An overview of HEXITEC and HEXITEC MHz and its applications

Dr Diana D Caprotti et al

8th of July 2025
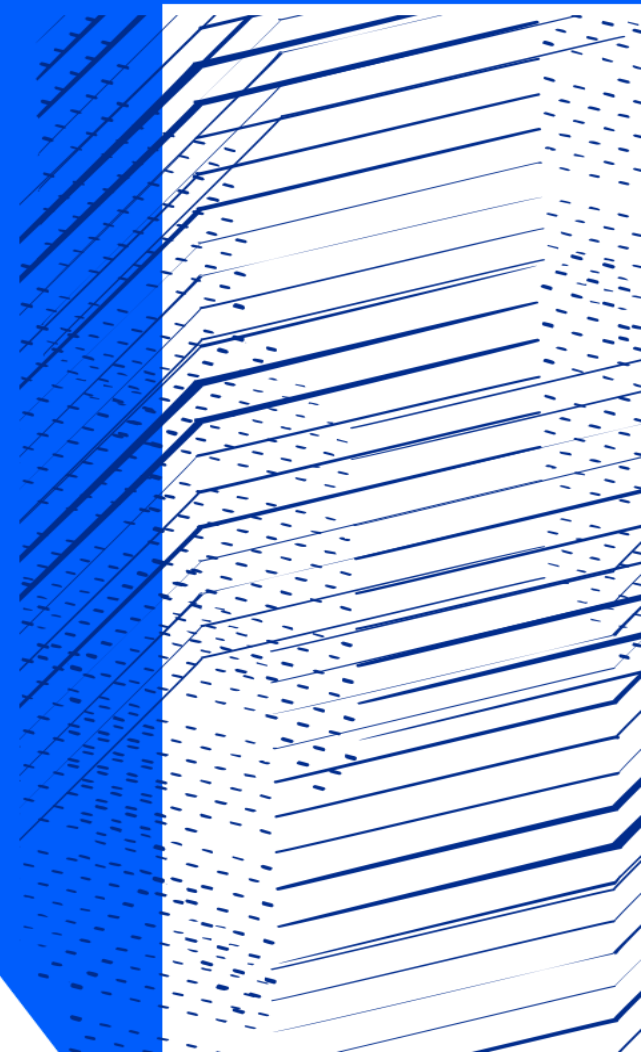
Agenda

1 Who are we - UKRI-STFC-RAL

An introduction to the UKRI Science and Technologies Facilities Council Rutherford Appleton Laboratory.
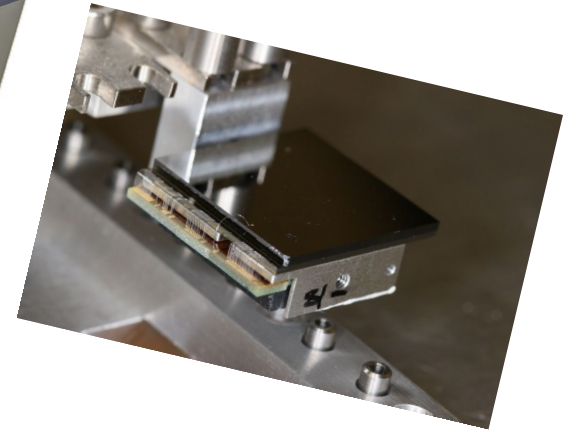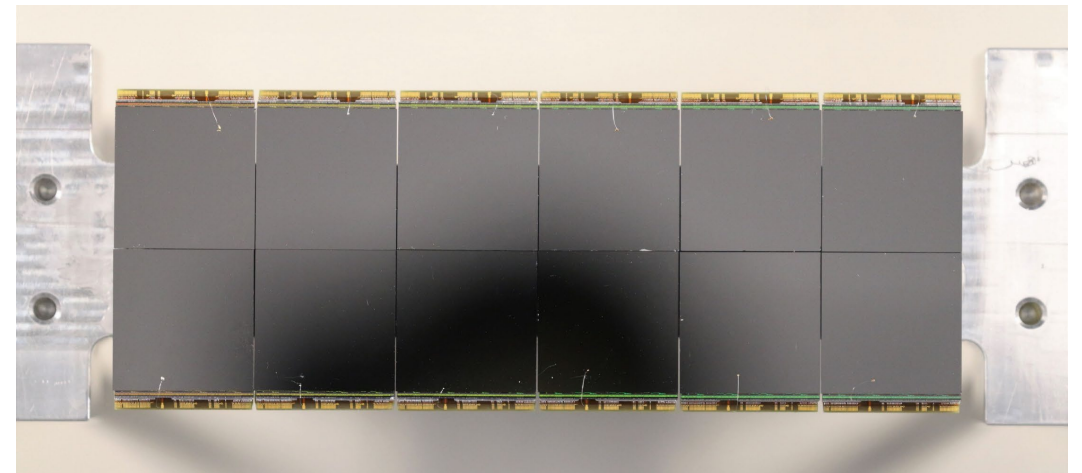
2 HEXITEC

Introducing the latest version of the technology, its architecture, initial results and camera status

3 HEXITEC applications

An overview of some of HEXITEC applications - credit to our collaborators

4 HEXITEC$_{MHz}$

Introducing the latest version of the technology and latest results

Who we are

Who we are

Boulby Underground Laboratory
North Yorkshire

UK Astronomy Technology Centre
Edinburgh, Scotland
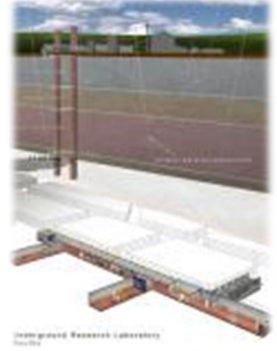
Daresbury Laboratory
Sci-tech Daresbury Campus, Liverpool City Region

Polaris House
Swindon, Wiltshire

Rutherford Appleton Laboratory
Harwell Didcot, Oxfordshire

Chilbolton Observatory
Stockbridge, Hampshire

UKRI Science and Technology Facilities Council

...and around the world

Who we are

Rutherford Appleton Laboratory

Home to:

Central Laser Facility

ISIS

Diamond Light Source

RAL Space

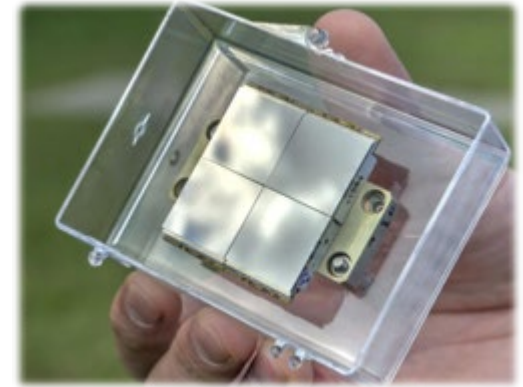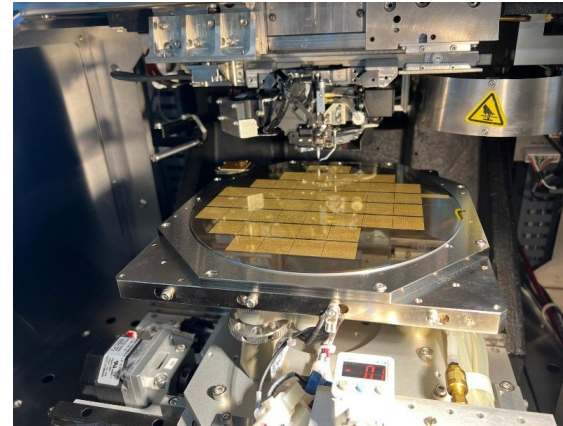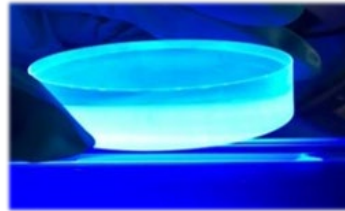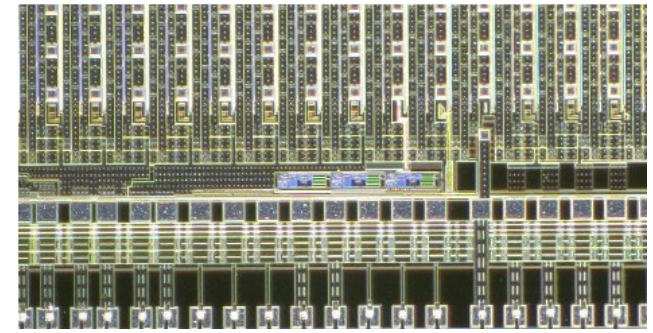UKRI Science and Technology Facilities Council

