CHAMP-ION
The European Ion Trap Pilot Line

the manufacturing challenges for **trapped ions quantum computing**

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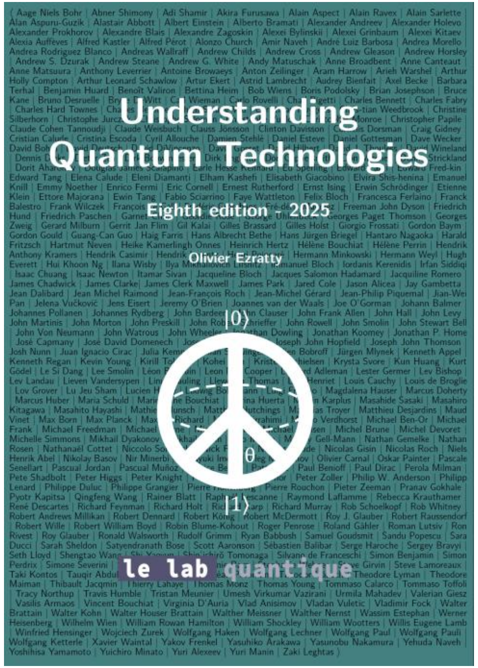
Champ'Ion inauguration, Villach, May 26th, 2026

#QEI
the quantum energy initiative



2025, 1,524 pages
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6.7 Trapped ions qubits

Trapped ions are positively ionized atoms that are trapped by electrodes and sometimes also magnetically in a confined space and placed next to each other. The atoms are generally alkaline metals from the second column of Mendeleev's table (called "Group IIA" in Mendeleev's notation or group 2 in the modern notation, with beryllium, magnesium, calcium, strontium, barium), then as ytterbium which is a rare earth in the lanthanide family, and finally, quite rarely, metals of group IIB or 12 (zinc, cadmium, mercury) [3145, 3146].

6.7.1 History

Before the very notion of a qubit even existed, scientists tried to control ions in space. **Wolfgang Paul** created in 1953 a way to control ions with a mass spectrometer avoiding the use of a magnetic field, named the "Paul trap". He got the Nobel prize in Physics in 1989. Later, in 1959, **Frans Penning** and **Hans Dehmelt** were able to control individual electrons with a magnetron trap that was later named the "Penning trap". Penning traps are still being studied, particularly in their 2D variant.

In the USA, **David Wineland** from NIST created the laser cooling technique starting in 1979, using Doppler effect with magnesium ions. He was a laureate of the Nobel prize in physics in 2012 along with Serge Haroche. In 1989, he used the technique to cool ions at their zero-point energy of motion with the sideband cooling technique that goes farther than Doppler cooling [3147].

Juan Ignacio Cirac and **Peter Zoller** from the University of Innsbruck in Austria proposed in 1995 a blueprint to create a gate-based quantum processor with a linear trap of ions controlled by laser beams [1760, 3148]. They initiated a long-lasting experience in the field at Innsbruck, which led to the creation of the startup **AQT** in 2017.

6.7.2 Science

Here are some specifics of trapped ions qubits...(Figure 468).

Why ions? One interest with ions as well as with cold atoms is that they are all the same by nature, and therefore have less variability than with other qubit modalities like superconducting qubits and spin qubits. There is still some variability but it sits in the ion traps and microwaves, RF signals and lasers control signals. The interest of exploiting ions is to trap them magnetically or with electrodes. It is also possible to couple them over long distance, in the order of several tens of microns. It can also be hybridized with several ion types mixed together, like calcium and strontium, to get their related benefit such as fast gates for calcium and stability for strontium [3149, 3150]. The used elements have several common characteristics related to their electron layer configuration such as excitation levels from the ground state that are of short duration and allow their use for atoms cooling with laser and the Doppler effect. The energy levels corresponding to the $|0\rangle$ and the excited energy level corresponding to $|1\rangle$ state are both stable over time, which facilitates the implementation of quantum gate operations.

Long coherence time. Trapped ions usually have a rather long coherence time of up to several tens of seconds. Although gate times are long, the ratio between coherence time and gate time is currently quite good at up to 10^6, while it is at 10^3 for superconducting qubits and about 200 for cold atoms qubits.

