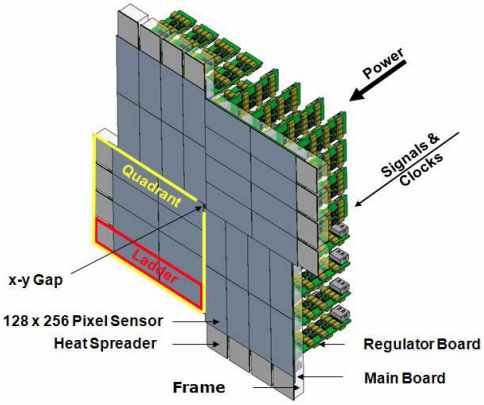
Dynamic Range 10^5 ph/px/pulse@12 keV

Single Photon Sens. Yes

Memory ≈512 images

Pixel Size 500×500 µm²

DePFET Sensor with Signal Compression (DSSC)



4.5 MHz

Energy Range 0.5 – 6 (25) keV

Dynamic Range 6000 ph/px/pulse@1 keV

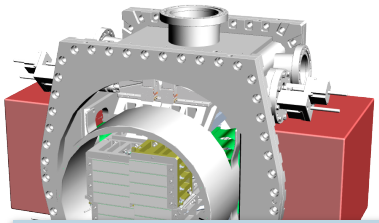
Single Photon Sens. Yes

Memory ≈800 images

Pixel Size 236×236 µm²

European XFEL Fast 2D Imagers

Adaptive Gain Integrating Pixel Detector (AGIPD)

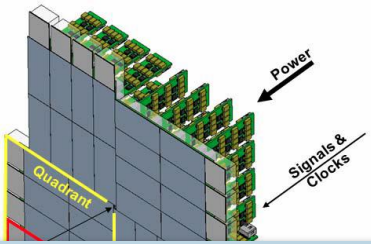


4.5 MHz

Energy Range
3 – 13 (25) keV
Dynamic Range
10^4 ph/px/pulse@12 keV
Single Photon Sens.

Project Leader: H. Graafsma, DESY
PSI/SLS Villingen, University Bonn, University Hamburg, DESY

MiniSDD Sensor with Signal Compression (DSSC)



4.5 MHz

Energy Range
0.5 – 6 (25) keV
Dynamic Range
≈100 ph/px/pulse@1 keV
Single Photon Sens.

Project Leader: M. Porro, European XFEL
University Heidelberg, Politecnico di Milano, Università di Bergamo, DESY, European XFEL

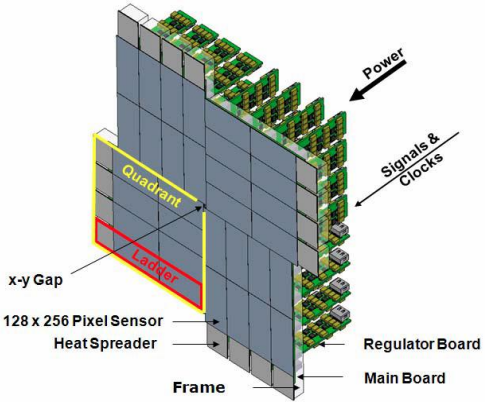
Large Pixel Detector (LPD)

4.5 MHz

Energy Range
3 – 13 (25) keV
Dynamic Range
10^5 ph/px/pulse@12 keV
Single Photon Sens.

Project Leader: M. Hart, RAL/STFC
Rutherford Appleton Laboratory/STFC
University of Glasgow

DePFET Sensor with Signal Compression (DSSC)



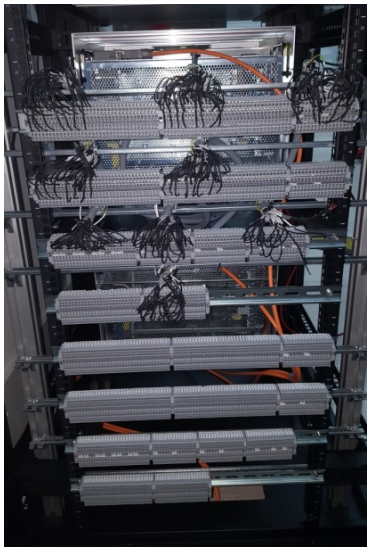
4.5 MHz

Energy Range
0.5 – 6 (25) keV
Dynamic Range
6000 ph/px/pulse@1 keV
Single Photon Sens.
Yes
Memory ≈800 images
Pixel Size 236×236 μm²

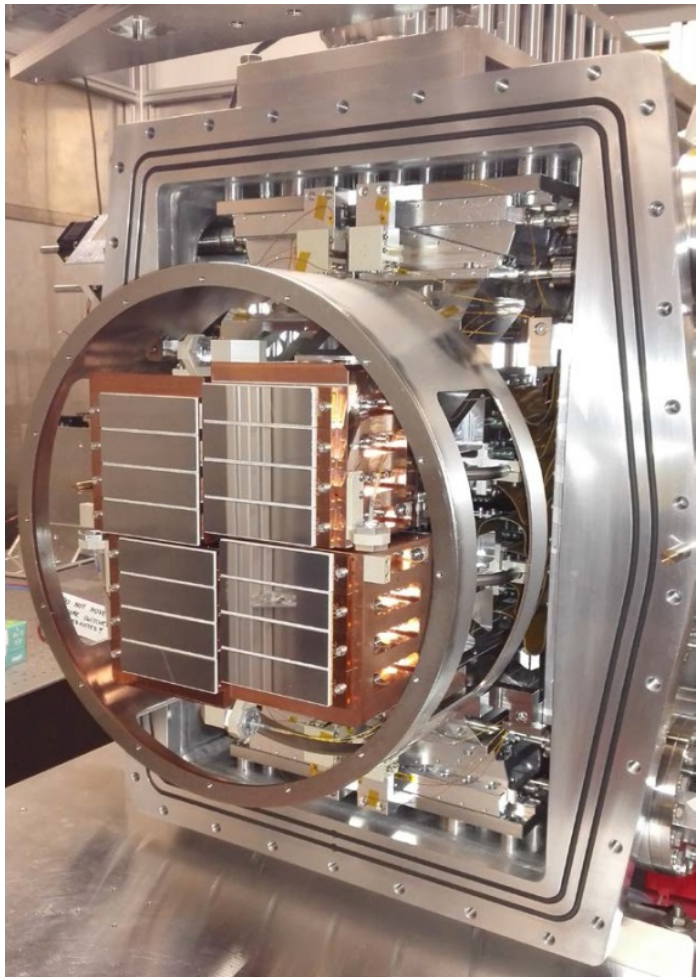
Adaptive Gain Integrating Pixel Detector – AGIPD

- Focused on testing and integrating the 1st detector in our DAQ/control system before integration at SPB
- Integration of 2nd detector is progressing in parallel at DESY
- Characterization of new generation ASIC is in progress

Power System for AGIPD



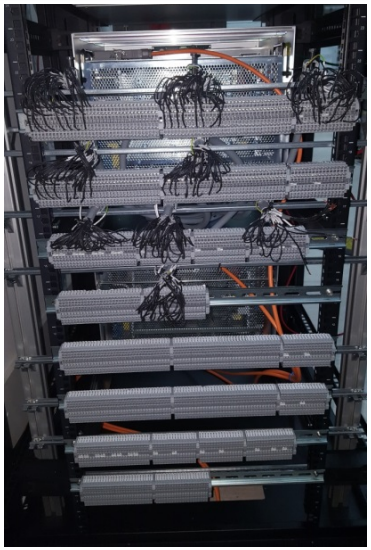
Inside View on the AGIPD Sensor Plane



Adaptive Gain Integrating Pixel Detector – AGIPD

- Focused on testing and integrating the 1st detector in our DAQ/control system before integration at SPB
- Integration of 2nd detector is progressing in parallel at DESY
- Characterization of new generation ASIC is in progress

Power System for AGIPD

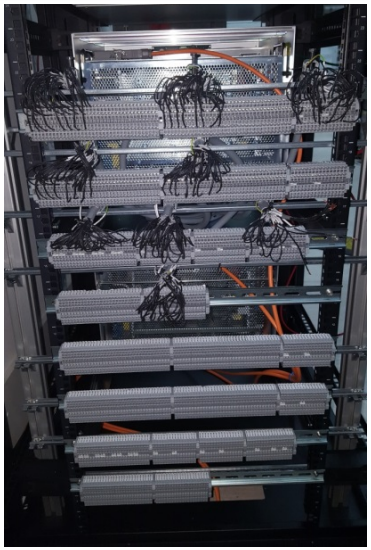


1st AGIPD Arriving at XFEL (Bahrenfeld)

