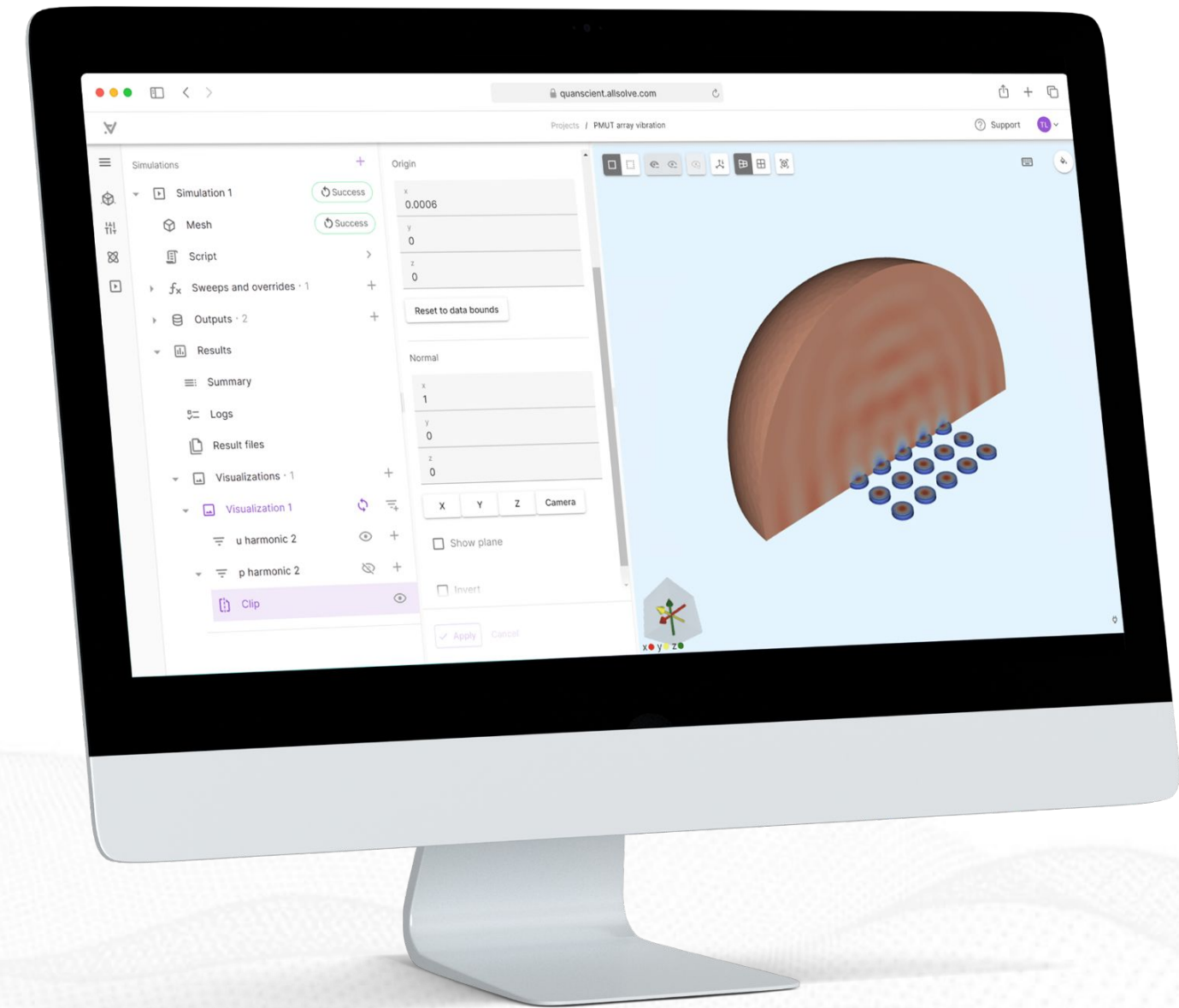


Analyze your **MUT** design with cloud-based multiphysics simulation

Dr. Andrew Tweedie
UK Director & Co-founder
Quanscient

Jukka Knuutinen
Head of Marketing
Quanscient



Housekeeping items

Before we start

QUANSCIENT

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

QUANSCIENT



Jukka Knuutinen

Head of Marketing
Quanscient



Dr. Andrew Tweedie

UK Director & co-founder
Quanscient

Webinar agenda

QUANSCIENT

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

QUANSCIENT

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



QUANSIENT

Customer use case
Proxima Fusion & Atled Engineering

2024



With Quanscient API, Atled Engineering automated simulation workflows

This workflow involves preparing a mesh with appropriate tagging information, which is then passed to the API.

The API subsequently estimates the required computational resources (node count and type), and executes a preliminary simulation to determine the background field.

A full-fidelity coil analysis is then performed using a refined mesh and the previously obtained background field.

Finally, the API facilitates the export of relevant results, including field maps and mechanical data.

QUANSIENT
WEBINAR
Cloud-based FEM for Ultrasonics:

15x15 PMUT array with +30M unknowns solved in less than 4 minutes

See the groundbreaking effects cloud-computing can have on ultrasonics simulations

Aug 14, 2023

Technical speaker
Dr. Alexandre Halbach
CTO, Co-Founder
Alexandre is our CTO and simulation algorithms expert. He has developed our state-of-the-art multiphysics simulation algorithms and has years of hands-on HPC experience.

OVERVIEW

This webinar provided a practical demonstration of Quanscient Allsolve's application in ultrasonic simulations. It covered an eigenmode analysis of a cooling blade, a multiphysics simulation of an ultrasound transducer, and a large-scale simulation of a 15x15 PMUT array, effectively demonstrating the software's capabilities in handling complex simulations with over 31 million degrees of freedom efficiently using cloud computing.

KEY DEMONSTRATIONS AND RESULTS

Eigenmode Analysis of a Cooling Blade:

Objective: To introduce the workflow in Quanscient Allsolve through a basic mechanical simulation.

Process: Dr. Halbach demonstrates the creation of a project, importing a step file, and de-featuring a cooling blade. He focuses on how Allsolve simplifies this process, making complex simulations accessible.

Key Benefits: The simulation highlights the platform's user-friendly interface, versatile meshing options, and the efficient setup of materials and physics, culminating in a swift eigenmode analysis.

Results: The analysis reveals several clusters of resonance frequencies, each corresponding to different vibration modes of the blade, effectively showcasing the software's precision and computational power.

Multiphysics Simulation of a Single Ultrasound Transducer (PMUT):

Objective: To demonstrate a multiphysics simulation involving piezoelectric and acoustic interactions.

Process: The setup involves defining materials (including monocrystalline silicon and PZT piezoelectric material), setting up physics (solid mechanics, electrostatics, and acoustic waves), and applying boundary conditions. Dr. Halbach explains each step, demonstrating the platform's comprehensive capabilities.

Key Benefits: This simulation exemplifies the platform's ability to handle complex multiphysics interactions seamlessly. The ease of setting up is highlighted, along with the platform's flexibility in editing material properties.

Results: The simulation results showcase the transducer's vibration and emitted pressure field, illustrating Allsolve's capability to render detailed physical phenomena.

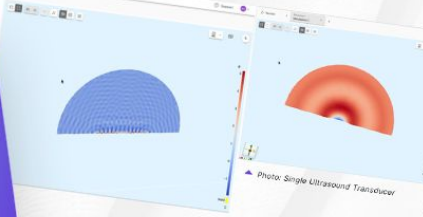


Photo: Single Ultrasound Transducer

Key Benefits: The demonstration emphasizes Allsolve's robust computational power, capable of handling over 20 million unknowns efficiently. The platform's scalability and ability to perform multiple simulations in parallel are showcased.

Results: The final visualization presents a detailed pressure field across the array, highlighting the software's capability to manage and visualize extensive data sets rapidly.

Number of Cores Used: 100
Degrees of Freedom (DoFs): 31,149,998
Runtime: 222.95 seconds (approximately 3.7 minutes)

QUANSIENT ALLSOLVE

Book your session now

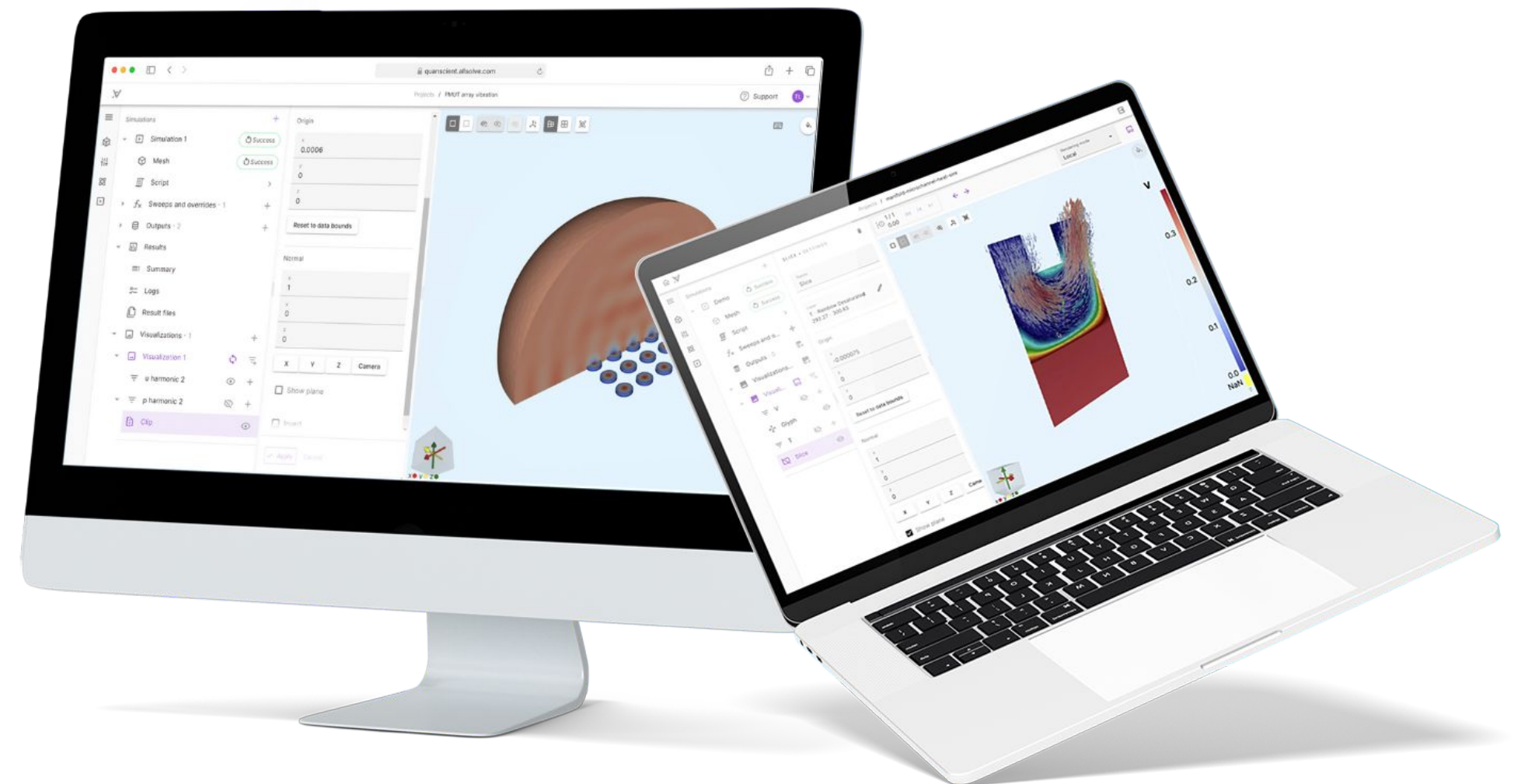
Not ready for a call just yet but still curious? Fill out [this form](#) to describe your use case. Our technical team will review your information and respond within one business day.

quanscient.com info@quanscient.com

Introduction to Quanscient Allsolve Overview

QUANSIENT

- 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

QUANSIENT



Introduction to Quanscient Allsolve

4 key benefits

QUANSCIENT

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!

Technical content & demo

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

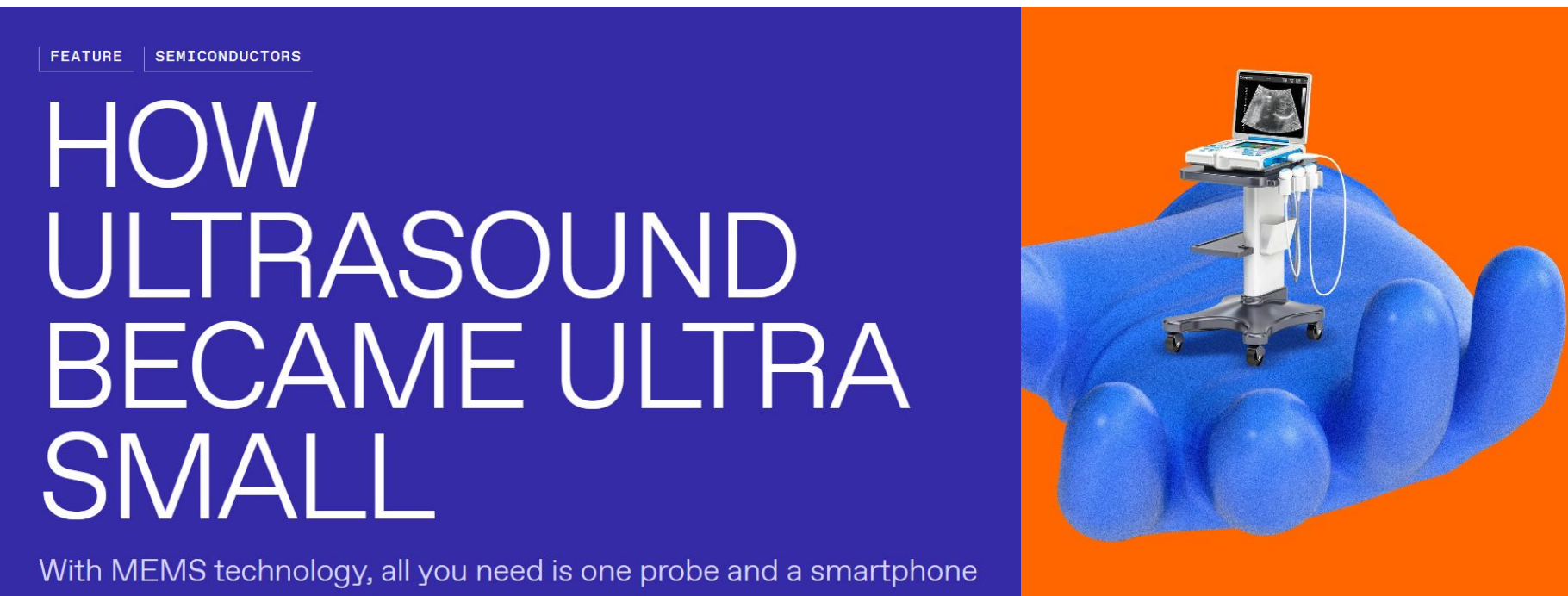
Challenges in MUT design with traditional tools



Why MUTs?

Transforming medical ultrasound

QUANSCIENT



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

Why MUTs? Transforming medical ultrasound

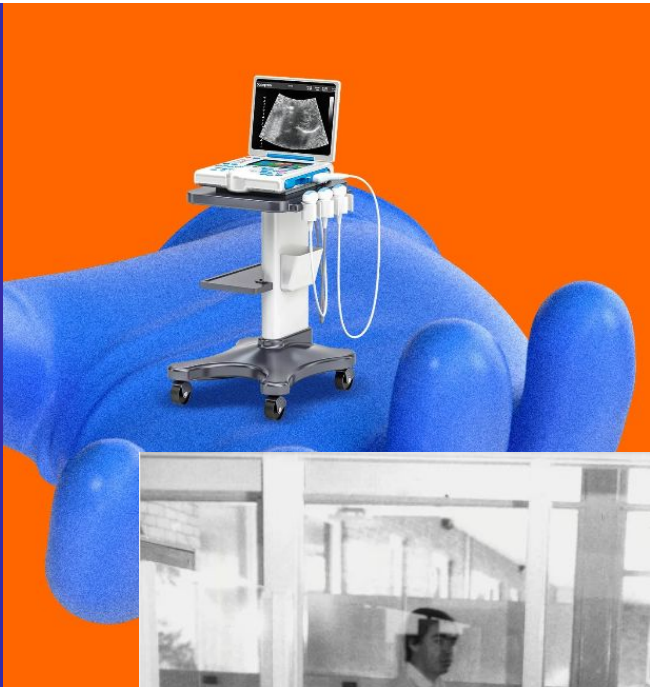
QUANSIENT

FEATURE SEMICONDUCTORS

HOW ULTRASOUND BECAME ULTRA SMALL

With MEMS technology, all you need is one probe and a smartphone

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

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

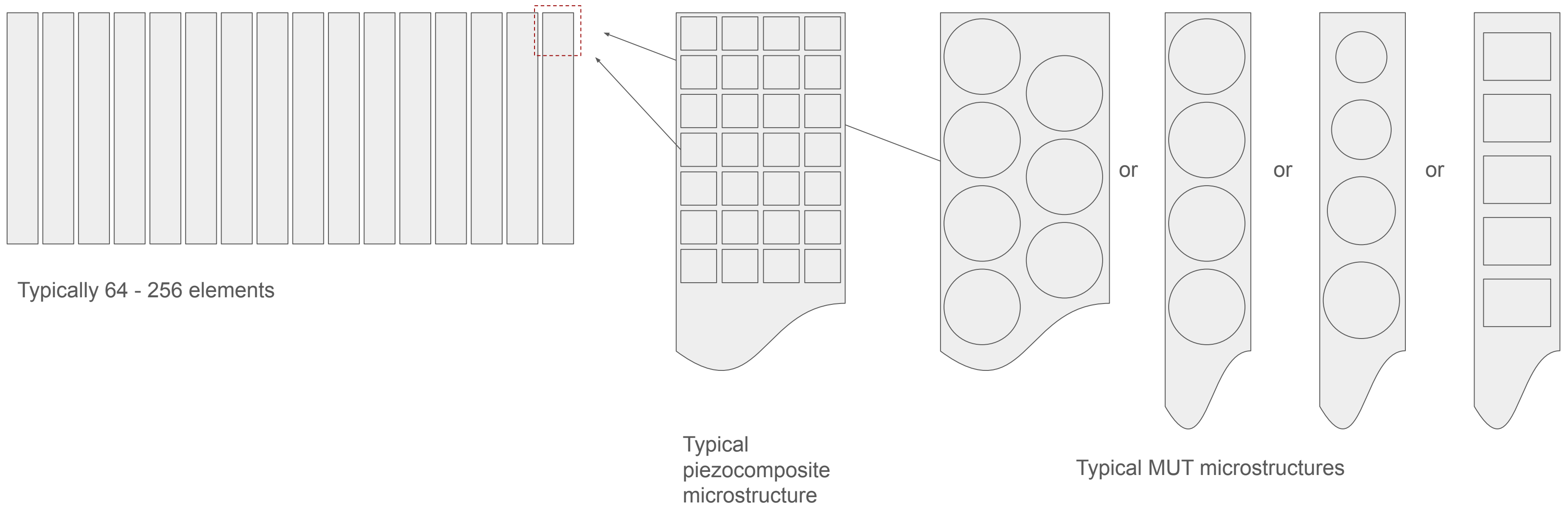


Exo Imaging developed a handheld ultrasound machine using piezoelectric micromachined ultrasonic transducer (PMUT) technology. EXO IMAGING

