The ARCADIA Depleted Monolithic Active Pixel:
X-ray characterization and industrial applications

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[2]*INFN, Padova Section*
[3]*University of Padova, Department of Physics and Astronomy G.Galilei*
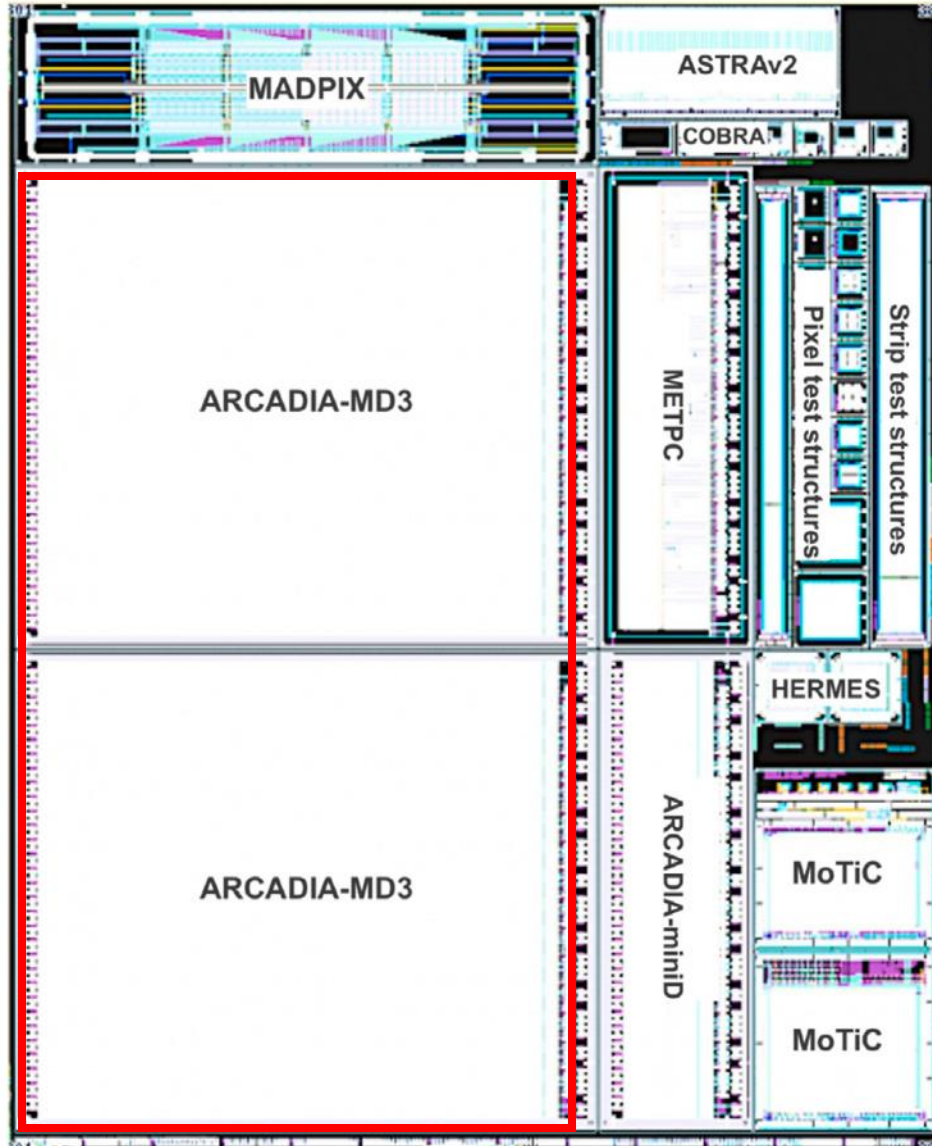[4]*University of Cassino and Southern Lazio, DICEM*

ELMA Workshop on Energy loss measurements with MAPS
Trieste, 10-11 Sept. 2025

ARCADIA R&D at INFN

## Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

- CMOS sensor design and fabrication platform on **LFoundry 110nm technology**
- Scalable FDMAPS architecture with very low power
- Custom Back Side Implantation process allow to develop fully-depleted thick sensors (up to 500 µm)

Different R&D in the same platform
- **ARCADIA Main Demonstrator 3** (MD3) full chip
- Pixel and strip test structures down to 10um pitch
- MADPIX multi-pixel active demonstrator chip for fast timing
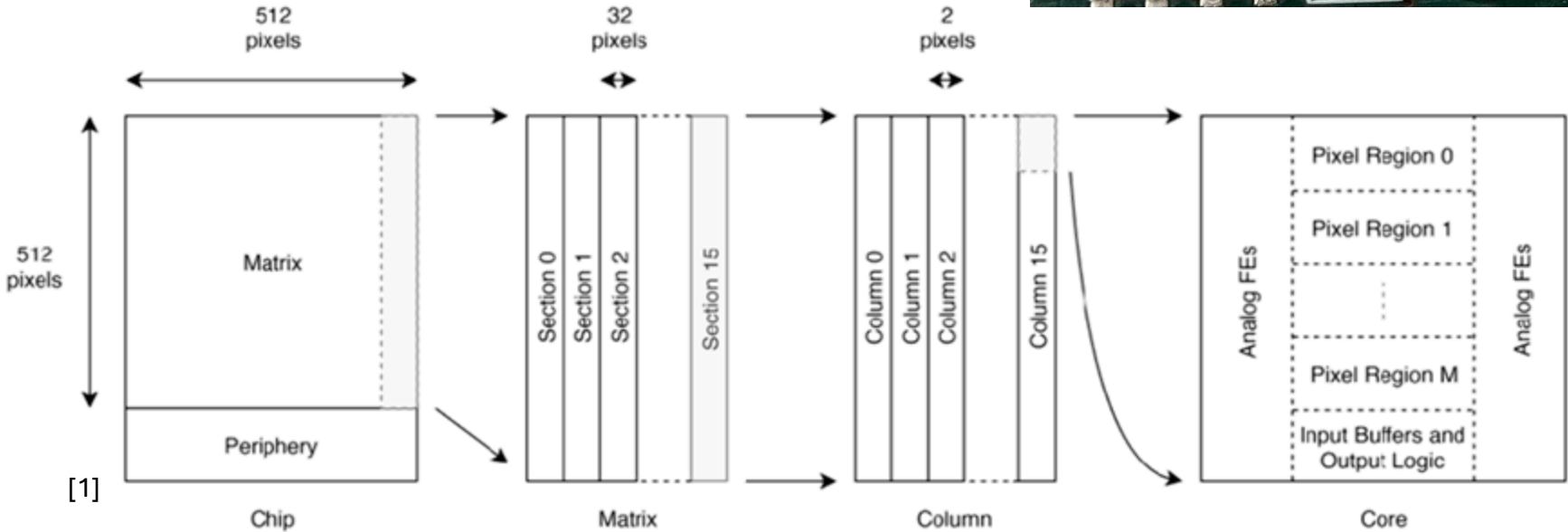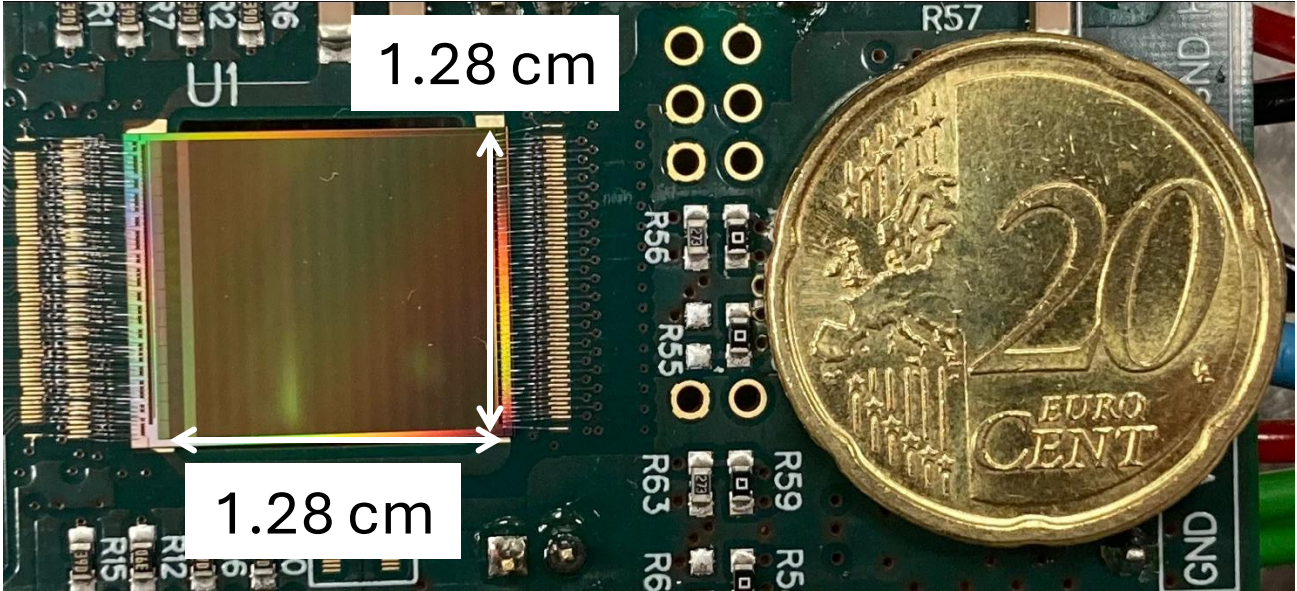- Small scale matrix prototypes (low power, fast timing, etc.)

[1]

1

ARCADIA R&D at INFN

Fully Depleted Monolithic Active Pixel Sensor (FD-MAPS)

• Signal collection only via drift mechanism

• Depletion starts from the p+ back-side region

• Voltages needed for sensor depletion and read-out electronics are separated

up to 500 μm
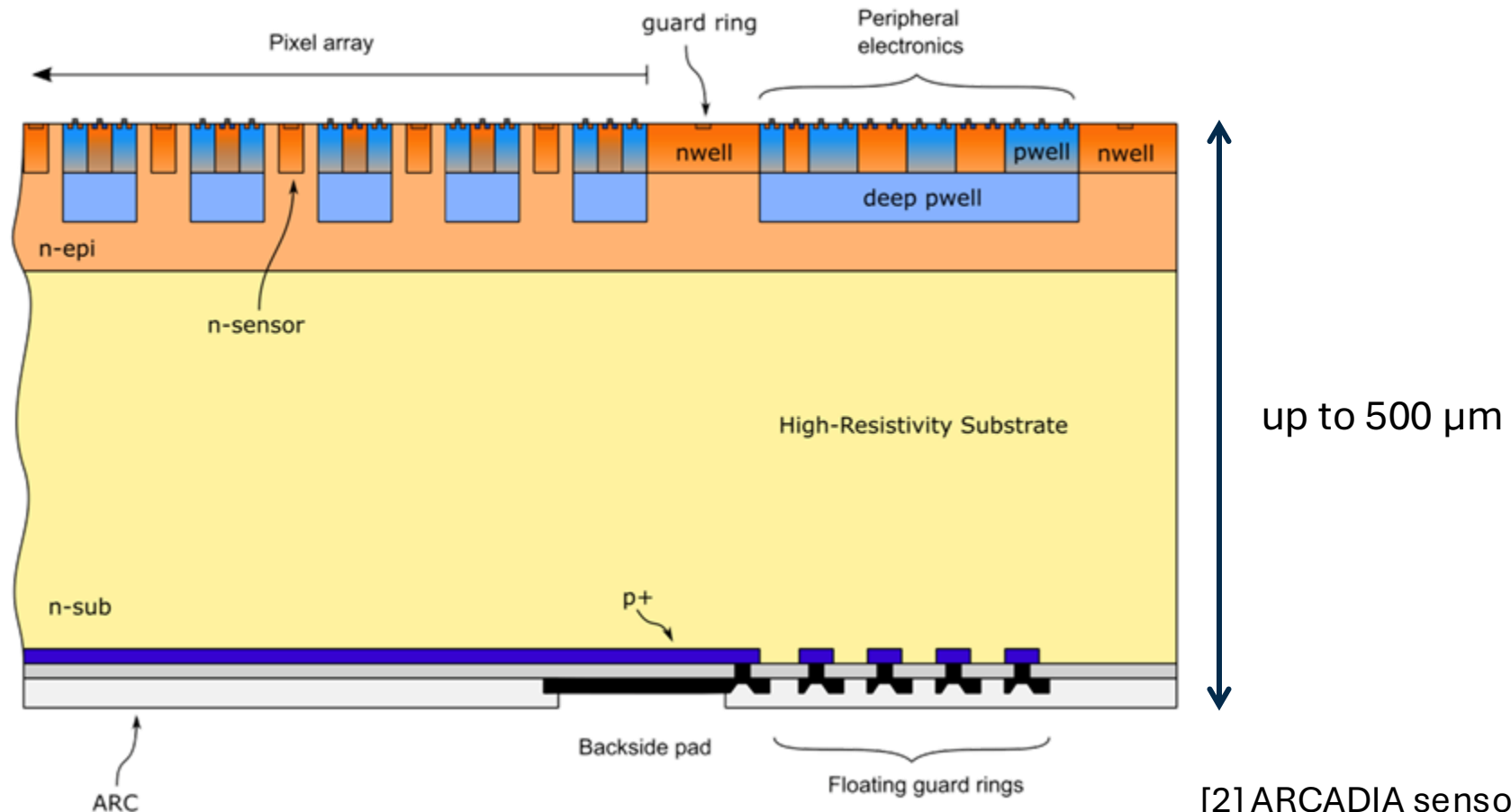
[2] ARCADIA sensor cross-section

ARCADIA MD3

Matrix	512 × 512 pixels divided in 16 sectors (32 pixels wide) clockless
Pixel pitch	25 µm
Thickness	200 µm
Readout	Data-push

1.28 cm

1.28 cm

512 pixels

512 pixels

Matrix

Periphery

[1]

Chip

32 pixels

Section 0 · Section 1 · Section 2 ... Section 15

Matrix

2 pixels

Column 0 · Column 1 · Column 2 ... Column 15

Column

Analog FEs | Pixel Region 0 | Pixel Region 1 | ... | Pixel Region M | Input Buffers and Output Logic | Analog FEs

Core

Digital output
No analogue information
(energy, ToT) accessible

ARCADIA MD3 applications

Space

high rate mode

low rate mode

[1]
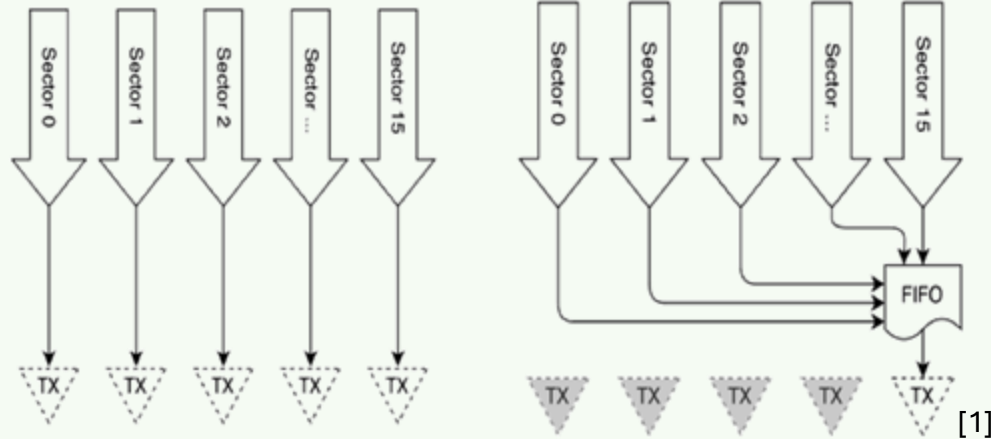
high rate mode: sectors send data in parallel