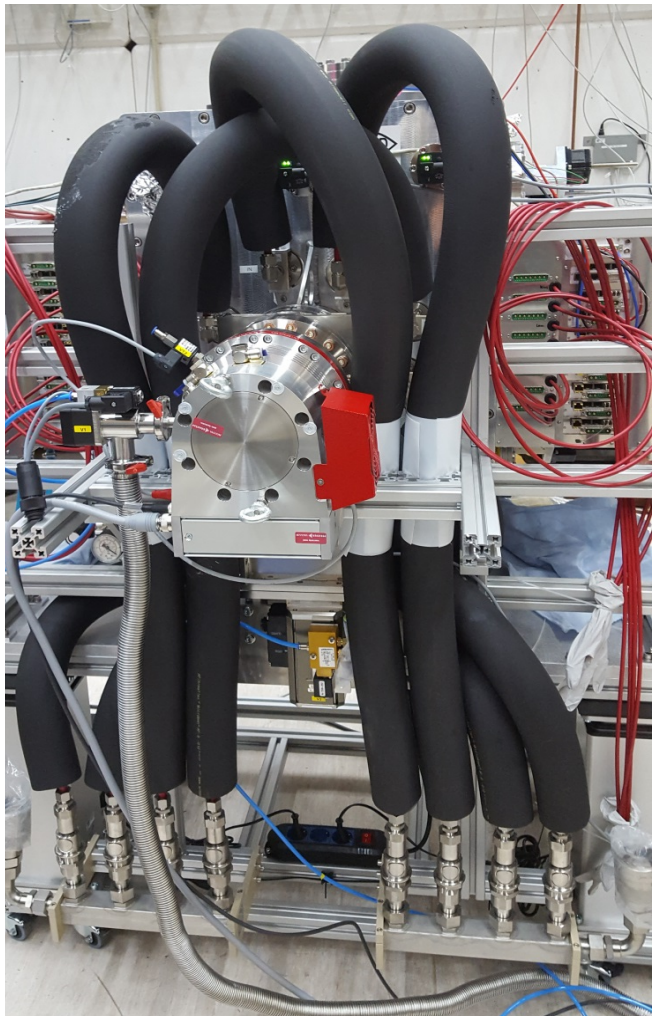
Adaptive Gain Integrating Pixel Detector – AGIPD

- Focused on testing and integrating the 1st detector in our DAQ/control system before integration at SPB
- Integration of 2nd detector is progressing in parallel at DESY
- Characterization of new generation ASIC is in progress

Power System for AGIPD



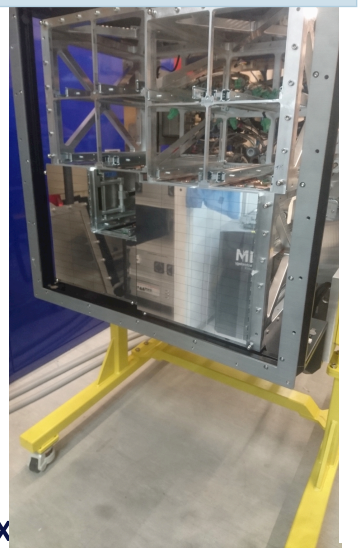
AGIPD Connected to Cooling System



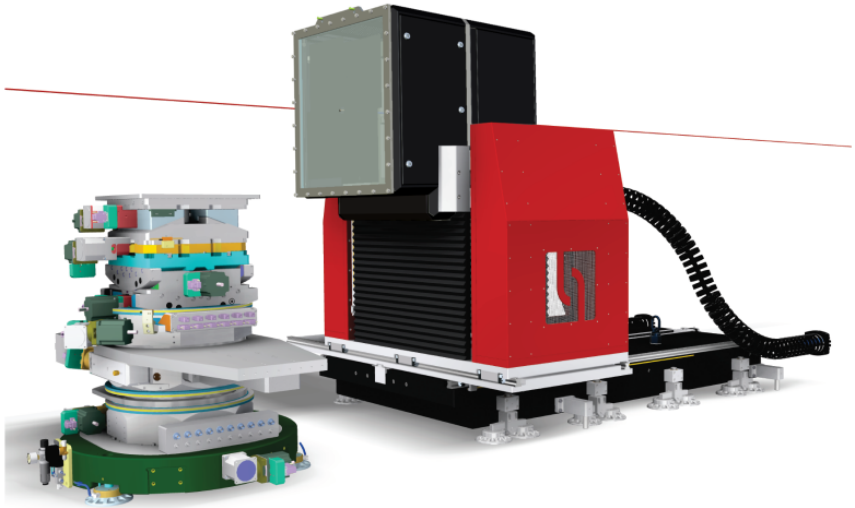
Large Pixel Detector – LPD

- Final steps of integration at RAL before transport to and start of testing phase at XFEL in February and integration at FXE
- Sensors tiles produced and under test
- Prototype detectors have seen several beam times
- In-house calibration measurements with LPD prototype systems at XFEL ongoing

LPD Housing and ½ Mpix Assembled



Final Installation of LPD at FXE

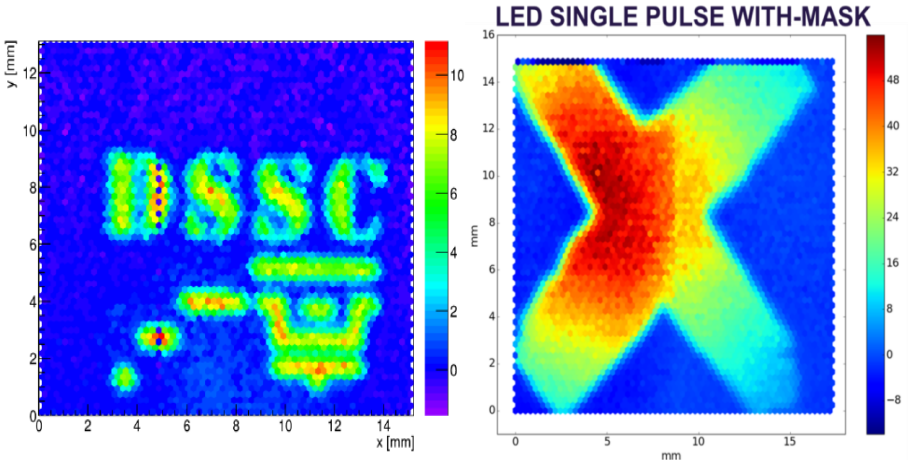


LPD ¼ Megapixel Detector at XFEL

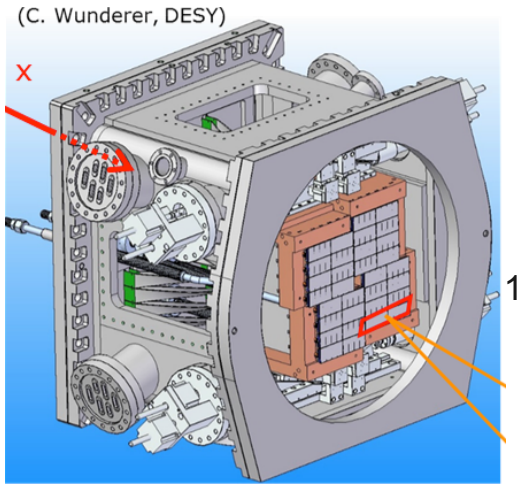
MiniSDD/DePFET Sensor with Signal Compression (DSSC)

- Project started one year later
- First X-ray light seen with several prototype detector systems end of 2016
- Collaboration is focused on building the first full size 1 Mpix camera based on MiniSDD sensors
- Full spec DEPFET based camera will follow later

First Images with 64 x 64 pixel^2 MiniSDD/DePFET Matrix

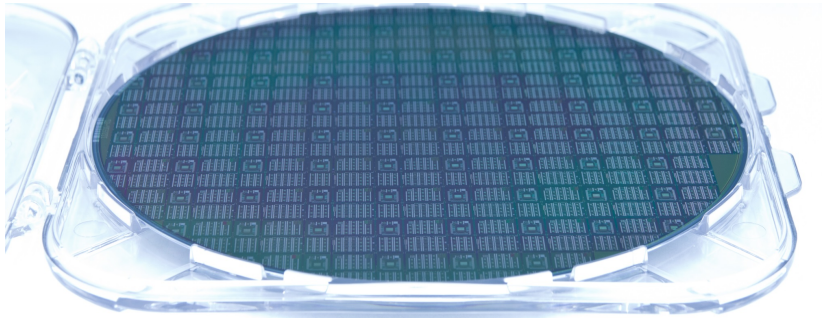


DSSC Mpix Detector



16 Ladder Modules
128 x 512 pixels
each

DePFET Sensors pnSensor/IMS (Future)



“Low Speed” Imagers for 10 Hz Applications

FastCCD

Detector arrived at XFEL

Beamline integration at SCS is in progress

Calibration is in progress

Ready for installation at experiment July 2017

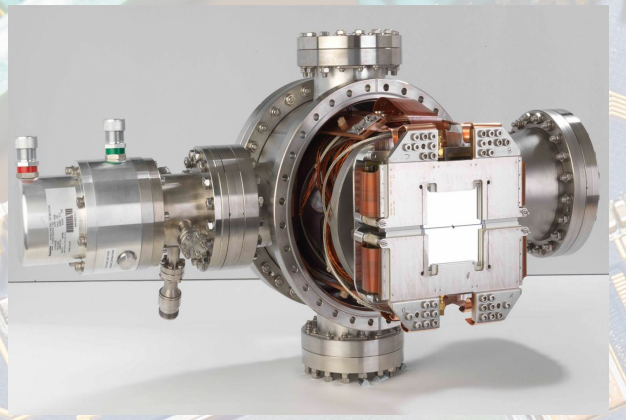
pnCCD

Option for soft- and hard X-ray imaging experiments.

