PAUL SCHERRER INSTITUT

PSI

Sophie Redford :: Postdoc :: SLS detectors group :: Paul Scherrer Institut

First experiments with the JUNGFRAU charge integrating photon detector

International Workshop on Radiation Imaging Detectors :: 24-28 June 2018 :: Sundsvall, Sweden

Outline

- **Photon detector development at PSI**
- **The JUNGFRAU detector:**
  - a charge integrating detector for SwissFEL
  - pedestal and gain corrections
  - hardware: single modules to larger systems
- **FEL applications**
  - time-resolved pump-probe phase transitions
- **Synchrotron applications**
  - pump-probe with storage cells
  - macromolecular protein crystallography

Hybrid photon detector development at PSI

Microstrips 50 um

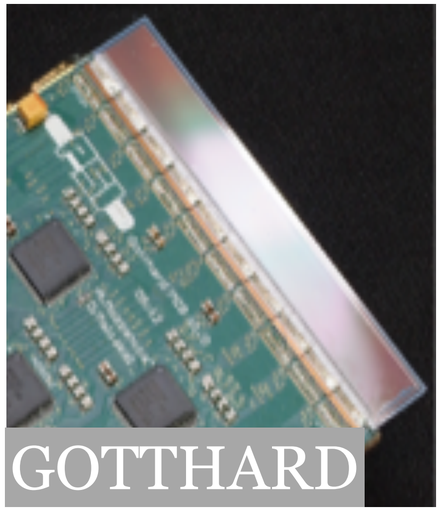
Pixels

25 um

75 um

200 um

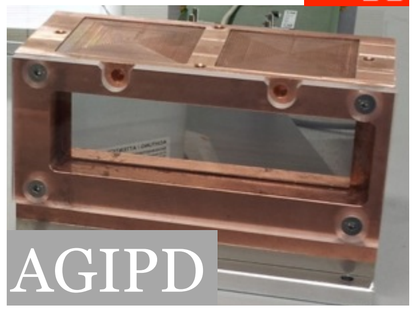
Charge Integrating



GOTTHARD

MÖNCH

JUNGFRAU

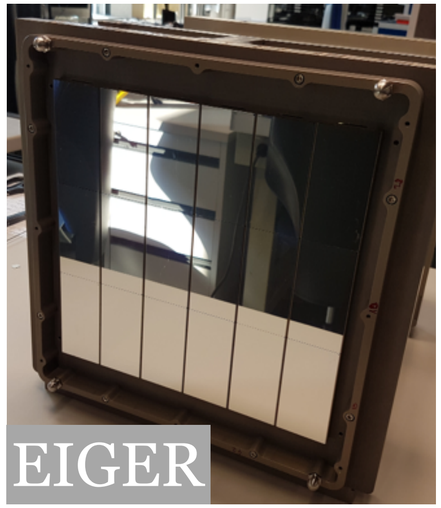


AGIPD

Single Photon Counting

MYTHEN

✗



EIGER

172 um

PILATUS

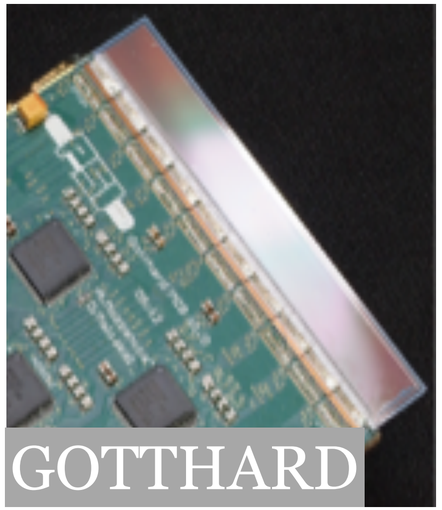
Hybrid photon detector development at PSI

Microstrips

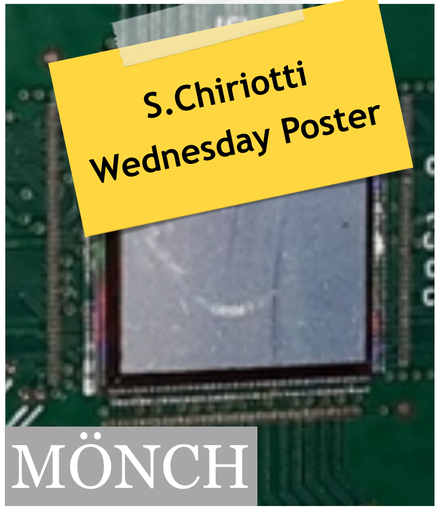
Pixels

50 um | 25 um | 75 um | 200 um

Charge Integrating



GOTTHARD



S.Chiriotti
Wednesday Poster

MÖNCH

D.Greiffenberg
Tomorrow 9:40

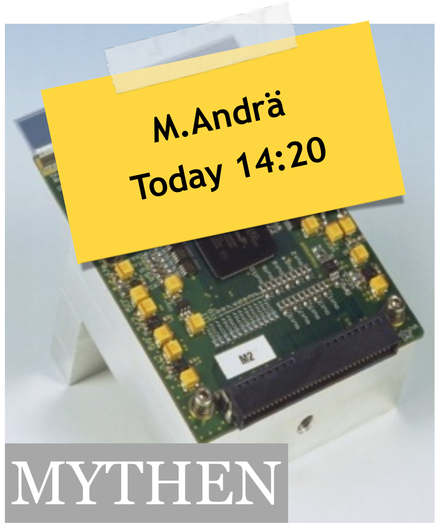
Now!