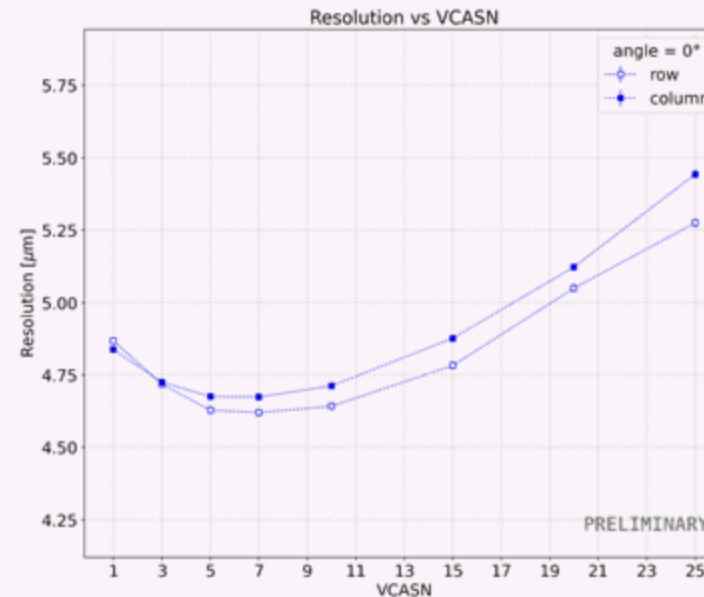**low rate mode:** sectors send data to one transceiver

→ **low power consumption**
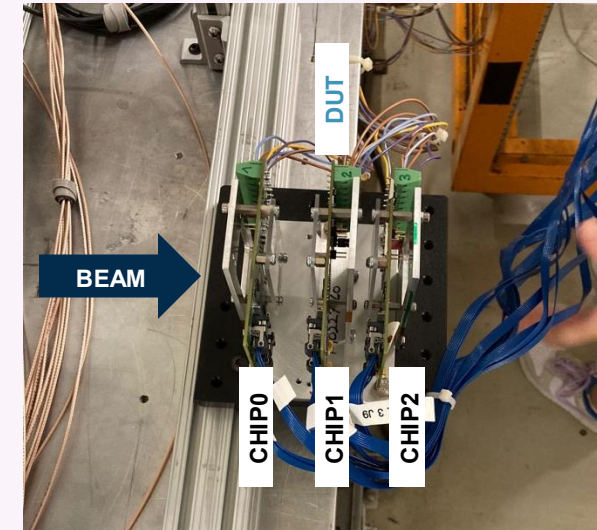
O(10 mW/cm²)

Medical
(proton CT)

[3]
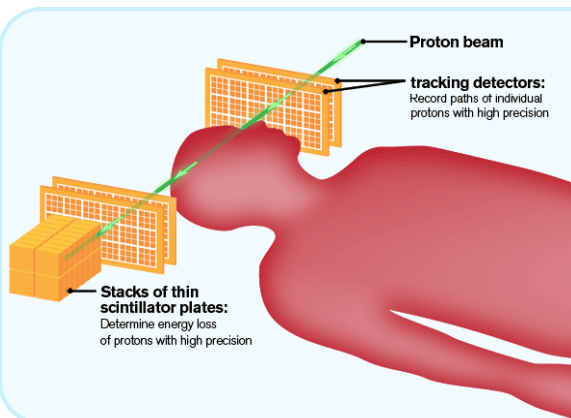
Future leptonic colliders

Tracking performances tested with a Test
Beam @ Fermilab with 120 GeV protons
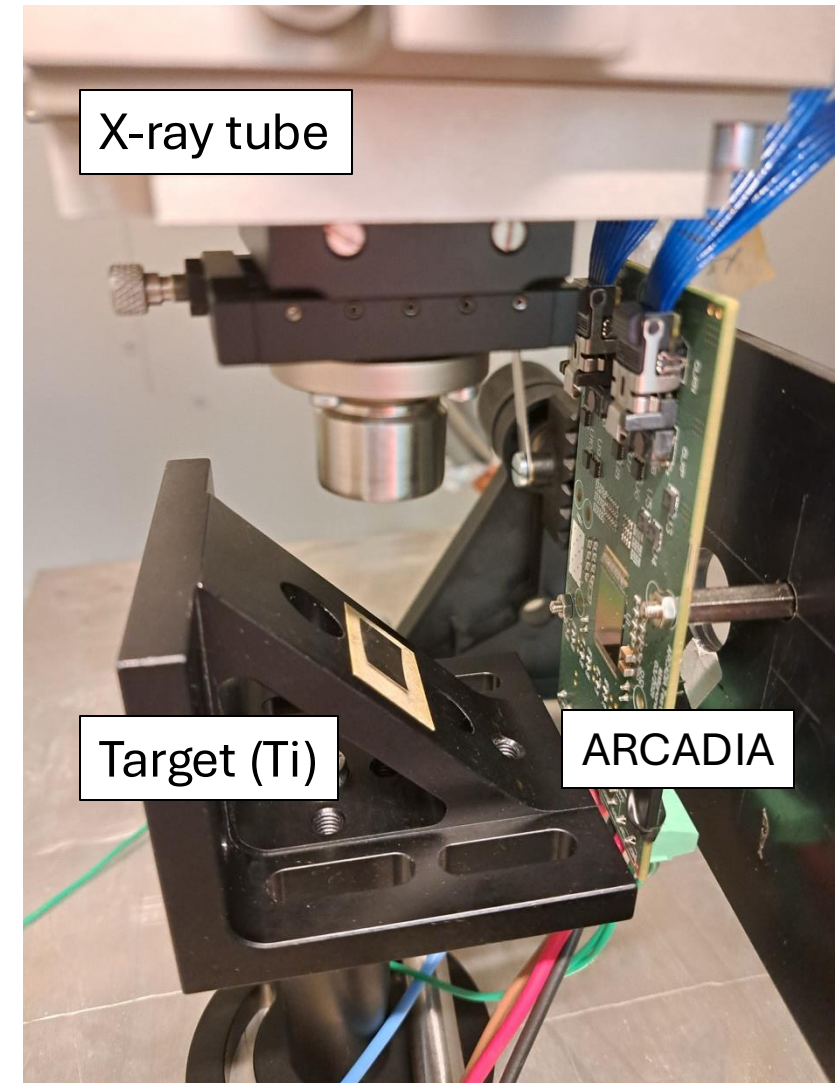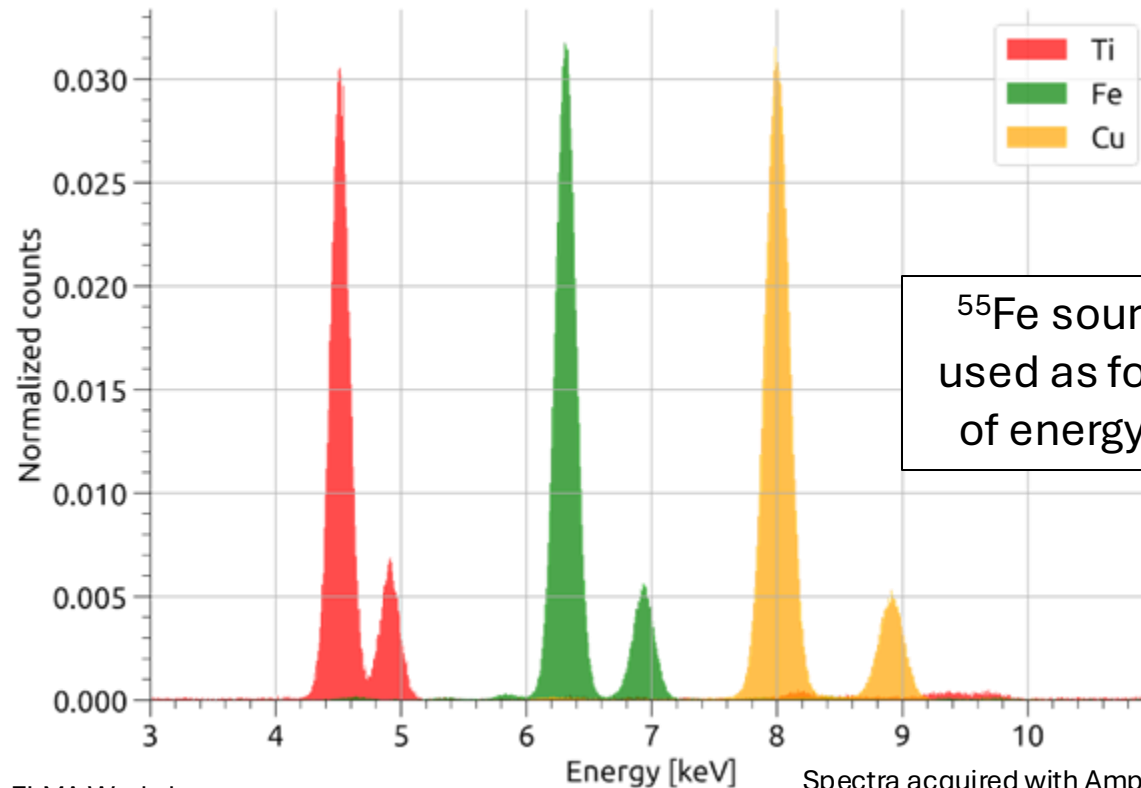
decreasing threshold

Stay tuned for new results!

MD3 characterization: X-ray

Fluorescence is a source of very monochromatic X-ray.
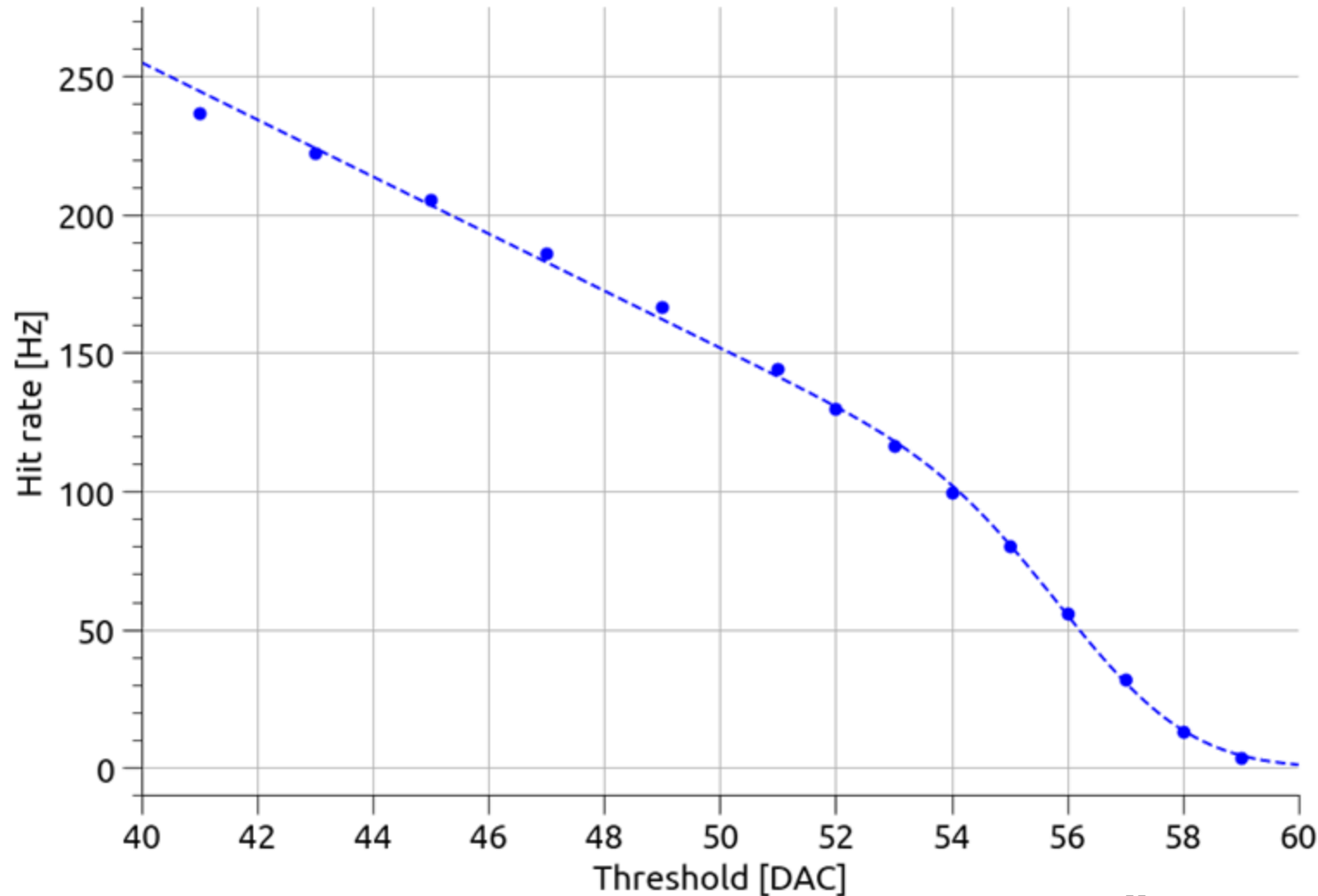It can be exploited to calibrate the sensor.

Setup:

- X-ray tube with Tungsten anode used at 40kV and 50 mA
- Target of different materials at 45°
- 16×16 pixel array tested

^{55}Fe source is also used as fourth value of energy (5.9 keV)

Spectra acquired with Amptek XR-100CR detector

MD3 characterization: fluorescence

Hit rate vs threshold: the electronic cloud released by X-ray diffuses in silicon leading to charge sharing, therefore the fit model is modified with respect to test pulse s-curve [4].


Example of ^{55}Fe s-curve for the 16x16 array

MD3 characterization: fluorescence

Hit rate vs threshold: the electronic cloud released by X-ray diffuses in silicon leading to charge sharing, therefore the fit model is modified with respect to test pulse s-curve [4].

linear term takes into account charge sharing
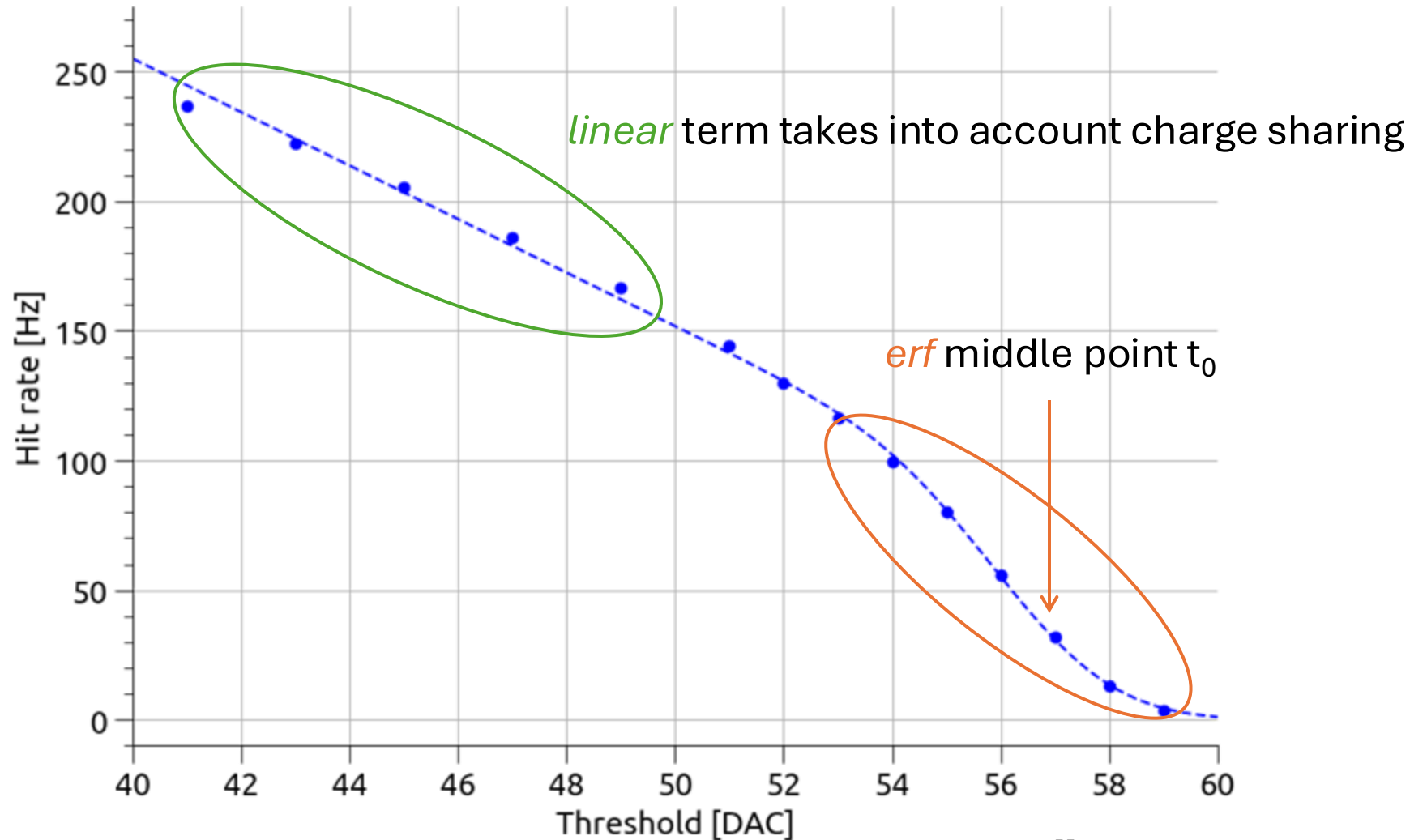
erf middle point t_0

