Elastographie : imagerie sismique du corps humain

LOA: Stefan Catheline, Laurent Sandrin, Jean-Luc Gennisson, Jeremy Bercoff, Mickaël Tanter, Ros Kiri Ing, Nicolas Quieffin, Christophe Barrière, Xavier Jacob, Daniel Royer, Didier Cassereau, Mathias Fink

LAU: Carlos Negreira, Xavier Brum, Nicolas Benech, Thomas Gallot

LGIT: Thomas Gallot, Philippe Roux, Soumaya Latour, Eric Larose, Michel Campillo

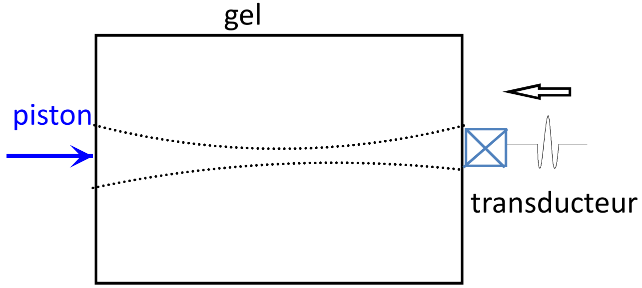
Palpation = élasticité de cisaillement

Échographie = élasticité de compression

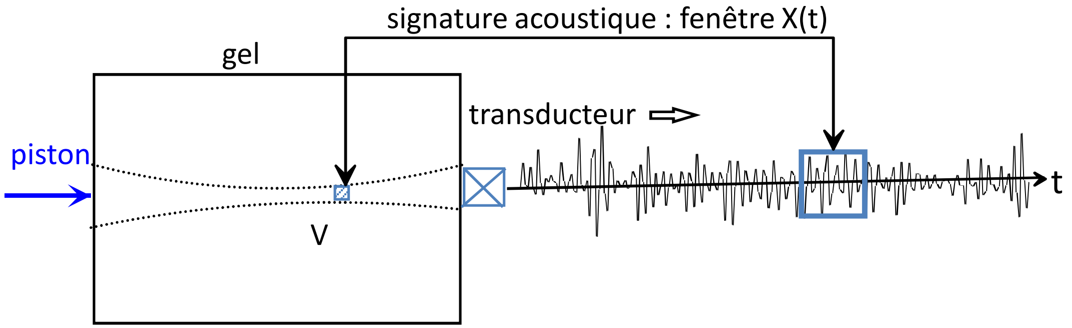
Enjeu : -imagerie de palpation
-physique des ondes dans la matière molle

Qu’est-ce que l’élastographie?

Interférométrie speckle ultrasonore

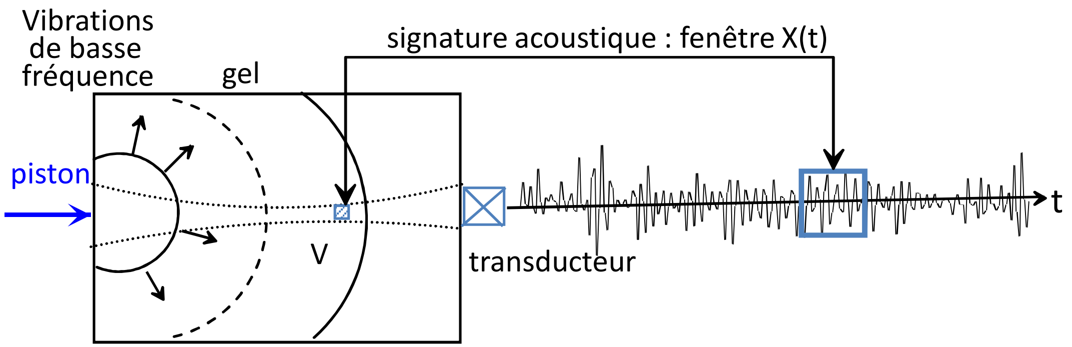


Interférométrie speckle ultrasonore



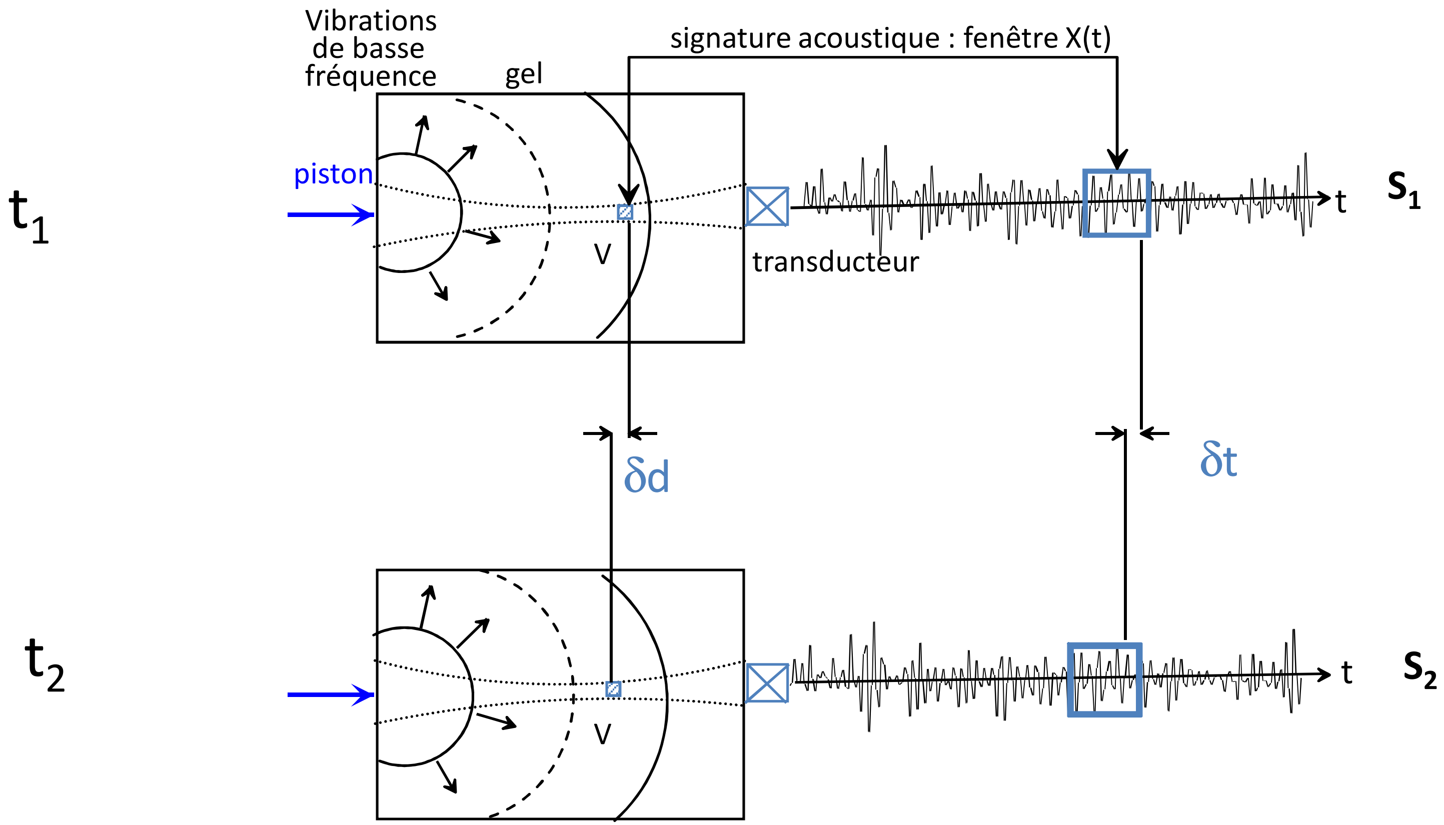
Interférométrie speckle ultrasonore

t_1

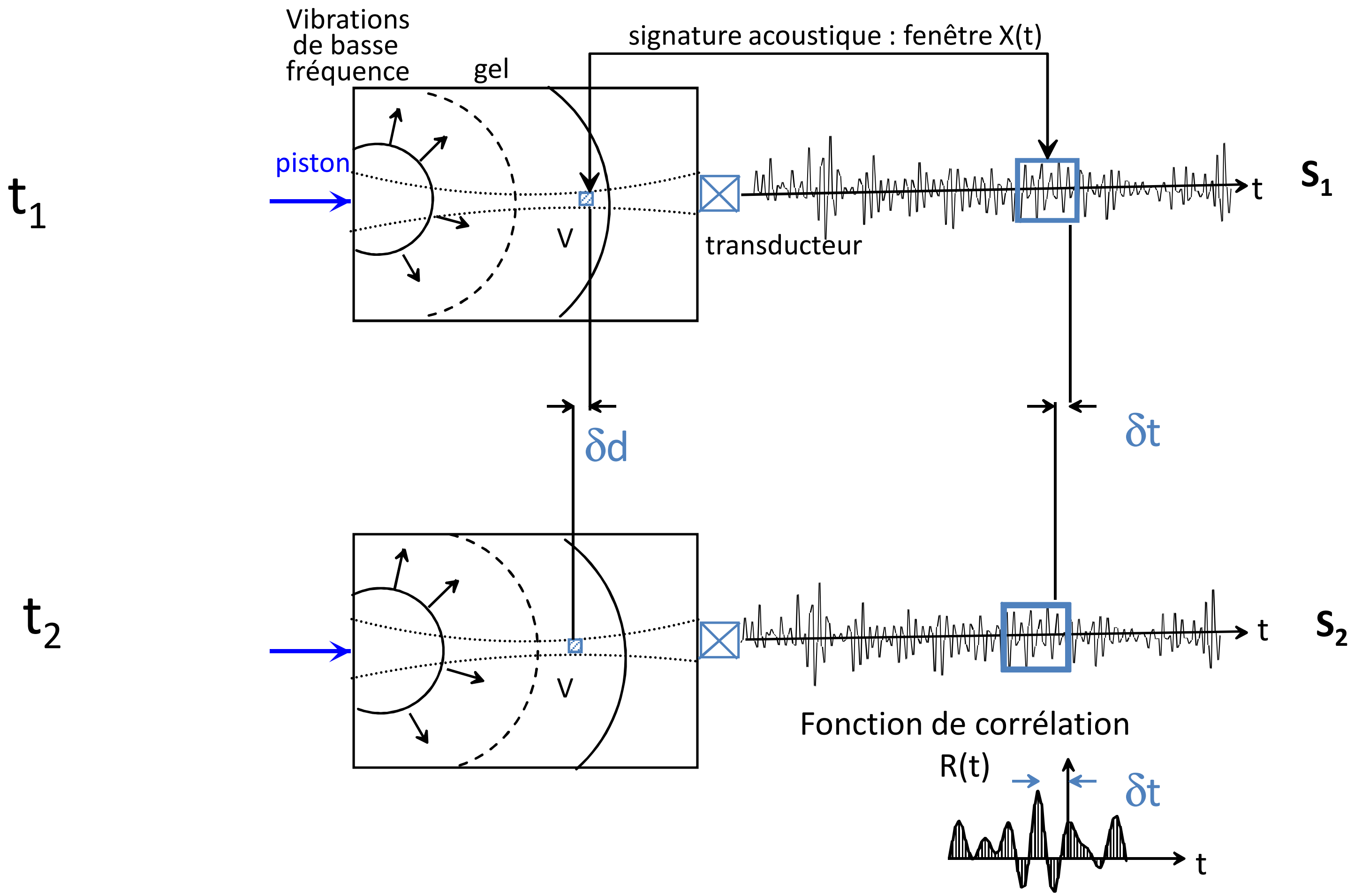


S_1

Interférométrie speckle ultrasonore



Traitement de signal : intercorrélation interpolée



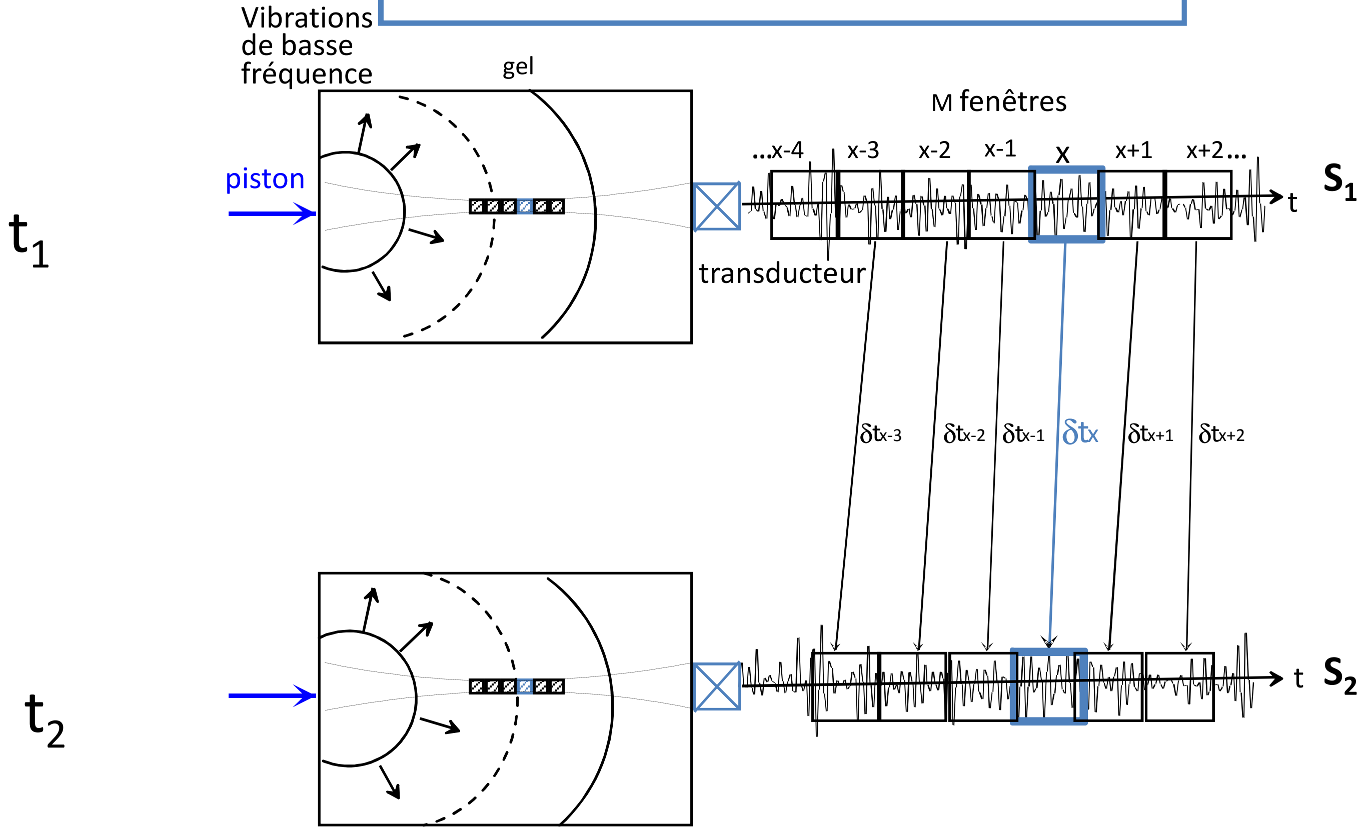
RESULTAT:

Déplacement AXIAL de la fenêtre X

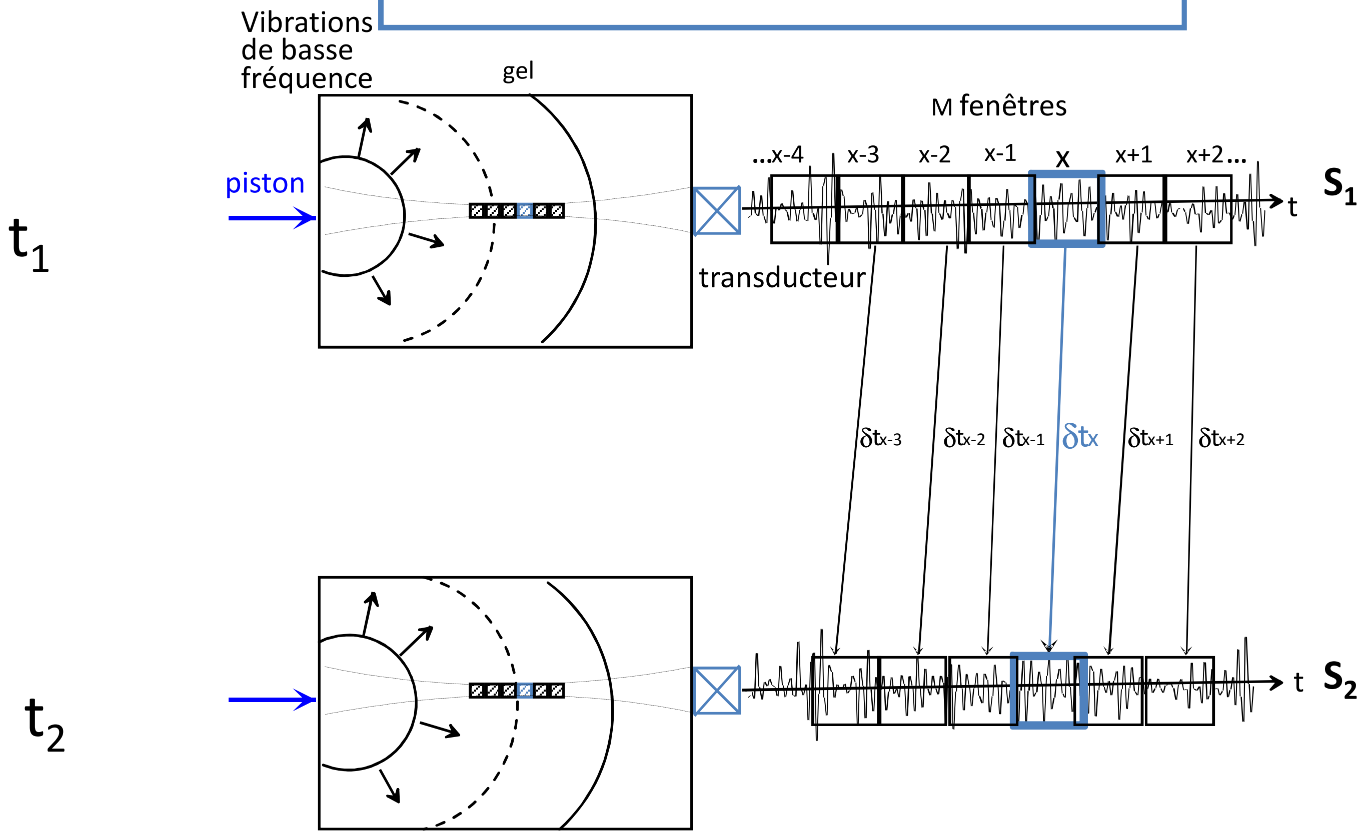
$\boxed{\delta d = c\ \delta t/2}$

(Precision 1 µm)

