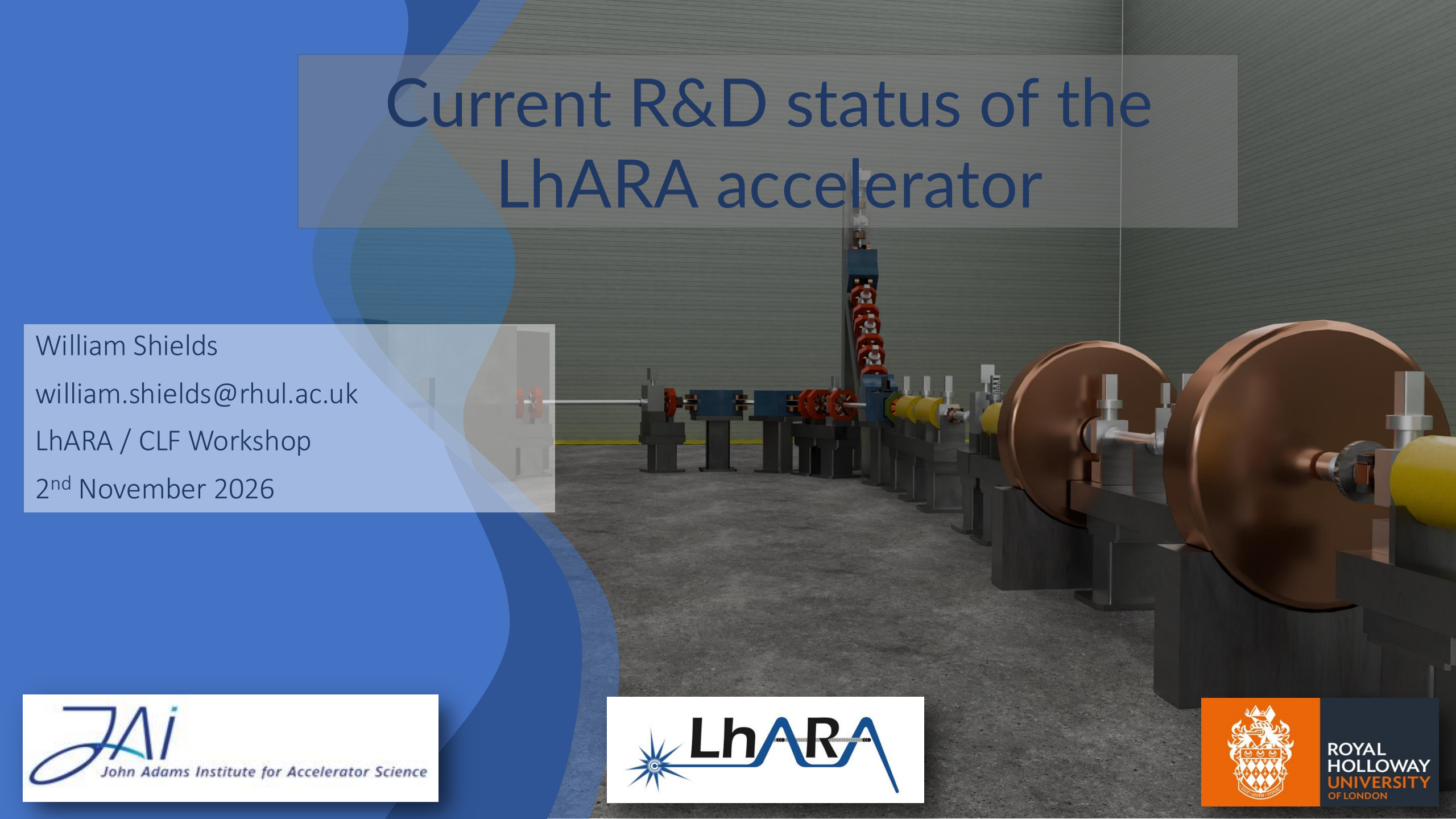
Current R&D status of the LhARA accelerator

William Shields

william.shields@rhul.ac.uk

LhARA / CLF Workshop

2nd November 2026



John Adams Institute for Accelerator Science

LhARA

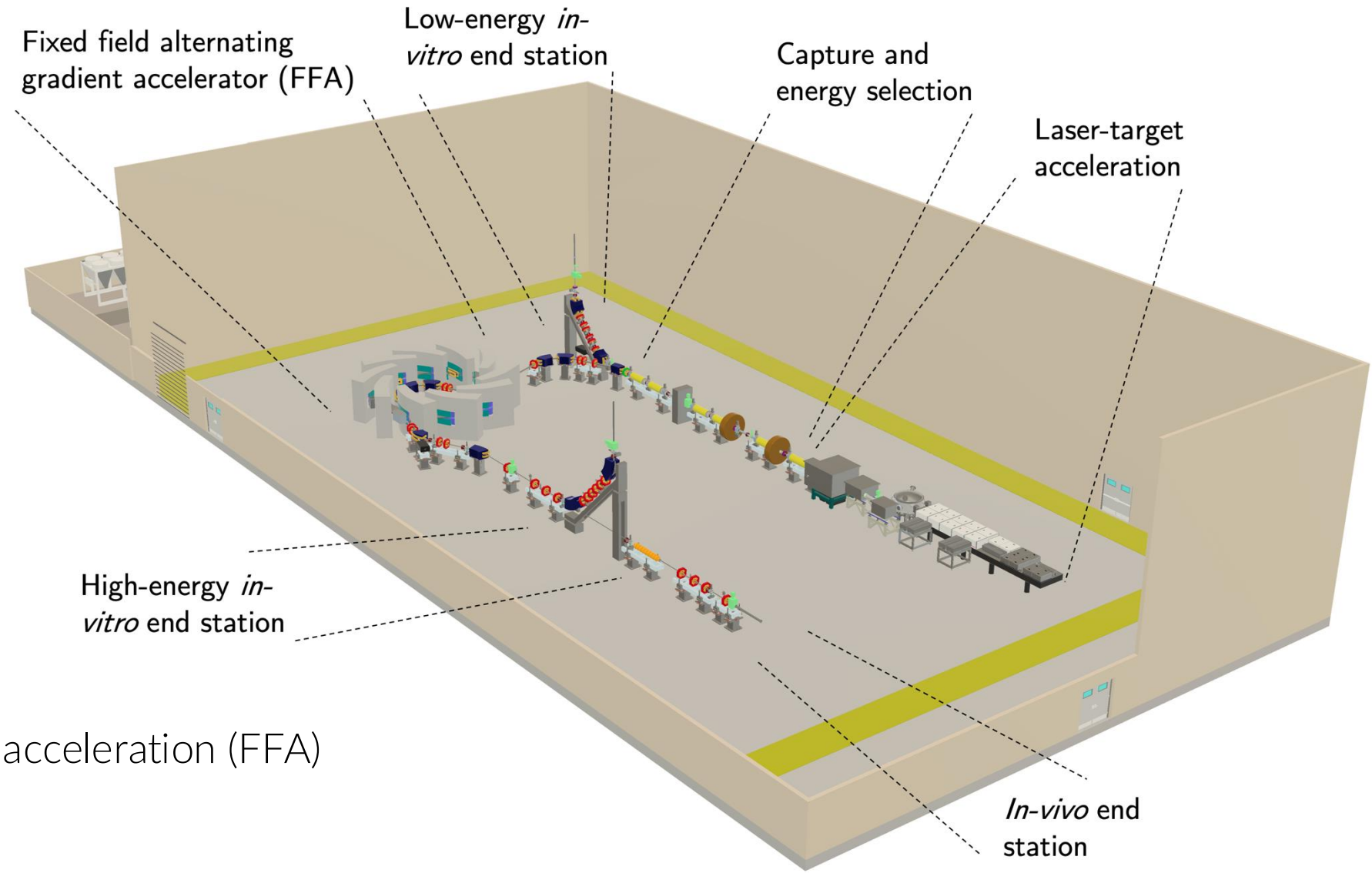
ROYAL HOLLOWAY UNIVERSITY OF LONDON

The LhARA Accelerator

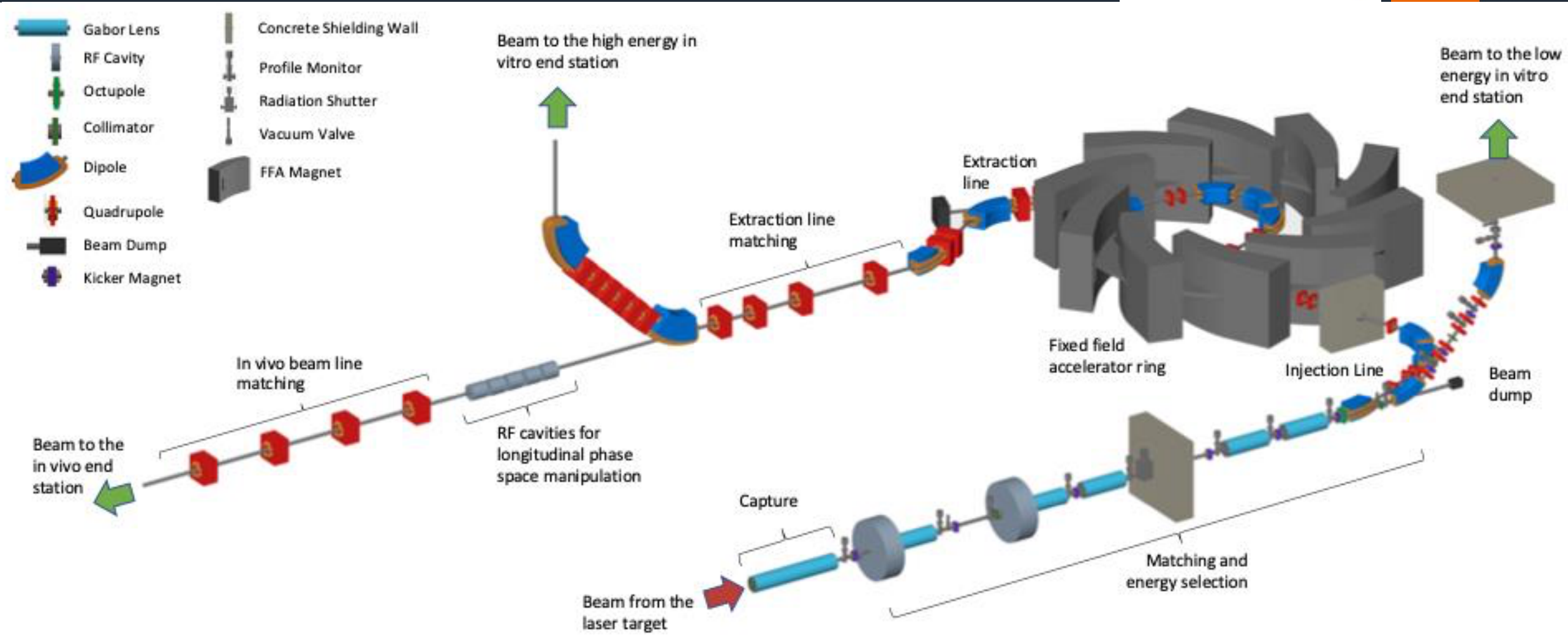
- Laser-driven, high-flux proton/ion source
  - Overcome instantaneous dose-rate limitation
  - Delivers protons or ions in 10-40 ns pulses
  - Triggerable; arbitrary pulse structure

