Design of LhARA – Laser-hybrid Accelerator for Radiobiological Applications

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INTRODUCTION

LhARA will prove novel technologies for future therapy facilities by developing a dedicated facility for extensive and systematic in vitro and in vivo radiobiological studies that will investigate RBE dependencies on various physical and biological properties.

- Accelerator technologies: Gabor lens, Fixed-field accelerators (FFAs).
- Detector technologies: dose verification, beam diagnostics.
- Online image processing: machine learning algorithms, very high data rates using specialised firmware processing.

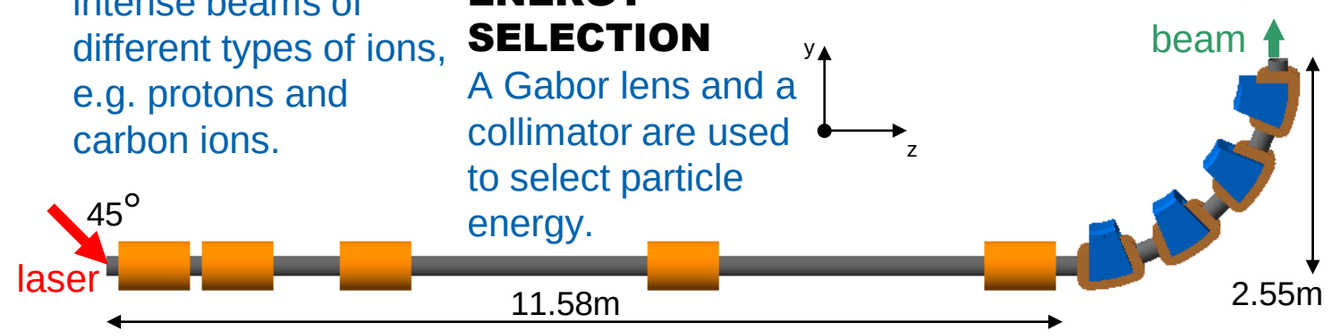
- Stage I – In vitro studies with protons up to 15 MeV.
- Stage II – FFA to provide higher energy protons for in vivo studies and carbon 6+ ions for in vitro studies.
- Laser source naturally produces ultra-high dose rates which can be used to study flash therapy.

LhARA STAGE I

LASER TARGET
Laser used to generate intense beams of different types of ions, e.g. protons and carbon ions.

ENERGY SELECTION
A Gabor lens and a collimator are used to select particle energy.

END STATION
Where the cells will be irradiated. The beam will be delivered vertically from below the cell culture plate.

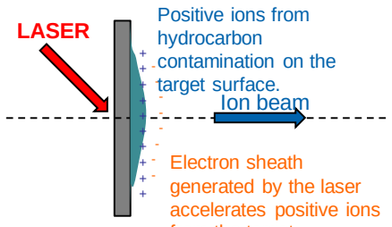


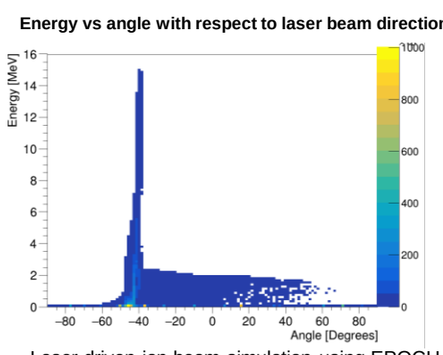
CAPTURE SECTION
Gabor lenses used for compact focussing to capture the large divergence and energy spread of the laser-driven ion beam.

MATCHING
Two Gabor lenses are used to adjust the beam size and divergence in the end station.

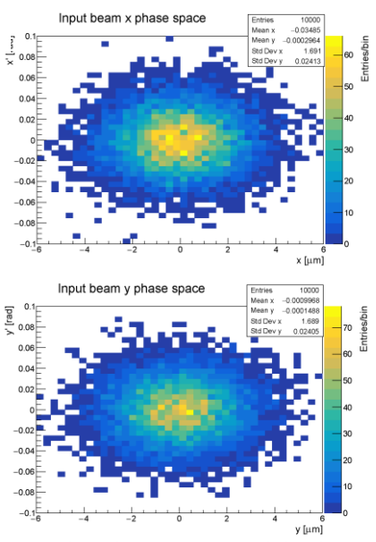
90° VERTICAL BEND
Combined function magnets deliver the beam vertically to the end station.

LASER SOURCE





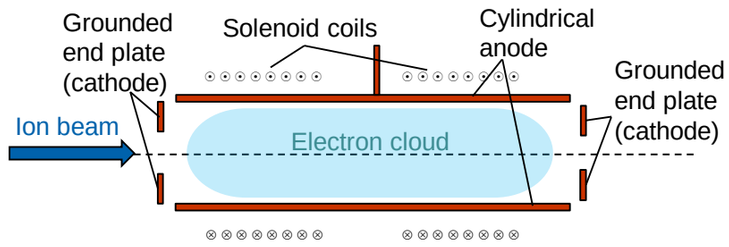
Laser driven ion beam simulation using EPOCH.

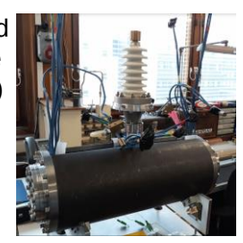


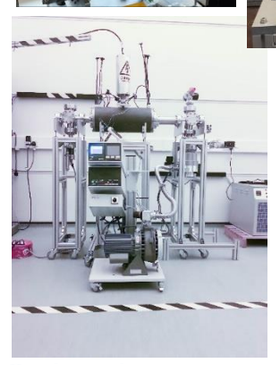
x and y phase space of the input beam generated by BDSIM.