1) Itération sur les fenêtres

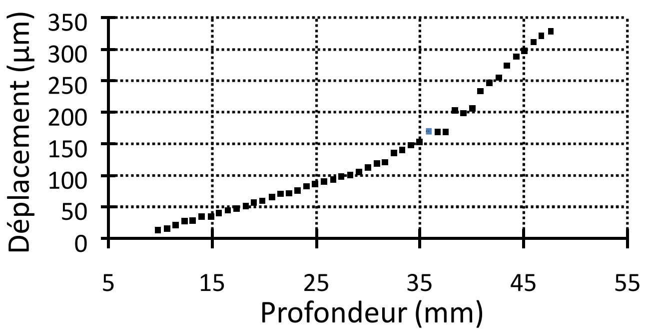


1) Itération sur les fenêtres

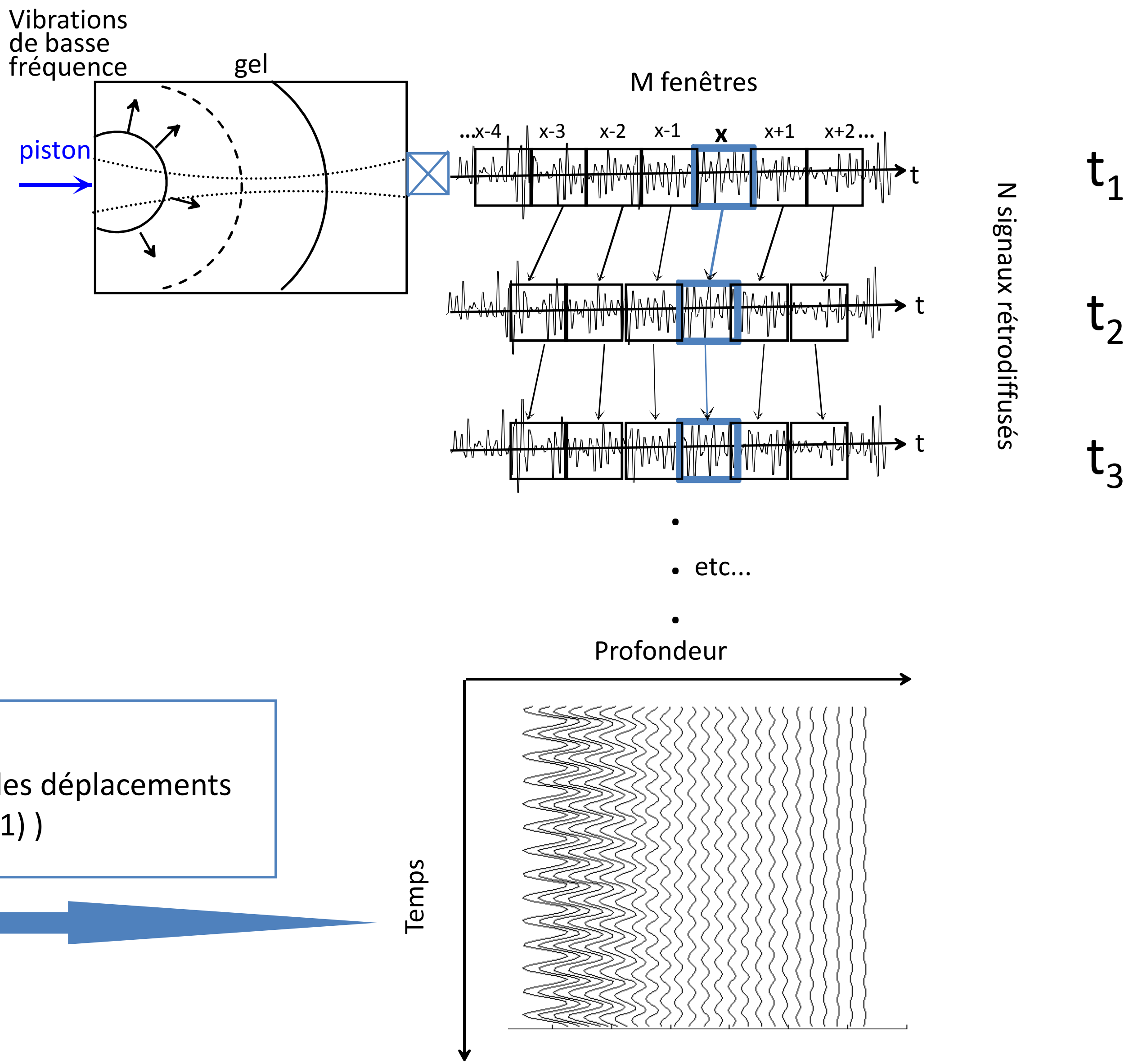


RESULTAT:

Déplacement des M fenêtres entre S_1 et S_2

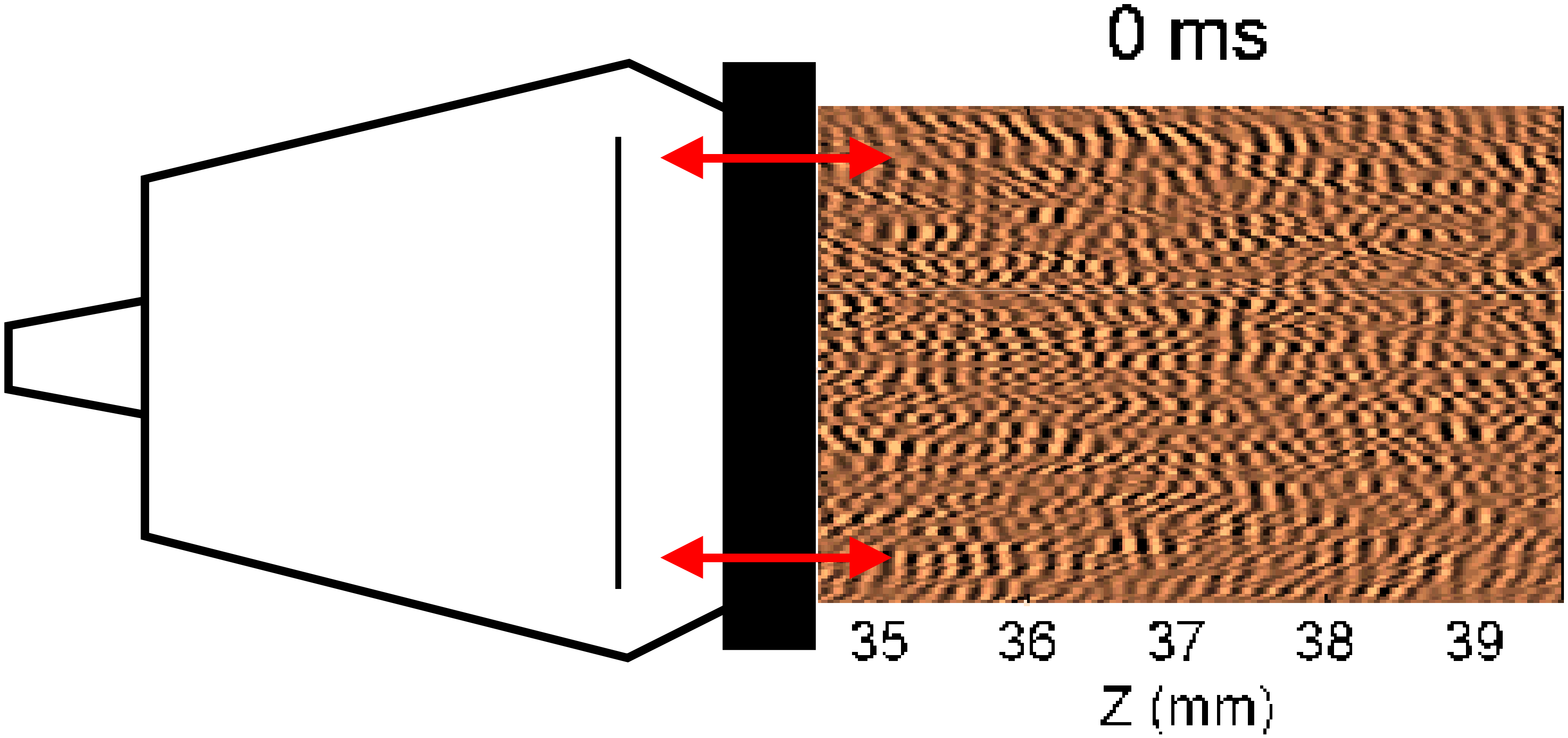


2) Itération sur les tirs ultrasonores

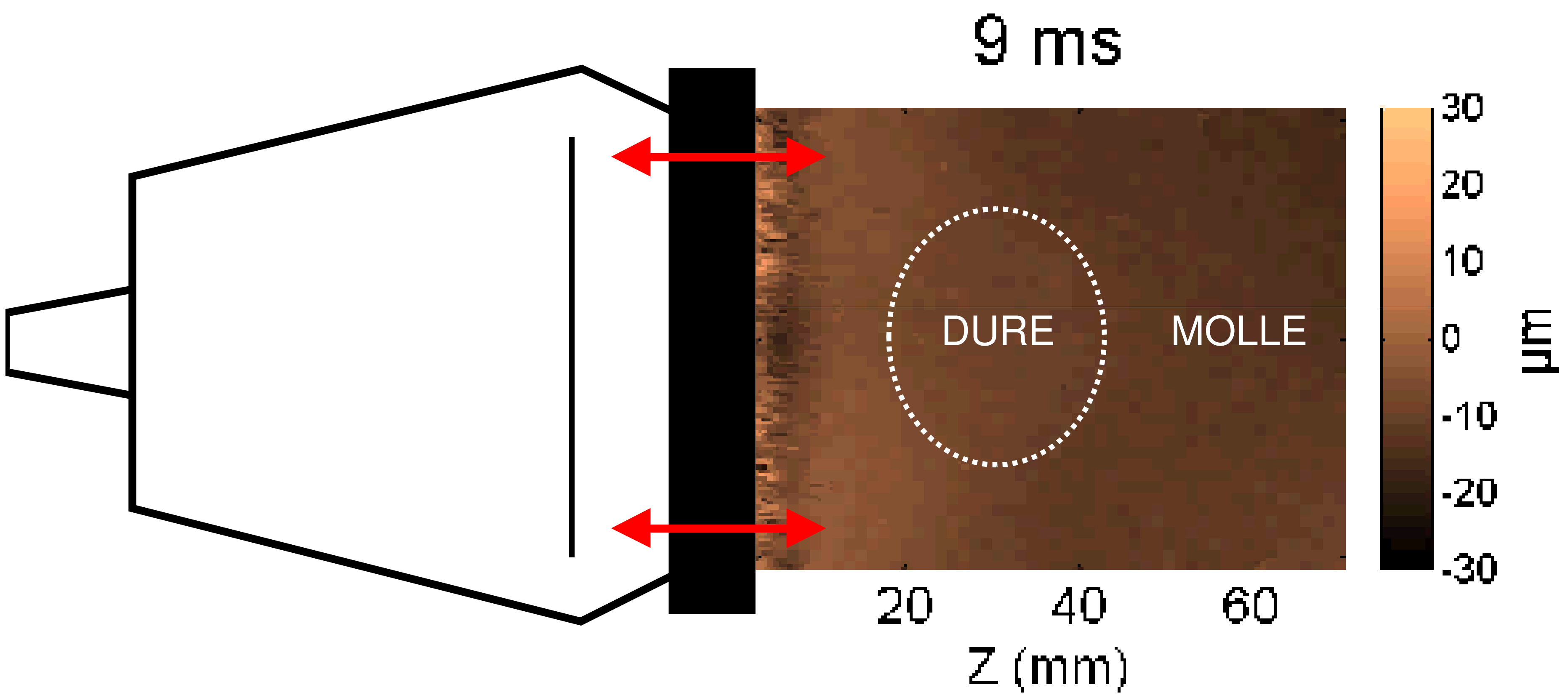


RESULTAT:
Sismogramme des déplacements
(matrice Mx(N-1))

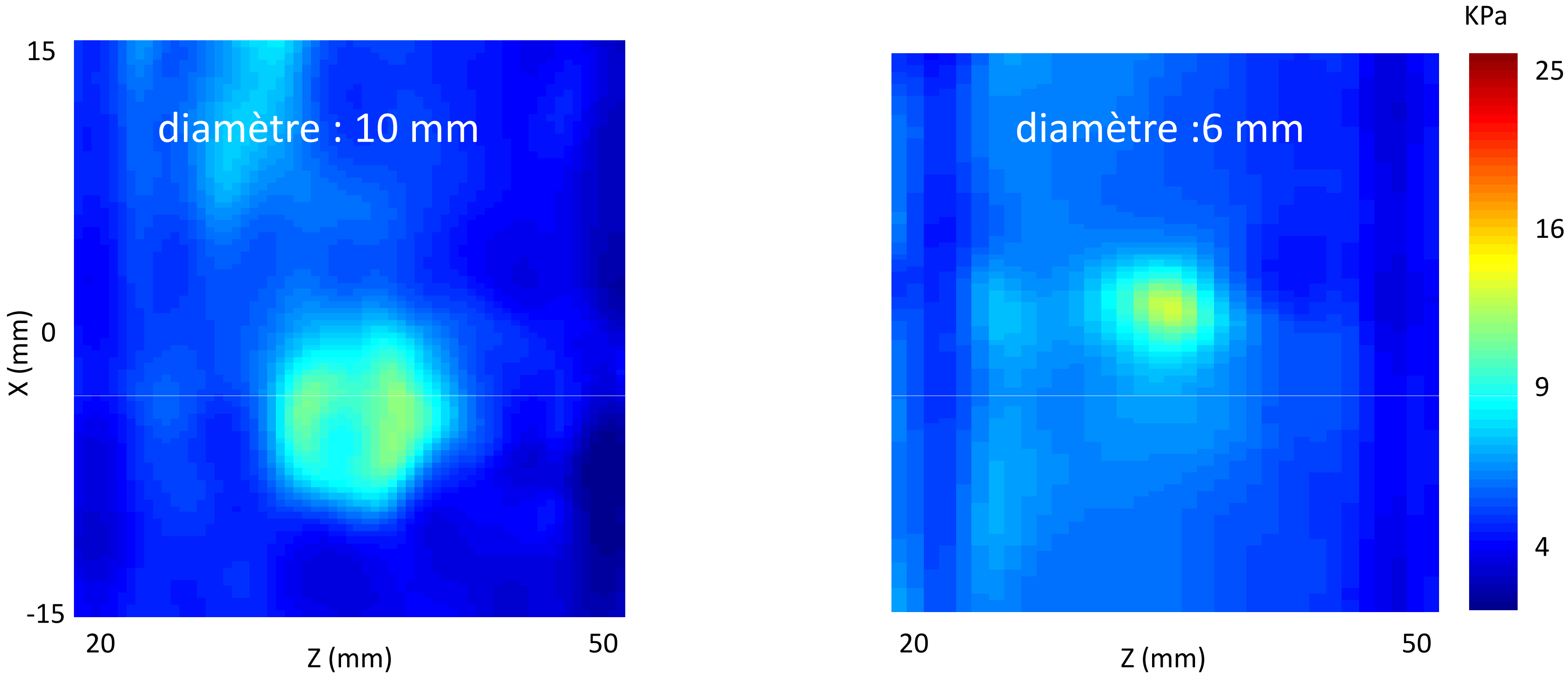
3) Itération sur les transducteurs ultrasonores



Film de la composante z des déplacements



Problème inverse: résultats expérimentaux dans des gels



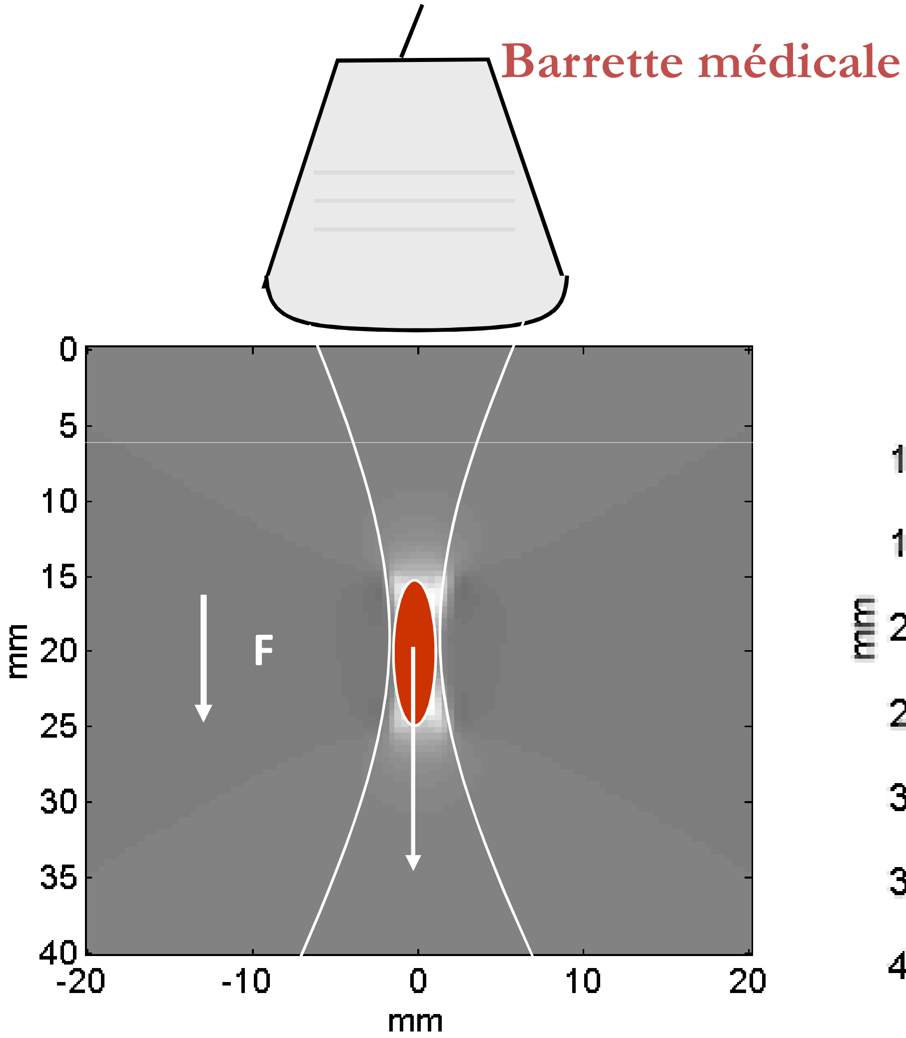
Quelques grandeurs caractéristiques: V_P~ 1500ms^{-1}, λ= 2.25 Gpa f~0.5-20Mhz

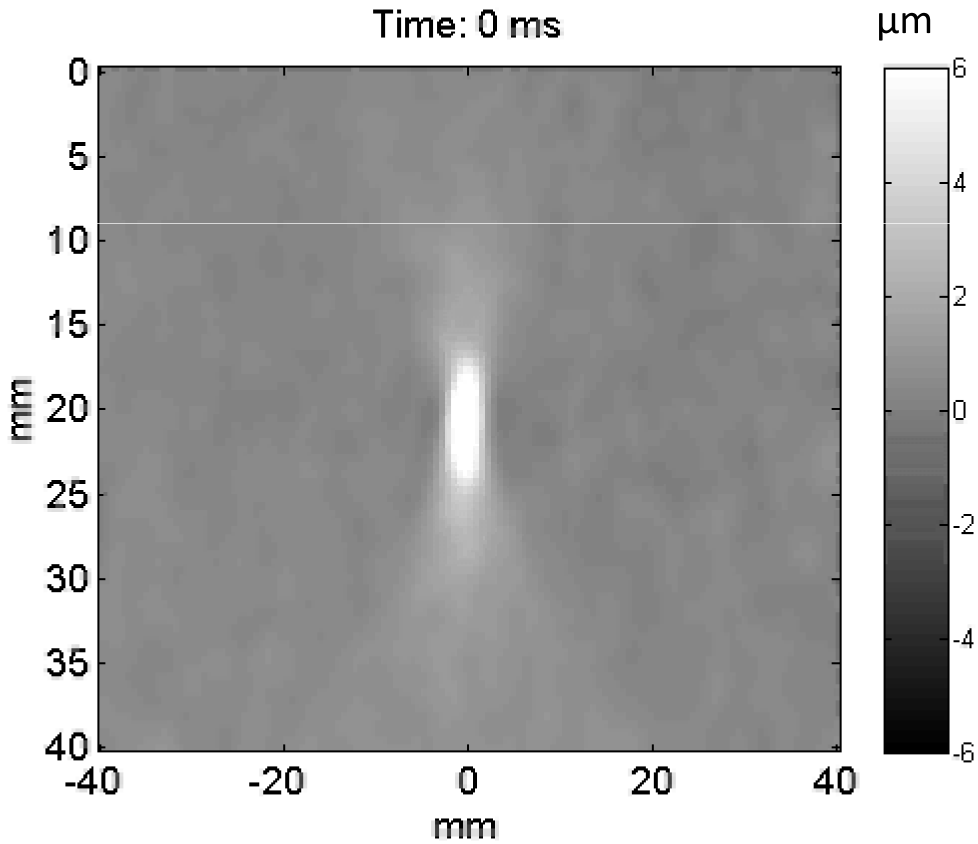
V_S~ 2ms^{-1}, μ = 2.5 kPa, f~10hz-1kHz

Echographe du commerce: 50Hz Ultrafast: 5000Hz

Brevet n° FR99 03157 déposé le 16 Mars 1999 : "Imagerie sismique des ondes de cisaillement",
Laurent Sandrin, Mickael Tanter, Stefan Catheline, Mathias Fink

