LhARA: The Laser-hybrid Accelerator for Radiobiological Applications

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On behalf of the LhARA Collaboration

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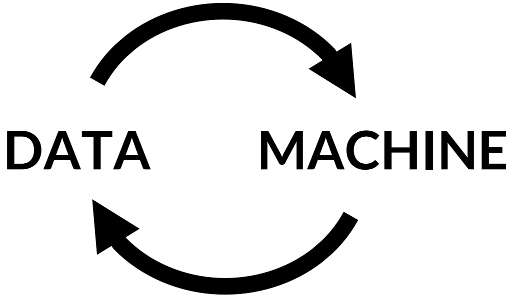
IOP Particle Accelerators and Beams Conference

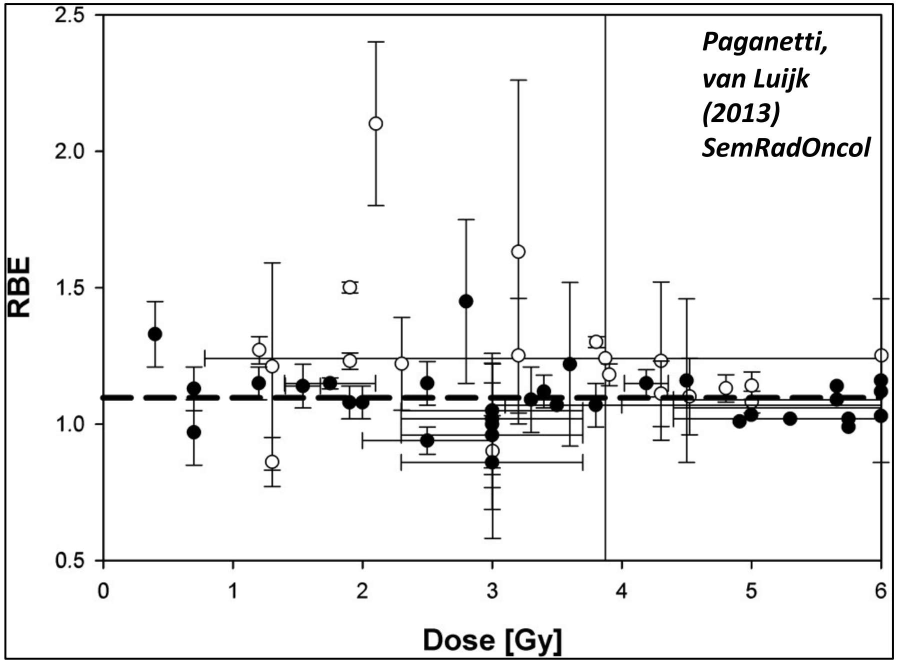
29th June 2023

The Case for LhARA

- Growing global requirement for radiotherapy
  - Improve availability & accessibility
  - Develop new & cost-effective technologies

- Systematic study of the radiobiology of ion beams
  - Treatment planning is RBE dependant
  - Uncertainties due to:
    - Energy, ion species, dose, spatial distribution, dose rate, tissue type, biological endpoint
  - Proton RBE variation
    - All p-treatment planning uses RBE = 1.1





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

- **Further research is required, both in-vitro and in-vivo**

The LhARA Collaboration

LhARA Laser-hybrid Accelerator for Radiobiological Applications

Royal Holloway University of London

Imperial College London
ICR The Institute of Cancer Research
Medical Research Council, UKRI, 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 Laser-hybrid Accelerator for Radiobiological Applications

Manchester 1824, The University of Manchester
University of Birmingham
University of Liverpool
NHS University Hospitals Birmingham NHS Foundation Trust
NHS The Clatterbridge Cancer Centre NHS Foundation Trust
NHS The Christie NHS Foundation Trust
institut Curie
Queen's University Belfast
Swansea University Prifysgol Abertawe
UCL Medical Physics & Biomedical Engineering

Netherlands Cancer Institute Antoni van Leeuwenhoek
Hampton University Proton Therapy Institute
University of Strathclyde Glasgow Department of Physics
Royal Holloway University of London
Lancaster University
UKRI Science and Technology Facilities Council
ASTeC
Daresbury Laboratory
Particle Physics Department
ISIS Neutron and Muon Source
CLF central laser facility
University of Birmingham | Cyclotron Facility | Positron Imaging Centre
Corerain 鲲云科技
INFN Catania
The Cockcroft Institute of Accelerator Science and Technology
CERN
LEO Cancer Care
Maxeler Technologies Maximum Performance Computing
The Rosalind Franklin Institute
NPL National Physical Laboratory

