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

ROYAL HOLLOWAY UNIVERSITY OF LONDON

BDSIM

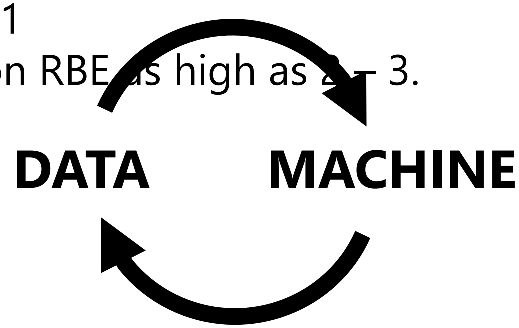
LhARA Laser-hybrid Accelerator for Radiobiological Applications

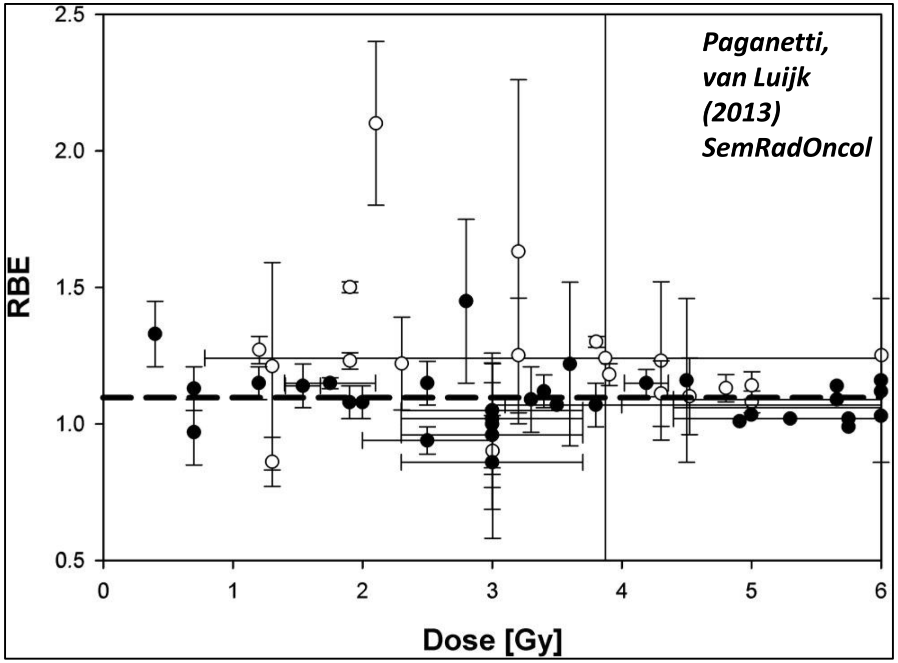
JAI John Adams Institute for Accelerator Science

The Case for LhARA

- Growing global requirement for radiotherapy
  - Improve availability & accessibility with 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
    - Ion RBE as high as 2 – 3.





- 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

University — Clinical — Laboratory — Industry — Accelerator

Partners

ASTeC
Daresbury Laboratory
Particle Physics Department
ISIS Neutron and Muon Source

