The Evolution of AGIPD

From SPB and MID to SFX and HiBEF

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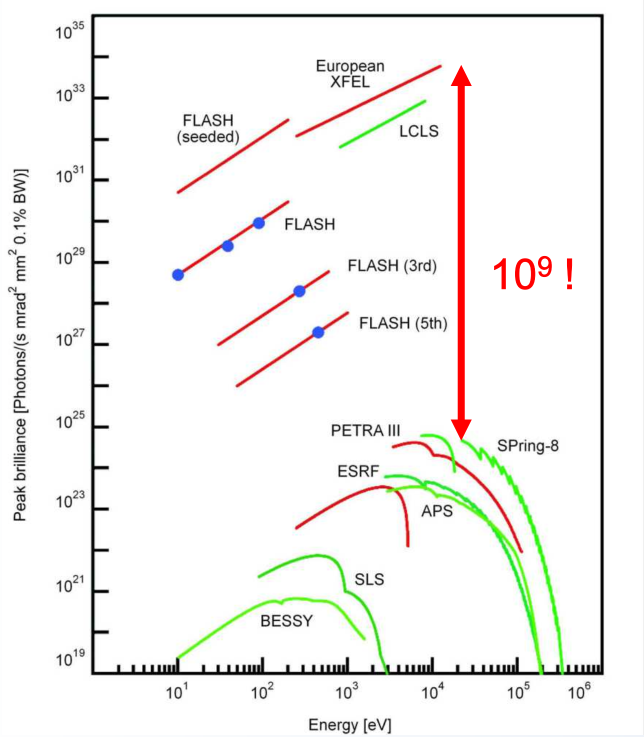
Outline

The AGIPD System	European XFEL Single molecule imaging Requirements
AGIPD 1.1 Readout ASIC	Architecture Dynamic gain switching Performance
AGIPD Detector systems: SPB & MID	Overview First user experiments Results
AGIPD Detector Systems: SFX & HiBEF	Readout boards Optical communications Cooling and mechanics
ecAGIPD for HiBEF	Electron-collecting AGIPD AGIPD06 demonstrator
Beyond AGIPD	
Conclusion	Summary Outlook

European XFEL

Inaugurated September 1st 2017

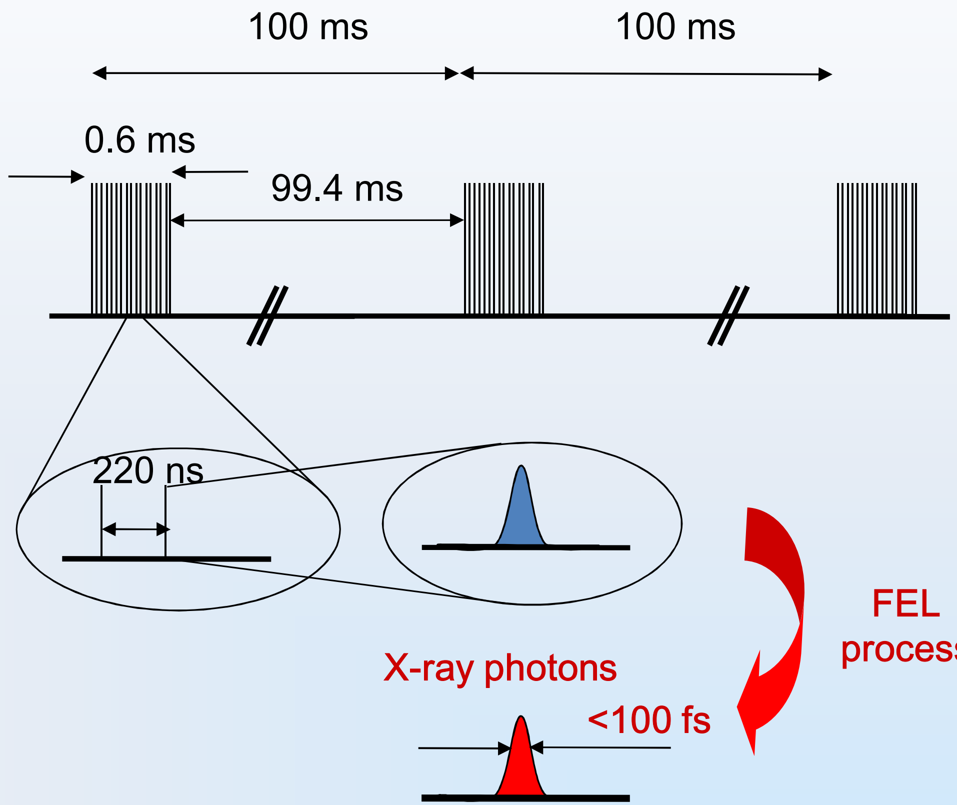
European XFEL properties



Eγ=250eV…12keV

av. Rate:

- 27kHz XFEL
- 120Hz LCLS
- 60Hz SCSS



Detectors:

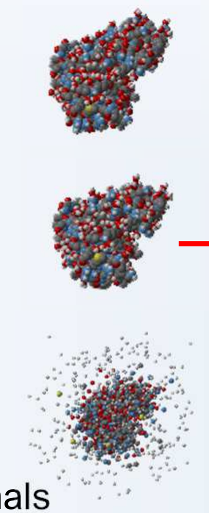
- LPD (500µm x 500µm) - 1Mpix installed
- AGIPD (200µm x 200µm) - 1Mpix installed, 1Mpix commissioning, 4Mpix & 1Mpix under construction
- DSSC (230µm x 200µm) - 1Mpix under construction

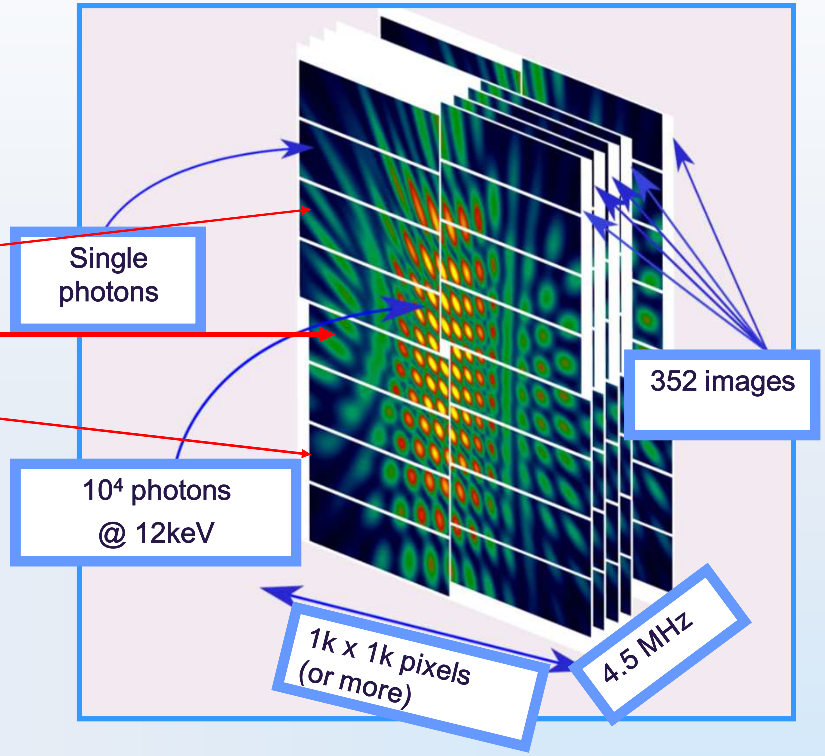
AGIPD Scientific Case: Single Molecule Imaging & SFX

Just before XFEL pulse

During the pulse

After pulse

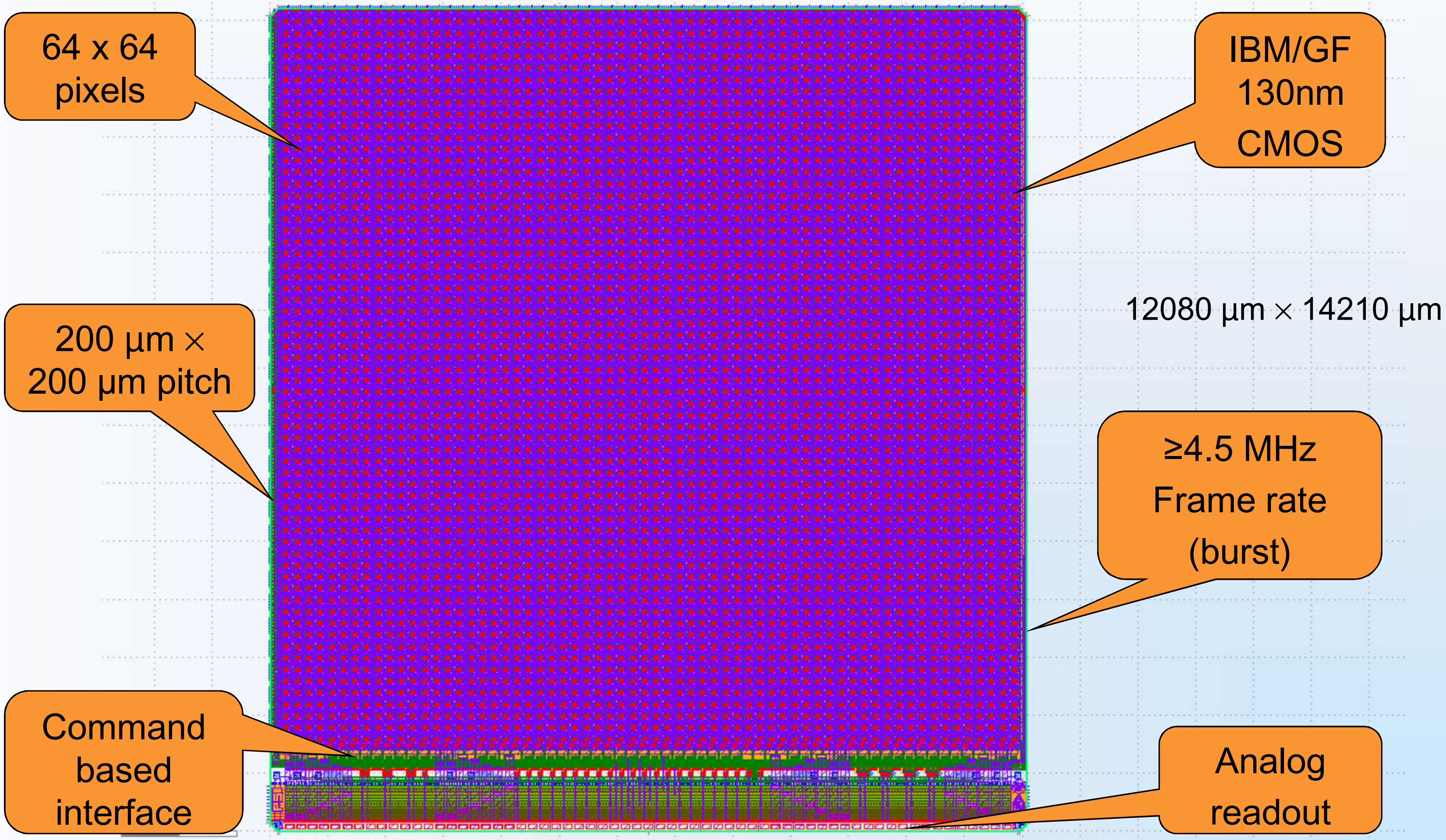




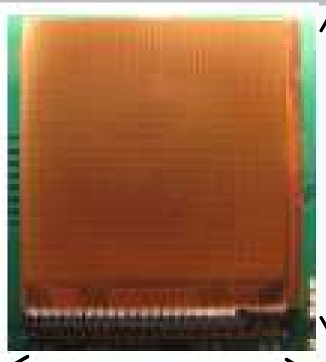
- Time structure of the photon signals
  - Pipelined architecture
  - Random access mode
    - External veto capability
- High radiation dose at small angles: 10^4 photons/(pixel shot)
- over 3 years: 1 GGy @sensor
  - Radiation damage of silicon sensor
  - Radiation damage of underlying electronics (≫10 MGy)
    - Radiation hard design

