QUANDELA

Modular Optical Quantum Computing

available on the cloud

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CINECA – Bologna (IT)

60 people dedicated to Quantum Computing & Quantum Photonics

QUANDELA

Founded in 2017

- Paris-Saclay
- Munich
- Barcelona
- Rome

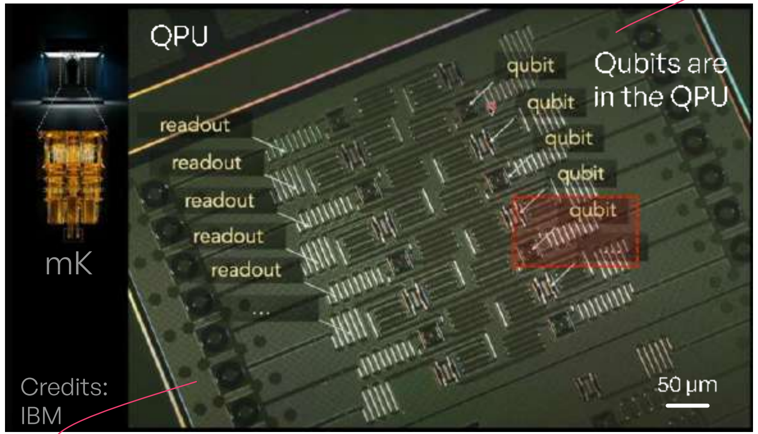
>40 PhDs and engineers in semiconductors, quantum information theory, quantum optical technologies and computer science

Digital Quantum Computing Approaches

1 Matter Qubits: Ions, Superconductors, Cold Atoms...

Static qubits: physically located in a QPU

Control Signals IN

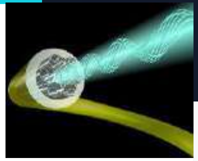


Read-OUT Signals

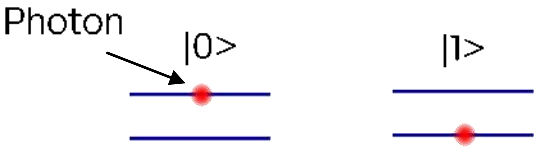
- **+** Highly EFFICIENT 2-qubit GATES (deterministic)
- **BUT** Qubits have a physical size → Manufacturability roadblocks
- **BUT** Each qubit undergoes DECOHERENCE → errors with #qubits

2 Photonic Qubits

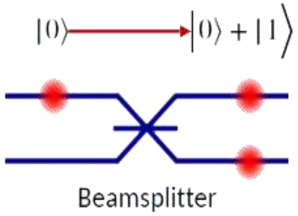
Photons are Flying Qubits → moving through the QPU and through optical fibers



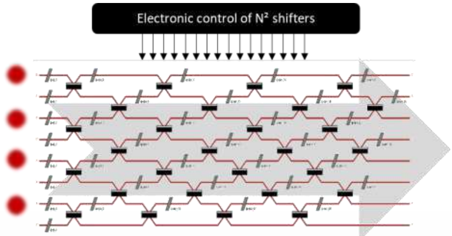
1 PHOTON IN 2 SPATIAL MODES (DUAL RAIL ENCODING)



ONE-QUBIT GATE



SEQUENCE OF N-QUBIT GATES

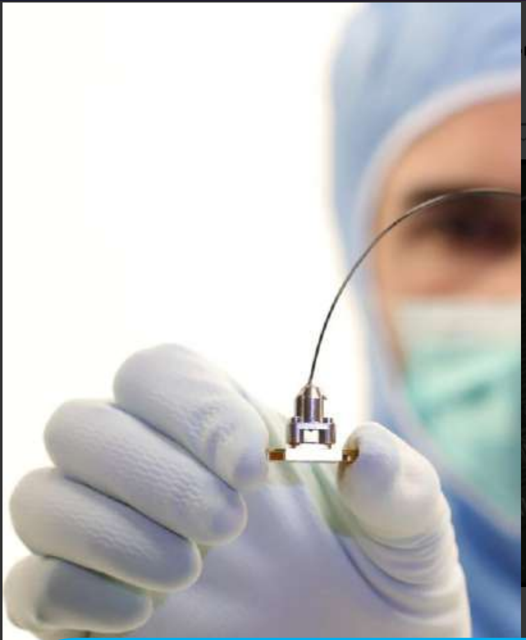


SUCCESS PROBABILITY << 50%

- **+** ROBUST qubits (no decoherence)
- **+** MANIPULATION with classical elements (telecom, linear optics)
- **BUT** 2-qubit GATES are NOT EFFICIENT (probabilistic) → HARD to scale

