Le calcul quantique, vers la grande échelle en France

Maud Vinet – Quobly

Présidente et co-fondatrice

QUOBLY JOURNEY

GRENOBLE ALPES
A digital & semiconductor community
with over +40,000 jobs

'00 -'10s

2019-2022
QUANTUM RESEARCH
+ €30 Million invested

QUANTALPS CREATED
+200 researchers in 20 labs
2022

2022 | **2023** | **2024+** → company

GROWING EXPONENTIALLY
+45 employees

quobly
LAUNCHED

€19M SEED ROUND

research

TECHNOLOGY – SCIENCE - INNOVATION
The foundations of Quobly

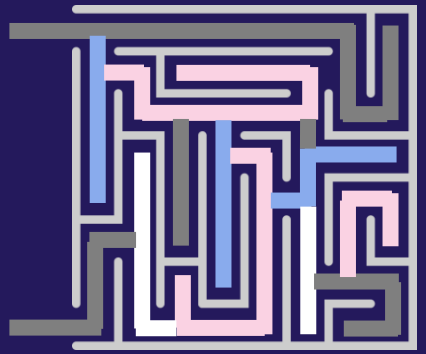
Les Questions adressées

- Q1 – Pourquoi parle t'on de "calcul quantique" ?
- Q2 – Quel sont les principaux verrous ?
- Q3 – Quelles seront les premières / principales applications
- Q4 – La position de la France ?
- Q5 –Quobly …

Q1 – Pourquoi le calcul quantique ?

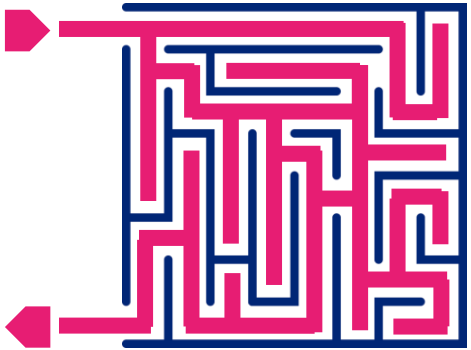
NEW POSSIBILITIES ARISE

Classical computing



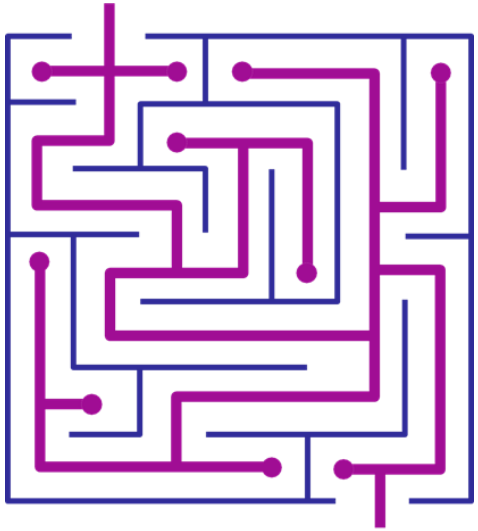
Each dead-end requires a separate operation

Quantum computing



All operations happen in parallel. For many problems, this makes computation faster.

La puissance du calcul quantique

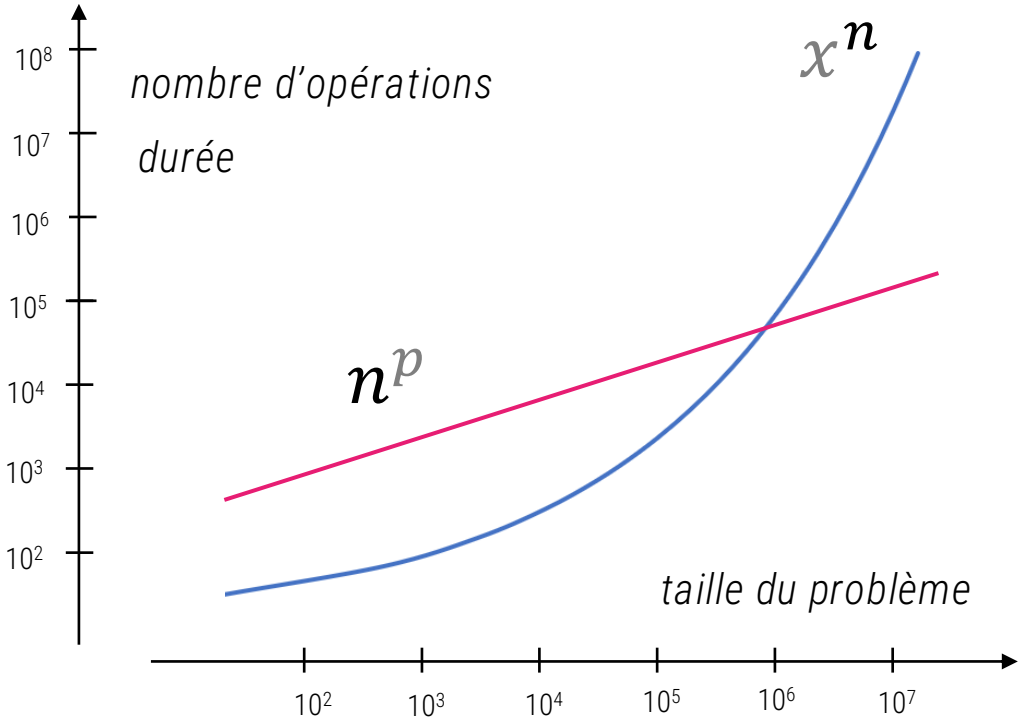


$f(q_1; q_2; q_3; \ldots q_n)$

$$|00 \ldots 0\rangle + |00 \ldots 1\rangle + |01 \ldots 1\rangle + |01 \ldots 0\rangle$$
$$+ \ldots$$
$$+ |10 \ldots 0\rangle + |10 \ldots 1\rangle + |11 \ldots 0\rangle + |11 \ldots 1\rangle$$

$$|01 \ldots 0\rangle$$

Classique vs Quantique



suprématie

avantage

Q2 – Quels sont les principaux verrous ?

