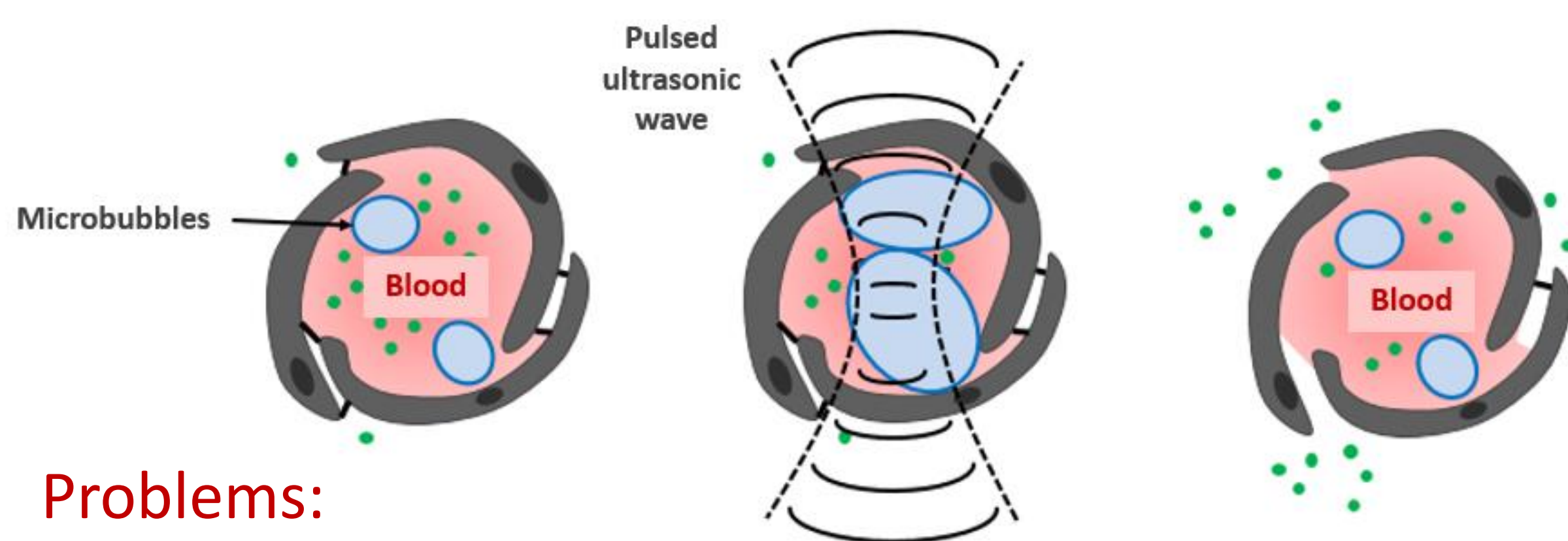


Fast transcranial ultrasound simulations based on time-of-flight minimization

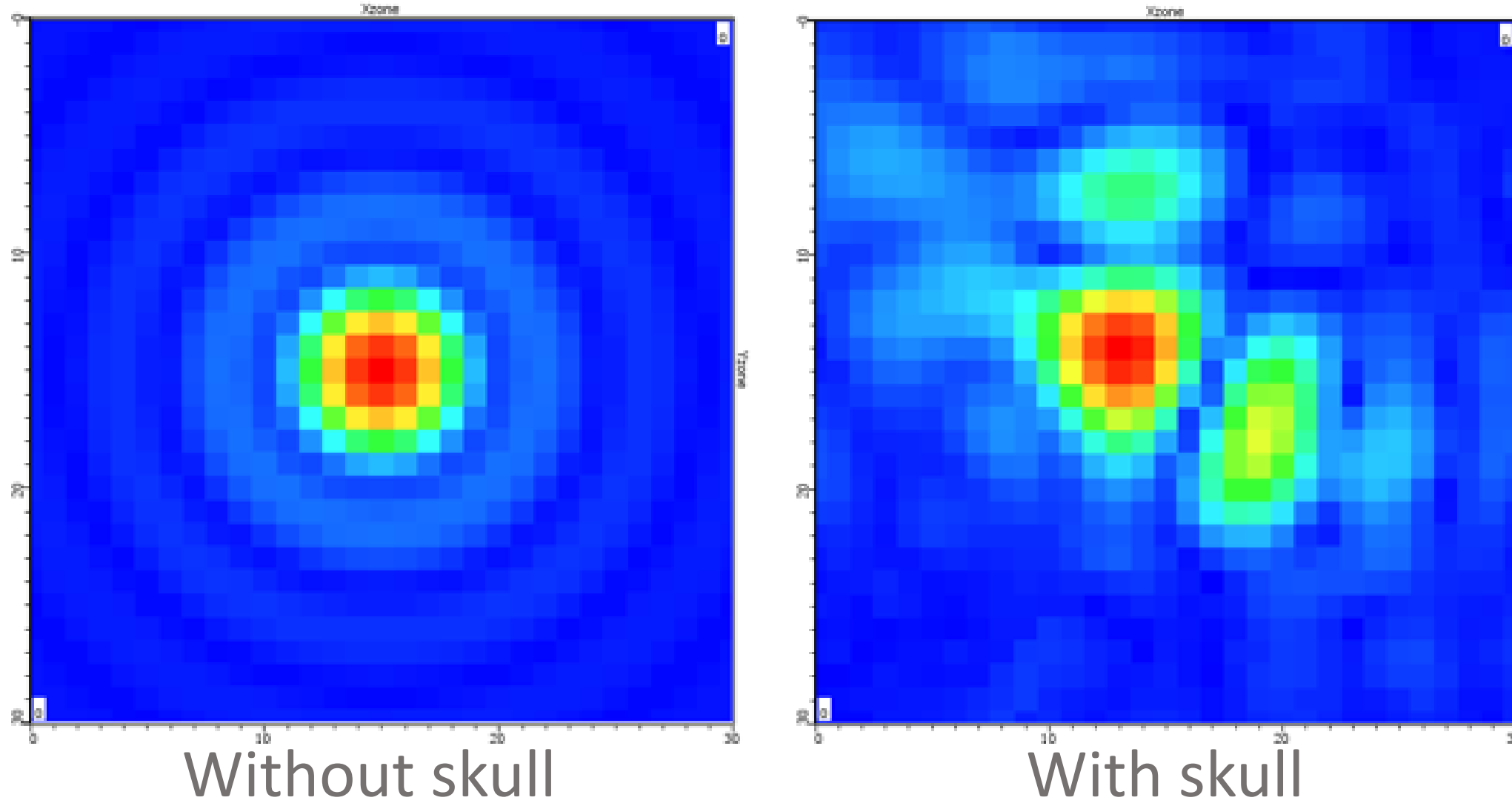
Célestine Angla, Hamza Chouh, Paul Mondou, Gwenael Toullelan, Kévylin Perlin, Emmanuel De Schlichting, Jean-Luc Gennisson, Benoit Larrat, Sylvain Chatillon

Context: ultrasound brain therapy



Problems:

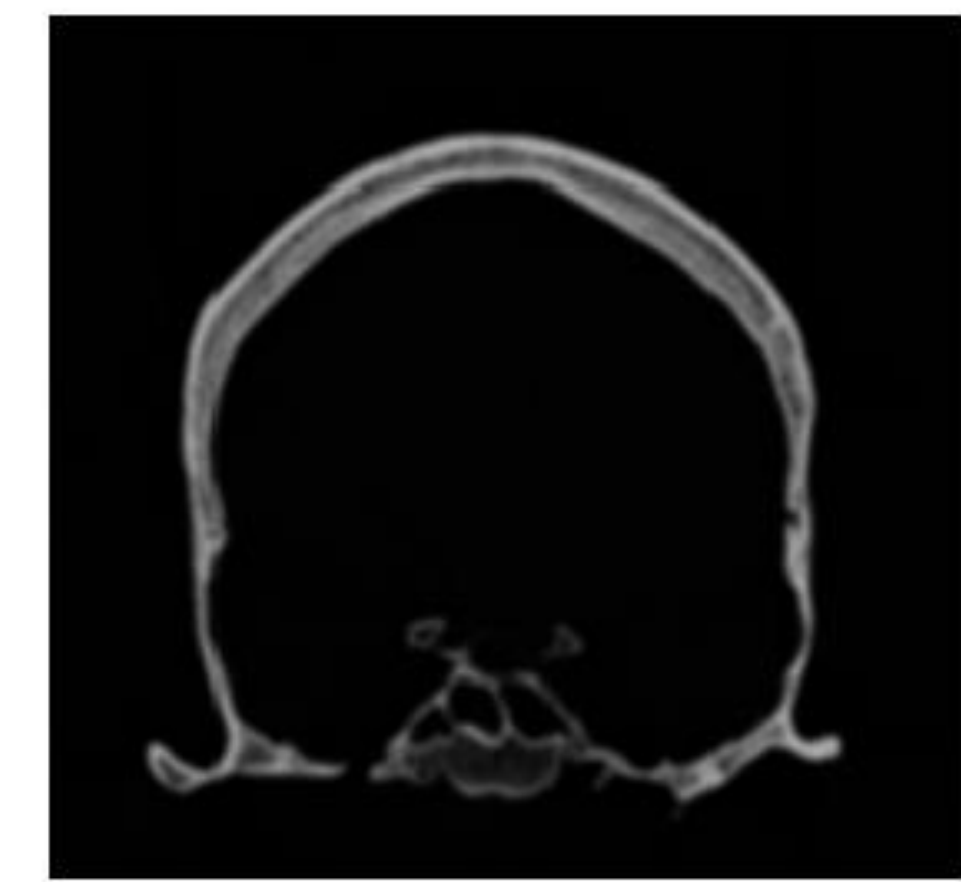
- The skull is a very complex medium.



- The inter/intra skull variability.



CT scan patient n°1



CT scan patient n°2

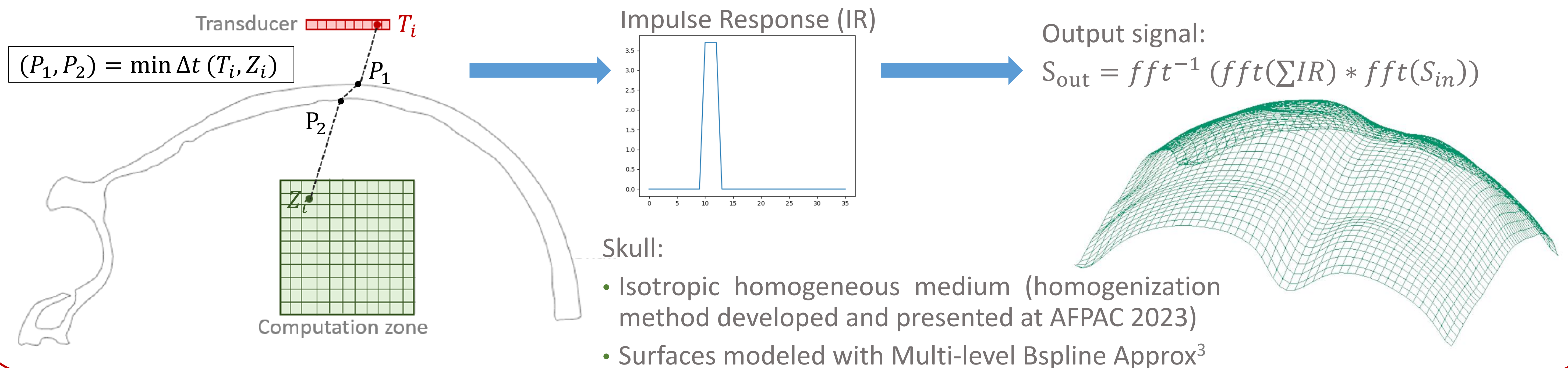
Solution: personalized simulations to optimize and ensure the safety of ultrasound brain therapies.

The widely used numerical methods (FDTD, k-space) are time and memory consuming.

➔ **Goal:** develop a fast and precise semi-analytical method on Civa Healthcare platform.



