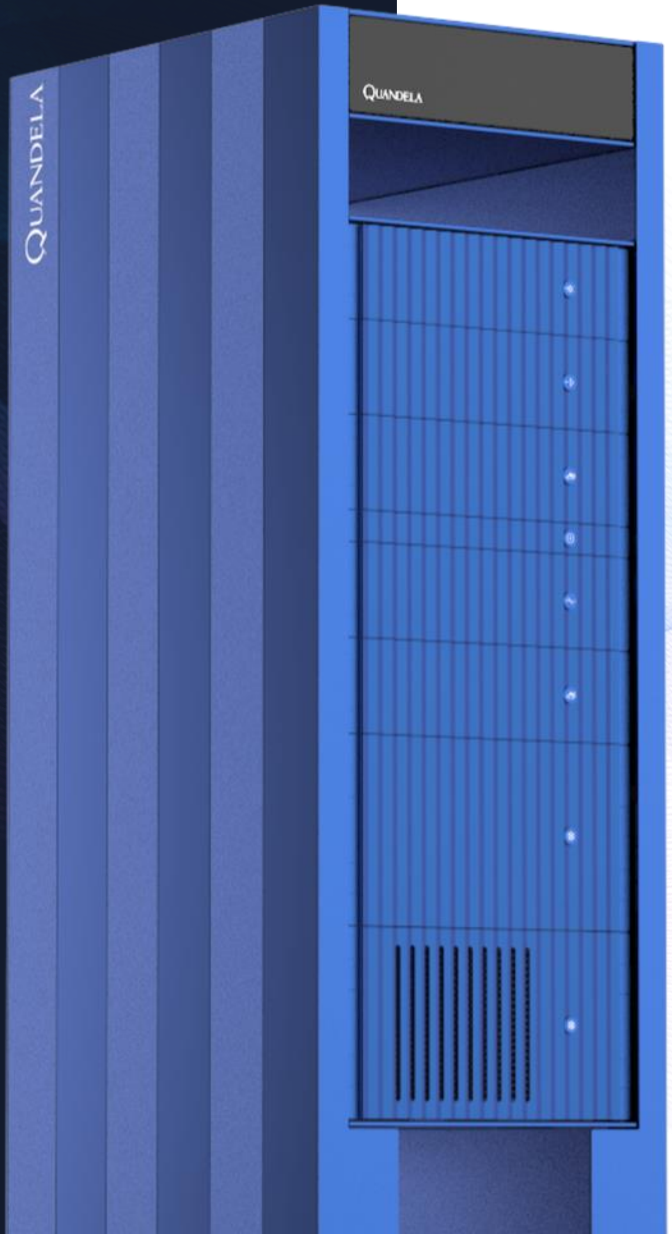
QUANDELA

# Scaling Quantum Computing

## Challenges, and Practical Solutions for the Photonic Approach




Jean Senellart & Nicolas Maring

05/09/2024

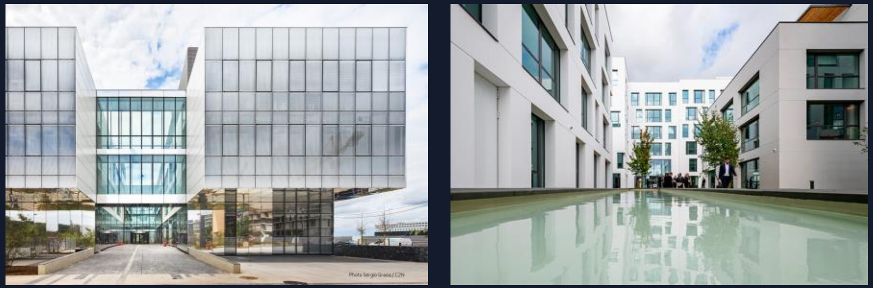
# Photonic Quantum Computing leader in EU
## with a large team of experts in quantum photonic technologies

100 people dedicated to photonic quantum computing
>60 PhDs and engineers in algorithms, semiconductors, photonics

