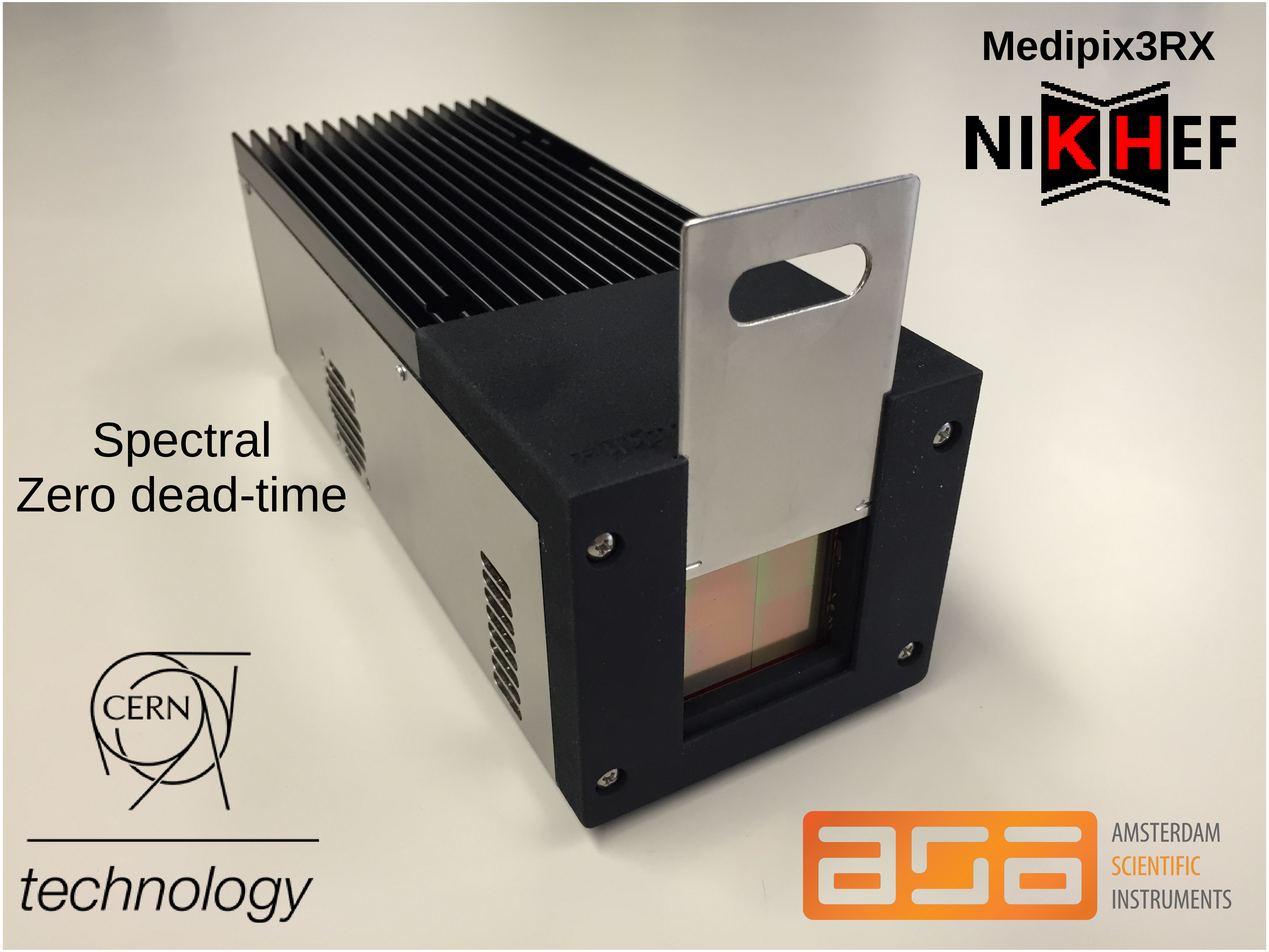


John Idarraga

High Sensitivity Mammography with a new generation of silicon pixel sensors

NIKHEF | AMSTERDAM SCIENTIFIC INSTRUMENTS

Fast readout (SPIDR), mechanics and software.

Universiteit Utrecht
A. Mischke

UMC Utrecht
H. de Jong

Contact with radiology group and Physicians. Test on a working Mammography setup.

CERN

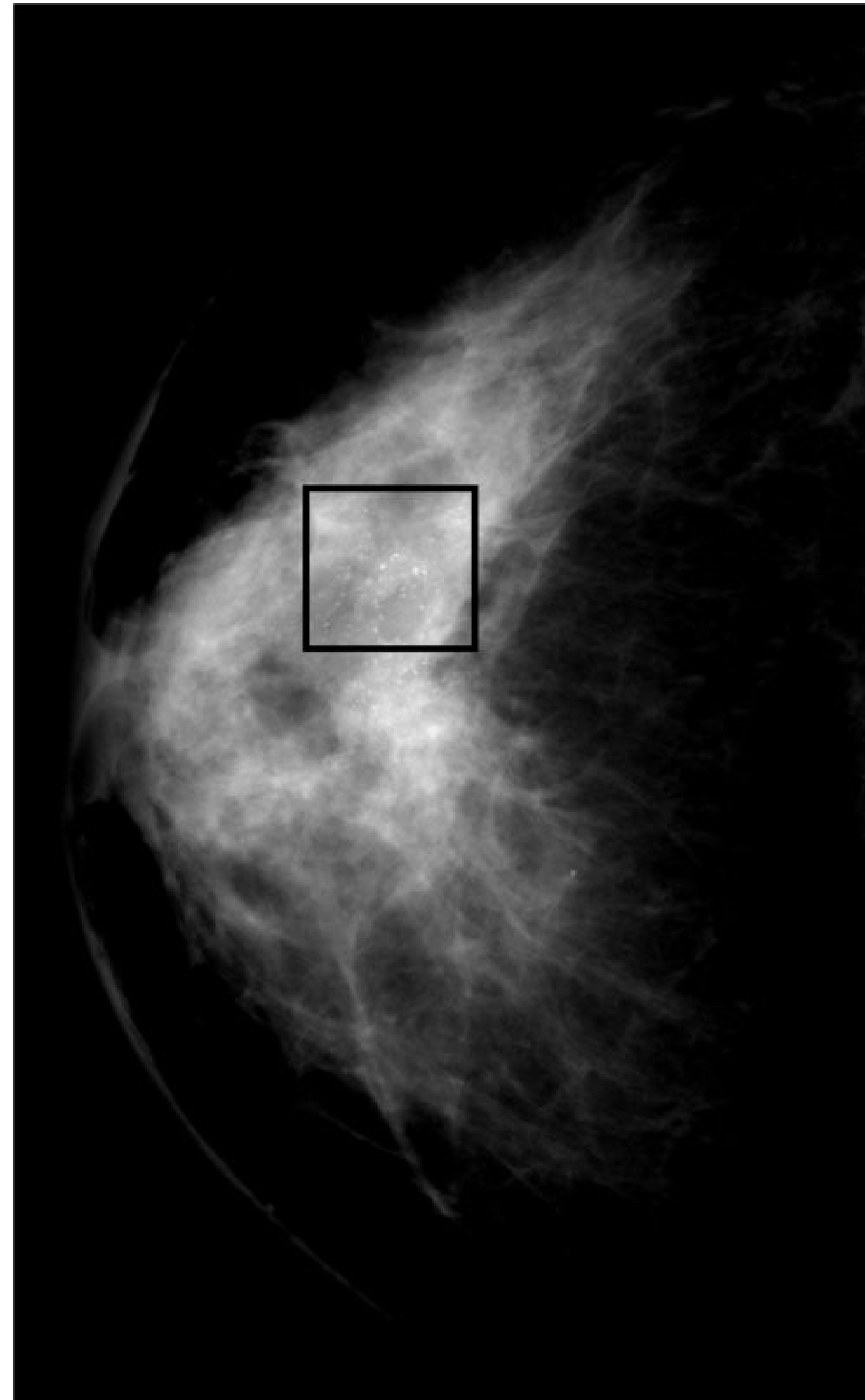
Chip design and test-beam.