- Novel electron-plasma-lens capture & focusing
  - Strong focusing (short focal length) without high-field solenoids

- Fast, flexible, fixed-field post acceleration (FFA)
  - Protons: 15—127 MeV
  - Ions: 5—34 MeV/u



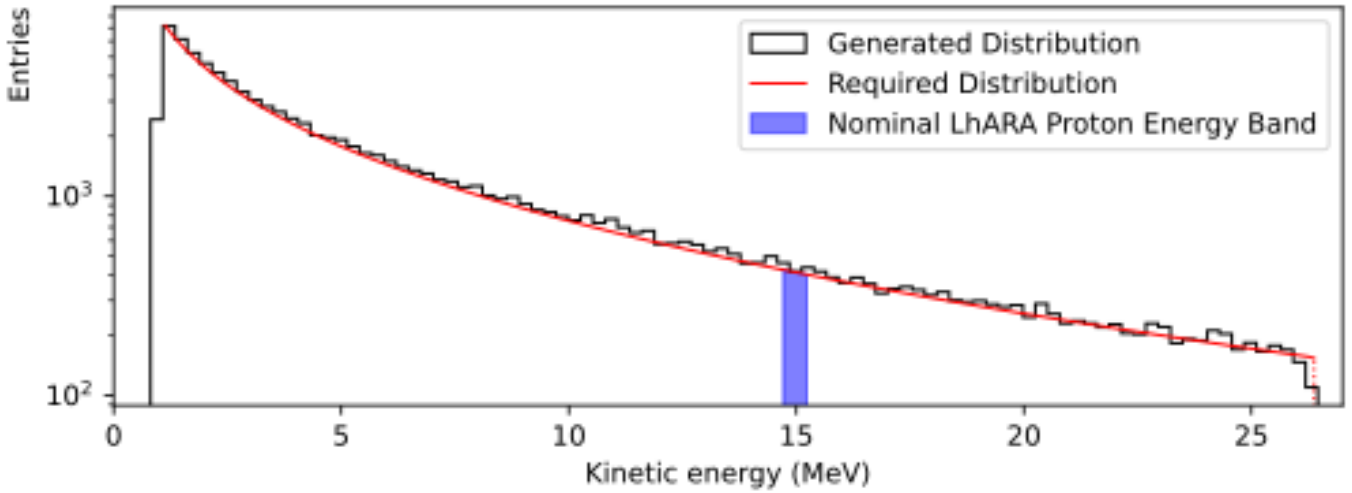
The LhARA Accelerator



BDSIM Beam Delivery Simulation

RF-Track

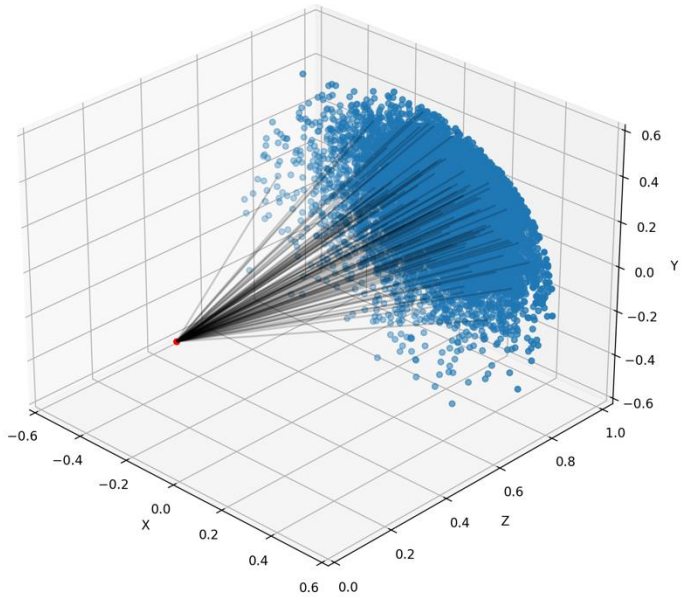
Laser-Target Beam Generation Modelling

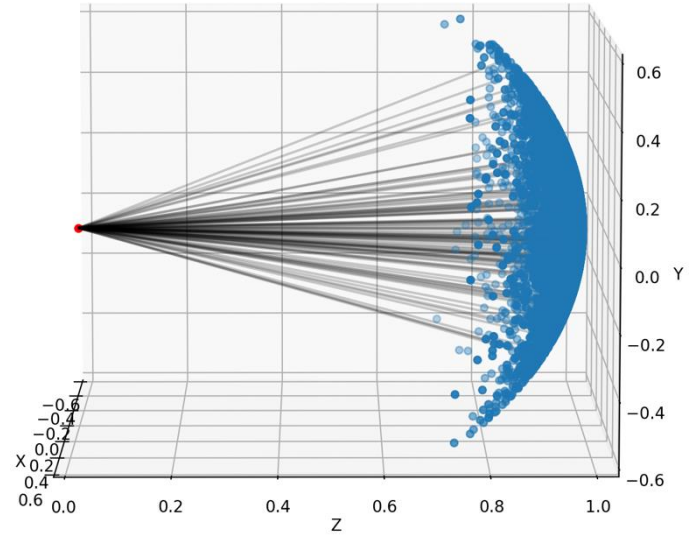


- Broad quasi-thermal particle spectrum
- 10^9 protons / 10^8 ions in a narrow energy band
  - 15 MeV protons
    - 4 MeV/u ^{12}C +

$$\sigma_{\theta_s}(E) = 20° - 15° \frac{E}{E_{max}}$$

Laser Parameters		
Central wavelength	800	nm
Energy after amplifier	>18	J
Energy stability (shot to shot)	<2	%
Energy stability (over 12 hours)	<5	%
Pulse length (FWHM)	<50	fs
Pulse length stability	<5	%
Rep. rate	10 (100)	Hz
Contrast at 5 ps	10^{-8}	
Contrast at 10 ps	10^{-9}	
Contrast at 100 ps	10^{-10}	
Laser Delivery Parameters		
Peak power	100	TW
Energy on target	> 10	J
Strehl ratio (measured)	> 0.5	
Angle of incidence	30	degrees
Focal intensity	9×10^{20}	W/cm^{-2}



