# Design and Integration of the Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

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On behalf of the LhARA Collaboration

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ROYAL HOLLOWAY UNIVERSITY OF LONDON

BDSIM

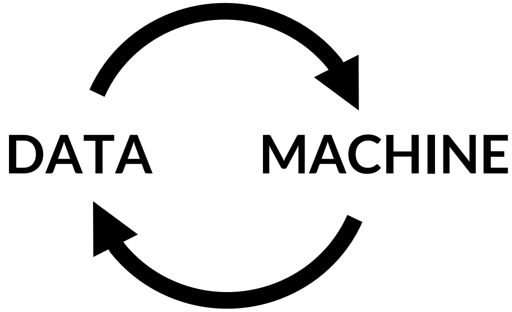
LhARA Laser-hybrid Accelerator for Radiobiological Applications

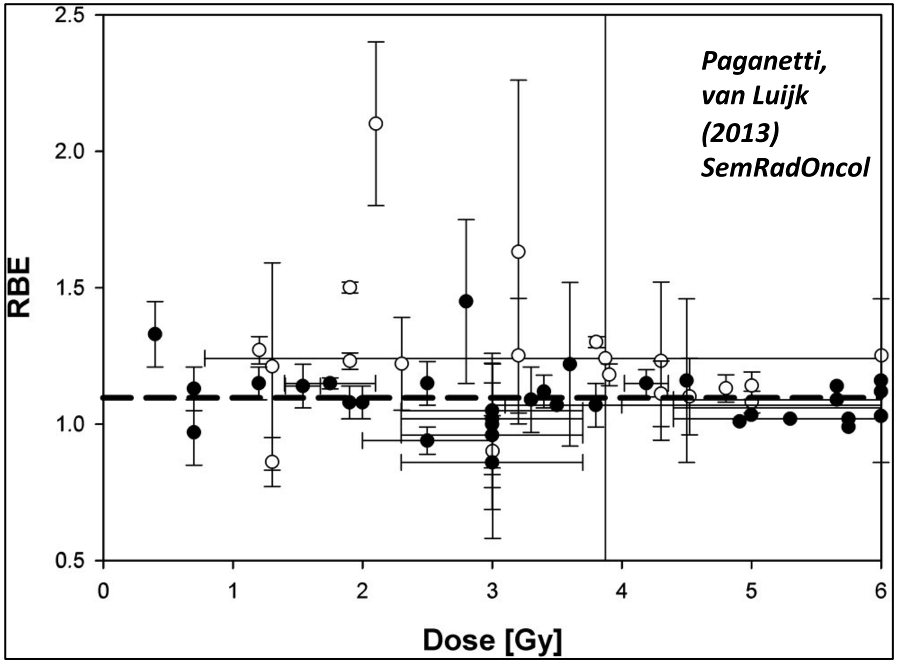
JAI John Adams Institute for Accelerator Science

# The Case for LhARA

- Growing particle therapy demand
  - Improve availability & accessibility with new & cost-effective technologies

- Systematic study of the radiobiology of proton & ion beams
  - Uncertainties due to:
    - Energy, ion species, dose, spatial distribution, dose rate, tissue type, biological endpoint
  - RBE variation
    - Proton treatment planning RBE = 1.1
    - Ion RBE even higher




- Novel treatment modalities
  - Ultra-high dose rates: FLASH
  - Spatially fractionated – mini-beams
  - …

- **LhARA: a dedicated radiobiology research facility**

# The LhARA Collaboration

Partners

University — Clinical — Laboratory — Industry — Accelerator

- *Deliver a systematic and definitive radiobiology programme*
- *Prove the feasibility of the laser-driven hybrid-accelerator approach*
- *Lay the technological foundations for the transformation of PBT*

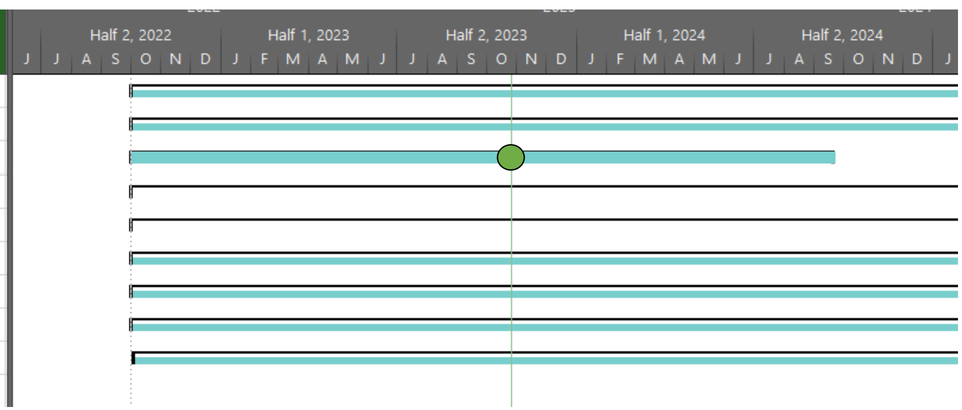
# LhARA & ITRF

- £2M UKRI Infrastructure Fund grant – establishment of Ion Therapy Research Facility (ITRF)
  - Compact, single-site national research facility
  - 2 year "Preliminary Activity 1" phase
    - 3 year preliminary activity 2 phase (pre-construction) – awaiting funding decision
  - <u>Facility CDR by October 2024</u>

