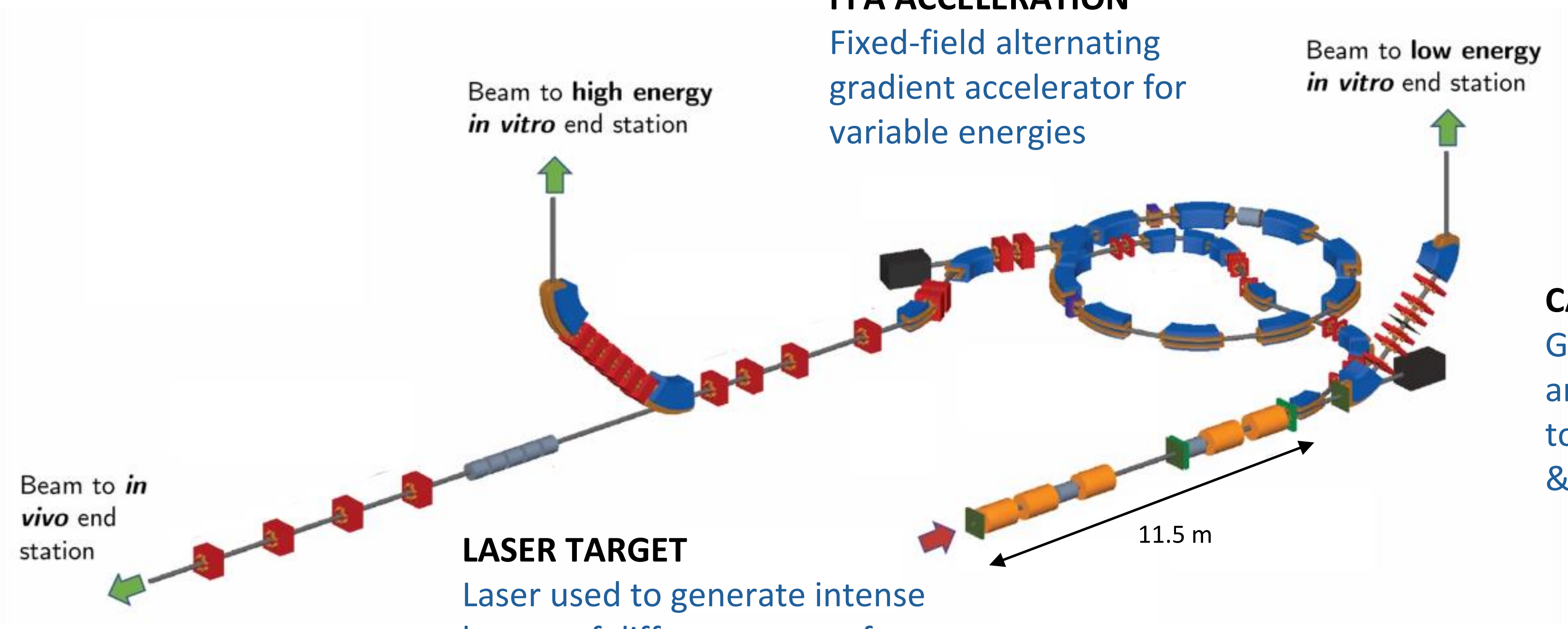
Design of an Ion-Acoustic Proof-of-Principle Experiment for ITRF/LhARA

M. Maxouti[1,2,3], P.R. Hobson[4], O. Jeremy[1], B. Cox[5], N. Dover[1], S. Gerlach[6], J. Lascaud[6], R.A. Amos[5], C. Whyte[7], J. Schreiber[6], K. Parodi[6], J.C. Bamber[8], K. Long[1,2,3]

1 Department of Physics, Imperial College London, UK
2 John Adams Institute for Accelerator Science, UK
3 Particle Physics Department, STFC Rutherford Appleton Laboratory, UK
4 School of Physical and Chemical Sciences, Queen Mary University of London, UK
5 Department of Medical Physics and Biomedical Engineering, University College London, UK
6 Department of Medical Physics, Ludwig-Maximilians-Universität München, Germany
7 Department of Physics, University of Strathclyde, UK
8 Institute of Cancer Research and Royal Marsden NHS Foundation Trust, UK

Laser-hybrid Accelerator for Radiobiological Applications



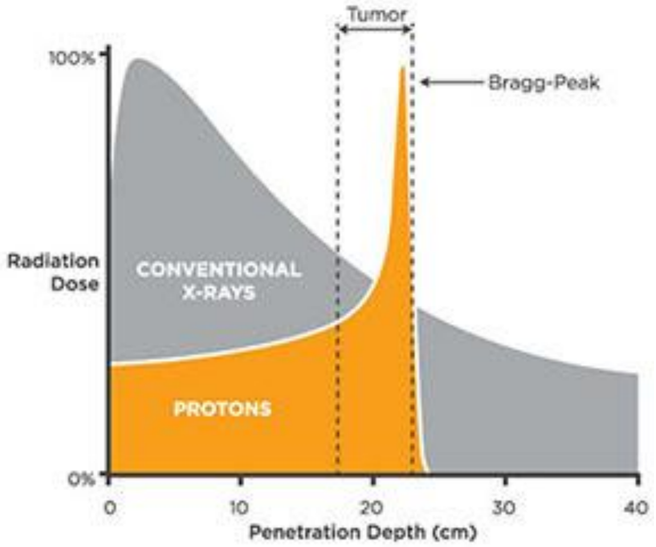
FFA ACCELERATION
Fixed-field alternating gradient accelerator for variable energies

CAPTURE SECTION
Gabor lenses provide a compact and cost-effective capture system to magnetically focus minibeams & microbeams

LASER TARGET
Laser used to generate intense beams of different types of ions, e.g. protons and carbon ions at instantaneous FLASH dose rates

[1] G Aymar et al., "LhARA: The Laser-hybrid Accelerator for Radiobiological Applications" Front Phys 9 (2020) 567738

