[WEPAB139] Beam Tracking Simulations for Stage 1 of the Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

Hin Tung Lau (on behalf of the LhARA collaboration)

Department of Physics, Imperial College London

Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

LhARA [1] is proposed as a **novel** and **flexible** facility for radiobiological research (More detail in [MOPAB136]).

- Laser-driven source.
- Gabor lenses for beam capture.
- Fixed field alternating gradient accelerator (FFA) for post acceleration.
- Ultra high dose rates.

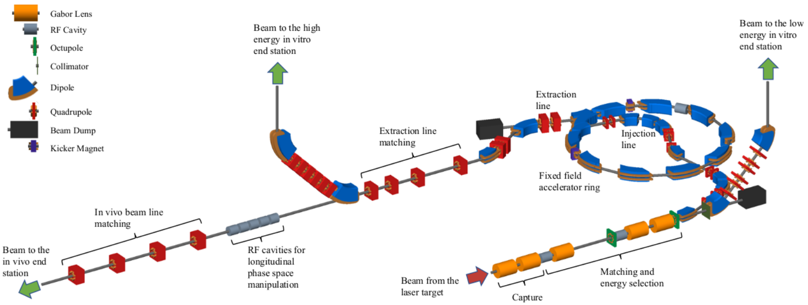

Figure: Schematic diagram of the LhARA beam lines [1]. The beam coming from the laser-driven source is represented by the red arrow.

Staged development:

- Stage 1: *In vitro* studies with proton beams up to 15 MeV.
- Stage 2: *In vitro* and *in vivo* studies with proton beams up to 127 MeV and ion beams (including C^{6+}) with energies up to 33.4 MeV/u.

Stage 1 Beamline

Stage 1 of LhARA consists of the beamline elements from the laser source to the low energy *in vitro* arc.

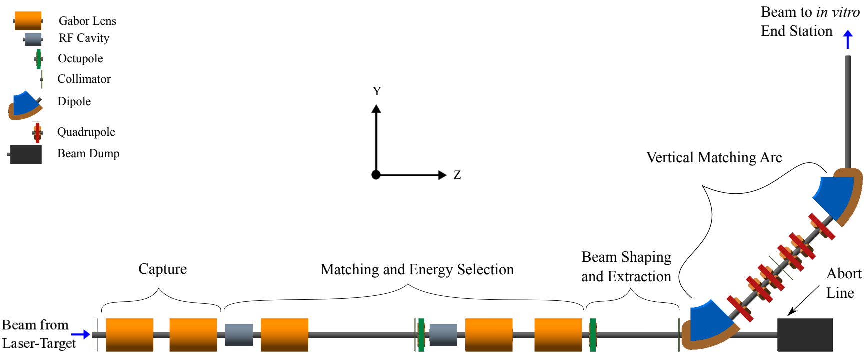

Figure: Stage 1 sections visualised with BDSIM [3].

- Capture high energy protons/ions from laser source using Gabor (plasma) lenses (more detail in [WEPAB140]), hence evading the space-charge limitations of conventional sources.
- Beam transport designed using BeamOptics [4] and MAD-X [5].

TNSA Mechanism

Target Normal Sheath Acceleration (TNSA) Mechanism:

- **Intense** laser pulse ($\gg 10^{18}$ W/cm^2).
- Interaction with a thin foil creates a **sheath field**.
- Ions on the **surface** are ionized and accelerated.
- The laser required to deliver a significant proton flux at 15 MeV is **commercially available**.

Laser Parameter	**Value**	**Unit**
Power	100	TW
Energy	2.5	J
Pulse length	25	fs
Rep. rate	10	Hz
Focal spot size	3	µm
Intensity	9.2×10^{20}	W/cm^2
a0	20.75	

Table: Table of some expected parameters for the laser system.

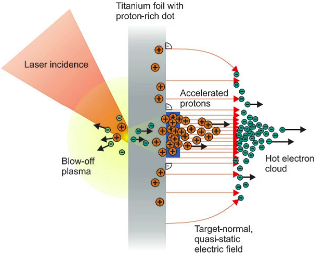

Figure: Schematic diagram of the TNSA process from Schwoerer [2].

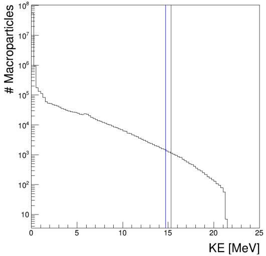

Figure: Example of kinetic energy spectrum of protons from a TNSA simulation. Blue bars indicate the selected energy range.

Particle-in-cell (PIC) code Smilei [6] was used to simulate the laser-plasma interaction in two-dimensions (2D):

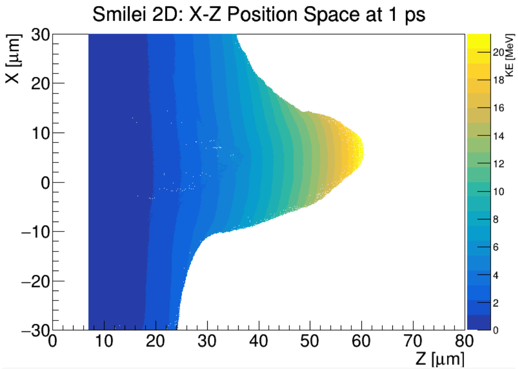

Figure: Position of proton macroparticles emerging from rear foil surface (located at $z = 5\ \mu$m) 1 ps after laser strike. Colour in the plot corresponds to the kinetic energy.