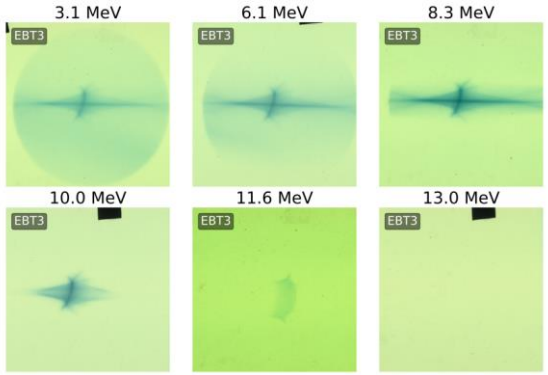


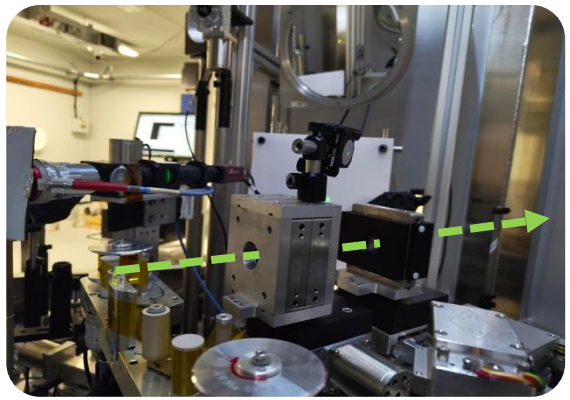
LhARA laser-driven source R&D

Support for PoPLaR

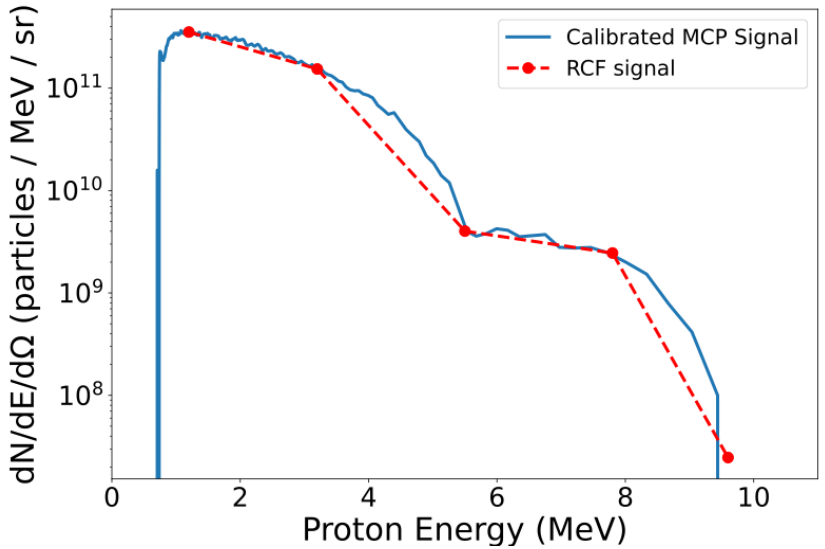
PMQ focusing

RCF dosimetry & Lanex imaging





B. C. Torrance et al



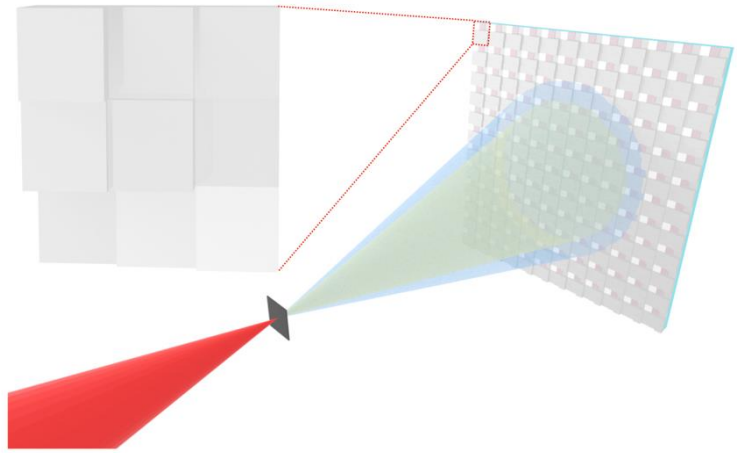
Diagnostic development

- High rep. rate Thomson parabola spectrometer at SCAPA
- ML analysis code
  - Spectrum extraction
- RCF calibration

B. C. Torrance et al

High repetition rate (debris, optics damage, etc)

- PROBIES diagnostic



Challenges:

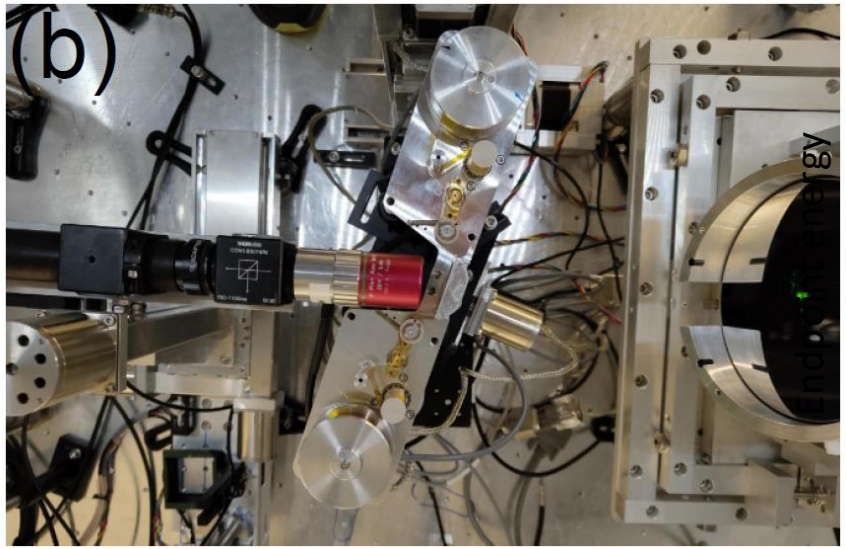
- Rapid source solving – CNN
- Filter thickness – Bayesian
- Electron background – MC (BDSIM)

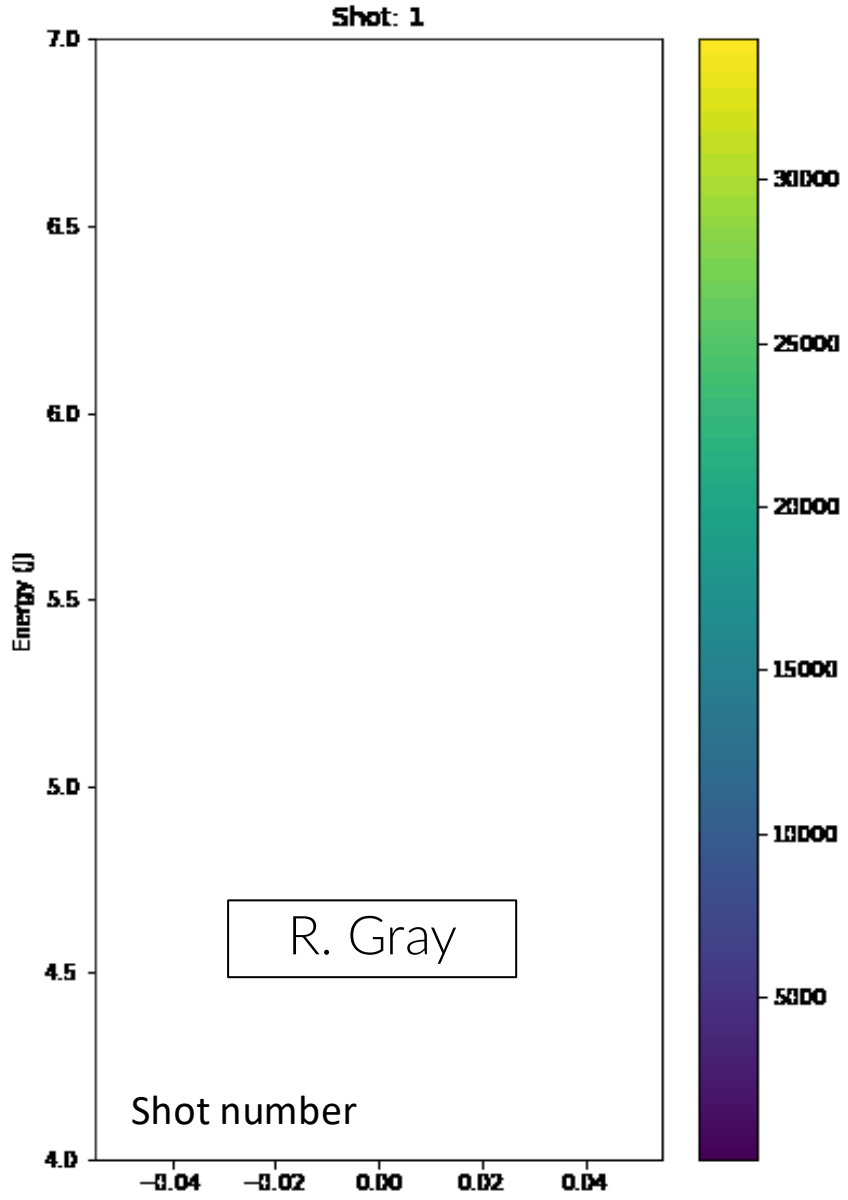
N. Dover et al

Source (all): LhARA collaboration meeting, Sept 2025

Experiments at SCAPA







SCAPA Experiment Team….

University of Strathclyde
R. Wilson, T. Frazer, E. Dolier, C. McQueen, B. Torrance, R. Nayli and P.McKenna

Imperial College
O. Ettlinger, G. Casati and N.P. Dover

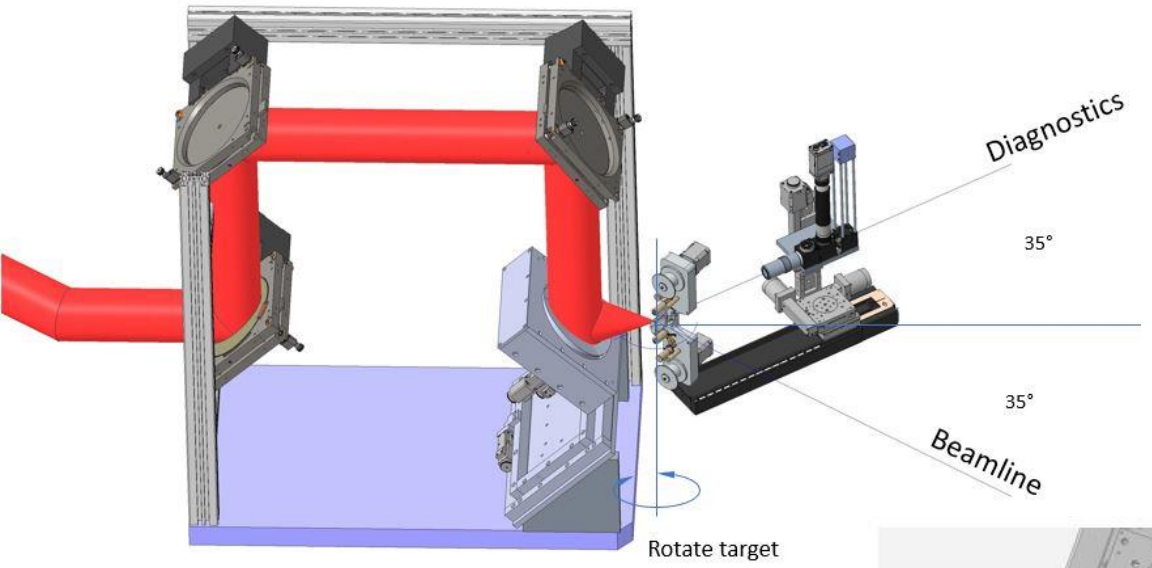
Queens University Belfast
P. Parsons and C. Palmer