Real-Time Dose Mapping System



Bragg peak localization

Quantitative 3D dose mapping

Pulse-to-pulse adaptive treatment

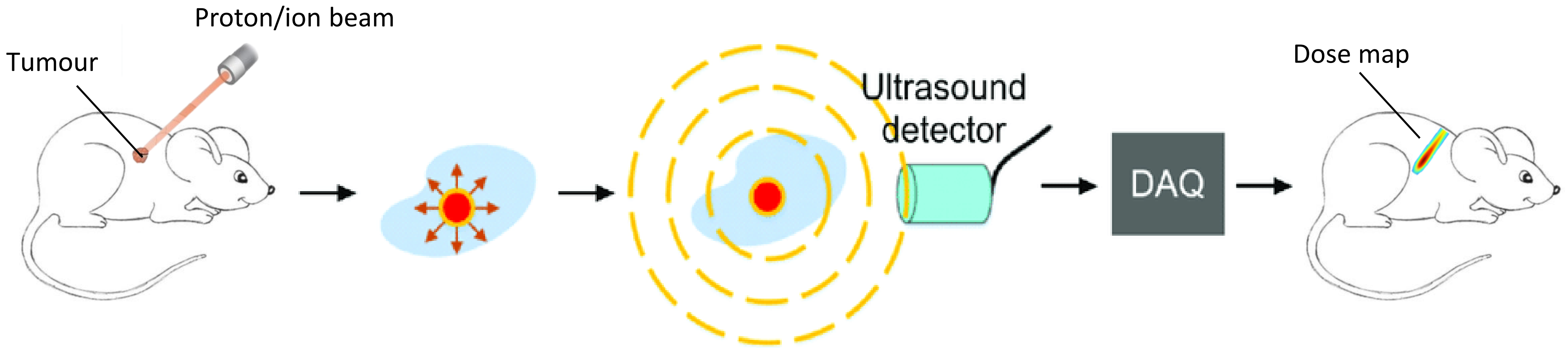
Simultaneous anatomical imaging

Ion-acoustic imaging

[2] Lehrer E.J. et. al., Proton and Heavy Particle Intracranial Radiosurgery. Biomedicines

Ionacoustic Process

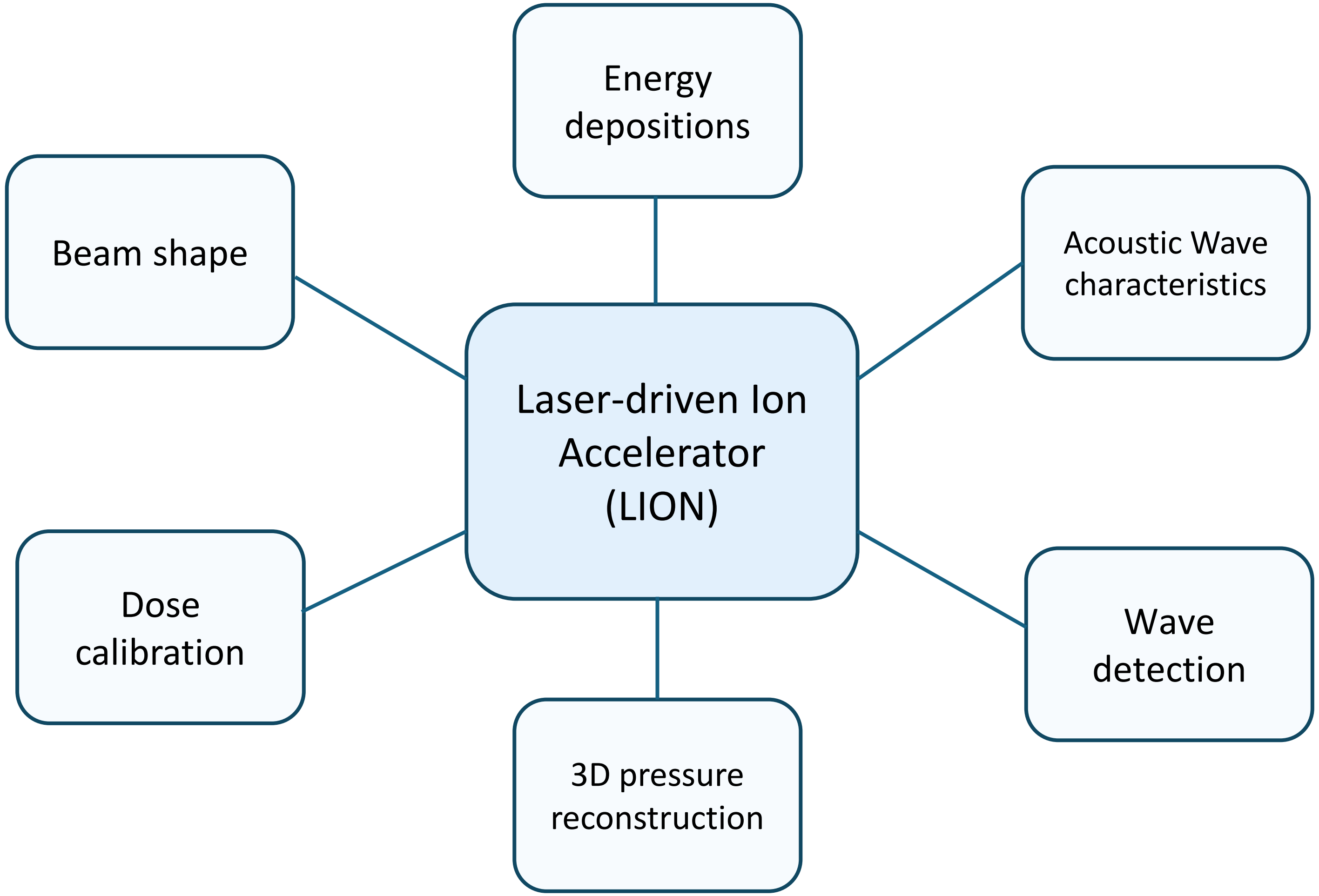
Proton/ion pulse energy absorption → Transient pressure rise → Acoustic wave propagation → Acoustic wave detection → Data acquisition and image reconstruction



[3] Freijo C, Herraiz JL, Sanchez-Parcerisa D, Udias JM. Dictionary-based protoacoustic dose map imaging for proton range verification

Developing an Ion-Acoustics Proof-of-Principle Experiment

IMPERIAL



Laser-Driven Source

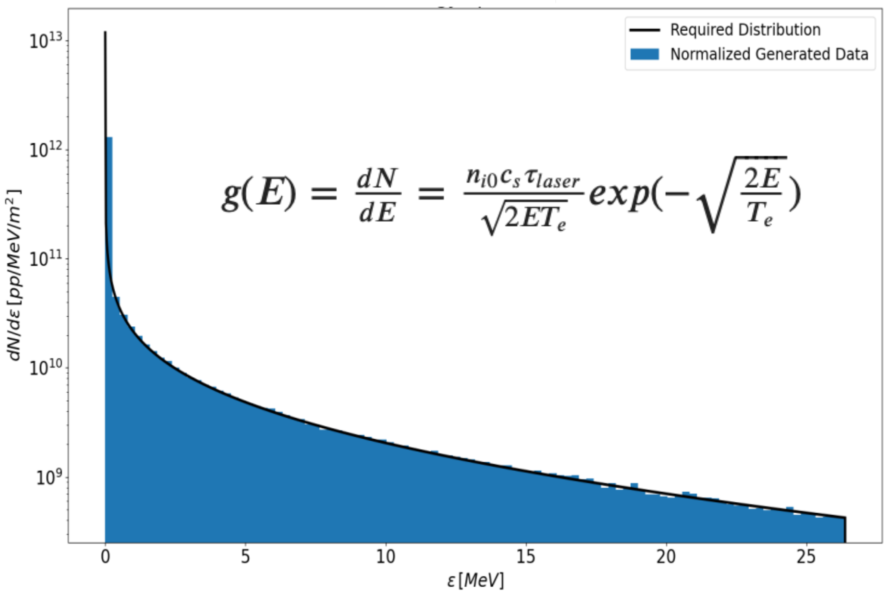
Laser & Target Parameters

ATLAS3000 laser at the Centre for Advanced Laser Applications (CALA)

