University of BRISTOL

100 1920-2020

Swansea University Prifysgol Abertawe

Dosimetry and Verification of Intensity Modulated Radiotherapy: Monolithic Active Pixel Sensors

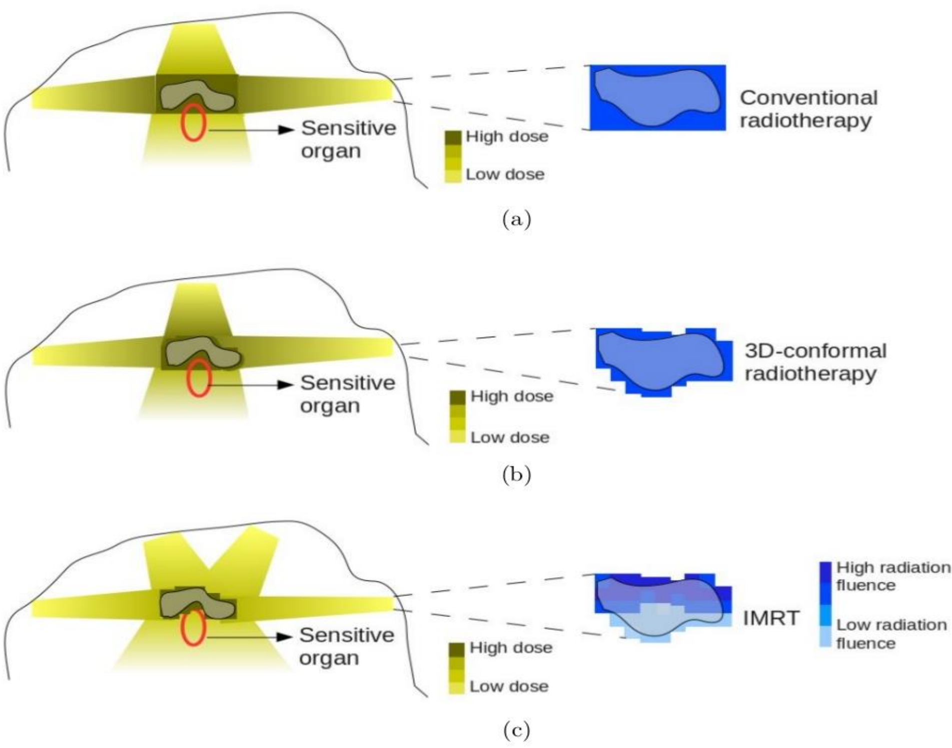
Dr. Lana Beck, Dr. Richard Hugtenburg, Dr. Chiara de Sio, Dr. Jaap Velthuis

Outline

- Intensity Modulated Radiotherapy (IMRT)
- Treatment Verification
- Monolithic Active Pixel Sensors
- Leaf position reconstruction
- Radiation Hardness
- Dosimetry with MAPS
- Current status
- Summary

Intensity Modulated Radiotherapy

- In IMRT X-rays from a LINAC typically using multi-leaf collimators (MLC) to form complex beam shapes of varying intensity
- Unlike conventional and 3D-conformal radiotherapy, standard methods of in-vivo dosimetry don’t work as the beam portal shape is no longer well defined
- Dosimetry methods have been developed that use either pre-treatment or a real-time verification



Treatment verification

- There remains a need for independent verification of RT treatments – which is now mandated in many parts of the world

- Online dosimetry provides verification without pre-treatment measurements
  - Enhances safety
  - Relaxes demand on the accelerator

- Online systems measure two things:

- The collimator positions
- The photon fluence profile

Radiation Offers New Cures, and Ways to Do Harm – NY Times

Published: January 22, 2010

Fatal Radiation

Software problems and poor quality control at St. Vincent's Hospital cause a fatal overdose.