Time scale for integration and commissioning 1 year.

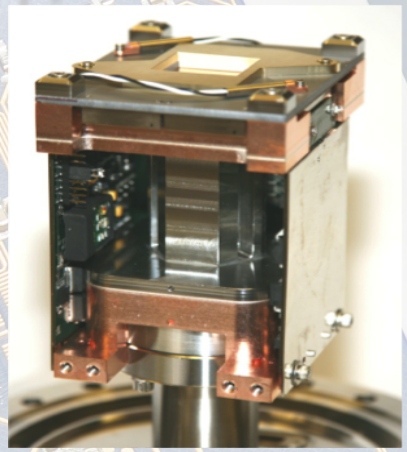
Primary experiments
SQS and SCS

pnCCD



Energy Range
0.03 – 25 keV
Pixel Size 75 x 75 µm^2
1024 x 1024 Pixels^2
Dynamic Range
6000 ph@1.keV
Frame Rate
up to 150 Hz
Noise
6 e$^-$ at high gain

FastCCD



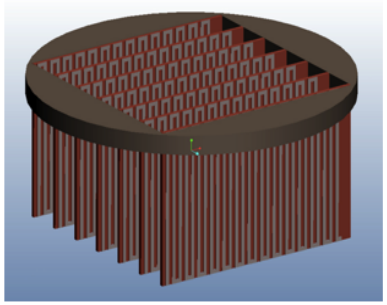
Energy Range
0.25 – 6 keV
Pixel Size 30 x 30 µm^2
1920 x 960 Pixels^2
Dynamic Range
Approx. 350 ph@1 keV
Frame Rate
up to 200 Hz
Noise
25 e$^-$ at high gain

PNSensor

BERKELEY LAB

Other Detectors for the European XFEL

MCP with Delay Line Readout



4.5 MHz

Energy Range
0.25 – 2 keV

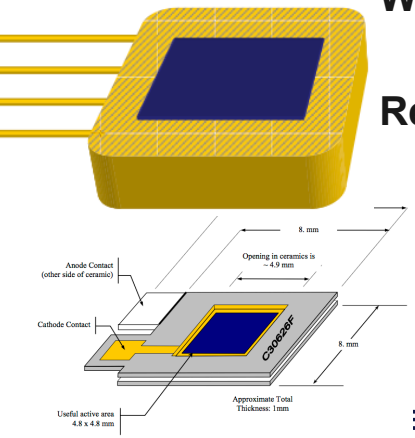
Dynamic Range
Max. 100 ph/pulse

Single Photon Sens.
Yes

Memory None

Pixel Size ≈50×156 μm²

Si Avalanche Photo Diodes (Excelitas)



Wave Length Range
340 – 1000 nm

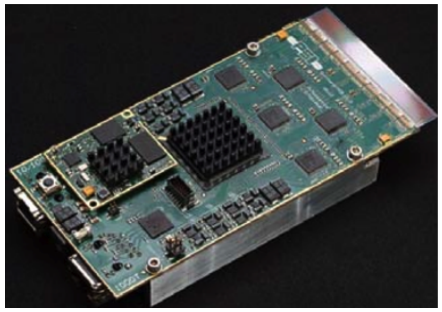
Responsibility
22 A/W @ 900 nm (peak)

Rise Time
5 ns

Single Photon Sens.
Yes

Active Area 4.8×4.8 cm²

Gotthard V2



4.5 MHz

Energy Range
3 – 13 (25) keV

Dynamic Range
10^4 ph/px/pulse@12 keV

Single Photon Sens.
Yes

Memory 2700 images

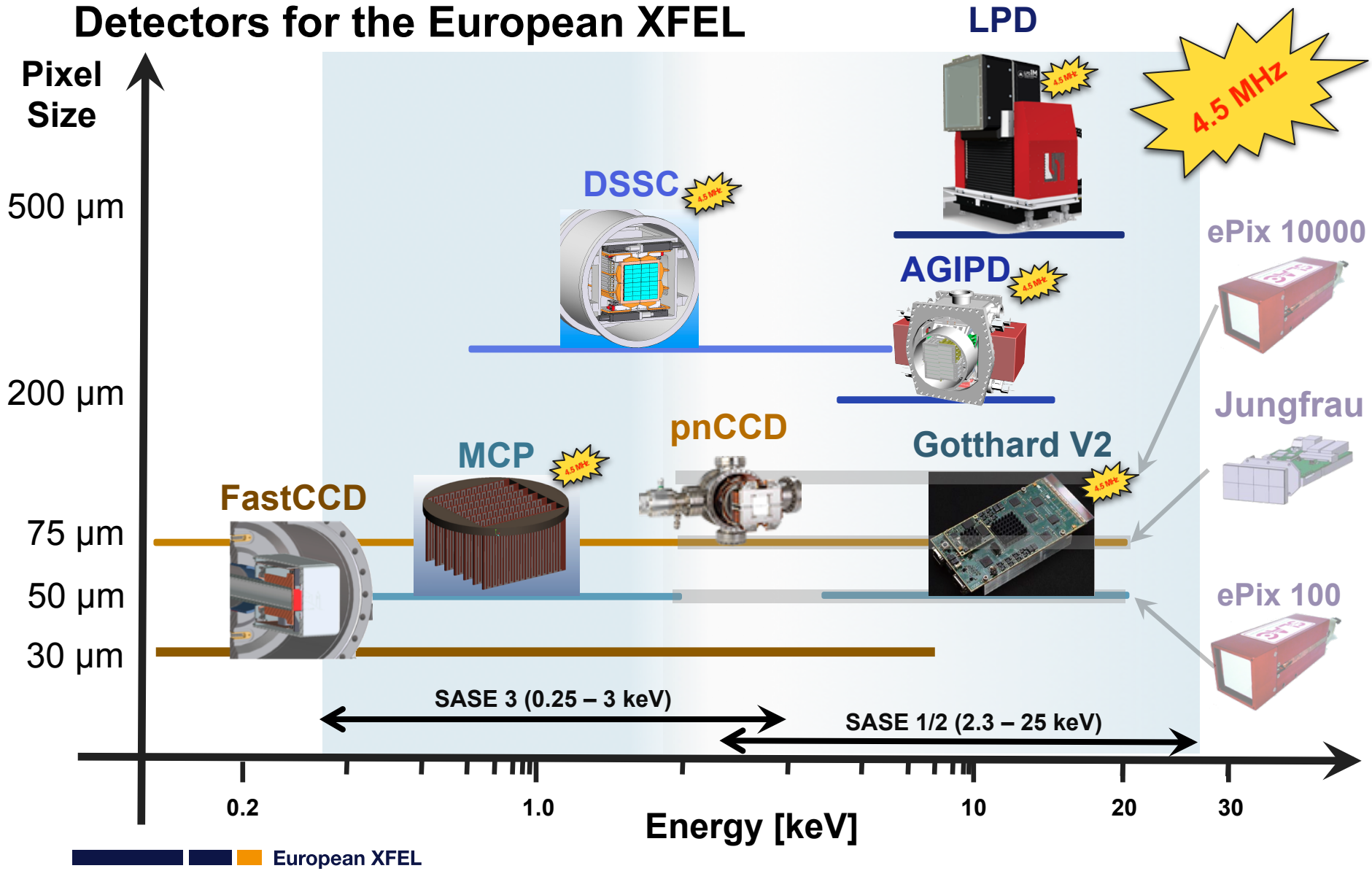
Strips 1280 25/50 μm²

Veto Capability
Yes

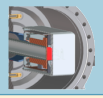
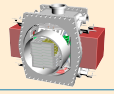
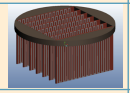
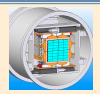
On day-1 Gotthard V1 will be available