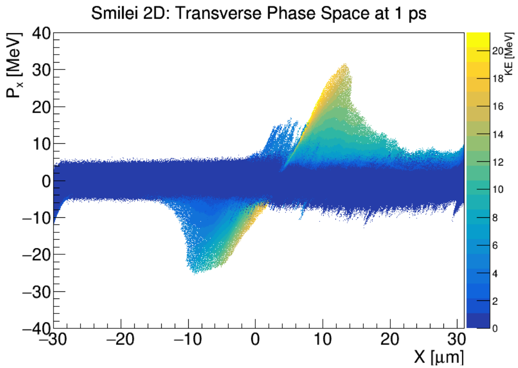

Figure: Transverse phase space of proton macroparticles emerging from rear foil surface (located at $z = 5\ \mu$m) 1 ps after laser strike. Colour in the plot corresponds to the kinetic energy.

- Laser is incident on a foil at 45°, with ions primarily accelerated in the longitudinal z direction.
- High energy proton macroparticles emerge both **off-axis** and at an **angle**.

Obtaining 3D Particle Distributions from 2D Simulations

- 3D simulation of laser source necessary for beam tracking but requires considerable computing resources.
- Generated a 3D particle distributions from 2D simulations following the steps outline below:

Summary of Method

1. **Assume the same correlations** for both transverse axes as in simulation.
2. Sample the kinetic energy.
3. Sample the momentum components from momentum correlations in simulations.
4. Sample the position coordinates based on correlations between momentum and position.
5. Center the distribution for momentum and position for energies in the range of interest.

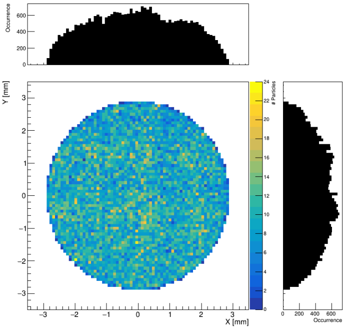

Figure: Beam position in transverse plane at exit of vacuum chamber (near the entrance to first Gabor lens); colours represent the number of proton macroparticles.

Beam Size Evolution

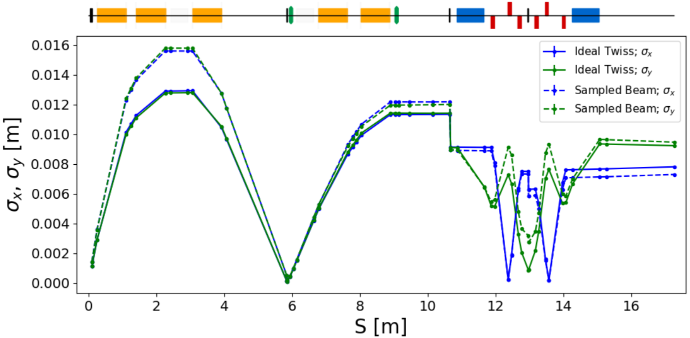

Figure: Transverse dimensions of an idealised 15 MeV Gaussian proton beam (solid lines, simulated with an initial bunch of $\sim 10^4$ particles) and sampled beam (dashed lines, simulated with an initial bunch of $\sim 3 \times 10^4$ particles) as a function of position in Stage 1 beamline.

- Particle tracking results using a combination of simulation codes: BDSIM [3] (beam line tracking) and GPT [7] (inclusion of space charge effects on beam).
- Sampled beam evolution **similar** to an idealised Gaussian beam.
- Analysis and optimisations are ongoing.

Conclusion

- Beam tracking results obtained for LhARA.
- Techniques developed to generate approximate 3D particle distributions from 2D laser source simulations.
- A semi-realistic beam can be transported through the beam line with a beam size evolution comparable to an idealised beam.
- Analysis and optimisations are ongoing to improve the simulations and tracking.

References

[1] G. Aymar *et al.*, "Lhara: The laser-hybrid accelerator for radiobiological applications," *Frontiers in Physics*, vol. 8, p. 432, 2020.

[2] H. Schwoerer *et al.*, "Laser-plasma acceleration of quasi-monoenergetic protons from microstructured targets.," *Nature*, vol. 439, pp. 445 – 448, 2006.

[3] L. J. Nevay *et al.*, "Bdsim: An accelerator tracking code with particle-matter interactions," *Computer Physics Communications*, p. 107200, 2020.

[4] Y. Chao, "BeamOptics: a Symbolic Platform for Modeling and the Solution of Beam Optics System," tech. rep., CERN, Geneva, Nov 2000.

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[6] J. Derouillat *et al.*, "Smilei : A collaborative, open-source, multi-purpose particle-in-cell code for plasma simulation," *Computer Physics Communications*, vol. 222, pp. 351 – 373, 2018.

[7] S. Van der Geer and M. De Loos, "Applications of the general particle tracer code," in *Proc. 5th Eur. Part. Acc. Conf.*, p. 1241, 1996.