le lab quantique

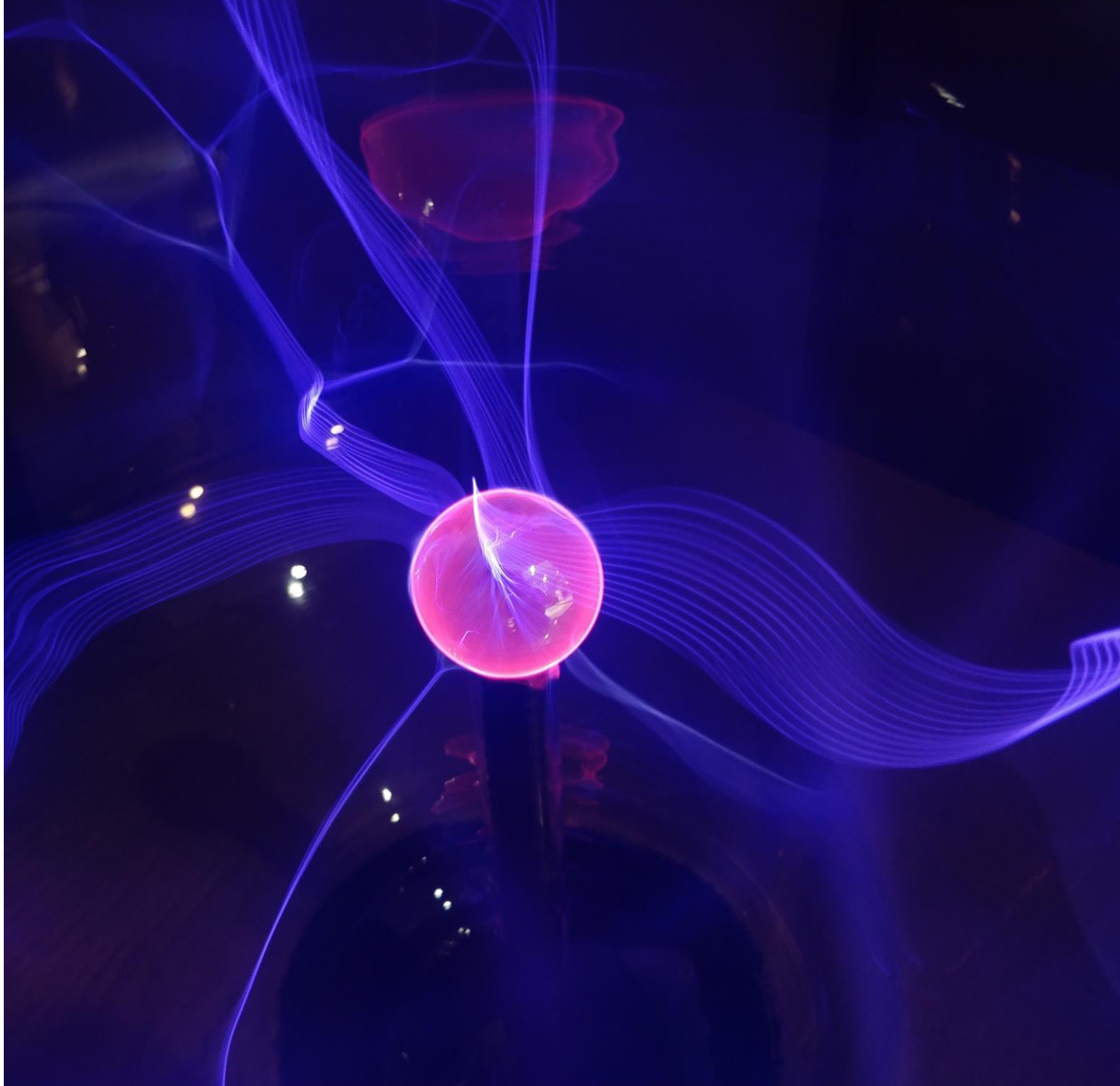
Promoting quantum technologies since 2018

