QUEST 2025: CIRCUIT AND DEVICE 1

Physical design automation for superconducting qubits

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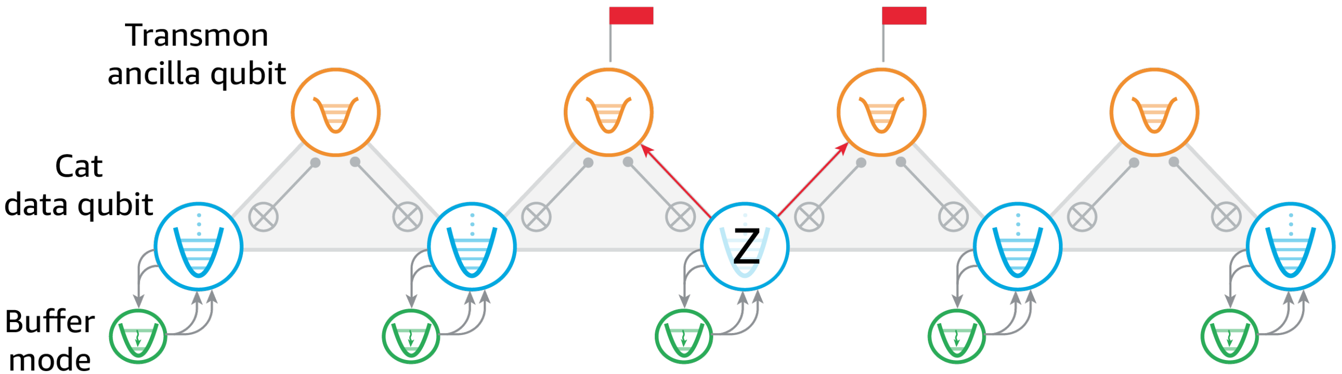
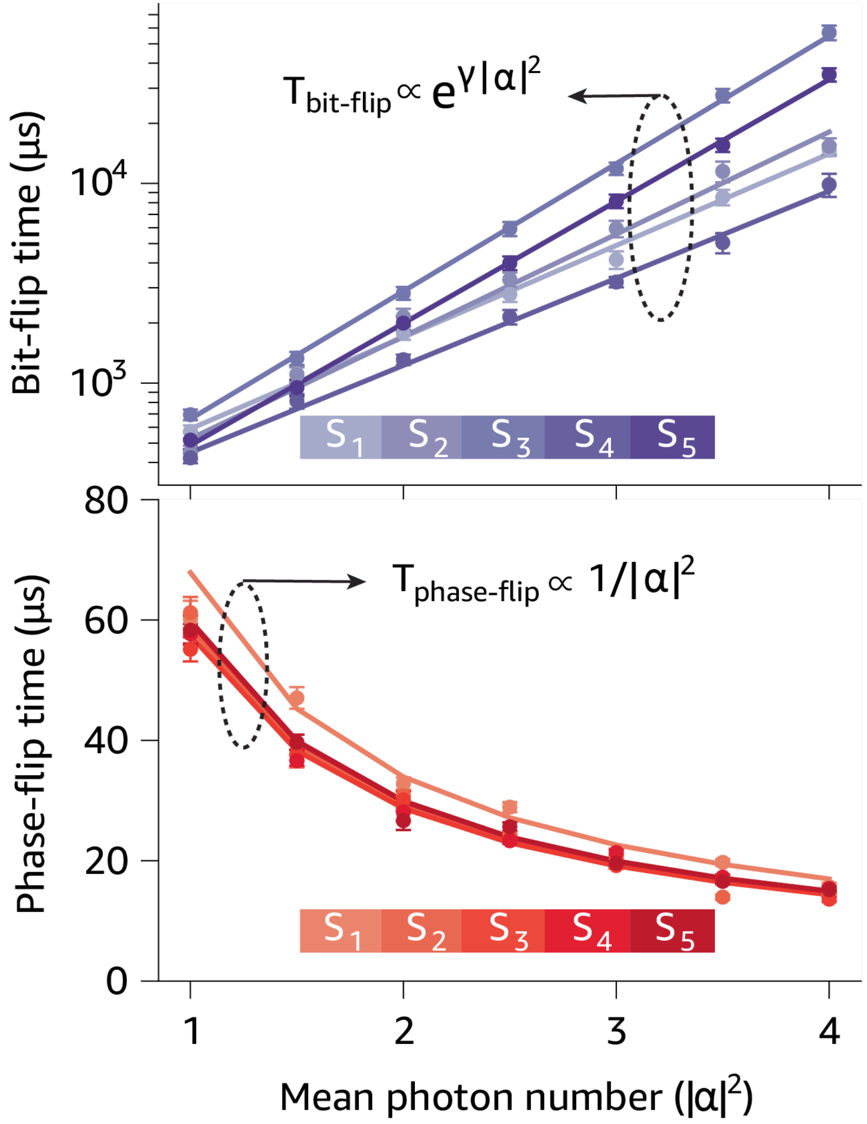
IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 62, Jan. 2026. Presentation given at QUEST 2025, Yokohama, Japan, Oct. 2025.

Superconducting qubits at AWS



H. Putterman, et al. Nature 2025



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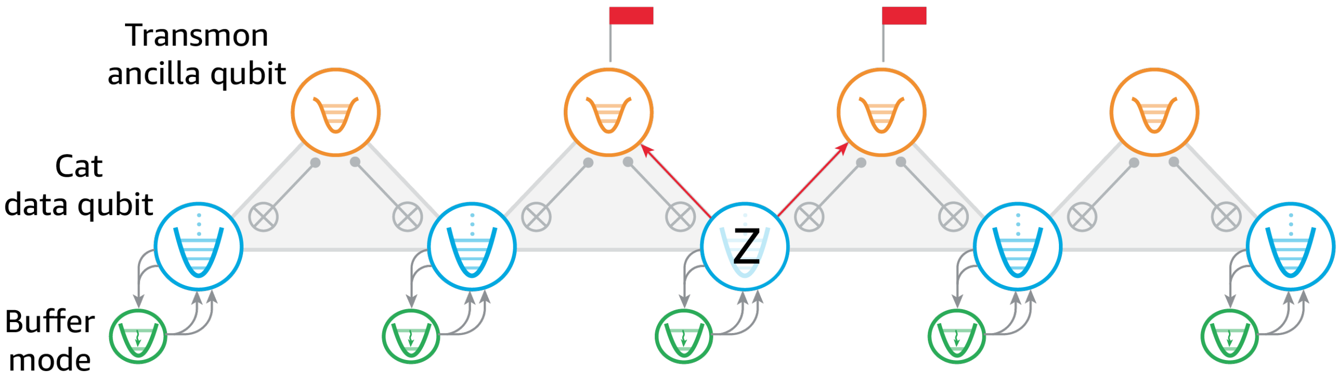

