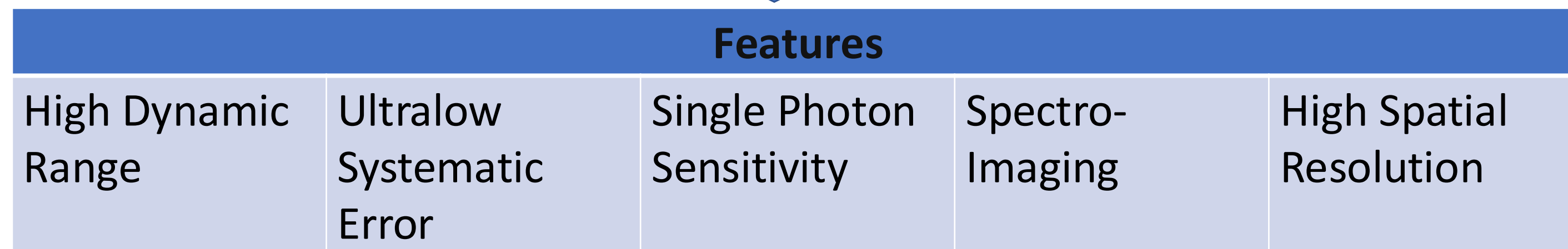
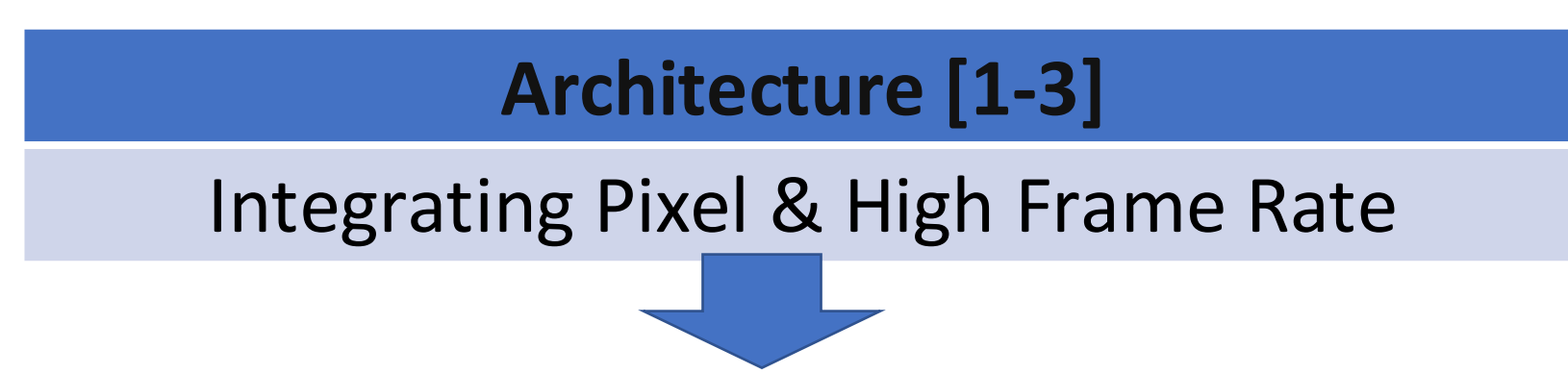


Abstract

We are developing a new X-ray imaging detector, the 20.2 Mpixel CITIUS, for Serial Femtosecond Crystallography (SFX) at the X-ray free electron laser (XFEL) facility, SACLA. With 20.2 million pixels, it will be the world's largest direct detector for XFEL. We aim to improve the spatial resolution of SFX with higher-Q measurements. The detector operates in the XFEL mode of CITIUS and runs at a maximum frame rate of 5 kHz. At SACLA, the detector runs at 960 frames per second, where 16 frames are recorded for each pulse at 60 Hz. This results in a noise floor of 25 e-rms, which is equivalent to 0.015 photons (rms) at 6 keV, while the detector's peak signal is 17,000 photons. The detector generates 107 GB/s of data. We have launched dedicated servers to record, calibrate, transfer, and compress the data. Data-framing boards (DFBs) in the servers reduce the data rate to 15 GB/s by accumulating frames. The detector was deployed in an experimental hutch at SACLA in April 2024. In the summer of 2024, we conducted the first beamtime of the 20.2 Mpixel CITIUS detector using XFEL beams. This poster presents the status of detector development and commissioning.

