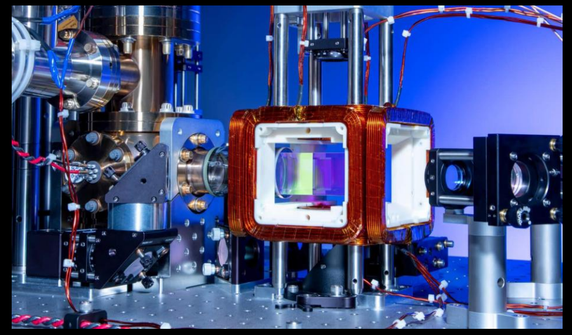
Defining the Accelerated Quantum Supercomputer

Yun Yuan Wang (Pika Wang), Sr. Solutions Architect | NVAITC, NVIDIA Taiwan

Year of Quantum Breakthroughs

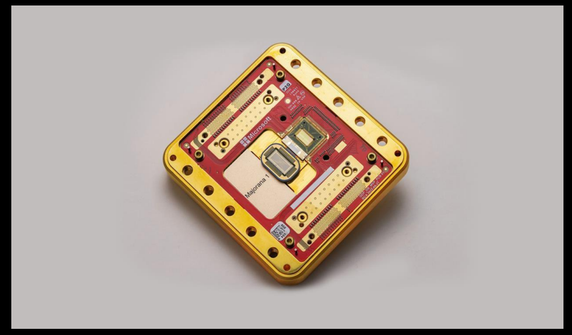
Quantum Error Correction

Google Quantum AI

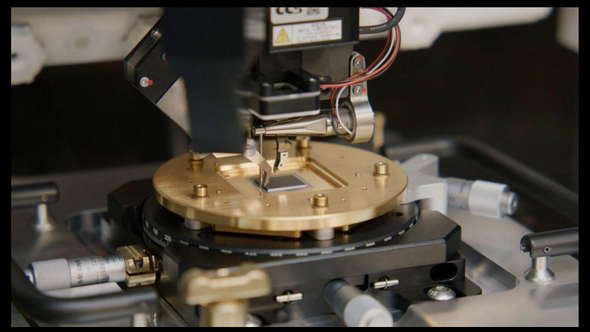


IQuEra

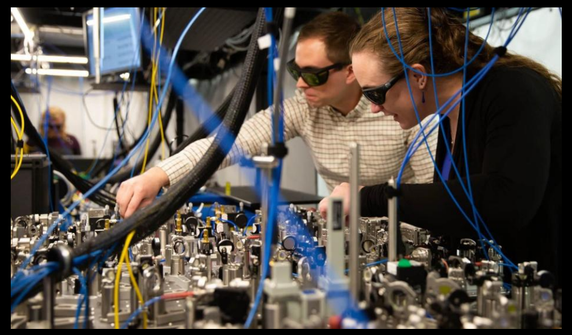
New Architectures



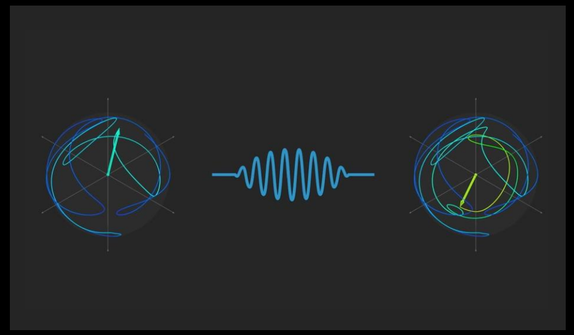
Microsoft



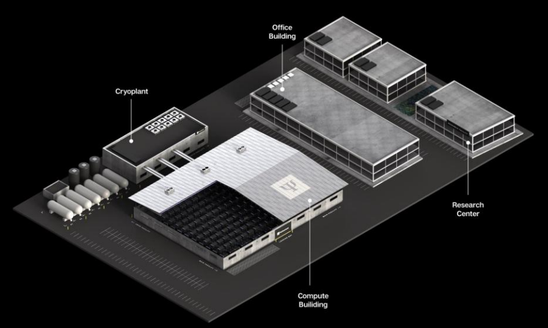
aws



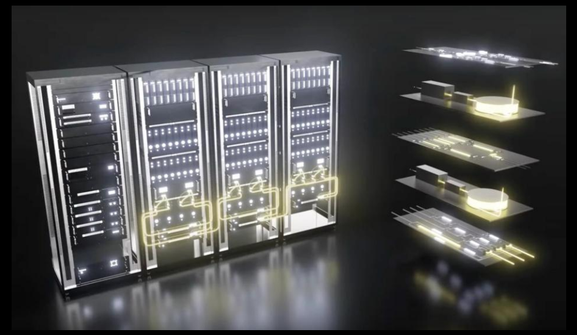
QUANTINUUM



Infleqtion



PsiQuantum



XANADU

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NVIDIA Quantum Product Map

CUDA-Q is the entry point into our products for most users

NVIDIA Quantum Cloud

CUDA-QX Libraries

CUDA-Q

Libraries | Programming Model | Tools | Infrastructure

Quantum

cuQuantum

Libraries for simulating applications and hardware

QPU

CUDA-Q supports range of QPU vendor backends

OQC · Quantinuum · ORCA Computing · Alice & Bob · IonQ · Quantum Brilliance · Pasqal · IQM · QuEra Computing Inc. · seeqc · rigetti · Infleqtion · Anyon Technologies

