Upstream Dosimetry using a Monolithic Active Pixel Sensor (MAPS)

Ryan Page[1], J. J. Velthuis[1,3], S. Blake[3], S. Fletcher[3], S. D. Gregory[3], A. John[3], P. H. Stevens[3], R. P. Hugtenburg[2].

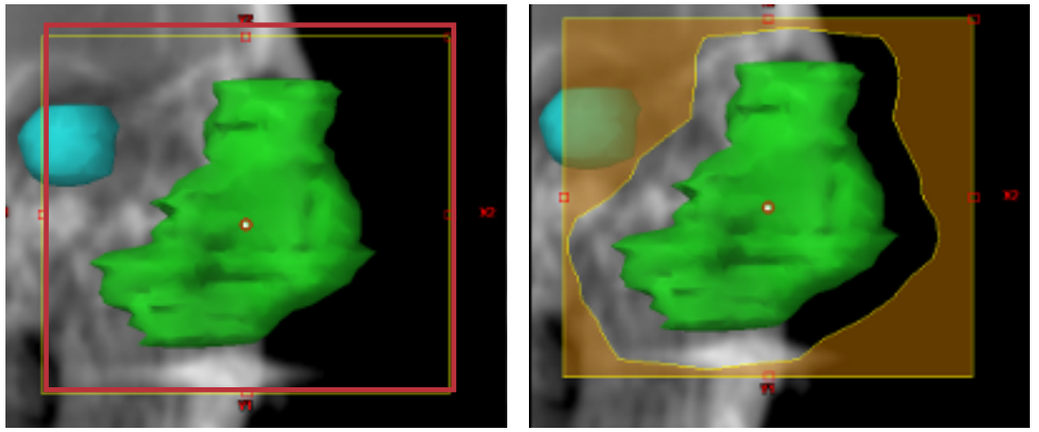
The University of Bristol[1],
Swansea University[2],
Bristol Haematology and Oncology Centre, University Hospitals Bristol, NHS Foundation Trust[3].

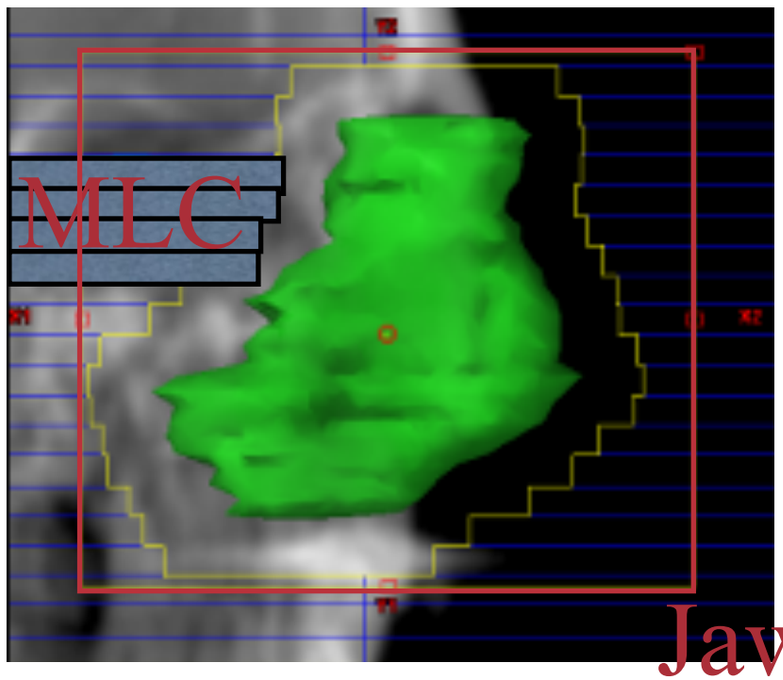
Overview

- Radiotherapy.
- Motivation for online monitoring and verification.
- Current upstream system.
- Multi Leaf collimator edge reconstruction.
- Upstream dosimetry.
- Conclusion.

Radiotherapy

- Important treatment for patients with cancer - used in 40% of curative cases.
- Uses MeV X-rays to kill tumour cells.
- Intensity Modulated Radiotherapy uses Multi Leaf Collimators (MLC) to conform dose to the tumour.
- Spares the healthy tissue.

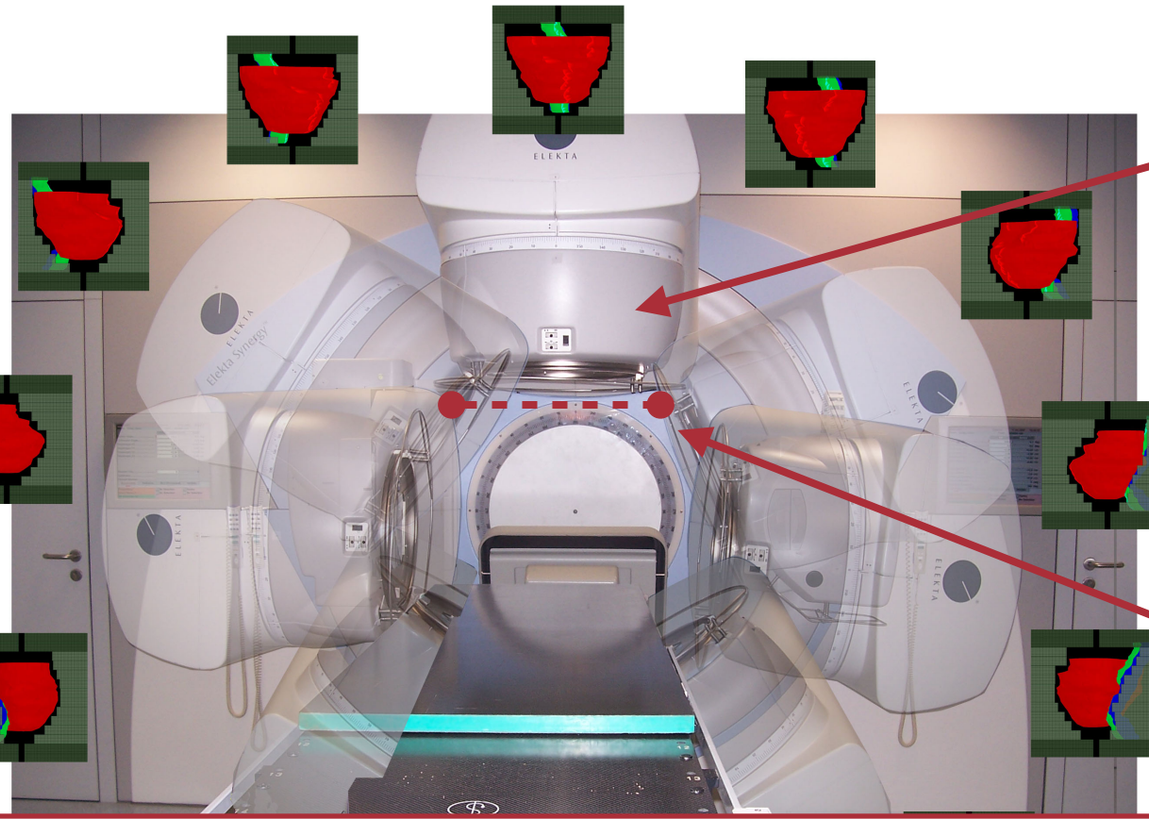




Intensity Modulated Radiotherapy

Multi Leaf Collimators

Linac - X-ray source



Multiple field configurations.

