ICR The Institute of Cancer Research

in partnership with The ROYAL MARSDEN NHS Foundation Trust

WP4: Ion-acoustic dose mapping

Maria Maxouti, Josie McGarrigle, Anthea MacIntosh-LaRocque, Vania Lay, Yu Hu, Ben Cox, Ben Smart, Colin Whyte, Kenneth Long, Emma Harris, Jeff Bamber

LhARA Laser-hybrid Accelerator for Radiobiological Applications

CCAP Centre for the Clinical Application of Particles

Imperial College London

UCL

UKRI Science and Technology Facilities Council

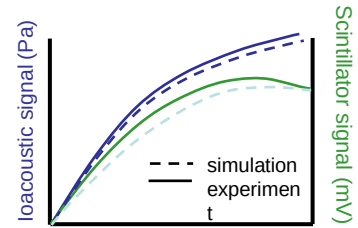
WP4: Ion-acoustic dose mapping

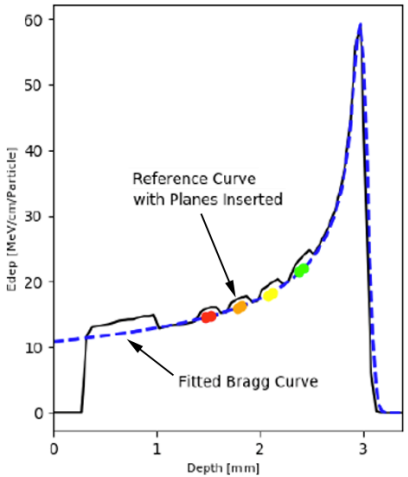
2 Years

- Validated models for the simulation of dose and ion-acoustic signals

GEANT4 A SIMULATION TOOLKIT

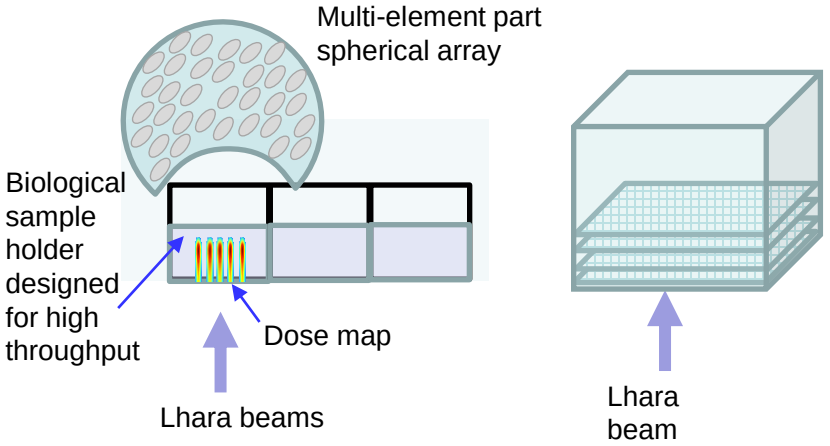
k-Wave A MATLAB toolbox for the time-domain simulation of acoustic wave fields





- Experimental testing/evaluation of initial components for ion-acoustic and scintillation systems.

5 years



- Ion-acoustic system for dose mapping on a pulse-by-pulse basis
- Smart phantom system for cross-calibration of dose/range estimation

- Validated models for the simulation of dose and ion-acoustic signals for LhARA
- Results from initial biology experiments

2-year Objectives,Tasks, Milestones

Objectives:

- The development of a Geant4 MC simulation of the forward model
- The development of a k-wave acoustic forward model

Tasks:

- The detailed design of a proof of principle experiment to be executed during the Preconstruction Phase of the project, identifying potential suppliers for components.
- Reports on progress towards above objectives.

Milestones:

- 18-month report: forward simulation of energy deposited in a water phantom (SmartPhantom) and deposited energy resolved in 4D.
- 24-month report: results of forward simulation and its use to optimise SmartPhantom performance to provide the power density spectrum as input to the acoustic model.

Agenda

1. ~~Jeff - Introduction, aims and objectives~~

2. Maria - Python ➔BDSIM ➔ Geant4 ➔k-Wave simulation and plans for future validation experiment at LMU

3. Jeff - Photoacoustic simulation experiment (work of MRes student, Yu Hu)

4. Jeff – Summing up of status

Preliminary photoacoustic “experimental simulation” – Yu Hu (MRes project)

