Predicting the acoustic emissions from clinical proton beams: a step towards ionacoustic dosimetry in proton therapy

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The Problem: In-vivo beam monitoring in proton therapy is essential to reduce uncertainties caused by anatomical changes and internal organ motion during treatment.

The Ionacoustic Solution: Ionacoustic imaging offers a promising route for real-time, non-invasive dose verification, using ultrasound signals generated by proton energy deposition.

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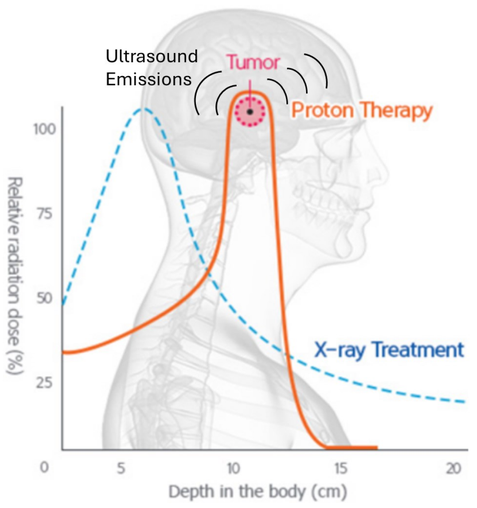


Fig. 1 Schematic displaying the differences in energy deposition between proton and radio therapy and conceptual ionacoustic emissions (adapted from [1]).

What is proton therapy?

- It is an advanced form of radiotherapy used to treat cancerous tumours.
- It delivers highly targeted radiation, minimising damage to surrounding healthy tissue (see Fig. 1).
- Physical properties of protons allow for this precise dose deposition, especially at the Bragg peak.
- Requires accurate beam dosimetry (absorbed dose in tissue) and robust quality assurance (QA).
- **Ionacoustic imaging:** emerging method for real-time dosimetry & QA using ultrasound signals from proton energy deposition.

What is ionacoustic imaging?

- Back-projection of acoustic waves generated by proton energy deposition via the **ionacoustic effect.**

Advantages:

- No contrast agents. Non-invasive, real-time feedback.

Challenges:

- Requires detection of very weak, low frequency ultrasound signals.
- Current piezocomposite ultrasound detectors: ≈ 0.1 Pa pressures over 1 MHz bandwidth—will this be enough?

This work:

- Modelling framework to understand the acoustic pressures and frequencies produced by a range of clinical proton beams.
- Water is used as a stepping stone to in-vivo dosimetry.

The ionacoustic effect:

1. At room temperature, water molecules vibrate with low amplitude.
2. When protons enter the water, interacting molecules gain energy.
3. This makes them vibrate more which causes a localised pressure gradient.
4. This spreads out as an acoustic wave and can be measured by an ultrasound transducer.

