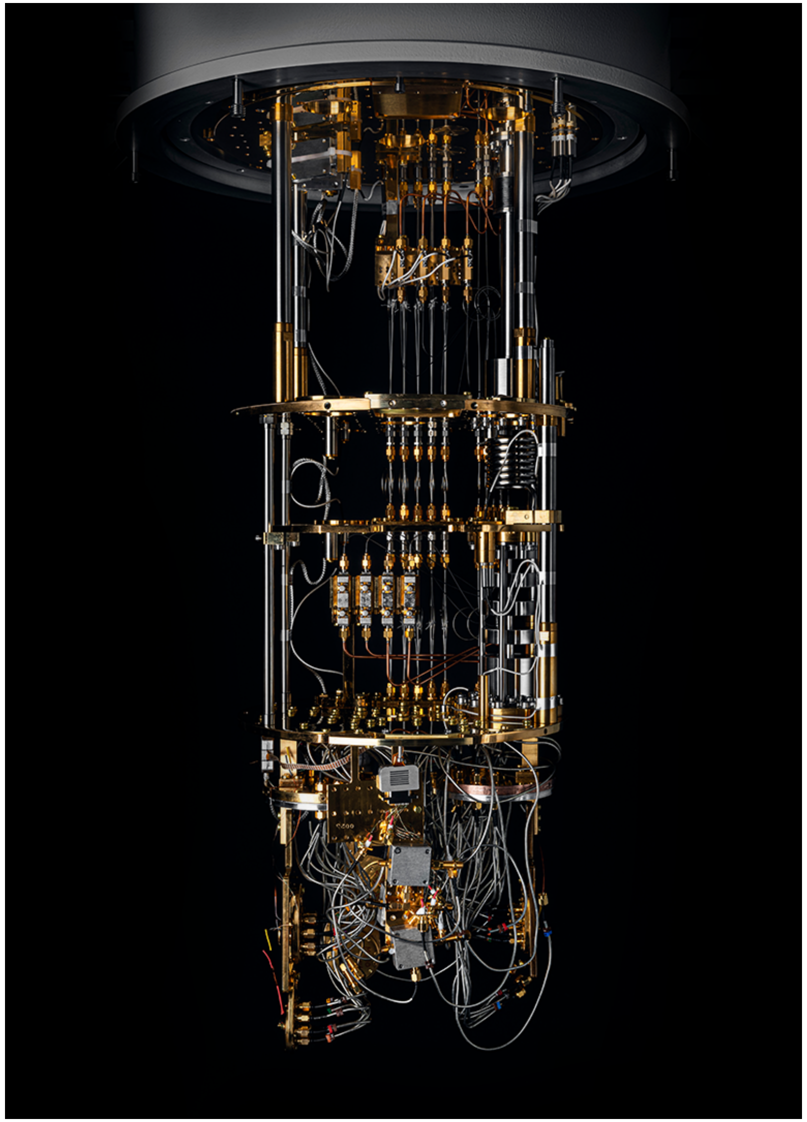
IQM

Co-Designing Quantum Computers @ IQM

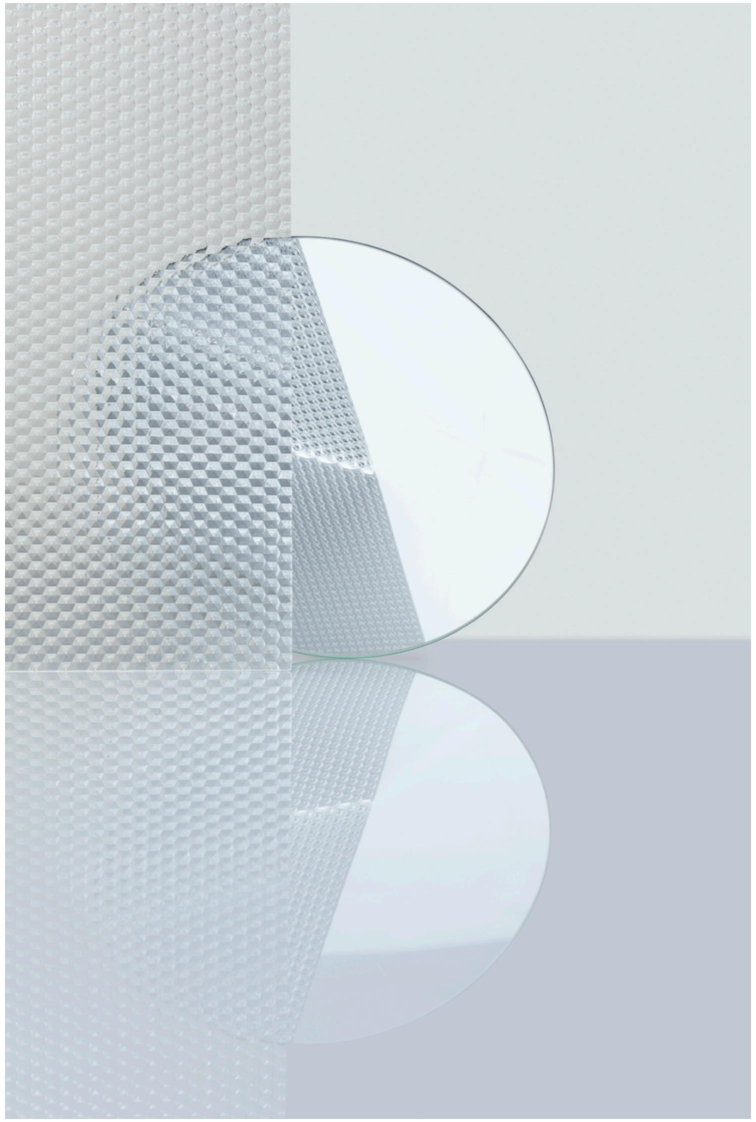
Bruno G. Taketani

bruno.taketani@meetiqm.com



Outline

- Introduction to IQM
- Co-designing quantum computers
- Latest results



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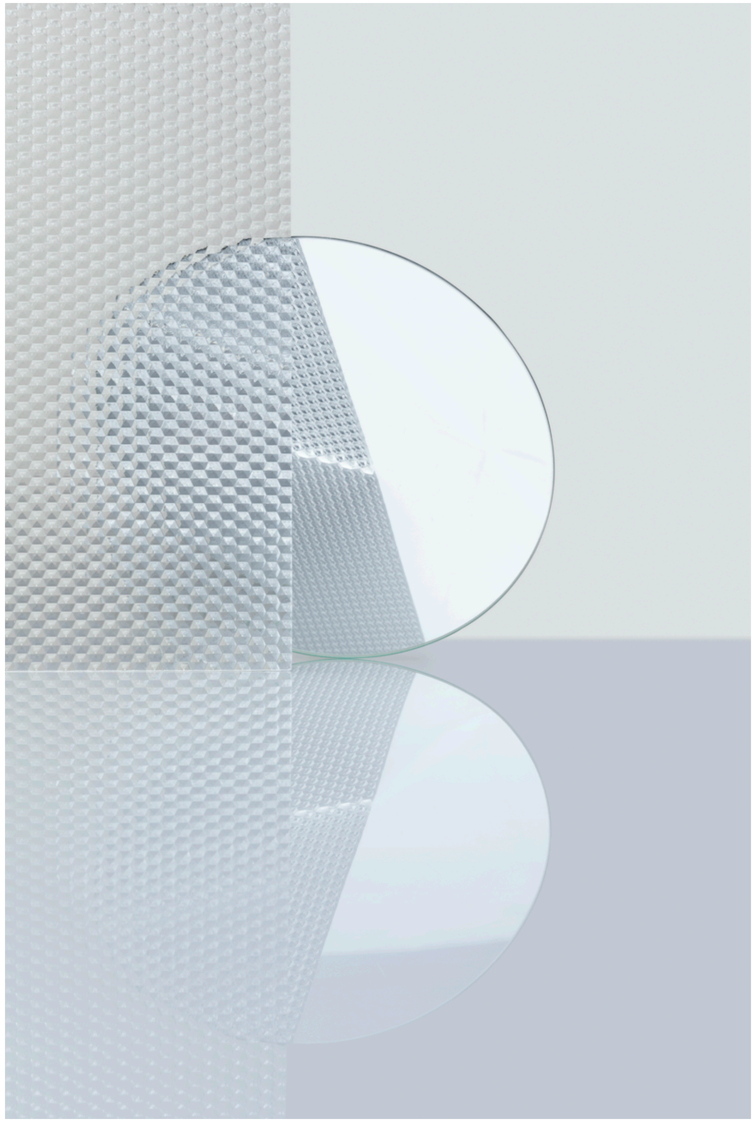


