Overview of detectors at SACLA and introduction of new detectors under development

T. Kameshima & T. Hatsui

On behalf of SACLA detector team

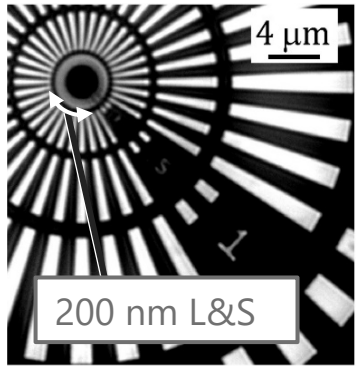
Outlines

- New detectors to be deployed
  - New variants of KamCam
  - CITIUS
- Summary and discussion points from facility point of view

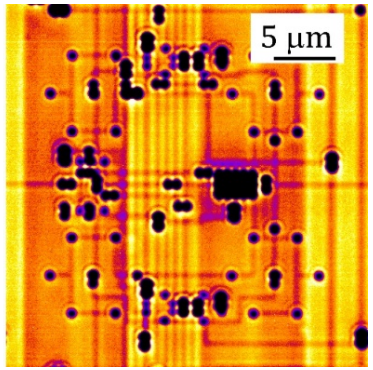
Details will be presented at Poster #9

KamCam: high spatial resolution X-ray detector

Resolving power



X-ray transmission image of test chart



X-ray transmission image of VLSI

- Indirect lens-coupled detector
- 200 nm L&S resolution achieved
- Field of view was limited to 0.13 mm x 0.13 mm
- So far about 10 detector systems are deployed at SPring-8/SACLA mainly for the beam characterization

T. Kameshima, Optics Letters Vol. 44, Issue 6, pp. 1403 (2019)

New Variants Deployment candidates

In combination with a state-of-art CMOS image sensor, the following combination are now achievable.
CMOS image sensor spec. 14,192 x 10,640 pixels, 16 bit depth

		Custom lens	Commercial off-the-shelf lenses			
L&S resolution	**[nm]**	~200	450	600	1000	1900
Field of view	**[mm^2]**	2.6 x 1.9	7.6 x 5.7	10.3 x 7.7	15.2 x 11.4	53.3x 40.0
Conversion	**[e-/X-ray]**	10.6 @ 10 keV	1.98 @ 10 keV	1.21 @ 10 keV	0.78 @ 20 keV	0.33 @ 30 keV
DQE	**[%]**	15 @ 10 keV	42 @ 10 keV	44 @ 10 keV	31 @ 20 keV	21 @ 30 keV

