

Superconducting Quantum Chips as the Foundation for Quantum Computing

Juha Hassel

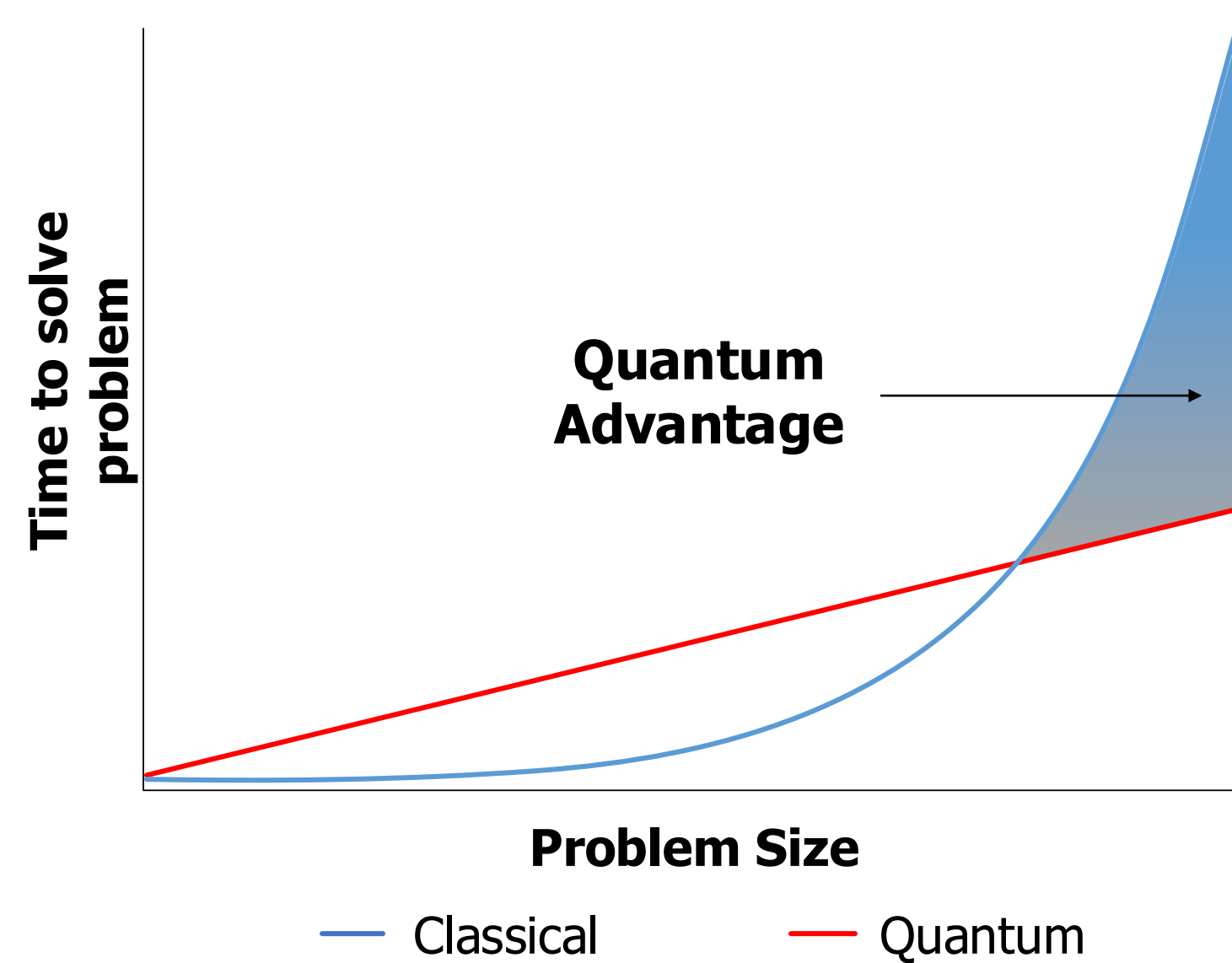
VP of Quantum Technologies

Semicon Europa 2025, Nov 19th 2025, Munich, Germany

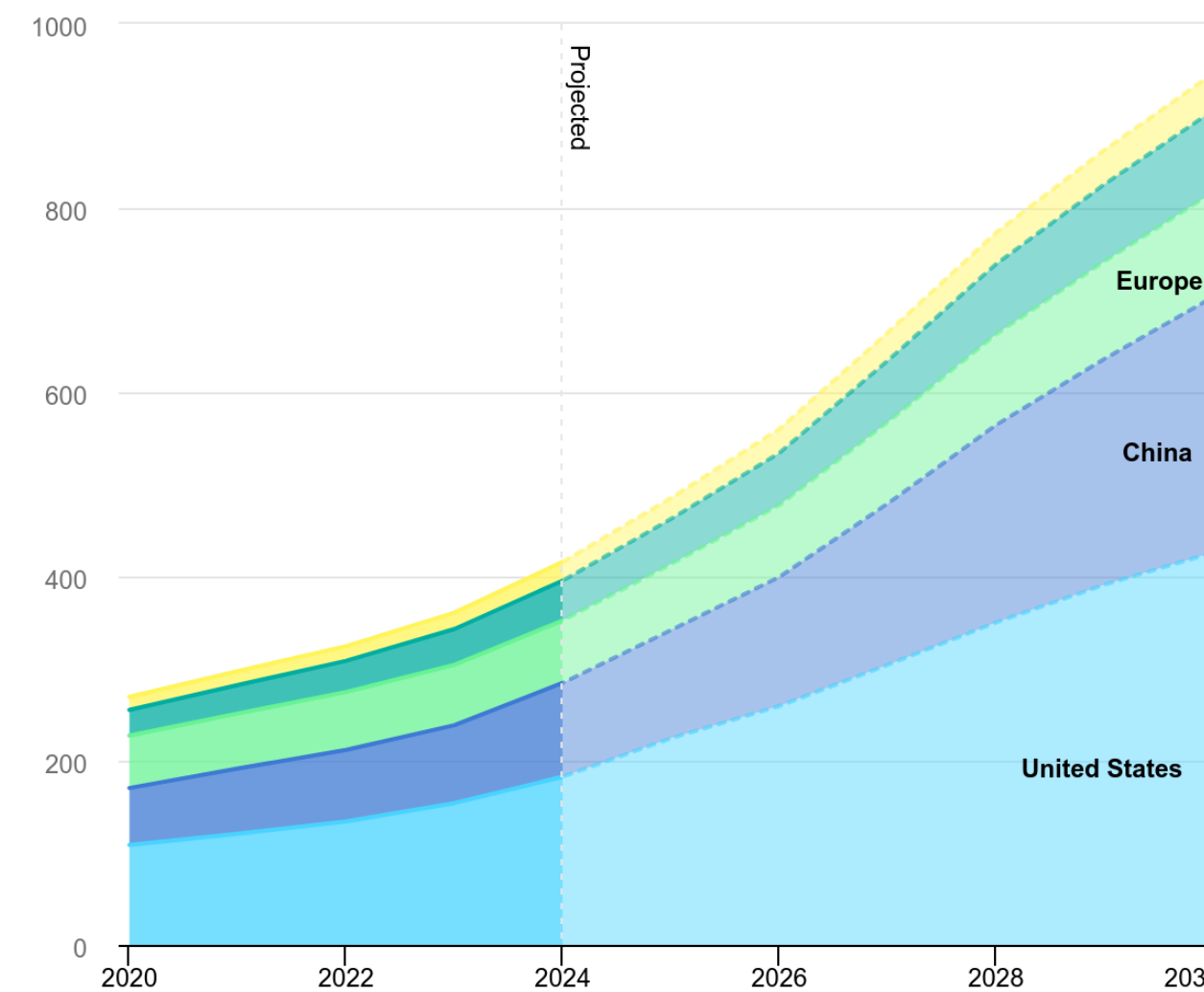


Why quantum?

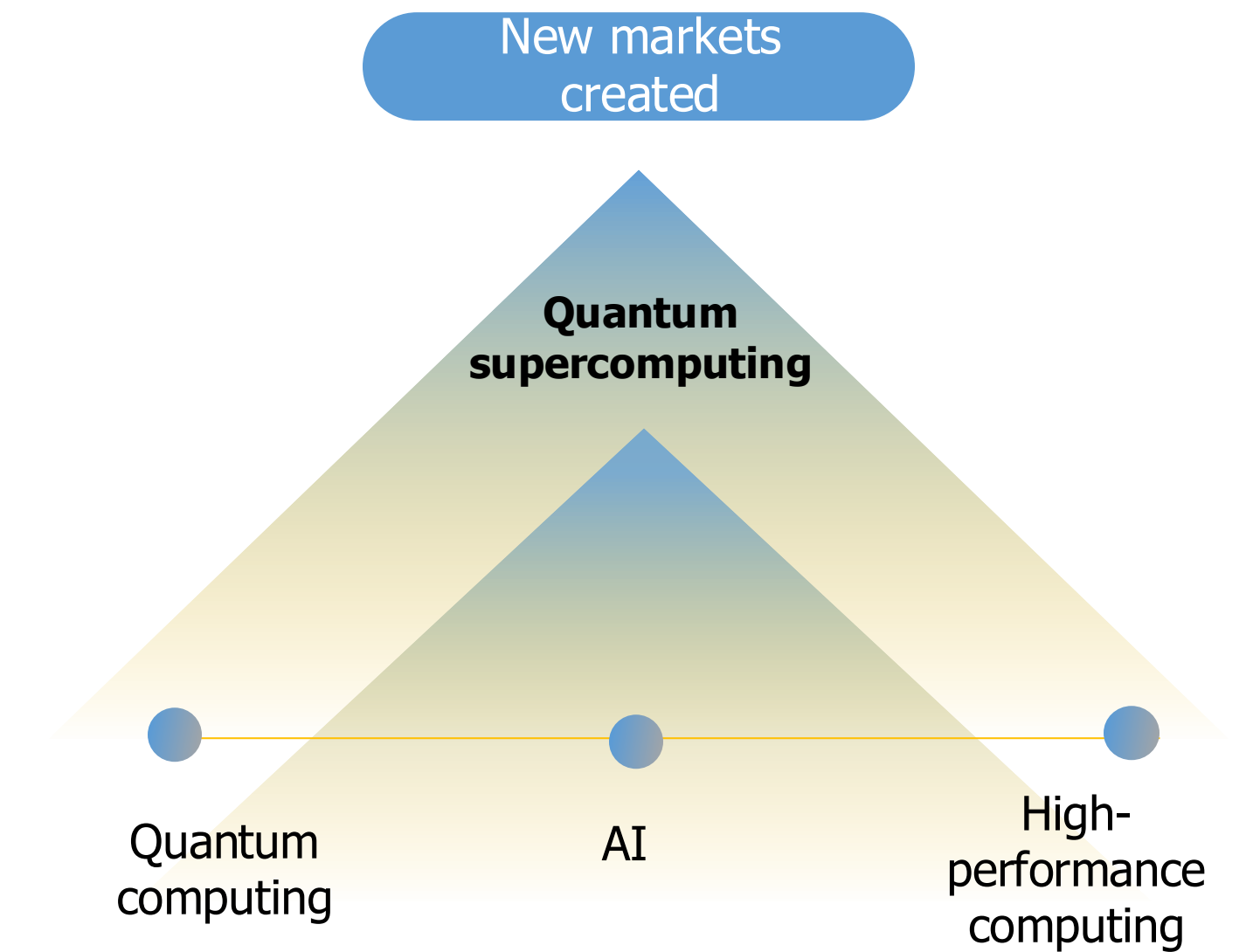
Quantum computing enables exponential growth in compute potential



Quantum computing tackles the energy problems of data centers



Quantum supercomputing is the merger of three exponential technologies



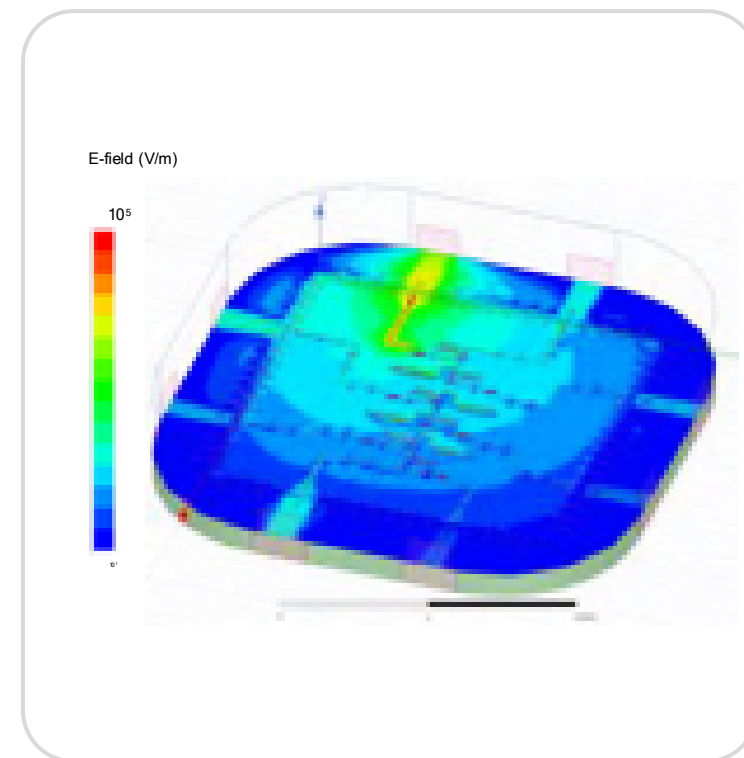
Quantum computers can solve problems that are out of reach with today's (or any future) conventional computer or AI machine

Increasing energy demand required for data centers is not sustainable – quantum computers require only kilowatts instead of megawatts

In combination with AI and high-performance computing, quantum supercomputing is soon solving the most relevant problems for mankind

Provider of full-stack quantum computers

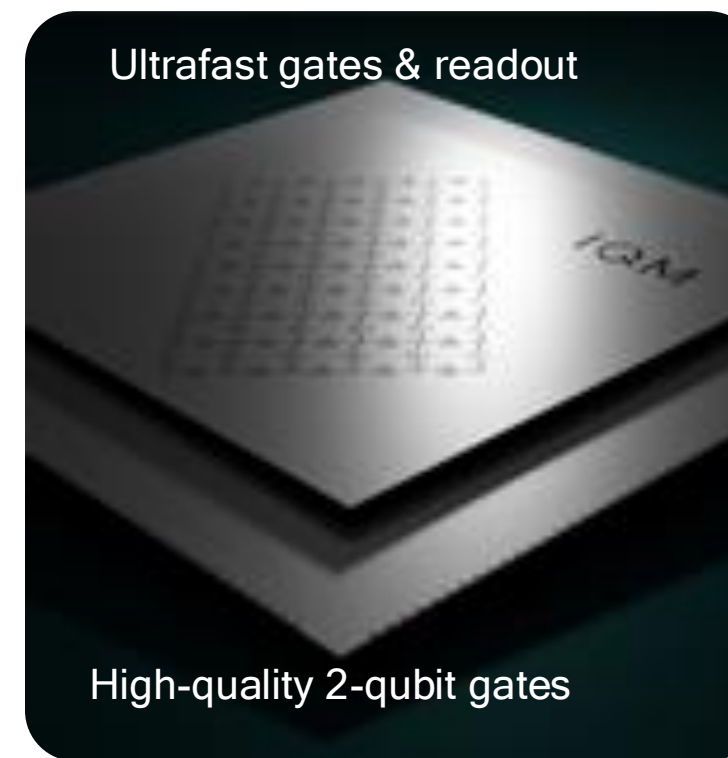
IQM provides full-stack superconducting quantum computing solutions to customers offering them both as on-premises systems and with cloud-based access.