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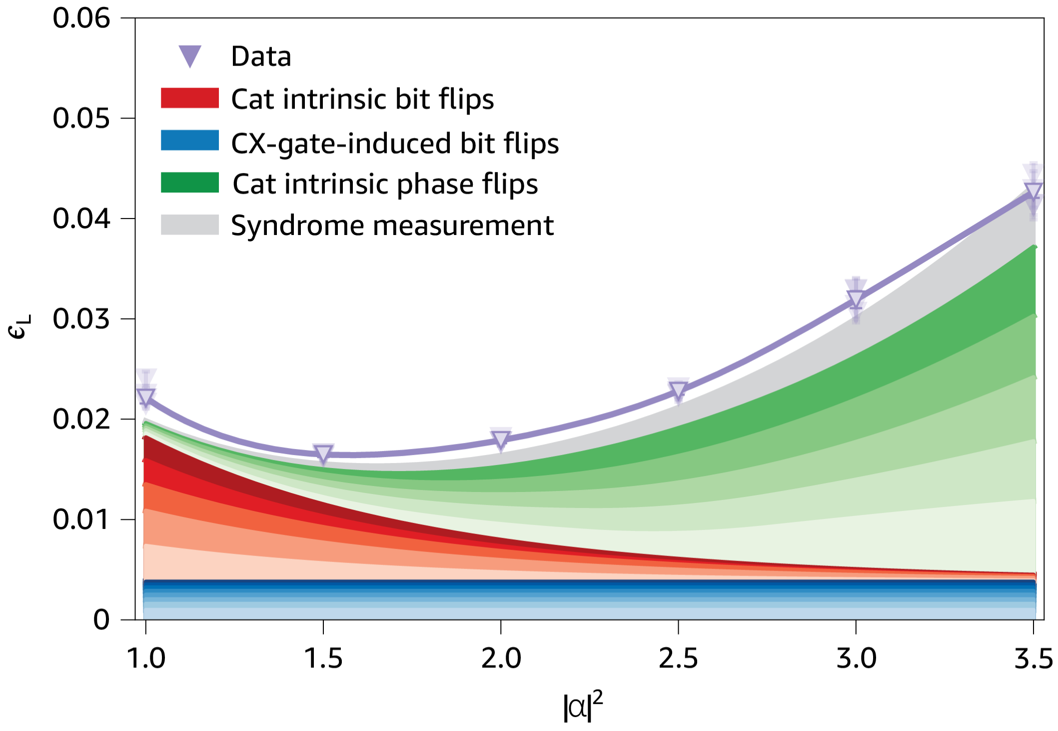

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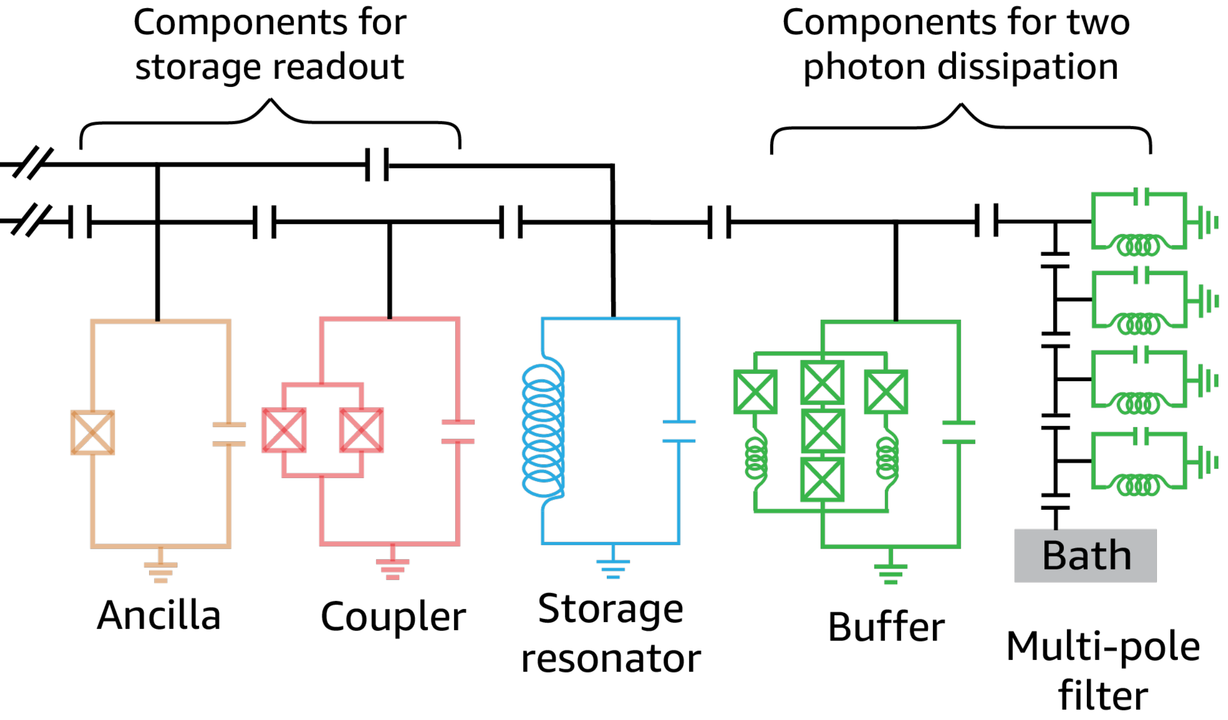
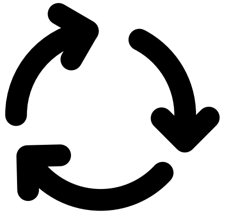
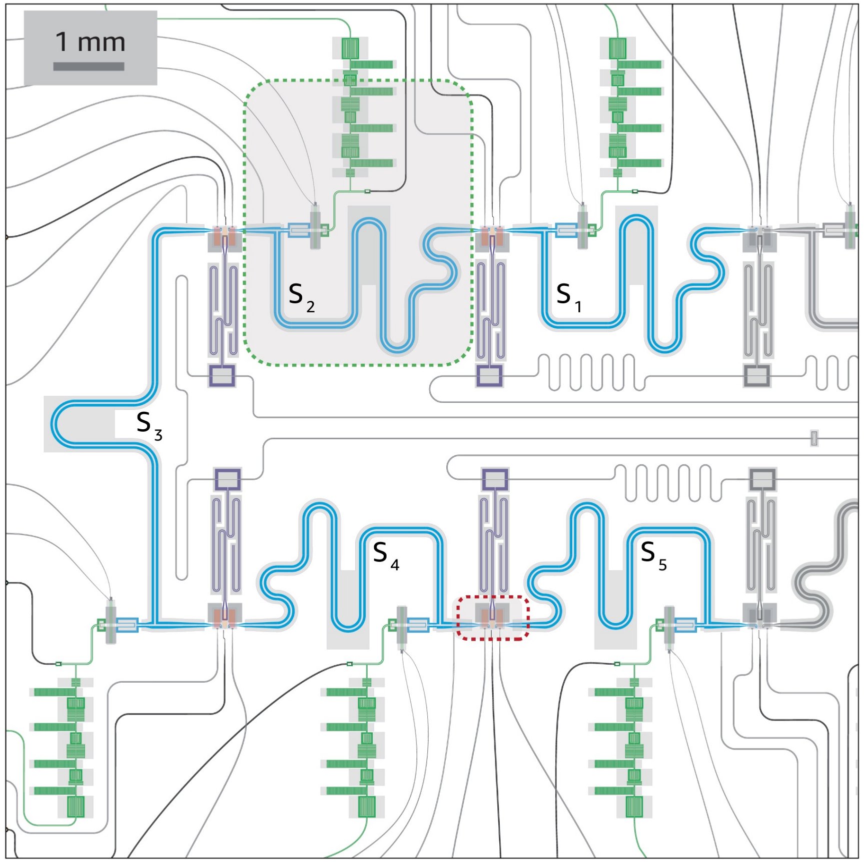
Physical design automation opportunities







