Acoustic holography techniques for rapid validation of acoustic holograms

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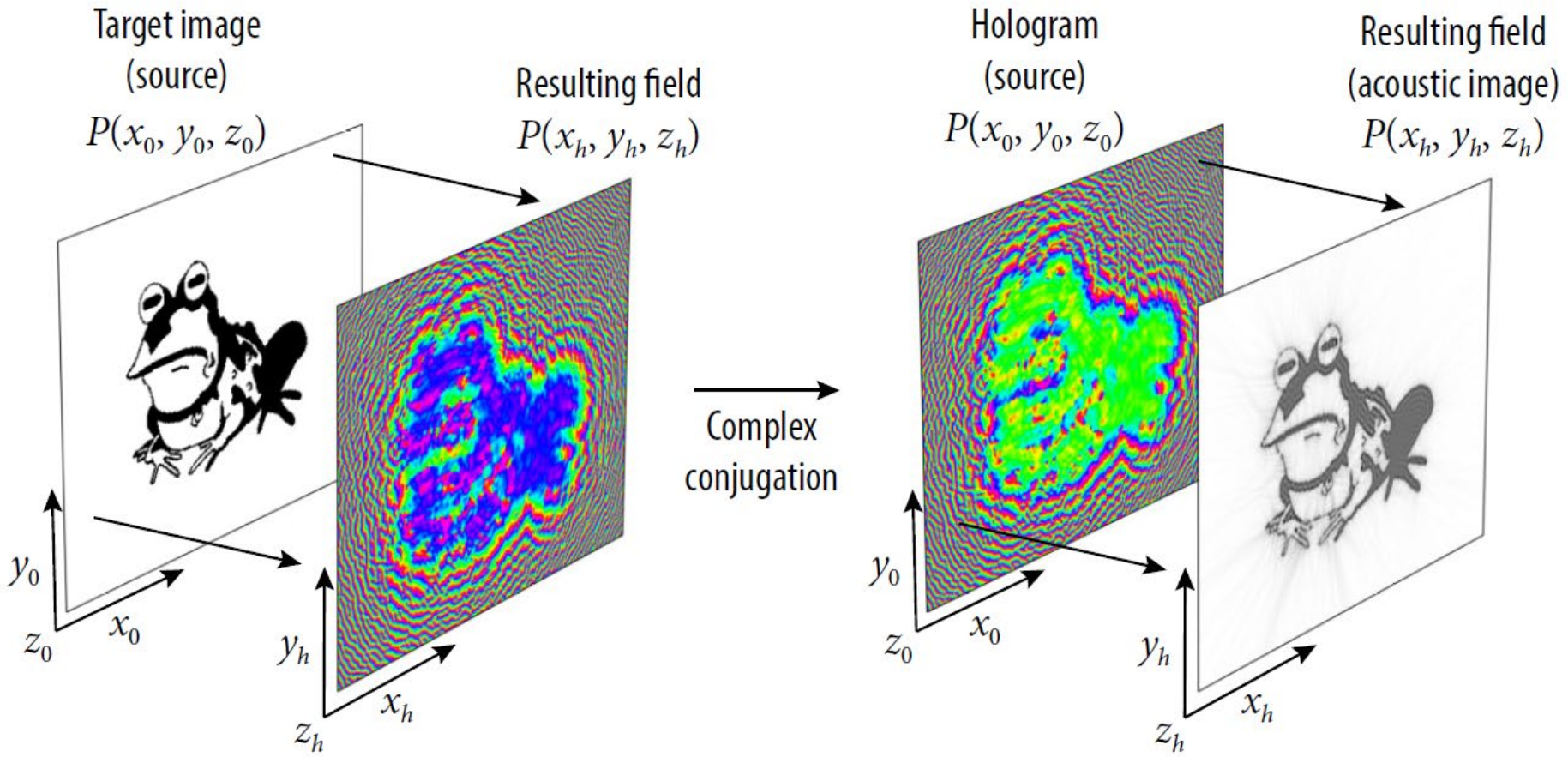
53º Congreso Español de Acústica -Tecniacústica 2022- incorporará el XII Congreso Ibérico de Acústica, November 2-4 2022, Elche, Spain



Introduction

Acoustic holograms

- Hologram generation process



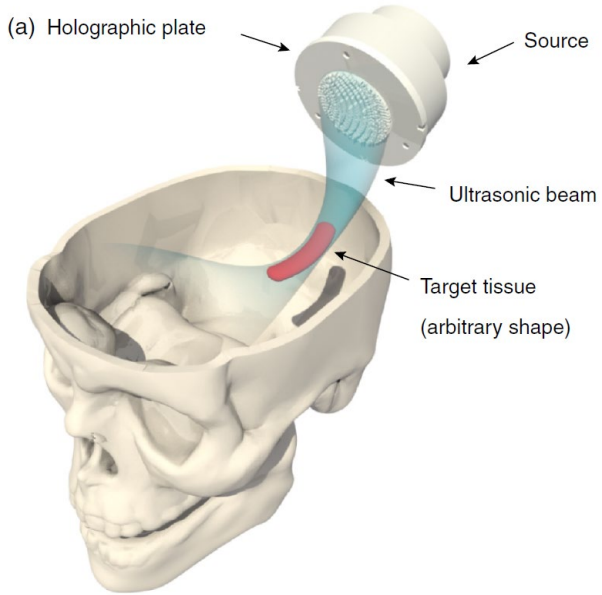
Introduction

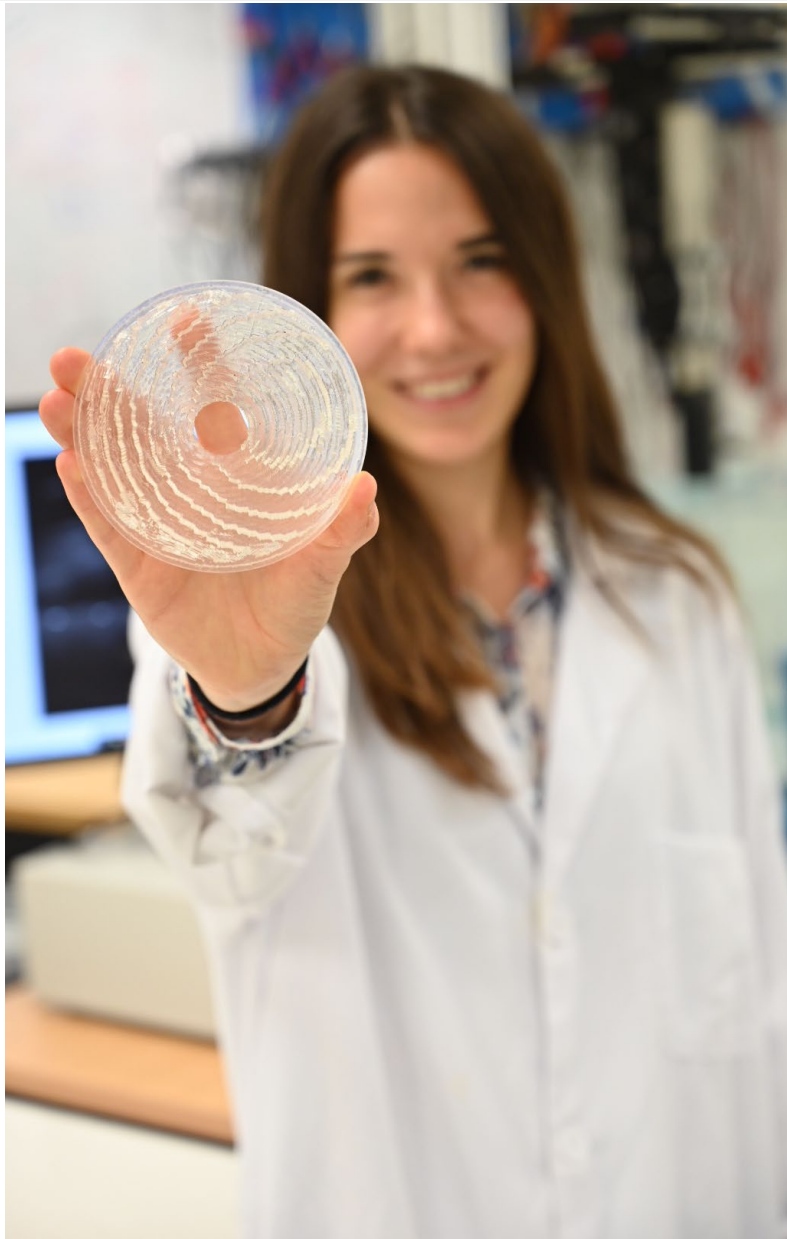
Acoustic holograms

- Essentially acoustic lenses
- The transmitted phase is spatially modulated
- The wavefront propagates and generates and arbitrary acoustic image

Application in neurology

- The phase aberrations of the **skull** can be corrected
- The **pixel density** can be improved
- The image can be tailored to a **therapeutic target**
- **Low-cost** ultrasound devices