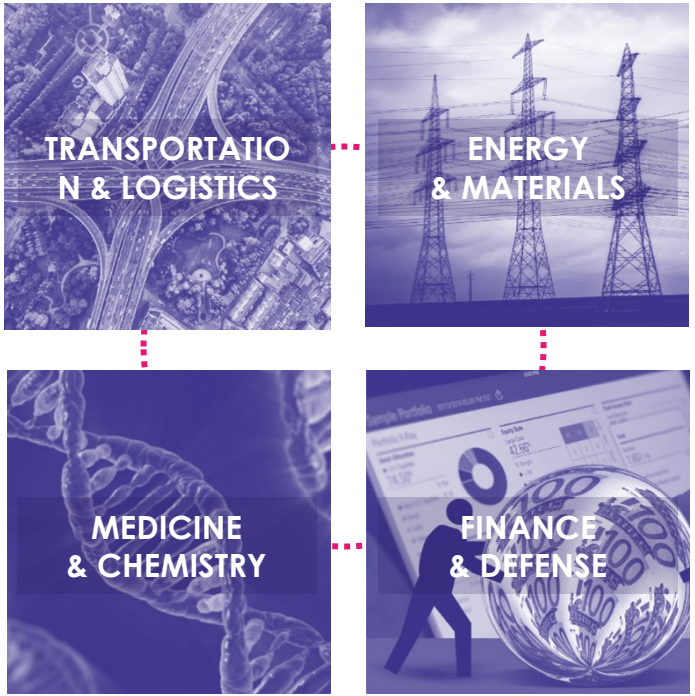
THE PROMISE

Our computers will solve problems that are currently **UNSOLVABLE.**

Perspectives of joint markets with AI

Value creation at stake:

$620B – $1,270B (1)



(1) McKinsey & Company "Quantum Technology Monitor", April 2023

THE CHALLENGE

Quantum computers will be useful once they reach over **1 MILLION** total qubits.

TODAY

SCALE-UP BEGINS

FULL SCALE FAULT TOLERANT

NISQ

SUPERCONDUCTORS ~1000

ATOMS/IONS ~1000

PHOTONICS ~100

SILICON SPIN QUBITS ~10

Scaling up is challenging...

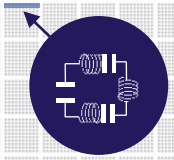
... but less so for spin qubits

1,000 QUBITS

1 MILLION QUBITS & BEYOND

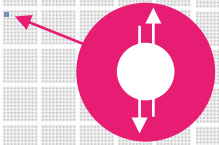
THE SCALABILITY DILEMMA

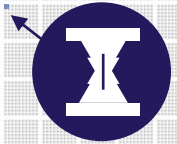
If 1 dot = 100 qubits, there are 1M qubits below, the minimum for a useful quantum computer.



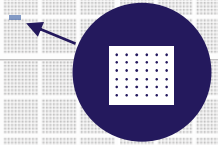
Superconductors

Spin qubits



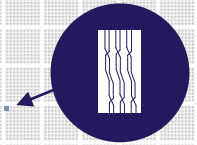


Trapped ions



Neutral atoms

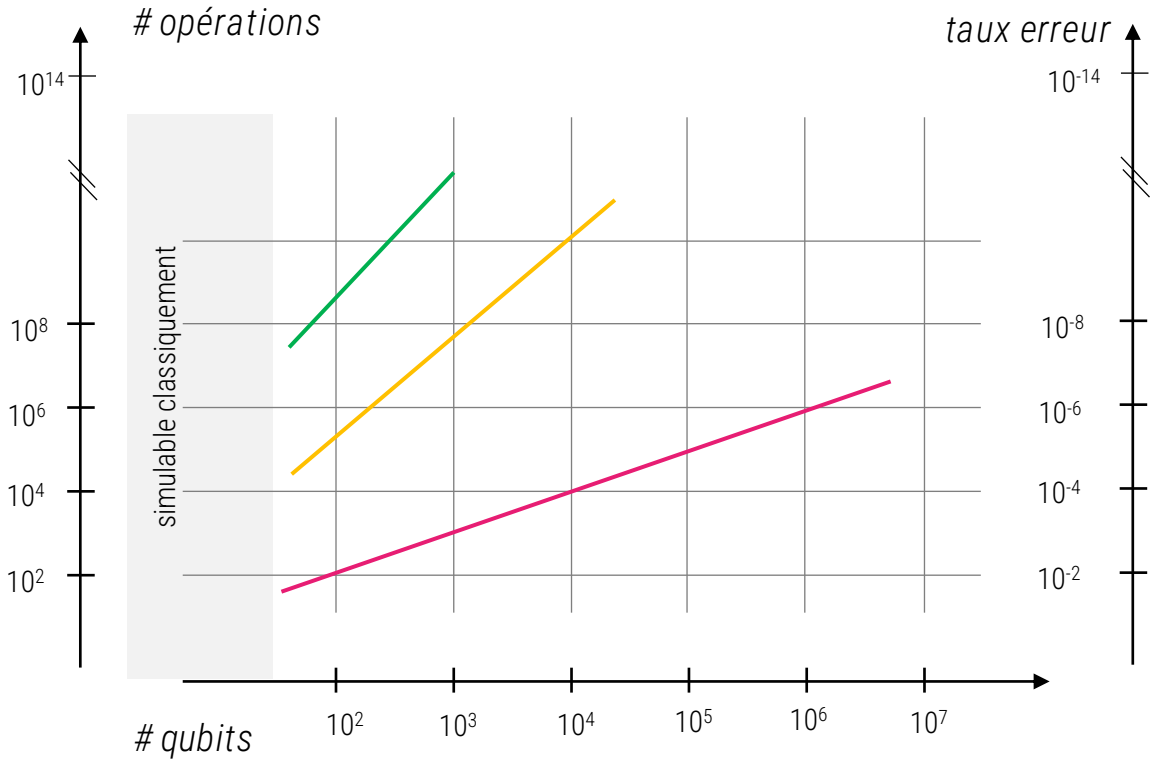
This is about where each architecture is right now.