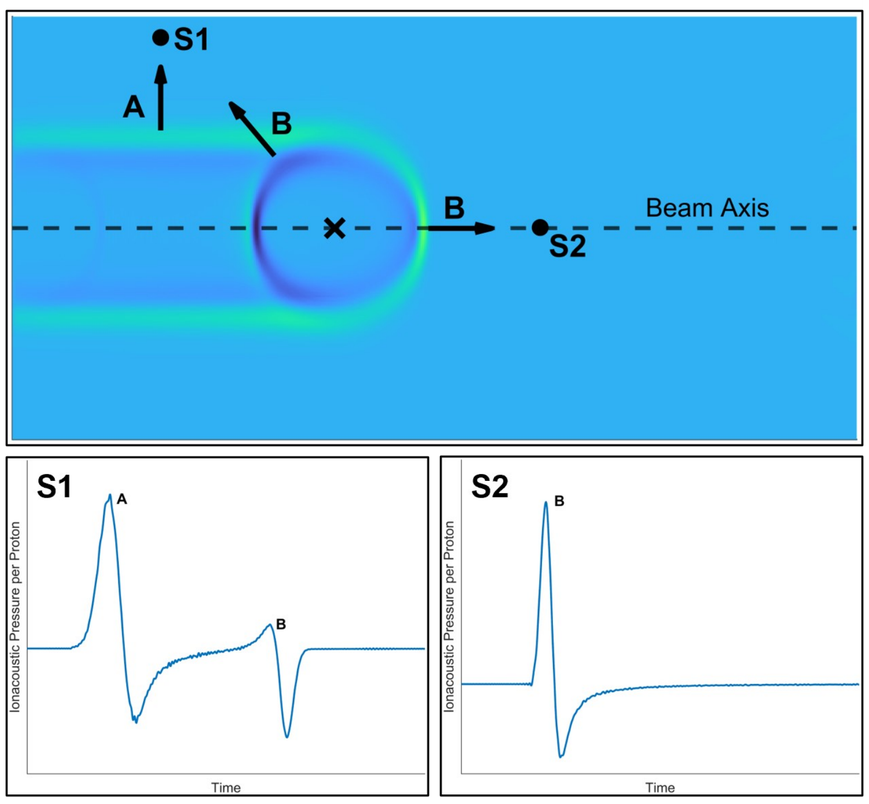


Fig. 3: Schematic showing the characteristic ultrasound signal from a proton beam formed of a cylindrical (labelled A) and spherical (labelled B) wave form. The expected waveforms from two sensor positions S1 and S2 are also shown.

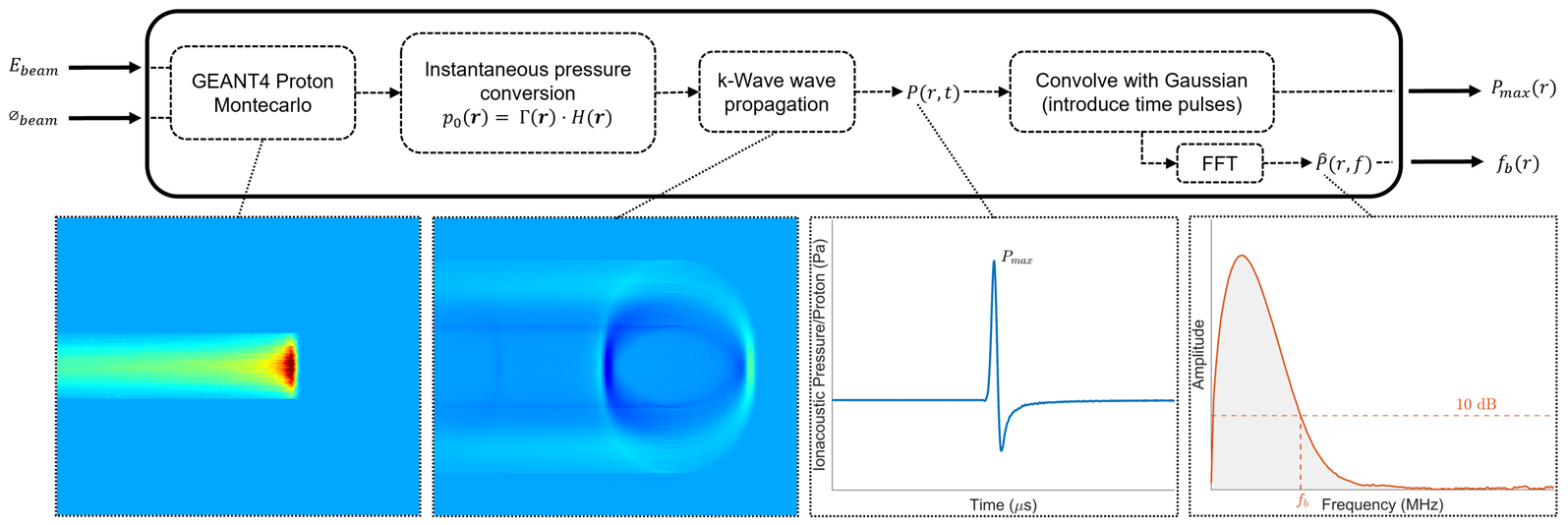


Fig. 2: Modelling framework flow diagram displaying each stage of the of the simulation pipeline. Callouts highlight typical data characteristics and signal trends.