Example of ^{55}Fe s-curve for the 16x16 array

MD3 characterization: calibration

Comparison of s-curve for all targets from fluorescence and from ^{55}Fe source.
The rate is normalized to have the s-curve middle point (t_0) at rate equals to 1.
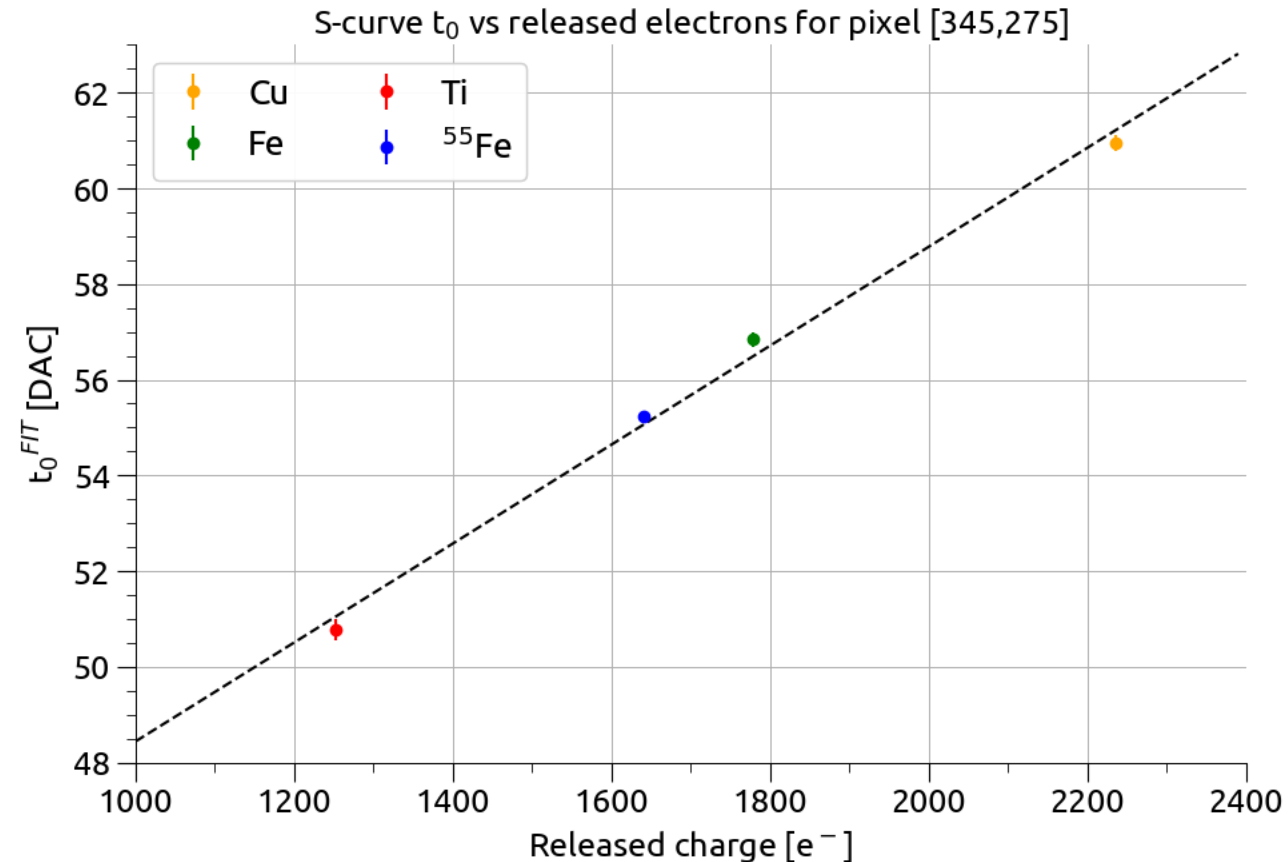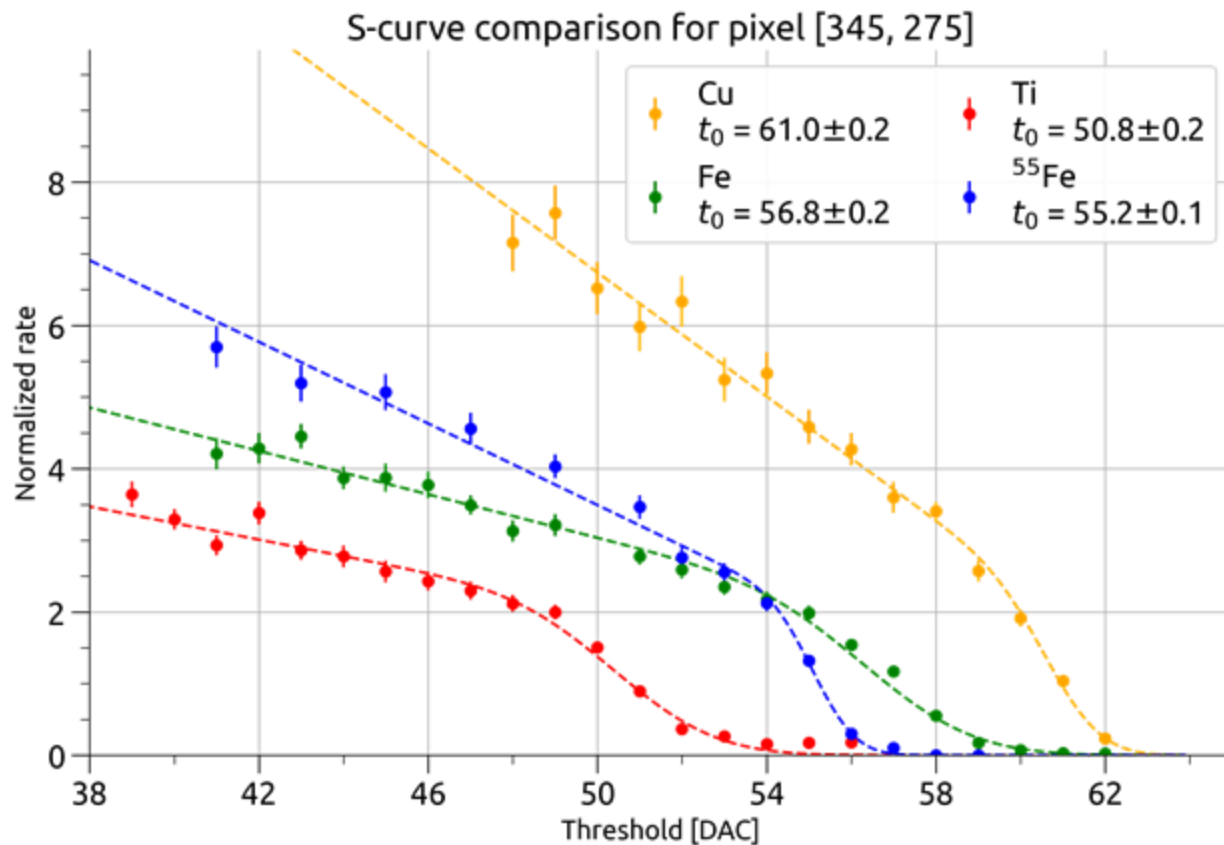
MD3 characterization: rate

Rate response is evaluated as function of the current of the X-ray tube.
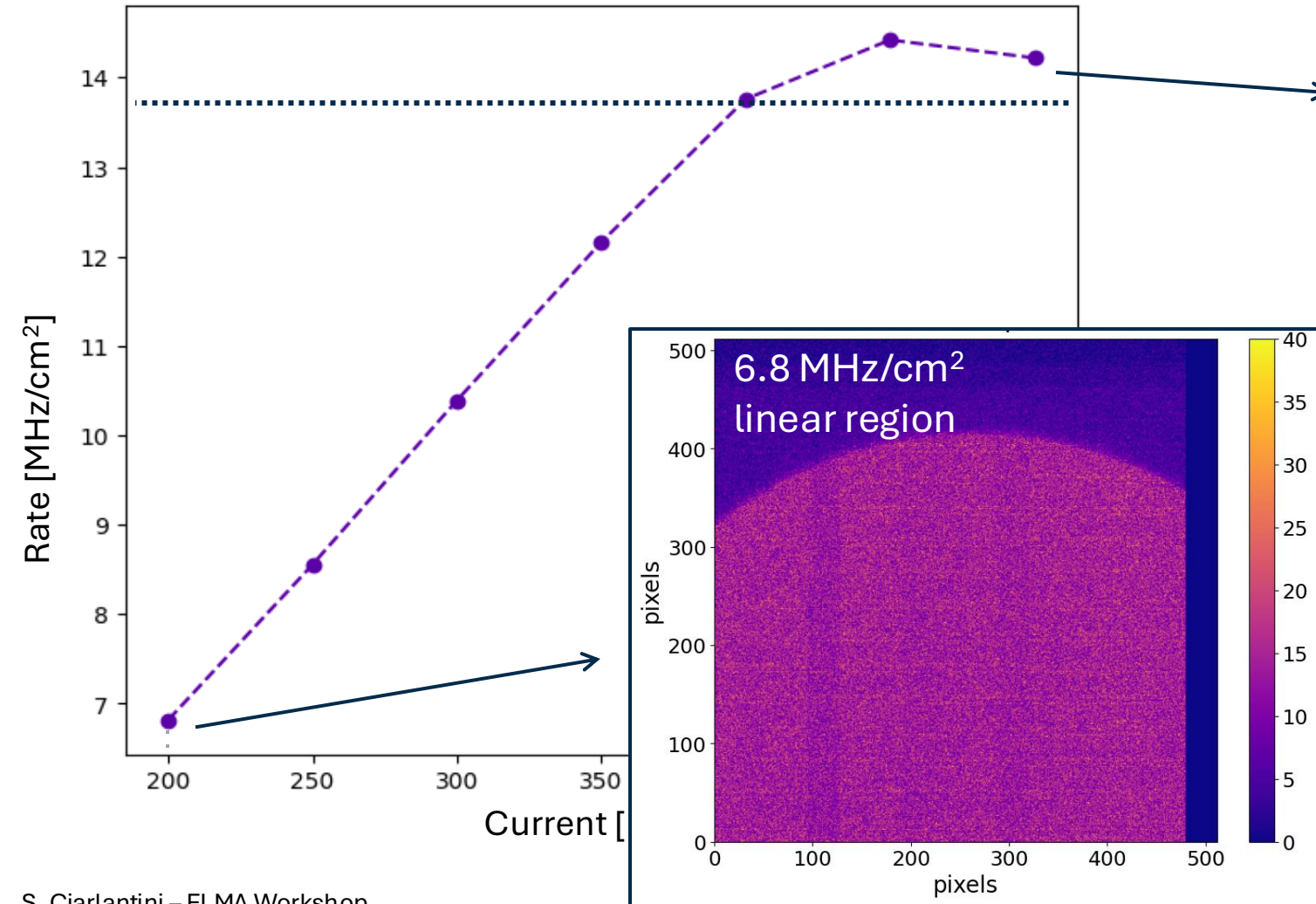Results for cluster rate on full matrix @80kV X-ray tube voltage.
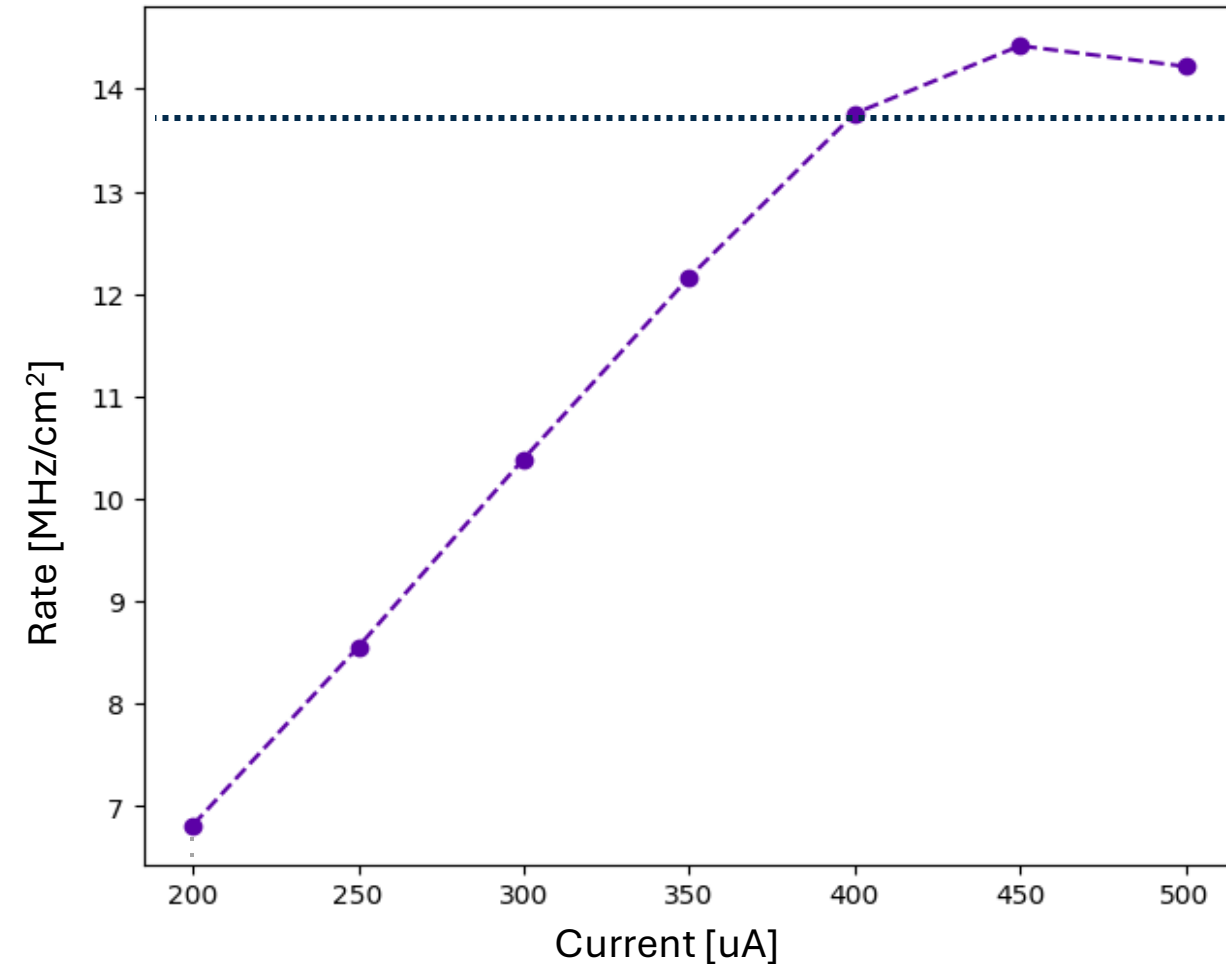
13.757 ± 0.005 MHz/cm^2

Linearity of cluster rate
verified up to 14 MHz/cm^2

MD3 characterization: rate

Rate response is evaluated as function of the current of the X-ray tube.
Results for cluster rate on full matrix @80kV X-ray tube voltage.

