Quantum Computer
- Why and how?

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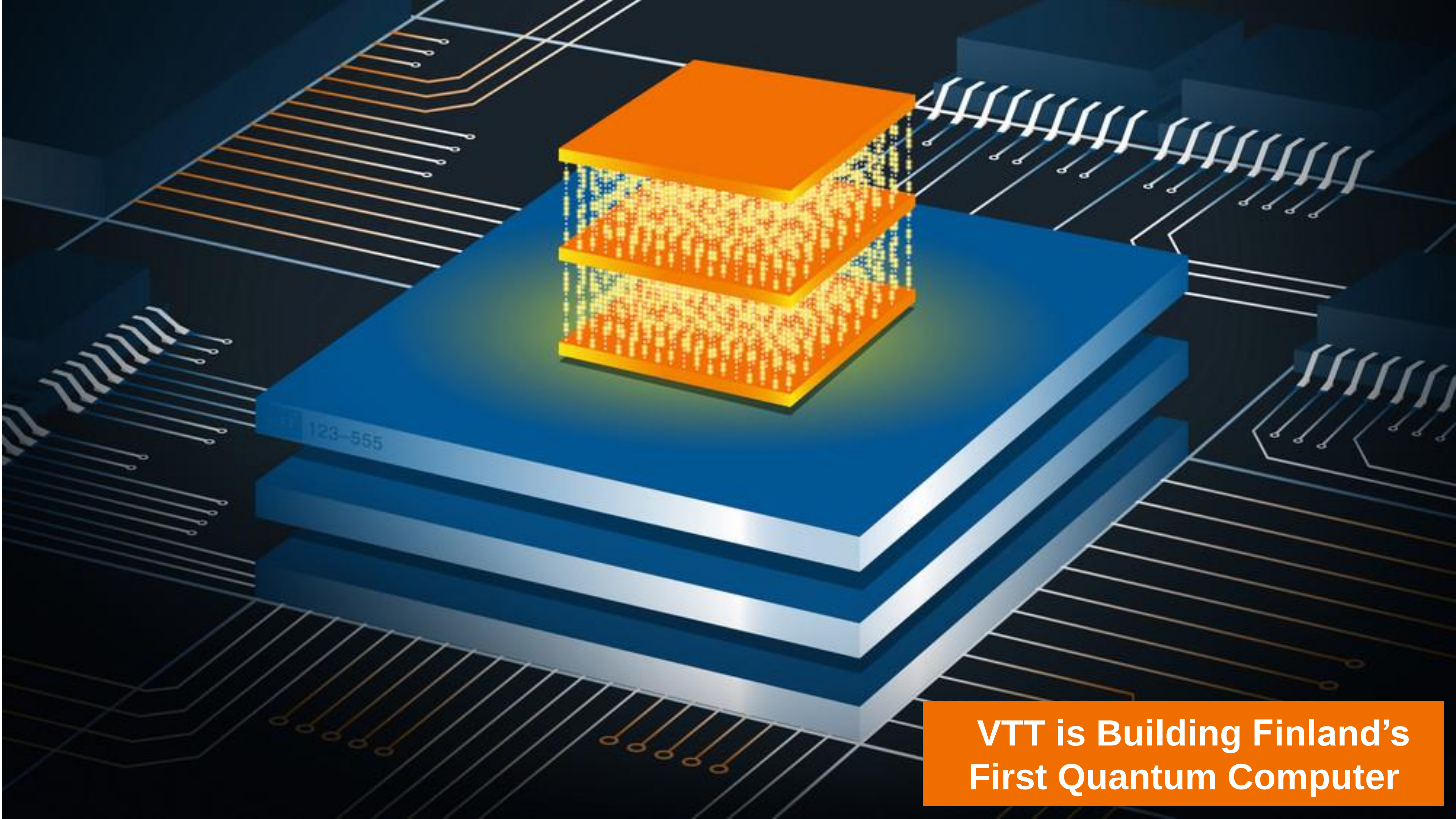


VTT is Building Finland’s First Quantum Computer

Applications and market of Quantum Computers

Pharma Biology
- Drug discovery
- Genomics
- Enzyme design
- Patient diagnostics

Finance
- Asset pricing
- Risk analysis
- Portfolio optimization

Transport
- Traffic simulation
- Logistics
- Autonomous driving

Applications of Quantum Computing
Estimated business benefit >25 B€ in 2030
Existing industries as end-users

Materials
- Materials simulation
- New materials design

Industry
- Process optimization
- Weather forecasting
- Smart grid

Building of Quantum Computers
Estimated market size 2 B€ in 2030
New industry of Quantum technology builders!

