Design of an Ion-Acoustic Proof-of-Principle Experiment for LhARA

M. Maxouti[†1,2,3], P.R. Hobson[4], B. Cox[5], O. Jeremy[1], R.A. Amos[5], C. Whyte[6], J.C. Bamber[7], K. Long[1,2,3]

1 Dept of Physics, Imperial College London. 2 John Adams Institute for Accelerator Science, Imperial College London. 3 Particle Physics Dept, STFC Rutherford Appleton Laboratory. 4 School of Physical and Chemical Sciences, Queen Mary University of London. 5 Dept of Medical Physics and Biomedical Engineering, University College London. 6 University of Strathclyde and Cockcroft Instituite for Accelerator Science. 7 The Institute of Cancer Research and Royal Marsden NHS Foundation Trust.

Imperial College London

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.

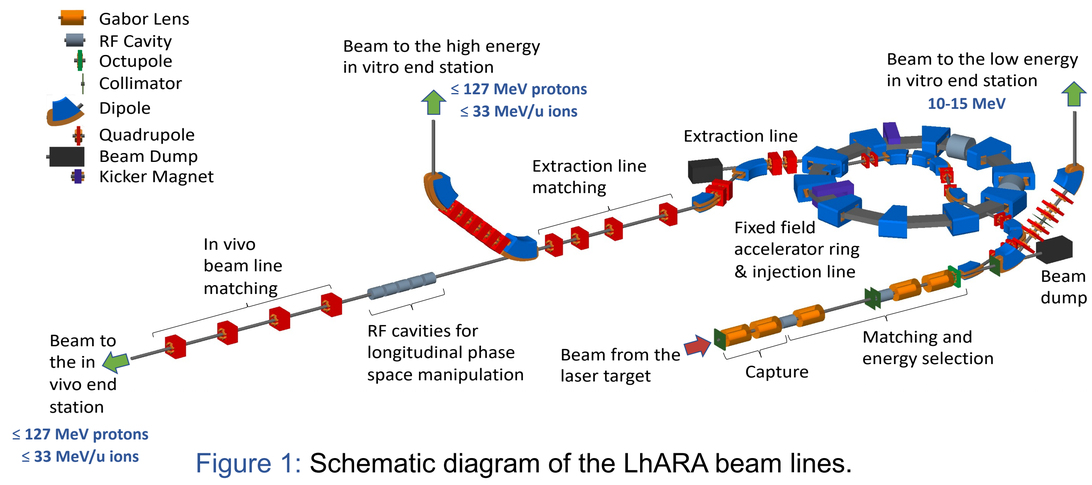

Figure 1: Schematic diagram of the LhARA beam lines.

- Deliver a variety of **ion species** at **ultra-high dose rates**.
- Requirement: 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].
- Liquid scintillator: emission of scintillation light caused by the absorbed beam energy[4].
- Combination: potential to allow **real-time 3D dose monitoring**.

METHOD

- Designed and simulated the **SmartPhantom** in **Geant4**[5]: beam energy absorber and propagating medium.
- Employed a **20 MeV proton beam** to irradiate the phantom.
- Simulated the acoustic waves and scintillation light caused by the beam energy absorption using **k-Wave**[6] and Ansys Zemax **OpticStudio**[7].
- Utilized a matrix and a linear array ultrasound transducers for acoustic reconstruction.
- Used appropriate optical systems to reconstruct the 3D light distribution.

SMARTPHANTOM

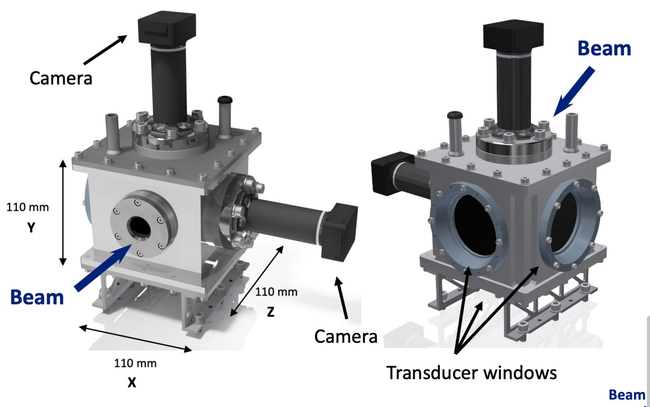

Figure 1: External view of the SmartPhantom. The design allows for simultaneous detection of the acoustic waves and scintillation light.

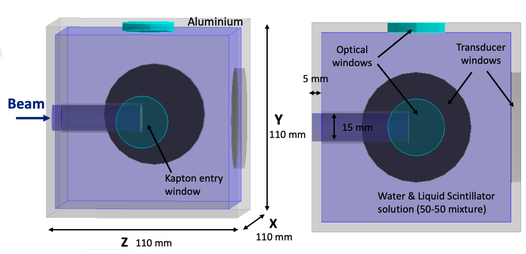

Figure 2: Geant4 simulation of the SmartPhantom.

ACOUSTIC WAVE GENERATION & DETECTION

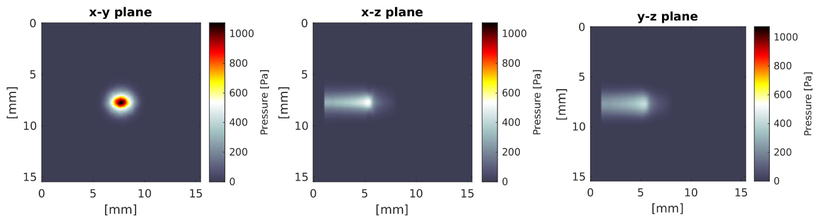

Figure 3: Calculated source pressure when a 20 MeV proton beam is absorbed in the SmartPhantom.

