
AWS
re:Invent
NOV. 28 – DEC. 2, 2022 | LAS VEGAS, NV

QTC201

How AWS is making quantum technologies a practical reality

Scott Buchholz

Global Quantum Computing lead
Deloitte

Oskar Painter

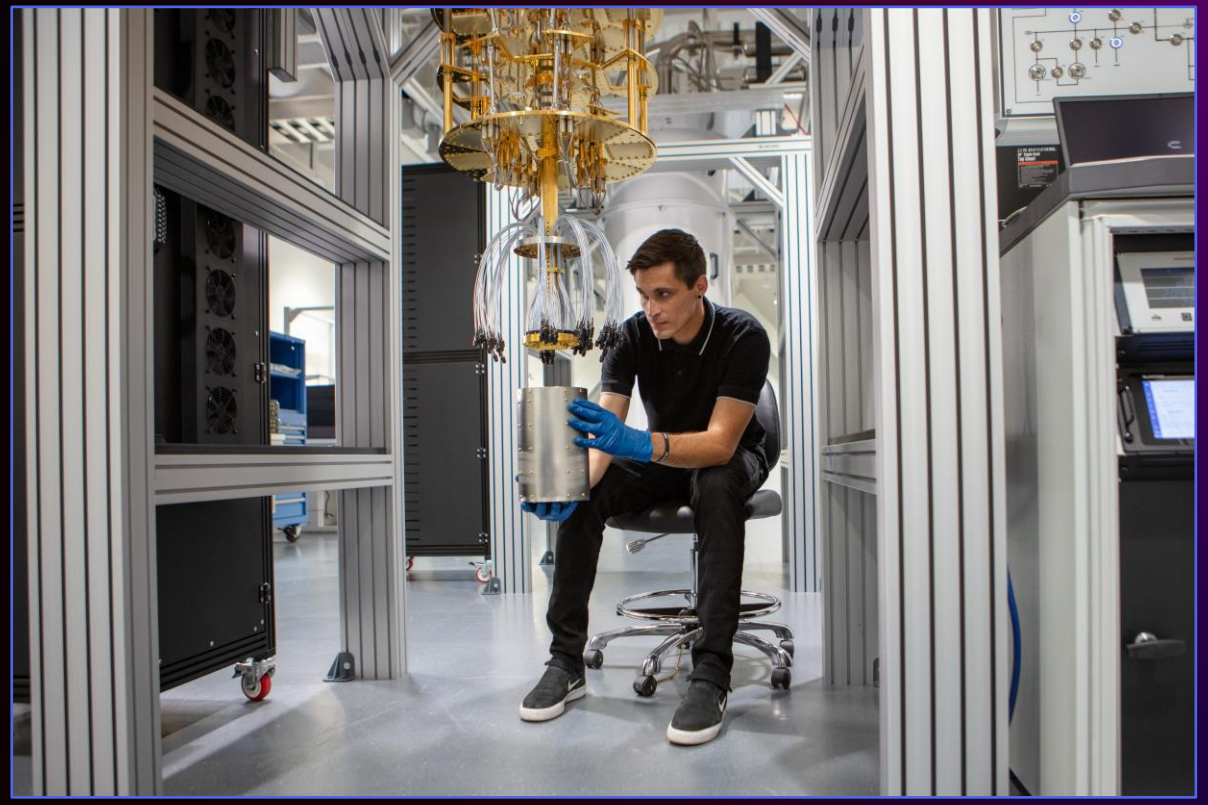
Director, Quantum Hardware
AWS

Simone Severini

GM, Quantum Technologies
AWS

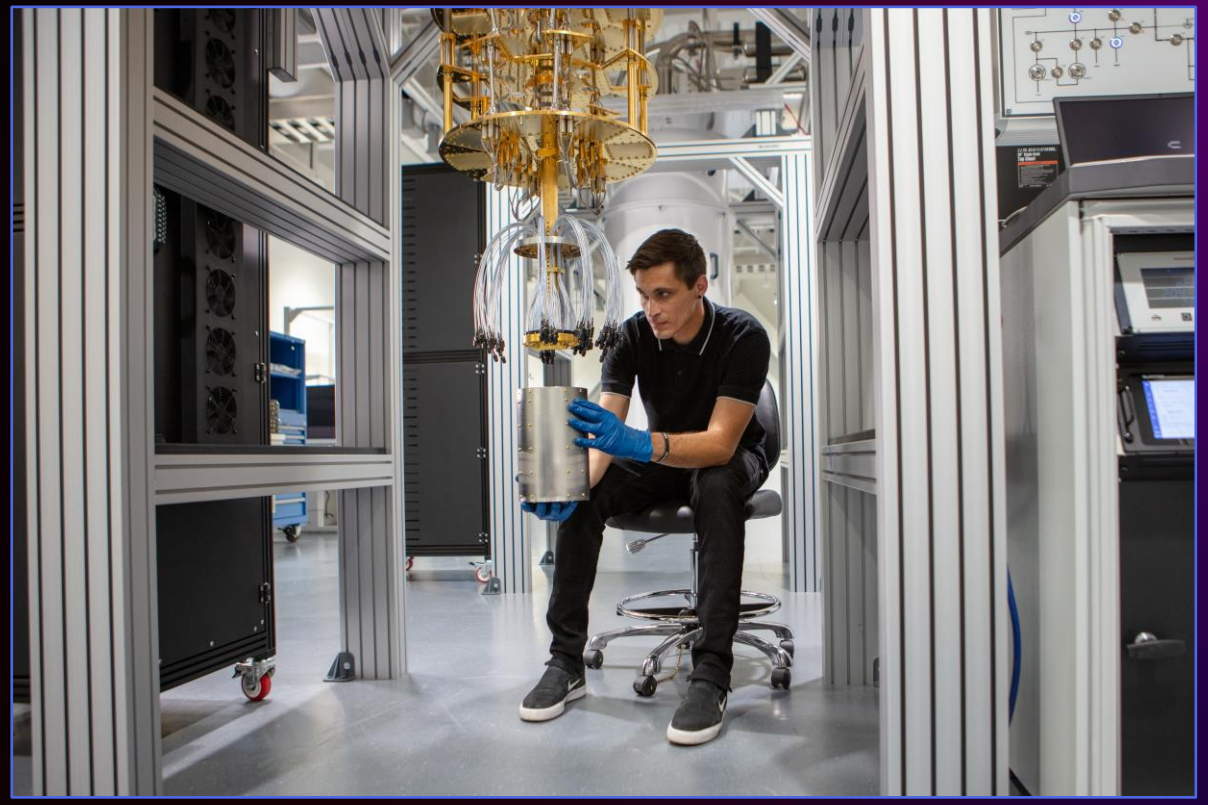
What is quantum computing?

- A **new paradigm** for computation that leverages the laws of quantum physics
- Will potentially solve certain problems **much more efficiently**
- Building hardware at scale is a **difficult challenge** because quantum computers are prone to errors



What is quantum computing?

- A **new paradigm** for computation that leverages the laws of quantum physics
- Will potentially solve certain problems **much more efficiently**
- Building hardware at scale is a **difficult challenge** because quantum computers are prone to errors



Where is quantum computing today?

- The quest for **practical quantum advantage** is ongoing
- The **elephant in the room:** today there is no advantage in business
- “If a company doesn't do anything about the market right now [...], when quantum advantage becomes real, it might be **too late**”

Marco Pistoia, JPMorgan

Where is quantum computing today?

- The quest for **practical quantum advantage** is ongoing
- The **elephant in the room**: today there is no advantage in business
- “If a company doesn't do anything about the market right now [...], when quantum advantage becomes real, it might be **too late**”

Marco Pistoia, JPMorgan

Customer problem (2019)

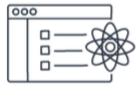
Customers need a one-stop shop for exploring quantum computing

Amazon Braket

Service dashboard

Reset to default layout | + Add widgets

Welcome to Amazon Braket



Example Jupyter notebooks

Explore real world examples of all features offered by Amazon Braket.

Braket Python SDK

A feature rich open source library to ease your experience.

Developer guide

Learn the fundamentals to get the most out of Amazon Braket.

Recent jobs Info

No recent jobs

Amazon Braket Hybrid Jobs combines classical compute resources with quantum computing devices to optimize the performance of today's quantum systems.

Create job

View all jobs

Community support

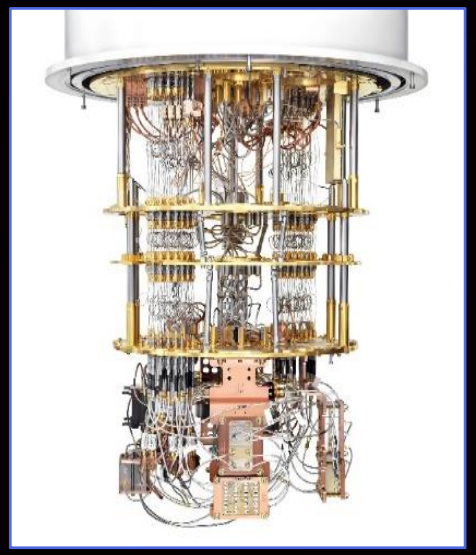
AWS re:Post

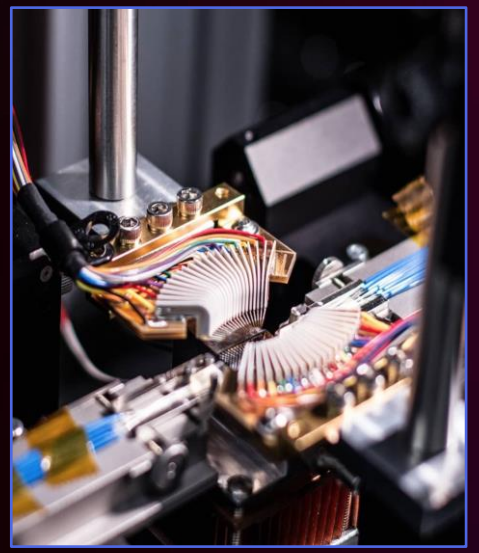
AWS re:Post enables you to ask questions about anything related to designing, building, deploying, and operating workloads on AWS, and get answers from community experts, including AWS customers, Partners, and employees.

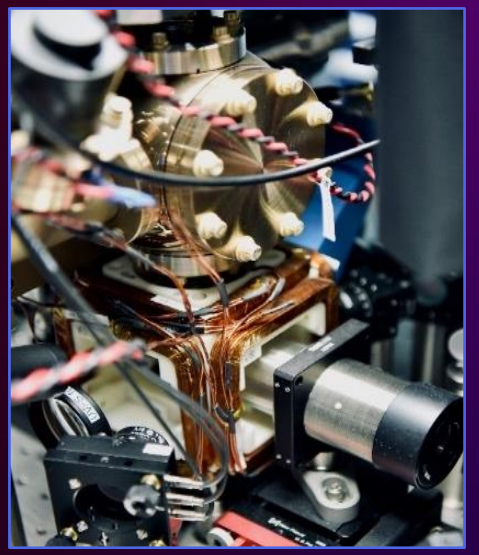
AWS Quantum Computing Blog

Follow the latest news and announcements.

