SEMICON® TAIWAN

Europe and France quantum technologies ecosystems

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⟨ quantum technologies author ⟩

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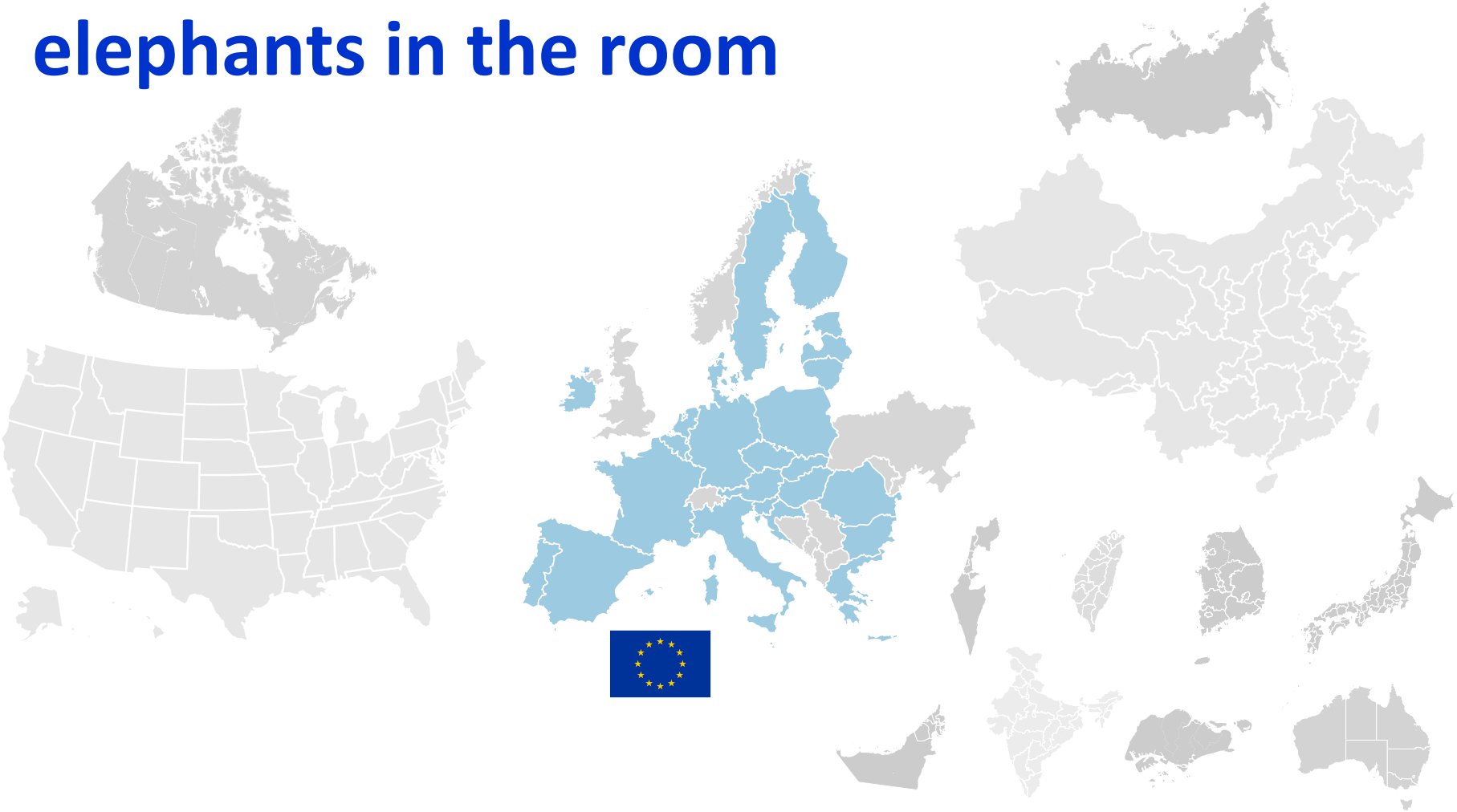
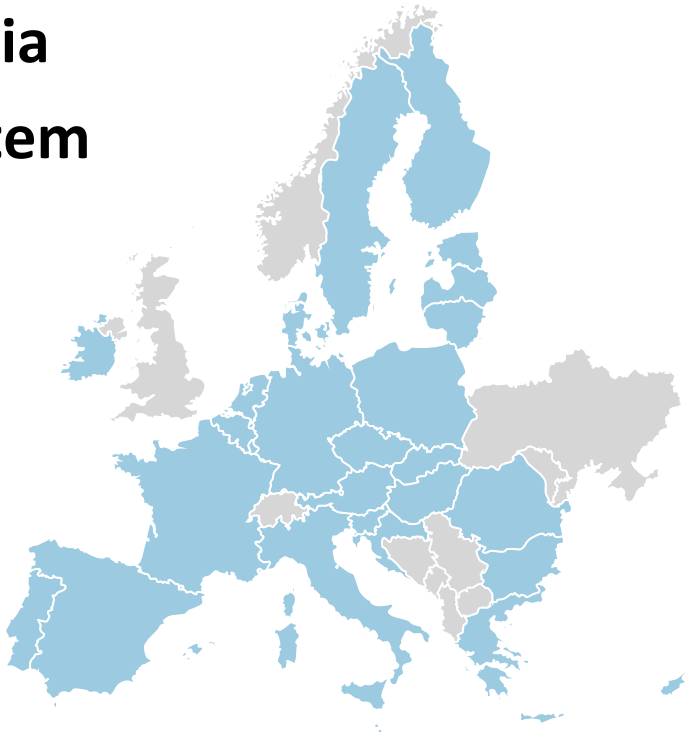
Semicon Taiwan – Quantum Taiwan Forum, Taipei, September 6th,2023

elephants in the room



what makes EU* unique in quantum

1. **strong public research and academia**
2. **dynamic quantum industry ecosystem**
3. **enabling technologies leadership**
4. **HPC and early pilot projects**
5. **responsible innovation**