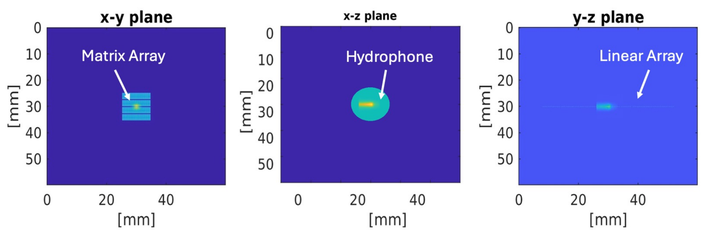

Figure 4: Transducers' location relative to the beam depositions in the SmartPhantom.

LIQUID SCINTILLATOR

- Liquid scintillator chosen: **Ultima Gold XR.**
- Generates **8000 photons/MeV**.
- Primary compound: di-isopropyl naphthalene (**DIPN**).

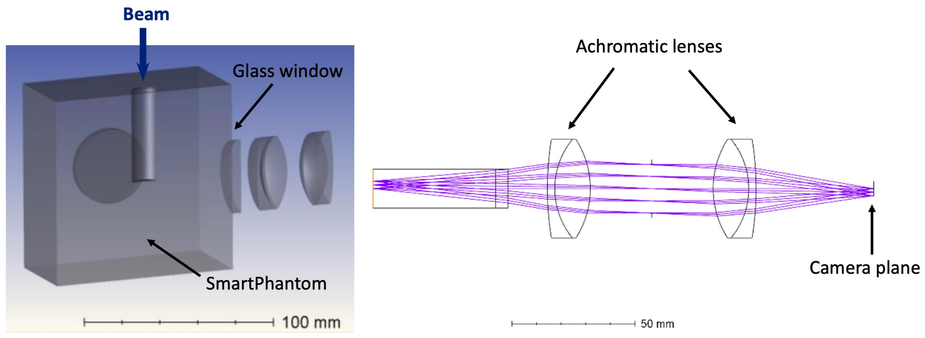

Figure 5: Zemax simulation of the SmartPhantom (left) and system of two identical lenses used for collimation and focus (right).

RESULTS

- **Iterative time-reversal** image reconstruction technique.
- **4 iterations** regarded sufficient for achieving convergence to the desired outcome.

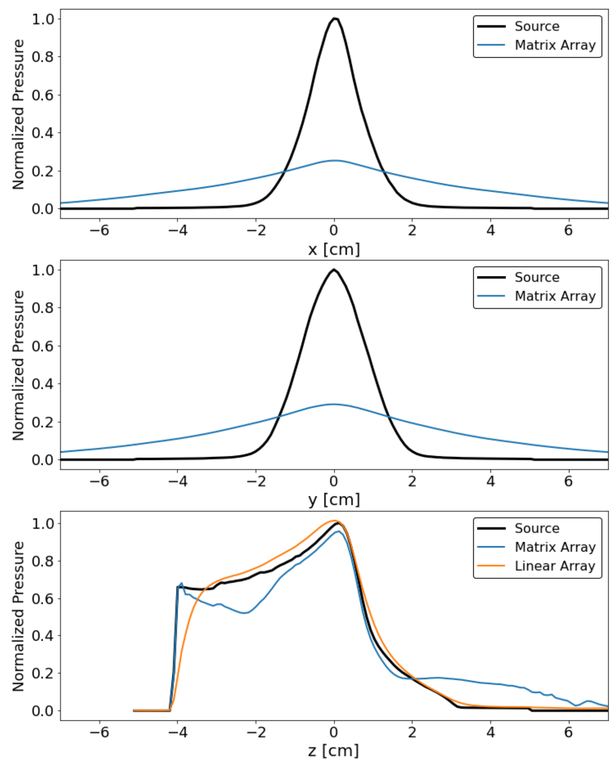

Figure 6: Reconstructed pressure distribution, in the three orthogonal axes, relative to the source pressure (black lines).

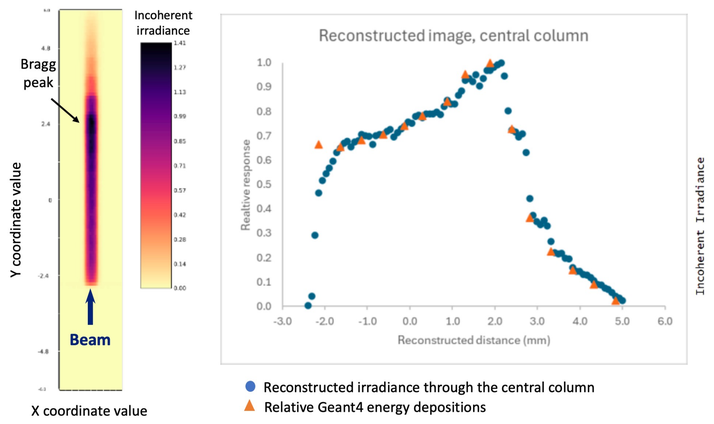

Figure 7: Reconstructed image irradiance on the camera plane (left) and reconstructed irradiance through the central column (right), binned in 50 μm × 100 μm pixels.

CONCLUSION

- Acoustic and Optical Reconstructions: The **transducers** and the **optics system** are **successful** in reconstructing the simulated **3D pressure and energy distributions** in the SmartPhantom.
- Bragg Peak and Radial Profiles: Effective Bragg peak reconstruction using the matrix array; improved radial profile accuracy expected from the linear array.
- A combination of the optical and acoustic systems can lead to a **calibrated 3D dose map**.
- Further development and validation would enable **real-time dosimetry** during ion-beam radiation with **LhARA**.

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