CITIUS detector

A new charge-integrating X-ray imaging detector, CITIUS, has been developed for high photon fluxes onto samples with upgraded synchrotron radiation facilities. The integration of CITIUS detectors into synchrotron radiation experiments is in progress at SPring-8. In parallel, we are also developing another larger version, the 20.2 Mpixel CITIUS, with high spatial resolution for Serial Femtosecond Crystallography (SFX) at SACLA. The 20.2 Mpixel CITIUS has the world's largest number of pixels as a direct X-ray detector for XFEL. In comparison with the current detector MPCCD (Phase-III) in operation, CITIUS-20.2M has a seven times higher peak signal, seven times smaller noise, and five times more pixels.



[1] SPring-8 II CDR (2014) with updated values.
[2] T. Hatsui, presented at iWorld (June, 2014).
[3] T. Hatsui, AOSFRR (Nov. 2015)

Specifications of CITIUS and MPCCD for SACLA

Parameters	Value		unit
	CITIUS for XFEL (SACLA)	MPCCD (Phase III)	
Sensor	Sensor Material	Silicon	N/A
	Thickness	650 $\times 2.1$	300 μm
	Pixel Size	72.6 $\times 1.5$	50 μm
	Pixel Number	0.28 $\times 0.6$	0.5 Mpixels/sensor module
	Peak Signal	17,000 $\times 7$	2,400 phs/pixel@6 keV
	Typical noise	25 $\times < 1/7$	250 e-rms
	Frame Rate	60*	60 Hz
System	Data Rate	1.6**	0.06 GB/s @ digital out
	Imaging area	321 \times 393	100 \times 100 mm ²
	Pixel Number	20.2 $\times 5$	4 Mpixels
	Data Rate	107* $\times 242$	0.48 GB/s @ digital out

