MHz X-ray imaging with Silicon Pixel Detectors

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on behalf of the Detector Group of European XFEL

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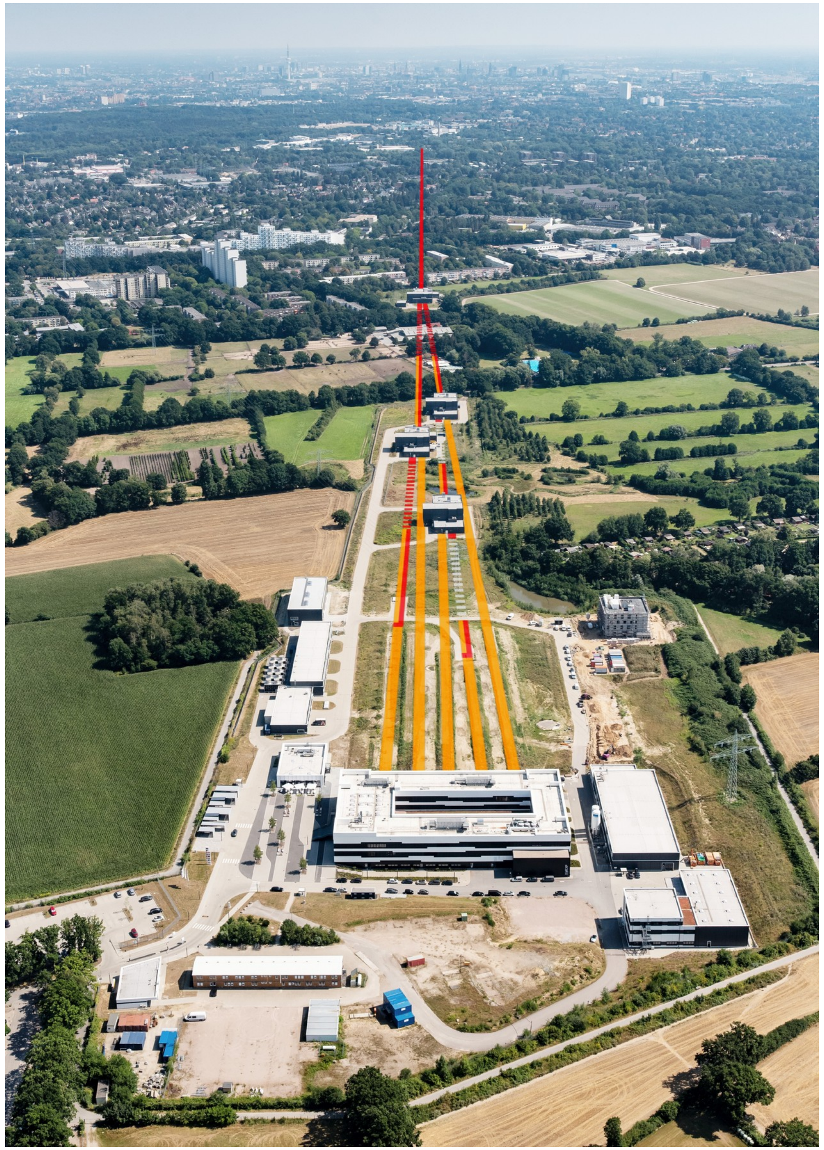
Outline

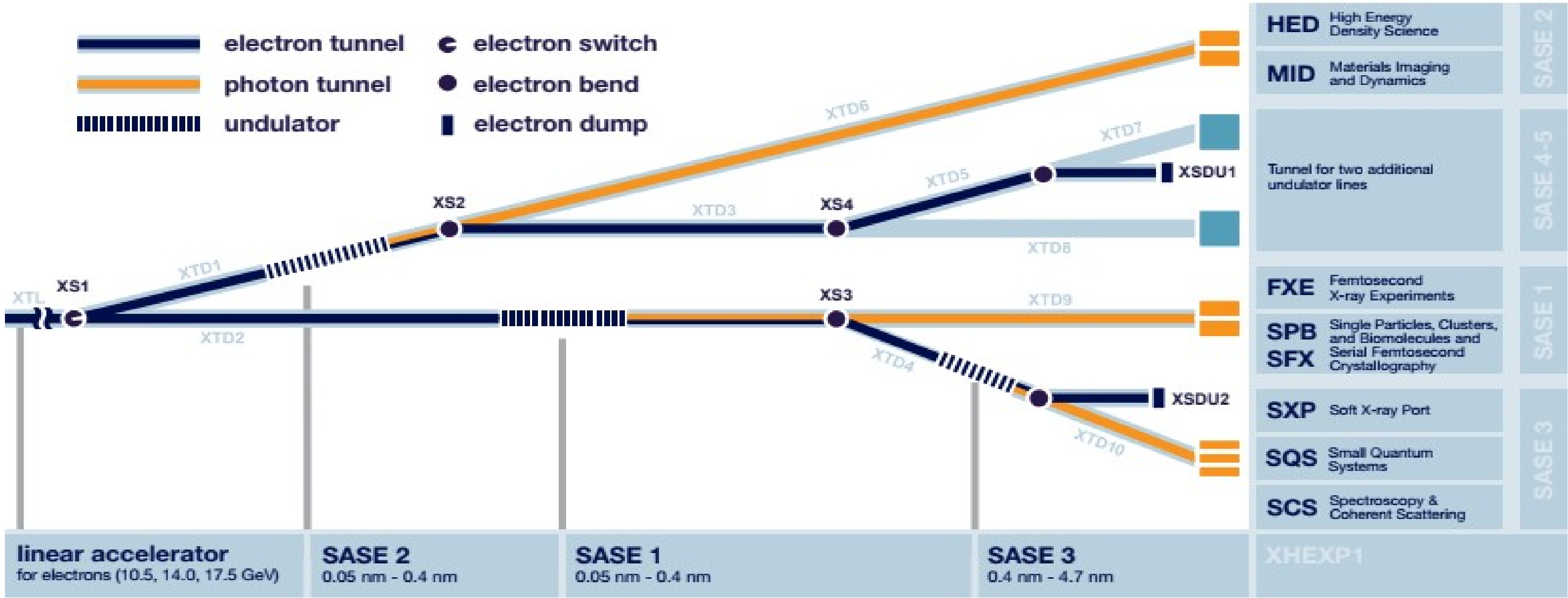
- Introduction
  - The European XFEL beam
  - Experiments at EuXFEL
- Detector Requirements
- How to deal with high dynamic range
  - Dynamic gain switching (AGIPD)
  - Non-linear response (DEPFET DSSC)
- MHz burst mode operation
  - Analog storage cells (AGIPD)
  - On-chip analog-to-digital conversion (DSSC)
- Raw data correction at European XFEL
- Conclusions

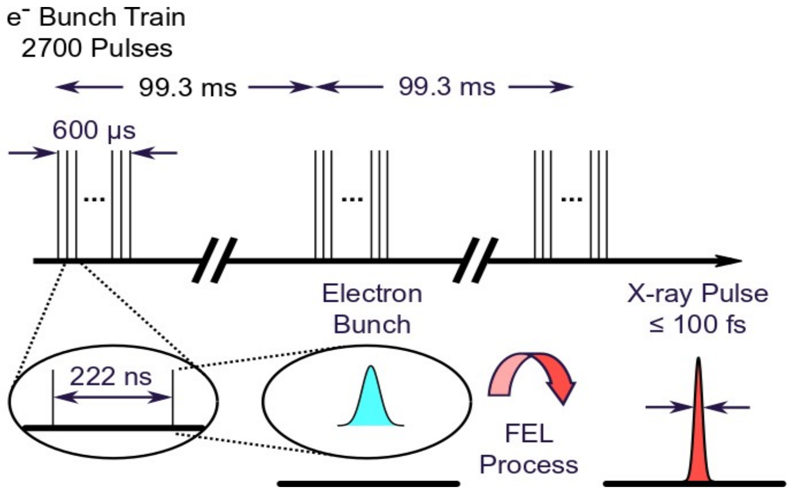


Acknowledgment

- AGIPD Consortium (H. Graafsma)
  - DESY, PSI, Uni Bonn, Uni Hamburg
- DSSC collaboration (M. Porro)
  - EuXFEL, DESY, PoliMi, Uni BG, Uni Heidelberg, pnSensor, MPG-HLL, INFN
- European XFEL
  - Data Department (S. Aplin)
    - ► **DET Group**, CTRL, 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)

Introduction: European XFEL



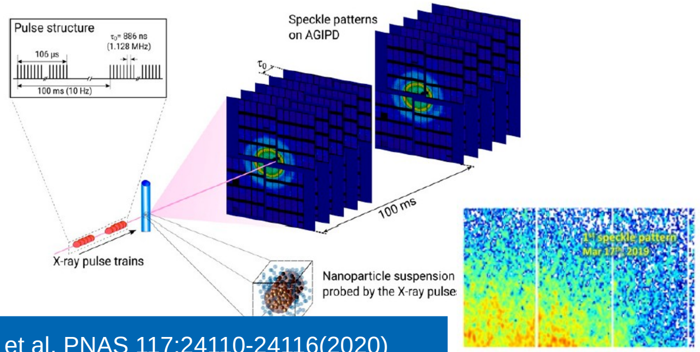


- Three main undulator systems (SASE 1, 2, 3)
  - Supply seven scientific instruments
  - SPB/SFX, FXE, MID, HED (‘hard X-ray’)
    - ► 6 keV < E < 25 keV
  - SCS, SQS, SXP (‘soft X-ray’)
    - ► 0.25 keV < E < 3 keV

- 10 Hz train rate
- Bunch train internal structure
  - **2700 pulses** for 600 μs
  - **4.5 MHz pulse rate** (~222 ns spaced)
  - Lasing pulses < 100 fs width
- **Pulses of ~ 10^{14} photons**
  - Most experiments are pulse-resolved
  - Detectors need to cope with bunch train structure

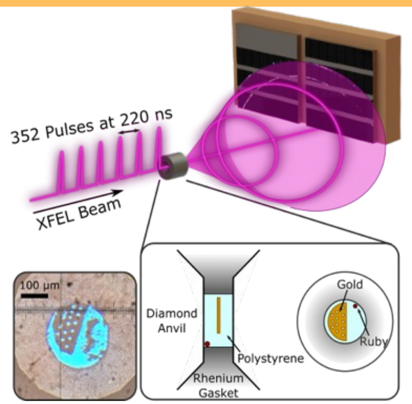
Introduction: experiments

MHz XPCS to look at system dynamics



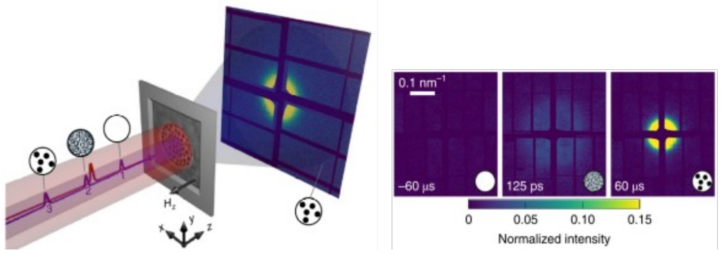
Lehmkühler et al. PNAS 117:24110-24116(2020)

Study of materials in extreme conditions



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

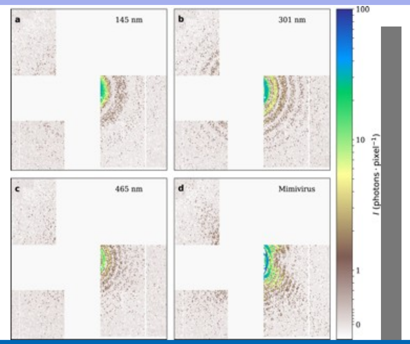
X-ray scattering experiments



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

Single-particle imaging

Examples of scattering patterns from IrCl3 and Mimivirus.

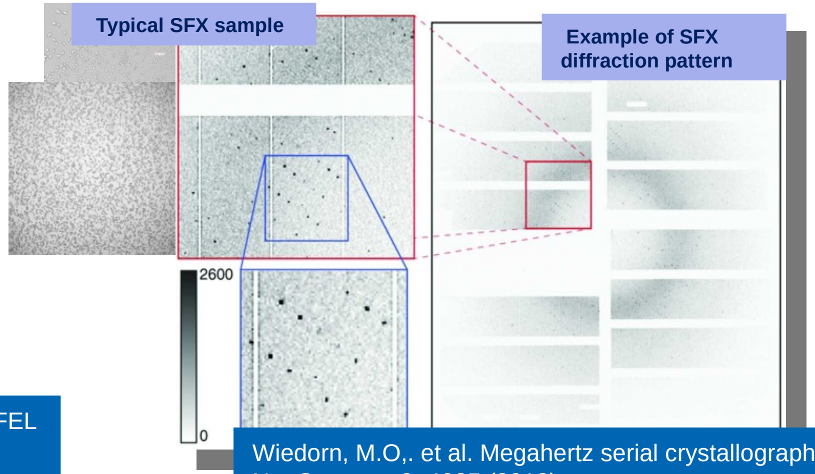


Sobolev, E. et al. Megahertz single-particle imaging at the European XFEL Commun Phys 3, 97 (2020)

Serial femtosecond protein crystallography (SFX)

Typical SFX sample

Example of SFX diffraction pattern



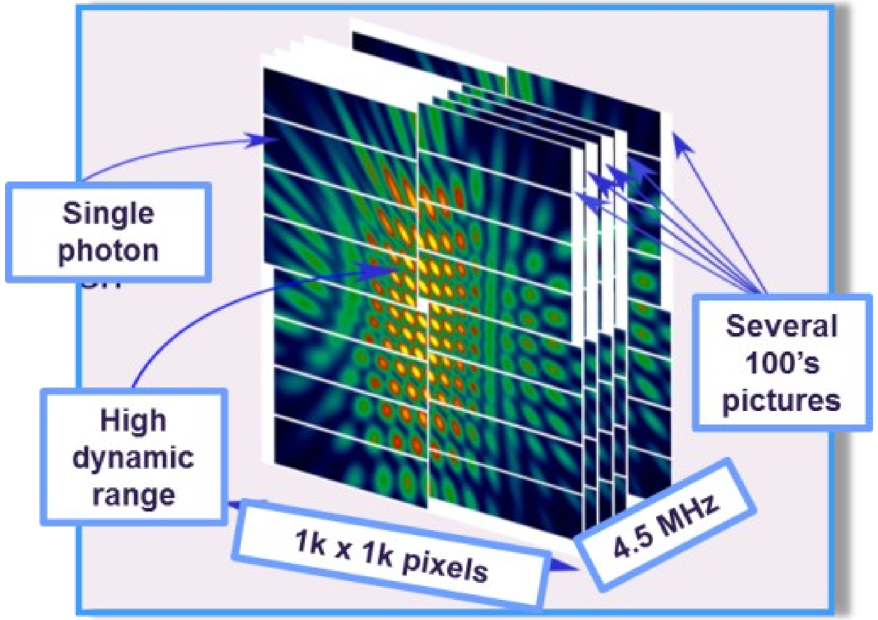
Wiedorn, M.O,. et al. Megahertz serial crystallography. Nat Commun 9, 4025 (2018)

Oversimplifying:

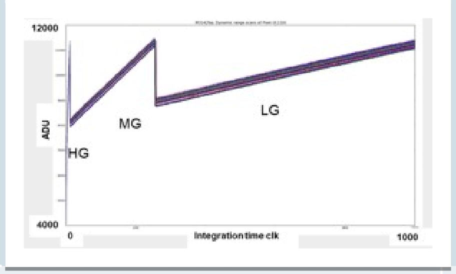
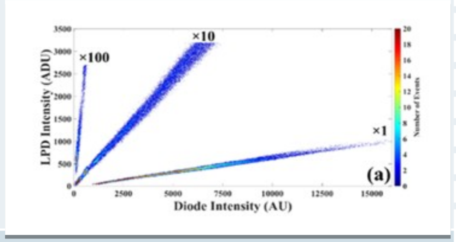
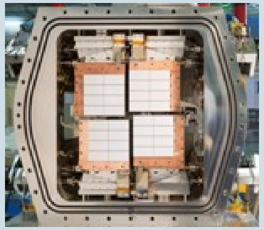
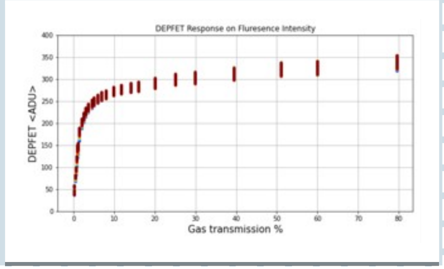
- X-rays from pulse interact with sample
  - (sample often destroyed)
- Interaction creates a 2D X-ray ‘pattern’
  - Contains physical information
- Detectors need to image this pattern

Detector requirements

- **The detector needs to cover as much solid angle as possible**
  - Reduced pixel pitch for spatial resolution
    - ~1 Mpix with ~200 µm pixel pitch
- **The detector needs to cope with 4.5 MHz burst pulse rate**
  - High detector occupancy
    - No event-driven readout
  - No time to read out the whole image in between pulses
    - Images have to be stored and then readout in between trains
- **Huge difference in signal in the same image**
  - The detector needs a wide dynamic range
  - The same pixel needs to accurately detect:
    - Single photons
    - Tens of thousands of photons (~ 10^4 ph/pixel)
- **European XFEL environment is harsh for the detector**
  - High doses are delivered (sometimes instantaneously)
    - Detector should be radiation tolerant as much as possible
    - Calibration constant need to be updated frequently