Quantum hardware available on Amazon Braket







IONQ

rigetti

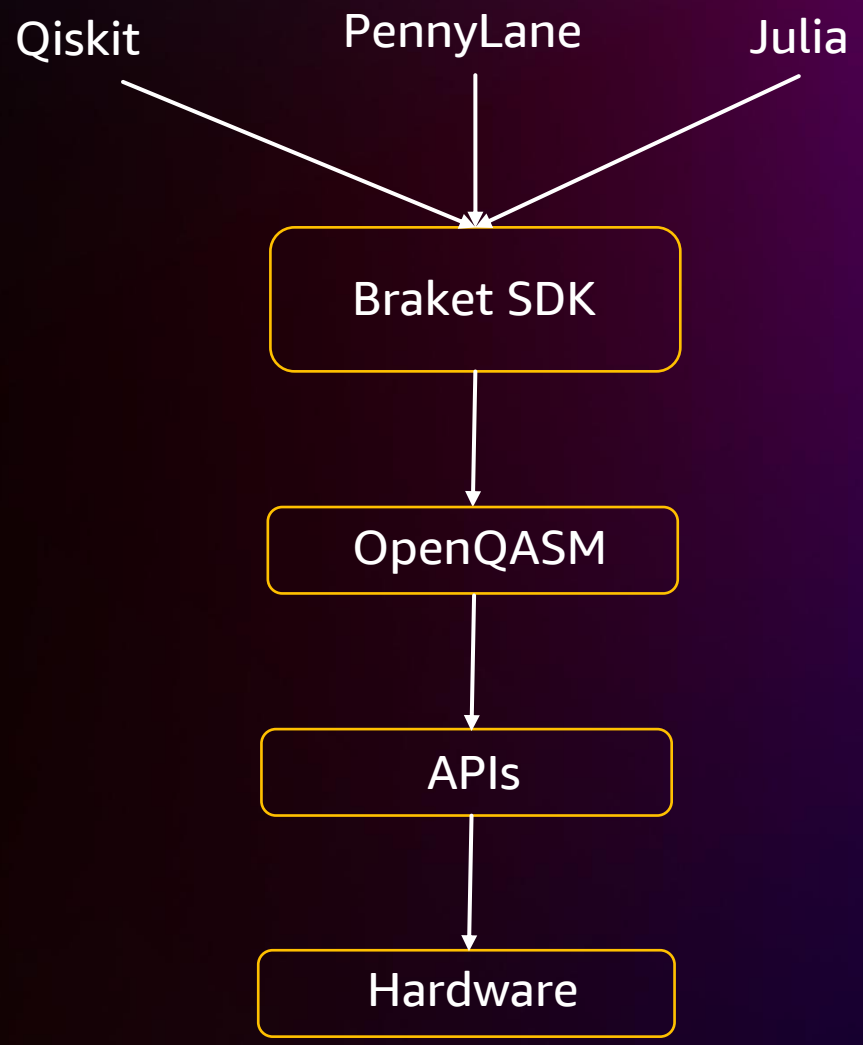
OQC

XANADU

QUERA COMPUTING INC.

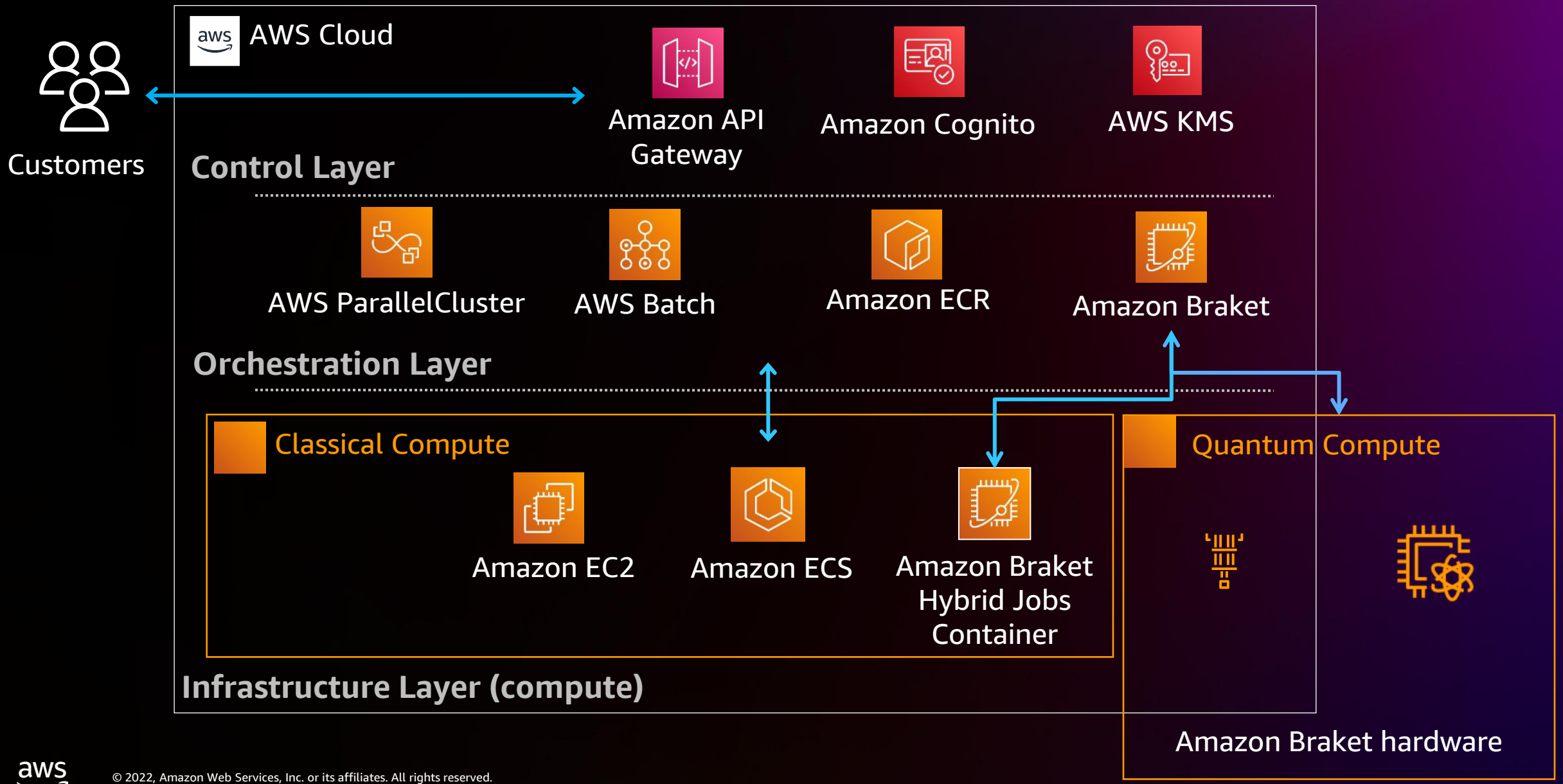
Amazon Braket software stack

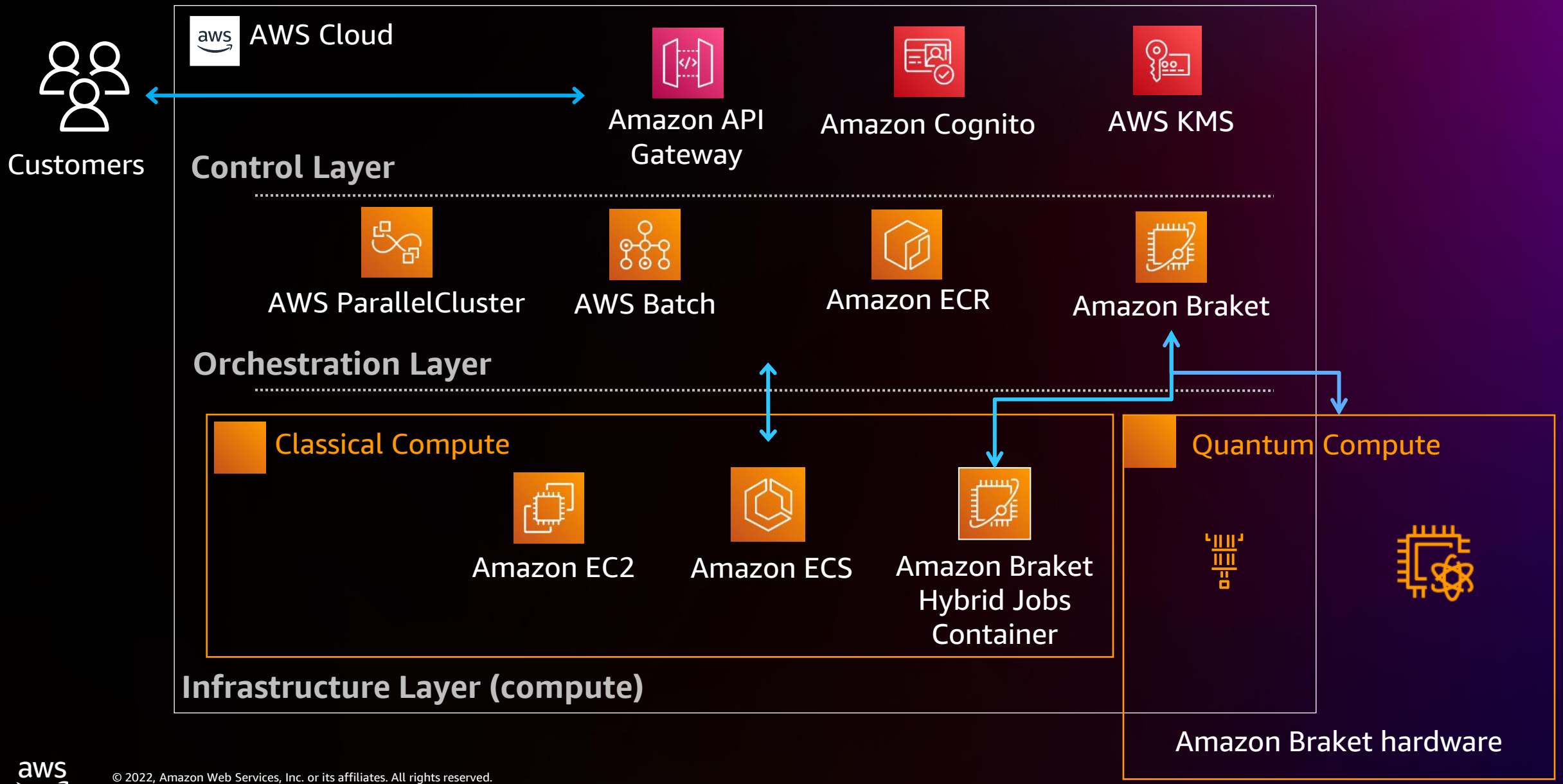
- **One-stop shop interface** for accessing different quantum computers and state-of-the-art simulators
- **Compatible** with popular tooling such as PennyLane, TensorFlow, Qiskit, Julia
- **Choice** of interfaces to enable builders operate at different levels depending on their application



Customer problem (2019)

Customers need quantum hardware integrated with cloud resources





Preparing for your quantum future:

Start your journey today!

