Q2B

an (educated) end-user view of hardware roadmaps

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⟨ … | free electron | QEI cofounder | … ⟩

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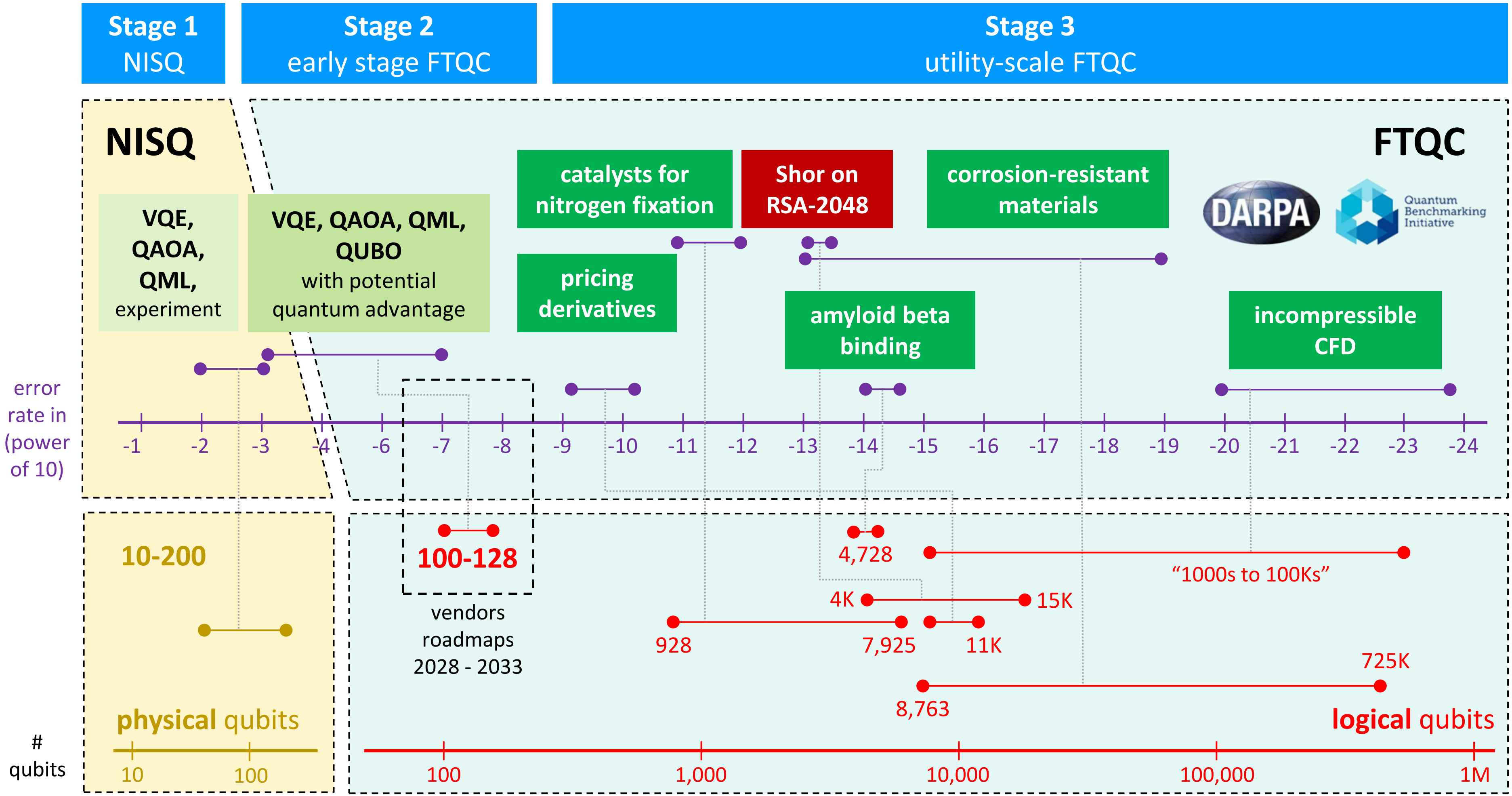
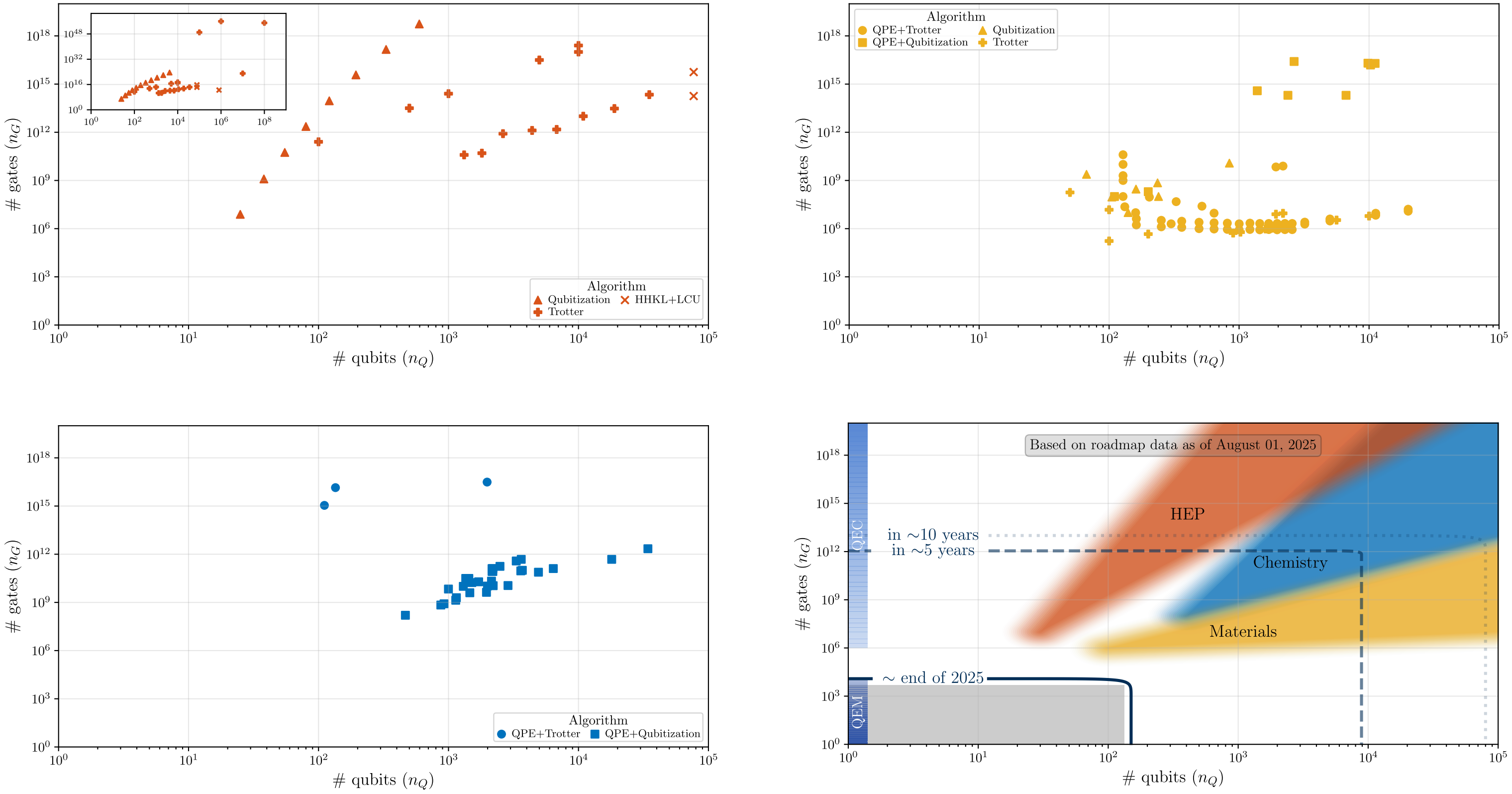
Q2B Paris, September 24th, 2025