La pression de radiation

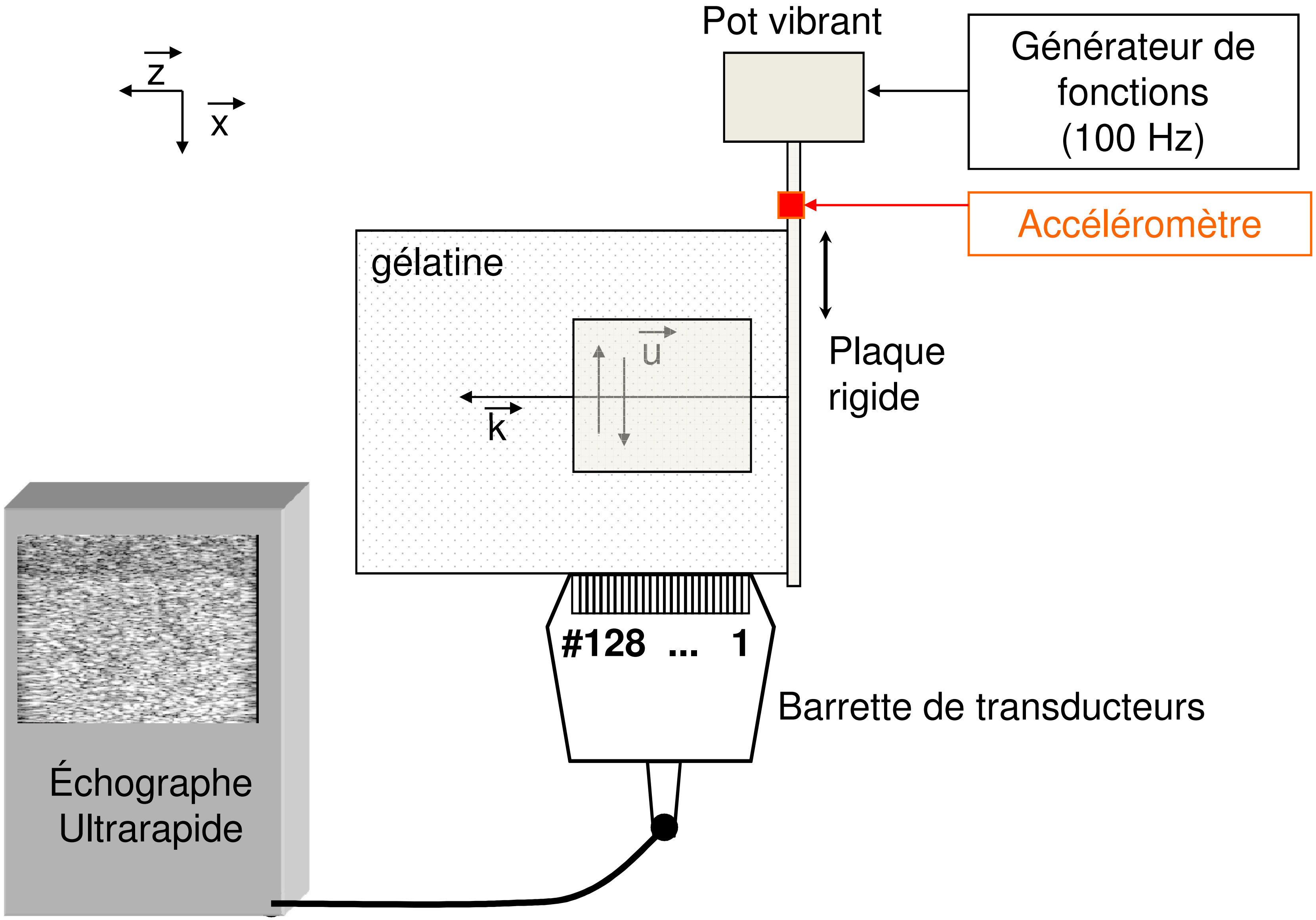




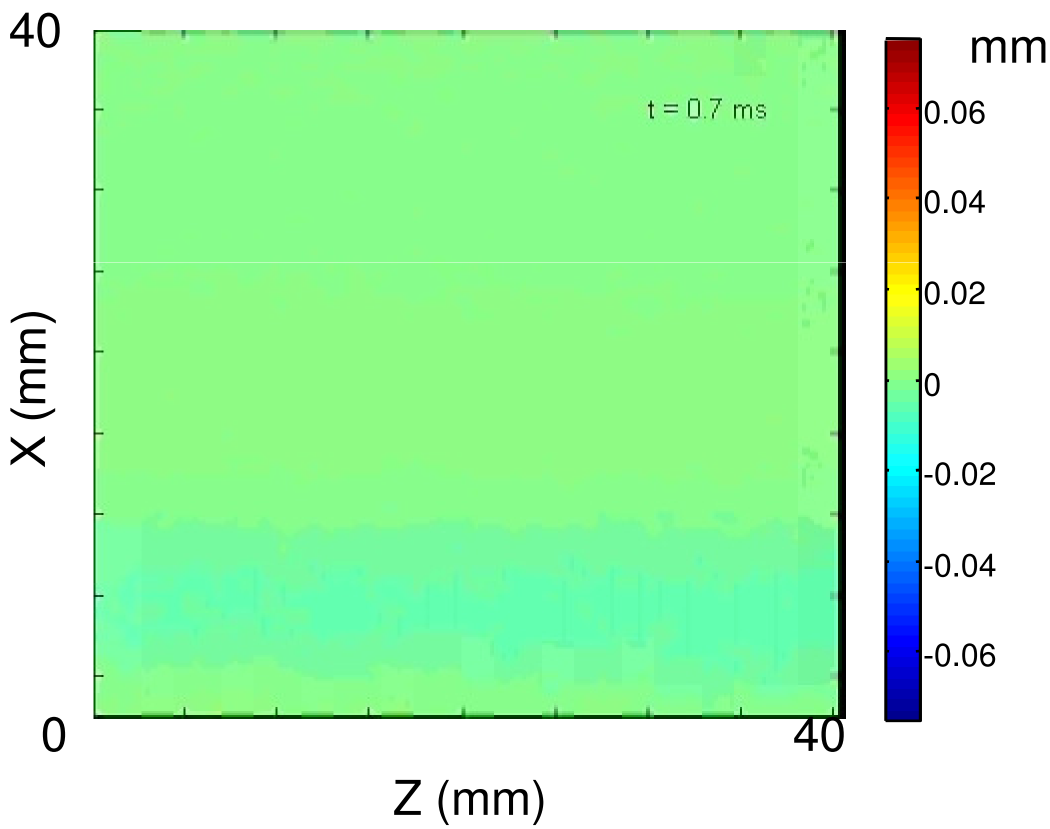
Echosens (2002): le Fibroscan

Supersonic Imagine (2005): l'Aixplorer

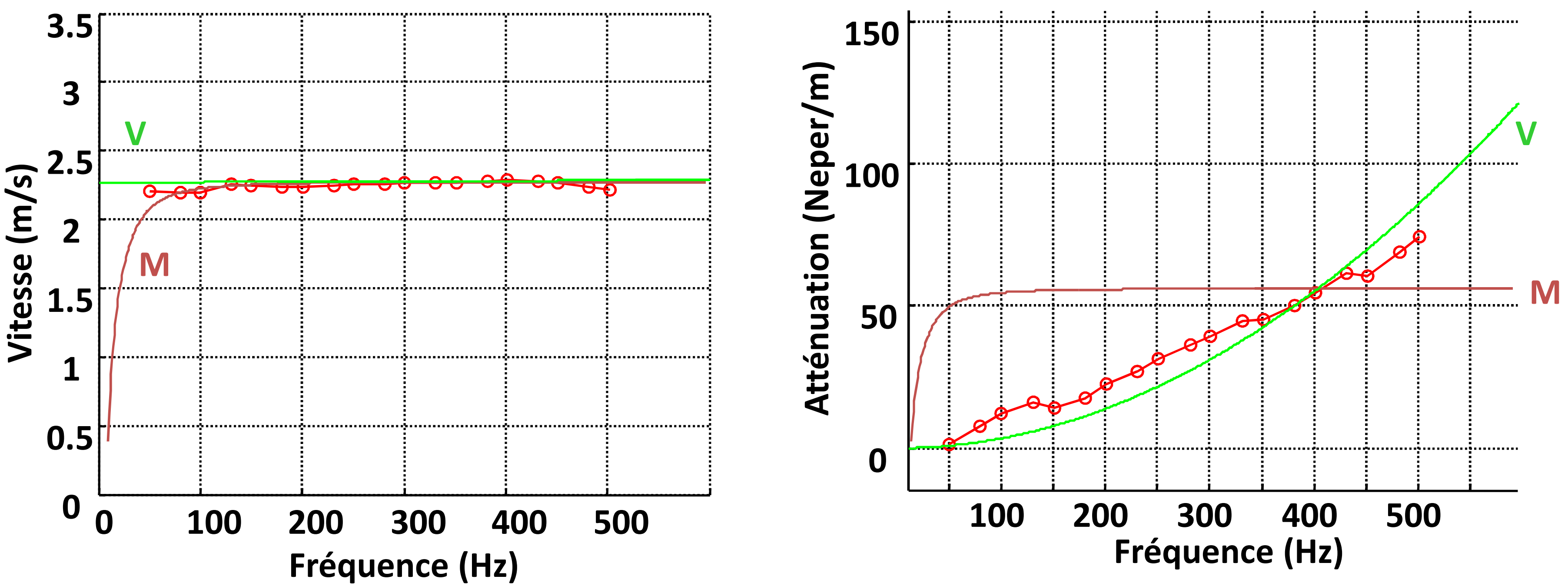
Montage expérimental: onde S plane



Expérience d' onde S plane



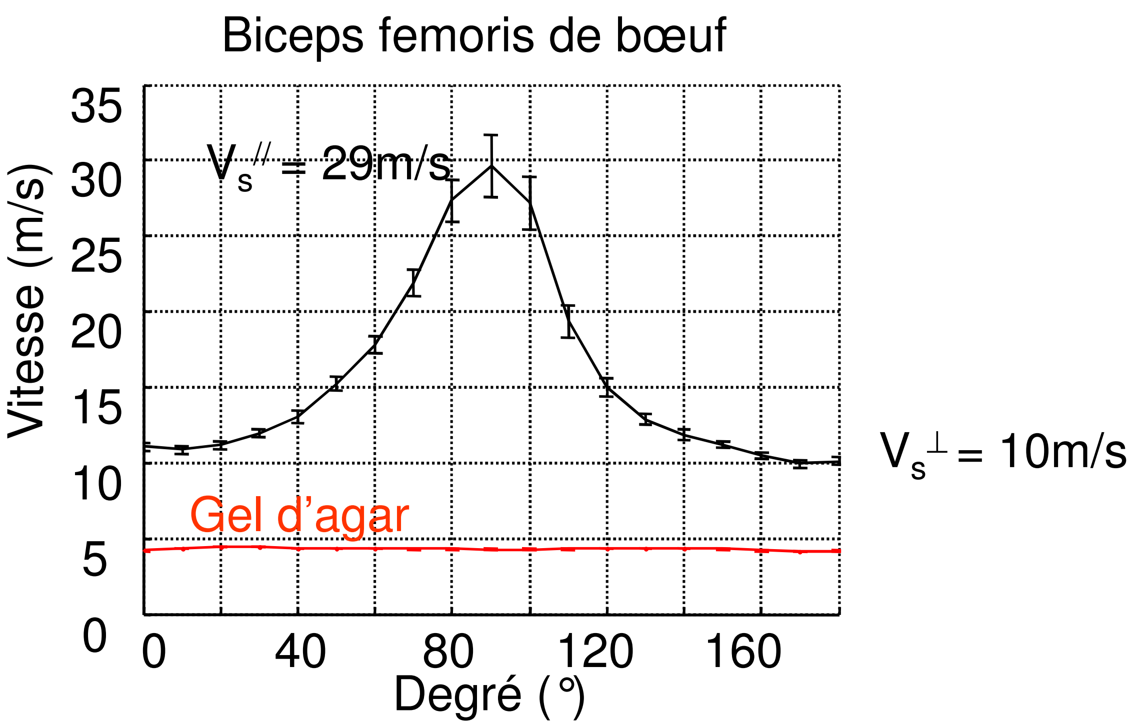
Modèle rhéologique simple



Modèle simple : le solide de Voigt

S.Catheline, J.-L. Gennisson, G. Delon, R. Sinkus, M. Fink, S. Abouelkaram, J. Culioli
Measurement of viscoelastic properties of soft solid using transient elastography
J. Acoust. Soc. Am. **116** (6), pp 3734-3741, 2004

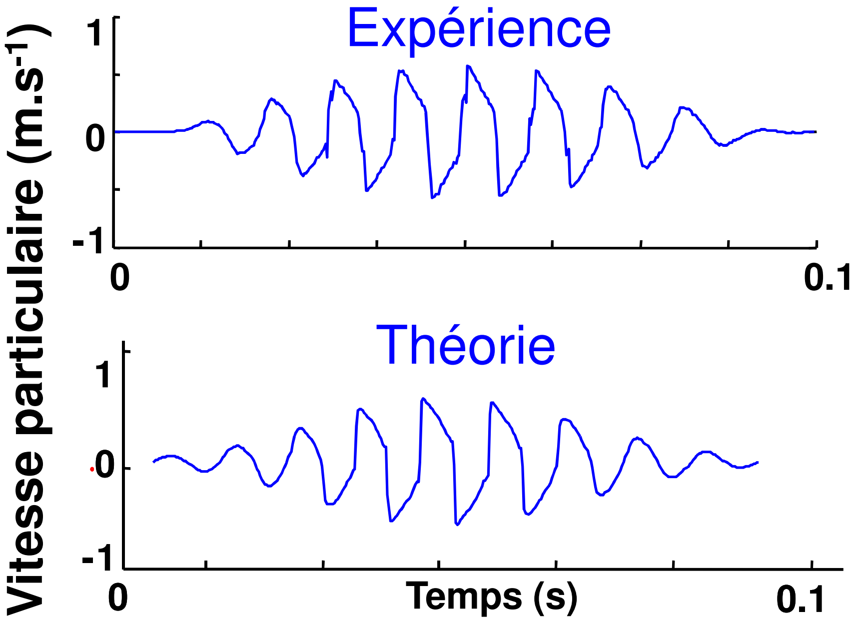
Anisotropie



Coefficients élastiques correspondant : c_{44} = 875kPa
c_{66} = 100kPa

J-L. Gennisson, S. Catheline, S. Chaffaï and M. Fink, "Transient elastography in anisotropic medium: Application to the measurement of slow and fast shear waves velocities in muscles.", J. Acoust. Soc. Am. **114** (1), pp 536-541, 2003.

Résultats quantitatifs



μ= 2.5 kPa

μ_2= 0.4 Pa.s

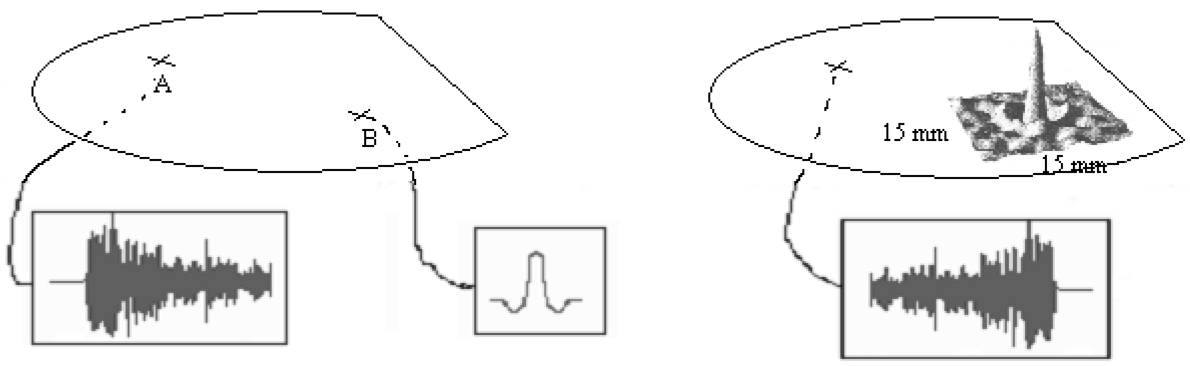
β_T = 5.1 kPa

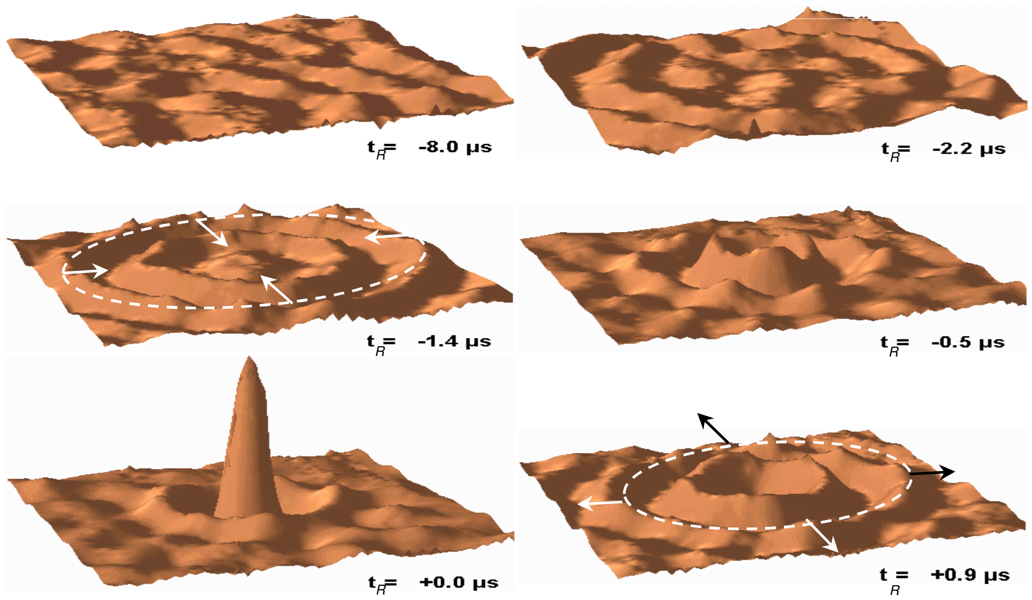
$$\beta_T = \mu + \frac{A}{2} + \frac{\lambda}{2} + B + G$$

Coef. Linéaire~ Coef. non linéaire

S. Catheline, J-L. Gennisson, M. Tanter and M. Fink, "Observation of Shock Transverse Waves in Elastic Media"
Physical Review Letters **91** (16), pp 43011-43014, 2003

