
**Aldo Mozzanica**
**for the Swiss Light Source Detector Group**

# Status of the *JUNGFRAU project: detector design and result from the SwissFEL pilot experiment phase*

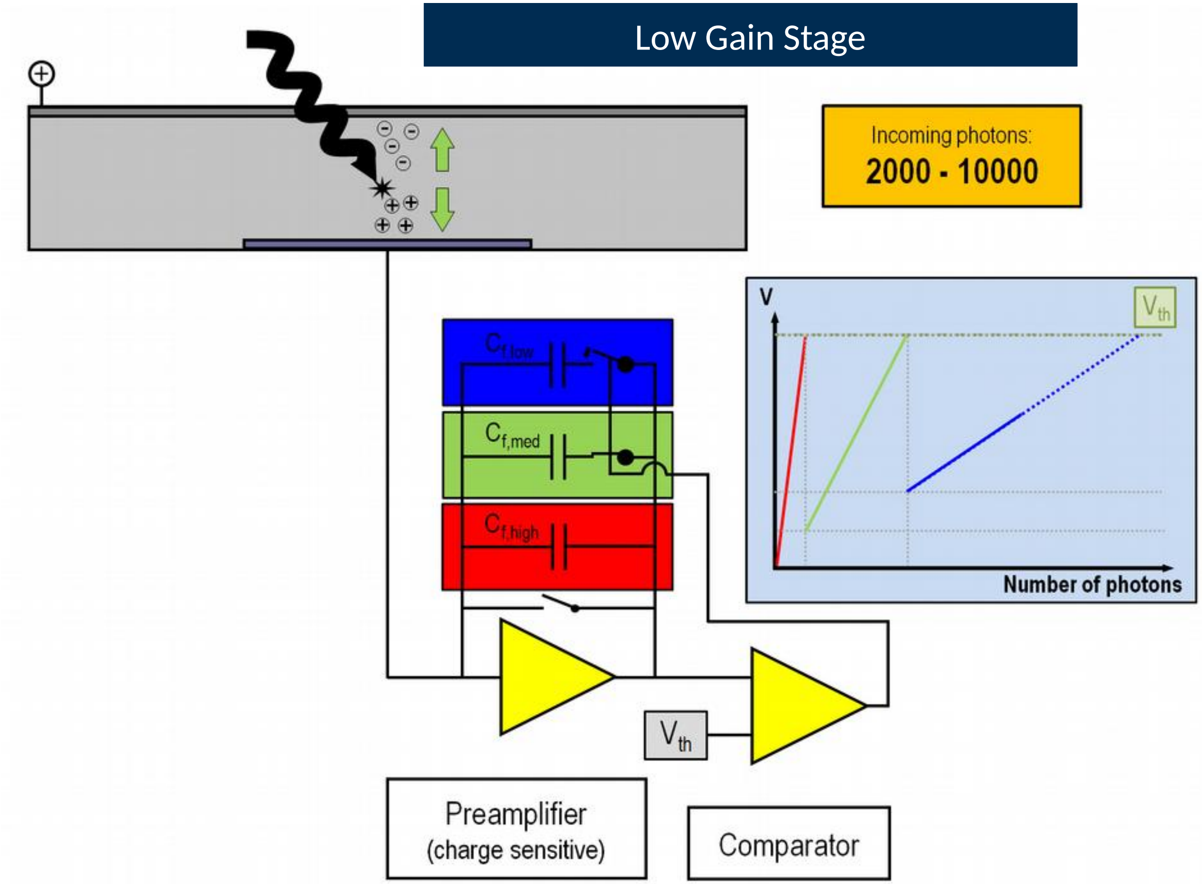
**IFDEPS08, Annecy, March 2018**

PAUL SCHERRER INSTITUT

# Outlook

- Principle of operation (Short!)
- Channel and ASIC architecture
- Module components, and module production experience
- Overview of the different cameras
- DR response , noise in Gain0 and High Gain 0
- The setup @ swissfel
- First experiment at Bernina station
- First experiment at Alvra station
- Results obtained at the SLS PX beamline
- Storage cells: theory, operation and results
- Conclusions

# Jungfrau principle of operation

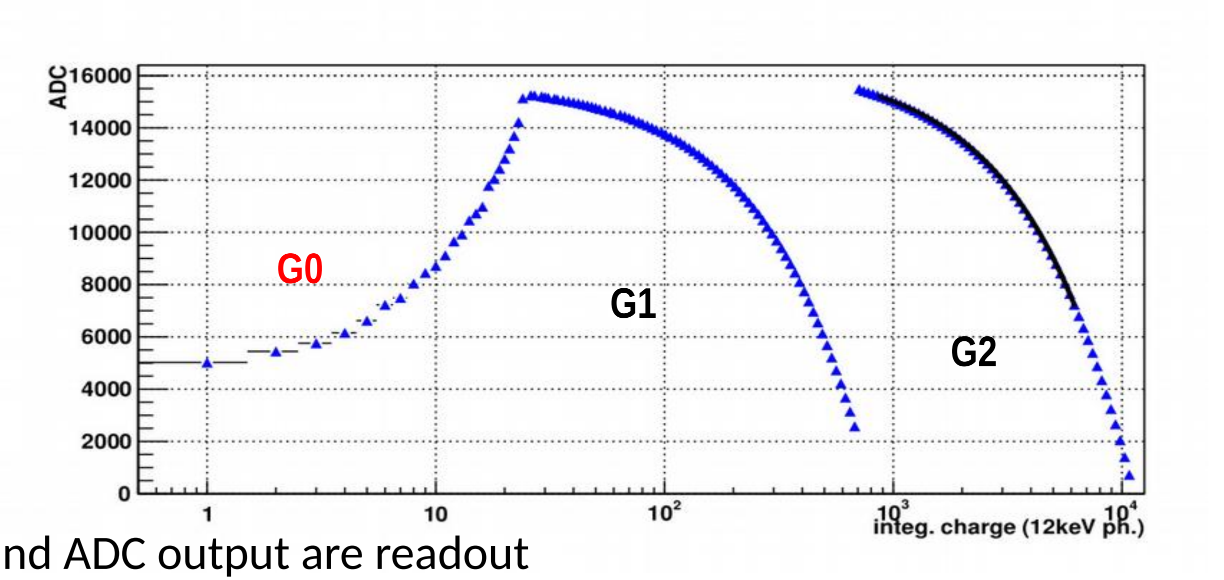



- Used by GOTTHARD and AGIPD before Jungfrau
- Basic idea: Dynamically adding capacitors in the feedback loop of the preamplifier to adapt the gain to the number of incoming photons
- Comparator monitors preamplifier output and add capacitors if the dynamic range is ~ exceeded

<u>Three gain:</u>

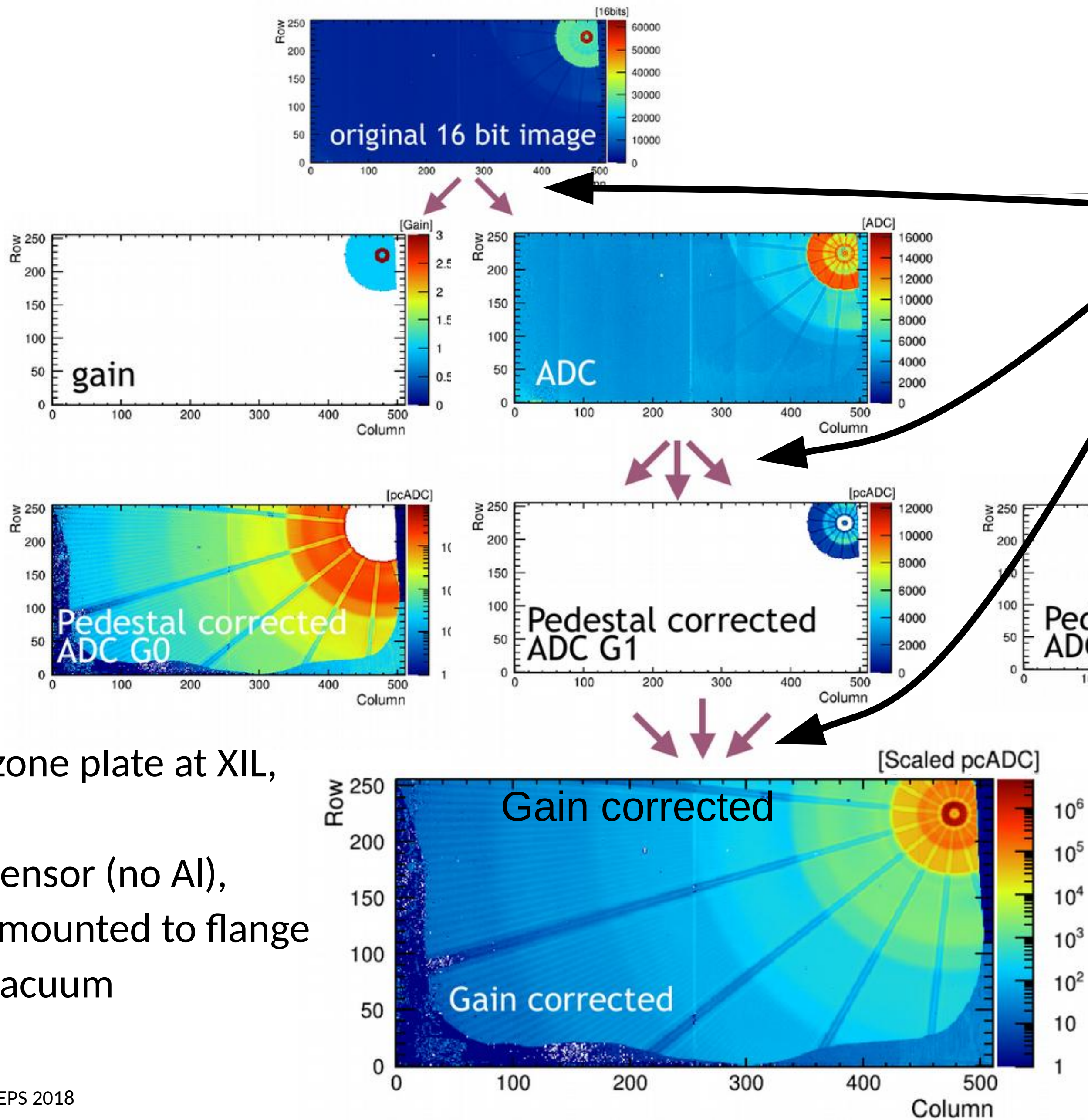
High (G0): **1 … 20** x 12.4 keV photons
Medium (G1): *20* **… 700** x 12.4 keV photons
Low (G2): 700 **… <10800** x 12.4 keV photons

# From output to photon number




- Gain bit and ADC output are readout
- per channel, a calibration set of 3 gains and 3 offsets are needed to recover the number of photons
- the 3 gains are determined with a specific calibration procedure
- the 3 offsets, called pedestals, are dark images collected just before the measurement
  - easy to collect, just close shutter
  - depends on temperature, dose, etc., “frequent” collection is needed.

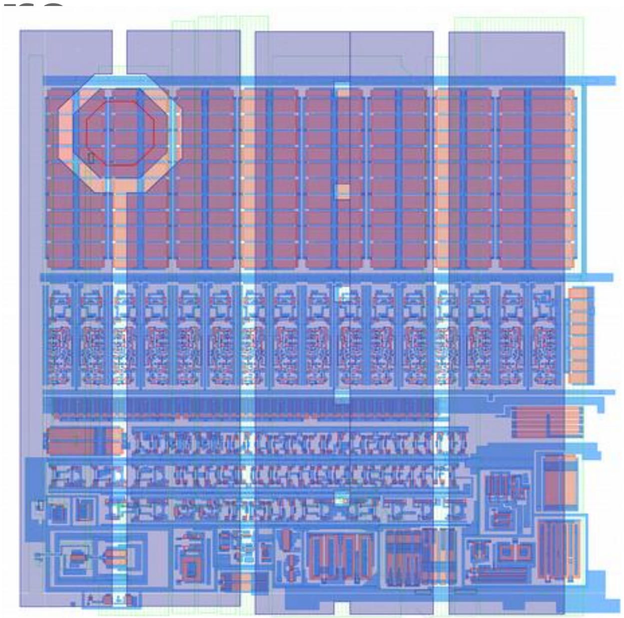
# .. an Example



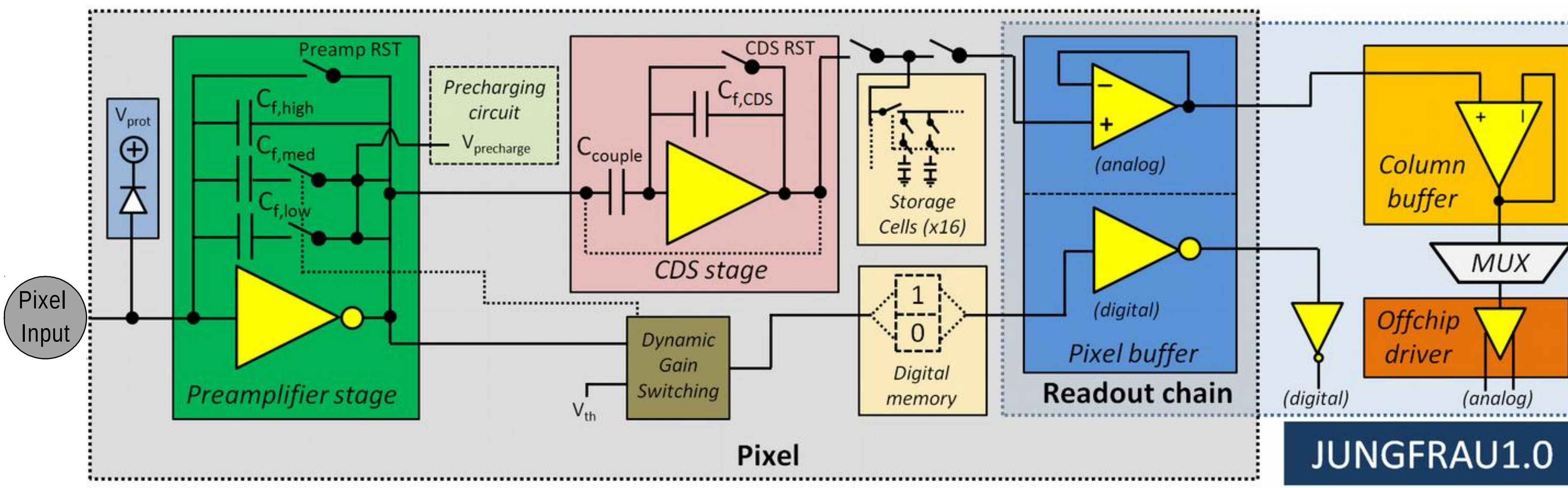

- bitmasking
- pedestals
- Gain factors

- Fresnel zone plate at XIL, 92eV
- etched sensor (no Al), module mounted to flange in high vacuum