La FRENCH TECH

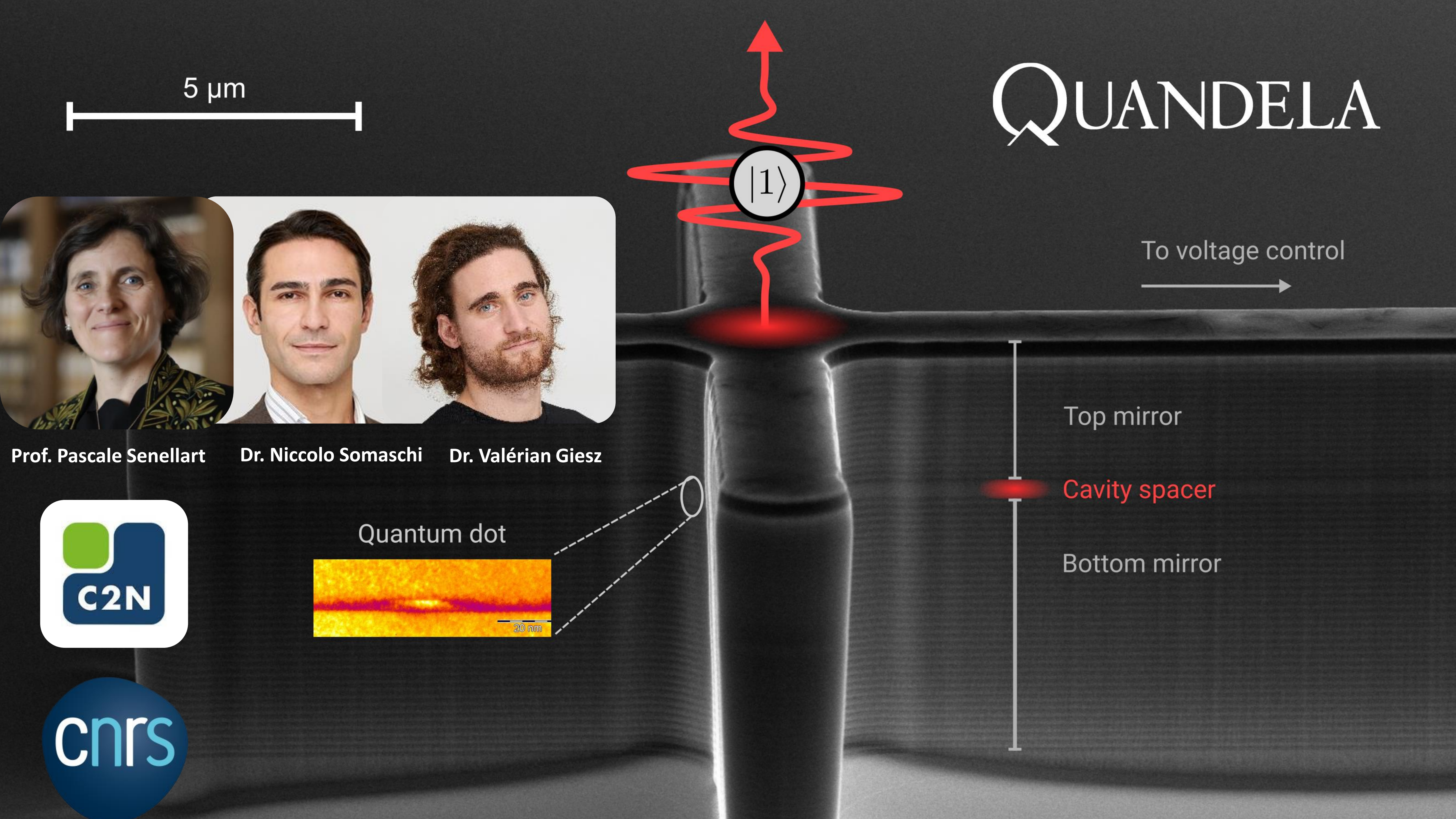
QUANDELA

R&D Centers



Production Centers

Offices based in
***Paris***
***Munich***
***Seoul***
***Montreal***

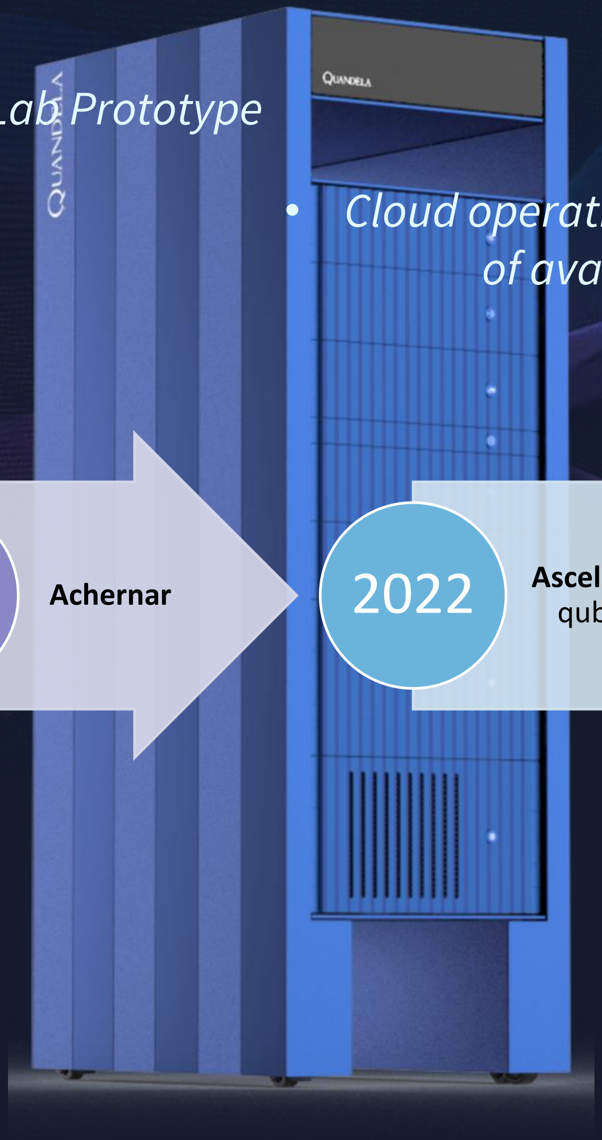


5 µm
QUANDELA
|1⟩
To voltage control
Prof. Pascale Senellart
Dr. Niccolo Somaschi
Dr. Valérian Giesz
Top mirror
Cavity spacer
Bottom mirror
Quantum dot
20 nm
C2N
cnrs

# MosaiQ



## A roadmap to Fault-Tolerant QC through the stars



- *First Lab Prototype*
- *Cloud operation 92% of availability*

***UTILITY***

- *First Fully Integrated*
- *Application Specialized*
- *Fully Upgradable*

***TOWARD FTQC***

2021 — **Achernar**

2022 — **Ascella** - 6 qubits

2023 — **α-Crucis** - QRNG
**Altair** – 10 qubits QML

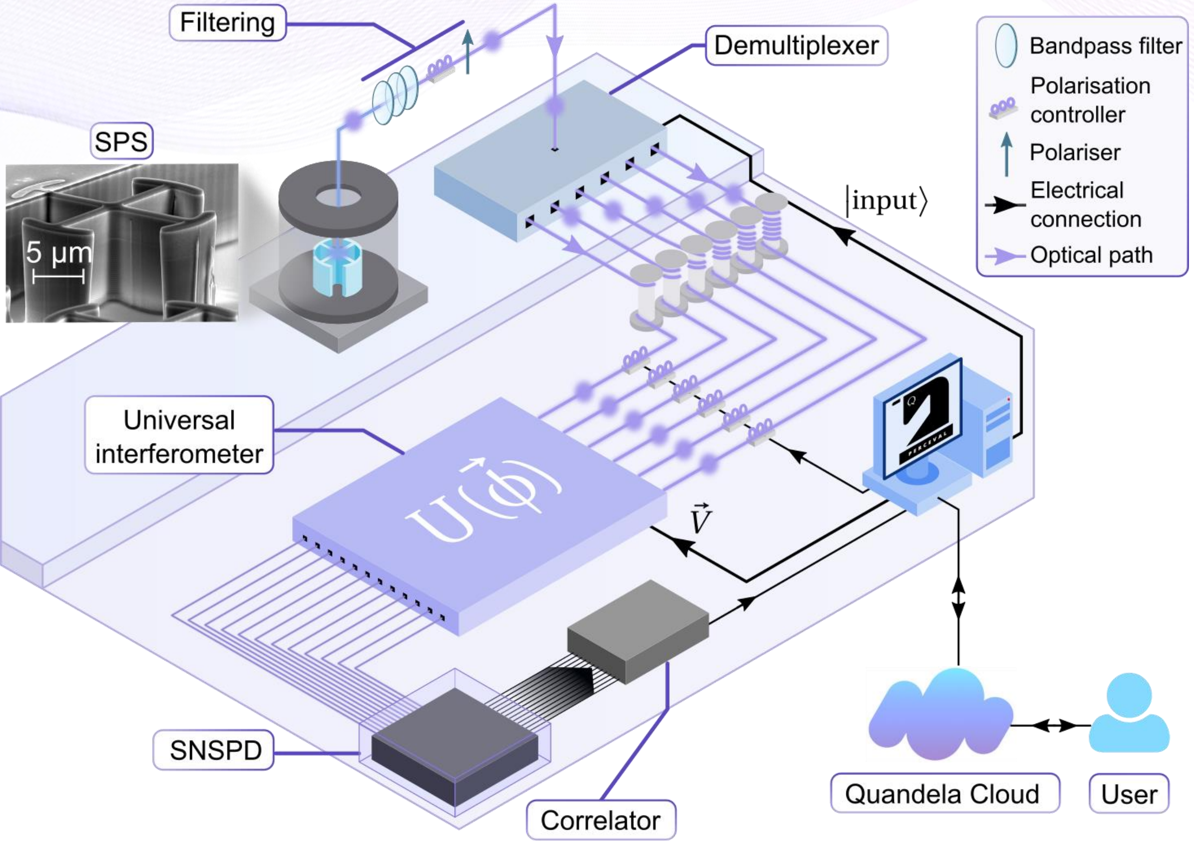
2024 — *Production * 2*
**Bélénos** - 12 qubits