- Produces intense beams and multiple species, e.g. proton and carbon ions.
- BDSIM (Geant4 based code) used to generate a beam from Twiss parameters:
  - $\beta_{x,y} = 71 \times 10^{-6}$ m, $\epsilon_{x,y} = 4 \times 10^{-8}\ \pi.\mathrm{m.rad}$ and $\alpha_{x,y} = 0$.
  - Maximum kinetic energy = 15 MeV.

GABOR LENS





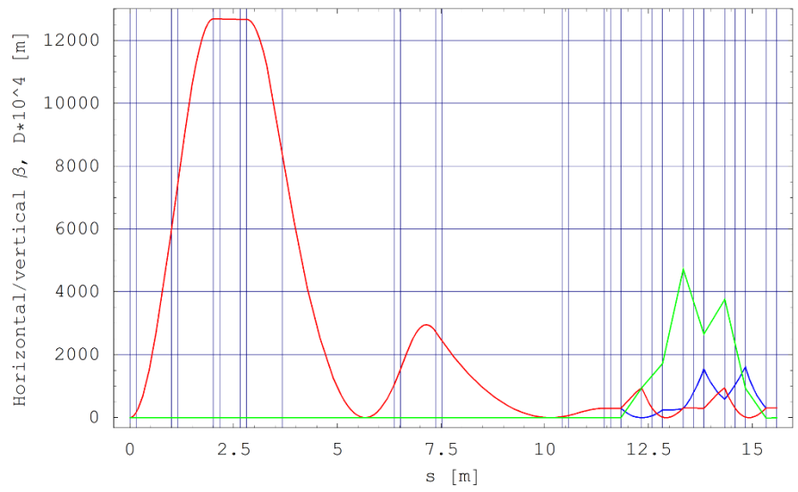


- The Gabor lens uses a confined plasma to generate a strong electro-static focusing field.
- Upgraded Gabor lens is being tested at Imperial.
  - Vacuum tests completed.
  - Tests with a radioactive source on-going.
  - Future tests will be done with a laser-driven ion beam.

Gabor lens tests at Imperial College London.

OPTICS DESIGN

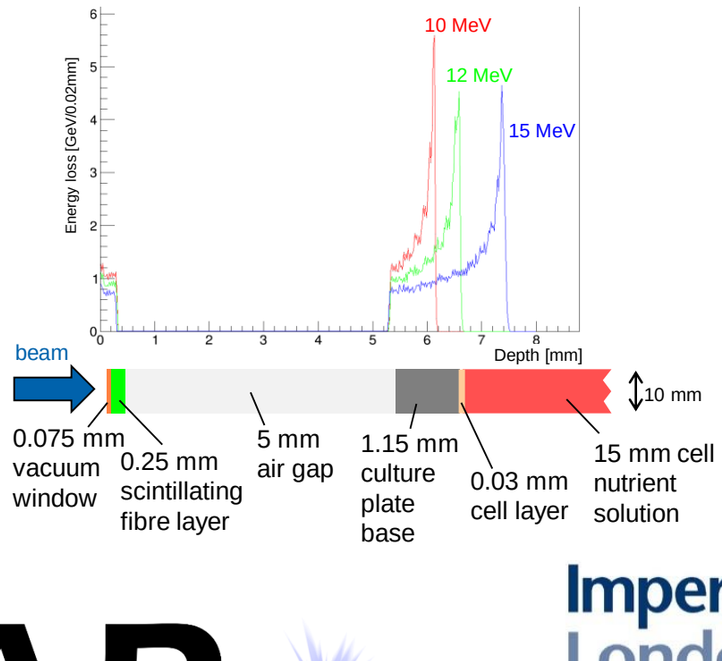
- Capture of the beam from the laser target is performed using the first two Gabor lenses. The third Gabor lens and a collimator is used to select particles of the required energy, exploiting the fact that the focus of the Gabor lens is energy dependent. The matching section is then used to reduce the divergence of the beam.
- Tilted combined function sector magnets are used in the vertical bend. This suppresses dispersion in the end station and preserves the optics at the end of the matching section.
- The beam from the laser has a very high bunch intensity, which produces a self-repulsive force (space charge) that will affect the optics. These effects are being studied using the software code General Particle Tracer (GPT) to perform particle tracking simulations. BDSIM will be used to compare beam distribution in the end station and determine the dose delivered to the cell layer.



Vertical (red) and horizontal (blue) betatron functions, and dispersion (green, scaled by 10^4) of LhARA Stage I.

END STATION

- Material budget in the end station needs to be carefully considered.
- Energy deposition and dose calculations are important in order to determine the location of the Bragg peak. These are done using BDSIM.



CONCLUSIONS

- LhARA aims to demonstrate novel technologies that can drive a step-change in the provision of proton and light ion therapy.
- LhARA will deliver a systematic programme of radiobiological studies to improve our understanding of RBE and lead to improved particle therapy.
- A new optics design of LhARA Stage I has been completed.
  - Particle tracking simulations to verify the design is underway using GPT (includes space charge effects) and BDSIM (includes energy loss in the end station).
- Radiation source testing of the upgraded Gabor lens is in progress and the lens will then be tested with a laser-driven beam.

CCAP Centre for the Clinical Application of Particles
Imperial College London
NHS Imperial College Healthcare NHS Trust
ICR The Institute of Cancer Research
JAI John Adams Institute for Accelerator Science
University of Oxford