Introduction for RIXS to functionality and observed performance of the ePixM detector

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Outline

Theory and measurement principles

- **Physical layout of the ePixM detector**
- **Difference between CCD and ePixM, and physical principle of the ePixM detector**
  - *Difference between CCD, hybrid pixel detector (ePix10k, Jungfrau) and monolithic detector (ePixM)*
- **Measurement principle of the ePixM detector**
  - *How a measurement happens (fixed and auto-ranging)*
  - *"Gain modes" for the ePixM*
  - *Detector timing*
  - *Basics on what needs to be calibrated for an auto-ranging detector;*

Current performance

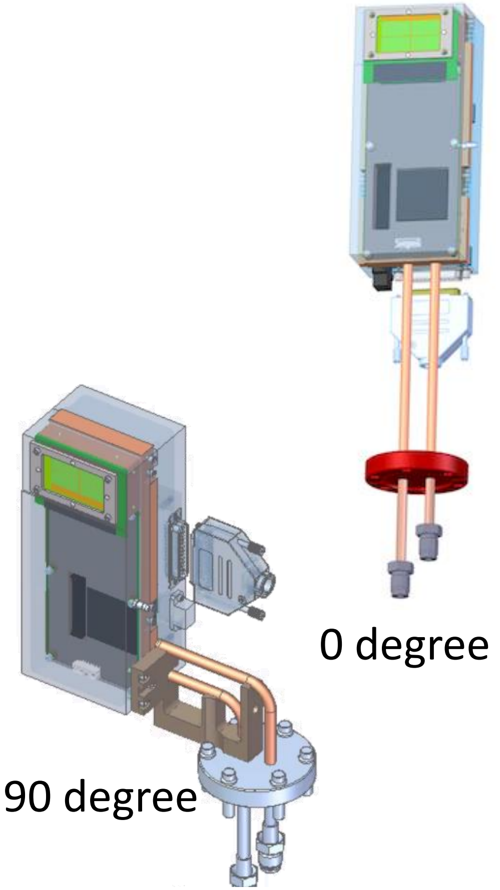
- **Performance so far:**
  - *Production module quality so far*
  - *Noise, Pedestals, and gains in high;*
  - *Switching points in different "gain modes"*
  - *Maximum evaluated frame rate and the cross-talk problem;*
  - *Issues:*
    - *Crosstalk drift*
    - *Lack of CompEn*
    - *How do we calibrate.*

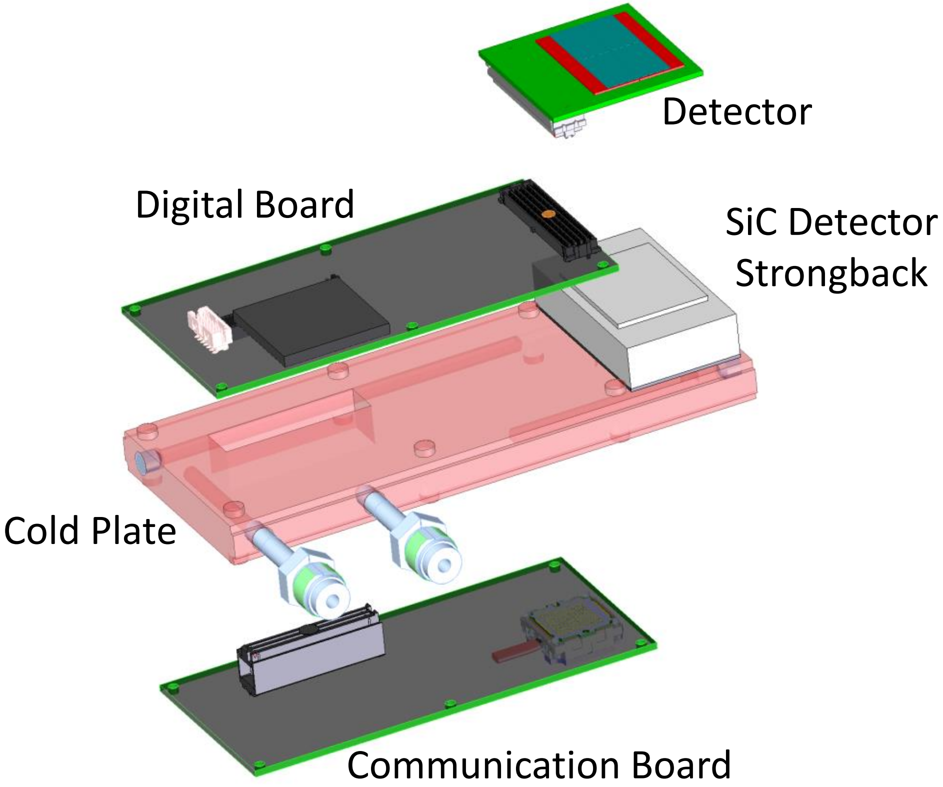
Going forward

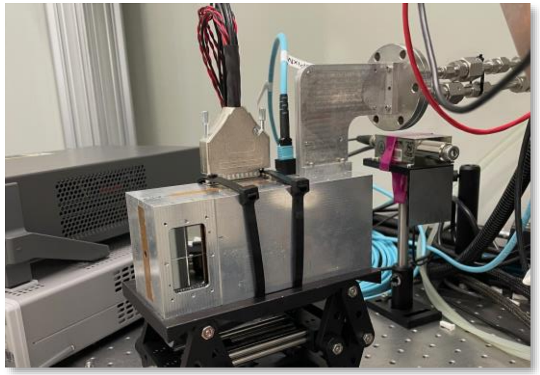
- **Going forward – need for partnership with RIXS in the final stretches of getting the detector running:**
  - *What are the applications the ePixM is going to see;*
  - *How do we set up the detector to optimize the measurements;*

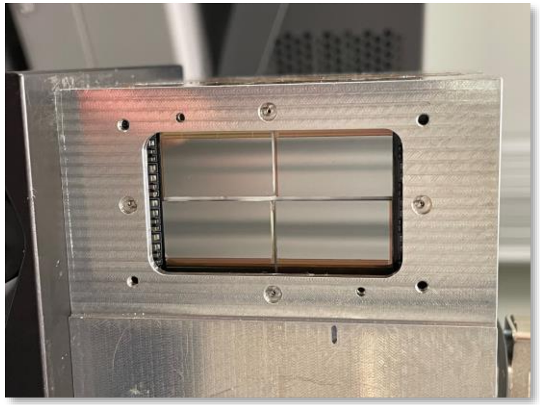
Theory and Measurement principles

Physical layout of the ePixM detector









- 2 geometries – 90 and 0 degree
- Only colling pipe difference.

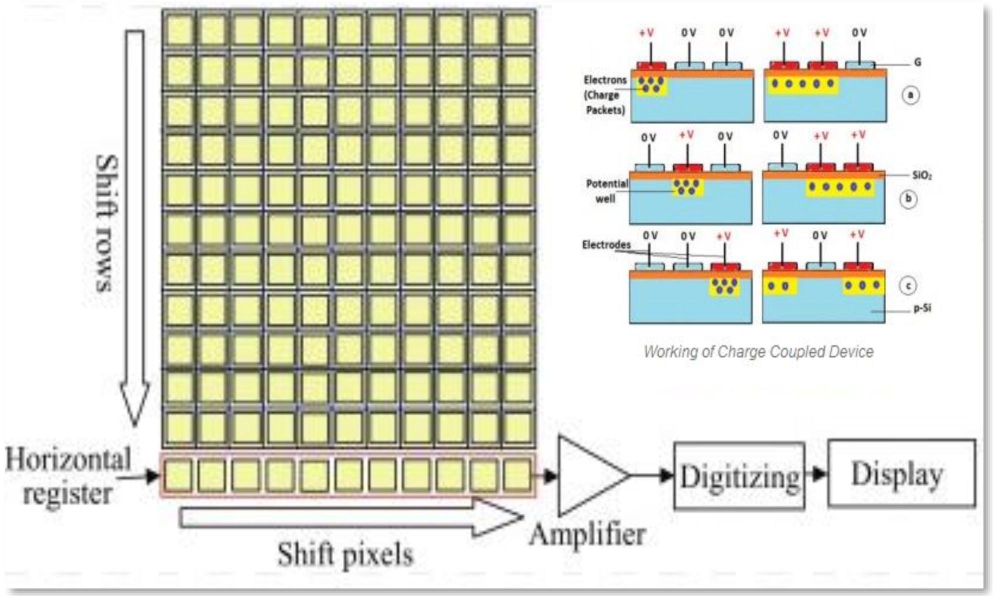
- Coldplate and strongback;
- Analogue and digital boards;
- Detector module containing carrier board, ROIC and Sensor

- Physical layout of 90 degree geometry detector
- 4 ASIC+ROIC pairs per detector module.

Physical detection principle and readout – CCD, hybrid, monolithic

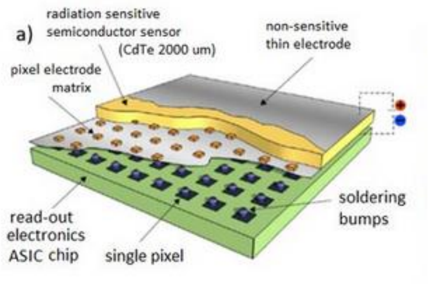
CCD

(Andor, RIXccd)



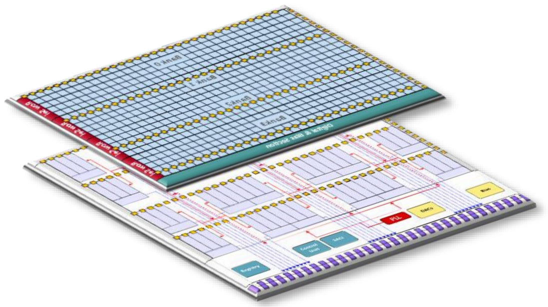
Hybrid pixel detector

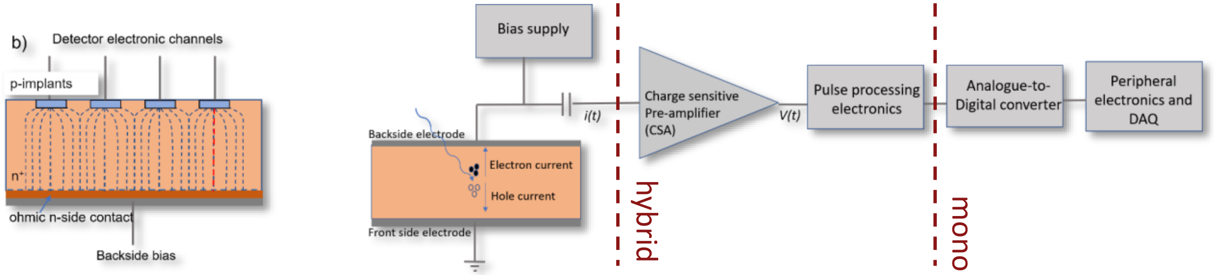
(ePix100, ePix10k, Jungfrau, etc.)



Monolithic pixel detector

(ePixM)





CCD

- X-ray created electron hole pairs in sensor. Transported to potential well under pixel electrode.
- Charge shifted from electrode to electrode, rows and then shift.
- Sensing takes place sequentially i.e. signal detected at end of readout by single sensing node.

Hybrid pixel detector and monolithic pixel detector

- X-ray creates electron-hole pairs in the sensor. The movement of the carriers directly induces a signal on the electrode.
- Each electrode has its own readout channel with amplifier, filter, and CDS (front end electronics).

Hybrid pixel detector

- In hybrid pixel detector the sensor and front end electronics are in different chips and bump-bonded together.
- Creates more noise, but any sensor can be used.

Monolithic pixel detector

- In monolithic sensor of ePixM type the sensor and electronics is in the same piece of silicon and this piece bonded to the ADC chip.
- Lower noise, but limits the real estate forcing less functionality.