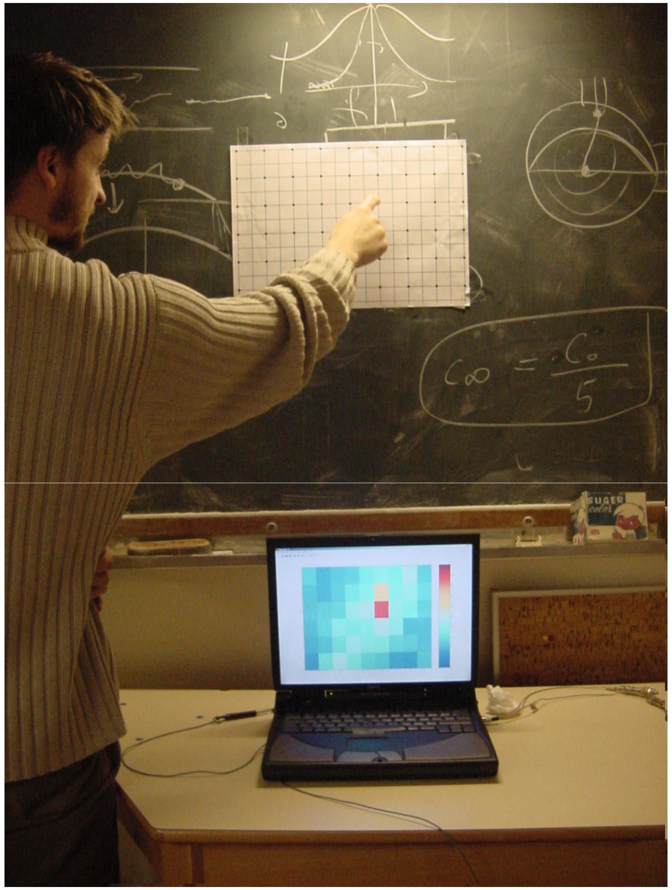
Time reversal in reverberating cavity





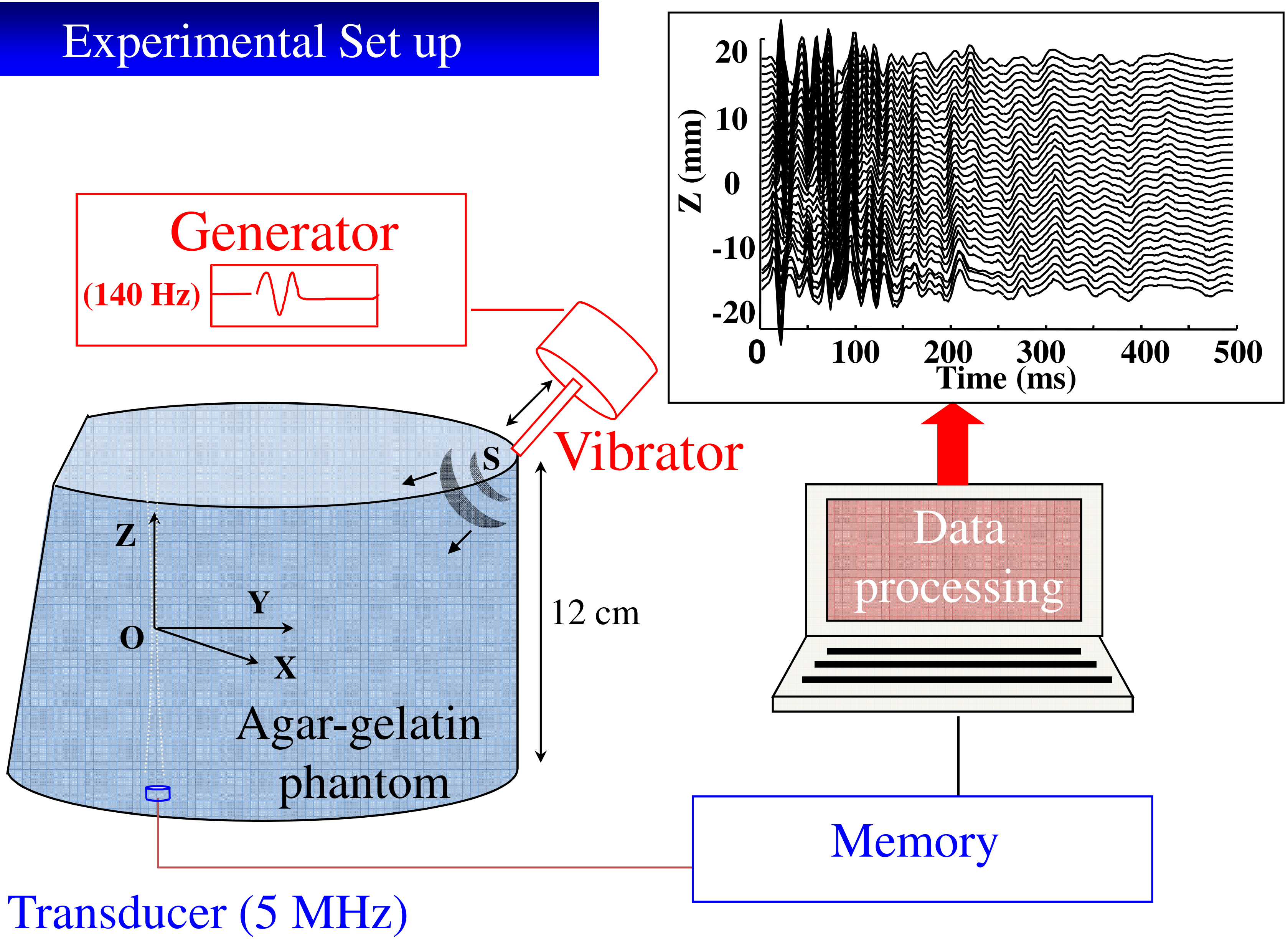
C.Draeger, M. Fink, *Phys. Rev. Letter* 79, 407 (1997).

Time reversal interactivity



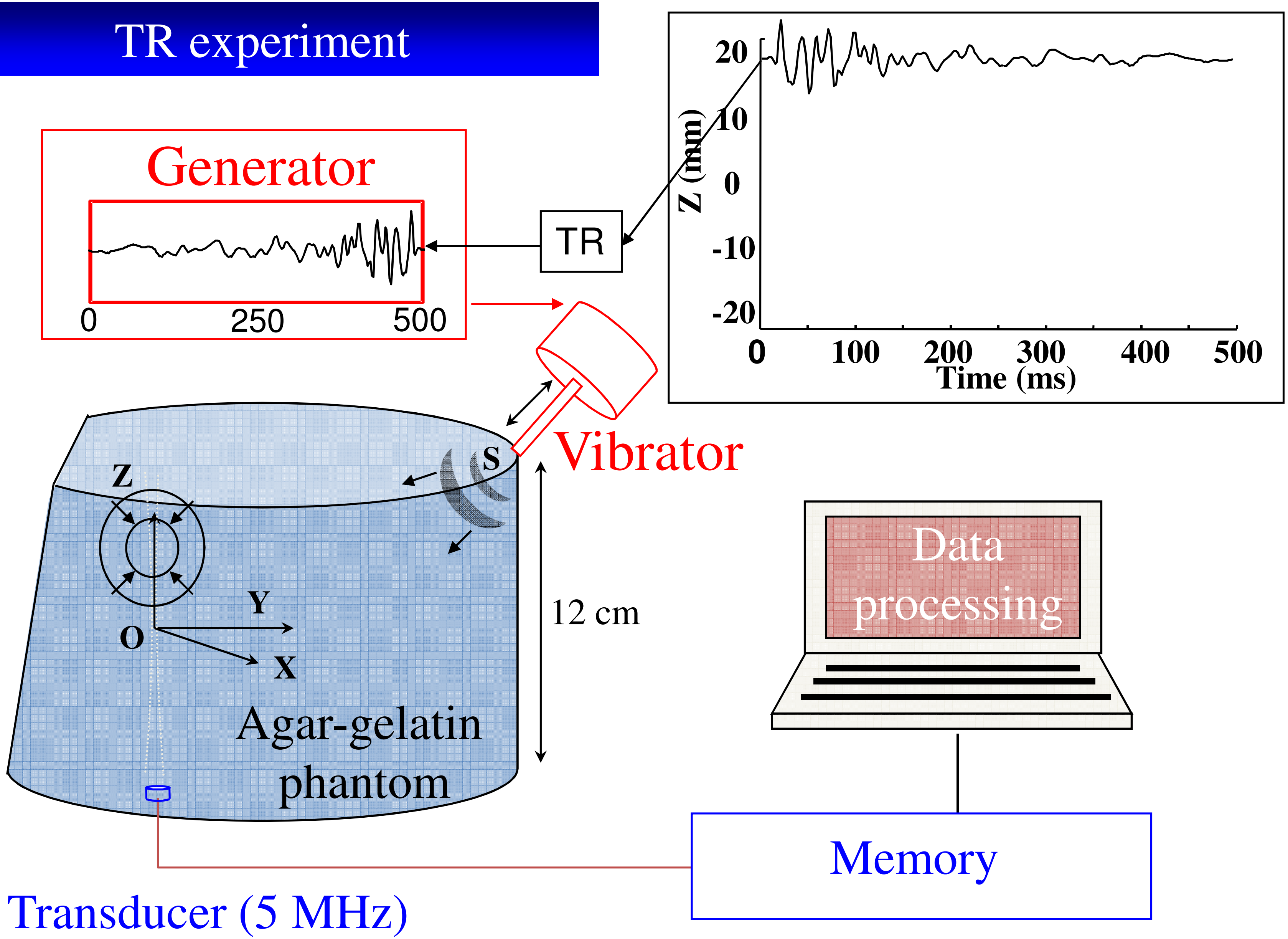
R. K.Ing, N. Quieffin, S. Catheline, M. Fink, *Appl. Phys. Letter,* 87, 204104 (2005).

Experimental Set up



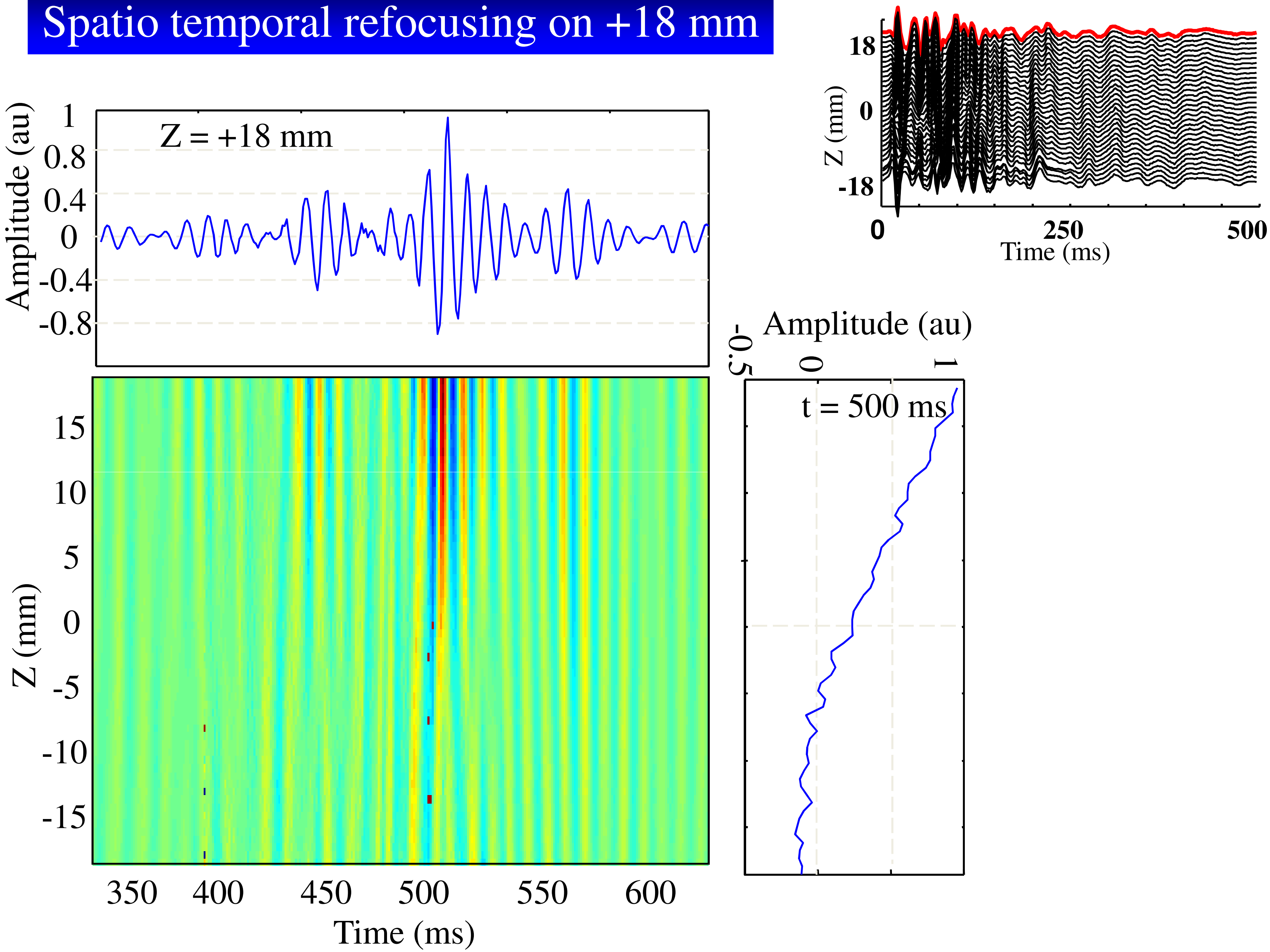
S.Catheline, N. Benech, X. Brum, and C. Negreira, *Phys.Rev.Letter.* **100**, 064301 (2008).

TR experiment

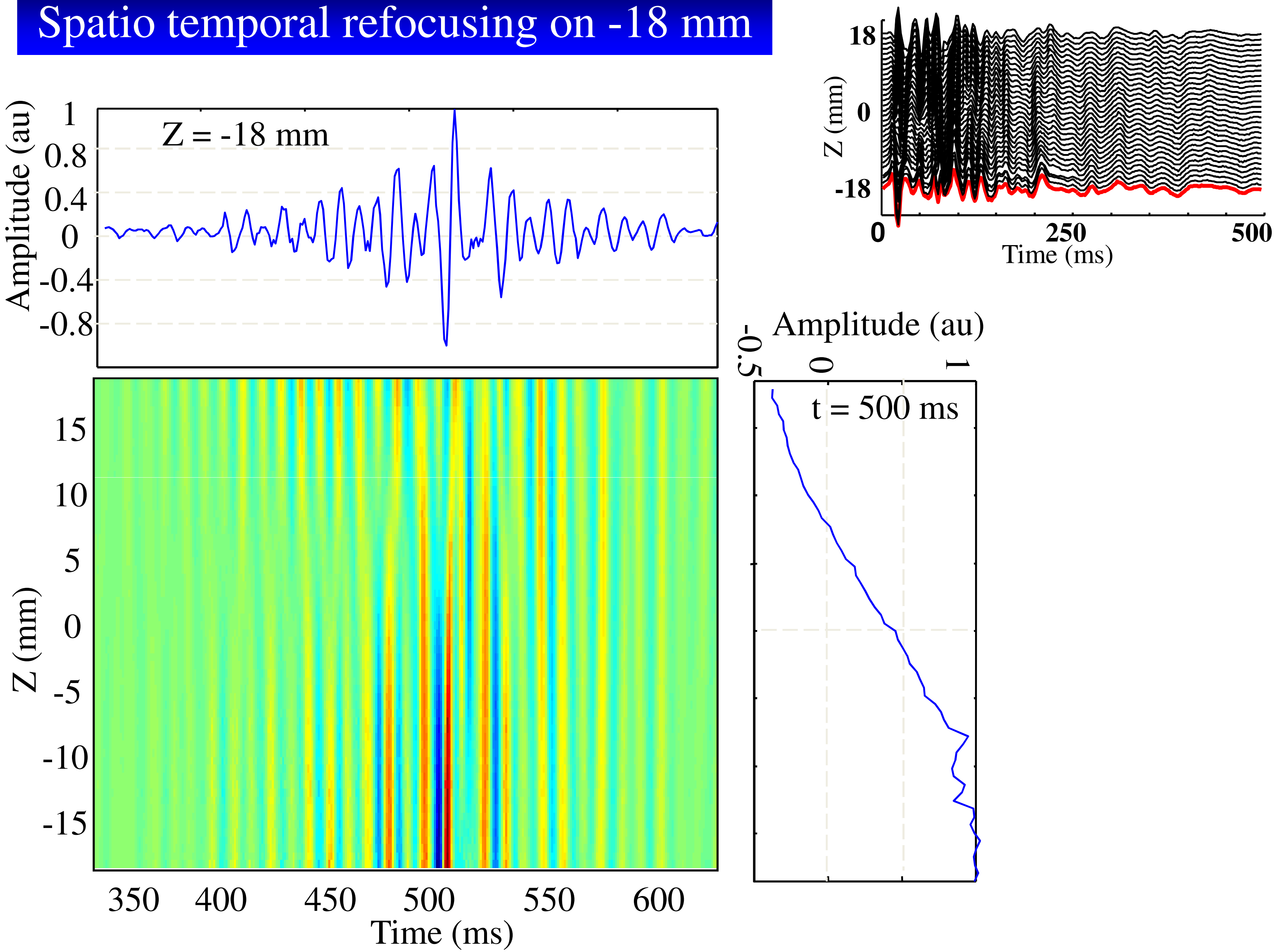


S.Catheline, N. Benech, X. Brum, and C. Negreira, *Phys.Rev.Letter.* **100**, 064301 (2008).