- ***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***

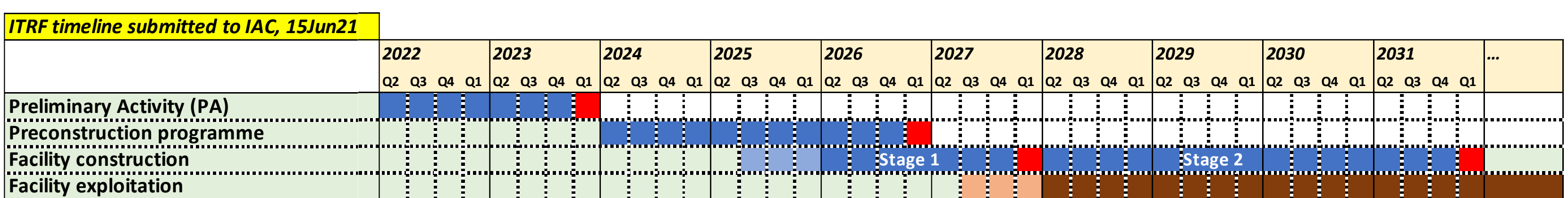
LhARA & ITRF

- £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>

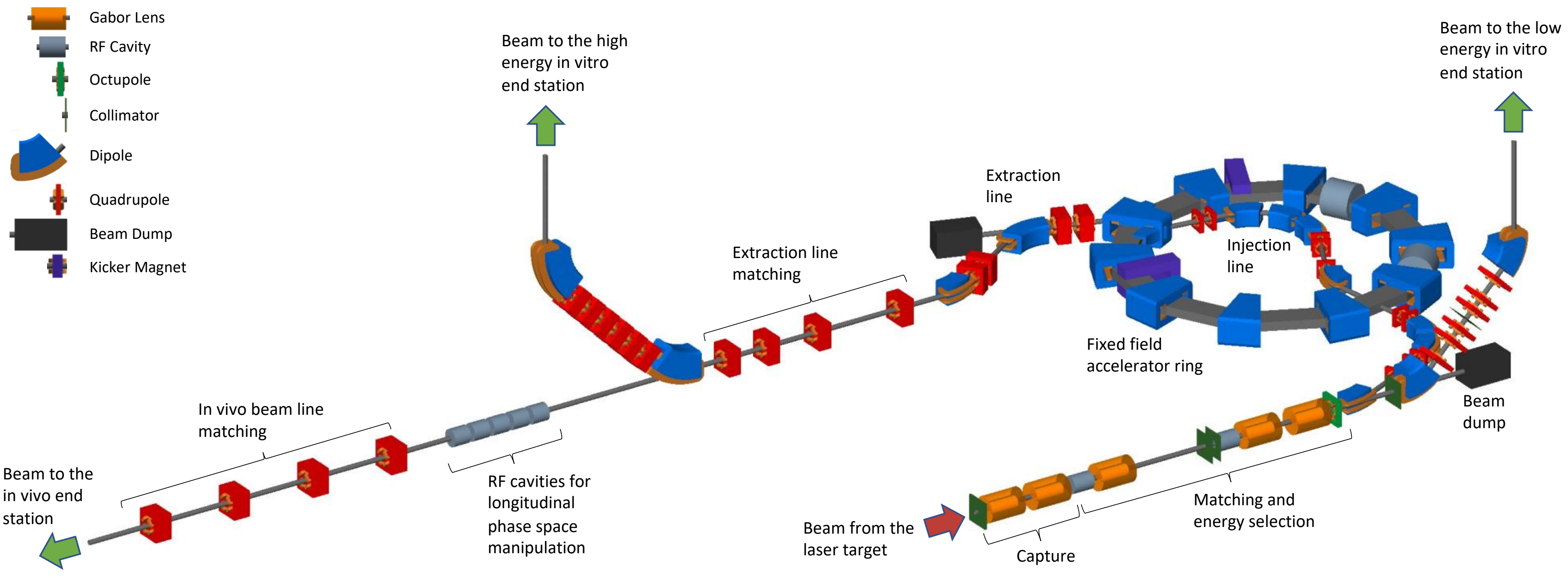
- LhARA work package structure:
  - WP1.1: Project management
  - WP1.2: Laser-driven source
  - WP1.3: Beam capture
  - WP1.4: Ion acoustic diagnostics
  - WP1.5: Novel end station
  - WP1.6: Design & integration

- 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

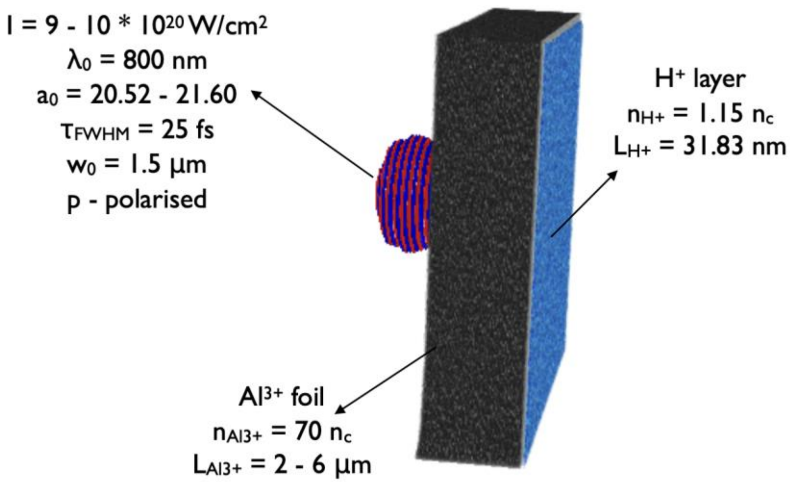
LhARA baseline design technical note:
https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Communication/Notes/CCAP-TN-11-LhARA-Design-Baseline.pdf

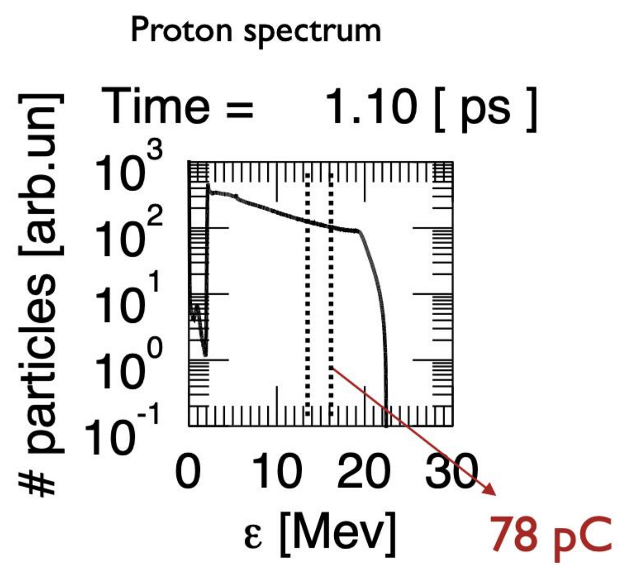
LhARA performance summary arXiv:2006.00493

	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

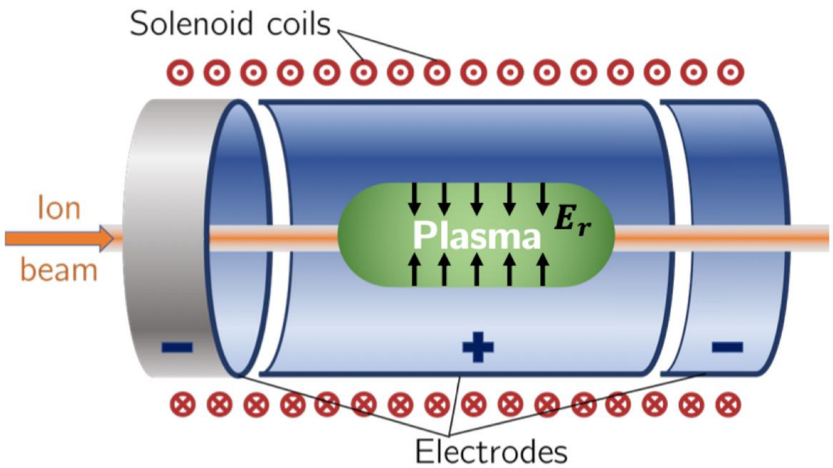
- High intensity laser driven ion sources:
  - High instantaneous dose rate - 10-40 ns bunches
  - Triggerable; arbitrary pulse structure
  - High energy from source (up to ~100 MeV)
- Proton & ion source prediction
  - 3D TNSA simulations
  - SCAPA facility & experimental beam time
- **Identify LhARA 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