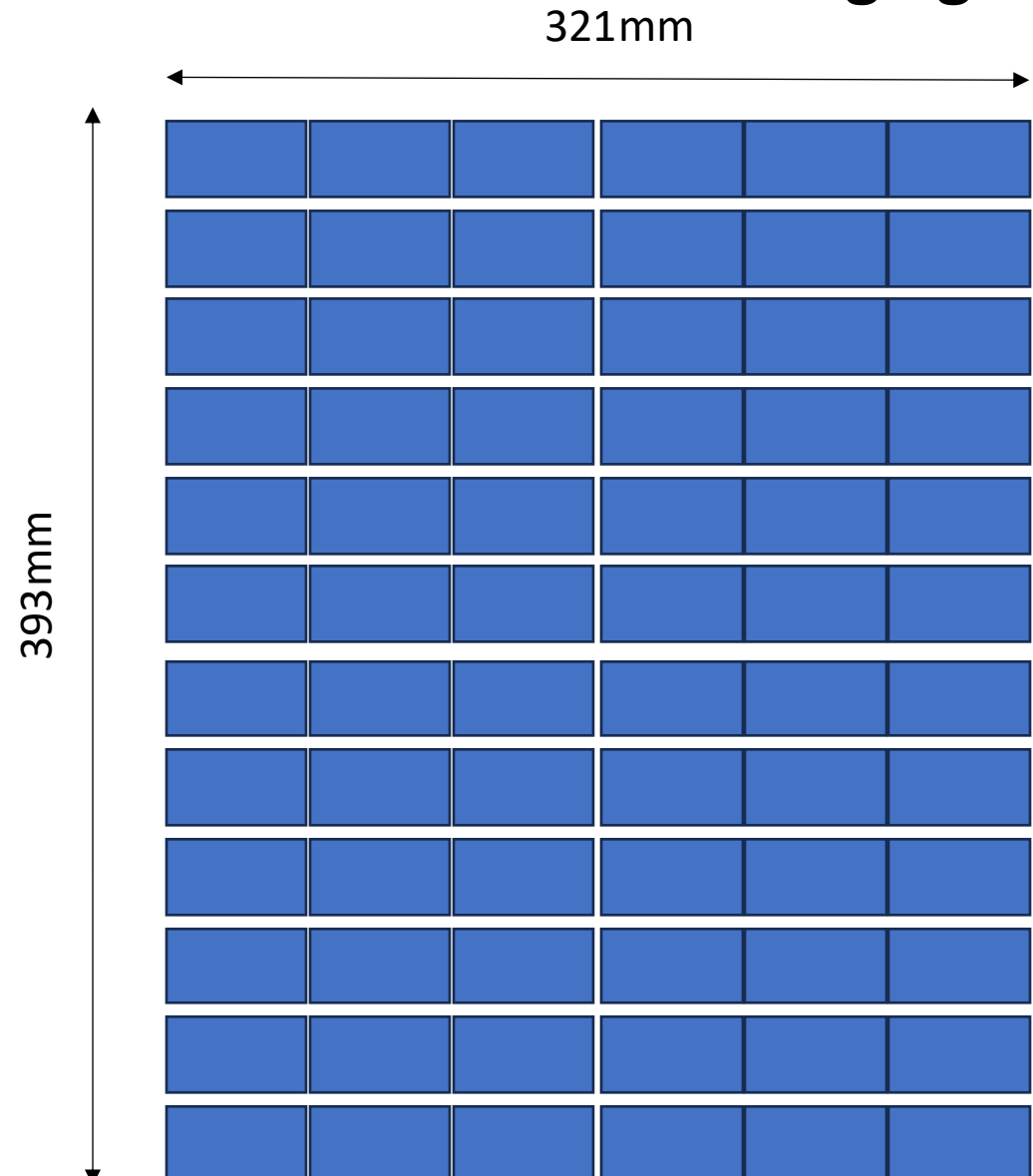
* The maximum frame rate of CITIUS (XFEL variant) is 5 kHz.

