Pixel detectors in patient treatment

Navrit Bal

1. Hybrid pixel detector overview
2. Medical use cases
   - FleXray
   - NKI
   - VELO

Particle detection

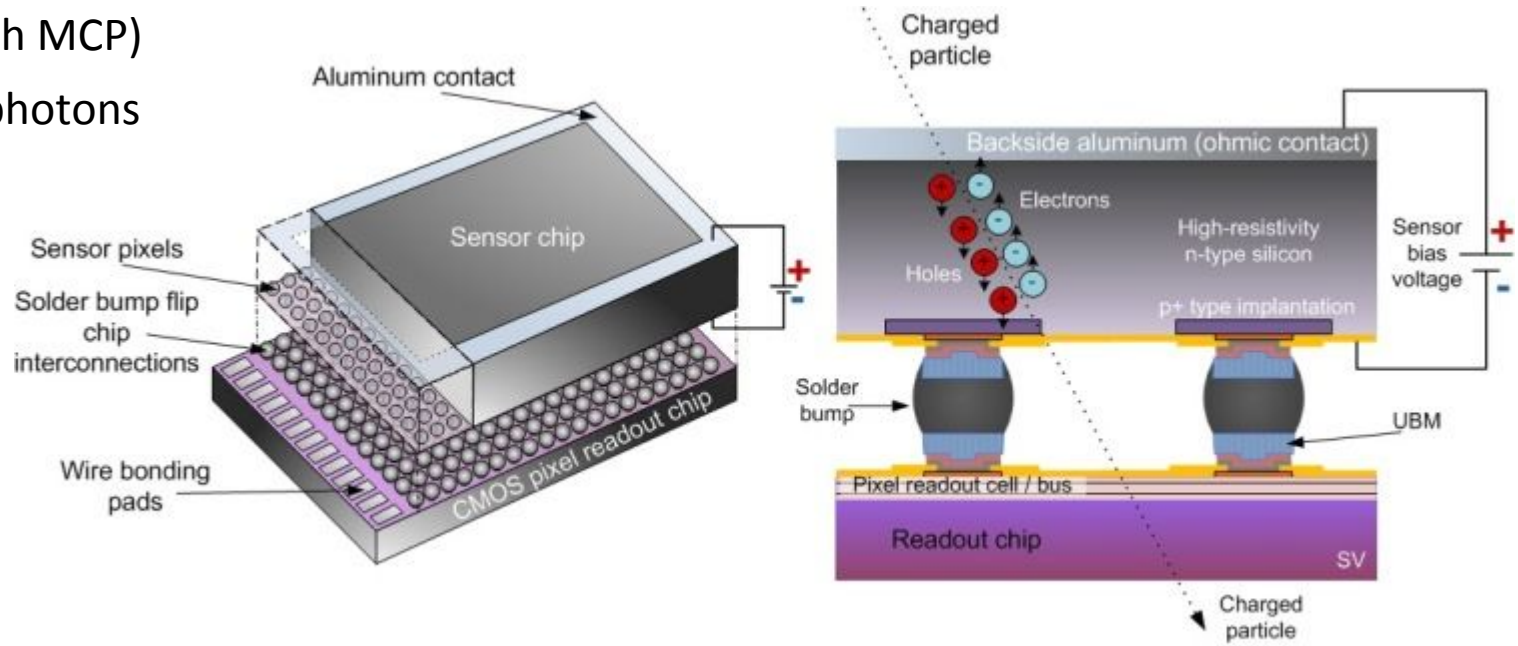
Photons

Electrons

Protons/ions

Neutrons (with MCP)

Even optical photons

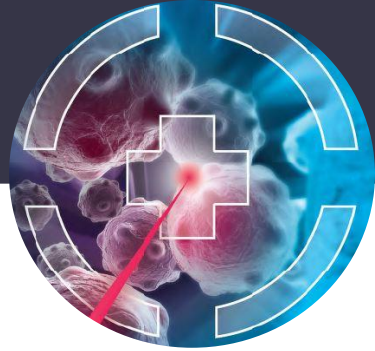


Generic pixel detector

Cross-sectional cut

http://x-ray.camera/technology/flip-chip-bonding/

Hybrid pixel detector overview



Radiation hardness	Failure at ~300 MGy
Readout speed	2+ kHz
Sensor materials	Many (solid, gas, MCP) - any thickness
Pixel pitch	55 or 110 µm
Dynamic range	Very high Medipix3 - Up to 24 bits per frame - 16.7M counts
Energy resolution	Medipix3 - 1 KeV FWHM - Si 10 KeV
Charge summing on-chip	Yes
Signal to Noise	Ultimate - particle counting
Dark current	None
Dead time	Can be 0
Cooling	Air/water cooling
Maintenance	None

