Certifying Quantum Hardware

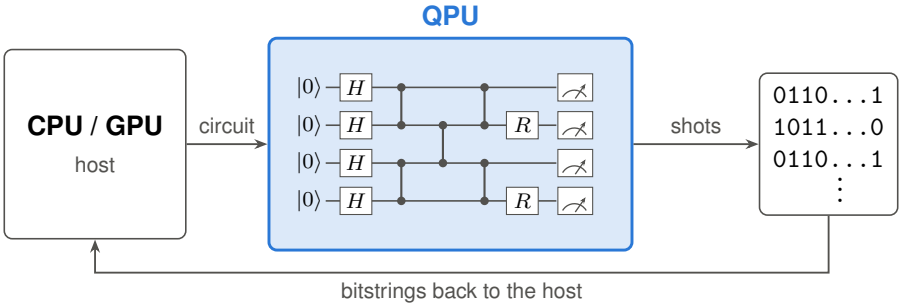
Ryszard Kukulski
with collaboration: Petr Ptáček, Nur Keleşoğlu, Łukasz Pawela

VSB TECHNICAL UNIVERSITY OF OSTRAVA | IT4INNOVATIONS NATIONAL SUPERCOMPUTING CENTER

Quantum Computing Lab at IT4Innovations National Supercomputing Center

10th IT4Innovations Users' Conference, November 2026

A QPU



At IT4I: VLQ (24 qubits) coupled to Karolina

What quantum computers promise

Factoring

$$N = p \cdot q$$

Shor 1994
exponential

Linear systems

$$A\,x = b$$

HHL 2009
exponential*

Differential equations

$$\partial_t u = \mathcal{L} u$$

via linear solvers or
Hamiltonian simulation*

Physics & chemistry

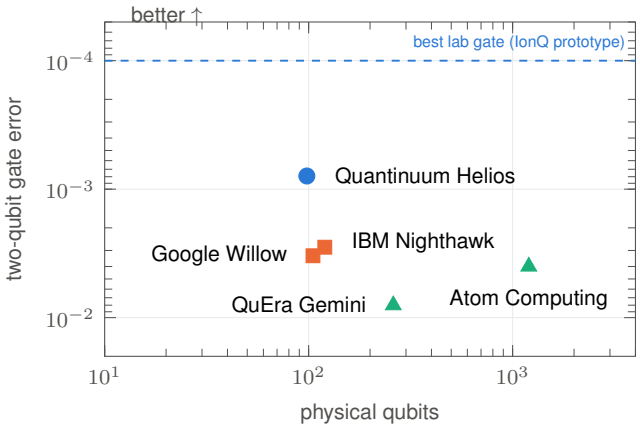
$$e^{-iHt}$$

Feynman 1982
exponential

* with caveats: loading the data, reading the answer, conditioning

All of them need fault-tolerant hardware

Gate-based devices today (November 2026)



- trapped ions
- superconducting
- neutral atoms

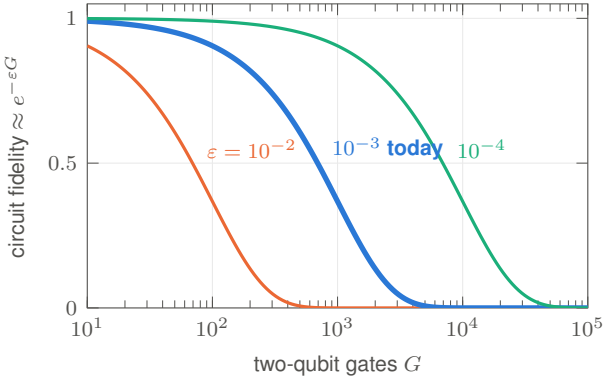
Logical qubits

96 (QuEra, 448 atoms)
48 corrected (Quantinuum)

≈ 100 **good qubits,** $\approx 10^{-3}$ **error per gate**

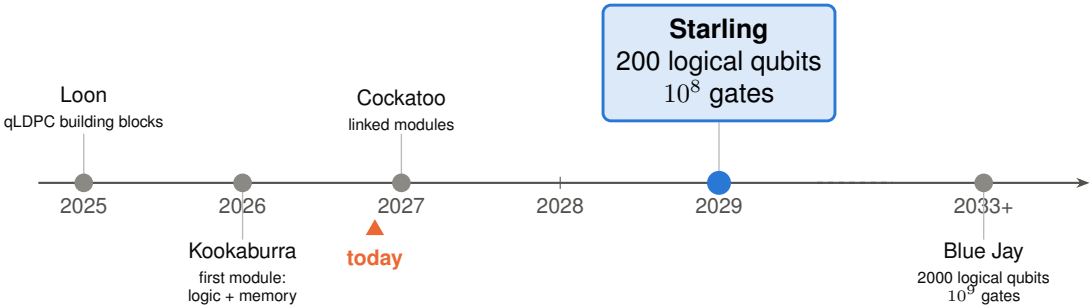
Quantinuum (Nature, 2026); IBM calibration data ibm_miami (June 2026); Google Quantum AI (Nature, 2024); QuEra/Harvard (Nature, 2026).

NISQ: small and noisy



NISQ = Noisy Intermediate-Scale Quantum: J. Preskill, Quantum 2, 79 (2018).