01 Design of QC processors



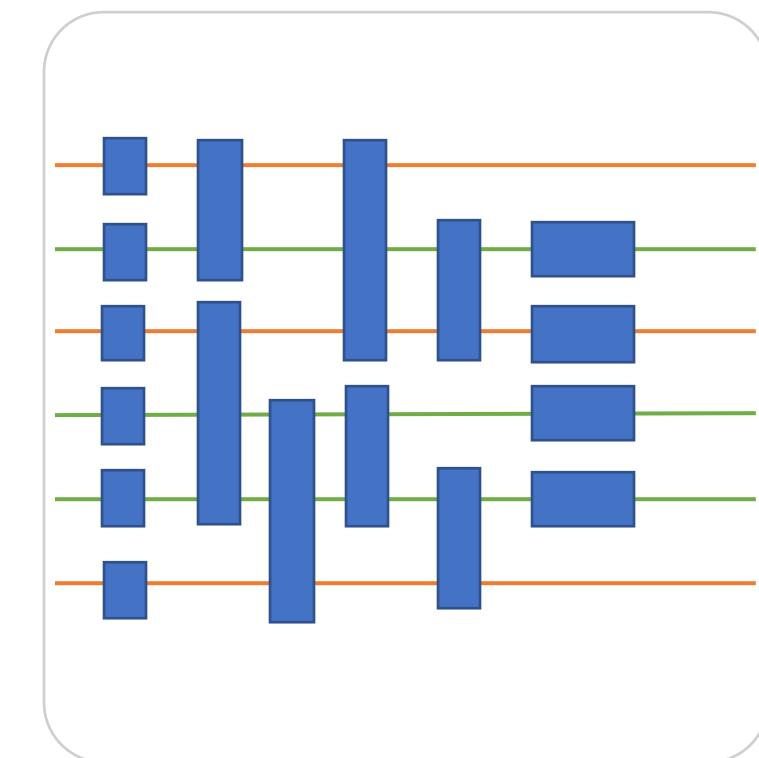
02 QC processor fabrication



03 Full system integration



04 Complete software stack for HPC and Cloud



05 Algorithm & Error Correction

Deliver best customer experience

Accelerated innovation cycle

IQM in numbers

314

Employees

132

PhDs

\$600M

investments

30+

full systems
built

15+

full systems
sold

2018

Founded

50+

Nationalities

150

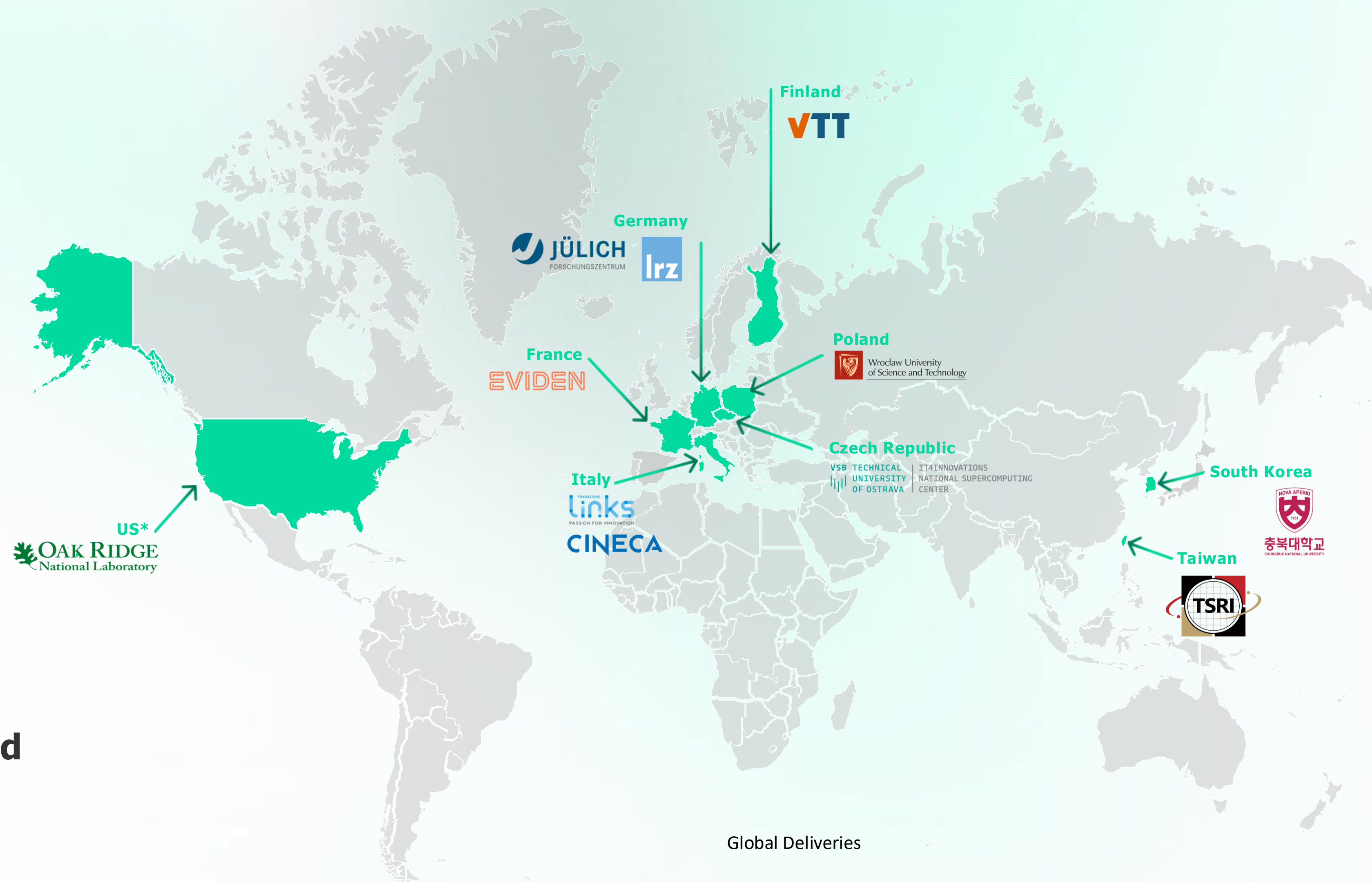
qubit chip in
development

2000+

Cloud users

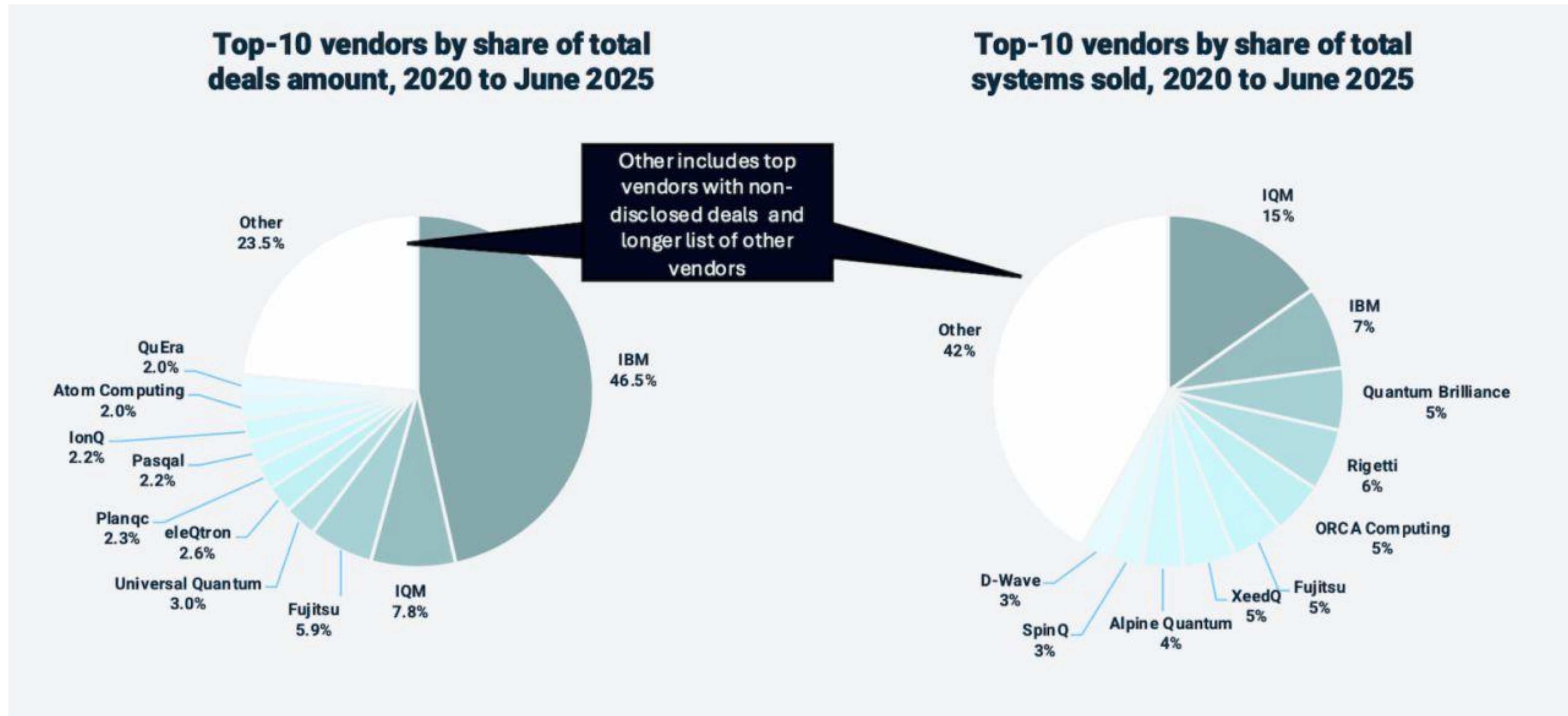
**On-prem
& cloud**

IQM Customer Deliveries



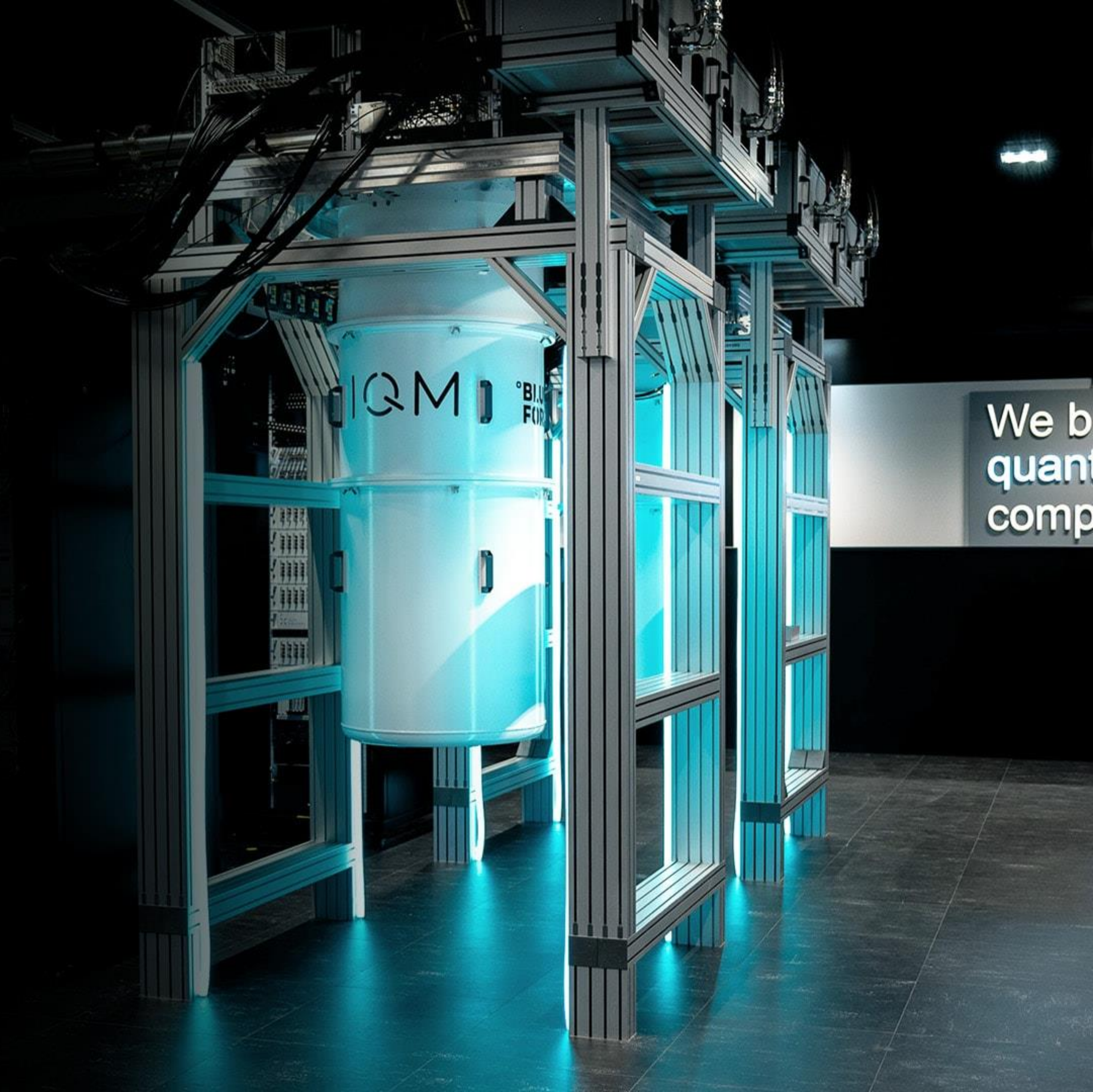
**10+ full systems
delivered and installed**

IQM leads in on-prem quantum computers



Source: <https://thequantuminsider.com/2025/08/19/in-initial-stages-of-quantum-computing-commercialization-sales-stats-show-ibm-leads-in-quantum-deal-value-iqm-in-units-sold/>

Core technology in IQM's quantum computers



Quantum computing players, with superconducting raising highest awareness

Nobel prize
2025

Superconducting

- Uses charge, current, or energy of superconducting circuits
- Manipulated with electrical energy
- Closest to classical computing chips

IQM IBM

rigetti Google

FUJITSU OQC

ALICE & BOB

IQM

Ion trap

- Single ions are trapped in an electromagnetic trap
- Manipulation with laser energy

AQT IONQ

QUANTINUUM

oxford
ionics

Photonic

- Uses photon properties (e.g. polarization, spin numbers) to represent information
- Manipulation via optical media, laser and photodetectors

XANADU

QANT

PsiQuantum

QUANDELA

Annealers

- Sacrifices qubit controllability in favor of scalability. Limited to specific applications
- Often trying to find concepts to re-use semiconductor investments

D-WAVE The Quantum Computing Company™ NEC

QILIMANJARO
QUANTUM-TECH

Neutral atoms

- Individual atoms trapped by laser tweezers
- Manipulated into highly excited states by laser

planqc Infleqtion

atom computing IQEra

PASQAL

IQM leads the way in superconducting

All major players invest
in superconducting

IQM

IBM

rigetti

Google

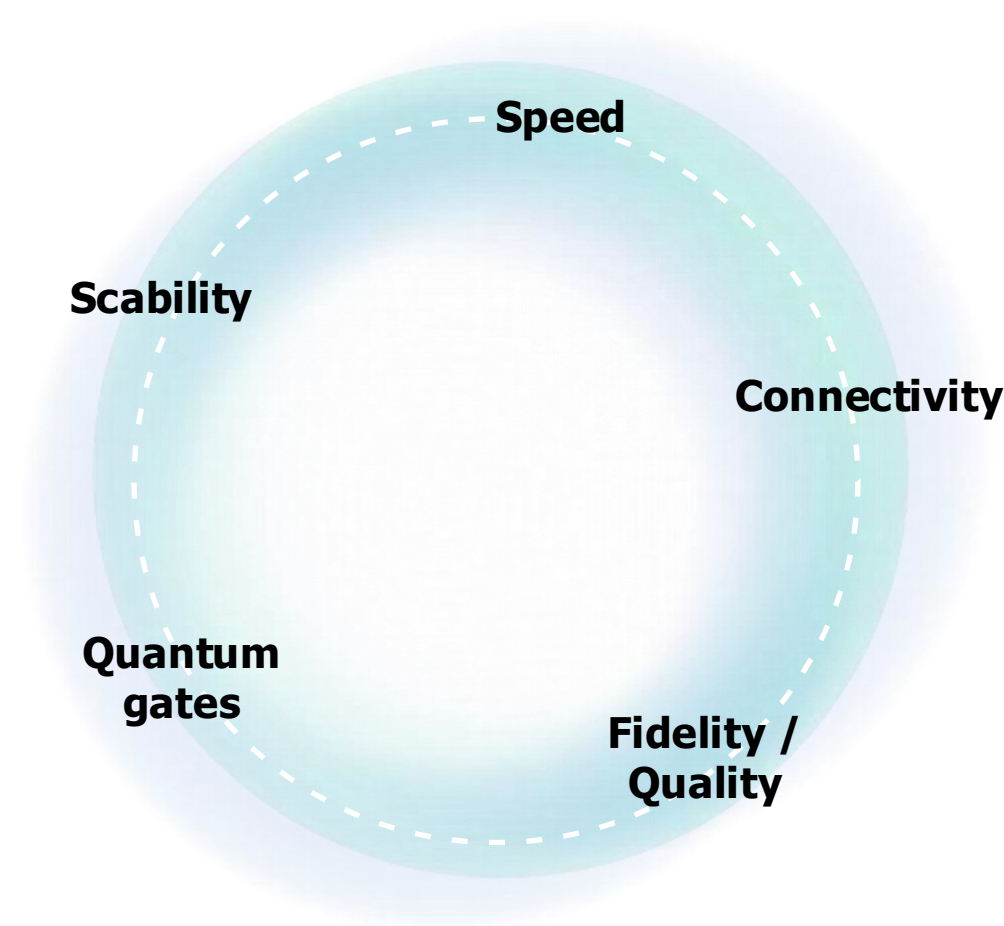
FUJITSU

OQC



ALICE & BOB

Superconducting is the most
promising quantum solution



IQM is at least on par
with competition

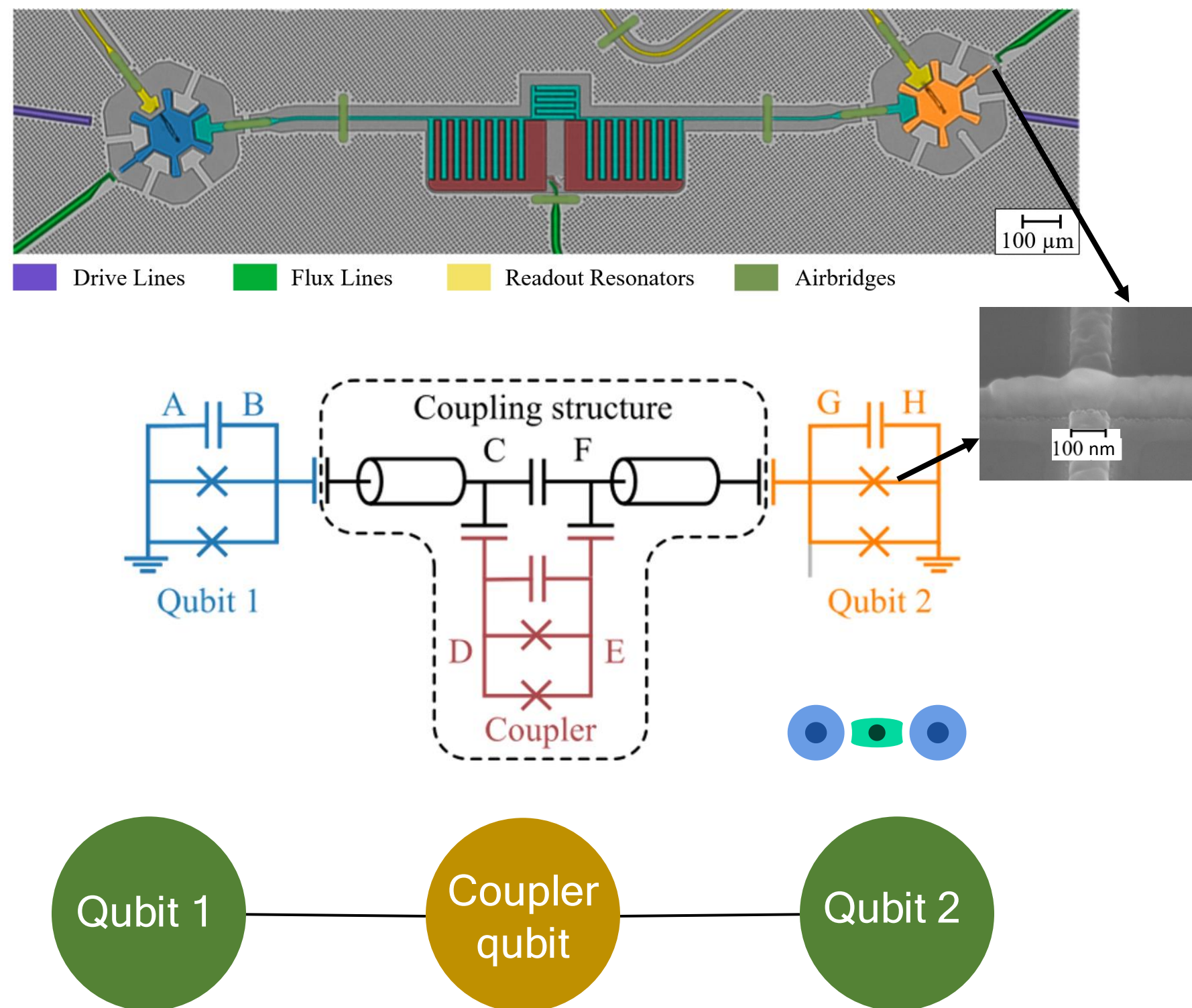
IQM

Fidelity	99.9%
QPU scale	54 qubits (soon 150 qubits)
Gate speed	< 20 ns
Readout speed	~170 ns
Connectivity	> 6 nearest neighbors

*individually demonstrated

Superconducting qubits and processors

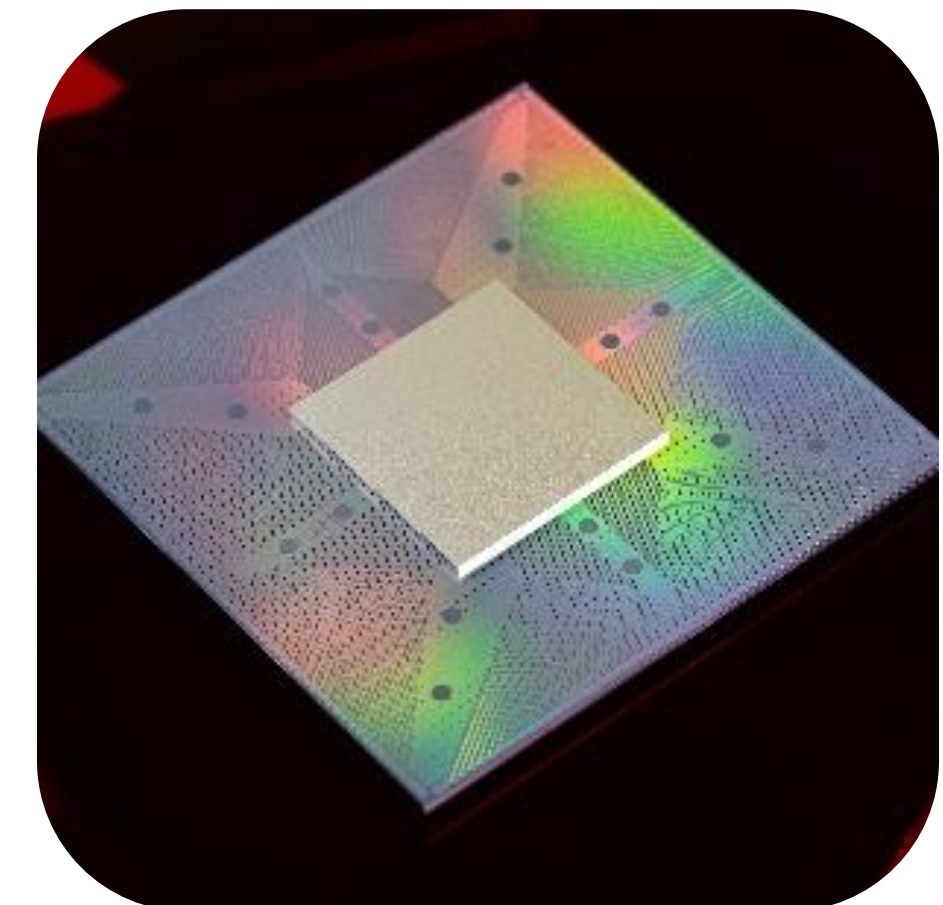
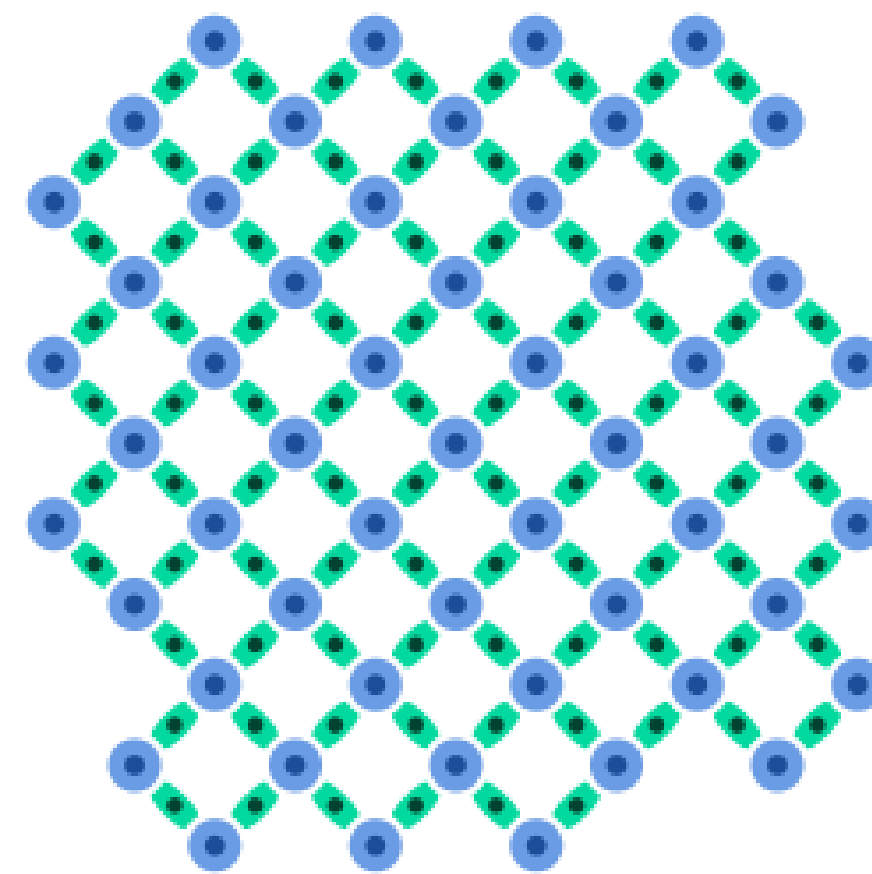
Superconducting qubits as building blocks for quantum information processing



Coupled structure with two qubit; schematics and microphotographs.