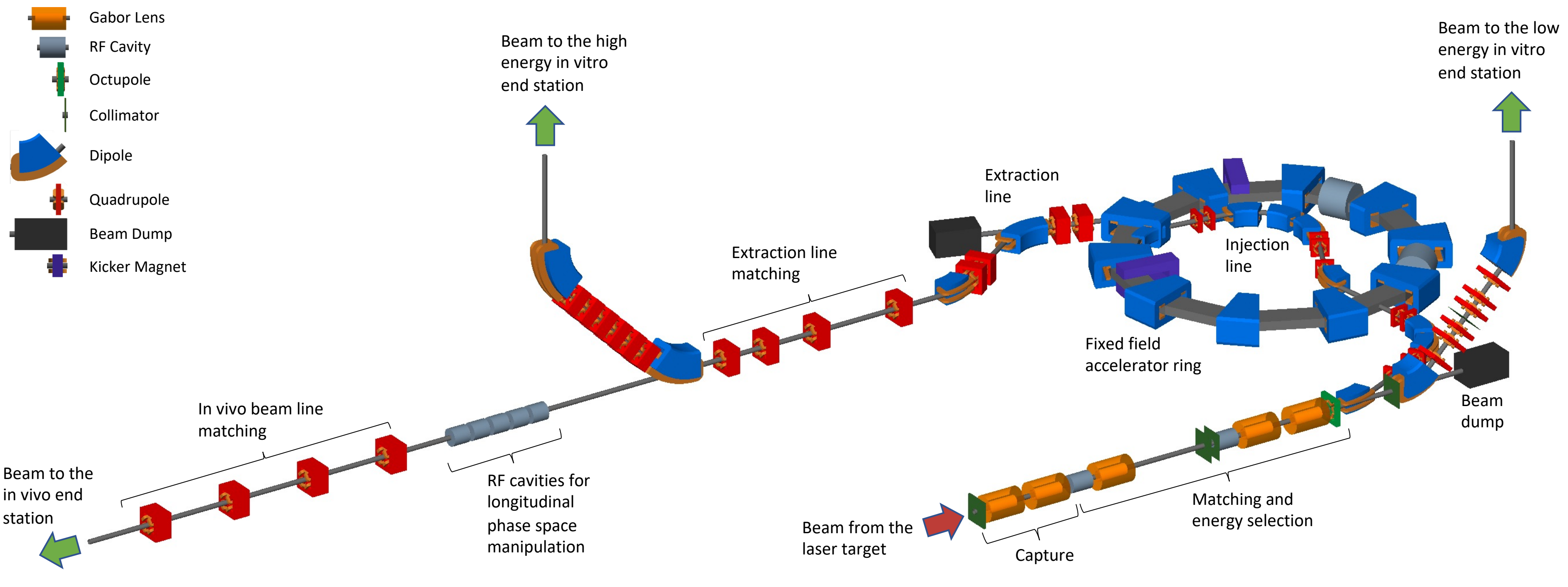
- LhARA to serve ITRF
  - Conventional technology study (NIMMS)
    - Synchrotron & injector from established ion sources & acceleration methods

- Outreach & engagement
  - Users, Patient and Public Involvement
  - Website

| Task Name | Work Package | Start | Finish |
|---|---|---|---|
| LhARA Project | | Sat 01/10/22 | Mon 01/11/27 |
| WP1 Project Management | WP1 | Sat 01/10/22 | Thu 30/09/27 |
| Project Deliverables | WP1 | Sat 01/10/22 | Thu 19/09/24 |
| Tasks | WP1 | Sat 01/10/22 | Thu 30/09/27 |
| WP2 Source | WP2 | Sat 01/10/22 | Fri 01/10/27 |
| WP3 Proton and ion capture | WP3 | Sat 01/10/22 | Thu 30/09/27 |
| WP4 Ion-acoustic | WP4 | Sat 01/10/22 | Thu 30/09/27 |
| WP5 Novel End station Development | WP5 | Sat 01/10/22 | Fri 01/10/27 |
| WP6 System design | WP6 | Mon 03/10/22 | Thu 30/09/27 |