#QEI
the quantum energy initiative

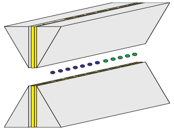

Stage 1
NISQ
Stage 2
early stage FTQC
Stage 3
utility-scale FTQC
NISQ
FTQC
VQE, QAOA, QML, experiment
VQE, QAOA, QML, QUBO with potential quantum advantage
catalysts for nitrogen fixation
Shor on RSA-2048
corrosion-resistant materials
pricing derivatives
amyloid beta binding
incompressible CFD
DARPA
Quantum Benchmarking Initiative
error rate in (power of 10)
-1 -2 -3 -4 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -24
10-200
100-128
vendors roadmaps 2028 - 2033
4,728
"1000s to 100Ks"
4K
15K
928
7,925
11K
725K
8,763
physical qubits
logical qubits
qubits
10 100
100 1,000 10,000 100,000 1M

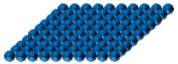


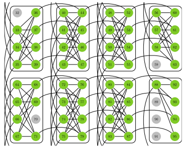
[Quantum Computing Technology Roadmaps and Capability Assessment for Scientific Computing - An analysis of use cases from the NERSC workload] by Daan Camps, et al, arXiv, September 2025 (69 pages).

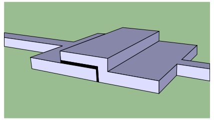
>90 QPUs industry vendors!

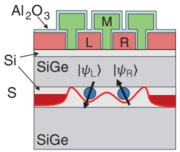
atoms	electrons *controlled spin and microwave cavities*	photons

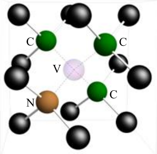


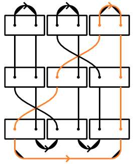


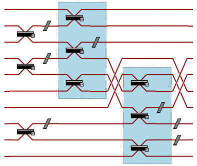












trapped ions

1. QUANTINUUM, AQT, NEXT, ZuriQ, Quantum Art, FOXCONN, 华翊量子
2. IONQ, eleQtron, Qudora Technologies
3. CRYSTAL QUANTUM COMPUTING

cold atoms

4. QuEra, Pasqal, Infleqtion, QUANTier, planqc, logiqal
5. atom computing
6. Atom Quantum Labs

annealing

D-Wave The Quantum Computing Company™, QILIMANJARO QUANTUM TECH, NEC

superconducting

7. IBM, rigetti, IQM, Google, 本源量子 Origin Quantum, ANYON, OQC, FUJITSU, QOLAB, QuamCore, Peak Quantum
8. ALICE & BOB, Nord Quantique, amazon, qci, ATLANTIC QUANTUM, Z-Axis Quantum

silicon

9. diraq, quobly, QπAI, QUANTUM MOTION
10. Groove Quantum, equal1.labs, ARQUE, intel
11. Silicon Quantum Computing, EeroQ, C12, ARCHER

vacancies

12. QUANTUM BRILLIANCE, TURING, XEED, SaxonQ, Quantum Transistors, FUJITSU
13. photonic

topological

Microsoft, QUOHERENT, QUANTUM GRAVITY RESEARCH, NOKIA

photons

14. PsiQuantum, QUANDELA, QUIX QUANTUM, ORCA COMPUTING, DUALITY QUANTUM PHOTONICS, aegiq, TUNDRASYS
15. XANADU, QUANFLUENCE
16. QCi, QBoson

August 10, 2018

2025:
84 qubits (Ankaa)
36 qubits (better fidelities)

IonQ Has the Most Powerful Quantum Computers With 79 Trapped Ion Qubits and 160 Stored Qubits