- ***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***

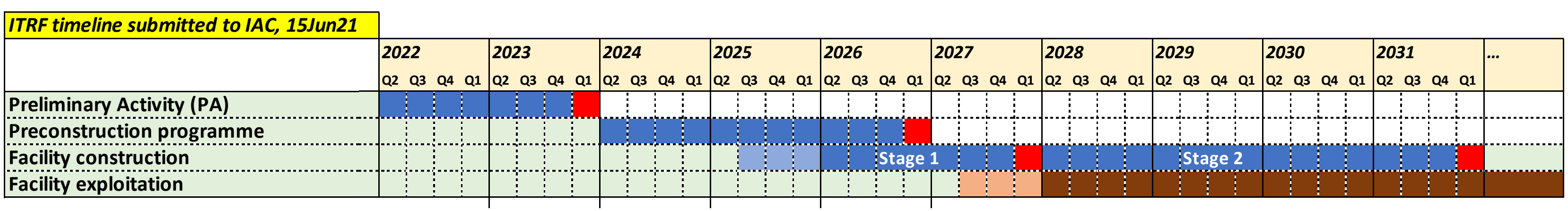
LhARA & ITRF

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

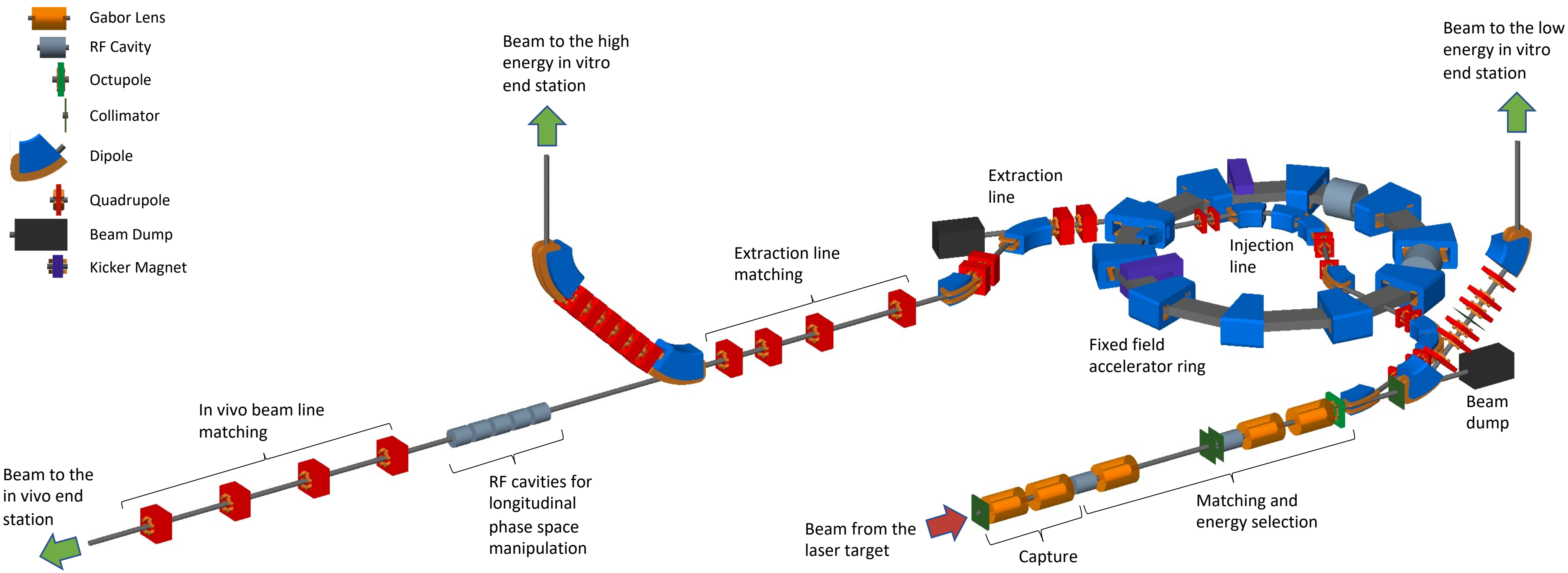
- LhARA work package structure:
  - WP1.1: Project management
  - WP1.2: Laser-driven source
  - WP1.3: Beam capture
  - WP1.4: Ion acoustic diagnostics
  - WP1.5: Novel end station
  - WP1.6: Design & integration

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

- Outreach & engagement
  - Users, Patient and Public Involvement
  - Website
  - Peer group consultation meetings, Dec 2022, June 2023.



The LhARA Accelerator



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

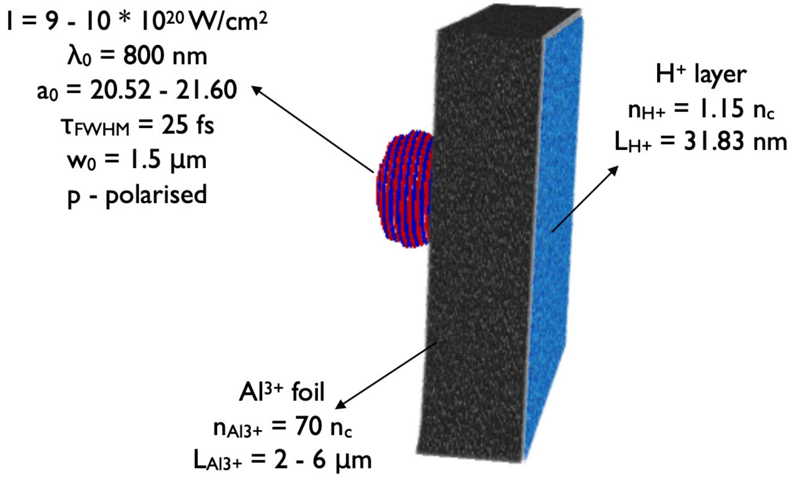
LhARA baseline design technical note:
https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Communication/Notes/CCAP-TN-11-LhARA-Design-Baseline.pdf

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	1.0×10^9 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

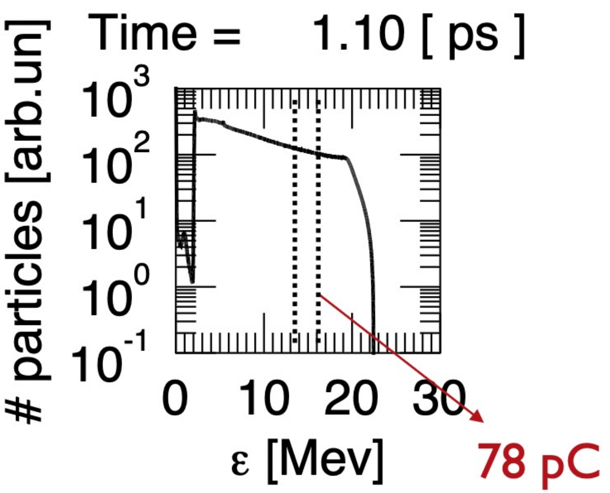
Laser-driven Proton & Ion Source

- High intensity laser driven ion sources:
  - 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