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

Typical array structures

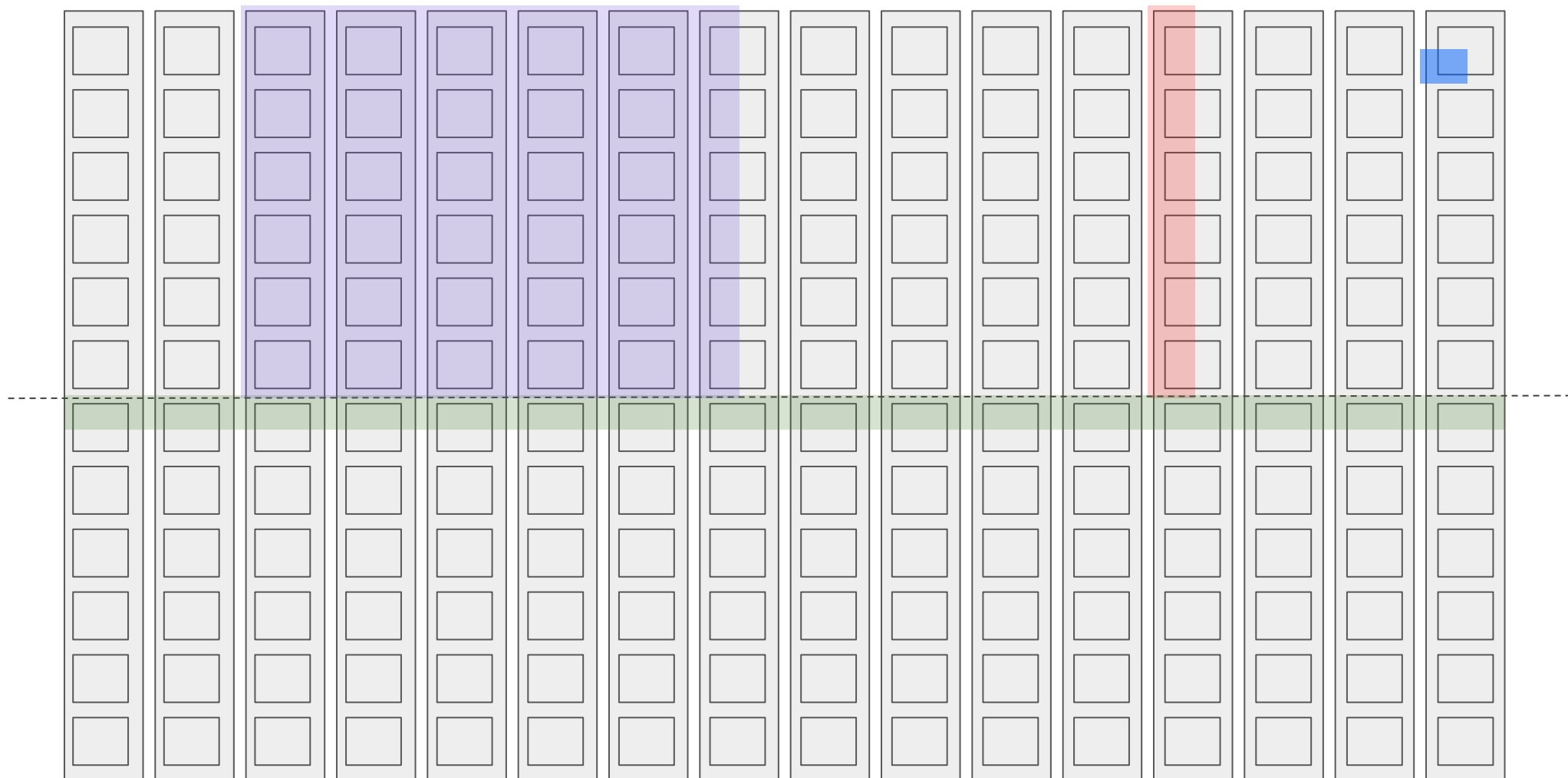
Example: diagnostic linear phased array



Array simulation approaches

Focus on what's important

QUANSCIENT

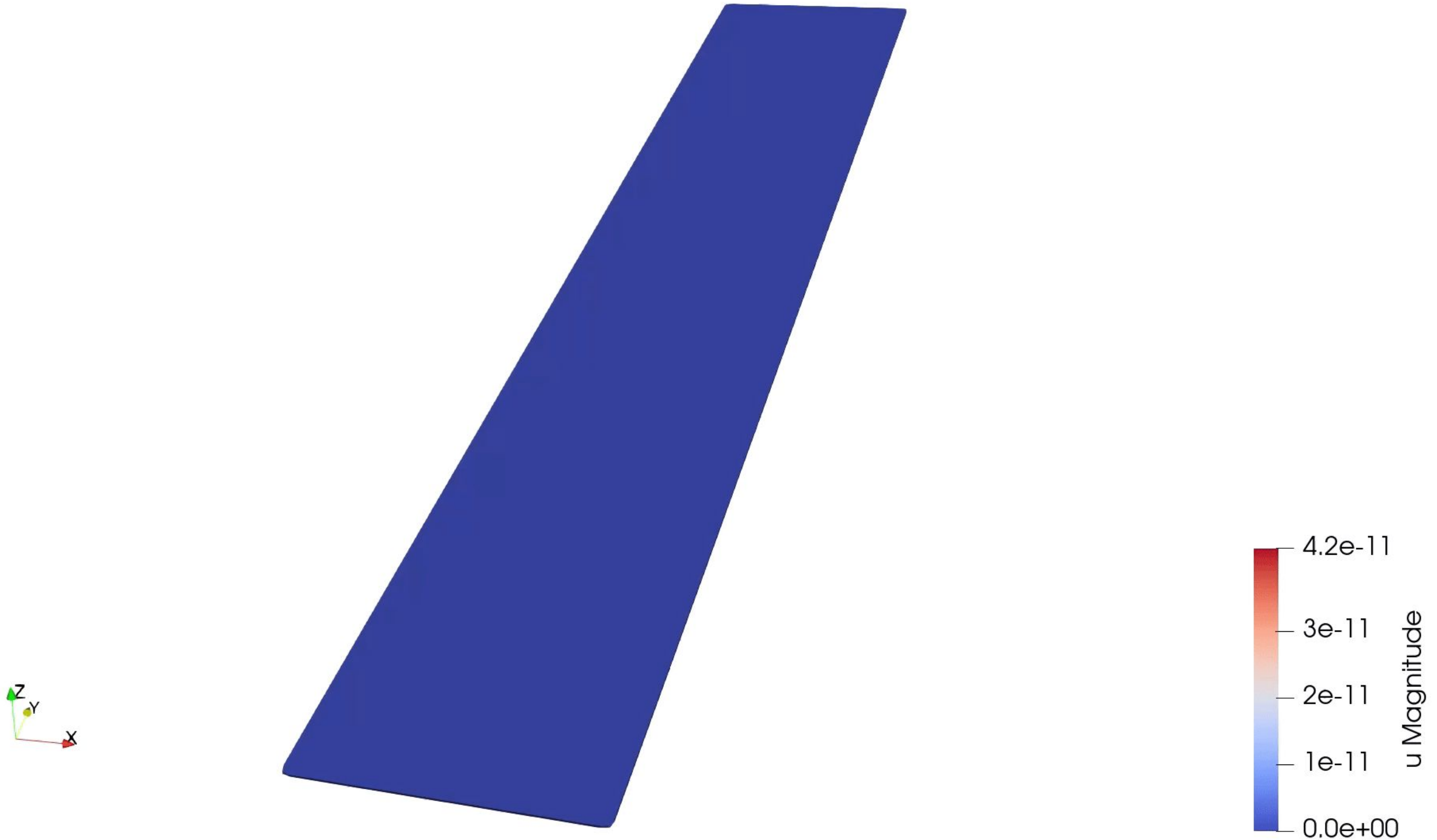


- **Unit cell**
 - Good for evaluating fundamental MUT design
 - Impedance, surface displacement
- **Elevation cross section**
 - Typically $\frac{1}{4}$ or $\frac{1}{2}$ element depending on symmetry
 - Elevation beam pattern and array impedance
- **Azimuthal cross section**
 - $\frac{1}{2}$ or 1 cell in vertical, depending on symmetry
 - Azimuthal beam pattern, crosstalk, element impedance
- **Full 3D section**
 - Typically $\frac{1}{4}$ or $\frac{1}{2}$ symmetry
 - Excellent prediction of array imaging performance

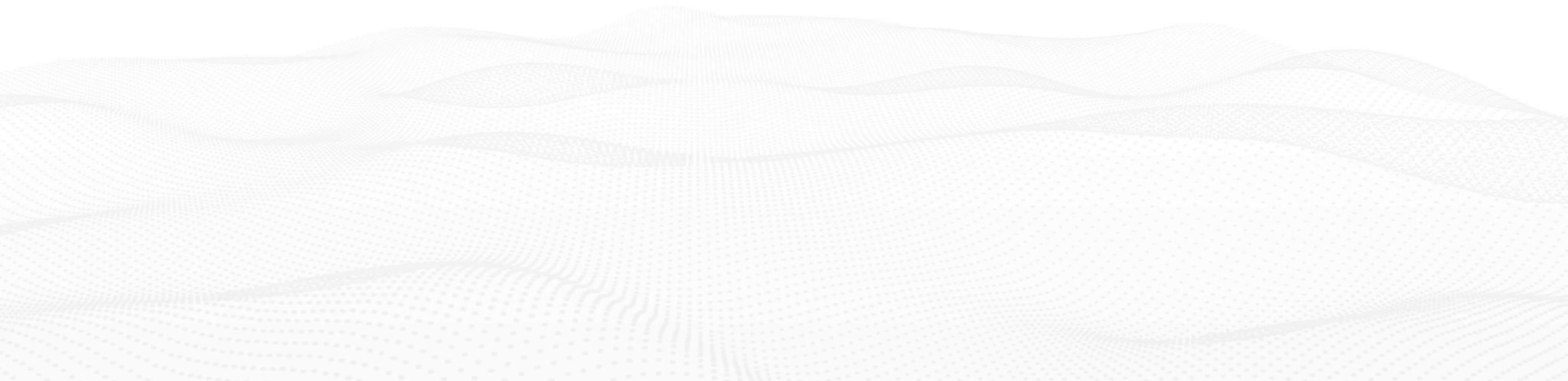
Full 3D array section

Allsolve is capable of scaling to 100s of MUTs

QUANSCIENT



PMUT: Live demo and results



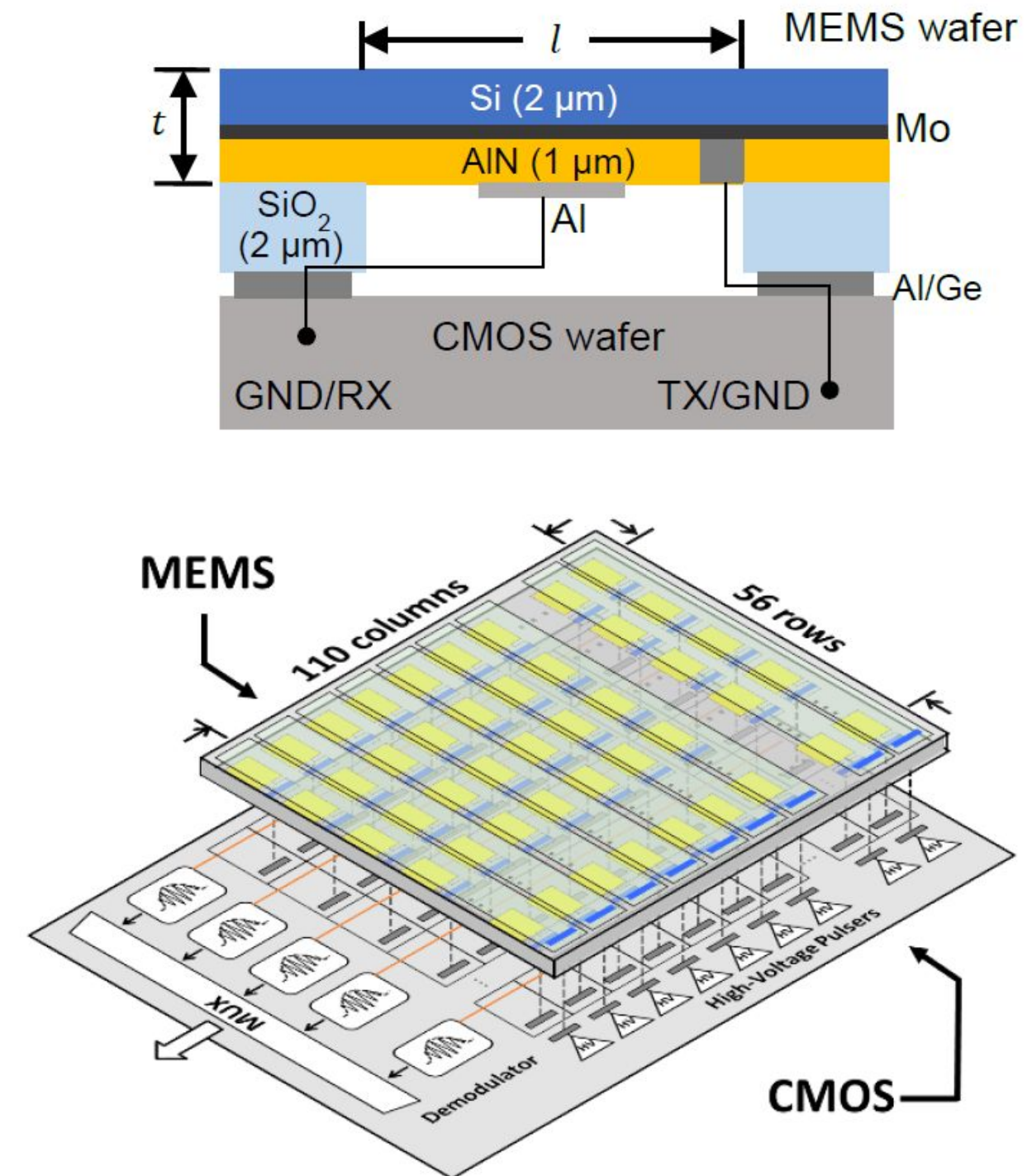
PMUT reference design

110×56 cell array

QUANSCIENT

- 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

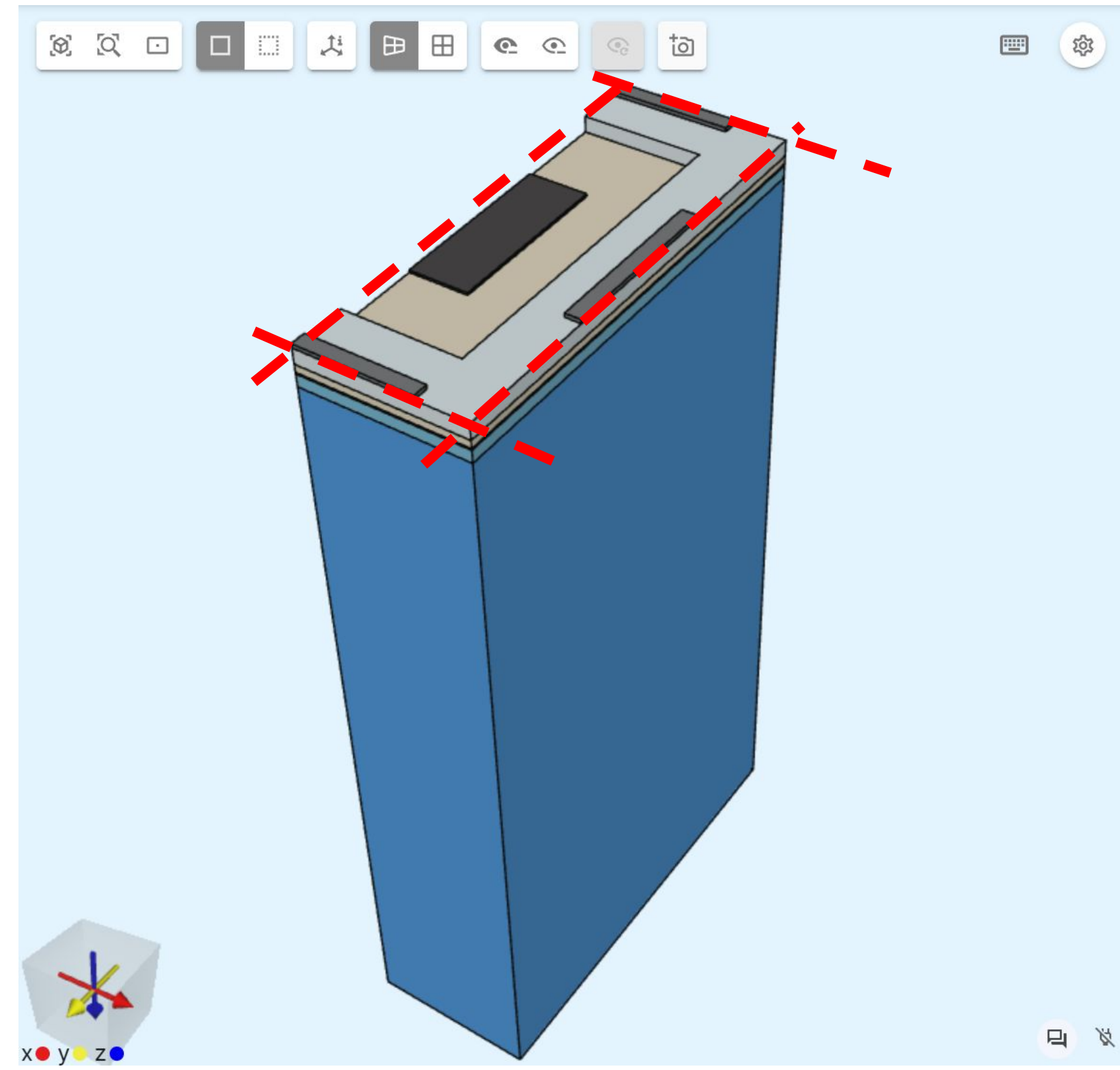


1. D. A. Horsley *et al.*, "Ultrasonic fingerprint sensor based on a PMUT array bonded to CMOS circuitry," 2016 IEEE International Ultrasonics Symposium (IUS), pp. 1-4.

