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

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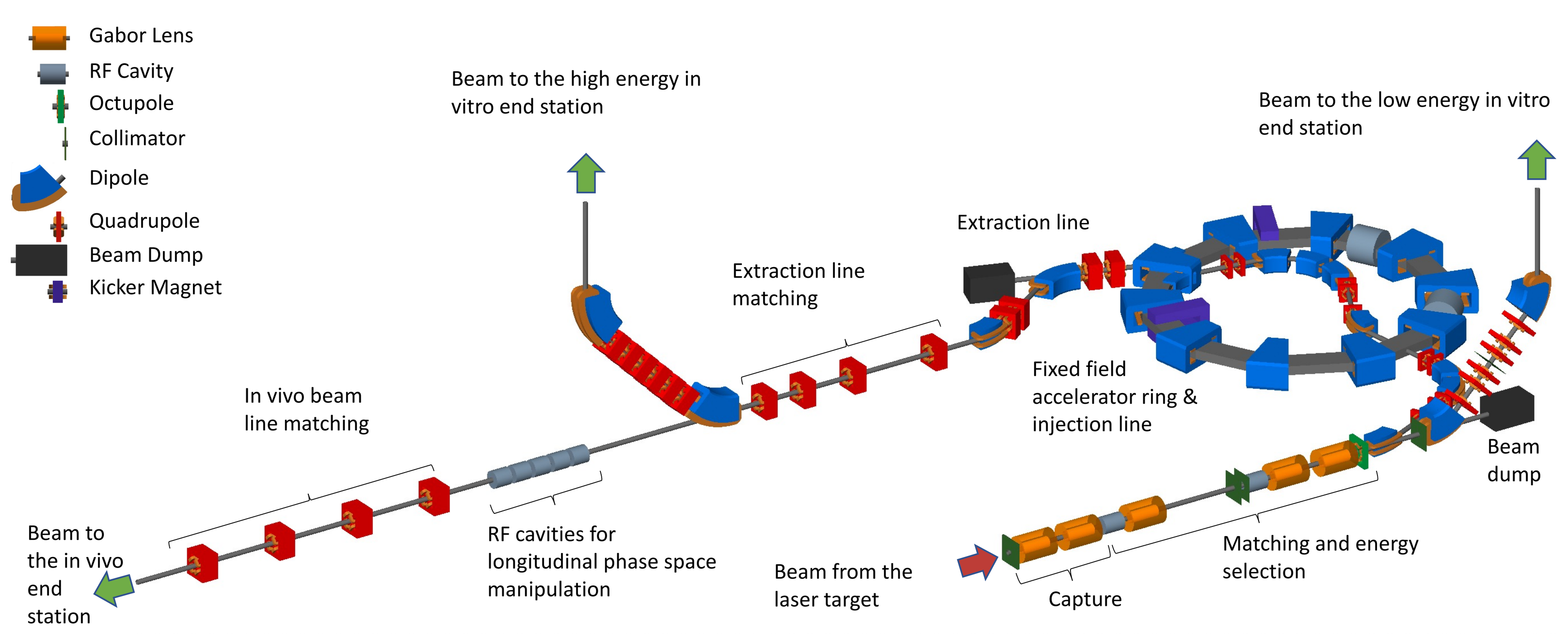
## Abstract

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

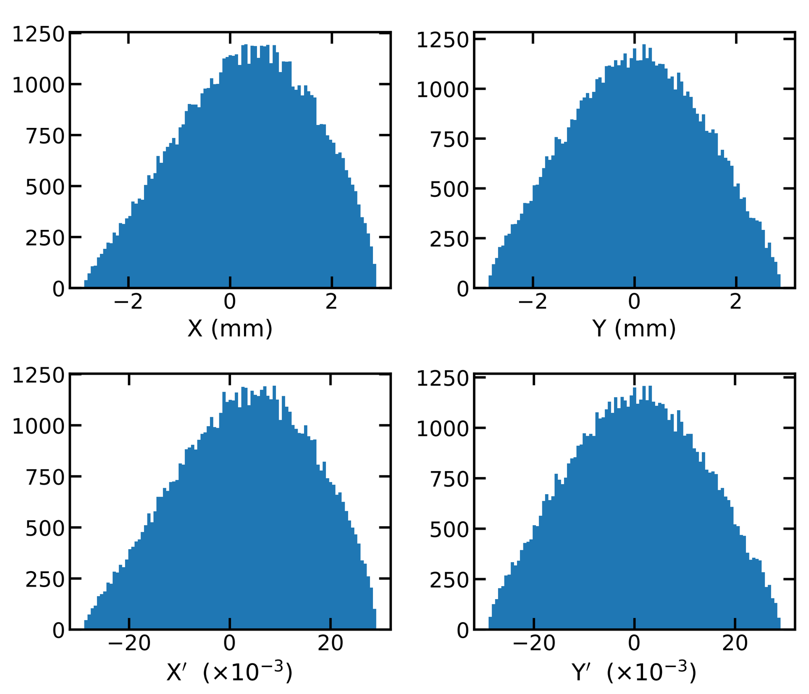
- LhARA is a proposed state-of-the-art accelerator for radiobiological research that serves the Ion Therapy Research Facility (ITRF).
  - We aim to develop & demonstrate novel technologies for generating and delivering proton & ion beams at FLASH dose rates.
  - A systematic radiobiology program is in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