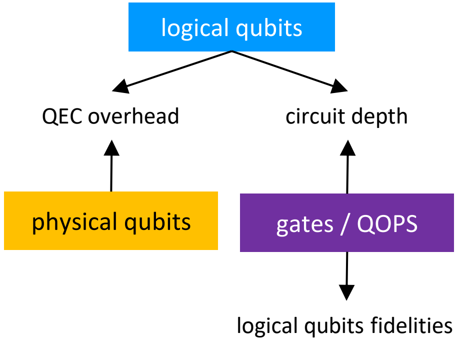
December 11, 2018 by Brian Wang

2025:
36 qubits (Forte)

what should we have in FTQC roadmaps?

bare minimum

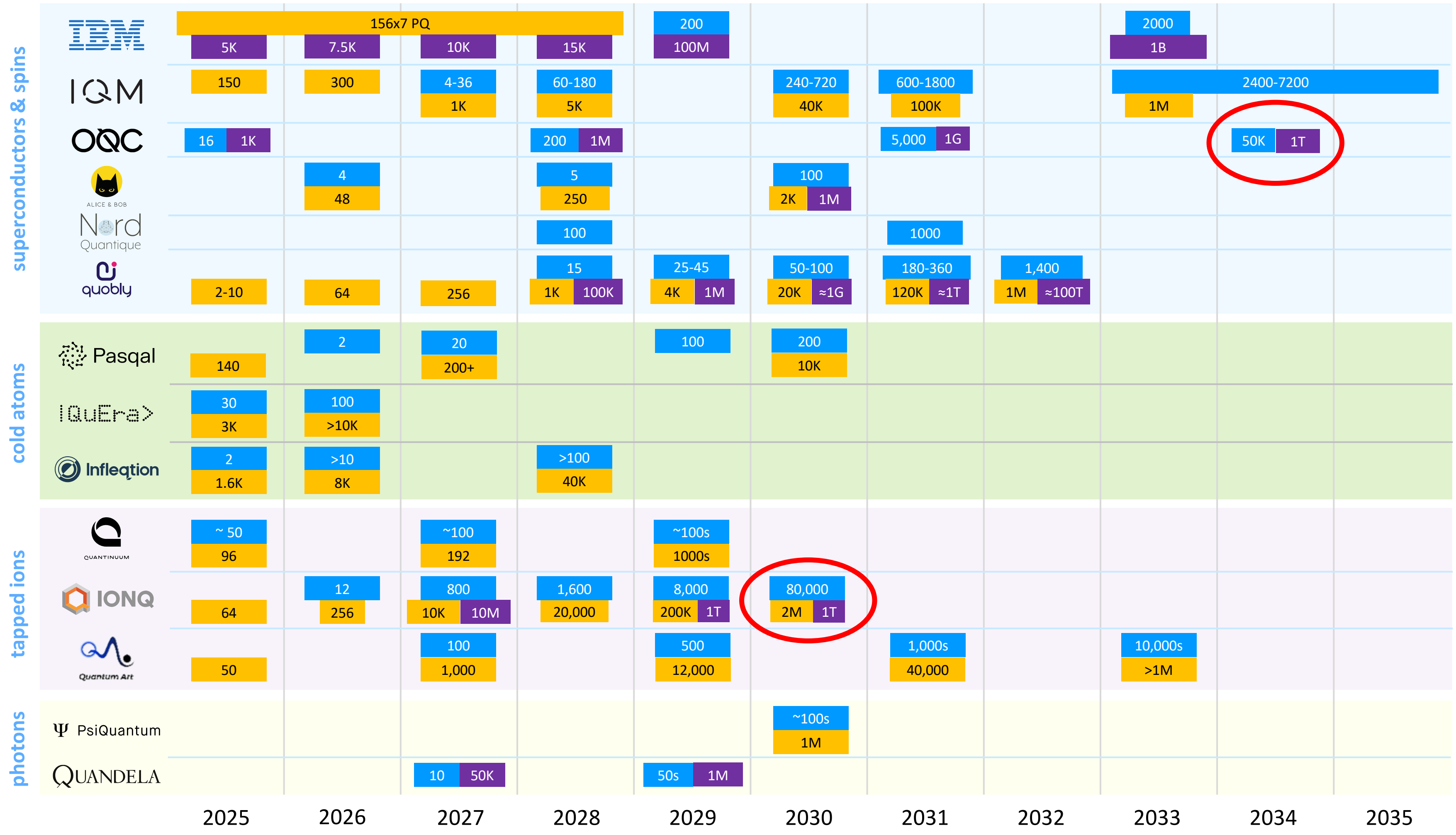
- # logical qubits.
- supported circuit size / logical error rates.
- # physical qubits.