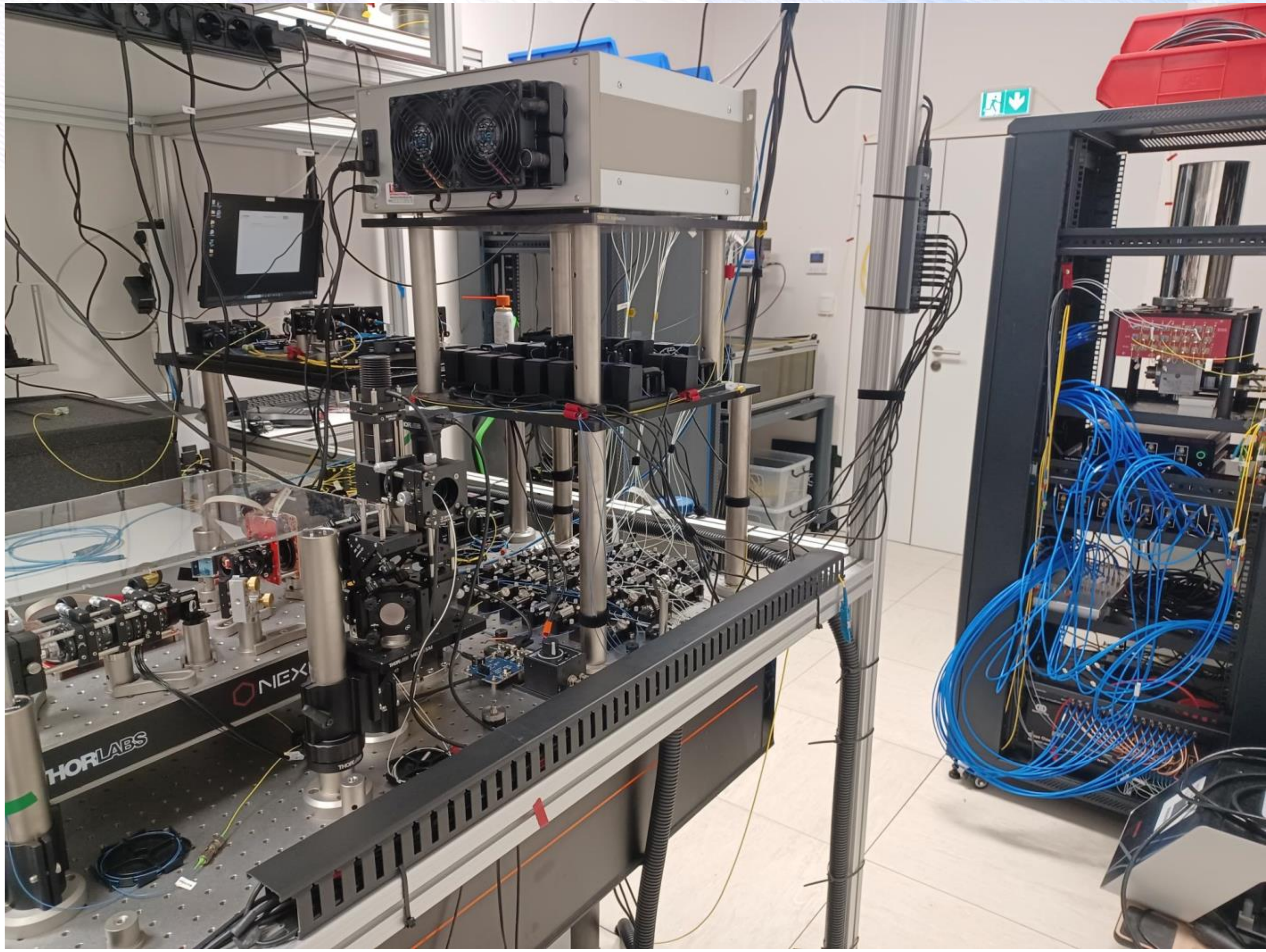
2025 — *Production * 4*
**Canopus** - 24 qubits with cluster states

