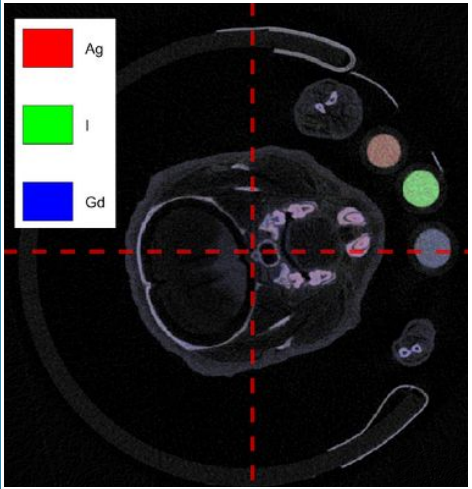
X-ray spectral micro-CT imaging with GaAs and CdTe Timepix4 hybrid pixel-detector



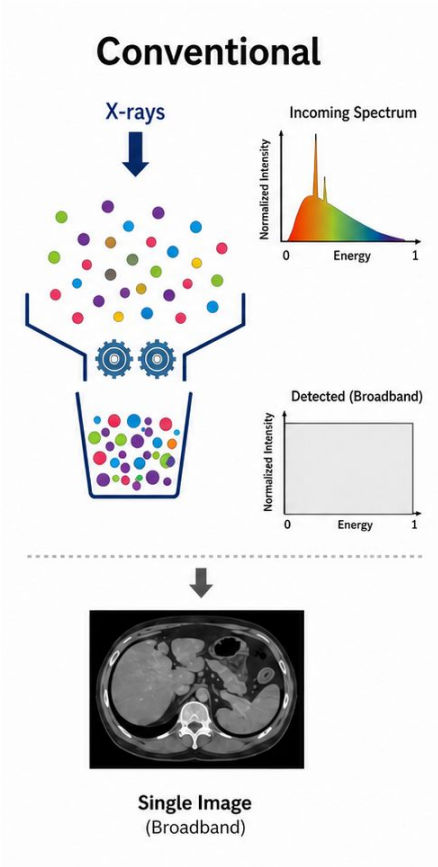
27th International Workshop on Radiation Imaging Detectors

June 28, 2026 - July 2, 2026 Ghent, Belgium

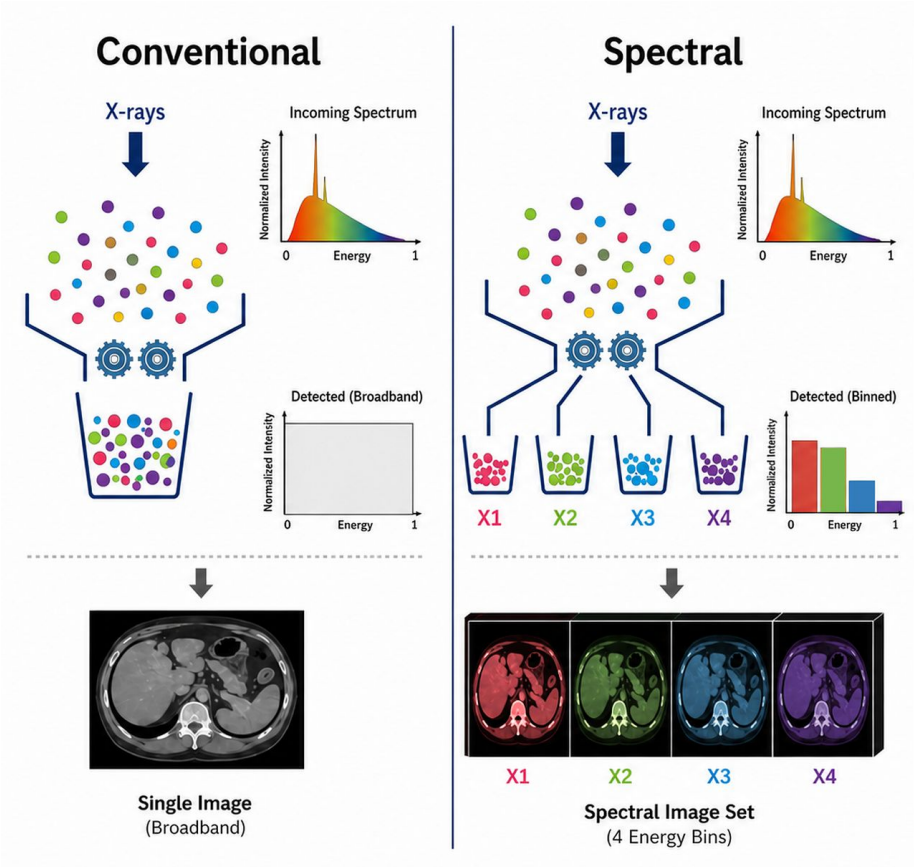
S. Velardita[1], N. V. Biesuz[1], L. Brombal[2], F. Brun[2], P. Cardarelli[1], V. Cavallini[1], A. Feruglio[3], M. Fiorini[1], R. Longo[2], V. Mazzini[1]

[1]INFN - Ferrara Division, [2]INFN - Trieste Division & Università degli studi di Trieste, [3]INFN - Pisa Division

