Science and Technology Facilities Council

LhARA

A proposed Ion Therapy Research Facility

Hywel Owen (for collaboration)

30 June 2026

https://www.lhara.org/

Acknowledgements

IMPERIAL

ICR The Institute of Cancer Research

Medical Research Council — Oxford Institute for Radiation Oncology

University of Oxford

JAI John Adams Institute for Accelerator Science

CCAP Centre for the Clinical Application of Particles

Imperial College Academic Health Science Centre

Cancer Research UK — Imperial Centre

NHS Imperial College Healthcare NHS Trust

LhARA

Swansea University Prifysgol Abertawe

Queen's University Belfast — 180 Years

University of Birmingham

LMU Ludwig-Maximilians-Universität München

cnrs

Central Laser Facility

UKRI Science and Technology Facilities Council

ASTeC
Daresbury Laboratory
Particle Physics Department
ISIS Neutron and Muon Source

Stanford University

ASU Arizona State University

UCSF University of California San Francisco

Partners: University, Clinical, Laboratory, Industry, Accelerator

institut Curie

The Royal Marsden NHS Foundation Trust

UCL University College London

Royal Holloway University of London

USC Universidade de Santiago de Compostela

NHS University Hospitals Birmingham NHS Foundation Trust

University of Strathclyde Glasgow

Queen Mary University of London

INFN Catania

LEO Cancer Care

ISMO

University of Liverpool

Manchester 1824

The Cockcroft Institute of Accelerator Science and Technology

Berkeley Lab — Lawrence Berkeley National Laboratory

CERN

The Rosalind Franklin Institute

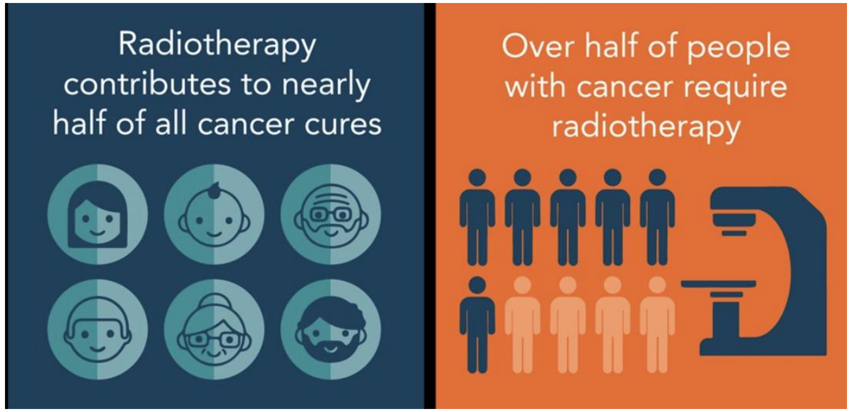
NPL National Physical Laboratory

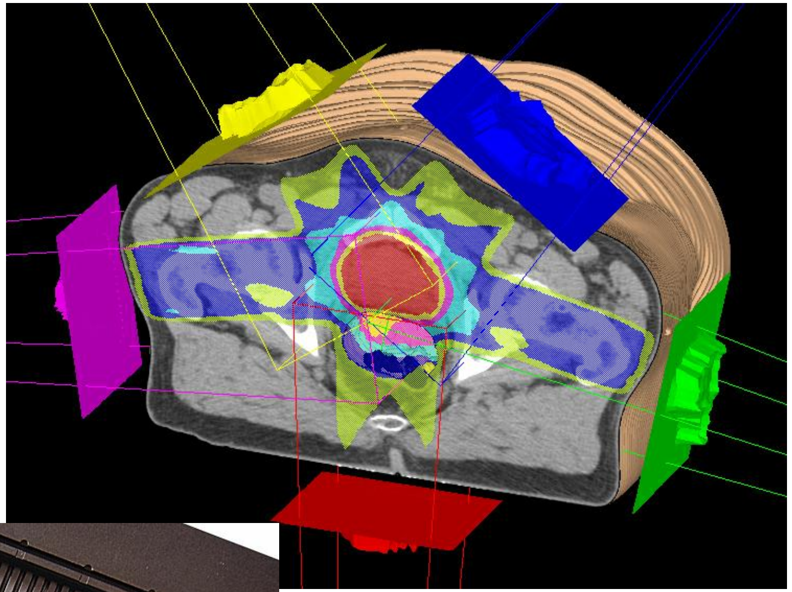
UKRI Science and Technology Facilities Council

Cancer & The Radiotherapy Challenge

Growth in cancer cases & deaths[1]:

- 14.1 million new cases in 2012 > 24.6 million by 2030
- 8.2 million cancer deaths in 2012 > 13.0 million by 2030





- 2017: £467m spent on radiotherapy
- 62% on equipment costs: £1.7m / linac, £3.8m / SBRT system
- Mean total cost of radiotherapy per patient = £3,672

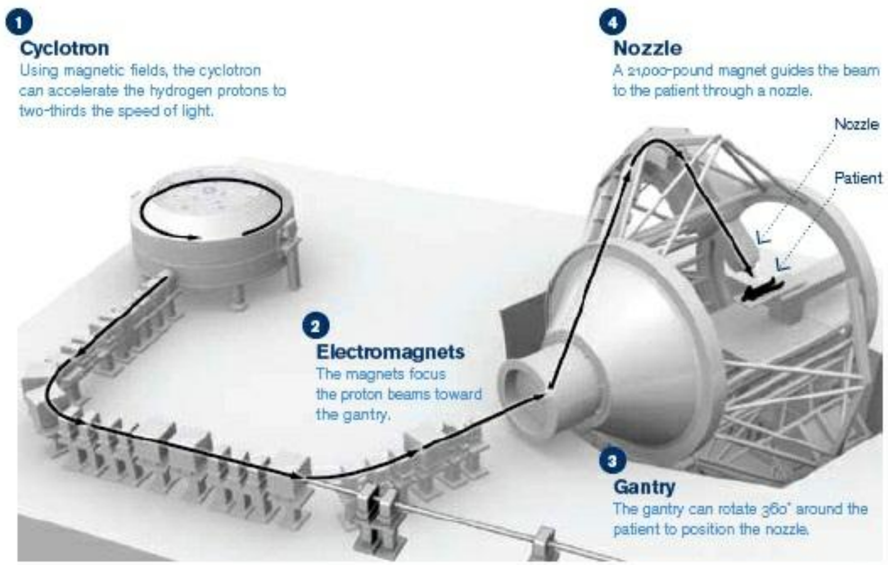
- 2020-21: £336m spent on cancer drugs
- Mean cost per patient =just under £24,000

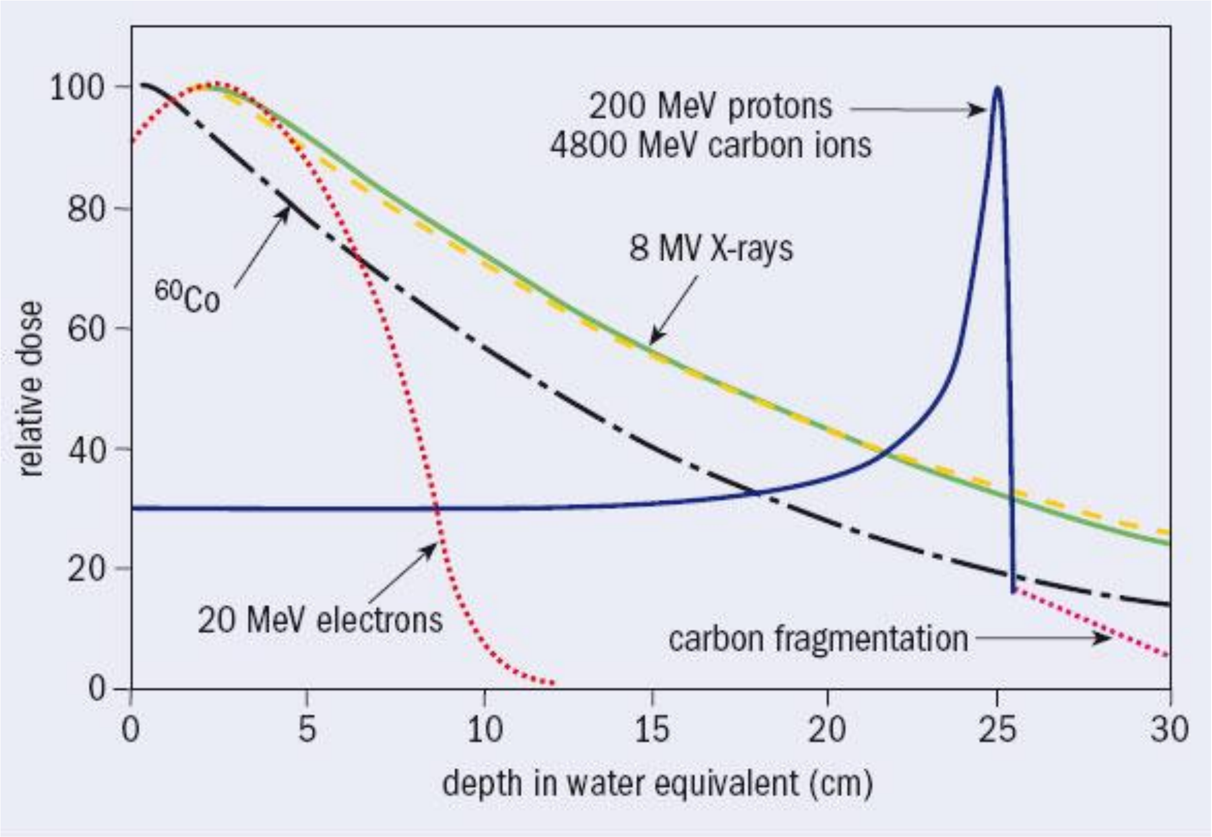
(National costs and resource requirements of radiotherapy: costing estimate for England from the ESTRO-HERO project)

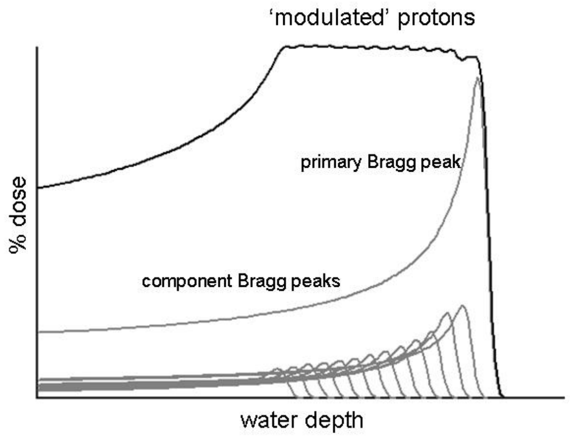
[1] Atun, Lancet Oncol. 2015 Sep;16(10):1153-86

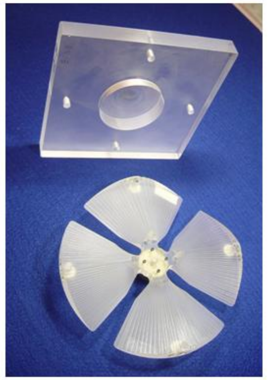
[2] www.cancerresearchuk.org (2025)