Who we are

Technology's Detector and Electronics Division

- ASIC design
- CMOS sensors design
- Detector Development
- Electronics system design
- Interconnect

One stop shop for detector systems
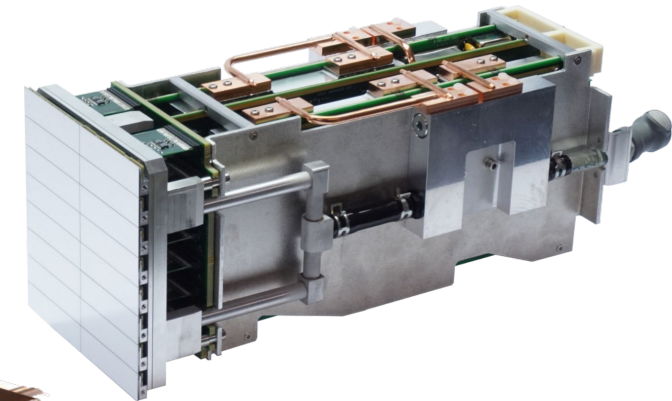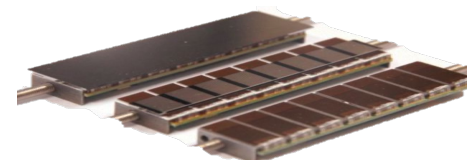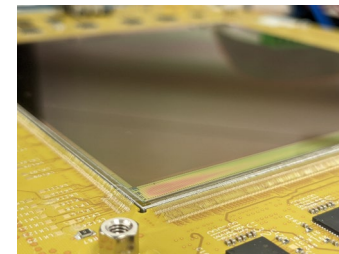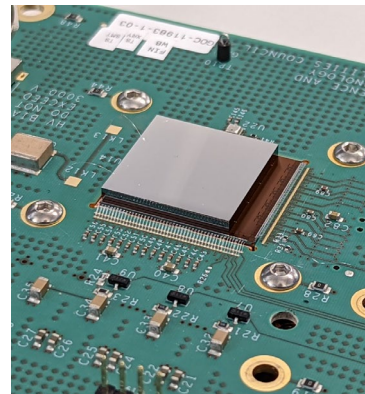
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![HEXITEC — HIGH ENERGY X-RAY IMAGING TECHNOLOGY]

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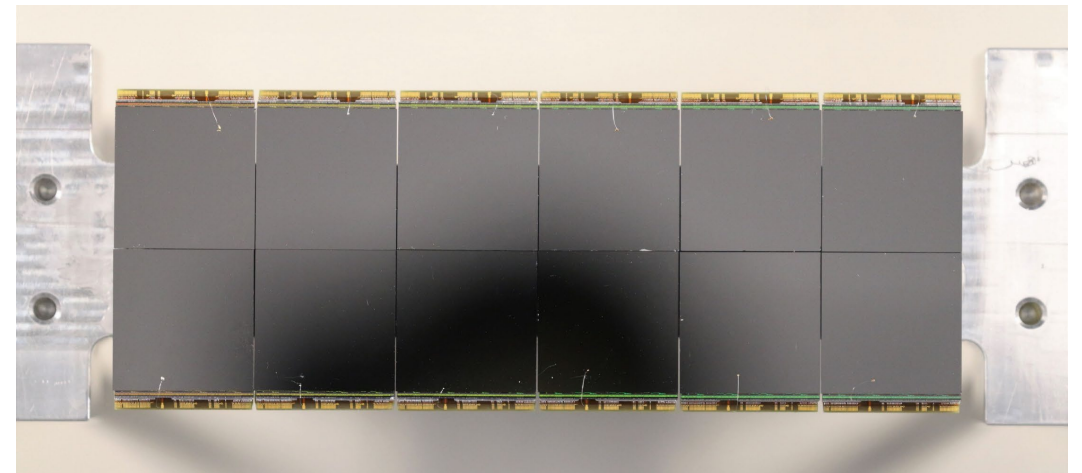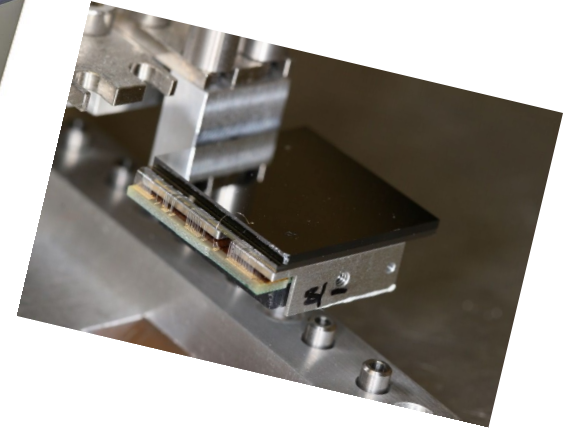
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An overview of the HEXITEC system

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An overview of some of HEXITEC applications - credit to our collaborators

4 HEXITEC$_{MHz}$

Introducing the latest version of the technology and latest results

![UKRI Science and Technology Facilities Council logo]

The HEXITEC system

HEXITEC

HIGH ENERGY X-RAY IMAGING TECHNOLOGY

- Priority: **High resolution hard X-ray spectroscopy**

- 250 μm pixel pitch choice
  - Limited charge sharing events
  - Moderate spatial resolution

- 20 × 20 test chip delivered in 2009

- Full 80 × 80 system delivered in 2014

- 2014+ large area systems delivered

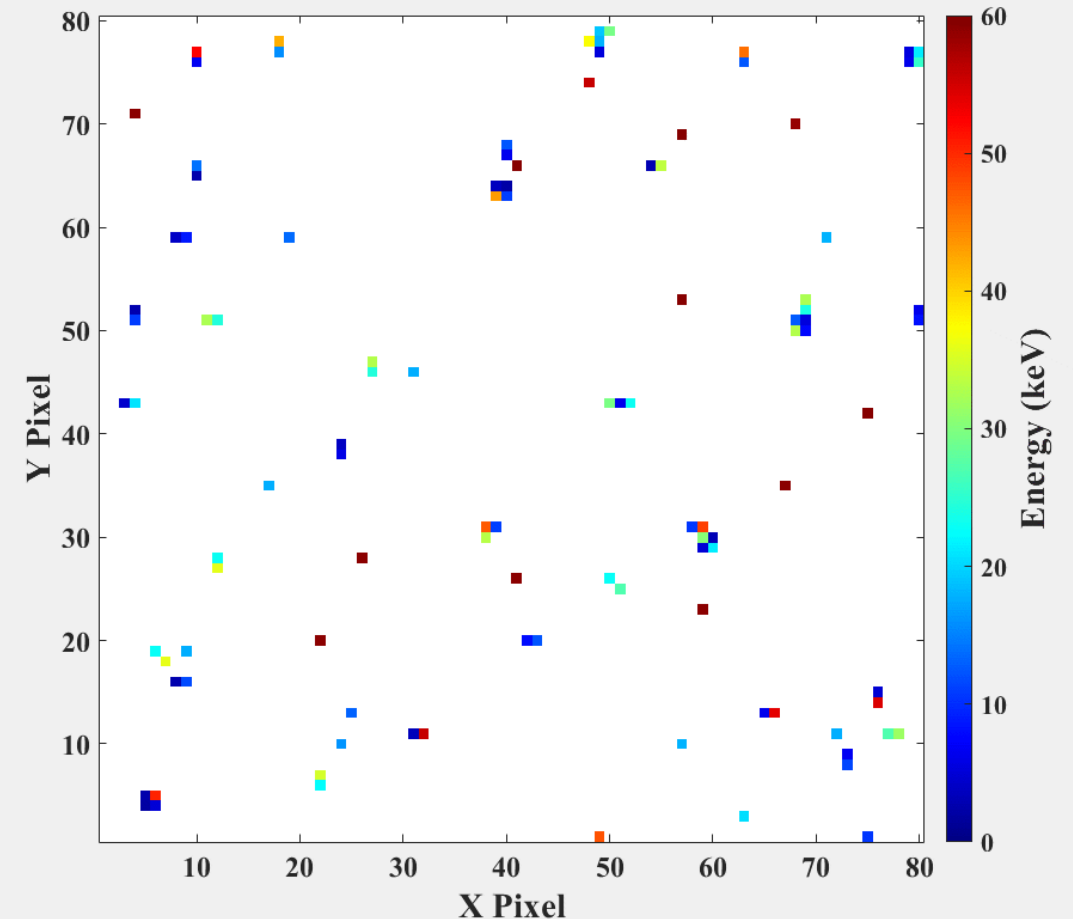| Parameter	Value
Pixel Pitch (mm)	250
Array Size	80 × 80
Max Frame Rate (kHz)	9.3
High Gain (keV)	2 – 200
Low Gain (keV)	6 – 600
$FWHM_{@60keV}$ (keV)	< 1
Max flux rate (photons s^{-1} mm^{-2})	< 2×10^4