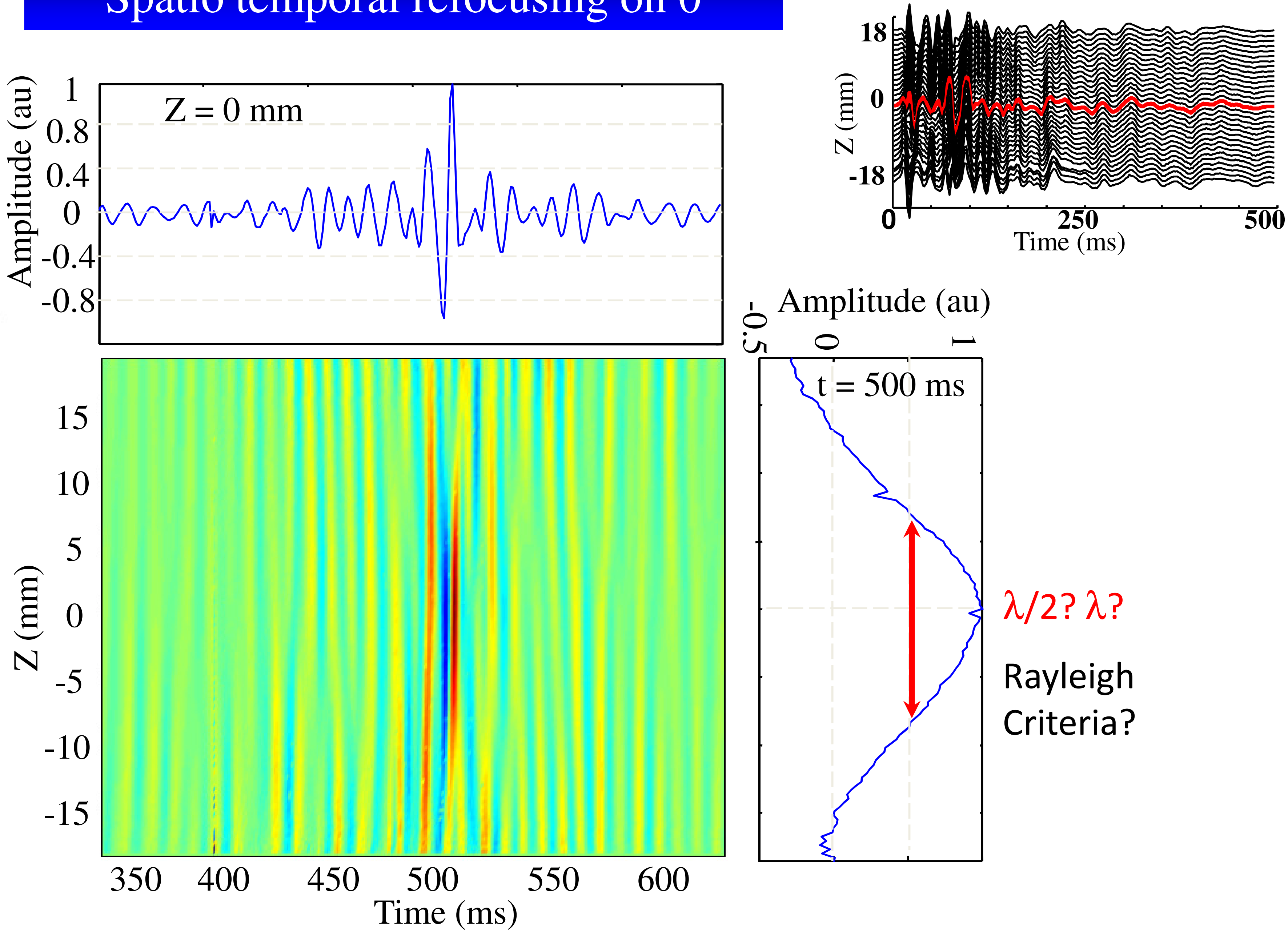
Spatio temporal refocusing on +18 mm

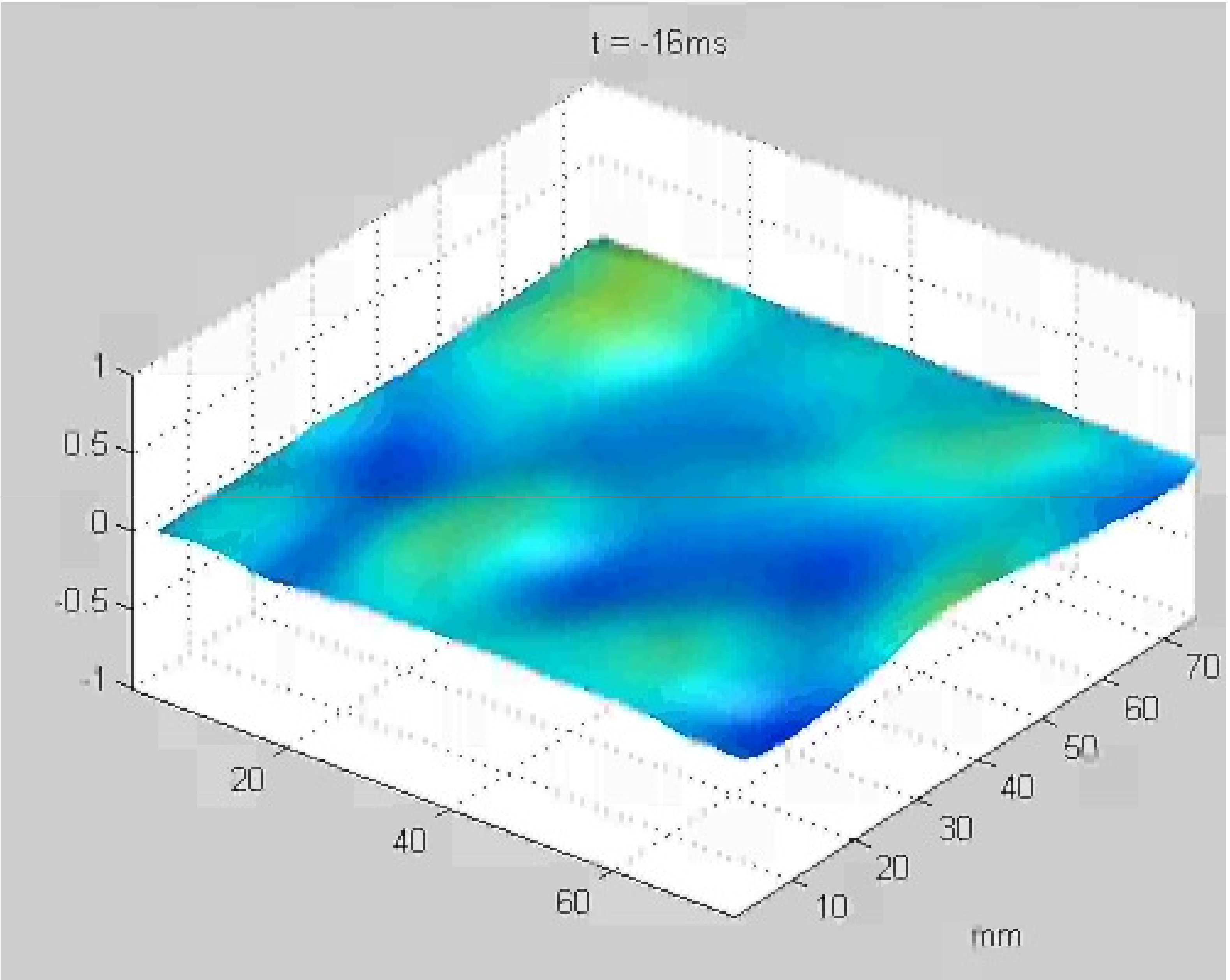


Spatio temporal refocusing on -18 mm

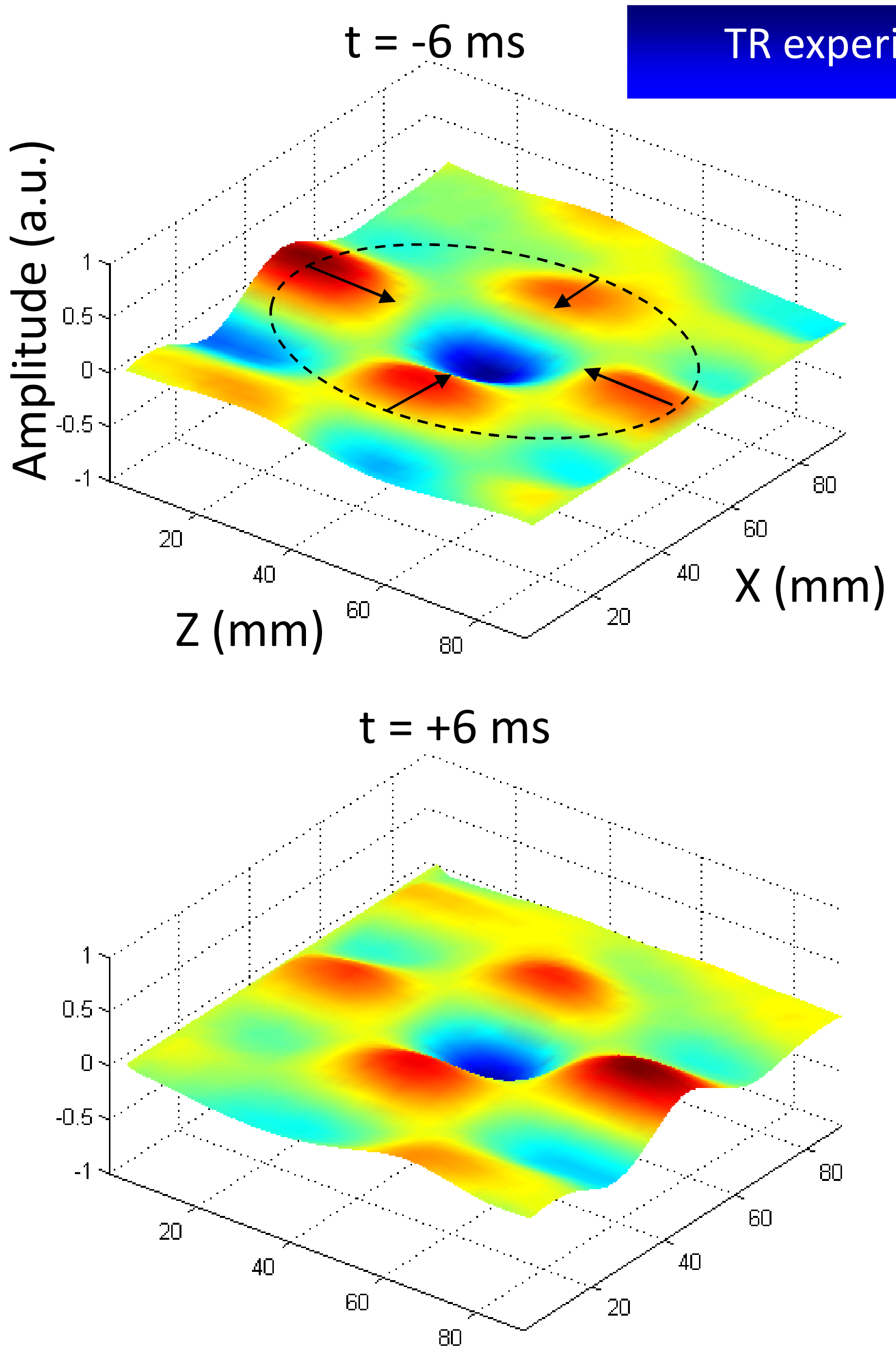


Spatio temporal refocusing on 0



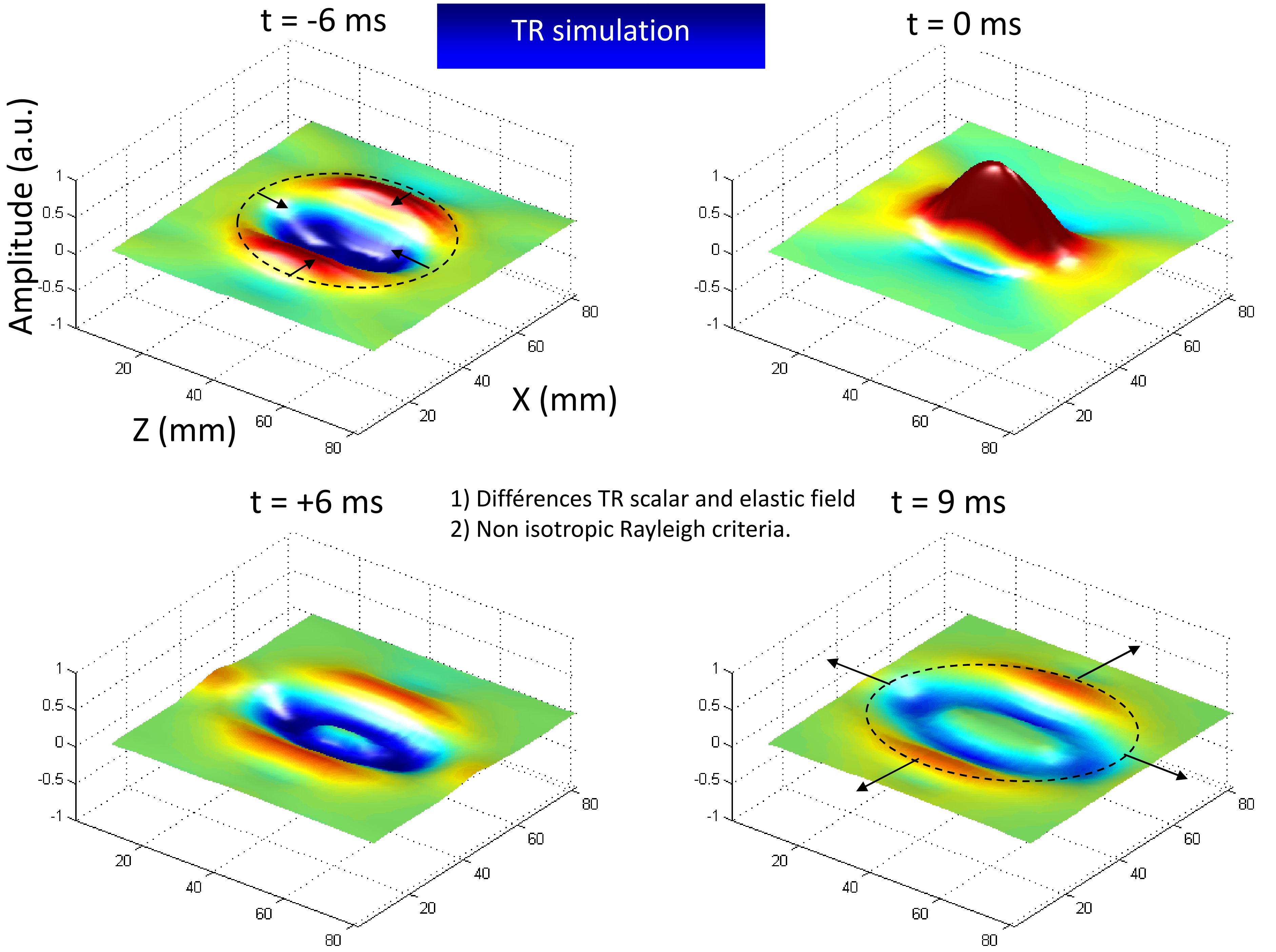


t = -16ms
1
0.5
0
-0.5
-1
20
40
60
10
20
30
40
50
60
70
mm



TR experiment
t = -6 ms
t = 0 ms
t = +6 ms
t = +9 ms
Amplitude (a.u.)
X (mm)
Z (mm)

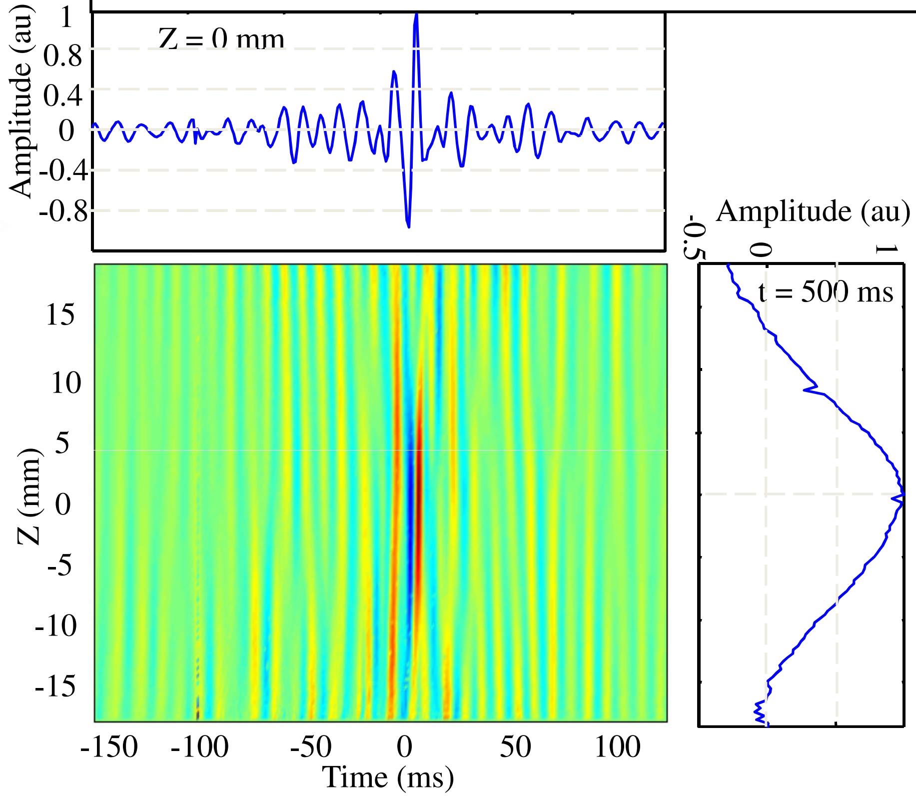
TR simulation

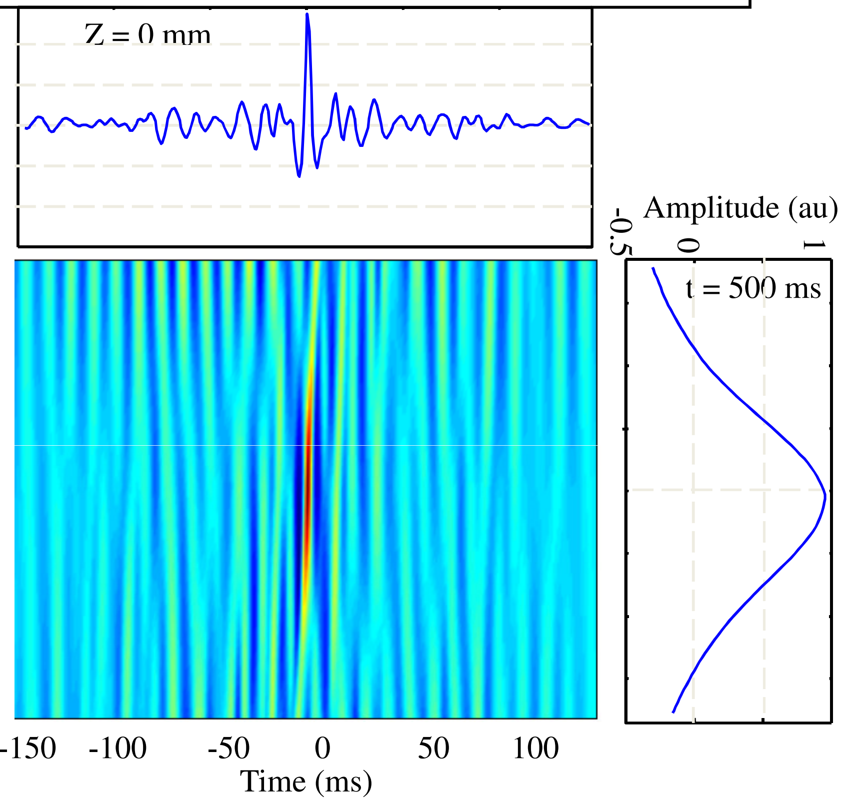


1) Différences TR scalar and elastic field
2) Non isotropic Rayleigh criteria.

Correlation Map

TR $\psi^{RT}(x_0,x;t)$ $\Leftrightarrow$ Correlation $C(x_0,x;t)$





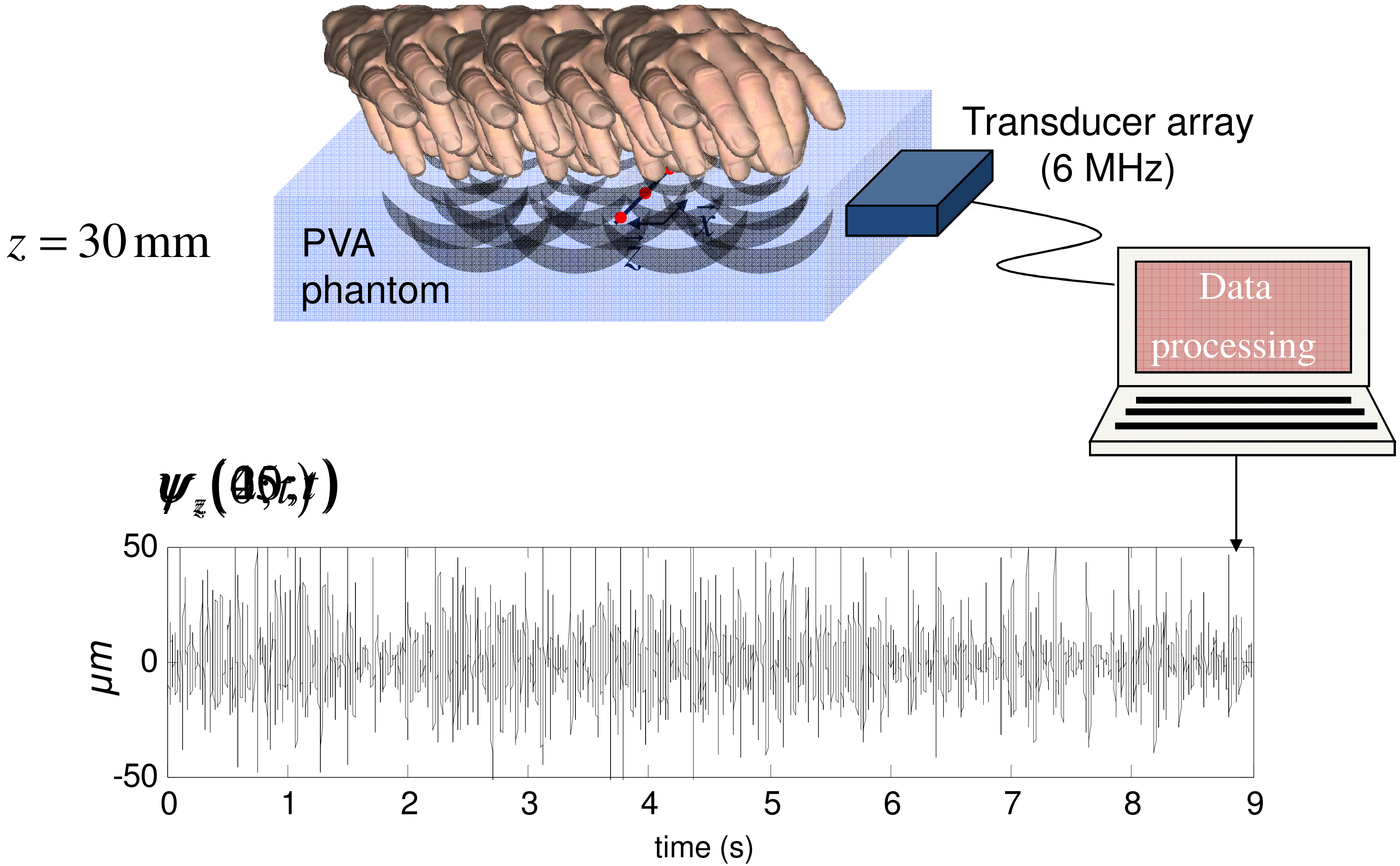
$$\psi_z^{RT}(x_0,x;t)=\left[e(T-t)\otimes h_z(s,x_0;T-t)\right]\otimes h_z(s,x;t)$$

$$C(x_0,x;t)=\left[e(T-t)\otimes h_z(s,x_0;T-t)\right]\otimes\left[e(t)\otimes h_z(s,x;t)\right]$$

