Progress on the Conceptual Design of the Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

W. Shields [1] on behalf of the LhARA Collaboration

[1] John Adams Institute, Royal Holloway, University of London

THPM083

Abstract

LhARA, the Laser-hybrid Accelerator for Radiobiological Applications, is a proposed novel facility capable of delivering high intensity beams of protons and ions that will enable radiobiological research to be carried out in completely new regimes. A two-stage facility, the first stage utilizes laser-target acceleration to produce proton bunches of energies up to 15 MeV. A series of Gabor plasma lenses will efficiently capture the beam which will be delivered to an in-vitro end station. The second stage will accelerate protons in a fixed-field alternating-gradient ring up to 127 MeV, and ions up to 33.4 MeV/nucleon. The beams will subsequently be deliverable to either an in-vivo end station or a second in-vitro end station. The technologies demonstrated in LhARA have the potential to underpin the future of hadron therapy accelerators and will be capable of delivering a wide variety of time structures and spatial configurations at instantaneous dose rates up to and significantly beyond the ultra-high dose rate FLASH regime. We present here recent progress and the current status of the LhARA accelerator as we work towards a full conceptual design.

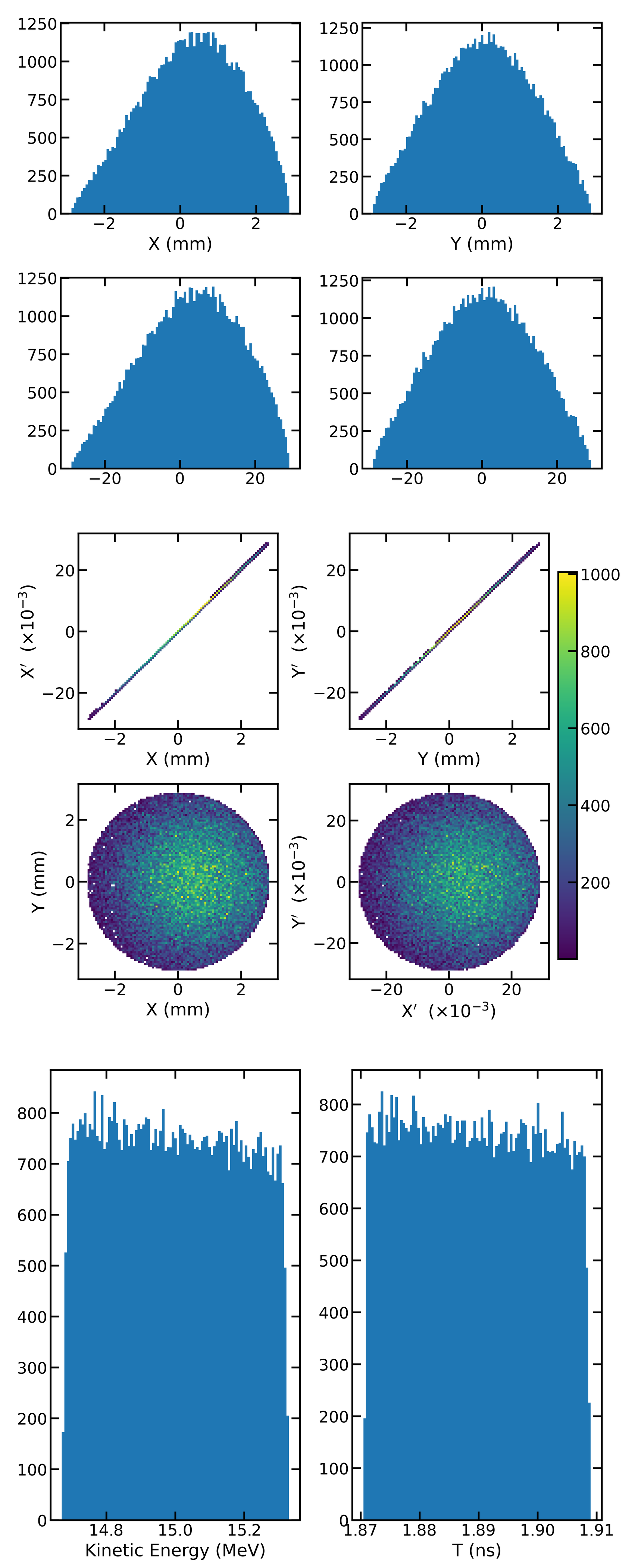
LhARA

- LhARA is a proposed state-of-the-art accelerator for radiobiological research that serves the Ion Therapy Research Facility (ITRF).
  - We aim to develop & demonstrate novel technologies for generating and delivering proton & ion beams at FLASH dose rates.
  - A systematic radiobiology program is in development, laying the foundations for future generations of radiotherapy.