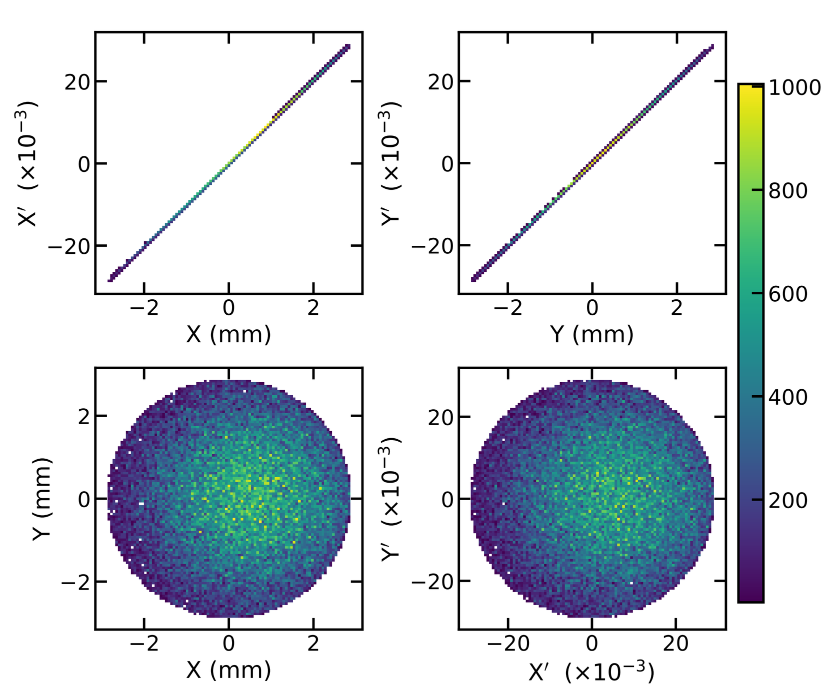
- LhARA is conceived to be developed in two stages [1,2]:
  - Stage 1 will generate high flux beams from a laser-target interaction via the Target Normal Sheath Acceleration (TNSA) mechanism.
  - Gabor electron plasma lenses will capture & focus the beam.
  - Stage 2 accelerates the beam in an FFA ring, with an extraction line transporting the beams to two further end stations.




- Work towards a full conceptual design is underway. Here, we show progress on understanding of the generated beam and subsequent tracking performance.
  - A broader update on the status of LhARA can be found in [3].

## Simulated TNSA Beam & Transport Performance




| 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 |

- LhARA's baseline design modelled 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].

