Air Liquide

Cryogenics for Quantum Computer Upscale challenges

Global Markets & Technologies

TQCI Seminar September 5th 2024, Bois-Colombes, France
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Introduction

Air Liquide Advanced Technologies, Grenoble, the largest subsidiary of Air Liquide Group (1200 persons) specialised in low temperature cryogenics engineering and manufacturing

- Big Science & DeepTech (ITER, CERN, …)
- Space (Cryogenics for launcher or satellites)
- H2 applications
- Biogas applications
- Multiple workshops
- Test Area

SIMON CRISPEL
Quantum Technical Road Map - Air Liquide Advanced Technologies

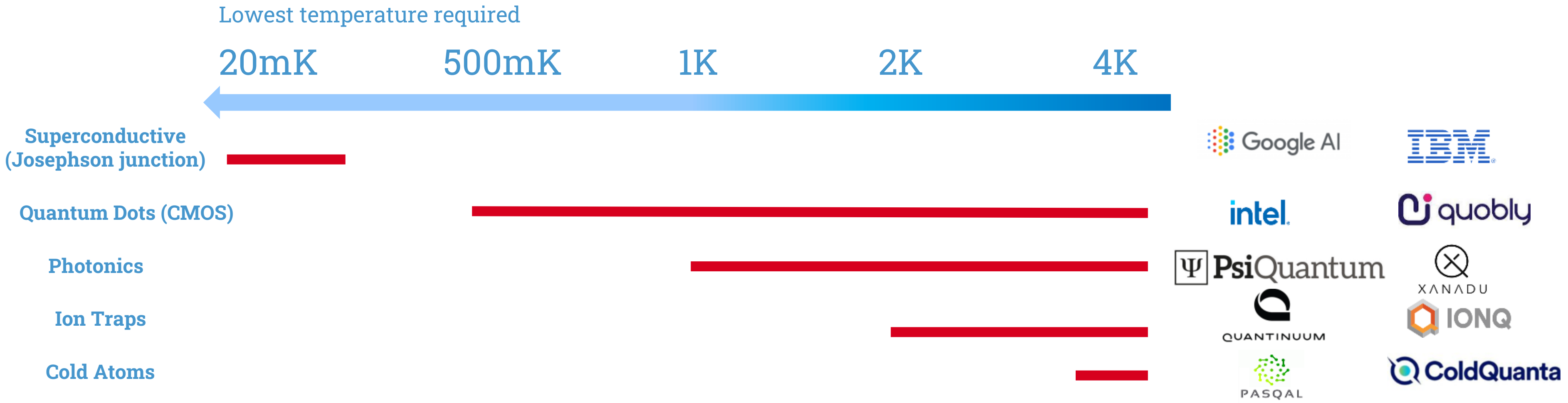
Strong connection to cryogenics academic experts (Institut Néel-CNRS, CEA Grenoble and Saclay)

Agenda

- Cryogenics for Quantum Computing
- Upscale solution and challenges for Cryogenics
- Focus on Cryogenic distribution design
- Summary & Conclusion

Cryogenics for Quantum Computing : Technologies

The promise is to unlock computing speed by using quantum entanglement.



Several technologies are on the run,
all requiring cryogenic temperatures.

Companies with ambitious roadmaps are working to **industrialize and up scale solution.**