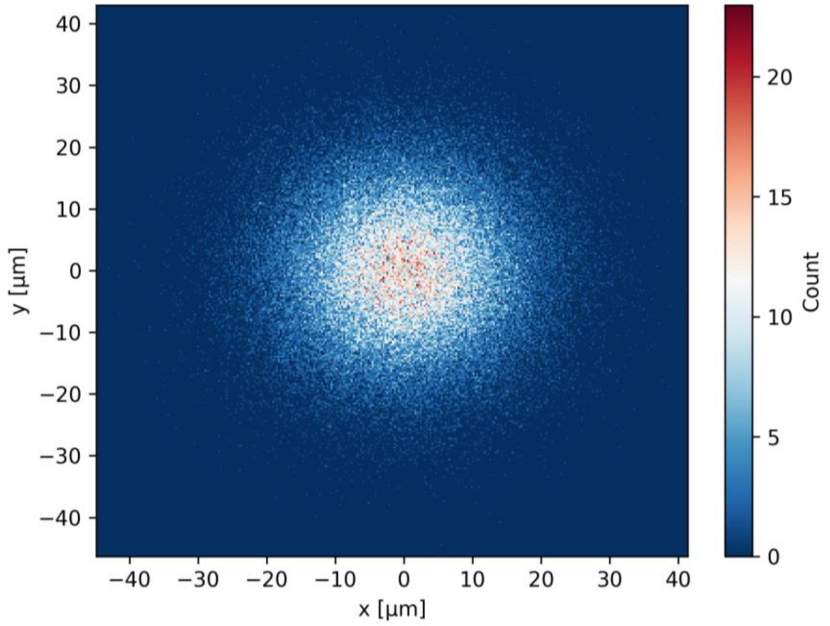
Parameters	
Laser Power [TW]	200
Laser Energy [J]	5
Laser Intensity [W/cm^2]	4x10^{20}
Laser Wavelength [nm]	800
Pulse Duration [fs]	28
Foil target thickness [nm]	400-600

(current parameters that are still being ramped up)

Energy Distribution



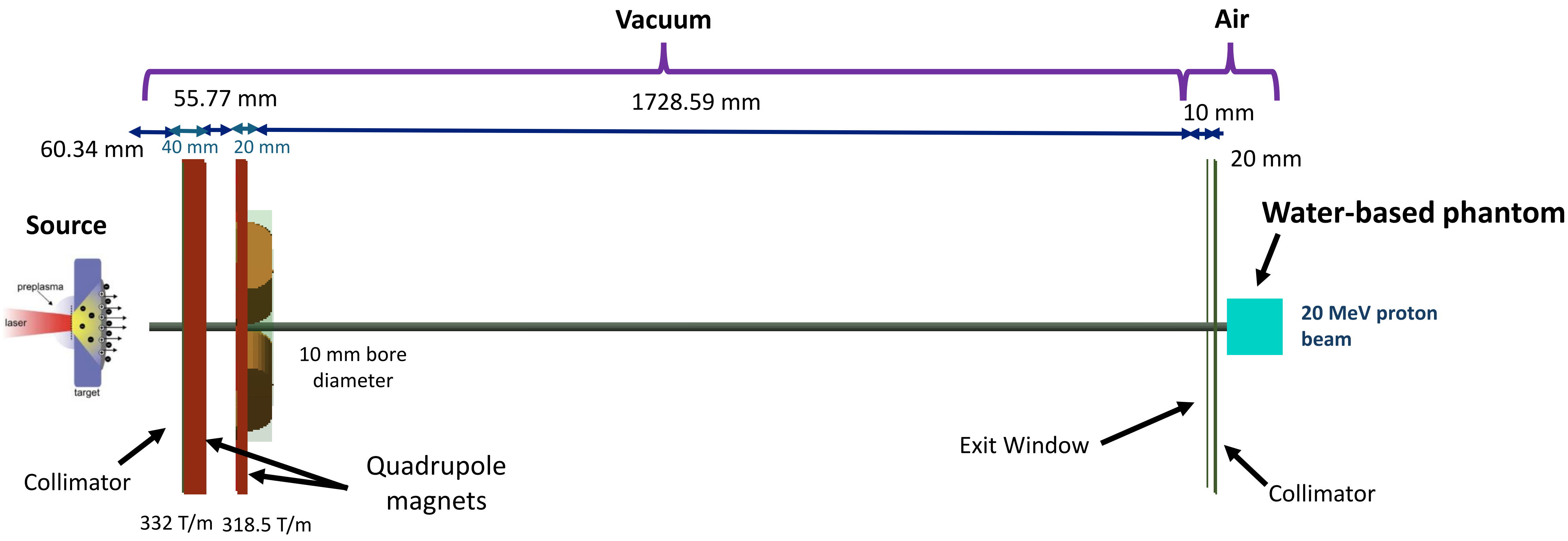
Spatial Distribution



[4] Krausz, F. (2016). *cala*. cala-laser.de

[5] Fuchs, J. et al. Laser-driven proton scaling laws and new paths towards energy increase

