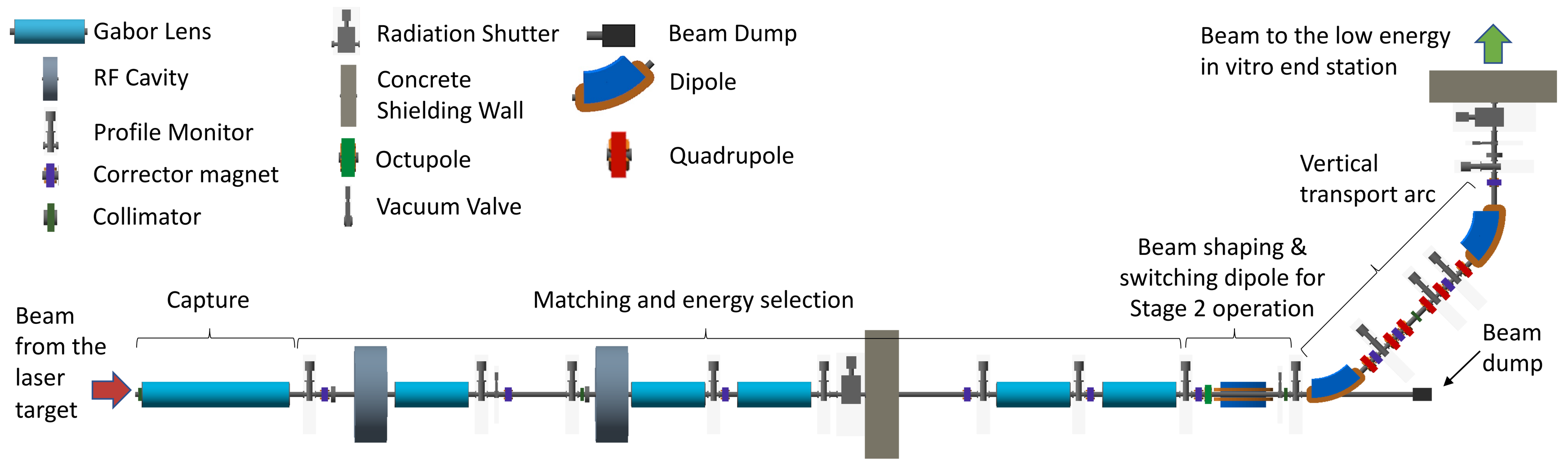
The Laser-hybrid Accelerator for Radiobiological Applications (LhARA): An Update Towards the Conceptual Design

