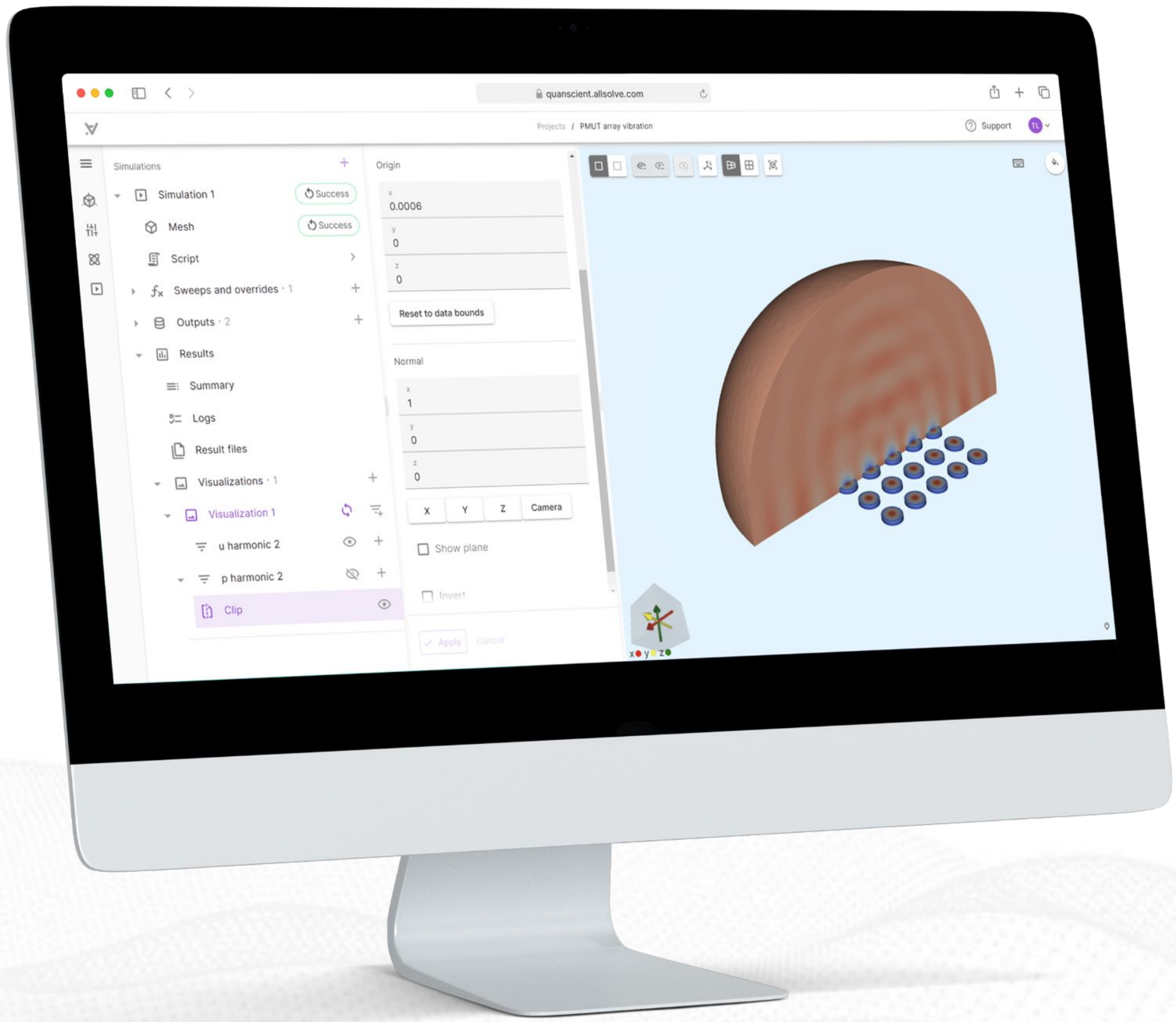
QUANSCIENT

17th December 2024

Analyze your **MUT design** with cloud-based multiphysics simulation



Dr. Andrew Tweedie
UK Director & Co-founder
Quanscient

Jukka Knuutinen
Head of Marketing
Quanscient

Housekeeping items

Before we start

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Submit your questions at any time

We'll address them throughout the event.

In addition, we'll have a dedicated Q&A session at the end.

We will give out some resources

During the event, we will be handing out some PDF documents.

Download them from the sidebar.

The cast

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Jukka Knuutinen

Head of Marketing

Quanscient

Dr. Andrew Tweedie

UK Director & co-founder

Quanscient

Webinar agenda

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1

Introduction (10 min)

Jukka Knuutinen
Head of Marketing, Quanscient

→ Welcoming words

→ Housekeeping items

→ Introduction to Quanscient Allsolve

2

Challenges in MUT design with traditional tools (5 min)

Dr. Andrew Tweedie
UK Director & co-founder, Quanscient

→ Overview of the challenges faced with traditional simulation packages

→ How Quanscient Allsolve is used to tackle these challenges efficiently

3

Live demo and results
PMUT array simulation (15 min)

Dr. Andrew Tweedie

→ Live demonstration of a PMUT array

→ Detailed simulation results showcasing key performance metrics (e.g., pressure distribution, frequency response, cross-talk)

Webinar agenda

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4

Case examples of CMUT (10 min)

Dr. Andrew Tweedie

→ Overview of challenges and considerations for simulating capacitive micromachined ultrasonic transducers CMUTs

→ Key results and performance indicators from case examples

5

Q&A (15 min)

All speakers

→ Live discussion and answers to your questions about Quanscient Allsolve and cloud-based simulations in MUT design

6

Conclusion and key takeaways (5 min)

Jukka Knuutinen

→ Summary and key takeaways of the webinar

→ Additional resources to learn more

Handouts

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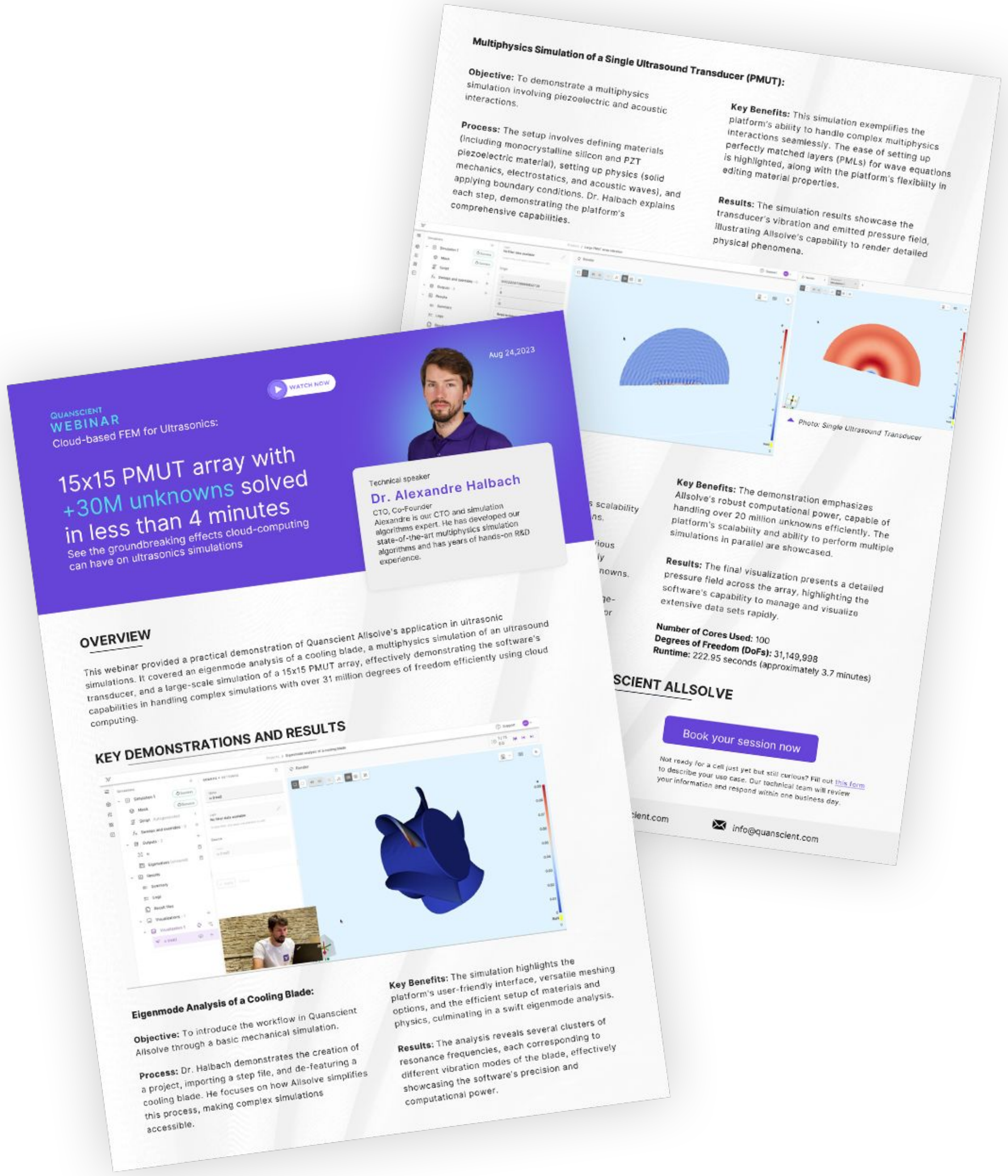

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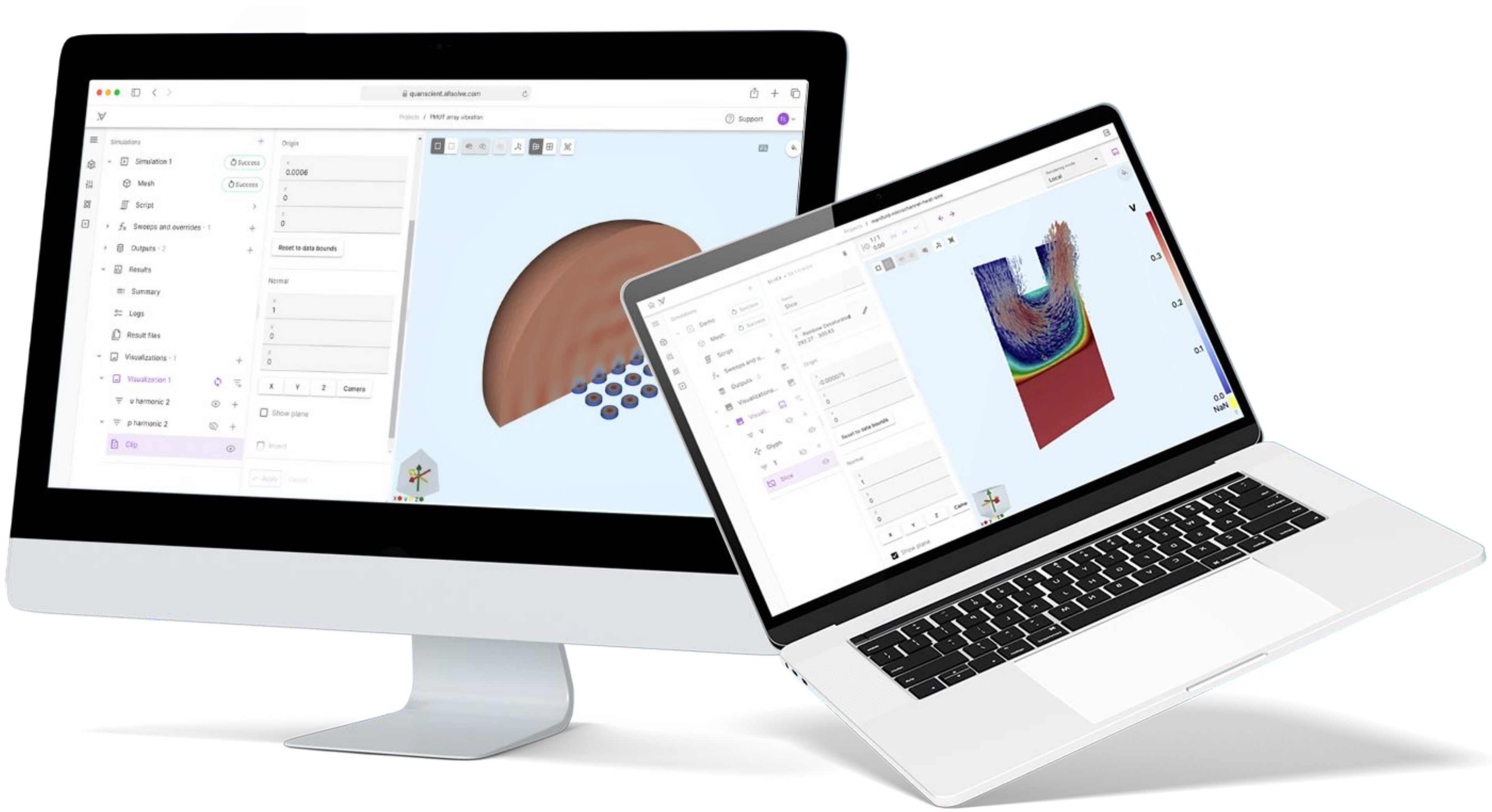
Introduction to Quanscient Allsolve
Overview

→ A cloud-based FEM multiphysics simulation platform

→ Developed by Quanscient, a company established in 2021 in Tampere, Finland

→ Built upon the open-source solver Sparselizard developed by our CTO, **Dr. Alexandre Halbach**



Introduction to Quanscient Allsolve

Trusted in industry and academia

UK Atomic Energy Authority

infineon

TERA LOOP

Massachusetts Institute of Technology

Proxima Fusion

kiutra

VEXLUM

PAUL SCHERRER INSTITUT PSI

ENEA

imec

albis

Tampere University

Introduction to Quanscient Allsolve
4 key benefits

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Speed

- → Runtime from weeks to hours and days to minutes
- → Next-to-unlimited computing capacity and RAM
- → Speedups enabled by our proprietary algorithms

Scalability

- → Thousands of simulations in parallel with zero added computational time
- → Optimization studies, parameter sweeps, manufacture-aware design
- → Increased product reliability, faster iterations and eventually faster product-to-market

Flexibility

- → No hardware investments
- → All physics and features are also included in every plan
- → Unlimited number of users with every plan
- → Sharing a project as easy as sharing a link
- → Automatically generated Python script
- → Usage-based pricing

Automation

- → Programmatic control of simulations
- → Proprietary design workflows
- → Removing lengthy manual setups and repetitive tasks

Handout of the executive summary of our API webinar available now!

Overview

Technical content & demo

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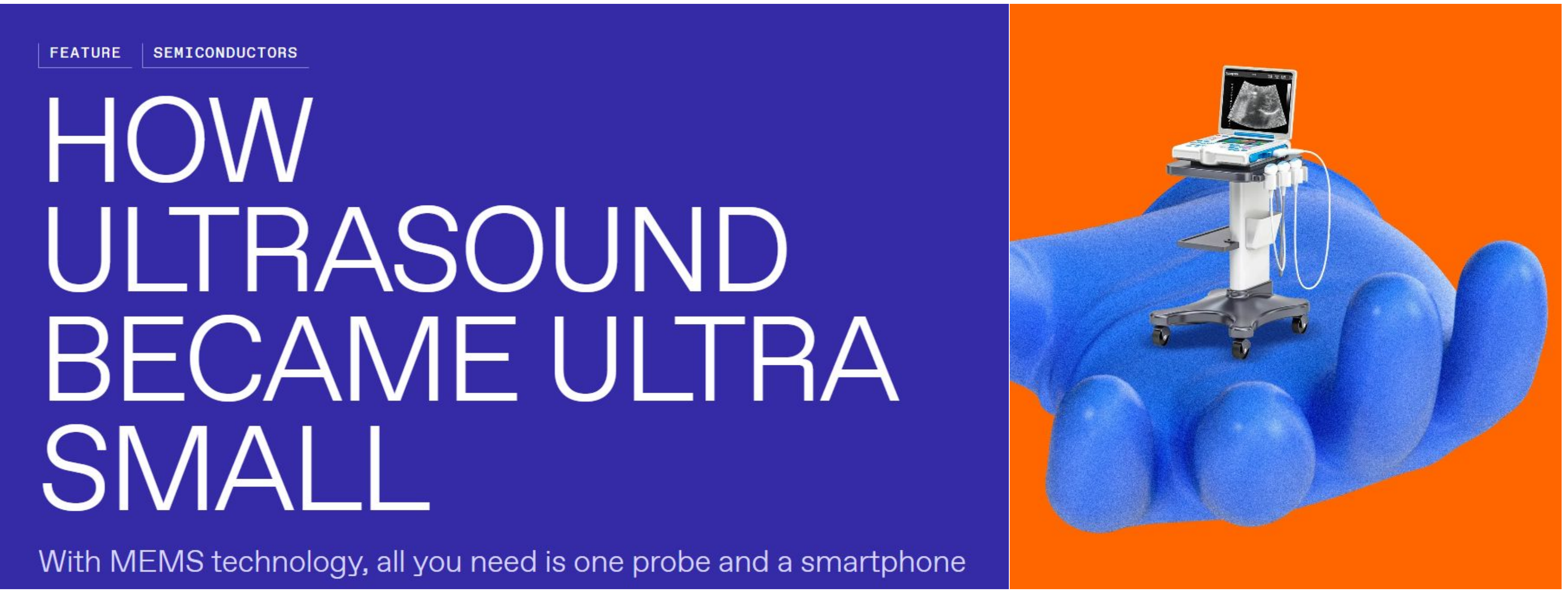
- Challenges in MUT design with traditional tools
- PMUT: Live demo & results
- CMUT: Case study example
- Questions to the audience
- Conclusions