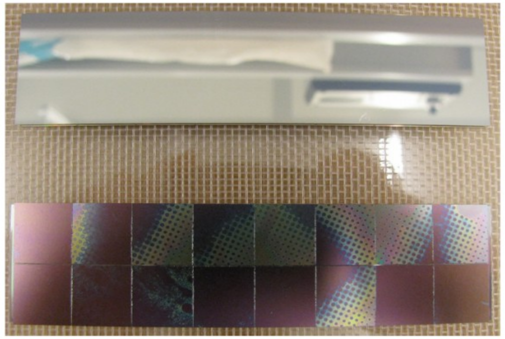
MHz Imaging detectors for EuXFEL

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

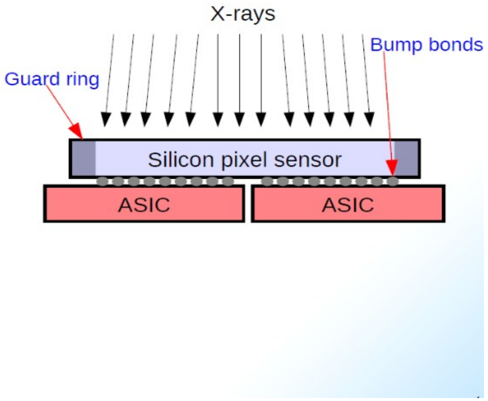
Hybrid pixel detector technology

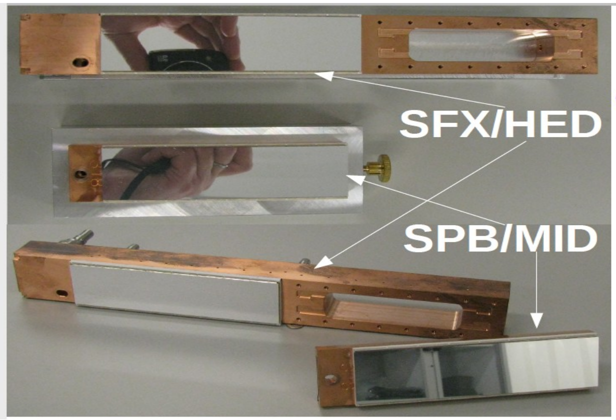
- **Detection component and front end readout are developed separately**
  - Pixellated sensor
    - ► Typically silicon in proportional mode
    - ► Other solutions possible e.g.:
    - ► CdZnTe, GaAs for higher photon energy detection
    - ► LGADs to improve S/N ratio at soft X-ray energies
    - ► DEPFET ...
  - Signal generated in sensor is read out by ASIC
    - ► ASIC is also pixellated
- Sensor and ASIC are connected on a pixel-by-pixel basis
  - Bump-bonding between contacts
  - ASIC output wire-bonded to rest of read out chain

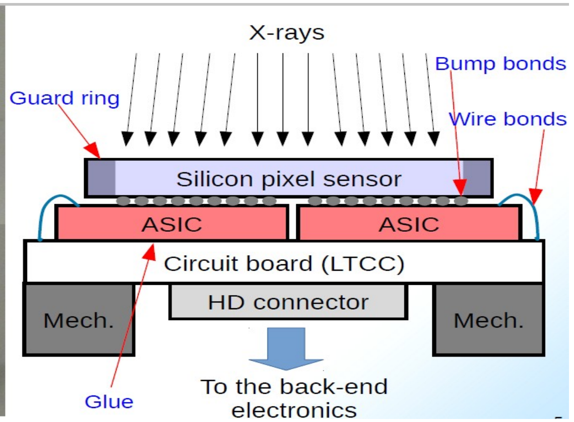
Sensor side



ASIC side



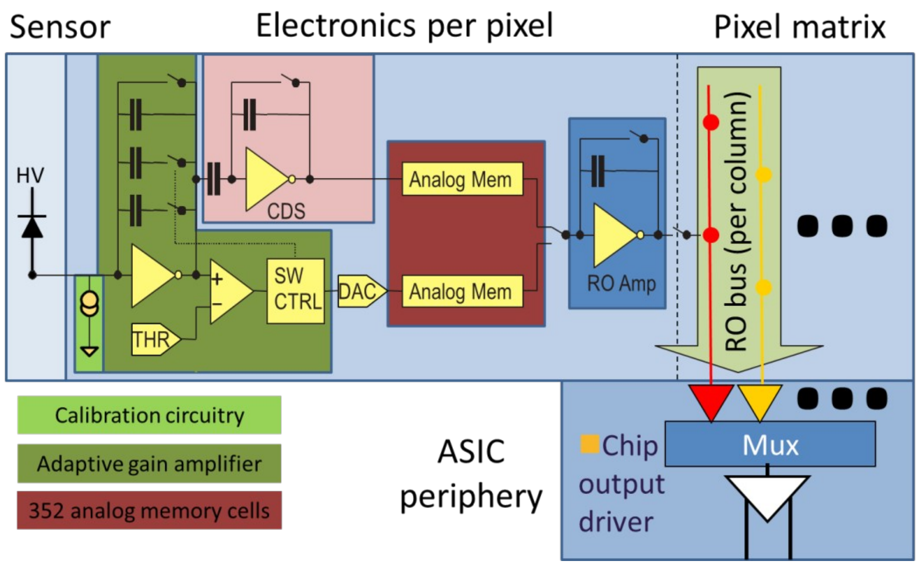




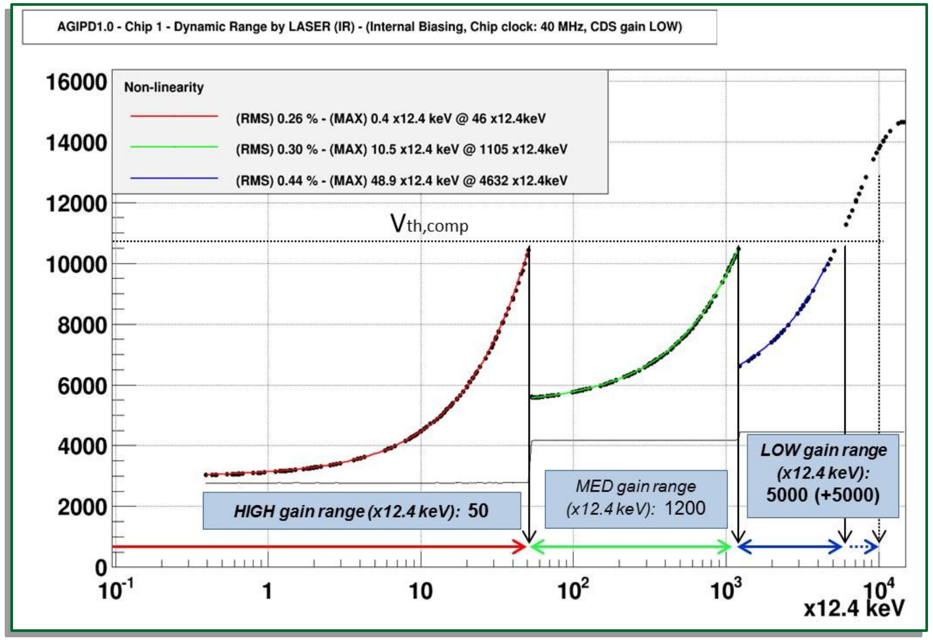
Example of single AGIPD module:
Sensor 128 x 512 pixels
2 x 8 read-out chips connected to sensor via bump-bonding

High dynamic range requirement

High dynamic range adaptive gain: the AGIPD detector



$$V_{out} = \frac{-Q_i}{C_f}$$

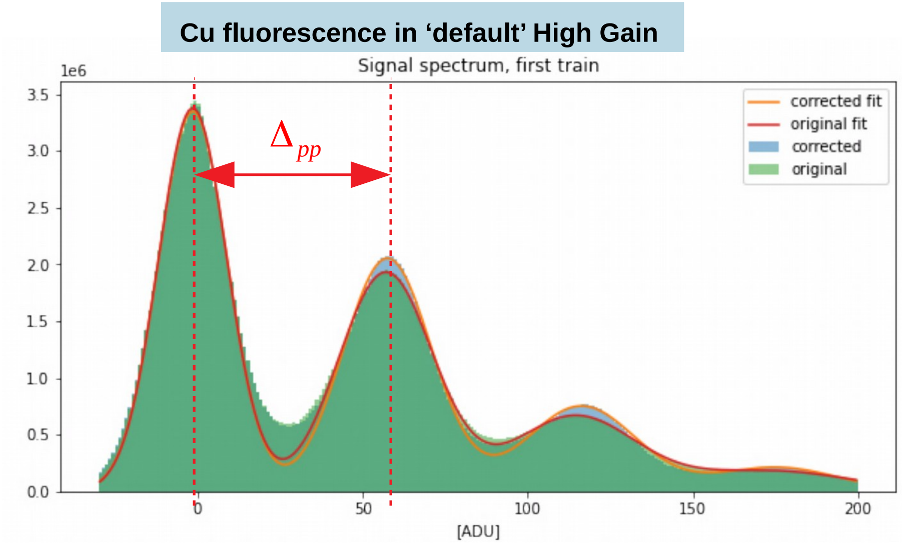


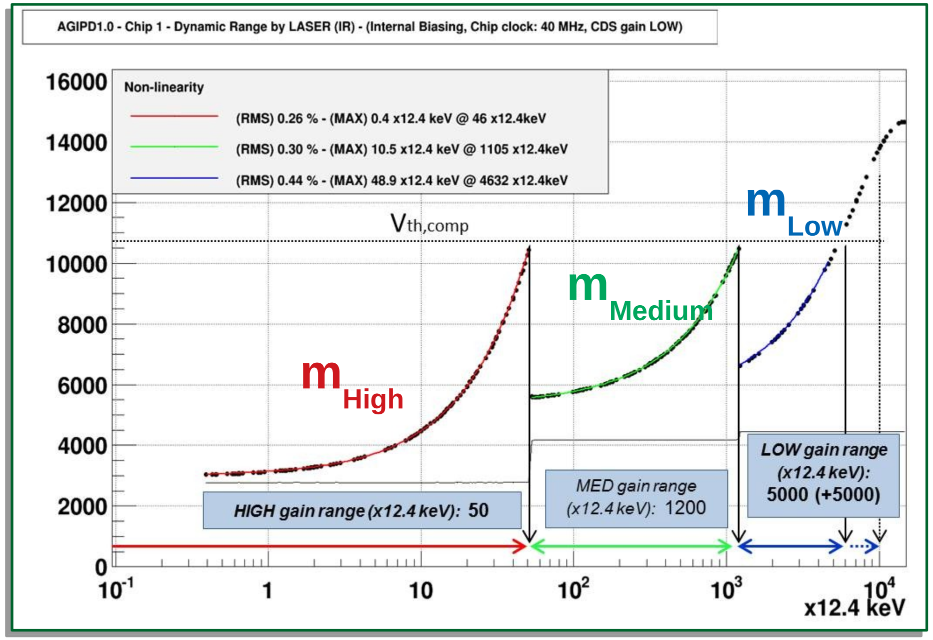
- Charge-integrating pre-amplifier (pre-amp)
- Pre-amplifier with **dynamic gain switching (DGS)**
  - Three feedback capacitors C_f
    - Three gains (High, Medium, Low)
  - Threshold comparator at the output node of pre-amp
    - If signal above V_{thr} additional capacitor is switched in
- Correlated Double Sampling (CDS)

- Readout output stored in analog storage cell
- 'gain stage' also stored analogically
- To correct raw data
  - Pedestal value to subtract
  - Conversion factor into physical unit (*gain factor*)
  - Information about the the 'gain stage'
    - **Six constants per pixel and per storage cell**

Sztuk-Dambietz, J. et al. "Operational experience with Adaptive Gain Integrating Pixel Detectors at European XFEL" Front. Phys., Volume 11 – 2024
https://doi.org/10.3389/fphy.2023.1329378

Dynamic gain switching calibration





- **Fluorescence spectra for High Gain calibration**
  - "absolute" calibration: conversion factor from ADC units → keV
- **Dynamic range scans for lower gains calibration** (Medium and Low)
  - Raw output as function of input signal
  - Linear fit of the response
  - "relative" calibration: fit slope **m** → slope ratio → gain factors ratio
- **Pedestal estimated with 'dark' runs**
  - Pre-amp forced switch for Medium and Low gain

$$G_{High}=\frac{\Delta_{pp}}{E_{ph}}$$

$$R_{HM}=\frac{m_{High}}{m_{Medium}};\ R_{ML}=\frac{m_{Medium}}{m_{Low}}$$

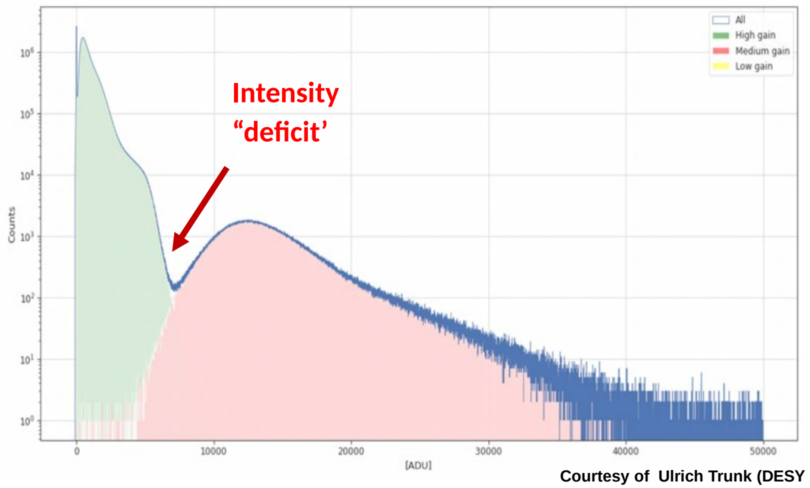
$$G_{Medium}=\frac{G_{High}}{R_{HM}}$$

$$G_{Low}=\frac{G_{High}}{R_{HM}\times R_{ML}}$$

Dynamic gain switching data quality

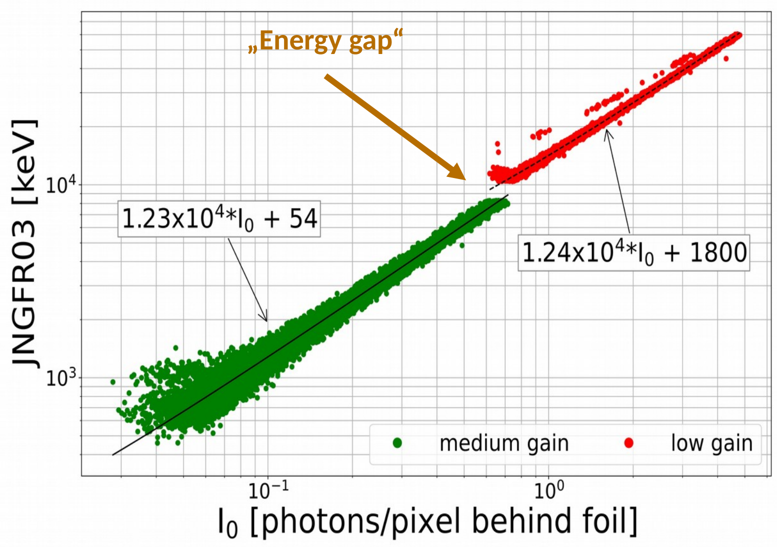
- The AGIPD detector is in operation since 2017
  - Plenty of User Operation hours
    - ‘stress test’ of the goodness of calibration
- The dynamic gain switching has been proved working
  - A few issues have been identified
- Gain switching region may show issues
  - Intensities not mapped
    - Reliability of the pedestal determination
    - Forced gain switch not always predictive
- Issues manifest in other detectors with dynamic gain switching architecture

AGIPD: Intensity spectrum



Courtesy of Ulrich Trunk (DESY FS-DS)

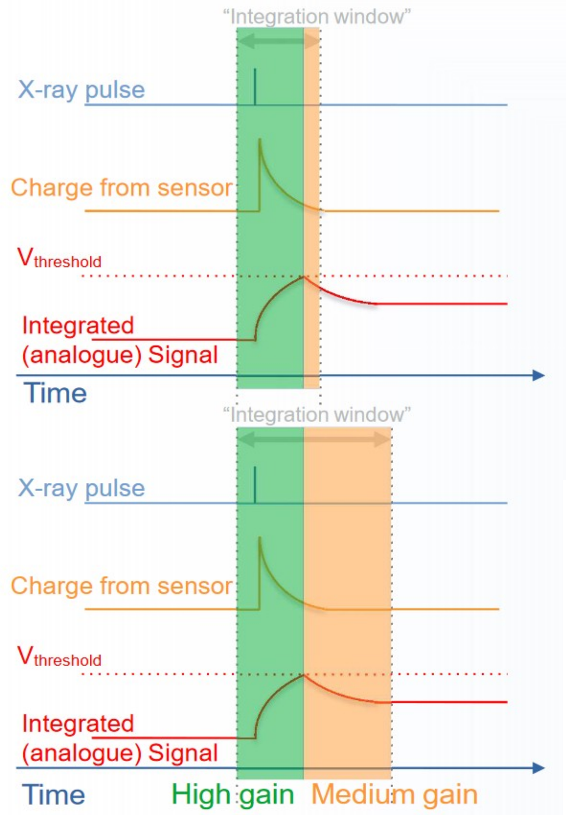
JUNGFRAU: Intensity scan



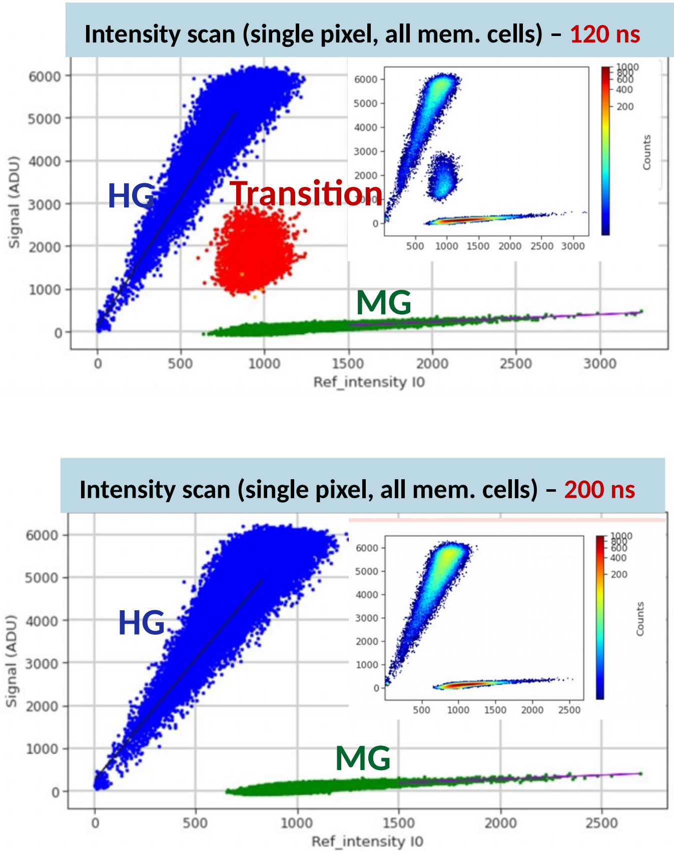
Sikorski, M.; Ramilli, M. . et al. “ First operation of the JUNGFRAU detector in 16-memory cell mode at European XFEL” Front. Phys., Volume 11 – 2024 https://doi.org/10.3389/fphy.2023.1303247

