NTNU
Innovation and Creativity

Comparison of numerical seismic modeling results with acoustic water-tank data: multi-offset experiment

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05. may 2014
ROSE meeting

Outline

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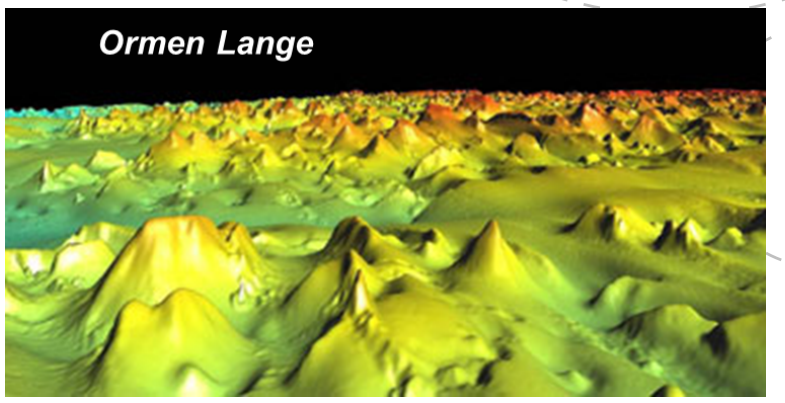
Motivation

- 3D seismic modeling is an important tool nowadays
- Difficulties in simulating 3D wave propagation due to the presence of shadow zones, head waves, diffractions and edge effects
- How to check the validity of the results?



Benchmarking of numerical modeling methods

- Against analytical solutions for simple canonical problems.
- Against other numerical modeling methods (e.g. SEAM project).
- Via direct comparison with real data acquired in situ.
- With data obtained in the laboratory under controlled conditions (small-scaled modeling)

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Seismic modeling vs. Ultrasonic laboratory experiment

Main assumption: scaled physical mechanisms are identical to field physical mechanisms (Ebrom and McDonald, 1994)

Scale ratio $\mu = 2 \cdot 10^4$

Table : scale ratio between parameters at seismic scale and laboratory scale

Distance (m)	d_{seis}	=	μd_{lab}
Wavelength (m)	λ_{seis}	=	$\mu \lambda_{lab}$
Time (s)	t_{seis}	=	μt_{lab}
Frequency (Hz)	f_{seis}	=	$\mu^{-1} f_{lab}$
Velocity (m/s)	v_{seis}	=	v_{lab}
Density (kg/m^3)	ρ_{seis}	=	ρ_{lab}
Quality factor (adim.)	Q_{seis}	=	Q_{lab}

The BENCHIE project

Main goal: reveal the strong points and limitations of numerical methods (accuracy and computational cost)

Methods in the project:

- Tip-Wave Superposition Method
- Spectral-Element Method
- Discontinuous Galerkin
- Born-Integral Method

Link

http://www.benchie.cnrs-mrs.fr

Synthetic data vs. Laboratory data

- Laboratory data for zero- and multi-offset experiments obtained in the Laboratoire de Mécanique et d'Acoustique in Marseille, France
- Numerical seismic modeling carried out using the Tip-wave Superposition Method (Ayzenberg et al., 2007 Geophysics 72)

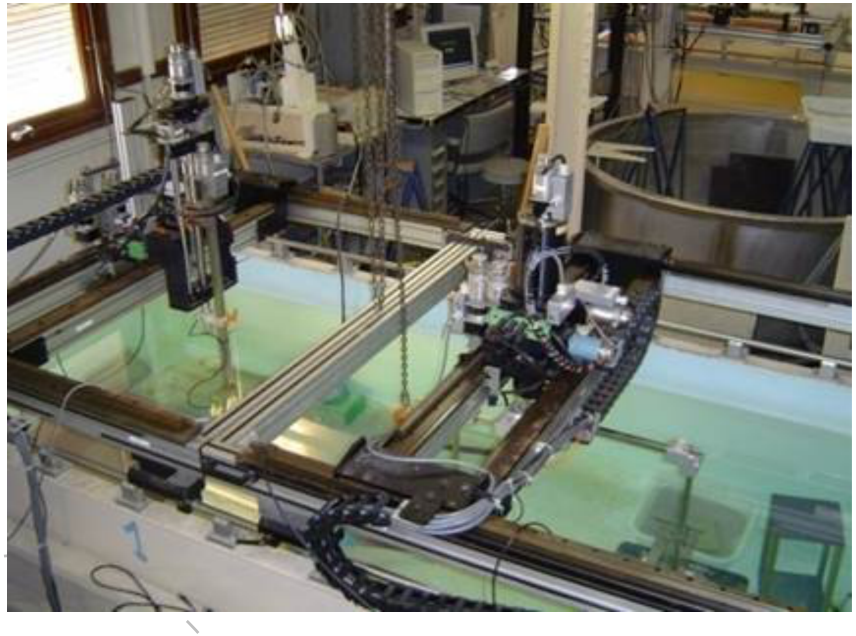

Figure : Zero-offset acquisition

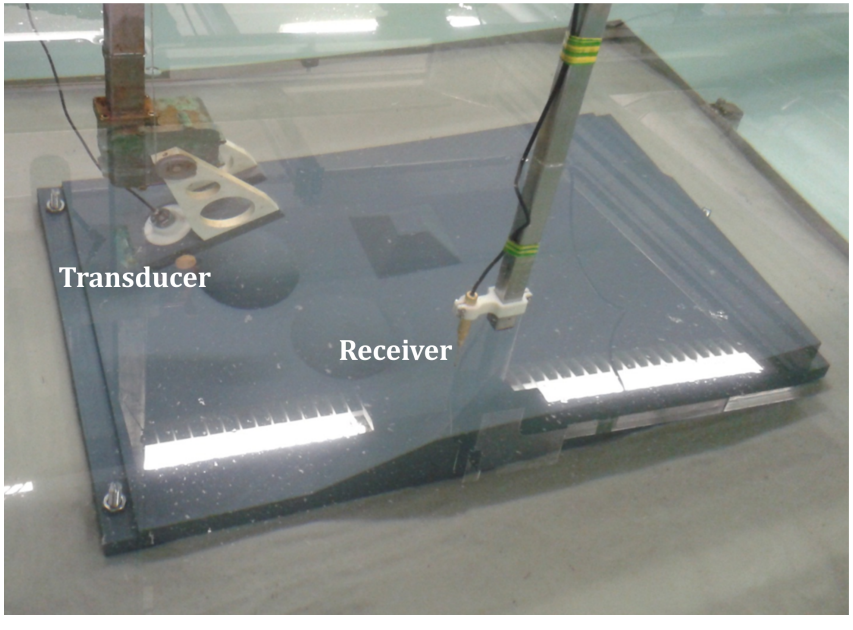

Figure : Multi-offset acquisition

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Marseille model

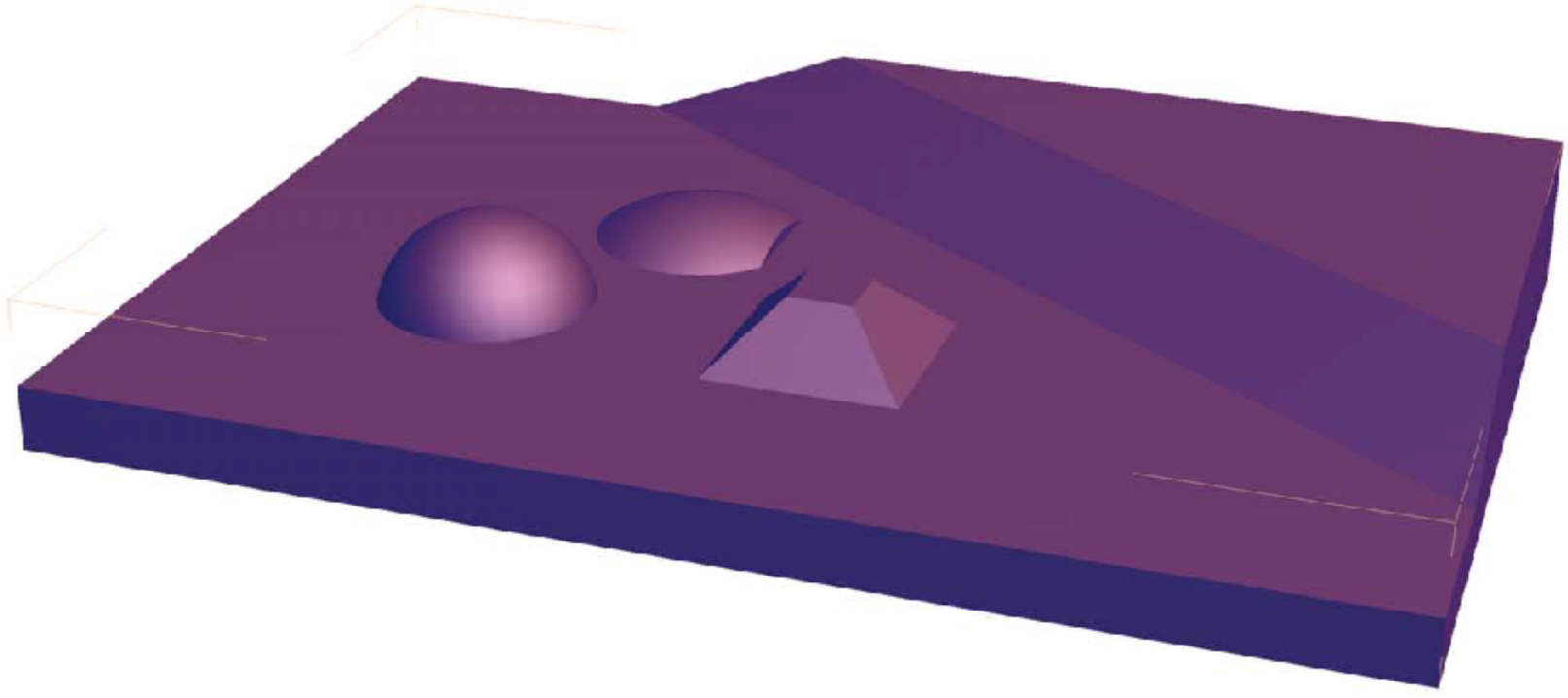
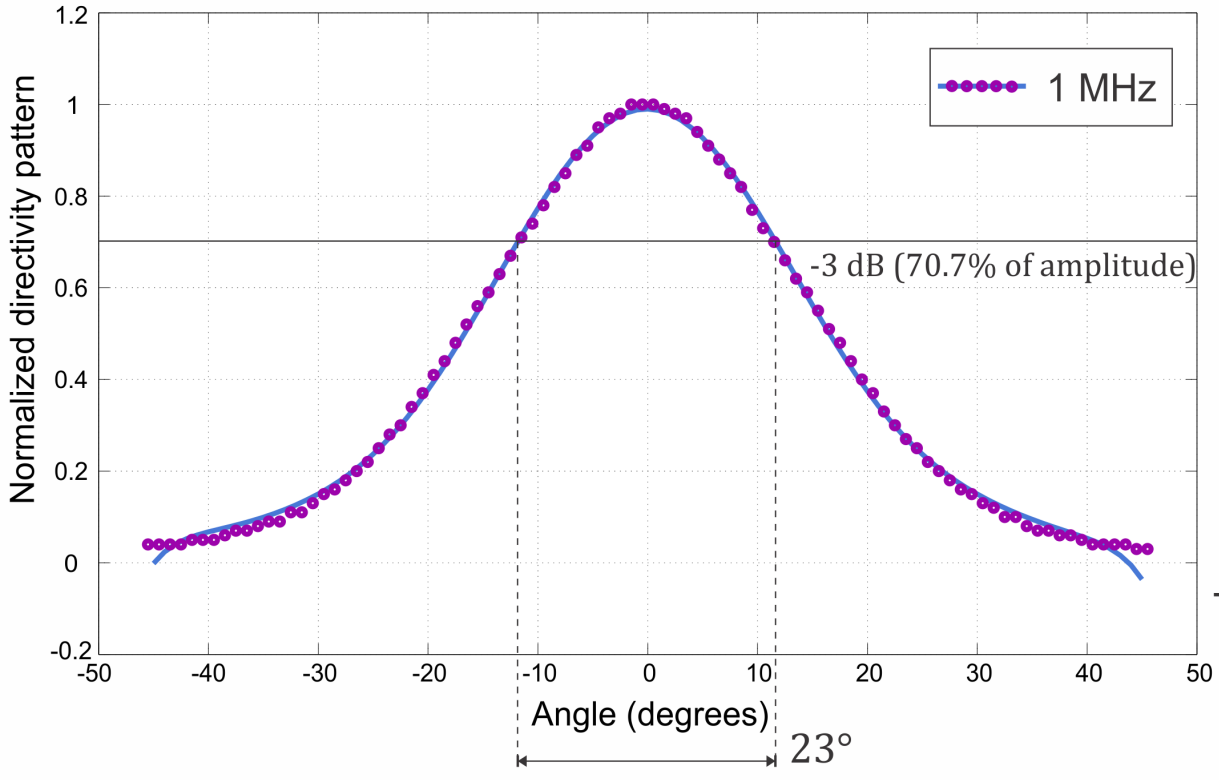