Challenges in MUT design with traditional tools

Why MUTs?
Transforming medical ultrasound



F. Levent Degertekin, IEEE Spectrum, March 2024.
https://spectrum.ieee.org/mems-ultrasound-history

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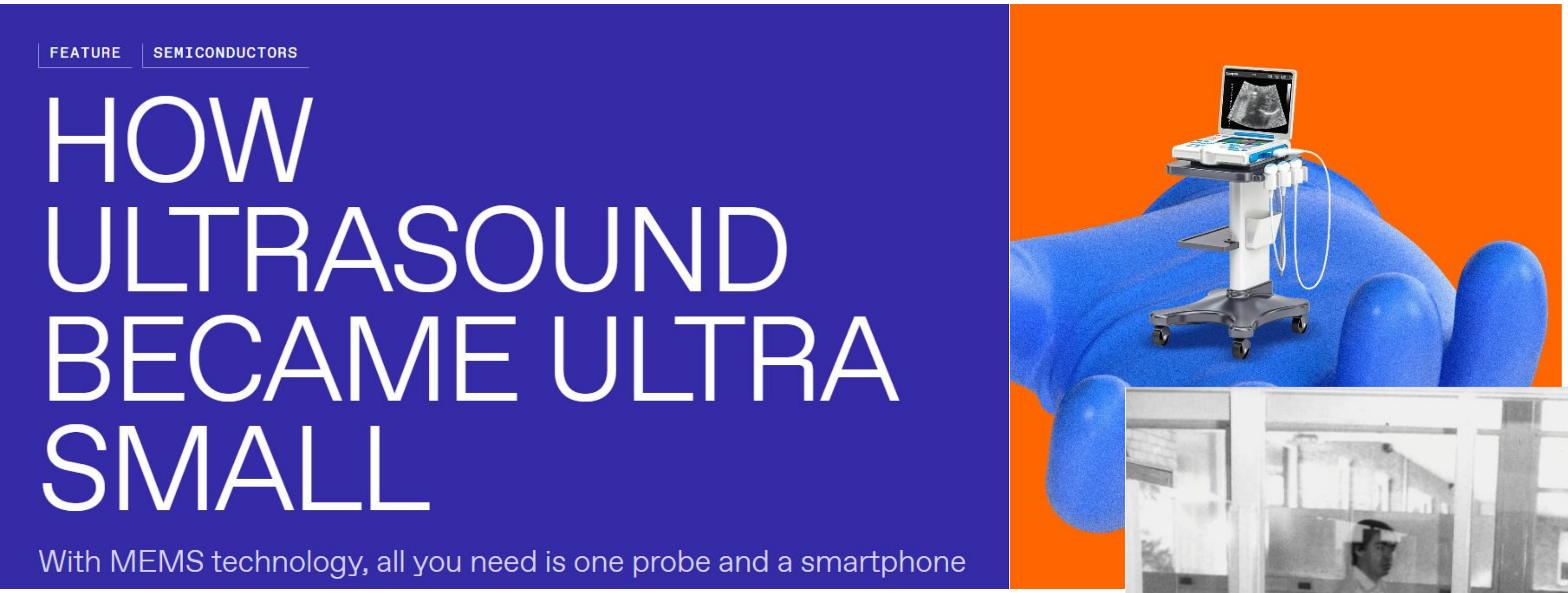
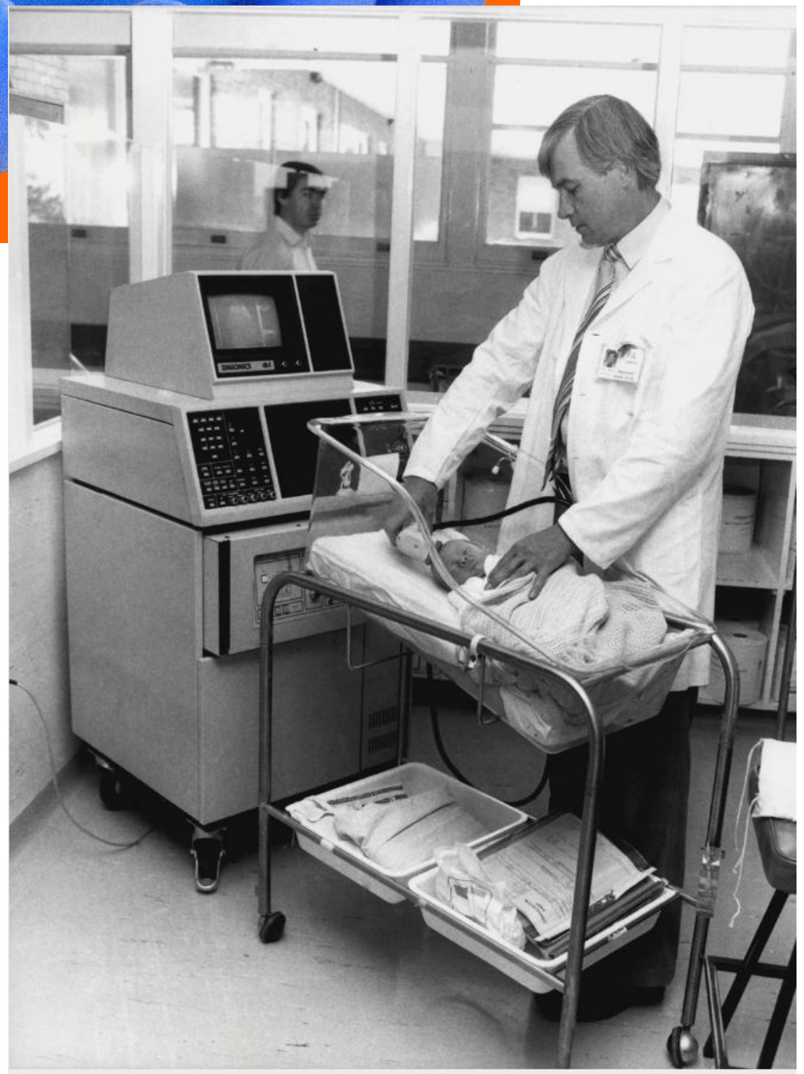
Why MUTs?
Transforming medical ultrasound



F. Levent Degertekin, IEEE Spectrum, March 2024.
https://spectrum.ieee.org/mems-ultrasound-history

1980s



Ultrasound technology has historically required bulky machinery with multiple probes. JULIAN KEVIN ZAKARAS/FAIRFAX MEDIA/GETTY IMAGES

2024

Butterfly Network developed a handheld ultrasound machine using capacitive micromachined ultrasonic transducer (CMUT) technology. BUTTERFLY

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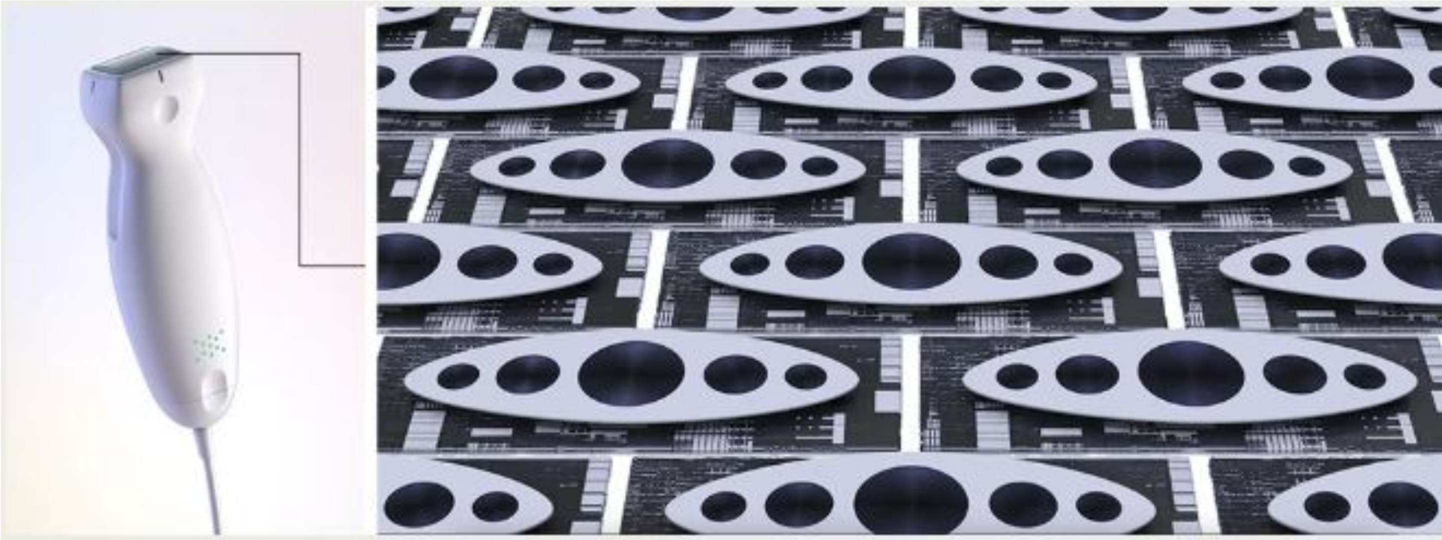
Overview and challenges

Why are MUTs so complex to simulate?

- Highly complex sensor structure with many small layers
- Arrays can comprise many 1,000s of elements
- Often a large elastic or acoustic load
- As a result simulations can easily reach 100M DoF
- Broadband, so transient analysis generally required
- Multiphysics simulation is essential
- Many innovative structures being explored
- CMUTs introduce additional complexities



Exo Imaging developed a handheld ultrasound machine using piezoelectric micromachined ultrasonic transducer (PMUT) technology. EXO IMAGING

F. Levent Degertekin, IEEE Spectrum, March 2024.
https://spectrum.ieee.org/mems-ultrasound-history

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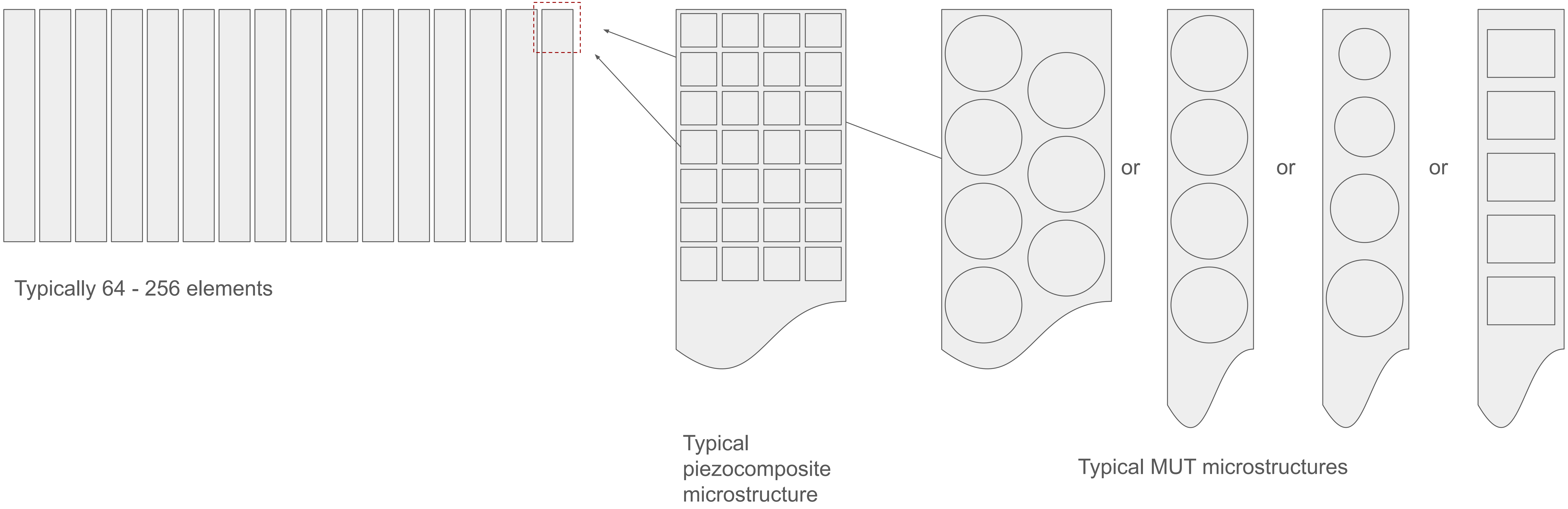
Typical array structures
Example: diagnostic linear phased array

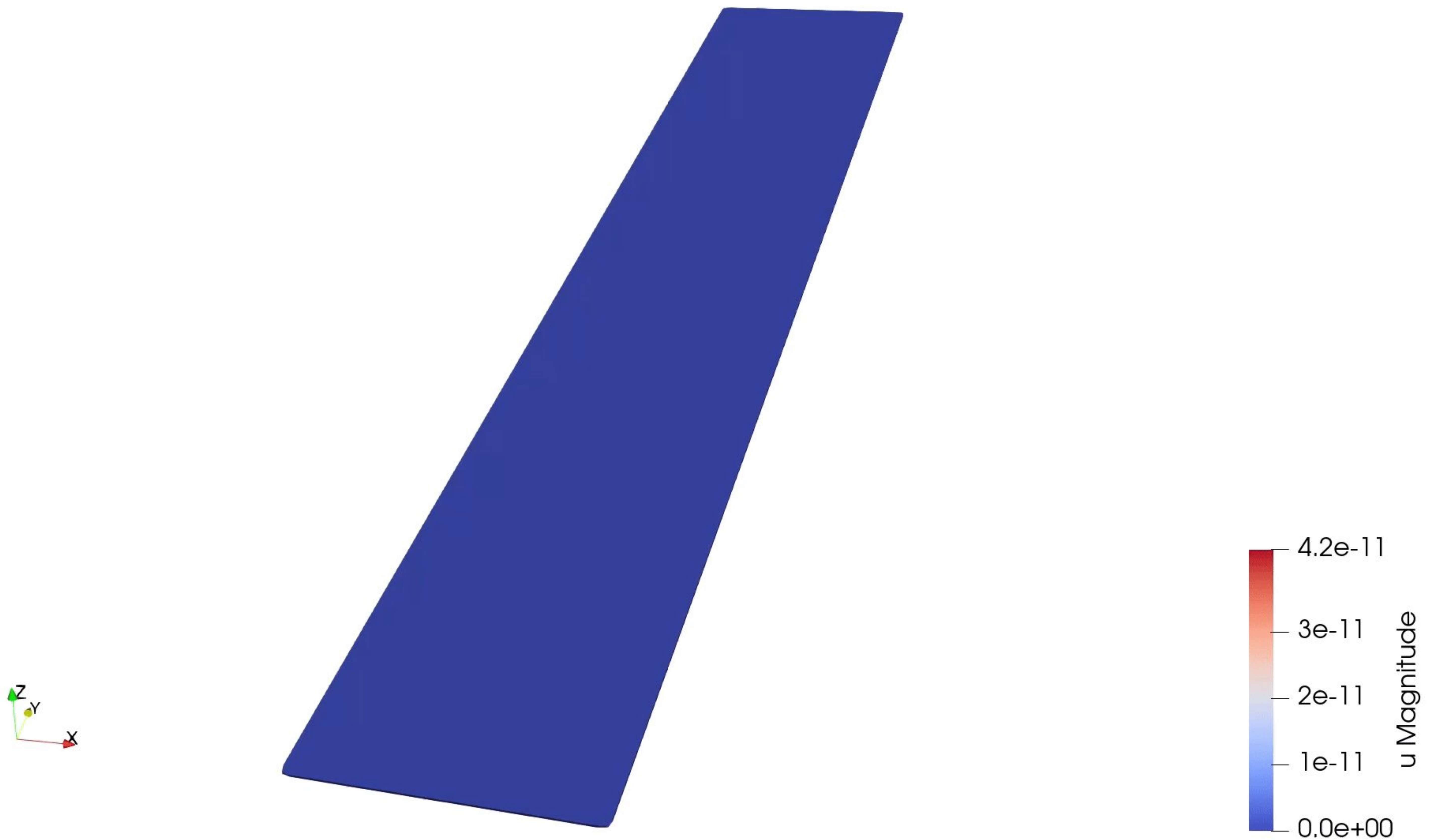


Array simulation approaches
Focus on what's important

- Unit cell
  - Good for evaluating fundamental MUT design
  - Impedance, surface displacement
- Elevation cross section
  - Typically ¼ or ½ element depending on symmetry
  - Elevation beam pattern and array impedance
- Azimuthal cross section
  - ½ or 1 cell in vertical, depending on symmetry
  - Azimuthal beam pattern, crosstalk, element impedance
- Full 3D section
  - Typically ¼ or ½ symmetry
  - Excellent prediction of array imaging performance

Full 3D array section

Allsolve is capable of scaling to 100s of MUTs



PMUT: Live demo and results

PMUT reference design
110×56 cell array

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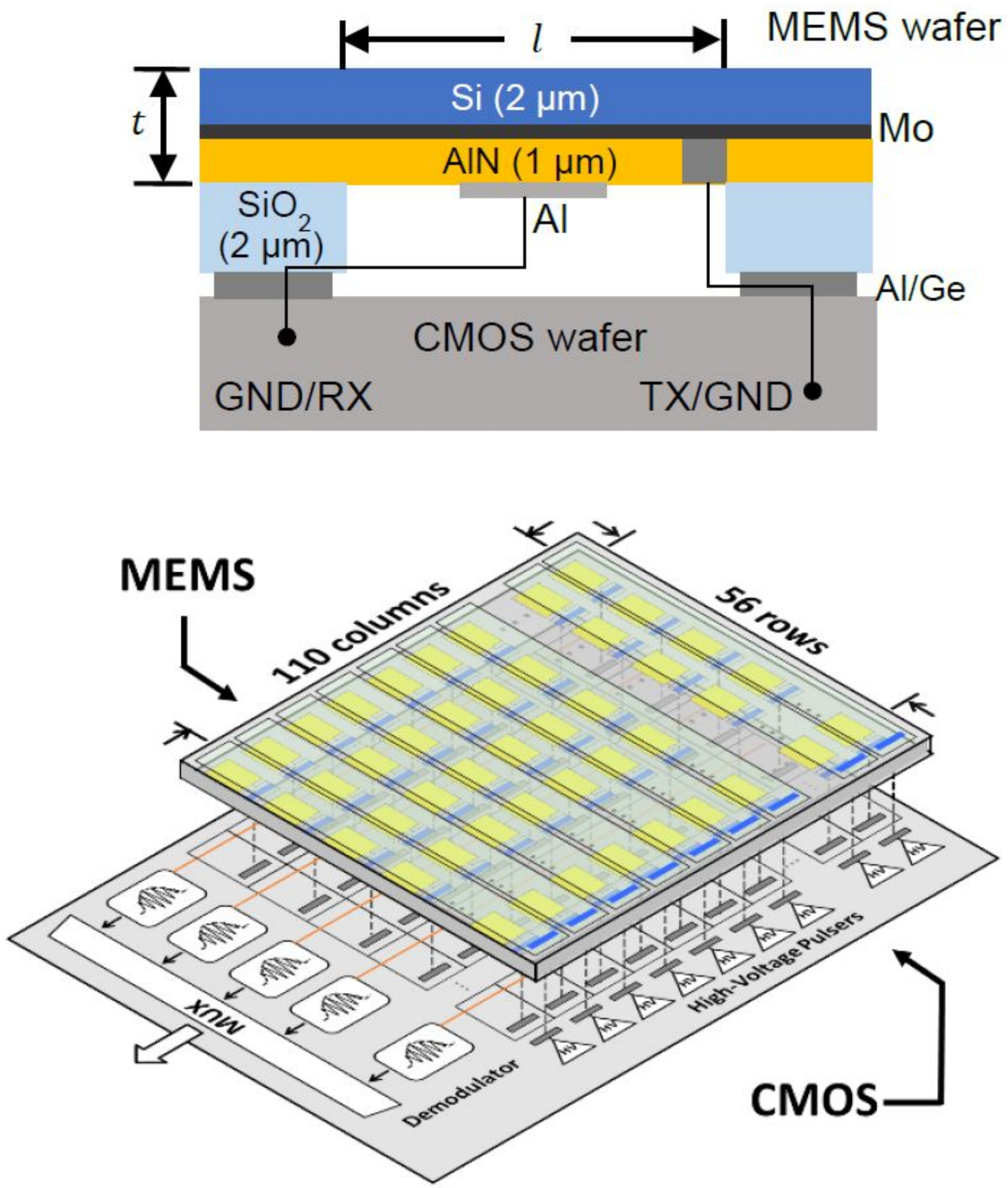
- Example array was designed as a fingerprint sensor
- Designed to be operated in a row-column scheme to allow beamforming in azimuth (tx) and elevation (rx)
- We will analyse it as a purely linear array operating into a water load
- Structure:
  - SiO2 standoff
  - Al drive electrode
  - AlN active layer
  - Mo ground electrode
  - Si elastic layer
  - Water load

Example PMUT array for fingerprint imaging showing PMUT stack (top) and array layout (bottom) [1]



1. D. A. Horsley *et al.*, "Ultrasonic fingerprint sensor based on a PMUT array bonded to CMOS circuitry," *2016 IEEE International Ultrasonics Symposium (IUS)*, pp. 1-4.