Basic structure and operation of gain switching architecture

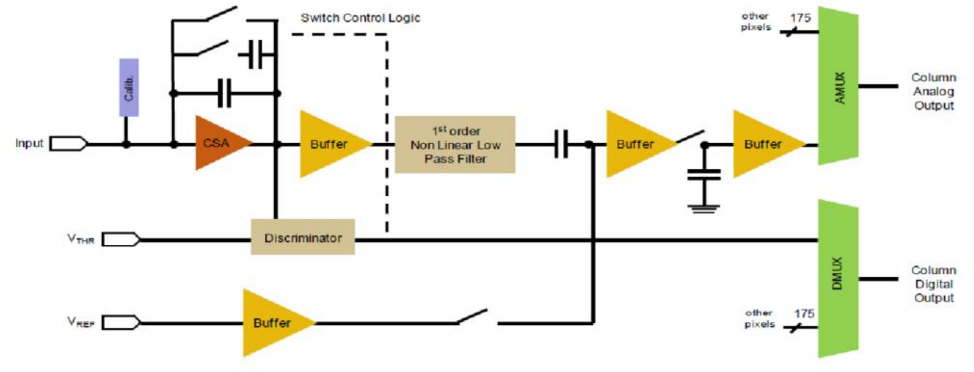
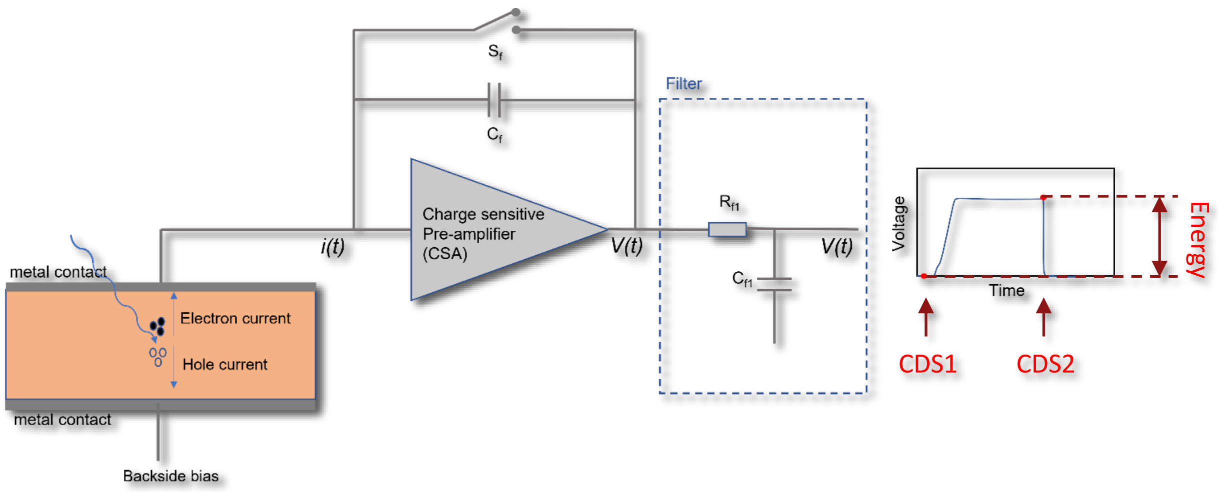
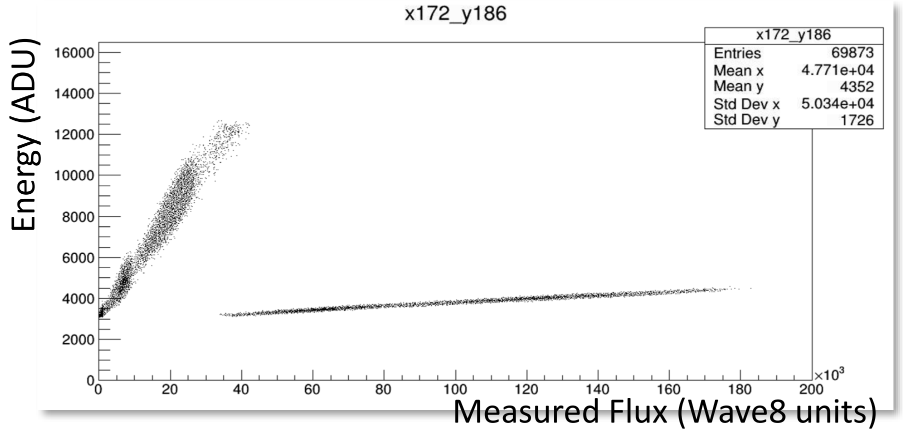


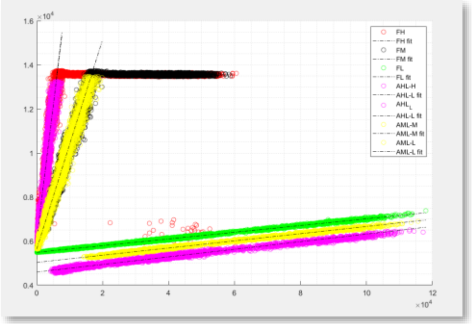
Figure 4. Simplified block diagram of the ePix10k pixel.



Basic operation:

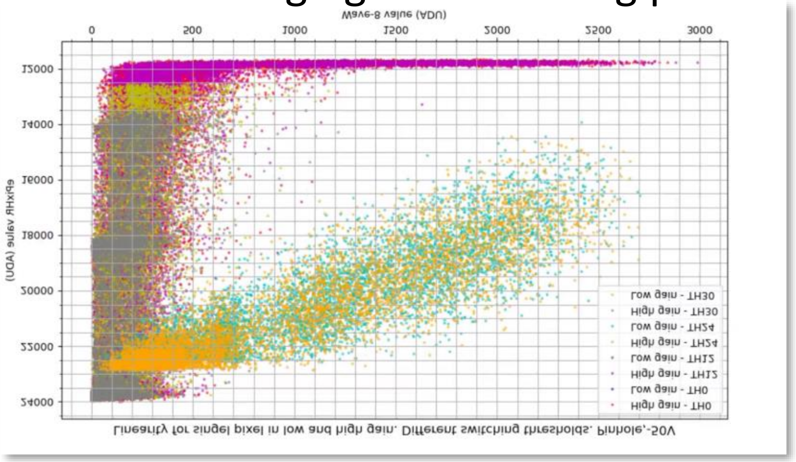
- Charge integrating detectors;
- Charge integrating onto CSA;
- The output of the CSA is sampled twice using the CDS, and the difference is reported as the photon signal;
- Gain switching – the channel change gain in the middle of the measurement.
- For ePixM only a single autoranging gain mode exists (AHL), but two pseudo modes have been tested (softHi and SoftLow)





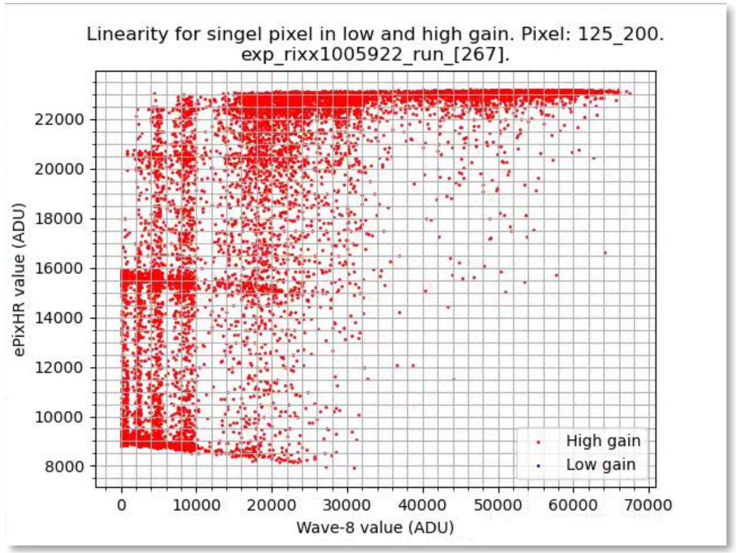
“Gain modes” for ePixM detector

Effect of changing the switching point

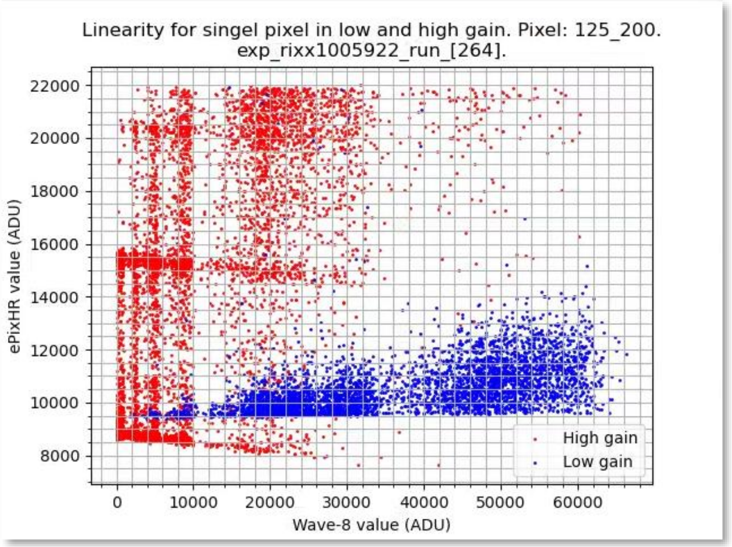


- Unlike ePix10k and ePixHR, ePixM only has a single , autoranging, gain mode – AHL.
- By changing the switching point position in energy we have created 2 pseudo modes: soft high and soft low,
- Auto-ranging mode AHL was the originally intended mode. However, it suffers from a CompEn issue, as will be described in the result section, that could cause issues in measurements. Hence we evaluated the two pseudo modes.
- Soft high avoids the complexities of auto ranging and only have single gain. The drawback is that this mode is limited to ~20keV dynamic range.
- Soft low maximize the dynamic range we have for the low range.

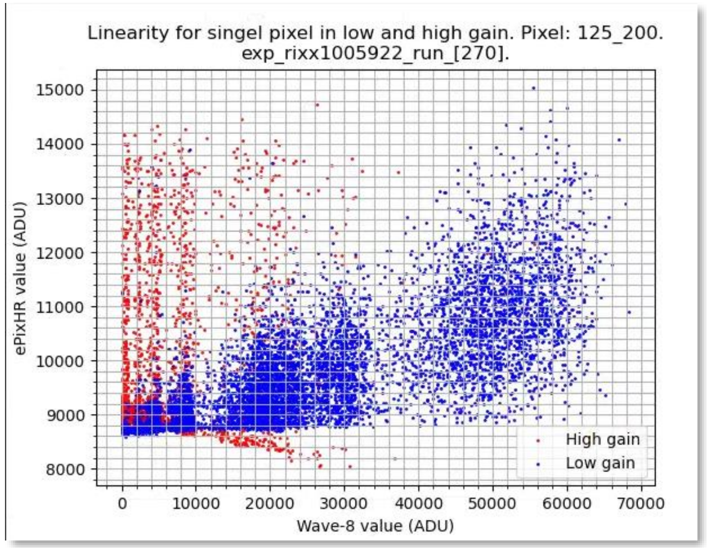
Soft-high



AHL



Soft-low



Detector timing: pixel readout cycle, Run and DAQ trigger

ePix10k block diagram – used for illustration purposes

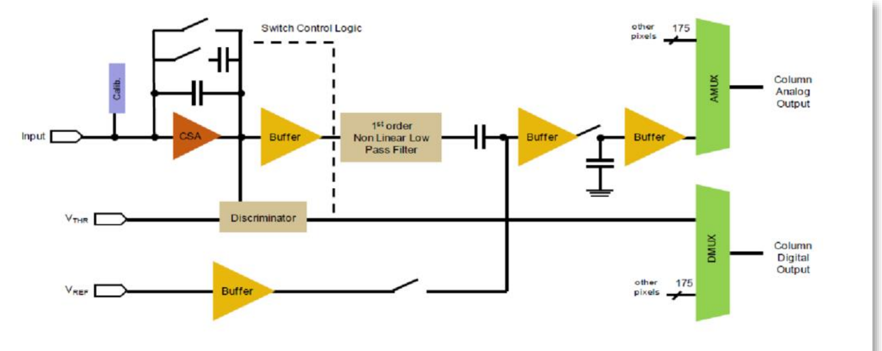
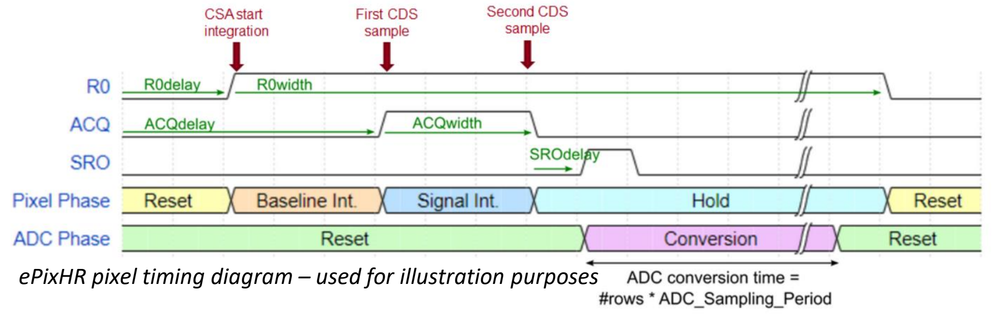


Figure 4. Simplified block diagram of the ePix10k pixel.

Pixel readout cycle



ePixHR pixel timing diagram – used for illustration purposes

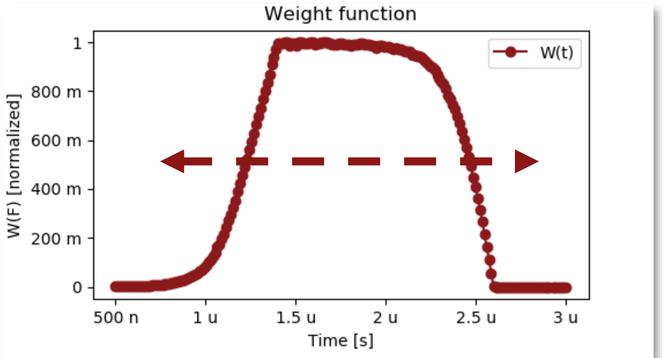
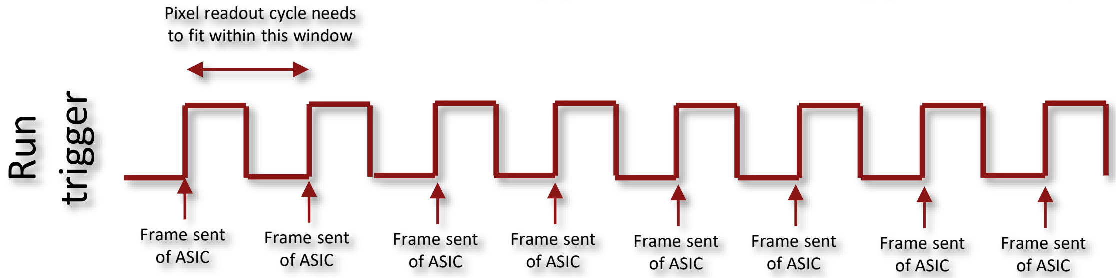
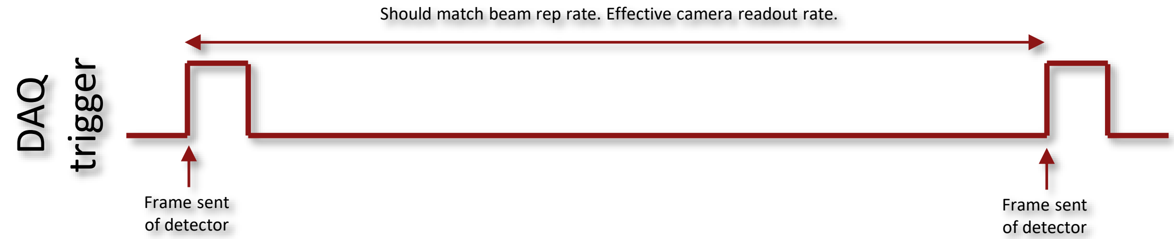


Illustration of run trigger and DAQ trigger principle





- The top-level detector timing is dictated by three timings, the *pixel readout cycle*, the *run trigger* and the *daq trigger*.