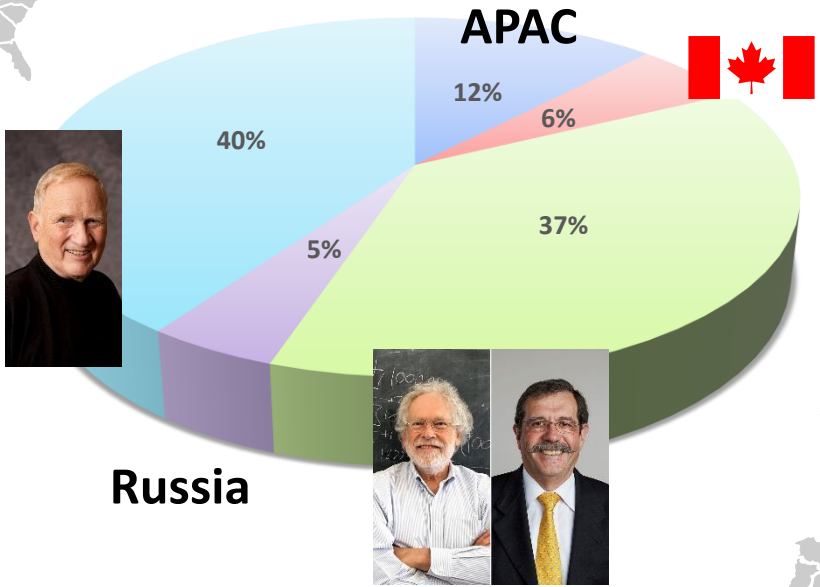
* adding UK and Switzerland when convenient

public research and academia

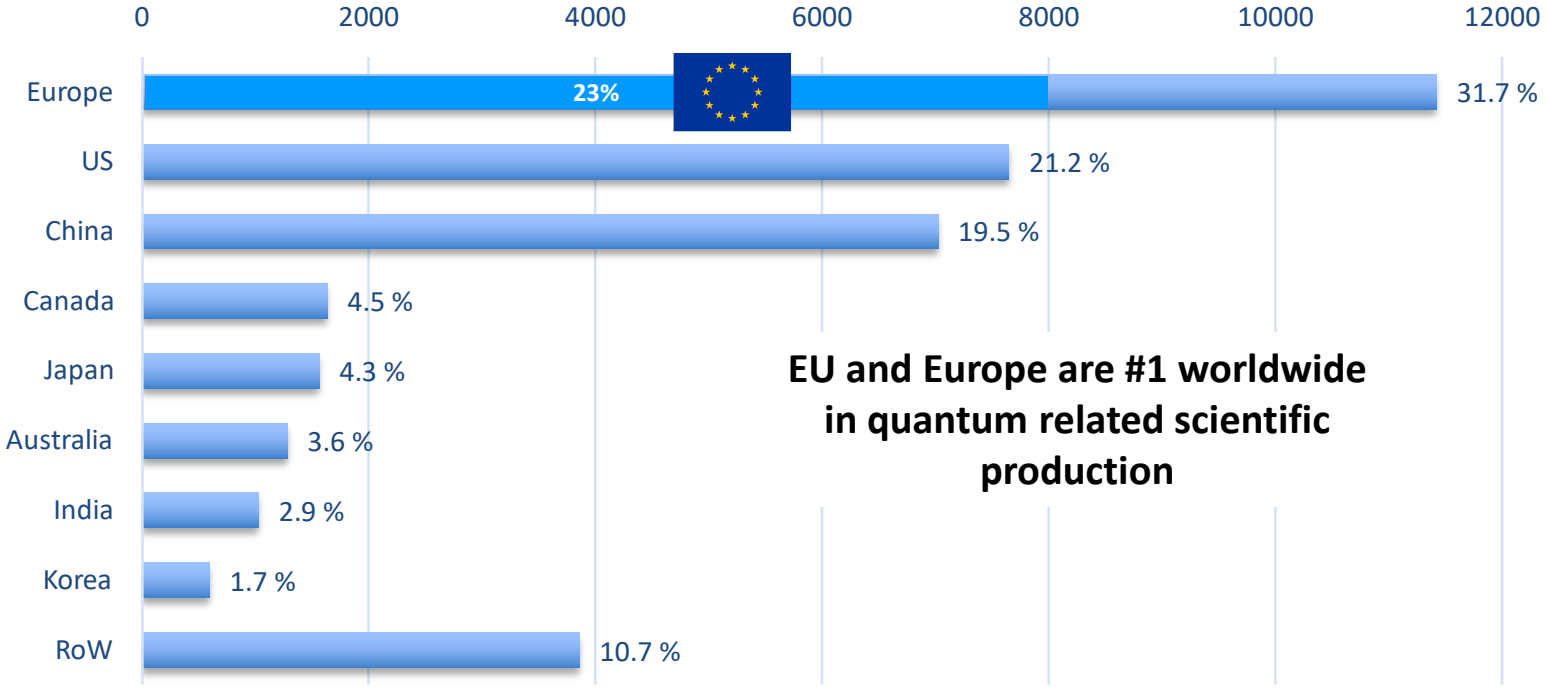
Nobel prizes in physics

share of Nobel prizes in physics since 1980

LTD Europe share is 46% (103 / 222)



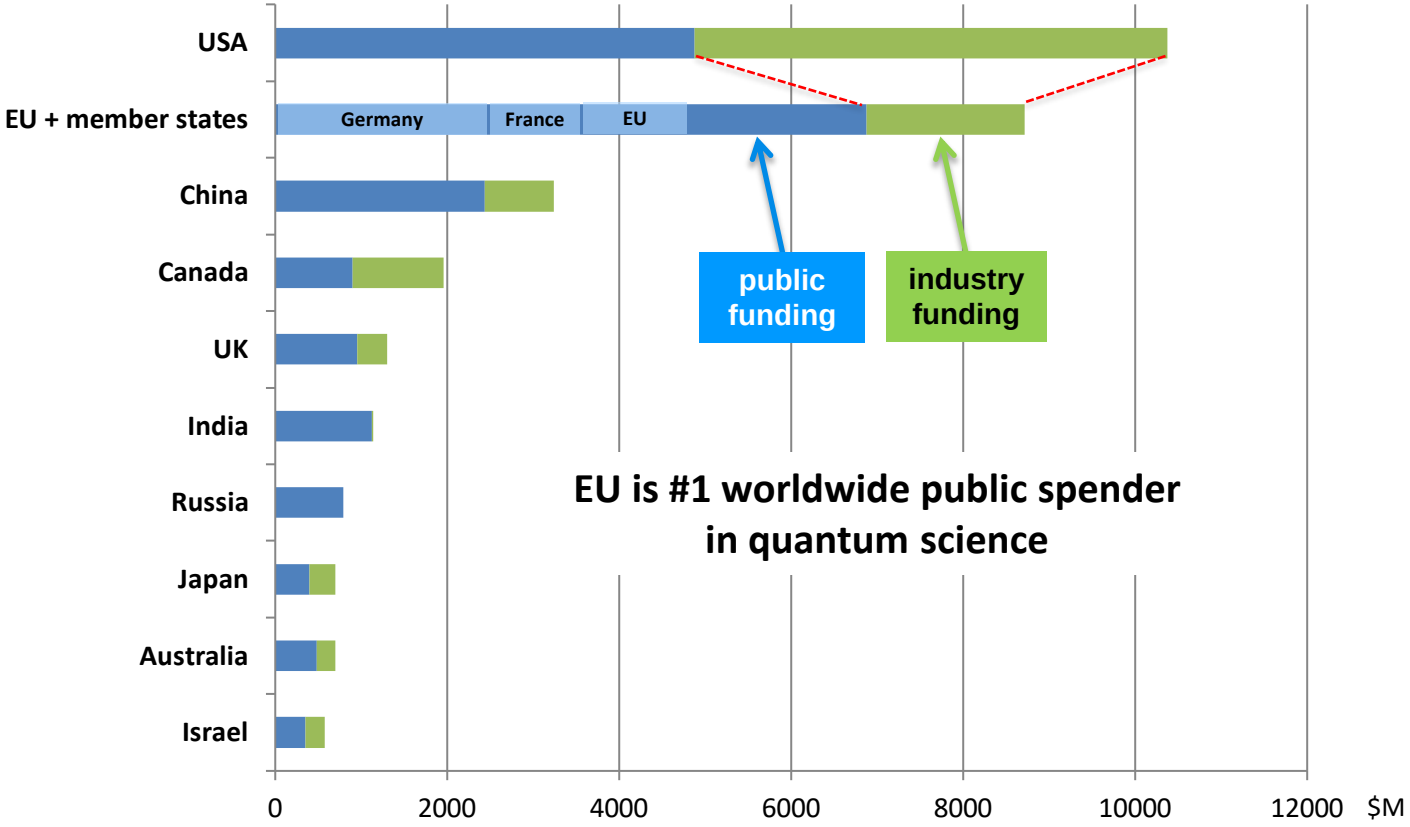
Breakdown of scientific publications by country of origin over the period 2010 - 2020