Deloitte.

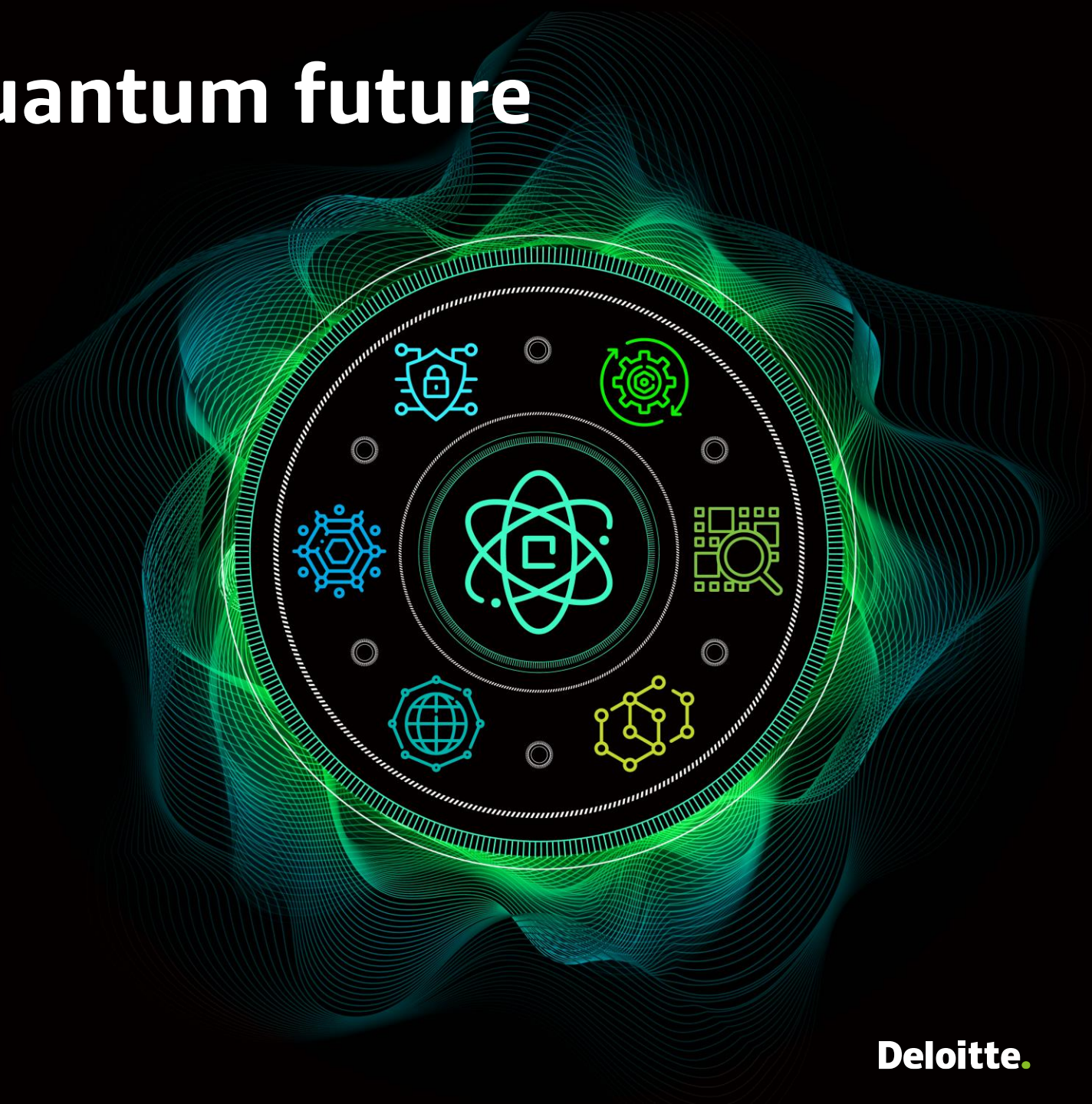
aws

Preparing for your quantum future

At Deloitte, we help you …

- Explore and understand
- Connect and discover
- Amplify and accelerate

… your quantum journey



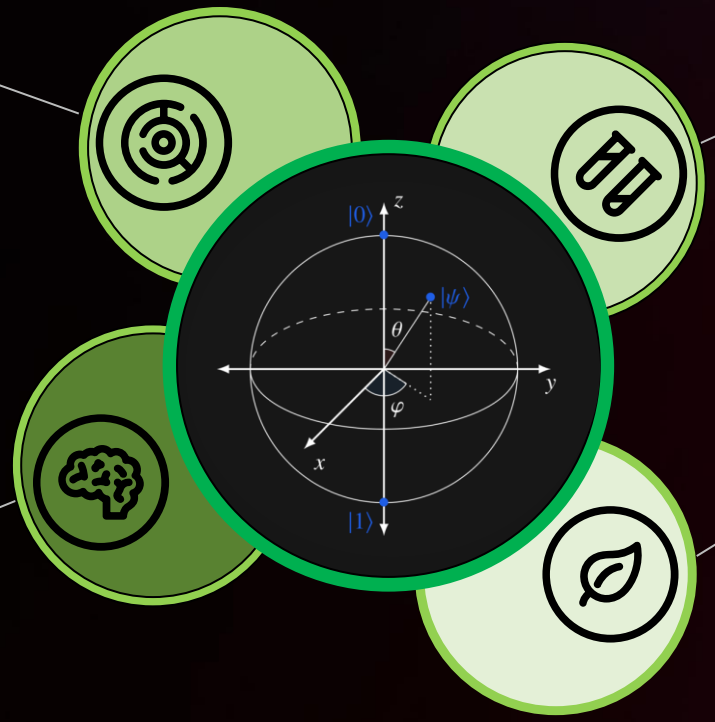
Why quantum computing?

Problem complexity

Quantum computers should be able to solve problems that are unsolvable by classical and high performance computers.

Giant state spaces

Quantum computers leverage the power of quantum mechanics to simulate the laws of nature such as the bonding of different atoms.



Model training effort

AI applications require significant training efforts. Hybrid algorithms using quantum computers should provide dramatic improvements.

Energy consumption

Quantum computers should produce more results per unit of energy used compared to conventional high performance and classical computing.

Sometimes, physics beats math

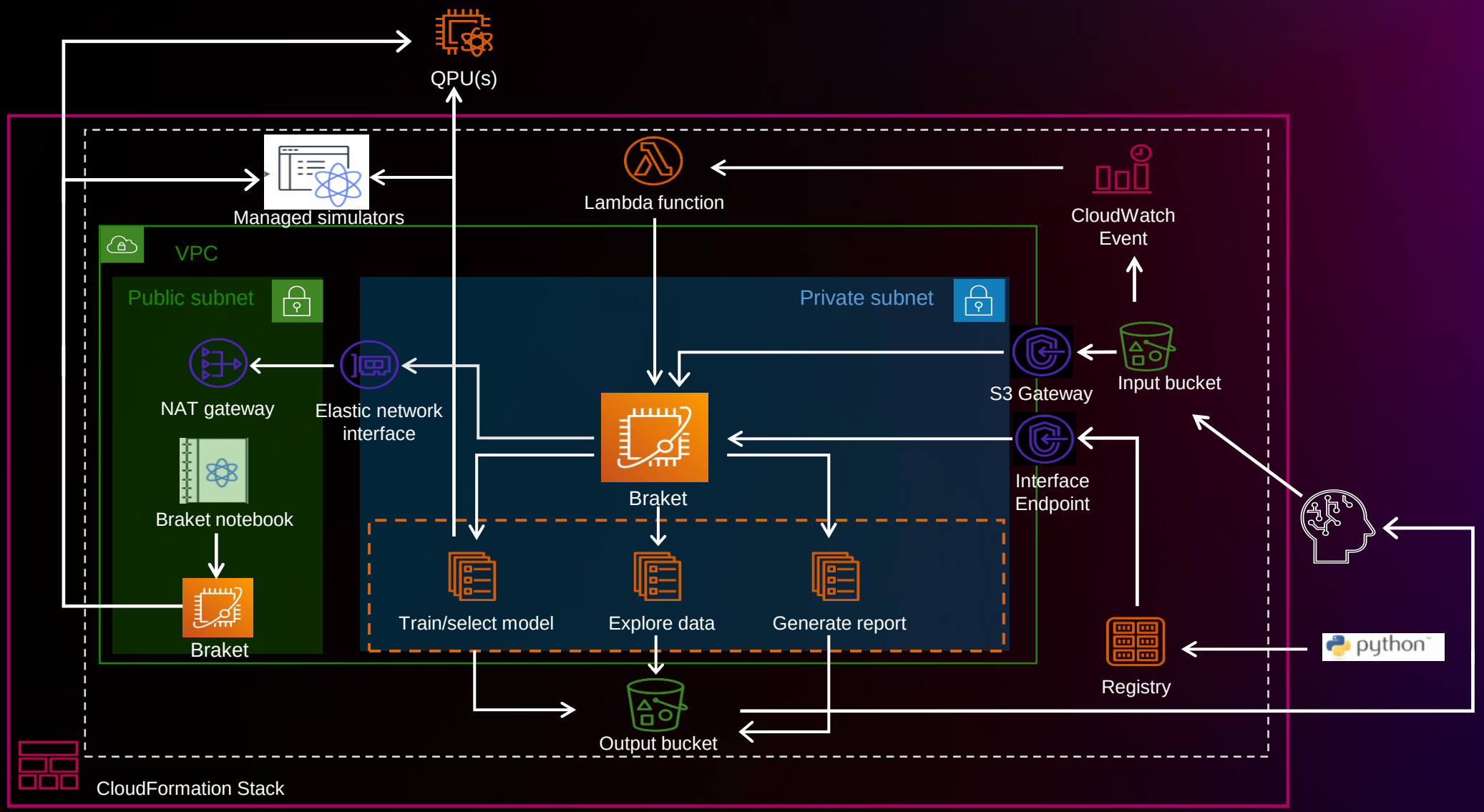
Quantum will be a game changer

Quantum computing and related technologies are steadily advancing, showing promising results

Global investments are surging across the Fortune 500, startups, governments, and academia

New skills are required across different disciplines from the sciences to math to IT and beyond

A representative “as built” architecture



Join Us

To learn more, join us for a joint AWS/Deloitte Event in February 2023 to accelerate your Quantum Computing journey!