Image courtesy UMC Utrecht

1) X-Ray source

2) Detector

Mammography
3) Object
Human breast
Phantom



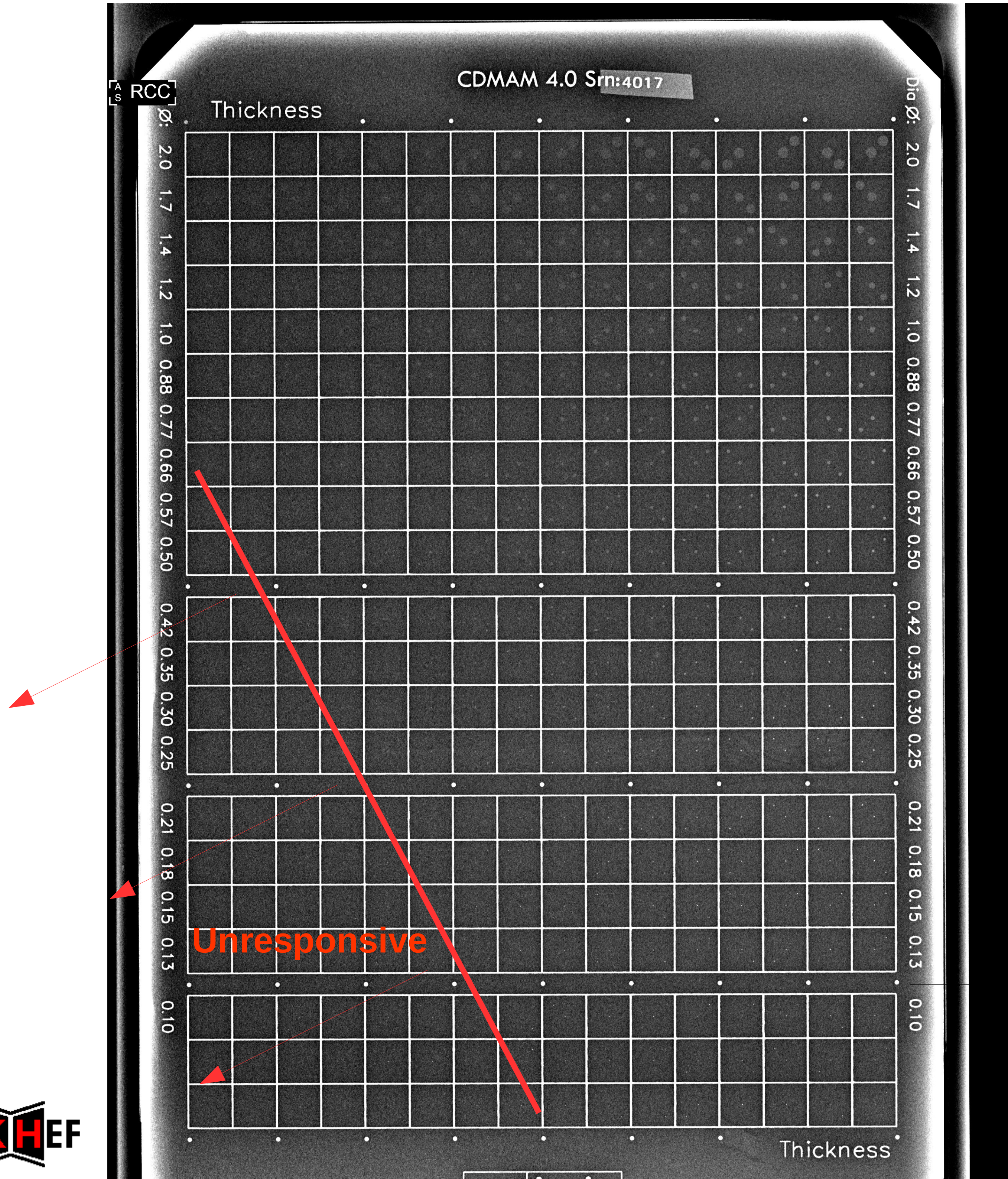
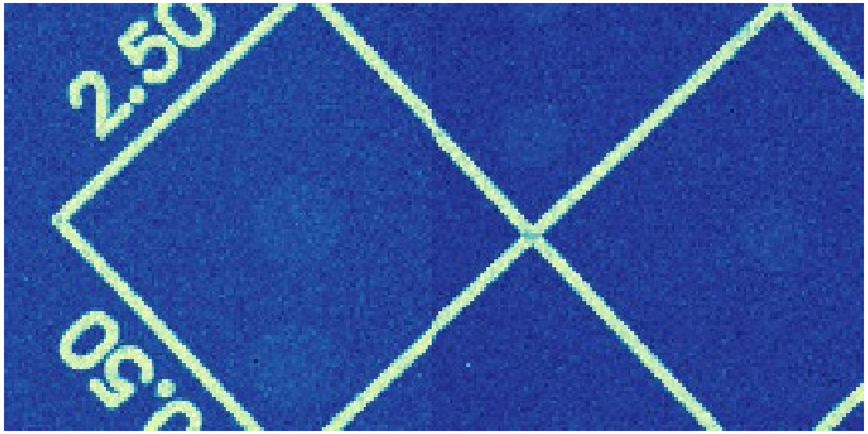
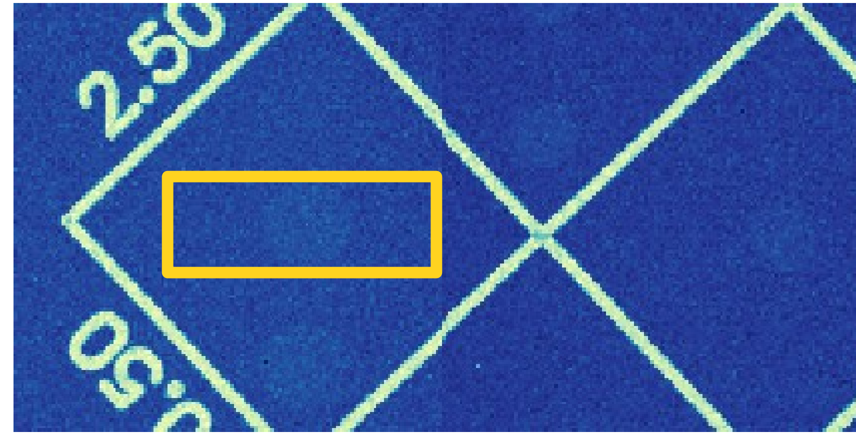


