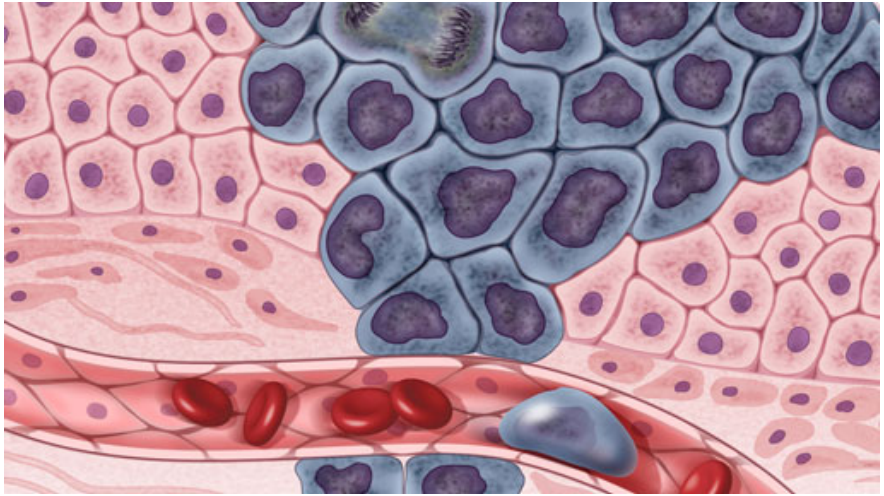
# Calorimetry for Proton Therapy

**Dr. Raffaella Radogna**

University College London
Proton Beam Therapy group

# What is cancer?

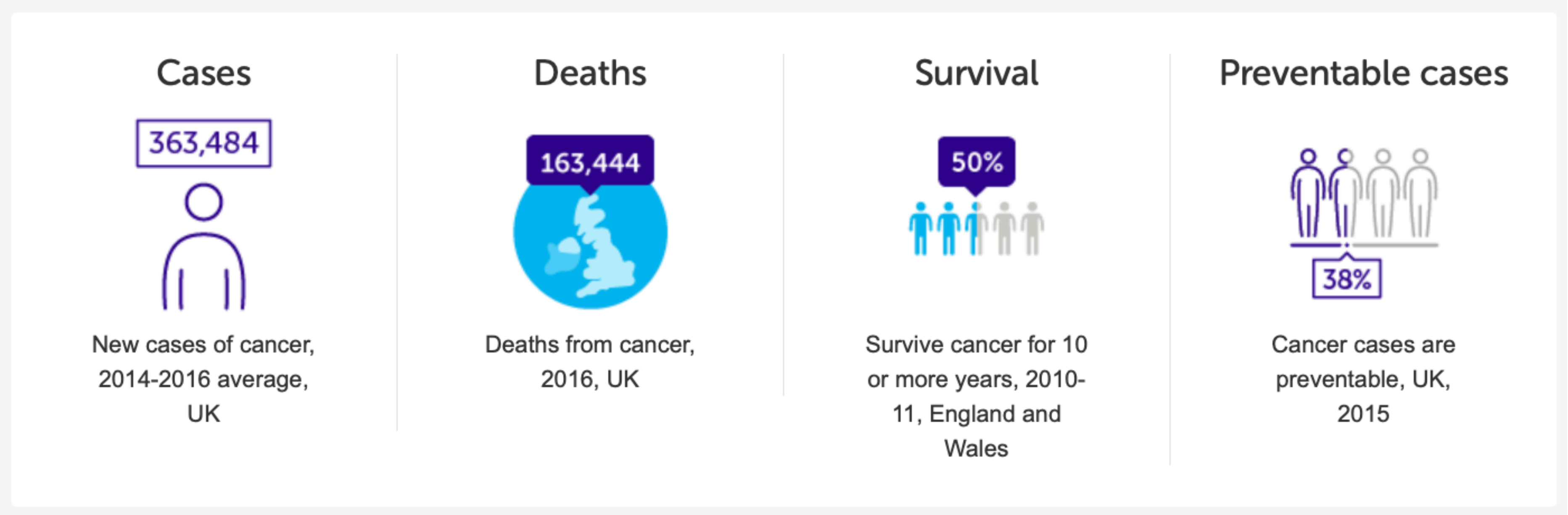
- Cells reproduce through *mitosis* (cell division).
- All cells in the body have a pre-programmed lifespan.
- If the cell becomes abnormal it is programmed to die.  This is called *apoptosis*.



https://www.genome.gov

- If a sequence of mutations occurs the cell begins to divide uncontrollably (tumour) and eventually spread to other parts of the body: cancer.

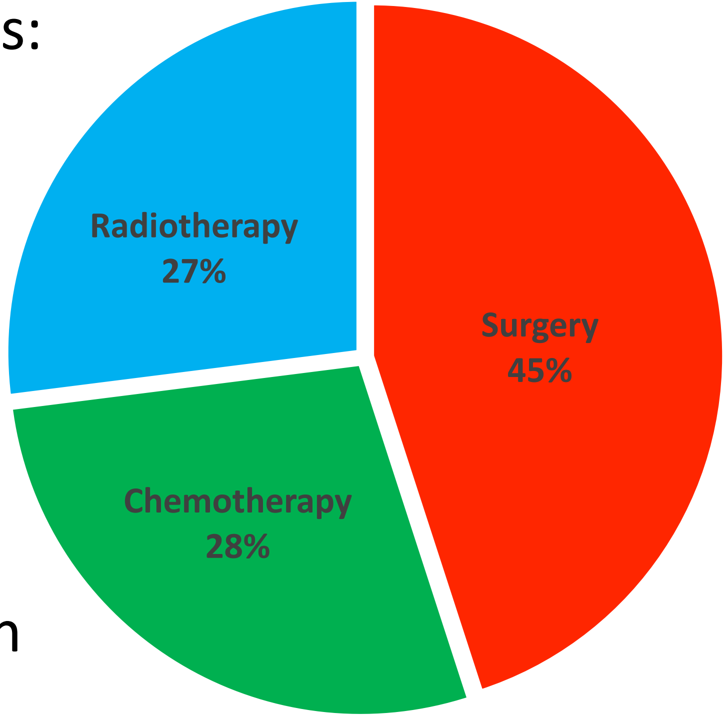
# Cancer in the UK




https://www.cancerresearchuk.org

# Cancer Treatment

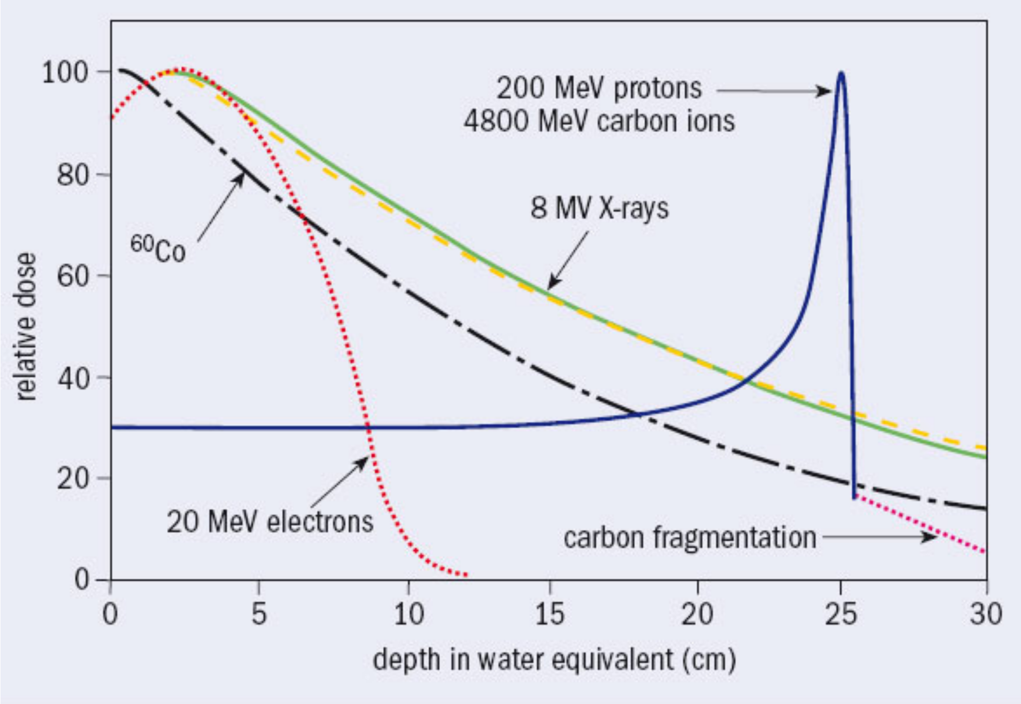
- Cancer treated with 3 different modalities:
    - Surgery
    - Chemotherapy
    - Radiotherapy
- Often used in combination
- If you want to cure cancer, be a surgeon!
- If you can't remove it with surgery, radiotherapy is often the next best option




https://www.cancerresearchuk.org

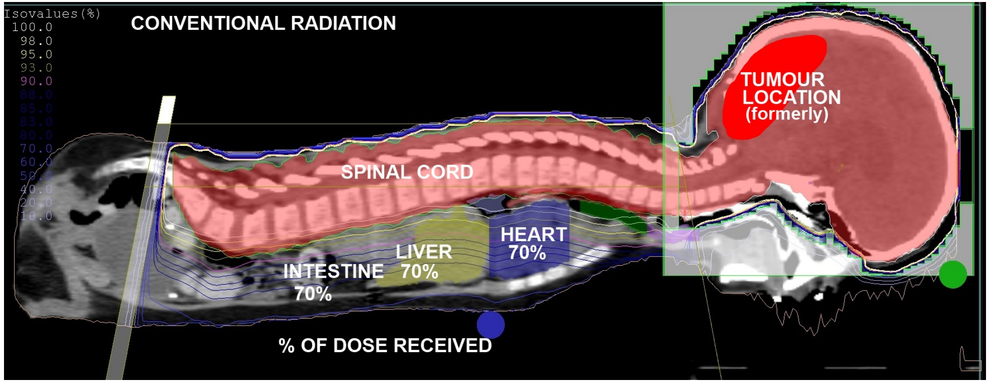
# Proton Beam Therapy (PBT)

- Unlike X-rays, charged particles stop!
- Electrons, being lighter, scatter and spread out.
- Protons deposit most dose at the *end* of their path: the ***Bragg Peak***.
- Protons stop, but you need to know where…