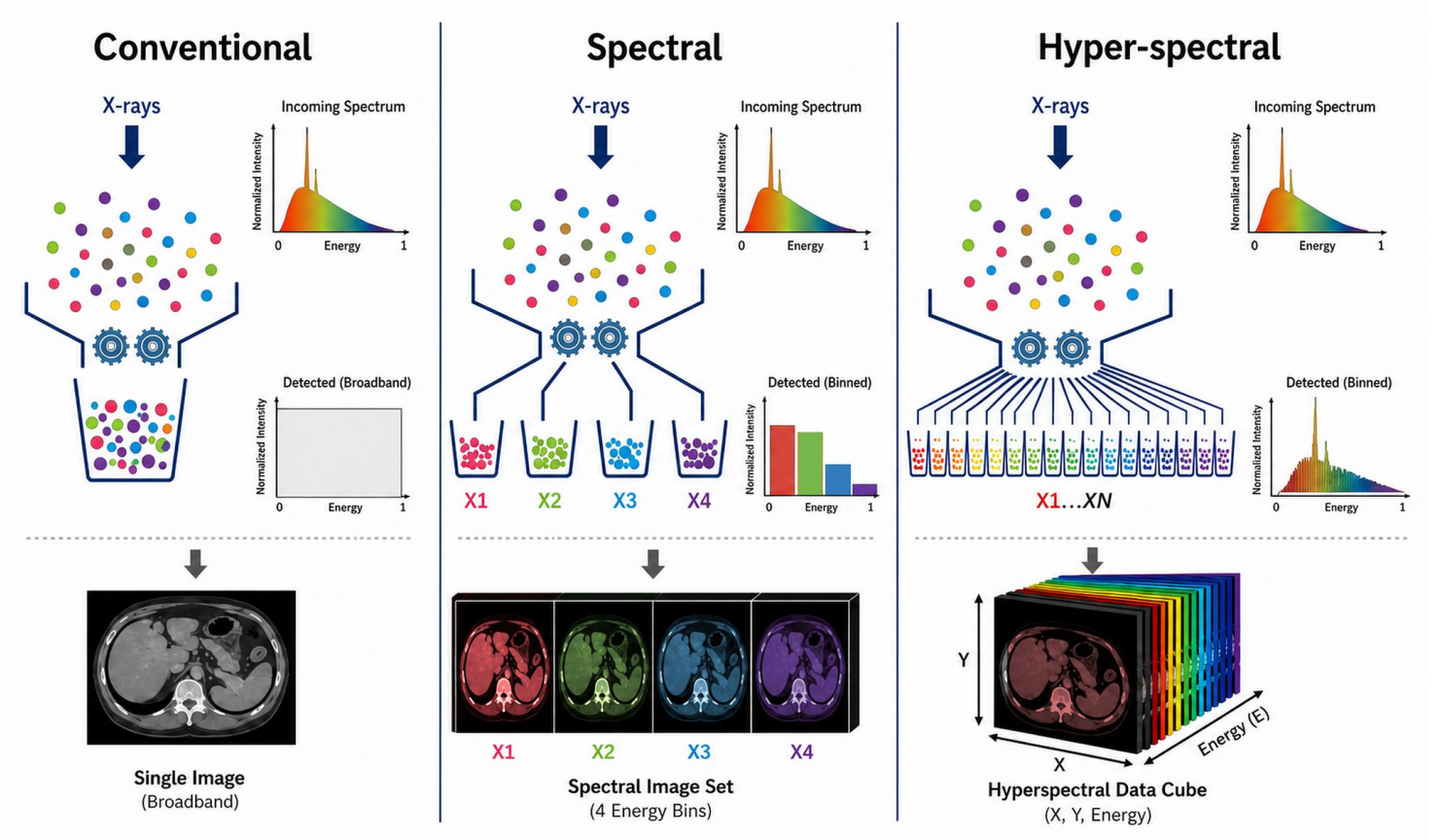
From conventional to hyper-spectral CT



From conventional to hyper-spectral CT

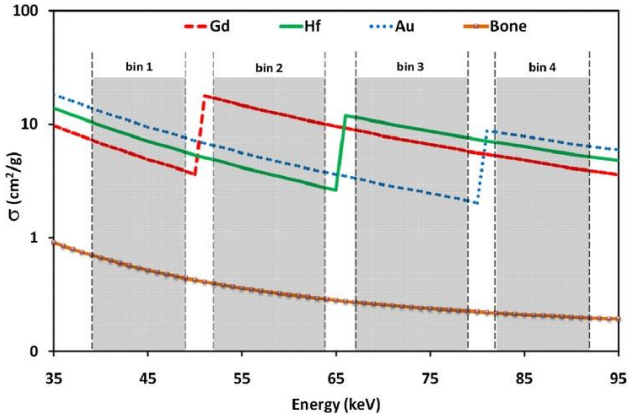


From conventional to hyper-spectral CT



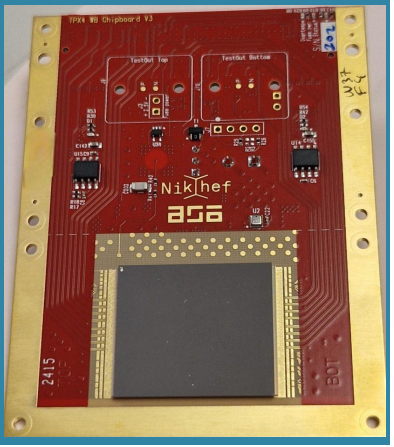
From conventional to hyper-spectral CT

- Energy-integrating detector (EID) → **one μ value** per voxel
  - materials at matched attenuation → indistinguishable
- Energy-resolved μ(E) → **K-edge jump** at element-specific energy
  - jump position → fingerprint, concentration-independent
- **Material decomposition**: one element per channel
  - multi-agent imaging needs energy-resolving photon-counting detector