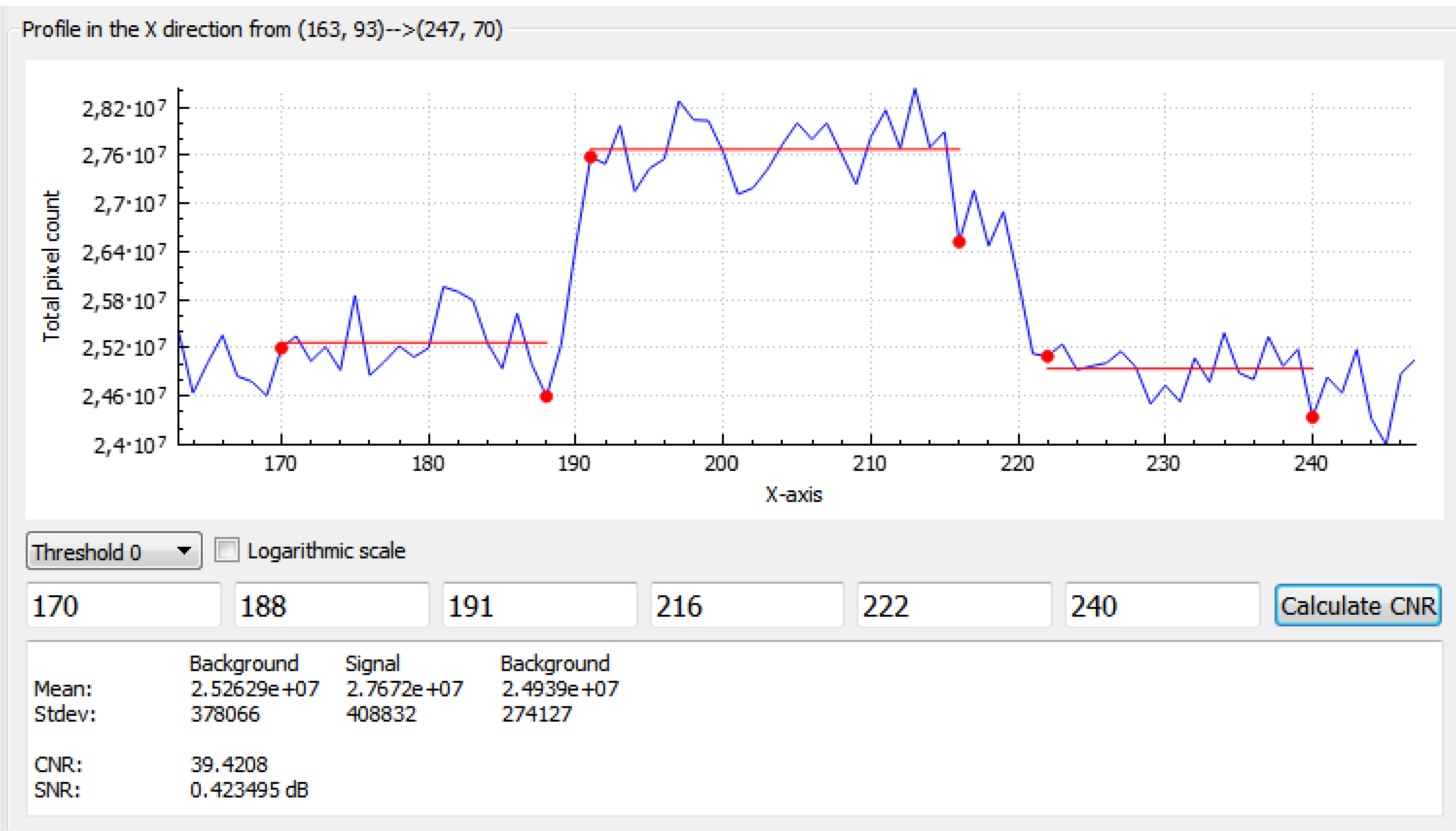
Image taken @ UMC with the mammographer

~ limit of the resolution

Rose criteria - CNR

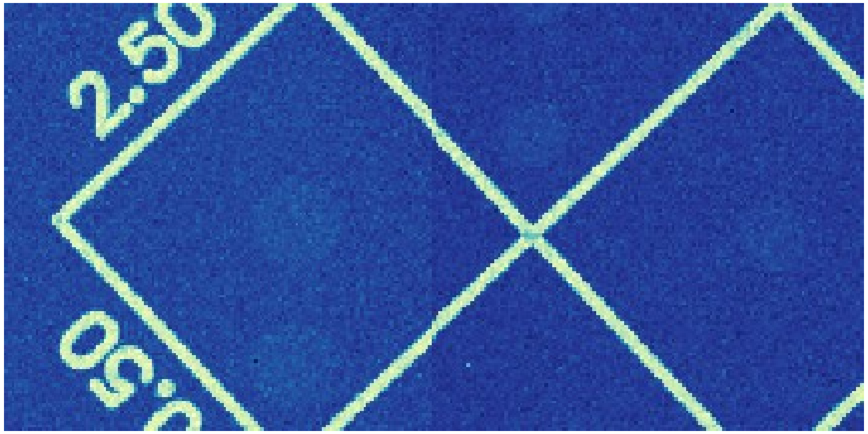


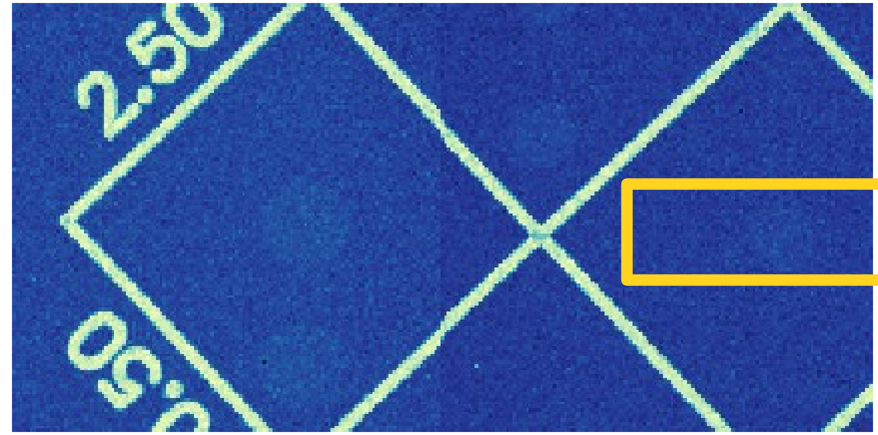


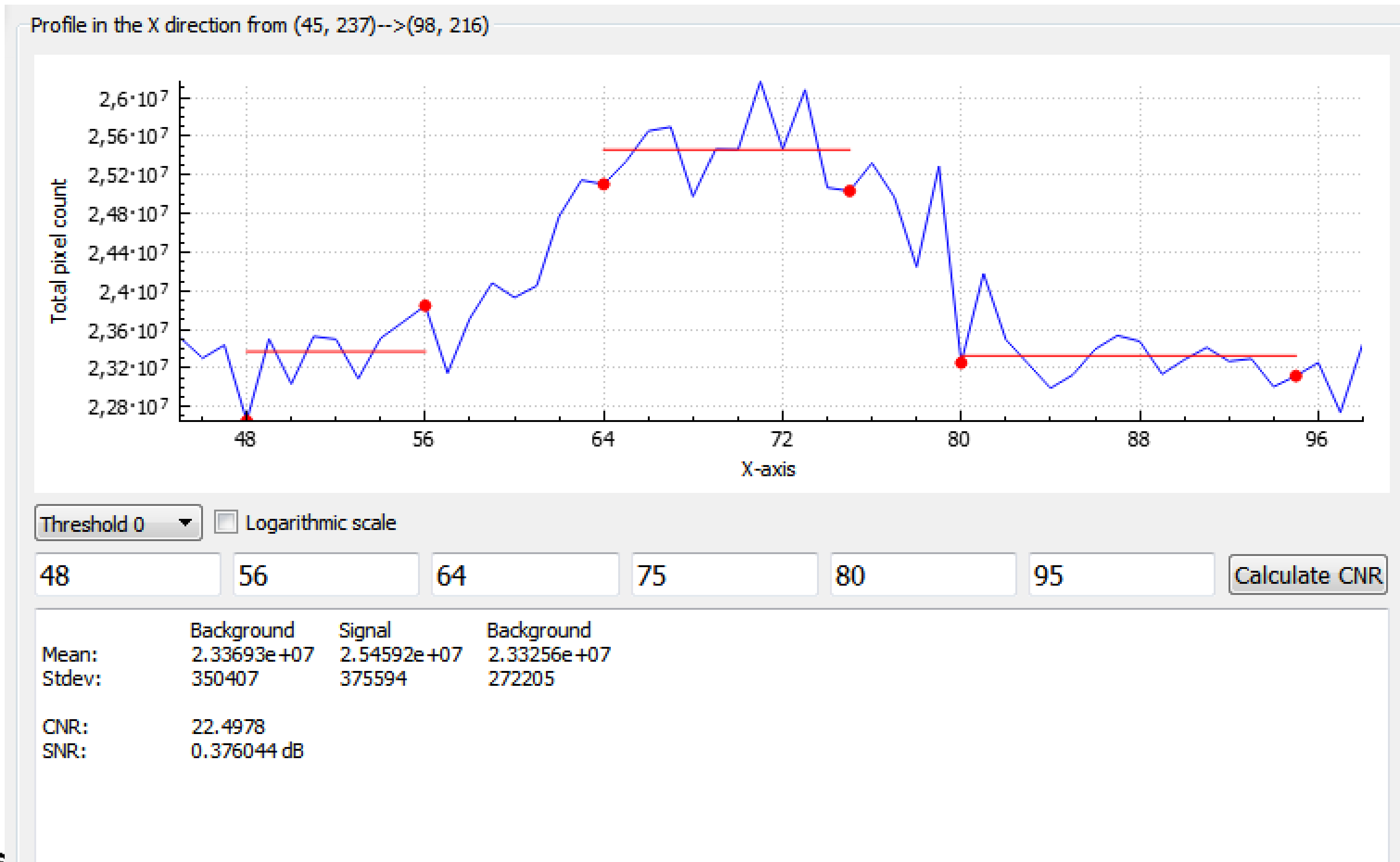


Constrat
Noise
Ratio (CNR)

CNR: 39.4



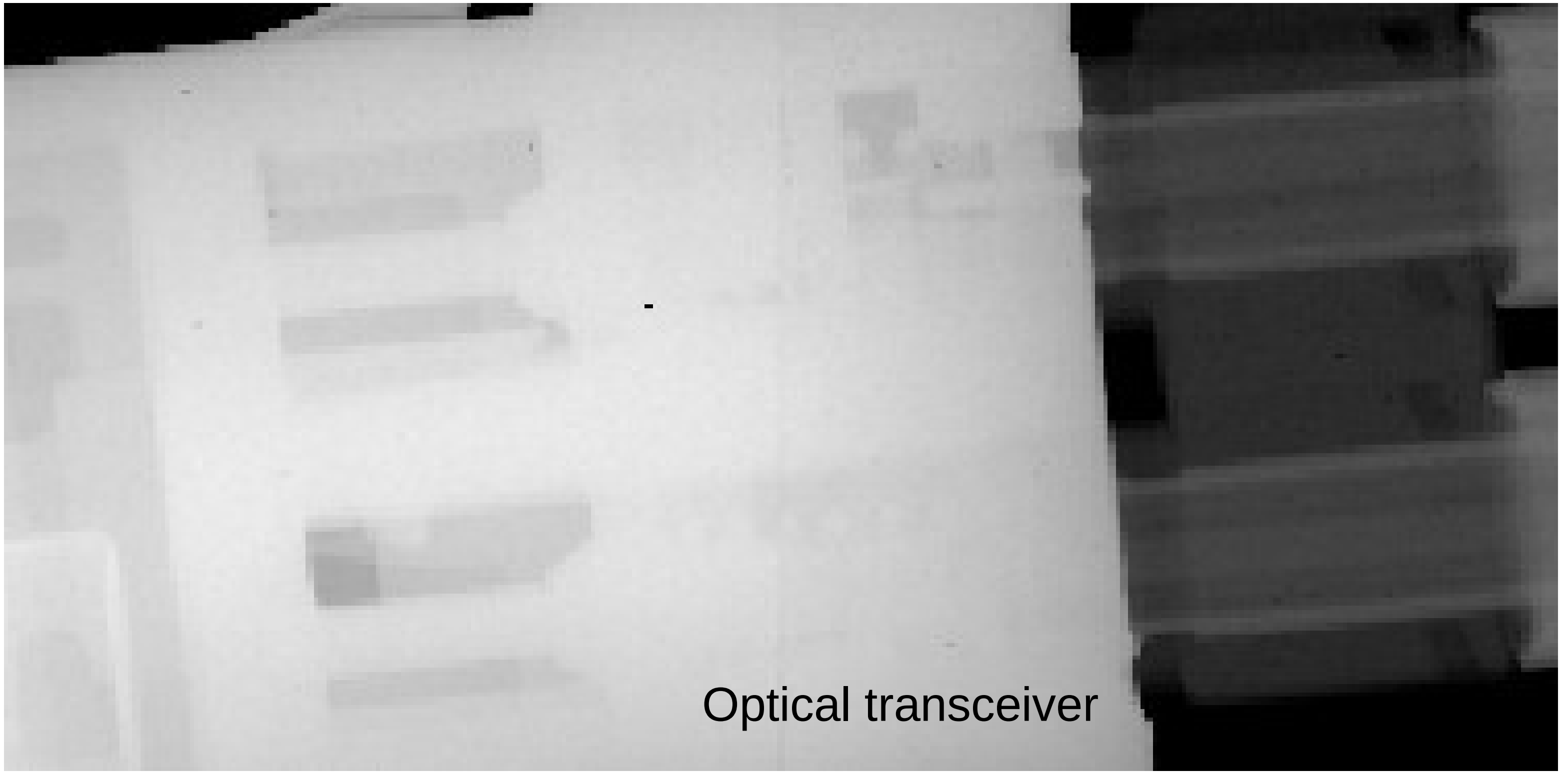




Constrat Noise Ratio (CNR)

