WP4: Ion-acoustic dose mapping:

J. Bamber, B. Cox, J. Matheson, E. Harris

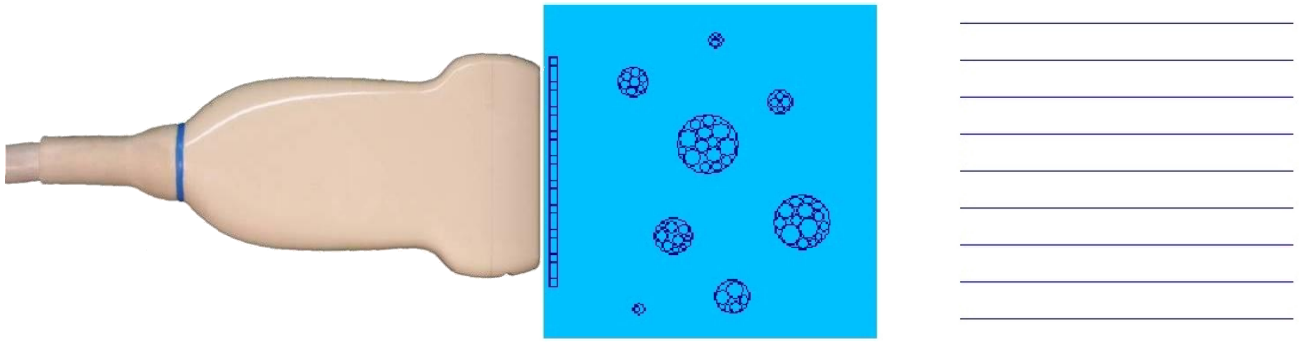
1.	Background, overview and hardware concept	J. Bamber (Ultrasound and Photoacoustics, ICR/RMH)	5 min
2.	Forward modelling and dose-map reconstruction	B. Cox (Photocoustics, UCL)	5 min
3.	Field standard dose-measurement reference	J. Matheson (Particle Physics, RAL)	5 min
4.	Long-term vision for use and impact	E. Harris (Ultrasound and Radiotherapy, ICR/RMH)	5 min
5.	Q&A	All	10 min

Modern Ultrasound Imaging

Transducer generates pulses of ultrasound waves that travel into the body

Echoes from tissue structures return at a time and with a wave curvature dependent on their depth and lateral position

Echoes are recorded simultaneously by arrays of multiple transducer elements and used to reconstruct images of the **location and strength of acoustic scattering**



Full aperture focusing ➔ high resolution over whole field simultaneously

1 pulse per image/volume ➔ frame/vol rates < 20 kHz (powerful noise reduction)

Other processing:

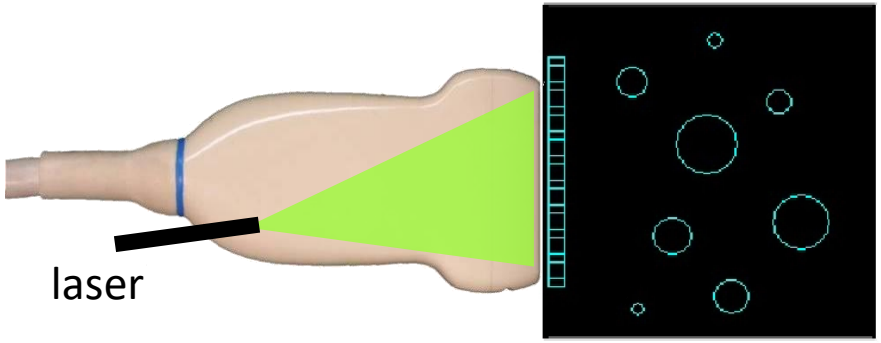
- **Microbubbles** recognised by pulse sequences that detect nonlinear scattering (DCE-US)
- Doppler shift allows **blood velocity imaging**
- **Tissue motion tracking** and deformation for **biomechanical properties**
- **Sound speed** and **Attenuation Coefficient** quantitative imaging

Photoacoustic imaging

Replace the ultrasound pulse with a short (< 10 ns) light pulse

Absorption of light by tissue → heating → pressure → **acoustic emission**

Ultrasound emissions are recorded by multiple transducer elements and used to reconstruct images of the **location and strength of optical absorption**



Varying the wavelength of light brings **absorption spectroscopy** to ultrasound imaging

Endogenous contrast: melanin, Hb, HbO_2, saO2, lipid, …

Exogenous contrast: ICG, meth blue, nanoparticles, …

Thanks to Michael Jaeger, University of Bern, for the simulation

Ion-acoustic imaging

- Works in a similar way to photoacoustic imaging.
- Ion-acoustic Ambition: in-vivo real-time 3D dose localisation and quantitative mapping, for real-time pulse-to-pulse adaptive treatment as the beam is moved around.
  - Localise the Bragg peak (submillimetre accuracy possible), to avoid damage to healthy tissue and under-dosing of the tumour.
  - Measure the deposited-energy distribution in the tissue, preferably on a pulse-by-pulse basis.
  - Simultaneous multimodality ultrasound and photoacoustic images registered to planning CT/MRI - track tissue motion, image anatomy, perfusion, microvasculature, hypoxia, elastography, speed of sound, molecular biomarkers and dose enhancement distribution from molecularly targeted dose enhancers.
  - Suitable for organs where acoustic access is possible: breast, prostate, liver, pancreas, pelvic, head and neck, etc.
  - Enable preclinical research to provide the radiobiology knowledge needed to take full advantage of the new accelerator, and for its optimal clinical use.
  - Especially applicable to mini/micro-beam and FLASH irradiation.