Outlines

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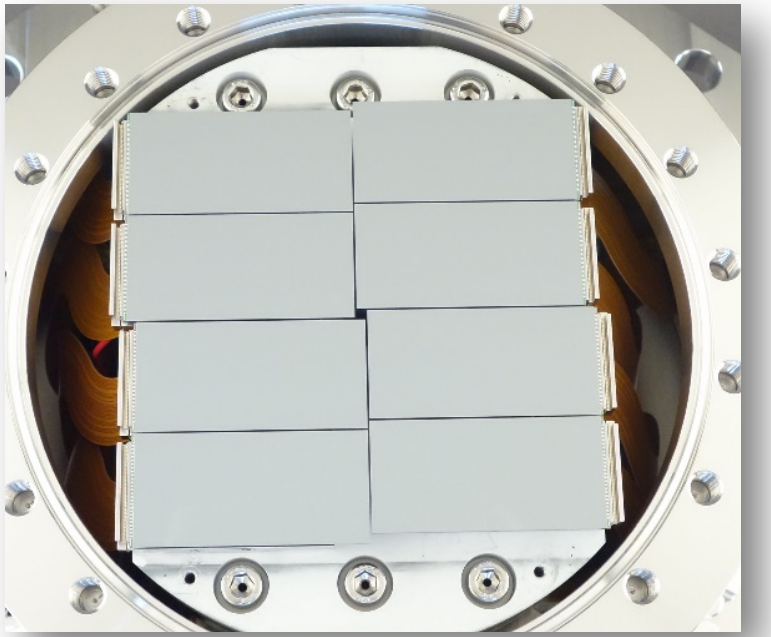
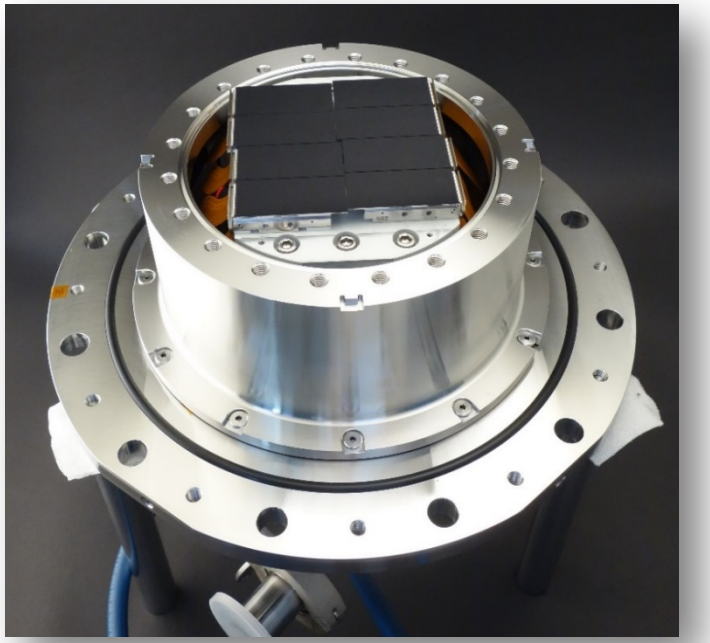
  - New variants of KamCam
  - CITIUS
- Summary and discussion points from facility point of view

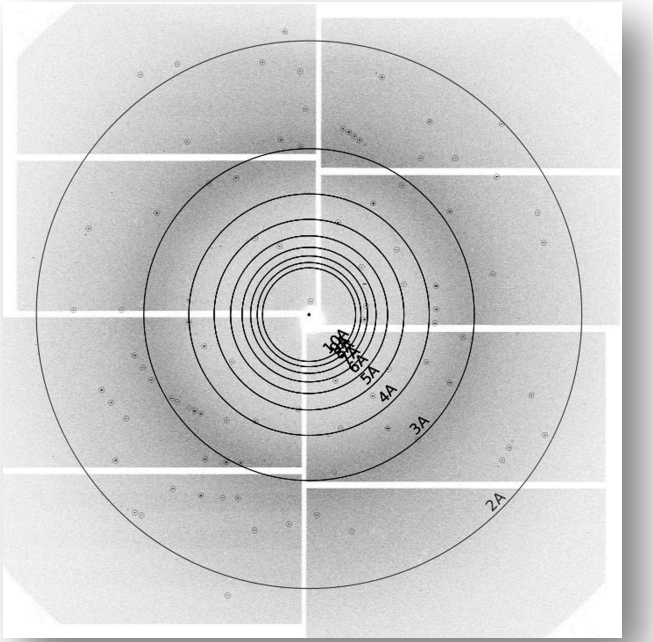
MPCCD at a glance

Kameshima et al., Rev. Sci. Instrum. 85, 033110 (2014)