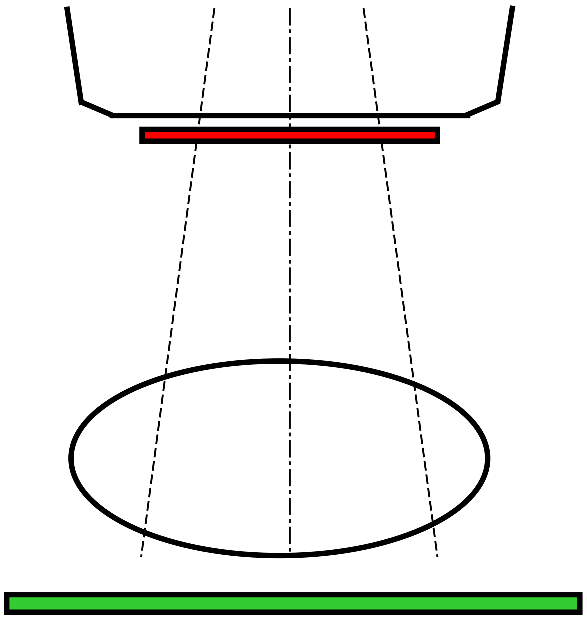
1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | NEXT

March 16, 2005
Mr. Jerome-Parks's medical physicist ran a series of tests on the equipment. All of them showed that the collimator was wide open, and the hospital realized that a serious overdose of radiation had been administered.

February 2007
After two years of declining health, including loss of sight, hearing and balance, Mr. Jerome-Parks, 43, died of his radiation injuries.

Online Verification of IMRT treatments

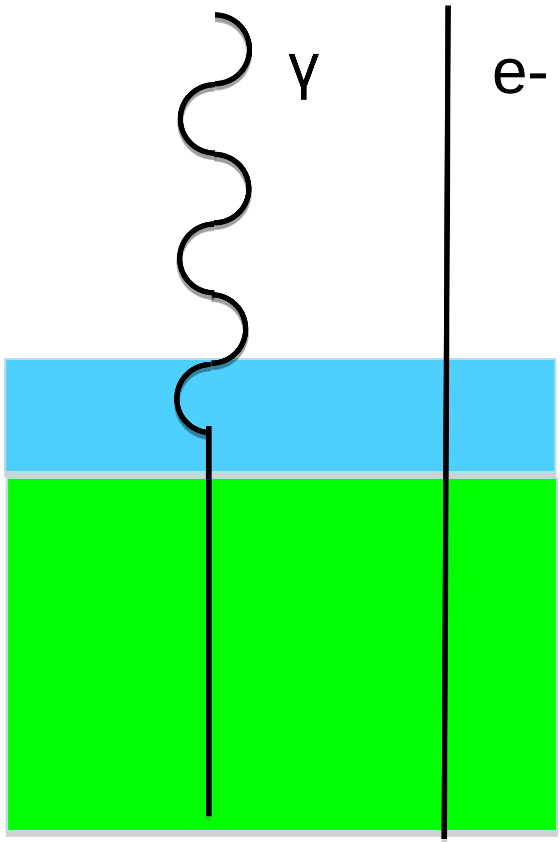
- Can be done in two ways:
  - Upstream, i.e. transmission dosimetry
  - Downstream i.e. EPID dosimetry



- EPID dosimetry is difficult due to non-uniform and varying interactions in the patient
- Transmission dosimetry systems need to be thin to reduce scattering and attenuation of the beam
- The challenge with the latter is then the separation of the photon fluence from other beam components/ contaminants