Hybrid pixel detector overview

CSM vs SPM

Energy resolution

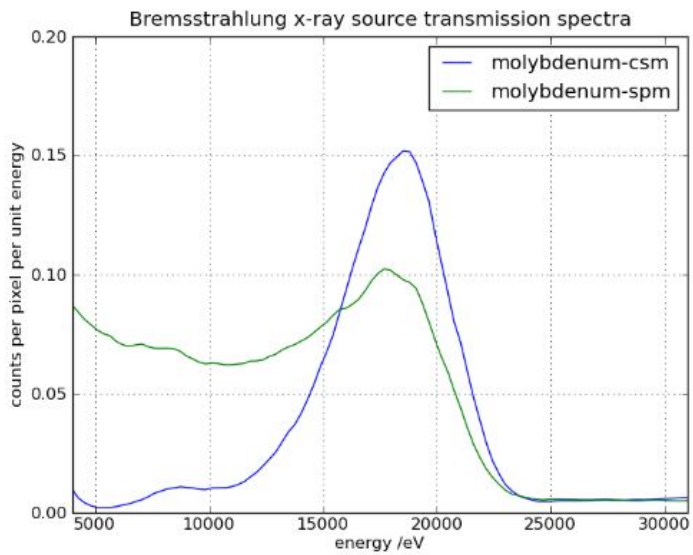


Figure 7. SPM and CSM spectra from fluorescence x-rays generated in a 100 μm molybdenum filter placed within the beam of the x-ray tube. ($V = 50$ kVp.)