- The *pixel readout cycle* controls the timing of the processes making up an X-ray pulse measurement.
- The *Run trigger* controls the frame rate at which the ASIC is read out. A pixel readout cycle must fit within the run trigger rate.
- The *DAQ trigger* rate sets the rate at which a frame is sent from the electronic boards to the DAQ system. i.e. detector frame rate. The *run trigger* rate has to be a multiple of the *DAQ trigger* rate.
- The *DAQ* and *Run trigger* rates are separate so we can move to lower frame rates without changing the thermal stability of the ASIC.

LCLS_II machine rates and resulting ePixM frame rates

Allowed Subharmonic	Repetition Rate (Hz)	PUMP LASER 92857 Hz Subharmonics [0.3 mJ @ 800 nm]	PUMP LASER 35714 Hz Subharmonics [0.93 mJ @ 800 nm]	PUMP LASER 33163 Hz Subharmonics [1.0 mJ @ 800 nm]	DET ePix100	DET ePix10k	DET ePixHR	DET ePixHR-M
1	928,571.429							
2	464,285.714							
4	232,142.857							
5	185,714.286							
7	132,653.061							
8	116,071.429							
10	**92,857.143**	Yes						
13	71,428.571							
14	66,326.531							
16	58,035.714							
20	**46,428.571**	Yes						
25	37,142.857							
26	35,714.286		Yes					
28	33,163.265			Yes				
35	26,530.612							
40	23,214.286	Yes						
50	18,571.429	Yes						
52	17,857.143		Yes					
56	16,581.633			Yes				
65	14,285.714							
70	13,265.306	Yes						
80	11,607.143	Yes						
91	**10,204.082**							
100	9,285.714	Yes						
104	8,928.571		Yes					
112	8,290.816			Yes				
125	7,428.571							
130	7,142.857	Yes	Yes					
140	6,632.653	Yes		Yes				TENT
175	5,306.122							TENT
182	**5,102.041**		Yes				OK	OK
200	4,642.857	Yes					OK	OK
208	4,464.286		Yes				OK	OK
250	3,714.286	Yes					OK	OK
260	3,571.429	Yes	Yes				OK	OK
280	3,316.327	Yes		Yes			OK	OK
325	2,857.143						OK	OK
350	2,653.061	Yes					OK	OK
364	2,551.020		Yes	Yes			OK	OK
400	2,321.429	Yes					OK	OK
455	2,040.816						OK	OK
500	1,857.143	Yes				OK	OK	OK
520	1,785.714	Yes	Yes			OK	OK	OK
560	1,658.163	Yes		Yes		OK	OK	OK

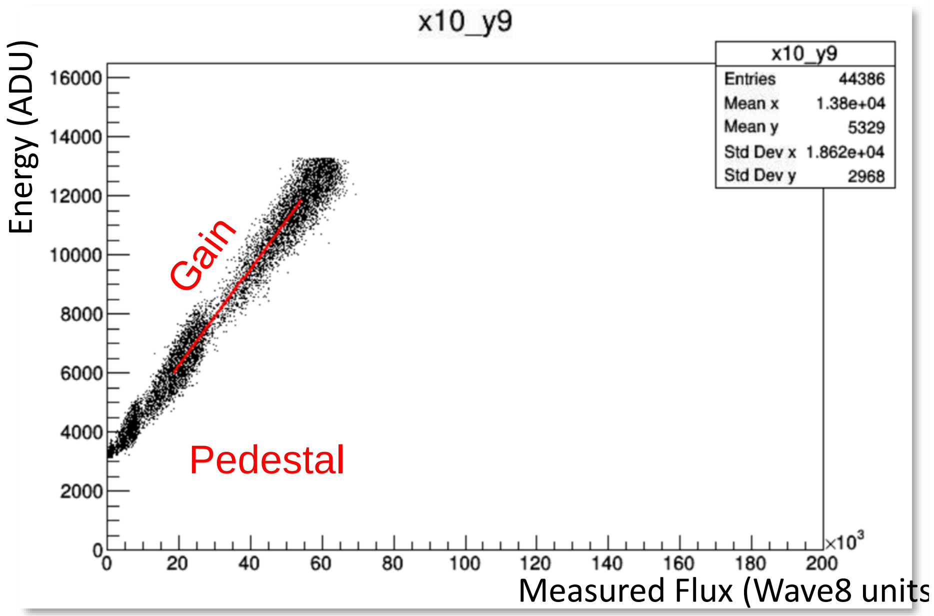
Currently the highest DAQ trigger rate

- LCLS-II machine rep rates and pulse laser rates
- The Run rate should be set to the highest rep rate expected at the station.
- The highest proper readout of the detector by the DAQ currently tested is 4680 Hz.

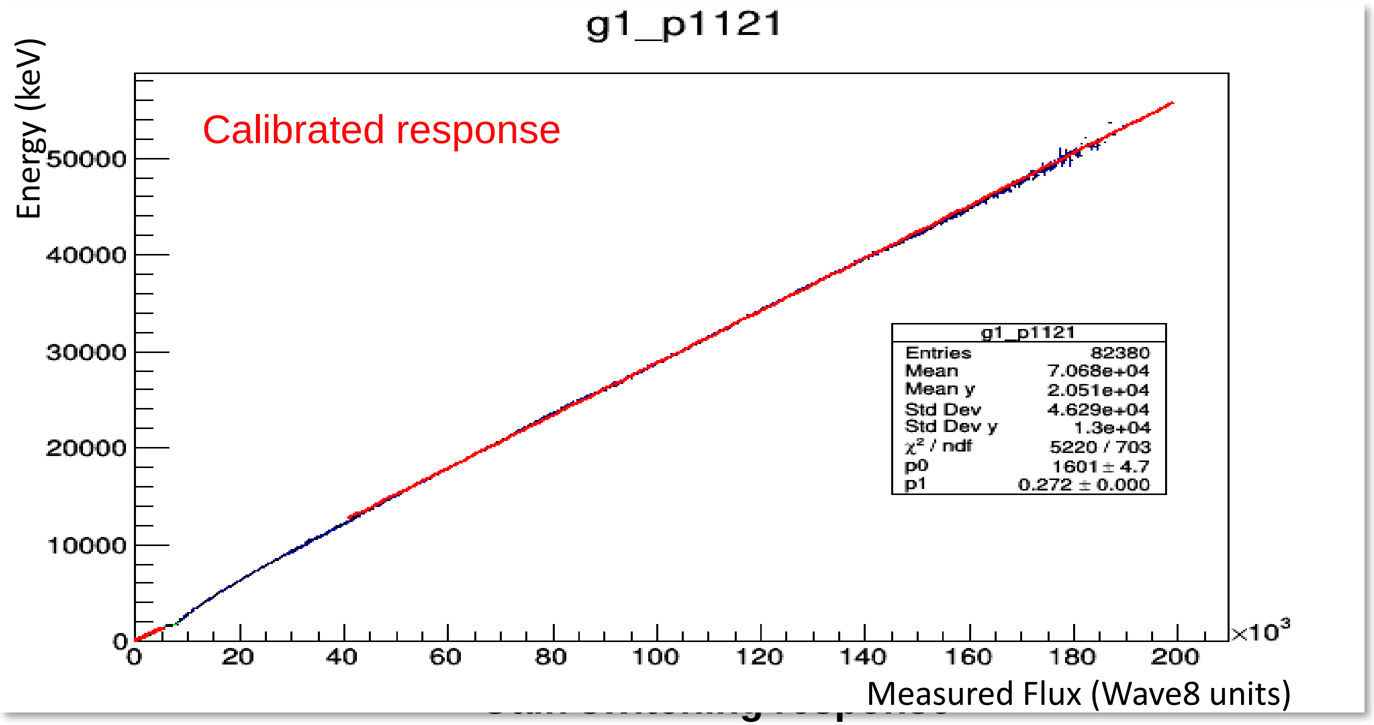
Run trigger	5305.551	5101.491	4642.357	4463.805	3713.886
Allowed DAQ triggers	5305.551	5101.491	4642.357	4463.805	3713.886
	2652.776	2550.746	2321.179	892.761	1856.943
	1326.388	1275.373	928.4714	637.6864	928.4714
	1061.11	1020.298	663.1939	178.5522	742.7771
	663.1939	637.6864	464.2357	127.5373	530.5551
	530.5551	510.1491	357.1044	35.71044	464.2357
	408.1193	255.0746	331.5969	25.50746	371.3886
	331.5969	204.0597	185.6943	7.142088	285.6835
	265.2776	127.5373	178.5522	5.101491	265.2776
	212.222	102.0298	132.6388	1.020298	185.6943
	204.0597	51.01491	92.84714	0	142.8418
	132.6388	40.81193	71.42088	0	132.6388
	106.111	25.50746	66.31939	0	106.111
	102.0298	20.40597	51.01491	0	92.84714
	81.62386	10.20298	35.71044	0	71.42088
	66.31939	8.162386	26.52776	0	66.31939
	53.05551	5.101491	25.50746	0	57.1367
	51.01491	4.081193	14.28418	0	53.05551
	40.81193	2.040597	13.26388	0	40.81193
	26.52776	1.020298	10.20298	0	35.71044
	25.50746	0	7.142088	0	28.56835
	20.40597	0	5.101491	0	26.52776
	16.32477	0	2.040597	0	20.40597
	13.26388	0	1.020298	0	14.28418
	10.20298	0	0	0	13.26388
	8.162386	0	0	0	10.20298
	5.101491	0	0	0	8.162386
	4.081193	0	0	0	7.142088
	2.040597	0	0	0	5.101491
	1.020298	0	0	0	4.081193
	0	0	0	0	2.040597
	0	0	0	0	1.020298

- Run rates matching allowable machine rates and the corresponding allowed DAQ trigger rates

Energy calibration principle



Single gain stage response



In theory only two values needed for each gain configuration to energy calibrate it: **gain** (ADU/keV) and **pedestal** (ADU)

2 calibrations:

- Energy
- Geometry

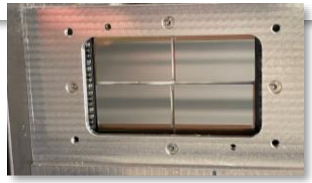
Parameter	ePix10k	epixM
Gains	3 – Fixed (H, M, L)	2 (H/L)
Gain modes	5 – (FH, FM, FL, AHL, AML)	1 (3)– AHL (softLow, softHigh)
No of pedestals	7 (FH,FM,FL, AHL, AML, AHL-L, AML-L)	2 (AHL-H, AHL-M)
Switching position for autoranging modes	AHL: ~100x8keV AHL: ~100x8keV	

Current production module quality (1)

These tests were done with digital board C00-01

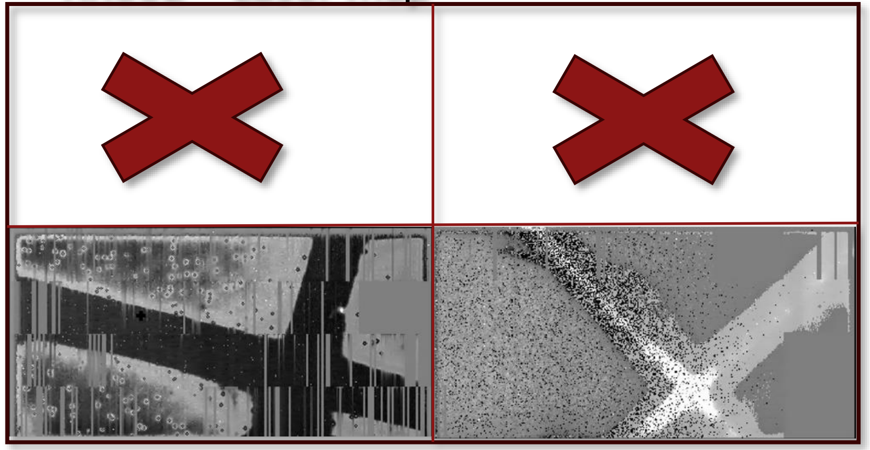
ASIC 0 | ASIC 1

ASIC 3 | ASIC 2

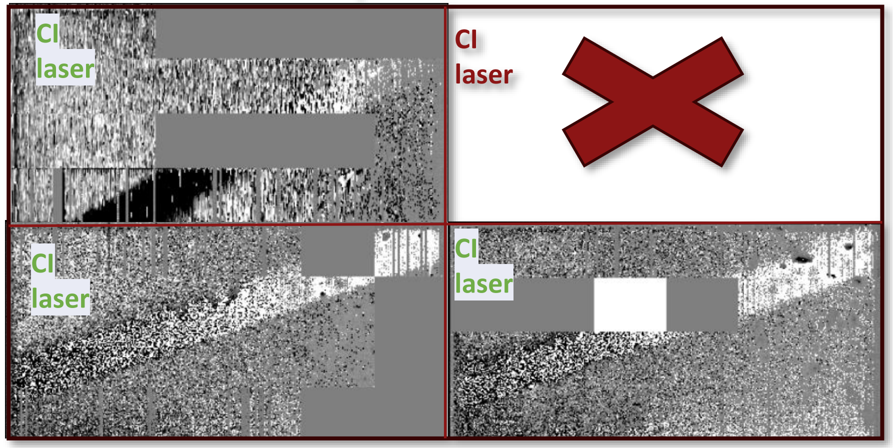


ID	Locked lanes	Charge injection	Laser	BIAS	ASIC2 Failing lanes	ASIC3 failing lanes	Charge injection Notes
RX002	42 / 48	ASIC2, ASIC3	✅	✅	16, 22, 23	2, 21, 22	ASIC 3 charge injection does not seem to respond to pulser value
RX003	44 / 48	ASIC2, ASIC3	✅	✅	16, 22, 23	21	
RX004	43 / 48	ASIC2, ASIC3	✅	✅	16, 20, 22, 23	21	
RX005	44 / 48	ASIC2, ASIC3	✅	✅	16, 22, 23	21	ASIC 3 charge injection does not seem to respond to pulser value
RX006	41 / 48	ASIC2, ASIC3	✅	✅	16, 22, 23	0, 3, 6, 21	
RX007	43 / 48	ASIC2, ASIC3	✅	✅	16, 21, 22, 23	21	ASIC 3 charge injection does not seem to respond to pulser value