QTC201

Anatomy of a (practical) Quantum Computer

Oskar Painter

Director, Quantum Hardware,
AWS

Criteria for a “practical” quantum computer

Quantum computers, capable of commercially-relevant computations at significant quantum advantage, will require:

1) Quantum processors supporting $\gtrsim$ 100 (logical) qubits
2) A universal set of gate operations between qubits
3) Error-free circuit operation at a circuit depth (number of gate steps) ~ 1B
4) Clock rate (limited by quantum gate times) exceeding tens of kHz

The most demanding criteria is the required gate error rate, which for a circuit of depth 1B operating over 1000 qubits, requires gate error rates < 1e-12 (0.000001%).
This is 9 orders of magnitude beyond the current state-of-the-art.

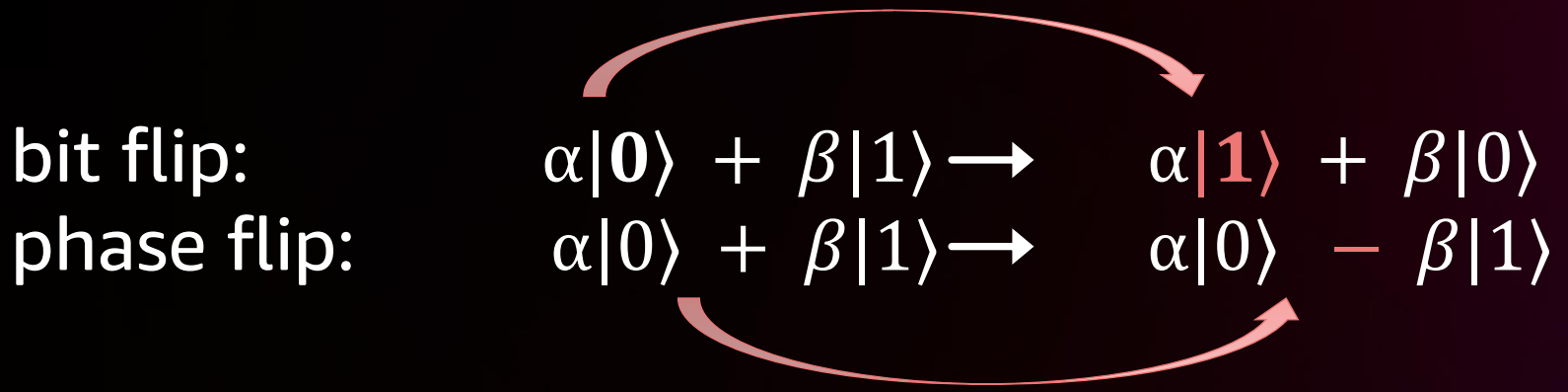
Lowering error rates

1. **Noise filtering:** Reduce the amplitude of the noise
   - Cooling and shielding systems
   - Design and packaging of processor
2. **Hardware-level error protection:** Reduce errors at the physical level
   - Materials and processing improvements
3. **Quantum Error Correction:** Detect and correct errors
   - Redundant encoding of information

Quantum error correction (QEC)

Q: Is it possible, even in principle?

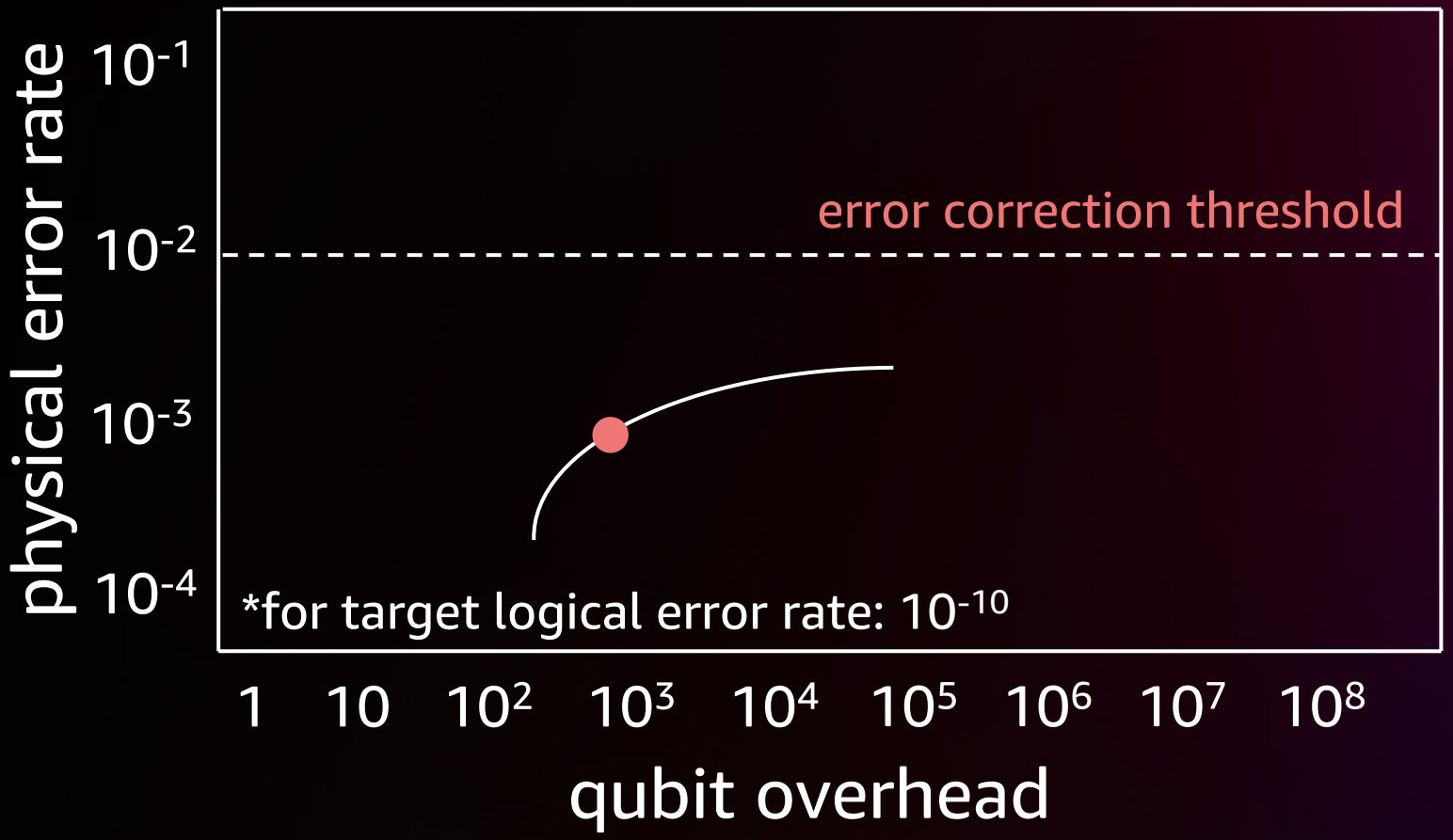
Two types of errors on a qubit ($\alpha|0\rangle + \beta|1\rangle$)



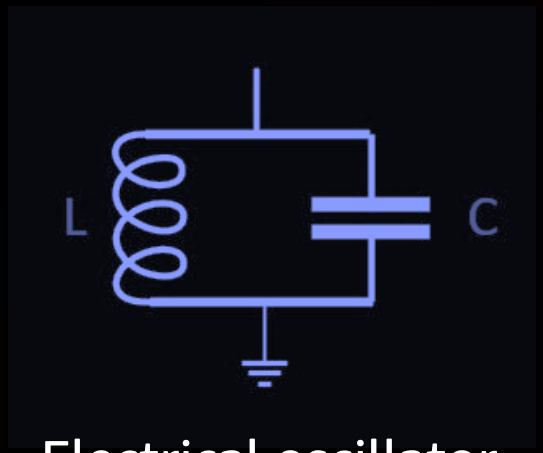
Can't measure qubit state in a single-shot ('quantum collapse')

Quantum error correction overhead

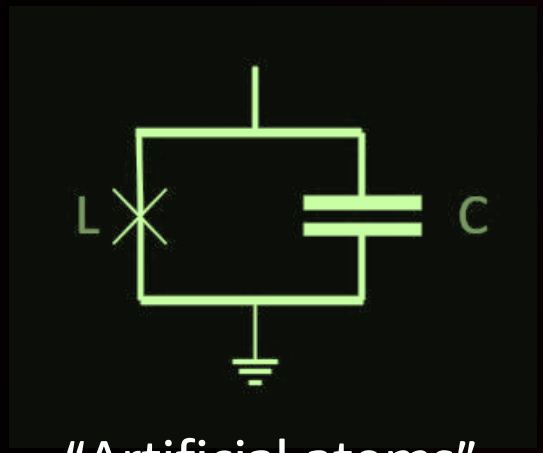
A: Yes, but only with special encoding into ‘logical’ qubits



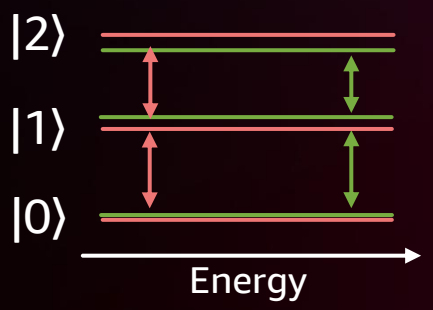
Superconducting qubit



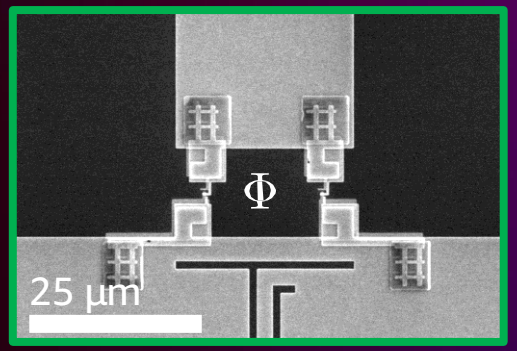
Electrical oscillator



“Artificial atoms”