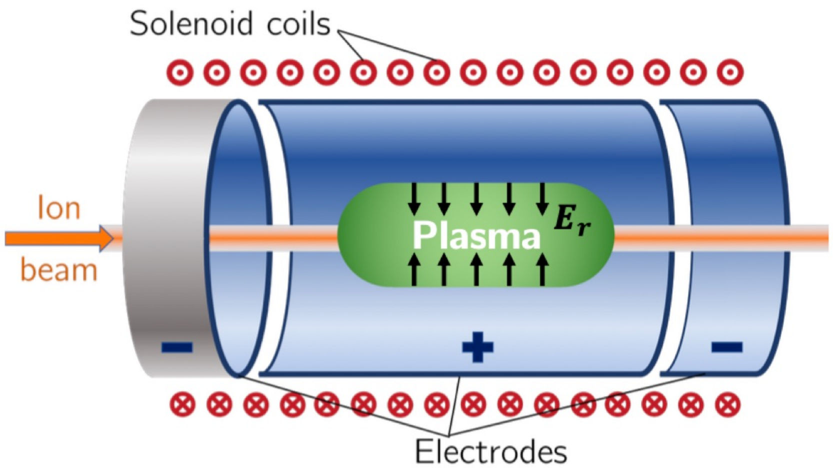
Proton spectrum



- **Identify LhARA facility laser requirements**
  - Generation of proton (15 MeV) and carbon (4 MeV/u) beams using existing "tape" targets
  - 10 Hz operation
  - Understanding of debris & stabilisation schemes

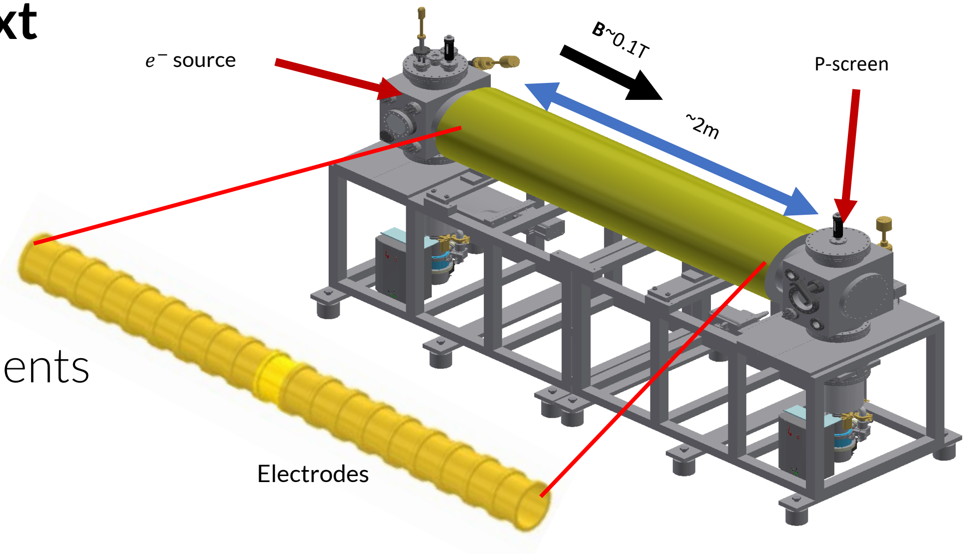
Proton & Ion Capture

- 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



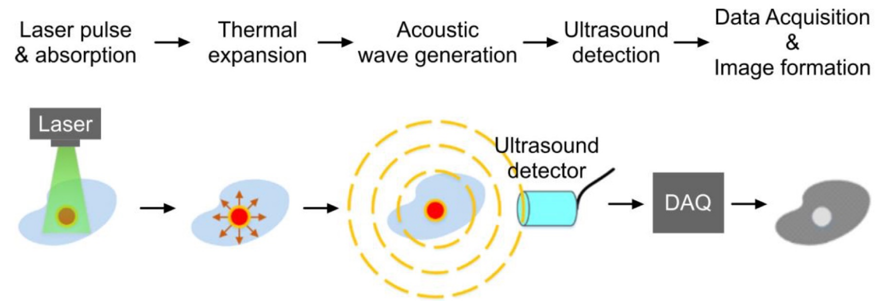
Ion-Acoustic Dose Mapping

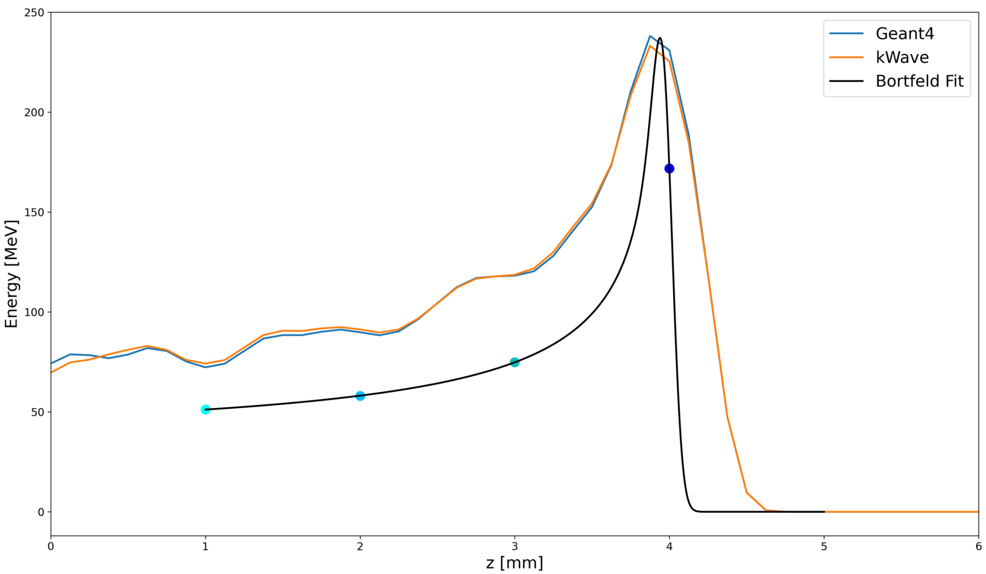
- **On-the-fly, non-invasive, range verification system**
  - Real-time dose deposition profile
  - Bragg peak localization