- 500 µm silicon sensor
- 200 µm square pixels
- Vacuum compatibility
- Detector with central hole

AGIPD 1.1 ASIC

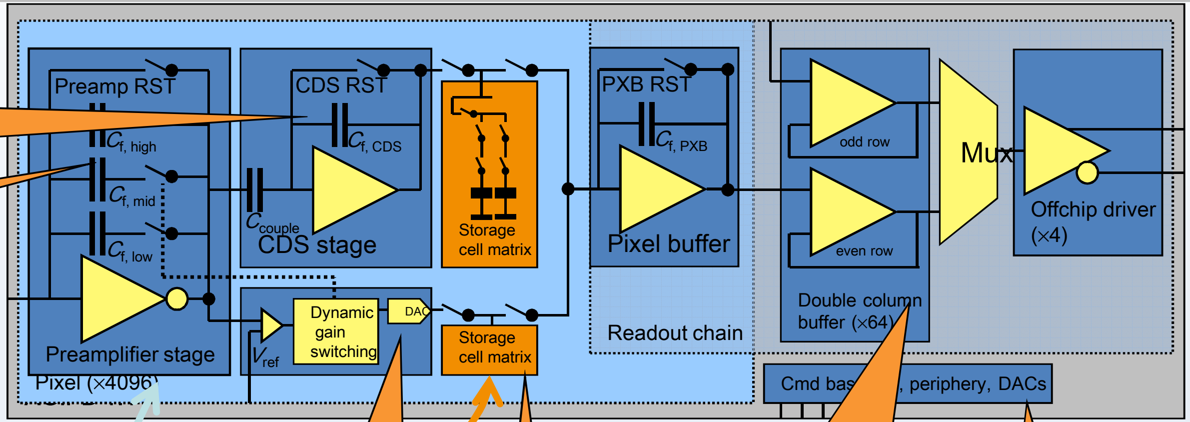


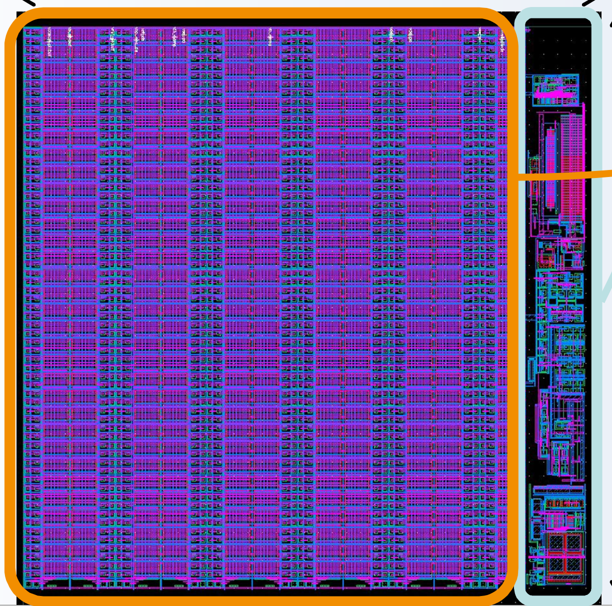
AGIPD 1.1 ASIC



Correlated double sampling

Adaptive gain
C_f=60fF, 3pF, 10pF





Analogue encoding of gain

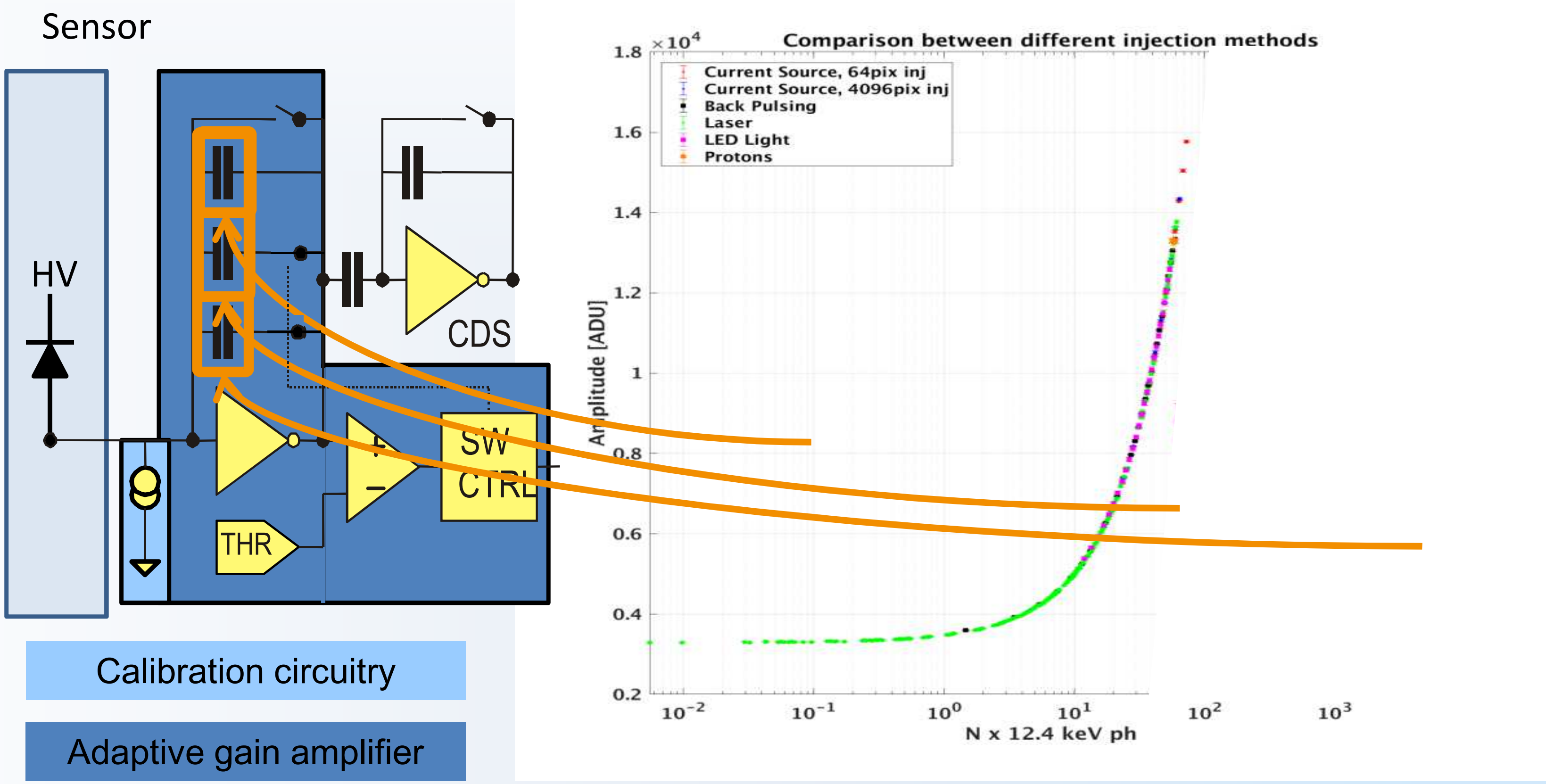
Analogue RAM for 352 images

Interleaved row Double column readout

Command based control via serial IF

Remaining Issue:
Separation between med/low gain signals disappearing with burst length → AGIPD 1.2

Adaptive gain switching



Calibration circuitry

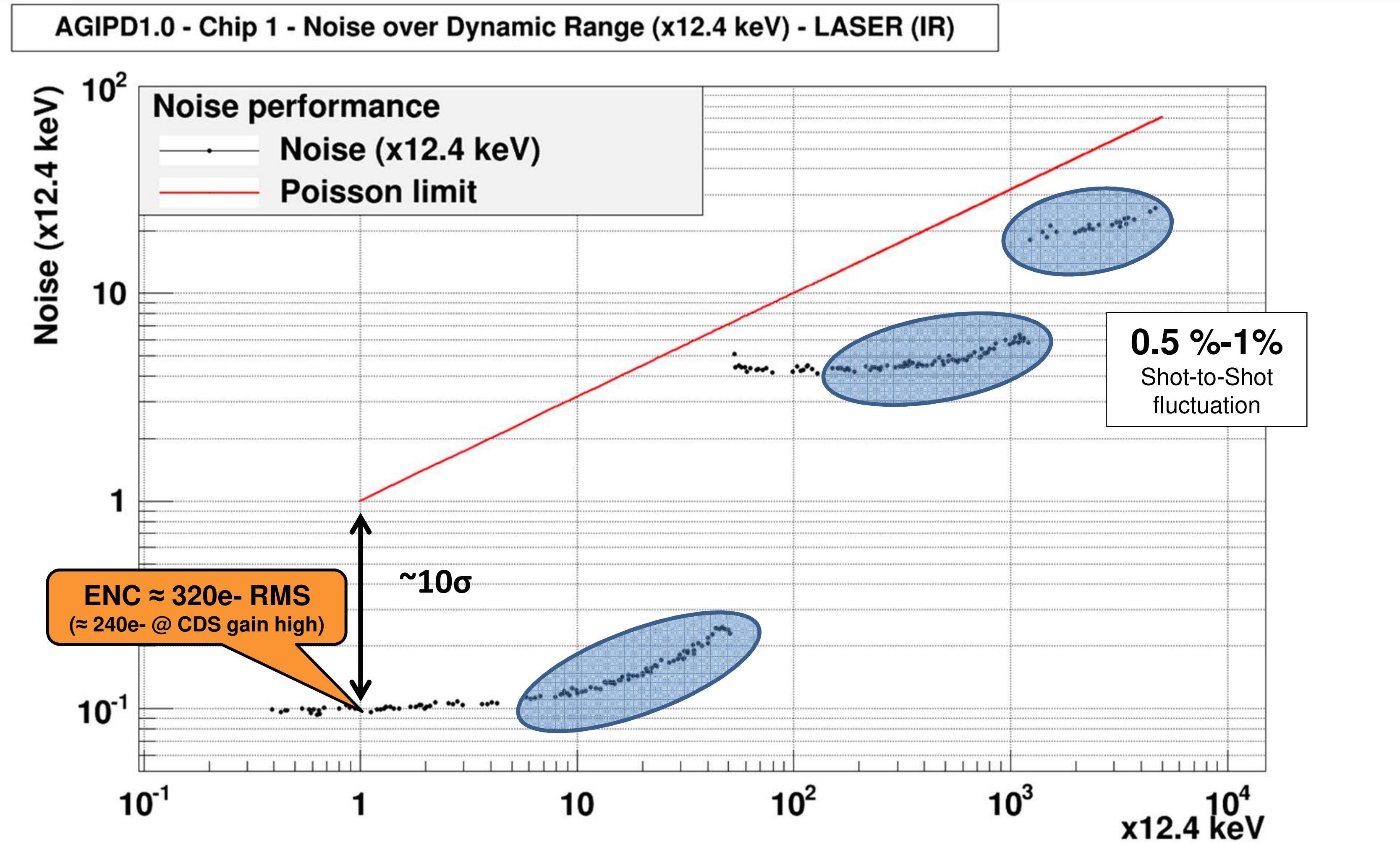
Adaptive gain amplifier

Line spectra covering all 3 gains with (1MeV) Protons@LABEC

High gain: 50-80 Photons with single photon sensitivity.