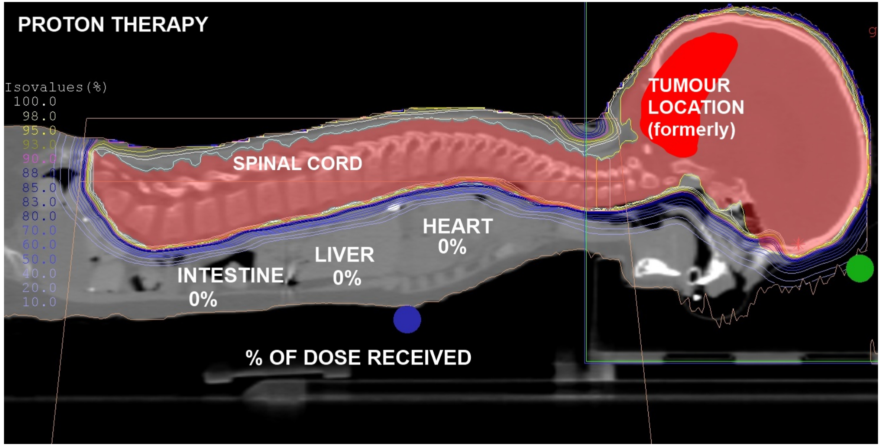


# Medulloblastoma Comparison

X-rays




Protons

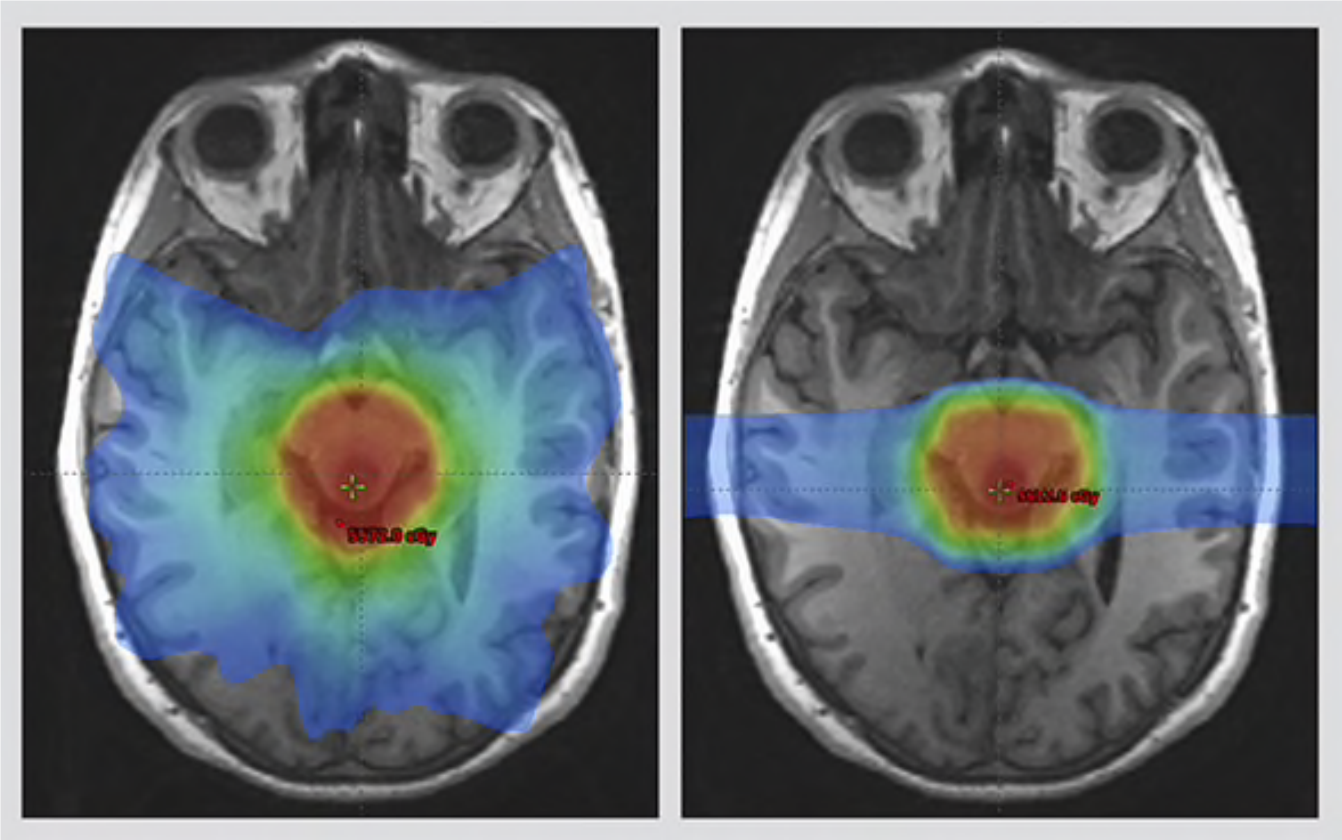





https://www.itnonline.com/content/pediatric-brain-tumor-patient-uk-undergoes-first-treatment-proton-therapy

# Brain Comparison

X-rays



Protons



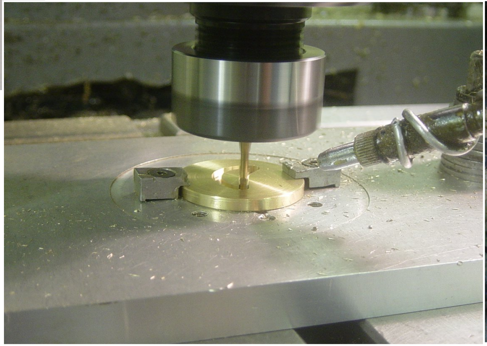
https://www.mayoclinic.org/medical-professionals/neurology-neurosurgery/news/proton-beam-therapy-in-minnesota-and-arizona/mac-20430872

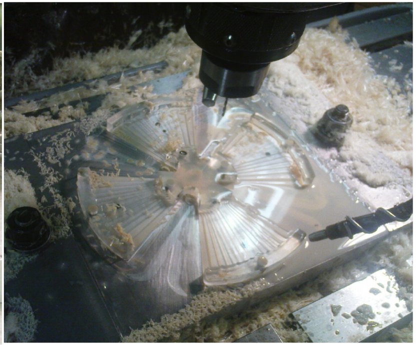
# Proton Therapy Around The World

- Almost 100 particle therapy centres expected around the world by 2020, over 30 in Europe
- Clatterbridge Cancer Centre (UK) is the world's first hospital-based PBT centre: first two patients in June 1989

# Clatterbridge Cancer Centre

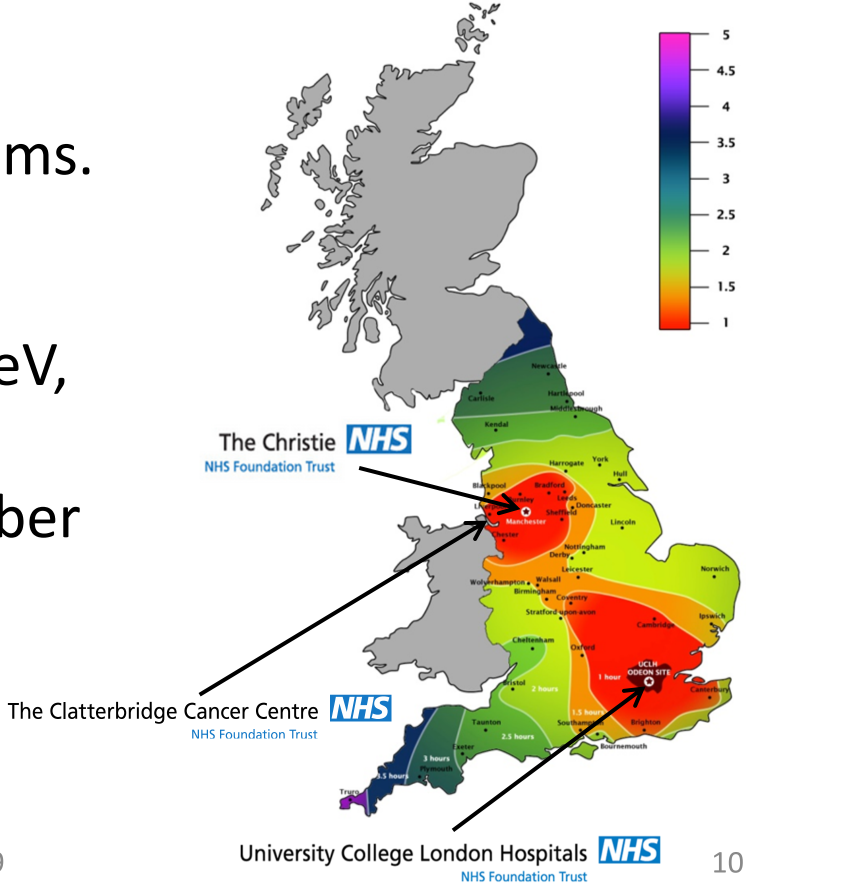

- 60 MeV cyclotron treats eyes with double scattering beamline.



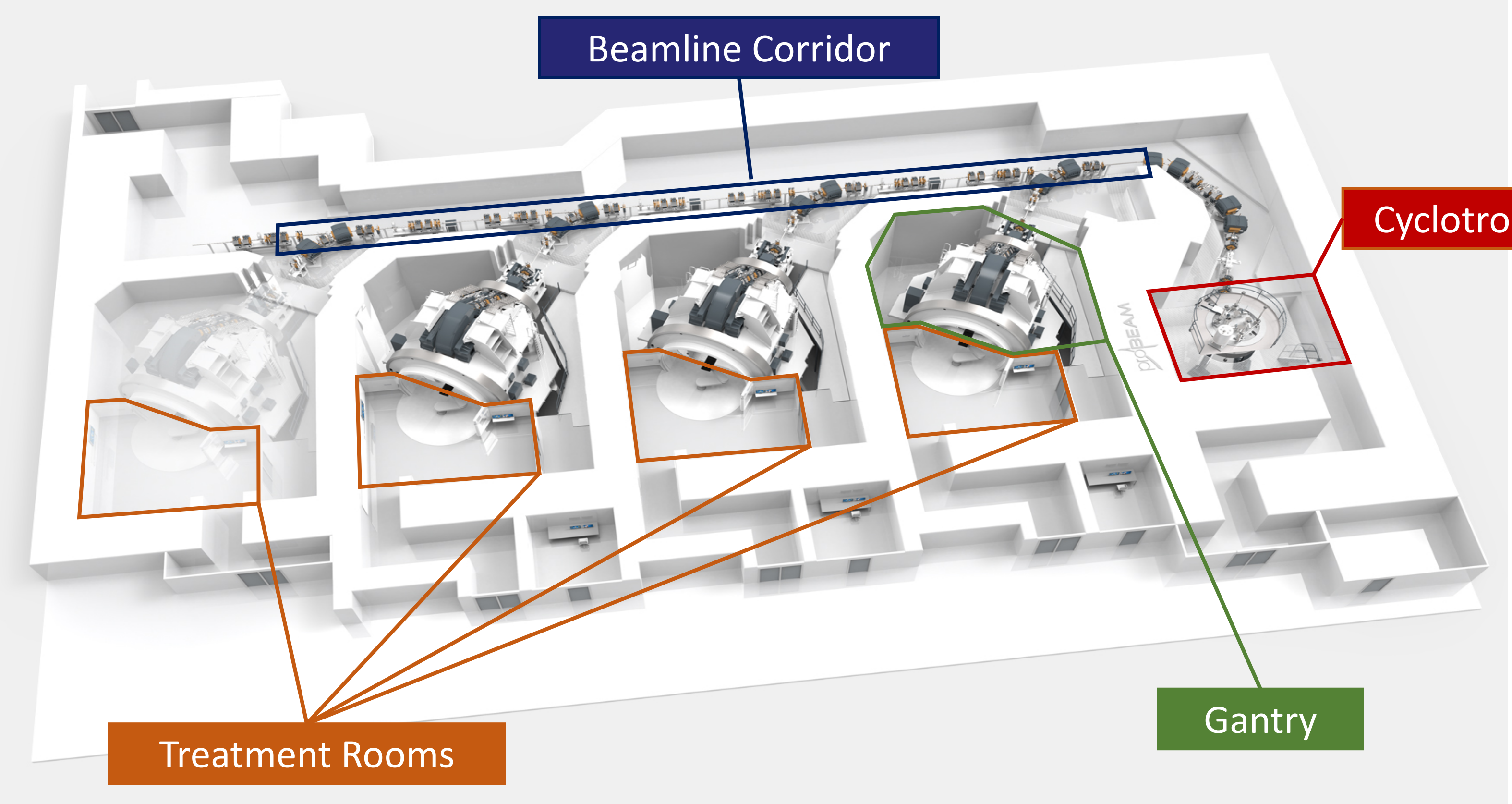


# NHS England PBT Centres

- Two new national centres:
  - UCLH (London): 4 treatment rooms.
  - The Christie (Manchester): 3 treatment rooms.
  - Pencil beam scanning 70-245 MeV, 360° rotating gantries
- The Christie started treating December 2018; UCLH will start in 2020.
- More private centres in Wales, the Northeast and Reading