Qubit fidelities. Trapped ions show a low error rate with up to single-qubit fidelities of 99.99987% and two-qubit gate fidelities of over 99.9%, the record being 10^{-7} error rates, achieved in 2024 by an Oxford and Osaka Universities team [3151] (Figure 466 and Figure 467). These fidelities depend on the quantum gate implementation and used ions. This and long coherence time make it possible to theoretically execute "deep algorithms" with a large number of quantum gates and to obtain a good quantum volume, to use IBM's terminology. However, this error rate seems to increase with the number of qubits, at least in 1D architectures like the one from IonQ.

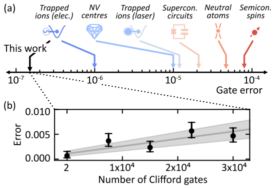


Figure 466: The record in single-qubit gate fidelity obtained in 2024 compared to best-in-class lab fidelities for other qubit modalities. Source: [3151].

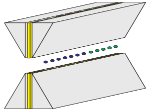
There's a tendency with trapped ions vendors like IonQ and Quantinuum to measure qubit fidelities with the SPAM method which encompasses the whole process from state preparation to measurement. In March 2022, IonQ tested its new barium ions and improved fidelities with a record 99.96% SPAM fidelity. Quantinuum reached simultaneously a SPAM fidelity of 99.9904% also with barium ions [3152], which is clearly best-in-class in the qubit world.

Where are the residual errors coming from? The most frequently mentioned sources are control voltage variability in the case of microwave qubit drive, laser frequency,

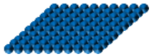
38 pages, 293 references

EU vs USA & RoW vendors

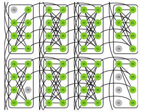
atoms | **electrons** *controlled spin and microwave cavities* | **photons**



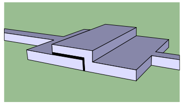
trapped ions



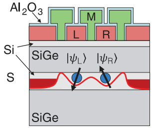
cold atoms



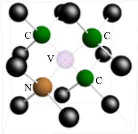
annealing



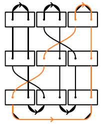
superconducting



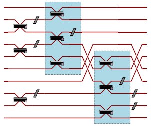
silicon



vacancies



topological



photons

USA

- trapped ions: Quantinuum, IONQ
- cold atoms: QuEra, atom computing, Infleqtion, logiqal, Google ORATOMIC
- annealing: D-Wave (The Quantum Computing Company™)
- superconducting: IBM, amazon, QOLAB, D-Wave (The Quantum Computing Company™), Google, rigetti
- silicon: EeroQ, intel
- vacancies: TURING
- topological: Microsoft
- photons: PsiQuantum, QCi

>10 qubits : 8 in USA vs 8 in EU
>50 qubits : 8 in USA vs 2 in EU

(gate based)