Photons

ACADEMIC ERA

Le challenge de la qualité des qubits



$\sim n$ pas accélération

$\sim n^2$ accélération incertaine

$\sim n^3$ accélération certaine

Les codes correcteurs d'erreur quantique

LSQ

Classique

$0 \equiv 000000000000$

$1 \equiv 111111111111$

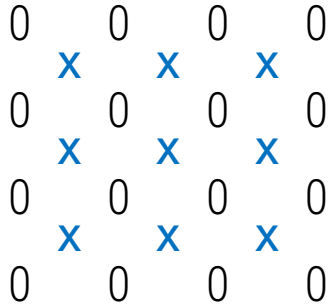
$000010000000 \longrightarrow 0$

Quantique

~~mesure~~

~~clonage~~

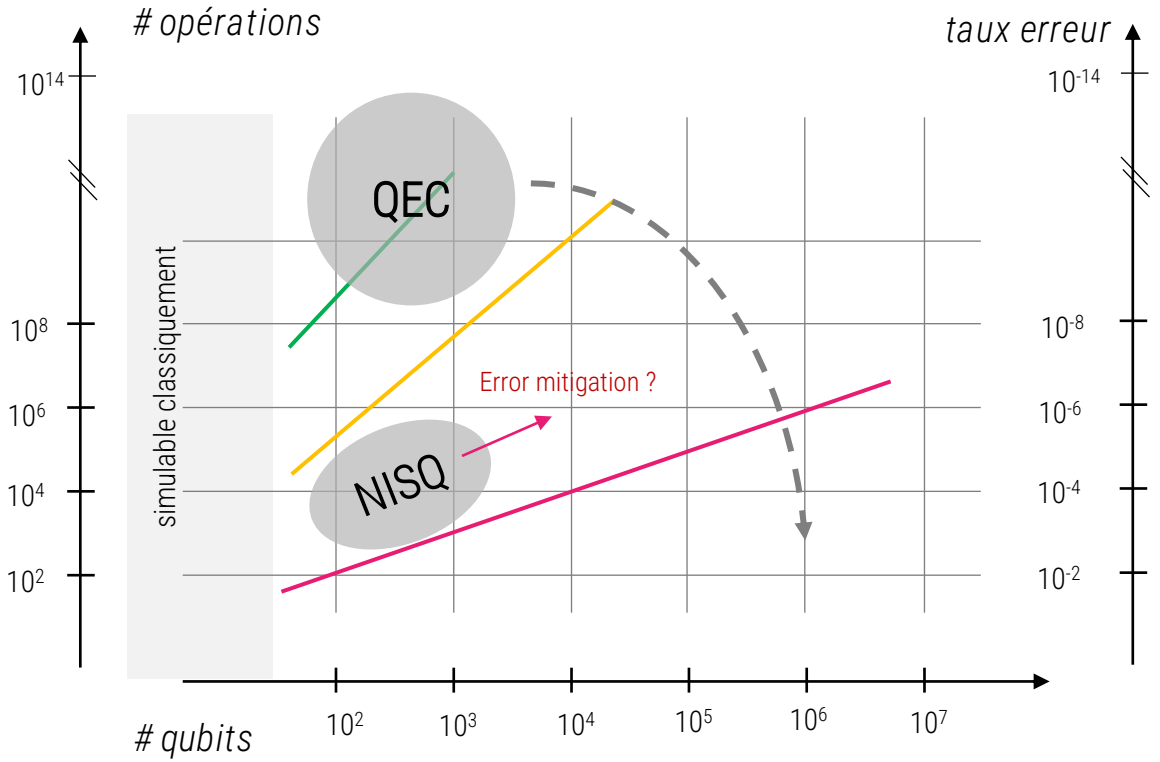
$0 \equiv$



facteur multiplicatif sur # qubits

amélioration exponentielle de la fidélité

L’enjeu du scaling



Q3 – Quelles seront les premières / principales applications ?

Le panorama complet ?

Quantum Annealing
Analog Quantum Simulator

Calcul universel

Simulation
Optimisation
(Calcul matriciel)

x

NISQ
LSQ

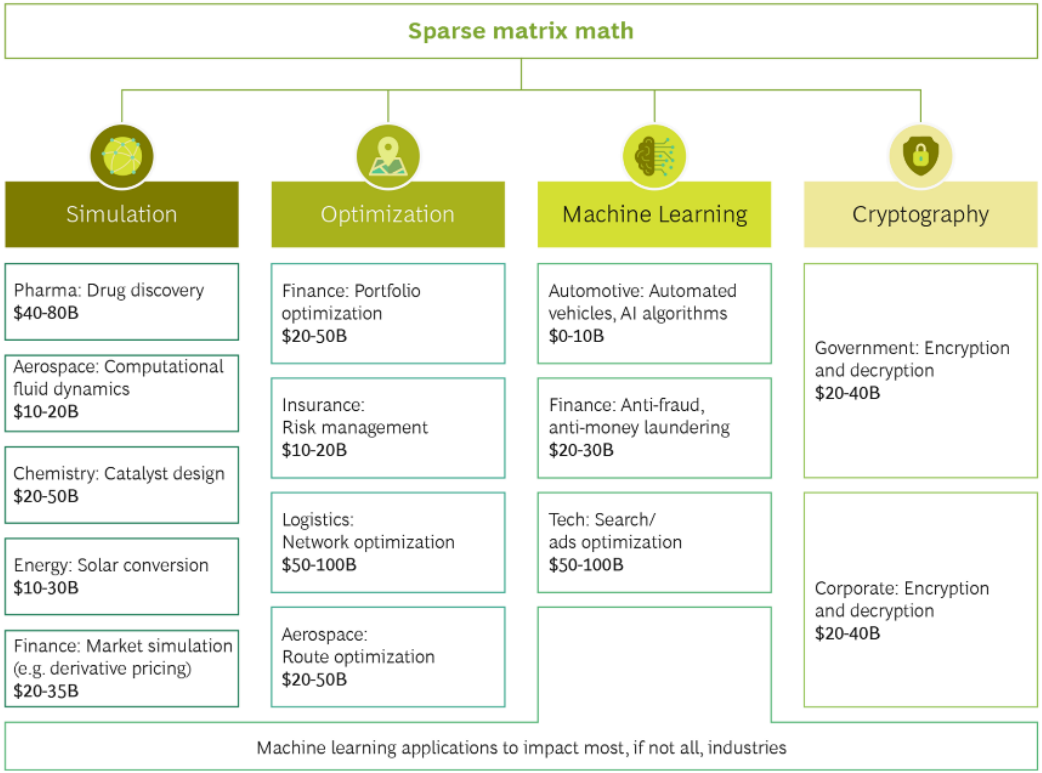
Aerospace
Automotive
Chemistry
Climate change
Defense and aerospace
Energy
Finance
Healthcare
Insurance
Intelligence service
Logistics
Pharma
Transportation