Unit cell
Fundamental MUT analysis

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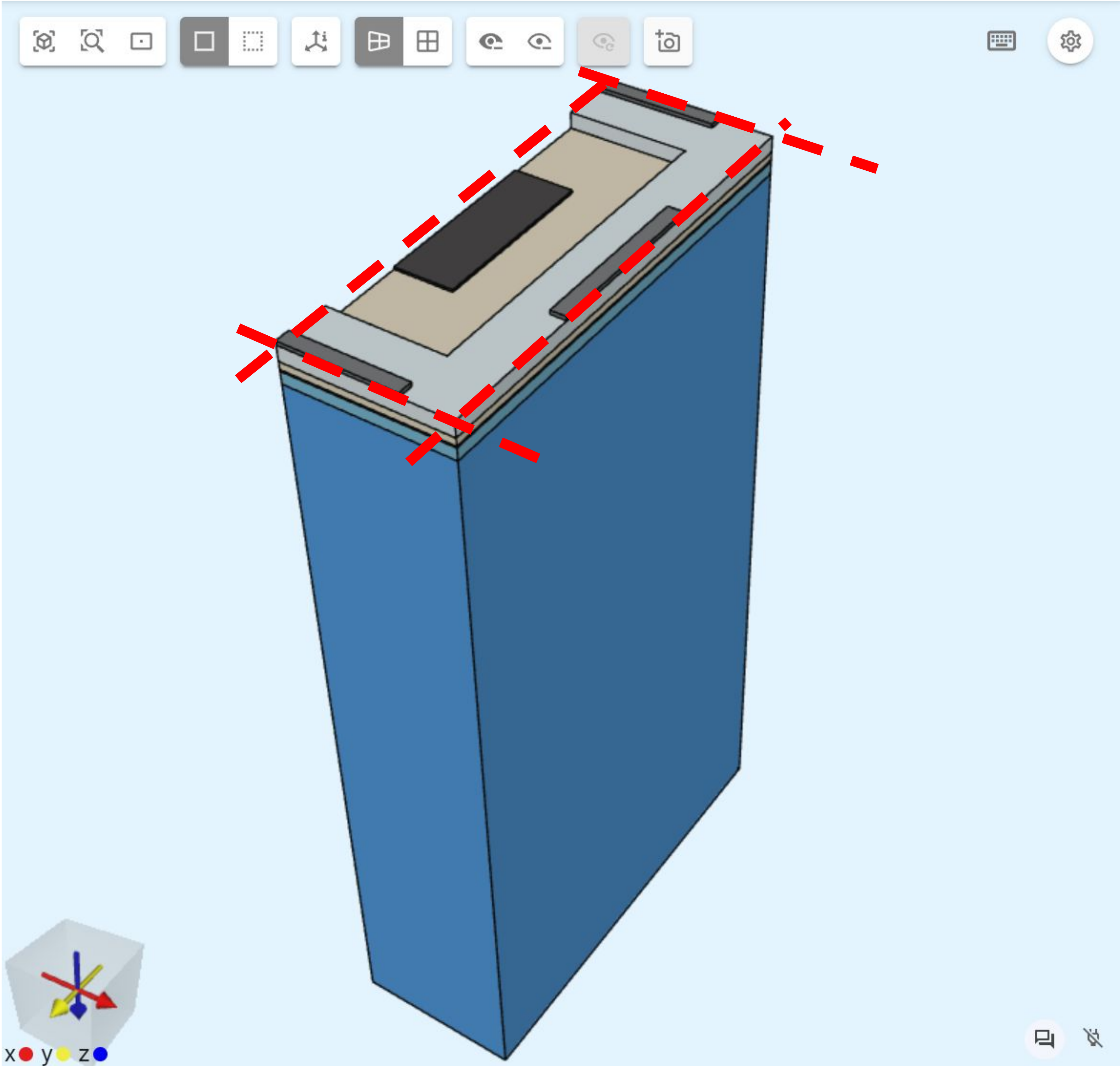
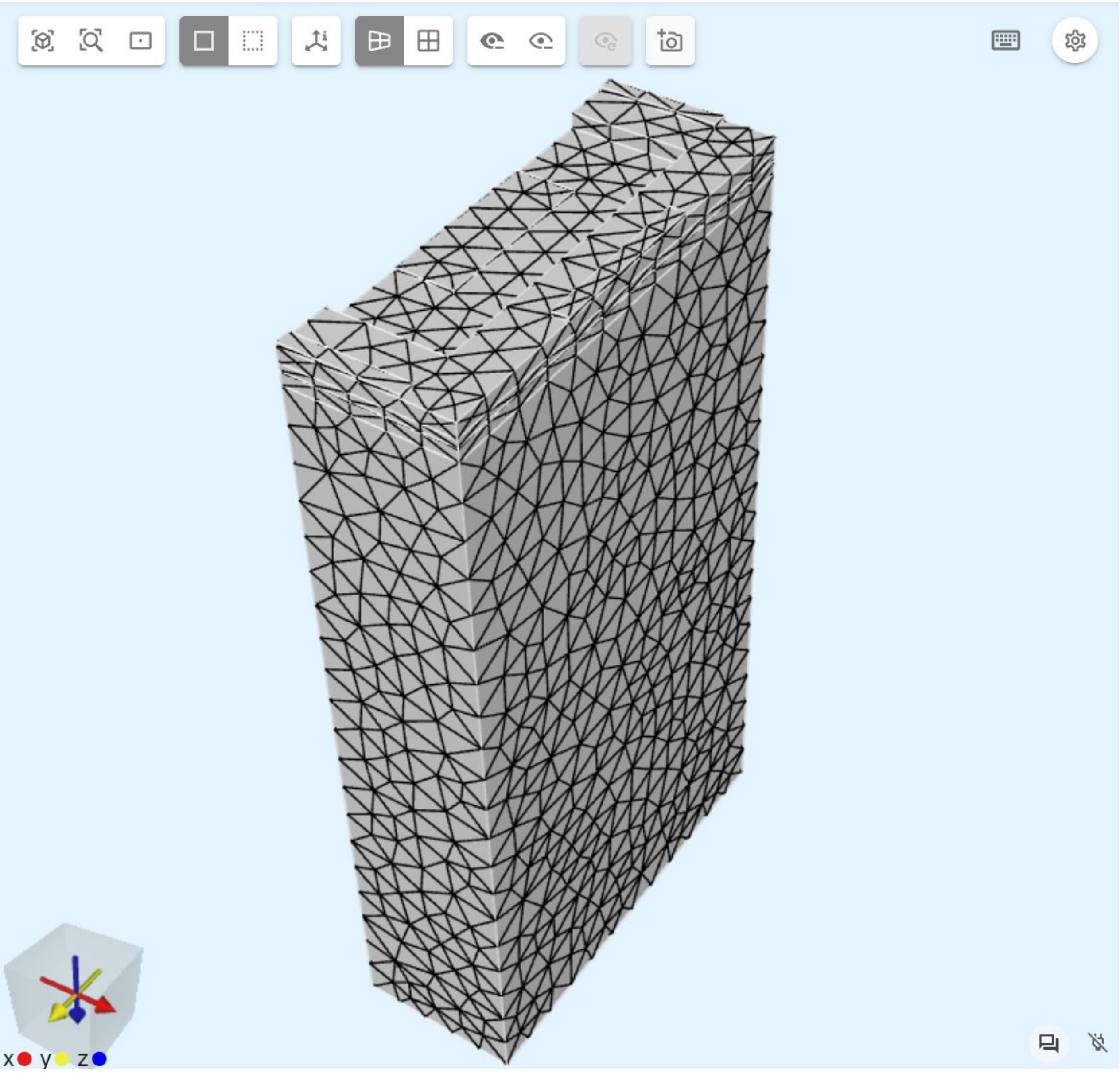
- Captures the smallest tileable section of the array
- Symmetry or periodicity is then used to construct a model of an infinite array of MUT cells
- Fast way to analyse:
  - Fundamental performance of the MUT "stack"
  - Electrical impedance
  - Surface displacement
  - Acoustic pressure output
  - Sensitivity (tx & rx)
- Harmonic and transient solutions possible
  - Here we will look at the transient results operating into a water load

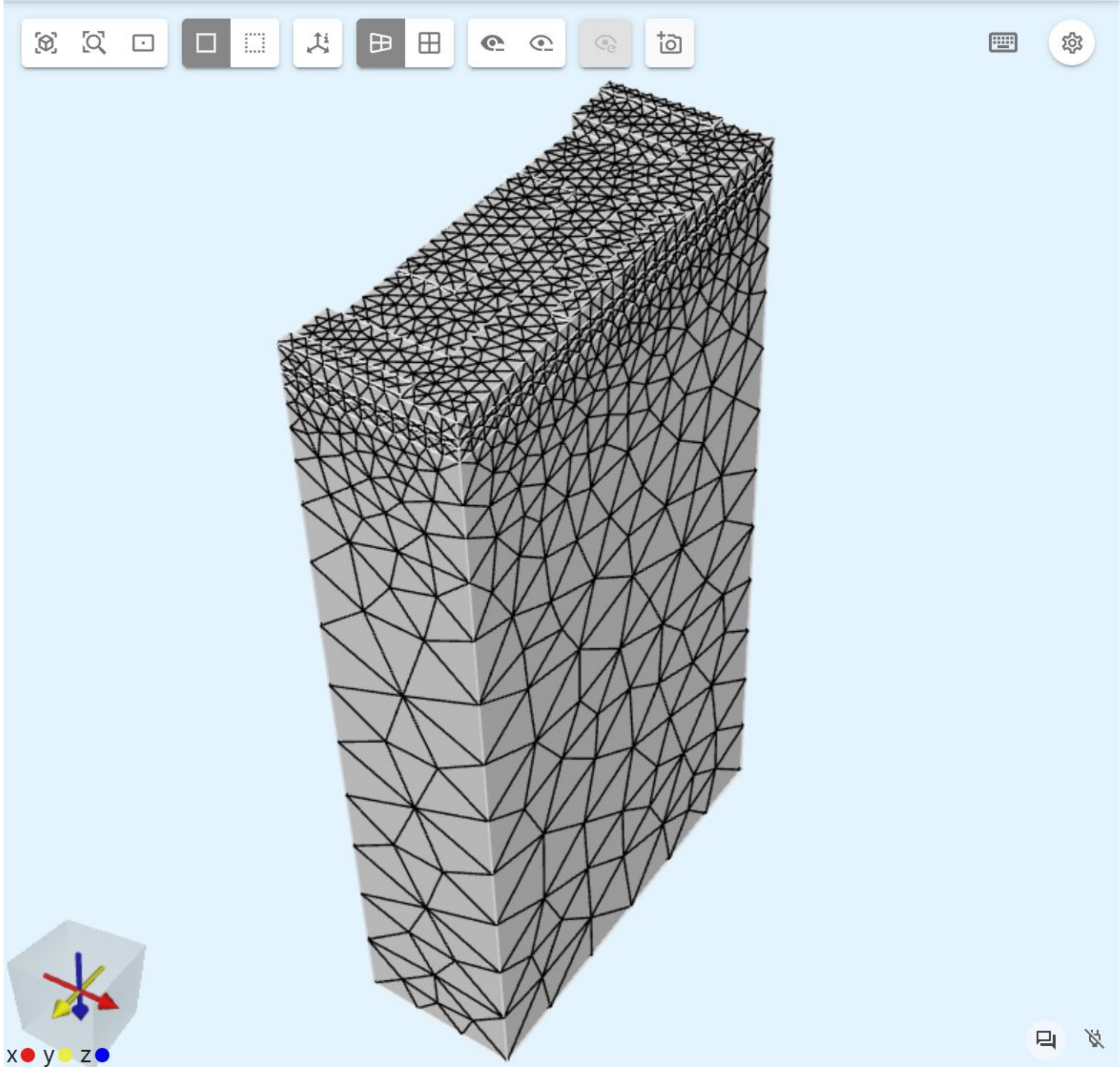


Unit cell mesh

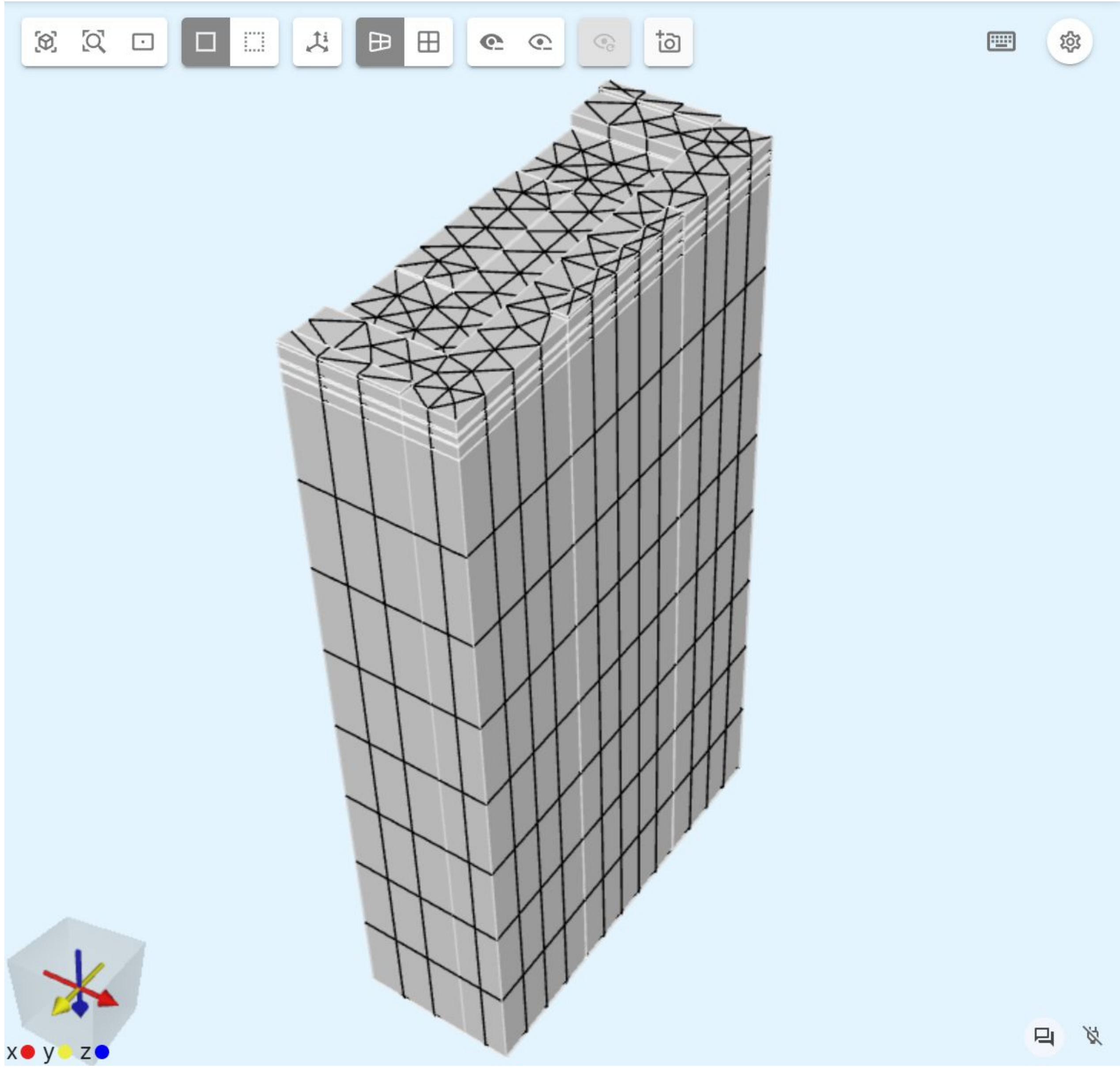
Flexibility over meshing & element order



5 um order 2 mesh



10 um order 2 mesh, refined to 2 um on MUT structure



5 um order 2 mesh, extruded in z axis

Unit cell transient simulation results
Voltage & current

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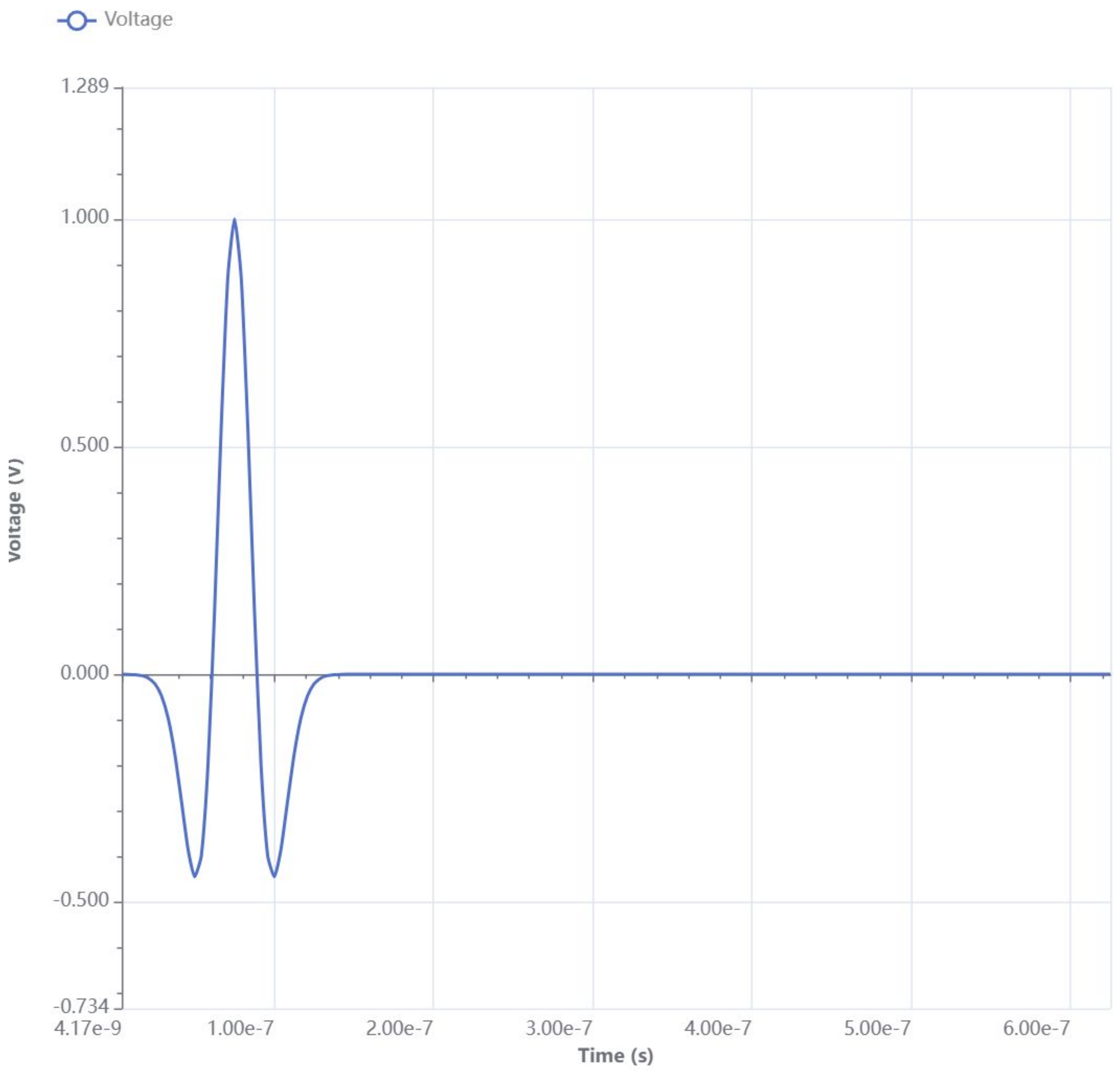