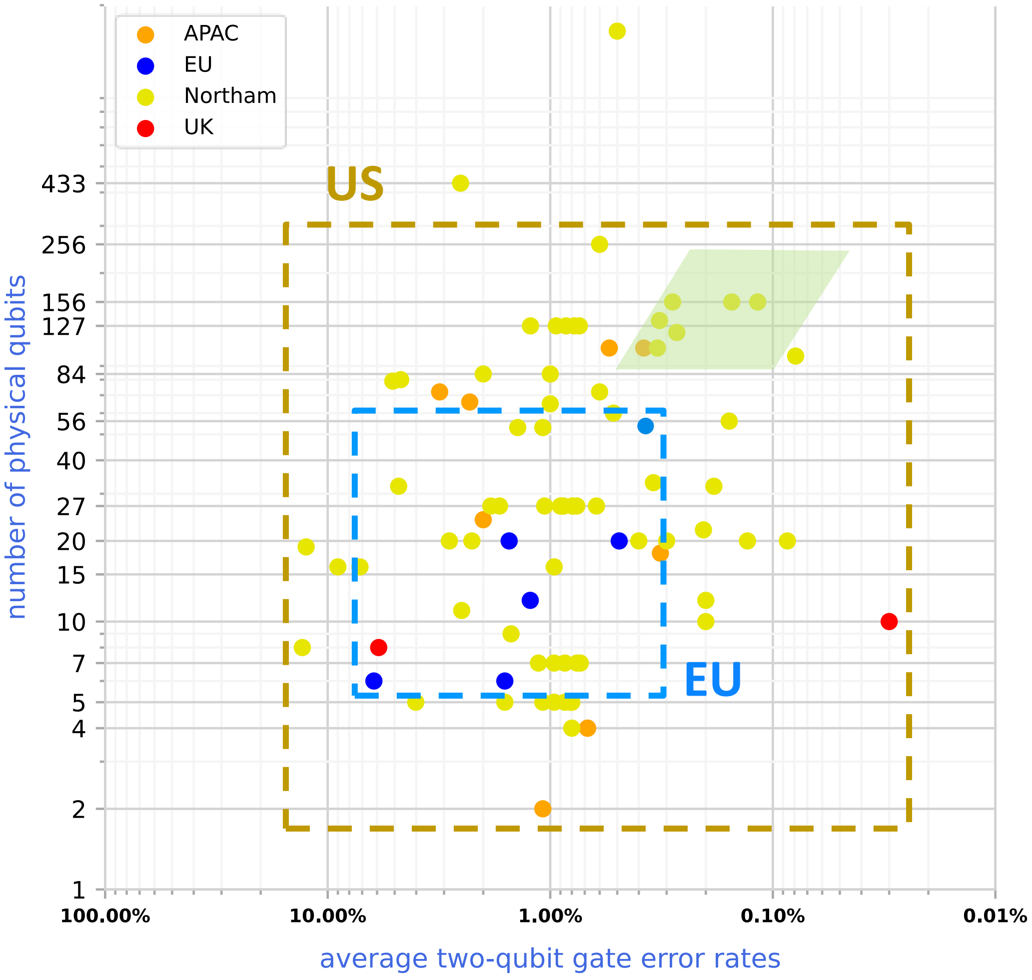
EU

- trapped ions: AQT, eleQtron, NEQxT, QUDORA Technologies, CRYSTAL Quantum Computing
- cold atoms: Pasqal, planqc, Atom Quantum Labs
- annealing: QILIMANJARO Quantum Tech
- superconducting: IQM, Alice & Bob, Peak Quantum, QUINT, Qolumbus
- silicon: Groove Quantum, ARQUE, quobly, SemiQon, equal1.labs, C12
- vacancies: Quantum Brilliance, SaxonQ, XEED
- topological: NOKIA
- photons: QUANDELA, QUIX Quantum

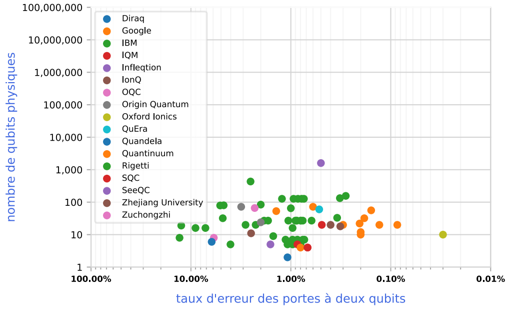
RoW

- trapped ions: Quantum Art, HYQ, Foxconn, Qubitcore
- cold atoms: Yaqumo, QUANTier, Q-Factor
- annealing: NEC
- superconducting: OQC, 本源量子 Origin Quantum, ANYON, FUJITSU, QuamCore, Nord Quantique, QπAI
- silicon: Silicon Quantum Computing, diraq, QπAI, Quantum Motion, ARCHER
- vacancies: Quantum Transistors, photonic, FUJITSU
- topological: Quantum Gravity Research, QUOHERENT
- photons: aegiq, ORCA Computing, XANADU, Boson, Duality Quantum Photonics, Tundra, OptQC, QUANFLUENCE