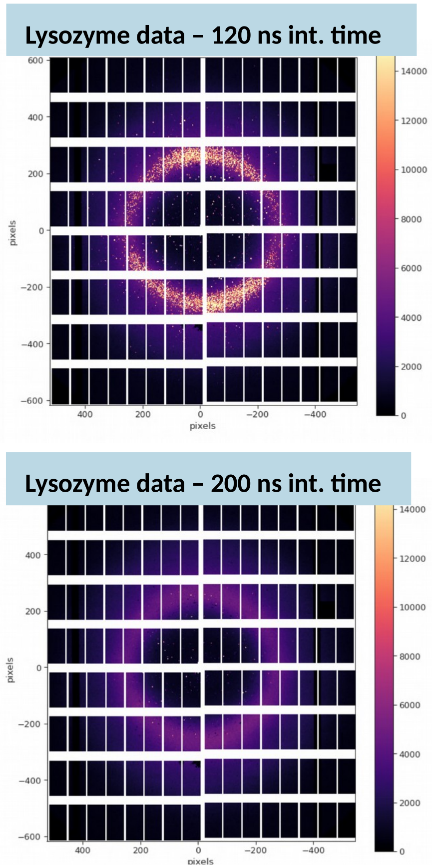
Dynamic gain switching data quality (cont'd)

- **Late gain switching**
  - Signal sampled while still settling
    - ► Artifact in corrected image
- Encountered in other DGS detectors
- Possible solutions
  - Increase exposure time
    - ► AGIPD, JUNGFRAU
  - Inhibit late gain switching
    - ► GOTTHARD-II



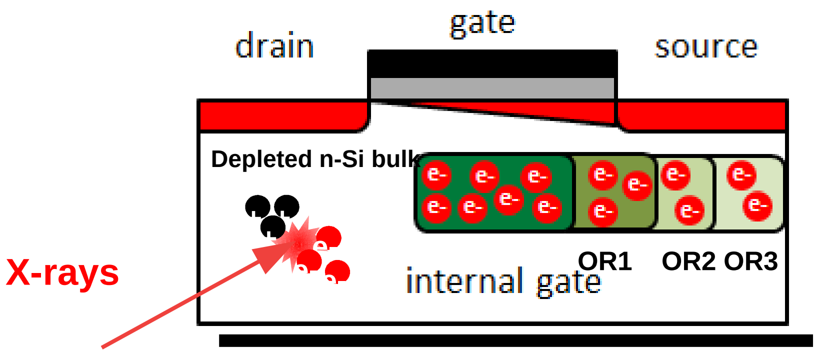
Courtesy of Ulrich Trunk (DESY FS-DS)





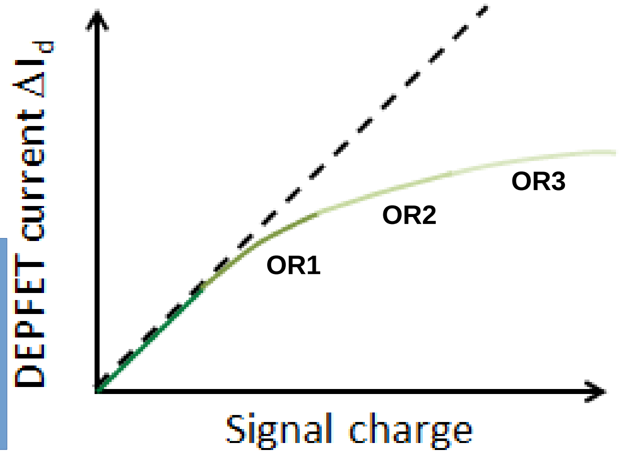
High dynamic range with non-linear response: the DSSC detector

- DSSC ASIC is bump bonded to **DEPFET sensors**
  - Depleted P-channel Field Effect Transistor
    - ► Invented by J. Kemmer and G. Lutz in late 1980s at MPI Munich
- FET integrated on a fully depleted n-Si bulk
  - In-pixel signal amplification
  - Potential minimum for electrons between source and drain
    - ► Charge accumulation induces charge in gate
    - ► Change of current between source and drain proportional to charge
- The DSSC DEPFET potential valley extends towards the source
  - Extracted charge will eventually fill the Overflow Regions (OR)
    - ► Gating effect of charge in OR less pronounced
- **The sensor response is not completely linear with extracted charge**
  - For small amounts it maintains a linear response
  - For increasing amounts it will eventually deviate from linearity



DEPFET: FET integrated on a fully depleted Si bulk

Non-linear DEPFET

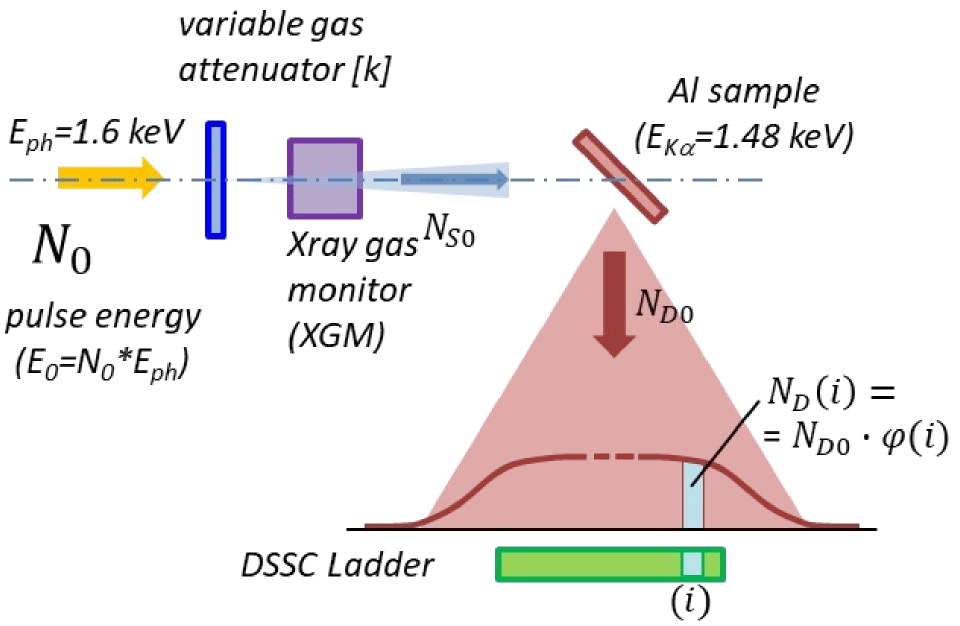


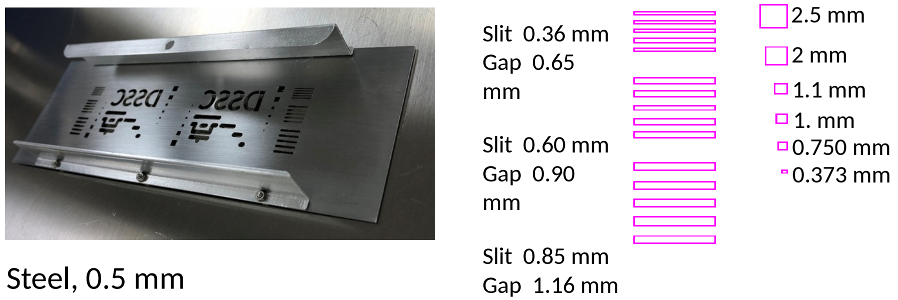
Lechner, P. et al. " DEPFET active pixel sensor with non-linear amplification" (2012) art. no. 6154112, pp. 563-568
doi:10.1109/NSSMIC.2011.6154112

Aschauer, S.; et al. "First Results on DEPFET Active Pixel Sensors Fabricated in a CMOS Foundry -
a Promising Approach for New Detector Development and Scientific Instrumentation". *J. Inst.* 2017, 12, P11013–P11013
doi:10.1088/1748-0221/12/11/p11013

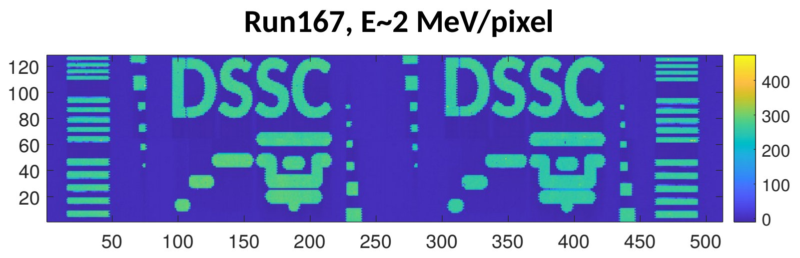
DEPFET response calibration

- Accurate calibration of the sensor response is needed
- **Intensity scan of the whole dynamic range**
- Performed in Nov. 2022 with Al fluorescence setup
  - EuXFEL beam used to generate K_α emission from Al target
    - Intensity on Al target provided by Gas Monitor (GM)
    - DSSC module illuminated by Al fluorescence
- Calibration idea:
  - Acquire the whole non-linear response (NLR) curve
    - Detector output as function of the GM output
  - Linear part → absolute calibration
    - Used to intercalibrate with GM
  - **Absolute calibration of detector response to flux**
  - **Do it for every pixel**