- LhARA is conceived to be developed in two stages [1,2]:
  - Stage 1 will generate high flux proton and ion beams from laser-target interactions via the Target Normal Sheath Acceleration (TNSA) mechanism. Gabor electron plasma lenses will capture & focus the beam.
  - Stage 2 will see the beam injected into an FFA ring. An extraction line will transport the beams to in-vitro and in-vivo end stations.

- Work towards a full conceptual design is underway. Here, we show progress on understanding the beam generation and subsequent tracking performance.
  - BDSIM [3] and GPT [4] are used in start-to-end Monte Carlo simulations.
  - The baseline design and a new experimental configuration are modelled.

Simulated TNSA Beam Transport Performance



- LhARA's baseline design performance was ascertained with beams simulated by the laser-target interaction PIC code Smilei [5]
  - Computational resources limited the beam to 2D, with the third dimension generated by extrapolation [6].

- New full 3D simulations with the PIC code OSIRIS [7] modelled the SCAPA facility which shares many similarities with the proposed LhARA setup.
  - A factor 4 difference compared to the original pre-CDR beam is observed, an improvement over the Smilei beam which is over an order of magnitude different.

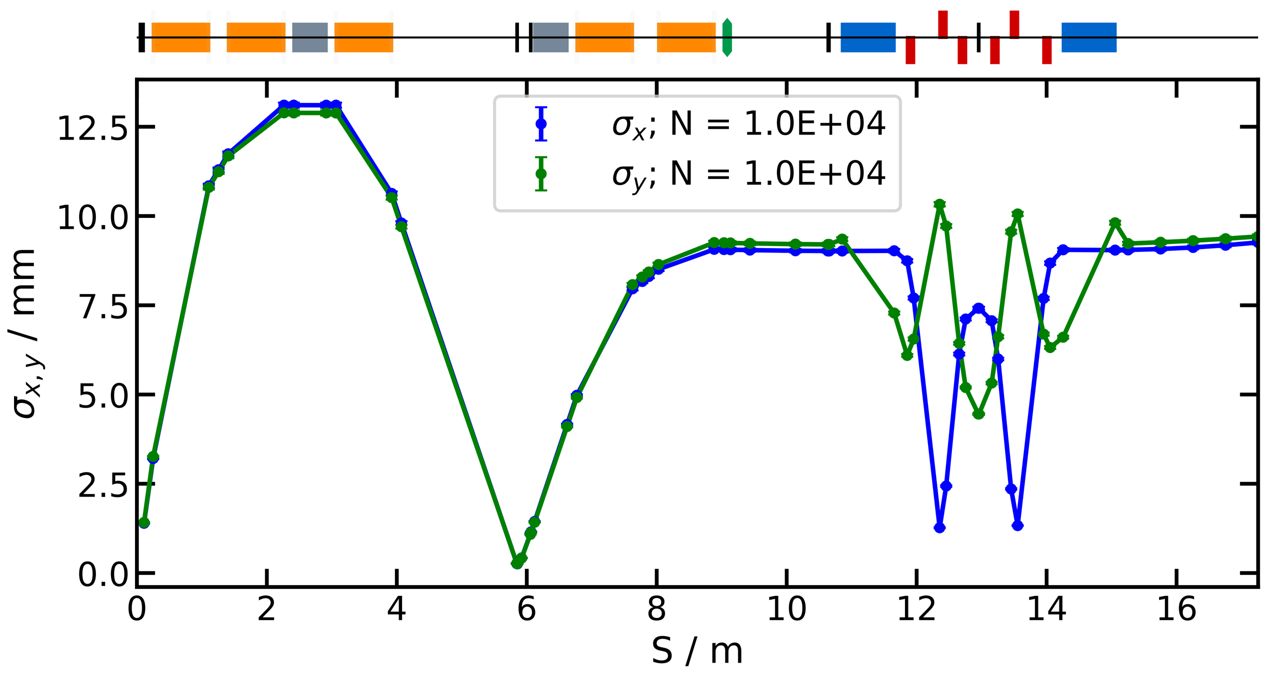
Beam	Emittance (m)	Beta (m)	Alpha
Pre-CDR	$3.26e^{-7}$	4.89	-50.22
Smilei	$1.43e^{-8}$	141.34	-1418.43
SCAPA	$7.98e^{-8}$	21.62	-222.23

- A slight horizonal asymmetry is observed in the beam phase space after the laser-target vacuum nozzle
  - Normal angle of incidence of the laser
  - Beam transport performance is not adversely affected.