… and more to come in the near future …

Detectors for the European XFEL



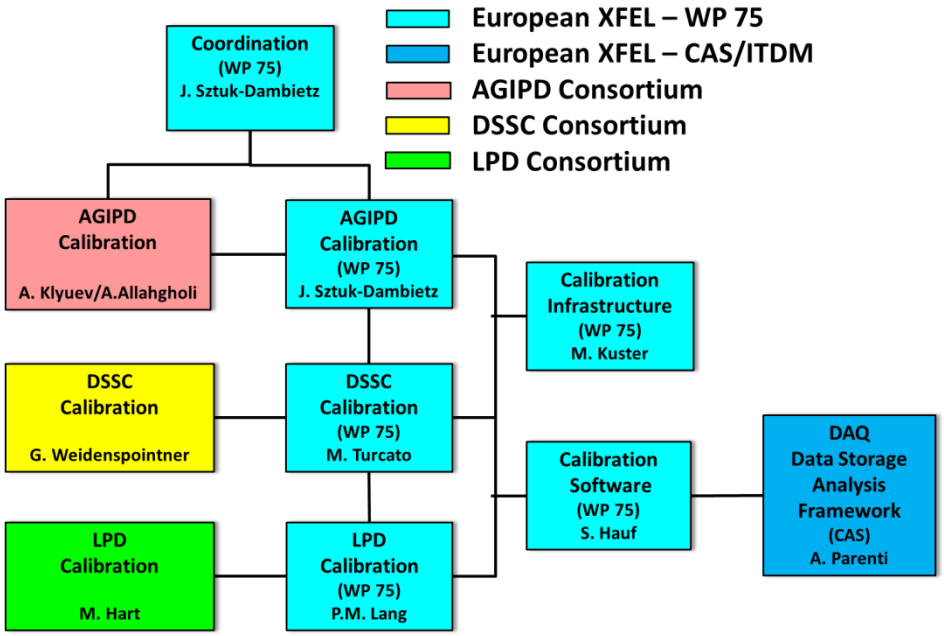
Detectors – Timeline and Status

Detector System	Beam Line	Scientific Instrument	Project Status	Arrival at XFEL	Ready for Installation at Experiment
AGIPD 	SASE I	SPB	DAQ/Control Integration	December 2016	May 2017
LPD 	SASE I	FXE	Integration/ Testing	February 2017	June 2017
FastCCD 	SASE III	SCS	DAQ/Control Integration	May 2016	July 2017
AGIPD 	SASE II	MID	Integration	February 2017	September 2017
Gotthard V2 	SASE I-III	FXE/HED/ MID/SPB/ Diagnostics	Development	February 2018	April 2018
DSSC MiniSDD 	SASE III	SCS	Development	February 2018	May 2018
MCP DLD 	SASE III	SQS	Development	February 2017	
DSSC DEPFET 	SASE III	SCS/SQS	Development	Sensors available 2017	

External

Development → Integration → Testing → Commissioning Calibration DAQ/Control Integration → End-2-End Test → at XFEL: Beam Line Integration Commissioning → User Operation

Calibration Working Group (since 2012)



Gotthard
MCP
pnCCD
FastCCD
…

- Who?
  - Calibration experts from development groups
  - XFEL calibration and software groups
  - Involvement of beam line scientists

- **What is it about?**
  - Conversion of detector signals (AU) to physical quantity
- **Why?**
  - Well calibrated detectors
    - ► high quality scientific results
- **What?**
  - Coordinate calibration activities
  - Define and build calibration infrastructure at XFEL
  - Calibrate detectors and maintain calibration data base (QA)
  - Develop and provide user friendly software tools to apply calibration

Data Correction and Calibration – Parameter Space

Example LPD
x 512 memory cells
x 1 million pixel
= 5 x 10^8 parameters
and
3 Gain Stages
2 Gain Settings
~ 10^9 parameters

Parameter Dependence
Temperature,
Integration time/sampling speed,
Irradiated dose,
Bias Voltage and …

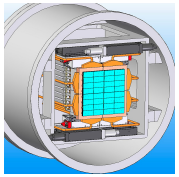
Conclusions

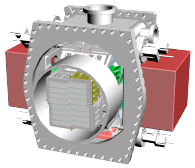
- Impossible to calibrate and commission many parameter combinations for first day of operation
  - Focus on most important operating conditions for day one
  - Need for data management and quality assurance

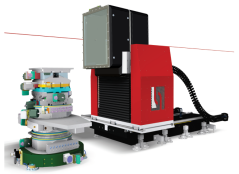
Day-one operation modes

Calibration Data Base

Base Line Detector Operation Modes – For Day One





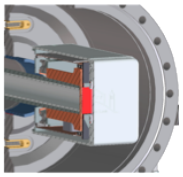


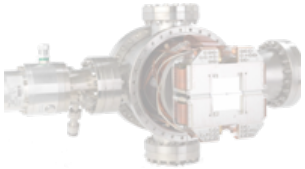
	DSSC			AGIPD			LPD		
	Mode I	**Mode II**	**Mode III**	**Mode I**	**Mode II**	**Mode III**	**Mode I**	**Mode II**	**Mode III**
Read Out Frequency	4.5 MHz			4.5 MHz			4.5 MHz		< 4.5 MHz
Photon Energy	1 keV	1.5 keV	0.7 keV	8.3 keV[#]	15 keV	7 keV	12 keV[*]	20 keV	12 keV[*]
Max # of ph/pulse/ pixel	3×10^3 @1keV (maximum achievable)			10^4 @12.4 keV (maximum achievable)			$> 10^4$ @12.4 keV (maximum achievable)		
Read Out Geometry	Full Frame			Full Frame			Full Frame		
Single Photon Sensitivity	No			Yes 0.15 ph RMS Noise		No	Yes 0.35 ph RMS Noise	Yes 0.21 ph RMS Noise	Yes[$] < 0.21 ph RMS Noise
Alignment Precision	1/10 of the pixel size (quadrant level)			1/10 of the pixel size			1/10 of the pixel size		
Veto Capability	Yes			Yes			Yes		
Memory	800 Cells (full memory)			352 Cells (full memory)			512 Cells (full memory)		

