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ePixHRM320k
A Detector System for Soft X-ray Imaging for LCLS-II

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SLAC X-ray Detector R&D Program

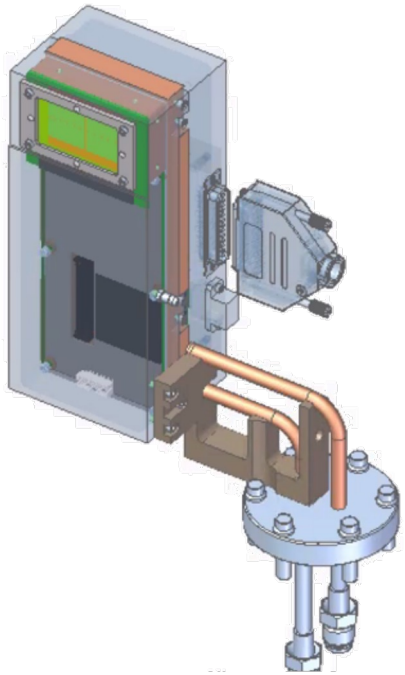
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

Outline

- Project goals
- Project requirements
- Detector concept
- Status of the demonstrator:
  - Pixel performance and new fabrication run
  - Back-end ASIC performance
  - Assembled modules

ePixHRM320k



90 degree

0 degree

Project Goal

- ePixM project aims at developing a high-rate camera for soft X-rays scattering/imaging experiments at LCLS-II

- Key detector for NEH 2.2 beamline:
  - QRIXS Instrument
    - Soft x-ray (SXR) resonant elastic X-ray scattering (REXS) experiments
    - X-ray Photon Correlation Spectroscopy (XPCS)
  - ChemRIXS Instrument
  - Other Coherent Scattering (CS) experiments

Project requirements

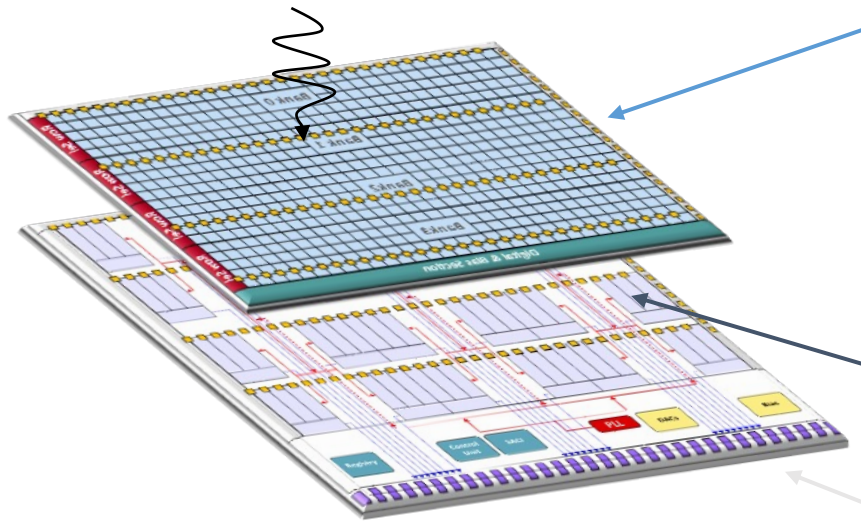
Parameter	Threshold	Goal	REXS	XPCS	CS	0.3 Mpix ePixM
Pixel pitch [um]	50	50	✓	✓	✓	50
Read noise [e^- rms]	15	10		✓	✓	12
Well depth [Number of 530eV photons]	1000	3000	✓	✓	✓	>1000
Quantum efficiency [%, 275eV-1500eV]	70	90	✓	✓	✓	~84
Frame-rate [kHz]	5	10	✓	✓	✓	7.5
Array size [pixels]	512x512	1024x1024	✓		✓	768 * 384
Vacuum outgassing rate [torr*L/s]	2E-8	1E-8	✓			2E-8
Cabling and cooling length [m]	2	4	✓		✓	2
Physical package envelope [WxLxD]	100x175x75 mm	75x150x50 mm	✓			75x175x58 mm
Maximum power dissipation [W]	100*	50	✓	✓	✓	75