Protons and more…





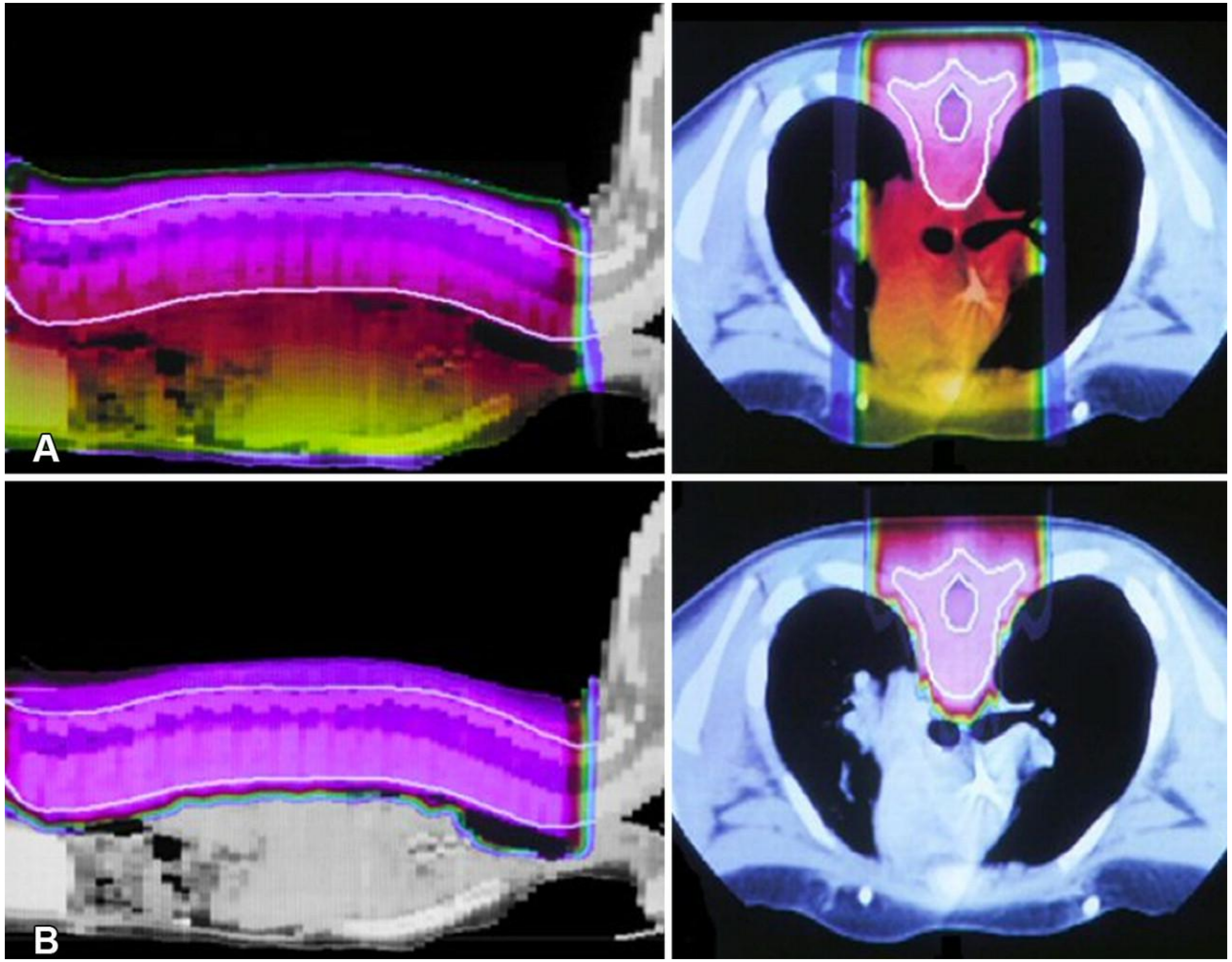




$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2\beta^2}{I\cdot(1-\beta^2)}\right) - \beta^2\right]$$

Owen et al.: https://doi.org/10.1142/S0217751X14410024
Owen et al: https://doi.org/10.1080/00107514.2014.891313
Owen, Lomax and Jolly: https://doi.org/10.1016/j.nima.2015.08.038

Proton vs X-ray treatment plan, pediatric medulloblastoma



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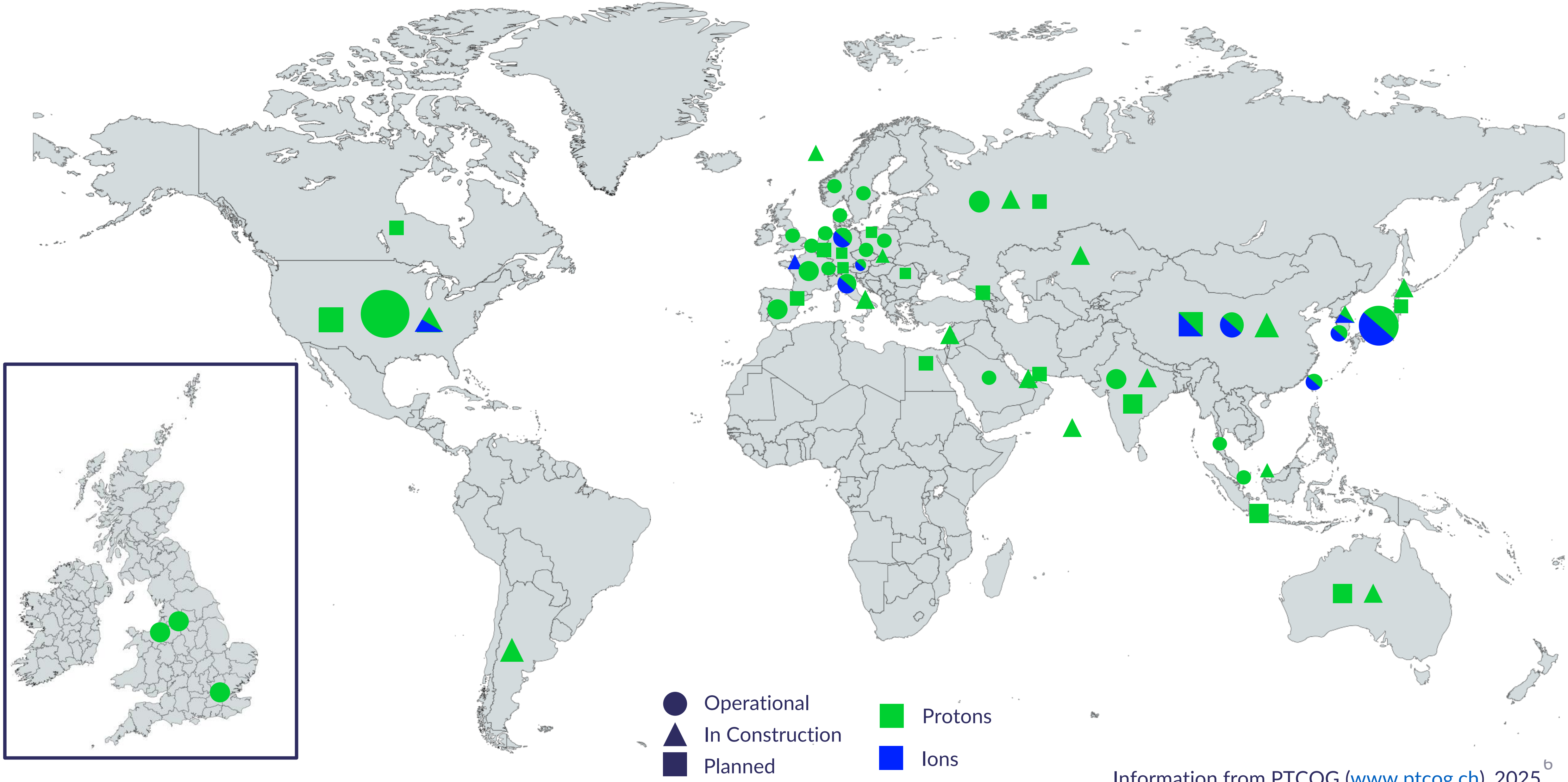
Proton and Ion Therapy Across the World

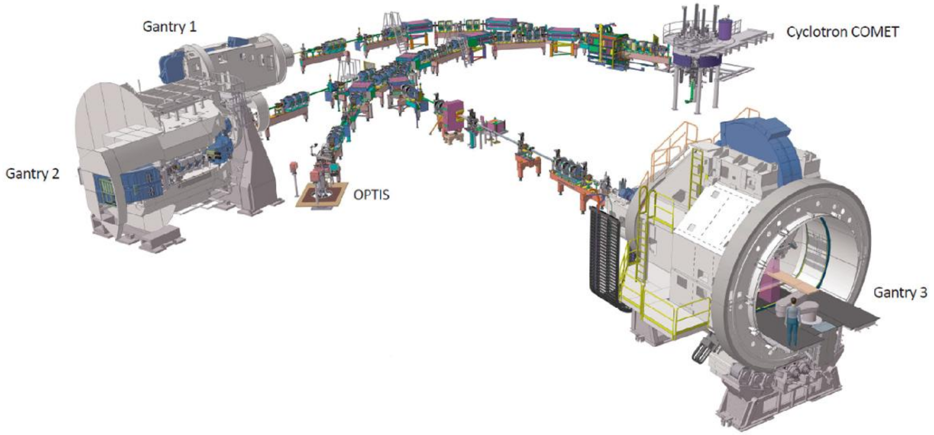


Information from PTCOG (www.ptcog.ch), 2025

Why not cyclotrons?

Liverpool 37” cyclotron, 20 MeV, 1939

Varian ProBeam (C14) “Emmeline”

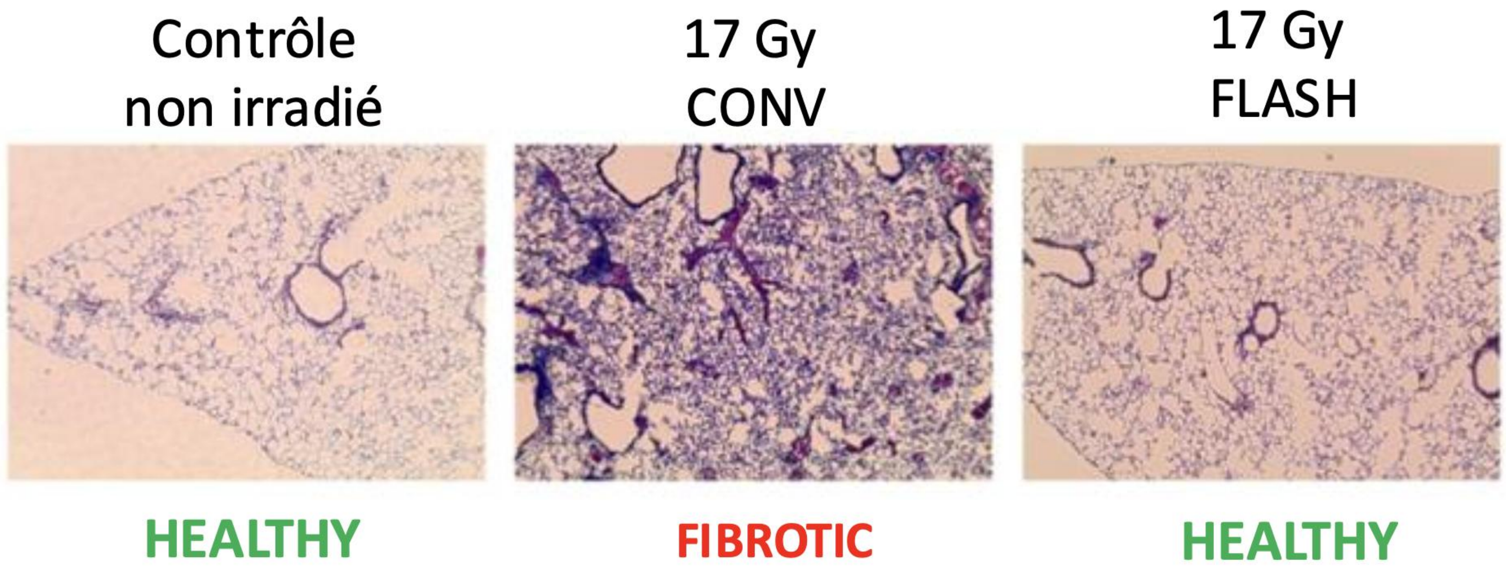


Science and Technology Facilities Council

Jolly et al., https://doi.org/10.1016/j.ejmp.2020.08.005

Novel Beam Therapies: FLASH

Very high instantaneous dose rates, often considered at **>40 Gy/s.**



Biological effect: absence of radiation-induced toxicity in normal tissue.