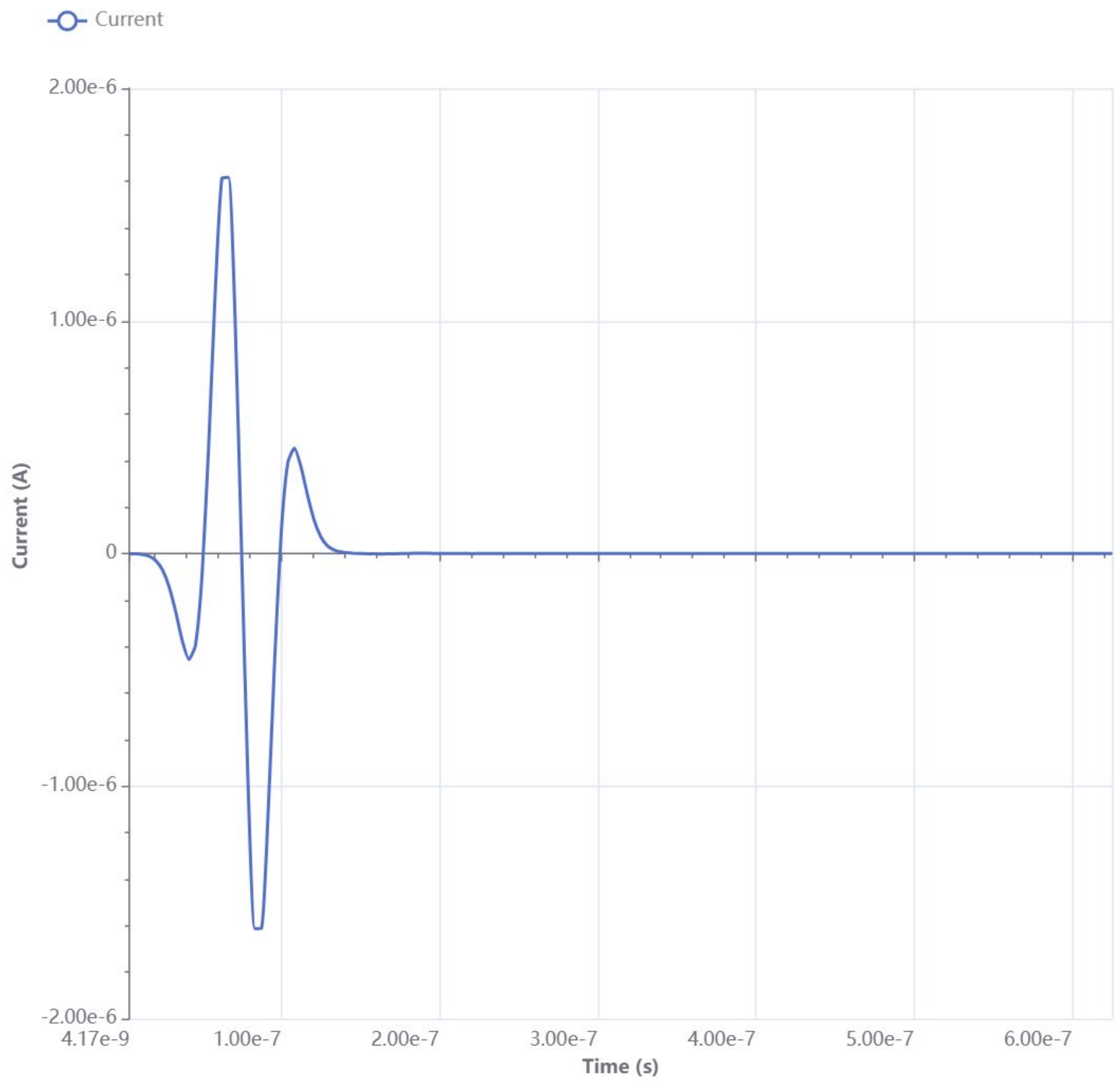

35k DoFs

1 Core

0.8 Minutes

0.02 Core-hours

Unit cell transient simulation results
Displacement & acoustic field

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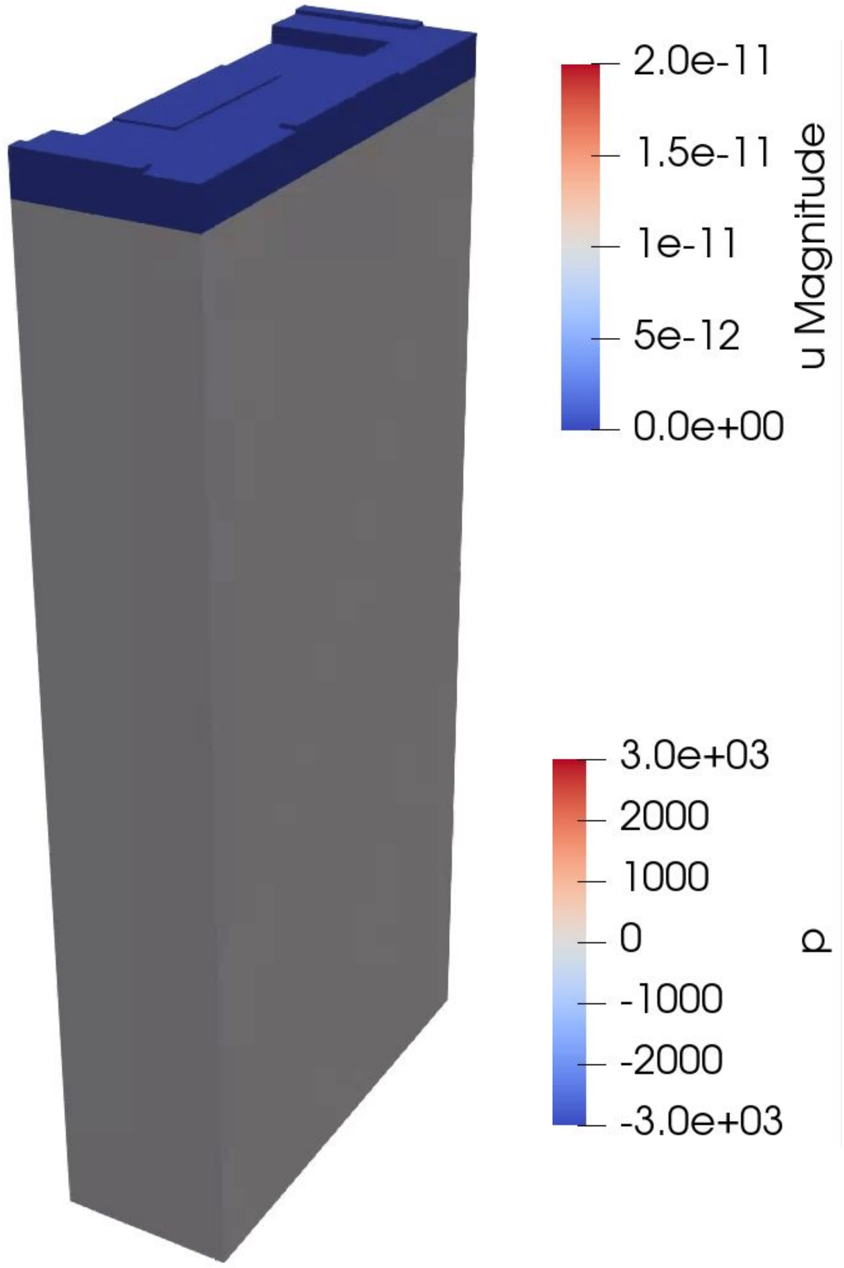

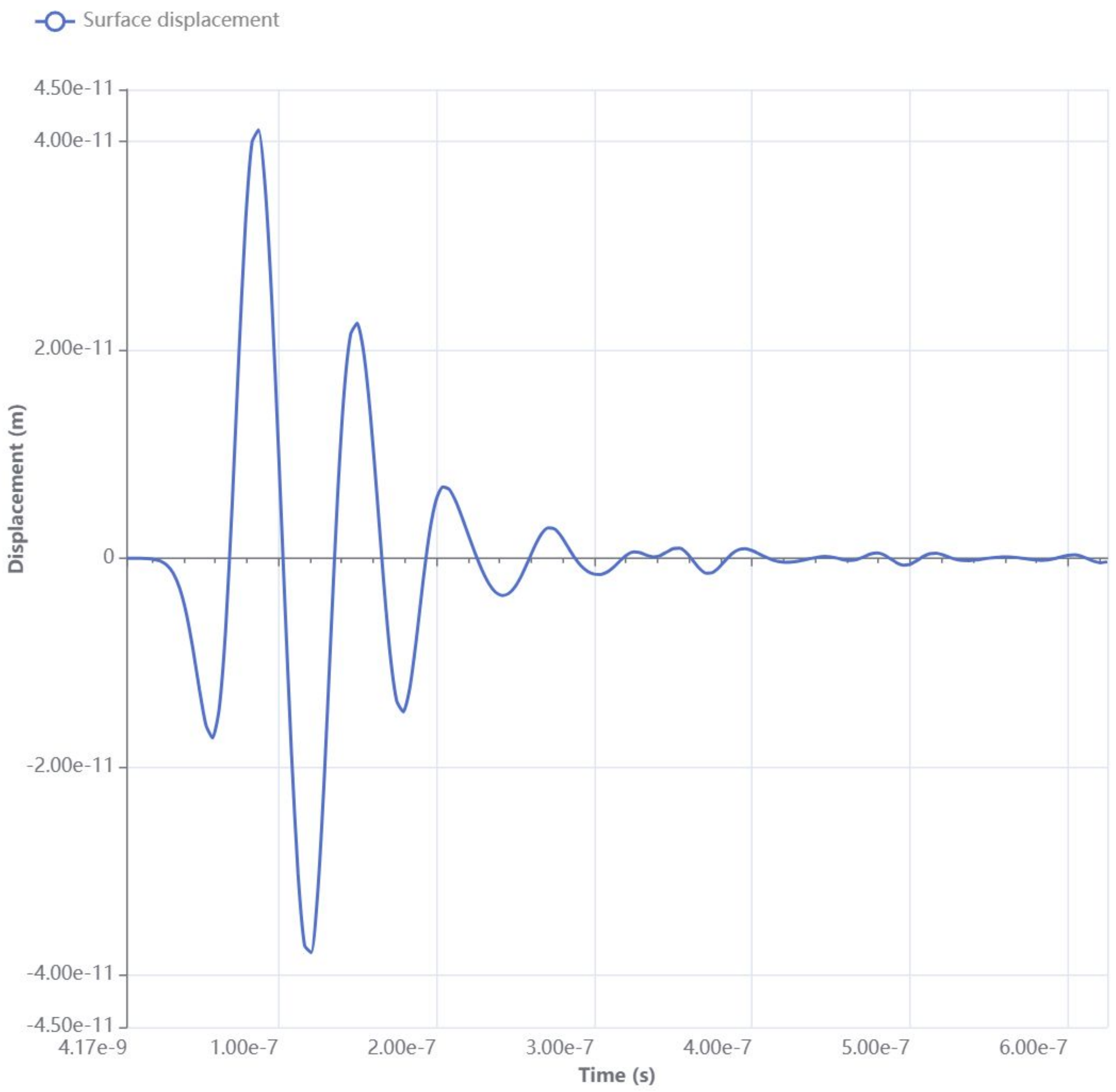

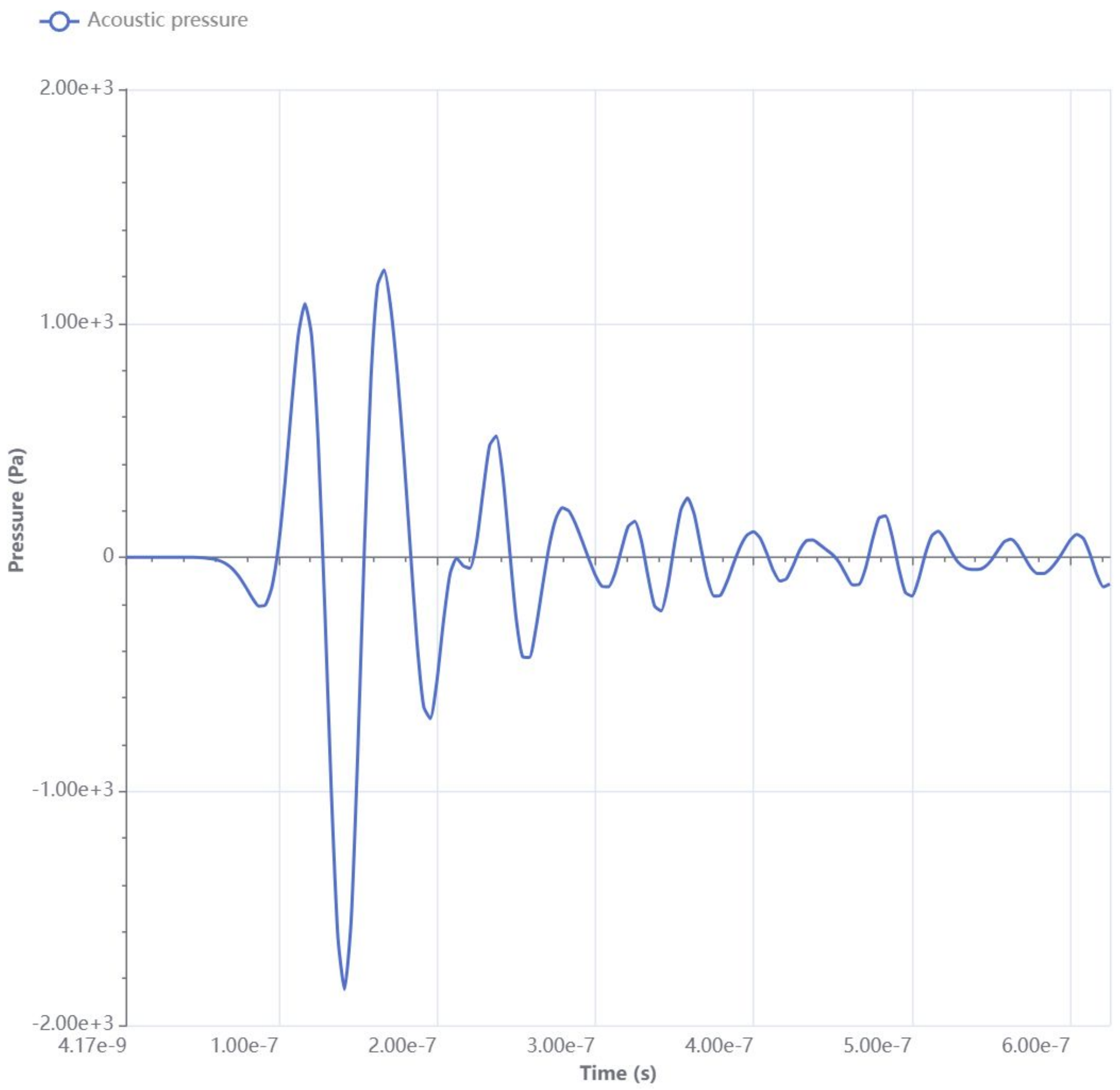

35k DoFs

1 Core

0.8 Minutes

0.02 Core-hours

Elevation cross section

Elevation beam pattern

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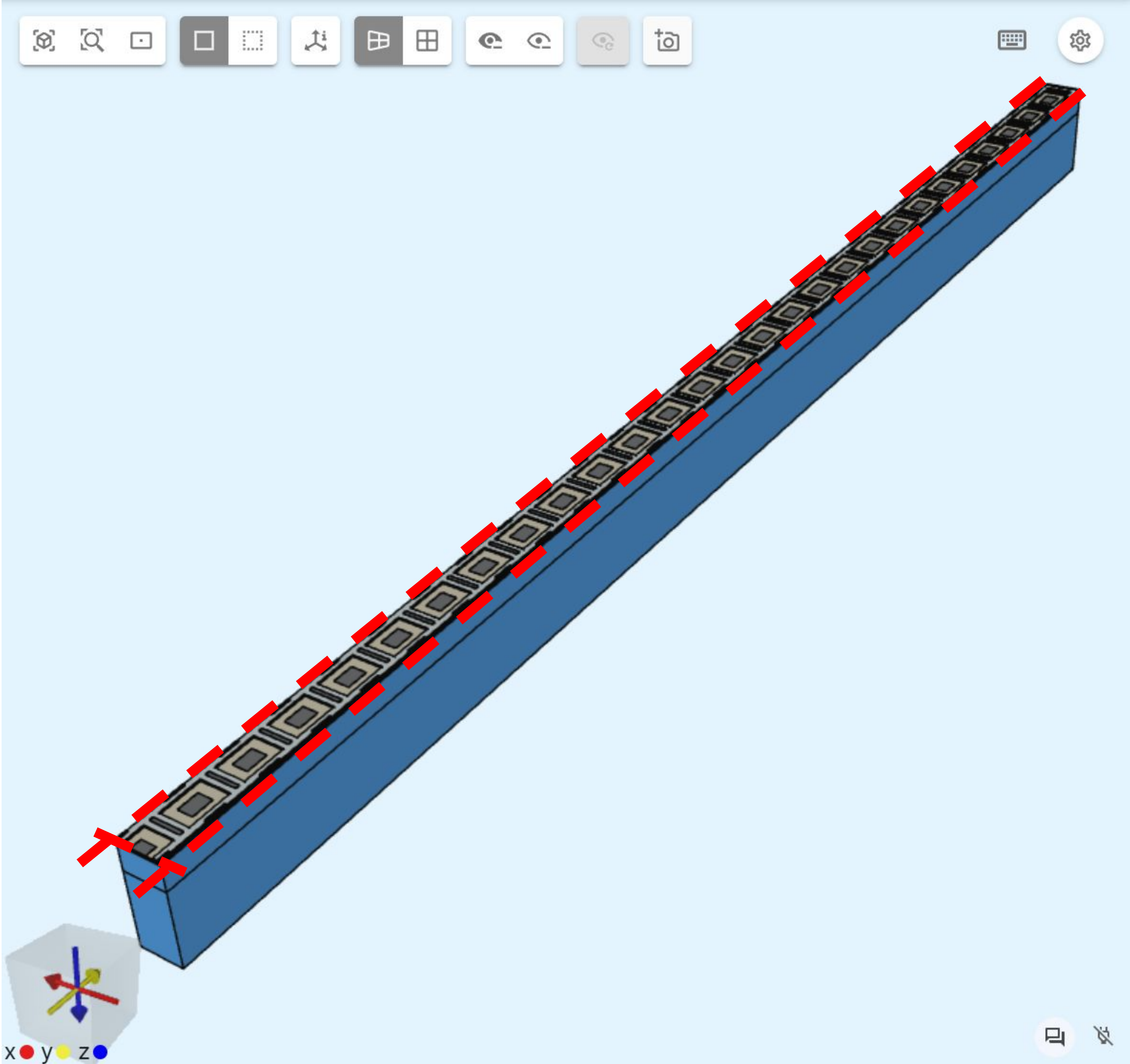
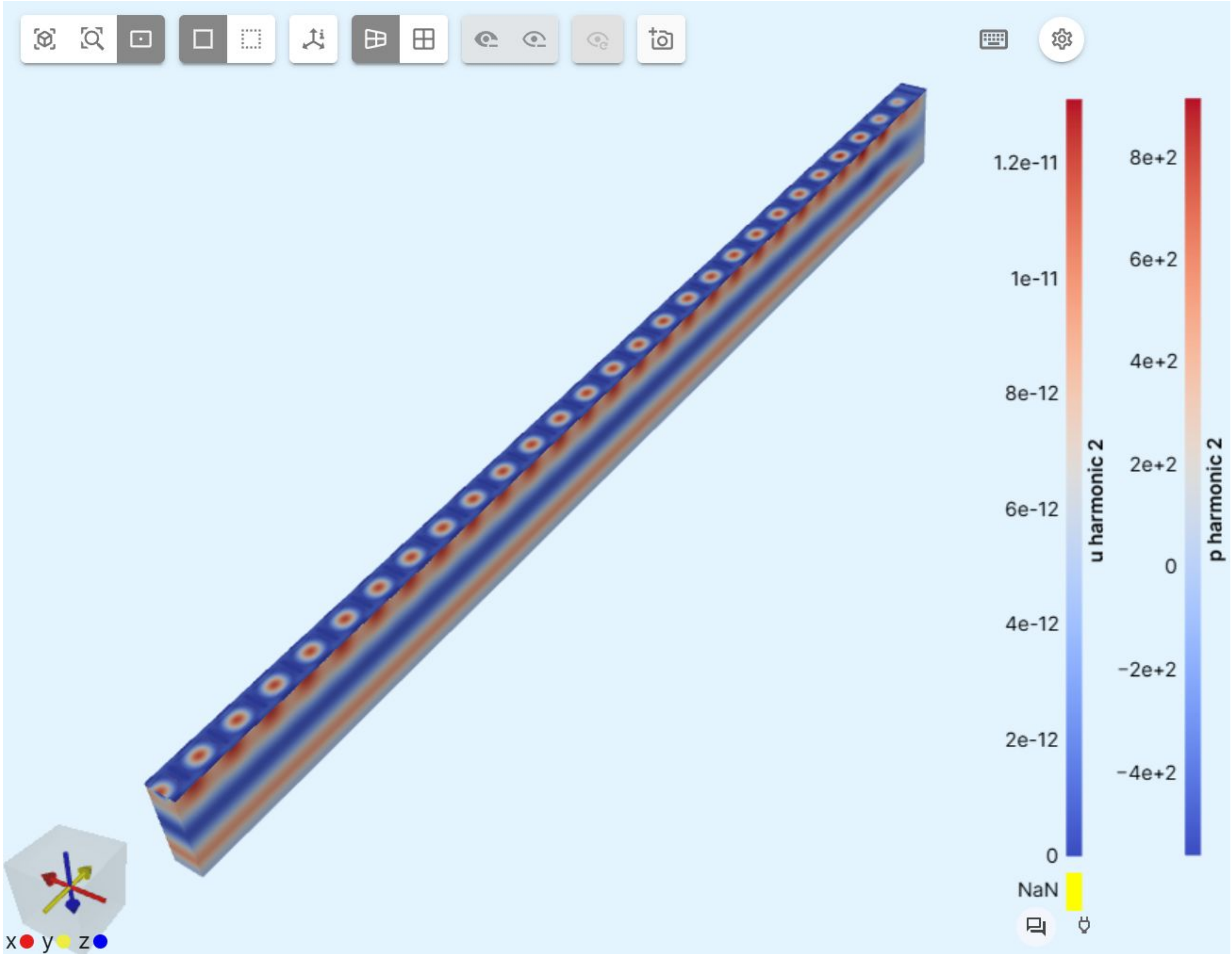
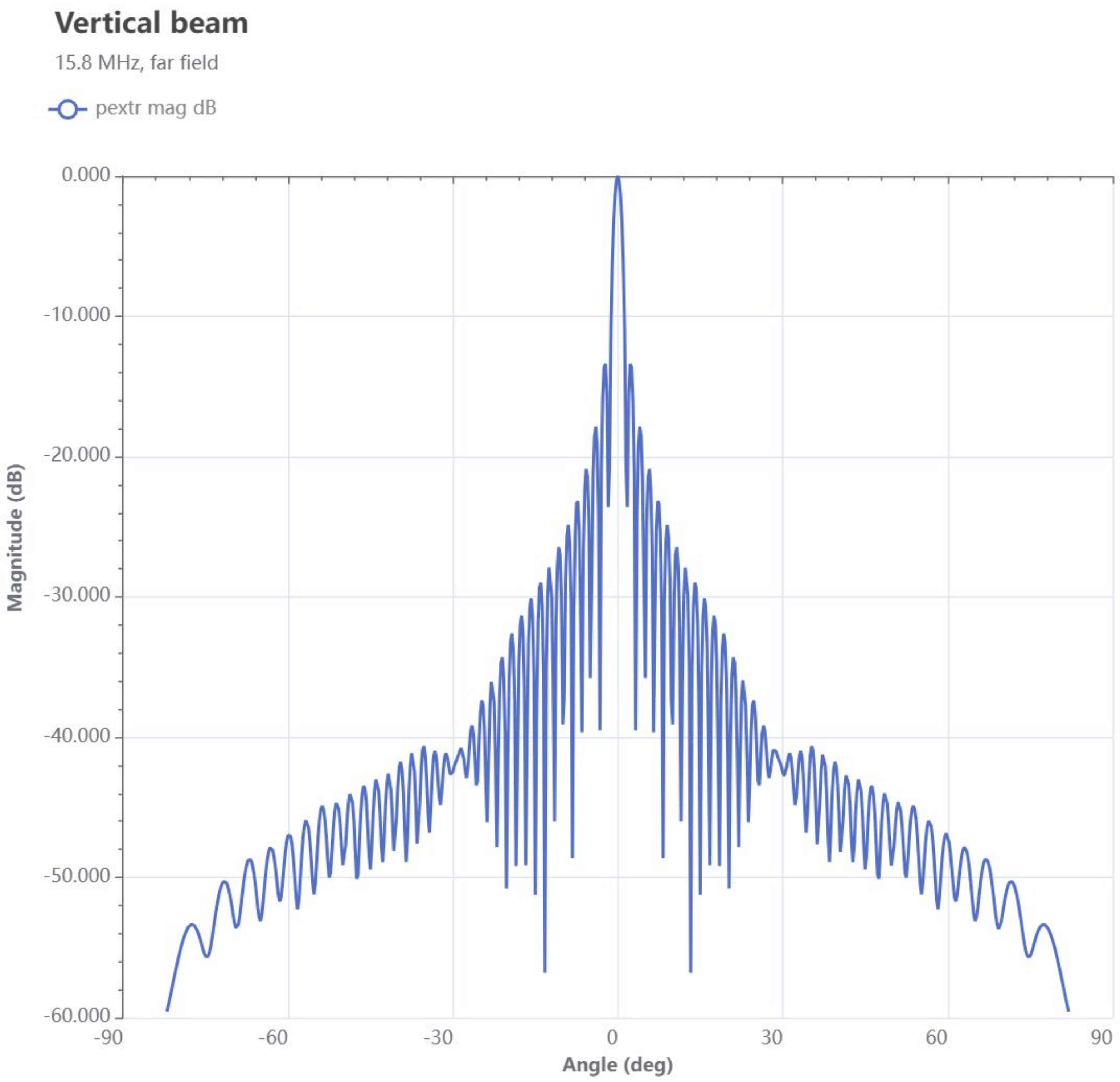
- Taking a cross section in the y axis (elevation) provides information on the following:
  - Elevation beam pattern
  - Full array impedance
- Simulate a column of cells with symmetry in x
  - Periodicity also possible
- Symmetry typically applied in x and y
  - Essentially simulating an infinite number of elements driven in parallel
- Harmonic and transient solutions possible
  - Here we will look at the harmonic results