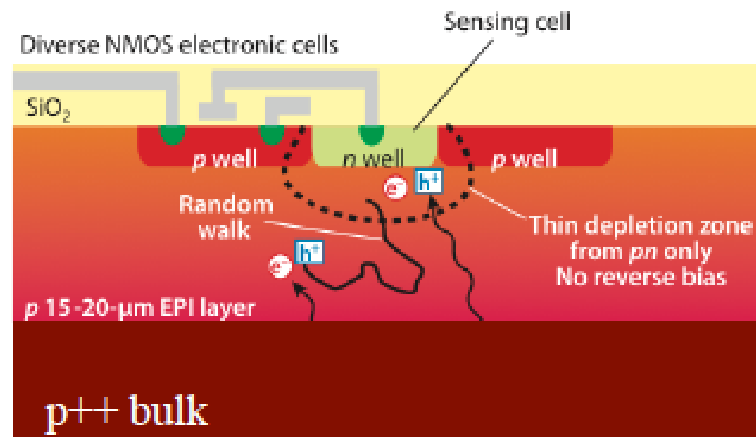
Electron-photon separation

- The beam consists of therapeutic photons and contaminant electrons/ positrons
- Current up-stream detector systems use a thick layer to convert photons into the charge particles that are detected
- The number of photons detected needs to significantly outnumber the contaminant particles
- A converter increases the thickness of the device and disturbs the beam



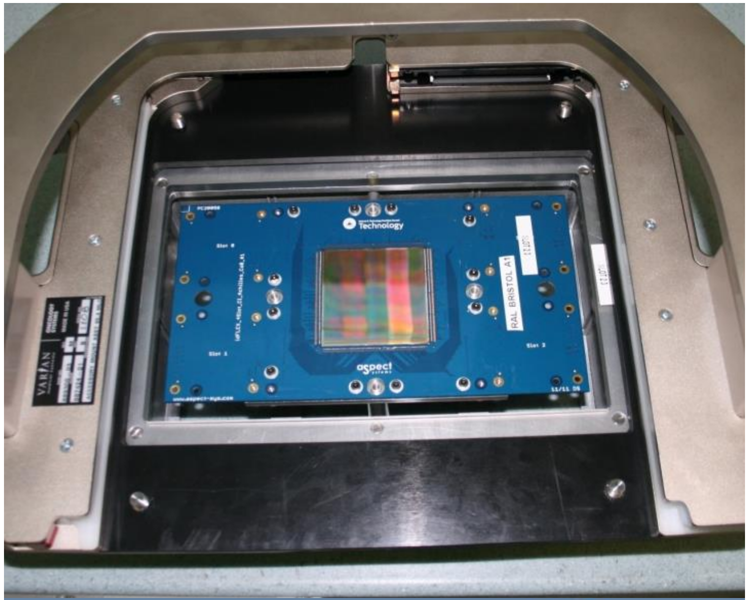
Monolithic Active Pixel Sensors

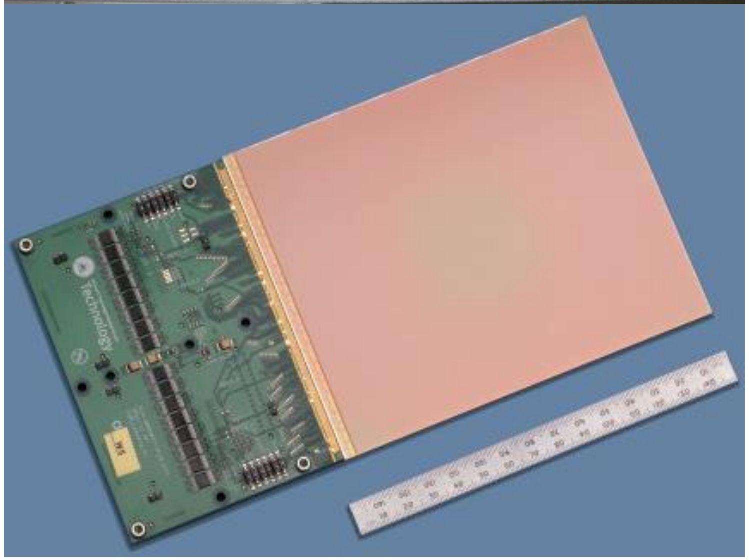
- MAPS are ideal for upstream monitoring: Thin, have small pixels, and are fast and cheap
- Signal generation is in a thin epitaxial layer (<20μm)
- Bulk is for mechanical support: 30 μm thick detectors are easily constructed < 0.1 % attenuation for 6 MV photons
- Each pixel has in-pixel amplification with high S/N and a fast readout process