Monte Carlo simulation

↓

3-D dose distribution

↓

Threshold and tessellate 3-D surface

↓

3-D printer to produce mould

↓

Optically absorbing gel phantom in the shape of the deposited dose distribution

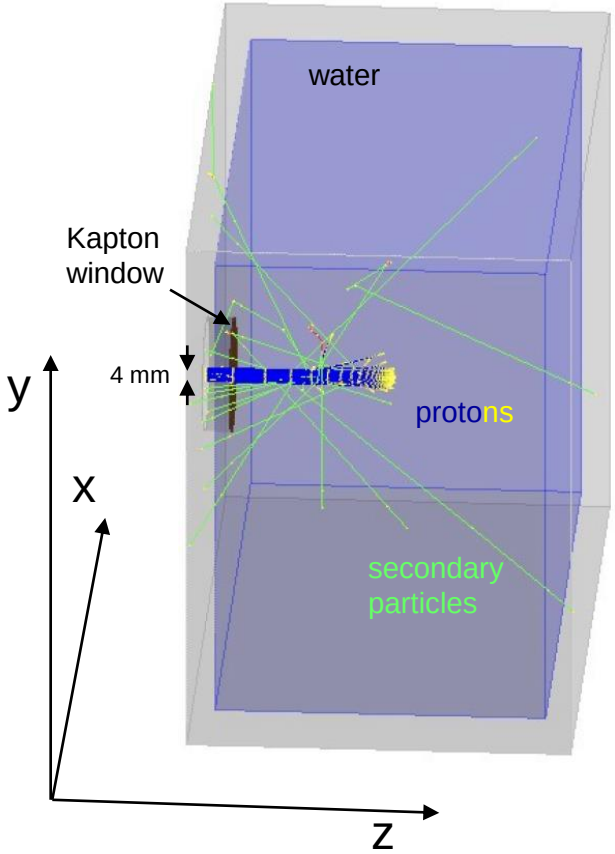
↓

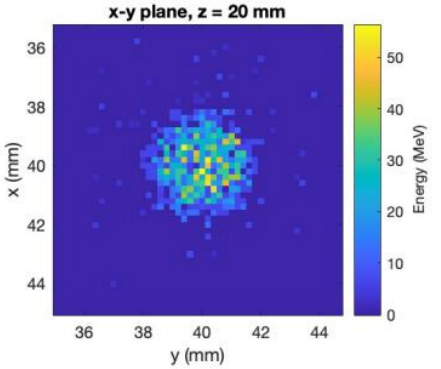
Image using the photoacoustic system (part-spherical cup, and part-circular ring, arrays) at ICR

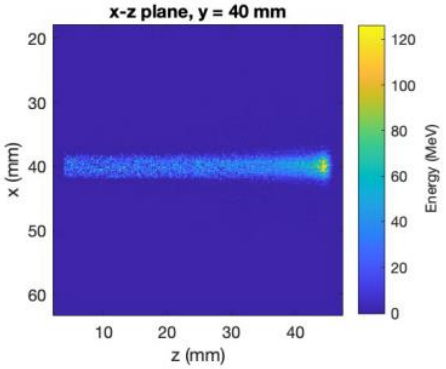
↓

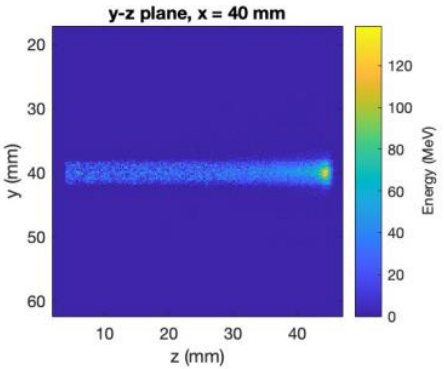
Evaluate received acoustic frequencies and reconstructed images in terms of analytical predictions and compare with k-Wave predictions