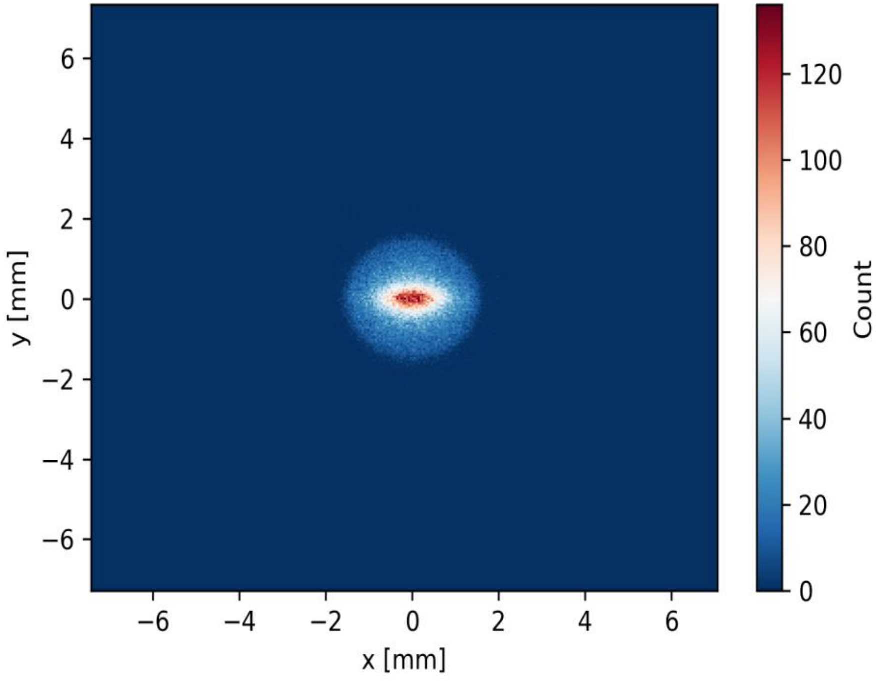
LION Beamline



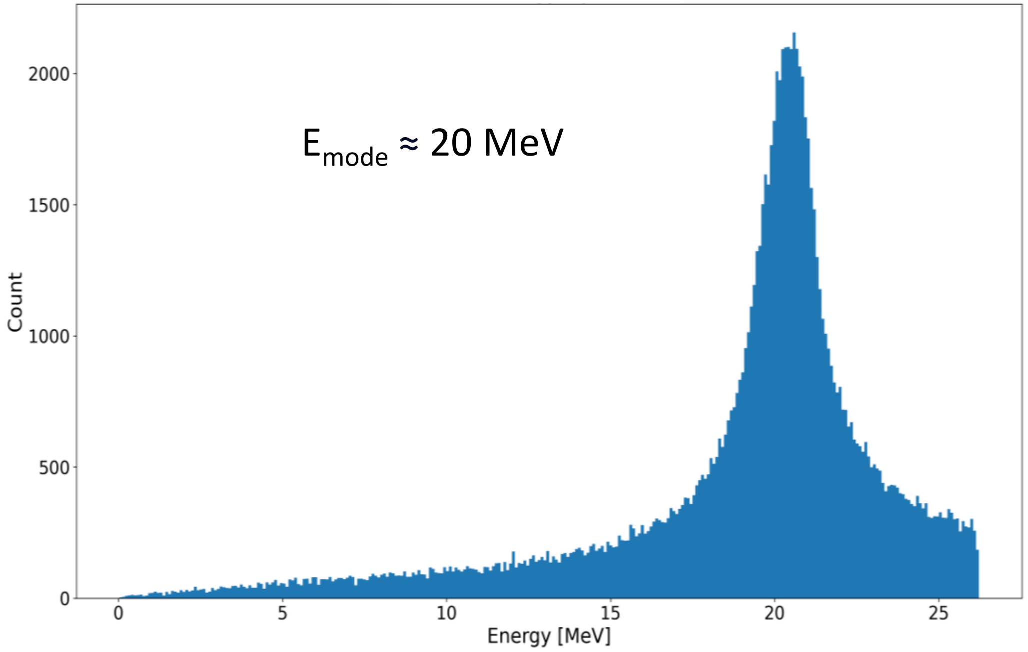
[6] T. F. Rösch et al., Laser-driven ION (LION) acceleration at the centre for advanced laser applications (CALA)

Emerging Proton Beam

Spot Size



Energy Spectrum



Acoustic Detection: Transducers

Matrix Array

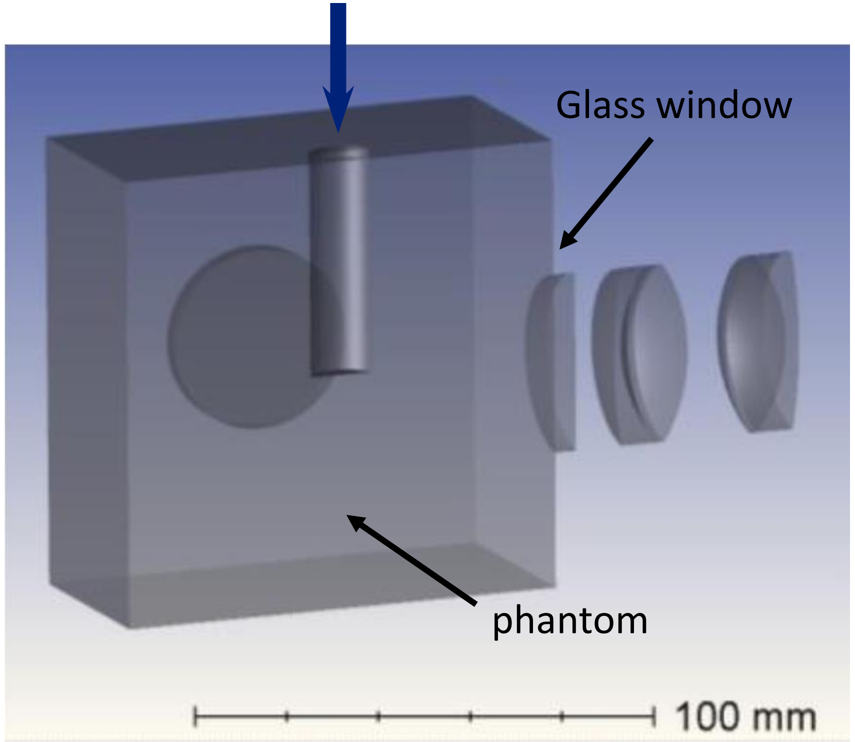
Center Frequency	3.5 MHz
Bandwidth	60%
Elements	1024 (32x32)
Pitch	0.3 mm