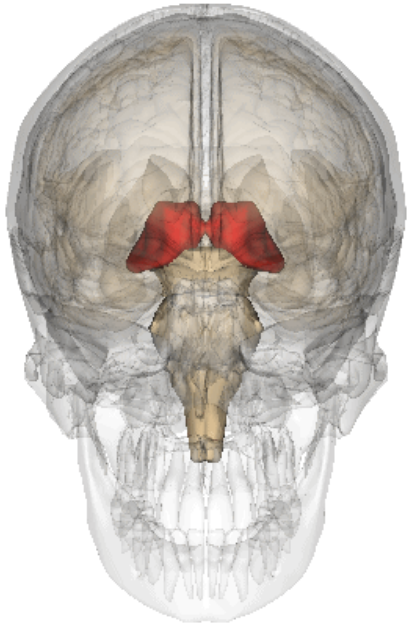


Introduction

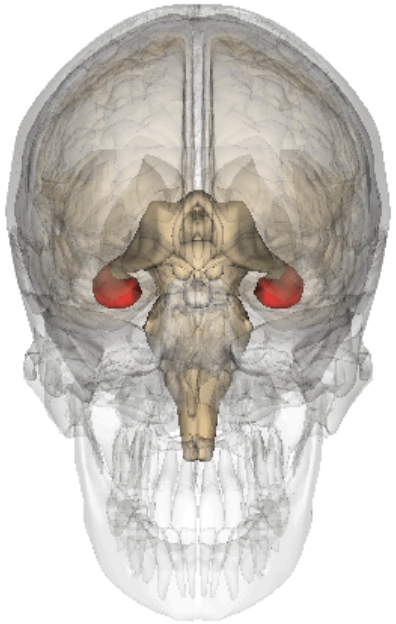
Acoustic holograms

- The image can be tailored to a **therapeutic target**

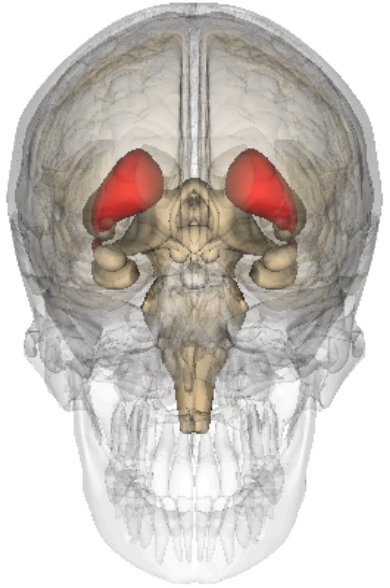
Thalamic nuclei



Hippocampus



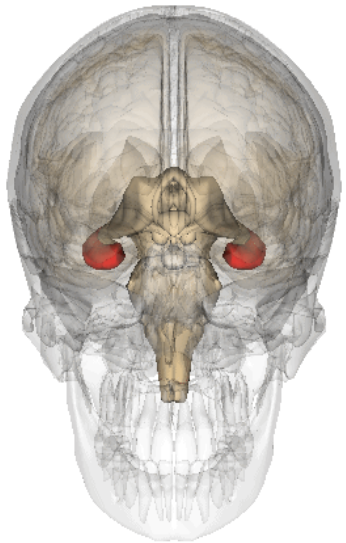
Caudate nucleus

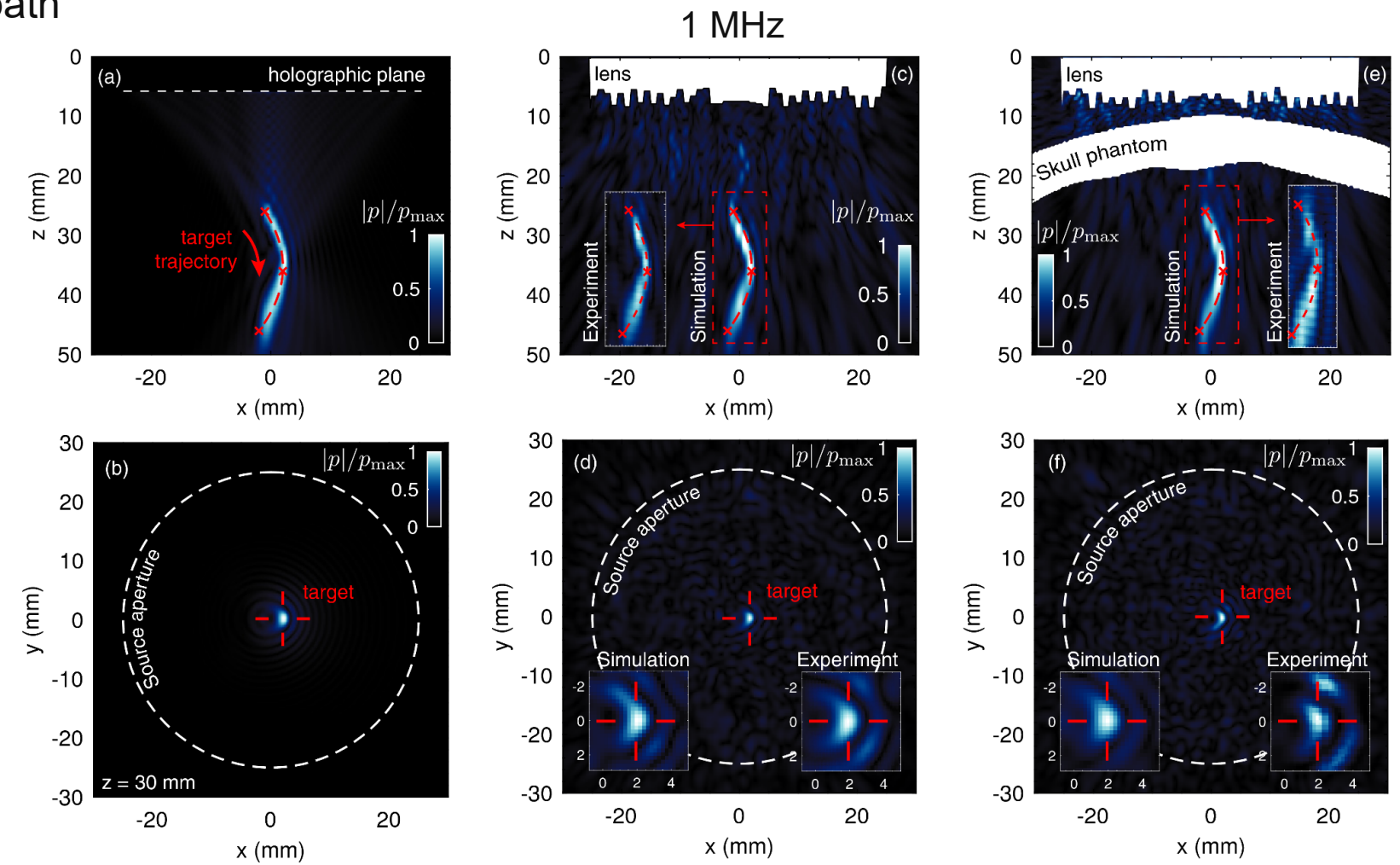


Introduction

Self-bending beams

- Beam can follow an arbitrary path
- Aberration-free propagation
- Diffraction limited beams





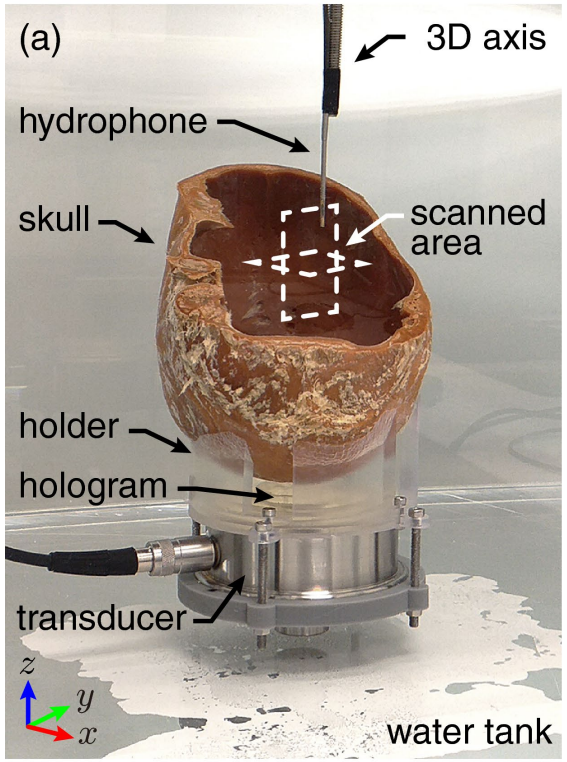
Jiménez-Gambín, et al. Phys Rev Appl 12 014016 (2019)