** The data rate of CITIUS is the total raw data rate from the sensor. Each frame data has 16 multi-AD sampled data.

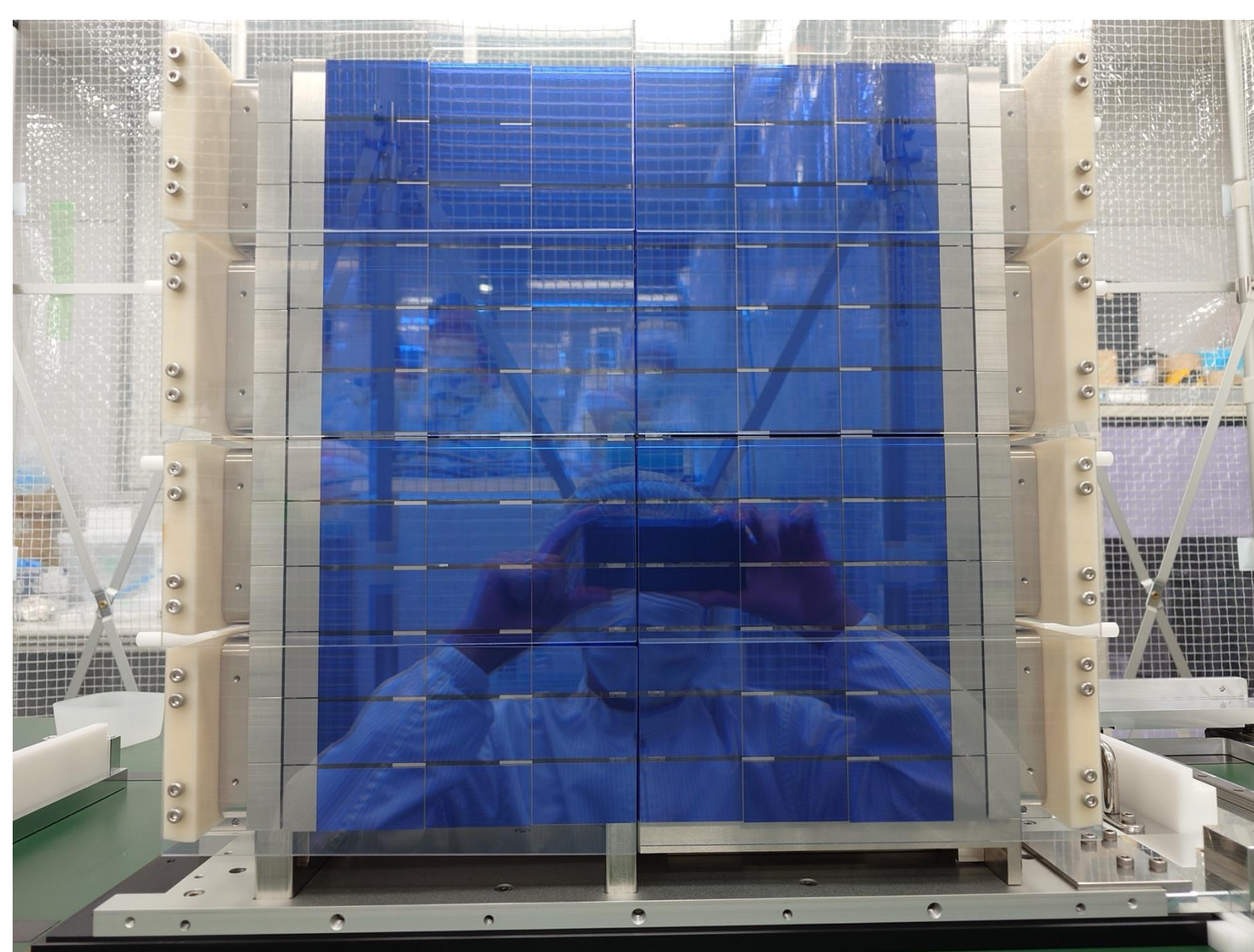
20.2 Mpixel detector

The CITIUS sensor module has 0.28 Mpixels (384 x 728 pixels) and an imaging area of 28 x 52 mm². The 20.2 Mpixel CITIUS was built by tiling 72 sensor modules, as illustrated in the figures and pictures below.

