MEDICAL APPLICATIONS OF ULTRASOUND FROM PLASMA-ACCELERATED ELECTRONS

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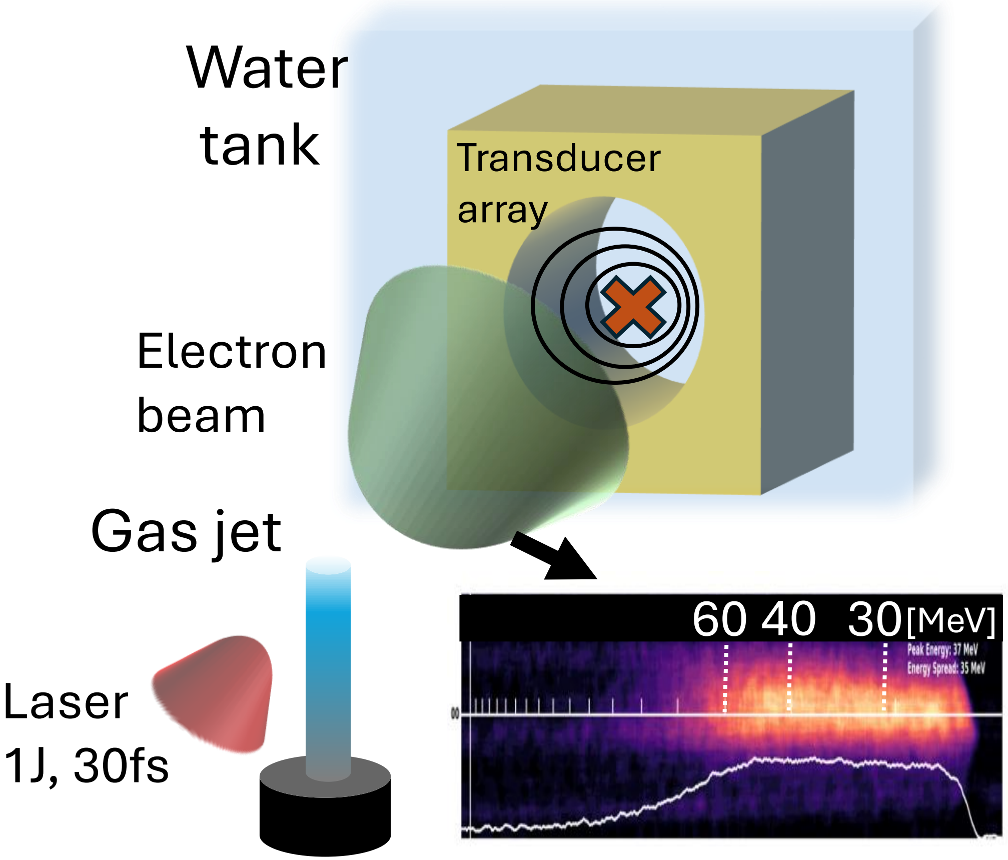
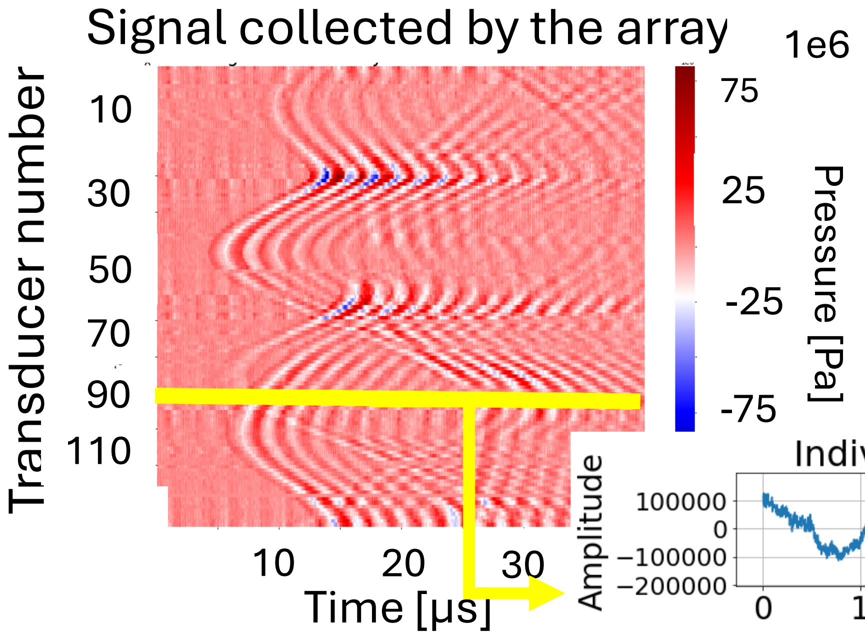
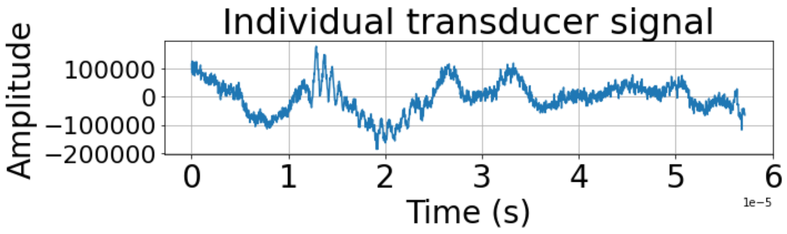
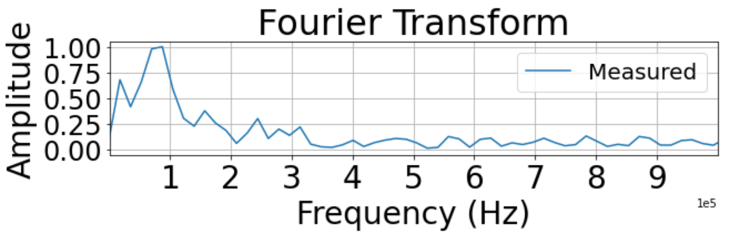