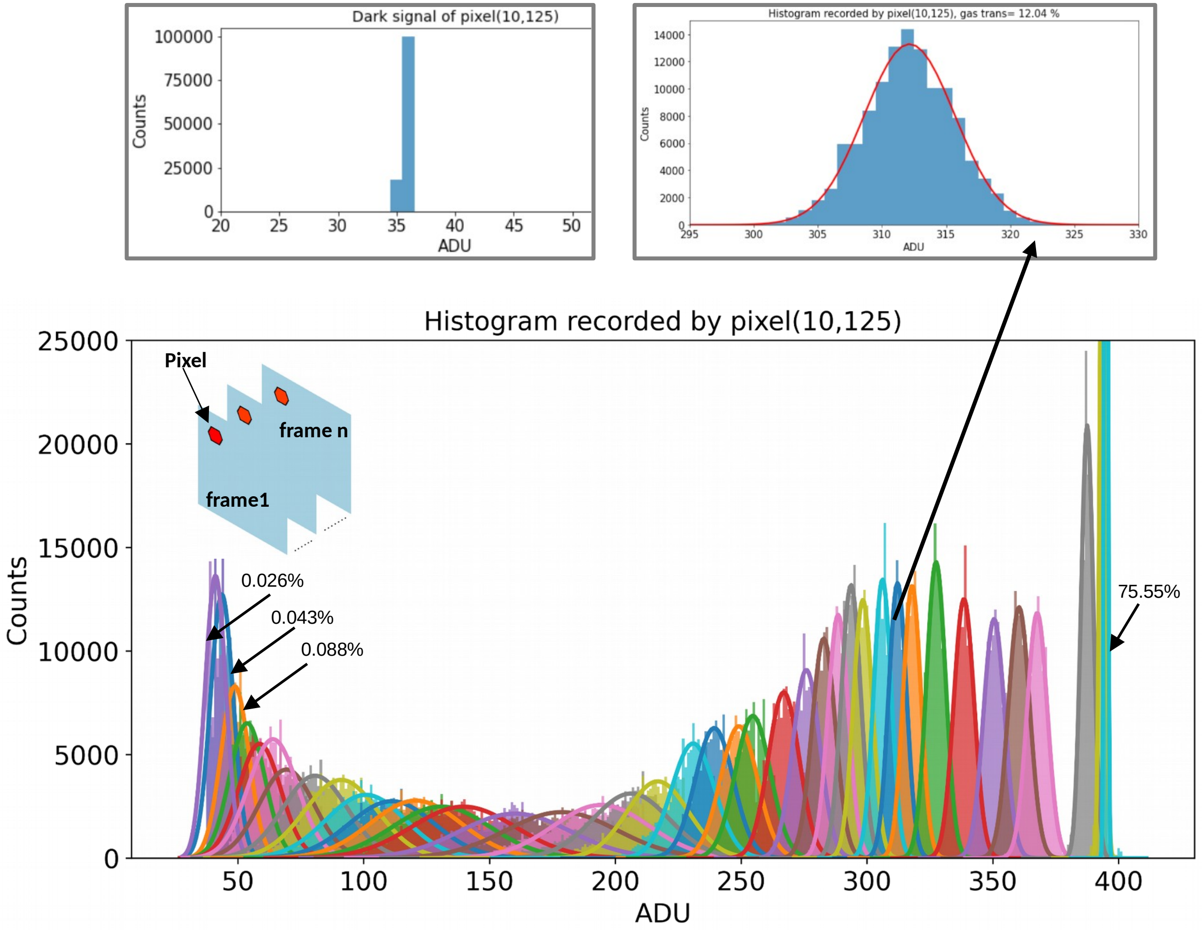




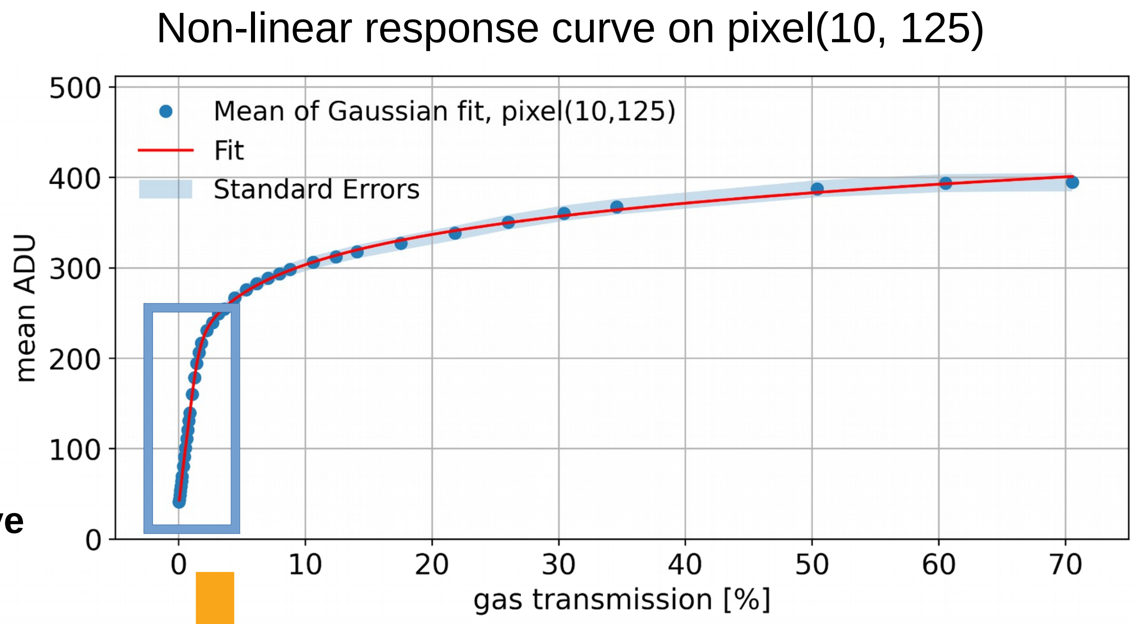
Steel, 0.5 mm

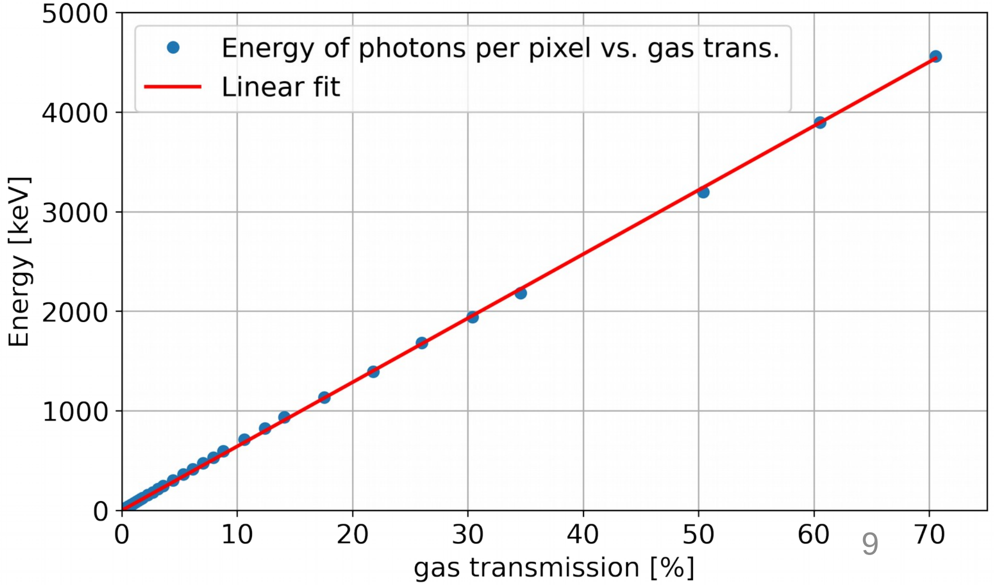


DEPFET response calibration



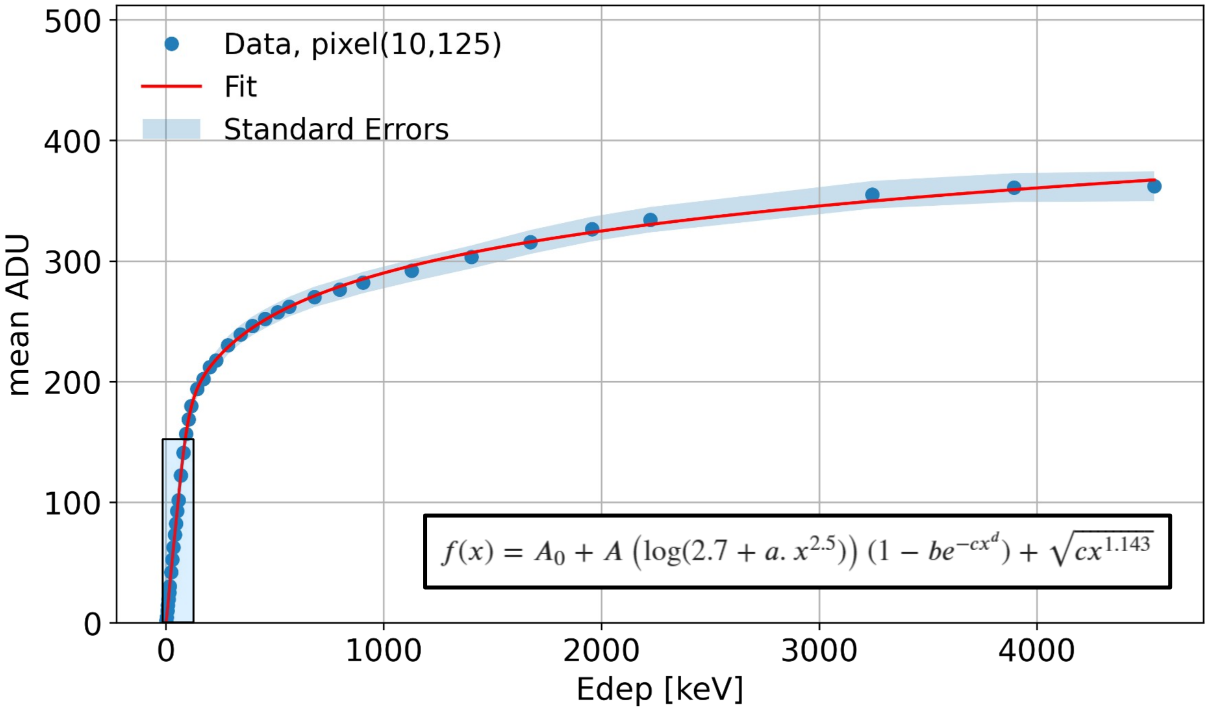
NLR curve





DEPFET response calibration

Non-linear response of a DEPFET pixels(10, 125)



$$f(x) = A_0 + A\left(\log(2.7 + a.\,x^{2.5})\right)(1 - be^{-cx^d}) + \sqrt{cx^{1.143}}$$

Low X-ray intensity → **High X-ray intensity**

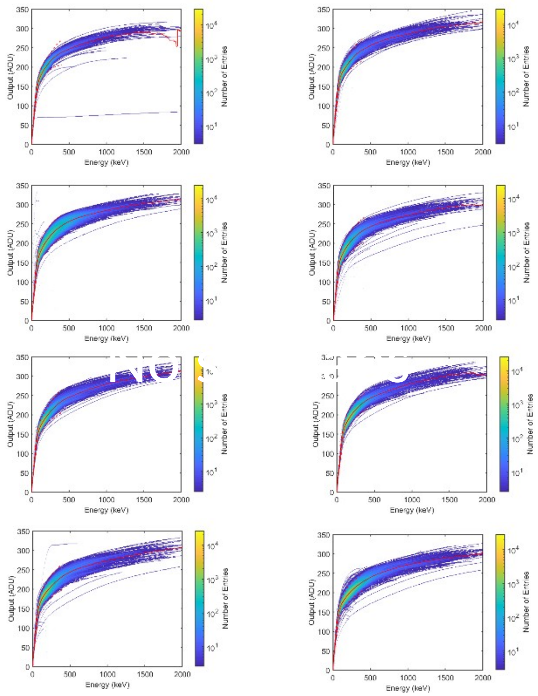
- **Fit with phenomenological function**
  - From fit a look up table is generated
    - ► Connects ADC value to Energy
- This is repeated for every pixel

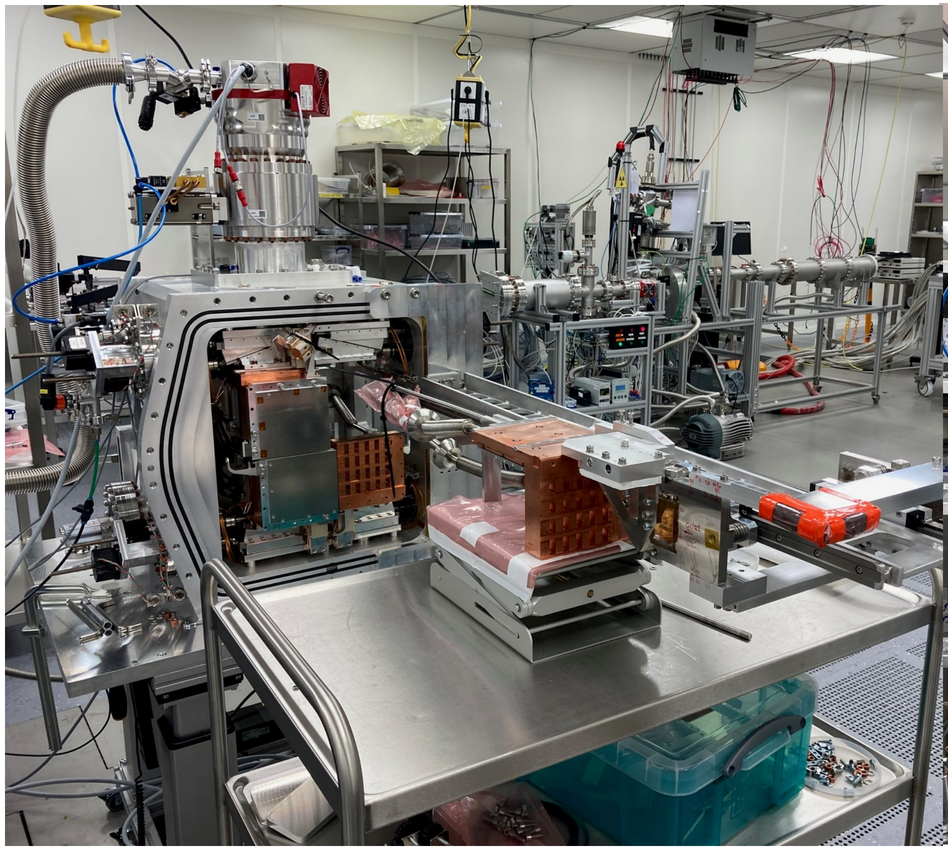
```
# parm[0]=A0, parm[1]=Amp, parm[2]=a, parm[3]=b, parm[4]=c, parm[5]=d, R_Square
139.59288,17.66534,3.14228,8.95974,1.47839,1.36720,0.99907
149.63412,16.24460,2.96456,10.24886,1.46595,1.36926,0.99835
153.23758,15.58930,2.86062,10.90080,1.49613,1.37310,0.99810
145.84819,16.64584,3.49679,9.77680,1.66485,1.38416,0.99863
152.02387,16.08610,2.82930,10.41920,1.55998,1.40136,0.99819
149.56305,15.97035,3.10646,10.37618,1.59072,1.37933,0.99836
145.75167,17.07453,3.79575,9.56307,1.69869,1.37940,0.99877
151.58520,16.07358,2.67402,10.40057,1.54317,1.40521,0.99838
160.71455,15.18214,1.99593,11.52752,1.40690,1.41611,0.99777
151.21675,16.02773,3.12803,10.43871,1.56256,1.37852,0.99814
148.79032,15.75136,2.85120,10.38592,1.55957,1.39627,0.99839
154.54887,16.25751,2.75022,10.48473,1.52285,1.40947,0.99828
156.56064,15.68574,2.44789,10.95754,1.48388,1.40490,0.99813
155.95891,15.32486,2.53394,11.14475,1.46531,1.38668,0.99803
157.38548,15.20947,2.49415,11.33803,1.45577,1.39745,0.99827
143.51220,15.61933,2.56789,10.16151,1.56978,1.40634,0.99854
```

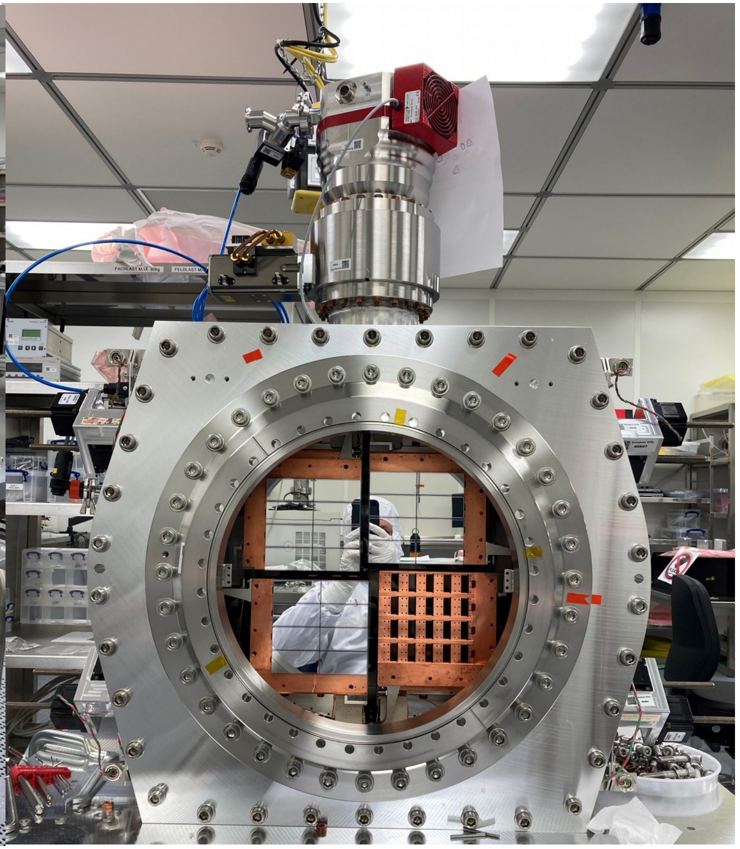
Maffessanti, S., Hansen, K. et al., "A 64k pixel CMOS-DEPFET module for the soft X-rays DSSC imager operating at MHz-frame rates". Nature Sci Rep 13, 11799 (2023) https://doi.org/10.1038/s41598-023-38508-9

A. Castoldi et al. "Qualification of the X-ray spectral performance of the DEPFET pixels of the DSSC imager", NIM A, 2023

DEPFET DSSC 1 Mpix camera assembly





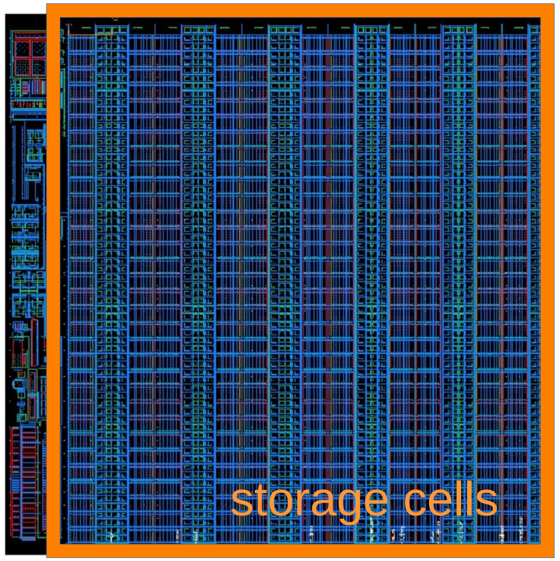


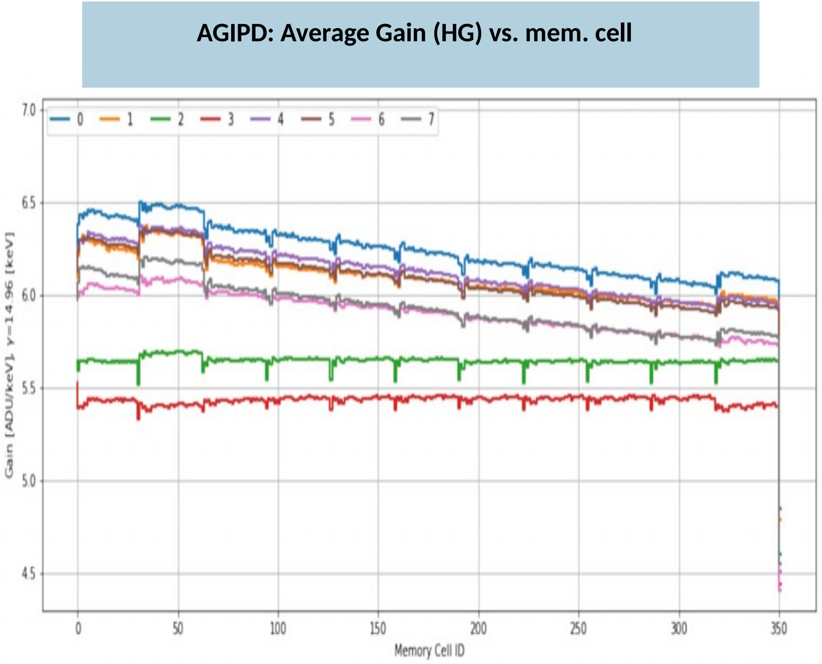
- DSSC equipped with DEPFET is being assembled at European XFEL
  - 3 out of 4 quadrants are in place
    - More DEPFET are being produced
- **First users in 2025**

MHz burst frame rate requirement

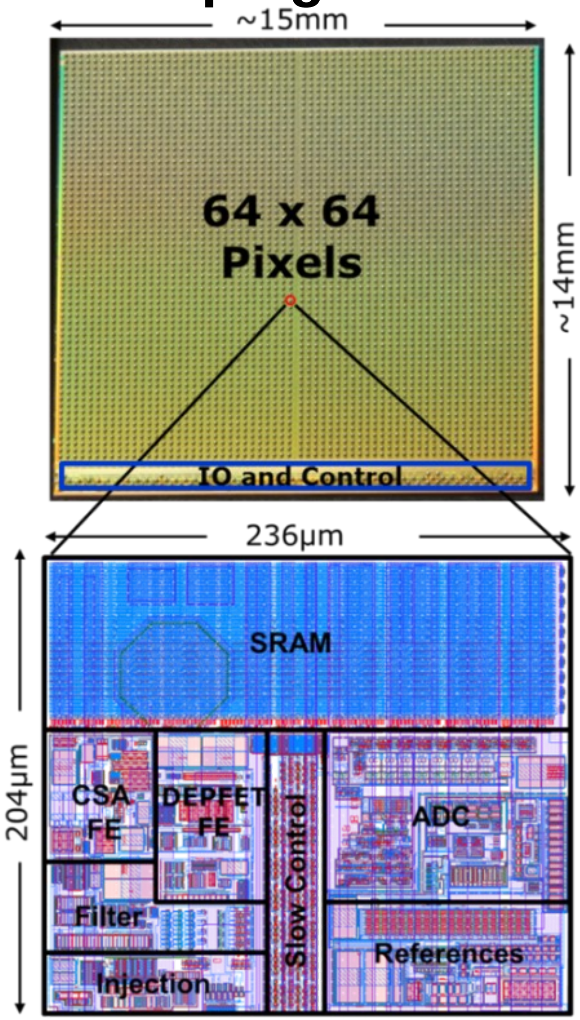
Coping with MHz frame rate: analog storage