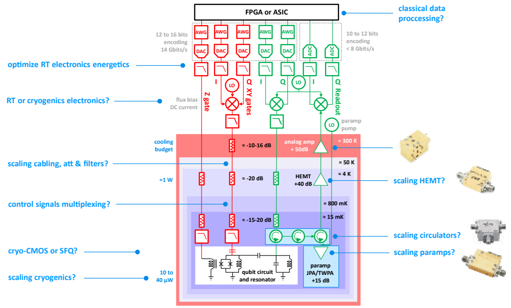
scaling the hardware in the EU



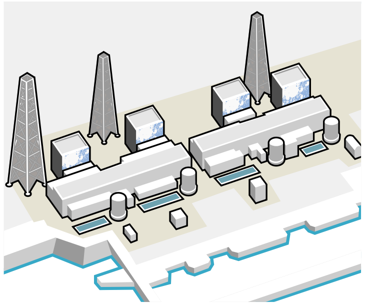
key FTQC hardware challenges



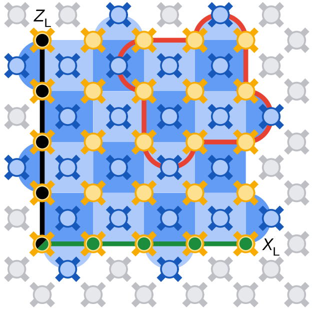
qubit fidelities



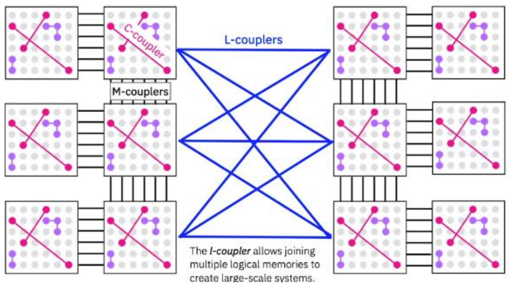
electronics, cabling, cryogeny



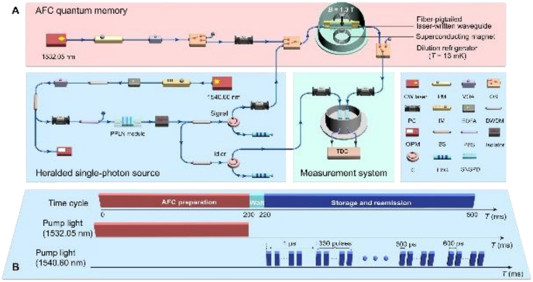
cost and power/energy



error correction



interconnection



quantum memory

FTQC blueprints

QOLAB

How to Build a Quantum Supercomputer:
Scaling from Hundreds to Millions of Qubits

Masoud Mohseni,[1,*] Artur Scherer,[2] K. Grace Johnson,[1] Oded Wertheim,[3] Matthew Otten,[4] Namit Anand,[1,5,6] Navid Anjum Aadit,[7] Yuri Alexeev,[8] Gilad Ben-Shach,[3] Kirk M. Bresniker,[9] Kerem Y. Camsari,[7] Barbara Chapman,[10] Soumitra Chatterjee,[10] Shuvro Chowdhury,[7] Gebremedhin A. Dagnew,[2] Tom Dvir,[3] Aniello Esposito,[9] Farah Fahim,[11] Michael Ferguson,[1] Marco Fiorentino,[1] Archit Gajjar,[9] Katerina Gratsea,[4] Gaurav Gyawali,[1] Christian Heiter,[1] Ali H. Z. Kavaki,[2] Abdullah Khalid,[2] Xiangzhou Kong,[2] Bohdan Kulchytskyy,[2] Elica Kyoseva,[8] Ruoyu Li,[12] P. Aaron Lott,[1,5,6] Igor L. Markov,[13] Robert F. McDermott,[4,14] Lucas Morais,[9] Giacomo Pedretti,[9] Pooja Rao,[8] Eleanor Rieffel,[6] Allyson Silva,[2] John Sorebo,[13] Panagiotis Spentzouris,[11] Ziv Steiner,[3] Boyan Torosov,[2] Davide Venturelli,[6,15] Robert J. Visser,[12] Zak Webb,[2] Xin Zhan,[1] Yonatan Cohen,[3] Pooya Ronagh,[2,16,17,18] Alan Ho,[14] Raymond G. Beausoleil,[1] and John M. Martinis[14,†]

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[10]*Hewlett Packard Enterprise, TX, USA*
[11]*Fermi National Accelerator Laboratory, IL, USA*
[12]*Applied Materials, CA, USA*
[13]*Synopsys, CA, USA*
[14]*Qolab, WI, USA*
[15]*USRA Research Institute for Advanced Computer Science, CA, USA*
[16]*Institute for Quantum Computing, University of Waterloo, ON, Canada*
[17]*Department of Physics & Astronomy, University of Waterloo, ON, Canada*
[18]*Perimeter Institute for Theoretical Physics, ON, Canada*
(Dated: March 16, 2026)

https://arxiv.org/abs/2411.10406 (91 pages)

IBM

Tour de gross: A modular quantum computer based on bivariate bicycle codes

Theodore J. Yoder[1], Eddie Schoute[1], Patrick Rall[1], Emily Pritchett[1], Jay M. Gambetta[1], Andrew W. Cross[1], Malcolm Carroll[1], and Michael E. Beverland[*1]

[1]IBM Quantum

https://arxiv.org/abs/2506.03094 (68 pages)

IONQ

Fault-Tolerant Quantum Computing with Trapped Ions: The Walking Cat Architecture

Felix Tripier, Woo Chang Chung, Jacob Young, Safwan Alam, Bryce Bjork, Aharon Brodutch, Finn Lasse Buessen, Nolan J. Coble, Thomas Dellaert, Dmitri Maslov, Martin Roetteler, Edwin Tham, Mark Webster, Min Ye, John Gamble, Andrii Maksymov, J. P. Marceaux, Nicolas Delfosse
IonQ Inc.
(Dated: April 22, 2026)

https://arxiv.org/abs/2604.19481 (110 pages)

