Ionacoustic Work Package

Collaboration Meeting
Glasgow
20th Sept 2023

LION Beamline

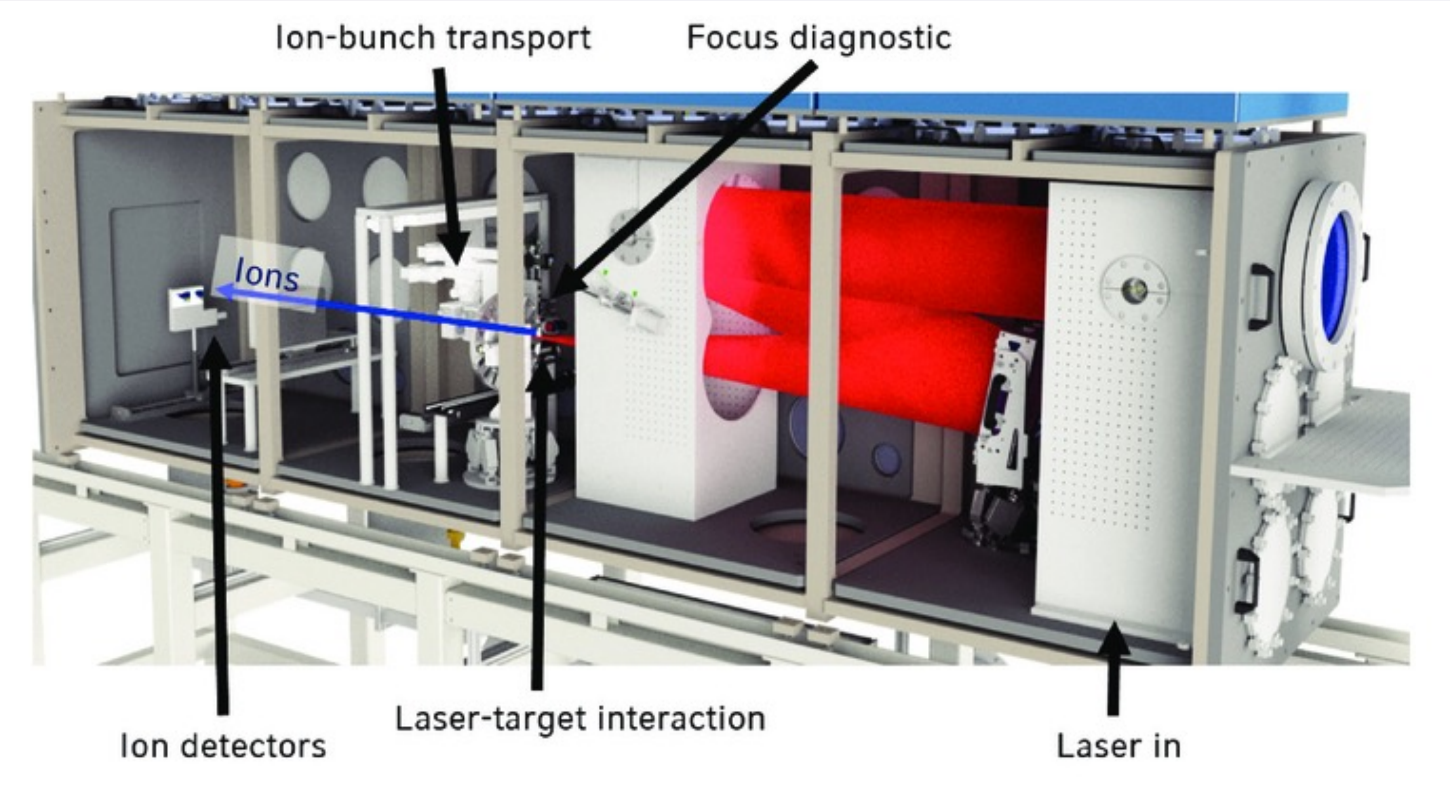


Figure 1: Rendered CAD model of the LION beamline [1].

Simulation Pipeline

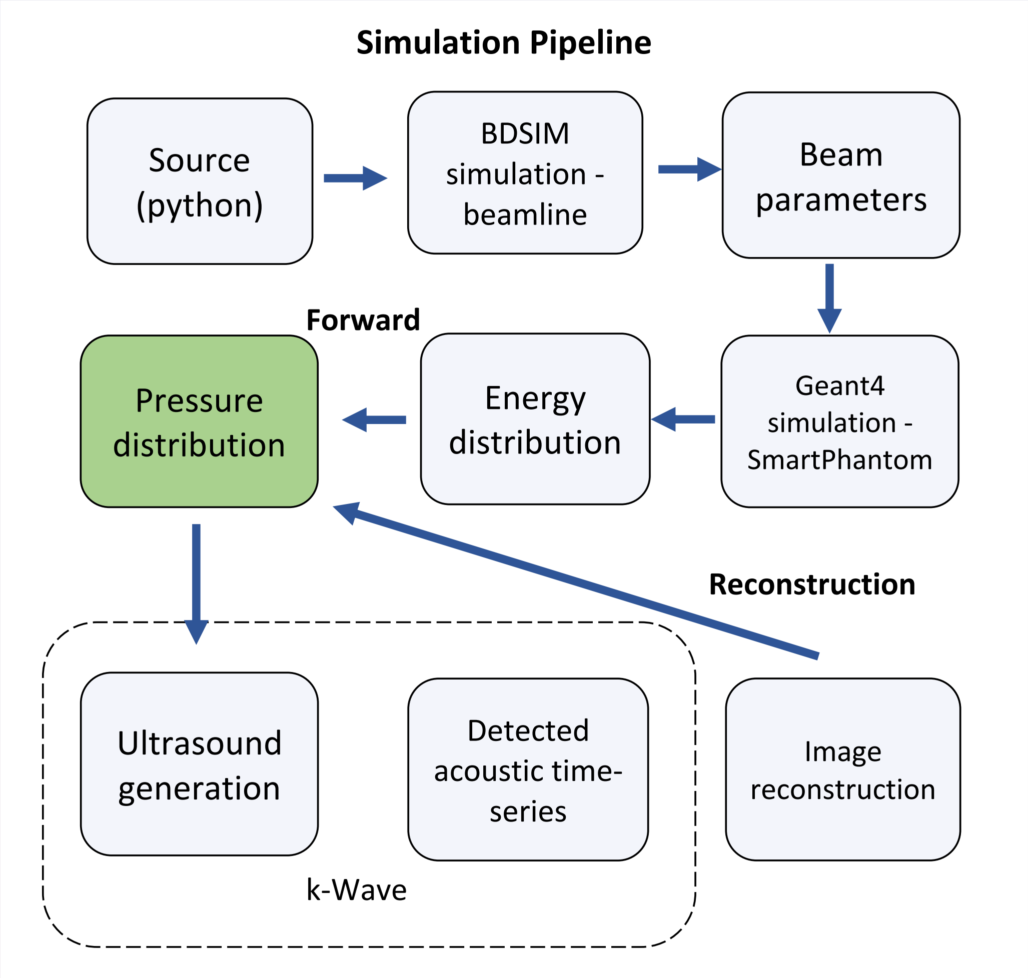


Figure 2: Simulation pipeline.

Python

Source

Energy Distribution

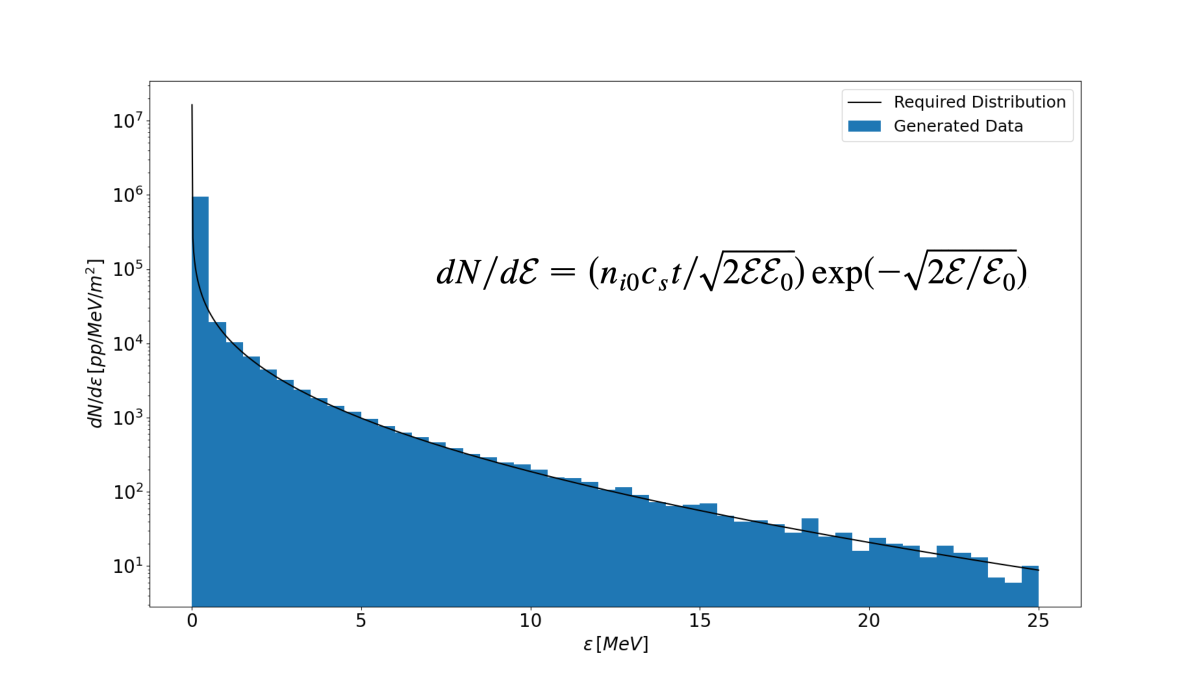


Figure 3: Simulated energy distribution [2].

