ALICE & BOB

Building a fault-tolerant quantum computer in the Paris region

18 MARCH 2024

Agenda

01

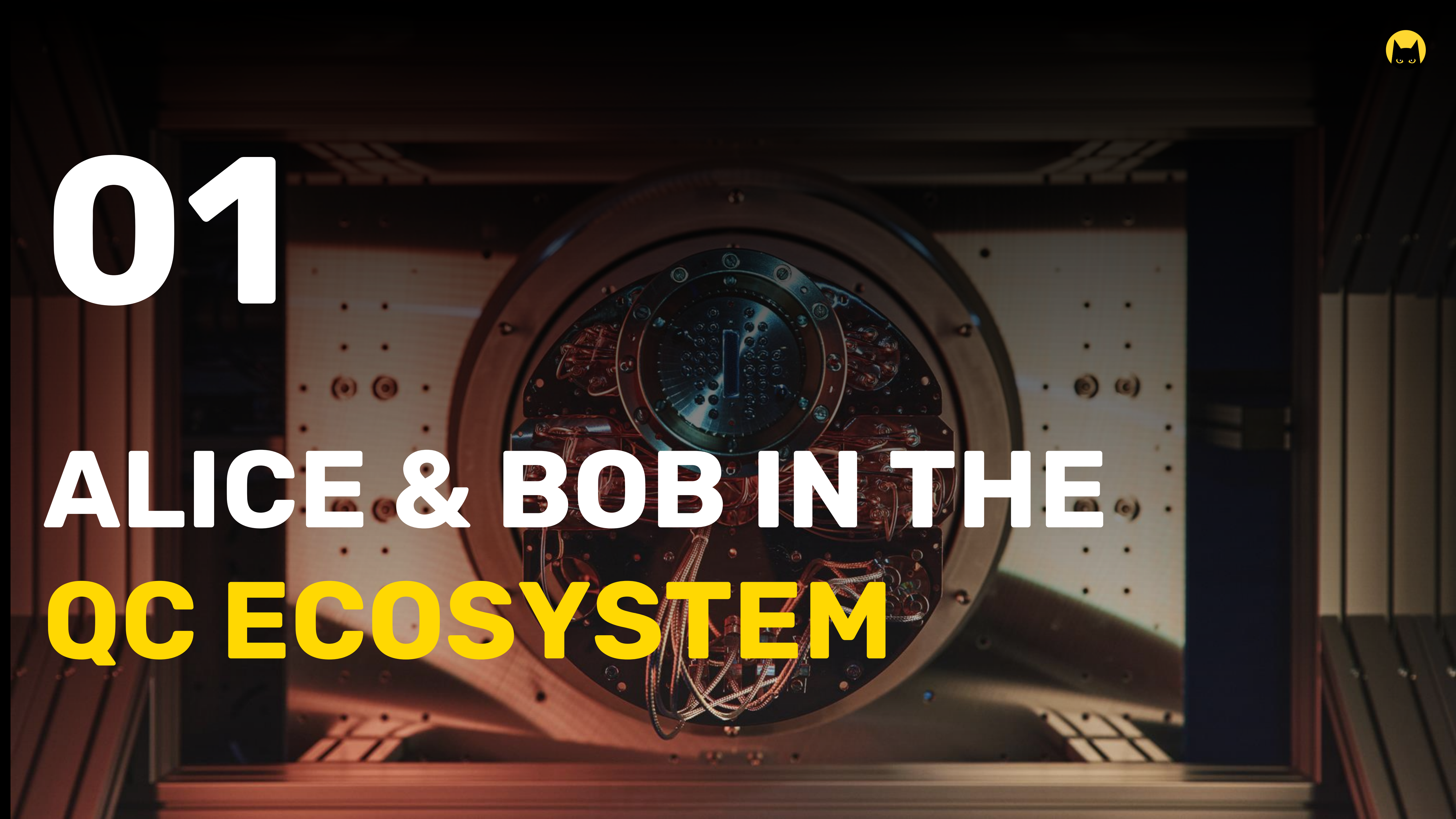
ALICE & BOB IN THE
QC ECOSYSTEM

02

ALICE & BOB IN THE
PARIS REGION

03

CAT QUBITS AND
QC USE CASES



01

ALICE & BOB IN THE QC ECOSYSTEM

Alice & Bob is a quantum hardware manufacturer founded in 2020, and it has rapidly grown since