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UKRI Engineering and Physical Sciences Research Council

MANCHESTER 1824 The University of Manchester
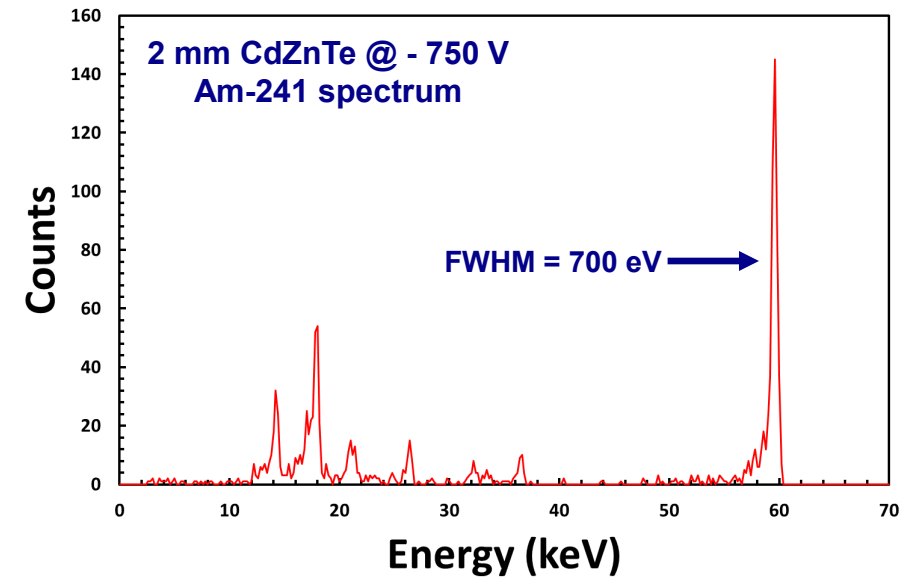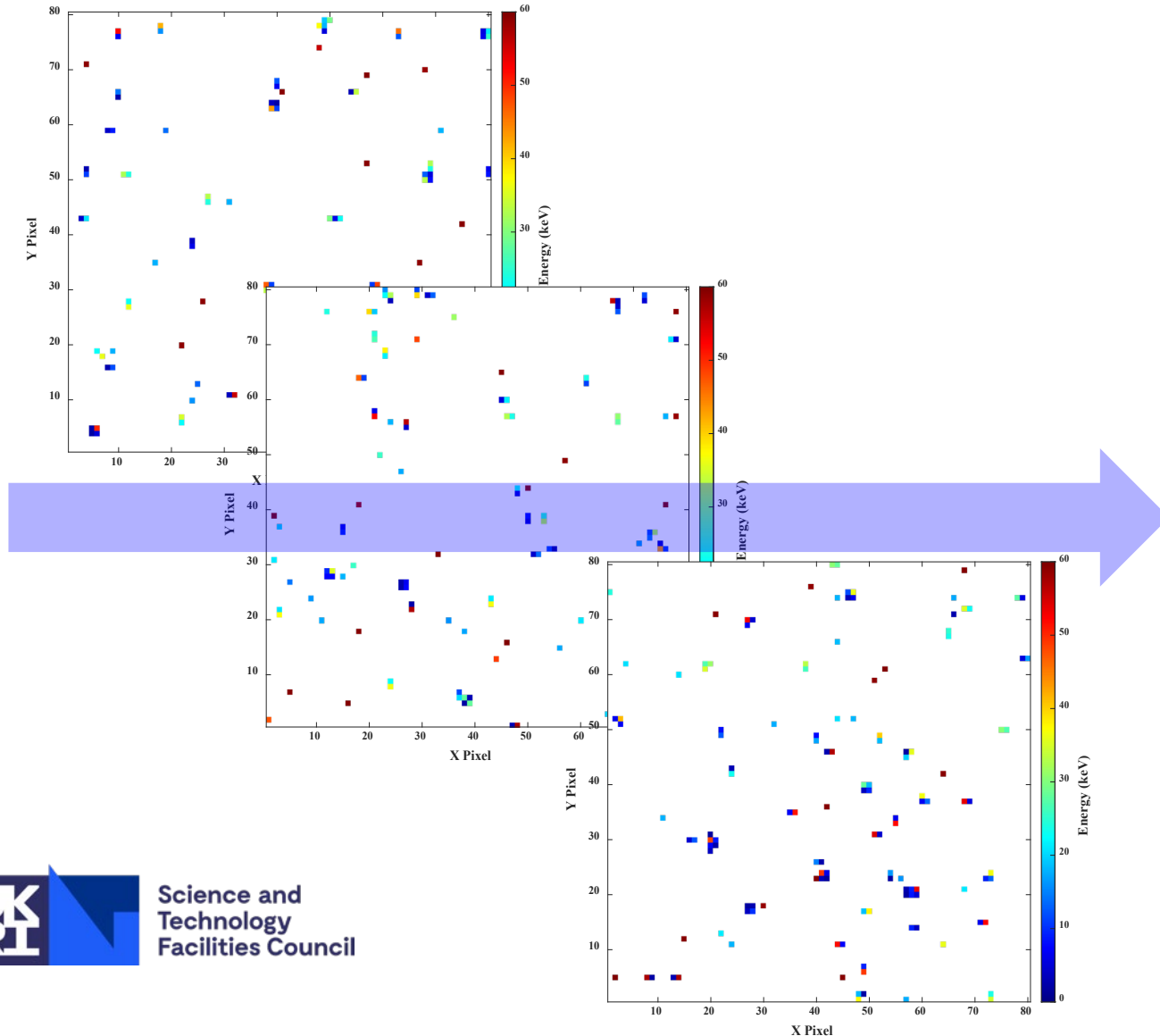
UNIVERSITY OF SURREY

Durham University

Birkbeck UNIVERSITY OF LONDON

The HEXITEC system

- Examples of typical frames of data

- 2mm CdZnTe sensor @ - 750 V

- 2 keV noise threshold applied

- $y = mx + c$ calibration

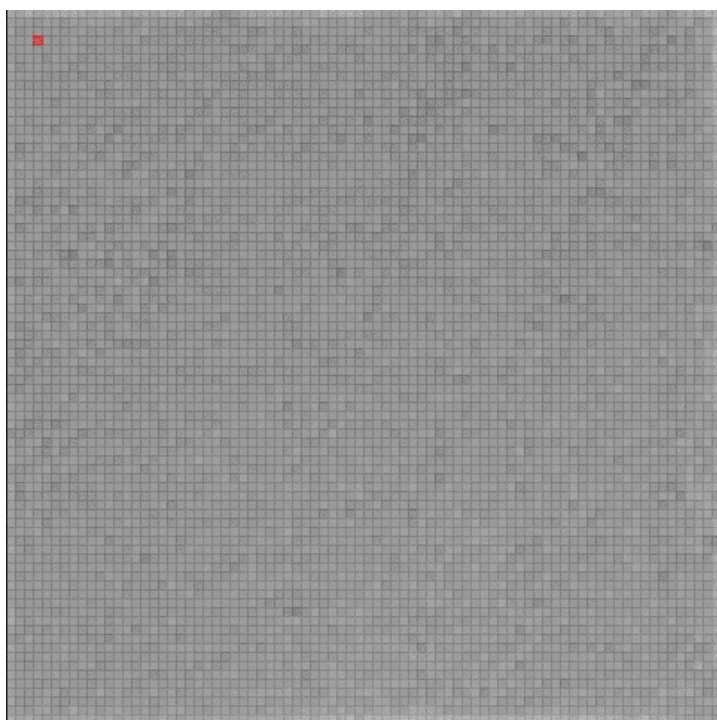- HEXITEC records the position and energy of each interaction