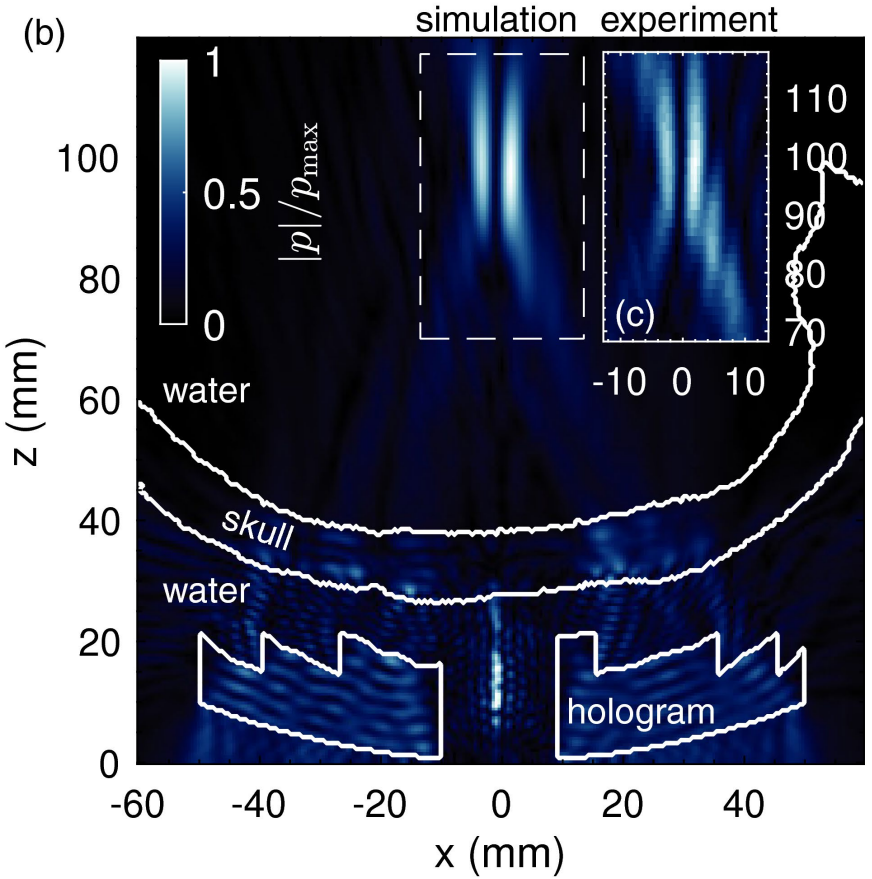
Motivation

Raster scan validation

- Extremely long acquisition times
- Multiple reflections on instrumentation



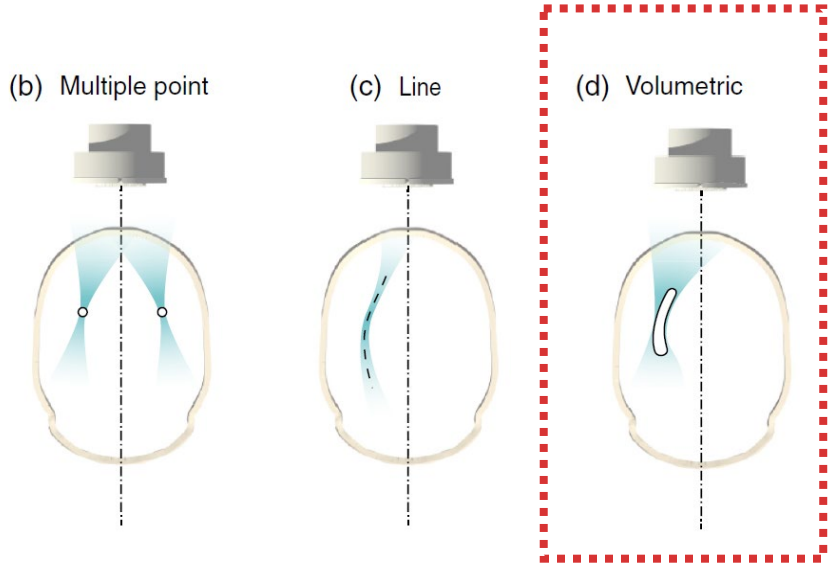




Motivation

Acoustic holograms

- The image can be tailored to a **therapeutic target**
- Complex **volumetric shape**



How can we measure and validate preclinically these therapeutic device?

Methods

Use acoustic holography to measure acoustic holograms

- The field is given by the Raileigh-Sommerfeld equation

$$p(\mathbf{r},t) = i\rho_0 c_0 k e^{i\omega t} \int_S \mathbf{v}_0(\mathbf{r}_0) \frac{e^{-ik|\mathbf{r}-\mathbf{r}_0|}}{2\pi|\mathbf{r}-\mathbf{r}_0|} dS_0$$

- It is a spatial convolution between the source radiation and the Green's function in 3D

$$G(r) = \frac{e^{-ikr}}{4\pi r}.$$

- The field can be obtained in the spatial frequency domain simply as a product

$$P(k_x,k_y,z,t) = i\rho_0 c_0 k e^{i\omega t} V(k_x,k_y) H(k_x,k_y,z)$$

- Where the propagator is given by

$$H(k_x,k_y,z) = \frac{\exp(-izk_z)}{ik_z},$$

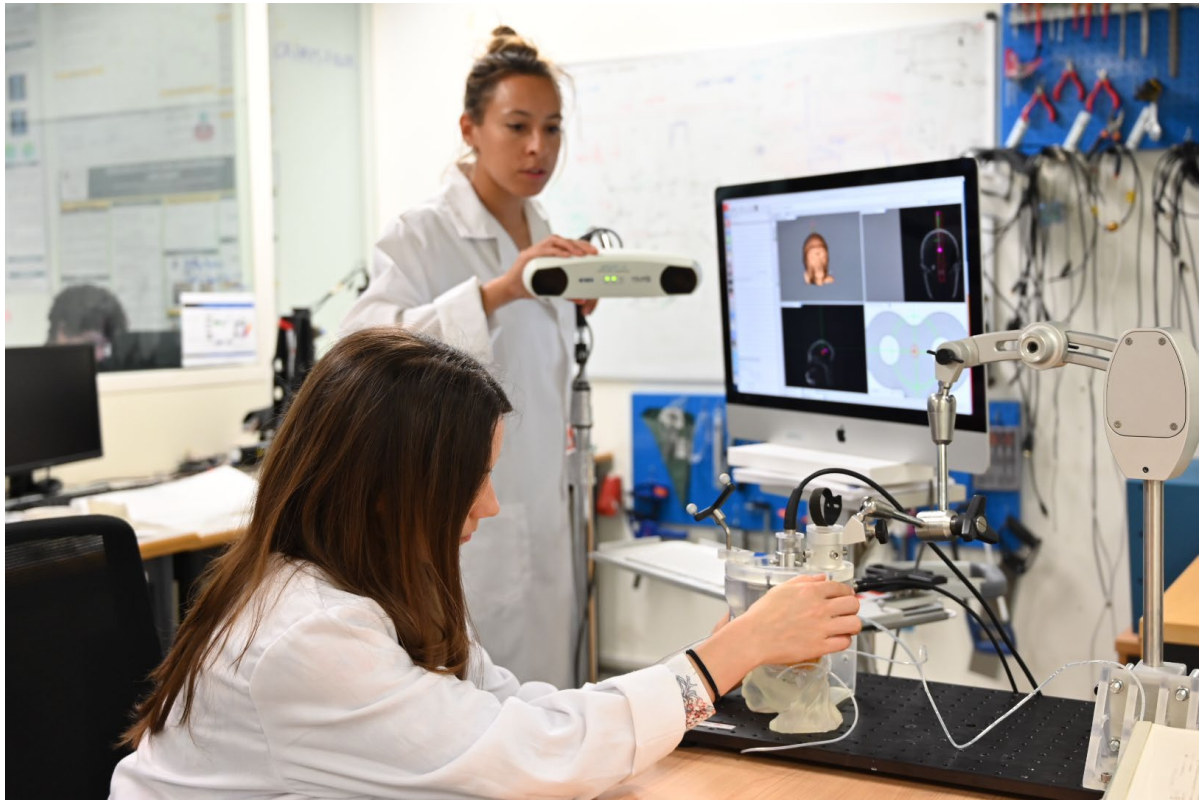
- And the axial, and transverse wave vector components are

$$k_z^2 = k^2 - k_x^2 - k_y^2 \qquad k_x = \cos(\theta)\cos(\phi)k, \qquad k_y = \sin(\theta)\cos(\phi)k,$$

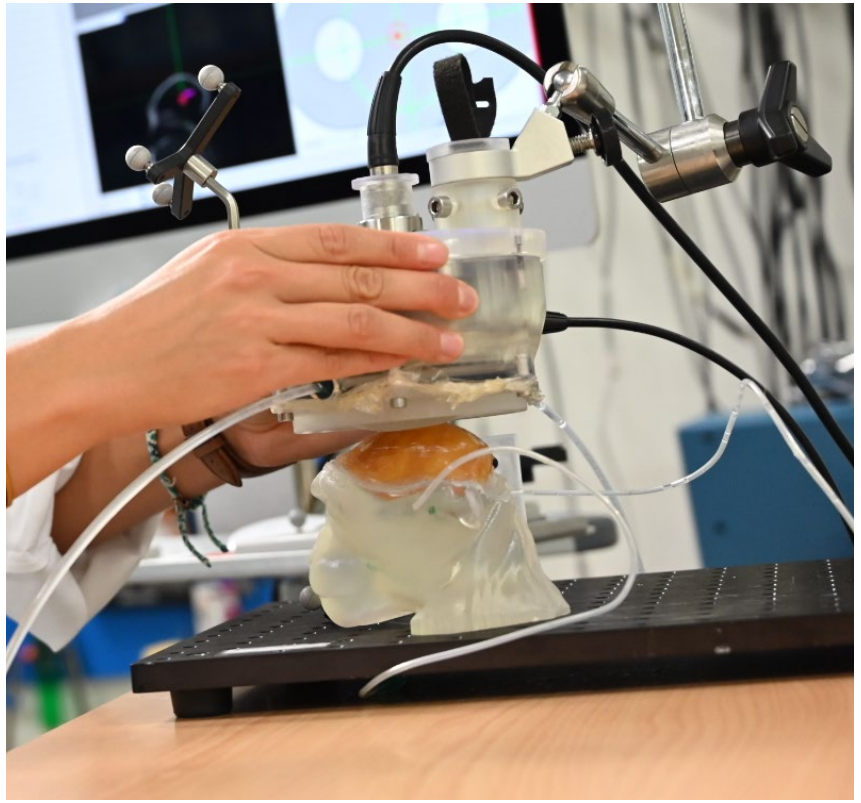
Application (1): transcranial propagation