Unit cell

Fundamental MUT analysis

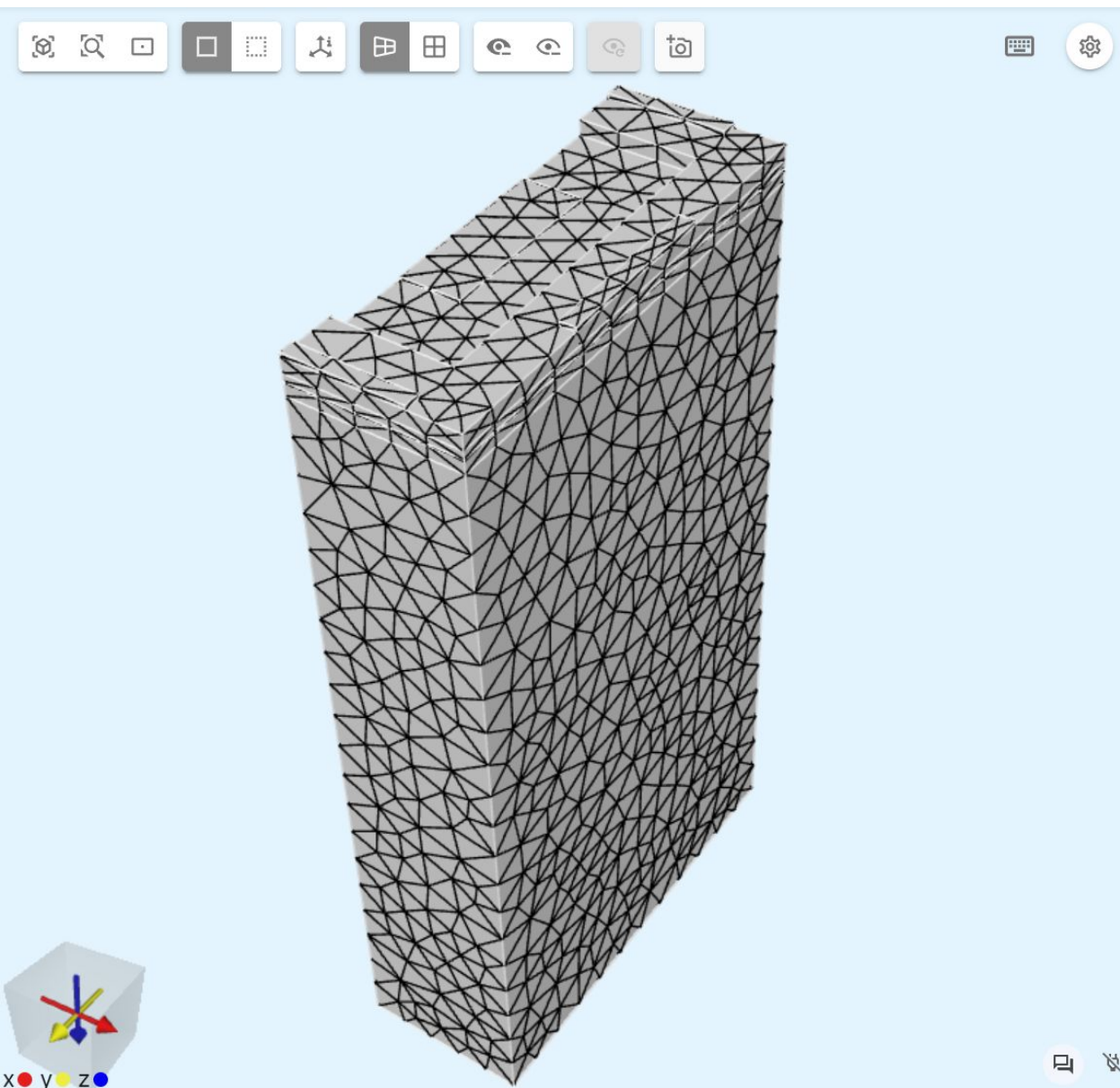
- Captures the smallest tileable section of the array
- Symmetry or periodicity is then used to construct a model of an infinite array of MUT cells
- Fast way to analyse:
 - Fundamental performance of the MUT “stack”
 - Electrical impedance
 - Surface displacement
 - Acoustic pressure output
 - Sensitivity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



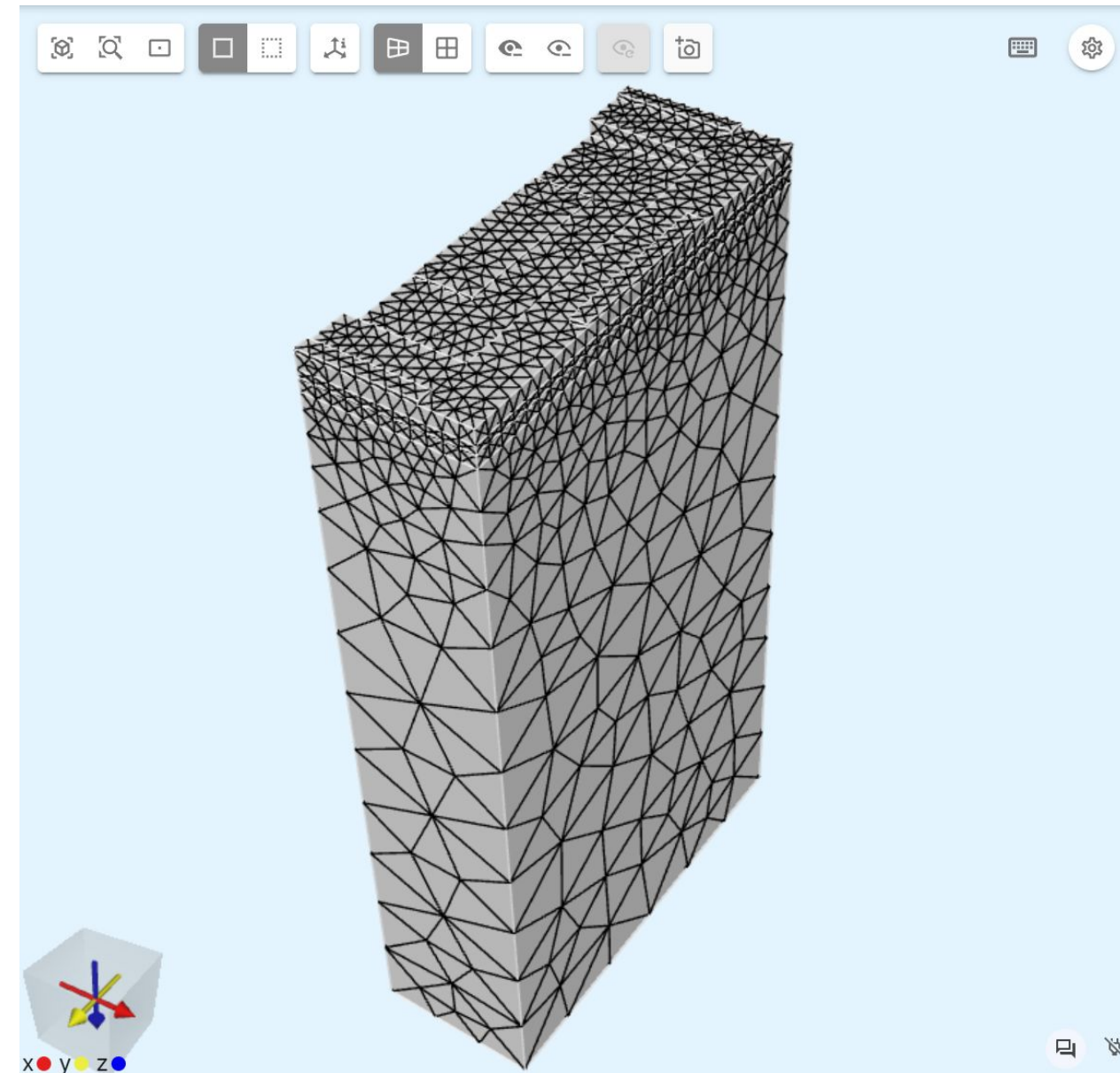
Unit cell mesh

Flexibility over meshing & element order

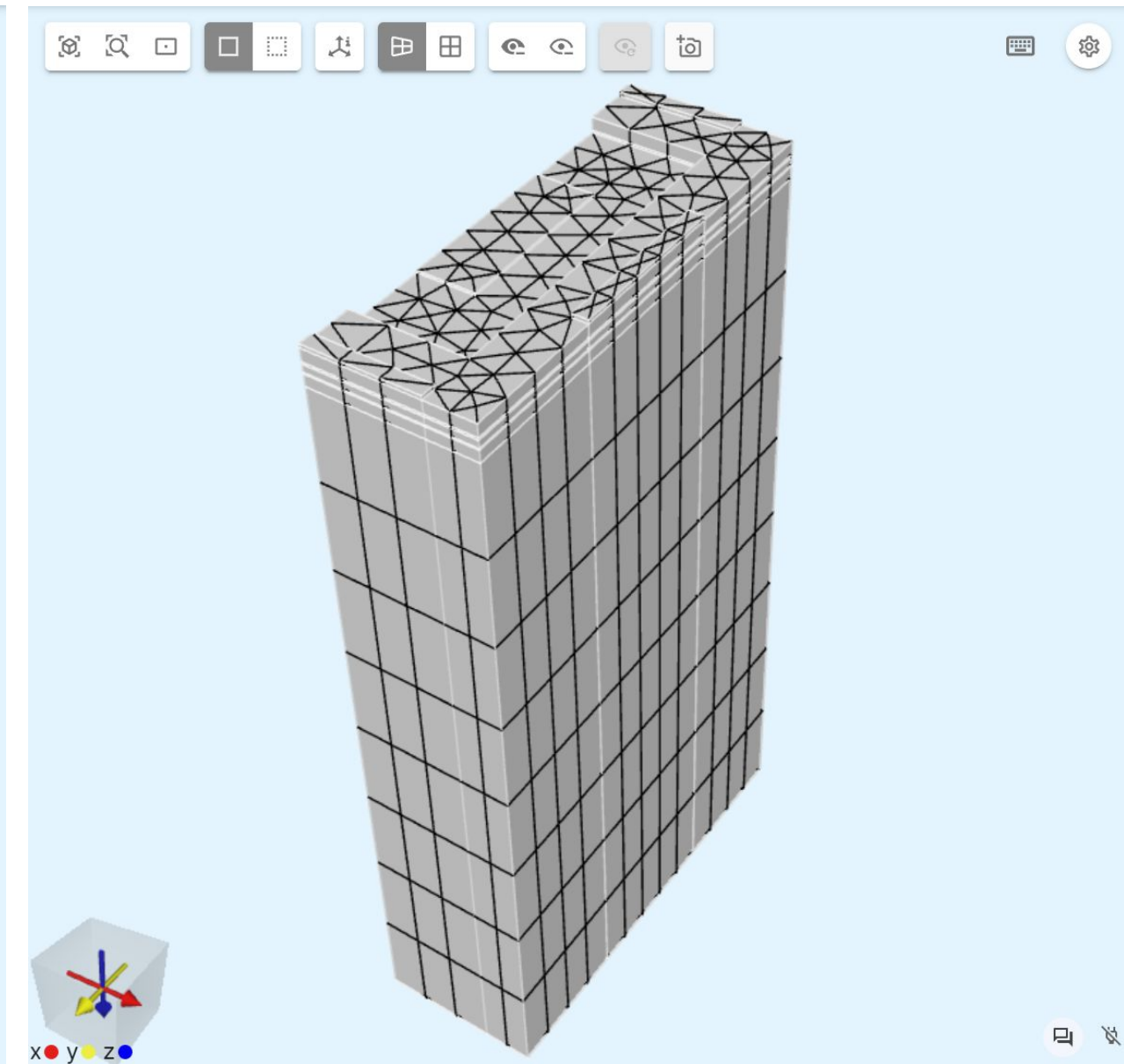
QUANSCIENT



5 um order 2 mesh



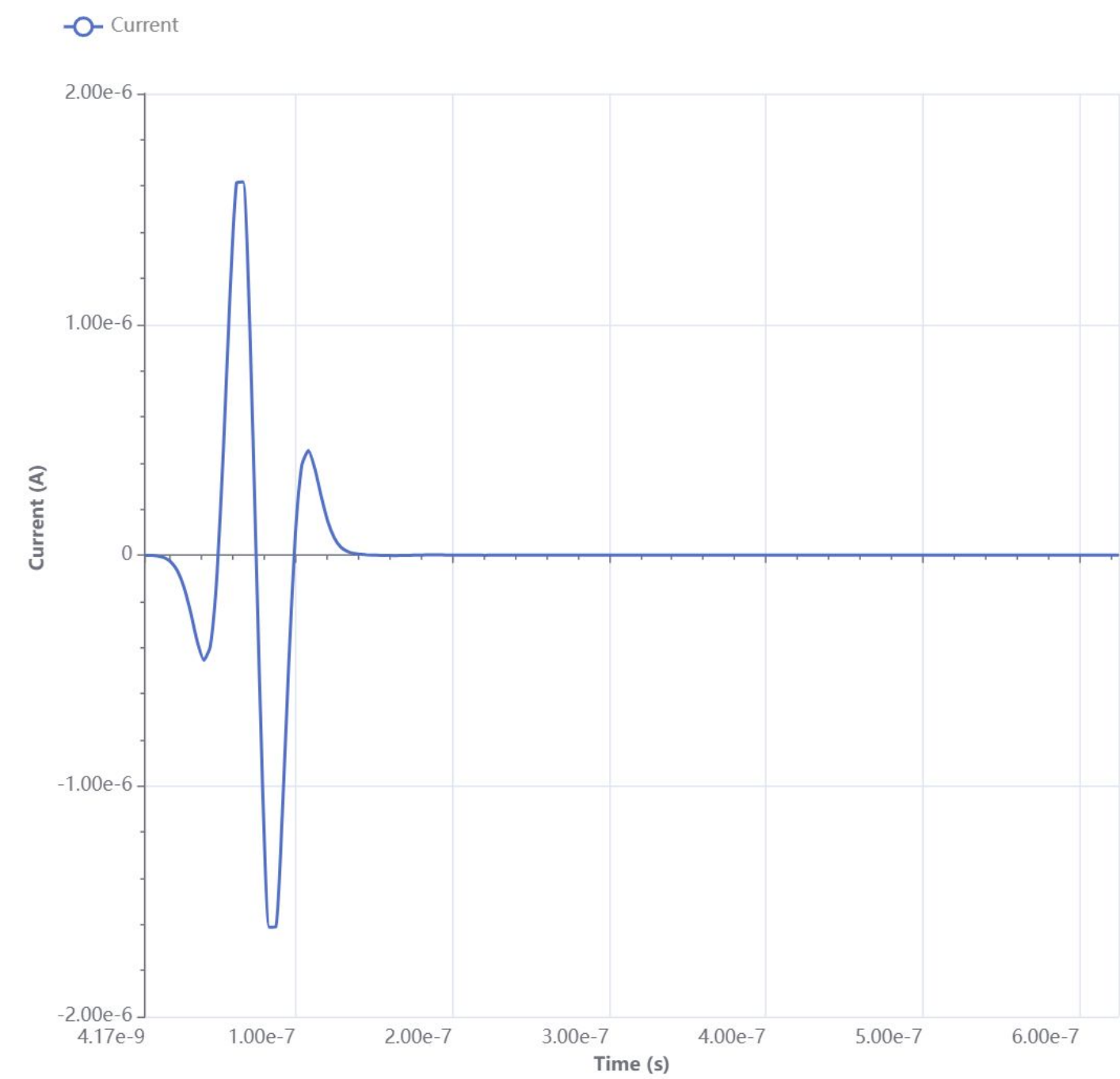
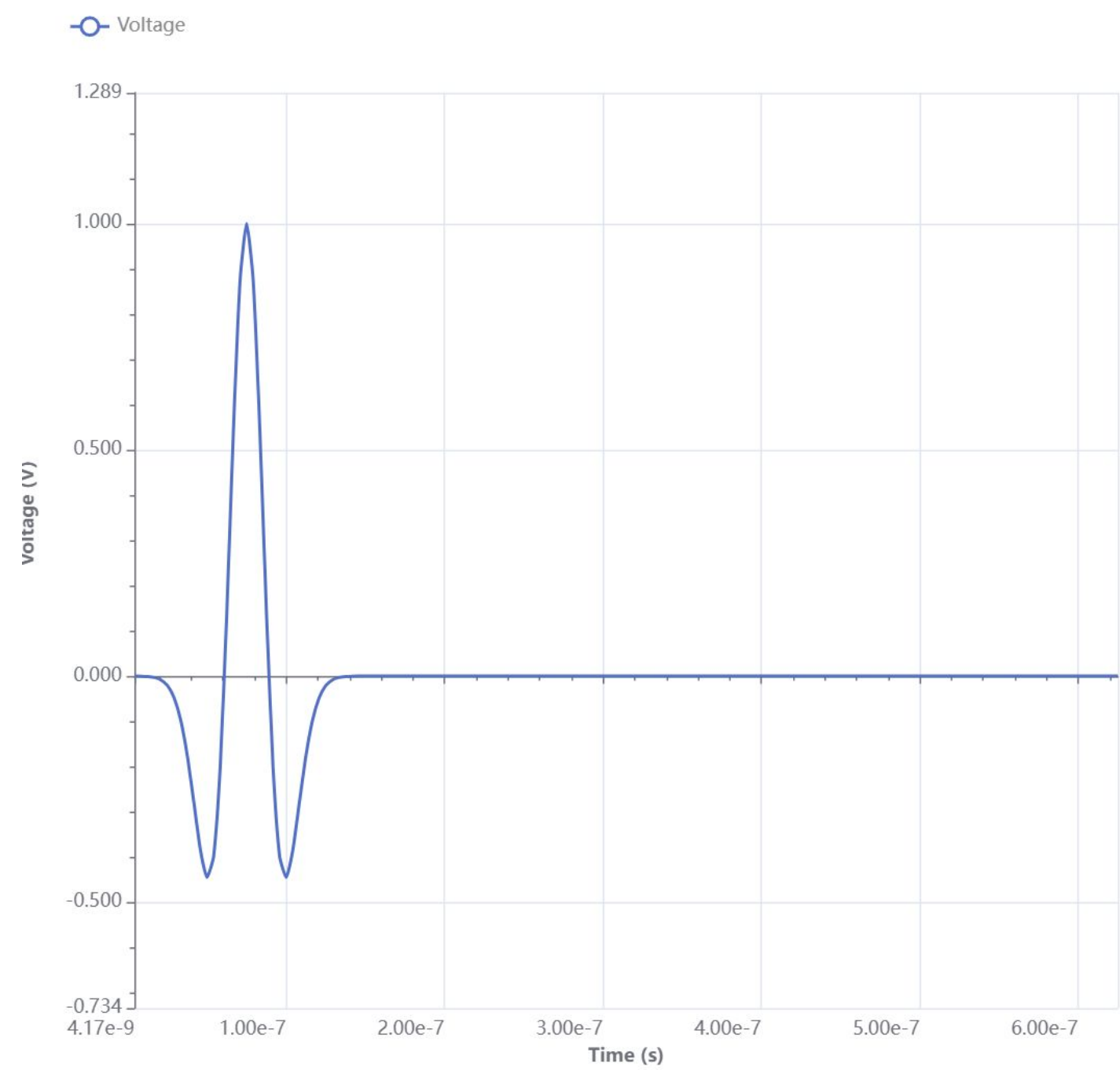
10 um order 2 mesh, refined
to 2 um on MUT structure