# MosaiQ Industrialization Roadmap



## 2022 - First generation – Lab prototype



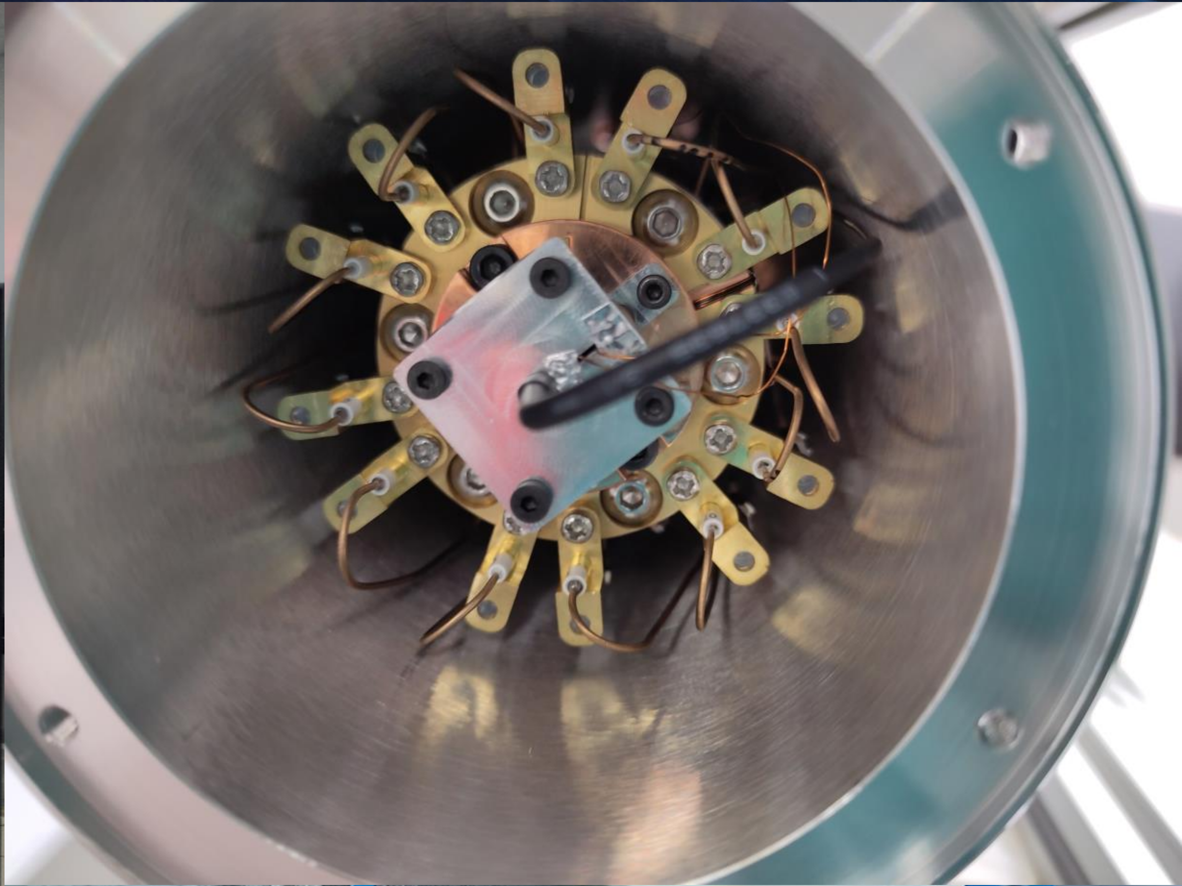
# MosaiQ Industrialization Roadmap

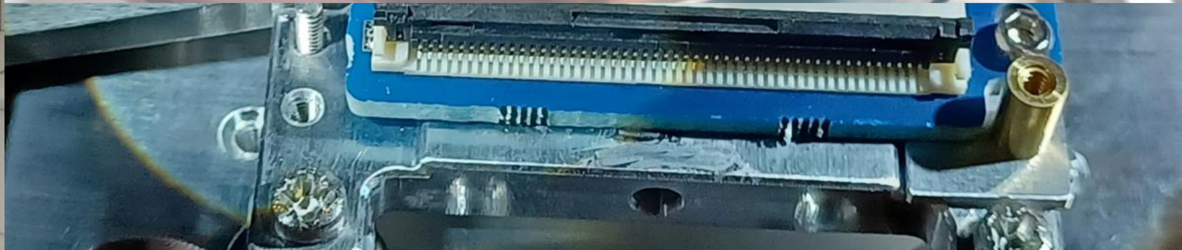
## 2023 - Second generation – Data center compatibility


# MosaiQ Industrialization Roadmap

## 2024 - Third generation - Modularity







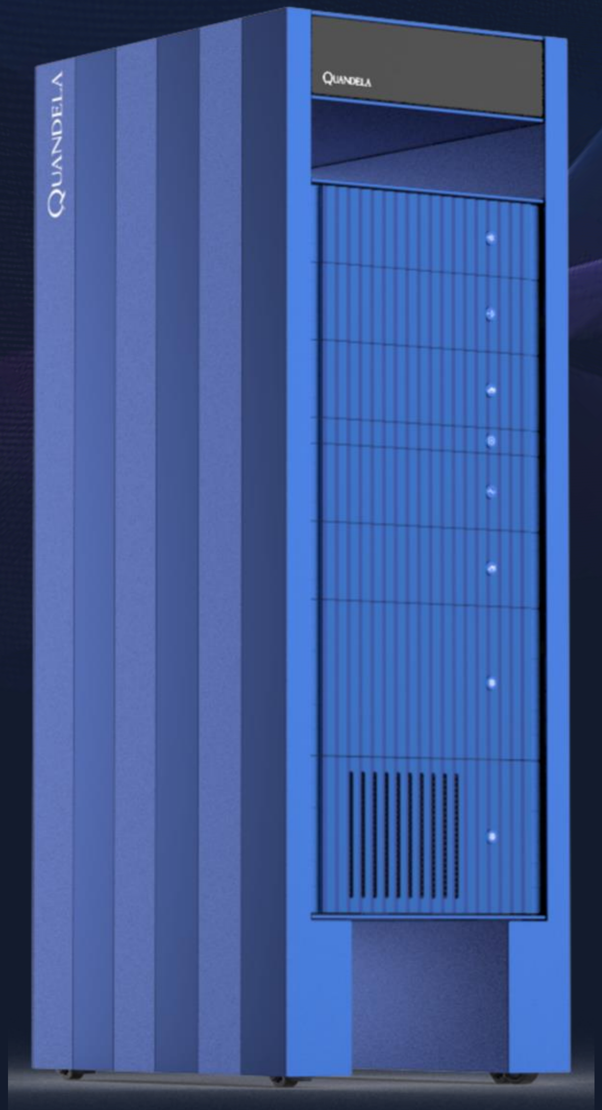
# MosaiQ

## The associated software stack



| | | | | |
|---|---|---|---|---|
| Simulation | Local Simulation<br>12 photons | SLOS<br>18 photons | GPU<br>24 photons | HPC<br>30 photons |
| Quantum Framework | Perceval | Qiskit-Connector | Exqalibur | |
| Cloud Service | Cloud 1.0 | Online Notebooks | Quantum Toolbox | |
| Compilation<br>Transpilation | ML Transpilation | Error mitigaton | | |
| Operating System | 3rd-Party<br>Drivers | MosaiqOS | Self-Calibration | Quandela Data Link |

