MICROSTRIP DETECTOR FOR ONLINE MONITORING DURING SYNCHROTRON MICROBEAM RADIATION THERAPY:
MEASUREMENTS WITH PHANTOMS AND VETERINARY PATIENTS

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ÉQUIPE PHYSIQUE NUCLÉAIRE ET APPLICATIONS MÉDICALES, LPSC, GRENOBLE

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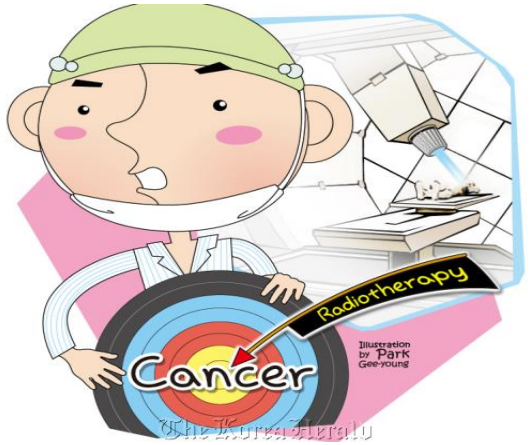
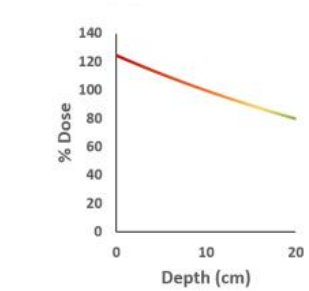
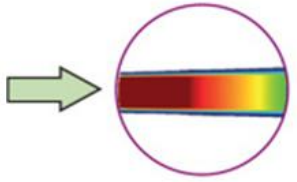
F. di Franco, *et al.*, *J. Synchrotron Rad.*, 2023.

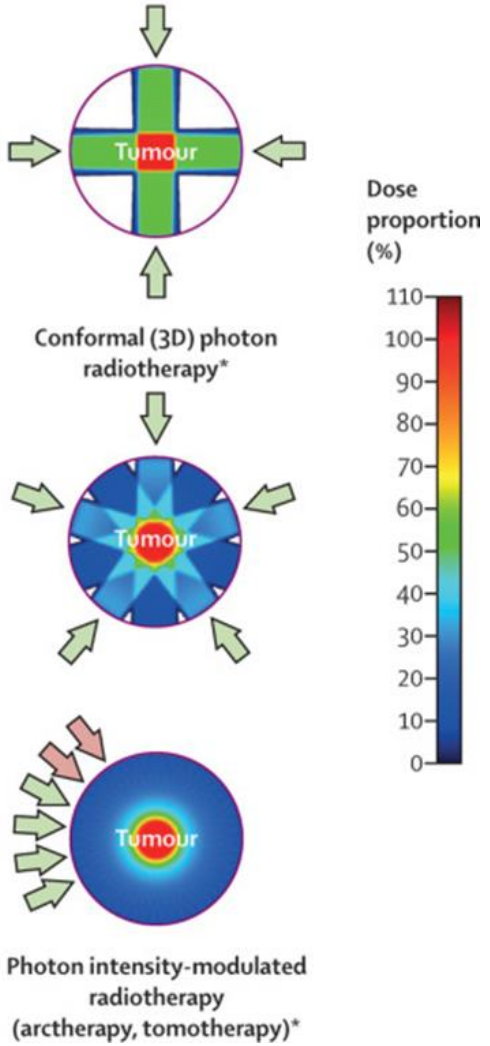
WHAT IS RADIOTHERAPY?



- Use of radiation (e.g. x-rays, electrons, protons, etc.) to treat a disease, such as cancer
- About half of all cancer patients will receive some form of radiotherapy during their treatment
- The goal of radiotherapy is of course to kill cancer cells…But not at the expense of healthy cells!



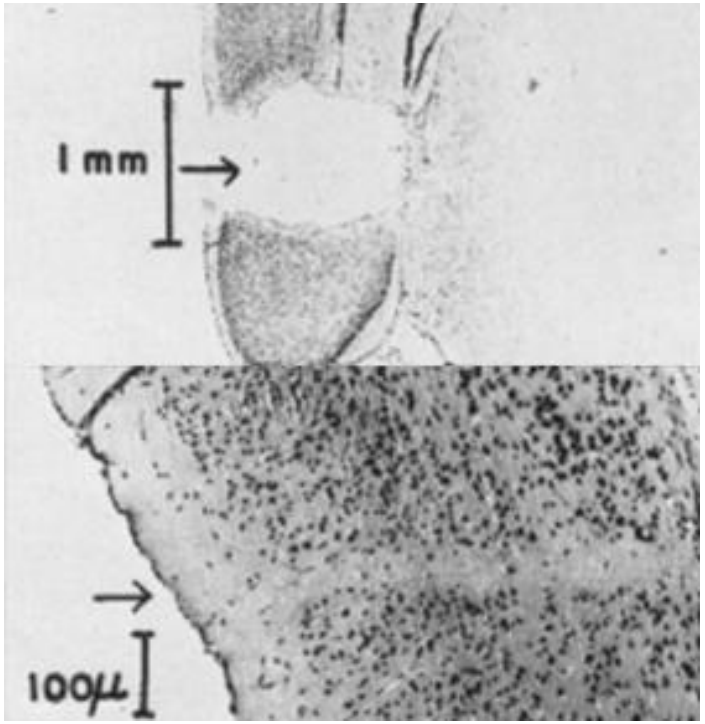




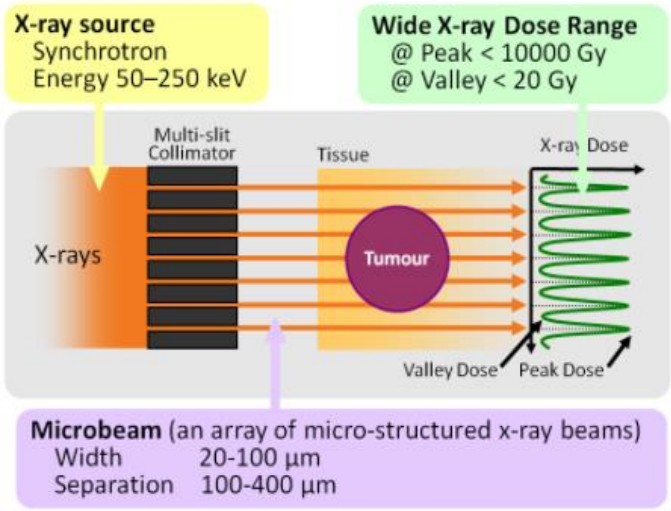
Adapted from Thariat J., *et al., Lancet*, **22**(12), 2021