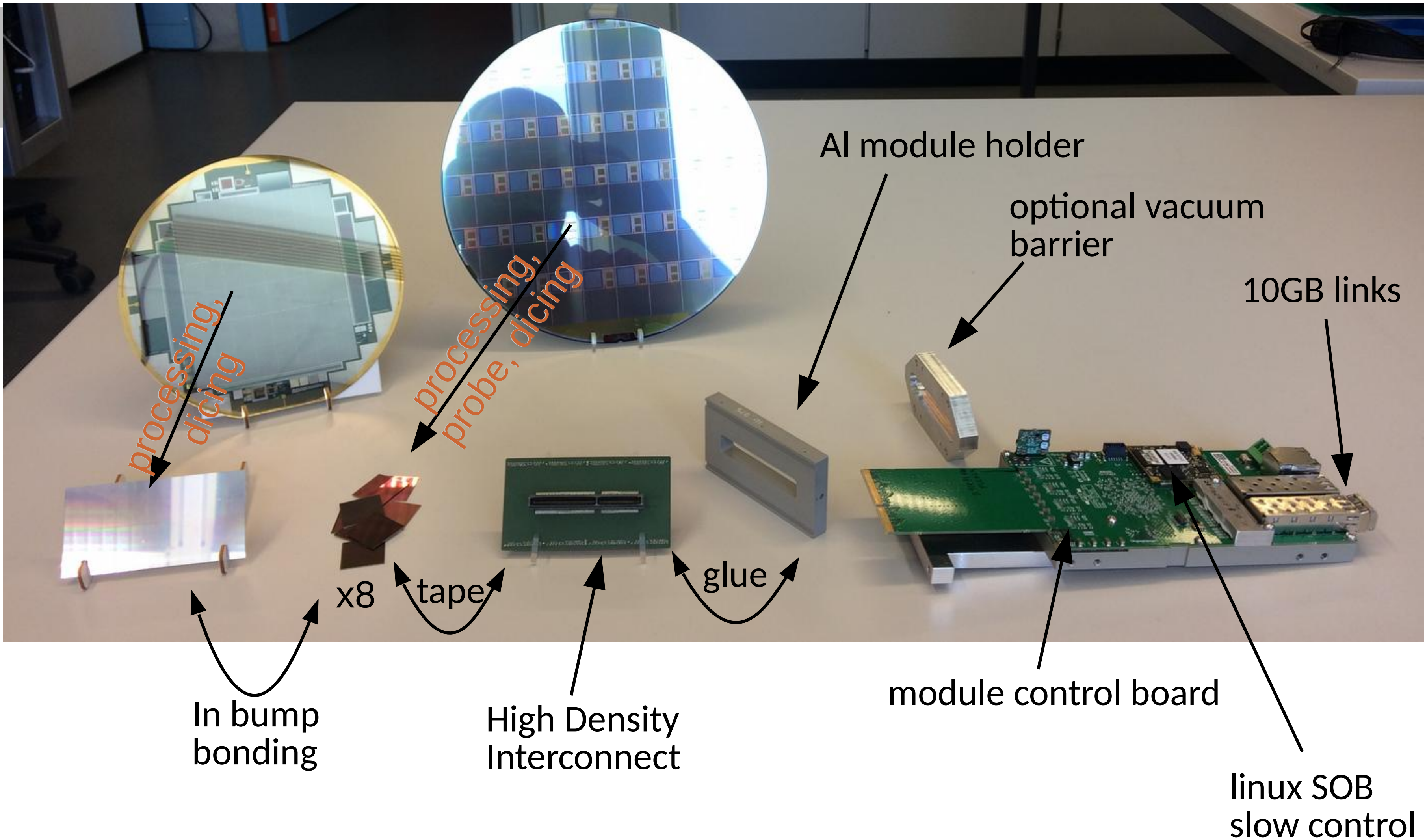
# Jungfrau pixel architectu



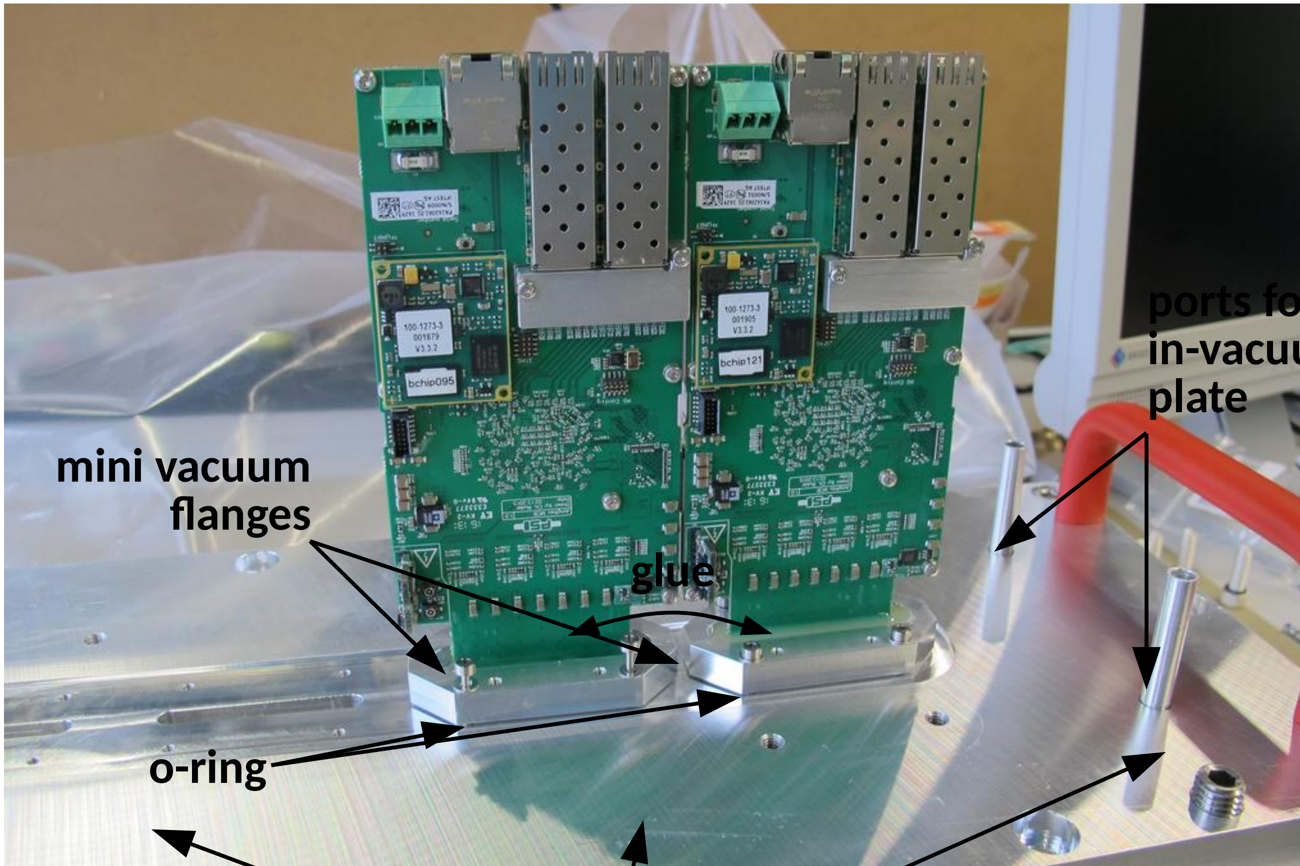
- Automatic gain switching preamplifier (3 gains)
- Based on the GOTTHARD and AGIPD experience
- with some refinements: precharge, CDS bypass in low gain, noise optimization
- (and 10% of the channel power budget)
- 16 analog (and digital) storage cells
- UMC110 technology
- 75 um pitch



# Module components

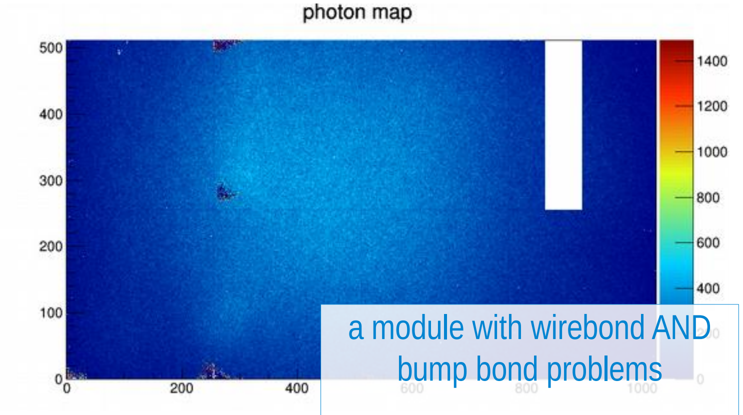


# In vacuum? easy if fixed to a wall

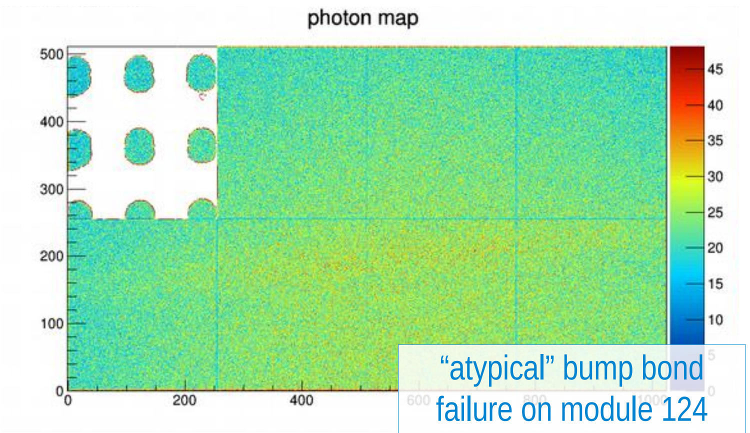


# Module production yield/issues

- “Good” module acceptance limit depends on application, generally #bad_pix < 100 (0.02%)
- ASIC yield during Wafer probing 65-80%
  - Chip accetted if #bad_pix < 7
- Initial Module production yield ~ 30%
- Current production run module yield ~75%
- Failure modes: 70% wireb. 20% bump. 10% varia
- 2 modules (out of ~40 deployed) showed failure (bad colums) in first week of operation
- Produced 75 modules in house, 45 in external company(ies)
- On the way to fullfill needs for the SwissFEL 2x16M cameras.



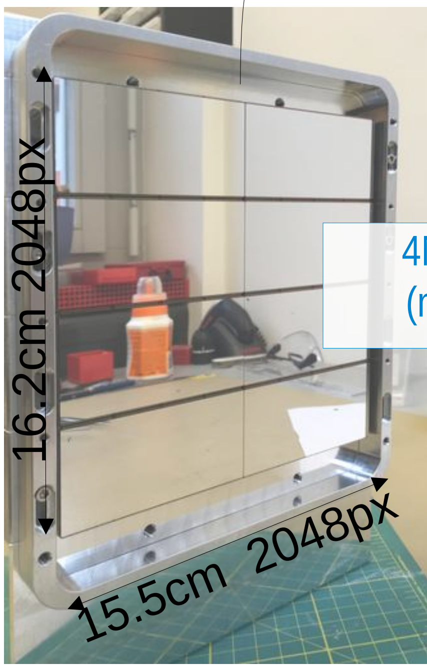

a module with wirebond AND bump bond problems




“atypical” bump bond failure on module 124

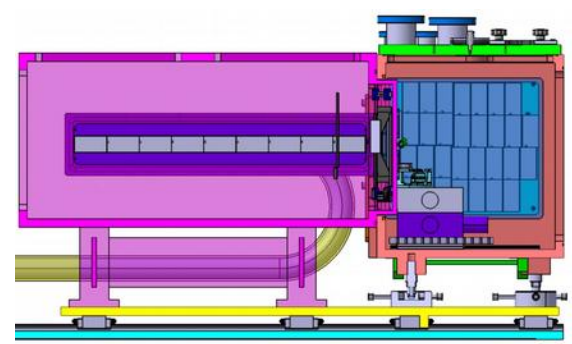
# From modules to systems

- 500k (one module), 1M (2 modules), 1.5M, 4M and 16M (ESA-ESB main instruments) systems
- same geometry as the EIGER systems (gaps,etc..)
- Gaps are small: total dead area <7%
- compact (~25cm) in the Z direction
- modules now at SLS, LCLS, ESRF, SOLEIL, PAL, DESY, EU-XFEL, BESSY



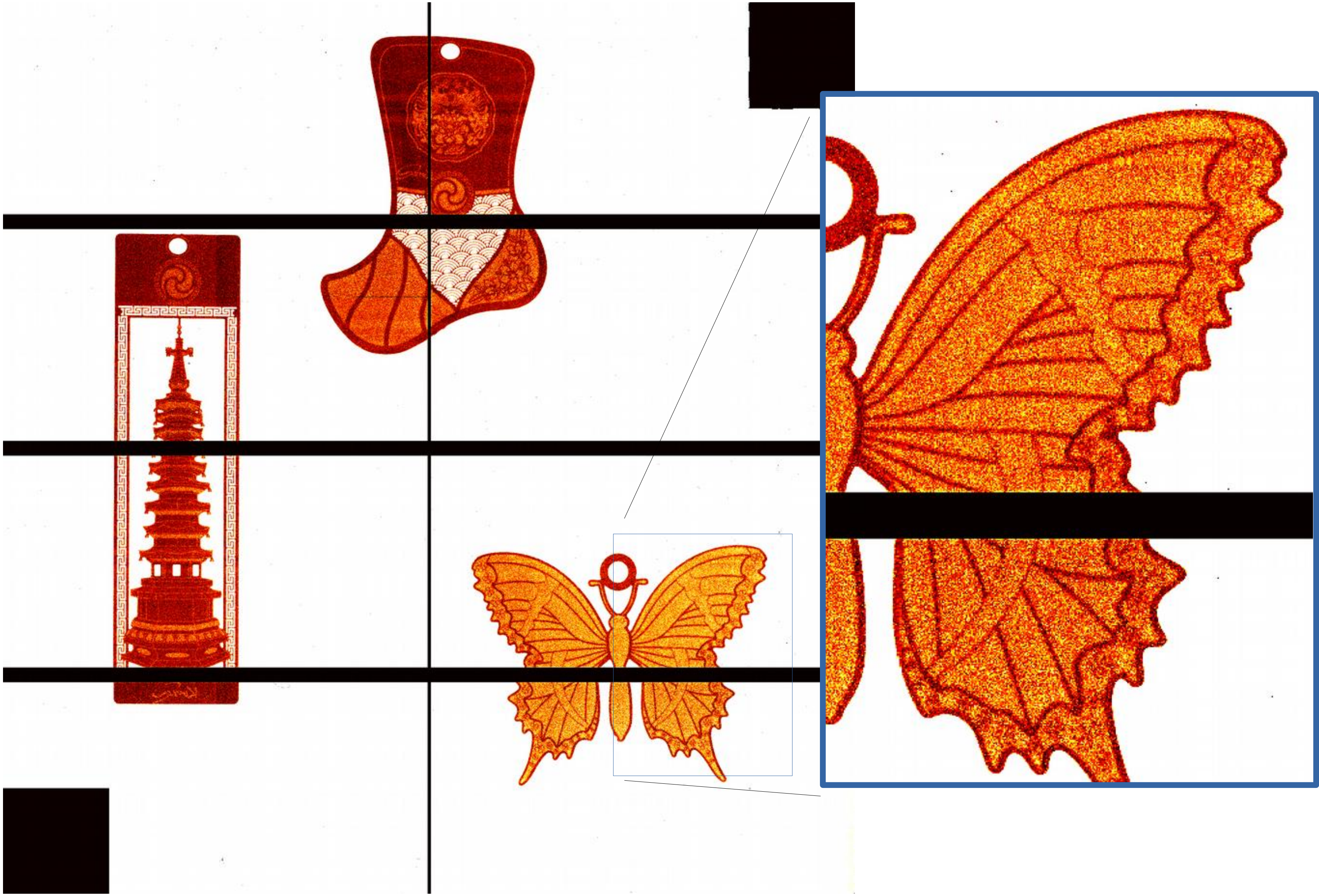

4M camera (mounting)