Favaudon et al., https://doi.org/10.1126/scitranslmed.3008973

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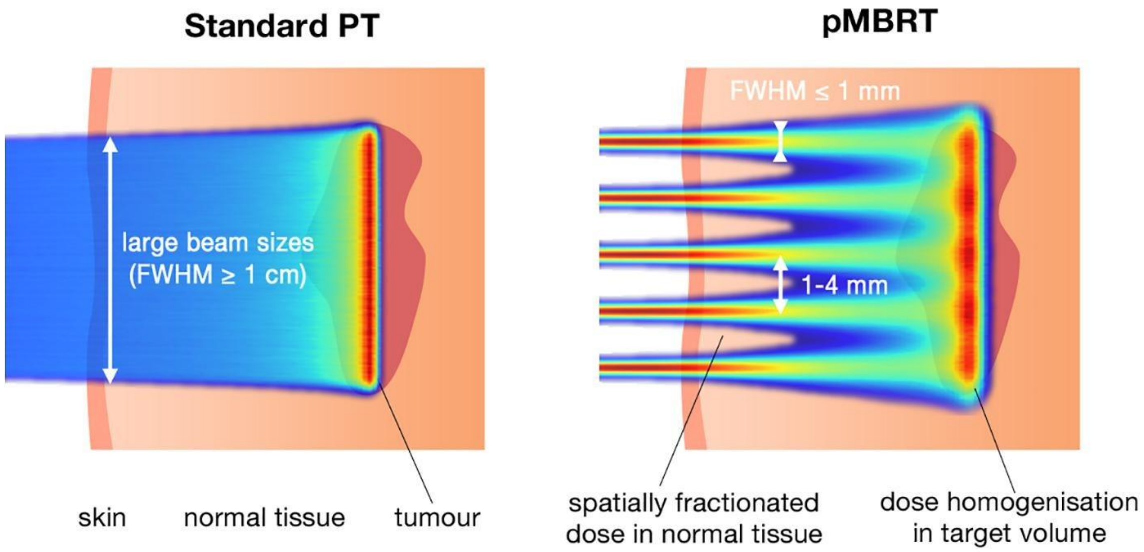
Novel Beam Therapies: Minibeams

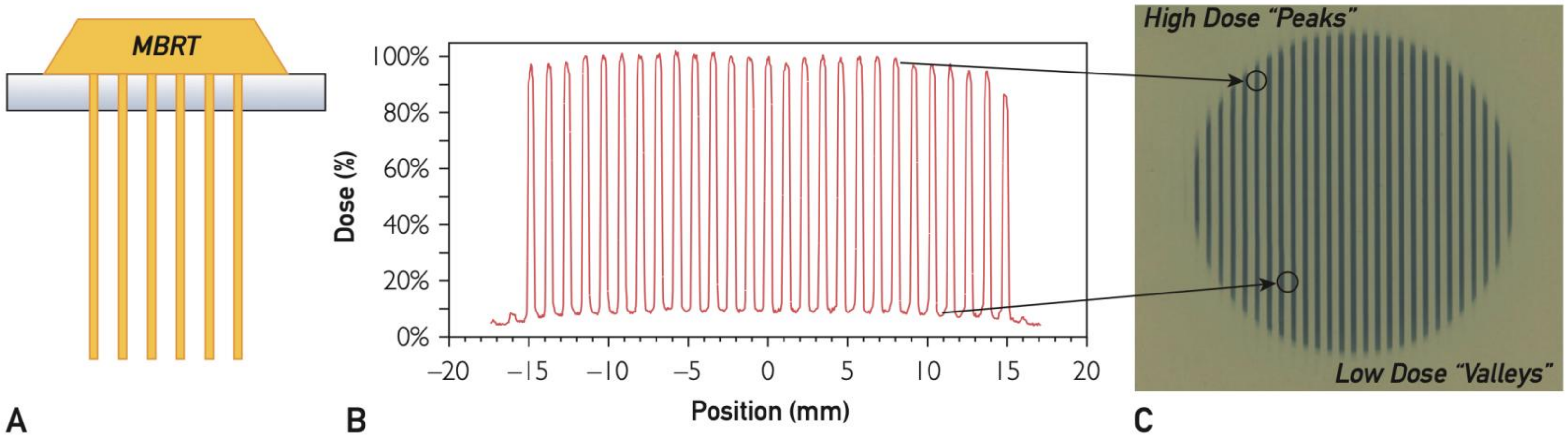
Minibeams

- Dose delivered in beamlets
    - Beam widths between 0.1 and 1 mm FWHM (regular beam sizes > 1cm).

Spatial fractionation dose delivery has been shown to reduce neurotoxicity and skin toxicity.



DOI: 10.1016/j.ejmp.2022.06.010



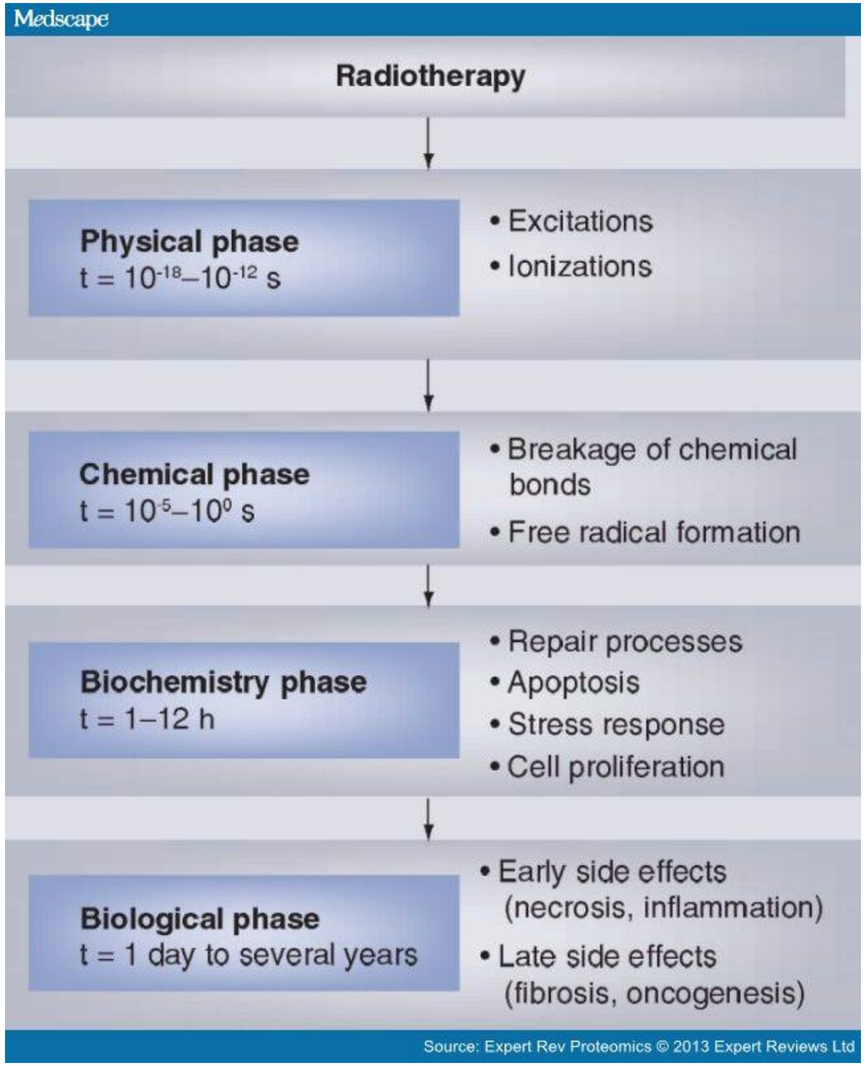
Science and Technology Facilities Co

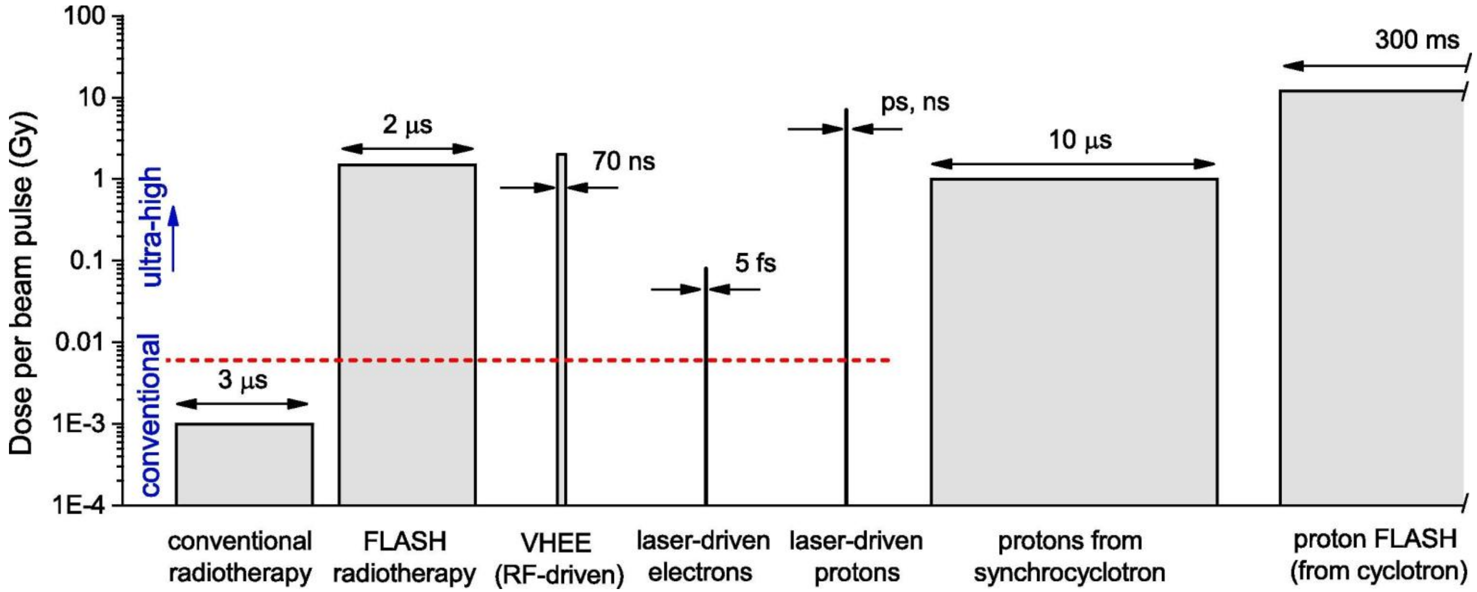
Mayo Clin Proc Inn Qual Out, August 2025;9(4):100640

https://doi.org/10.1016/j.radonc.2022.08.004

Timescales of radiobiology

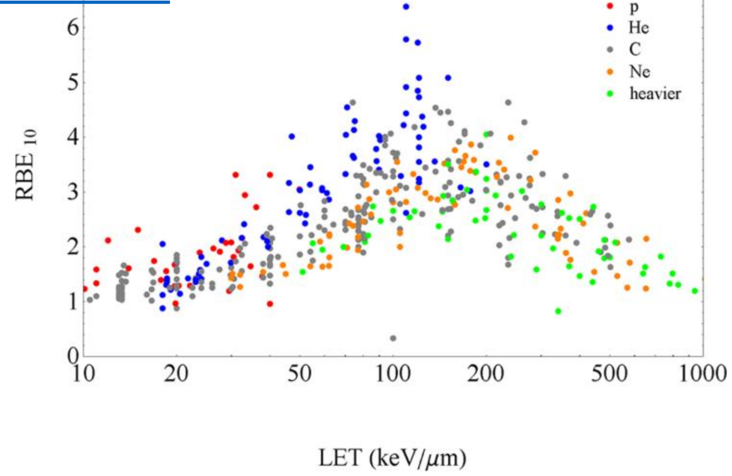
Schueller et al.: doi:10.1016/j.ejmp.2020.09.020





