Development of Novel Magnetically-Focussed Mini Beams for In Vivo and In Vitro End Stations for LhARA

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Abstract

Radiotherapy is an effective, non-invasive, widely used treatment for cancerous tumours that uses x-ray photon, electron and ion beam sources. The Laser-hybrid Accelerator for Radiobiological Applications (LhARA) is a novel laser-driven accelerator system under development that aims to prove the principle of the laser-driven approach to Particle Beam Therapy (PBT). This study aims at the development of a novel system to deliver different light ion minibeams to the in vivo and in vitro end stations. The desired minibeams will be delivered by magnetically focusing and steering the incoming proton and light ion beams, without the use of collimators. Minibeams with a diameter of approximately 1 mm spot will be delivered at an energy of 15 MeV to the in vivo and in vitro end stations. An update on the status of the development of this magnetic focusing technique will be presented here.

Background

Minibeam Radiation Therapy (MBRT) is a radiotherapy technique which uses very small and highly focussed beams to deliver ionising radiation into tumorous tissues [1]. Minibeams are defined as beams with diameters of between 0.3 - 1 mm [1].

To create the desired minibeams, a novel technique for **magnetic focusing** of the incoming ion **beams**, without collimation, is being developed.

The updated LhARA baseline design [2], delivers ultra-high dose rates of ∼120 Gy/s with 15 MeV protons to the Stage 1 in vitro end station [3]. This baseline design has limitations when delivering spot sizes of $<$ 1cm with the current optics. This gives further motivation to developing a magnetic beam focusing system.

LhARA Quadrupole Doublet

Fig. 1 shows the current magnetic beam focusing configuration for LhARA's stage 1 in vitro end station. The quadrupole doublet focusing configuration consists of:

- Defocusing quadrupole magnet:
  - L = 11.4 cm;
  - K = 11.695 m^{-2};
- Focusing quadrupole magnet:
  - L = 11.4 cm;
  - K = -22.712 m^{-2};

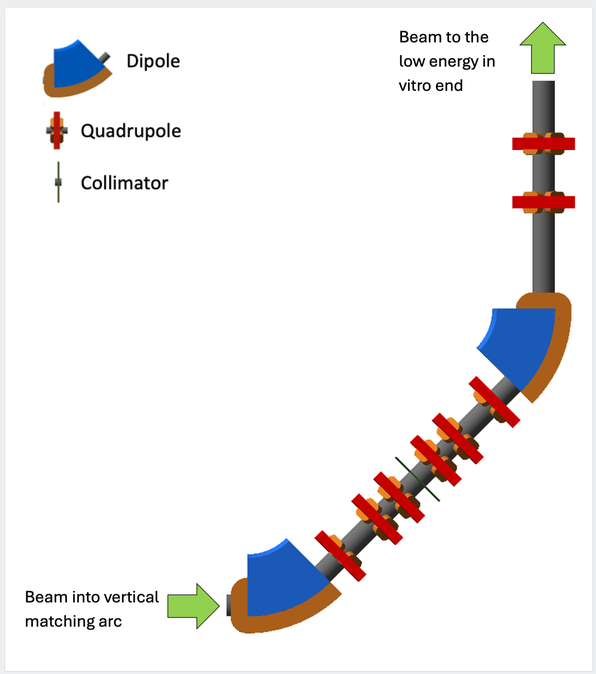

Figure 1. A schematic diagram of the vertical matching arc up to the low energy in vitro end station with the quadrupole doublet beam focusing configuration, along the vertical axis.

A spot size of 0.6 mm rms was achieved, indicating that the final simulated spot size delivered to the end station would be within the correct order of magnitude to produce a minibeam.

Poster Codes

- **WERP63**
- **SUPG028**
- LhARA reference poster - **THPR54**

Laser-hybrid Accelerator for Radiobiological Applications

Starting from this updated LhARA baseline design, displayed in Fig. 2 [4], a quadrupole magnet system is being developed to focus the incoming 15 MeV proton beam towards the minibeam regime and deliver it to the low energy in vitro end station at the end of the LhARA stage 1 beam line; Fig. 1.

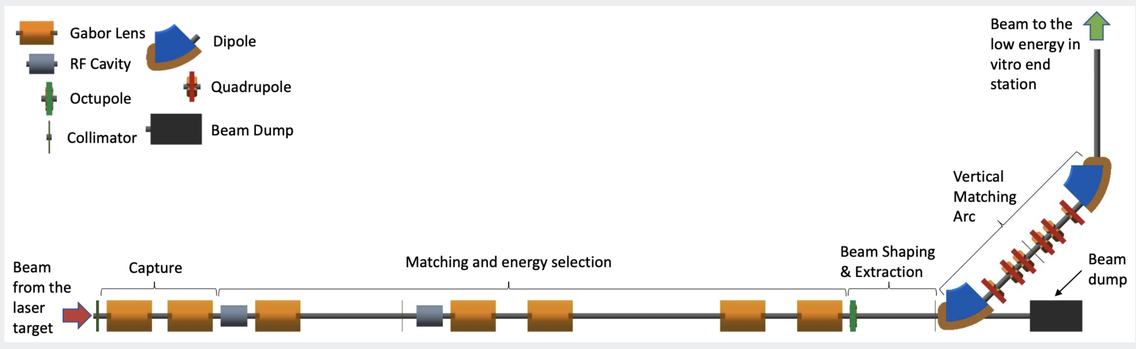

Figure 2. A schematic diagram of the seven Gabor lens configuration for the LhARA stage 1 beam line [4].