JUNGFRAU

D.Mezza
Today 14:00

AGIPD

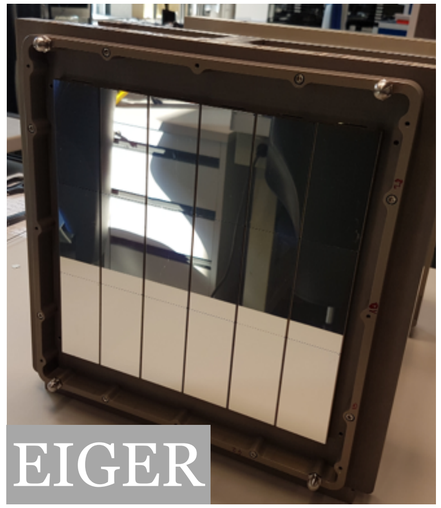
Single Photon Counting



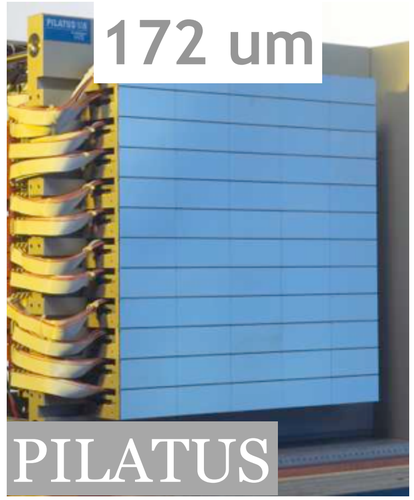
M.Andrä
Today 14:20

MYTHEN

✗



EIGER



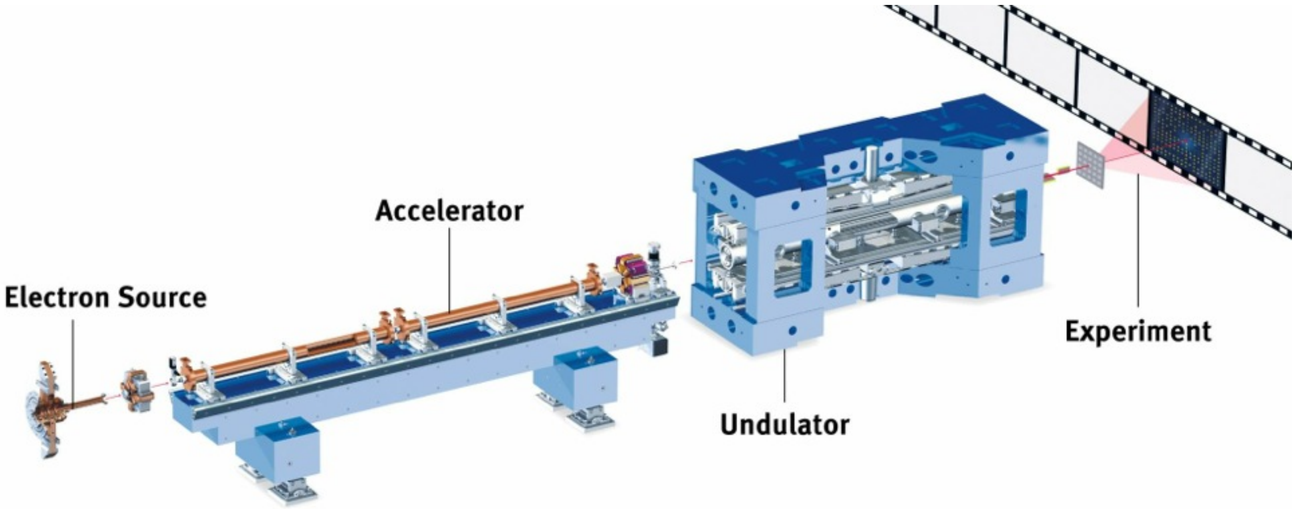
172 um

PILATUS

JUNGFRAU: a photon detector for SwissFEL

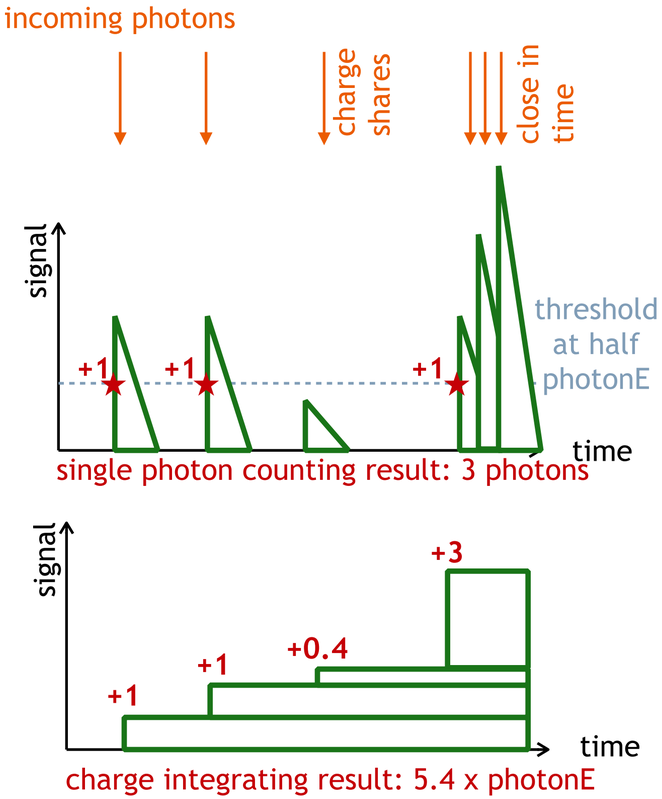
Key numbers

- **Repetition rate:** 100 Hz
- **Electrons per pulse:** 2 x 1.24 x 10^9
- **Undulators:** 12 x 1060 alternating neodynium magnets
- **Photon energy:** 0.25 - 12 keV
- **Duration of light pulse:** 1 - 60 fs
- **Brilliance:** 1.3 x 10^{33} γ / (s x 0.1% b.w. x mm^2 x mrad^2)
  = 10^{10} times the SLS



(Illustration not to scale)

What kind of detector can measure 10^4 12 keV photons all arriving within 10 fs?



Single photon counting

- every time the signal goes above a threshold, increment a counter

✓noiseless readout, fluorescence suppression

✦count loss due to charge-sharing and pile-up

Charge integrating

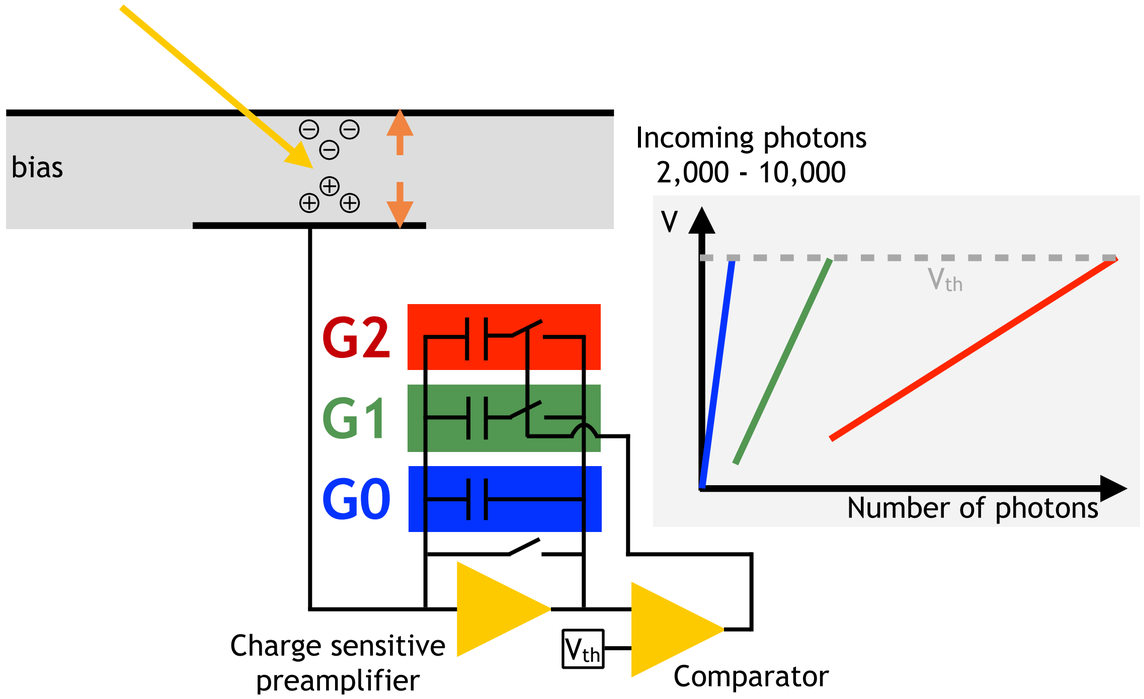
- collect charge throughout the integration window

✓detects fractions of a photon and pile-up photons

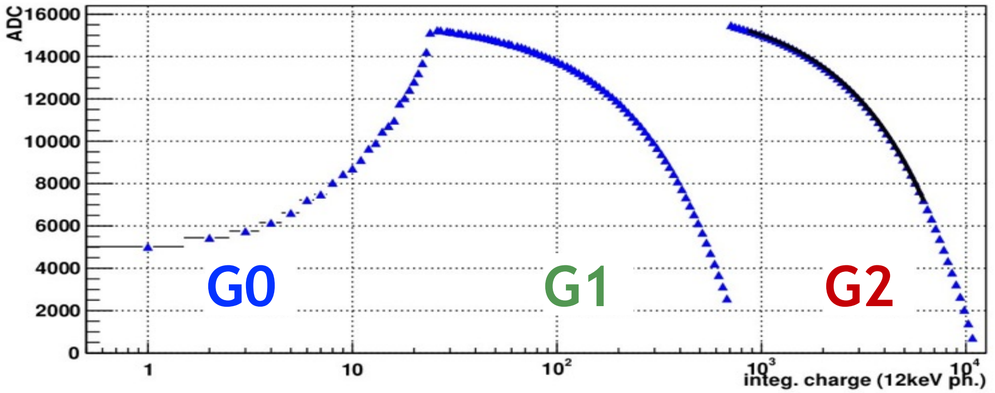
✦integrates leakage current

FELs require charge integrating detectors

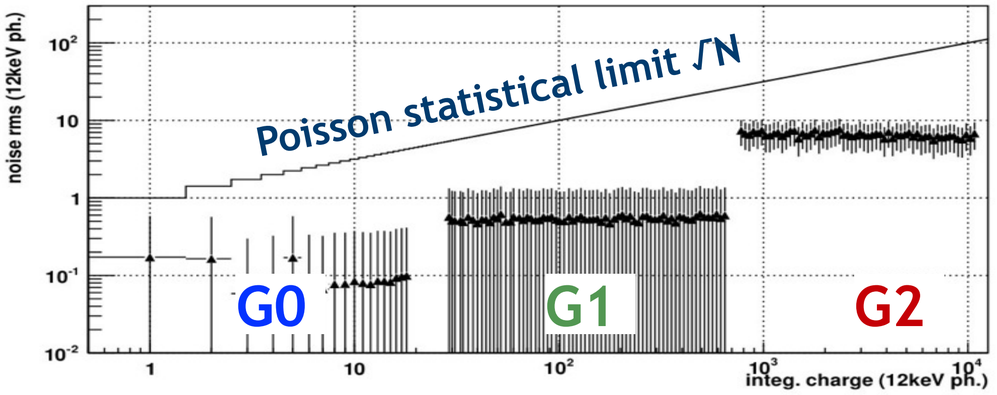
The JUNGFRAU charge integrating detector



Gain switching in action



Noise performance



How to ensure adequate amplification and limit noise?