5 um order 2 mesh, extruded
in z axis

Unit cell transient simulation results

Voltage & current



35k

DoFs

1

Core

0.8

Minutes

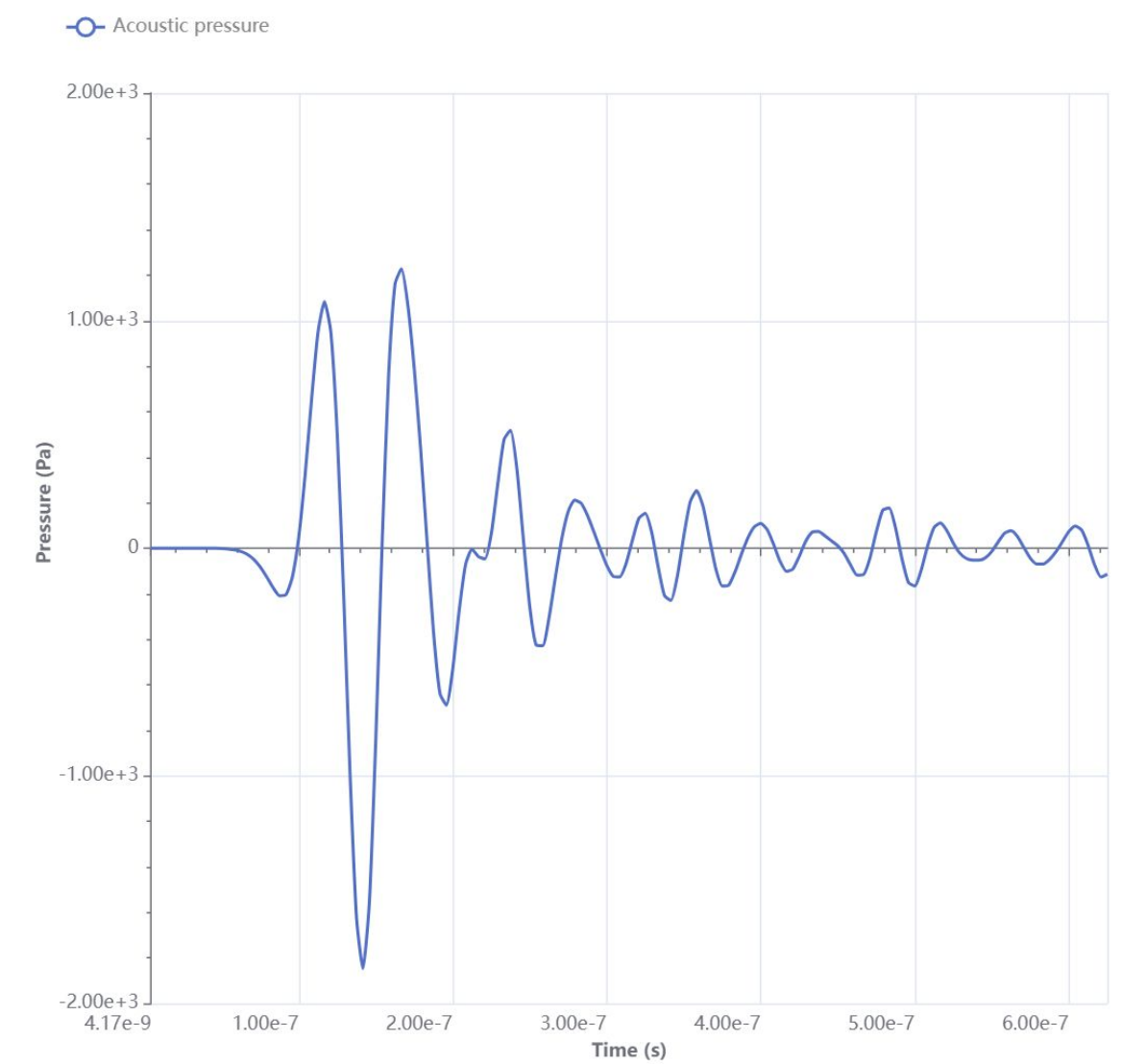
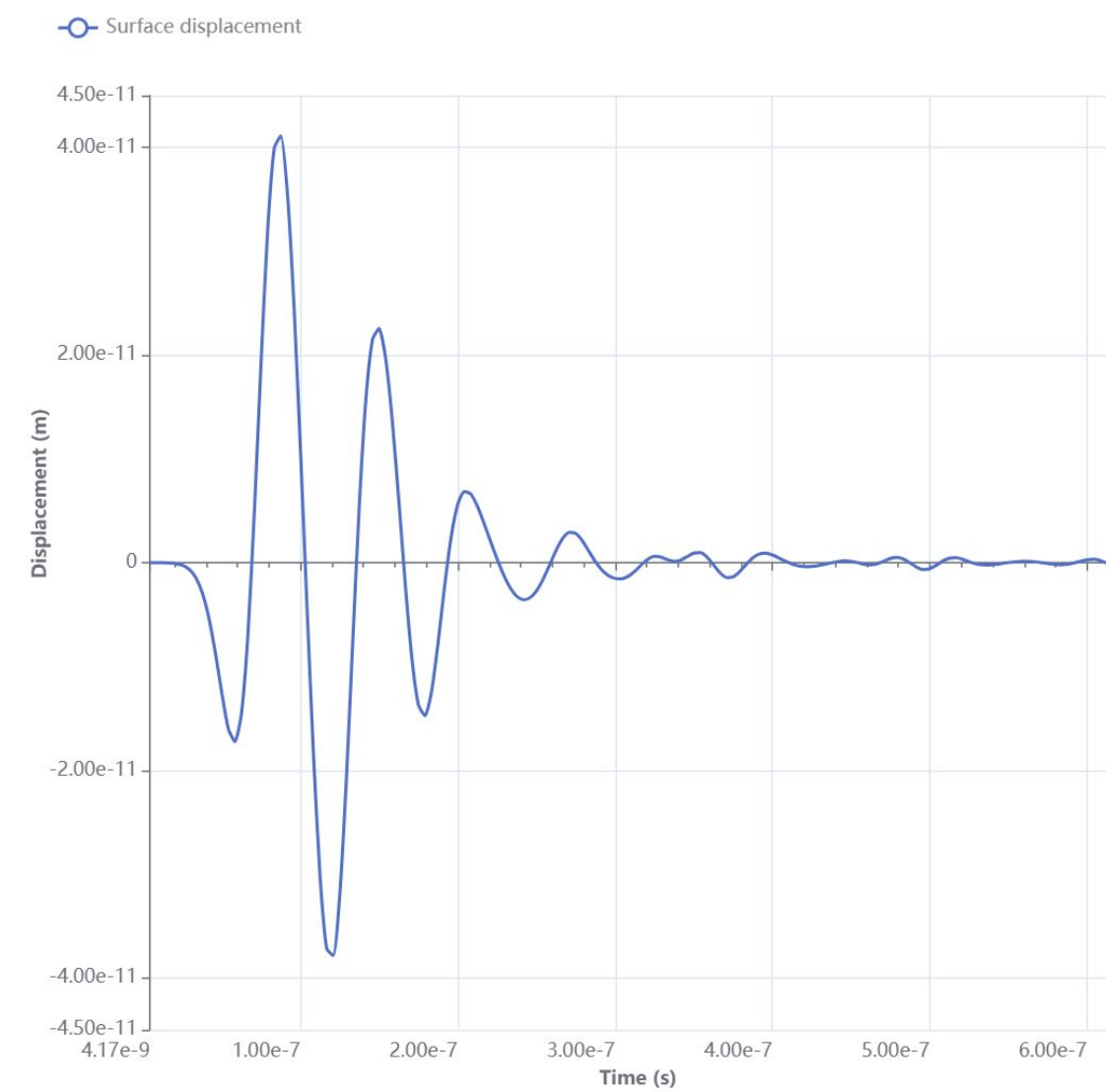
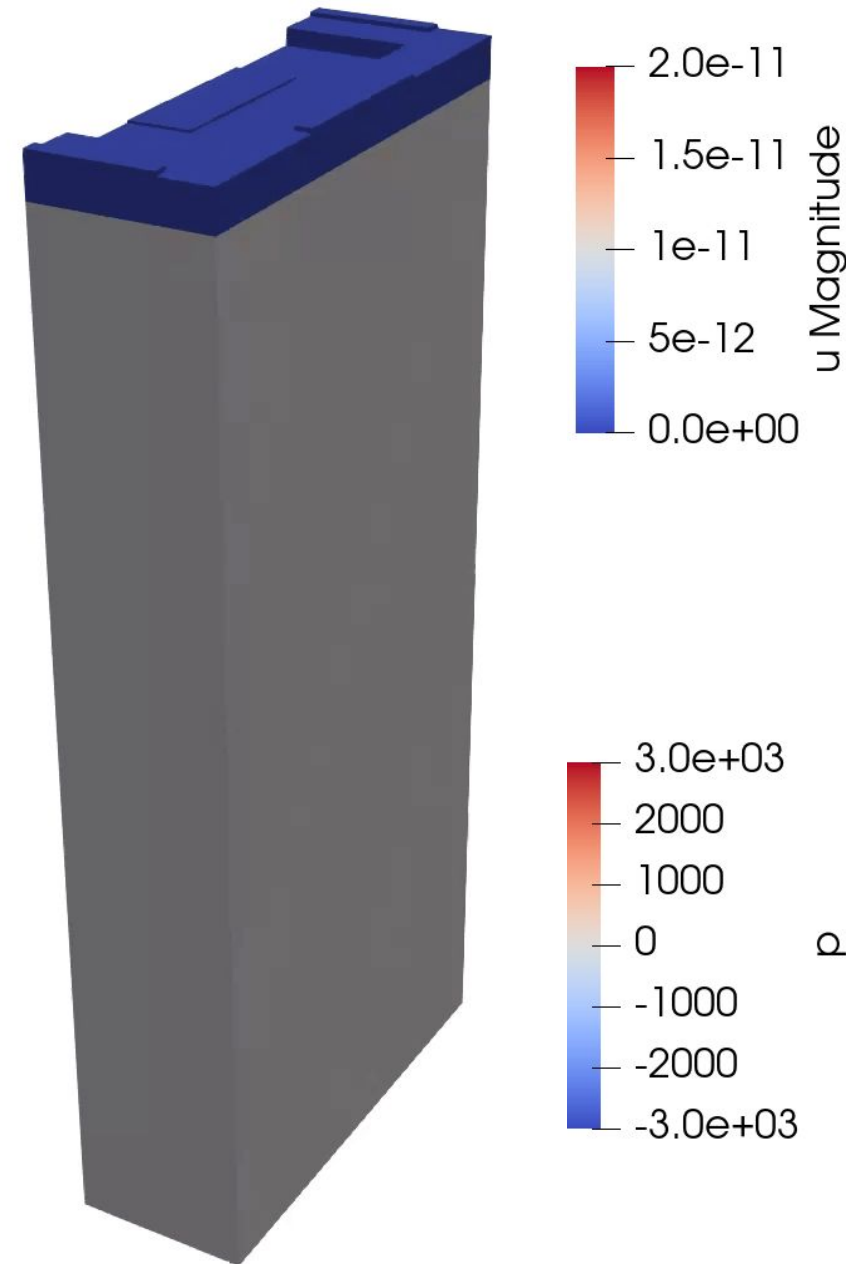
0.02

Core-hours

Unit cell transient simulation results

Displacement & acoustic field

QUANSCIENT



35k

DoFs

1

Core

0.8

Minutes

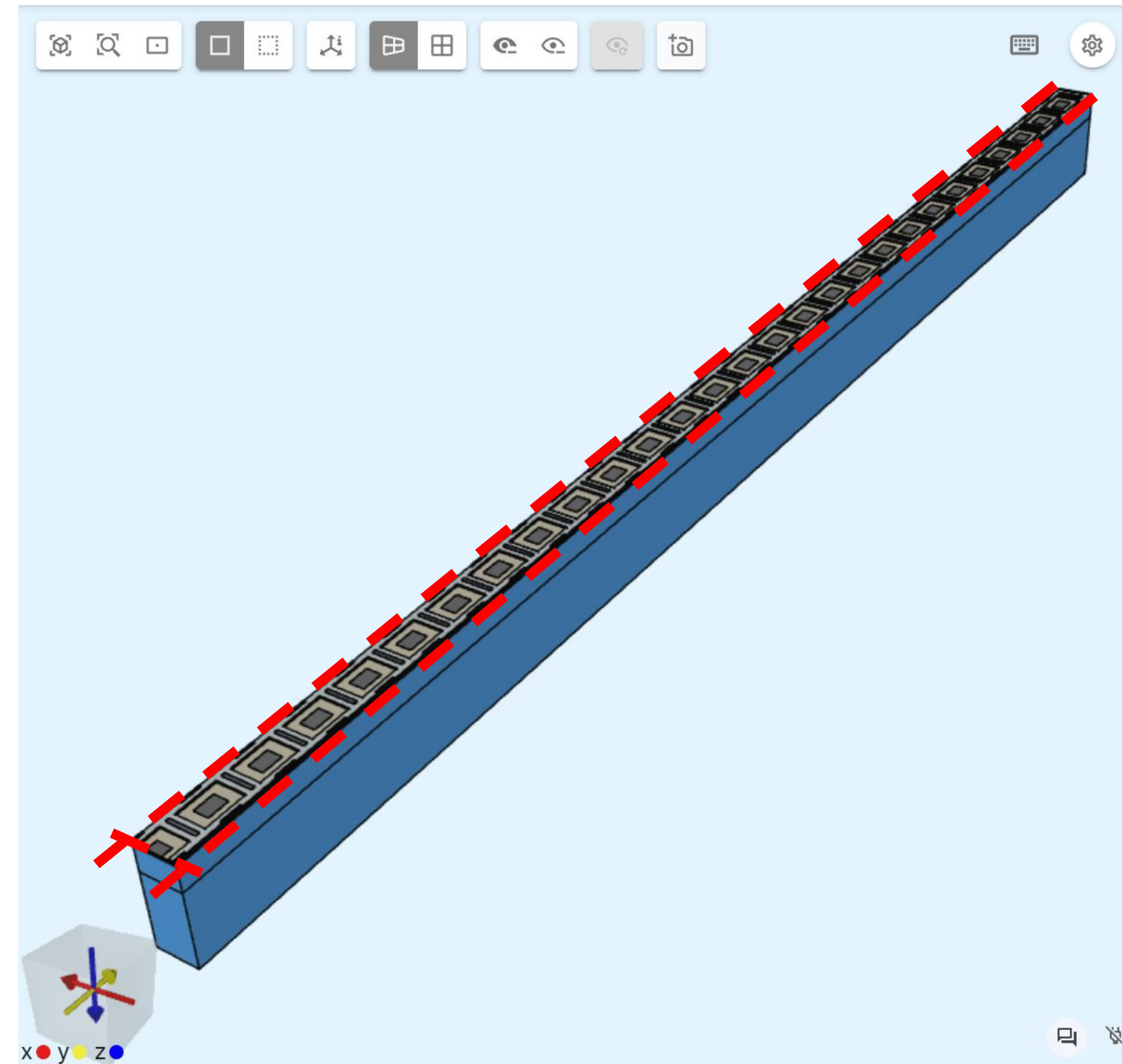
0.02

Core-hours

Elevation cross section

Elevation beam pattern

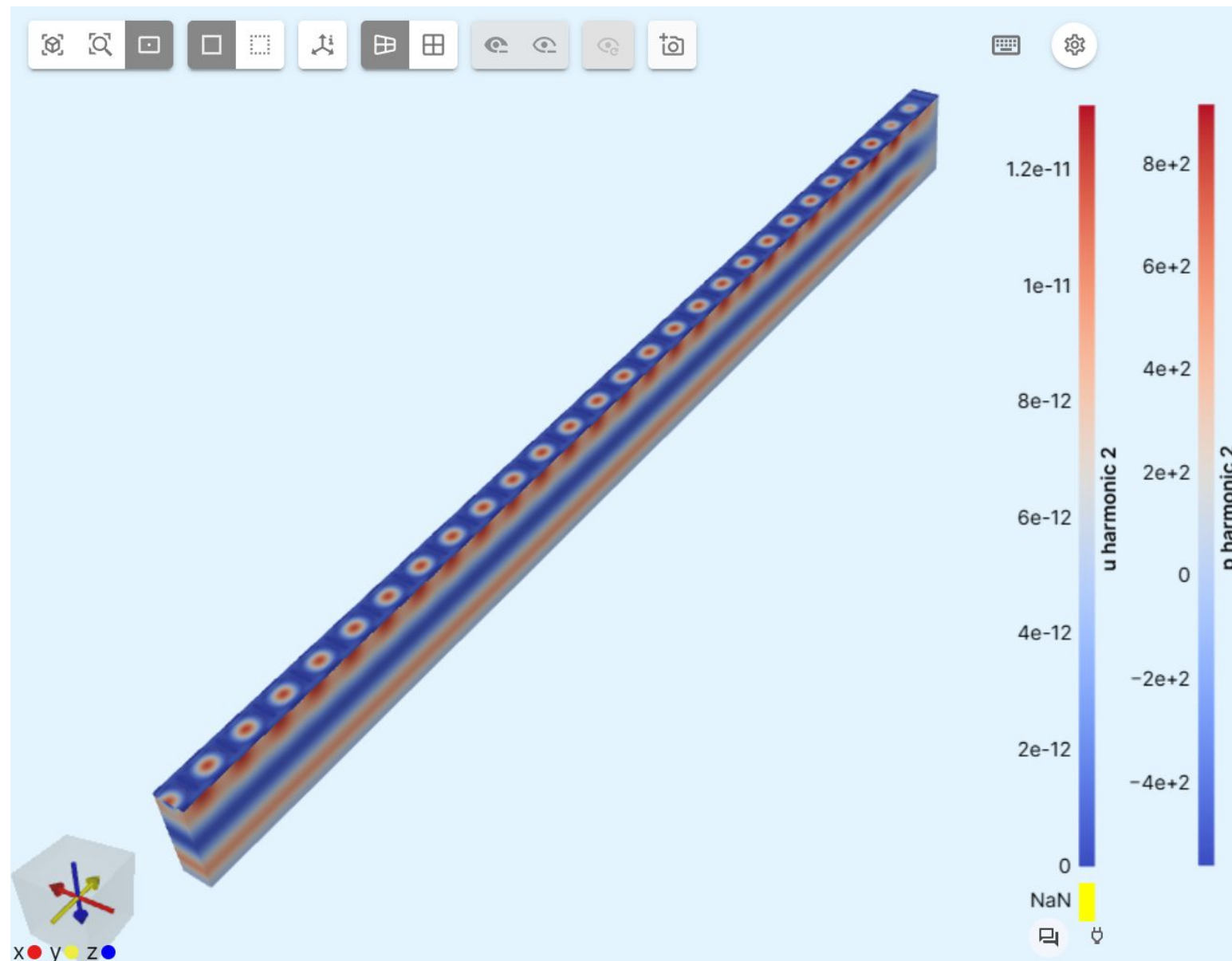
- Taking a cross section in the y axis (elevation) provides information on the following:
 - Elevation beam pattern
 - Full array impedance
- Simulate a column of cells with symmetry in x
 - Periodicity also possible
- Symmetry typically applied in x and y
 - Essentially simulating an infinite number 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