14 MHz/cm^2
saturation region

6.8 MHz/cm^2
linear region
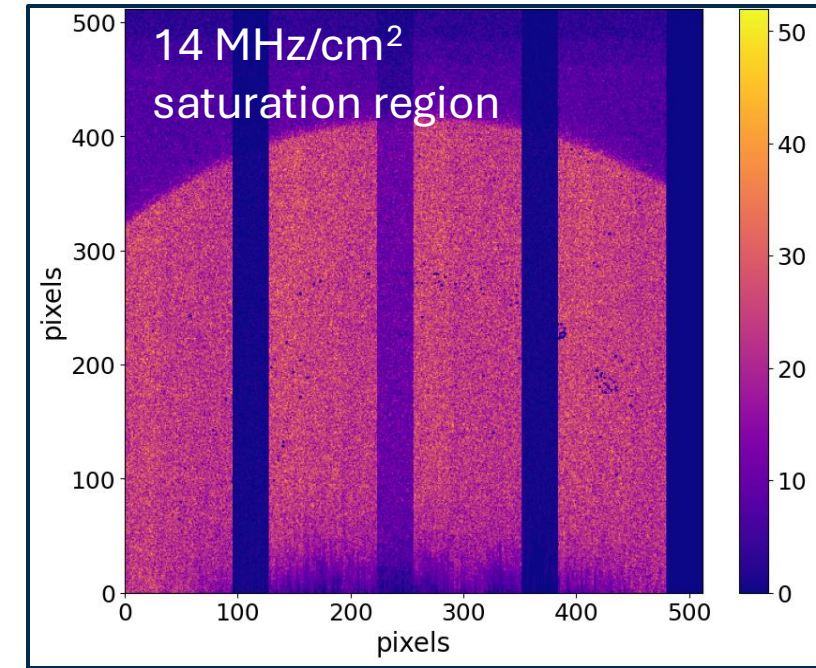
Saturation due to DAQ limits at firmware level

X-ray industrial applications

X-rays are widely used in industry for several applications

Precise Dimensional Metrology
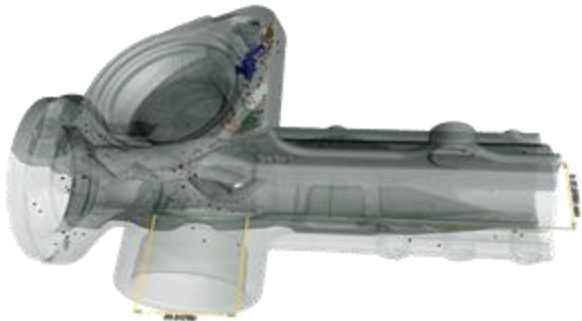
Quality Detection

Example of correct quad-flat no-lead connection.

Example of failed QFN joint connections due to lack of solder paste.
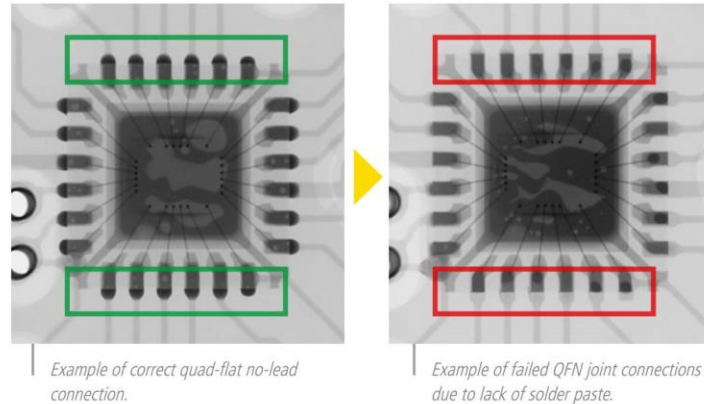
Sawmill industry
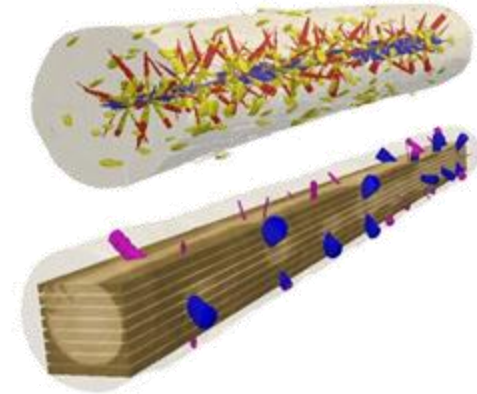
[5, 6]

Porosity study
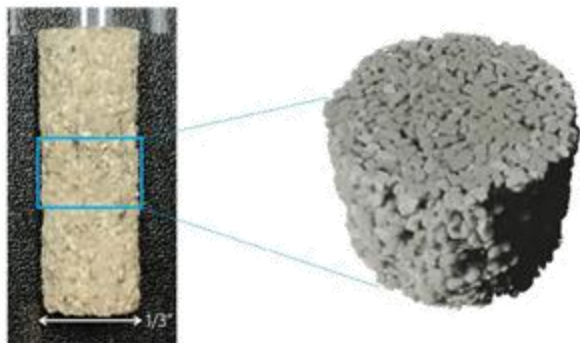
Defect Analysis

Food industry

MD3 X-ray imaging

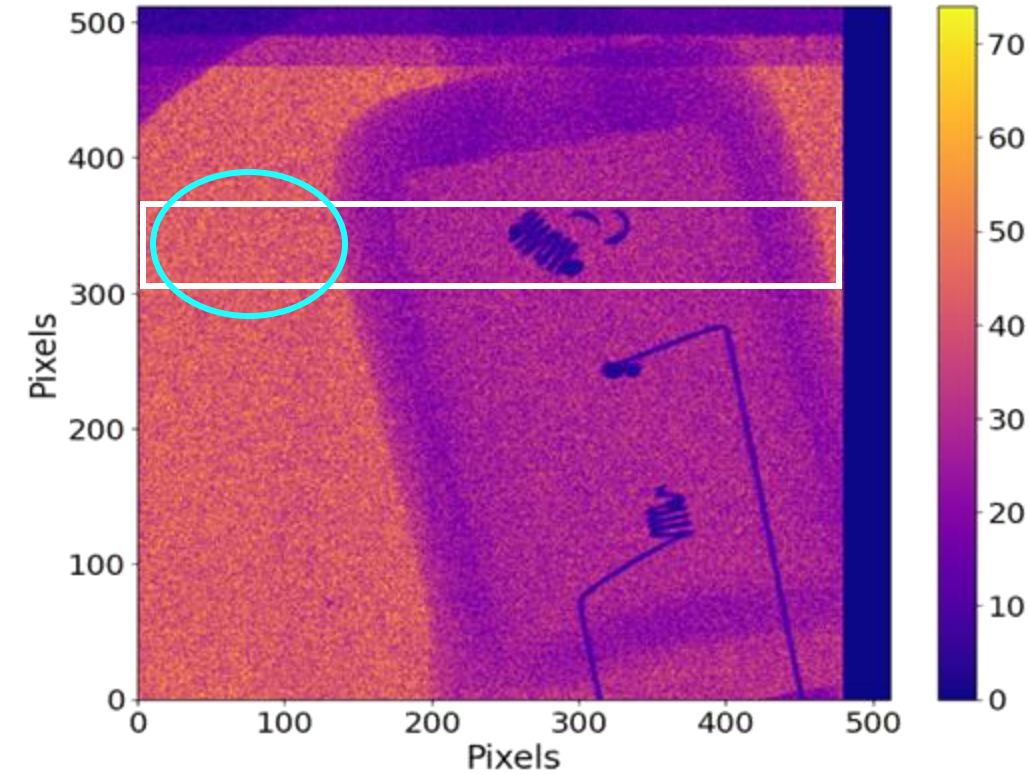Imaging performances of ARCADIA are tested with multi-material objects
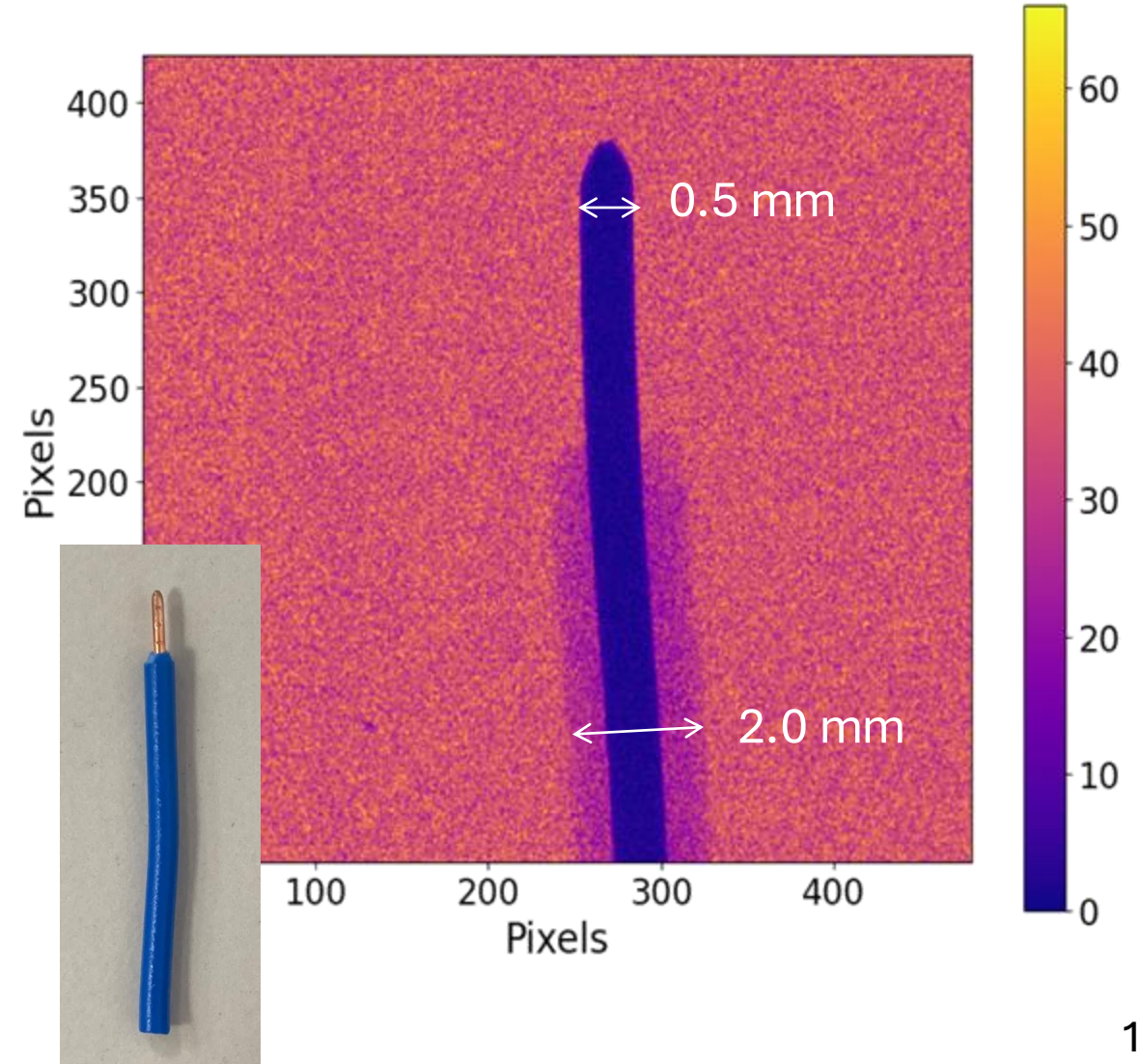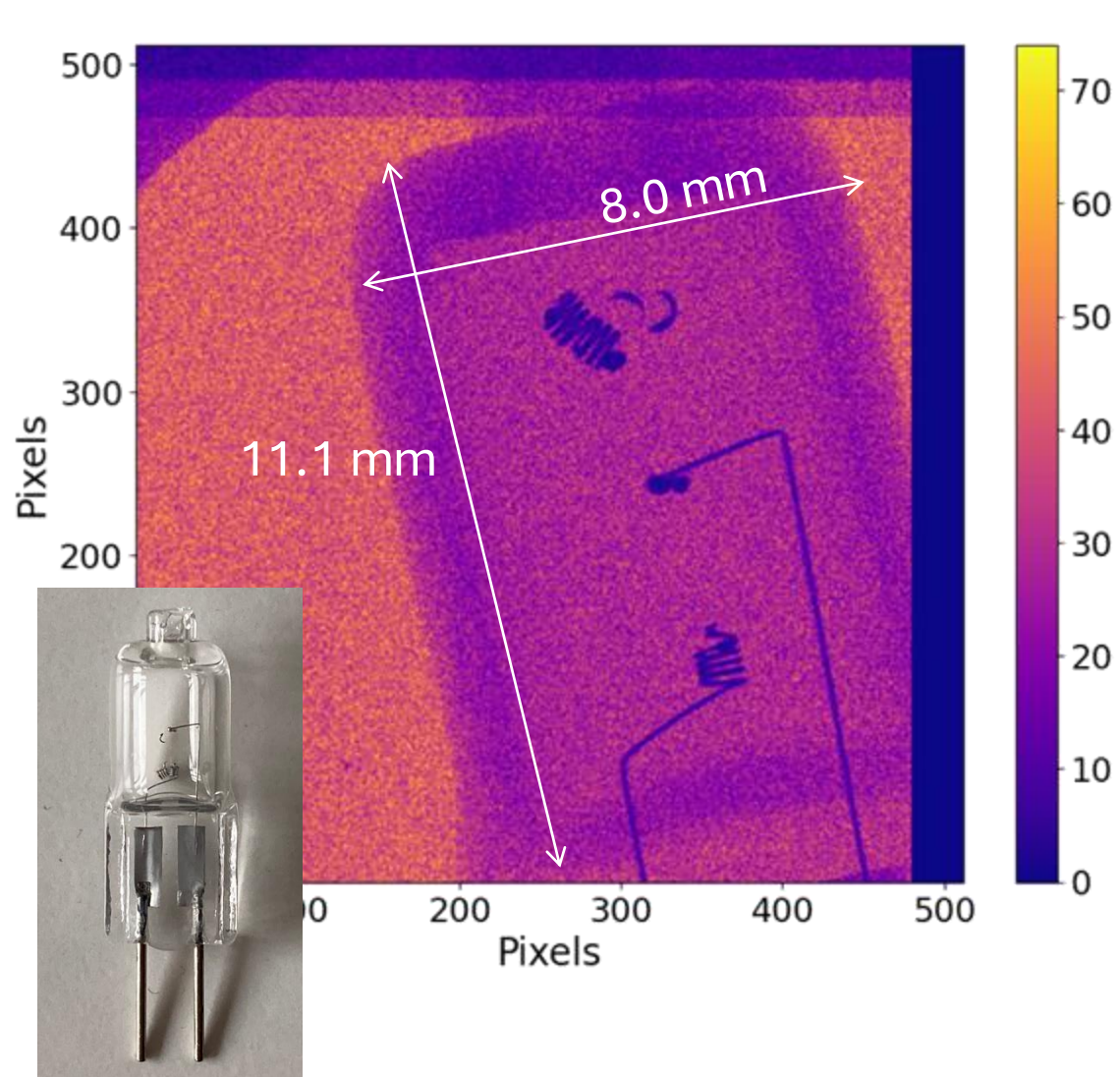
MD3 X-ray imaging