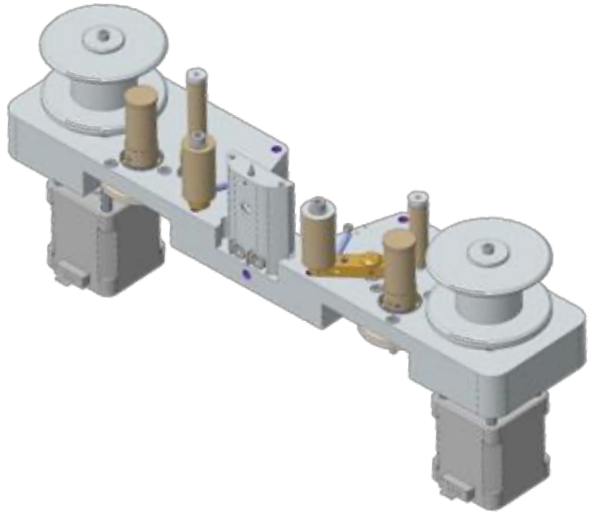
SCAPA, University of Strathclyde
M. Wiggins, E. Brunetti, G. Manahan, W. Li

Central Laser Facility
J. Green, C. Armstrong, C. Spindloe, W. Robins, S. Astbury

LhARA Source Engineering

C. Hill



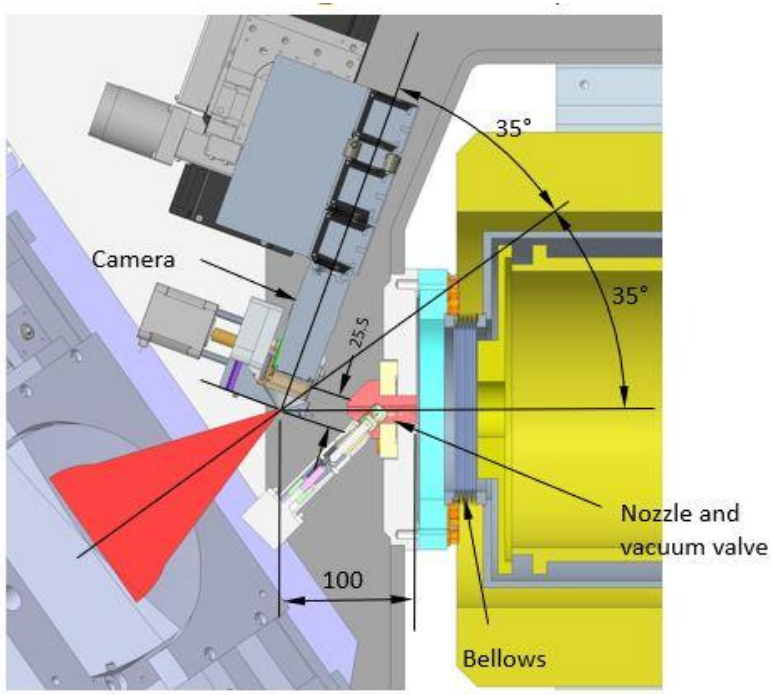


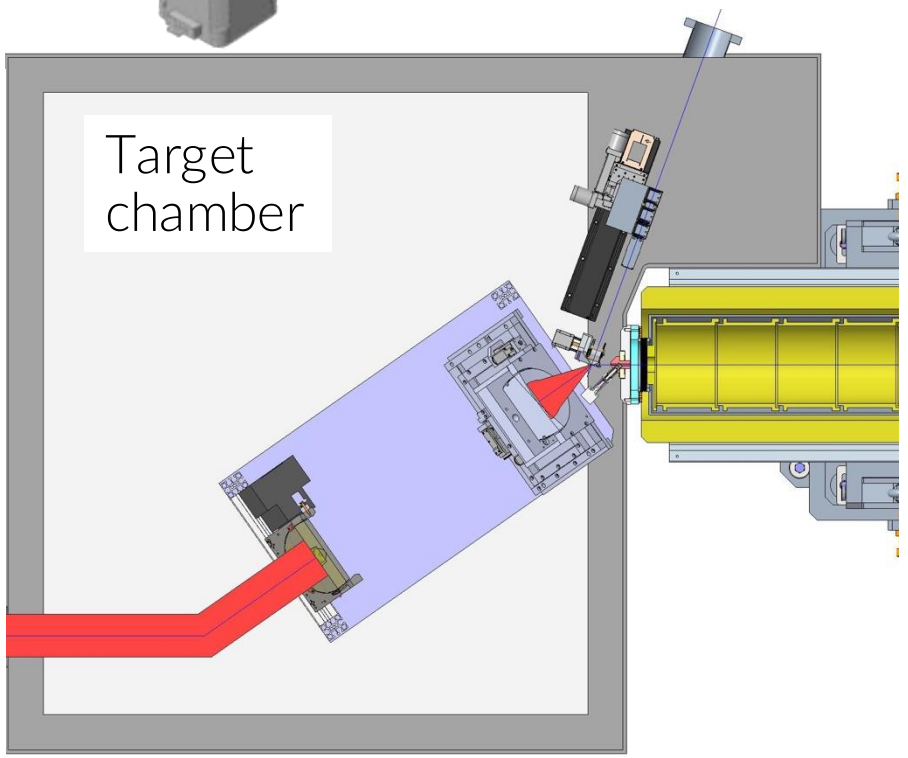
Tape target

Mirror and diagnostic assembly

Gabor lens 10cm from the target

Alignment & laser-target angle – geometrically constrained





LhARA laser-driven source challenges

Stability & Repetition Rate

- 10 Hz baseline, upgradable to 100 Hz
- Continuous operation for several hours/days

Diagnostics

- Spectrum & intensity
- Spatial distribution
- Non-destructive

Intensity

- Baseline 10^9 proton / shot at 15 MeV
  - Space charge
  - Deliverable dose rate

Challenges & Questions

Capture

- Emittance growth impacts downstream performance
  - Can pre-gabor lens focusing reduce it?

Beam composition

- Hot electron beam
- Potentially disruptive to plasma lenses
- Species/isotopes

Engineering

- Targetry
  - Alignment & operation
- Debris

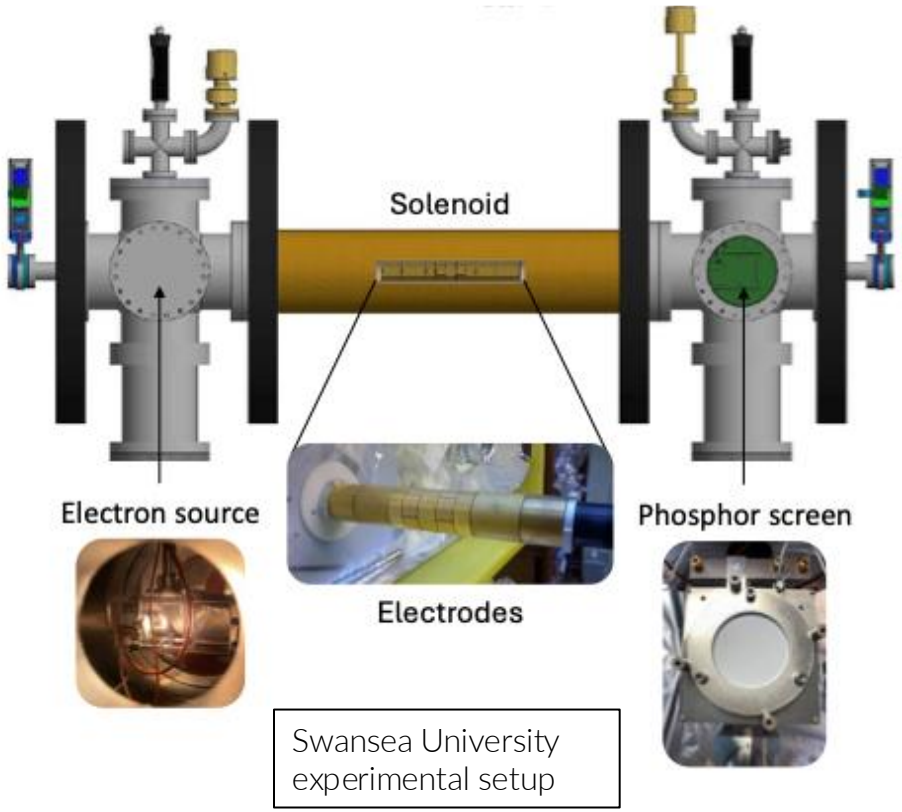
Ions

- Carbon beam understanding
- Helium (& Neon) - ???

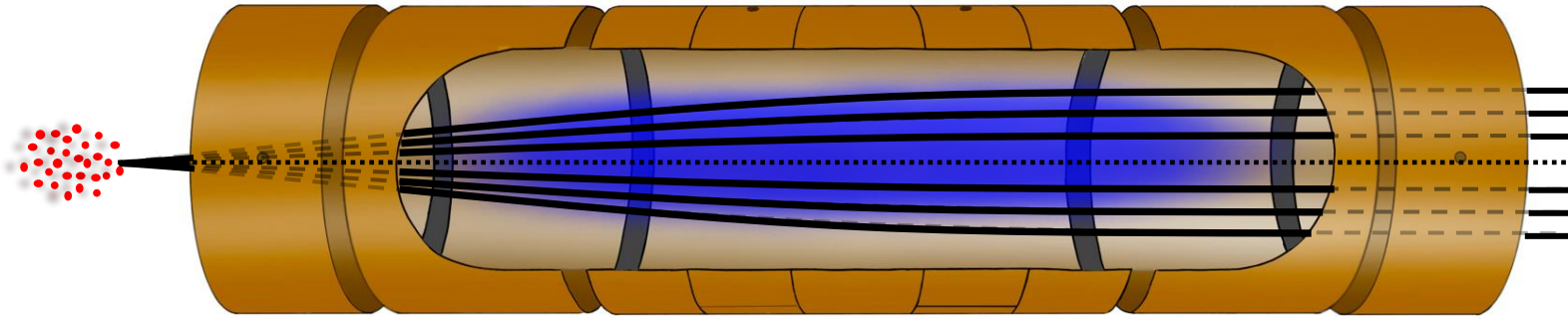
Gabor Plasma Lenses

- Plasma confinement with external E field & solenoid B fields
  - Penning-Malmberg trap