# The LhARA Accelerator




Pre-conceptual design report (pre-CDR) publication:
[Aymar, G. et al, Frontiers in Physics, (8), September 2020, 567738]

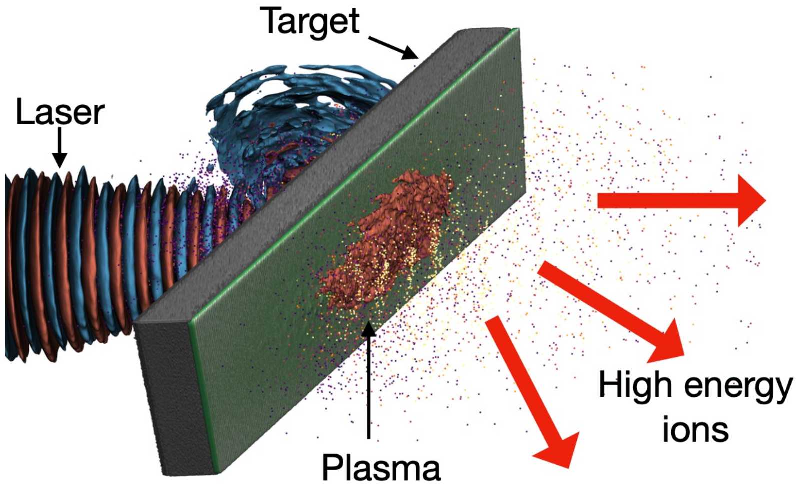
LhARA baseline design technical note:
https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Communication/Notes/CCAP-TN-11-LhARA-Design-Baseline.pdf

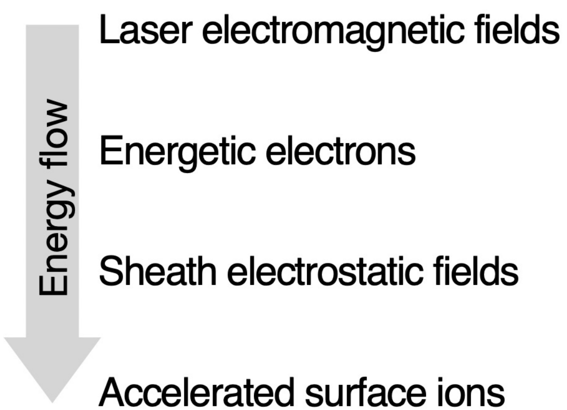
**LhARA performance summary** arXiv:2006.00493

| | 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 | $1.0 \times 10^9$ Gy/s | $1.8 \times 10^9$ Gy/s | $3.8 \times 10^8$ Gy/s | $9.7 \times 10^8$ Gy/s |
| Average dose rate | 71 Gy/s | 128 Gy/s | 156 Gy/s | 730 Gy/s |

# Laser-driven Proton & Ion Source

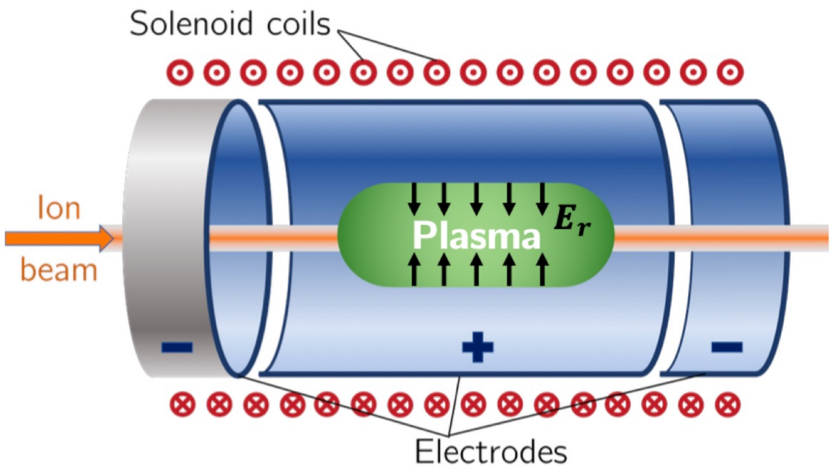
- High intensity laser driven ion sources:
  - 100 TW, high instantaneous dose rate
  - 10-40 ns bunches
  - Triggerable; arbitrary pulse structure
  - High energy from source (up to ~100 MeV)
- Proton & ion source prediction
  - 3D TNSA simulations
  - SCAPA facility & experimental beam time
- **Identify LhARA facility laser-target requirements**
  - Generation of proton (15 MeV) and carbon (4 MeV/u) beams using existing “tape” targets
  - 10 Hz operation
  - Understanding of debris & stabilisation schemes



