Laser-hybrid Accelerator for Radiobiological Applications

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LhARA [1] is conceived as a uniquely flexible facility that aims to demonstrate **novel technologies** and enable a **systematic programme of radiobiological studies**. With the potential to deliver multiple ion species in beams with a wide range of temporal and spatial profiles, and at high and ultra-high dose rates, LhARA will enable the exploration of a completely new regime of particle-beam therapy.

- A high-power laser will create a large flux of protons or light ions from a foil target.
- Particles are captured and focused using electron plasma (Gabor) lenses.
- Fixed-field alternating-gradient accelerator (FFA) provides rapid acceleration and preserves the flexibility of the beam as afforded by the source.

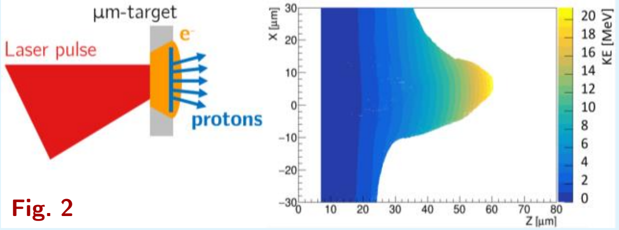

Fig. 2

Ions are generated via the target normal sheath acceleration (TNSA) mechanism.

- 100 TW commercial laser system with a pulse length of 25 fs and 10 Hz repetition rate can deliver a high proton flux ($> 10^9$ ppp).
- Particles captured at energies (≤ 15 MeV) significantly above those that pertain to conventional facilities, evading the limits on the instantaneous dose rates.
- Particle production at the source simulated in 2D with particle-in-cell (PIC) code [2].

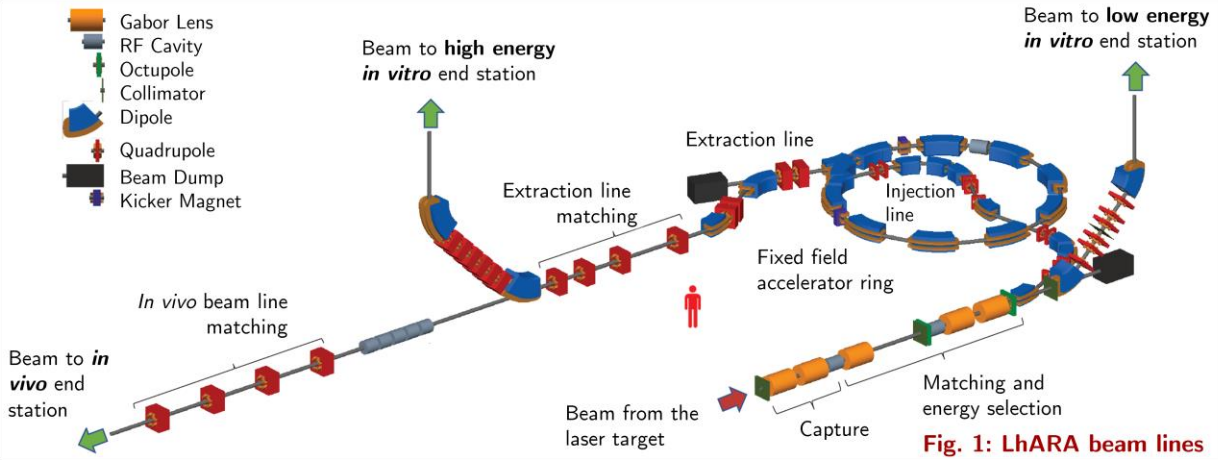

Fig. 1: LhARA beam lines

Stage 1 of LhARA contains all the components from the laser source to the low energy *in vitro* vertical arc designed for studies with protons up to 15 MeV.

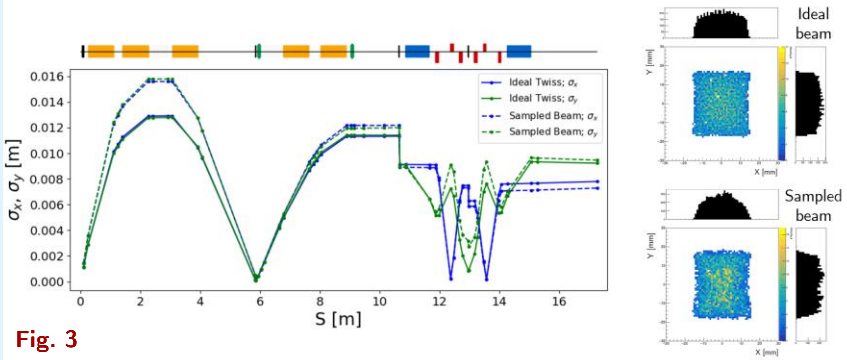

Fig. 3

Stage 2 of LhARA consists of the FFA and all the downstream elements that are planned to provide proton and ion beams for both *in vivo* and *in vitro* studies.

- Flexible optics configurations to deliver beams between 1 mm and 30 mm.

The ***in vitro* end stations** are envisioned for the irradiation of 2D monolayer and 3D-cell systems in culture.

- Sealed units allow for cells to be incubated prior to and during irradiation.
- Robotics will enable cell culture plates to be placed into and taken out of the beam.

The ***in vivo* end station** will be used to irradiate small-animal models.

- An image guidance system will be used to enable a high level of precision and accuracy.
- The flexibility in beam sizes allows for different irradiation conditions: passive scattering, pencil-beam scanning, and micro-beam irradiation at conventional and FLASH dose rates.

BDSIM [3] was used to evaluate the maximum dose distributions that LhARA can deliver.

- The integrated energy deposition within a fixed volume of water at the Bragg peak was recorded:

	Protons			Carbon 6+
	12 MeV	15 MeV	127 MeV	33.4 MeV/u
Dose per pulse	7.1 Gy	12.8 Gy	15.6 Gy	73.0 Gy
Instantaneous dose rate	1.0×10^9 Gy/s	1.8×10^9 Gy/s	3.8×10^8 Gy/s	9.7×10^8 Gy/s
Average dose rate	71 Gy/s	128 Gy/s	156 Gy/s	730 Gy/s

Studies in progress for the **key risk areas**:

- laser-driven particle production
- Gabor lenses
- real time dosimetry
- FFA model development and verification.

[1] G. Aymar *et al*., "LhARA: The Laser-hybrid Accelerator for Radiobiological Applications,"Frontiers in Physics, vol. 8, p. 432, 2020.
[2] H. Lau, "Beam Tracking Simulations for Stage 1 of the Laser-Hybrid Accelerator for Radiobiological Applications (LhARA)," in Proc. IPAC'21, no. 12 in International Particle Accelerator Conference, pp. 2939–2942. JACoW Publishing, Geneva, Switzerland, 08, 2021.
[3] L. J. Nevay *et al*., "BDSIM: An accelerator tracking code with particle-matter interactions,"Computer Physics Communications, p. 107200, 2020.