IQM

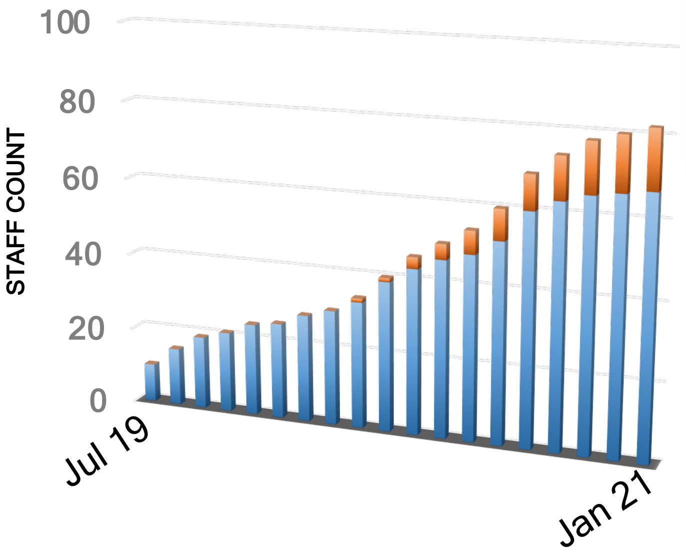
IQM in brief

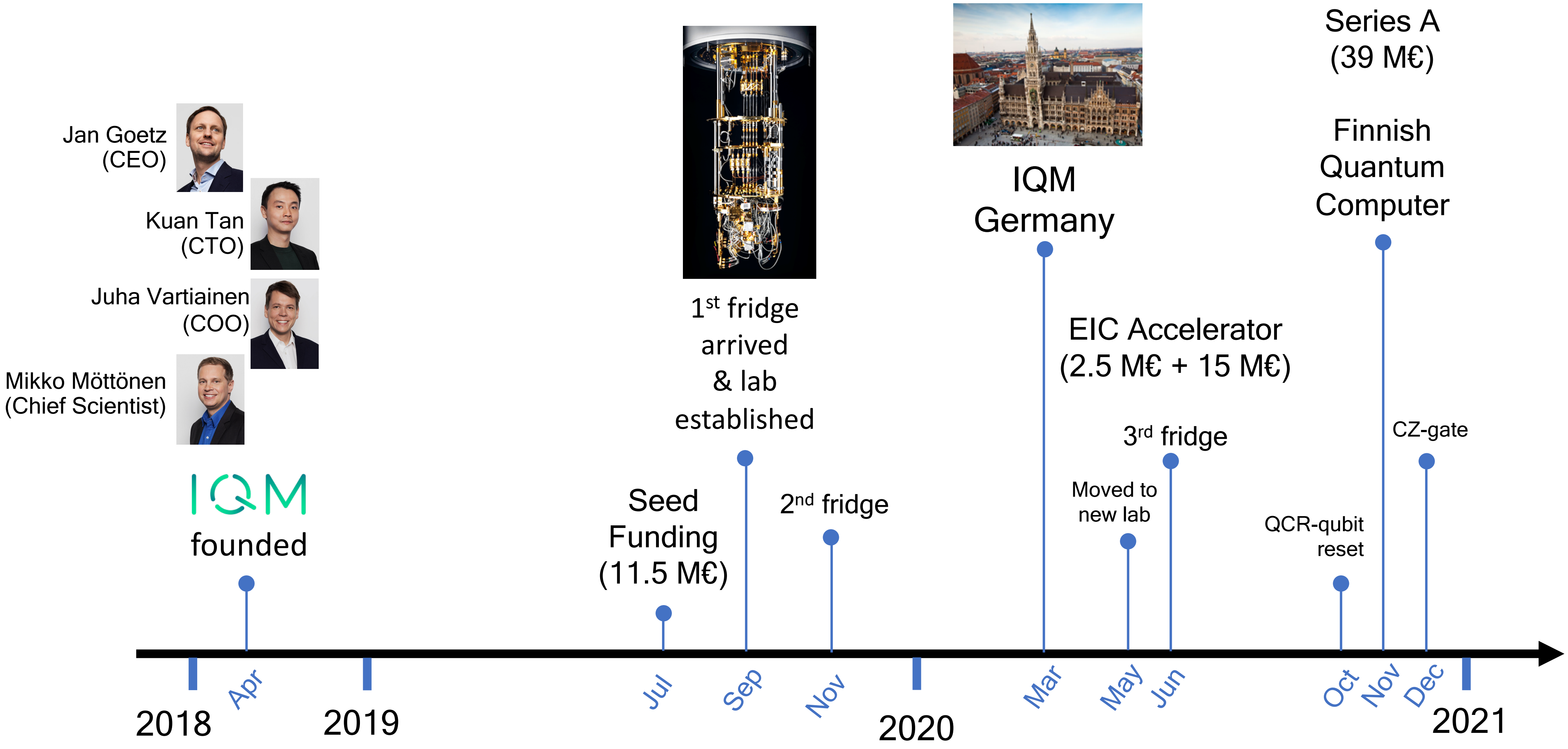
Quantum computing startup

- Spinout of Aalto University and VTT in July 2019
- Develop and sell quantum computers based on superconducting technology
- Hardware stack and co-design quantum computers
- Secured 2 rounds of private investment funding (Seed & A)

Employees (Jan. 2021)

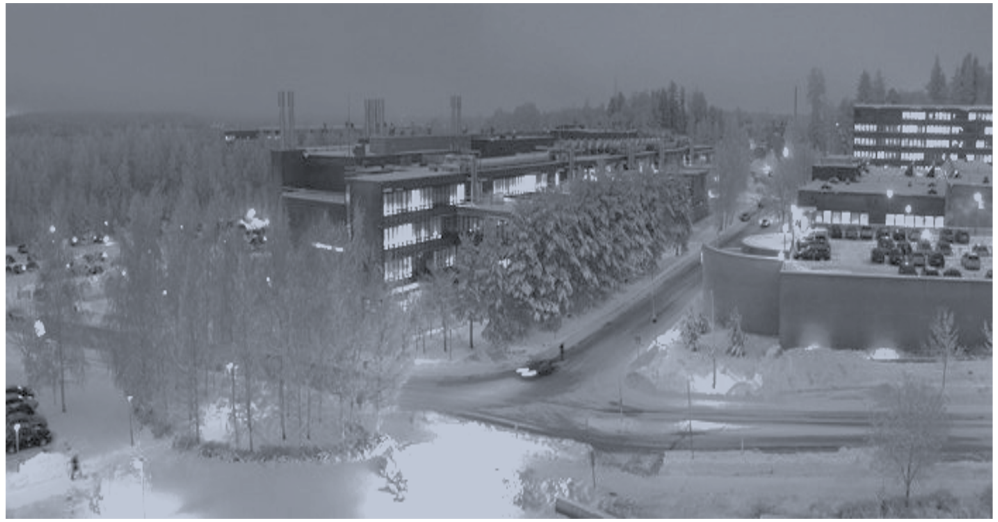
- IQM Finland 67 employees
- IQM Germany 15 employees