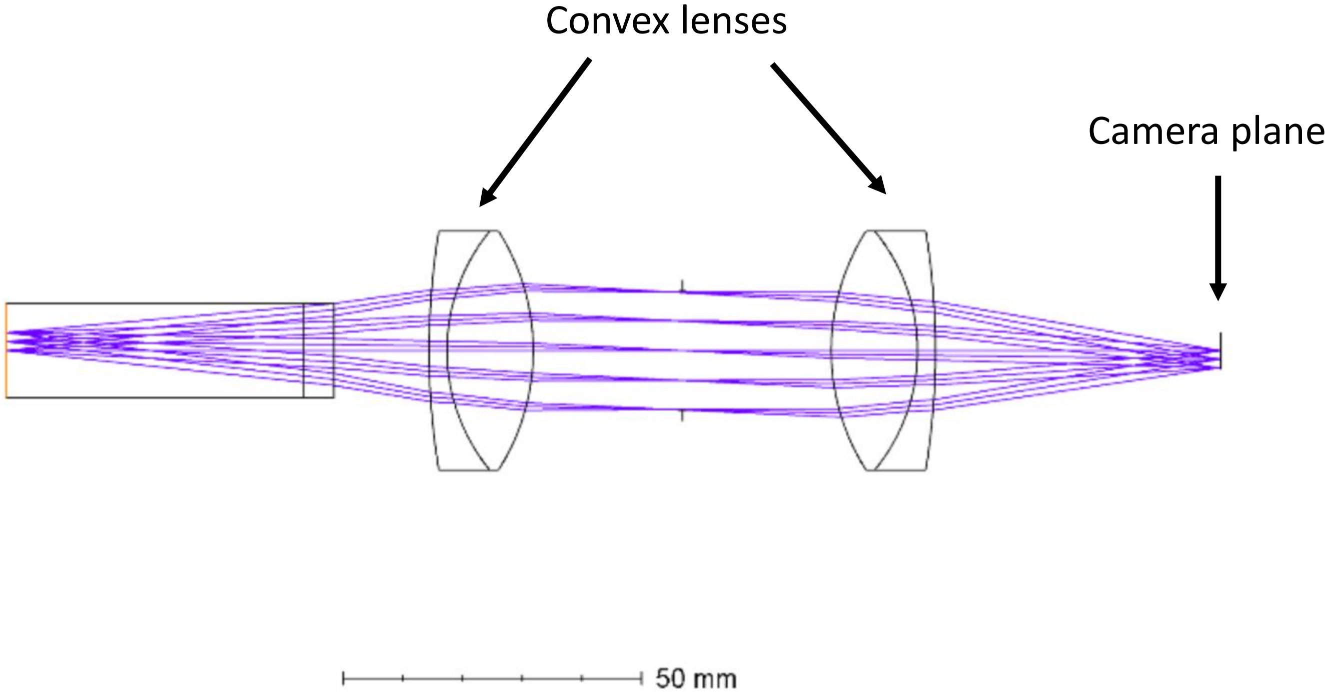
Linear Array

Center Frequency	5.3 MHz
Bandwidth	75%
Elements	192 (192x1)
Pitch	0.23 mm

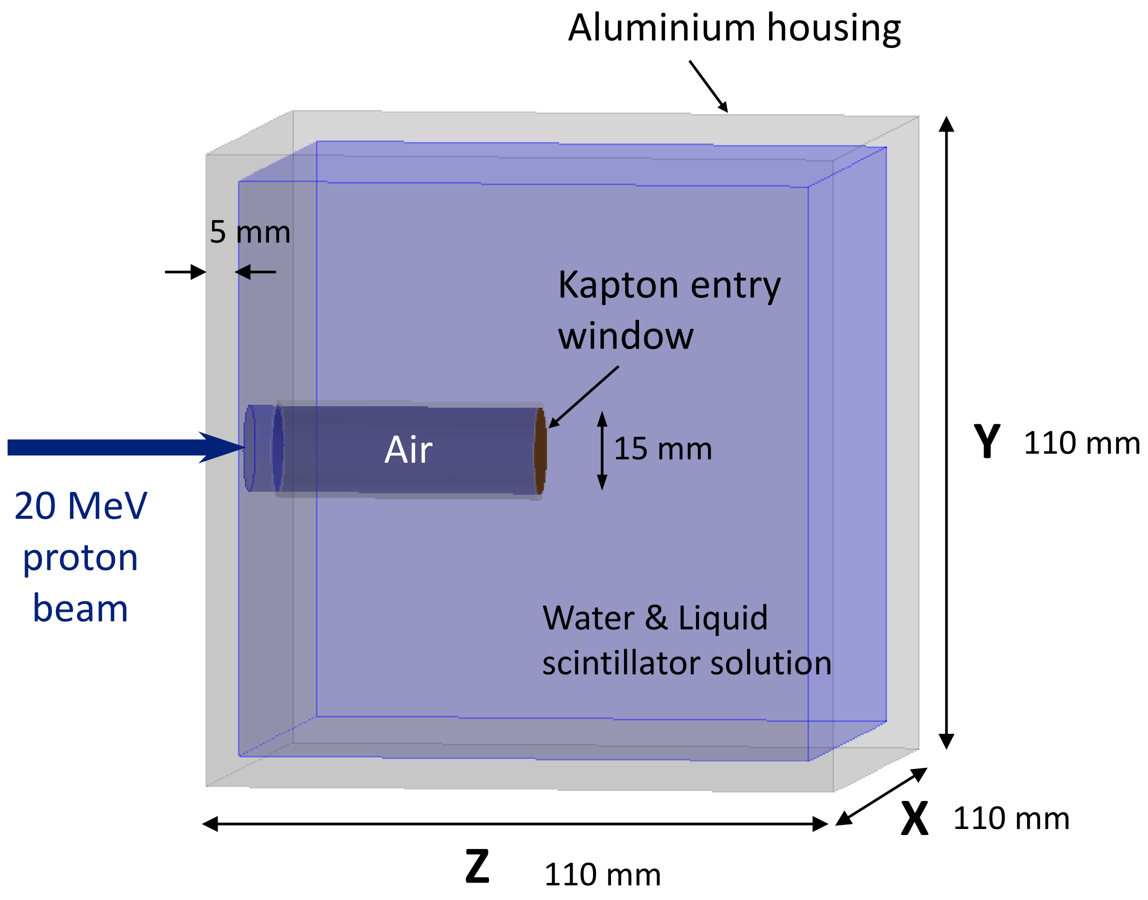
Dose Calibration: Liquid Scintillator

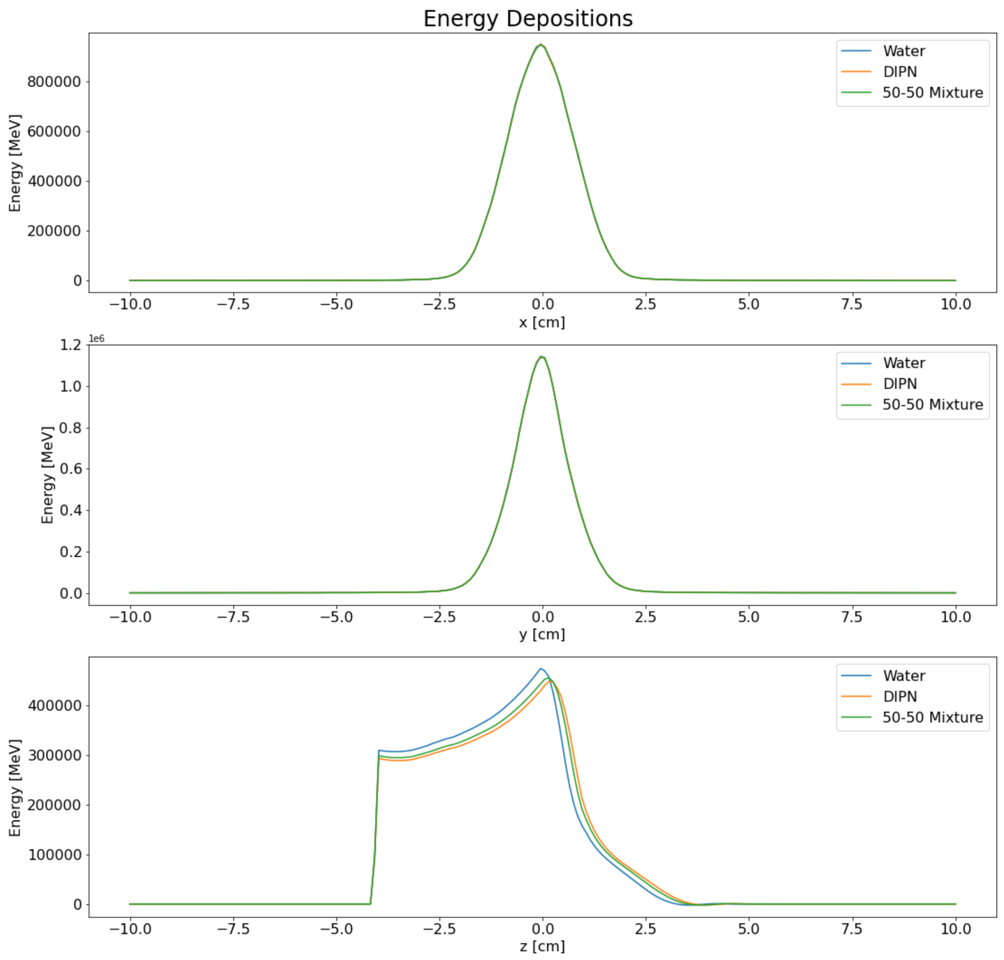
20 MeV proton beam