Gain switching

- Automatically add capacitors to extend the dynamic range
- Noise remains below Poisson statistical limit
- Output: the amplified charge and the amplification factor

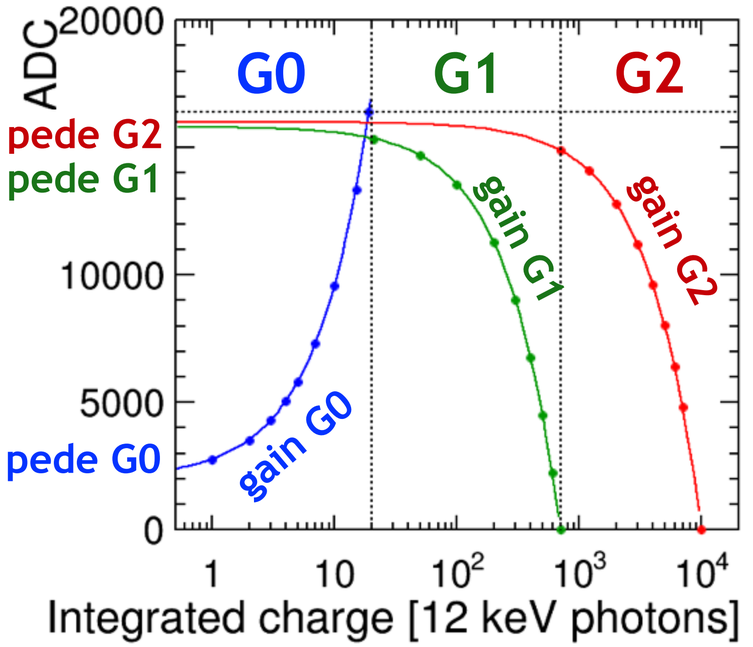
Calibration and pedestal measurement

How to convert JUNGFRAU output to number of photons?

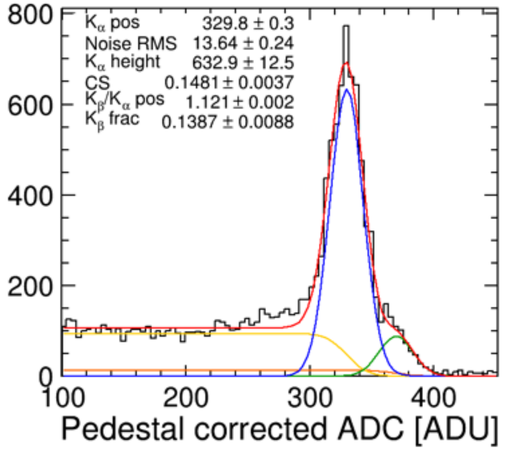
Need to know the six parameters characterise each pixel:

- three offsets (pedestals) regularly measured with dark runs
- three gradients (gains) measured with 3-step lab-based calibration

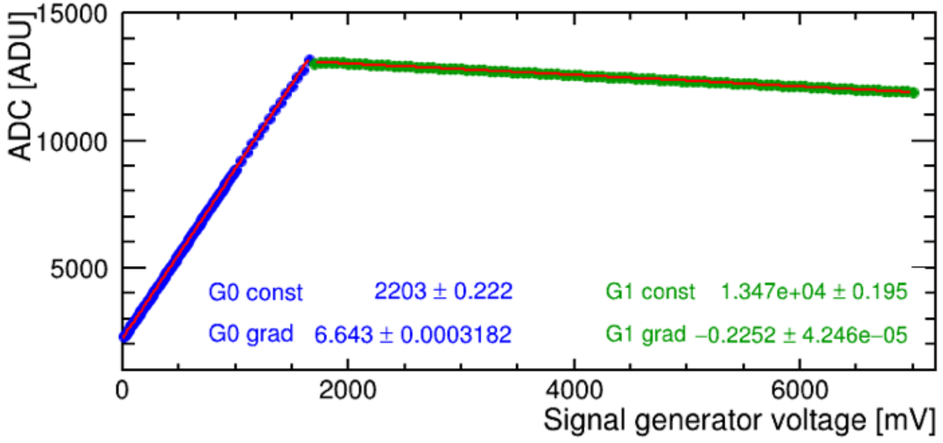
$$N_\gamma = \frac{|\mathrm{ADC} - \mathrm{pede}|\,[\mathrm{ADU}] \times \mathrm{gain}\,[\mathrm{keV/ADU}]}{E_{\mathrm{beam}}\,[\mathrm{keV}]}$$



G0: Cu fluo



G0/G1: Backplane pulse



G1/G2: Current source

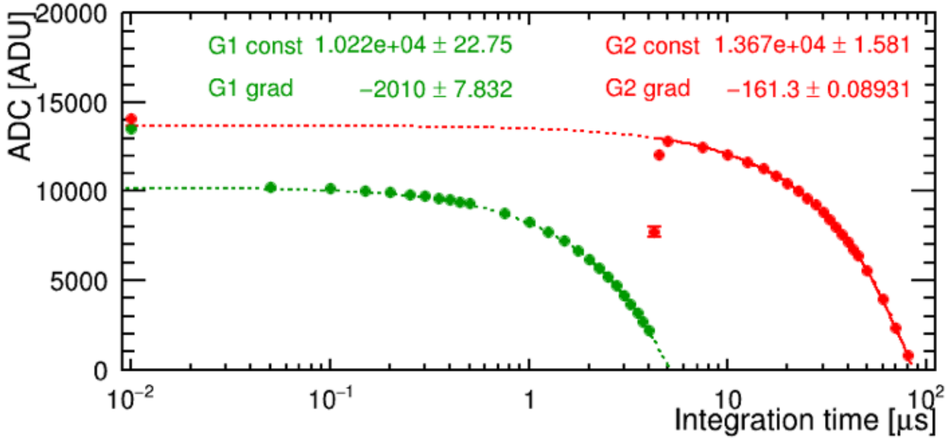
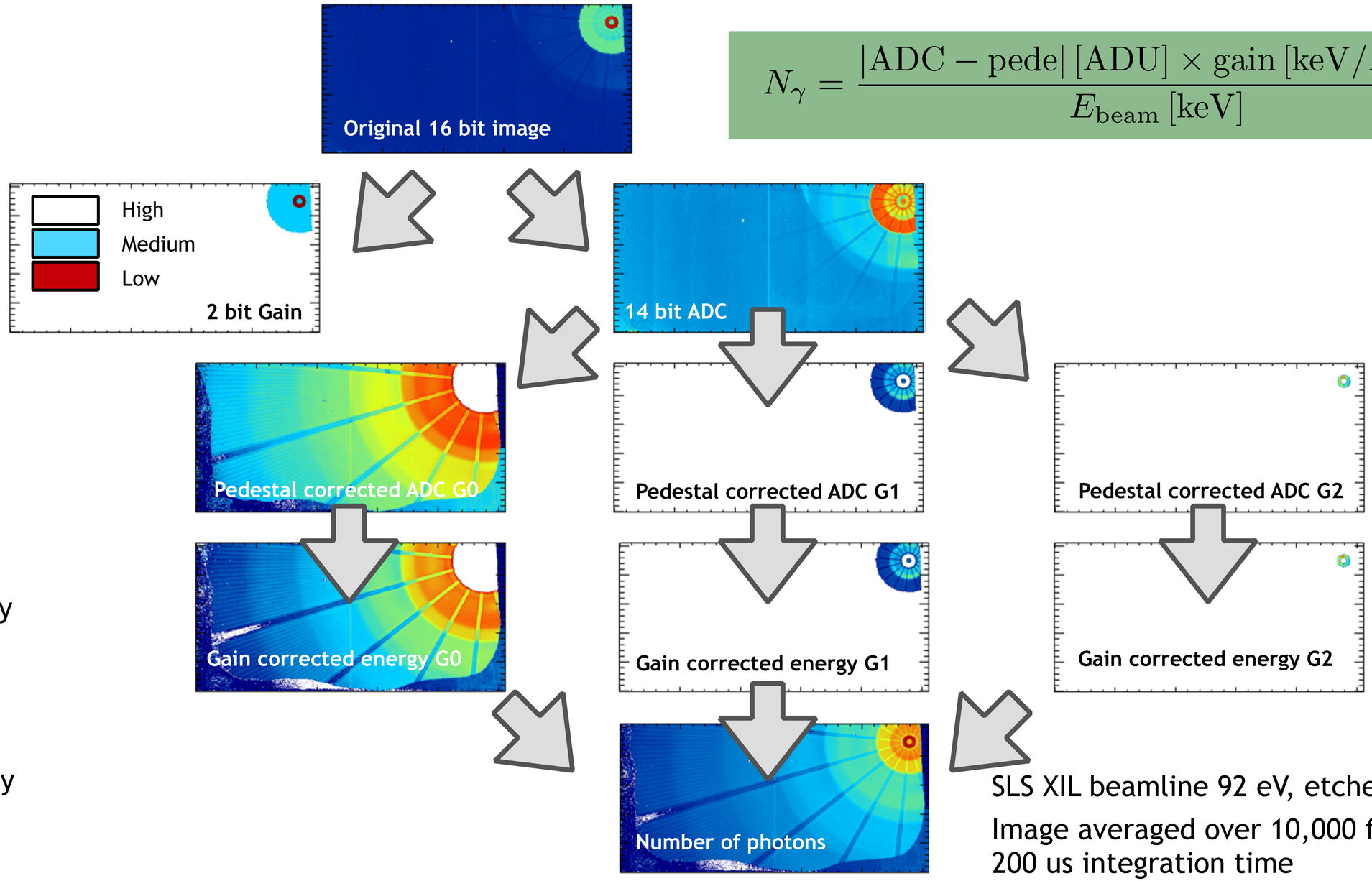