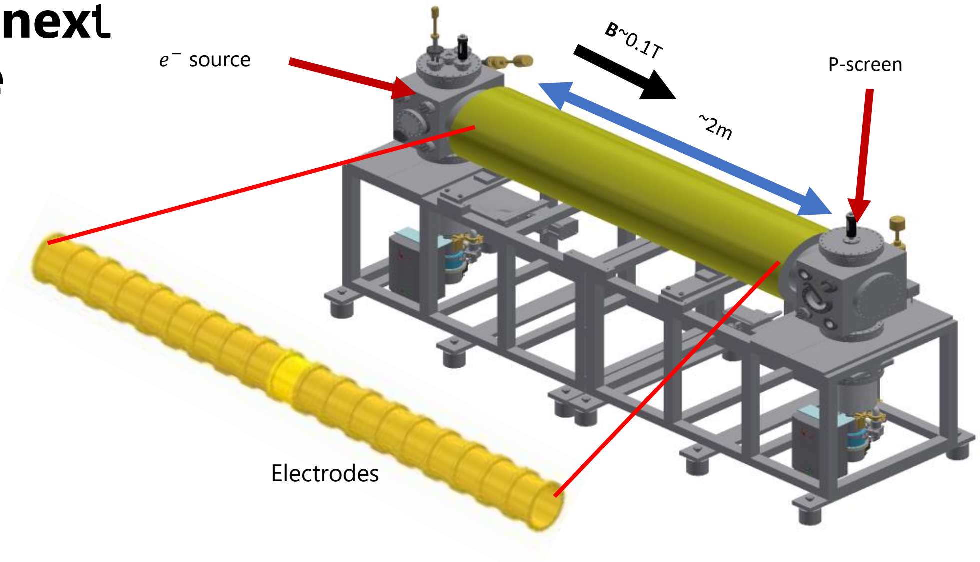
Proton & Ion Capture

- 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



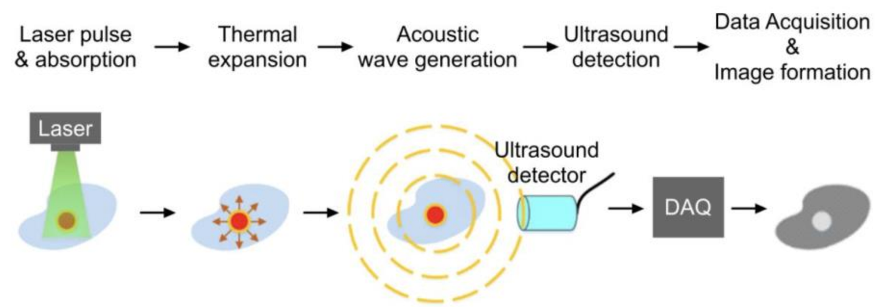
- **Develop a detailed design of the next generation Gabor-lens prototype**

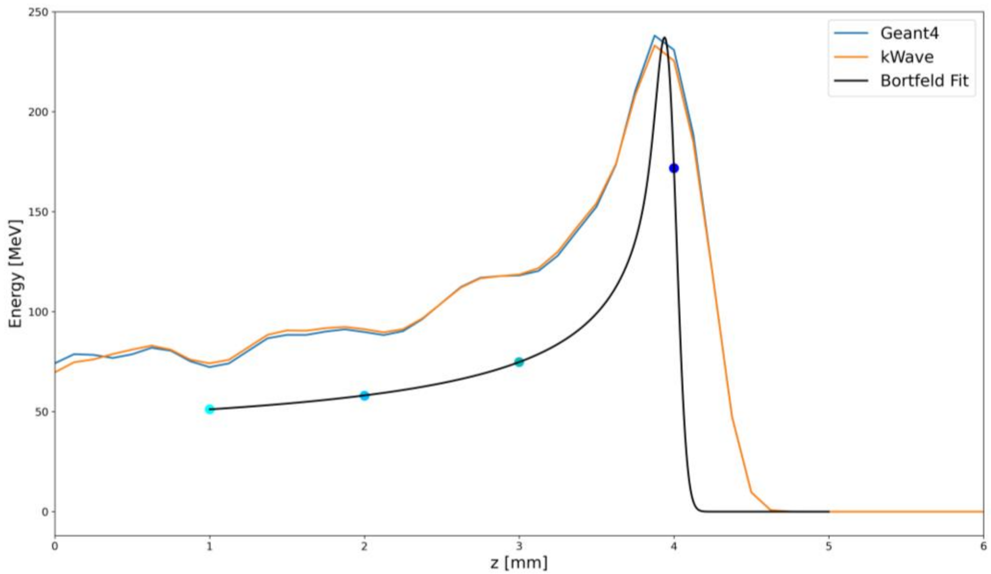
- Experimental setup at Swansea University
  - Electron-plasma dynamics measurements
  - Bench-mark simulations
    - VSim & WarpX