Angular Distribution - flat

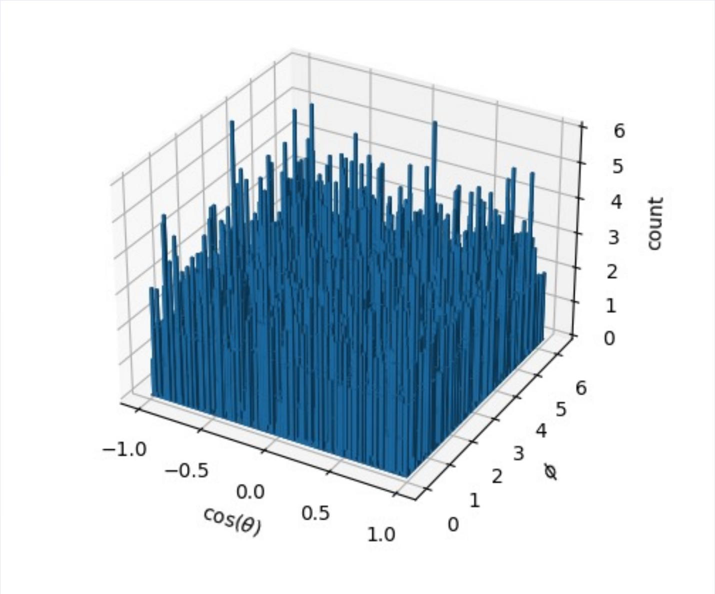


Figure 4: Simulated angular distribution.

BDSIM

LION beamline - BDSIM

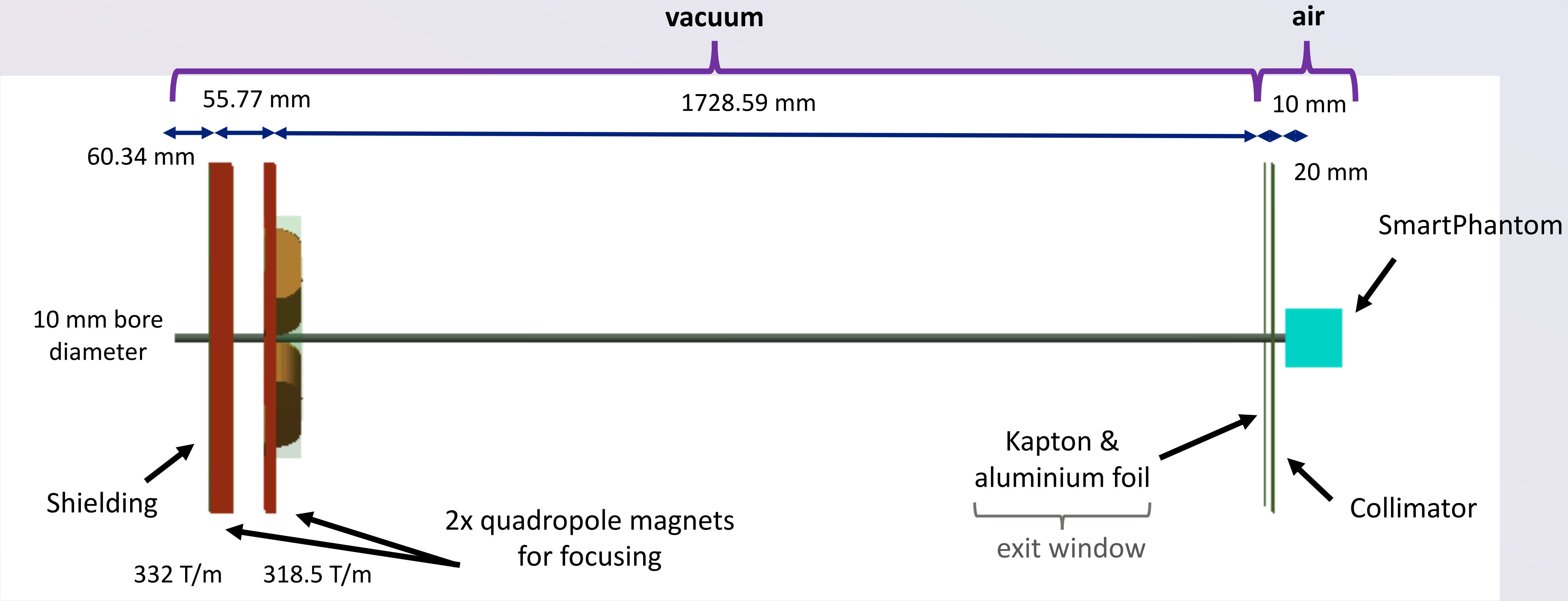


Figure 5: Side-on view of LION beamline in BDSIM.

Particle Depth

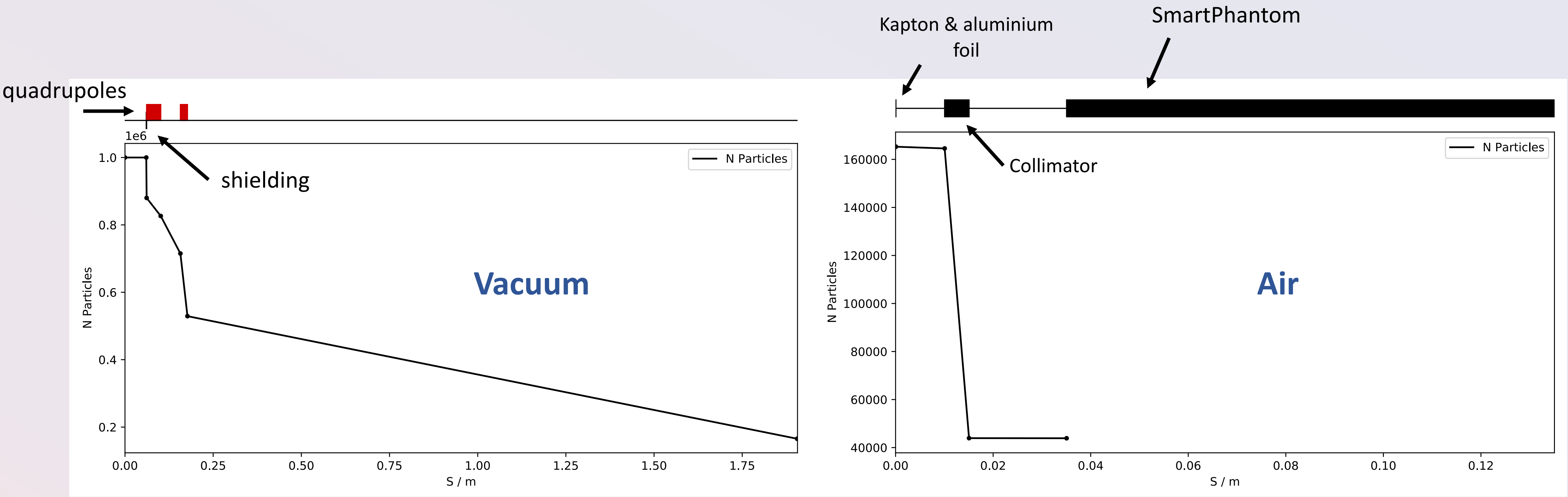


Figure 6: Particle depletion through the vacuum (left) and air (right) section of the simulated beamline.

Exit Window

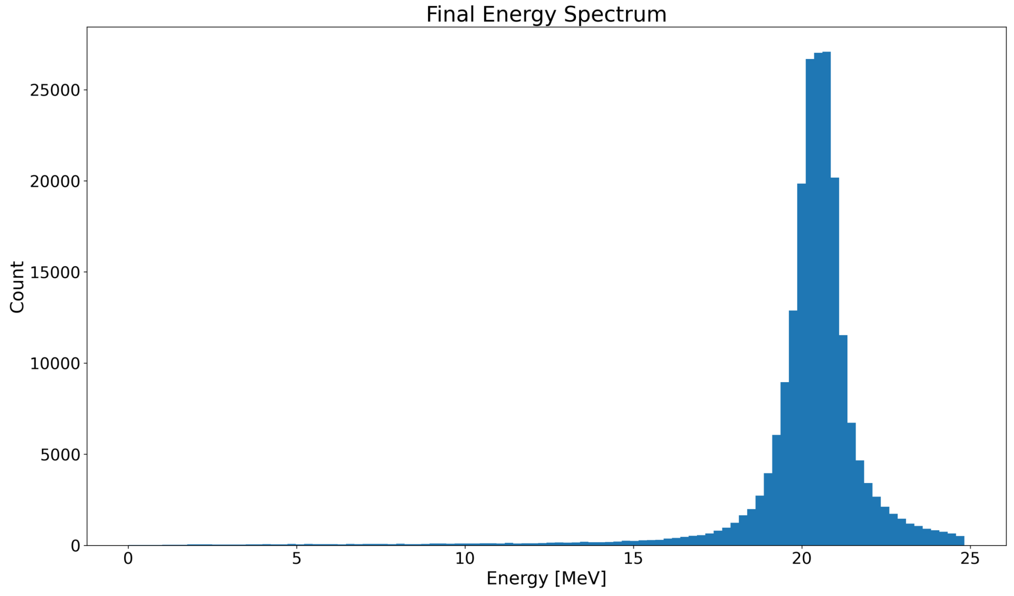


Figure 7: Energy spectrum at the exit window.