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Using scalability and elasticity of AWS for electromagnetics

- Trade between model fidelity, wall-clock time, and resources
- Unconstrained by proprietary software licensing models
- Large-scale full-wave EM modeling before fabrication and test

Blog post

AWS Quantum Technologies Blog

AWS releases open-source software Palace for cloud-based electromagnetics simulations of quantum computing hardware

by Sebastian Grimberg, Hugh Carson, and Andrew Keller | on 22 FEB 2023 | in Announcements, AWS Center for Quantum Computing, High Performance Computing, Open Source, Quantum Technologies | Permalink | Share

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Palace

Parallel **La**rge-scale **C**omputational **E**lectromagnetics

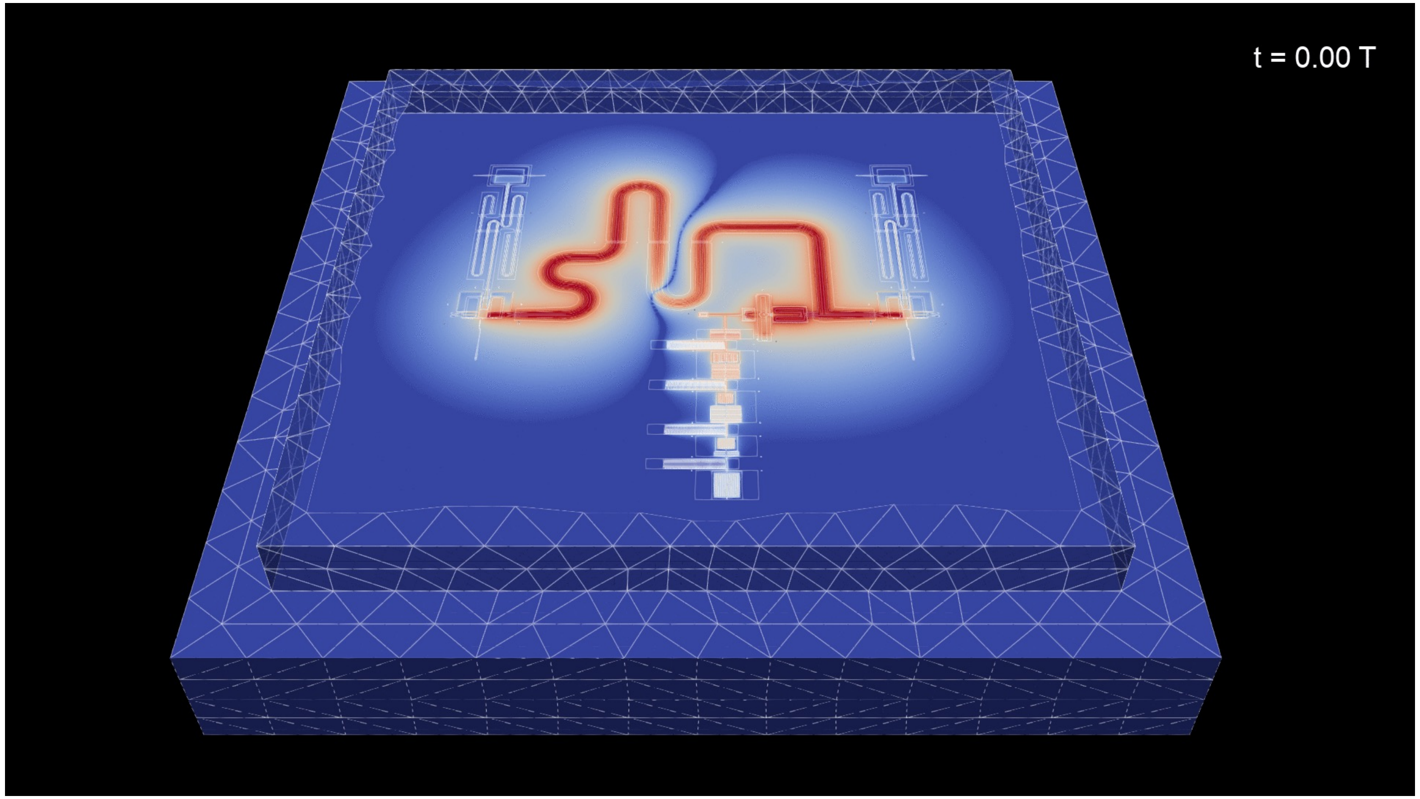
Palace repository:
https://github.com/awslabs/palace

$$\nabla \cdot \epsilon \overrightarrow{E} = \rho$$

$$\nabla \cdot \overrightarrow{B} = 0$$

$$\nabla \times \overrightarrow{E} = -\frac{\partial B}{\partial t}$$

$$\nabla \times \mu^{-1} \overrightarrow{B} = \overrightarrow{J} + \epsilon \frac{\partial \overrightarrow{E}}{\partial t}$$



Linear eigenmode analysis of repetition cat code processor including a storage resonator, buffer, four-pole lumped element filter, two adjacent coupler-ancilla-coupler subsystems including readout resonators, all in flip-chip configuration

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Palace features and capabilities

- Electrostatics and magnetostatics
- Driven, transient, and eigenmode analysis
  - Anisotropic and lossy material properties
  - Absorbing, periodic (including Floquet), impedance boundary conditions
  - Lumped ports and wave ports
  - *Transient:* Adaptive time stepping
  - *Driven:* Adaptive frequency sweeps using projective reduced-order models
  - …
- Non-conforming solution-based adaptive mesh refinement