* Assuming a 512x512

Detector Concept

Standard modular hybrid approach

X-rays E_γ = 250 eV – 2keV



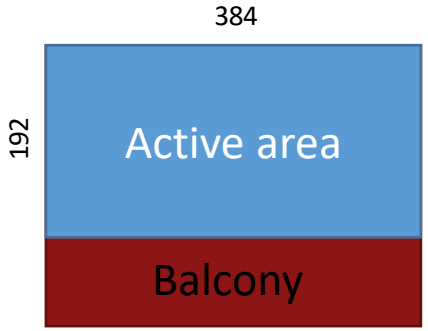
ePixM Monolithic Active Pixel Sensor (MAPS)

- On-sensors amplifier reduces noise
- Fully-depleted and back-illuminated
- Entrance window optimized for soft X-rays

Standard micro-bumps

ePixHR-M Readout ASIC (ROIC)

- 4 arrays of 192 ADCs



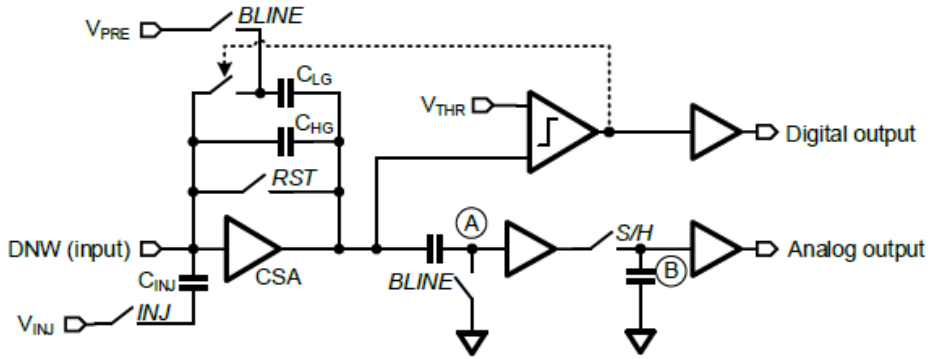
ePixM CMOS sensor with 384 * 192 pixels.