The HEXITEC system

Energy values histogrammed for each pixel across many frames
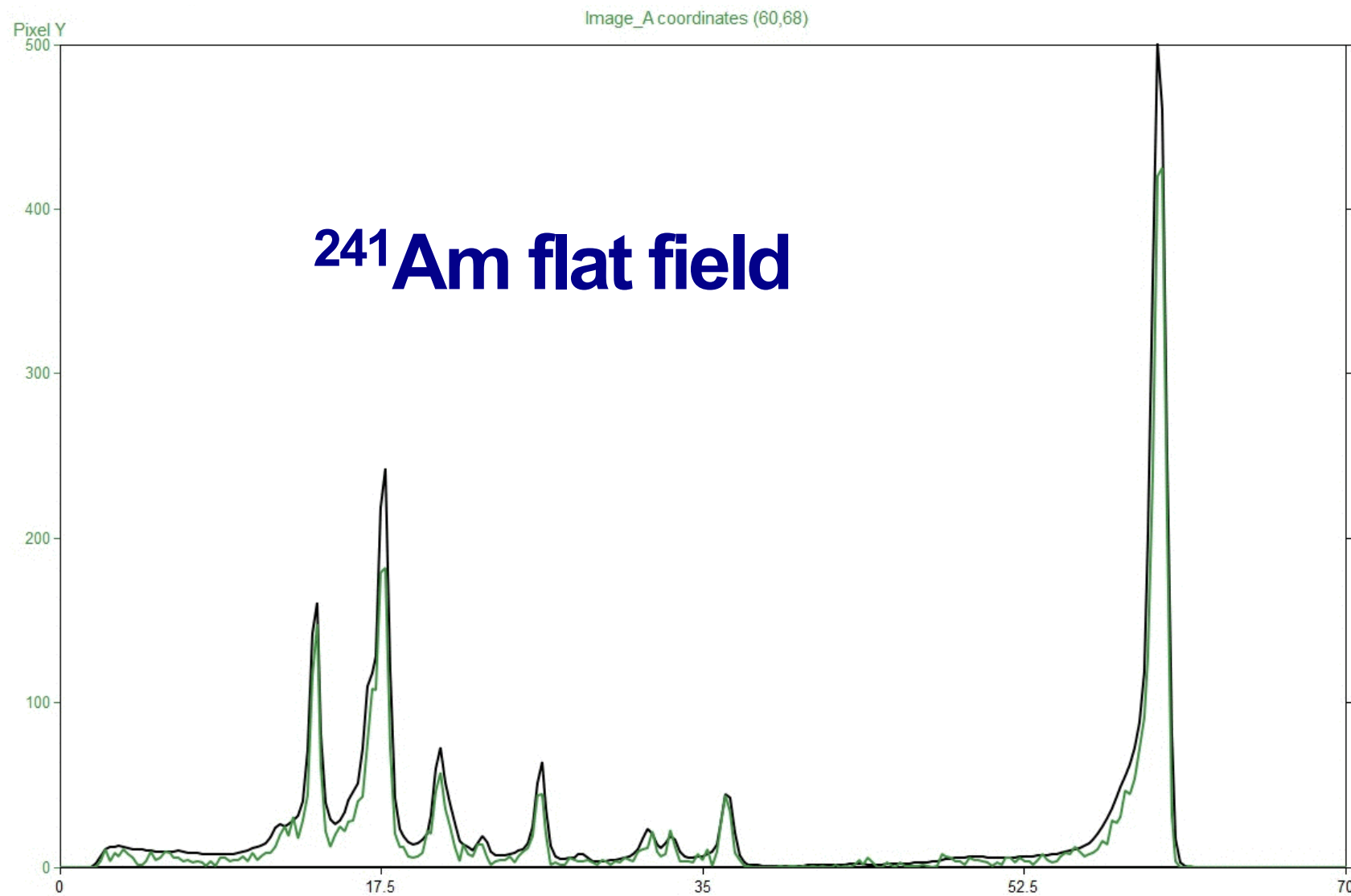
Result: high resolution spectra!

80 Pixels

Image_A coordinates (60,68)

Pixel Y

²⁴¹Am flat field

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HEXITEC
HIGH ENERGY X-RAY IMAGING TECHNOLOGY

The HEXITEC system

- Detector Module

- Gig E System

- 2x2 System

- 2x6 System

- 2x8 System

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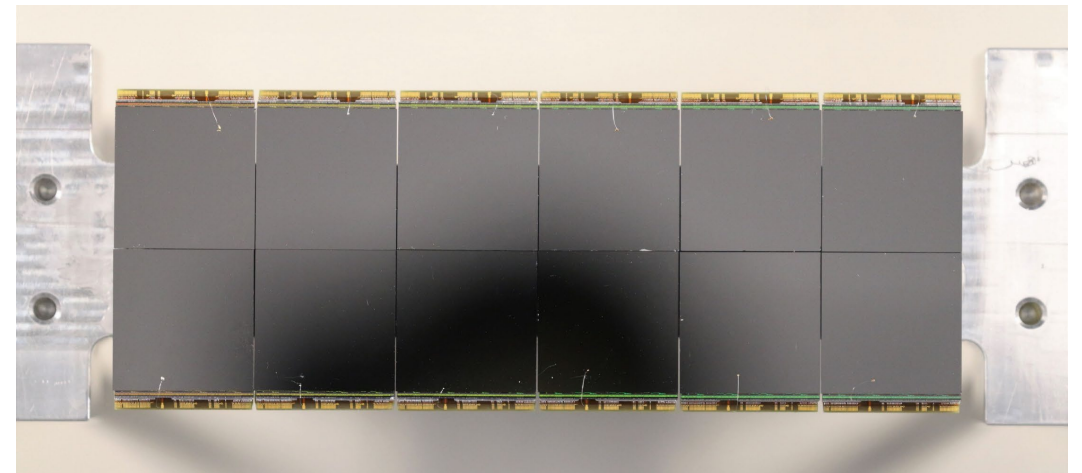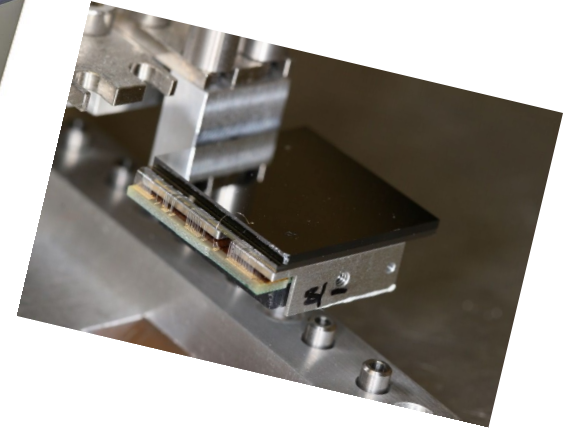
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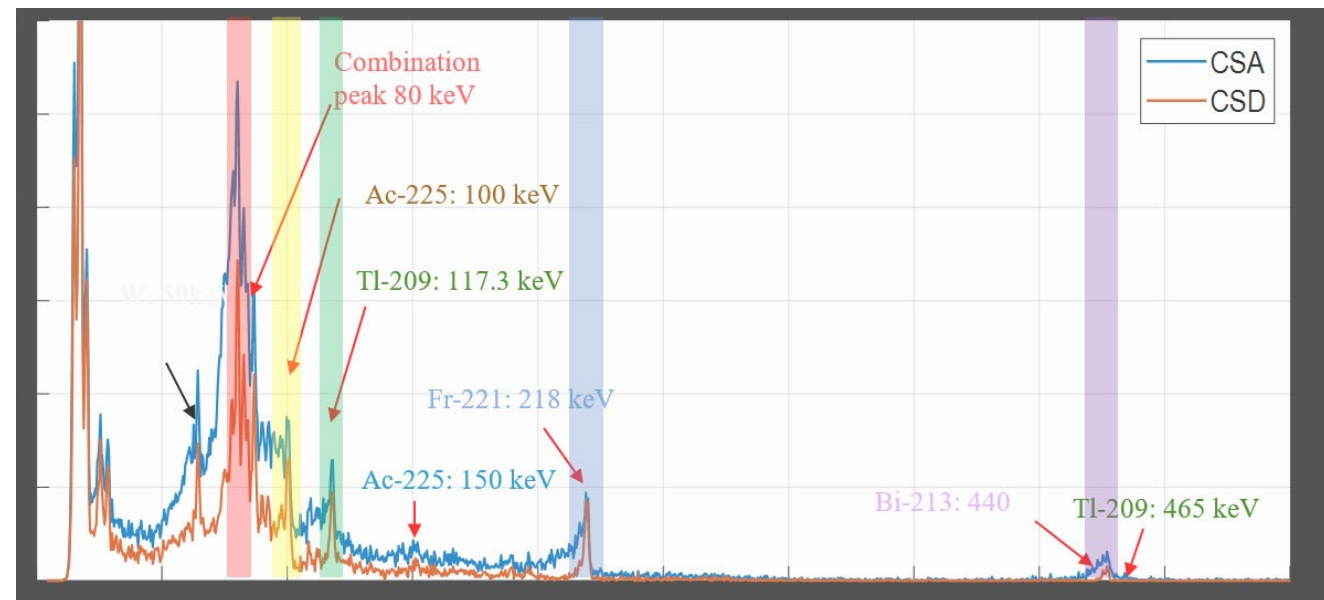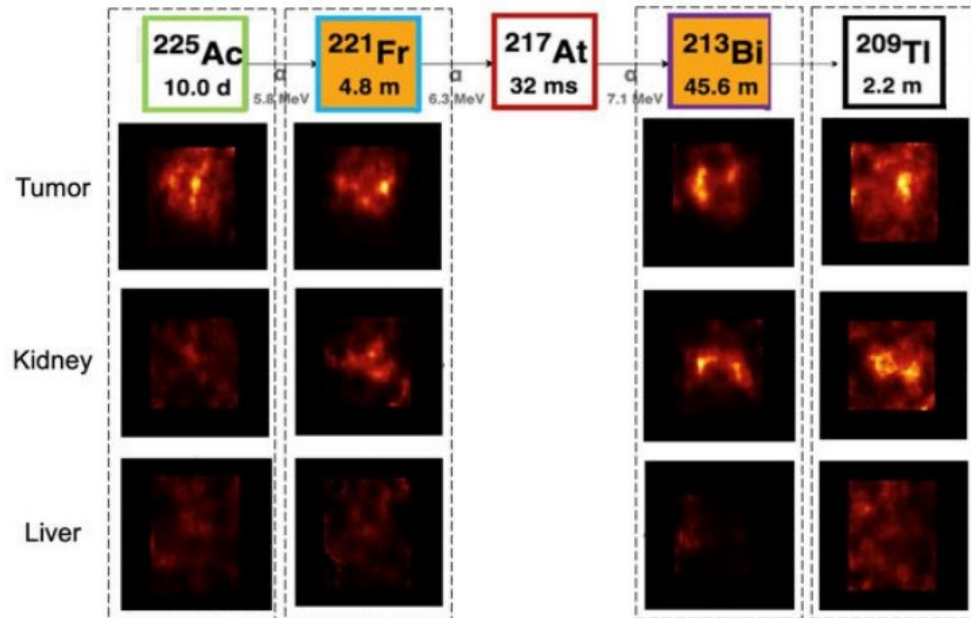
4 HEXITEC$_{MHz}$