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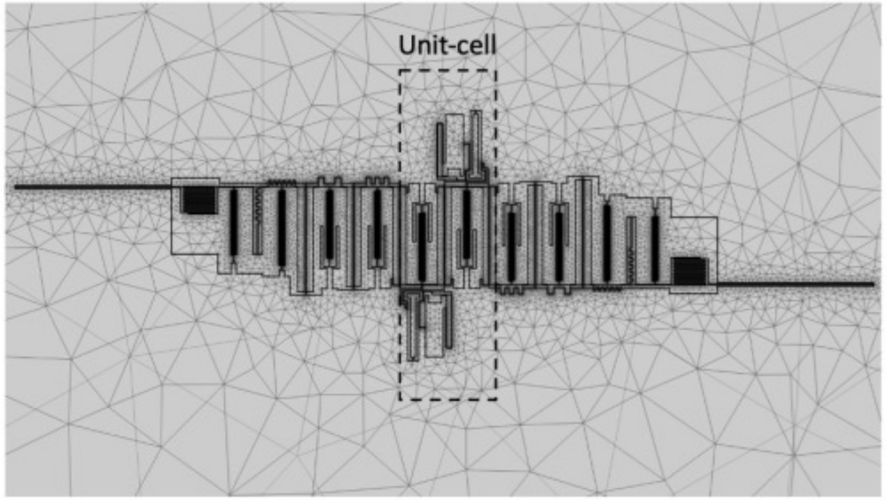
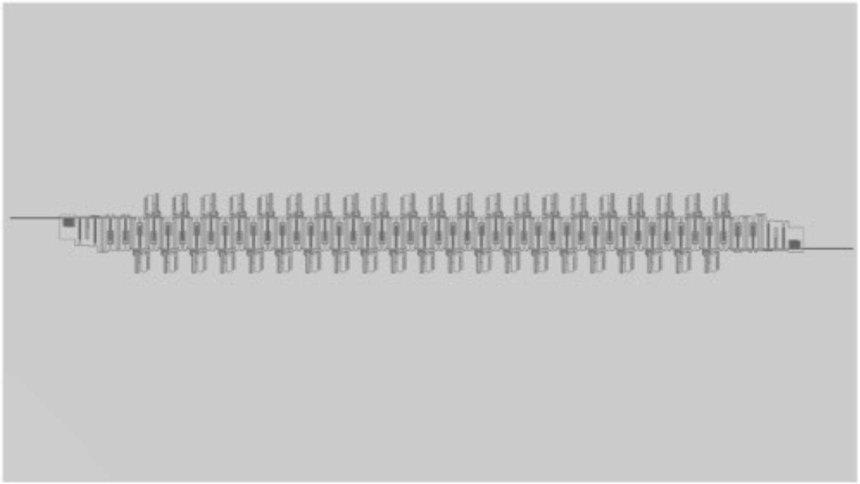
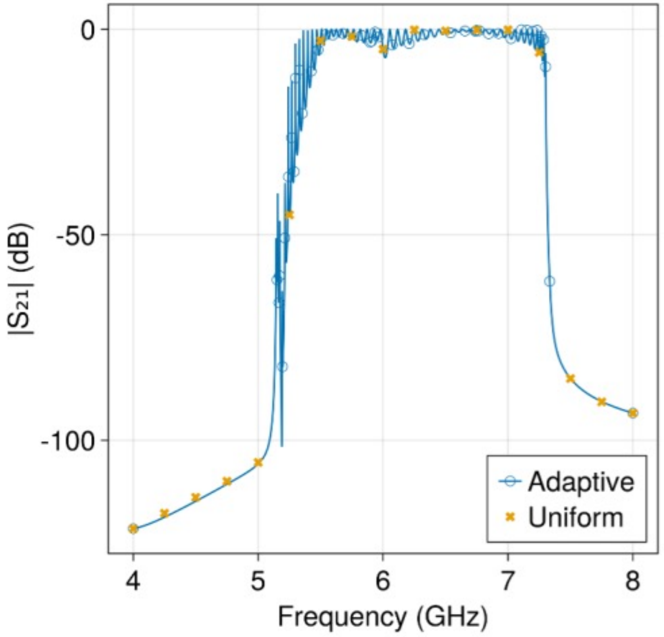
Driven simulation of a lumped-element waveguide

- 3D models ranging up to 1.4 billion degrees of freedom
- Used 12,800 AWS Graviton2 cores, networked using Elastic Fabric Adapter (EFA)
- Adaptive frequency sweep simulation took approximately 3 hours







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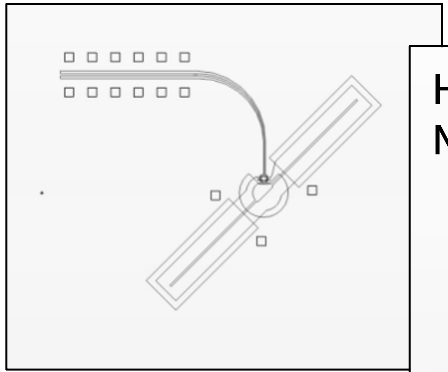
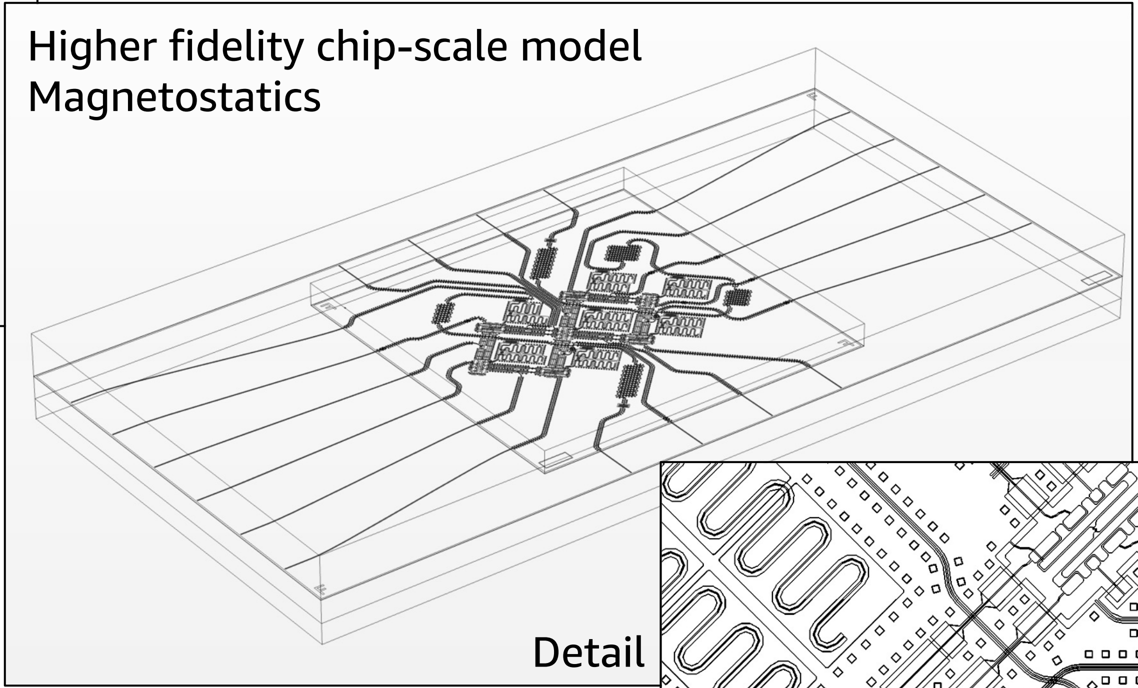
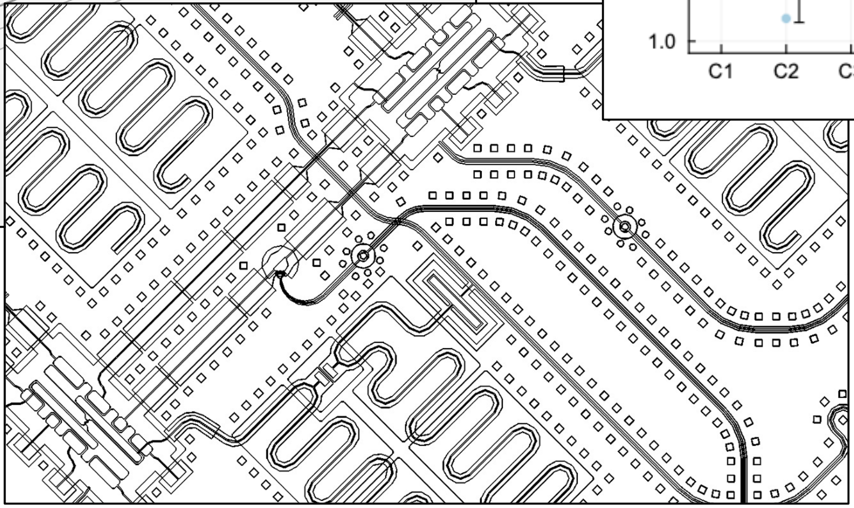
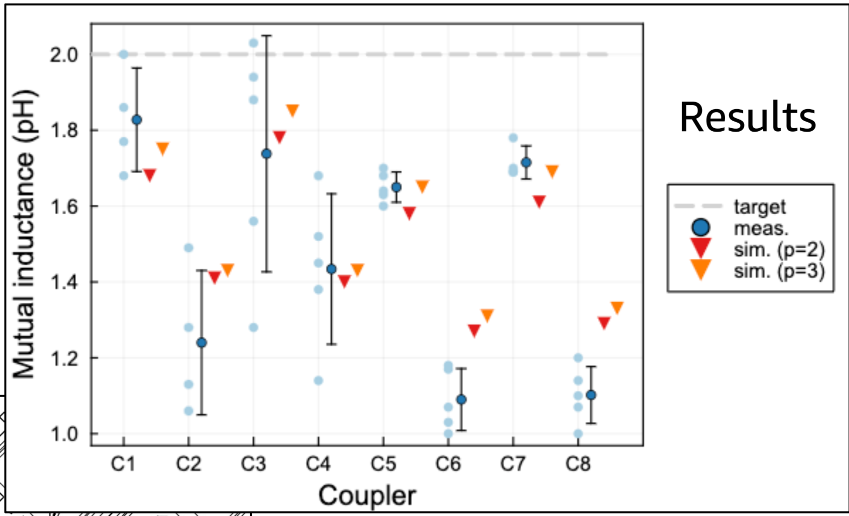
Magnetostatics: mutual inductance targeting



