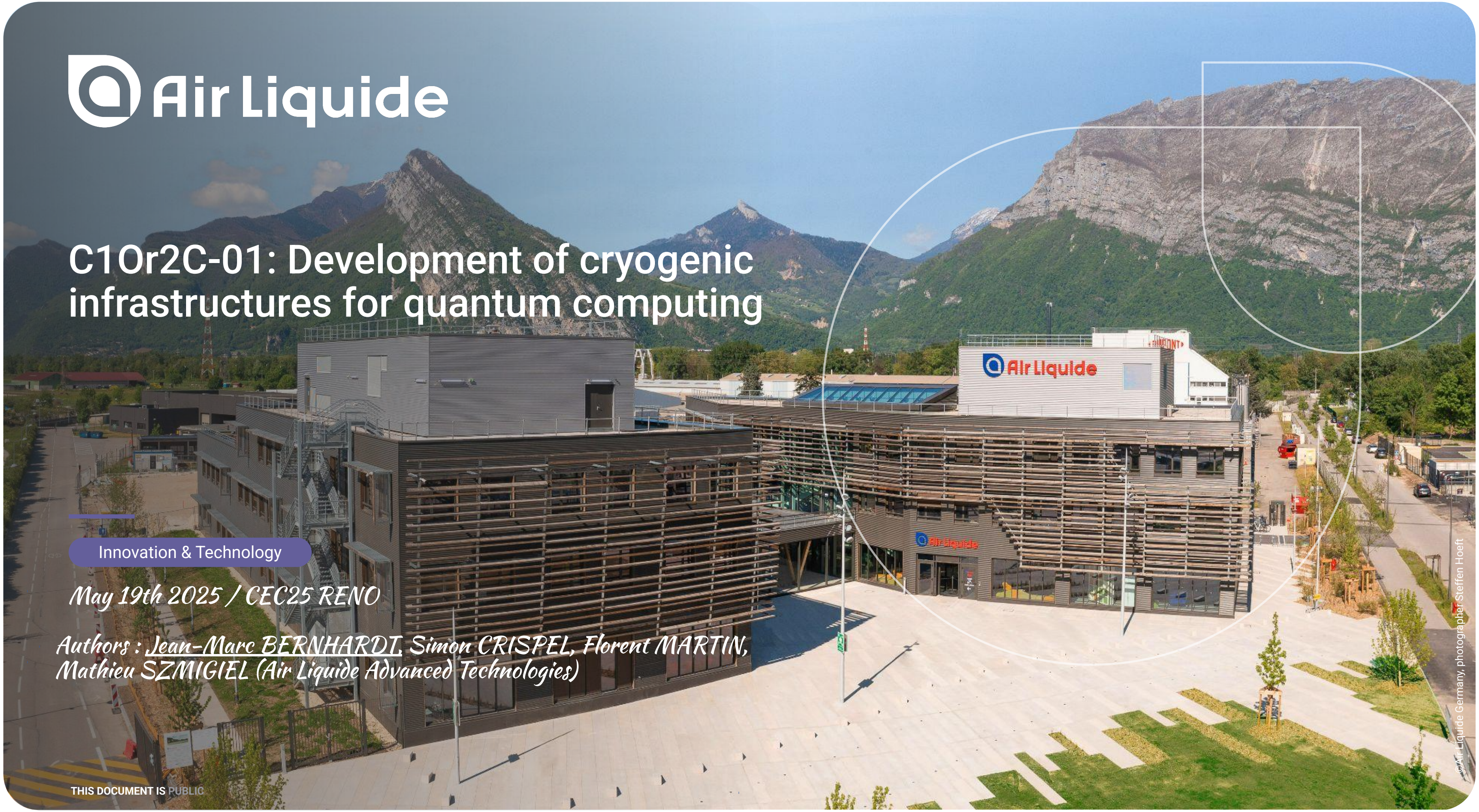

Air Liquide

C1Or2C-01: Development of cryogenic infrastructures for quantum computing

Innovation & Technology

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Summary

1. What cryogenics for scaling quantum computing
2. Scale-up Challenge for Dilution Refrigerators
3. Scale-up Challenge for Cold Distribution
4. Development pathways