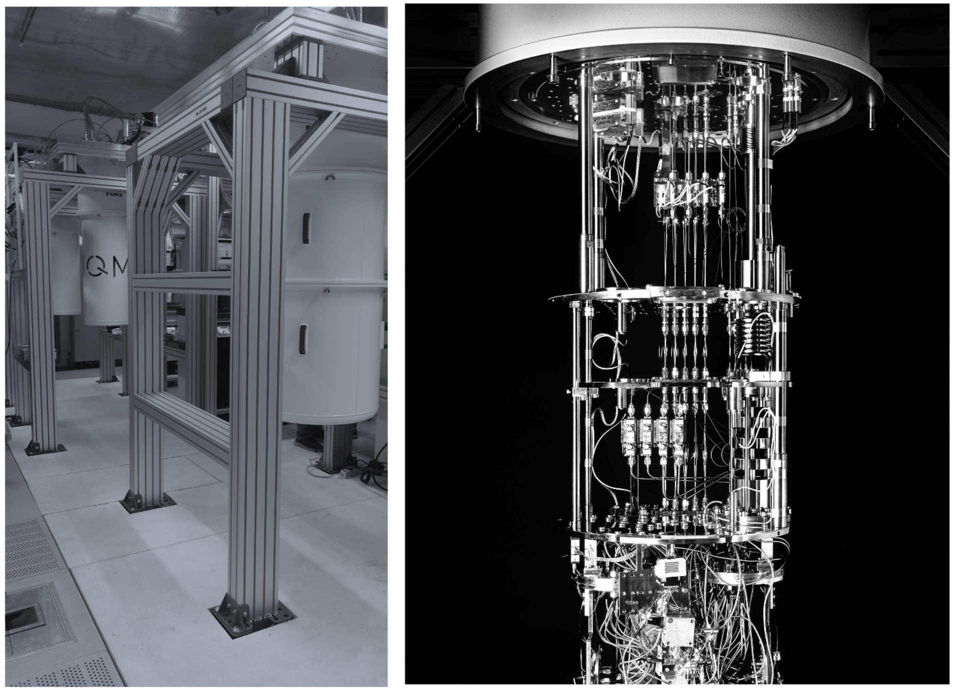

Jan Goetz
(CEO)
Kuan Tan
(CTO)
Juha Vartiainen
(COO)
Mikko Möttönen
(Chief Scientist)
IQM
founded
Seed
Funding
(11.5 M€)
1st fridge
arrived
& lab
established
2nd fridge
IQM
Germany
EIC Accelerator
(2.5 M€ + 15 M€)
Moved to
new lab
3rd fridge
QCR-qubit
reset
Series A
(39 M€)
Finnish
Quantum
Computer
CZ-gate
2018
Apr
2019
Jul
Sep
Nov
2020
Mar
May
Jun
Oct
Nov
Dec
2021

IQM's R&D infrastructure

- 3 dilution refrigerators installed, 5 more in H1 2021 in an EM shielded underground facility
- Clean room operations in Micronova, Espoo



Cleanroom: Micronova, Otaniemi



Experimental facilities: Keilaniemi, Espoo.

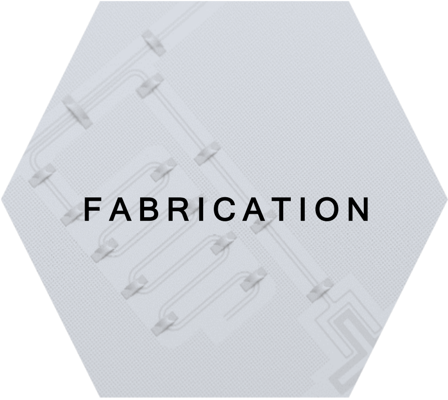
Finnish Quantum Computer

VTT IQM

A! ETH zürich JÜLICH Forschungszentrum

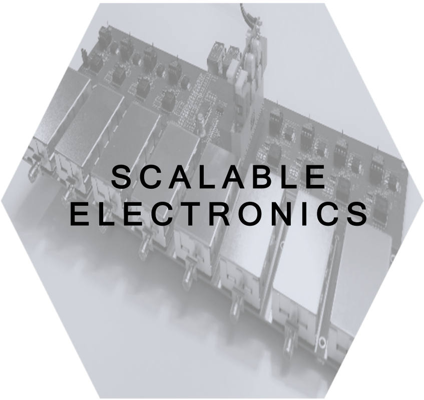
- Finland’s first quantum computer
- IQM will build the computer with VTT, with partners from Aalto, ETH, and Jülich
- Co-development project to strengthen the Finnish quantum ecosystem
- Collaboration also with CSC and Atos
- 3 phases: 5-, 20- and 50-qubit processors deployed over the next ~3.5 years

IQM’s R&D team

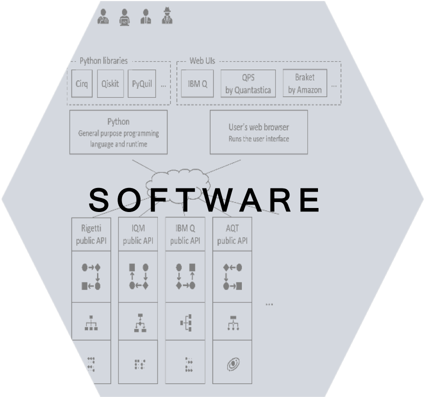


Manufactures IQM quantum processors in the largest cleanroom of the Nordics

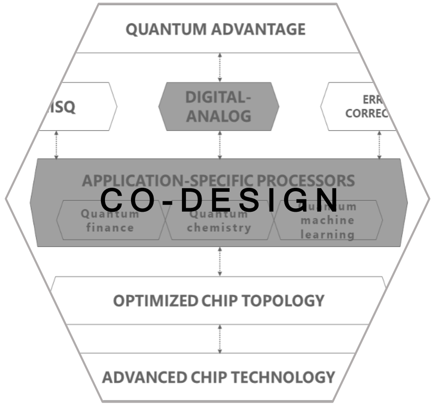
Takes IQM quantum processors into operation in weekly feedback cycles



Provides the control equipment for IQM quantum processors



Builds solutions to design and operate IQM quantum processors



Develops application-specific algorithms and co-design blueprints for QPUs

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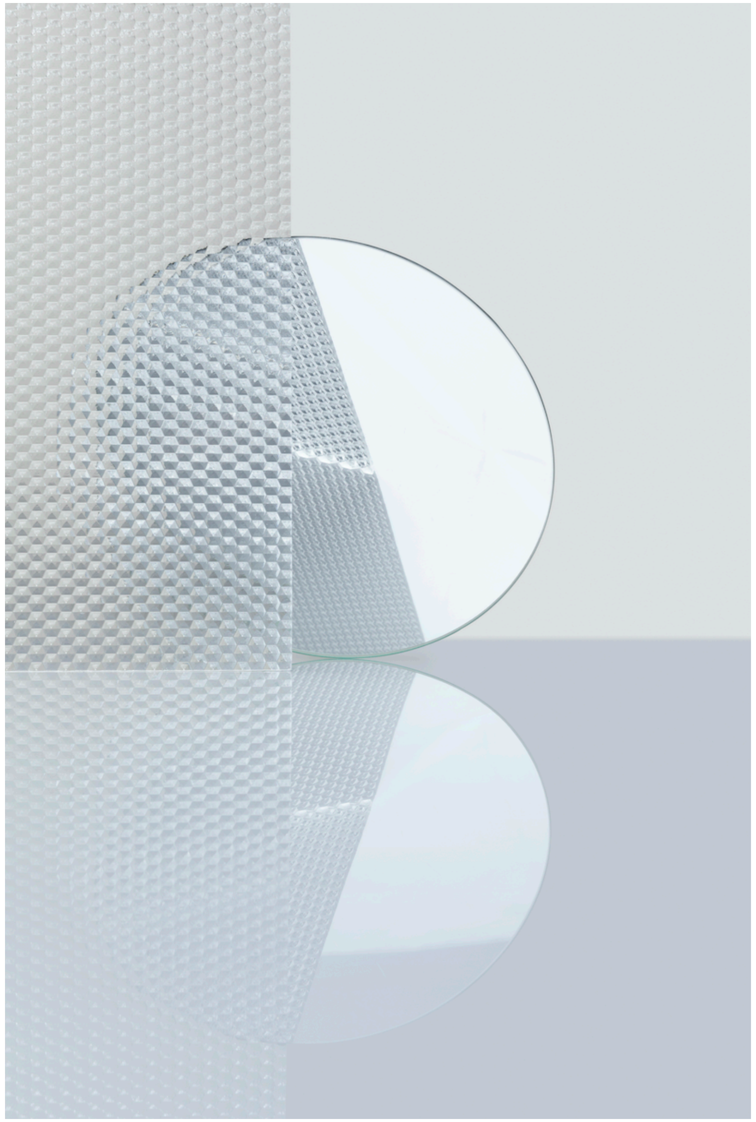