Original flux line tune-up geometry







Results

Runs in < 1 hr on 24x c6i.32xlarge machines

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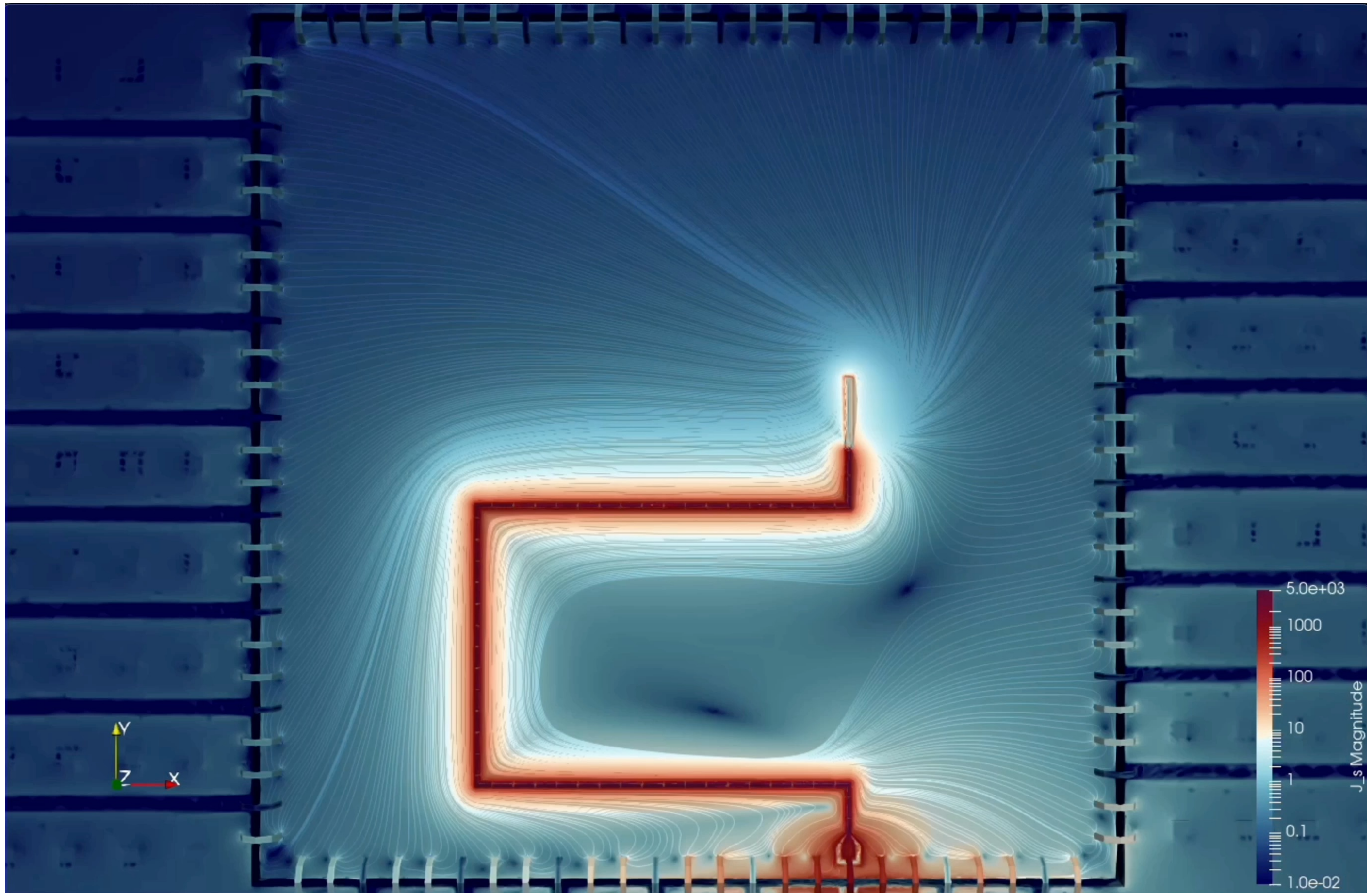
Transient: diagnosing flux transient settling