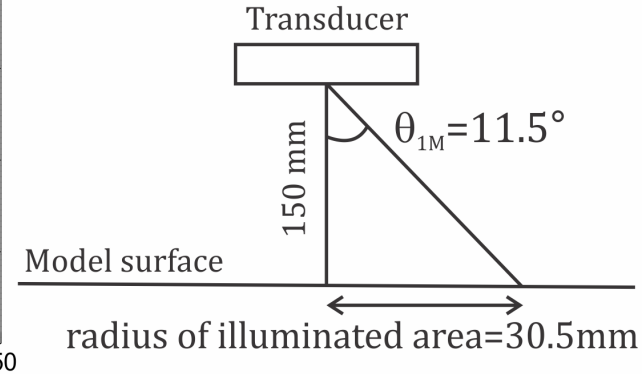
Figure : Based on the French model (French, 1974)

Material properties

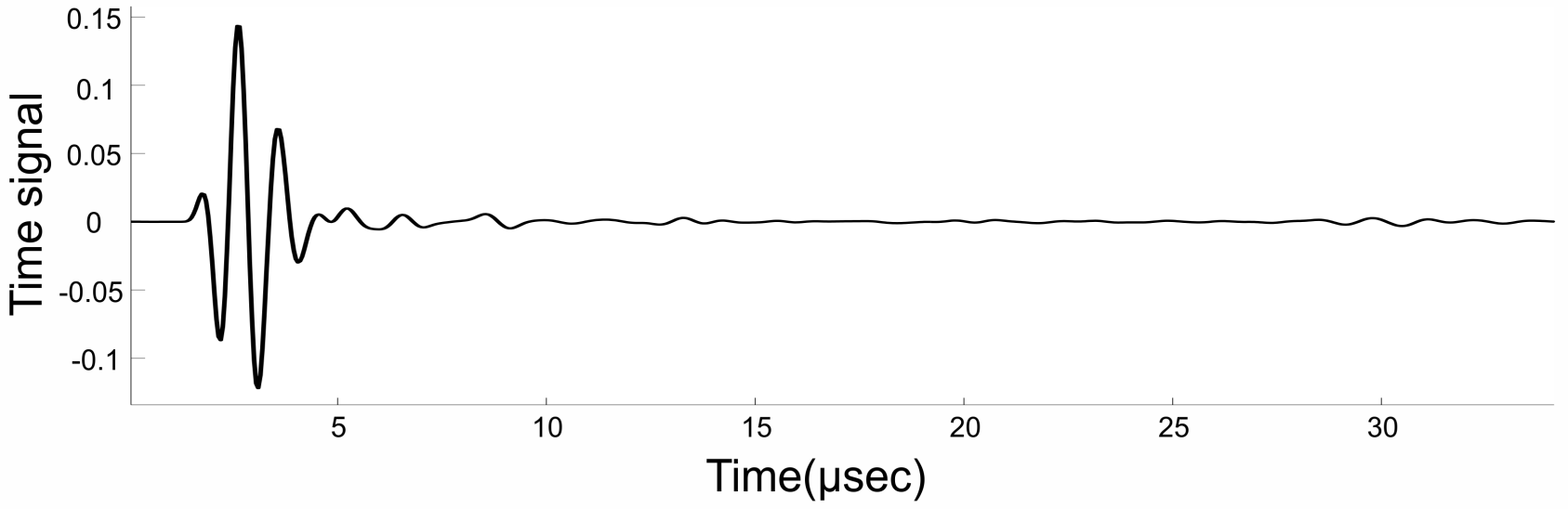
	V_p	V_s	ρ	Q_p	Q_s
Water	1476-1493 m/s	-	1000 kg/m^3	-	-
PVC	2220 m/s	1050 m/s	1412 kg/m^3	40-60	27-31
Sand	1660-1675 m/s	50 m/s	2004 kg/m^3	120	-
Aluminum	6440 m/s	3170 m/s	2700 kg/m^3	-	-

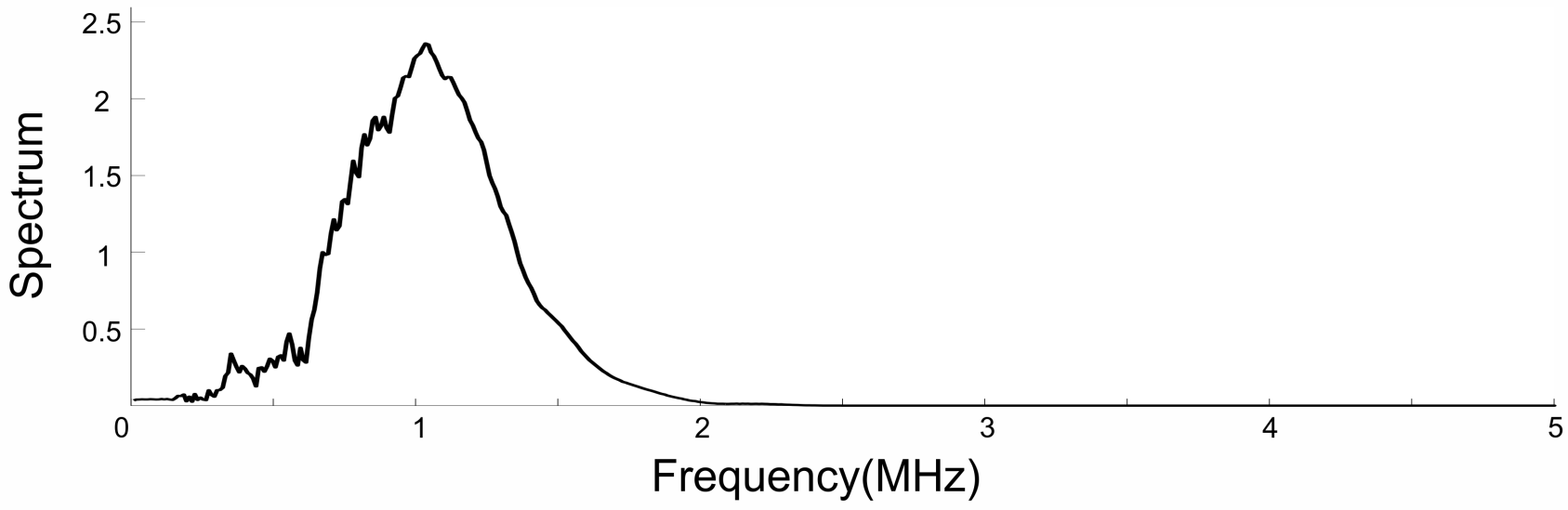
Directivity pattern



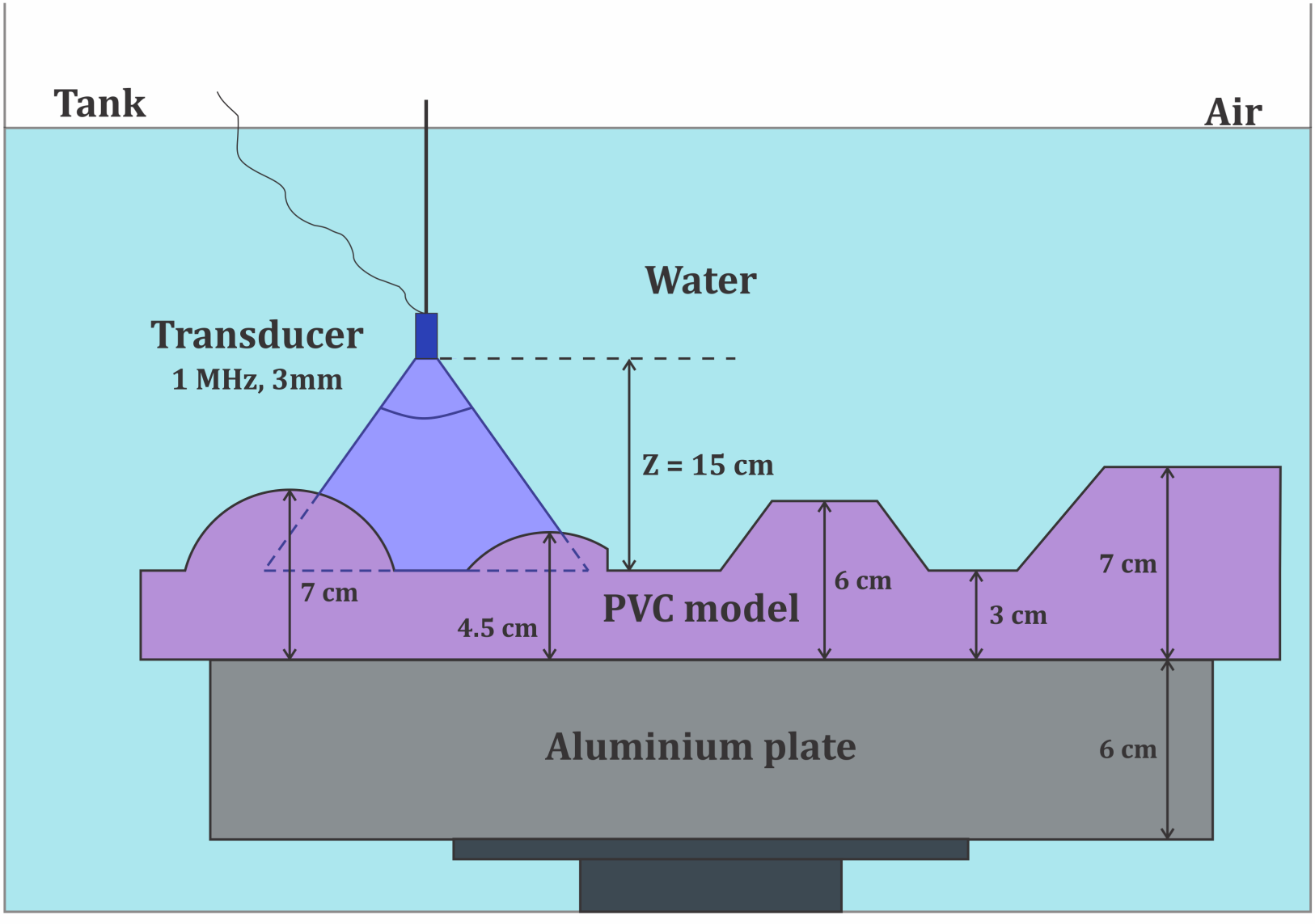


Broad-beam transducer (1 MHz, $\varnothing = 3$ mm)