DGX-Q

Reference architecture for low-latency QPU/DGX integration

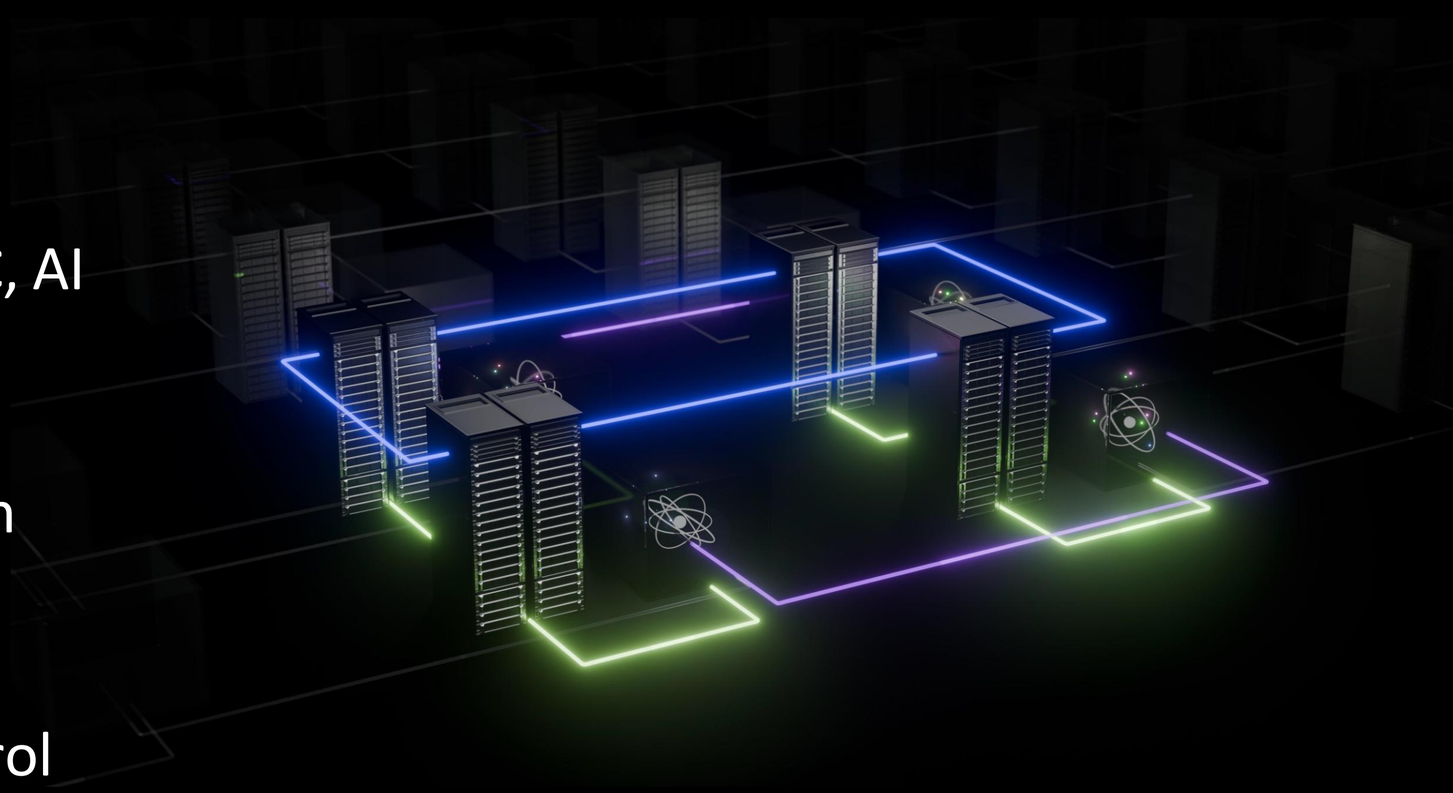
Classical

DGX-SuperPOD

NVIDIA

The Accelerated Quantum Supercomputer

- AI supercomputing architecture **connecting quantum hardware**
- **Hybrid applications** – combining HPC, AI and QC resources
- A **software platform** enabling domain scientists
- **Qubit-agnostic** development of control and error correction



The NVIDIA Quantum Platform

Bringing AI Supercomputing to Enable Useful Quantum Computing

CUDA-Q

Open-Source Software Platform for Accelerated Quantum Supercomputers

The NVIDIA Quantum Platform

Bringing AI Supercomputing to Enable Useful Quantum Computing

CUDA-Q

Open-Source Software Platform for Accelerated Quantum Supercomputers

Pasqal — New at GTC25

QUANTINUUM — Free Access to H1-1 Through CUDA-Q

Anyon Technologies
aws
Infleqtion
IONQ
IQM
ORCA Computing
OQC
Pasqal
QUANTINUUM
QUANTUM BRILLIANCE
QuEra Computing Inc.
rigetti

The NVIDIA Quantum Platform

Bringing AI Supercomputing to Enable Useful Quantum Computing

CUDA-Q
Open-Source Software Platform for Accelerated Quantum Supercomputers

cuQuantum
Accelerated Quantum Simulations

Cirq
PENNYLANE
QIBO
Qiskit
Quest
Qulacs
TKET™
Torch Quantum

The NVIDIA Quantum Platform

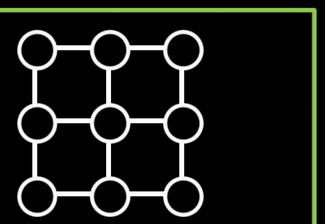
Bringing AI Supercomputing to Enable Useful Quantum Computing

CUDA-QX
Turnkey Quantum Research and Application Development

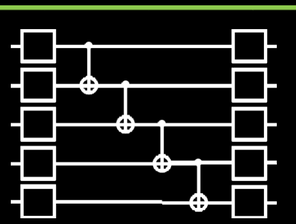
CUDA-Q
Open-Source Software Platform for Accelerated Quantum Supercomputers

cuQuantum
Accelerated Quantum Simulations

DGX Quantum
Reference Architecture for Low Latency Integration



CUDA-Q QEC



CUDA-Q Solvers

QUANTUM MACHINES

NVIDIA

CUDA-Q Python Bindings

Core C++ compiler platform exposed via builder API
JIT compile Quake representation at runtime