EU and Europe are #1 worldwide in quantum related scientific production

Quantum technologies: patent applications vs. scientific publications across the world by Sébastien Ragot and Michel Kurek, November 2021

global investments in quantum



source: Olivier Ezratty compilation, September 2023, on a 5-year period, past, present or future depending on the country. Euro/$ parity.

computers

- OpenSuperQPlus — superconducting qubits
- ATION — trapped ion qubits
- microQC — trapped ion qubits
- QLSI — silicon qubits
- QUANTUM FLAGSHIP — **European Flagship Quantum Technologies > 1B€ over 10 years**

simulators

- Qombs — cold atoms
- PASQuanS2 — cold atoms and trapped ions
- PhoQuS (Photons for Quantum Simulation) — photons
- SQUARE — trapped ions (simulation and universal QC)

software

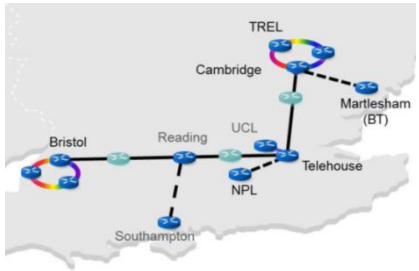
- NE|AS|QC — software applications

telecoms

- QIA QUANTUM INTERNET ALLIANCE — repeater network, interface with qubits
- CiViQ — QKD on photonics, telcos
- UNIQORN (Affordable Quantum Communication for Everyone) — system on chip
- QMiCS — IPC micro-waves
- QRANGE — QRNG, CMOS SPADs
- S2QUIP — photonic
- 2D-SIPC — photonic

sensing

- ASTERIQS — NV centers
- MetaboliQs — IRM & NV centers
- macQsimal — cold atoms
- iqClock — optical clock
- PhoG — photons



Netherlands
Delft, Leiden, Amsterdam, The Hague OpenQKD project 2019

Germany
QKD project, 165M€
2019-*

Tchekia
OpenQKD project
2019

Poznan
2021

Denmark
Dantze Bank
DTU
2022

Ireland
2022

Cambridge – London - Bristol 2018

Ile de France
2020-*
OpenQKD project

Nice/Sophia
2020
3 sites

Madrid
2018
Telefonica & Huawei

Canaries
2007/2010
144 km free to air

Barcelona
2020

(cc) Olivier Ezratty, 2022-2023

Vienna
2008
SECOQC, 5 nodes, 20/25 km

Geneva
1993, 1995, 2007, 2018 (400 km)