4 Mpixel system







C. Song, et.al., J. Appl. Cryst. (2014). 47, 188–197.

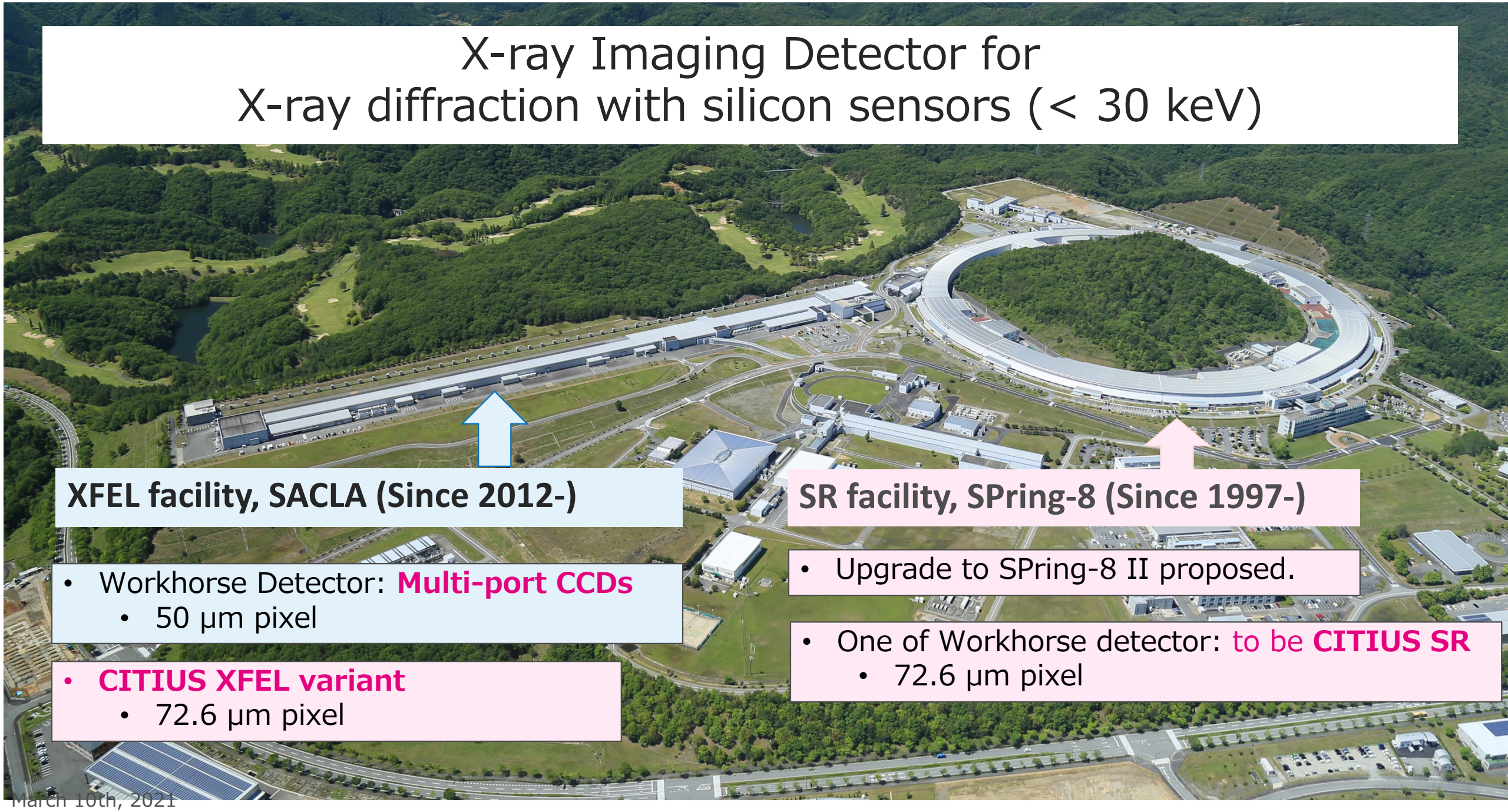
1st XFEL detector with 50 μm□ pixel

Currently, 38 systems, 118 sensors, 59 Mpixels are deployed* since March 2012.

After 9 years of operation, the performance is not at the forefront of XFEL detectors.

*) as of Oct. 2020

X-ray Imaging Detector for X-ray diffraction with silicon sensors (< 30 keV)



XFEL facility, SACLA (Since 2012-)

- Workhorse Detector: **Multi-port CCDs**
  - 50 μm pixel
- **CITIUS XFEL variant**
  - 72.6 μm pixel

SR facility, SPring-8 (Since 1997-)

- Upgrade to SPring-8 II proposed.
- One of Workhorse detector: to be **CITIUS SR**
  - 72.6 μm pixel