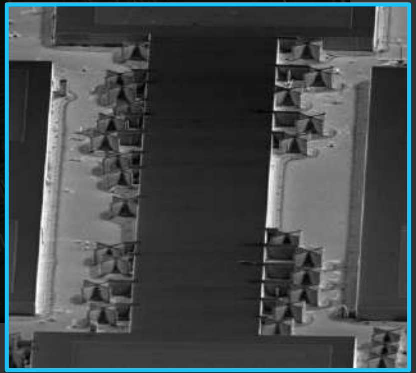
Quandela exploits the efficient manipulation of optical qubits but tackle probabilistic nature of gates with a matter-based qubit generator

1 & 2



cated in a QPU (fixed)

ontrol Signals IN



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ility roadblocks

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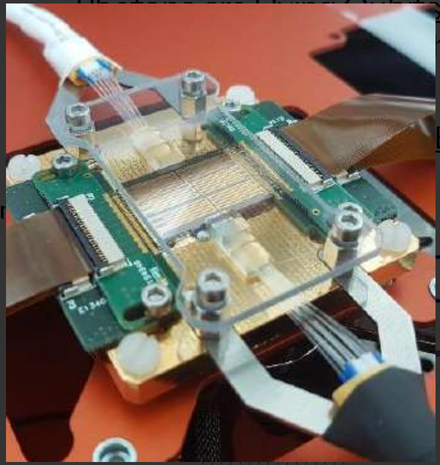
Photor

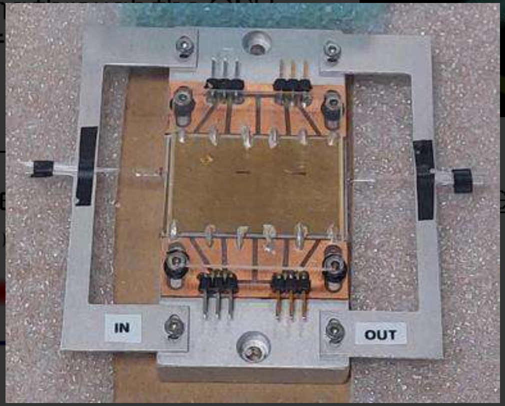
moving

optical f

ES (DUAL

ONE





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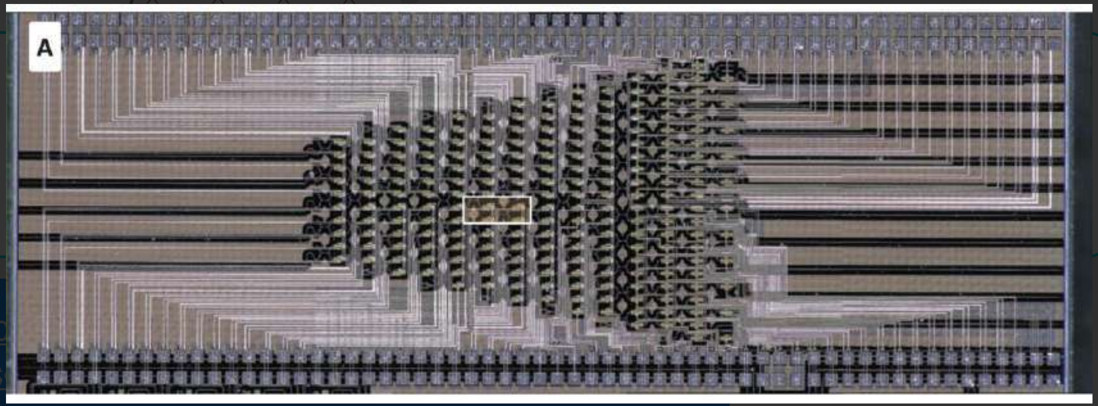


the efficient manipulation of op
of gates with a matter-bas

Scalability & manufacturability with Photonic Quantum Computers

Quandela's OS: classical control based on QC protocol + error correction

Feedback control ("FEED-FORWARD")