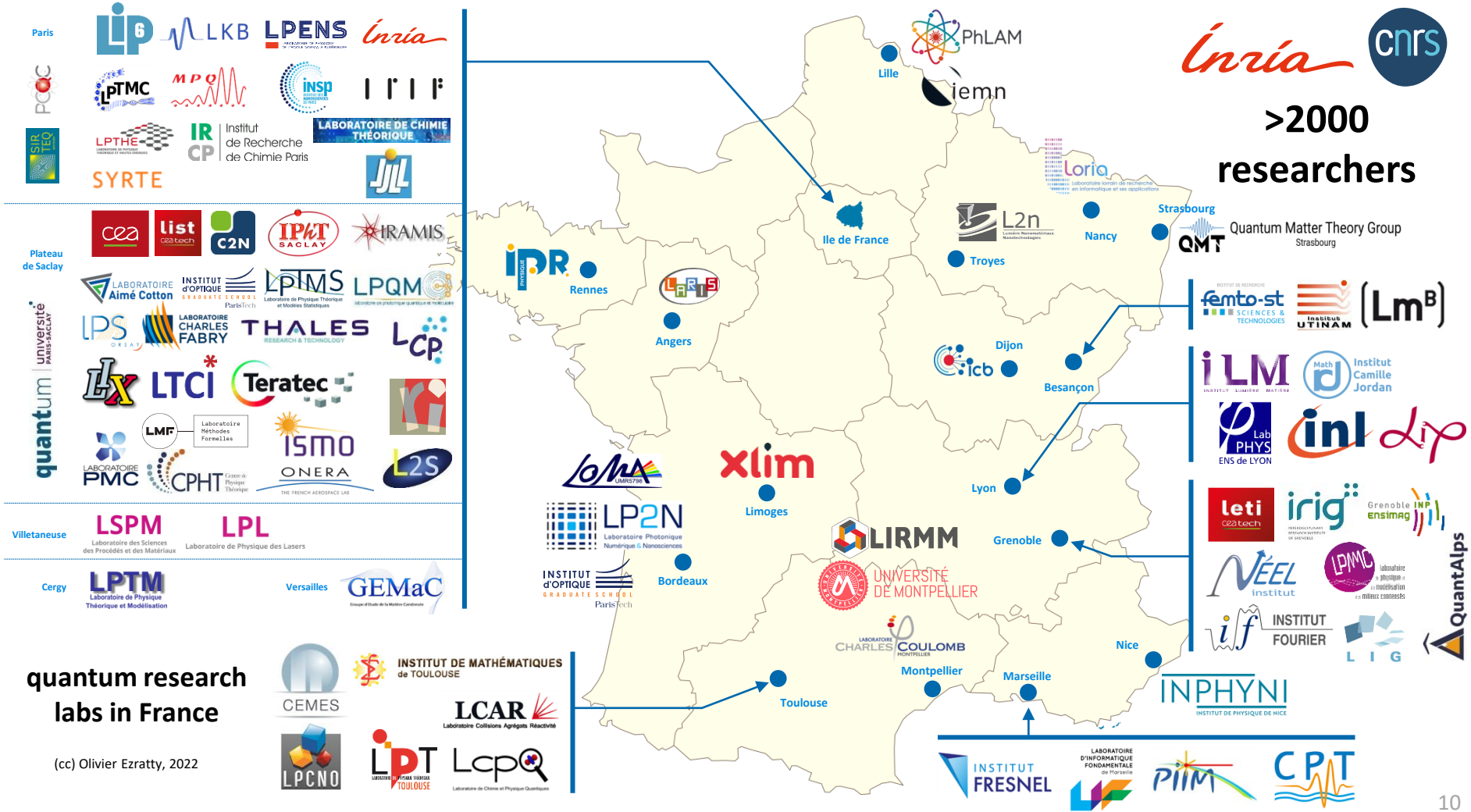
Italy-Slovenia-Croatia network

Italian Quantum Backbone (IQB) 1,850 km QKD link connects Turin, Milan, Bologna, …, a 150 km fiber reaches Modane in France, and connects to Grenoble, Lyon and Paris, then Europe + Padua satellite/ground QKD experiment

Athens
2019
OpenQKD project DataCom

quantum research labs in France

(cc) Olivier Ezratty, 2022



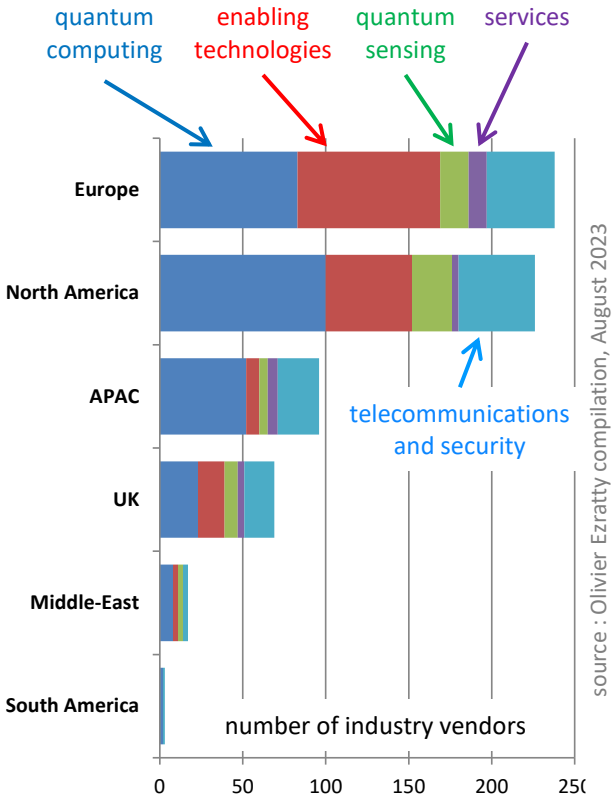
dynamic quantum industry ecosystem

quantum industry vendors per country

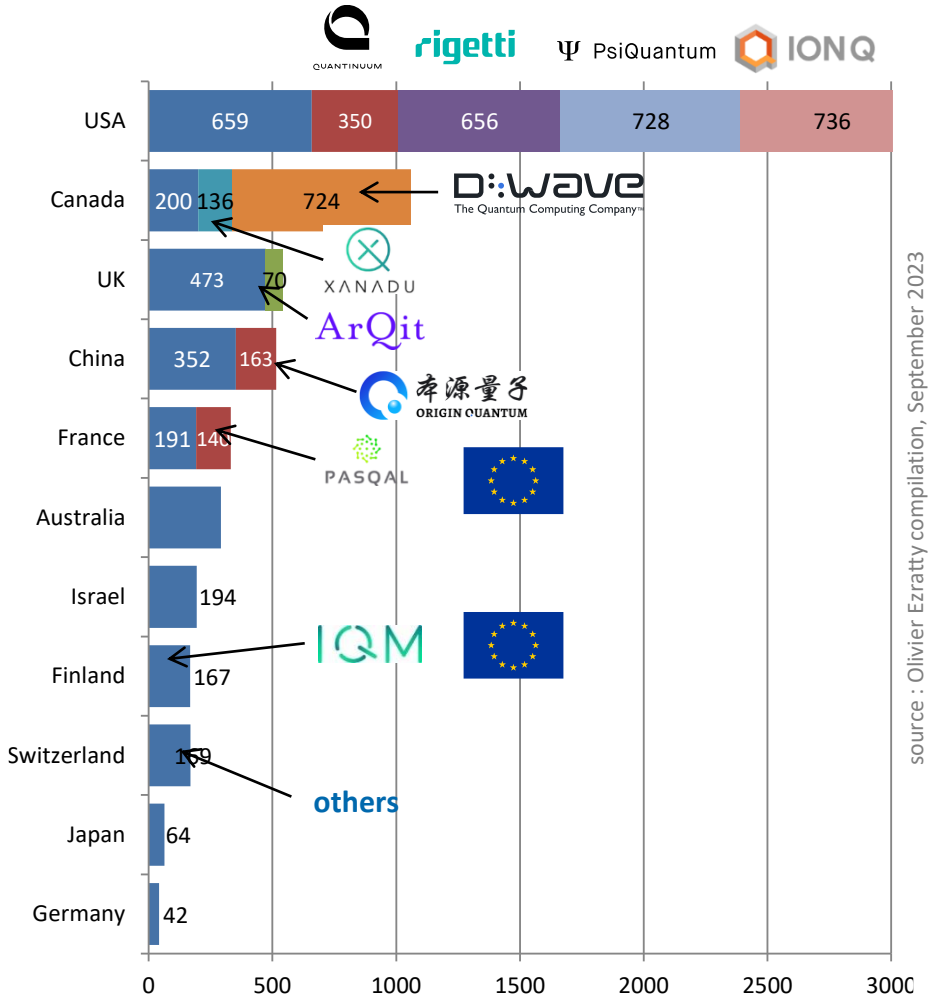
Country	Computing	Enabling	Sensing	Services	Comm - Sec	Total
USA	67	44	19	4	32	166
UK	23	16	8	5	19	71
France	14	29	10	4	6	63
Canada	33	8	5		14	60
Germany	24	20	4	1	7	56
Japan	13	7		1	4	25
China	11		2		10	23
India	13			3	5	21
Switzerland	4	9	1		5	19
Netherlands	7	4	1	1	3	16
Spain	8	3			2	13
Finland	5	3		2	3	13
Israel	5	2	2		3	12
Australia	6		3	1	2	12
Italy	3	3	1	1	3	11
Denmark	3	6			2	11
Singapore	6	1	1	1	1	10
Sweden	2	4				6
Russia		2			4	6
Poland	3				2	5
South-Korea	2				3	5
Taiwan	1	1			2	4
Austria	3				1	4
Tchekia				1	1	2
UAE	2					2
Turkey		1	1			2
Bulgaria	1				1	2
Belgium		2				2
Hong-Kong	2					2
Estonia	2					2
Greece	2					2
Lybia	1					1
Chile					1	1
Ukraine	1					1
Bielorussia	1					1
Luxembourg		1				1
Uruguay	1					1
Norway	1					1
Columbia	1					1
Total	**271**	**166**	**58**	**25**	**136**	**656**