Anharmonicity

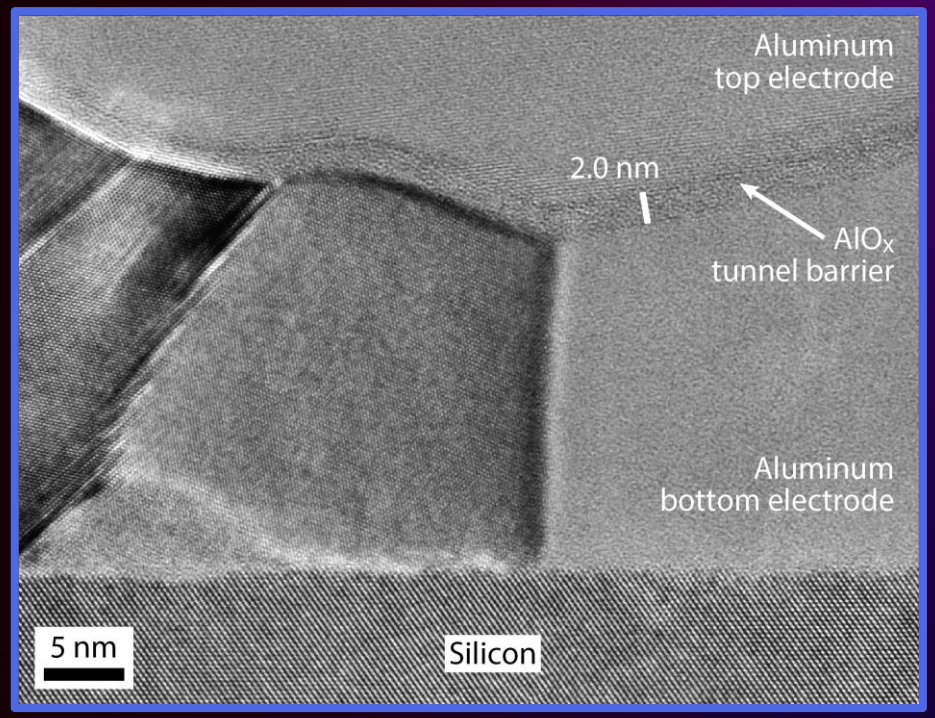


Josephson junction

- Wafer-scale microfabrication
- Flexible architecture
- Fast quantum gates
- Single-shot, high-fidelity qubit read-out

Physical qubit development

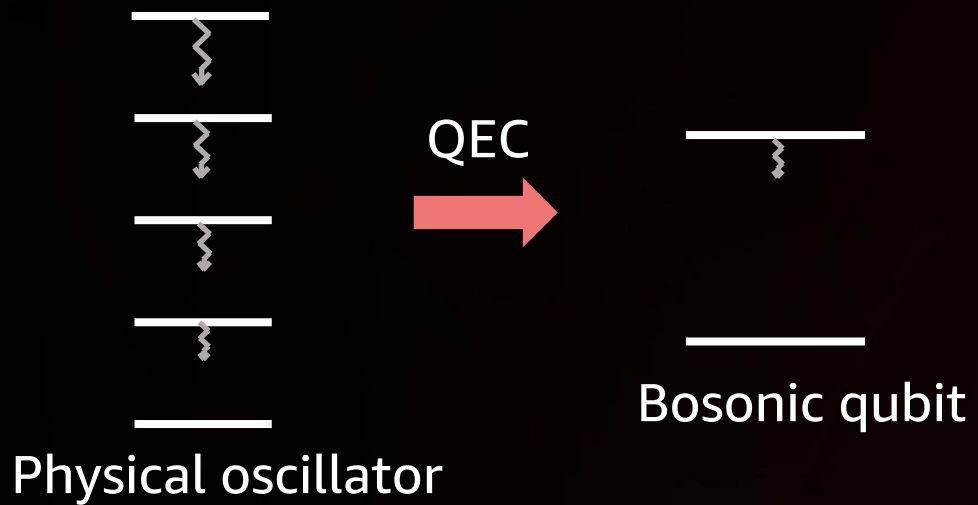
- **10-100X** reduction in physical qubit gate and read-out error rates is required in order to efficiently use QEC
- **How are we going to get there?**
- Investment in physical qubit development from top to bottom:
  - New physical qubits
  - Materials development
  - Josephson junction manufacturability



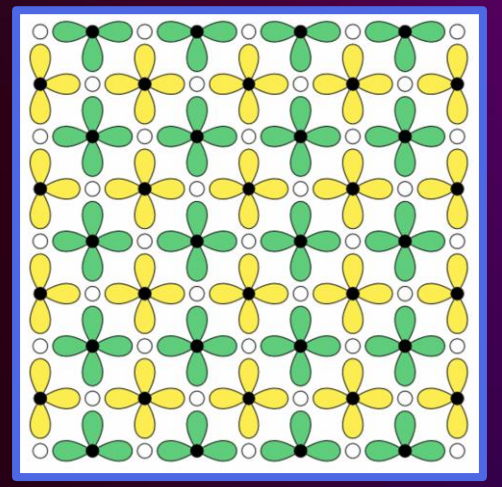
Logical qubits

Multi-qubit QEC

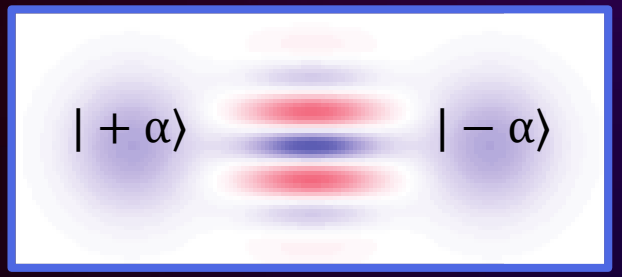
Bosonic QEC



surface code



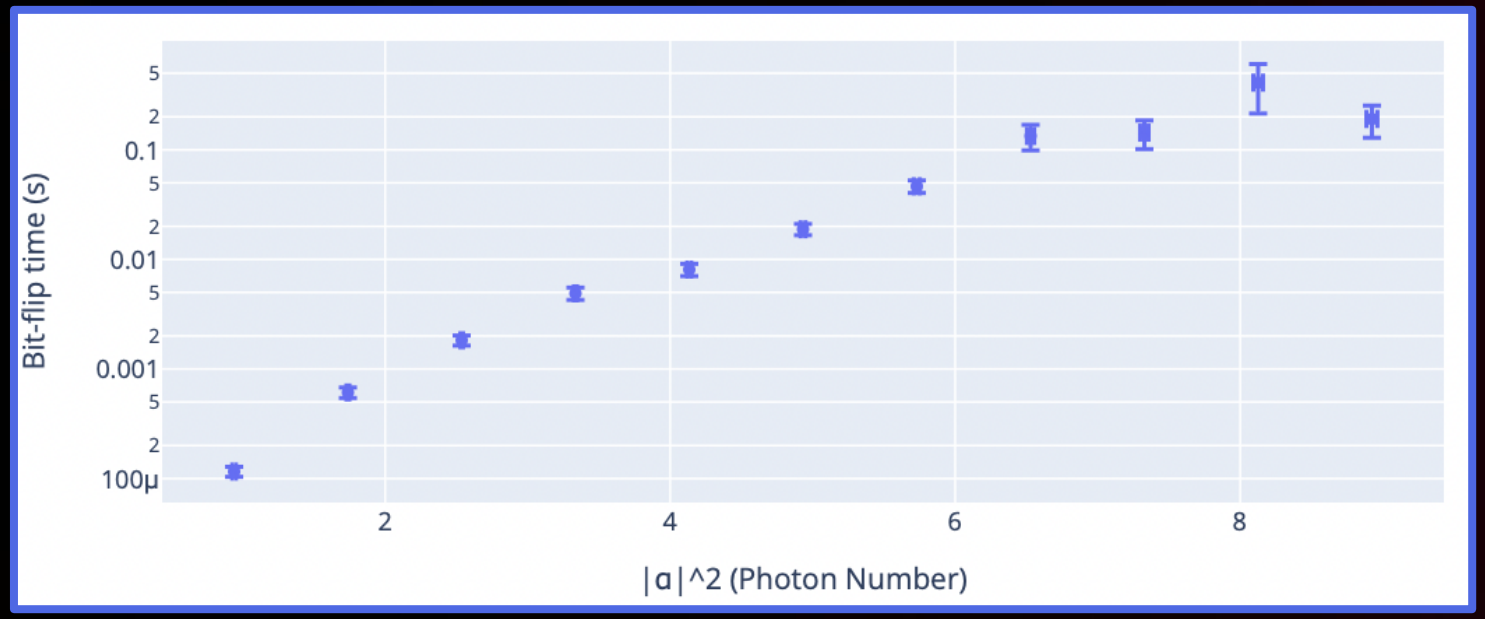
cat states

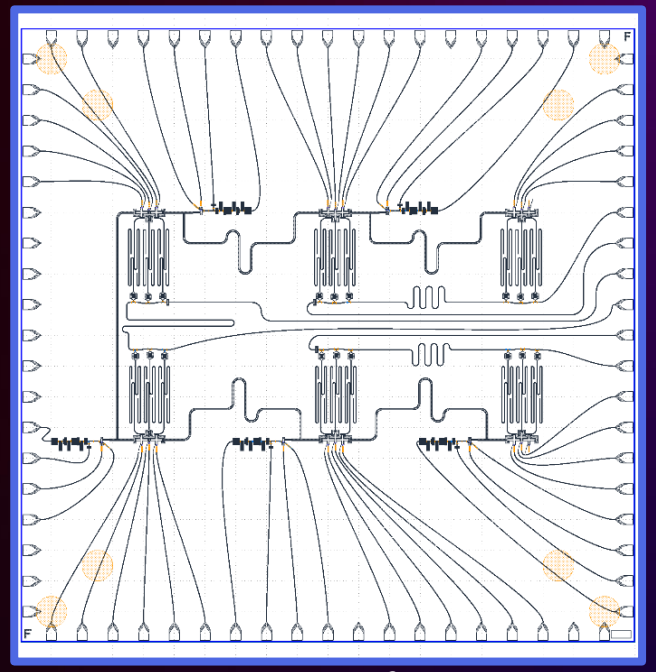


Repetition cat code: hardware-efficient QEC

Bit flips are exponentially suppressed through special dissipation engineering of cat qubits, while **phase flips are corrected by a repetition code**