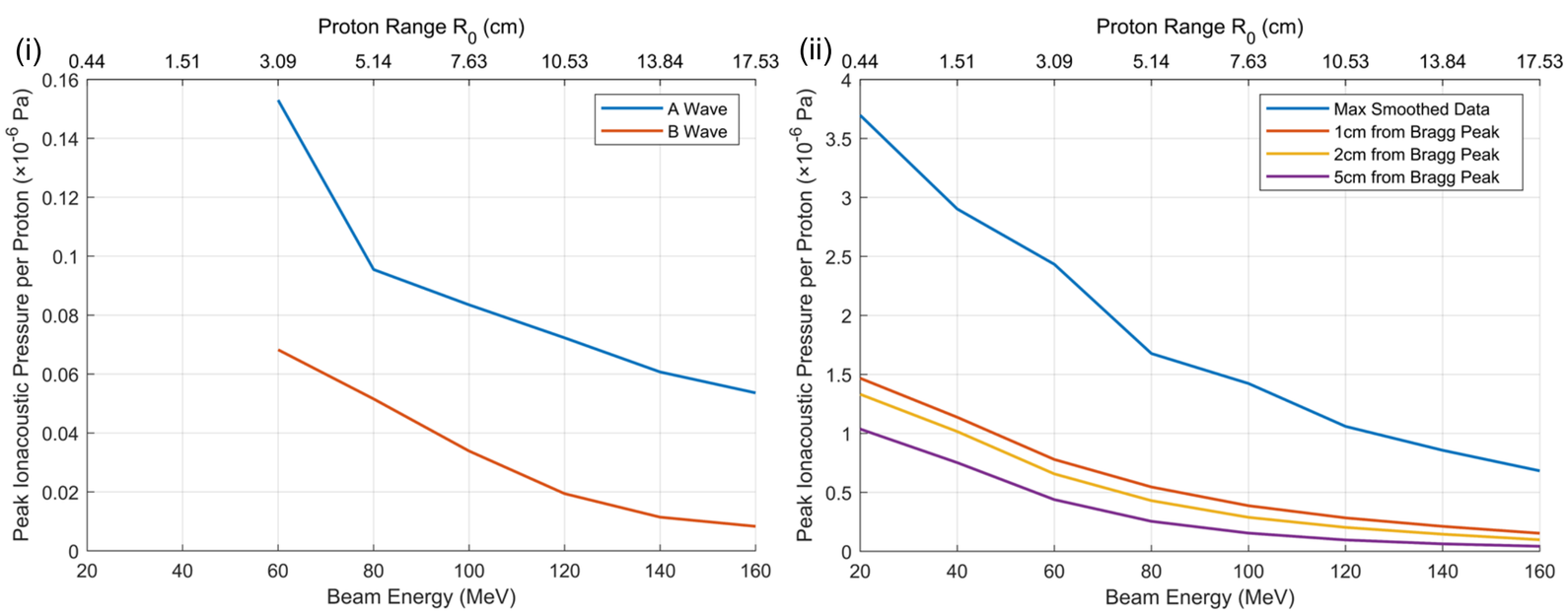


Fig. 4: Changes in peak ionacoustic pressure per proton with beam energy. (i) The response of a sensor positioned at S1 with the contributions from the cylindrical (A) and spherical (B) waves separated. (ii) The response of a sensor positioned along the central axis starting at S2 and travelling away from the initial beam position. Both show a decreasing trend in peak pressure with increasing beam energy.

Discussion/Conclusions:

- Developed a flexible simulation framework for understanding the ionacoustic signals produced by clinical proton beams.
- It shows that pressure decreases with increasing beam energy → proton range straggling.
- Fills gap in existing literature as it clarifies underlying physical principles and trends.
- Guides transducer selection and frequency band design for optimal signal detection.

Future Work:

- Inclusion of higher proton energies up to 220MeV into the framework and results.
- Further analysis of signal frequency content and the effect of proton pulse duration.
- Validation of model using literature case studies and experimental measurements.

References:

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