4M camera under test

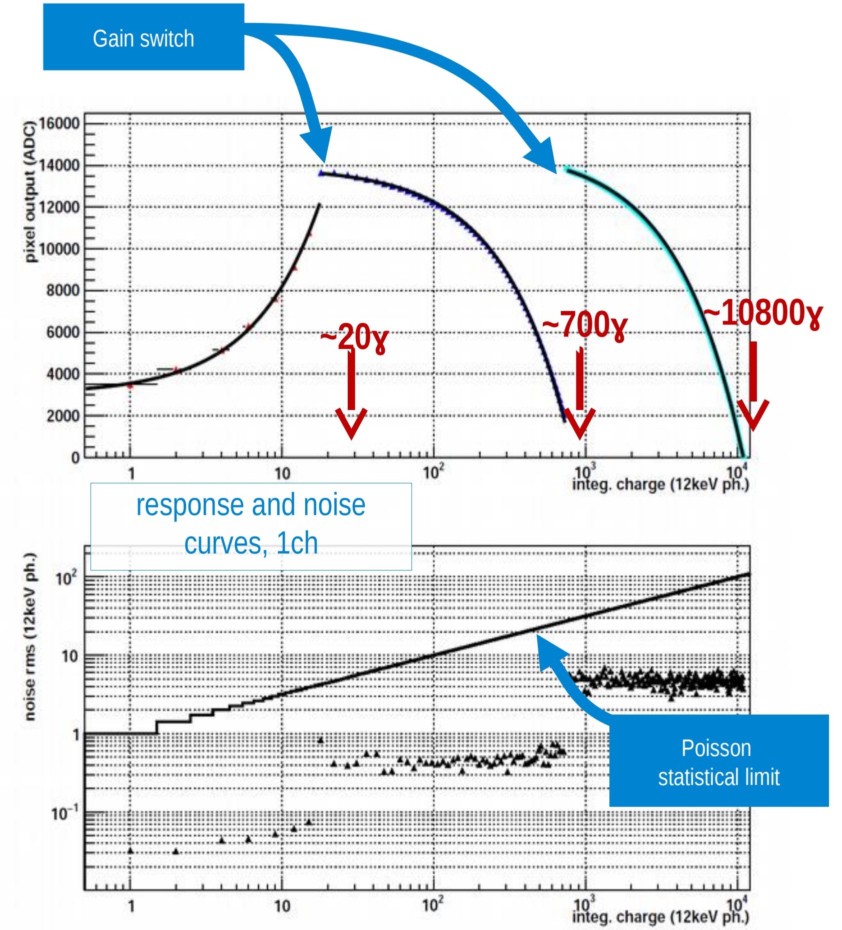


ESA vacuum chamber 16M+4.5M

# first 4M image (march 18)



# Summary of characterization results

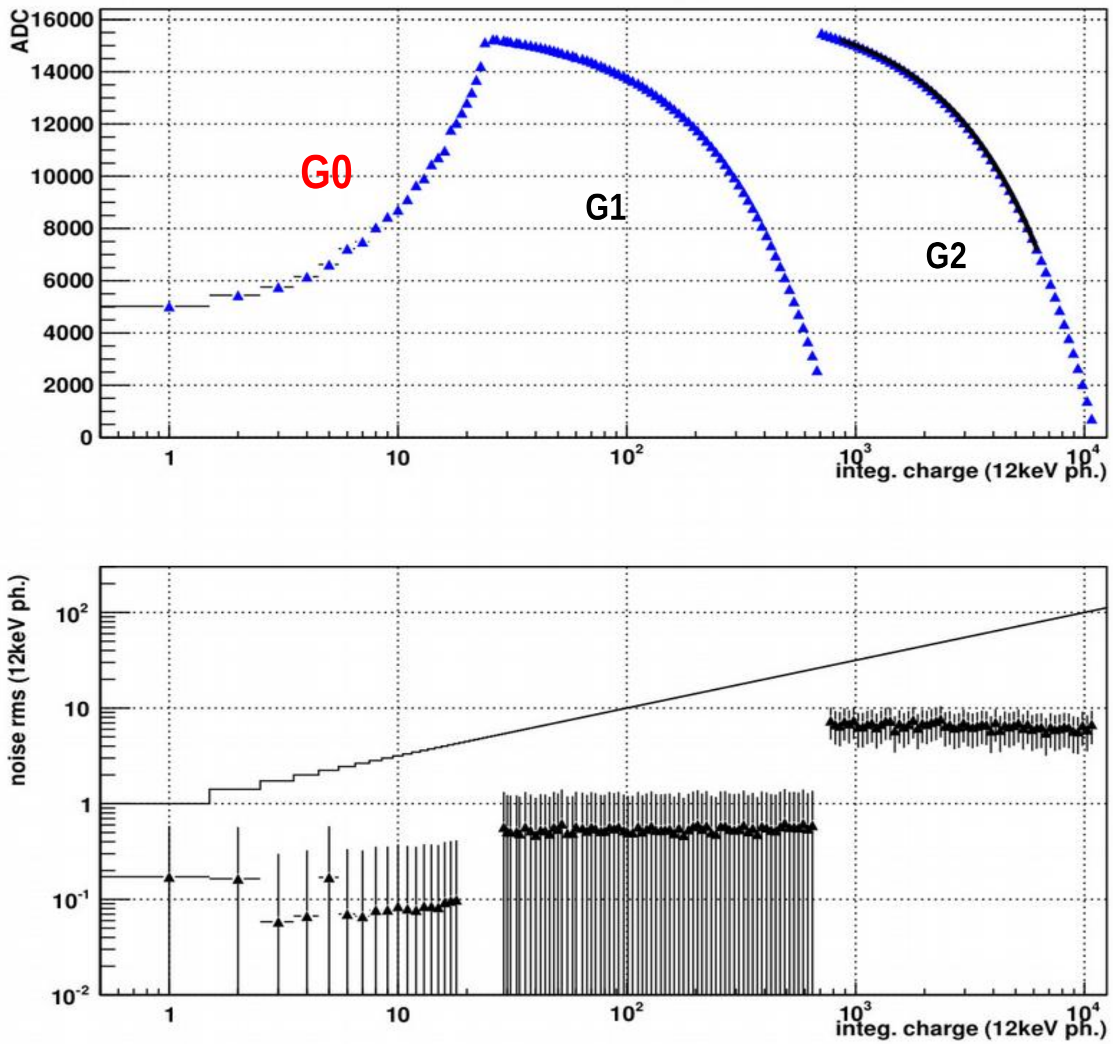



| | |
|---|---|
| noise in G0 (@10us integration) | 80±3 E.N.C. rms |
| noise in HG0 (low energy operation) | 50±2 E.N.C. rms |
| min energy @ with photon detection | 1.5keV |
| noise in G1/G2 | 3keV/50keV rms |
| nominal gain values (G0-G1-G2) | 40-1.4-0.11 ADU/keV |
| non linearity error | <1% (w. optimal calibration) |
| Saturation | ~11K 12keV photons per frame |
| Saturation flux for continous sources | 12MHz/pix @ 1.13kHz,12keV<br>50MHz/pixel @2.4kHz,6KeV |
| Min integration time | 500ns |
| Frame rate | max 2.4kHz, 1.13kHz with current FW and PCB |
| Min period between frames | 1/frame rate (now 880us)<br>3us in burst mode (current FW) |

# High gain operation for low energies

**Gain switching is automatic (per pixel) but: two options for the first gain stage:**

- Normal gain **G0**
- High gain HG0 for low energies



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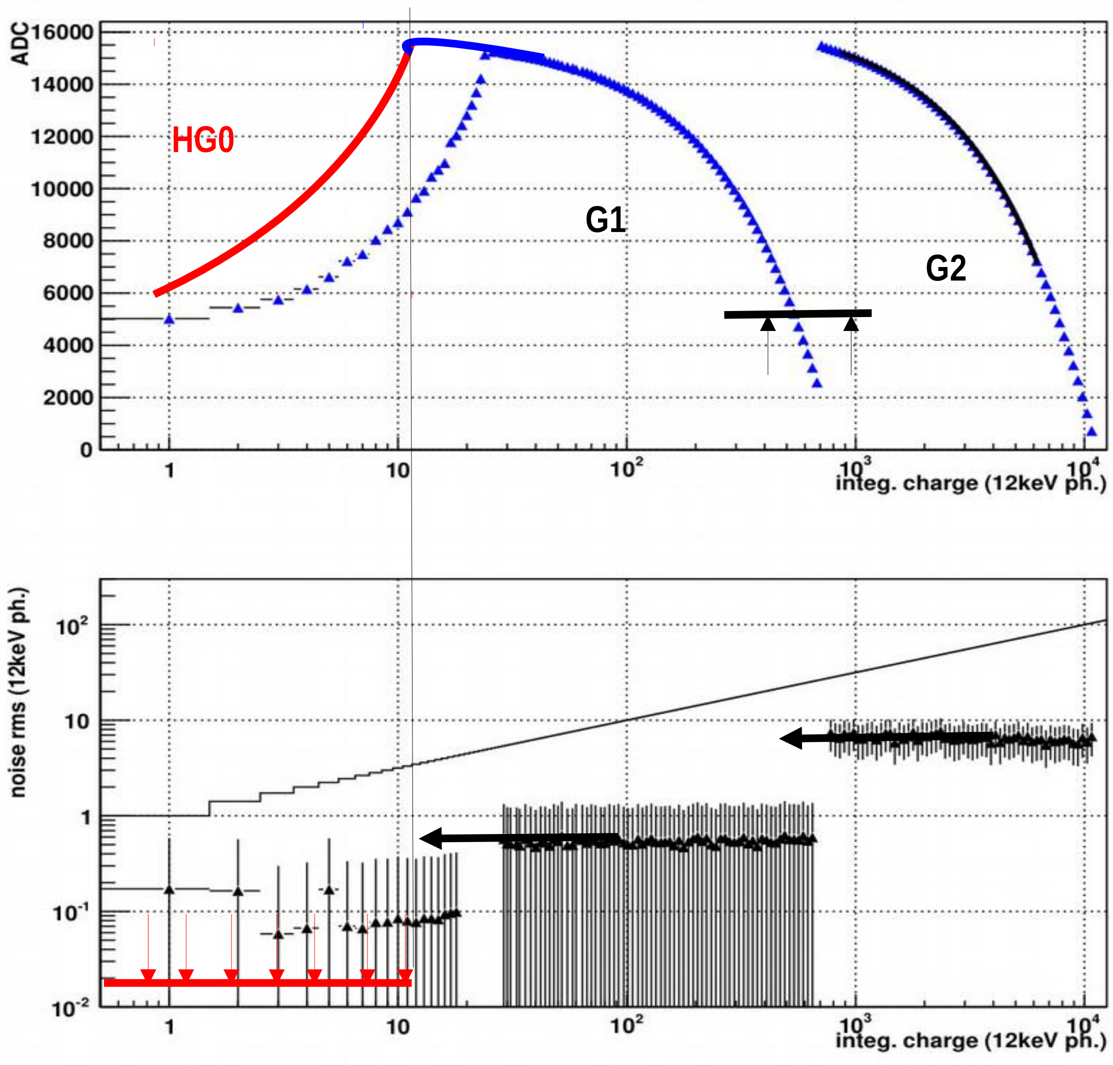
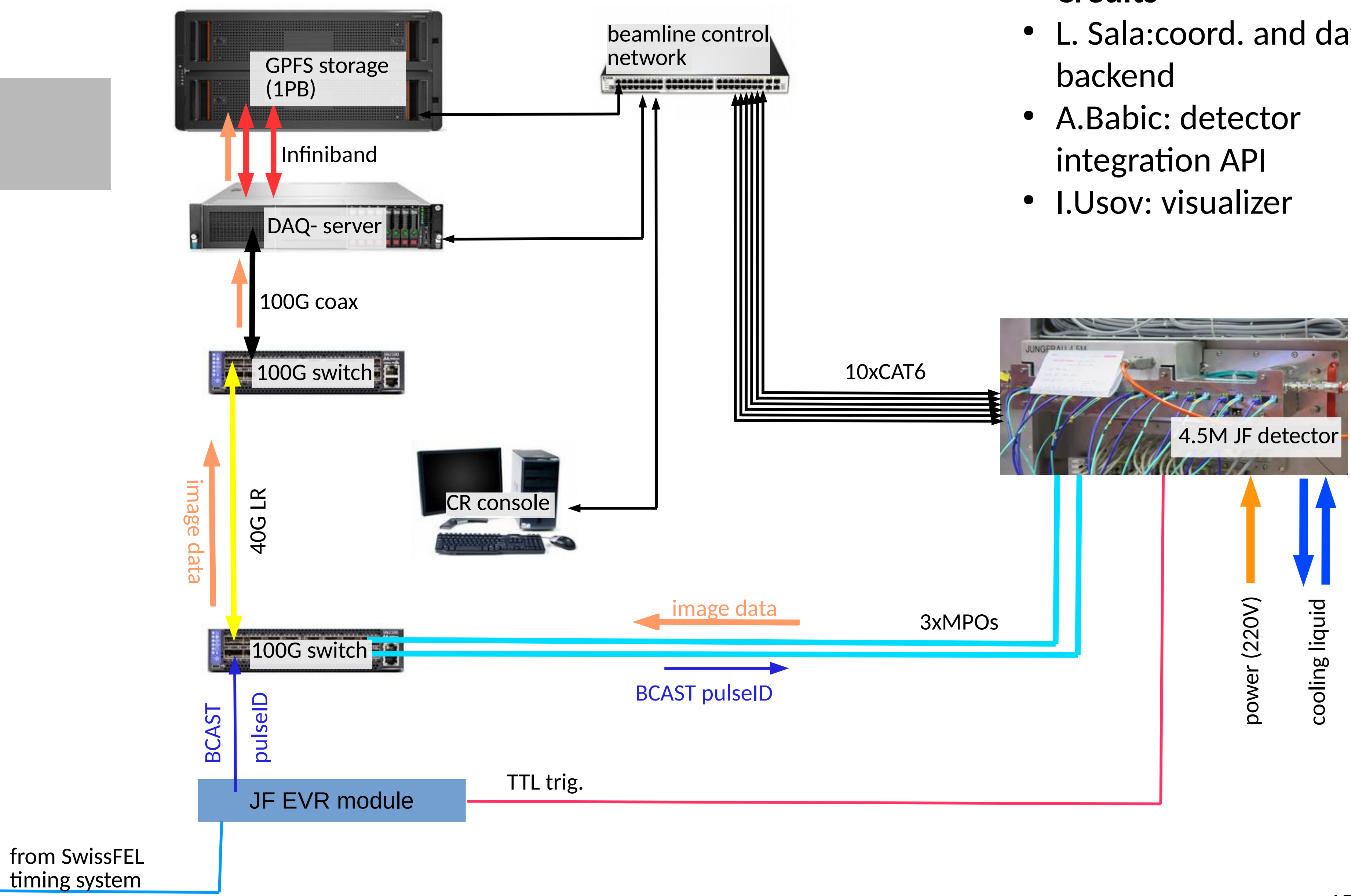
- Normal gain **G0**
- High gain HG0 for low energies

This is a global (module wide) manual selection



# JF DAQ setup @ SwissFEL




**Credits**

- L. Sala:coord. and data backend
- A.Babic: detector integration API
- I.Usov: visualizer