Superconducting quantum processor structure

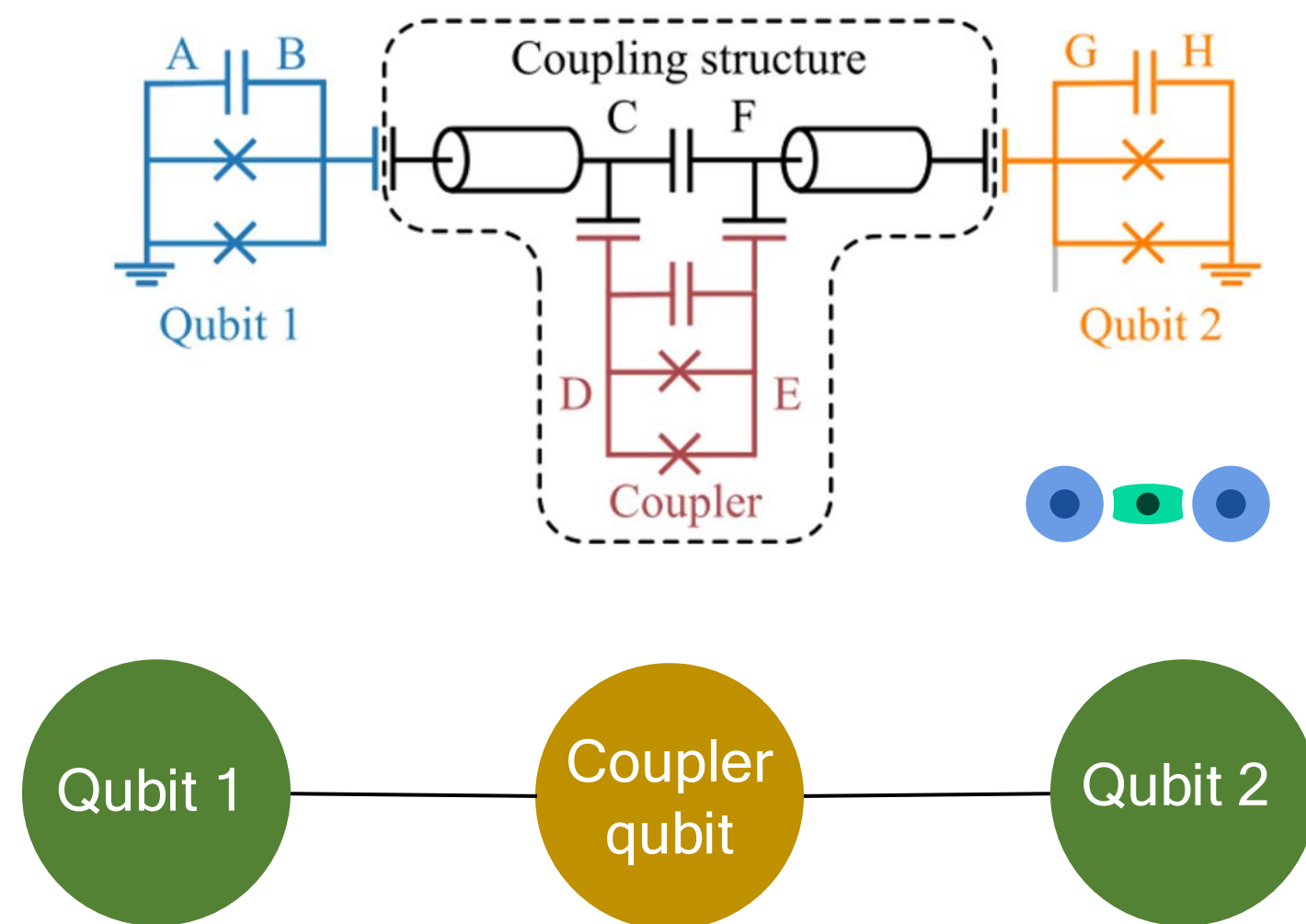
- Superconducting QPUs are high-end microwave ICs (4 - 8 GHz)
- Superconducting ultra-low-loss thin-film structures ($\text{CD} \geq 1 \mu\text{m}$) as on-chip microwave building blocks
- Josephson junctions ($\text{Al}/\text{AlOx}/\text{Al}$, $\text{CD} \sim 100 \text{ nm}$) as core qubit elements
- Infrastructure for high-performance microwave connectivity



Quantum processing unit (QPU) as “artificial atom” lattice. Example topology of IQM Crystal-54 with 54 qubits and 90 couplers.

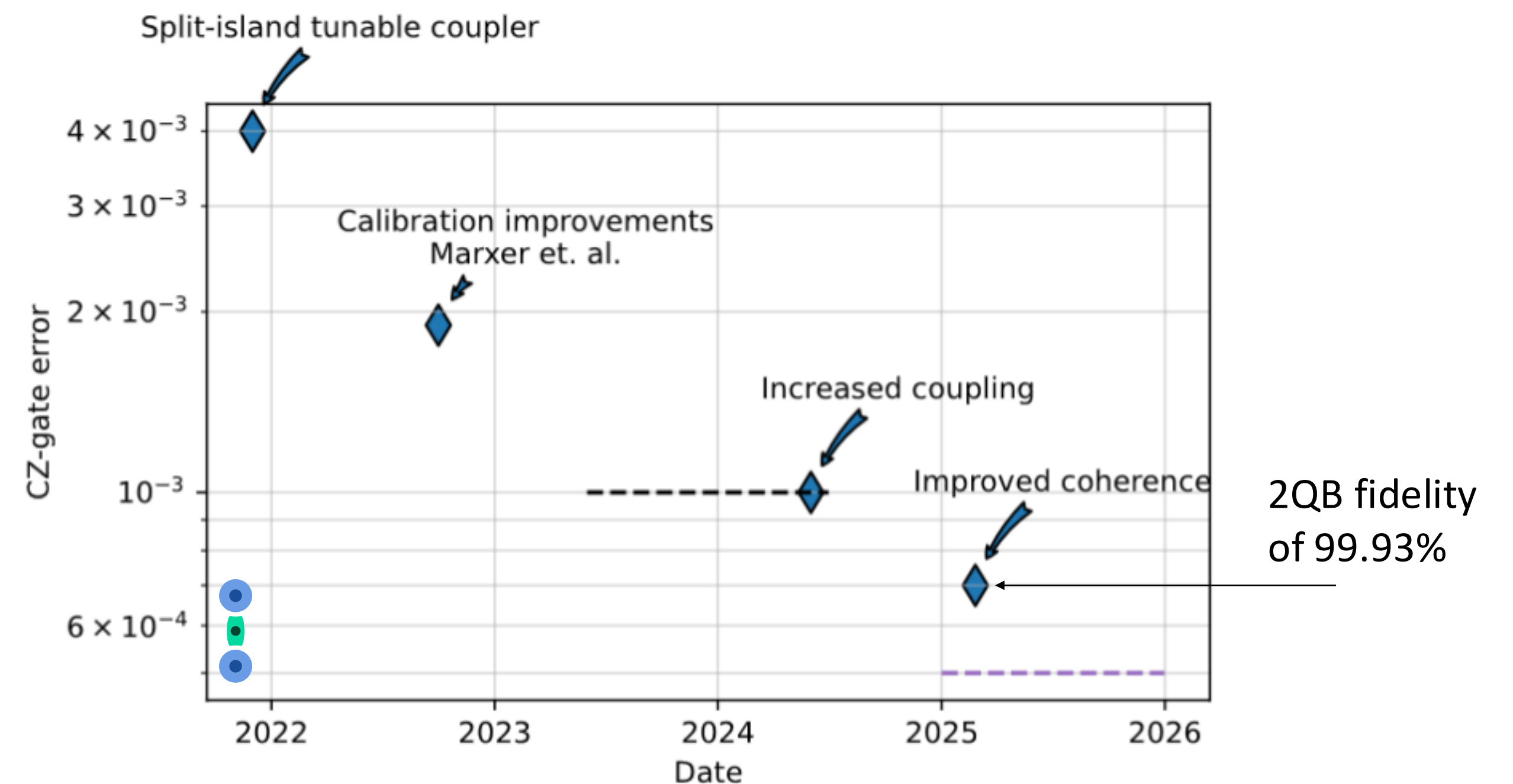
Key KPIs: quality (fidelity) and speed

IQM's tunable coupler architecture



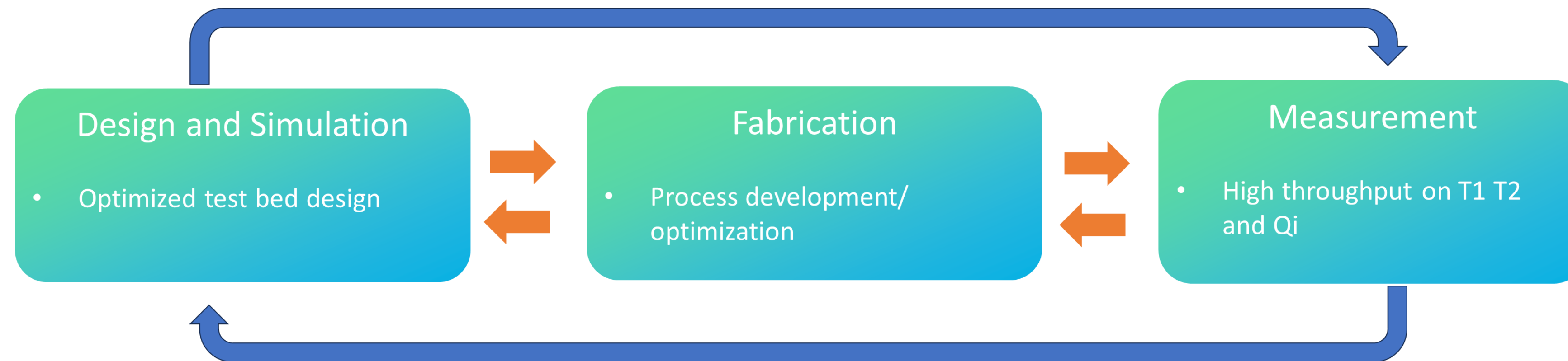
- ✓ Faster gates (30 ns) for higher fidelity
- ✓ Control optimization with SoA automated tune-up and recalibration procedures

2-qubit gate fidelities of 99.93% (error 0.07%) reached.



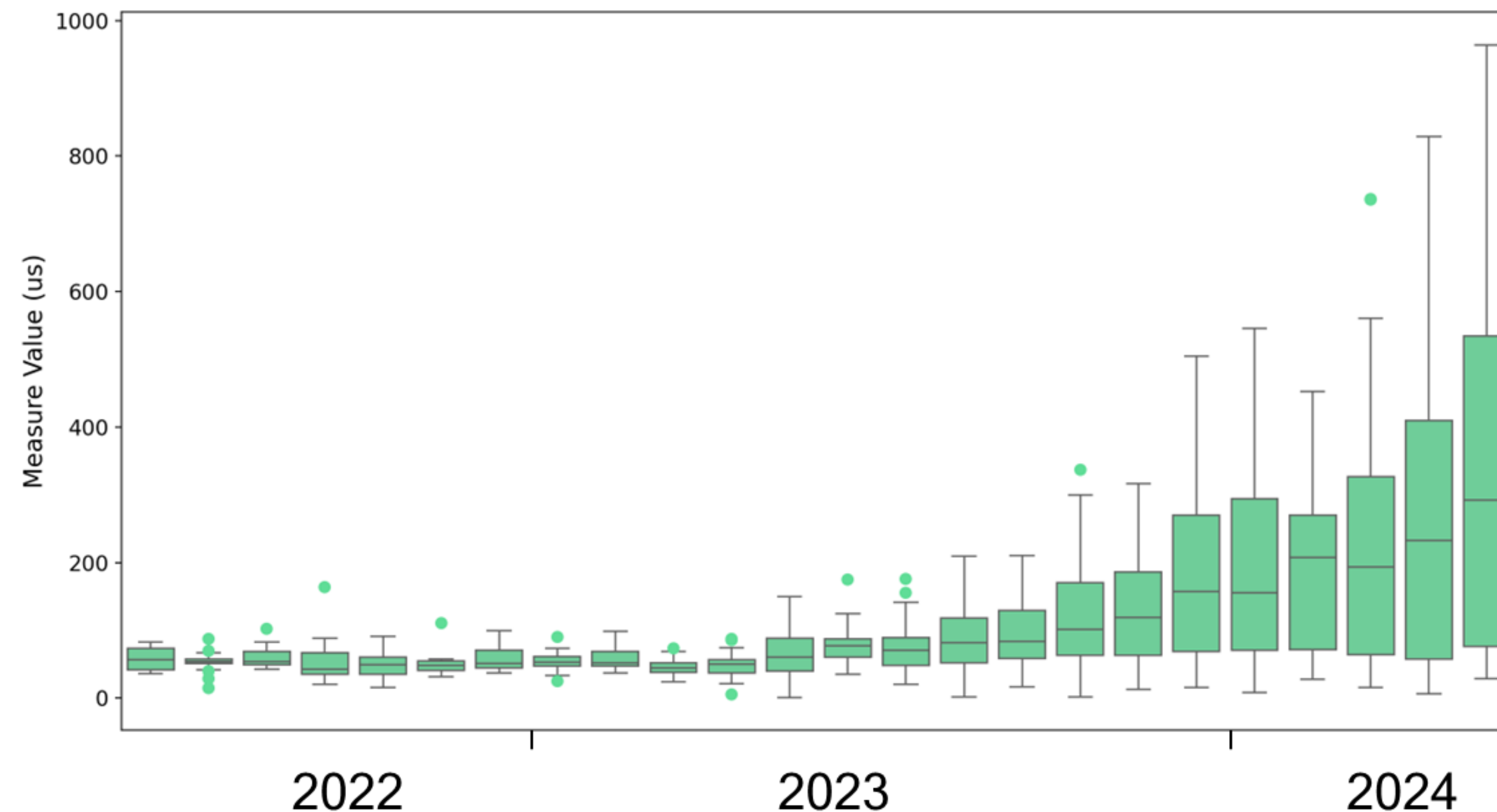
- Read more: [F. Marxer et al., PRX 4, 010314, 2023](#); [F. Marxer et al., arxiv: 2508.16437, 2025](#).

Key fidelity enabler: coherence



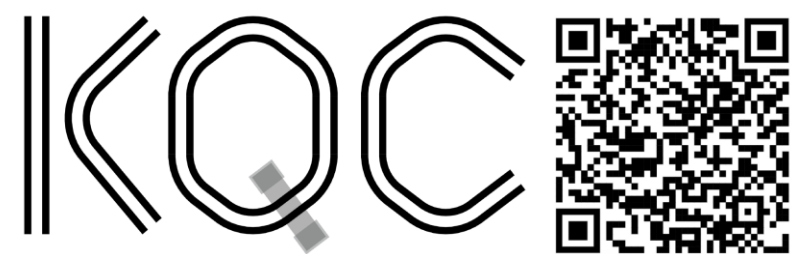
- Fast-feedback process in design – chip fabrication – simulation
- T1 time improved by 20 times over 1 year of R&D efforts