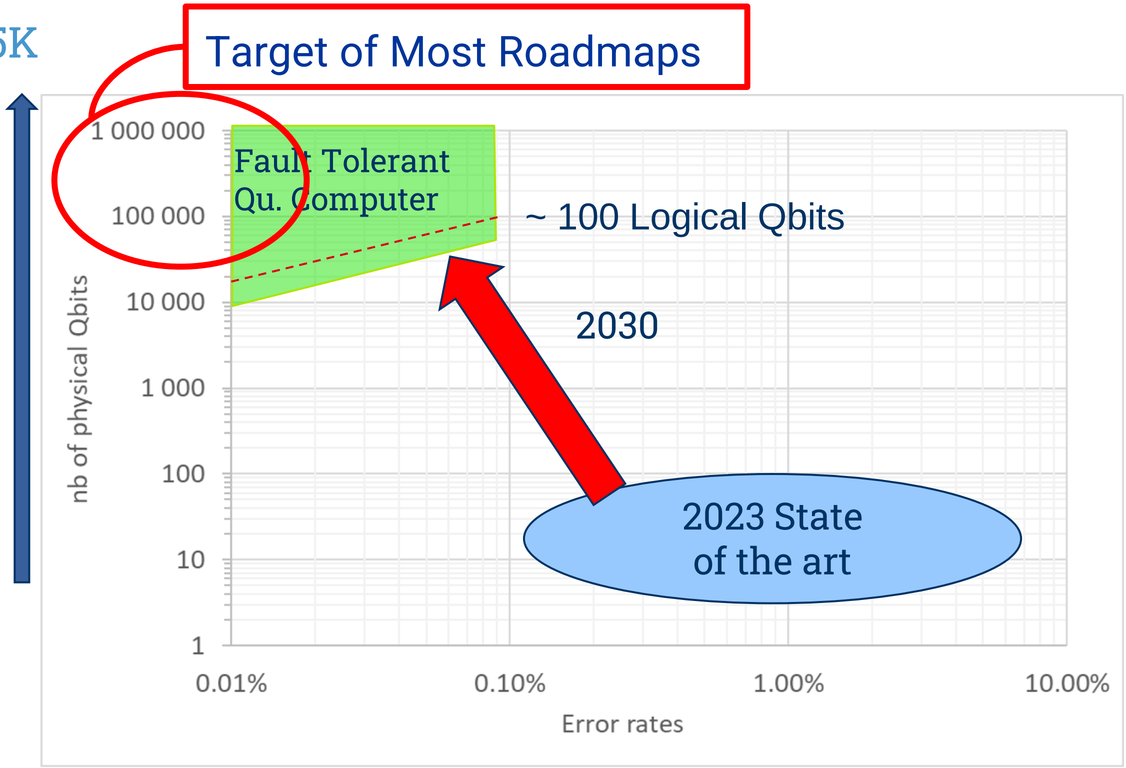
Cryogenics for Quantum Computing : Roadmaps

A **Quantum Bit** is the smallest phys. brick of Qcomputer, like a **transistor** for **classical computer**