Le top 15 – la vision de BCG

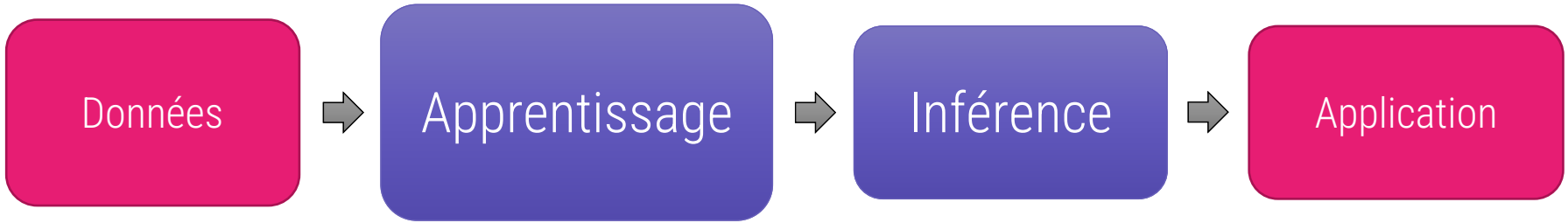
1 Quantum-advantaged mathematical function

4 Computational problem types

100+ High-value industry use cases
*Sizing at tech maturity

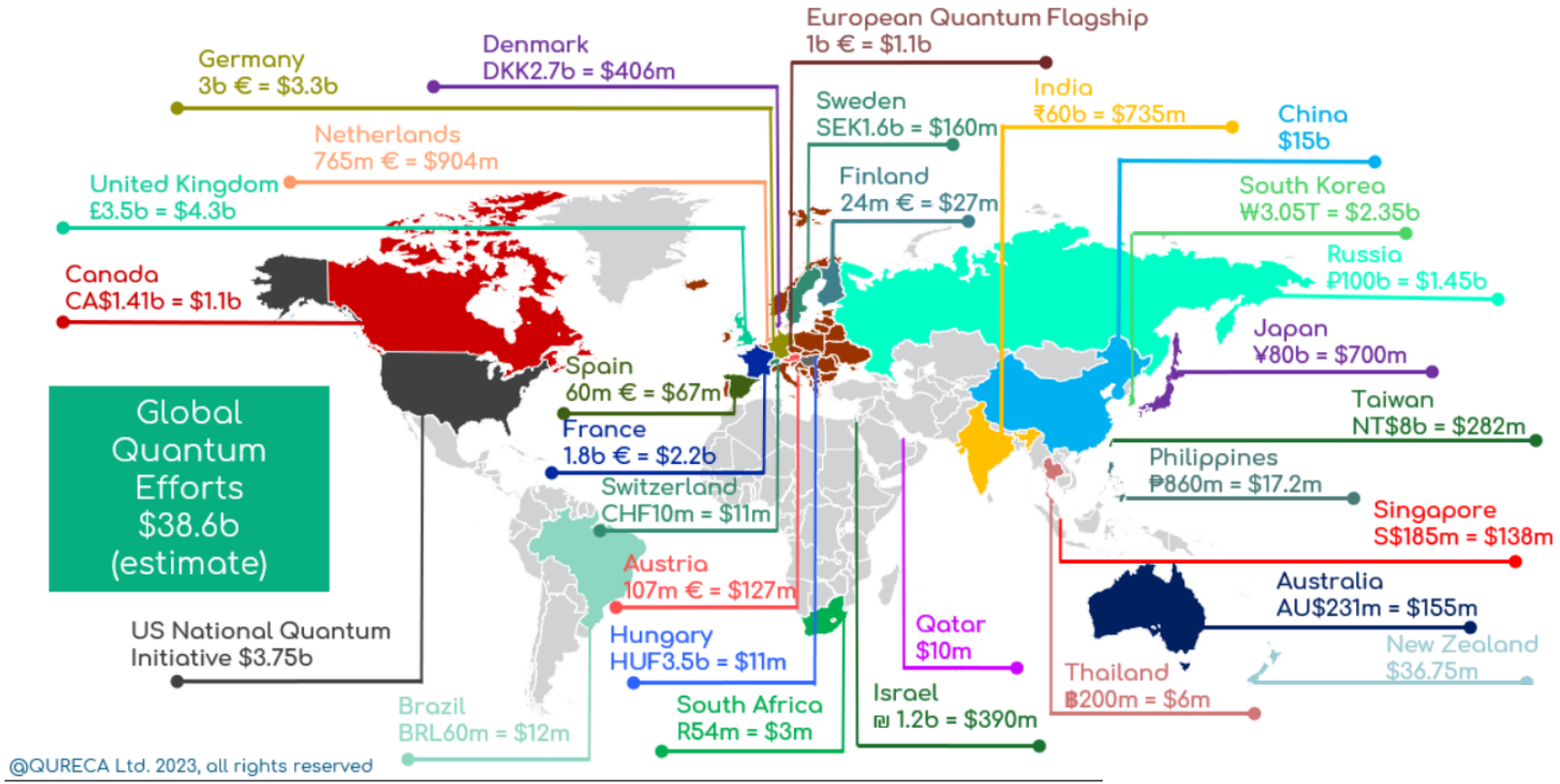


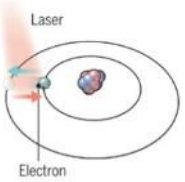
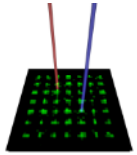
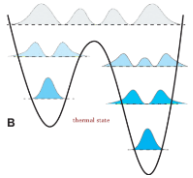
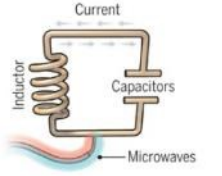
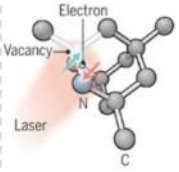
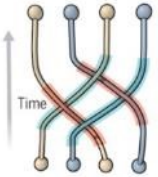
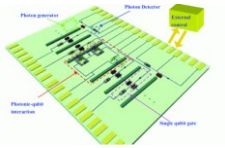
Le Quantique et l'IA ?



Q4 – Le monde, la position de la France ?