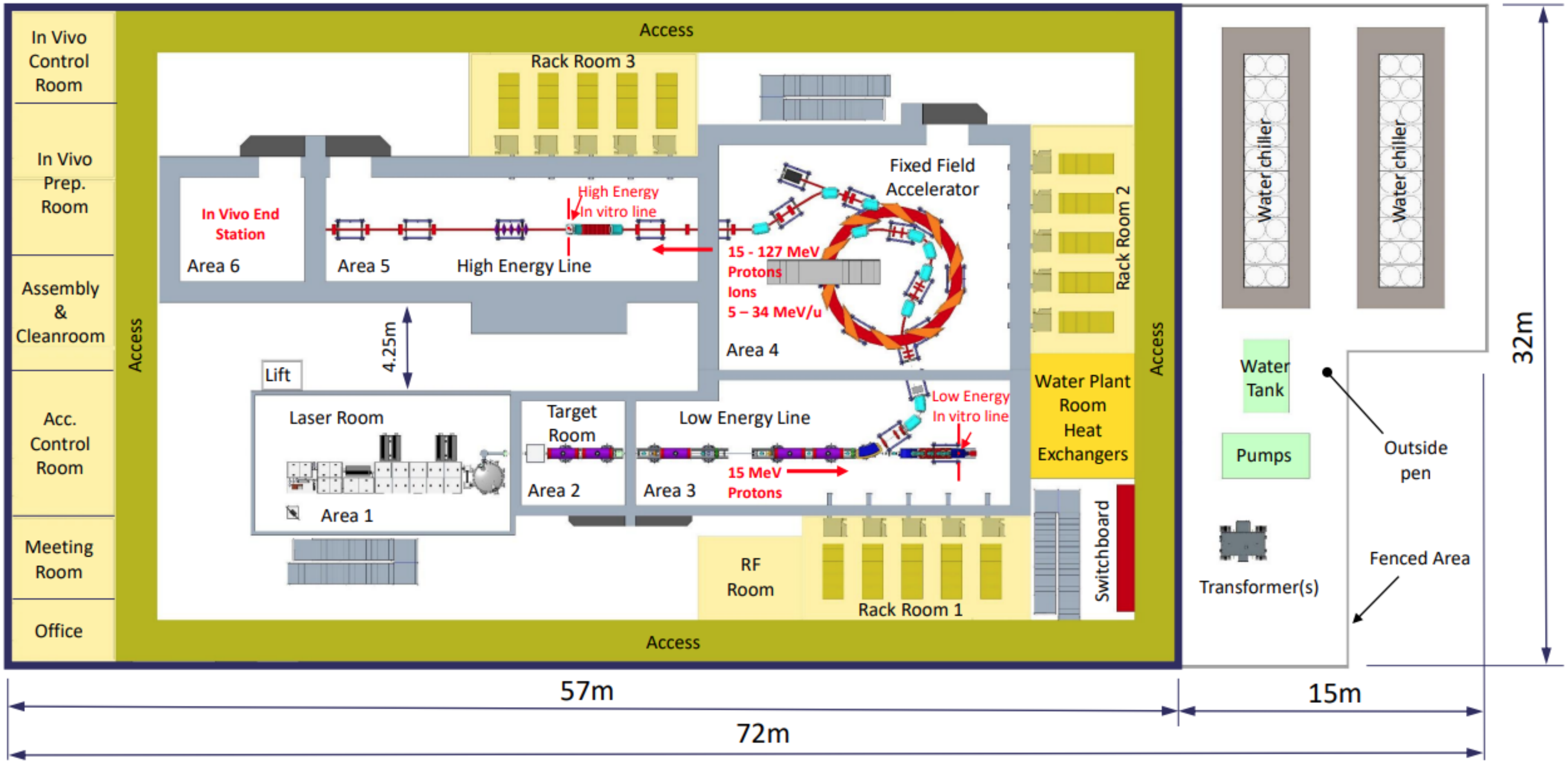
Ion-Acoustic Dose Mapping

- **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





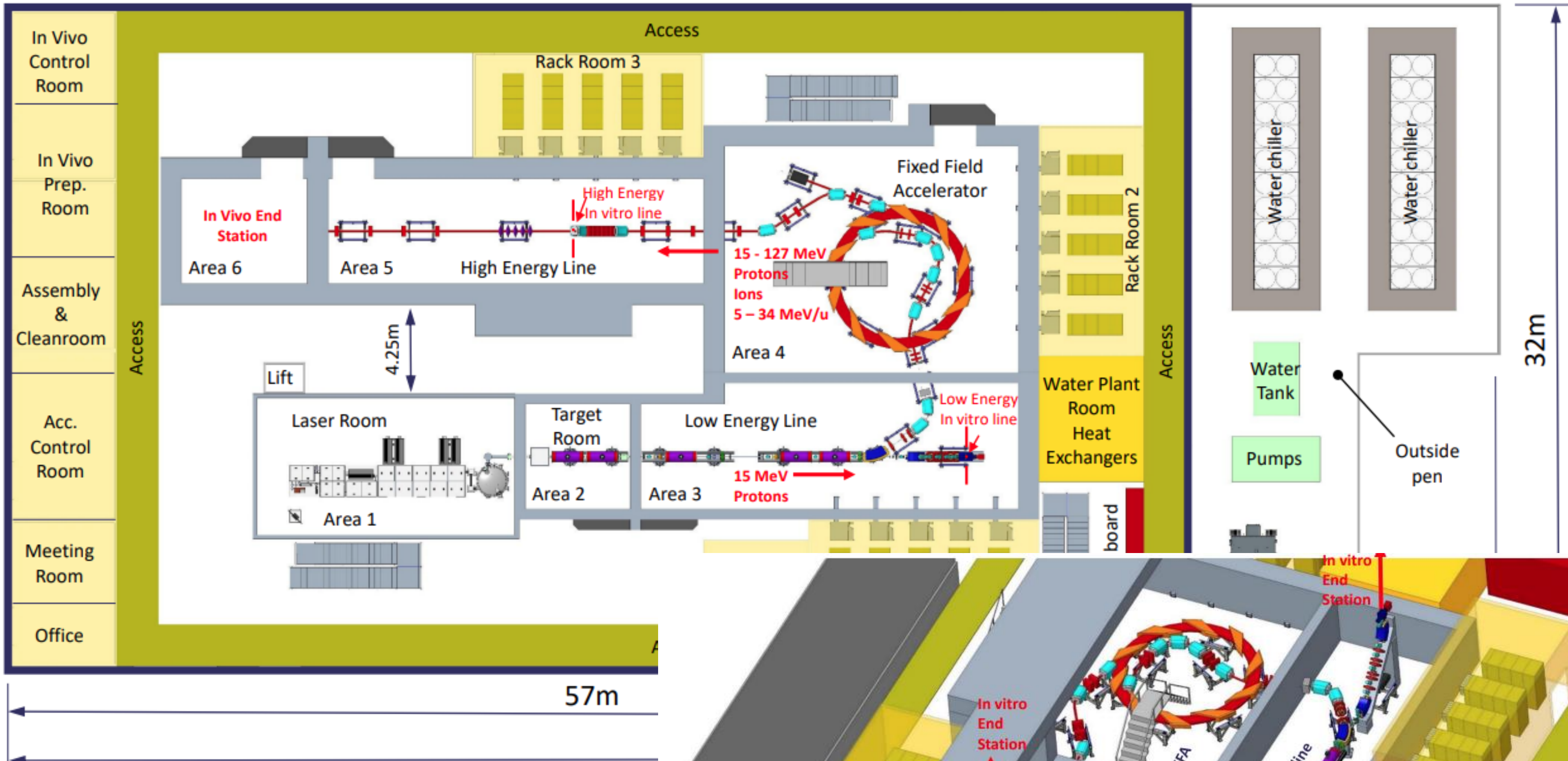
LhARA Facility Infrastructure

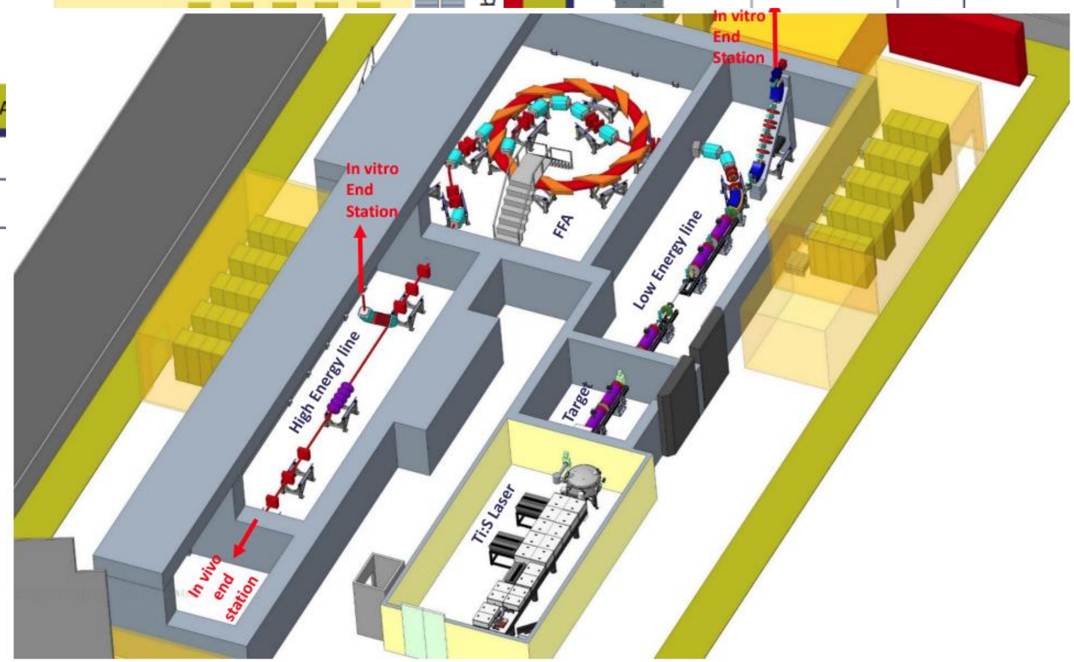


- Engineering design underway