Upstream camera

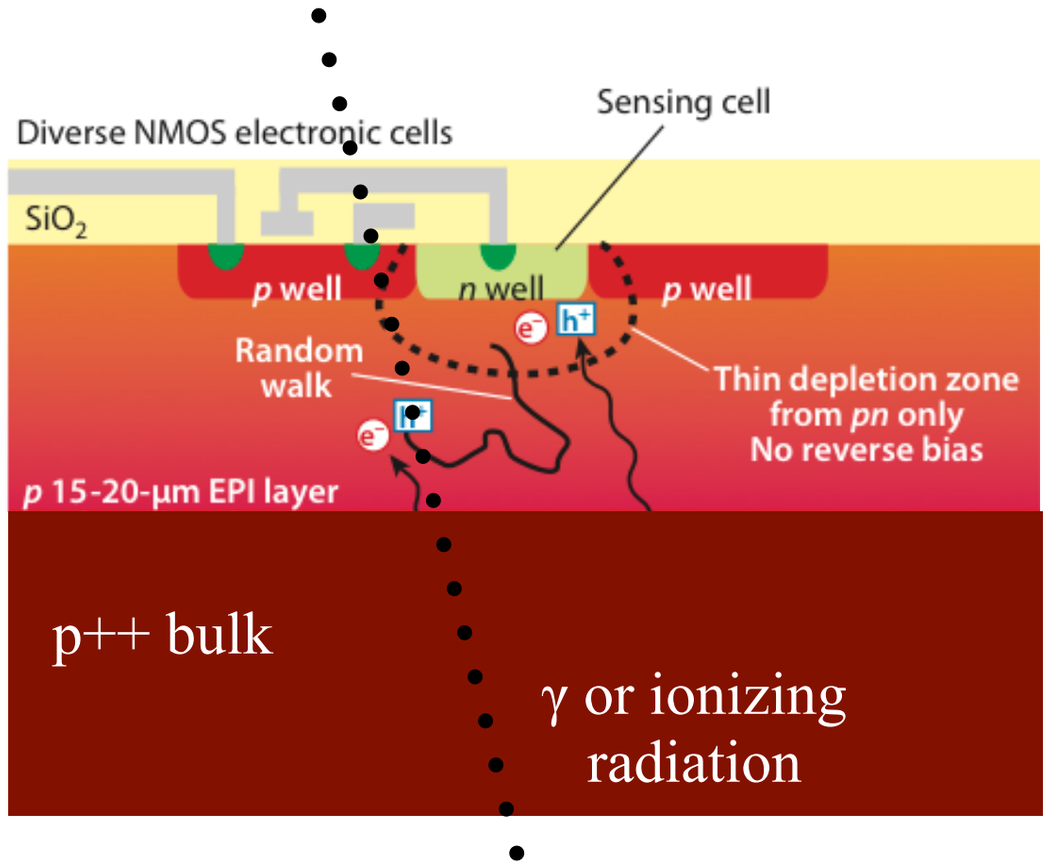
Measure: Dose and Collimator Positions.

Motivation for Online Monitoring

- Safety: Treatments are complex - Chief Medical Officer in the UK endorsed report calling for independent monitoring of IMRT.
- AIM: In case of gross error stop treatment.
- Time: Increase patient through put through use of online verification - National UK Cancer Action Team strategy is to aim for 30% of radiotherapy courses to use IMRT by 2012.
- AIM: Increase efficiency up from the order few %.

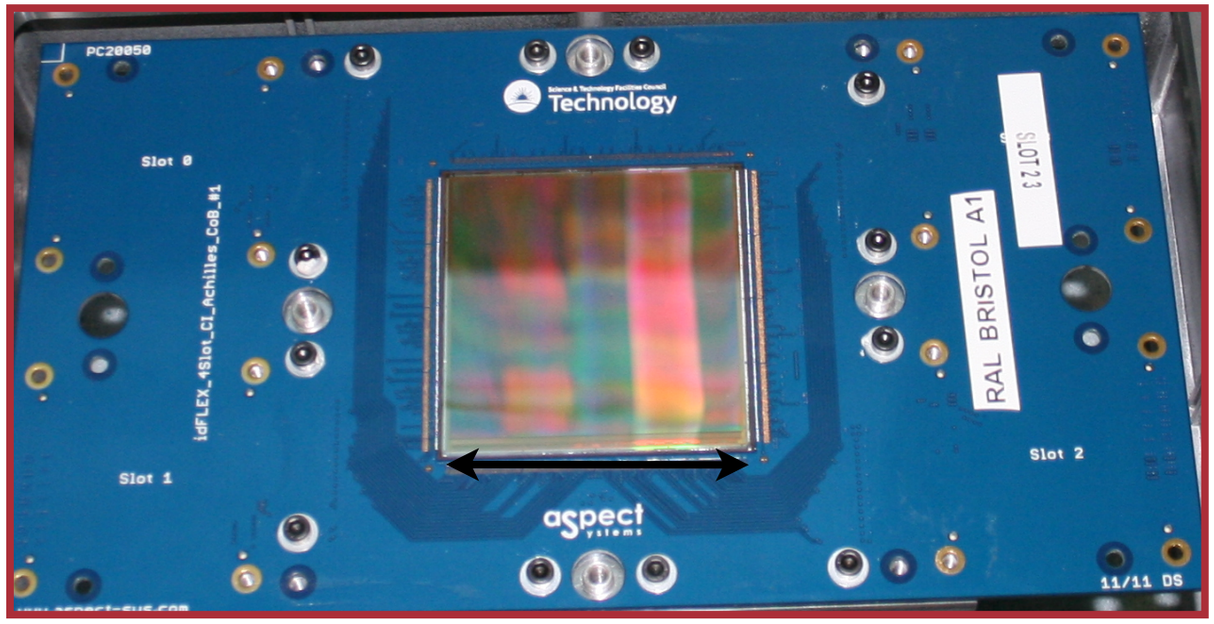
Rationale for MAPS

- Attributes:
  - Fast ⇒ Treatment time feedback.
  - Good S/N ⇒ Precise monitoring.
  - Thin ⇒ Low attenuation of therapeutic photons.



ACHILLES Sensor

- Thickness 100µm - 0.1 % attenuation for 2 MeV photons.
- 14µm epitaxial layer.
- 4096 x 4096 pixels.
- 3T pixels 14.5µm pitch.
- S/N for Fe^{55} ~16.
- 40 fps - Fast Readout.

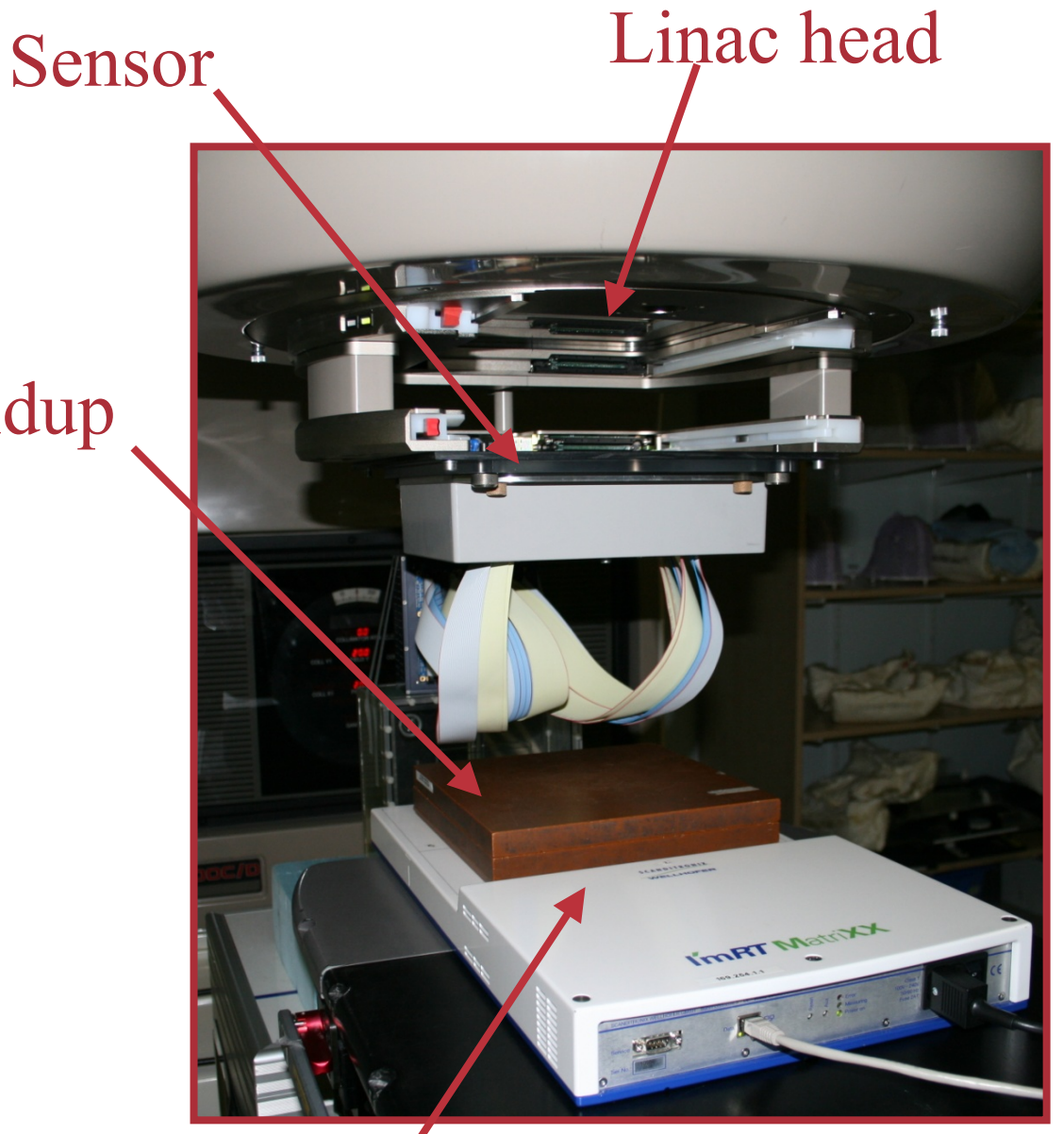


~ 6cm

N. Guerrini, R. Turchetta, and et al.
A High Frame Rate 16 million pixels radiation hard CMOS sensor.
Journal of Instrumentation, Volume 6, March 2011.
Previously presented at IWORID, 11-15th July 2010.