http://iopscience.iop.org/article/10.1088/1748-0221/6/01/C01056/meta

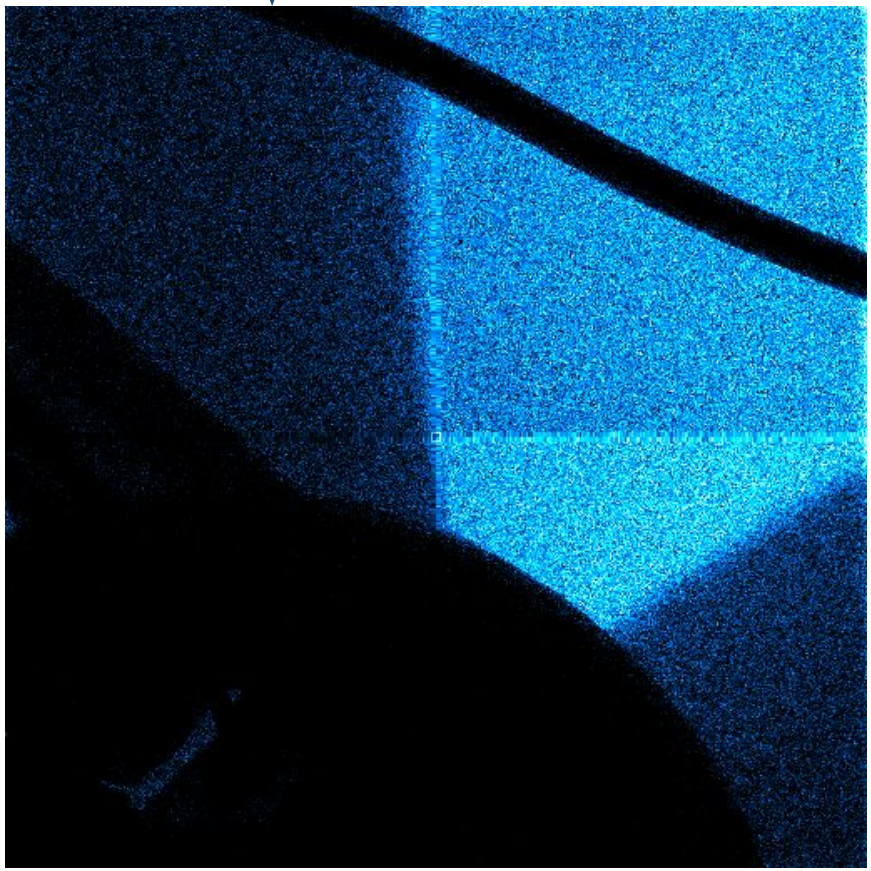
Hybrid pixel detector overview

Configurable pixel pitch	Any multiple of the pixel size without a new chip
Pile up	Not a bottleneck. The small pixel size and fast shaper means this isn't a problem
Pixel to pixel variation	Slightly different gain and noise baseline
Data rate	Currently limited by 10 Gbit ethernet Next generation has to use PCIE (100+ Gbit)
Fabrication technology	130 nm Next generation - 65 nm
Time resolution	Timepix3 - 1.56ns Next generation: Timepix4 - ~200ps
Synchrotron accident recovery	Yes!

Medical use cases

FleXray

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



Standard 12V computer fan

Frame rate : 2000 Hz

Unknown fan rotation speed

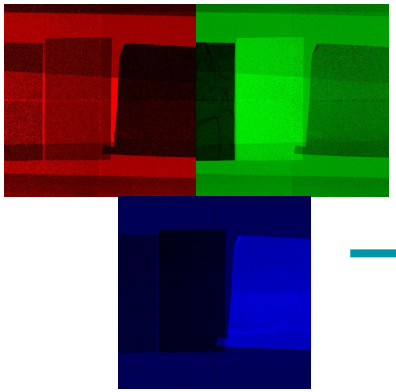
Real-time CT reconstruction in development from CWI

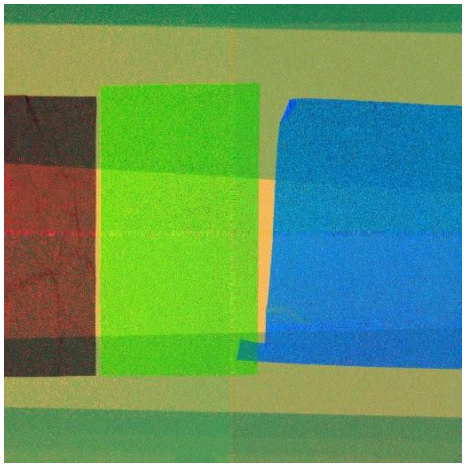
FleXray

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

Colour x-ray reconstruction

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

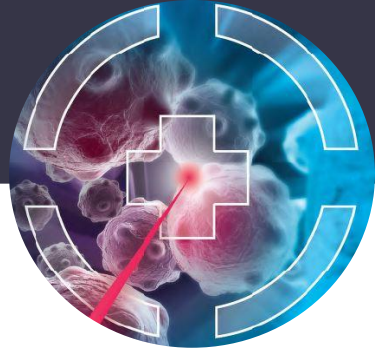




Colour x-ray sample - Si 500 µm - 50kVp - 6x360ms

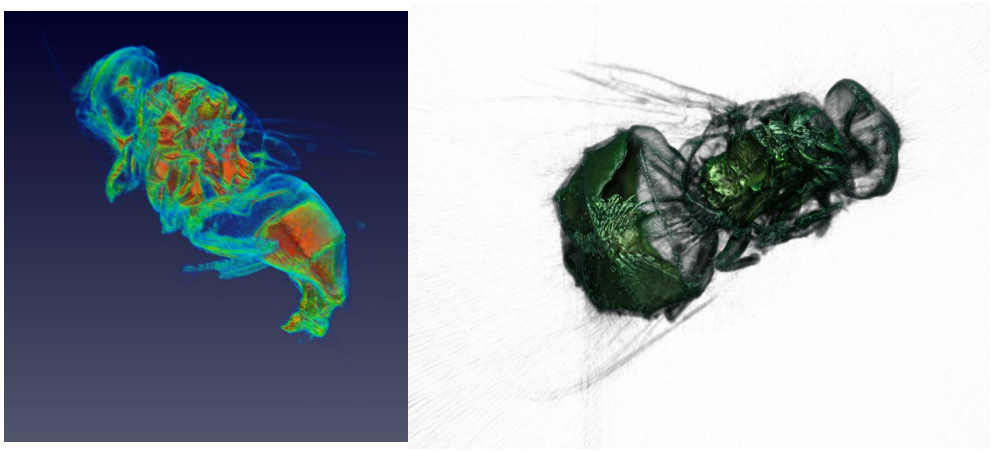
Colour reconstruction

FleXray



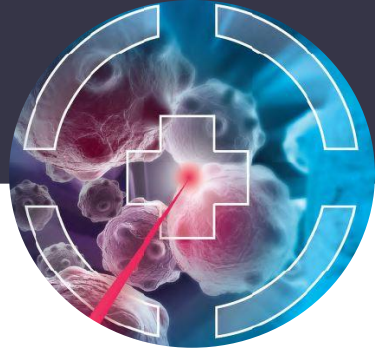
Real-time + Adaptive + Spectral + X-ray CT system

