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STARLIGHT

A kilohertz Hybrid Pixel Array Detector for SHINE with Charge Integrating Readout

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On Behalf of the STARLIGHT Collaboration

2026.10.14

Outline

- SHINE Facility
- PAD requirements of SHINE
- STARLIGHT R&D
- Summary

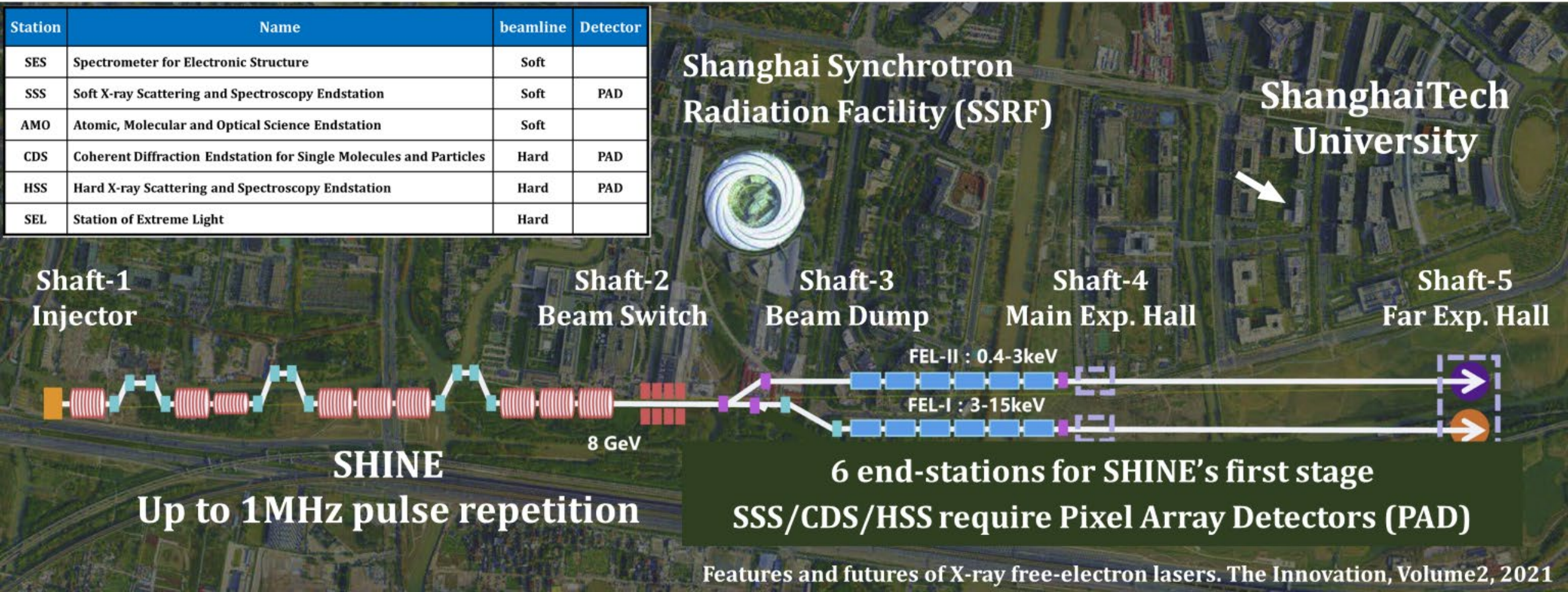
SHINE : Shanghai HIgh repetitioN rate XFEL and Extreme light facility

High repetition rate ~ 1MHz, CW. High brilliance ~ 10^{12}ph./pulse. Short pulse width ~ 100fs. Strong coherence

8 GeV SC Linac. 1 soft XFEL, 1 hard XFEL, 6 Stations. 50-100 PW Ultra-Intense Ultra-Short laser

Tunnels 29m underground, 3.1 km Length

Station	Name	beamline	Detector
SES	Spectrometer for Electronic Structure	Soft	
SSS	Soft X-ray Scattering and Spectroscopy Endstation	Soft	PAD
AMO	Atomic, Molecular and Optical Science Endstation	Soft	
CDS	Coherent Diffraction Endstation for Single Molecules and Particles	Hard	PAD
HSS	Hard X-ray Scattering and Spectroscopy Endstation	Hard	PAD
SEL	Station of Extreme Light	Hard	



Features and futures of X-ray free-electron lasers. The Innovation, Volume2, 2021

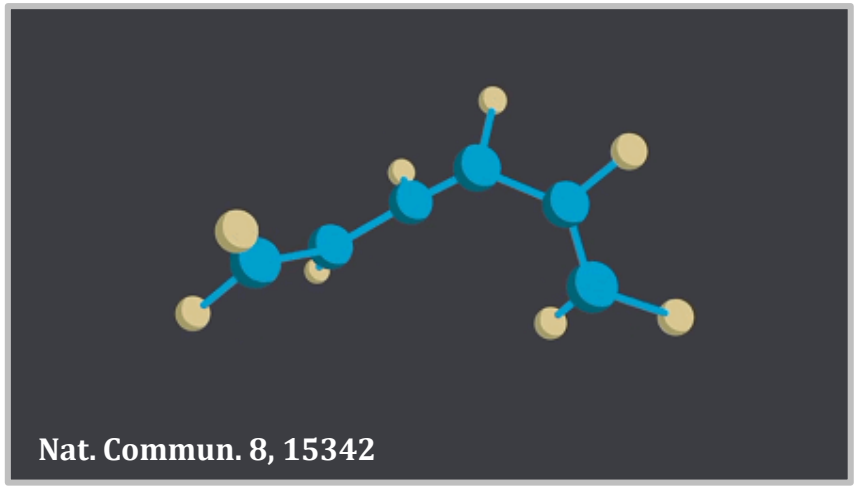
Challenge @ SHINE： requirements for Pixel Array Detector (PAD)