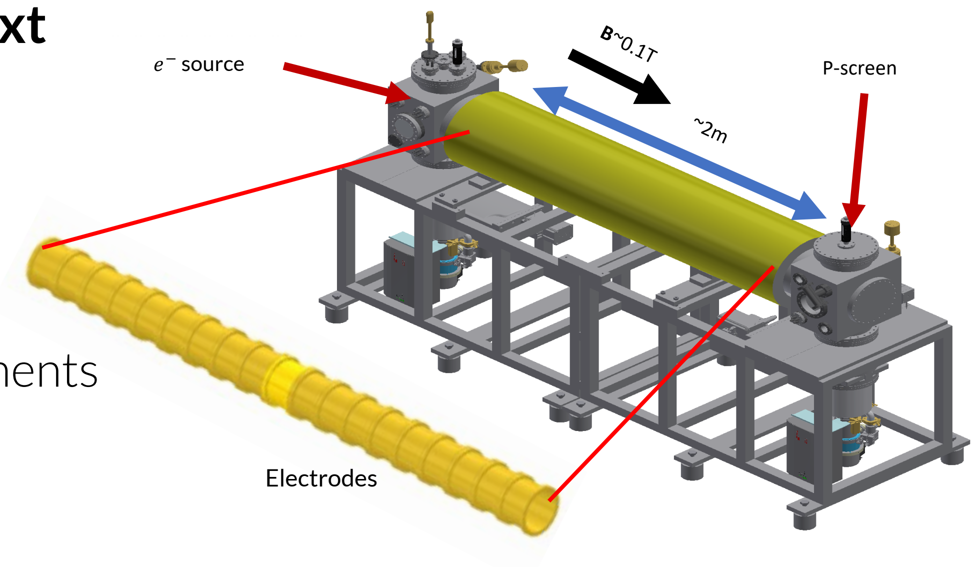
# Proton & Ion Capture

- Novel Gabor electron-plasma-lens
  - Capture & focusing
  - Solenoid-like strong focusing without high power, high-field magnet
  - Radial focussing in both planes simultaneously
  - Energy-dependent focusing strength




- **Develop a detailed design of the next generation Gabor-lens prototype**

- Experimental setup at Swansea University
  - Electron-plasma dynamics measurements
  - Bench-mark simulations
    - VSim & WarpX



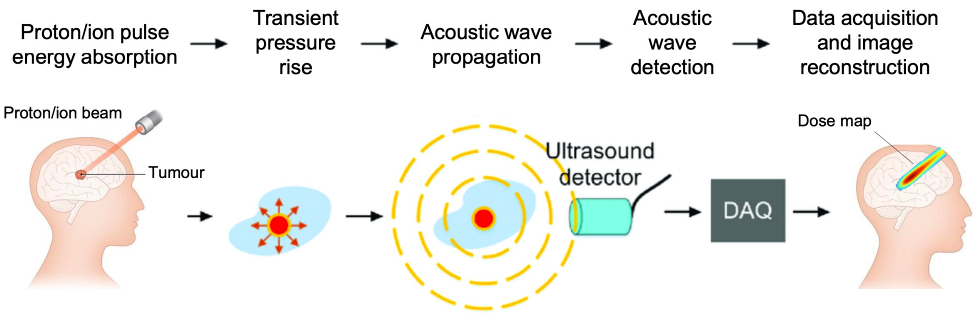
# Ion-Acoustic Dose Mapping

- **In-vivo, real-time, non-invasive range verification system**
  - 3D Bragg peak localisation with sub-mm accuracy
  - Dose profile distribution measured pulse-by-pulse

- Beam induced thermoelastic expansion
  - Increase in pressure - acoustic wave (thermoacoustic effect)
  - Ultrasound detector
  - Iterative image reconstruction

- Design proof of principle experiment
  - Geant4 MC simulation
  - K-wave acoustic model