Computed Tomography reconstruction



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

FleXray

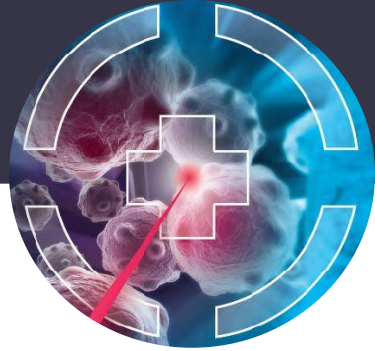


Real-time + Adaptive + Spectral + X-ray CT system

1. Fast CT
2. Zoom in on ROI and add to reconstruction
3. Use the information from the spectrum (per voxel element identification)
4. Relatively low dose

Could be scaled to human size once the techniques and technology have progressed

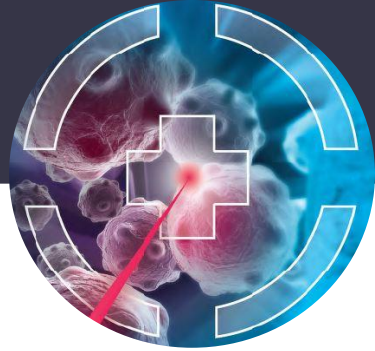
NKI



1. A doctor finds a cancerous tumour through existing methods (x-ray CT etc.)
2. The patient has a biopsy
3. ~4-6 weeks after, the results come in from the Pathology department
   a. The surgeon missed the edge of the tumour and the cancer spreads…
   b. The surgeon removed the targeted cancer, the surgery was successful!

This happens all the time.

NKI

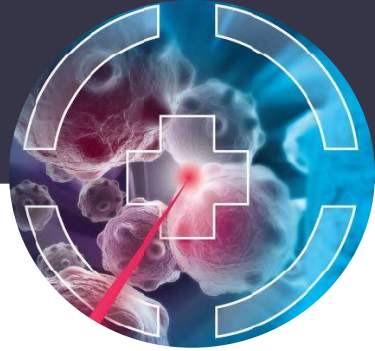


1. A doctor finds a cancerous tumour through existing methods (x-ray CT etc.)
2. The patient has a biopsy
3. ~4-6 weeks after, the results come in from the Pathology department
   a. The surgeon missed the edge of the tumour and the cancer spreads…
   b. The surgeon removed the targeted cancer, the surgery was successful!

This happens all the time.

It can be improved!

NKI



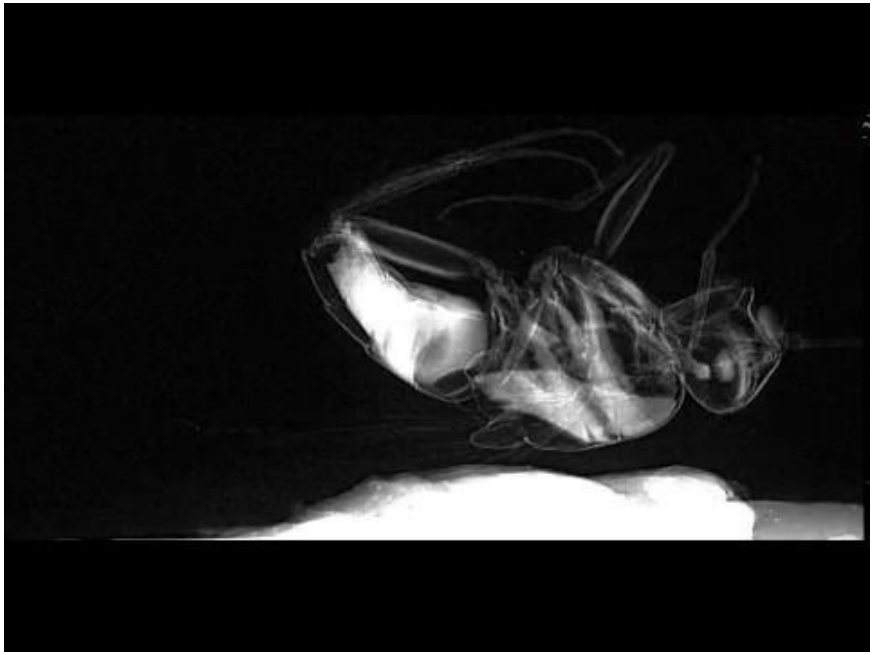
1. A doctor finds a cancerous tumour through existing methods (x-ray CT etc.)
2. The patient has a biopsy
3. ~~~4-6 weeks after, the results come in from the Pathology department~~
   a. ~~The surgeon missed the edge of the tumour and the cancer spreads…~~
   b. The surgeon removed the targeted cancer, the surgery was successful!