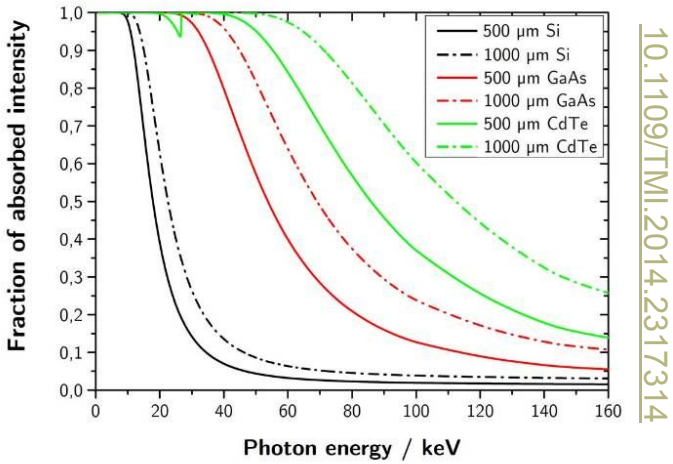


10.1259/bjr.20130308

High-Z Timepix4 Assemblies



- X-ray imaging target energy range **10-100 keV**
- **High-Z** Timepix4 assemblies (512*448 matrix, 55µm pitch)
  - 1 GaAs 0.5 mm (S. Velardita *et al.* 2026 *JINST* 21 C01023)
  - 3 CdTe 1 mm
- Readout
  - SPIDR4 electronics + DataPix4 software (V. Cavallini et al., 2025)



Timepix4 readout

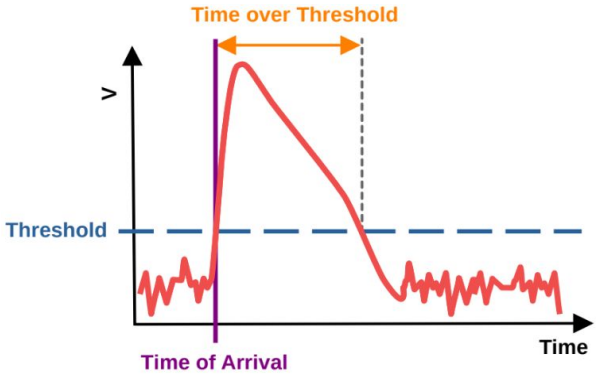
Two different readout modes:

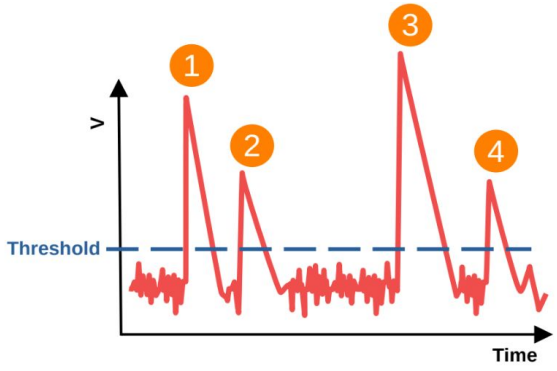
Data-driven

- Event-based readout, sending only relevant data (particle hits)
- Output [X, Y, ToA, **ToT**]
- Full spectral information at limitated rate

Frame-based

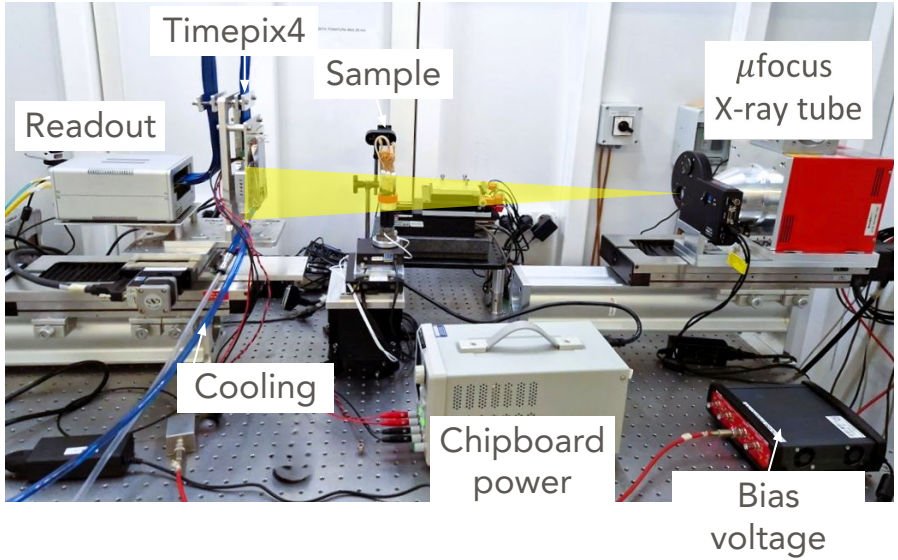
- Photon-counting mode
- Output [X, Y, **Counts**]
- Full frame readout with continuous read-write (CRW)





Micro-CT setup at INFN-PEPI lab

- Timepix4 integrated in the **PEPI** micro-CT setup
- Compact Multi-modal X-ray system:
  - Phase-contrast imaging
  - Spectral micro-CT

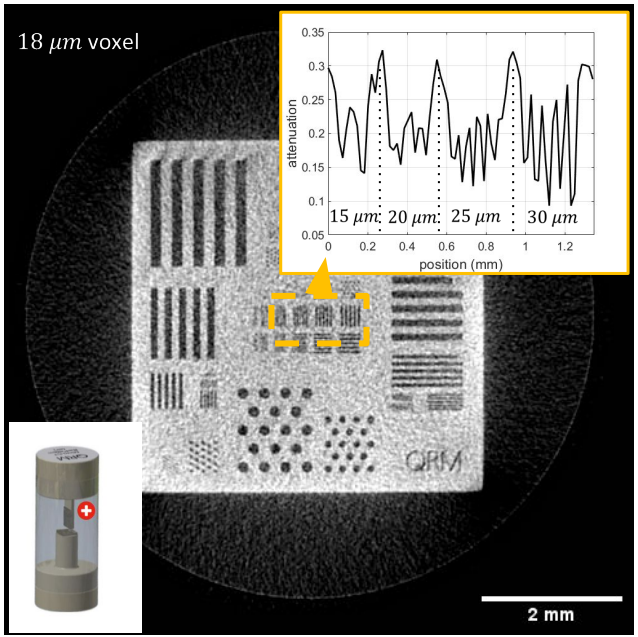


Brombal, L., et al. *Scientific Reports* 13.1 (2023): 4206.