# UCLH Proton Therapy Facility

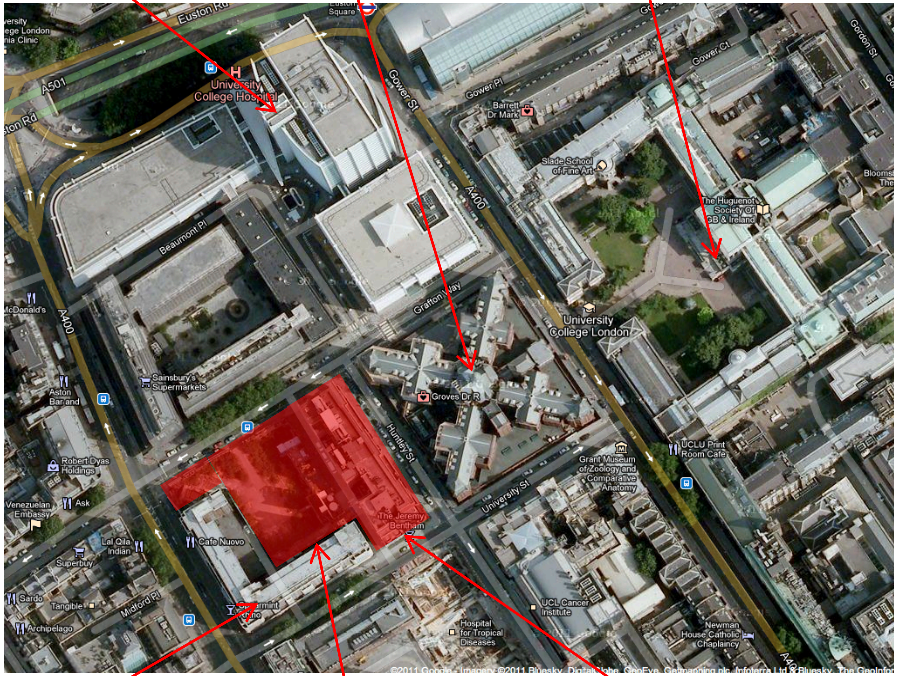





Images courtesy of UCLH/Varian Inc. (not for reproduction)

# UCLH PBT: July 2019

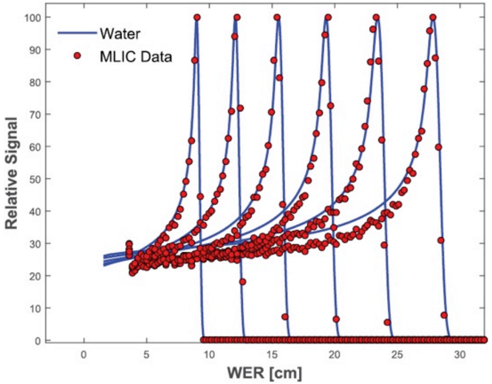
https://www.uclh.nhs.uk/aboutus/NewDev/NCF/Pages/Blogandupdates.aspx

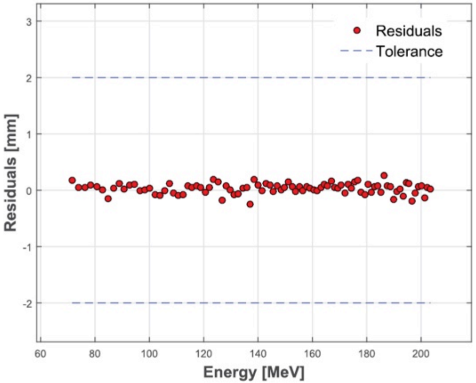


# Proton Beam Quality Assurance

- A range of QA checks are necessary for safe PBT treatment:
  - Daily, Weekly, Monthly.
- Daily checks carried out before treatment:
  - Absolute dose, Pencil beam position and size, Range and Energy
- Average time per day per room: 44 min

# Daily Range QA @PSI



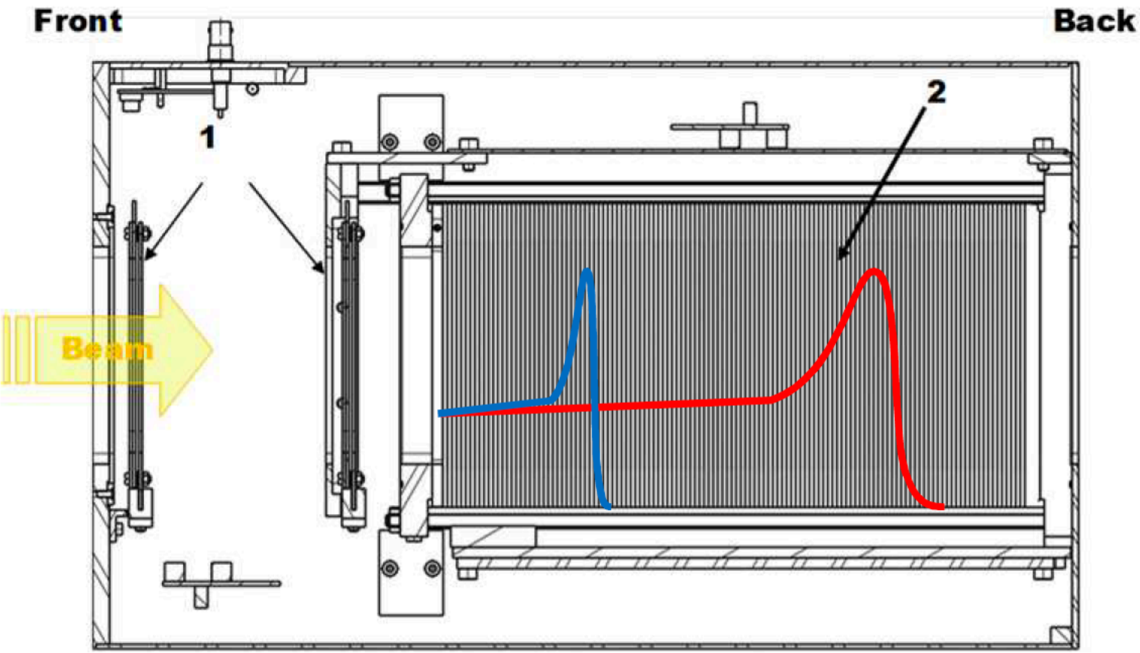




O. Actis *et al.* 2017 *Phys. Med Biol.* **62** 1661

# Daily Range QA: MLIC

- Combination of ionization chambers are commonly used
- MLICs are expensive, have fast acquisition time but long setup time

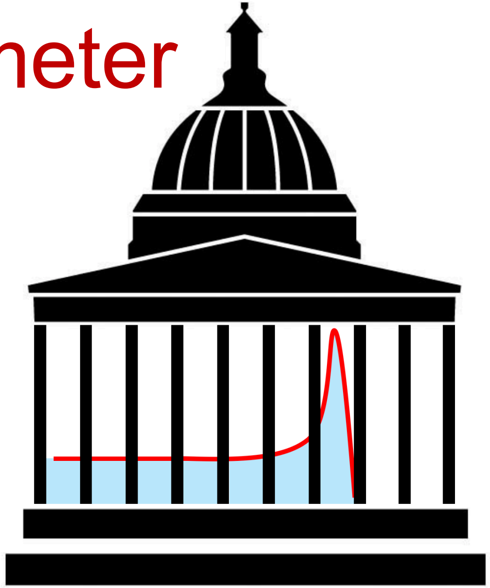
## Multilayer ionization chambers (MLICs)



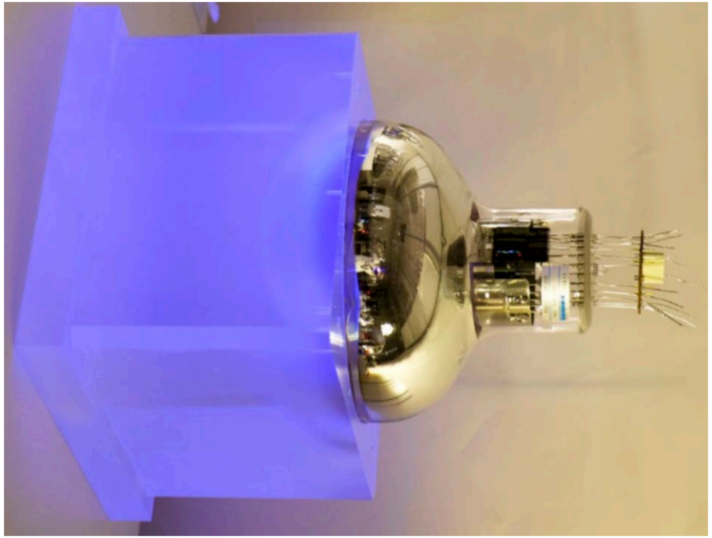

O. Actis *et al.* 2017 *Phys. Med Biol.* **62** 1661

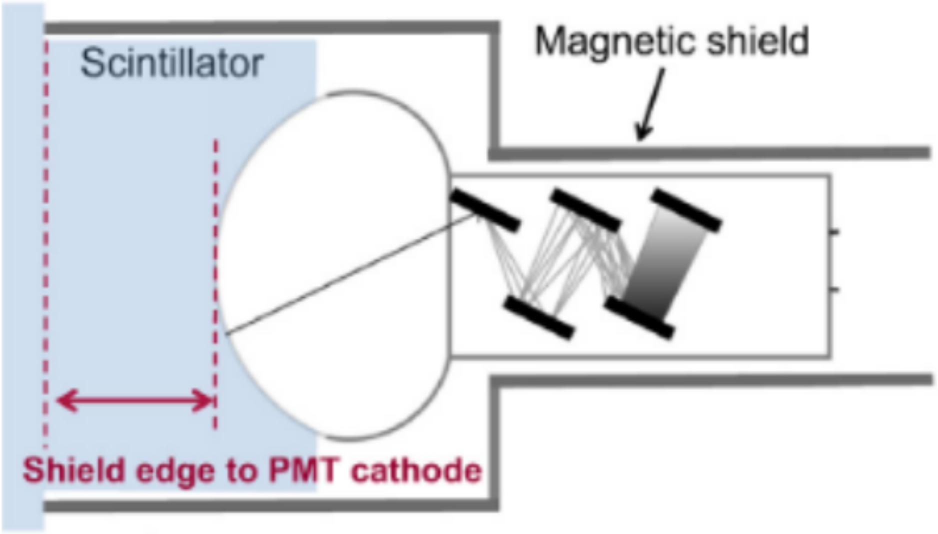
# QuARC:

## Quality Assurance Range Calorimeter



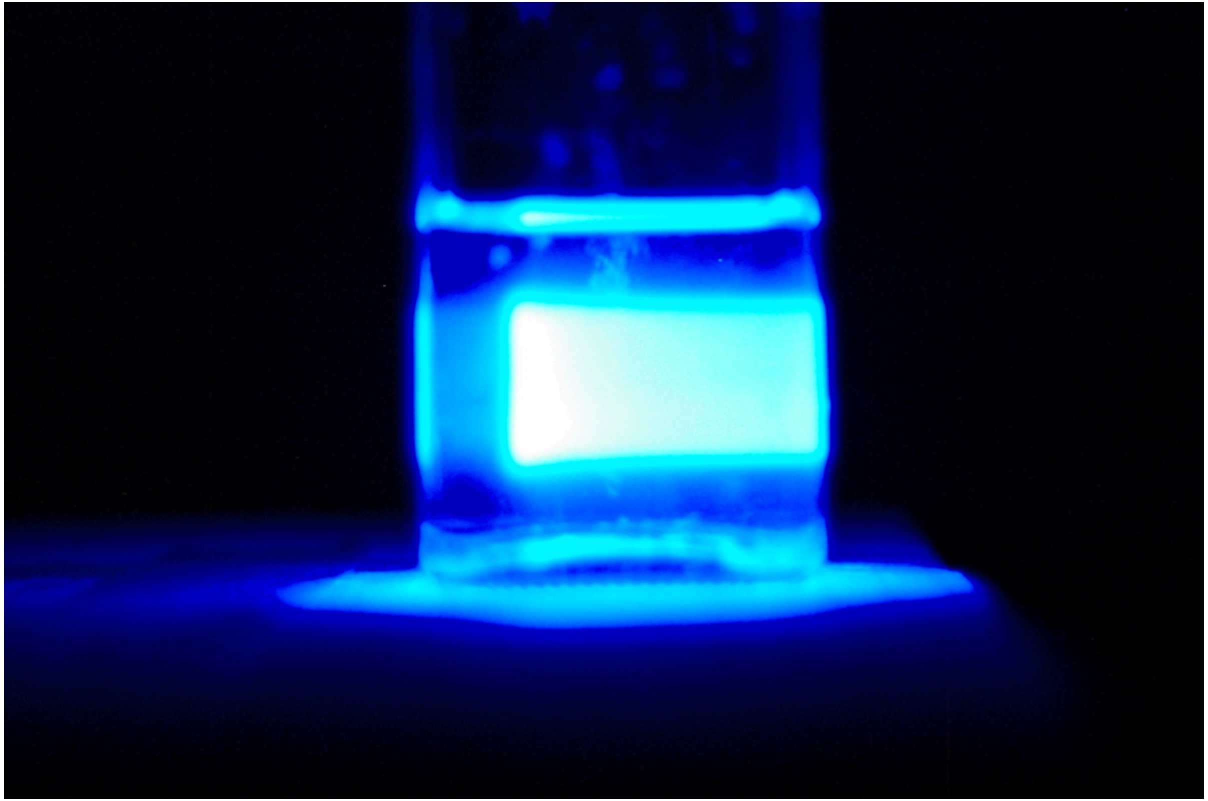
# UCL HEP: SuperNEMO Calorimeter





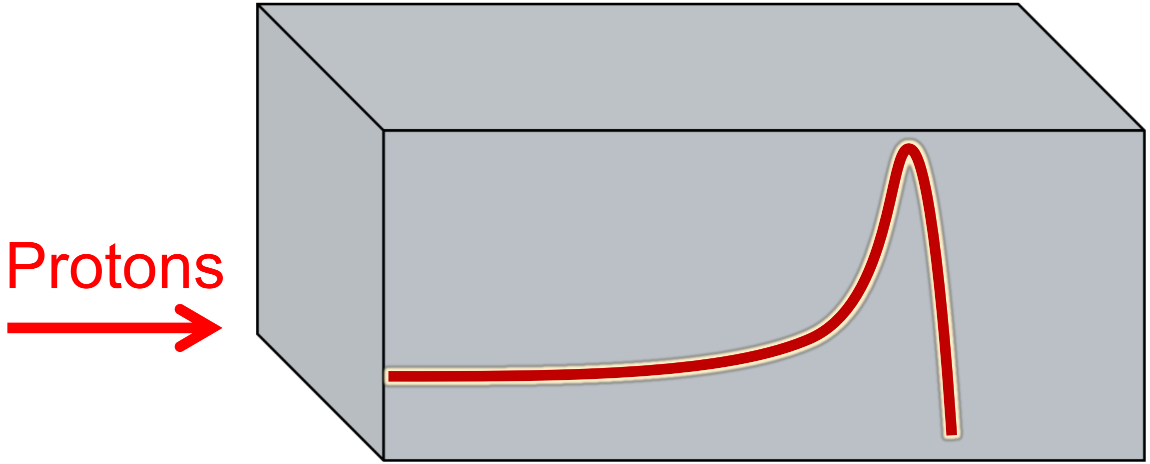

https://doi.org/10.1016/j.nima.2017.06.044

# A Real Bragg Peak!



# Calorimeter for Range verification

## Plastic scintillator



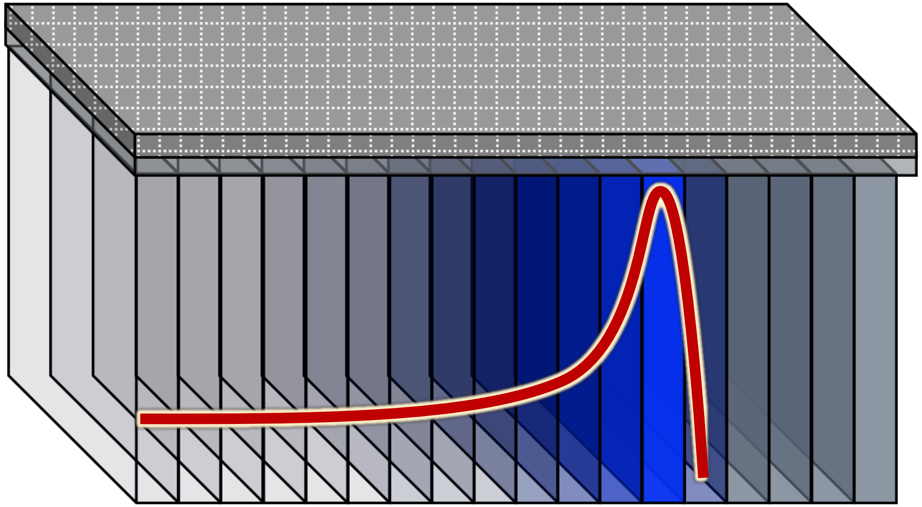

### Advantages

- Price
- Light output
- Water equivalent material

### Disadvantages

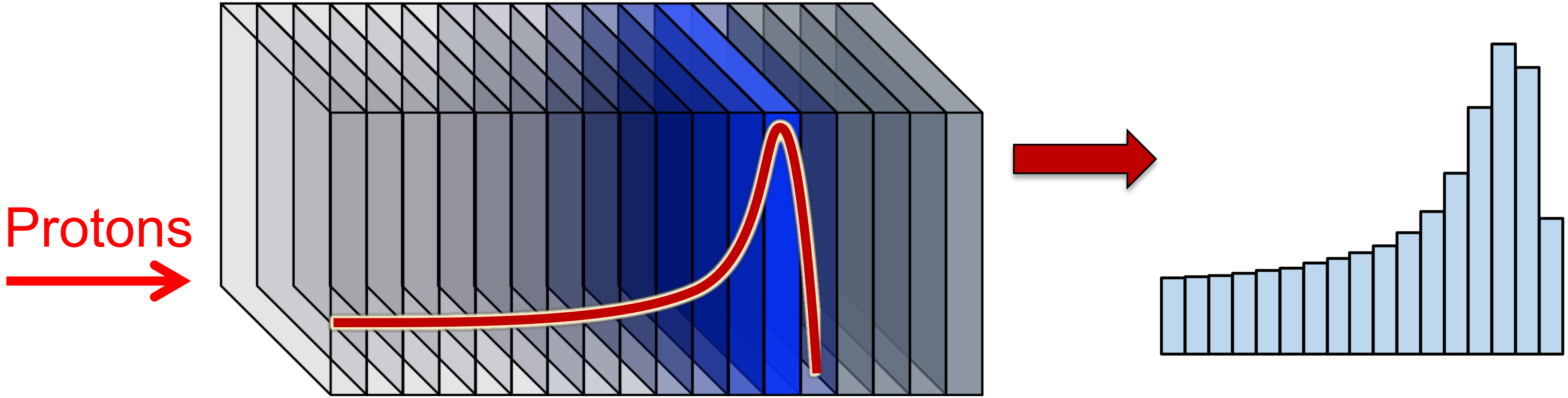
- Radiation hardness
- Quenching

# Calorimeter for Range verification




- Segment block into slices and read out light from each slice individually
- Current prototype uses simple, stable light detection: DSLR/pixel sensor