Google

The FLuid Allocation of Surface code Qubits (FLASQ) cost model for early fault-tolerant quantum algorithms

William J. Huggins,[1,*] Tanuj Khattar,[1] Amanda Xu,[1,2] Matthew Harrigan,[1] Christopher Kang,[1,3] Guang Hao Low,[1] Austin Fowler,[1] Nicholas C. Rubin,[1] and Ryan Babbush[1]

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[2]*University of Wisconsin–Madison, Madison, WI, USA*
[3]*Department of Computer Science, University of Chicago, Chicago, IL, USA*
(Dated: November 12, 2025)

https://arxiv.org/abs/2511.08508 (60 pages)

scaling the hardware enables FTQC

General information			QEC features						FTQC features											
quantum computing hardware vendor	number of logical qubits	supporting physical qubits	main QEC codes	logical memory experiment	breakeven logical error rate	leakage error correction	erasure error correction	correlated error correction	< breakeven fidelities	single qubit logical gate	singe logical error rate	two qubit logical gate	two qubit error rate	lattice surgery	magic state preparation	gate teleportation	code switching	postselection or detection	logical GHZ fidelity	full universal gate set support
QuEra	96 [40]	448 [40]	color codes	[42]	[42]	[40]	[40]	[40]	[42]	[40, 42]	[40]	[40, 42]	[40, 42]	[40, 43]	[40]	[40]	[40]	[40]	[40]	[42]
Infleqtion	12 [44]	114 [44]	qLDPC variants	[44]	[44]	[44]	[44]			[44]		[44]								
Atom Computing	24 [45]	208 [45]	Bacon Shor, 4D code, and other codes [45]	[45]			[45, 46]			[45]		[45]						[45]		
Pasqal	2	4																yes		
Quantinuum	48 [47]	98 [48]	Tesseract, Iceberg, concat	[49]	[50]		[49]		[50]	[49, 51]	[50]	[49, 51]	[50]		[52]	[52]		[49]	[50]	[52]
IonQ	12 (2026)	256 (2026)	qLDPC bb [53]	[54]	[54]		[55]													
AQT	2	30	cc	[56, 57]	[58]	[59]				[57]	[57]	[60]	[61]	[58]	[60]	[60]	[60]			[60]
Google	1 [62]	105 [62]	sc, cc	[62]	[62]	[62]		[62]	[62]					[63]	[63]		[63]	no		
IBM	200 (2029)	n×120	gross code (bc)		[25]	[25]				[25, 64]		[25, 64]		[25]	[25, 26, 65–67]	[25]	[68]			[25, 67, 68]
IQM	4-36 (2026)	54 (2025)	bc, tile codes (qLDPC)	[69]						[70]		[70]								
Alice & Bob	100 (2030))	2000 (2030)	LDPC, elevator codes							[71]		[71, 72]		[73]	[73]					
PsiQuantum	100 (2030))	1M (2030)	qLDPC, sc, dual rail				[74, 75]			[74, 75]		[74, 75]		[76]	[74–76]					
Xanadu			GKP, qLDPC, bb				[20, 77, 78]			[20, 77, 78]		[20, 77, 78]			[20, 77, 78]					
Quandela		12	Floquet							[79]		[80]								
ORCA Quantum		12	qLDPC, sc			not applic	[81]			[81]		[81]								

main WW ions traps clean rooms

USA

- Sandia National Laboratories
- skywater
- NIST
- Translume
- Georgia Tech
- Honeywell
- MIT
- GLOBALFOUNDRIES

European Union

- CHAMP-ION – The European Ion Trap Pilot Line
- PTB
- JG|U
- Leibniz Universität Hannover
- infineon
- universität innsbruck
- SAL SILICON AUSTRIA LABS
- LioniX INTERNATIONAL