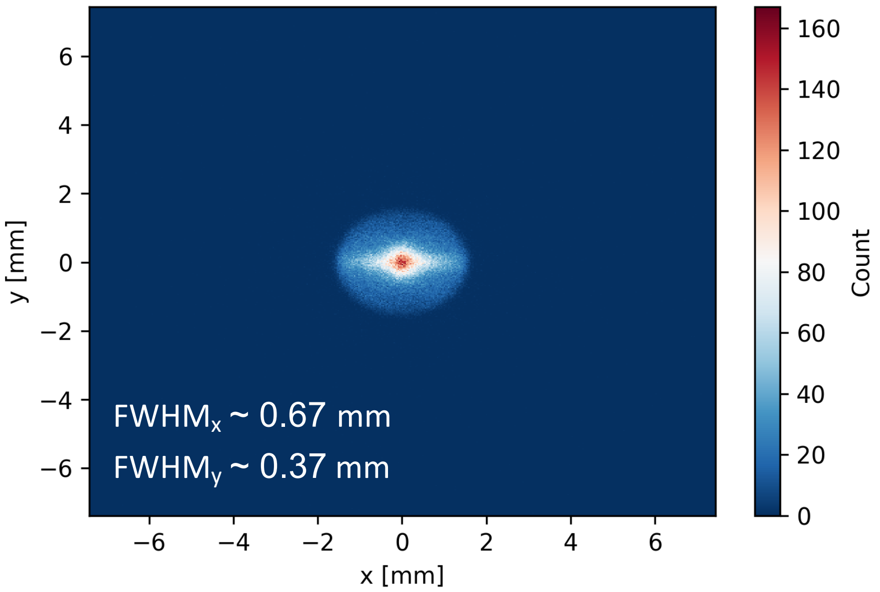


Figure 8: Spot size at the exit window.

Geant4

SmartPhantom

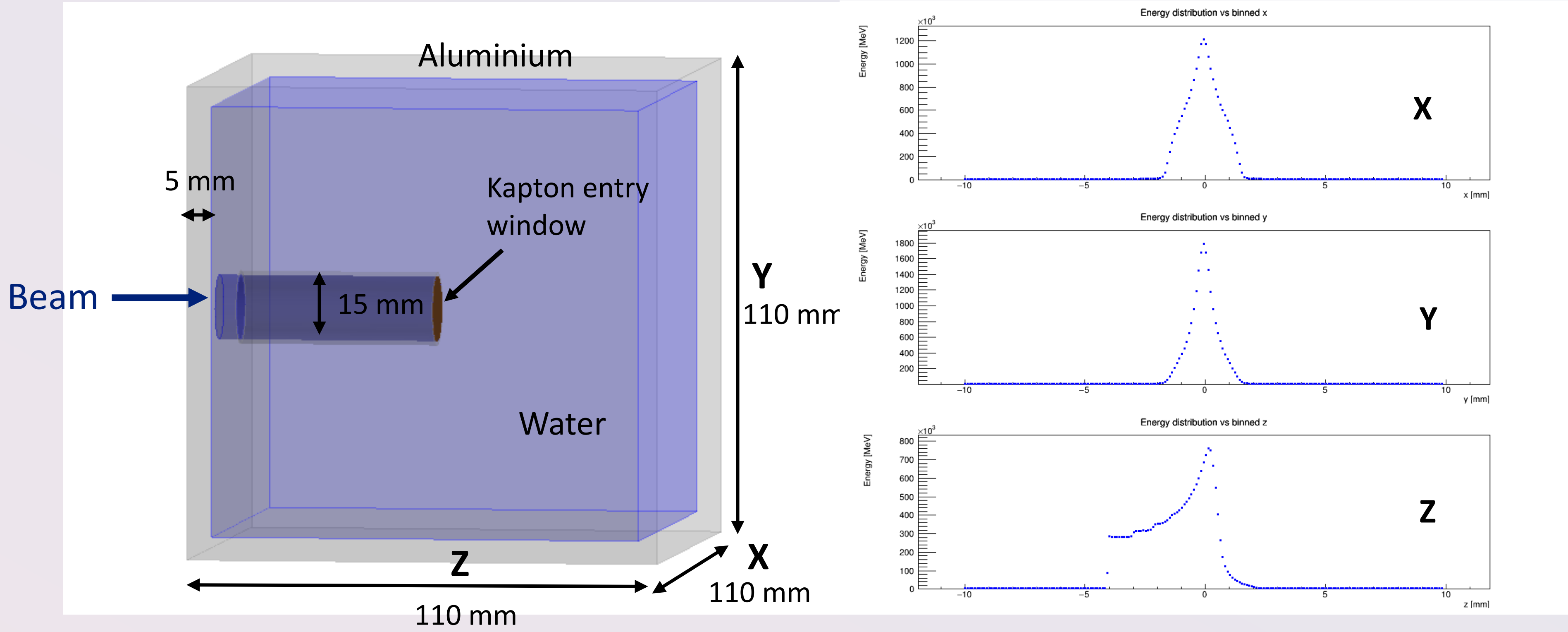


Figure 9: Geant4 simulation of the SmartPhantom (left) and binned energy depositions along the three axis (0.1 mm voxels).

K-Wave

Pressure Distribution & Acoustic Sensor

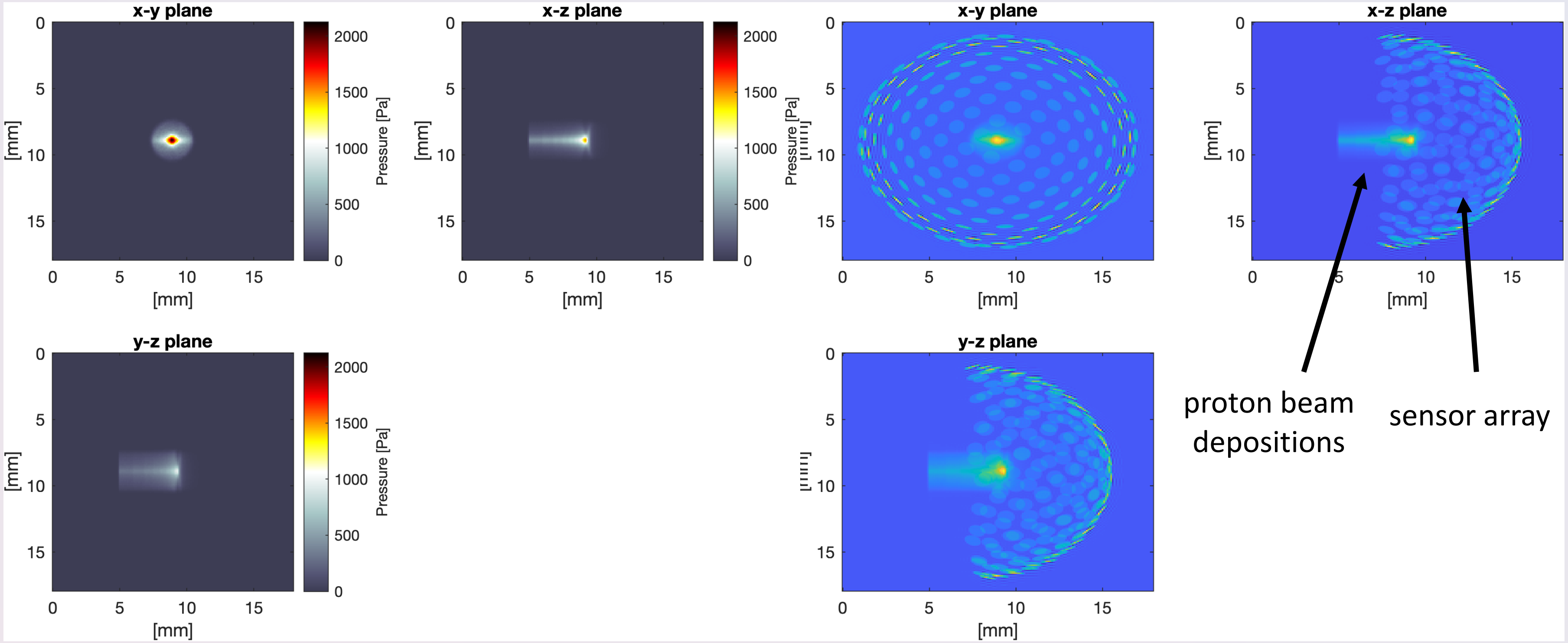


Figure 10: Source pressure distribution (left) and sensor location and geometry with respect to the beam depositions (right).