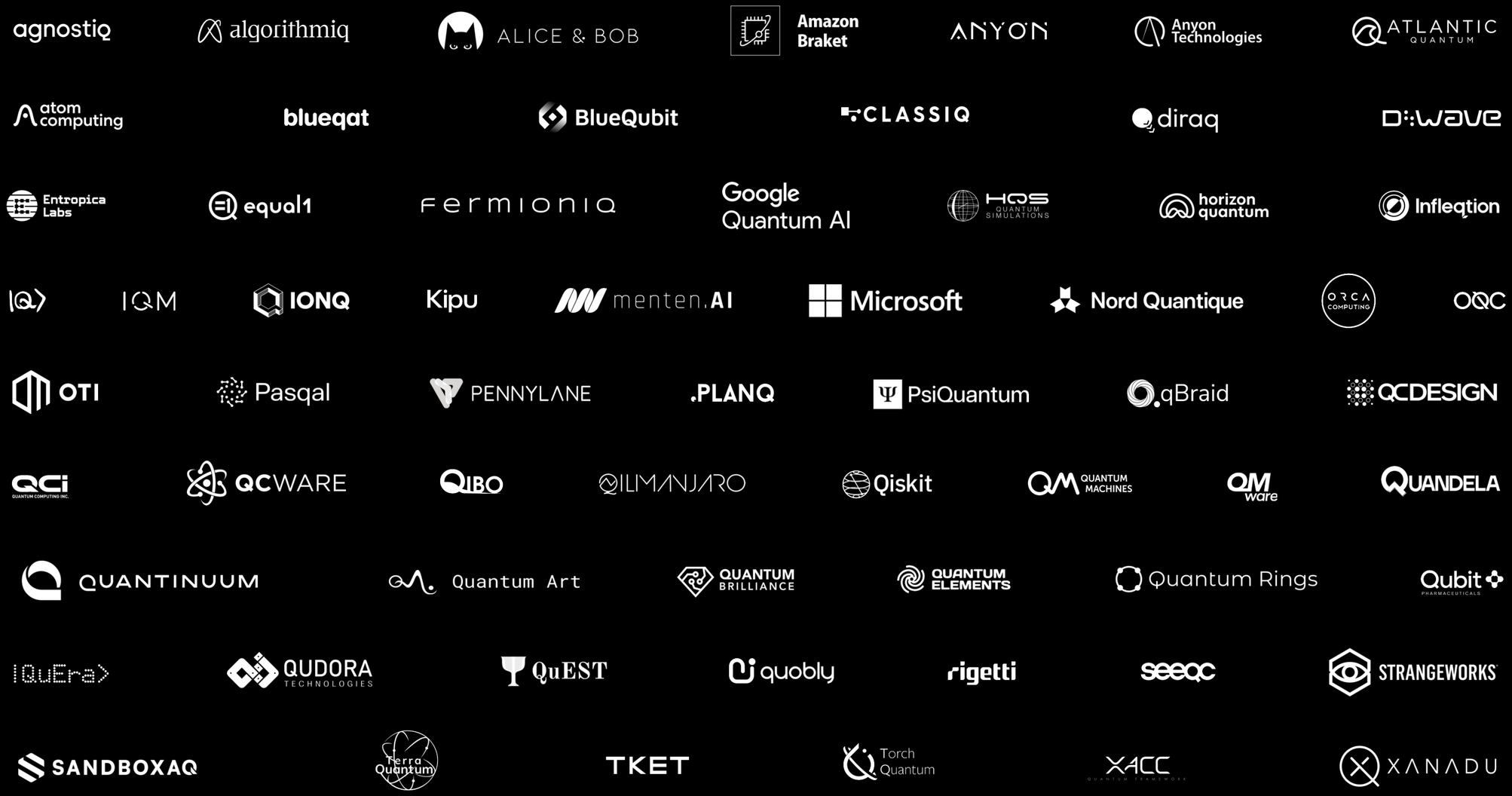
- Simple ways to create quantum kernels

```python
import cudaq

@cudaq.kernel
def kernel():
  # A single qubit initialized to the
  ground / zero state
  qubit = cudaq.qubit()

  # Apply the Pauli x gate to the qubit
  x(qubit)

  # Measurement operator
  mz(qubit)


# Sample the qubit for 1000 shots to gather
statistics
result = cudaq.sample(kernel,
shots_count=1000)
```

```python
import cudaq

@cudaq.kernel
def kernel(angles: List[float]):
  # Allocate a qubit that is initialized to
  the |0> state.
  qubit = cudaq.qubit()

  # Apply parameterized gates to the qubit
  rx(angles[0], qubit)
  ry(angles[1], qubit)

# Gate parameters which initialize the qubit
in the zero state
initial_parameters = [0, 0]

# Draw the circuit diagram for the kernel
print(cudaq.draw(kernel, initial_parameters))
```

The NVIDIA Quantum Ecosystem

Accelerating the Quantum World



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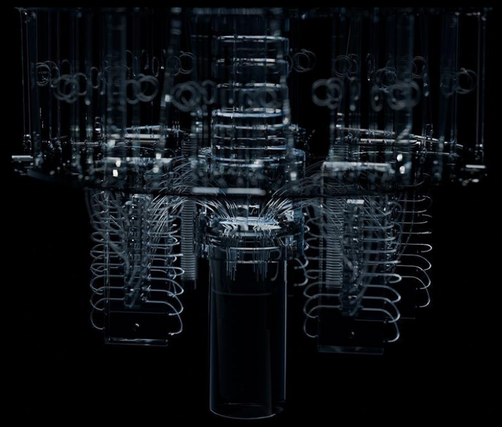
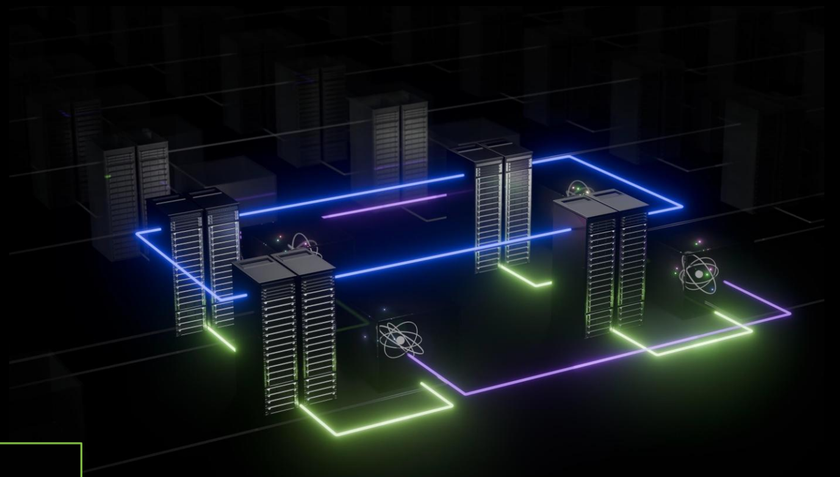
Challenges Ahead