Q-Bit makes errors: many physical Q-bits to get one logical Qbit

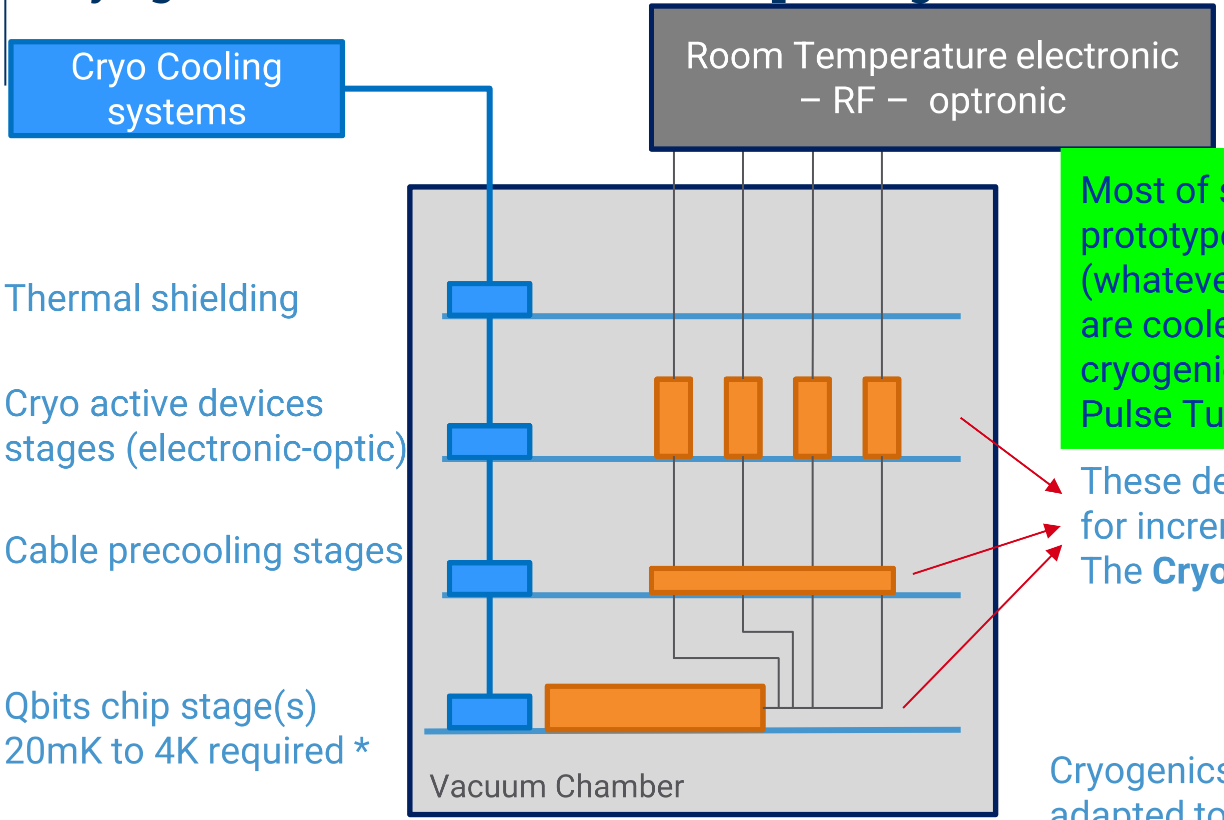
Decreasing error rates reduced the number of required physical Qbits

Cooling power is linked to the number of **physical Qbits**.



The challenge is to increase the number of physical qbits and reducing the error rates by 2030 (~100 000 to 1 000 000 Qbits)

Cryogenics for Quantum Computing : Quantum computer module



Most of small scale prototype cryostats (whatever Quantum techno) are cooled down with local cryogenic systems (Ex : Pulse Tube)

These devices have to be easily **replaceable** for incremental improvement or maintenance: The **Cryomodule** needs a **dedicated design**

Cryogenics cooling systems have to be adapted to the **specific needs** (Power, Temperature, integration)