Prezado: https://doi.org/10.1017/erm.2021.34

- Many factors determine the tumour response:
  - Dose
  - Dose rate
  - Particle species
  - Beam energy
  - Beam spatial profile
  - Temporal profile
  - Tissue type
  - Tissue location



Durante et al. https://doi.org/10.1016/j.physrep.2019.01.004

Ion Therapy Research Facility Using LhARA

Laser-driven, high-flux proton/ion source

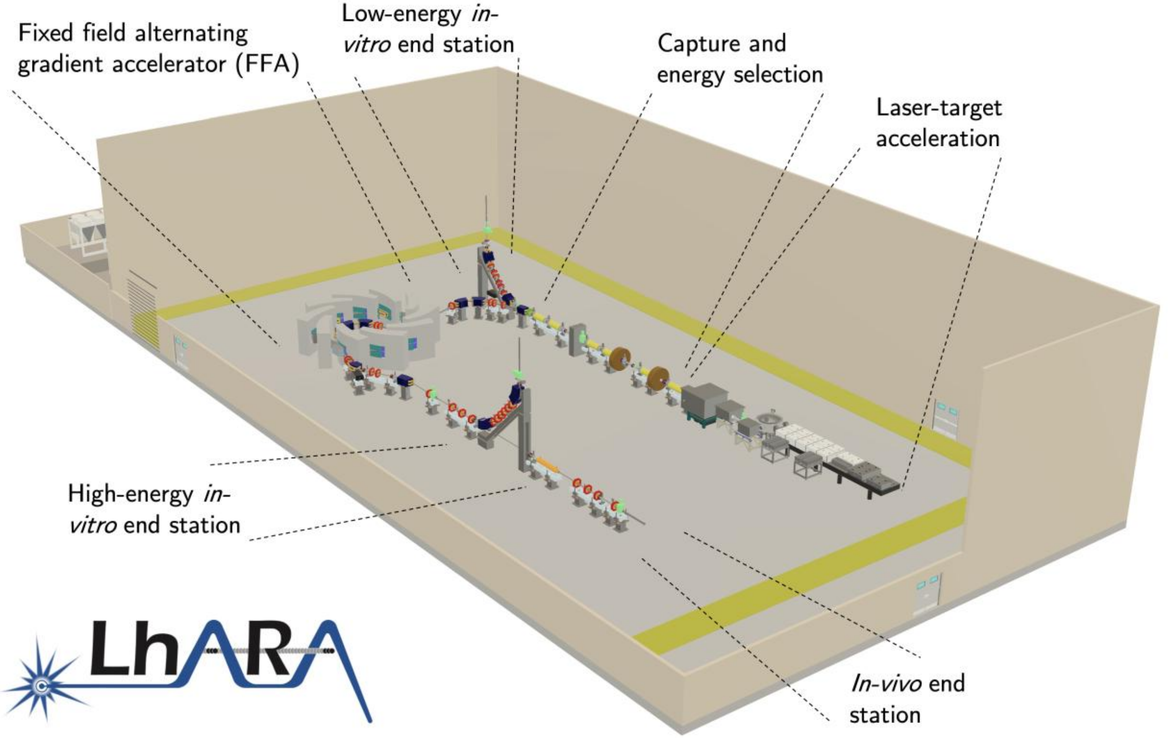
- Overcome instantaneous dose-rate limitation
- Delivers protons or ions in 10-40 ns pulses
- Triggerable; arbitrary pulse structure

Novel electron-plasma-lens capture & focusing

- Strong focusing (short focal length) without high-field solenoids
- Fast, flexible, fixed-field post acceleration

Protons: 15-127 MeV

Ions: 5-34 MeV/u



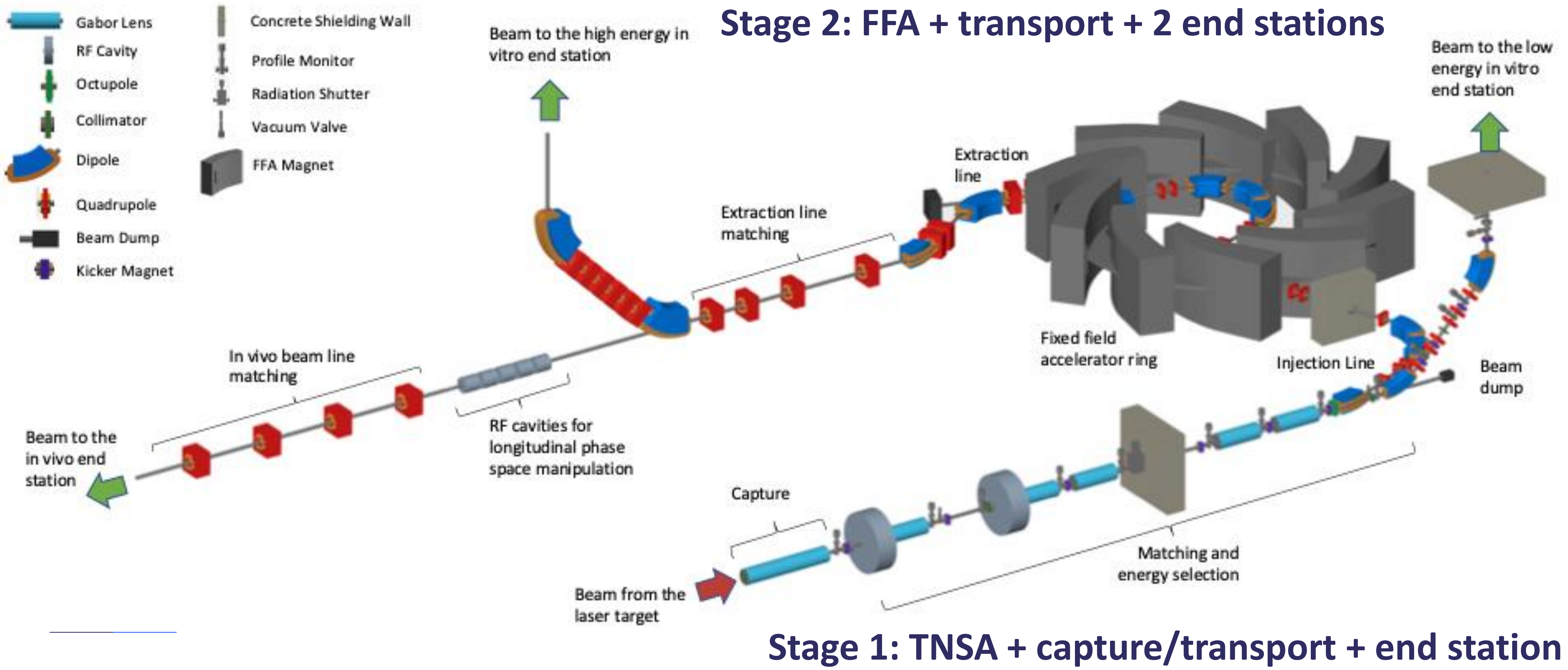
LhARA performance summary arXiv:2006.00493

	12 MeV Protons	15 MeV Protons	127 MeV Protons	33.4 MeV/u Carbon
Dose per pulse	7.1 Gy	12.8 Gy	15.6 Gy	73.0 Gy
Instantaneous dose rate	1.0×10^9 Gy/s	1.8×10^9 Gy/s	3.8×10^8 Gy/s	9.7×10^8 Gy/s
Average dose rate	71 Gy/s	128 Gy/s	156 Gy/s	730 Gy/s

Science and Technology Facilities Council

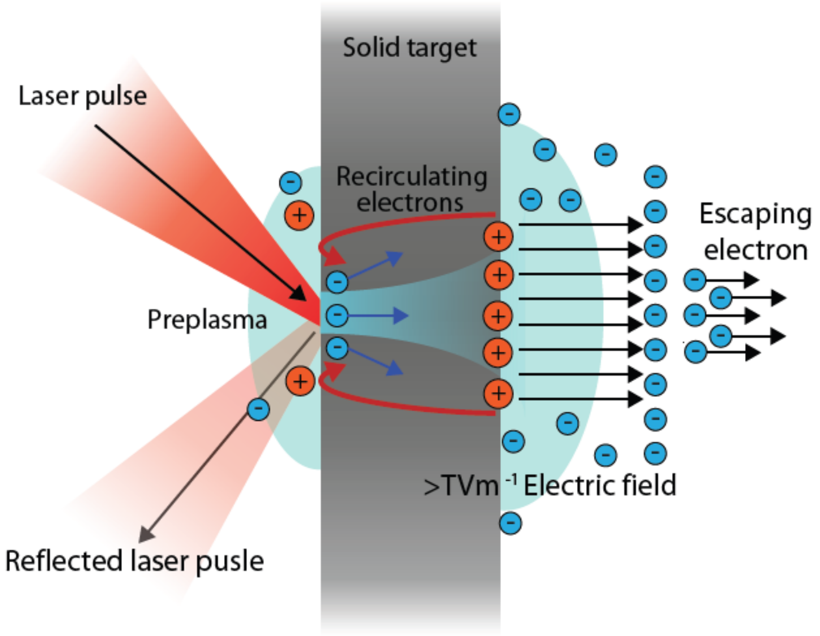
UKRI Infrastructure Fund 2022 – 2025, Preliminary Activity + extensions

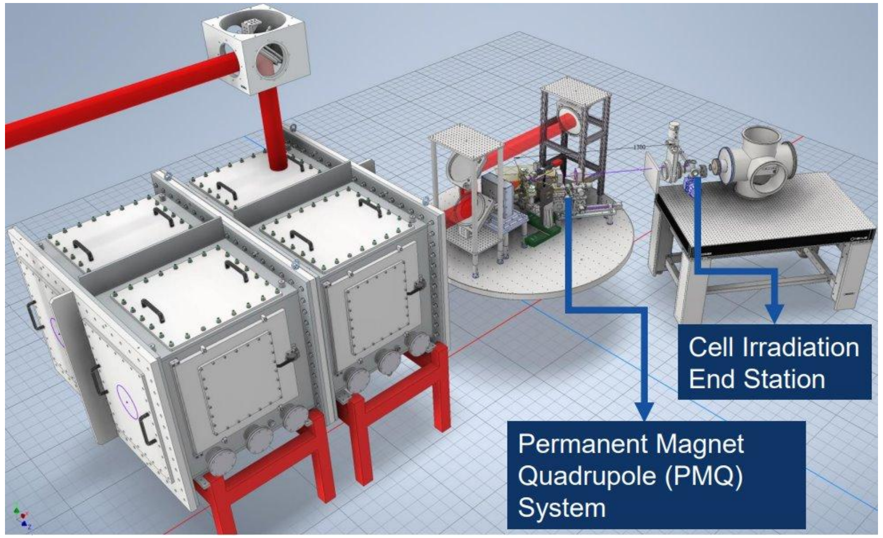
LhARA Schematic



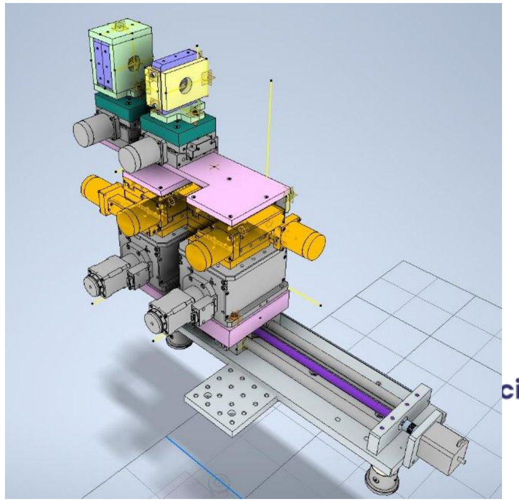
Laser-Target Source Generation

University of Strathclyde, C Whyte, R. Wilson + N. Dover (Imperial) + others





- Laser-driven Target Normal Sheath Acceleration (TNSA)
  - 10 GV/m - up to ~40 MeV/u.
  - ps - ns pulses
  - Small beam size ≃ laser spot size
    - Low transverse emittance ($<10^{-2}$ mm-mrad)
  - Highly divergent
  - High bunch charge
  - Co-propagating electrons – space charge neutralization.
  - 10 Hz repetition rate (laser)