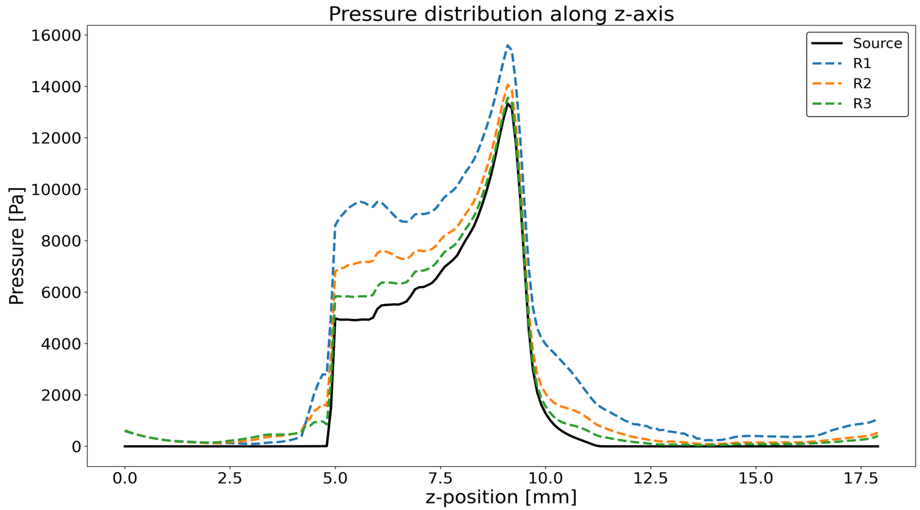
- LION beamline at CALA (LMU Munich)
  - BDSIM modelling of experimental setup