Elevation harmonic simulation results

Displacement, pressure and far field beam pattern





2.3M
DoFs

16
Cores

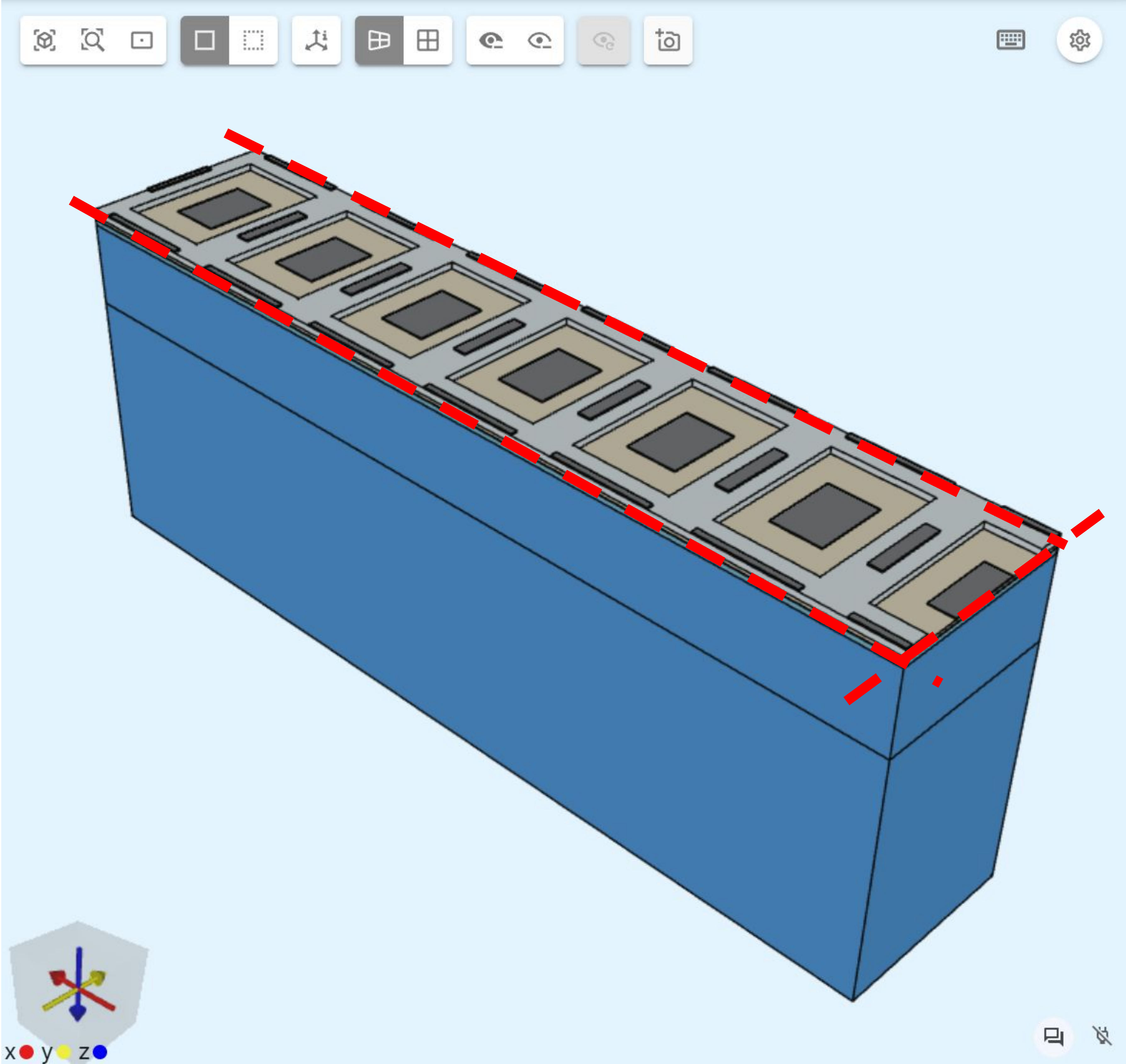
0.8
Minutes

0.2
Core-hours

Azimuthal cross section

Simulating crosstalk

- Taking a cross section in the x axis (azimuth) provides information on the following:
  - Mechanical and electrical crosstalk
  - Azimuthal beam pattern
  - Element impedance
- Typically simulate N elements in x
  - Where N is large enough to provide sufficient crosstalk information
  - Here we consider 13
- Symmetry typically applied in x and y
  - Essentially simulating an infinite column of MUTs
- Harmonic and transient solutions possible
  - Here we will look at the harmonic results



Azimuthal harmonic simulation results
Crosstalk and far field beam pattern

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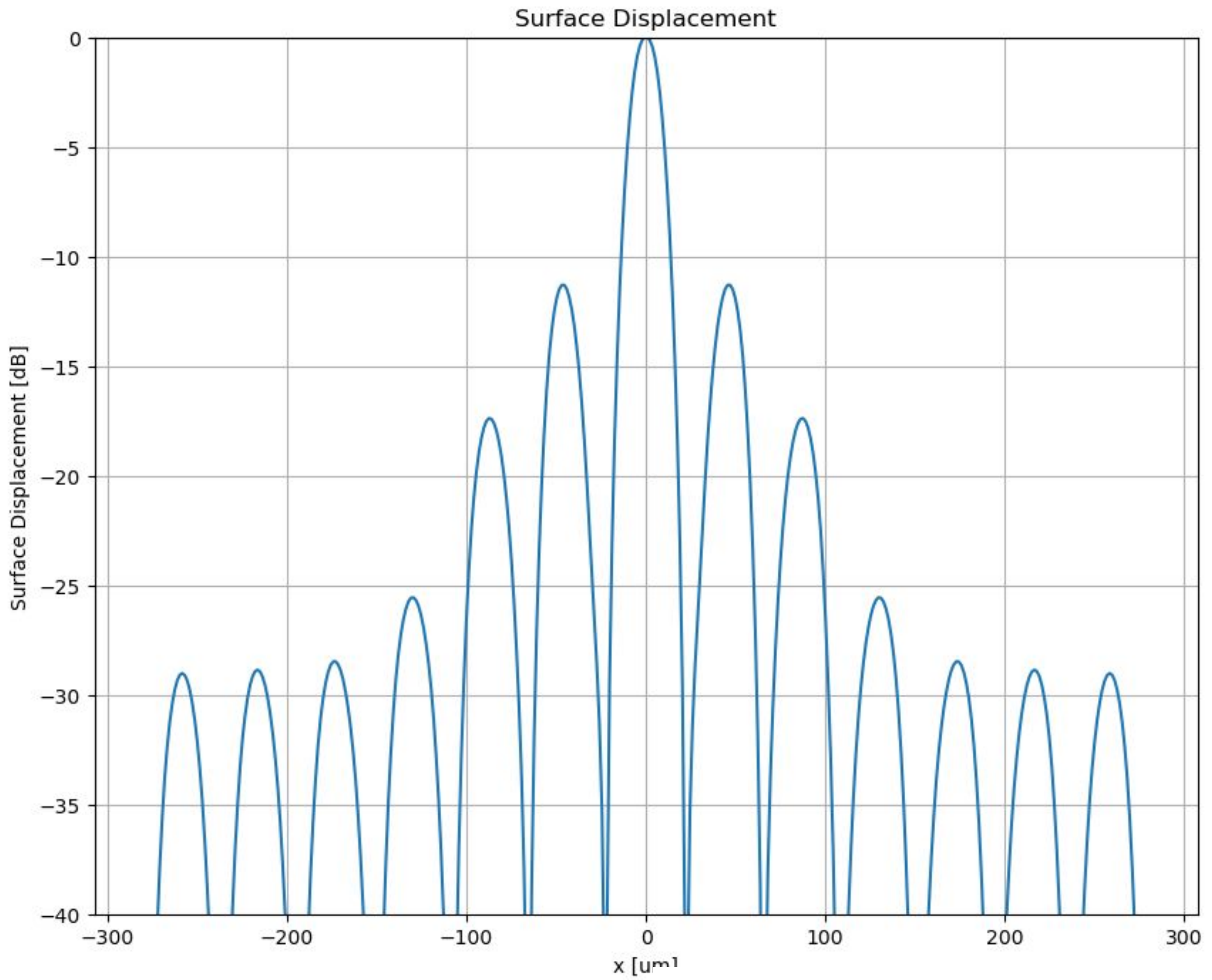

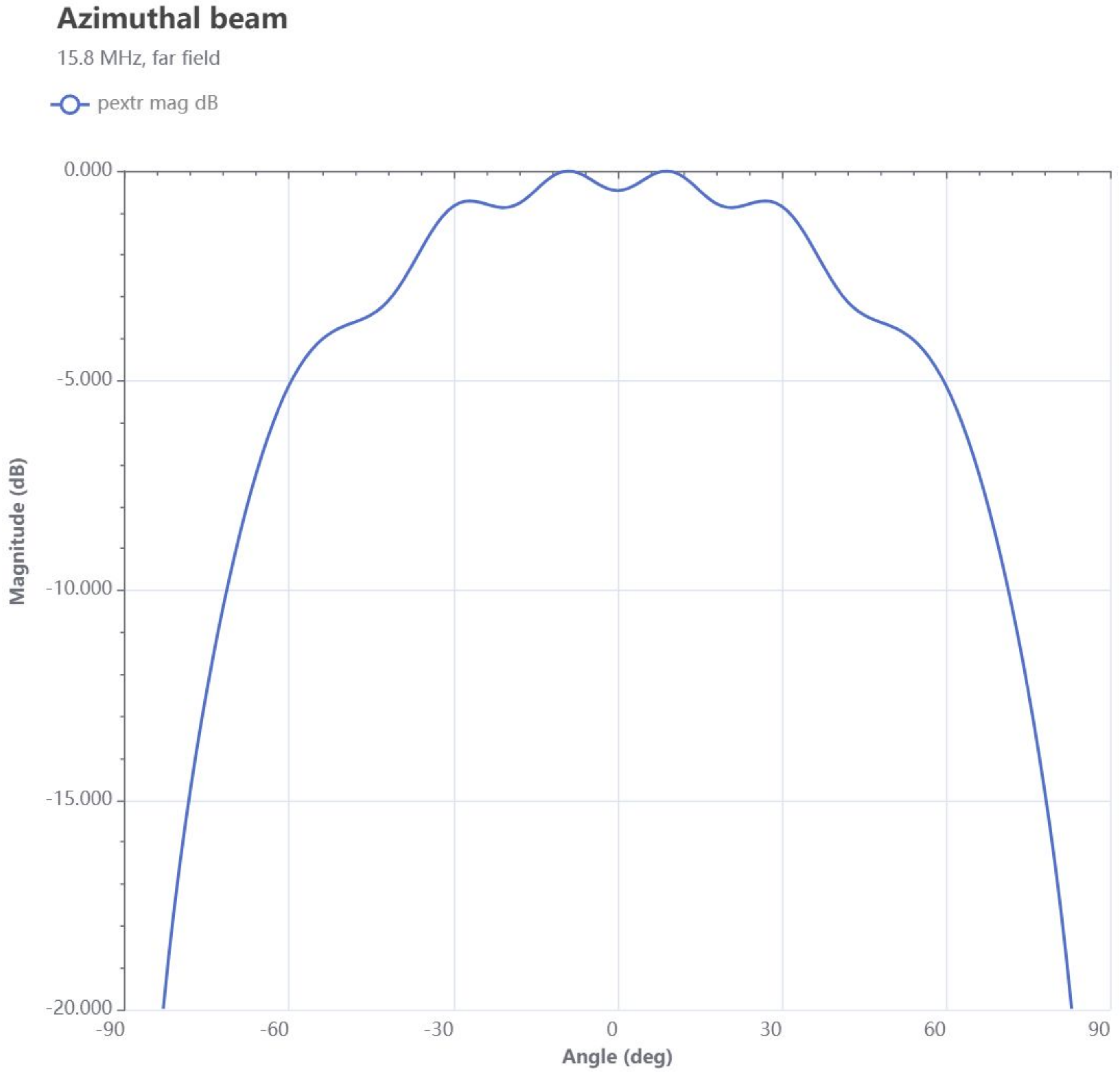

557k DoFs

1 Cores

3.7 Minutes

0.06 Core-hours

Full 3D section

Geometry

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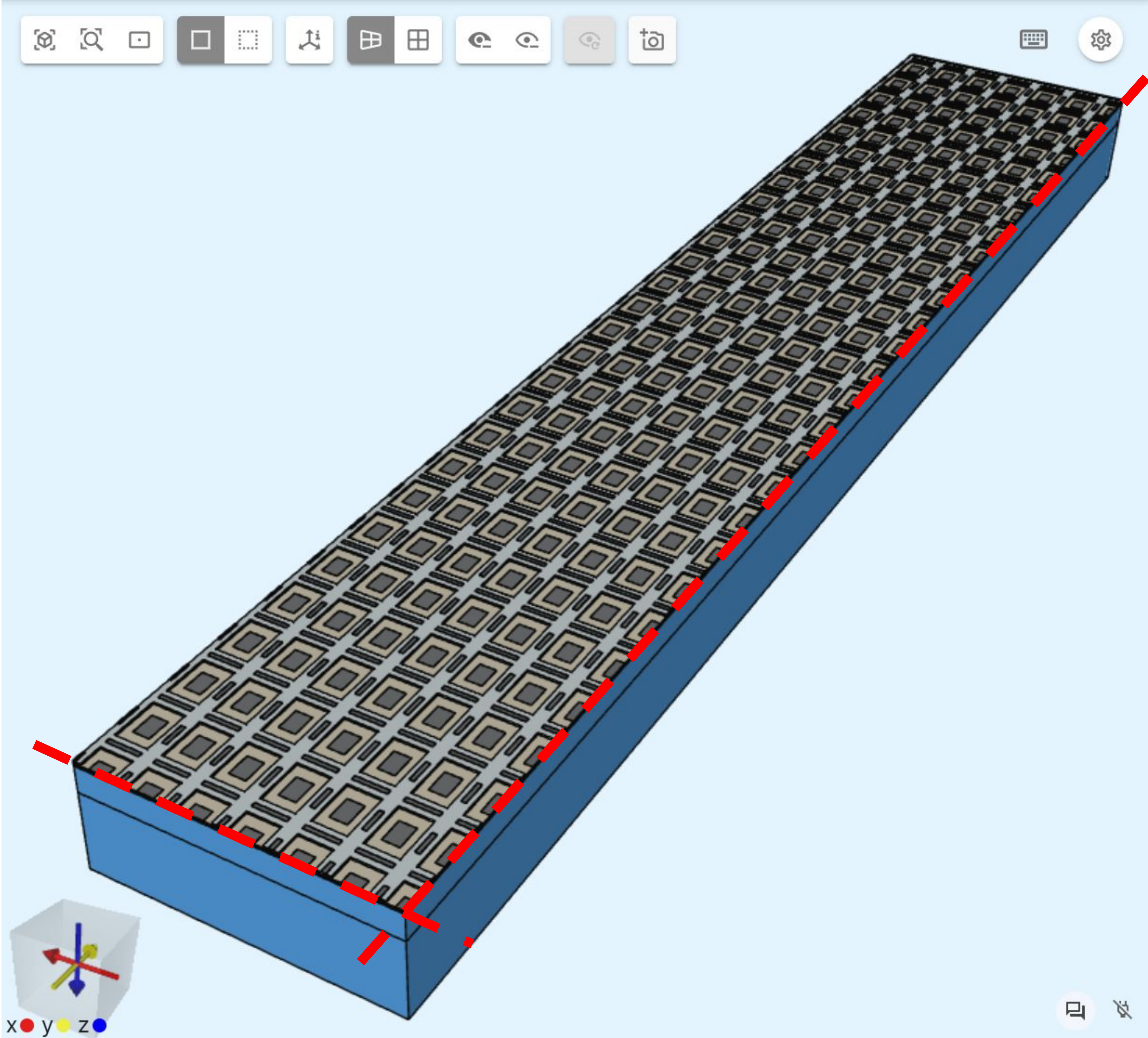
- This combines the cross sections analysed in the previous two models
  - 13 elements in x
  - 55 MUTs in y
  - 715 cells in total
- Symmetry is employed in x and y
- A single element is excited
  - column of 55 MUTs
- Harmonic and transient solutions calculated
- Near field can now be simulated in detail if required