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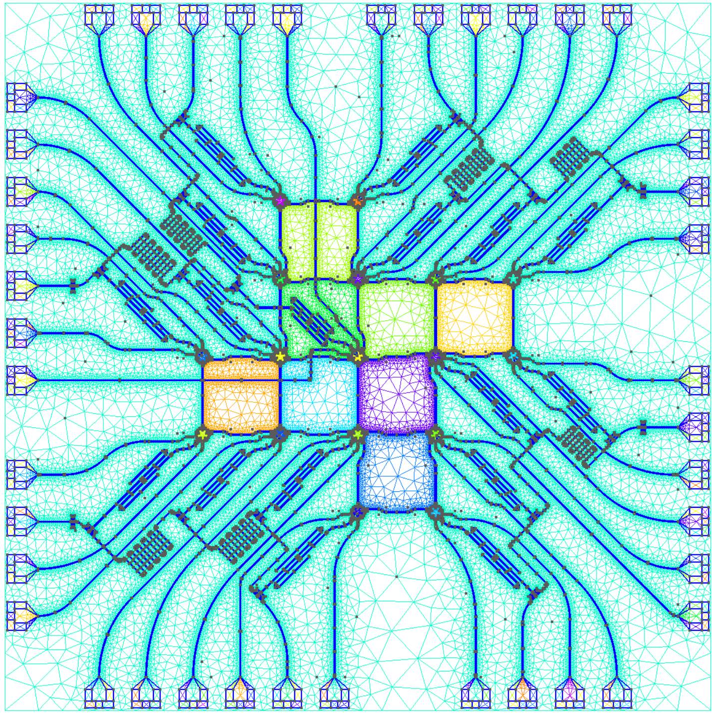
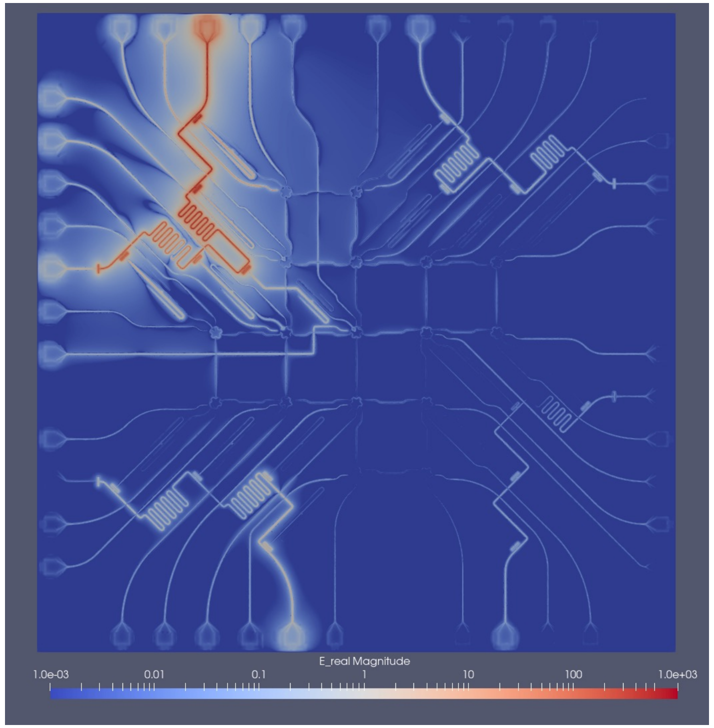
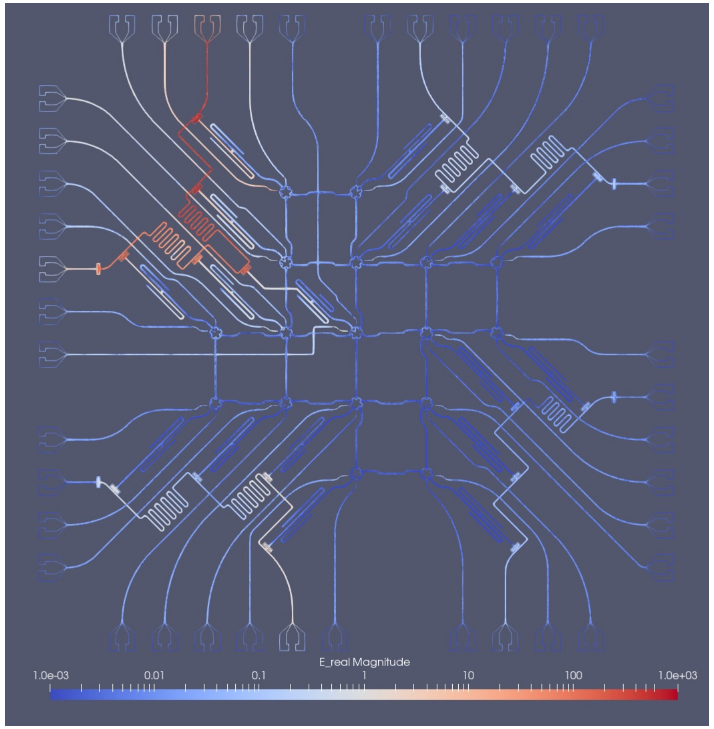
Eigenmode: whole-chip analysis







- Example mock-up of design from Quantum Device Lab at ETH Zurich (e.g. Krinner *et al.*, *Nature* (2022))
- Whole chip eigenmode simulations using 4th order basis functions
- 32x Graviton 3 (c7g.16xlarge) instances (2048 cores) with EFA + OpenMPI → 6 hours for lowest 9 modes