W. Shields [1] on behalf of the LhARA Collaboration
[1] John Adams Institute, Royal Holloway, University of London, UK

THPR54

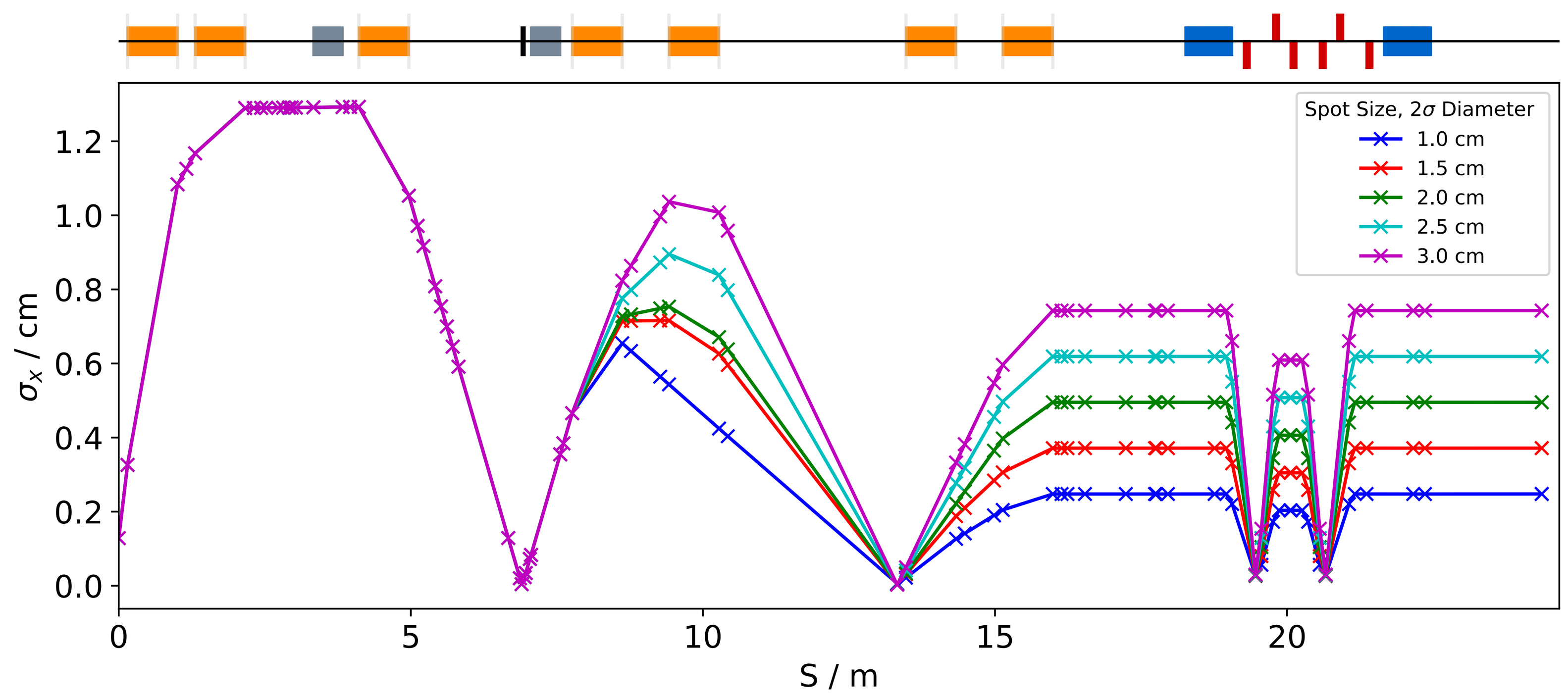
LhARA

- LhARA is a proposed novel particle accelerator designed to advance radiobiological research [1,2].
- A two-stage facility, LhARA will employ the TNSA mechanism in a laser driven ion source to produce a wide proton spectrum up to ~ 30 MeV.
  - The Stage 1 baseline design will capture and transport protons at 15 MeV ± 2%.
    - 10^9 protons per bunch are assumed at a 10 Hz repetition rate from the laser.
  - A series of Gabor plasma lenses will capture and focus the beams.
    - Spot sizes ranging from 1-3 cm will be delivered to an *in vitro* end station.
    - Production of minibeams with quadrupoles is also being studied [3].
  - LhARA can deliver maximum theoretical dose rates in Stage 1 of ~120 Gy/s.
    - Studies into the biological "FLASH" effect at ultra-high dose rates will be possible.
    - A novel ion-acoustic dose mapping system is being developed. The design of a proof-of-principle experiment can be found in [4].
- Stage 2 will see an FFA ring accelerate protons to 127 MeV.
  - These beams will be delivered to an *in vivo* or a second *in vitro* end station.
- LhARA is currently in a 2-year preliminary activity phase that will generate a full conceptual design.