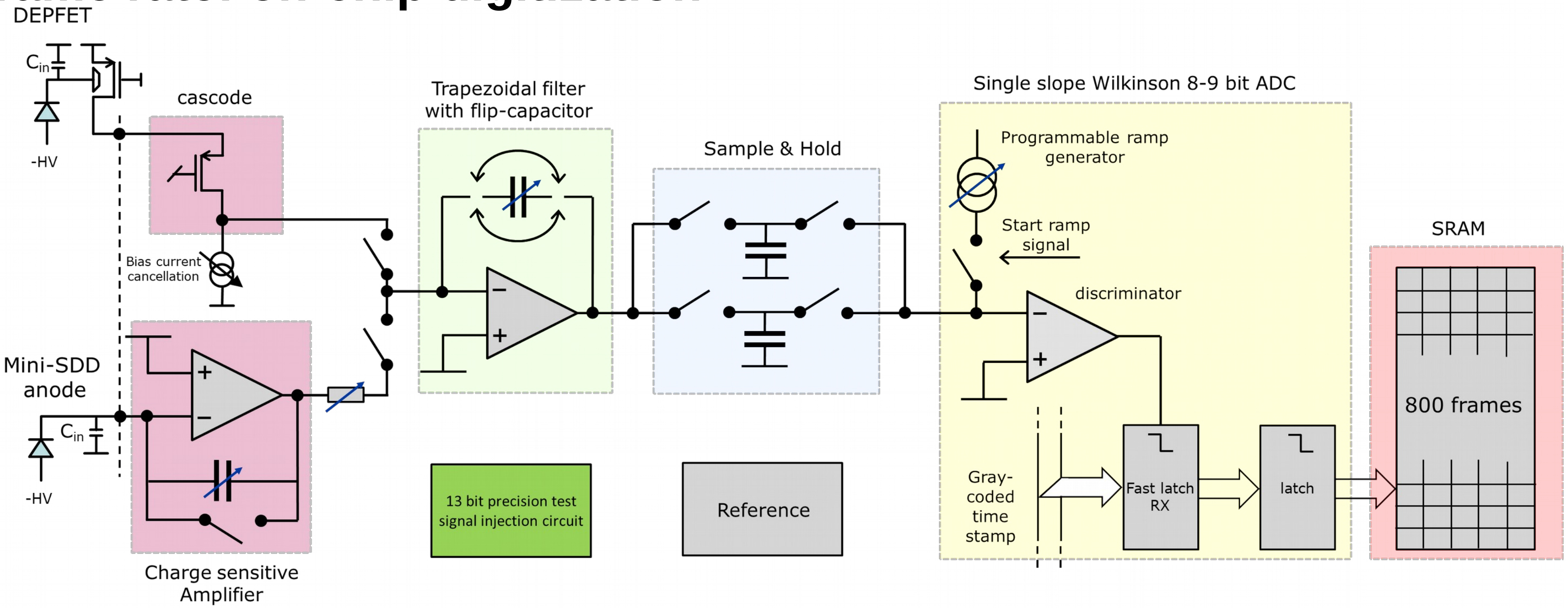
- Detector cannot be read out in less than 200 ns
- Images have to be stored somewhere and read out in between trains
- AGIPD chose the **analog storage cell solution**
  - **Each pixel is endowed with 352 capacitors**
  - Each capacitor holds the output of one acquisition
  - Capacitor values is read out and passed on the (off chip) ADC in between trains
- This simple solution has some drawback
  - The footprint for all these storage cells is ~80% of the pixel area
  - The storage cells are appreciably different from each other
    - ► **All the constants have to be produced for each storage cells**
    - ► To calibrate one pixel 6 x 352 = 2112 constants are needed!
  - Other effects:
    - ► Cross talk
    - ► Charge leak
- This simple solution requires substantial calibration effort to mitigate its effects





Coping with MHz frame rate: on-chip digitization





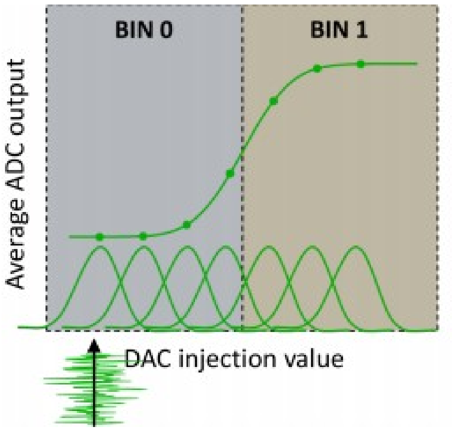
- DSSC opts for **on-chip digitization of the signal**
  - Signal passes amplification and filtering
  - Sample and hold stage
    - One capacitor stores the signal
    - The other has it read out and digitized by an analog-to-digital converter
  - ADC output stored in an SRAM with 800 images depth

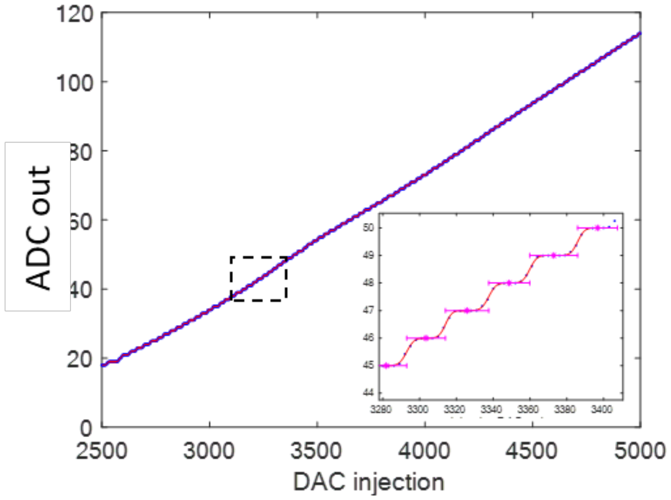
Porro, M. et al. " The MiniSDD-based 1-Megapixel Camera of the DSSC Project for the European XFEL" April 2021, IEEE Transactions on Nuclear Science PP(99):1-1 https://doi.org/10.1109/TNS.2021.3076602

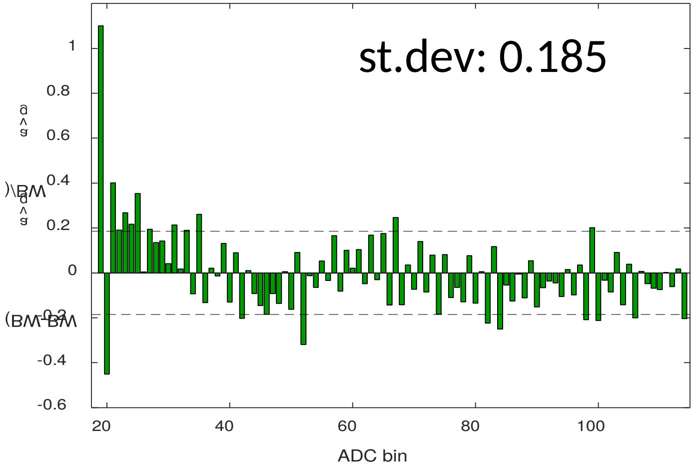
Coping with MHz frame rate: ADC calibration

- The on chip ADC has 8 at 4.5 MHz
  - 9 bit at frame rates ≤ 2.2 MHz
    - Limited resolution (AGIPD off-chip ADC has 14 bits)
- **Differential non-linearity (DNL)**
  - One of the main qualifiers for ADC performances
  - **Deviation w.r.t. the ideal step of one LSB**
    - Measure of the “actual bin width” of the ADC
- Can be measured by injecting voltage in ADC in a controlled way
  - In this way the output is characterized
- DSSC DNL has been characterized with a 13 bit input DAC

$$DNL(i) = \frac{W(i) - W_{ideal}}{W_{ideal}}$$





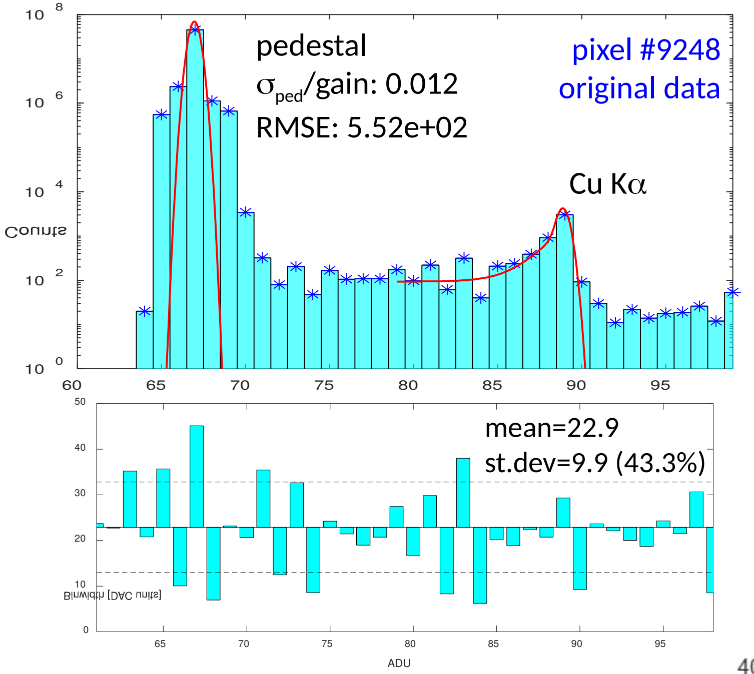


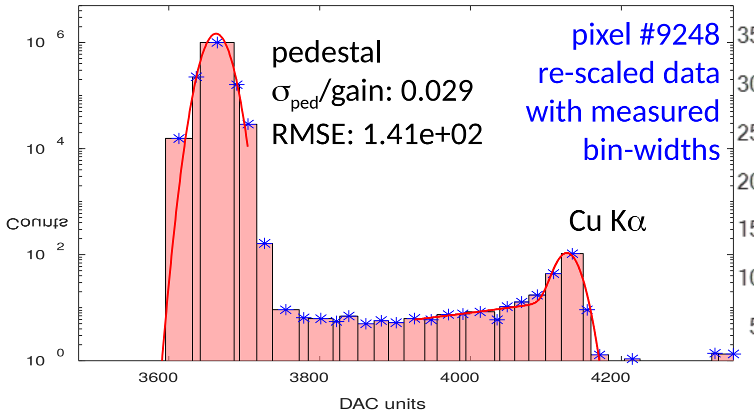
Coping with MHz frame rate: DNL correction

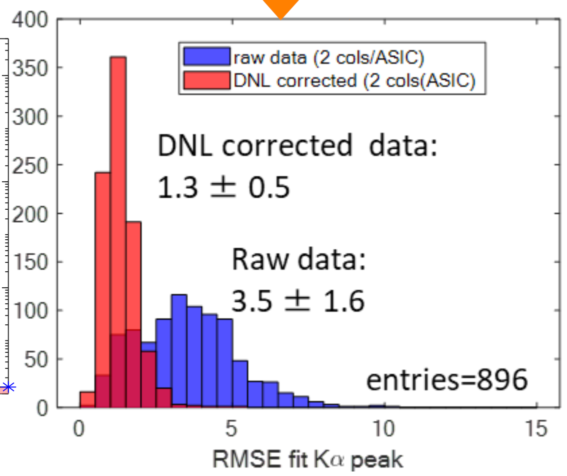
- Fluorescence measurements on DSSC
  - Some bins are over/under sampled
- DNL correction may be relevant
  - Spectroscopic measurements
  - weight the occurrences *N* in the i-th bin
    - ► Marked improvement of the peak resolution
    - ► Drop of the error on gain value estimate
- **Characterization of the DNL can be necessary**
- This information is then used in offline analysis

$$N(i)_{corr} = \frac{N(i)}{DNL(i)+1}$$

PulXar Cu Ka spectrum (single pixel)





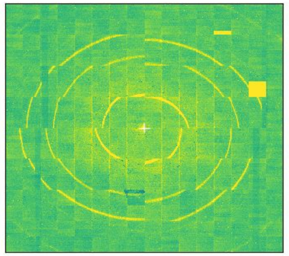


Calibration and raw data correction

Calibration effort at European XFEL

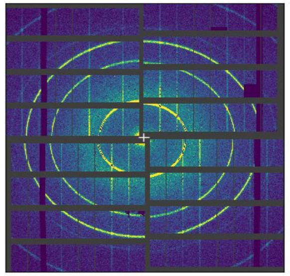
European XFEL aims to provide facility users with a fully corrected and calibrated dataset as the primary data product.

SRN **27.4**, 35 (2014)



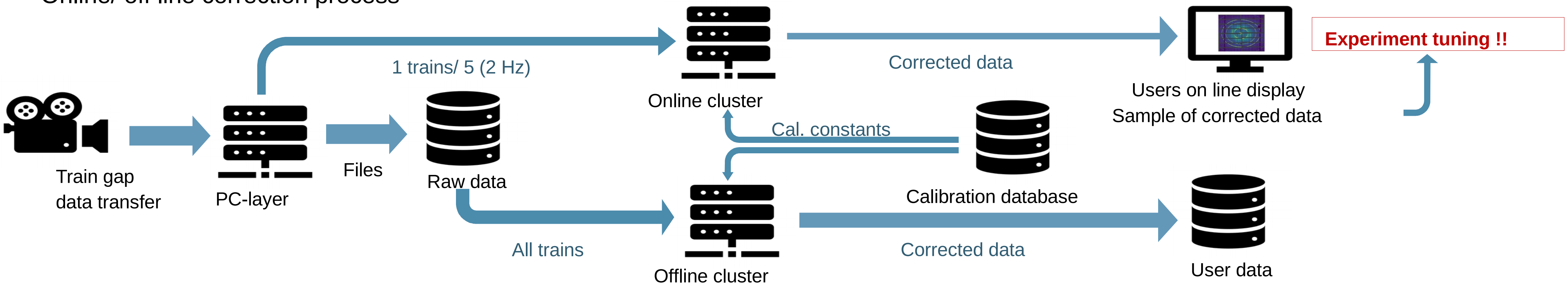
Raw data

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



Corrected data

Online/ off line correction process

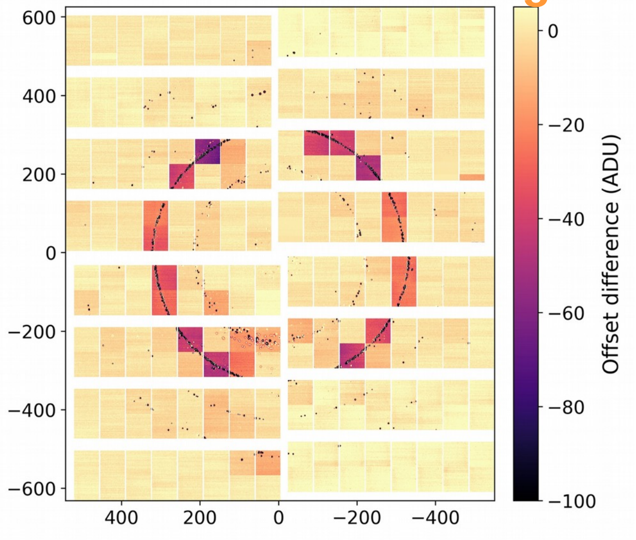


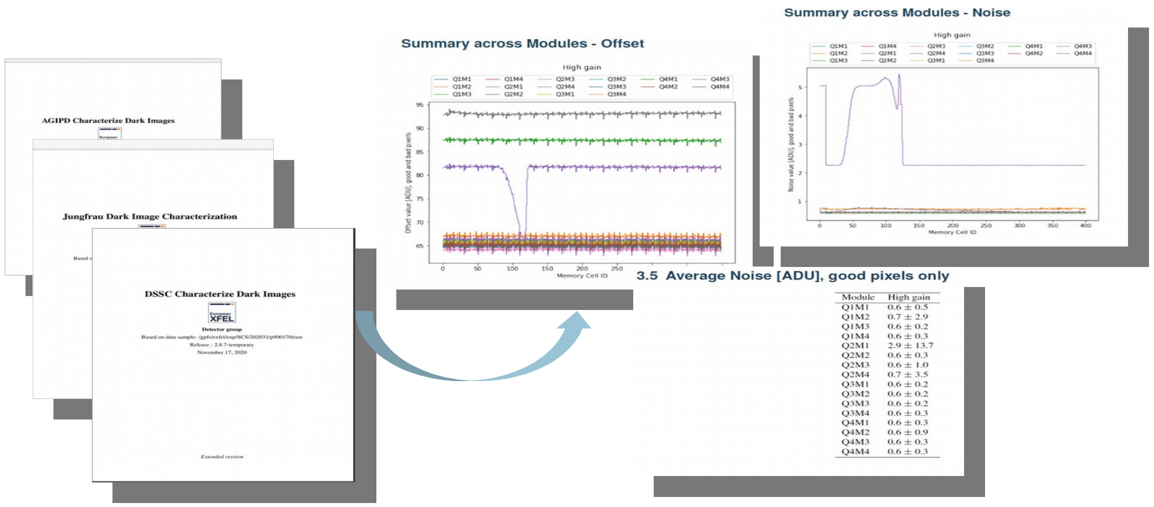
Schmidt, P. et al. “Turning European XFEL raw data into user data”
Front. Phys., Volume 11 – 20234
https://doi.org/10.3389/fphy.2023.1321524

Keeping the calibration constants updated

- EuXFEL must provide the tools to achieve best data quality
  - Provide high quality corrected data
  - provide a reliable online preview
- We need to **update the correction constants regularly**
- **Quick to gather data: dark run constants**
  - Frequently updated (at least once per shift)
  - Pedestal and noise
  - Bad pixel classification (from pedestal and noise values)
    - ► Automatized procedure for acquisition and calculation
    - ► No need to expert supervision
- **Special calibration procedures**
  - Need expert contribution to acquire and process
    - ► Gain constants
    - ► NLR curves
    - ► DNL
    - ► …
  - Automation of procedures still on the way
  - Updated when possible (e.g. during shutdowns)

AGIPD radiation damage





Module	High gain
Q1M1	0.6 ± 0.5
Q1M2	0.7 ± 2.9
Q1M3	0.6 ± 0.2
Q1M4	0.6 ± 0.3
Q2M1	2.9 ± 13.7
Q2M2	0.6 ± 0.3
Q2M3	0.6 ± 1.0
Q2M4	0.7 ± 3.5
Q3M1	0.6 ± 0.2
Q3M2	0.6 ± 0.2
Q3M3	0.6 ± 0.2
Q3M4	0.6 ± 0.3
Q4M1	0.6 ± 0.3
Q4M2	0.6 ± 0.9
Q4M3	0.6 ± 0.3
Q4M4	0.6 ± 0.3