More quantitative analysis: profile plot of the intensity
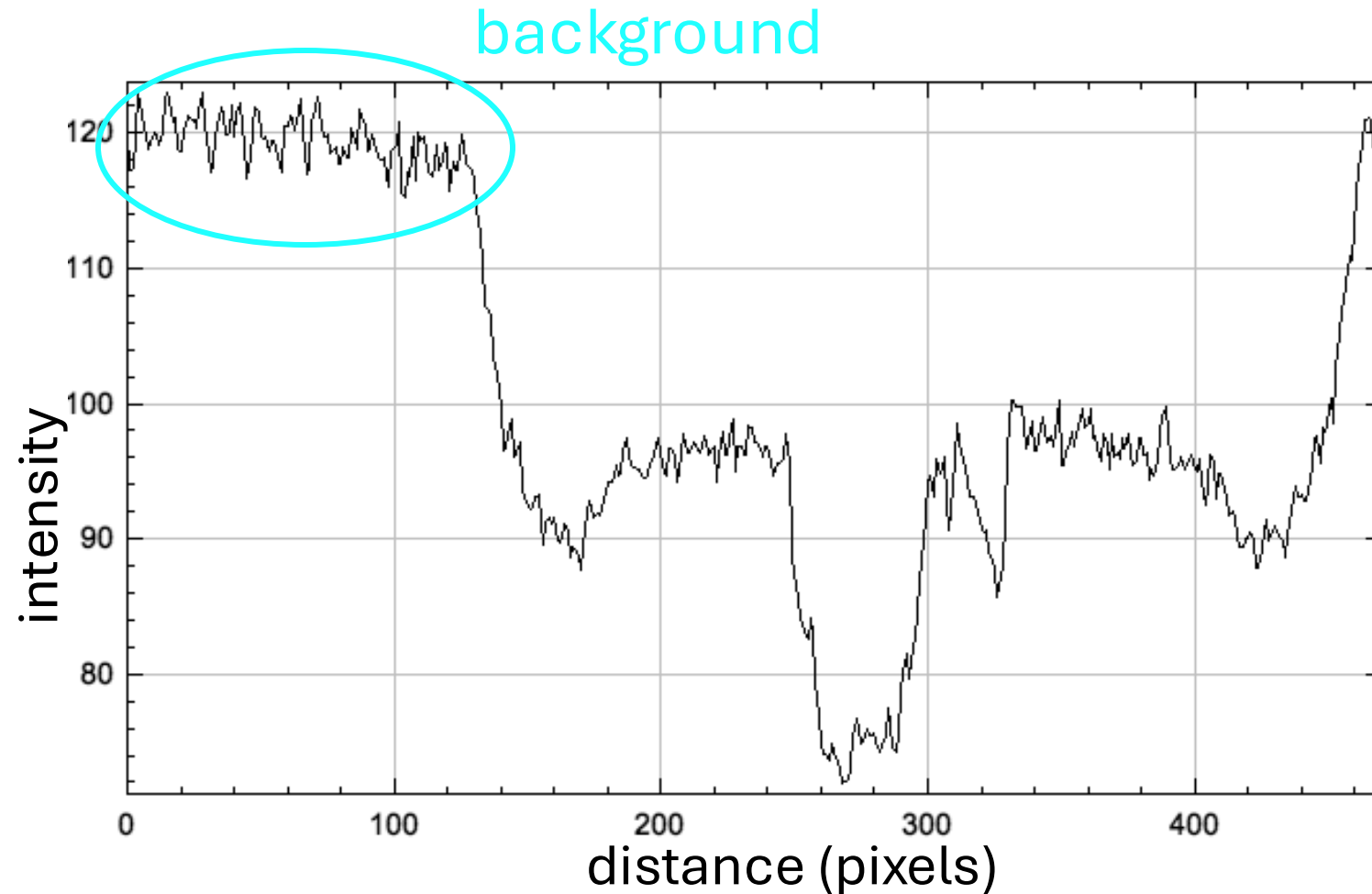
MD3 X-ray imaging

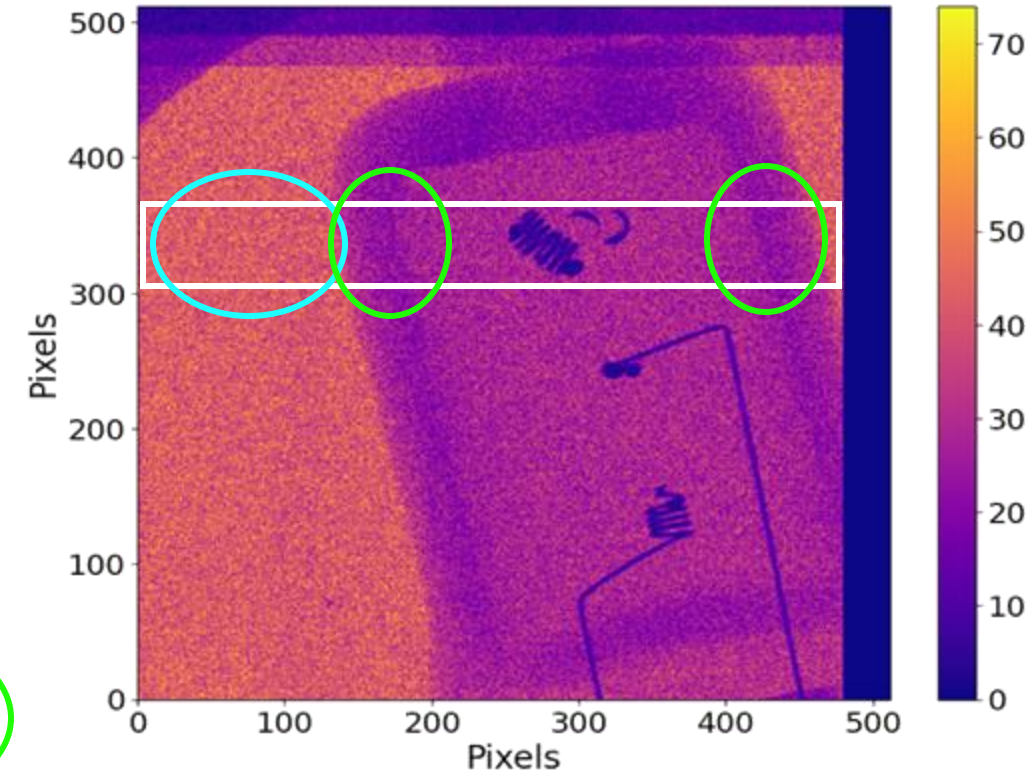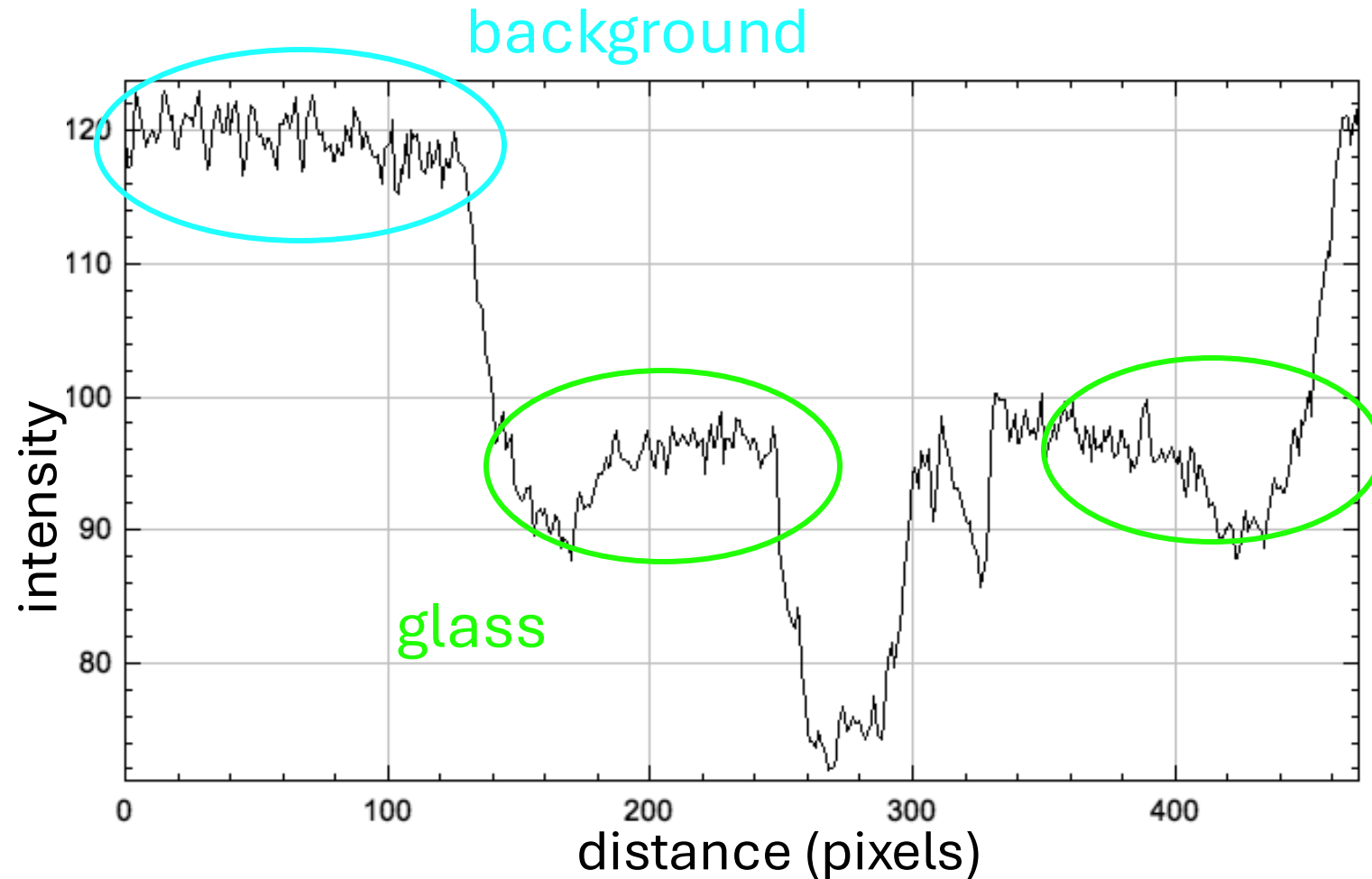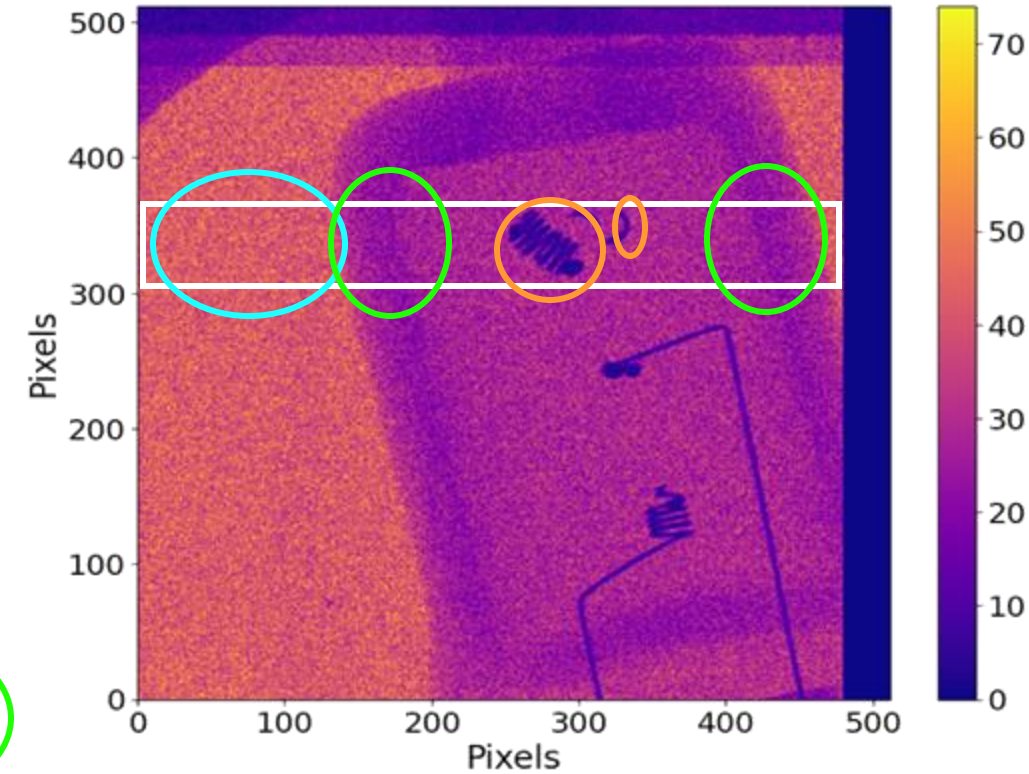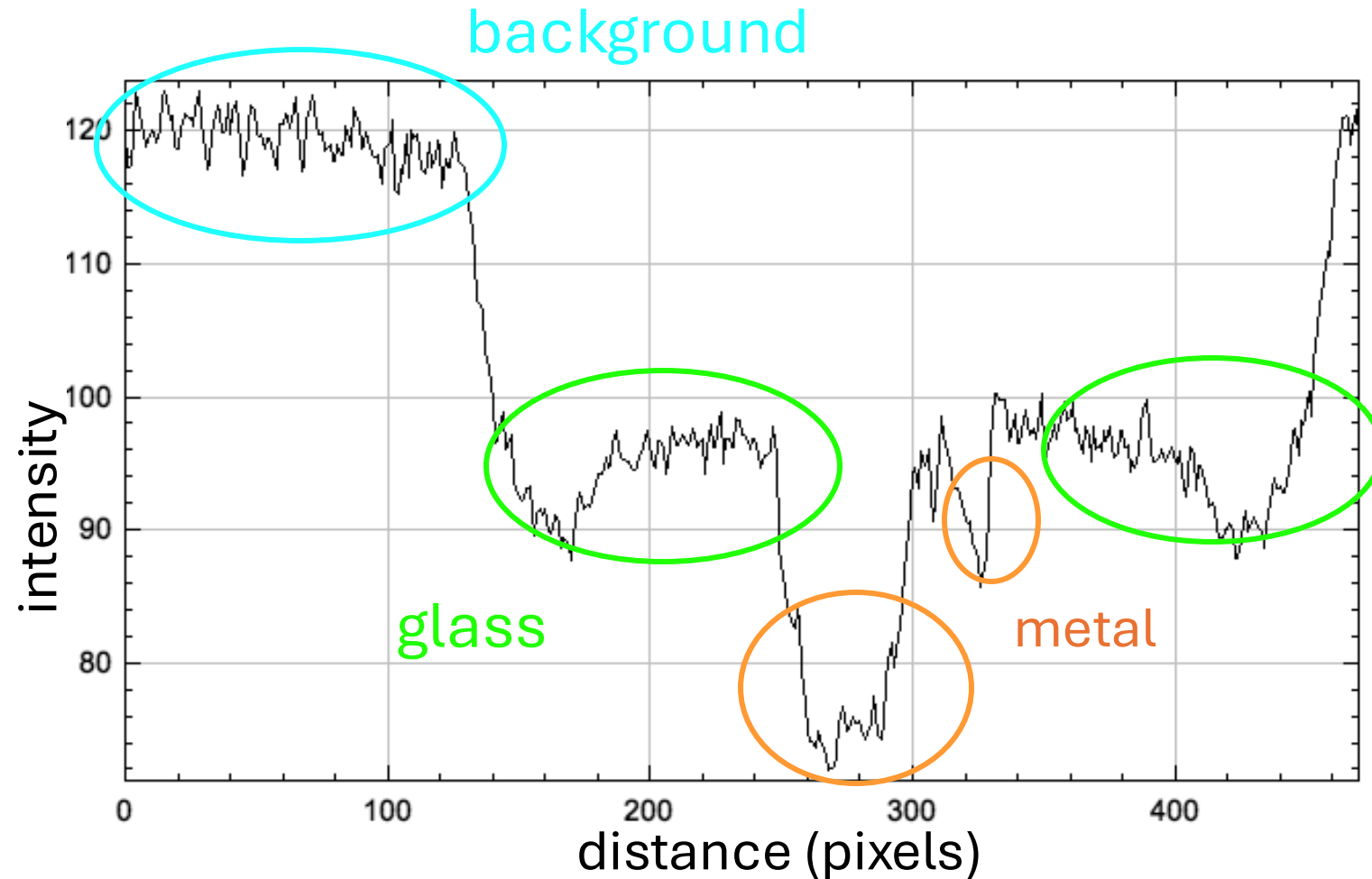More quantitative analysis: profile plot of the intensity