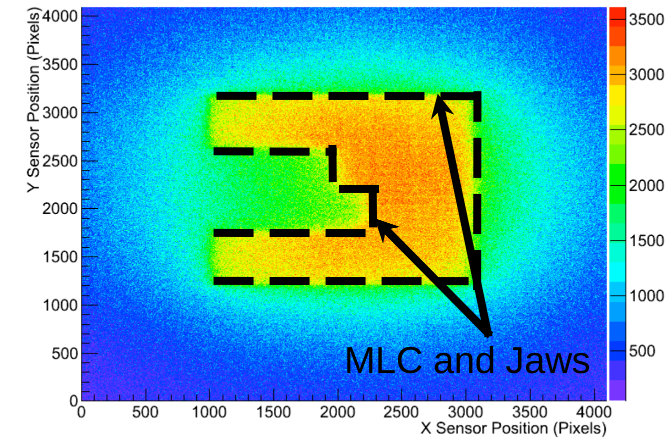
Prototypes

- Achilles (STFC developed)
  - 6x6 cm sensor
  - 14 µm thick epitaxial layer
  - 3T pixel architecture with 14 µm pitch
- LASSENA
  - 12 × 14.5 cm sensor
  - 3-side buttable: allows 2 × N tiling
  - 50 µm pitch
  - 32 analogue outputs operating at 10 Mpixel/sec = 34 fps