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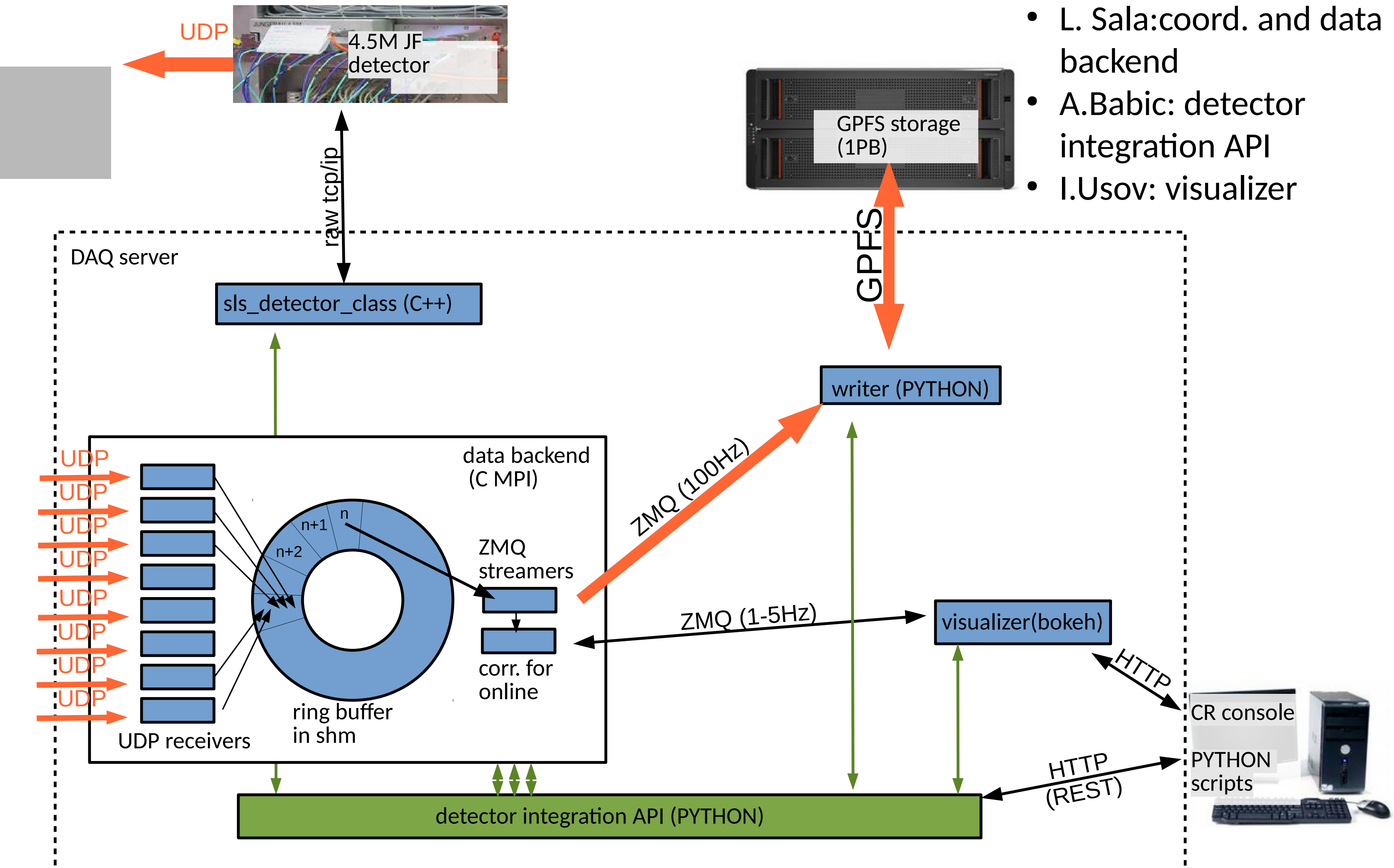
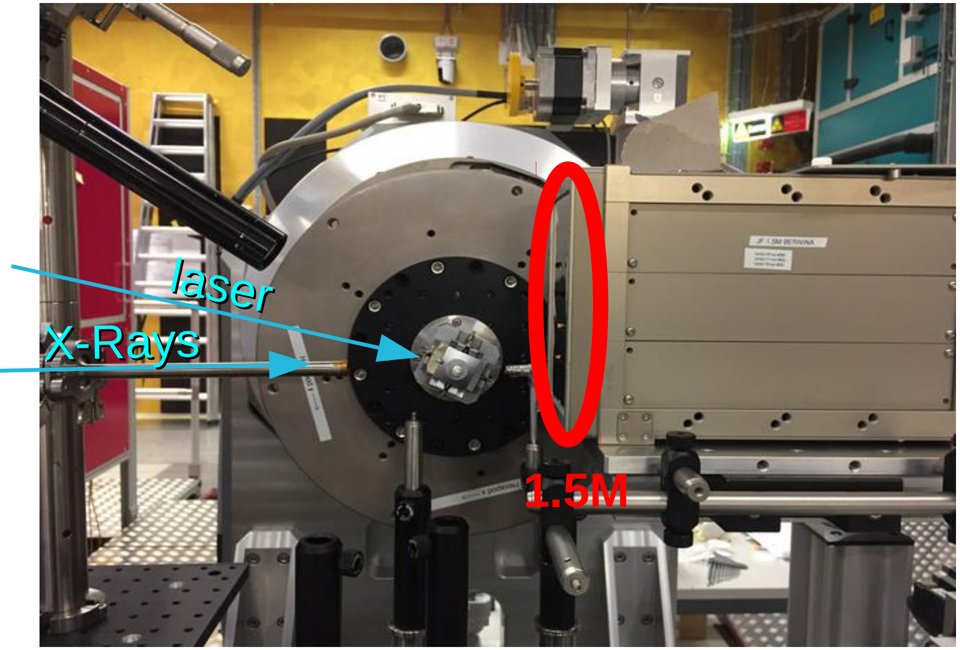


# First experiment @ SwissFEL Semiconductor to metal transition in Ti3O5 nanocrystals

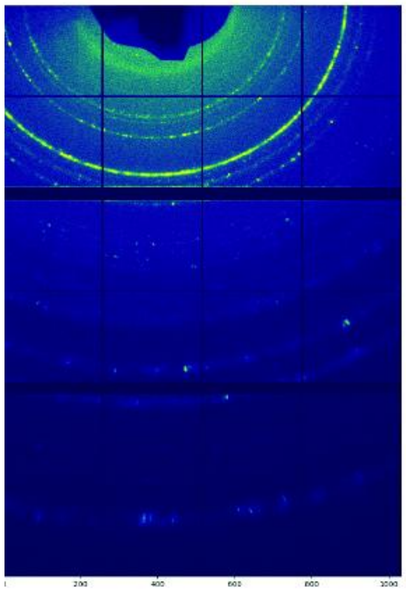
**1.5M JF installed in Oct. 17 in the Bernina hutch**

- later to be used on the diffractometer
- 2.2keV foundamental, but 6.6keV 3rd Harmonic used: weak beam
- diffraction rings from a solid sample, at grazing incident
- P-P delay scan, but no timing tool: sub ps time resolution
- 10Hz beam, 5Hz laser
- First real life test of DAQ, timestamping, everithing

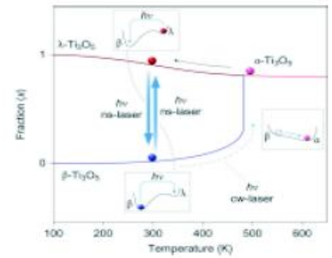


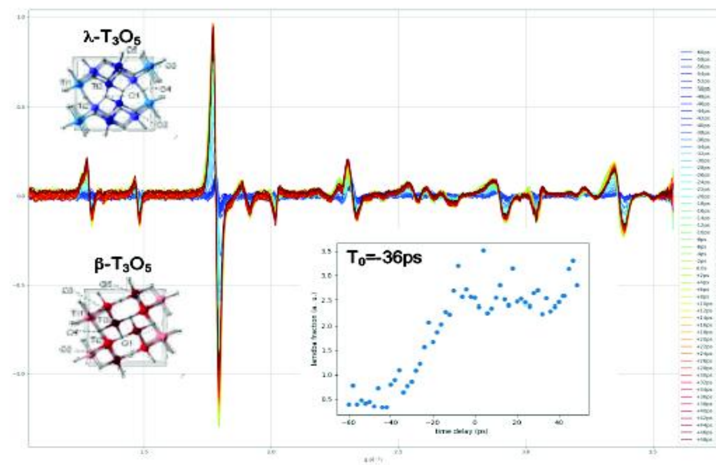
# First experiment @ SwissFEL Semiconductor to metal transition in Ti3O5 nanocrystals

*Collaboration:*
*SwissFEL and M. Cammarata et al., Univ. Rennes*



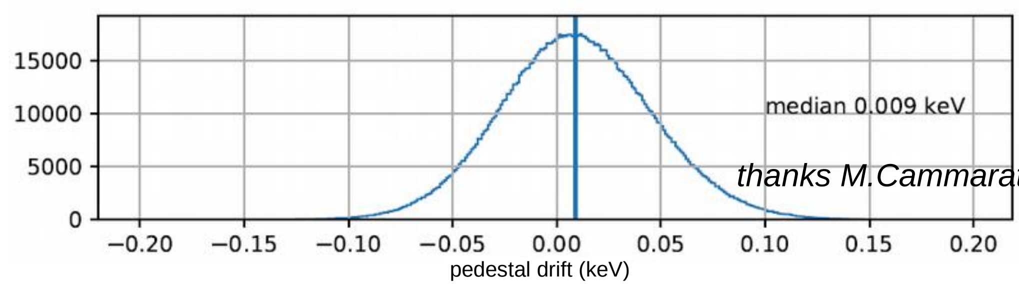
-3rd Harm: 6.6 KeV
(fund. 2.2 KeV 220 μJ)
-Laser: 800nm, 42 mJ/cm²




good pedestal stability: between 2 pedestals 1 week apart:

- max drift <200ev
- median drift <10ev
- with 6keV photons, i.e. no dose on ASIC

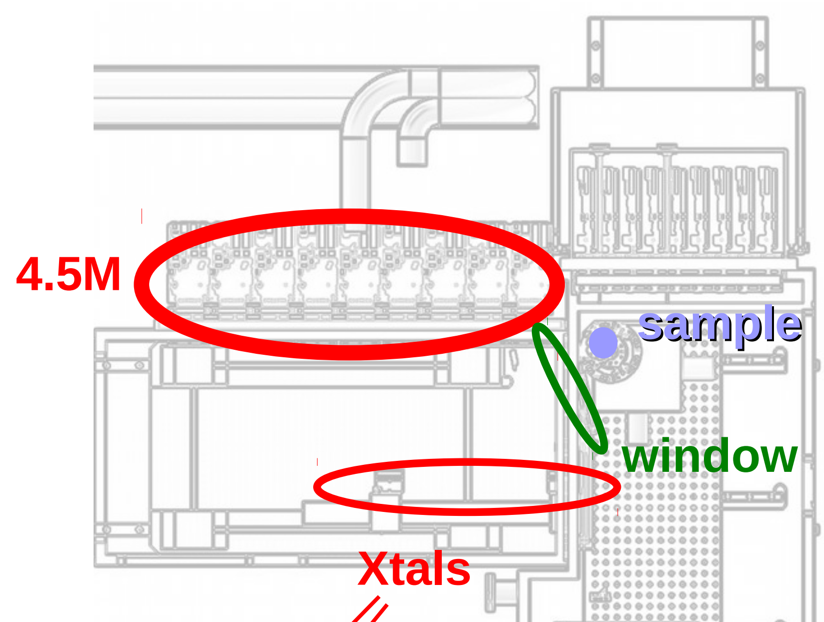


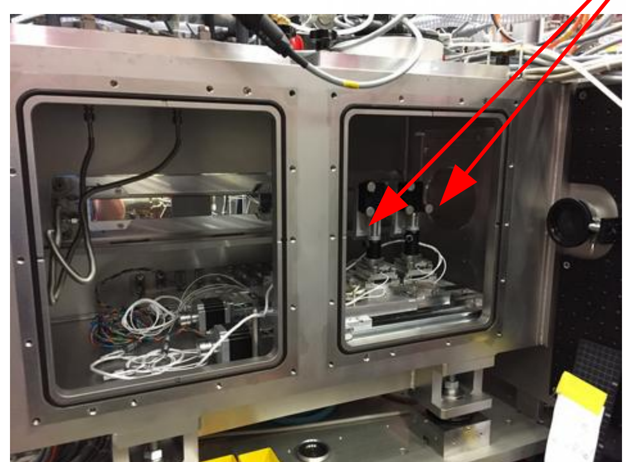

*thanks M.Cammarata*

# SwissFEL ALVRA 4.5M spectormeter detector

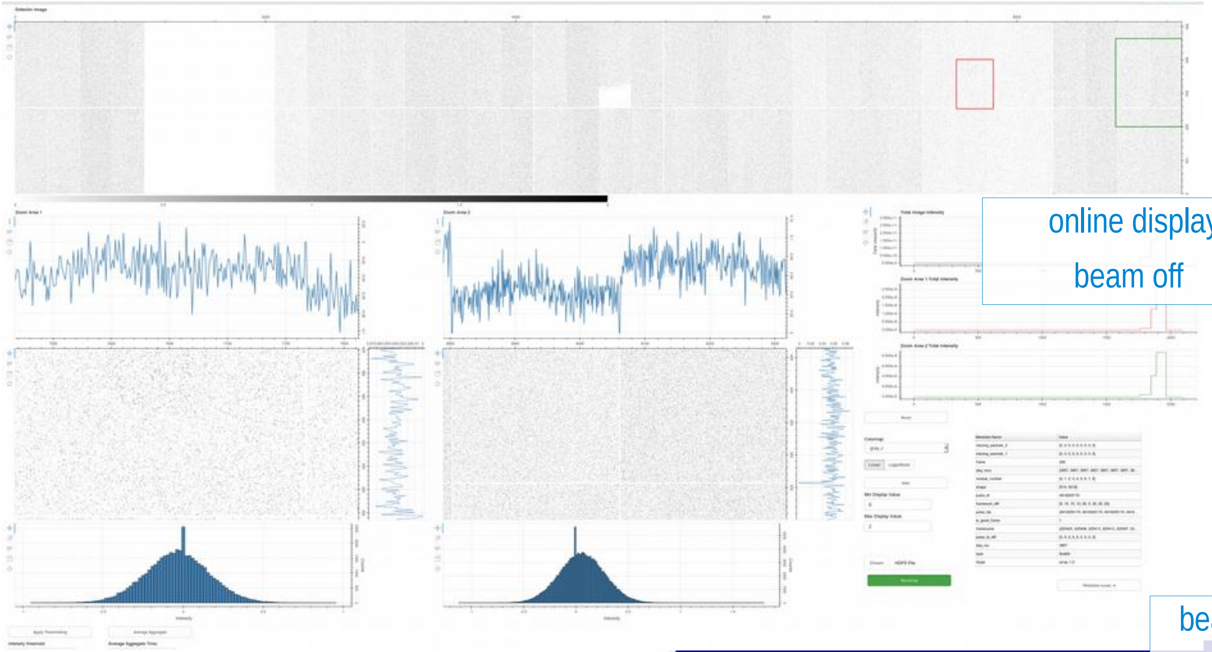
**4.5M JF installed Nov. 17**

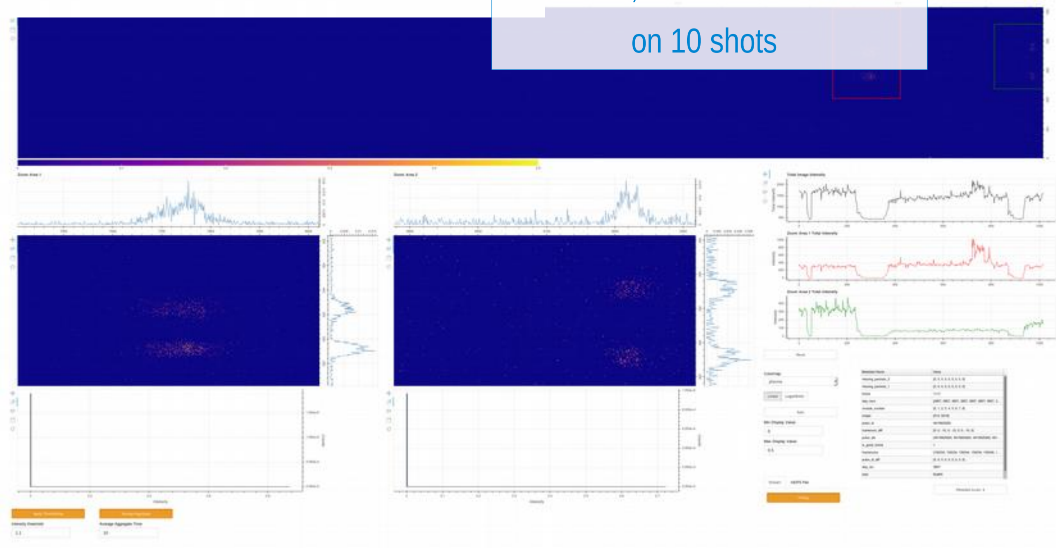
- 9000x512 pixels
- 2 movable van-Hamos Xtals
- No need to move the detector
- vacuum operation (<1E-5 mbar)
- HG0, single photon operation
- 2 Modules slightly warm, still ok
- 1 Module overheats, shut down