READ-OUT electronics

QPU

Input

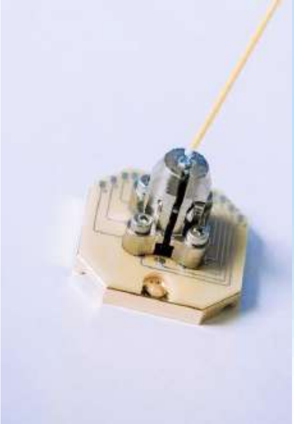
Qubit GENERATOR

Photons

Qubit MANIPULATION

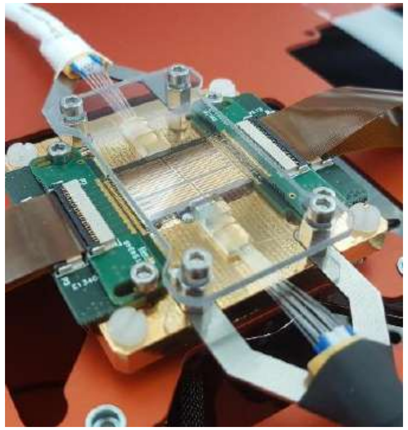
Photons

Qubit MEASUREMENT



→ 96 % *

→ 99.54 % purity **



→ 0.05 dB/cm

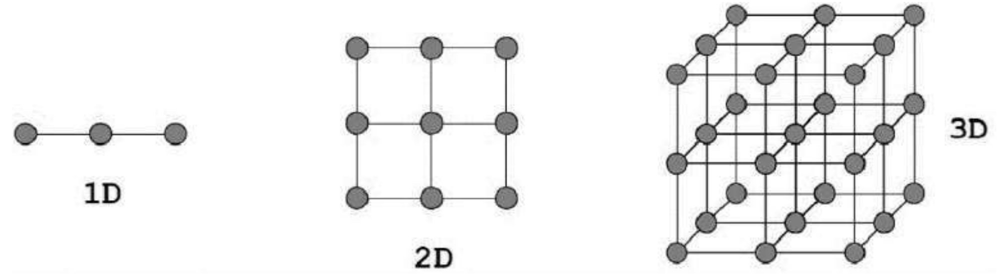
→ 99,9%

* "Micropillar single-photon source design with near-unity efficiency and indistinguishability": N. Gregersen, et al, Phys. Rev. B 102, 125301 (2020)

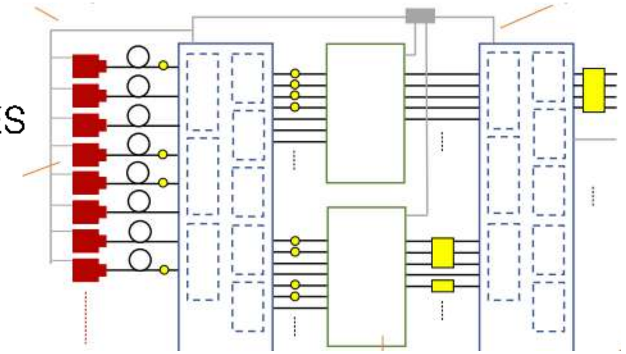
** "Near-optimal single-photon sources in the solid state": N. Somaschi at al, Nature Photonics, 10, 340,2016 -