Image Reconstruction

Iterative Time-Reversal

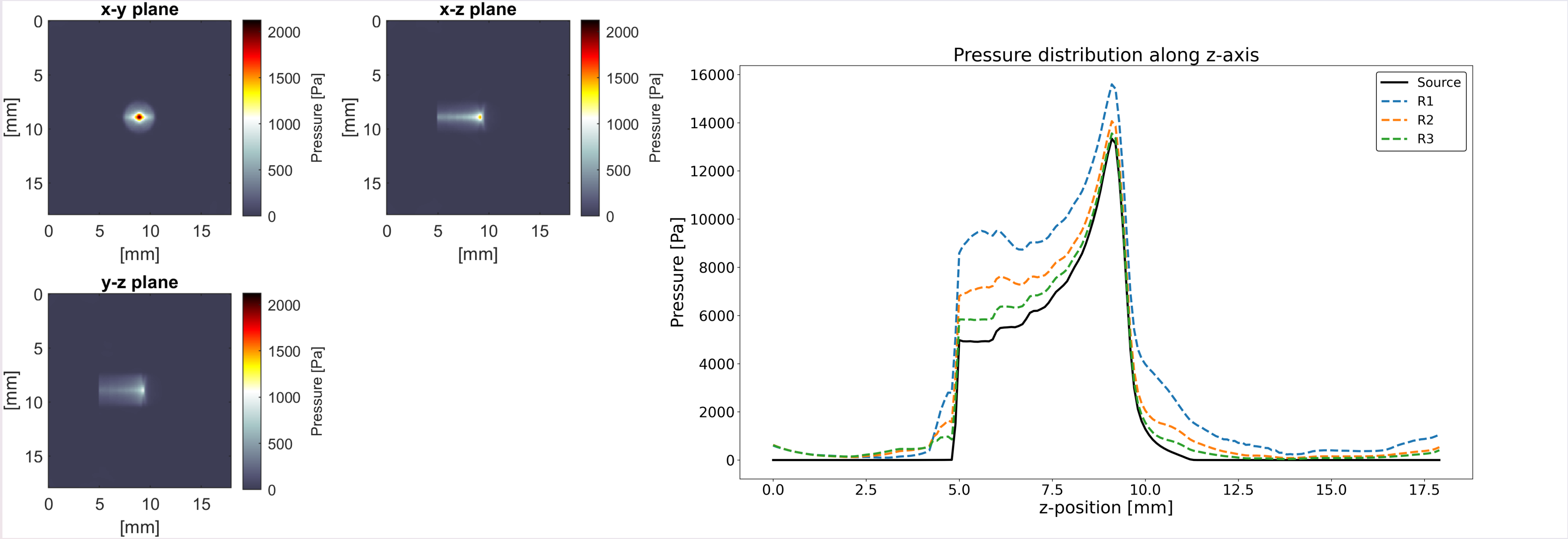


Figure 11: Reconstructed pressure distribution using an iterative time reversal algorithm.

SciFi Planes

Scintillating Fibre Planes

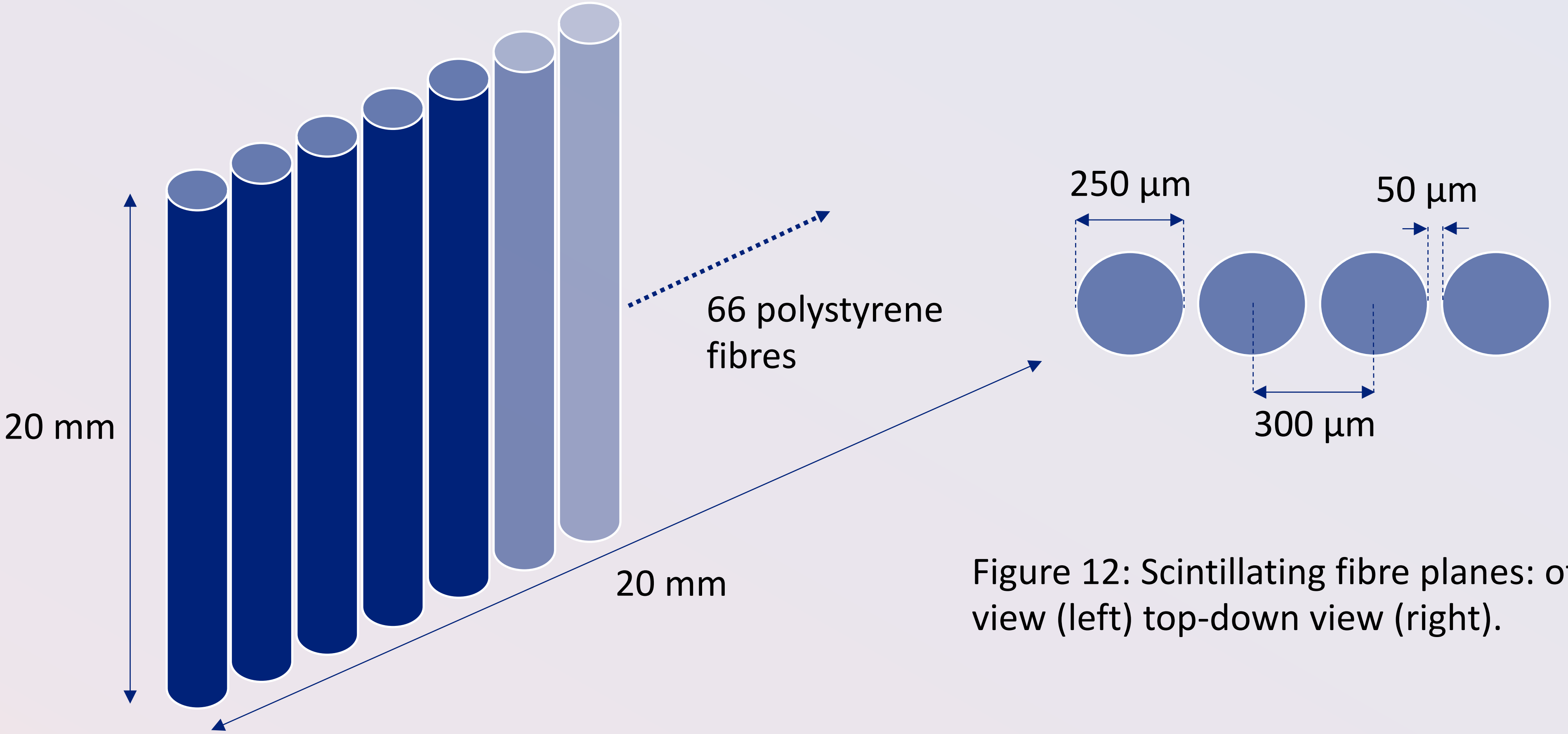


Figure 12: Scintillating fibre planes: off-axis view (left) top-down view (right).

Scintillating Fibre Planes

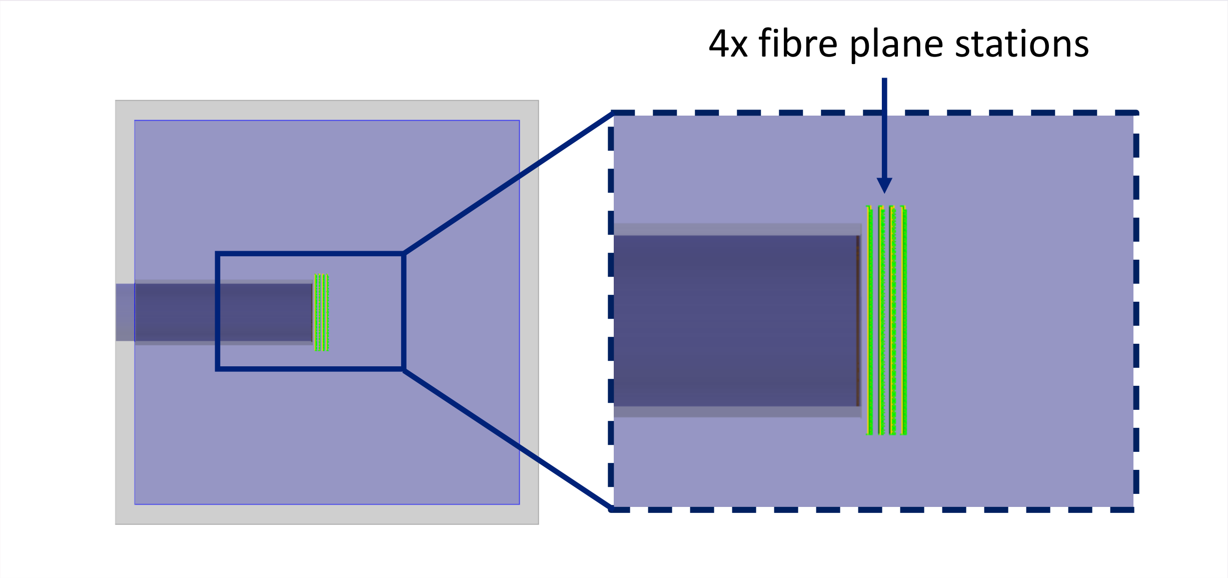


Figure 13: Scintillating fibre plane stations (green) in the Geant4 simulation geometry, Off-axis view (left), side-on view (right).