# Calorimeter for Range verification

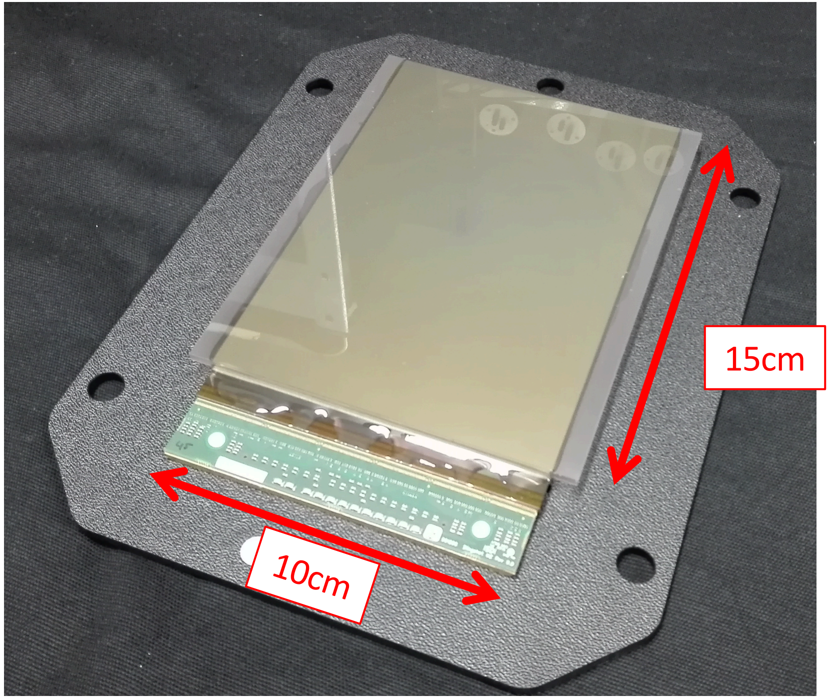


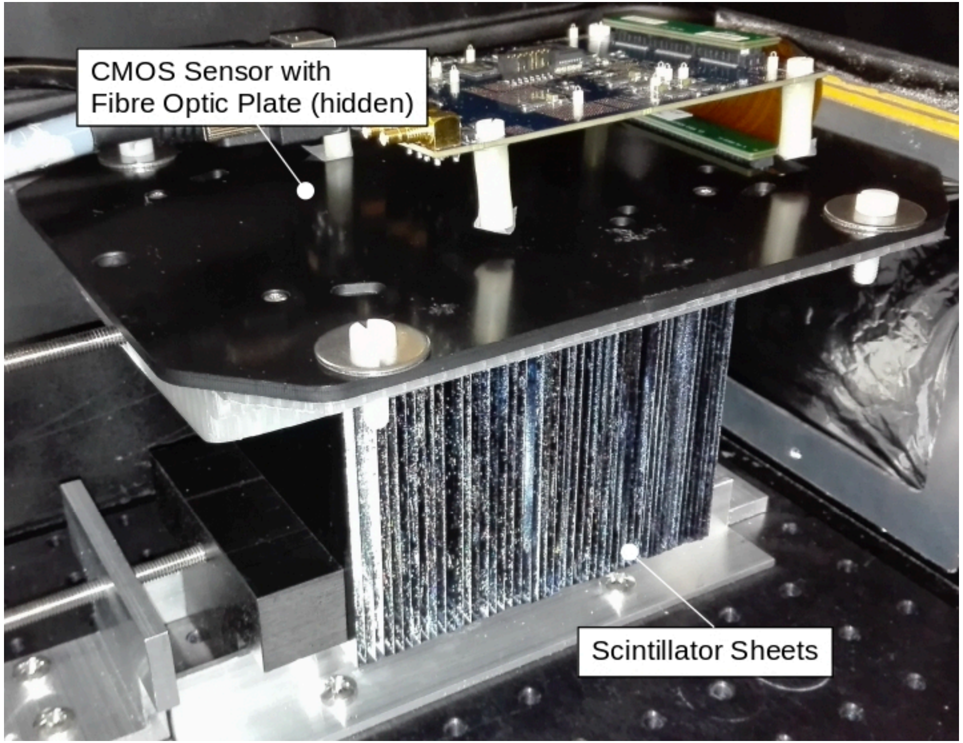

- Integrate signal from many protons: very large output from $10^{10}$/s
- The proton beam range is estimated from the light-dose distribution

# Scintillator Sheets

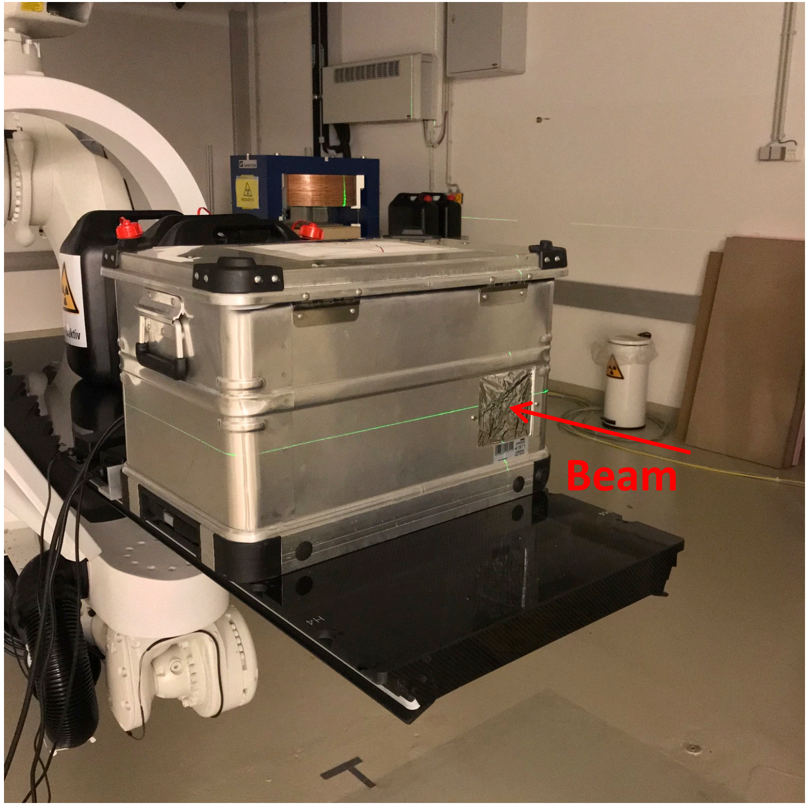
- Active area: 10 cm x 10 cm
- Thickness: 2- 3mm

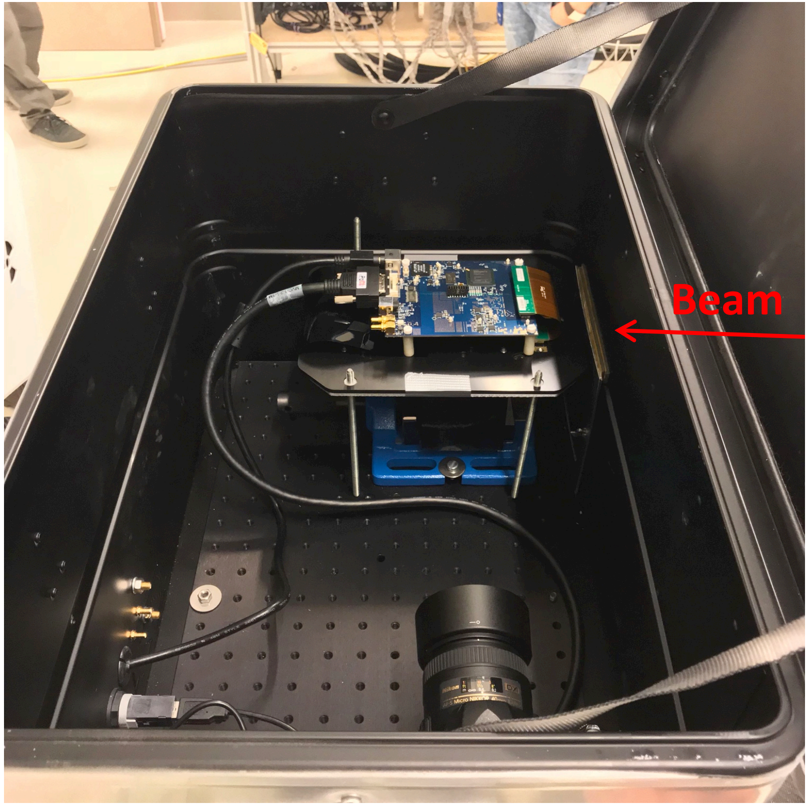
# Readout: CMOS Pixel Sensor



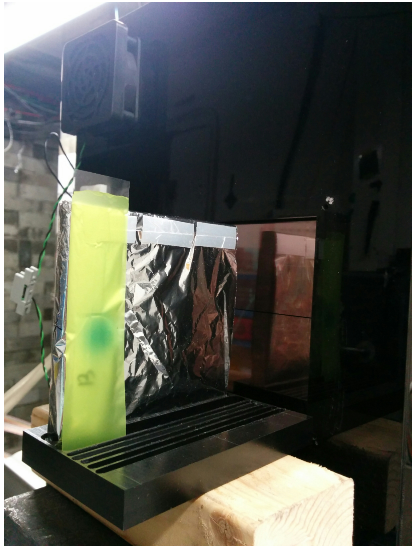
# Experimental Setup



# Experimental Runs

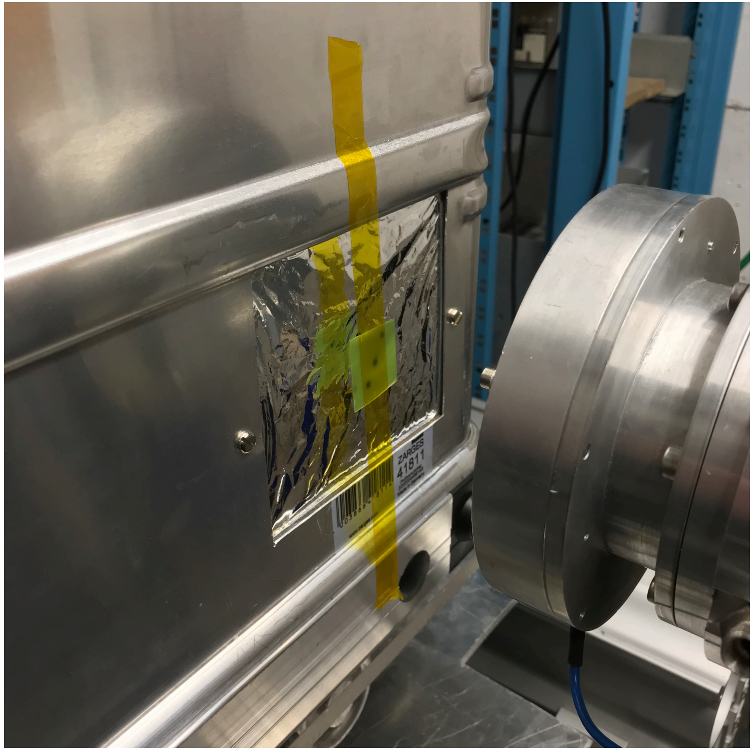
| 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|
| | Birmingham | Birmingham<br>MedAustron<br>Heidelberg<br>Clatterbridge | Heidelberg |



**Sep. 2017**

Beam tests of 10 mm, 4 mm and 3 mm scintillator sheets with PRaVDA CMOS pixel sensors (PRIAPUS) at the Birmingham Cyclotron (28 MeV beam)

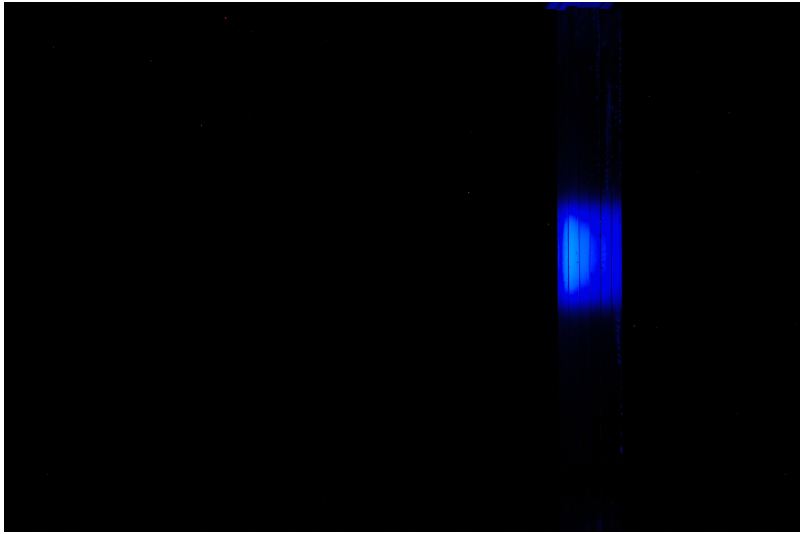
# First Bragg Peak!