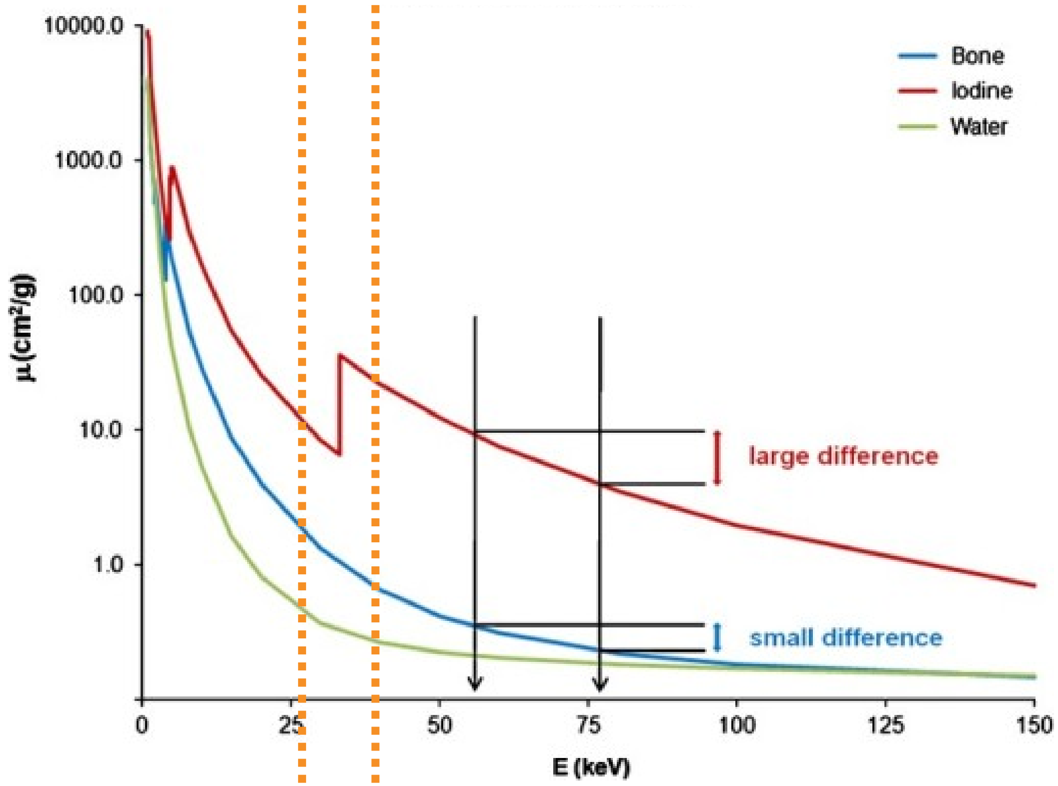
CNR: 22.5

Guided Color reconstruction Vs. conventional X-ray

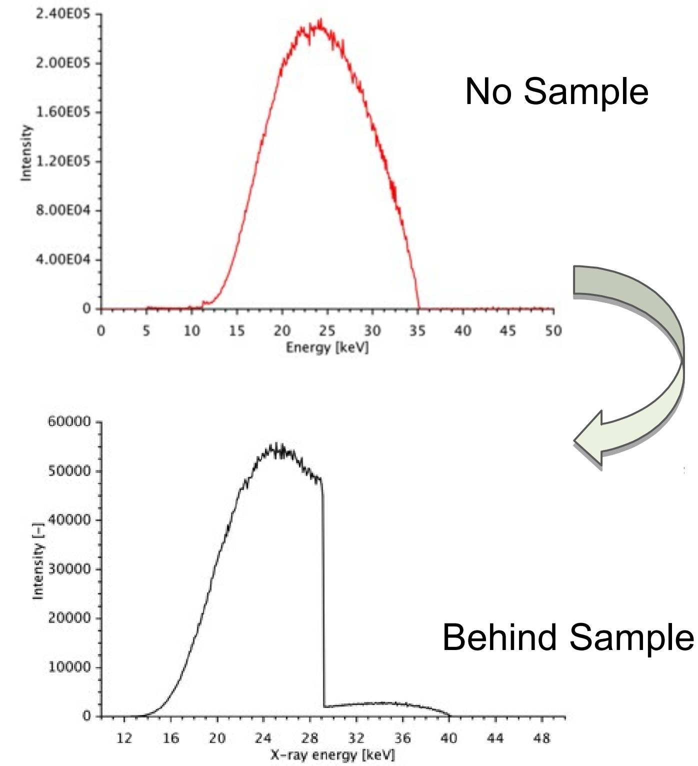


Materials ?

Resolving material using k-edges



X-ray Attenuation Curves
http://www.xrayphysics.com/attenuation.html



Camera Signal

A series of images can be taken with varying energy thresholds.

Different materials will have different combination of signal level at the thresholds.

Material-resolved reconstruction – NO edges
Attenuation coeff reco

Attenuation $I/I_0 = \exp(-\mu t)$

Taking $-\log(I/I_0) = \lambda$

$$\lambda = \mu t.$$

materials →

$$\begin{pmatrix} \lambda_0 \\ \vdots \\ \lambda_{N_E} \end{pmatrix} = \begin{pmatrix} \mu_0^0 & \cdots & \mu_0^{N_M} \\ \vdots & \ddots & \vdots \\ \mu_{N_E}^0 & \cdots & \mu_{N_E}^{N_M} \end{pmatrix} \begin{pmatrix} t^0 \\ \vdots \\ t^{N_M} \end{pmatrix}$$

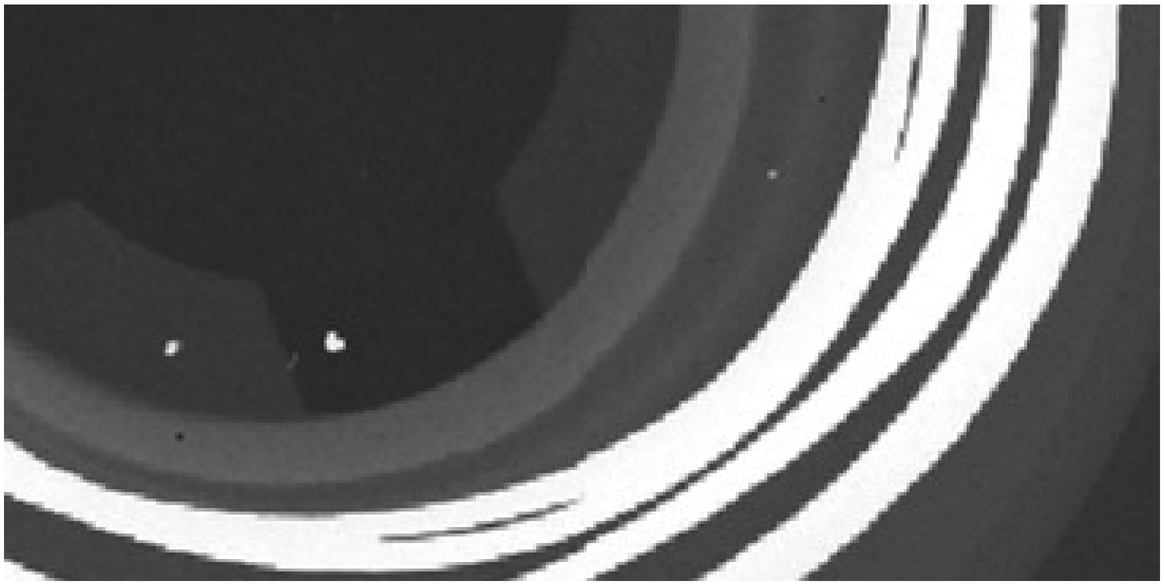
↓ energies ↓ thicknesses

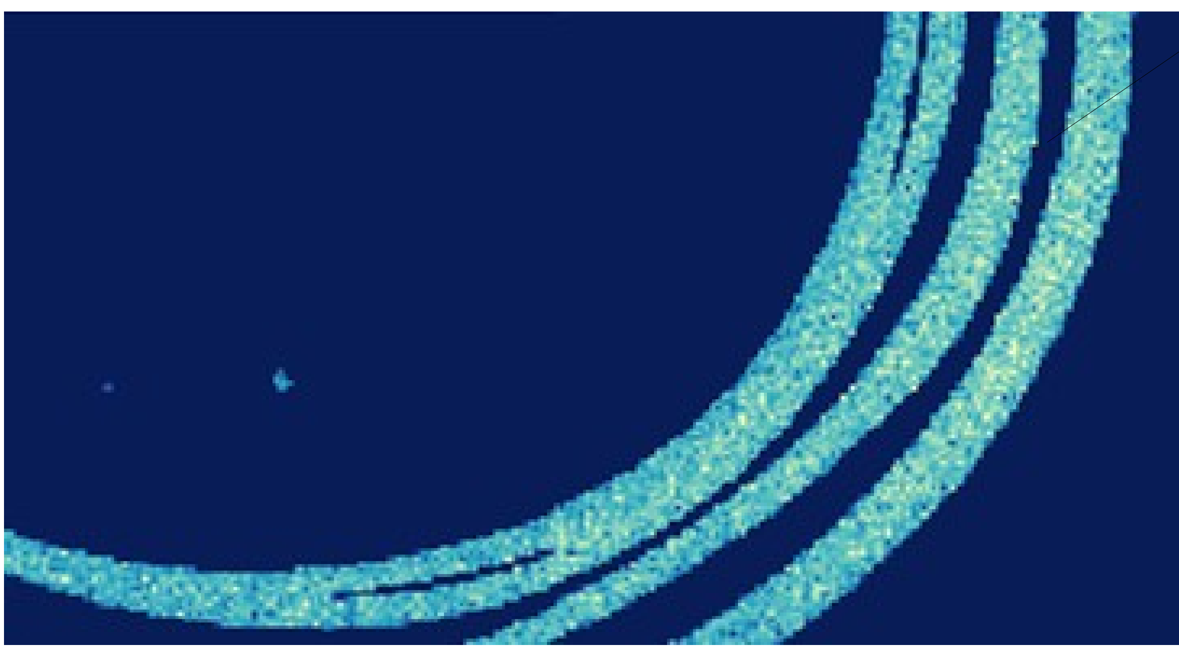
$$\vec{\lambda} = \boldsymbol{\mu}\vec{t}.$$

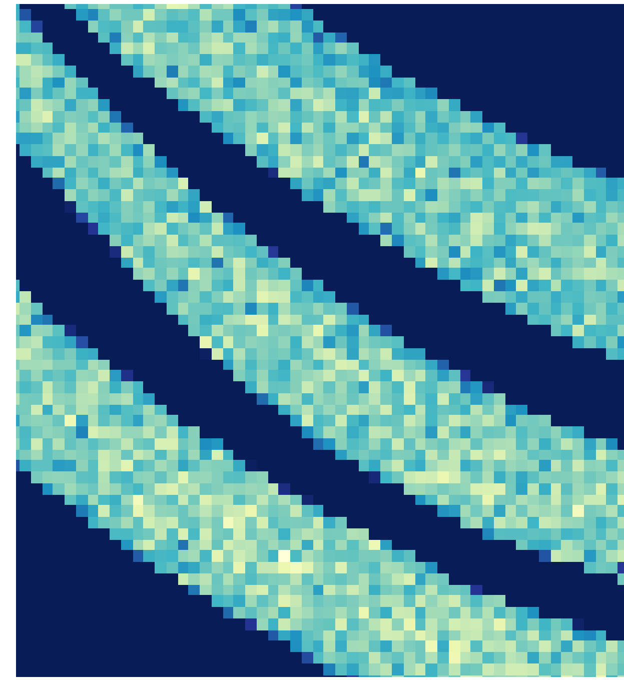
Planar Color reconstruction

Making the invisible visible

Conventional X-ray can not resolve entangled material structure. **Color X-ray can !**







Al 99% C.L.

Cu 99% C.L.