MICROBEAM RADIOTHERAPY: SPATIAL FRACTIONATION OF THE DOSE

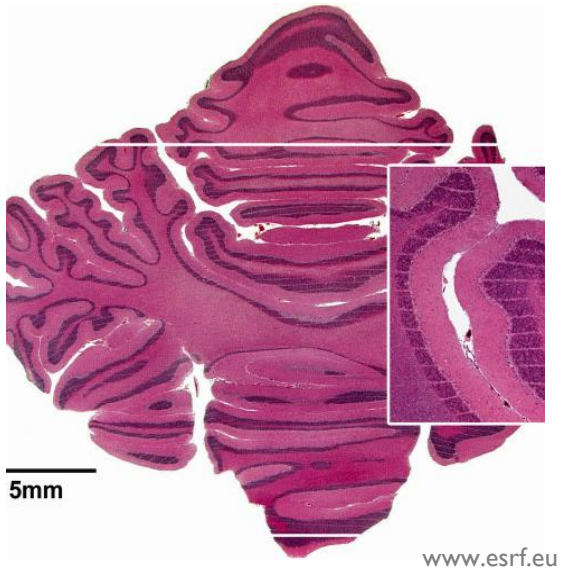
Dose volume effect



Curtis, H. J., *Radiat. Res., Suppl. 7.*, 1967



http://mswebs.naist.jp



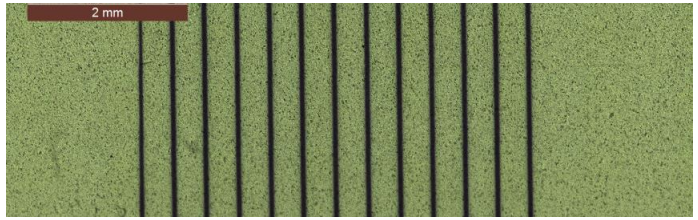
www.esrf.eu

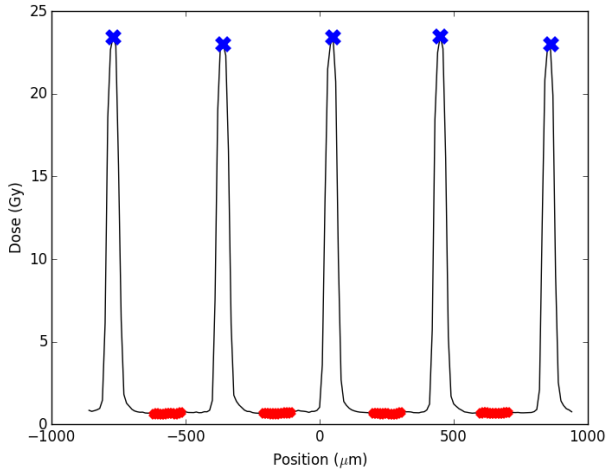
Up until now has been confined to synchrotron sources due to spectrum (kV) and high dose rates (10^2 – 10^3 Gy/s) required

Dedicated beamlines:

- ID17, ESRF (until mid-2023)
- IMBL, Australian Synchrotron

EXPERIMENTAL MRT DOSIMETRY





μm beamlets
high dose gradients
high dose rate
keV spectrum

1D dose profile

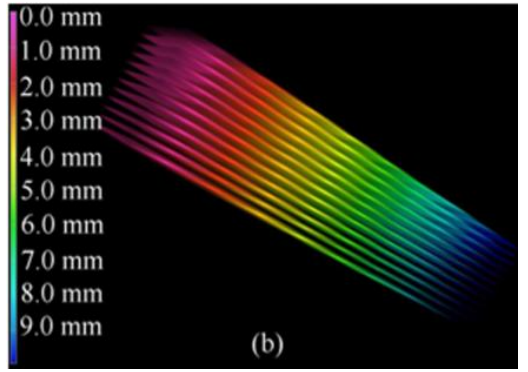
- Si strip detector (10 μm thick SV)
  University of Wollongong, Australia
- PTW microdiamond (1 μm thick SV)
  J. Livingstone, *et al., Med. Phys.*, 2016.
- Optical fibres (10 μm thick scintillator)
  J. Archer, *et al., Sci. Rep.*, 2019.

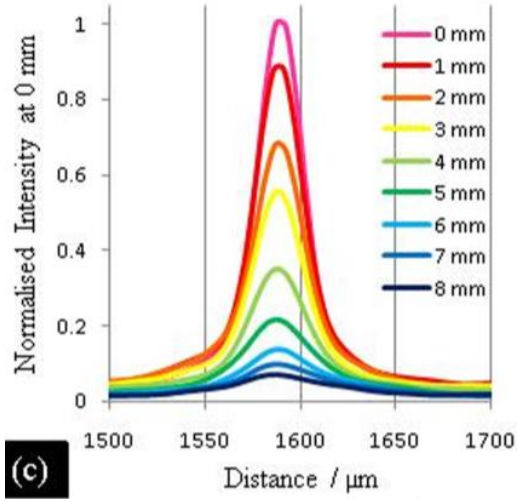
2D dose distribution

- Radiochromic film
  J. Crosbie, *et al., Phys. Med. Biol.*, 2008.
  S. Bartzsch, *et al., Med. Phys.*, 2015.
  A. Ocadiz, *et al., Phys. Med.*, 2019.
  And others….

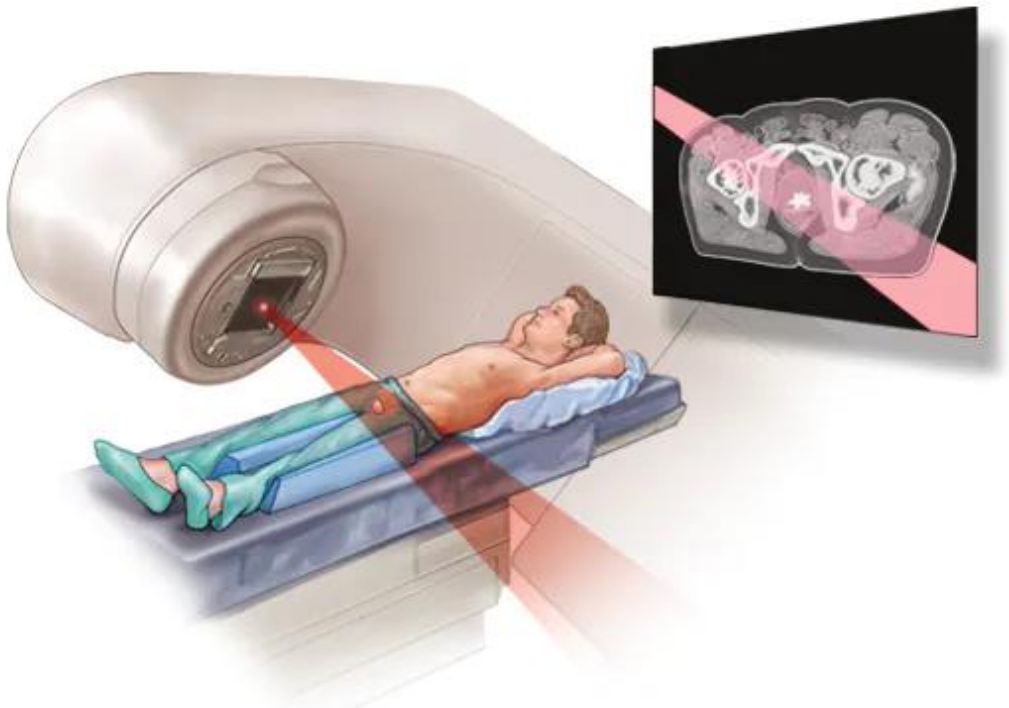
3D dose distribution

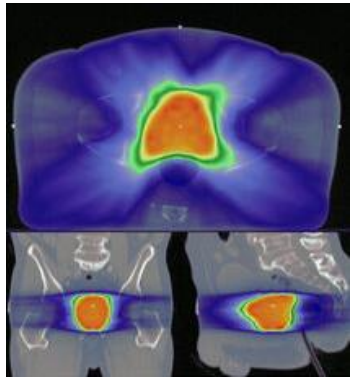
- Gel dosimeters (PRESAGE)
  S. Doran, *et al., Phys. Med. Biol.*, 2013.
  F. Gagliardi, *et al., Med. Phys.*, 2015.
  And others…



