Laser-hybrid Accelerator for Radiobiological Applications

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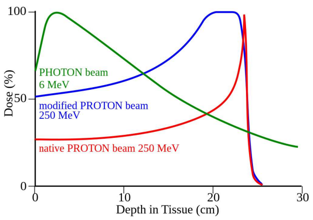
Introduction

According to the WHO [2], cancer was responsible for over 15% of deaths worldwide in 2020, yet over 25 million life-years could be saved in low- and mid-income countries alone 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 – hence the dozens of PBT centres worldwide. These centres typically deliver low does rate (<1Gy/s) treatments over several weeks to the target volume.

Illustrated by the peak in the example Bragg curve [4] (see fig. 1, right), owing to the nature of beam-target interactions, PBT allows the dose to be confined to the tumour, while the impact to healthy tissue is minimised.



Recently, evidence has been reported of the therapeutic benefit of using ultra-high dose-rates (>40Gy/s, so-called FLASH-RT), although the underlying radiobiological mechanisms are yet to be fully understood.

LhARA

The Laser-hybrid Accelerator for Radiobiological Applications (LhARA) [5], 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.

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.

Facility & Beamline

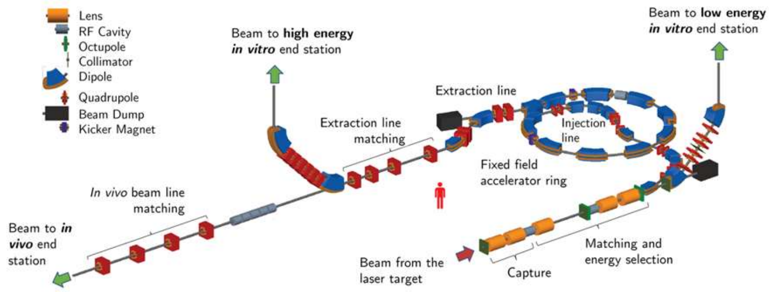
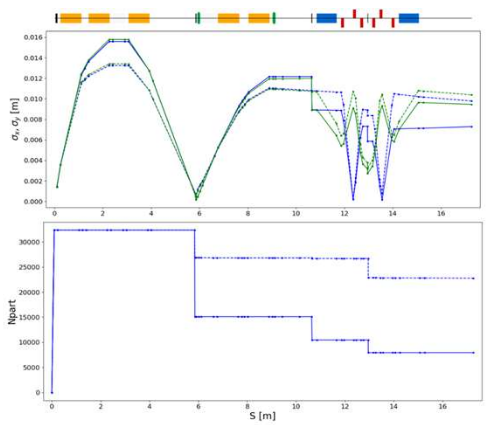


Fig. 2 (above) shows a CAD illustration of the proposed beamline(s). The lens elements indicated in yellow, are proposed to be electrostatic (see Gabor lens, right) for flexibility, cost effective, and environmental sustainability.

Fig. 3 (below) shows the sizes (standard deviation in x and y planes) of an illustrative 15 MeV proton beam produced by the target normal sheath acceleration (TNSA) mechanism traversing 2 configurations of the proposed beamline (see fig. 2). As illustrated in the lower plot, losses occur where expected due to energy and momentum selection apertures, and can be minimised.



Status

Through the Science and Technology Facilities Council (STFC), LhARA has successfully attracted UK Research and Innovation (UKRI) Infrastructure Fund financing as a scoping project to further the programme towards a pre-Conceptual Design Report and explore the key risk areas (which includes the lens elements)

Particle beam optics – Gabor Lens

Although particle beam optics typically utilise magnetic-field focusing techniques, owing to the potentially higher strengths, electric-field-based techniques are of extreme interest.

First proposed by Gabor in 1947 [6], the internal electric field of a cylindrical non-neutral plasma 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:

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

In the case of an electron plasma within a Penning-Malmberg trap, whose density is limited by the confining magnetic field, B_{GBL}, (i.e. Brillouin limited) the focal length of a proton beam is reduced by a factor of 43 when compared to the solenoid alone.

Unfortunately, reliably establishing such plasma beyond the laboratory has hitherto proved elusive. The LhARA collaboration thus intend to approach the problem, not from the high temperature discharge plasmas employed to date, but from that of low-temperature equilibrated plasma extensively studied for decades. By bringing together the standard diagnostic and manipulation techniques (image charge analysis, MCP/P-screen detection, rotating-wall coupling, etc.), significant progress towards suitable large, stable, high density plasma is expected.

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] en.wikipedia.org/wiki/Bragg_peak
[5] Aymar et al. Fronteirs of Physics **08** (2020), 567738
[6] Gabor, Nature **4055** (1947) 89
Fig's 2 & 3 modified from HT Lau PhD Thesis, Imperial College, London (2022)