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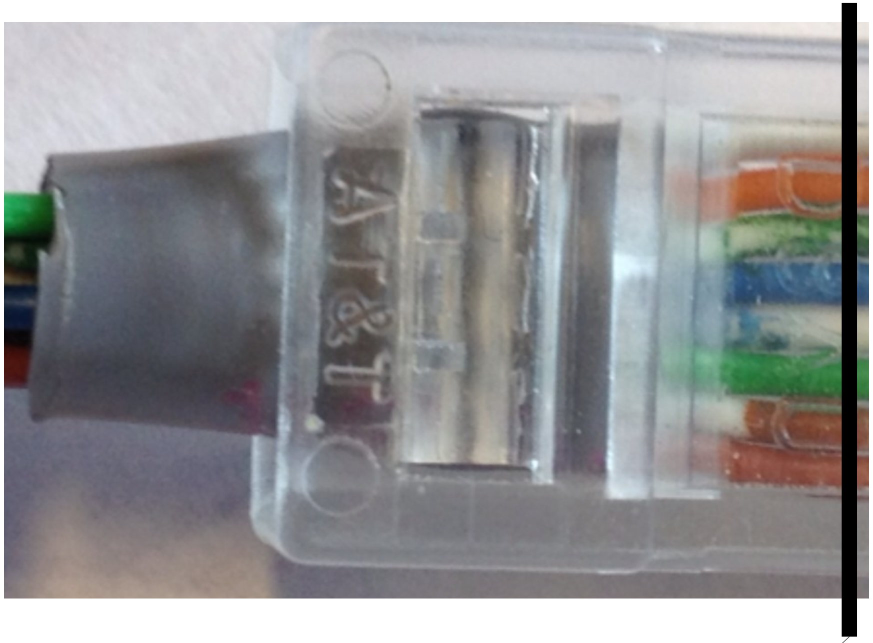
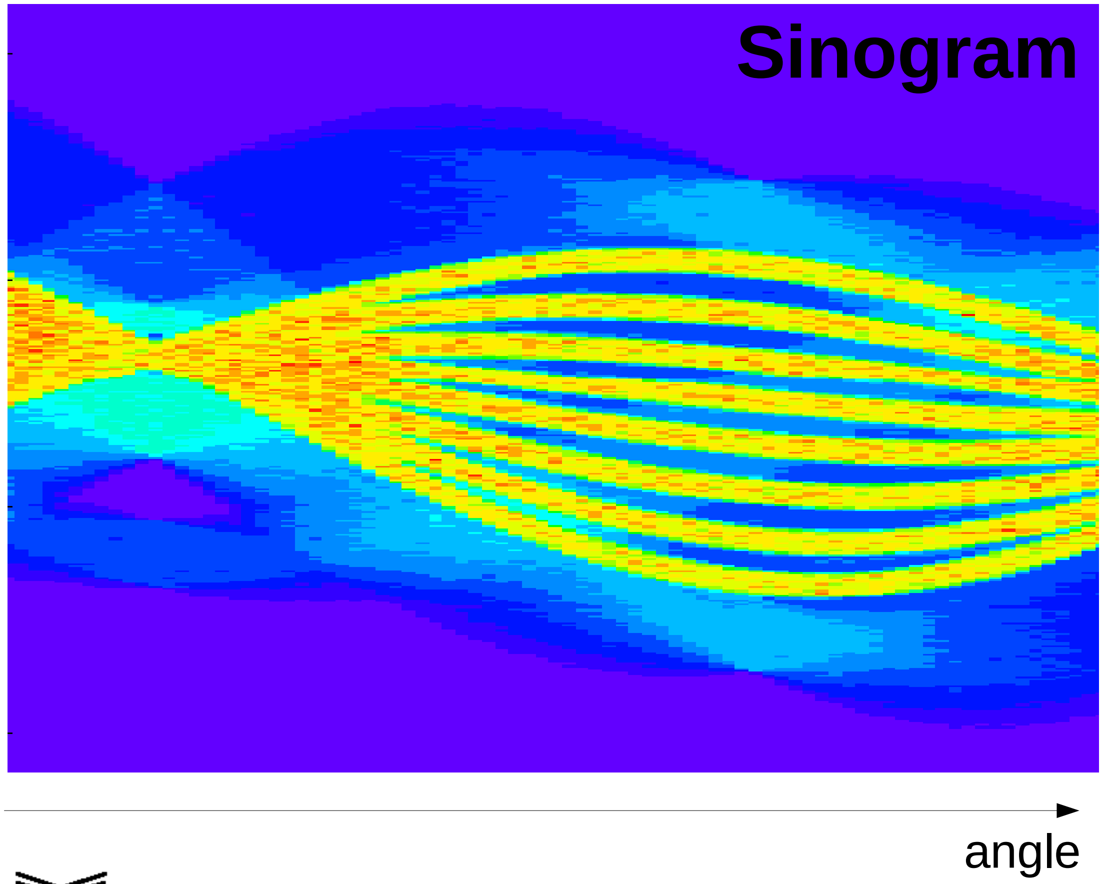
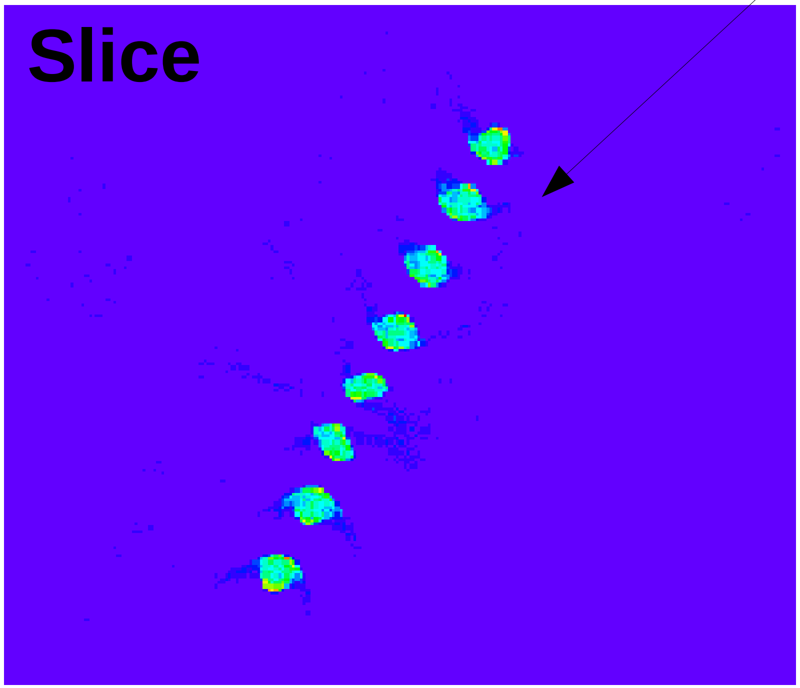
CT reconstruction







Multi-threshold → Fast material ID

Charge Summing Mode → Improves energy resolution

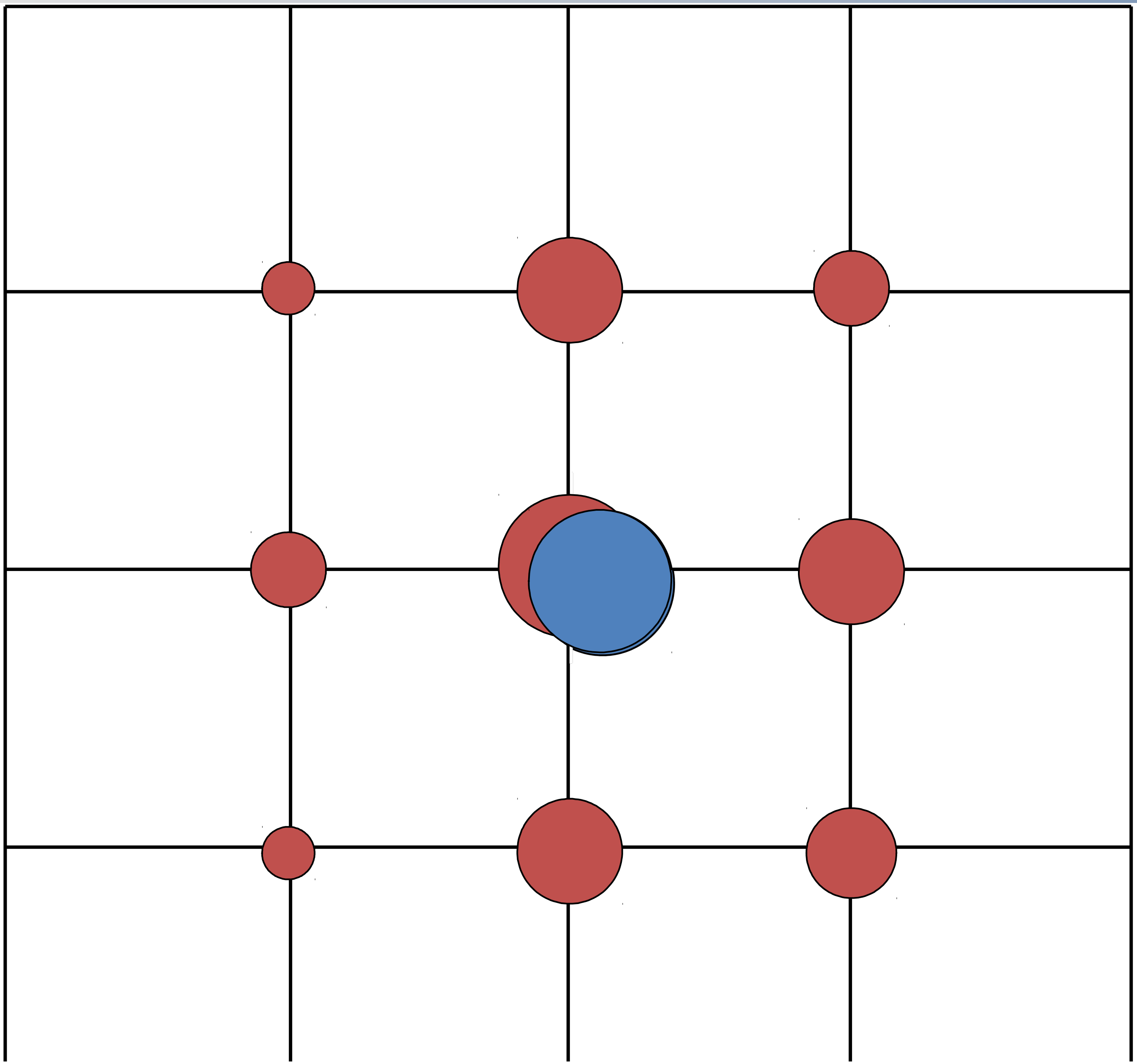
Programmable gain (4) → Enhances work energy range

THL(E) calibration linear → Reliable calibration

Pixel readout chip specifications

Pixels	512 x 512 / 256 x 256
Pixel size	55 µm x 55 µm (Fine Pitch Mode)
	110 µm x 110 µm (Spectroscopic Mode)
Technology	0.13 µm CMOS
Input polarity	both electrons and holes
Minimum energy threshold	~1.8keV or ~500e⁻
Energy thresholds	8
Peaking time	120 ns