MD3 X-ray imaging

More quantitative analysis: profile plot of the intensity

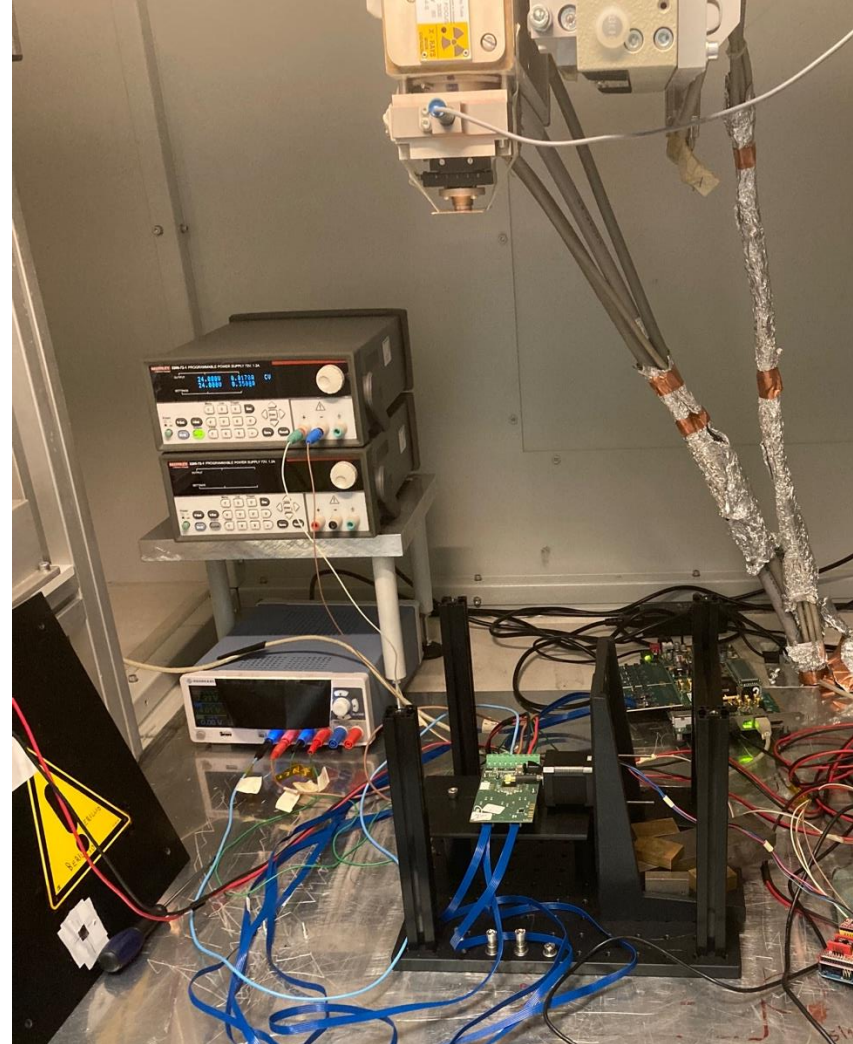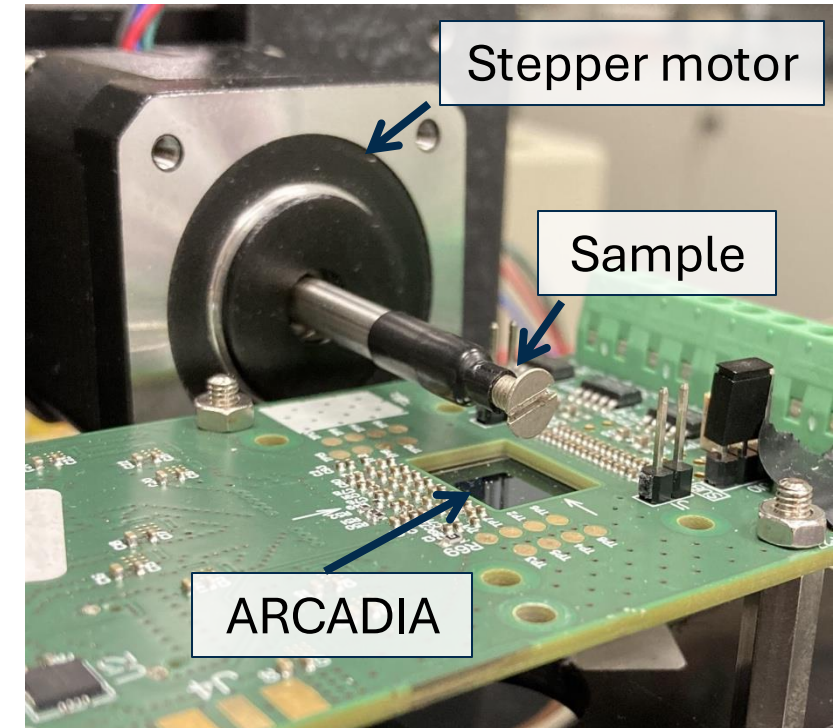glass and metal can be distinguished from intensity variation

MD3 X-ray imaging

Quality control in industry exploits the Computer Tomography 3D imaging tecnique

[7]

- X-ray tube setting: 40kV -2mA
- Cu absorber (91% attenuation)
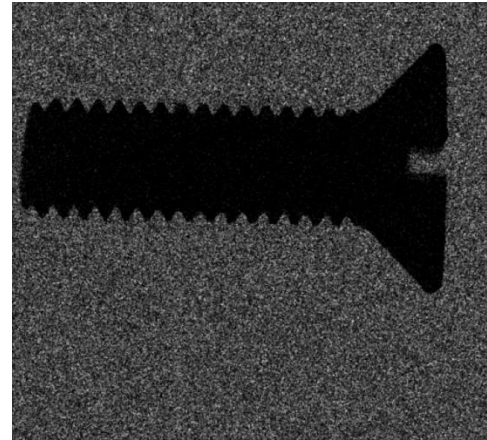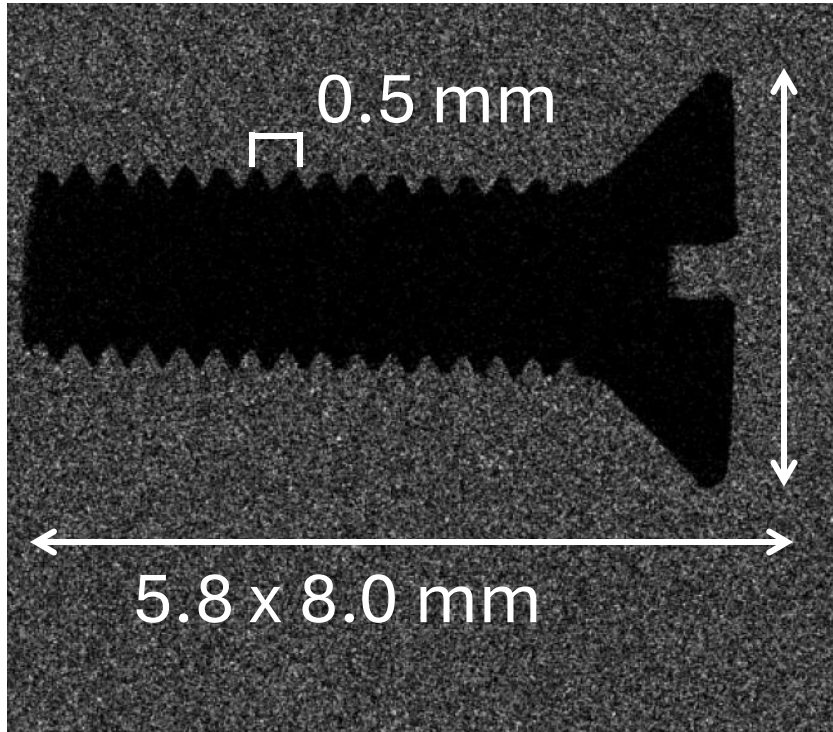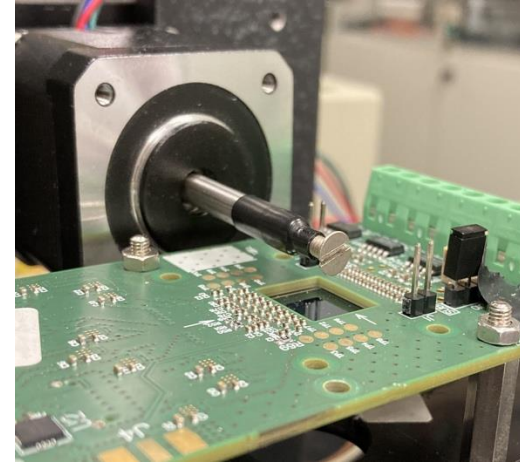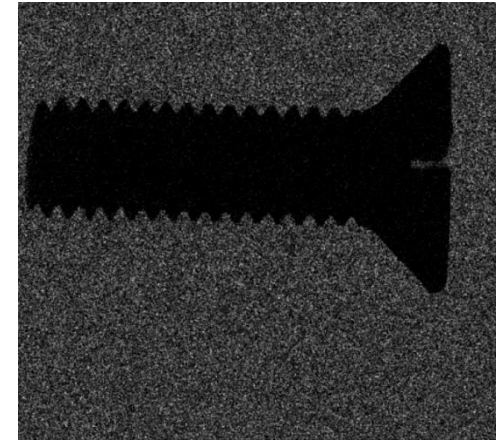- Stepper motor to rotate the sample

Stepper motor

Sample

ARCADIA

MD3 X-ray imaging

Quality control in industry exploits the Computer Tomography 3D imaging tecnique

- Sample rotated by 3.6° each step
- Discrete CT image made of 50 radiographs

0.5 mm

5.8 x 8.0 mm

step 1

step 2

step n

MD3 X-ray imaging

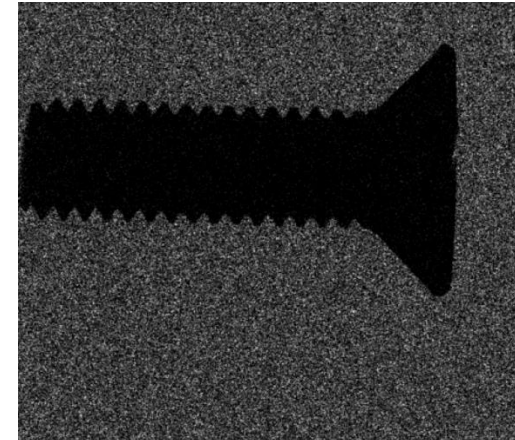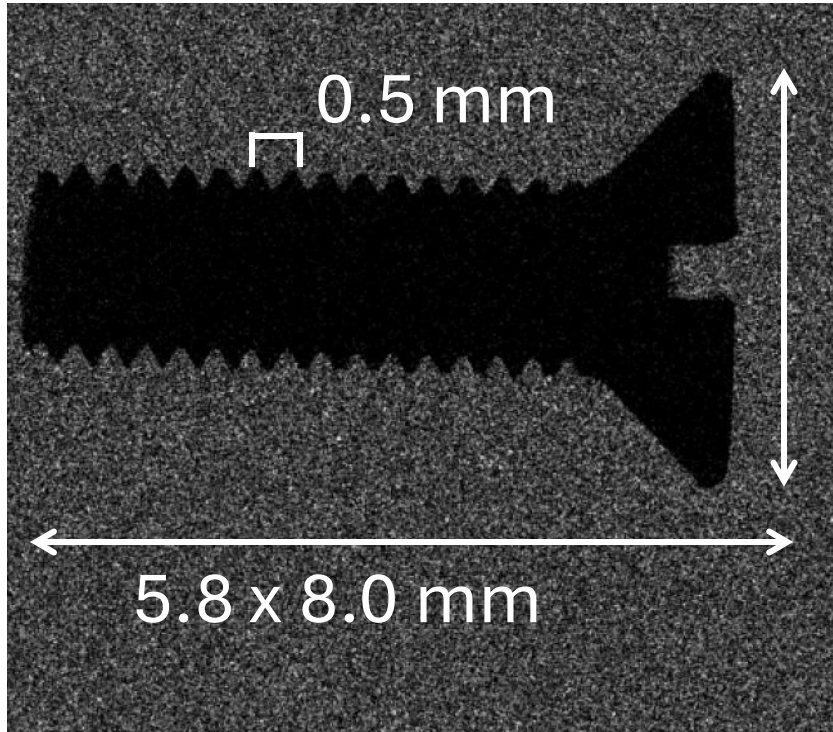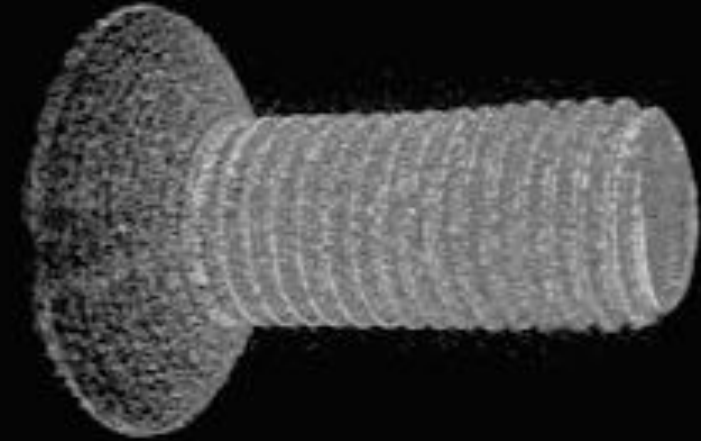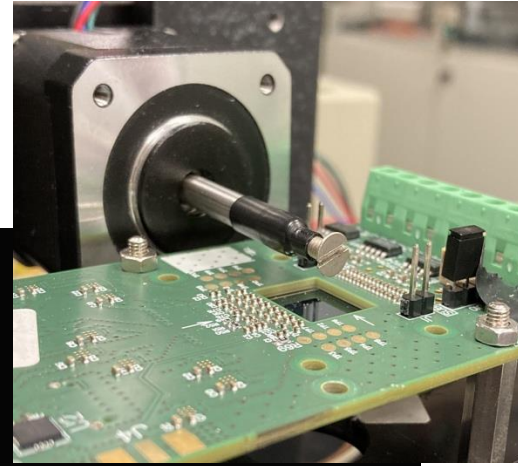Quality control in industry exploits the Computer Tomography 3D imaging tecnique

Reconstruction of 3D image recombining the 2D radiographs (projections).

0.5 mm

5.8 x 8.0 mm

3D reconstruction

(using Java based software ImageJ)

Conclusions

X-ray characterization

- thresholds calibrated in the [4, 9] keV energy range

- The linearity of cluster rate has been shown

Industry applications

- Successful 2D imaging of different objects

- Proof of material discrimination from the intensity profile

- Successful 3D reconstruction without any conversion layer (e.g. scintillator) used

Thank you for your attention

References

[1] Da Rocha Rolo, Manuel, et al. "ARCADIA Fully-Depleted CMOS MAPS development with LFoundry 110nm CIS." Frontiers in Sensors 6 (2025): 1603755.

[2] Corradino, Thomas, et al. "Design and characterization of backside termination structures for thick fully-depleted MAPS." Sensors 21.11 (2021): 3809.

[3] NIM A 699 (2013) 205–210

[4] Kraft, P., et al. "Performance of single-photon-counting PILATUS detector modules." *Synchrotron Radiation* 16.3 (2009): 368-375.