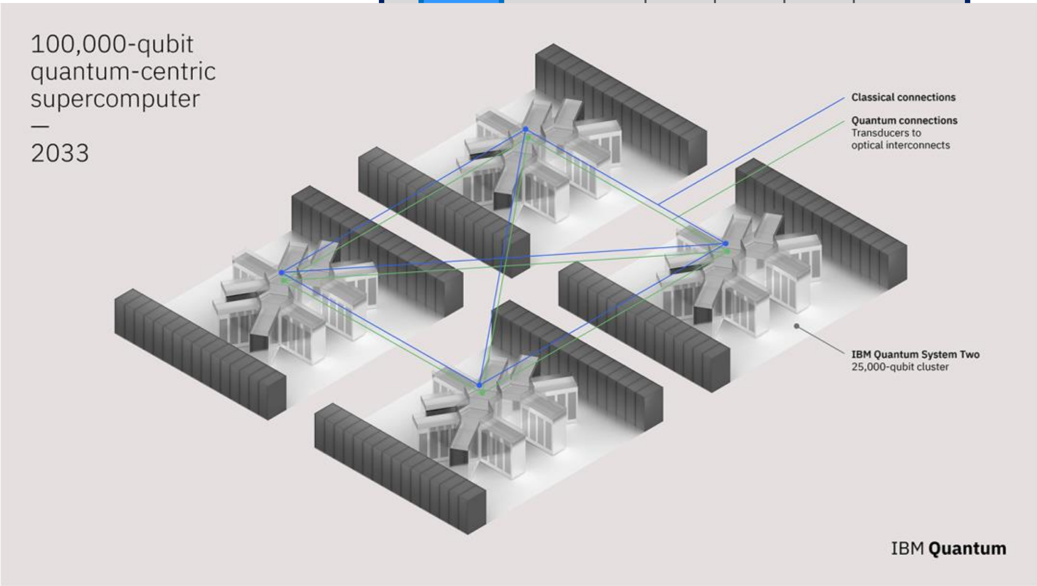
(*) depending of technology used

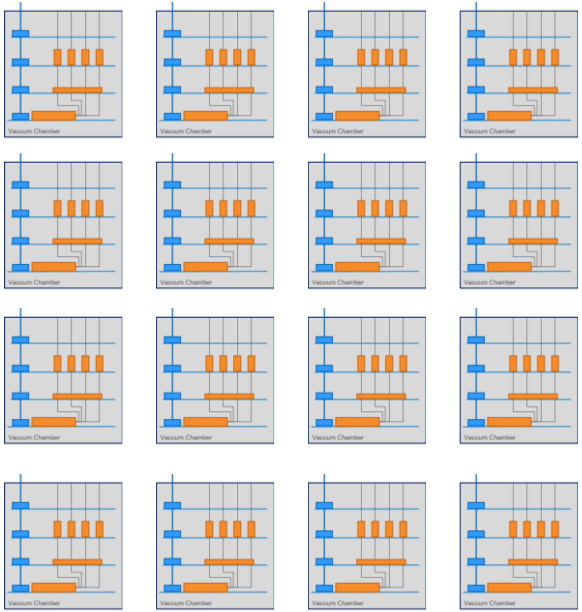
Upscale challenges for Cryogenics

Cryo Cooling systems

Room Temperature electronic – RF – optronic

A quantum computer requires many modules of this kind to reach a high number of Qbits