Bit flip times extended by 5-orders of magnitude

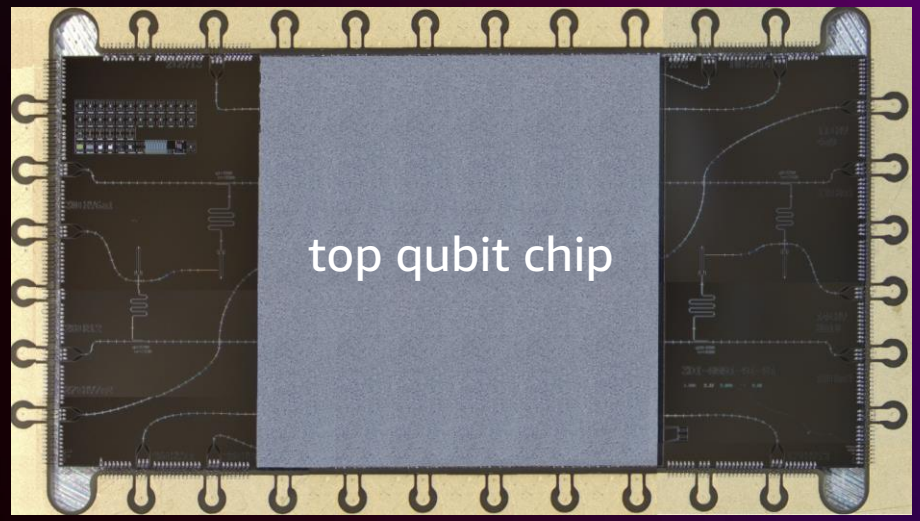


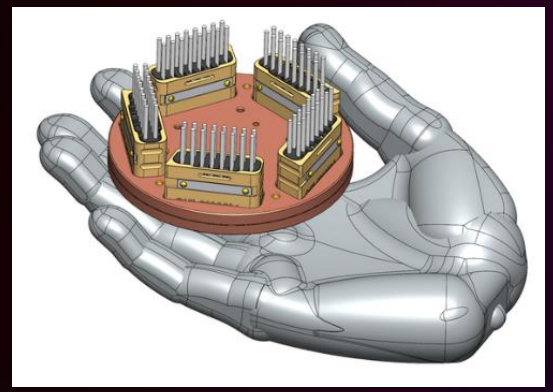


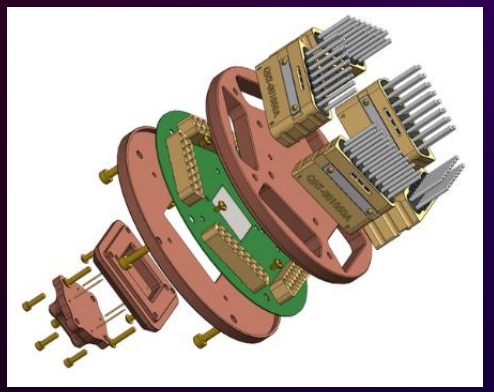
Chip layout of 2x2 cm^2, d=5 rep code

Processor scaling and packaging

- **3D chip integration:** scalable, low x-talk signal routing
- **Package design:** large format chips (>2x2cm)
- **Connectors:** RF/microwave, high pitch-density
- **Scale-out:** inter-processor connectivity

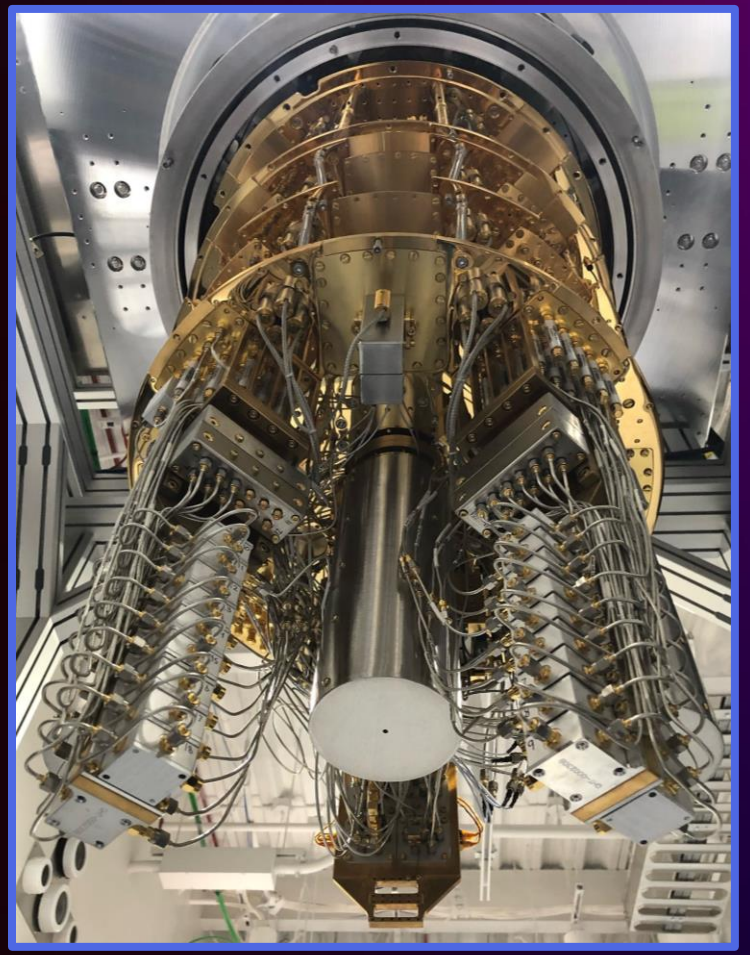






Fridge and wiring infrastructure

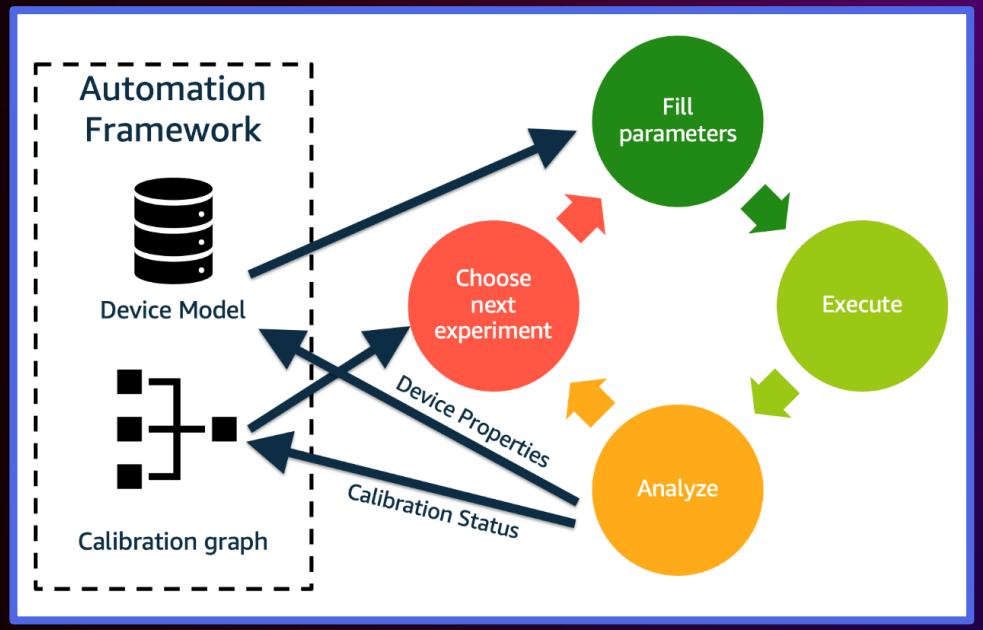
- Scalable fridge technologies that can support **100,000+ physical qubits**
- Scalable cryogenic wiring:
  - Microwave, DC, and thermal performance
  - High density form-factor
  - Drop-in components (filters, attenuators, etc.)



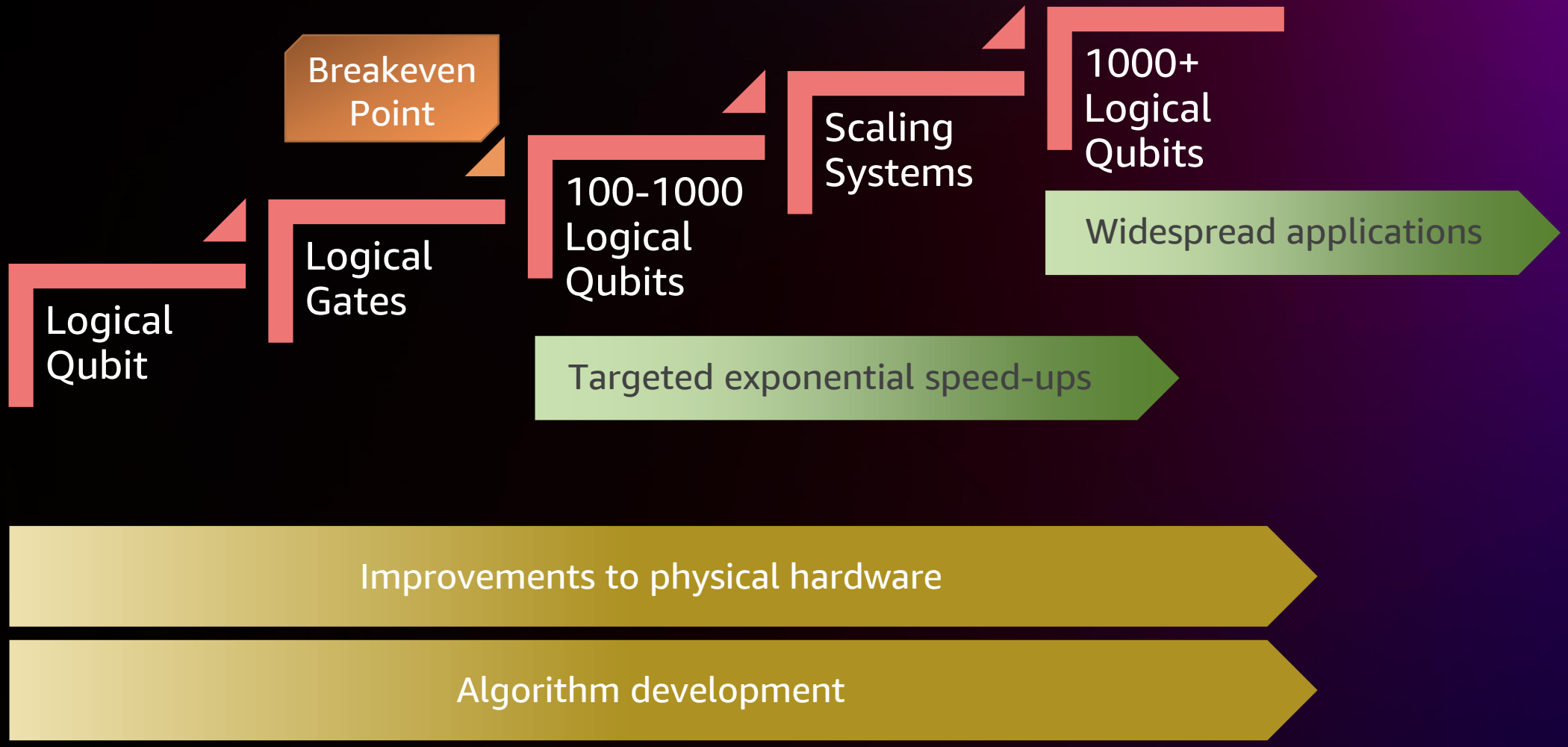
Software stack

Quantum error correction requires **tight integration between software and (classical) control hardware:**