[5] DOI: 10.13140/RG.2.2.16987.28960

[6] https://www.biometic.com/it/soluzioni-ispezione-alimentare/ispezione-raggi-x-3d-mito

[7] https://www.microtec.eu/it/prodotti/ct-log

Backup

Timing application

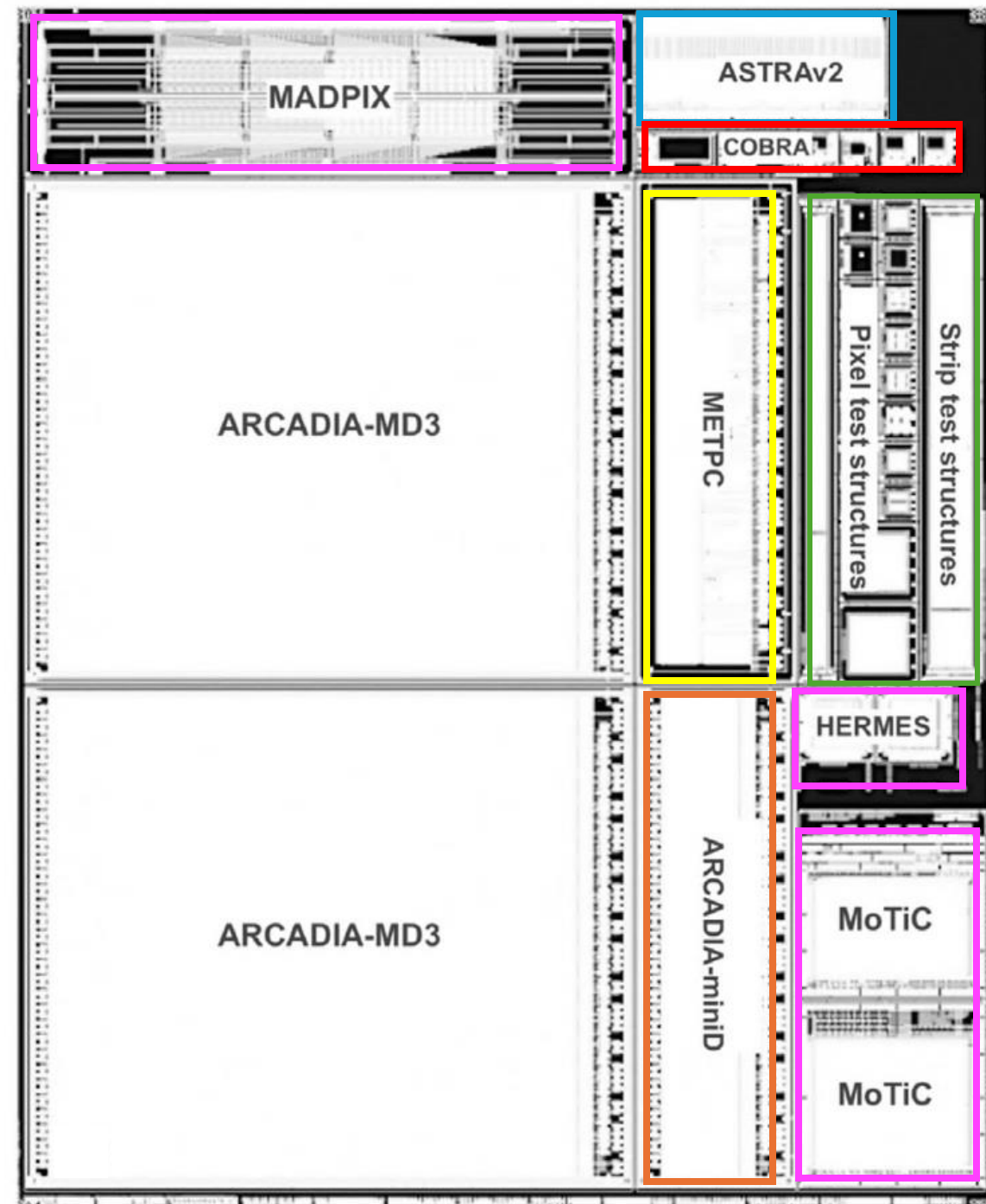Passive structures for electrical characterization

X-ray application (multi photon counter)

Debugging implemented power management IPs

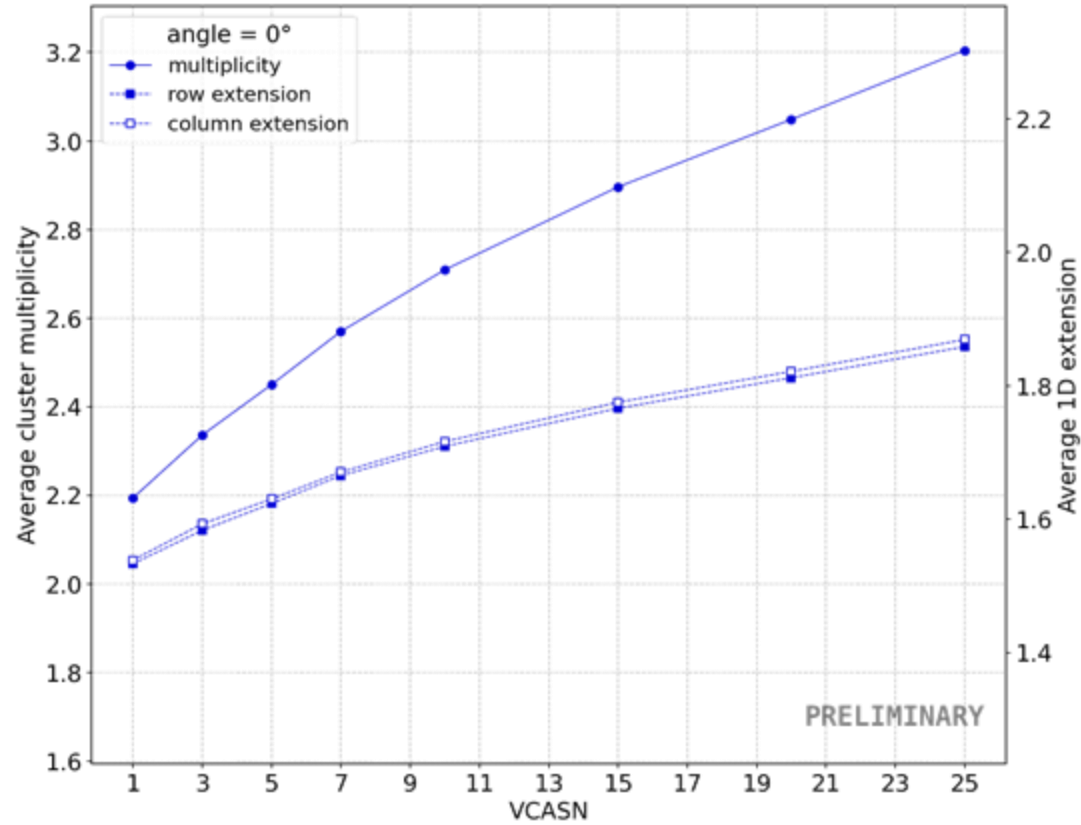Space-borne applications

Tracking and dosimetry

More info in
Da Rocha Rolo, Manuel, et al. "ARCADIA Fully-Depleted CMOS MAPS development with LFoundry 110nm CIS." Frontiers in Sensors 6 (2025): 1603755.
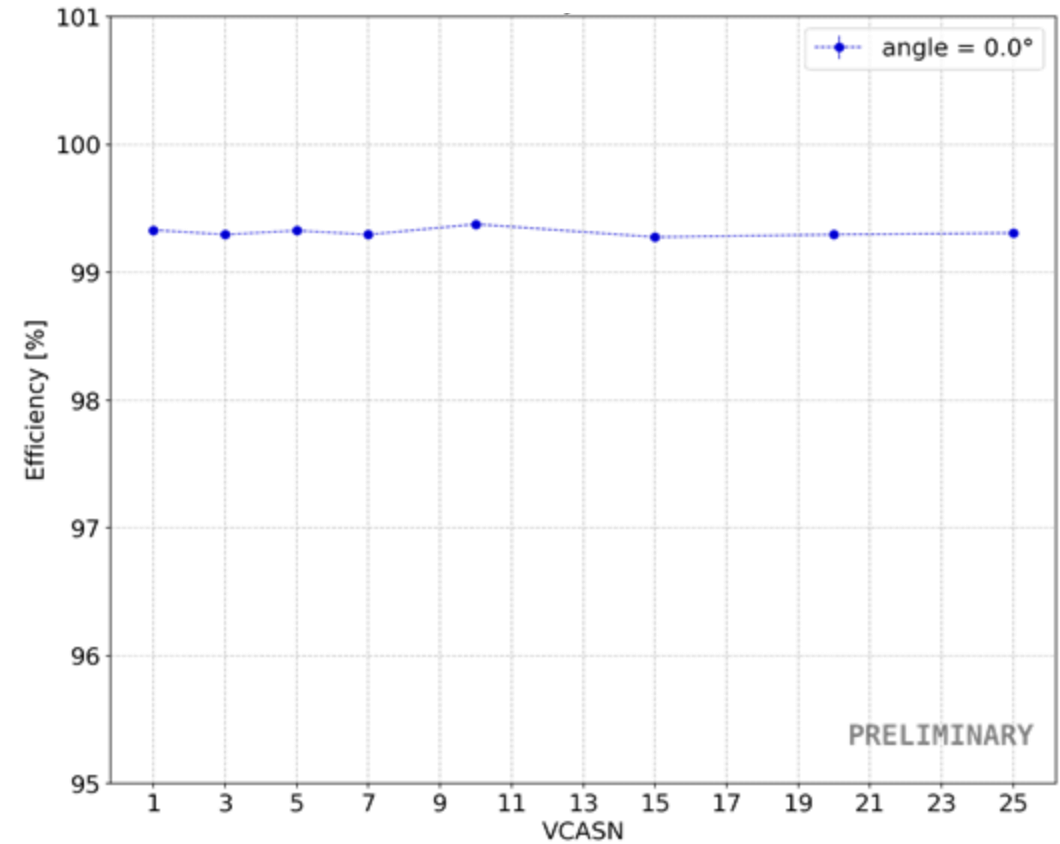
Backup

Test Beam preliminary results: cluster size and efficiency vs threshold (VCASN)

Cluster size

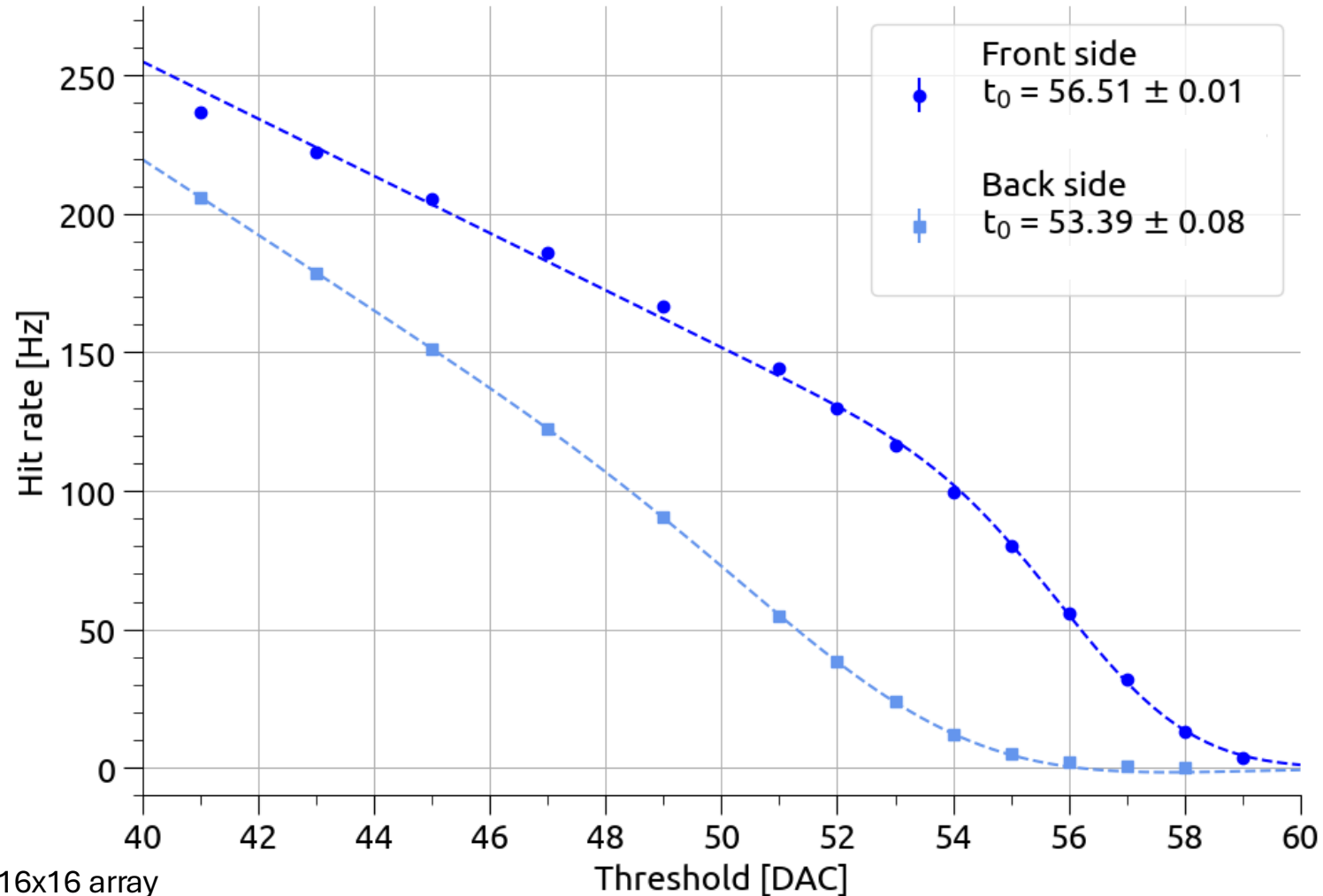**Efficiency**

decreasing threshold

decreasing threshold

Average efficiency : 99.23 %

Backup

The electronic cloud released by X-ray diffuses in silicon leading to charge sharing.
More charge sharing when illuminating from the back side

Legend:
Front side
$t_0 = 56.51 \pm 0.01$

Back side
$t_0 = 53.39 \pm 0.08$
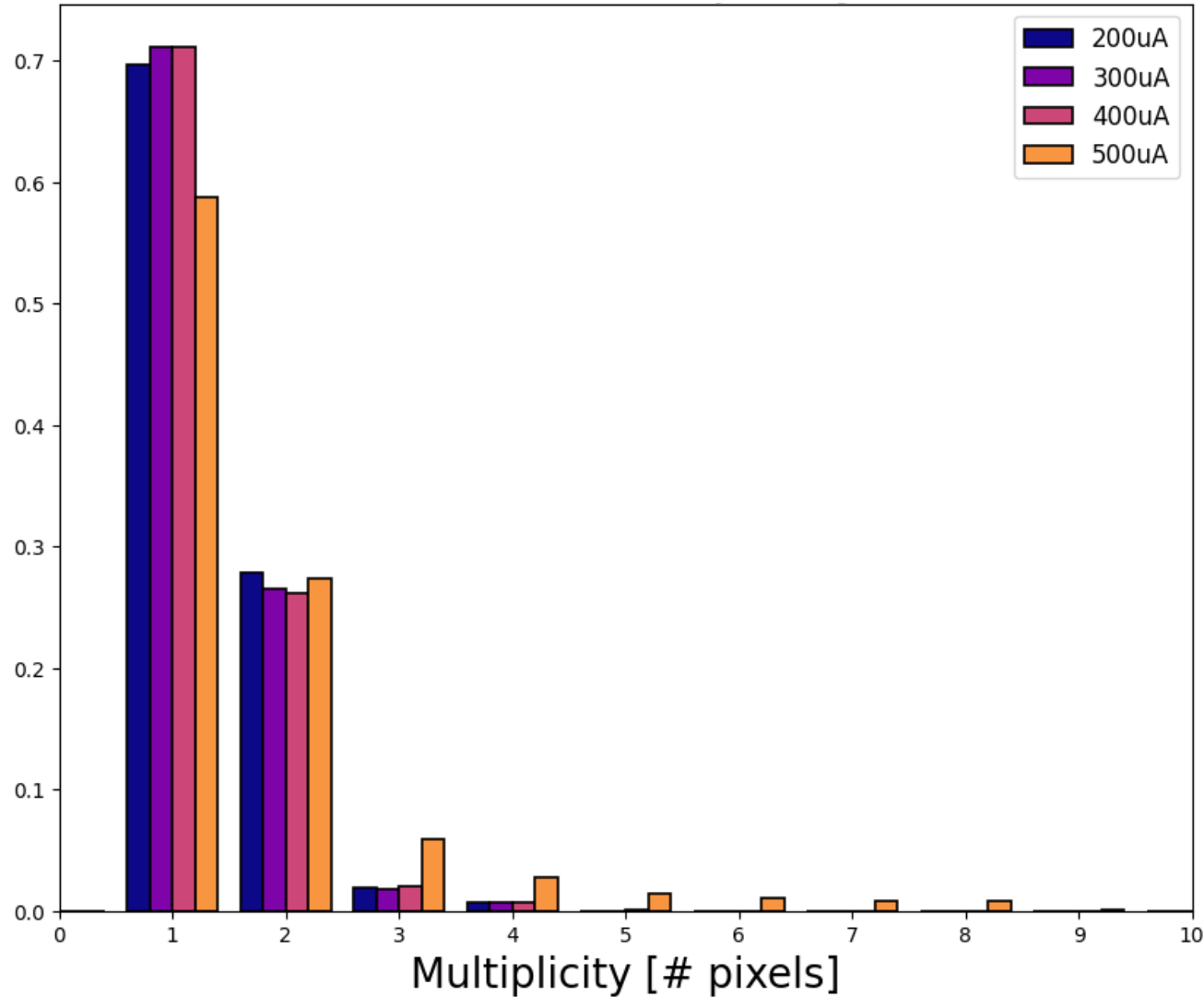
Example of ^{55}Fe s-curve for the 16x16 array