This happens all the time.

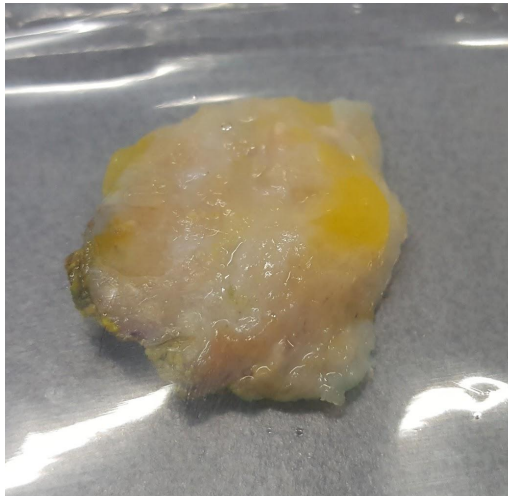
It can be improved!

NKI

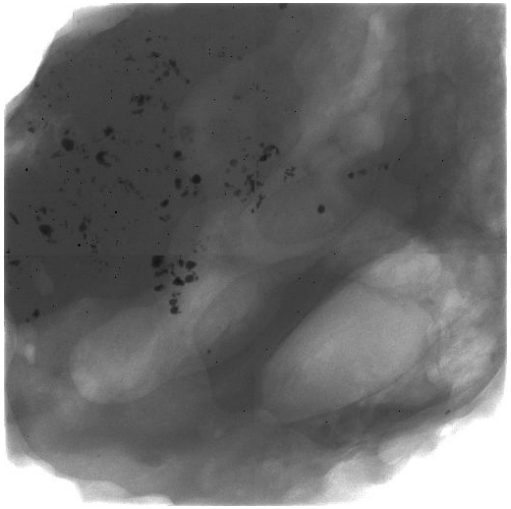
1. A doctor finds a cancerous tumour through existing methods (x-ray CT etc.)
2. The patient has a biopsy
   a. During the procedure, the tissue is scanned by a Medipix3 based x-ray detector. It makes a high quality micro CT scan, also using the spectral information.
   b. The boundary of the tumour is found within the biopsied tissue.
   c. Total analysis time: < 10 minutes
3. The surgeon removed the targeted cancer, the surgery was successful!