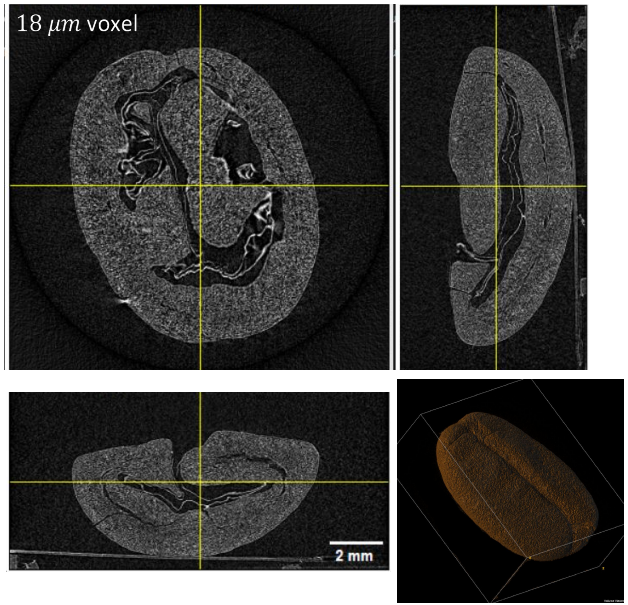
Frame-Based µCT

- **Frame-based** µCT at PEPI using the **GaAs** assembly
  - 50 kVp · 150 µA · 2 s/proj · 1440 proj / 360°
- Resolution with QRM bar pattern
  - fine bar groups (~25 µm) resolved at **18 µm voxel**

μCT bar pattern – by QRM



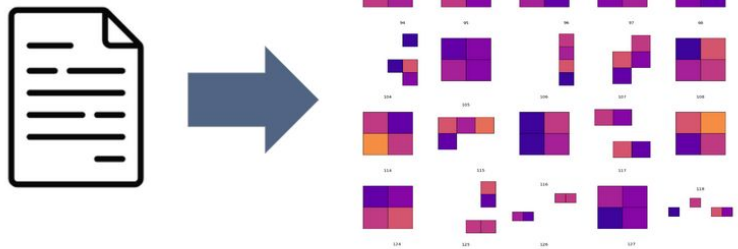
coffee-bean

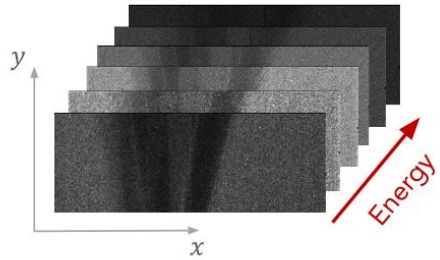


From raw data to spectral-CT

Clustering algorithm

Energy calibration





Data-driven raw data .bin

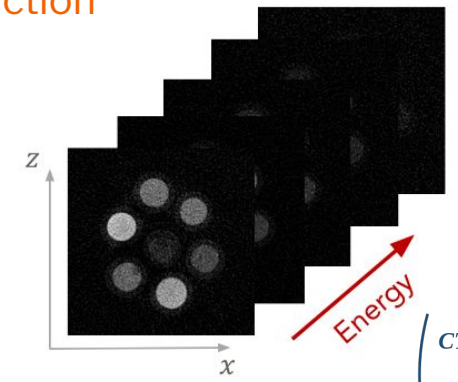
Cluster event

Energy-binned projections

➔ Steps 1–3: common to all data-driven imaging

From raw data to spectral-CT

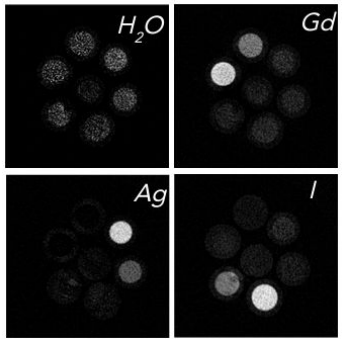
FDK CT reconstruction



Energy-binned CT slices

Multi-material decomposition

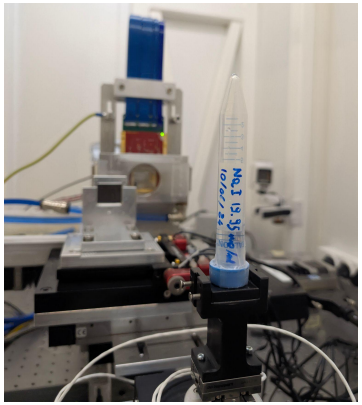
$$\begin{pmatrix} CT(E_1) \\ \vdots \\ CT(E_n) \end{pmatrix} = \begin{pmatrix} \mu/\rho^1(E_1) & \cdots & \mu/\rho^m(E_1) \\ \vdots & \ddots & \vdots \\ \mu/\rho^1(E_n) & \cdots & \mu/\rho^m(E_n) \end{pmatrix} \begin{pmatrix} \rho^1 \\ \vdots \\ \rho^m \end{pmatrix}$$