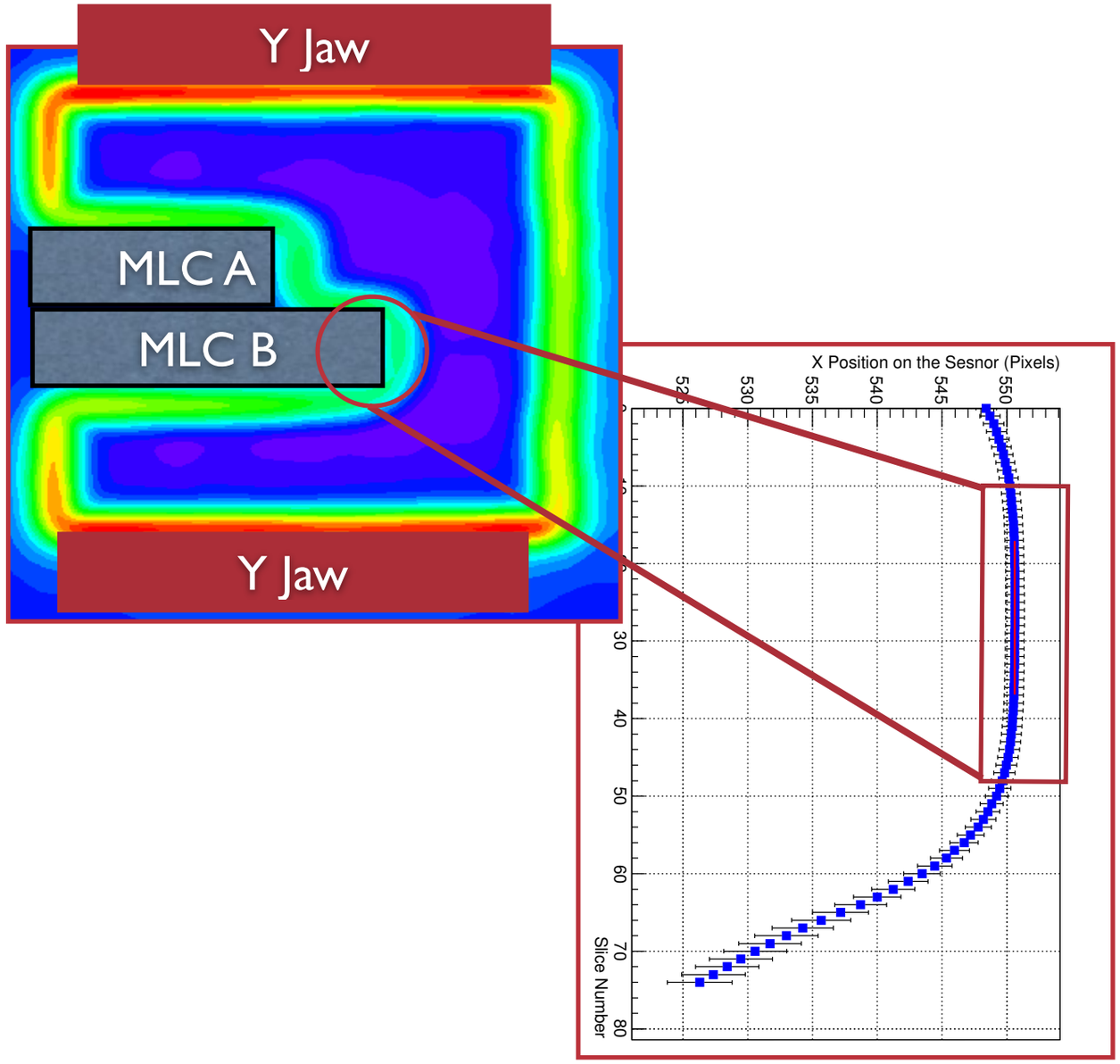
Current Upstream System

- Radiochromic film / MatriXX placed at 100cm from source (isocentre) with 5 cm of build up.
- Operational Settings:
  - Specific MLC fields used to allow field reconstruction to be tested.
  - Linac operated at nominal working conditions of 400 MU/min (Pulse Repetition Frequency ~ 400Hz).
  - Sensor running at 10 fps.



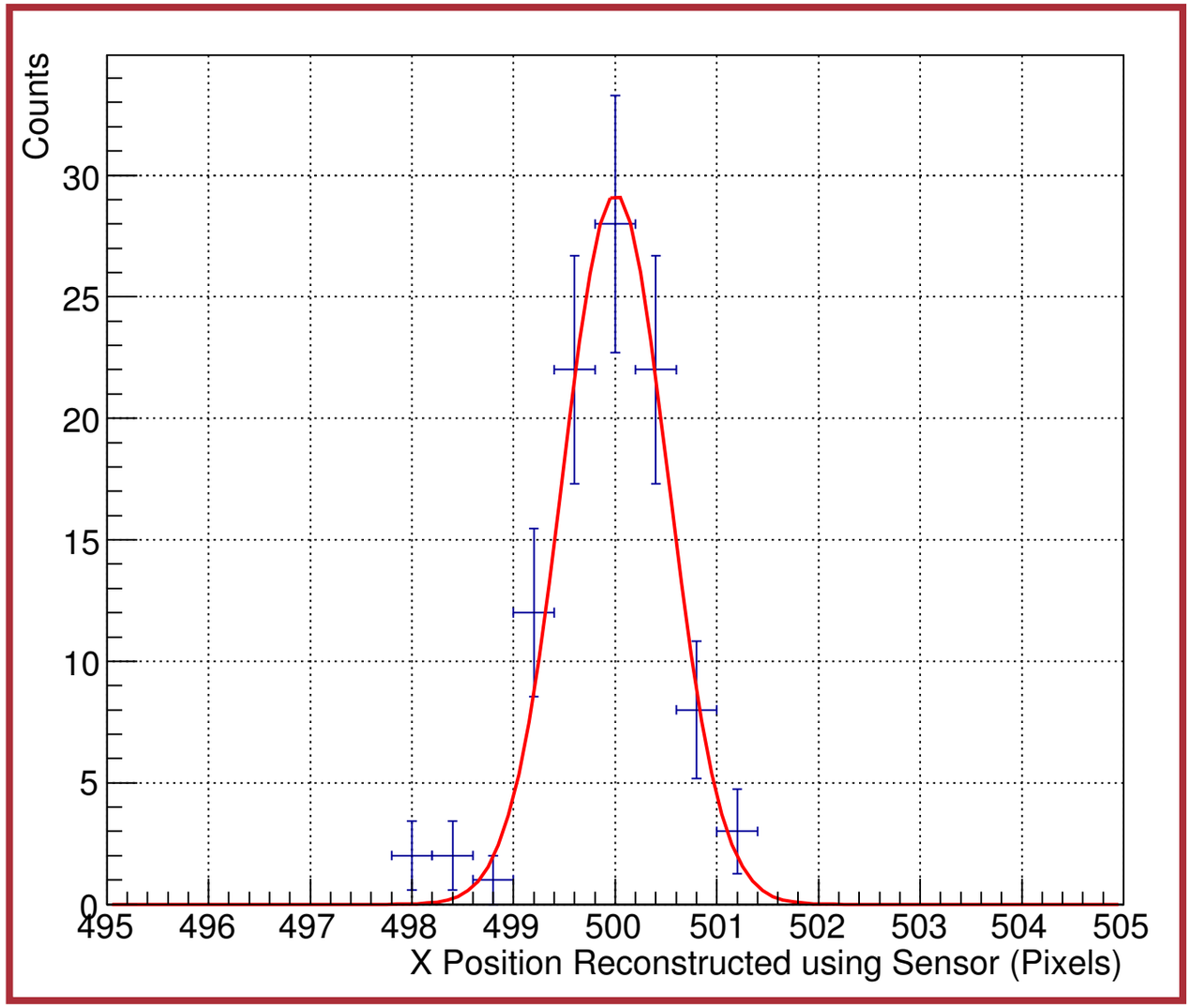
Leaf Edge Reconstruction

- Image Processing:
  - Resize image to 1024 x 1024, Smooth image with gaussian kernel, convolute with Sobel gradient kernel.
  - Combine images using the magnitude.
  - Use points with minimum change along contour to define leaf position.