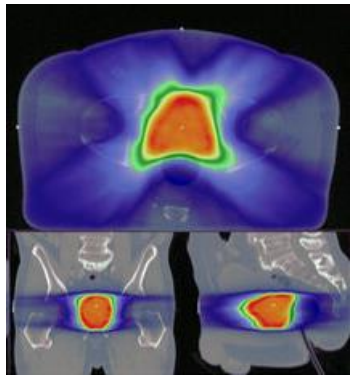


IN VIVO DOSIMETRY: PORTAL IMAGING

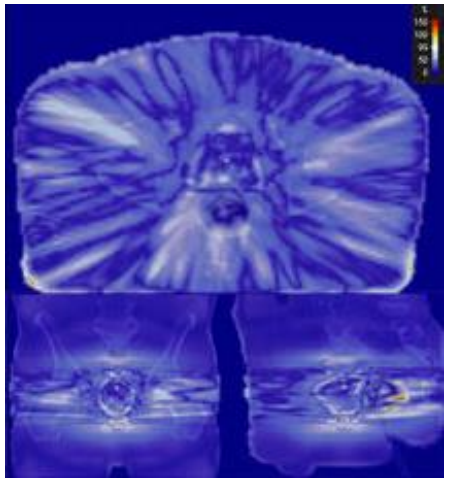




Prescription

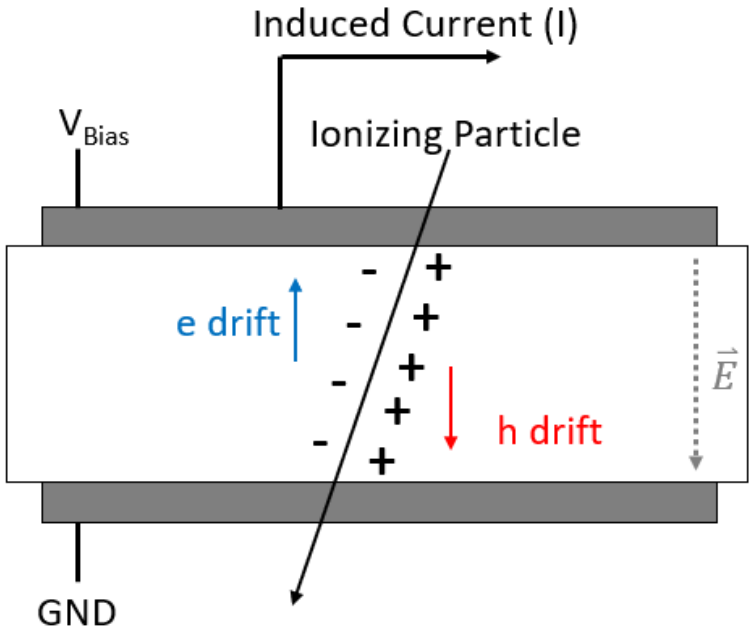


Reconstructed dose



Agreement / Disagreement

DIAMOND-BASED DETECTORS



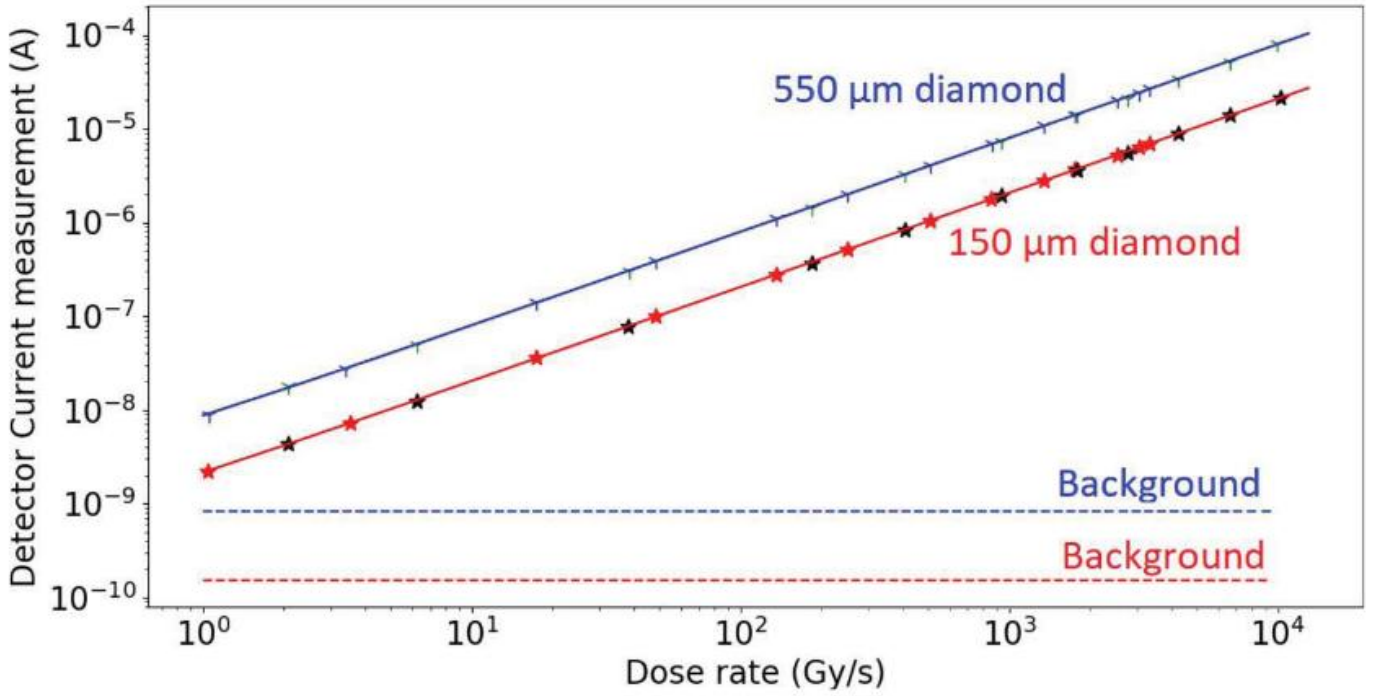
I. Zahradnik, PhD Thesis, 2021.