[#]Same performance is expected for 7 – 12 keV

[*]Same performance is expected for 7 – 9 keV
[$]Feasibility to be confirmed

Base Line Detector Operation Modes – For Day One

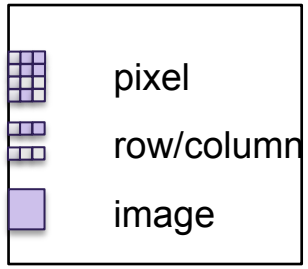
FastCCD 

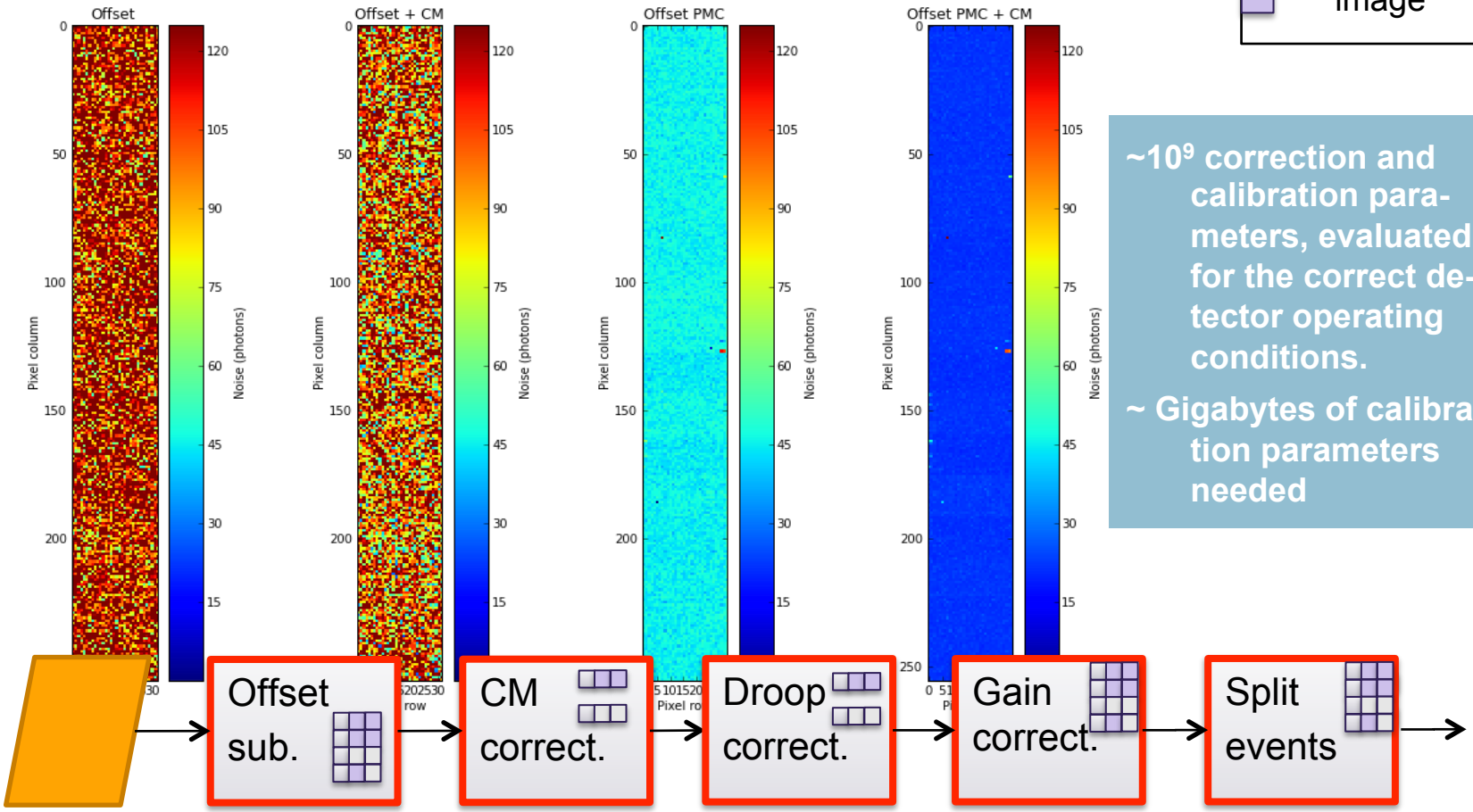
pnCCD 

	Mode I	Mode II	Mode III	Mode I
Read Out Frequency	10 Hz			10 Hz
Photon Energy	1 keV	1.5 keV	0.7 keV	0.05 – 20 keV (To be confirmed)
Max # of ph/pulse/ pixel	2.5×10^2 @1 keV (maximum achievable)			6000 @1 keV (maximum achievable)
Read Out Geometry	Full Frame			Full Frame
Single Photon Sensitivity	Yes			Yes
Alignment Precision	1/10 of the pixel size			To be defined
Veto Capability	Not available			Not available
Memory	Not available			Not available

Calibration Pipeline – Example LPD

In terms of e.g. offset correction the LPD is 1.5 Gpixel detector:
1 Mpix x 512 memory cells x 3 gains
→ “Offset Map” will have approx. 3 GB in size

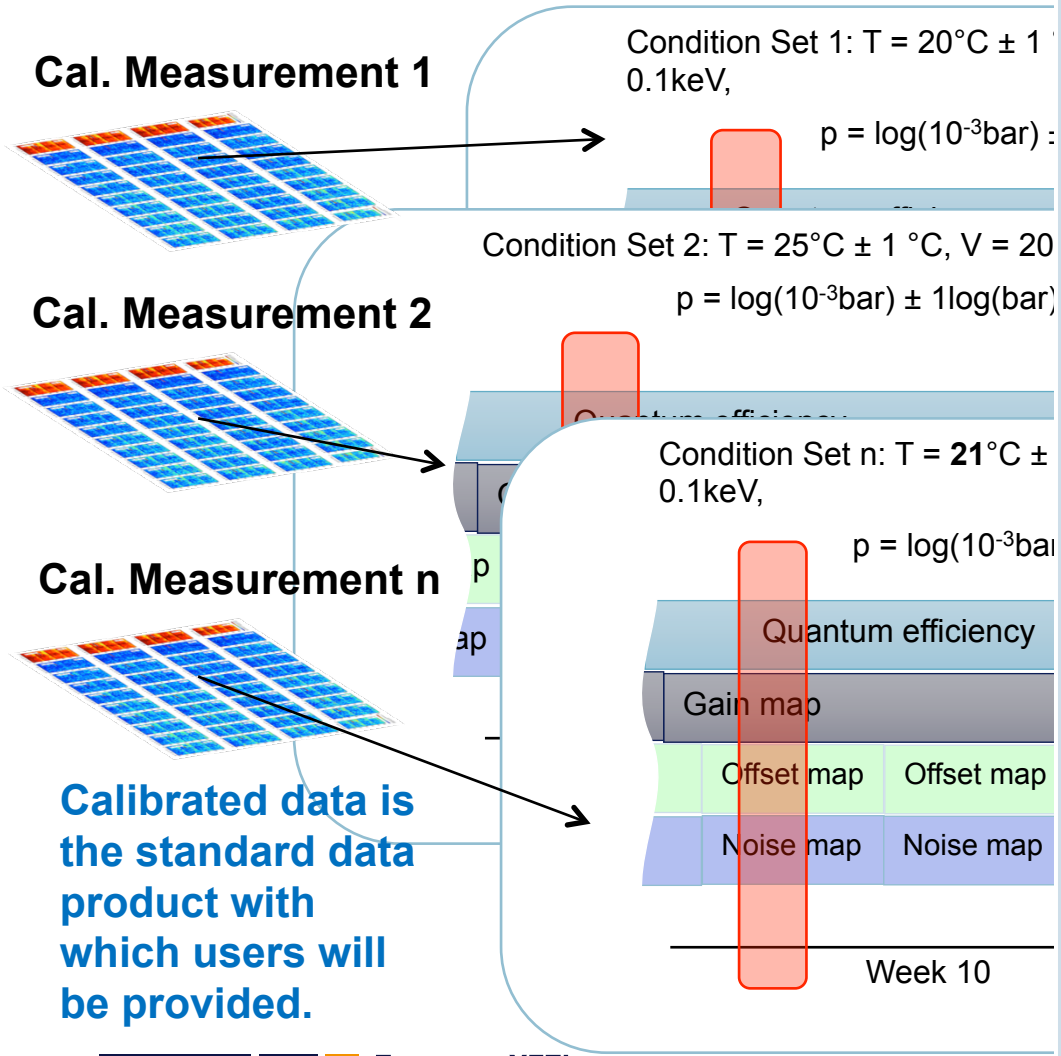




~10^9 correction and calibration parameters, evaluated for the correct detector operating conditions.

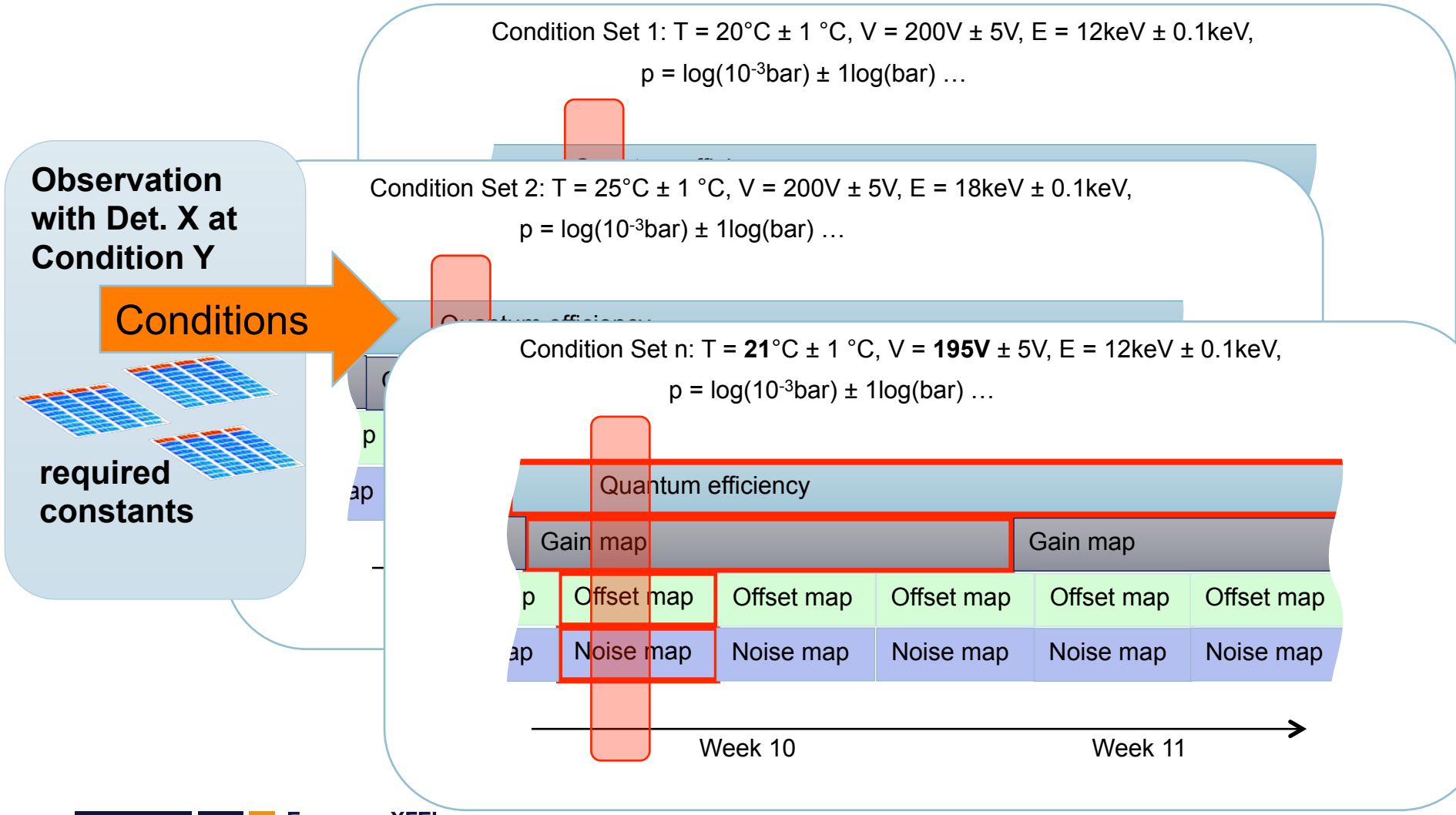
~ Gigabytes of calibration parameters needed