The algorithm for charge reconstruction and hit allocation: Charge Summing Mode



1. TH0 is applied to the local signal

2. Arbitration circuitry identifies the pixel with largest charge and supresses the pixels with lower signal

3. In parallel, the charge has been reconstructed in the analog summing circuits

4. The pixel with highest charge checks the adjacent summing circuits to see if at least one of them exceeds TH_1

Advantage of small pixels without disadvantage of charge sharing

Single Pixel Mode (SPM)

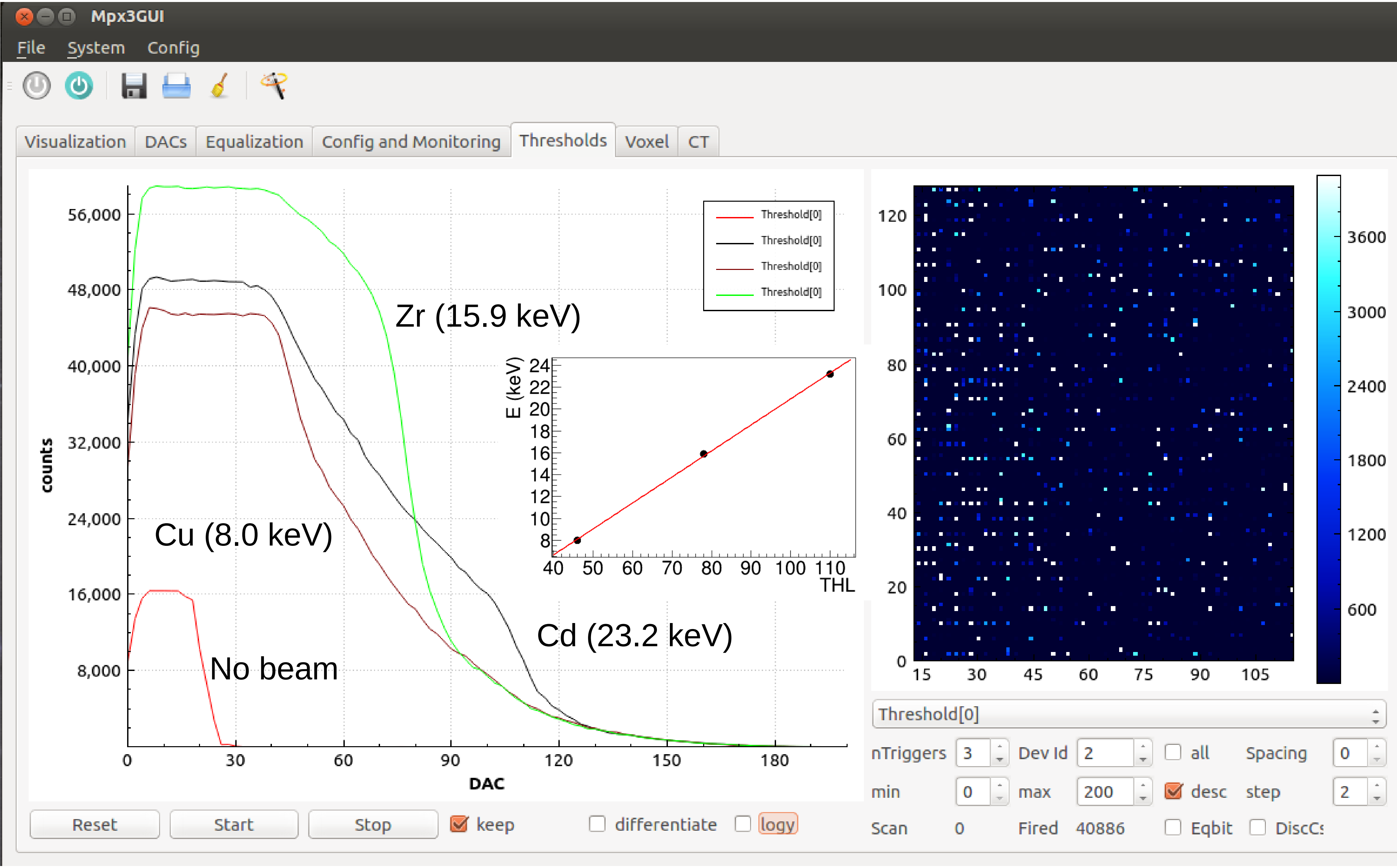
Counter depth	24 / 12 / 6 / 1-bit in zero-dead-time mode
Maximum count rate	2.5 x 10^6 counts-per-second/pixel
	4.55 x 10^6 counts-per-second/pixel
Energy resolution	1.37 keV @ keV (FWHM), 300 μm Si
	1.43 keV @ 10 keV (FWHM), 300 μm Si
Electronic noise	~80 e^- rms
Power consumption	7.5 μW/pixel / 30 μW/pixel

Charge Summing Mode (CSM)

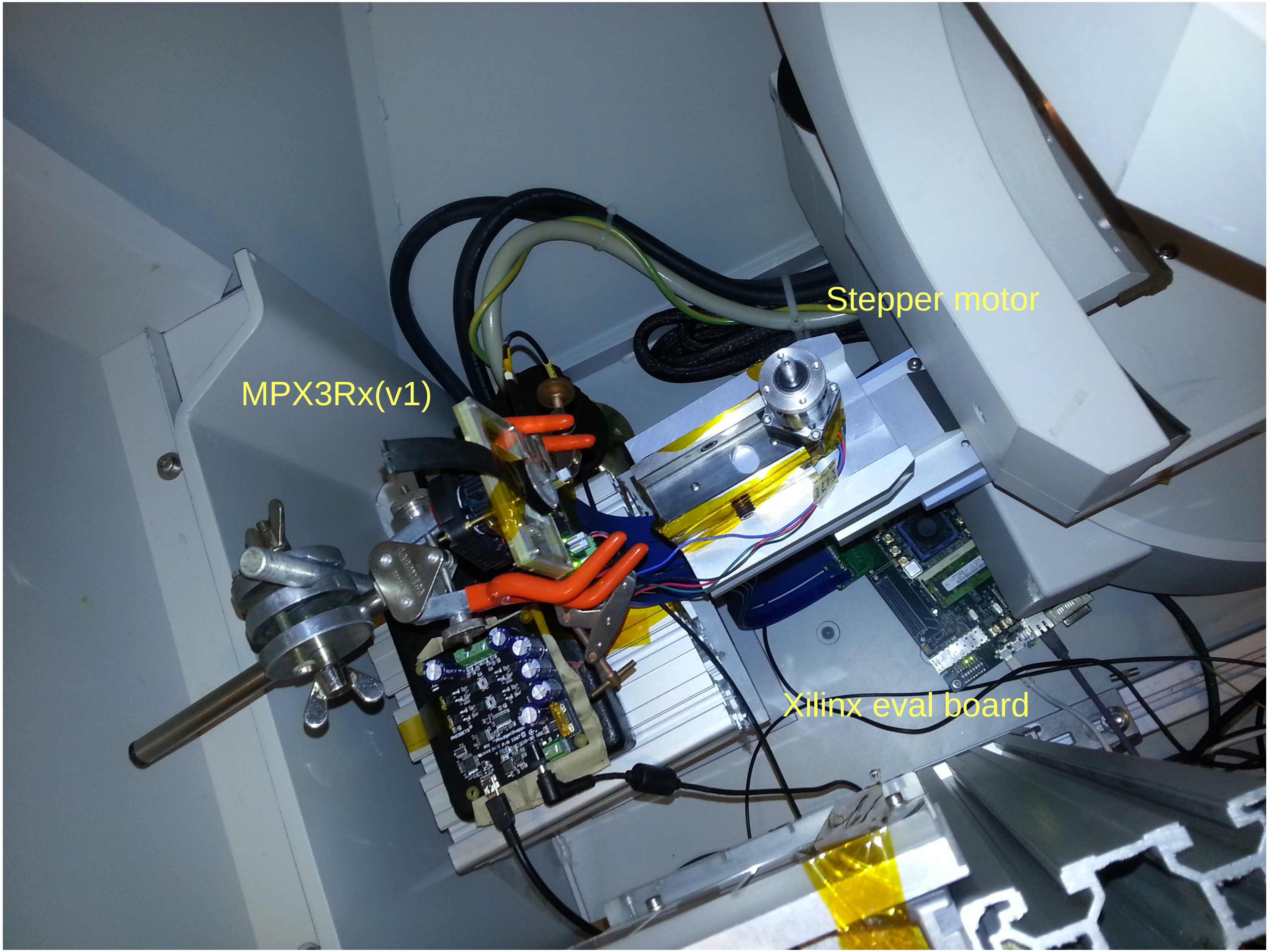
Counter depth	24 / 12 / 6 / 1-bit in zero-dead-time mode
Maximum count rate	0.5 x 10^6 counts-per-second/pixel
	4.55 x 10^6 counts-per-second/pixel
Energy resolution	2.03 keV @ 10 keV (FWHM), 300 μm Si
	4.4 keV @ 60 keV (FWHM), 2 mm CdTe
Electronic noise	~174 e^- rms
Power consumption	9.3 μW/pixel 37.2 μW/pixel

Backup slides

Threshold calibration



Setup



Achieved.