Ion-acoustic imaging

- Overcoming the main challenges:
  - Very weak signals.
    - Employ the laser-hybrid accelerator technology to generate 10 - 40 ns pulses.
    - Massively parallel ultrasound electronics and transducer arrays, and front-end compressive sensing, for noise averaging and signal enhancement.
    - Techniques described below will also enhance signal to noise ratio.
  - Signal frequency content needs to be matched to ultrasound transducers.
    - Novel acoustic beamforming and transducer arrays that take advantage of LhARA to adjust the PB (mini- or micro) beam size.
    - Use of expected dose distribution as a prior in dose-map reconstruction
  - Ultrasound transducers must permit dose and other imaging, as well as PBT access, in the treatment room without an operator to do the scanning.
    - Flexible ultrasound detector system, based on inter-communicating subarrays with an organ-specific array configuration that allows volumetric imaging and PBT access.
    - For some situations, use existing technology such as the ring arrays. For others, take advantage of simultaneous work around the world to develop conformable arrays.
  - The acoustic properties for which compensation is needed to enable accurately localised and quantitative dose imaging, are patient specific.
    - Speed of sound and attenuation imaging are being developed for diagnostic imaging.
    - Use ultrasound contrast microbubbles as beacon signals, to correct for acoustic wave aberrations and attenuation for dose-image resolution enhancement and quantification.
    - Dose-enhancing nanoparticles for self-adaptive ion-acoustic imaging.

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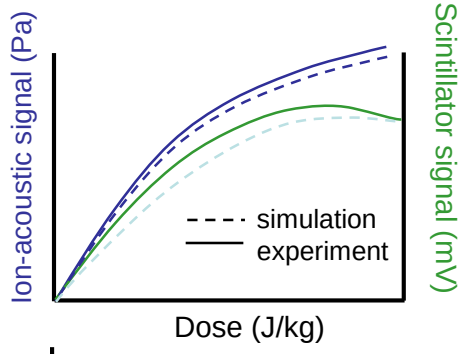
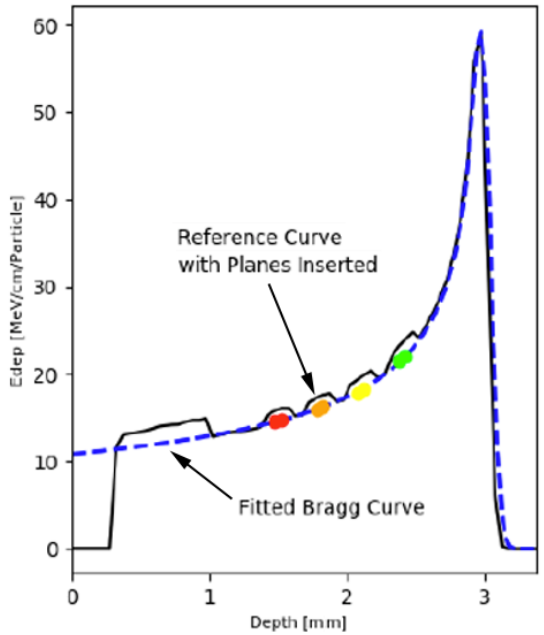
2 Years

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

GEANT4 A SIMULATION TOOLKIT

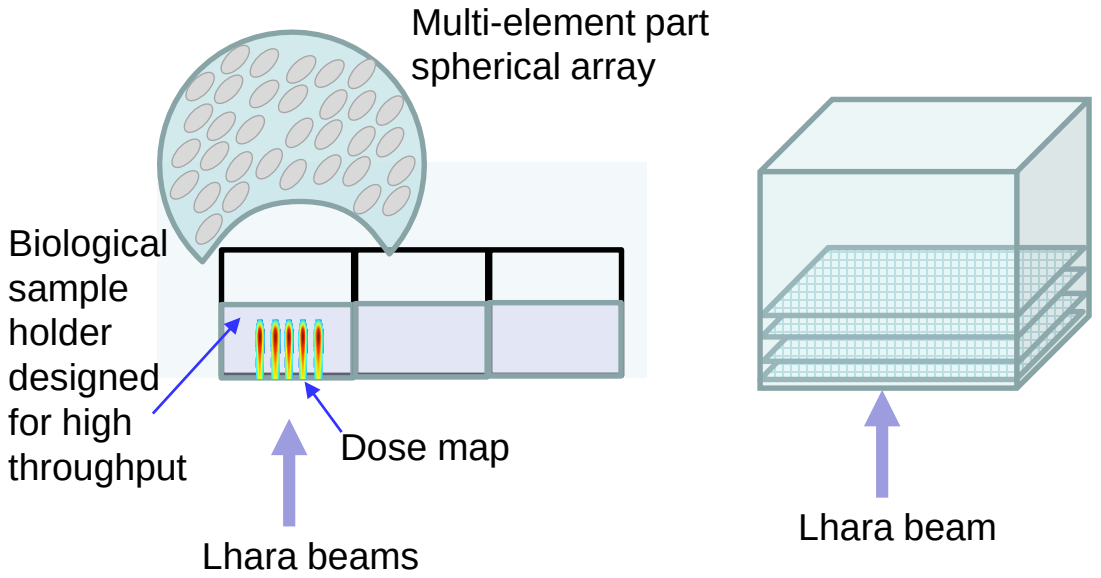
k-Wave
A MATLAB toolbox for the time-domain simulation of acoustic wave fields