IQM

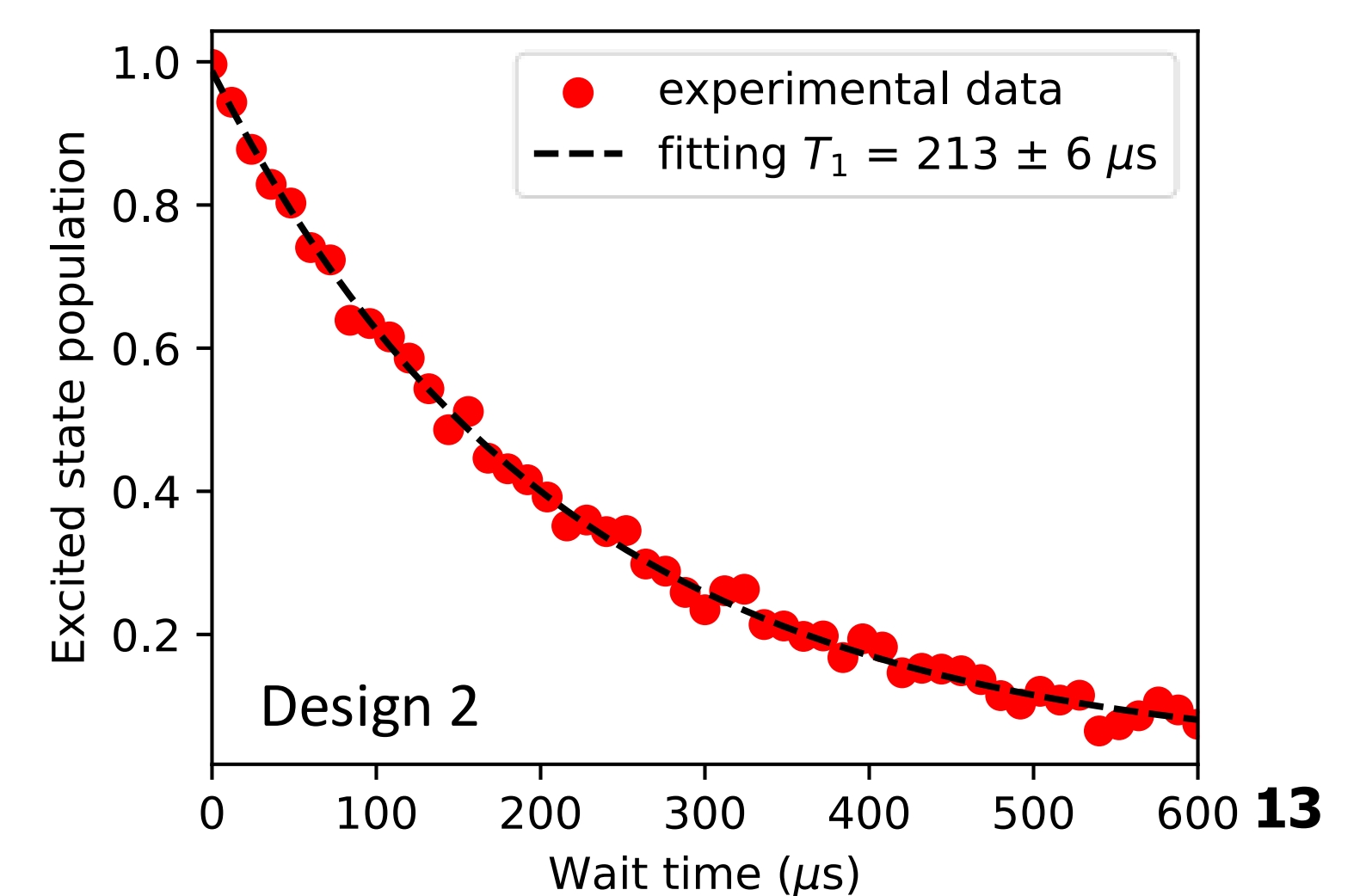
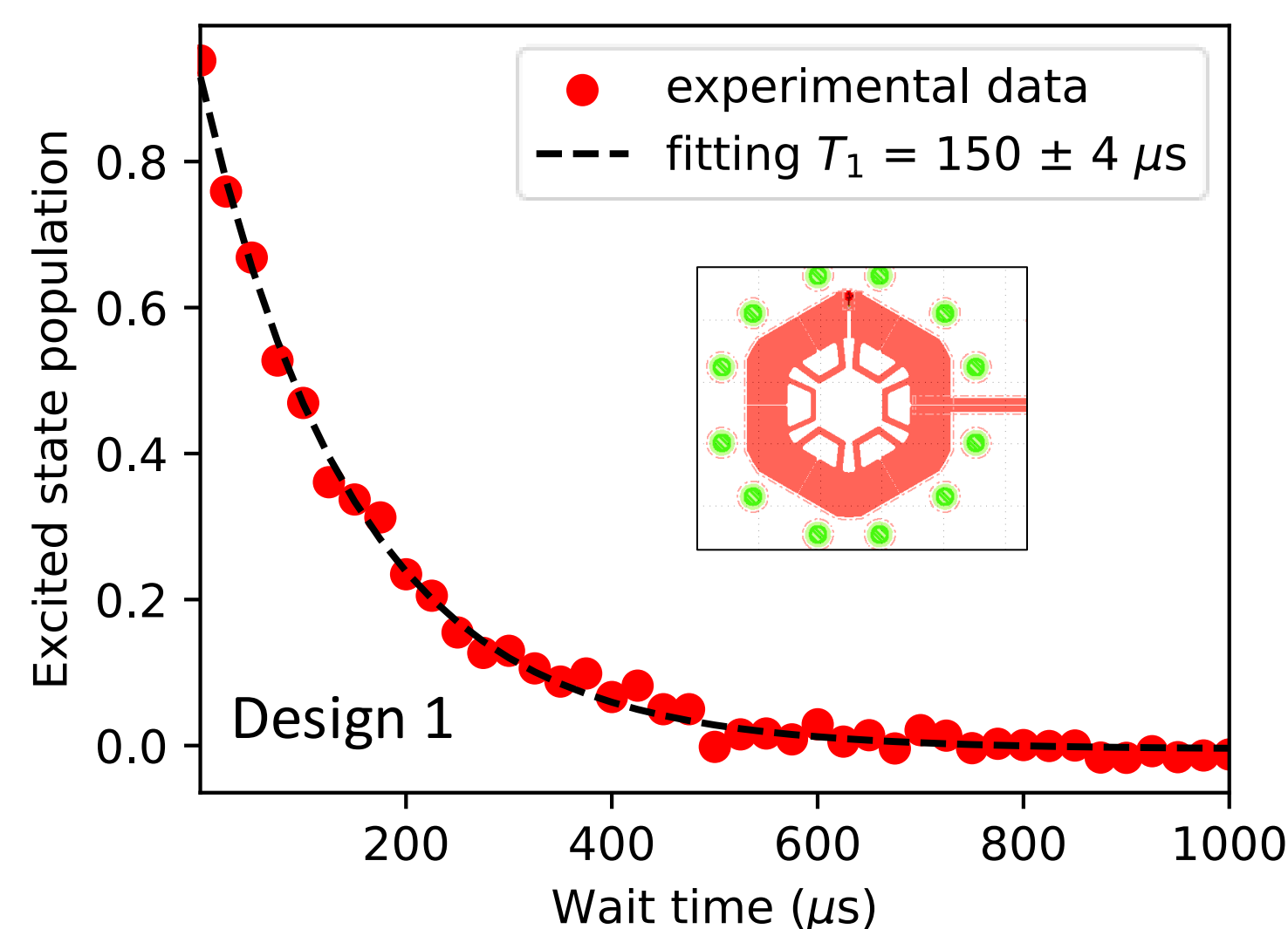
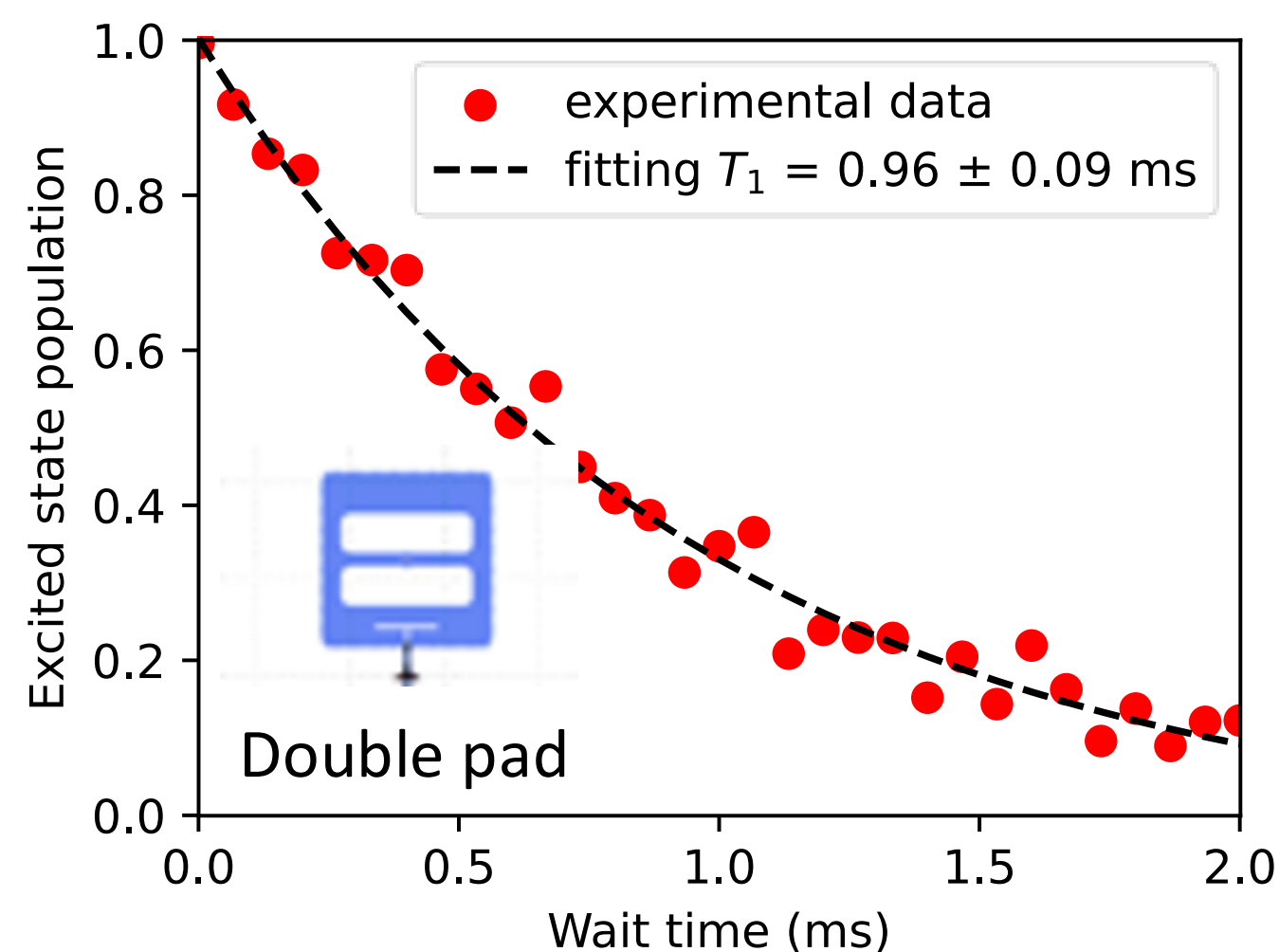
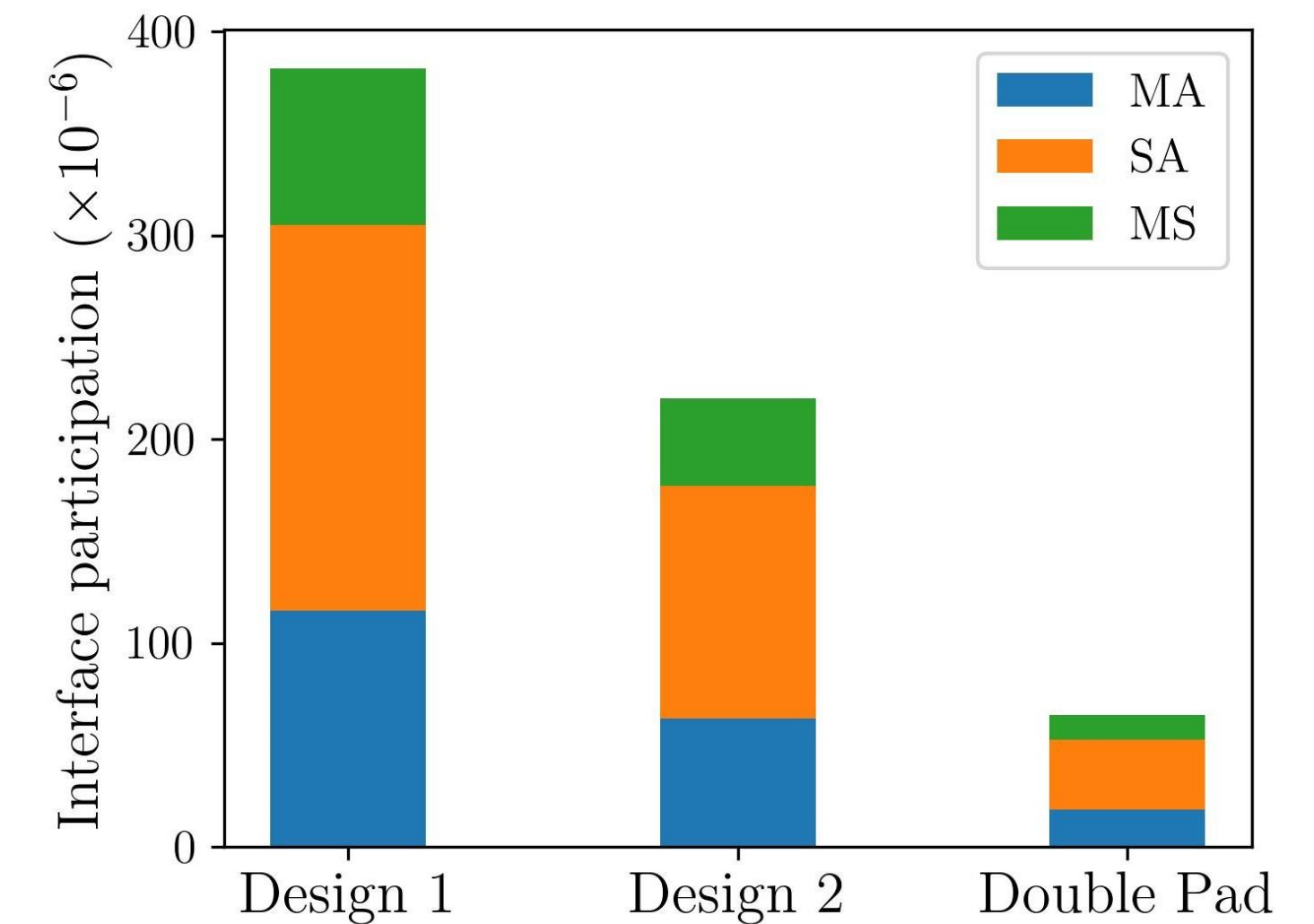
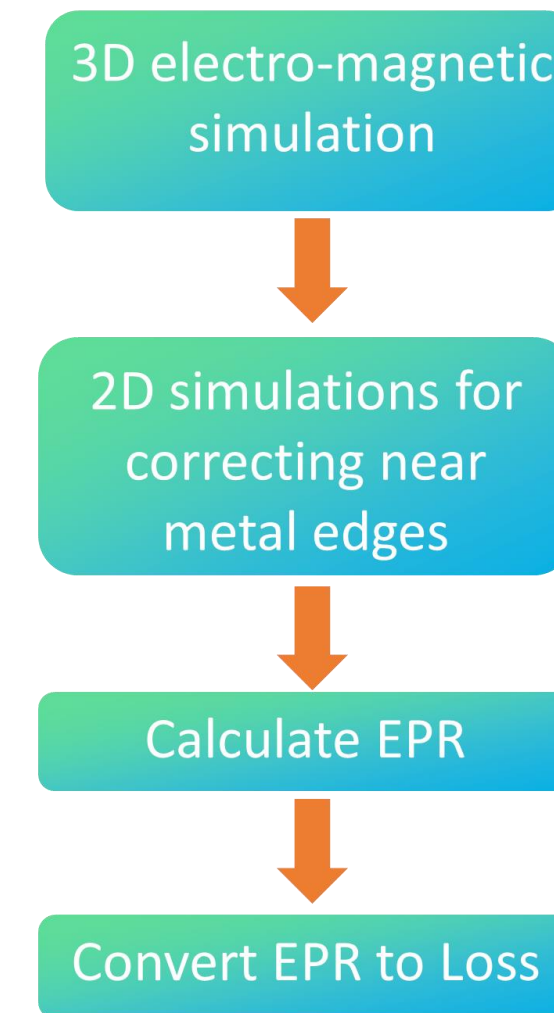


Key fidelity enabler: coherence

- Typical decoherence mechanisms related to surface nonidealities (e.g. native oxides);
- Surface quality to be optimized in fabrication
- Energy participation ratio (EPR) to be minimized by design
- IQM and collaborators developing open-sourced tools for design automation and simulation

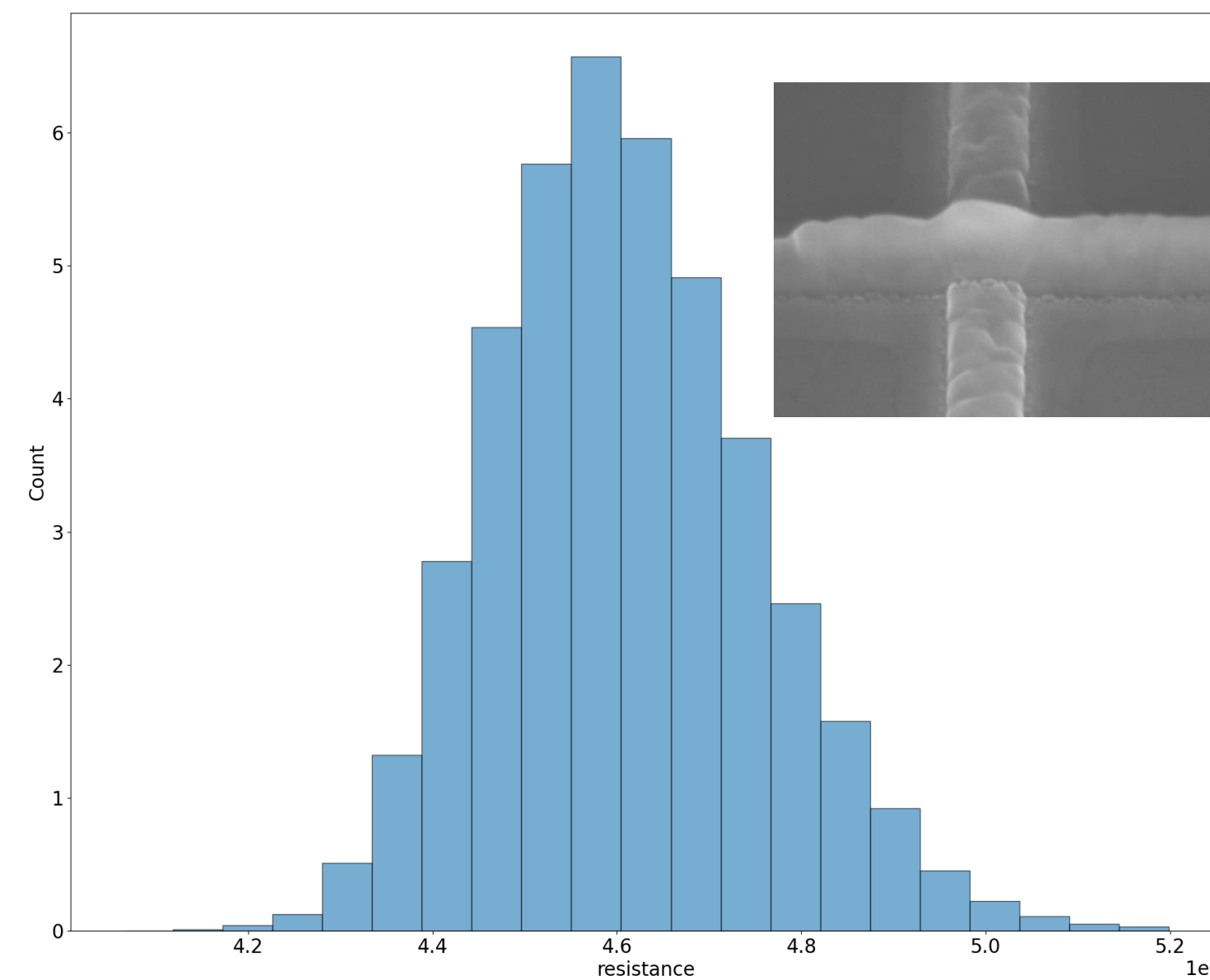
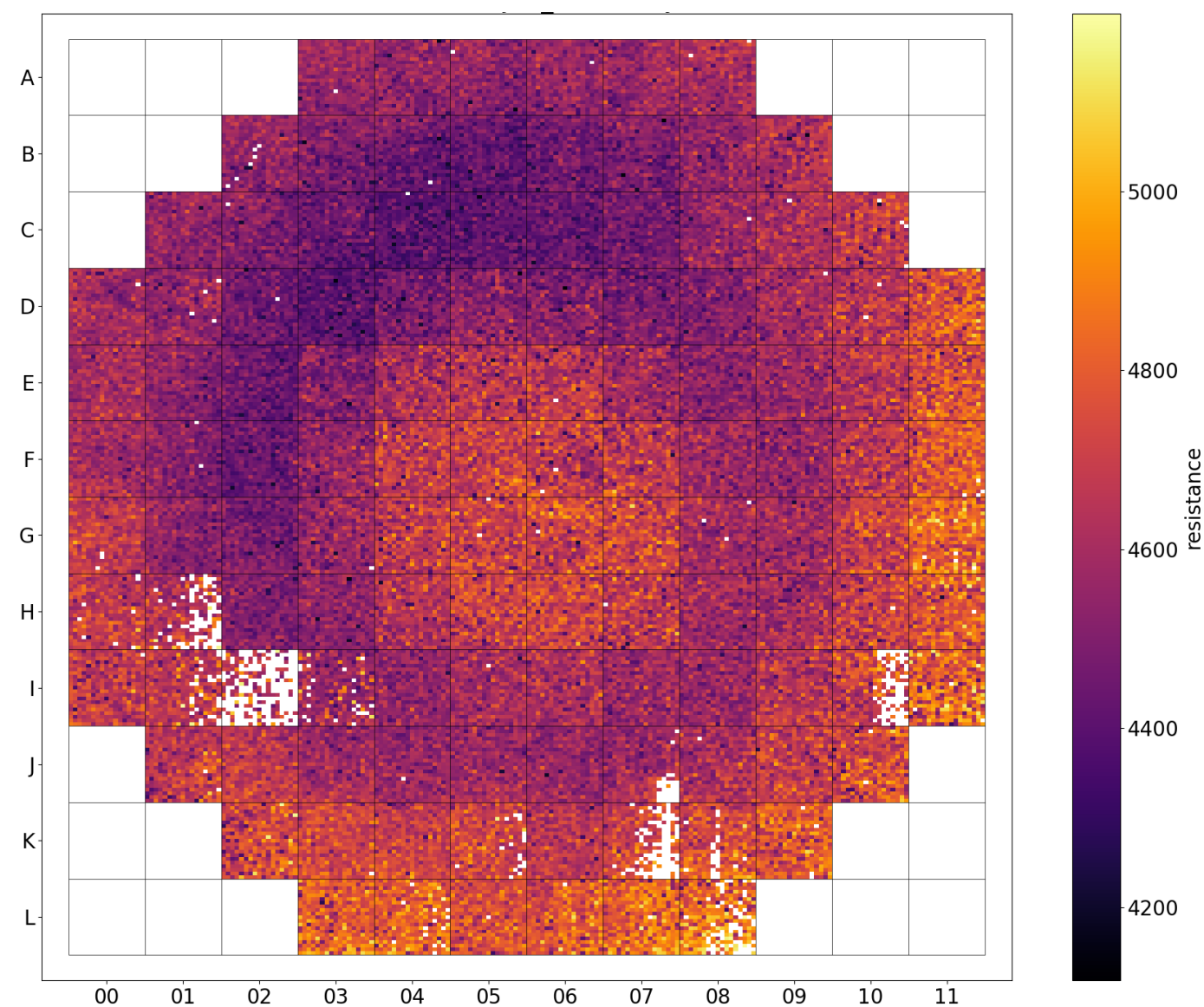


<https://github.com/iqm-finland/KQCCircuits>



Scaling: junction yield

Basic building block is the Josephson junction (JJs). Low-spread high-yield process is a necessity



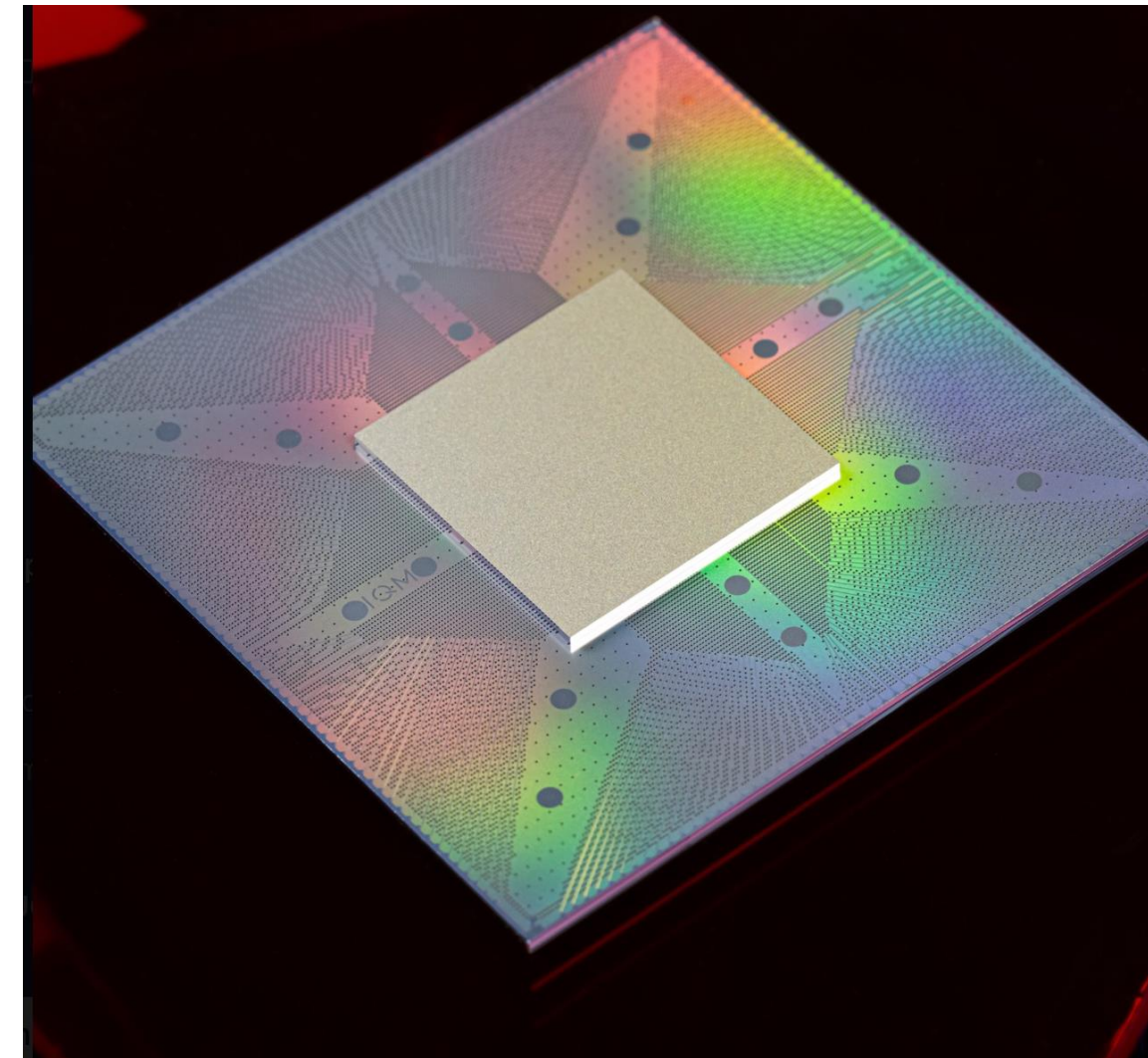
Junction yield and spread characterized over 200 mm wafers (>80 000 junctions):

- Junction size 100 – 200 nm
- Yields up to 99.7% recorded
- Resistance spreads (STD) over wafer down to 3.1%