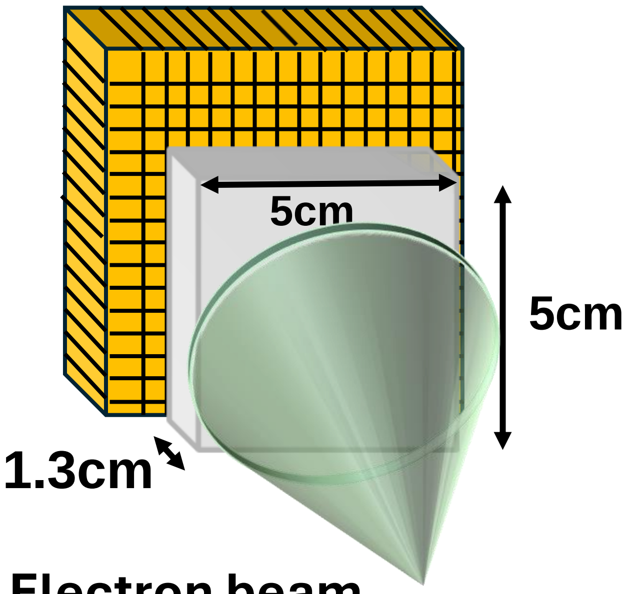


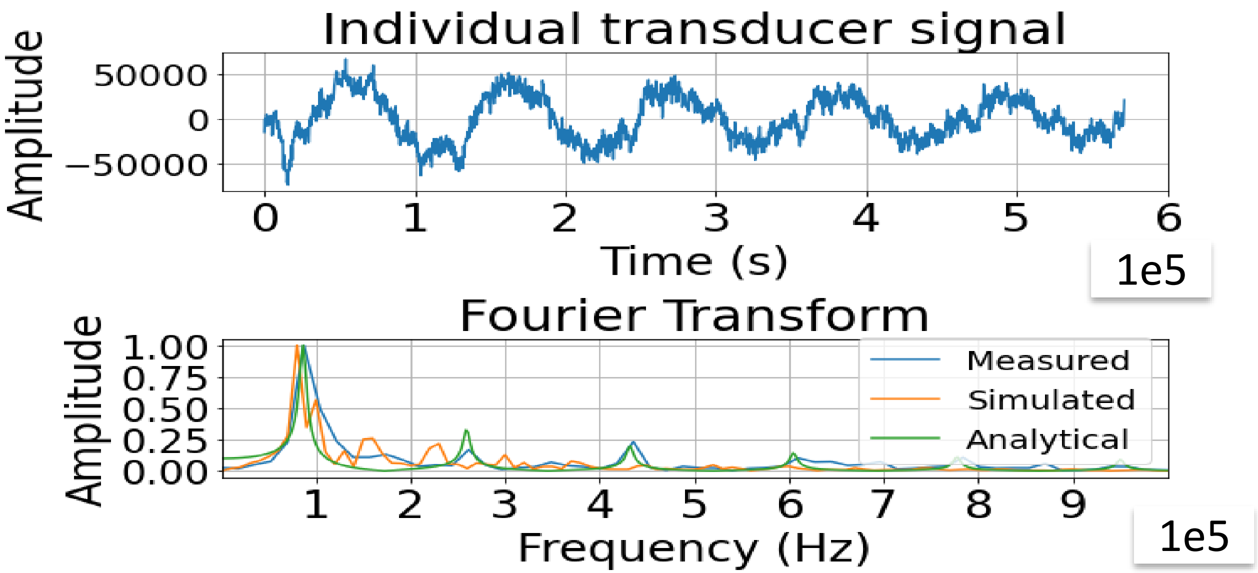




Material Characterization: Slab

For symmetrical objects, the acoustic emission can Be treated analytically [1]





Resonance condition for a slab:

$$\sin q_{slab} + i\,\hat{c} q_{slab} \cos q_{slab} = 0$$

occurring at $\cos q_{slab} = 0$, therefore

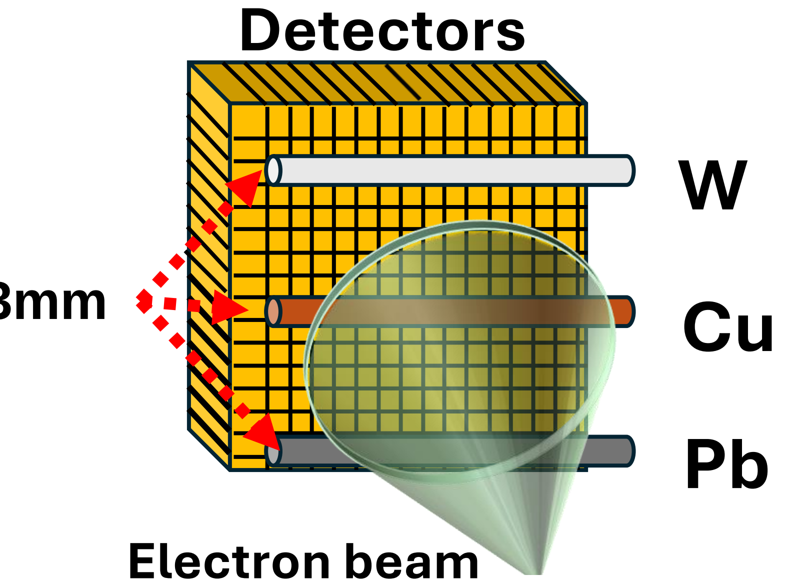
$$q_{slab} = n\pi/2 \;\; (n = 1,3,5\ldots)$$