- The beam remains highly divergent as a result of space charge forces
  - The temporal and spectral profiles remain approximately uniform over the regions of interest.

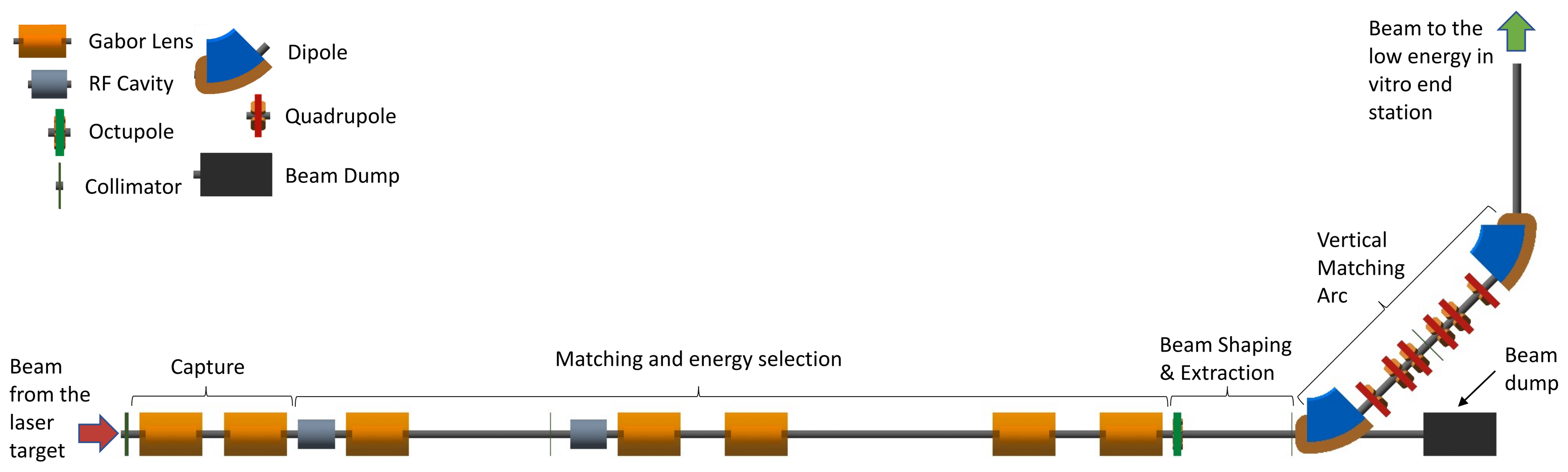
- GPT simulations with space charge demonstrated further emittance growths.

- Model optimized for:
  - A parallel beam after Gabor lenses 2 & 5
  - A beam waist at the energy collimator



- Although successful optimized, solutions for smaller spot sizes remain challenging. This impacts spot-size flexibility and transport in the stage 2 FFA injection line which requires a Twiss β = 50m after the fifth Gabor lens.