Théau Peronnin

CO-FOUNDER AND CEO

Raphaël Lescanne

CO-FOUNDER AND CTO

2020
Year of founding

86
Employees

2
Offices - Paris / Boston

€30m
Raised so far

Each cat qubit
Already equivalent to 49 physical qubits of Google

10+ seconds
Bit-flip lifetime of a single cat qubit (compared to 1 ms for others)

24
Core patents on cat qubits

140
Mentions of Alice & Bob's technology by Amazon

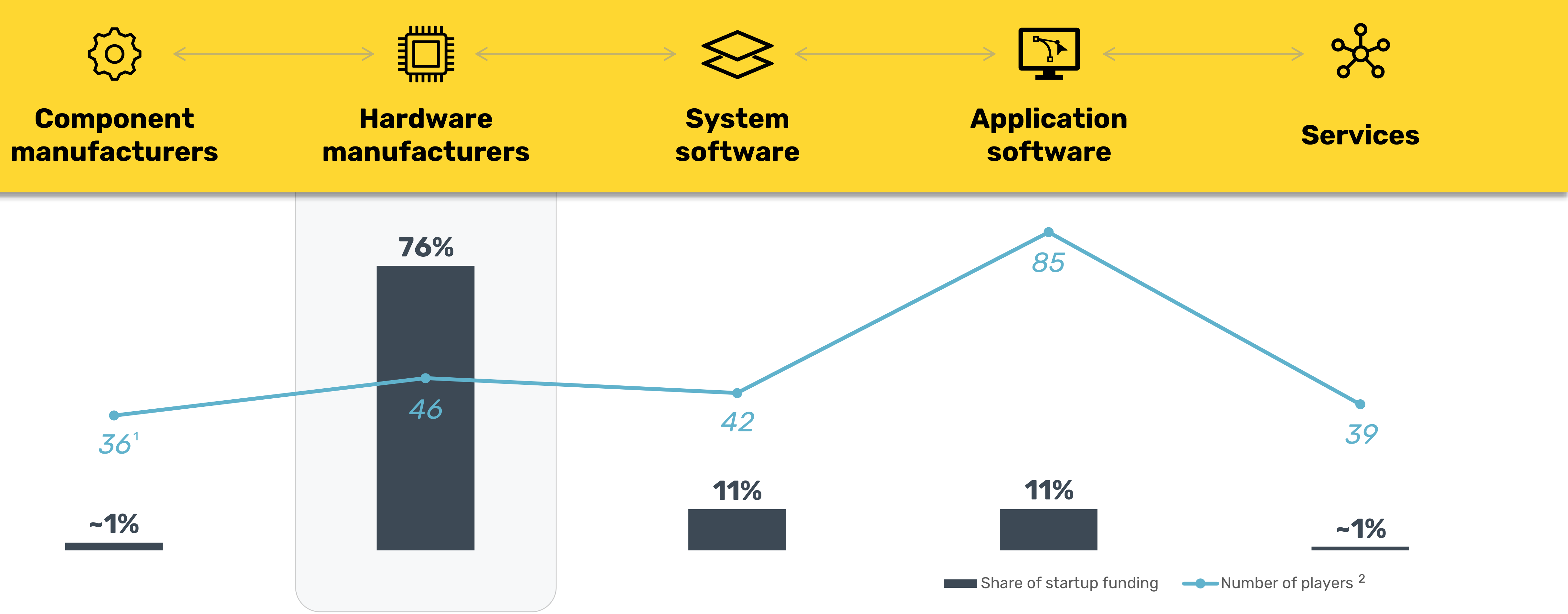
Up to €100m
Public procurement plan (PROQCIMA)

Cloud access
Signed with major providers

"The Box"
Establishing commercial relationships

10+
"The Box" clients in the pipeline

Hardware manufacturers build the highly complex computers and correspondingly receive the most VC investment



SOURCE

1. McKinsey

NOTES

1. There are more than 100 suppliers; however, only 36 are start-ups specific to quantum computing
2. Based on public investments in start-ups recorded on Pitchbook; actual investments are likely higher

Alongside Alice & Bob, France is represented by 4 other start-ups in the hardware manufacturer segment

