A versatile high-speed radiation detection platform using Medipix3

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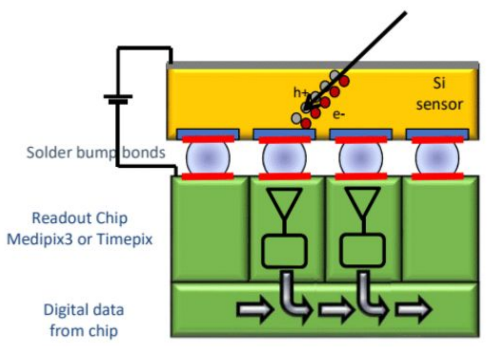
Introduction

The Medipix3 is a hybrid pixel detector chip developed primarily at the Medipix group in CERN as part of the Medipix family of chips. The family of chips have been developed by many research institutes, universities and private companies over the past 20 years.

They all have very complex pixels compared to more conventional imaging technologies, such as CCDs or simple photodiode based CMOS devices, by having 1000s of transistors per pixel whereas other technologies typically use <10 transistors per pixel. This enables a multitude of highly configurable 'smart' features, including those below (specifics for Medipix3 included):

1. **Versatility** - sensor materials can be optimised and changed independently of the readout chips, enabling relatively fast development cycles
    a. Can be used for many radiation types (any ionising radiation and neutrons): x-rays, protons (therapy & scientific), ions (therapy, MS), neutrons (with an MCP), electrons (EM, STEM, STM etc.)
2. **High speed** - kHz frame rates can be achieved (1-24 kHz)
3. **Sensitive** - single quantum counting
4. **Multiple images per readout** (1, 2, 4 or 8)
5. **Smart** - charge summing mode - enables the use of high Z sensors such as CdTe, CdZnTe, GaAs etc.
6. Energy sensitivity - **colour x-ray imaging** ~ 1-2 keV for Si
7. **Variable counter depths** - 1, 6, 12, 24 bit depths, i.e. 1, 64, 4096 or 16777216 counts per pixel per frame
8. **Good linearity** - e.g. saturation limit is far above EBT3 film
9. **High spatial resolution** - 55 or 110 μm pixel pitch
10. **Very low noise floor** - 4-5 keV is the minimum detectable charge with Si
11. **Instant readout** - millisecond range latency to image acquisition

Hybrid pixel detector



Objectives

Overall

1. Get the Medipix3 working to full design specifications and verify it
2. Explore and pursue medical, clinical and industrial applications using our system with various partners
3. Use our system to support other OMA fellows' projects

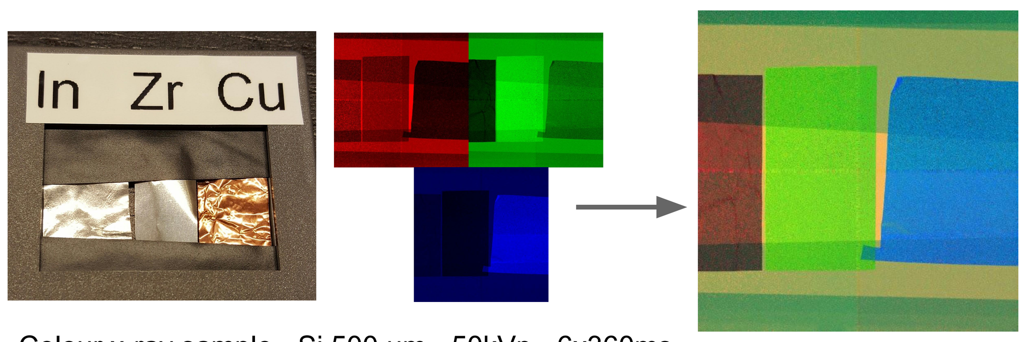
More specifically

1. Primarily work within Nikhef and ASI with chip designers (at CERN), electrical engineers, FPGA programmers and programmers. Enabling all the chip features at maximum performance and reliability are on-going.
2. Collaboration with the NKI (Dutch National Cancer Institute) and the FleX-ray consortium (Nikhef, ASI, CWI and TESCAN (used to be XRE)) → New project application: '**Spectral microCT system for online 3D evaluation of surgical margins**'.
    a. 'We aim to show that the SPμCT will allow for: fast (<10 minutes), high resolution 3D imaging (<110 μm voxels), with sufficient spectral contrast to discriminate tumour from normal tissue for different tumour types.'
3. Collaboration with Jacinta Yap → Is the Medipix3 chip good for clinical proton beam quality assurance, relative to EBT3 film, the current 'gold standard'?
    a. How does the Medipix3 behave in a clinical facility in terms of count rate linearity?
    b. How consistent with EBT3 film is it?
    c. How stable is the detector in beam?
    d. Could it be used to cross-check the VELO detector?
4. Possible collaborations with Roland Schnuerer and Anna Baratto Roldán.