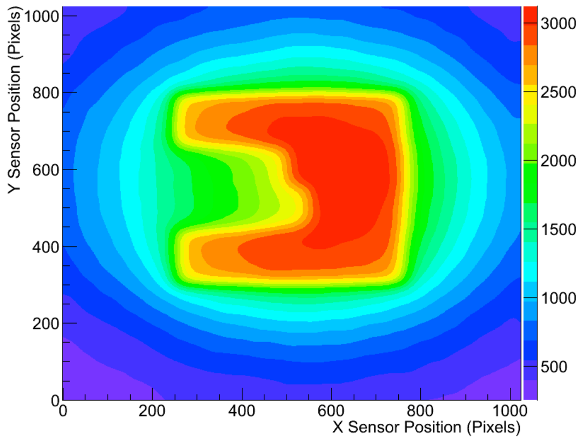




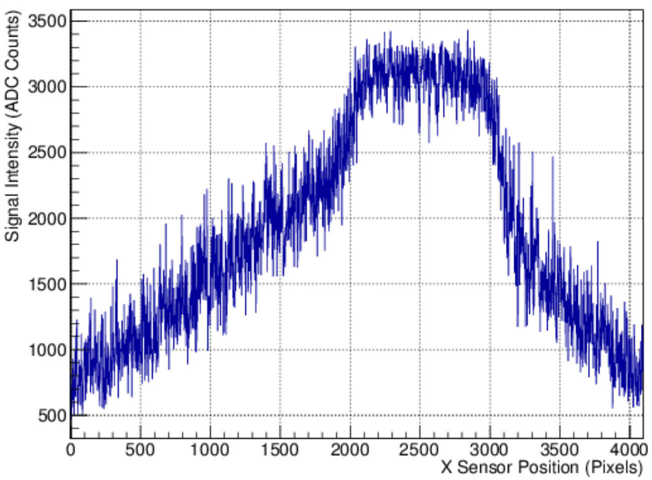
MLC leaf-finding

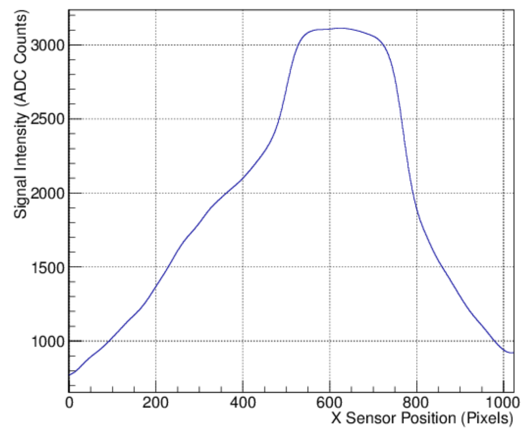


4096 x 4096 acquisition

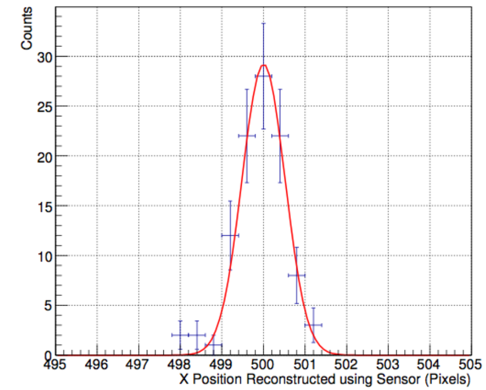


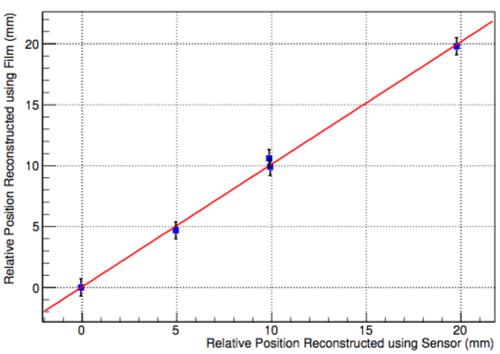
1024 x 1024 Gaussian smoothing with a 15 pixel radius kernel