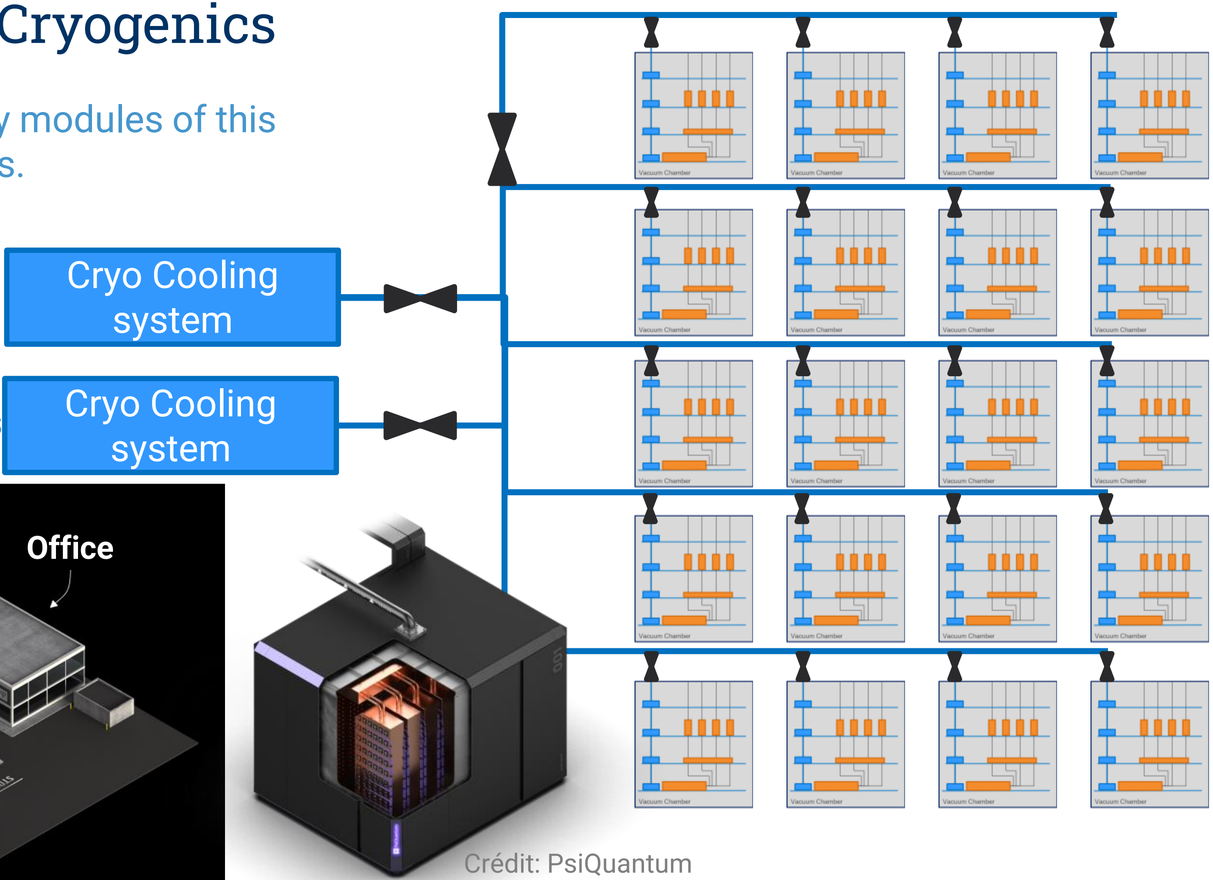
Crédit: IBM

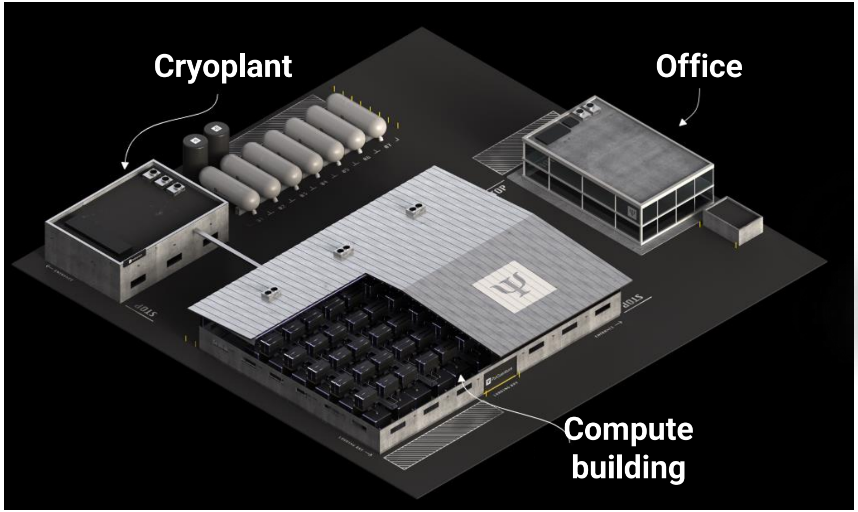
Upscale challenges for Cryogenics

A quantum computer requires many modules of this kind to reach a high number of Qbits.

Cooling system has to be:

- **Efficient**
- **Reliable** – allow redundancy
- Allow module **maintenance**
- **Extend** the number of modules





Crédit: PsiQuantum

Valves & cryogenic lines need dedicated cooling power.

Scientific applications inspiration

A distribution with

1) Few cryomodules (Tarla):

2 modules – 1 control cold box

Cryomodules ~ 200 Wex@4.5K

Helial Refrigerator ~ 250 Wex

Distribution efficiency ~ 80%

2) Numerous cryomodules (Spiral 2):