  - Iterate as systems develop

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

LhARA Facility

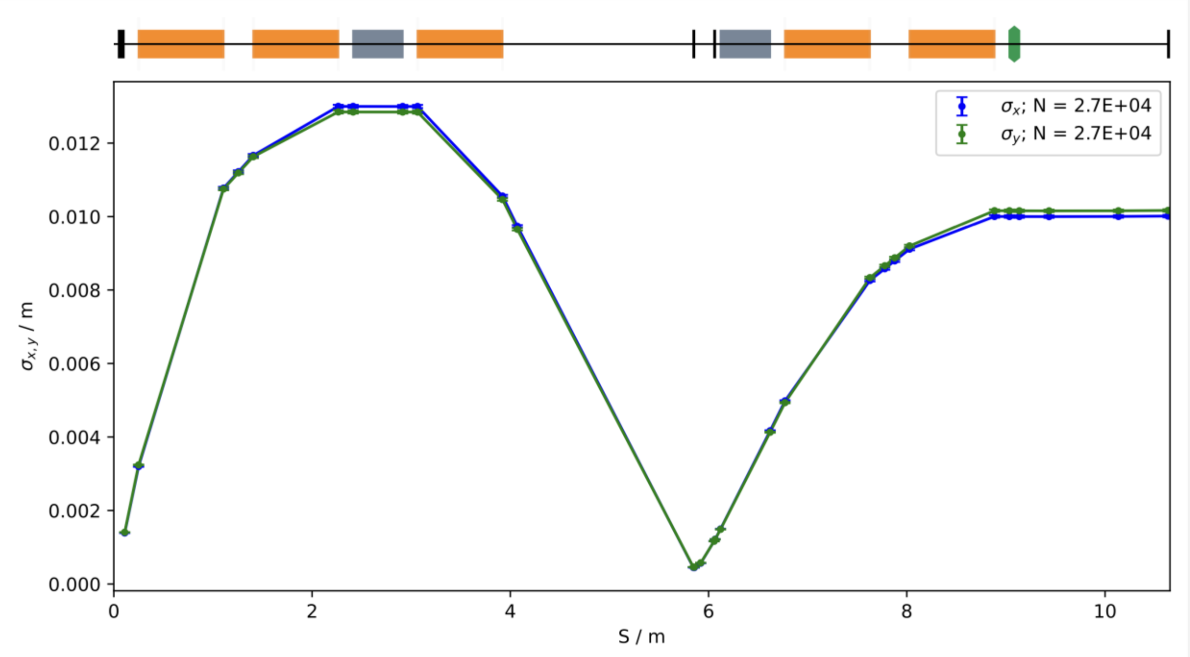




- Engineering design underway
  - Iterate as systems develop
- CAD modelling
  - Survey generation from BDSIM