Schematic view of the imaging area

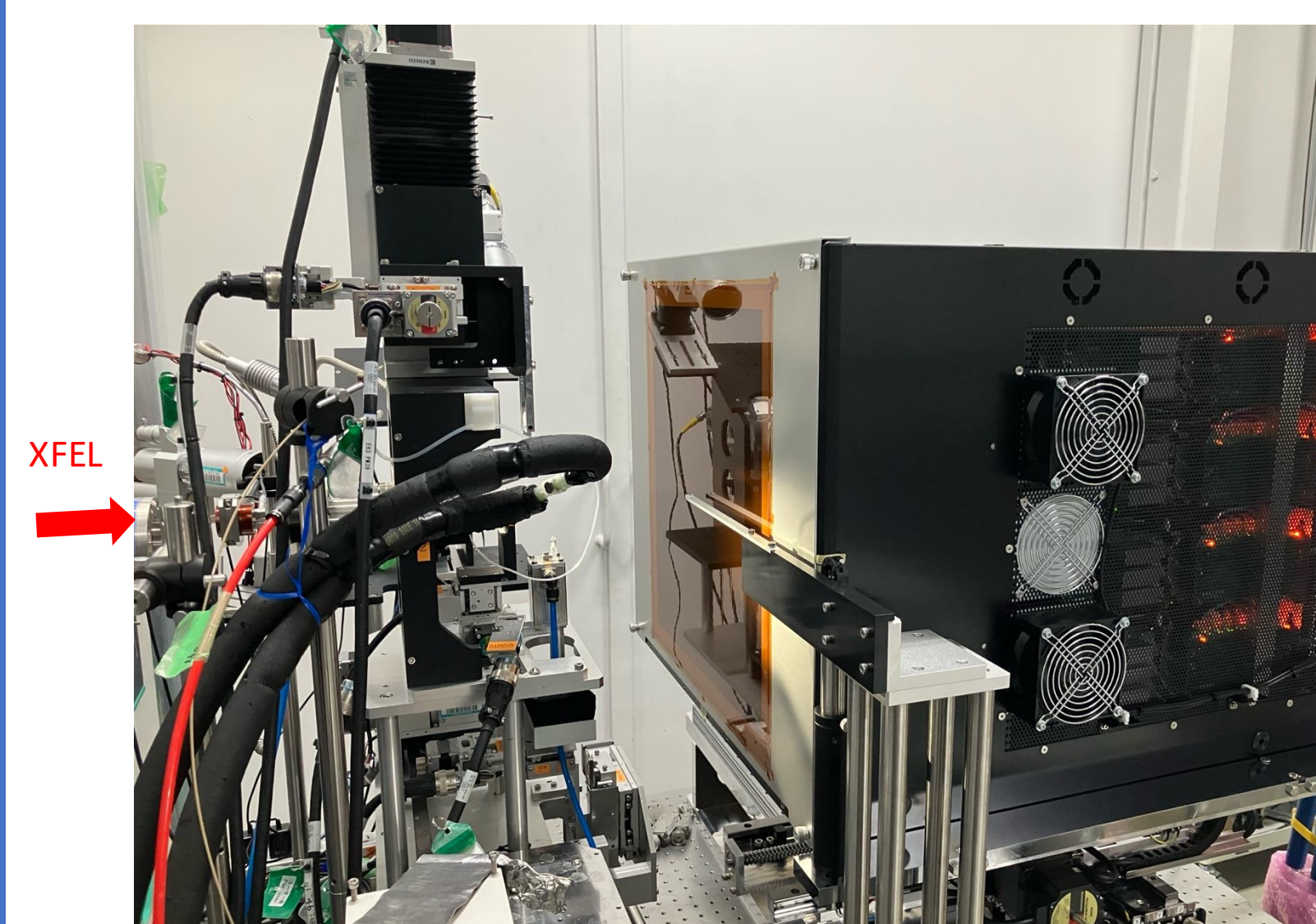


20.2 Mpixel with the fully assembled sensors



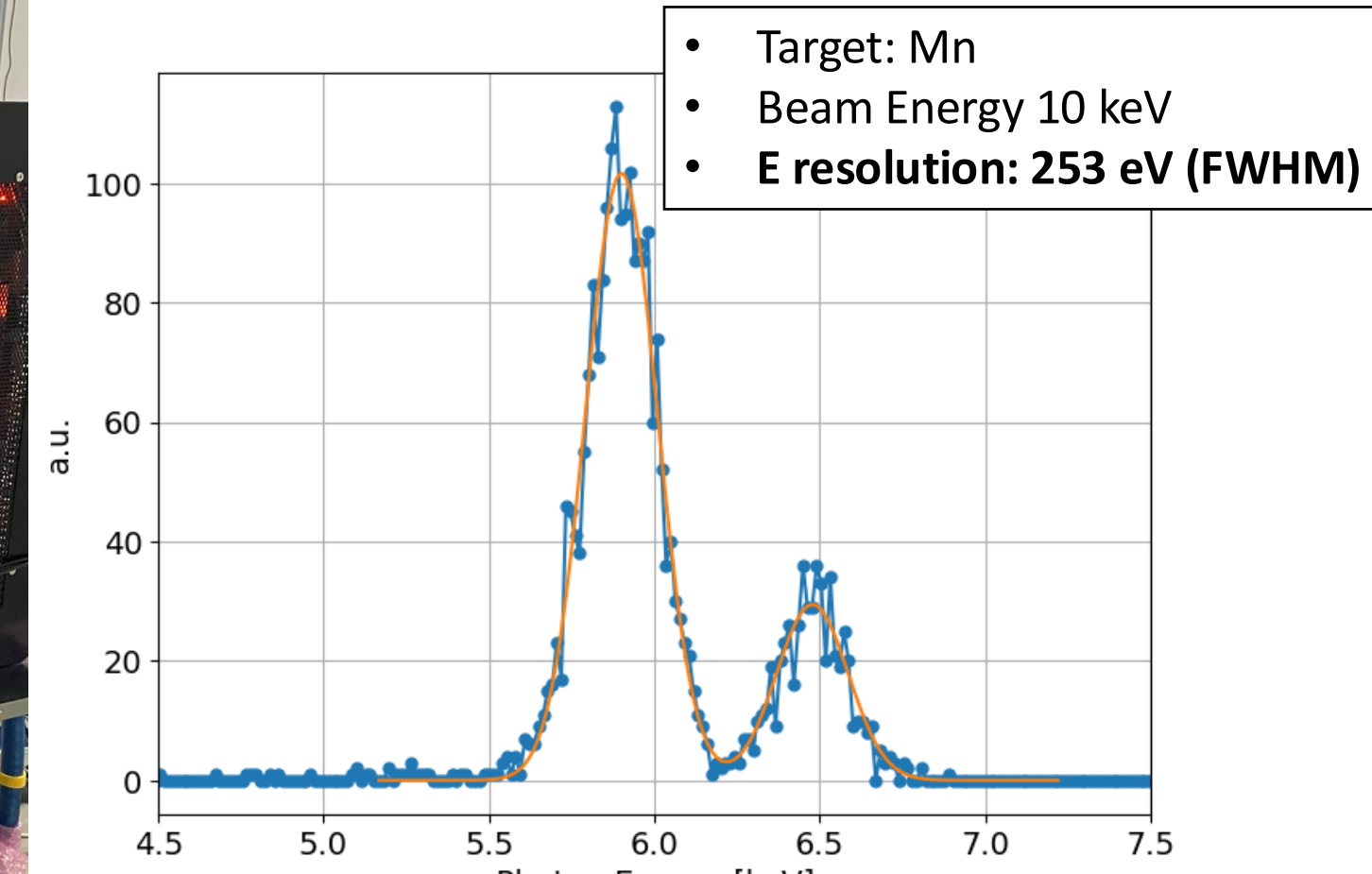