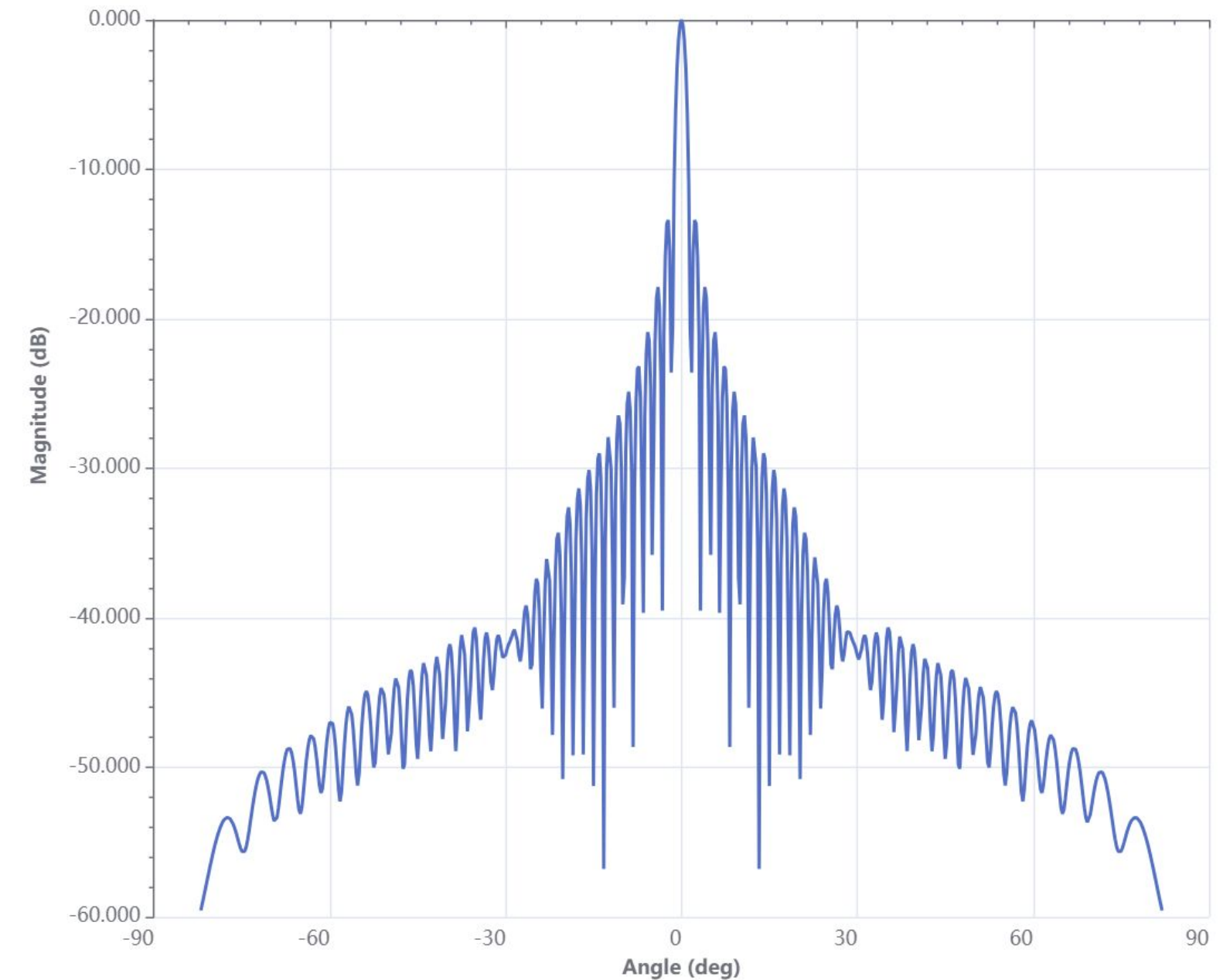
QUANSCIENT



Vertical beam

15.8 MHz, far field

○ pextr mag dB



2.3M

DoFs

16

Cores

0.8

Minutes

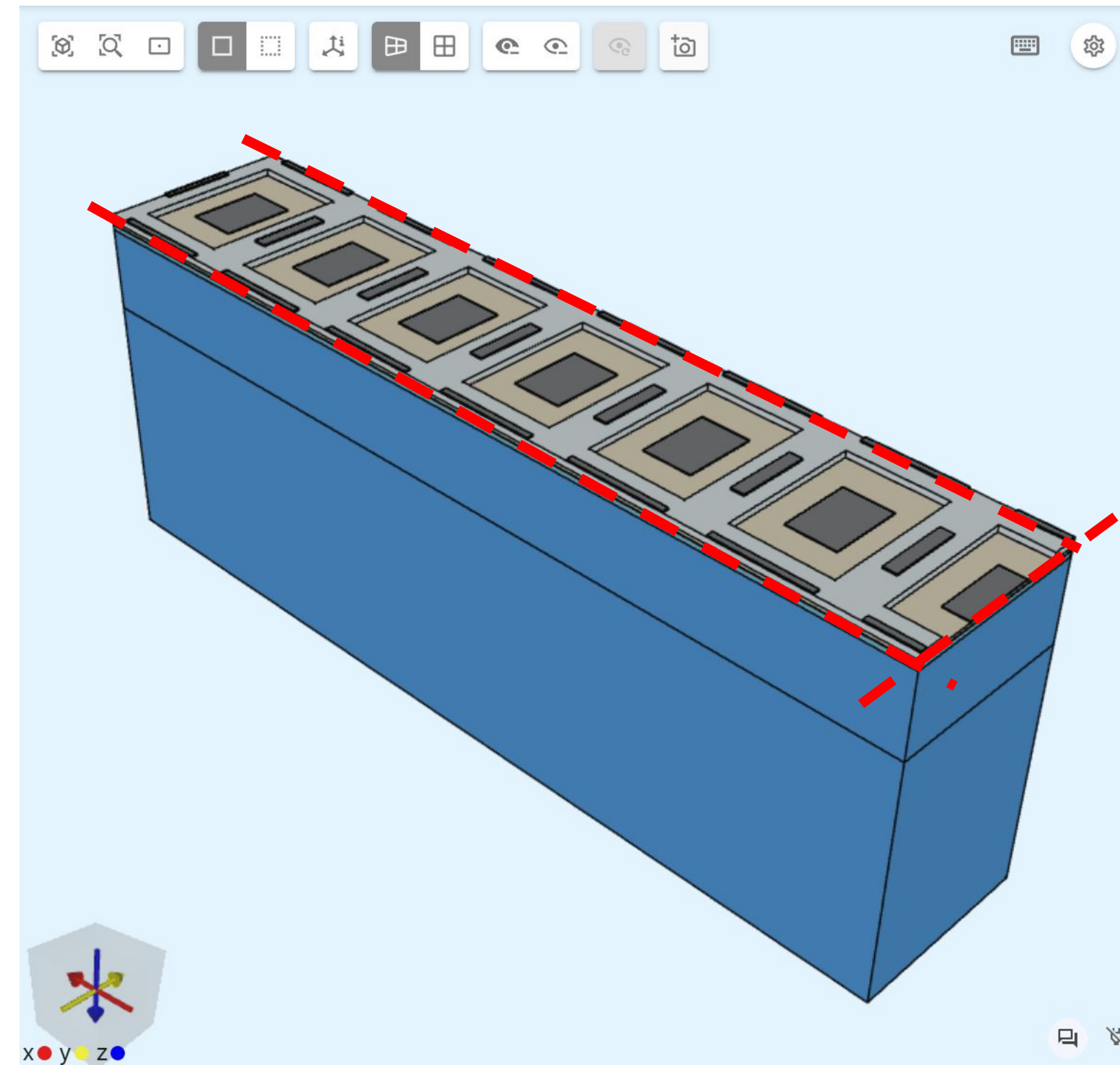
0.2

Core-hours

Azimuthal cross section

Simulating crosstalk

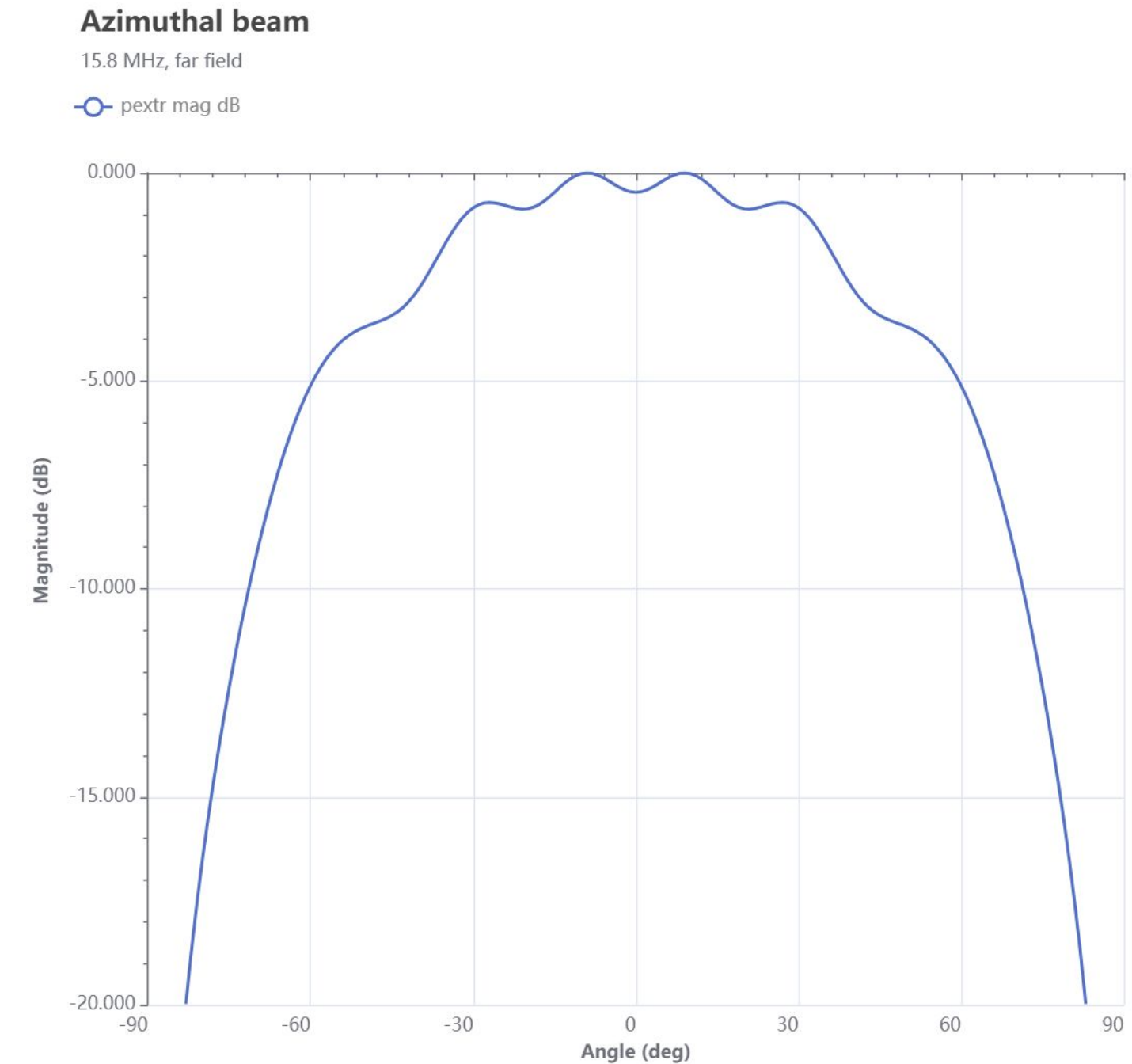
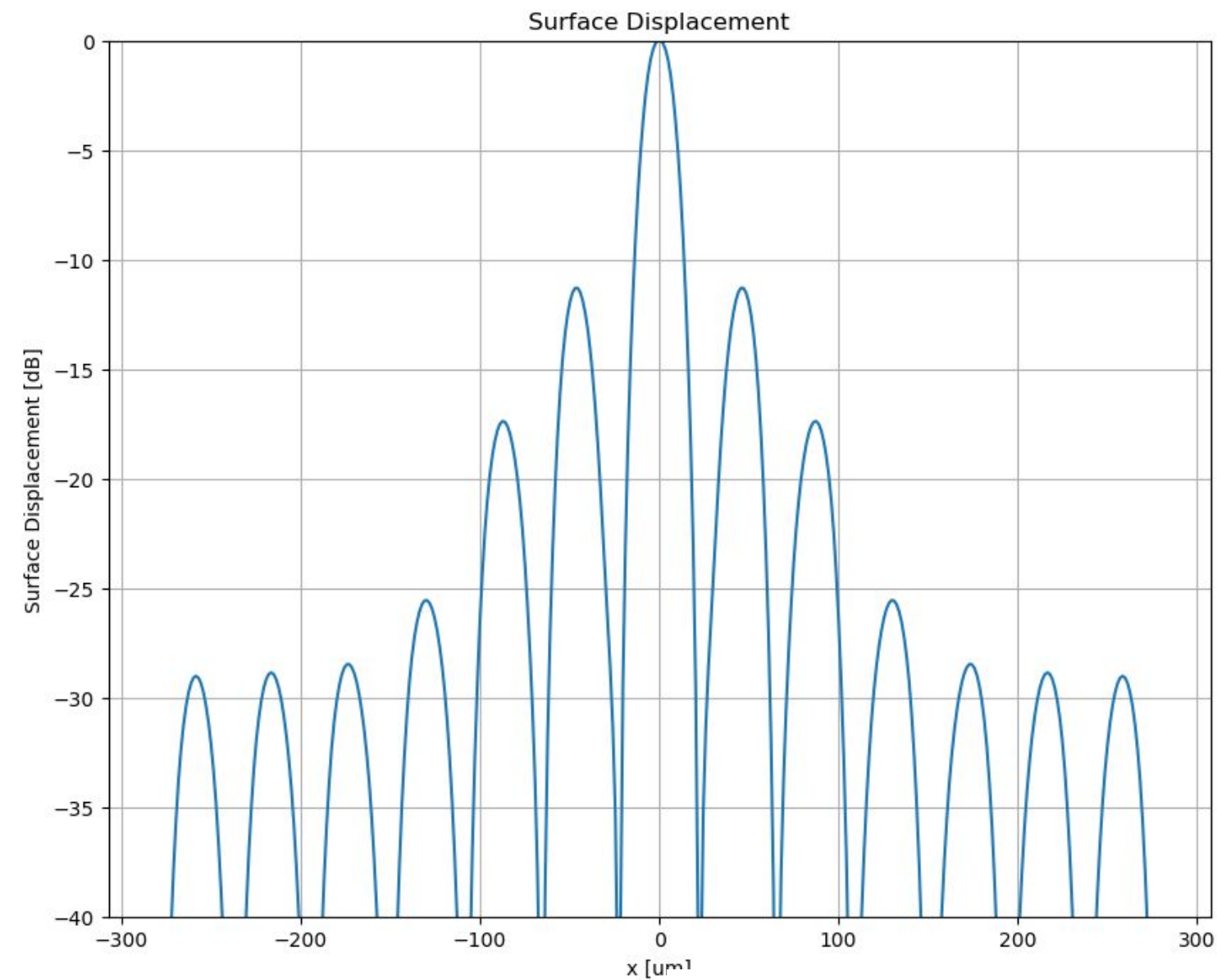
- Taking a cross section in the x axis (azimuth) provides information on the following:
 - Mechanical and electrical crosstalk
 - Azimuthal beam pattern
 - Element impedance
- Typically simulate N elements in x
 - Where N is large enough to provide sufficient crosstalk information
 - Here we consider 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