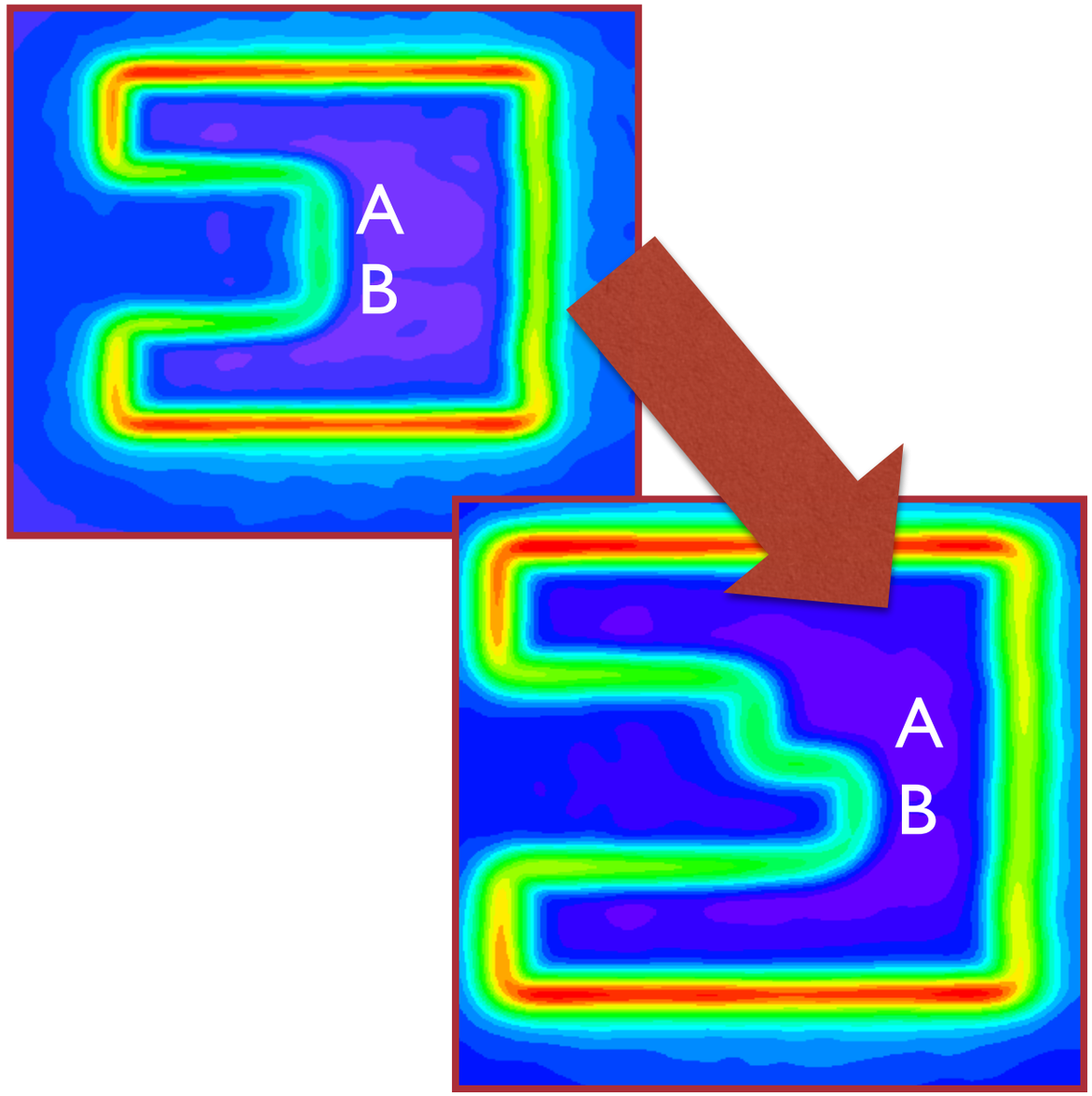
Leaf Reconstruction Precision

- Quantise the precision of reconstruction using the distribution for 100 single frames.
- Results in precision at the iso-centre of **52 ± 4 µm** and **6 µm for 10 seconds** of data.



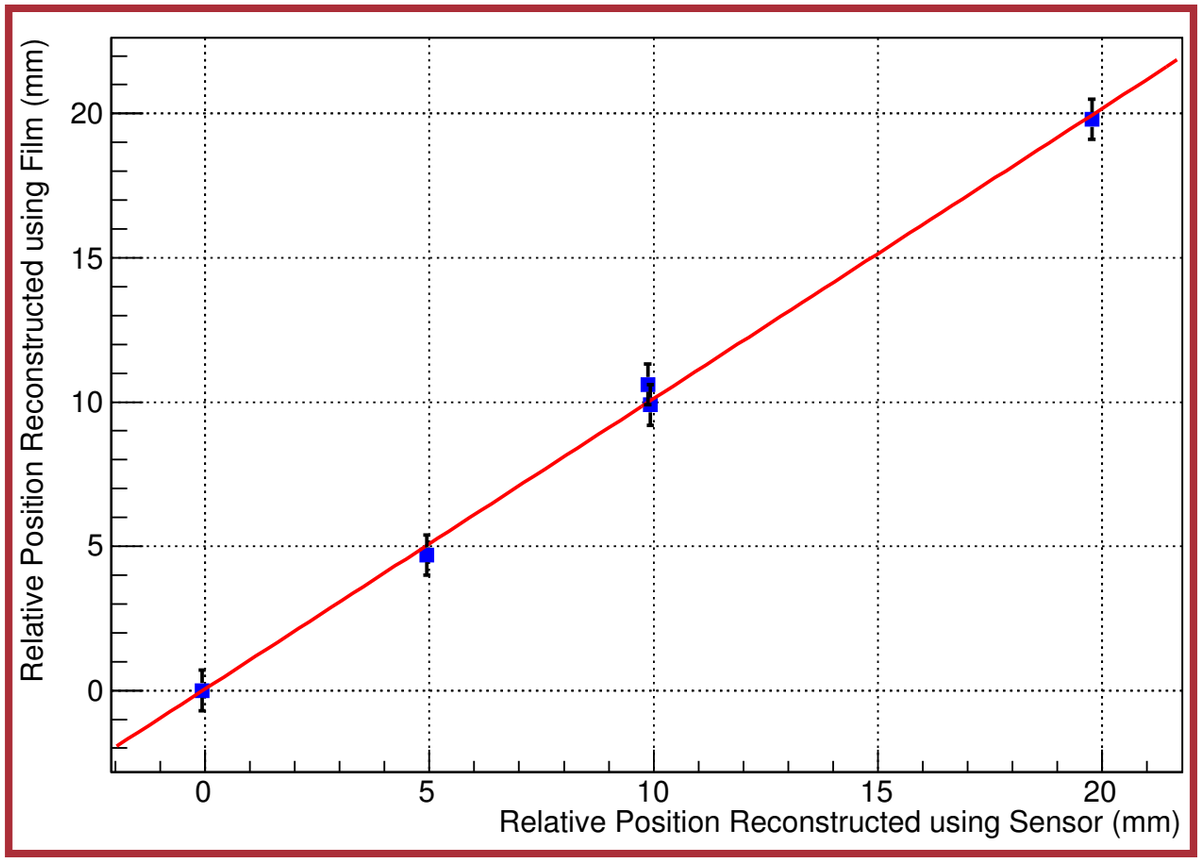
Leaf Reconstruction Accuracy

- Analysed accuracy using radiochromic film as a benchmark.
- Test: Move MLC B with respect to MLC A and reconstruct difference.
- Compare reconstructed difference with film measurement.



Leaf Reconstruction Accuracy

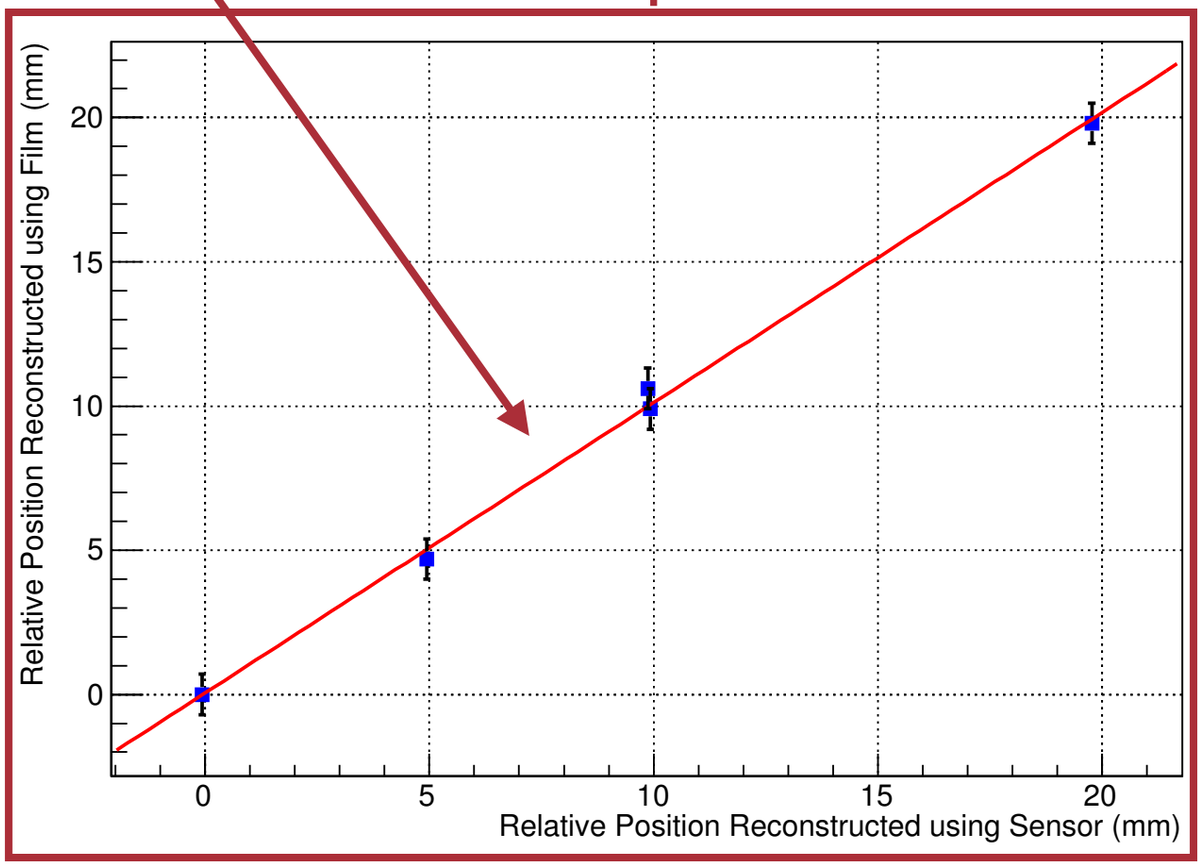
- Analysed accuracy using radiochromic film as a benchmark.
- Test: Move MLC B with respect to MLC A and reconstruct difference.
- Compare reconstructed difference with film measurement.