Image correction: Fresnel Zone Plate

$$N_\gamma = \frac{|\mathrm{ADC} - \mathrm{pede}|\,[\mathrm{ADU}] \times \mathrm{gain}\,[\mathrm{keV/ADU}]}{E_{\mathrm{beam}}\,[\mathrm{keV}]}$$

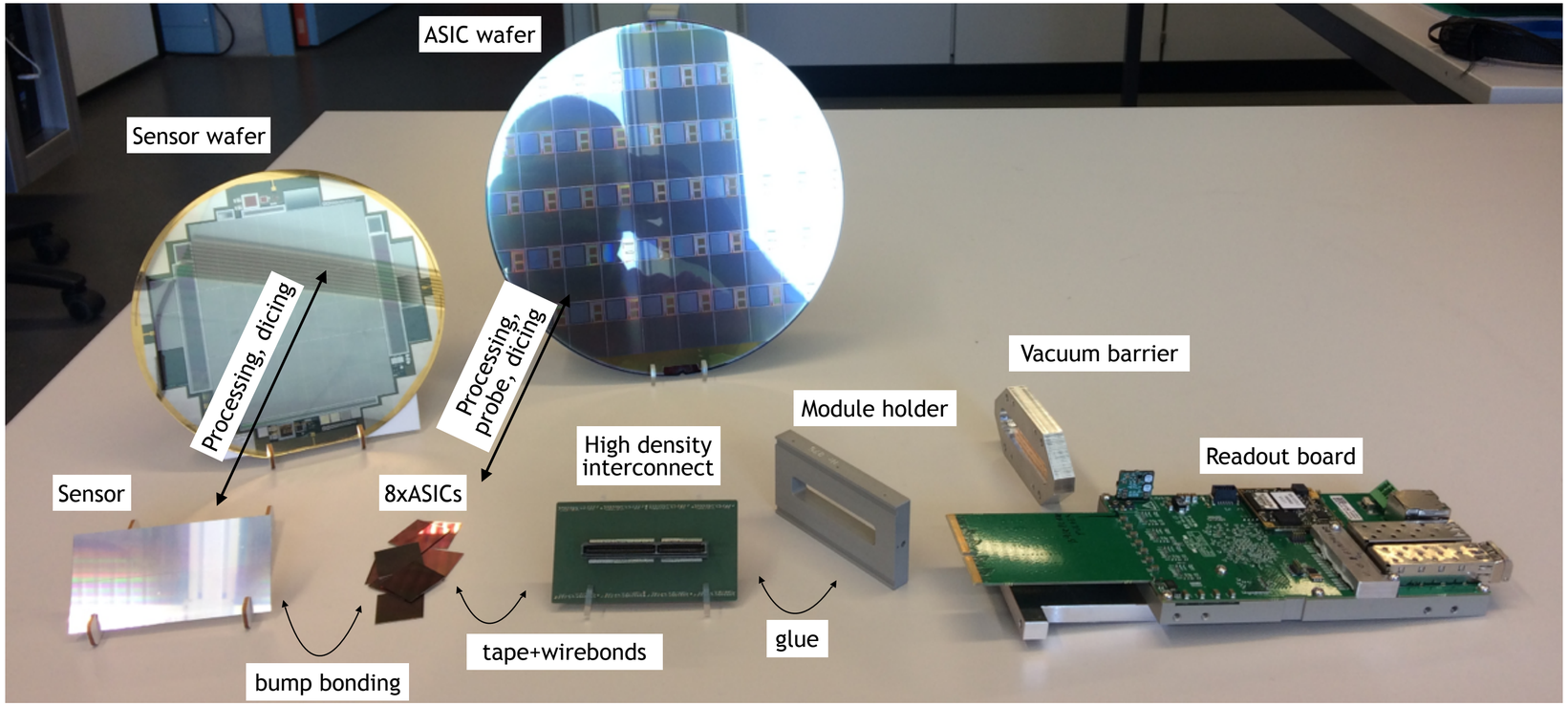
1. Split gain and ADC
2. Pedestal correct ADC
3. Gain correct to energy
4. Divide by beam energy

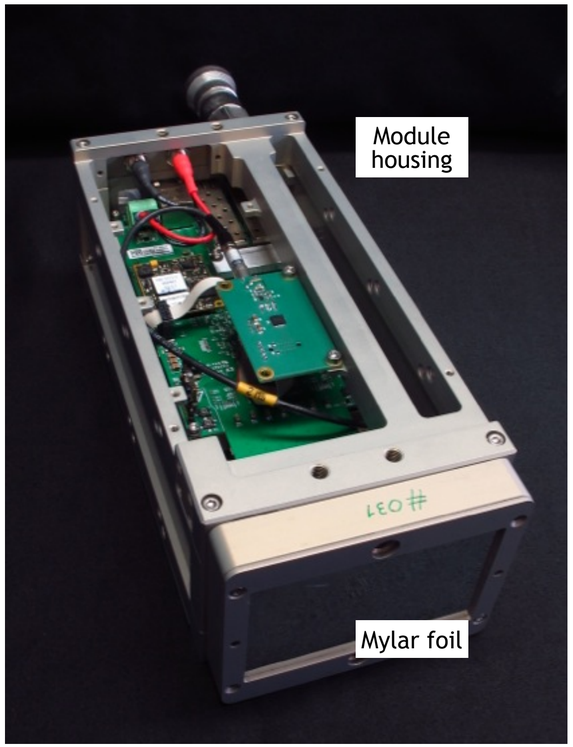


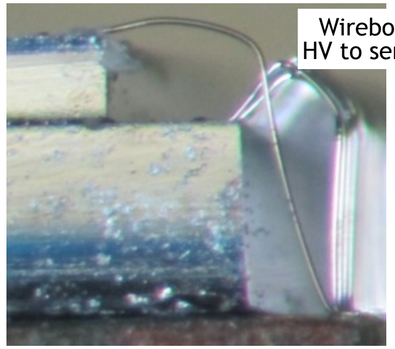
SLS XIL beamline 92 eV, etched sensor

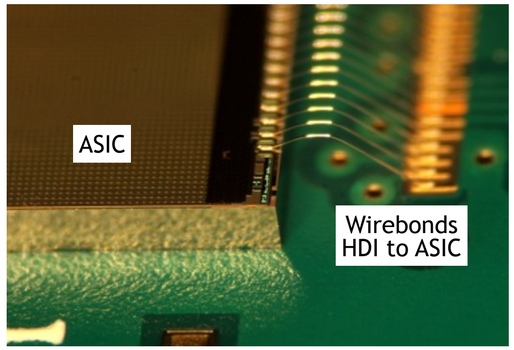
Image averaged over 10,000 frames of 200 us integration time