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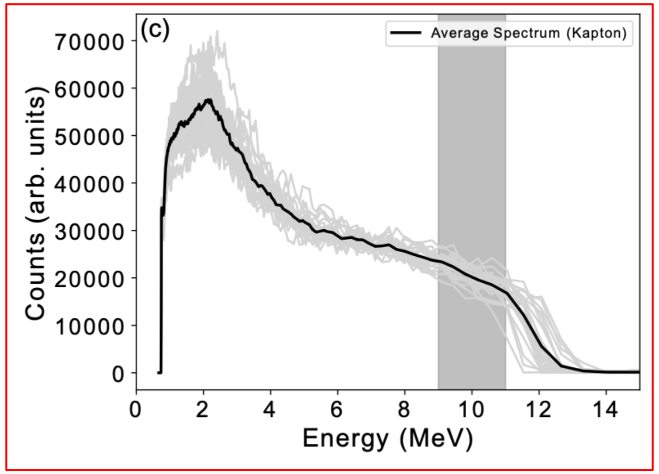
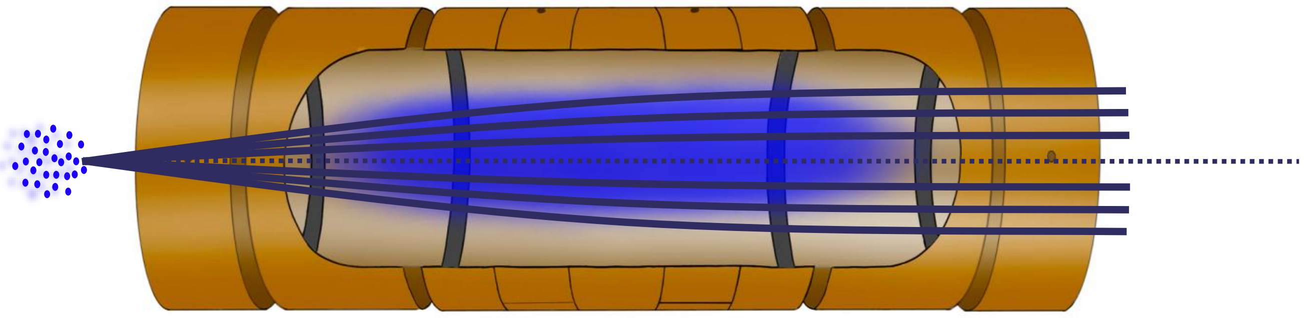
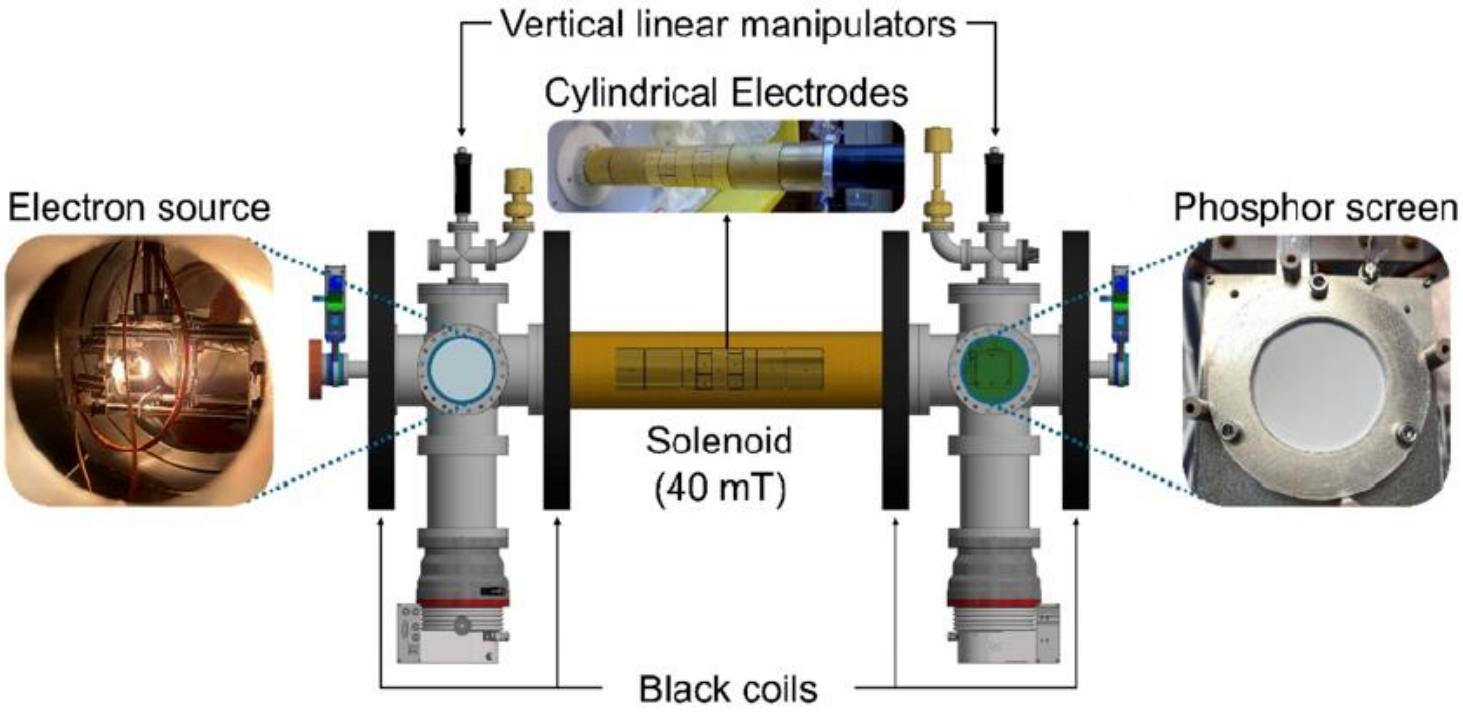


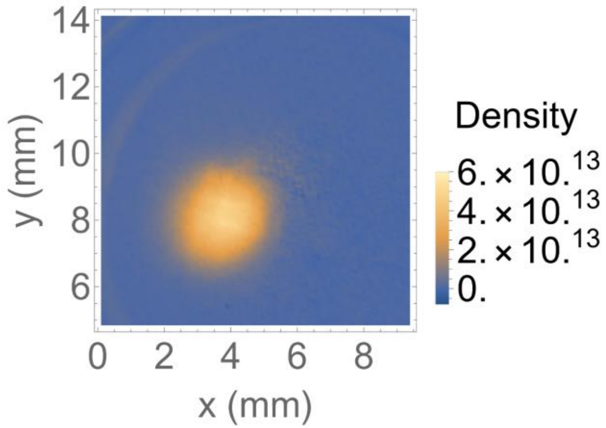
Gabor Plasma Lenses

- Plasma confinement with external E field & solenoid B fields
  - Penning-Malmberg trap
- Radial solenoid –like focusing $\frac{1}{f} = \frac{e^2 n_e l}{4\varepsilon_0 U}$





- Focussing strength proportional to plasma density.
- Equivalent solenoid strength for LhARA: 1.4 T
  - Confinement solenoid field: ~ 35 mT

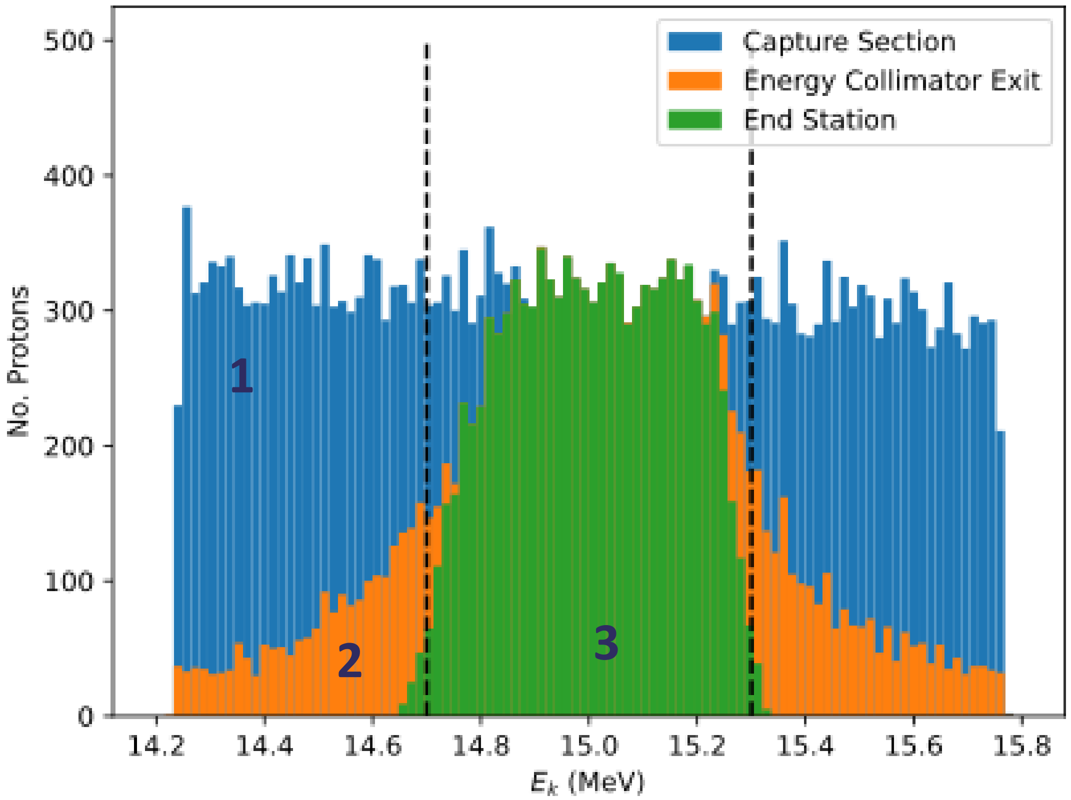


University of Swansea, P. Rususukchai and others

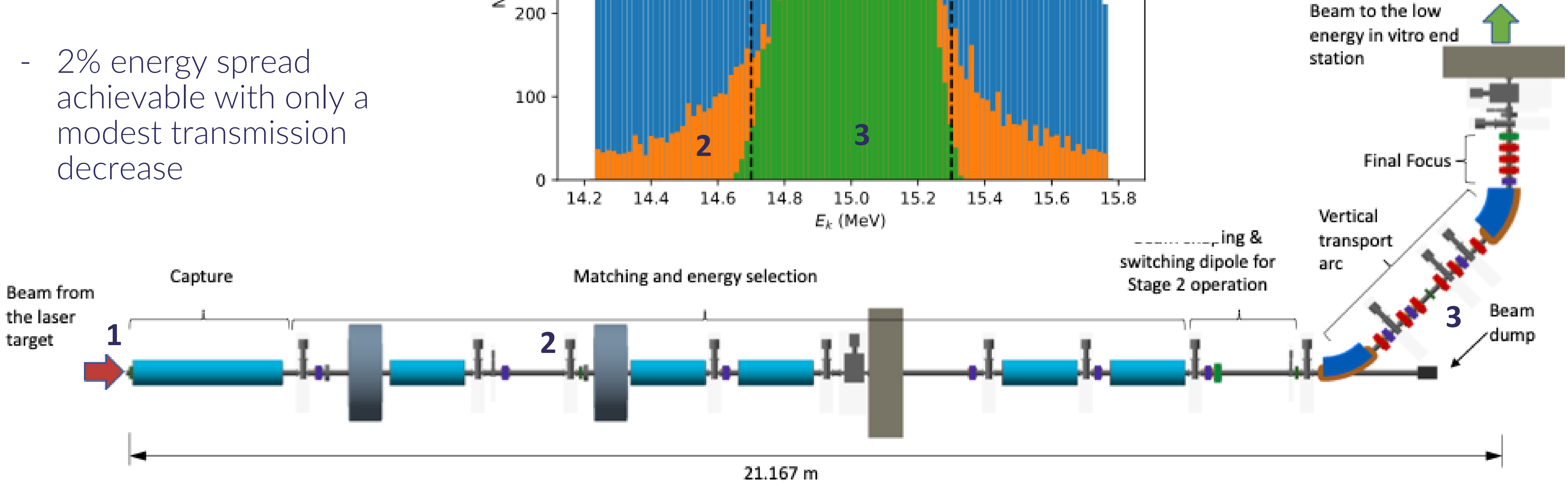
Stage 1 Energy/Momentum Cleaning

- LhARA energy/momentum cleaning:
  - 1: Source (15 MeV ± 2%)
  - 2: Energy selection
  - 3: Momentum cleaning