QUANSCIENT



557k

DoFs

1

Cores

3.7

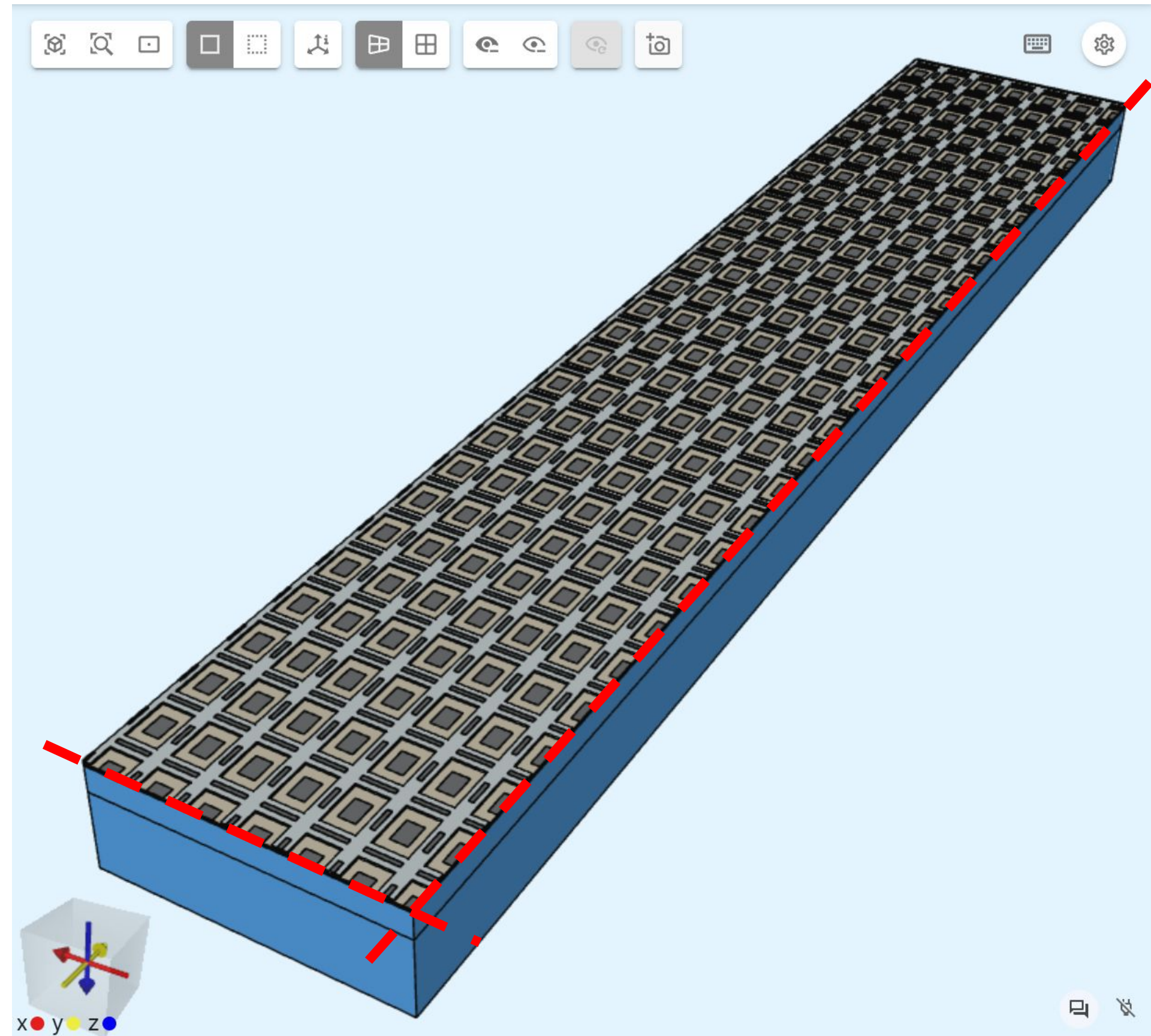
Minutes

0.06

Core-hours

Full 3D section Geometry

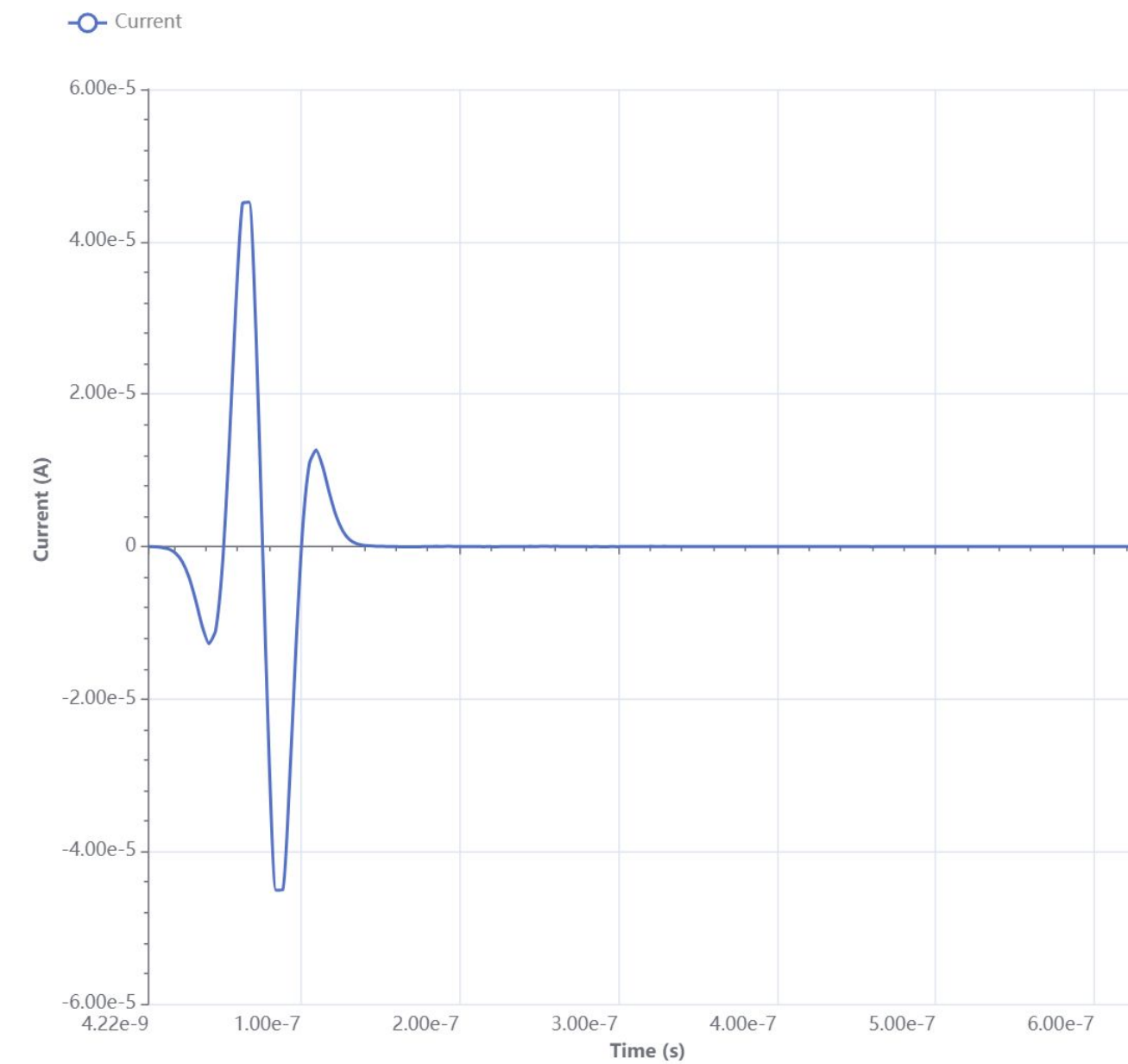
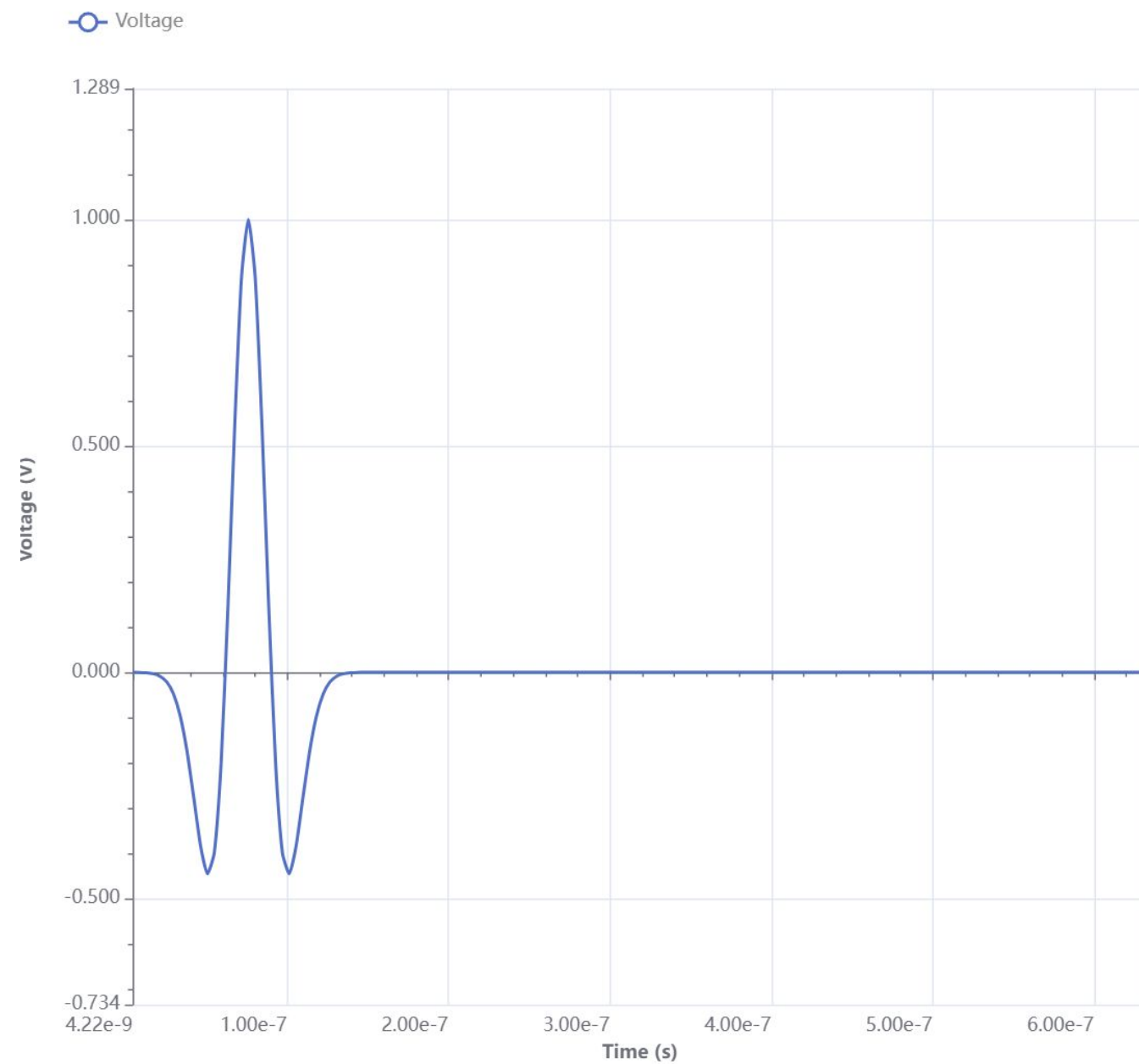
- This combines the cross sections analysed in the previous two models
 - 13 elements in x
 - 55 MUTs in y
 - 715 cells in total
- Symmetry is employed in x and y
- A single element is excited
 - column of 55 MUTs
- Harmonic and transient solutions calculated
- Near field can now be simulated in detail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



Full 3D transient simulation results

Drive voltage and current

QUANSCIENT



5.3M

DoFs

32

Cores

14.5

Minutes

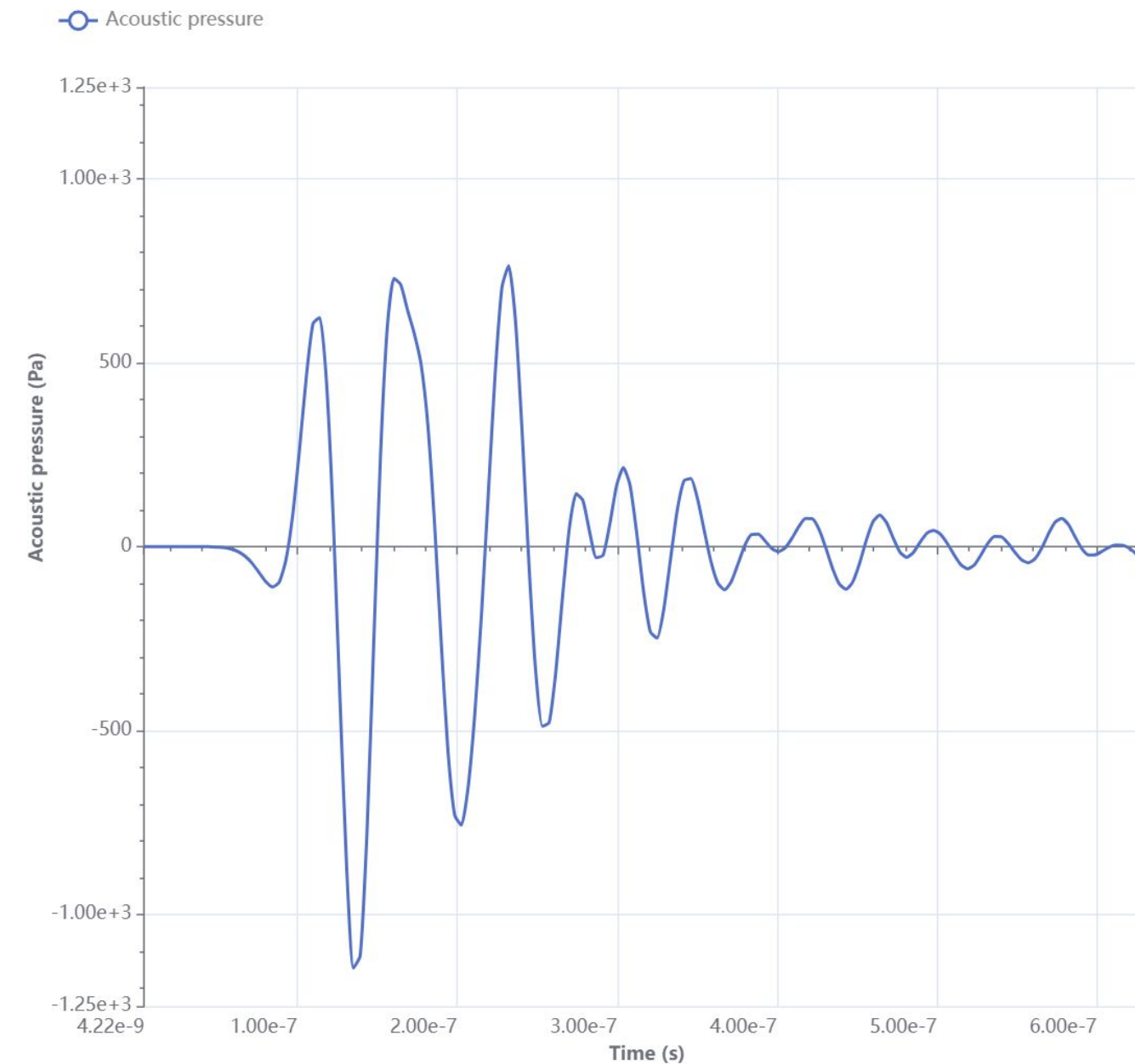
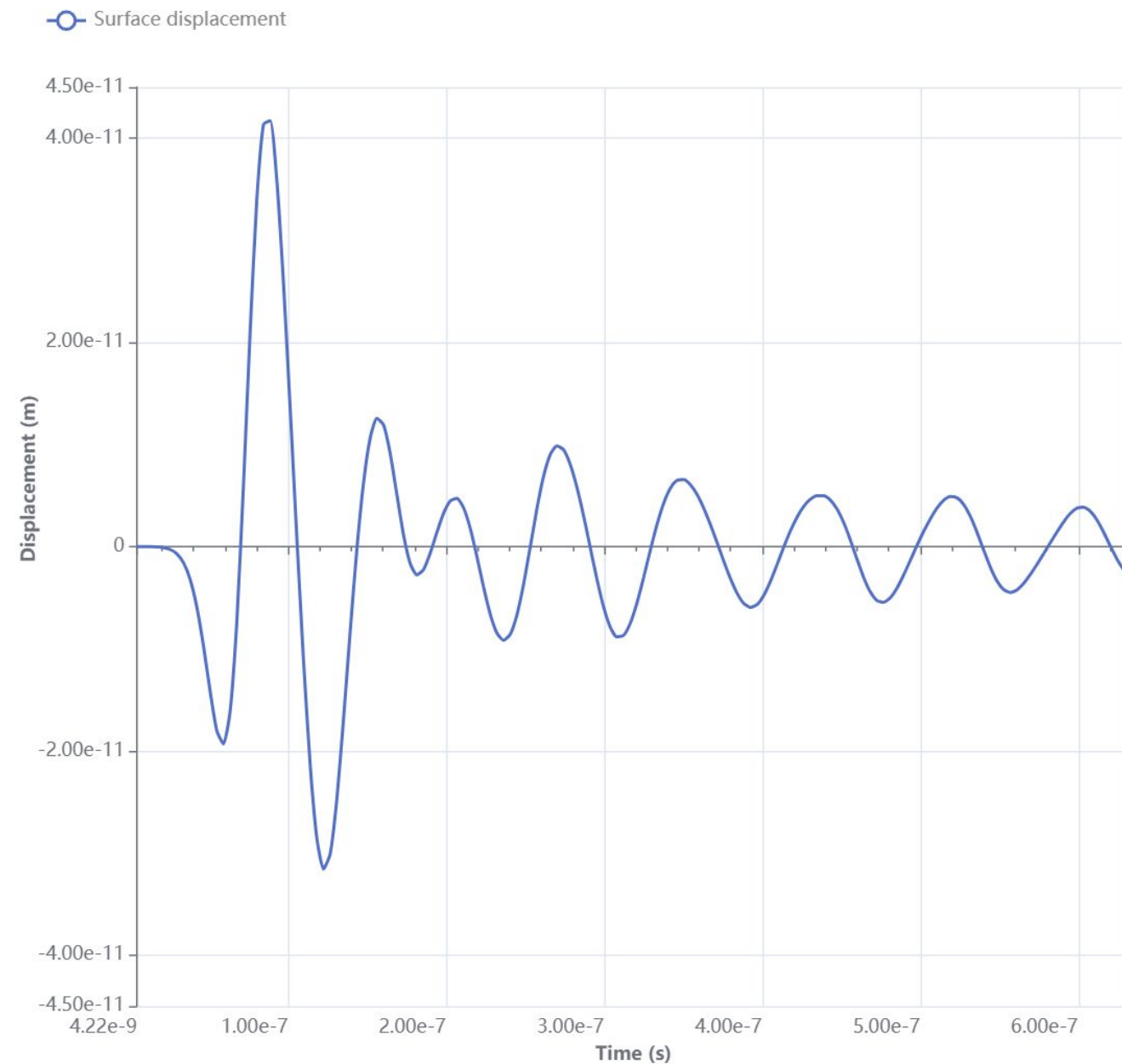
7.7