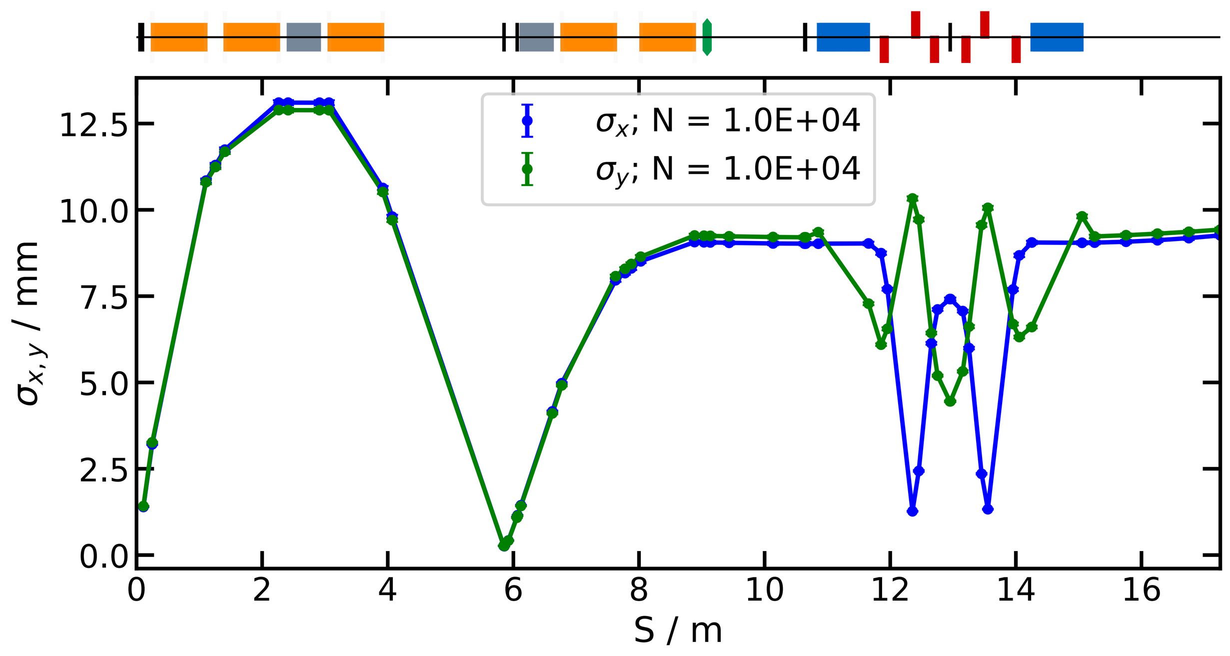
- New full 3D simulations with the PIC code OSIRIS [7] modelled the SCAPA facility
  - Similarities shared with the proposed LhARA setup.
  - Normal laser angle of incidence.
  - Beam down-sampled to the nominal 15 MeV +/- 2%.

- A slight horizonal asymmetry is observed in the beam phase space, however downstream 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.

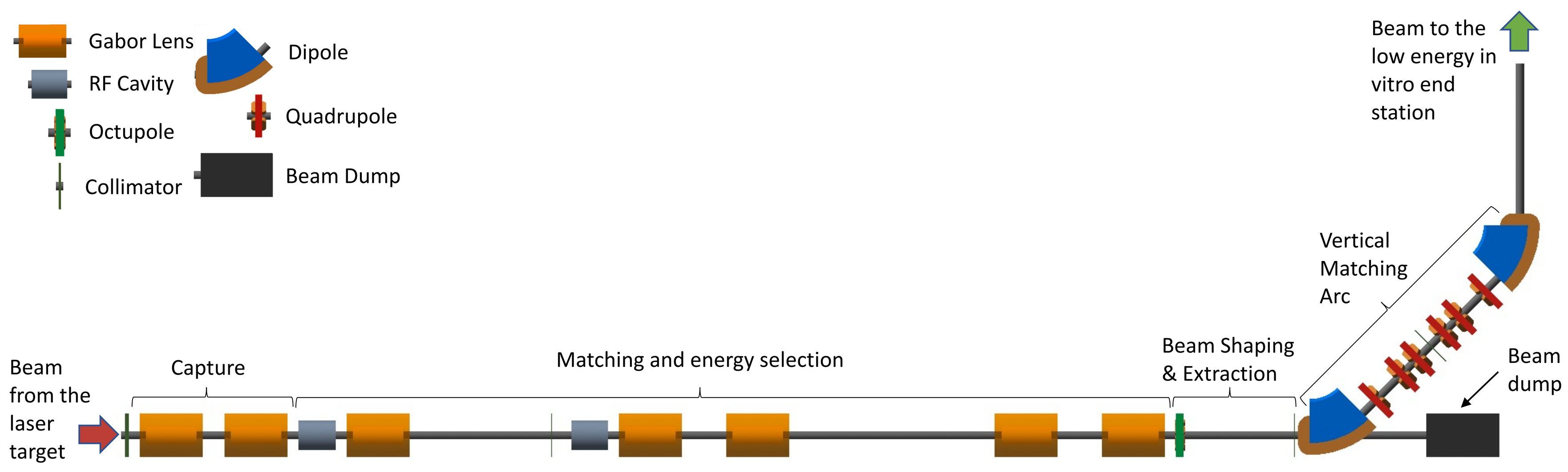
- BDSIM [3] and GPT [4] are used in start-to-end Monte Carlo simulations.
  - Space-charge modelling revealed further emittance growths.