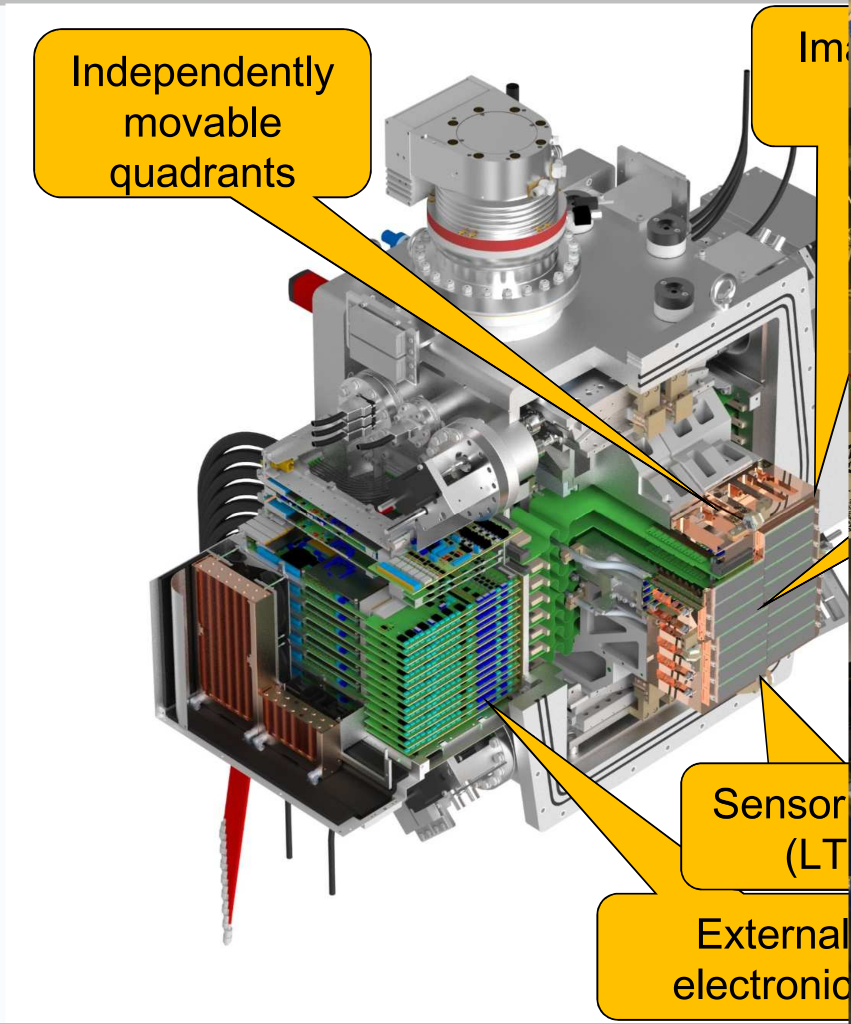
Low gain: 5000 photons with linear gain +5000 photons with 1% nonlinearity.

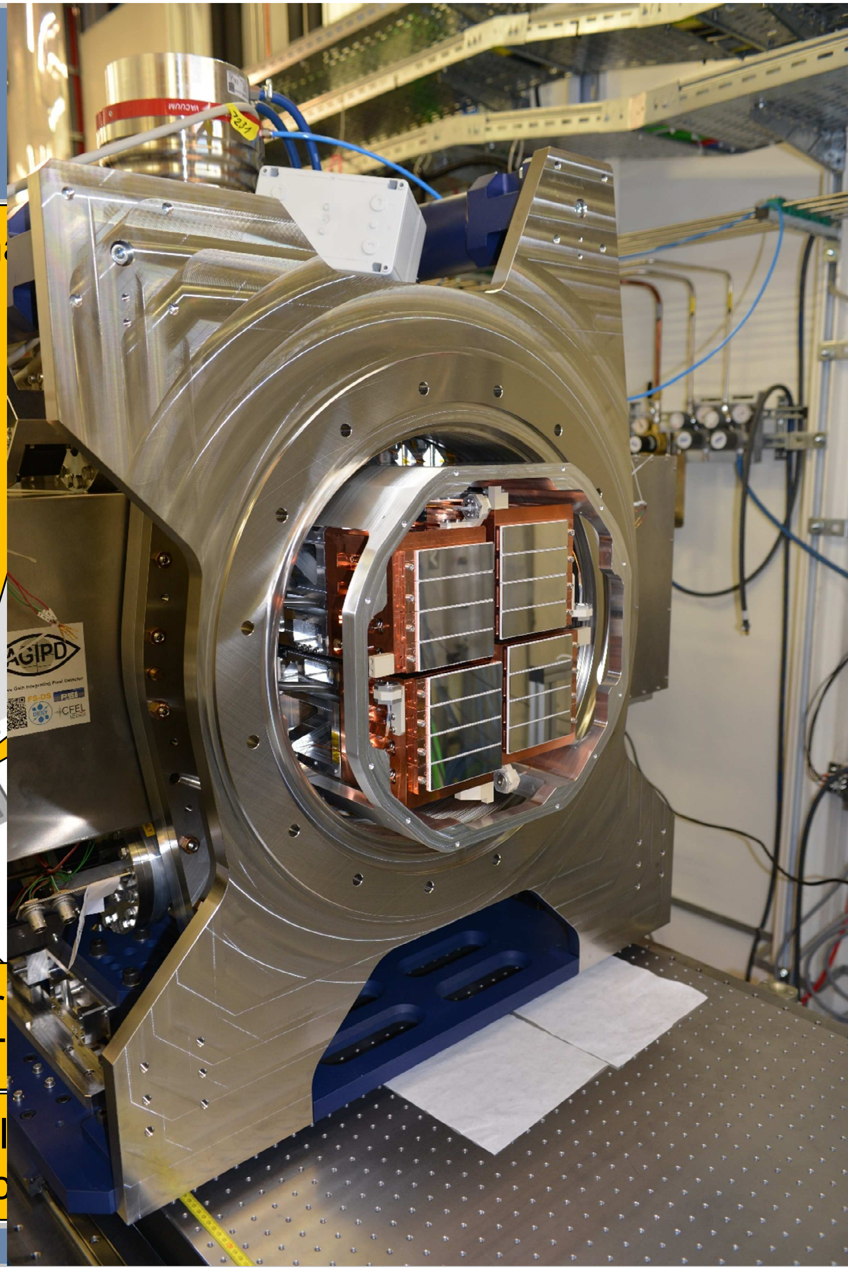
AGIPD Detector noise



AGIPD 1Mpix Systems

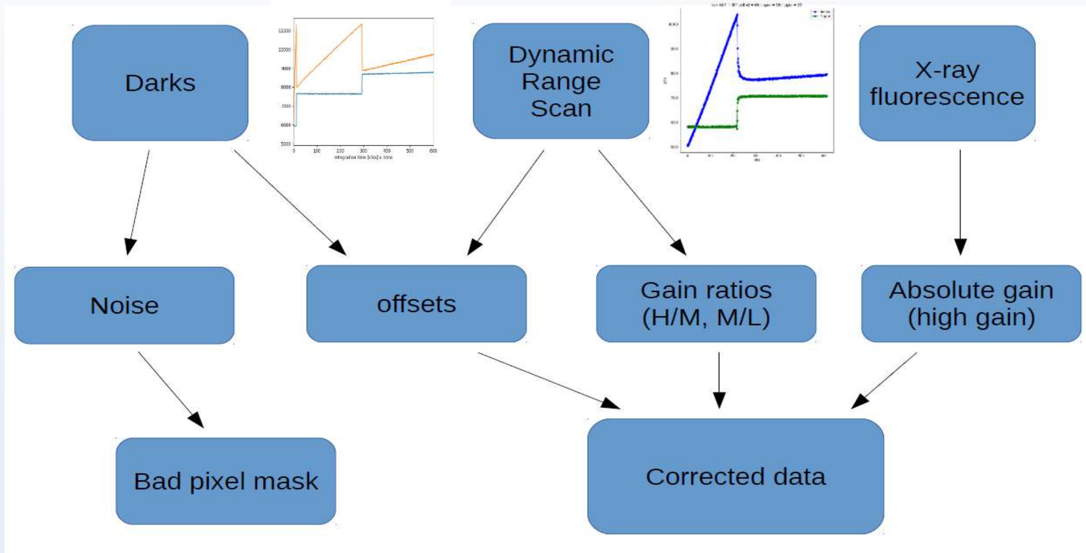
(SPB and MID Beamlines at European XFEL)