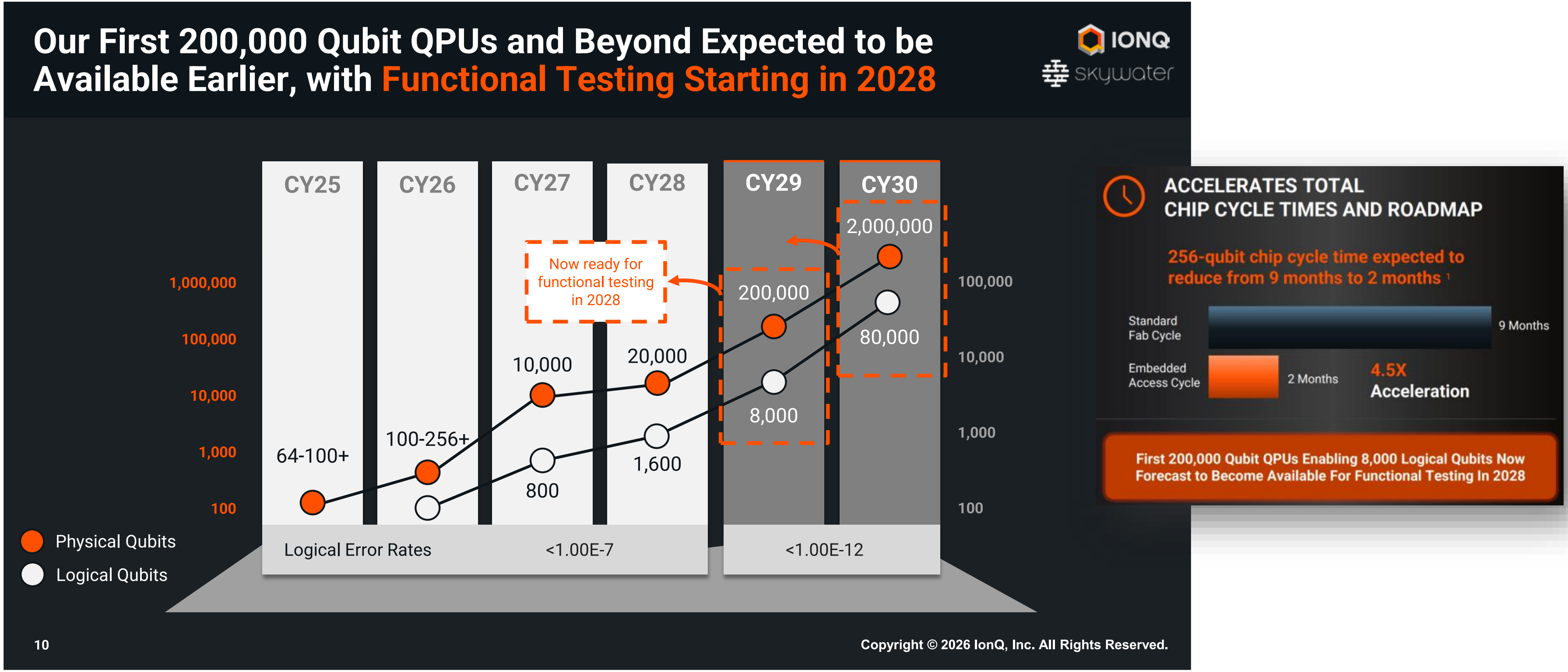
extended Europe

- ETH
- NPL
- UNIVERSITY OF OXFORD
- US UNIVERSITY OF SUSSEX

APAC

- OIST
- 大阪大学 THE UNIVERSITY OF OSAKA
- Institute of Microelectronics A*STAR IME
- INSTITUTE OF APPLIED PHYSICS SEOUL NATIONAL UNIVERSITY
- 清華大学 交叉信息研究院

aggressive competition…



US gov quantum manufacturing funding

NIST

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UPDATES

Department of Commerce Announces Letters of Intent With 9 Companies for $2 Billion to Accelerate U.S. Leadership in Quantum Computing

The CHIPS Research and Development Office's incentives will support and accelerate critical research and manufacturing of technologies for the quantum ecosystem to ensure continued United States leadership and national security.