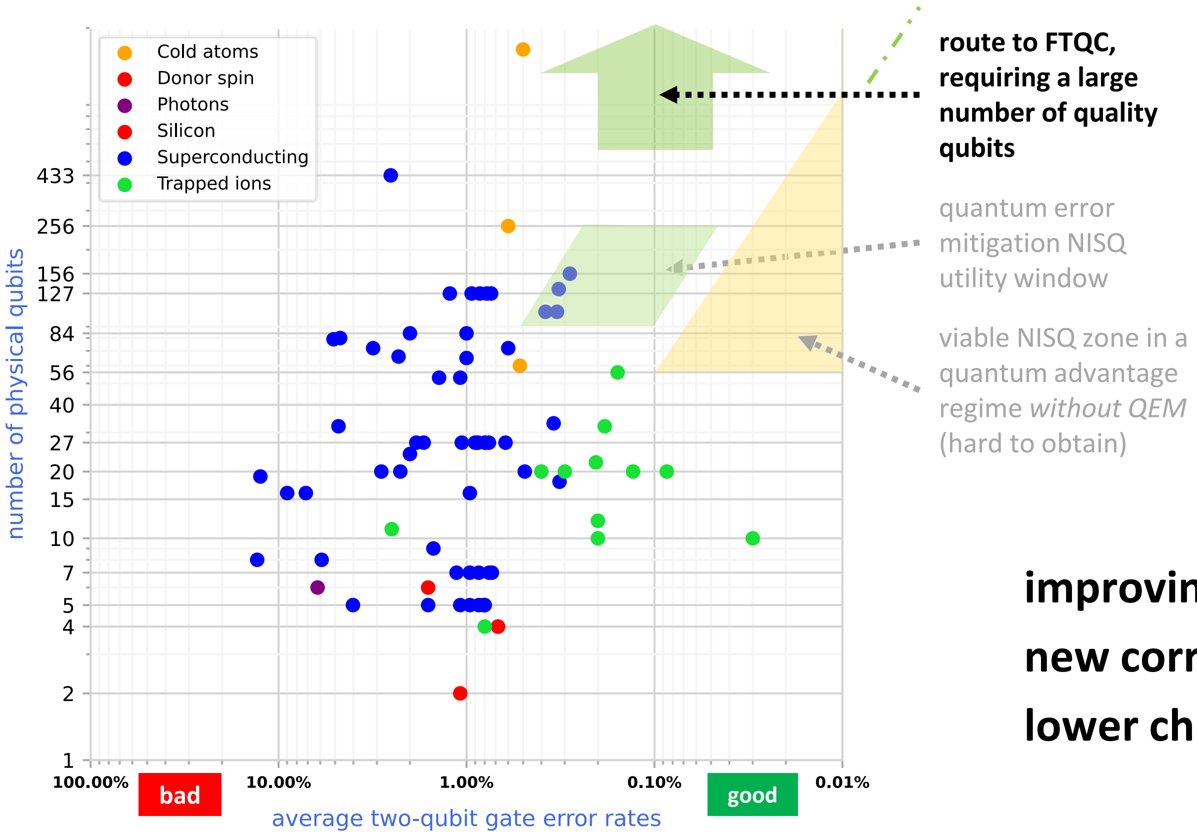
nicer to have

- clock speed and QLOPs/s.
- planned QEC codes and methods.
- processor size & reliance on QPU interconnect.
- peak power consumption in W.
- components operating temperature.
- QPU weight and size.
- operational constraints like temperature variability.
- components MTBF.
- capex/opex cost structure.