Exceptional precision is obtained. 52 ± 4 μm in a single frame



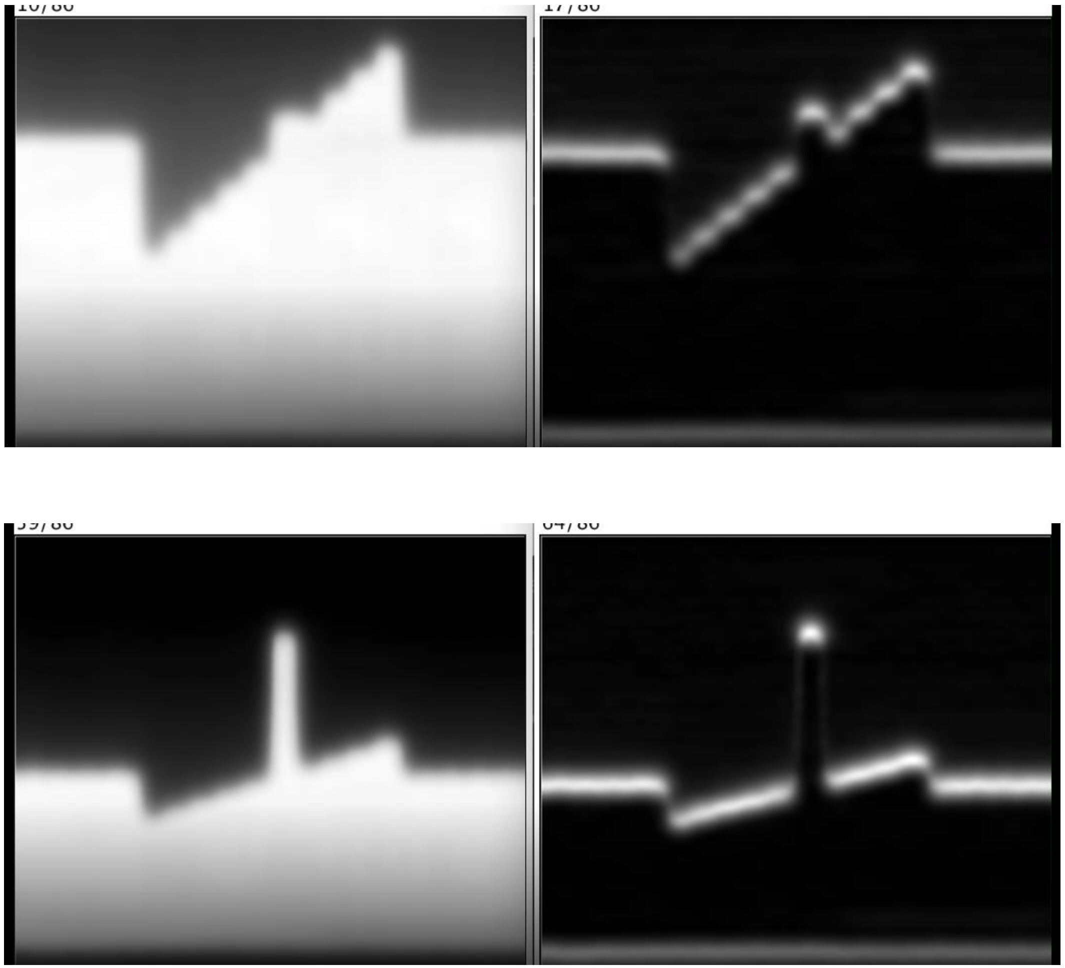


University of BRISTOL

1920–2020

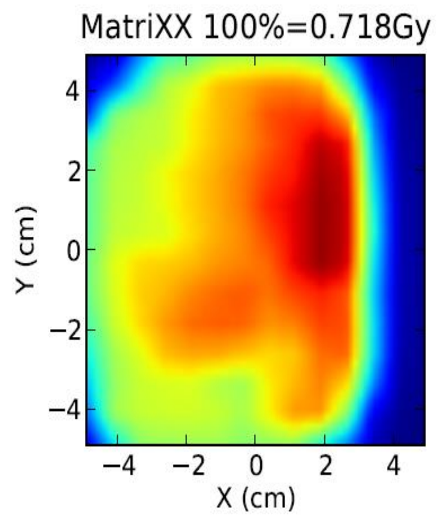
Swansea University Prifysgol Abertawe

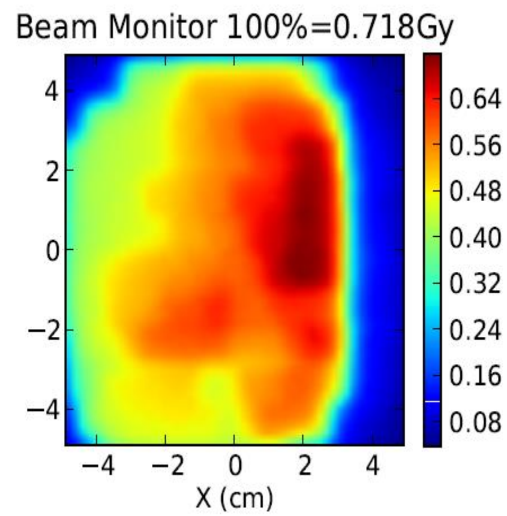
Video demonstration of leaf edge finding

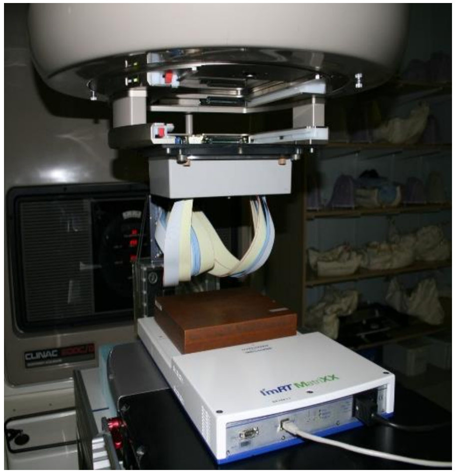


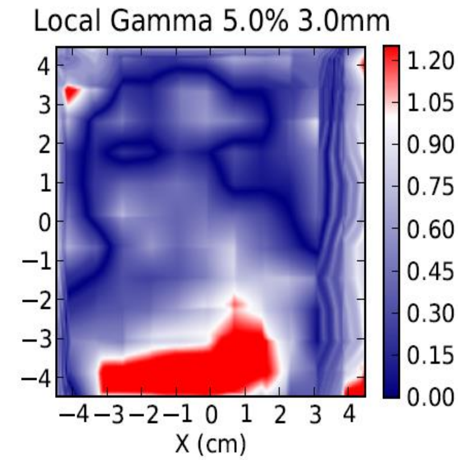
Dosimetry with a MAPS

- A conversion layer is used to convert photons into electrons
- We have shown that acceptable accuracy can be achieved for small fields with a thin layer of plastic achieving 5% precision and 1% attenuation
- Better precision can be achieved with a more adventurous converter designs.