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

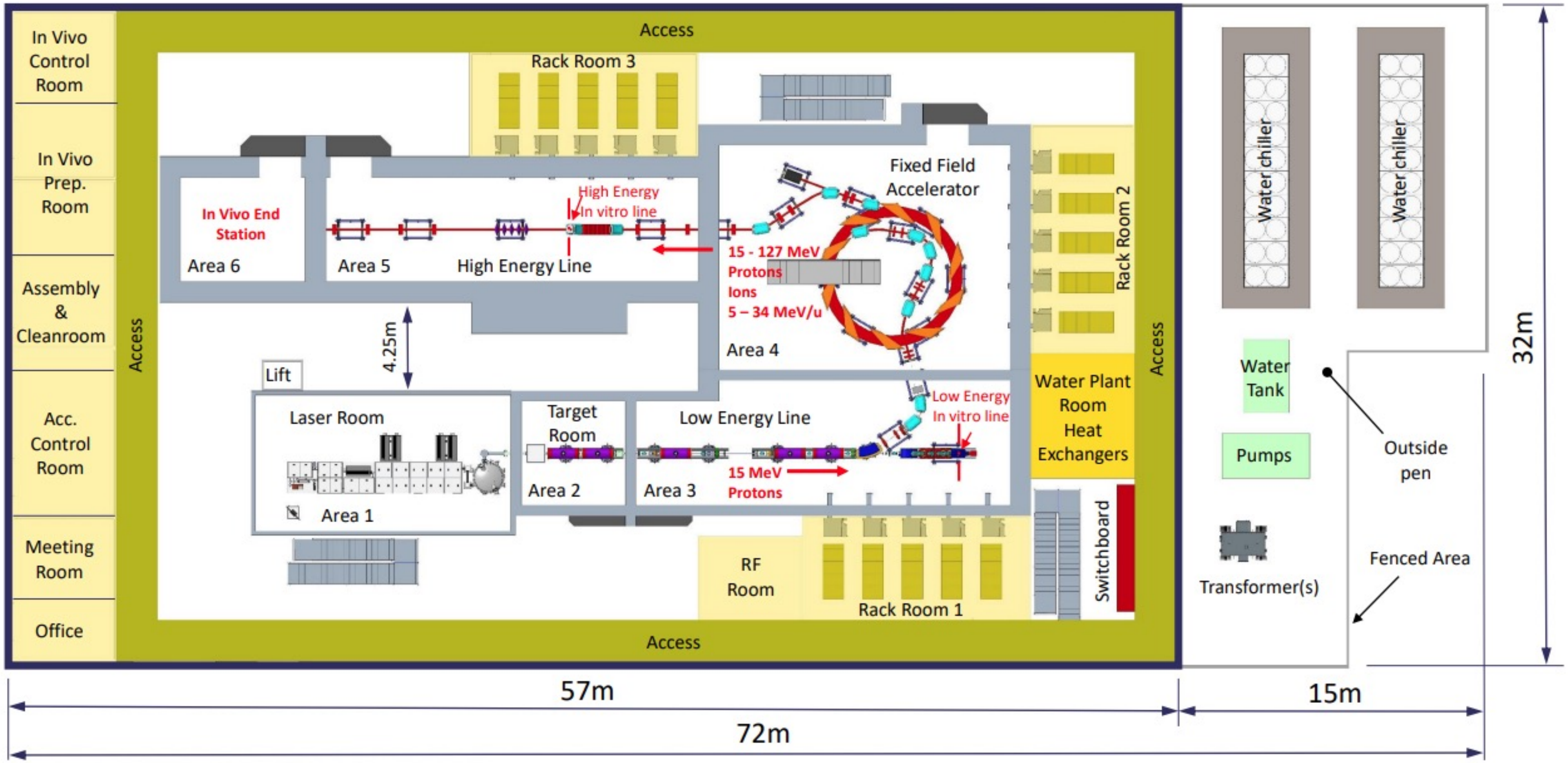
- Design proof of principle experiment
  - Geant4 MC simulation
  - K-wave acoustic model