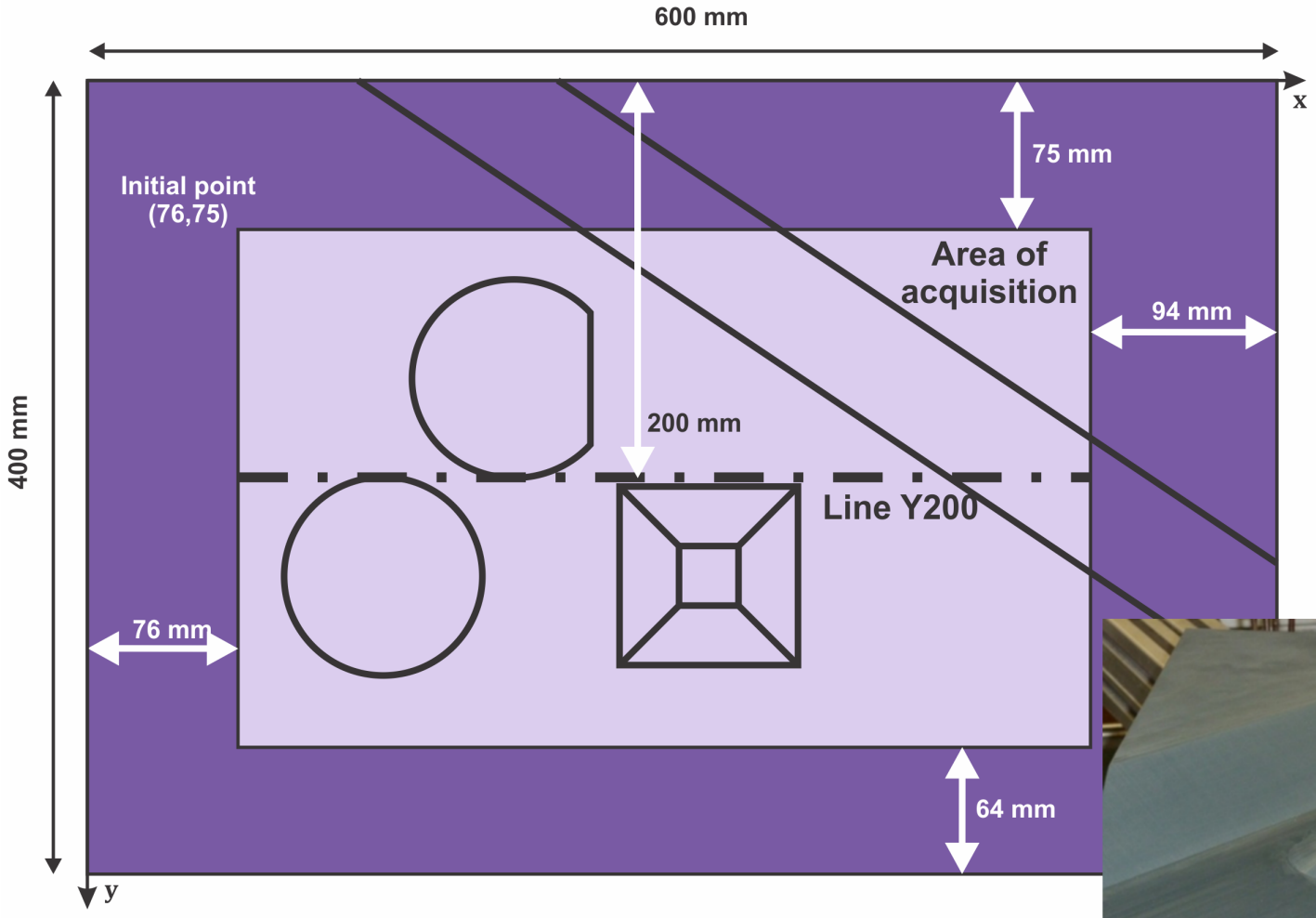


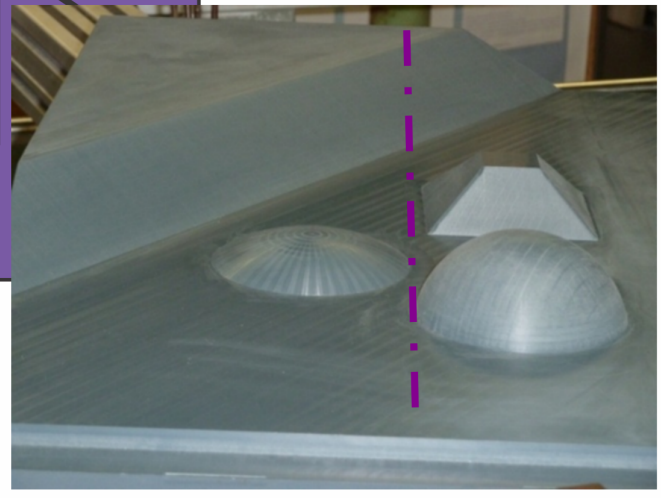


Zero-offset experimental set-up

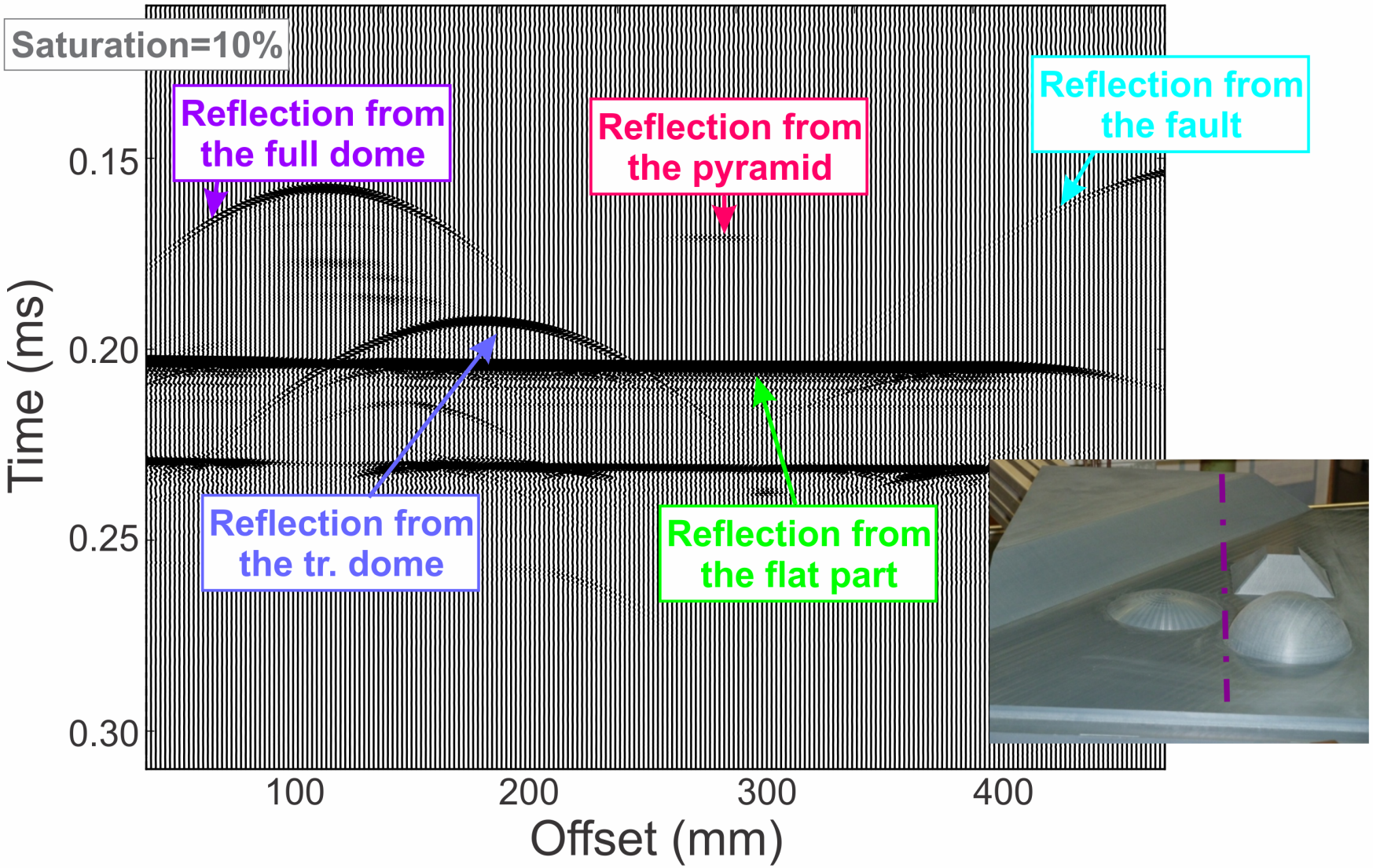


Zero-offset acquisition

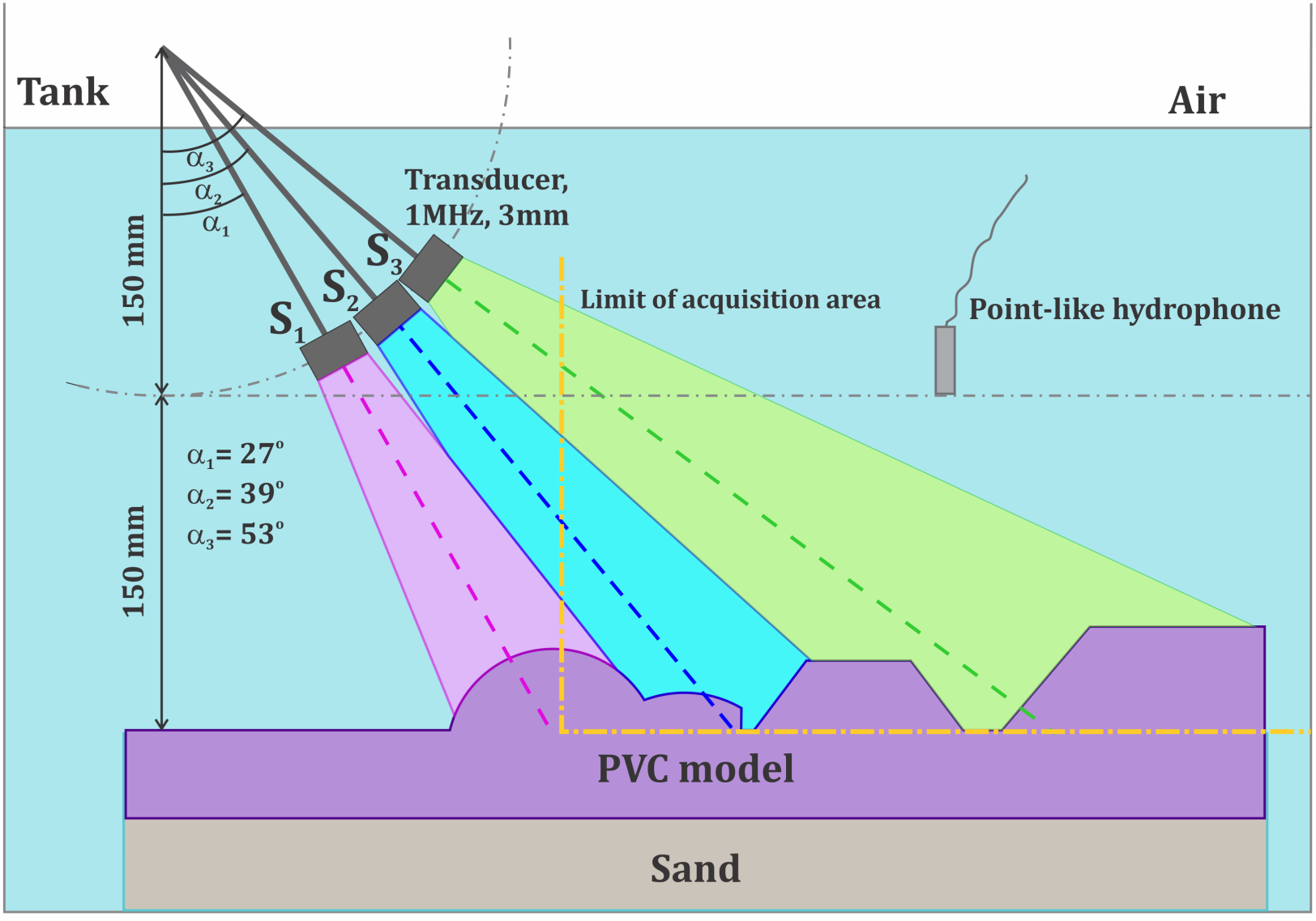




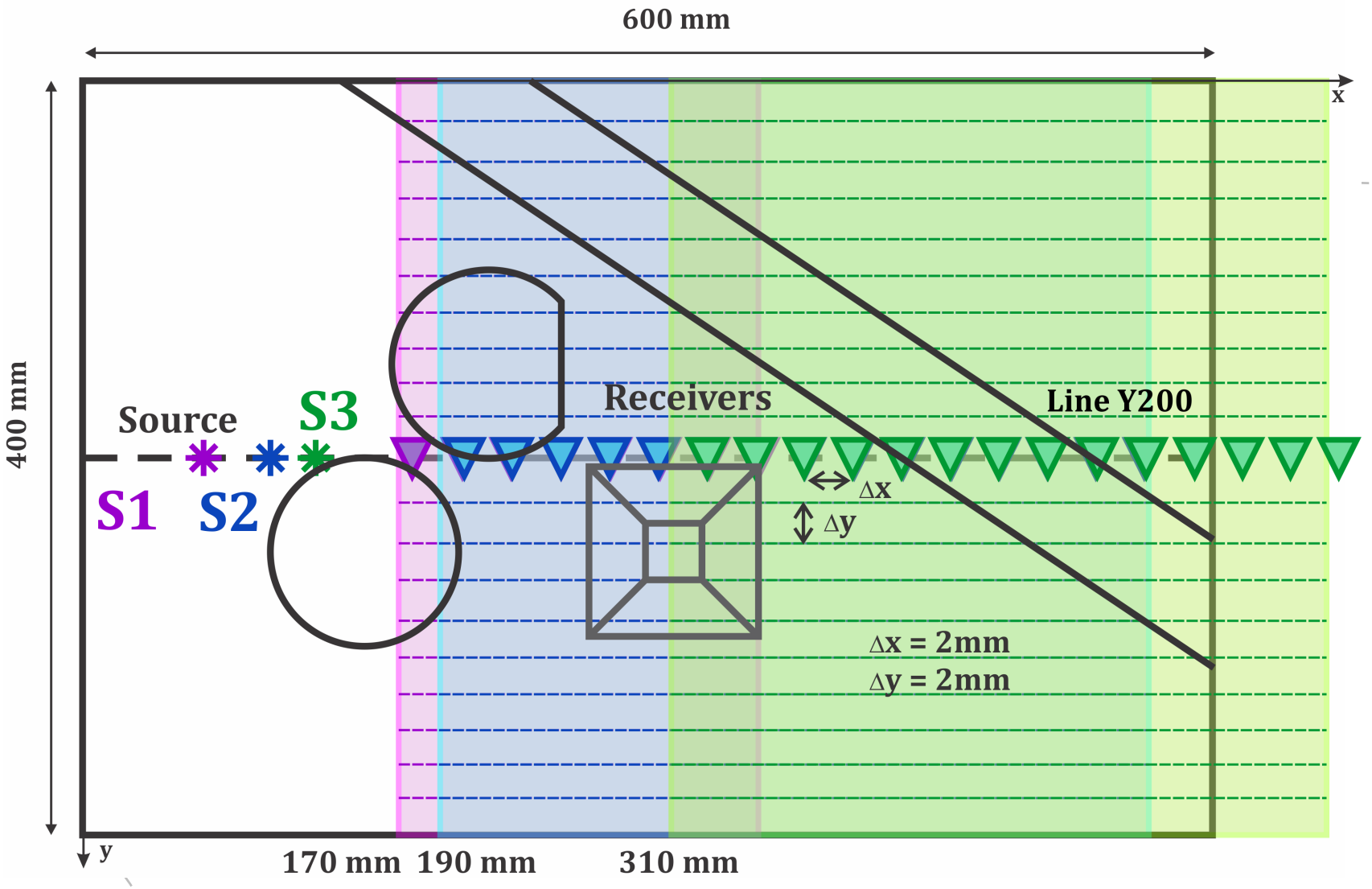
Laboratory data, zero-offset



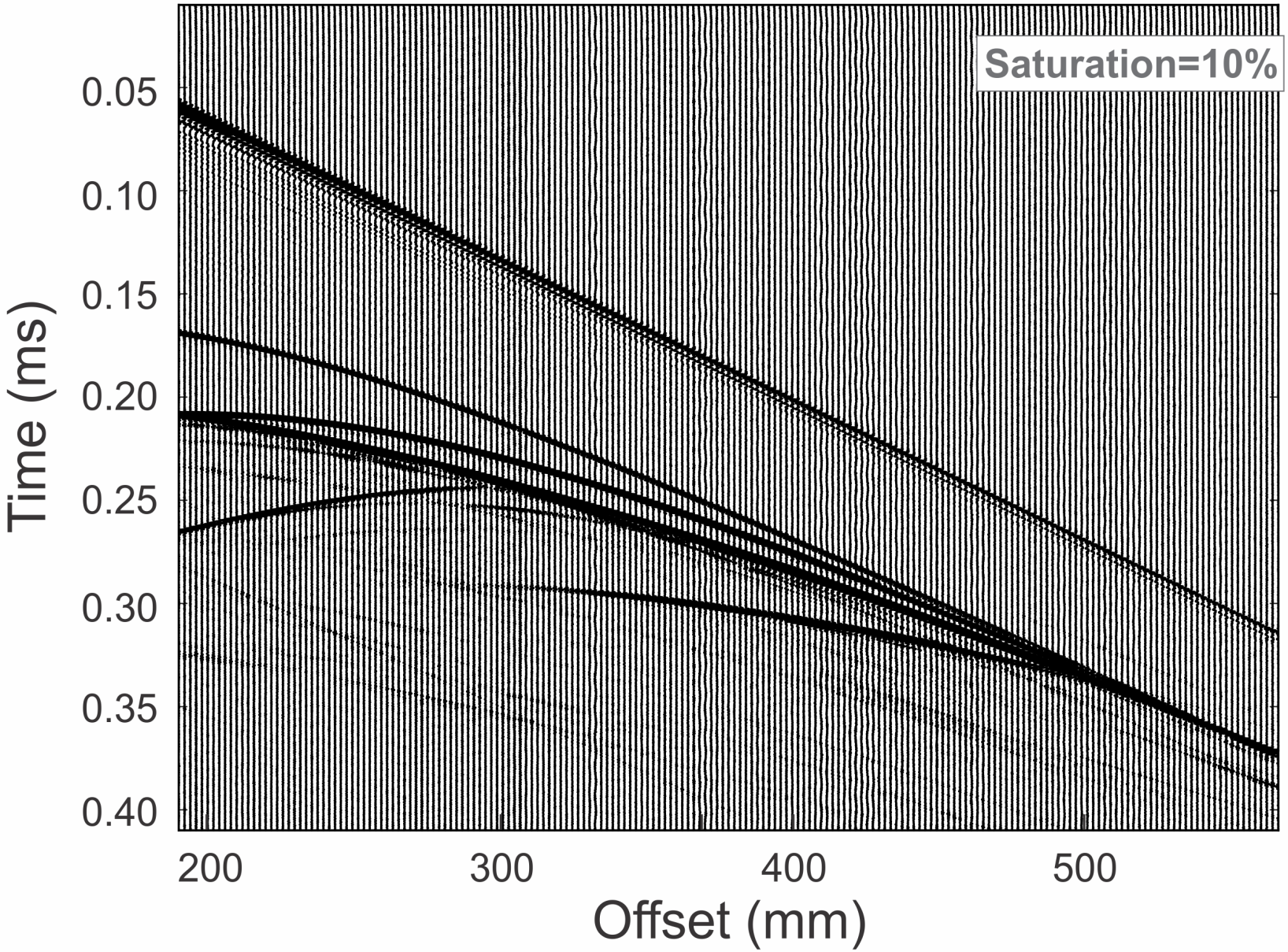
Multi-offset experimental set-up



Multi-offset acquisition

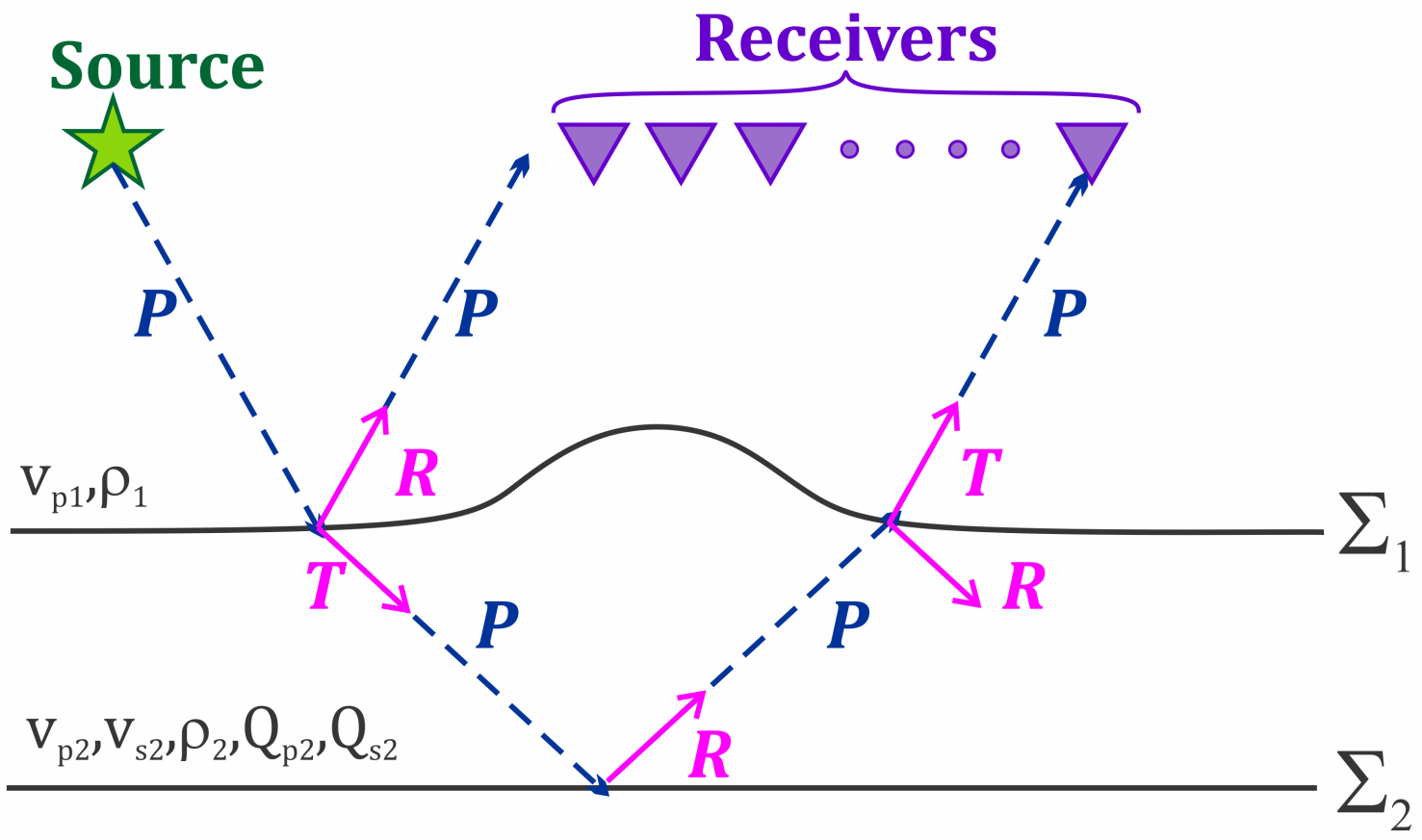


Laboratory data, multi-offset



Outline

Tip-wave Superposition Method



Tip-Wave Superposition Method

The surface integral propagator $\mathbf{P}$

$$\mathbf{P}(\mathbf{x};\mathbf{s})\langle\ldots\rangle = \frac{1}{4\pi}\iint_{\Sigma}\left[\frac{\partial G(\mathbf{x};\mathbf{s})}{\partial \mathbf{n}(\mathbf{s})}\langle\ldots\rangle - G(\mathbf{x};\mathbf{s})\frac{\partial}{\partial \mathbf{n}(\mathbf{s})}\langle\ldots\rangle\right] d\Sigma(\mathbf{s}) \tag{1}$$