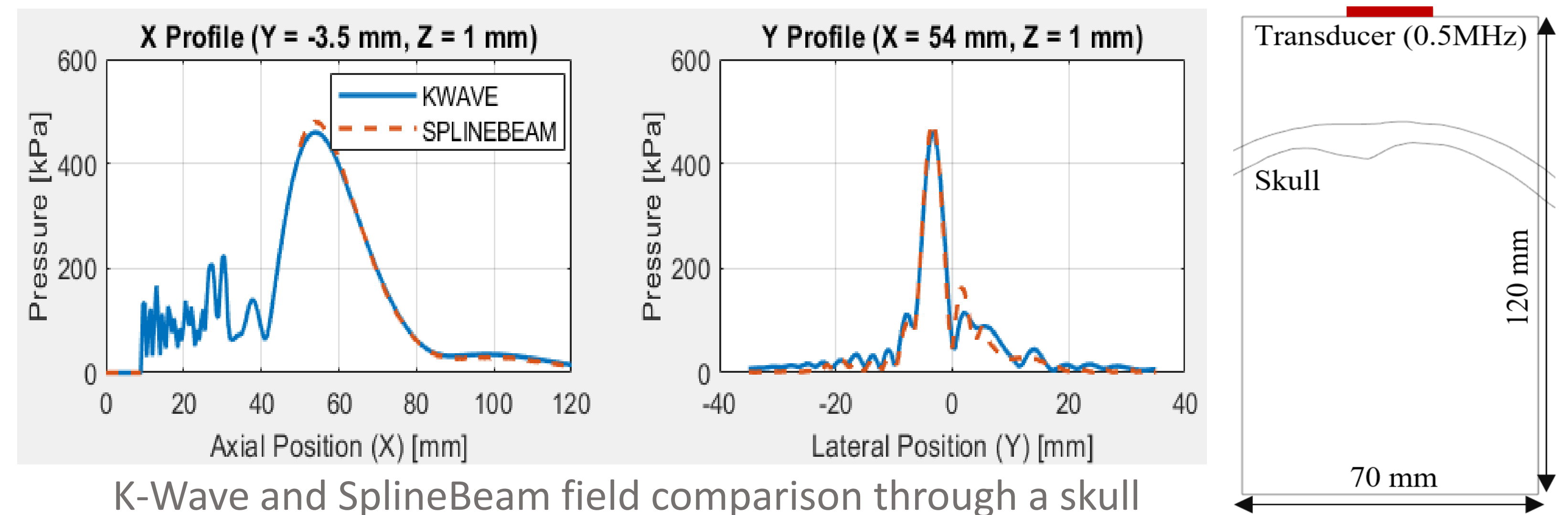
Field computation method: SplineBeam



Numerical validation

Comparison with 11 other solvers (including K-Wave) on 10 configurations given by a benchmark study⁴. Errors relative to K-Wave averaged on all configurations:

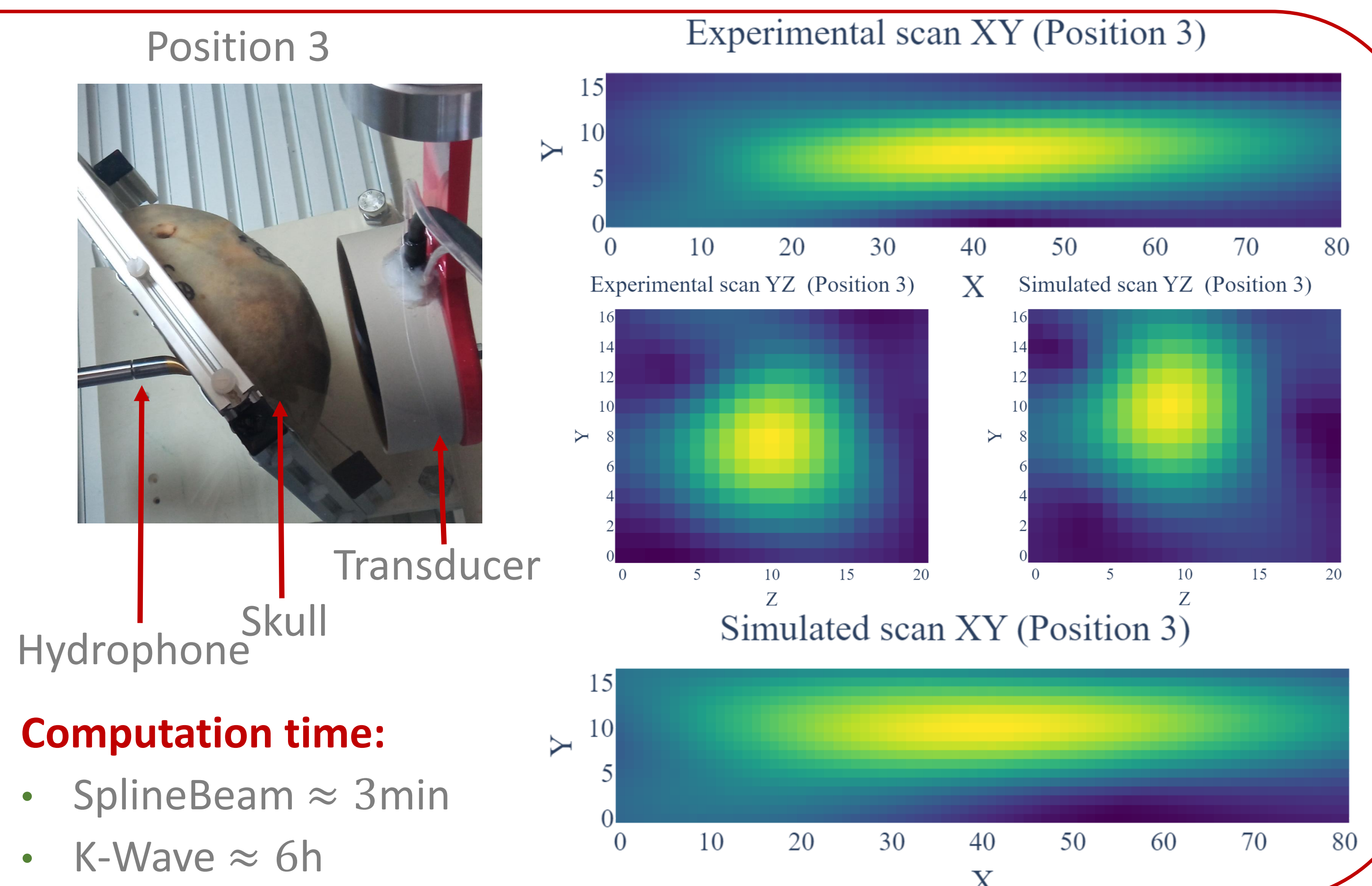
- Focal position error: 0.21mm
- Maximum pressure error: 3.19%



Experimental validation

- Hydrophone 3D scan for 3 transducer positions
- For each position: scan with and without skull

Pos	Comparison	ΔX_{max}	ΔP_{max}	ΔV_{focal}
1	With/without skull	4.64mm	-13.12dB	2.43%
	SplineBeam/Exp	1.58mm	-0.14dB	0.28%
	K-Wave/Exp	1.58mm	-2.00dB	6.16%
2	With/without skull	1.73mm	-13.70dB	6.44%
	SplineBeam/Exp	1.00mm	+0.17dB	11.70%
	K-Wave/Exp	1.12mm	-1.98dB	18.26%
3	With/without skull	2.12mm	-17.91dB	48.43%
	SplineBeam/Exp	1.12mm	+0.54dB	14.82%
	K-Wave/Exp	2.60mm	-0.11dB	15.38%



Conclusion and perspectives

- A fast and realistic simulation method was developed.
- Improvements: precision (include reflections and mode conversion, extension to N interfaces), speed (GPU version of optimization algorithm).

References

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- [2] Robertson J, Martin E, Cox B, Treeby BE. Sensitivity of simulated transcranial ultrasound fields to acoustic medium property maps. *Phys Med Biol*. 2017;62(7):2559–80.
- [3] Byung-Gook Lee, Joon Jae Lee and Jaechil Yoo, "An efficient scattered data approximation using multilevel B-splines based on quasi-interpolants," *Fifth International Conference on 3-D Digital Imaging and Modeling (3DIM'05)*, Ottawa, Ontario, Canada, 2005, pp. 110-117, doi: 10.1109/3DIM.2005.18.
- [4] J.-F. Aubry et al., "Benchmark problems for transcranial ultrasound simulation: Intercomparison of compressional wave models," *J. Acoust. Soc. Am.*, vol. 152, no. 2, pp. 1003–1019, Feb. 2022, doi: 10.1121/10.0013426.