- Diamond satisfies requirements (rapidity, tissue equivalence, radiation resistance)
- Operated as a solid ionisation chamber
  - Front and back metal electrodes deposited via laser lithography
- Induced current due to motion of charge carriers in vicinity of electrodes
  - Shockley-Ramo

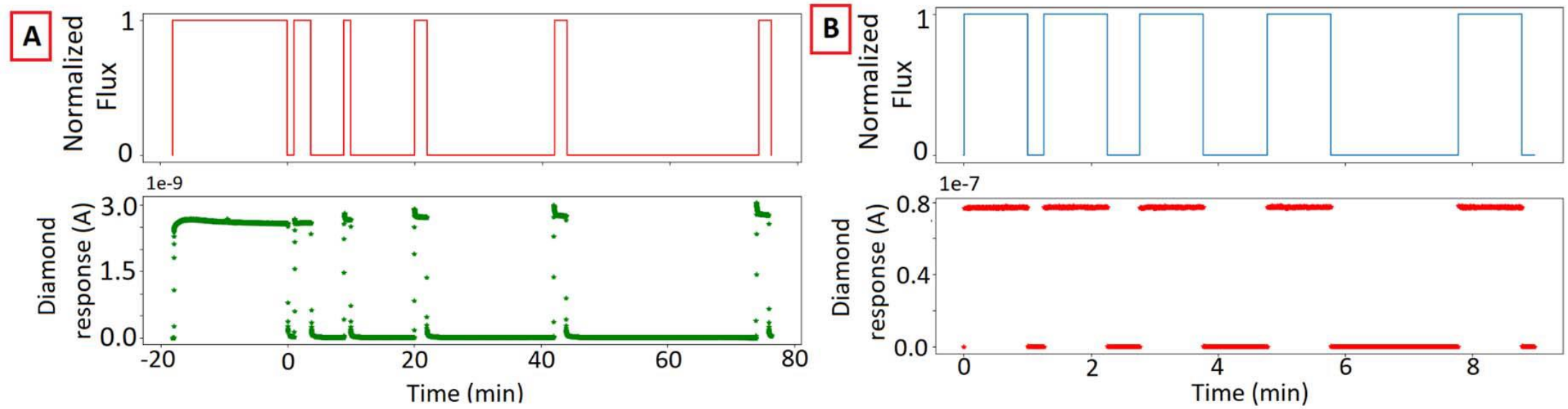
$$I = q \cdot \overrightarrow{v_{drift}} \cdot \vec{E}$$

PRELIMINARY TESTS: DOSE RATE RESPONSE

- 2x monocrystalline CVD diamond detectors 4.5 x 4.5 mm² with Al metallisation
  - 150 µm thick
  - 550 µm thick
- Irradiated at ID17 (ESRF) to investigate dose rate dependence in the range $1 - 10^4$ Gy/s
- ~100% charge collection efficiency measured using ^{241}Am 5.5 MeV alpha particles (M. L. Gallin-Martel, *et al., Frontiers in Physics*, 2021.)



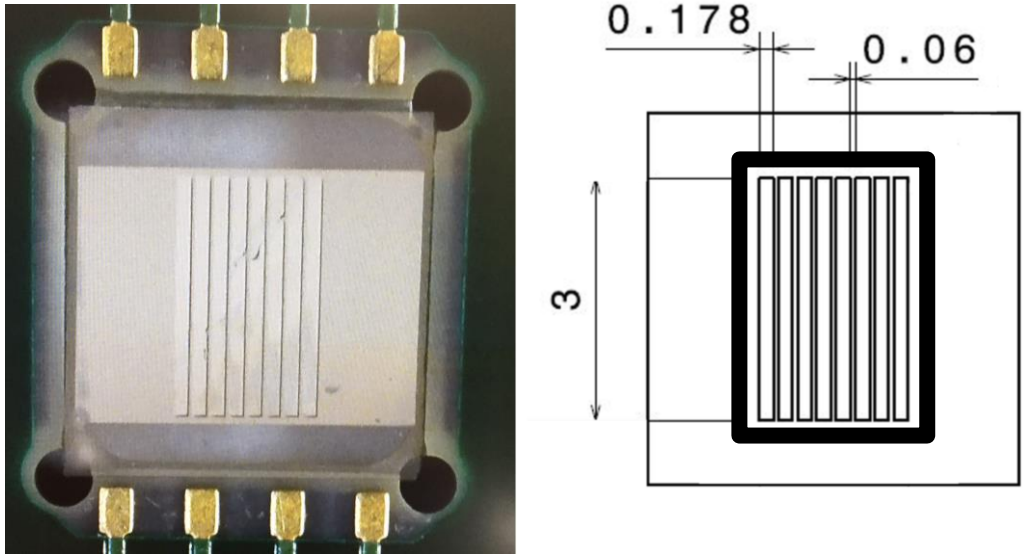
PRELIMINARY TESTS: DOSE RATE RESPONSE



160 kV x-ray tube, 1 Gy/min

95 keV monochromatic x-rays, 0.5 Gy/s

LPSC MICROSTRIP DIAMOND DETECTOR



LPSC 8-microstrip diamond detector prototype. All measurements in mm.

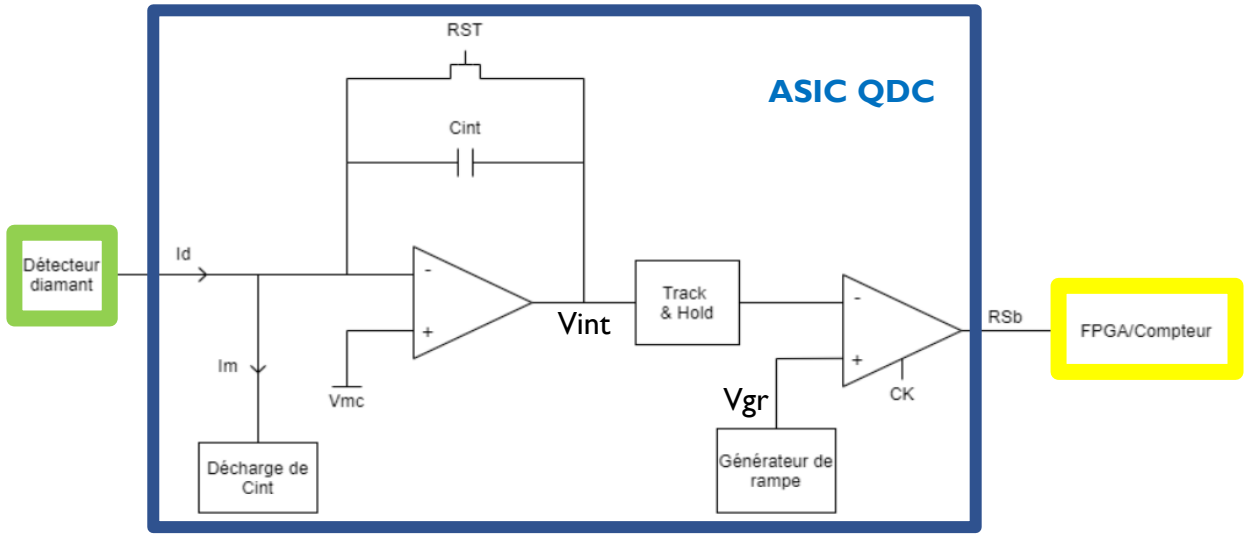
8-strip prototype device

- 550 μm thick monocrystalline CVD diamond
- 8 strips: 3 mm high, 178 μm wide, 60 μm between adjacent strips
- 100 nm thick Al metallisation layers
- 1 V/μm electric field
- Guard-ring surrounding strips
- Simultaneous integrated charge readout
- Aluminium housing with aluminised mylar beam window