Les investissements mondiaux

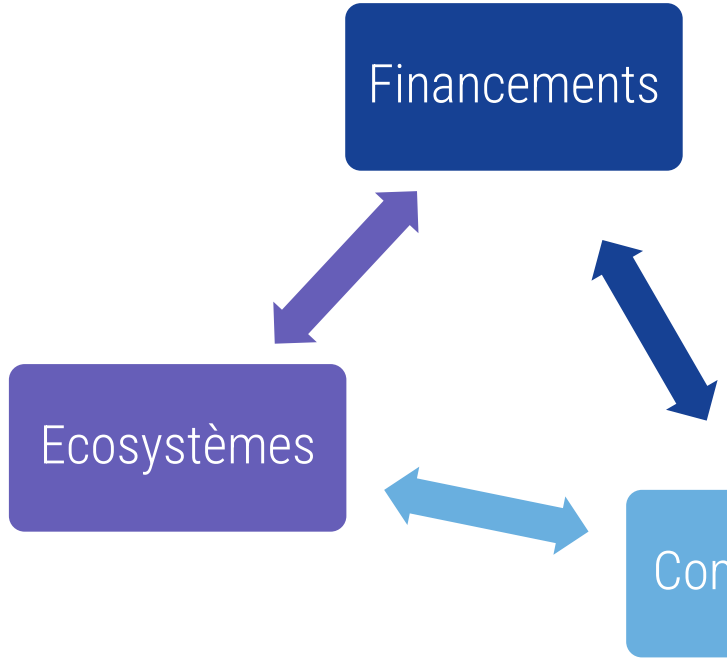


atoms		electron *superconducting loops & controlled spin*					photons
							
trapped ions	**cold atoms**	**quantum annealing**	**super-conducting**	**silicon**	**spin vacancies**	**topological**	**photons**
QUANTINUUM IONQ AQT OXFORD IONICS eleQtron FOXCONN	PASQAL ColdQuanta ATOM COMPUTING QuEra COMPUTING INC. planqc	D-Wave The Quantum Computing Company QILIMANJARO QUANTUM TECH NEC	IBM rigetti amazon Google OQC qci Nord Quantique OXFORD QUANTUM IQM ALICE & BOB ANYON Alibaba Origin Quantum EeroQ Baidu 百度 bleximo FUJITSU	C12 intel Silicon Quantum Computing diraq equal1.labs QUANTUM MOTION ARCHER	TURING QUANTUM BRILLIANCE photonic XEED The Quantum Transcendence	Microsoft NOKIA	PsiQuantum XANADU ORCA Computing QUANDELA Wooson DUALITY QuiX QUANTUM BardeenQ QCi Ready-to-Run Quantum Systems TUNDRA SYSTEMS GLOBAL
IQST MIT KIT IQI universität innsbruck Sandia National Laboratories JGU NIST JOHANNES GUTENBERG UNIVERSITÄT MAINZ HARVARD UNIVERSITY US UNIVERSITY OF SUSSEX	cnrs INSTITUT d'OPTIQUE GRADUATE SCHOOL HARVARD UNIVERSITY Caltech JÜLICH Forschungszentrum PennState EPFL THE OHIO STATE UNIVERSITY	NEDO Stanford University MIT KIT MCQST ETH zürich (*) non exhaustive inventory, missing Chinese labs among others	cea cnrs MIT Inria UCSB QuTech UMassAmherst MCQST ETH zürich UNIVERSITÄT DES SAARLANDES Berkeley Yale UNIVERSITY OF CALIFORNIA Caltech 東京大学 THE UNIVERSITY OF TOKYO	cea cnrs University of BRISTOL UNIVERSITY OF OXFORD UNSW SYDNEY Yale HRL LABORATORIES ETH zürich THE UNIVERSITY OF WISCONSIN MADISON EPFL RIKEN PRINCETON UNIVERSITY NTT QuTech	cea cnrs MIT UNIVERSITY OF MARYLAND TU Delft HARVARD UNIVERSITY Universität Stuttgart THE UNIVERSITY OF CHICAGO	cea cnrs UNIVERSITY OF MARYLAND UCSB TU Delft QuTech Niels Bohr Institutet THE UNIVERSITY OF SYDNEY	cnrs University of BRISTOL UNIVERSITY OF OXFORD SAPIENZA Università di Roma UNIVERSITÄT DES SAARLANDES universität wien 東京大学 THE UNIVERSITY OF TOKYO

vendors

labs (*)

Les enjeux …



Institutionnel
Capital Risque
Commande publique
…

HW / SW
R&D / Industriels
Technologie / Métier

Physique Q.
Calcul Q.
Technologies H.

entreprises de l'offre quantique

computing

PASQAL

ALICE & BOB

CRYSTAL QUANTUM COMPUTING

QUANDELA

Atos

software

Qubit pharmaceuticals

Atos

QuantFi

QbitSoft Quantum as a Service

VeriQloud

ColibriTD

AQEMIA

cybersecurity

CRYPTONEXT SECURITY

CRYPTO EXPERTS

ravel

SECURE-IC THE SECURITY SCIENCE COMPANY

(cc) Olivier Ezratty, 2022 Mise à jour 2024

sensing

THALES

iXblue PHOTONICS

wainvam

Syrlinks

orolia

chipiron

MAG 4He alth

photonics

cailabs SHAPING THE LIGHT

Lytid

iXblue PHOTONICS

SPARK LASERS

LUMIBIRD MORE THAN LASERS

AUREA TECHNOLOGY

AZURLIGHT SYSTEMS

GLOphotonics

QUANDELA

cryogeny

Air Liquide

CryoConcept

ABSOLUT SYSTEM

MYCRYOFIRM CRYOGENIC SOLUTIONS

electronics

SILENT WAVES

WeLinQ

Radiall

ATEM

SILENTSYS

manufacturing

PLASSYS

RIBER

isotopes

orano

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Mise à jour 2023

quantum computing cloud offerings

emulation

computing

hybrid computing centers

OVHcloud | IBM | aws | Microsoft | Google

40 qubits
Atos

hybrid quantum

TGCC

JÜLICH

LUMI

in 2023

Atos — 36 qubits | 34-50 qubits | 30 qubits | 40 qubits

PASQAL

QUANDELA

...

IBM
5 to 127 qubits

D:WAVE
5000 qubits

PASQAL
100 qubits (q. simulation)

IONQ
32 qubits

IONQ
32 qubits

IONQ
11 qubits

rigetti
80 qubits

rigetti
80 qubits

et aussi...

D:WAVE
QCWARE
XANADU
Quantum Inspire - By QuTech

OQC
8 qubits (**)

QUANTINUUM
12 qubits

QuEra COMPUTING INC.
XANADU

Q5 –Quobly …

WHY USE SEMICONDUCTORS FOR QUANTUM COMPUTING?