LES MAISONS DU QUANTIQUE

Gather

Empower

Represent



OVERVIEW OF LE LAB QUANTIQUE

Understanding The Distributive Quantum Computing Ecosystem

1. Introduction
2. The Growing Interest in Distributive QC
3. The Ecosystem Is Bound to Evolve

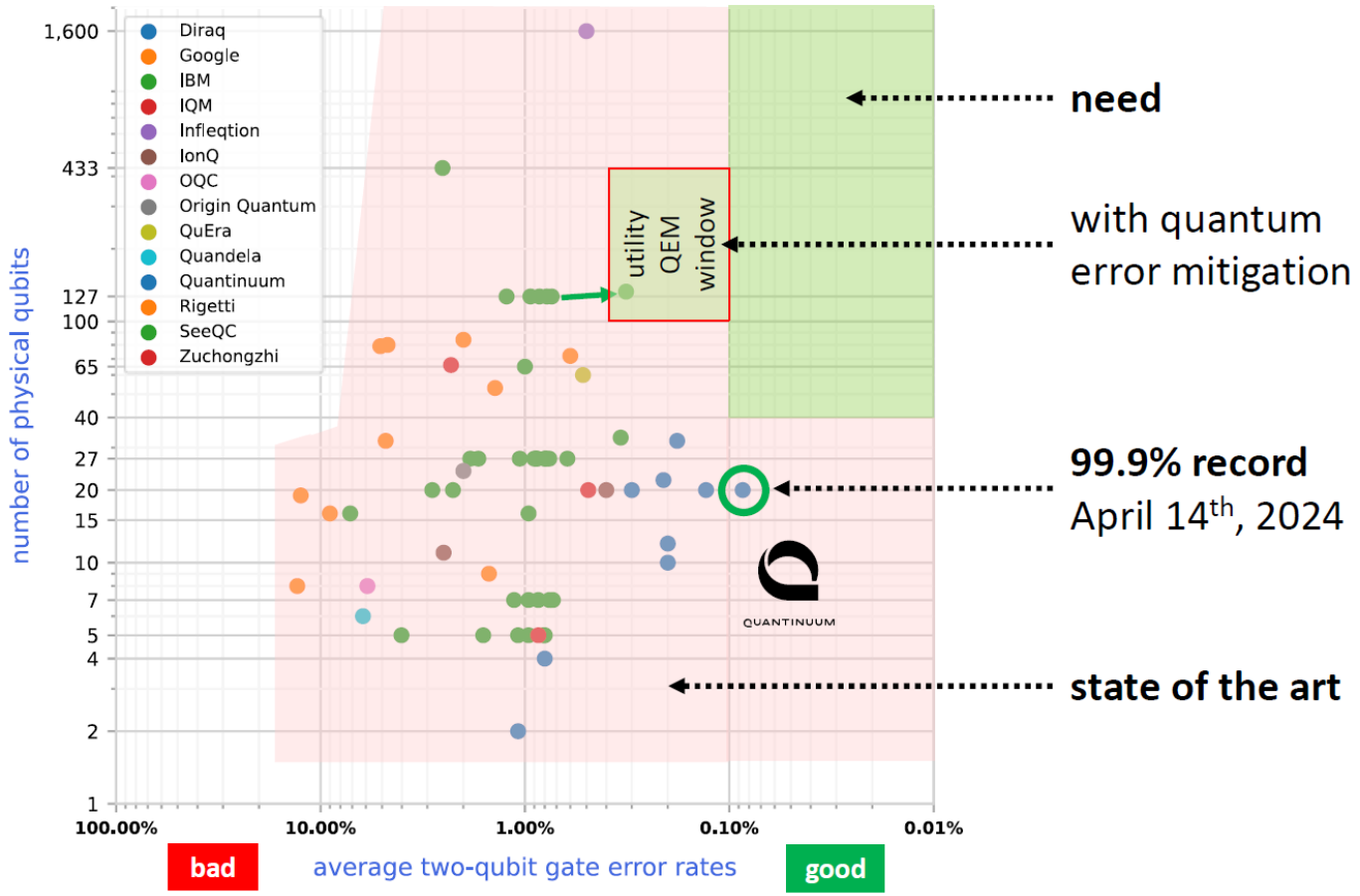
WHAT ARE THE OBSTACLES THE ECOSYSTEM IS FACING TO SCALE UP QPUS?