Commissioning at SACLA

20.2 Mpixel CITIUS at BL2EH3 of SACLA

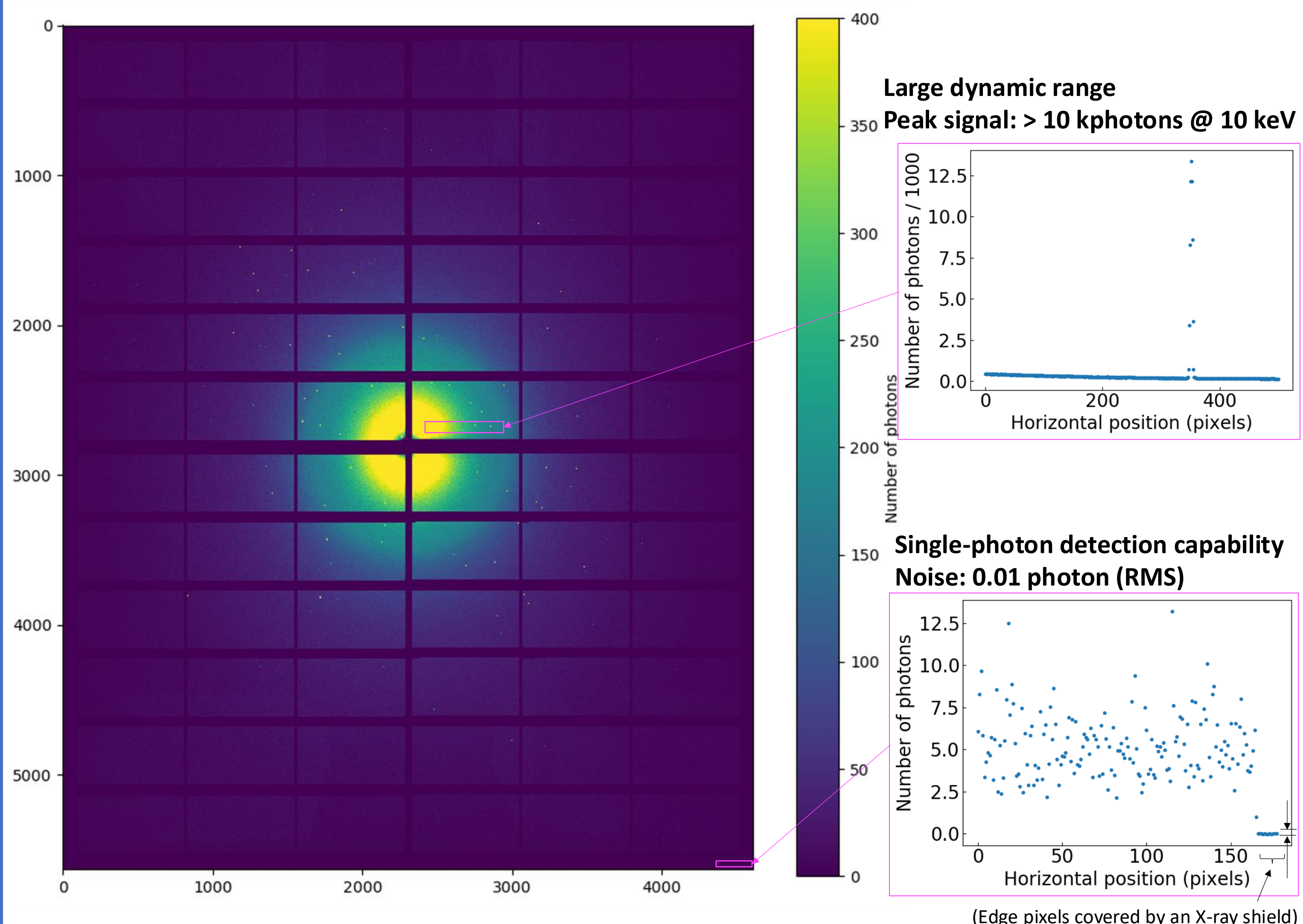


Energy resolution

- Noise level
 - Without AD multi-sampling: 40 e-rms
 - 16-frame multi-sampling for each pulse: 25 e-rms
- Target: Mn
- Beam Energy 10 keV
- E resolution: 253 eV (FWHM)