Geant4 – 20000 protons, 40 ns, 70 MeV

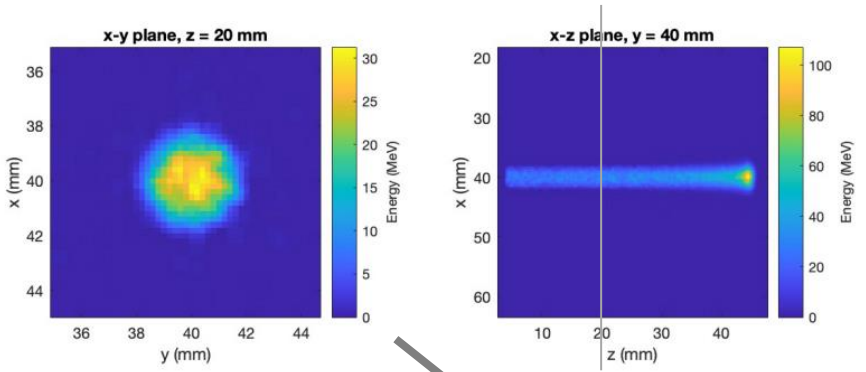


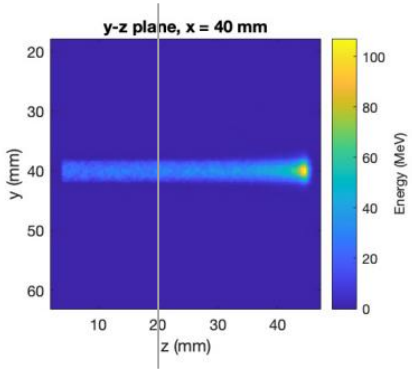


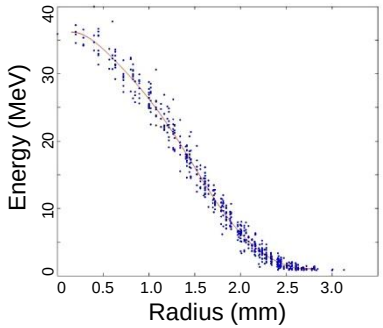




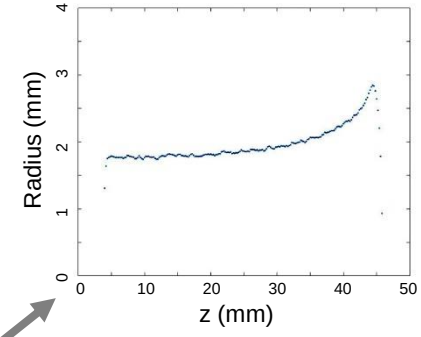
Further processing of deposited energy distribution

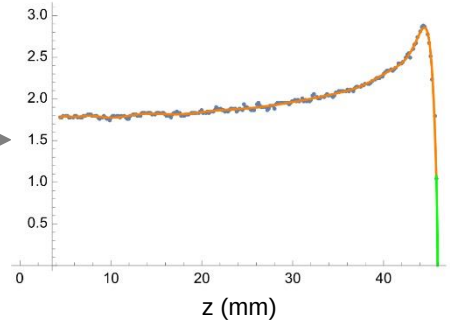




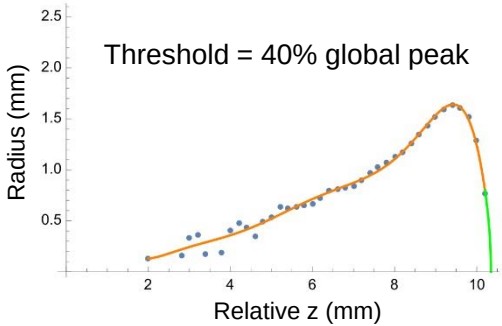


Threshold = 5% global peak



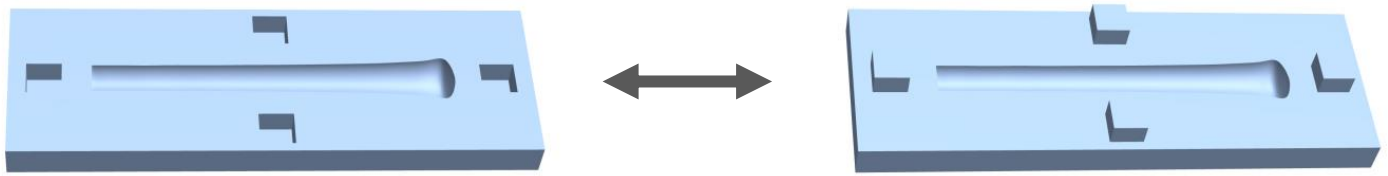


Threshold = 40% global peak

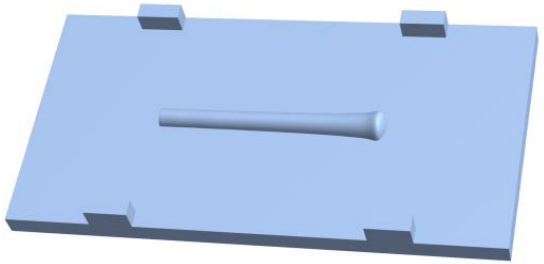


Mould designs for beam insert and background impression, from surface of revolution from radius-depth plots

Two halves of beam insert



Mould to create a hollow impression in the background



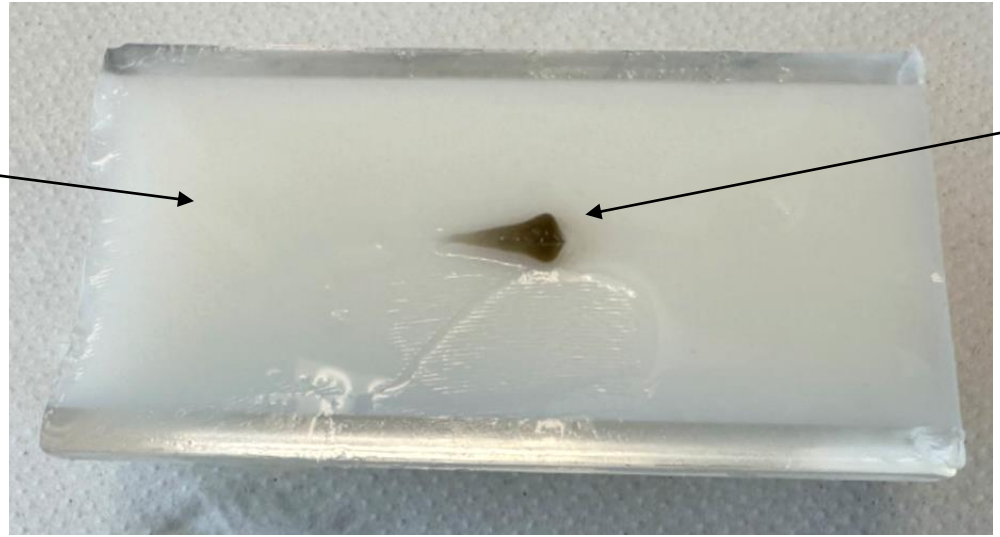
3D printed mould examples (5%)