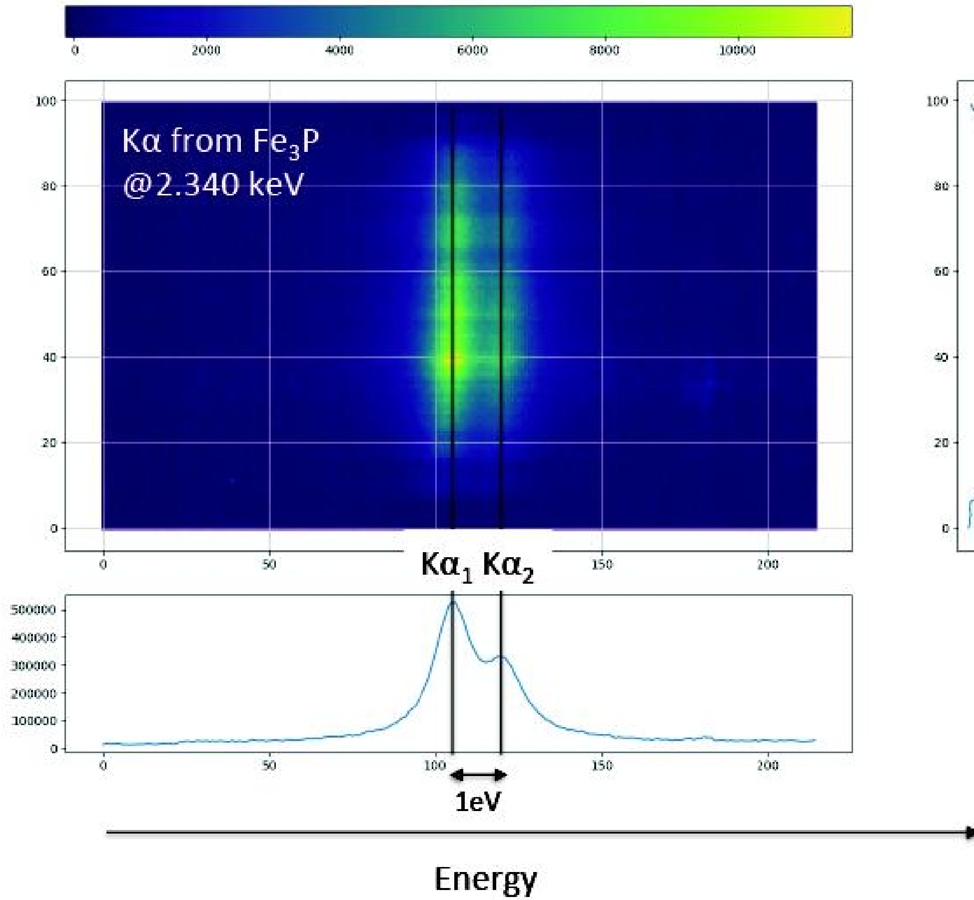
# SwissFEL ALVRA 4.5M operation

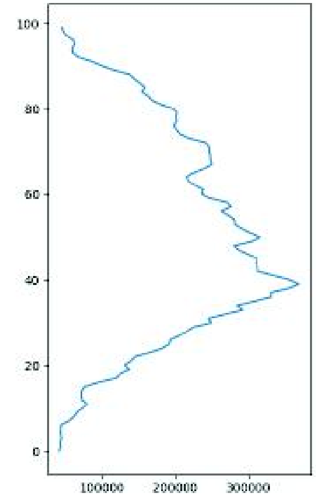



- Noise as expected, CM and chip to chip CM visible on the online (Z scale is 0-2keV), but:
- with 1keV threshold, O(10) fake hits on the full 4M
- Few photons also in the signal region, <<1ph/frame/pix

# First XE spectra from SwissFEL ALVRA



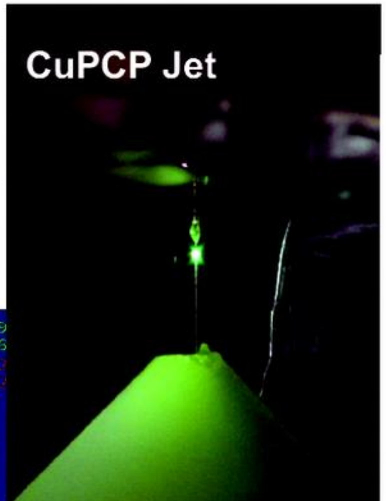



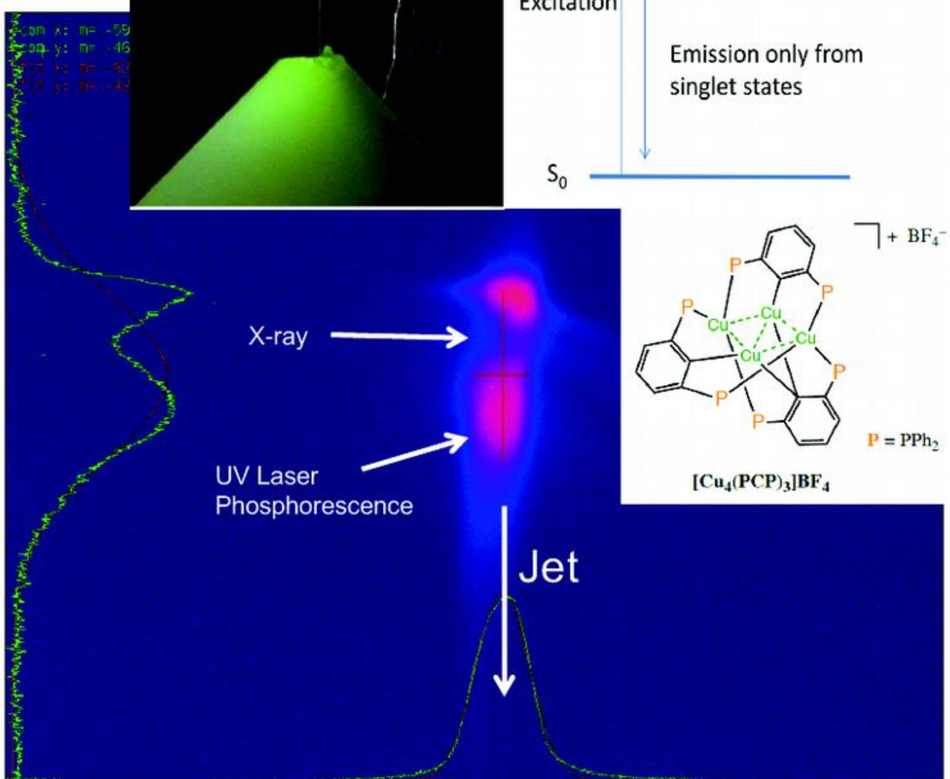

- resolution is as expected, limited by Xstals and beam size

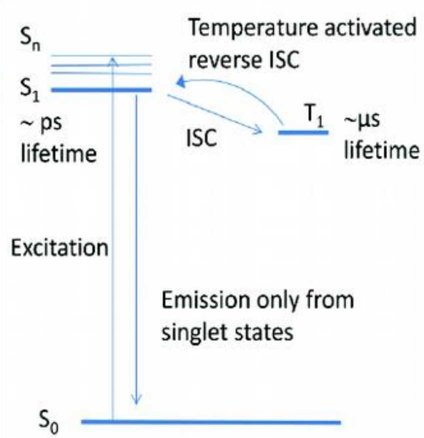
**on the detector side:**

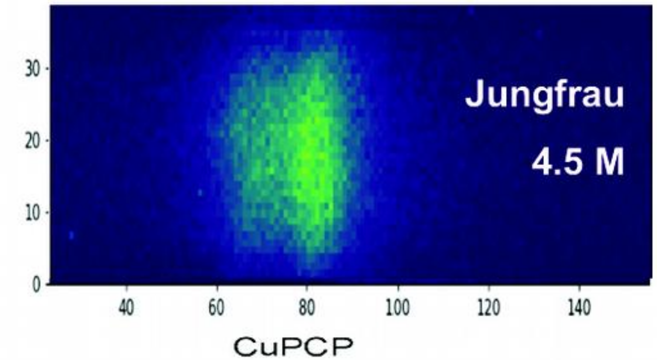
- stable operation, hardware and (partly) software wise
- single photon resolution at <2keV
- at this low energies more frequent pedestals are needed (e.g. 3x a day)

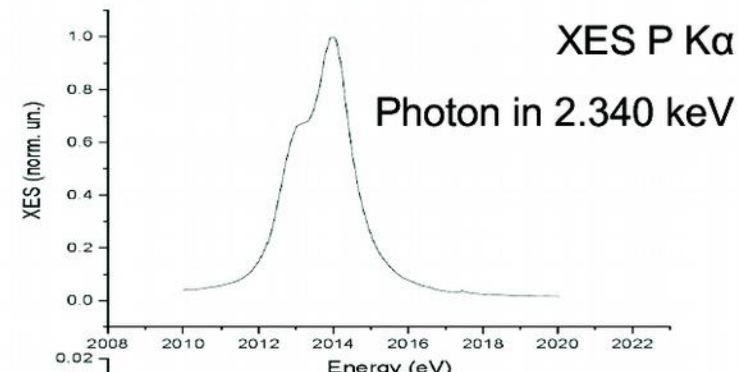
# First Pilot Experiment by SwissFEL-Alvra:
UV photo-induced charge transfer in

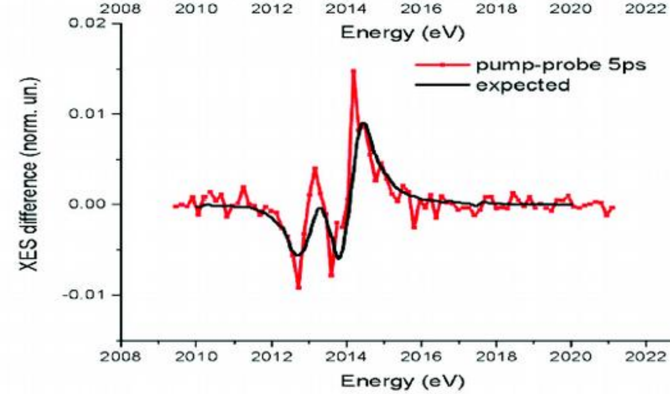


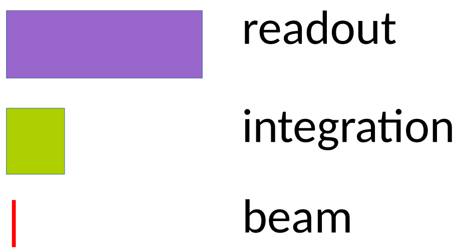



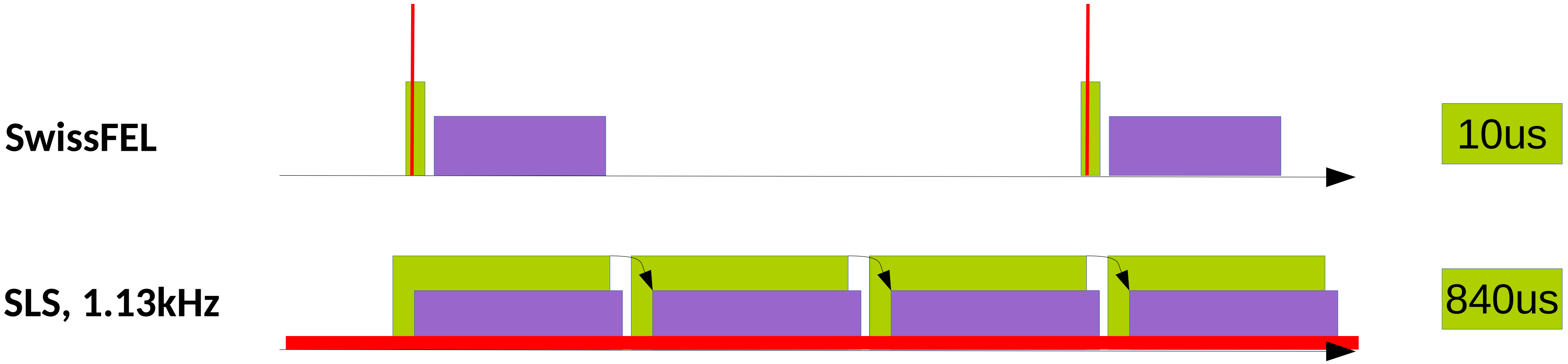



# JUNGFRAU at SLS PX

- Working with a continous source requires long integration times: cooling to readuce leakage current, noise.
- Forced to work at full speed
- Readout during integration: 96% duty cycle
- As a plus, rate capabilities scale with frame rate
- Noise at 840us integration goes up to 160-200e- r.m.s.
  3keV single photon sensitivity should be possible