source : Olivier Ezratty compilation, September 2023

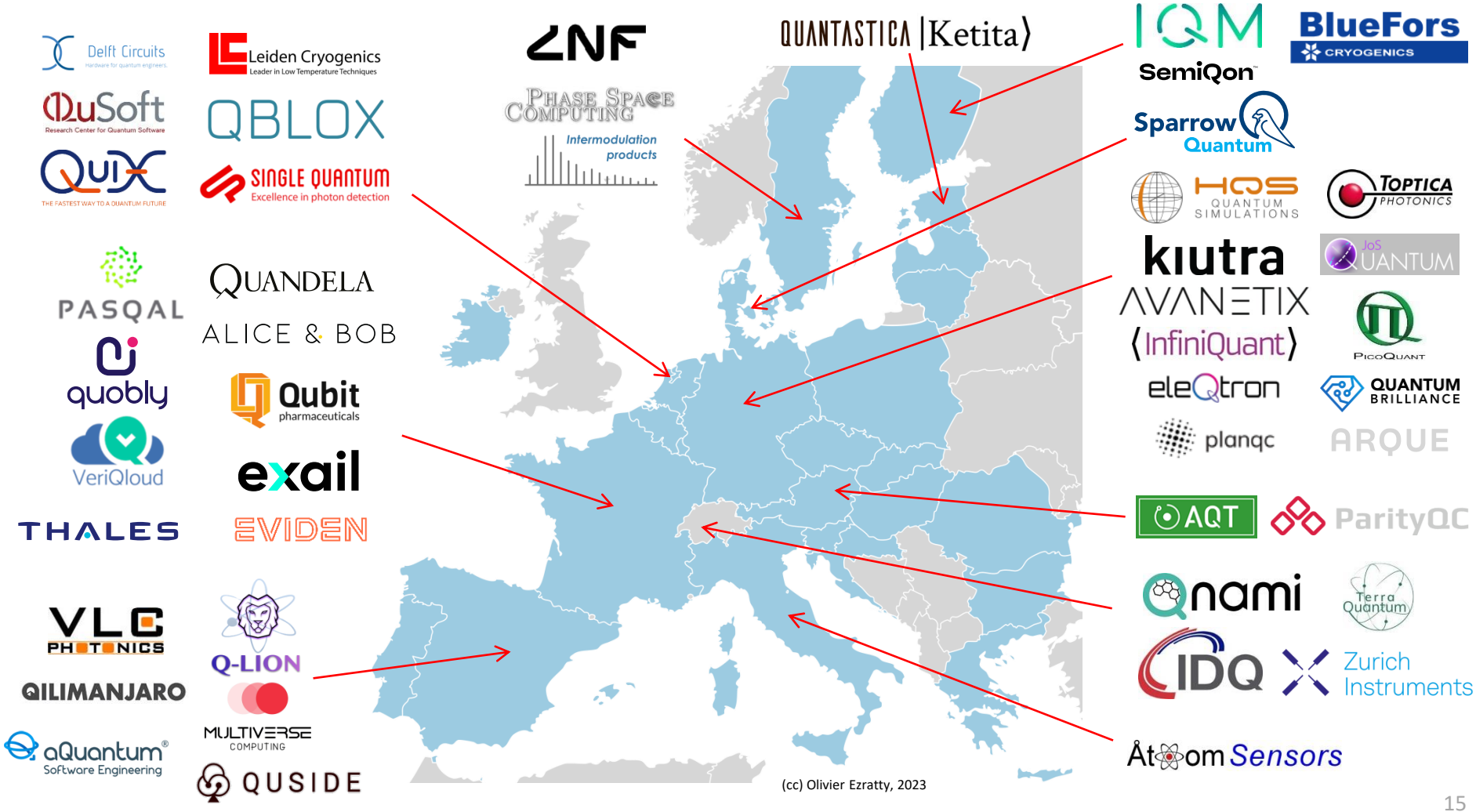
Europe is #1 in number of industry vendors in quantum technologies with a stronger hold on enabling technologies



Europe businesses got 10.5% of the capital funding vs 64% in North America with an equivalent number of companies



as of August 2023 the top 10 quantum startups got 58.5% of worldwide startups (visible) funding including two from Europe


Delft Circuits
Hardware for quantum engineers.
Leiden Cryogenics
Leader in Low Temperature Techniques
ZNF
QUANTASTICA |Ketita⟩
IQM
SemiQon
BlueFors
CRYOGENICS
QuSoft
Research Center for Quantum Software
QBLOX
Phase Space Computing
Intermodulation products
Sparrow Quantum
QuiX
THE FASTEST WAY TO A QUANTUM FUTURE
SINGLE QUANTUM
Excellence in photon detection
HQS
QUANTUM SIMULATIONS
TOPTICA PHOTONICS
PASQAL
QUANDELA
ALICE & BOB
kiutra
JoS QUANTUM
AVANETIX
⟨InfiniQuant⟩
PicoQuant
quobly
Qubit pharmaceuticals
eleQtron
QUANTUM BRILLIANCE
VeriQloud
exail
planqc
ARQUE
THALES
EVIDEN
AQT
ParityQC
Qnami
Terra Quantum
VLC PHOTONICS
Q-LION
IDQ
Zurich Instruments
QILIMANJARO
MULTIVERSE COMPUTING
aQuantum®
Software Engineering
QUSIDE
Atom Sensors
(cc) Olivier Ezratty, 2023