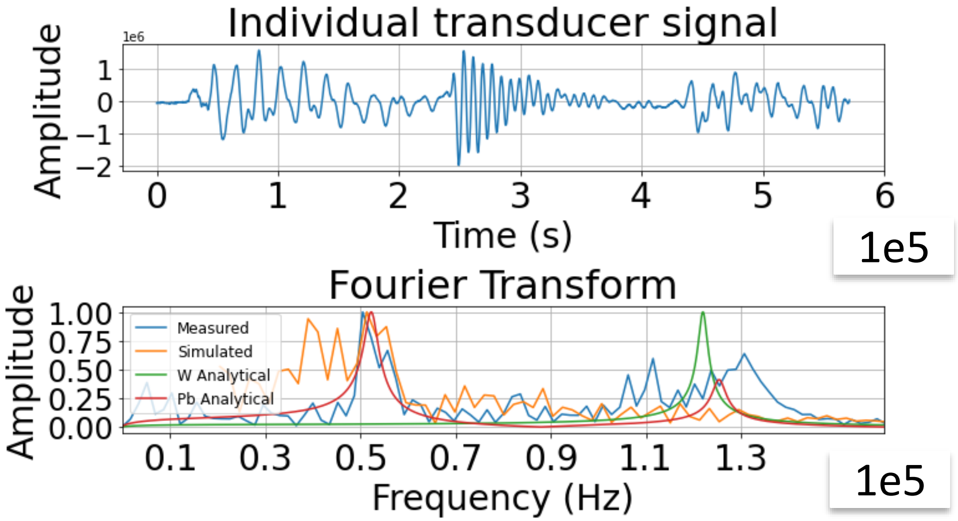
with

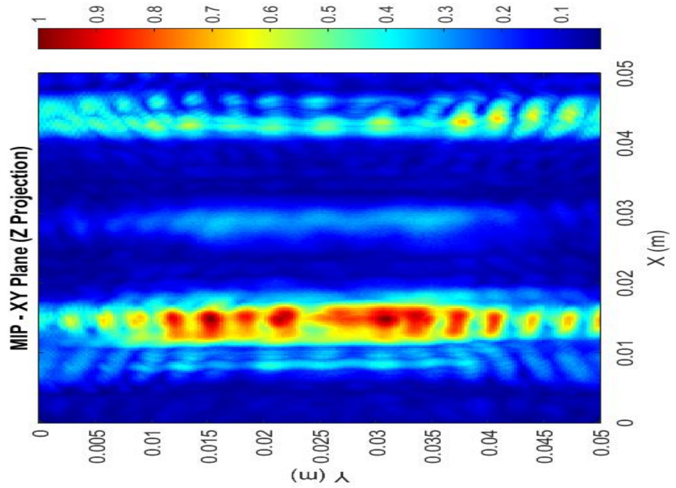
$$q_{slab} = \omega l / 2c_s$$

[1] L. V. Wang, *Photoacoustic Imaging and Spectroscopy*, CRC Press, 2009. Chapter 1.

Material Characterization: Rods







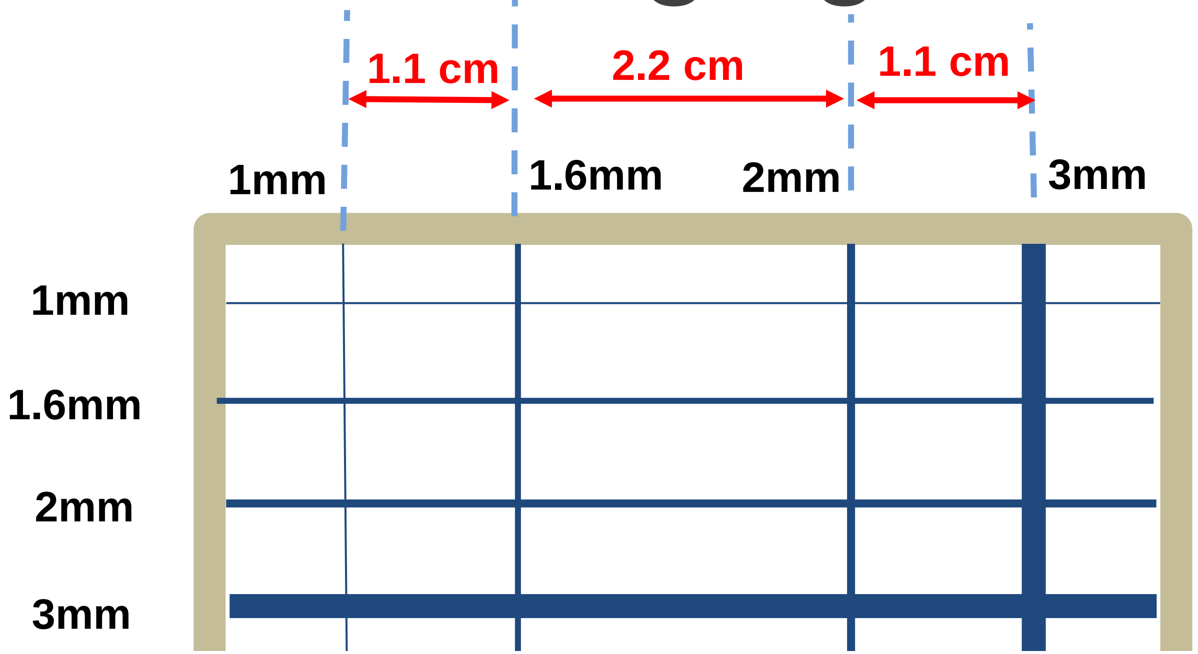
Resonance condition for a rod:

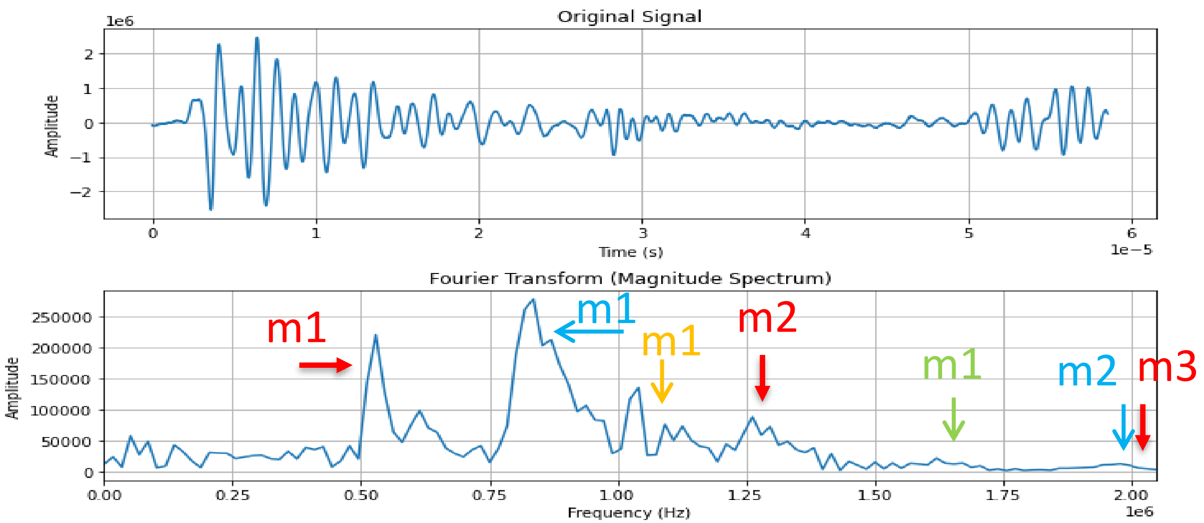
$$J_0(q_{rod}) - \hat{c}J_1(q_{rod})/q_{rod} = 0$$