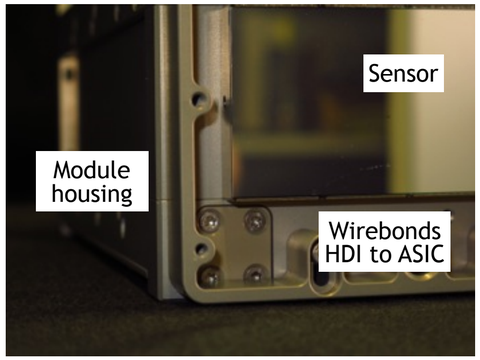
JUNGFRAU single module hardware



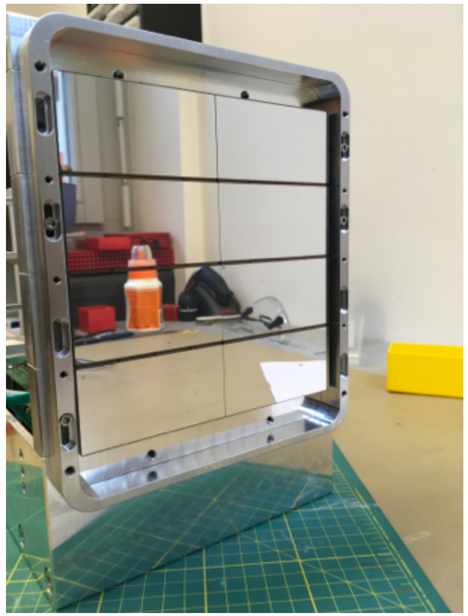








From single modules to larger systems

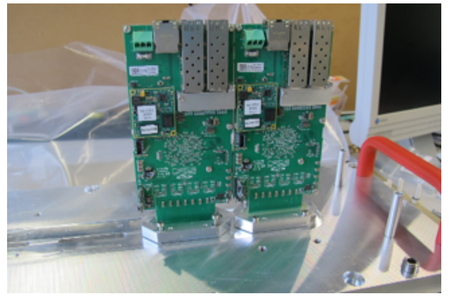


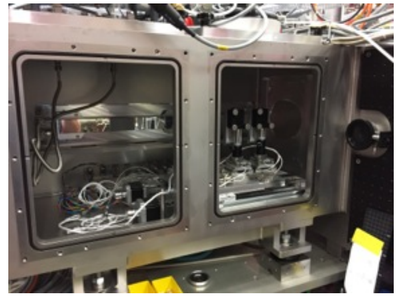
JUNGFRAU 4 Mpixels

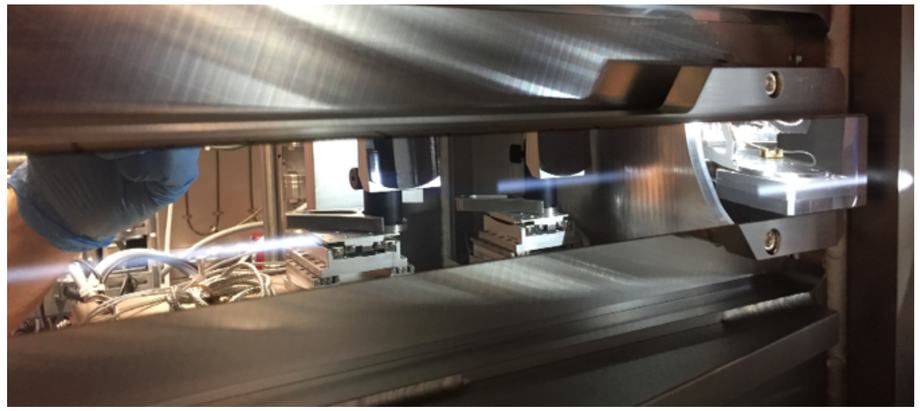
- inter module gaps of 36 (vertical) and 8 (horizontal) pixels
- dead area when tiled of 7%
- extra power control board
- water cooled
- control and data in parallel

First JF4M image

Xray tube with Korean bookmarks - thank you PAL!







JUNGFRAU 4.5 Mpixels

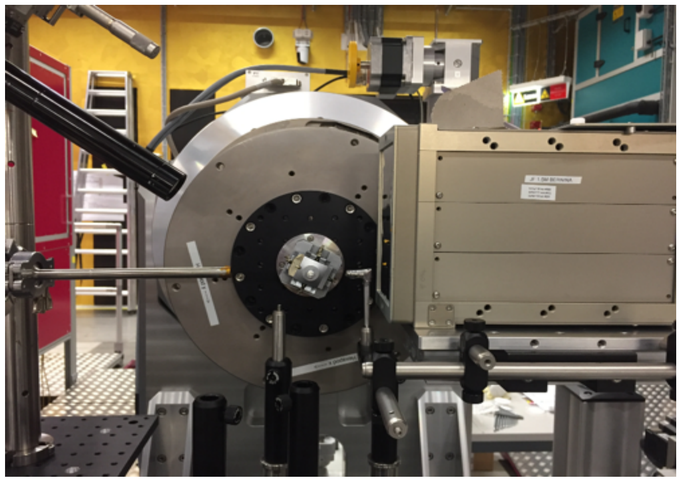
- SwissFEL ESA diffractometer arm
- in vacuum

JUNGFRAU 16 Mpixels

- two systems currently under construction for SwissFEL ESA+ESB

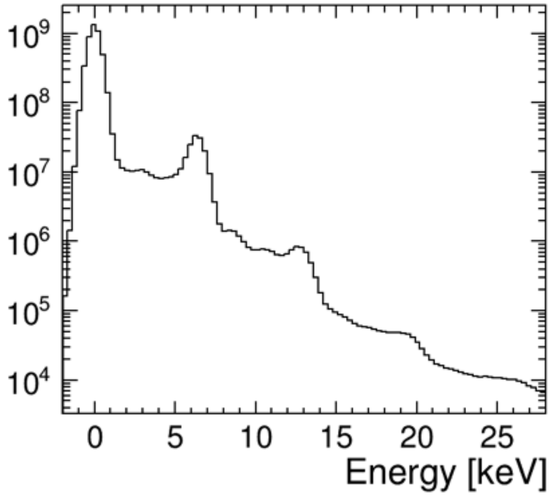
FEL applications - pump-probe at SwissFEL ESB

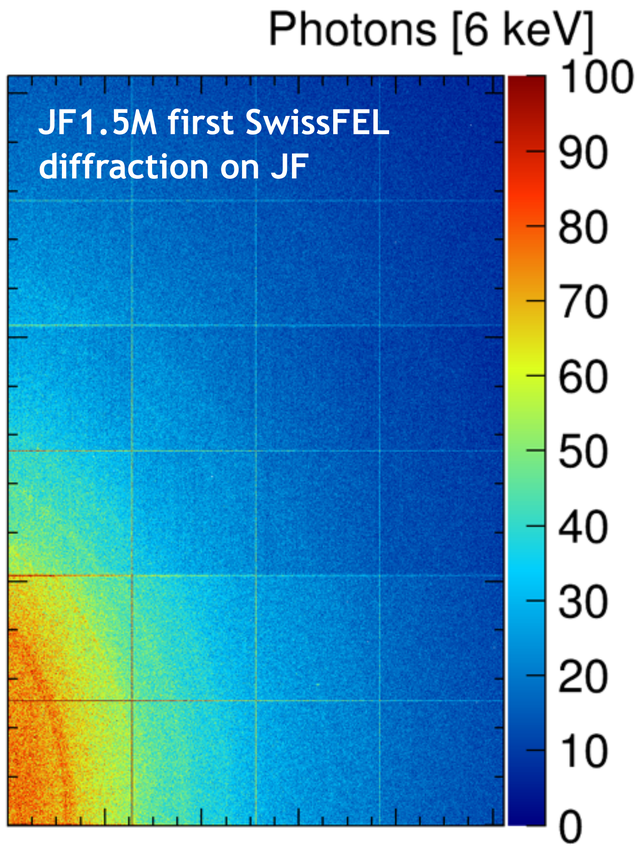
in collaboration with M.Camarata et al., U.Rennes