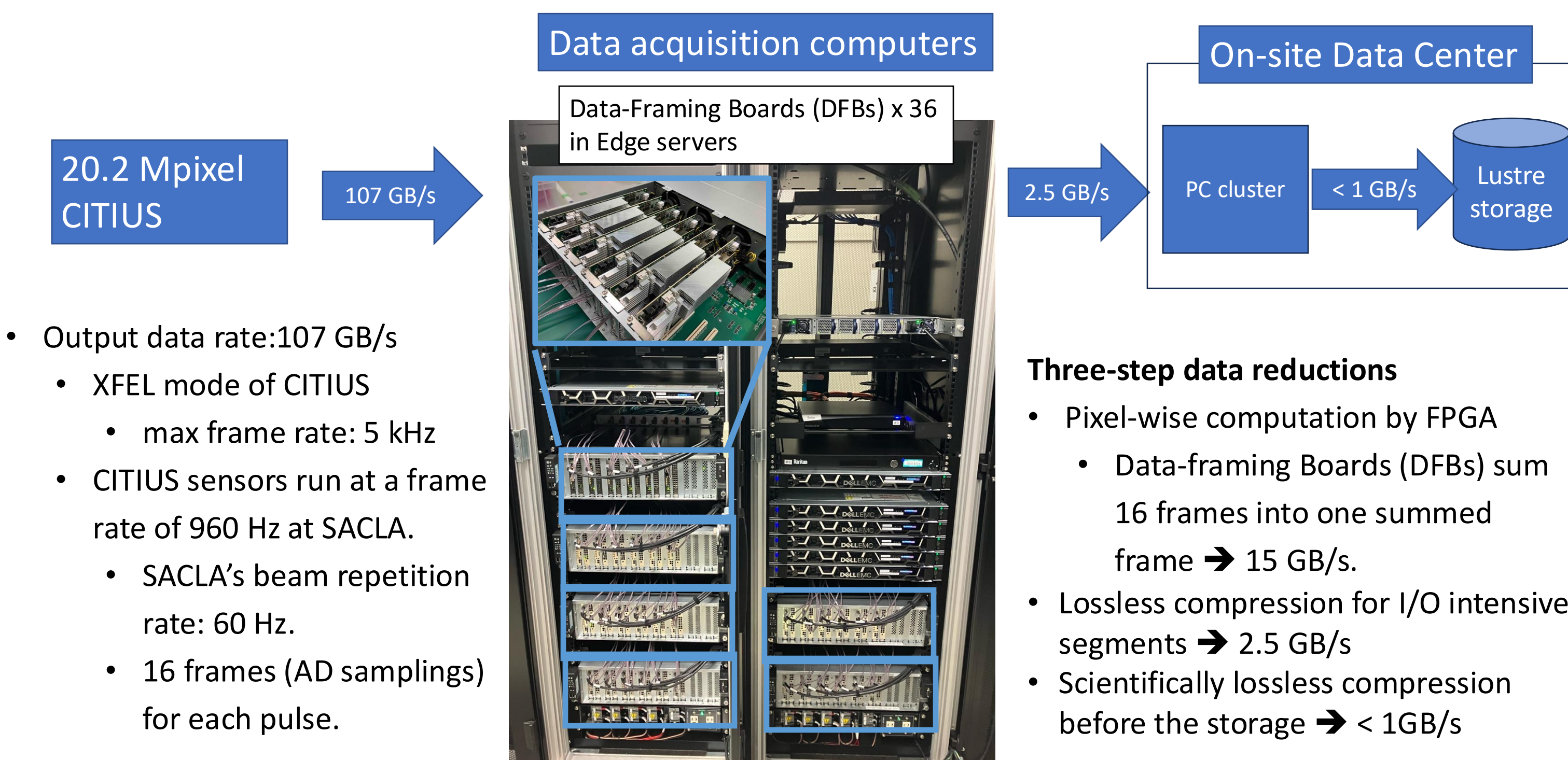


SFX with Lysozyme at 10 keV (single-shot image)



Data acquisition and reduction

The 20.2 Mpixel CITIUS generates orders of magnitude more data than the data rate of MPCCD. This amount requires dedicated computers for data acquisition and data reduction. The new computing system along with the on-site data center reduces the data rate to lower than 1 GB/s. The computing system have started running in the server room of SACLA since January 2024.



Summary

- The 20.2 Mpixel CITIUS is the world's largest direct X-ray detector developed with high spatial resolution of SFX at SACLA.
- The successful DAQ integration to the Run Control of SACLA, the lower noise, and higher dynamic range have been confirmed by the feasibility studies.
- In July 2024, we conducted the first beamtime of 20.2 Mpixel CITIUS and took the first SFX data with standard samples.
- After the verifications through test experiments, the detector will be provided for users' experiments.

Acknowledgements

We would like to thank the following team members and companies for their supports with the detector developments and the experiments.

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