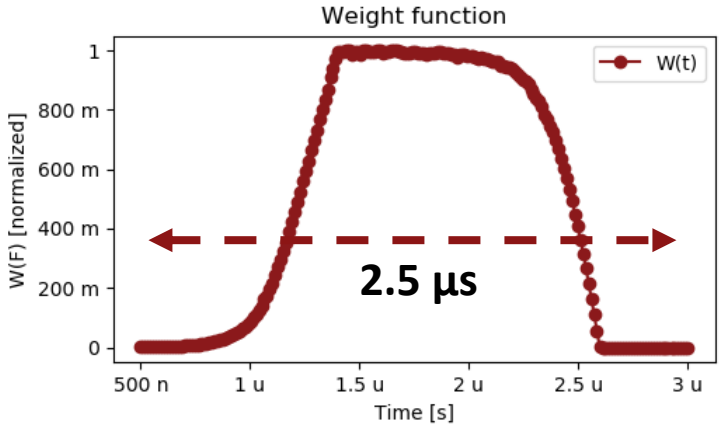
- Size is 19.772 x 10.371 mm

ePixHRM readout

- Size is 20.072 x 14.932 mm

ePixM: pixel electronics

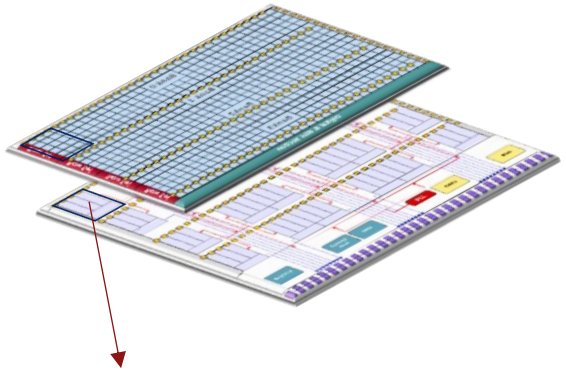




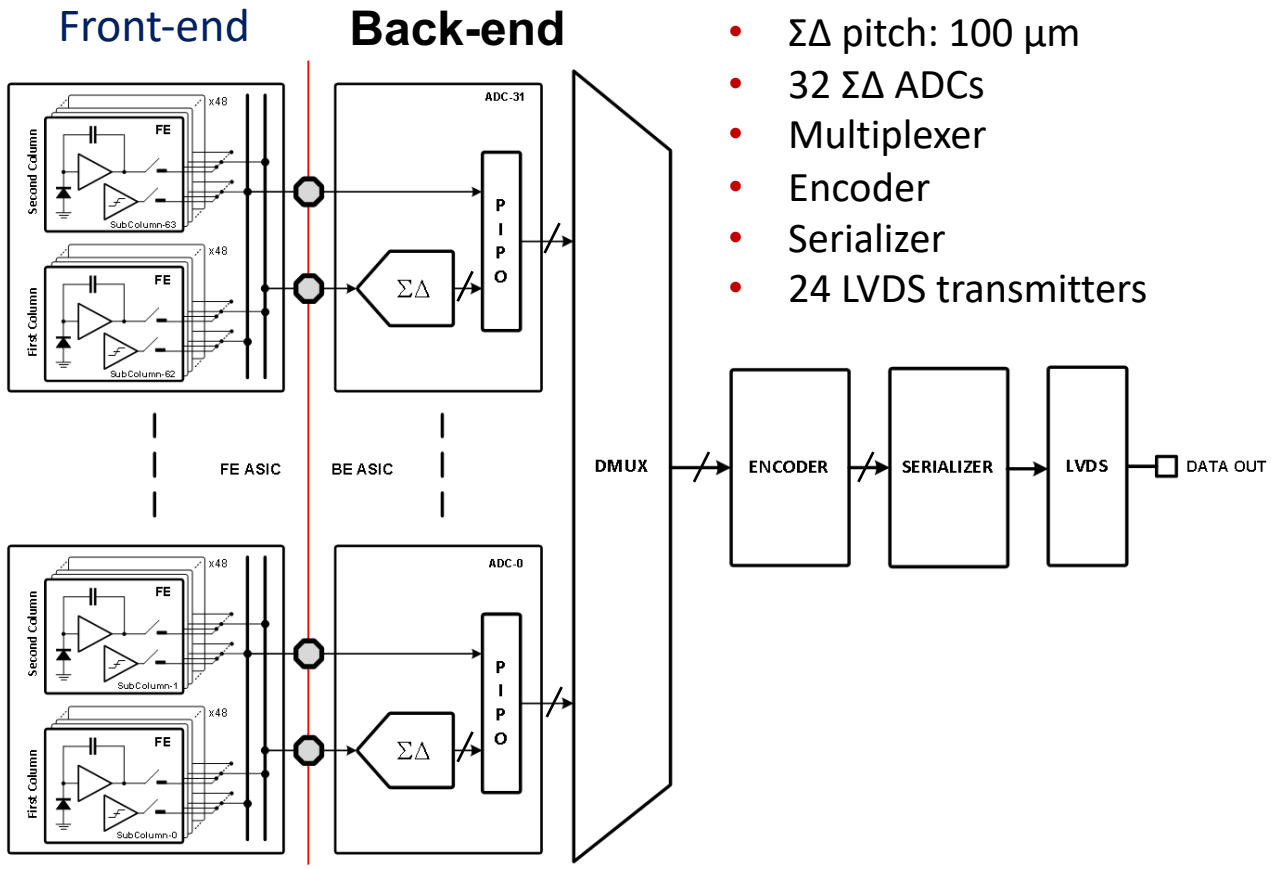
- Charge Sensitive Amplifier (CSA) with auto-ranging capability
- Injection capacitance for calibration
- Correlated Double Sampling (CDS) → quasi-trapezoidal shaping
- Sampling stage and 2x column buffers for analog and comparator (gain) output

Rota L. *et al.*, Design of ePixM, a fully-depleted monolithic CMOS active pixel sensor for soft X-ray experiments at LCLS II, 21st International Workshop on Radiation Imaging Detectors, July 7-12 2019, Kolympari, Chania, Crete, Greece

ePixM interface between CMOS sensor and ROIC



- Pixel pitch: 50 µm
- Subgroup of 48 x 2 pixels



- ΣΔ pitch: 100 µm
- 32 ΣΔ ADCs
- Multiplexer
- Encoder
- Serializer
- 24 LVDS transmitters