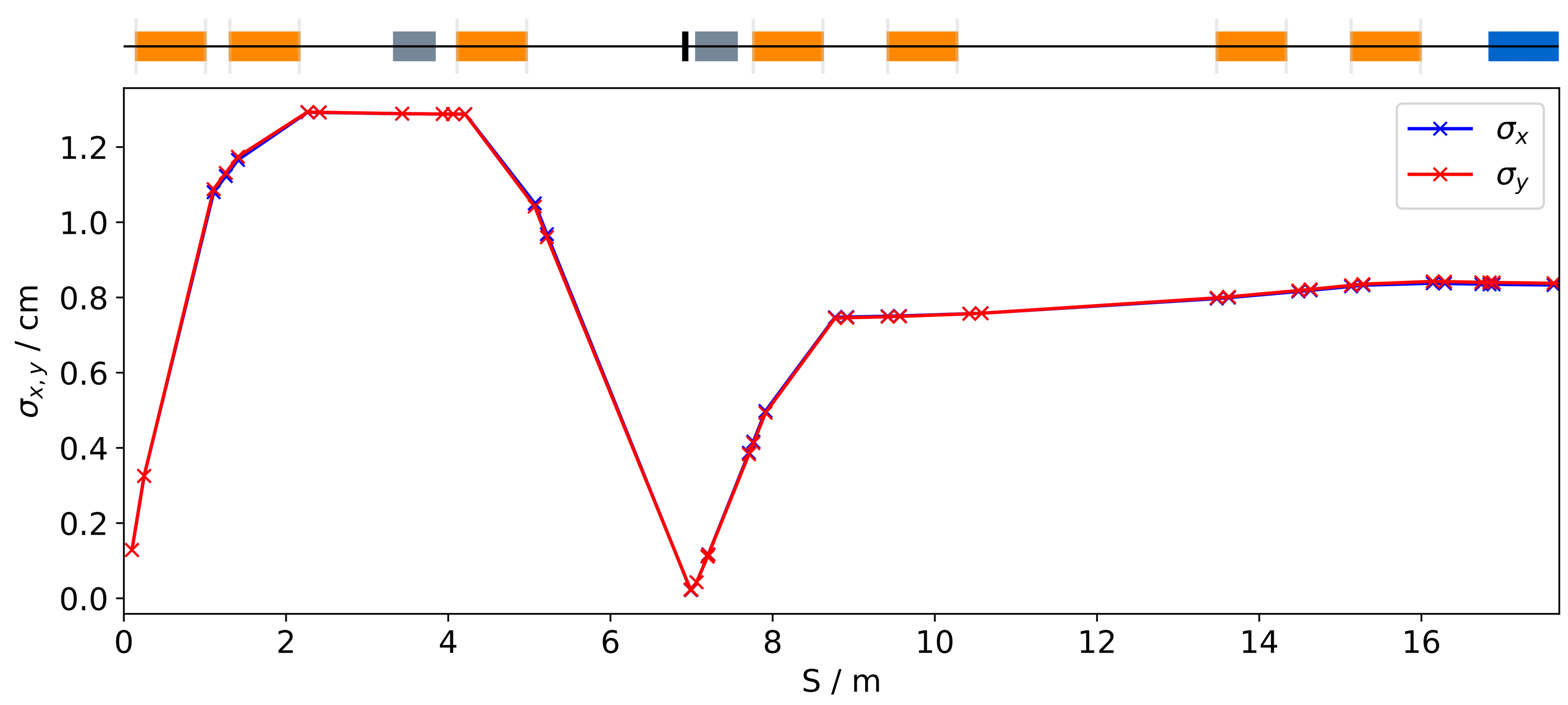


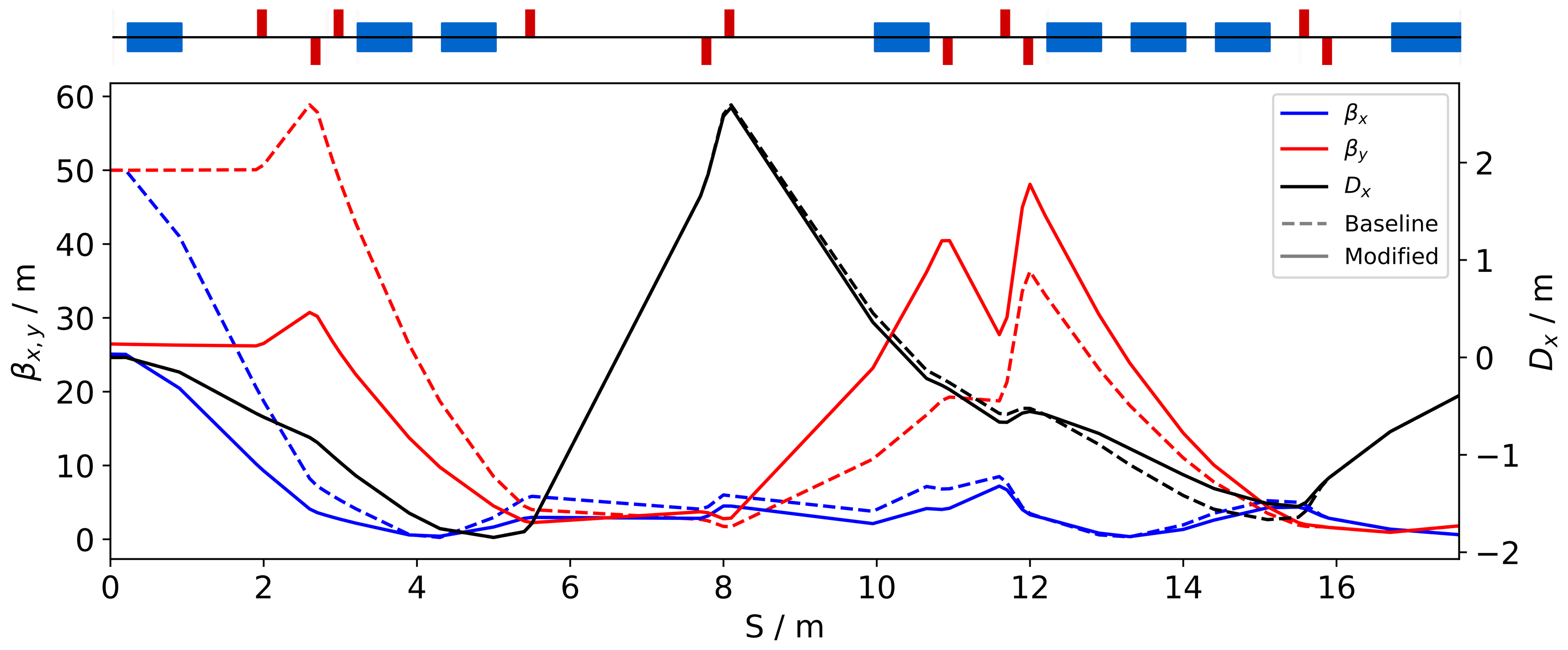
Tracking Performance and Optimization

- Engineering models have recently identified a necessary repositioning of some Gabor lenses to accommodate diagnostics, collimators, shielding, corrector magnets, radiation shutters, etc.
- The Gabor lenses are optimized in MADX [5] as equivalent strength solenoids.
  - Solenoid positions are indicated by the orange boxes in the plot surveys.
  - New optics solutions preserve the end station spot size flexibility.
  - A focus at S = 13.3m will permit the installation of either:
    - An optional energy cleaning collimator (similar to the S = 6.9m focus), or
    - A Wien filter for particle selection should LhARA be constructed in its fallback solenoid configuration.