How to Turn Qubits into Accelerated Quantum Supercomputers





Qubits

Better QPUs

GPU

Better Algorithms

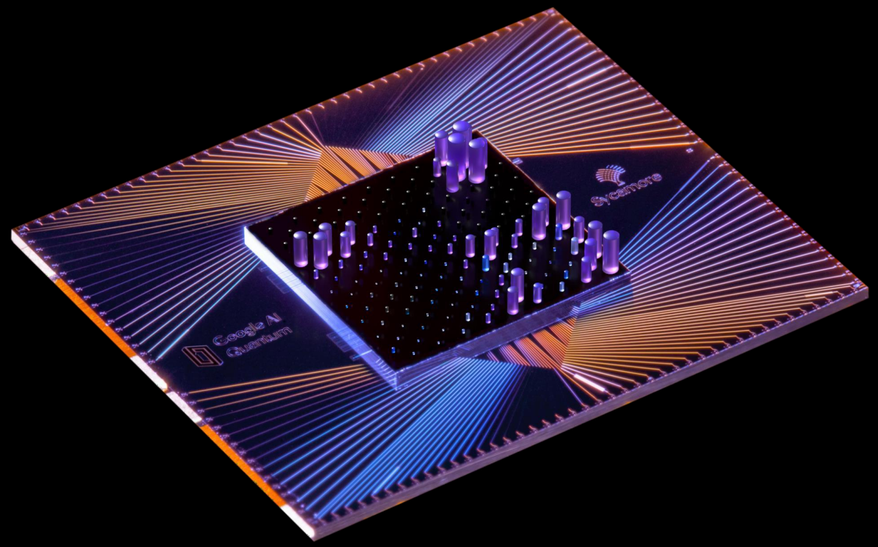
Scaling QEC

Accelerated Quantum Supercomputers

Developing Better QPUs with Simulation

NVIDIA

Google Quantum AI



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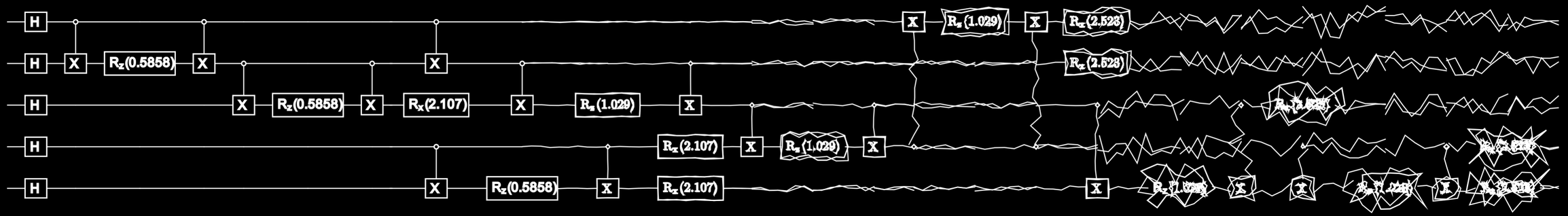
Noise Limits Today's Quantum Hardware