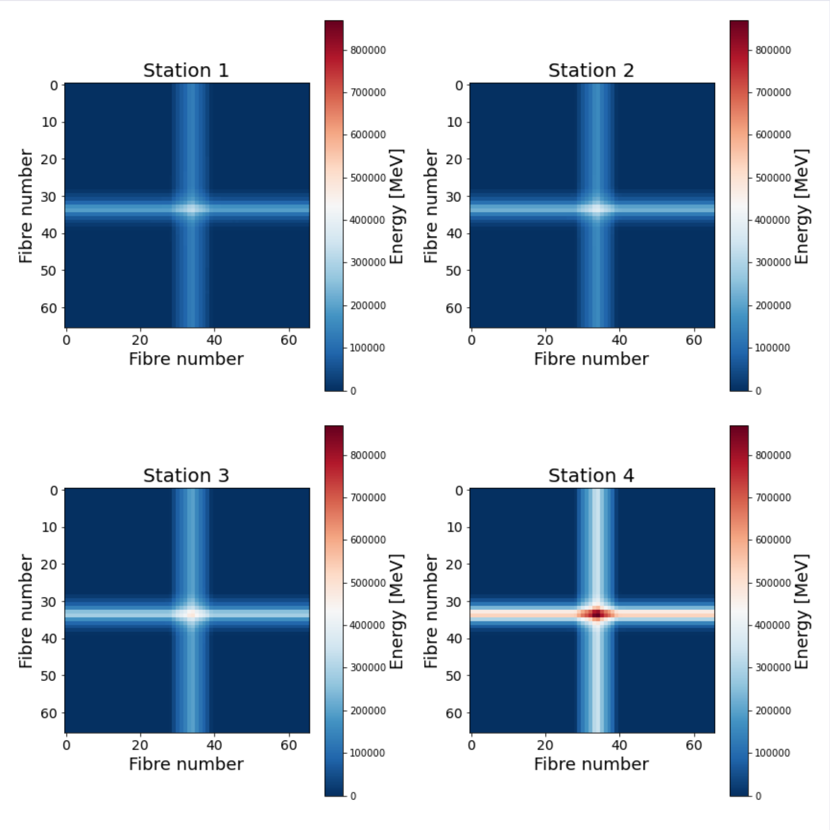


Figure 14: 2D energy distribution reconstruction at each SciFi station.

Depth-Dose Reconstruction

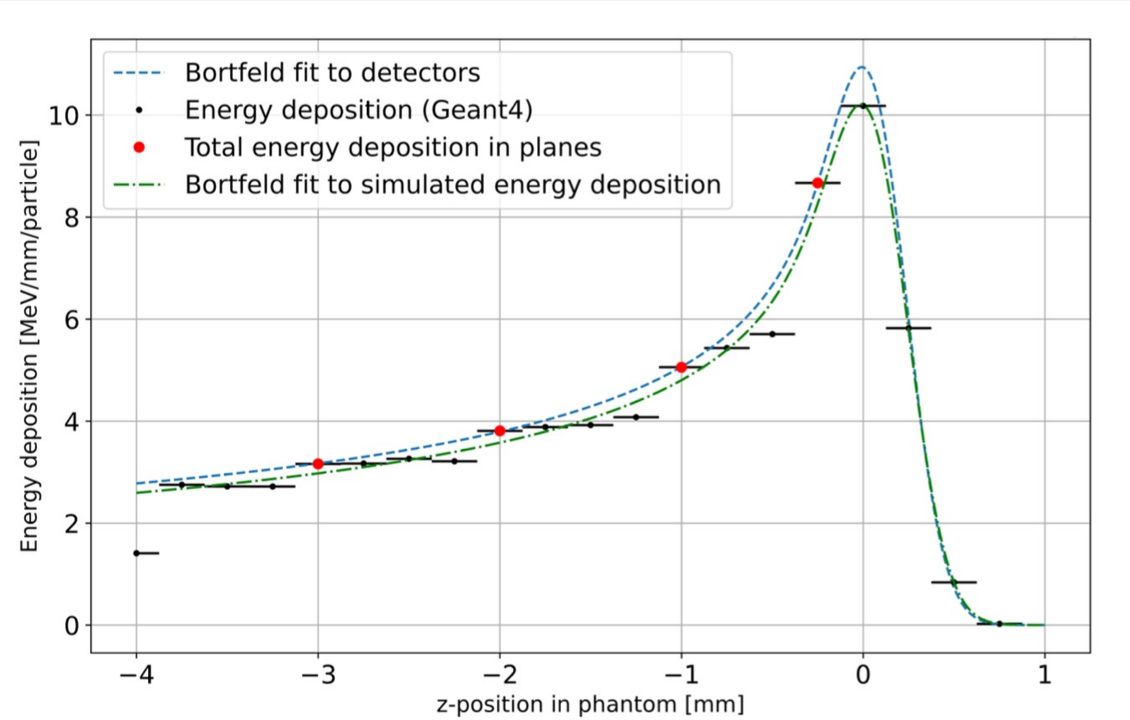


Figure 15: Histogram of the energy deposited by the proton beam in the water phantom as a function of position (taken from Anthea's & Vania's thesis).

Bortfeld approximation:

$$D(z) \approx \begin{cases} \hat{D}(z) & for\ z < R_0 - 10\sigma \\ D(z) & for\ R_0 - 10\sigma \leq z \leq R_0 + 5\sigma \\ 0 & otherwise. \end{cases}$$

$$\hat{D}_{H_20}(z) = \frac{\Phi_0}{1 + 0.012R_0}\left[17.93(R_0 - z)^{-0.435} + (0.444 + 31.7\epsilon/R_0)(R_0 - z)^{0.565}\right.$$

$$D_{H_20}(z) = \Phi_0 \frac{e^{\frac{-(R_0-z)^2}{4\sigma^2}}\sigma^{0.565}}{1 + 0.012R_0} \times \left[11.26\sigma^{-1}\mathfrak{D}_{-0.565}\left(-\frac{R_0 - z}{\sigma}\right) + (0.157 + 11.26\epsilon/R_0)\mathfrak{D}_{-1.565}\left(-\frac{R_0 - z}{\sigma}\right)\right.$$

3D Reconstruction with SciFi Planes

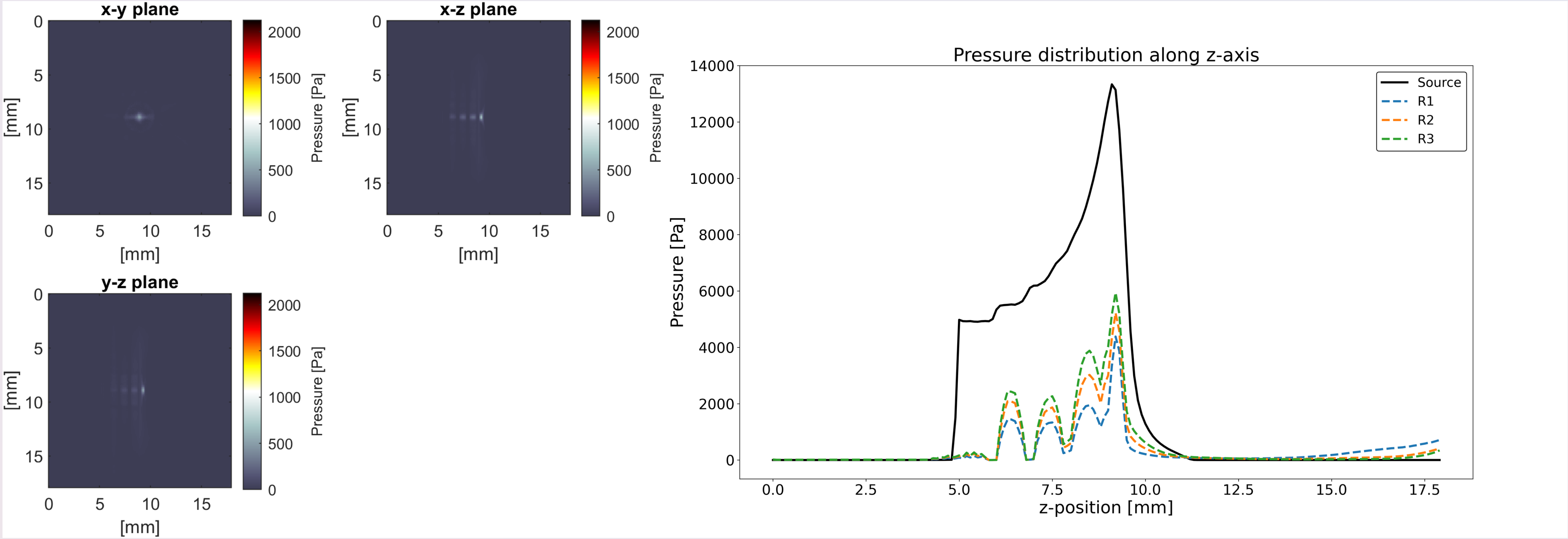


Figure 16: Reconstructed pressure distribution using an iterative time reversal algorithm , with 4 stations of scintillating fibre planes.