When considering the main challenges to solve in the next years, six current issues seem to be of the utmost importance

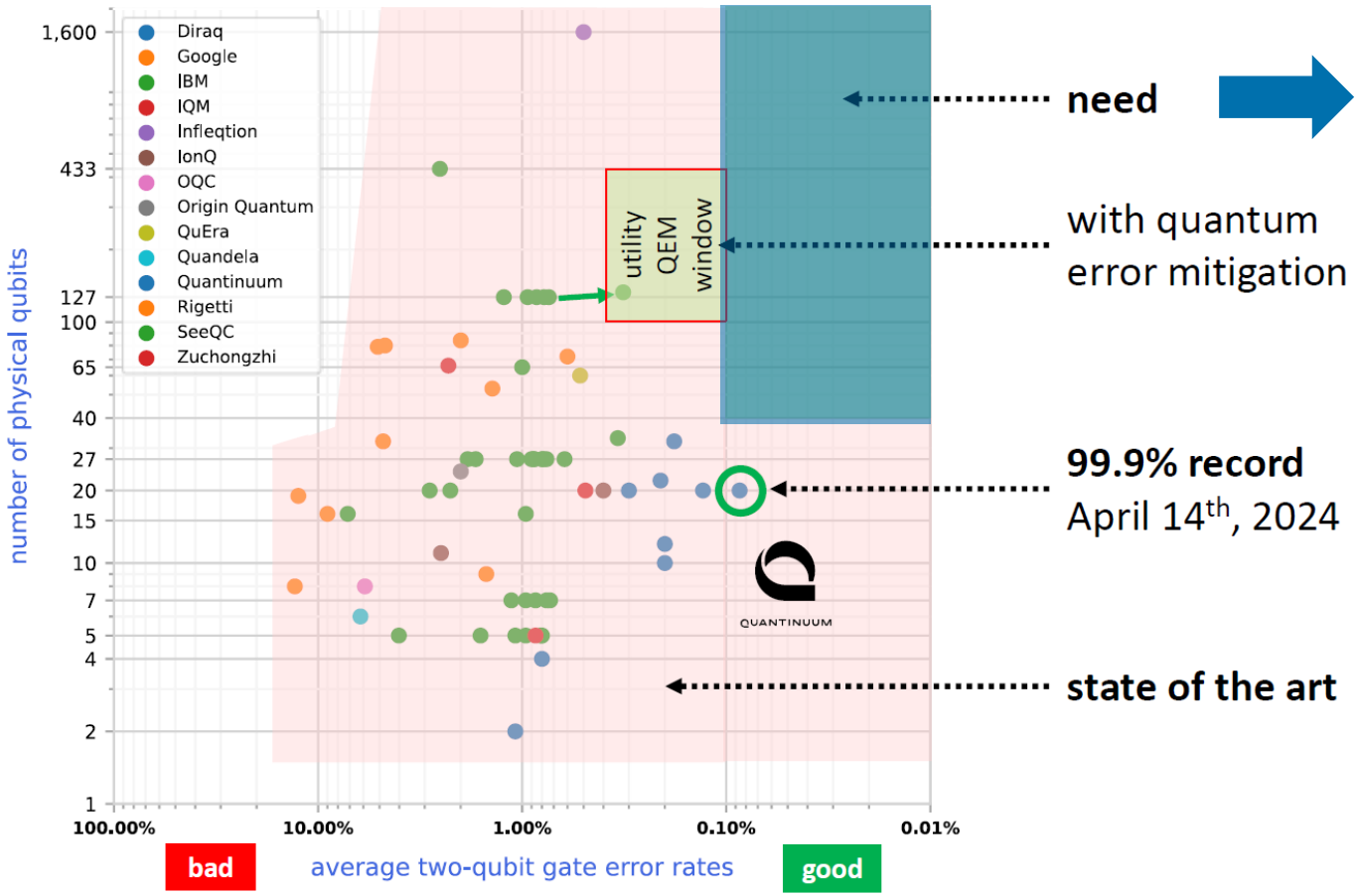
Qubit Size	The physical size of qubits limits the number that can be fit onto a single chip, making it harder to scale up quantum processors.
Chip Size	Larger chips become difficult to manufacture and manage, increasing signal latency and thermal management challenges.
Crosstalk	Unintended interactions between qubits or control signals cause noise and errors, which become harder to mitigate as qubit density increases.