Requirements table

Parameter	Threshold	Goal	REXS	XPCS	CS	0.3 Mpix ePixM
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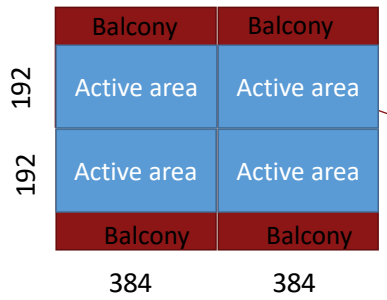
Well depth [Number of 530eV photons]	1000	3000	✓	✓	✓	>1000
Quantum efficiency [%, 275eV-1500eV]	70	90	✓	✓	✓	~84
Frame-rate [kHz]	5	10	✓	✓	✓	7.5
Array size [pixels]	512x512	1024x1024	✓		✓	768 * 384
Vacuum outgassing rate [torr*L/s]	2E-8	1E-8	✓			2E-8
Cabling and cooling length [m]	2	4	✓		✓	2
Physical package envelope [WxLxD]	100x175x75 mm	75x150x50 mm	✓			75x175x58 mm
Maximum power dissipation [W]	100*	50	✓	✓	✓	75

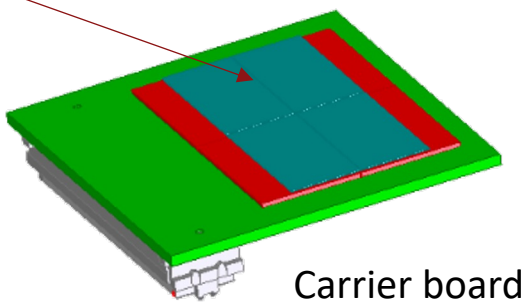
* Assuming a 512x512

System structure

- Carrier board
  - Focal plane with 4 ASICS
- Digital board
  - FPGA and voltage regulators for the ASICS
- Power and communication board
  - Input power at 24V gets reduces and distributed at 6V
  - LeapOn Transceiver implements 12 lanes of fiber optics communication

