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

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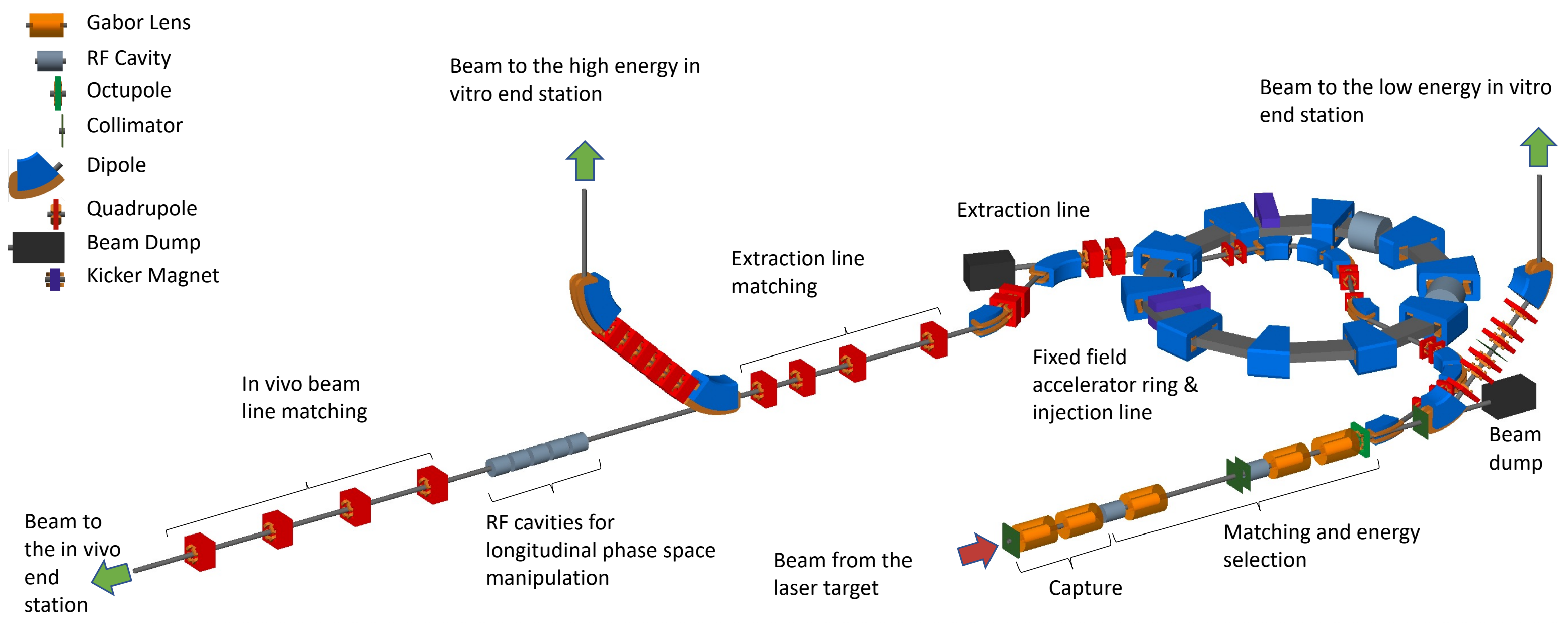
Abstract