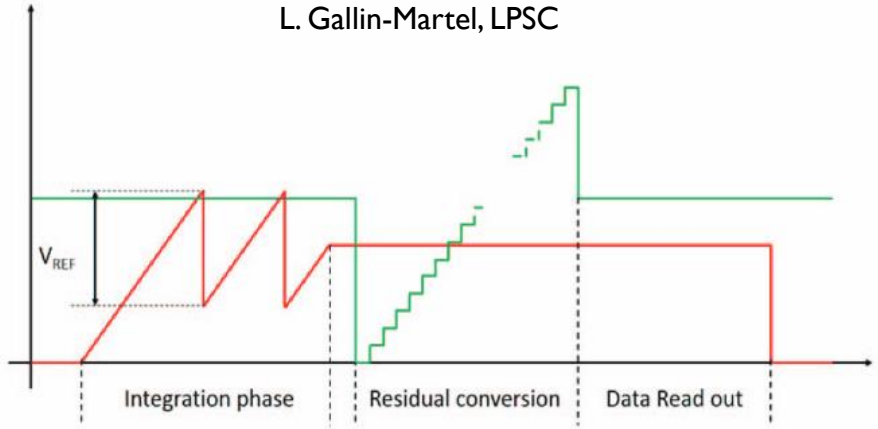
DETECTOR READOUT

- ASIC featuring a charge to digital converter (QDC)
  - Coarse measurement
- DAC accounts for residual charge
  - Fine measurement
- Integration time 1 ms – 100 ms
- High dynamic range
  - 10 nA – 100 µA

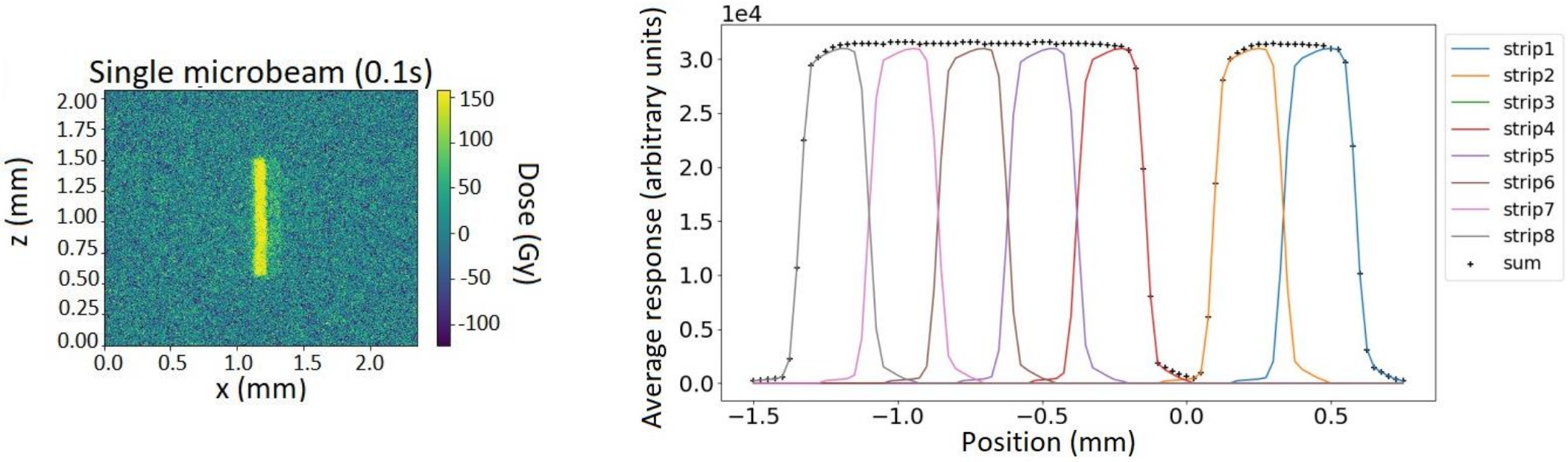
$$Q = \beta(CPT + \alpha RES)$$



L. Gallin-Martel, LPSC

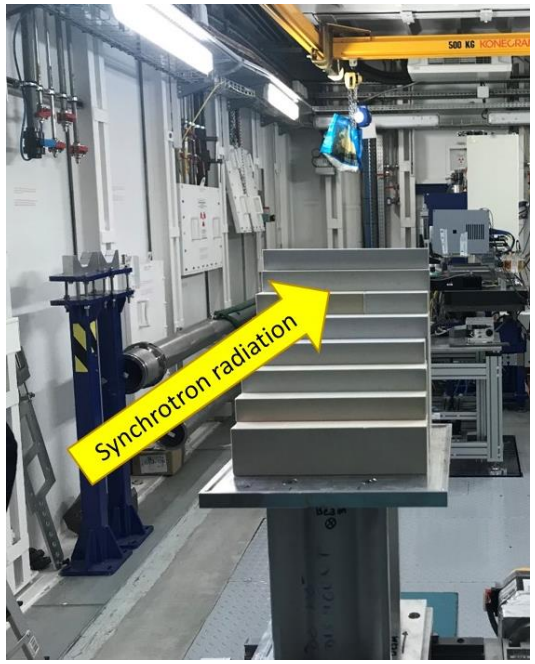


DETECTOR RESPONSE TO SINGLE MICROBEAM



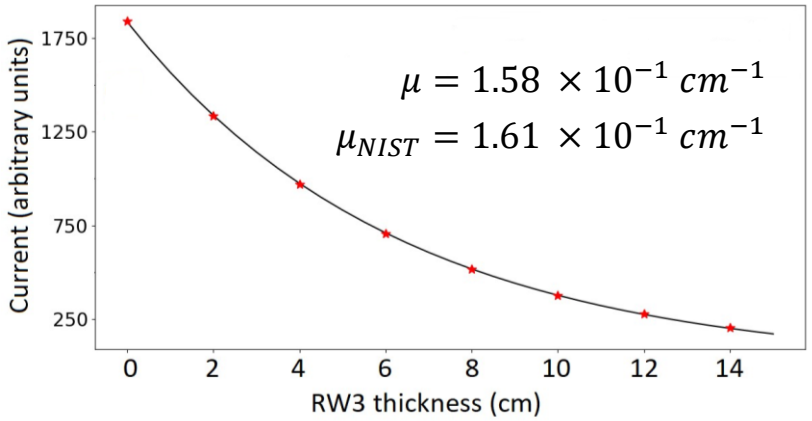
A single microbeam (as visualised using Gafchromic ® film, left) was scanned horizontally across the microstrip detector.