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

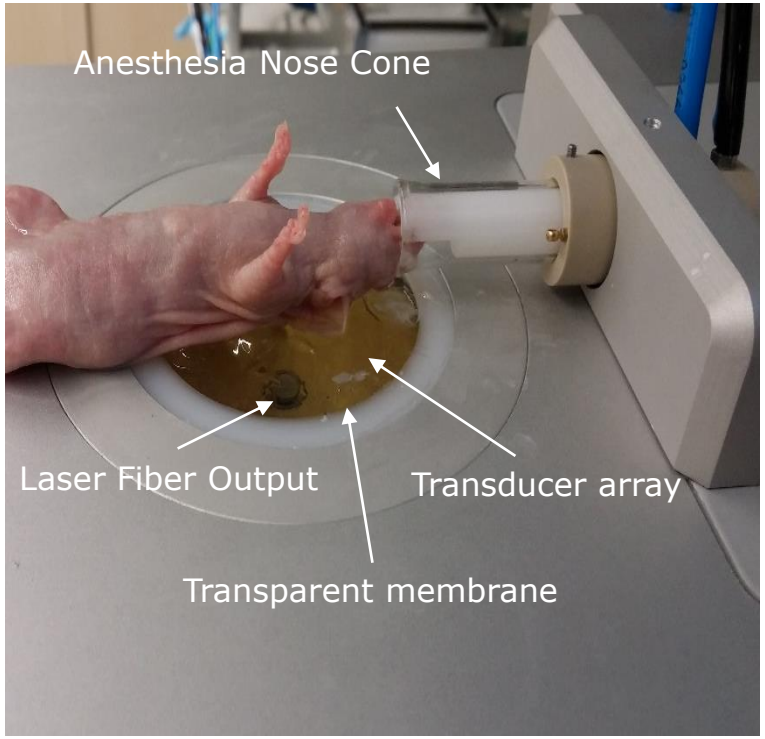
5 years



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

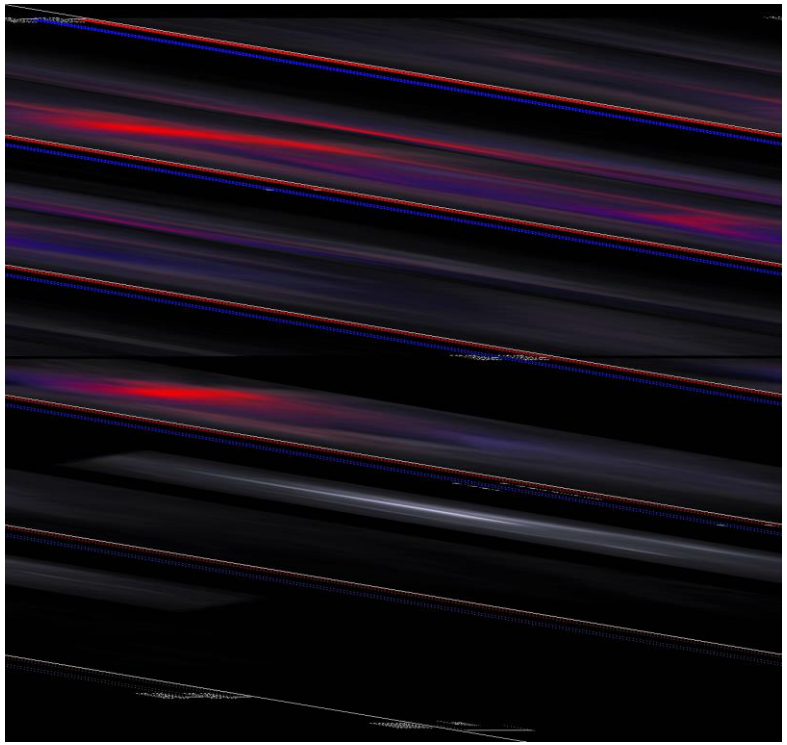
- Validated models for the simulation of dose and ion-acoustic signals for LhARA
- Results from initial biology experiments

Example plausible imaging concept and transducer array - based on existing photoacoustic small animal imaging



Current 4 MHz
384-element array

Example rapid volumetric imaging using multiple NIR wavelengths



4 mm