- 2% energy spread achievable with only a modest transmission decrease

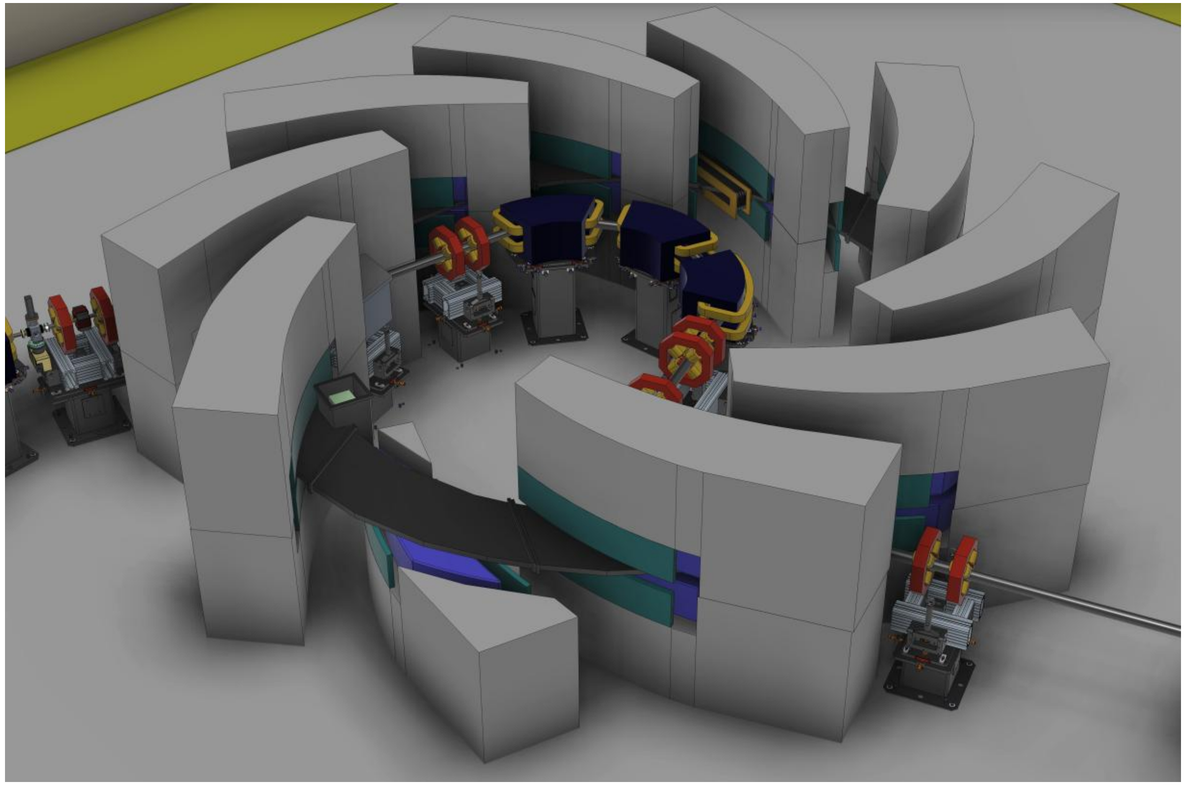


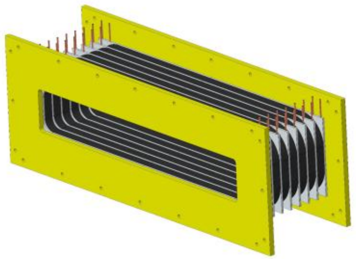
W. Shields, M. Pereira (RHUL)



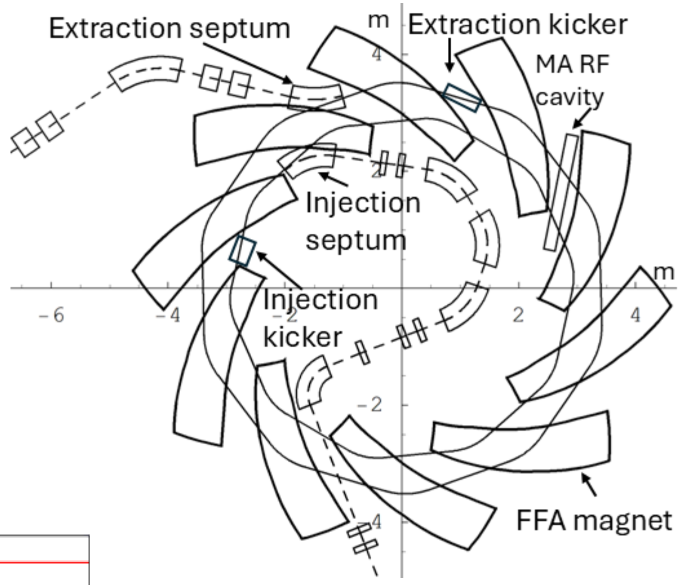
Stage 2: LhARA FFA

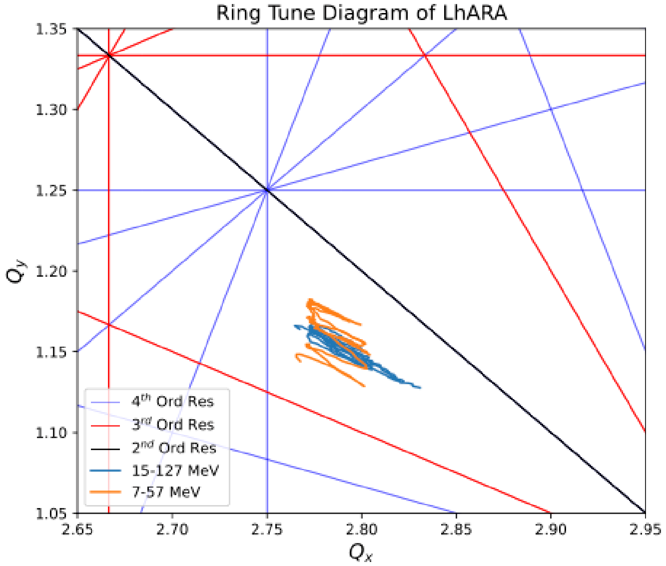
- Proton acceleration from 15 MeV to 127 MeV
  - Carbon ions - 4 MeV/u to 33.4 MeV/u
- 10 cell, single spiral scaling FFA
- Maintain short pulse structure
- Fast extraction rates (up to ~100 Hz)





- Two RF cavities
  - Ferrite loaded or Magnetic-alloy





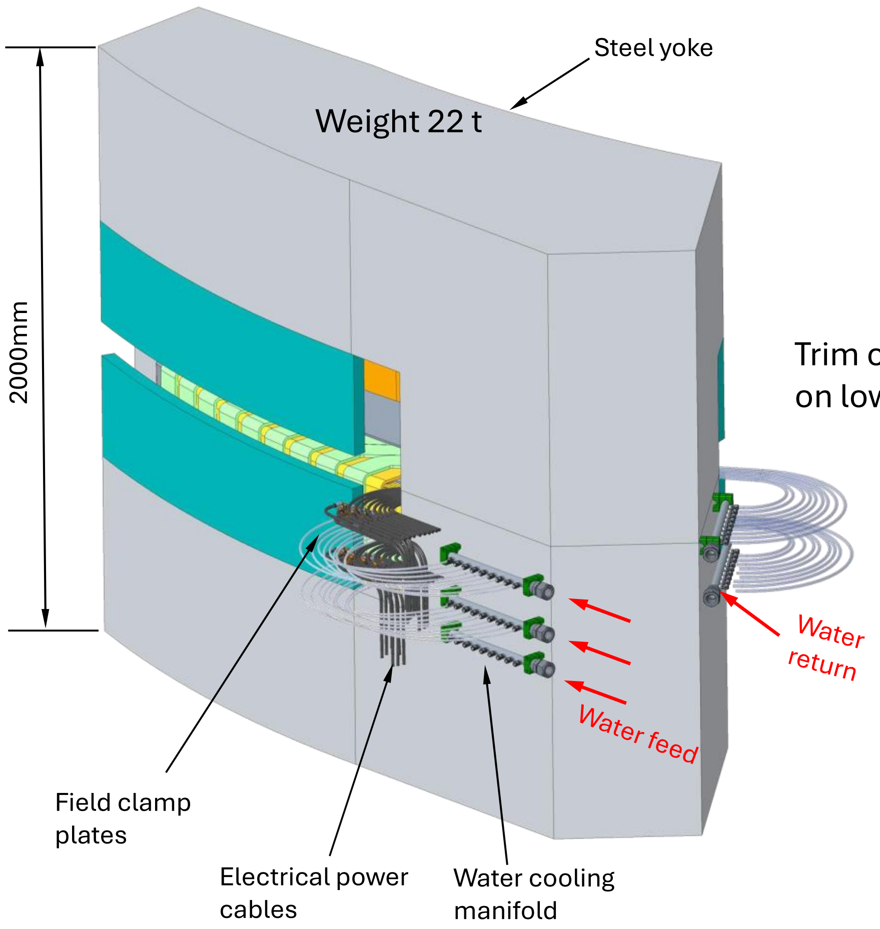
J. Pasternak, T-J Kuo (Imperial)

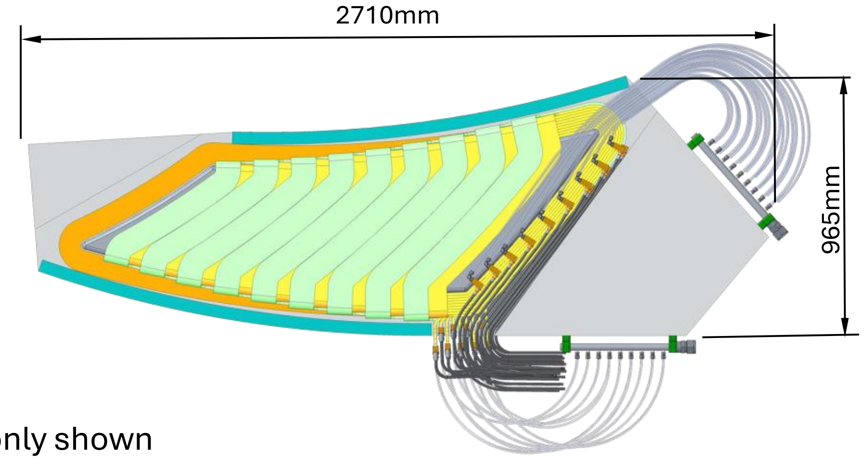
EMMA: https://doi.org/10.1038/NPHYS2179
PAMELA: https://doi.org/10.1103/PhysRevSTAB.16.030101

FFA Magnet Design

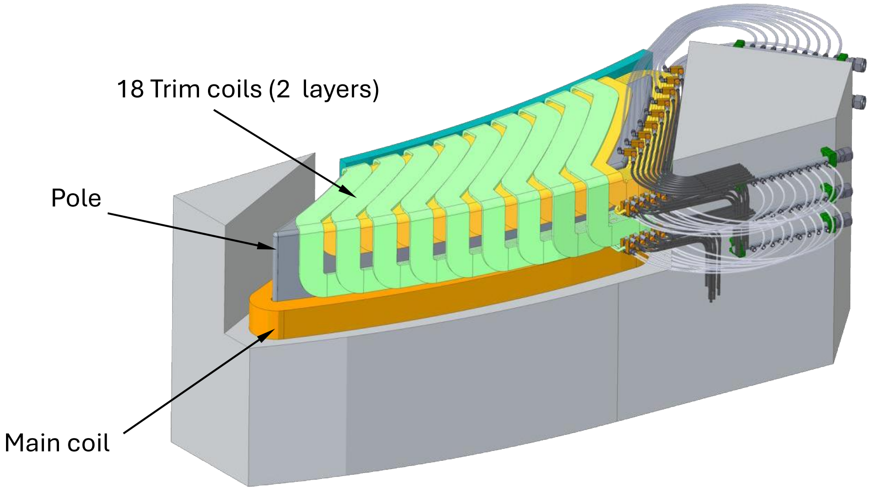
OPERA 3D magnet model - optimised field clamps and trim-coil configurations.