CDI (Coherent Diffraction Imaging)、Pump Probe、Serial crystallography (SFX) ……

Diffraction before Destruction



Molecular photos → Molecular movies

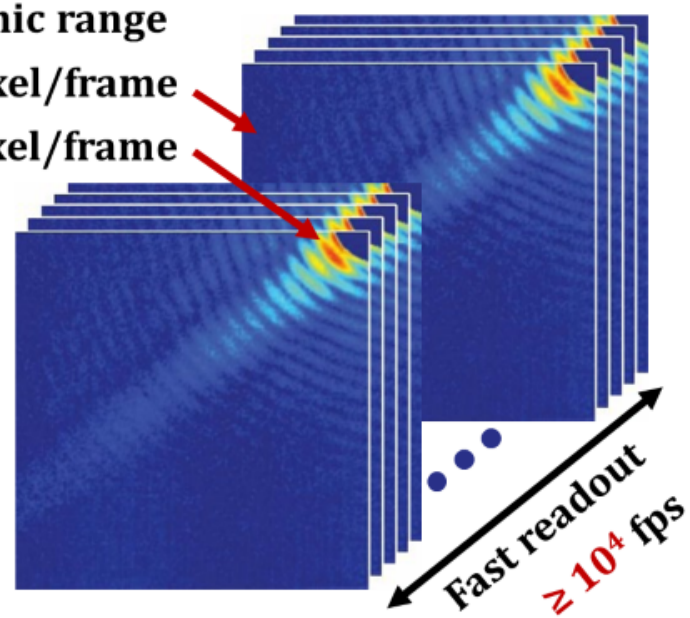


Requirements of CDI

Large dynamic range

0, 1 ph./pixel/frame

≥ 10^4 ph./pixel/frame



Small Pixels： ≤ 150 μm × 150 μm

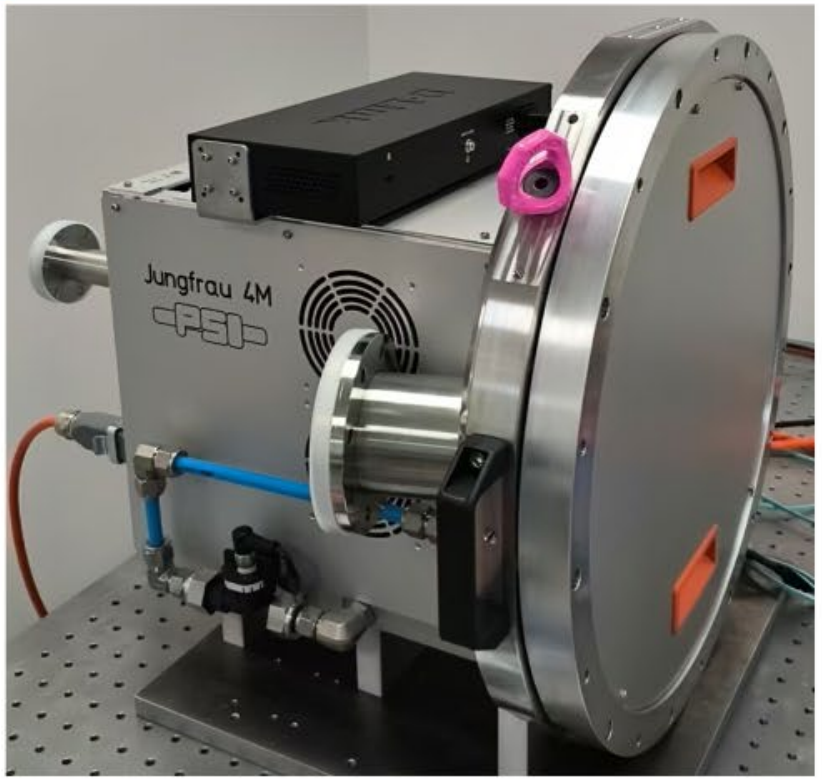
Large size： ≥20cm×20cm, ≥ 4M Pixels

Big data： ~ 30TB @ 1h、4M Pixels、1kHz

PADs for SHINE : JUNGFRAU, STARLIGHT

Facility	PAD	Pixel Size (μm)	ENC (e^-)	Dynamic Range (ph./Pixel/Pulse)	Frame Rate (Hz)
LCLS	CSPAD	110	~ 330	2.5k @ 8keV	120
SACLA	MPCCD	50	~ 250	2.5k @ 6keV	60
	SOPHIAS	30	~ 180	1.14k @ 6keV	60
	CITIUS	72.6	~60	1800 @ 12keV	5k
European XFEL	AGIPD	200	~ 265	10k @ 12keV	4.5M
	DSSC	200	< 50	6k @ 1keV	4.5M
	LPD	500	~ 1000	100k @ 12keV	4.5M
SwissFEL	JUNGFRAU	75	~ 65	10k @ 12keV	2.4k
LCLS-II	ePix100	50	< 60	100 @ 8keV	2k
	ePix10k	100	~ 120	10k @ 8keV	5k
SHINE	STARLIGHT	100	~ 180	10k @ 12keV	10k

JF 4M for SHINE-CDS



JF 0.5M for HSS

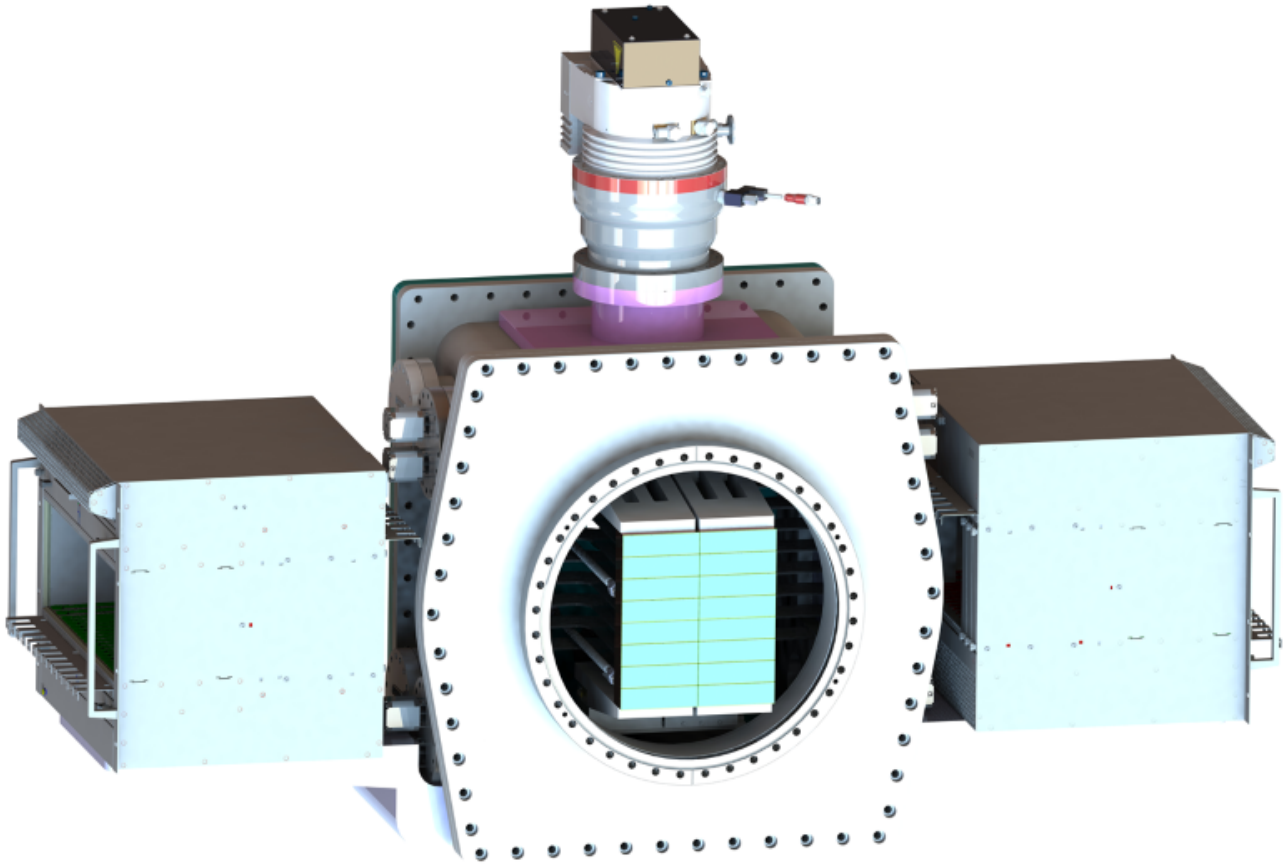


- Regular Photon Counting PADs (PC-PAD) cannot be used for XFEL because of the pulse photons.
- Only Charge Integrating PADs (CI-PAD) can be used for XFEL.
- JUNGFRAU (JF) has been chosen as the basic PAD of SHINE.
- A new PAD called STARLIGHT (SL) is developed for the faster frame readout requirements of SHINE.

STARLIGHT : PAD R&D for SHINE

STARLIGHT* : *SemiconducTor Array detectoR with Large dynamIc ranGe and cHarge inTegrating readout

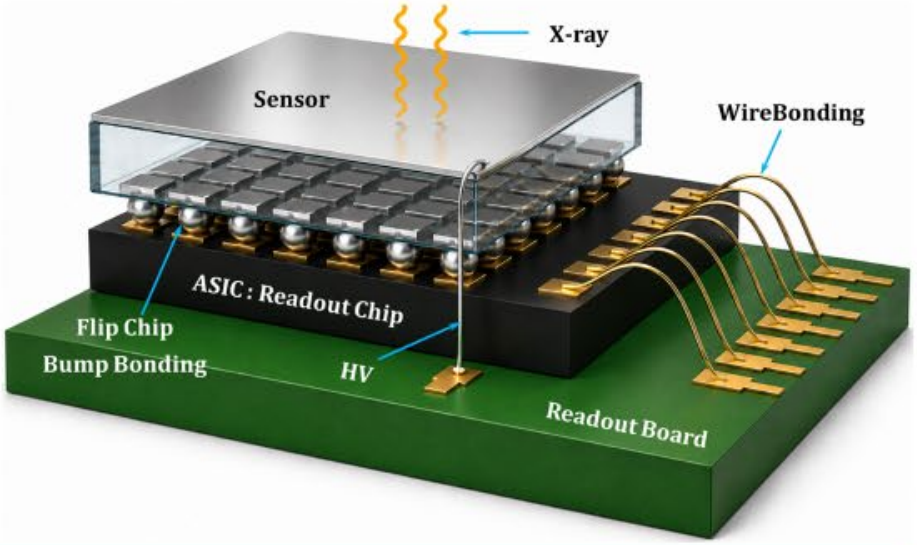
Parameters	STARLIGHT0/SL0	STARLIGHT1/SL1
Operation Mode	Charge Integrating, CW	Charge Integrating, CW
Readout Chip / ASIC	HYLITE 200F	HYLITE 100F
Frame Rate	≥ 1k Hz	≥ 10k Hz
1 photon sensitive	Yes， @ 12keV	Yes， @ 12keV
Dynamic Range	0, 1 – 10^4 ph./pixel/pulse @ 12keV	0, 1 – 10^4 ph./pixel/pulse @ 12keV
Energy Range	5keV – 25keV	5keV – 25keV
Quantum Efficiency	≥ 80% @ 8keV	≥ 80% @ 8keV
ASIC Pixel Size	≤ 200μm × 200μm	≤ 100μm × 100μm
Module Pixel Array	(64×64)×2×8 ≈ 65k	(128×128)×2×8 ≈ 256k
Data Throughput	≥ 135 MB/s	≥ 5 GB/s
Vacuum Compatible	≤ 10^{-6} mBar	≤ 10^{-6} mBar



- Collaborations : ShanghaiTech Uni., IHEP, IME and SIMIT. Leader : Prof. Zhi LIU.
- Characteristics : Charge Integrating Readout, Single photon sensitivity and Large dynamic range, High speed.