May 21, 2026

$100M

QUANTINUUM

chip integration challenges

Chiplet technology for large-scale trapped-ion quantum processors

Bassem Badawi[1], Philip C. Holz[2], Michael Raffetseder[1], Nicolas Jungwirth[1], Juris Ulmanis[2], Hans-Joachim Quenzer[3], Dirk Kähler[3], Thomas Monz[1,2], and Philipp Schindler[1]
[1] *University of Innsbruck, Institute of Experimental Physics, Technikerstraße 25/4, 6020 Innsbruck, Austria*
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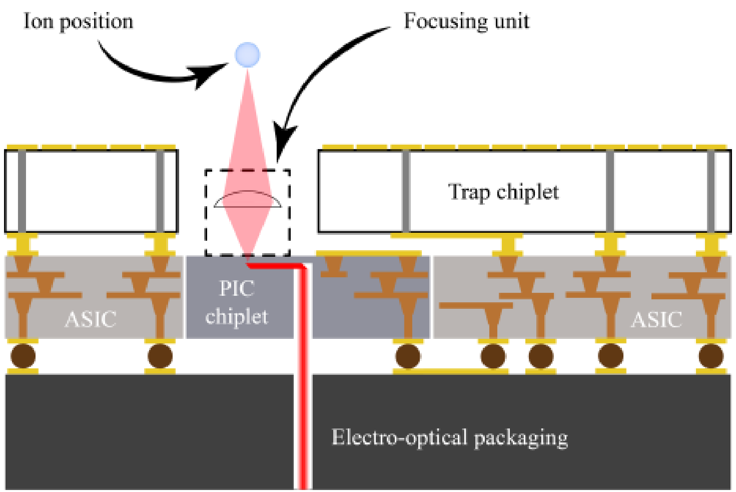
[3] *Fraunhofer Institute for Silicon Technology ISIT, Fraunhoferstraße 1, 25524 Itzehoe, Germany*

(Dated: December 3, 2025)