Magnetic Beam Focusing Simulations

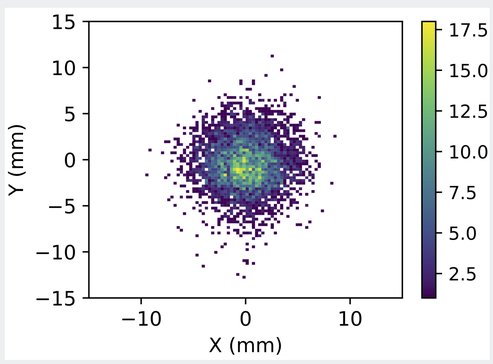

Figure 3. Beam profile in the x-y plane 20 cm downstream of the second dipole magnet in the vertical matching arc.

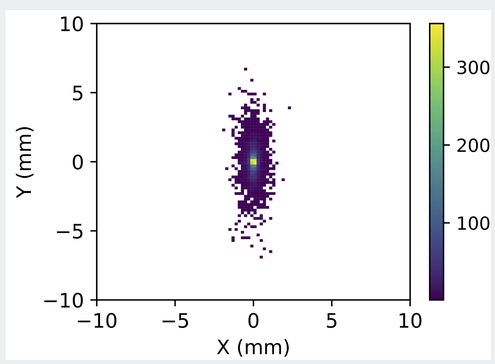

Figure 4. Beam profile in the x-y plane at end of the final drift at the low energy in vitro end station exit; after the quadrupole doublet.

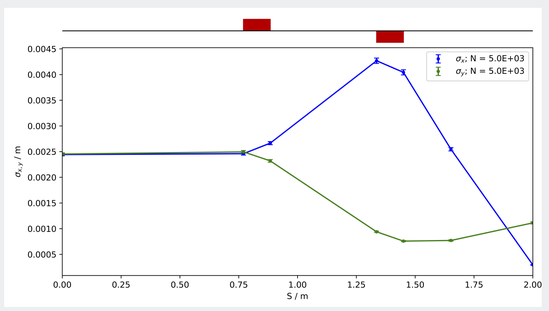

Figure 5. Horizontal and vertical beam radii from 20 cm downstream of the second dipole magnet in the vertical matching arc to the final drift at the low energy in vitro end station exit.

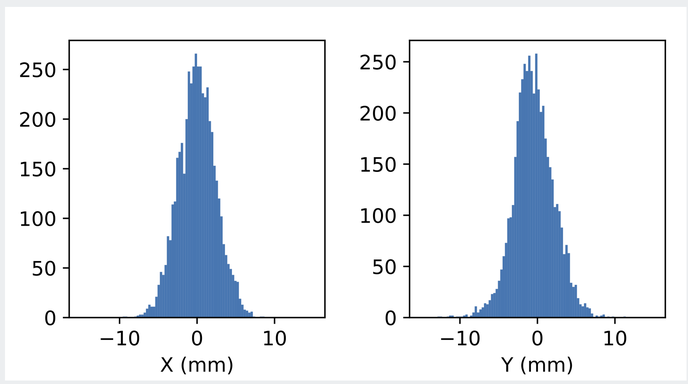

Figure 6. Horizontal and vertical spatial projections 20 cm downstream of the second dipole magnet in the vertical matching arc.

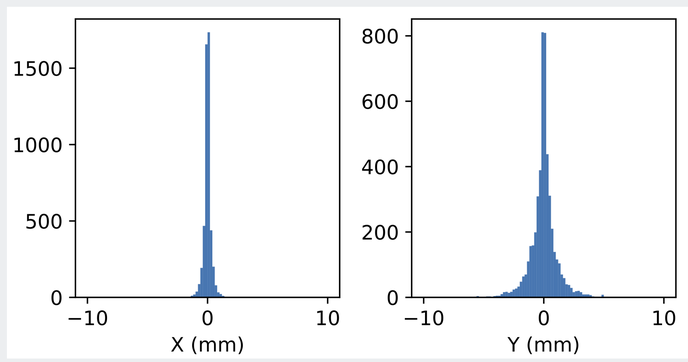

Figure 7. Horizontal and vertical spatial projections at the end of the final drift at the low energy in vitro end station exit; after the quadrupole doublet.

Conclusion

The quadrupole double configuration presented demonstrates that this simple focusing system is capable of producing a 1 mm spot size in the xy-plane, at the end station. This suggests that further optimisation of the system will allow for production of minibeams which satisfy the $<$ 1 mm diameter condition in both the horizontal and vertical planes. This 1 mm minibeam will then allow for a novel spot-scanning beam system to be developed to deliver the beam to "spots" in a treatment.

References

[1] T. Schneider. "Advancing the generation of proton minibeams for radiation therapy". PhD thesis. Orsay, France: CNRS, IJCLab, Université Paris-Saclay, 2020.

[2] W. Shields et al. "The Laser-hybrid Accelerator for Radiobiological Applications (LhARA): An Update Towards the Conceptual Design". In: *Proc. 14th International Particle Accelerator Conf. (IPAC'24)*. paper THPR54, this conference. Nashville, Tennessee, USA, May 2024.

[3] G. Aymar et al. "LhARA: The Laser-hybrid Accelerator for Radiobiological Applications". In: *Frontiers in Physics* 8 (2020). DOI: 10.3389/fphy.2020.567738.

[4] W. Shields. "Progress on the conceptual design of the Laser-hybrid Accelerator for Radiobiological Applications (LhARA)". In: *Proc. 14th International Particle Accelerator Conf. (IPAC'23)*. Venice, Italy, May 2023, pp. 5071–5074. DOI: 10.18429/JACoW-IPAC2023-THPM083.