STEP PHANTOM: MEASUREMENTS VS THEORY

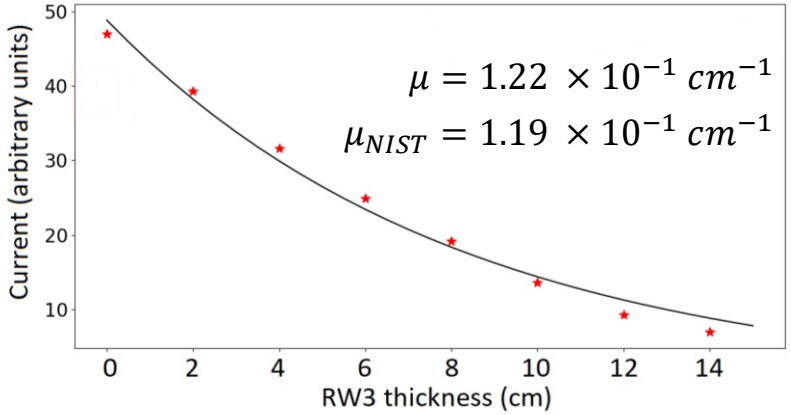


$$I = I_0 e^{-\mu x}$$

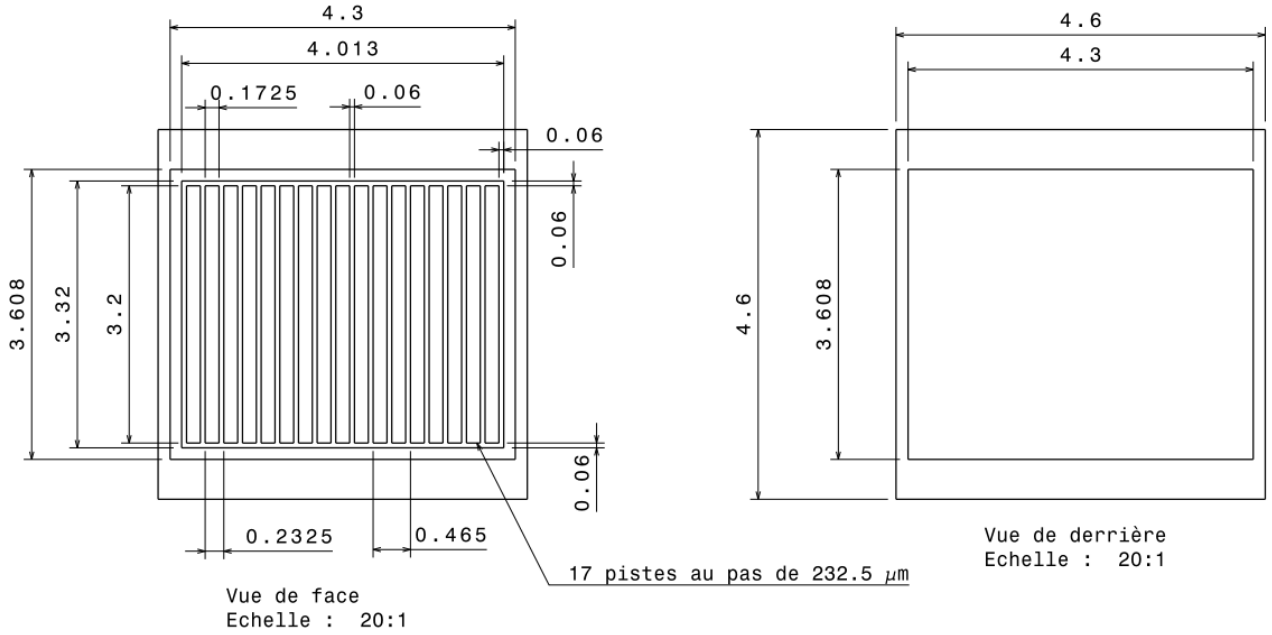
In-beam (E_{ave} = 123.7 keV)

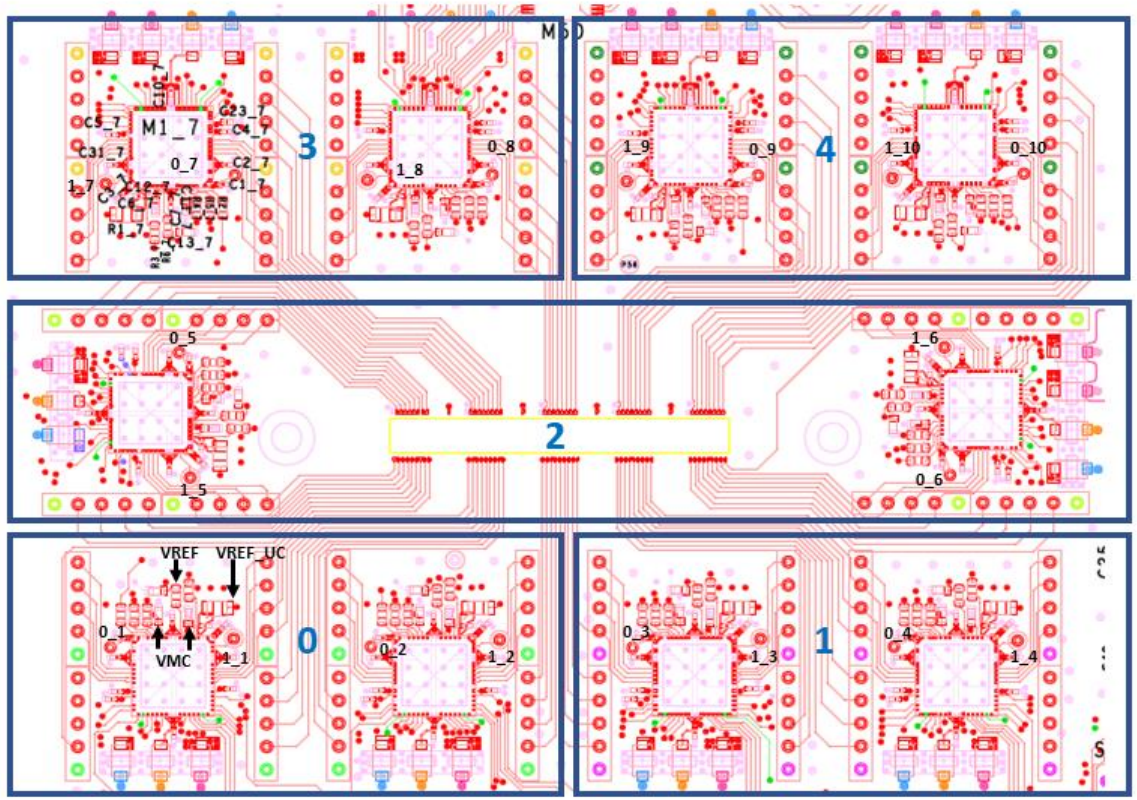


Inter-beam (E_{ave} = 308.0 keV)