Leaf Reconstruction Accuracy

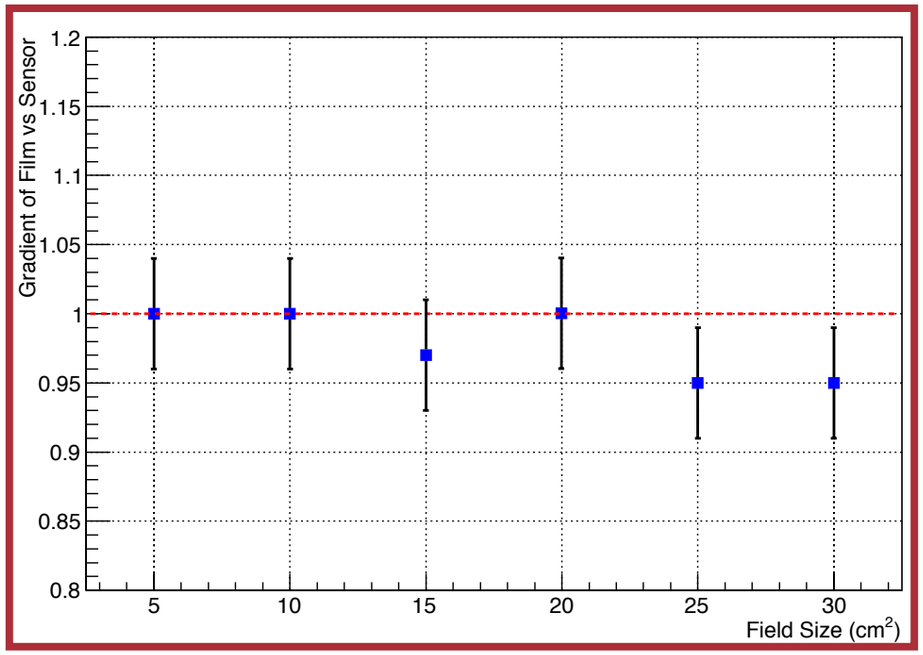
- Analysed accuracy using radiochromic film as a benchmark.
- Test: Move MLC B with respect to MLC A and reconstruct difference.
- Compare reconstructed difference with film measurement.

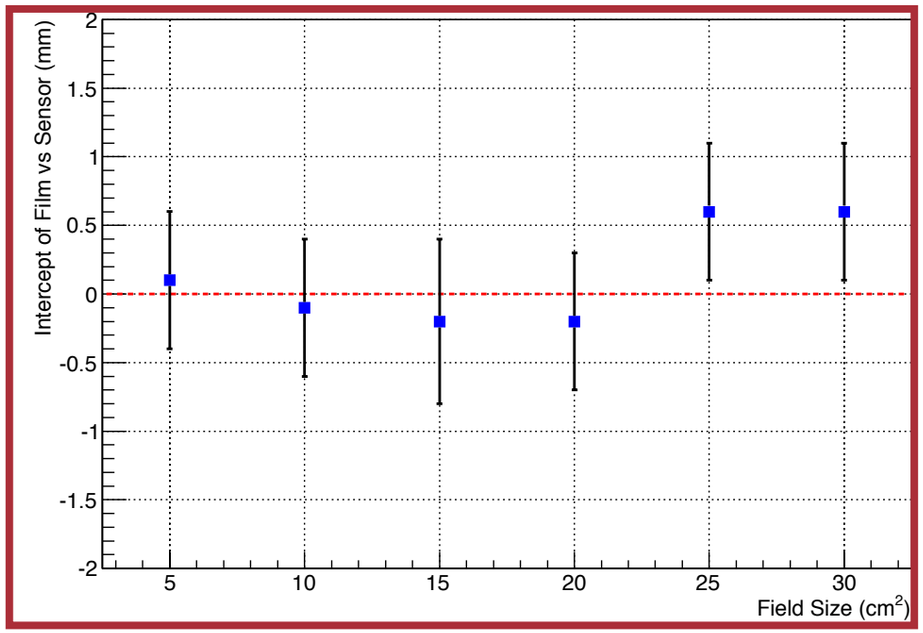
Expect linear relationship with gradient of 1 and intercept of 0



Leaf Reconstruction Accuracy

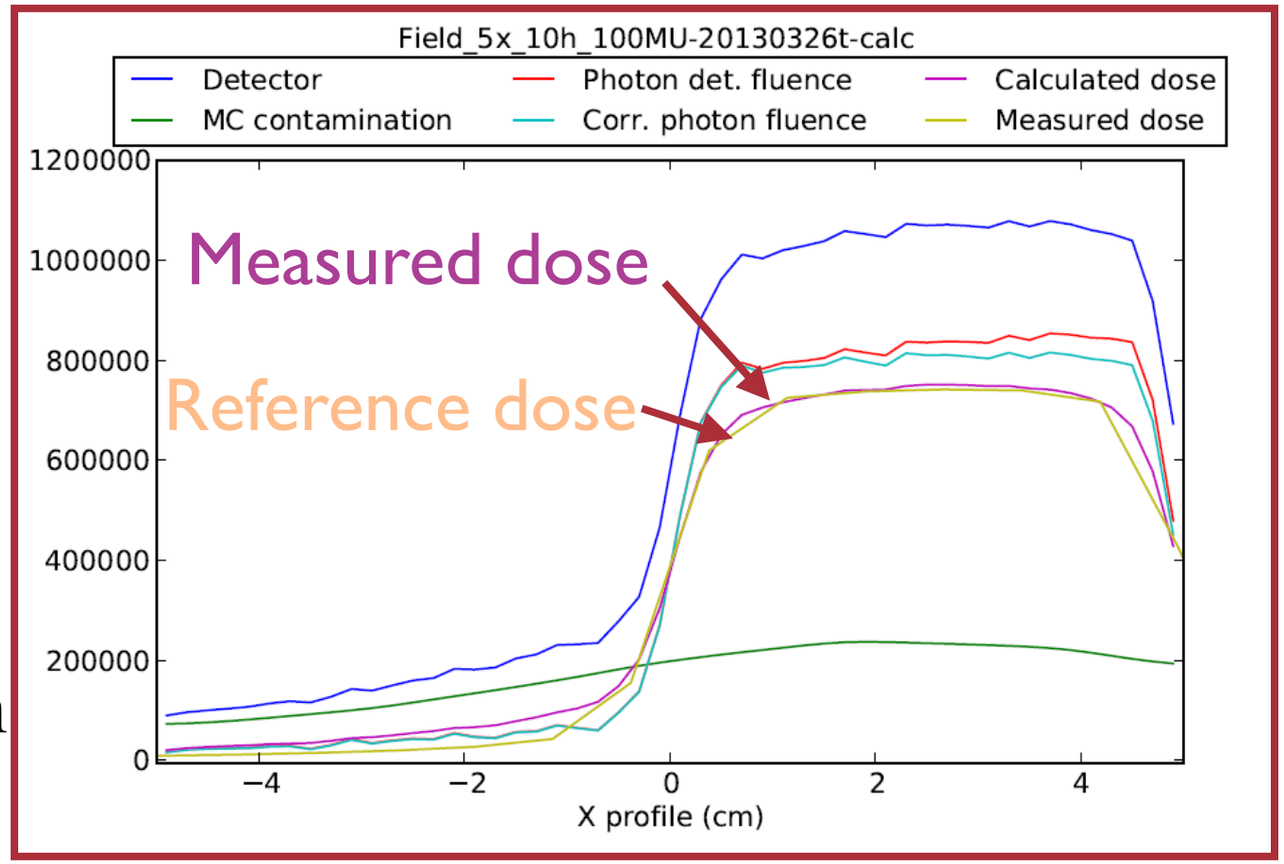
- Carried out test for six square fields.
- Excellent linearity - all measurements within 0.05 of 1.
- Method independent of field size and does not require MC modelling.