The reflection and transmission operators $\mathbf{R}$ and $\mathbf{T}$

$$\mathbf{R}\left(\mathbf{s},\mathbf{s}'\right) = \mathfrak{F}^{-1}\left(\mathbf{s},\mathbf{q}\right)\hat{\mathbf{R}}(\mathbf{q})\mathfrak{F}\left(\mathbf{q},\mathbf{s}'\right) \tag{2}$$

and

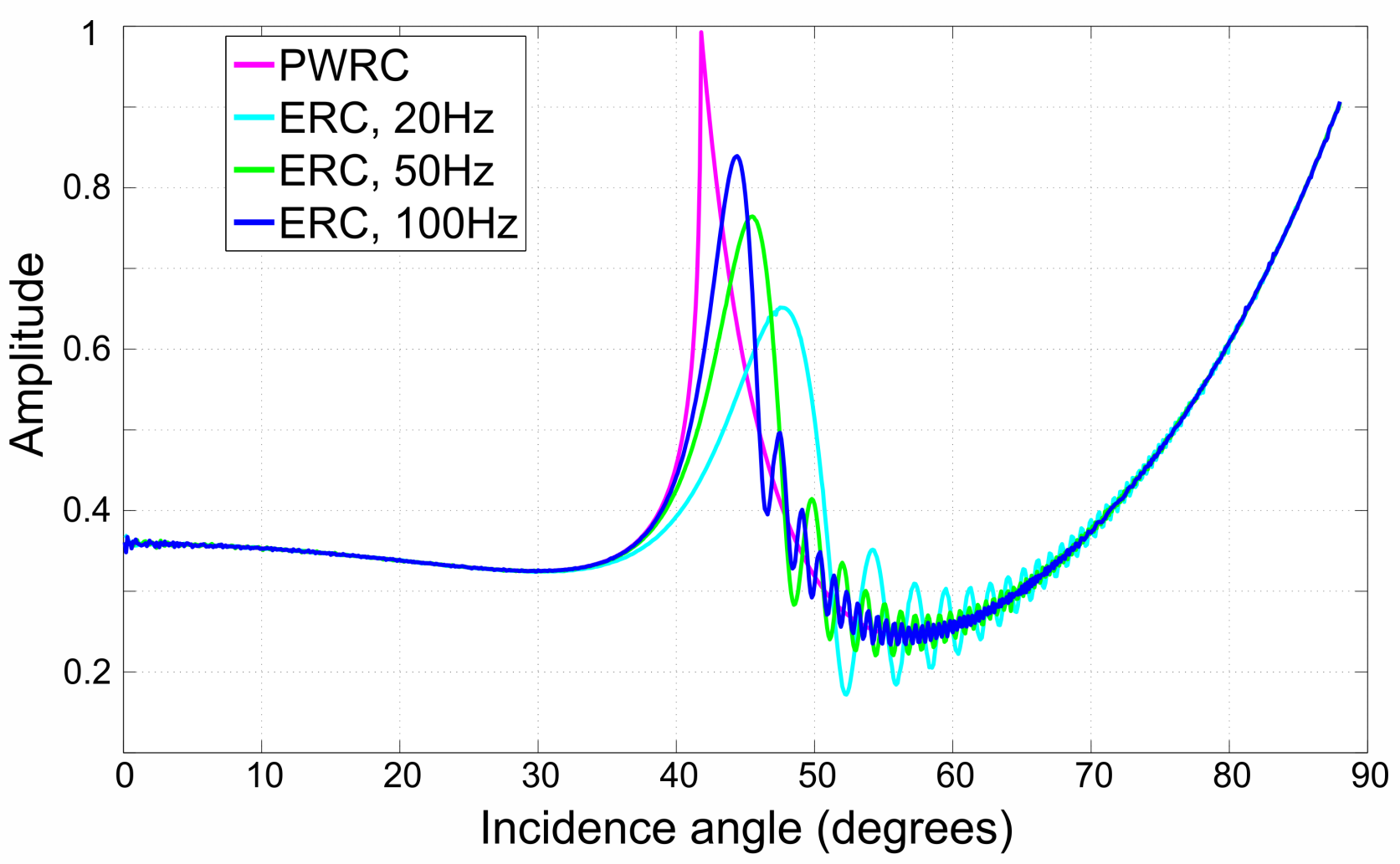
$$\mathbf{T}\left(\mathbf{s},\mathbf{s}'\right) = \mathfrak{F}^{-1}\left(\mathbf{s},\mathbf{q}\right)\hat{\mathbf{T}}(\mathbf{q})\mathfrak{F}\left(\mathbf{q},\mathbf{s}'\right) \tag{3}$$

- Interface split into small elements, propagation operator approximated by propagation matrix.
- Reflection operator approximated by effective or plane-wave reflection/transmission coefficients.

Tip-Wave Superposition Method

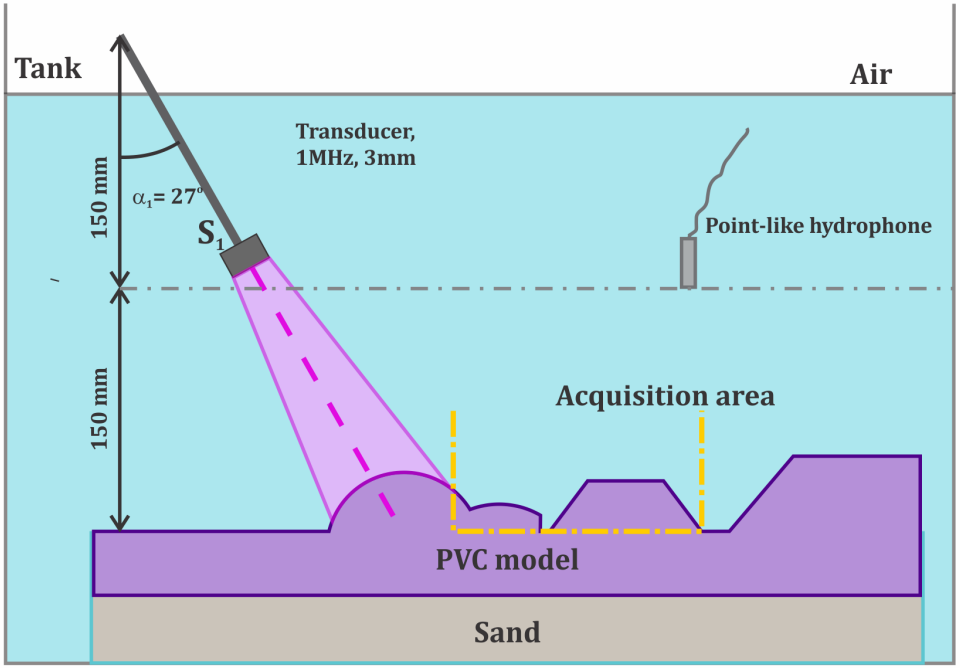
- Plane-wave reflection coefficient (PWRC) $\Longrightarrow$ conventional Kirchhoff modeling
  - Fast and accurate
  - Artificial diffractions
- Effective reflection coefficients (ERC)
  - Slower, but high accuracy
  - Seismic frequency range
  - Head waves
- Effective coefficients on dominant frequency (DRC)
  - Trade-off between speed and quality
  - No artificial diffractions
  - No head waves