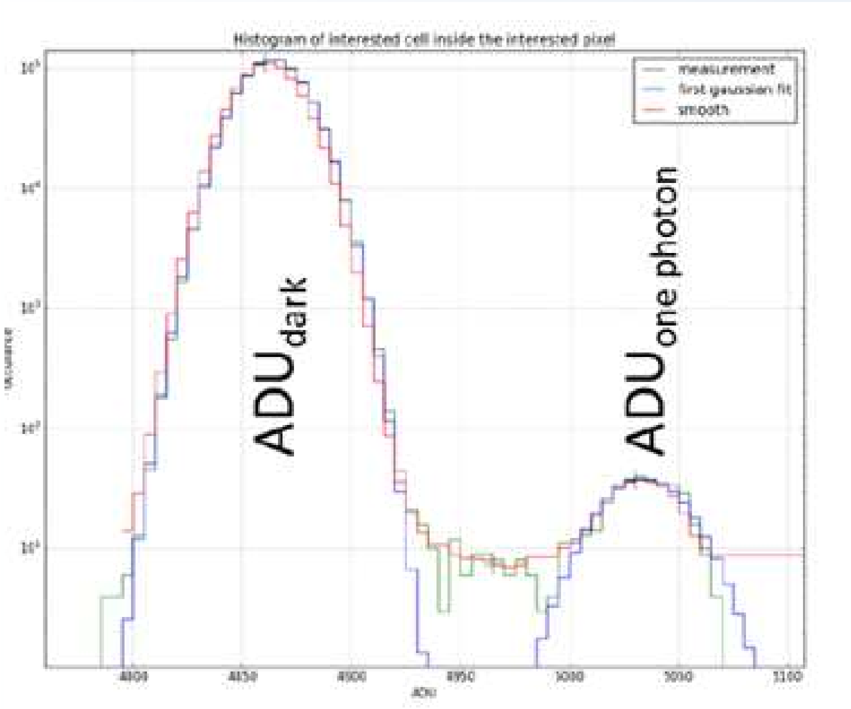




AGIPD 1Mpix Systems:
Calibration

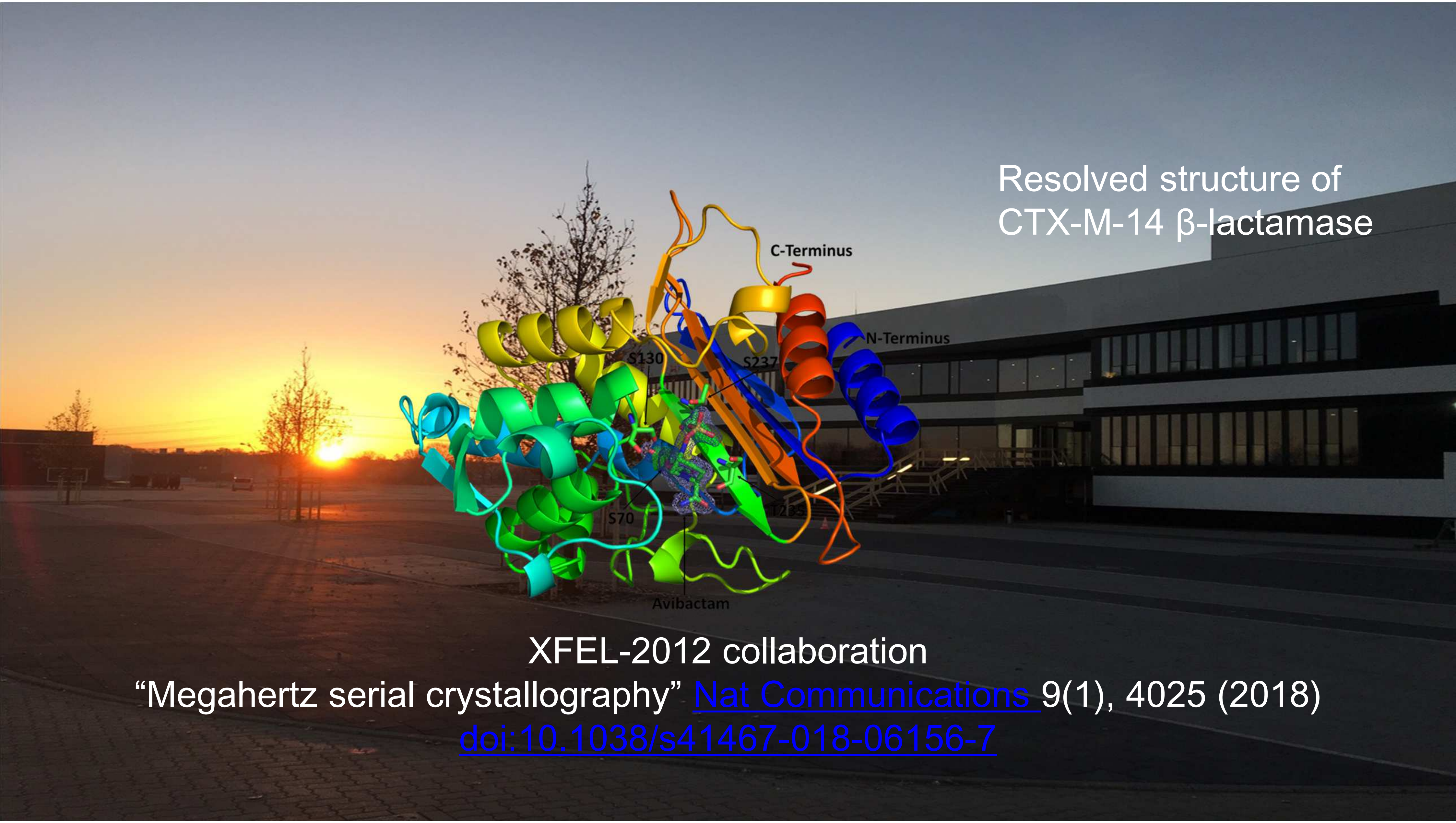
Feed calibration frame work with
- Pulsed capacitor dynamic range scans for all memory cells used
- Cu-K_{α} data at XFEL
- Dark data for High and Medium gain level





Calibration framework follows a modular concept and allows removing, adding and exchanging building blocks
- Huge number of fits!
- 65,536 pixels
- 352 memory cells
- 3 Gains + 3 Offsets
- ≈138,000,000 fits / module
- 16 Modules → 2.2×10^9 constants
- computation time, fit quality, non-constant fit ranges

Also on this Topic:
- J. Becker: N-24-01
How to determine 2.8 billion calibration constants for a 1 MPix AGIPD camera at the European XFEL
- D. Mezza: N-22-382
Calibration concept for the AGIPD detector



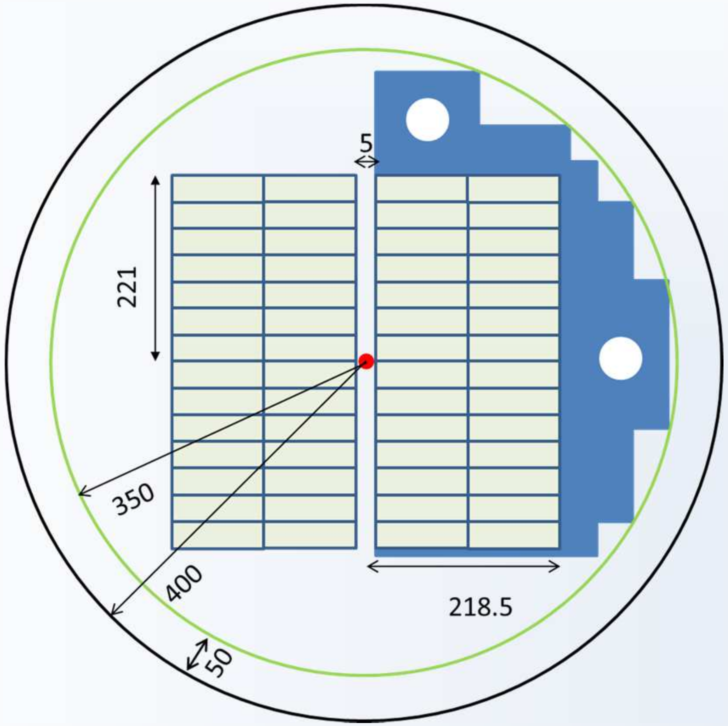
Resolved structure of
CTX-M-14 β-lactamase

XFEL-2012 collaboration

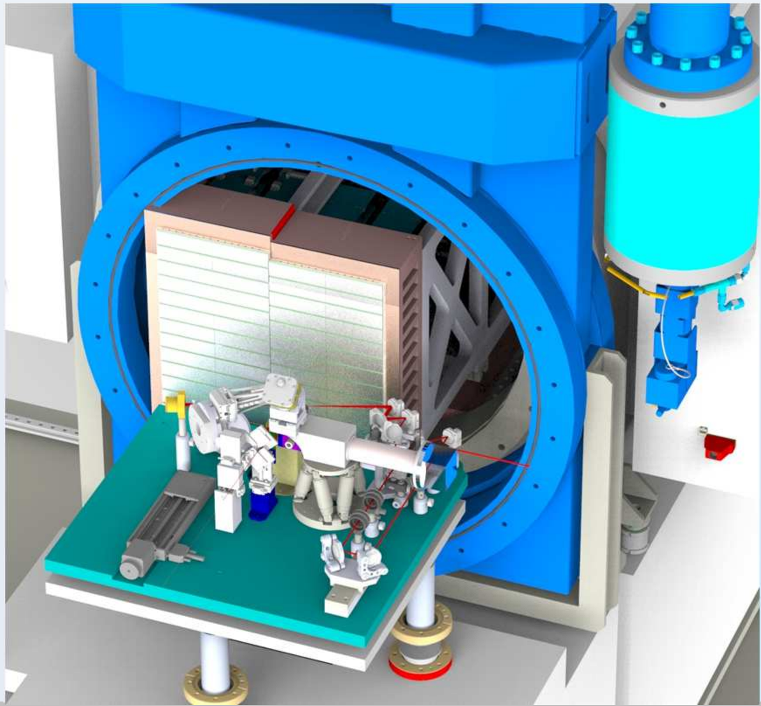
“Megahertz serial crystallography” Nat Communications 9(1), 4025 (2018)

doi:10.1038/s41467-018-06156-7

AGIPD 4M Detector for SFX

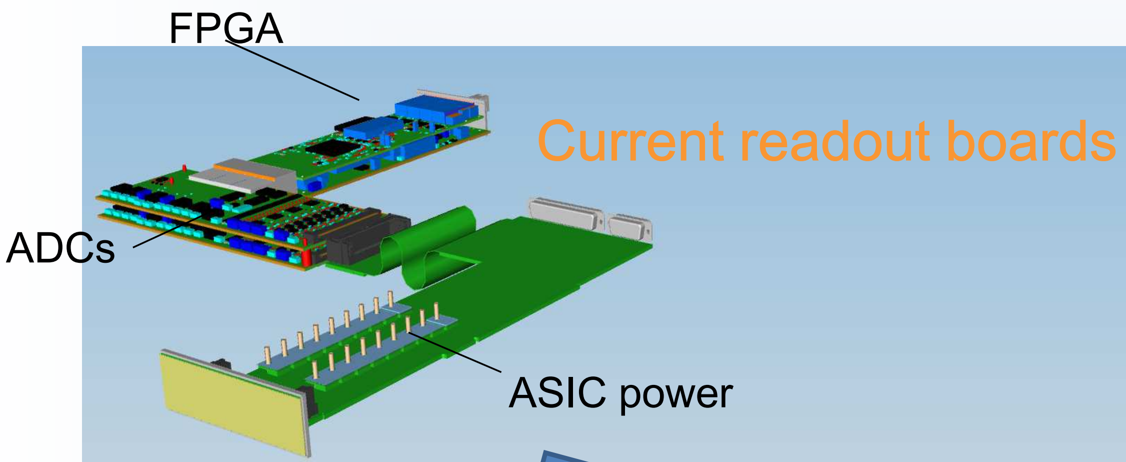


- 4 x 14 Front-End-Modules, arranged in
  - 2 x 14 Double-Modules
- Two halves
  - 2 x 14 FEMs each
  - Independent in-vacuum x-motion



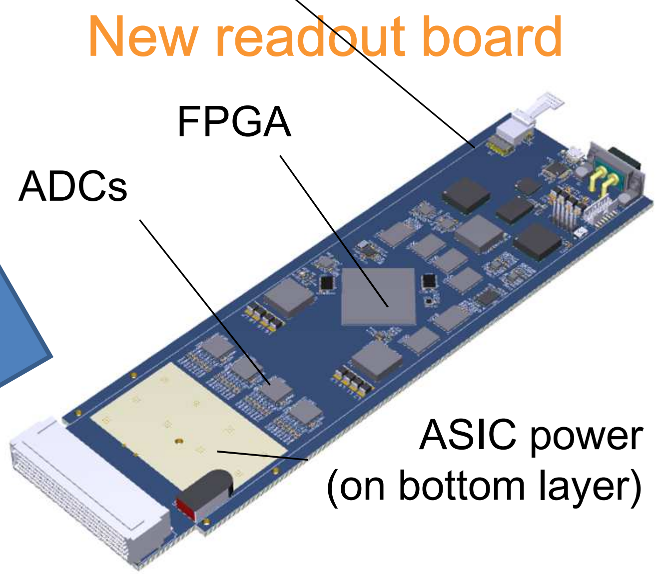
- In-vacuum z-motion
  - through gate valve
    - inner diameter 800mm
  - into sample chamber
  - travel range of 400 mm

AGIPD 4M Detector for SFX

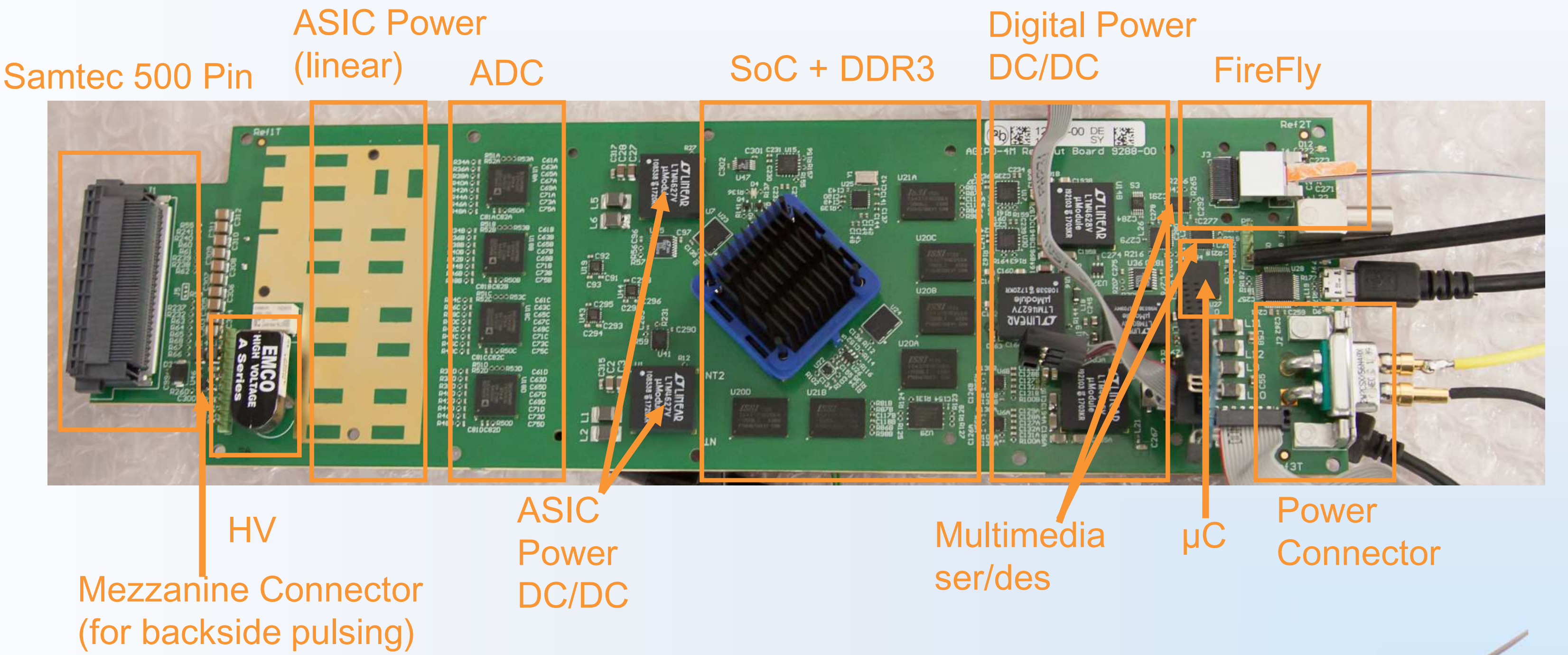


Challenges
- Complete redesign of two boards
  - Readout board in vacuum
  - Receiver board outside vacuum
- Cooling of PCB in vacuum