Handling raw data: correction pipeline

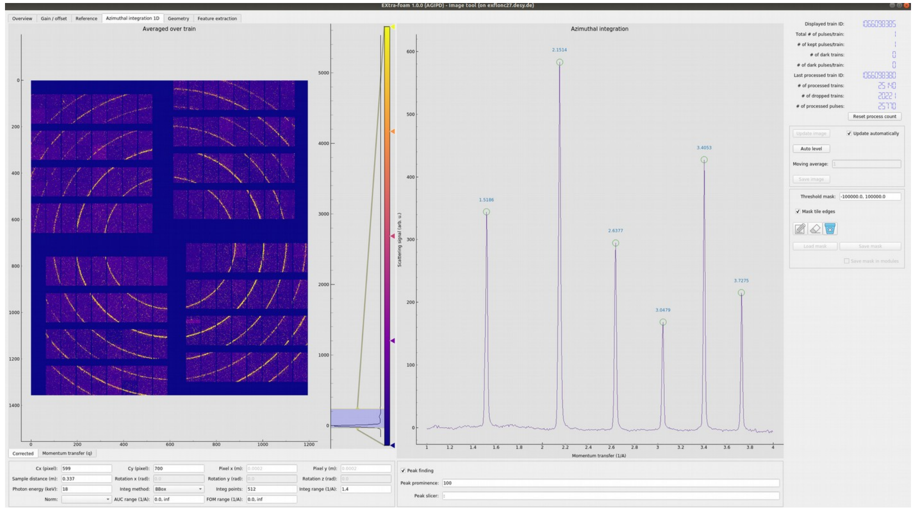
Constants loaded in DB

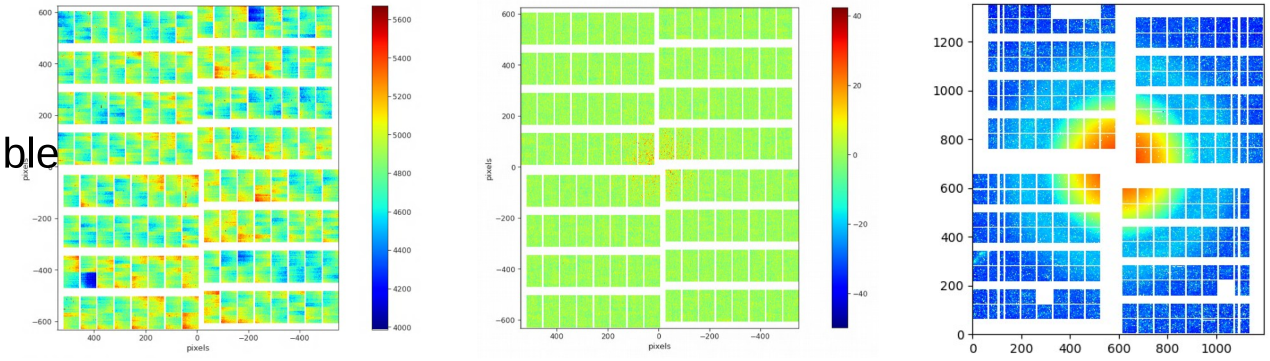
Online correction

- Implemented in EuXFEL control software (Karabo)
  - Detector class specific
  - Basic correction only
  - Code optimized for speed
  - Run on high performance machines
- Accessible from GUI
- Output corrected image
  - **Necessary for experiment tuning!**

Offline correction

- Implemented in scripts
  - Detector class specific
  - Algorithm aims to most complete correction possible
    - ►Common mode correction
    - ►Clustering
    - ►Baseline shift compensation …
  - Code written to handle large data volumes
- Correction triggered by Metadata Catalogue
  - Scripts run a SLURM jobs on Maxwell Cluster





raw

corrected

averaged

single shot

Summary

- European XFEL is an X-ray user facility with challenging requirements for detector development
  - **MHz-level pulse rate** in bursts
  - Up to 10^{14} photons per pulse
    - ► **High dynamic range required!**
    - ► High doses delivered to the detector
- How we deal with high dynamic range
  - **Dynamic gain switching (AGIPD)**
    - ► Proven effective
    - ► Calibration issues
  - **Non-linear response (DEPFET DSSC)**
    - ► Calibration procedure successfully established
    - ► First user experiments will come soon
- How to deal with MHz-level frame rates
  - **Analog storage cells (AGIPD)**
    - ► Cumbersome calibration
  - **On-chip analog to digital conversion (DSSC)**
    - ► Get rid of all analog storage cells effects
    - ► Limited resolution (8 bits)

- Calibration constants updated when needed
  - **Effort to automatize calibration**
- Provide the infrastructure to correct raw data
  - **Database to store the constants**
    - ► Offline correction pipeline
    - ► Online correction pipeline

Backup

Detectors for EuXFEL

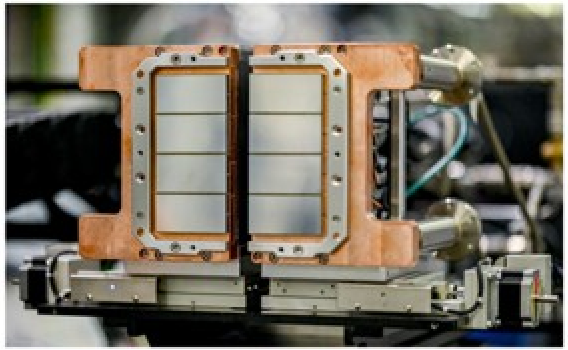
Hard
X-rays
6-25 keV

X-ray energy

Soft
X-rays
0.5-3 keV

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

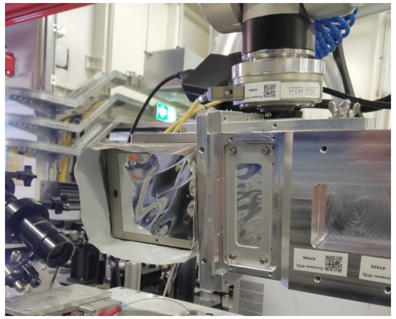
ePix100 (MID, HED)



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

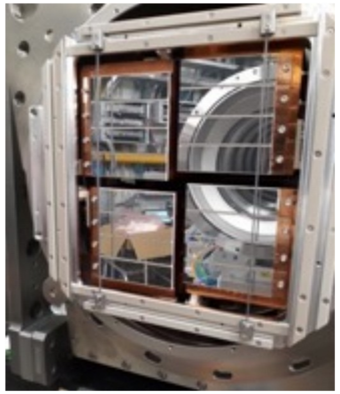
Noise: 80 e- (HG)
Dyn range: 10^4 12 keV ph

GOTTHARD-II (all instr.)



Strip detector
Noise: 280 e- (HG)
Dyn range: 10^4 12 keV ph
Up to 2700 images/train

AGIPD (SPB/SFX, MID)

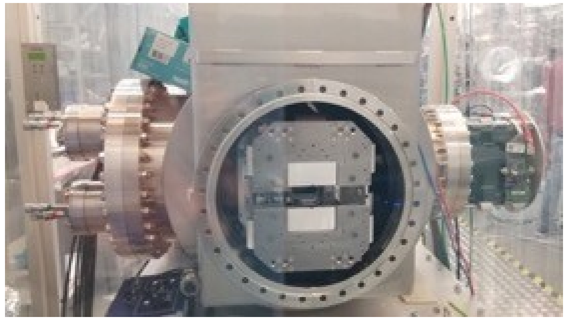


Noise: 350 e- (HG)
Dyn range: 10^4 12 keV ph

LPD (FXE)

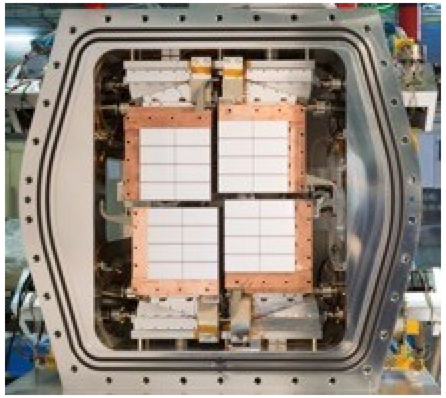
Noise: 2010 e- (HG)
Dyn range: 10^5 12 keV ph

pnCCD (SQS)



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

DSSC (SCS, SQS)



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

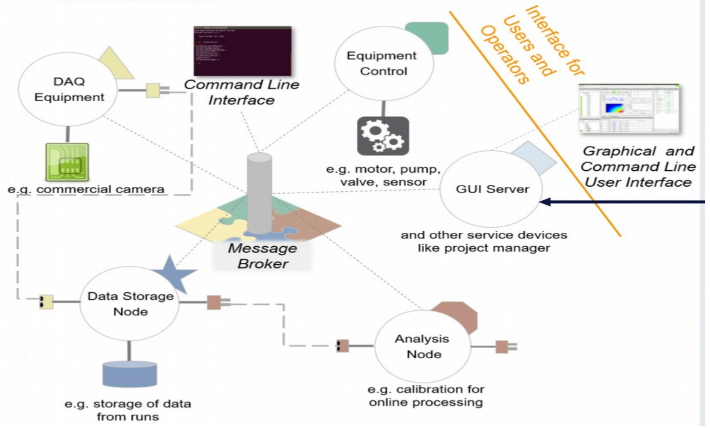
Rate

Detector integration in Karabo

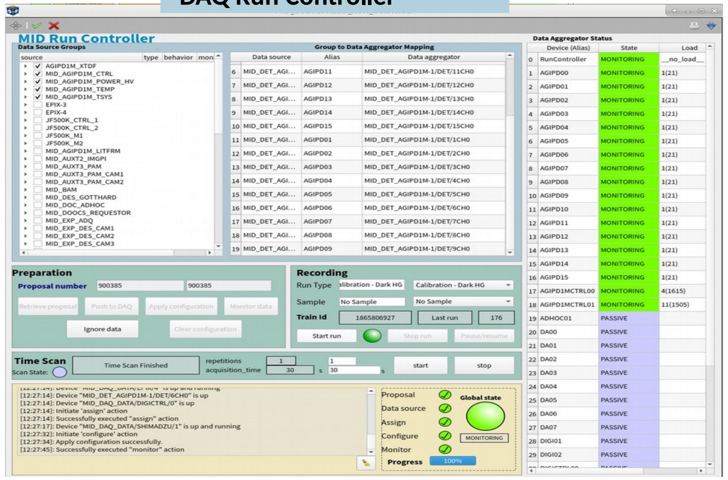
- Karabo - European XFEL's Control System framework for control, DAQ and monitoring
  - Distributed system of devices (physical and 'logical') that communicate with each other through a message broker
  - Devices are aggregated in topics (one topic per instrument)
  - GUI Client facilitates interaction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

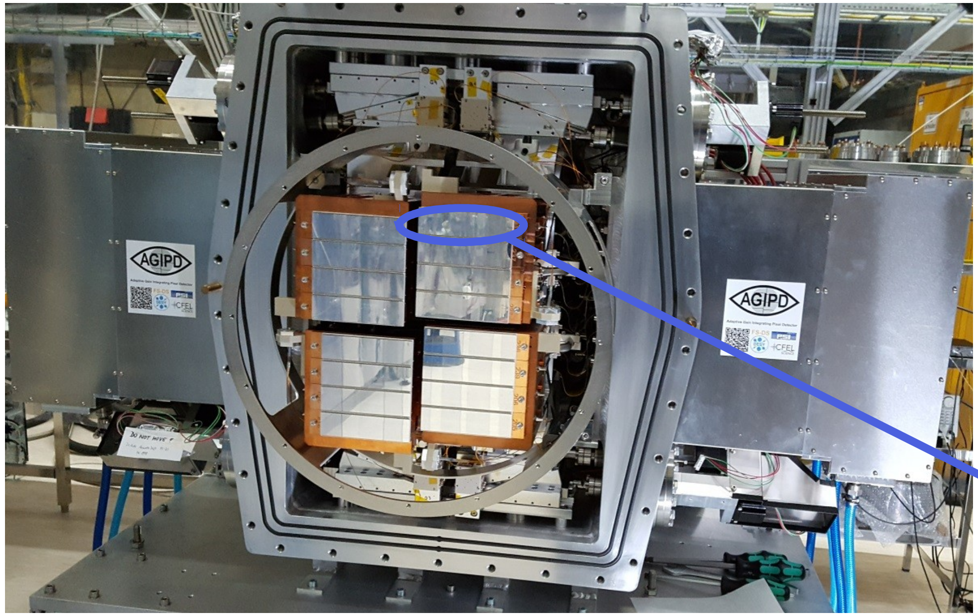
- Integration of detectors in Karabo
  - Enables control of the detector and its infrastructure
  - Supports complex procedures, including detector startup and calibration data collection
  - Provides monitoring capabilities (e.g., temperatures, power, detector status) and 2nd level detector protection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



DAQ Run Controller

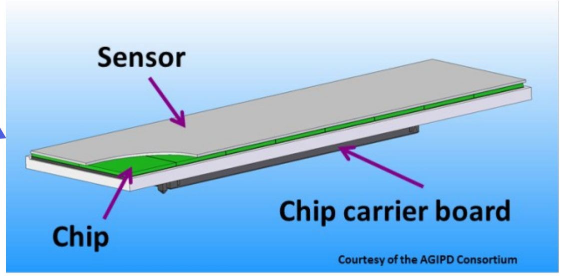


AGIPD1M detector system for SPB/SFX and MID instruments



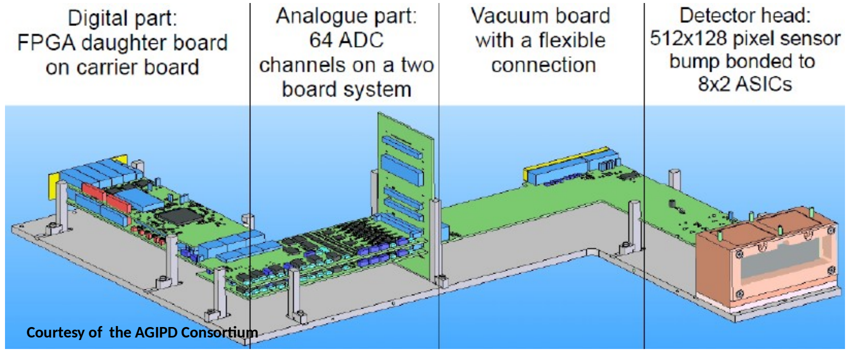
Hybrid detector module

- 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

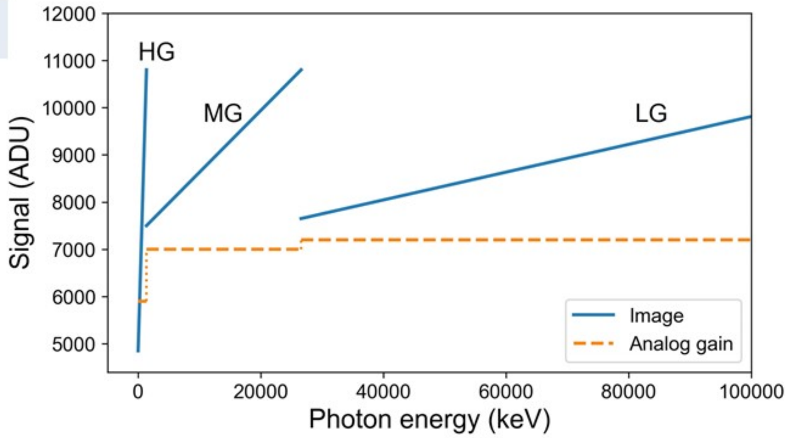
- 16 modules are mounted on four independently movable quadrants
- Vacuum operation (P< 10^{-5} mbar)
- Electronics/Control: two independent detectors: 'half 1' and 'half 2'
- Readout: 16 independent detectors