STARLIGHT : PAD R&D for SHINE

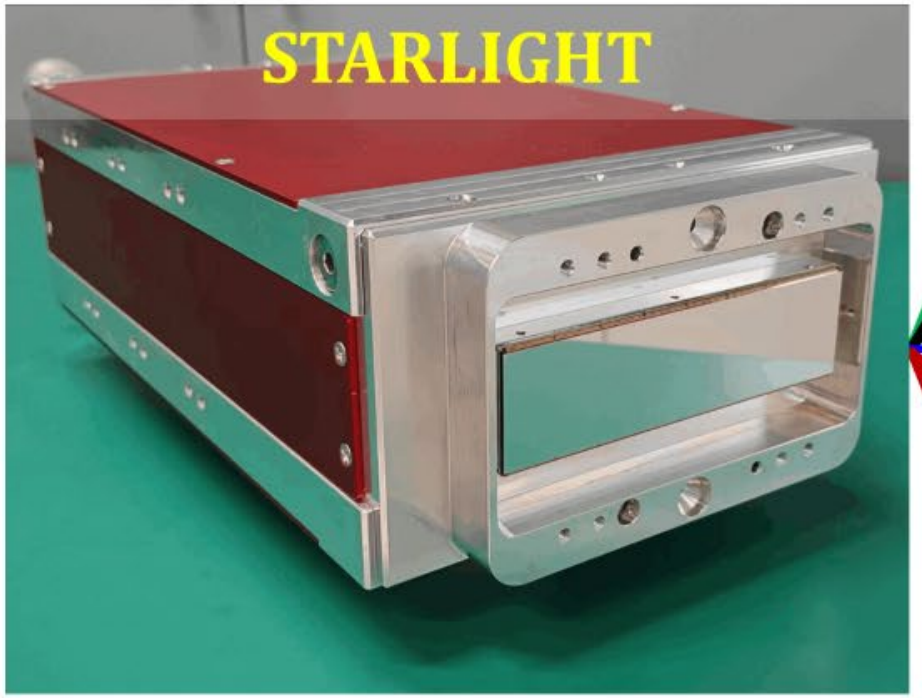
STARLIGHT : SemiconducTor Array detectoR with Large dynamIc ranGe and cHarge inTegrating readout



Hybrid Pixel Array Detector (HPAD)

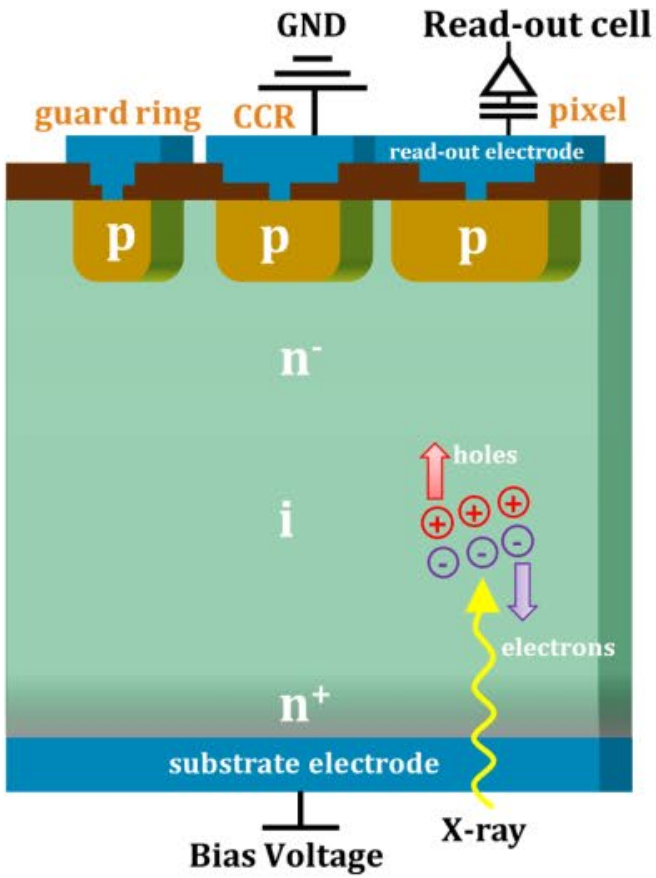
Charge Integrating readout

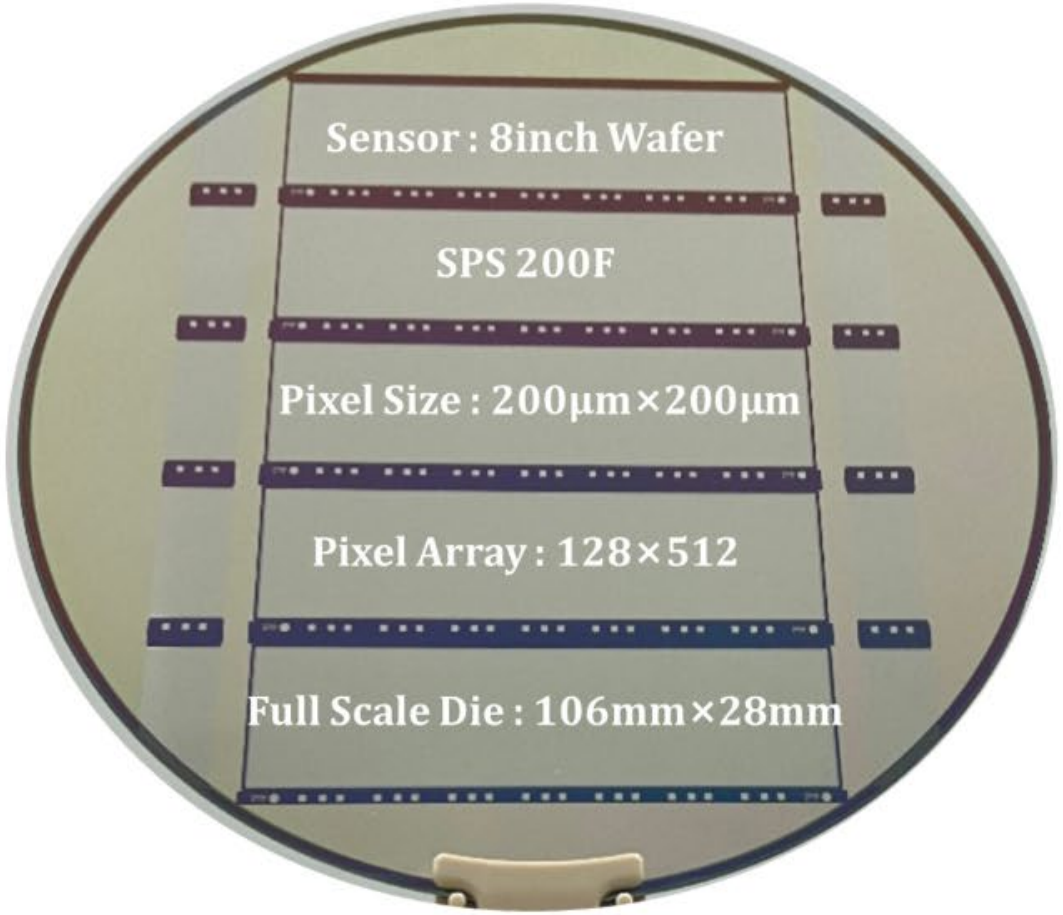
- **Sensor : Silicon**
- **Front End Readout Chip : ASIC**
- **Back End Electronics : BEE**
- **Front End Module : FEM**
- **Data Acquisition : DAQ**
- **Mechanics, Cooling and Vacuum : MCV**