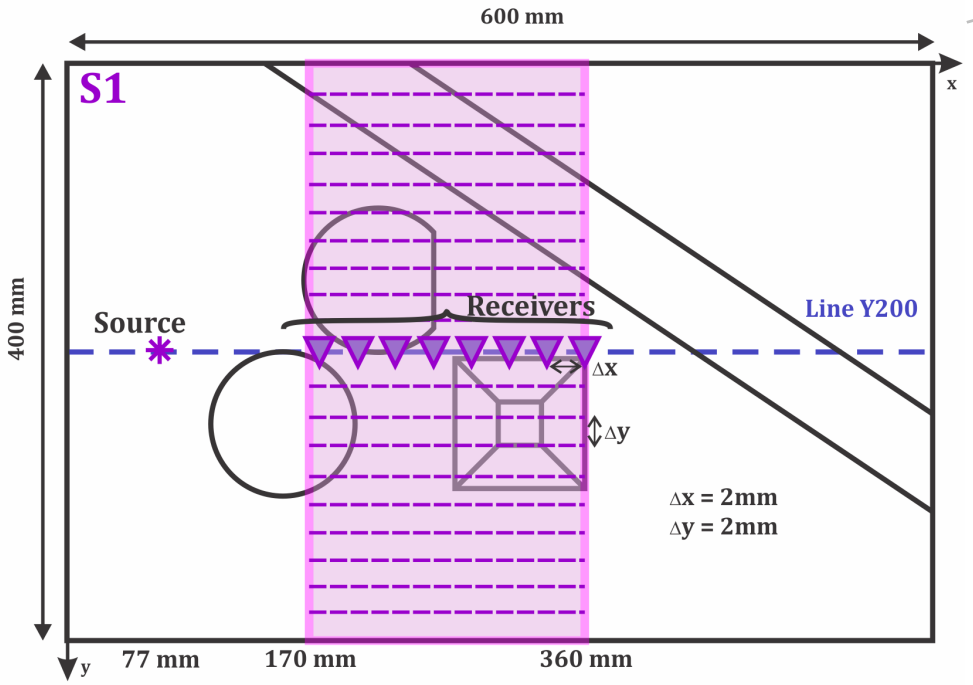
Tip-wave Superposition Method



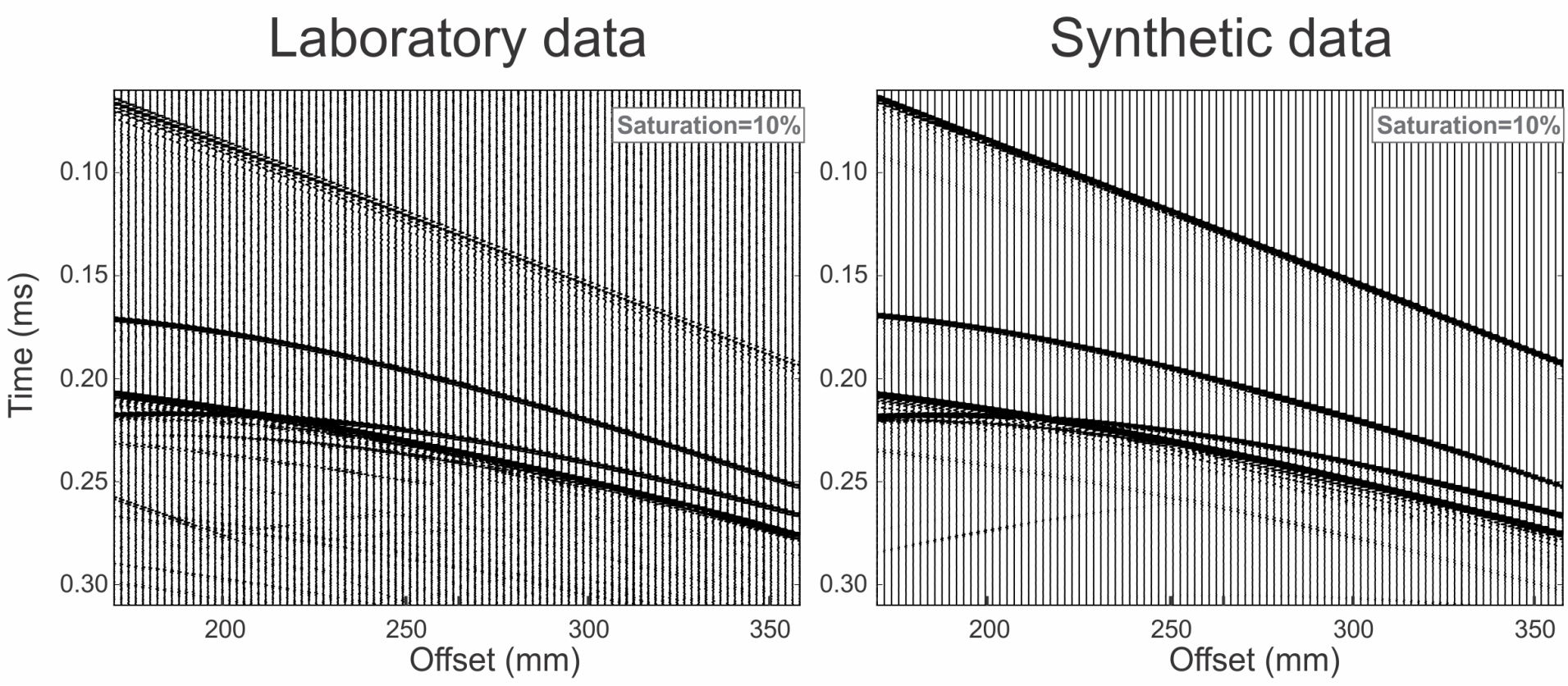
Outline

Multi-offset experiment, S1

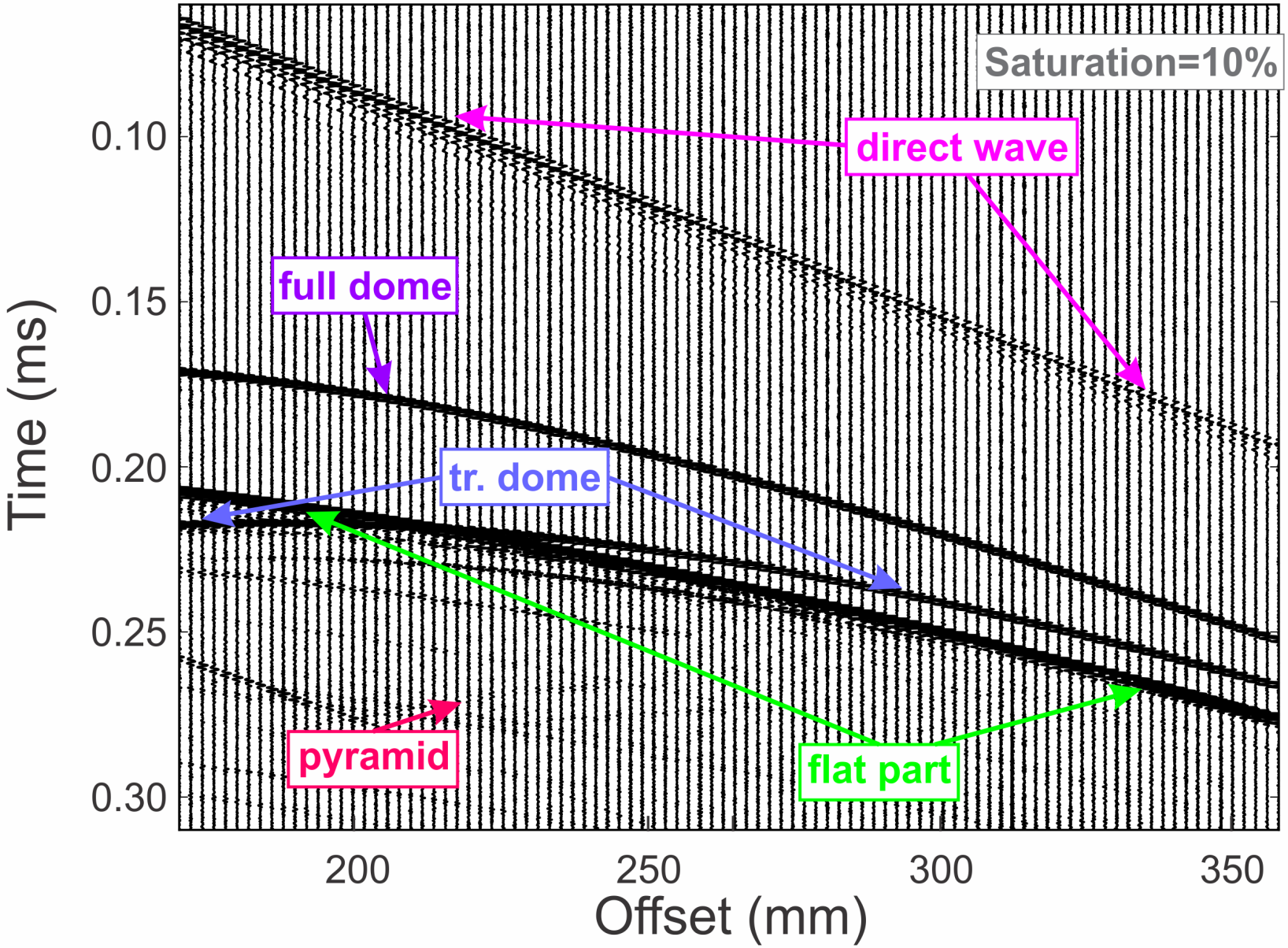




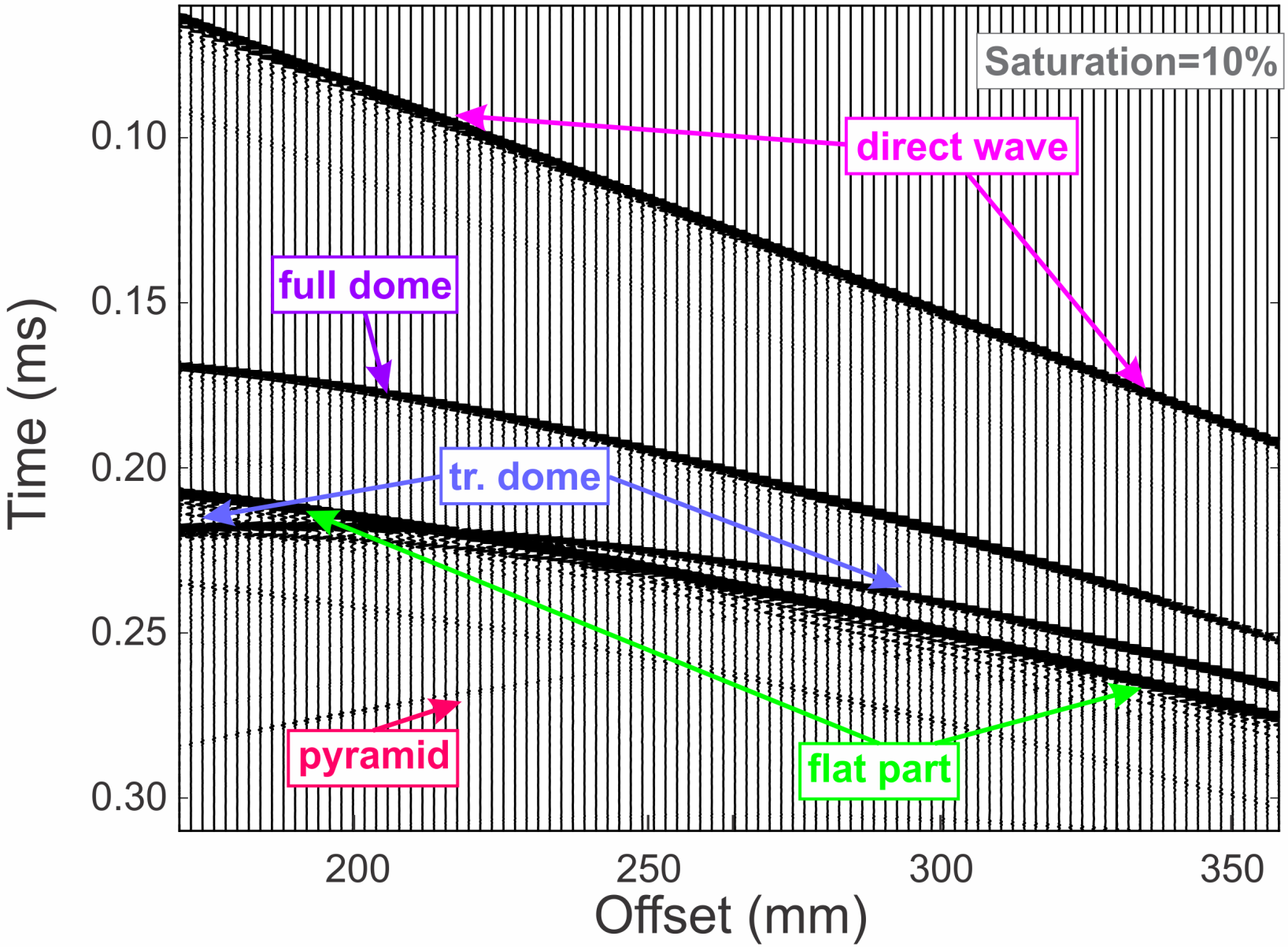
Comparison of laboratory and synthetic data, S1