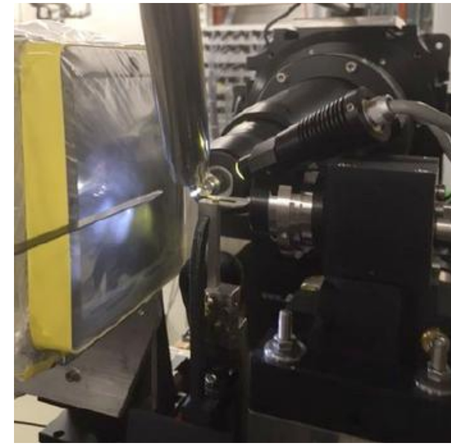


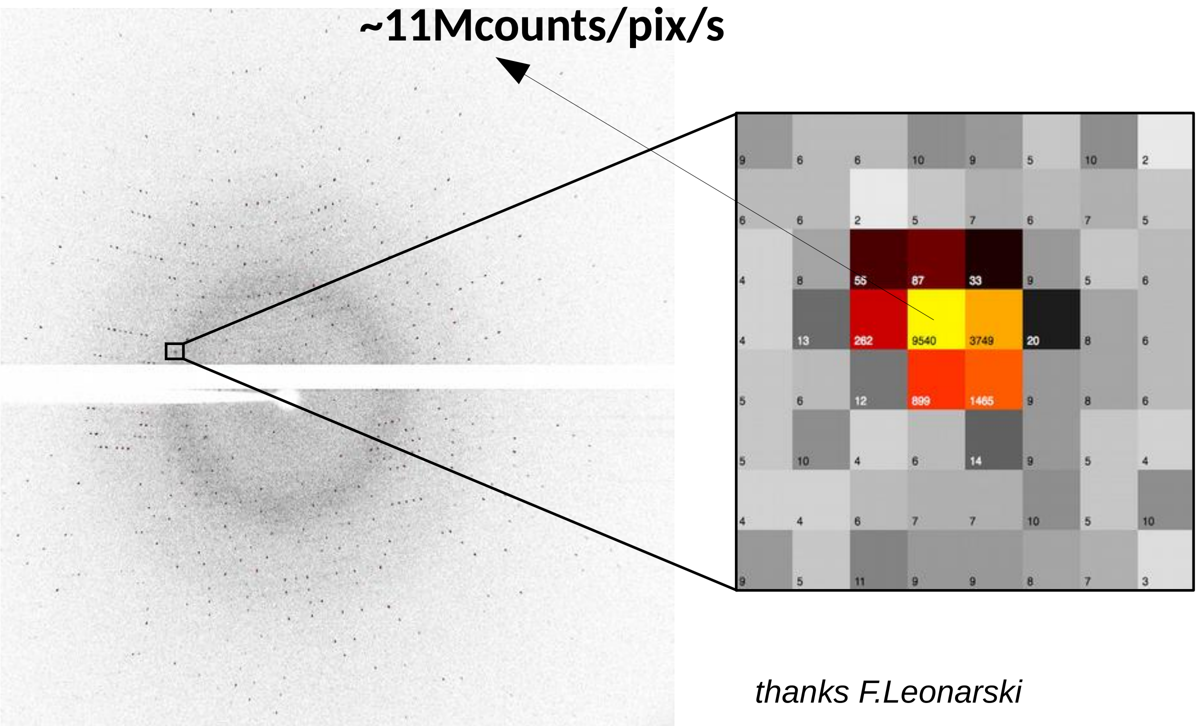



# JUNGFRAU at SLS PX

**Protein crystallography data recorded with crystals of:**

- Insulin, Lysozyme, Thaumatin
- 3 beamtimes , last in Oct. 17

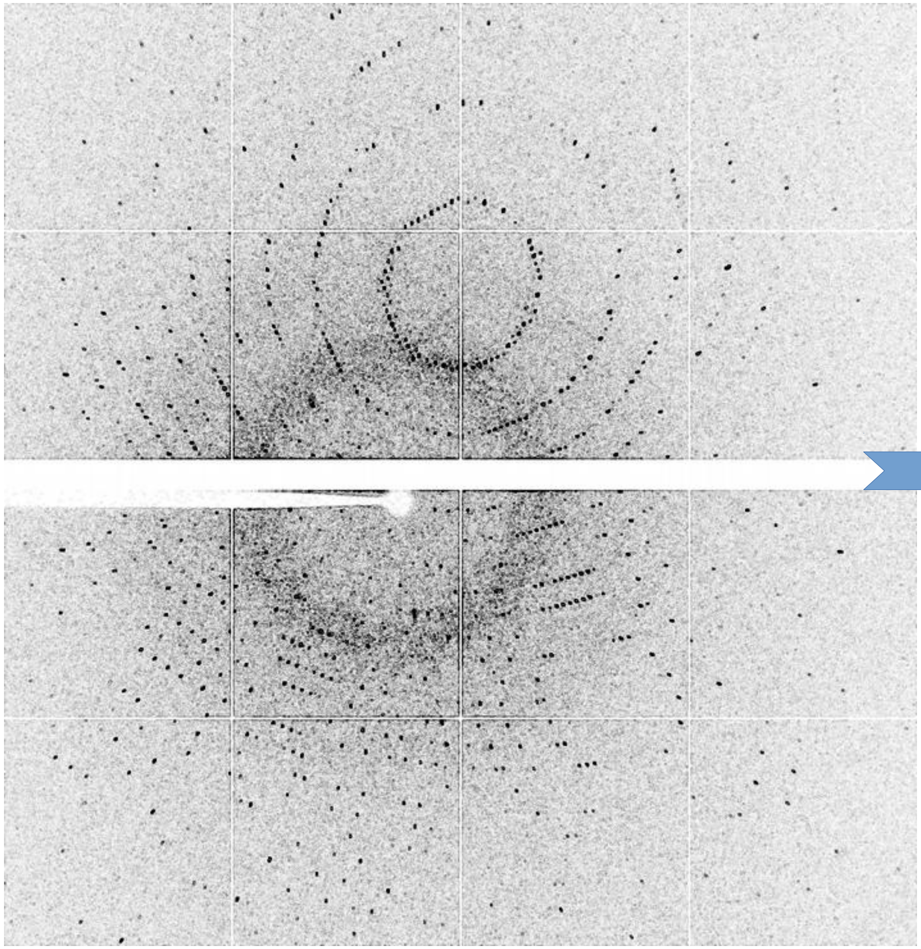


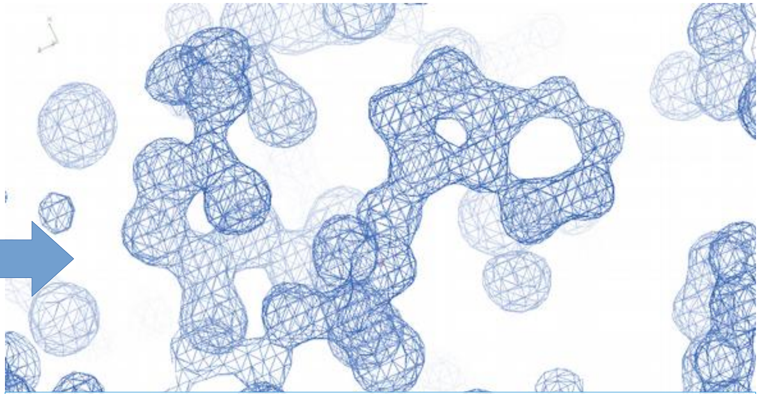



- JF 1M
- cool at -12.5 – $N_2$ flux
- 840 us integration time
- 1.13 kHz frame rate
- (4% dead time)
- BL: X06SA (SLS)
- Photon energy: 12.4 keV
- BL flux: $1.6x10^{12}$ ph/s.
- Crystal: lysozyme

*thanks F.Leonarski*

# JUNGFRAU at SLS PX





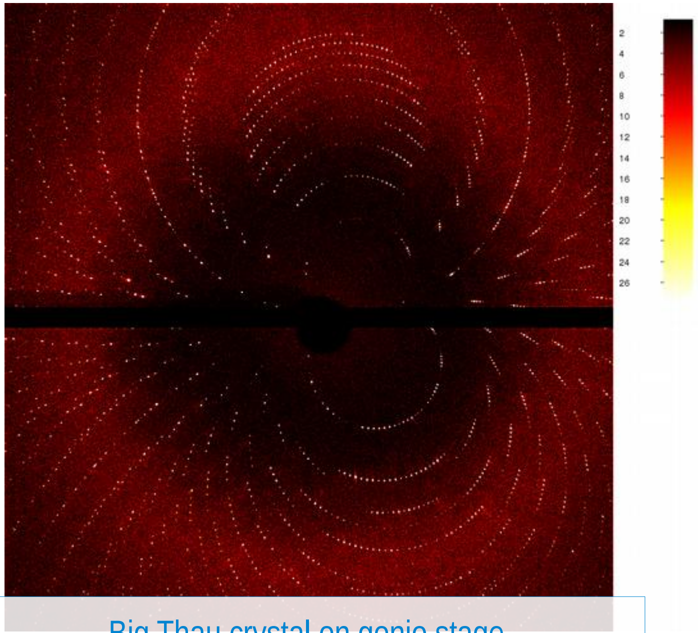
Lysozyme electron density map
Native-SAD (sulphur) at 1A wavelength

- structures could be easily solved, with native-SAD, also at 12keV

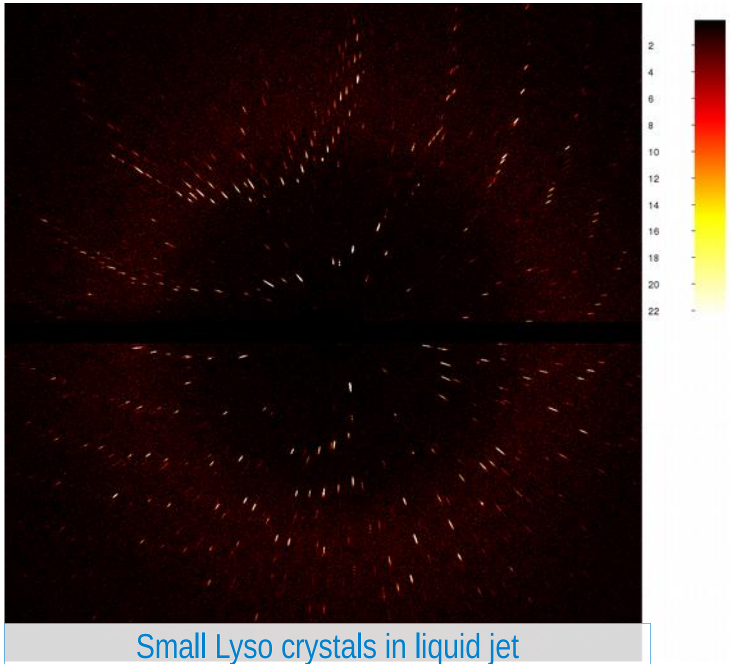
# JUNGFRAU with pink beam (chopper)

**First serial Xtallography with JF**

- Pink beam at APS BioCARS beamline
- full beam transmission
- chopped down to single bunch (or few)
- <10 um beam size
- Makes liquid jet experiments possible at SYNs



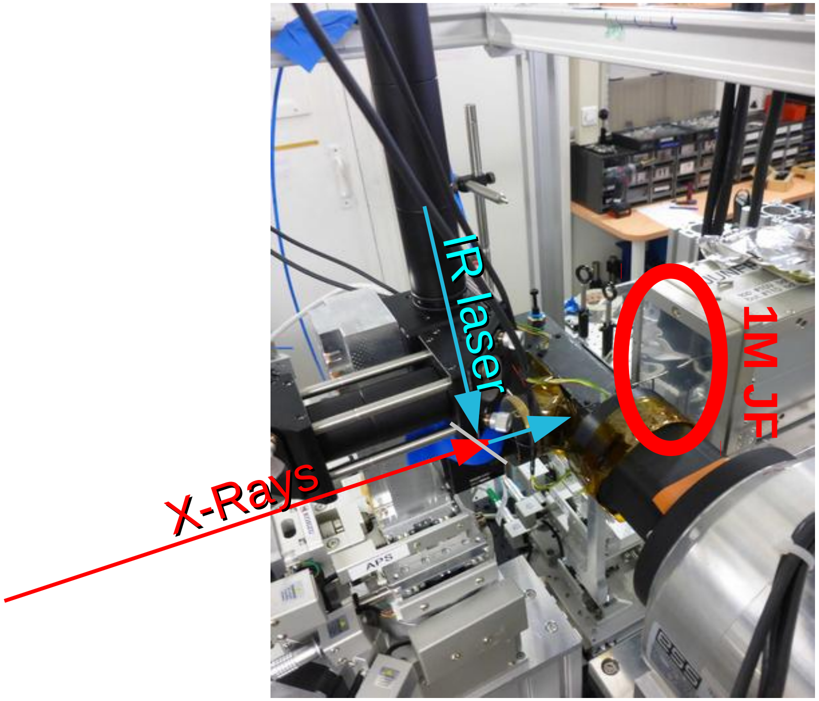
Big Thau crystal on gonio stage



Small Lyso crystals in liquid jet

# Measuring with storage cells/ ID09 setup

- 15keV wide BW beam (ML mono), 100um spot size
- 10Hz pump laser
- 10Hz X-ray, chopper set at 30us aperture
- Roadrunner chip delivery system
- Xtals grown on chips
- Humid He environment
- ESRF ID09 timings: 2.8us int., 5us period, 10Hz train rep rate

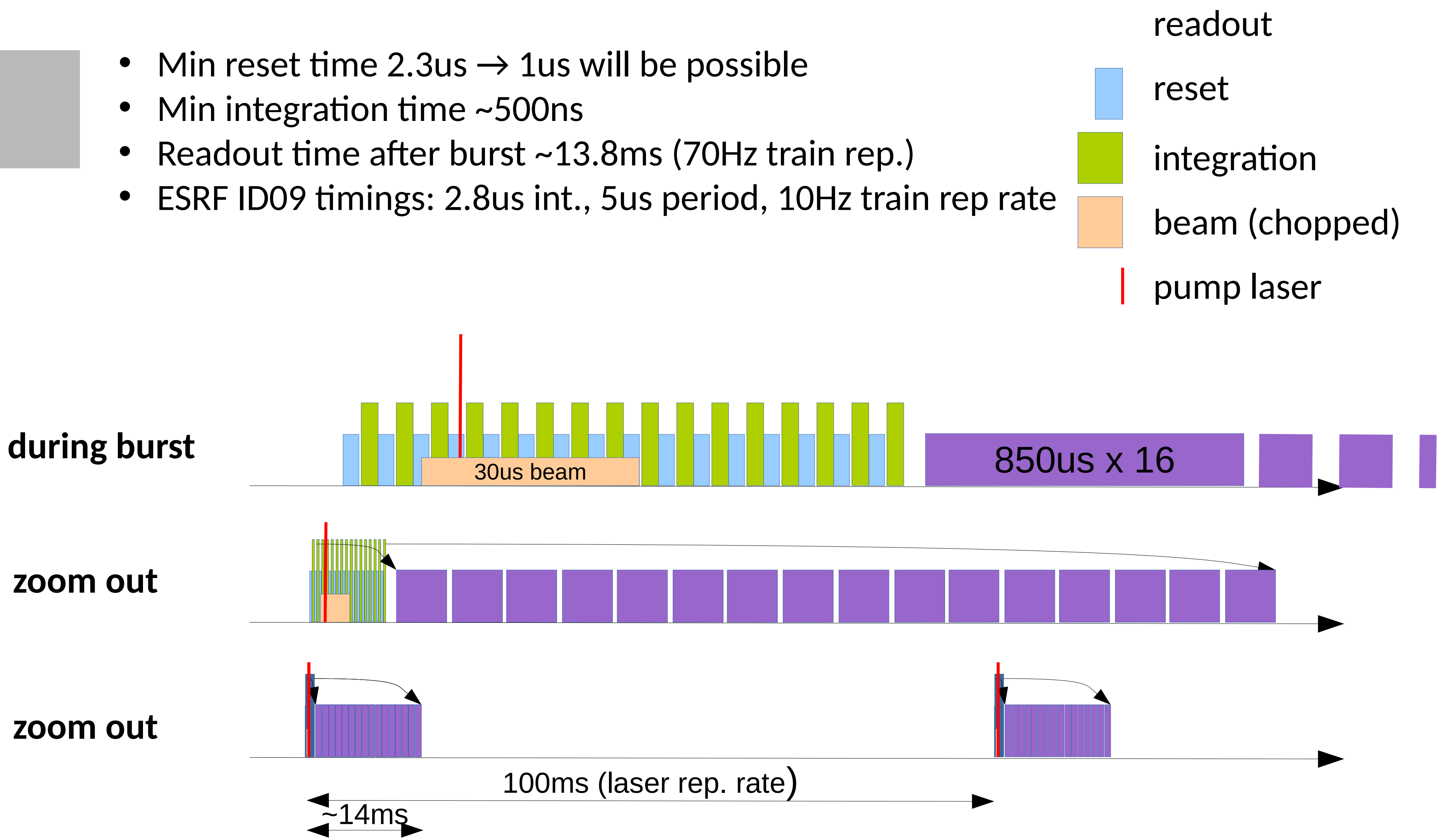




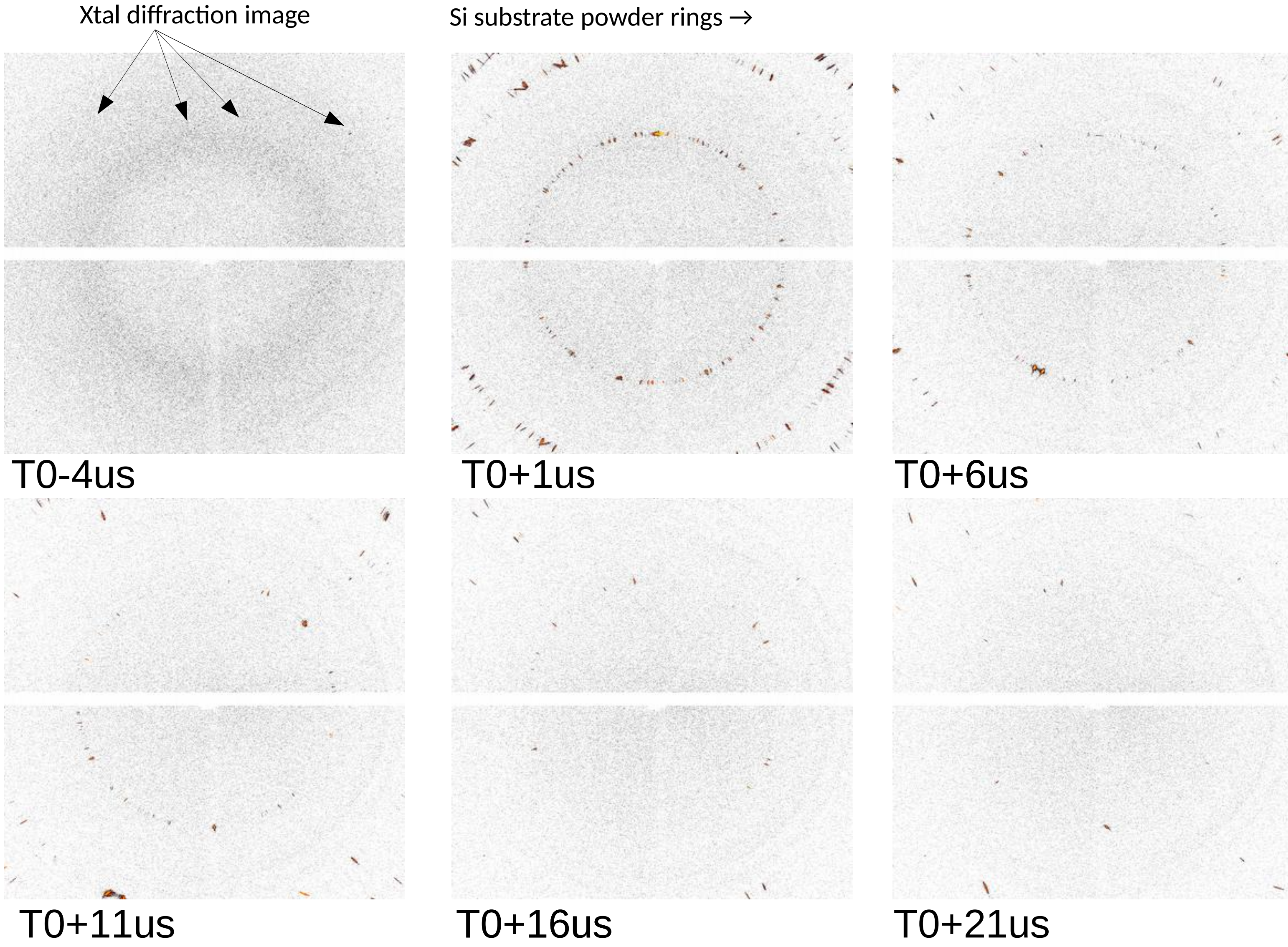
*thanks A. Meents*

# Measuring with storage cells/timing

- Min reset time 2.3us → 1us will be possible
- Min integration time ~500ns
- Readout time after burst ~13.8ms (70Hz train rep.)
- ESRF ID09 timings: 2.8us int., 5us period, 10Hz train rep rate