Two halves of beam insert

Half the beam hollow impression in half the cylindrical background

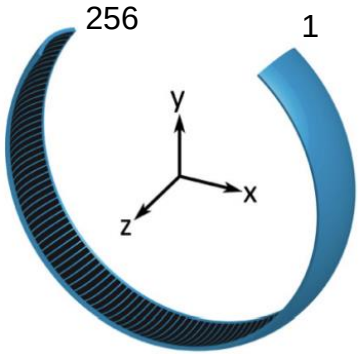
Half phantom example (40%)

Background (TiO^2 in gelatine)

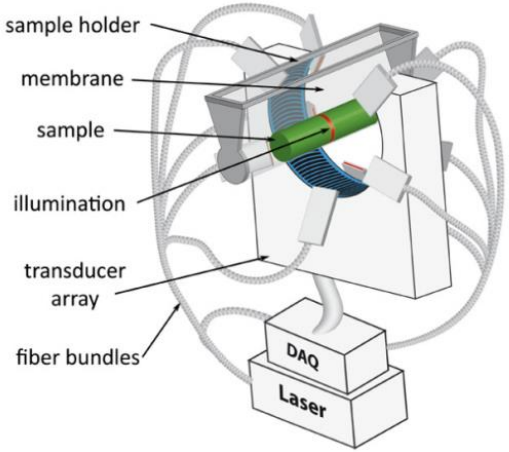


Beam insert at 40% threshold (India ink pigmented)