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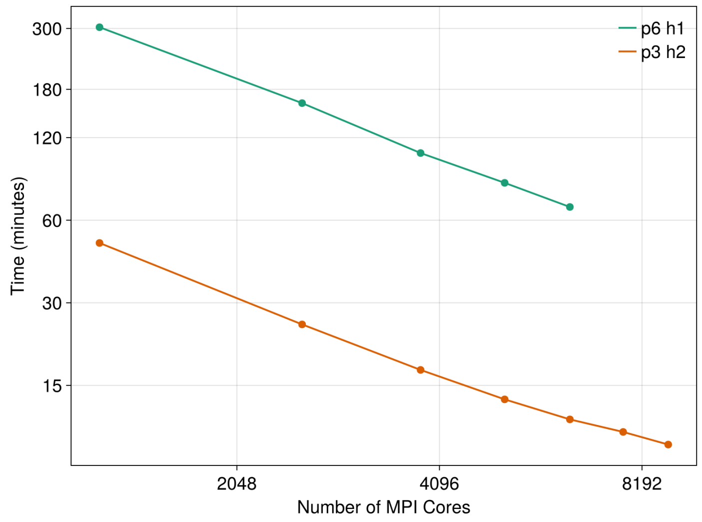
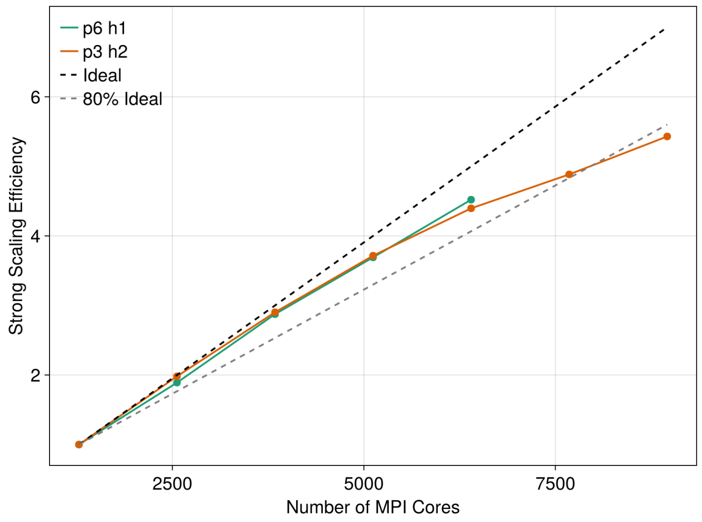
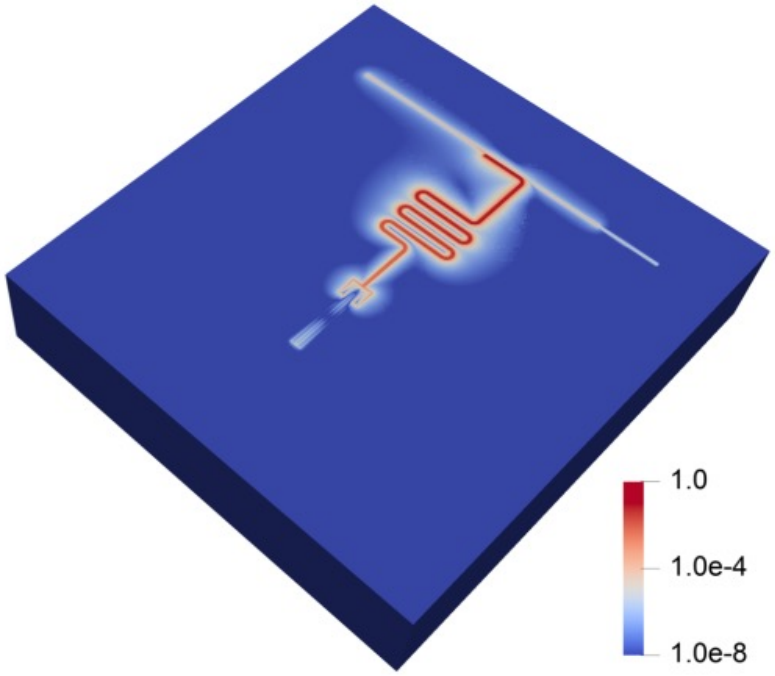
Component-scale electromagnetics simulation







- Palace exhibits strong scaling to thousands of cores for component design, exploiting higher-order basis functions
- P3 h2: 262 MDOF, P6 h1 225 MDOF
- Graviton 3 (c7g.16xlarge) instance with EFA + OpenMPI

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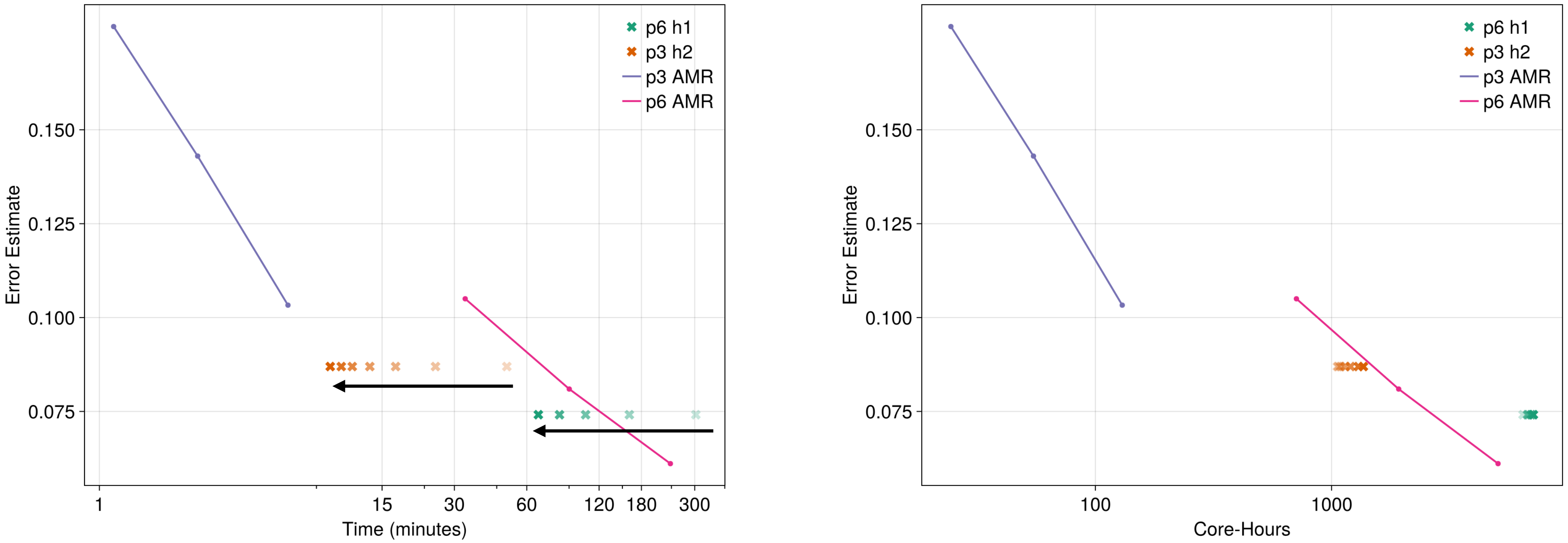
Component-scale electromagnetics simulation



- Adaptive Mesh Refinement (AMR) significantly reduces core-hours (cost) per given accuracy
- AMR gives cheaper results using only 1280 cores
- Graviton 3 (c7g.16xlarge) instance with EFA + OpenMPI