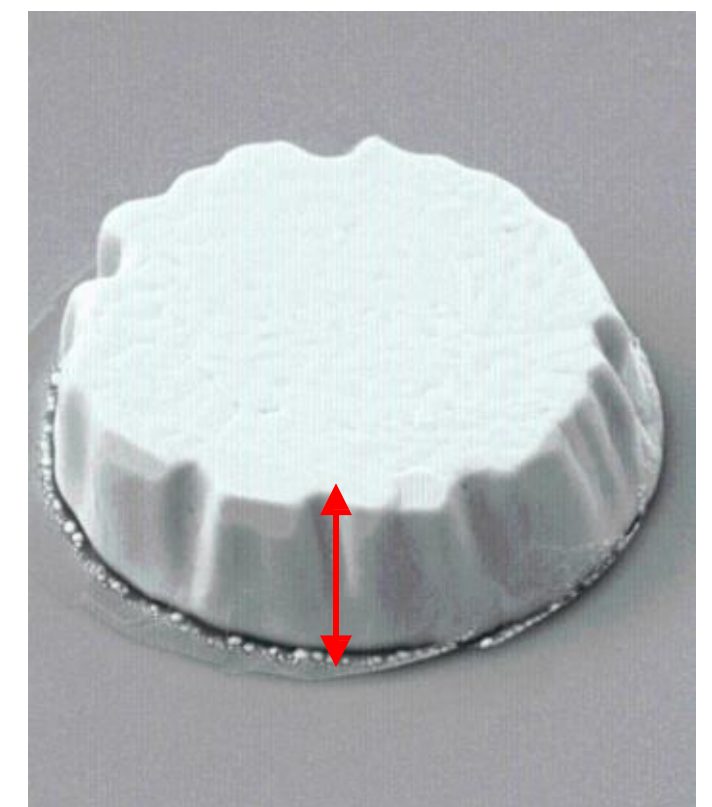
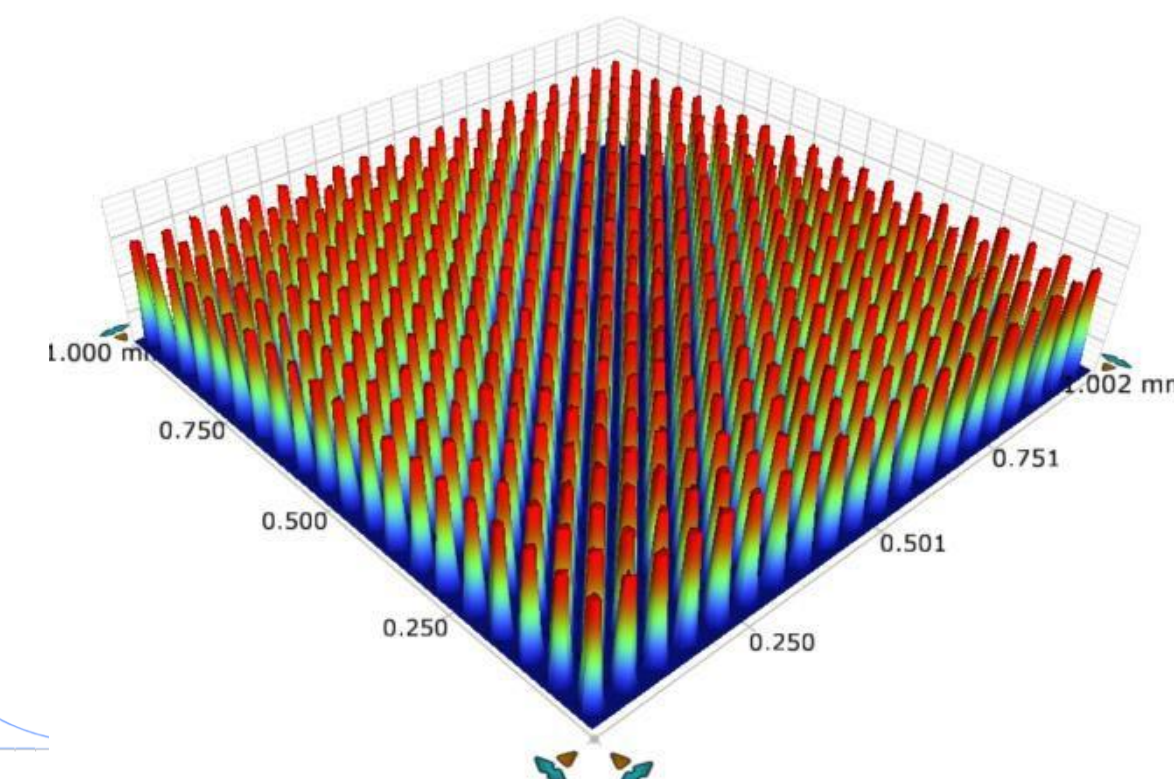
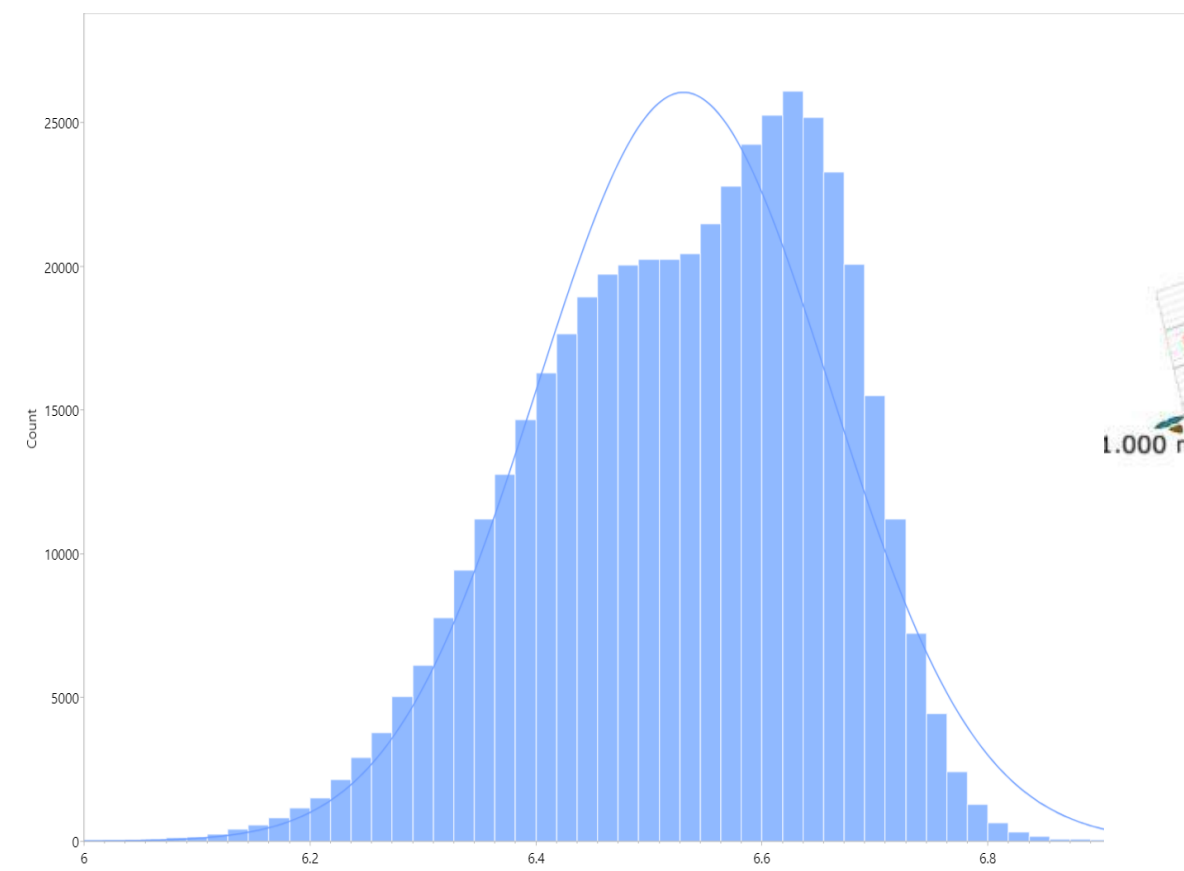
Scaling: 3D integration

- Coherence-preserving microwave design and signal routing calls for 3D integration techniques

- Multi-chip modules with superconducting interconnections
- Through-silicon vias

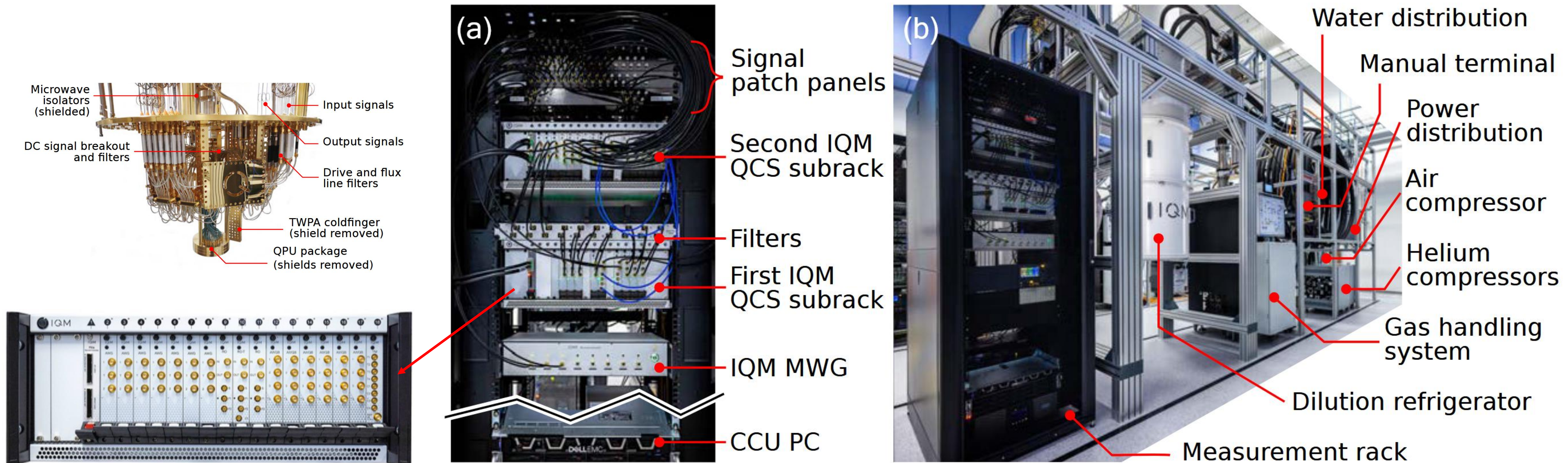


- Height are measured with optical profilometer
- Bumps number 780,000
- Mean = $6.53 \pm 0.12\mu\text{m}$
- Yield = 100%

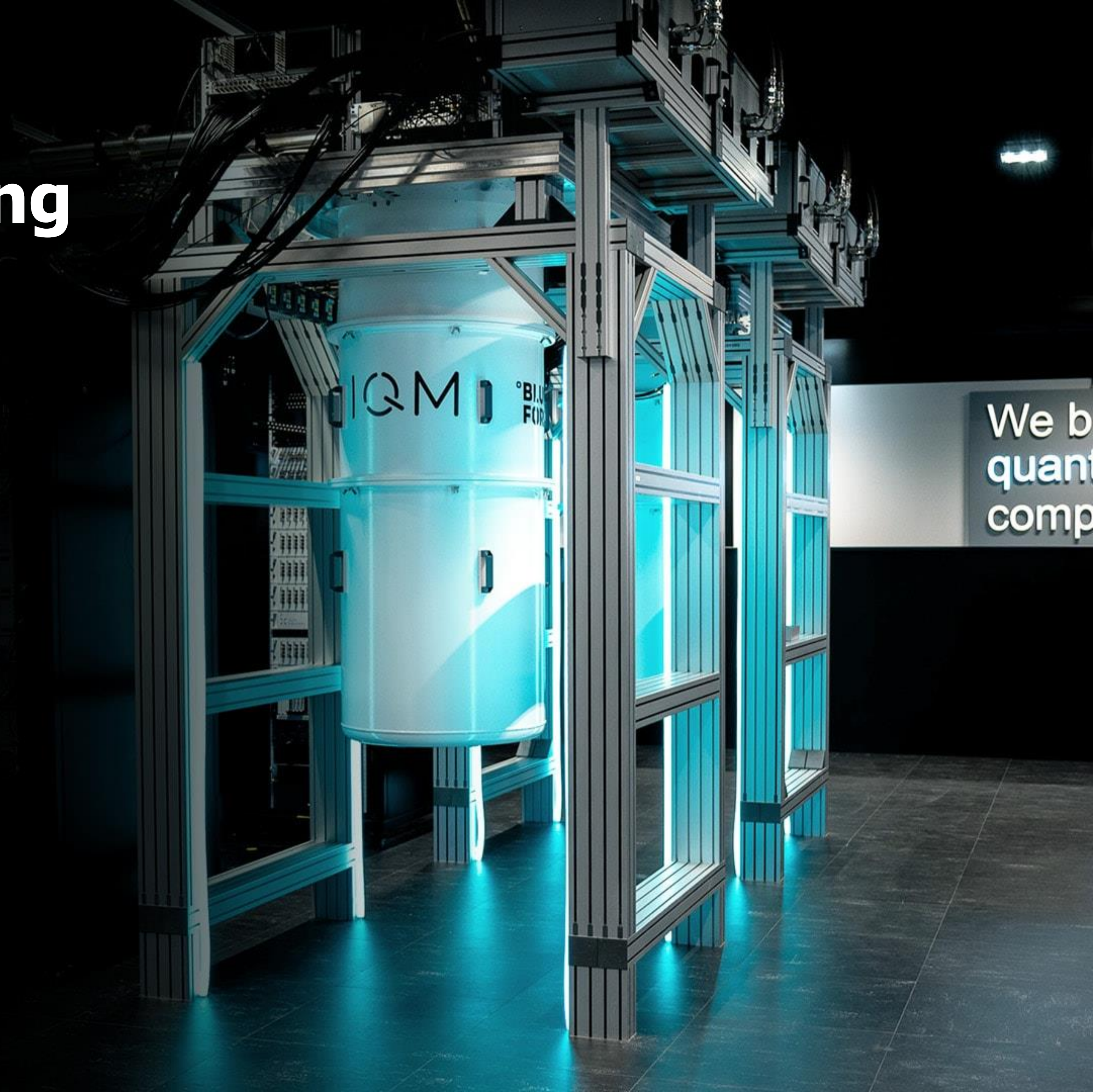


System integration

- Fully integrated system building on in-house and 3rd party subsystems and components
 - In-house developed control electronics for fast high-quality fast control signal generation and readout



Facilities for production and testing



Quantum processing unit chip design and fabrication

Largest QPU production in Europe. Our facility in Espoo, Finland features over **560 sqm clean room space**

- Ramped up in 2022, **piloting** and **commercial production up to 150 qubit systems**
- 200 mm wafer size
- Equipment and methodology for Josephson junctions, 3D-integration techniques, and materials research
- **Expansion of clean room to enable scaling to 1000+ qubits in 2025 - 2026**
 - New/improved methodologies and throughput maximization
 - 350 m² added space, tools down-selection and purchase processes ongoing



Cryogenic facility for piloting and testing

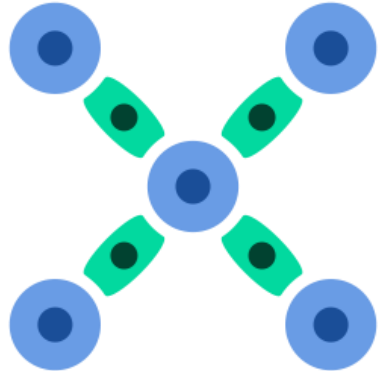
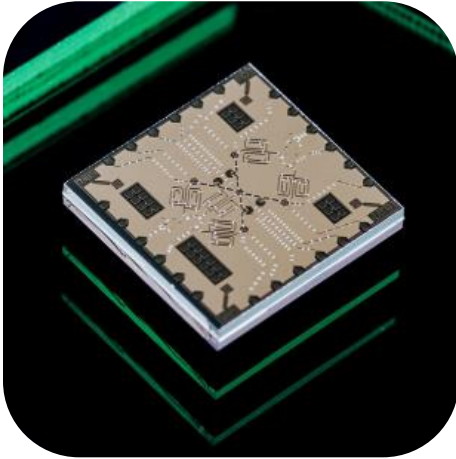
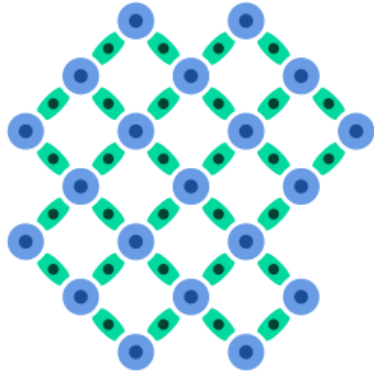
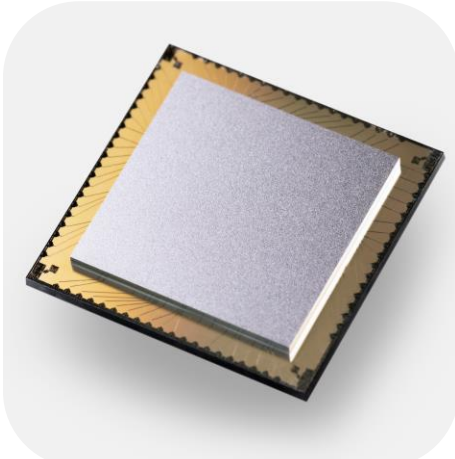
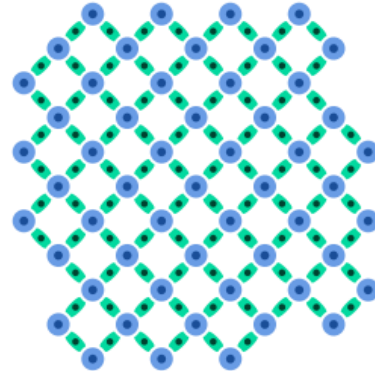
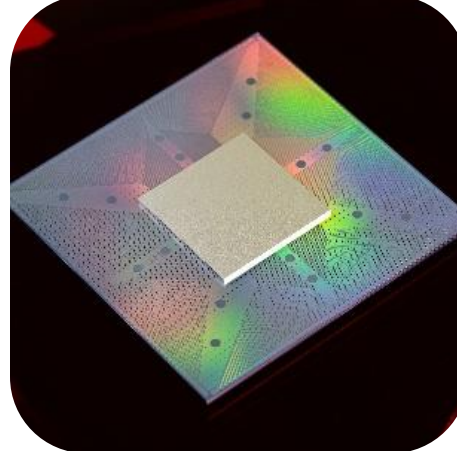
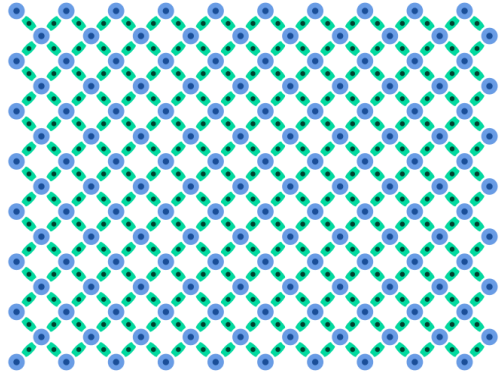
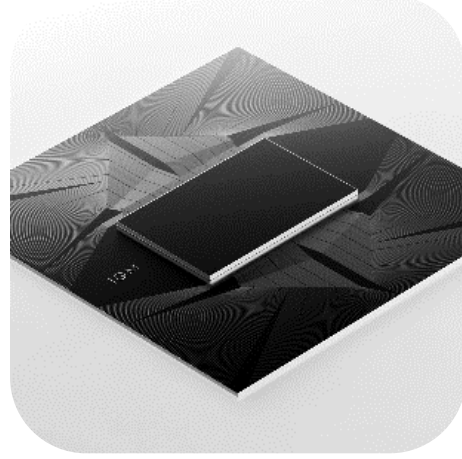
- **IQM hosts tens of cryogenic quantum computing and testing stations:**
 - Full quantum computers with 5 – 150 qubits
 - Cryogenic testing for design optimization and chip quality control
- **Testing bottleneck:**
 - In-line quality control steps at room temperature on wafer and chip level
 - Full materials and performance characterization does require chip cooldown to operating temperature of about 10 mK
 - IQM cools down typically about 5 chips daily on average



Quantum computer generations and products



Quantum processor generations – Crystal family

	IQM CRYSTAL 5	IQM CRYSTAL 20	IQM CRYSTAL 54	IQM CRYSTAL 150
QUBIT COUNT	5 comp qubits 4 couplers	20 comp qubits 30 couplers	54 comp qubits 90 couplers	150 comp qubits 266 couplers
AVAILABILITY	Since 2022	Since 2023	Since 2024	H2 2025
QPU TOPOLOGY	 	 	 	 

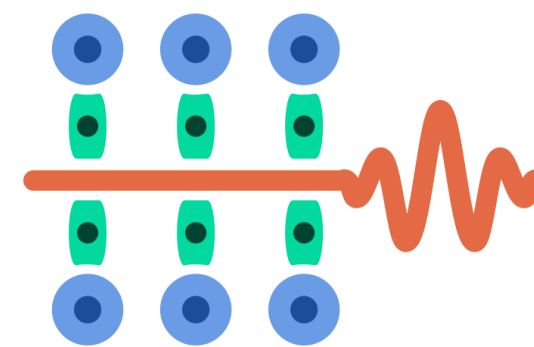
Quantum processor generations – Star family

IQM Star

- Higher-connectivity family optimal for certain computational problems
- Effective all-to-all connectivity
- Complements IQM's Crystal topology
- Supplements IQM HW toolbox