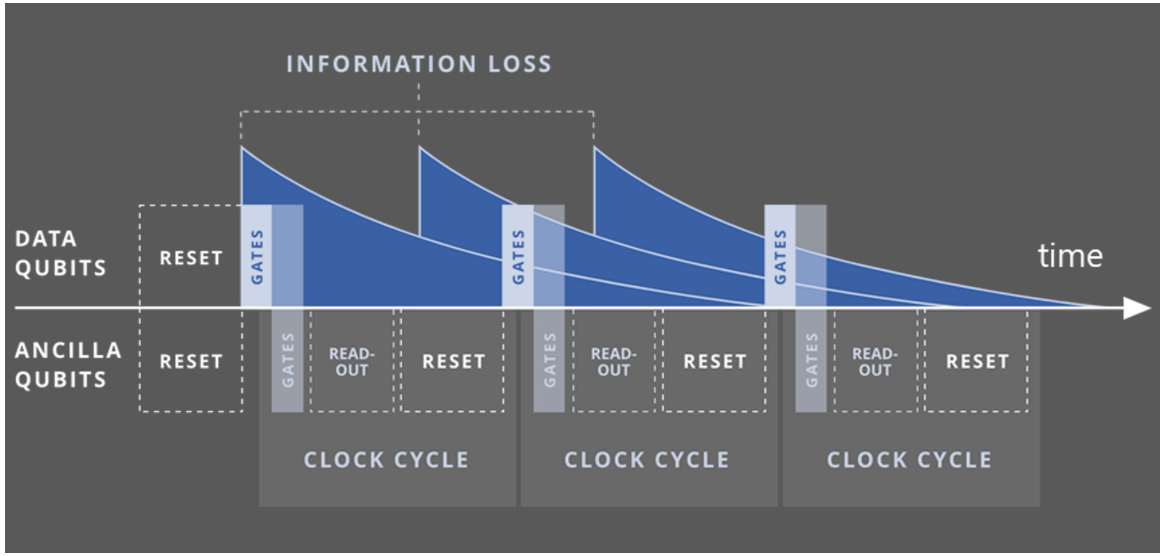
Unique chip technology

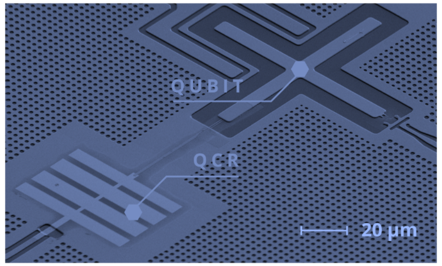
PROBLEM

Quantum operations too error prone for **quantum advantage** and too slow for **error correction**.

SOLUTION

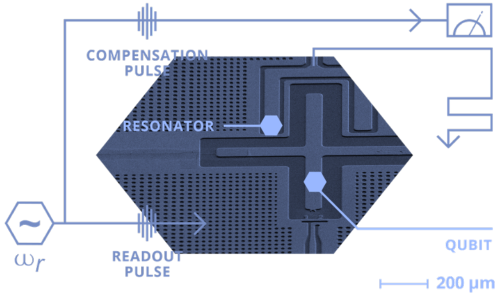
IQM builds the most precise and fastest quantum processors by improving the three basic quantum operations: reset, gates, readout.





FASTER RESET: QCR WITHOUT FEEDBACK

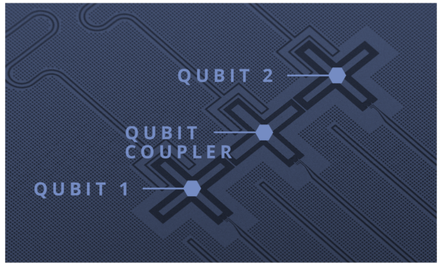
- Unconditional reset
- Resets also higher quantum states (leakage errors)
- No RF fields required (quasi-DC technology)
- Suitable for active on-chip cooling



FASTER READOUT: MULTICHANNEL INSTEAD OF SINGLE DRIVE

- Based on a multichannel driving scheme
- No on-chip overhead

Phys. Rev. Lett. **122**, 080503 (2019)

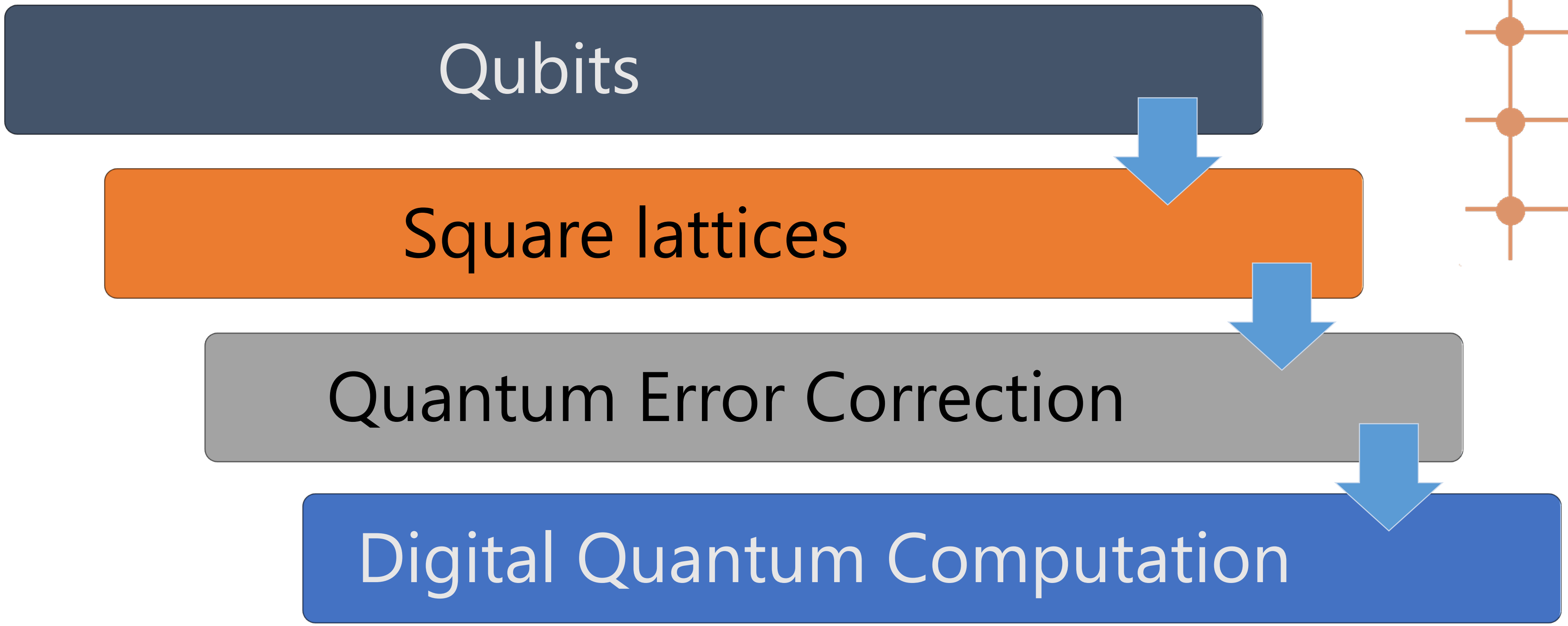


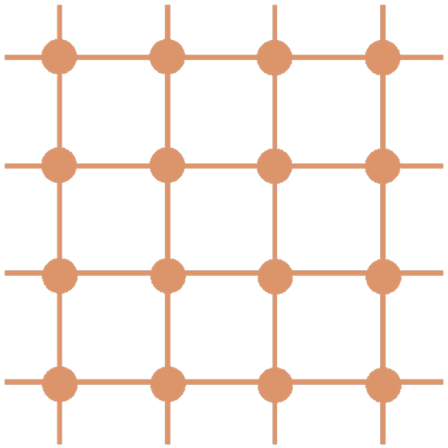
FASTER GATES: TUNABLE COUPLER & *N*-JUNCTION QUBITS

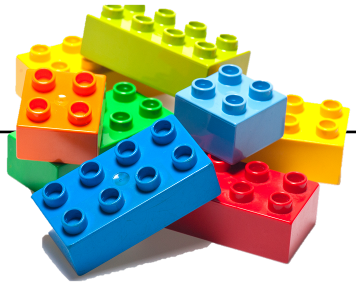
- Tunable coupler with ultrafast gate times
- Utilizing higher nonlinearity of novel qubit types