Quantum chips are prone to defects during fabrication, leading to low yields that hinder scaling and increase costs.	**Manufacturing Yields**
Scaling up qubits requires increasingly complex and noise-prone control electronics, which also generate more heat in cryogenic environments.	**Control Electronics Limitations**
In laser-controlled quantum systems, scaling requires more precise and powerful lasers, leading to optical crosstalk and power constraints.	**Laser Power and Objective Lenses**

SOME EXPERTS BELIEVE THAT DISTRIBUTIVE QUANTUM COMPUTING COULD PAVE THE WAY TO SCALE UP QPUS (1/3)



SOME EXPERTS BELIEVE THAT DISTRIBUTIVE QUANTUM COMPUTING COULD PAVE THE WAY TO SCALE UP QPUS (2/3)



need

with quantum error mitigation

99.9% record
April 14th, 2024

state of the art

Interconnected error-corrected QPUs might lead to FTQC

SOME EXPERTS BELIEVE THAT DISTRIBUTIVE QUANTUM COMPUTING COULD PAVE THE WAY TO SCALE UP QPUS (3/3)

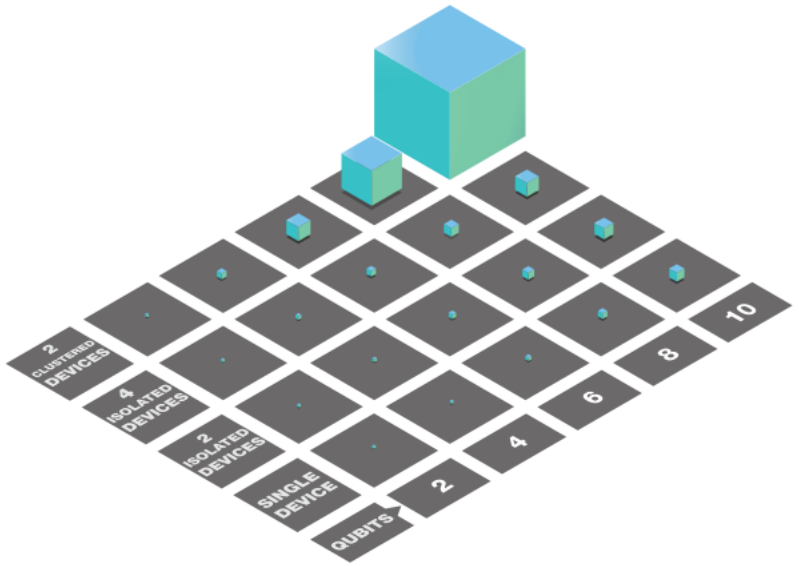


Fig. 1. Distributed Quantum Computing speed-up. The volume of cubes represents the ideal quantum computing power, i.e., in absence of noise and errors. As evident by comparing the power available at isolated devices versus the power achievable through *clustered* devices, the interconnection of quantum processors via the Quantum Internet provides an exponential computing speed-up with respect to isolated devices.

> A single 10-qubit processor can represent 2^{10} states thanks to the superposition principle; hence two isolated 10-qubit processors can represent 2^{11} states.
>
> But **if we interconnect the two processors, the resulting virtual device can represent up to 2^{18} states,** depending on the number of qubits devoted to fulfil the communication needs of the clustered processors.

Cuomo, Daniele & Caleffi, Marcello & Cacciapuoti, Angela Sara. (2020). Towards a distributed quantum computing ecosystem. IET Quantum Communication. 1. 10.1049/iet-qtc.2020.0002.