Core-hours

Full 3D transient simulation results

Surface displacement and acoustic pressure

QUANSCIENT



5.3M

DoFs

32

Cores

14.5

Minutes

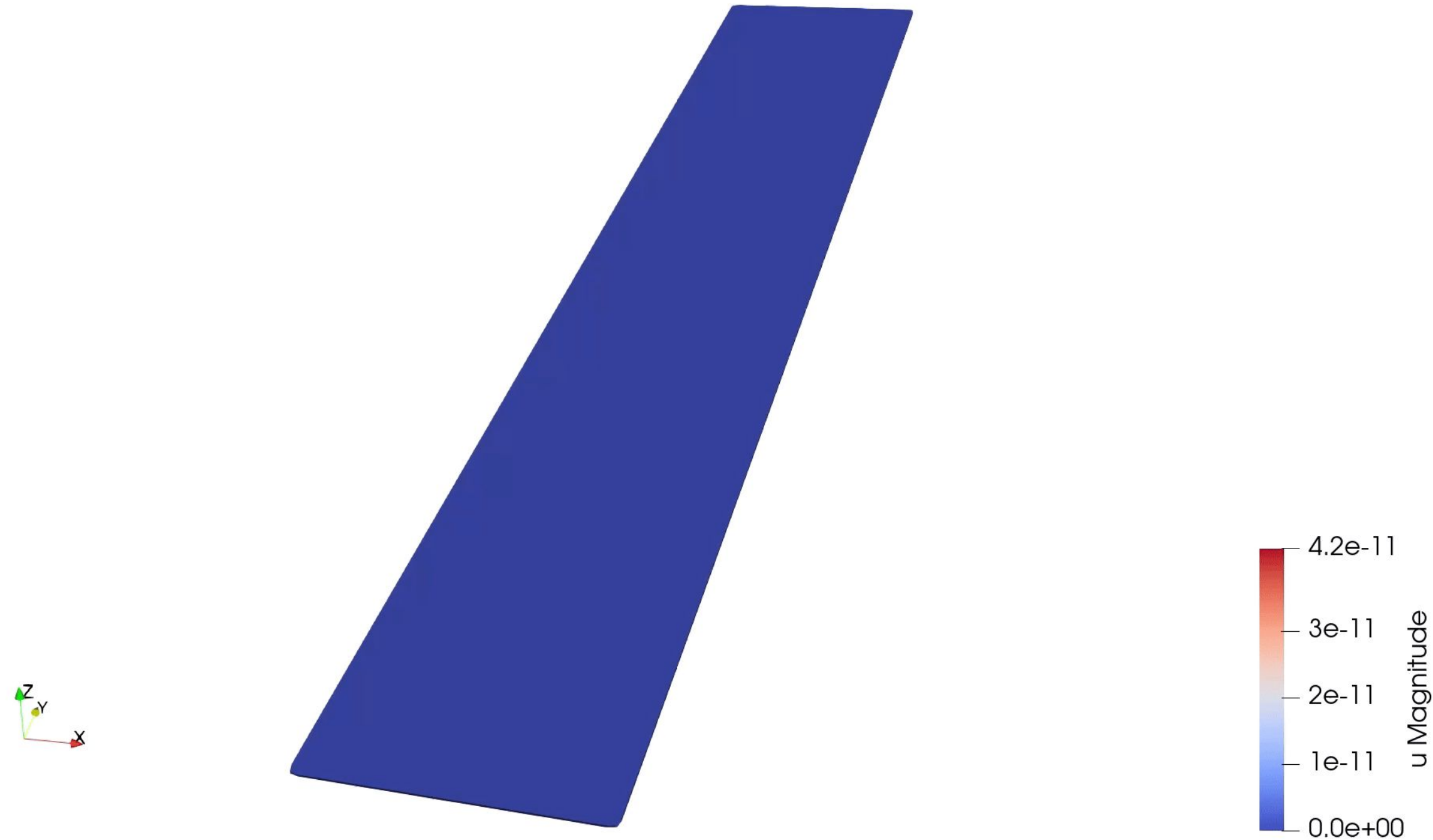
7.7

Core-hours

Full 3D transient simulation results

Crosstalk under pulsed excitation

QUANSCIENT



5.3M

DoFs

32

Cores

14.5

Minutes

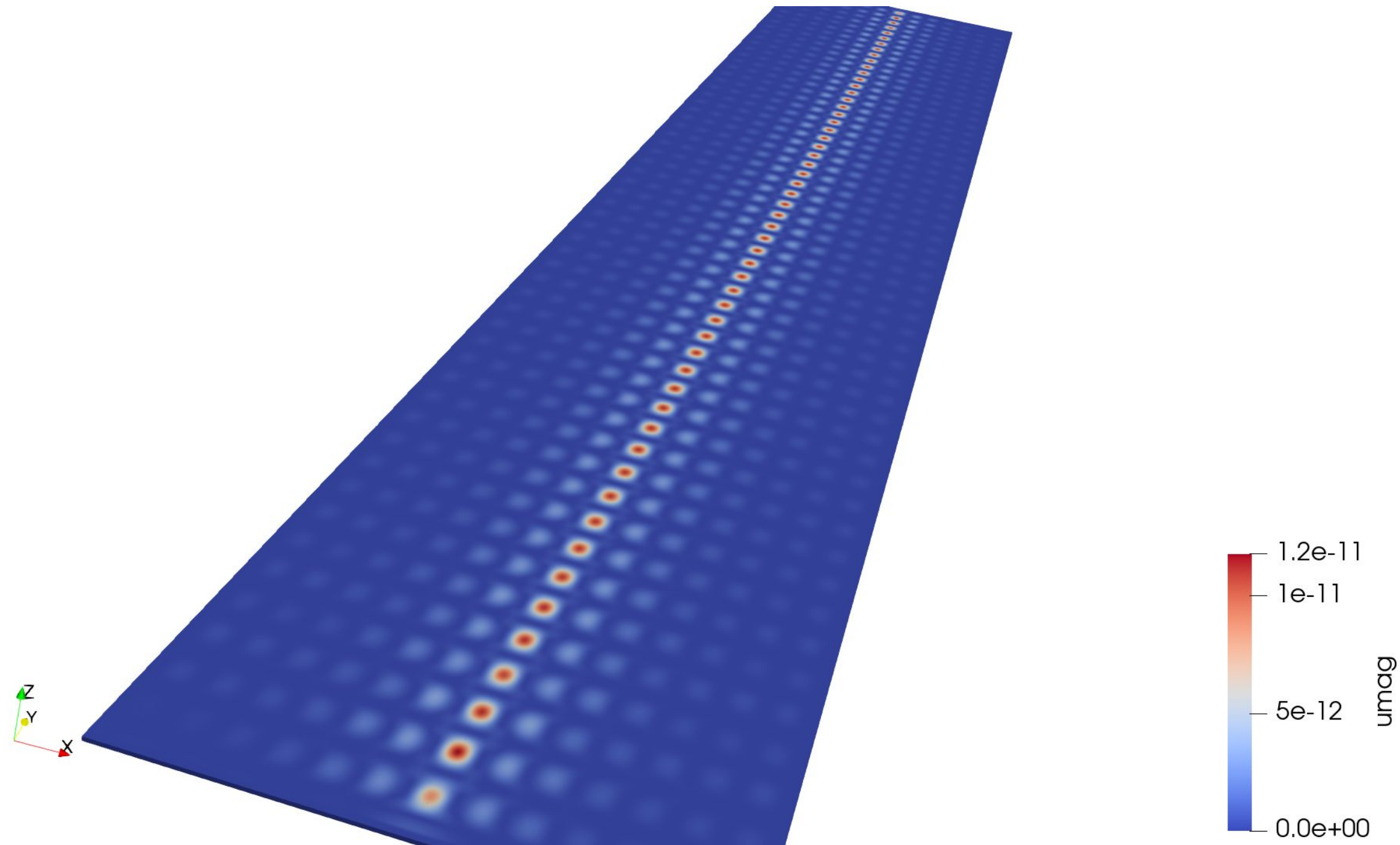
7.7

Core-hours

Full 3D harmonic simulation results

Crosstalk under CW excitation

QUANSCIENT



8.9M

DoFs

32

Cores

6.7

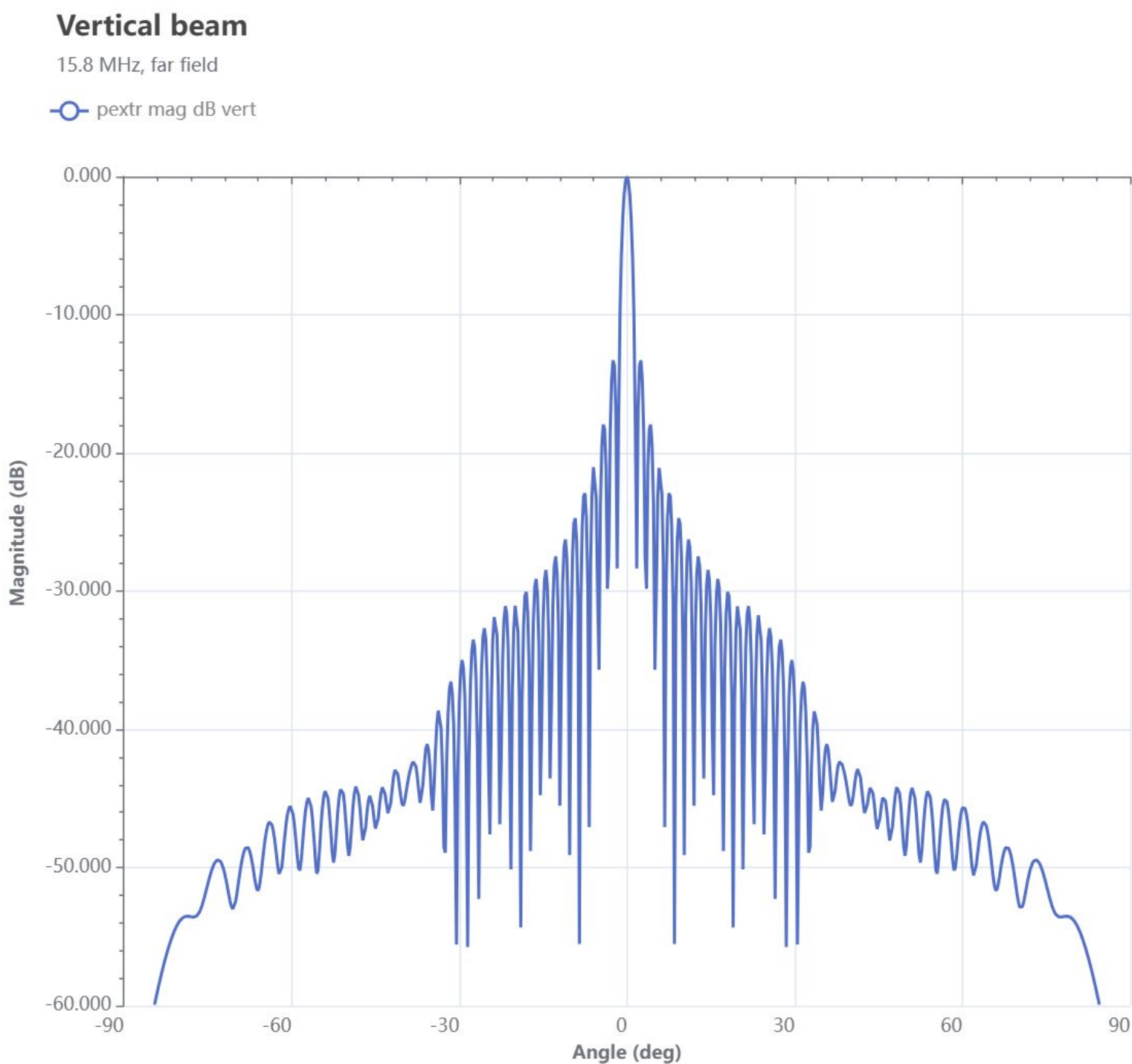
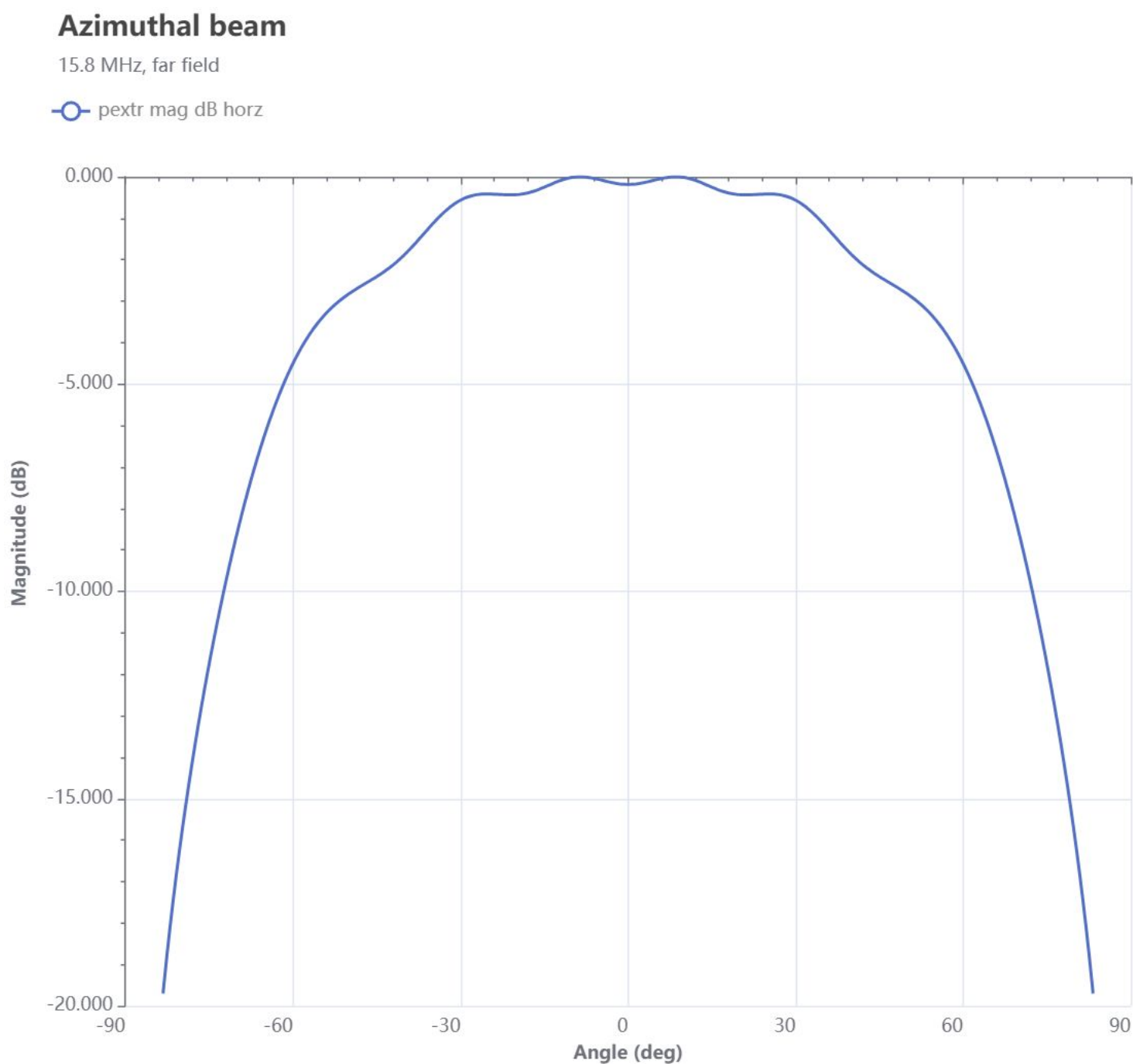
Minutes

3.6

Core-hours

Full 3D harmonic simulation results

Far field beam patterns



8.9M

DoFs

32

Cores

6.7

Minutes

3.6

Core-hours

CMUT: Case study example



CMUT Overview

Like PMUT with additional challenges

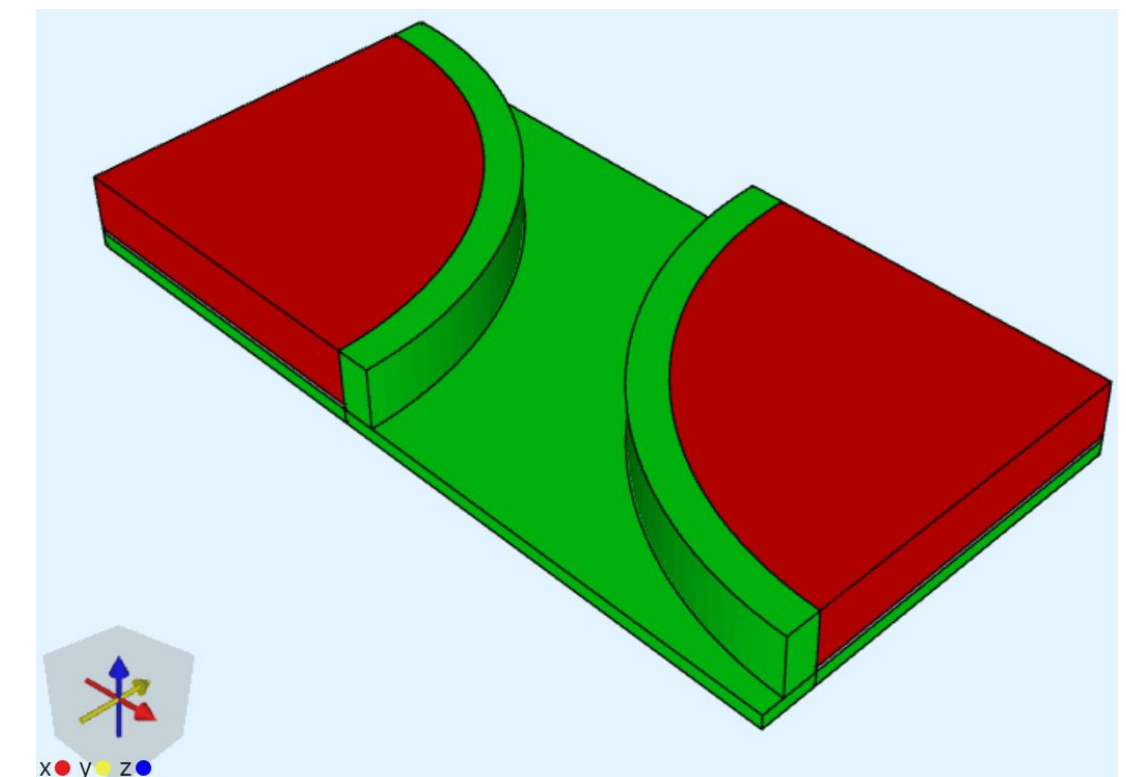
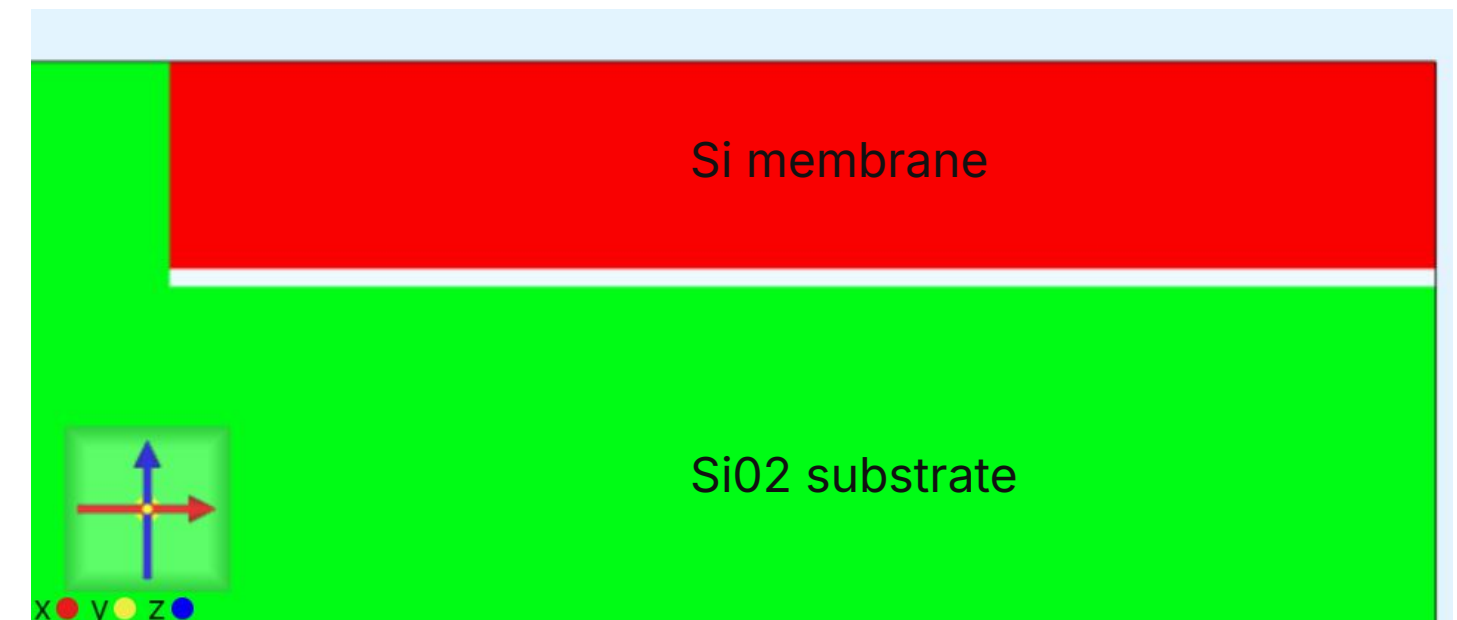
- CMUTs and PMUTs share many features:
 - MEMS construction
 - Simulation strategies
- CMUTs introduce additional complexities
 - biasing
 - nonlinear analysis
 - contact (if operated in collapse-mode)

CMUT reference design

General overview of example

- 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)