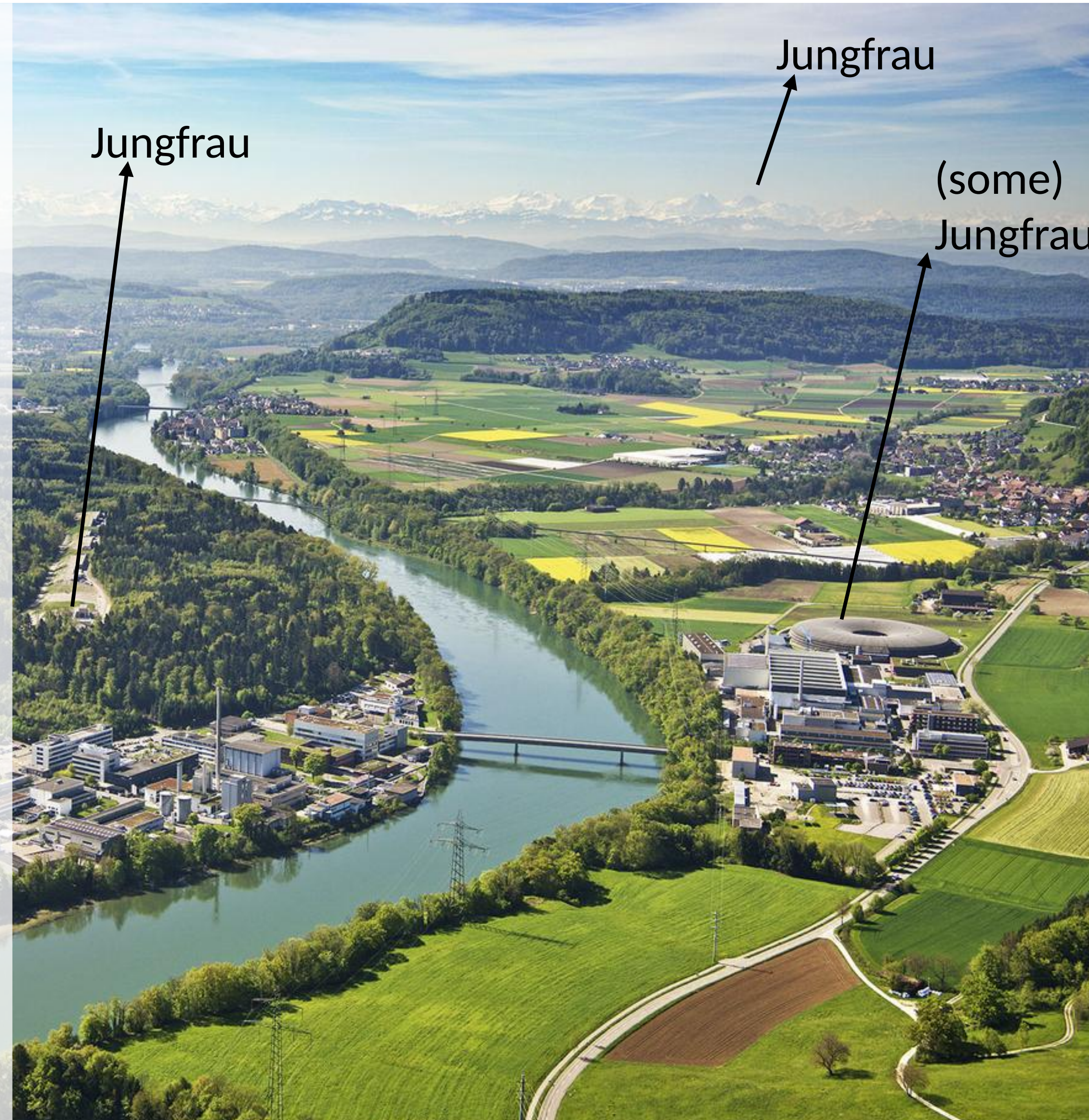


# Measuring with storage cells/pump and destroy



# Conclusions

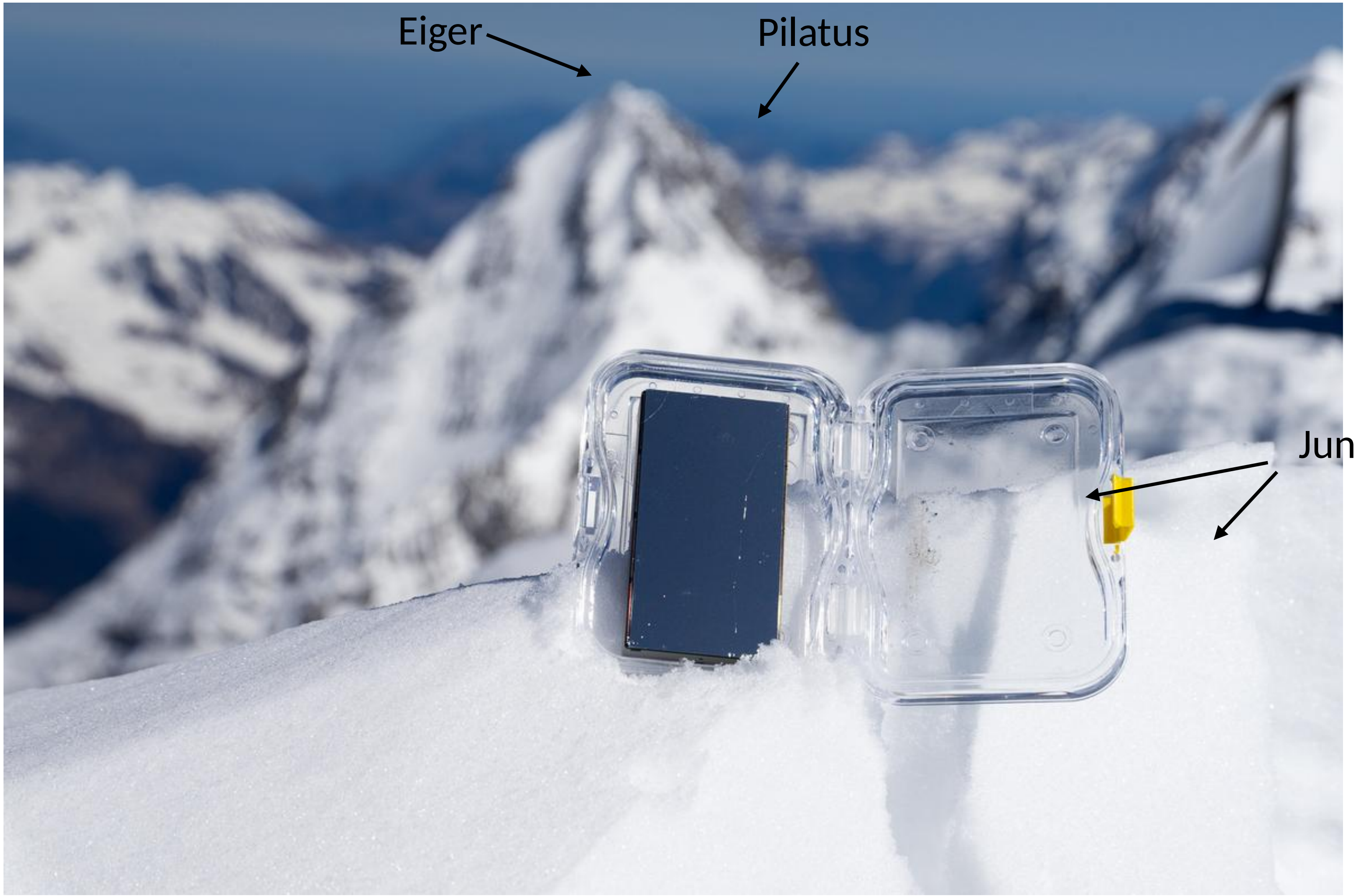
- 75um pixel detector developed for SwissFEL, with automatic gain switching
- Tilable design, 500k 8x4 cm² modules
- noise in high gain 50e.n.c.
- low noise on the full DR
- Data quality in FEL and Synch. pilot experiments looks good
- 4-4.5M cameras have been commissioned, 16M to be commissioned this summer



# Acknowledgements


Back: **Marie Ruat**, Bernd Schmitt, **Sophie Redford**, **Aldo Mozzanica**, Erik Fröjdh.
Middle: Jiaguo Zhang, **Carlos Lopez**, Marie Andrae, Rebecca Barten, **Martin Brueckner**, **Christian Ruder**, Dominic Greiffenberg, **Seraphin Vetter**.
Front: Xintian Shi, **Dhanya Thattil**, Gemma Tinti,  Anna Bergamaschi, Marco Ramilli, Roberto Dinapoli, Davide Mezza.
Not in pic:  Sabina Chiriotti

# Jungfrau on top of Jungfrau

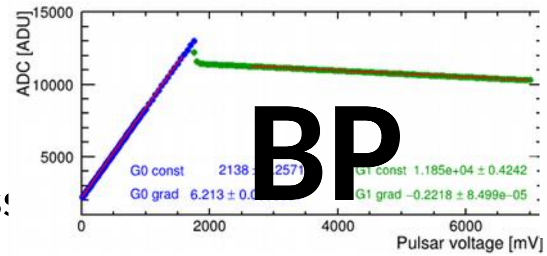


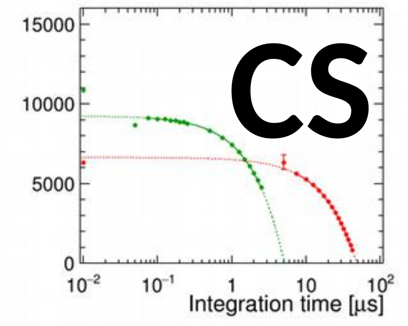
# Backup Slides

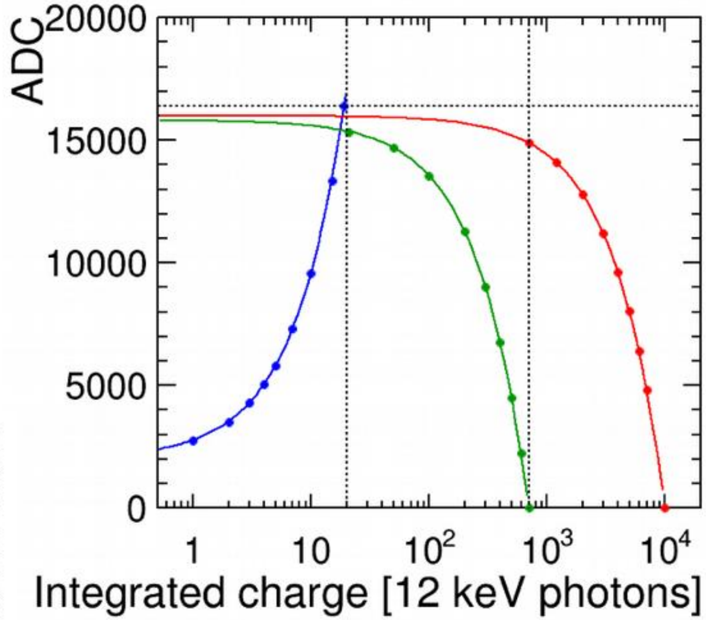
# JUNGFRAU calibration procedure(s)

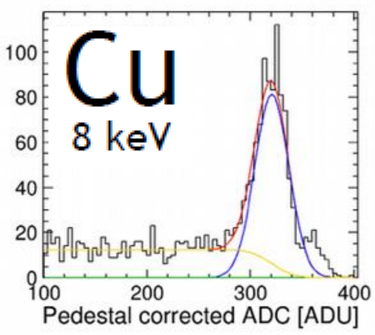
**Second version of calibration procedure established for JUNGFRAU**

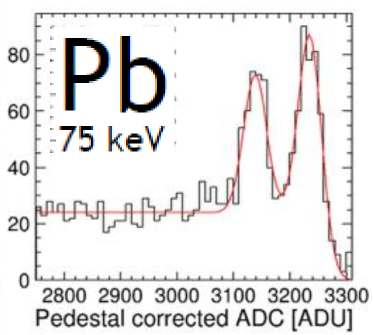
- Single or multi photon peaks for G0 (absolute)
- Backplane Pulsing (BG) for G1/G0 cros calib.
- Internal Current Source (CS) for G2/G1 cross calib.
- Calibration uncertainty <<1% for G0 and G1, order 1% for G2
- Validation of procedure on SLS and LCLS data ongoing