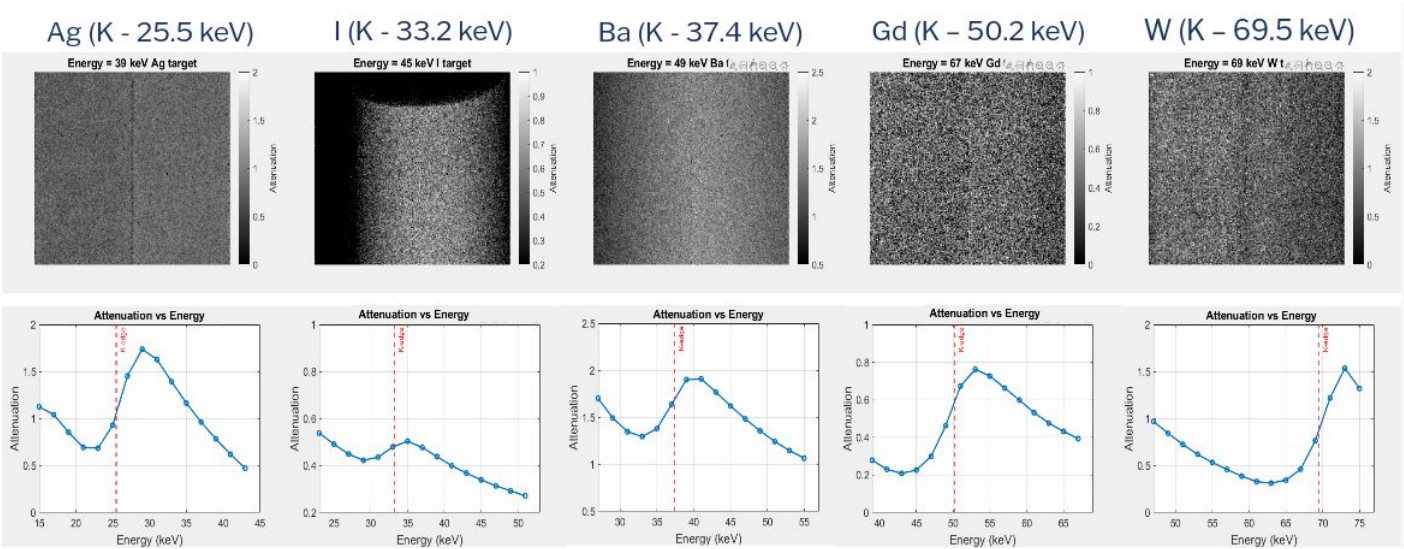
Material-specific density map

➔ Steps 4–5: CT-specific

On-site calibration check

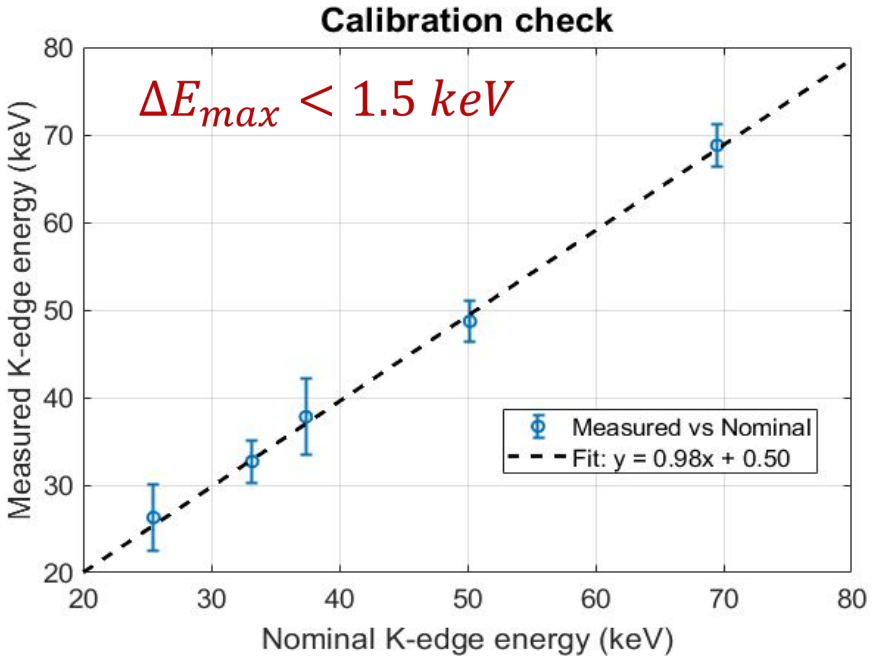


- Independent check with known K-edge materials
  - Ag, I, Ba, Gd, W
- Measured transmission curve N/N_0
  - attenuation vs energy



On-site calibration check

- Independent check with known K-edge materials
  - Ag, I, Ba, Gd, W
- Measured transmission curve N/N_0
  - attenuation vs energy
- Measured vs nominal K-edge
  - ΔE_max < 1.5 keV across 25–70 keV



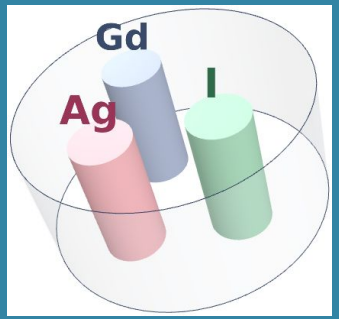
Data-driven µCT

At the end of 2025 first in-lab micro-CT scans in data-driven mode using the **CdTe** assemblies

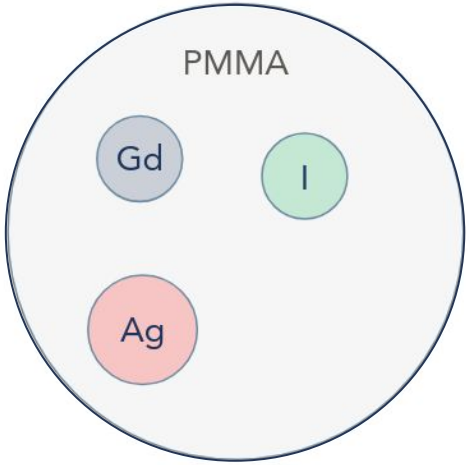
- Measurements on **plastic phantom** with 3 contrast media **(Ag, I, Gd)**