- ① Sensor — IME
- ② ASIC — IHEP
- ③ BEE — IHEP
- ④ FEM — SIMIT
- ⑤ MCV — SHTU
- ⑥ DAQ — SHTU
- ⑦ Systems — SHTU

SL0 : Sensor, Large scale pixel array, Large breakdown Voltage



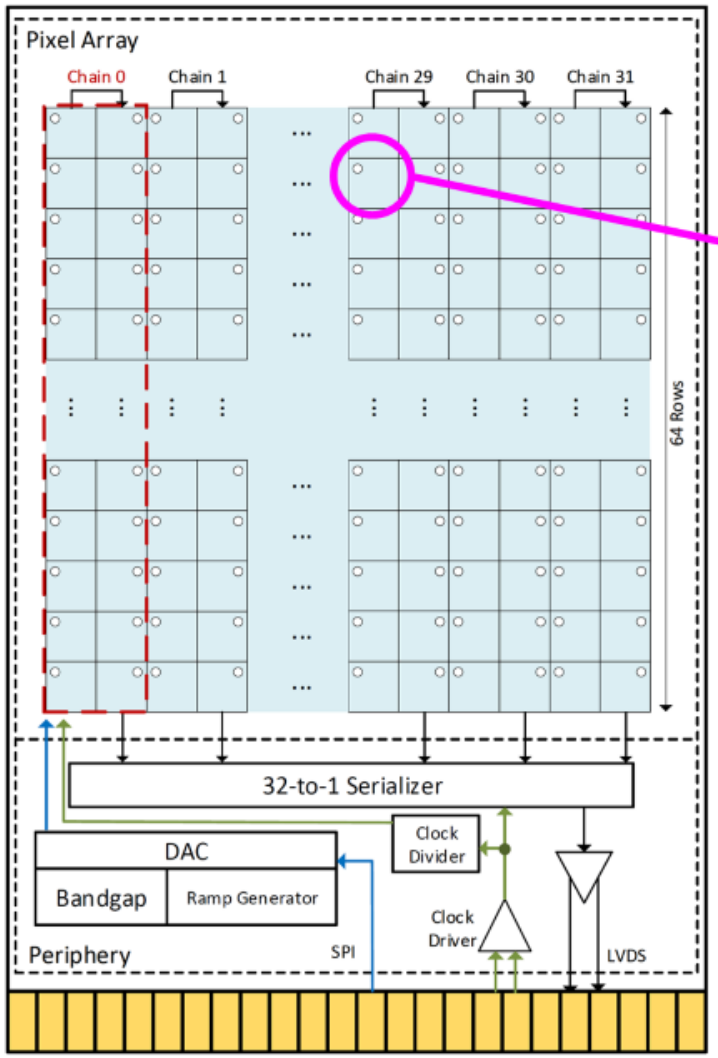


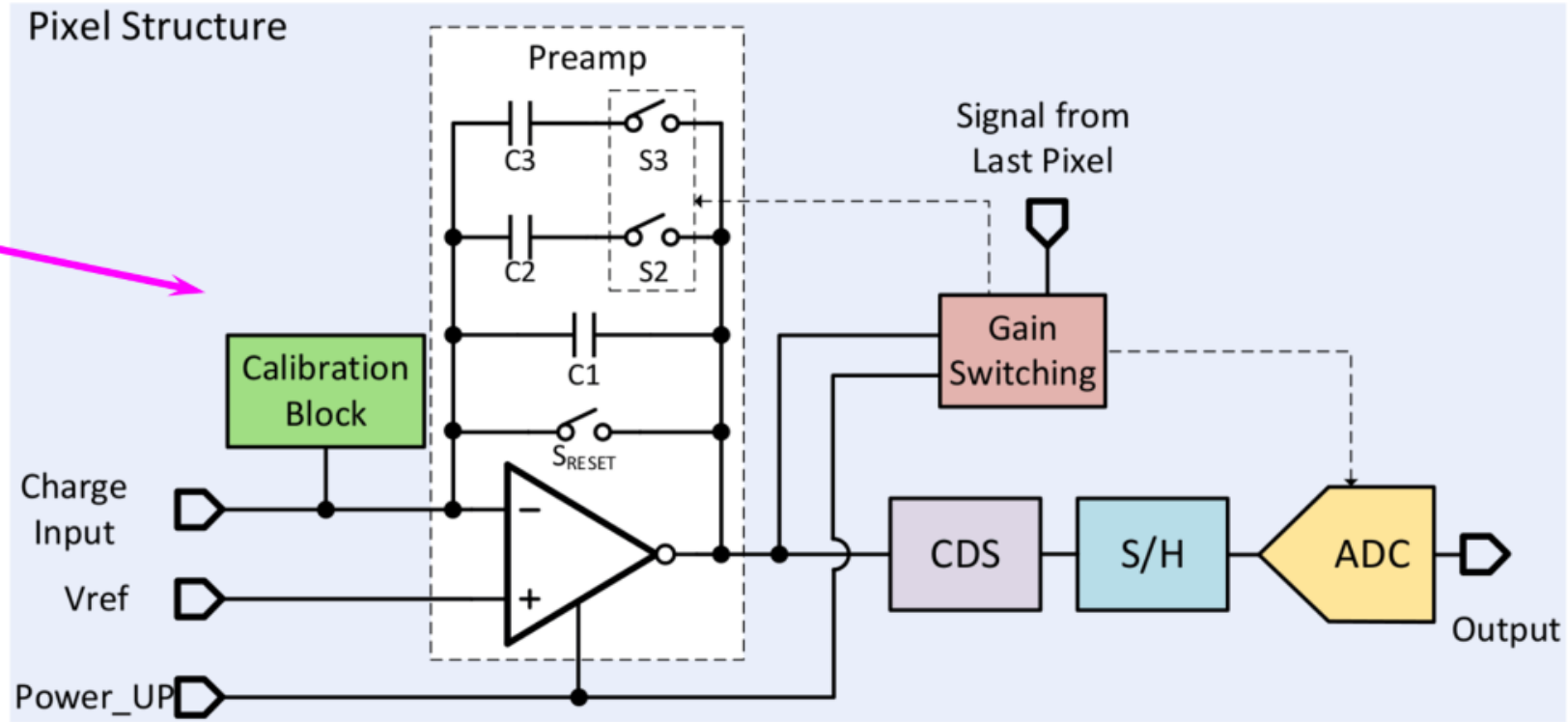
Peng Sun, Ultra-large scale array silicon pixel sensors with uniform and low leakage current for advanced X-ray light sources, JINST, 2024

- Traditional Si P-I-N structure. Thickness is 500μm. Using stitching technology to achieve large-sized die.
- The breakdown voltage is > 200V with CCR leakage current < 200nA w/o irradiation.

SL0 : ASIC, HYLITE series readout chip

HYLITE : High dYnamic range free electron Laser Imaging deTEctor



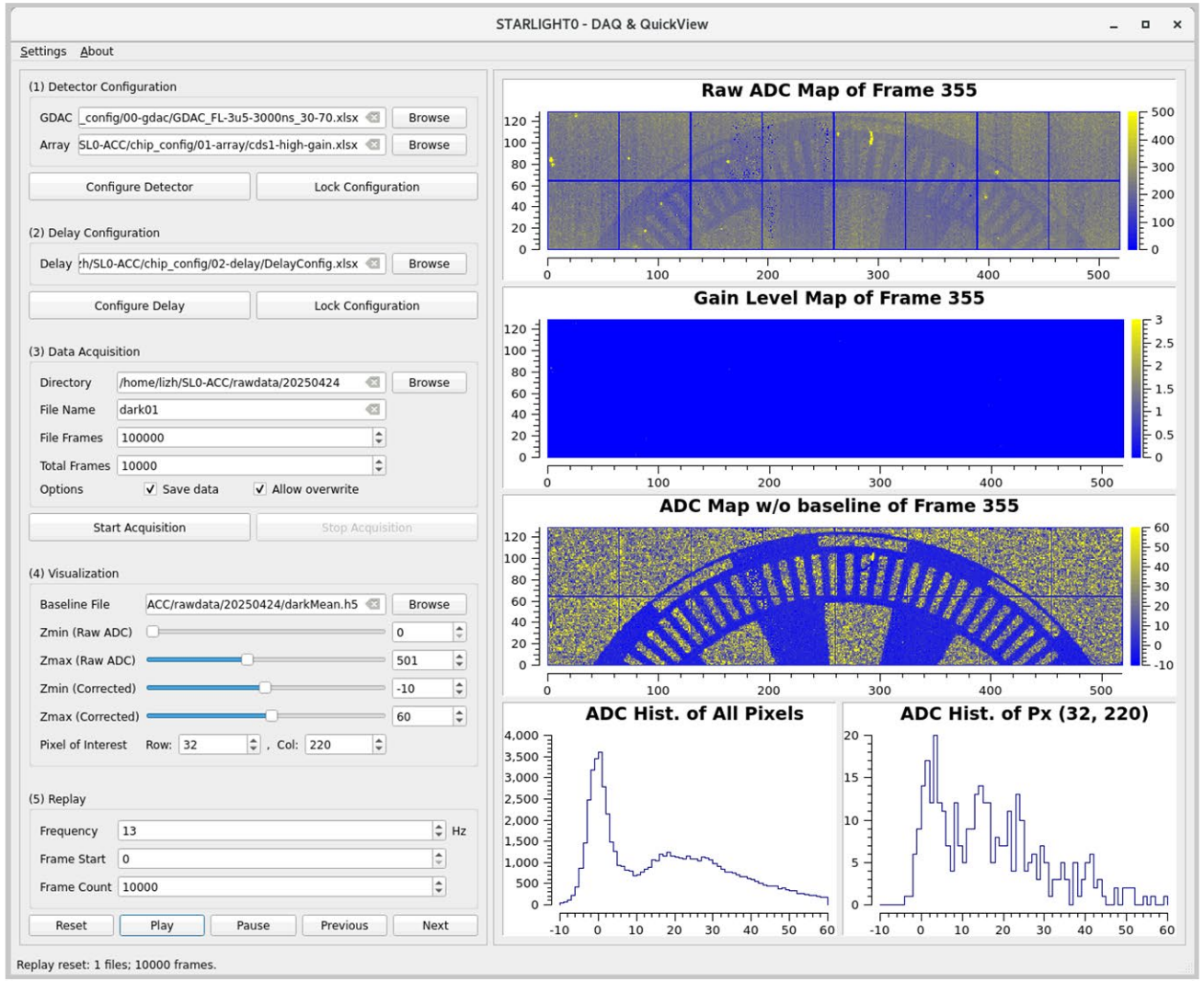


Schematics of HYLITE 200F

- Charge Sensitive Pre-Amp : three-stage automatic gain switching function
- In-Pixel Analog-to-Digital Converter : 10-bit single-slope ADC
- CDS、Sleep-Wake Mechanism、Calibration Block