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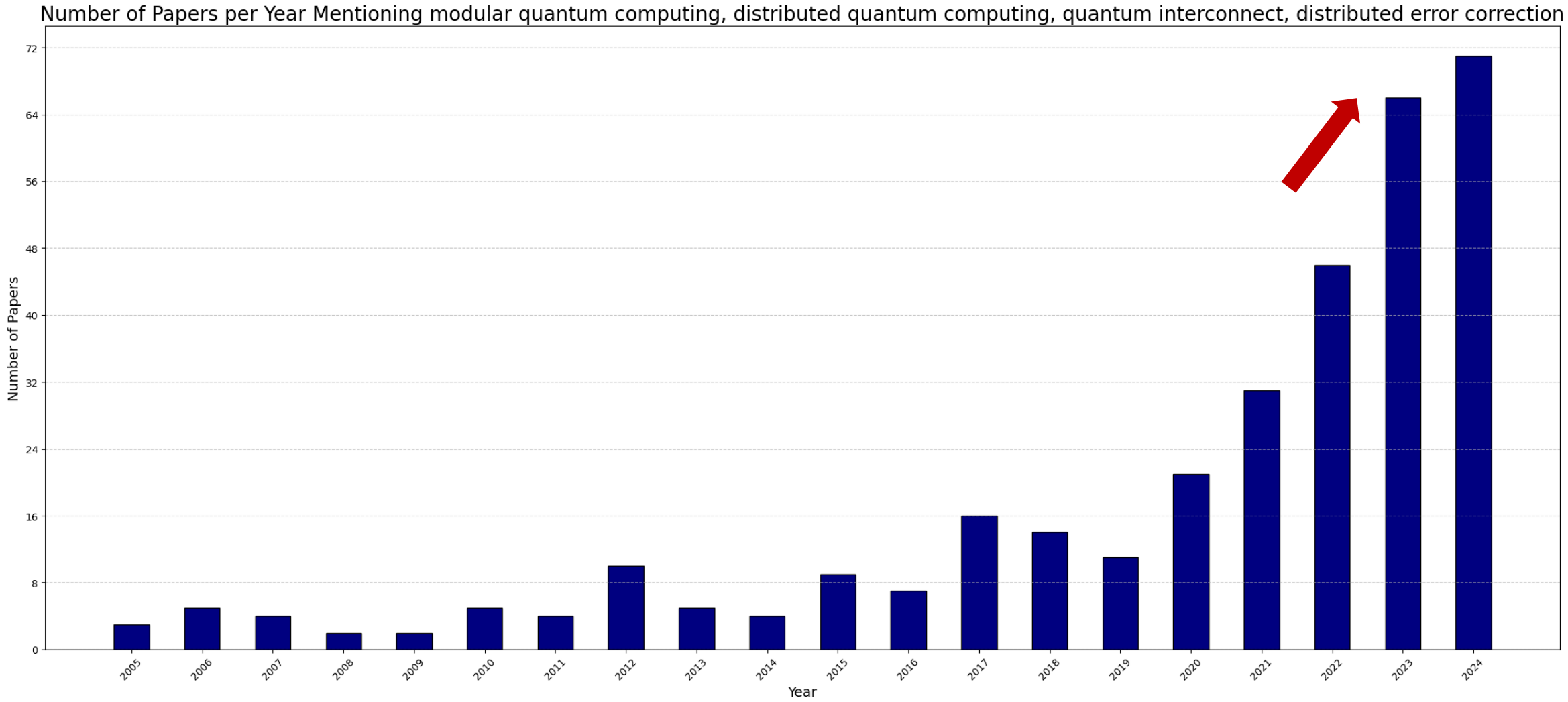
DISTRIBUTED QUANTUM COMPUTING: AT LEAST A WEAK SIGNAL THAT CERTAINLY POINTS TO A RENEWAL OF THE INTEREST



Source: arXiv, Google Scholar (10/01/2024)

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THE NEED FOR INTERCONNECTIONS DEPENDING ON THE TECHNOLOGY TYPE HIGHLIGHTS THE BENEFITS OF AN ECOSYSTEM