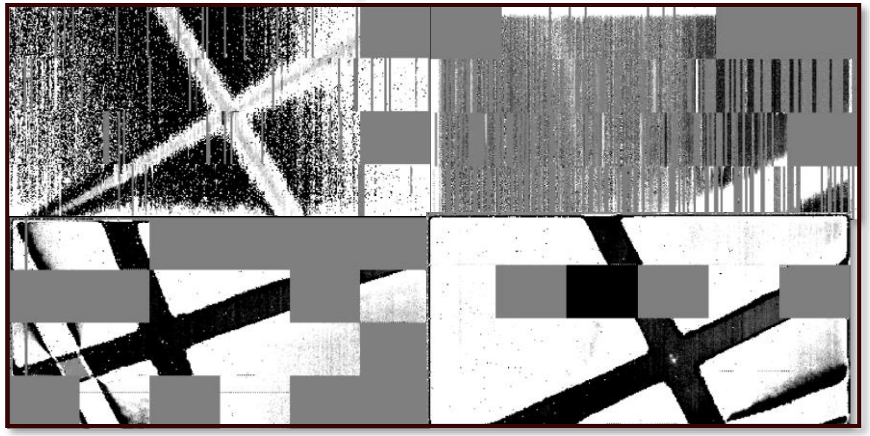
RX002 – Laser map



RX003 – laser map

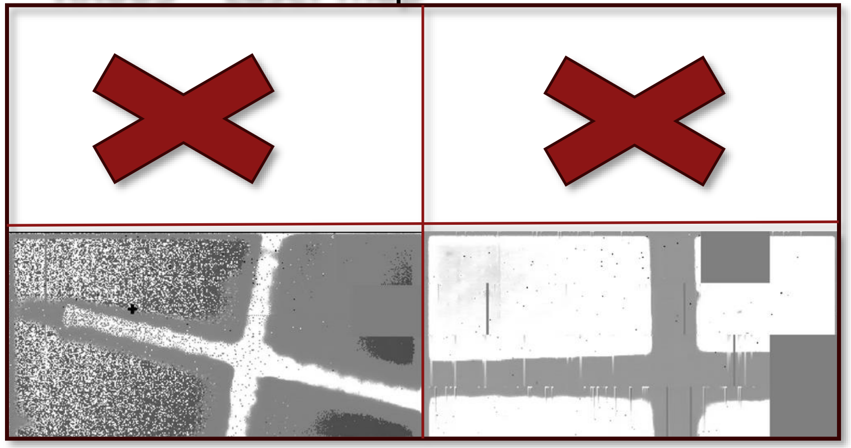


RX004 – Laser map

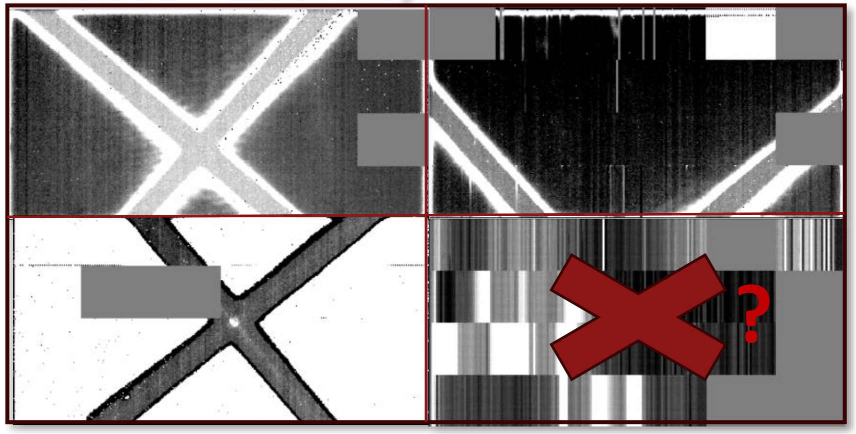


Current production module quality (2)

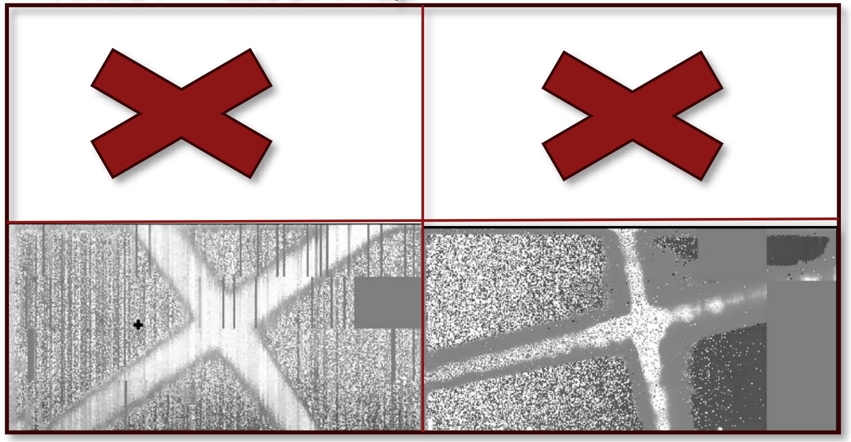
RX005 – Laser map



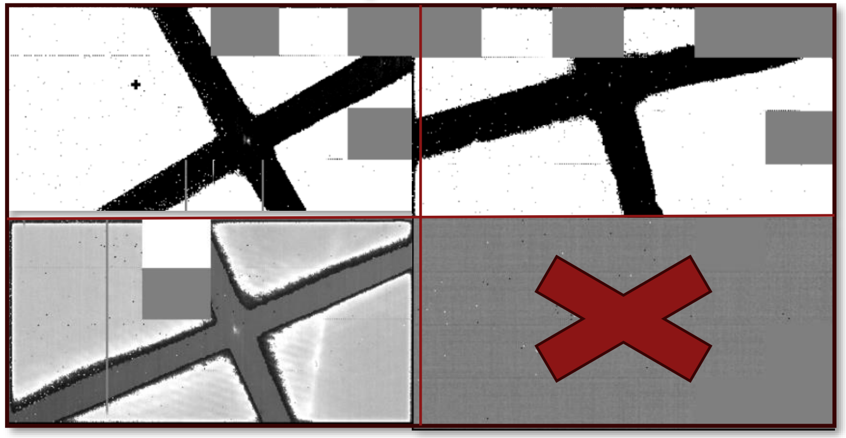
RX006 – Laser map



RX007 – Laser map

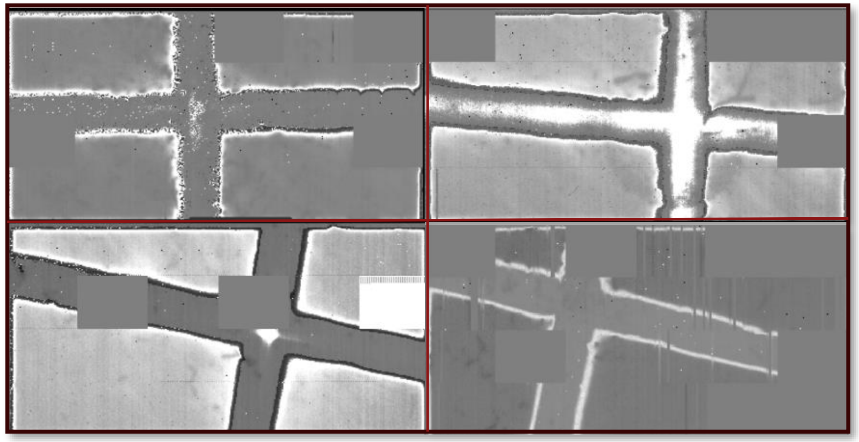


RX008 – Laser map

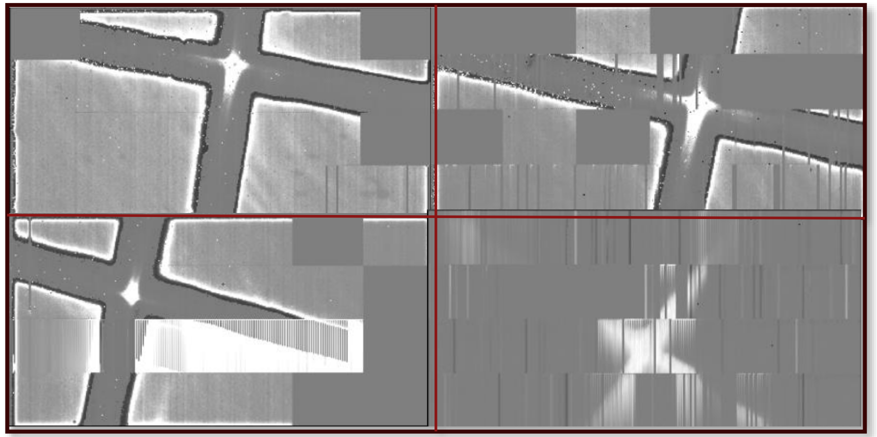


Current production module quality (3)

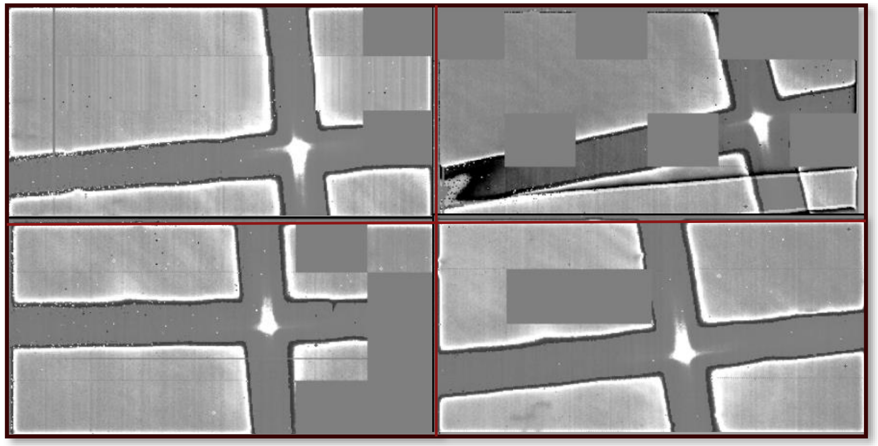
RX010 – Laser map



RX011 – Laser map



RX012 – Laser map



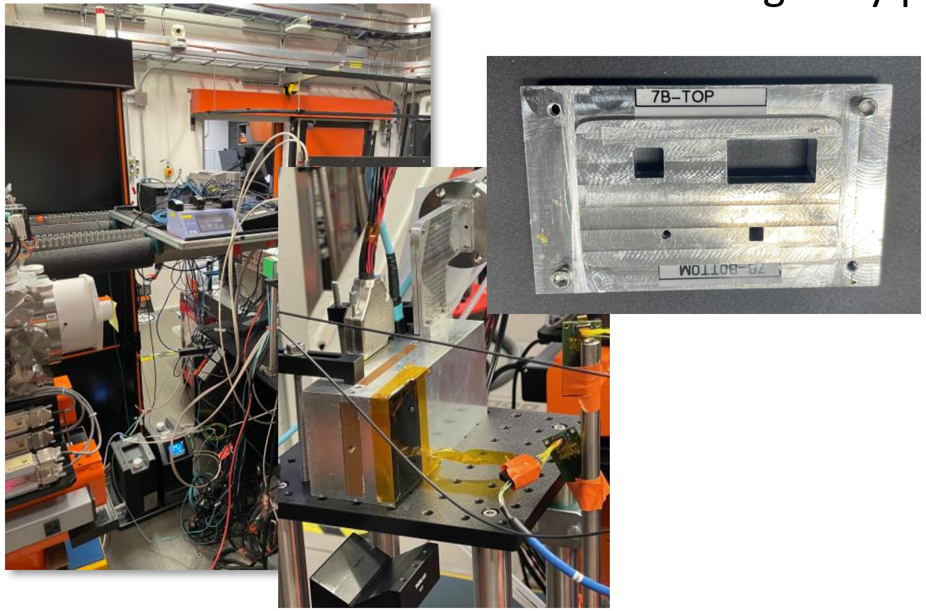
Overview

- 10 modules have been produced, 20 more are being made.
- All ASICs have regions, small or large, that can not be used.
- Less than half of the modules have all 4 ASICs active.
- Of the total 30 modules being produced, the best will be selected and incorporated into the cameras that will be delivered to RIXS.