M. Li, Optimized design and characterization of HYLITE, a charge-integration readout chip of XFEL, JINST, 2024

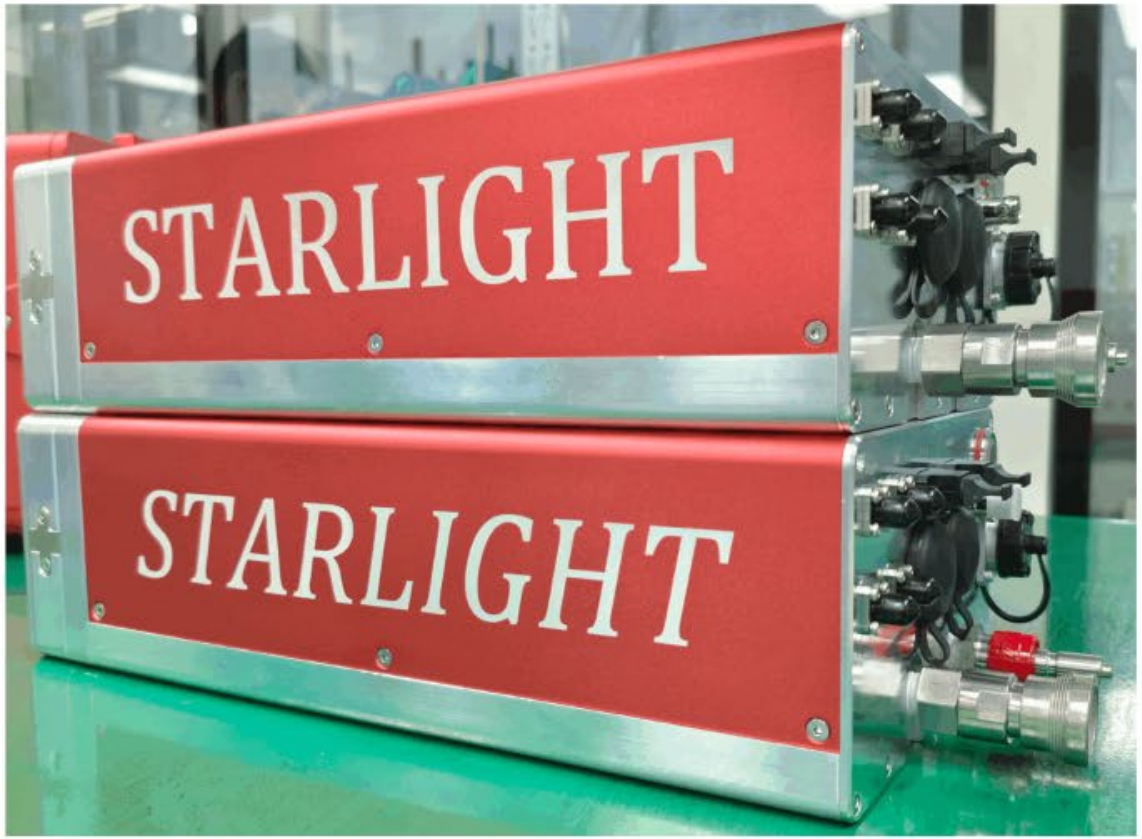
SL0 : DAQ, High Speed and Large Volume Data Processing





Distributed parallel data processing with data throughout up to 80GB/s for SLM16 @ 10kHz.