- Tests on **plastified mouse** sample with 3 contrast media **(Ag, I, Gd)**

Spectral test phantom

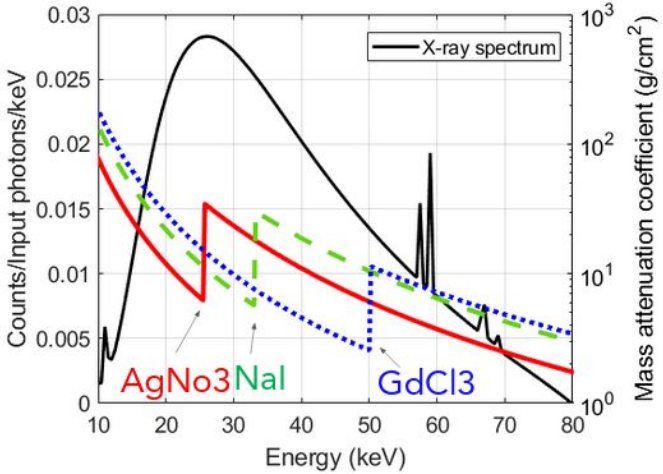


XY



NaI ~ 70 mg/ml
$AgNO_3$ ~ 70 mg/ml
$GdCl_3\ 6(H_2O)$ ~ 70 mg/ml

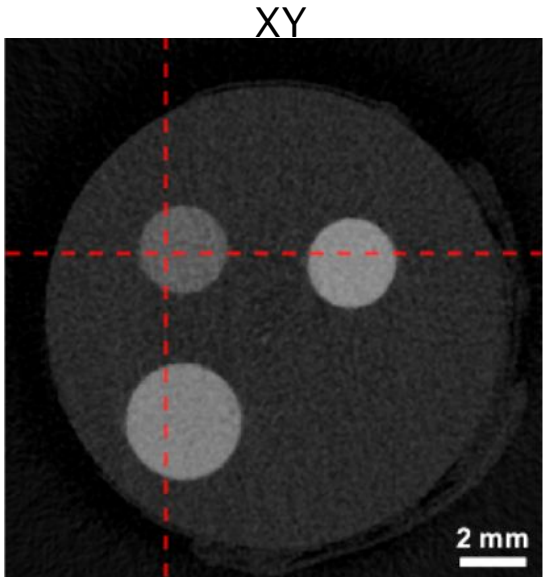
Simulated spectra

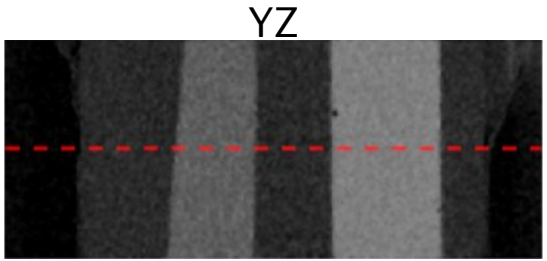


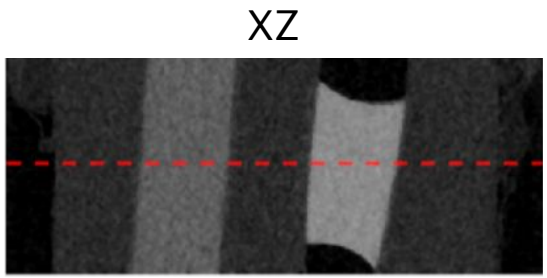
CT acquisitions:

- 80 kV – 5 µA (W-anode)
- 360 - 720 projections over 360°
- 20 - 30 s/projection (2 to 6 h/scan)
- Flux ~2.5×10^4 ph/s/mm^2 (over half matrix)
- Integrated flux ~10^7 ph/s