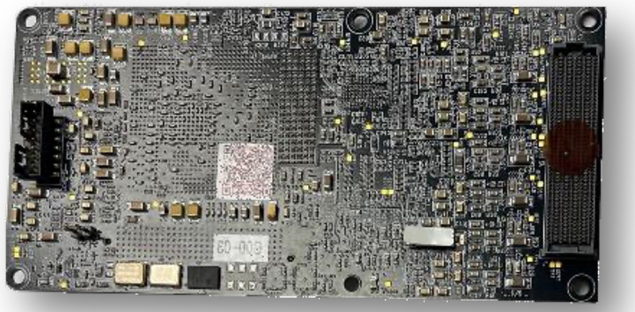


Read out ASIC & Sensor

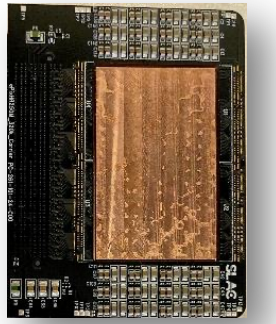


Carrier board

Digital Board



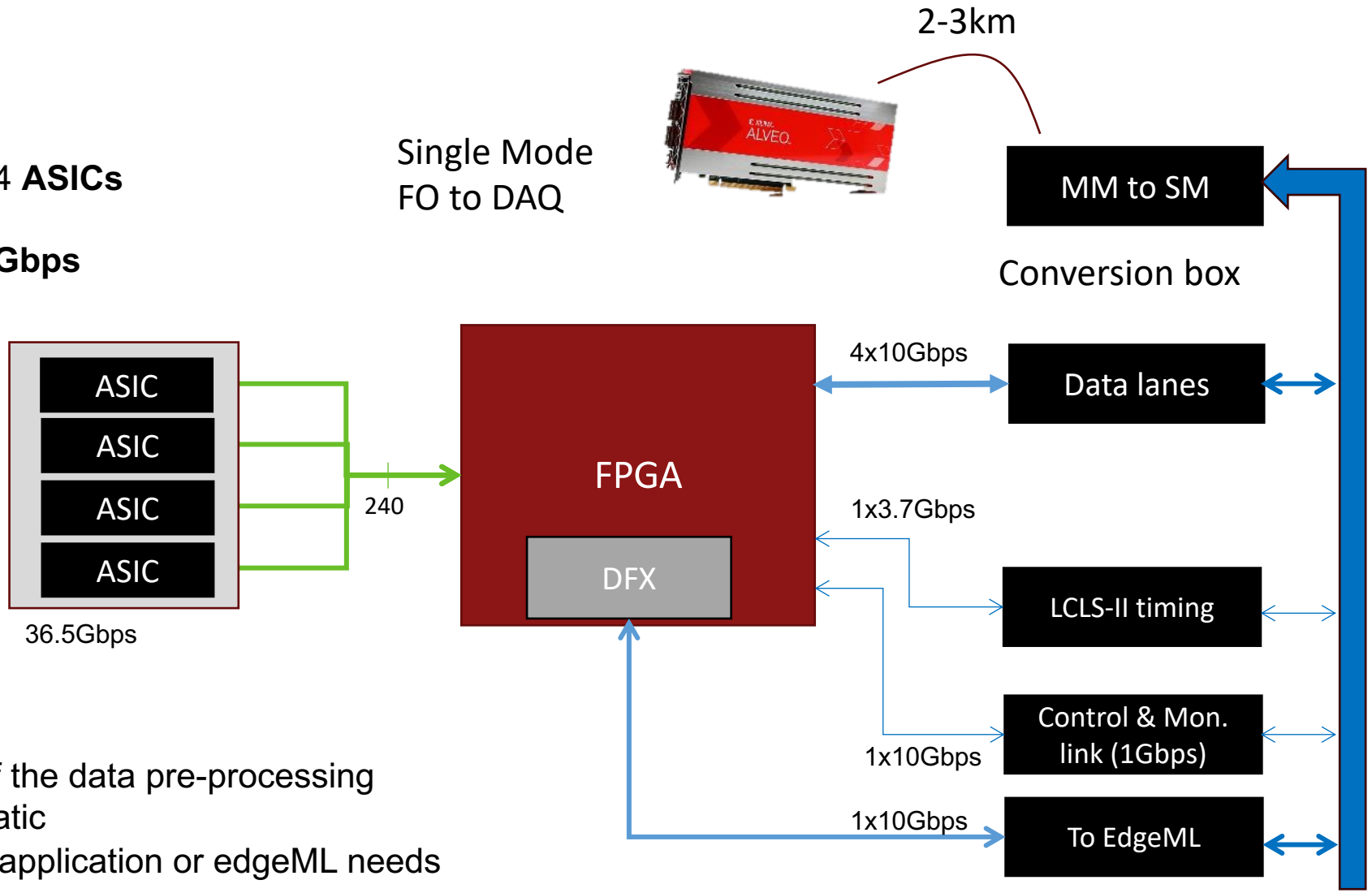
Carrier board



Power and communication

Camera data flow

- ePixM 7.5 kfps data rate
  - 384*192 **pixels** *16 **bits** * 4 **ASICs**
  - *7500 **frames per second**
  - *66/64 **encoding** => **36.5-Gbps**