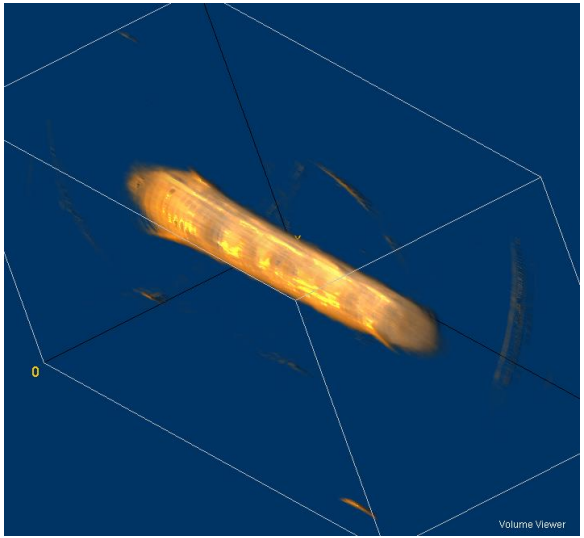
Photoacoustic imaging system



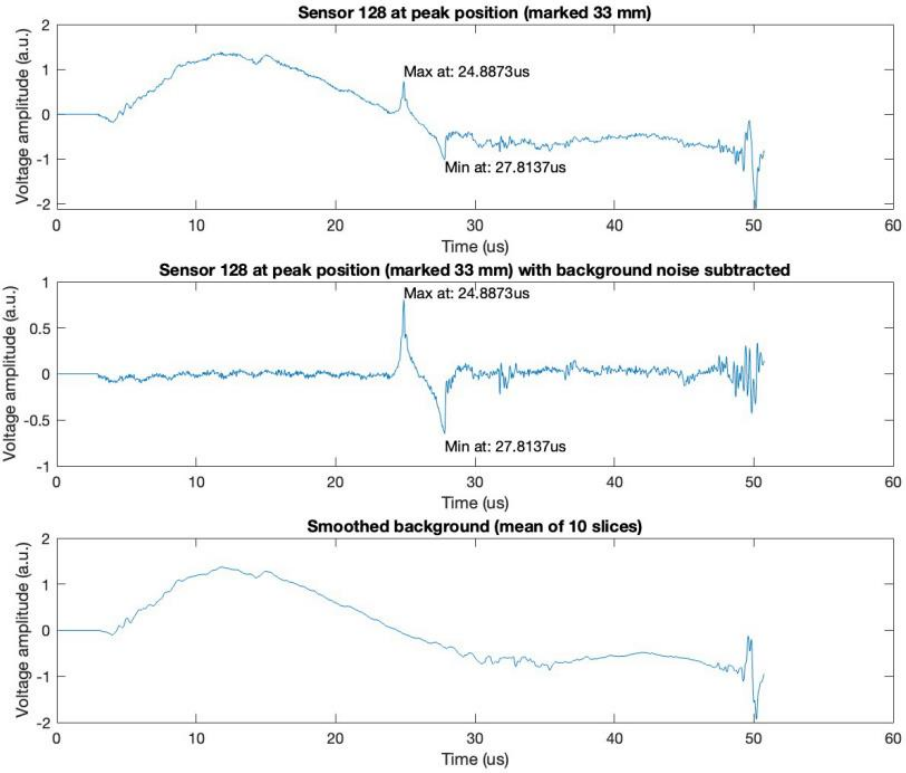
Acoustic sensor elements

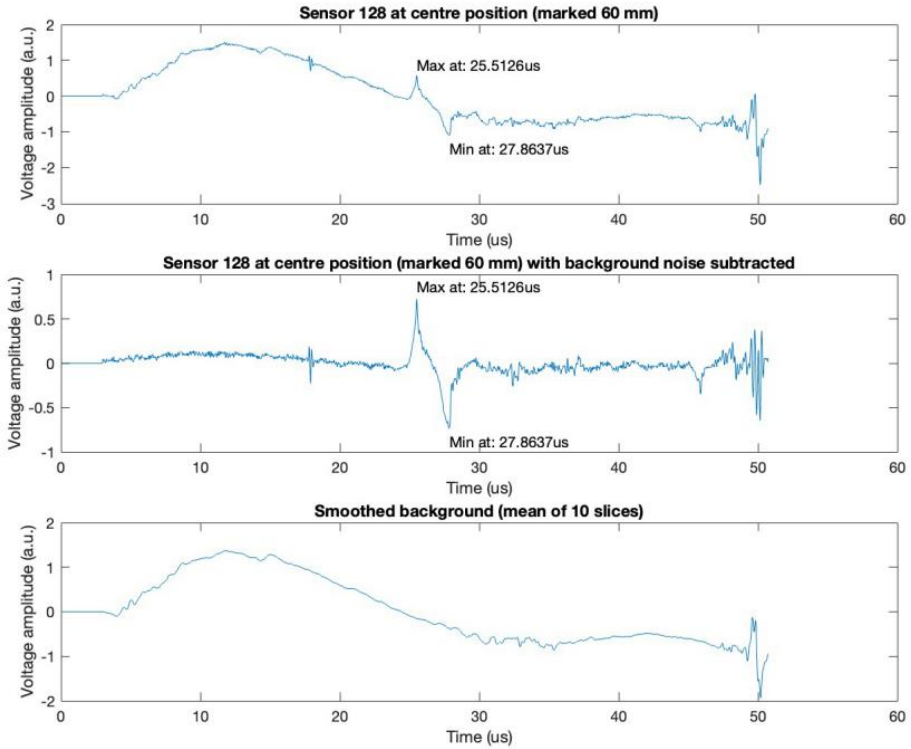


Example photoacoustic images (5%)

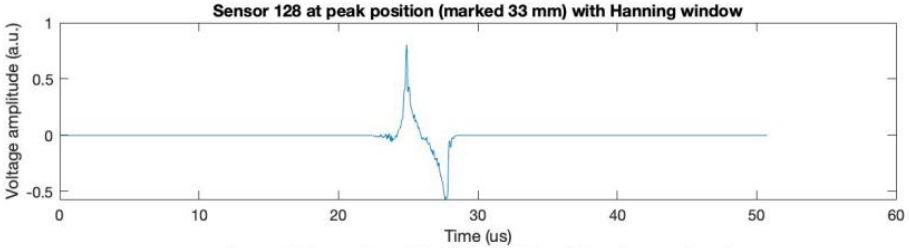


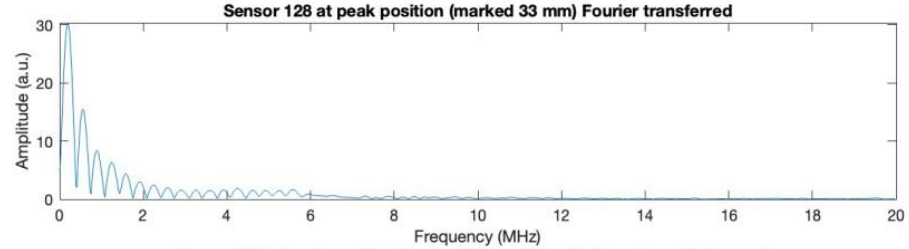
Acoustic signals received at sensor element 128