Standard Digital QC

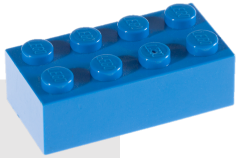
BUILDING A UNIVERSAL QC







Standard Digital QC



- Qubits
- Square lattices
- Single-qubit gates
- Two-qubit gates

Co-Design QC

Level 3 Co-Design
- Qubits
- Qudits
- Bosonic modes
- …

Level 2 Co-Design
- Square lattices
- Hexagonal lattices
- Triangular lattices
- …

Level 1 Co-Design
- Single-qubit gates
- Two-qubit gates
- Analog blocks

Application-specific processors

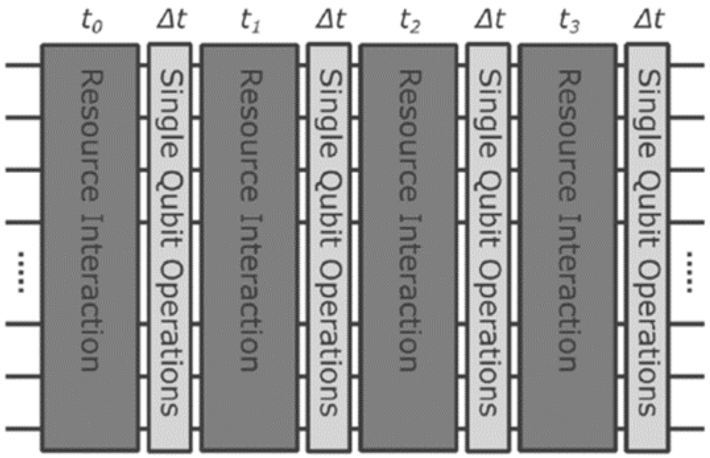
PROBLEM

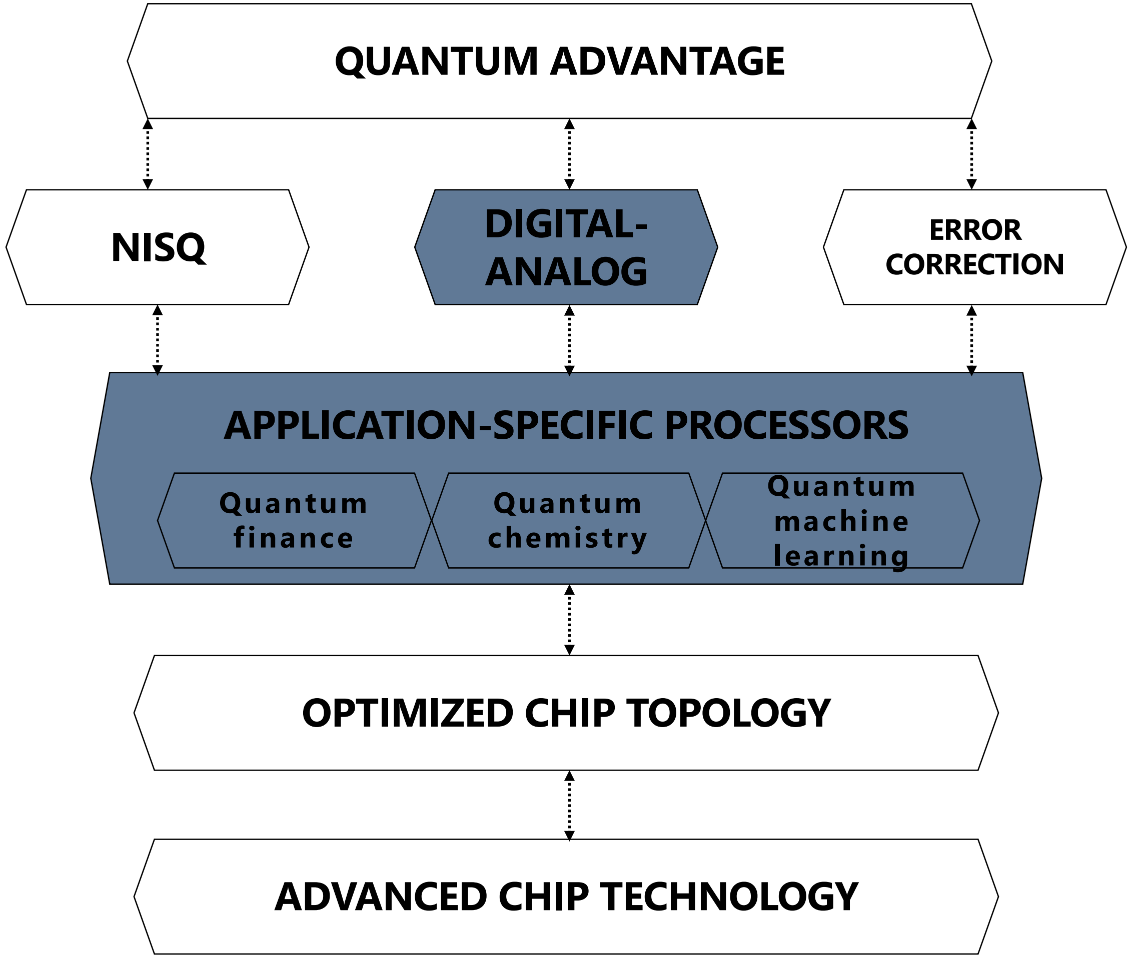
Universal quantum computers require millions of qubits, which are not expected soon.

SOLUTION

IQM uses a hardware-software co-design approach for unique QuASICs based on digital-analog quantum computing. We are creating a shortcut to **quantum advantage**.

Digital-Analog algorithm (arXiv:2002.12215):





Refs:
- arXiv:2002.12215 (2020)
- PRX Quantum **1**, 110304 (2020)

IQM

Chemistry and pharma applications

WHY QUANTUM?

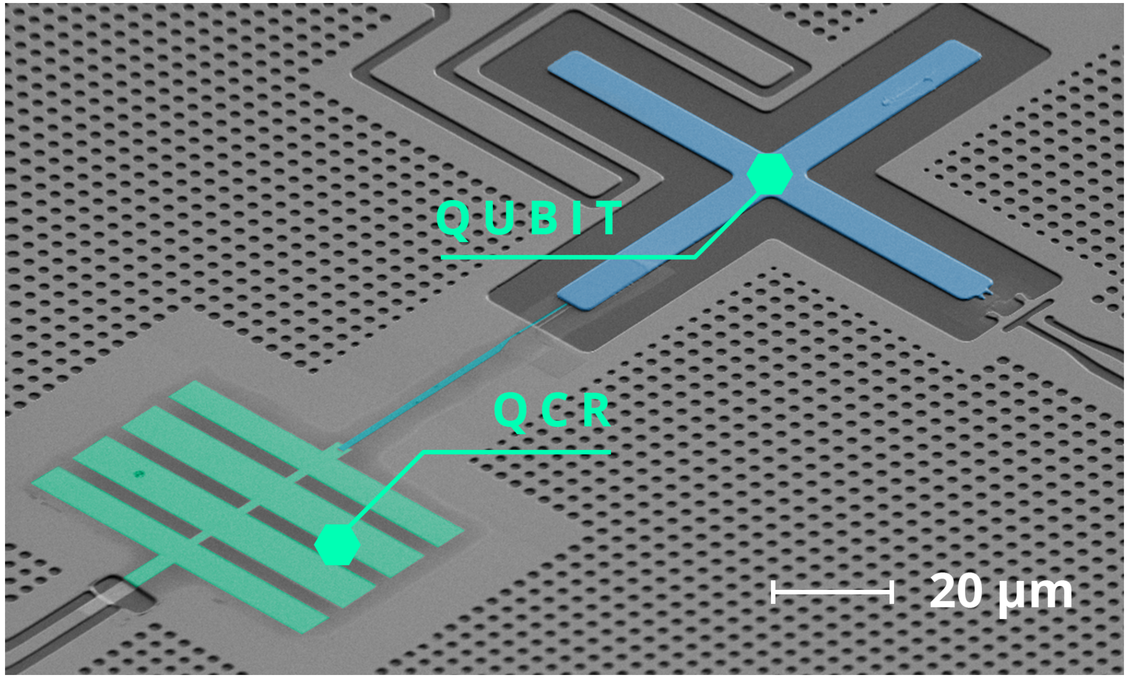
- Inherent exponential complexity
- Original systems often quantum.