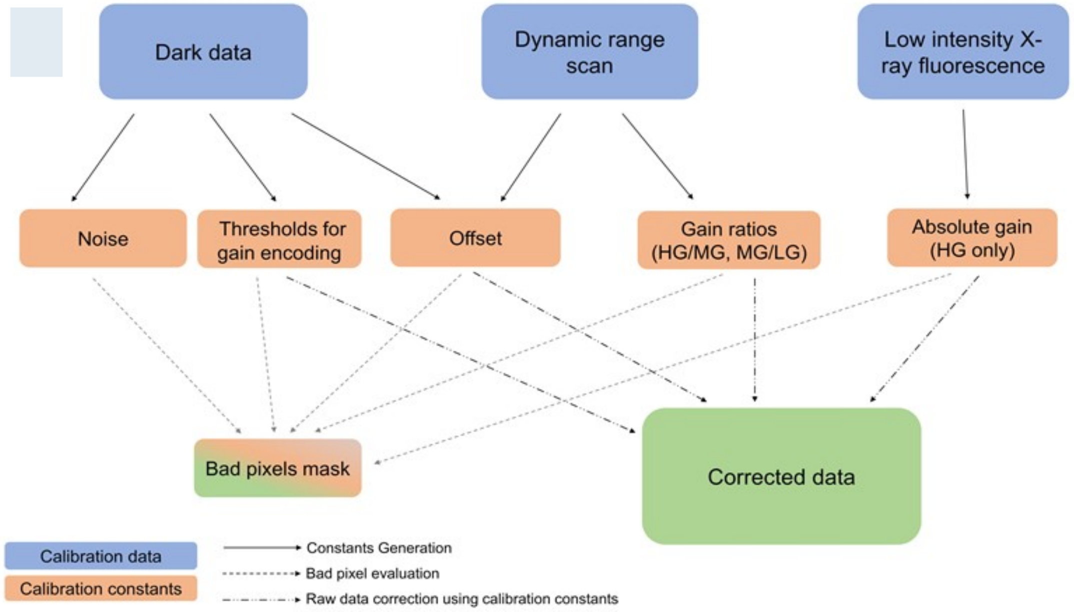


In ambient

In vacuum

Dynamic gain switching calibration





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

Radiation hardness sensor design

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

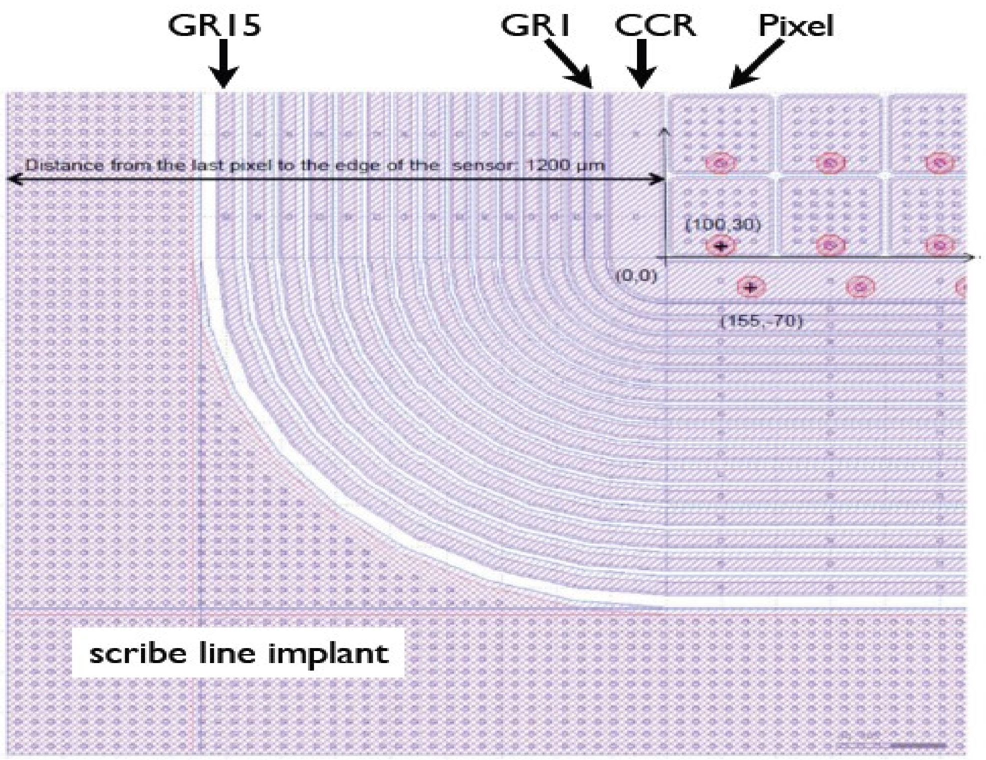
  BUT

- **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

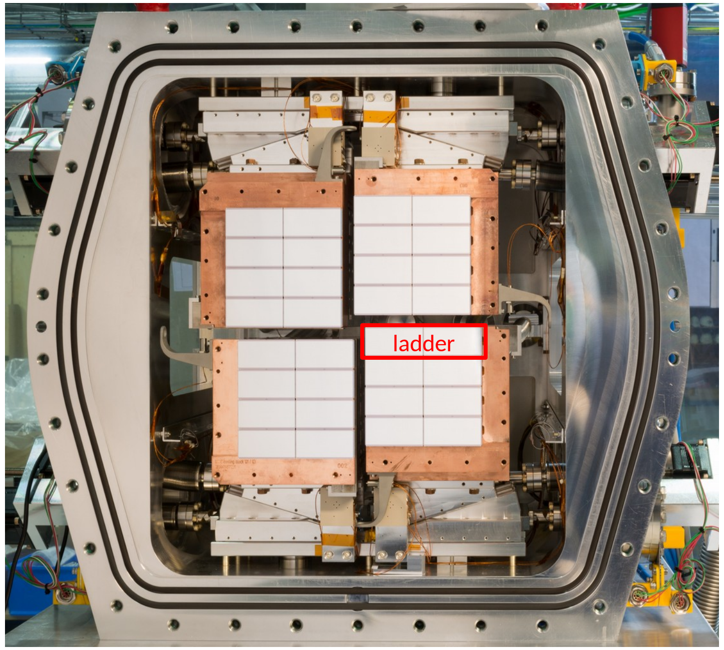
- introduced additional non-sensitive area between detector modules

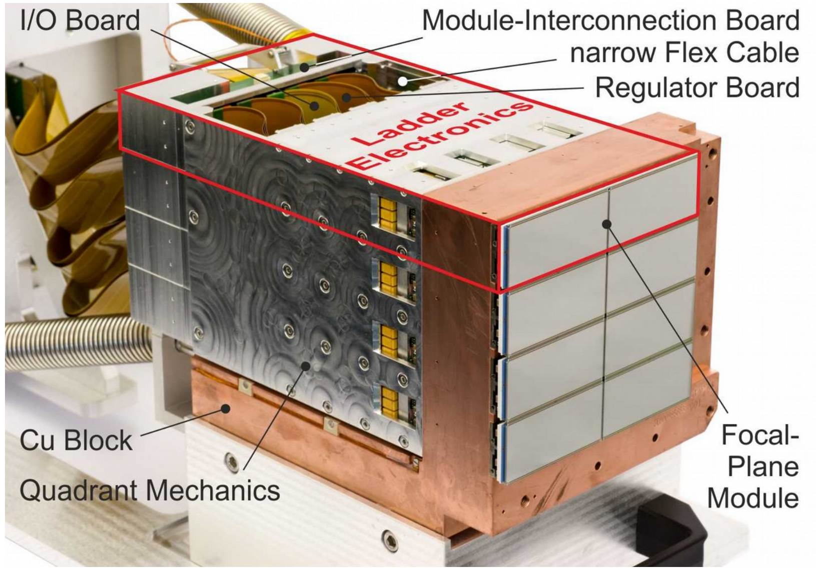


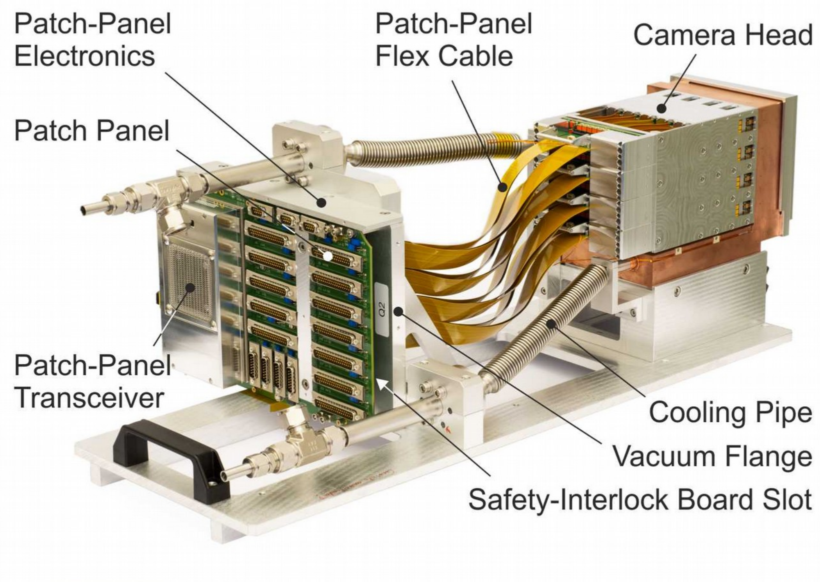
Distance from the last pixel to the edge of the sensor 1200 µm

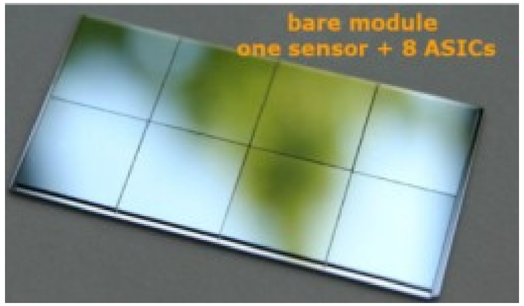
JINST (2013) 8 C12015,
DOI: 10.1088/1748-0221/8/01/C01015,
e-Print: arXiv:1210.0430 [physics.ins-det]

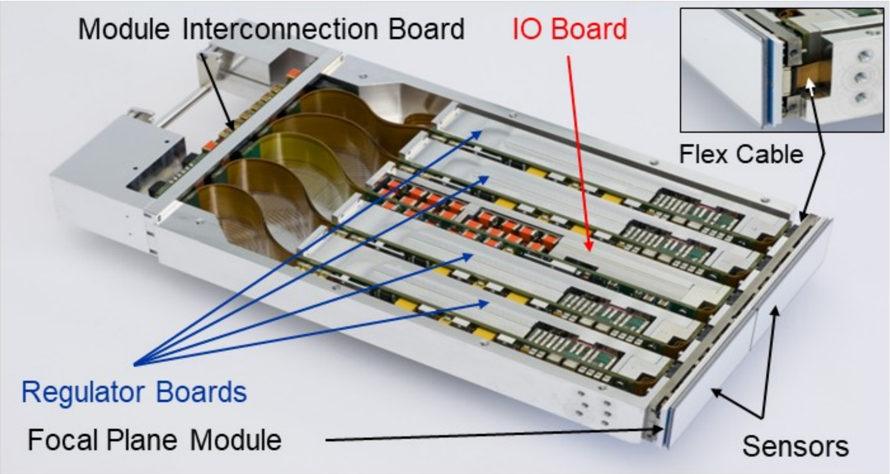
DSSC Detector System Overview 2/2

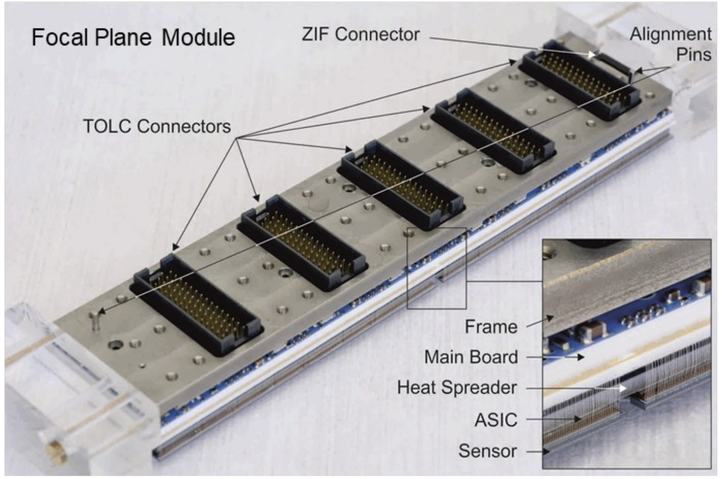






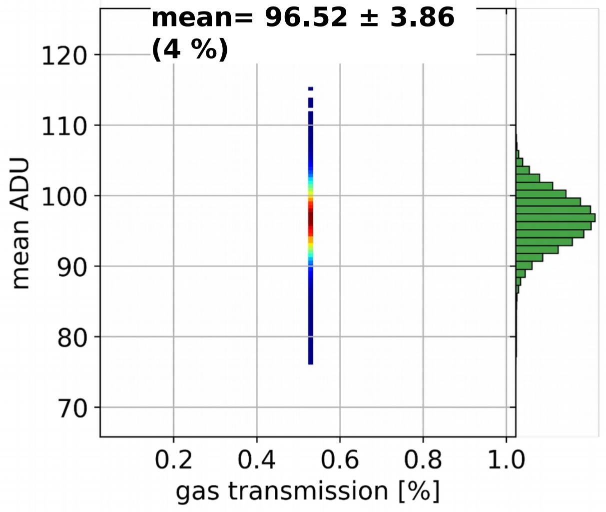


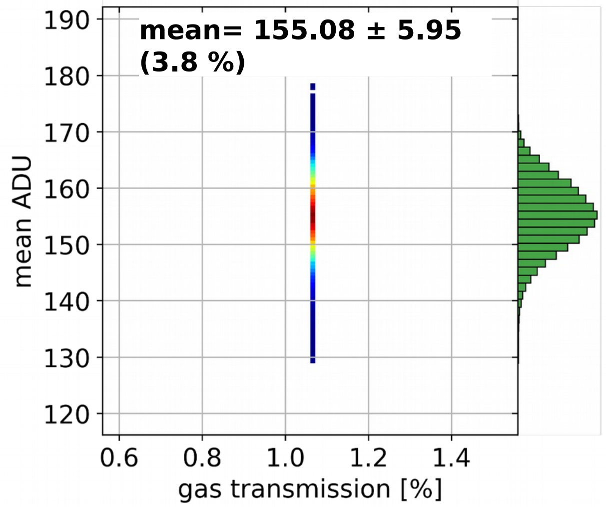




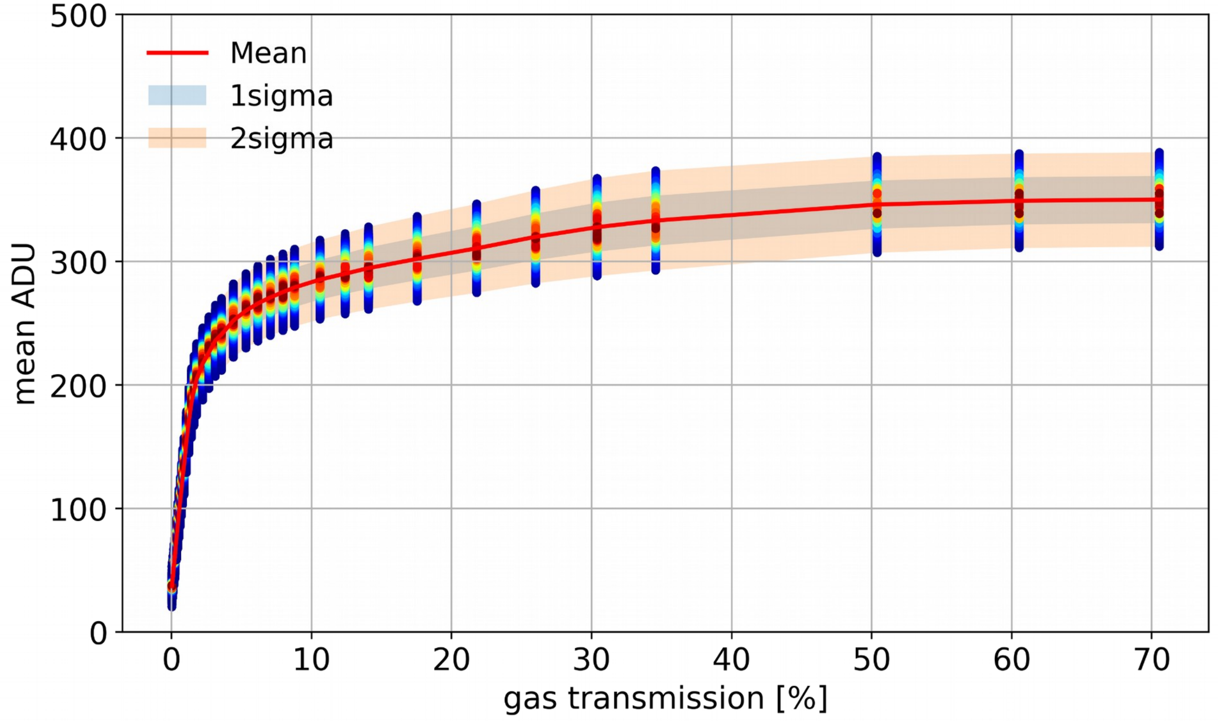
- Movable quadrants
- “service position’ in the pic
- Total active area ~ 505 cm^2
- Minimum insensitive area ~15%