IQM Star-6

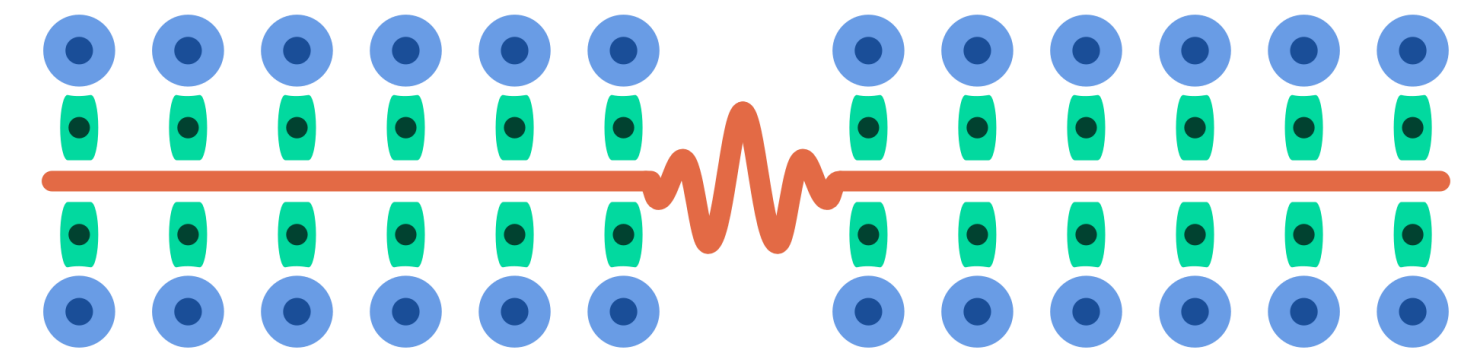
6 qubits, 6 couplers, 1 resonator



Since 2024

IQM Star-24

16-24 qubits, 16-24 couplers, 1 resonator

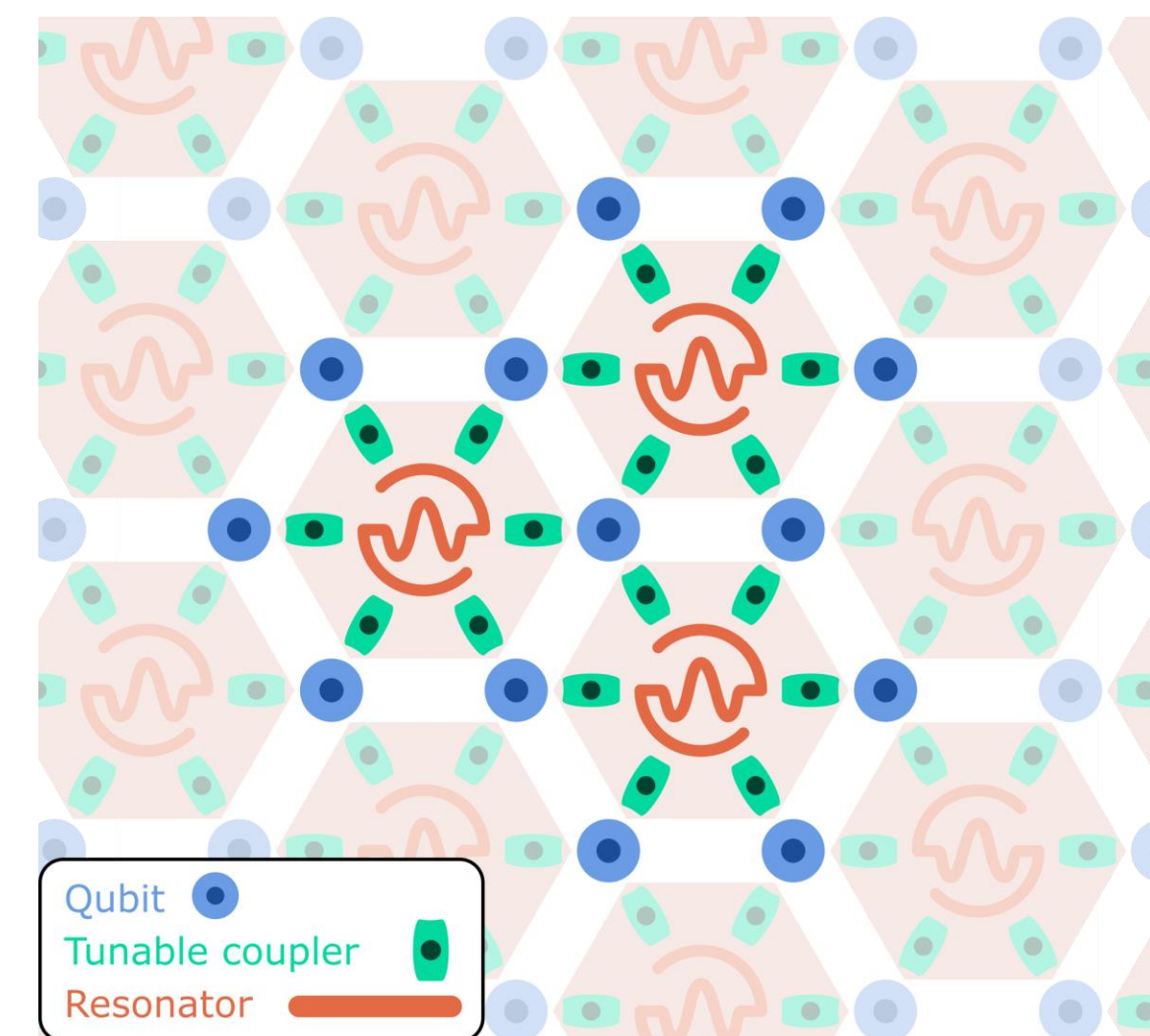


Since 2025

IQM Constellations

- Family of topologies enabling HW-efficient way towards quantum error corrected advantage

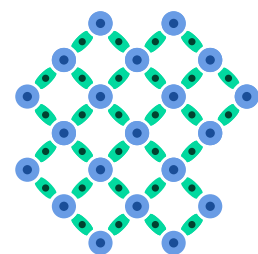
IQM Constellations



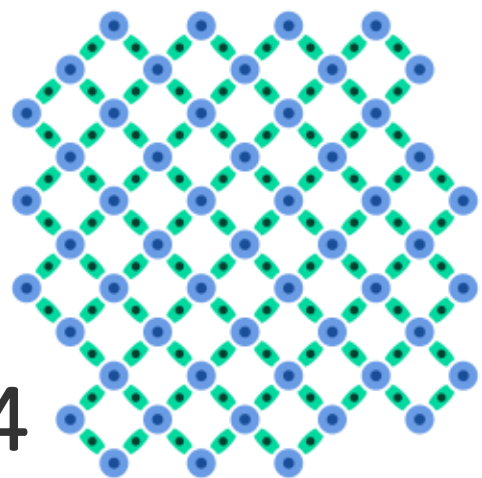
Family of topologies to support fault-tolerant roadmap

IQM QPU benchmarks

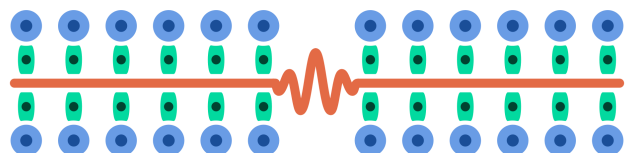
Crystal-20



Crystal-54



Star-24



Qubit count 20

1Q fidelity median 99.92 %
best 99.9440±0.0001 %

2Q fidelity median 99.51 %
best 99.82 ± 0.02 %

Largest GHZ genuinely entangled state 20

Quantum volume 32
(Classical simulation complexity)

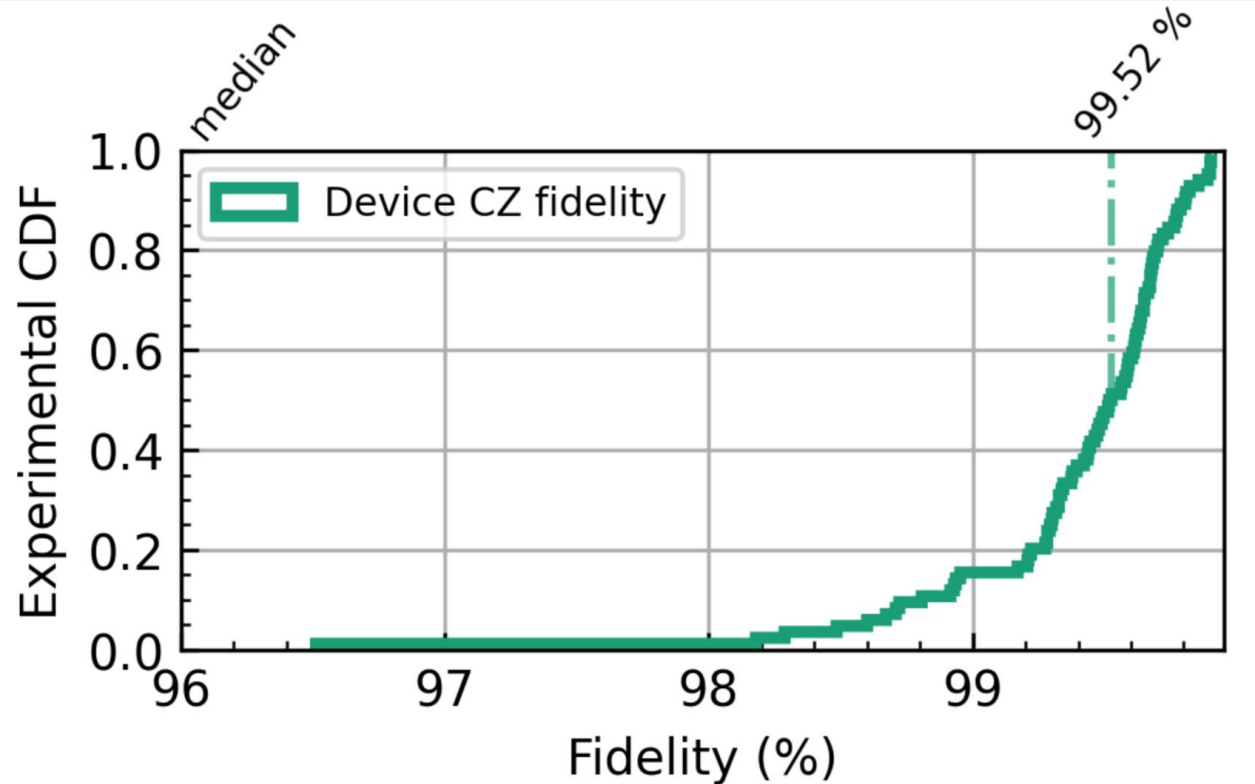
CLOPS 2600
(Quantum circuit execution speed)

Q-score 15
(Size of combinatorial optimization task solved)

Qubit count 54

1Q fidelity median 99.92 %
best 99.96 %

2Q fidelity median 99.52 %
best 99.85 %

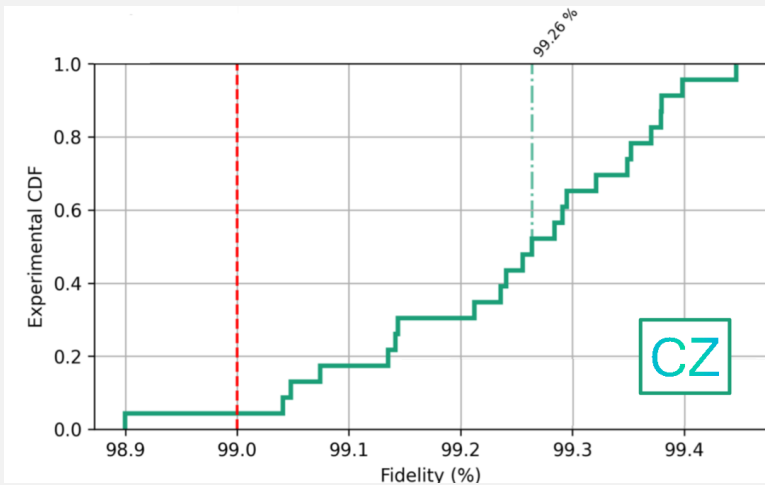
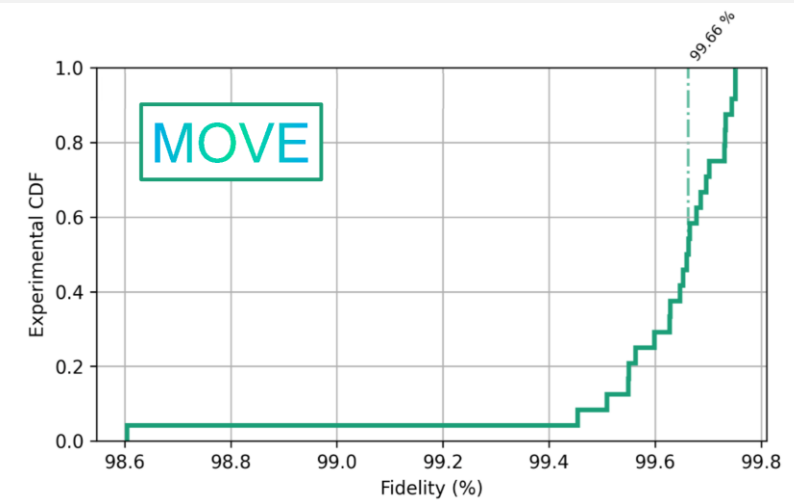


Element count 24 Q + 1 R

1Q fidelity median 99.91 %
best 99.96 %

Q-R fidelity CZ median 99.26 %
best 99.45 %

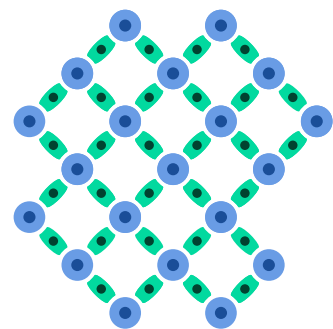
MOVE median 99.66 %
best 99.75 %



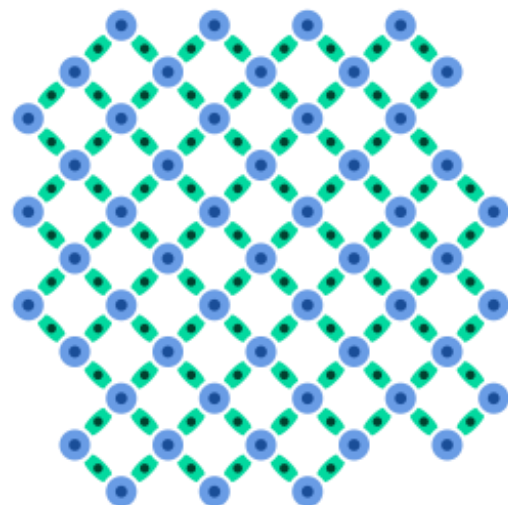
IQM Resonance – the cloud service

- All these are also available through IQM Resonance cloud service (<https://meetiqm.com/products/iqm-resonance/>)

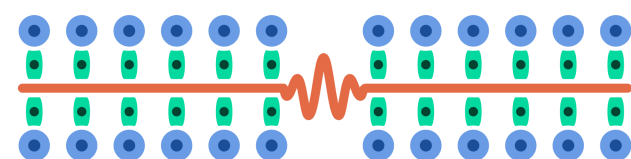
Crystal-20



Crystal-54



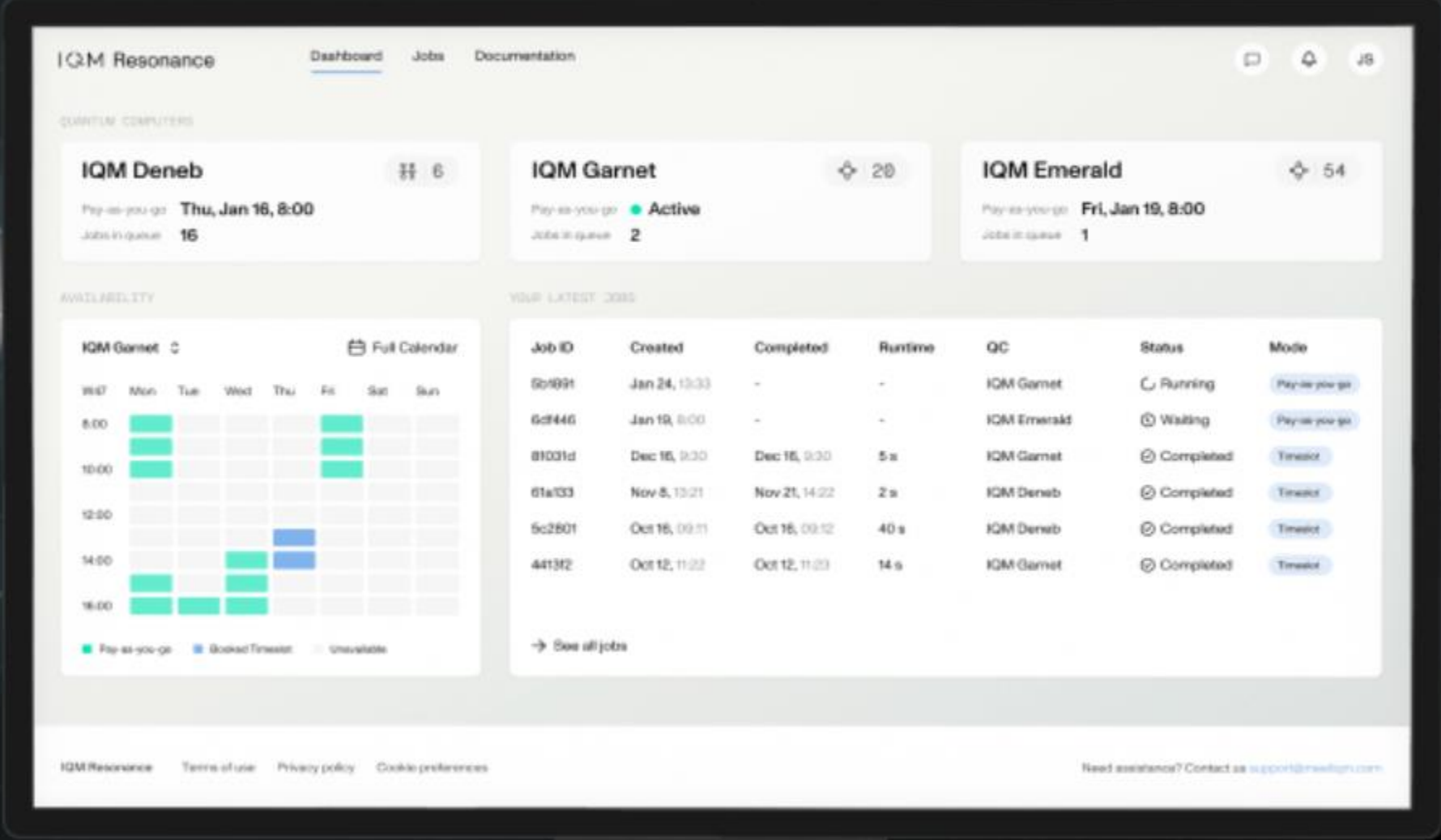
Star-24



Find out how IQM Resonance will work for you

See it for yourself

[Book a demo ↗](#)



The screenshot displays the IQM Resonance dashboard. At the top, there are tabs for 'Dashboard', 'Jobs', and 'Documentation'. Below this, a section titled 'QUANTUM COMPUTERS' lists three systems: IQM Deneb (6 qubits), IQM Garnet (20 qubits), and IQM Emerald (54 qubits). Each system shows its 'Pay-as-you-go' status and the number of jobs in the queue. To the left of the job list is a calendar view for IQM Garnet, showing availability for the next week. On the right, a table titled 'YOUR LATEST JOBS' lists recent jobs with columns for Job ID, Created, Completed, Runtime, QC, Status, and Mode. The footer includes links for Terms of use, Privacy policy, and Cookie preferences, along with a contact email for support.

Job ID	Created	Completed	Runtime	QC	Status	Mode
5b199f	Jan 24, 13:33	-	-	IQM Garnet	Running	Pay-as-you-go
6d446	Jan 19, 8:00	-	-	IQM Emerald	Waiting	Pay-as-you-go
81031d	Dec 16, 9:30	Dec 16, 9:30	5 s	IQM Garnet	Completed	Timeout
61a133	Nov 8, 13:21	Nov 21, 14:22	2 s	IQM Deneb	Completed	Timeout
5c2501	Oct 16, 09:11	Oct 16, 09:12	40 s	IQM Deneb	Completed	Timeout
44132	Oct 12, 11:22	Oct 12, 11:23	14 s	IQM Garnet	Completed	Timeout

IQM Radiance™

Our most advanced
superconducting quantum
computing platform

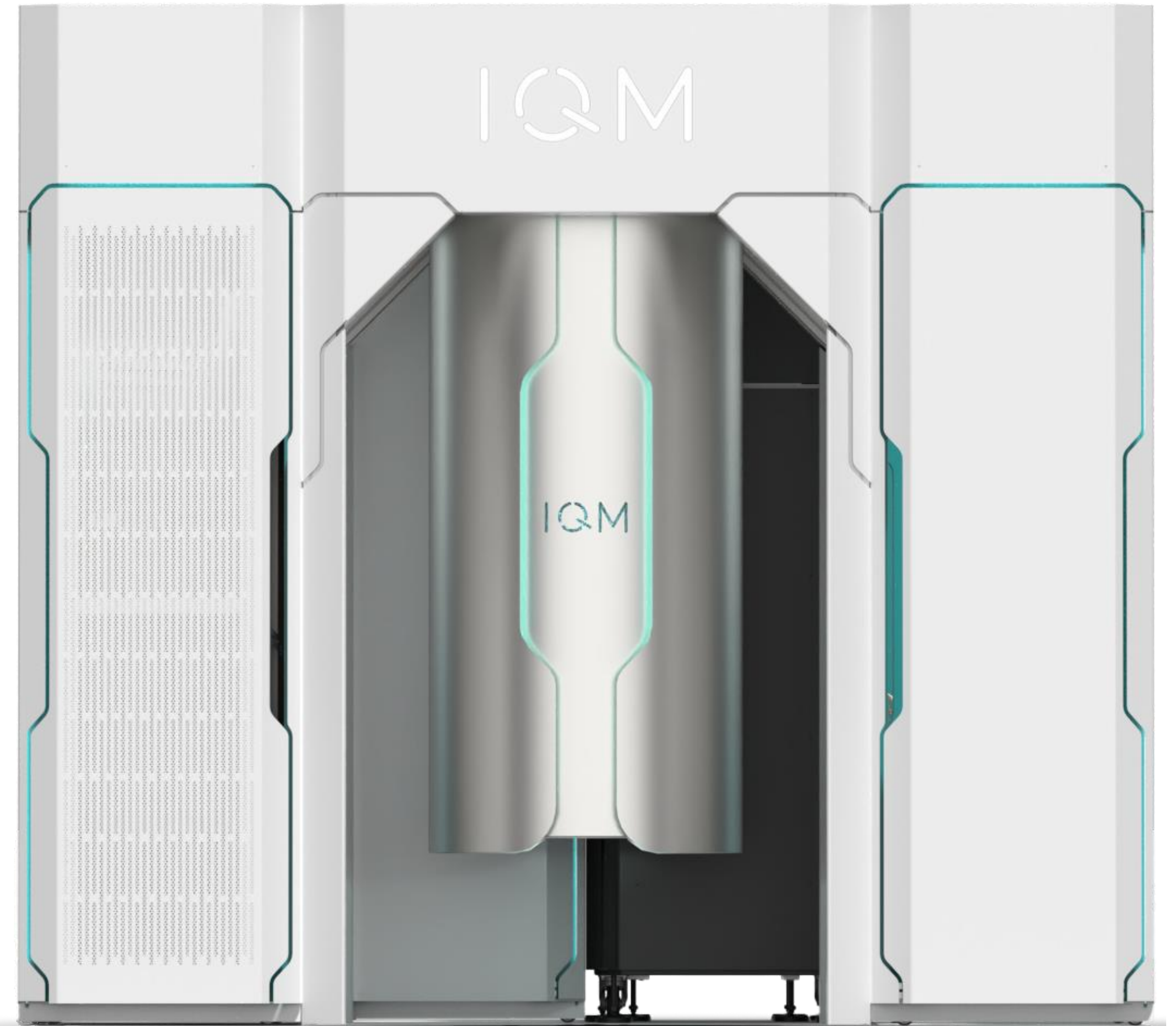
Scalable.
More
Powerful.