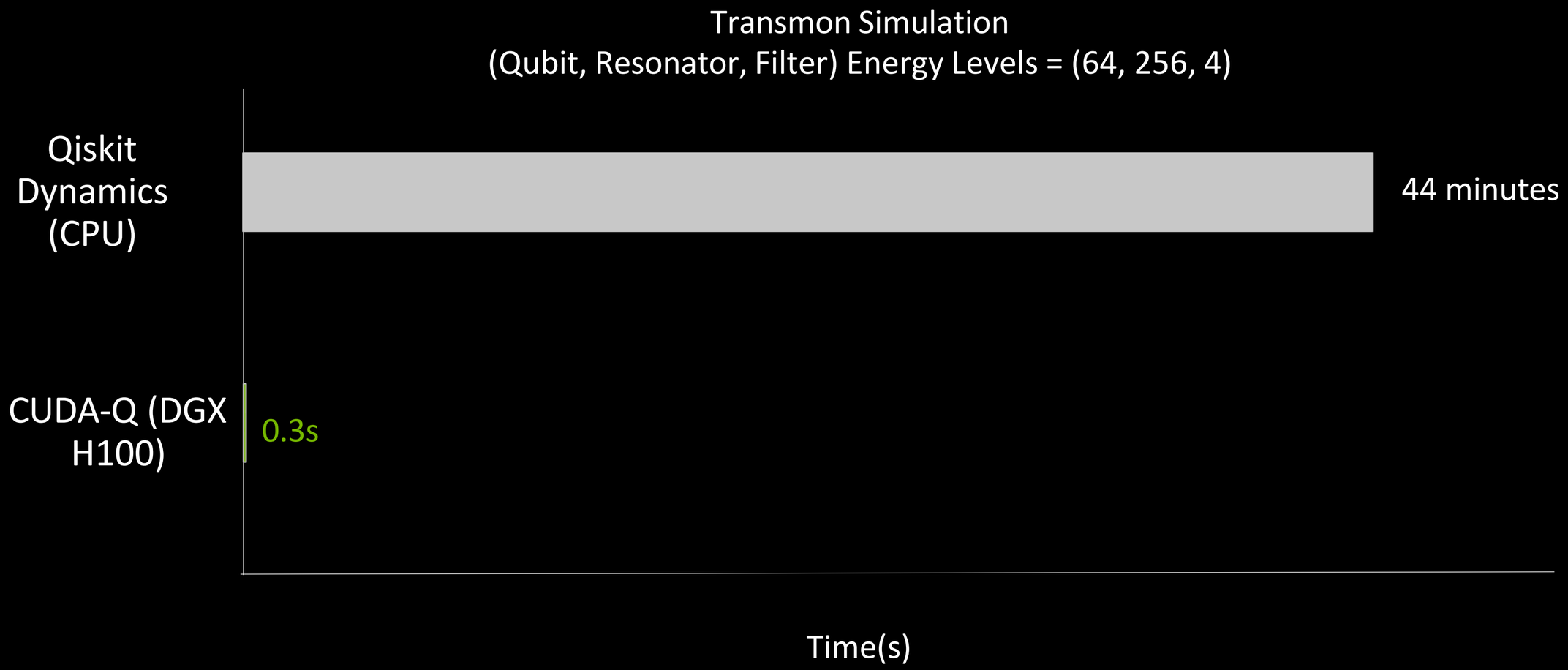


Current quantum hardware is limited to just hundreds of instructions by noise

Quantum
Processor

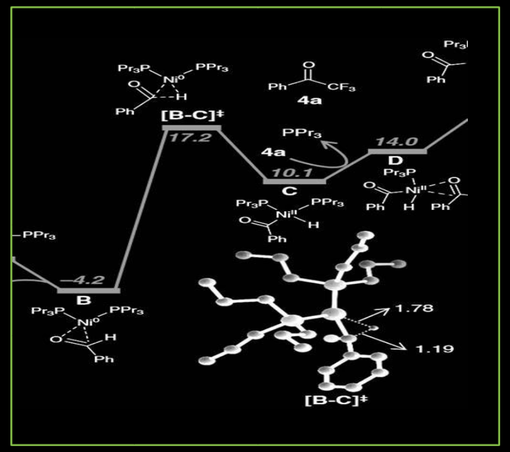
Dynamics in CUDA-Q

Enabling Better QPU Designs

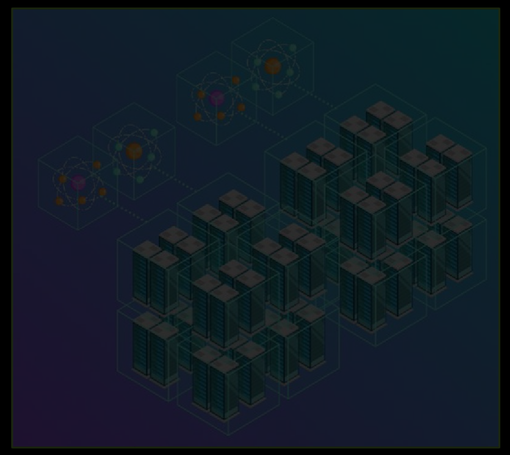


CPU: Intel Xeon 8480CL | GPU: H100
Energy levels: 64 Transmon x 128 Resonator x 4 Purcell Filter

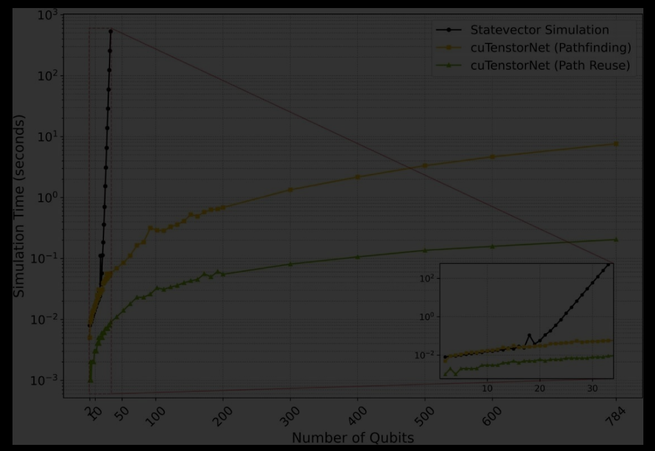
Better Algorithms with Large-Scale Simulations and AI



IonQ/AWS/AstraZeneca
AF-QMC simulation for electronic structure modeling



HPE Labs
Distributed QC with Adaptive Circuit Knitting



NCHC
784 qubit simulation to validate QML approaches

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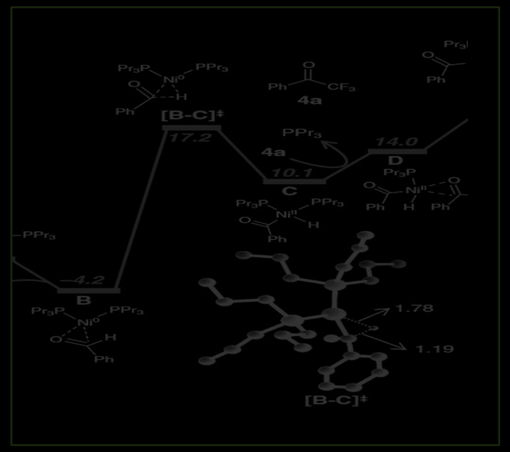

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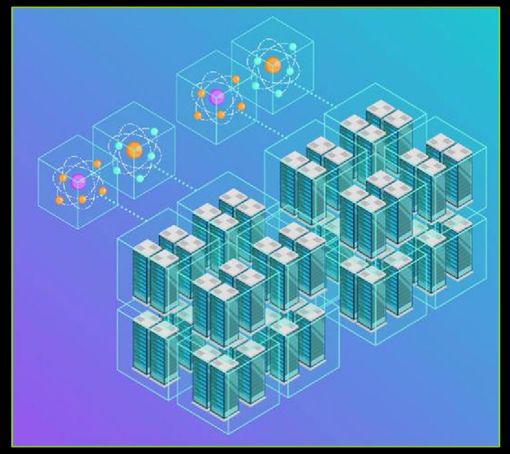

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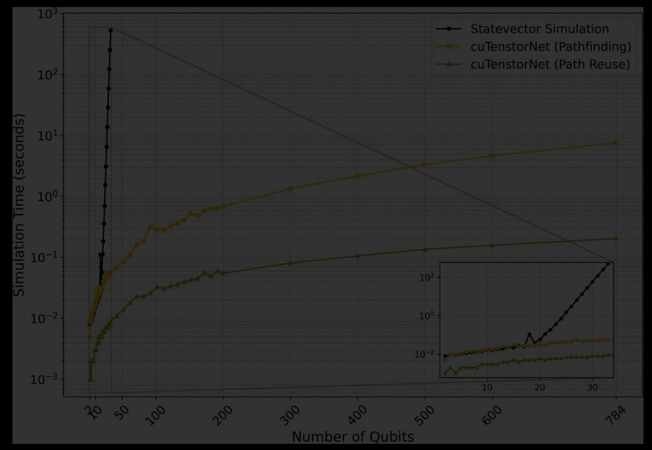

NCHC
784 qubit simulation to validate QML approaches

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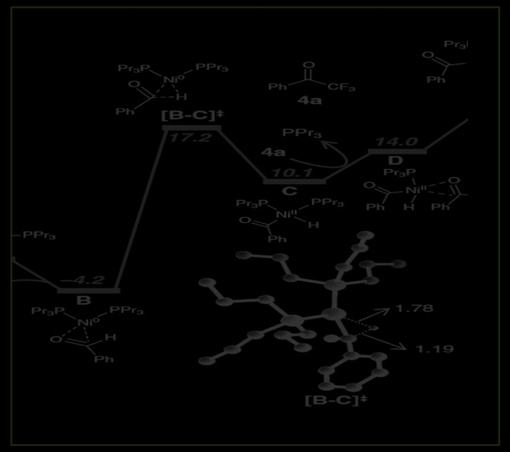
Mohseni *et. al*. How to Build a Quantum Supercomputer: Scaling Challenges and Opportunities
https://arxiv.org/html/2411.10406v1 (2024) GTC Talk DD73669