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 Baseline Design

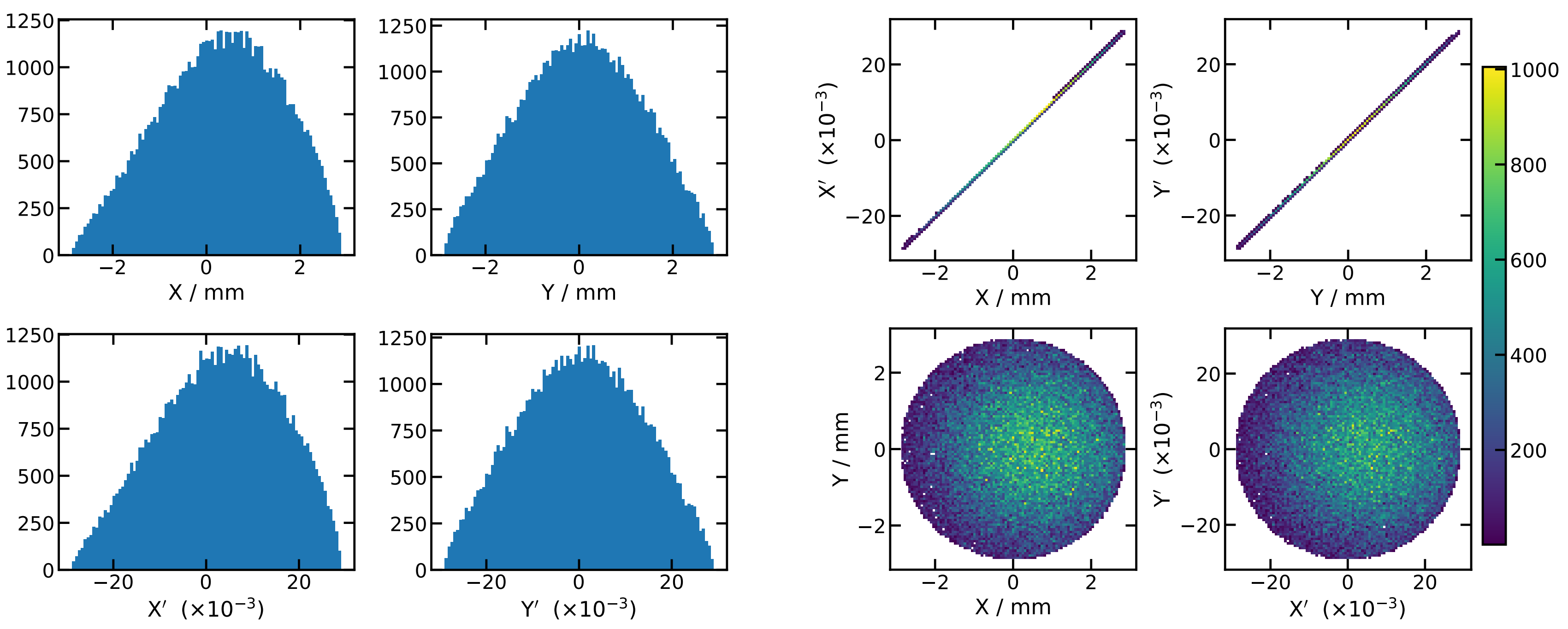
- LhARA is a proposed state-of-the-art accelerator for radiobiological research that serves the Ion Therapy Research Facility (ITRF).
  - We aim to develop & demonstrate novel technologies for generating and delivering proton & ion beams at FLASH dose rates.
  - A systematic radiobiology program is in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


Gabor Lens
RF Cavity
Octupole
Collimator
Dipole
Quadrupole
Beam Dump
Kicker Magnet
Beam to the high energy in vitro end station
Beam to the low energy in vitro end station
Extraction line
Extraction line matching
In vivo beam line matching
Fixed field accelerator ring & injection line
Beam dump
Beam to the in vivo end station
RF cavities for longitudinal phase space manipulation
Beam from the laser target
Capture
Matching and energy selection

- 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	3.26×10^{-7}	4.89	-50.22
Smilei	1.43×10^{-8}	141.34	-1418.43
SCAPA	7.98×10^{-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].