Calibration Data Base - CalDB

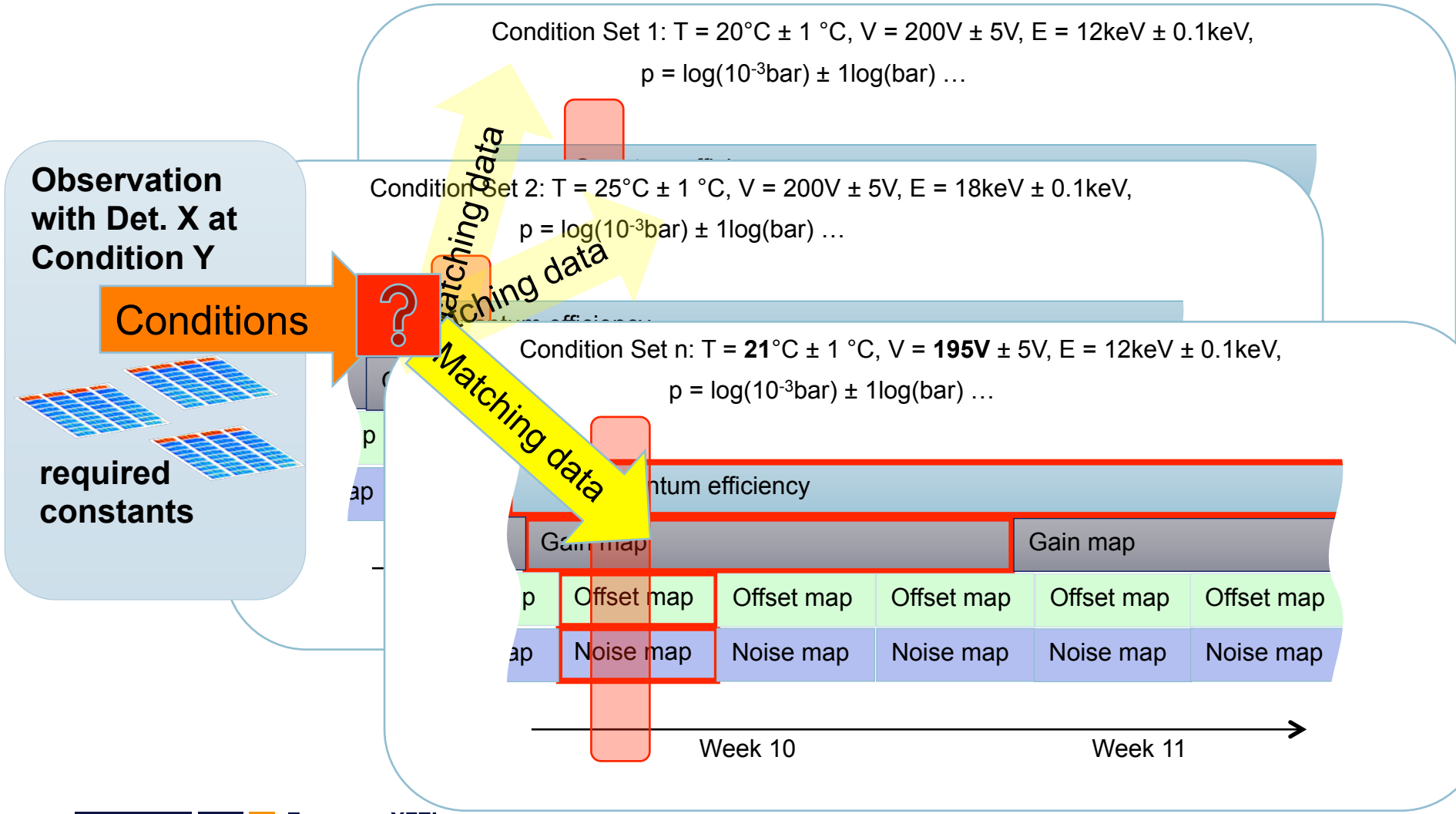


- Centralized storage and management of calibration data
  - Provide up-to-date data to user community (default)
  - Provide calibration data for specific scientific needs if required
- Karabo integrated user software interfaces
- Regular updates of calibration data if required
- History of calibration data → version management