AQT

universität innsbruck

Fraunhofer SIT



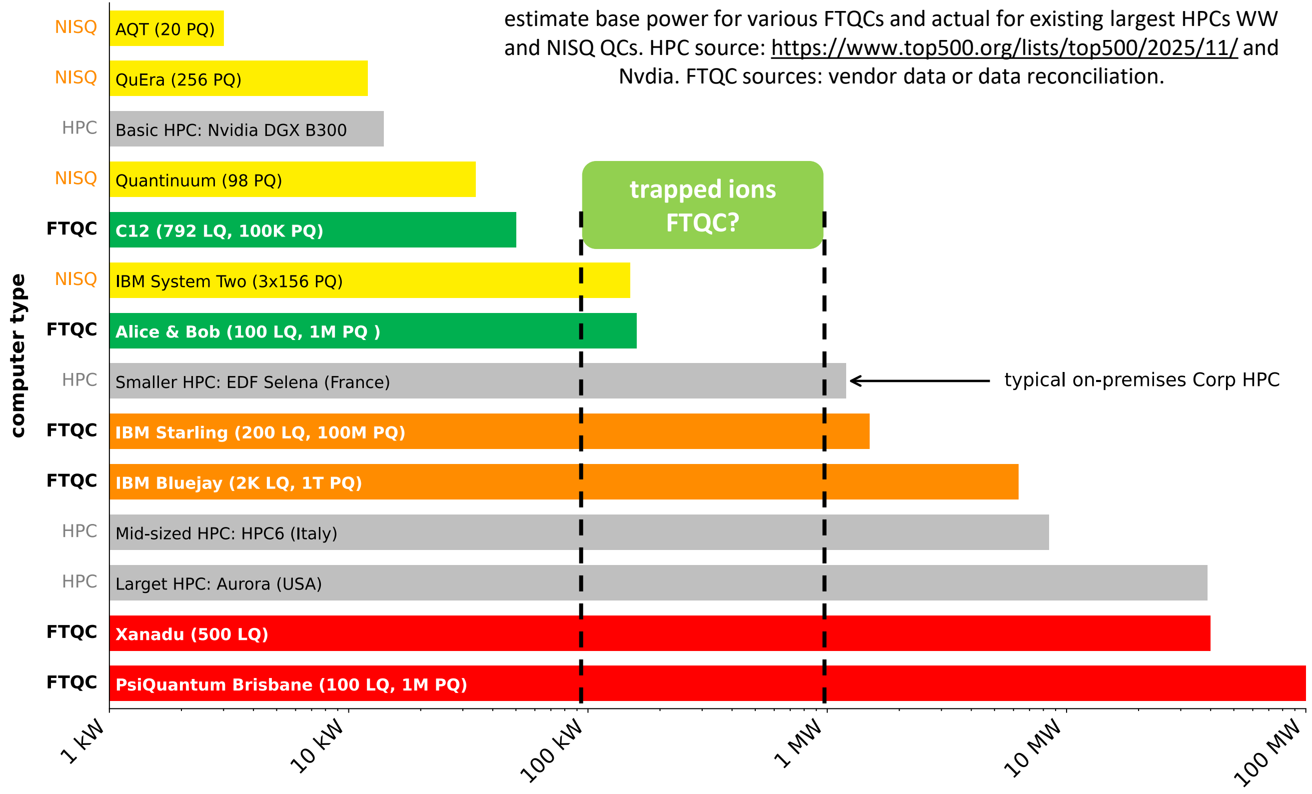
heterostructures

wiring density

thermal dissipation

FTQC vs HPC power baseline guesstimates

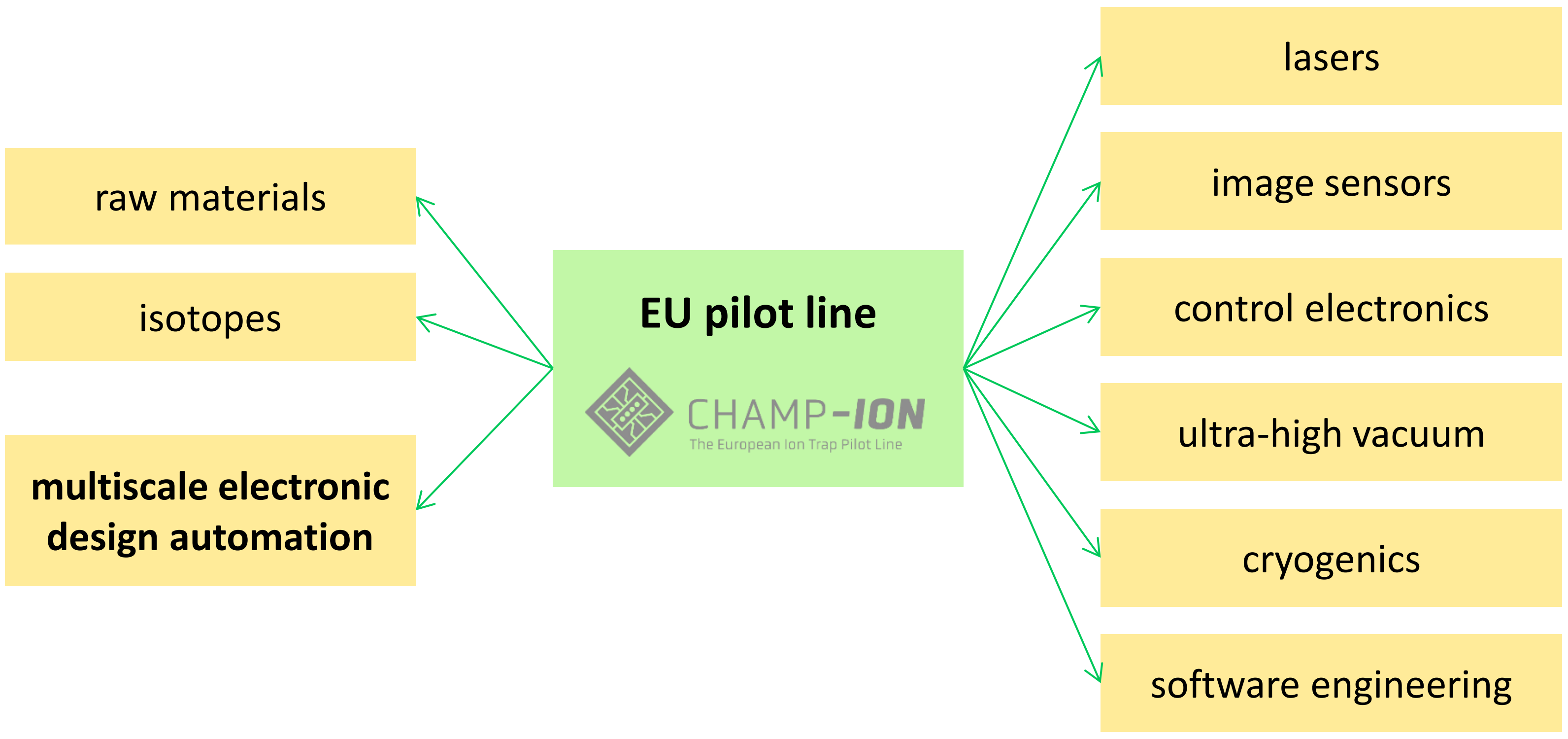
estimate base power for various FTQCs and actual for existing largest HPCs WW and NISQ QCs. HPC source: https://www.top500.org/lists/top500/2025/11/ and Nvdia. FTQC sources: vendor data or data reconciliation.



needs

- comparisons using standard workloads.
- account for total computing time.
- account for hardware cost.

strategic autonomy beyond cleanrooms



discussion

get the slides