Start-up	Qubit technology	Headquarters	Fundraising stage
C12	Spins in carbon nanotubes	Paris 5th	Seed (€10m)
PASQAL	Neutral atoms	Massy	Series B (€100m)
QUANDELA	Photons	Massy	Series B (€50m)
quobly	Spins in silicon	Grenoble	Seed (€19m)

In addition to hardware manufacturing, Alice & Bob works with clients through its 5-phase “The Box” offering

Quantum strategy development		Use case development		
Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**
Use case identification	**Quantum strategy design**	**Algorithm development**	**Hardware-specific optimization**	**Software implementation**
We identify and prioritize use cases where quantum computing could be useful to the organization	We develop a clear roadmap and a workplan to deliver quantum solutions for the prioritized use cases	We design a hardware-agnostic quantum algorithm to solve a prioritized use case	We adapt the quantum algorithm to specific hardware and optimize its computational performance	We help you develop the classical software to deliver the use case into a production environment

02

ALICE & BOB IN THE PARIS REGION

Starting with its co-founders, Alice & Bob is a product of the Parisian academic environment

THÉAU PERONNIN
Co-founder & CEO

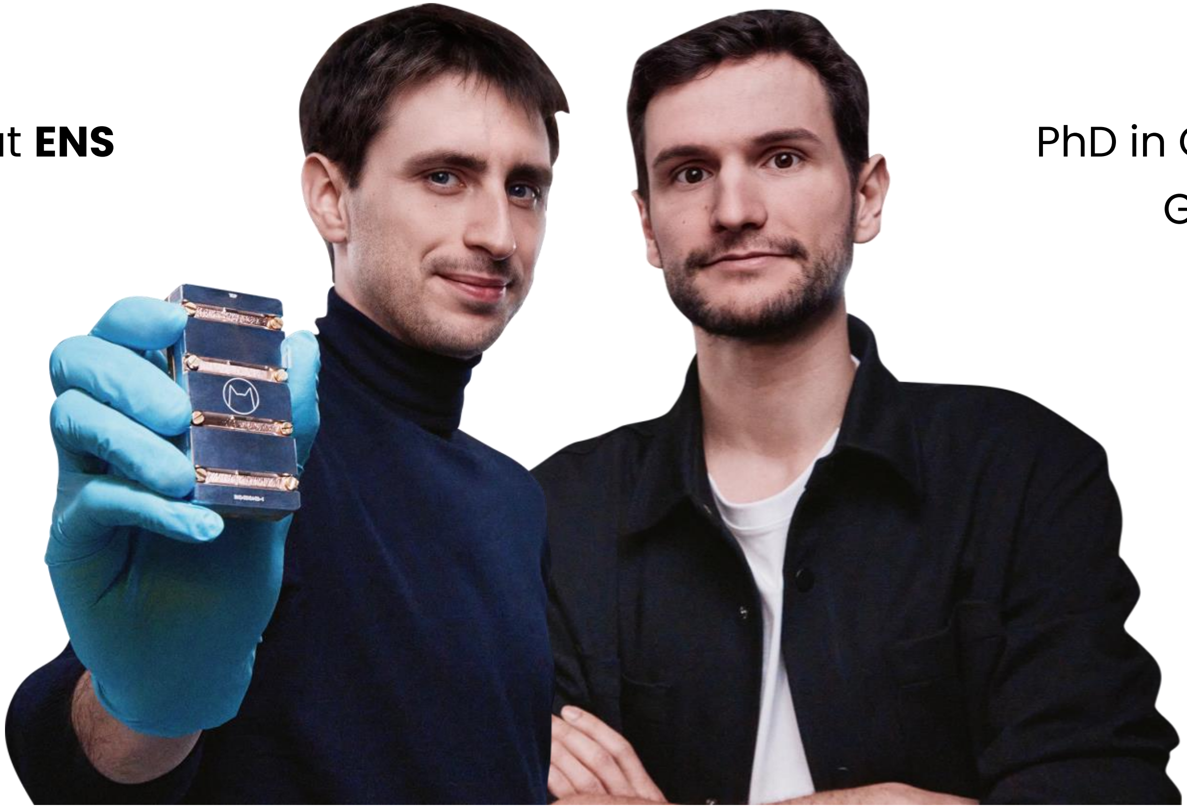
PhD in Quantum Physics at **ENS**

Graduated from **École Polytechnique**

RAPHAËL LESCANNE
Co-founder & CTO

PhD in Quantum Physics at **ENS**

Graduated from **ENS Ulm**



Alice & Bob devotes a lot of effort to academic collaborations and joint publications