Validation for a preclinical treatment

- Preclinical setup

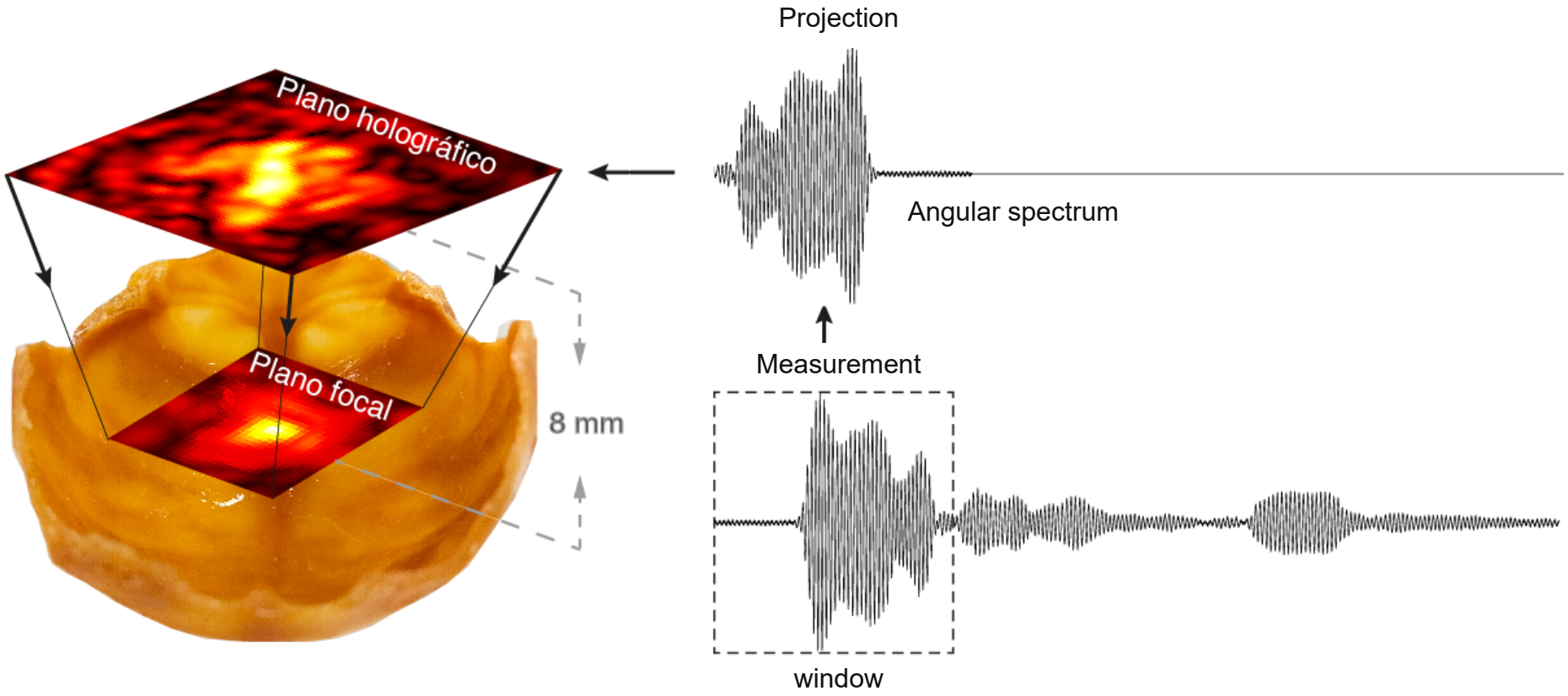


Quantify field inside the skull?



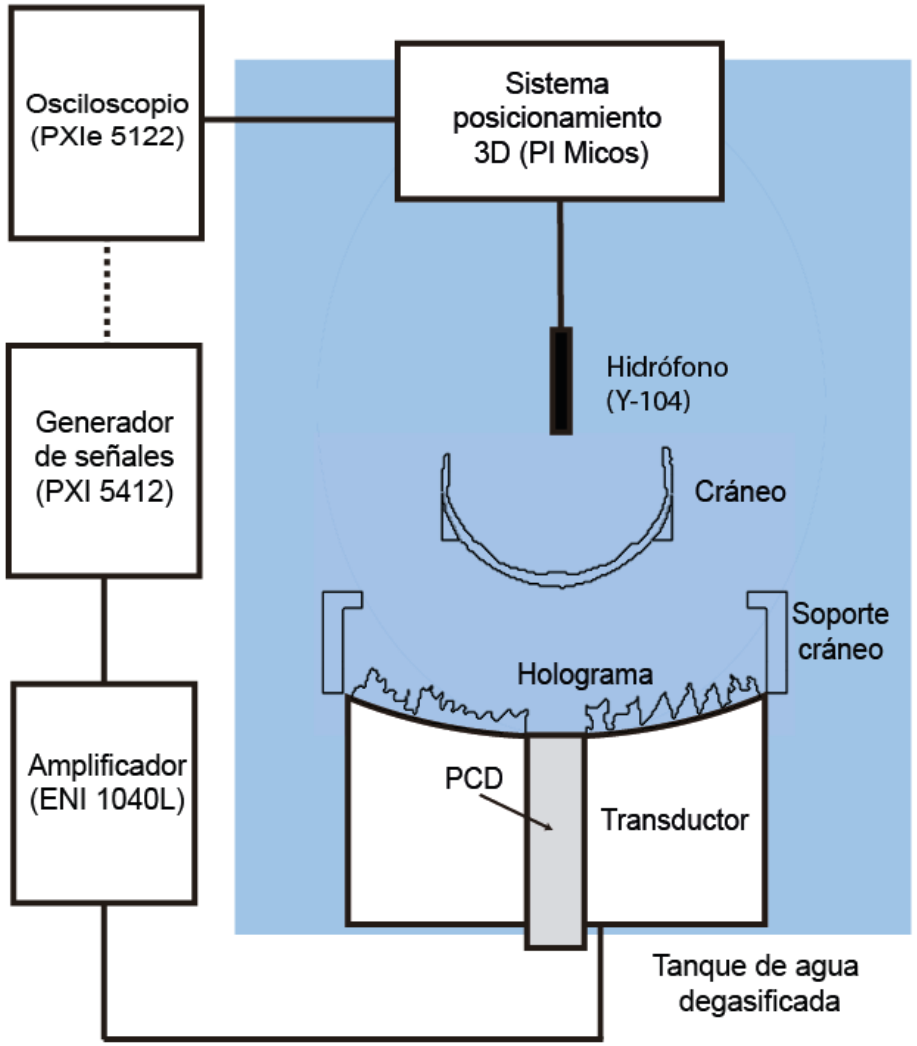
Application (1): transcranial propagation