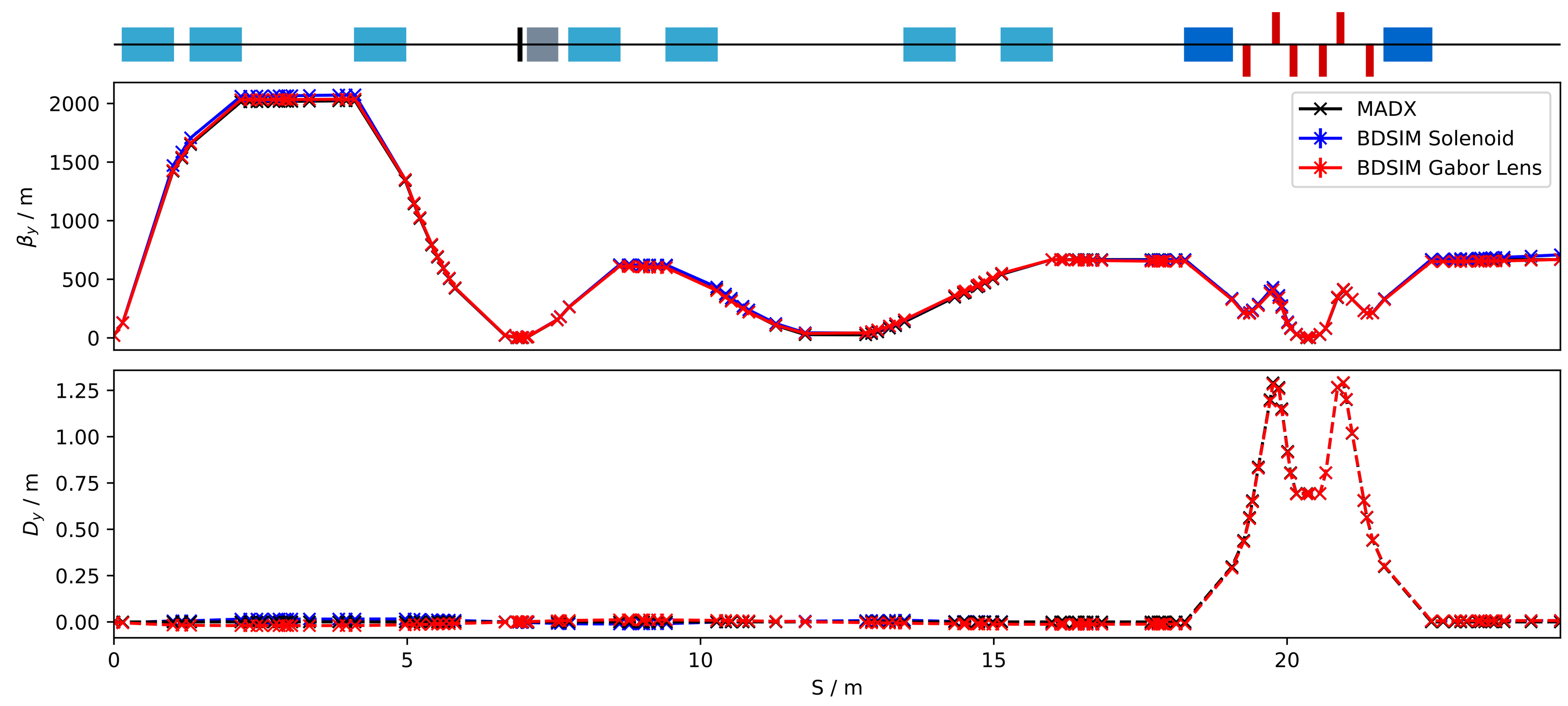
- For Stage 2, a switching dipole after the 7th Gabor lens directs the beam through the FFA injection line.
  - One of the beam conditions at the switching dipole, $\beta_{x,y}$=50m, could not be met.
  - The beam emittance grows from 8.6x10^{-8} to 3.5x10^{-6} m rad due to space charge forces when LhARA is modelled in GPT [6].
    - The switching dipole would require an impractically large aperture.
  - A solution reduced Twiss $\beta_{x,y}$ from 50m to ~27m whilst preserving Twiss α = 0.