- Radial solenoid –like focusing



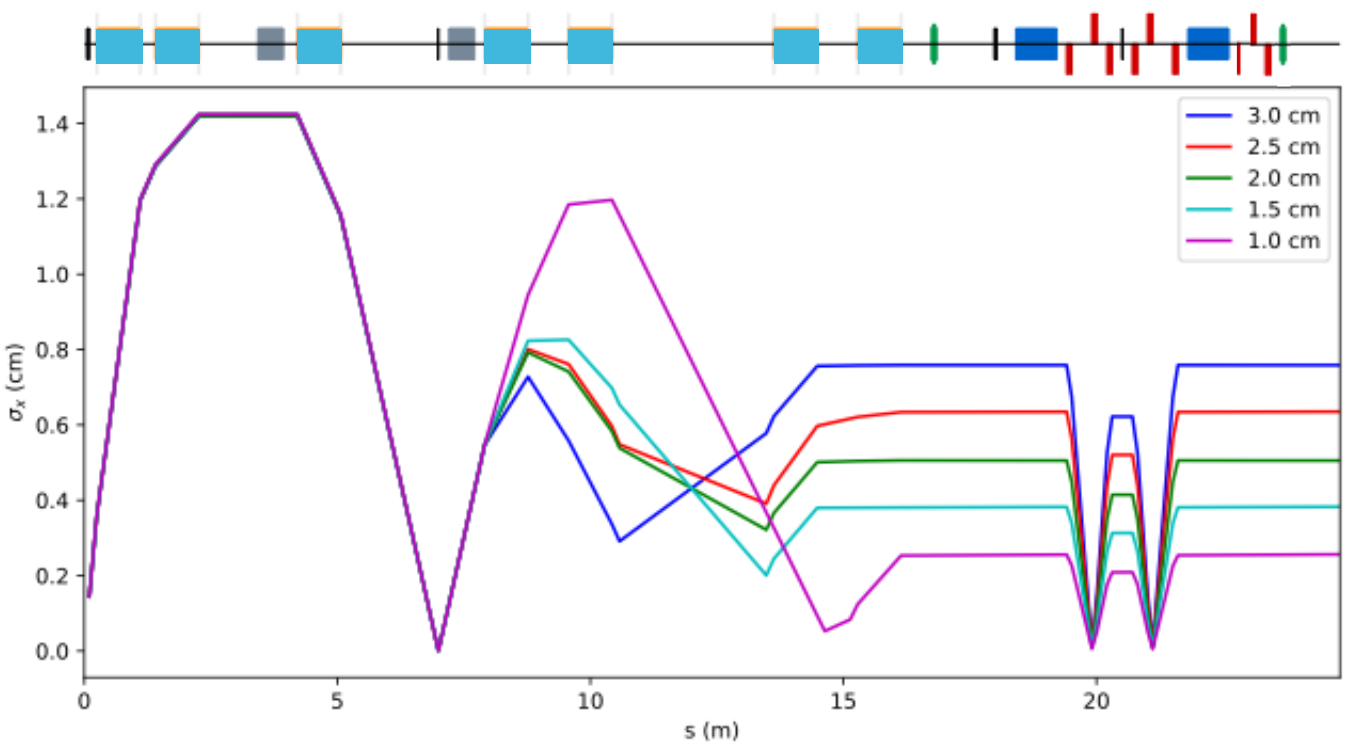
Swansea University experimental setup

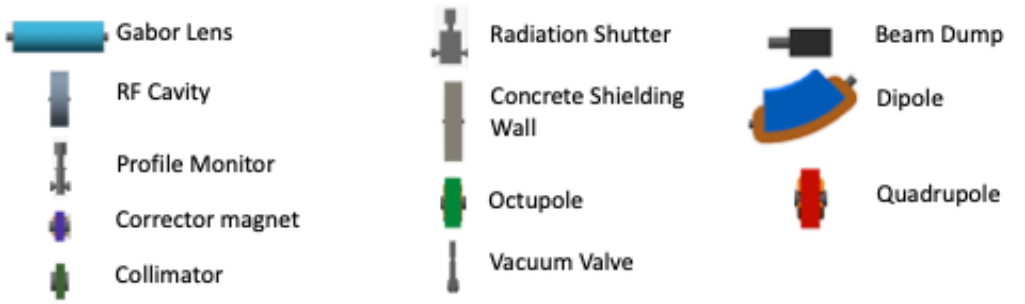


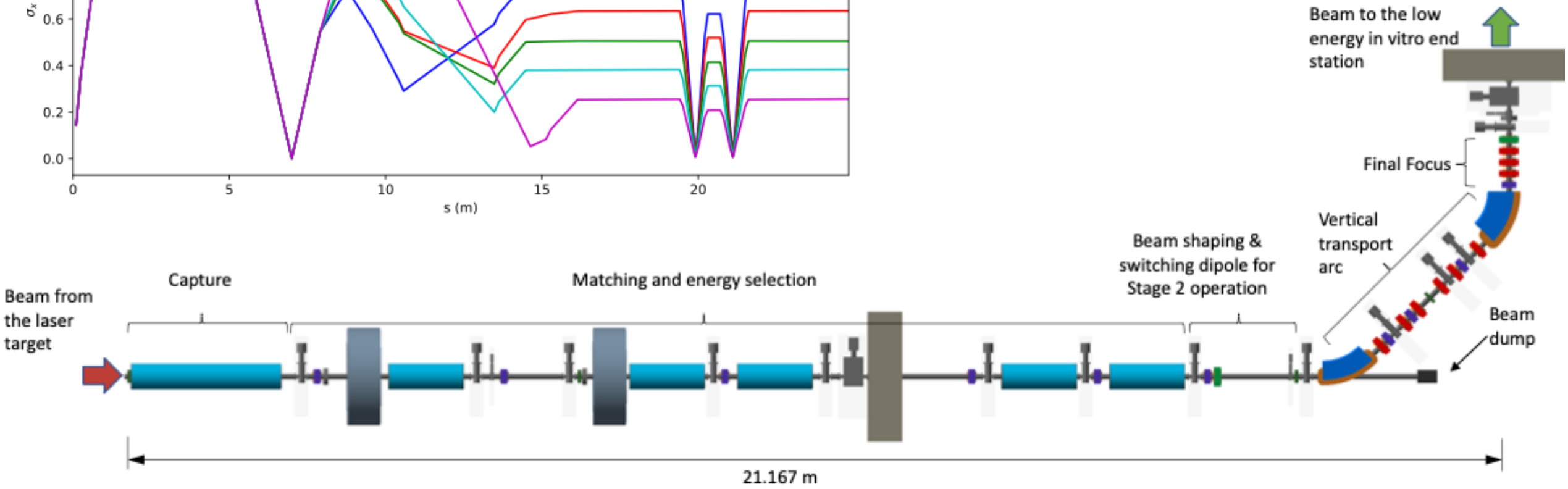
- Focussing strength proportional to plasma density.

- LhARA Gabor lens baseline design:
  - Equivalent solenoid strength for LhARA: 1.4 T
    - Plasma density ~ 5×10^{15} m^{-3}
    - Confinement solenoid field: ~ 35 mT
  - Plasma region length 85.7cm
    - +30cm for device length

LhARA: Stage 1 Beam Transport







Holistic Optimisation of LhARA Stage 1

Five Settings, tuned together across Stage 1

Energy Selection RF Voltage

Gabor Lens 3 Field Strength

Energy Selection Collimator Aperture

Phase Rotation RF Voltage

GL4-GL7 Fixed

Momentum Selection Collimator Aperture

Assessed Only Here

In-Vitro End Station In-Band Gain, Yield, Bunch Length

Measured Gains

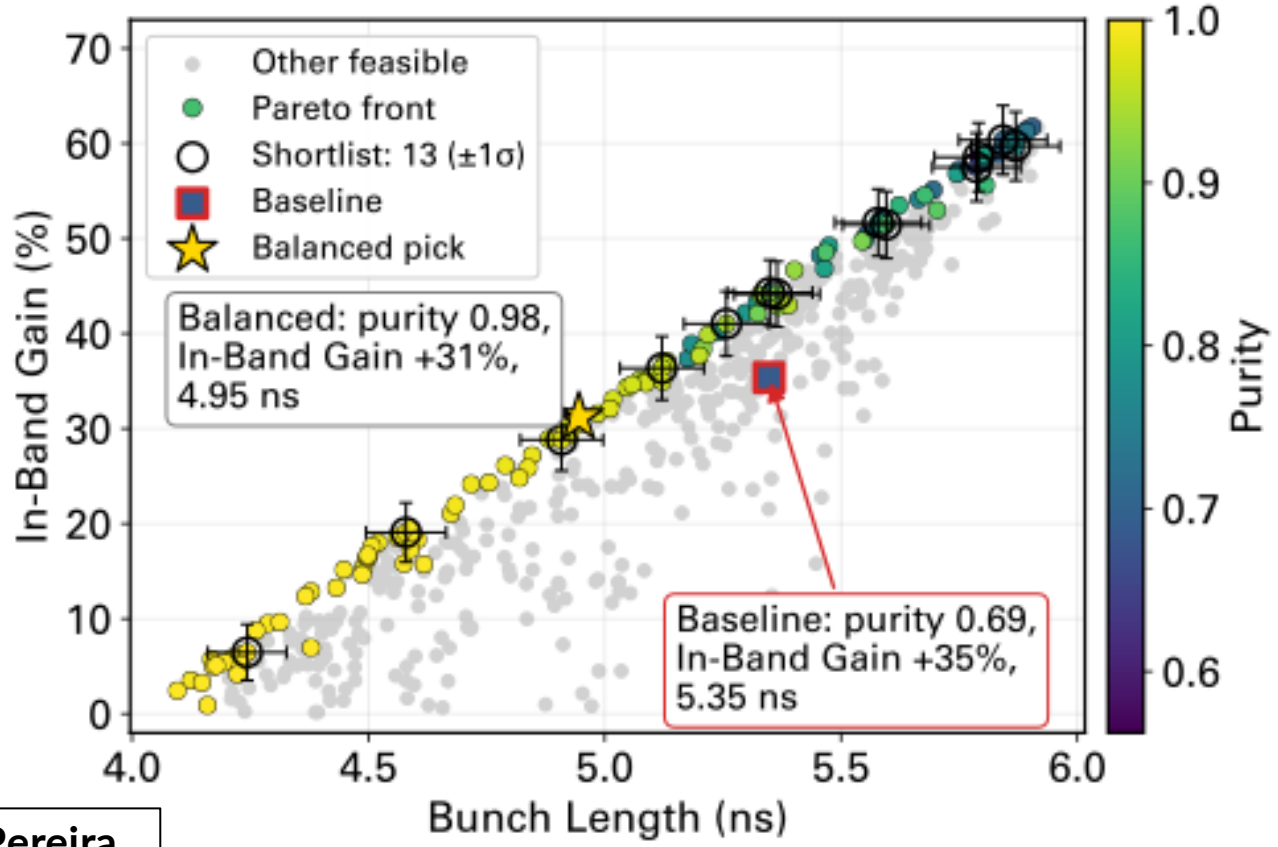
Against the sequential optimisation baseline in two of three objectives. Sacrificing ~4% yield for significant improvement elsewhere.