Holographic projection

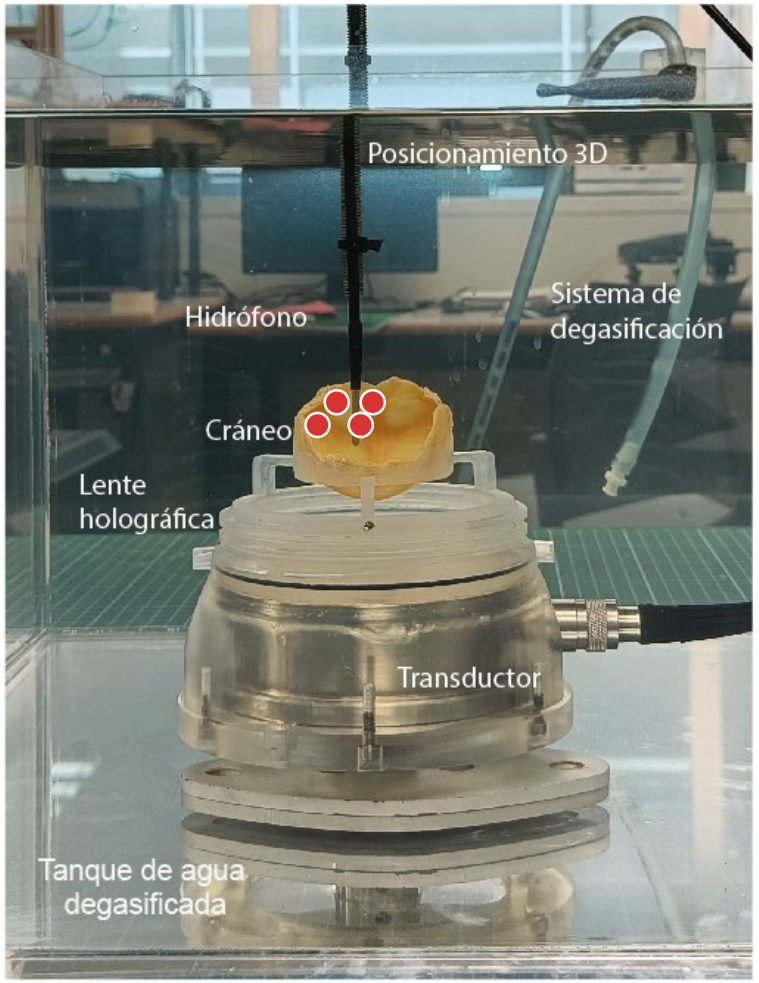


Application (1): transcranial propagation

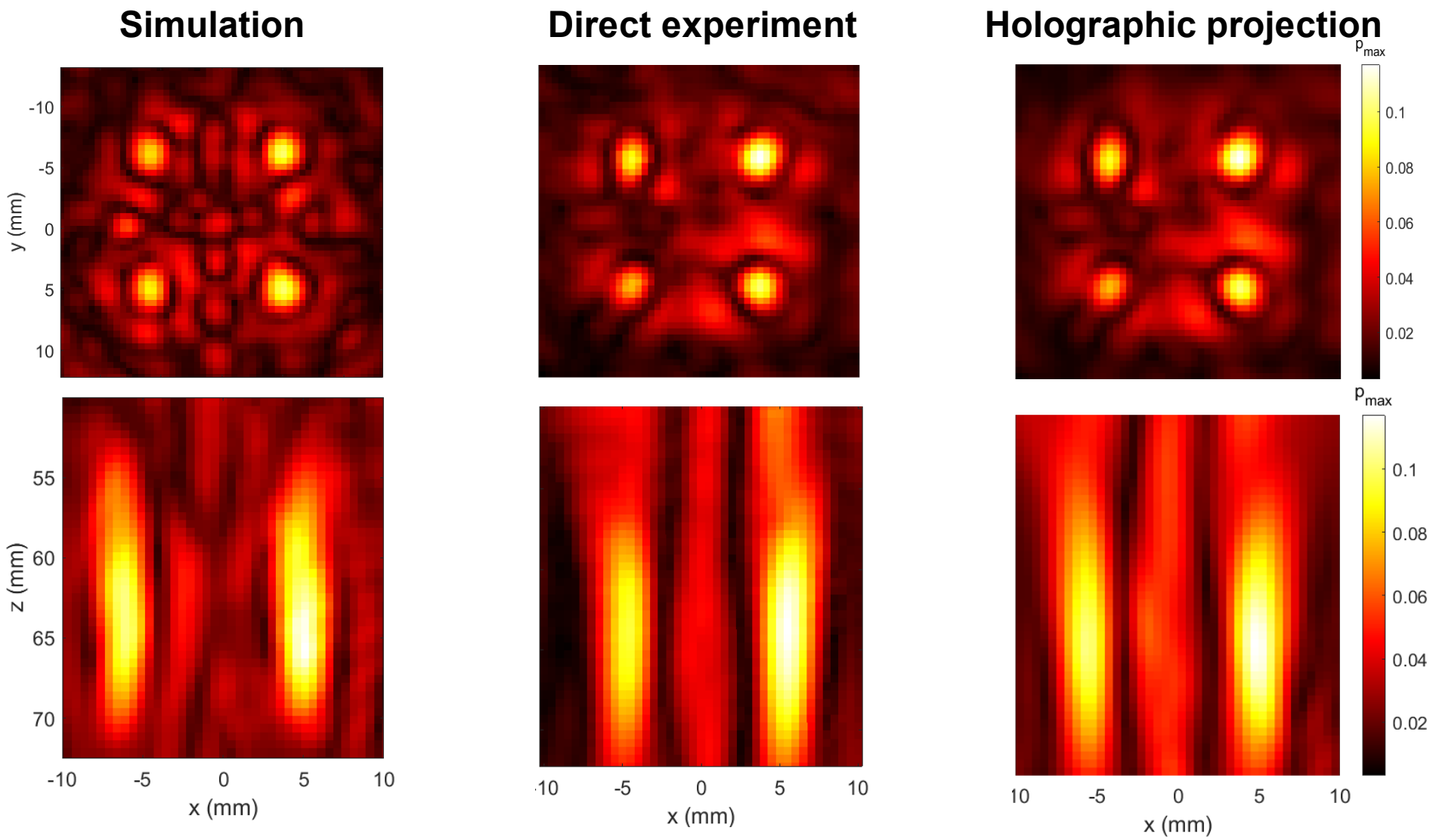
Validation for a preclinical treatment



Multiple target lens



Application (1): transcranial propagation



And beyond …

Holograms

- Acoustic holograms can shape very complex 3D fields

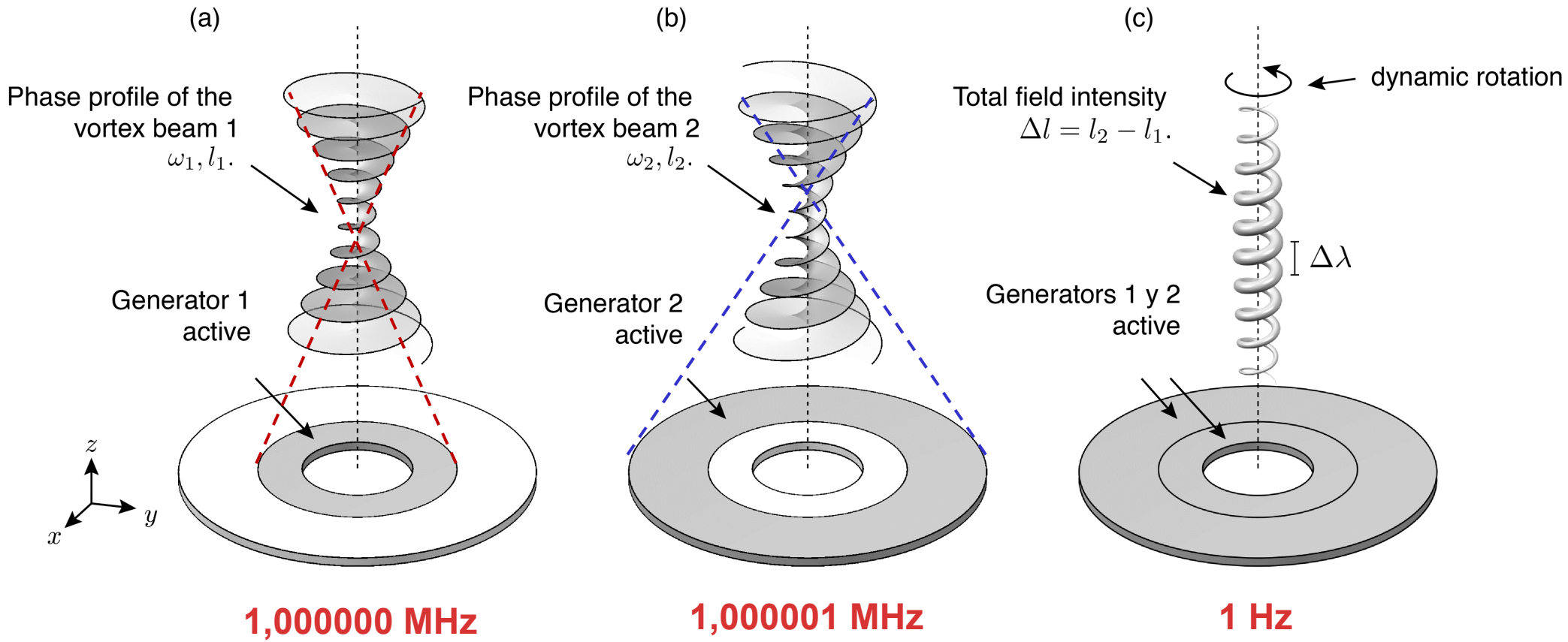
Can we measure 3D complex and dynamic fields generated by acoustic holograms?

Application (2): Acoustic drills

Complex beams

- Spatio-temporal interference of detuned beams.
- Detuning in **axial wavenumber**, **topological charge**, and **frequency**.

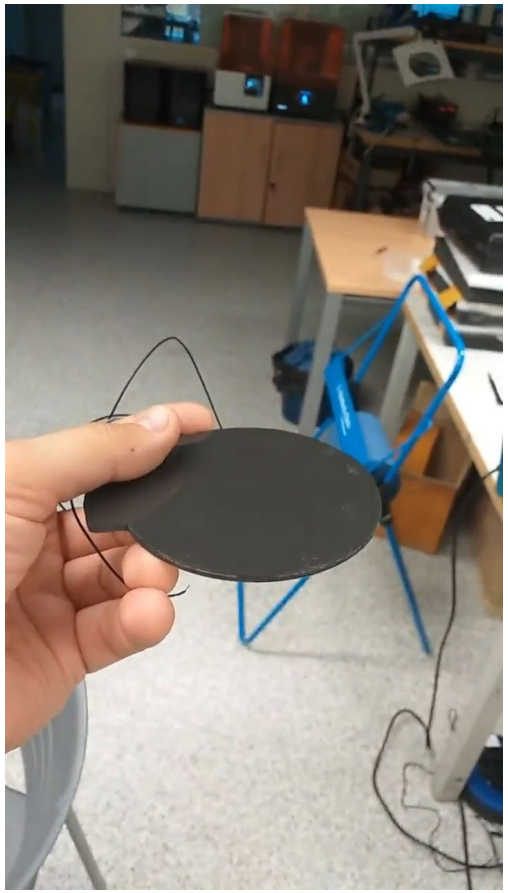
Acoustic drills
ULT-0 Sala 2, Miércoles 2 Noviembre