NVIDIA

Better Algorithms with Large-Scale Simulations and AI



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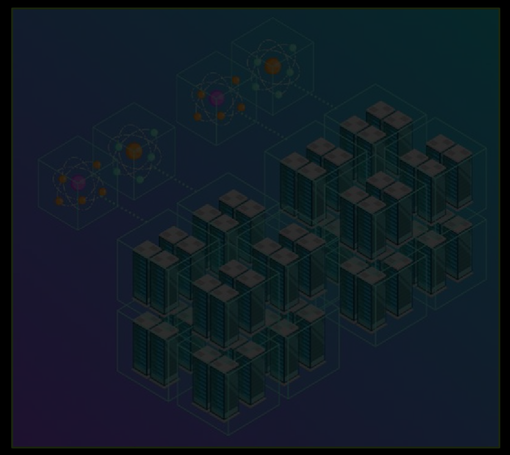

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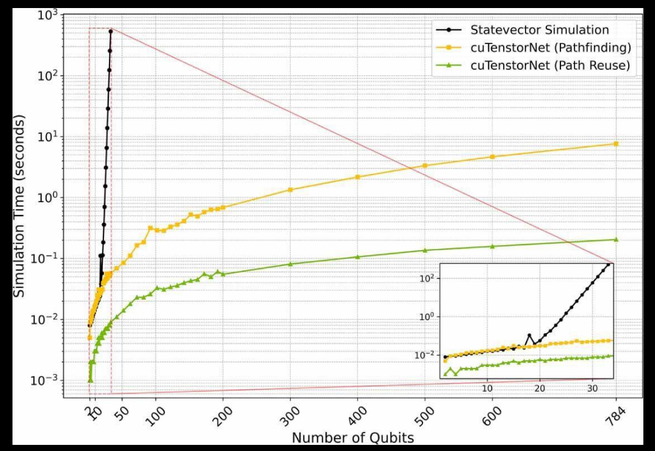

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784 qubit simulation to validate QML approaches

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Chen *et. al*. cuTN-QSVM: cuTensorNet-accelerated Quantum Support Vector Machine with cuQuantum SDK. https://arxiv.org/html/2405.02630v2 (2024)

Solar Energy Prediction with NVIDIA CUDA-Q

Demonstration of hybrid neural networks for sustainable energy

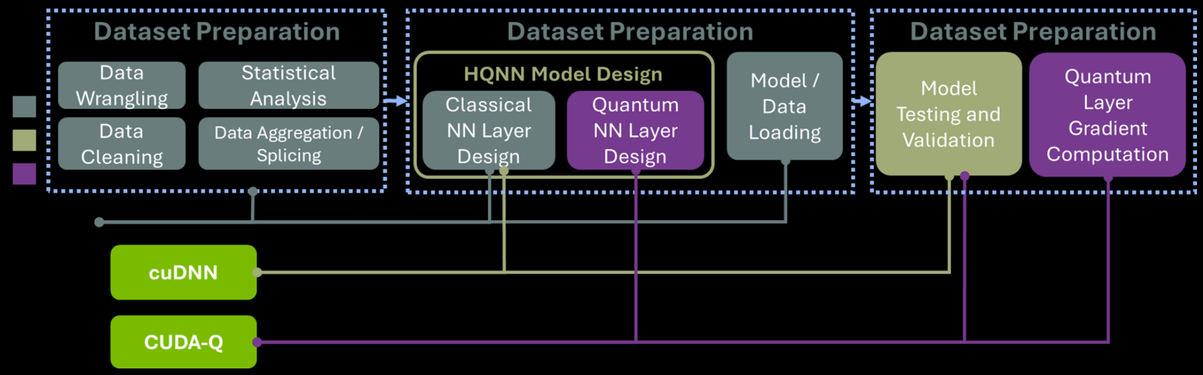
CUDA-Q + 

Challenge

- Variations in renewable energy generation calls for highly reliable forecasting
- Conventional machine learning approaches to solar energy prediction are computationally challenging

Solution

- Hybrid Quantum+Classical neural networks offer promise for improved solar energy forecasting
- Accelerated workflow with CUDA-Q allows exploration and assessment of hybrid forecasting techniques

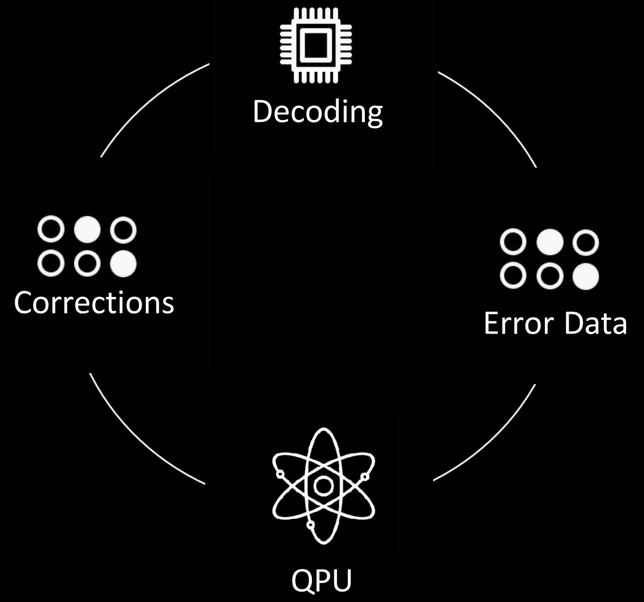


Faster training times

Increased model accuracy

Ying-Yi Hong, Dylan Josh Lopez, et al. "Accelerating Quantum Algorithms for Solar Energy Prediction with NVIDIA CUDA-Q and NVIDIA cuDNN" NVIDIA Technical Blog (2024).