1 SCALABILITY.

Potential for leveraging CMOS technology to produce millions of qubits

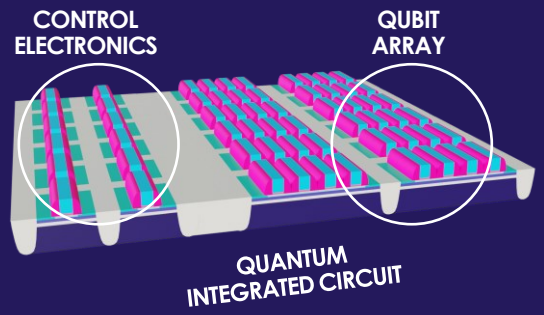
2 QUALITY.

Potential for producing excellent qubits

Low footprint (100nm2) / Speed of operation (~usec) / Fidelity (>99%)

3 ENERGY EFFICIENCY.

Energy-efficient way to control & program multicore qubit architectures



*FDSOI is a low power silicon technology developed in collaboration with ST, CEA and IBM and produced in ST (Crolles, France) and GF (Dresden, Germany)

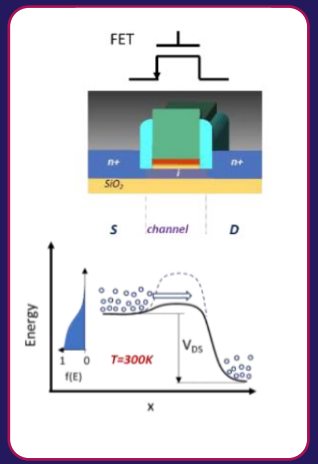
SILICON COMPETITION

A handful of players have identified the scaling potential of semiconductors

TRANSISTORS AND QUBITS ARE ALIKE BUT DIFFERENT

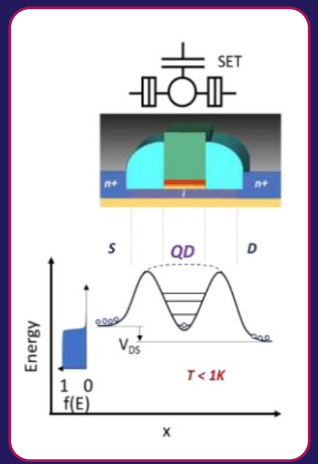
TRANSISTOR

- Room T
- Lots of charges



QUBIT

- Low T
- Single charge



HOW TO WIN THE RACE

1 - Start from and customize **existing standard technologies** - FDSOI* technology has a competitive advantage

2 – Leverage our longstanding **relationships with semiconductor ecosystems**

*FDSOI is a low power silicon technology developed in collaboration with ST, CEA and IBM and produced by ST (Crolles, France)

OUR ECOSYSTEM

CRYOWIRES & CONNECTORS

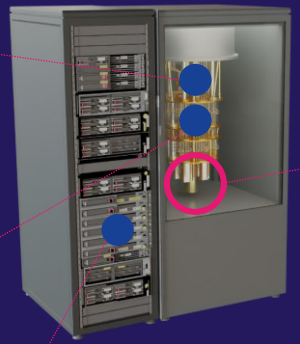
cnrs Radiall

CRYOSTATS

cnrs ABSOLUT SYSTEM CryoConcept Air Liquide

CLOUD ACCESS AND SW

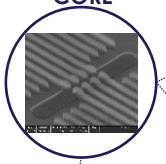
OVHcloud aws EVIDEN

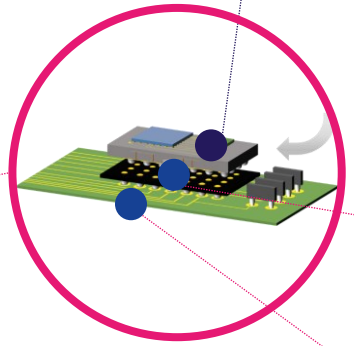


cea cnrs

Universal quantum server

QUANTUM CORE





Fully-integrated quantum processor

SUBSTRATES

cea soitec Air Liquide orano

DEVICE PERFORMANCE ARRAY ARCHITECTURE

cea cnrs GlobalFoundries

CRYO CONTROL ELECTRONICS

cea cnrs GlobalFoundries

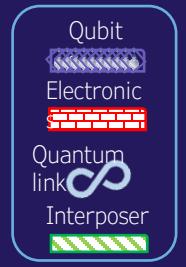
PACKAGING

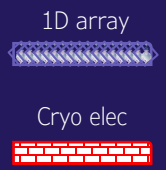
cea

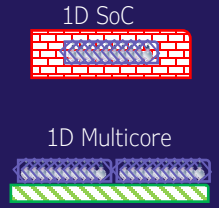
OTHER STAKEHOLDERS

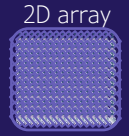
QuantAlps MINALOGIC France Quantum conference le lab quantique #QEI the quantum energy initiative