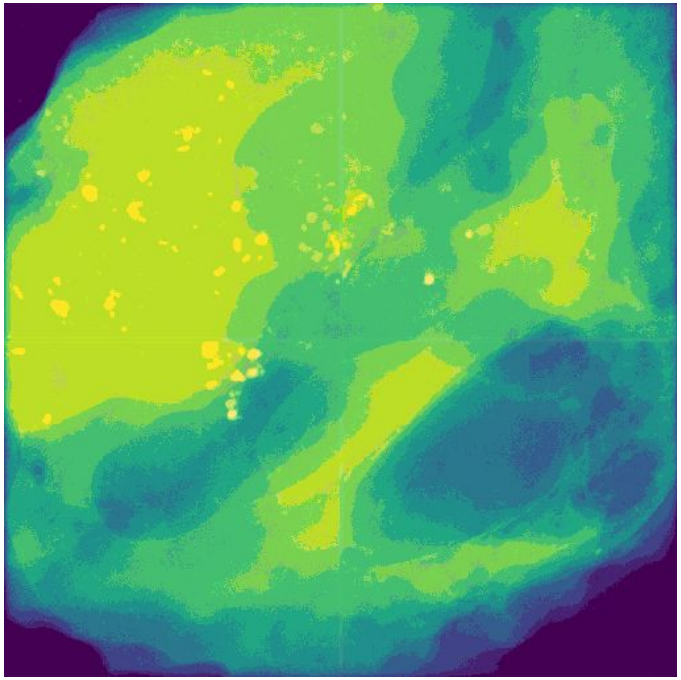
First measurement



Visible image



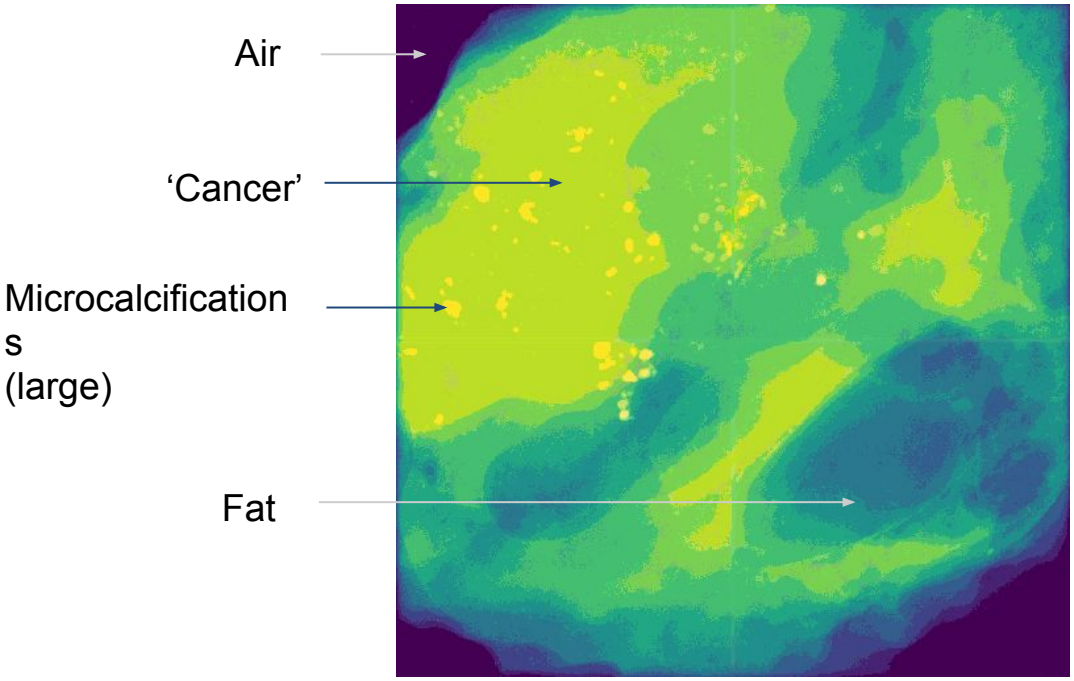
X-ray image - greyscale



Clustering analysis over energy
The tissue boundaries are visible.