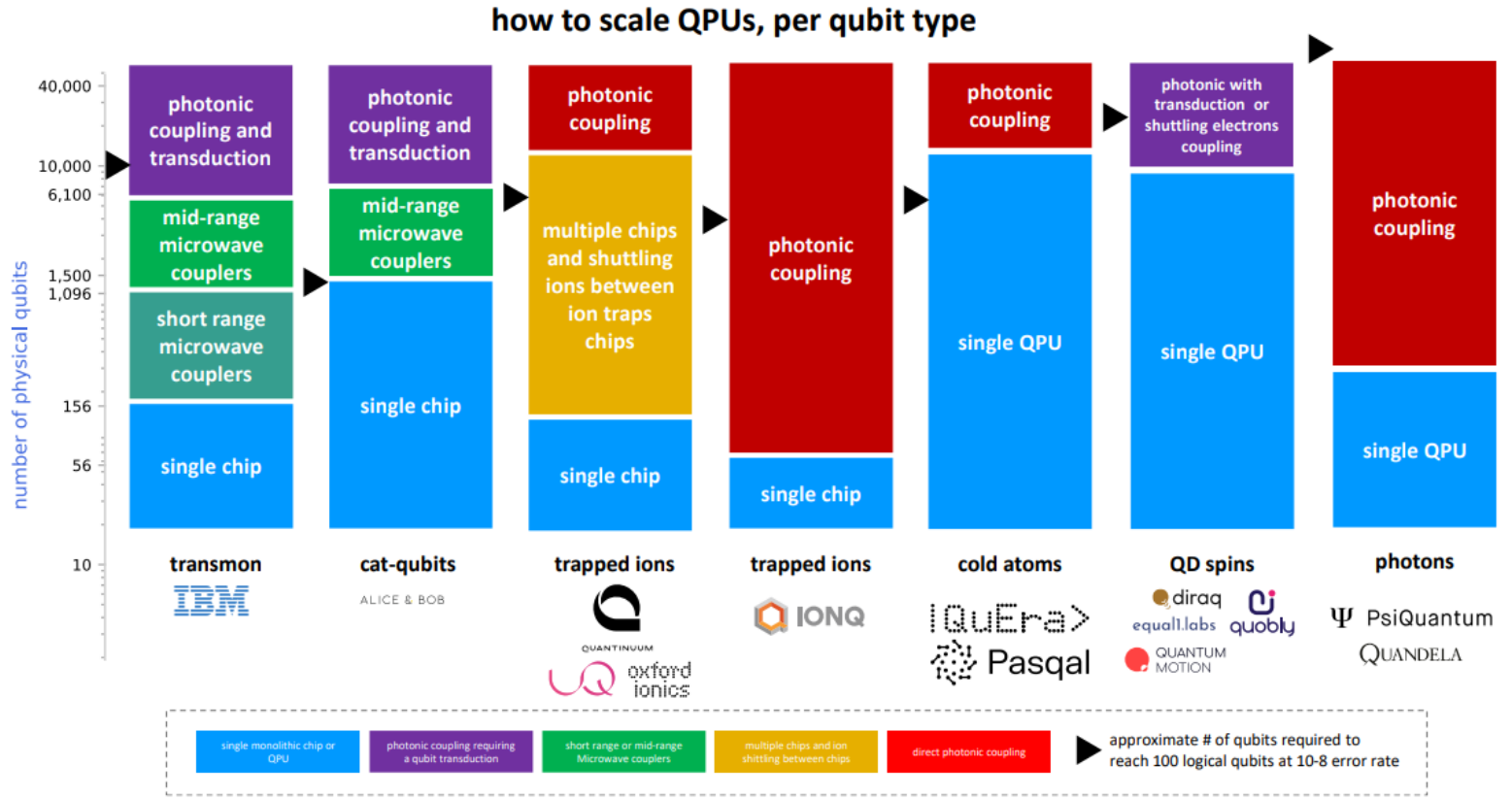
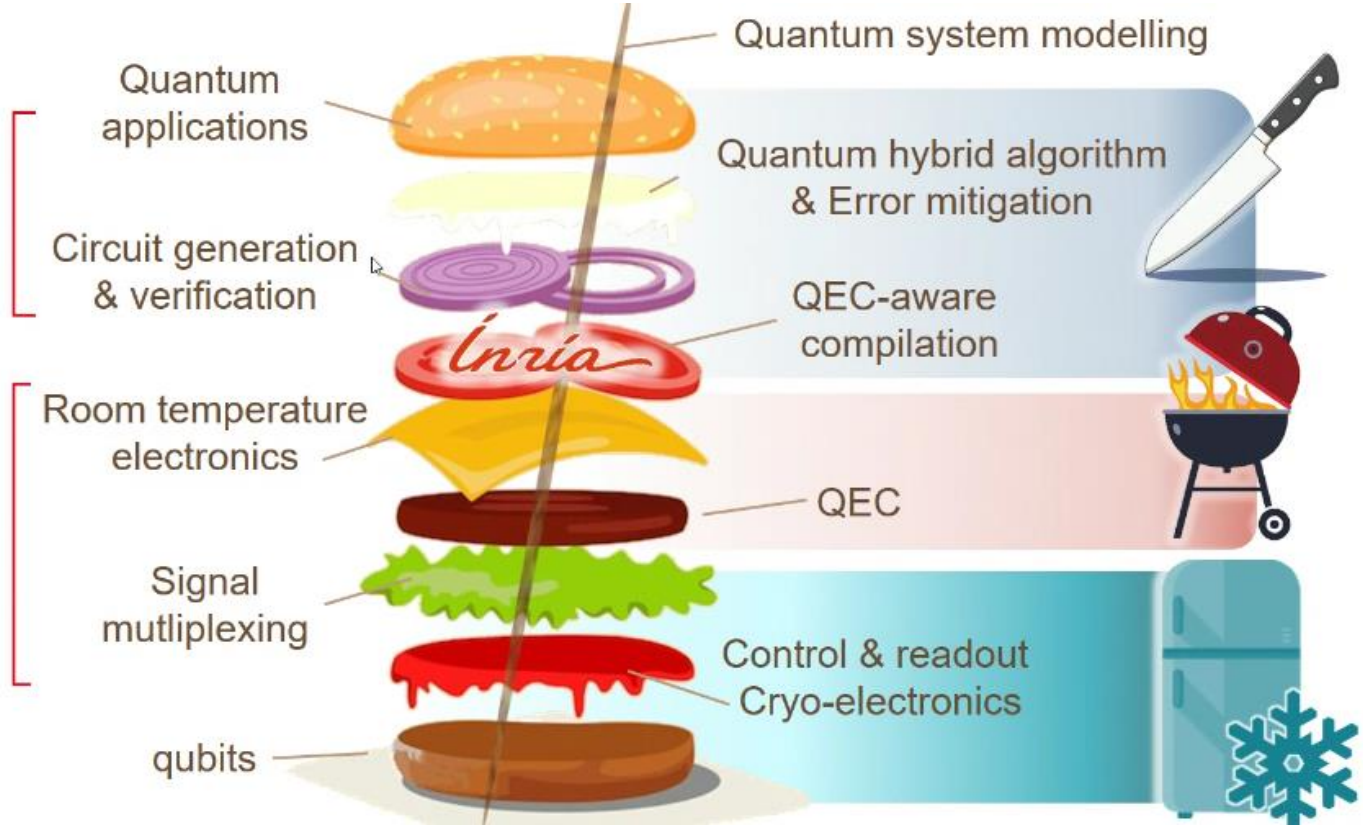