CITIUS development History

- April 2013
  - Technical investigation started
- 2014
  - Basic concept and target performance reported in SPring-8-II CDR
- 2015
  - Sony and RIKEN agreed on the development
- March 2016
  - Project Schedule finalized
  - First X-ray Image capture scheduled on June 2020
- Sep. 9th, 2020
  - First Optical Image capture
  - System evaluation started
- Oct. 2nd, 2020
  - First X-ray Image capture
  - Delayed by 3.5 months

On-site collaborators happy with
their first X-ray image taken at Sep. 9th, 2020

CITIUS Detector

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

Architecture [1-3]

Integrating Pixel & High Frame Rate

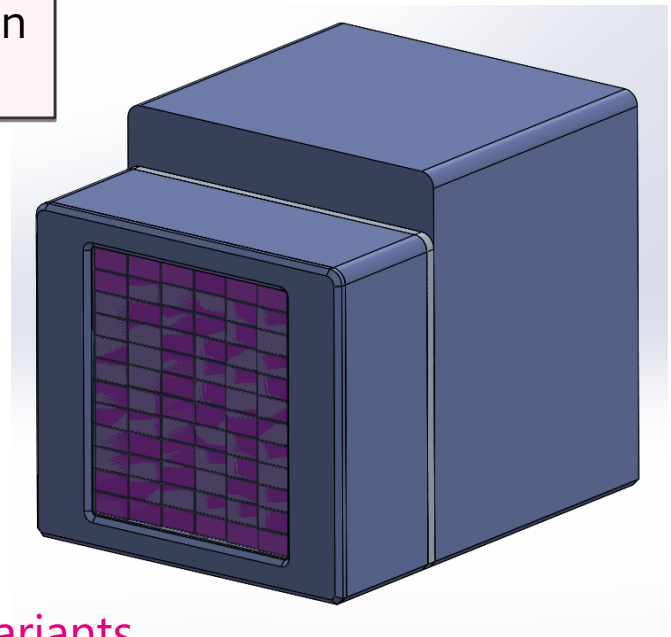
Feature

High Dynamic Range	Ultralow Systematic Error	Spectro-Imaging	High Spatial Resolution	Single Photon Sensitivity

Detector Performance

Parameters		Value	
Sensor	Thickness	650 μm	
	Pixel Size	72.6 μm	
	Pixel Number	0.28 Mpixel/sensor	
	Noise	0.027 phs.@8 keV (60 e-)	
	Peak Signal	1,800 phs. @ 12 keV	17,000 phs. @ 6 keV
	Frame Rate	17.4 kHz	5 kHz
	Sat. Count Rate @12 keV	30 and 600 Mcps	-
Largest System	Pixel Number	20.2 Mpixel	
	Image Area	325 x 363 mm	