100% of papers by Alice & Bob have been published in collaboration with our academic partners

~80 scientists with whom Alice & Bob researchers maintain close collaborations

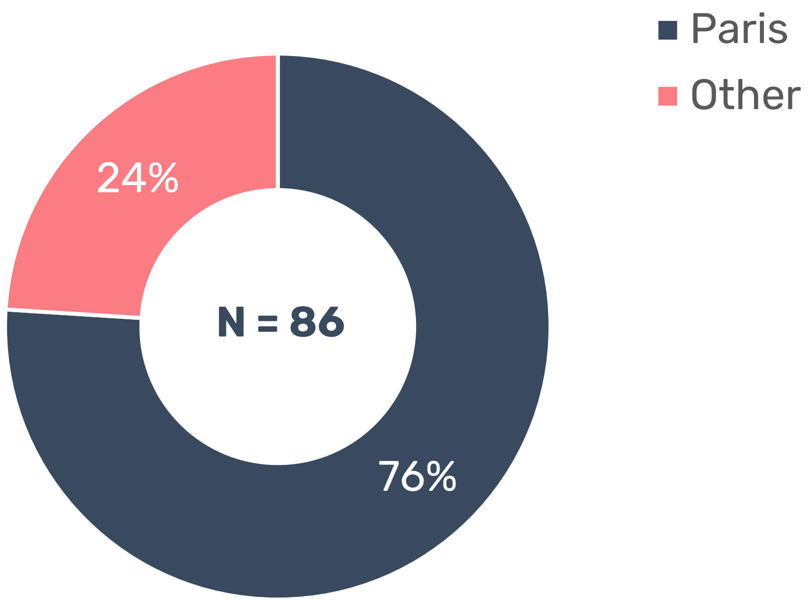
~15 PhD students hosted at Alice & Bob in collaboration with their academic institutions

2 academic boards: 1 scientific and 1 consultative; each staffed with top scientists in the field to ensure scientific rigor

Alice & Bob's core partners for scientific publications

In addition to scientific collaboration, Alice & Bob also heavily recruits from the academic institutions around Paris

Alice & Bob colleagues by location of their Master's or PhD degree



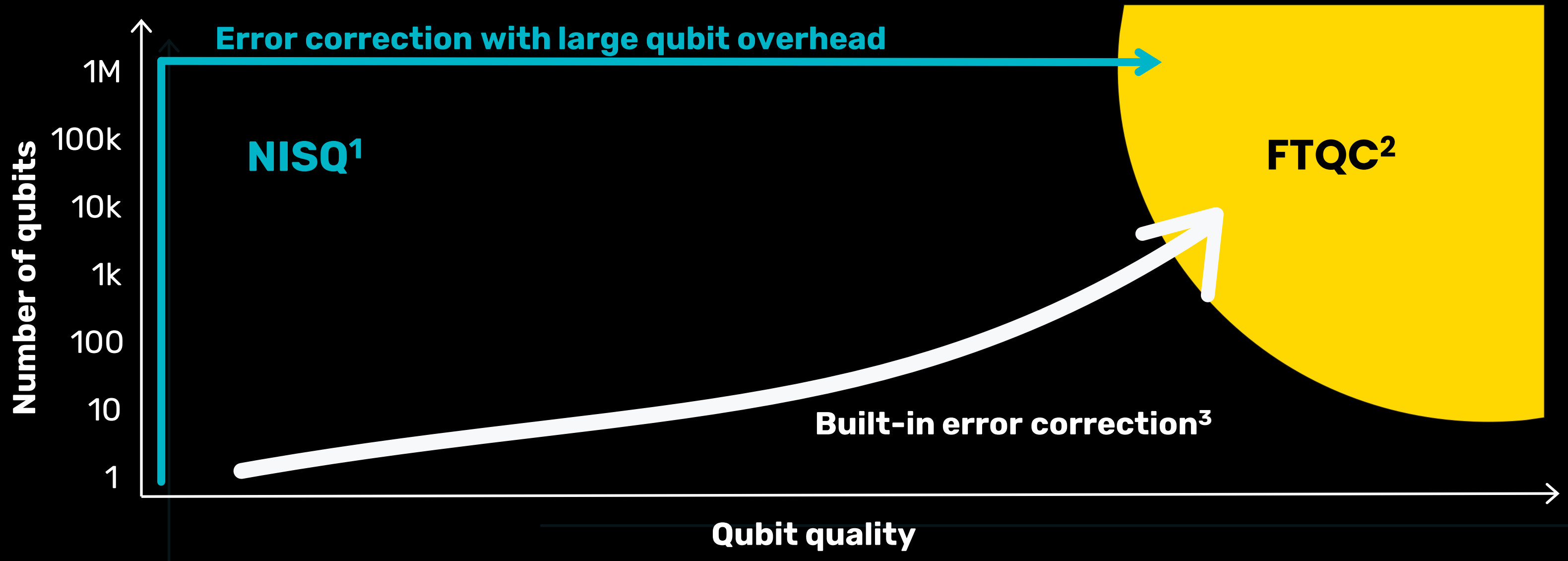
Most common educational institutions of Alice & Bob colleagues