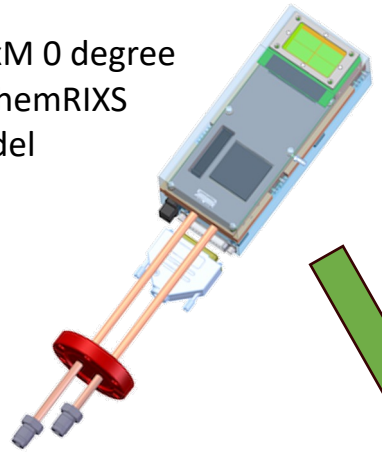


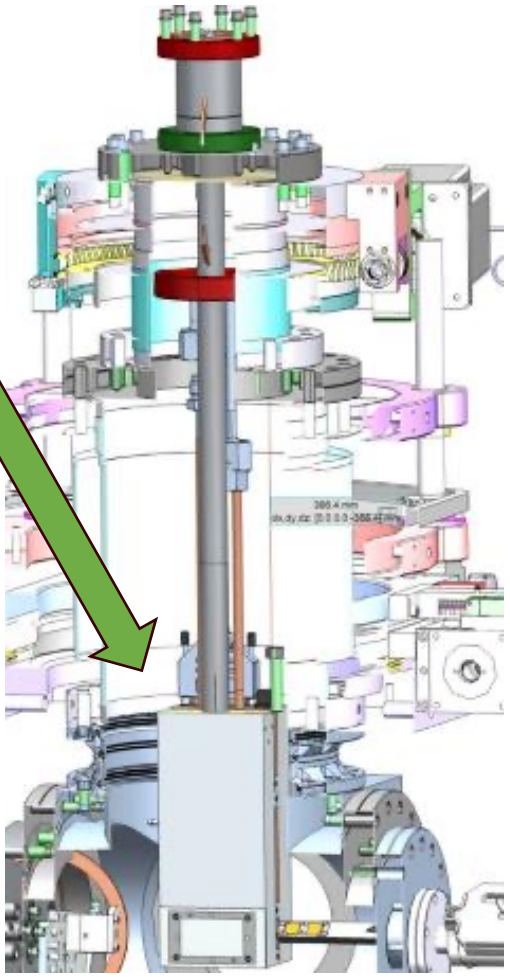
DFX
- Enables dynamic optimization of the data pre-processing
- Image acquisition and control static
- Can be tailored for custom user application or edgeML needs

Mechanical concept

- Overall dimensions: 75x175mmx58
- Side entrance window with Shield
- Cooling lines, one inlet and one outlet
- Vacuum requirements implemented with no water to vacuum joints