# QUANDELA




Cloud based QPUs

**Perceval**
Open-source programming framework

**Algorithm toolbox**
Solutions for Industry applications

**MosaiQ QPU**
Data-center ready systems

Accessible from:
Scaleway
cloud.quandela.com

**Available to since Nov 2022**

- 5000+ hours of QPU jobs
- 1-nine availability
- > 1000 users, 200 entitites

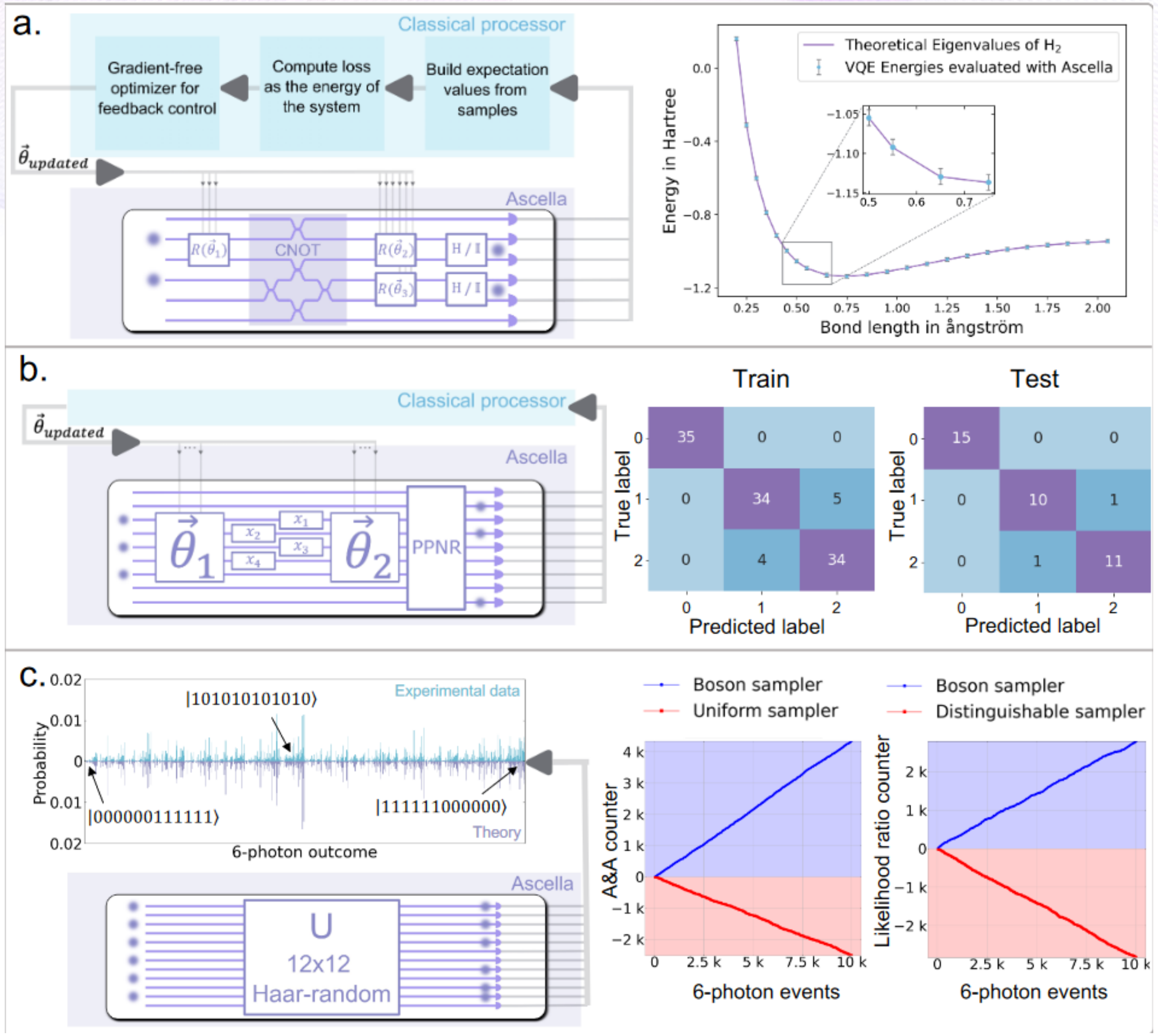
Assembled and delivered to data-centers

OVHcloud
exaion EDF GROUP

# MosaiQ Ascella - 6 qubits



## Gate Based – Photon based computations




Hybrid variational quantum eigensolver

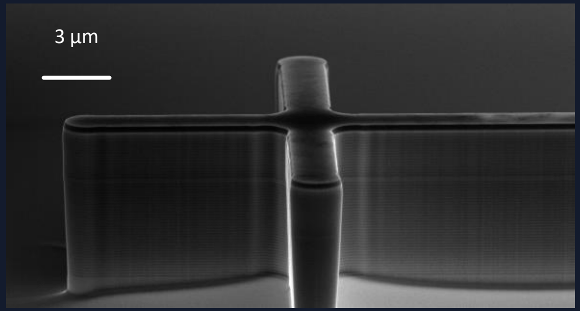
Quantum neural network

6 single-photon Boson Sampling

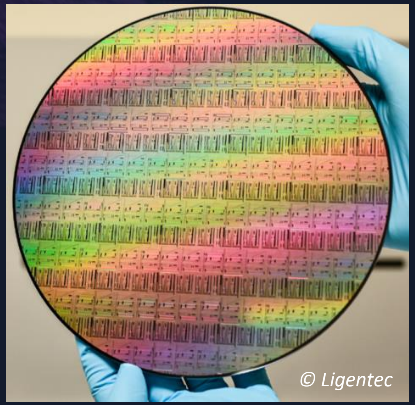

00:00:00

# Photonic Quantum Computers: the general scheme


Quandela:
Solid-state emitters = on-demand process

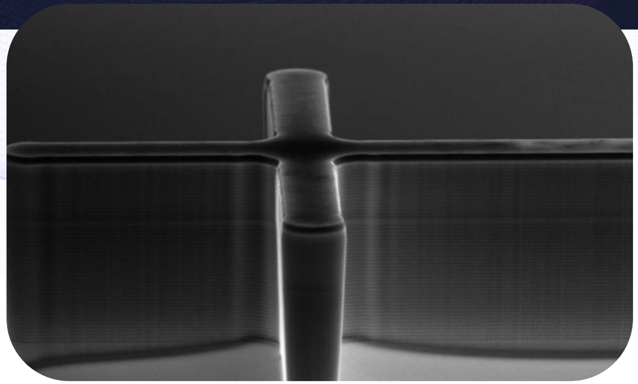