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





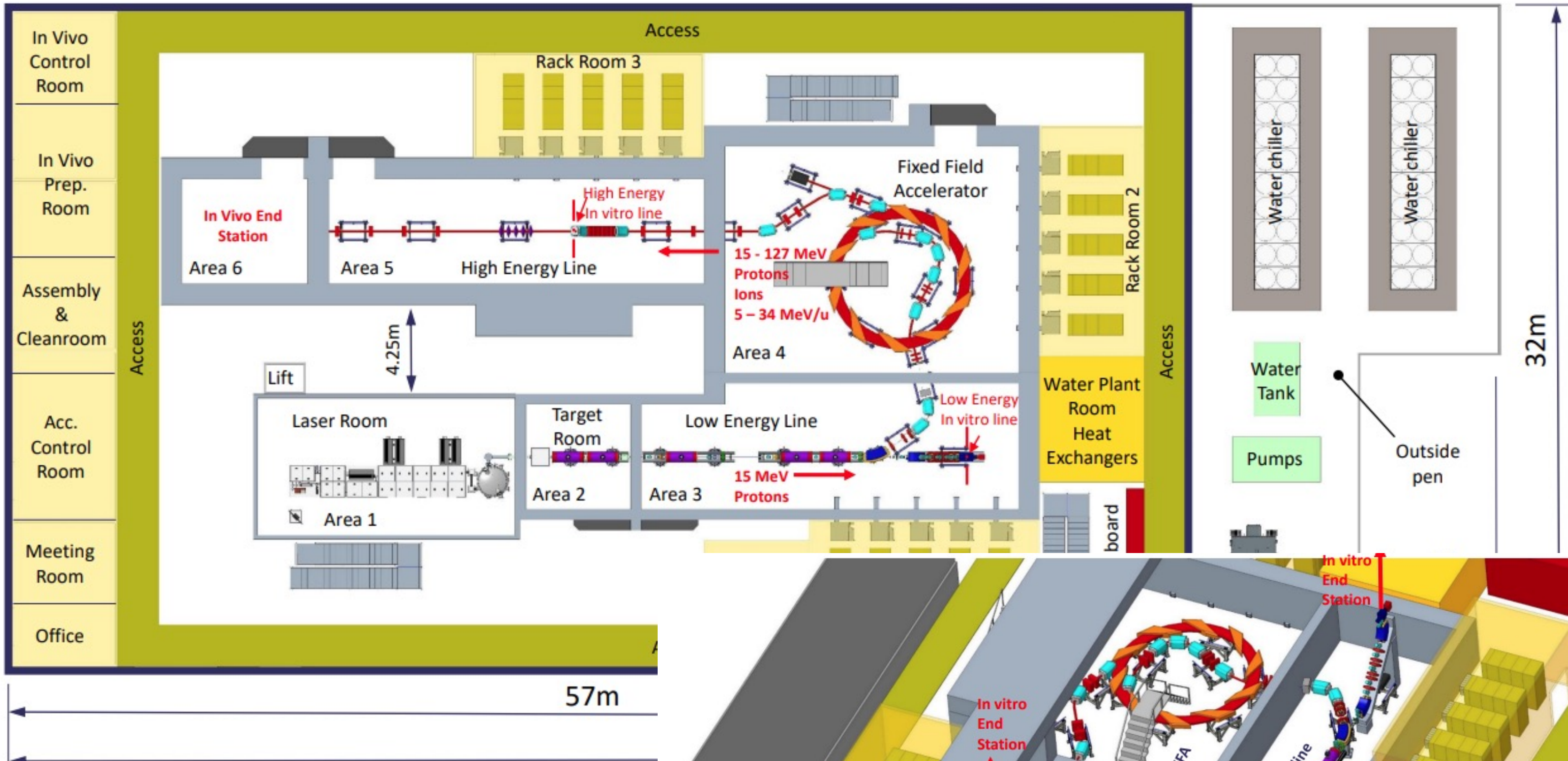
LhARA Facility Infrastructure

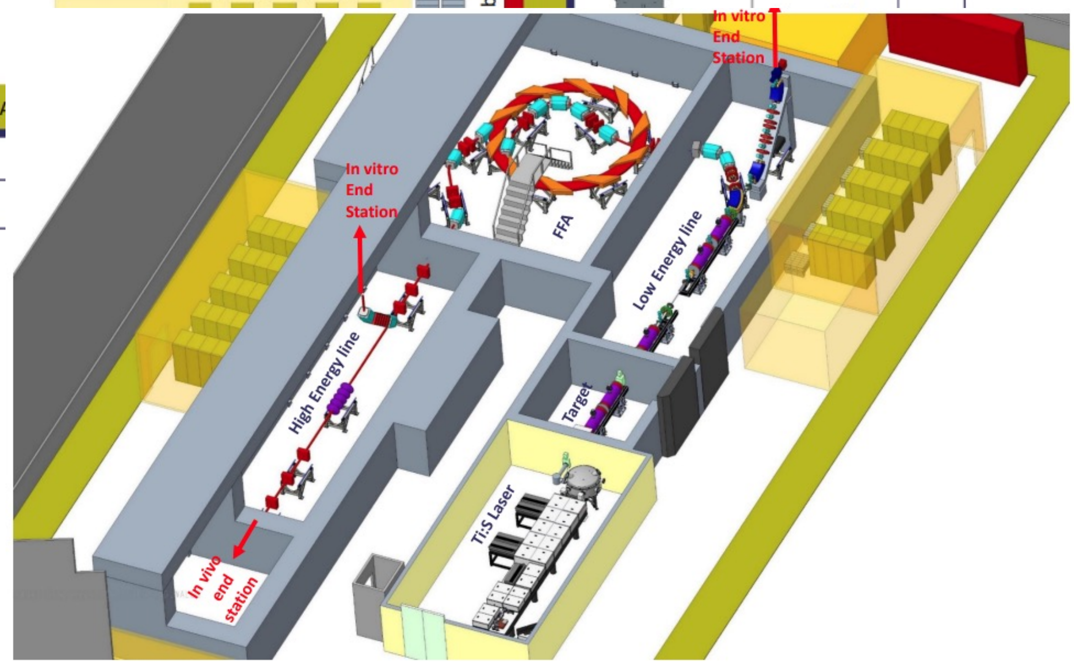


- Engineering design underway
  - Iterate as systems develop