Backup

Fine tuning of the sectors Background Reference using ^{55}Fe source to obtain uniform response
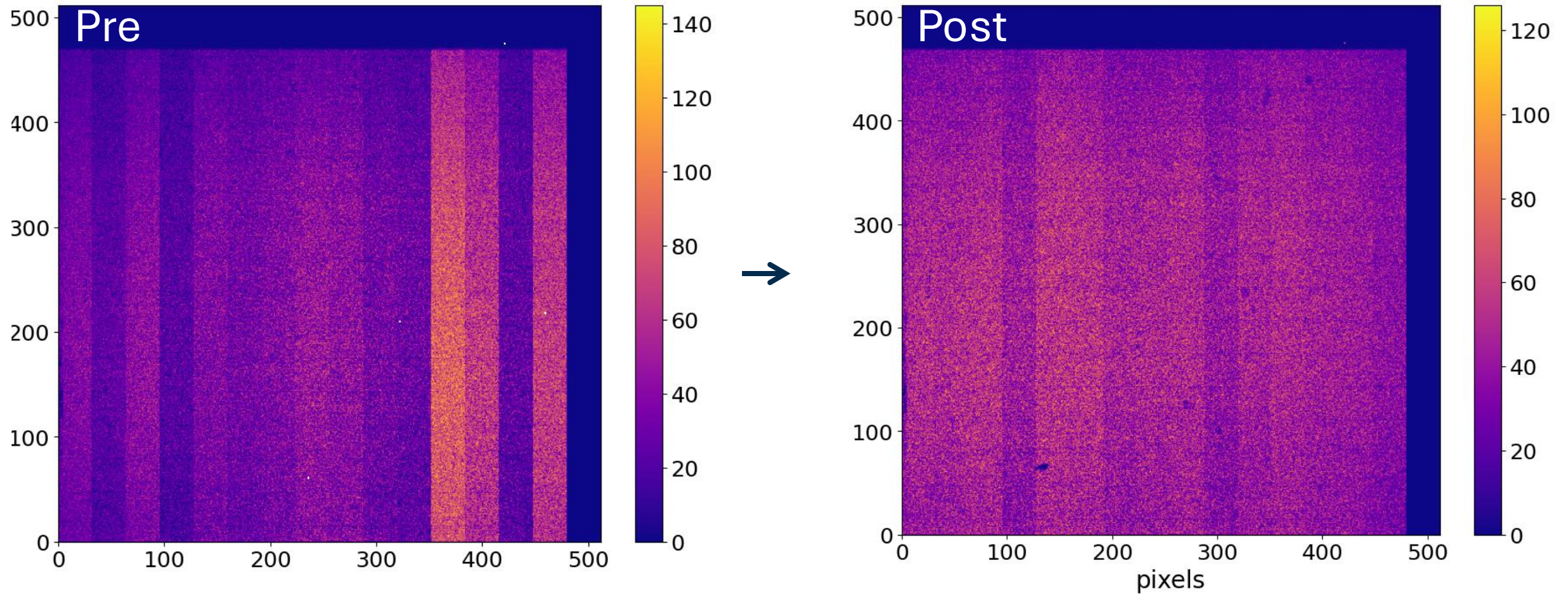
Backup

Cluster size (number of pixel) for 80kV X-ray tube photons
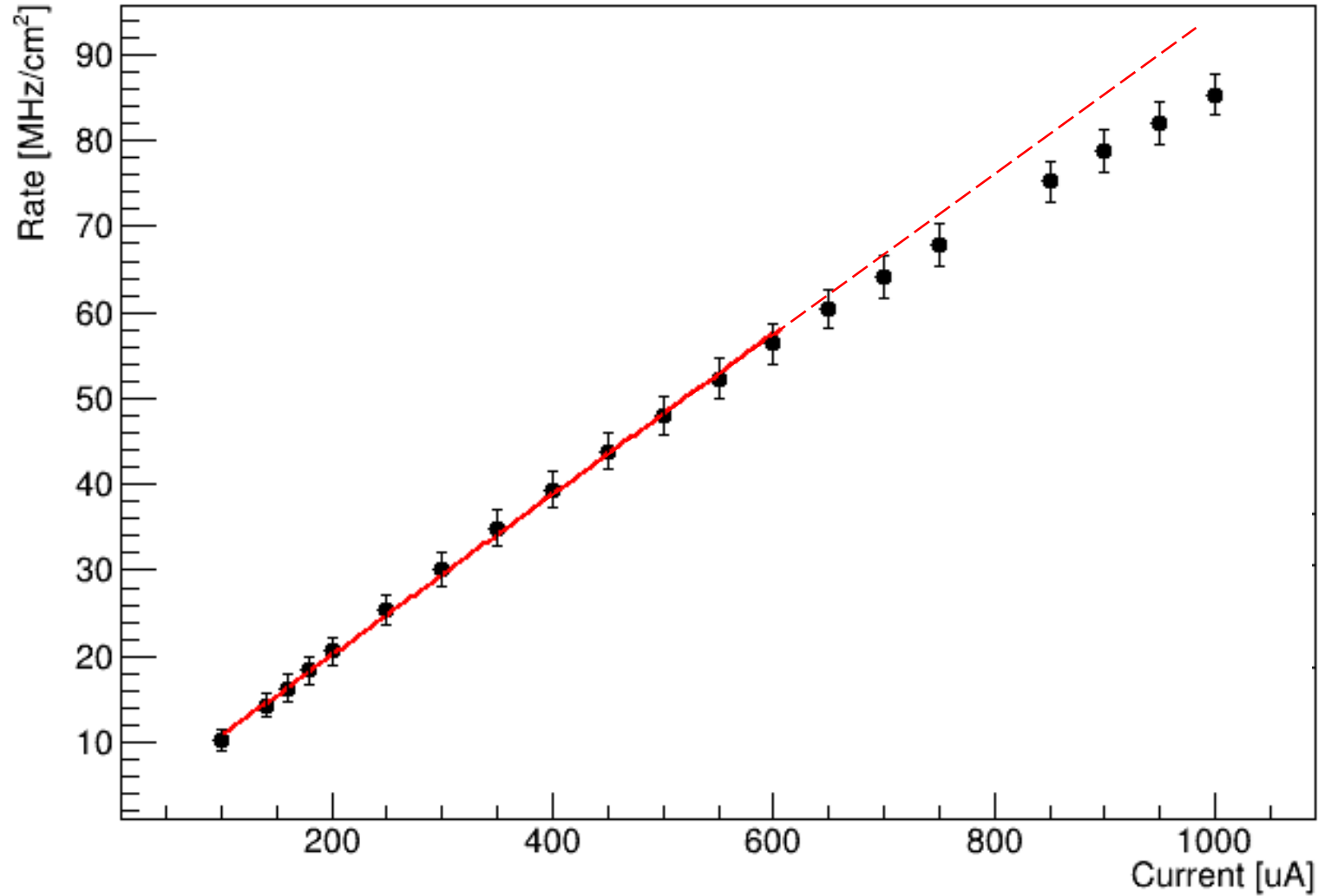

Clustering algorithm applied with
- Time proximity threshold: 5 timestamps
- Spatial proximity threshold: 2 pixel

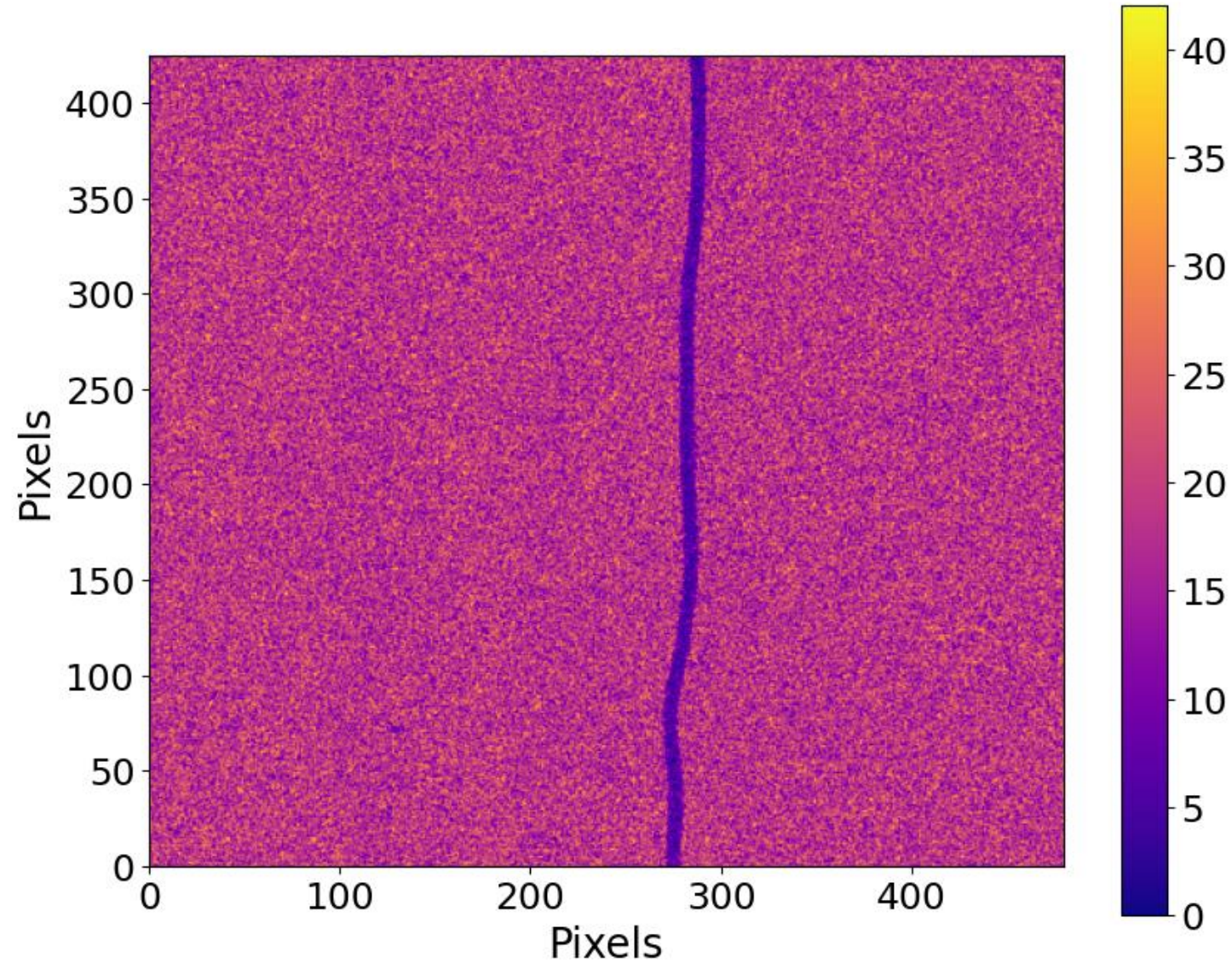Majority of single and double pixel clusters

Backup

Cluster rate of 32x32 pixel array @80kV X-ray tube voltage.
Linearity verified up to 60 MHz/cm^2
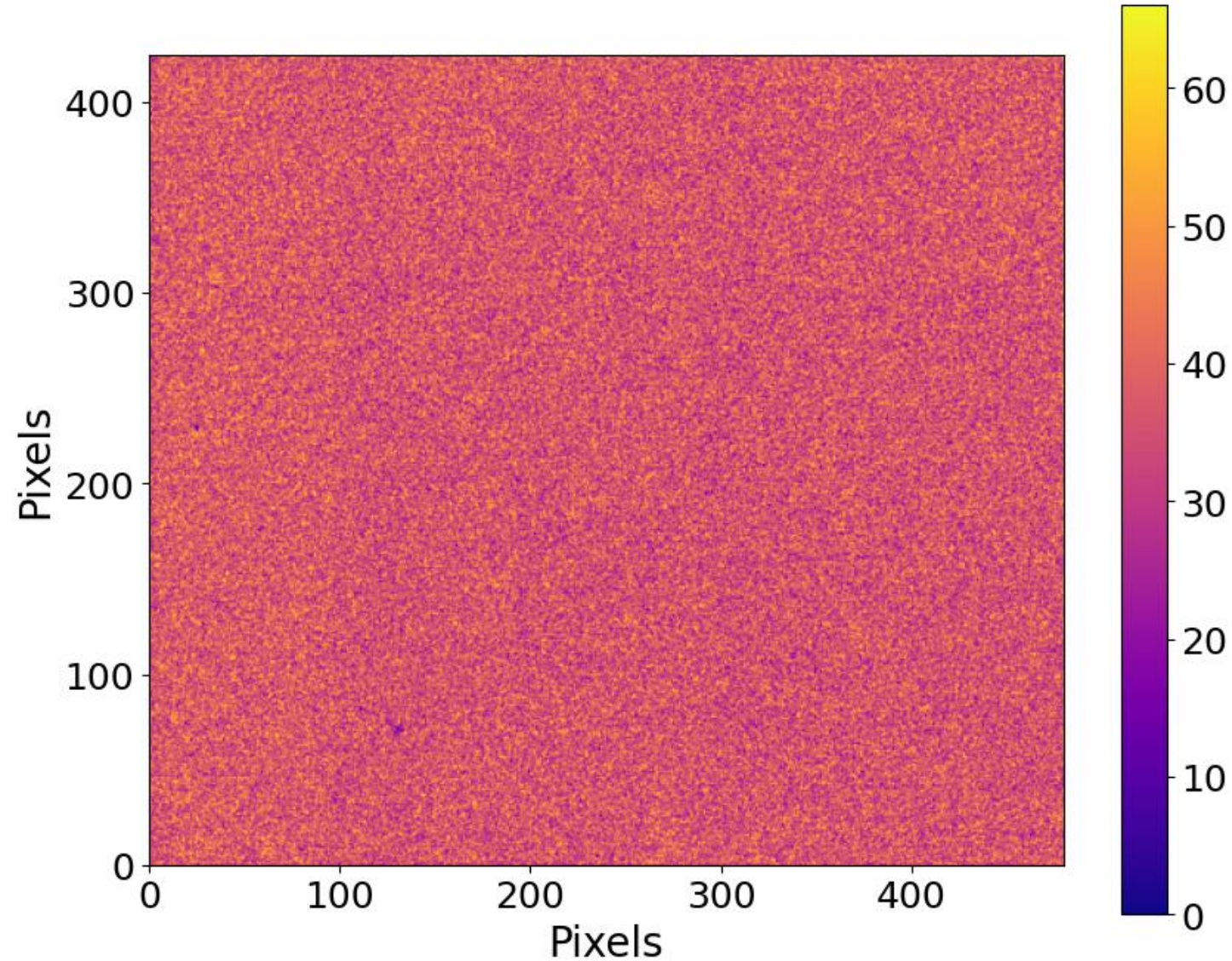
Backup

X-ray imaging of metallic wire

200 μm thickness resolved with 8 pixel resolution of 25 μm

Backup

X-ray imaging of wood stick

9.2 mm

thickness 1.3 mm

Wood is too light
not enough contrast to spot it on the image