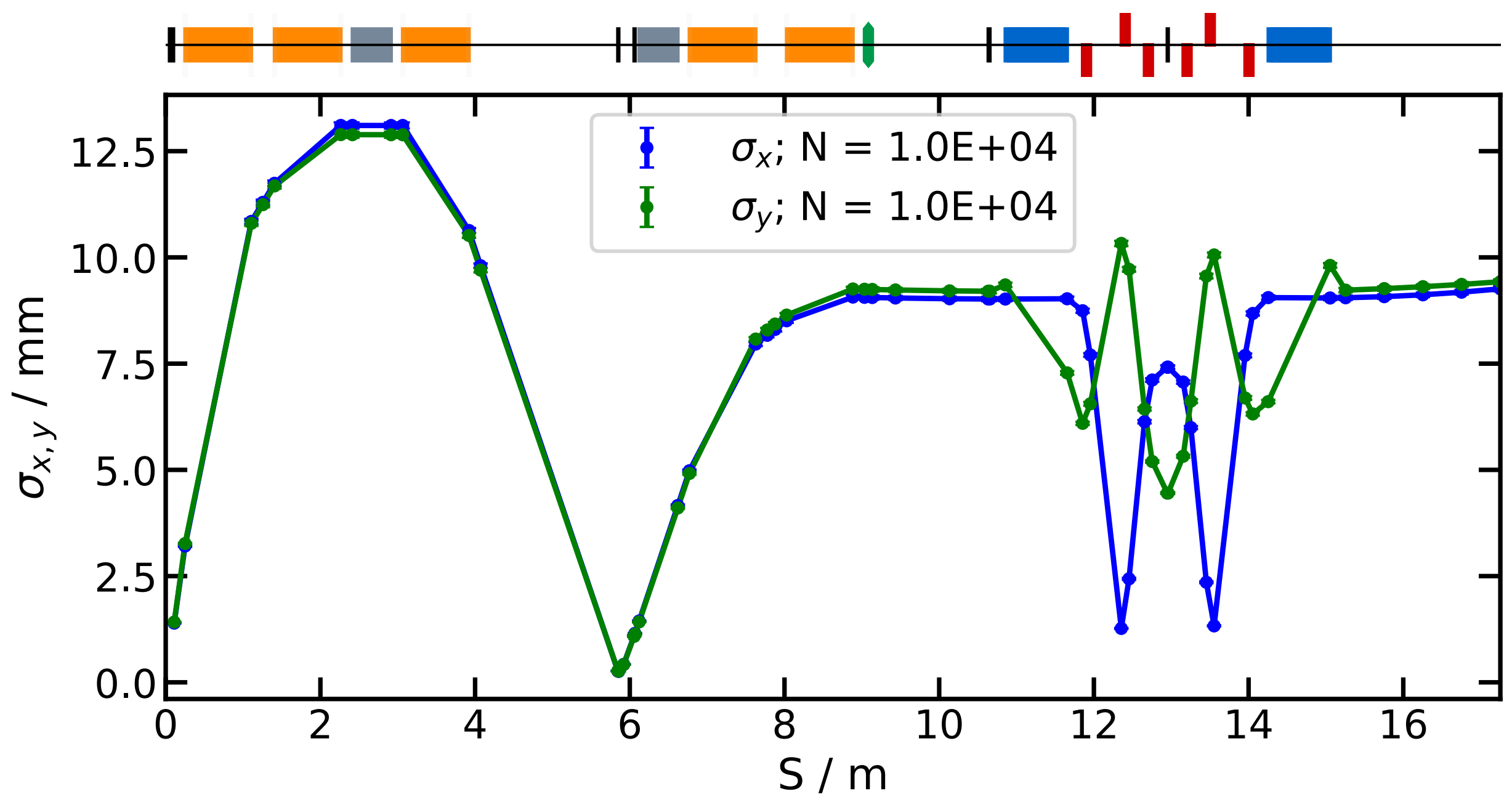
- New full 3D simulations with the PIC code OSIRIS [7] modelled the SCAPA facility
  - Similarities shared with the proposed LhARA setup.
  - Normal laser angle of incidence.
  - Beam down-sampled to the nominal 15 MeV +/- 2%.

- 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.

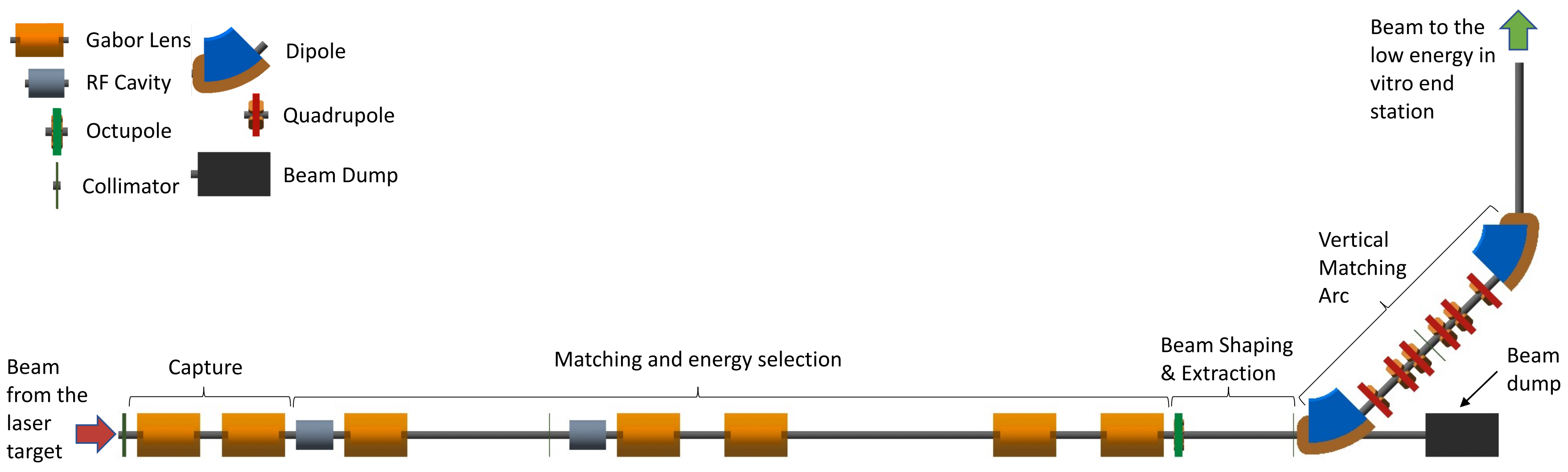
- BDSIM [3] and GPT [4] are used in start-to-end Monte Carlo simulations.
  - Space-charge modelling revealed further emittance growths.

- 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.