XFEL variants

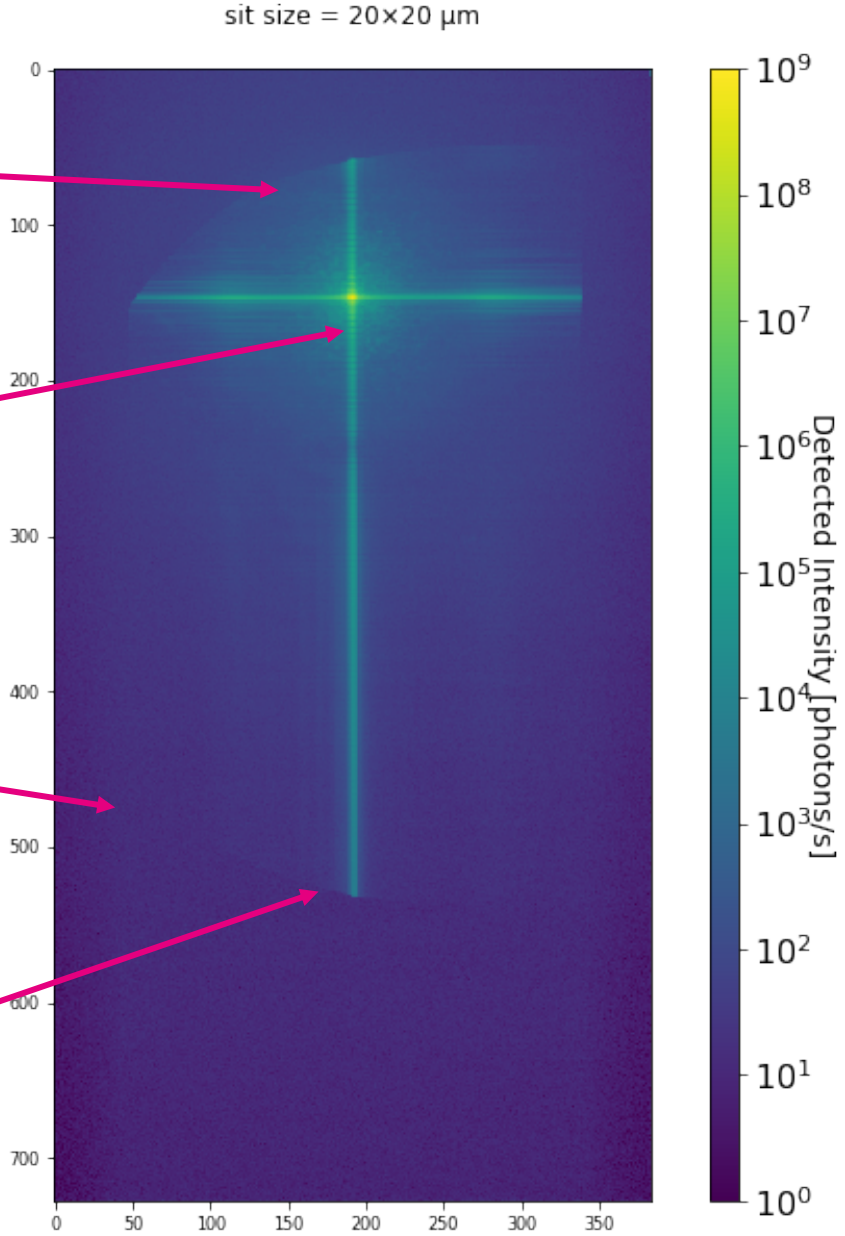


All the performance was verified with a 280k detector

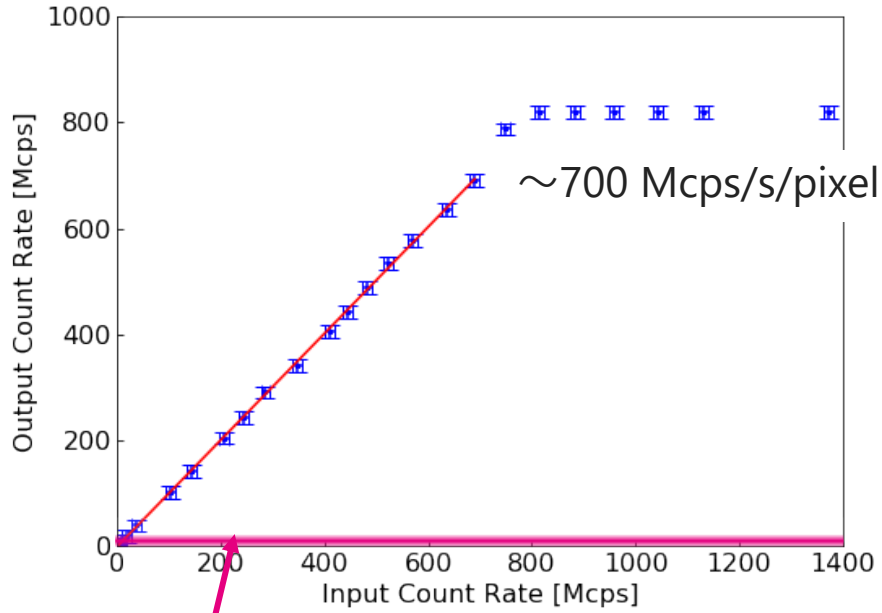
CITIUS SR variant

Direct beam through 20 μm□ slit at SPring-8 BL29XU

Y. Honjo, K. Ozaki, et.al.,



Date = 2020.11.24~26
SPring-8 , BL29XU (undulator beamline)
Photon Energy = 10keV
Slit to CITIUS distance = 15m
Slit 20×20μm