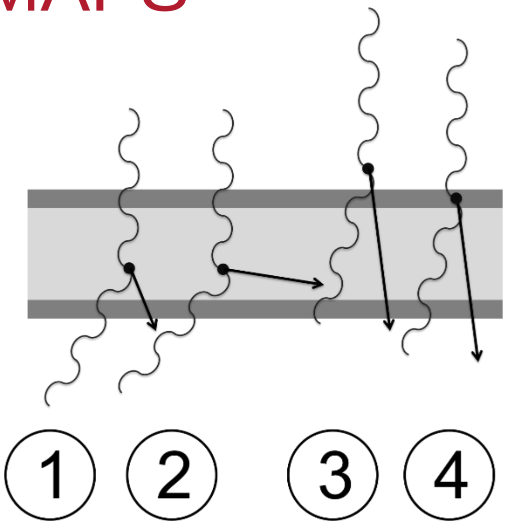


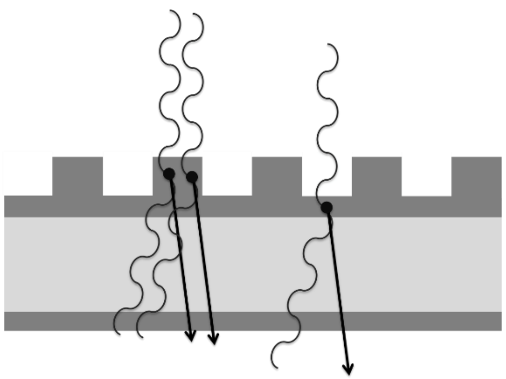
University of BRISTOL

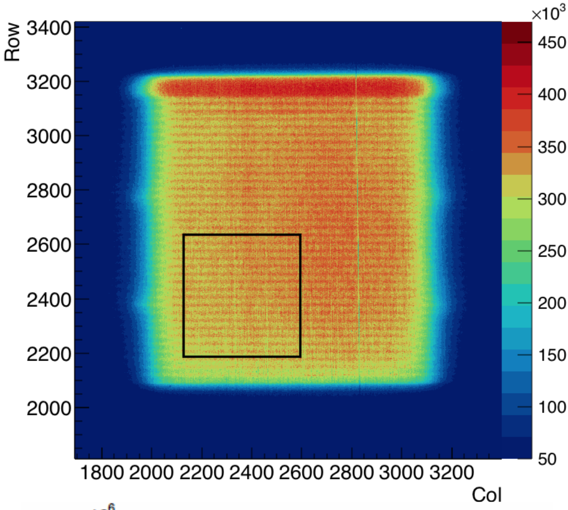
100 1920-2020 Swansea University Prifysgol Abertawe

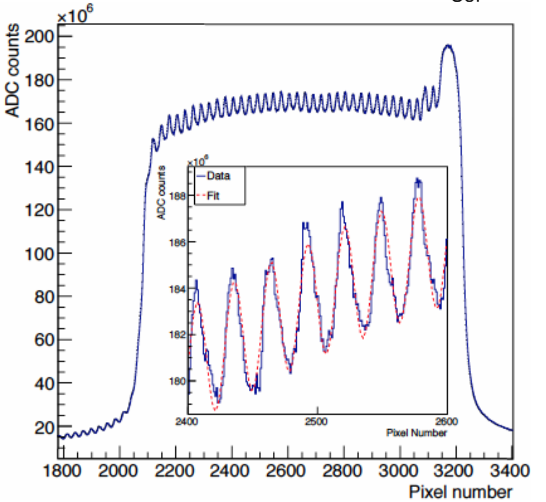
Dosimetry with a MAPS

- There are are four signal generating processes
- Modulate of process 4 can be achieved by changing the amount of material upstream of the sensitive layer
- A modulation pattern can be etched in the silicon bulk on the under-side of the detector