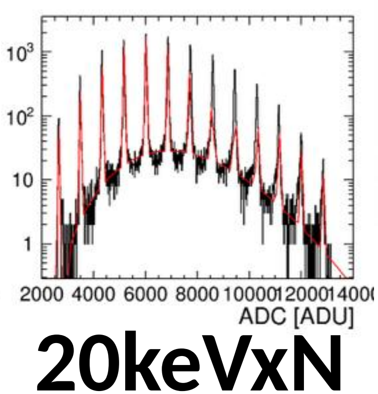


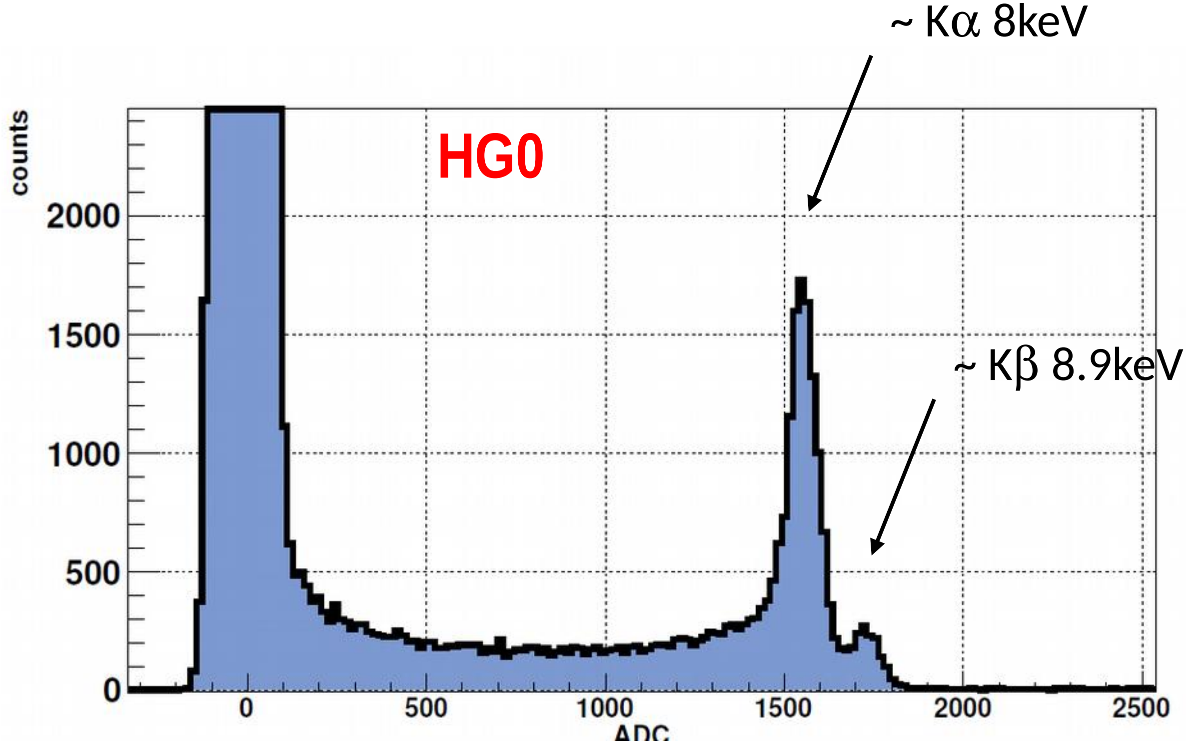



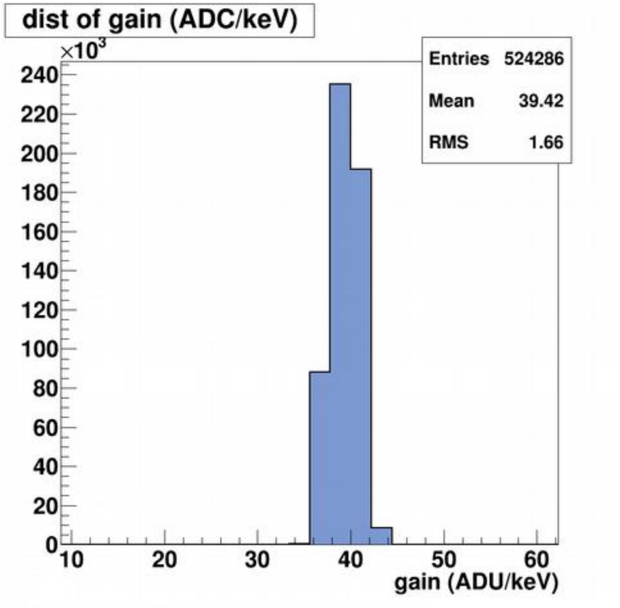
# Single photon measurements

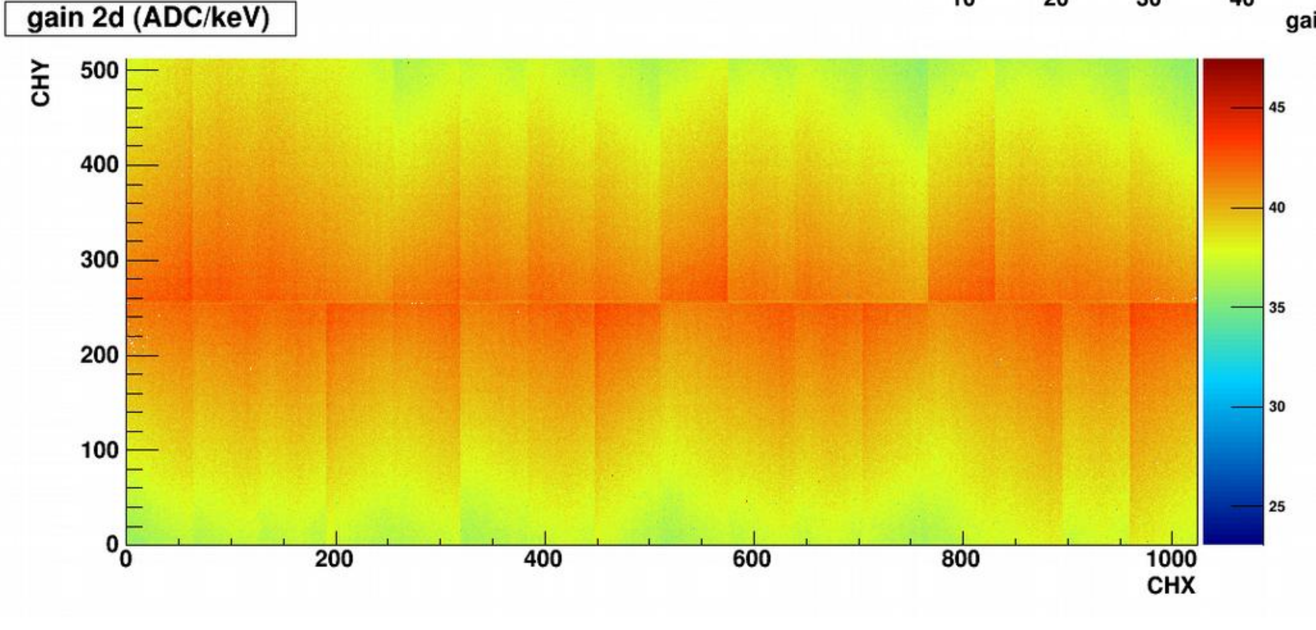
- X-Ray tube, W anode
- Cu Fluorescence target
- 10μs integration time
- **HG0**
- HV=200V
- Readout at 500-700Hz
  - limited by prototype firmware
  - 20MHz ASIC readout



# Gain map and distribution (G0)

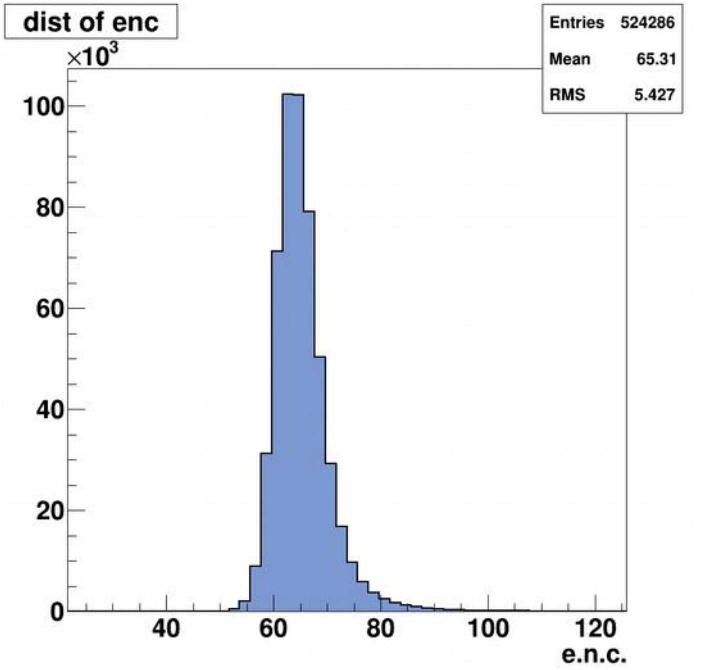
- for every pixel a Gaussian + charge sharing model function is fit to the P.H. data
- Gain is extracted as Gaussian peak position
- gain variation ~3.5% r.m.s.
- gain depends (slightly) on power distibution and on readout (ADC+buffers mismatch)

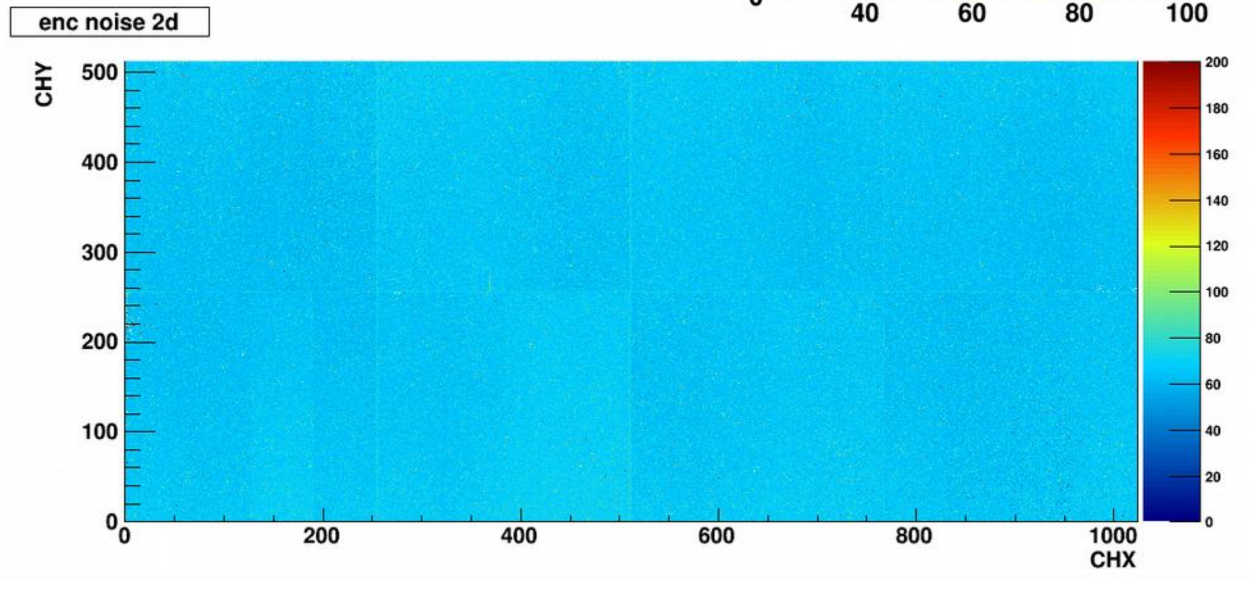


# Noise map and distribution (G0)

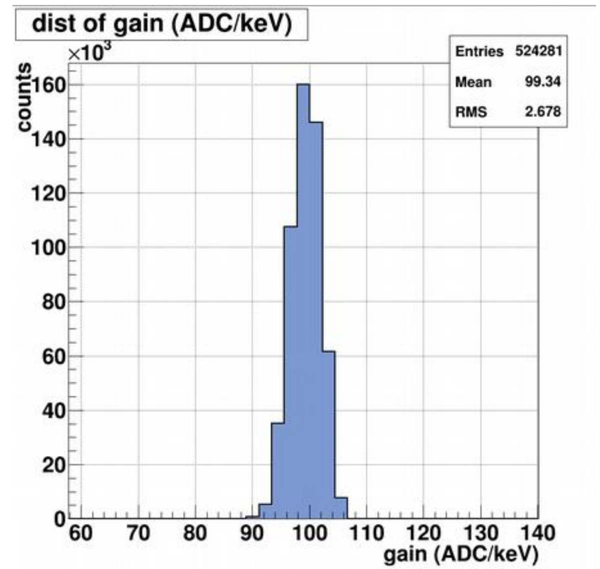
- Average noise of 65 electrons r.m.s.
- Noise map quite uniform
- Some tails in the noise distribution:
  - 1% pixels above 85e-
  - 0.1% pixels above 100e-

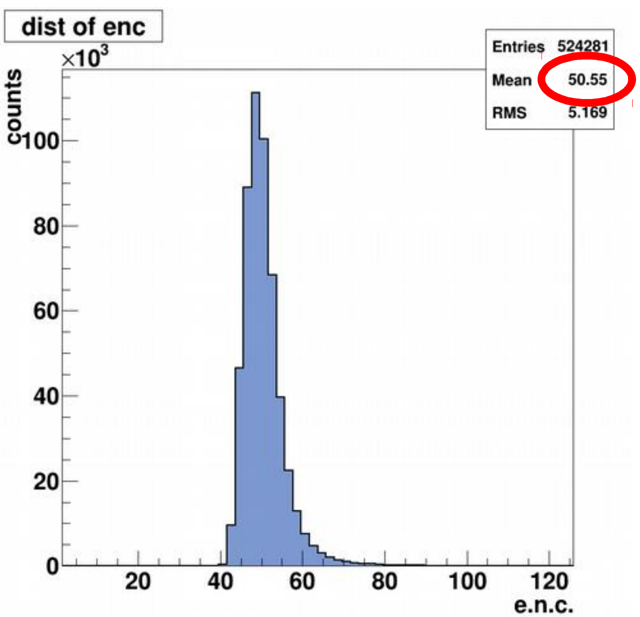


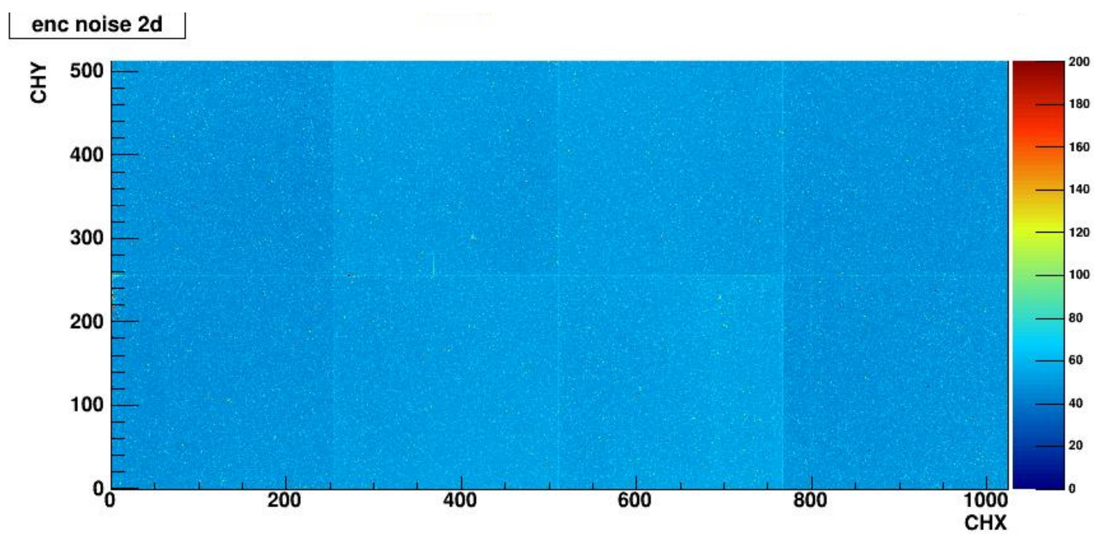



# Noise map and distribution (HG0)

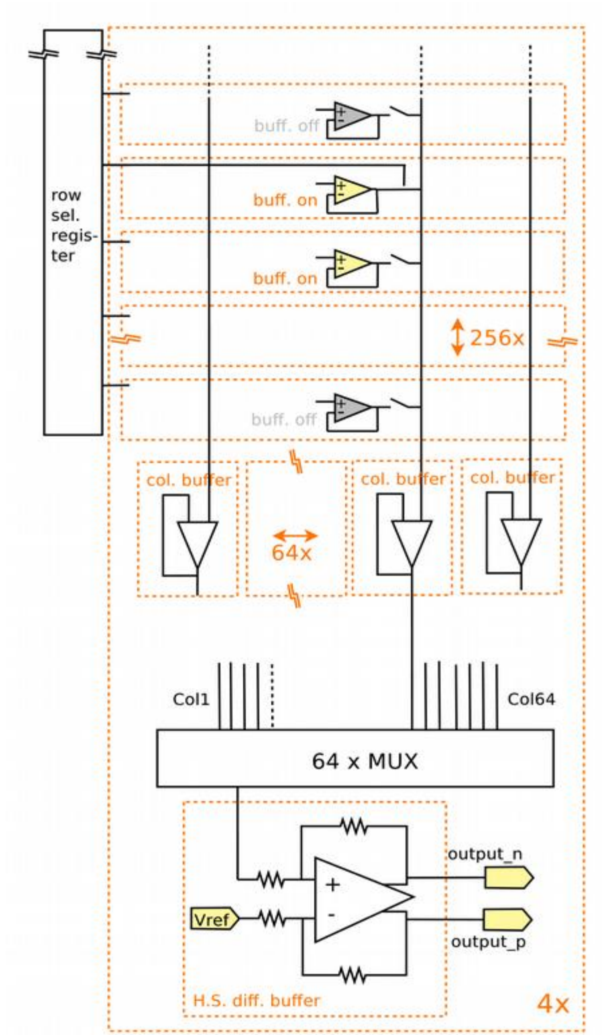
- In HG0 the gain is ~2x WRT G0
- Gain uniformity 2.7%
- Noise is 30% less
- Noise map uniform
- MPV < 50 e.n.c.

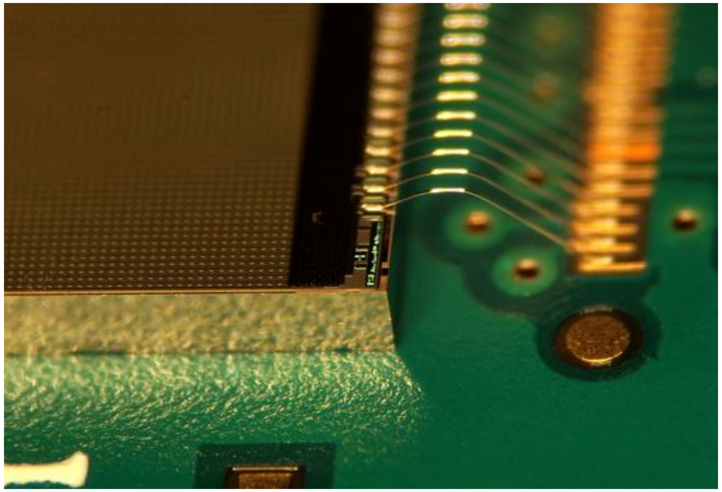


# The ASIC



- 256x 256 pixels
- >50M transistors
- designed for small inter-chip, inter-module gaps
- 19.2x19.7mm2
- Per row readout with bottom MUX (@ 40MHz max)
- 4 diff. analog output per chip (32 per module)
- Total readout time = 64x265/40=0.4ms
- Max frame rate 2.4 kHz (curr. FPGA FW: 1.12kHz)

# How low can we go in energy?

- PHOENIX beamiline
- in vacuum
- 2μs integration time
- **HG0**
- HV=300V
- Readout at  500Hz
- Beam energy 1.75keV (top) and 1.5keV (bottom)
  - 1.5 keV possible for FELs (short int. time)
  - 2-2.5 keV will be possible at synchrotrons (long int. time)