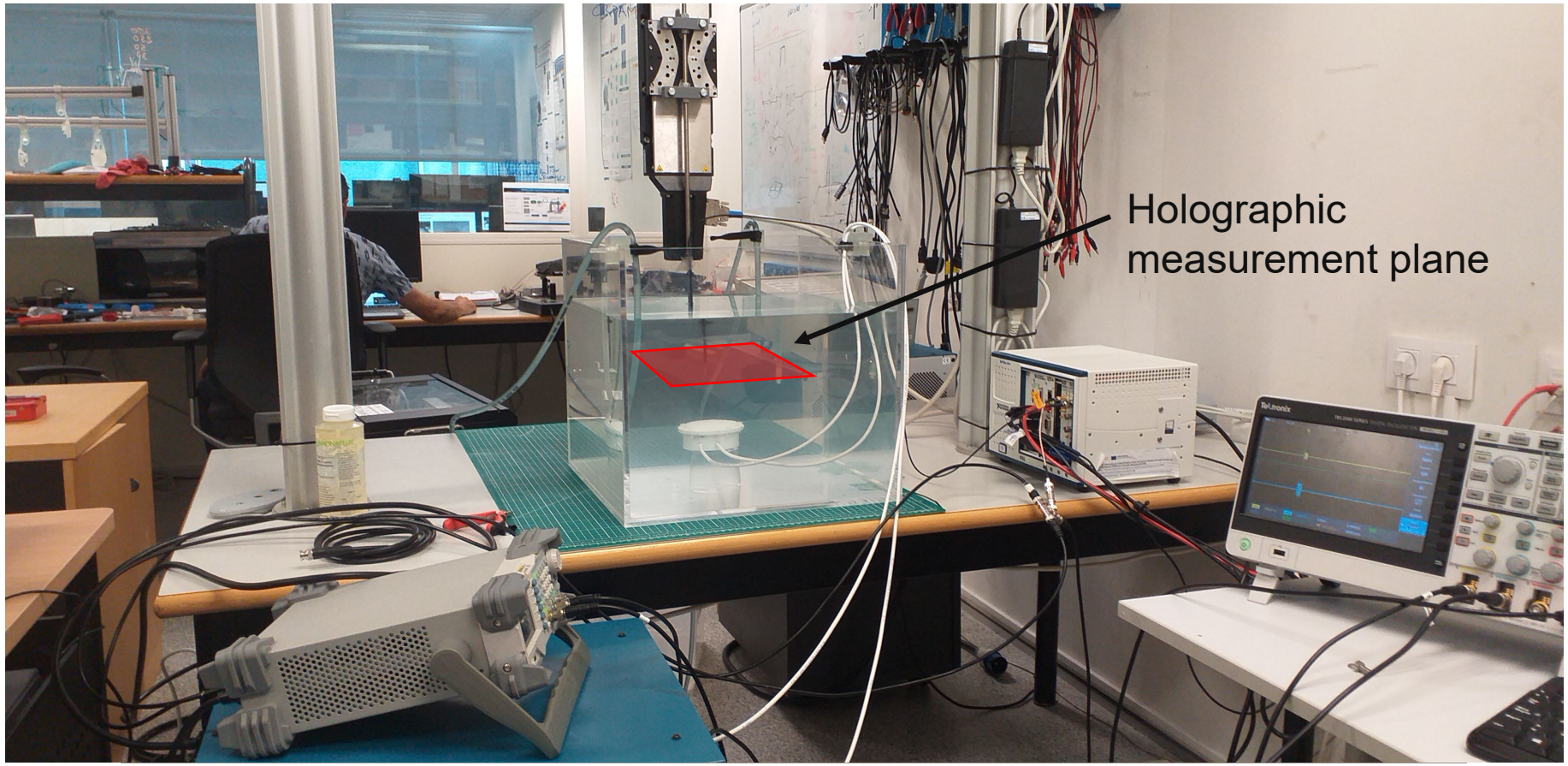


Application (2): Acoustic drills

Lenses and holograms

Holographic projection method
PSA-0 Sala 1, Jueves 3 Noviembre



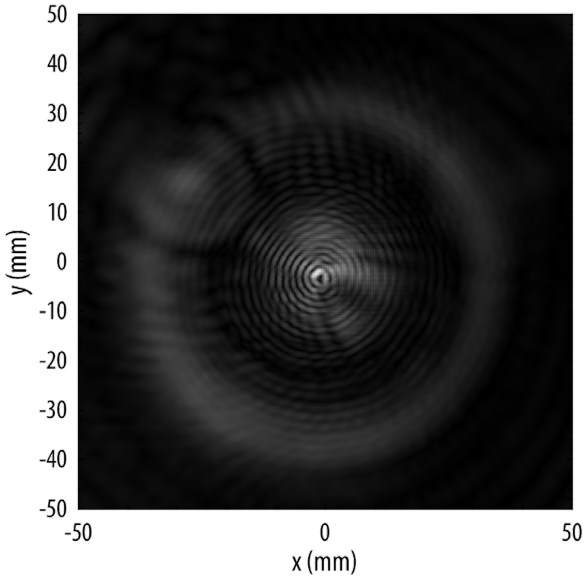


Application (2): Acoustic drills

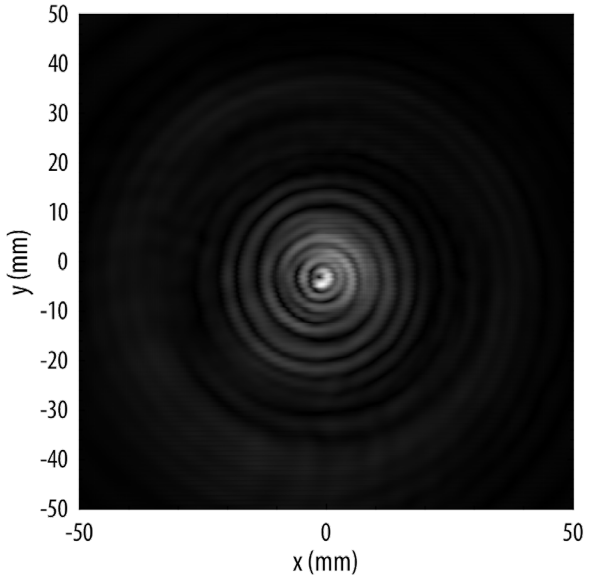
Realistic acoustic drill beam

- Topological charge 1: $l_1 = 1$
- Topological charge 2: $l_2 = -2$
- Nominal frequency: $f_0 = 1$ MHz
- Detuning frequency: $f_d = 1$ Hz