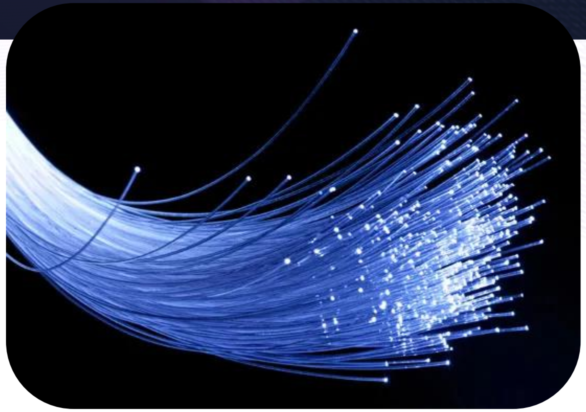

Integrated photonics,
fibers and detectors

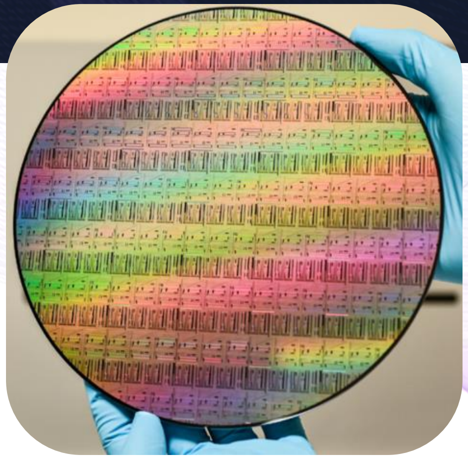


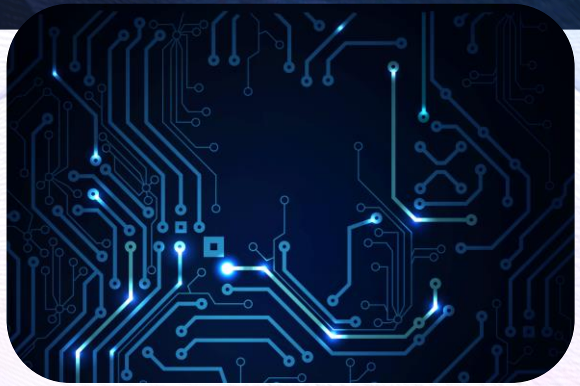
# Enabling technologies

## *For photonic quantum computing*









III-V semiconductors

Efficient Fiber optics components

Photonic Integrated Circuits

Electronics

Lasers

Fiber interconnects

High efficiency Detectors

low consumption cryogenics

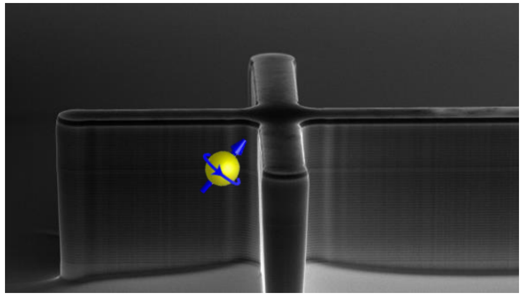
Optical filters

# Fourth generation - Towards Fault-tolerant

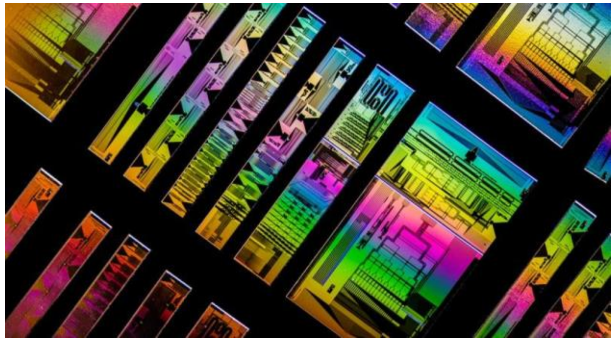
## SPOQC Blue print for fault-tolerant quantum computing architecture

# A Spin-Optical Quantum Computing Architecture

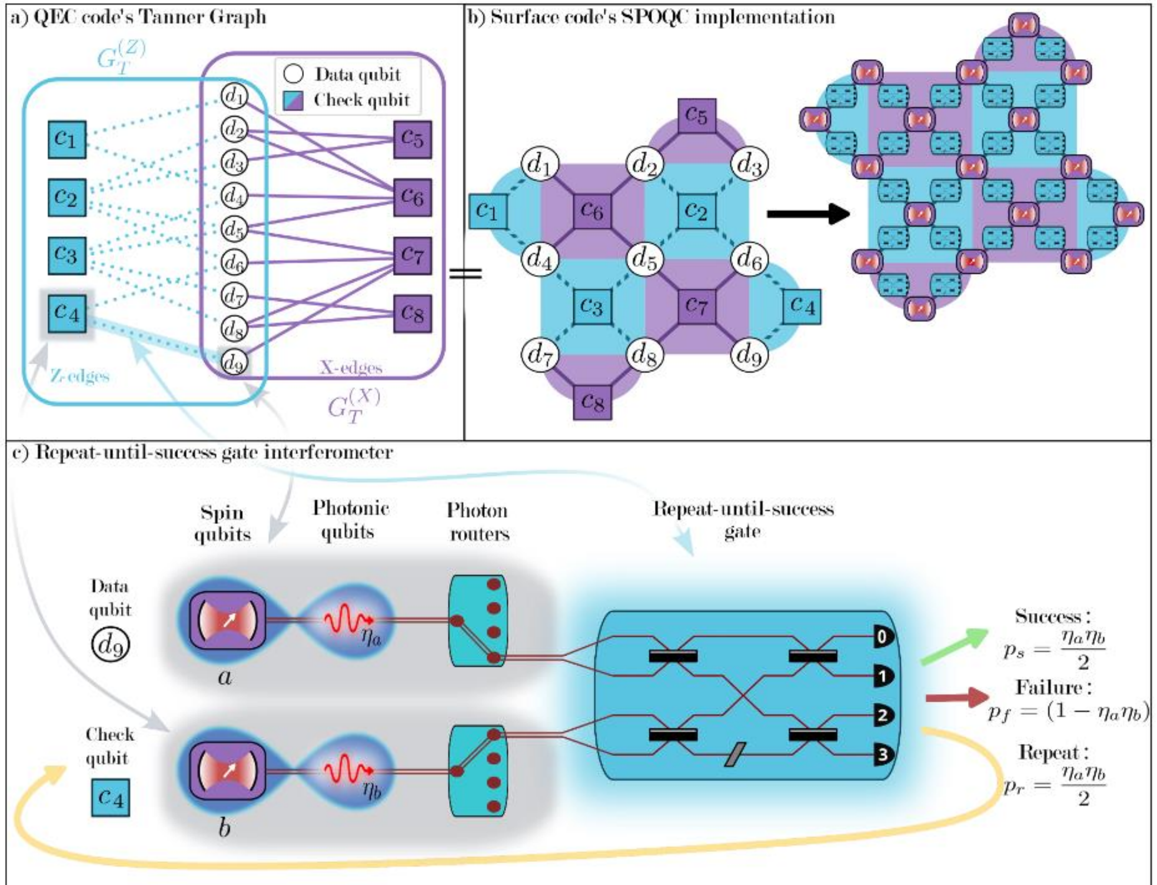
Grégoire de Gliniasty[1,2], Paul Hilaire[1], Pierre-Emmanuel Emeriau[1], Stephen C. Wein[1], Alexia Salavrakos[1], and Shane Mansfield[1]