Detector requirements

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

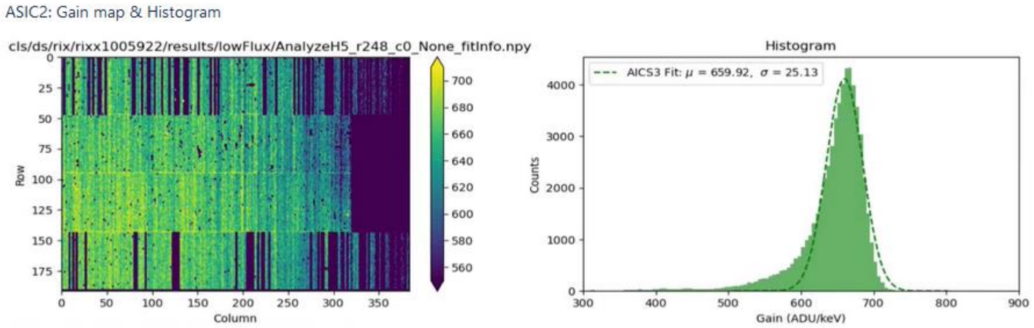
- List of originally provided requirements for the ePixM detector

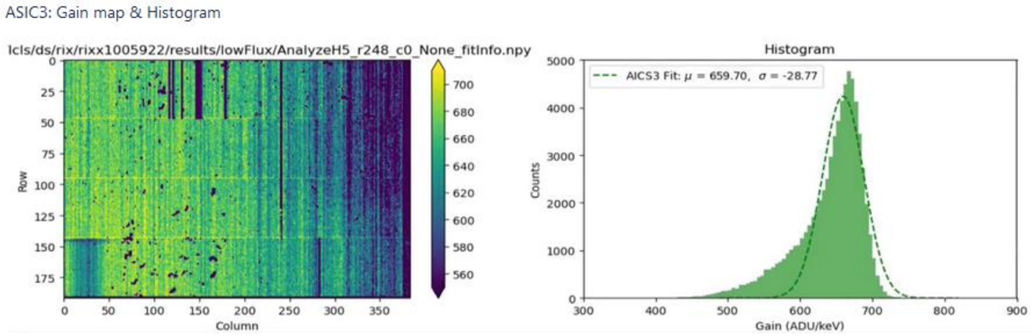


- Majority of testing performed at MFX using RIXS-DAQ
- Primarily evaluate the detector performance using air scattering at different attenuation levels (linearity scans and low flux data collection) and with various masks.

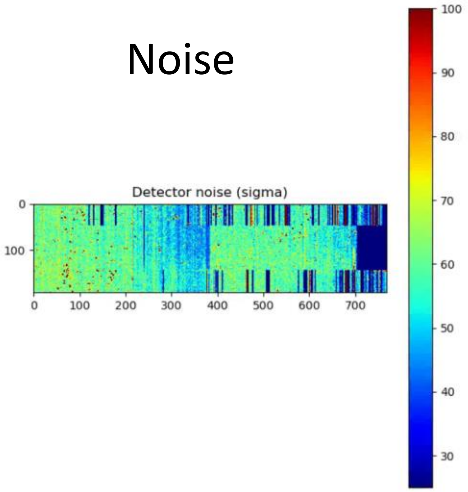
Noise, Pedestal, and gains in High gain region.

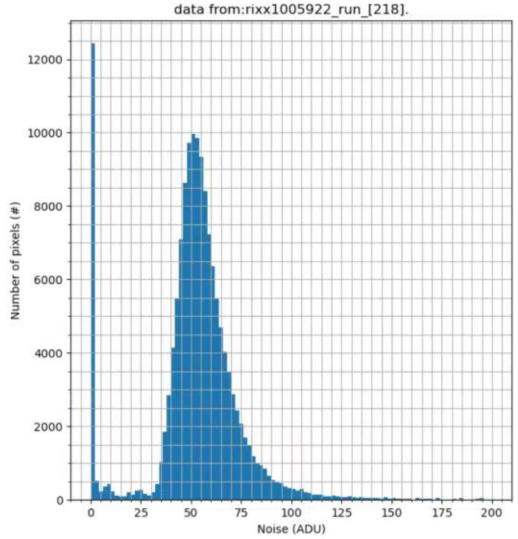
Measured gains



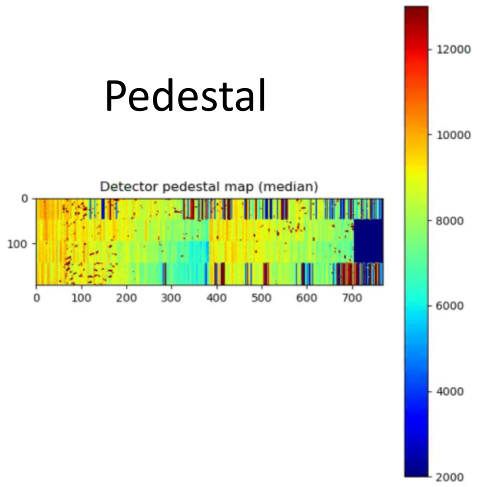


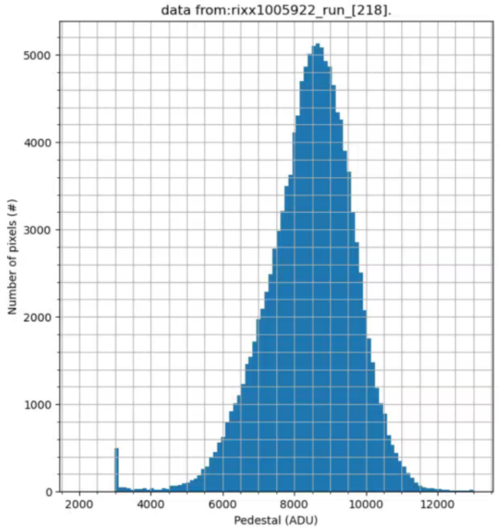
Noise





Pedestal

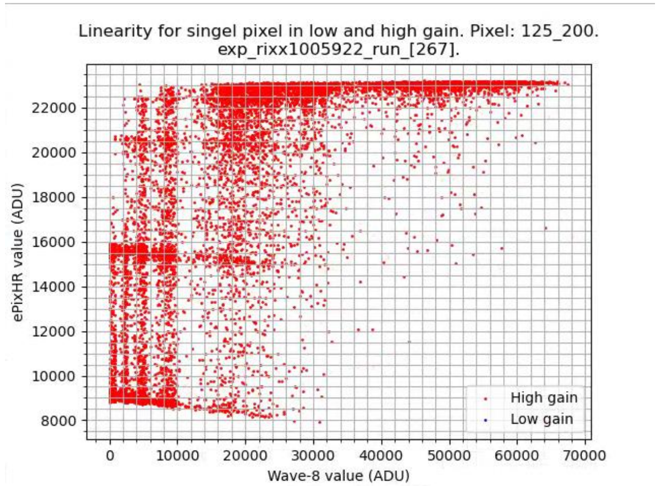


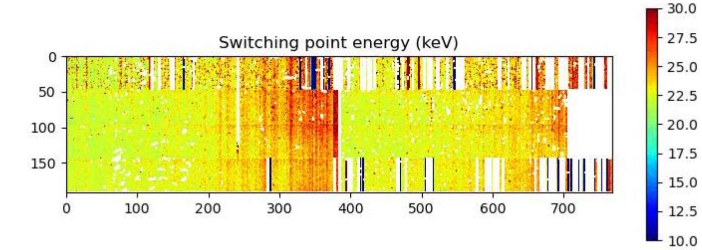


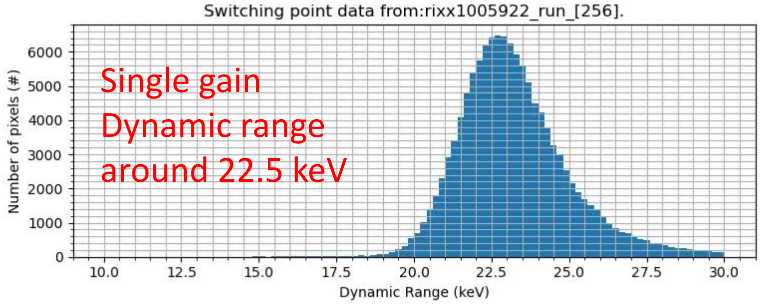
- Peak of noise distribution: ~50ADU
- Estimated gain: 659ADU/keV
- Noise: ~75.8eV = 21e-
- Spatial distribution present.

Switching point energy and variation for the different “gain modes”