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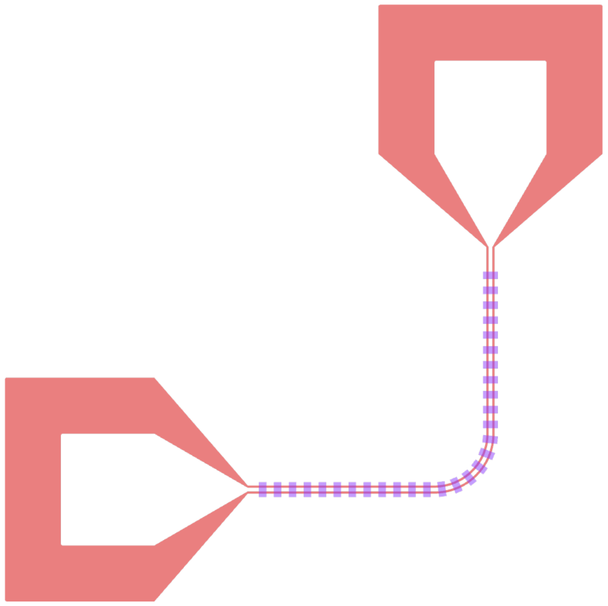
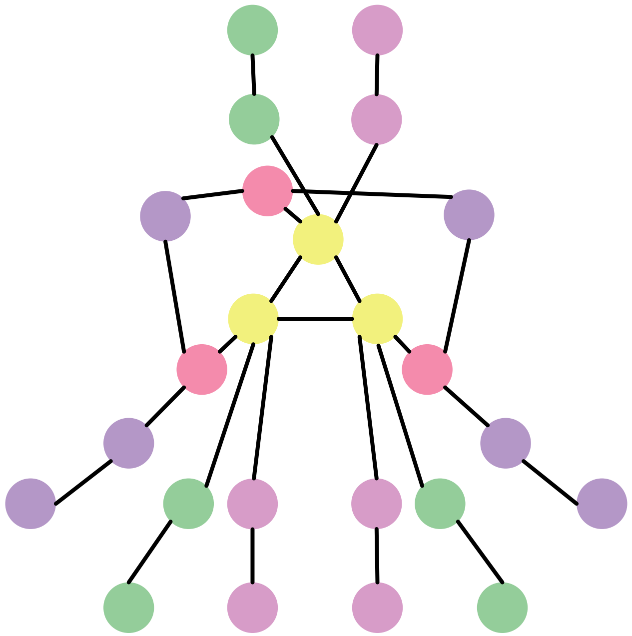
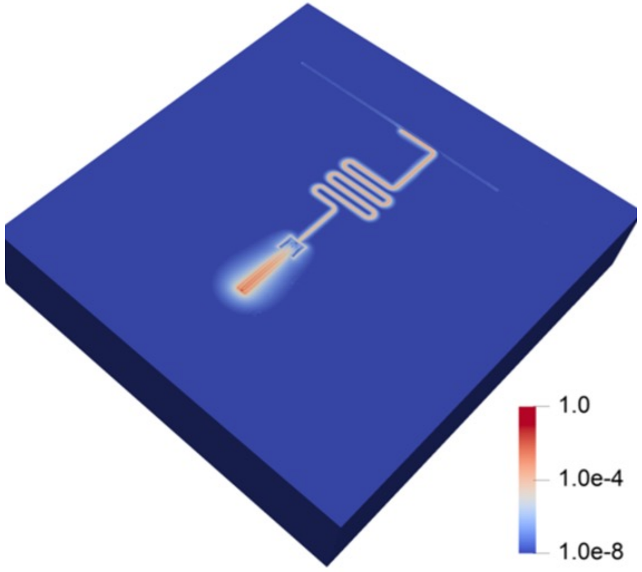
DeviceLayout.jl

DeviceLayout.jl repository:
https://github.com/aws-cqc/DeviceLayout.jl







Geometry

2D shapes with metadata

Schematics

Components and connectivity

Models

Physics content for simulation

Physical design automation stack

Workflow orchestration layer

CAD | Mesher | Electromagnetic solvers

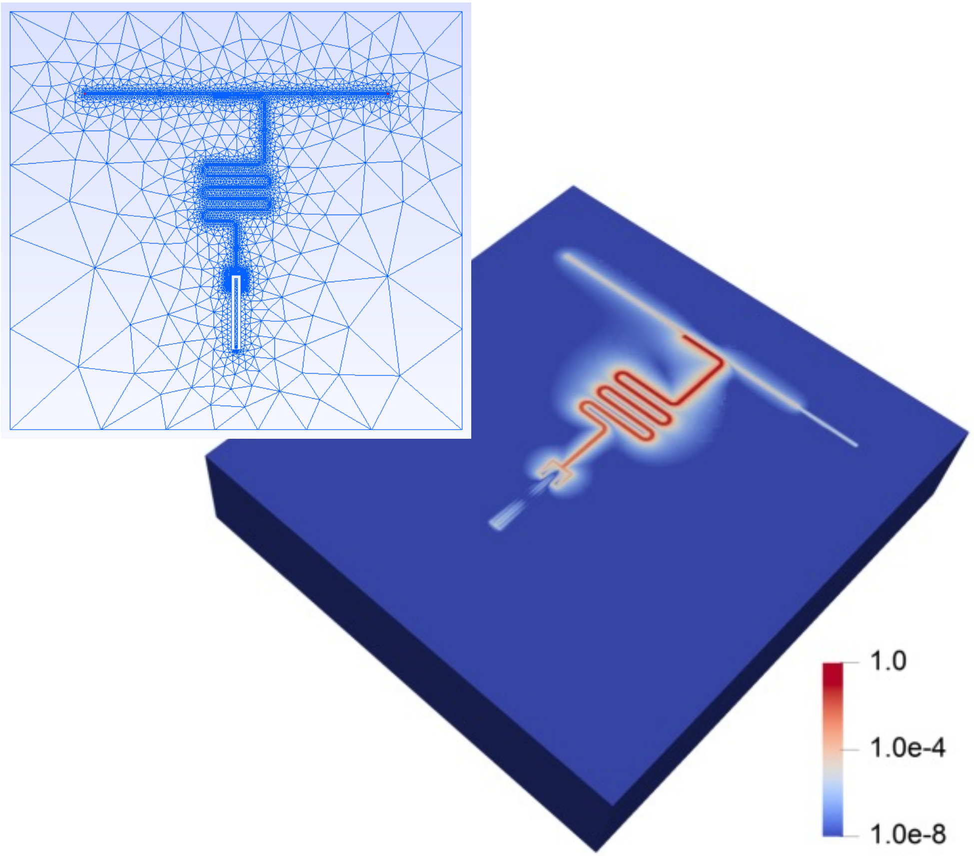
High-performance computing cluster

AWS ParallelCluster

AWS Parallel Computing Service

Elastic Fabric Adapter

Amazon FSx



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Thank you!

Palace repository:
https://github.com/awslabs/palace

kllrak@amazon.com

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- Patricio Arrangoiz Arriola, Gabriele Bozzola, Philipp Dumitrescu, Hugh Carson, Layla Ghaffari, Sebastian Grimberg, Simon Lapointe, Greg Peairs, Dzung Pham, Cameron Rutherford, *et al.*

We are grateful for feedback and contributions from the community, and are grateful to the developers and maintainers of open-source software we use in Palace:

- MFEM: J. Andrej, N. Atallah, J-P Bäcker, *et al. High-performance finite elements with MFEM.* The International Journal of High Performance Computing Applications 38(5), pp. 447–467, 2024.

- ARPACK, ButterflyPACK, GSLib, Hypre, LibCEED, LibXSMM, MAGMA, MUMPS, PARMETIS, PETSc, SLEPc, STRUMPACK, SuperLU, SUNDIALS, …