x100-x1000 improvement

Photon Counting detector limit

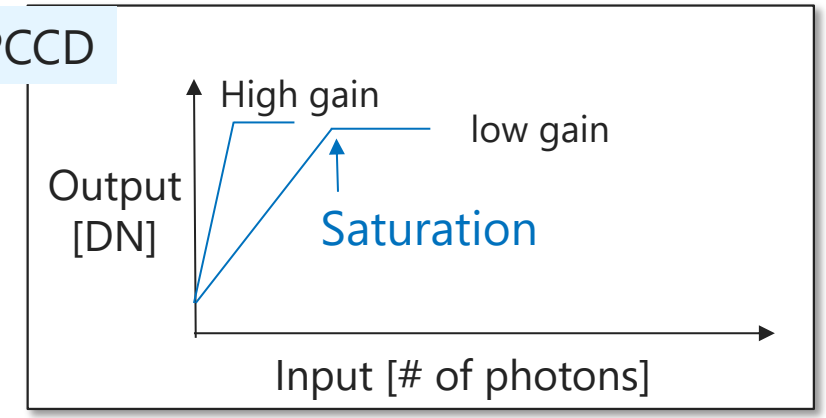
CITIUS XFEL variant

Parameters		Value: CITIUS XFEL for SACLA		Value: MPCCD Phase III/III-L	Unit
Sensor	Thickness	650	← x2.1	300	μm
	Pixel Size	72.6 μm	← x1.5	50	μm
	Pixel Number	0.28	← x0.6	0.5	Mpixel/sensor
	Image Format	384 x 728		512 x 1024	pixels
	Noise	60 e- or better		300/60	e-rms
	Peak Signal	17,000	← x7	2,400	Phs.@ 6 keV
	Frame Rate	60 (max. 5 kHz)		60 or 30 Hz	
Largest System	Pixel Number	20.2 Mpixel	← x5	4	Mpixel
	Image Area	325 x 363		100 x 100	mm^2
Tiling	Inter-module gap	~ 3 mm	← x3	< 1 mm	

As facility need to be ready for high repetition operation in long term, MPCCD need to be replaced by CITIUS. However, not all the spec. will be better.

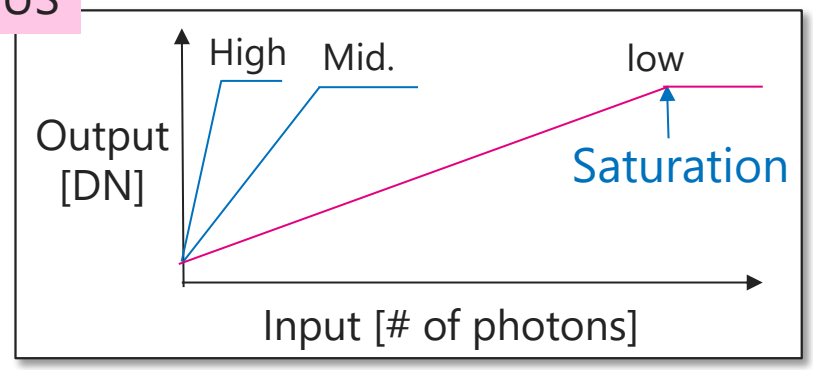
Architecture from Calibration point of view

MPCCD



Technology: CCD
On-chip Amplifiers: 8 ports / 0.5 Mpixels
Analog-to-Digital Conversion: 2 conv./pixel
Calibration: port wise

CITIUS



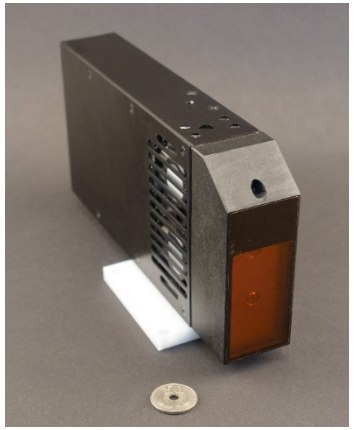
Technology: advanced CMOS image sensor
On-chip Amplifiers: 3 / pixel
Analog-to-Digital Conversion: 3 conv./pixel
Calibration: pixel wise

We are developing a calibration tools so that we do not ask users to calibrate detectors by themselves.