Experimental 7 Gabor Lens Configuration for Flexibility

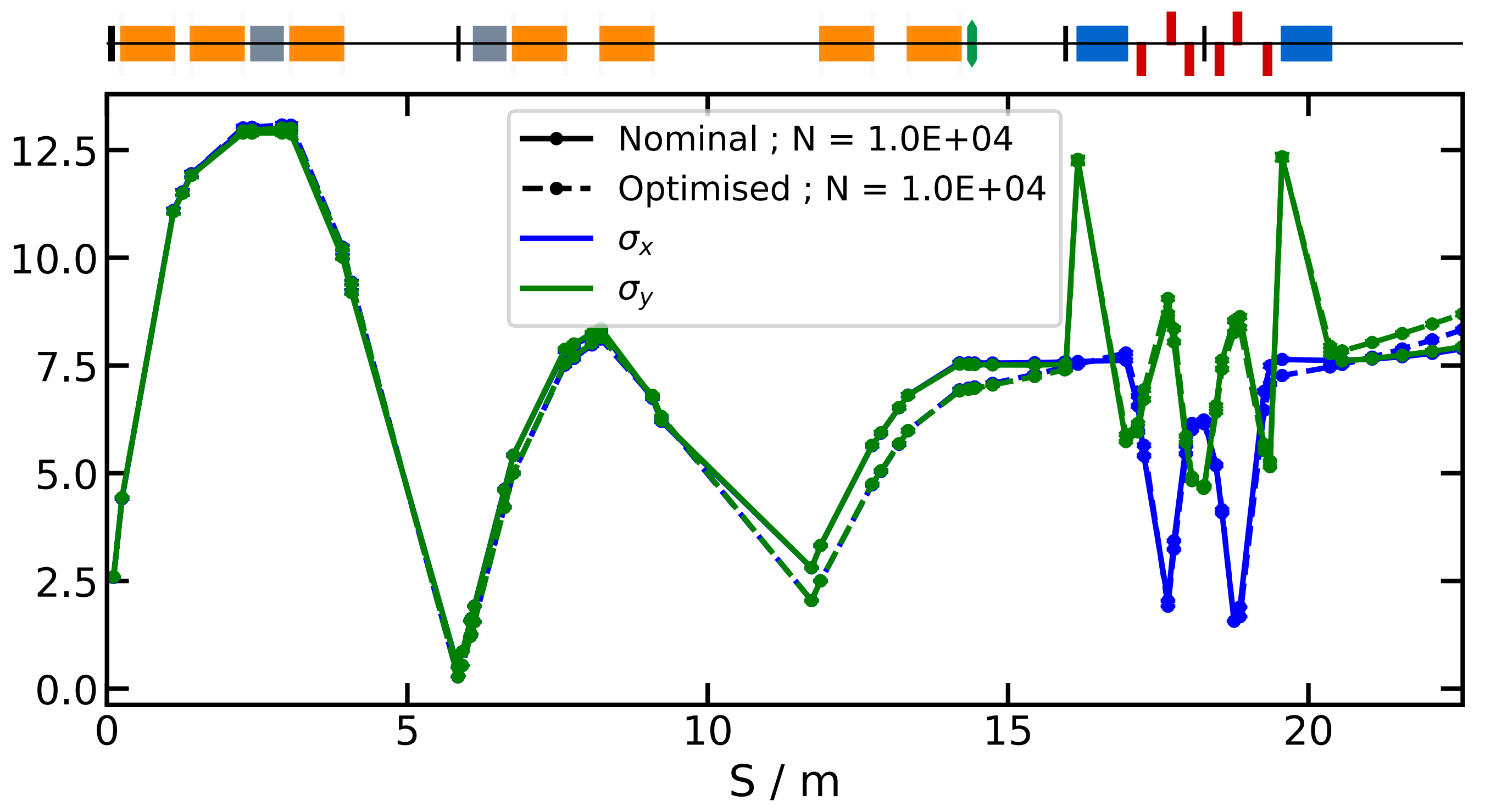

Gabor Lens
RF Cavity
Octupole
Collimator
Dipole
Quadrupole
Beam Dump
Beam to the low energy in vitro end station
Vertical Matching Arc
Beam dump
Beam from the laser target
Capture
Matching and energy selection
Beam Shaping & Extraction

- 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

[1]: The Laser-hybrid Accelerator for Radiobiological Applications, Imperial College, UK, Rep. CCAP-TN-01, 2020.
[2]: G. Aymar *et al.*, *Frontiers in Physics*, vol. 8, 2020.
[3]: C. Whyte, presented at the 14th Int. Particle Accelerator Conf. (IPAC'23), Venice, Italy, May 2023, paper THPM066, this conference.
[3]: L.J. Nevay *et al.*, *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

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