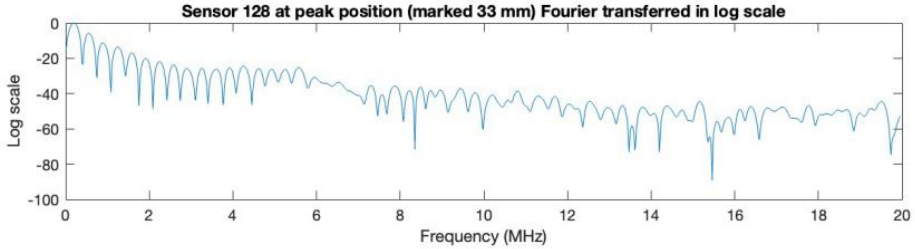


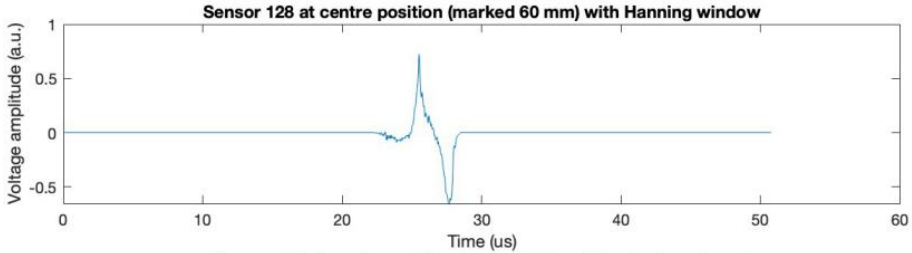


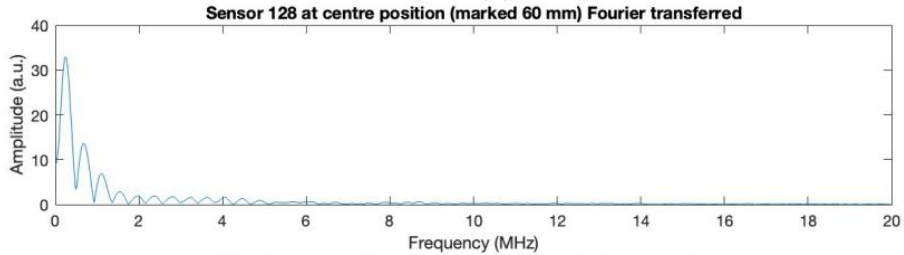
Acoustic signals received at sensor element 128