Cluster states generation for FTQC

MBQCs PROTOCOL



LINEAR OPTICAL ELEMENTES
- PROBABILISTIC
- 1000s of COMPONENTS

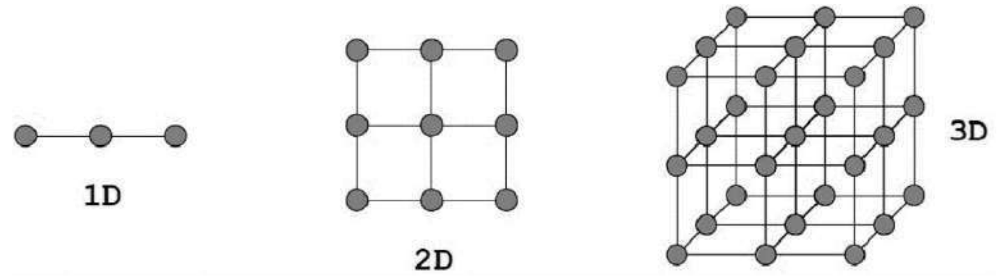


"Measurement-based quantum computation": H. Briegel at al, Nature Physics, 5, 19,2009
"Switching network for fusion based QC": S. Bertolucci, .. PSiQuantum arxiv:2109.13760

QUANDELA'S CLUSTER STATES GENERATOR

Cluster states generation for FTQC

MBQCs PROTOCOL



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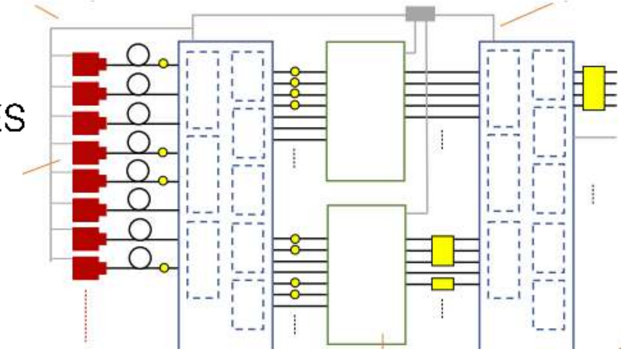

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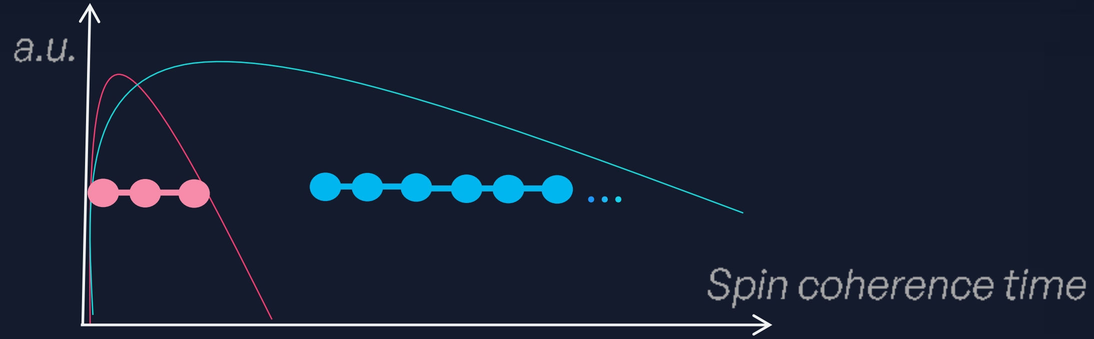
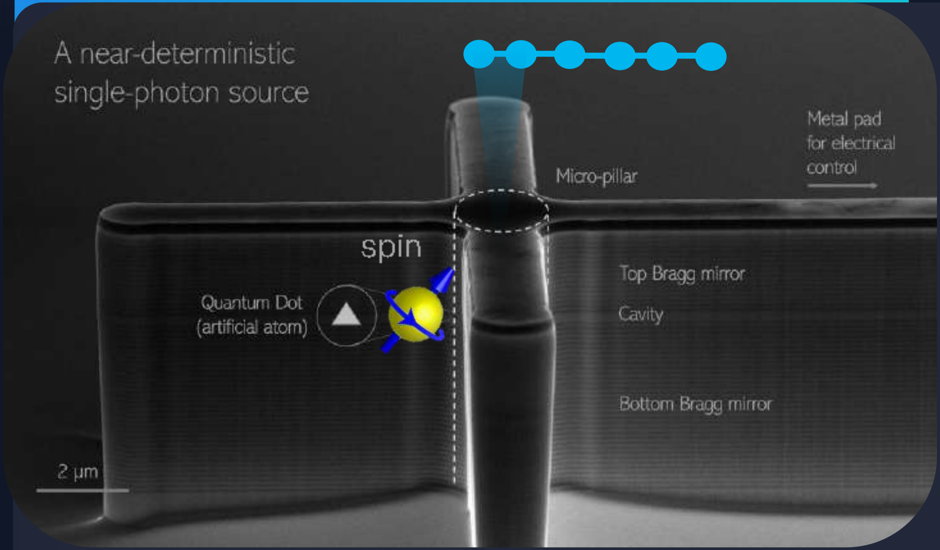