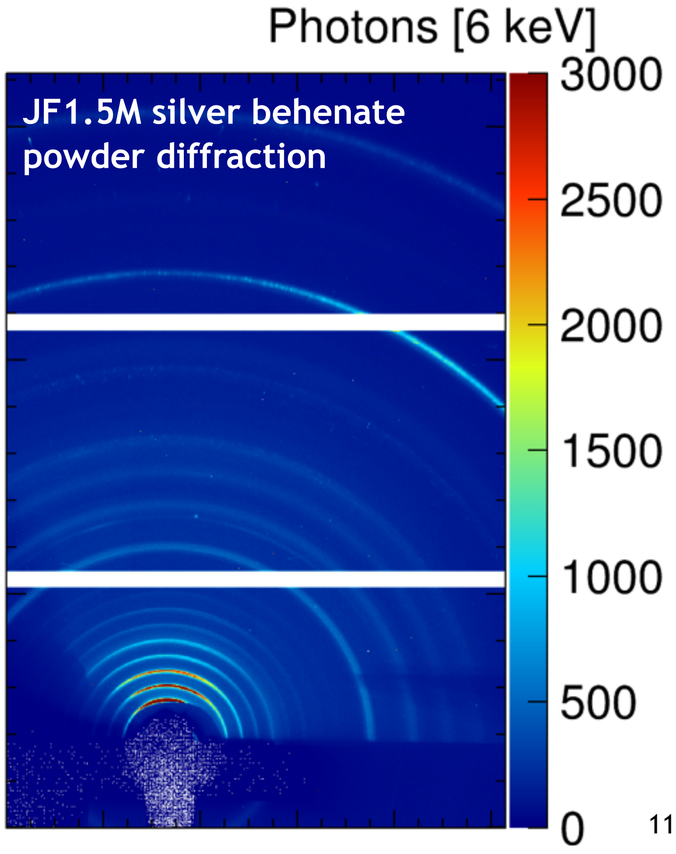


JF1.5M, Bernina beamline, SwissFEL

- pilot experiment in November 2017
- SwissFEL repetition rate 10 Hz, photon energy 6.6 keV (3rd harmonic)
- JF frame rate 100 Hz, integration time 10 us, room temperature

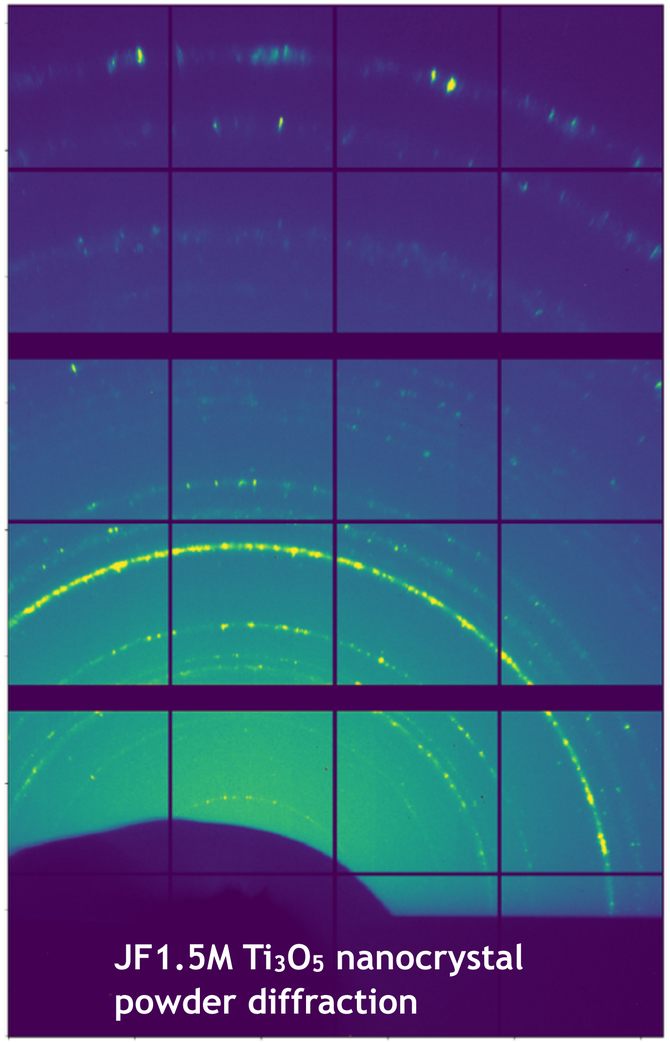






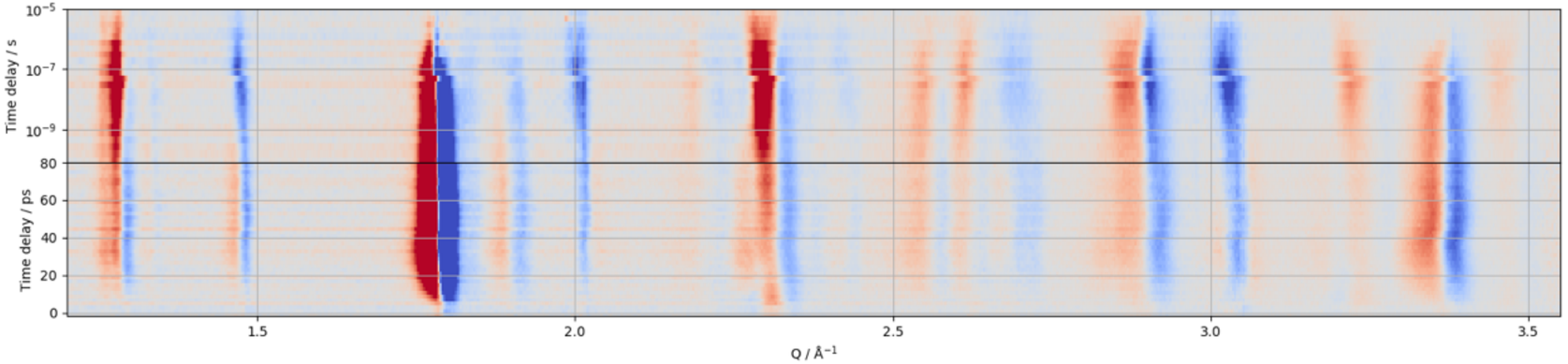
FEL applications - pump-probe at SwissFEL ESB

in collaboration with M.Camarata et al., U.Rennes

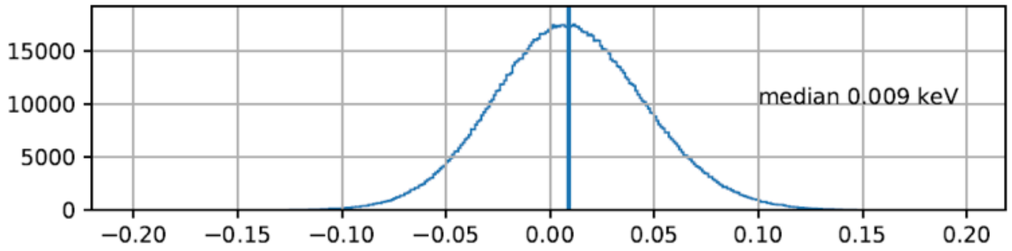


Semiconductor to metal phase transition of Ti_3O_5 nanocrystals

- pump-probe technique: 800 nm laser pump, X-ray probe
- delay scan and look for changing positions of diffraction rings
- first time resolved pilot experiment at SwissFEL



- good pedestal stability over 1 week
  - median drift < 10 eV
  - max drift < 200 eV



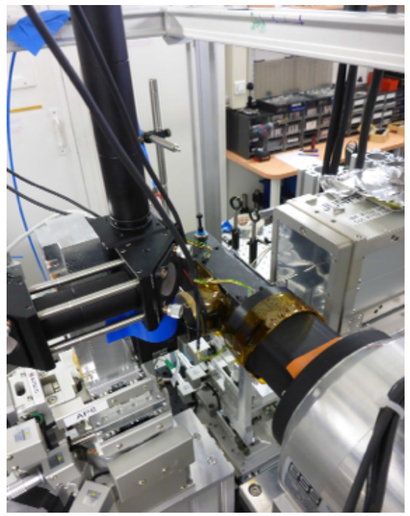
thanks M.Camarata

FEL-like synchrotron operation with storage cells

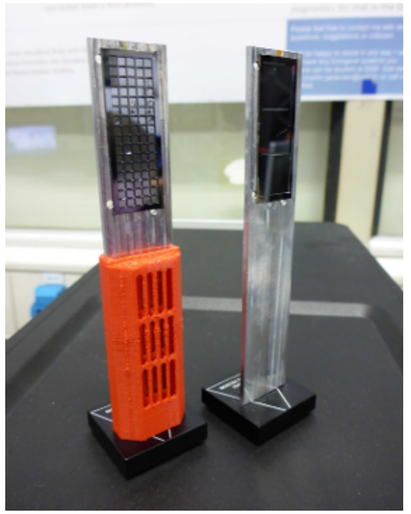
in collaboration with A.Meents et al., CFEL