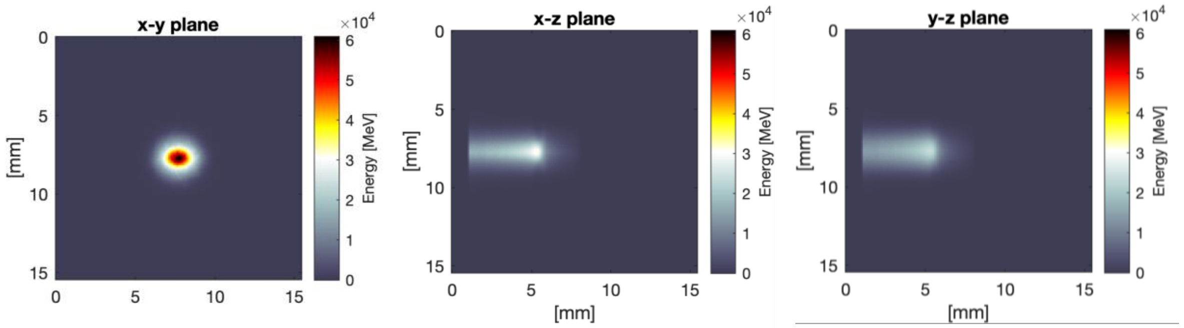


Predicted Energy Depositions: SmartPhantom





Pressure Distribution & Acoustic Wave Propagation

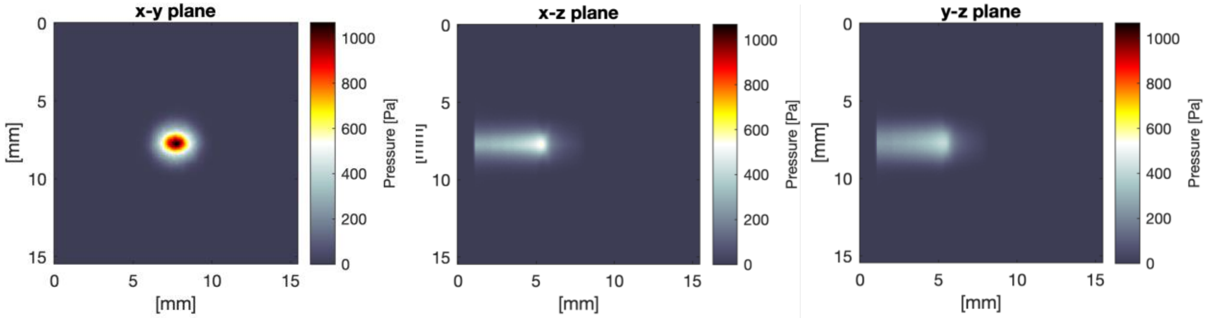


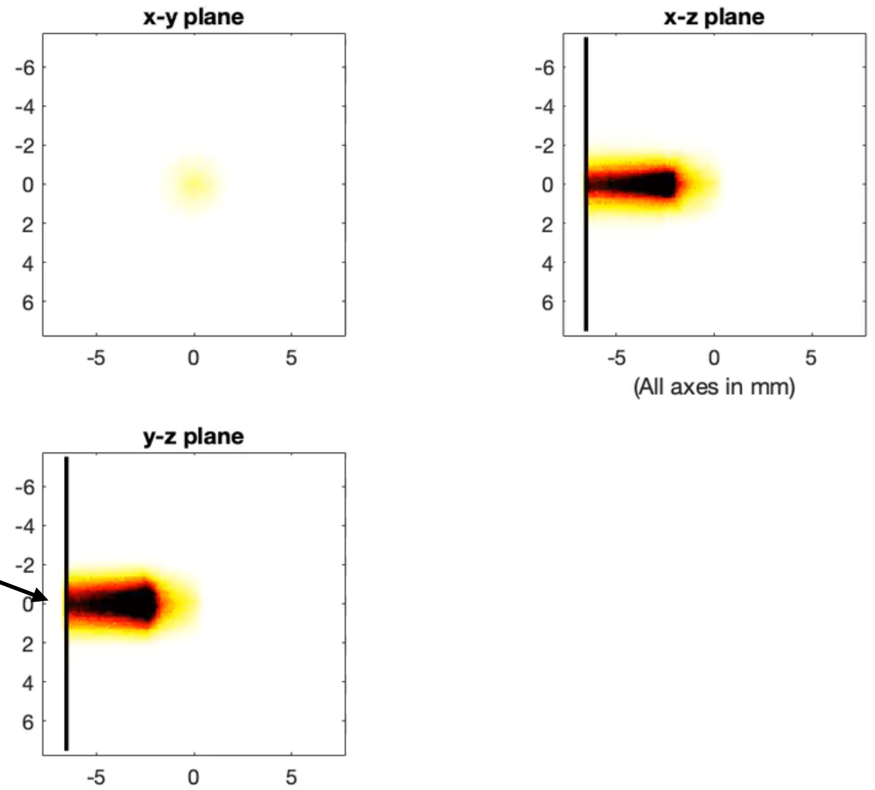
Energy deposited in the medium

$$p_0(r) = \Gamma(r)E(r)$$

Initial pressure