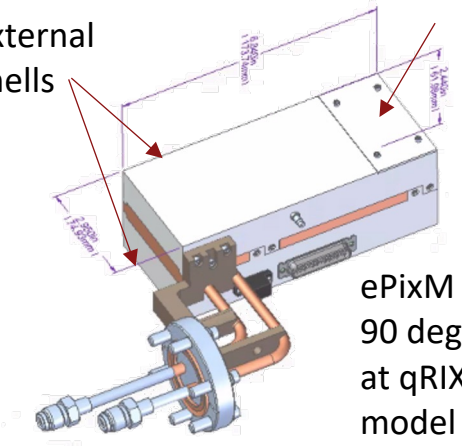
ePixM 0 degree at chemRIXS model



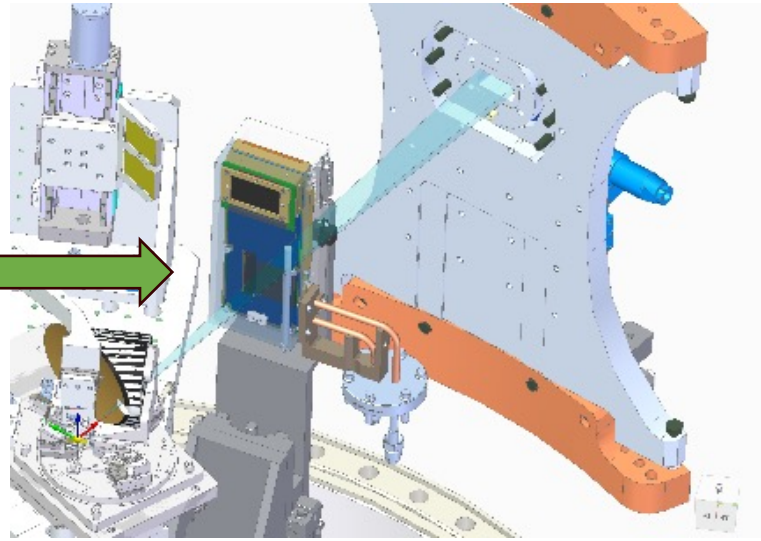


Protection cover

External shells



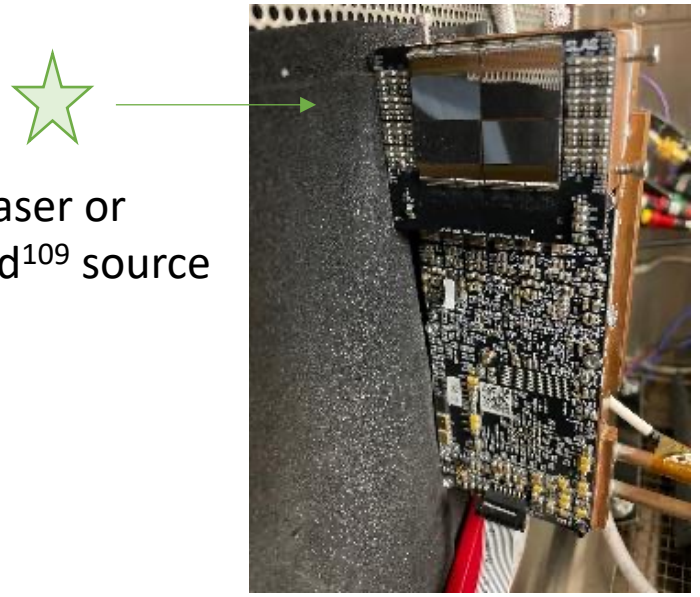
ePixM 90 degree at qRIXS model



ePixM 90 degree at qRIXS exp. chamber

Test results with full system

- **System level functionality**
  - ADC test using external DAC, Supply for four ASIC, Timing to the detector
- **ASIC level functionalities**
  - Noise, X-Ray with $Cd^{109,}$ Spatial data descrambling, Pixel gain



Prototype Detector

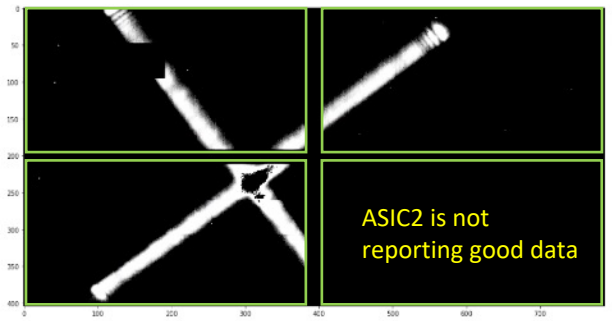
Note on sensor:

Batch IZM-0

- 700 micron thick sensor wafer – no entrance window – lowest risk
- Results presented today

Batch IZM-1

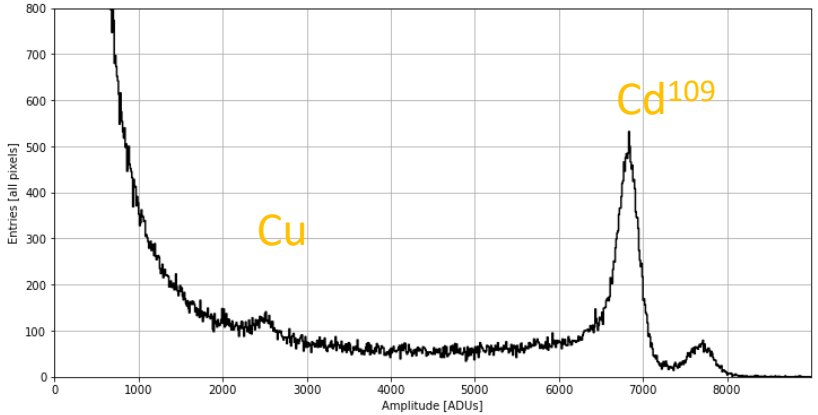
- First science modules
- SLAC will thin, polish, implant, metalize, anneal sensor wafers
- Sent to IZM by Q2 CY2023 and receive Q4 CY2023