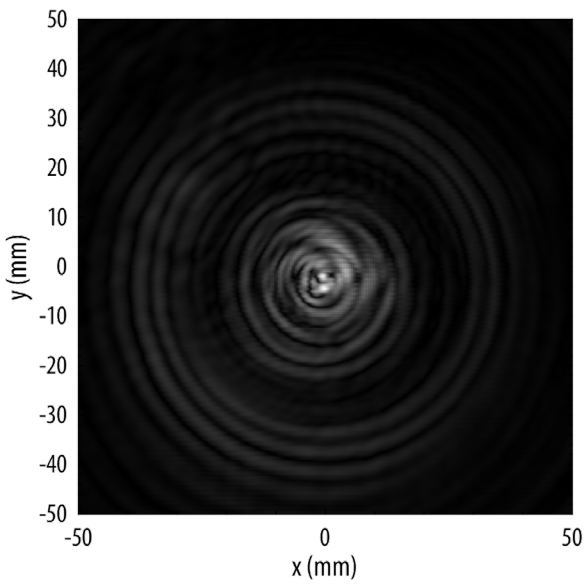
Beam A

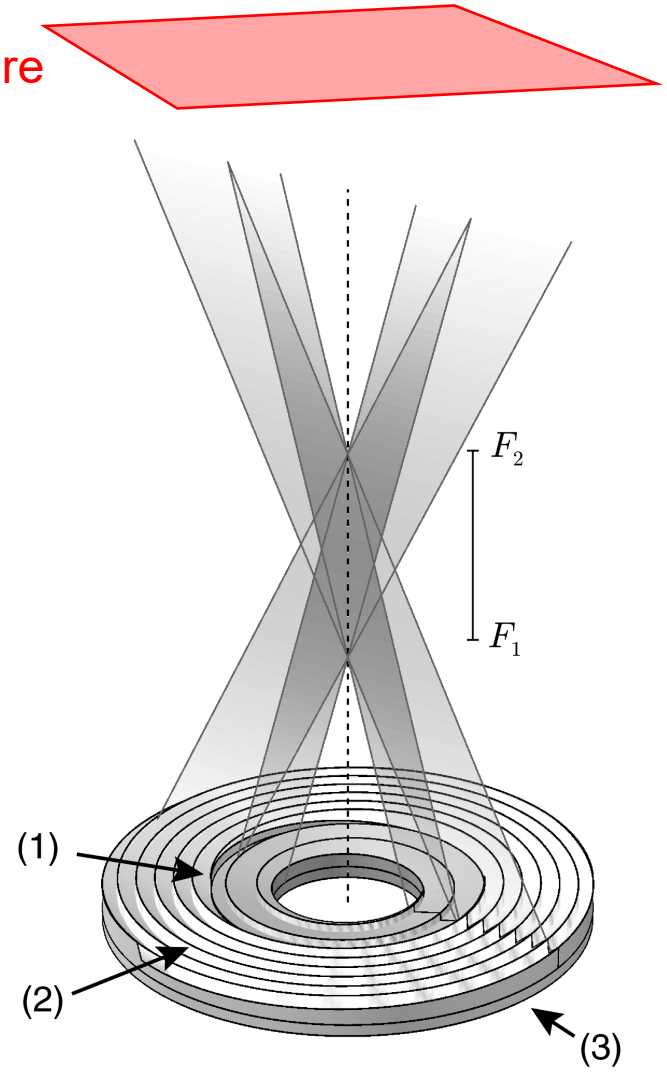


Beam B



Beams A+B



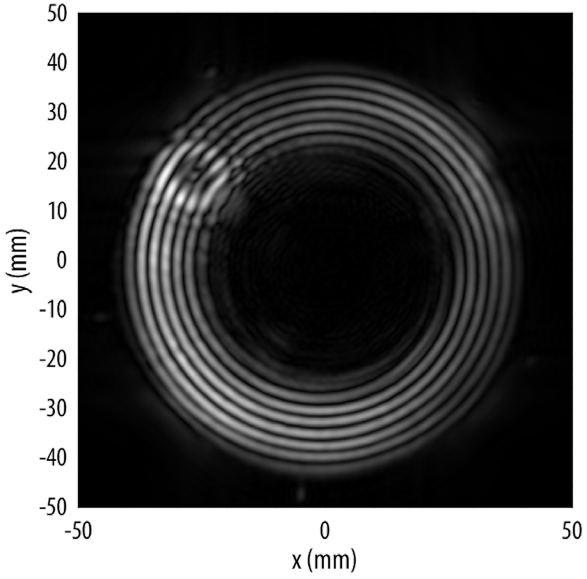


Application (2): Acoustic drills

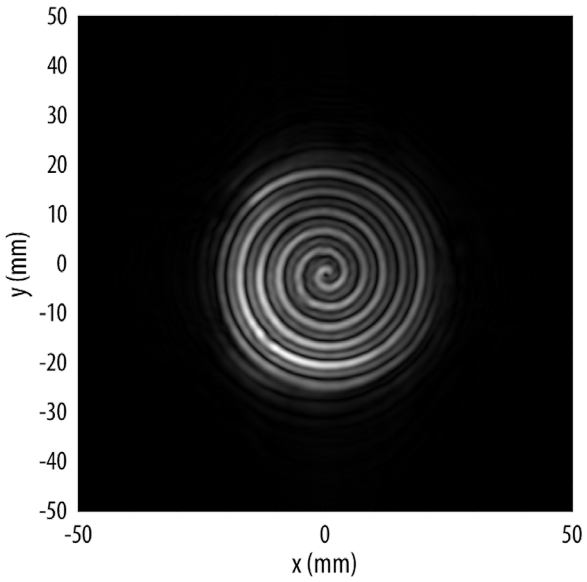
Realistic acoustic drill beam

- Topological charge A: $l_1 = 1$
- Topological charge B: $l_2 = -2$

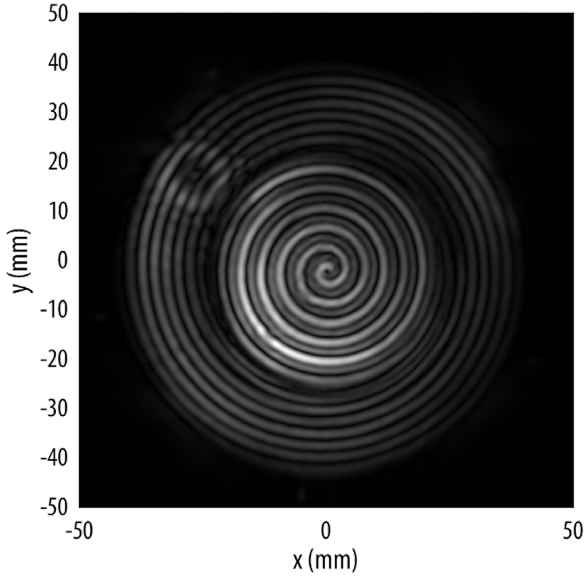
Beam A

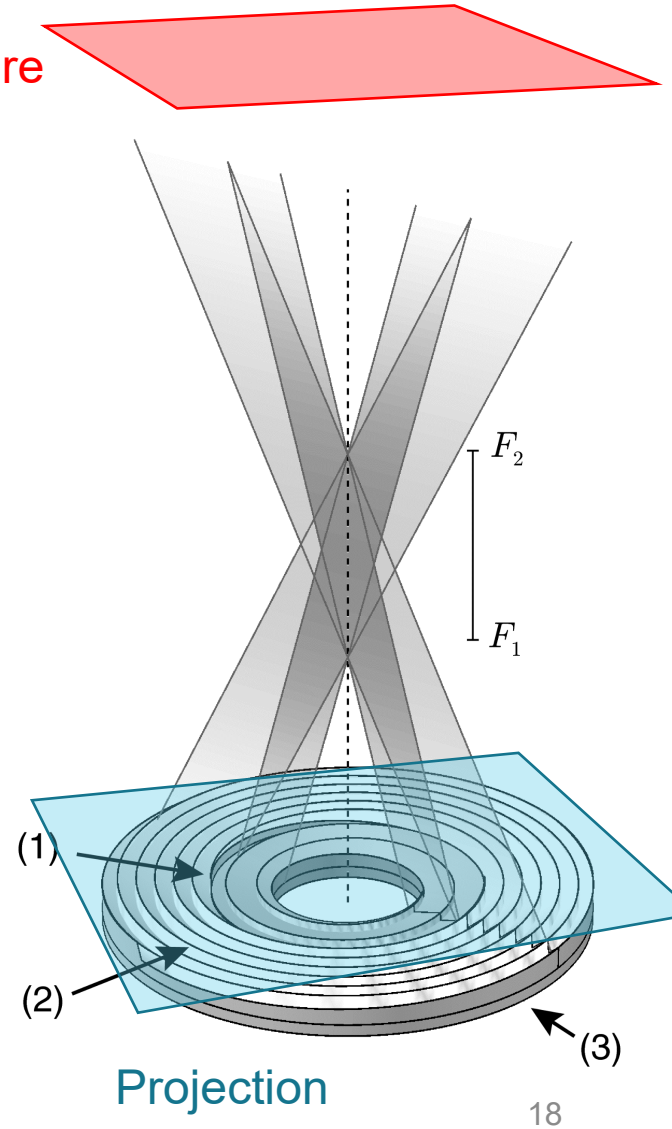


Beam B



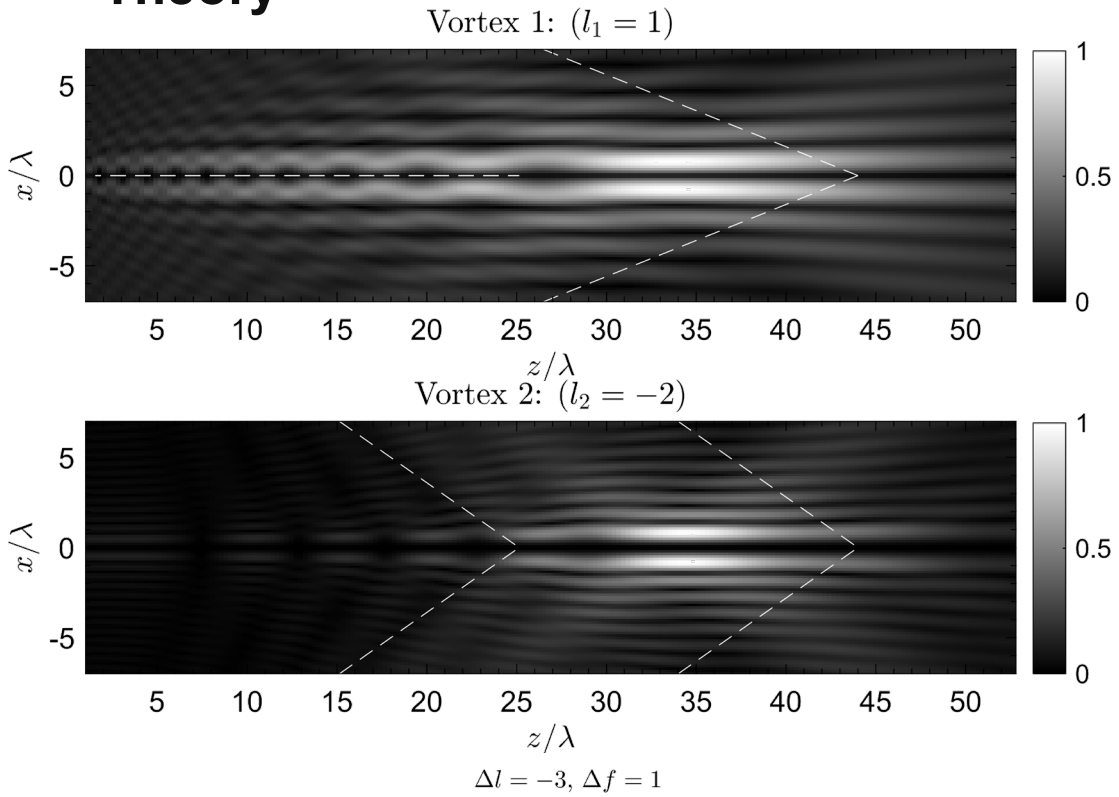
Beams A+B





Results

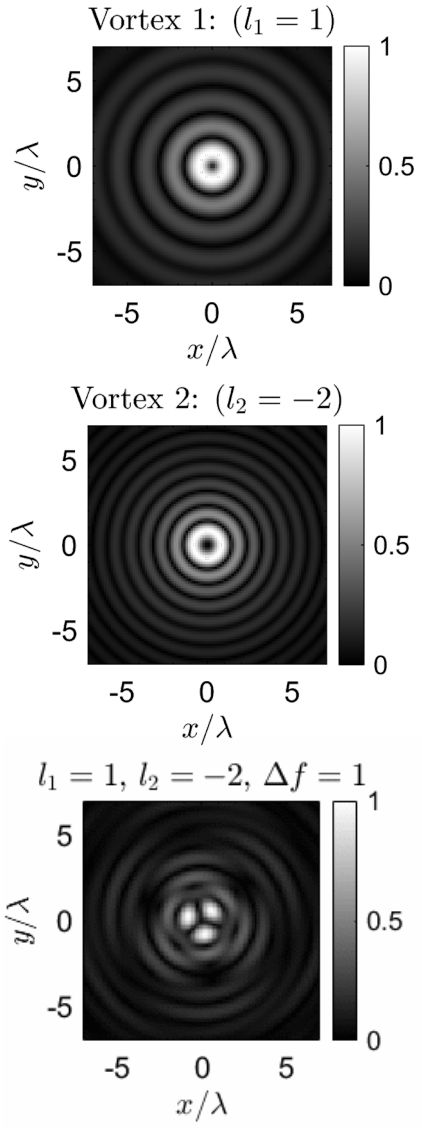
Theory



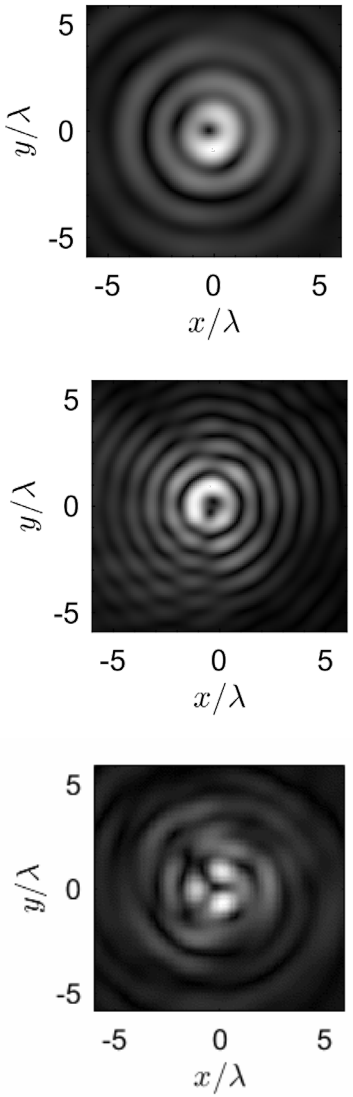
Theory



Theory



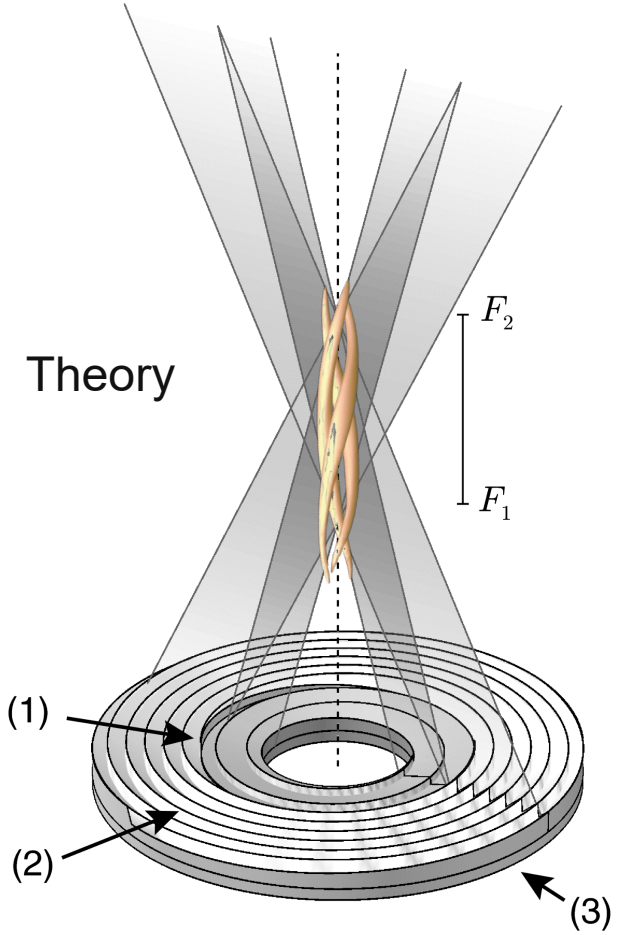
Experiment