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




- Although successful, solutions for smaller spot sizes remain challenging.
  - End station spot-size flexibility is impacted
  - Stage 2 FFA injection conditions (Twiss β = 50m) are crucial to meet.

## 7 Gabor Lens Configuration

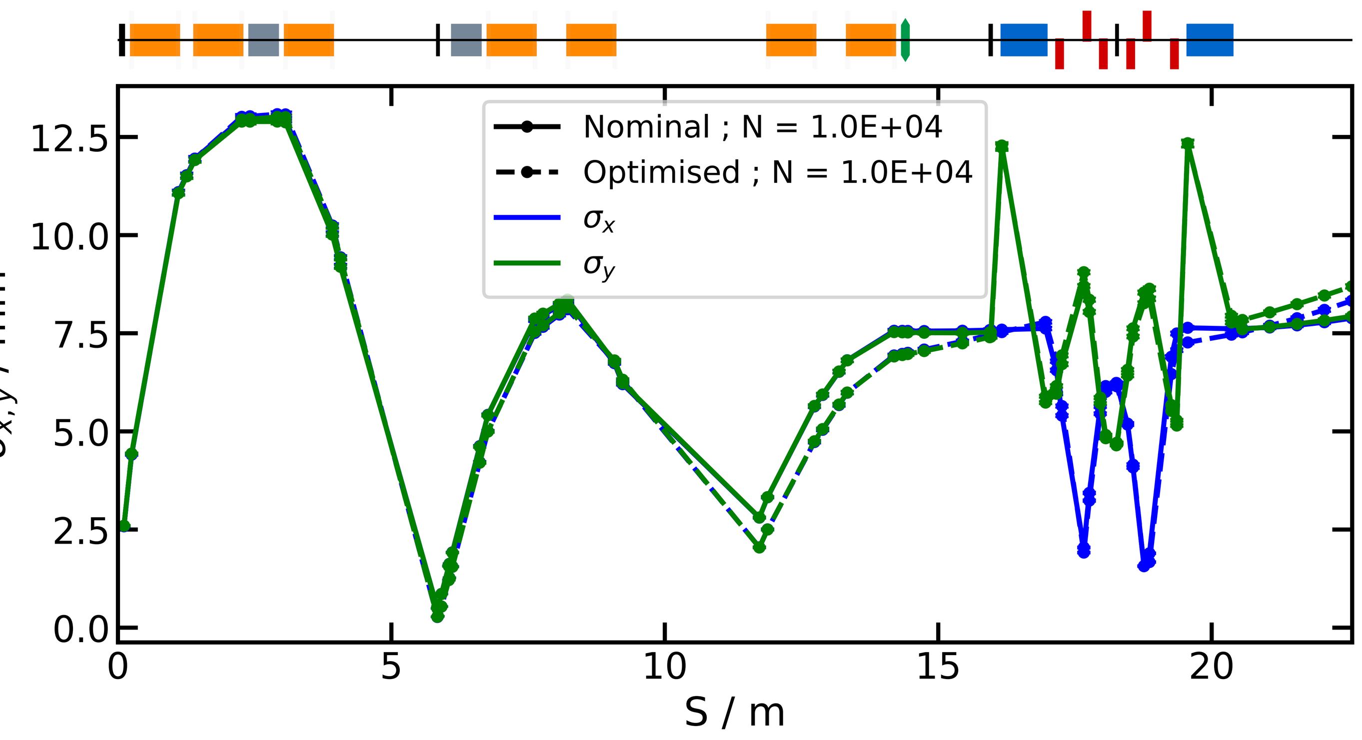



- A promising new configuration is being investigated that includes two further Gabor lenses.
  - Modelled 2.5m downstream of Gabor lens 5, in the same configuration as Gabor lenses 4 & 5, between which an additional 20 cm drift length is included.
  - Only one collimator required for both stage 1 and stage 2 operation. The total beam line length increase is 5.314 m.

- The SCAPA beam is tracked in Madx, BDSIM, and GPT models (excluding space charge effects) for validation, with good agreement observed.
  - Transport performance is once again impeded when space charge effects are considered, with further emittance growths observed.

- Optimization again mitigated the space-charge effects

- Solutions for smaller spot sizes have been found. Optimization studies remain ongoing.




## Summary

An improved understanding of LhARA's laser-target generated beam has highlighted potential issues with the flexibility & stage 2 operation of the baseline design. 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

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