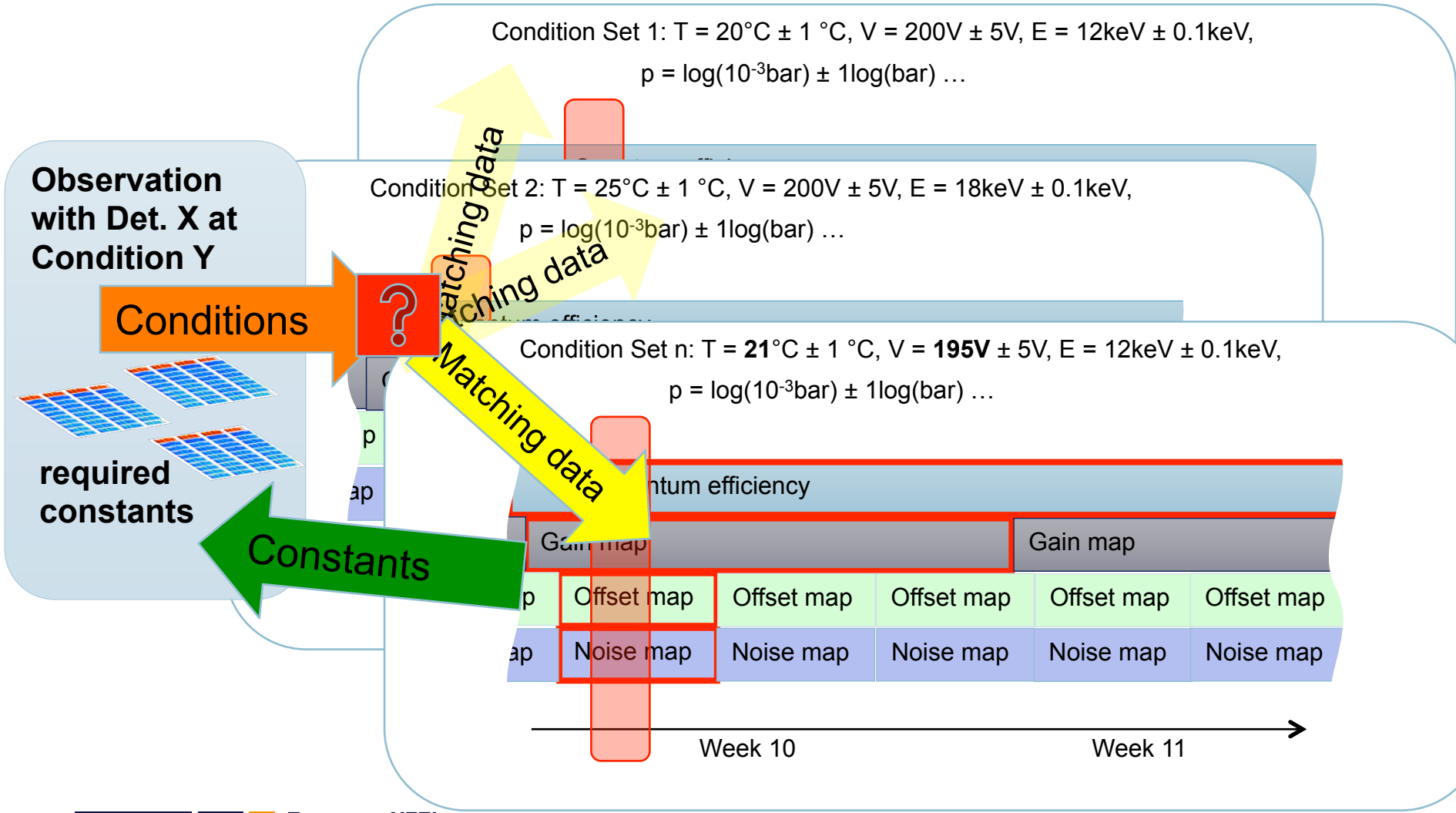
Calibration Data Base – CalDB Querying



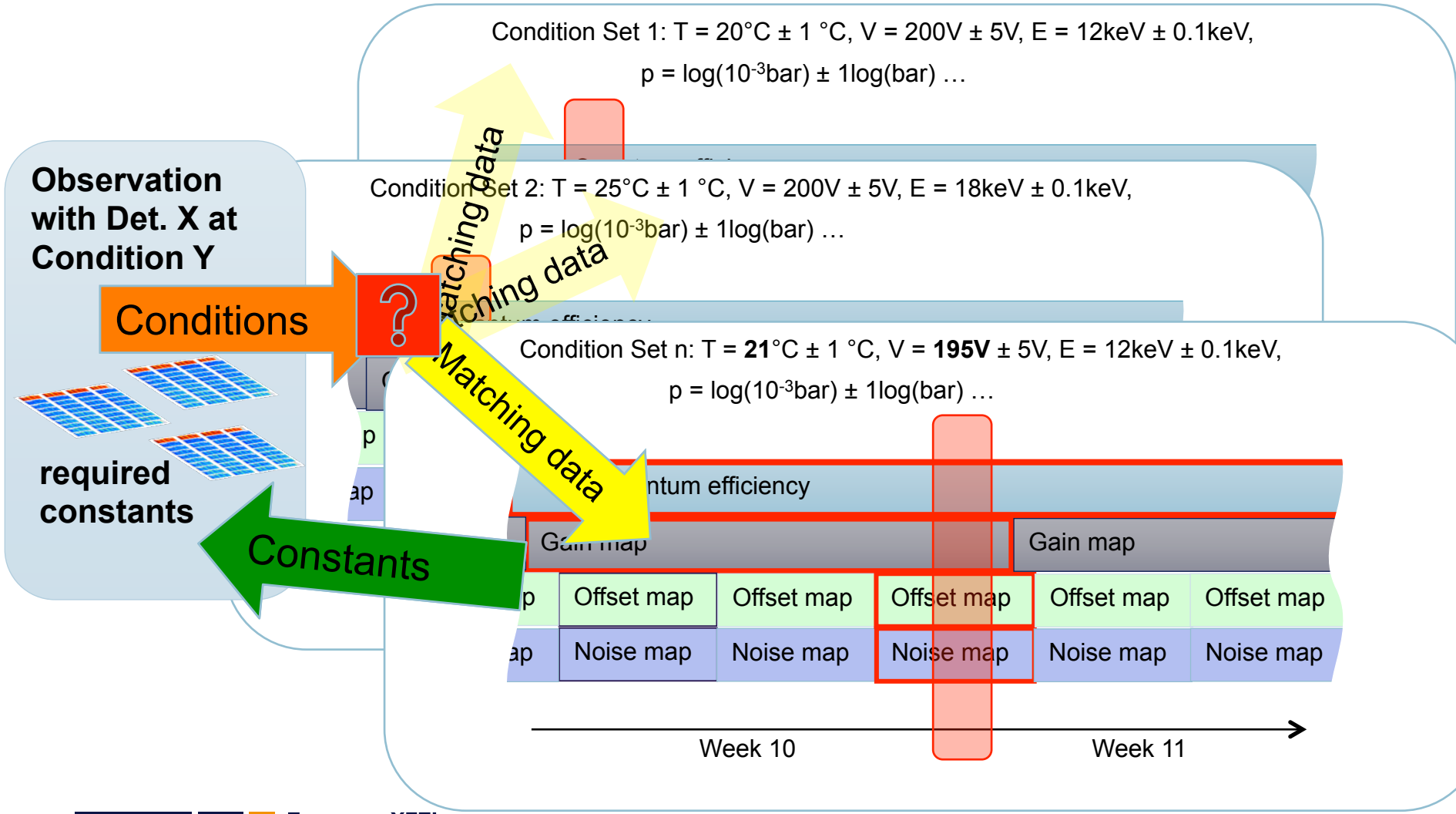
Calibration Data Base – CalDB Querying



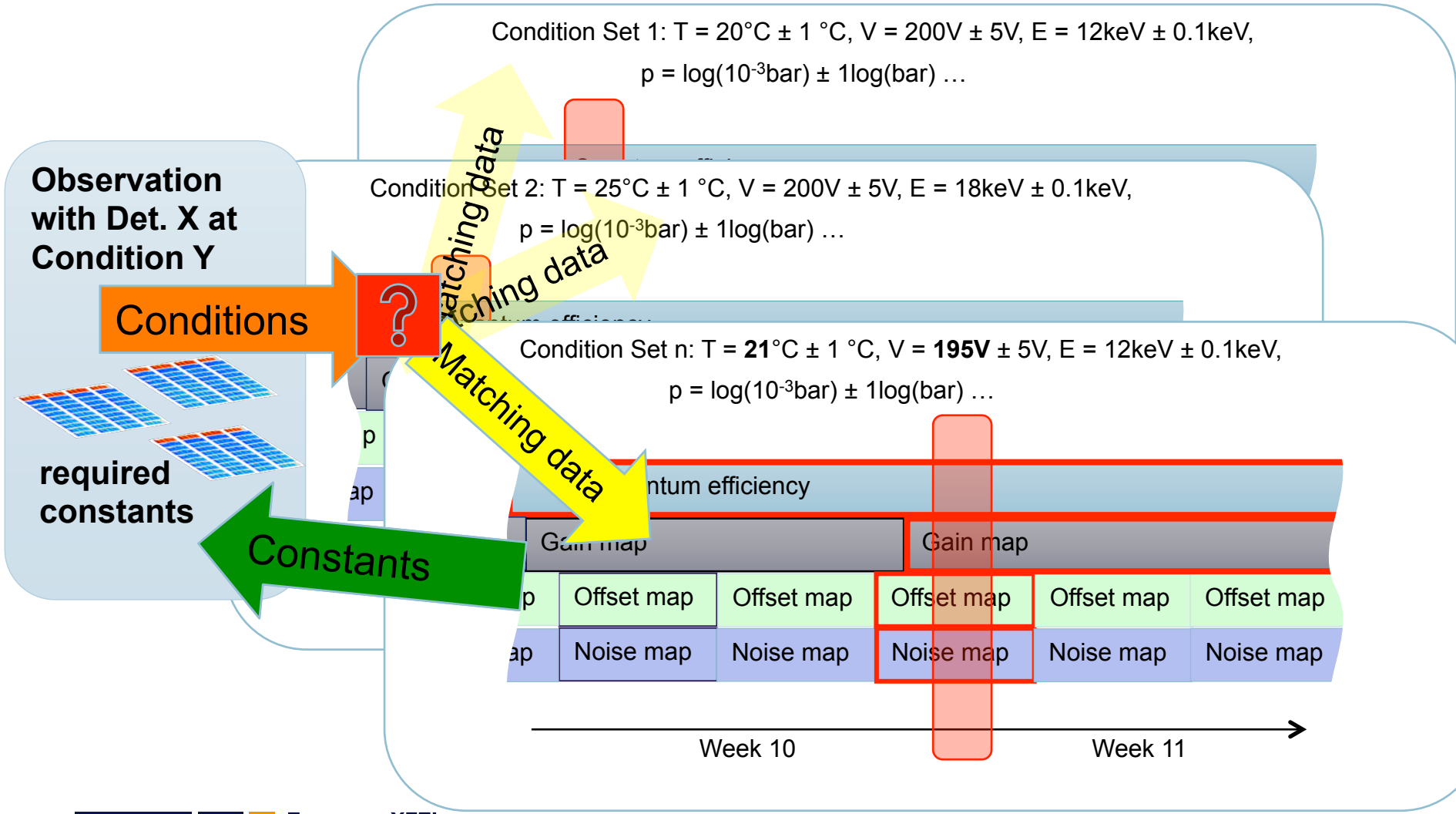
Calibration Data Base – CalDB Querying



Calibration Data Base – CalDB Querying



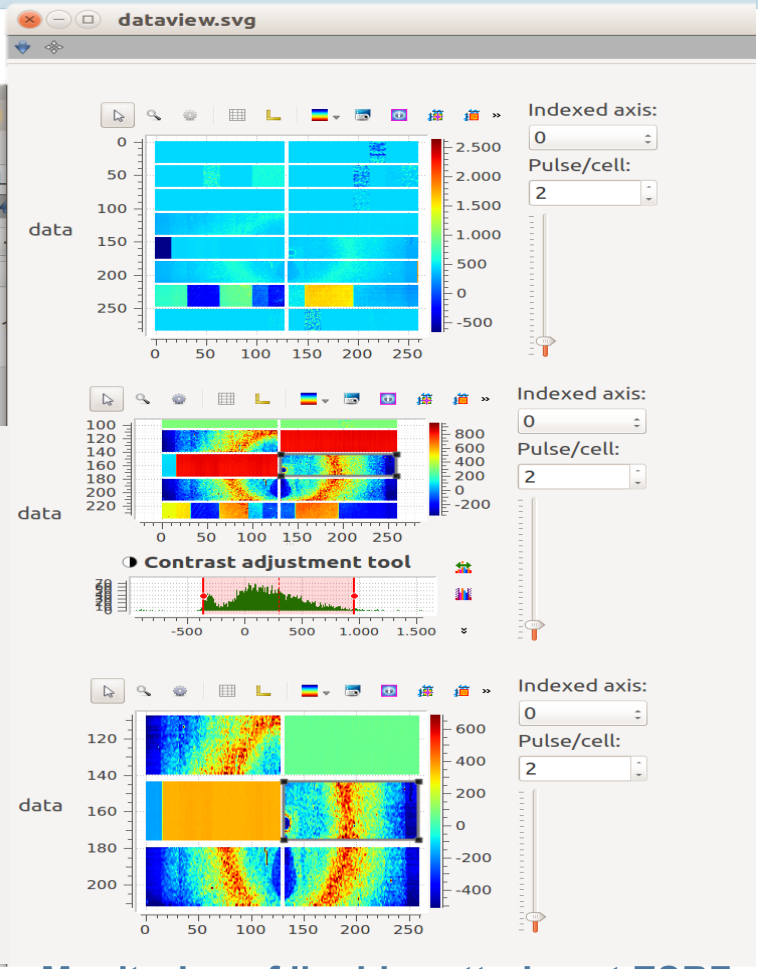
Calibration Data Base – CalDB Version Management



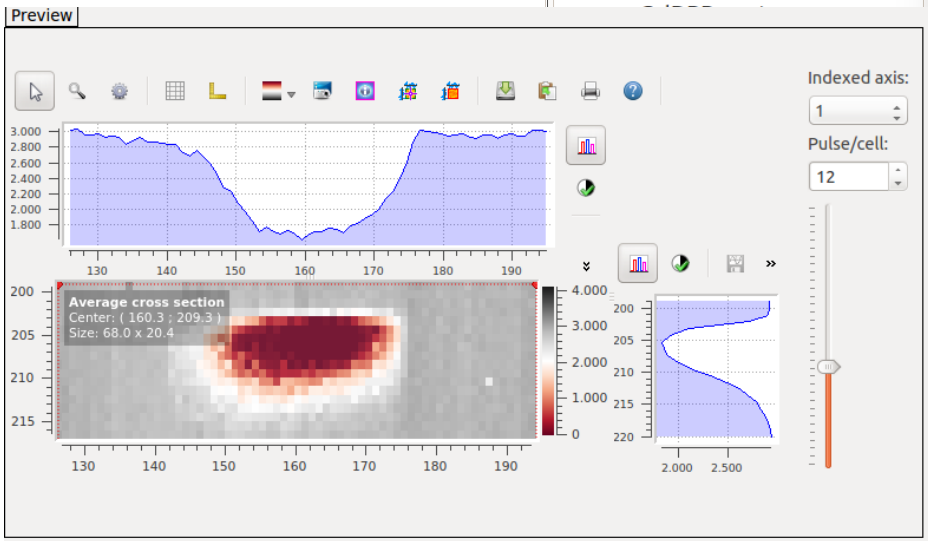
Karabo Based Control and Analysis Software

- Calibration and data processing pipeline, it is tested and has been used at several beam times
- Calibration data base CalDB is
- Detector control GUIs for real time monitoring

Correction/Online Visualisation Pipeline and Related GUIs for LPD/AGIPD/CCDs



Online view of APS direct beam on LPD



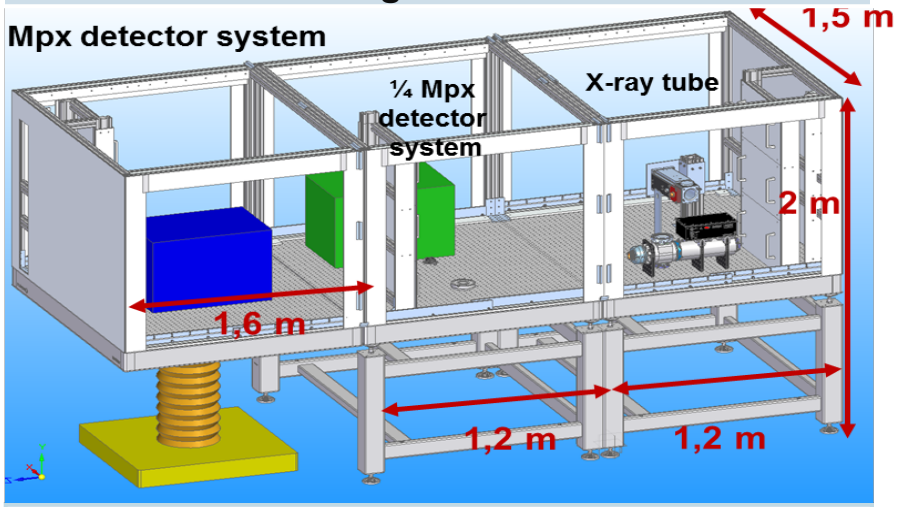
Online Monitoring of liquid scattering at ESRF