SL0 : Detector Systems

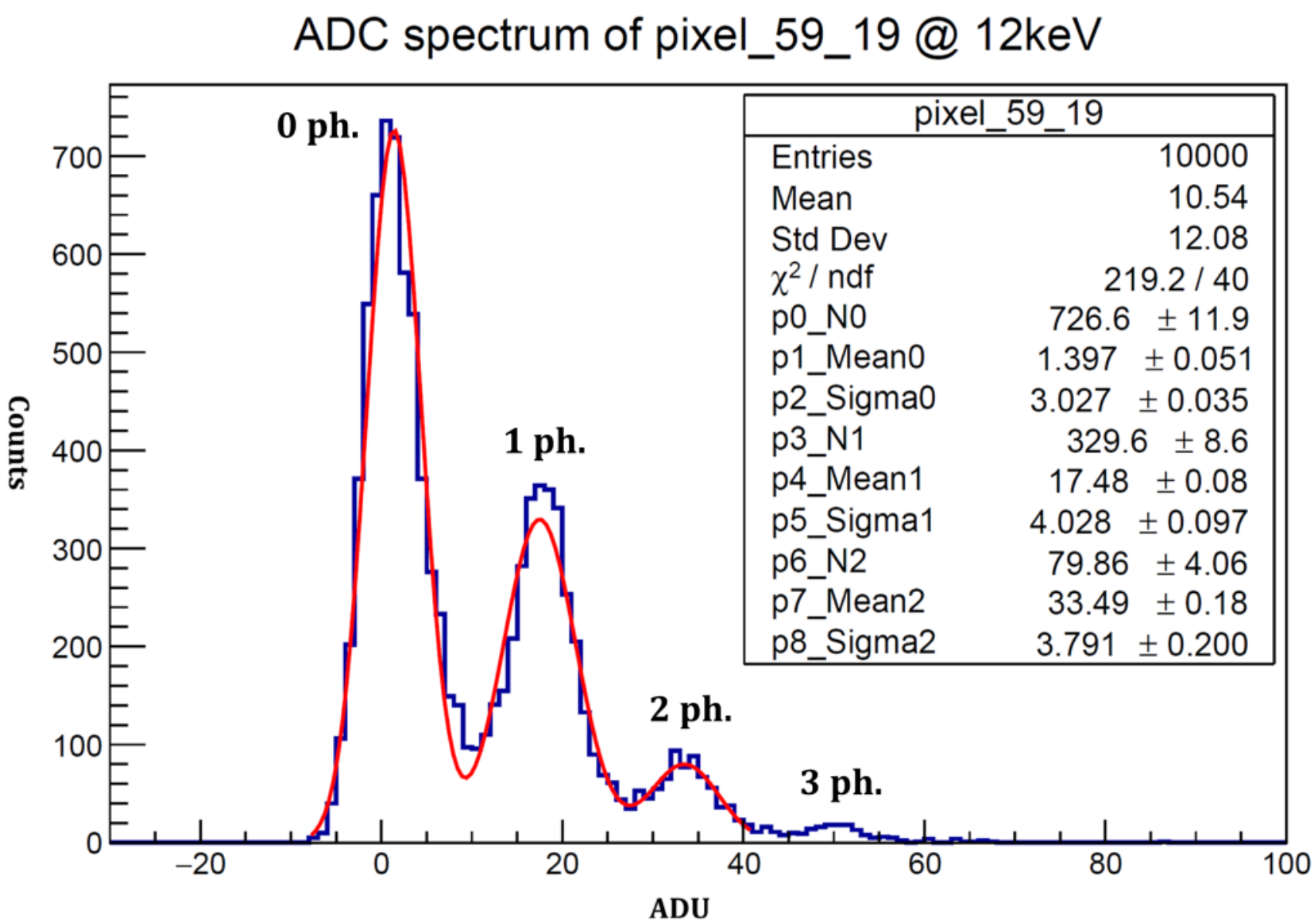


SLM1 (Ambient Version)
~ 103.8(X) × 25.8(Y) mm²

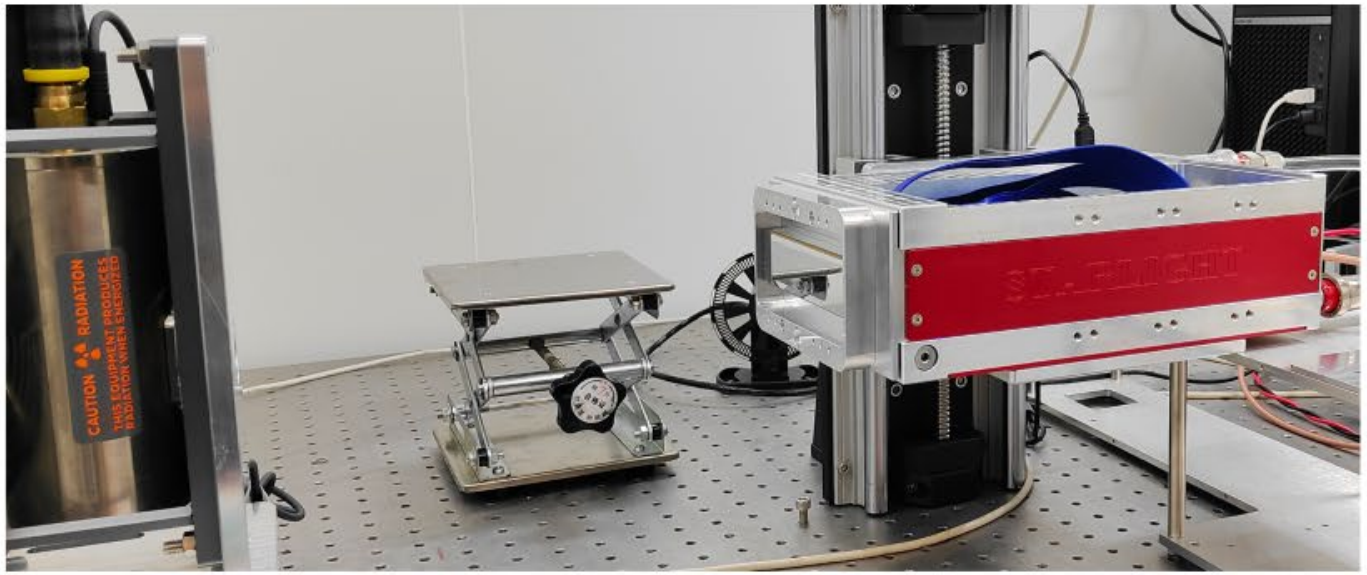


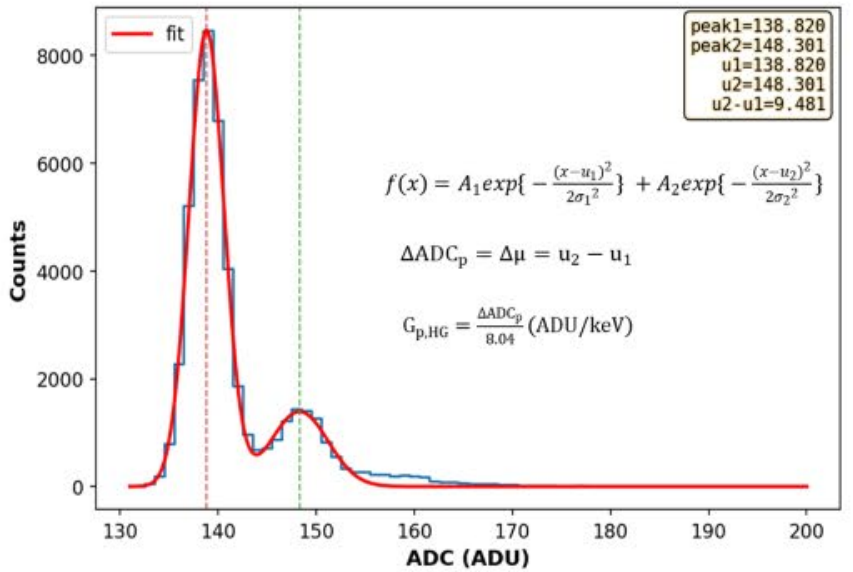
SLM4 (Ambient Version)
~ 103.8(X) × 103.2(Y) mm²

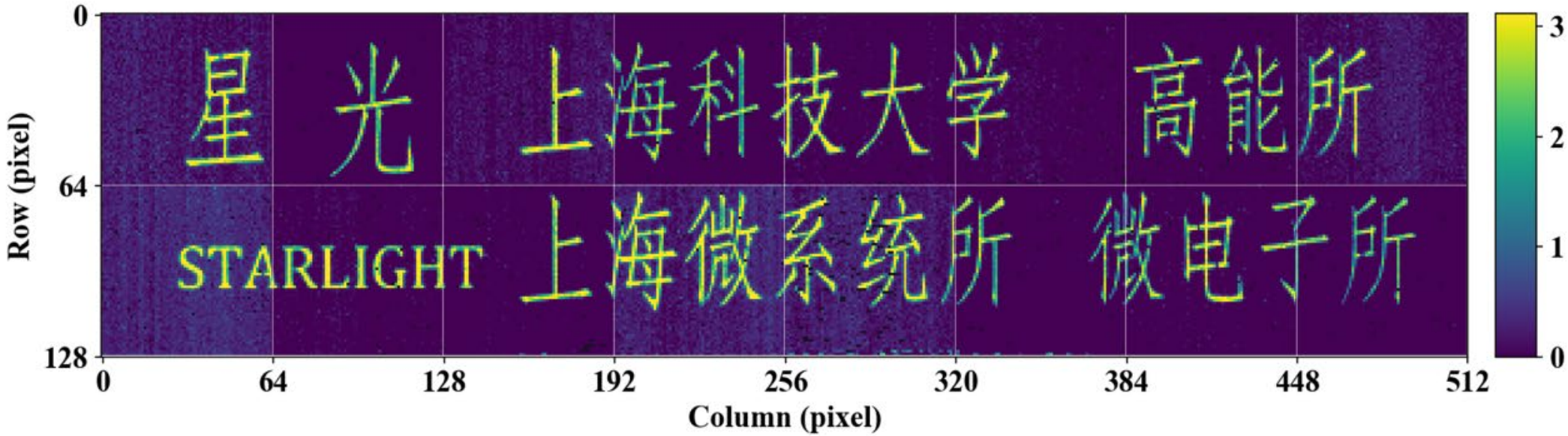
SL0 : Single Photon Sensitivity, SNR > 5 @ 12keV