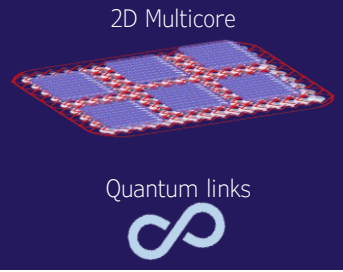
TECHNOLOGY AND BUSINESS ROADMAP

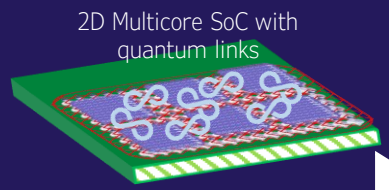












2023

2035+

Remote access

Gen1
HW PoC for prefered partners
Digital twin

PoV with end users

Working 100 qubits

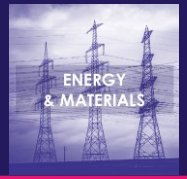
Noisy quantum systems

On premise – QaaS

Quantum advantage PoV

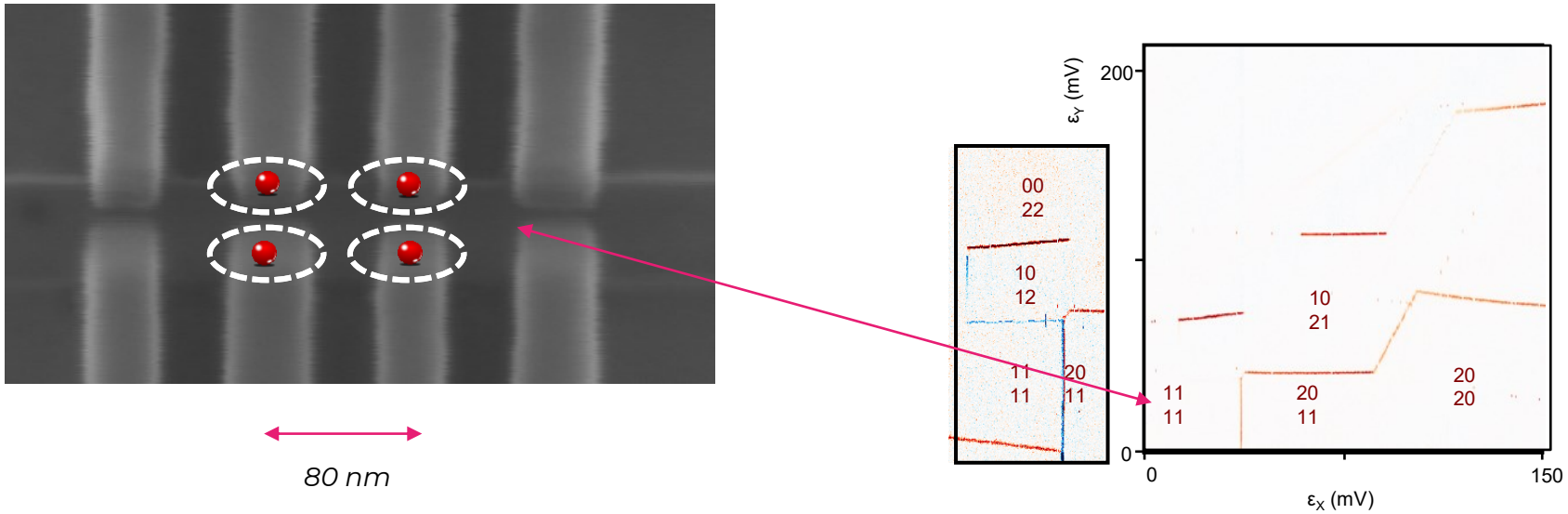
1000 logical qubits

Large scale quantum computing robust to errors



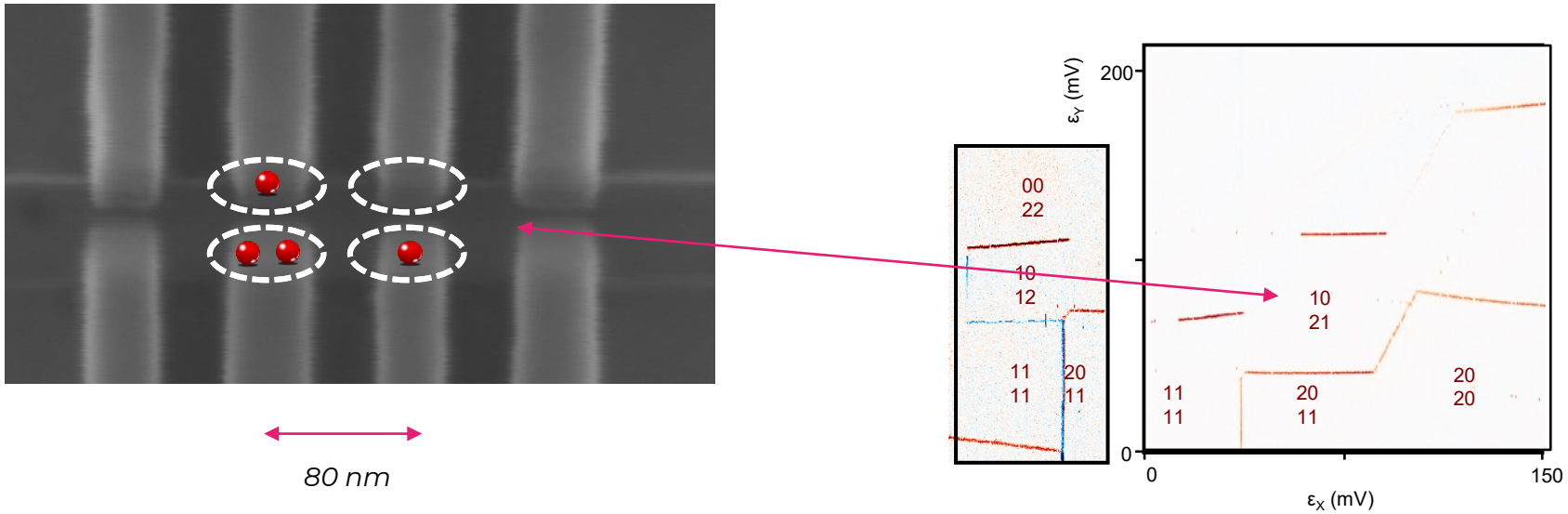
Vers la seconde revolution quantique

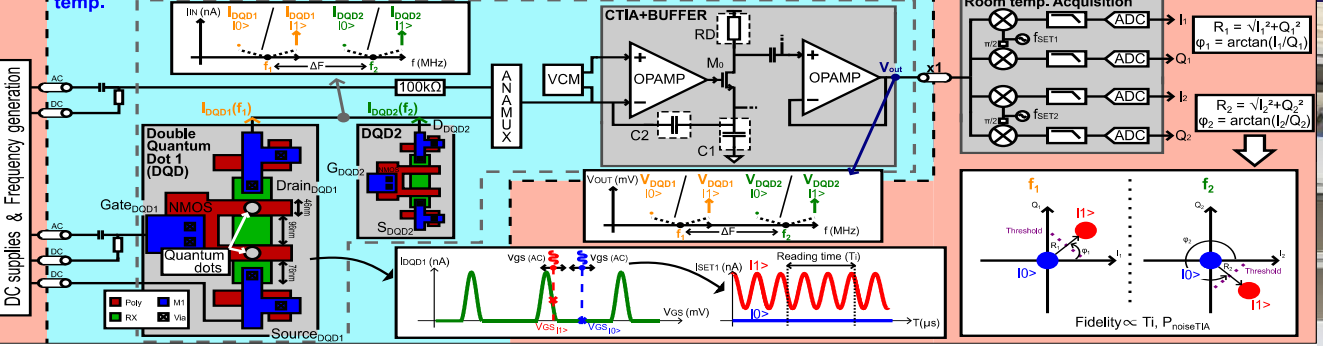
Des effets à “une particule quantique”