$$e(t)=\delta(t)\quad\Rightarrow\quad\boxed{\psi^{RT}(x_0,x;t)=C(x_0,x;t)}$$

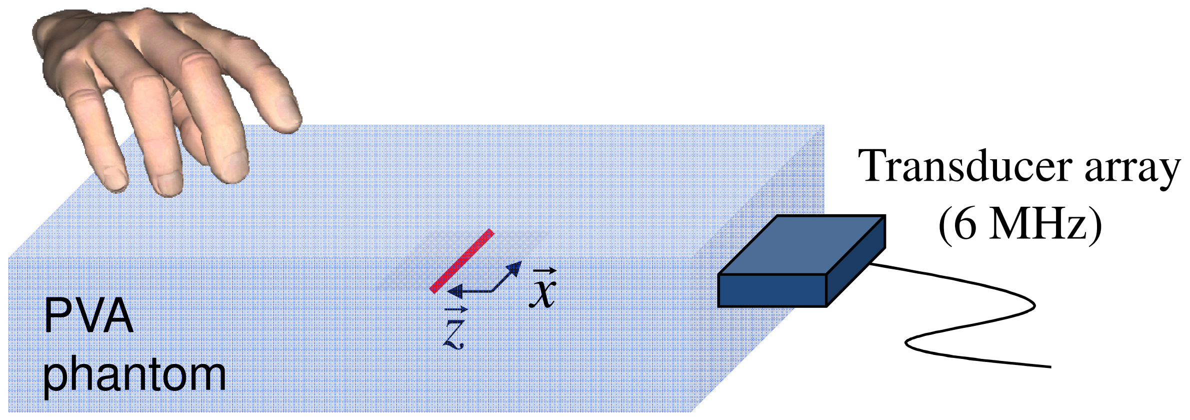
No need of programmable device

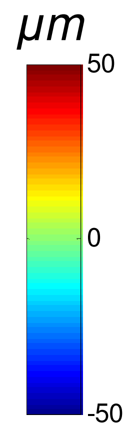
Noise Correlation : Experimental Set up



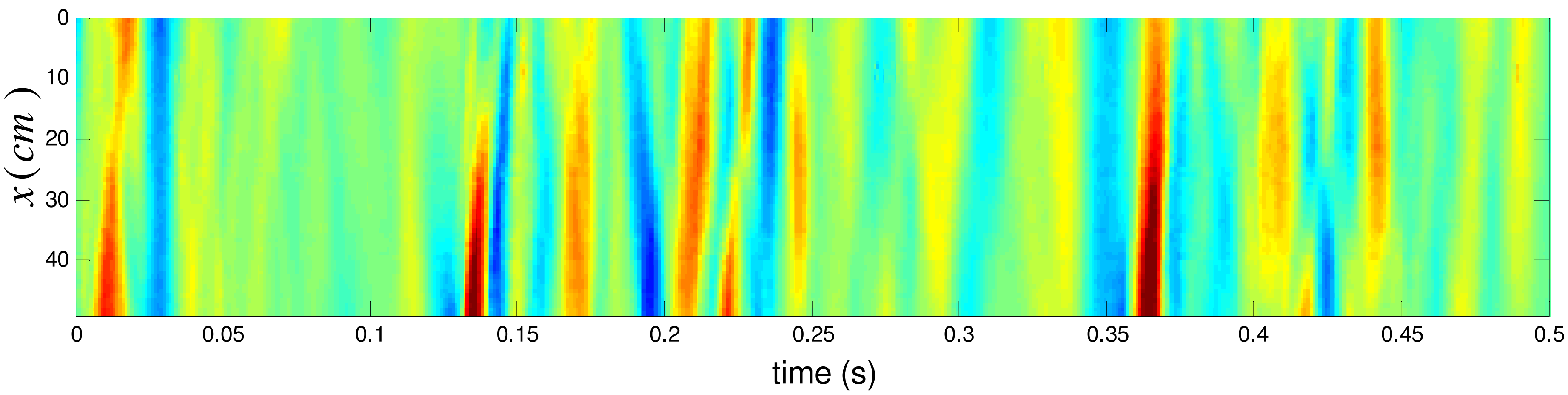
Displacement field allong the x-axis

$z = 30\,\mathrm{cm}$



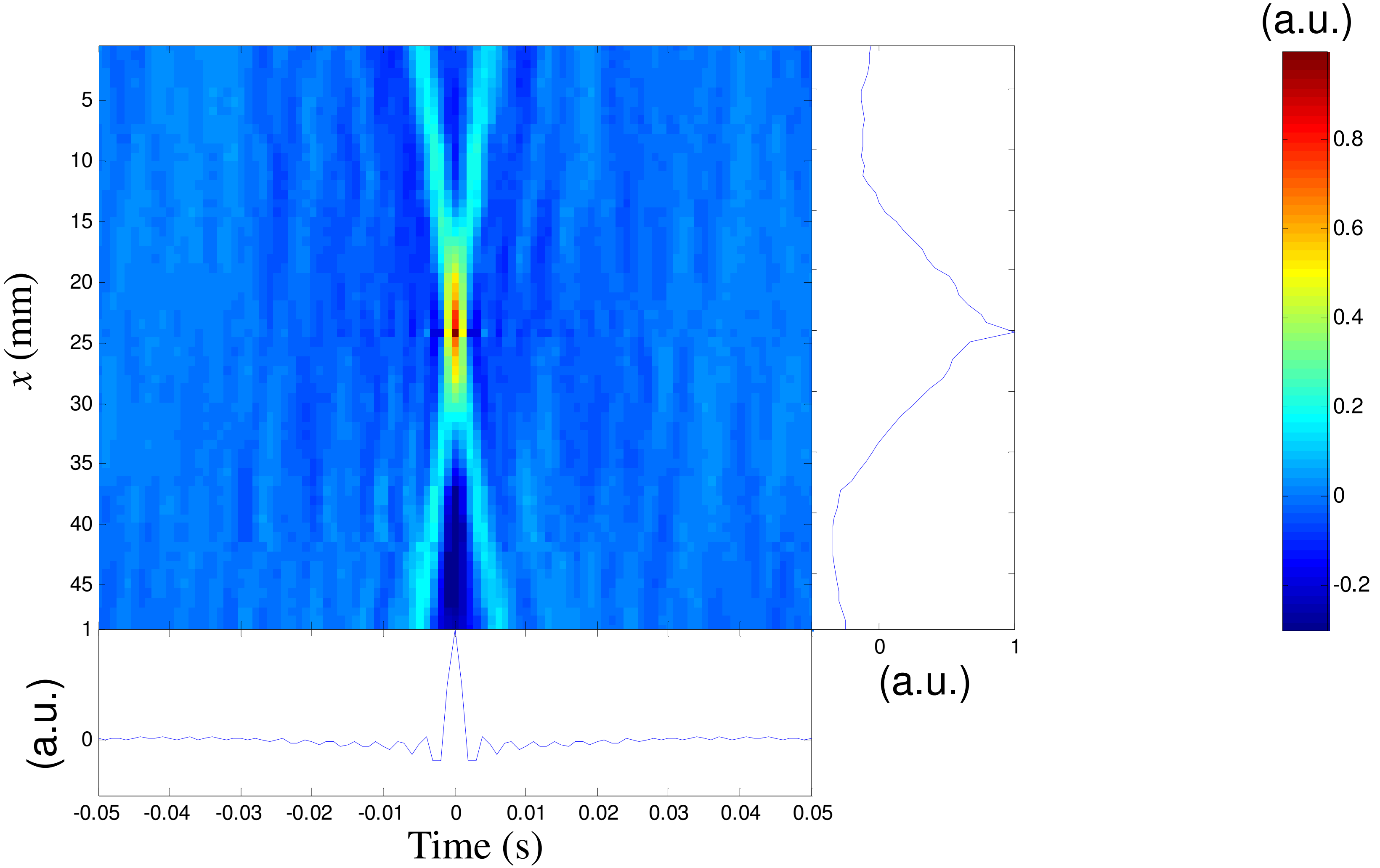


Zoom of half a second of $\psi_z(x;t)$ along x-axis

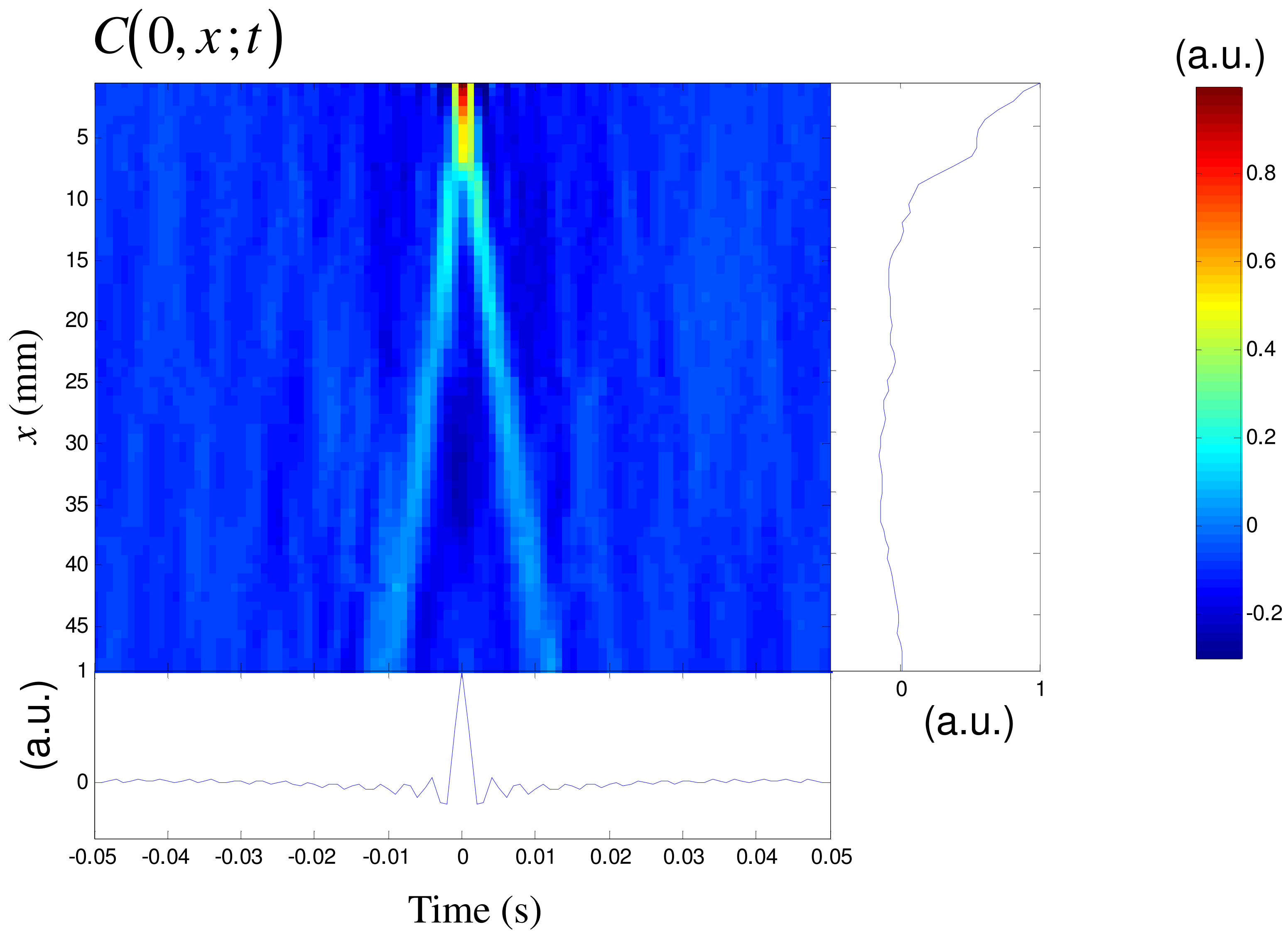


TR field from noise cross-correlation

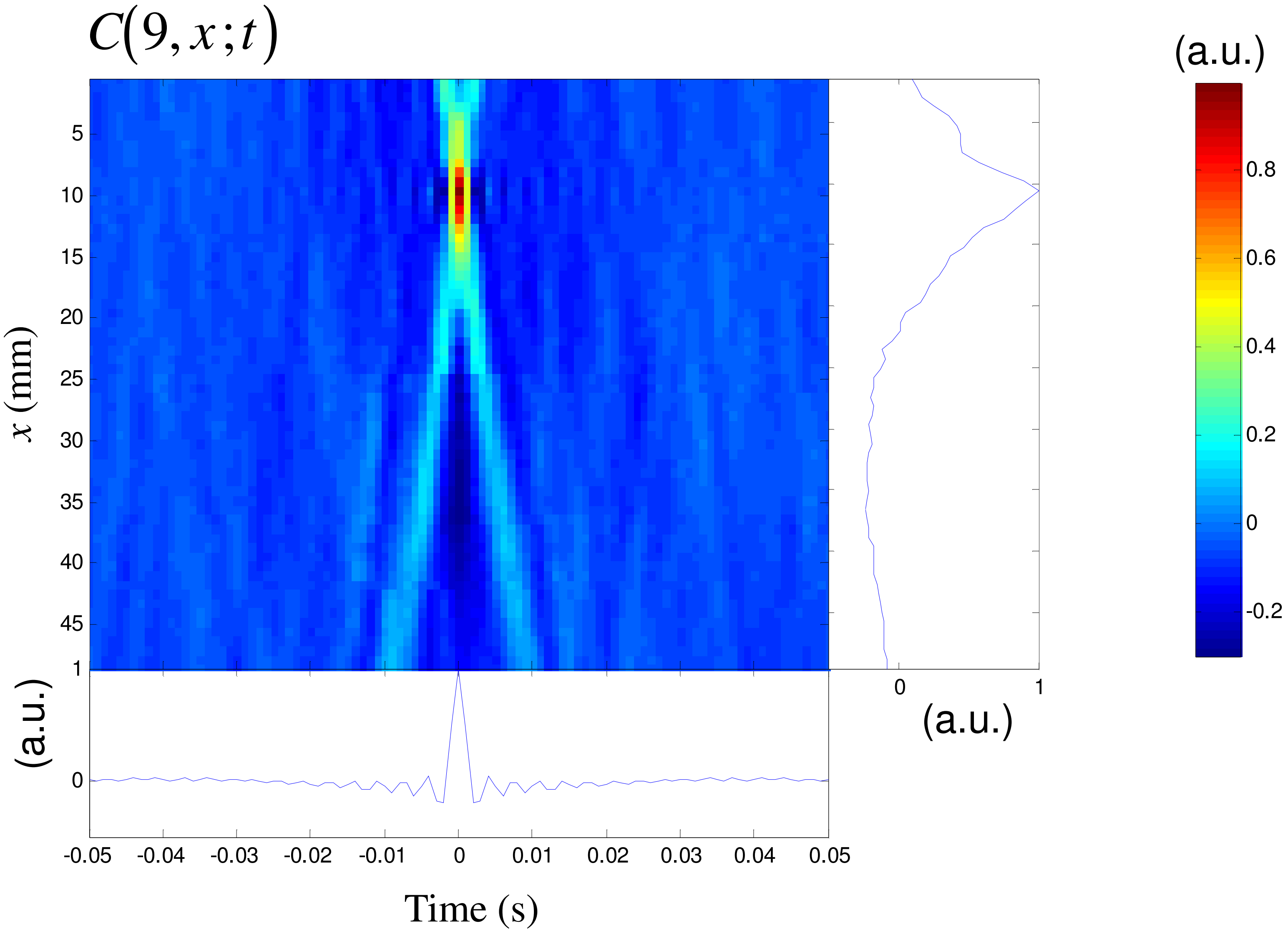
$$C(x_0, x; t) = \psi_z(x_0, T - t) \otimes \psi_z(x, t) \qquad \begin{cases} x_0 = 24\text{mm} \\ x \in [0;49] \end{cases}$$