Beam Delivery Simulation

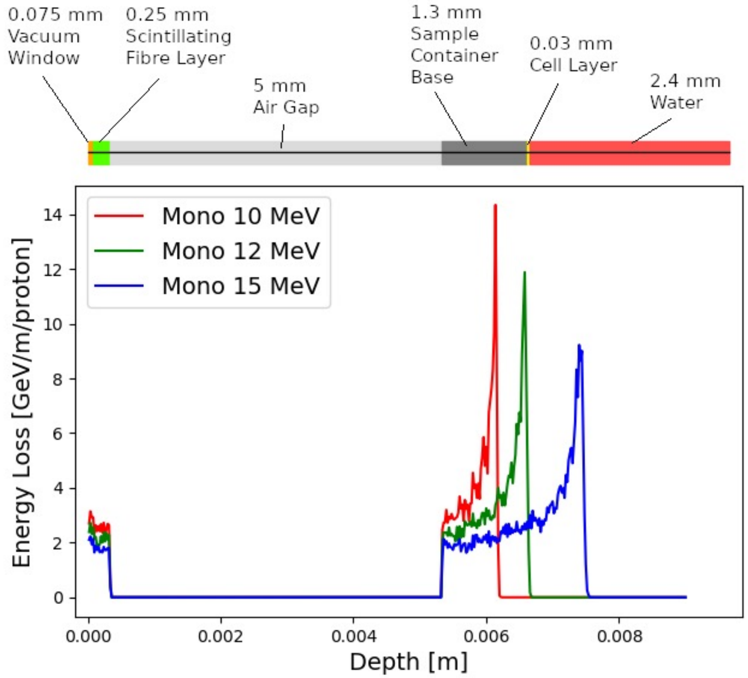
A SIMULATION TOOLKIT

A MATLAB toolbox for the time-domain simulation of acoustic wave fields



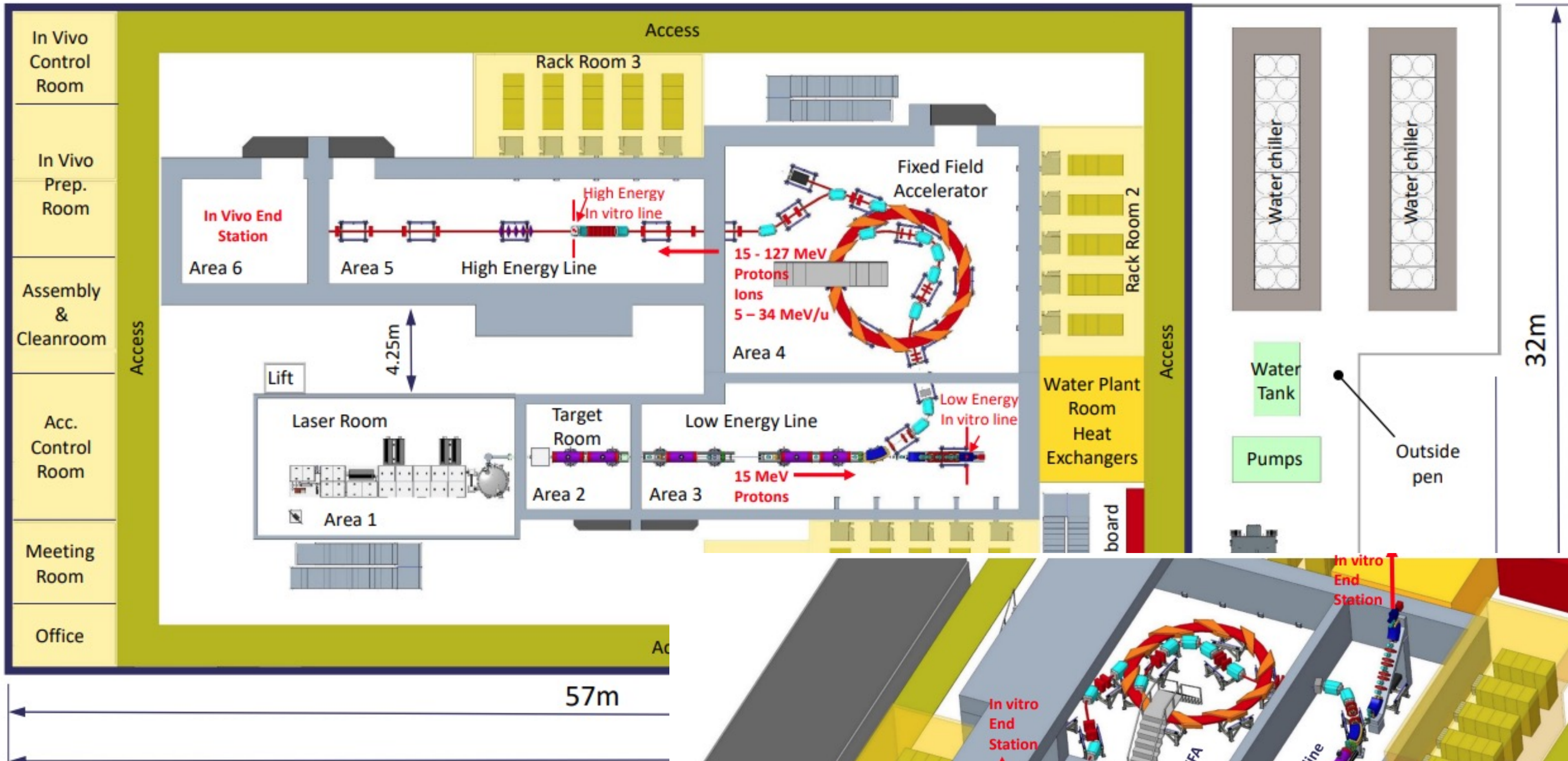
- **Develop definitive programme of in-vitro and in-vivo radiation biology**
  - Full specification for the in-vitro and in-vivo end stations in development
- Instrumentation and diagnostic specifications for beam characterisation
  - Scintillating-fibre detector (SciWire)
  - Gas jet beam profiler
- Automation
  - Cell-culture handling systems and appropriately automated in-vivo end station systems
  - Extended, high throughput operation
  - Programmable to match beam
- Control and reproducibility
  - Variable control of atmosphere
  - Pulse-by-pulse dosimetry validation
    - Acoustic imaging (in-vivo)
    - Cellular imaging (in-vitro)

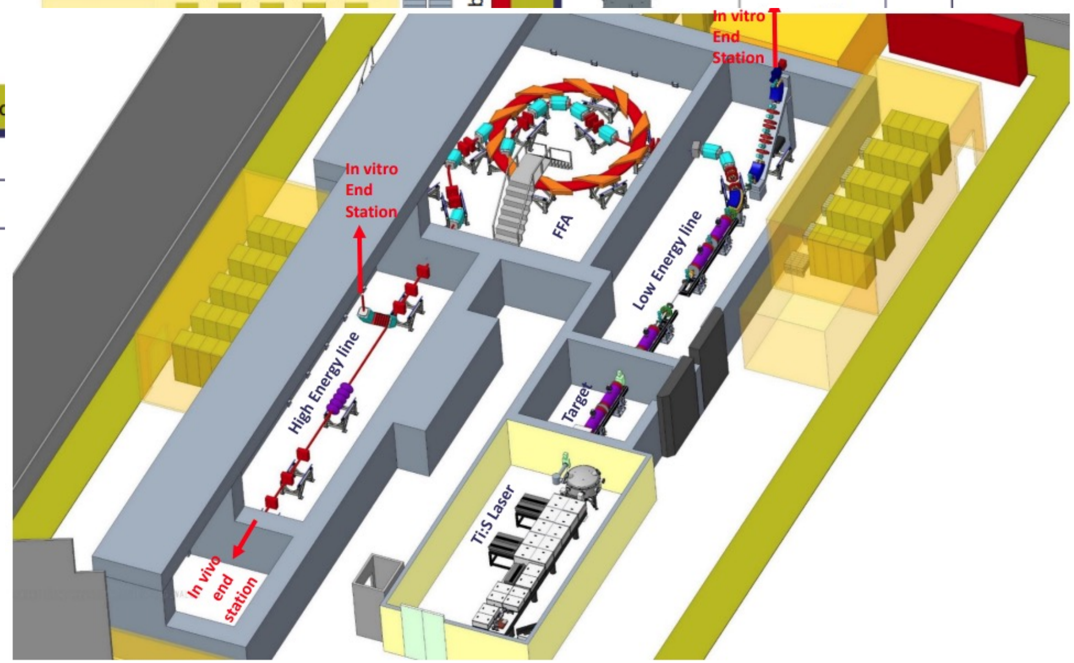
- Birmingham MC40 cyclotron operation
  - Instrumentation testing