Gruneisen parameter





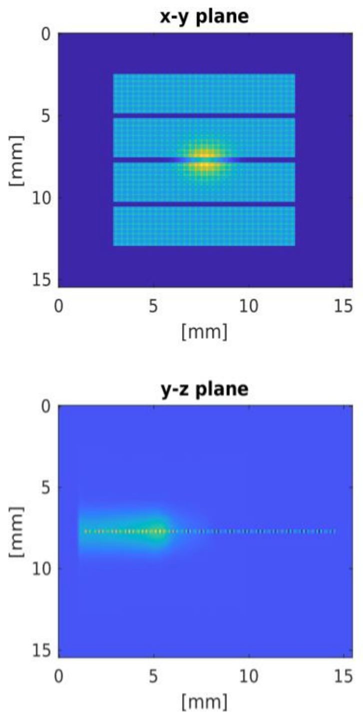
Kapton entry window

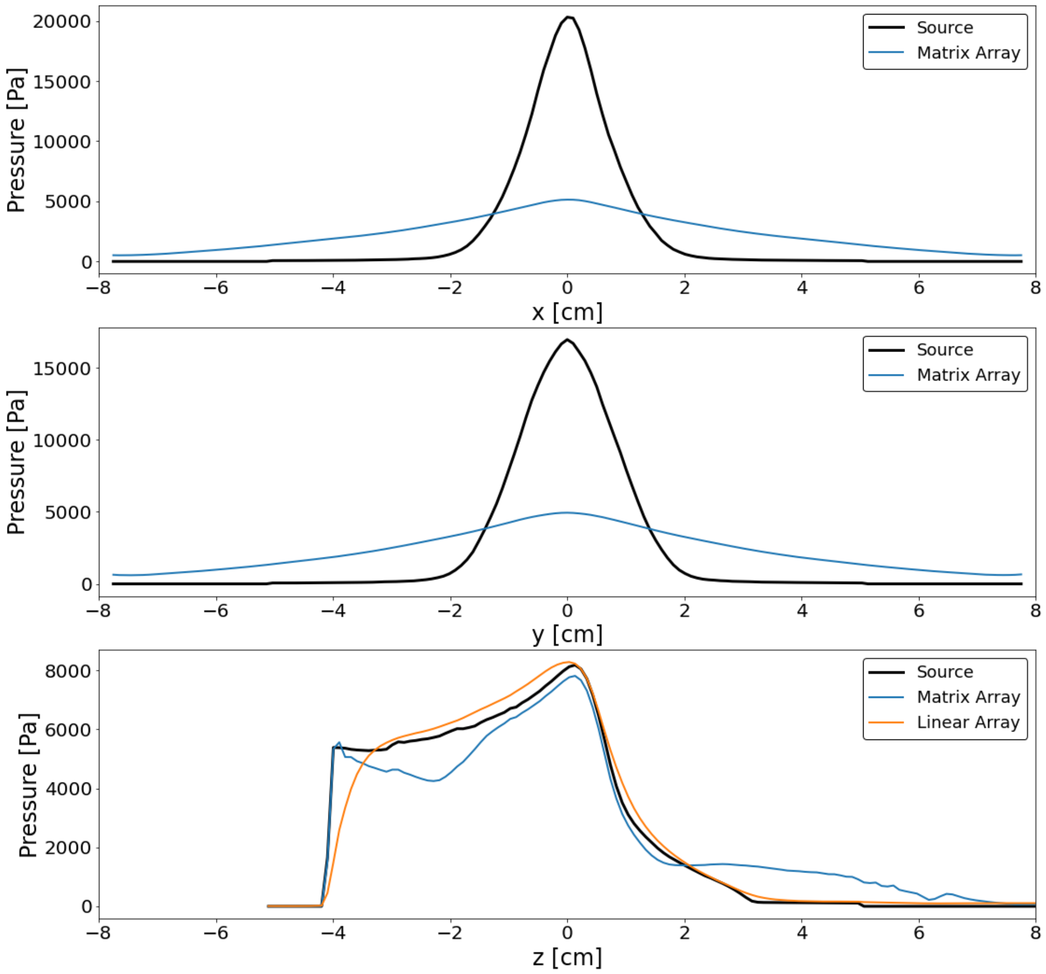
[3] Freijo C, Herraiz JL, Sanchez-Parcerisa D, Udias JM. Dictionary-based protoacoustic dose map imaging for proton range verification. Photoacoustics