Complete
Software
Stack.

Designed
for HPC
Integration.

Available on-premises
with **20, 54 and 150 qubits.**

IQM



IQM Spark™

To Start Your Quantum Journey

→ **5-qubit** on-premises superconducting quantum computer.

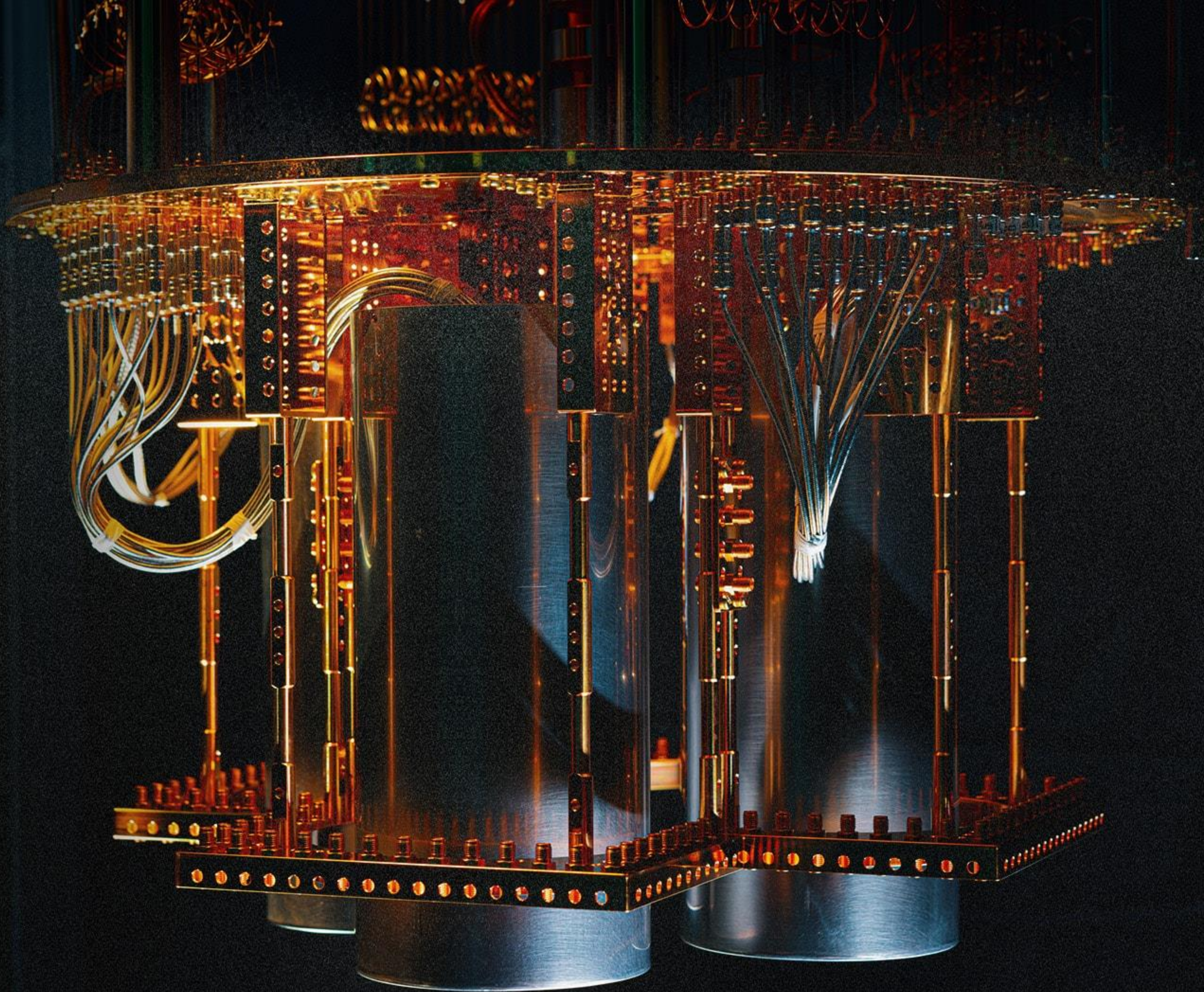
→ Cost-efficient.

→ Fast delivery.

→ For Research and Education.



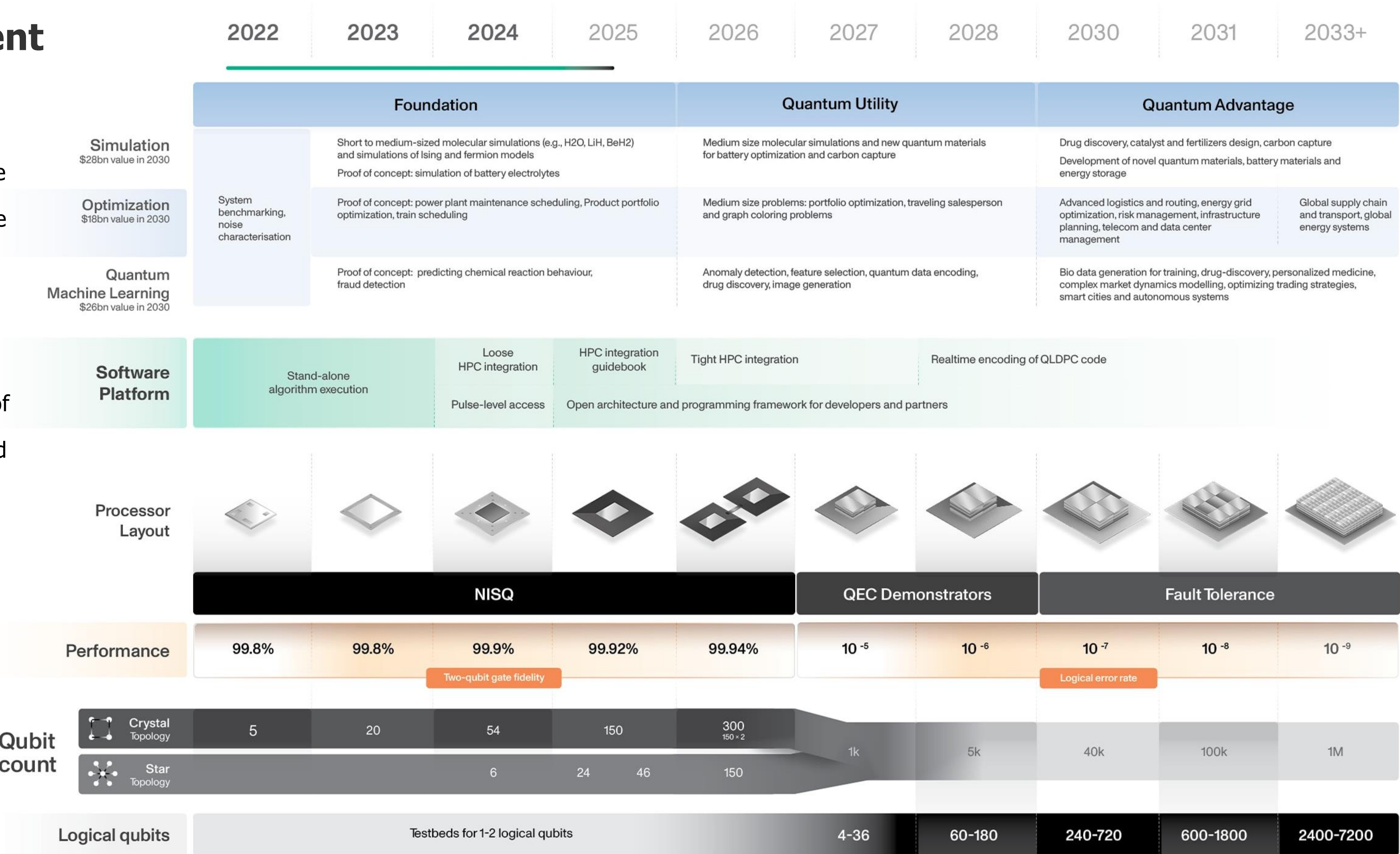
Roadmap



Development Roadmap

- Goal: quantum advantage enabled by fault tolerance
- IQM roadmap to the advantage builds on continued improvement of **quality** and **scaling**, and innovative solutions in **topology** optimization
- On chip fabrication, further-generation fabrication facilities preliminary planning ongoing

IQM



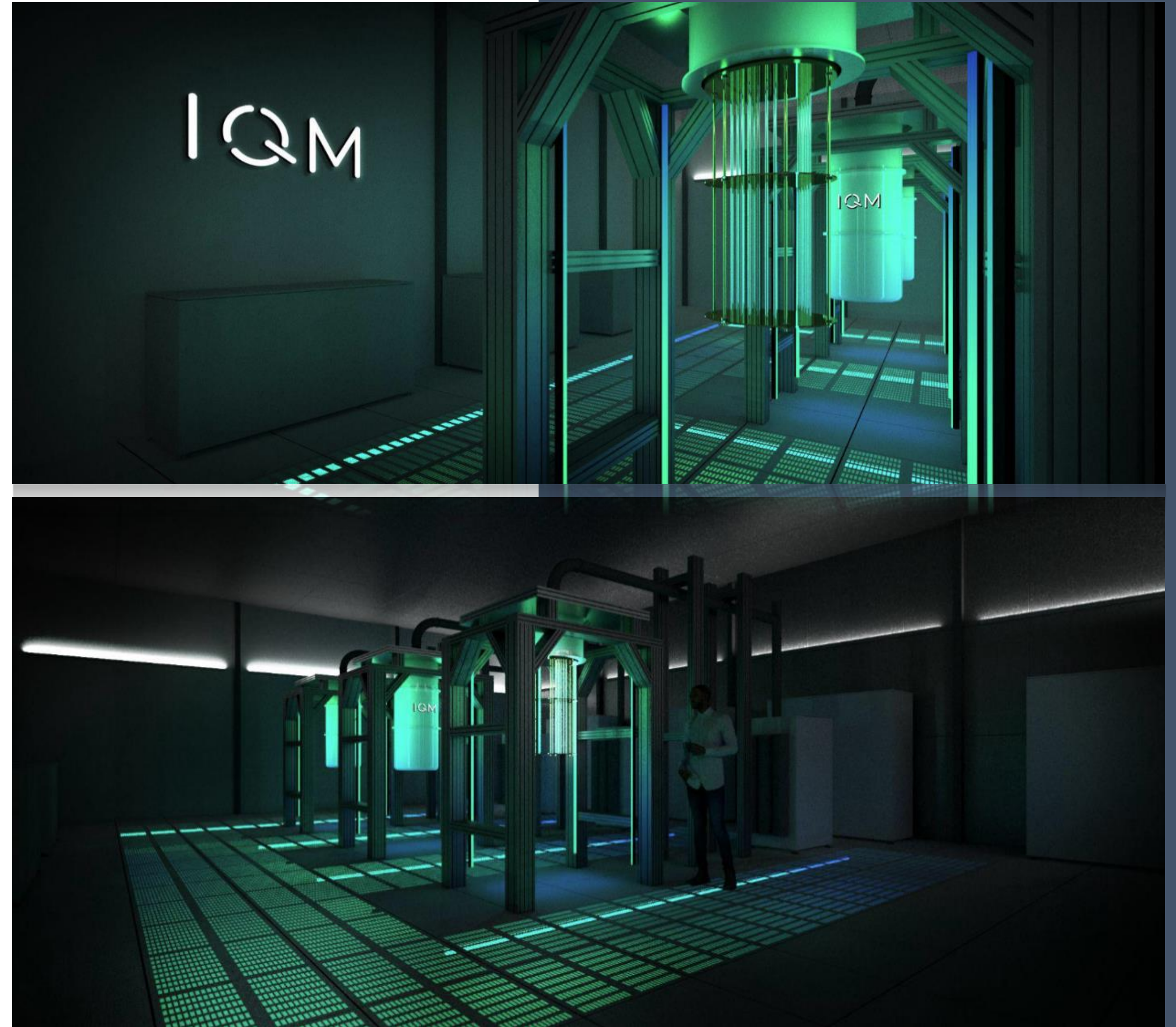
Summary

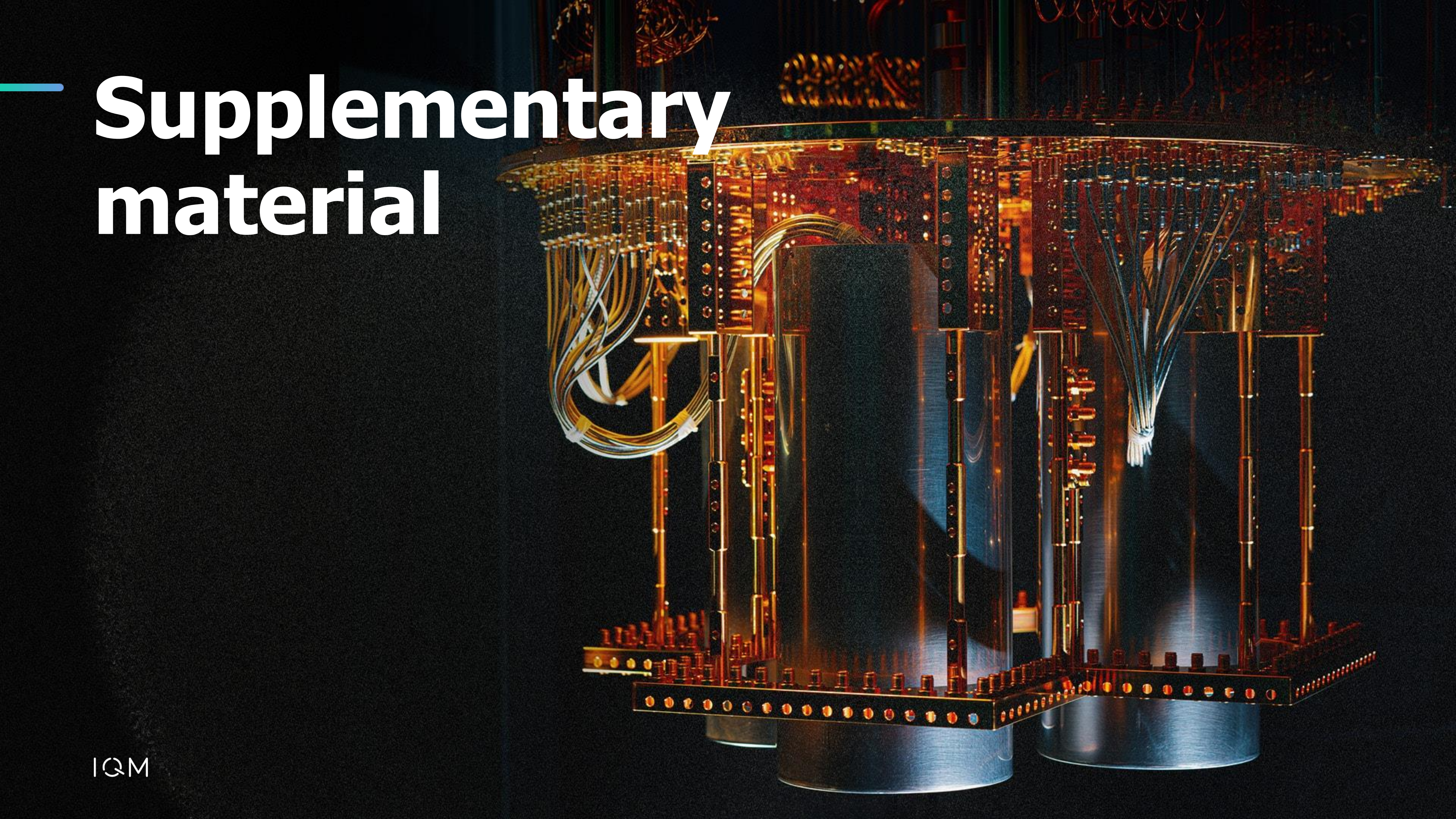
- ↳ IQM's approach on developing and producing superconducting QPUs was outlined
- ↳ High-quality quantum operations with SoA 2QB fidelities demonstrated with test devices and full QPUs
- ↳ Roadmap from today's NISQ application to unique QEC solutions enabling industrial quantum advantage

Contribution of the full IQM team creating the presented results acknowledged.

IQM

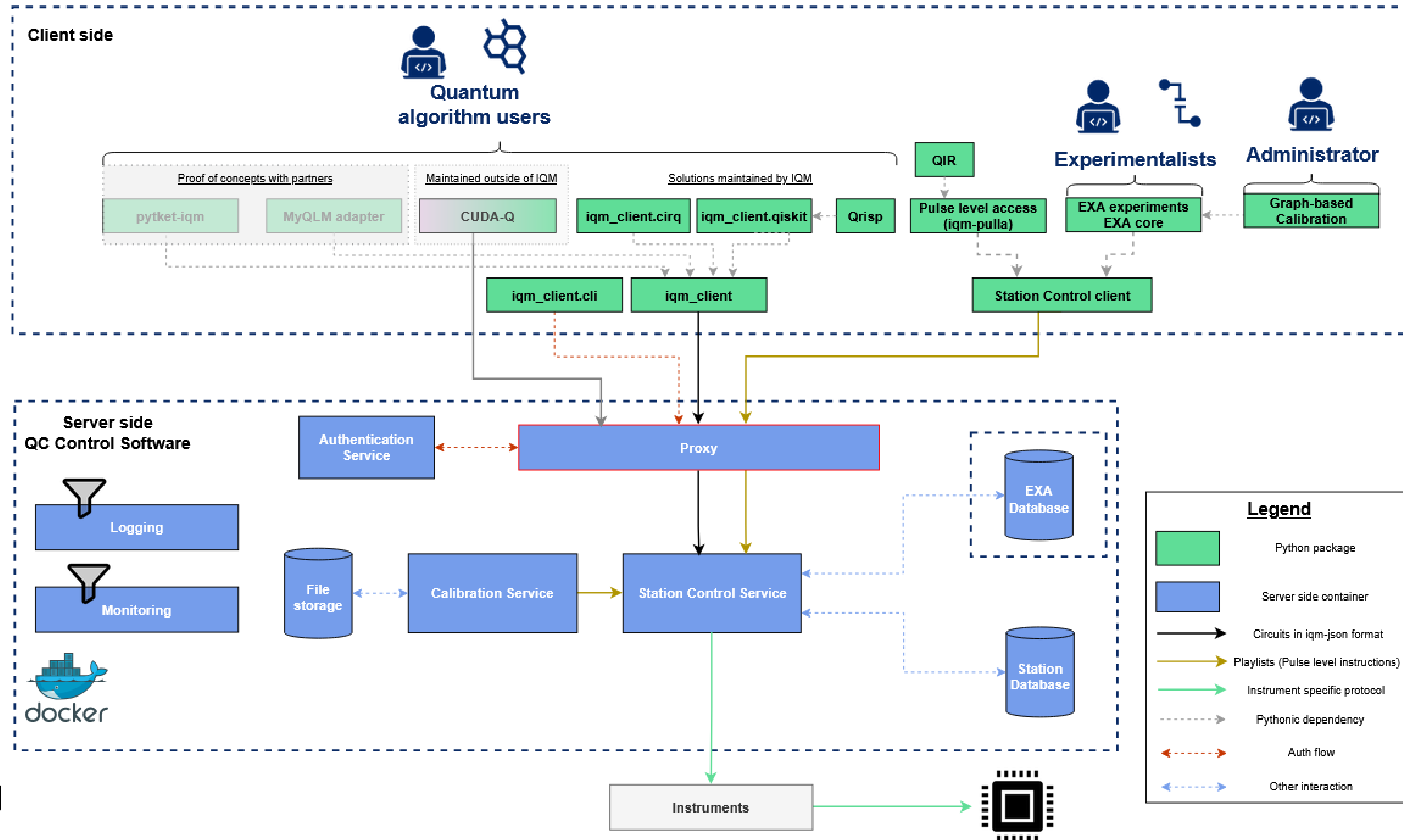
Thank you!