Quantum Error Correction – The Challenge of Decoding



10^{-3}
State of the art error rates

$<10^{-10}$
Expected Error rates needed

> 1000
Logical qubits needed to factor a 2,048-bit number in > 100 hours

~ 1 million
Physical qubits needed with QEC

Qubits

Better QPUs

GPU

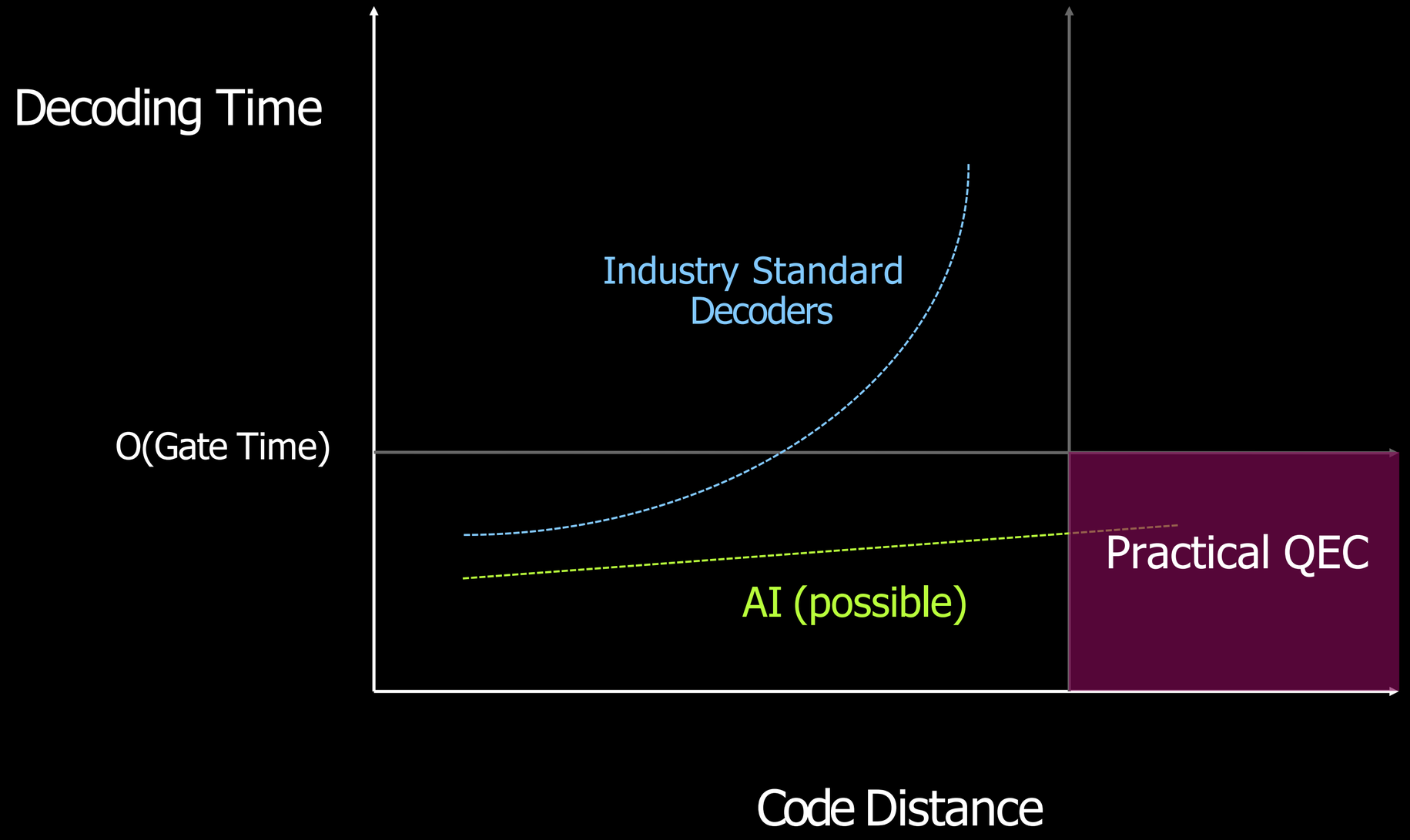
Better Algorithms

Scaling QEC

Accelerated Quantum Supercomputers

Craig Gidney. How to factor 2048 bit RSA integers with less than a million noisy qubits. https://www.arxiv.org/abs/2505.15917 (2025)

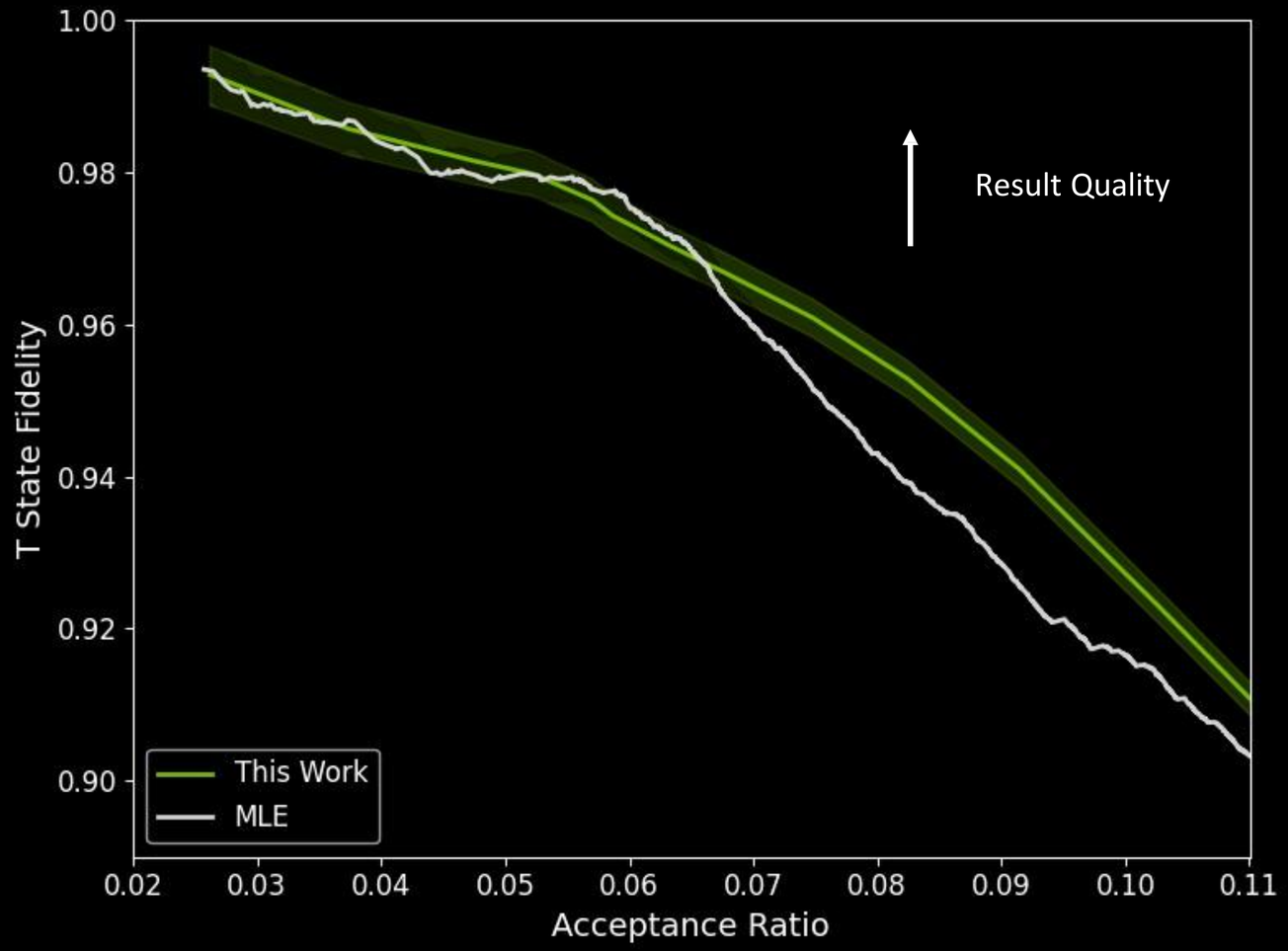
Quantum Error Correction – Why Quantum Computing Needs AI Supercomputing



