Development of an Ion-Acoustic Dose-Deposition Mapping System for LhARA

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LhARA Laser-hybrid Accelerator for Radiobiological Applications

INTRODUCTION

LhARA, the **Laser-hybrid Accelerator for Radiobiological Applications** [1], is proposed as a facility dedicated to the study of radiation biology using proton and ion beams.

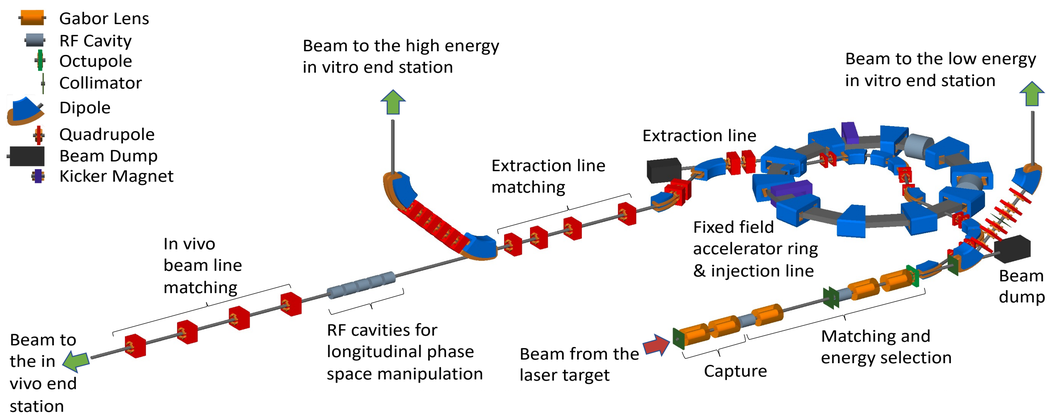

Figure 1: Schematic diagram of the LhARA beam lines.

- Deliver a variety of ion species over a wide range of spatial and temporal profiles at **ultra-high dose rates**.

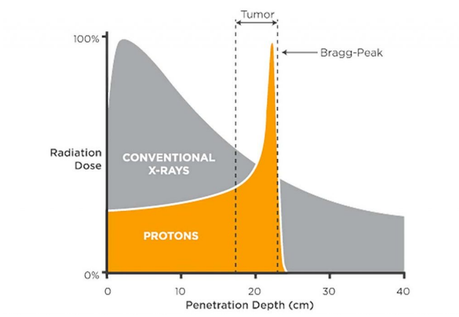

Figure 2: Relative dose deposition profile for photons (gray) and protons (orange).

- Required: measurement of the deposited dose distribution in **real-time** at a repetition rate of **10 Hz**.
- Ion-acoustic dose mapping is based on the acoustic (pressure) waves generated from the energy deposited by the passage of the ion beam [2,3].
- **Ion-acoustic system:** will allow **real-time monitoring** of the dose accumulation.

METHOD

- A **20 MeV proton beam** has been used to irradiate a **water-based phantom**, simulated in **Geant4**.
- The ion-acoustics process has been simulated in **k-Wave**.
- An **acoustic sensor array** has been simulated and the data collected were used to reconstruct the pressure distribution using an iterative time-reversal algorithm.

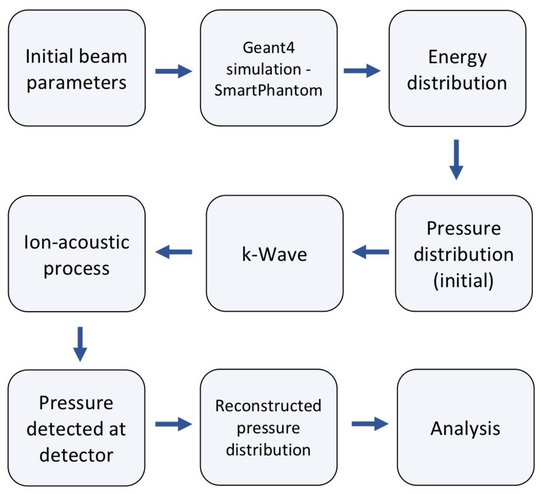

Figure 3: Simulation pipeline.

SMARTPHANTOM

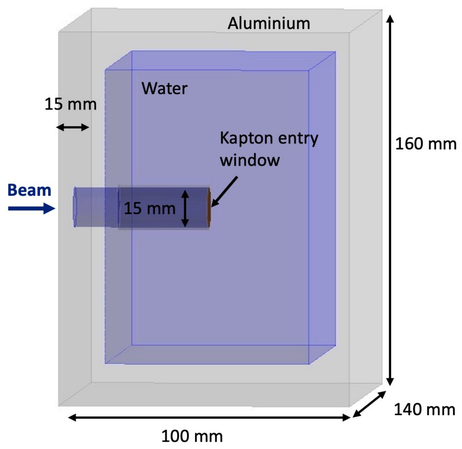

Figure 4: Geant4 simulation of the water phantom to be used as the propagating medium.