Sources: BCG 2019 and Yole 2021

Milestones of Quantum Computing

- Early 1980s: Theoretical idea presented by Paul Benioff, Yuri Manin and Richard Feynman (separately).
- 1994: Peter Shor publishes factorization algorithm for Quantum Computers, the Shor's algorithm, that could break RSA encrypting faster than classical computers.
- 1999: First coherent superconducting qubit demonstarted experimentally by Yasunobu Nakamura. Other qubit technologies in late 1990s, too.
- 2011: D-Wave presented it's first commercial Quantum Annealer
- 2019: Google announced Quantum supremacy, i.e. faster problem solving in quantum computer than in a classical supercomputer
  - …in simulating a quantum computer with 53 superconducting qubits
- 2020: Photonic QC supremacy demonstrated in boson sampling (100 I/O boson sampling experiment)

Flavors of Quantum Computing

- Superconducting qubits currently leading the race
  - Supercondcuting transmon qubits and gates well developed
  - control and cabling limiting scaling
  - Google 53 qubit computer, IBM Quantum experience, etc.
- Photonic quantum computers
  - Demonstrated in large, specific problems, programmability harder to achieve
  - Free-space optics, scaling a problem
- Silicon spin qubits / Silicon quantum dots
  - Currently in a few qubit level
  - Promises ”easy, CMOS-type” scaling, when single devices and basic gate operations are developed
- Trapped Ions (and neutral atoms)
  - Longer coherence times, but slower gates

Scaling Up Quantum Computers

Short term:

0-5 years

- NISQ (Noisy inter-mediate state quantum)
- Qubit count ~50-1000
- R&D and learning with toy problems

Mid-term:

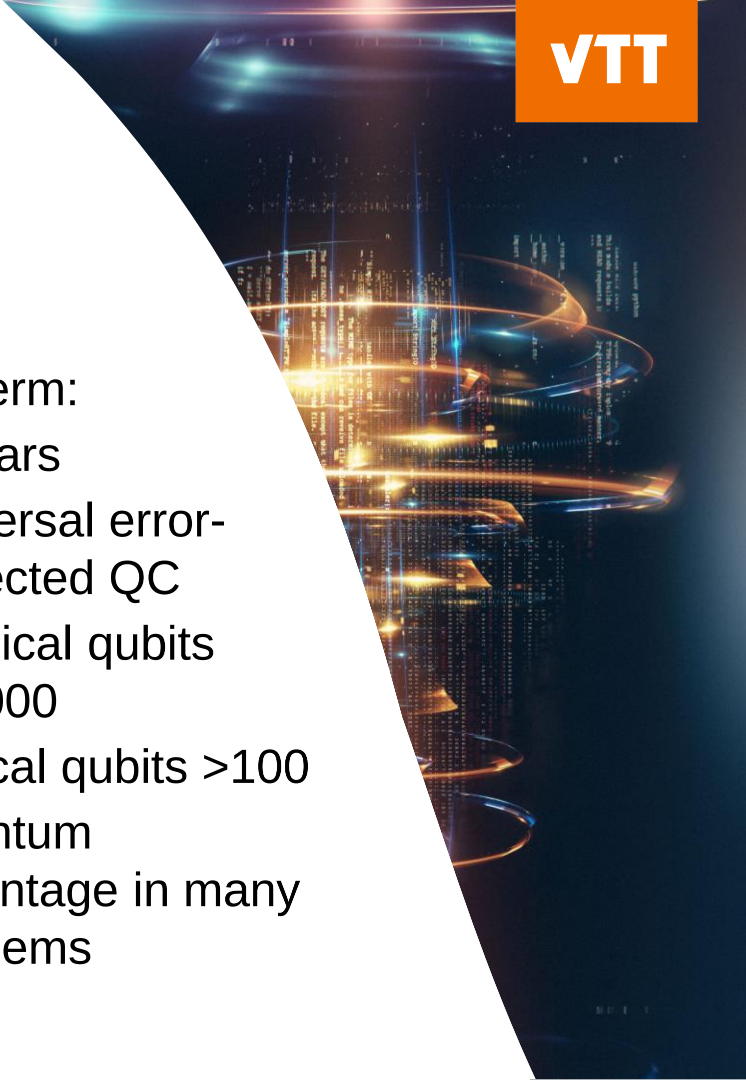
5-10 years

- Hybrid classical-quantum algorithms to demonstrate quantum benefit
- NISQ QCs optimized for specific problems

Long term:

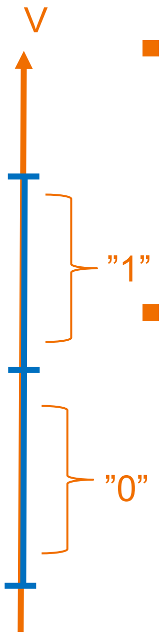
>10 years

- Universal error-corrected QC
- Physical qubits >>1000
- Logical qubits >100
- Quantum advantage in many problems

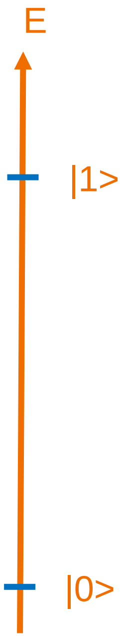


How Does a Quantum Computer Work?

Bits vs. Qubits

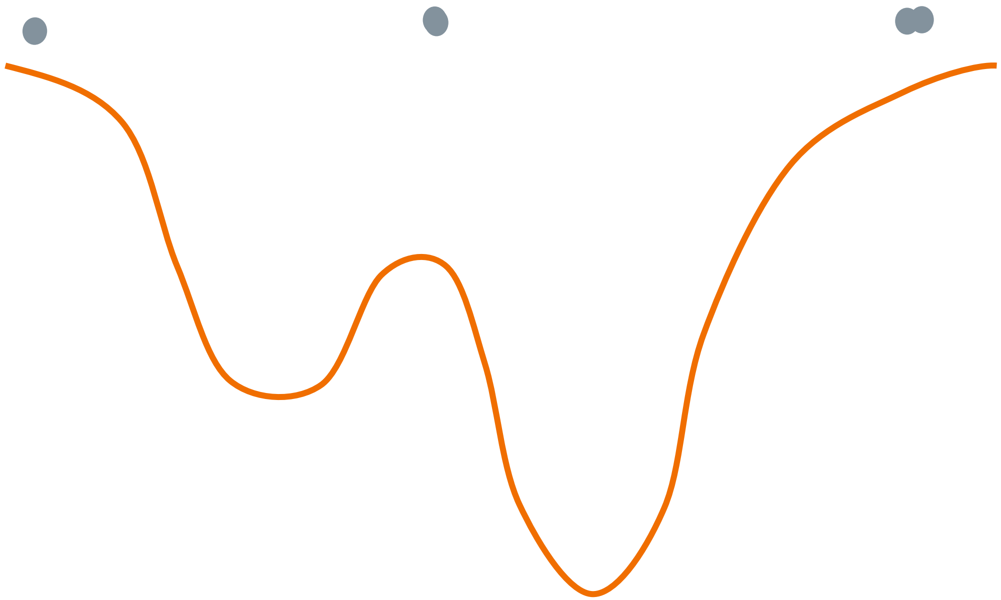


- In Classical computer, bits are based on continuous voltage values, which are interpreted as binary states ”0” and ”1” if voltage is below or above a threshold.
- Voltage can have all values between ”0”and ”1”, but the continuum of voltages is interpreted always as ”0” or ”1”



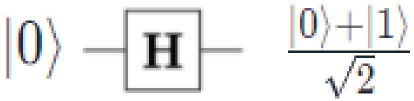
- In Quantum computer, qubits have only two possible states |0> or |1>.
- Qubit cannot be between the states.
- Qubit can **tunnel** between the states.
- Qubits can be in **superposition** α|0>+β|1>, where α and β are complex constants descibing the propability of finding the qubit in each state, when **measured**.

Optimizing with Bits and Qubits

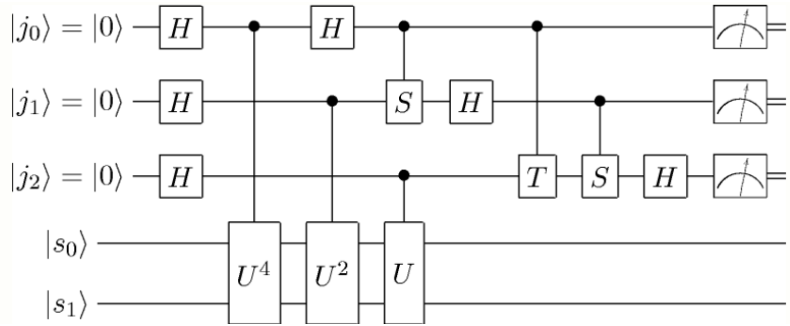


- Optimization goal: Find the energy minimum
- Classical algorithm can be stuck to local minimum, and calculation needs to be carried out with different initial conditions to find global optimum
- Qubit can have all the initial conditions at the same time, finding the global optimum in one step.
- In certain problems, Quantum computing can reduce computing time from exponential (2^N) to polynomial (N^x)