Full 3D transient simulation results
Drive voltage and current

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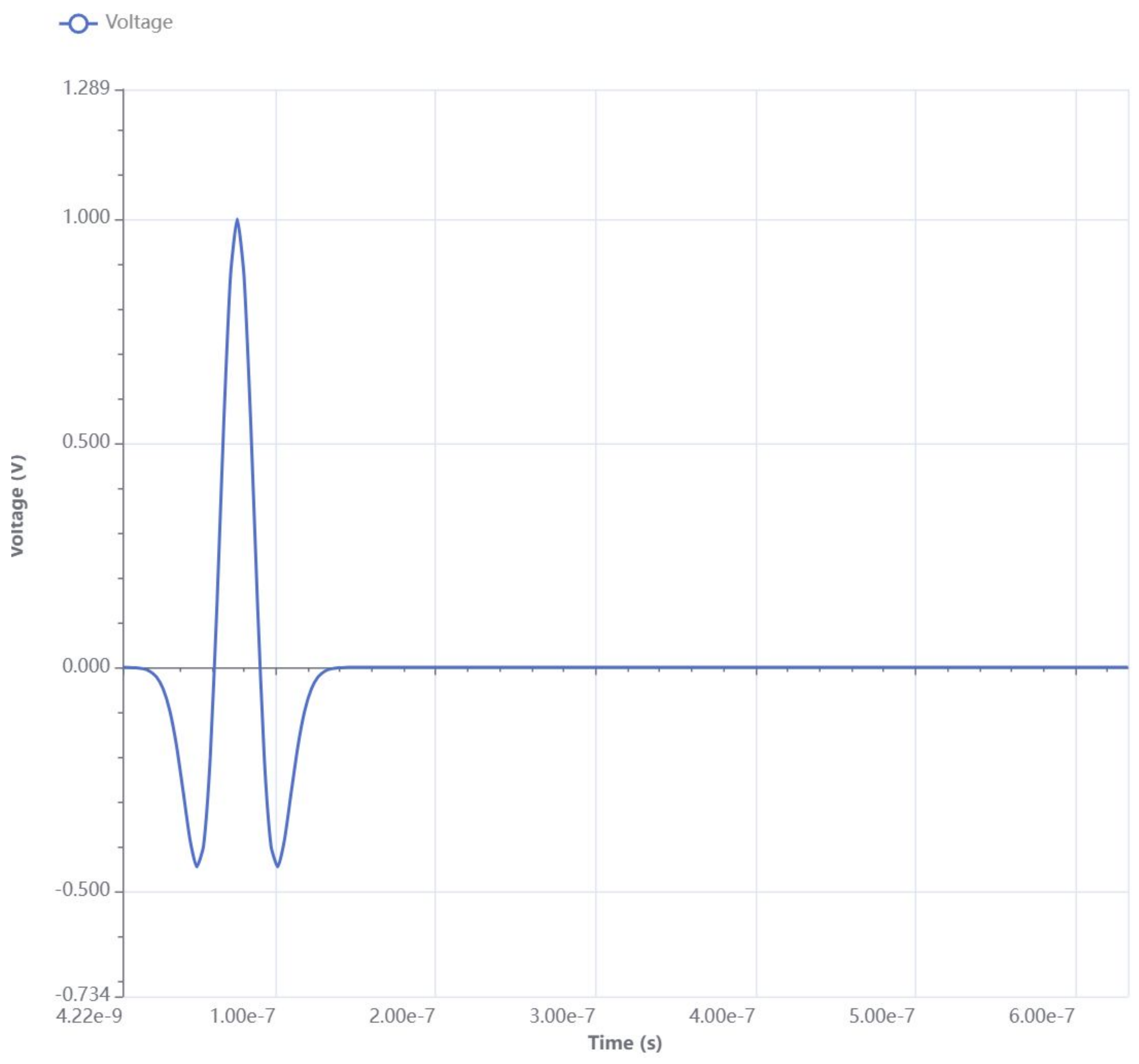

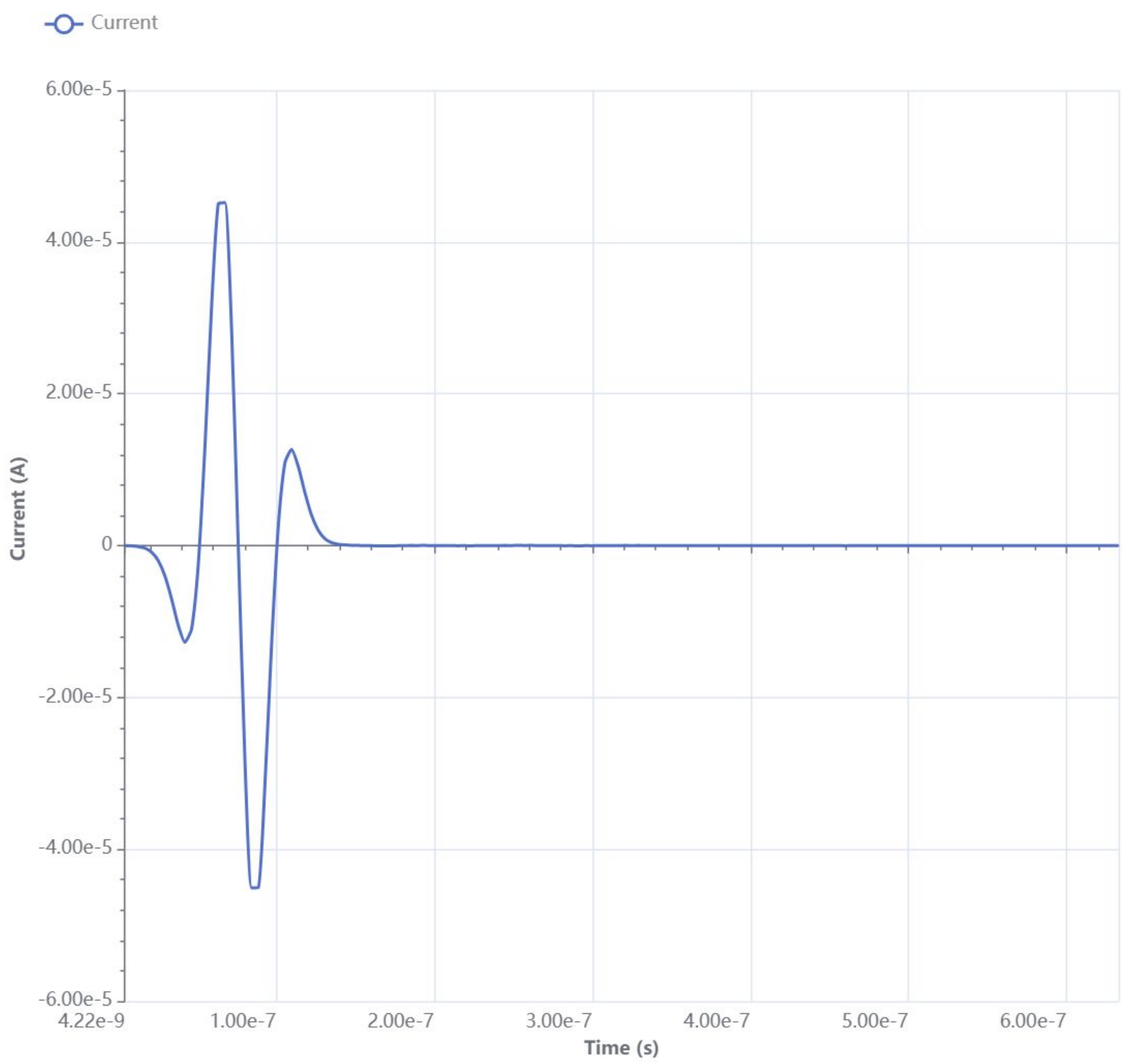

5.3M DoFs

32 Cores

14.5 Minutes

7.7 Core-hours

Full 3D transient simulation results
Surface displacement and acoustic pressure

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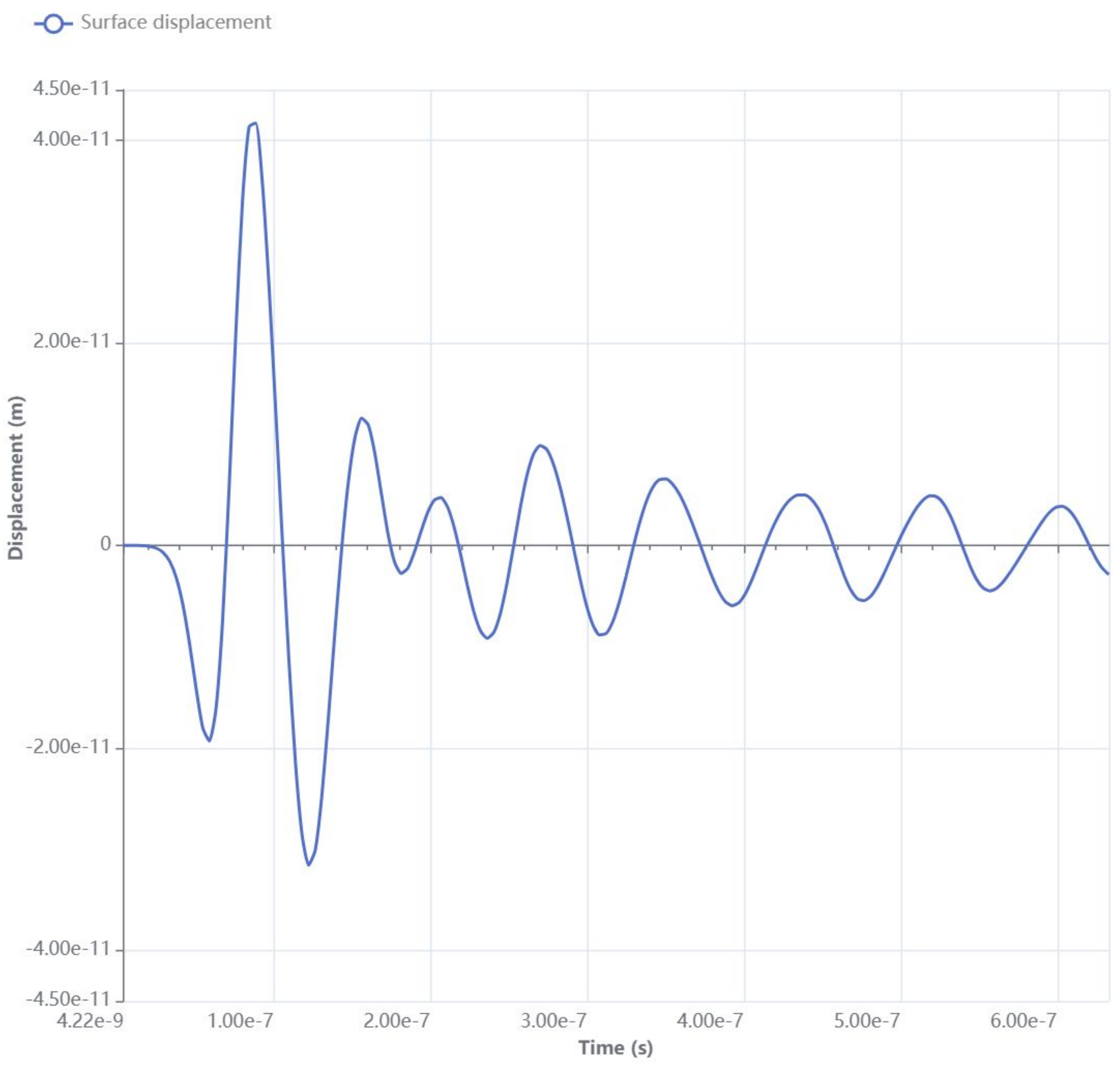

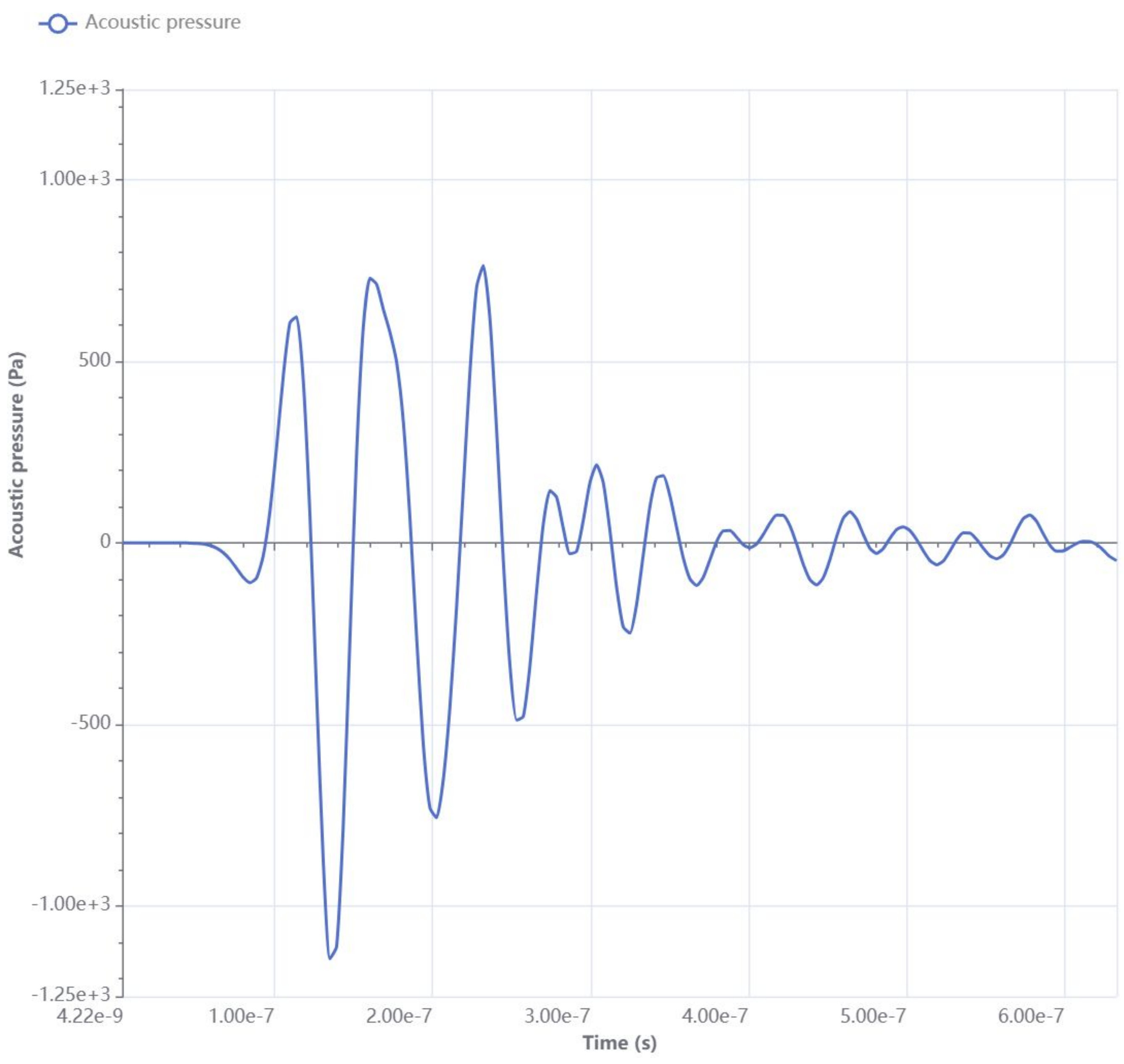

5.3M DoFs

32 Cores

14.5 Minutes

7.7 Core-hours

Full 3D transient simulation results

Crosstalk under pulsed excitation

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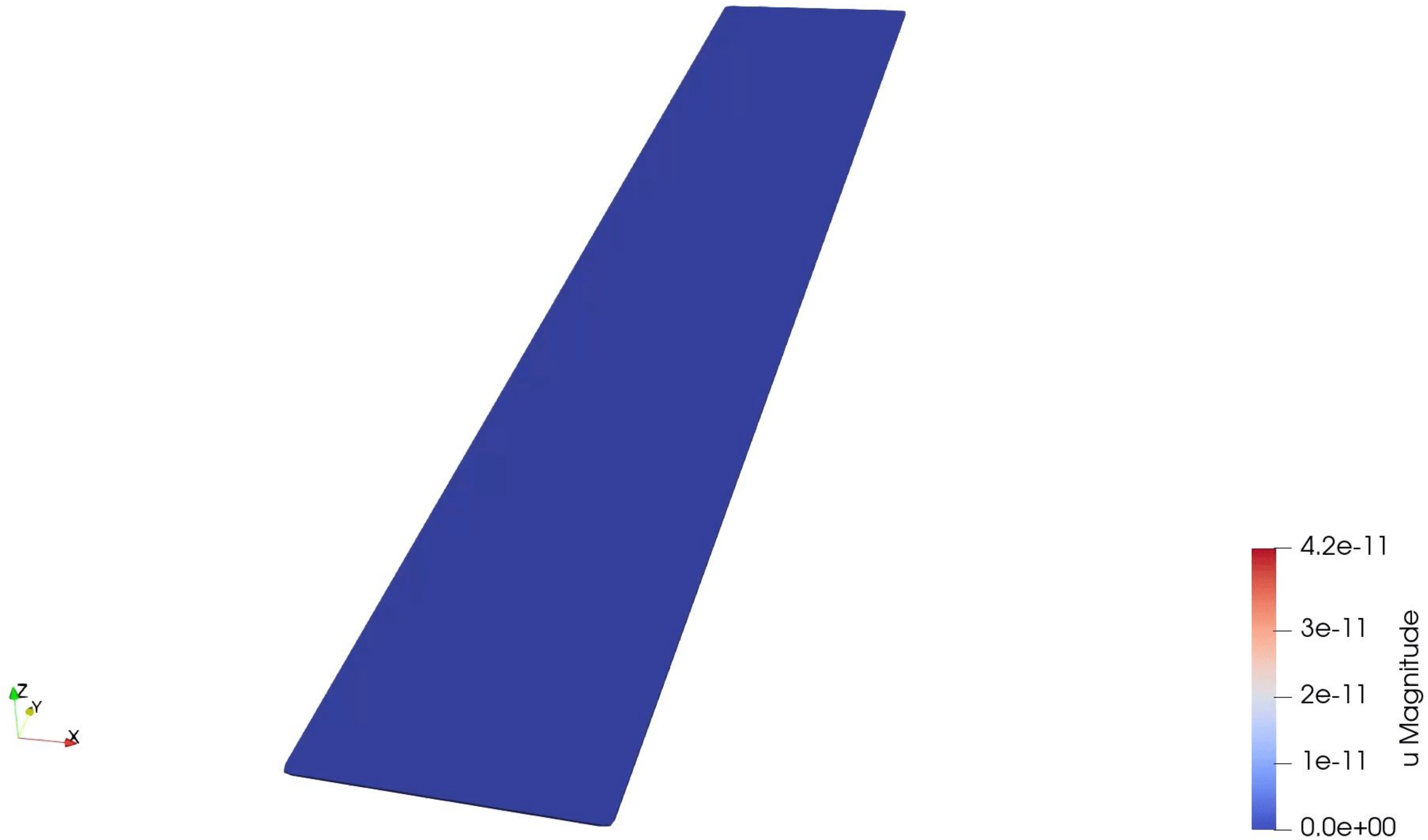