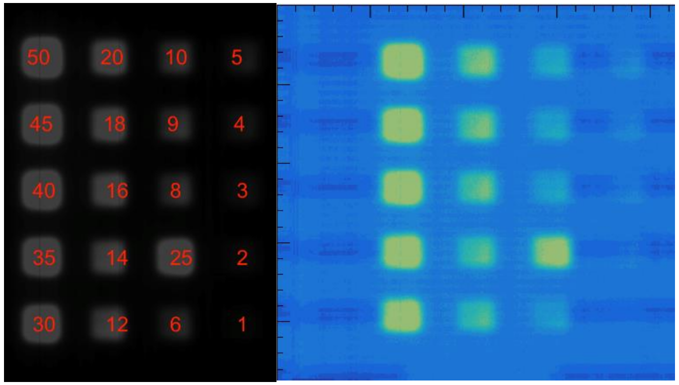


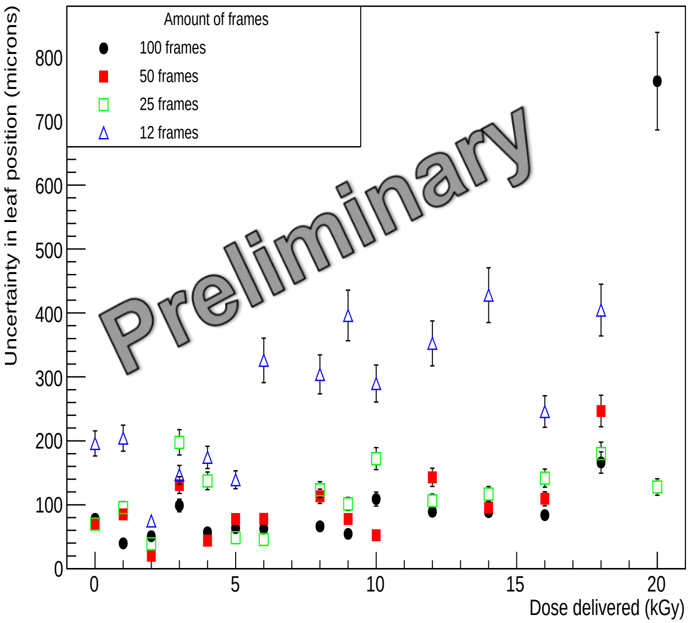


Radiation damage

- Fractions are typically 3 Gy
- One machine delivers ~10,000 treatments per year
- Only 10% of the dose is absorbed in the panel, so around 3 kGy per annum

- Sensor was damaged with a variety of doses of protons ranging from 1-50 kGy [needed to achieve this dose range, representing a worst-case scenario
- After 50 kGy no significant signs of degradation to logic and leaf finding
- Will survive long term clinical operation.





Current status

- A patent for transmission dosimetry using MAPS has been granted in the US and Europe
- Have recently applied for second patent for dosimetry
- Working with 2 industrial partners to get the device on the market.
- Currently building a full-size prototype.
- Team received STFC IPS funding until 31/10/2020
  - Will focus on testing sensor with higher dynamic range
  - Optimization of the converter layer

- The system could monitor the health of the accelerator and collimator systems and through collection at a central data-point assist in machine learning to improve accelerator performance and up-time.

Summary

- We have developed a real-time, thin, upstream beam profile and dose verification device
  - Patent granted in US and Europe
  - Excellent leaf position resolution.
  - Dosimetry is achieved in a thin form-factor using a silicon converter grating
  - Currently building a full size prototype.

- The device can verify treatment in real-time WITHOUT need for prior measurements
  - Enhances safety
  - Relaxes demands on the accelerator