7 Gabor Lens Configuration

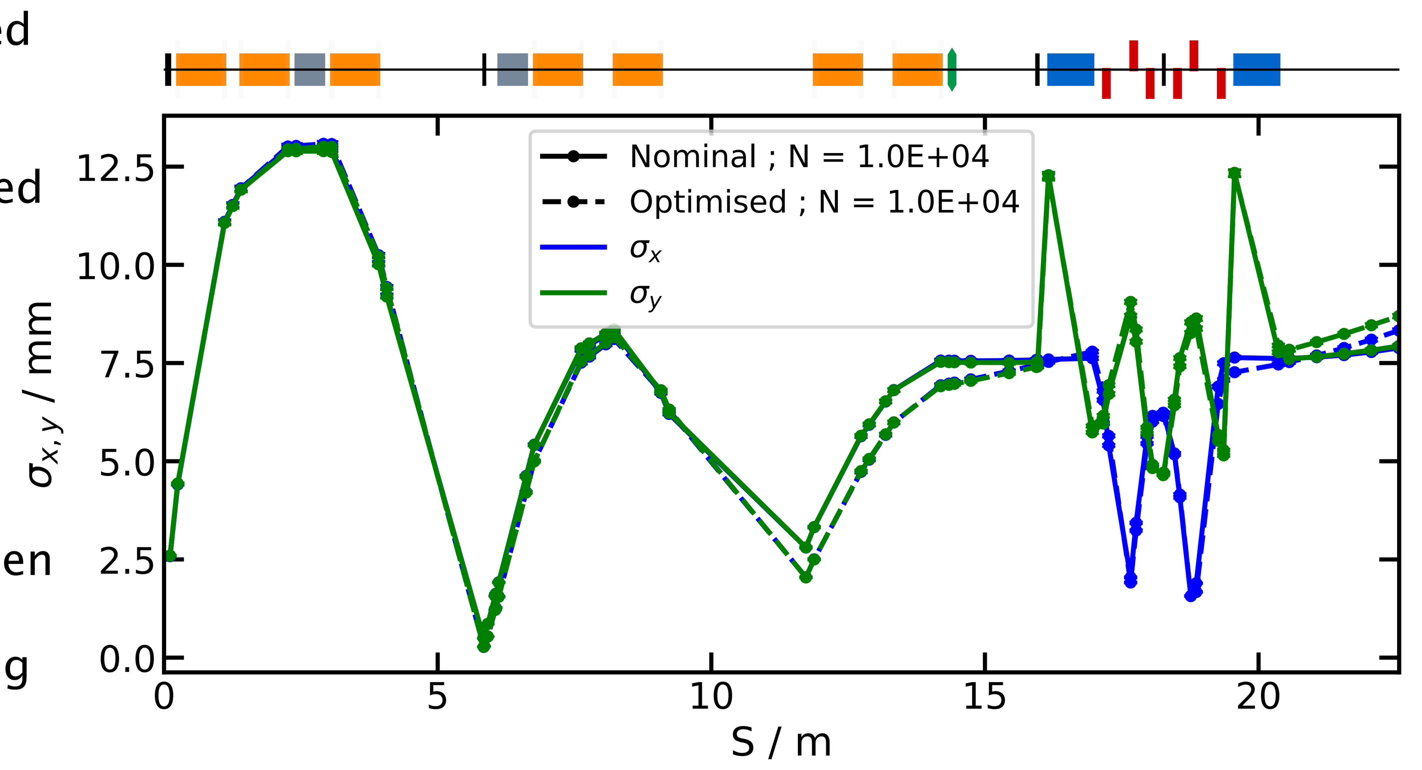


- A new configuration is being investigated that includes a further two Gabor lenses.
  - These are installed after a new 2.5 m long drift after Gabor lens 5, in the same configuration as Gabor lenses 4 & 5 which sees an additional 20 cm drift length included. Only one collimator required for both stage 1 and stage 2 operation. The total length increase is 5.314 m.

- The SCAPA beam is tracked through models in Madx, BDSIM, and GPT models (excluding space charge effects) for validation, with good agreement observed.
  - When space charge effects are considered, an emittance growth is again observed impeding nominal transport performance.

- Optimization again achieved mitigation of the space-charge induced emittance growth.

- Optimized solutions for smaller spot sizes have been found and forms ongoing studies.



Summary

An improved understanding of LhARA laser-target beam has highlighted potential issues with the flexibility & stage 2 operation of the baseline design of LhARA. Whilst optimization of the nominal optics configuration has been achieved, the requirement for smaller spot-sizes has prompted an investigation into a promising new configuration with seven Gabor lenses. Optimization of this design has yielded improved flexibility performance. Research remains ongoing to assess the feasibility of this new configuration.

References

[1]: The Laser-hybrid Accelerator for Radiobiological Applications, Imperial College London, UK, Rep. CCAP-TN-01, 2020.
[2]: G. Aymar *et al.*, *Frontiers in Physics*, vol. 8, 2020.
[3]: L.J.Nevay *etal.*, *Computer Physics Communications*, vol. 252, pp. 107200, 2020.
[4]: General Particle Tracer, http://www.pulsar.nl/gpt/ index.html
[5]: J. Derouillat *et al.*, *Computer Physics Communications*, vol. 222, pp. 351-373, 2018.
[6]: H.T. Lau *et al.*, *Proc. 12th Int. Particle Accelerator Conf. (IPAC'21)*, Campinas, SP, Brazil, 2021, pp. 2939-2942
[7]: R. A. Fonseca *et al.*, *Lect. Notes Comput. Sci.*, vol. 2331, pp. 342, 2002

Contacts

- John Adams Institute for Accelerator Science, Royal Holloway (University of London) & University of Oxford
- Email: william.shields@rhul.ac.uk