Introducing the latest version of the technology and latest results

Nuclear Medicine

- HEXITEC licensed to MH3D on the alpha-SPECT mini
- Target market: radiopharmaceutical development for Targeted Alpha Therapy

Distribution of Ac-225-Labeled Antibody in Mouse

K-edge Imaging

- Transmission Imaging to differentiate between different Al alloys
  - Using machine learning and neural networks to differentiate between different Al alloys
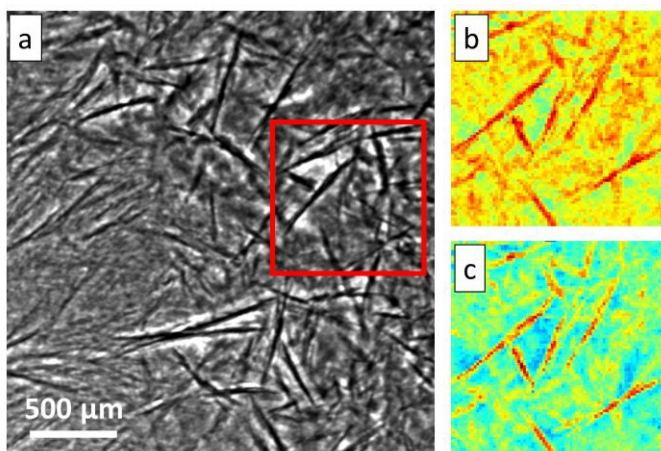

Figure 8.5: (a) A radiograph of an Al-Pt-Er alloy as prepared by arc melting, using the NSI apparatus. The red square indicates the field of view in the HEXITEC in (b) and (c). (b) Qualitative HEXITIC map of Er. (c) Qualitative HEXITEC map of Pt.
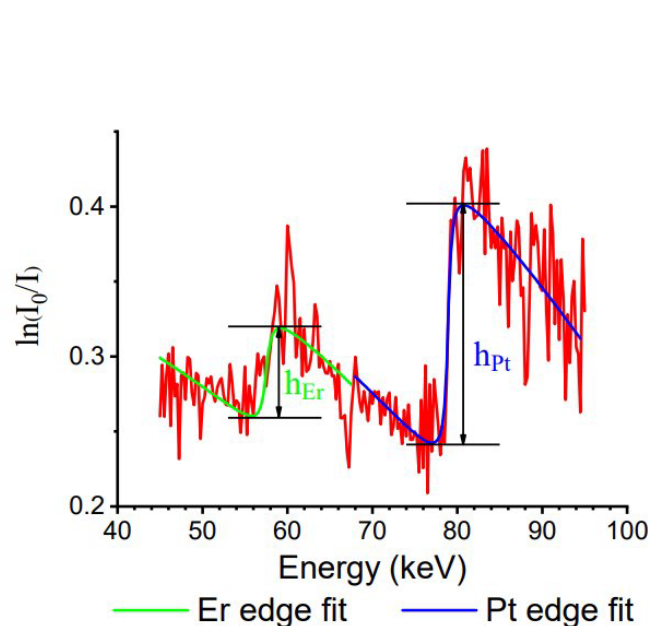

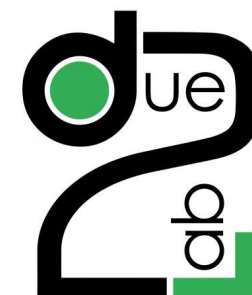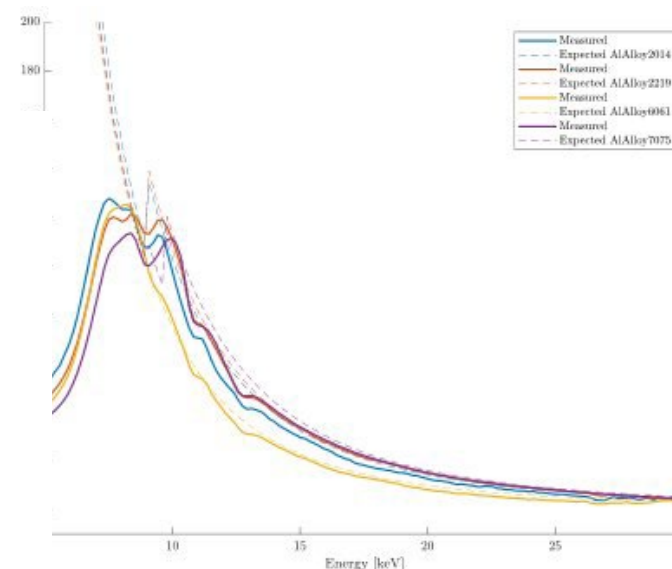Er edge fit — Pt edge fit

Figure 8.4: An example spectrum of $\ln(\frac{I_0}{I})$ as a function of photon energy from one pixel of the HEXITEC. h_{Er} and h_{Pt} are the sizes of the Er and Pt K-edges in the spectrum. The green and blue curves are the best-fit curves of the Er and Pt edges respectively.