X-rays and proton therapy results

Colour x-ray reconstruction

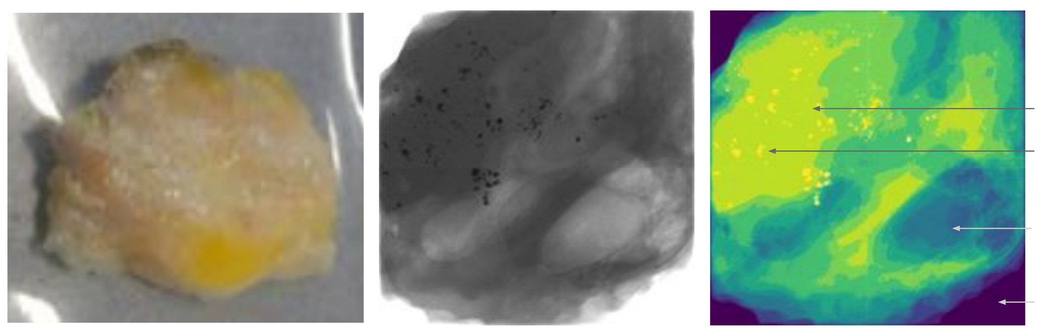
Red: 6-10 keV
Green: 13-18 keV
Blue: 22-26 keV



Colour x-ray sample - Si 500 μm - 50kVp - 6x360ms

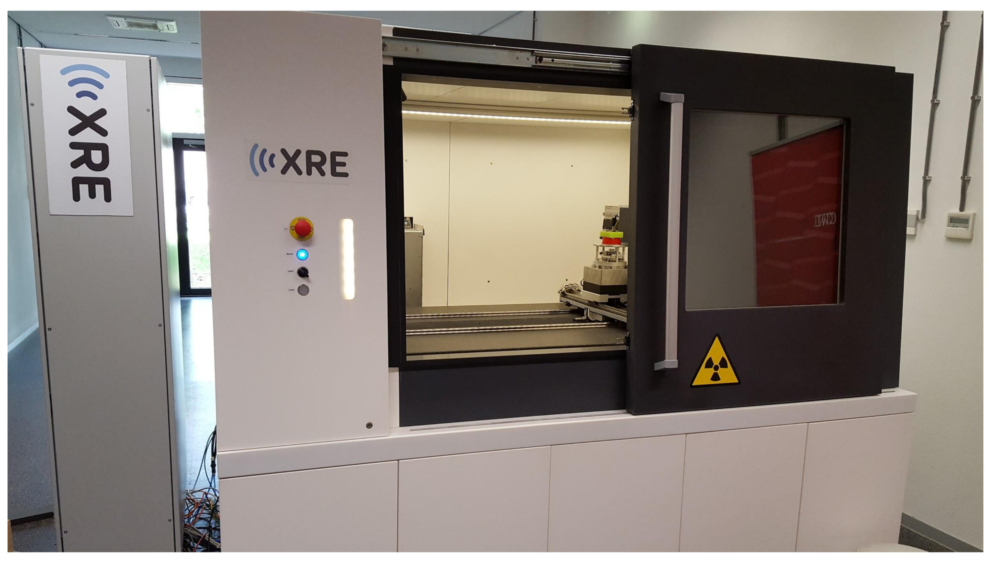
Colour reconstruction

Spectral x-ray imaging of breast cancers

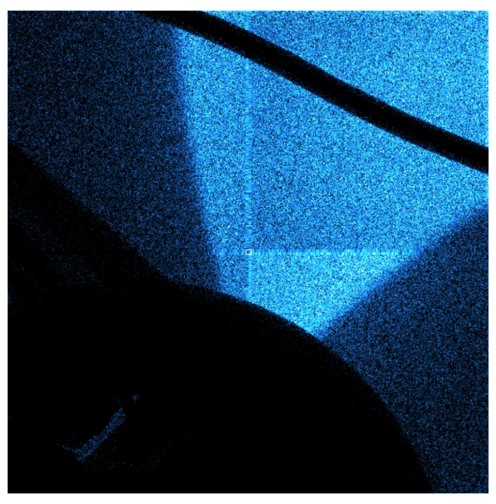


Breast tissue specimen imaged with the Medipix3 detector. Left image photograph of the specimen; Centre: a classic x-ray projection image (integrated all energies); Right: the spectral image after an energy based reconstruction. The data is clustered into 18 categories where each colour is categorised as a different tissue combinations. The homogeneous region in the top left with a high density of calcifications (bright yellow) is the tumour.