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

LhARA Facility

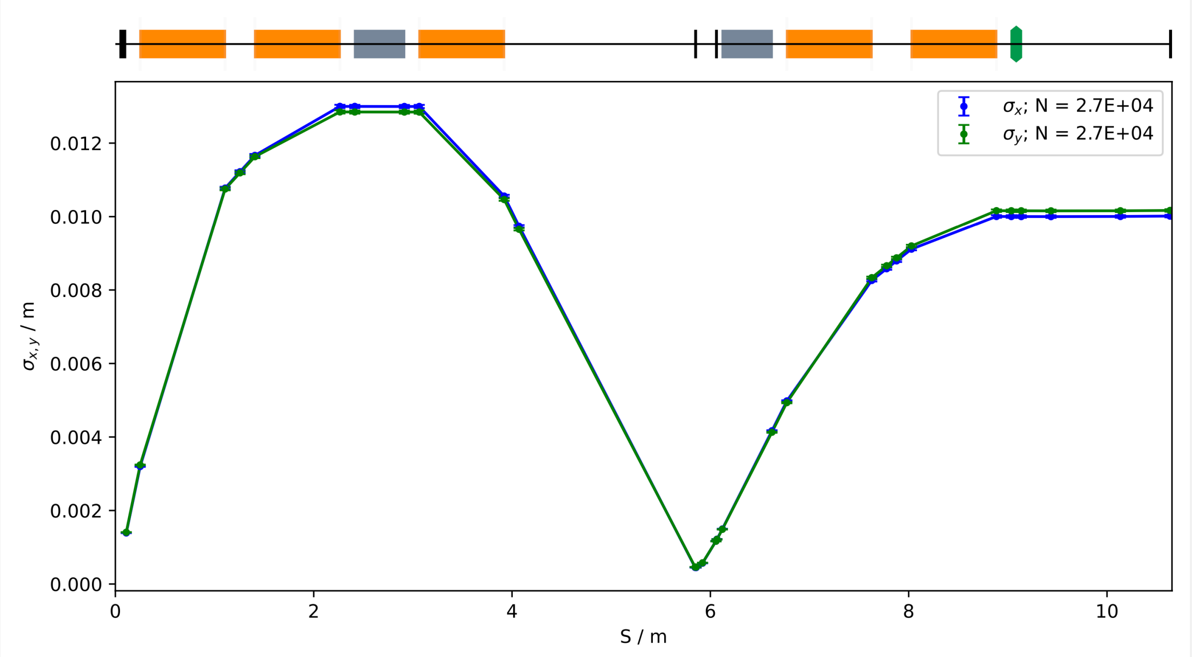




- Engineering design underway
    - Iterate as systems develop
- CAD modelling
    - Survey generation from BDSIM