W. Shields

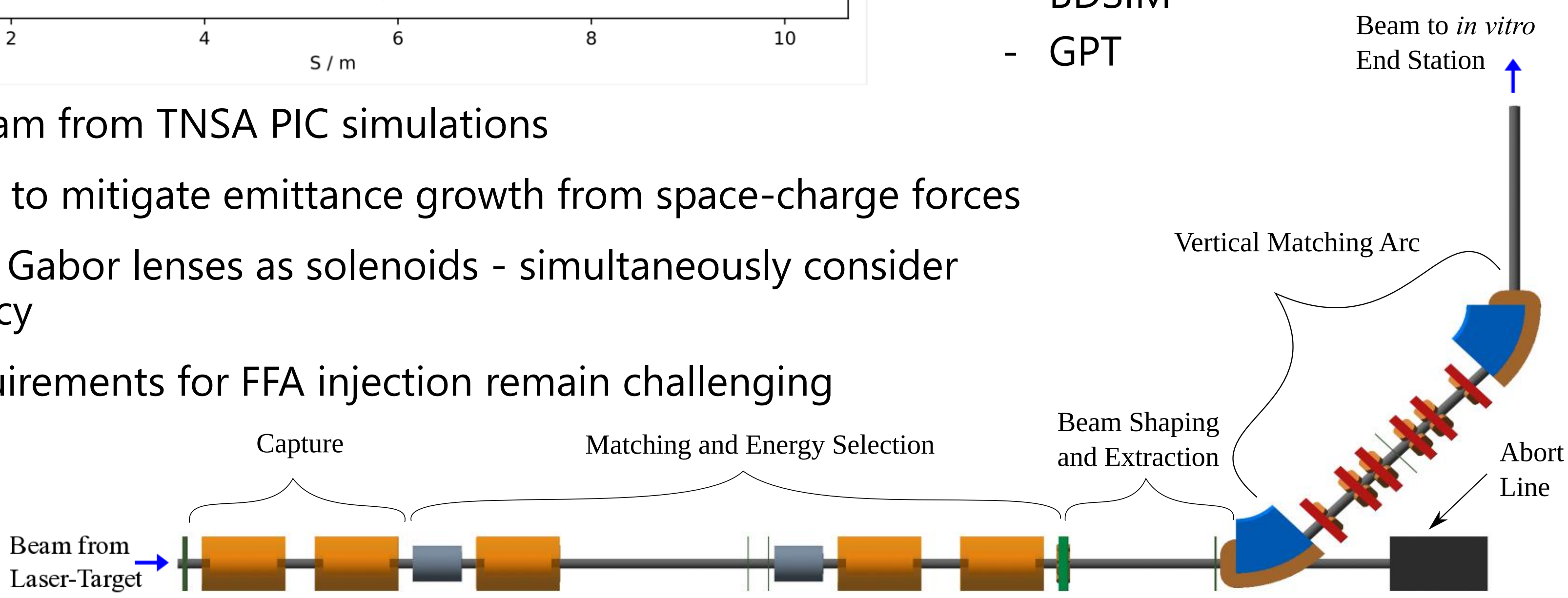
LhARA Stage 1



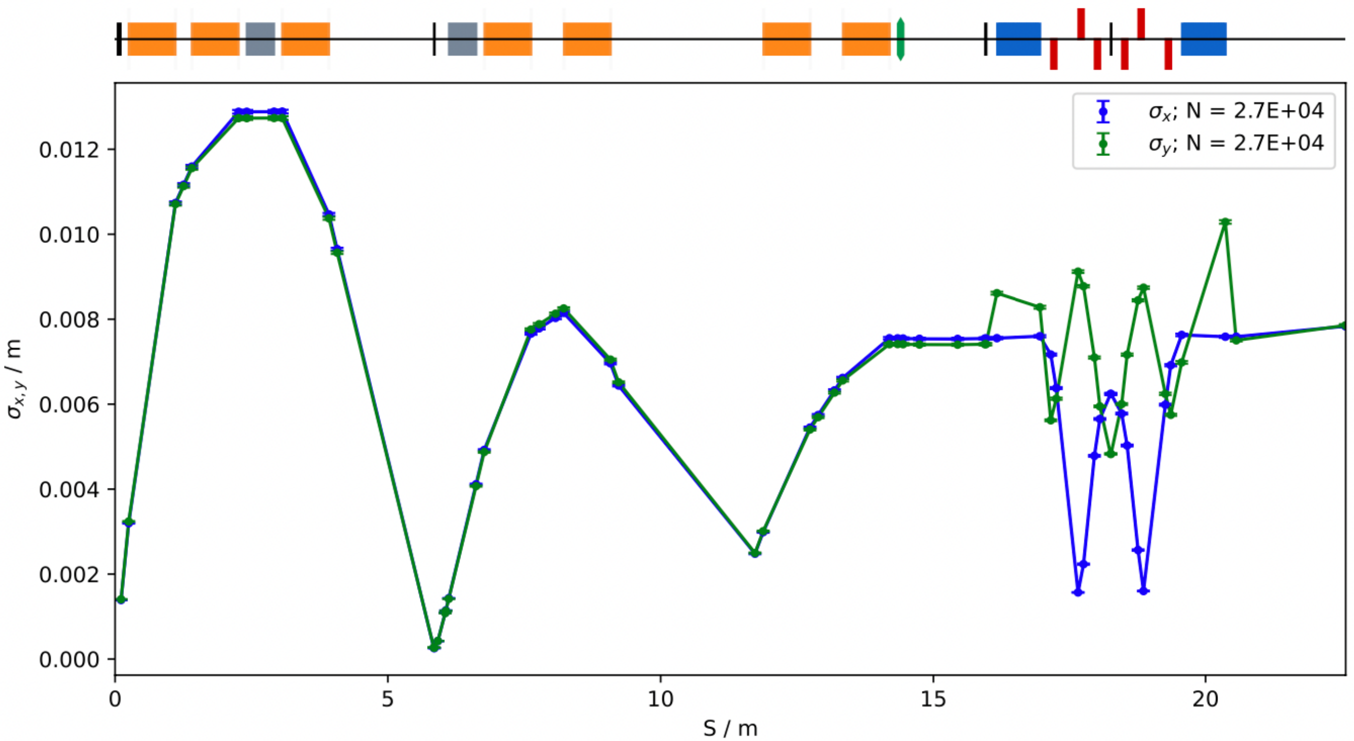
- **Conceptual design of the LhARA facility, the accelerator systems, and their integration with the end station**

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