QUANDELA'S CLUSTER STATES GENERATOR



Massive reduction of overheads:

1 vs 1000s components

Generation rate > x 100 higher than other quantum technologies (QDs & atom based)

N. Coste et al, " High-rate entanglement between a semiconductor spin and indistinguishable photons", arxiv:2207.09881, (2022)

2024:
Spin coherence time 10s ns & >98% purity
→ >5 photons cluster

On-premise & cloud accessible, optical QC - today

Upgradability offered by modularity

Scalability by the use of optical fibers and semi-conductor tech.

Low energy consumption (~3 kW) with optimised and integrated cryostats, ready for deployment

MOSAIQ

End-users

Front end

Compiler

Assembler

Hardware Modules

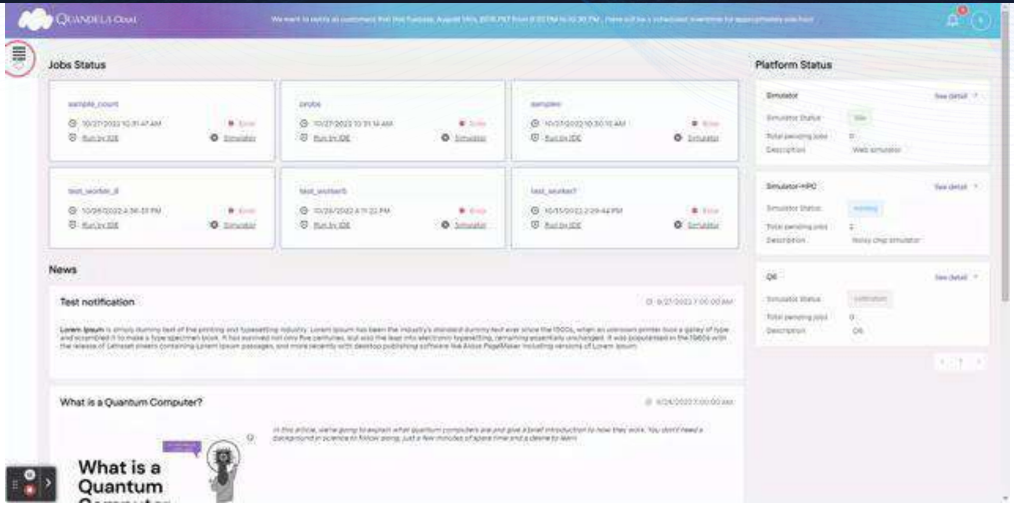
Semiconductors

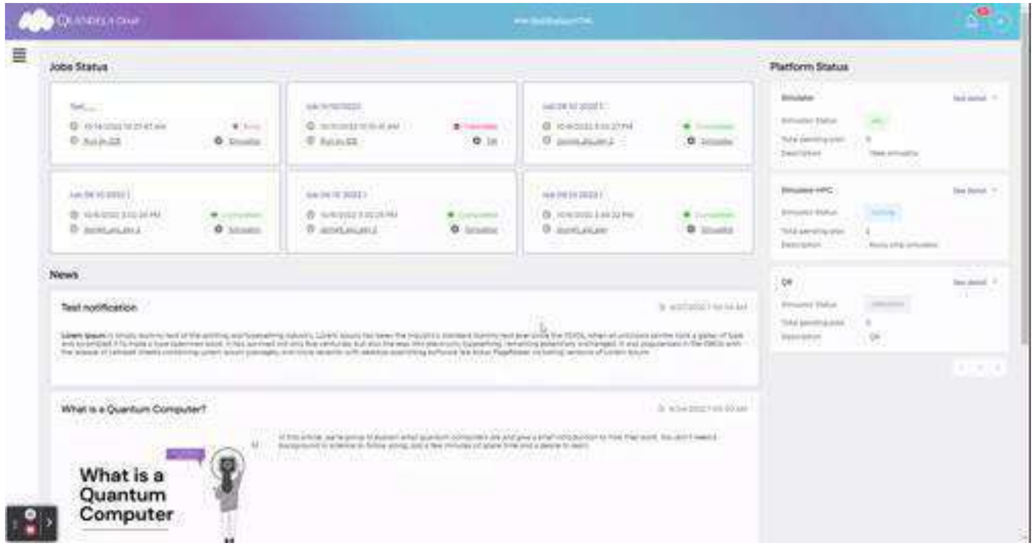
Perceval OS + Simulator

1. Quandela's OS
2. Lasers & Electronics
3. Photonic Integrated on Chip (PIC)
4. Qbit-controller module
5. Photonic Qubit Demultiplexer (DMX)
6. Cryogenically cooled qubit generator & detectors

= 1st European QC-on-cloud provider

- Access to powerful "noisy" simulators (up to 15-20 photons) and real Quantum Processor Units
- Generate and manage your tokens and keep track of your projects
- Manage your company account and follow the activities of your collaborators
- Intuitive Interface with Extensive Documentation





Optical QPUs in the cloud
https://cloud.quandela.com

Quandela is Delivering Real Life Use Cases for Customers Today