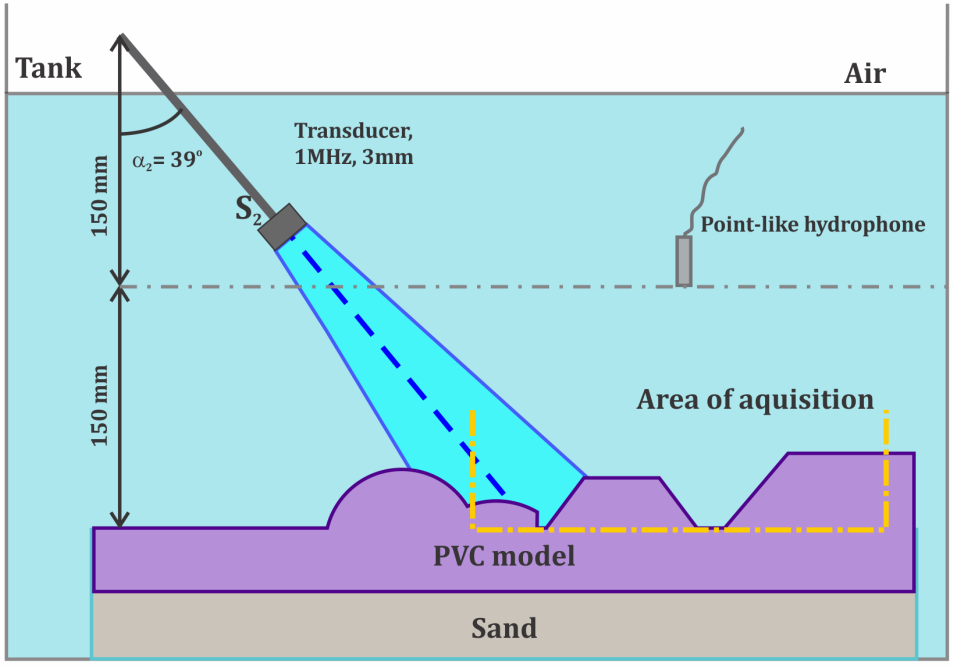
Laboratory data, S1

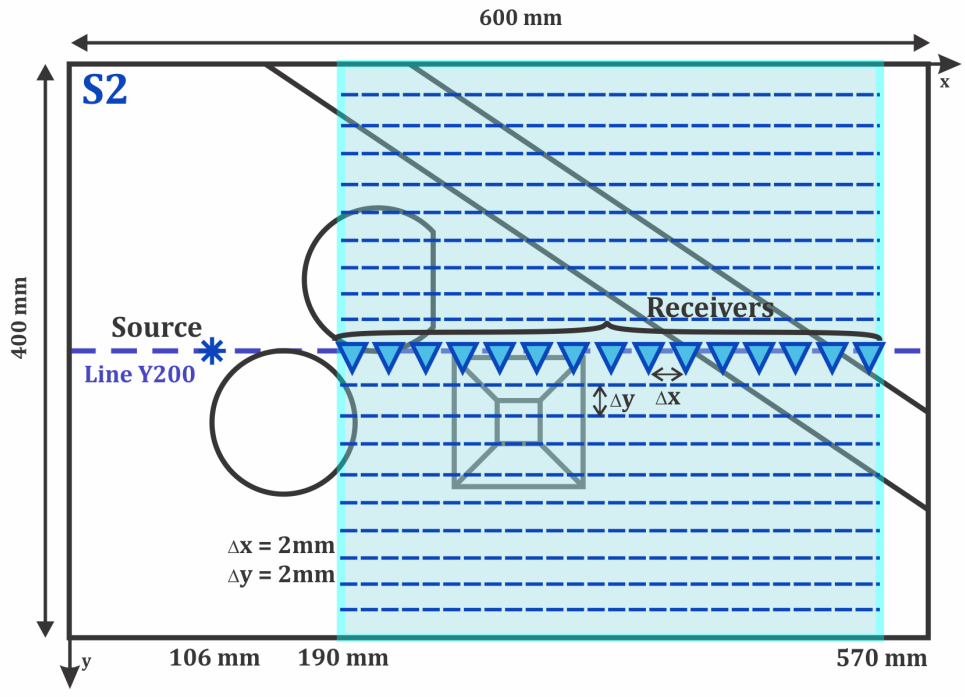


Synthetic data, S1

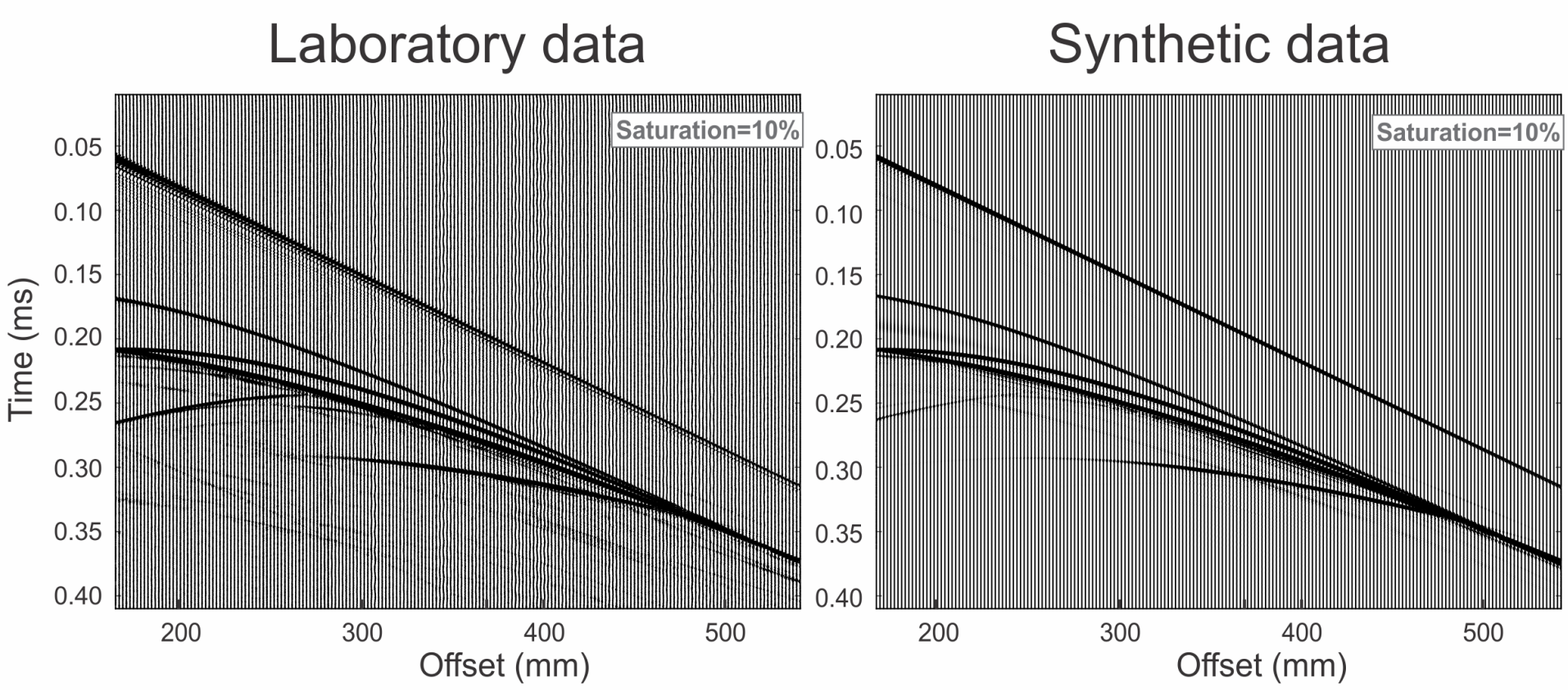


Multi-offset experiment, S2

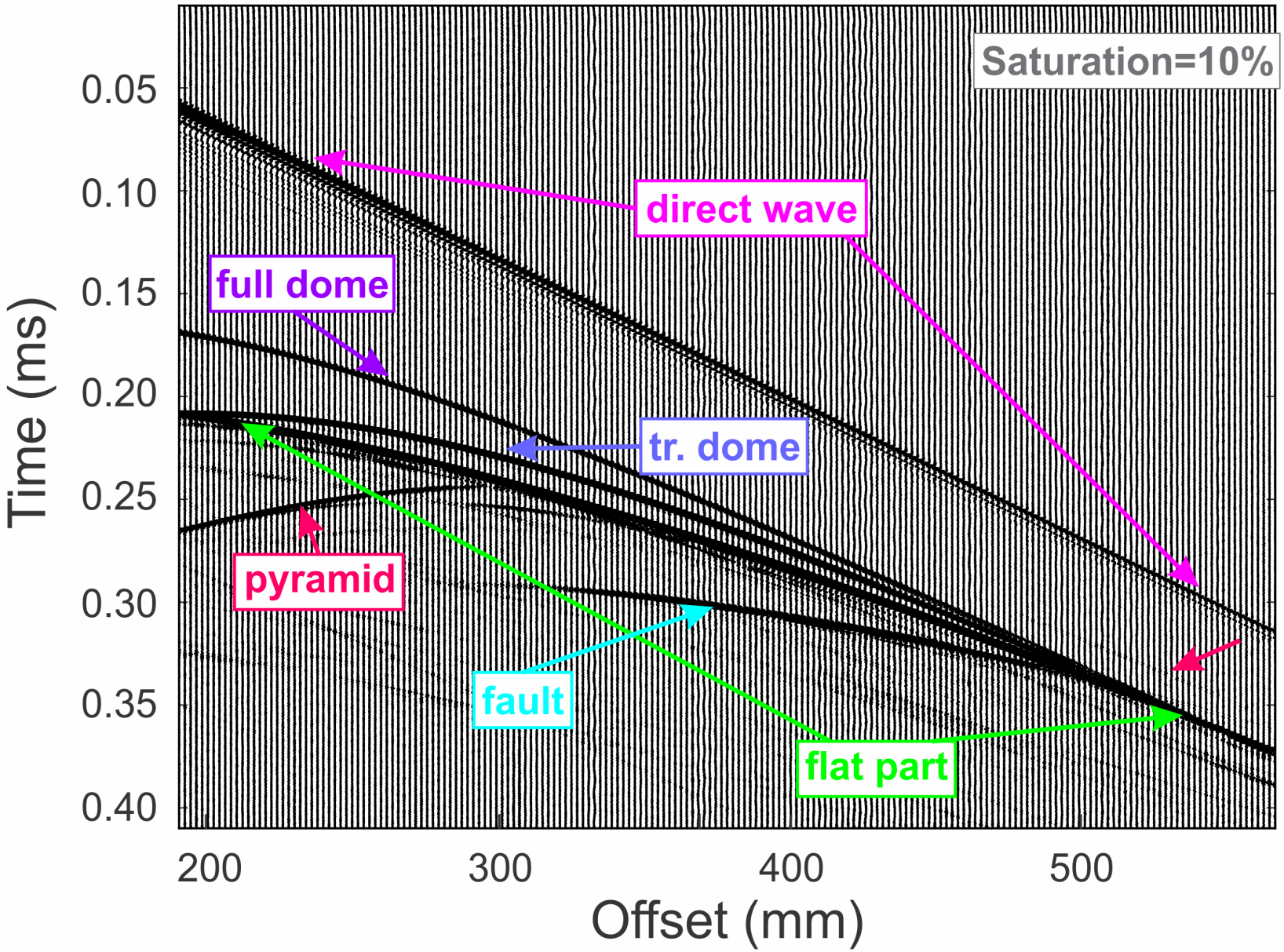




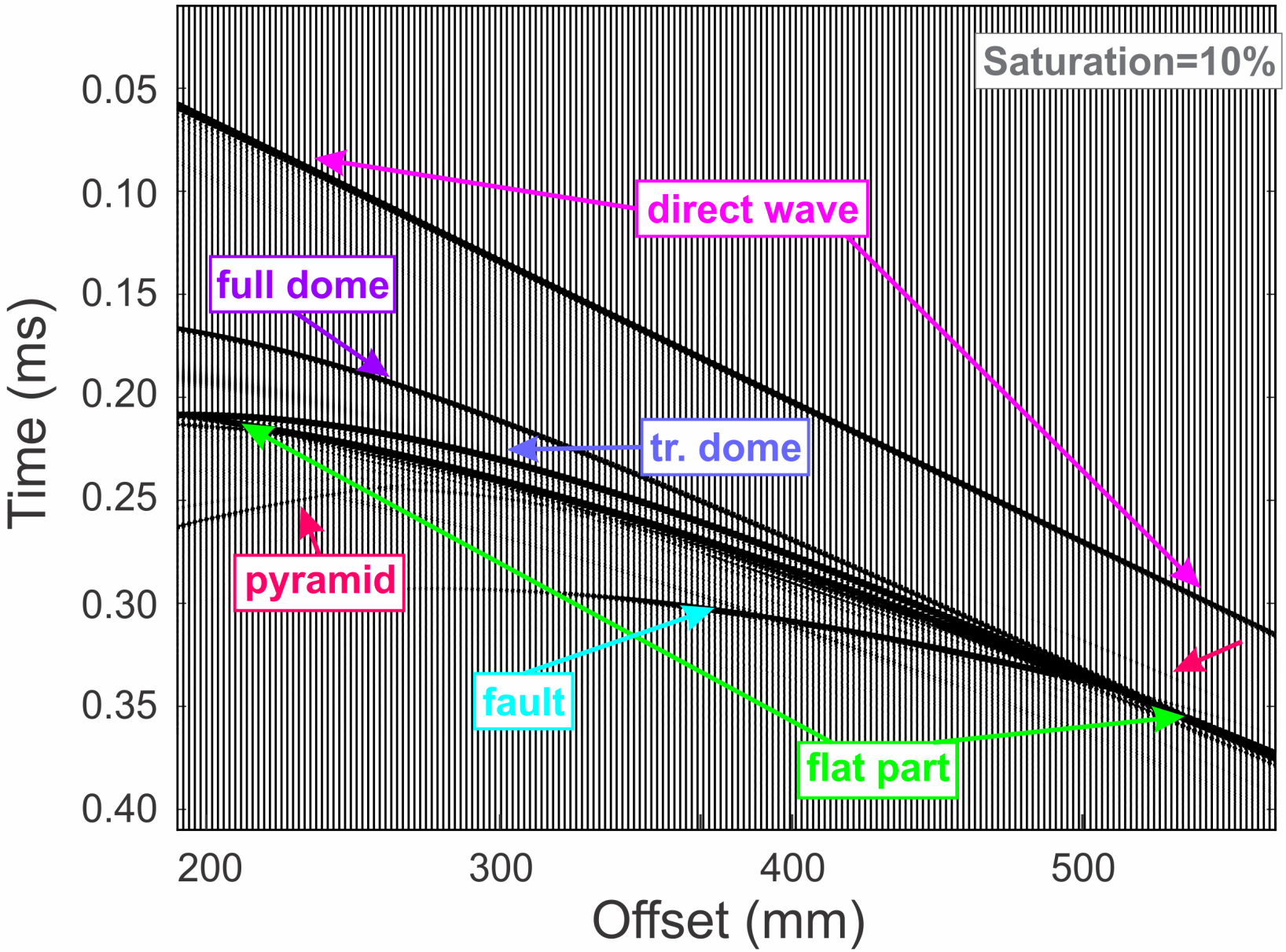
Comparison of laboratory and synthetic data, S2