Interactions Captured

No setting is optimised purely on its own local metric. Elements are tuned in line with all modelled parameters

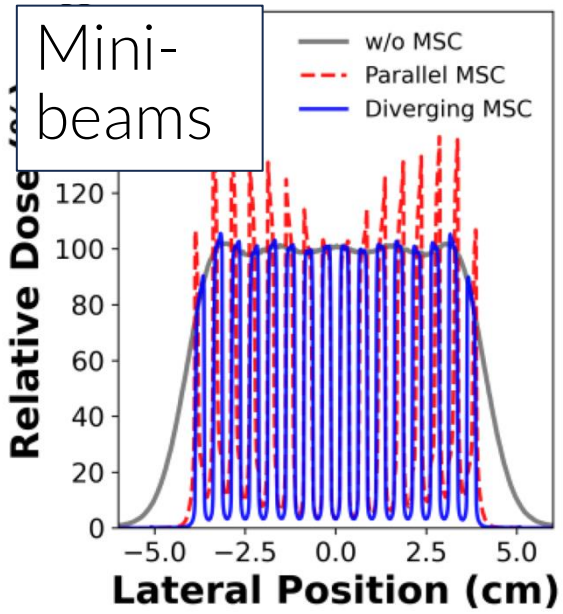
Flexible to Feedback and Changing Priorities

The output pareto front is a selection of the best possible compromises between objectives.

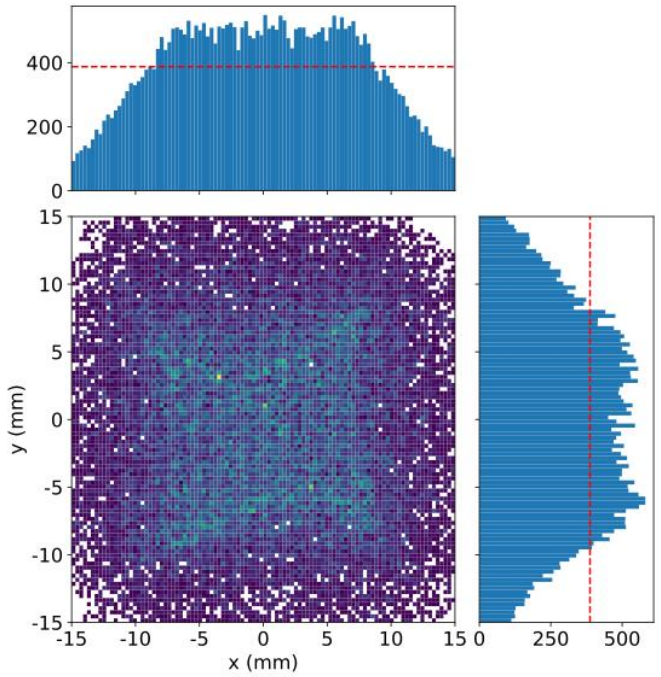


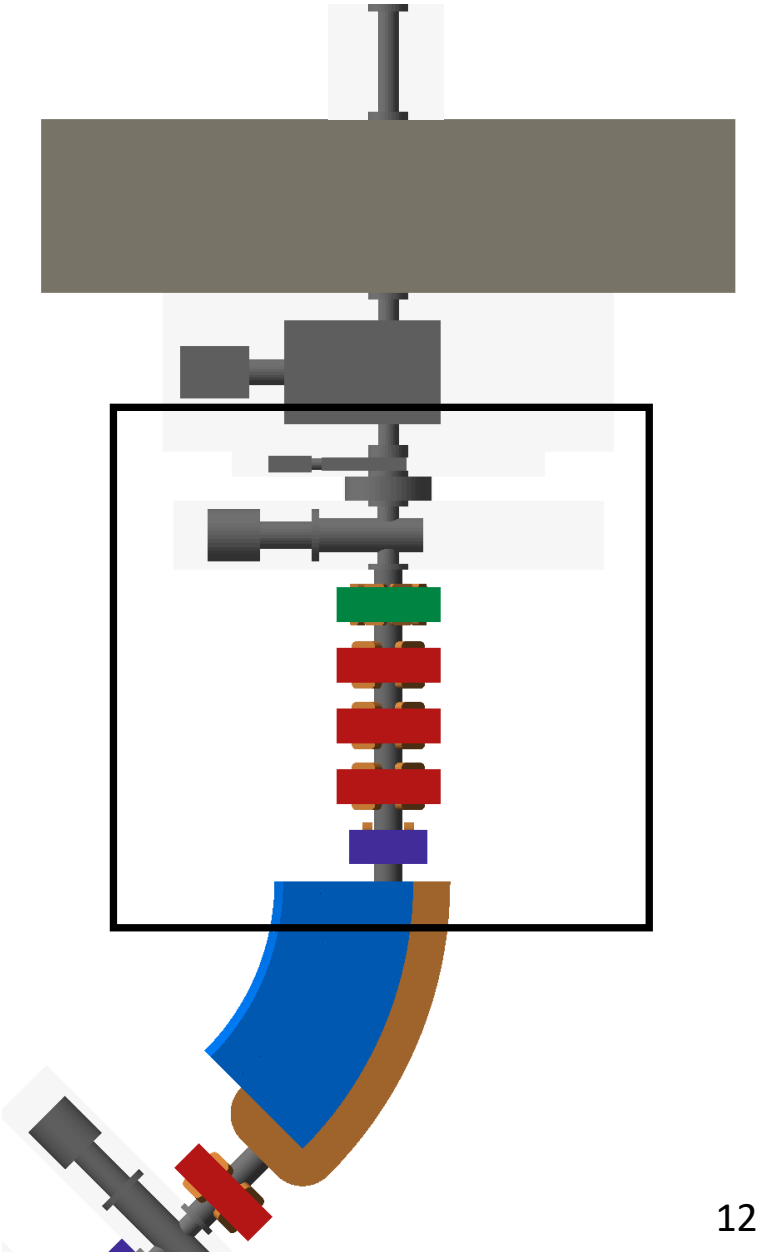
Matt Pereira (RHUL)