**Quantum Dot Spin-control**

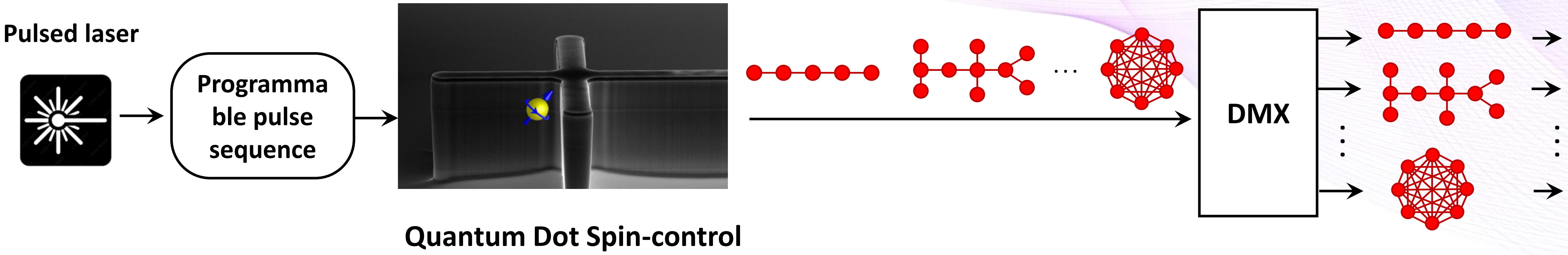


**Linear optics**



# Towards fault tolerant

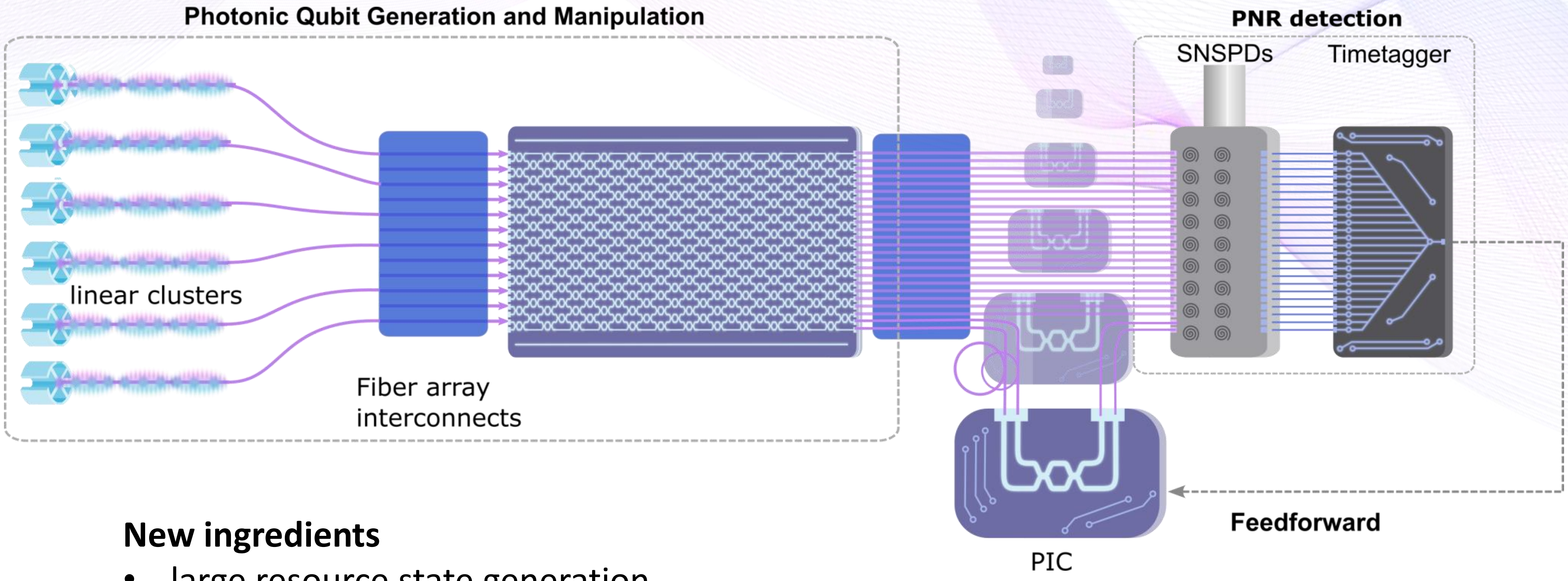
## Spin-Optical Resource state generation for MBQC




*N. Coste, …,N. Somaschi, P. Senellart, " High-rate entanglement between a semiconductor spin and indistinguishable photons" , Nature Photonics (2022)*

# Towards fault tolerant

## Adaptive Measurement – Feedforward



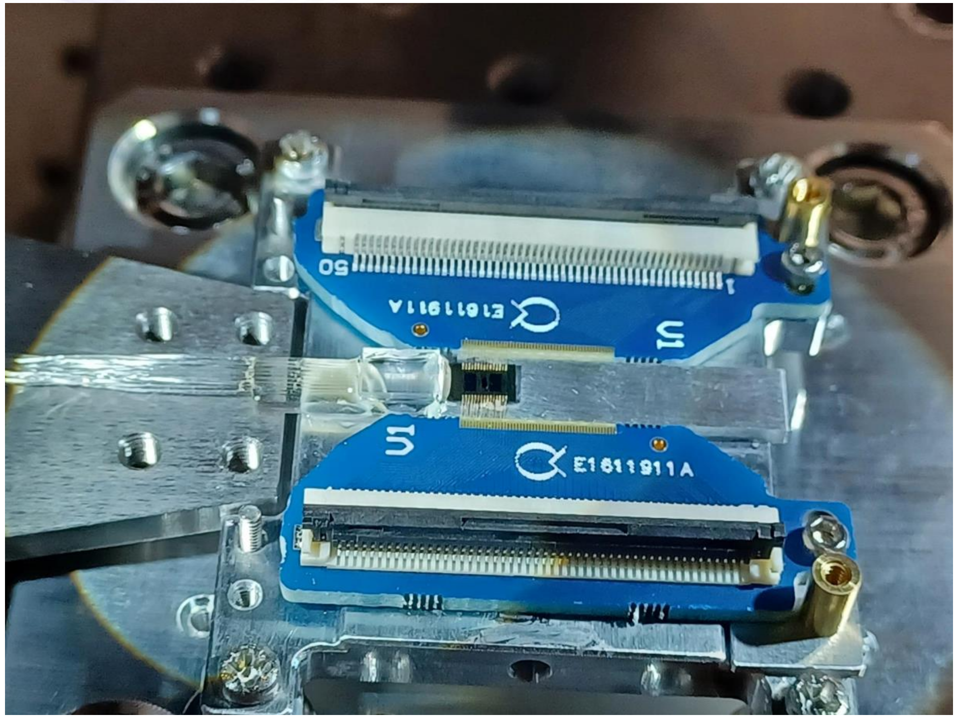

**New ingredients**

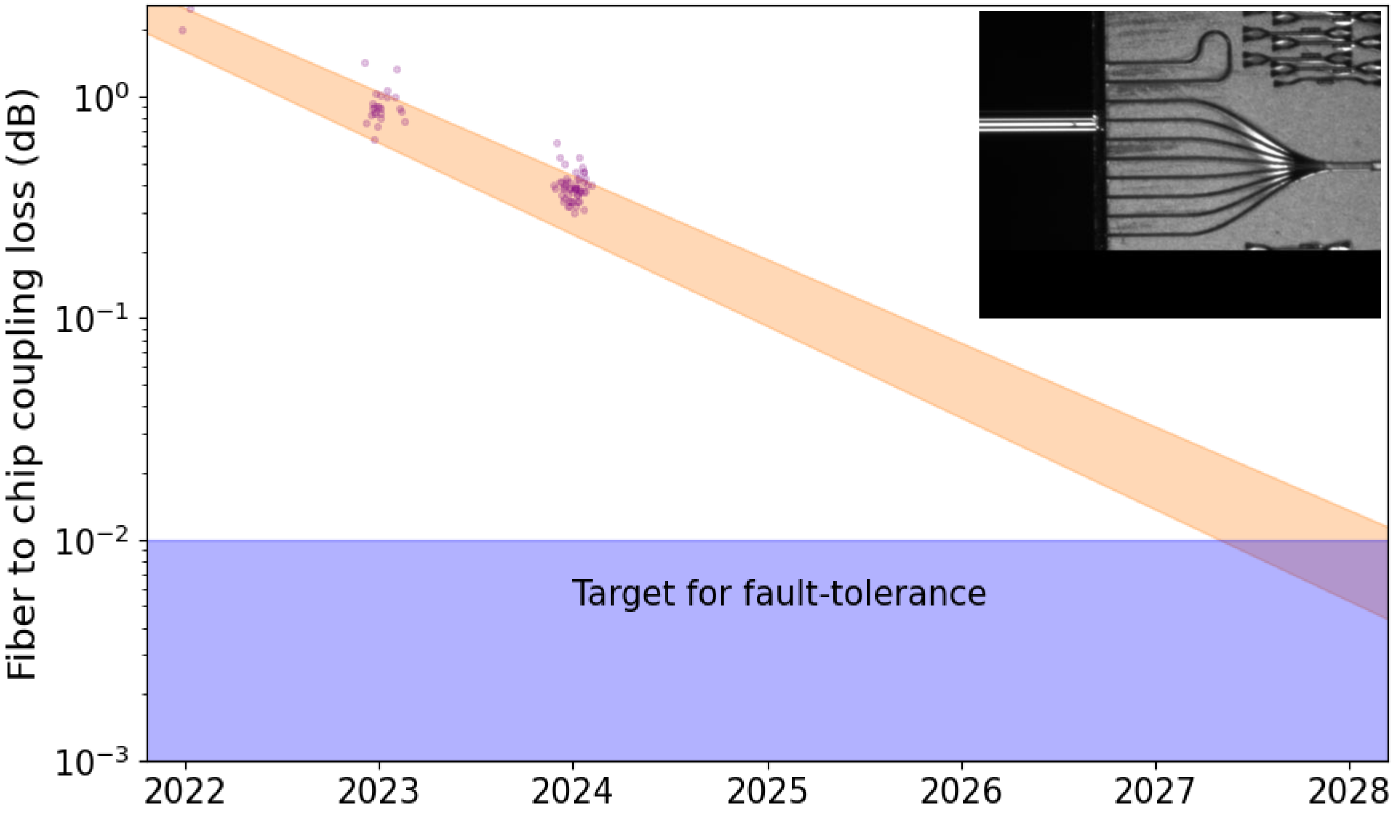
- large resource state generation
- high speed reconfigurability
- ultra low latency electronics
- PNR detection