Programming a quantum computer



$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$



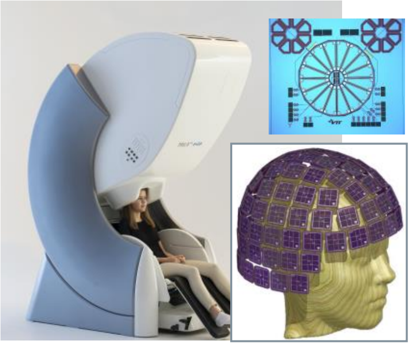
- Writing code on gate level, similar to *very* early computers
  - E.g. Hadamard-gate creates a superposition of two states
- See e.g. https://www.youtube.com/watch?v=whoTr3zM3jU for excellent introduction by Mikael Johansson from CSC
- Everybody can try it out in the cloud, e.g. https://www.ibm.com/quantum-computing/

VTT's Expertise in Quantum Technologies

Background: Quantum expertise in Finland and VTT

Enablers

Quantum 1.0 Devices and systems



SQUID magnetormeters for MEG brain activity imaging by Aivon and VTT

Development tools and infra

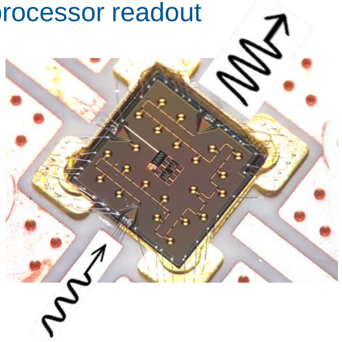
Quantum 1.0 and 2.0

Bluefors dilution refridgerators

Finland has excellent position to gain from the Quantum revolution:

- **Decades of background and expertise in Quantum research**
- **Micronova infra enabling commercial device manufacturing (since 1990's for SQUIDs)**
- **Company ecosystem growing**