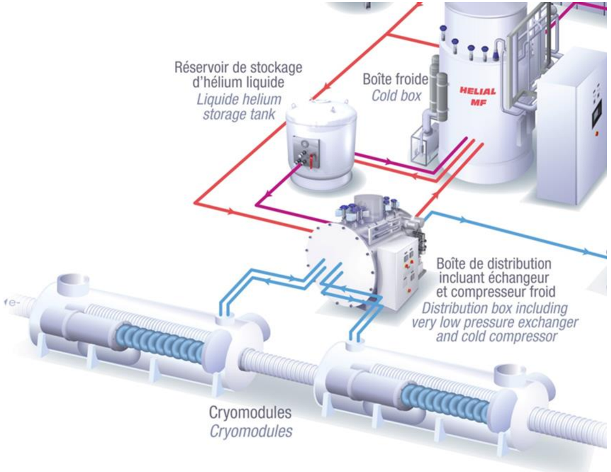
19 modules – 19 control boxes

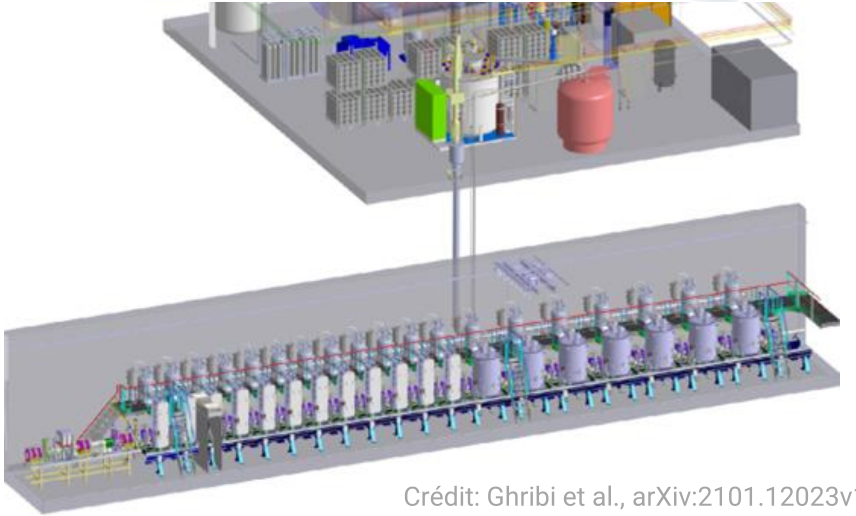
Cryomodules ~ 400 Wex

Helial Refrigerator ~ 1200 Wex

Distribution efficiency ~ 33%

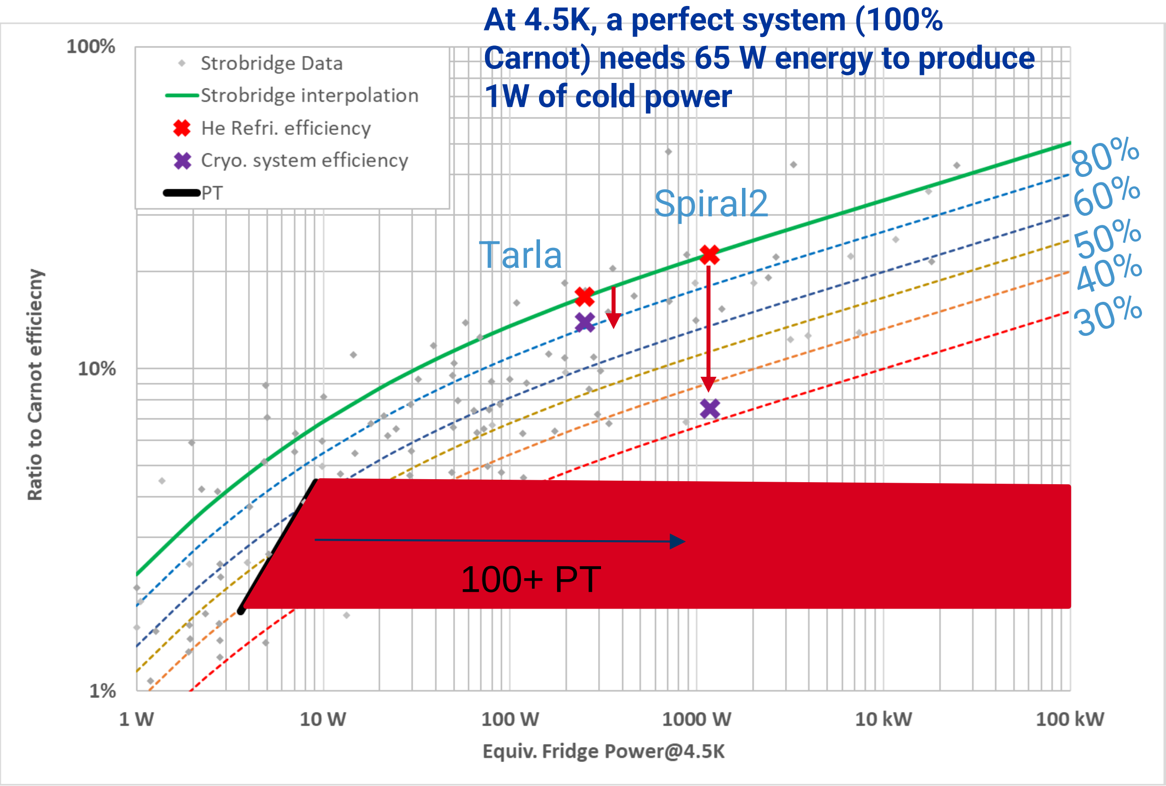
=> Choice of distribution impacts the fridge operation and specification