- Peer group consultation meetings
  - **Next meeting coming soon**
  - https://indico.stfc.ac.uk/event/923/

# LhARA Facility Infrastructure



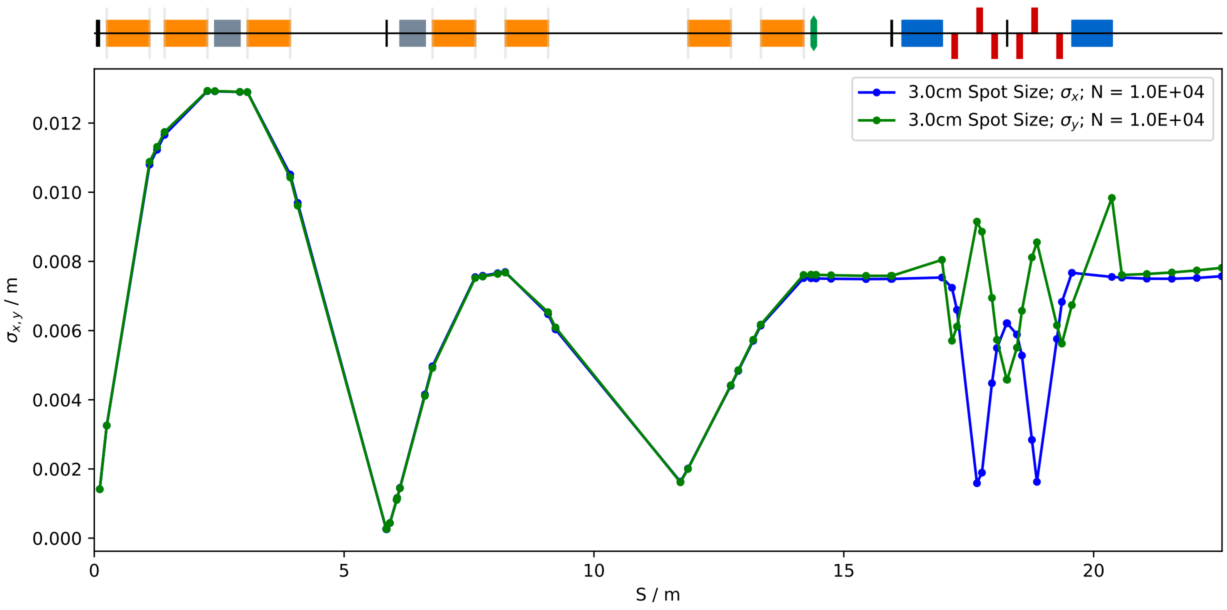




- Engineering design underway

> Magnets, RF, Diagnostics, End stations, Shielding, Electrical power, Cooling, Vacuum, Controls, …

