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**

- e⁻ Bunch Train
  - 2700 Pulses 600 µs
  - 99.3 ms
- X-ray Photons
  - 220 ns
  - < 100 fs

Selected proposals
- Adaptive Gain Integrating Pixel Detector
- Large Pixel Detector
- DEPFET Sensor with Signal Compression
European XFEL Fast 2D Imagers – Hybrid Pixel Detectors

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

**Pixelated Silicon Sensor**
- p-type silicon layer
- high resistivity n-type silicon
- aluminium layer
- flip chip bonding with solder bumps
- single pixel read-out cell

**Pixelated Readout Chip (ASIC)**
- Analog or digital memory
  - Capacity up to 800 cells/pixel
- Veto and trigger capability
  - Overwrite empty images
European XFEL Fast 2D Imagers

Adaptive Gain Integrating Pixel Detector (AGIPD)

- **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

Large Pixel Detector (LPD)

- **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

MiniSDD Sensor with Signal Compression (DSSC)

- **Energy Range**: 0.5 – 6 (25) keV
- **Dynamic Range**: ≈100 ph/px/pulse@1 keV
- **Single Photon Sens.**: Yes
- **Memory**: ≈800 images
- **Pixel Size**: 236×236 µm²

DePFET Sensor with Signal Compression (DSSC)

- **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)

- 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

Large Pixel Detector (LPD)

- 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

MiniSDD Sensor with Signal Compression (DSSC)

- 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

DePFET Sensor with Signal Compression (DSSC)

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

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

DSSC Mpix Detector

(C. Wunderer, DESY)

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

DePFET Sensors pnSensor/IMS (Future)

16 Ladder Modules
128 x 512 pixels each
“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

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**pnCCD**
Energy Range
0.03 – 25 keV
Pixel Size
75 x 75 µm²
1024 x 1024 Pixels
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 µm²
1920 x 960 Pixels
Dynamic Range
Approx. 350 ph@1 keV
Frame Rate
up to 200 Hz
Noise
25 e⁻ at high gain
Other Detectors for the European XFEL

MCP with Delay Line Readout

- 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

- Energy Range: 3 – 13 (25) keV
- Dynamic Range: 10⁴ 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

Pixel Size

- 500 µm
- 200 µm
- 75 µm
- 50 µm
- 30 µm

Energy [keV]

- 0.2
- 1.0
- 10
- 20
- 30

Detectors:
- DSSC
- AGIPD
- LPD
- pnCCD
- Gotthard V2
- FastCCD
- Jungfrau
- ePix 10000
- ePix 100

SASE 3 (0.25 – 3 keV)
SASE 1/2 (2.3 – 25 keV)

Gotthard V2

4.5 MHz

European XFEL
# Detectors – Timeline and Status

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

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

European XFEL
Calibration Working Group (since 2012)

**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

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

<table>
<thead>
<tr>
<th></th>
<th>DSSC</th>
<th>AGIPD</th>
<th>LPD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DSSC</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>AGIPD</strong></td>
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<td><strong>AGIPD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LPD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Read Out Frequency</strong></td>
<td>4.5 MHz</td>
<td>4.5 MHz</td>
<td>4.5 MHz</td>
</tr>
<tr>
<td><strong>Photon Energy</strong></td>
<td>1 keV, 1.5 keV, 0.7 keV</td>
<td>8.3 keV, 15 keV, 7 keV</td>
<td>12 keV, 20 keV, 12 keV</td>
</tr>
<tr>
<td><strong>Max # of ph/pulse/pixel</strong></td>
<td>$3 \times 10^3 \times 1 \text{keV}$ (maximum achievable)</td>
<td>$10^4 \times 12.4 \text{keV}$ (maximum achievable)</td>
<td>$&gt; 10^4 \times 12.4 \text{keV}$ (maximum achievable)</td>
</tr>
<tr>
<td><strong>Read Out Geometry</strong></td>
<td>Full Frame</td>
<td>Full Frame</td>
<td>Full Frame</td>
</tr>
<tr>
<td><strong>Single Photon Sensitivity</strong></td>
<td>No</td>
<td>Yes, 0.15 ph RMS Noise</td>
<td>No</td>
</tr>
<tr>
<td><strong>Alignment Precision</strong></td>
<td>1/10 of the pixel size (quadrant level)</td>
<td>1/10 of the pixel size</td>
<td>1/10 of the pixel size</td>
</tr>
<tr>
<td><strong>Veto Capability</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Memory</strong></td>
<td>800 Cells (full memory)</td>
<td>352 Cells (full memory)</td>
<td>512 Cells (full memory)</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th></th>
<th>Mode I</th>
<th>Mode II</th>
<th>Mode III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Out Frequency</td>
<td>10 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photon Energy</td>
<td>1 keV</td>
<td>1.5 keV</td>
<td>0.7 keV</td>
</tr>
<tr>
<td>Max # of ph/pulse/pixel</td>
<td>$2.5 \times 10^2 \text{ @1 keV}$ (maximum achievable)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read Out Geometry</td>
<td>Full Frame</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Photon Sensitivity</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alignment Precision</td>
<td>1/10 of the pixel size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Veto Capability</td>
<td>Not available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>Not available</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### pnCCD