Figure 884: all qubit technologies will require QPU interconnect at some point. Some may be able to create 100 logical qubits (black triangle) on a single monolithic QPU, other will need to interconnect multiple QPUs with either microwave or photonic interconnect solutions creating entanglement resources between qubits from these QPUs. These thresholds are approximations based on vendor public roadmaps. (cc) Olivier Ezratty, July 2024.

This figure points out the dependencies between QPUs and interconnect solutions to scale QPUs. The stakeholders recognize the key role of the ecosystem in building state-of-the-art interconnected QPUs

THE CURRENT PARADIGM OF THE QPU ECOSYSTEM COULD EVOLVE DUE TO INTERCONNECTION



When considering the current ecosystem, we may well note that **the quantum stack and thus the ecosystem are bound to evolve** to include the specific layers enabling interconnection

Source: CEA List, 2023

BUILDING A STRONG ECOSYSTEM IN DISTRIBUTED QUANTUM COMPUTING IS THEREFORE A NECESSITY…

The Strength of the ecosystem

- Trough AQADOC, the ecosystem is going to structure itself to build **the layers of interconnected QPUs**
- It is the job of the Lab Quantique to help the stakeholders come together to **foster new collaborations**
- Distributed quantum computing is still in its infancy compared to other parts of the quantum ecosystem, so there is little private effort and no standard open-source software. Therefore, **AQADOC is essential to stay one step ahead**