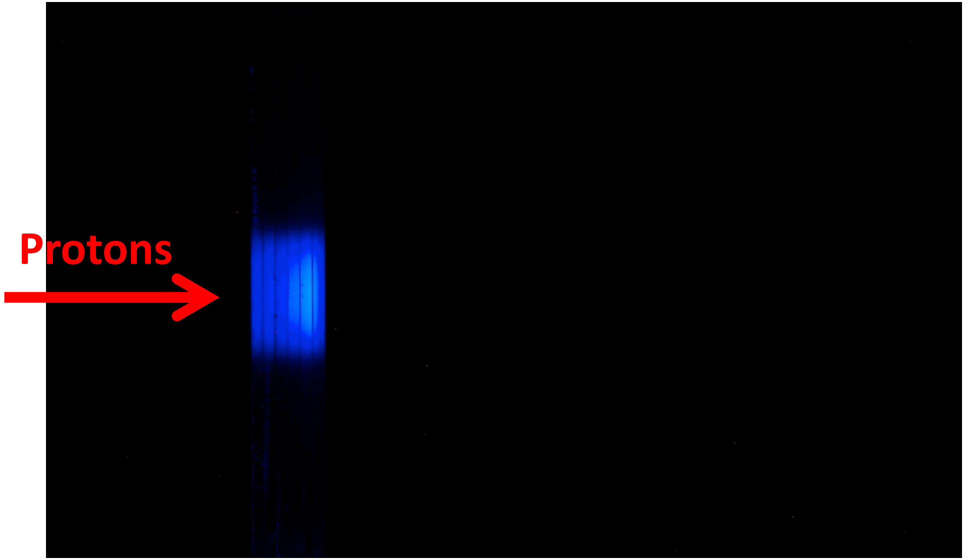
**March 2018**

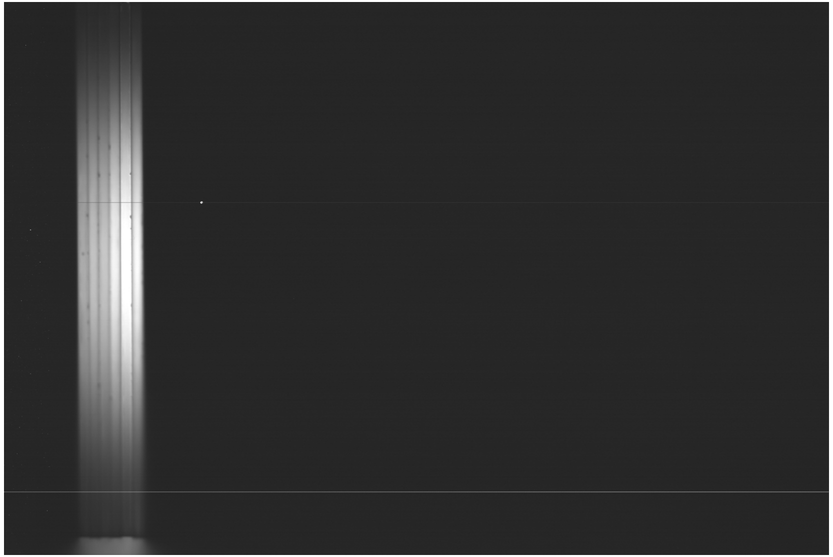
Beam test at the Birmingham Cyclotron (**36 MeV**).