H&E staining at the hospital to verify

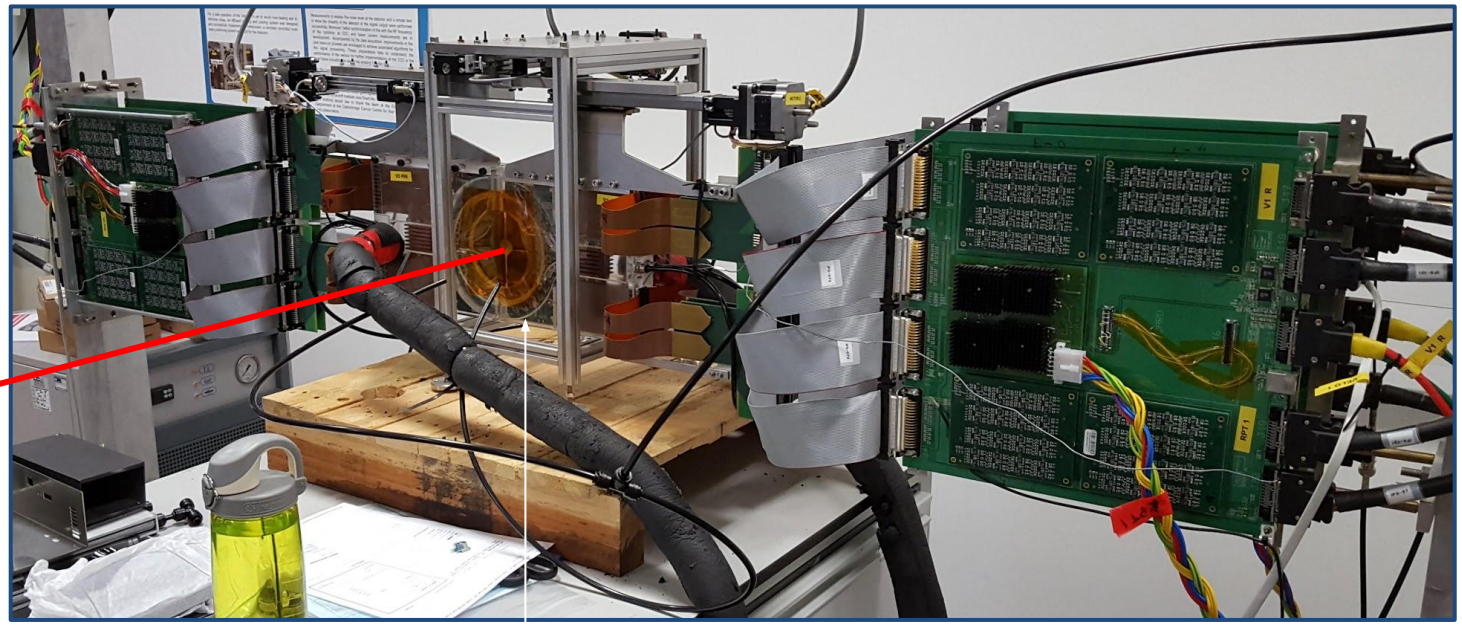
First measurement



Clustering analysis over energy
The tissue boundaries are visible.