VTT's 1600-JJ travelling wave parametric amplifier quantum processor readout



Quantum 2.0 components

Quantum 2.0 systems

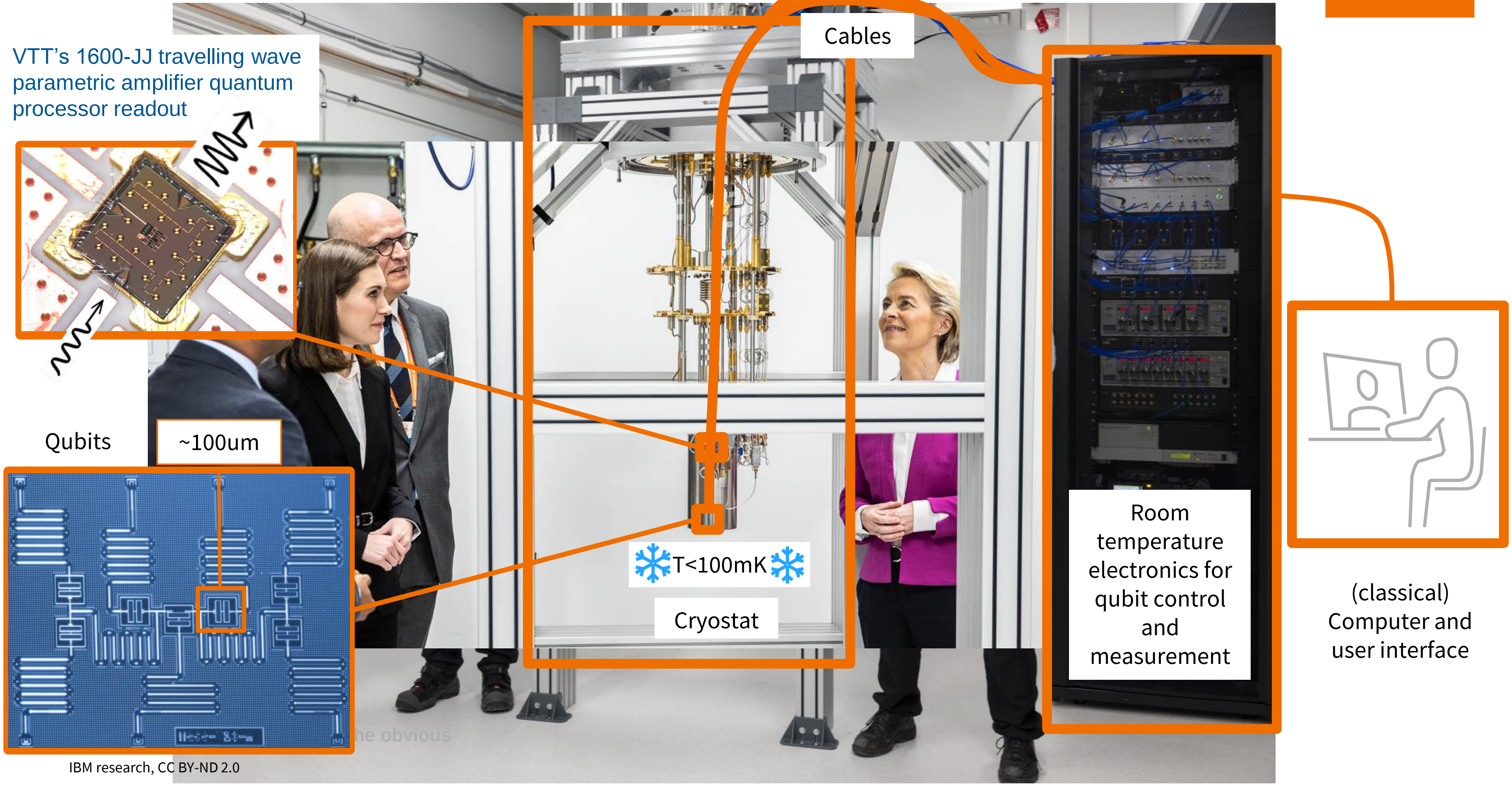
IQM quantum computers

VTT

The Quantum computer build project at VTT

- Based on 20,7M€ funding received from Govt. of Finland
- Joint project with Finnish start-up IQM resulting from a public procurement process
- Based on superconducting platform
- 3-phase project with targets to build at least 5, 20 and 50 qubit machines
- 5 qubits in 2021, 50 qubits in 2024

The Quantum computer build project at VTT

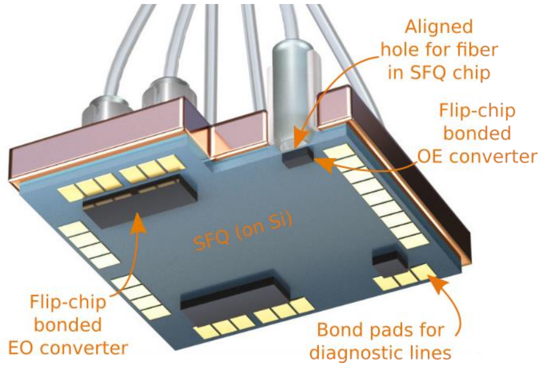


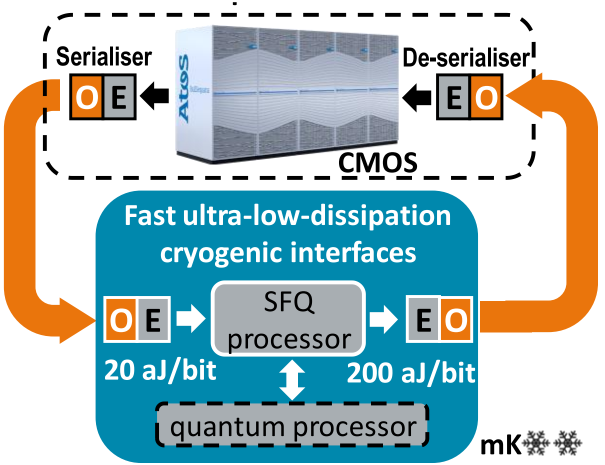
VTT Vision

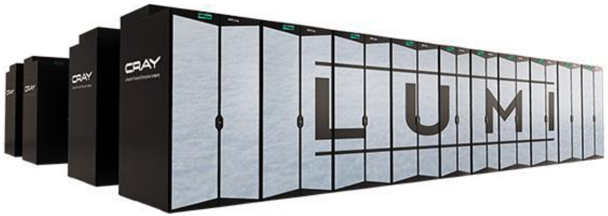
Quantum Computer Combined with a Classical Supercomputer

Requires fast (optical) link to cryostat, including

- Methods for scaling beyond100 qubits
- Josephson parametric amplifier for qubit read-out (world's most-sensitive amplifier)
- Superconducting classical logic (SFQ)
- Single-photon detectors
- Algorithms for real-life problems
- Connect Quantum Computer with LUMI at CSC







beyond

the obvious