operational metrics


superconductors & spins
IBM
156x7 PQ
5K
7.5K
10K
15K
200
100M
2000
1B
IQM
150
300
4-36
1K
60-180
5K
240-720
40K
600-1800
100K
2400-7200
1M
OQC
16
1K
200
1M
5,000
1G
50K
1T
ALICE & BOB
4
48
5
250
100
2K
1M
Nord Quantique
100
1000
quobly
2-10
64
256
15
1K
100K
25-45
4K
1M
50-100
20K
≈1G
180-360
120K
≈1T
1,400
1M
≈100T
cold atoms
Pasqal
140
2
20
200+
100
200
10K
QuEra
30
3K
100
>10K
Infleqtion
2
1.6K
>10
8K
>100
40K
tapped ions
QUANTINUUM
~ 50
96
~100
192
~100s
1000s
IONQ
64
12
256
800
10K
10M
1,600
20,000
8,000
200K
1T
80,000
2M
1T
Quantum Art
50
100
1,000
500
12,000
1,000s
40,000
10,000s
>1M
photons
PsiQuantum
~100s
1M
QUANDELA
10
50K
50s
1M
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035

challenge 1: **qubit *in*fidelities**

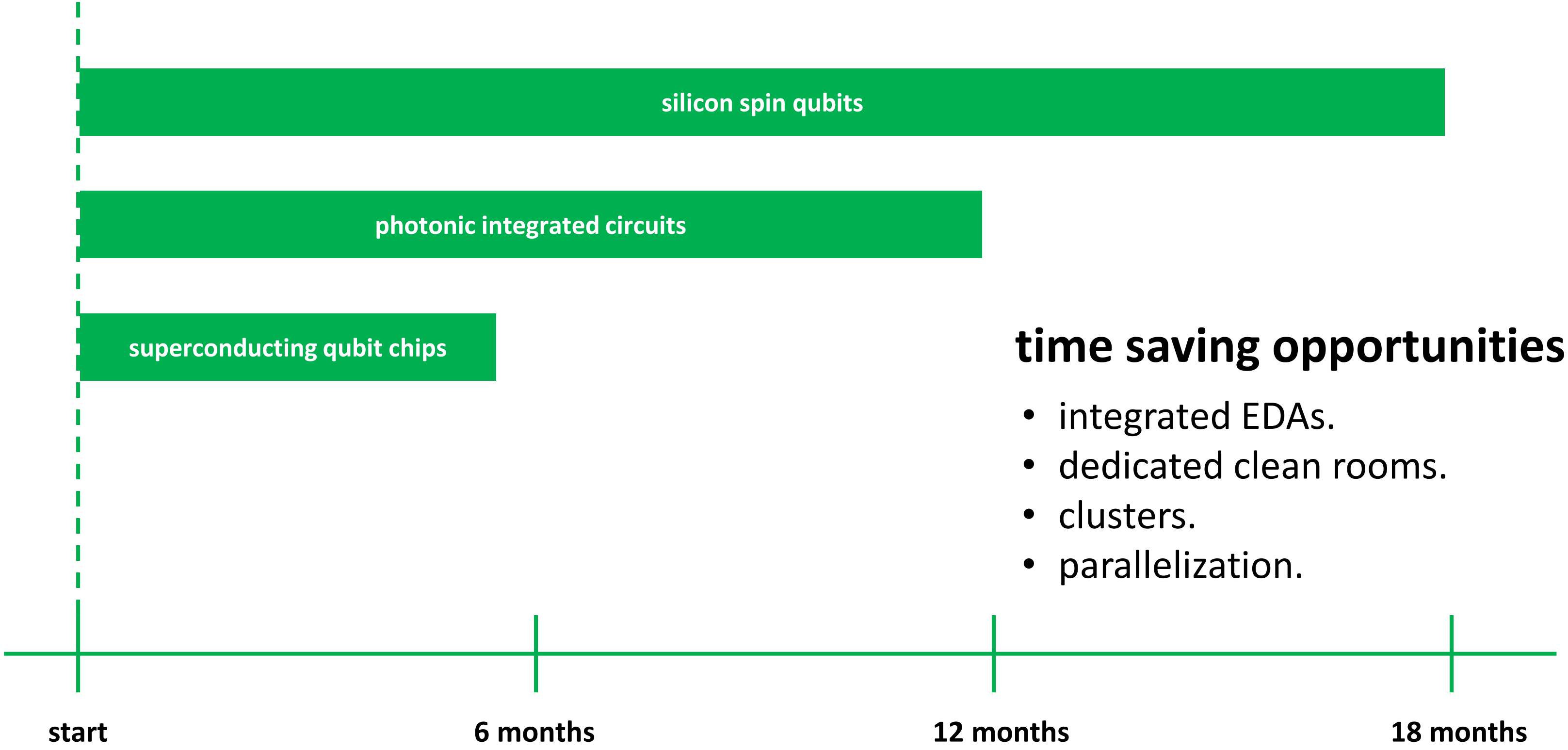


improving qubit fidelity at scale?

new correlated noise sources?

lower chips variability?

challenge 2: **chips iteration cycles**



time saving opportunities

- integrated EDAs.
- dedicated clean rooms.
- clusters.
- parallelization.

challenge 3: **QEC/FTQC integration**

real-time error syndrome detection | **code switching**

logical memory qubit | **single-qubit logical gate** | **two-qubit logical gate (*)** | **magic-state preparation (T) and teleportation** | **leakage error correction** | **correlated errors correction**

qubit connectivity | **calibration** | **qubit fast measurement**

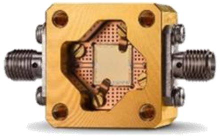
qubit physical gate fidelities >99.9% at scale

scaling QPU with interconnect and gate teleportation + circuits partitionning

(*): not using post-selection which doesn't scale to deep circuits.

blue QEC basic component.
green FTQC component.
grey QEC hardware enablers.

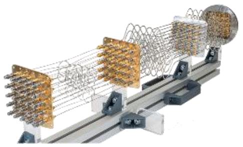
challenge 4: **enabling technologies**



control and readout signals multiplexing ⟷ ? ⟷ control signals quality

room temperature electronics ⟷ ? ⟷ cryo-electronics ⟷ ? ⟷ cryogenics scaling

QPU scaling ⟷ ? ⟷ cabling scaling



manufacturing quality, crosstalk ⟷ ? ⟷ QPU interconnect ⟷ ? ⟷ mw/optical photons transduction