Compton Scattering

HEXITEC
HIGH ENERGY X-RAY IMAGING TECHNOLOGY

- Measuring and imaging Li$^+$ ion diffusion *in operando* inside a solid-state Li metal battery
  - Compton scattering intensity related to electron density and thus charge in the battery
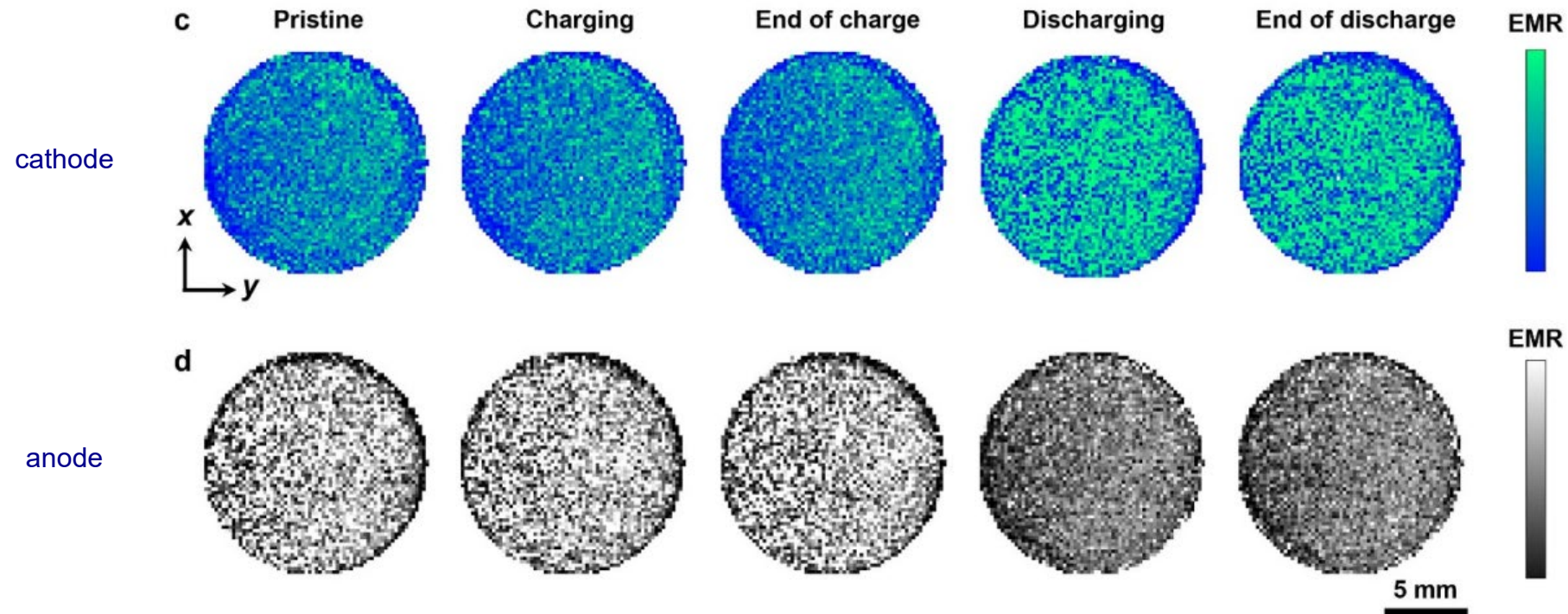
Uranium quantification

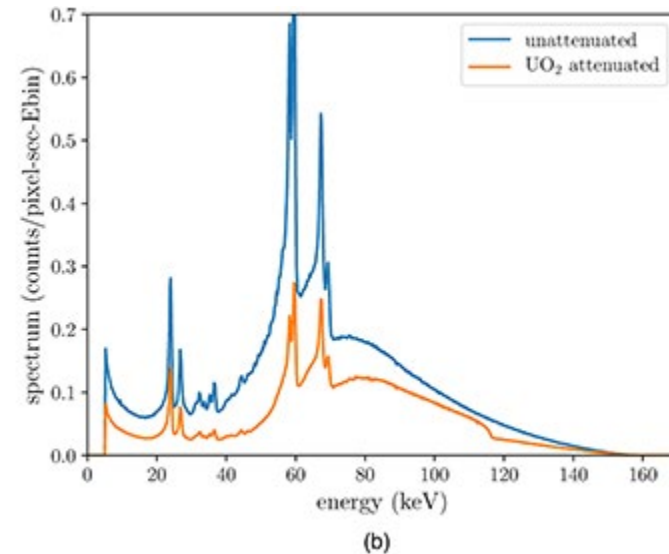- Uranium quantification in Nuclear Fuel:
    - Determine the mass of Uranium and Uranium Oxide powders using spectral radiography

A radiograph of the depleted UO powder
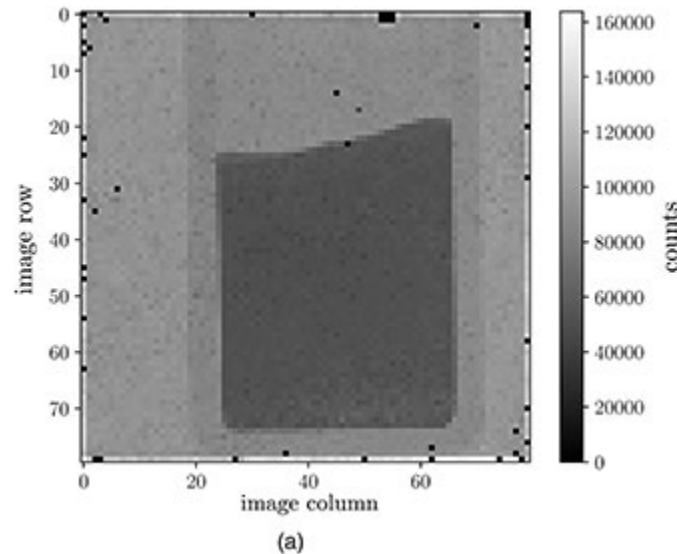
- σ = 0.62 % with HEXITEC compared to σ = 0.20 % COMPUCEA, but COMPUCEA destroys the sample
- HEXITEC provides a stable and accurate non-destructive characterisation of Uranium

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HEXITEC *MHz*

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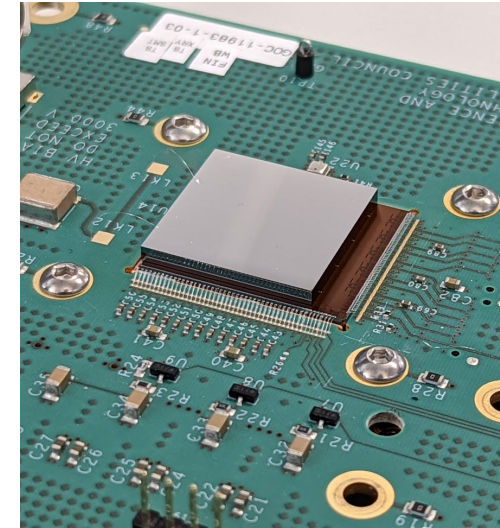
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HEXITEC MHz spec