Spectral test phantom- grey scale

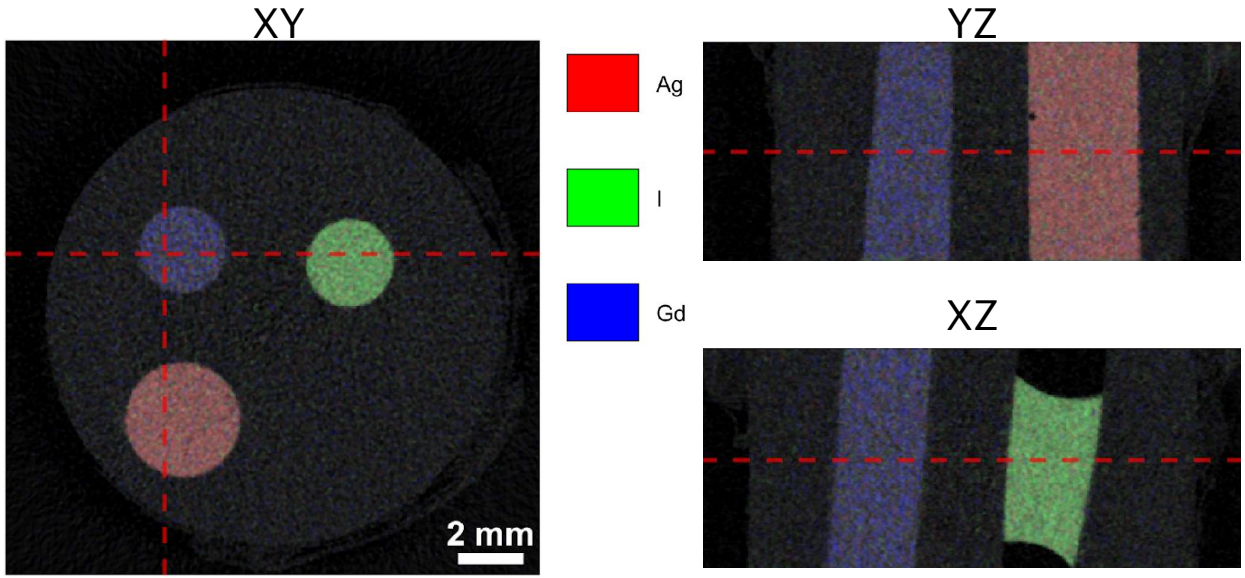






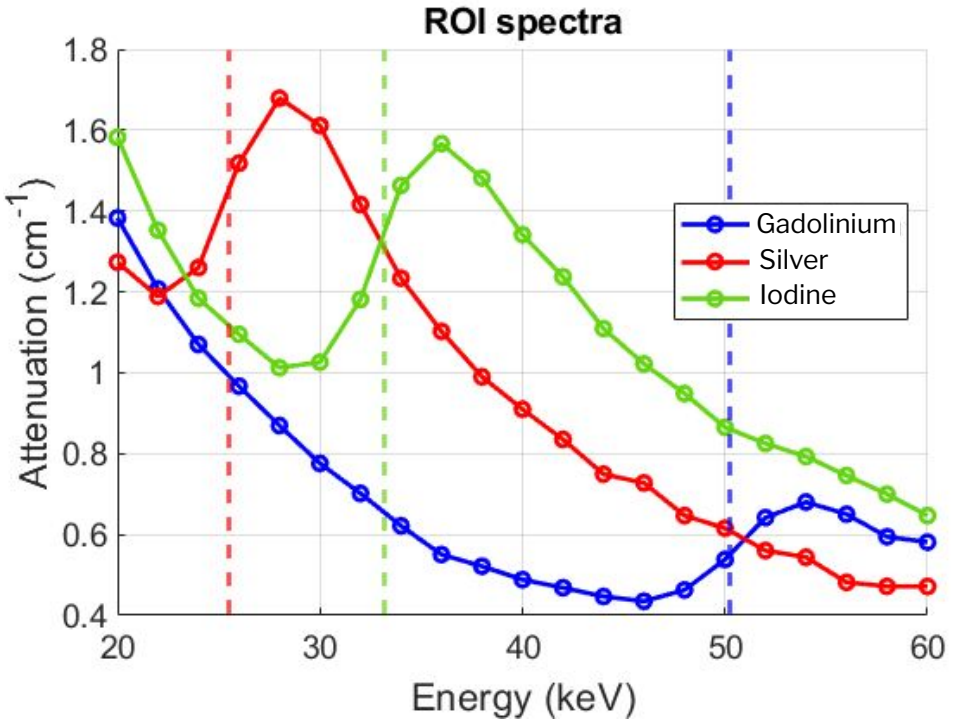
- ➔ Greyscale CT: three inserts visible
  - ◆ but indistinguishable by attenuation alone

Spectral test phantom-color coded



➔ Material decomposition
- Ag, I, Gd each isolated in its own channel

Spectral test phantom-attenuation spectra



- ROI attenuation vs energy
  - 25.5 / 33.2 / 50.2 keV, matching the on-site check

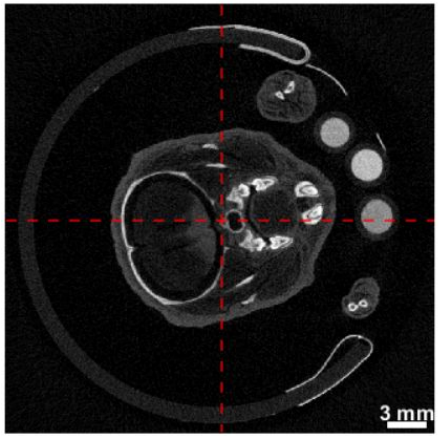
Plastified mouse

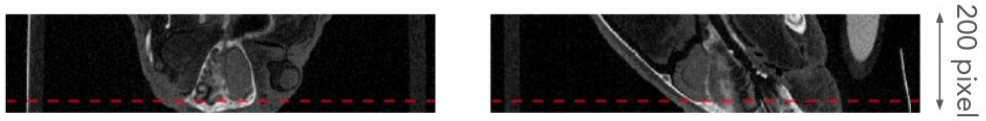
➔ Realistic test: PlastiMouse + 3 contrast cuvettes:

$AgNO_3$ - 95 mg/ml
NaI - 103 mg/ml
$GdCl_3$ - 149 mg/ml

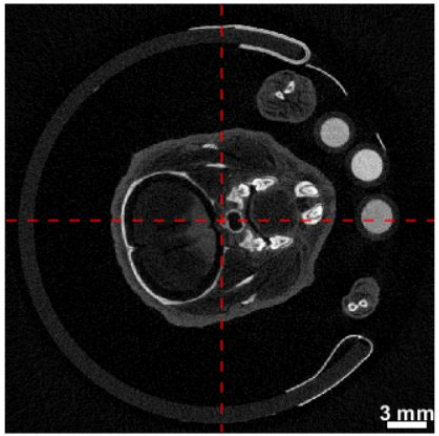
PlastiMouse by SmART Scientific Solutions BV

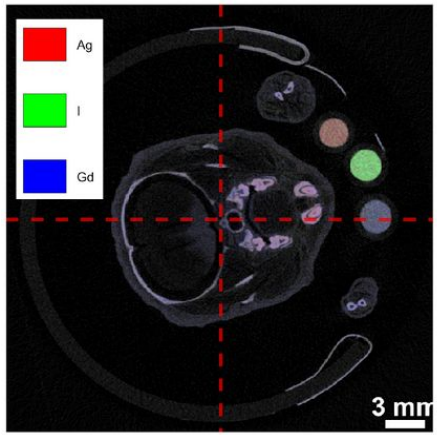
Plastified mouse: material decomposition