APPLICATIONS

- Dynamics and static properties of complex materials and molecules
- Electron transport and transfer processes
- Quantum sensing

CO-DESIGN APPROACH

- Problem encoding in non-qubit units



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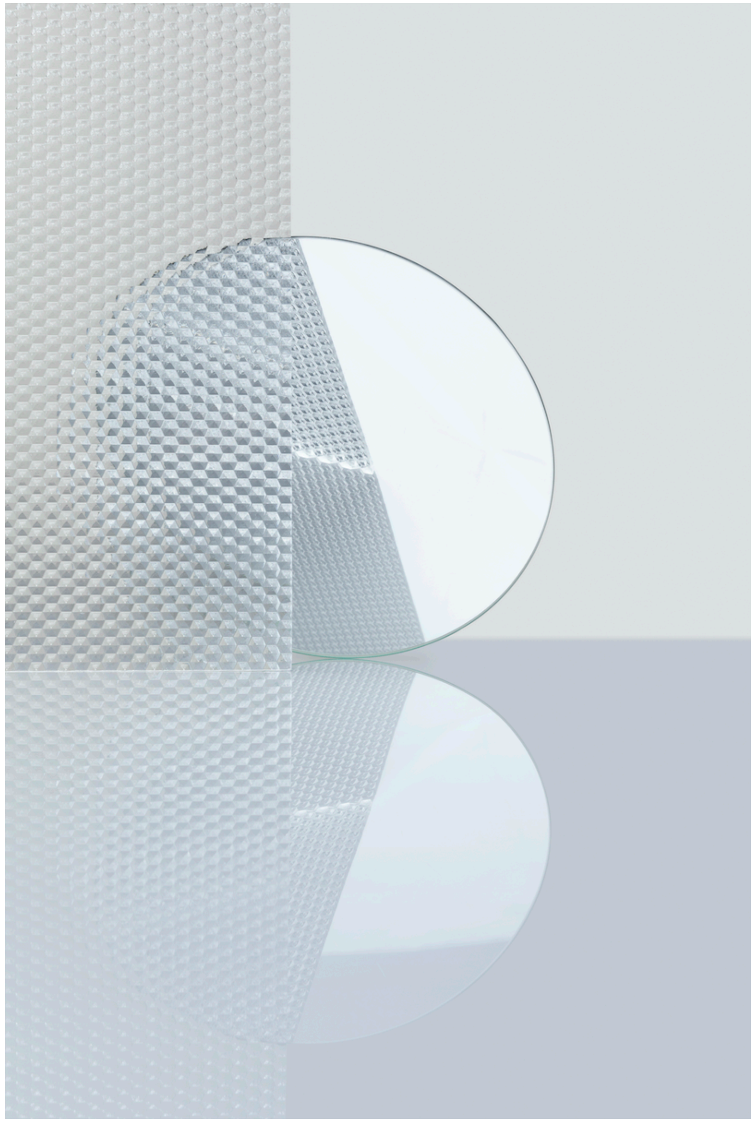
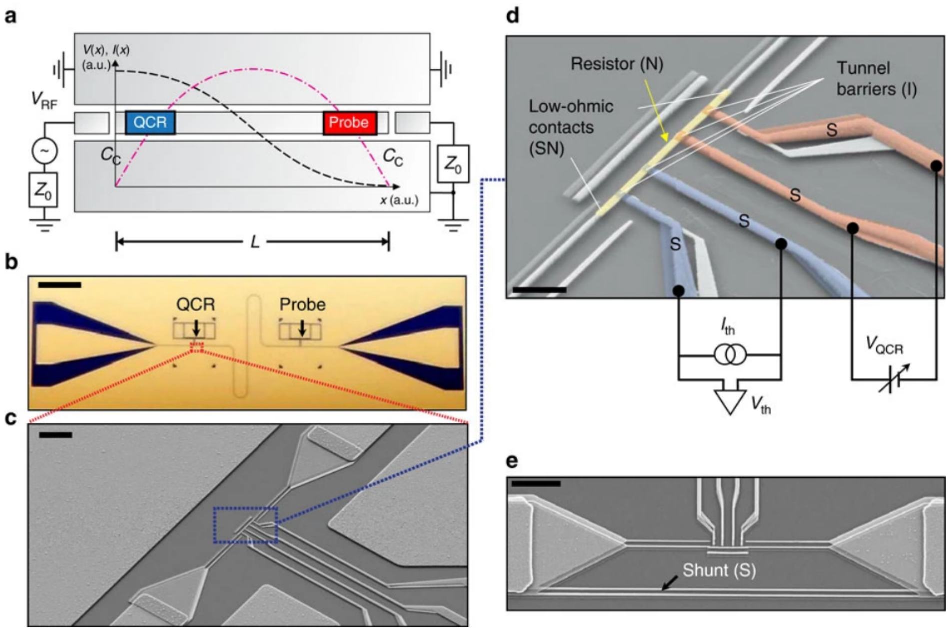


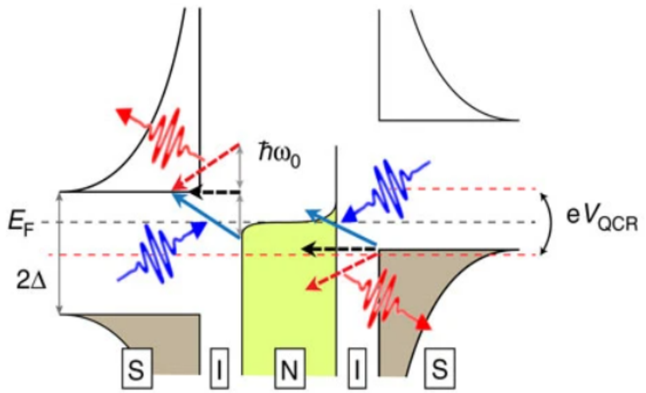
Example 1: Quantum-circuit refrigerator for resetting a qubit

Background

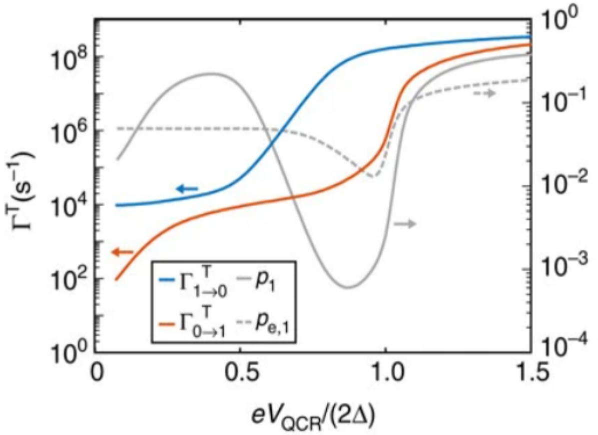


Quantum-circuit Refrigerator

Absorption and emission at QCR



Photon assisted tunneling across normal-metal-insulator-superconductor (NIS) junctions



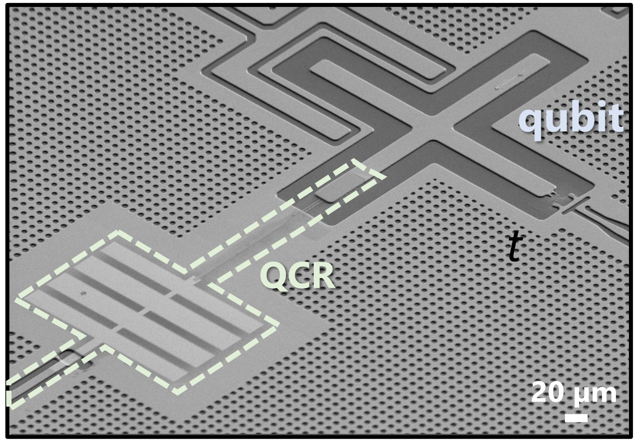
Bias 'sweet-spots' in which absorption over emission rates are highest, enabling optimum cooling of photonic modes of the resonator

Nat. Comm. **8**, 15189 (2017)