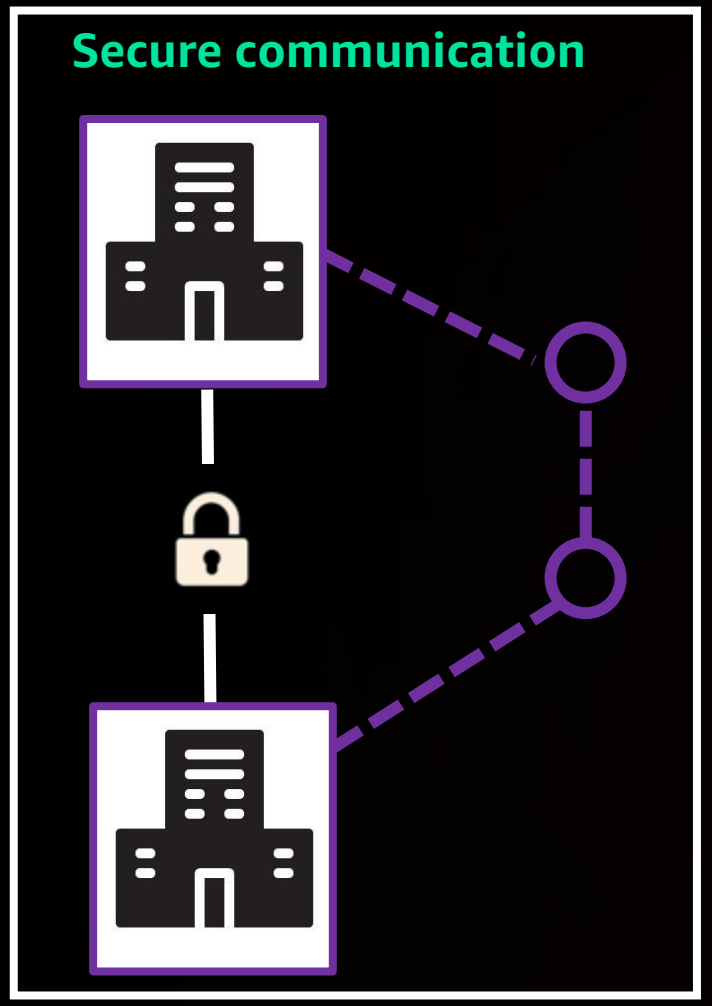
- Distributed computation and real-time feedback with ultra-low latency (< 10 microseconds)
- Error correction operating system for coordinating the classical hardware
- Customers/developers will program at the quantum layer, shielded from underlying details of the control hardware

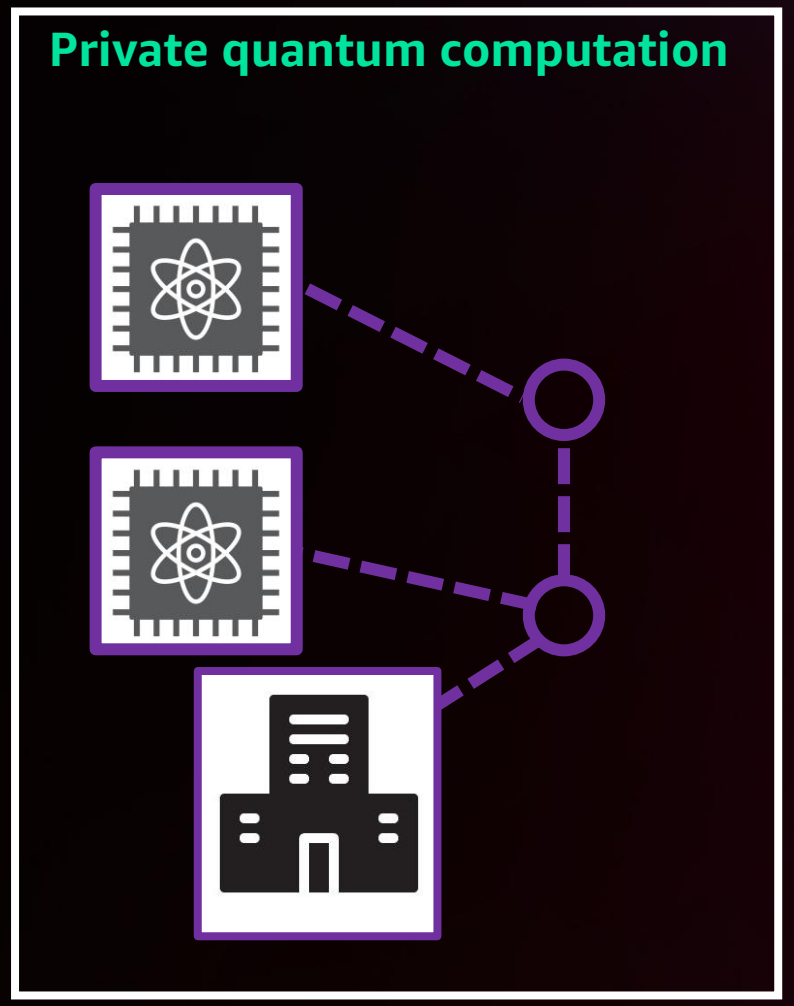


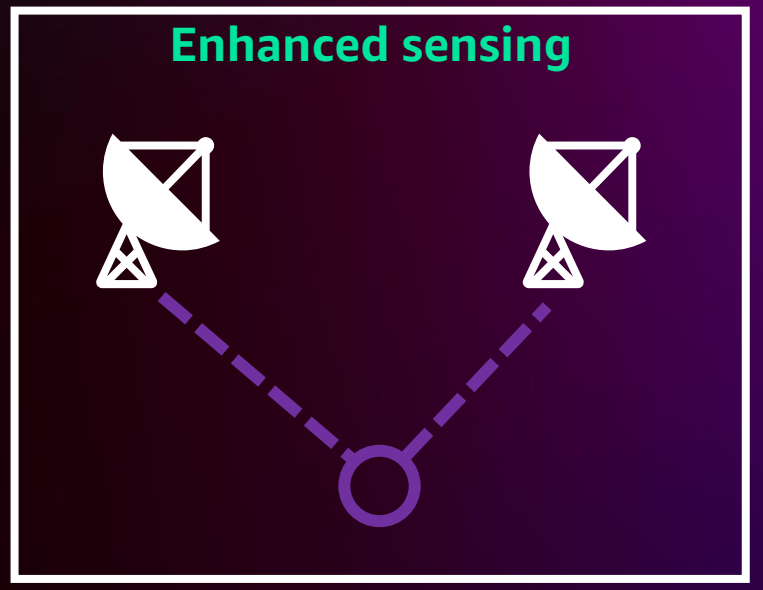
Development path



Quantum networks







Entanglement distribution

Quantum network nodes

AWS Center for Quantum Networking

AWS Quantum Computing Blog

Announcing the AWS Center for Quantum Networking

by Denis Sukachev and Mihir Bhaskar | on 21 JUN 2022 | in Amazon Quantum Solutions Lab, Announcements, AWS Center For Quantum Computing, Quantum Technologies | Permalink | Share

Over the last decade, governments and technology companies have invested heavily in research and development of quantum computers that have the potential to revolutionize science and technology. While there is still a long way ahead, these investments have already transformed quantum computers: They have evolved from delicate laboratory systems accessible to only a few research […]

Adam Selipsky
@aselipsky

Introducing the #AWS Center for Quantum Networking, our new home for #quantum networking R&D. We're on a mission to build the underlying technologies that will enable the distribution of quantum information anywhere on Earth.

Who are the customers for quantum computing today?

Pioneers

Academic researchers

Quantum solution providers

Enterprise quantum centers of excellence

Enablers

Global system integrators

Quantum solution providers

Pragmatists

Enterprises

Who are the customers for quantum computing today?

Pioneers

Academic researchers

Quantum solution providers

Enterprise quantum centers of excellence

Enablers

Global system integrators

Quantum solution providers

Pragmatists

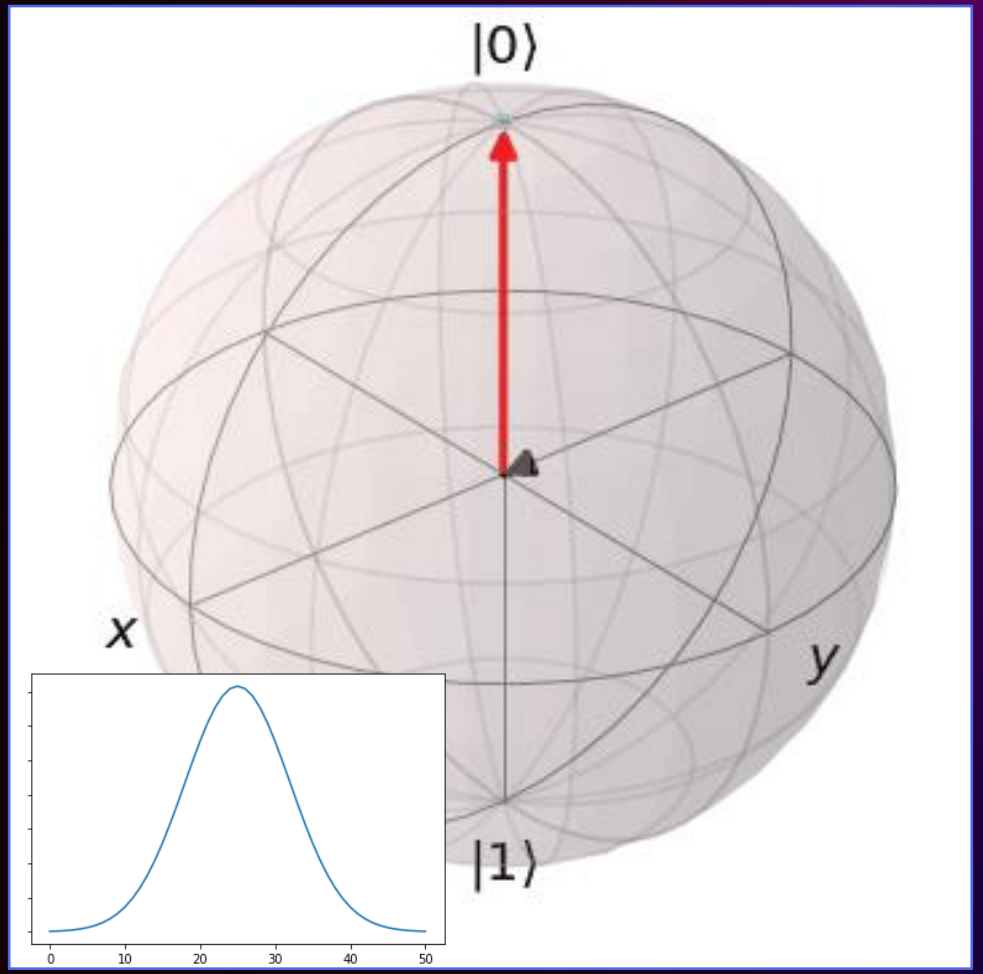
Enterprises

Customer problem (2022)

Pioneers need tools to get the most out of quantum computers

Amazon Braket Pulse

- Program quantum computers with **bare-metal access** down to the analog signals that control qubits
- Improve performance of quantum devices by **understanding noise and mitigating errors**