Crédit: Ghribi et al., arXiv:2101.12023v1

Cryogenic distribution design as a key challenge



Distribution can lower significantly the cryo. system Carnot efficiency

Distribution efficiency

Standard Pulse tube have distrib. efficiency ~100%

but with the upscale a **Helium Fridge** with a distribution is still **more efficient**

Cost of operations can be much less important

Summary of challenges

Certainties 1. Cooling Power will increase => Nb of PT will become prohibitive 2. Centralised HeRU (Helium Refrigeration Unit) is intrinsically more efficient (efficiency increases with the size) 3. Reliability of large HeRU is recognised (ITER, SLAC, Neurospin) and referenced	**Challenges** 1. Integrate end-user constraints and expected current developments 2. Interface between HeRU and Cryostat 3. Overall HeRU and distribution architecture optimization => for capex and energy saving 4. Develop demonstrators or/And test infrastructure
Uncertainties - Issues 1. Quantum Cryostat development (Cabling, Cryogenic electronics, Qbit connection) 2. TCO comparison between HeRU (Helium Refrigeration Unit) and PTs to be precised but some estimates : a. Over ~100 PT, CAPEX HeRU **<** CAPEX PT b. for Large infrast., OPEX HeRU **<** OPEX PT	**Initiatives / Opportunities** 1. French Quantum Initiative for enabling technologies (many actors) 2. Initiate Feasibility study with end-users (as we use to do in scientific applications) 3. R&D Collaborations with academics

Conclusion & Outlooks

- **Quantum computing** is a **fast developing** technology with a need of **high cryogenic power**
- The **efficiency** of the overall **cryogenic system** will depend on the **complexity** of the **cryo distribution**
- The **cryogenic system** has to be **thought** as a whole **from cryomodule to cryoplant** to get the best trade-off between **functionalities and efficiency**
- The development of **quantum computing requires the expertise of the cryogenic community from mK fridge up to Liquid Helium plant**

Advanced Technologies

Extreme cryogenics for big science, fusion, quantum computing and the industry

Probing the origins of matter, mastering new energy sources such as fusion, solve problems that are too complex for conventional computers: the possibilities offered by cryogenics are immense. This is why Air Liquide, an expert in very low temperatures, is a recognized partner in scientific research. For laboratories, large-scale scientific equipment, quantum computing, but also the industry, we design and supply systems for cold production, storage and distribution of cryogenic fluids (helium, hydrogen, oxygen, nitrogen and LNG notably), liquefaction, boil-off reliquefaction as well as associated gases purification technologies. Today, we offer our customers a complete range of solutions to push back the frontiers of science and unlock industry progress.

From **300 Kelvin** (ambient air temp.) **to less than 10 millikelvin** (-273.14°C)

The largest helium liquefiers manufactured in the world in Qatar and for the ITER project in France

Turbo-Brayton for LNG boil-off reliquefaction and biomethane liquefaction

Since 2012, **more than 200 units sold**

Thank you for your attention