Pump-probe with a chopped synchrotron beam

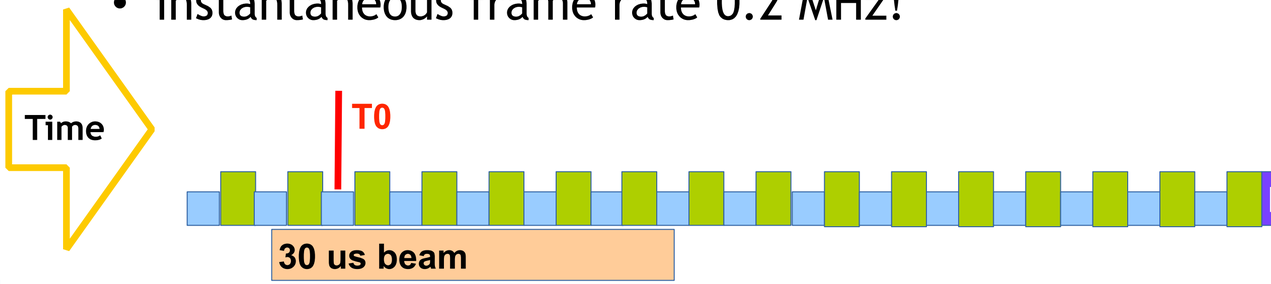
- JF1M, ID09 beamline, ESRF
- roadrunner chip delivery system
- chopped 30 us beam pulse at 10 Hz
- JF storage cells provide time resolution and speed
- 2.6 us integration, 2.4 us reset per storage cell
- instantaneous frame rate 0.2 MHz!



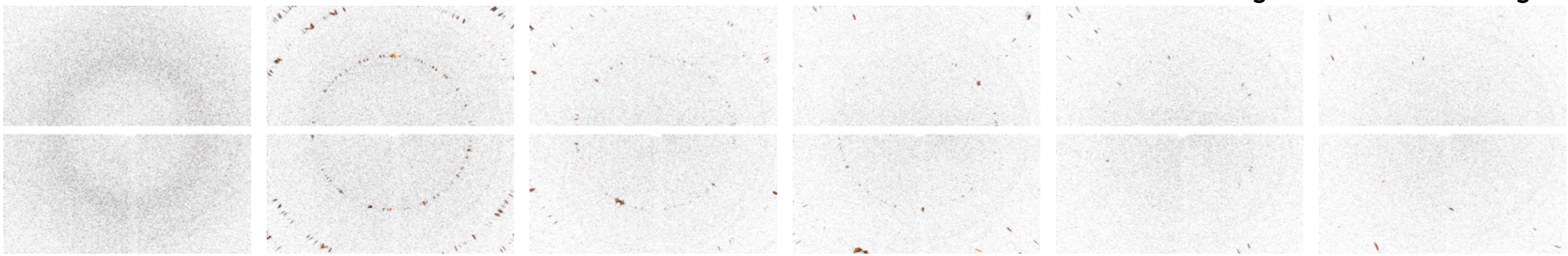
JF1M + Roadrunner at ESRF ID09



Crystal chips



JF1M first storage cell diffraction images



T0-4us diffraction image

T0+1us laser destroys chip substrate

T0+6us

T0+11us

T0+16us

T0+21us

High duty cycle synchrotron applications: MX

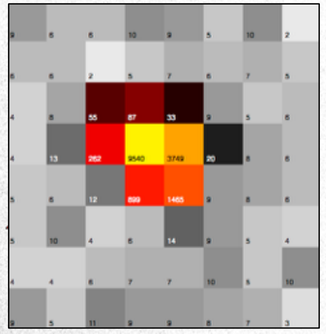
in collaboration with M.Wang et al., SLS PX1

JUNGFRAU can be used in high duty cycle synchrotron applications such as MX

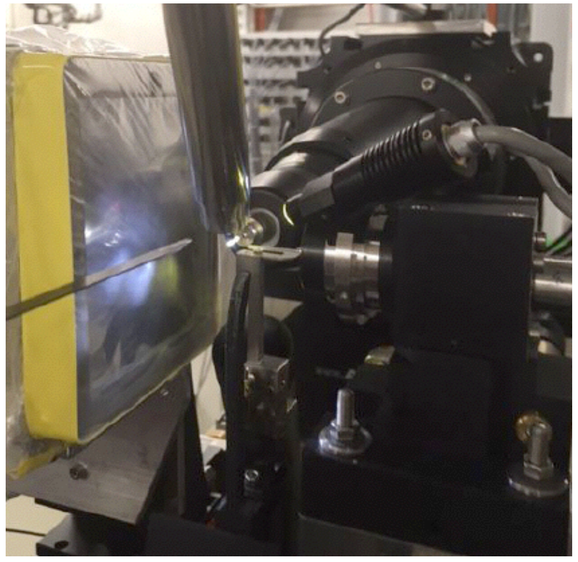
But there are challenges…

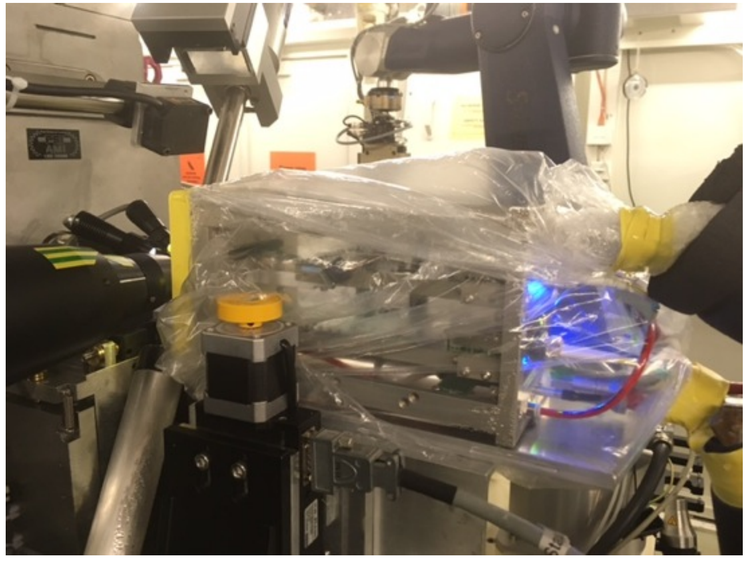
- requires maximum frame rate of 1.13 kHz
- requires long integration time of 840 us
- requires cooling to -12°C
- requires condensation protection
- requires saving huge amounts of data
- requires offline data conversion

JF1M thaumatin crystal diffraction

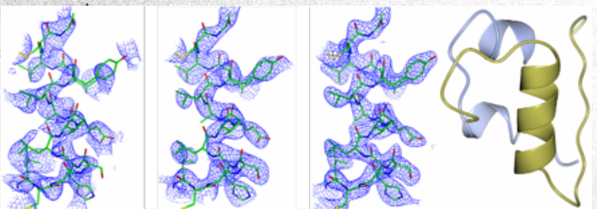


JF1M at SLS PX1





First structure solved by JF - Insulin
October 2016 - thanks K.Nass

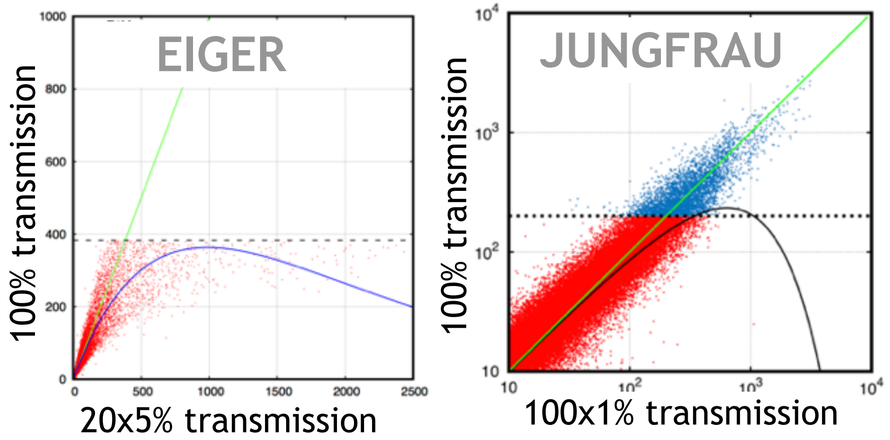


Benefits of JUNGFRAU for MX

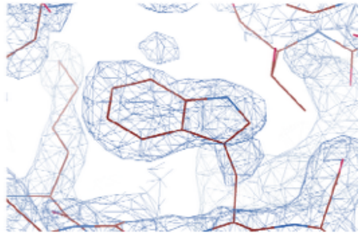
in collaboration with M.Wang et al., SLS PX1