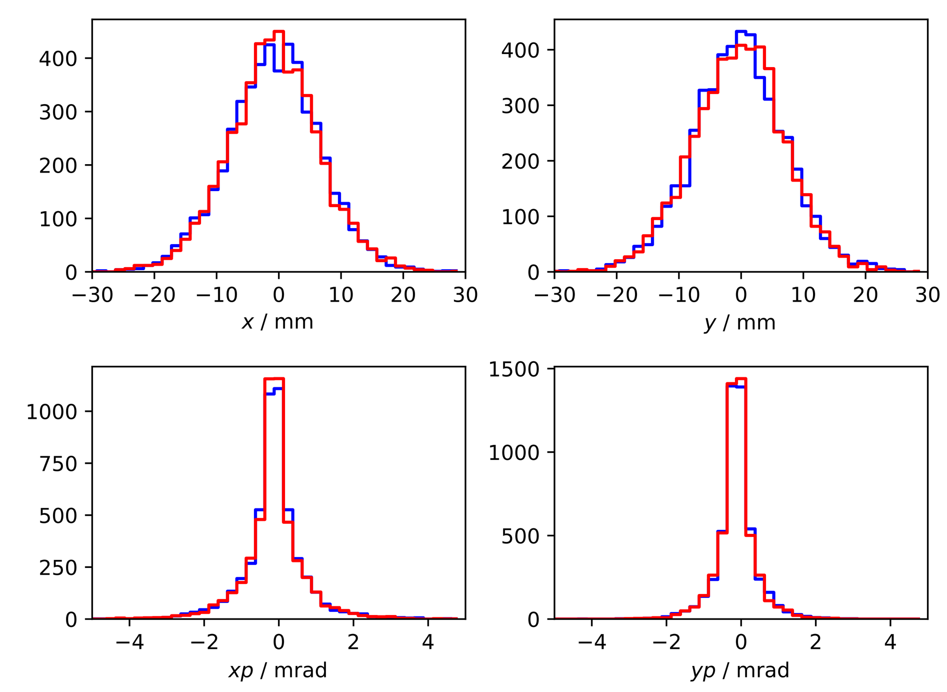


- The FFA injection line was re-optimized with a solution found meeting the beam conditions FFA injection septum (S=17.6m).
- A region of low β_x and high dispersion is preserved.
  - A collimator here will reduce the beam energy spread to the target 15 MeV ± 2%.

Stage 1 Beam Transport With Gabor Lenses



- LhARA's baseline design uses Gabor lenses for simultaneous focusing in the horizontal and vertical axes, similar to solenoids.
  - A Gabor lens' confined plasma will generate electrostatic focusing
  - The magnetic plasma confinement field for a Gabor lens is estimated to be a factor of ~ 43 smaller than the 1.4 T maximum solenoid field.
  - Until recently, LhARA was modelled exclusively with solenoids. Gabor lenses have recently been added to BDSIM [7]. These are shown as light blue boxes in the above optics plot survey.
- Tracking simulations in BDSIM [8] show excellent agreement between LhARA's solenoid and Gabor lens configurations.
  - The beam's transverse distributions at the end station (S = 24.36m) also shows good agreement (red = Gabor lenses, blue = solenoids).
  - Gabor lenses and solenoids can achieve LhARA's desired beam transport performance.



Summary

Design changes to the LhARA accelerator have been shown to not impact its performance, with the spot size variability being preserved. LhARA's stage 2 FFA injection line was re-optimized with a smaller initial Twiss $\beta_{x,y}$ than the baseline design; the conditions at the exit of the FFA injection septum were met. Tracking simulations with Gabor lenses and solenoids demonstrated comparable beam transport performance.

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]: R. Razak *et al.*, presented at IPAC'24, Nashville, Tennessee, USA, May 2024, paper WEPR63, this conference.
[4]: M. Maxouti *et al.*, presented at IPAC'24, Nashville, Tennessee, USA, May 2024, paper WEPG91, this conference.
[5]: User's Reference Manual, The Mad-X Program.
[6]: General Particle Tracer, http://www.pulsar.nl/gpt/index.html
[7]: W. Shields *et al.*, presented at IPAC'24, Nashville, Tennessee, USA, May 2024, paper WEPR69, this conference.
[8]: L.J. Nevay *et al.*, *Computer Physics Communications*, vol. 252, pp. 107200, 2020.

Contacts

- John Adams Institute for Accelerator Science, Royal Holloway, University of London
- Email: william.shields@rhul.ac.uk
- Website: www.lhara.org