Next generation: fault-tolerant quantum computers

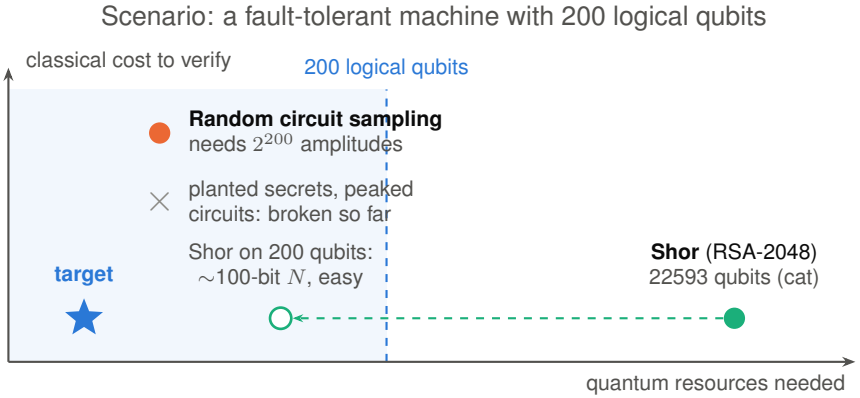


IBM roadmap

How will users check it?

IBM Quantum roadmap (2025, updated 2026).

Two ends of the spectrum

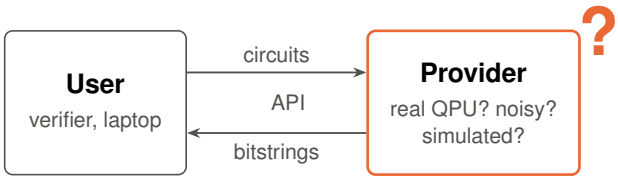


Shor qubit count: S. Beauregard, QIC 3, 175 (2003). RCS: F. Arute et al., Nature 574, 505 (2019). Peaked circuits: S. Aaronson, Y. Zhang, arXiv:2404.14493., arxiv:2610.37839

Certification: a must for users

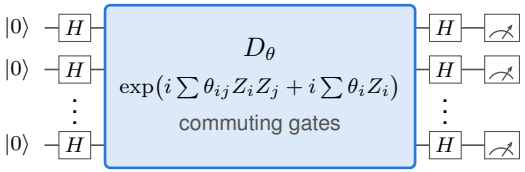
Benchmarks today

- Quantum volume, layered-gate error
- Standards: IEEE P7131, ISO/IEC JTC 3
- DARPA Quantum Benchmarking Initiative



Our requirement: API access only

Our method: IQP circuits, hard but tractable



- ✓ **hard** to sample classically
- ✓ $\langle Z_iZ_j\cdots\rangle$ **computable** classically
- ✓ **native** ZZ gates, shallow

ML designs θ
verifier, offline

→

QPU runs it
provider, S shots

→

Test the shots
verifier, laptop

→

Accept / reject
w.p. $\geq 1-\delta$

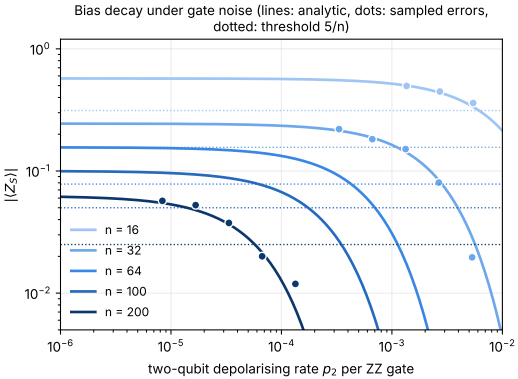
IQP: D. Shepherd, M. Bremner, Proc. R. Soc. A 465, 1413 (2009); M. Bremner, R. Jozsa, D. Shepherd, Proc. R. Soc. A 467, 459 (2011); M. Van den Nest, QIC 11, 784 (2011).

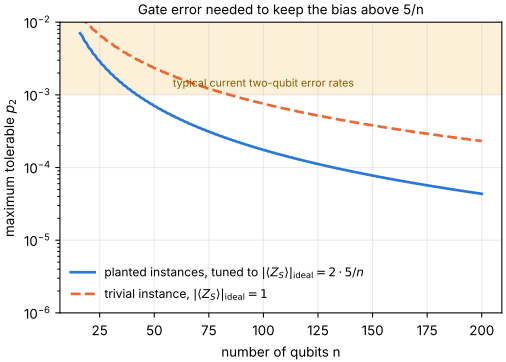
Results: simulation on a personal computer

n	χ	F	samples	sampling time [s]
70	512	0.9973	700000	428.7
90	512	0.9959	900000	653.9
95	512	0.9969	950000	310.4
100	1024	0.9956	1000000	662.
110	1024	0.9949	1100000	804.8

Hardware	NVIDIA GeForce RTX 3090, Intel(R) Core(TM) i9-10900KF CPU @ 3.70GHz (20 threads)
Software	CUDA-Q
Method	Tensor networks

Perspectives for QPU





Thank you

Thank you!

Questions?

Acknowledgments

This work was supported by the European Union under the Quantum error correction codes enhanced by reinforcement learning dedicated for the Ising model-based optimization, contract nr. 01906/2025/RRC via the Operational Programme Just Transition and Moravian-Silesian Region and by the Ministry of Education, Youth and Sports of the Czech Republic through the e-INFRA CZ (ID:90254)