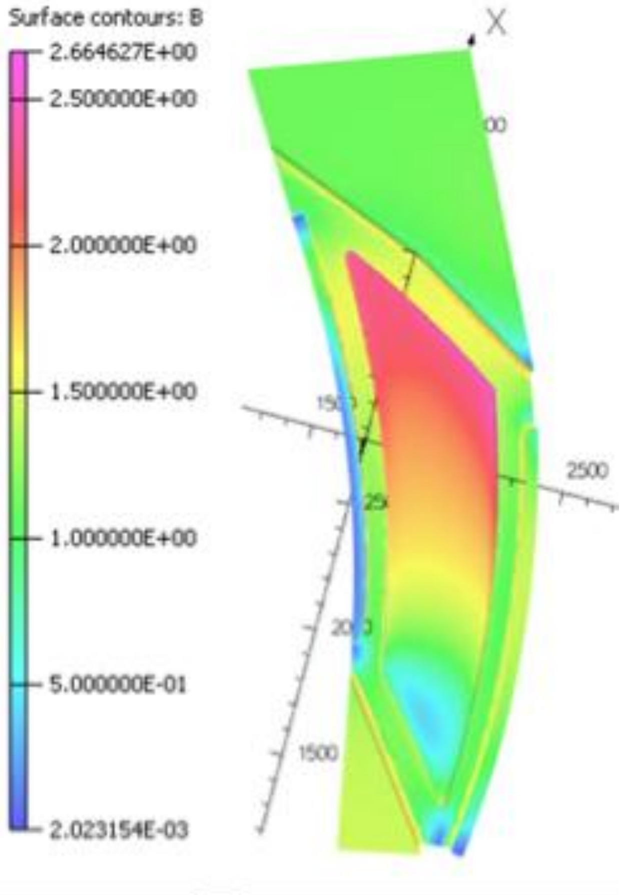
FFA Magnet





Trim coils only shown on lower pole



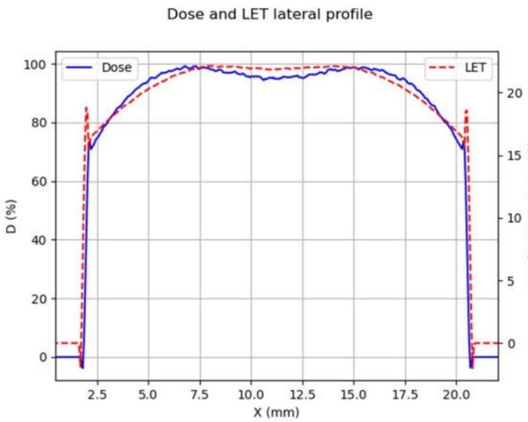


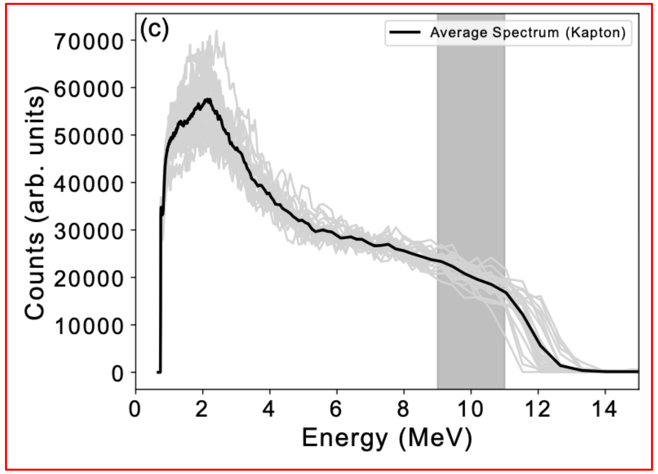
Ta-Jen Kuo (Imperial), Clive Hill (STFC) + others

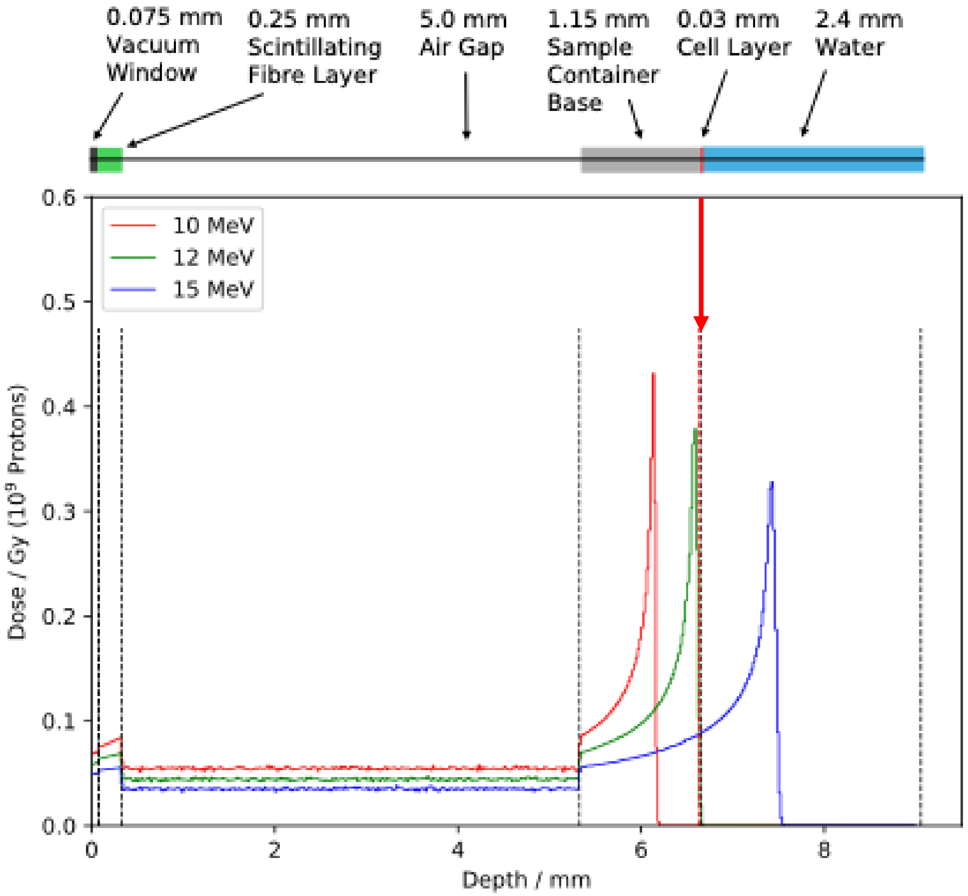
Stage 1: End Station Dose

W. Shields (RHUL), T. Price (Birmingham)

- End station dose deposition (BDSIM modelling)
  - Monoenergetic, idealised beams
  - Radiobiological effects from different Bragg curve regions.
- Dose recorded in the same volume as a Markus Ion Chamber (ionisation)





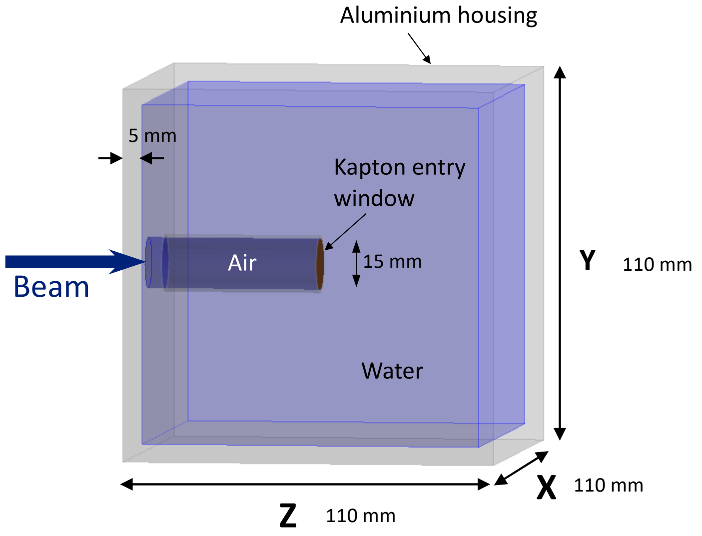


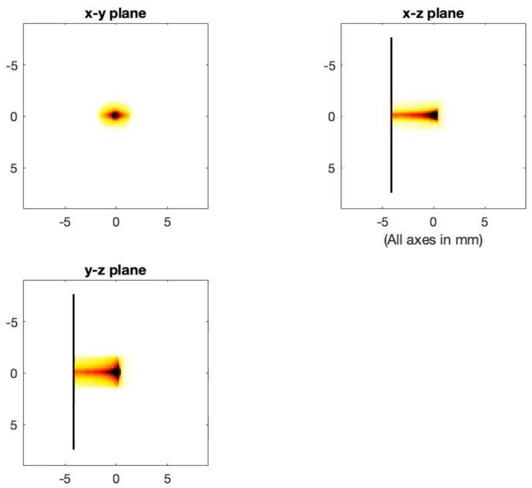
	12 MeV Protons	15 MeV Protons	127 MeV Protons	33.4 MeV/u Carbon
Dose per pulse	7.1 Gy	12.2 Gy	9.7 Gy	83.8 Gy
Instantaneous dose rate	0.7×10^9 Gy/s	1.2×10^9 Gy/s	2.3×10^8 Gy/s	1.1×10^9 Gy/s
Average dose rate	71 Gy/s	122 Gy/s	97 Gy/s	838 Gy/s

Scie
Tech
Facil

Ion Acoustic Dose Profiling

Ion-Acoustics Simulation: Energy Depositions, Acoustic wave generation & propagation