W. Shields

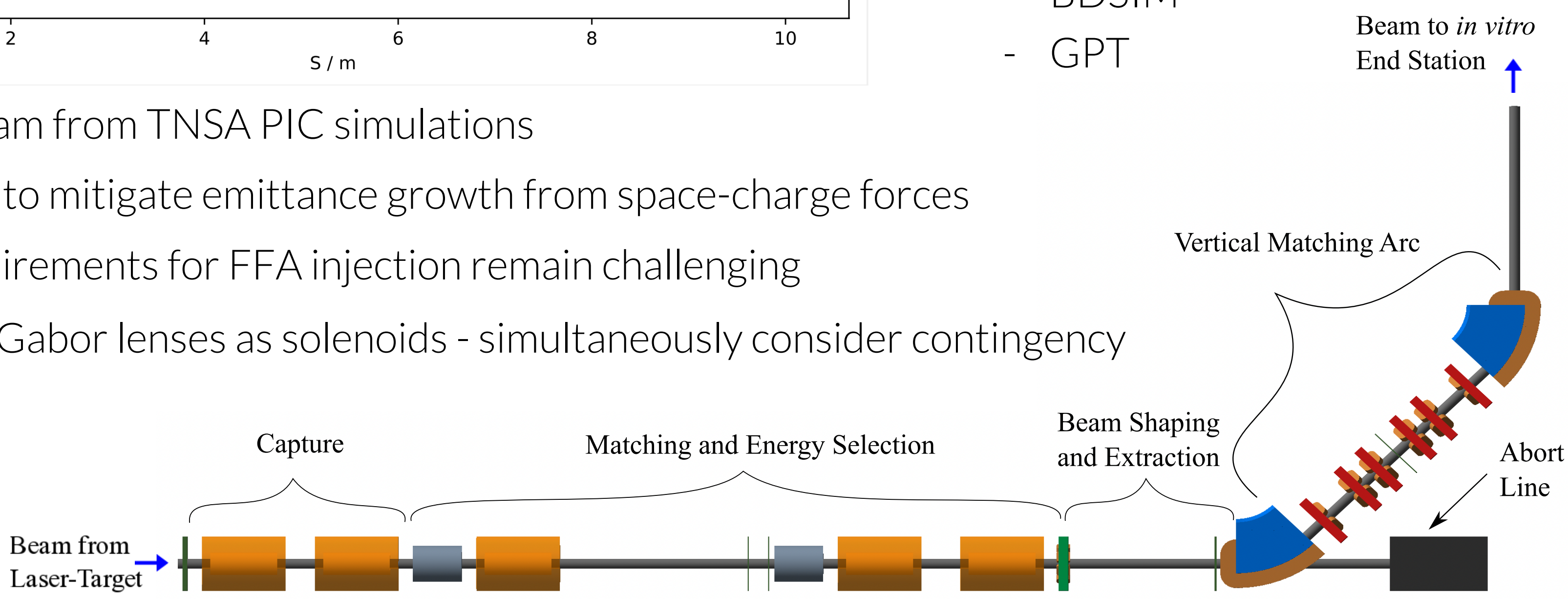
LhARA Stage 1



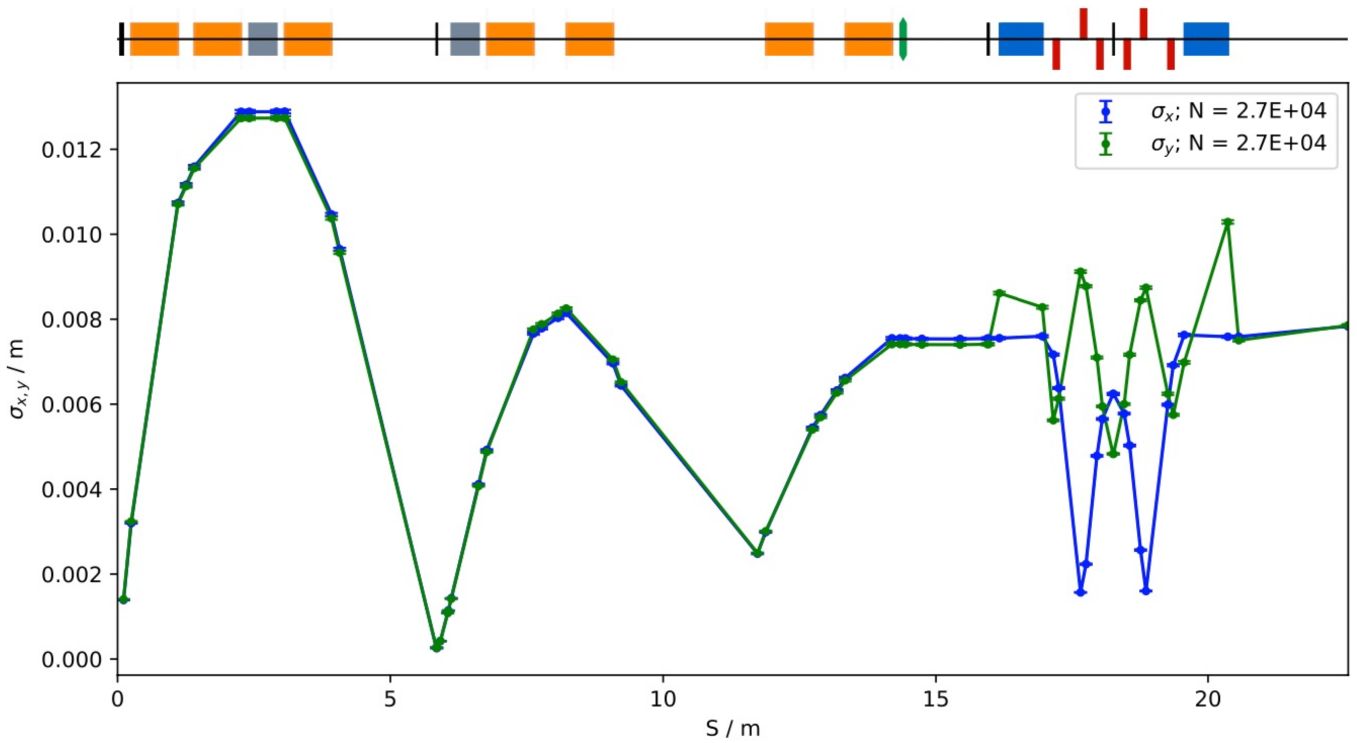
- **Conceptual design of the LhARA facility, the accelerator systems, and their integration with the end station**

- Hybrid simulation strategy
  - MADX & BeamOptics
  - BDSIM
  - GPT

- SCAPA beam from TNSA PIC simulations
- Optimised to mitigate emittance growth from space-charge forces
- Beam requirements for FFA injection remain challenging
- Modelling Gabor lenses as solenoids - simultaneously consider contingency