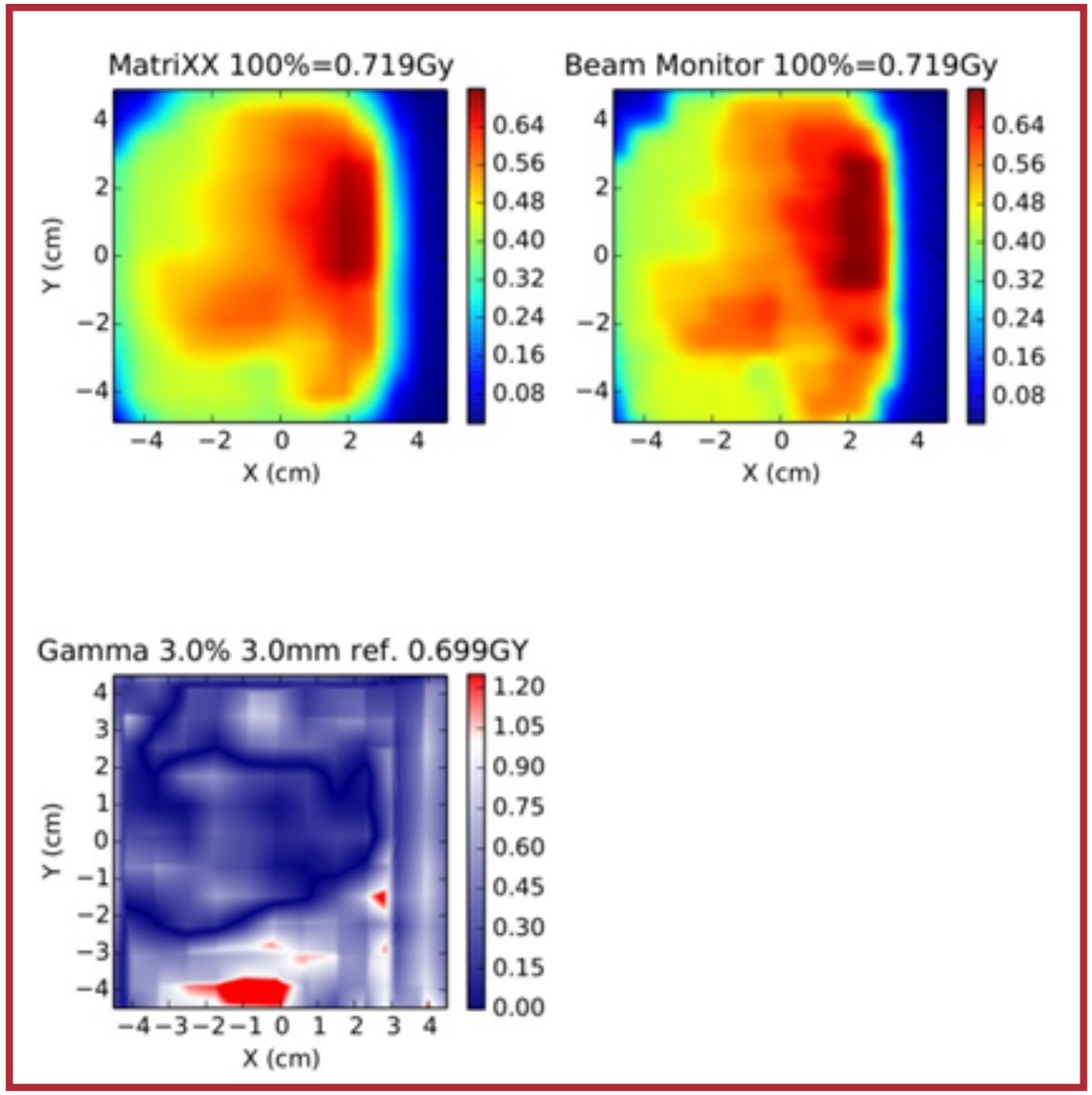
Upstream Dosimetry

- Use MC model of linac and detector to convert signal in the detector into photon fluence.
- Use dose kernel to convert from fluence at the detector to dose in the phantom / patient.
- Compare with measured dose from the MatriXX.



Upstream Dosimetry Results

- 2D IMRT distributions reconstructed from sensor and MatriXX.
- Anterior H&N fields compared.
- Gamma Factor -
  - 97% of points ≤ 1 for 3% and 3mm.
  - Excellent agreement.



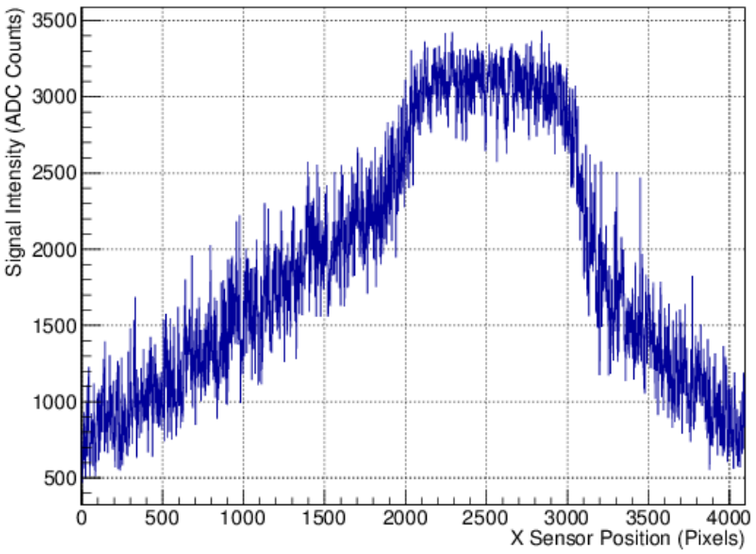
Conclusions

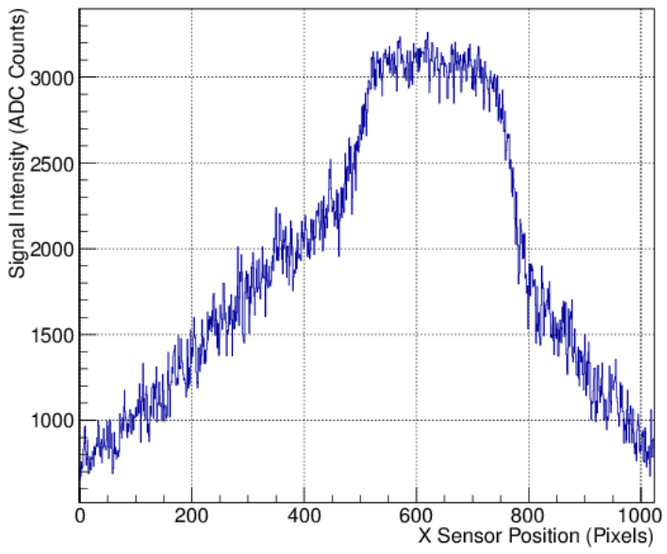
- Demonstrated proof of concept upstream dosimetry system.
- Excellent leaf edge position resolution.
- Verification of IMRT fields demonstrated.
- Going through final round for funding to build a clinical prototype.