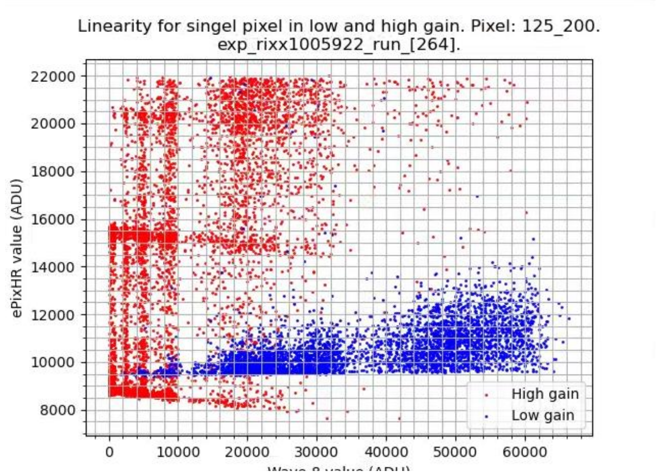
Soft-high

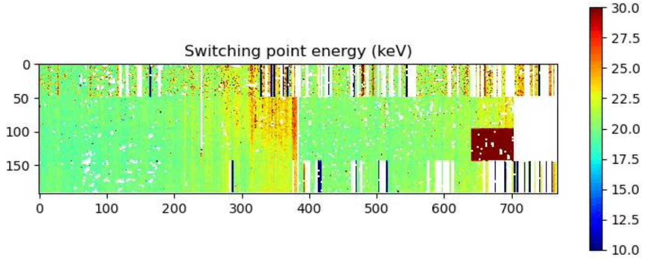


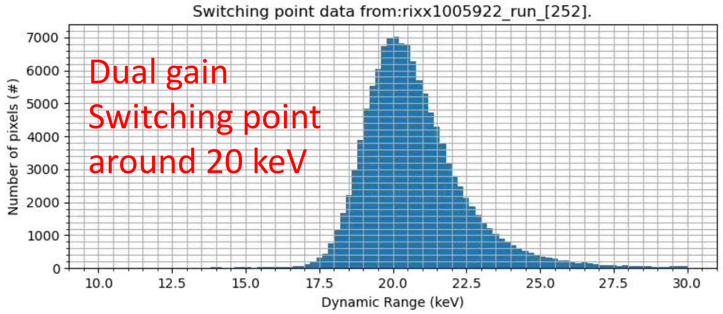




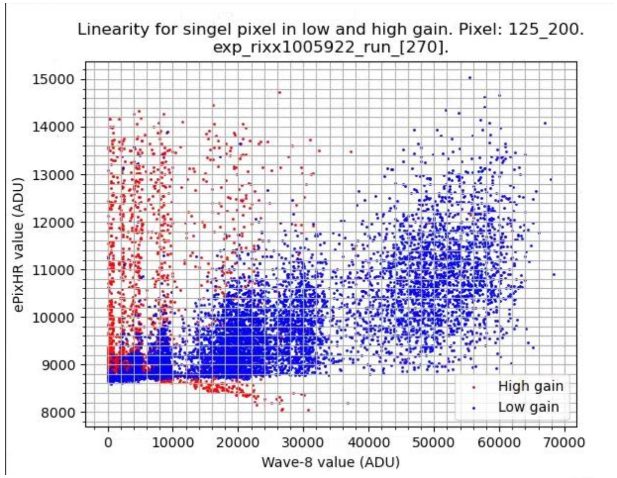
Auto-ranging

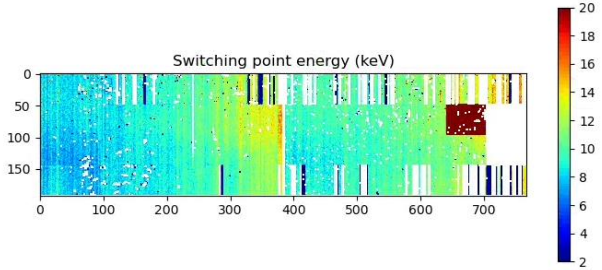


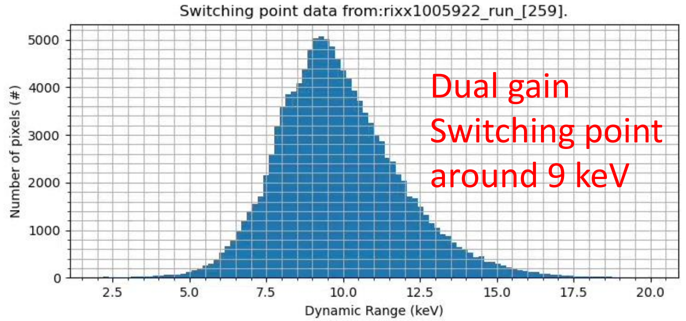




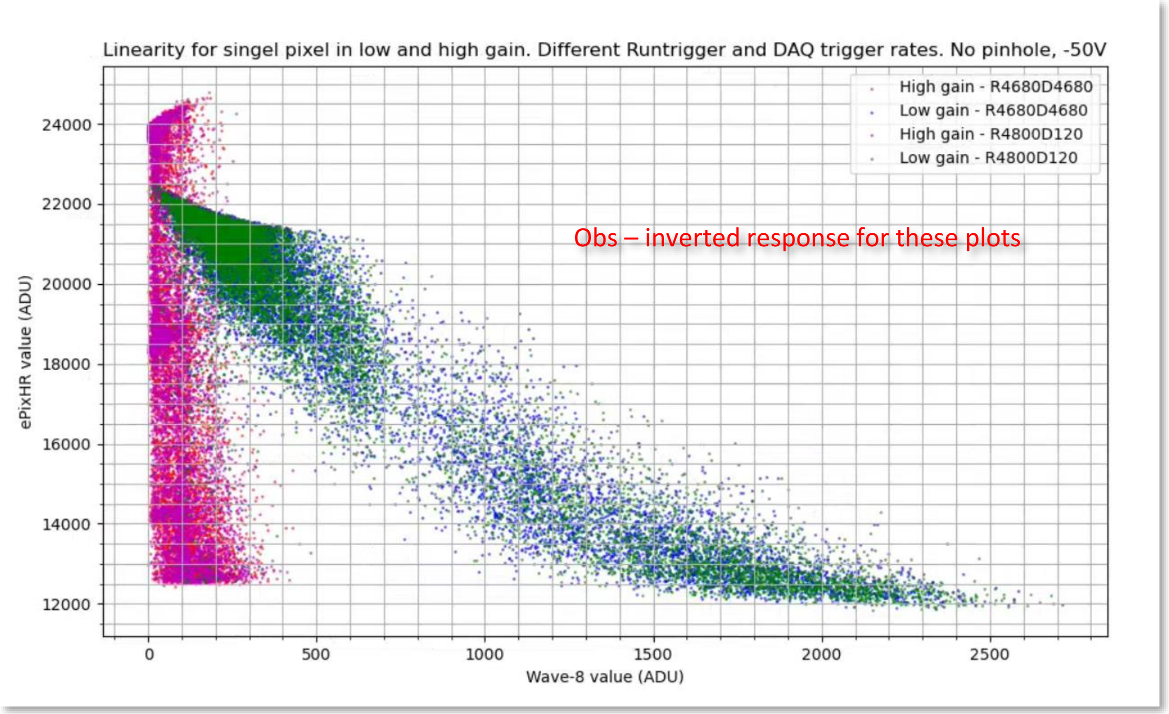
Soft-low

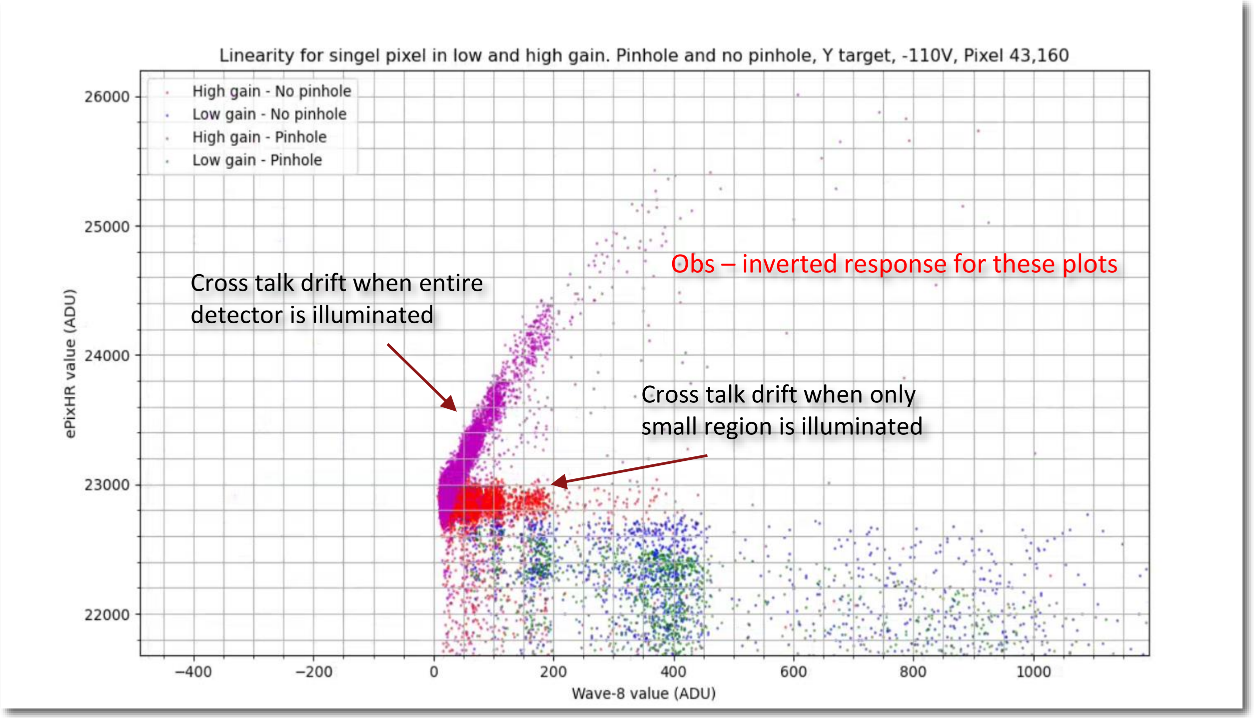






Maximum evaluated DAQ trigger rate and the crosstalk effect

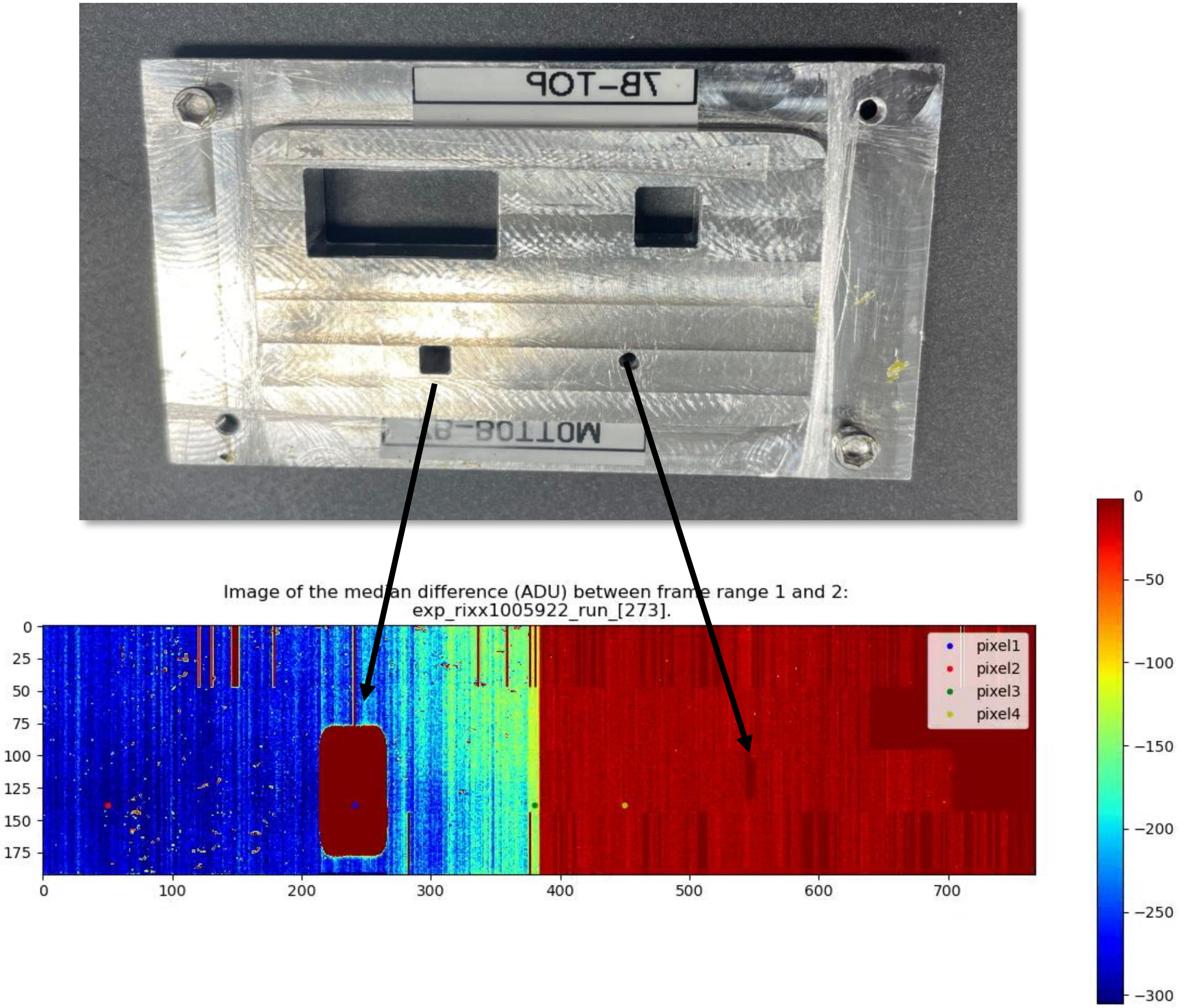


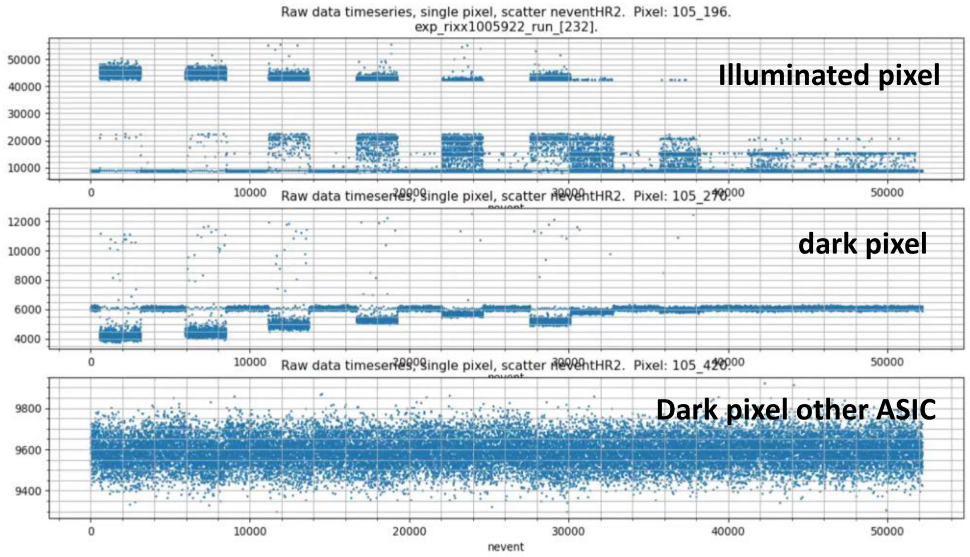


- Taken with full illumination;
- Two different run and daq trigger rates;
- Appear to have very similar response;
- Baseline drift observed in both (referred to as cross talk)

- Evaluation with and without a pinhole. Highlighting the Cross talk dependance on total flux the detector is seeing.

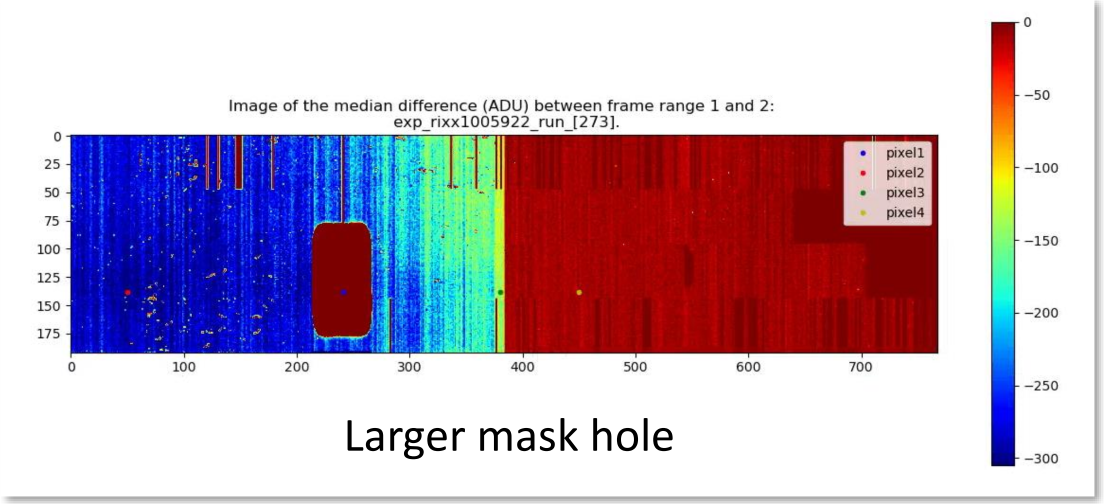
Evaluation of cross-talk effect



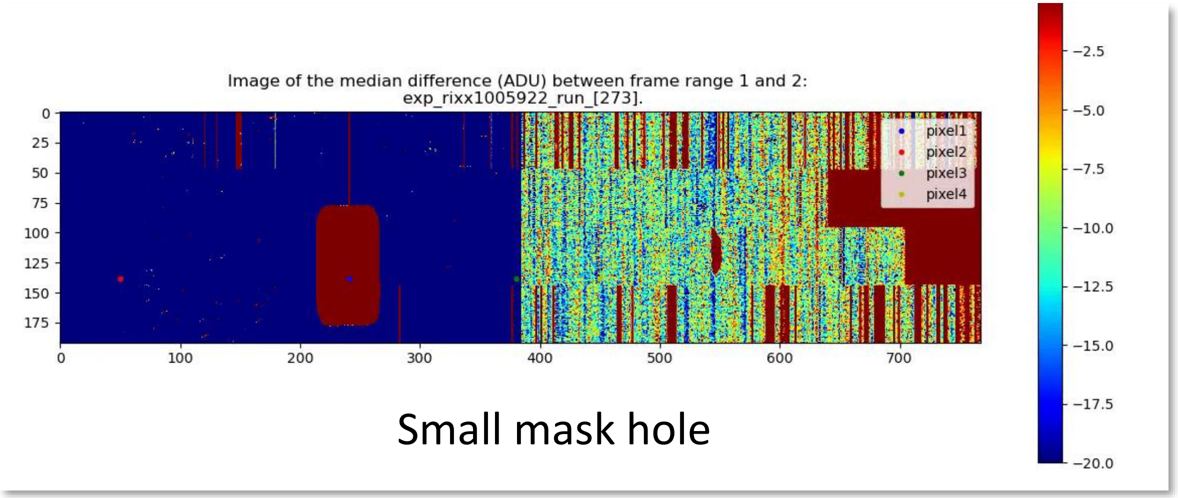


- Measurement campaign to understand cross-talk. Air scatter attenuation scans with different masks to evaluate the drift.
- The shift in non-illuminated pixels between zero beam transmission and full beam transmission was evaluated for different total X-ray energy deposited in sensor (different mask sizes).

