# Laser source and Gabor lens for use within a Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

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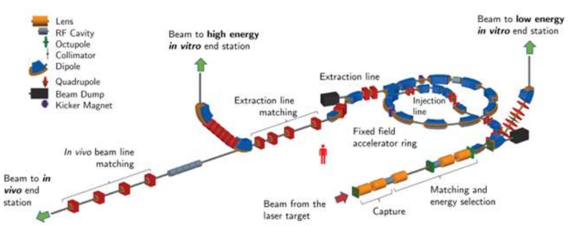
## Introduction

Cancer was responsible for over 15% of deaths worldwide in 2020 [2], yet over 25 million life-years could be saved if radiotherapy (RT) capacity can be scaled up [3].

Conventional RT is used to treat ~50% of patients, typically with MeV-energy X-rays, but particle (proton and ion) beam therapy (PBT) offer significant advantages. These therapies typically deliver low does rate (<1Gy/s) treatments over several weeks to the target volume.

But, recent evidence alludes to the therapeutic benefit of using ultra-high dose-rates (>40Gy/s, so-called FLASH-RT).




## LhARA

The Laser-hybrid Accelerator for Radiobiological Applications (LhARA) [4] facility (see fig. 1, above), is proposed as a highly flexible particle beam source to facilitate a programme of studies aimed at further exploring the biological response to ionising radiation and understanding the underlying radiobiological mechanisms of FLASH RT

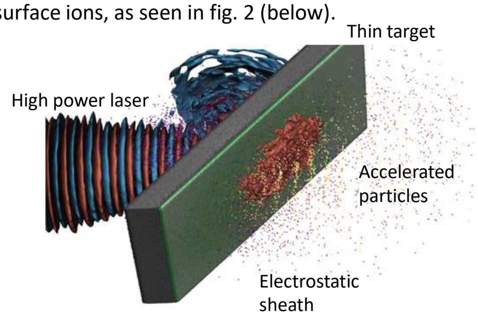
Utilising a high repetition rate laser directed at a suitable target, a large flux of protons (or light ions, such as $C^{6+}$) can be produced, captured, and formed into a beam for *in-vitro*, or FFA accelerated for *in-vitro* and *in-vivo*, studies.

## Laser driven ion source

Laser driven ion sources deliver some significant advantages over conventional sources for the proposed high peak current LhARA beamline:

- Ultrashort (<ps) beam generation time
- Overcome space charge limitations
- Variable ion species

The LhARA source is based on the Target Normal Sheath Acceleration (TNSA) mechanism. A commercial high power laser will be used to irradiate thin dense targets, coupling laser energy to target electrons which in turn generate short-lived electrostatic fields which accelerate target surface ions, as seen in fig. 2 (below).




We are currently performing experimental and numerical studies to inform the LhARA design. High fidelity 3D particle-in-cell simulations are being used to predict the target and laser parameters for optimal beam generation. These predictions will be validated by experiments at the SCAPA laser facility at the University of Strathclyde. Further issues with debris and target delivery are also being investigated at the Zhi laser at Imperial College London.

The LhARA design requires the following beam parameters, which we are designing the source to provide:

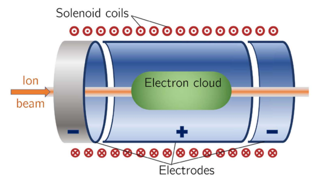
- $10^9$ protons at 15 MeV ± 10% within a 15 msr divergence
- $10^8$ carbon at 4 MeV/u ± 10% within a 15 msr divergence
- Production of other ion species
- 10 Hz repetition rate
- Long term operation

## Particle beam optics – Gabor Lens

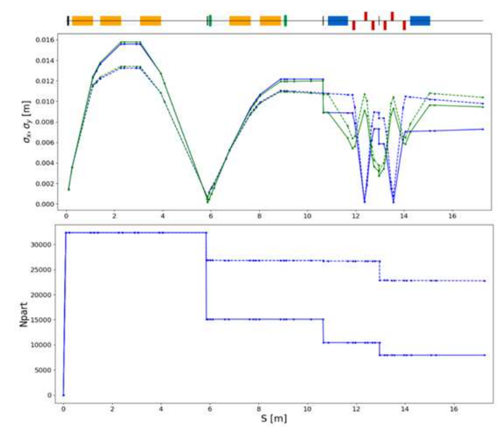
Beams typically utilise **B**-field focusing but, owing to the potentially higher strengths, **E**-field-based techniques are of extreme interest. A cylindrical non-neutral plasma [5] offers the ideal system whereby the focusing length, $f$ (in terms of the electron number density, $n_e$, plasma length, $l$, and ion energy, $U$) is given by

$$\frac{1}{f} = \frac{e^2 n_e l}{4\epsilon_0 U}.$$

These plasma are readily confined in cylindrical Penning-Malmberg traps (see fig 3 [4], right), and theoretically offer a significant (x40) reduction in focal length for a given **B**-field.




The x and y standard deviation of an illustrative proton beam traversing 2 configurations of lenses within the proposed beamline (see fig. 1) is shown in fig. 4 (right). The lower plot shows where losses occur due to energy and momentum selection apertures, which can be minimised.




## Summary

A facility to study the radiobiological effects of FLASH-RT has been proposed, and a detailed programme for achieving the aims set out. The UKRI national funding agency is supporting the effort with an initial 2 year scoping project.

A major component of this scoping project is to further the numerical simulation and design of a suitable Gabor lens based upon existing low-temperature, single-species (electron), equilibrated, non-neutral plasmas.

## References

[1] www.lhara.org
[2] www.who.int/news-room/fact-sheets/detail/cancer
[3] Atun et al., The Lancet Oncology **16** (2015), 1153
[4] Aymar et al. Frontiers of Physics **08** (2020), 567738
[5] Gabor, Nature **4055** (1947) 89
Fig's 1 & 2 modified from HT Lau PhD Thesis, Imperial College, London (2022)