- ENS École Normale Supérieure
- l'X École Polytechnique
- Sorbonne Université
- Arts et Métiers Sciences et Technologies
- EPITA School of Engineering & Computer Science
- MINES ParisTech
- CentraleSupélec

03

CAT QUBITS AND QC USE CASES

Two approaches to QC have emerged: Noisy Intermediate-Scale Quantum (NISQ) Computing and Fault-Tolerant QC (FTQC)



1. Noisy Intermediate Scale Quantum Computing
2. **F**ault-**T**olerant **Q**uantum **C**omputing
3. **Error correction** aims to slow down qubit decoherence and to extend computation time

→ **NISQ** aims to use currently available error-prone qubits to extract any potential business value.
It is aided by **error mitigation**, to extend the usability of quantum computers with a **larger number of qubits** and circuit depth

→ **FTQC** is focused on building "logical qubits" made of many physical qubits. Logical qubits have a much **better quality (or lower error rates)** than their underlying physical counterparts; they will enable the execution of larger algorithms when available

SOURCE
1. Olivier Ezratty

FTQC requires correction of two types of errors: bit flips and phase flips

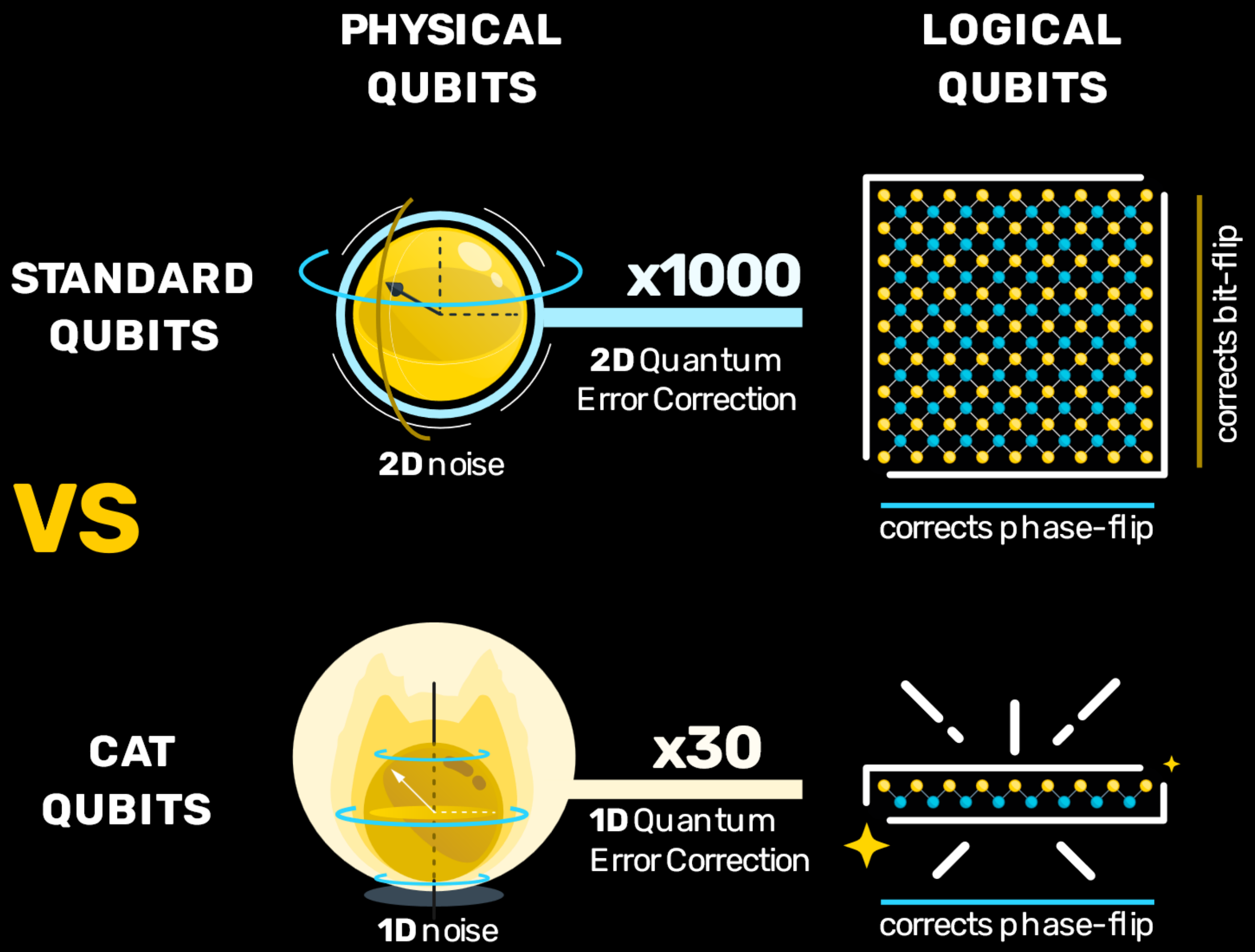
Qubits are sensitive to noise

Qubits affected by noise randomly change their state, which leads to **bit flips (0 and 1)** and **phase flips (+ and -)**

Noise introduces decoherence

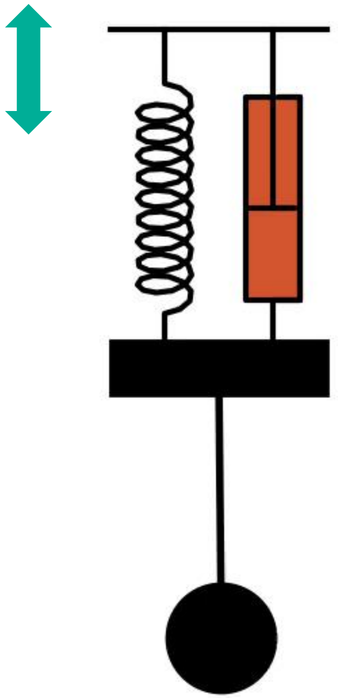
Random changes of state lead to the loss of the quantum information encoded in the qubit: this is qubit decoherence

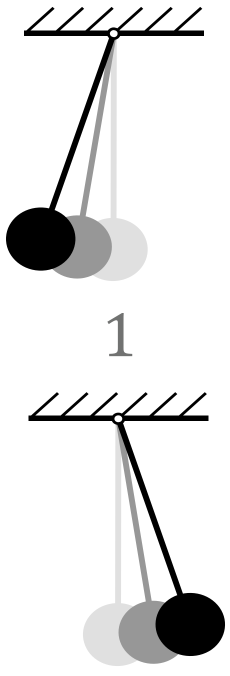
Cat qubit technology eliminates bit-flip errors and allows only one type of error to be corrected



The mechanical analog to a cat qubit is a driven pendulum with a dissipative element

Motion of a driven dissipative pendulum





Properties of the system

Symmetry of the problem requires that the system has two solutions
-> qubit 0 and qubit 1 assignment

Drive of the pendulum (the pump) and the dissipative element preserve the steady state once it has been achieved, and prevent the divergence of motion
-> qubit stabilization