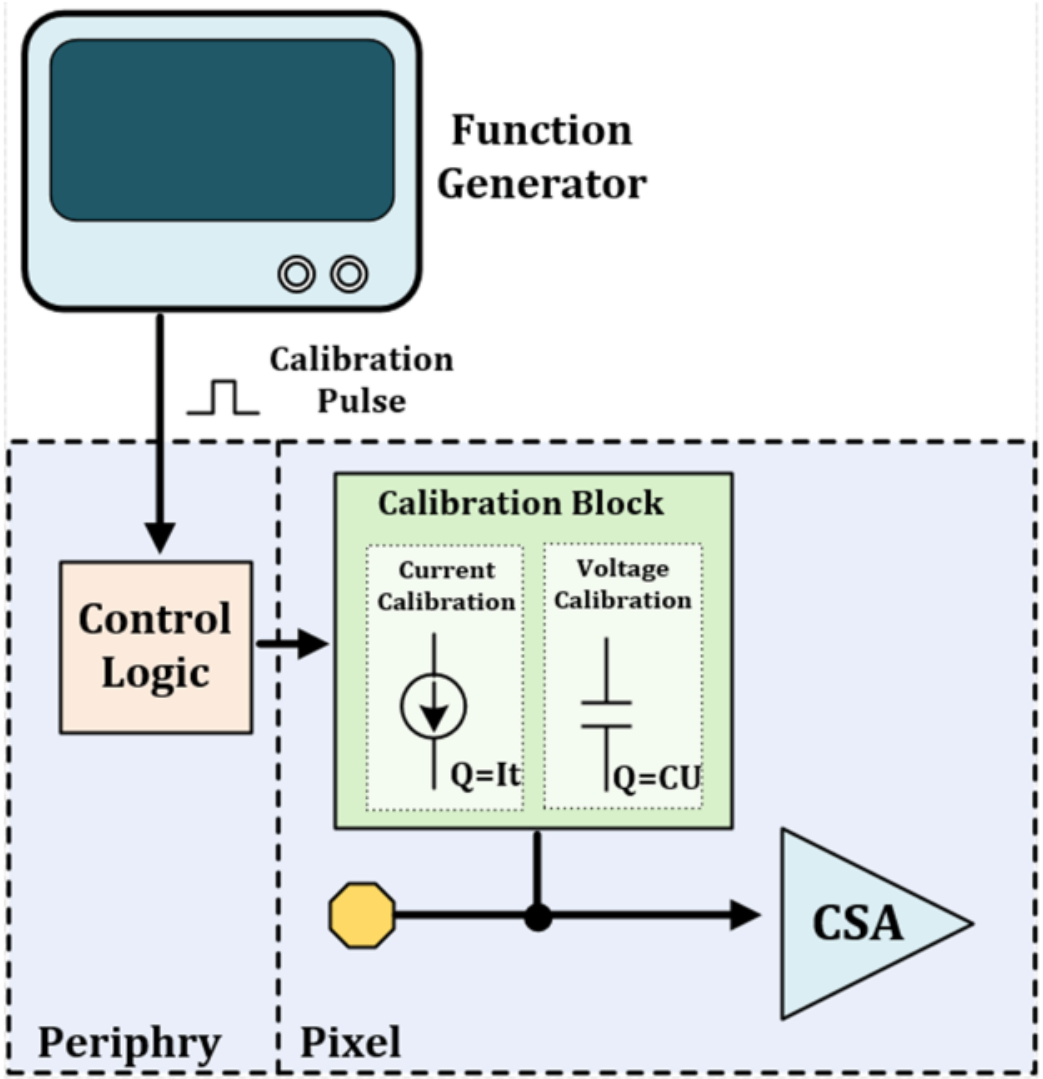
SL0 : Calibration, High Gain

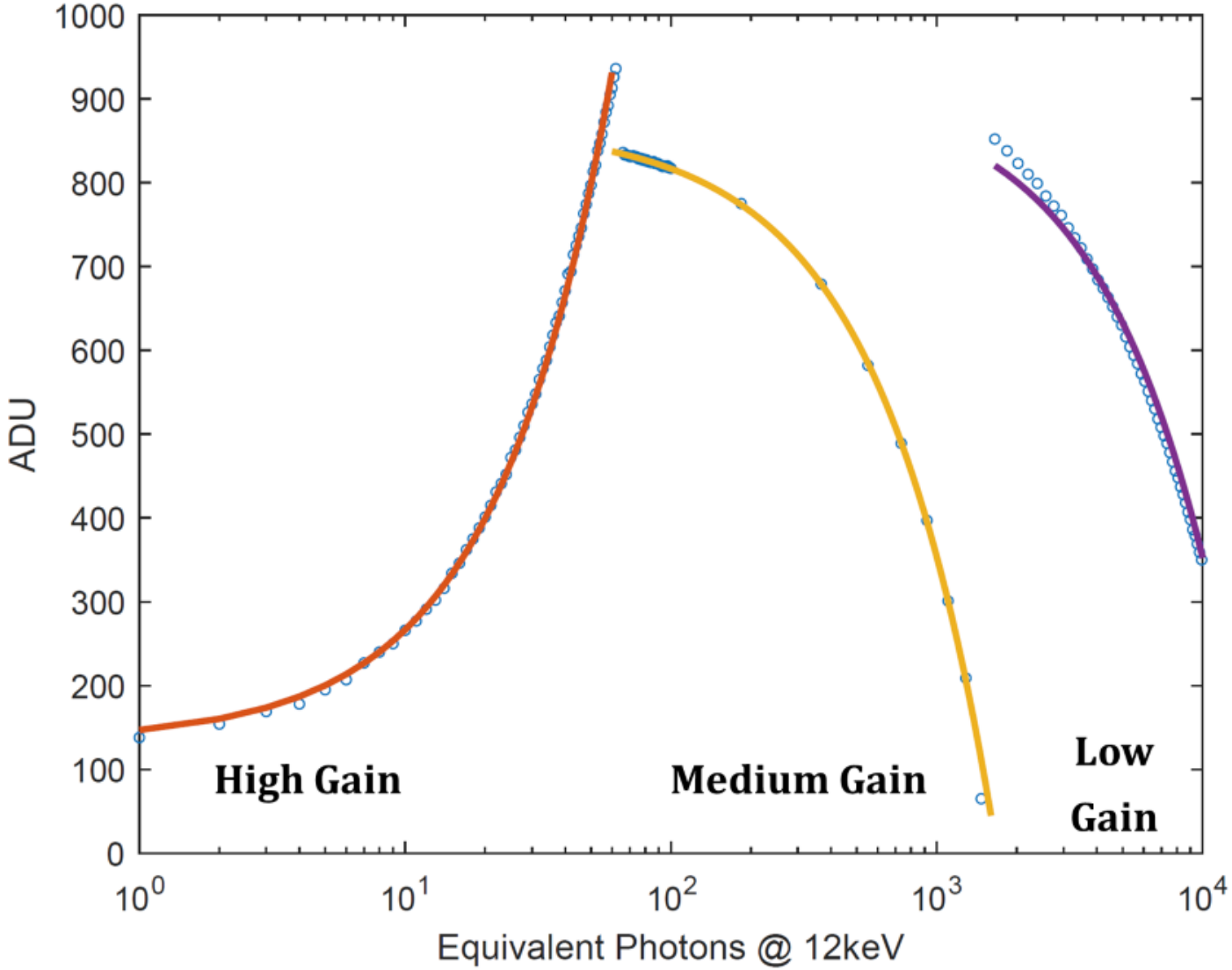






SL0 : Large Dynamic Range, ≥ 10^4 ph./pixel/pulse





X. Jia, Characterization results of the first full-scale readout HYLITE chip for STARLIGHT, JINST, 2025

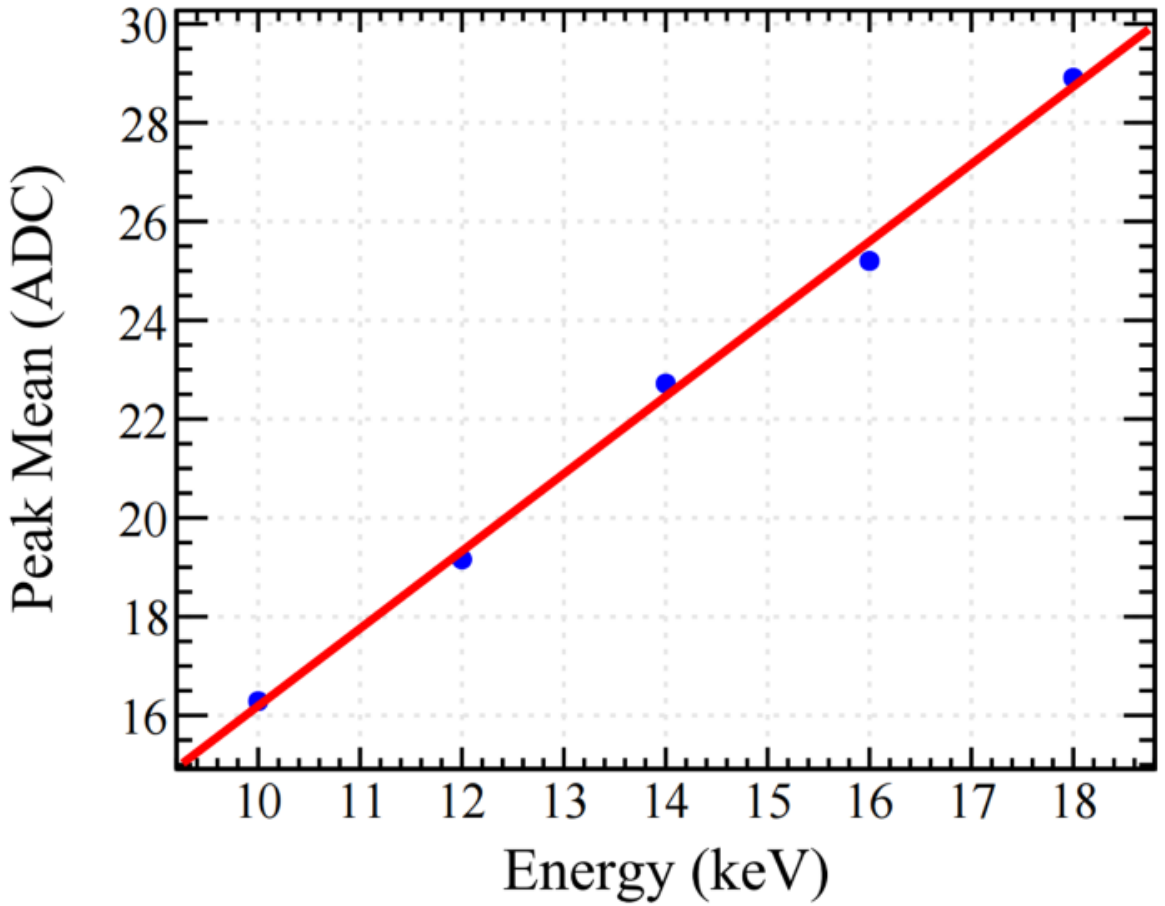
SL0 : Frame Rate, ≥ 1kHz



SL0 : Beam Test @ SSRF-BL09B

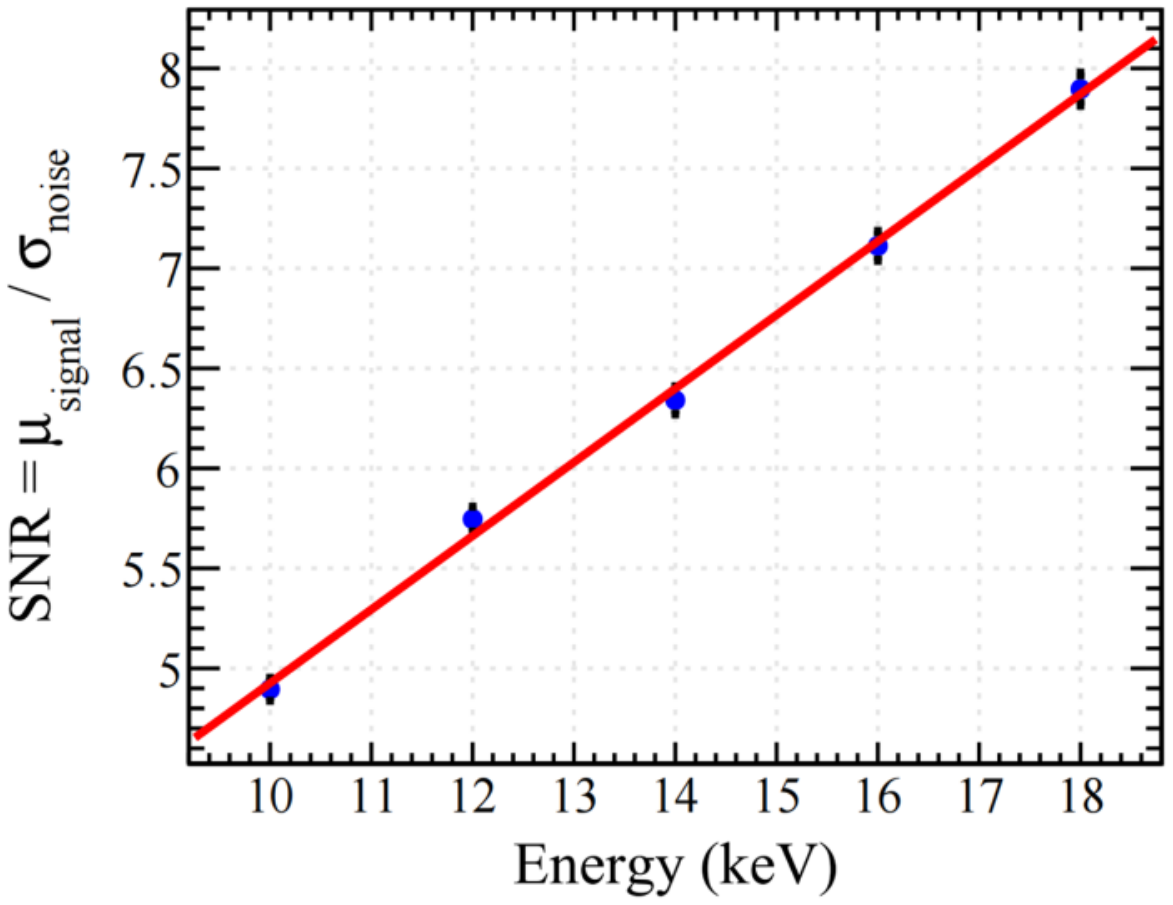
Support of Zhongliang LI

1 Photon Peak vs Energy



SL0 Linearity : 1 Pixel

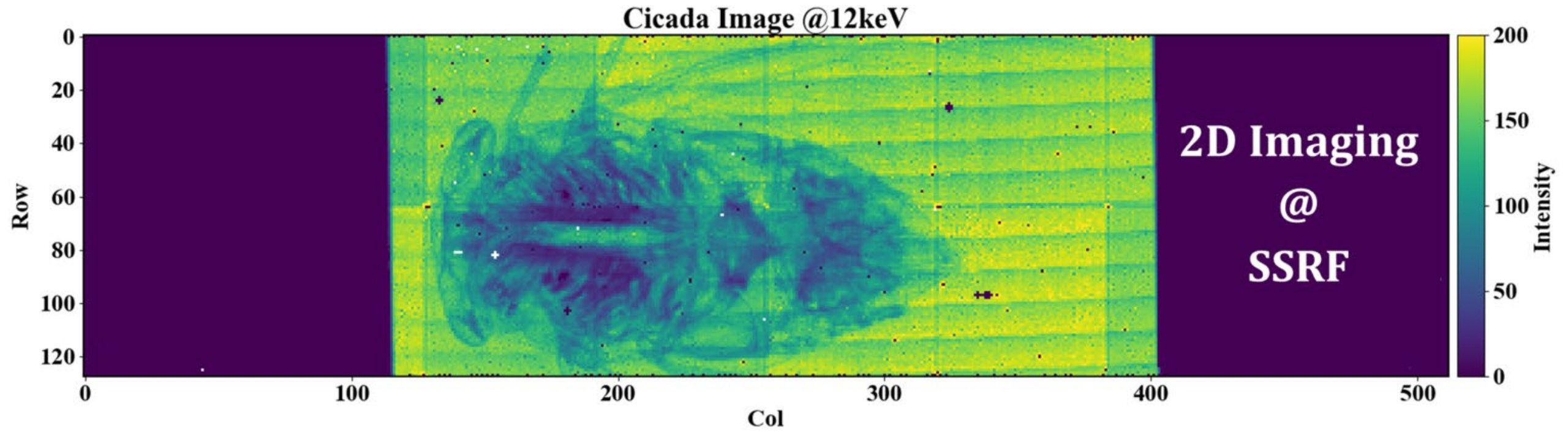
Signal-to-Noise Ratio vs Energy



SL0 SNR : 1 Pixel

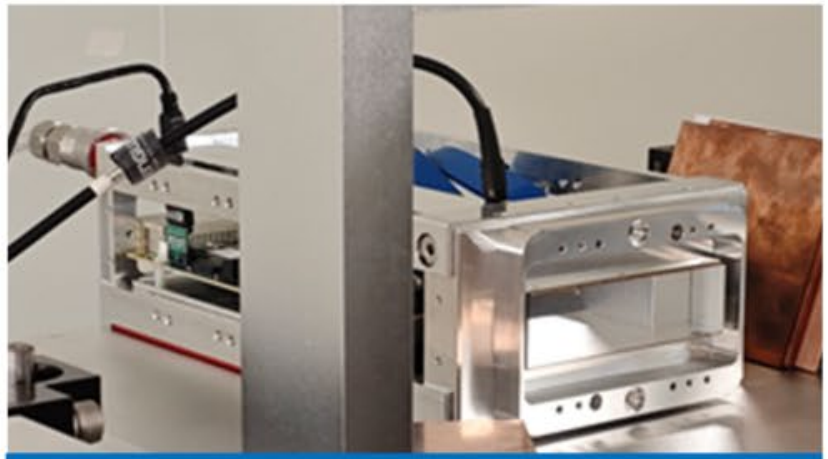
SL0 : Beam Test @ SSRF-BL09B





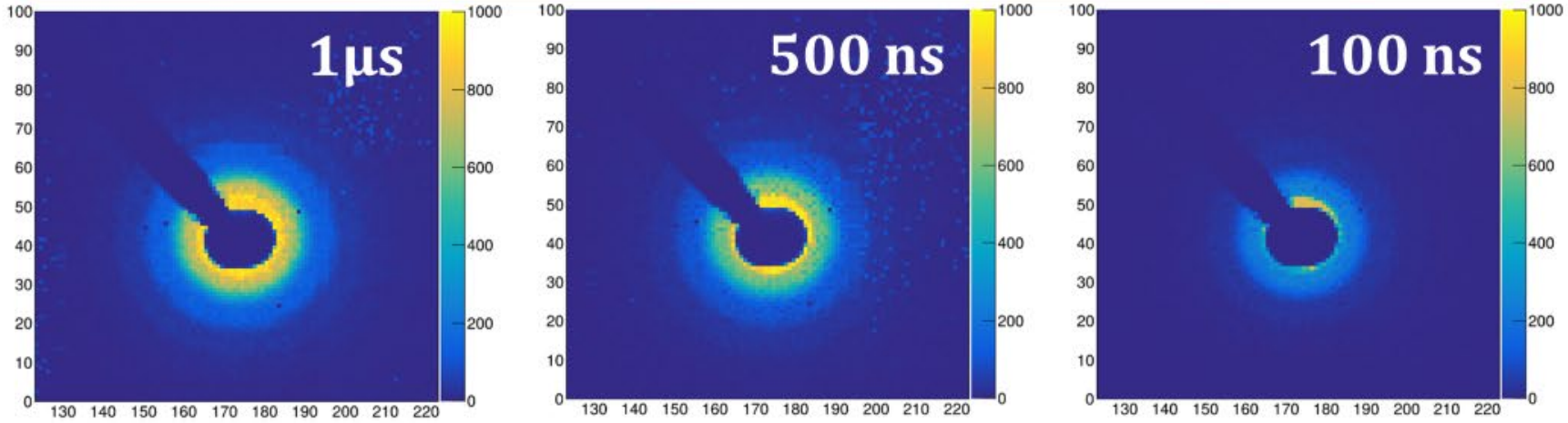
SL0 : Beam Test @ HEPS-SDB

Support of Bingbing ZHANG



SL @ HEPS-SDB， 2025.10.14

Time Resolved Small Angle Scattering， nano-Si powder @ 21.8keV



Ultrafast X-ray Diffraction : laser single-spot re-melting of textured polycrystalline pearlitic steel

1. Verification of UXRD.
2. In-situ characterization : additive manufacturing.
3. Dynamic evolution behaviors : lattice rotation, grain precipitation @ rapid melting and solidification of materials (@ 1kHz, 3μs).