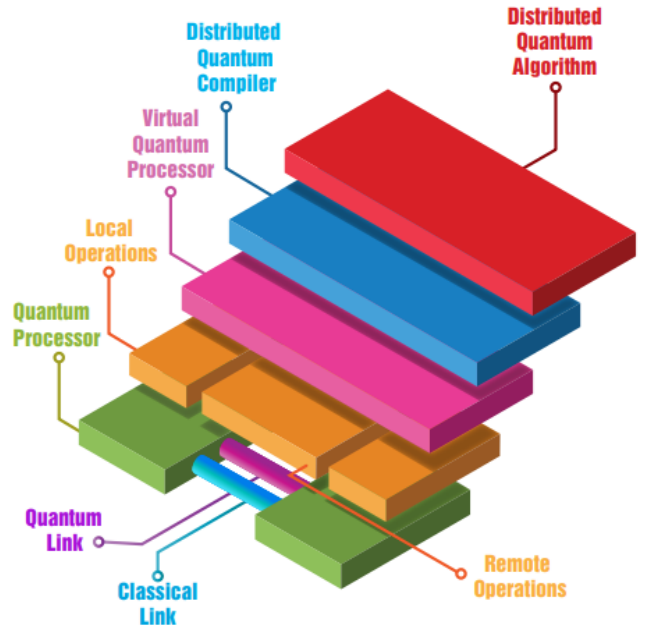
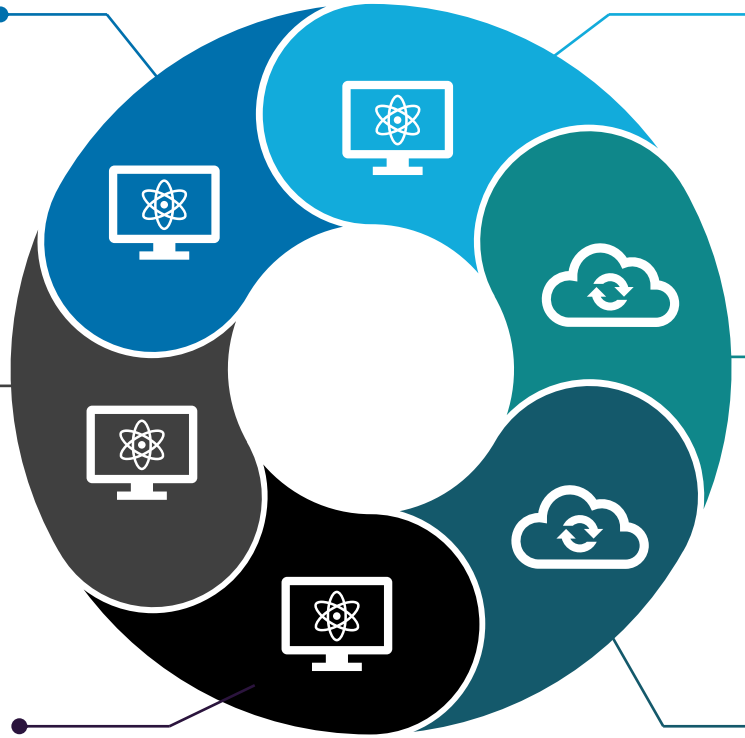


Fig. 2. A high-level system abstraction of the *distributed quantum computing ecosystem*. The lowest layer provides the communication/network functionalities and consists of quantum processors interconnected with both classical and quantum links. Thanks to the underlying communication infrastructure, both local and remote qubit operations can be executed. Hence, from a computing perspective, the two lowest levels concur to build a *virtual quantum processor* with a number of qubits that scales with the number of inter-connected physical quantum processors. The virtual processor acts as an interface for the *distributed quantum compiler*, which maps a quantum algorithm into a sequence of local and remote operations , so that the available computing resources are optimized with respect to both the hardware and the network constraints.

Cuomo, Daniele & Caleffi, Marcello & Cacciapuoti, Angela Sara. (2020). Towards a distributed quantum computing ecosystem. IET Quantum Communication. 1. 10.1049/iet-qtc.2020.0002.

… TO FACE THE SCALING UP CHALLENGE

Indeed, several hardware providers enhance their research on QPUs interconnection



IONQ

Focuses on ion-trap quantum processors and scalable quantum computing platforms, working primarily at the **quantum processor** and **local operations** layers. They are advancing trapped-ion qubits for both local and distributed quantum computing.

IONQ

Photonic

Builds a photonic quantum processor and interconnects, utilizing light-based qubits for quantum computation and communication. Their technology is based on "T defects" in silicon. Their focus is on the **virtual quantum processor** and **quantum link** layers.

photonic

IBM

The firm develops a broad range of quantum technologies including quantum processors and cloud-based quantum computing. IBM operates at multiple levels, including the **quantum processor**, **distributed quantum compiler**, and **classical link** layers.

IBM

NanoQT

It develops advanced qubit control and measurement systems, focused on optimizing the performance of quantum processors. They work on the **local operations (Nanofiber QED resonator)** and **quantum processor** layers, improving qubit stability and operations within the quantum computer

NanoQT
Nanofiber Quantum Technologies

Welinq

It focuses on quantum memory development and quantum interconnects for scaling quantum processors over long distances. It operates on the **quantum memory** and **quantum link** layers, addressing remote operations.

Welinq

Nu Quantum

It is specialized in quantum memories for quantum communication using photonic qubits, focusing on high-performance single-photon sources and detectors. It operates at the **quantum link** and **quantum processor** layers, focusing on the hardware needed for remote operations.

nu QUANTUM

Thank you!