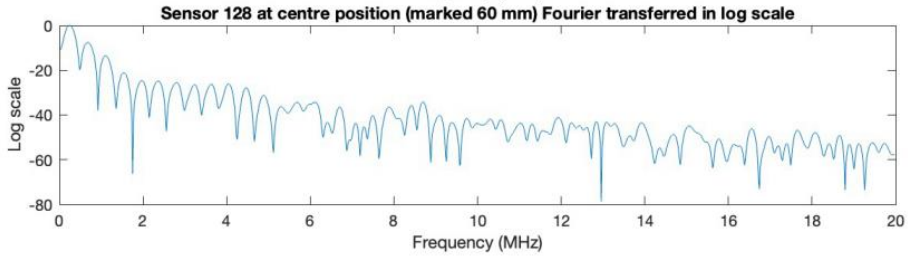




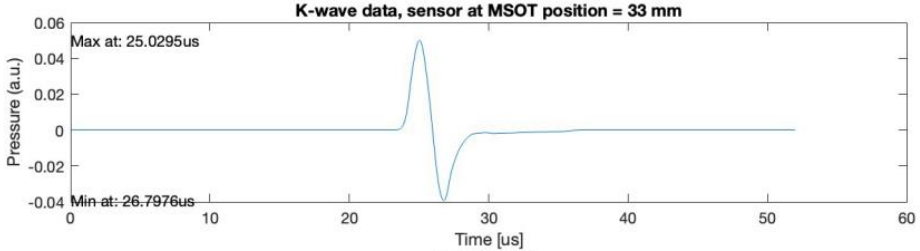


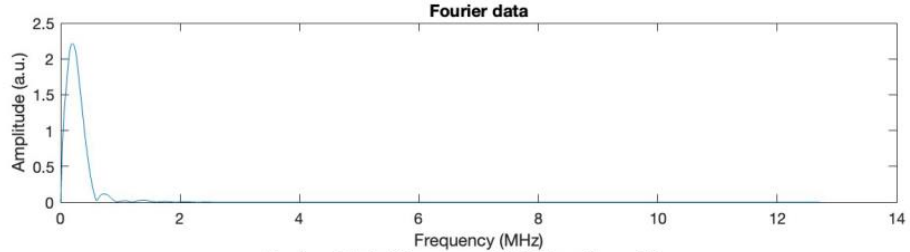


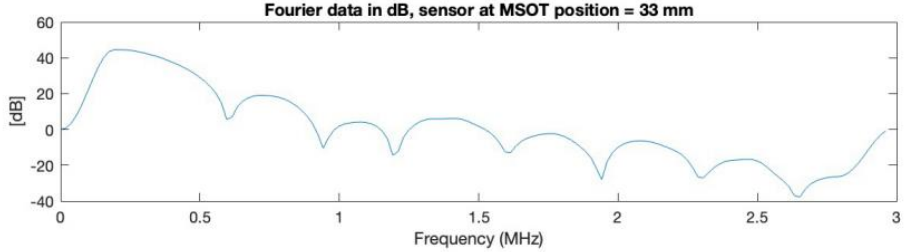


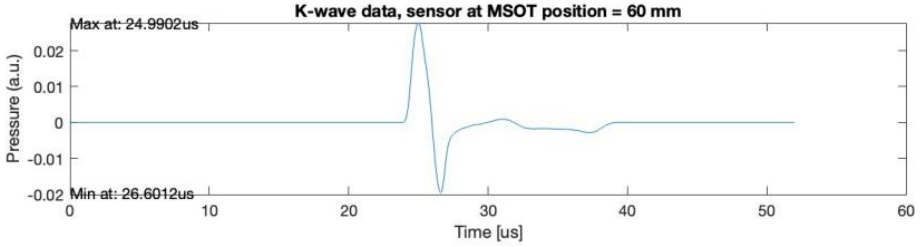


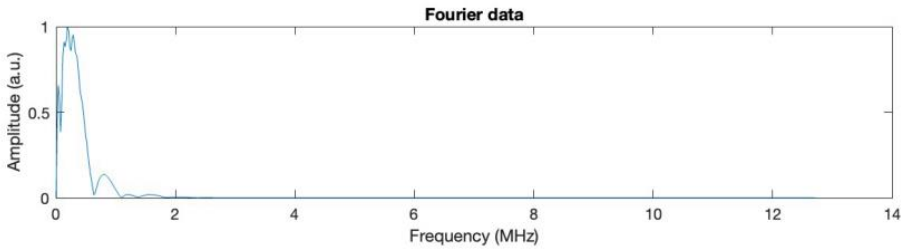
Simulated acoustic signals received at sensor element 128