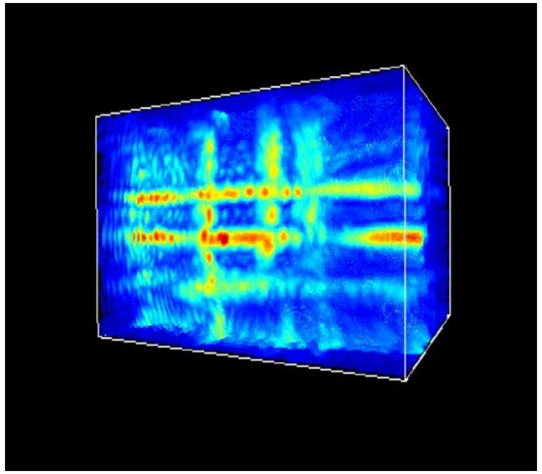
occurring at $J_0(q_{rod}) = 0.$

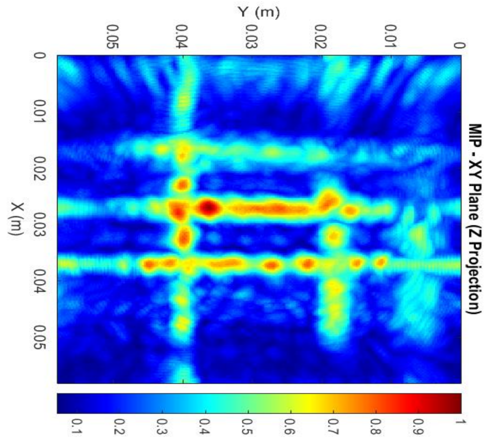
With $$q_{rod} = \frac{\omega a}{c_s}$$

Imaging of complex targets



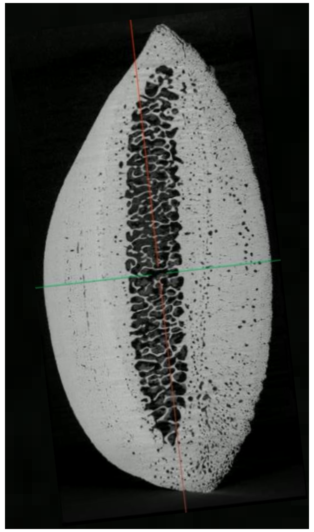


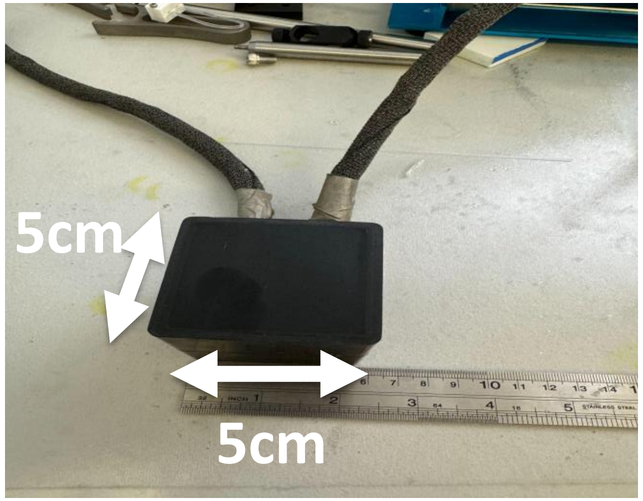


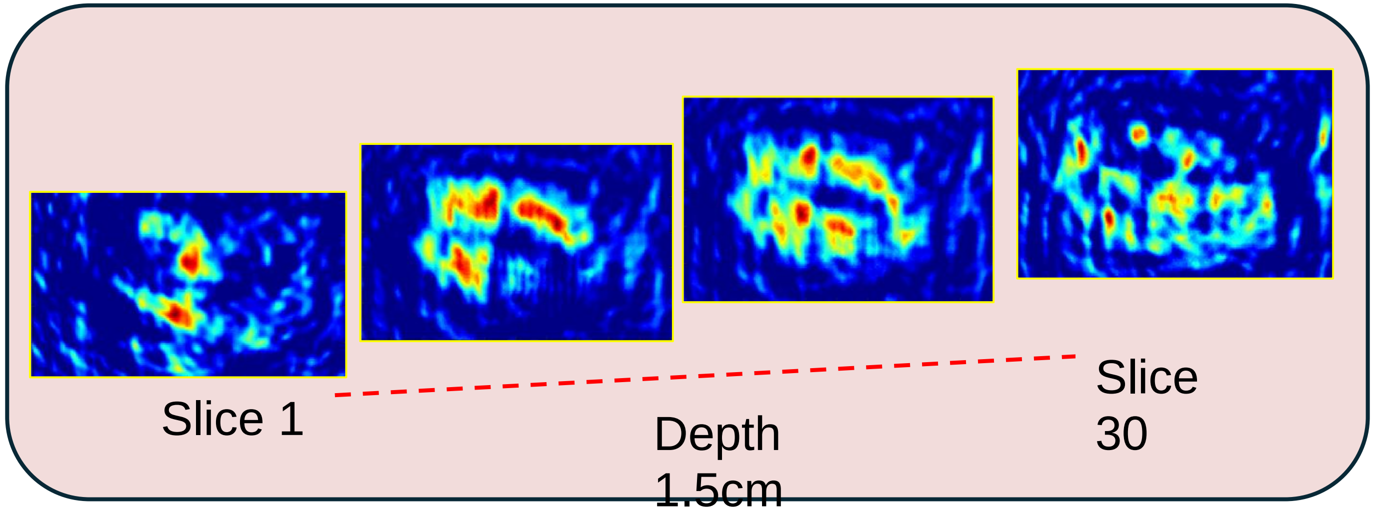


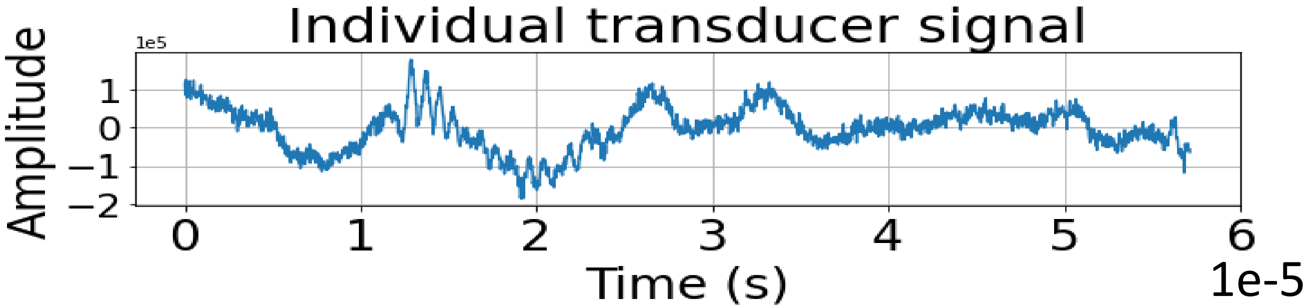
Diameter [mm]	m = 1 [MHz]	m = 2 [MHz]	m = 3 [MHz]
1	1.65	3.8	5.95
1.6	1.02	2.3	3.7
2	0.83	1.9	2.97
3	0.55	1.27	1.98

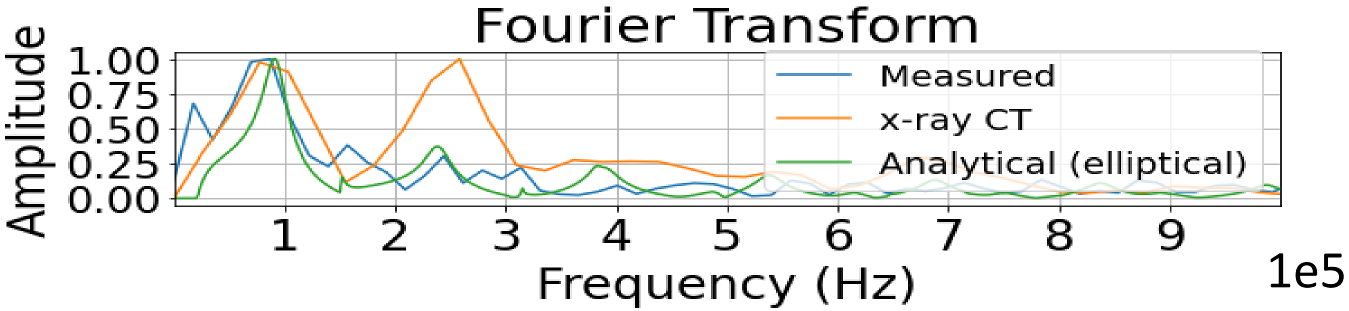
Irradiation of a bovine bone











Elliptical Solutions (?)