3D Pressure Reconstruction
Iterative-Time Reversal Algorithm

Matrix array

Linear array

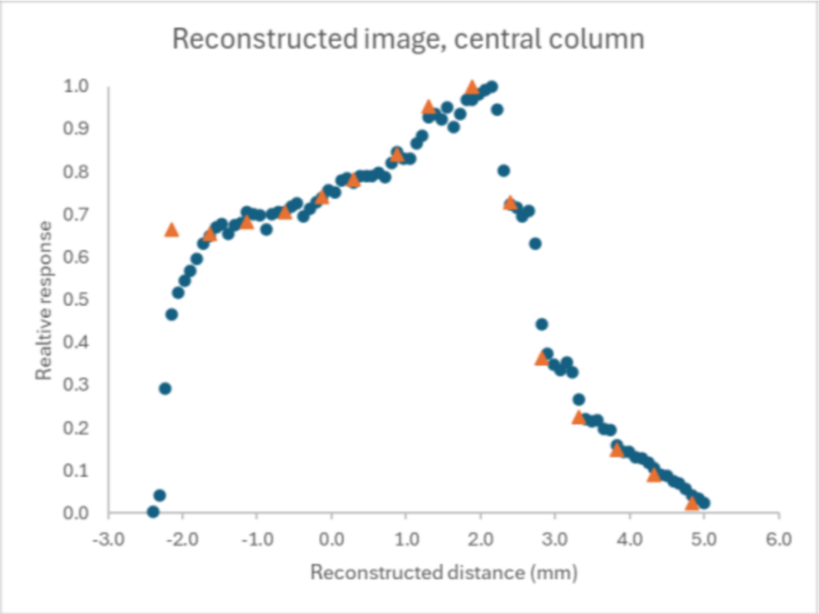




Infinite bandwidth

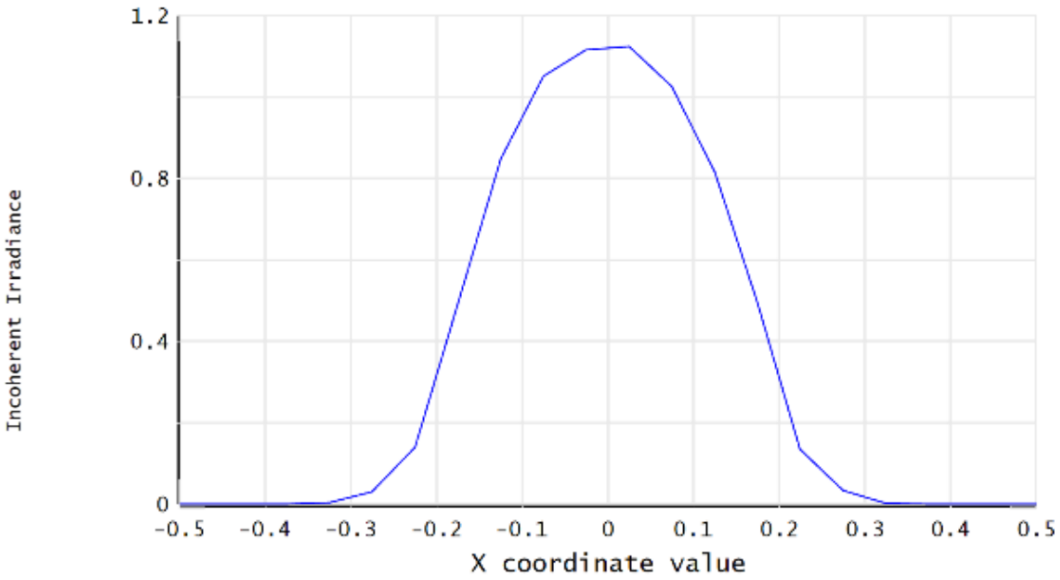
Optical Reconstruction

Central column reconstruction

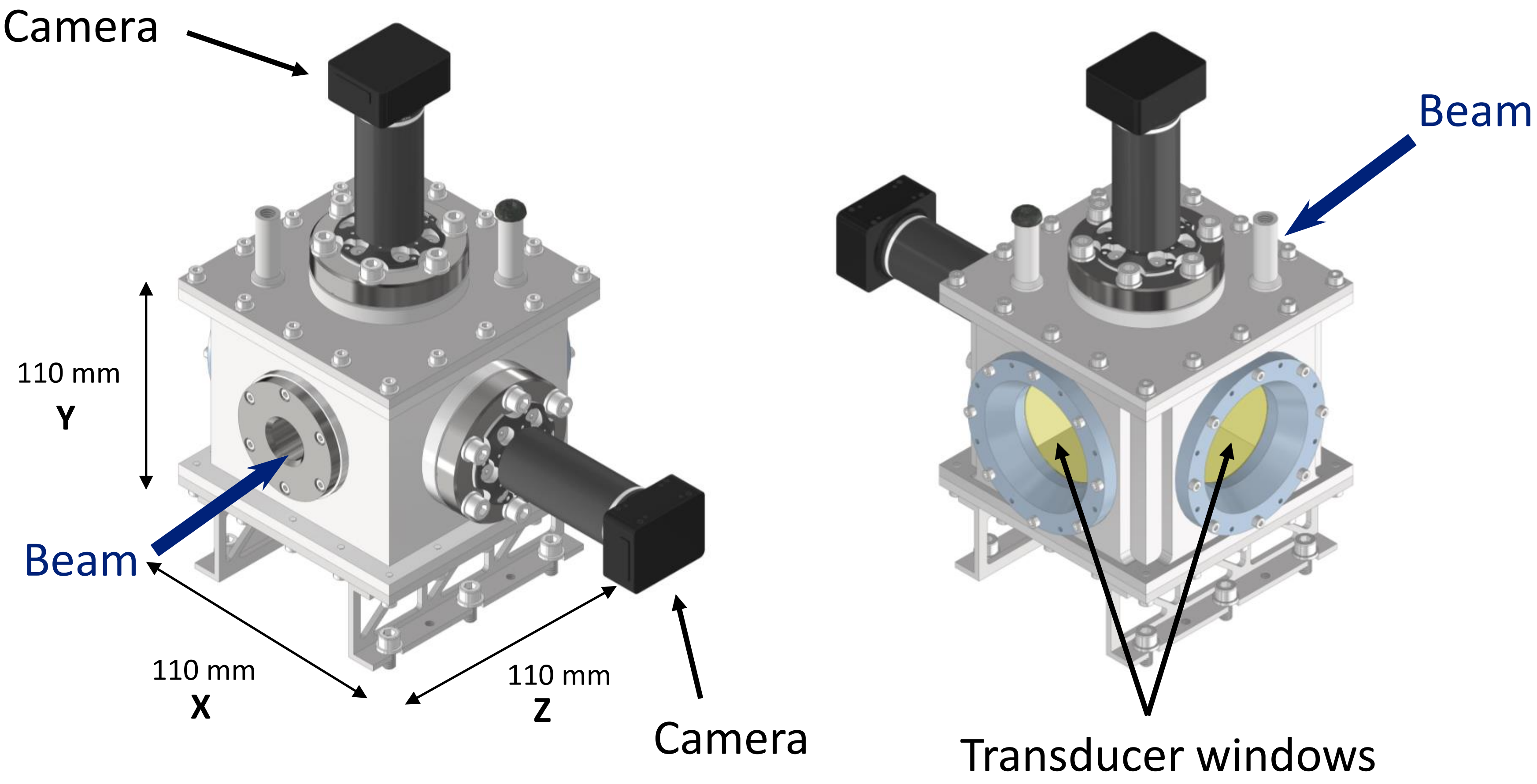


- Reconstructed irradiance through the central column
- Relative Geant4 energy depositions

Reconstruction across a row near the Bragg peak



Proposed Instrumentation
The SmartPhantom



Conclusion

- LhARA aims to explore radiobiology in new regimens
- Dose mapping possible with ion-acoustics & liquid scintillator
- Iterative time-reversal algorithm: 3D reconstruction
- Calibrated pulse-to-pulse 3D dose mapping possible with the proposed instrumentation

Experimental results in a few months!

Thank you!