Cybersecurity

- Using **quantum certified randomness** to generate **spy-proof hash keys**
- **Applications:** defense and security, post-quantum cryptography, banking industry

OVHcloud

CRYPTONEXT SECURITY

Molecular Design

- Using **Variational Quantum Eigensolver** (VQE) to resolve **3D-molecular configuration**
- **Application:** drug design in pharmaceuticals

MBDA MISSILE SYSTEMS

+ undisclosed users

Logistics

- Using **state superposition** to simultaneously explore a large number of paths to research solutions for **NP-hard problems**
- **Application:** drone cohort flight planning

THALES

Time-Series Forecasting

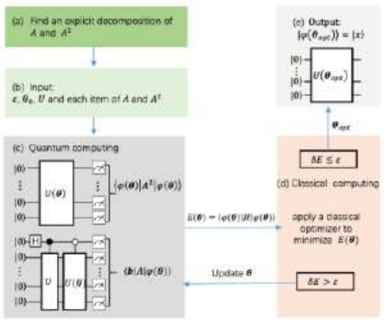
- Using **quantum forward propagation** to detect **weak signals** in long time series
- **Application:** finance & insurance industry

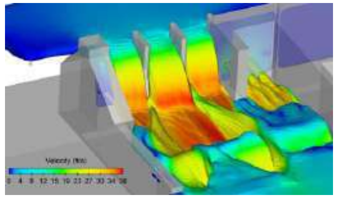
Undisclosed users

Quandela is Delivering Real Life Use Cases for Customers Today

ONERA – THE FRENCH AEROSPACE LAB / EDF: Solving Partial Differential Equations

- **Challenge** – reducing computing time and resources involved in PDE solving traditionally done on **HPC**
- Developed a **variational quantum circuit** by exploiting the quantum properties of photons
- Designed for **scaling-up** towards exponential **advantage** when compared to classical
- **Application:** to improve the **safety** of **hydroelectric dams** and **nuclear plant pipes**