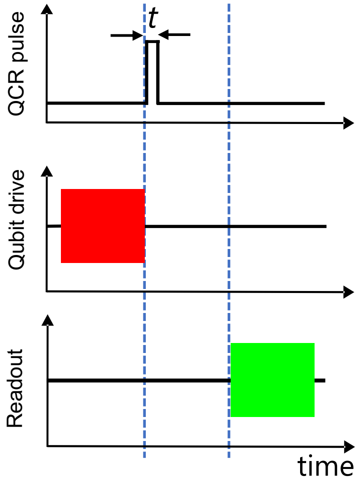
IQM

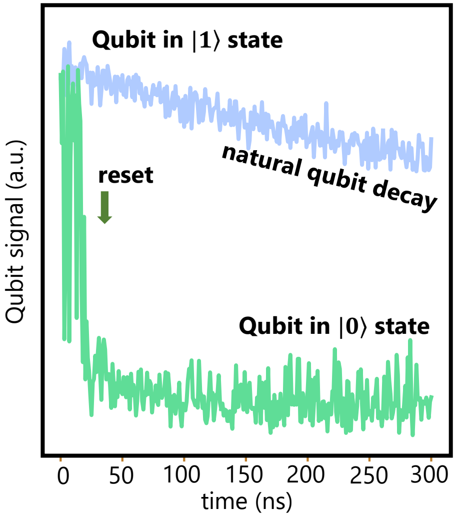
Example 1: Quantum-circuit refrigerator for resetting a qubit

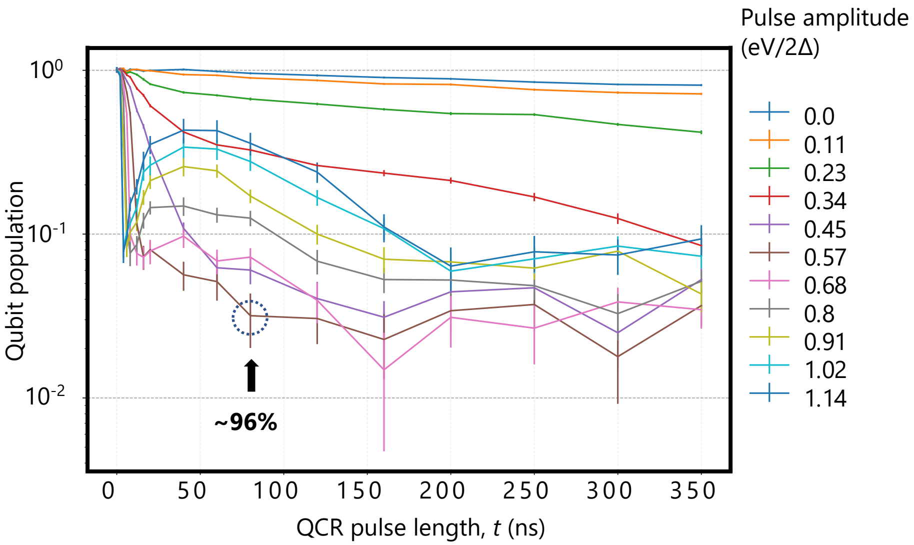
QCR-qubit



Transmon qubit capacitively-coupled to the QCR



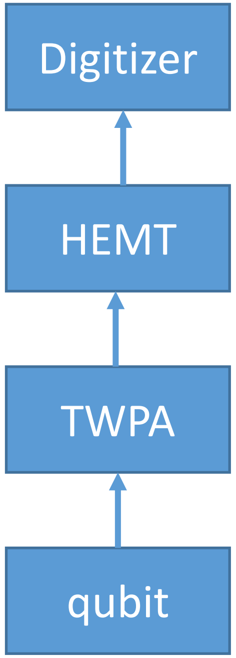


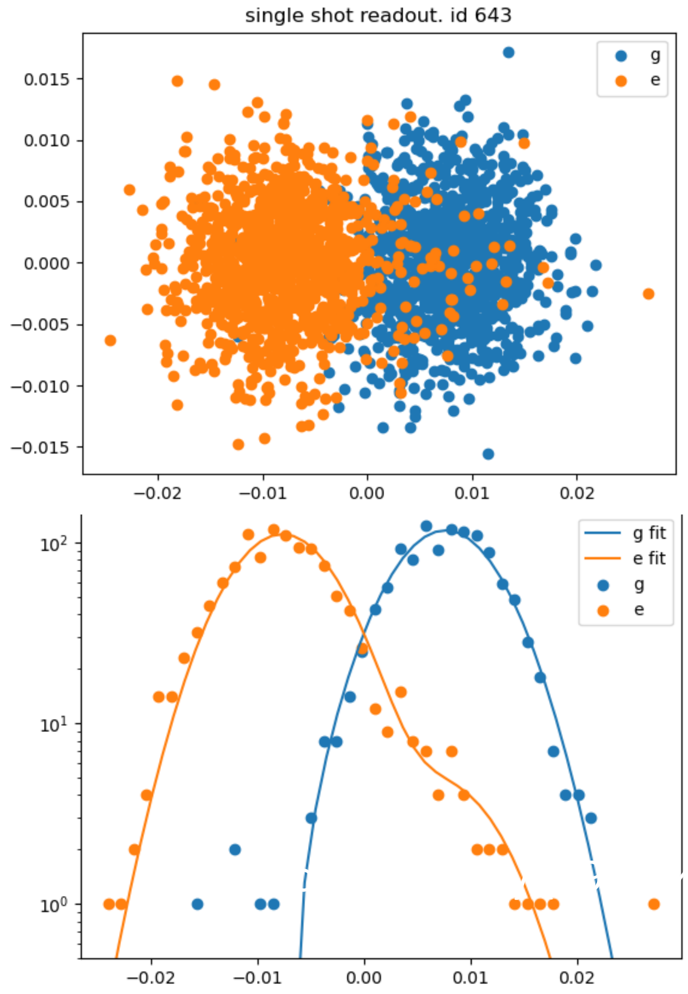


Mapping of pulse parameters to obtain optimum unconditional reset of qubit to |0⟩

Example 2: Readout optimization

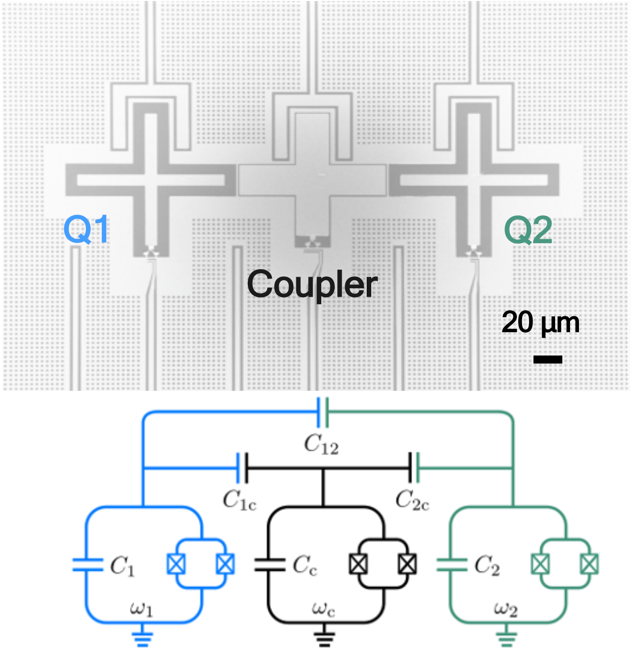
- Ongoing work
- Single-shot readout using VTT TWPAs
- Currently limited by TWPA gain / SNR and unoptimized readout circuit