FleX-ray Real-time + Adaptive + Spectral + X-ray CT system



High speed imaging



Standard 12V computer fan

Frame rate : 2000 Hz

Unknown fan rotation speed

Real-time CT reconstruction in development from CWI

Computed Tomography reconstruction

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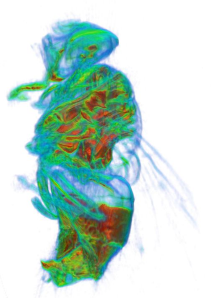

X-ray CT (Computed Tomography) reconstructions of a common housefly using CWI's Astra toolbox: www.astra-toolbox.com Colour scale for illustration purposes. 512 projections, 1s per projection, 50 kVp, 1mA

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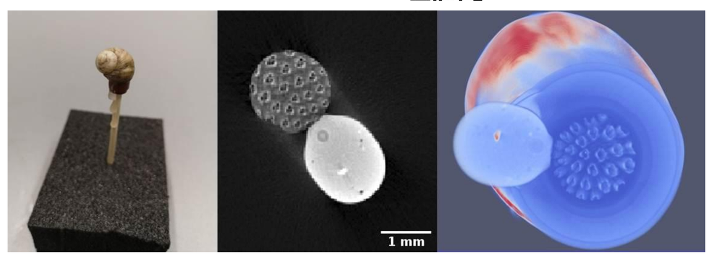

Left: photo of the phantom composed of **glue, wood, plastics and a snail shell**. Middle image is an axial slice showing the wooden toothpick with its microstructures and the glue with some small air pockets and dense material. Right image is a volume rendering of the reconstructed CT slices, the colour scale here represents the CT number (density).

Proton therapy - Clatterbridge Cancer Centre

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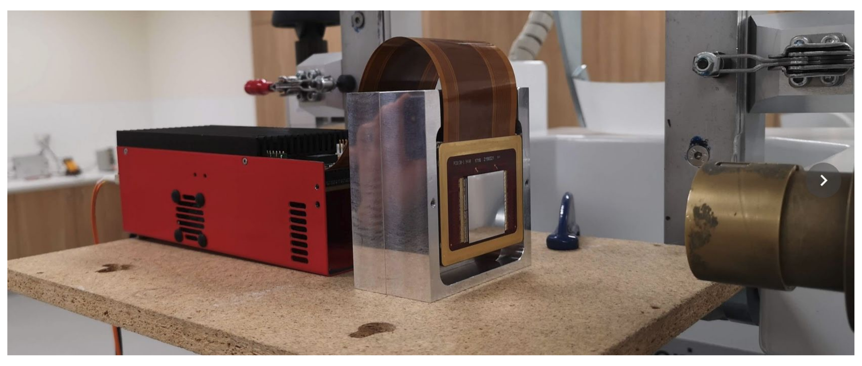
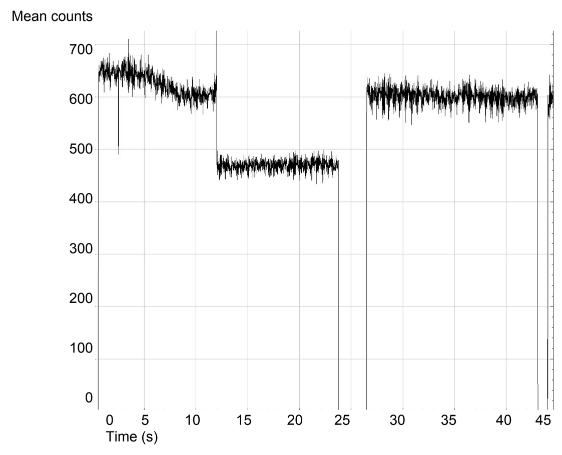
Preliminary results, analysis in progress