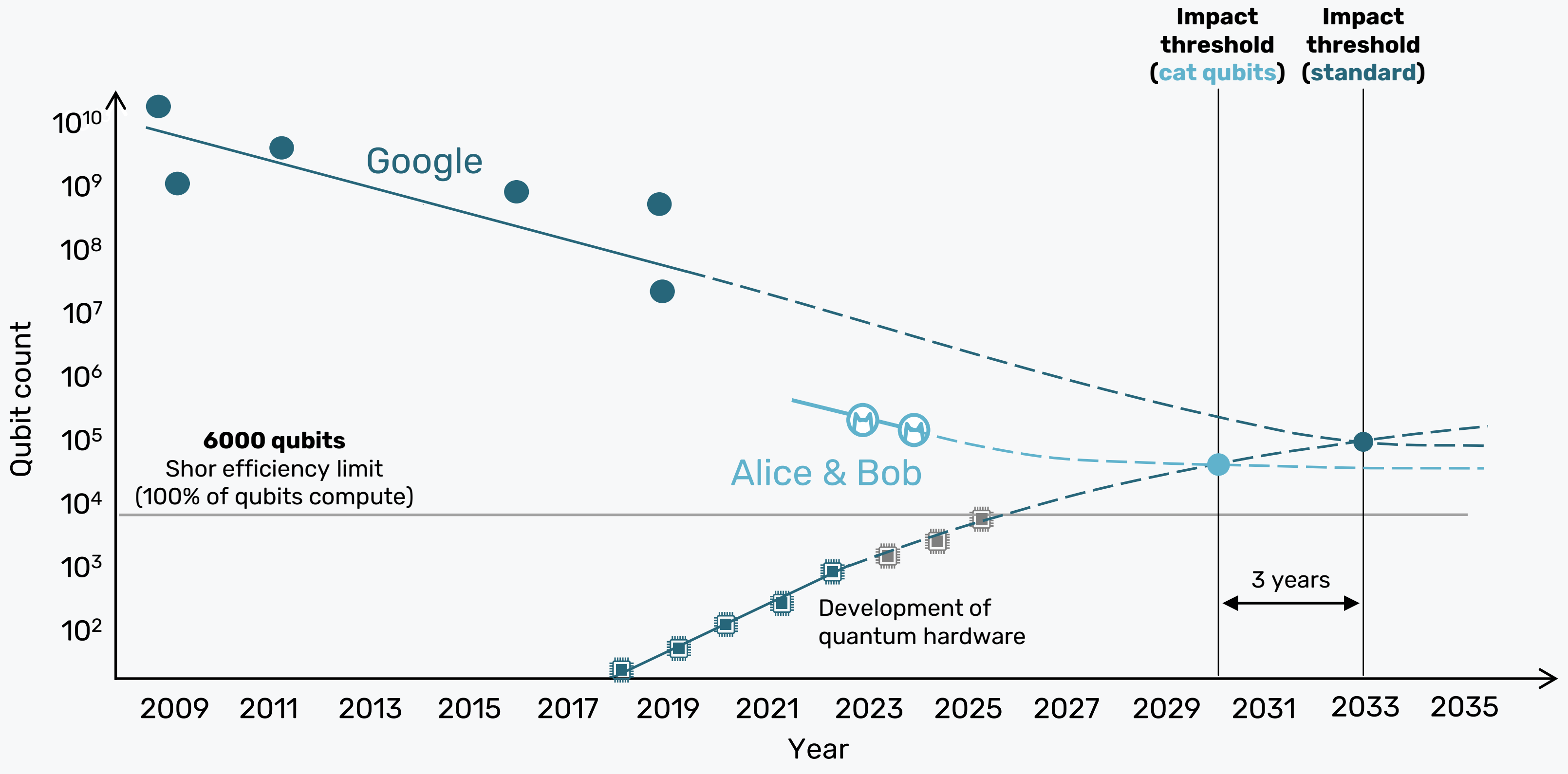
Stronger drive (larger amplitude) corresponds to less chance of switching between 0 and 1
-> exponential bit-flip suppression

SOURCE

1. Raphaël Lescanne

Leveraging cat qubits, Alice & Bob allows QC impact to be realized earlier

Illustrative example of A&B advantage to execute Shor's algorithm



Quantum resource requirements

- Standard superconducting qubits
- Cat qubits – new qubit architecture
- Extrapolated with cat qubits

Quantum hardware

- Achieved
- Announced
- Extrapolated without cat qubits

A&B approach

Cat qubits are protected from bit-flips by design

A&B can **reduce 200x the number of qubits** needed to run impactful algorithms (Shor's algorithm)