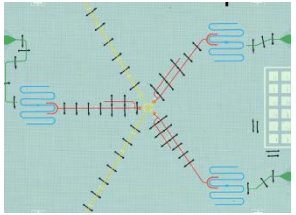
atoms		electron *superconducting & spins*					photons
trapped ions	cold atoms	quantum annealing	super-conducting	silicon	NV centers	topological	photons
🇺🇸 🇹🇼	🇺🇸	🇨🇦	🇺🇸 🇨🇳	🇺🇸	🇺🇸	🇺🇸	🇺🇸 🇨🇳 🇨🇦
🇪🇺 🇦🇹 🇩🇪	🇫🇷 🇩🇪	🇪🇸	🇫🇮 🇫🇷 🇩🇪	🇳🇱 🇫🇷 🇩🇪	🇳🇱 🇩🇪	🇳🇱	🇮🇹 🇫🇷 🇩🇪
🇬🇧			🇬🇧	🇬🇧 🇦🇺	🇦🇺		🇬🇧
		🇯🇵	🇯🇵				

strong research in the qubit type and/or major startup or established IT company in the domain

(cc) Olivier Ezratty, 2023

first quantum computers in EU

IQM

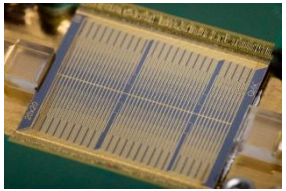


superconducting

AQT

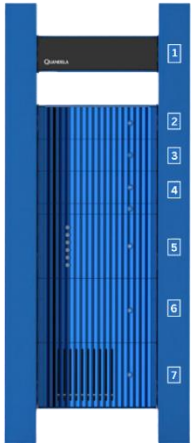
trapped ions

QuiX QUANTUM



photons

QUANDELA



photons

PASQAL

cold atoms

OpenSuperQPlus

ATION

QUDOT-TECH

PASQuanS2

industry vendors ecosystem

computing

- PASQAL
- ALICE & BOB
- 12
- quobly
- QUANDELA
- CRYSTAL QUANTUM COMPUTING
- EVIDEN an atos business

software

- Qubit pharmaceuticals
- EVIDEN an atos business
- QuantFi
- mol|ket
- QPerfect
- QbitSoft Quantum as a Service
- VeriQloud
- COLIBRITD
- AQEMIA

cybersecurity

- CRYPTONEXT SECURITY
- CRYPTO EXPERTS
- ravel
- SECURE-IC THE SECURITY SCIENCE COMPANY
- CYFERALL

sensing

- THALES
- exail
- wainvam
- Syrlinks
- orolia
- chipiron
- MAG4Health

photonics

- cailabs SHAPING THE LIGHT
- Lytid
- exail
- SPARK LASERS
- LUMIBIRD MORE THAN LASERS
- AUREA TECHNOLOGY
- AZURLIGHT SYSTEMS
- GLOphotonics
- QUANDELA

cryogeny

- Air Liquide
- CryoConcept
- ABSOLUT SYSTEM INNOVATIVE SOLUTIONS
- MYCRYOFIRM CRYOGENIC SOLUTIONS

electronics

- SILENT WAVES
- Viathor
- Welinq
- Radiall
- ATEM
- SILENTSYS ultralow noise systems

manufacturing

- PLASSYS
- RIBER

materials

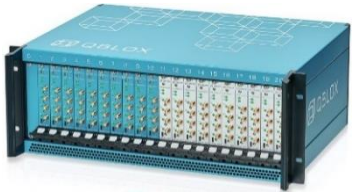
- orano
- HIQUTE DIAMOND

(cc) Olivier Ezratty, 2023

enabling technologies leadership

TOPTICA PHOTONICS

SINGLE QUANTUM

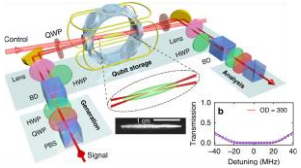


QBLOX

Zurich Instruments

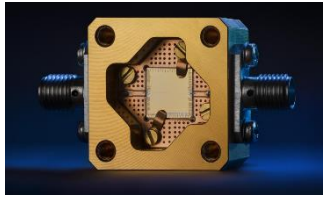
Delft Circuits
Hardware for quantum engineers.