HEXITEC$_{MHz}$

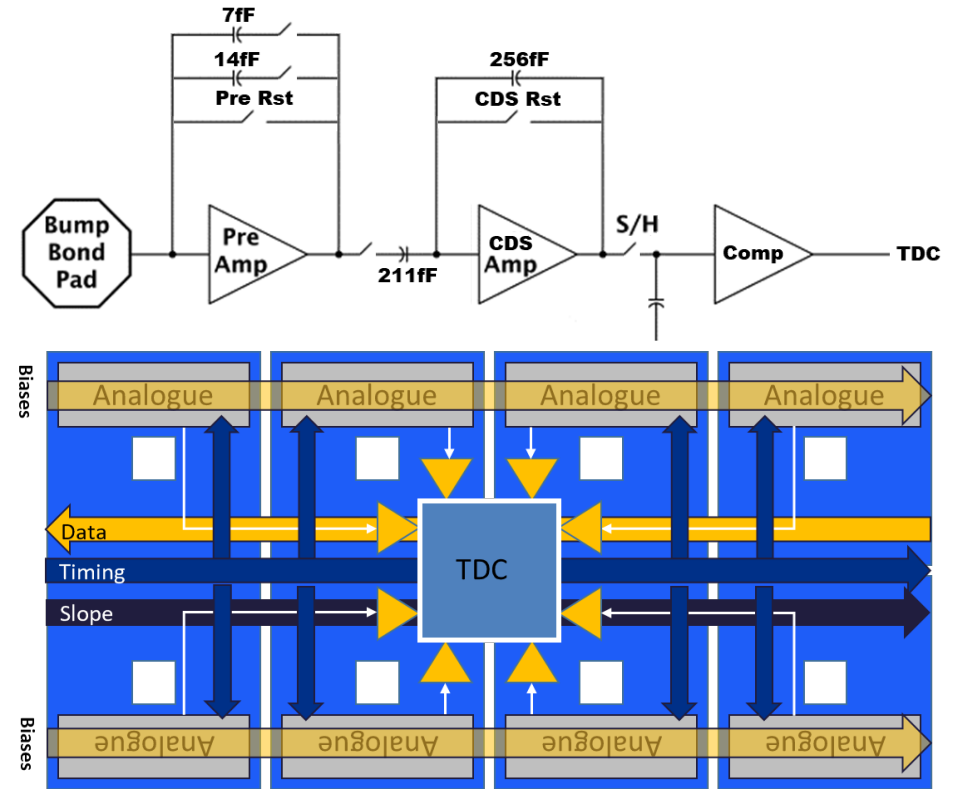| Parameter	HEXITEC	HEXITEC MHz
Pixel Pitch (mm)	250	250
Array Size	80 × 80	80 × 80
Max Frame Rate (kHz)	9.3	1000
Digitisation	Off-chip	On-chip
Detector type	Track + hold	Integrating
Energy range (keV)	2 - 600	2 - 300
FWHM$_{@ 60 keV}$ (keV)	< 1	<1
Max flux rate (photons s^{-1} mm^{-2})	< 2×10^4	> 10^6
Power consumption (W)	1.5	15
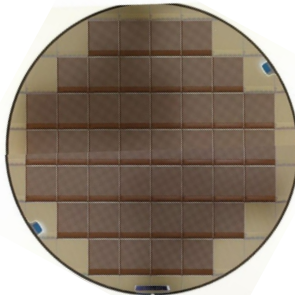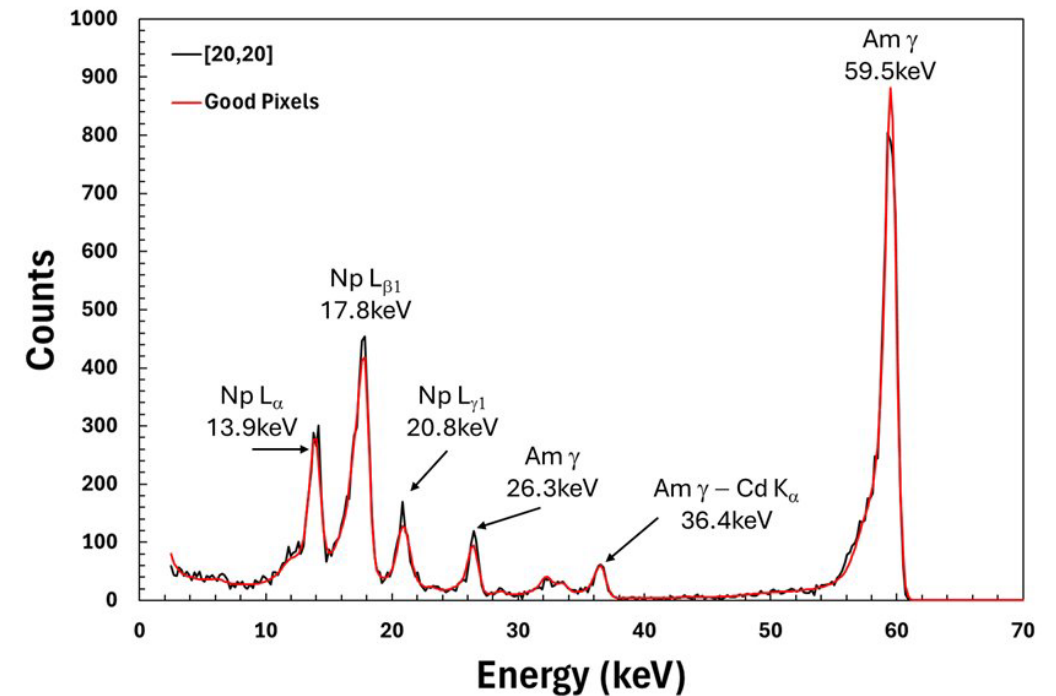
Designed in TSMC 180 nm

Full spectroscopy @ 2×10^6 ph s^{-1} mm^{-2}

Similar energy resolution capabilities to HEXITEC

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HEXITEC MHz architecture

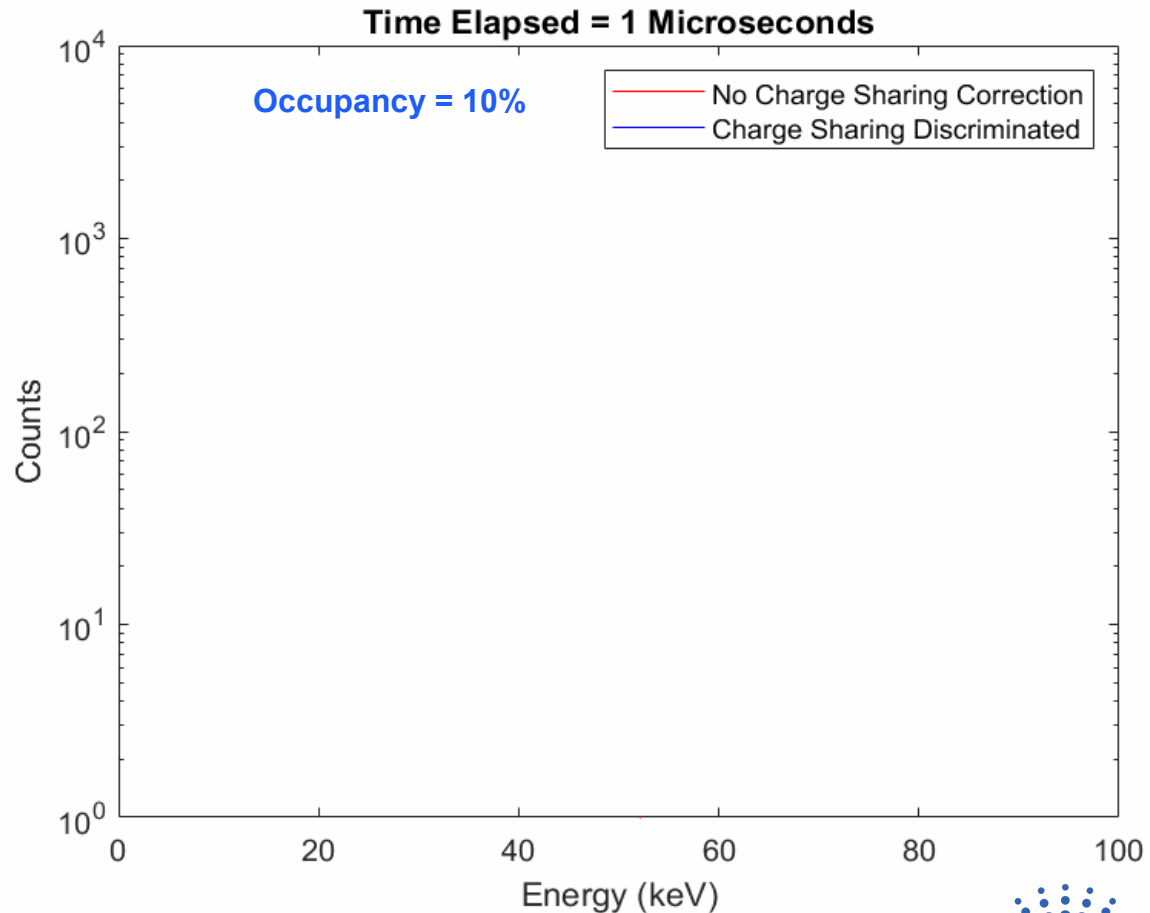## HEXITEC_{MHz}

- Integrating architecture

- t_{int} = 900 ns, t_{reset} = 100 ns

- Front end noise ~ 100 electrons

- TDCs shared in a 4×2 'super-pixel'