SOURCES

1. [C. Gidney and M. Ekerå, Quantum **5**, 433 (2021)]
2. [É. Gouzien *et al.*, Phys. Rev. Lett. **131**, 040602 (2023)]
3. [D. Ruiz et al., arXiv:2401.09541 (2024)]
4. IBM roadmap

With ~100 logical qubits, use cases interesting to quantum physicists and chemists become available

Spin system dynamics, e.g., Hubbard model

TABLE IV. Resources required for quantum simulation of a planar Hubbard model with periodic boundary conditions and spin, as in Eq. (56). The dimension of the system indicates how many sites (spatial orbitals) are on each side of the square model. The number of system qubits is thus twice the number of spatial orbitals. The number of logical ancillae is computed as Eq. (64). Finally, the number of T gates is computed using Eq. (63), which assumes that $u/t = 4$ and $\Delta E = t/100$. The first three problem sizes in the table are near the classically intractable regime.

Dimension	Spin orbitals	Logical ancilla	Total logical	T count
6×6	72	33	105	9.3×10^7
8×8	128	33	161	2.9×10^8
10×10	200	36	236	7.1×10^8
20×20	800	42	842	1.2×10^{10}

Highly correlated molecules, e.g., FeMoco

Table 1. Simulation time estimates

Structure	T gates	Cl. gates	Δt (10 ns)	Δt (100 ns)	Qubits
Quantitatively accurate simulation (0.1 mHa)					
Structure 1					
Serial	1.1×10^{15}	1.7×10^{15}	130 d	3.6 y	111
Nesting	3.5×10^{15}	5.7×10^{15}	15 d	4.9 mo	135
PAR	3.1×10^{16}	3.1×10^{16}	110 h	1.5 mo	1,982
Structure 2					
Serial	2.0×10^{15}	3.1×10^{15}	240 d	6.6 y	117
Nesting	6.5×10^{15}	1.0×10^{16}	27 d	8.9 mo	142
PAR	6.0×10^{16}	6.0×10^{16}	210 h	2.9 mo	2,024
Qualitatively accurate simulation (1 mHa)					
Structure 1					
Serial	1.0×10^{14}	1.6×10^{14}	12 d	3.9 mo	111
Nesting	3.3×10^{14}	5.6×10^{14}	1.4 d	14 d	135
PAR	3.0×10^{15}	3.0×10^{15}	11 h	4.6 d	1,982
Structure 2					
Serial	1.9×10^{14}	3.0×10^{14}	22 d	7.2 mo	117
Nesting	6.0×10^{14}	9.9×10^{14}	2.5 d	25 d	142
PAR	5.5×10^{15}	5.5×10^{15}	20 h	8.3 d	2,024

Listed are the number of Clifford and T-gate operations, the estimate of the run time (Δt), and the number of logical qubits required to obtain energies within 0.1 mHa or 1 mHa for two different structures of FeMoco on a quantum computer. Structure 1 is for spin state $S = 0$ and charge $+3$ elementary charges with 54 electrons in 54 spatial orbitals. Structure 2 is for spin state $S = 1/2$ and charge 0 with 65 electrons in 57 spatial orbitals (see *SI Appendix* for further details). These run times and gate counts are likely to be pessimistic.

SOURCES

1. [R. Babbush et al., PRX **8**, 041015 (2018)]
2. [M. Reiher et al., PNAS 114 (29) 7555-7560 (2017)]

QC could also impact business-relevant use cases

Business-application types and example use cases

Quantum Monte Carlo Simulation	Differential Equations	Machine Learning	Optimization	Molecular Simulation	Cryptography
Hedging strategies	Hydrodynamics	Fraud detection	Route optimization	Aging of materials	Improvement of data security
Risk management	Thermal design	Model training	Fleet optimization	Binding affinity calculations	
Energy distribution	Weather forecast	Diagnosis with image recognition	Portfolio optimization		
Protein folding scenarios	Chemistry kinetics				

SOURCES

1. BCG
2. Olivier Ezratty

While we build computers to unlock these use cases, we can do resource estimation and logical qubit emulation

Actions that can be taken now:

Resource estimation: estimate how many qubits and how much time is needed to run an algorithm

Logical qubit emulation: predict the behavior of future hardware

THE EMULATOR

THE CLOUD

ALICE & BOB