Advantages
- Short analogue signal path
- Local DC/DC -> less power cables
- Control and DAQ completely based on optical data transmission

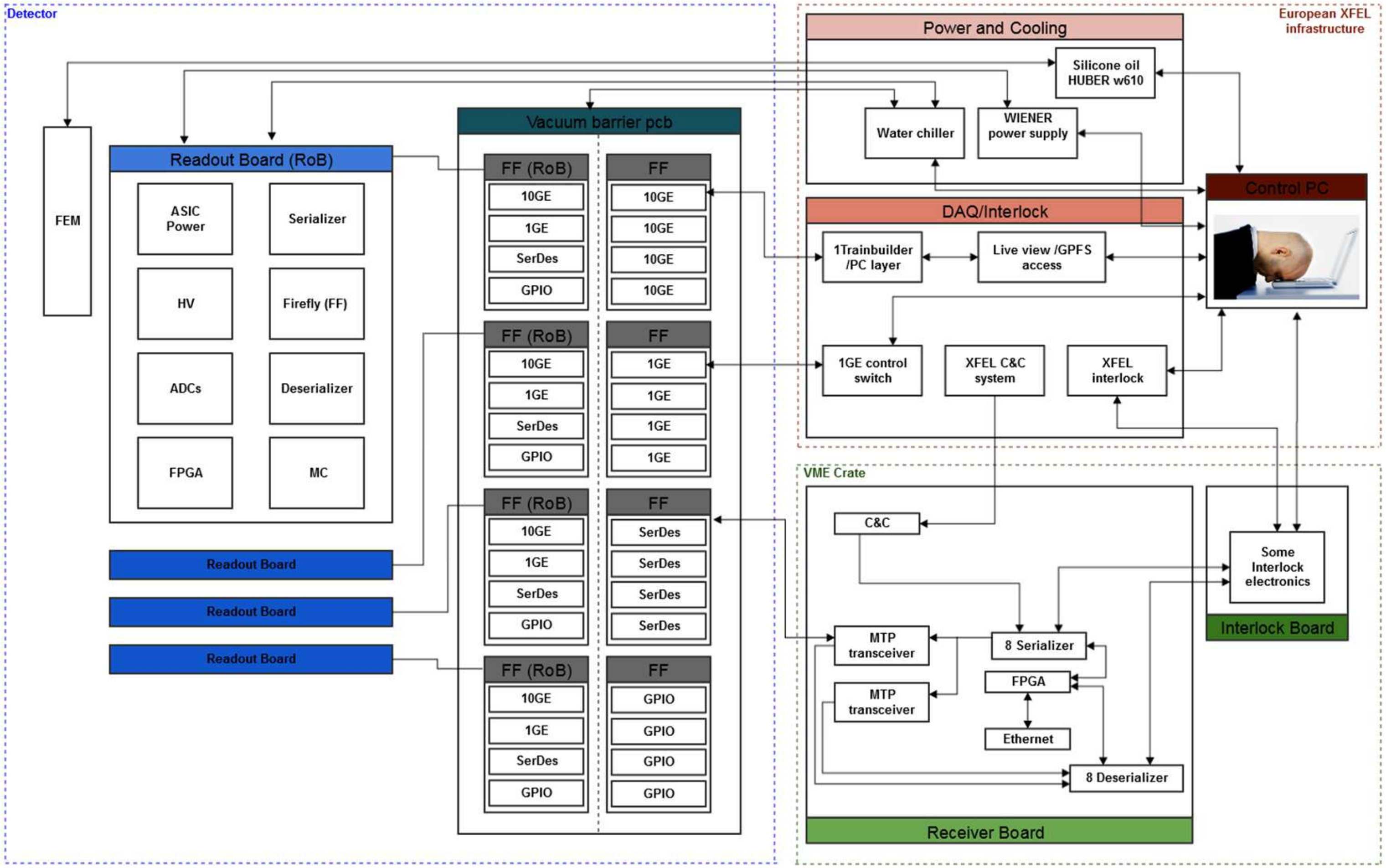


AGIPD 4M Detector for SFX



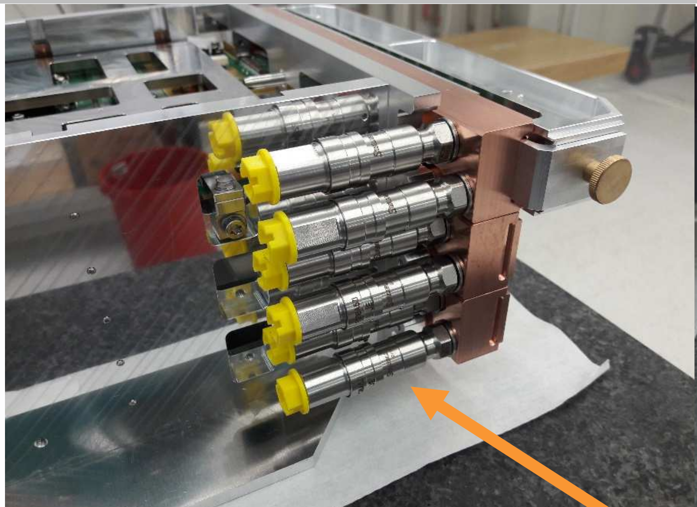
- Series production started
- Successful commissioning without major issues

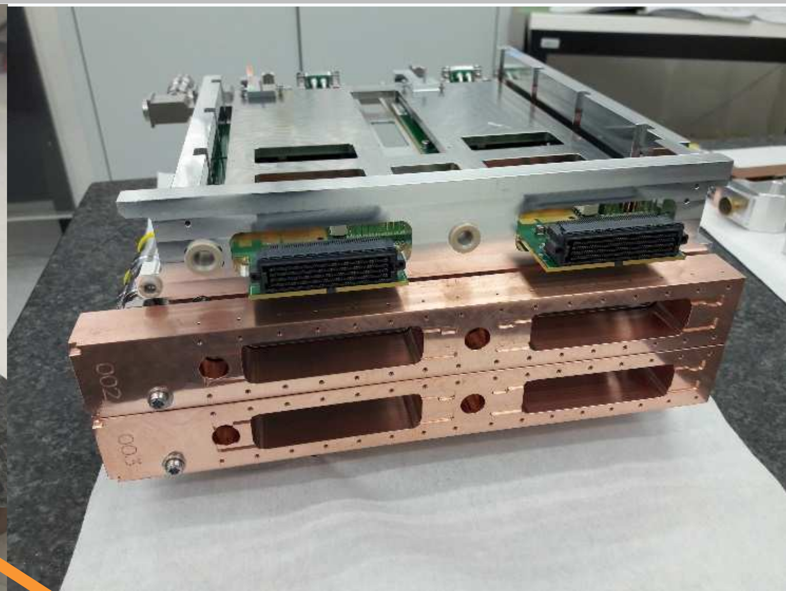
AGIPD 4M Detector for SFX

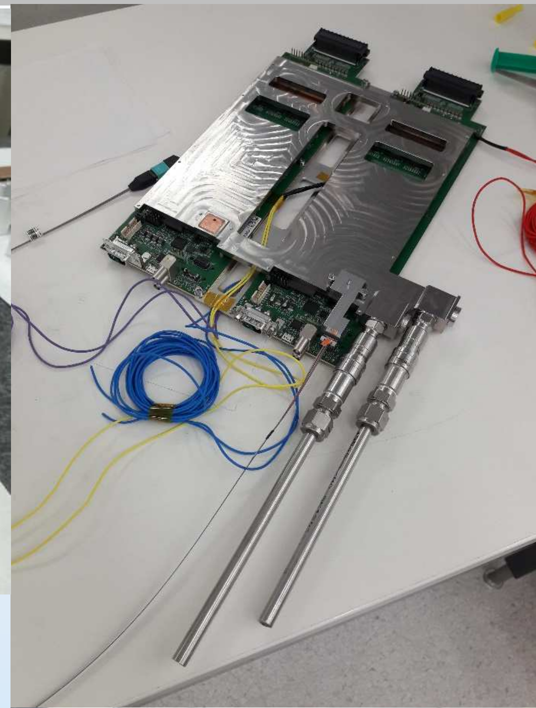


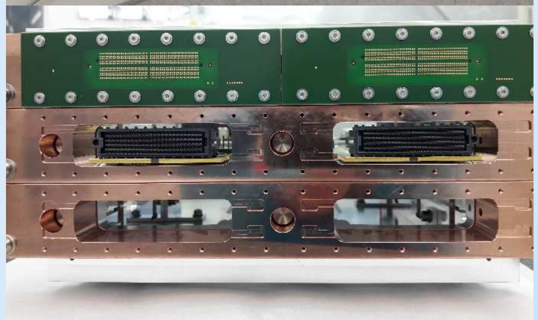
AGIPD 4M Detector for SFX

In-Vacuum Cooling







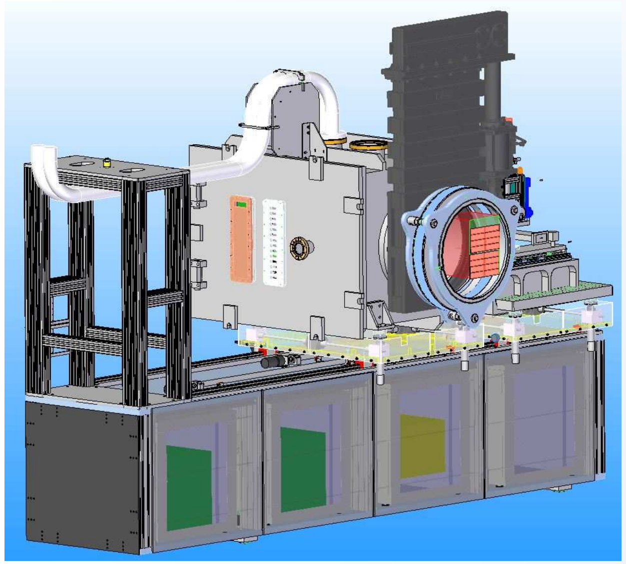


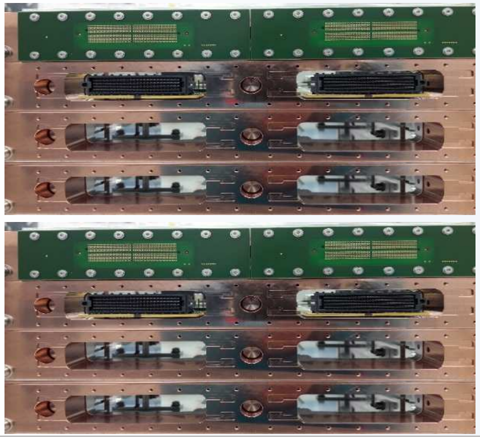
Liquid Cooling of

- Modules
  - Cooling channels in Copper frame
  - Coolant: Silicone oil
- Readout boards
  - Coolant: Water
- In-Vacuum connectors