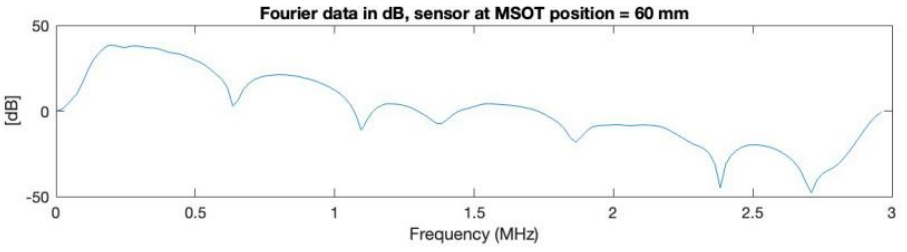












Analytical (and experimentally confirmed) predictions of pressure-time waveforms

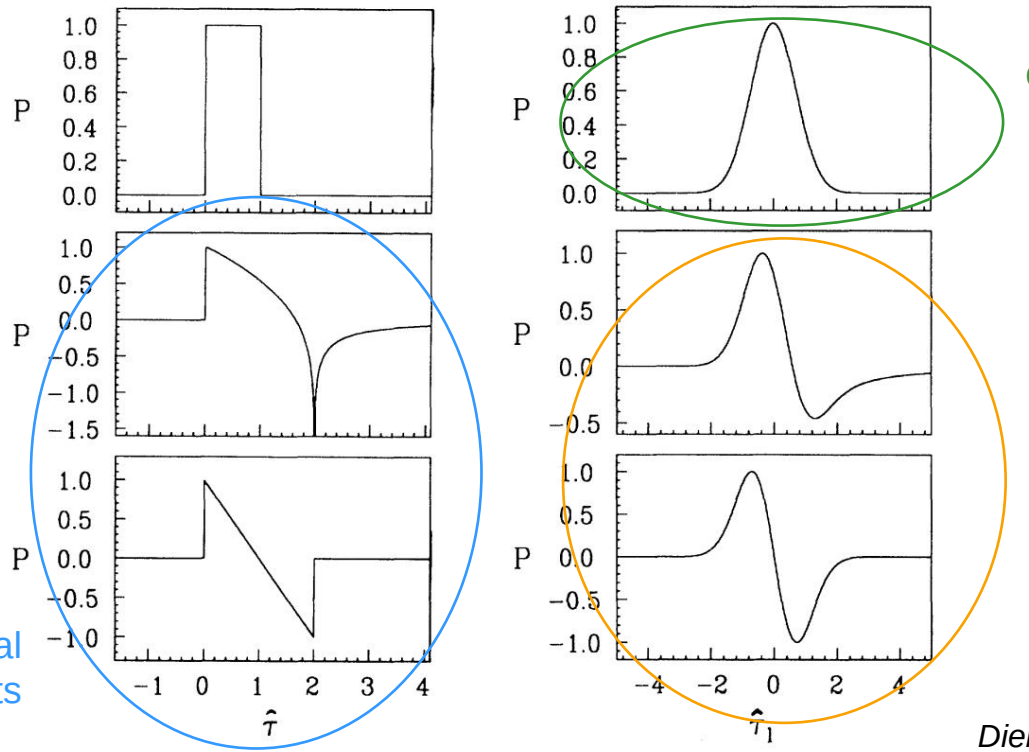
Energy delta function

Energy long Gaussian pulse

Parallel-sided slab

Cylinder

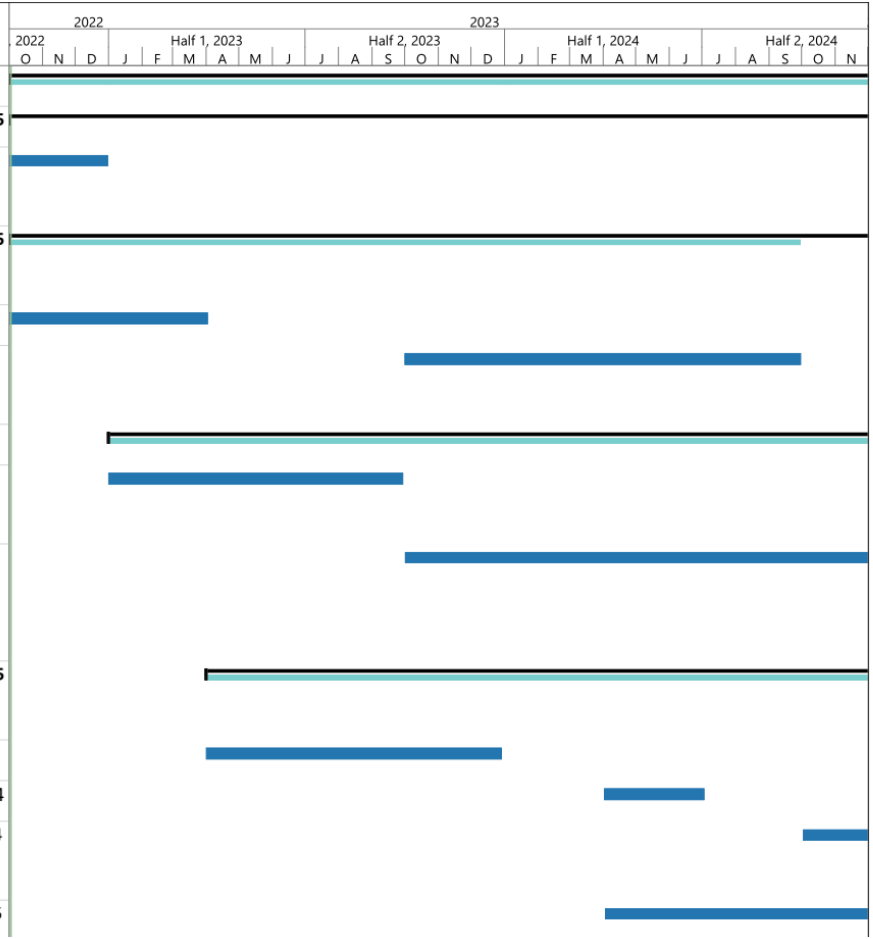
Sphere



c.f. simulation radial profile

c.f. simulation results

c.f. experimental results

Diebold et al, Phys Rev Let (1991)

Task Name	Work Package	Start	Finish
WP4 Ion-acoustic	**WP4**	**Sat 01/10/22**	**Thu 30/09/27**
PA1 yrs 1&2	**WP4**	**Sat 01/10/22**	**Mon 29/09/25**
1. Review - Current state of the art: ionacoustics / modelling of ionacoustics / proton dosimetry	WP4	Sat 01/10/22	Fri 30/12/22
2. Development of GEANT 4 Monte Carlo part of the forward model	**WP4**	**Sat 01/10/22**	**Mon 29/09/25**
2.1.Simulation of current beam line and smart phantom	WP4	Sat 01/10/22	Sat 01/04/23
2.2.Updated simulation of LhARA and smart phantom, as the specifications are developed in WPs 2,3,5 and 6.	WP4	Sun 01/10/23	Sun 29/09/24
3. Development of k-Wave forward acoustic model	**WP4**	**Sun 01/01/23**	**Fri 27/12/24**
3.1.Simulation of ionacoustic source, propagation and sensing, and design of array configuration for validation experiments	WP4	Sun 01/01/23	Thu 28/09/23
3.2.Updated simulation of ionacoustic source, and development of sensor array specification as Lhara specifications are developed	WP4	Sun 01/10/23	Fri 27/12/24
4. Implementation, simulation evaluation and development of inverse dose-map reconstruction software	**WP4**	**Sat 01/04/23**	**Wed 02/07/25**
4.1. Direct ionacoustic reconstruction with handling of sensor array c	WP4	Sat 01/04/23	Thu 28/12/23
4.2. Iterative reconstruction methods with model-based priors from	WP4	Tue 02/04/24	Tue 02/07/24
4.3. Iterative reconstruction methods with angular dependence of frequency content from 2 and 3	WP4	Wed 02/10/24	Mon 30/12/24
4.4. Implementation of various dose-map reconstruction programs o	WP4	Wed 03/04/24	Wed 02/07/25