5.3M DoFs

32 Cores

14.5 Minutes

7.7 Core-hours

Full 3D harmonic simulation results

Crosstalk under CW excitation

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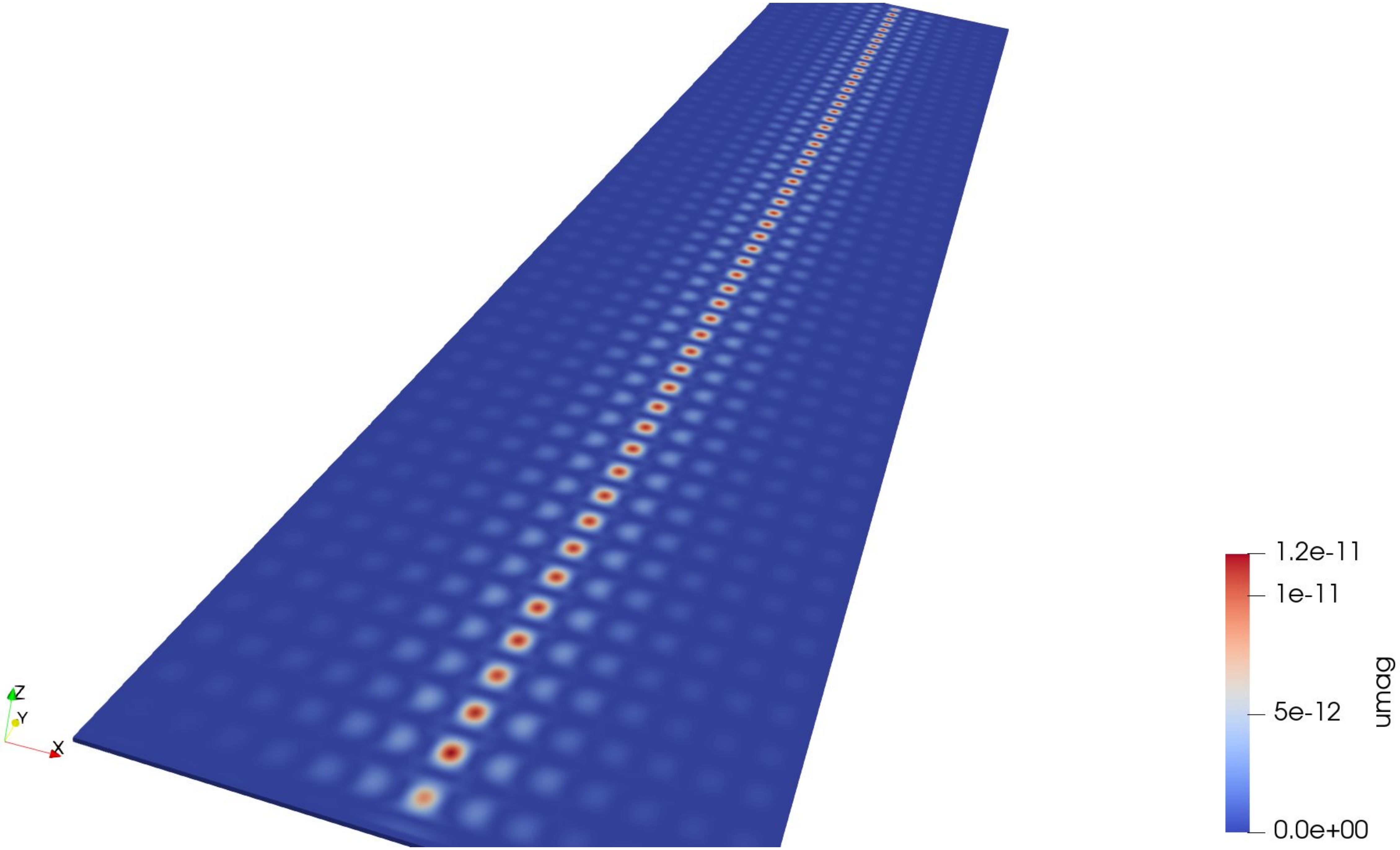

8.9M DoFs

32 Cores

6.7 Minutes

3.6 Core-hours

Full 3D harmonic simulation results
Far field beam patterns

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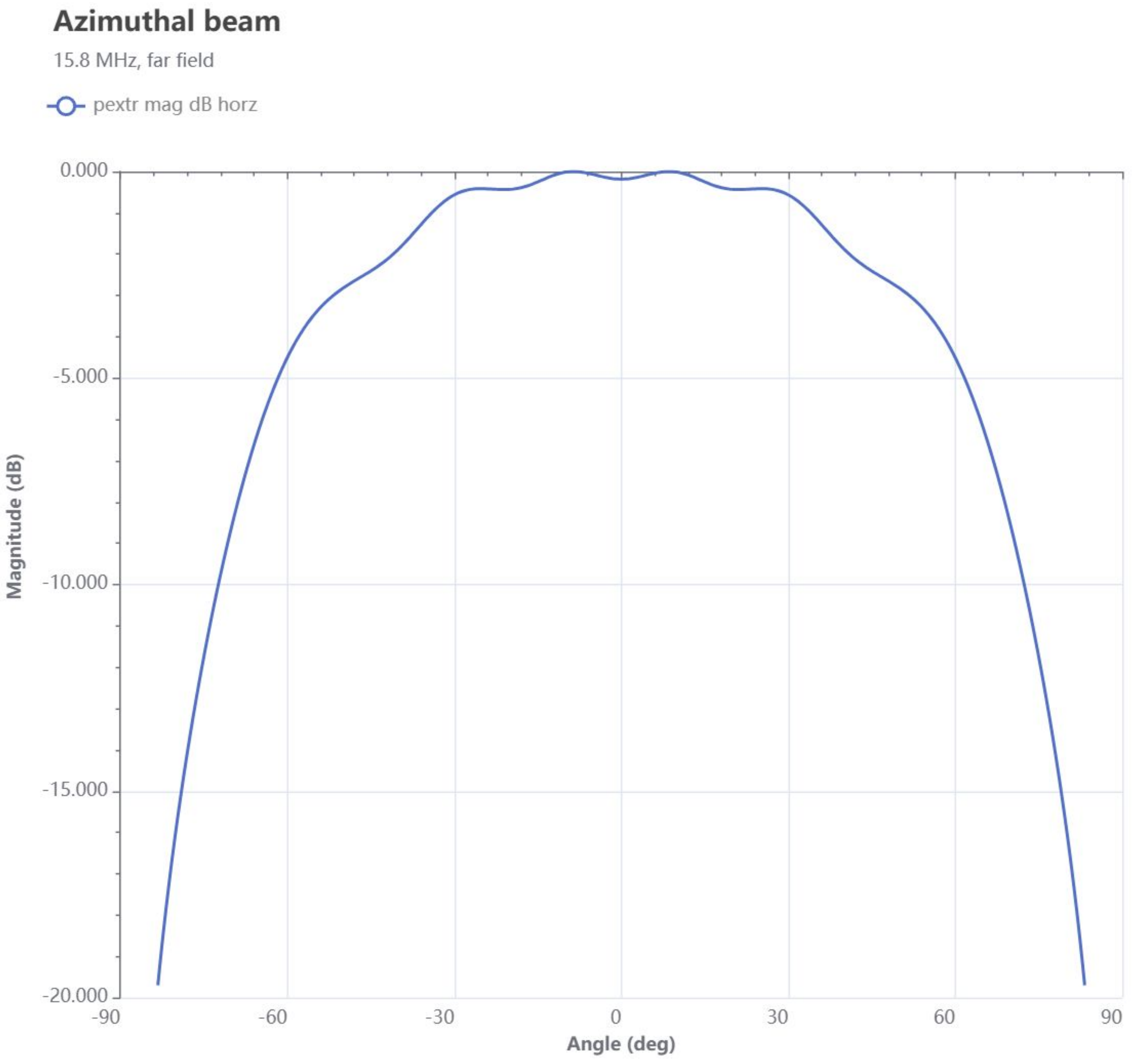

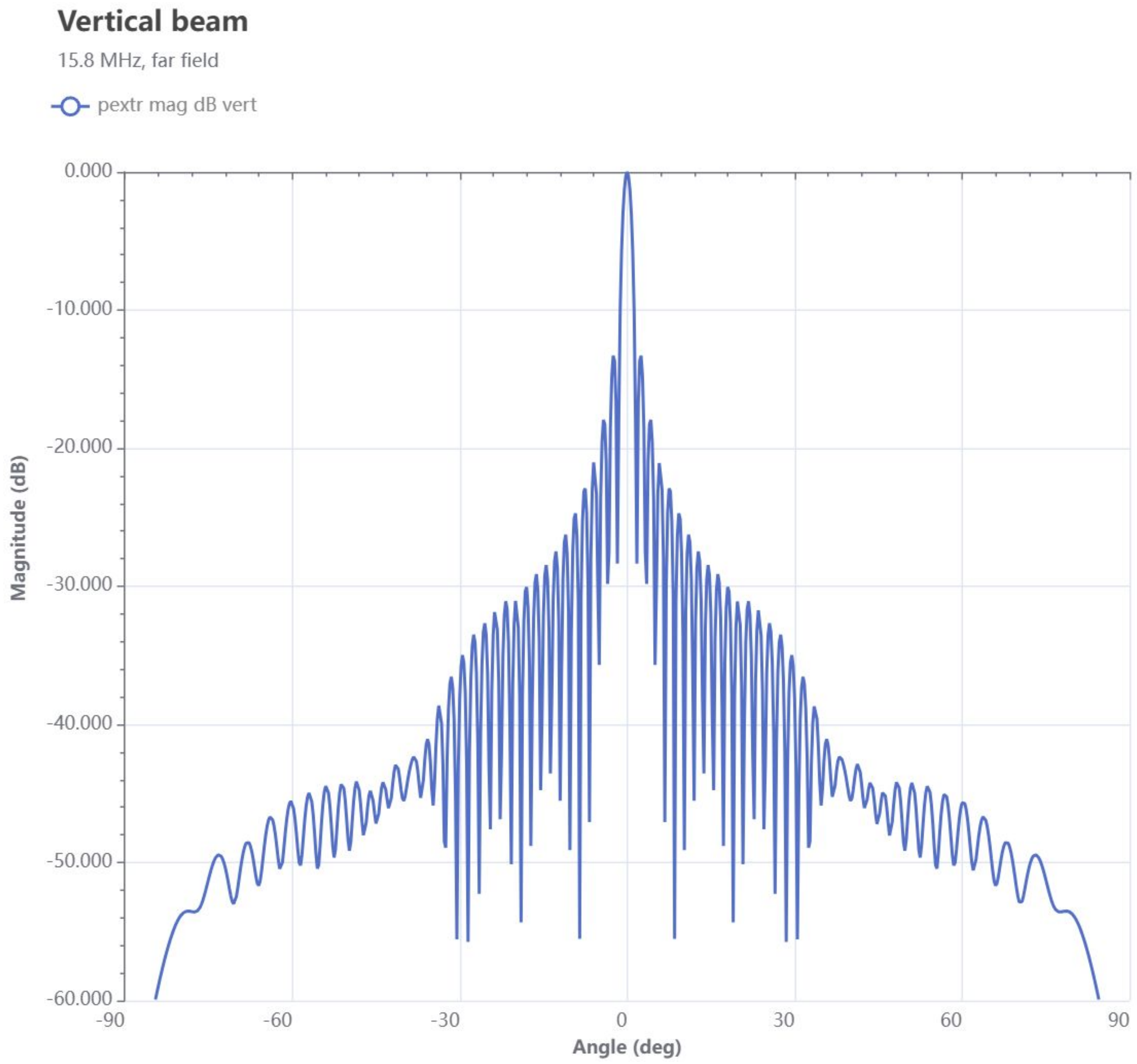

8.9M DoFs

32 Cores

6.7 Minutes

3.6 Core-hours

CMUT: Case study example

CMUT Overview

Like PMUT with additional challenges

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- CMUTs and PMUTs share many features:
  - MEMS construction
  - Simulation strategies
- CMUTs introduce additional complexities
  - biasing
  - nonlinear analysis
  - contact (if operated in collapse-mode)

CMUT reference design

General overview of example

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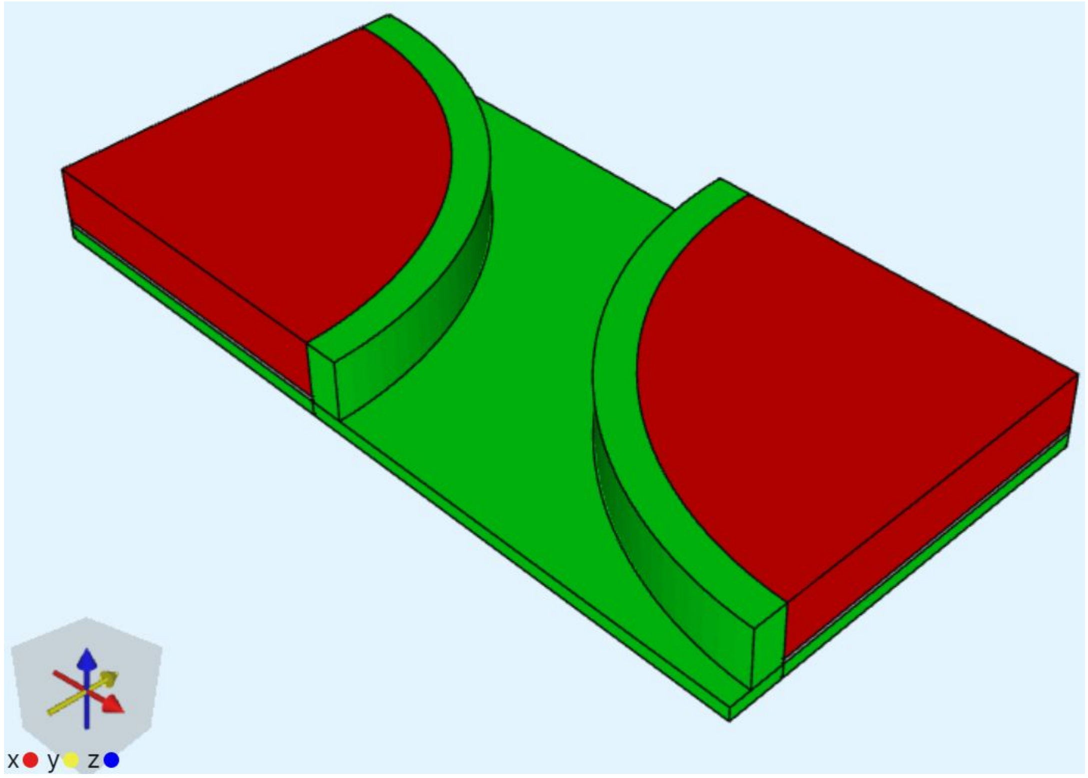
- Example array taken from the literature
- Carry out basic pull-in analysis
- Wideband transient analysis
- Multiharmonic analysis
  - Combines DC bias, multiple harmonics and nonlinearity into one solve
- 10 MHz centre frequency
- Structure:
  - SiO2 substrate
  - Si membrane
  - Water load (not shown)

Simple CMUT structure from [2], showing cross section (top) and cutaway of unit cell pattern (bottom)



2. M. Engholm *et al*, "Simulating CMUT arrays using time domain FEA," 2017 IEEE International Ultrasonics Symposium (IUS), Washington, DC, USA, 2017, pp. 1-1.

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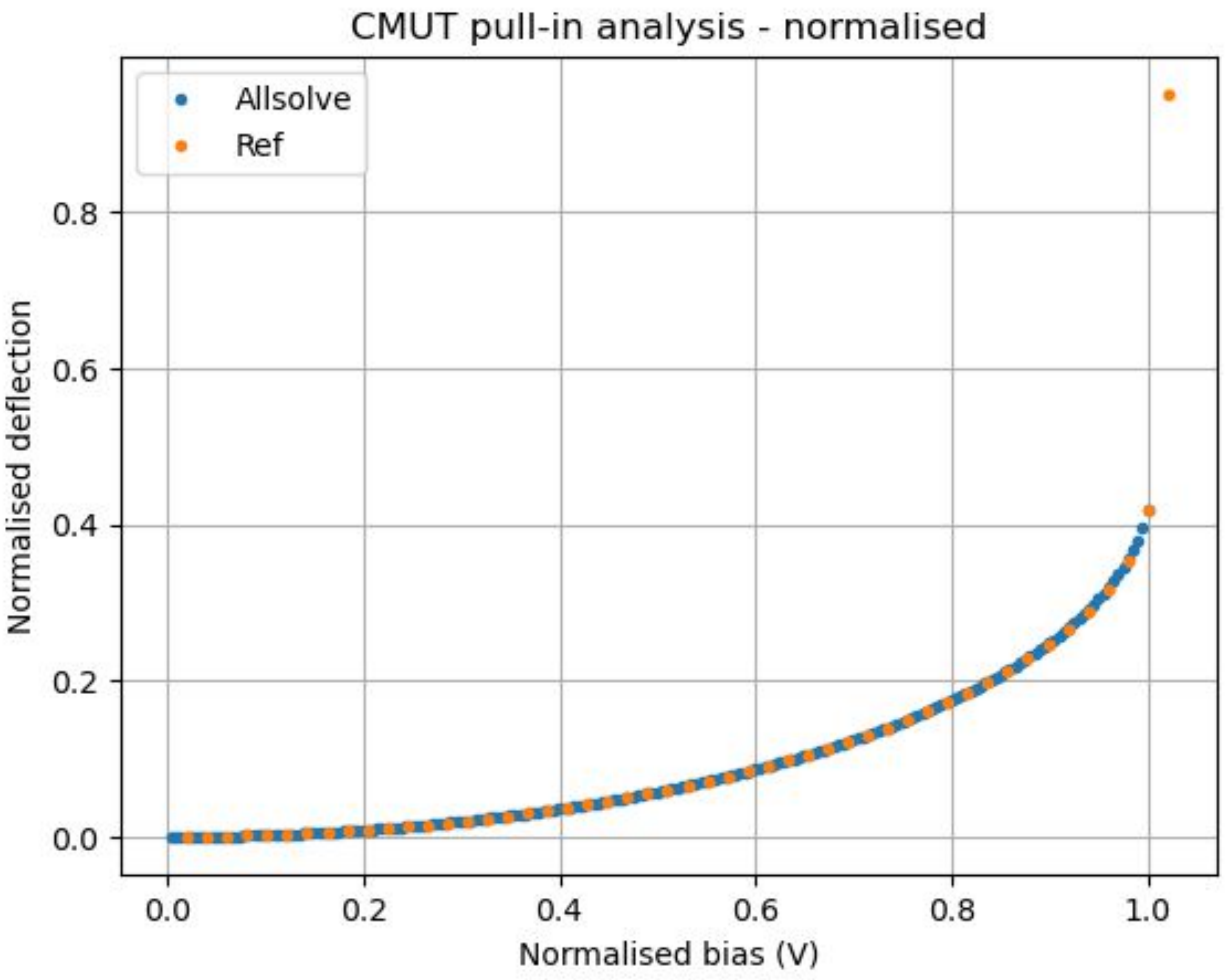
CMUT static simulation results
DC bias vs displacement

- 200 static sims run in parallel on the cloud
- Pull-in curve matches reference from literature
- Subsequent simulations are run at 50% of pullin voltage
- For transient, the static result can be used as an initial state for the model