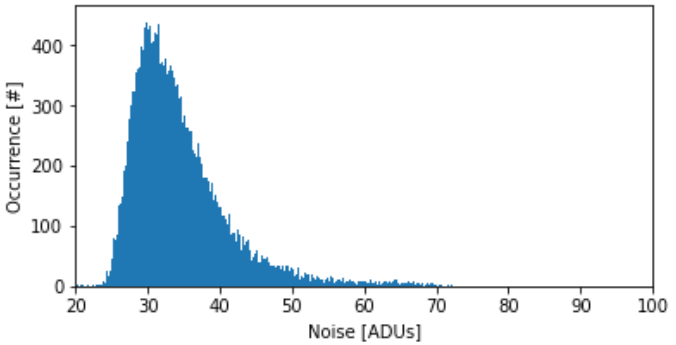
LASER pointer projected image

Testing with Cd109 source

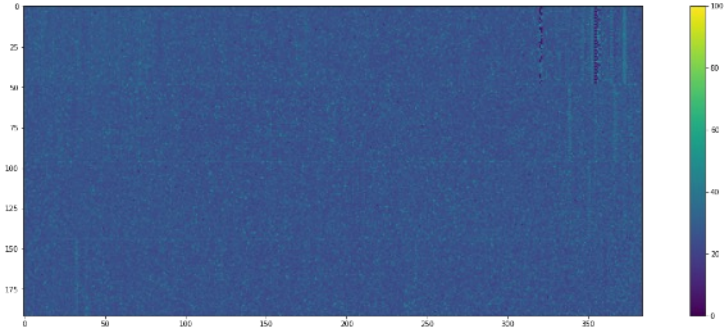
Cd109 spectrum @ 20us integration time



Noise distribution of pixels @ 1us integration



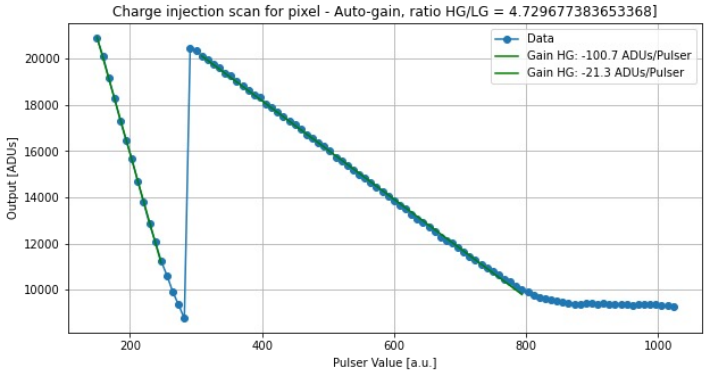
Noise map of 192x384 pixel array



- Thick sensor wafer (700um thickness, back-side not processed, not implanted/annealed)
- Sensor operating conditions: bias voltage =71V, leakage current 350 nA / ASIC (not processed!)
- 700um thick sensor noise performance, not fully depleted and not annealed: **28 e^-**
- Final sensor expected to have performance in line with the small prototypes
- Preliminary data processing:
  - Pedestal subtraction
  - Common-mode noise correction (8% improvement at low-occupancy)

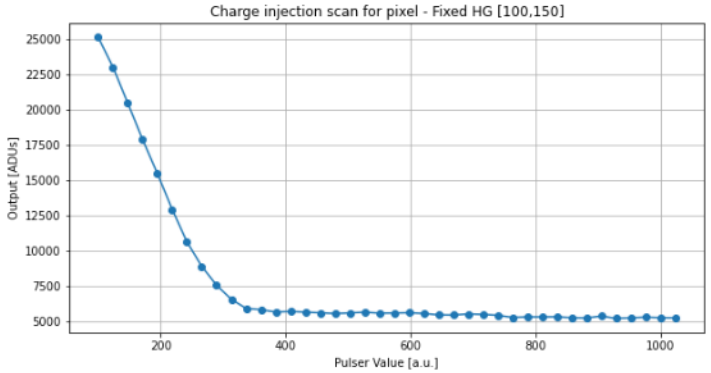
Pixel – different gain modes

- Due to area/noise constraints, the pixels do not contain registers which configure the functionality of the pixels.
- Pixel can be configured to run in different gain modes by adjusting comparator threshold



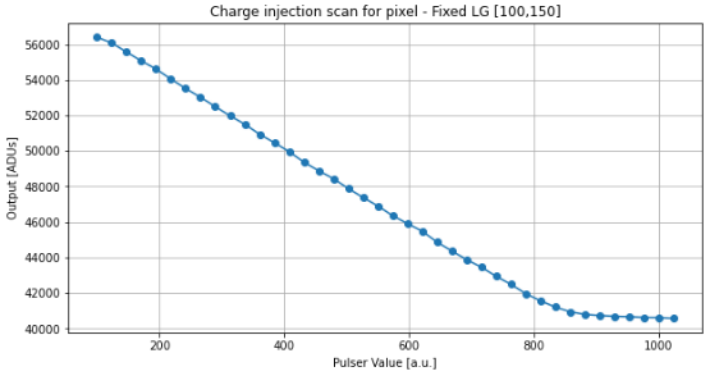
Auto-gain switching

Comparator in the high gain range



Fixed high-gain

Comparator maxed out



Fixed low-gain

Comparator at minimum level

Summary & Next steps

ePixM sensor, ePixHRM readout ASIC and detector

- The updates on the development of the sensor and ASIC module has been presented
- The integration of the detector into two experimental chambers has been presented
- Initial performance measurements with thick sensor has been demonstrated
- Next steps
  - DAQ integration
  - Assembly of thin sensor into a detector
  - Tests with LCLS super conducting linear accelerator beam