Sparrow Quantum



Welinq

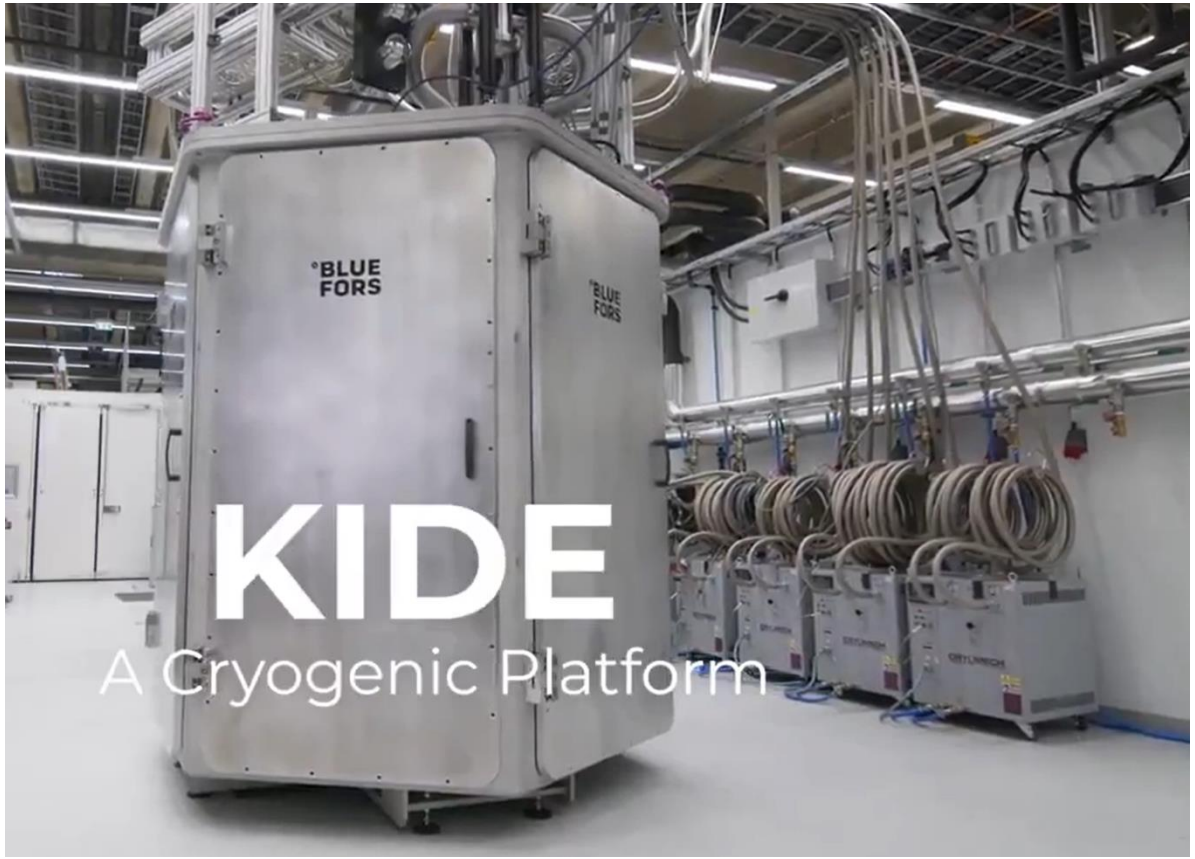
Radiall



SILENT WAVES

ZNF

Bluefors KIDE



Bluefors is #1 worldwide vendor of low temperature cryostats

dilutions

BLUEFORS

IBM

rigetti

cea

FormFactor™

seeqc

OXFORD INSTRUMENTS

Microsoft

D:wave
The Quantum Computing Company™

CryoConcept
an Air Liquide affiliate

NÉEL institut

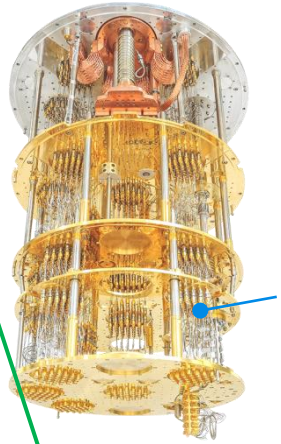
LPENS
LABORATOIRE DE PHYSIQUE DE L'ÉCOLE NORMALE SUPÉRIEURE

Leiden Cryogenics
Leader in Low Temperature Techniques

IBM

Maybell

DARPA



cabling and connectors

COAX CO., LTD.

Delft Circuits
Hardware for quantum engineers

Radiall™

ATEM
customized connectivity

pulse tubes and compressors

CRYOMECH

Sumitomo
(SHI) Cryogenics of America, Inc.

fabs

Fraunhofer IPMS
Fraunhofer IPM
JÜLICH Forschungszentrum
PTB
Leibniz ipht Leibniz Institute of Photonic Technology
ISTA Institute of Science and Technology Austria
cnrs
cea
myfab
VTT
ICFO
ETH zürich
EPFL
TU Delft
polifab Politecnico di Milano

research fabs

mostly small fabs, superconducting electronics and III/V

leti cea tech
imec
Fraunhofer IPMS

pre-industry research fabs

infineon
LionIX International
OMMIC innovating with III-V'S

foundry vendors

IQM
THALES

in-house vendor fabs

with 300 mm wafers capabilities in many cases

(cc) Olivier Ezratty, 2023

hybrid HPC/quantum computing and early pilot projects

EuroHPC
Joint Undertaking

⟨HPC|OS⟩

quantum emulator appliances

Eviden Qaptiva / Atos QLM
emulates up to 40 qubits with full state vector and 20 qubits with density matrices

+ simulation/annealing emulation

+ QPU drive

A density-matrix renormalization group algorithm for simulating quantum circuits with a finite fidelity

Thomas Ayral,[1] Thibaud Louvet,[2] Yiqing Zhou,[3] Cyprien Lambert,[1] E. Miles Stoudenmire,[4] and Xavier Waintal[2]
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[2] *PHELIQS, Université Grenoble Alpes, CEA, Grenoble INP, IRIG, Grenoble 38000, France*
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(Dated: August 30, 2022)

We develop a density-matrix renormalization group (DMRG) algorithm for the simulation of quantum circuits. This algorithm can be seen as the extension of time-dependent DMRG from the usual situation of hermitian Hamiltonian matrices to quantum circuits defined by unitary matrices. For small circuit depths, the technique is exact and equivalent to other matrix product state (MPS) based techniques. For larger depths, it becomes approximate in exchange for an exponential speed up in computational time. Like an actual quantum computer, the quality of the DMRG results is characterized by a finite fidelity. However, unlike a quantum computer, the fidelity depends strongly on the quantum circuit considered. For the most difficult possible circuit for this technique, the so-called "quantum supremacy" benchmark of Google Inc. [1], we find that the DMRG algorithm can generate bit strings of the same quality as the seminal Google experiment on a single computing core. For a more structured circuit used for combinatorial optimization (Quantum Approximate Optimization Algorithm or QAOA), we find a drastic improvement of the DMRG results with error rates dropping by a factor of 100 compared with random quantum circuits. Our results suggest that the current bottleneck of quantum computers is their fidelities rather than the number of qubits.

https://arxiv.org/abs/2207.05612

EVIDEN
an atos business

Europe early evaluation examples

Financial Risk Management on a Neutral Atom Quantum Processor

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Achraf Seddik[8], Oumaima Hammami[8], Hacene Isselnane[8], and Didier M'tamon[8]
[8] *Crédit Agricole Corporate and Investment Bank, 12 Place des États-Unis, 92545 Montrouge, France*
(Dated: December 7, 2022)

Machine Learning models capable of handling the large datasets collected in the financial world can often become black boxes expensive to run. The quantum computing paradigm suggests new optimization techniques, that combined with classical algorithms, may deliver competitive, faster and more interpretable models. In this work we propose a quantum-enhanced machine learning solution for the prediction of credit rating downgrades, also known as fallen-angels forecasting in the financial risk management field. We implement this solution on a neutral atom Quantum Processing Unit with up to 60 qubits on a real-life dataset. We report competitive performances against the state-of-the-art Random Forest benchmark whilst our model achieves better interpretability and comparable training times. We examine how to improve performance in the near-term validating our ideas with Tensor Networks-based numerical simulations.

https://arxiv.org/abs/2212.03223

CRÉDIT AGRICOLE CORPORATE & INVESTMENT BANK

PASQAL MULTIVERSE

goal: predict « fallen angels », businesses who could fail in loans reimbursements.

data set: 20 years + 90 000 items with 150 features on 2000 companies in 10 verticals and 100 sub-verticals from 70 countries. 65 000 items in training data and 26 000 items for tests.

quantum advantage: could show up with 150 - 342 neutral atoms when compared to a best-in-class classical tensor network, 2,800 atoms for the more precise subsampling method.

responsible innovation

#QEI

the quantum energy initiative

quantum-energy-initiative.org

343 community participants from 45 countries & 29 partners

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a Physical Review journal

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Perspective Open Access

Quantum Technologies Need a Quantum Energy Initiative

Alexia Auffèves
PRX Quantum **3**, 020101 – Published 1 June 2022

questions

- is there a **quantum energy advantage** vs classical computing as quantum processors scale up?
- how to avoid **energetic dead-ends** on the road to LSQ?

mission + goals

- create a new **transversal line of research** and collaborative projects.
- create a worldwide **community** working on this matter associating research and industry.
- create **optimization methodologies, frameworks** and **benchmarks** for quantum technologies, enabling technologies and software engineering,

Quantum Delta
Nederland

Action Line 4: Societal impact

Why?