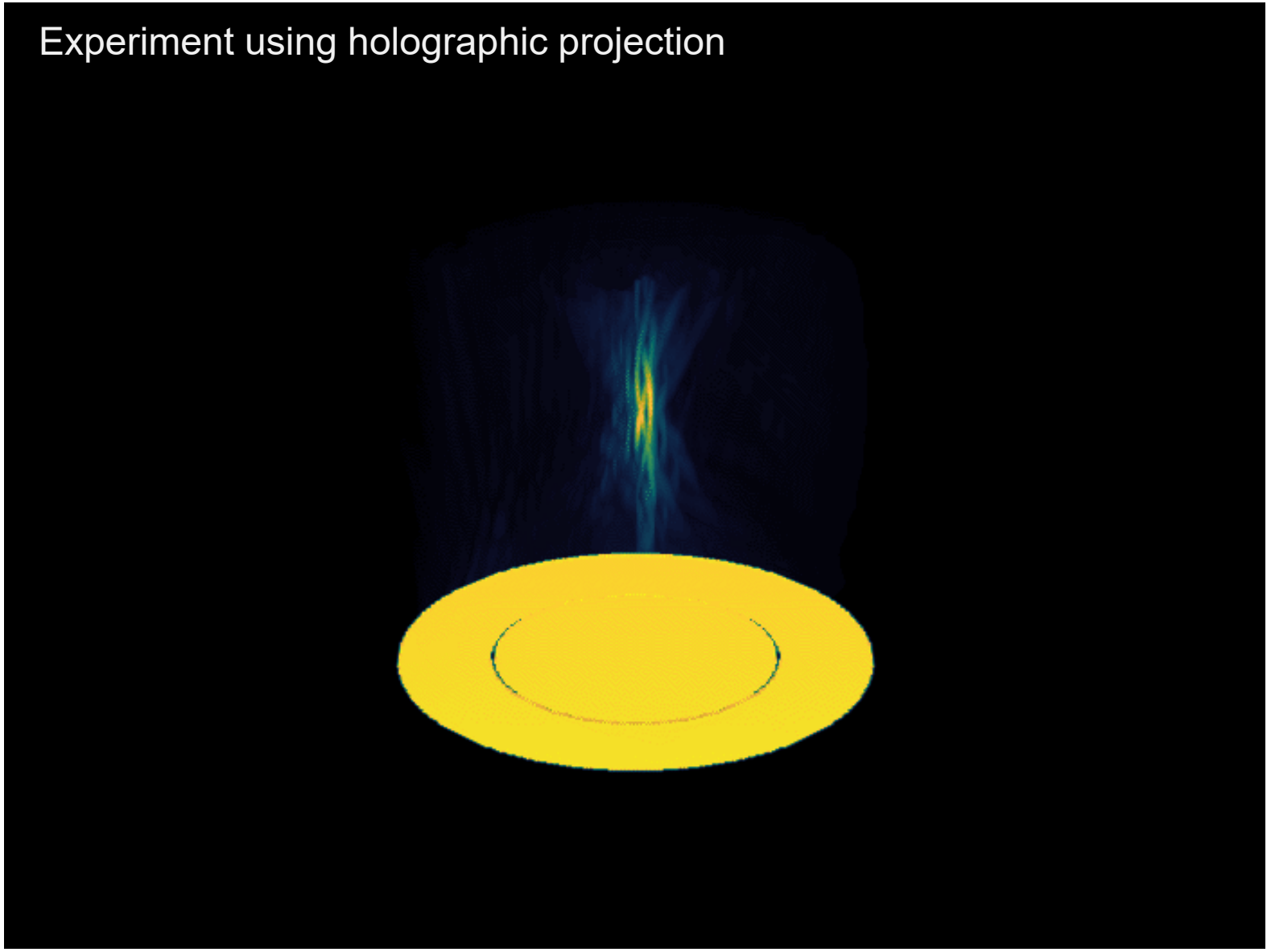


Application (2): Acoustic drills

Realistic acoustic drill beam

- Topological charge A: $l_1 = 1$
- Topological charge B: $l_2 = -2$





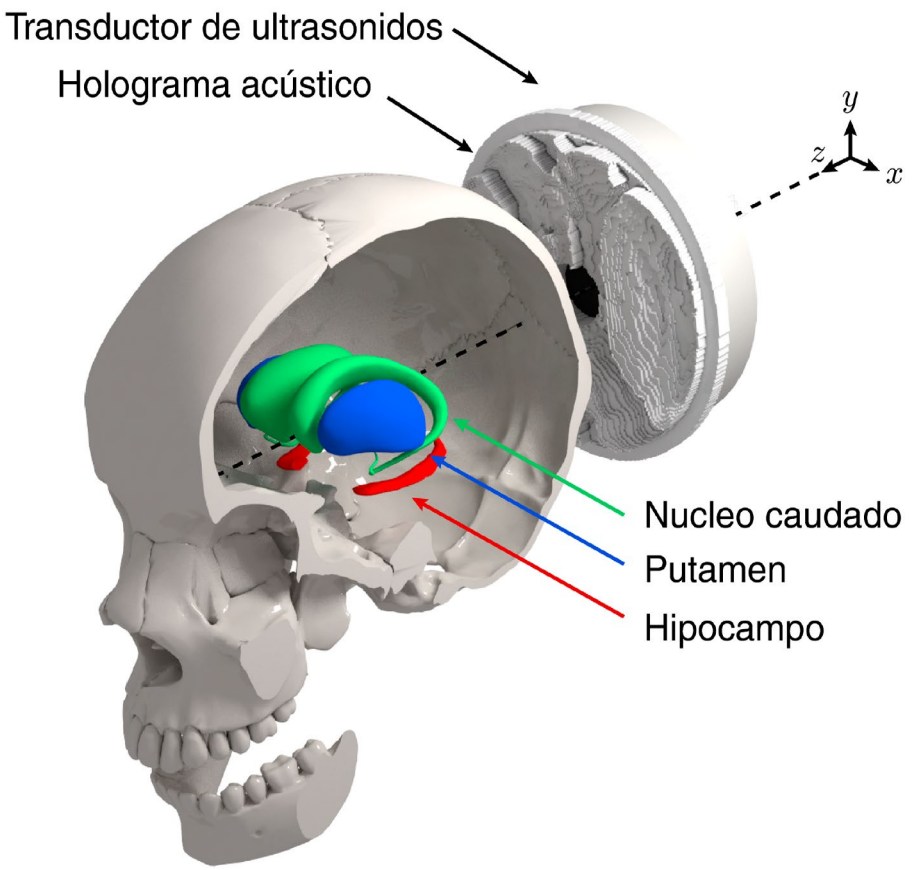
Conclusions

Acoustic holograms

- Are flexible to synthesize arbitrary acoustic field
- Waves can be tailored with a high degree of freedom in 3D
- Low-cost therapeutic systems for biomedical ultrasound
- Complex validation using tradition methods

Acoustic holography

- Can be used effectively to measure the source vibration
- Hologram performance in the near field
- Validate the 3D the wavefront structure



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