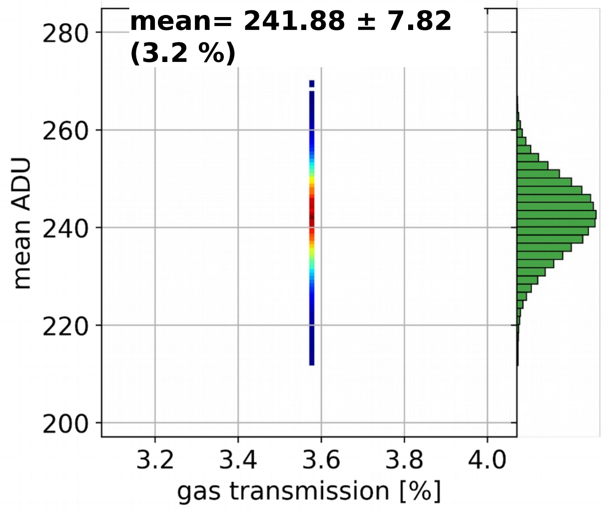
NLR curves of DEPFET pixels

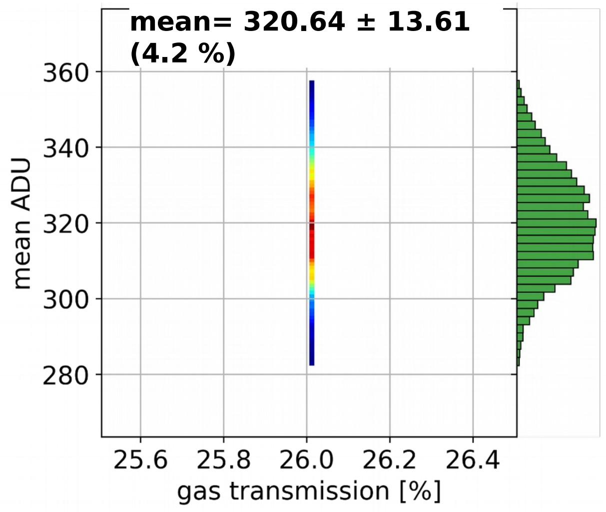




gain: Cfcf=3, T_{int}=50 ns, Freq=2.2 MHz, T=18 °C

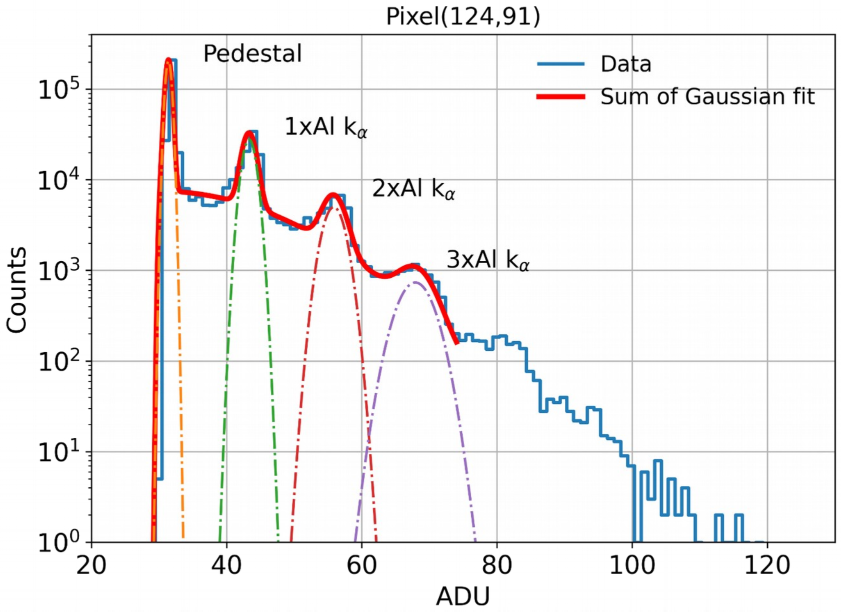


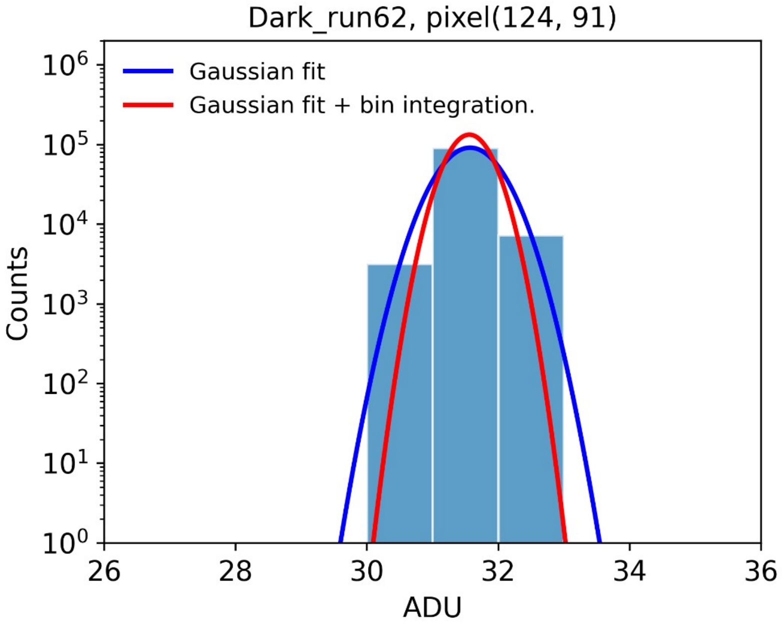




Spectroscopic performance of DEPFET: Single photon detection

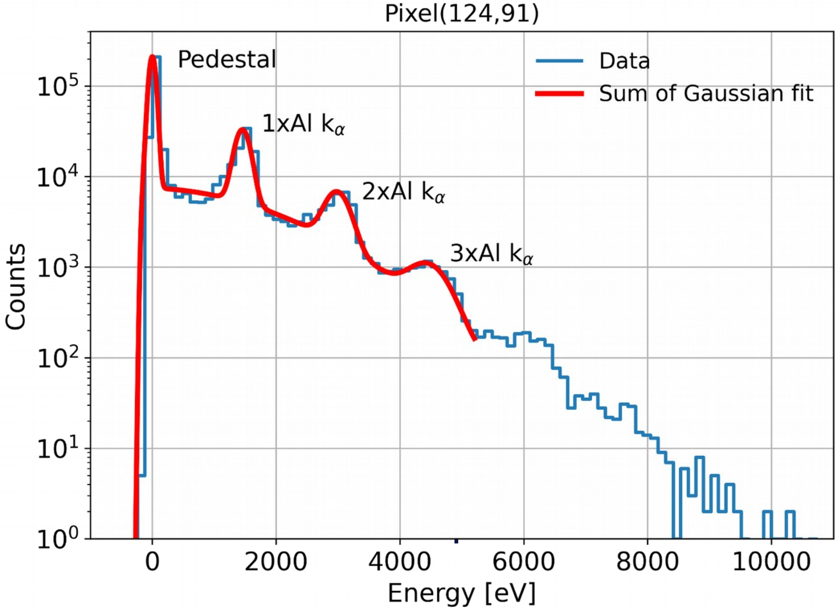
F= 1.1 MHz, T_{int}=100 ns, T=18 °C

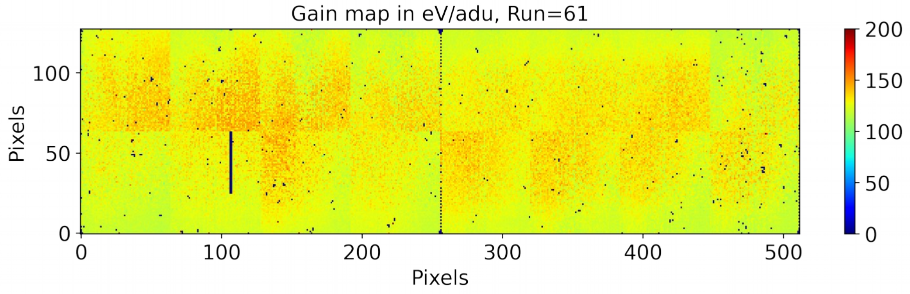


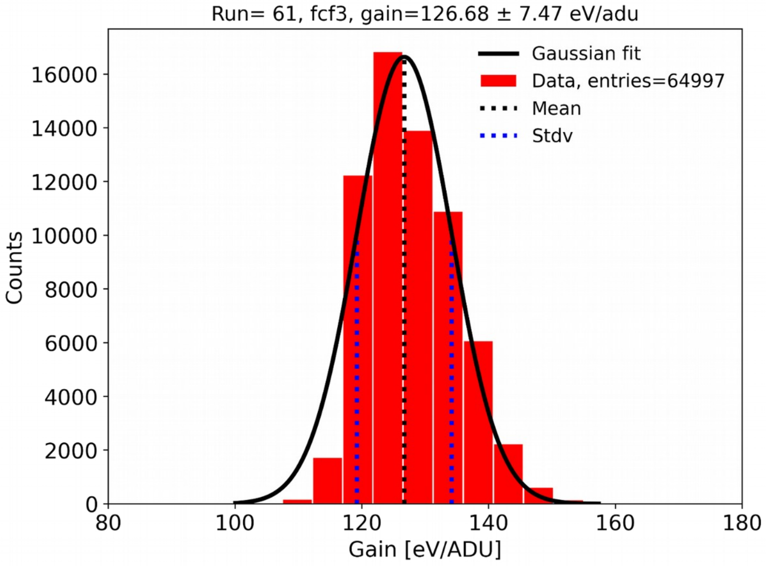


- F= 1.1 MHz, T_{int}=100 ns
- Gaussian: 31.57 ± 0.41
- Gaussian + bin intg.: 31.56 ± 0.3
- Pixel gain: 122 eV/adu
- Pixel noise: 10.1 ENC
- Pixel(124, 91) SNR = 40

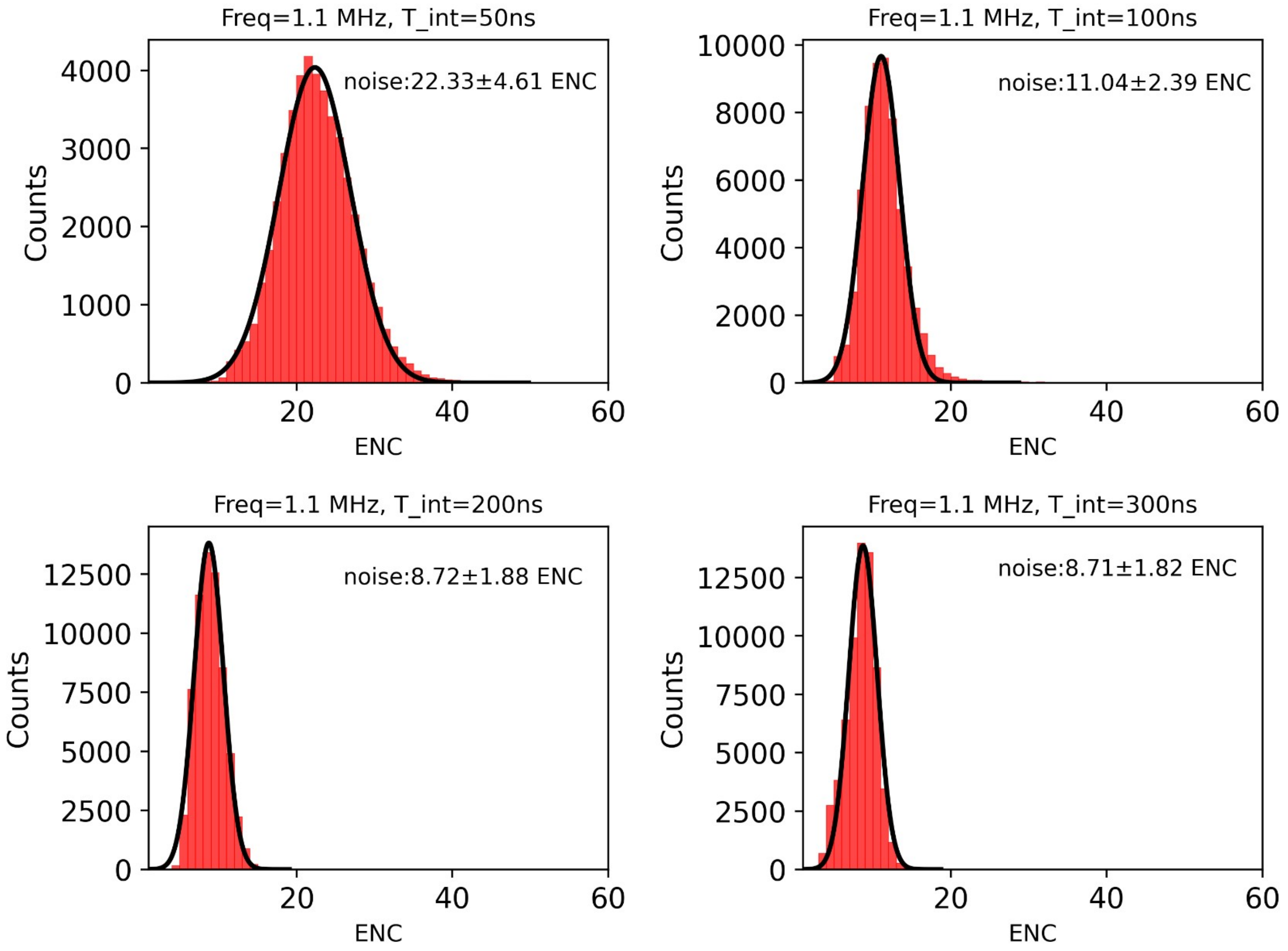
SNR = Energy of Al k_a photon/ noise

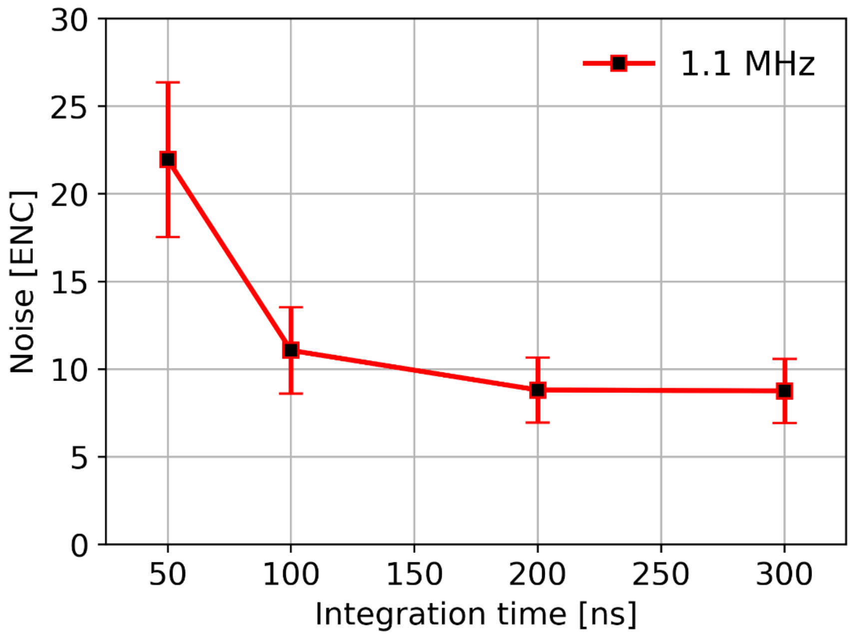






Noise performance of DEPFET pixels



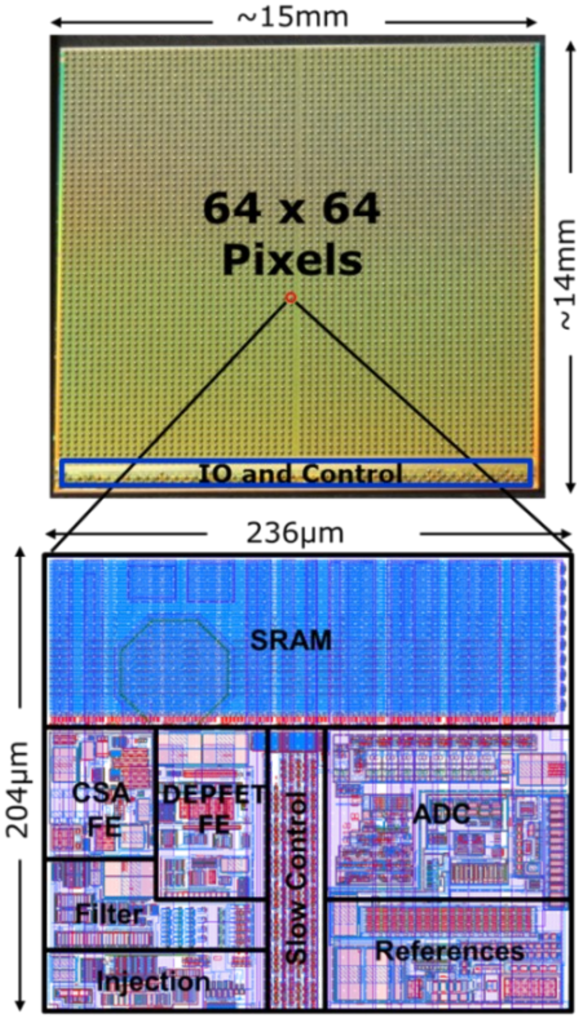


- Flip Capacitor Filter technique

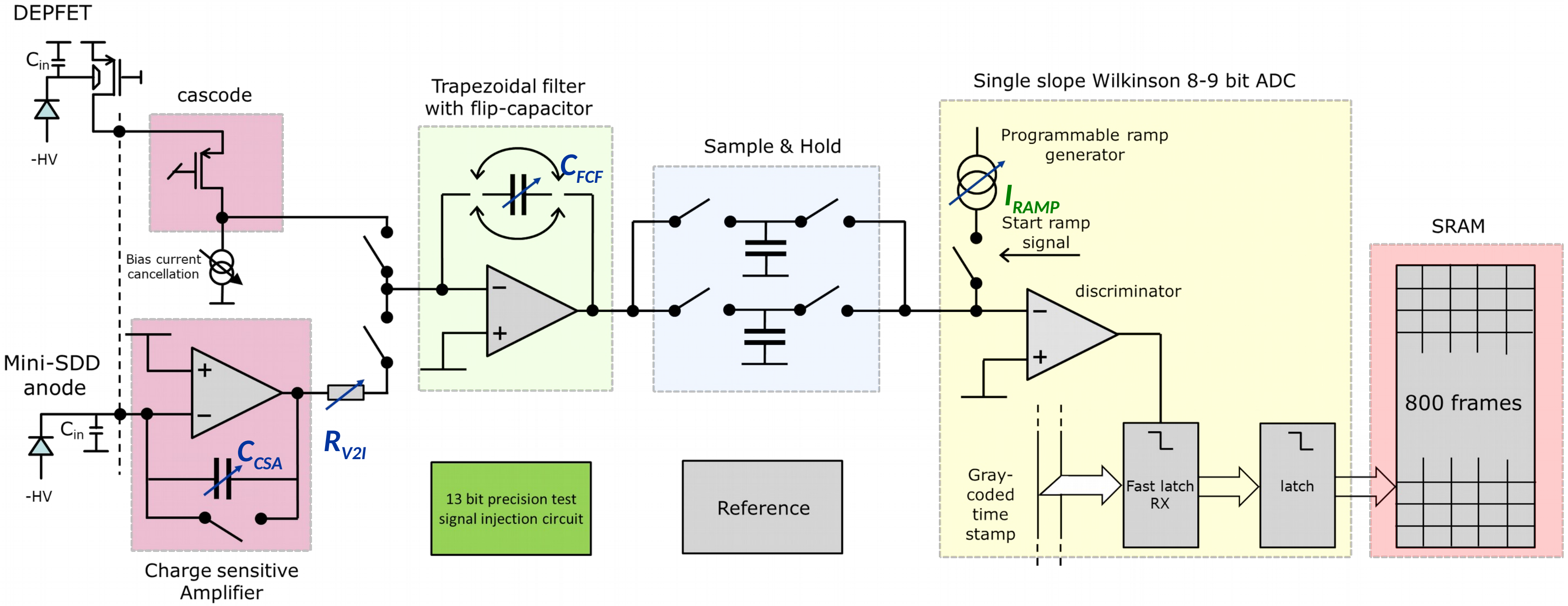
- Noise reduction with increasing integration time

- No MHz X-ray Camera can operates with such very low noise (i.e. 8 ENC)

Full Format Readout ASIC



130 nm CMOS Process with C4 bumps



- Gain and offset can be adjusted pixel-wise:
  - **11 bits of coarse gain setting** for ph. energy and input range selection
  - **6 bits of gain fine trimming** (nominal accuracy 2%)
  - 4 bits for offset trimming (1.5 LSB range with 8% of granularity)

Pixel-wise coarse gain parameters — Pixel-wise fine gain trimming

$$\frac{keV}{ADU} \propto \underbrace{C_{CSA} \cdot R_{V2I} \cdot C_{FCF}}_{\text{coarse gain}} \cdot \frac{1}{t_{filt}} \cdot \frac{1}{C_{S\&H}} \cdot \underbrace{I_{ramp}}_{\text{fine gain}} \cdot \frac{1}{2 \cdot f_{clock}}$$