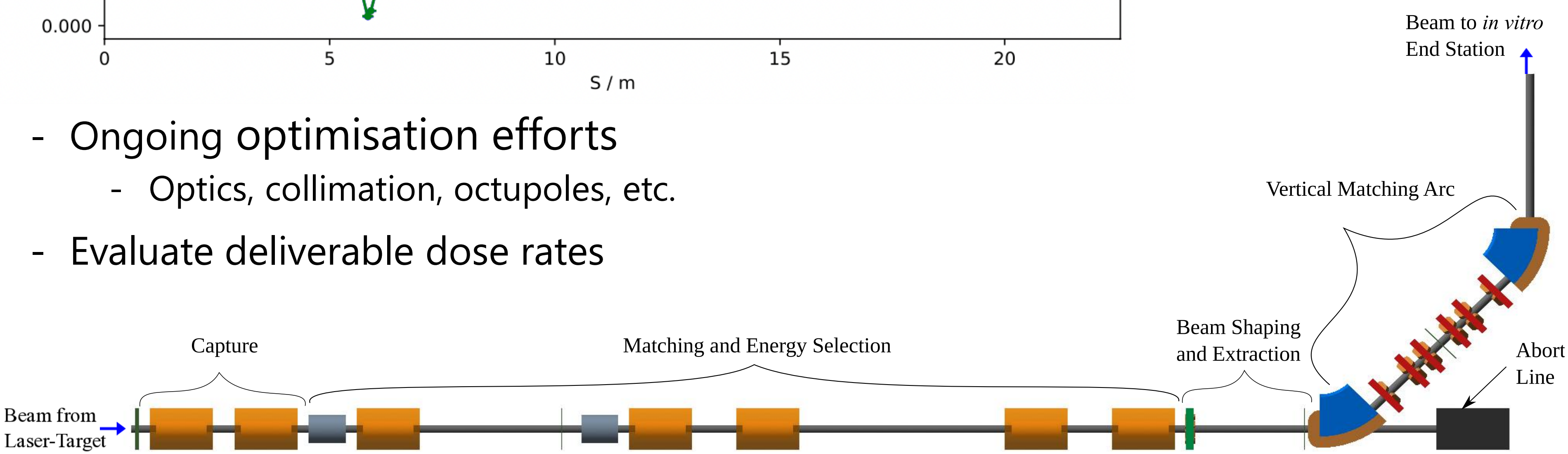
- SCAPA beam from TNSA PIC simulations
- Optimised to mitigate emittance growth from space-charge forces
- Modelling Gabor lenses as solenoids - simultaneously consider contingency
- Beam requirements for FFA injection remain challenging