- To make the Netherlands "Quantum Ready" attention is needed for the ethical, legal and societal aspects of quantum technology.
- Opportunity to engage society and create ground rules for safe and sustainable use of QT. NL can play an international pioneering role to address these aspects early on.

How?

- Collaboration in the quadruple helix – science, industry, government and society, and evidence-based interventions, are at the heart of the ELSA action line.
- The Living Lab QT and Society builds on research collaborations between universities, the public and private sector and is based in the House of Quantum.

What?

- A Living Lab QT and Society with two new interdisciplinary university positions.
- A desk that guides questions from society and industry with a practical toolkit for responsible innovation and entrepreneurship.
- Covenant signed by private and public entities for sustainable and safe use of QT.

Budget
20M€

Milestones

2021
Living Lab QT and Society founded

2025
Covenant for ethical and sustainable use of QT

hardware stacks

electronics

power drain, signals quality and jitter, less cabling and signals multiplexing, readout data deluge, error correction cycle length and classical processing, laser power

qubit chipset

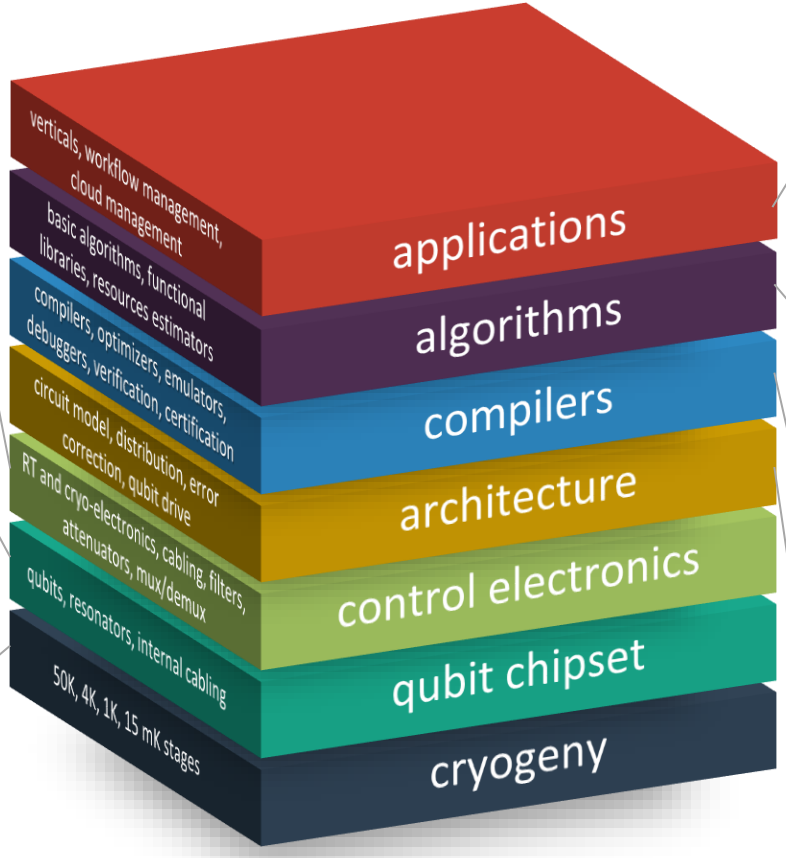
qubit fidelities, connectivity, gate and readout speed, materials, crosstalk, 3D stacking, deterministic photon source and detectors, production and testing cycle length

cryogeny

raw cryogeny cooling power, efficiency improvements, space capacity, cooling speedup

other key technologies

qRAM and quantum memory, QPU interconnect, energetics



blue =scientific challenge (« hard tech »)
black: technology challenge (« deep tech »)

software stacks

applications

addressed verticals, use case usefulness

algorithms

algorithms diversity, provable advantage, computing time, data frugality, multi-quantum paradigms support, hybrid algorithms, supporting real world data volumes

compilers and tools

languages abstraction level, transpilers and optimizer performance, hybrid computing drive, data loading performance

architecture

error correction codes efficiency, electronics signals data processing and bandwidth, cloud operations

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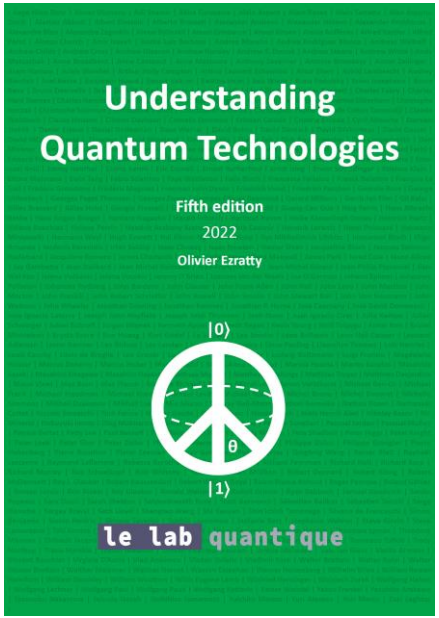
open knowledge sharing

coming end of September 2023



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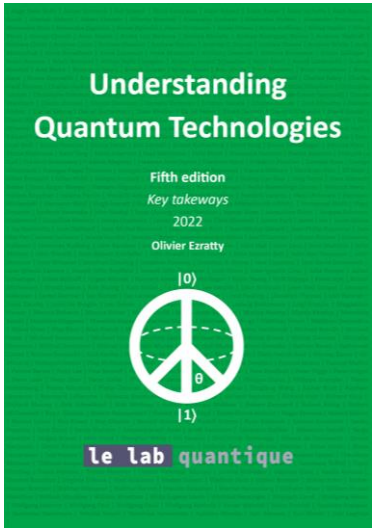

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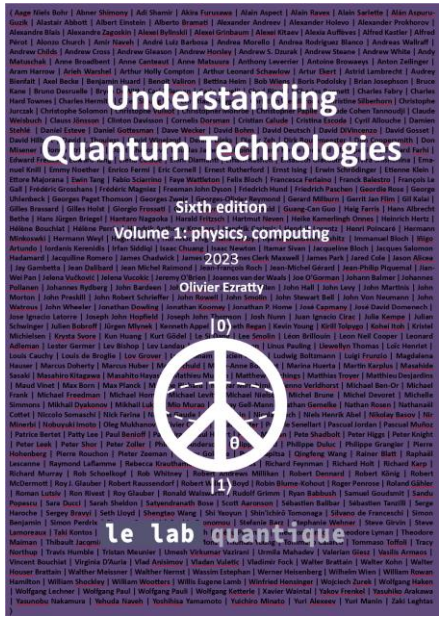

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thank you!