Work of Leslie Zhang*

The acoustic emission is governed by:

$$\left(\nabla^2 - \frac{1}{c_1^2}\frac{\partial^2}{\partial t^2}\right)\Phi^s = \frac{K\beta}{\rho_c c_1^2}\theta, \quad \theta = \frac{i\tilde{\alpha} I_0}{\rho_c C_p \omega} e^{-i\omega t}$$

Wave equation

Source Heating

VHEE dose

In elliptical coordinates:

$$\nabla^2 = \frac{1}{c^2(\sinh^2\xi + \sin^2\eta)}\left(\frac{\partial^2}{\partial \xi^2} + \frac{\partial^2}{\partial \eta^2}\right) + \frac{\partial^2}{\partial z^2}$$

with:

$$\xi = \arccos(r/c), \; c = \sqrt{a^2 - b^2}$$

The pressure outside the bone is:

$$P_f = \sum_{l=0}^{\infty}\sum_{n=0}^{\infty} B_n\, C_l \Phi_0 \rho_f \omega^2 ce_{fn}(\eta)\cdot Je_{fn}(\xi)\cdot \cos(\gamma_l . z)\, . \, e^{-iwt}$$

Where

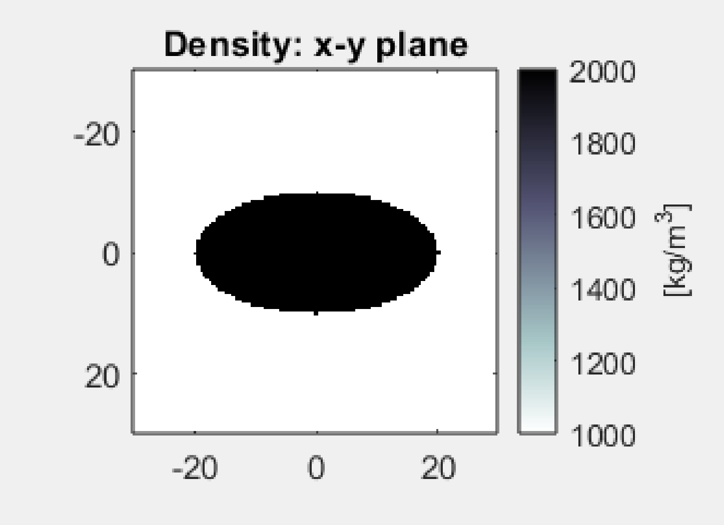
$$B_n = \frac{1}{\dfrac{\rho\, \mathrm{He}'_{fn}\, ce_{fn}}{\rho_f\, \mathrm{Je}'_{sn}\, ce_{sn}}\boxed{\left(2c_t^2\, ce_{sn}\, \mathrm{Je}''_{sn}\frac{1-h}{c^2} - \omega^2 ce_{sn}\, \mathrm{Je}_{sn}\right)} + \omega^2 ce_{fn}\, \mathrm{He}_{fn}}$$