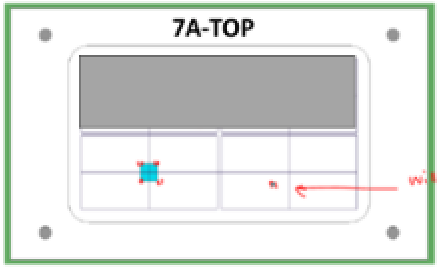
Spatial dependance of the cross-talk to the smaller mask openings.



Larger mask hole

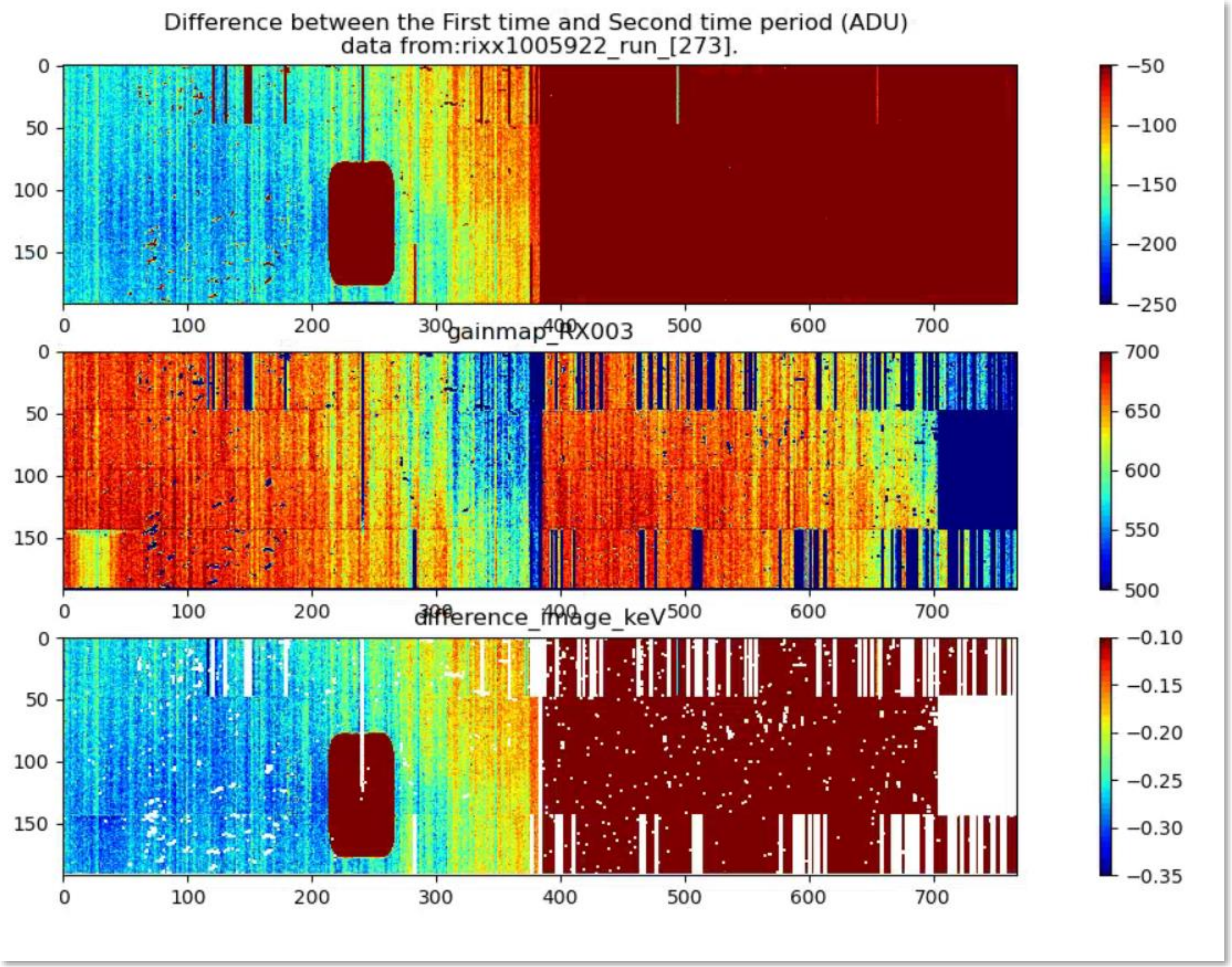


Small mask hole



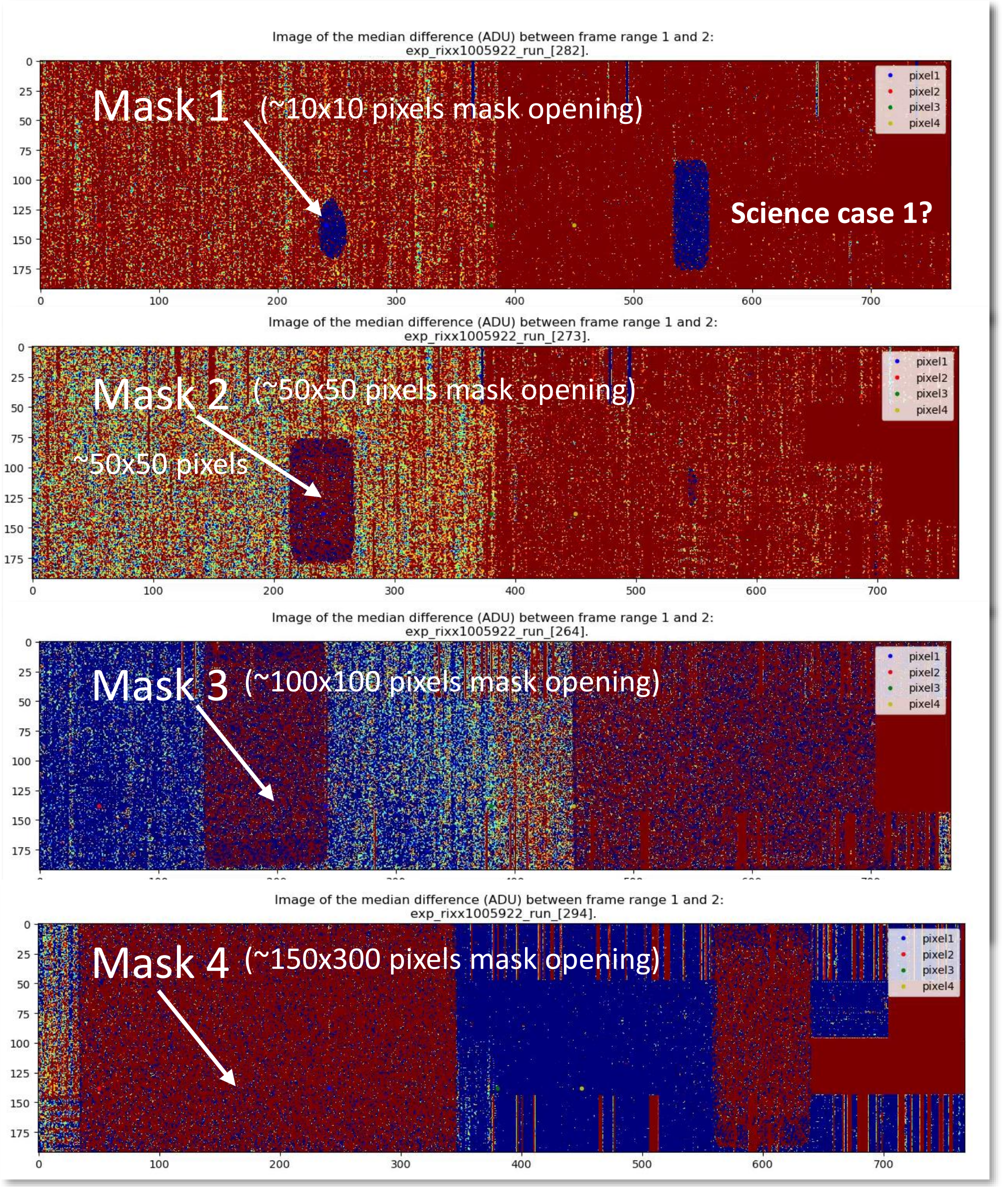
- Baseline shift appear to have a striped (column) behavior with a grading showing the same dip as the gain map.
- Potential correction method could use region of darked out pixels that allow for per shot drift monitoring,
- The columnar structure in the map above would suggest such a method is needed. It should be implemented using a row-blocking approach.

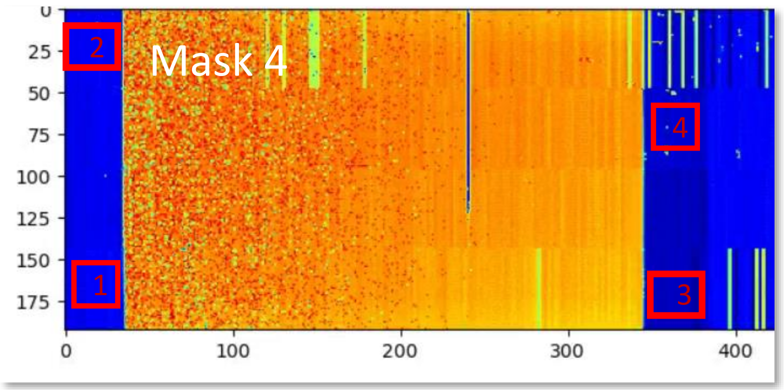
Update on previous slide: adding gain maps and resulting baseline shifts in keV



Gain correction does not appear to produce any significant increase of uniformity for the spatial variation of the baseline shift.

Baseline shift as a function of deposited charge (different masks) – including keV values





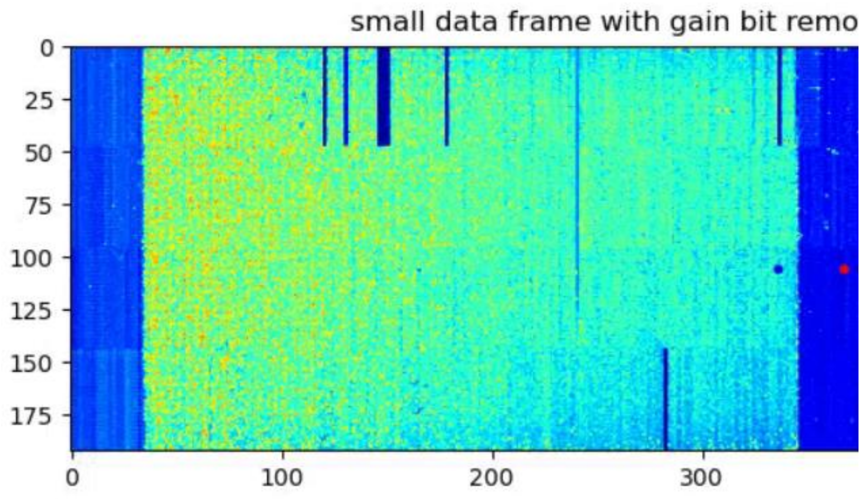
Mask	Region 1 baseline shift		Region 2 baseline shift		Region 3 baseline shift		Region 4 baseline shift		Run
	ADU	keV	ADU	keV	ADU	keV	ADU	keV	
4	3015.25	4.69	3027.5	4.65	2694.75	4.61	2653.75	4.82	294
3	1271.5	1.97	1139.0	1.83	783.0	1.31	676.5	1.21	264
2	182	0.28	168.5	0.26	112.0	0.18	96.0	0.17	273
1	13.5	0.022	13.0	0.017	8.0	0.013	5.5	0.009	282

All shifts are for the high gain.