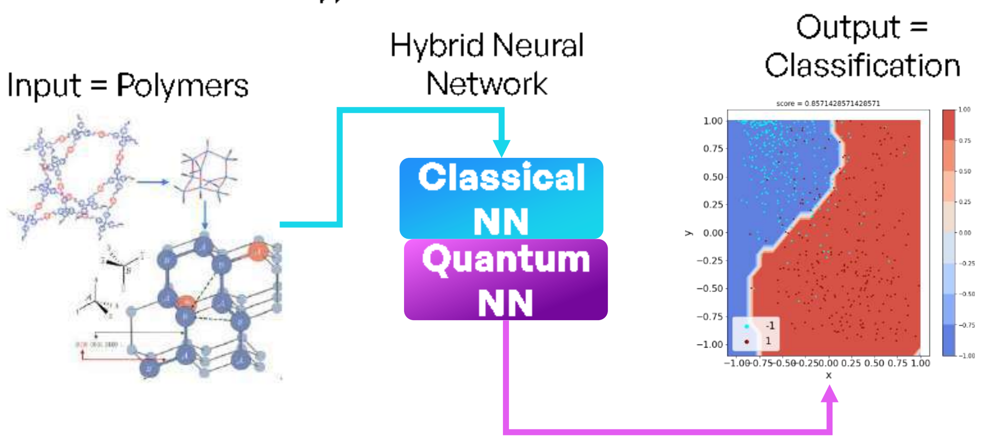




Patent + scientific paper

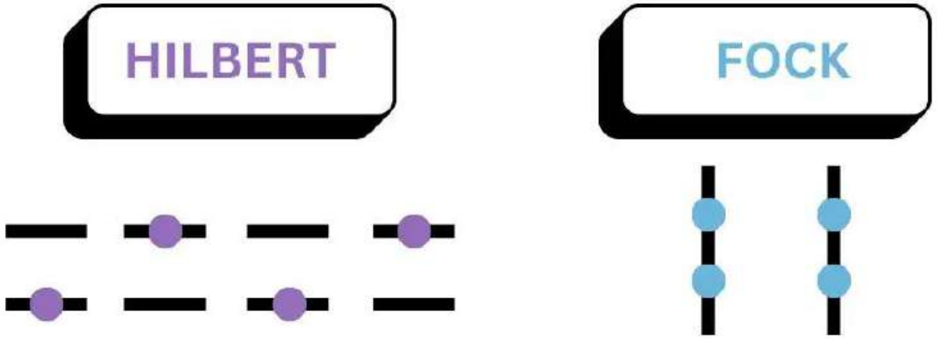
MBDA: Calculating the Behaviour of Polymer Materials

- **Challenge** – improve accuracy of classical machine learning for classification tasks on large and complex datasets with huge dimension of parameters
- Developed **classical-quantum neural networks** to classify polymers with state-of-the-art results
- **Application:** to allow the **faster** and **more efficient prediction** of **polymers' properties** (e.g., ductility, thermal stability)