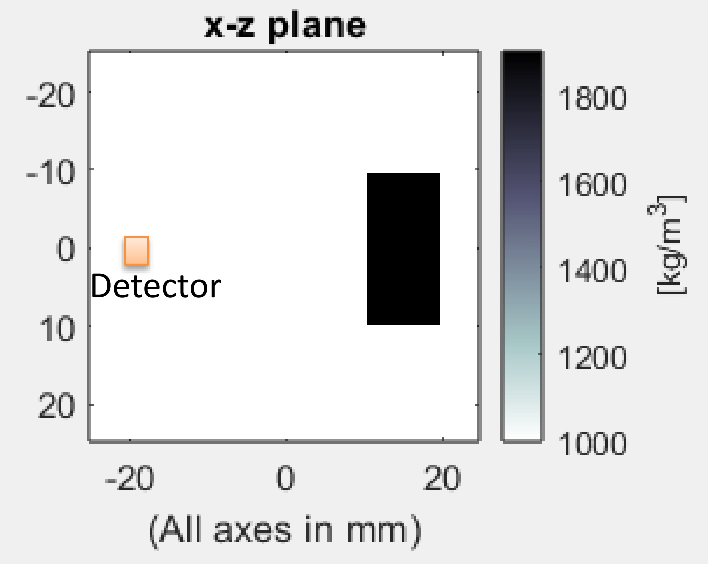
Resonance condition

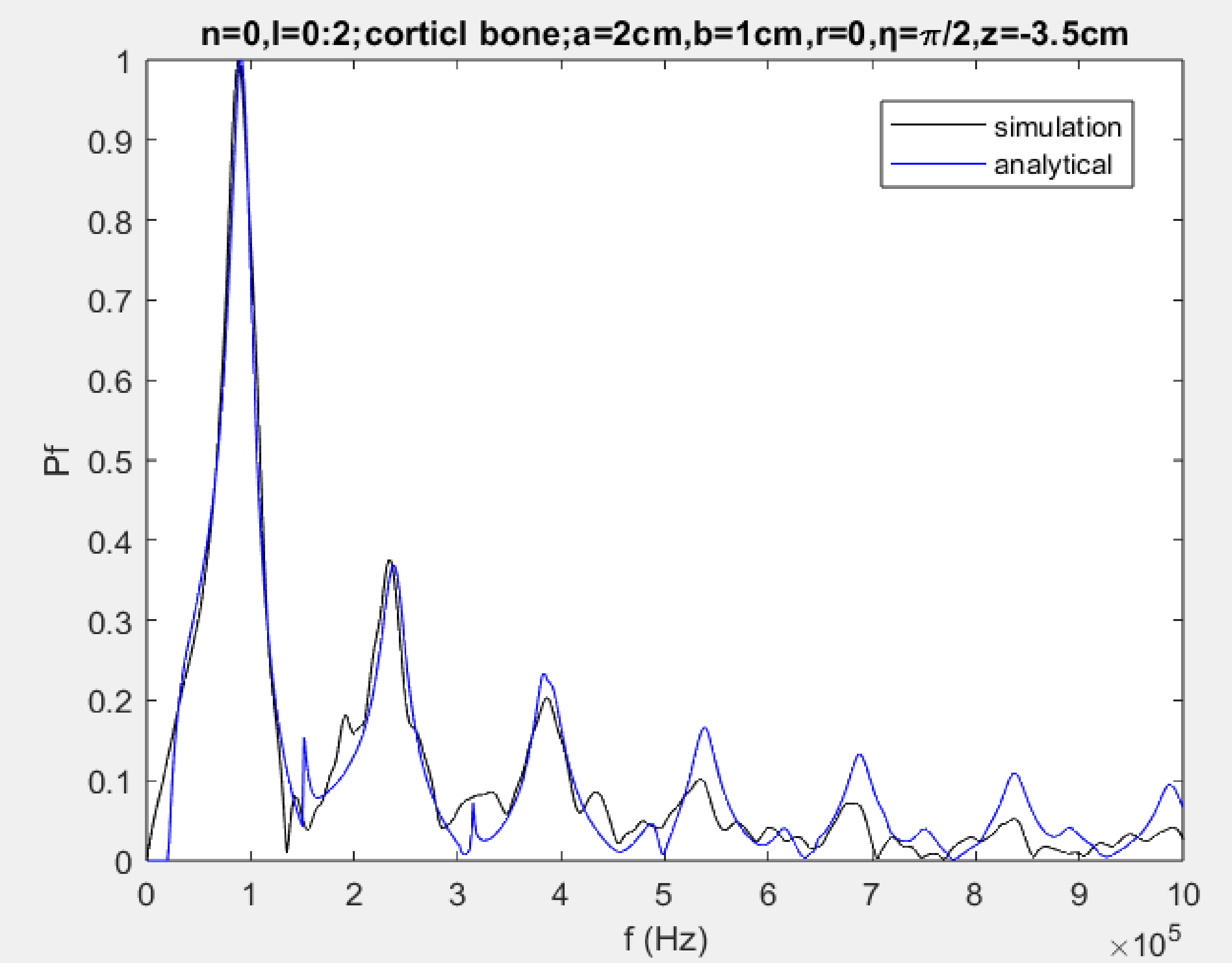
and

$$C_l = \frac{2\sin(\gamma_l L/2)}{\gamma_l}\left[\frac{L}{2} + \frac{\sin(\gamma_l L)}{2\gamma_l}\right]^{-1}$$