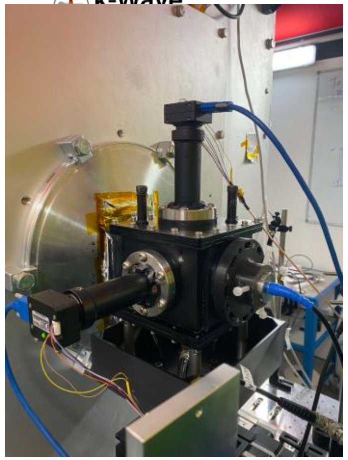




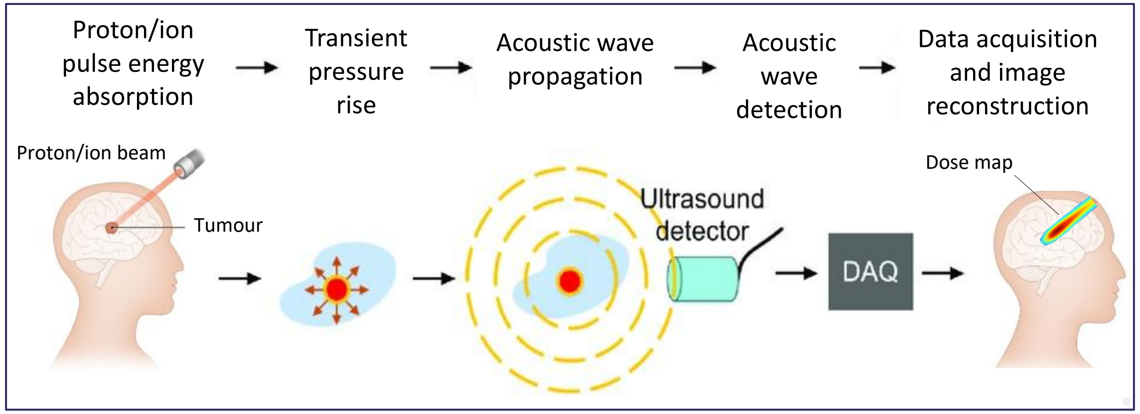
GEANT4

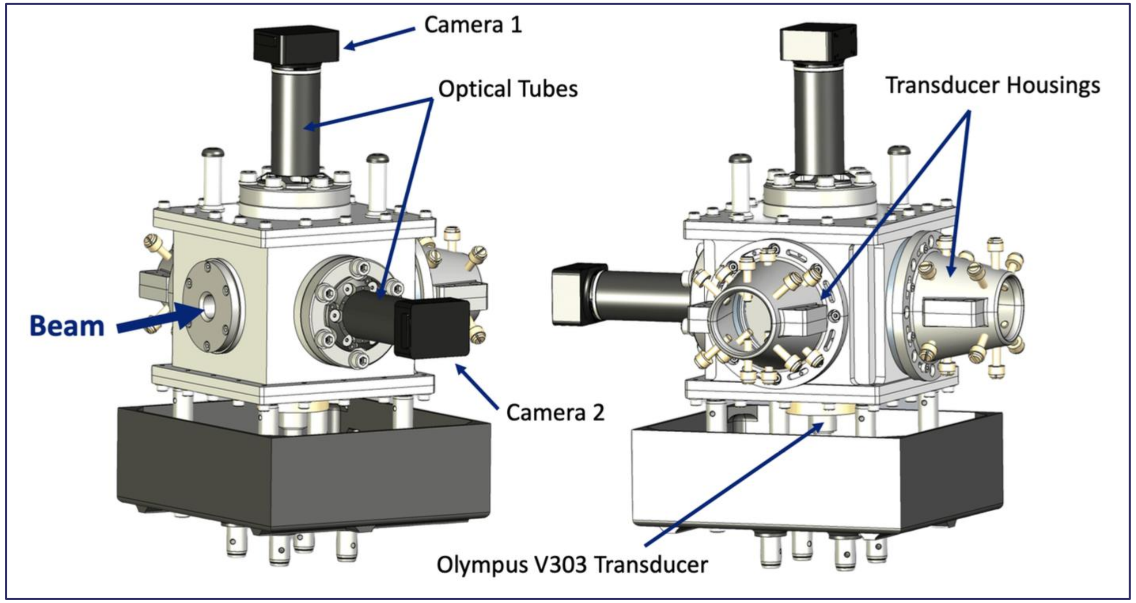
k-Wave

- Test exposure on LION at LMU
- Match experimental data to simulation (k-Wave & Geant4)



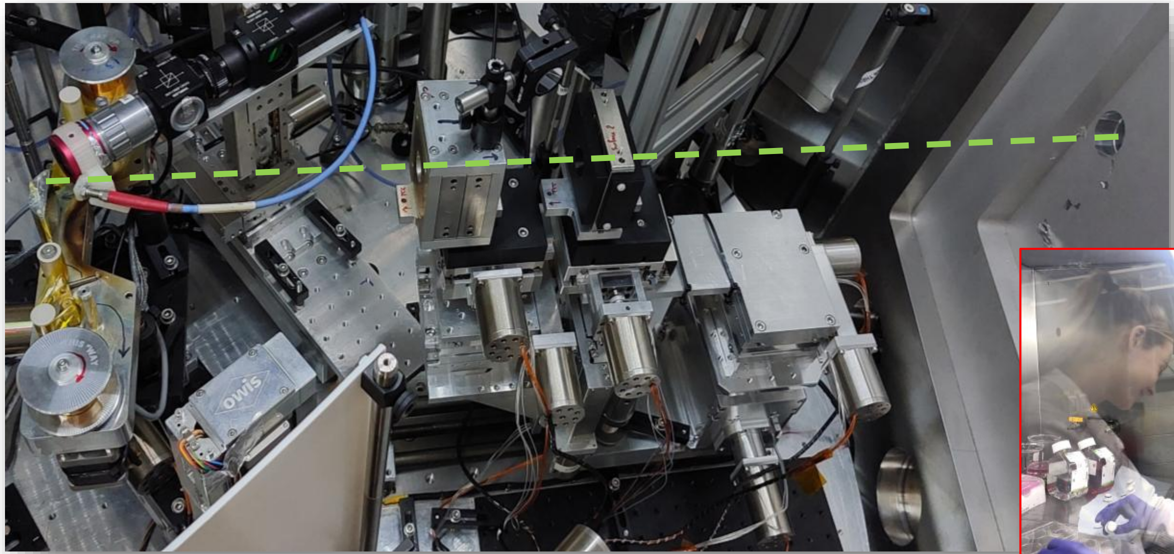
UKRI Science and Technology Facilities Council





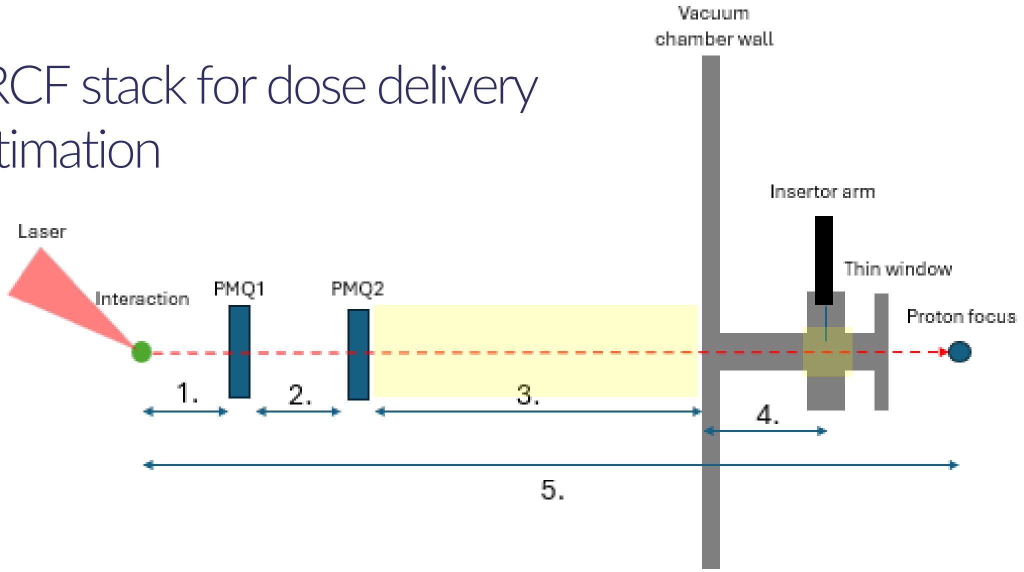
M. Maxouti + others (Imperial)

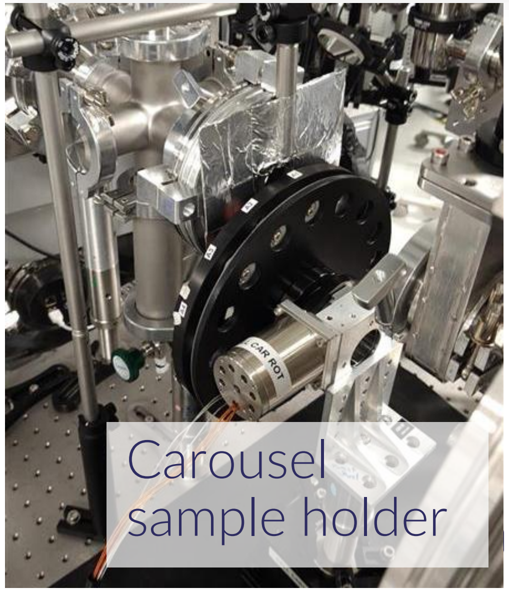
PoPLaR at SCAPA

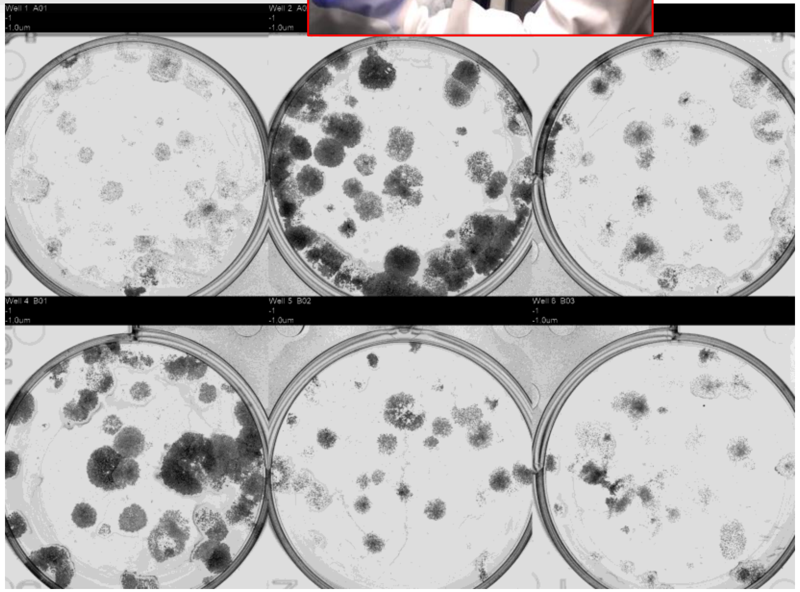


-Capture with 2 PMQs

- RCF stack for dose delivery estimation







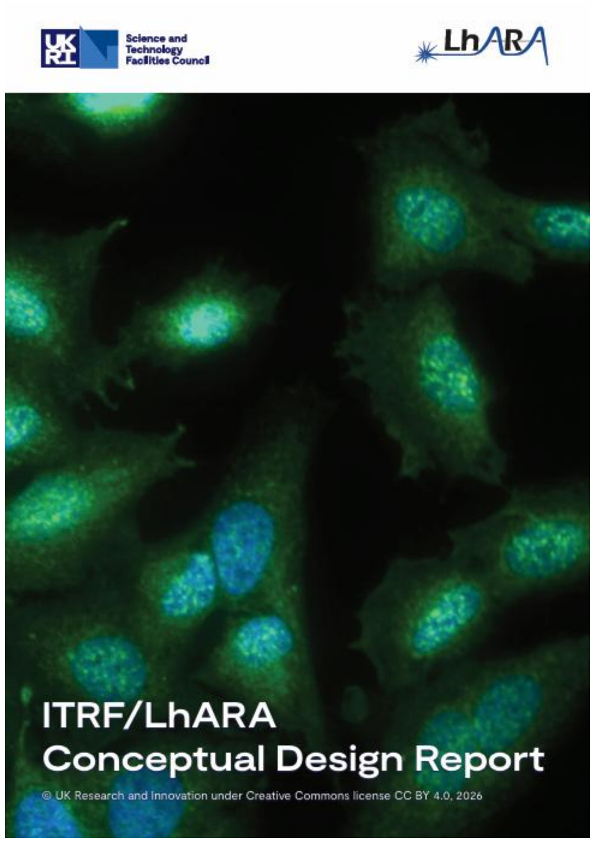
Emma Melia (Birmingham)

- Irradiation experiments to determine cell survival curves
  - Reproduce results from Birmingham cyclotron
  - 0, 1, 2, & 4 Gy
  - Promising results, uncertainty in delivered dose

Josie McGarrigle, Calvin Dyson (Imperial)

CDR and other publications:

https://epubs.stfc.ac.uk/search/result?q=orgunitid%3A57001466



Latest updates at IPAC26:
https://www.ipac26.org/prepress/pdf/TUP8018.pdf

https://doi.org/10.5286/stfctr.2026007

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https://www.lhara.org/royal-society
https://royalsociety.org/science-events-and-lectures/summer-science-exhibition/