A. Ricou et al, "Photonic quantum computing for polymer classification", arxiv:2211.12207, (2022)

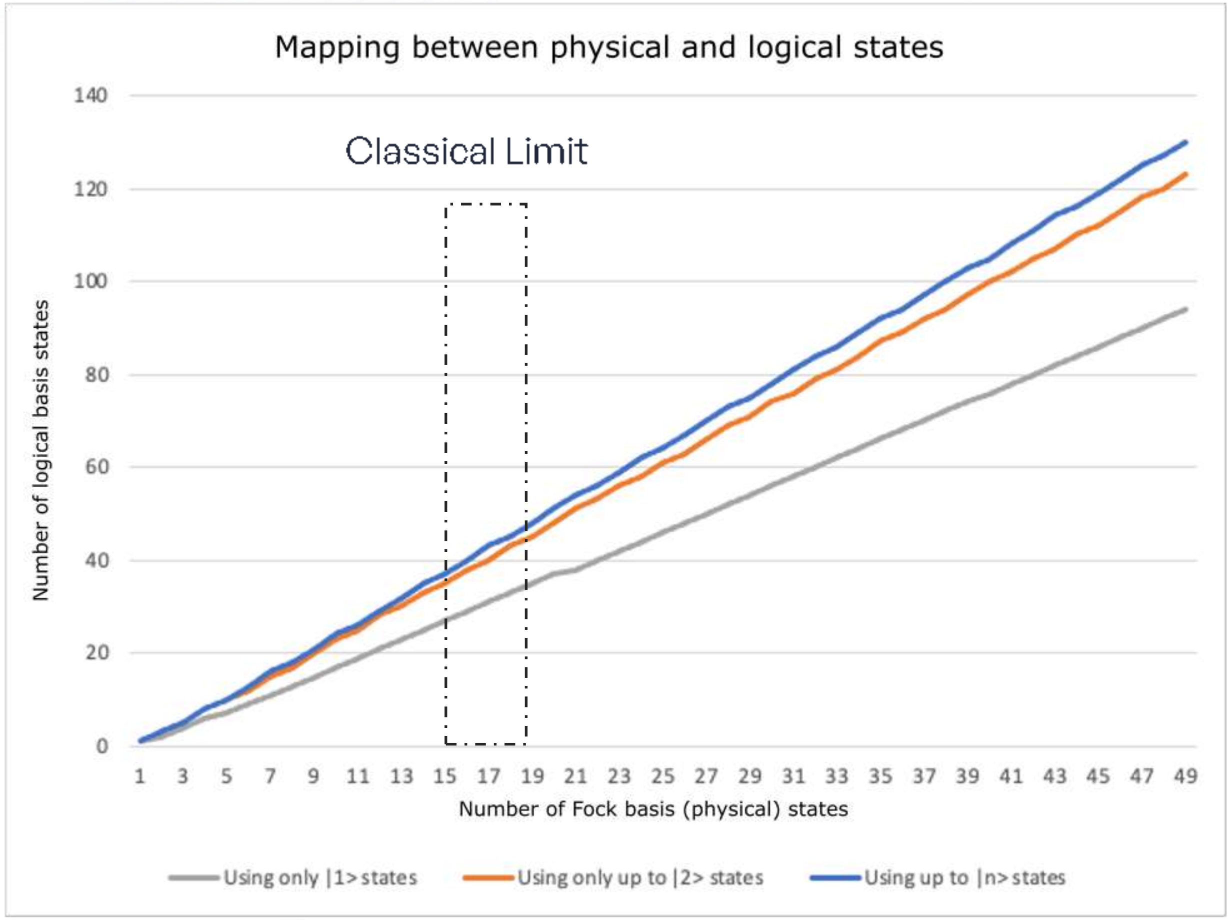
Towards QC “advantage” via photonics



With n photons, we count the particles in each m mode, the size of the space is

$$\binom{n+m-1}{n}$$

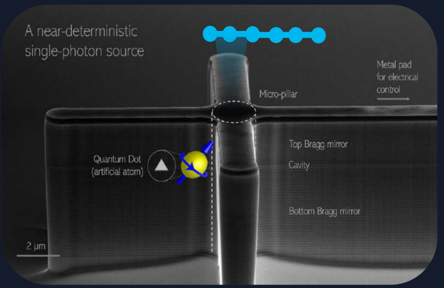
Quandela’s 24-photon QPU is equivalent to ~40qubits QC



Quandela - today

QPUs access on https://cloud.quandela.com & full-stack QC systems for *on-premise* deployment

State-of-the-art algorithms for tailored industrial use-cases



Demonstration of the most efficient generation of cluster states – resource for FTQC

"Thank you to Quandela for their ambition, their talent and for so many more projects yet to come! With confidence."

French President Emmanuel Macron

The underlying scientific validation: >8 scientific articles in 2022

Semiconductor Quantum Devices & Quantum Photonics

Coste et al., “High-rate entanglement between a semiconductor spin and indistinguishable photons”, arXiv:2207.09881

Pont et al., “High-fidelity generation of four-photon GHZ states on-chip”, arxiv 2211:1562

Algorithms and Quantum Information

Emeriau et al., “Quantum Advantage in Information Retrieval”, Phys. Rev. X Quantum

Heurtel et al., “Perceval: A Software Platform for Discrete Variable Photonic Quantum Computing”, arXiv:2204.00602

Clément et al., “A Complete Equational Theory for Quantum Circuits”, arXiv:2206.10577

Mezher et al., “Mitigating errors by Quantum Verification and Post-selection”, Phys. Rev. A 105

Kapourniotis et al., “Unifying Quantum Verification and Error-Detection: Theory and Tools for Optimisations”, arXiv2206.00631

Mezher et al., “Assessing the quality of near-term photonic quantum devices”, arXiv:2202.04735