Acoustic simulation for Elliptical bone





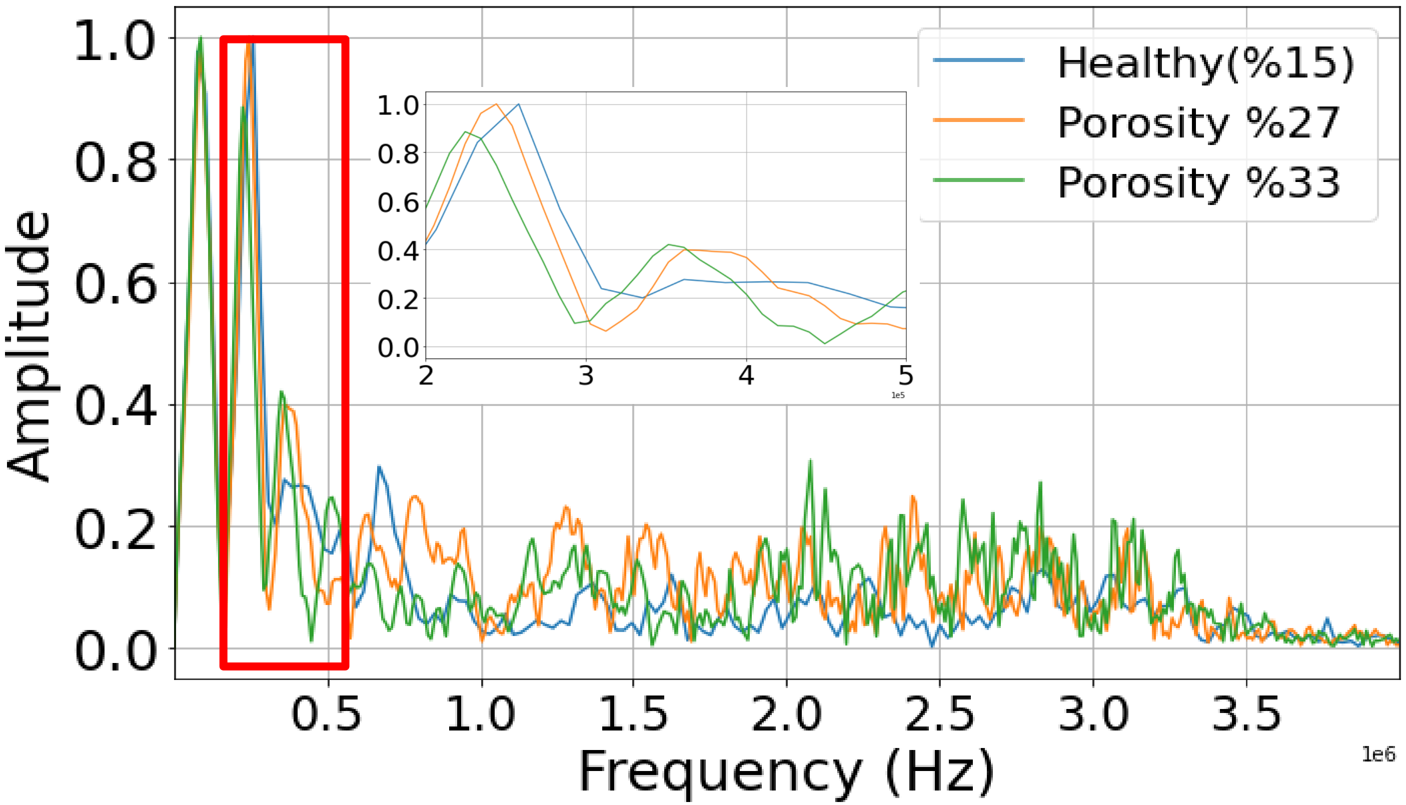


Diagnostic tool for Osteoporosis?

Simulations by Bryan Dinh*

Increased porosity in bones is associated with bone cancer.

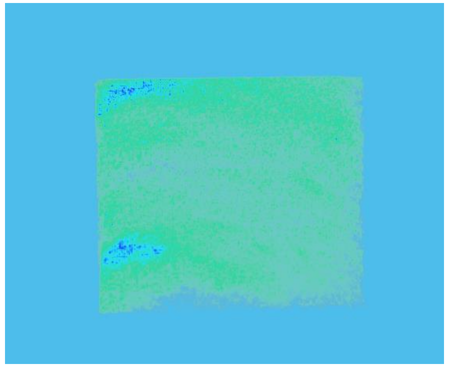
Porosity was artificially added to the simulations to study detection feasibility for osteoporotic bone. Preliminary results indicate higher frequency components and a shift of higher amplitudes towards lower frequencies.



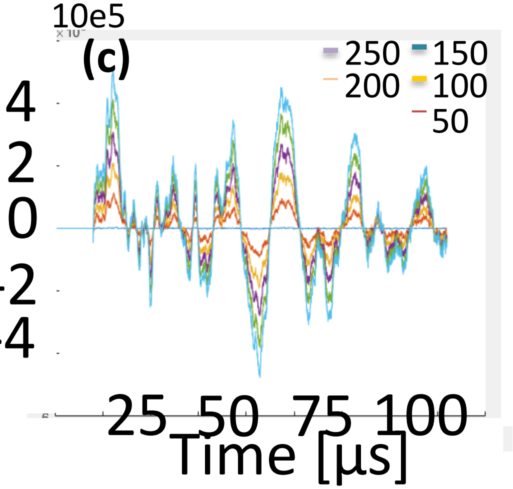
In-situ Dosimetry

Dosimetry in real time, especially in medical settings, is a challenging problem. Here, we irradiated a fatty tissue (pork belly) **(a)**. Over multiple shots, imaging of complex structures is possible **(b1),(b2)** and **(b3)**. Also importantly, accumulated signal **(c)** scales linearly with number of shot **(d)**, meaning this technique has potential for dosimetry in real time.

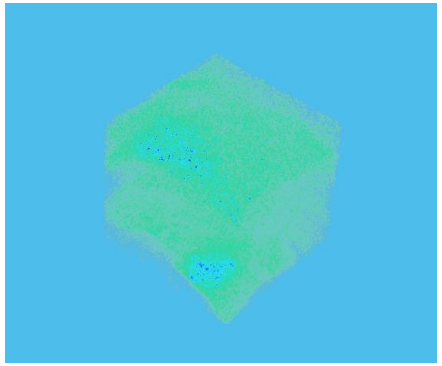
(b2) side view



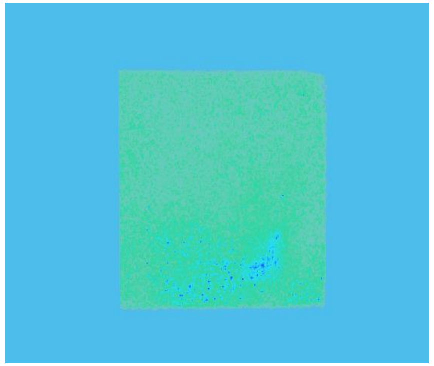
\# of shots

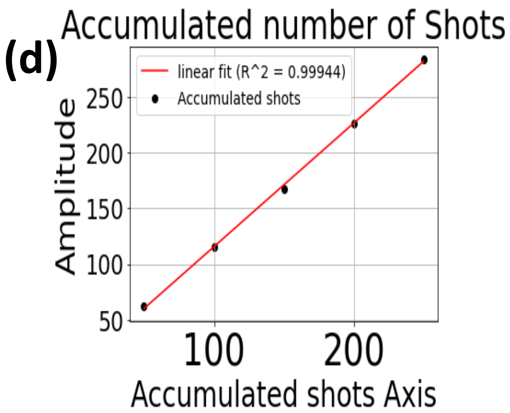


(b1) 3D view



(b3) top view





Conclusions

- LWFA's are a well suited to perform acoustic computed tomography due to their inherent bunch duration and their energy tunability.
- Acoustic computed tomography is a robust imaging technique that also allows retrieval of material properties such as density and speed of sound.
- Medically, this modality allows for different type of studies, such like bone health and *in-vivo* dosimetry.

Not a conclusions but repeating the experiments with x-rays should be straightforward. Samples in this presentation work as for a proof-of-concept. Next experiments should be done with medically graded targets.

Acknowledgments

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Thank you!