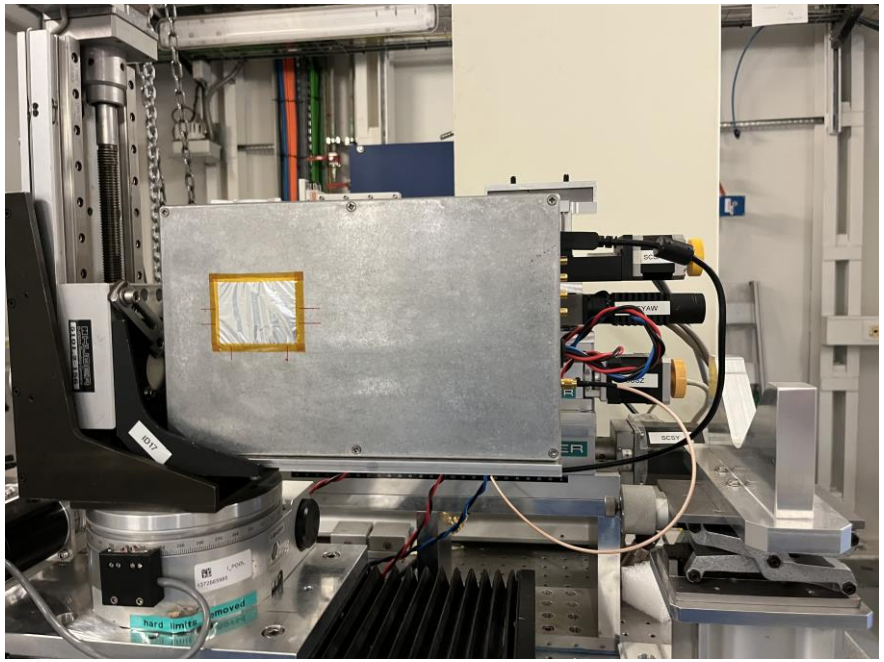


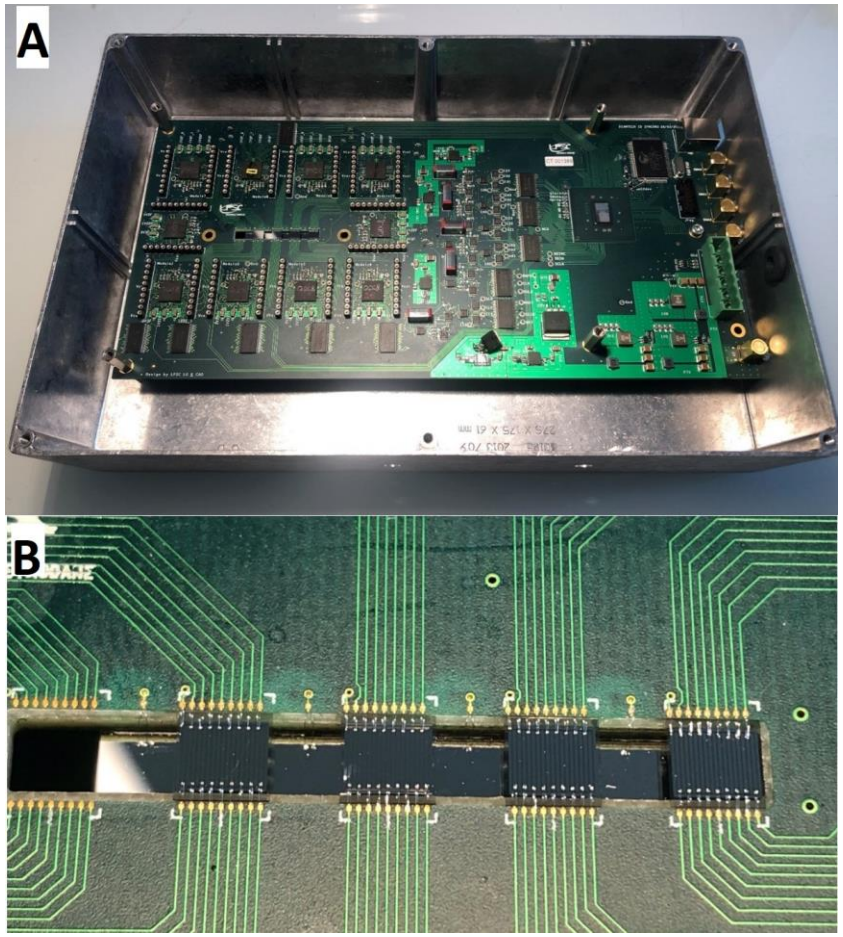
153-STRIP DETECTOR





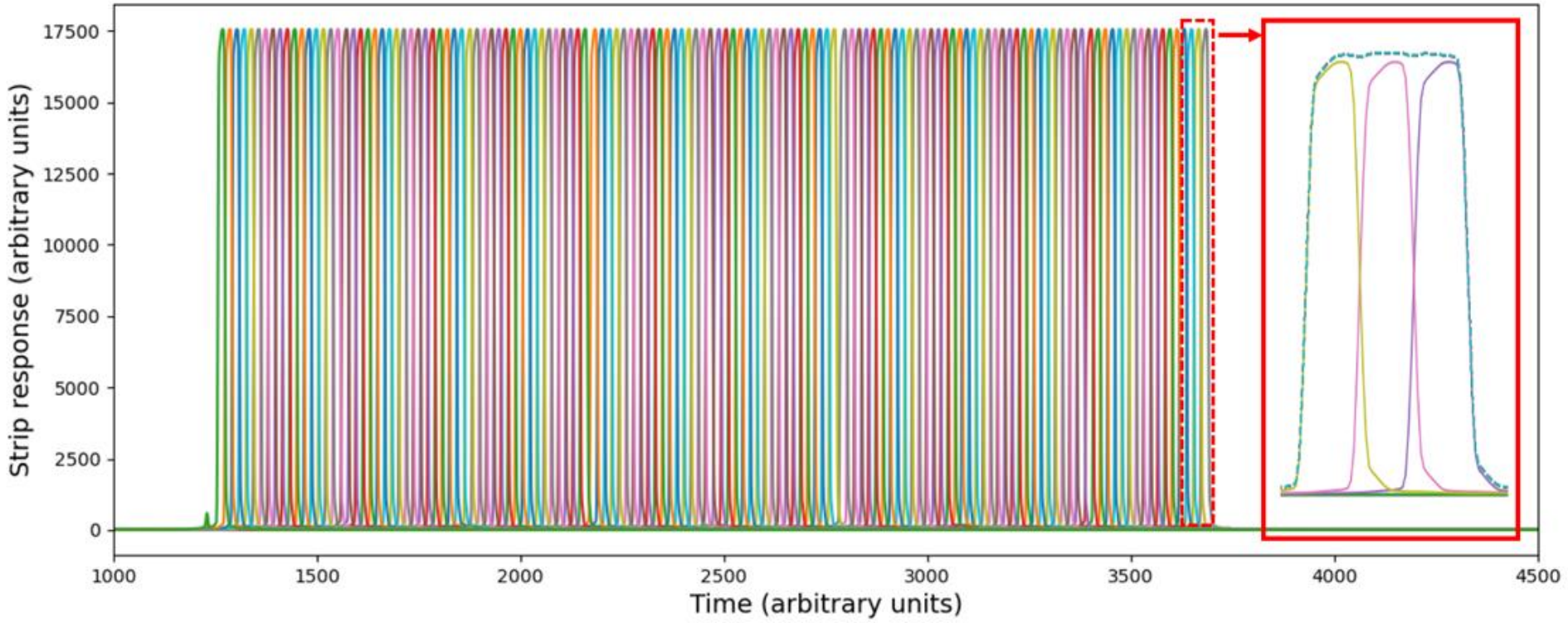
153-STRIP DETECTOR





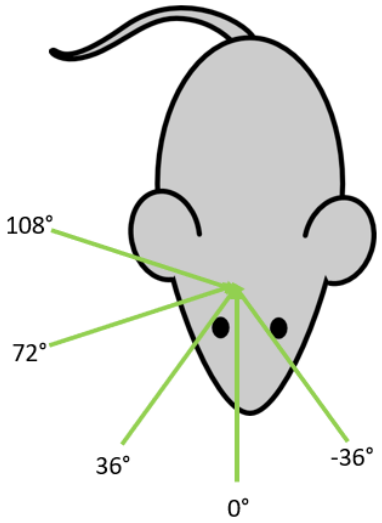
Juxtaposition of 9 x 17-strip diamond detectors:
150 μm thick monocrystalline diamond substrate