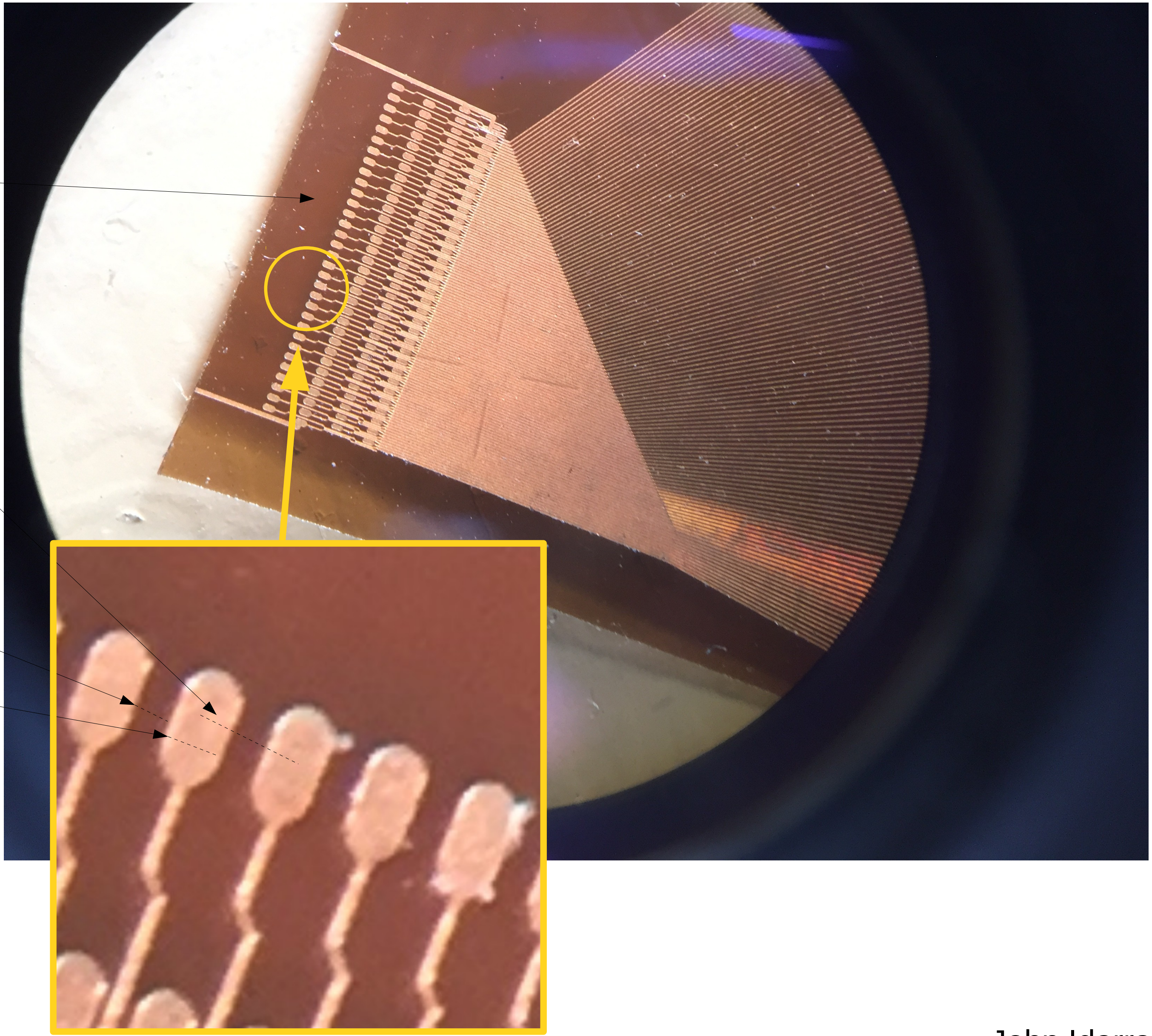
- Handshake: Firmware – LEON software – user software.
- The Medipix3RX is working multi-threshold.
- Equalization is ready for both high and low thresholds.
- Software to take and process images is coming together.
- Ready for mammo phantoms and CT.

Resolution – test patterns

32 lines
Left-most row
165um pitch

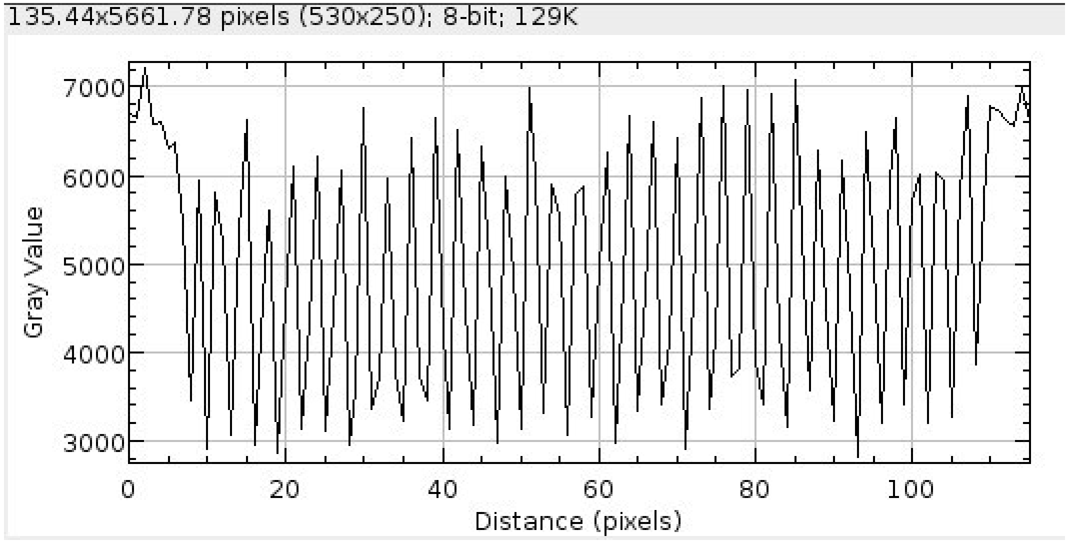
Gap 55um

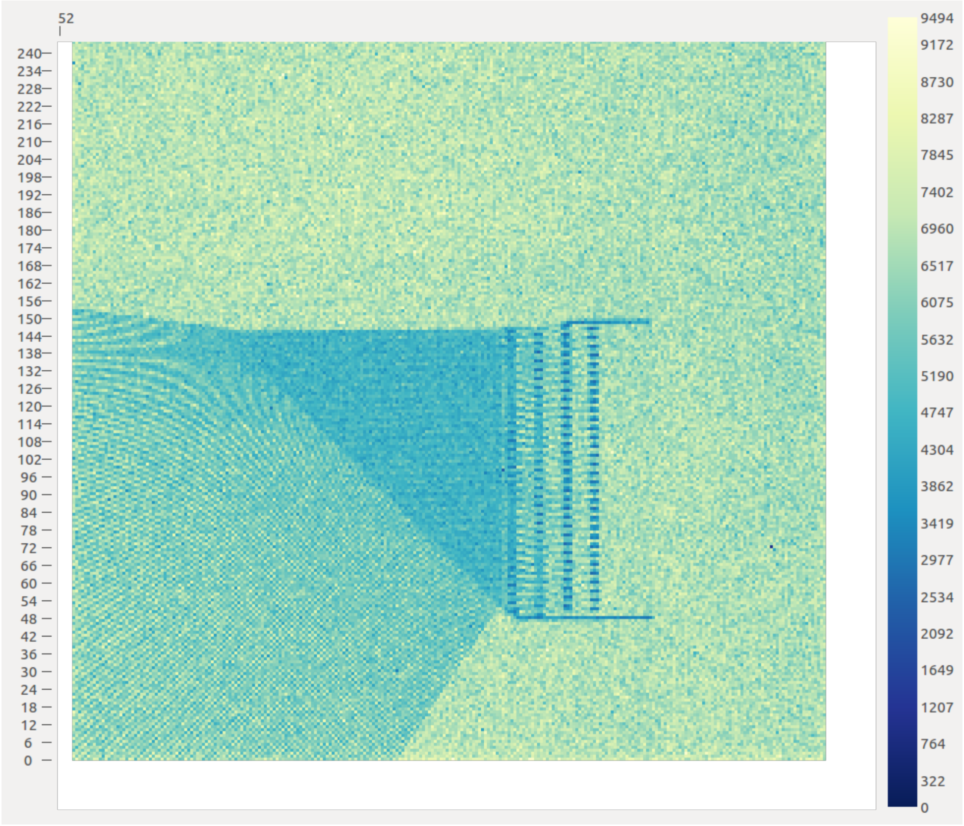
Pad size 110um

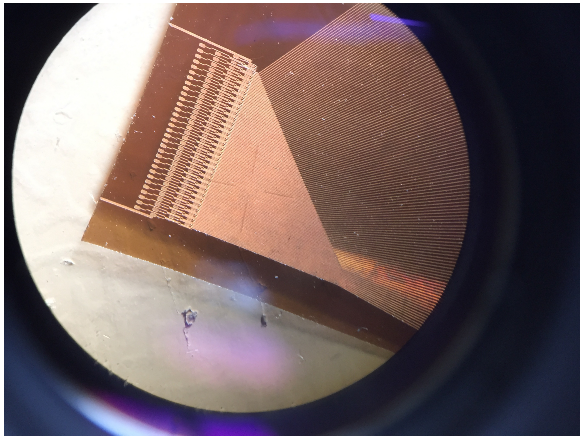


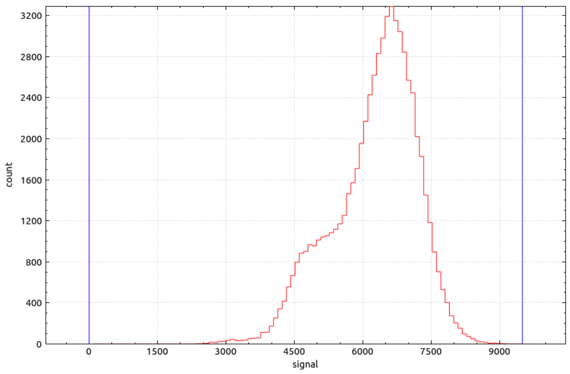
Spatial resolution – Fine pitch - 55um pitch