Scintillating Fibre Planes: Beam Divergence

Average beam divergence = 0.055 radians

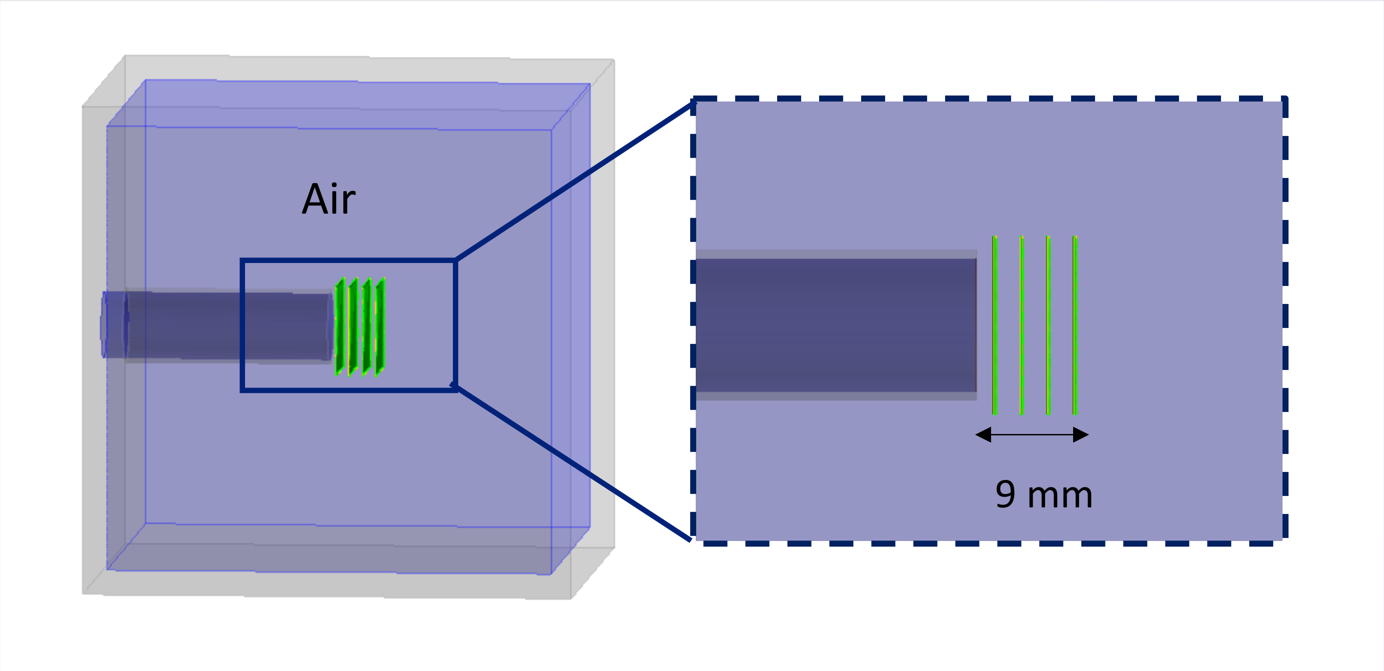


Figure 17: Scintillating fibre plane stations (green) in the Geant4 simulation geometry. Off-axis view (left), side-on view (right).

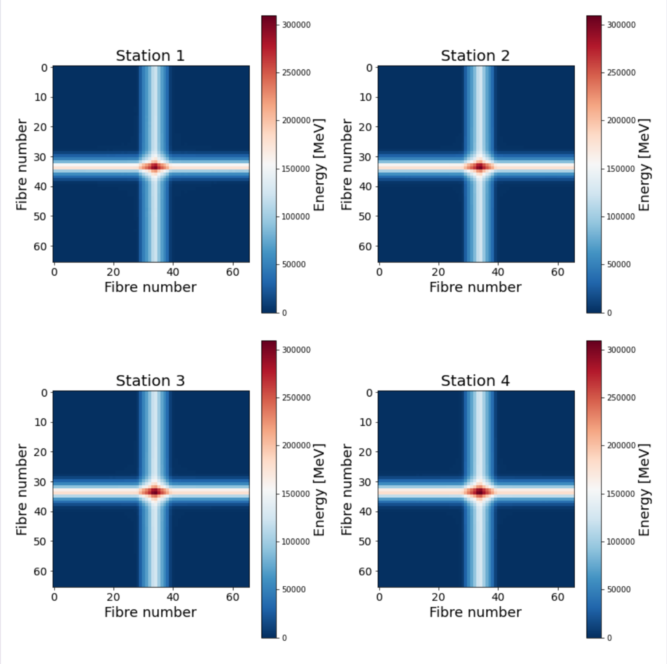


Figure 18: 2D energy distribution reconstruction at each SciFi station.

Scintillating Fibre Planes: Construction

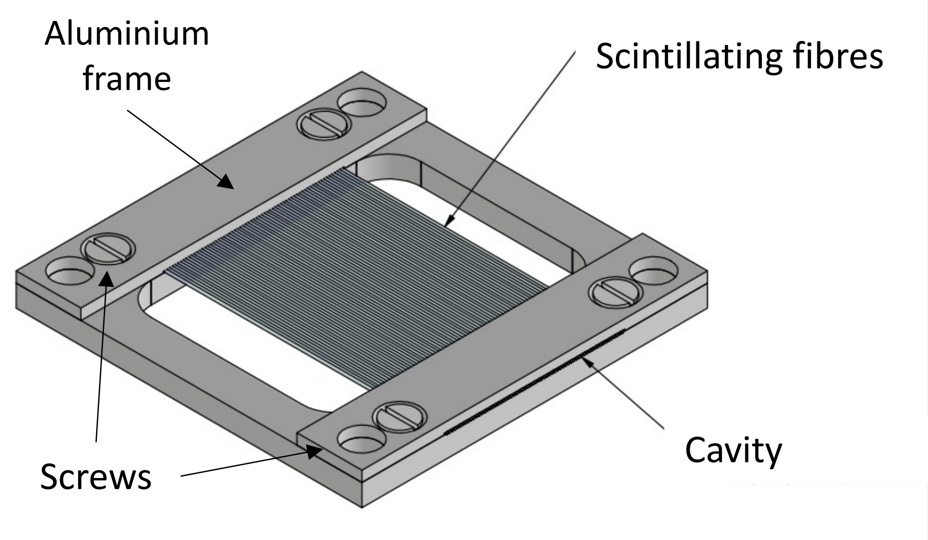


Figure 19: Fibre plane CAD design.

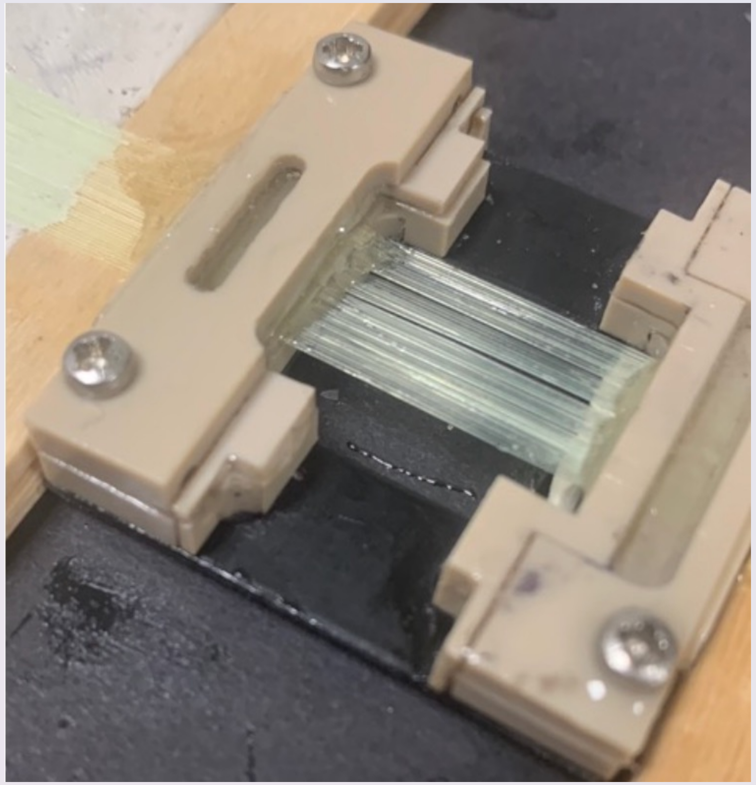


Figure 20: Fibre plane manufacturing (taken from Anthea's & Vania's thesis).

Liquid Scintillator

Ultima Gold XR

Liquid scintillator : Water
50 : 50

Component	Name	Composition [weight %]
Solvents	di-isopropyl naphthalene (DIN)	40-60
	ethoxylated alkylphenol	20-40
	bis(2-ethylhexyl) hydrogen phosphate	2.5-10
	triethyl phosphate	2.5-10
	sodium di-octylsulphosuccinate	2.5-10
	3,6-dimethyl-4octyne-3,6-diol	1.0-2.5
Scintillators	2,5 diphenyloxazole (PPO)	0-1.0
	1,4-bis (2-methylstyryl)-benzene (Bis-MSB)	0-1.0

Figure 21: Chemical composition of the liquid scintillator.