A Bragg Peak measurement was carried out to confirm the exact beam energy

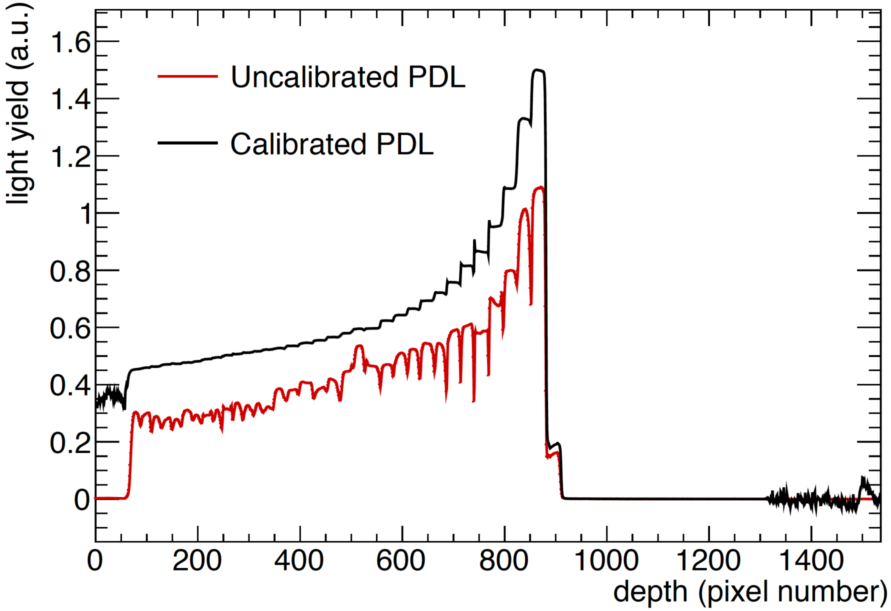


# Proton Beam: DSLR vs Sensor

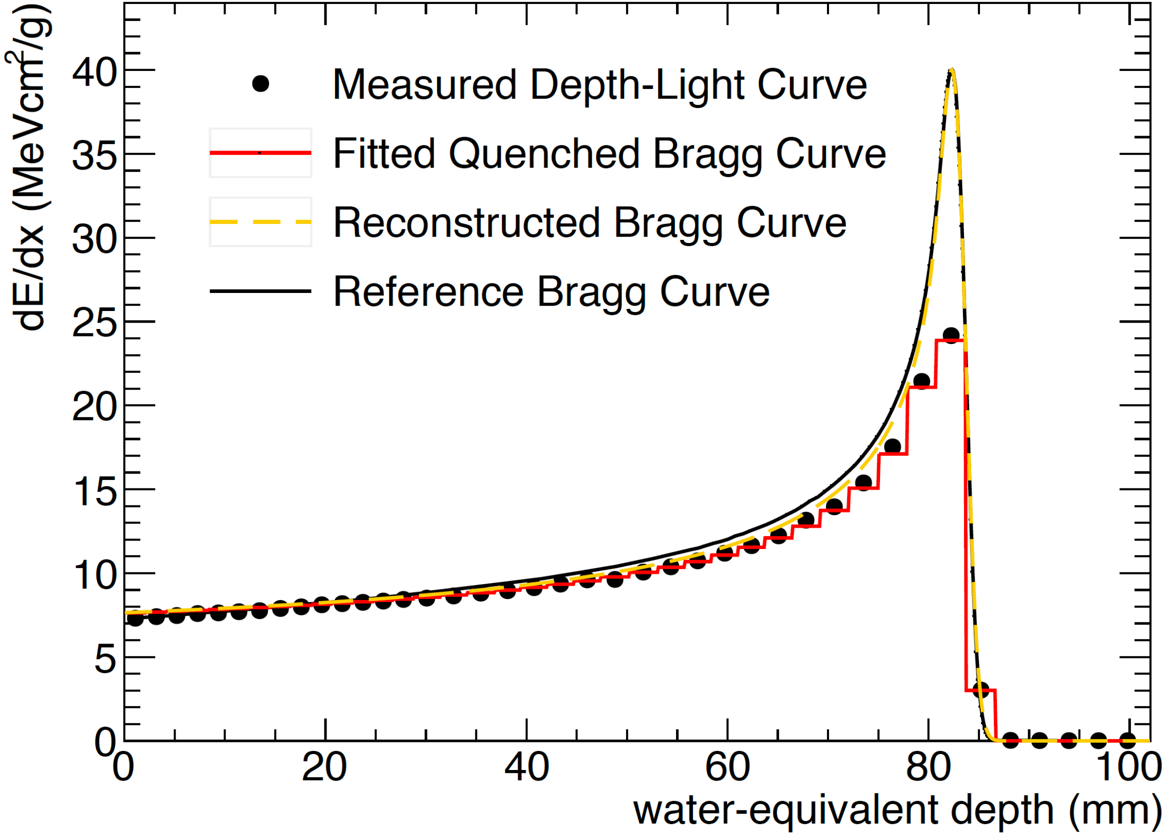


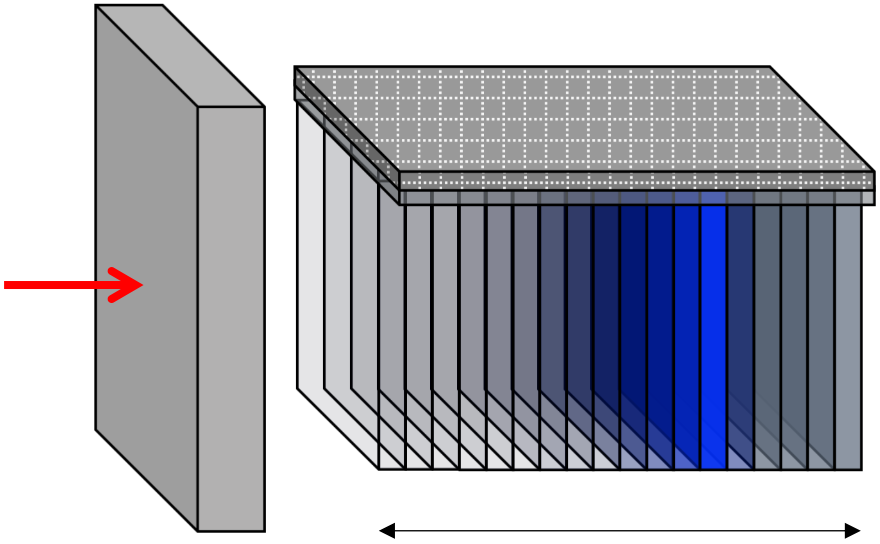
# Beam E 106.2 MeV

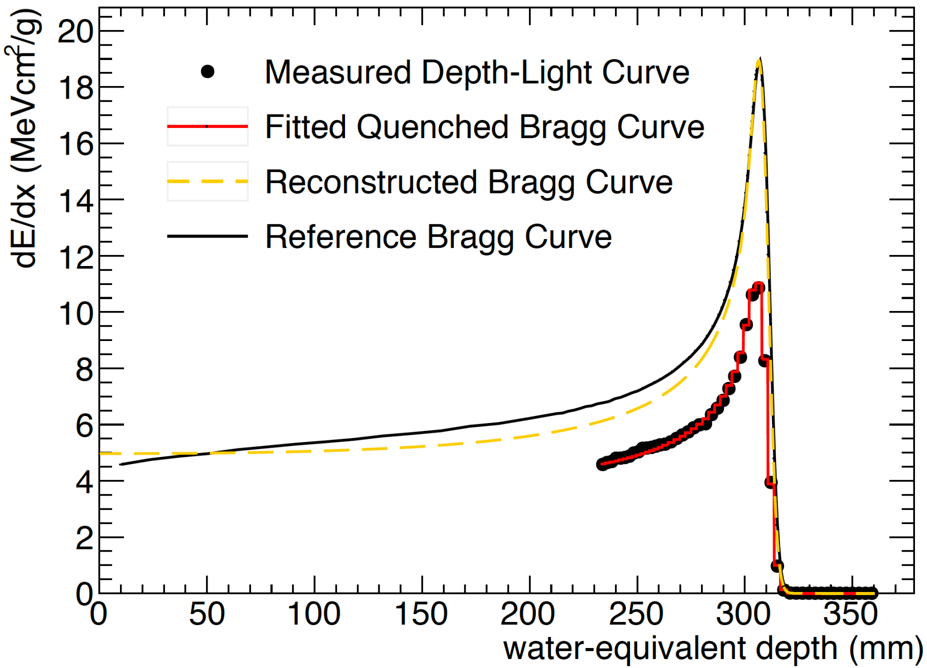



# Analysed Data: 106.2 MeV



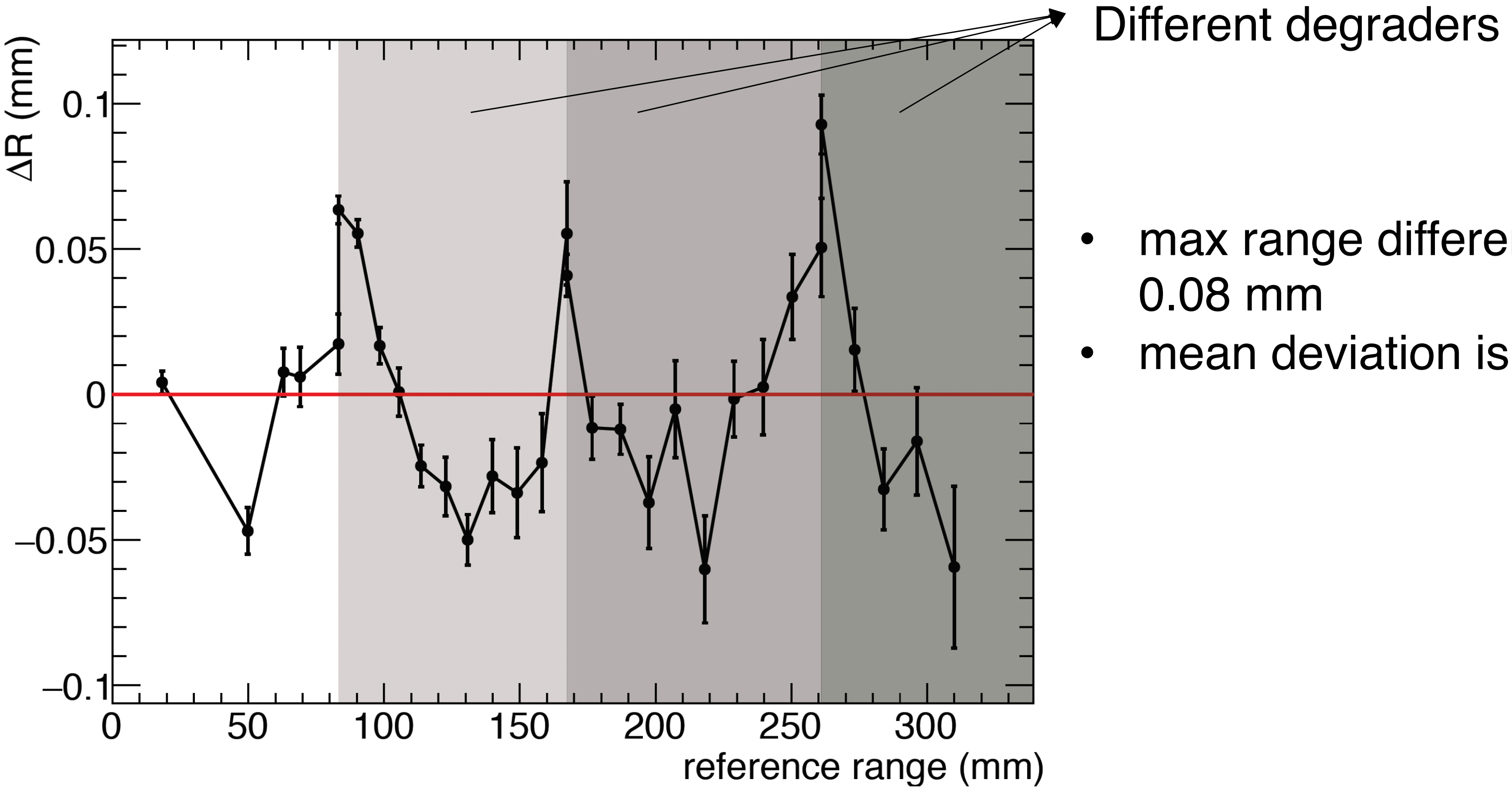
# Beam E 222.7 MeV




PMMA degraders needed to cover the full range of clinical proton energies

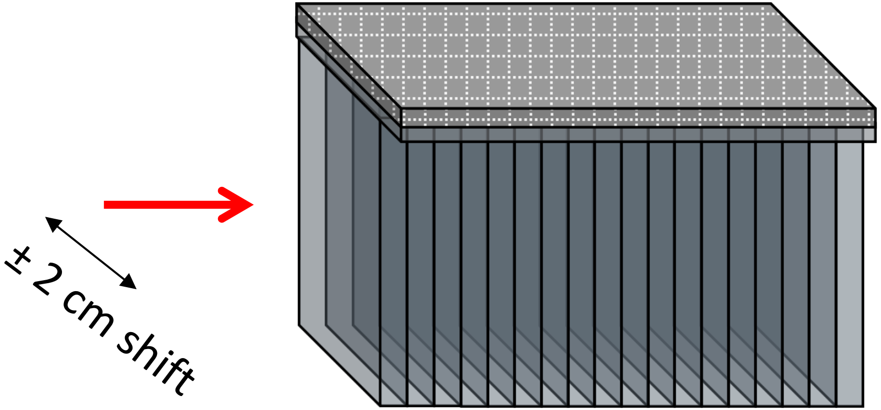
# Range Measurement Accuracy




- max range difference is 0.08 mm
- mean deviation is 0.04 mm

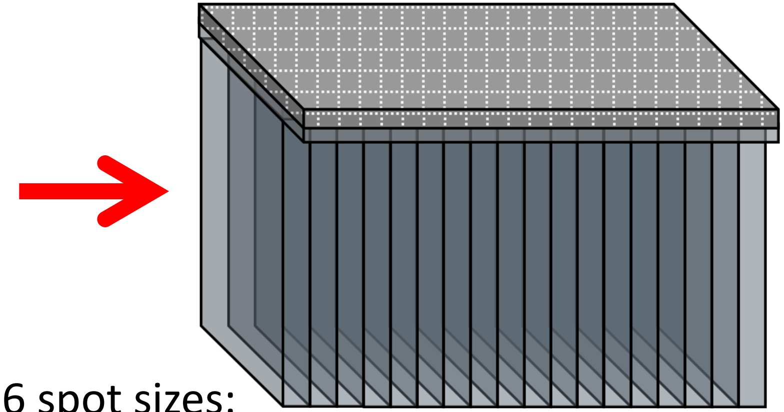
# Robustness checks

## Beam Spot Position




Range observed variation <0.05 mm

## Beam Spot Size

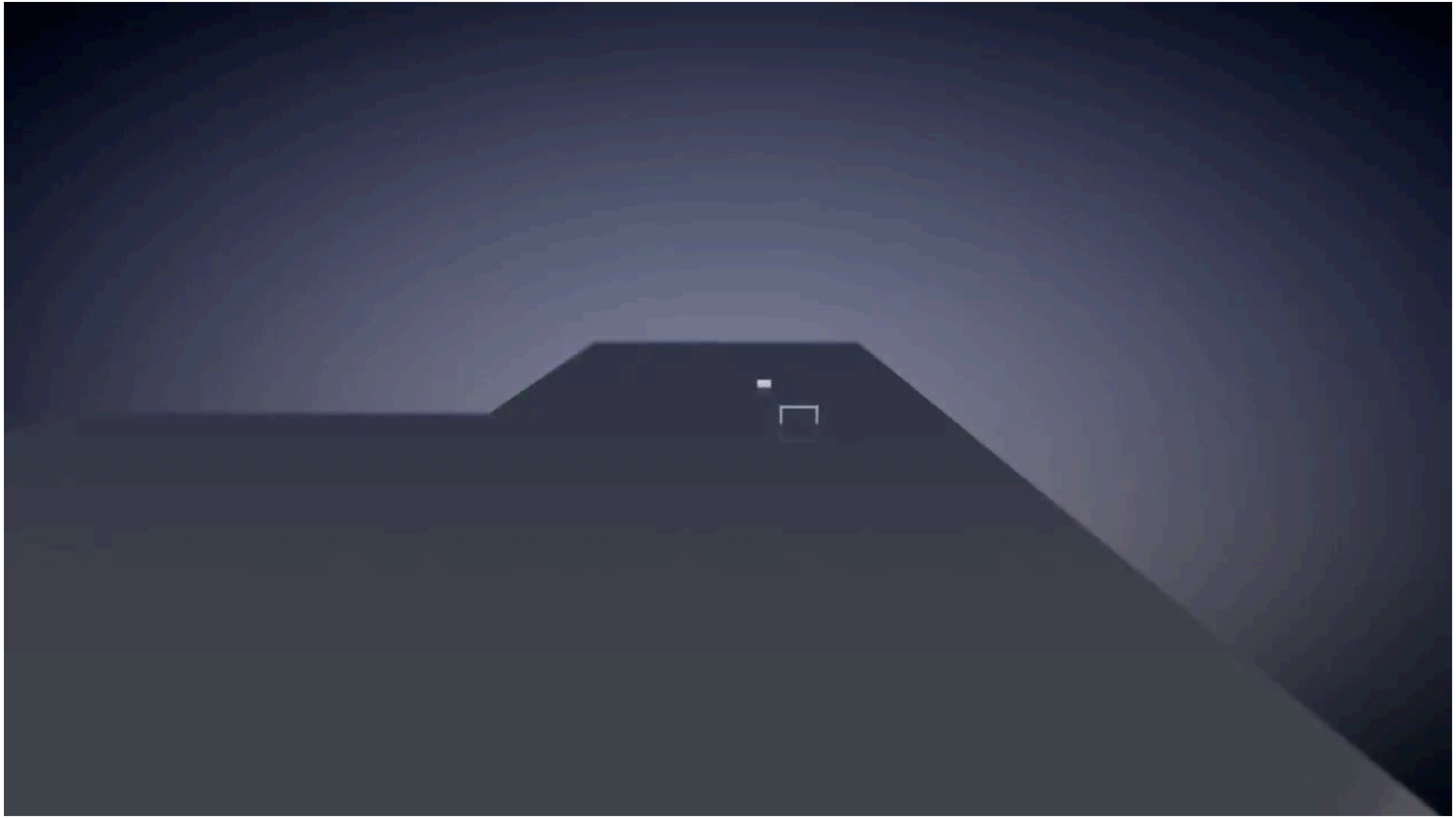