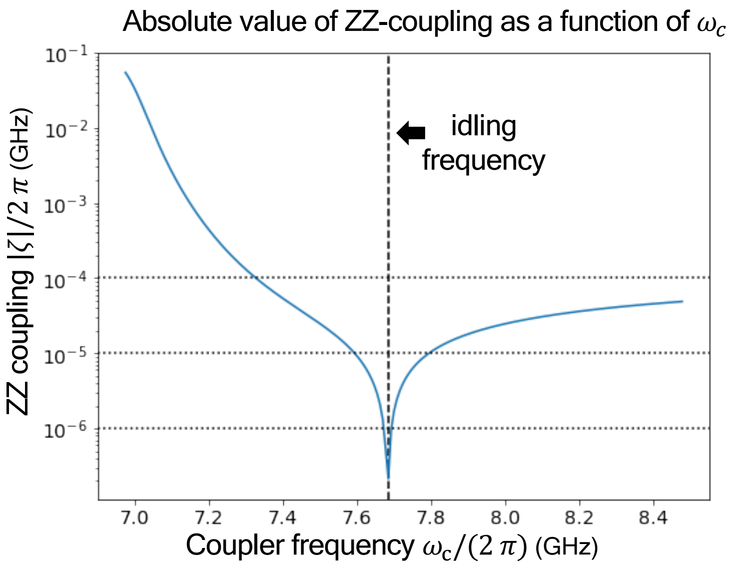


Readout fidelity (~94 %)

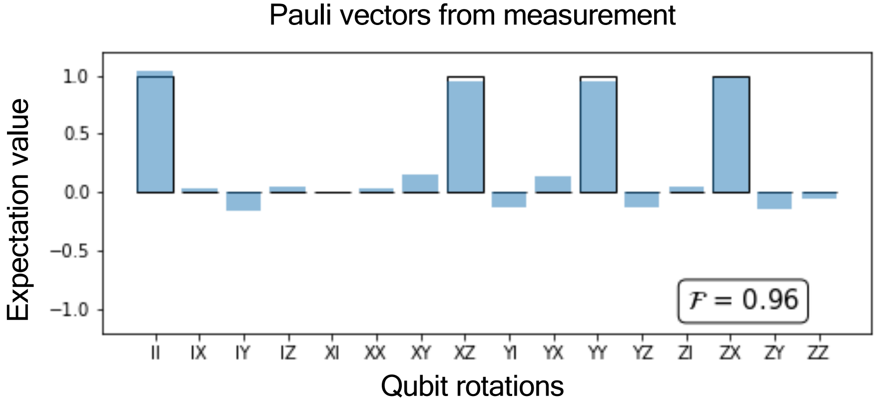
Example 3: CZ-gate



Two-qubit gate with a flux-tunable coupler



Adiabatic sweep of coupler to operating point and back to $|\zeta| \sim 0$ for CZ gating



Gate time ~20 ns

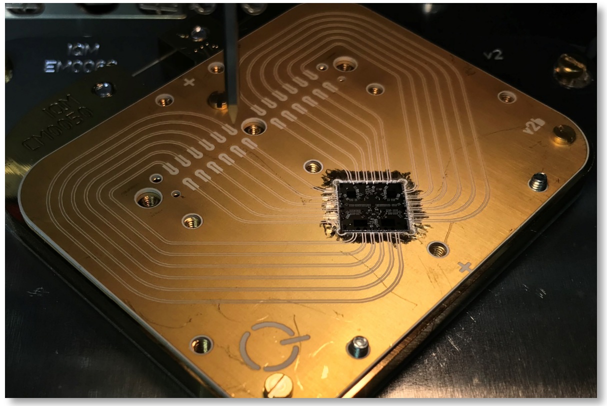
	Qubit 1	Coupler	Qubit 2
Frequency	6.893 GHz	7.79 GHz	6.977 GHz
T1	4 µs	5 µs	10 µs
T2*	7 µs	1 µs	7 µs

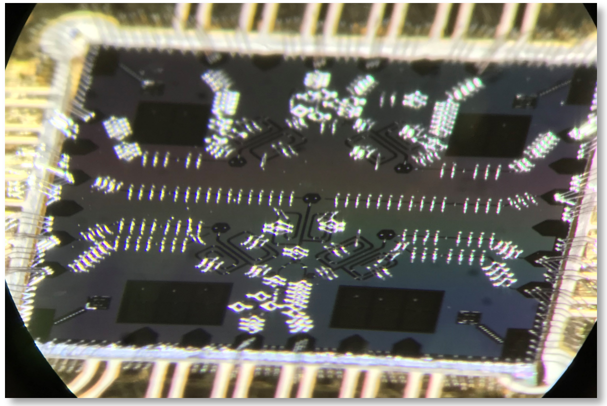
Qubit anharmonicity ~270 MHz

Refs:
- Phys. Rev. Applied **10**, 054062 (2018) - MIT
- arXiv:2011.01261 (2020) - MIT
- Phys. Rev. Lett. **125**, 240502 (2020) - ETH

Next steps

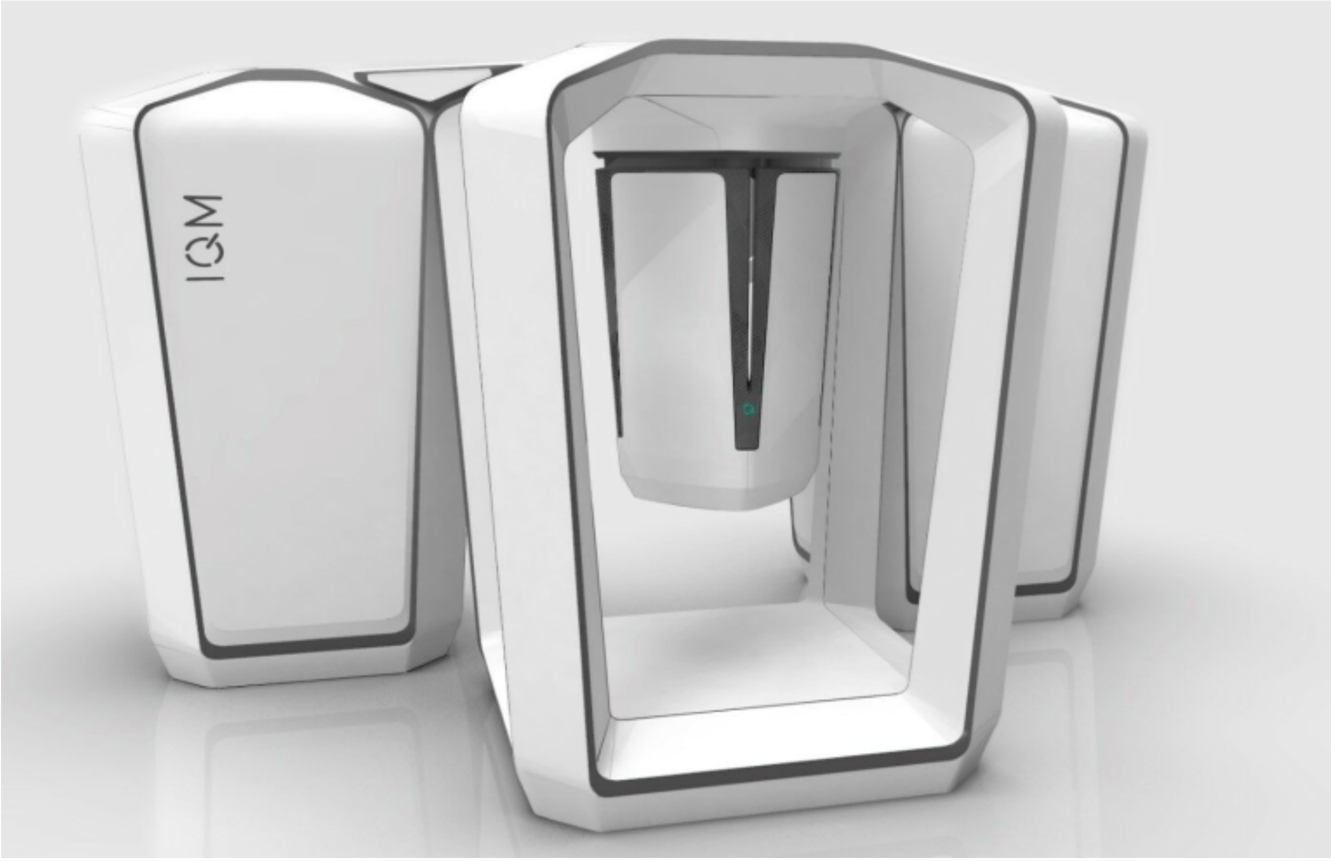
- IQM is taking into operation a 5-qubit QPUs
- Delivery of VTT Finnish quantum computer
- Execution of digital-analog quantum algorithms on the QPU





Thank you for tuning in

WE ARE HIRING!



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