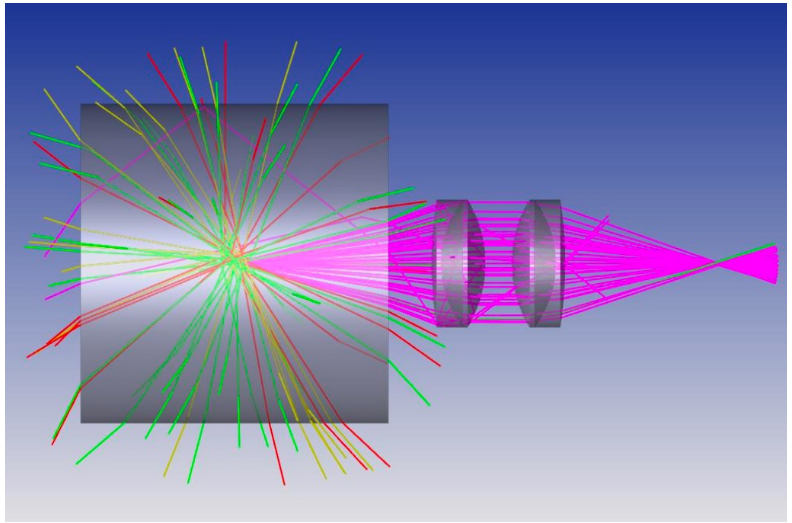


Figure 22: Liquid scintillator set up (taken from Peter Hobson’s slides).

Fluorescent Dye Testing

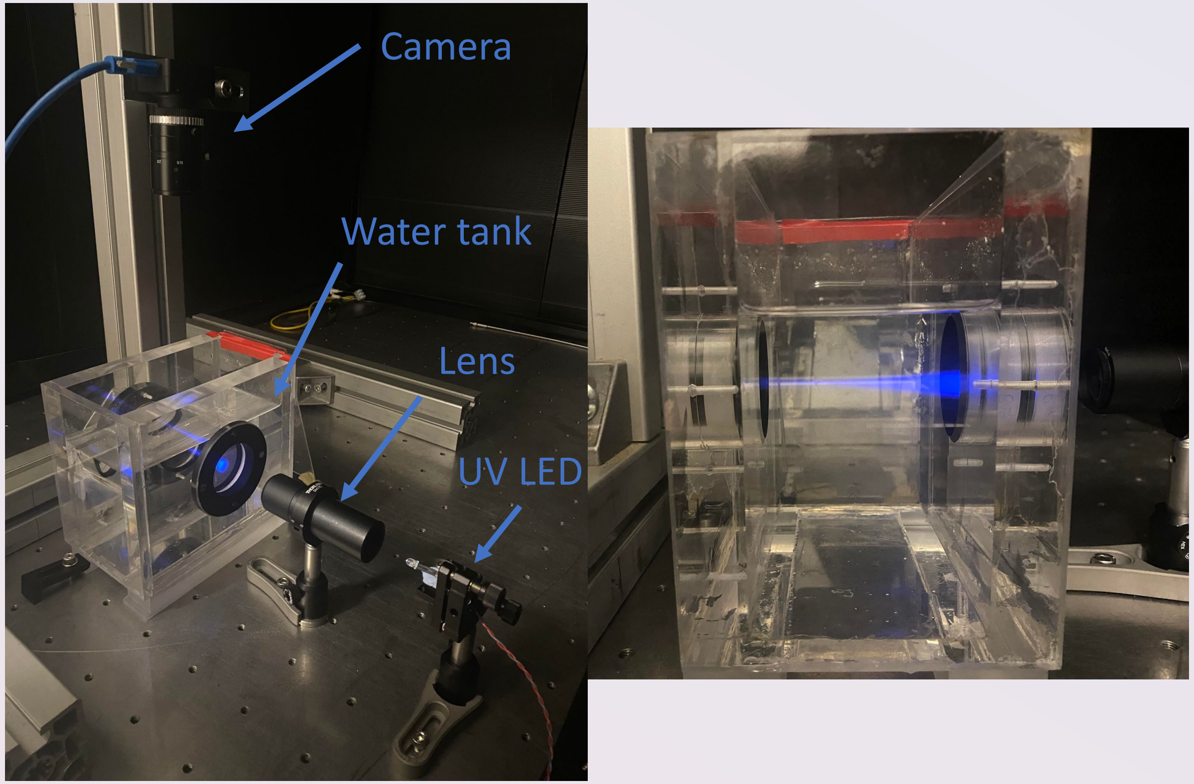


Figure 23: Fluorescent dye experimental set up: angled view (left), cross-section view (right).

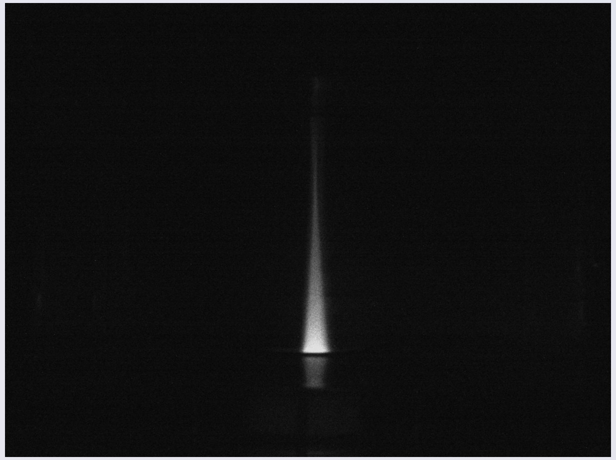


Figure 24: Captured image in grayscale.

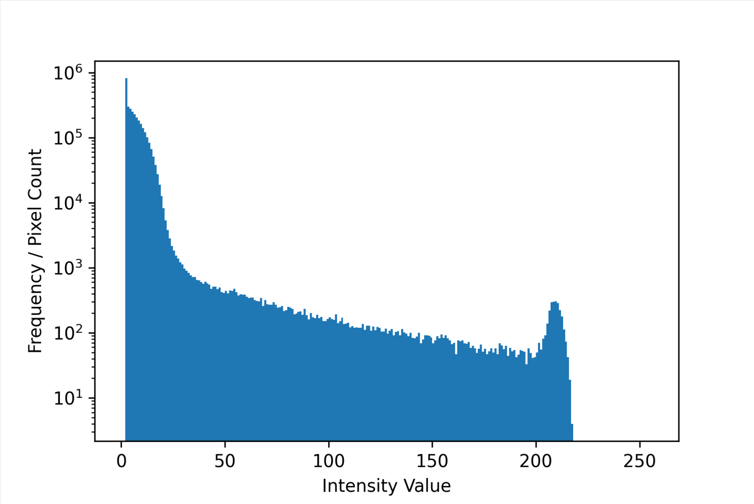
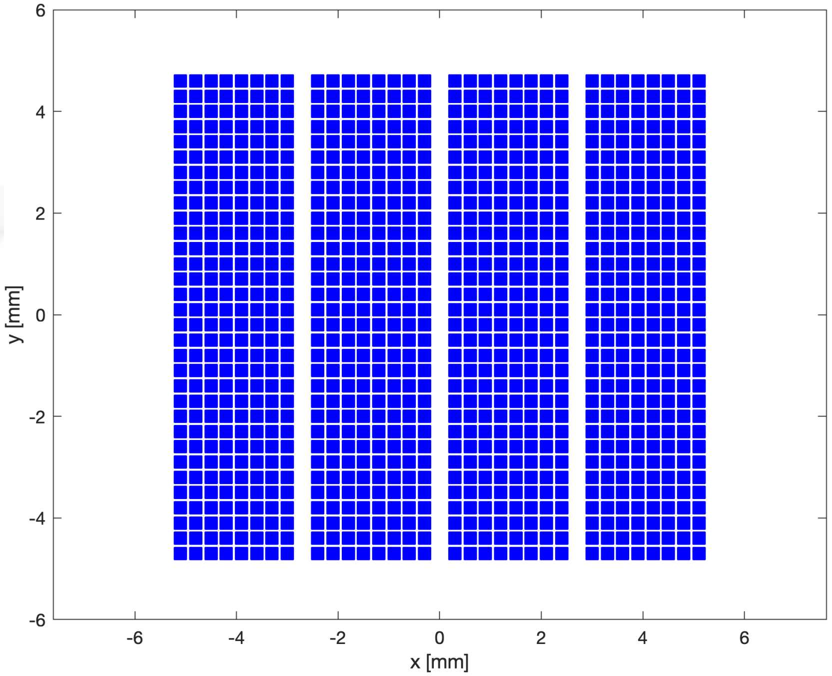


Figure 25: Pixel intensity histogram.

Acoustic Transducer

Verasonics Matrix Array



Specifications for Vantage Volume Imaging Matrix Array Transducers

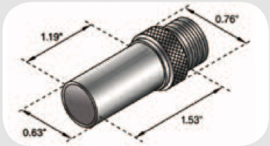
	3 MHz	8 MHz
Center Frequency	3.5 MHz	7.5 MHz
Bandwidth	60%	60%
Elements	1024 (32x32)	1024 (32x32)
Pitch	0.3 mm	0.3 mm
Elevation Aperture	12x14mm	12x14mm
Cable Length	Main cable = 1m; sub cables = 1m	Main cable = 1m; sub cables = 1m
Compatibility	Vantage 256	Vantage 256
Verasonics Part #	P01920	P01921

Figure 26: Matrix array shape (left), element configuration (middle) and detailed specifications (right) [3].