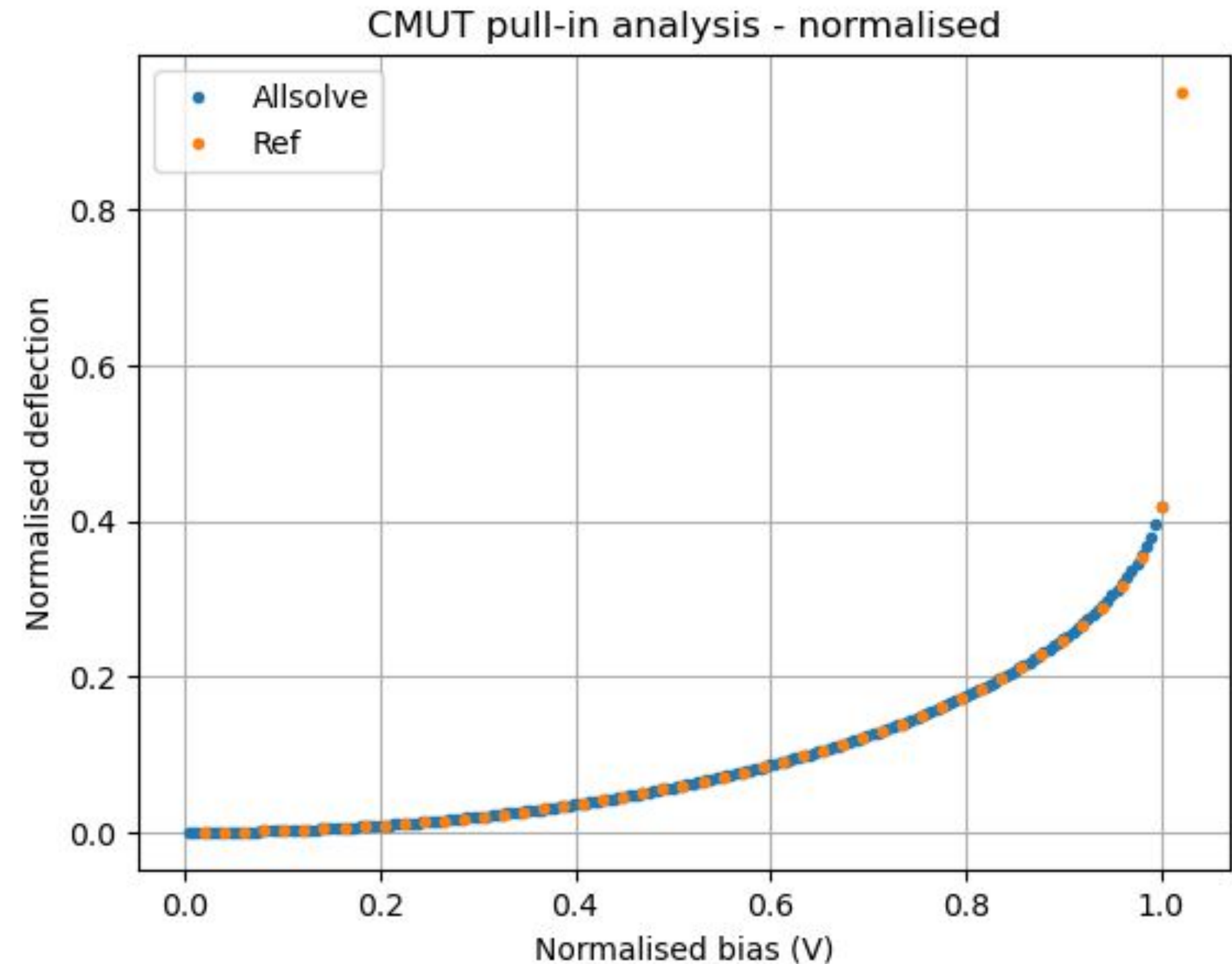


CMUT static simulation results

DC bias vs displacement

QUANSCIENT

- 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

DoFs

200

Cores

200

Sims

0.2

Minutes

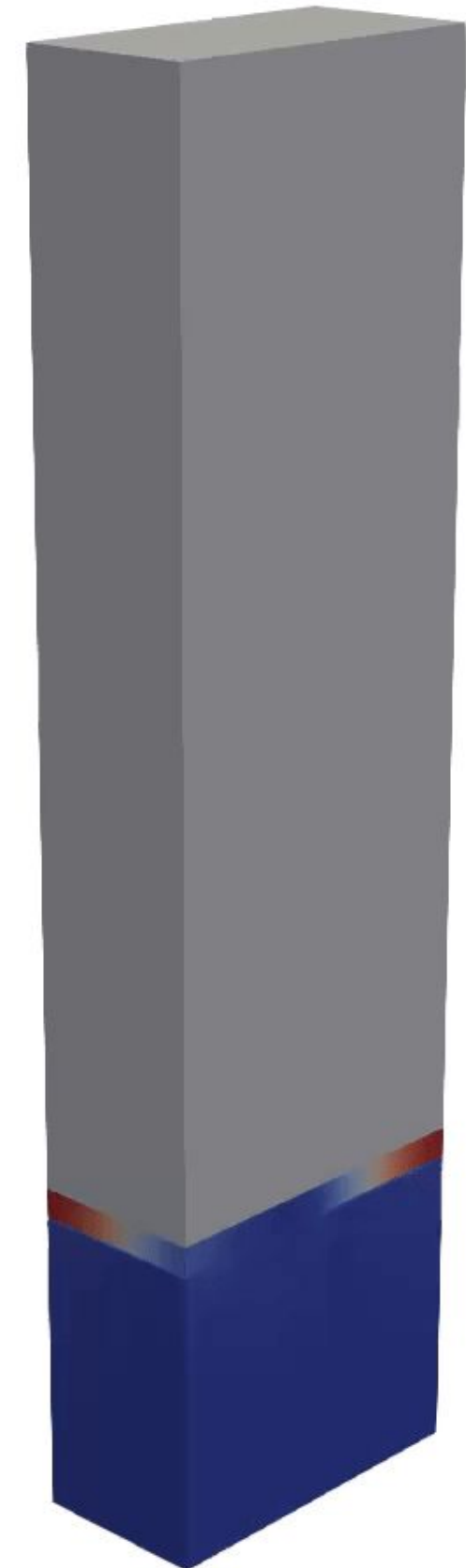
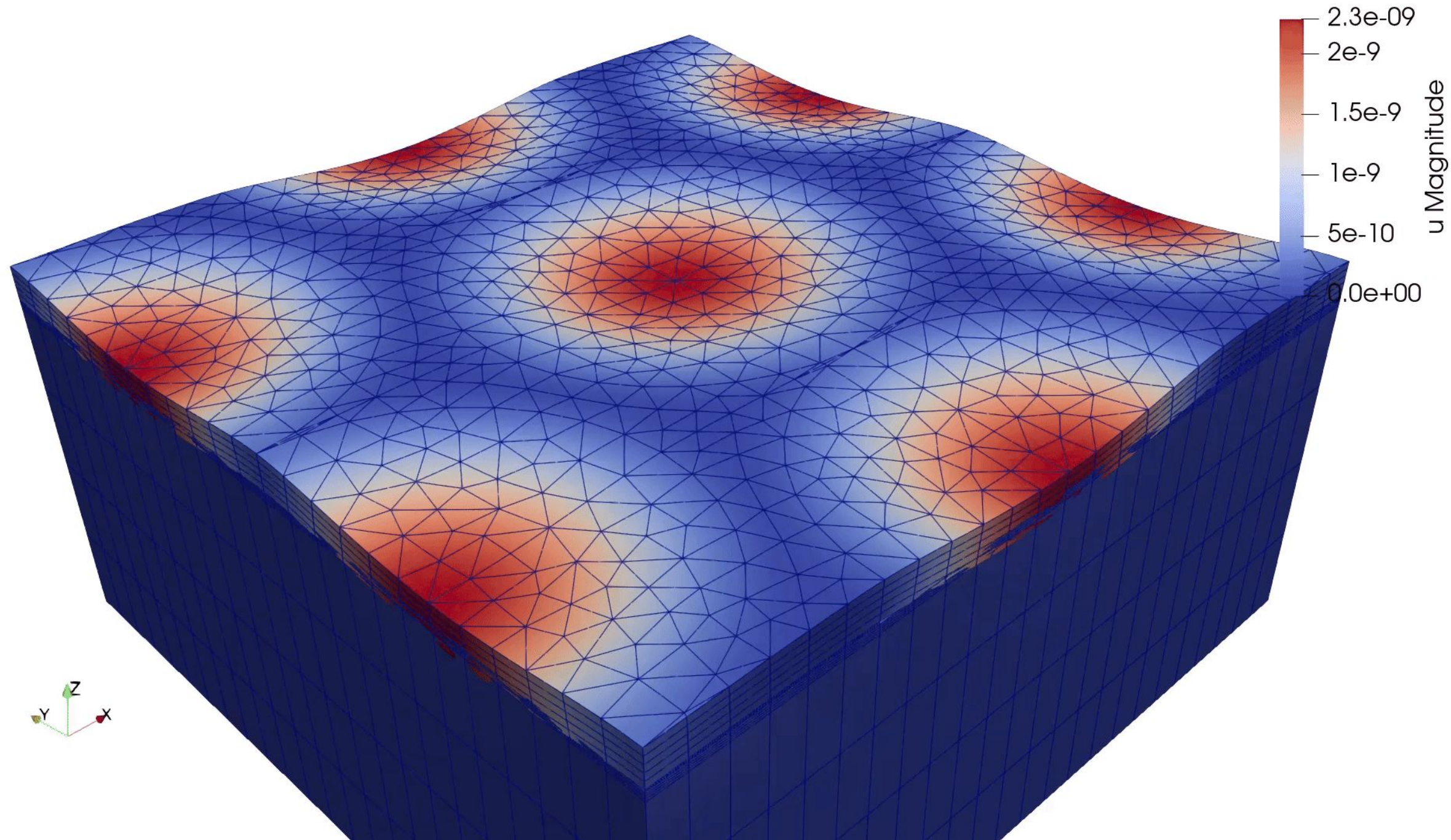
0.58

Core-hours

CMUT transient simulation results

Displacement & acoustic field

QUANSCIENT



47k

DoFs

1

Cores

35

Minutes

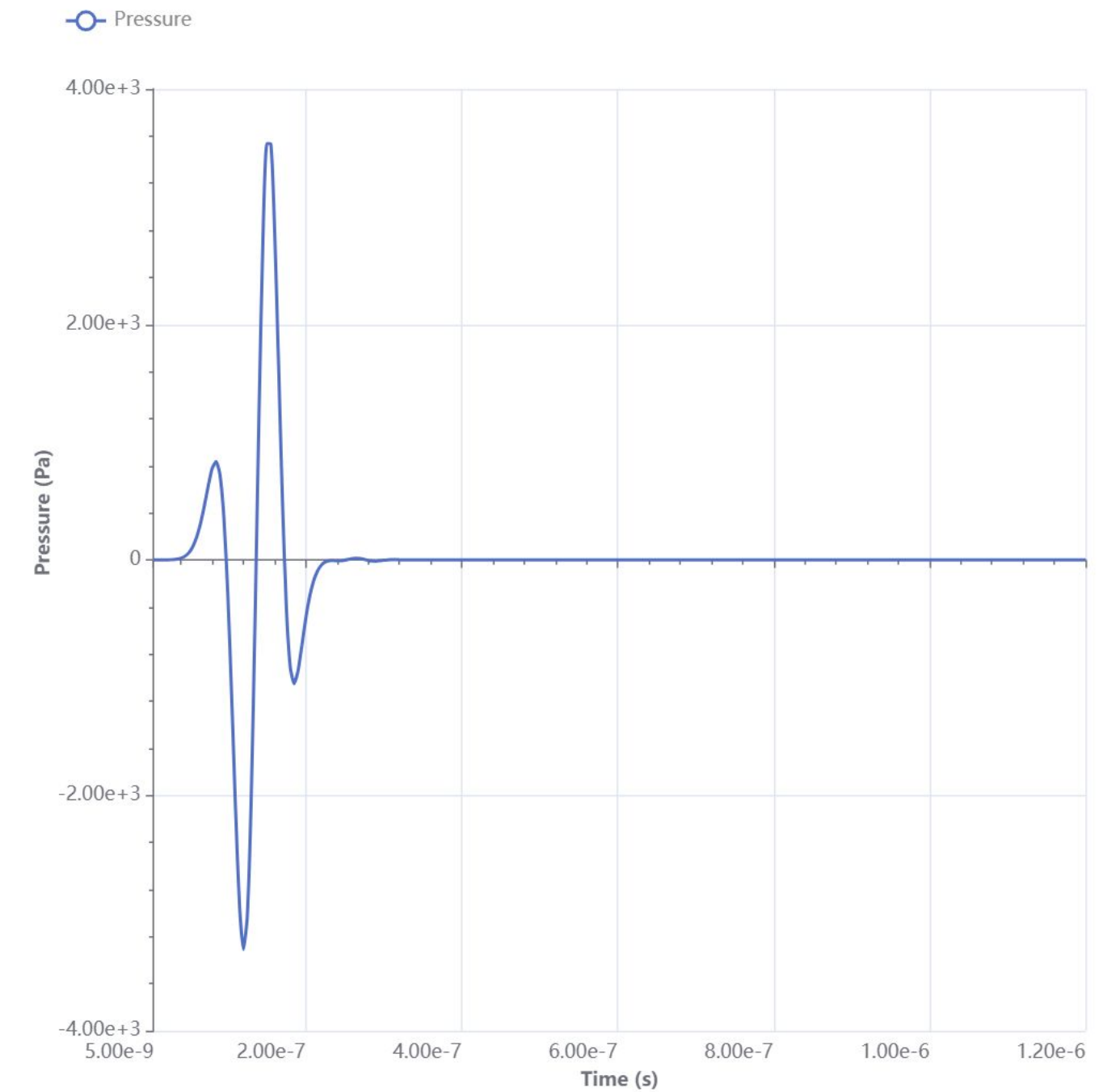
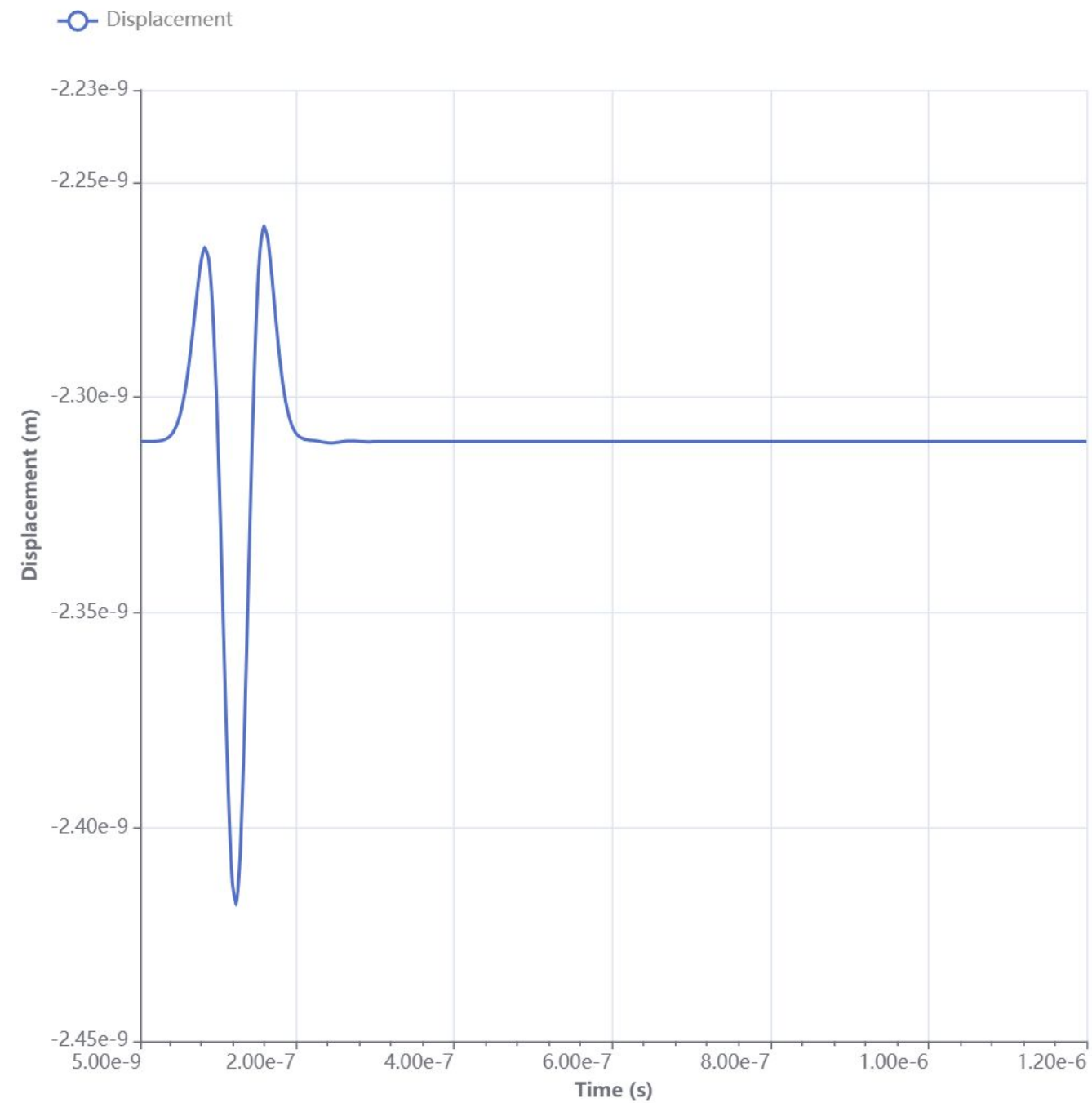
0.58

Core-hours

CMUT transient simulation results

Displacement & acoustic field

QUANSCIENT



47k

DoFs

1

Cores

35

Minutes

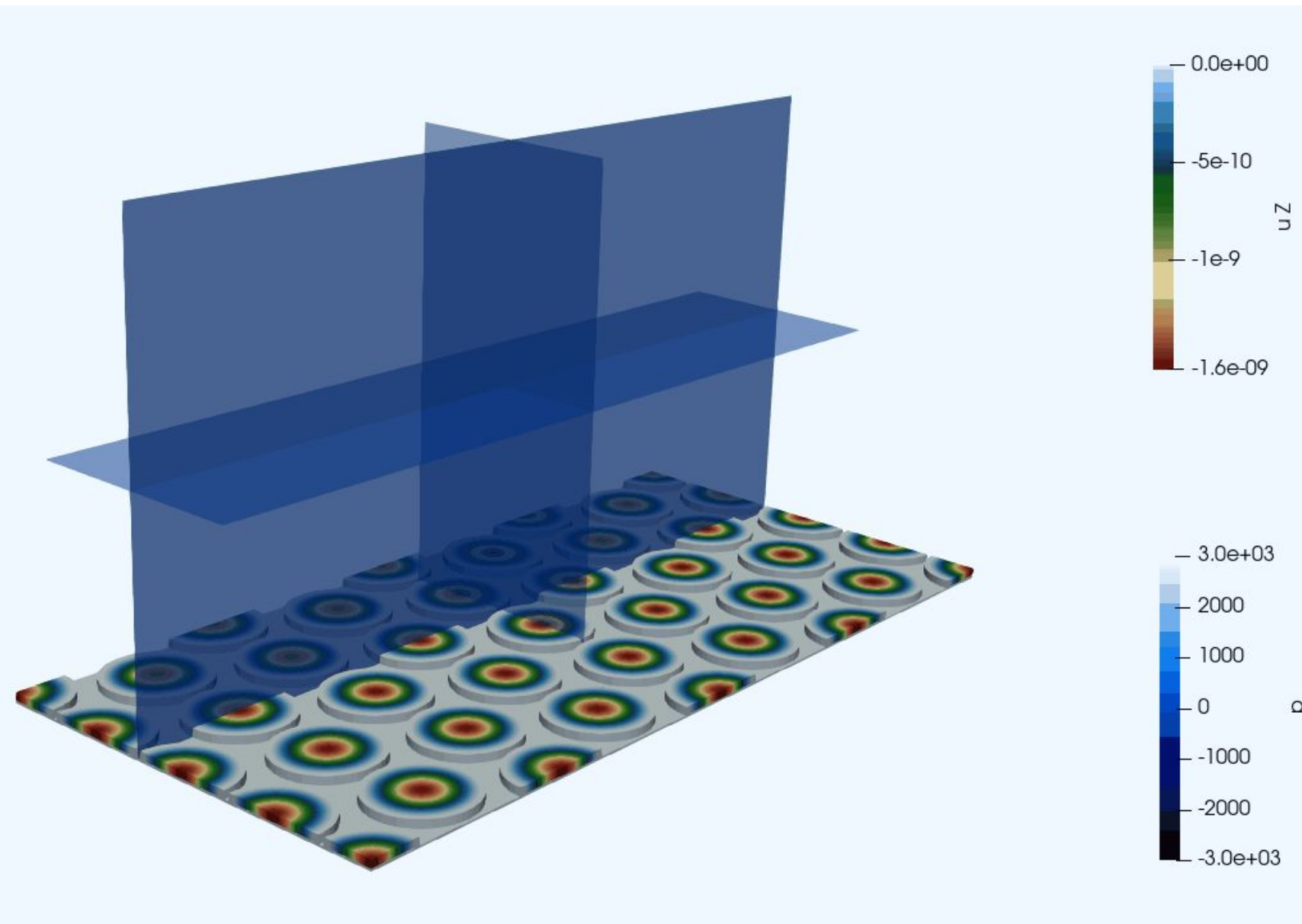
0.58

Core-hours

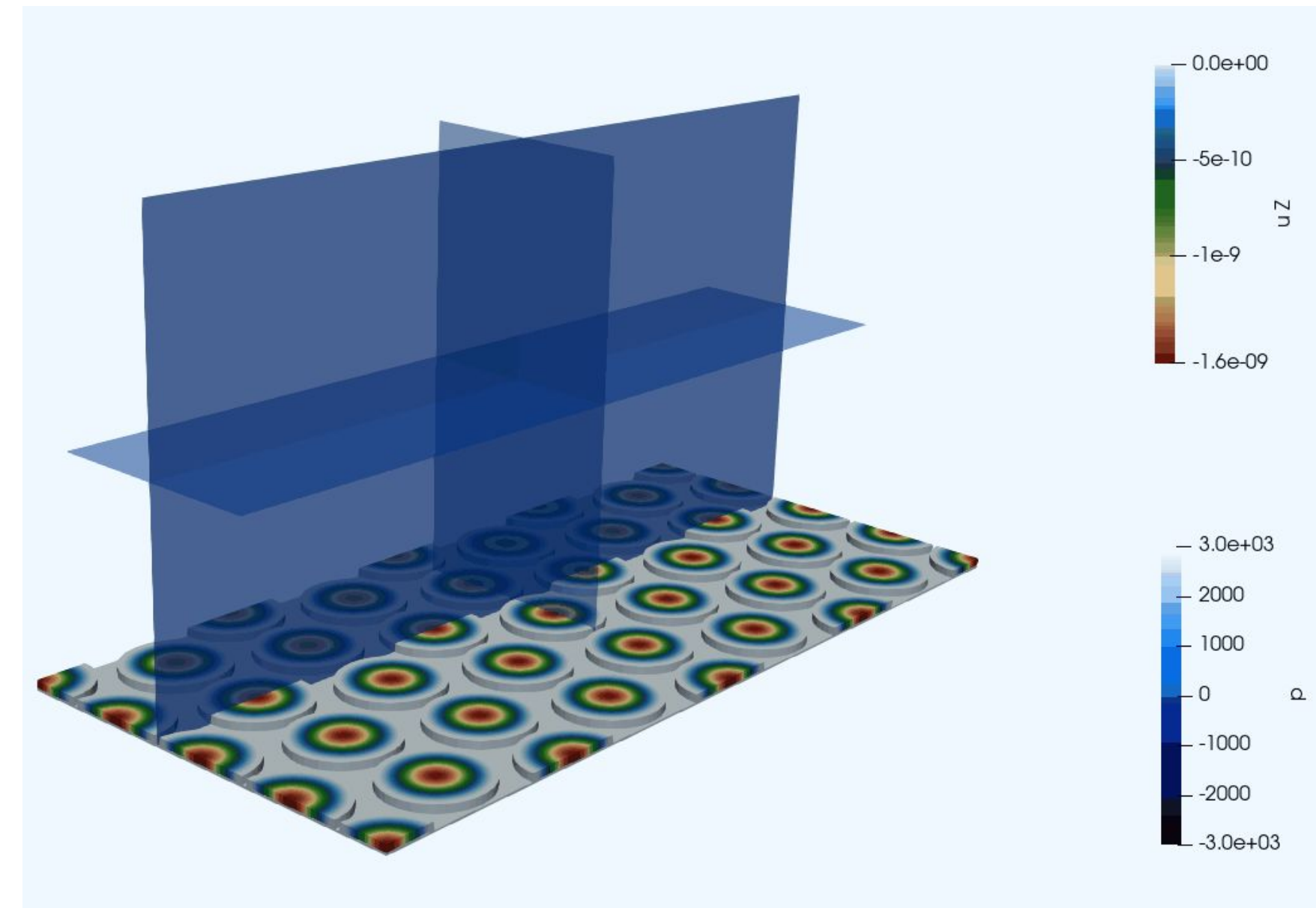
CMUT Multiharmonic simulation results

DC bias plus multiple harmonics in a single simulation

QUANSCIENT



In phase excitation



Out of phase excitation

463k

DoFs

20

Cores

10

Minutes

3.33

Core-hours

Audience questions and conclusions



Questions for you
Submit your answers in the chat!

QUANSCIENT

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

- 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***

Q&A

Submit your questions now!

QUANSCIENT

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!

QUANSCIENT

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>