BYO – Bring Your Own Detector

- Contact instrument groups
- Calibration and test infrastructure for detectors exists, is under commissioning or operational
- Access for external groups is possible
  - contract detector group
- However: access to infrastructure is limited during commissioning phase and the first days of operation

Parameter of e-gun	Pulsed mode	DC mode
Electron energy	1 - 20 keV	1 - 20 keV
Electron beam current	10 μA - 20 mA	10 μA – 6 mA
Beam diameter	0.15 - 10 mm	0.1 - 10 mm
Pulsed beam parameters	τ = 25 -150 ns -XFEL burst mode	n.a.

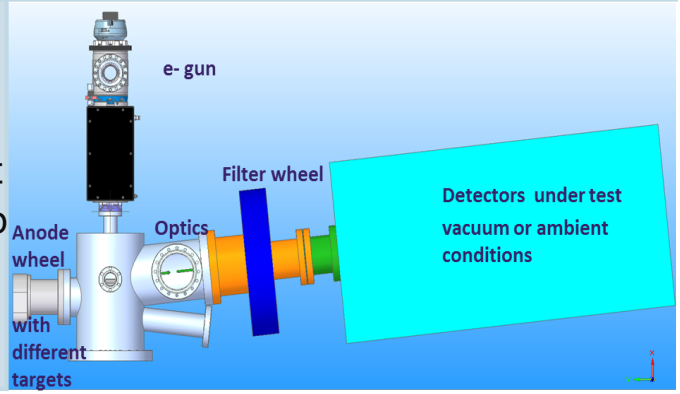
Modular setup for ambient detectors
Big Amber



High power X-ray tubes: (V<60 kV and P<1.6-2 kW), photon energy Cu 8 keV (Cu-K) and 17 keV (Mo-K)

+ Polycapillary focusing optics

Pulsed Multi-target X-ray Setup **PulXar**



There will be a bright light at the end of the tunnel …