<table>
<thead>
<tr>
<th></th>
<th>Mode I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Out Frequency</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Photon Energy</td>
<td>0.05 – 20 keV (To be confirmed)</td>
</tr>
<tr>
<td>Max # of ph/pulse/pixel</td>
<td>6000 @1 keV (maximum achievable)</td>
</tr>
<tr>
<td>Read Out Geometry</td>
<td>Full Frame</td>
</tr>
<tr>
<td>Single Photon Sensitivity</td>
<td>Yes</td>
</tr>
<tr>
<td>Alignment Precision</td>
<td>To be defined</td>
</tr>
<tr>
<td>Veto Capability</td>
<td>Not available</td>
</tr>
<tr>
<td>Memory</td>
<td>Not available</td>
</tr>
</tbody>
</table>

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**Notes:**
- FastCCD
  - Mode I: 10 Hz, 1 keV, $2.5 \times 10^2 \text{ @1 keV}$ (maximum achievable), Full Frame, Yes, 1/10 of the pixel size, Not available, Not available
- Mode II: Not defined
- Mode III: Not available

**pnCCD**
- Mode I: 10 Hz, 0.05 – 20 keV (To be confirmed), 6000 @1 keV (maximum achievable), Full Frame, Yes, To be defined, 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

Cal. Measurement 1

Condition Set 1: $T = 20 ^\circ C \pm 1 \, ^\circ C$, $V = 200V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$

Cal. Measurement 2

Condition Set 2: $T = 25 ^\circ C \pm 1 \, ^\circ C$, $V = 200V \pm 5V$, $E = 18keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$

Cal. Measurement n

Condition Set n: $T = 21 ^\circ C \pm 1 \, ^\circ C$, $V = 195V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$

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

Calibrated data is the standard data product with which users will be provided.
Calibration Data Base – CalDB Querying

Condition Set 1: $T = 20^\circ C \pm 1^\circ C$, $V = 200V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ …

Condition Set 2: $T = 25^\circ C \pm 1^\circ C$, $V = 200V \pm 5V$, $E = 18keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ …

Condition Set n: $T = 21^\circ C \pm 1^\circ C$, $V = 195V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ …

Quantum efficiency

Gain map

Offset map

Noise map

Week 10

Week 11
Calibration Data Base – CalDB Querying

Condition Set 1: $T = 20^\circ C \pm 1^\circ C$, $V = 200V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}bar) \pm 1\log(bar)$ ...

Condition Set 2: $T = 25^\circ C \pm 1^\circ C$, $V = 200V \pm 5V$, $E = 18keV \pm 0.1keV$, $p = \log(10^{-3}bar) \pm 1\log(bar)$ ...

Condition Set n: $T = 21^\circ C \pm 1^\circ C$, $V = 195V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}bar) \pm 1\log(bar)$ ...

Observation with Det. X at Condition Y

Conditions

required constants
Calibration Data Base – CalDB Querying

Condition Set 1: $T = 20^\circ C \pm 1^\circ C$, $V = 200V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ ...

Condition Set 2: $T = 25^\circ C \pm 1^\circ C$, $V = 200V \pm 5V$, $E = 18keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ ...

Condition Set n: $T = 21^\circ C \pm 1^\circ C$, $V = 195V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ ...

Observation with Det. X at Condition Y

Matching Data

Conditions

required constants

Constants
Calibration Data Base – CalDB Querying

Condition Set 1: $T = 20^\circ C \pm 1^\circ C$, $V = 200V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ …

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Condition Set n: $T = 21^\circ C \pm 1^\circ C$, $V = 195V \pm 5V$, $E = 12keV \pm 0.1keV$, $p = \log(10^{-3}\text{bar}) \pm 1\log(\text{bar})$ …

Observation with Det. X at Condition Y

Matching data

Constants

Matching data

Observers

Conditions

required constants

European XFEL
Calibration Data Base – CalDB Version Management

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 10</td>
<td>Week 11</td>
</tr>
</tbody>
</table>

## Condition Set 1
- **T**: 20°C ± 1°C
- **V**: 200V ± 5V
- **E**: 12keV ± 0.1keV
- **p**: log(10^{-3}bar) ± 1log(bar) …

## Condition Set 2
- **T**: 25°C ± 1°C
- **V**: 200V ± 5V
- **E**: 18keV ± 0.1keV
- **p**: log(10^{-3}bar) ± 1log(bar) …

## Condition Set n
- **T**: 21°C ± 1°C
- **V**: 195V ± 5V
- **E**: 12keV ± 0.1keV
- **p**: log(10^{-3}bar) ± 1log(bar) …
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

<table>
<thead>
<tr>
<th>Parameter of e-gun</th>
<th>Pulsed mode</th>
<th>DC mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy</td>
<td>1 - 20 keV</td>
<td>1 - 20 keV</td>
</tr>
<tr>
<td>Electron beam current</td>
<td>10 μA - 20 mA</td>
<td>10 μA – 6 mA</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>0.15 - 10 mm</td>
<td>0.1 - 10 mm</td>
</tr>
<tr>
<td>Pulsed beam parameters</td>
<td>τ = 25 -150 ns</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

**Modular setup for ambient detectors**

**Big Amber**

- Mpx detector system
- X-ray tube
- ¼ Mpx detector system

**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**

- e-gun
- Anode wheel
- Optics
- Filter wheel
- Detectors under test
- Vacuum or ambient conditions

European XFEL
There will be a bright light at the end of the tunnel ... take care that you will see it.

... and we ...

Thank you for your attention!