AGIPD 1M Detector for HiBEF

@HED Endstation of European XFEL





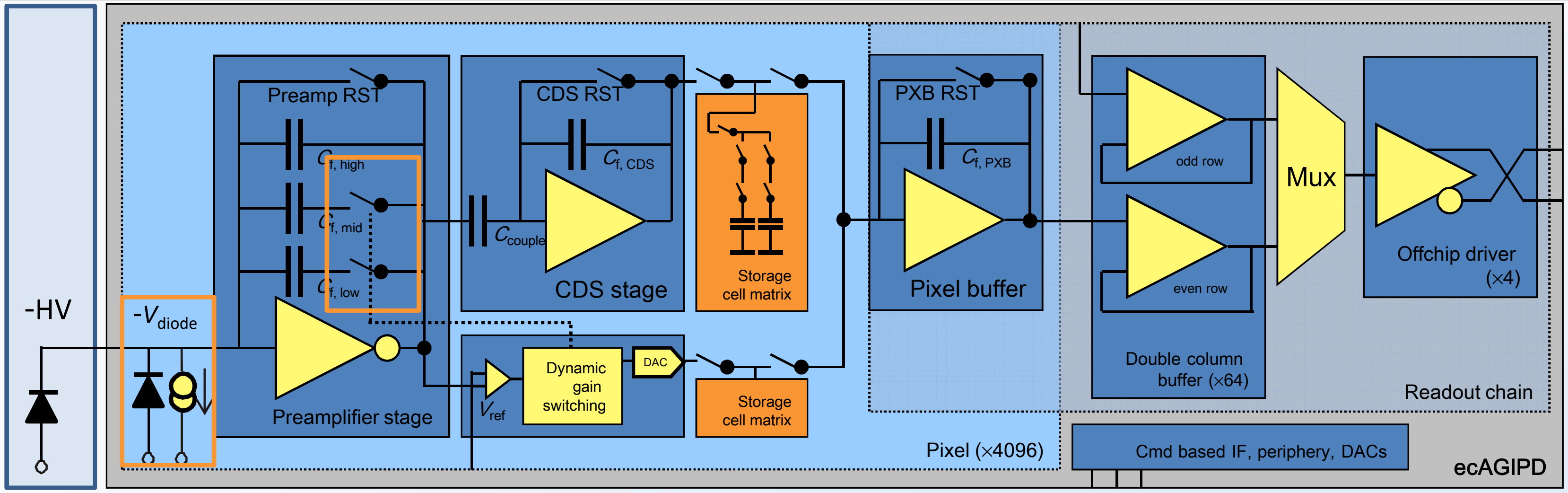
The HiBEF (Helmholtz International Beamline for Extreme Fields) experiment @ EuXFEL needs a 1Mpix detector for E_{ph}≥25keV

- The existing AGIPD detector collects positive charges (holes)
  - Easier to realise radiation hard sensors
  - Slower – less demanding to handle large charges (circuit wise)

- AGIPD is not suitable for experiments with photons above ~15keV
  - The Silicon sensor gets inefficient ~15keV

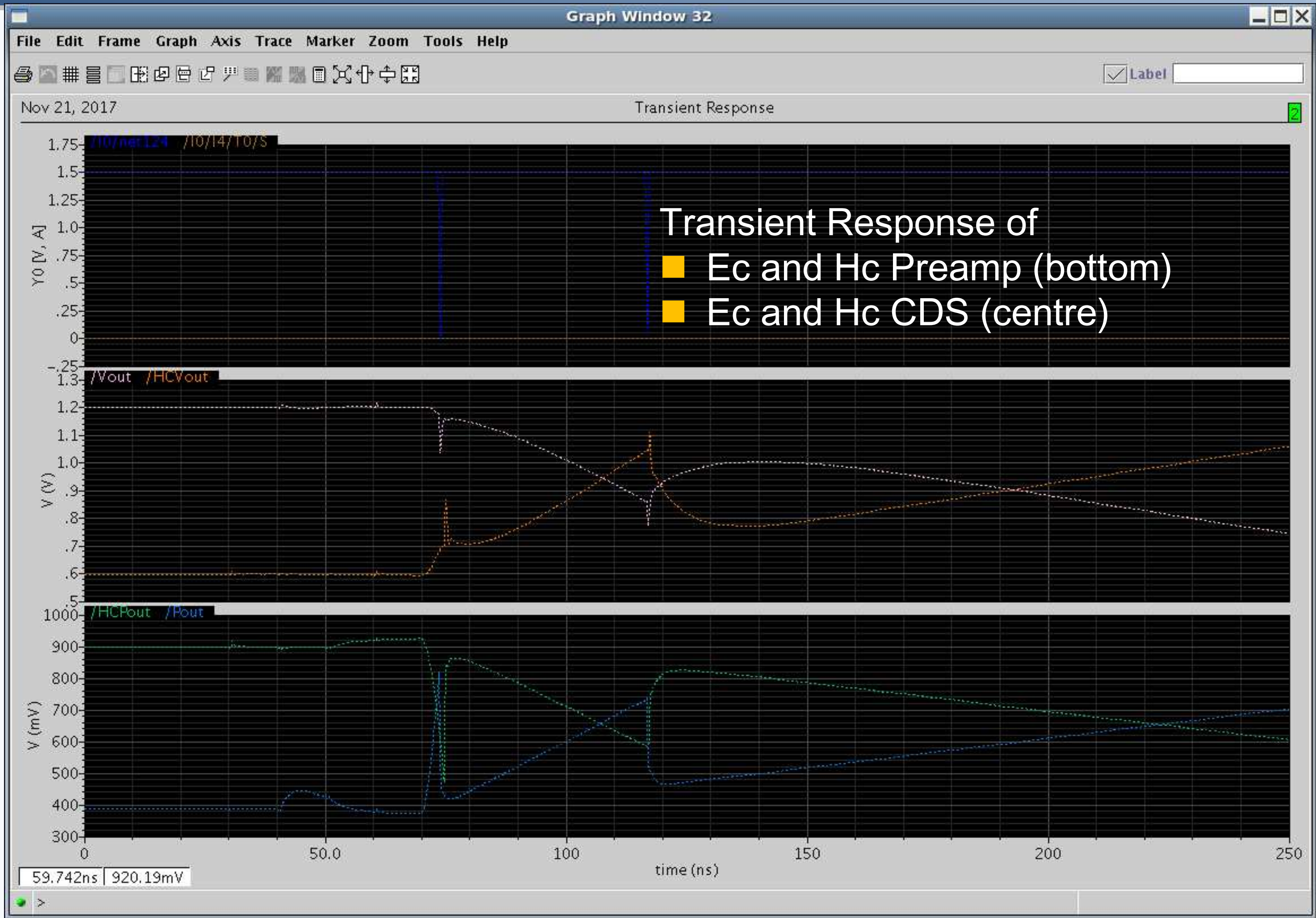
- High-Z Semiconductors, esp. GaAs promise efficient sensors for E_{ph}≥25keV
- Composite (III/V) Semiconductors feature relatively short charge carrier lifetimes
- Collection of Electrons (i.e. the fast component) is required

ecAGIPD

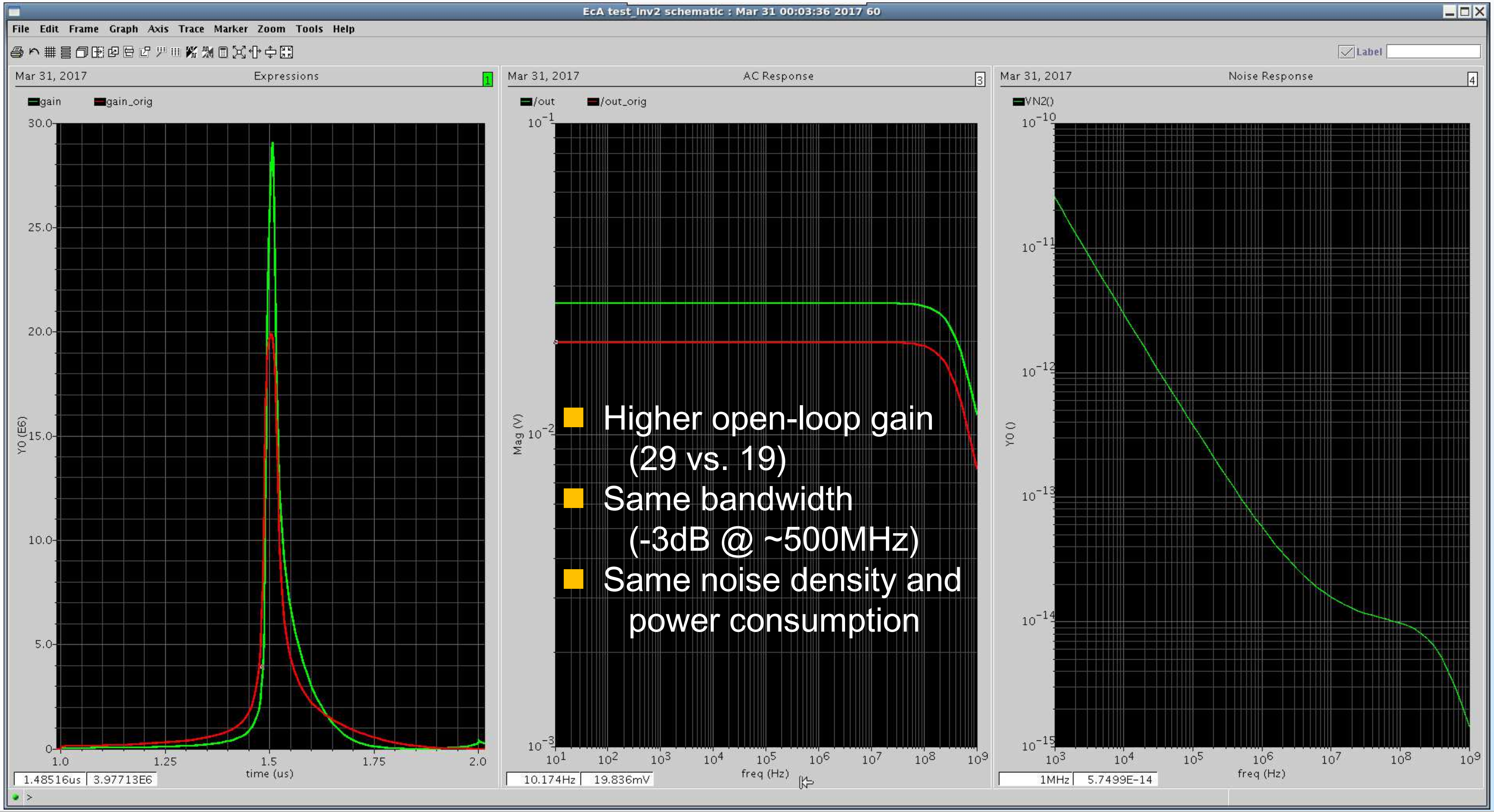


- Triple-well structure at negative (V_{diode}~-1V) voltage containing
  - Input protection diode
  - Current source for test stimulus = current mirror driven by existing source
  - Feedback switches
- Modified Preamp
  - New baseline at ~400mV
- Discriminator of opposite polarity
- Changed gain encoding
  - Hi <-> Lo
- Swapped output pads