Decoding QuEra's QPU with AI

Transformer-based decoder

- Trained on synthetic data with QuEra noise model
- Improved accuracy over MLE for small codes – d = 3
- Decoding time ~1ms, 50x improvement over SotA

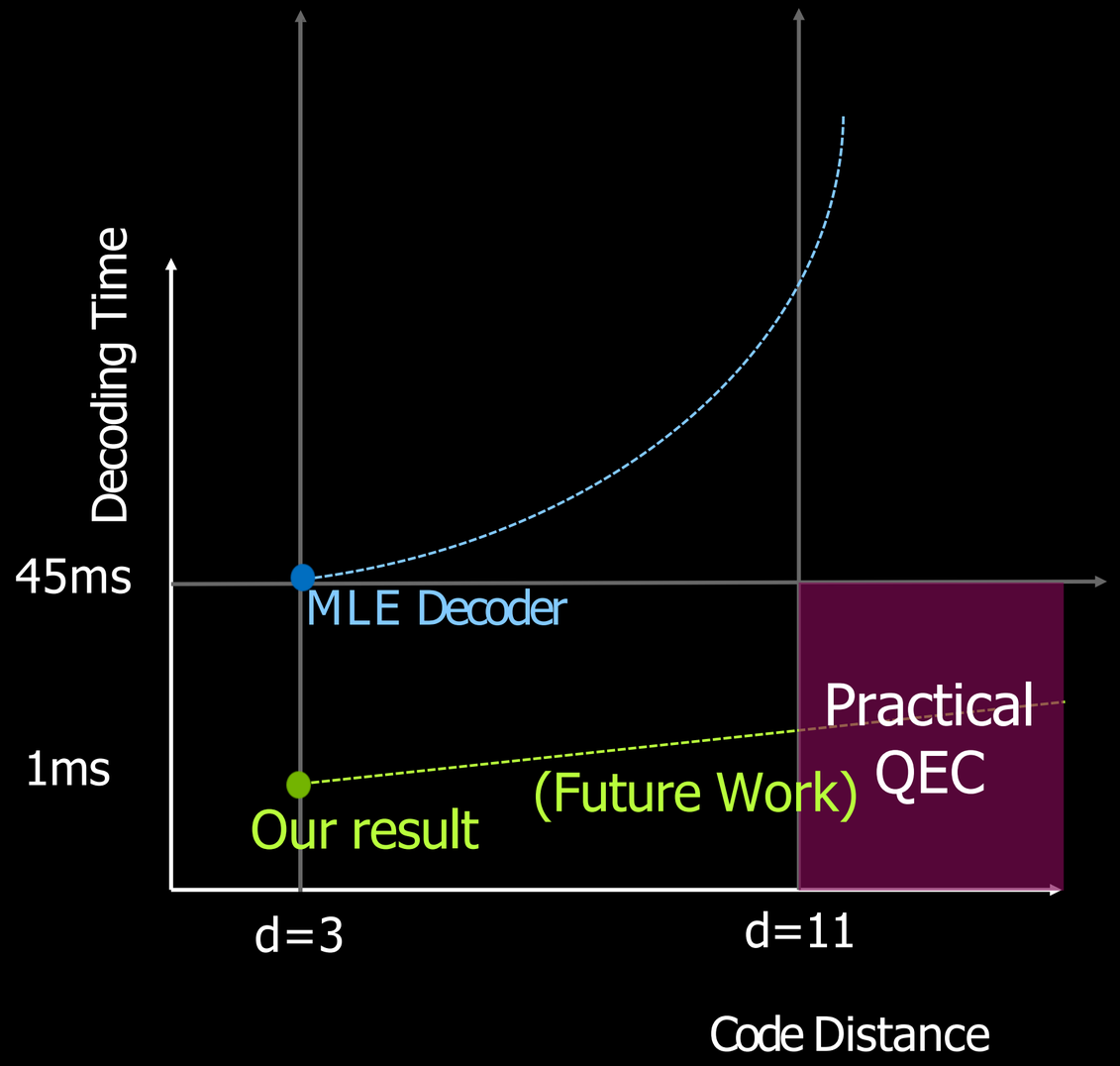


Decoding QuEra's QPU with AI

Transformer-based decoder

Future Work

- Larger codes – much more training data needed
- Fine-tune on QPU data for higher accuracy
- Deploy for real-time decoding



Let’s begin Hands-on