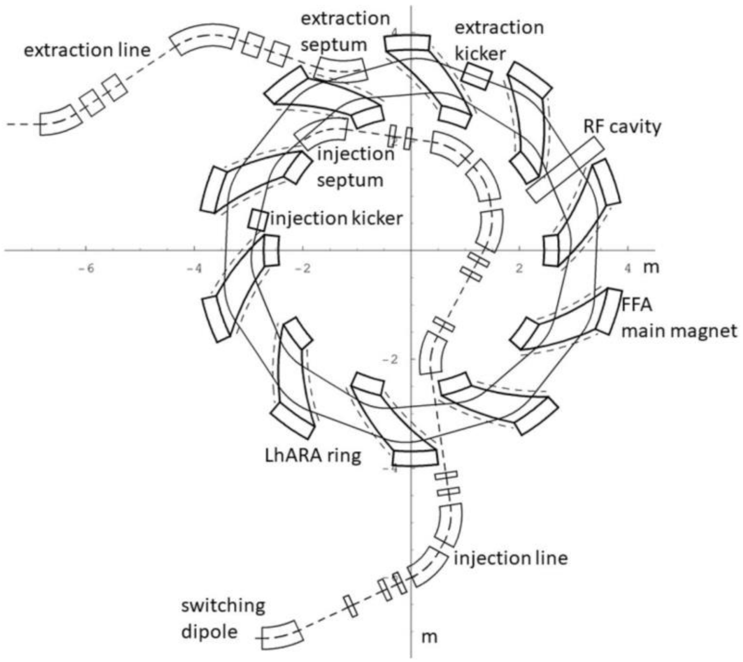
Alternative Configuration



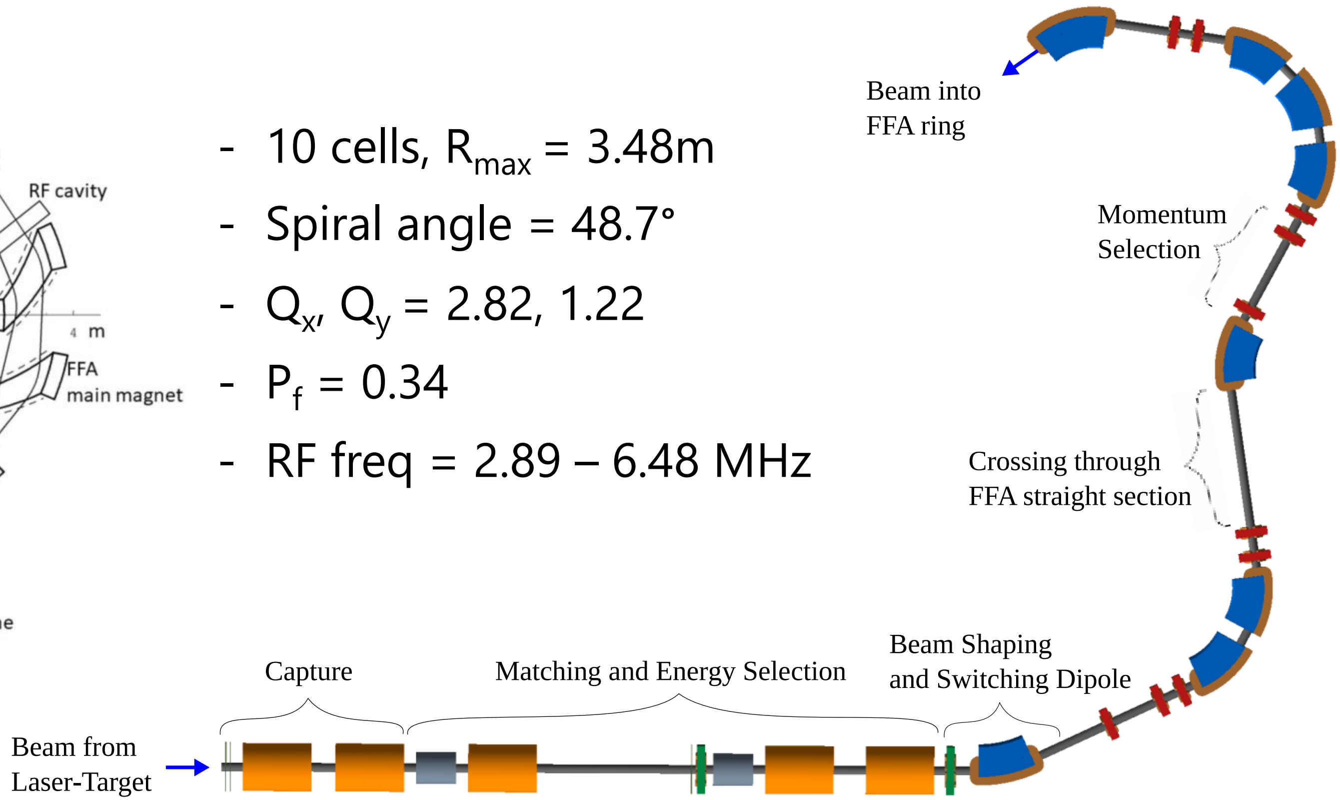
- Deliver spot-size flexibility
- FFA injection line requirements nominally achievable
  - Space charge considerations
- Ongoing optimisation efforts
  - Optics, collimation, octupoles, etc.
- Evaluate deliverable dose rates



- 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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