Correctly resolving the structure
It is possible to count the lines









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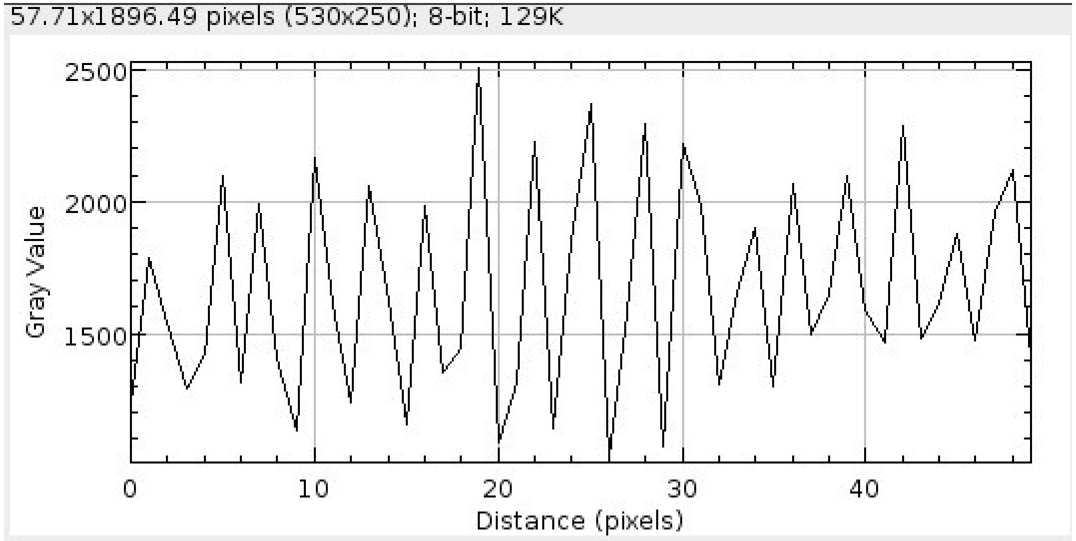
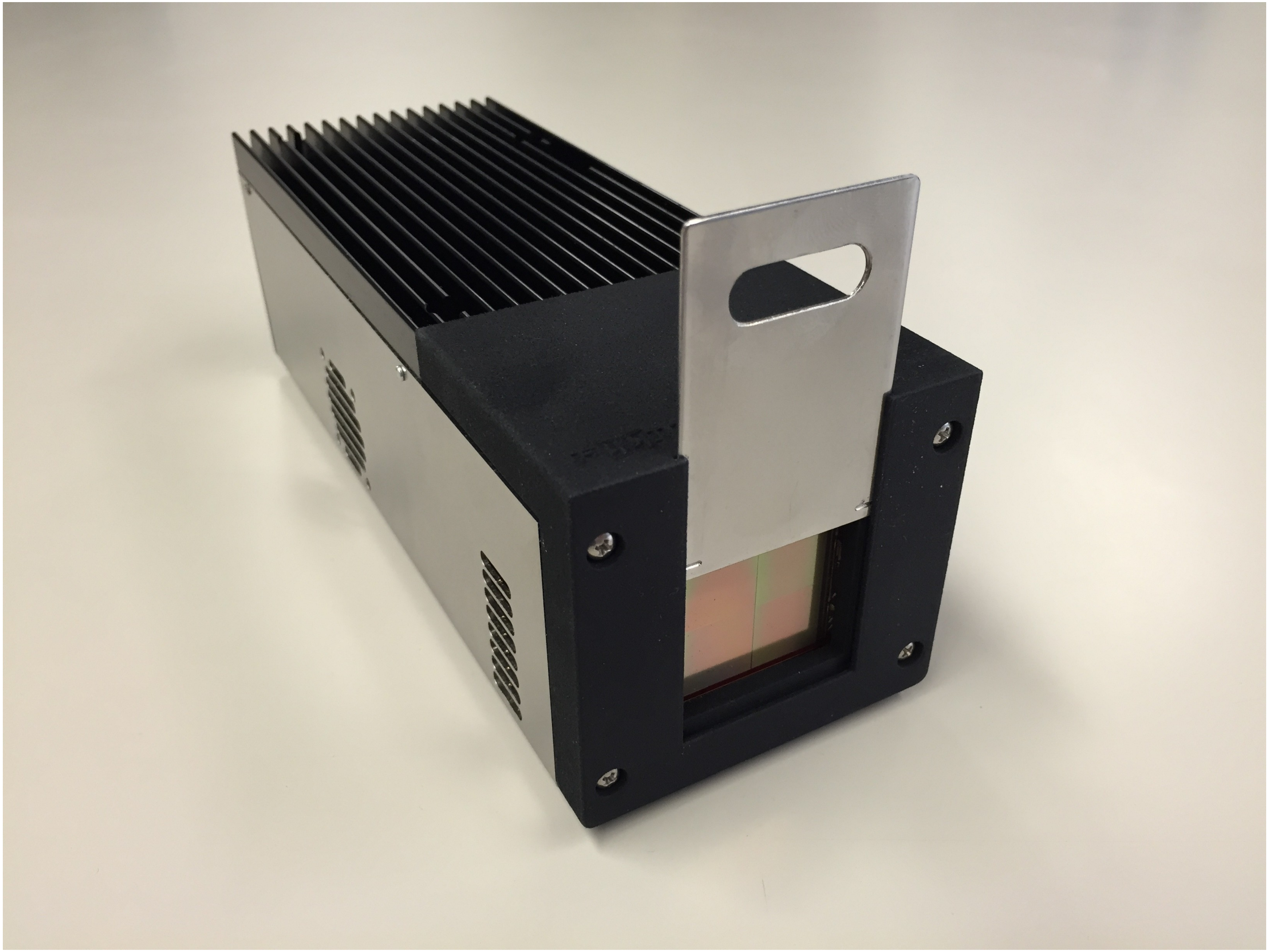
Spatial resolution – Spectroscopic - 110um pitch

Not able to resolve at 55um pitch →

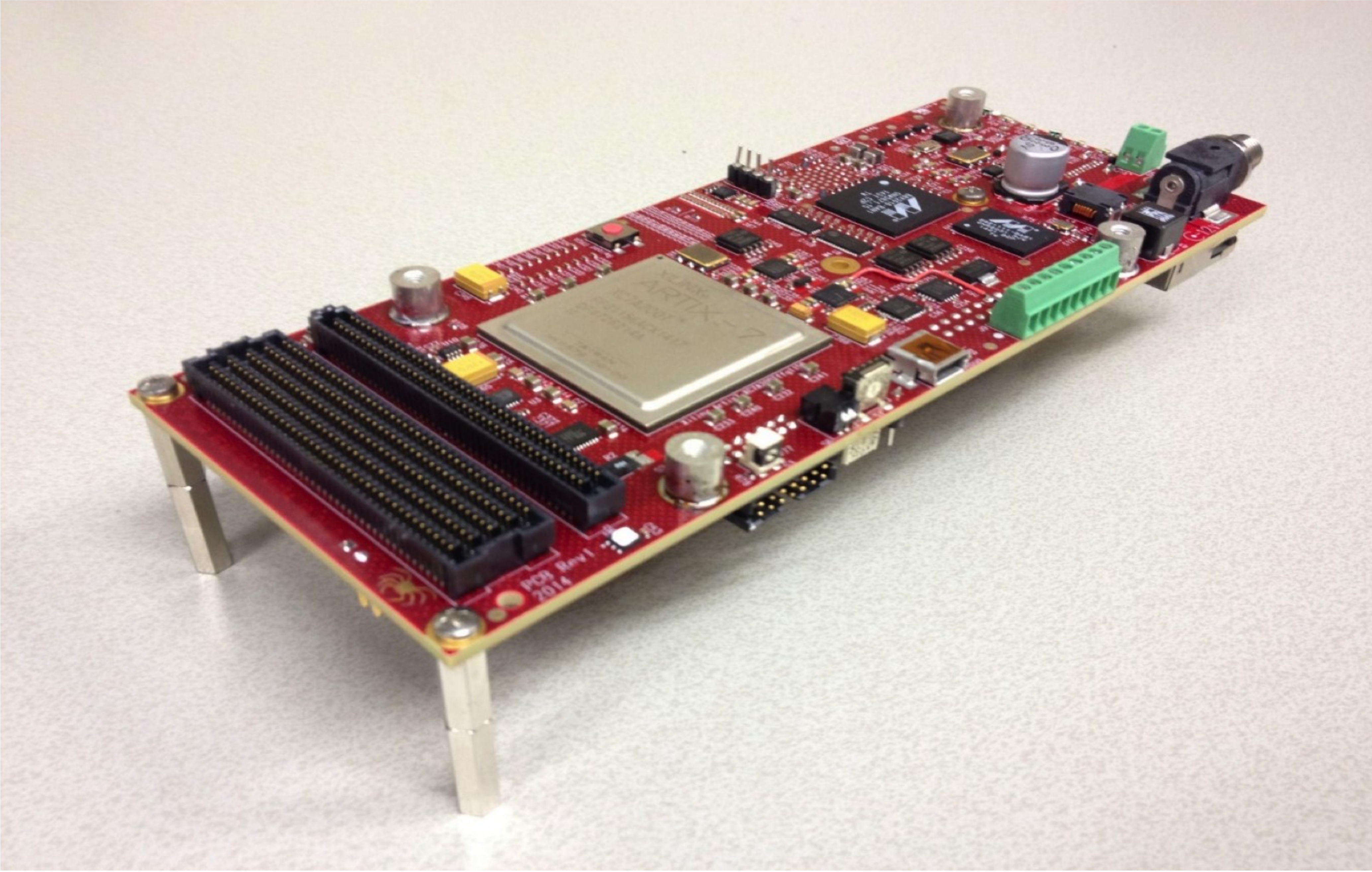


- Need to review and validate the equalization procedure
- Run a complete test with test patterns.
- Calibration of thresholds
- Beam hardening calibration
    Test the difference between Al and Glass attenuators
- Start the color reconstruction
- CT

New SPIDR



New SPIDR



Collaboration

NIKHEF

UMC Utrecht

Universiteit Utrecht

CERN

John Idárraga

08/14 - Now **Spectral X-ray imaging** — Nikhef - CERN

Amsterdam, Netherlands

Development of spectral imaging for breast cancer screening. Involvement in the development of FPGA-based hardware, micro-controller software and user software including spectral imaging reconstruction algorithms.

01/12 - 07/14 **Radiation monitoring for spacecraft** — University of Houston - NASA - CERN

Geneva, Switzerland

Involvement in the commissioning of hardware used as radiation monitor in the International Space Station. Assembly and calibration/characterisation work carried out at CERN(Geneva). The detectors were sent to Johnson Space Center and eventually five of them were sent to the International Space Station. I was also involved in the development of the analysis framework and a number of algorithms used in on-line data processing.

09/10 - 02/12 **R&D ATLAS pixel detector** — Laboratoire de l'Accélérateur Linéaire

Paris-Sud, Orsay

The Large Hadron Collider (LHC) at CERN has four main experiments. The ATLAS detector, being one of them, is scheduled for a number of upgrades all over the 20 years life-span of the detector. I participated in the first upgrade of the pixel detector; called the Insertable b-Layer (IBL). We addressed mostly problems related to radiation damage trying to push the usable life of the detector subsystem to its maximum.