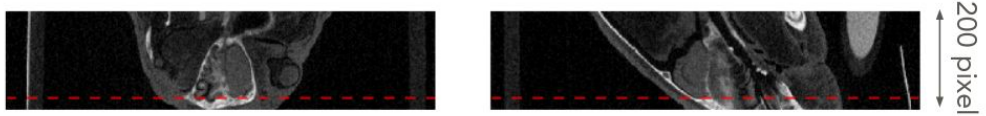




Plastified mouse: material decompositi on

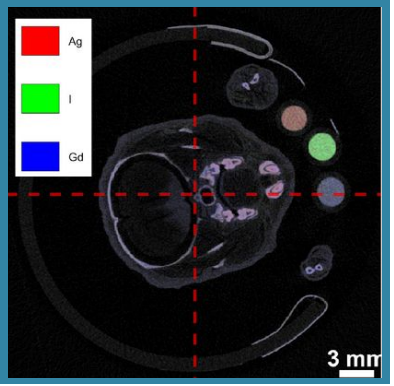






➔ Preliminary: this assembly not yet fully calibrated
- ◆ test-pulse calibration only

Summary and Outlook



Summary

- First spectral micro CT with Timepix4 at PEPI lab
  - frame-based GaAs → conventional μCT, ~25 μm resolution
  - data-driven CdTe → material decomposition, Ag/I/Gd separated
- Debugging and work pipeline optimization

Ongoing work and Outlook

- Processing of μCT using the recently acquired data at synchrotron*
- New μCT acquisition acquired and foreseen for the near future

*See Paolo Cardarelli's talk

Thank you for your attention

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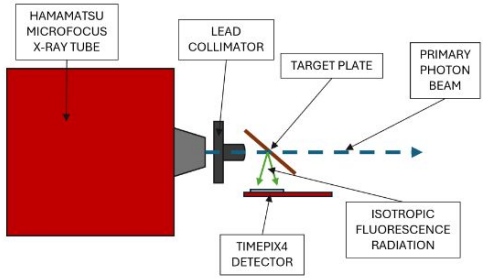
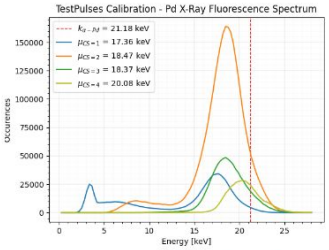
[1]INFN - Ferrara Division, [2]INFN - Trieste Division & Università degli studi di Trieste, [3]INFN - Pisa Division

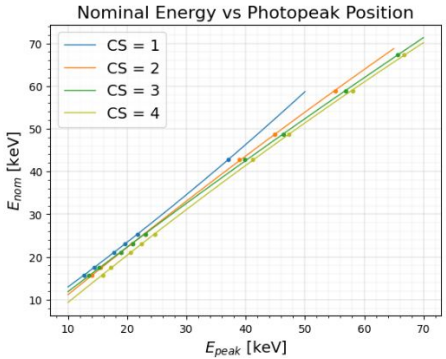
In lab energy calibration

- **Pixel-per-pixel calibration** performed using internally generated **test-pulses** (4-54 keV)
- Acquisitions with an external source to verify and refine the test-pulse calibration results. **X-ray fluorescence** from different materials were used to generate quasi-monochromatic photons:
  - $K_\alpha(\mathrm{Zr}) = 15.8$ keV
  - $K_\alpha(\mathrm{Mo}) = 17.5$ keV
  - $K_\alpha(\mathrm{Pd}) = 21.2$ keV
  - $K_\alpha(\mathrm{Cd}) = 23.2$ keV
  - $K_\alpha(\mathrm{Sn}) = 25.3$ keV
  - $K_\alpha(\mathrm{Gd}) = 43.0$ keV
  - $K_\beta(\mathrm{Gd}) = 48.7$ keV

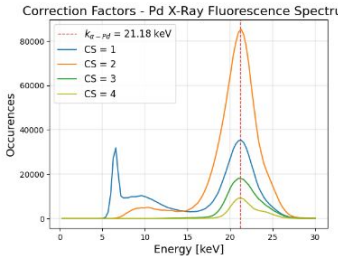


- **Charge loss effects** (under-threshold charge sharing)
- The fraction of lost charge depends on the photon impinging points and is related to cluster size



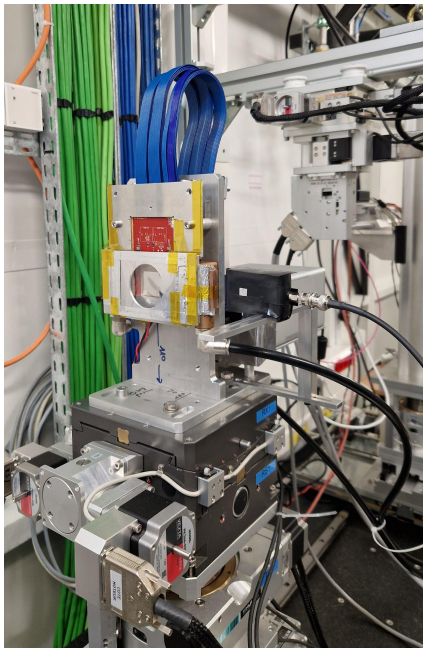


Calibrated Spectra with Correction Factors



SOLEIL synchrotron campaign

- METROLOGIE beamline @ SOLEIL, Feb 2026 (02-07):
  - tunable monochromatic hard X-ray (up to 40 keV)
- Acquired datasets for:
  - energy calibration
  - spatial resolution
- Results foreseen → pix-to-pix energy calibration
- Currently: data analysis work in progress *



* See P. Cardarelli talk