Phantom Design

Requirements

1. Elongated entrance window
2. Fill with/remove deionised water: entry tube
3. Ability to insert & remove SciFi detectors
4. Aluminium structure: no interaction with liquid scintillator
5. Black Kapton foil
6. Black interior: anodising
7. Two cameras placed perpendicular to each other
8. Matrix array placed at two (perpendicular) locations
9. Black Kapton foil & acoustic matching gel for matrix array
10. One fixed single element transducer (Olympus V311-SU [4]): reference



Current Design

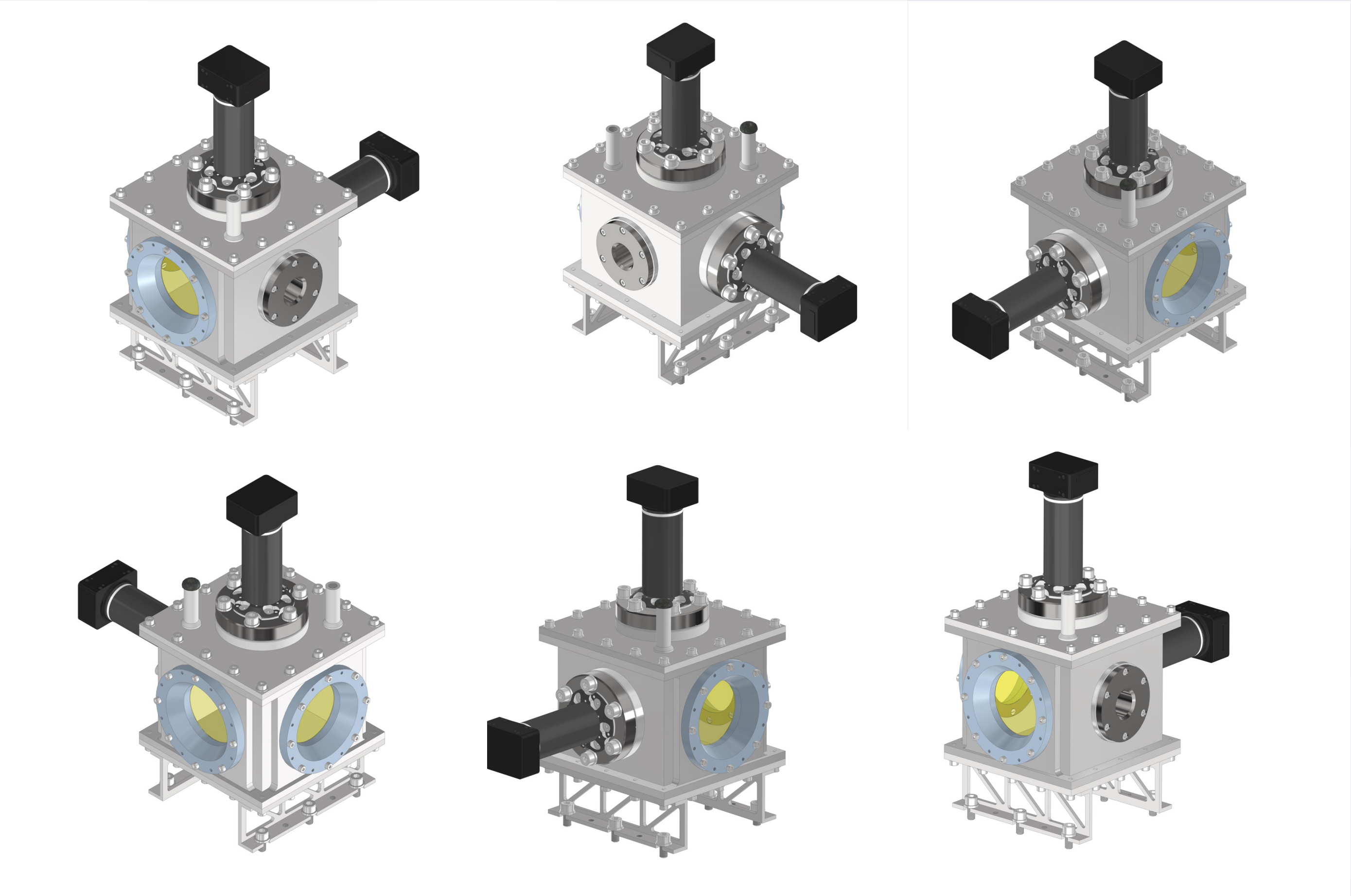


Figure 27: SmartPhantom design looked at different angles.

Current Design

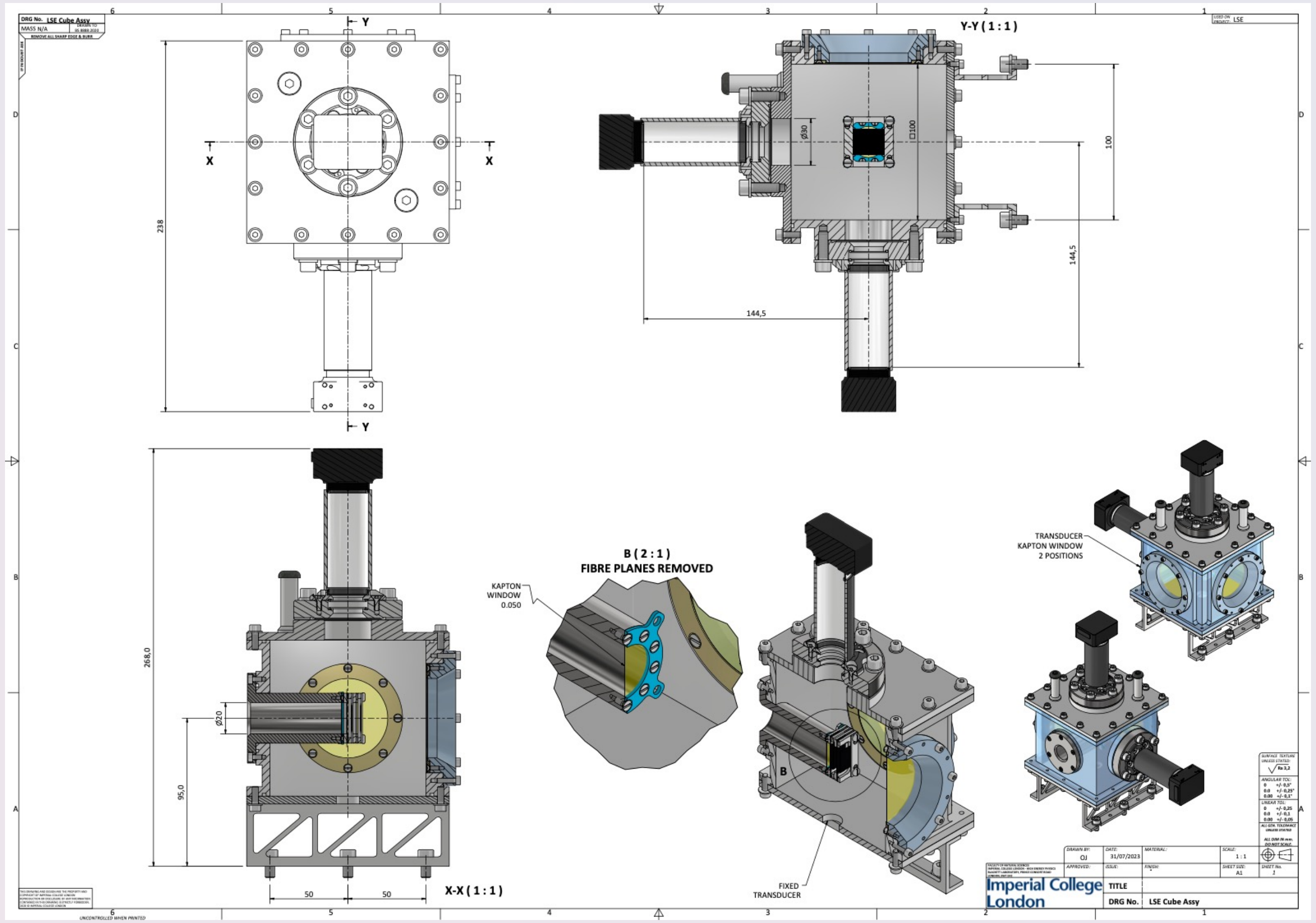


Figure 28: SmartPhantom cross-sections.

Next Steps

Next Steps

1. SciFi detector construction & quality assurance tests
2. Liquid scintillator
3. Reconstruction with matrix array
4. SmartPhantom manufacturing
5. Transducer mount & testing
6. SmartPhantom at a proton beam
7. SmartPhantom at the LION beamline

(Items 1–2: Proton beam testing)

References

[1] Balling, F., Hartmann, J., Rösch, T., Tischendorf, L., Doyle, L., Berndl, M., Gerlach, S., Parodi, K. and Schreiber, J. (2022). LASER-DRIVEN ION ACCELERATION BEAMLINE AT THE CENTRE FOR ADVANCED LASER APPLICATIONS. *Physica Medica*, 94, p.S66. doi:https://doi.org/10.1016/s1120-1797(22)01581-2.

[2] Mora P. Plasma expansion into a vacuum. Phys Rev Lett. 2003 May 9;90(18):185002. doi: 10.1103/PhysRevLett.90.185002. Epub 2003 May 7. PMID: 12786012

[3] Vega, M. (2018). *Matrix Arrays*. [online] Verasonics. Available at: https://verasonics.com/matrix-array/ [Accessed 15 Sep. 2023].

[4] Panametrics ® Ultrasonic Transducers. (n.d.). Available at: http://www.materialevaluation.gr/pdf/Flaw_Detectors/Transducers_And_Probes/UltraSonic_Transducers_Pana_UT_EN_201603.pdf [Accessed 15 Sep. 2023].

Thank you!