Design of the LhARA accelerator facility

J. Pasternak, LhARA Review, 31/03/2020
Outline

• Introduction and motivation
• Stage 1 baseline
• Stage 1 alternative
• FFA post-accelerator
• Stage 2 injection
• Optics for Stage 2 end stations
• R&D needs
• Conclusions
Introduction

• Laser hybrid Accelerator for Radiobiological Applications (LhARA) was proposed within the Centre for the Clinical Application of Particles (CCAP) at Imperial College London as a facility dedicated to the systematic study of radiobiology.

• It will allow study with proton beams with a flexible dose delivery (including a novel FLASH regime) at Stage 1

• It will open the study to use multiple ions (including Carbon) at Stage for both in-vitro and in-vivo end stations.

• It aims to demonstrate a novel technologies for next generation hadrontherapy.
Initial Beam from the Laser Source

- Small emittance (~4.1x10^{-7} \, \pi \, \text{m.rad})
- Huge energy spread
- Very small beam size
- Very large divergence
- Neutral at the beginning then space charge dominated
- Mixture of states

Details in O. Ettlinger’s talk
Optics in LhARA Stage 1, baseline lattice

- Energy selection by using a collimator between GL3 and GL4
- Combined with momentum selection collimator in the arc will produce PID selection
- RF cavities to manipulate the energy spread of the accepted beam and the bunch duration
LhARA Stage 1 parameters

- Initial beam assumed neutral first (5cm) and then space charge must be taken into account
- Strong focusing in both planes by Gabor Lenses (or solenoids) essential in the capture section, see C. Whyte’s talk for details
- Matching to very small spot size unavoidable and used for the energy selection
- Matching with two lenses to the optically transparent, achromatic arc
- Redistribution of phase space using octupoles to create an uniform beam
Lhara Stage 1, alternative design

- Alternative design uses quadrupoles to avoid focusing to the spot in both planes simultaneously (a space charge mitigation)
- Octupoles would be in the right optical locations
- Optics optimisation with the space charge to be done and the performance to be demonstrated

More results on Stage 1 performance, see W. Shields’ talk
Advantages of FFA for medical/radiobiological applications:
- High/variable dose delivery (high rep rate – 10-100 Hz)
- Variable energy operation without energy degraders
- Compact size and low cost
- Simple and efficient extraction
- Stable and easy operation
- Multiple extraction ports
- Bunch to Pixel active scanning possible.
- Multiple ion capability
Energy Variability using Laser Accelerated Ions

Variable input energy from the Laser Source (multiple ions are possible)

Variable extraction energy from FFA within 1 s (20-125 MeV) at fixed geometry

+ pulse by pulse variation with kicker could be implemented

Change of the value of magnetic field in FFA and transfer lines for a specific energy operation (laminated magnets)
Energy for LhARA Step 2

- FFA accelerator can typically accelerate by a factor of 3 in momentum (or more). This allows to easily achieve 127.4 MeV (starting from 15 MeV).
  - Acceleration by a factor of 4 would be possible. This corresponds to 217 MeV protons.
- This would correspond to 33.4 (58.7) MeV/u for C6+. 

![Graph showing the energy range in water for protons and carbon ions](image)
LhARA Ring Parameters

- $N = 10$
- $k = 5.33$
- Spiral angle $= 48.7^\circ$
- $R_{\text{max}} = 3.48 \text{ m}$
- $R_{\text{min}} = 2.92 \text{ m}$
- $(Q_x, Q_y) = (2.83, 1.22)$
- $B_{\text{max}} = 1.4 \text{ T}$
- $p_f = 0.34$
- Max Proton injection energy $= 15 \text{ MeV}$
- Max Proton extraction energy $= 127.4 \text{ MeV}$
- $h = 1$
- RF frequency for proton acceleration (15-127.4MeV) $= 2.89 – 6.48 \text{ MHz}$
- Bunch intensity $= \text{few} \times 10^8 \text{ protons}$
- Range of other extraction energies possible
- Other ions also possible
LhARA Ring Tracking

- Performed using proven stepwise tracking code
- It takes into account fringe fields and non-linear field components
- Results show dynamical acceptances are much larger than physical ones.
- No space charge effects included yet.
### FFA Ring with subsystems

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Injection optics

- Stage 1 can be tuned to match the injection line
- Focus point changes location and requires a dedicated collimation system
- Focusing can be realised with normal conducting solenoids

Optics from the switching dipole to the injection septum has been designed
Extraction optics

Optics for Stage 2 in-vitro end station, the arc optics scaled from the Stage 1

Optics for Stage 2 in-vivo end station, a dedicated final focus has been designed

For tracking results, see W. Shields’ talk
Magnet types to be considered

“Gap shaping” magnet:
• Developed by SIGMAPHI for RACCAM project
• Initially thought as more difficult
• Behaves very well
• Chosen for the RACCAM prototype construction

Magnet with distributed conductors:
• Parallel gap – vertical tune more stable,
• Flexible field and k adjustment,

• For LhARA magnet with parallel gap with distributed windings (but a single current) would be of choice with gap controlled by clamp. Concepts like an active clamp could be of interest too.

• Another important aspect of the R&D is the technology transfer for Magnetic Alloy (MA) loaded RF cavities for the ring

J. Pasternak, IC London
Layout of the full LhARA facility
Conclusions

• Conceptual design of LhARA is in a very good shape:
  • Stage 1 design is compact and flexible, and performs very well even including the space charge effects (see W. Shields’ talk).
  • LhARA at Stage 2 can use FFA-type ring as a post-accelerator enabling variable energy beams of various types of ions. The cost effective, spiral scaling FFA shows a good performance in tracking studies.
  • Feasible ring injection, extraction and beam transport to the end stations at Stage 2 have been designed.

• Essential R&D items:
  • the main FFA magnet, and
  • the RF system for the ring