Flexible Beam Delivery



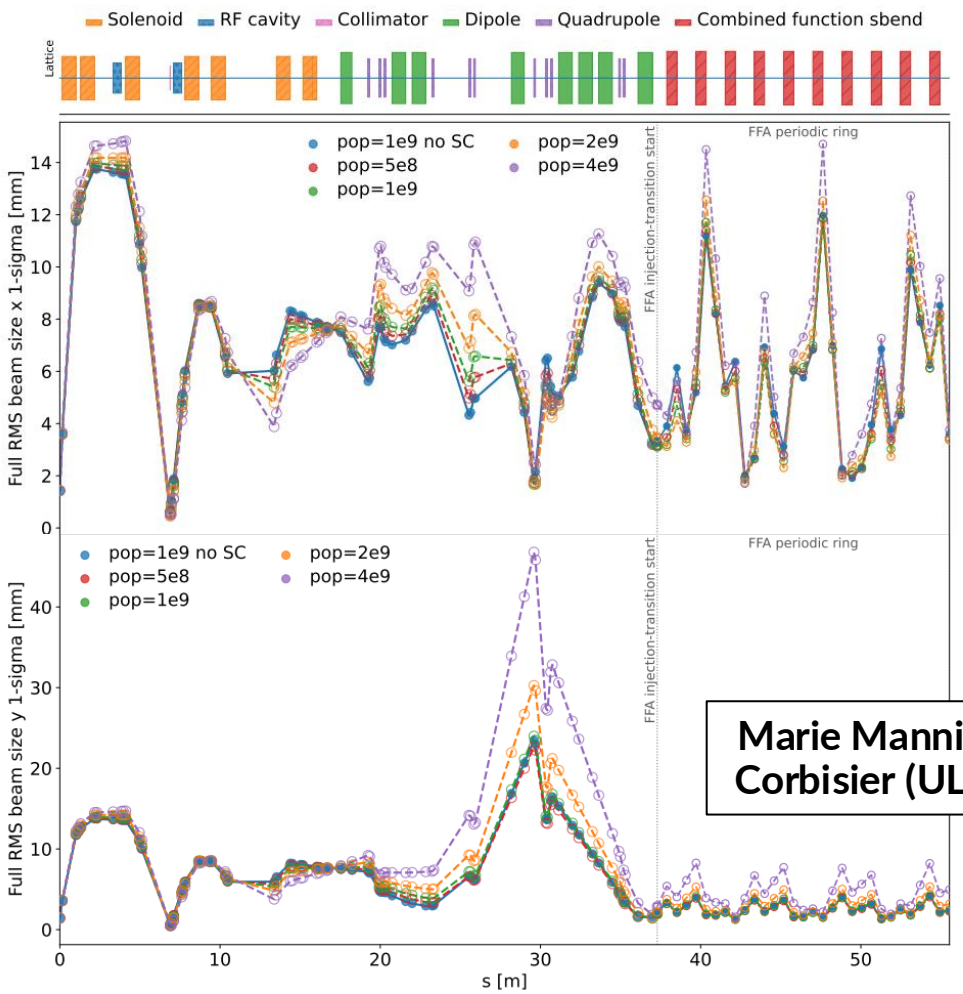
https://doi.org/10.3390/cancers14122888





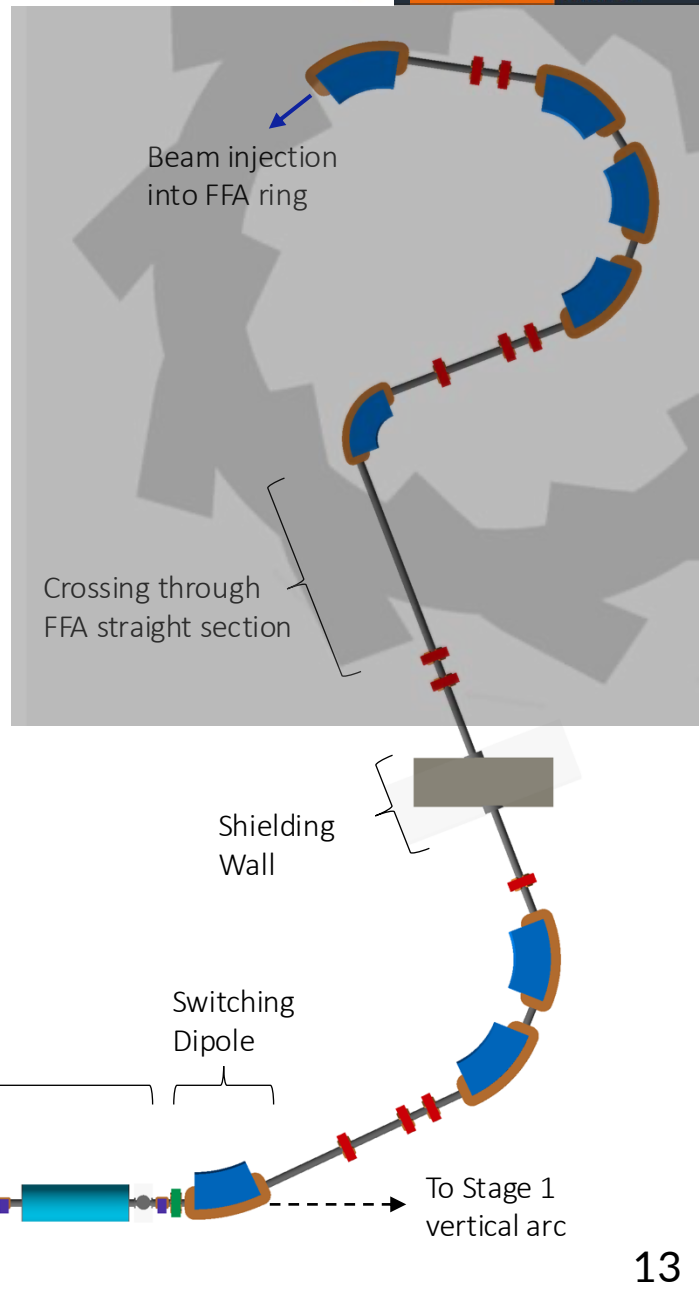
- 1– 3 cm conventional spot sizes
- Mini-beam (< 1mm) production (quadrupoles)
- Spot scanning
- Octupole for uniform profile (large field beams).

Stage 2 Injection Line



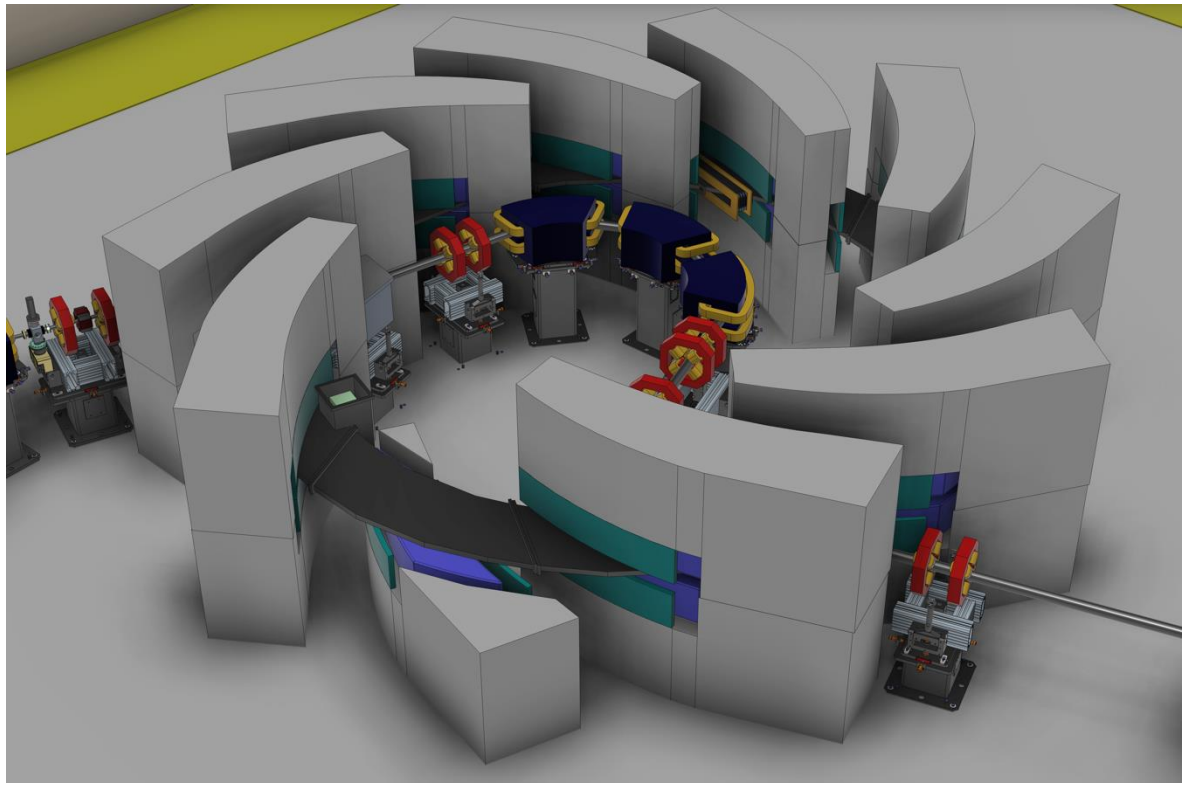
Marie Mannie-Corbisier (ULB)

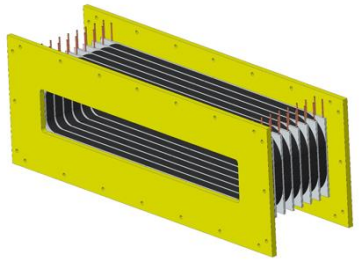
- Flexible injection line optics
  - Robust to emittance changes
  - Space-charge effects appear to be mitigatable
    - PhD project
- Crosses through injection line straight
  - Stray fields from FFA magnets.



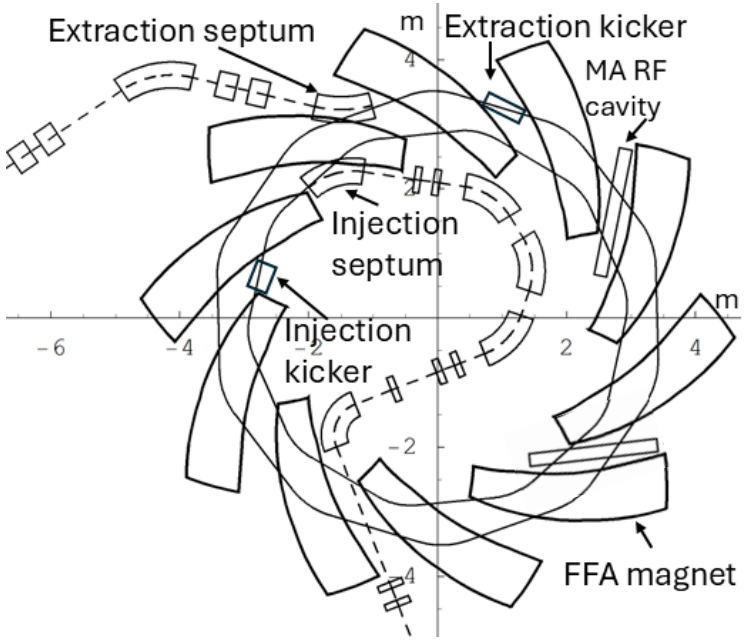
LhARA FFA

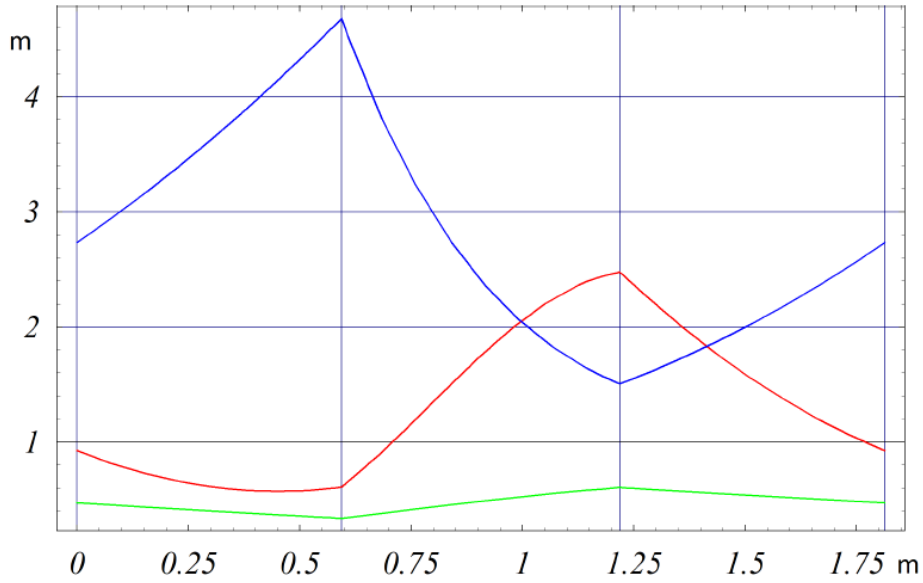
- Proton acceleration from 15 MeV to 127 MeV
  - Carbon ions - 4 MeV/u to 33.4 MeV/u
- 10 cell, single spiral scaling FFA
- Maintain short pulse structure
- Fast extraction rates (up to ~100 Hz)