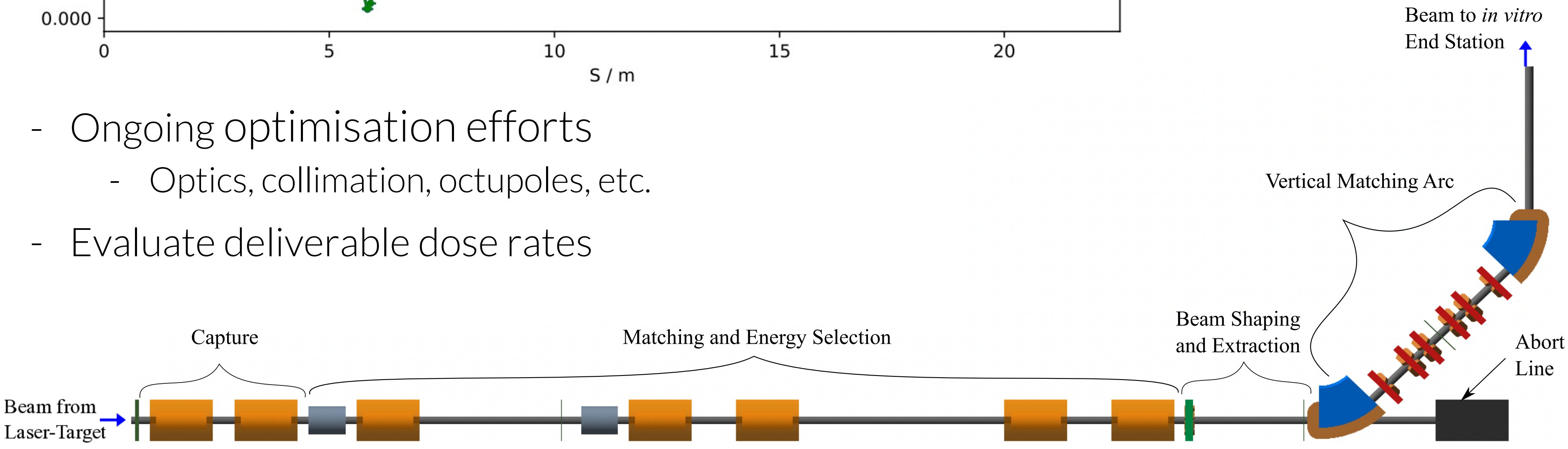


Alternative Configuration

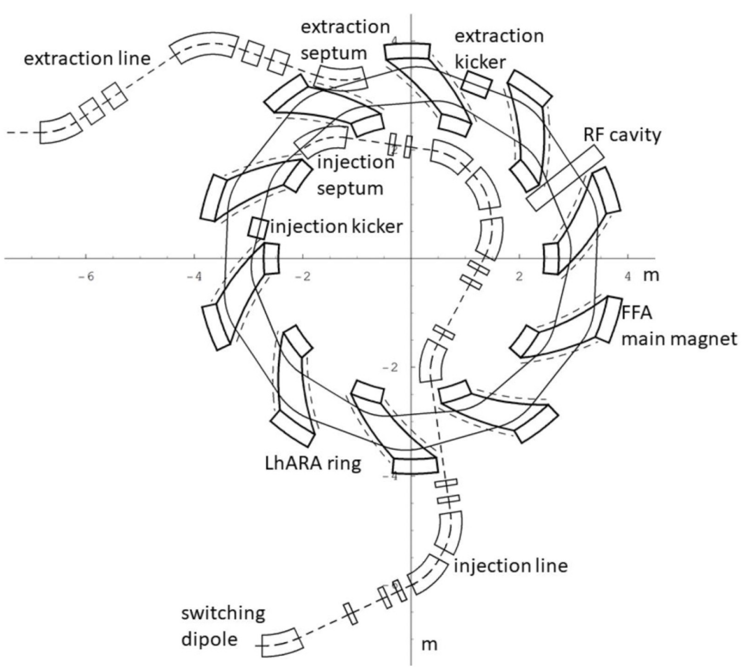


- Deliver spot-size flexibility
- FFA injection line requirements nominally achievable
  - Space charge considerations

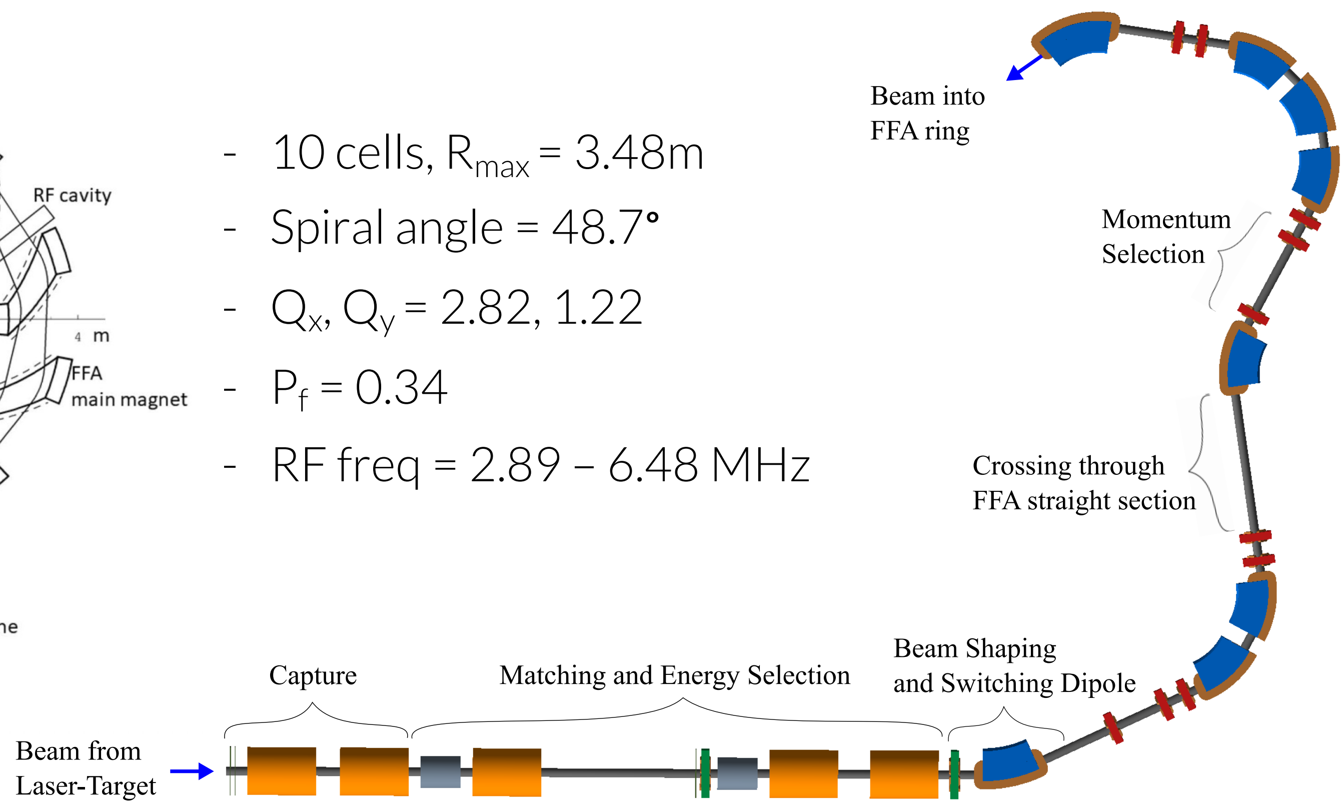
- Ongoing optimisation efforts
  - Optics, collimation, octupoles, etc.
- Evaluate deliverable dose rates



- Injection line, FFA ring, extraction line, 2 end stations
- FixField FFA tracking
  - Space charge considerations needed
- Injection line redesign to accommodate facility shielding
- FFA tunability



- 10 cells, R_{max} = 3.48m
- Spiral angle = 48.7°
- Q_x, Q_y = 2.82, 1.22
- P_f = 0.34
- RF freq = 2.89 – 6.48 MHz



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

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