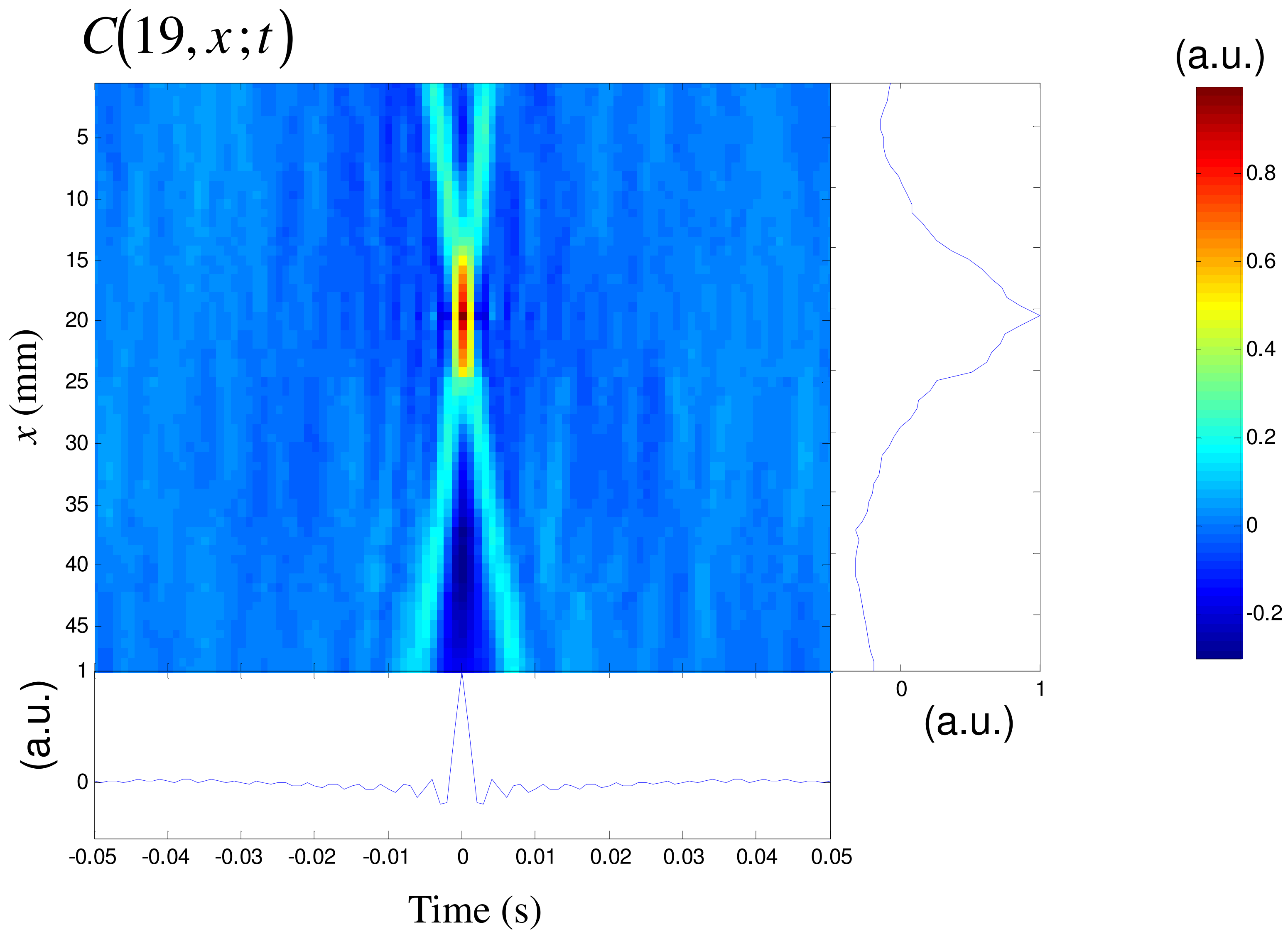
TR field from noise cross-correlation



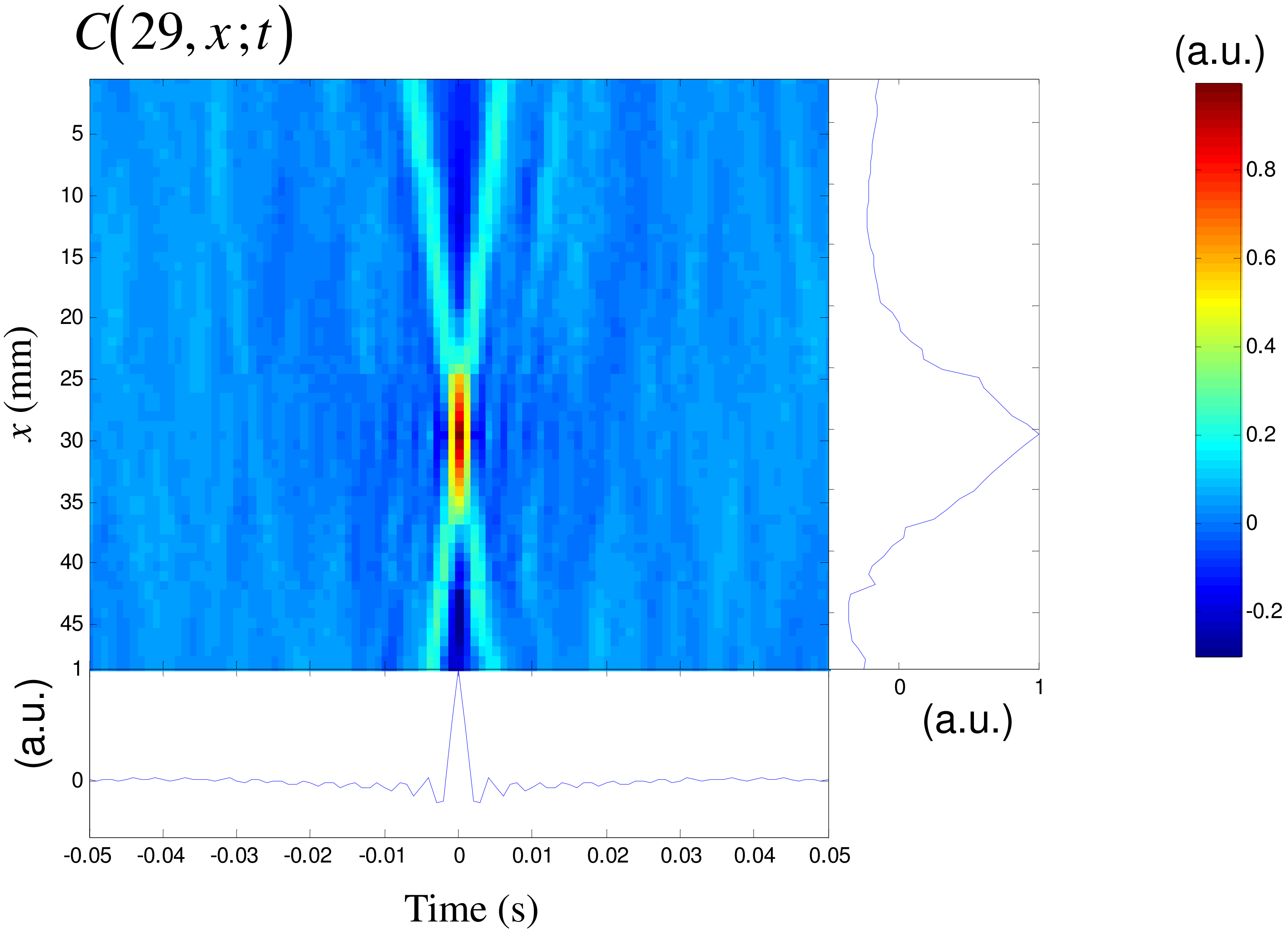
TR field from noise cross-correlation



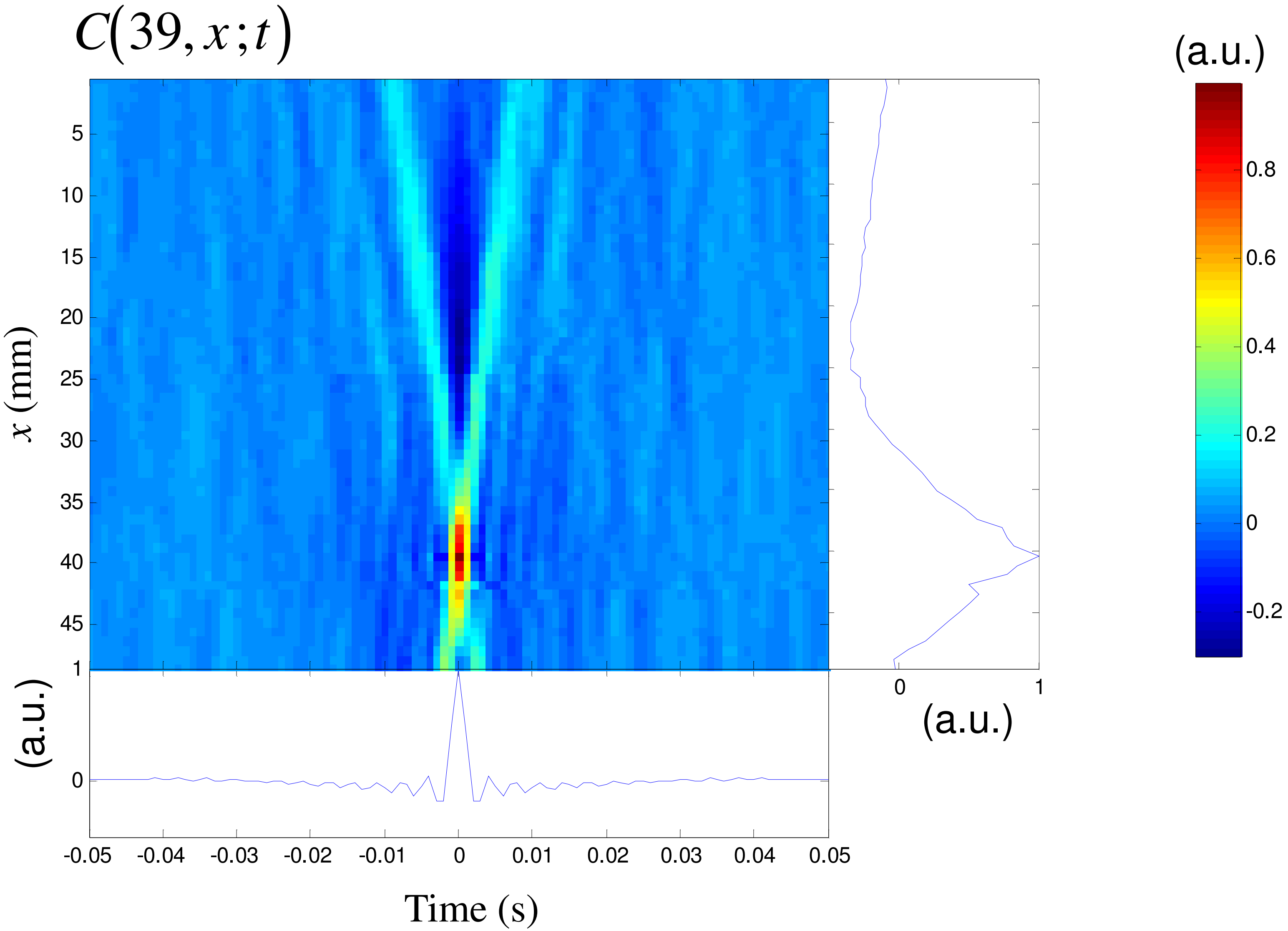
TR field from noise cross-correlation



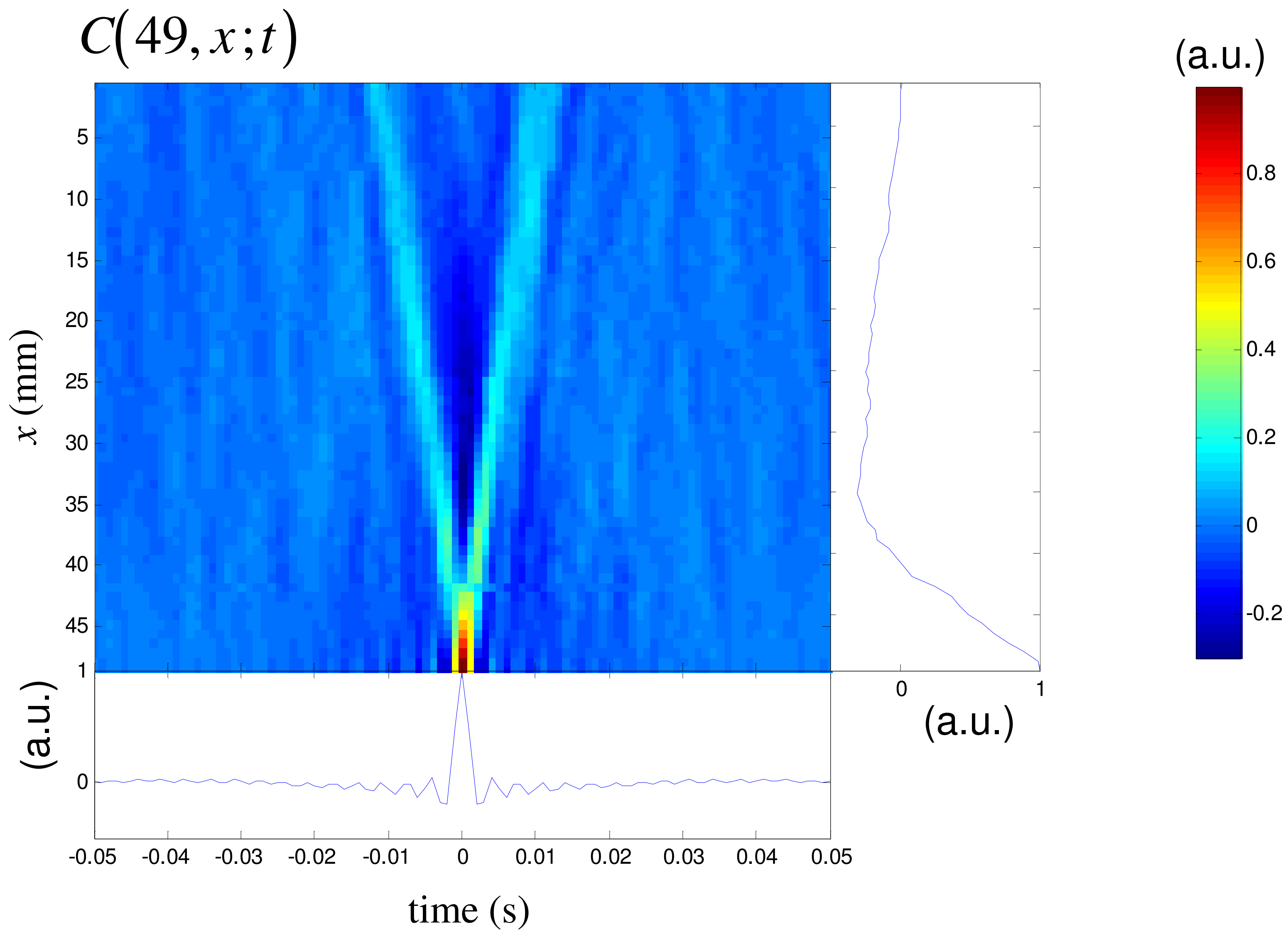
TR field from noise cross-correlation



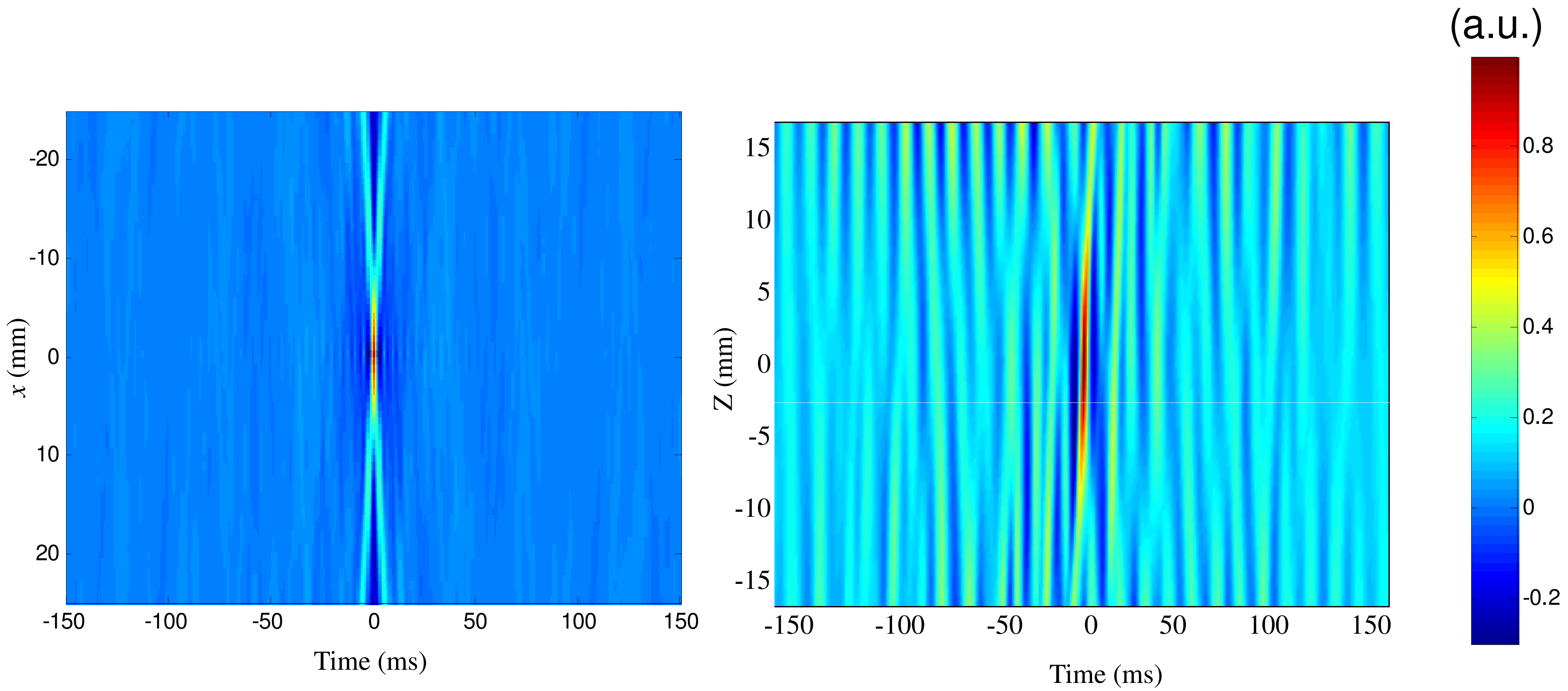
TR field from noise cross-correlation



TR field from noise cross-correlation

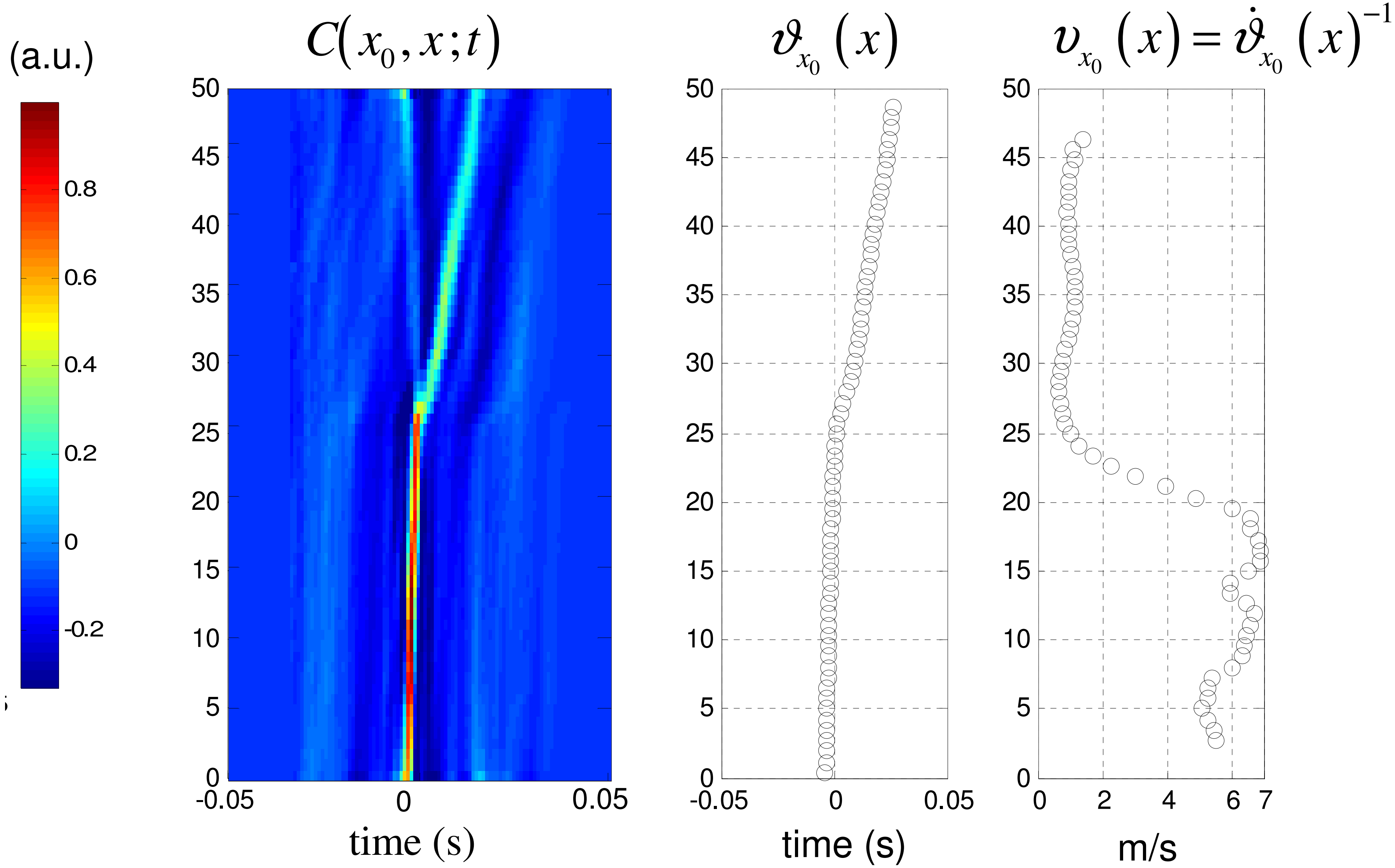


Comparison : noise/impulsion

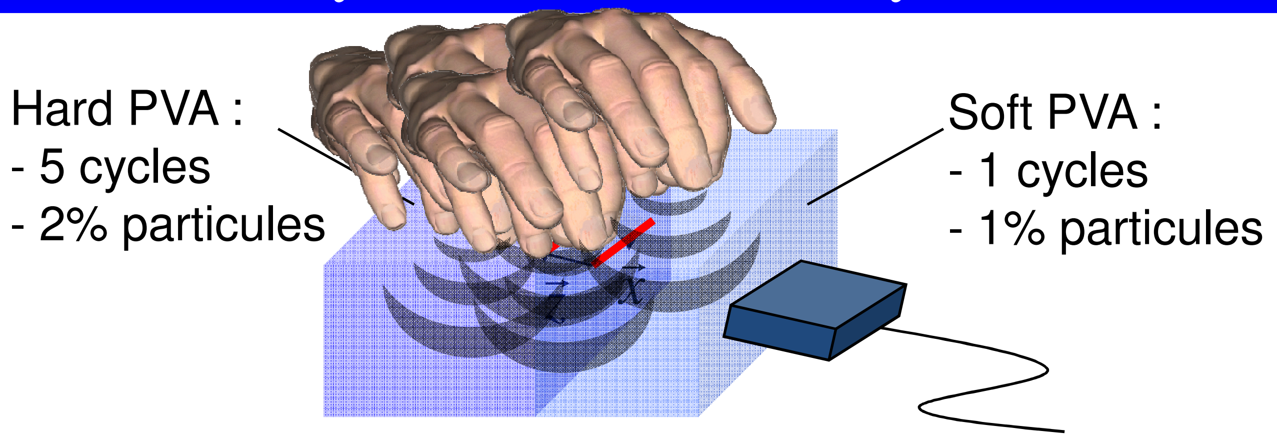


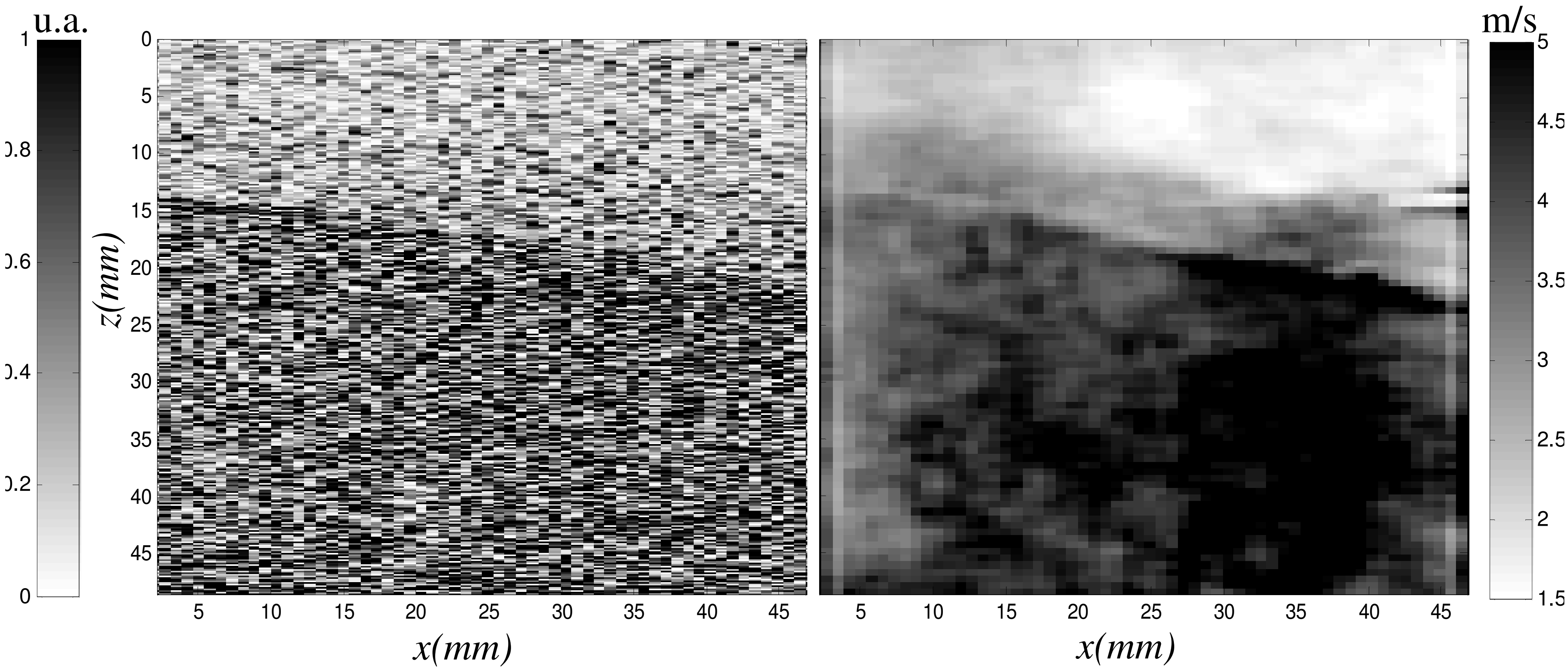
- Signal/noise ratio
- Refocusing everywhere => Imaging system