Summary

1. Charge Integrating PADs (CI-PAD) are urgently needed on SHINE, especially for end-stations like CDS and HSS.

2. A new CI-HPAD called STARLIGHT (SL) is developed in order to meet the demand for high pulse repetition of SHINE (up to 1MHz in CW mode),

3. SL's typical characteristics: fast frame readout rate (10kHz), both single photon sensitivity and large dynamic range (10^4 ph./pixel/pulse @ 12keV).

4. SL has undergone 2 versions : SL0 and SL1. The preliminary results of SL0 is shown in this report. More tests including calibration are still in progress and will be reported in the future.

5. SHINE is also looking forward to using more excellent PADs like JUNGFRAU, CITIUS, ePix and so on.

STARLIGHTers	
Leader	Zhi LIU
Sensor	Huaxiang YIN, Gaobo XU, Zhiyong LV, Qionghua ZHAI, Aodi YANG
ASIC	Wei WEI, Mujin LI
BEE	Jie ZHANG, Hangxu LI
FEM	Zhen SHENG, Tao SUN, Xinhai LIAO
DAQ	Zhengheng LI, Ping HUAI, Wujun SHI
MCA	Peng LIU, Wei LI, Fang LIU
Systems	Xudong JU, Shuaijie LI, Jiyu QIU
Manager	Xiangjun SHI, Lili JIN

Thanks for your attention!