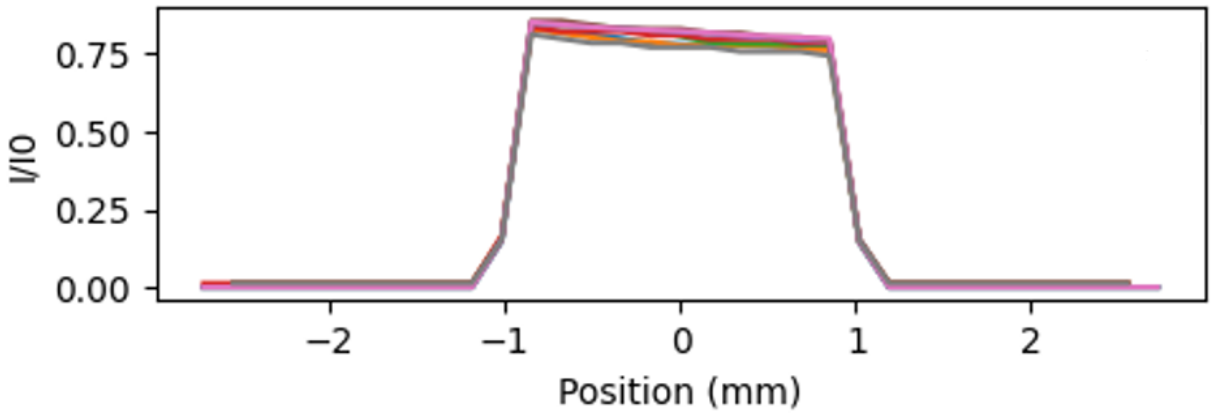
153-STRIP DETECTOR RESPONSE

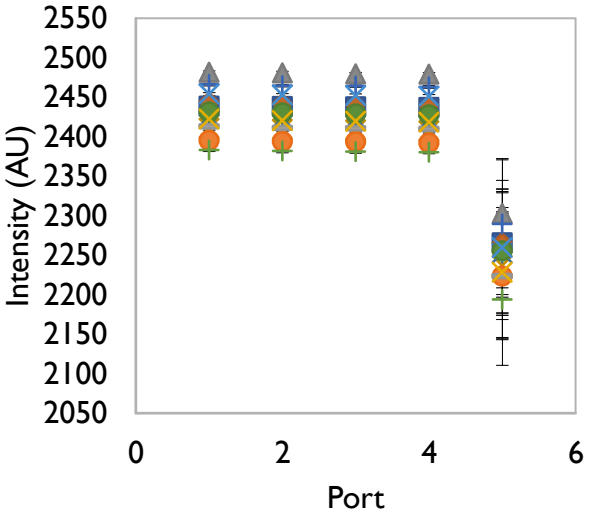


MONITORING FOR PRECLINICAL AND VETERINARY TRIALS (MRT) (M1 INTERNSHIP EIMEAR FINNEMORE)

Treatment of drug-resistant epilepsy in mice (Grenoble Institute of Neurosciences)

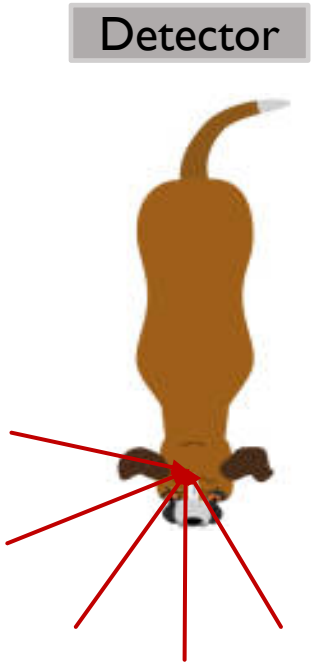


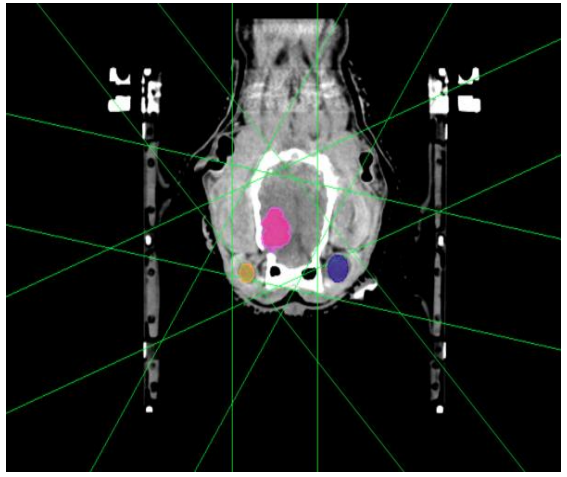




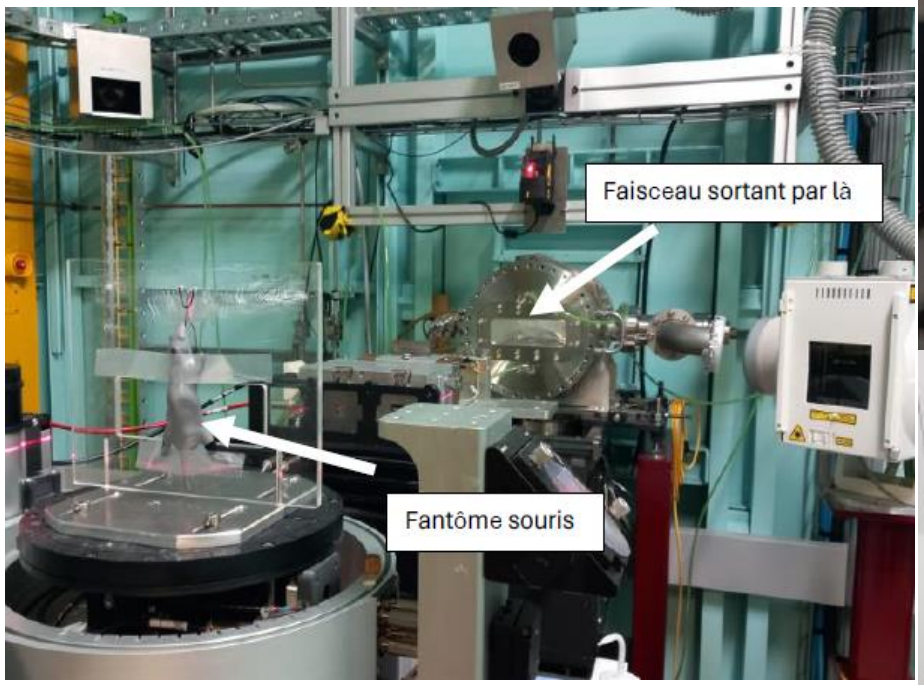
MONITORING FOR PRECLINICAL AND VETERINARY TRIALS (MRT) (PHD CANDICE MILEWSKI)

Treatment of brain tumours in pet dogs (STROBE & ESRF)





Treatment of mammary tumours in mice (Australia)



CONCLUSIONS

- Dose rate linearity over 1 – 10^4 Gy/s
- Homogeneous strip response with no charge loss
- Values of μ measured from transmitted beam in good agreement with theoretical values

Next steps:

- M1 internship Eimear Finnemore:
  - Analysis of preclinical trial data
- PhD project Candice Milewski:
  - Analysis of preclinical and veterinary trial data
  - Full characterisation of 153-strip detector at IMBL, Australian Synchrotron
  - Development of an upstream detector and dose reconstruction method