ecAGIPD-Preamp

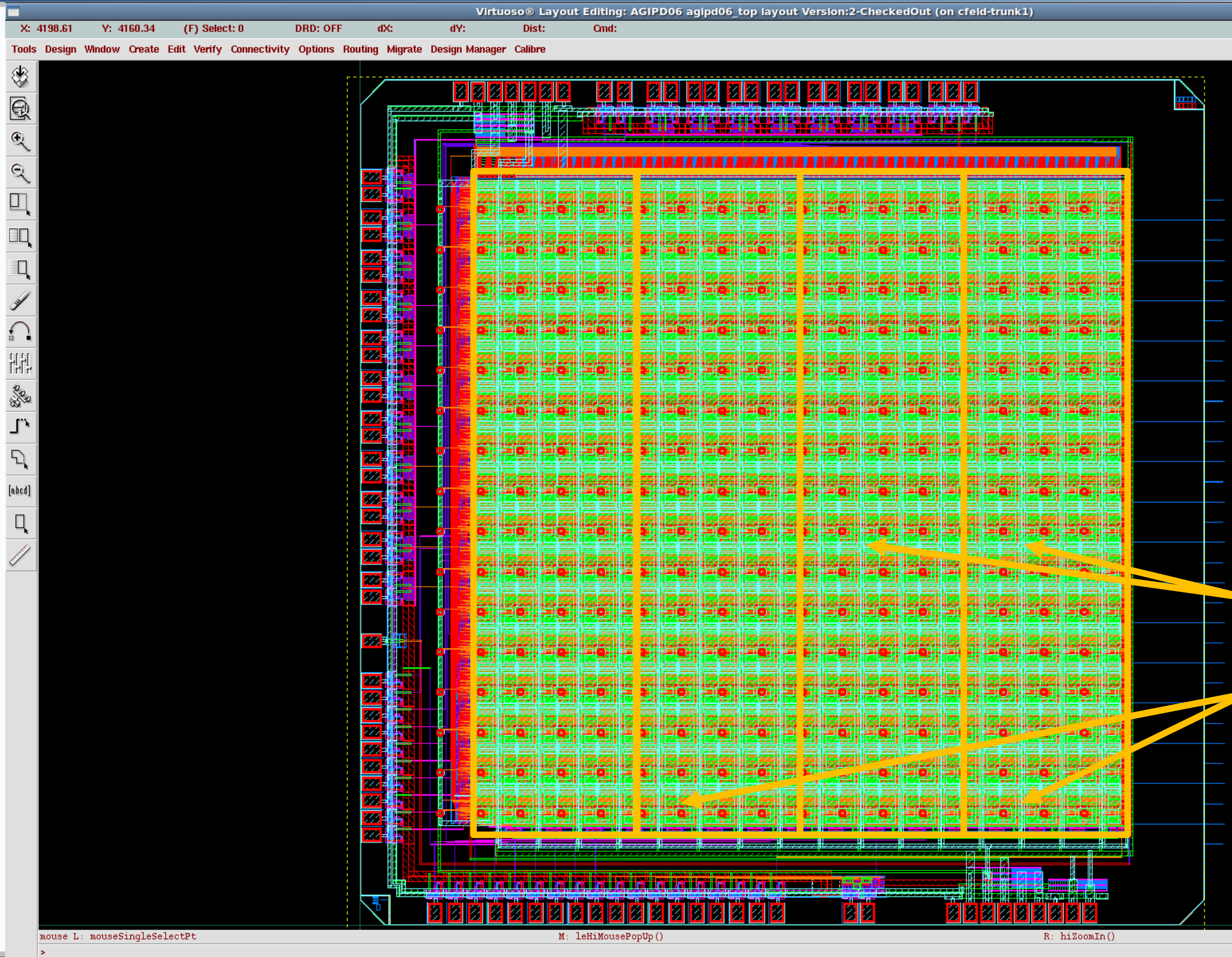


ecAGIPD-Preamp



- Higher open-loop gain (29 vs. 19)
- Same bandwidth (-3dB @ ~500MHz)
- Same noise density and power consumption

ecAGIPD: AGIPD06 Prototype



- 16x16 pixels
- SR (i.e. no) periphery
- RX outside guardring to make TW134 happy…

Modifications to investigate 'gain bit' issues:

- Mem cells like in AGIPD 1.2
- Order of mem row & column switches reversed

Beyond AGIPD

European XFEL operation will change in the 2nd half of the 2020s. Tentatively 2 additional operation modes are foreseen:

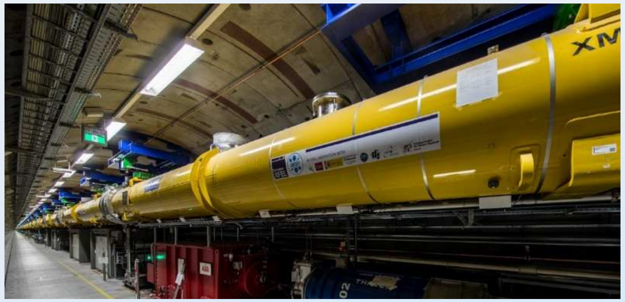
- CW operation at 100kHz
- ‘Long Pulse’ mode with ≤200kHz in 500ms bursts, i.e. 50% duty cycle

On the same time scale the PETRA IV DLLS will become available.

- Intensity will allow to record complete diffraction patterns in ≈10μs

Plans for a possible successor of AGIPD are

- ≥100kHz (CW) imager
- 100 μm × 100 μm Pixels
- Dynamic gain switching
- In-pixel (group) ADC
- (Very) Limited pipeline for burst mode



Going Faster:
With Analogue Readout

Ingredients (1st order):

- Digitisation with *n* bits
- at a rate of f_{ADC}

$$t = \frac{1}{f_{ADC}}$$

$$\tau = \frac{1}{2\pi \cdot Bw}$$

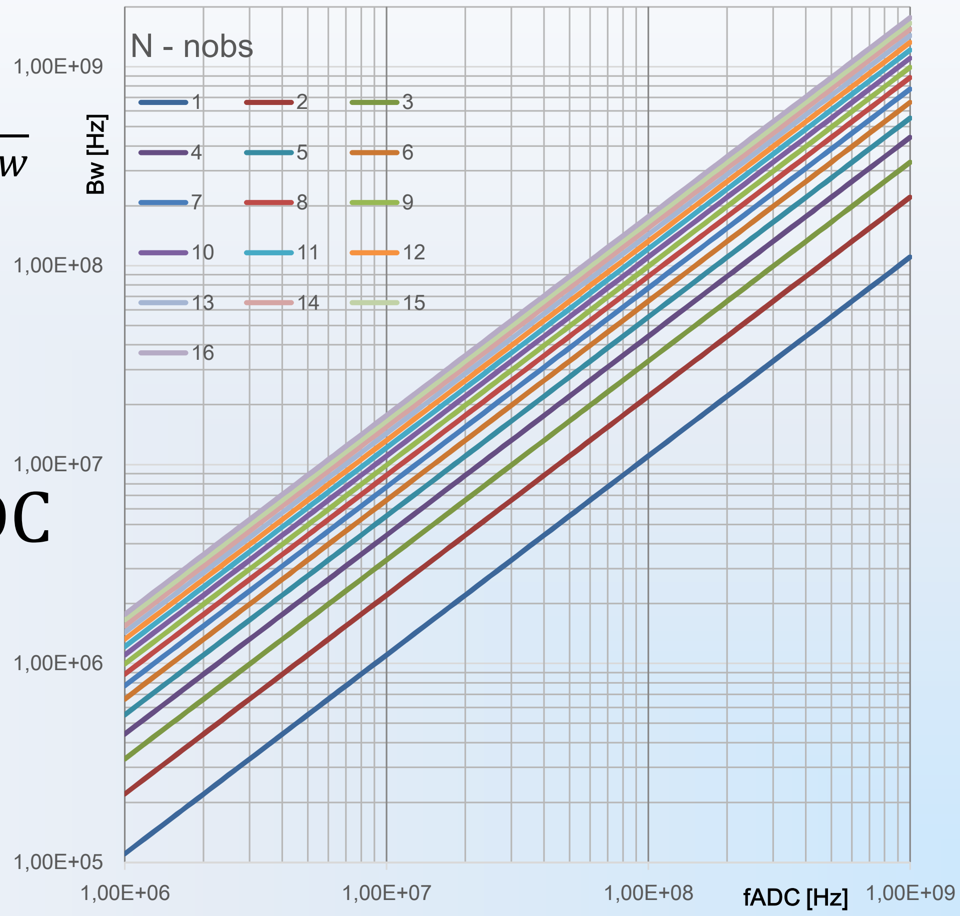
$$2^{-n} \geq e^{-\frac{t}{\tau}}$$

The required bandwidth *Bw* becomes:

$$Bw \geq \frac{\ln(2)}{2\pi} \cdot n \cdot f_{ADC}$$

In case of AGIPD:

- Digitising 2 values/pixel (gain & amplitude)
- 1024 pixel/port
- @ 33MHz
- ⇒ 16 kHz frame rate



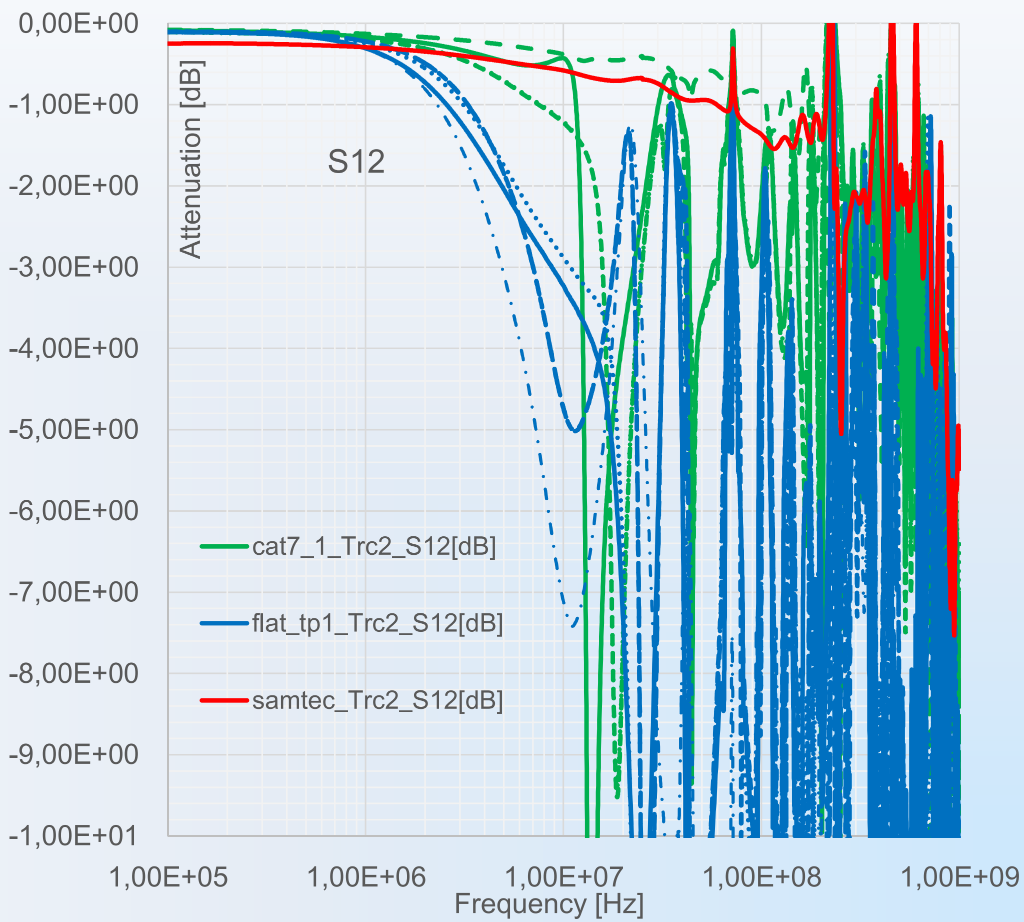
Going Faster:
Limits of Analogue Readout

2nd Order Effects:

- Skin-Effect (att.$\sim\sqrt{f}$)
  - can not be compensated with pre-emphasis ($\sim {}^{1}/_{f}$)
  - can be compensated with a digital (FIR) filter
- Reflections due to
  - Connectors
  - Bending of cables

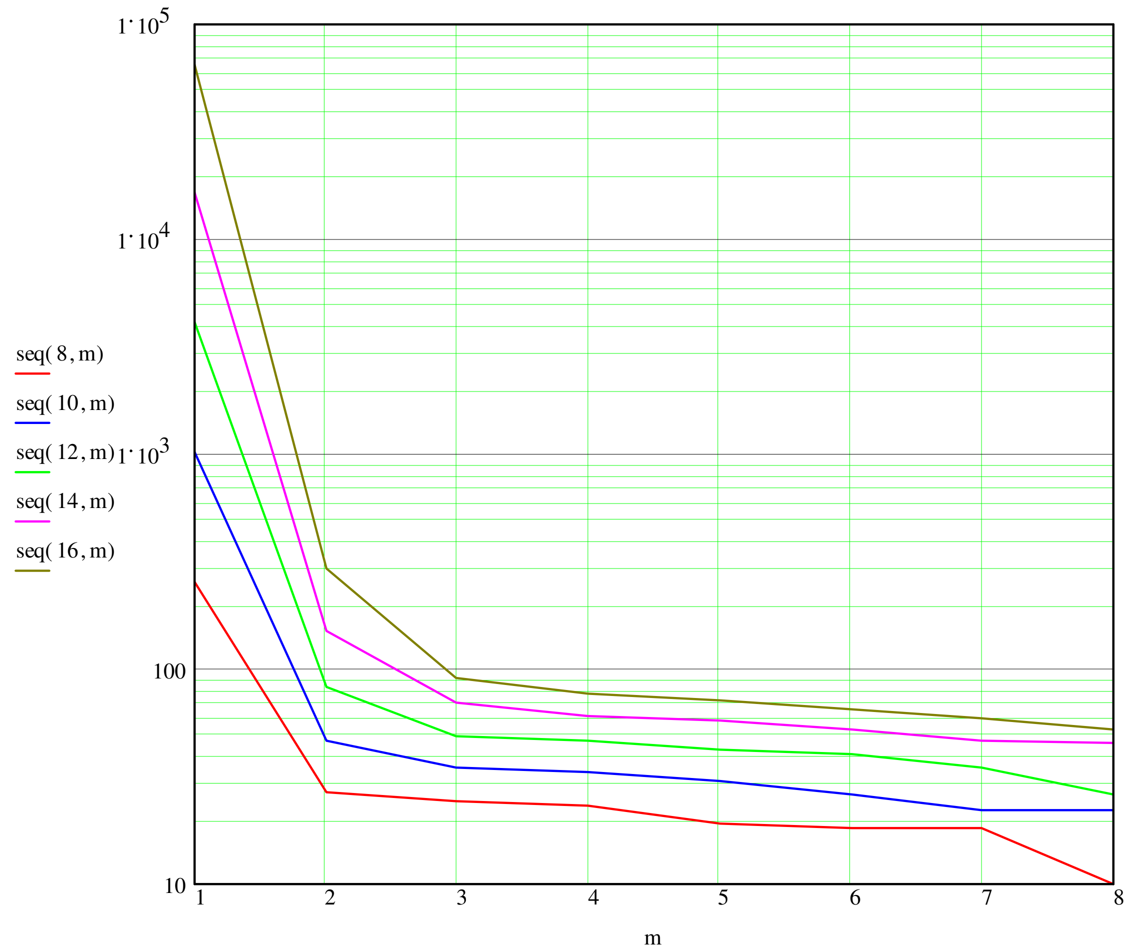
⇒ Very delicate above a few 10MHz

⇒ the same transmission line would be OK for the resulting digital data



Going Faster:
Going Digital

In-pixel digitisation architectures

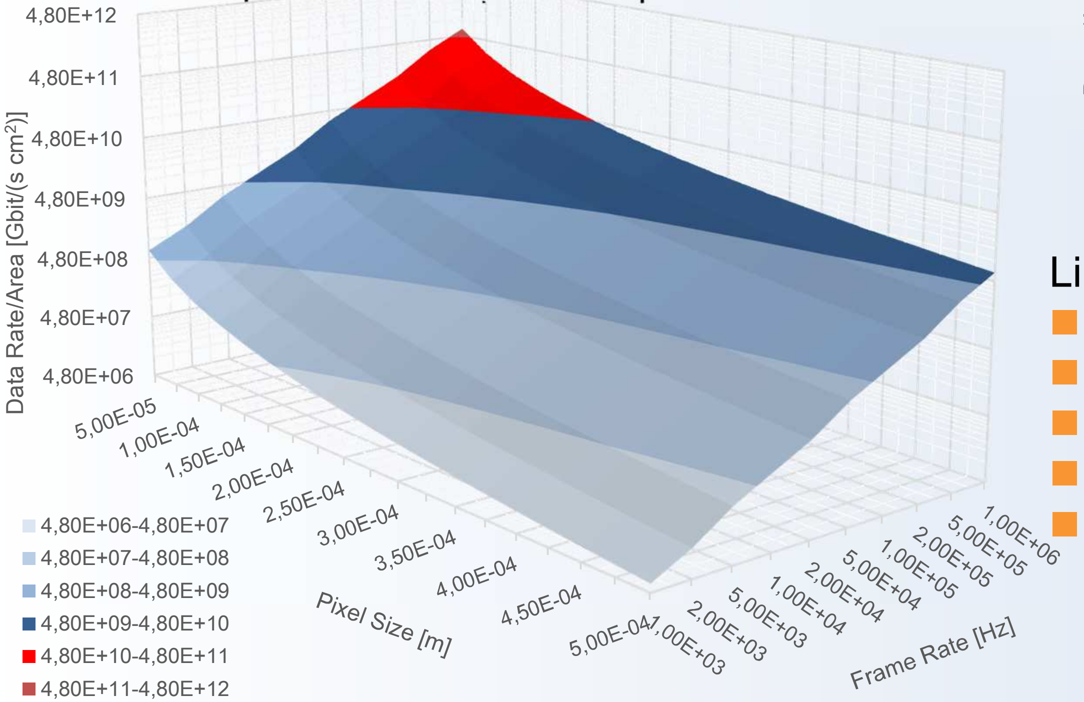


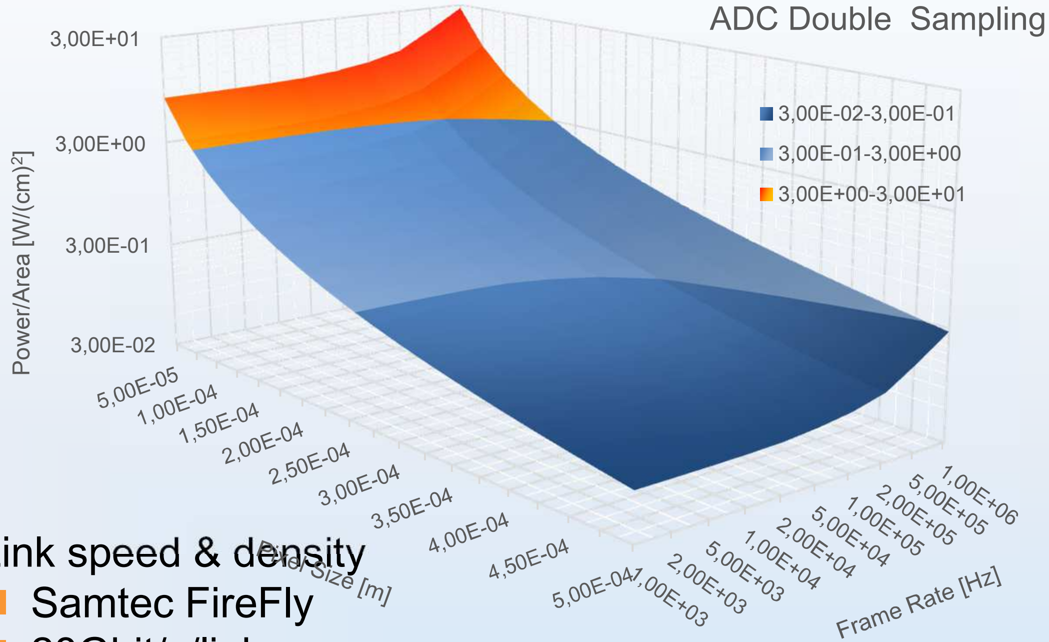
n^{th} Order Bitstream (ΔΣ)
16
f_{frame}
$\geq \sqrt[n]{2^{NoB}} \times f_{frame}$
$\geq \sqrt[n]{2^{NoB}} \times f_{frame}$ (before decimation filter)
Intrinsic
??(overhead)
(yes, digital)
Decimation filter, gain, (pulse shape analysis)
Simple analogue circuit, Low/no matching issues, noise shaping possible
Speed requirements, clock distribution, readout bandwidth

Going Faster:
Speed Limits

Power/area

- Dynamic gain switching
- Pixel size 50µm…500µm
- Digitisation with 16 bits
- at a frame rate of f_{ADC}
- Assumption: P=200µW+500pW/Hz





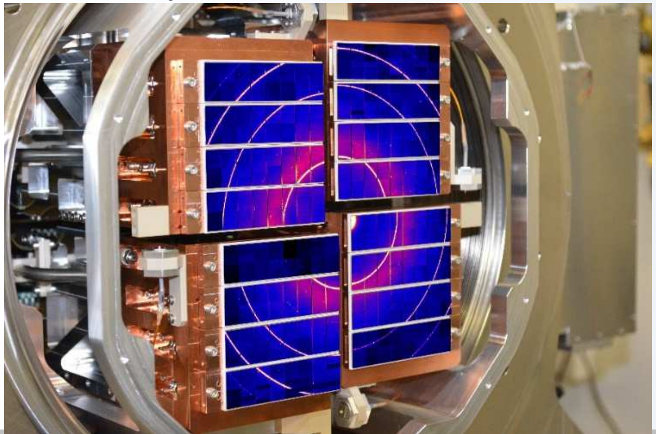
Link speed & density

- Samtec FireFly
- 28Gbit/s/link
- 24Gbit/s/link (net)
- 12 links/unit
- Footprint 20 x 30 mm²
  - 48Gbit/(s cm²)
  - 3Gs/(s cm²) (16bit/sample)
  - DAQ and analysis become „Big Data“ challenges

Summary & Outlook

AGIPD 1.1 (SPB/MID)
- System fulfils all requirements, esp. in terms of
  - Noise (<310e / <1.2 keV)
  - Single photon sensitivity
  - Dynamic range (>$10^4\gamma$ @ 12.4keV)
  - Speed
- 1st 1Mpix system (SPB) in user operation
- 2nd 1Mpix system (MID) has been delivered
- Issues with low/med gain discrimination
  - Mask fix (AGIPD 1.2) taped out 14. Aug. 2018

SFX AGIPD 4M and HiBEF 1M systems
- Commissioning of new readout boards currently ongoing
  - No major issues
- Evaluation of advanced cooling concepts
- Both systems will be delivered with Silicon sensors & AGIPD 1.x ASICs



ecAGIPD for HiBEF
- Will replace Silicon sensors with High-Z ones
- Changes
  - Electron collecting preamp
  - Reversed polarity of discriminator
  - New calibration circuit
  - Use of twin wells
  - Reversed gain encoding levels
- AGIPD06
  - 16 x16 ecAGIPD prototype
  - Submitted 13.11.2017
  - Manufacturing @ GF only started end of March (30.03.18)
  - Silicon back since July
- Only peripheral routing missing for an 64x64 EcAGIPD
  - Swapping of outputs
  - Layout (vDiode, some routing outside the matrix…)

100kHz Imager for CW-XFEL and PETRA IV
- Concept studies
- More specs needed

http://photon-science.desy.de/research/technical_groups/detectors/projects/agipd