6 spot sizes:
13 – 21 mm

Range observed variation <0.03 mm

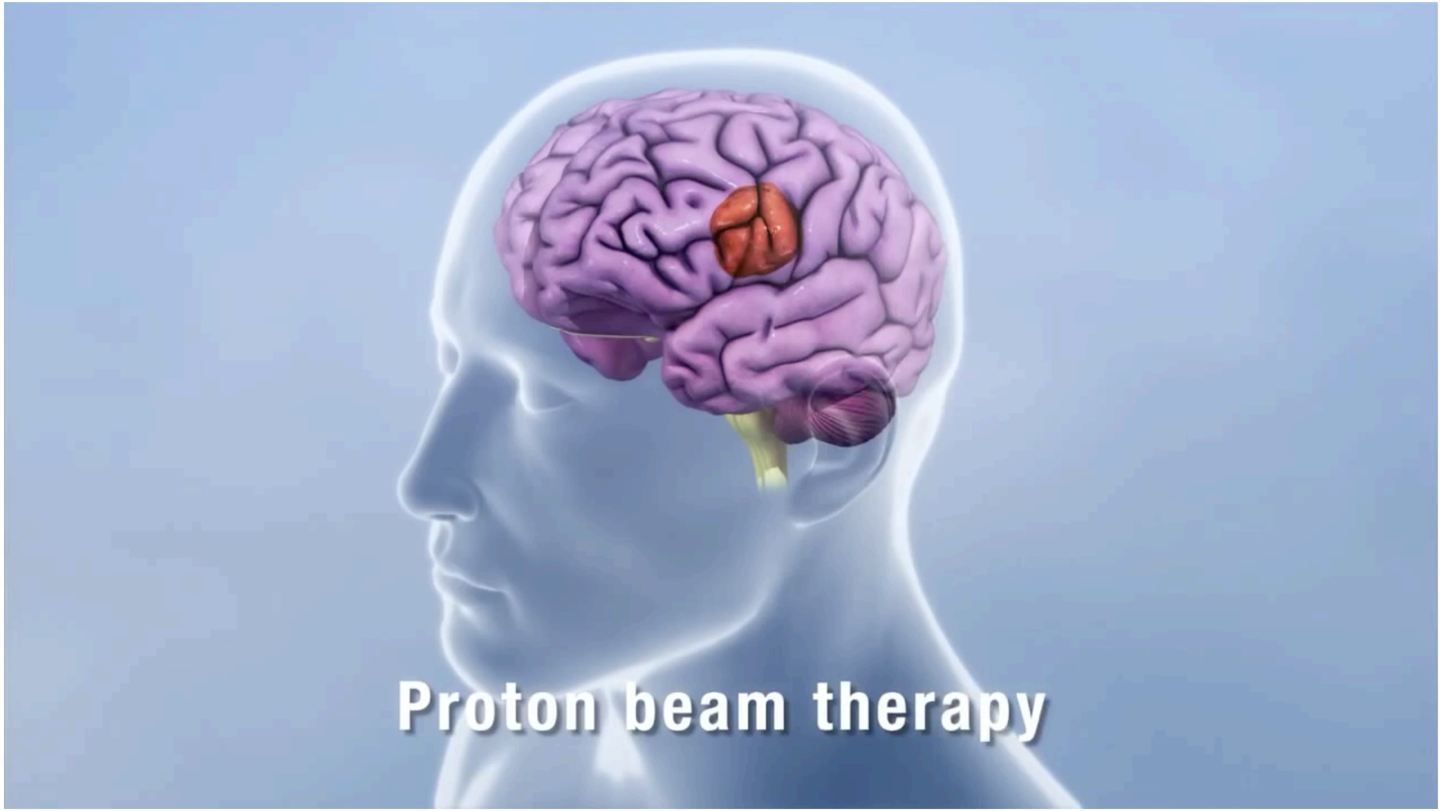
# Radiation Hardness

# UCLH PBT Facility

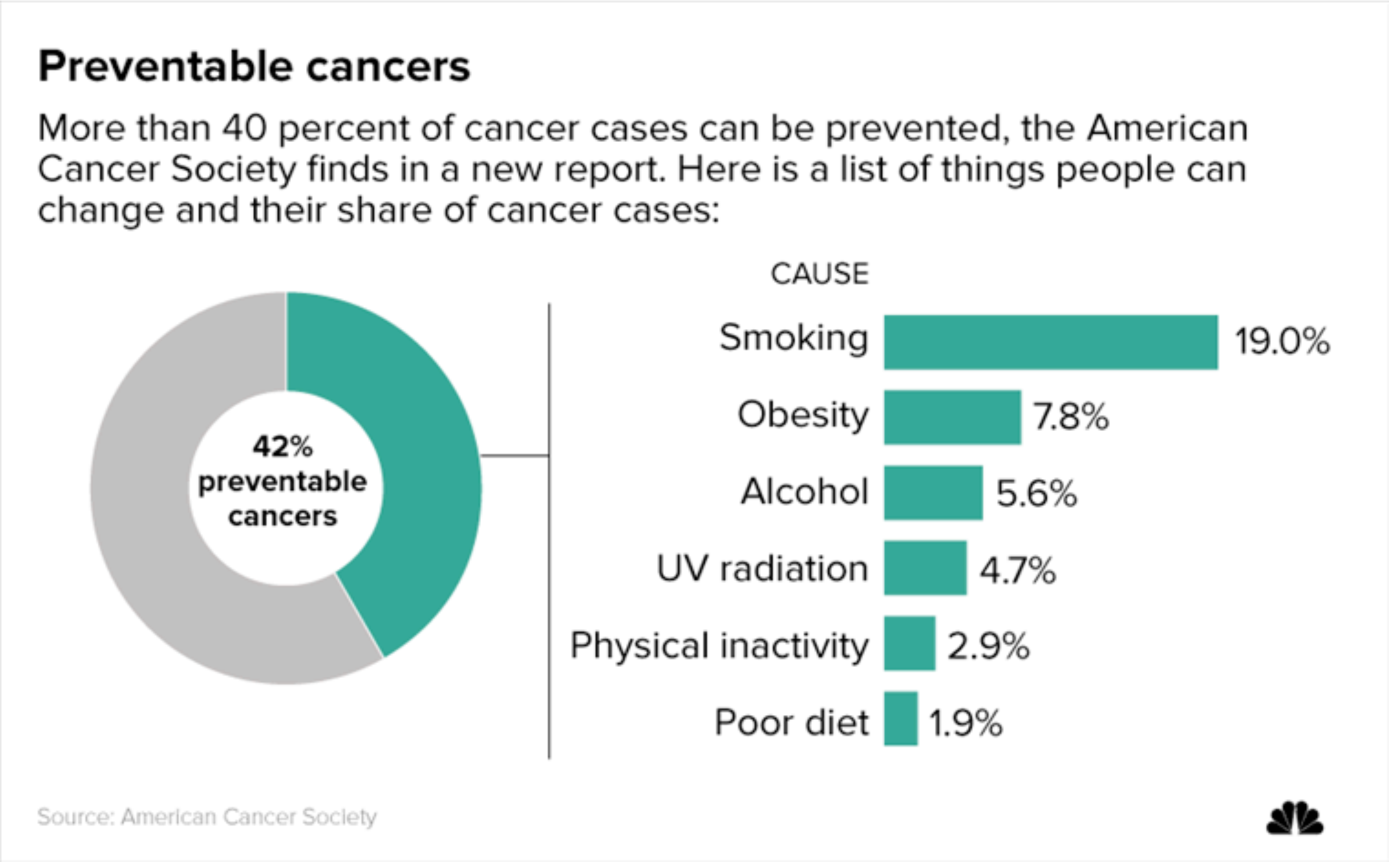


# UCLH PBT

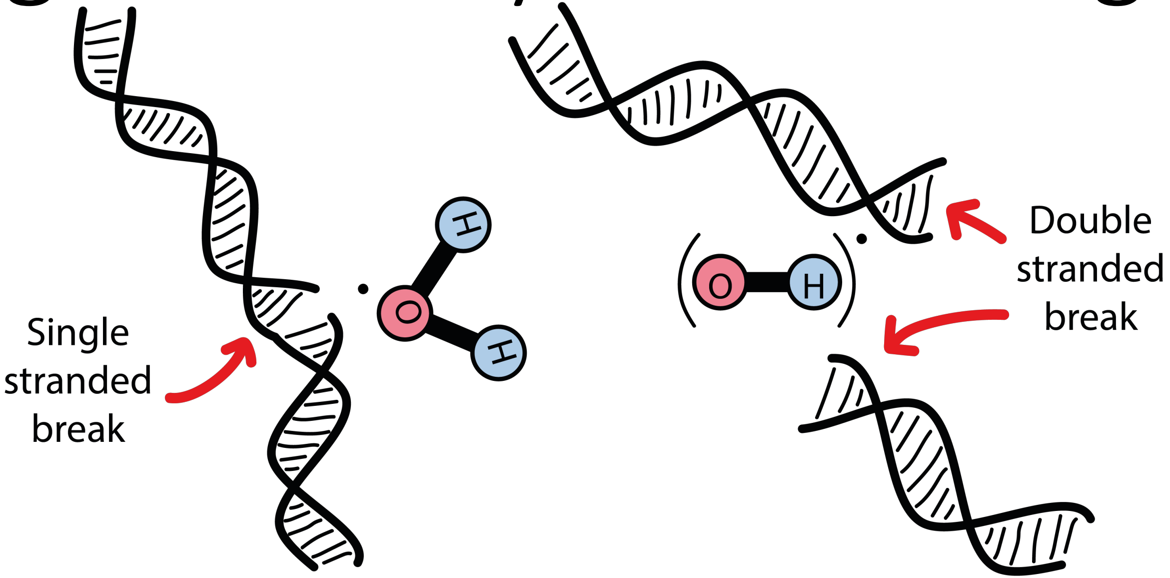
# Conformal Dose Delivery



# Cancer Causes

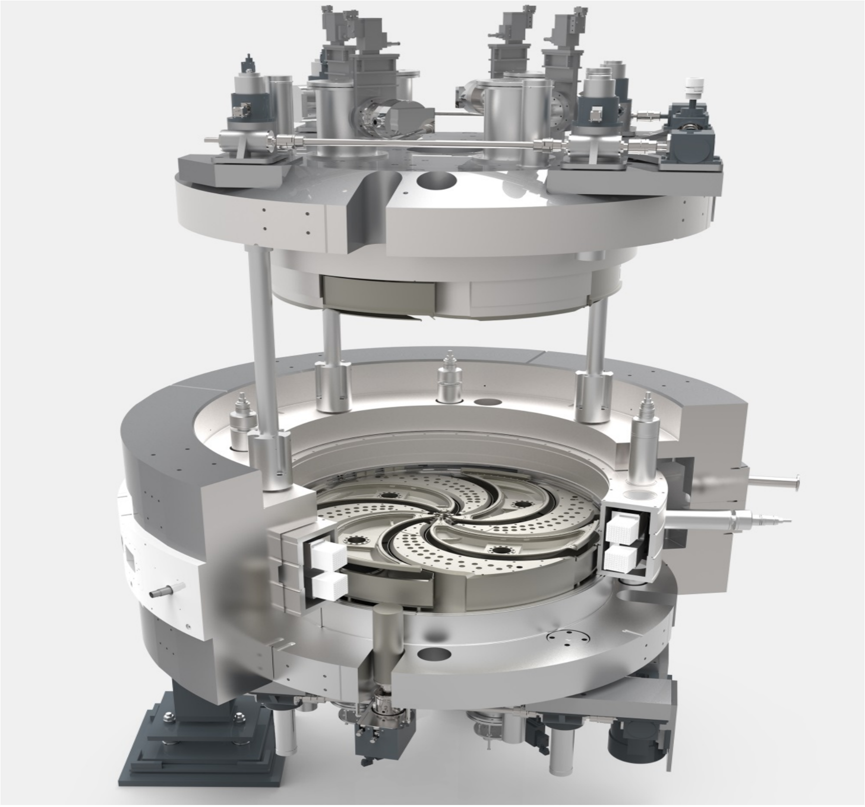


# Killing Cancer by DNA Damage




- Cell death occurs through DNA damage:
  - Single strand breaks: healthy cell can self repair.
  - Double strand breaks: self-repair much more difficult.
- Optimise clustering of breaks with targeted radiation intensity.
- With enough damage, apoptosis takes over…

# Cyclotrons

Images courtesy of Jan Timmer, Varian Inc. (not for reproduction)

# Heidelberg Gantry: 13 m x 22 m