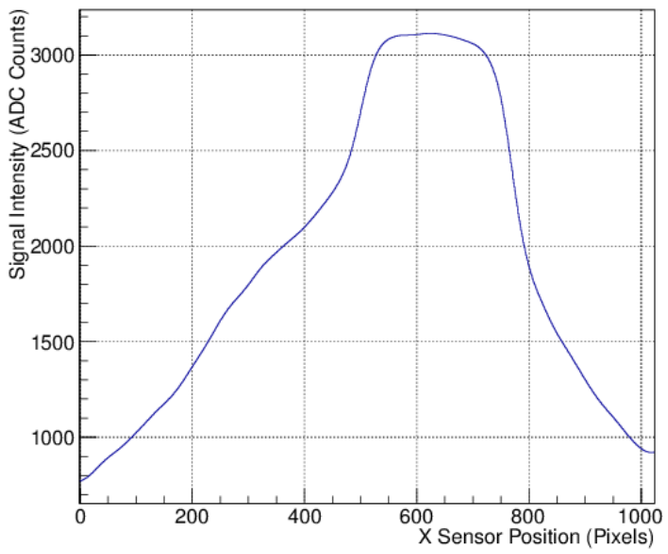
BACK UP

SLIDES

Image Processing







4096 x 4096

MLC and Jaws

1024 x 1024

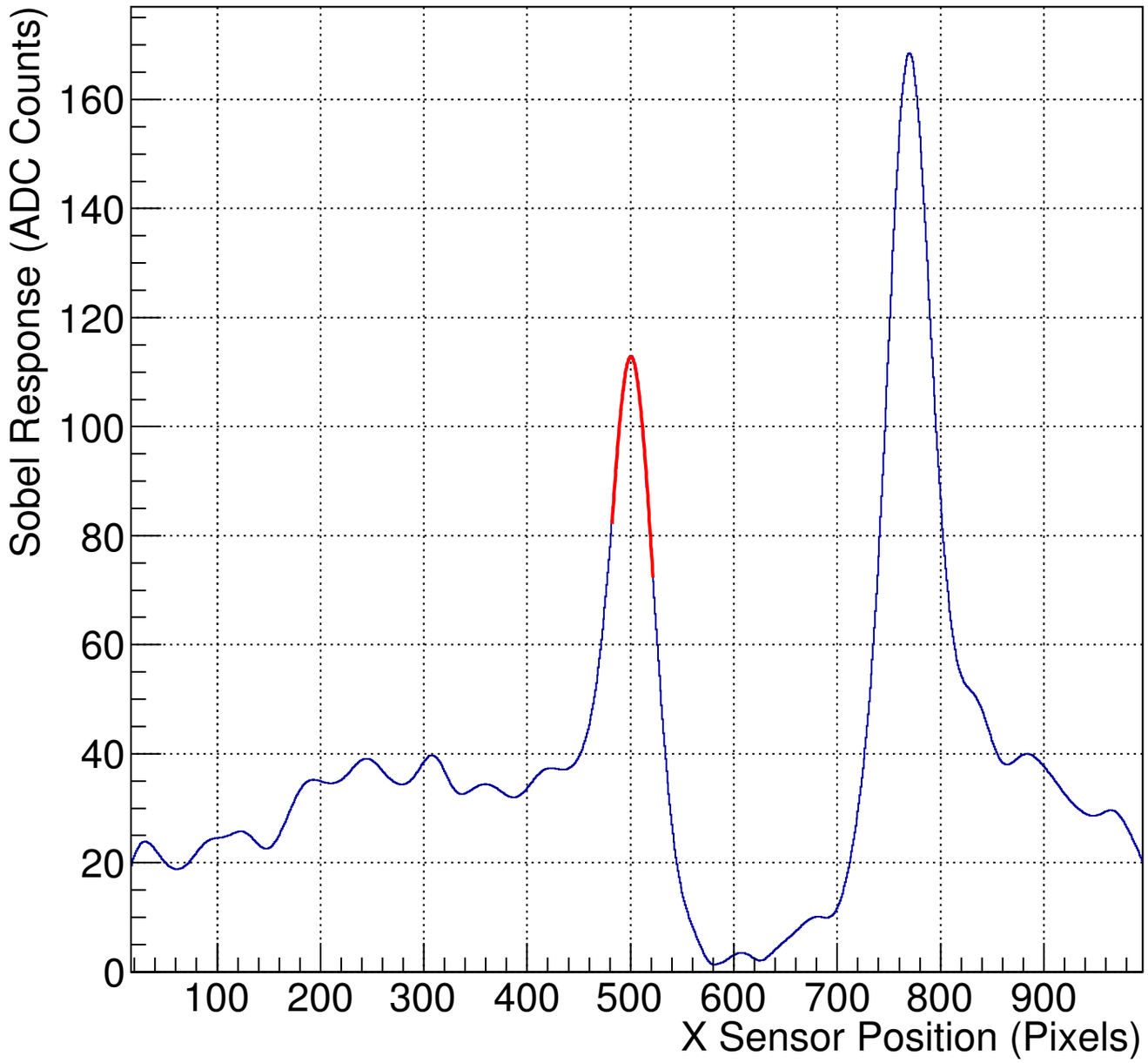
1024 x 1024 post Gaussian smoothing with a 15 pixel radius kernel

Photon Field Reconstruction

- To extract a position from the edge response slices are taken across each leaf pair.

- The peaks in the response are fitted with Gaussian distributions.

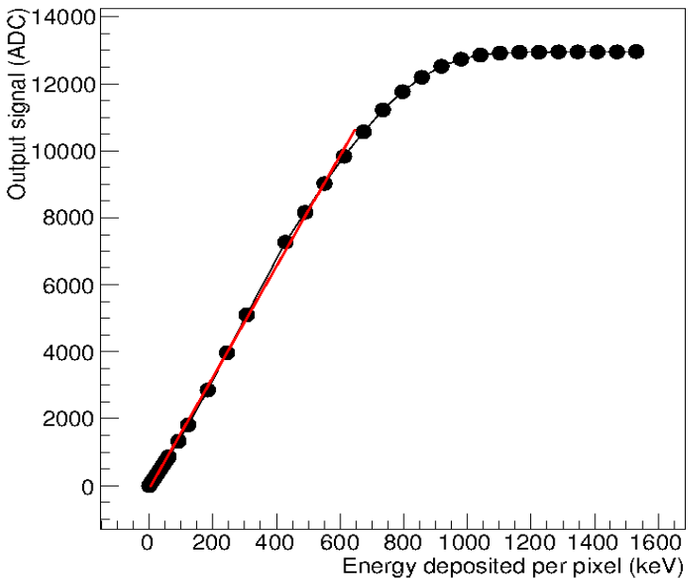
- The mean of the distribution corresponds to a point along a contour of maximal gradient.



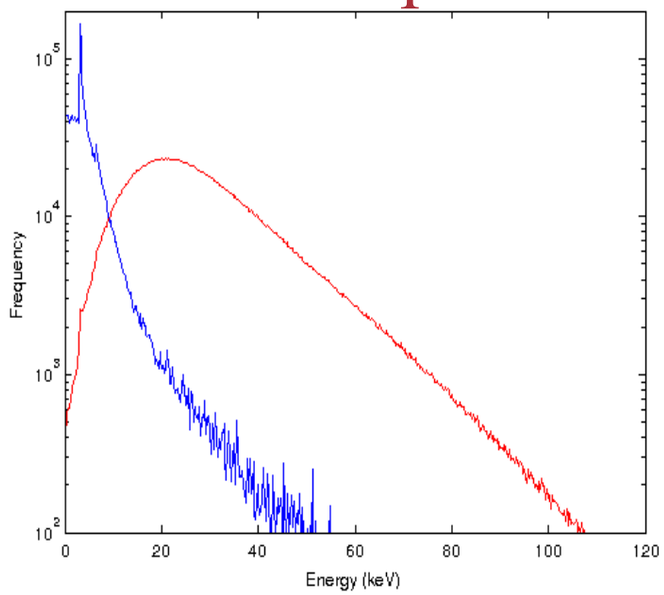
Linearity

- Linearity tested using laser system.
- Energy deposited per pulse and multiple pulses determined using MC.
  - Even for 100 overlapping pulses very few pixels would be in non-linear region.
  - Aim to increase the frame rate.