47k	**200**	**200**	**0.2**	**0.58**
DoFs	Cores	Sims	Minutes	Core-hours

CMUT transient simulation results
Displacement & acoustic field

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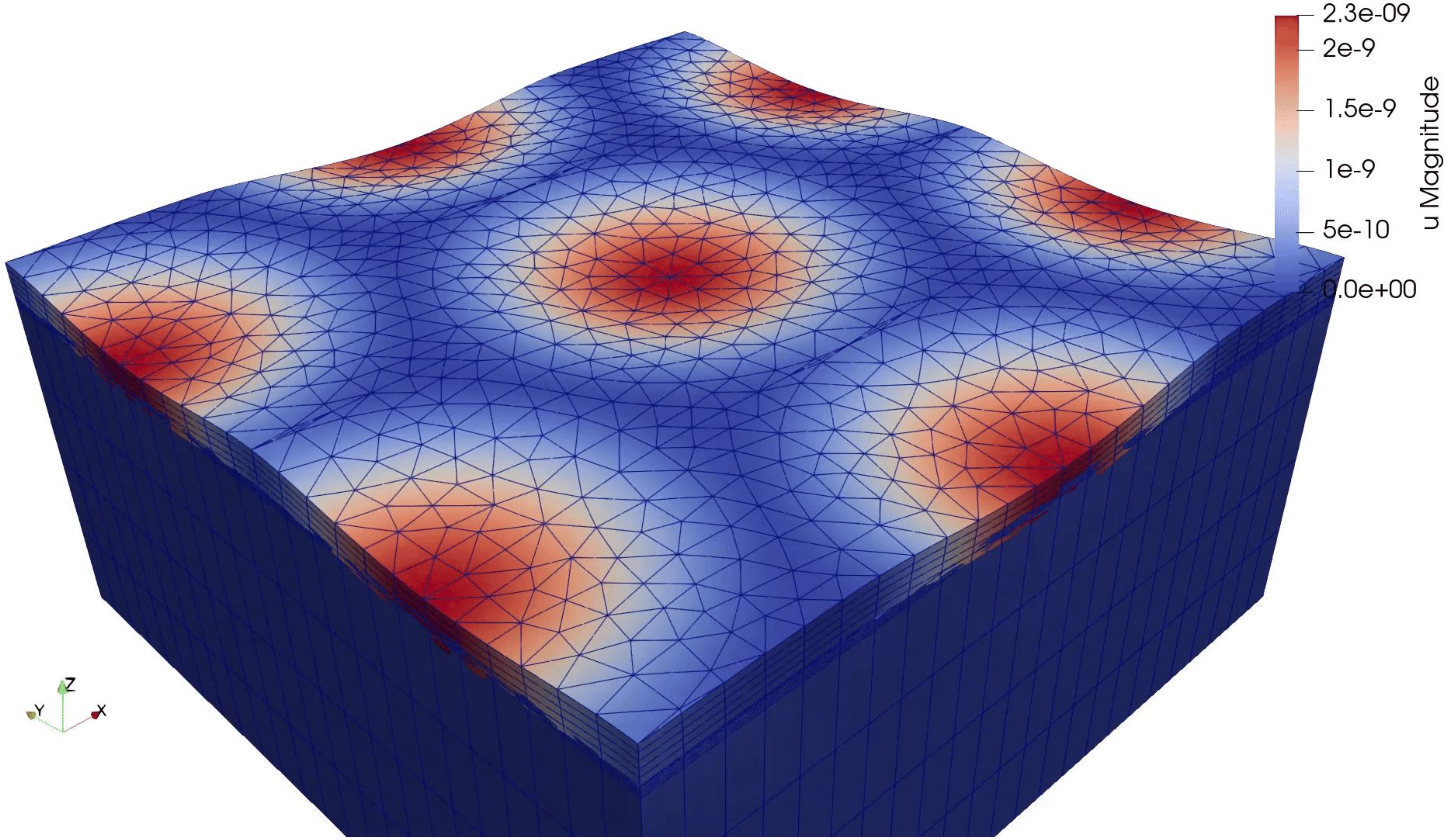
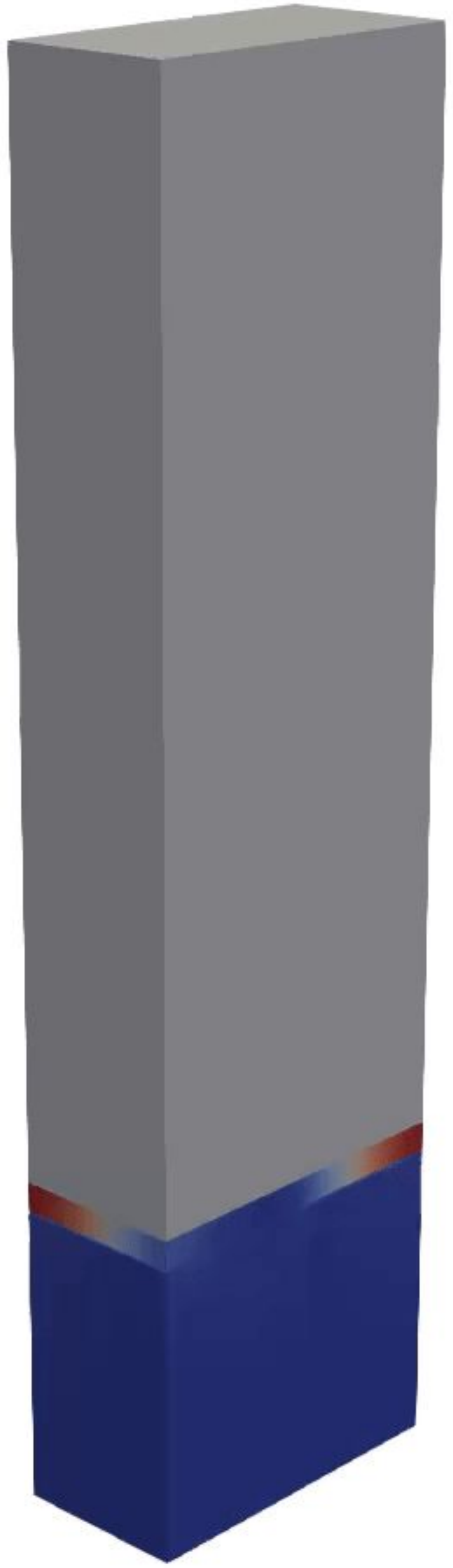




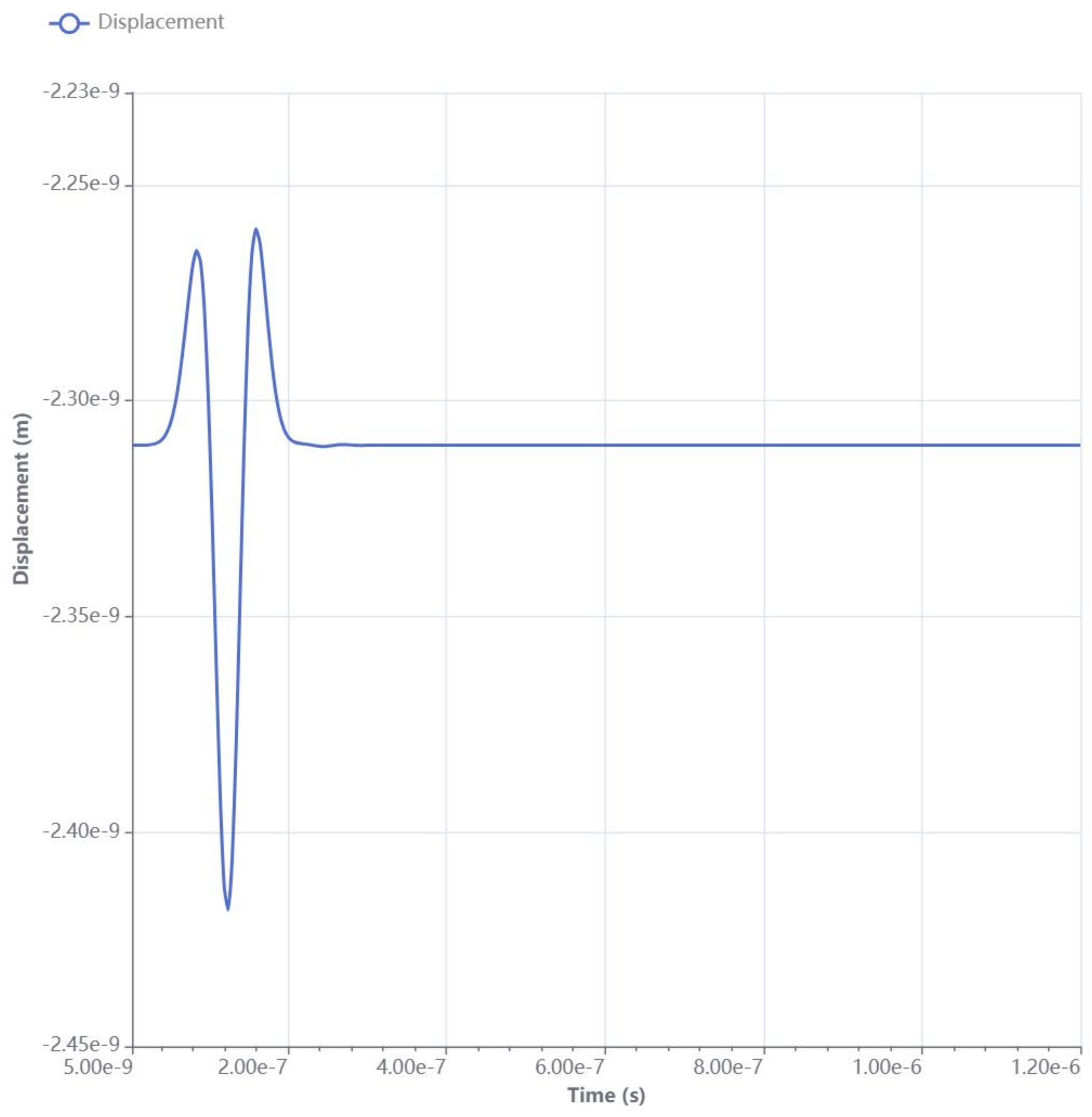
47k DoFs

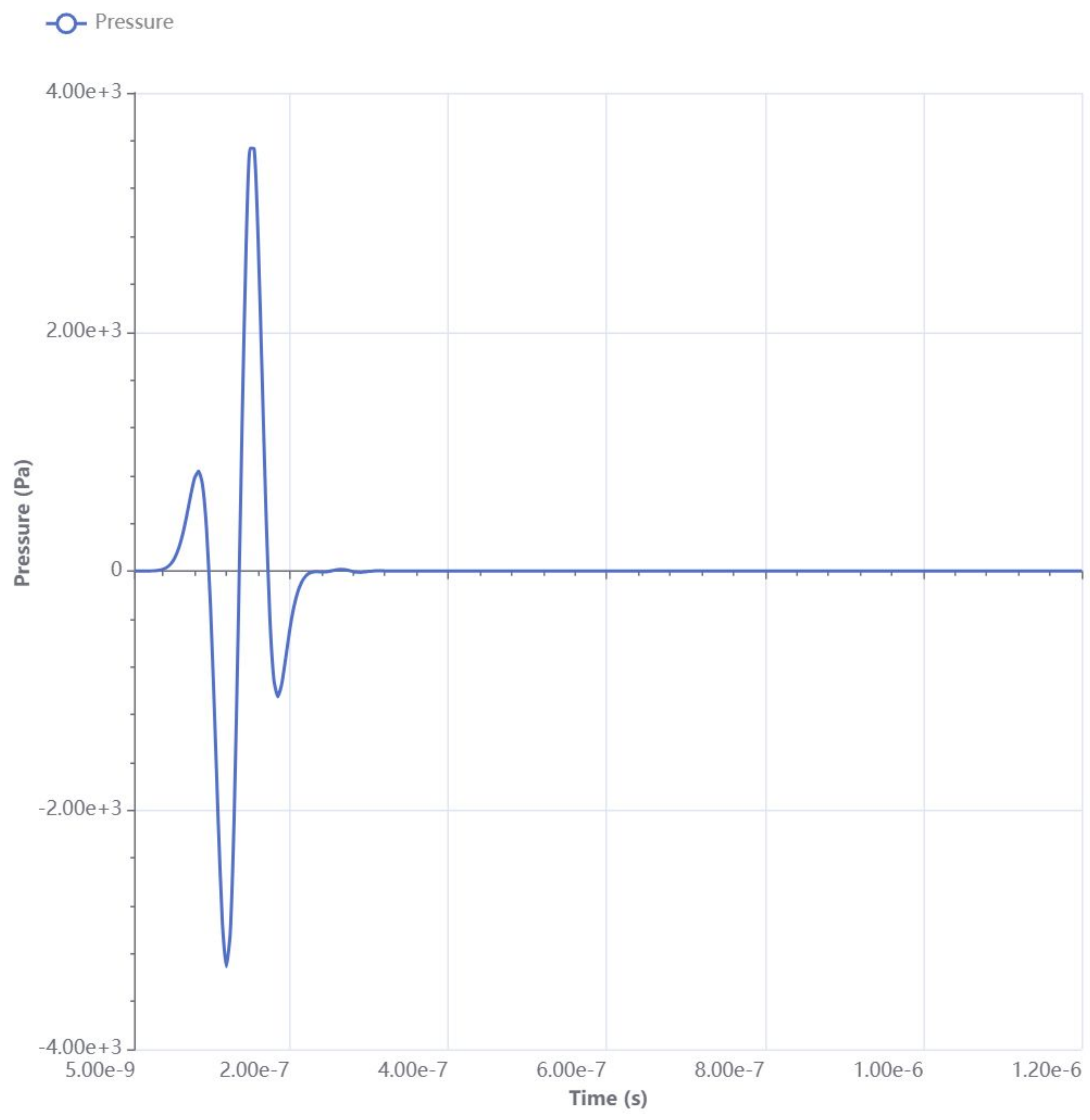
1 Cores

35 Minutes

0.58 Core-hours

CMUT transient simulation results
Displacement & acoustic field





47k DoFs

1 Cores

35 Minutes

0.58 Core-hours

CMUT Multiharmonic simulation results

DC bias plus multiple harmonics in a single simulation

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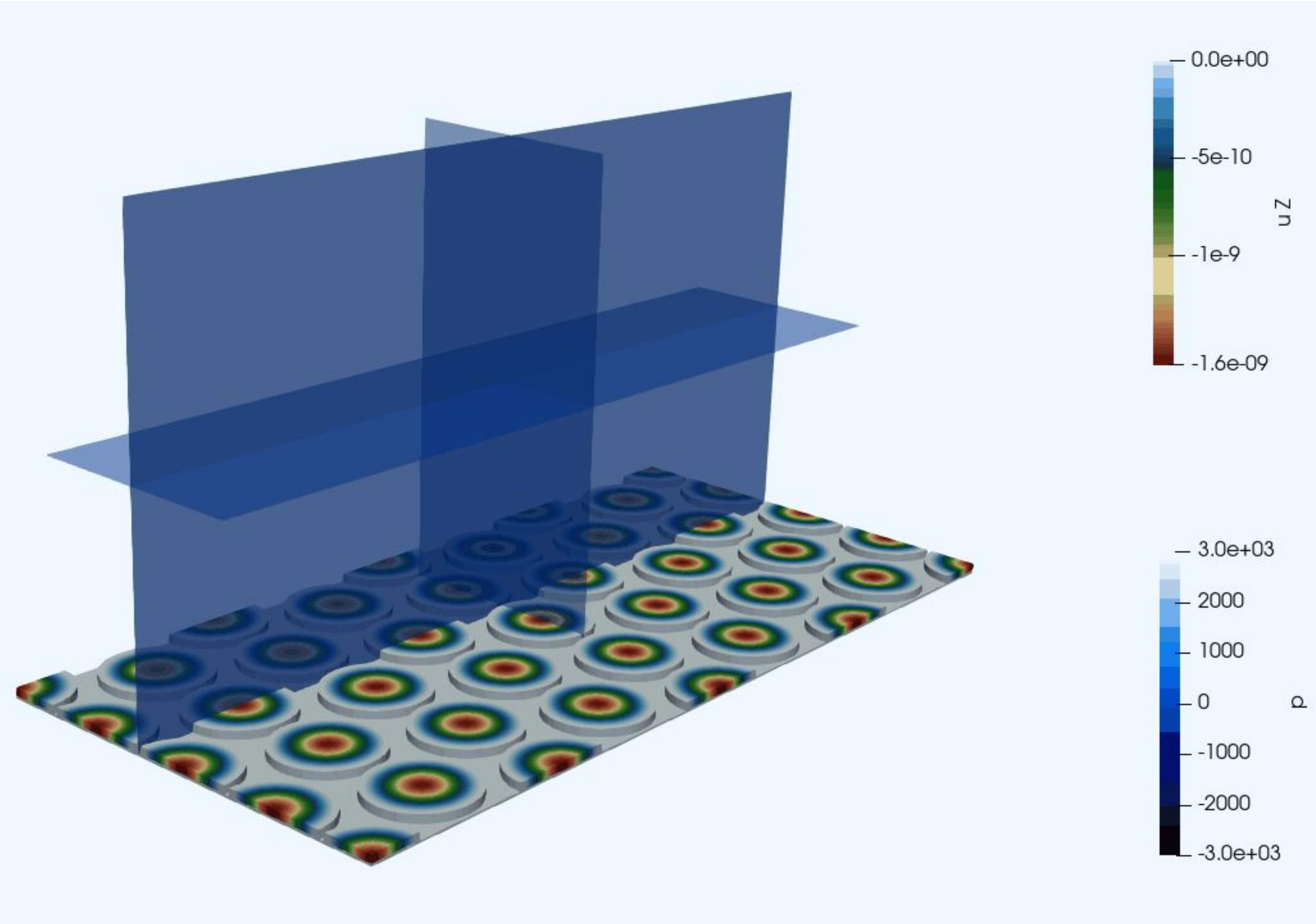
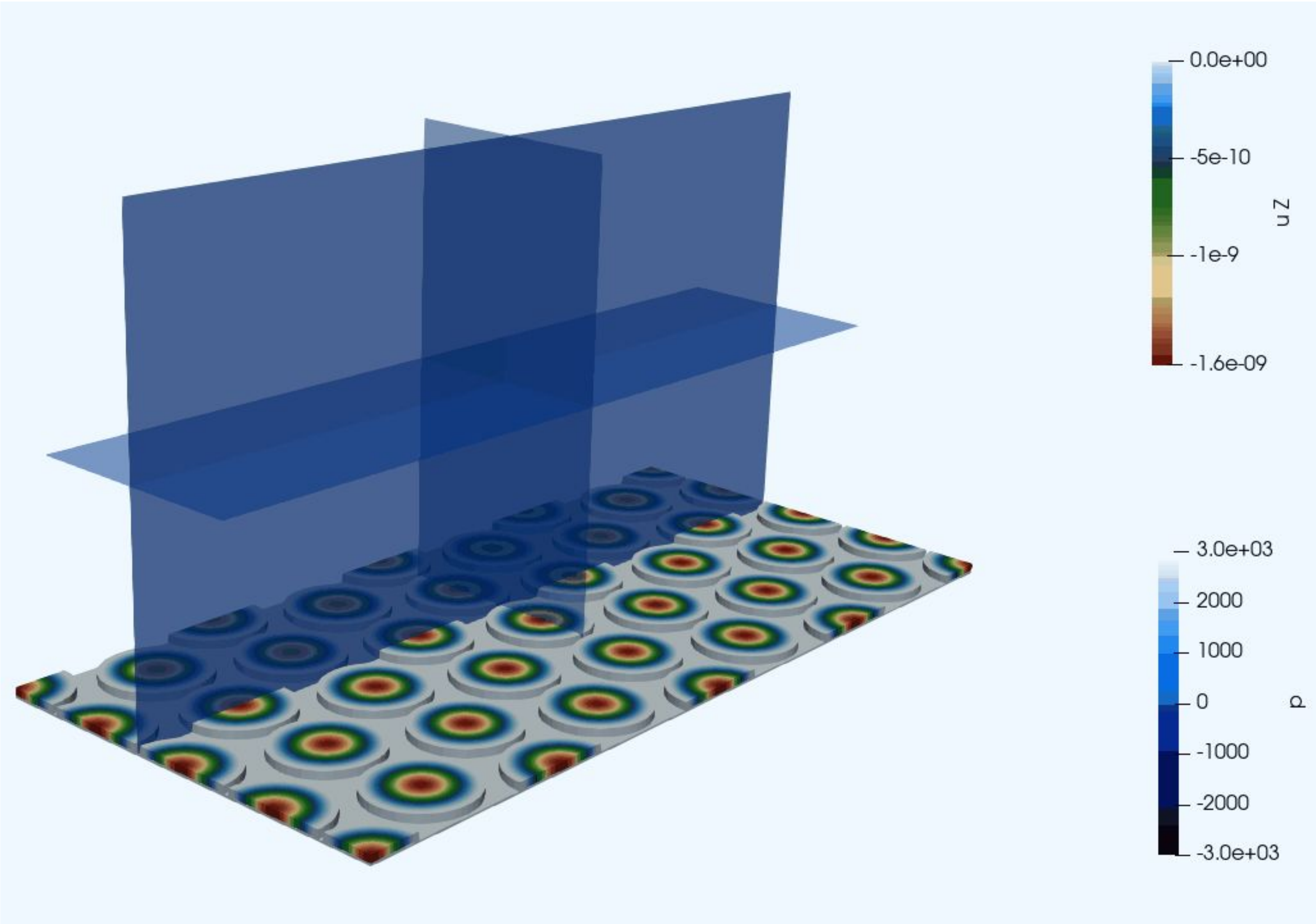


In phase excitation



Out of phase excitation

463k DoFs

20 Cores

10 Minutes

3.33 Core-hours

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Audience questions and conclusions

Questions for you

Submit your answers in the chat!

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In your opinion, what would be the biggest benefit from being able to accurately simulate your MUT arrays?

What is the most important effect or output you'd like to simulate but can't?

Conclusions

An outlook on the future of MUT simulation

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- MUT arrays pose significant challenges for traditional simulation packages
  - Array size, multiphysics, complex analysis
- Allsolve provides the capability and power to simulate MUT arrays at scale
  - Increase confidence in designs
  - Reduce physical prototypes
  - ***Faster time to market***

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Q&A

Submit your questions now!

Would Quanscient Allsolve replace my current tools?

How does the pricing work?

What file formats does Quanscient Allsolve support?

Can I trust a cloud-based product?

Thank you for your participation!

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You'll receive the executive summary PDF by the end of the week.

In the meantime, we want to invite you to get in touch with us!

Scan the QR-code and schedule a 30-minute introductory call with us to discuss

- → Specific challenges you'd like to solve
- → Particular aspects you're interested in exploring
- → Specific goals related to your work

Finally, join our active community of more than 6000 simulation experts by following us on LinkedIn!

https://quanscient.com/muts-webinar/contact