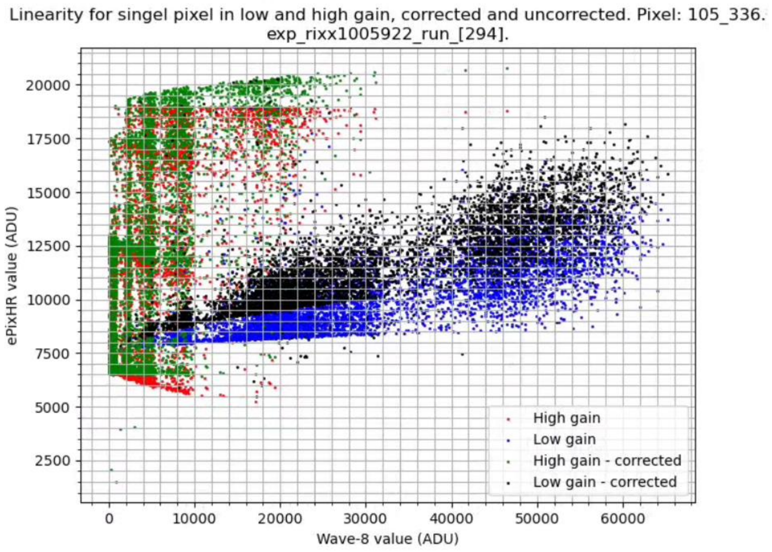
- The average cross-talk drift for 4 different regions was evaluated as a function of increasing the total amount of X-rays absorbed in the sensor (mask1-4). The drift is found in the table above.
- This is only evaluated for the high gain response here, the effect on low gain region still needs to be understood.
- The effect is neglable for small deposition doses; for larger doses, it is not. Which scenario are the RIXS applications going to have?

Potential correction (in high gain)

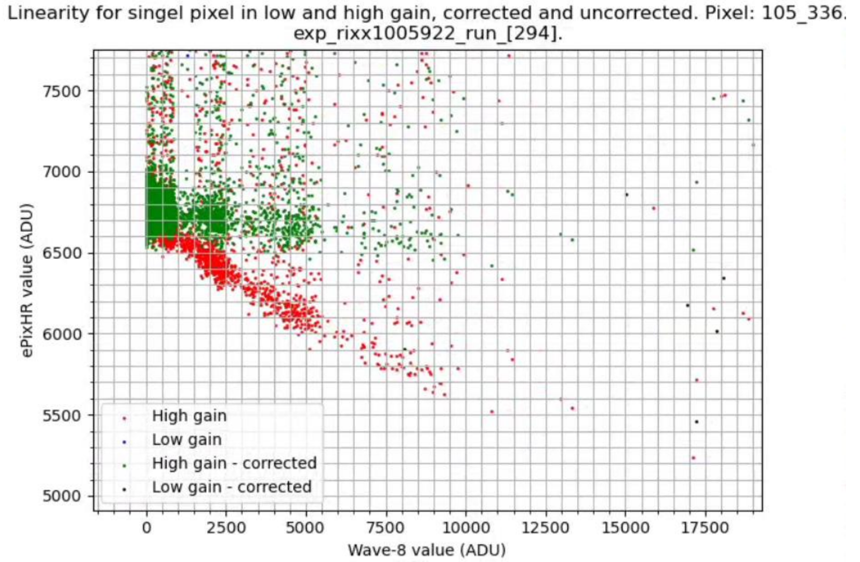
Pixel positions



Linearity comparison corrected and uncorrected

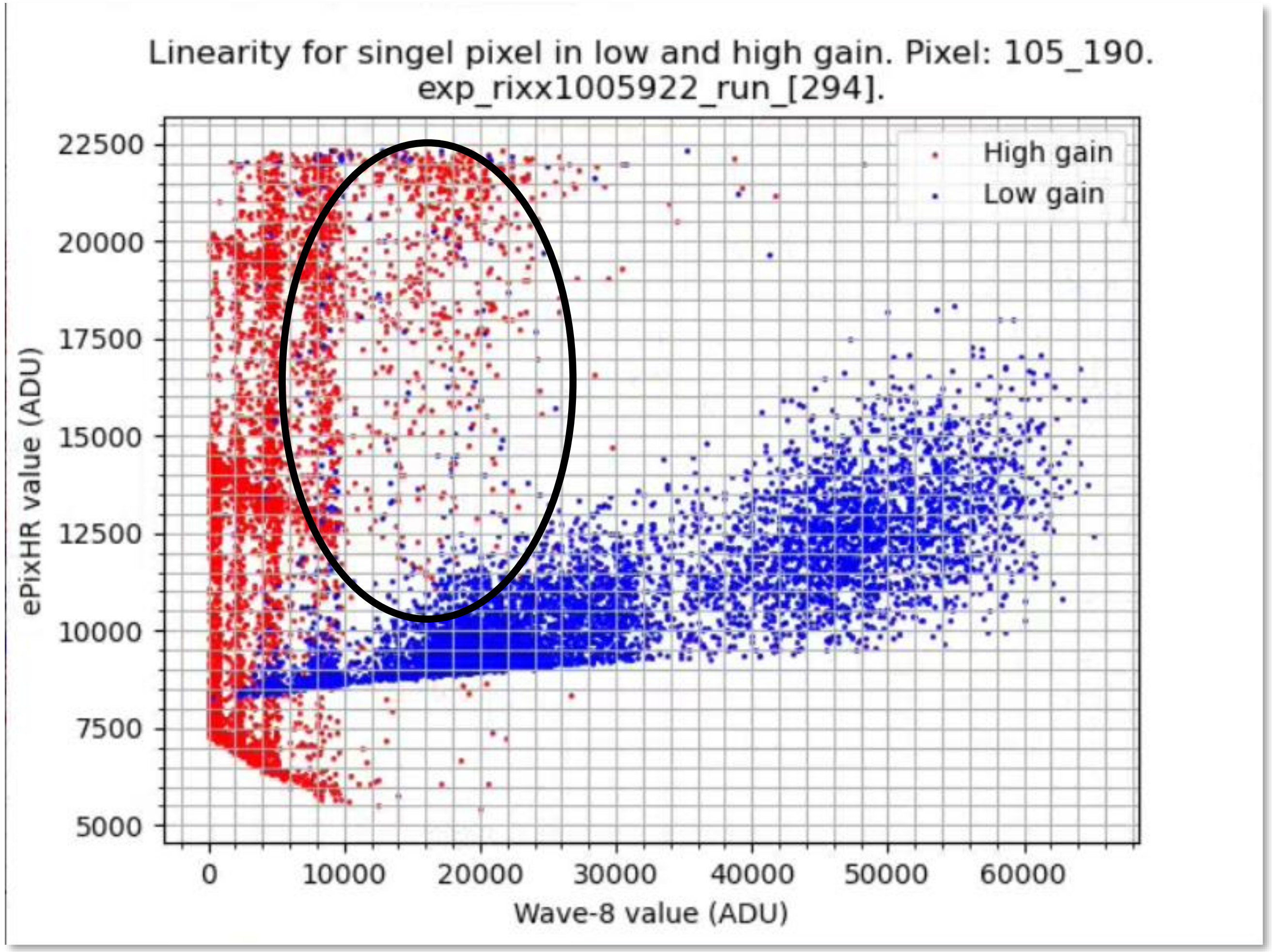


Baseline (pedestal)



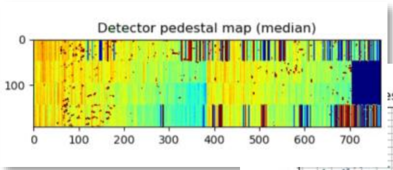
- Evaluation of the potential correction methodology – monitoring a dark pixel (red in image) and using its shift to correct for an illuminated pixel (blue).
- The corresponding correction using this method can be seen in the center and right plots.

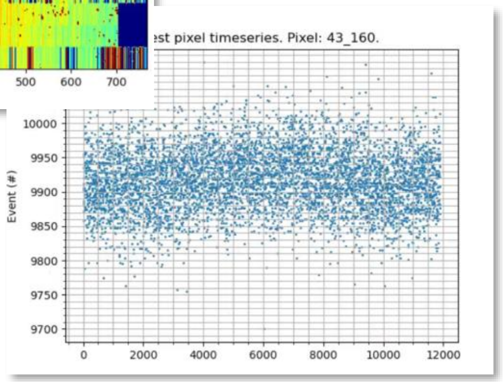
CompEn issue



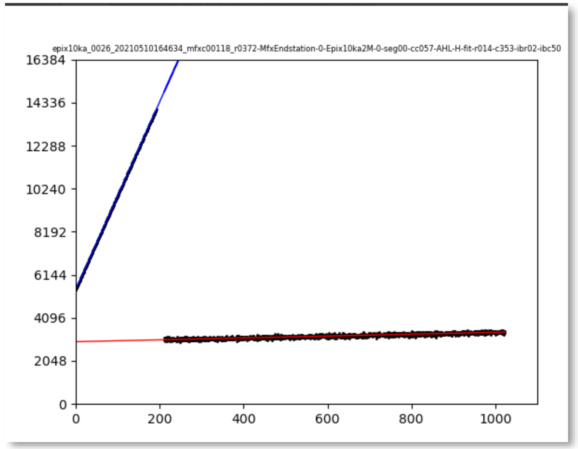
- CompEn problem: If the pixel is triggered to go into low gain mode to close to the second CDS, then the amplifier will not have enough time to settle to the new value and will be recorded as having a very high energy.
- This is more prevalent when the photon energy is close to the switching point energy of the pixel. This can not be corrected.

How do we calibrate?

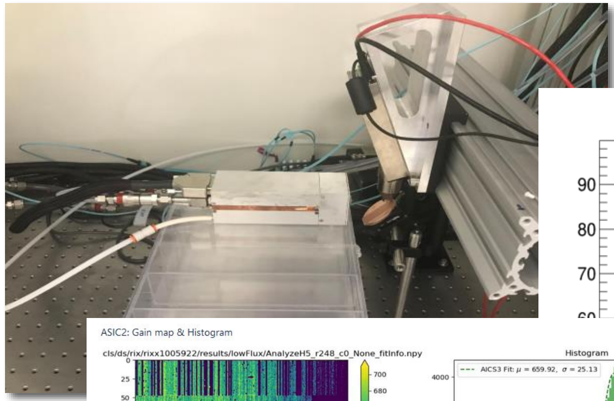


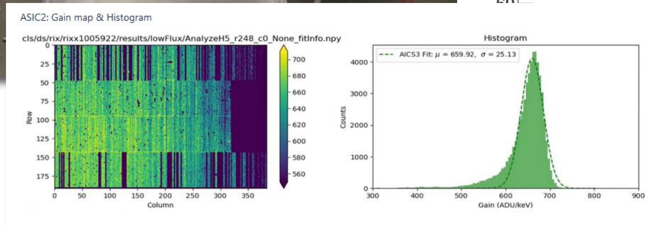


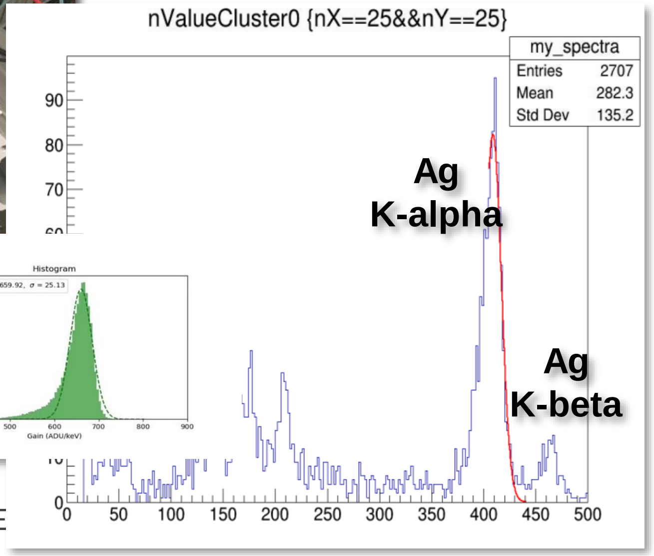
High pedestal: per pixel - average dark over 1000 frames



Low gain: per pixel - absolute high gain ratio multiplied by the relative gain ratio of high and low as determined using charge injection. **TBD**

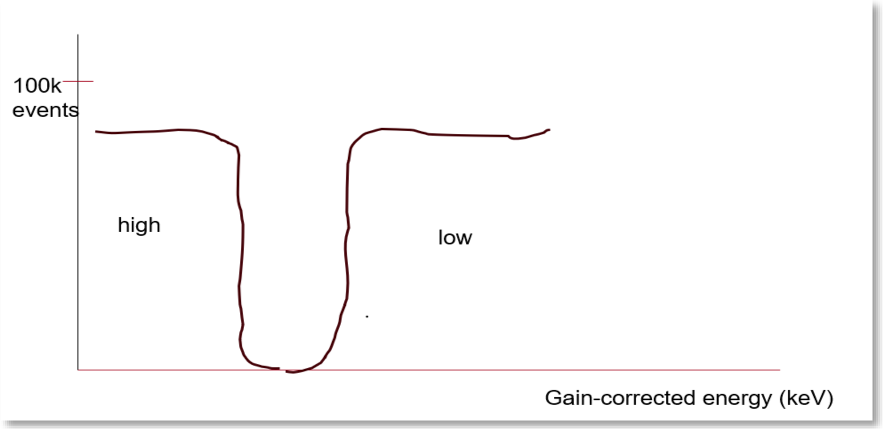






High gain: per pixel - photon peak (absolute gain)

SE



Low pedestal: per pixel - force the low response to fit to the high response (offset), and assume this value follows the high pedestal. **TBD**