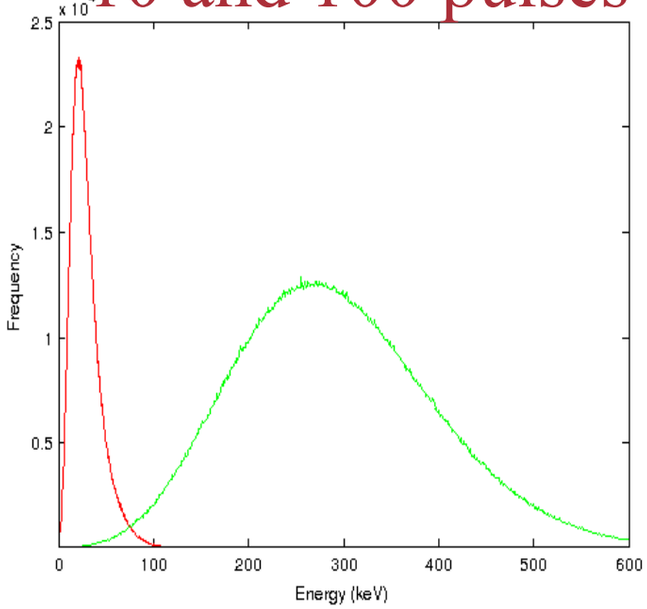
Continuous radiation



1 and 10 pulses

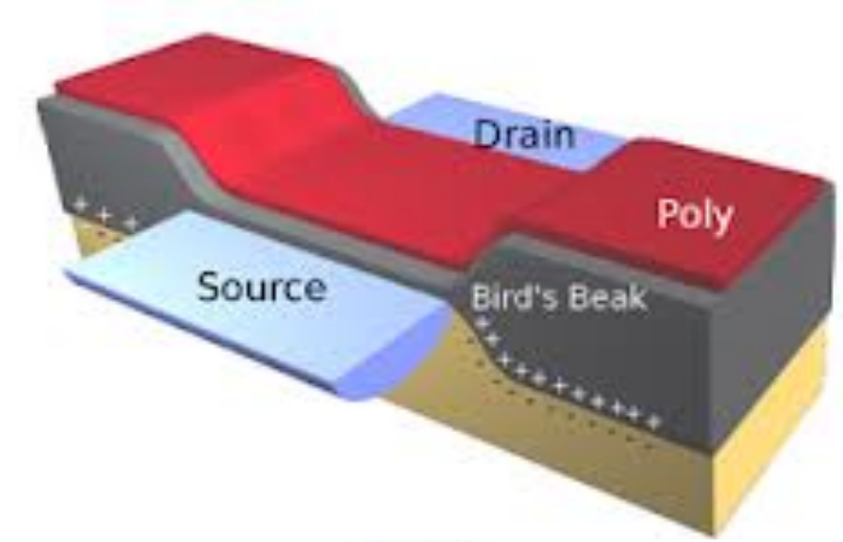


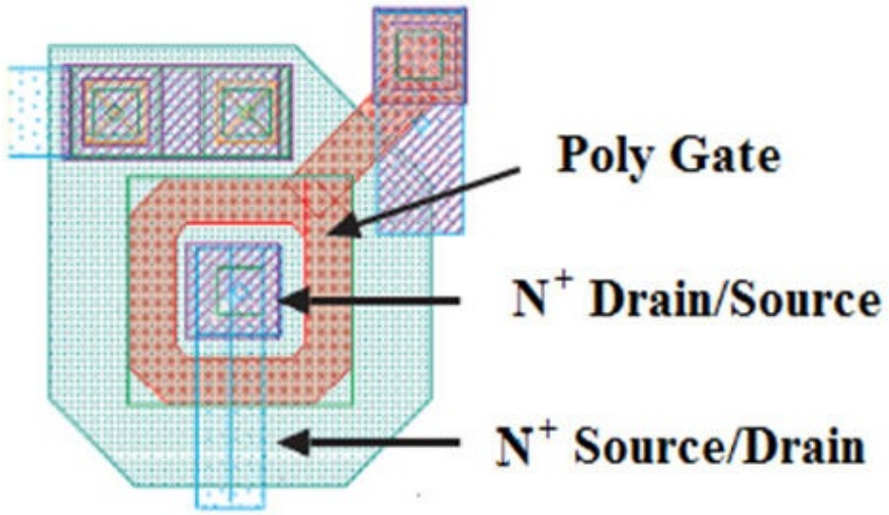
10 and 100 pulses



Radiation Hardness

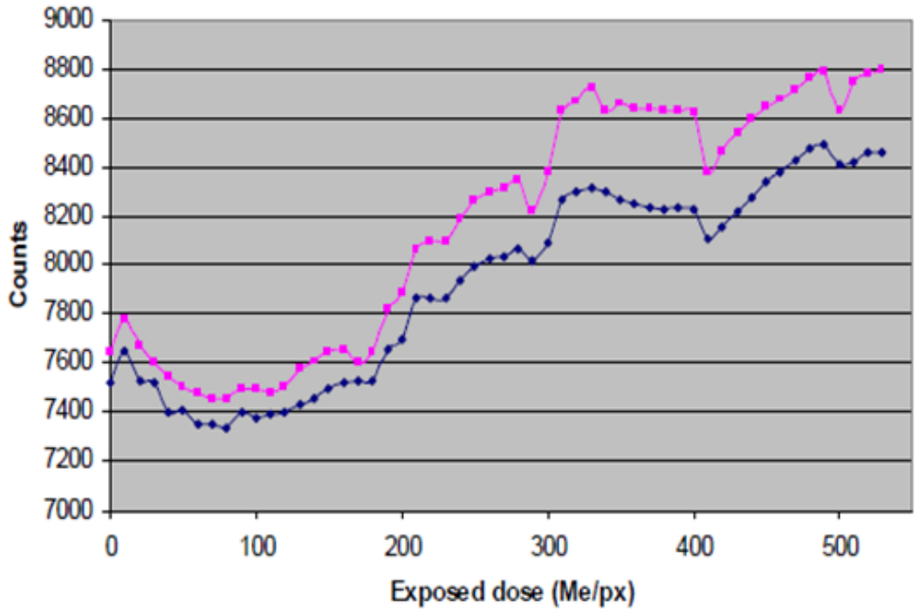
- ACHILLES pixels:
  - Built in 0.35 μm CMOS - thin oxide layer.
  - Uses gate geometry to reduce leakage current.

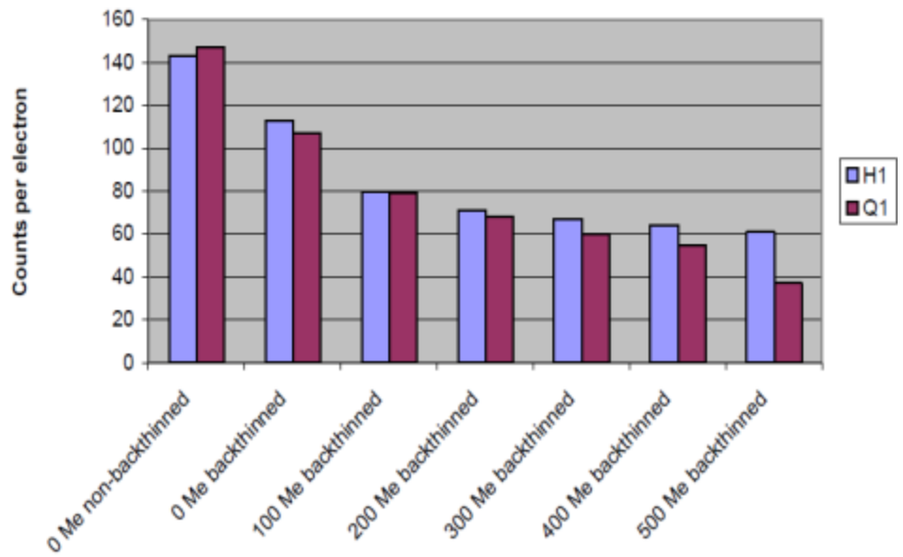




Radiation Hardness

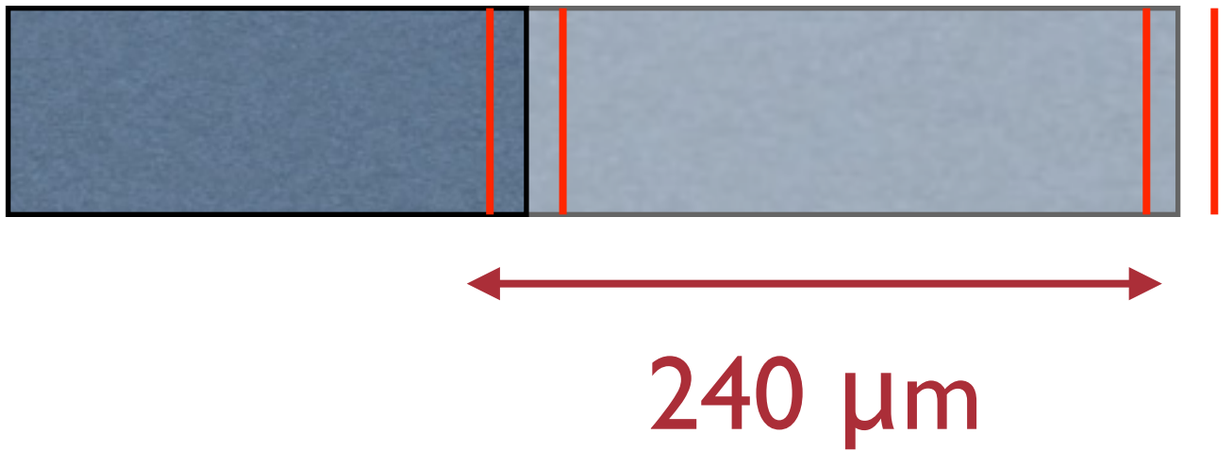
- Two slightly different Achilles tested for radiation hardness.
- The dark count changes slightly as function of the number of incoming 300 keV electrons. 500M 300 keV electrons corresponds to 20Mrad. Using 16 bit ADC, so no problem.
- 20 Mrad ≈ 500,000 fractions
- Gain slowly decreases. No issue as our signals are big and can be calibrated and monitored.





VMAT Considerations

- Maximum speed of the order 12 cm/s
- At 50 fps leaf would move 240 µm with an error of 54 µm on each position would have an uncertainty of ~75 µm.
- Don’t see any issue for leaf reconstruction.
- Dose is determined from integrated signal.



Characterisation

- Used radioactive source:
  - Fe55.
    - Noise ~ 100 e
  - Sr90.
    - MIP signal 990 e