Group velocity estimation from the TR field

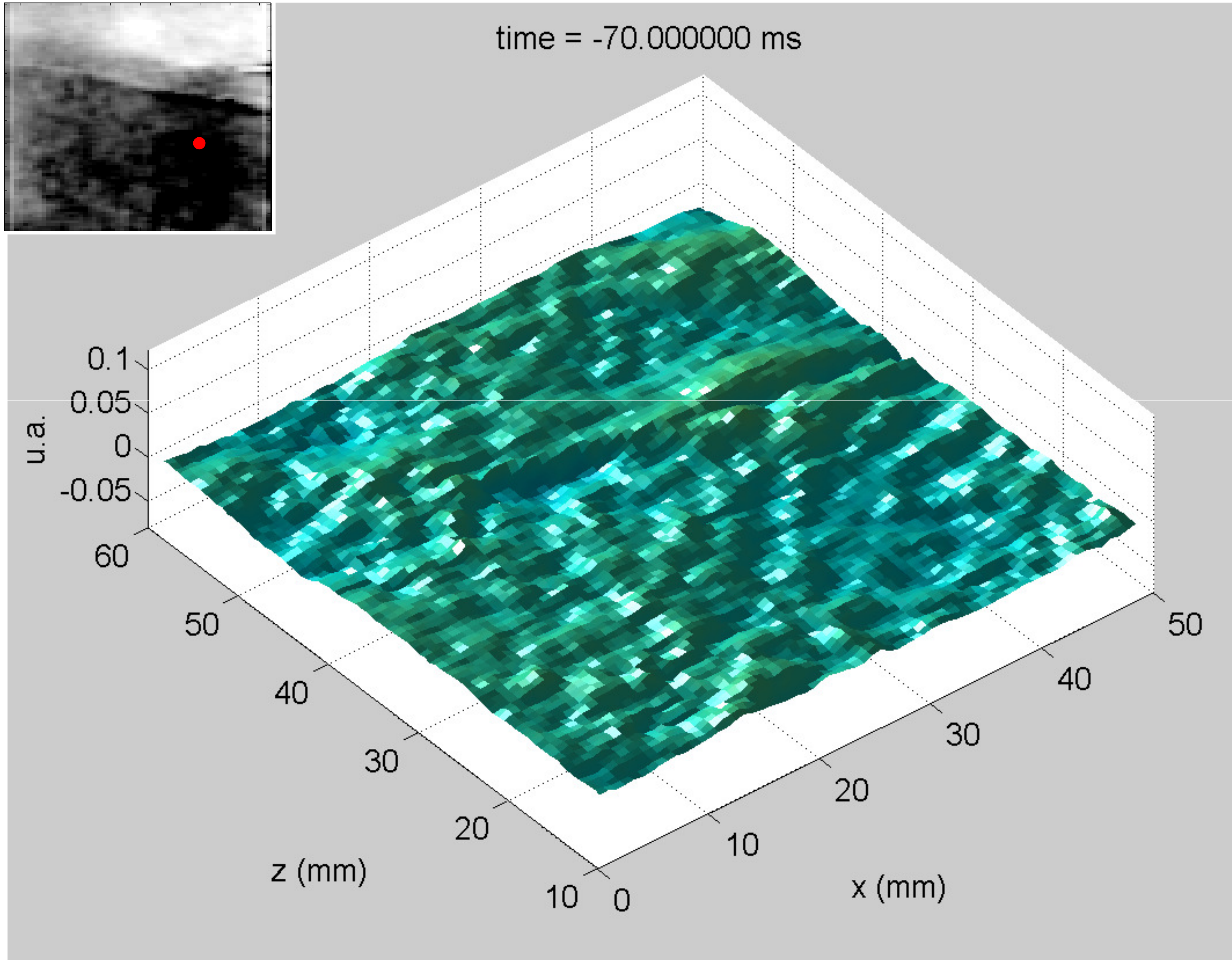


Shear velocity estimation in a bi-layer medium

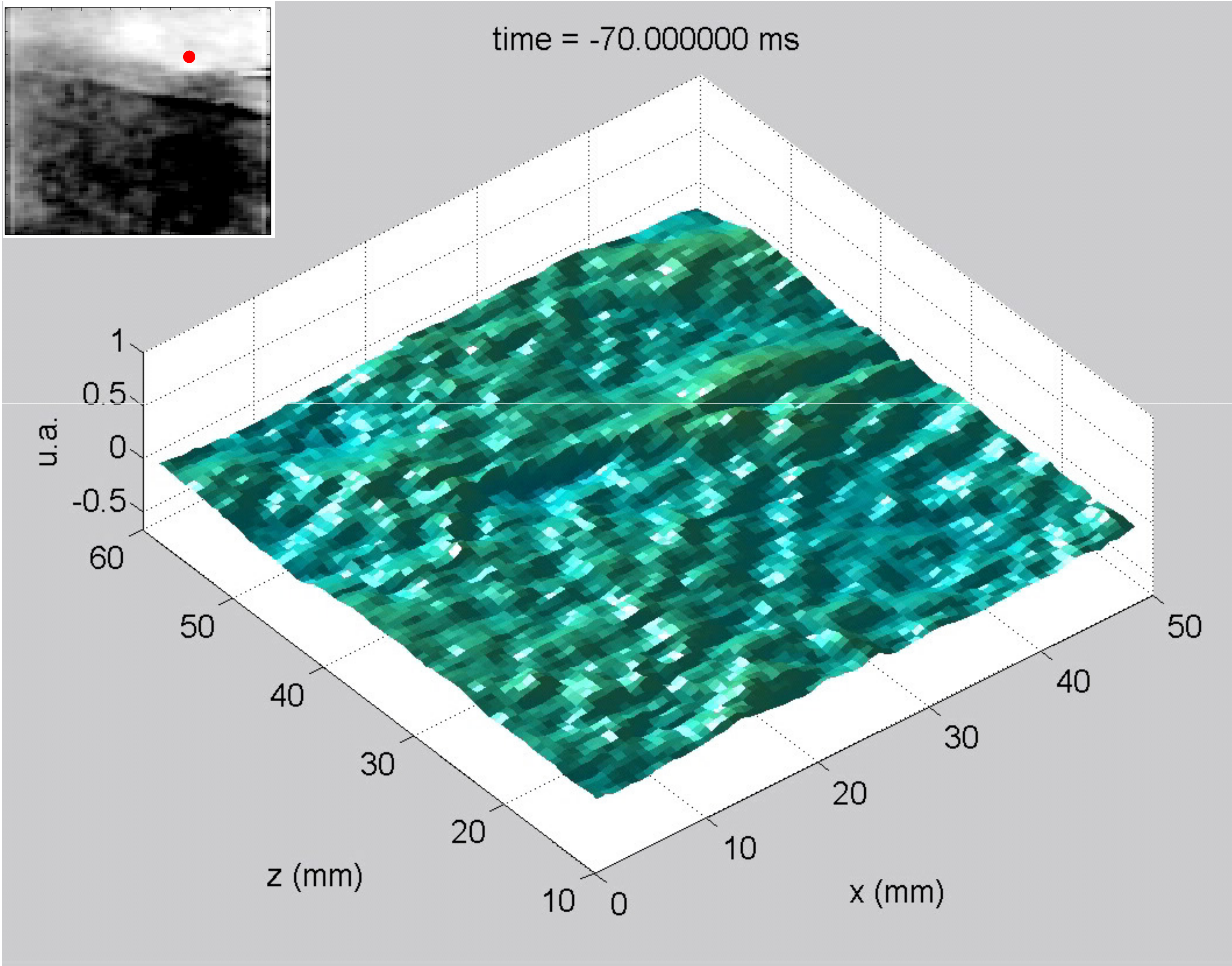




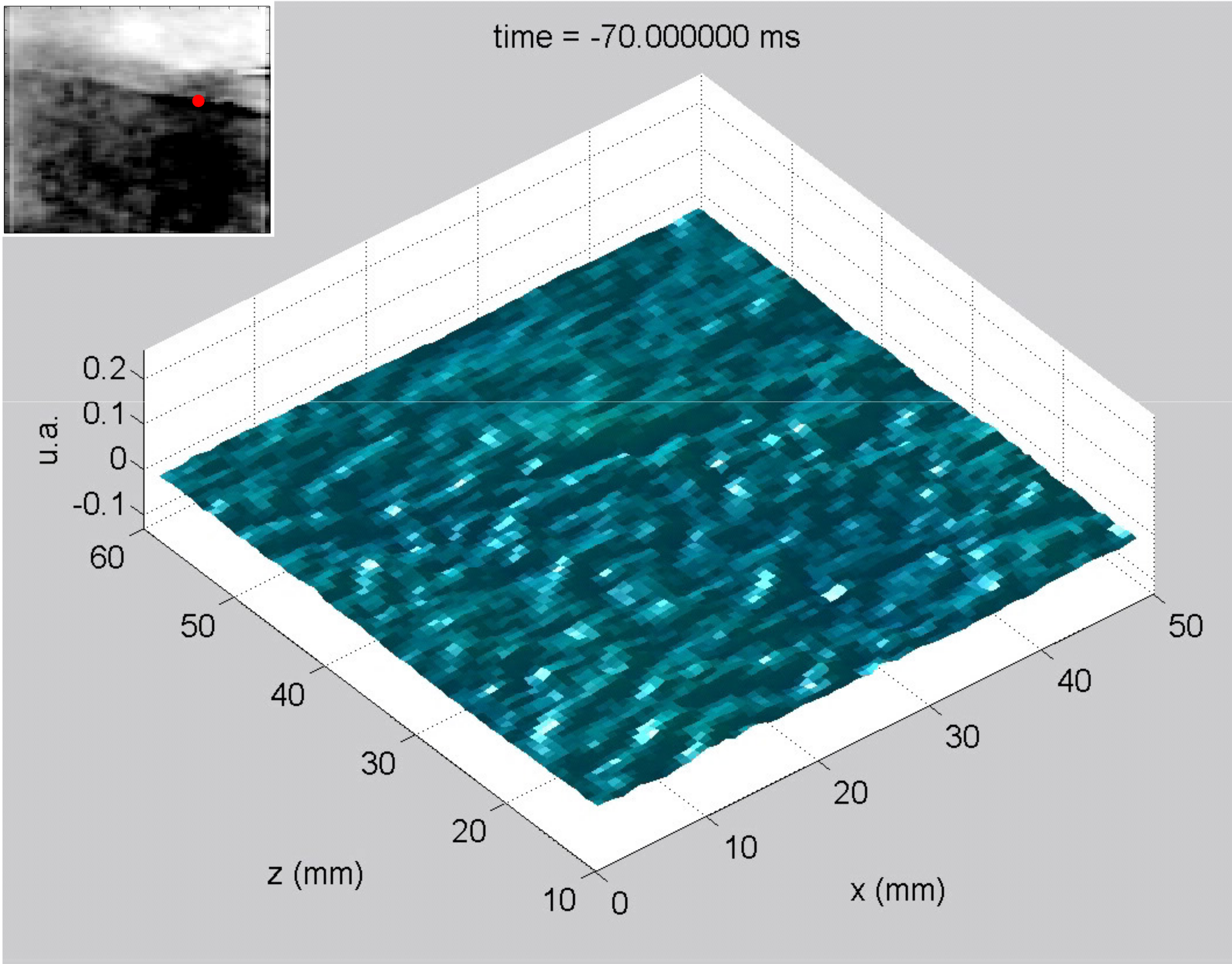
TR movie – Refocusing in the hard layer

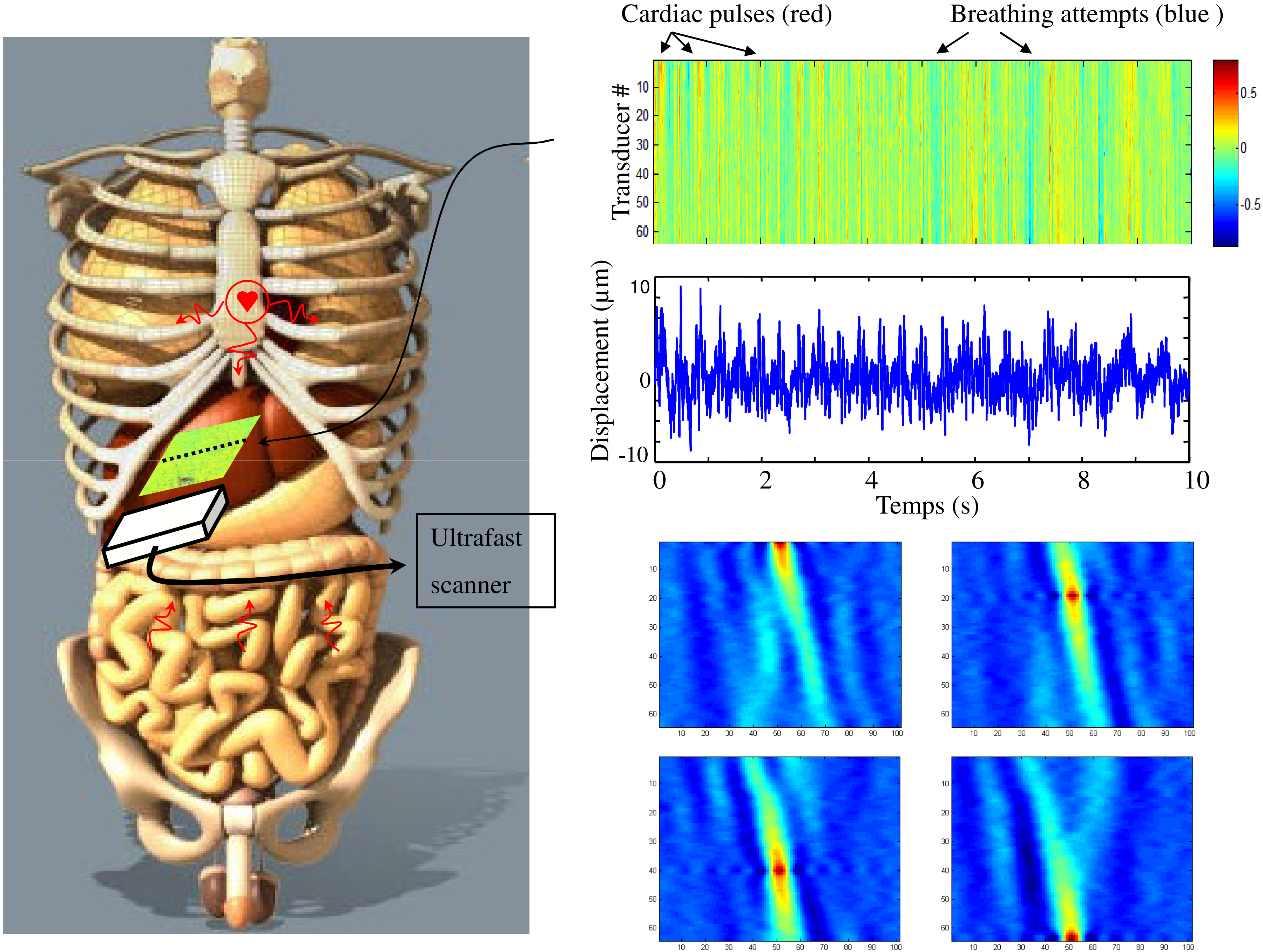


TR movie – Refocusing in the soft layer

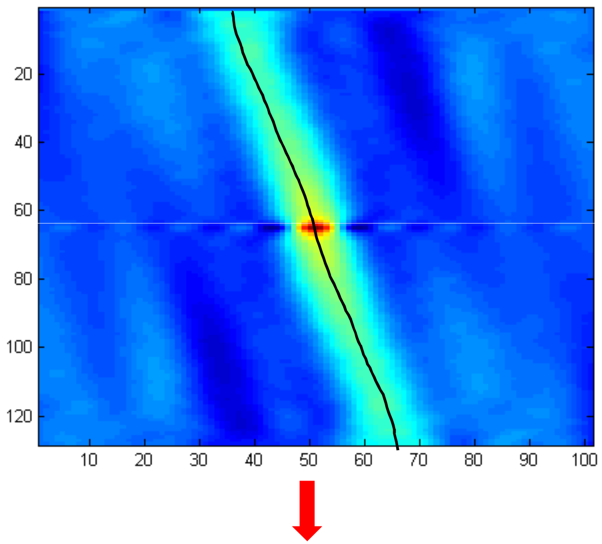


TR movie – Refocusing on the interface

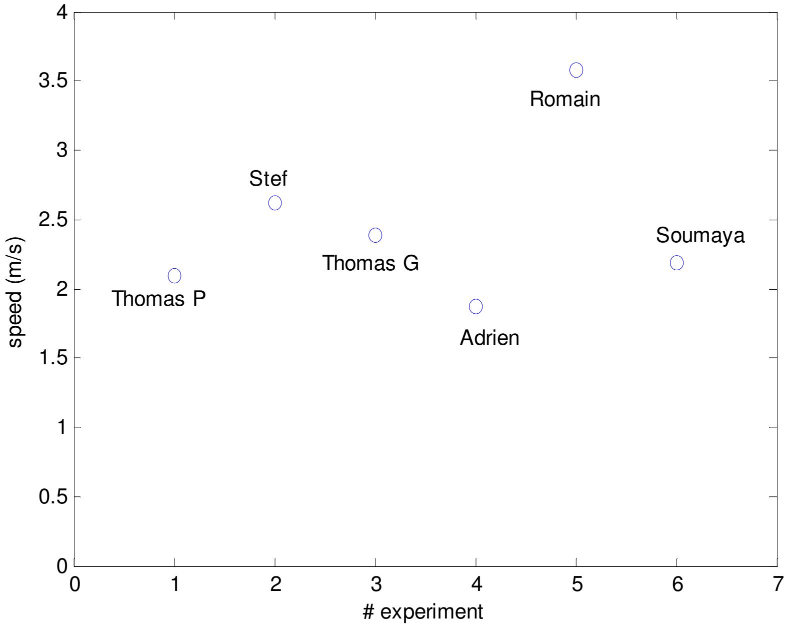




Cardiac pulses (red)
Breathing attempts (blue)
Transducer #
Displacement (µm)
Temps (s)
Ultrafast
scanner


20
40
60
80
100
120
10 20 30 40 50 60 70 80 90 100

V_S=2.39m/s


speed (m/s)
experiment
0 0.5 1 1.5 2 2.5 3 3.5 4
0 1 2 3 4 5 6 7
Thomas P
Stef
Thomas G
Adrien
Romain
Soumaya