# Towards fault tolerant

## Photon loss & Performance targets

Fiber interconnects

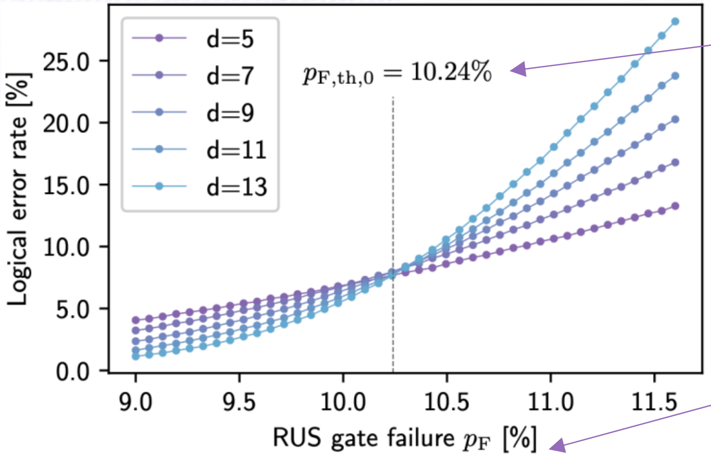




# SPOQC Error Correction Thresholds

## For a basic surface code

**Photon loss / RUS failure**



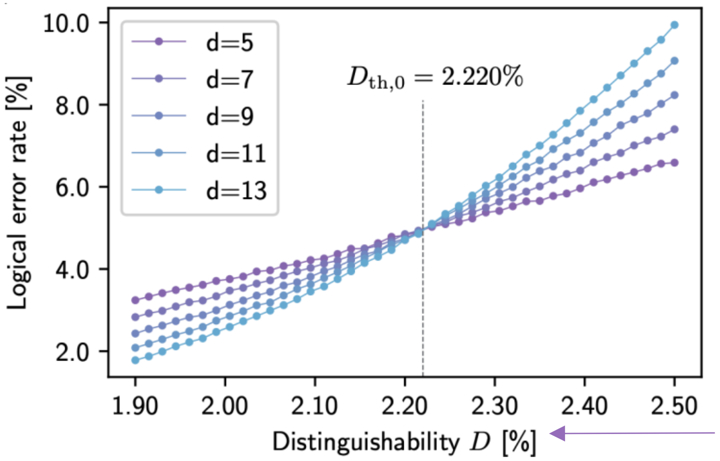

In terms of photon loss:

$$1 - \eta_{\mathrm{th}} = 2.75 \pm 0.02\%.$$

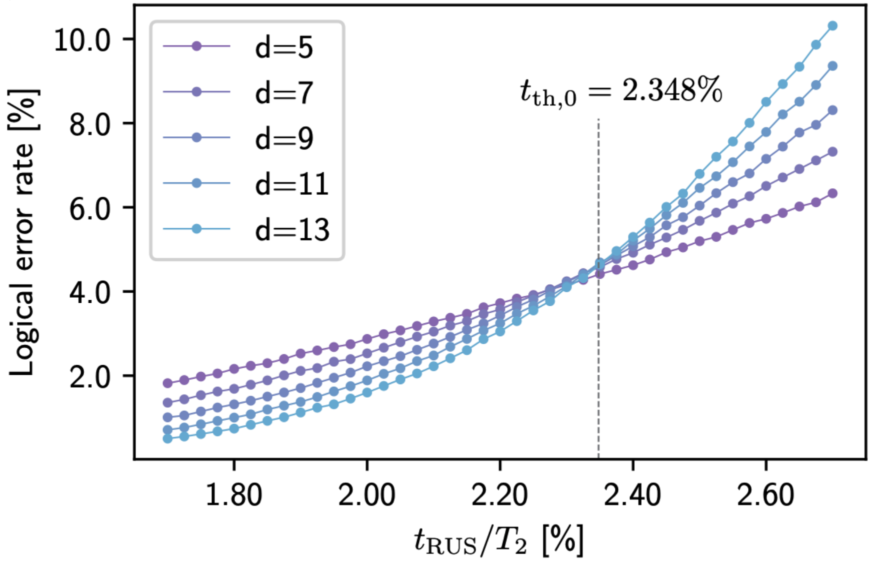
RUS Failure is a function of photon loss:

$$P_{\mathrm{RUS,f}}(\eta_a, \eta_b, k) = p_f \sum_{n=0}^{k-1} (p_r)^n = (1 - \eta_a \eta_b) \frac{1 - (\eta_a \eta_b / 2)^k}{1 - \eta_a \eta_b / 2} \xrightarrow[k \to +\infty]{} \frac{2 - 2\eta_a \eta_b}{2 - \eta_a \eta_b},$$

**Photon quality**




**Spin lifetime**



# MosaiQ

## A roadmap to Fault-Tolerant QC through the stars

*UTILITY* — *TOWARD FTQC*

**2025**
Production * 4
- **Canopus** - 24 qubits w/ cluster states

4 worldwide Endpoints

**2026**
Second Quantum Factory
**Deneb** - 48 qubits
*Logical qubit threshold*

**2027**
Large scale production solid-state sources
**Diadem** - 100 logical qubits

**2028**
**Electra** - 100s of logical qubit operations


Thank You!
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Questions?