H&E staining at the hospital to verify

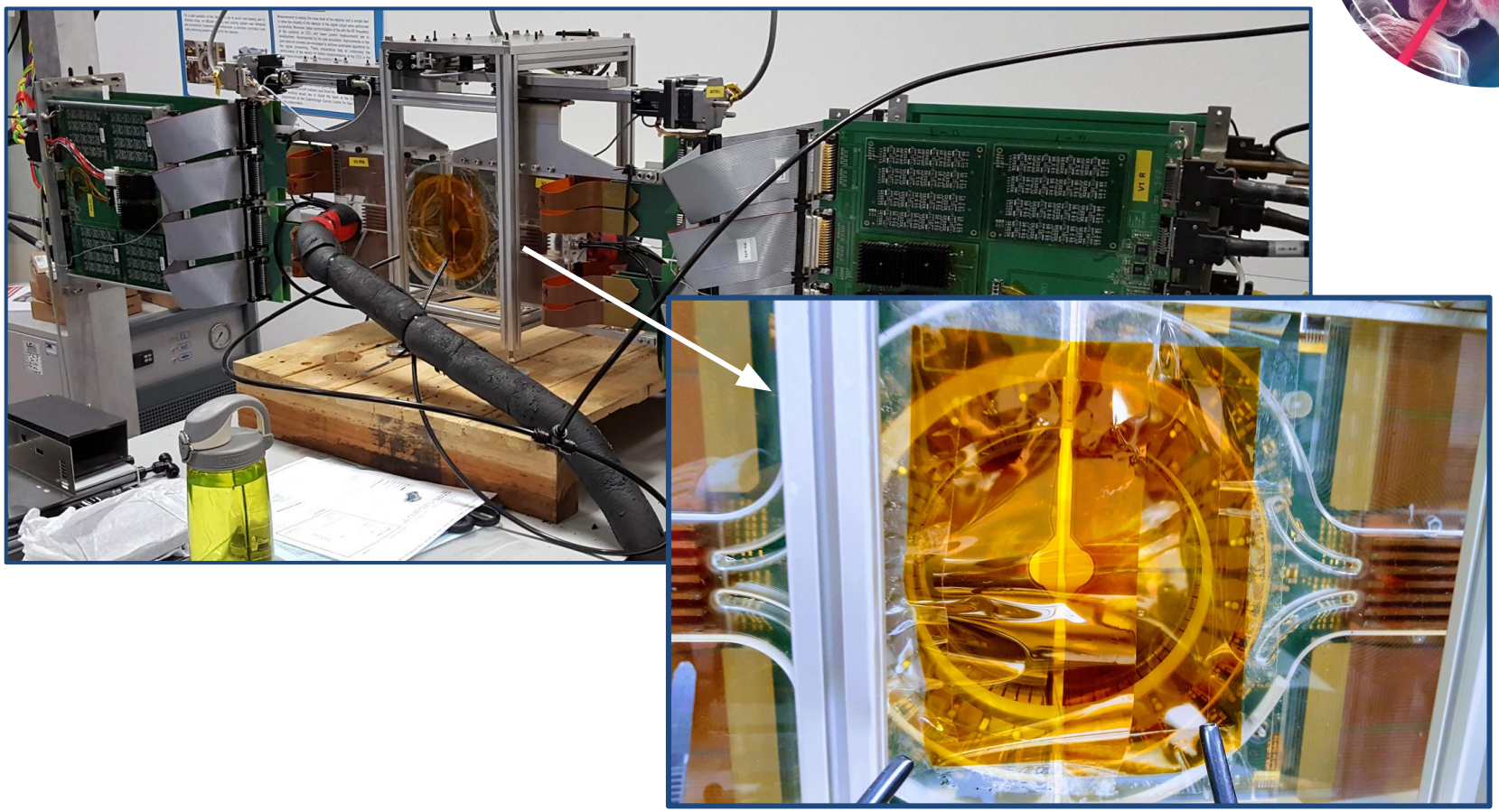
VELO



Proton beam

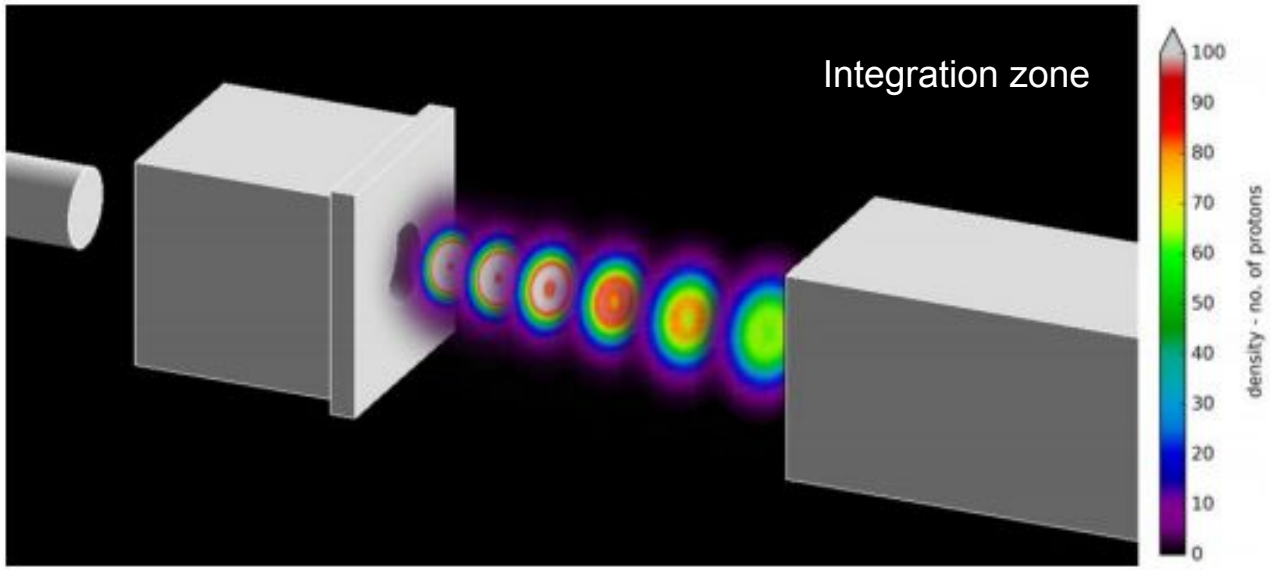
Detectors

VELO



VELO

See OMA Express, Issue 6 and D2.1, Jacinta Yap



Simulated beam density profile maps overlaid within the VELO integration zone.

Measure beam density profile. Medipix3: Position only, no energy information

Next generation: Timepix4 might be able to measure the bunch structure with ~200ps time resolution

https://indico.cern.ch/event/591299/contributions/2423187/attachments/1393307/2123191/Timepix4_specs.pdf

Questions?

Recommended review papers

http://iopscience.iop.org/article/10.1088/1748-0221/11/01/C01007/meta
http://iopscience.iop.org/article/10.1088/1361-6633/aab064/meta

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 675265, OMA – Optimization of Medical Accelerators.