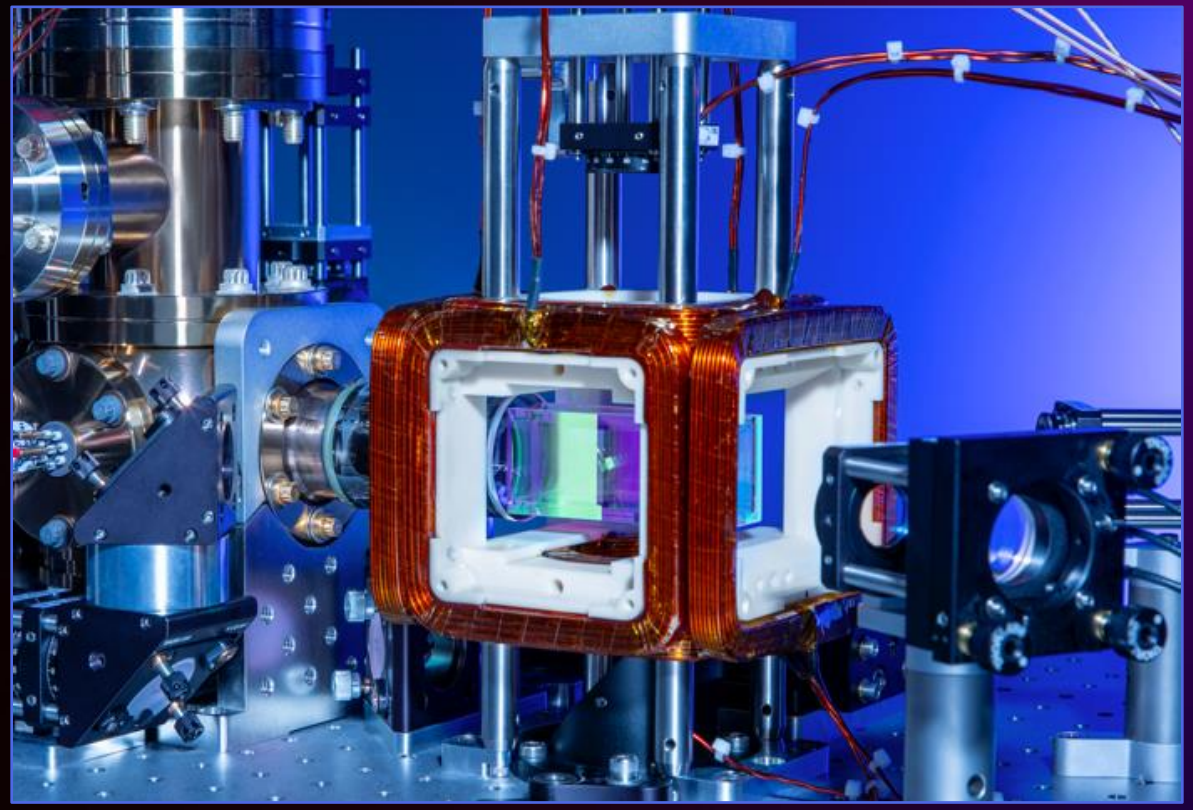


Customer problem (2022)

Pioneers want to explore novel use cases

Analog Hamiltonian Simulation

- First publicly accessible Analog Hamiltonian Simulation machine with up to **256 qubits**
- Map problems in **fundamental physics, materials science, and optimization** to Hamiltonians
- Simulates system sizes that are **difficult to solve with conventional hardware**

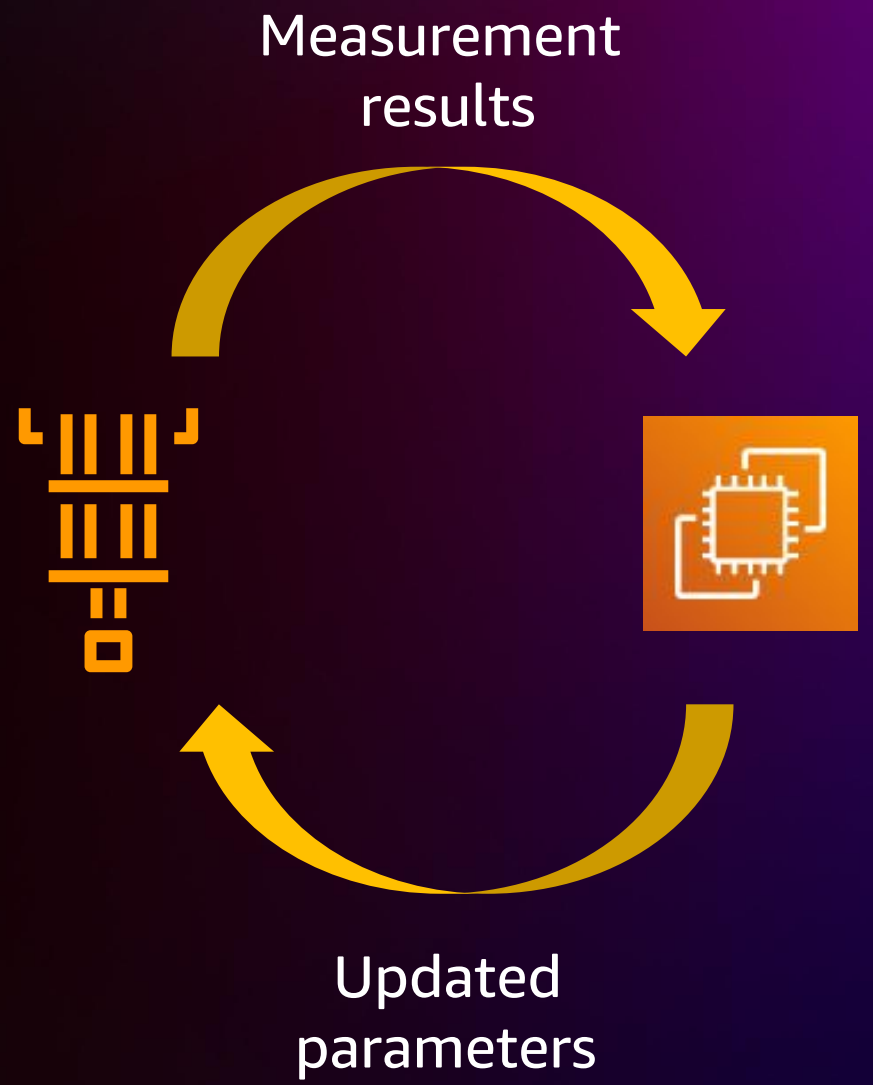


Customer problem (2022)

Enablers need programming interfaces to develop quantum applications

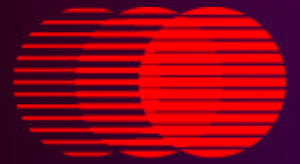
Amazon Braket Hybrid Jobs

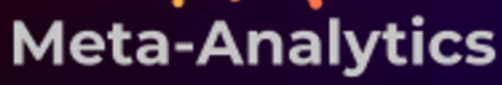
- Quantum computers will increasingly rely on **conventional co-processing**
- Application developers don’t care about detailed workings of quantum computers or **orchestrating conventional resources**



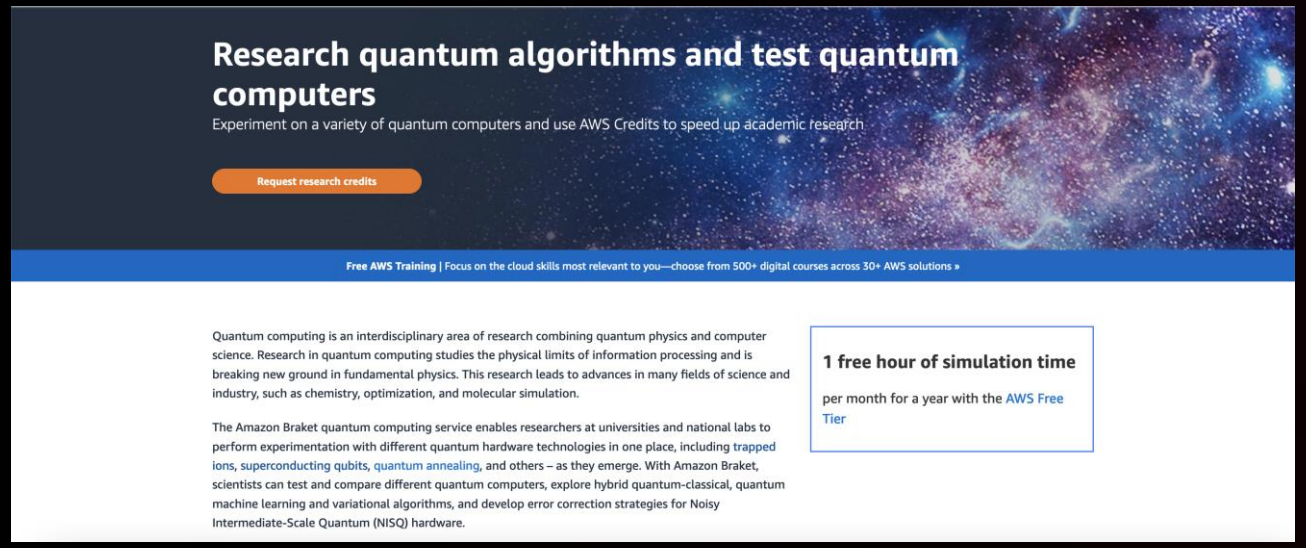
Customer problem (2022)

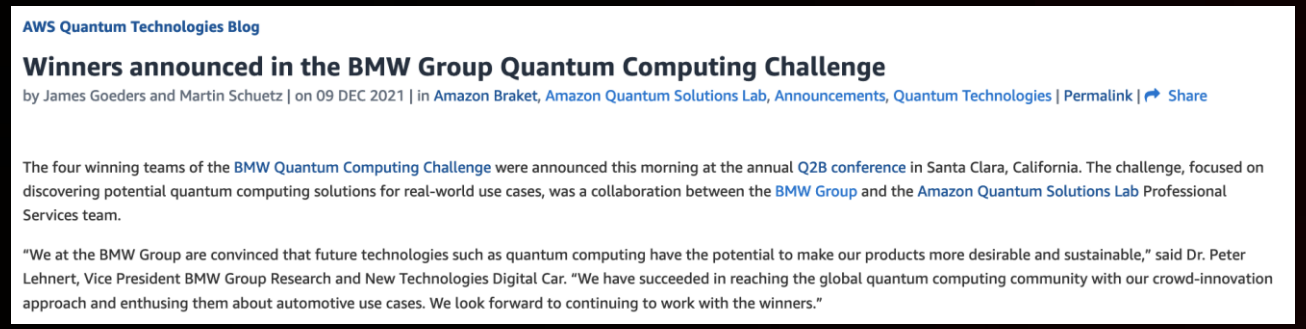
Pragmatists need support to understand how quantum computing will impact their business





So how can I get started?





- **Apply for AWS Cloud Credits for Research** to get research credits to explore new quantum workloads
- **Engage our partners** or the **Amazon Quantum Solutions Lab** to explore use cases
- **Sponsor hackathons and challengers** to develop use cases in your industry

Thank you!

Scott Buchholz

/buchholzscott

Oskar Painter

ojp@amazon.com

Simone Severini

/simoneseverini

Please complete the session survey in the **mobile app**