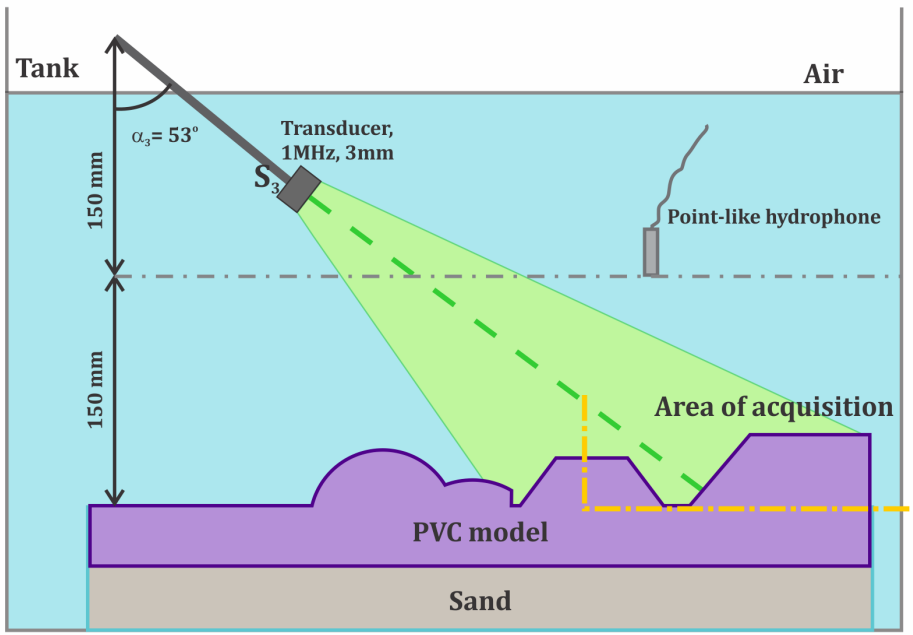
Laboratory data, S2

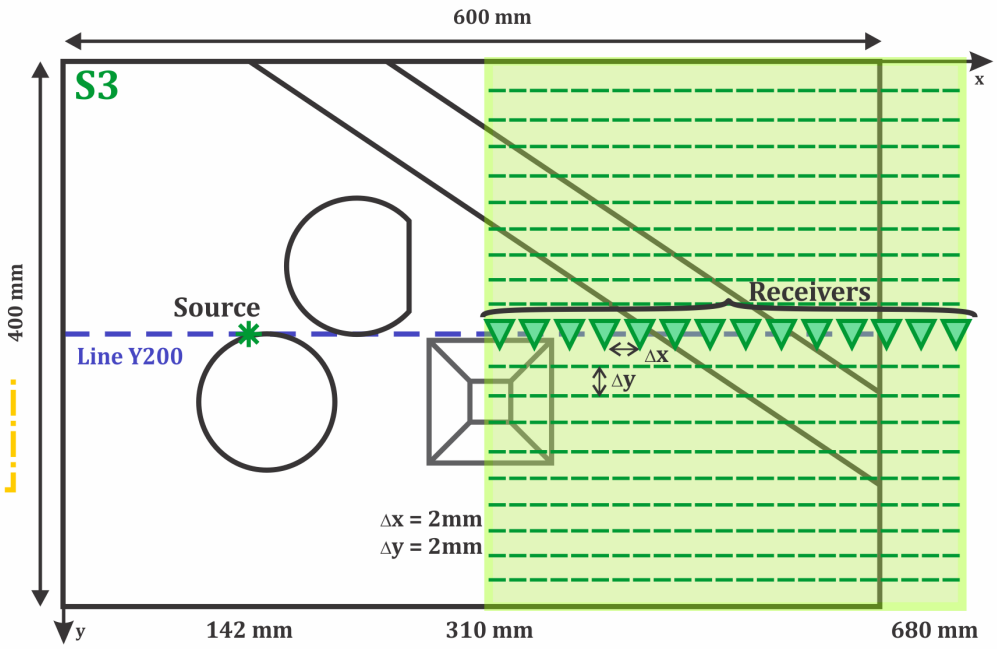


Synthetic data, S2



Multi-offset experiment, S3





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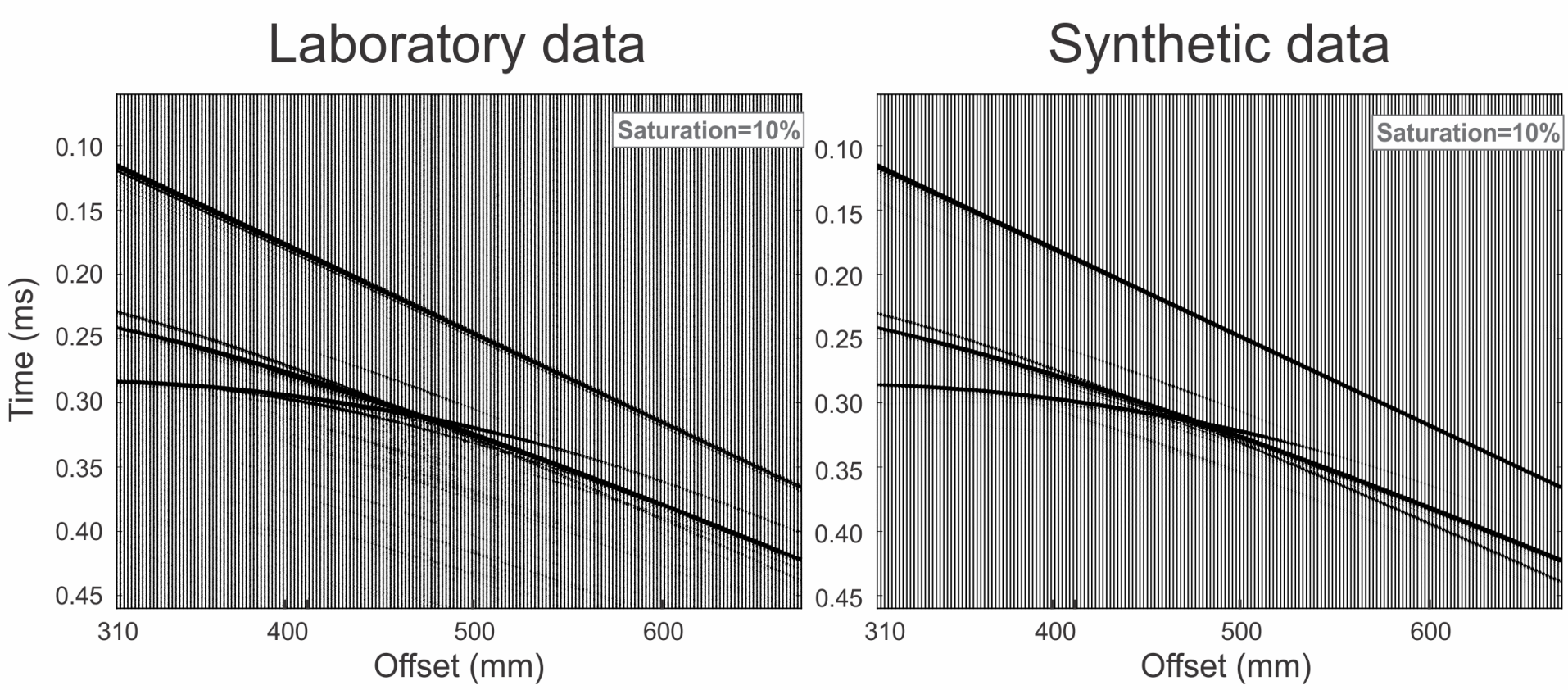
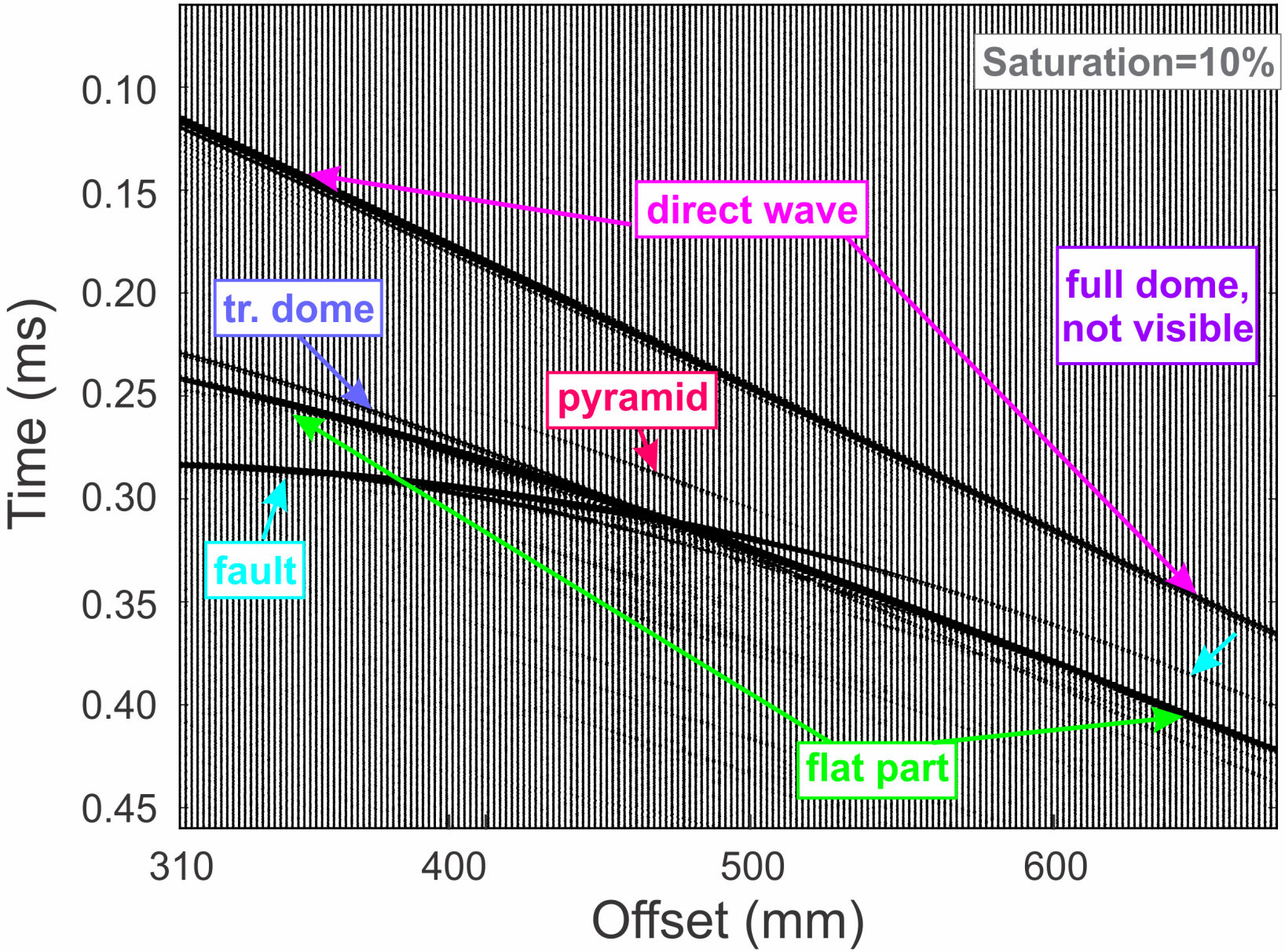
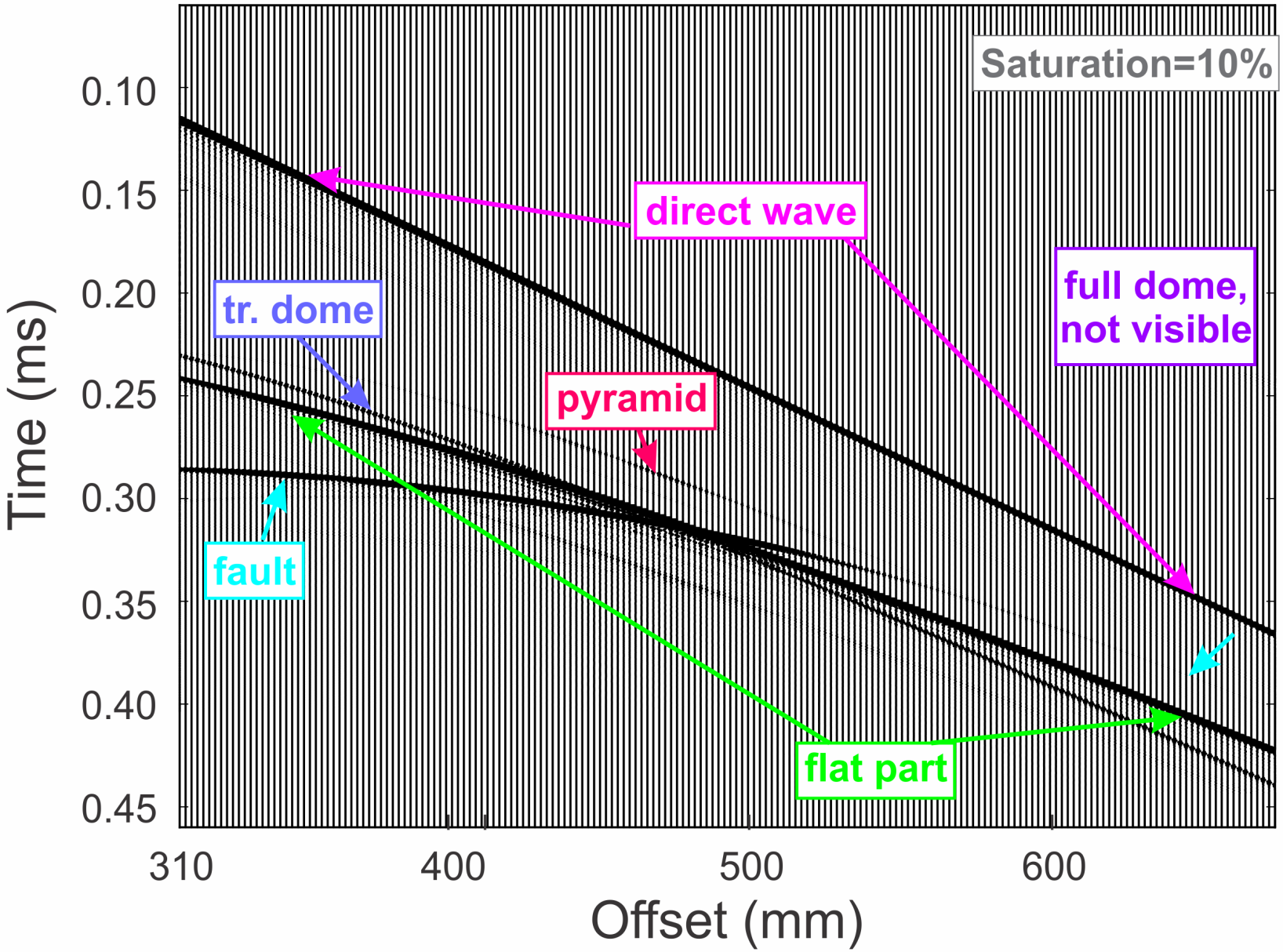


Laboratory data, S3



Synthetic data, S3



Conclusions

- Multi-offset seismic experiments using sources with unfocused beam and 2D array receivers covering the entire model.
- Comparisons indicate a good qualitative fit in time arrivals and amplitudes.
- Synthetic modeling helps in interpretation of the obtained laboratory data.
- More detailed study of the experiment conditions needed to perform quantitative evaluation of the results.

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Acknowledgements

- Stephan Devic (LMA Marseille) for his valuable contribution to the conception of the Marseille model
- For financial support