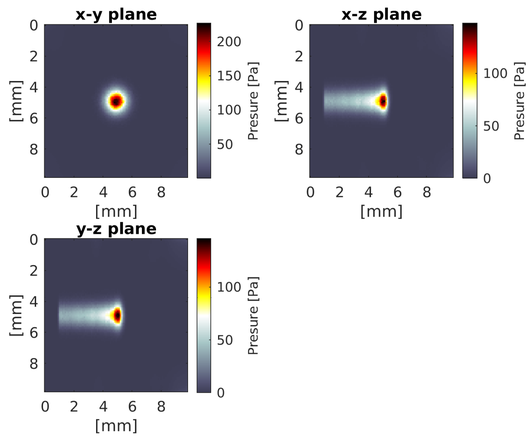

Figure 5: Source pressure distribution caused by the energy depositions of a 20 MeV proton beam. Voxel size: 0.1 mm.

ACOUSTIC SENSOR ARRAY

- **Hemispherical sensor array**, 8 mm diameter.
- 300 **disc elements**, 0.2 mm diameter each.
- Elements **evenly distributed** on the surface.

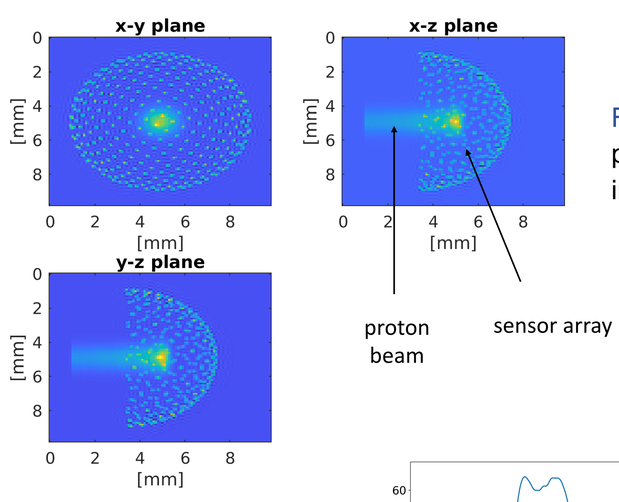

Figure 6: Sensor geometry and proton beam energy depositions in k-Wave. Voxel size: 0.1 mm.

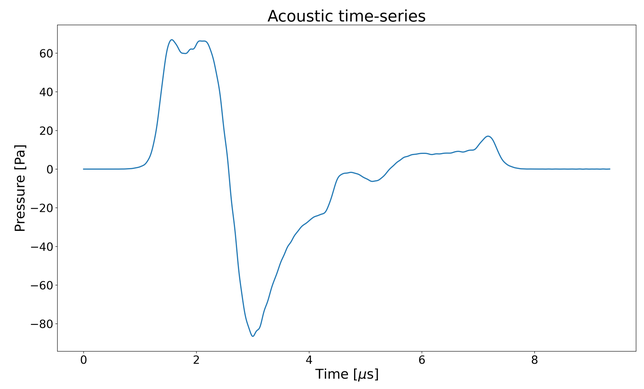

Figure 7: Temporal pressure distribution from the data received by the acoustic sensor.

3D IMAGE RECONSTRUCTION

- **Iterative time-reversal** image reconstruction technique.

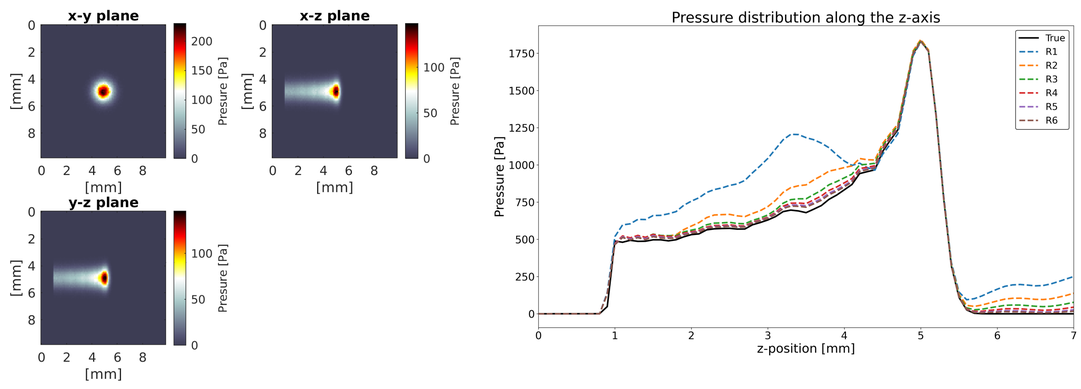

Figure 8: Reconstructed source pressure distribution in the three orthogonal planes (left) and reconstructed source pressure along the axis of beam propagation (right) using 6 iterations of the time-reversal algorithm. Voxel size: 0.1 mm.

CONCLUSION

- **Ion-acoustic** imaging can be used to get the dose deposition profile of a pulsed ion beam propagating in a medium.
- The iterative time-reversal algorithm gives an accurate reconstruction of the 3D pressure distribution using the pressure data received by the simulated acoustic sensor array.
- After six iterations, the pressure distribution profile was reconstructed with **submillimetre accuracy**.
- Further development of the system can lead to a real-time, **3D dosimetry system** during ion-beam therapy with **LhARA**.

REFERENCES

1. Aymar G. *et al*. *Front Phys.* 2020;0:432.
2. Haffa D. *et al*. *Sci Rep.* 2019;9(1):6714.
3. Kellnberger S. *et al*. *Sci Rep.* 2016;6:29305.
4. Allison J. *et al*. *Nucl. Instrum. Meth. A. 2016;*835:186-225.
5. Treeby BE, Cox BT. *J. Biomed. Opt.* 2010;15(2):021314.