We adopt a scheme similar to MPCCD, i.e., simultaneous digitization for all the gains. This scheme minimizes artifacts such as non-local cross-talks and anomalous behavior at switching point (at the expense of the frame rate). However, in the initial deployment phase, we may see artifacts and we need to have good communications with users.

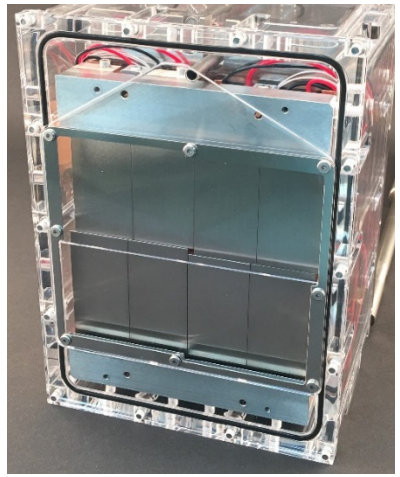
CITIUS: Camera Head Variants (under development)

280k Compact

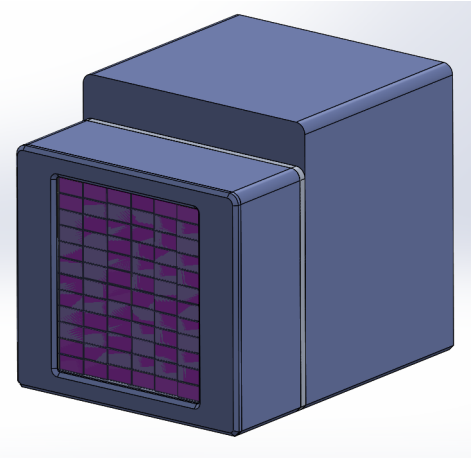


36 x 96 x 197 mm^3
～1 kg
Fan-less operation is possible.

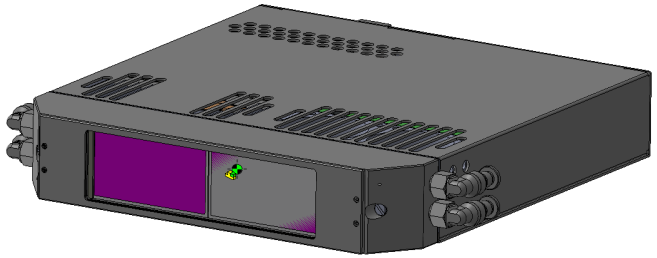
2.2M standard



20.2M standard



560k (Linear) Compact



SACLA goes to higher repetition operation in long term, MPCCD need to be replaced by CITIUS.
However,

- not all the spec. will be better.
- replacement demands significant budget and internal resources.

We would like to have user comments, especially, on

- Deployment Priority to CITIUS detector
- MPCCD detector not replaceable by CITIUS

We are finalizing deployment plan for FY2022-2023 by the end of April 2021.

Summary and discussion points from facility point of view

- KamCam
  - Under development
  - Custom DAQ need to be implemented.
  - Please get in touch with BL scientist if you are interested in.

- CITIUS
  - Developed for SPring-8-II, and reach > 600 Mcps/pixel
  - For SACLA, it has better performance than MPCCD, but not all the spec.
  - In the long term, MPCCD will be replaced to CITIUS.
    - Replacement demands significant budget and resources.
  - In the initial deployment phase, we may see artifacts and we need to have good communications with users.
  - We are finalizing deployment plan for FY2022-2023 by the end of April 2021.
    - We would like to have user comments, especially, on
      - Deployment Priority to CITIUS detector
      - MPCCD detector not replaceable by CITIUS