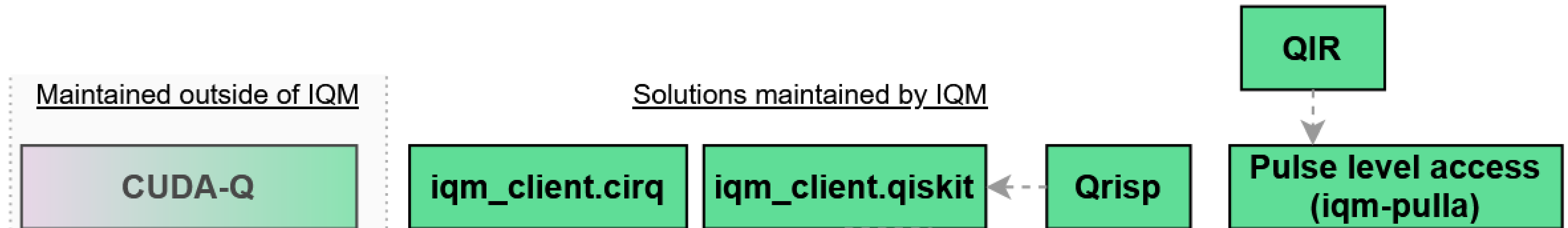


Supplementary material

Software stack



Software stack



- Open interfaces for access in different abstraction levels
 - Quantum circuit execution with common interfaces (CUDA-Q, Cirq, Qiskit)
 - Novel approach for higher abstraction with Qrisp
 - Physical-level control by Pulse level access (IQM-Pulla)
 - Supporting Quantum Intermediate Representation (QIR)



<https://www.qir-alliance.org/>

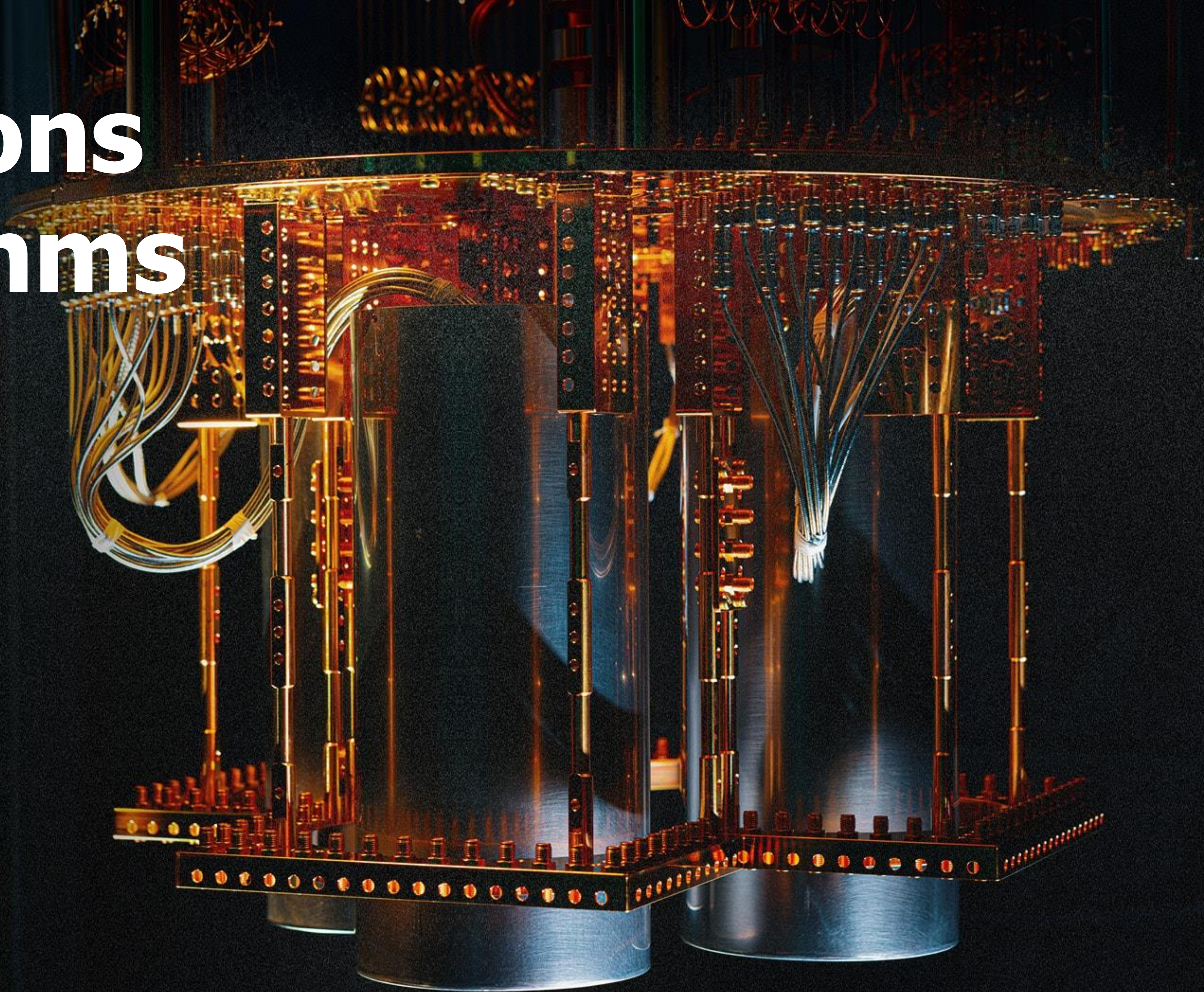


The next generation of quantum algorithm development

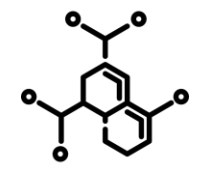
Qrisp is a high-level programming language for creating and compiling quantum algorithms. Its structured programming model enables scalable development and maintenance.

<https://qrisp.eu/index.html>

Applications & Algorithms



Applications



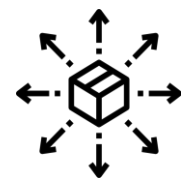
Chemistry & Materials

- Catalyst development
- Battery research



Life sciences

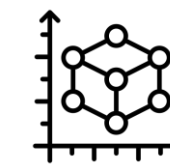
- Drug Discovery
- Protein Folding
- Data Analysis



Operations

- Portfolio Optimisation
- Supply Chain Optimisation
- Process Optimisation
- Route optimization
- Network Optimisation

Algorithms



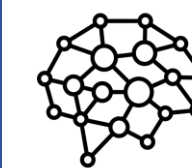
Quantum Simulation

- Preparing ground state
- Time evolving



Quantum Optimisation

- Creating good
quality solutions



Quantum Machine Learning

- Classification
- Generation

NISQ use case example: Product Portfolio Optimization

Partner: DATEV



Problem

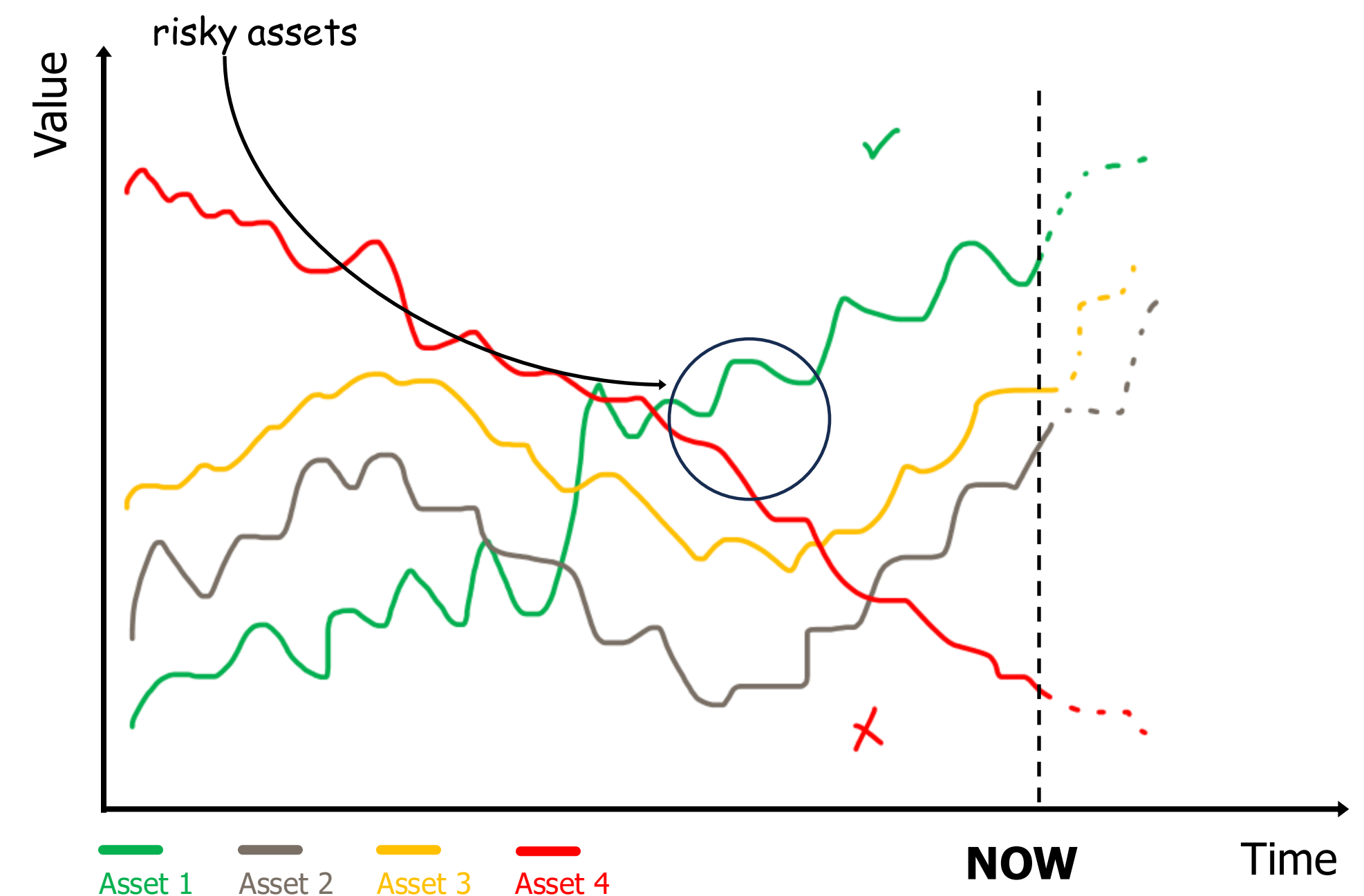
From a set of assets (such as stocks, bonds, or commodities) with a known historical value record, select a portfolio within a given budget to maximize returns while minimizing risks in the near term

Solution

Define the problem as Quadratic Unconstraint Binary Optimization (QUBO) amenable to be solved with QAOA. We implement an optimized QAOA algorithm tailored to our HW.

Why Quantum

QAOA can efficiently explore and optimize large solution spaces by leveraging quantum superposition, entanglement, and interference. Unlike classical algorithms, which evaluate solutions sequentially, QAOA simultaneously encodes and processes multiple candidate solutions, potentially offering faster convergence to optimal or near-optimal results for complex problems like combinatorial optimization.



NISQ use case example: Product Portfolio Optimization

Partner: DATEV



Executed on IQM Radiance Crystal 20

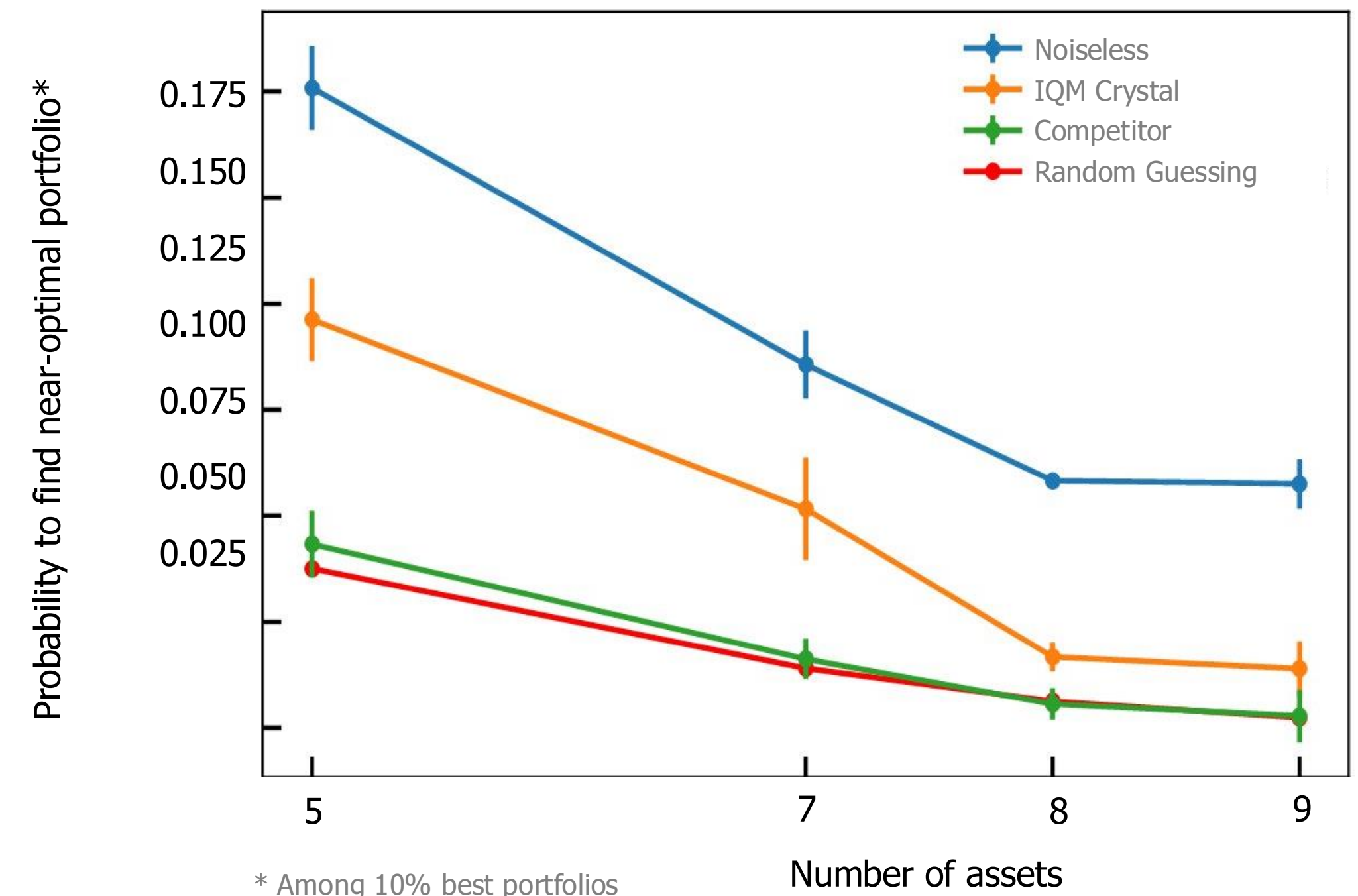
Probability to find near-optimal portfolio, solved with our optimized QAOA and routing

- Different number of assets (5,7,8,9) are considered. For each case, the budget is set to half the number of assets
- Data set provided by DATEV
- NP-hard problem

First results show

- When run in IQM machines, our optimized QAOA solution is closer to the noiseless simulation than standard Qiskit QAOA run on competitor systems.
- Standard Qiskit QAOA on competitor systems offers a solution very close to uniformly random guessing

IQM



Clearly better results on IQM quantum due to

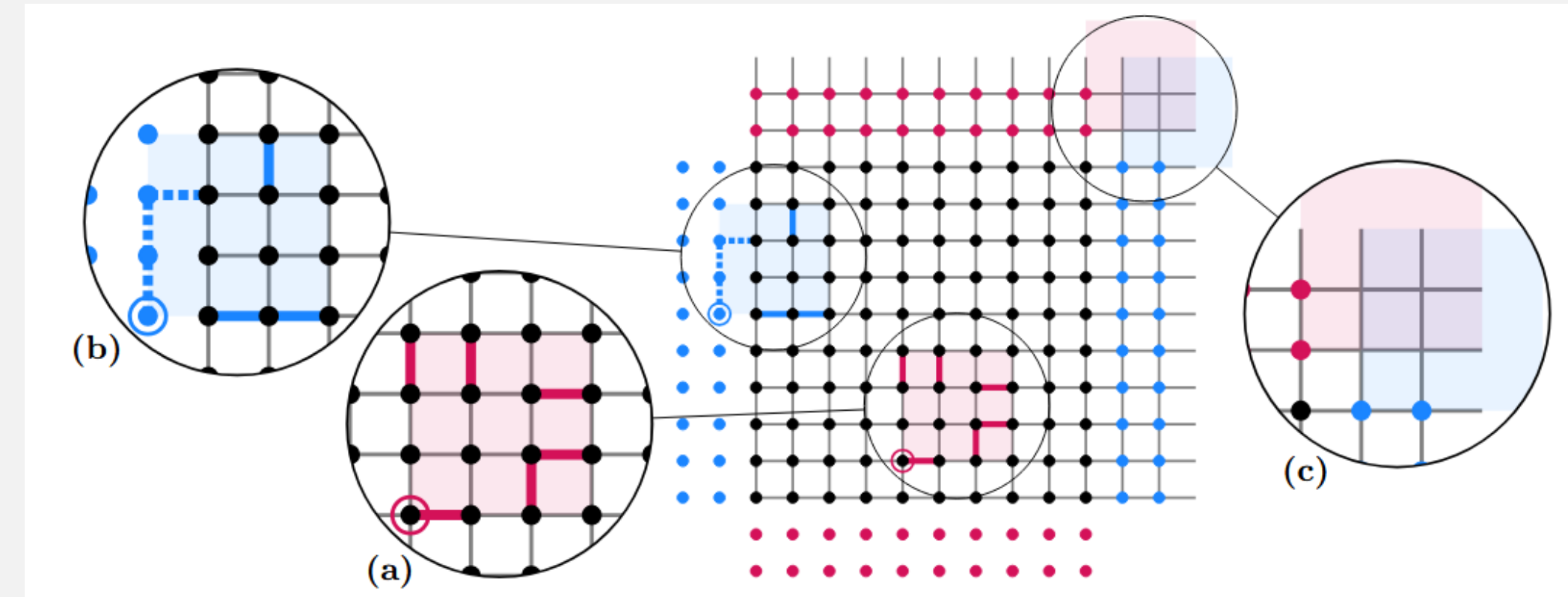
- grid topology of the IQM quantum processing unit (QPU)
- devising a specialized circuit for realizing the algorithm on IQM QPU

Approach towards QEC

Tile codes: optimal planar connectivity patterns local on planar 2D-lattice

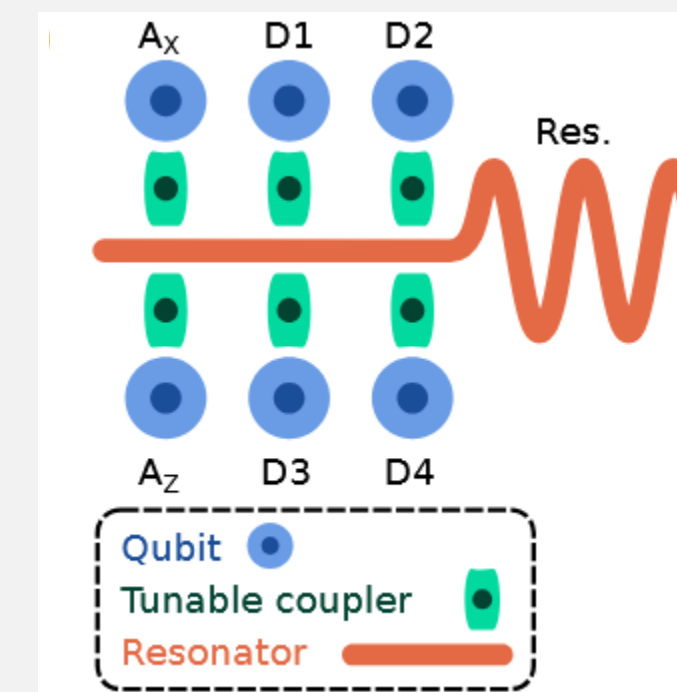
- A new powerful way of constructing codes local on 2D lattice
- Up to 12-times higher efficiency compared to the surface code

V. Steffan et al., arxiv:2504.0917



Hardware-efficient QEC with effective all-to-all connectivity in star topology

- Logical fidelity of 96.6% - 99.9% with $[[4,2,2]]$ code
- Demonstration of entanglement by encoding a logical Bell state



State	τ_{Z1} (μ s)	τ_{Z2} (μ s)	ϵ_{Z1} (%)	ϵ_{Z2} (%)
$ 00\rangle_L$	175(9)	157(1)	0.58(3)	0.64(5)
$ 01\rangle_L$	303(15)	204(38)	0.34(2)	0.50(8)
$ 10\rangle_L$	407(34)	155(8)	0.25(2)	0.65(3)
$ 11\rangle_L$	242(15)	138(12)	0.42(2)	0.73(6)

	τ_{X1} (μ s)	τ_{X2} (μ s)	ϵ_{X1} (%)	ϵ_{X2} (%)
$ ++\rangle_L$	129(5)	190(7)	0.79(3)	0.53(2)
$ +-\rangle_L$	134(9)	192(24)	0.76(4)	0.53(6)
$ - + \rangle_L$	111(4)	178(14)	0.91(3)	0.57(4)
$ --\rangle_L$	153(8)	249(25)	0.66(3)	0.41(4)

F. Vigneau et al., arxiv:2503.12869