more powerful lasers ⟷ ? ⟷ laser phase noise

challenge 5: **software**

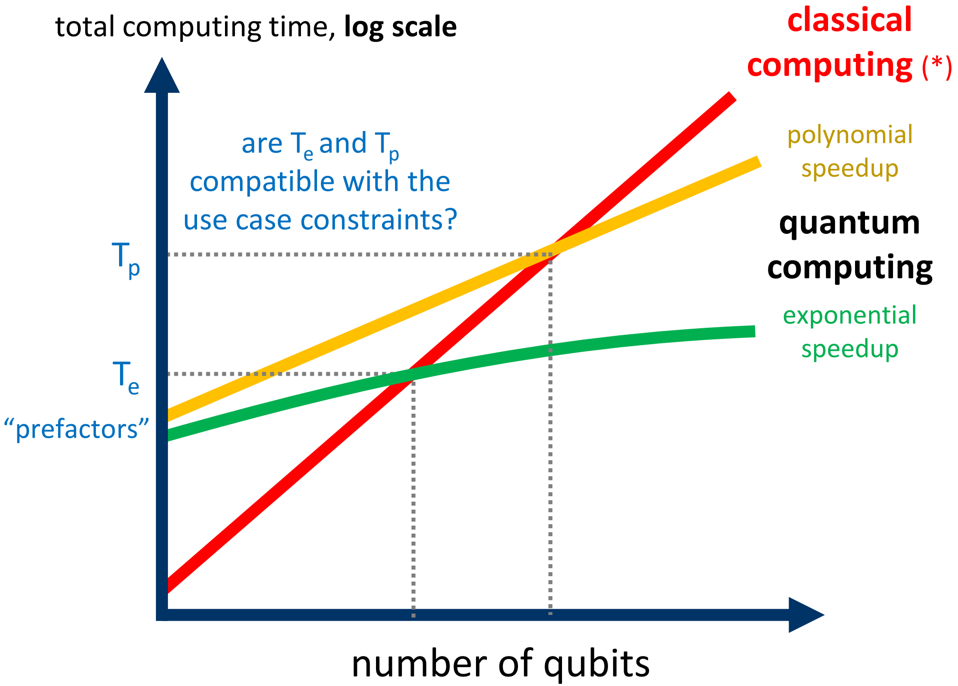
practical vs theoretical speedups

compiler & optimizers scalability

classical pre- and post-processing costs (chemistry)

verification, certification, benchmarking.

classical computing progress (MPS, DMRG).



inspired by [Opening the Black Box inside Grover's Algorithm] by E. Miles Stoudenmire and Xavier Waintal, PRX, November 2024.

(*) for a fair comparison, the classical computer can be as expensive and/or energy hungry as the QPU.

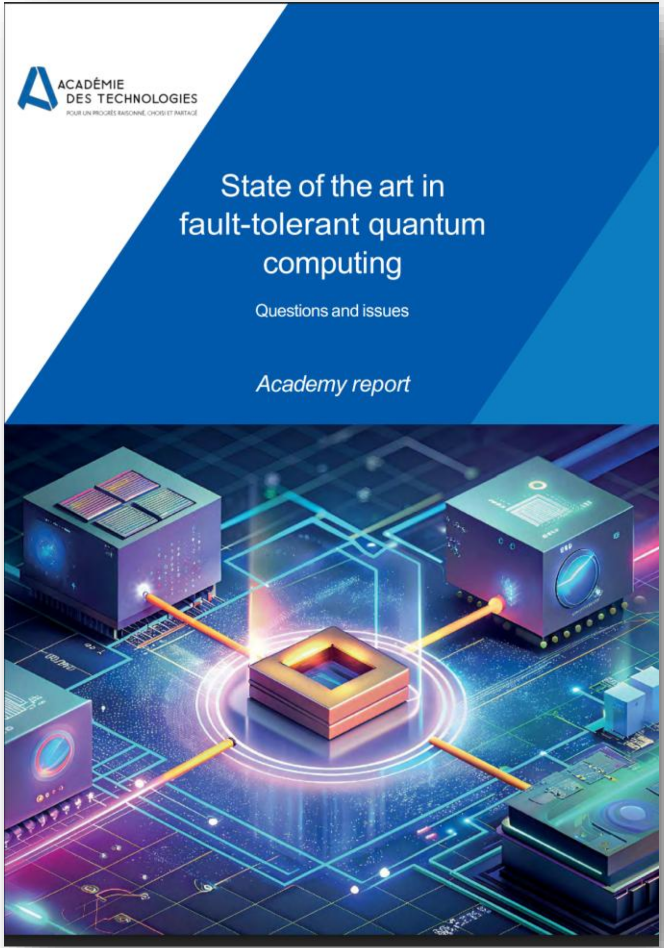
end-user dialog with vendors

vendors to end-users

- explain how challenges 1, 2, 3 and 4 are handled.
- information on R&D workload distribution (partners, academics).
- adopt benchmarking methods.
- update roadmap every year.

end-users to vendors

- provide key use cases needs and resource estimates.
- adopt benchmarking methods.
- learn classical best-in-class methods and hardware.
- track vendors roadmaps every year.
- look at QPU economics.


ACADÉMIE
DES TECHNOLOGIES
State of the art in
fault-tolerant quantum
computing
Questions and issues
Academy report

next: Thursday 25th, 4:00 PM

Q2B

the energetics challenges of FTQC

#QEI
the quantum energy initiative

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Q2B Paris, September 25th, 2025

discussion

get the slides
now