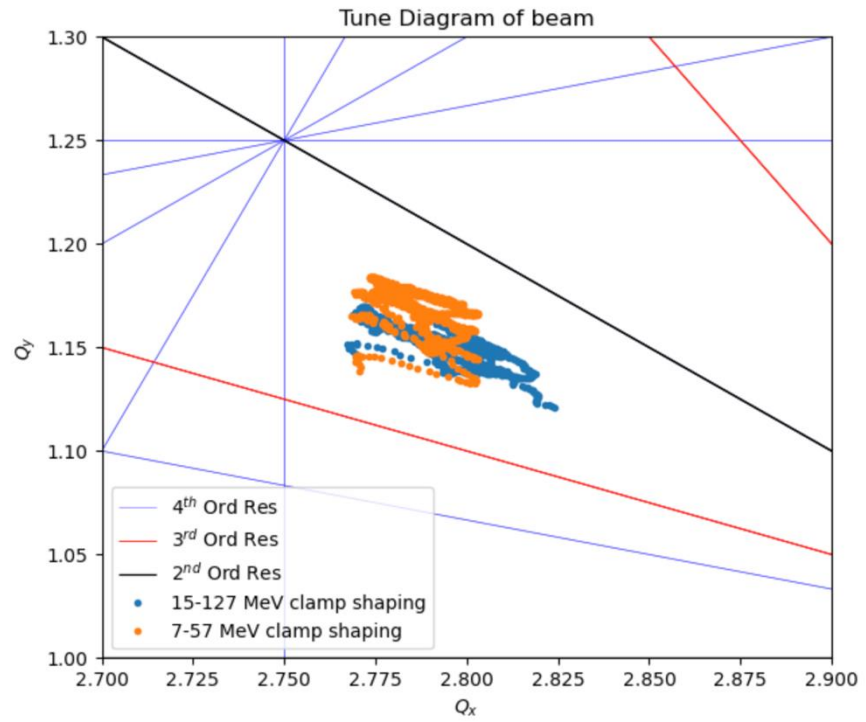
- Two RF cavities
  - Ferrite loaded or Magnetic-alloy

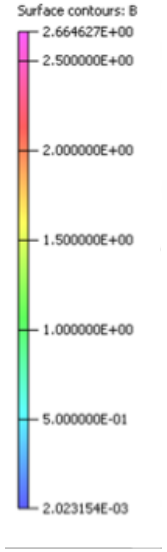


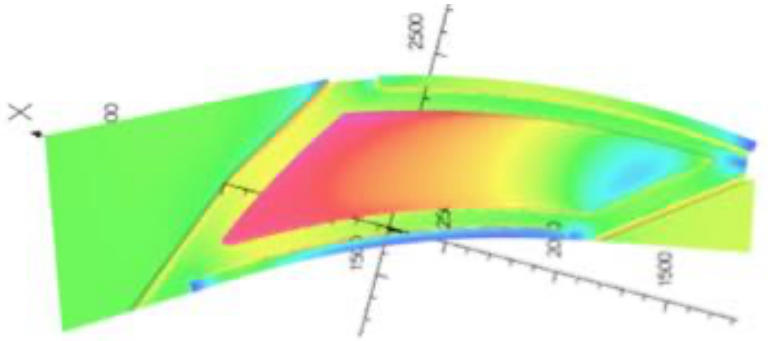


FFA Magnet Design

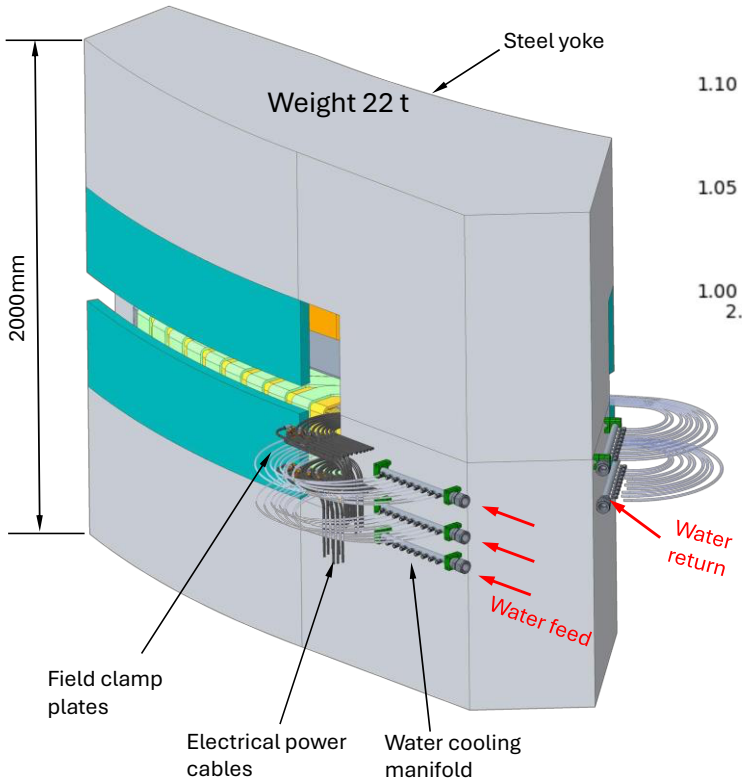
No tune crossing up to fourth order

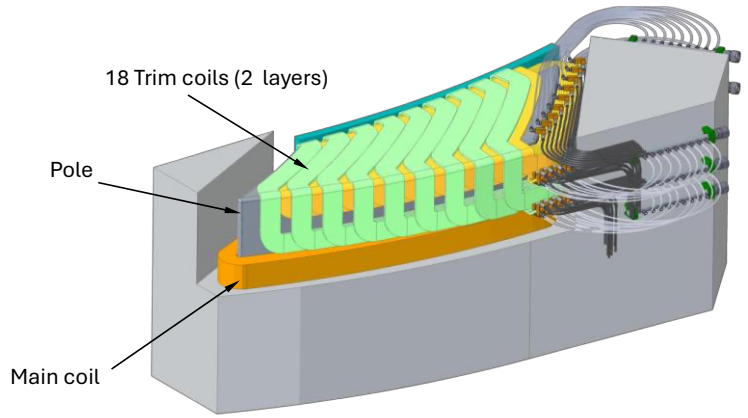






FFA Magnet





Optimised field clamps and trim-coil configurations.

Longitudinal dynamics & space charge studies ongoing

Collaborating with ISIS – 1/3 scaled FFA magnet prototype.

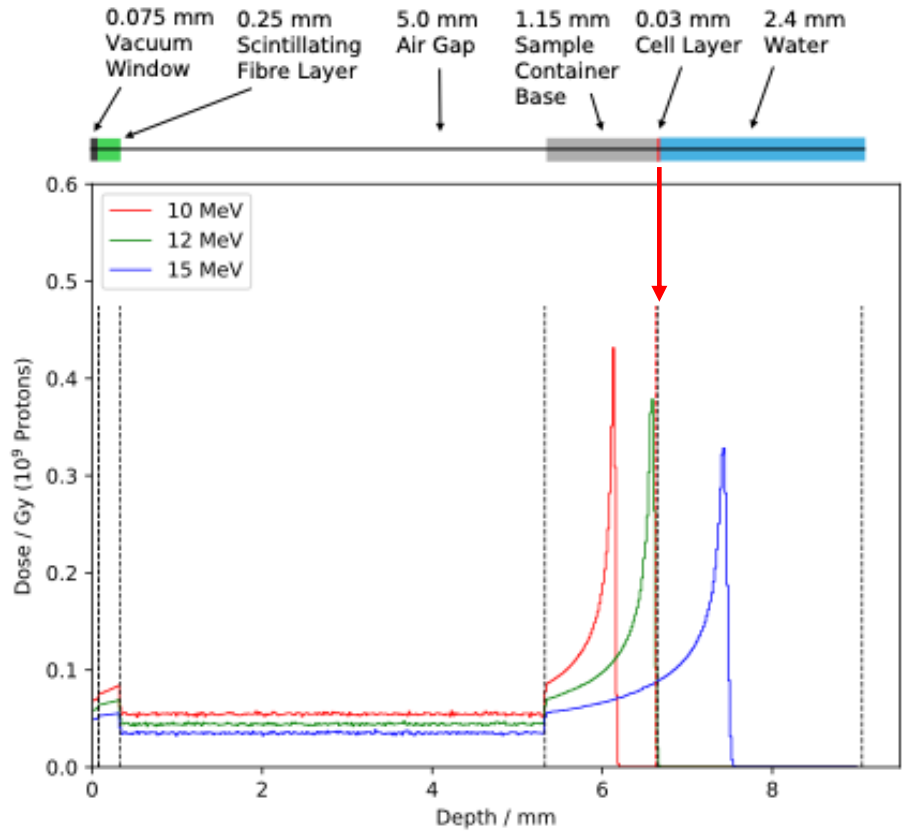
C. Hill (DL), T.J. Kuo (IC)

Dose Delivery Performance

- 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)

- **FLASH capable end stations**



	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

Summary

- Laser-driven acceleration fundamental to LhARA

- LhARA R&D ongoing (source, lens, FFA, performance, …)

- Many challenges still to be addressed – potential for collaboration!



Thank you for listening!

William Shields

william.shields@rhul.ac.uk

LhARA / CLF Workshop

2nd November 2026