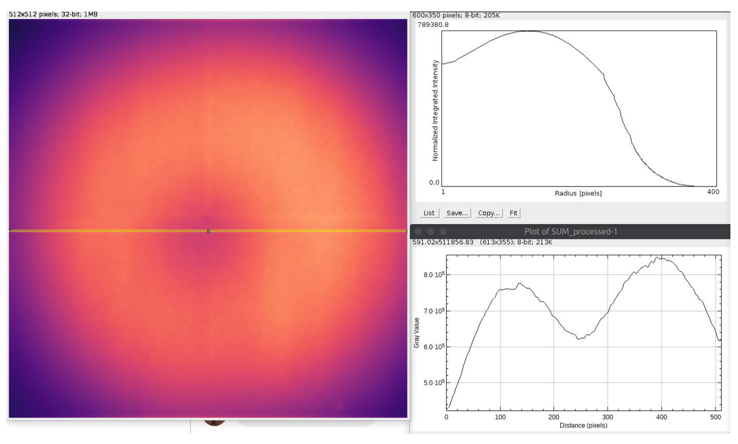


Above: An example of one of the detector layouts, after the nozzle.

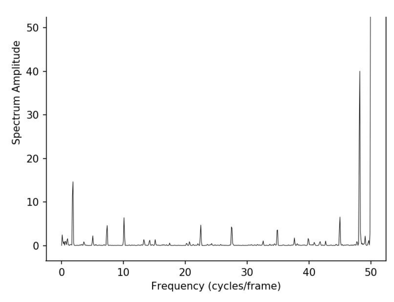


Left: An example of how the beam intensity is relatively unstable over the entire measurement period of ~10s. It starts with a large change at the start, two stable regions at different intensities and drops to 0 twice.

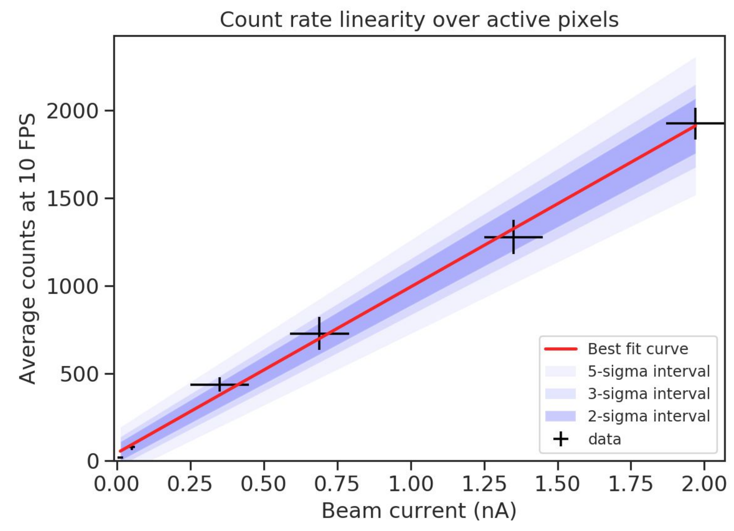
The jitter on the intensity can be seen, the frequency components are analysed on the right.



Left: A corrected beam profile within the integration zone, hence the non uniformity in the centre of the detector. The ROI selected is both radially summed (top right) and a line profile is calculated (bottom right). These can be compared to simulations from Jacinta directly.



Left: This spectrum amplitude splits the frequency components of the beam intensity for one measurement. It shows that there is a high amplitude 2 Hz component and a relatively lower amplitude 50.0 Hz component. 50.0 Hz is the mains frequency in the UK and so this is very likely to be directly related. The 2 Hz component is unknown, it is currently hypothesised to be related to the RF power to the dees of the cyclotron or the current source.



The count rate linearity of the Medipix3 (over all active pixels) appears to be very linear within the entire measurement range relative to the electrometer upstream, in the accelerator. This suggests that the Medipix3 could be a good chip to use for proton therapy quality assurance.

Looks good so far!

Comparison to EBT3 film and simulations in progress

Next steps

1. Medipix3
   - Continued software, driver, firmware improvements and thorough testing for improving reliability and performance
     - High frame rate readout indefinitely
     - Investigation into how CSM really works
     - Solve a readout bug in the firmware / gateware causing a variety of bugs in the software and driver

2. NKI & FleX-ray
   - Software integration of the detector into the system
   - Further scans with different cancerous tumours and verify with H&E stains (standard procedure)
   - Fuse the extra dimension (spectral data) into the CT reconstruction algorithm package, Astra. Multiple methods are in mind.

3. Proton therapy - CCC
   - Why is the beam intensity unstable over time?
   - What is causing the 2 Hz frequency component within the beam intensity?
   - Compare to beam profiles from Jacinta's simulations
   - Compare integrated dose measurements with film (RGB calibration using existing method)
   - Compare film sensitivity, spatial resolution, dose response etc.
   - What caused the strange looking patterns at low dose rate?

AMSTERDAM SCIENTIFIC INSTRUMENTS

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