JUNGFRAU charge integrating detector compared with
EIGER single photon counting detector
- same pixel, module, detector size
- almost the same sensor thickness

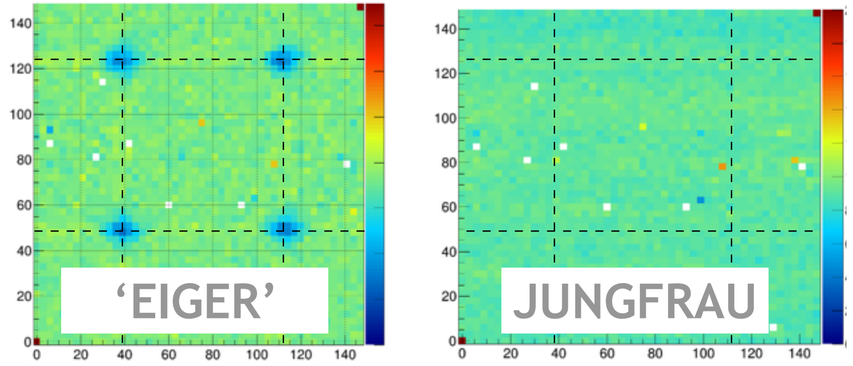
EIGER rate limited by pile-up → JUNGFRAU enables faster data collection



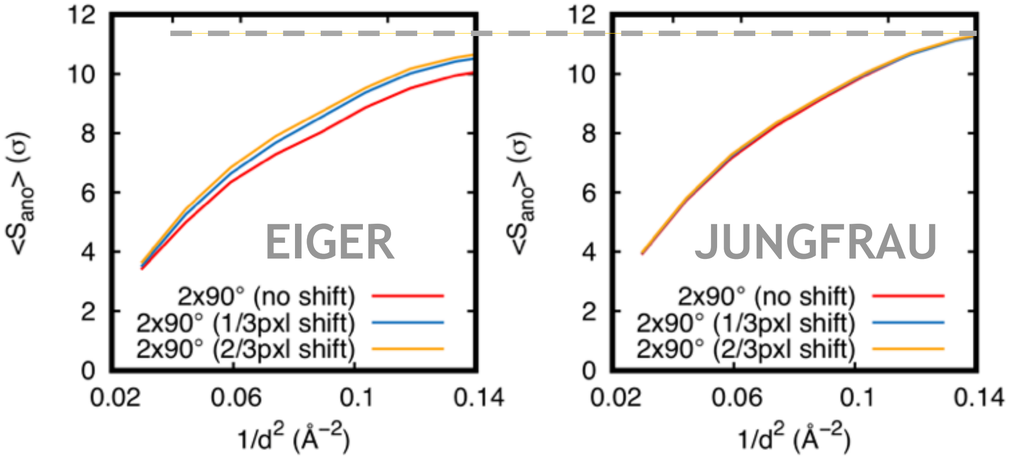
"Easy" native-SAD in 600 ms
- Thaumatin
- 100°/sec, 60°
- 6 keV, 5 × 10^{11} phs/sec (full beam)

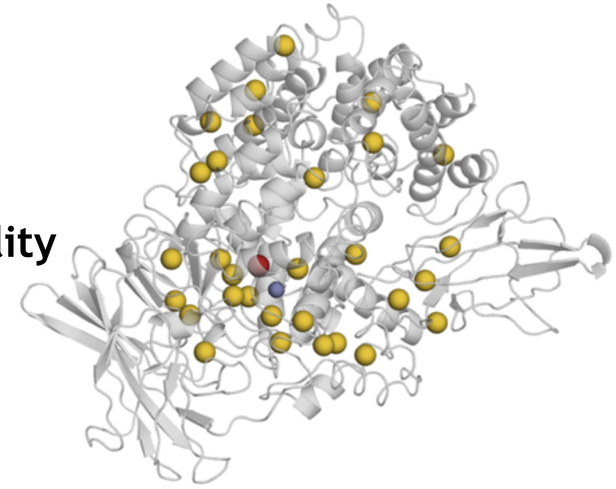


EIGER loses efficiency in the corner of pixels → JUNGFRAU provides better data quality



20 keV pencil beam scans





"Real-life" native-SAD in 60 s
- Aminopeptidase, 101 kDa
- 10°/sec, 600°
- 6 keV, 5 × 10^{11} phs/sec (full beam)

thanks F.Leonarski

Summary

The JUNGFRAU detector for photon science

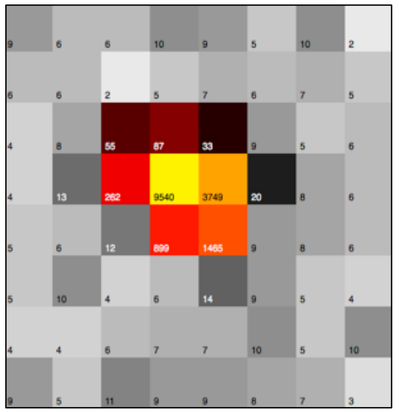
- hybrid silicon pixel detector
- charge integrating
- automatic gain switching reduces noise, extends dynamic range

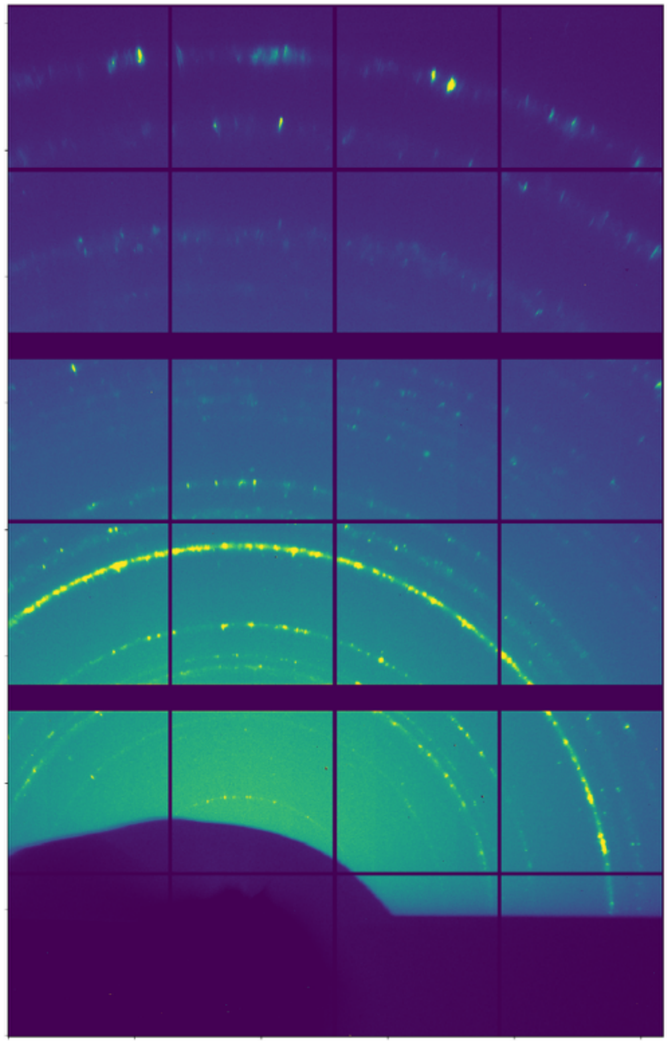
Pilot experiments at SwissFEL

- first time resolved measurements completed
- construction of large systems underway

JUNGFRAU also for synchrotron applications

- storage cells can give high rates
- brings benefits to MX over photon counting





My thanks go to:

SLS detector group

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