- 12-bit data out for each pixel

- 20 × 4.1 Gb s^{-1} serialisers

- Total data rate ≈ **10 GB s^{-1}** → FPGA histogramming of data set → **25 MB** time slice

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HEXITEC flux results

HEXITEC$_{MHz}$

Time Elapsed = 1 Microseconds

Occupancy = 10%

	No Charge Sharing Correction
	Charge Sharing Discriminated

Counts

Energy (keV)

1×10^6 ph s^{-1} mm^{-2}

Time Elapsed = 1 Microseconds

Occupancy = 50%

	No Charge Sharing Correction
	Charge Sharing Discriminated

Counts

Energy (keV)
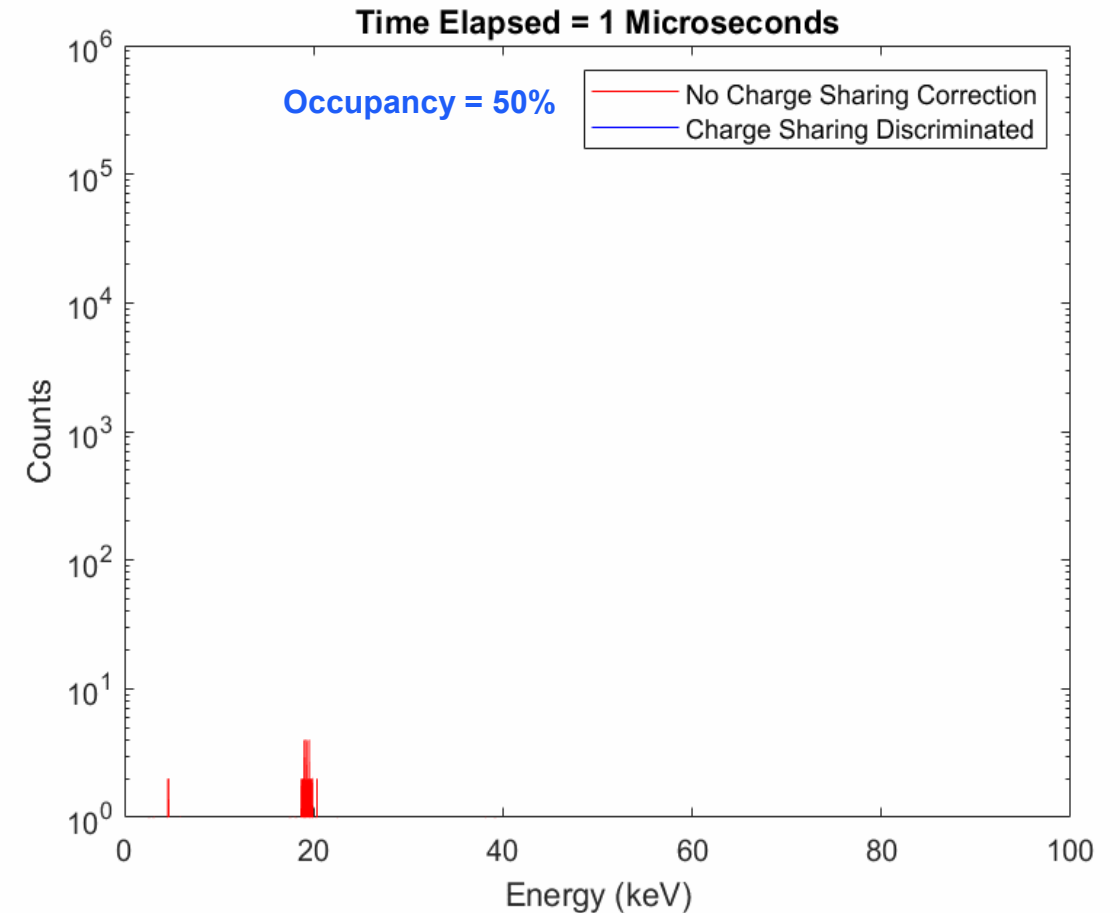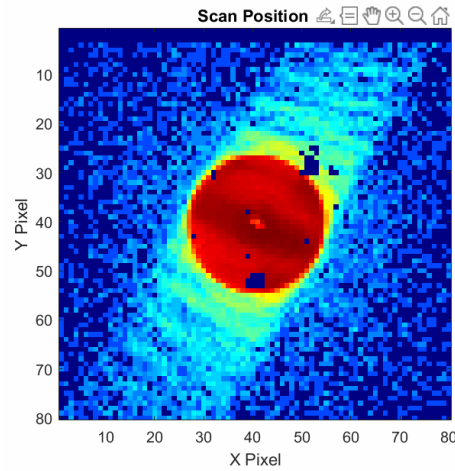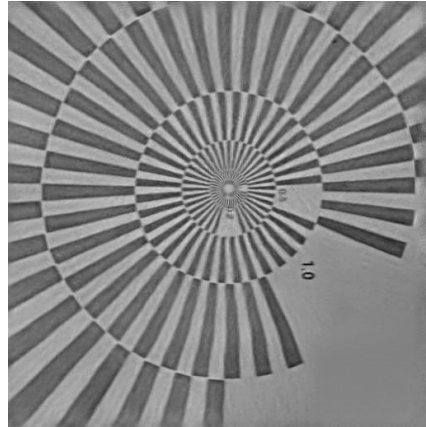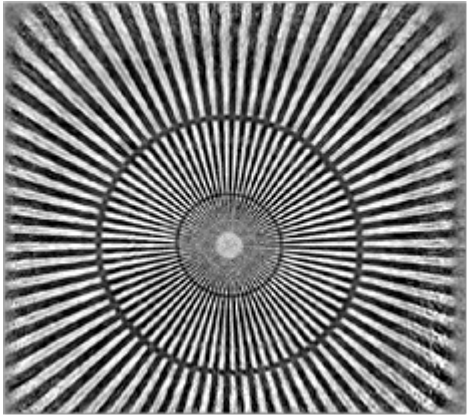
1×10^7 ph s^{-1} mm^{-2}

Hyperspectral Ptychography HEXITEC_MHz
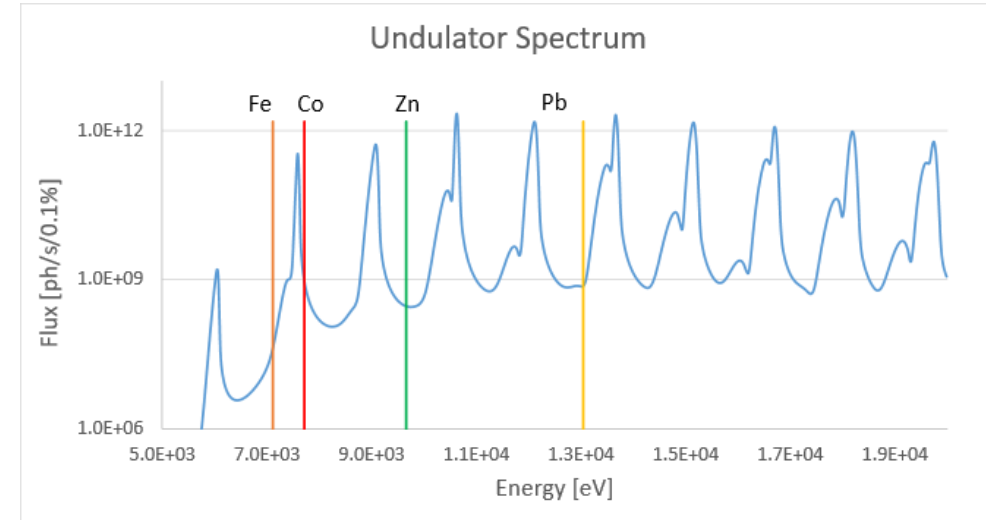
Ptychographic phase image of a test target (40 μm field of view). Data was recorded with a monochromatic beam on the single-chip HEXITEC detector.

- Match undulator spectrum with the absorption edges of the elements of interest

- HEXITEC-MHz enables simultaneous quantitative element-specific tomographic ptychograph with high spatial resolution

Final remarks

HEXITEC and HEXITEC MHz are spectroscopic detectors for use with high Z materials.

We are always looking for new collaborations and applications.

Please get in touch via <u>hexitec@stfc.ac.uk</u>

Thank you for listening!