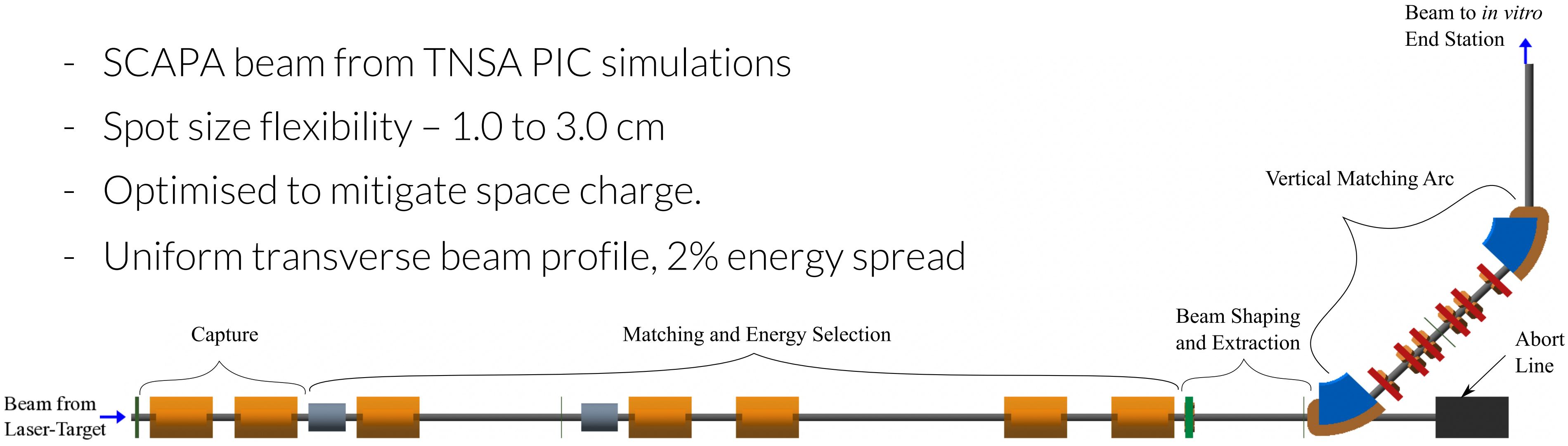
W. Shields

# LhARA Stage 1




- **Conceptual design of the LhARA facility, the accelerator systems, and their integration with the end stations**
- $10^9$ protons per pulse
  - 10000 macroparticles in Monte Carlo tacking studies

- SCAPA beam from TNSA PIC simulations
- Spot size flexibility – 1.0 to 3.0 cm
- Optimised to mitigate space charge.
- Uniform transverse beam profile, 2% energy spread



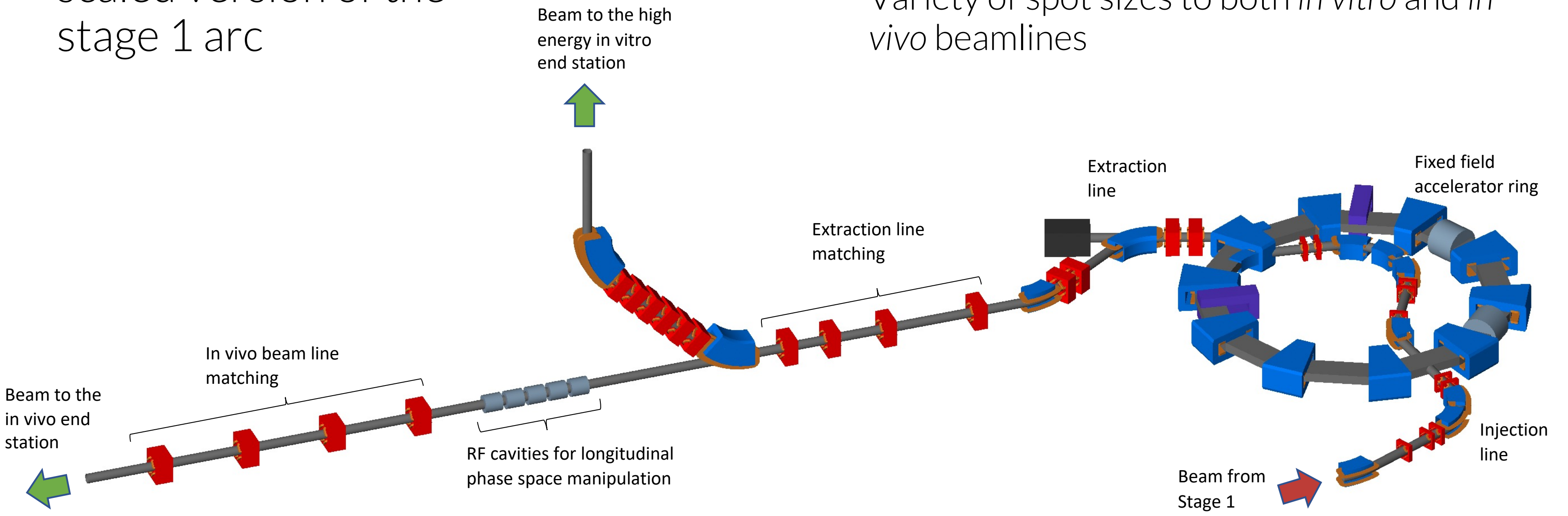
# LhARA Stage 2

- Injection line, FFA ring, extraction line, 2 end stations

- FFA offers acceleration to 127 MeV (protons) and 33.4 MeV/u (carbon)
  - Preservation of short bunch time structures
  - Ongoing redesign to accommodate shielding & improve flexibility

- Vertical arc is a scaled version of the stage 1 arc

- Extraction line flexibility
  - Variety of spot sizes to both *in vitro* and *in vivo* beamlines



# Summary

- **LhARA will serve the radiobiology community using a laser-hybrid approach**
  - Overcome dose-rate limitations of current and proton & ion therapy sources.
  - Offer unparalleled flexibility by deliver a range of ion species, energies, dose, dose-rate and time and spatial distributions.

- **The LhARA and ITRF "Preliminary Activity " programme is underway!**
  - Prove technical feasibility of novel accelerator technologies.
  - Develop & deliver a broad radiation biology programme.
  - Create the capability to transform proton and ion therapy.

# Thank you for listening

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