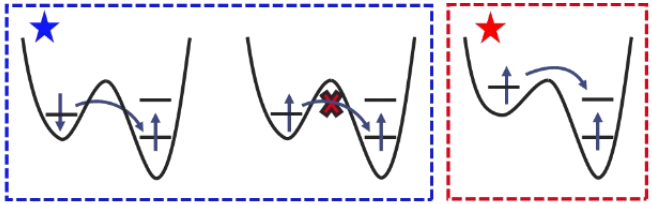


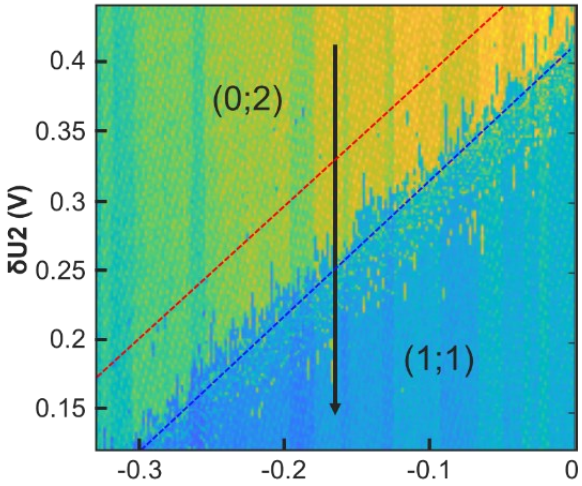
Vers la seconde revolution quantique

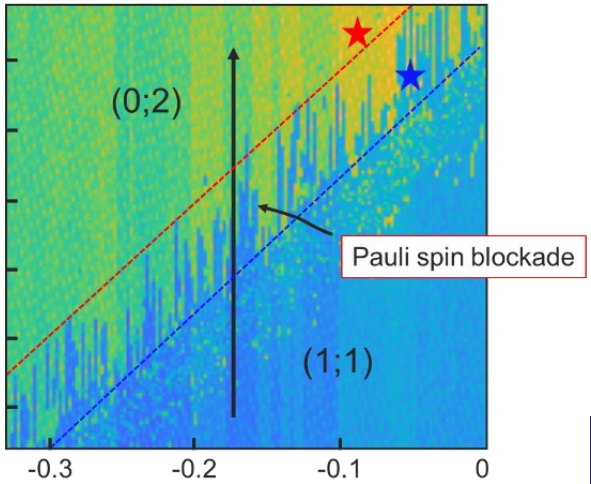
Des effets à “une particule quantique”

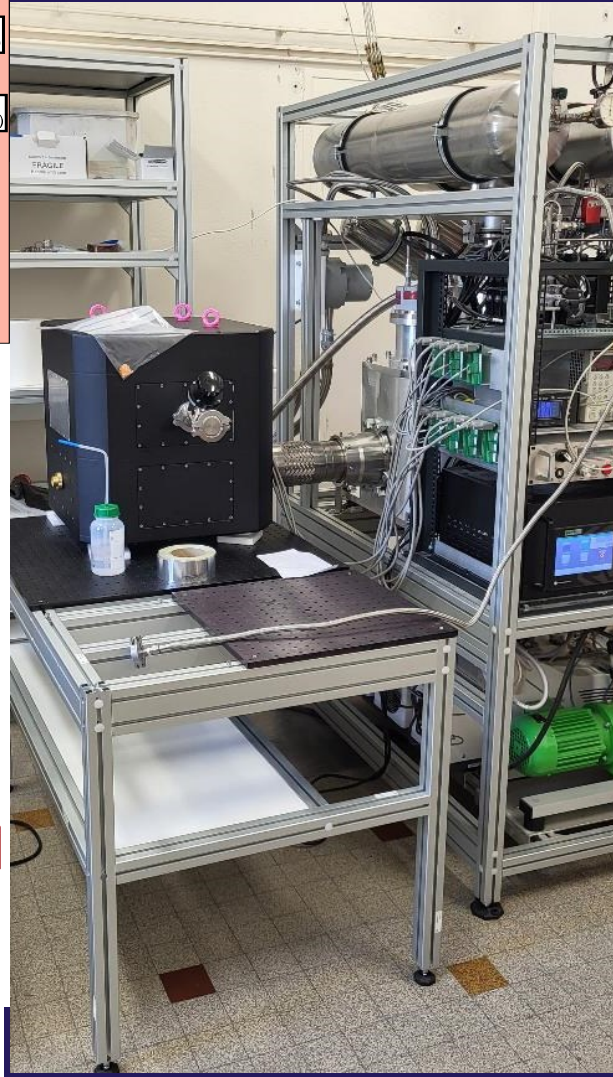



temp.
DC supplies & Frequency generation
CTIA+BUFFER
OPAMP
OPAMP
RD
C2
C1
VCM
100kΩ
ANAMUX
Double Quantum Dot 1 (DQD)
DQD2
Gate
NMOS
Drain
Quantum dots
Source
Poly
RX
M1
Via
Room temp. Acquisition
ADC
Reading time (Ti)
Fidelity∝ Ti, P noiseTIA
Threshold




(0;2)
(1;1)
δU2 (V)
0.4
0.35
0.3
0.25
0.2
0.15
-0.3
-0.2
-0.1
0


(0;2)
(1;1)
Pauli spin blockade
-0.3
-0.2
-0.1
0



CONCLUSION

Le calcul Quantique offre une potentielle révolution du calcul.

Toute l'industrie est potentiellement concernée.

La question aujourd'hui est comment passer à l'échelle après les premières demonstrations.

La France est très bien positionnée en termes de diversité des technologies et d'acteurs sur la chaîne de la valeur.

Quobly s'appuie sur l'industrie du semiconducteur pour proposer une roadmap jusqu'au million de bits quantiques.

An ambitious vision for quantum computing.

A VIABLE PLAN FOR BRINGING IT TO LIFE.

FABRIQUÉ EN FRANCE


Thank
You
Vinaka
köszönöm
Kiitos
Maake
Asante
Shukria
Dhanyavadagalu
Manana
Dankon
Kam Sah Hammida
감사합니다
Dank Je
Mauruuru
Biyan
Matondo
Blagodaram
Dziekuje
Chokrane
Tack
Grazie
Juspaxar
Arigato
Mochchakkeram
Gracias
Tingki
Grazas
cảm ơn bạn
Gratias Tibi
Ua Tsaug Rau Koj
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Kia Ora
ありがとう
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Hvala
Welalin
Djiere Dieuf
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Misaotra
Danke
Go Raibh Maith Agat
Eskerrik Asko
Merci
Salamat
Najis Tuke