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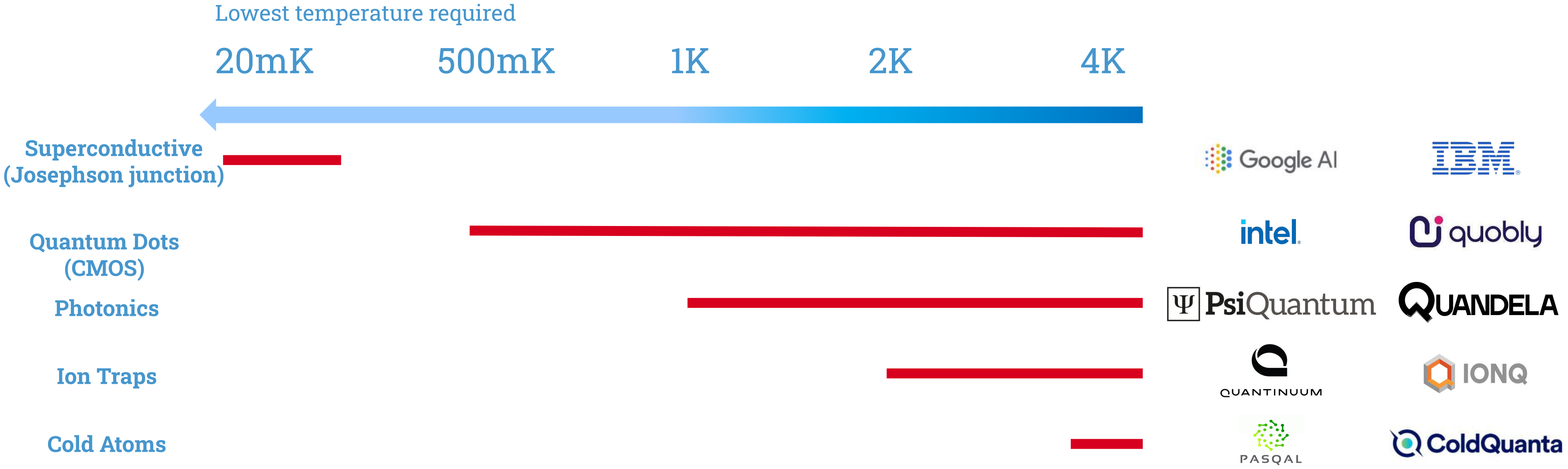
1- Cryogenics for Quantum Computing : Technologies

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.**

1- Cryogenics for Quantum Computing : Roadmaps

Equiv. Power@4.5K
Tens of kW

kW

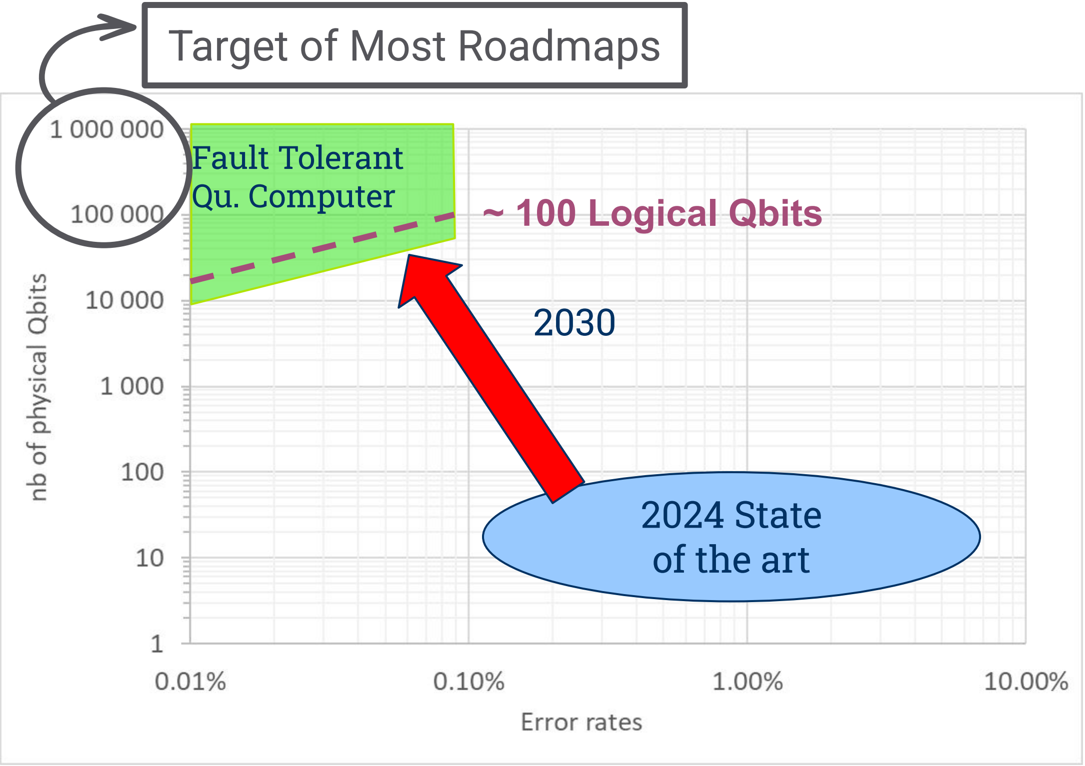
W

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.

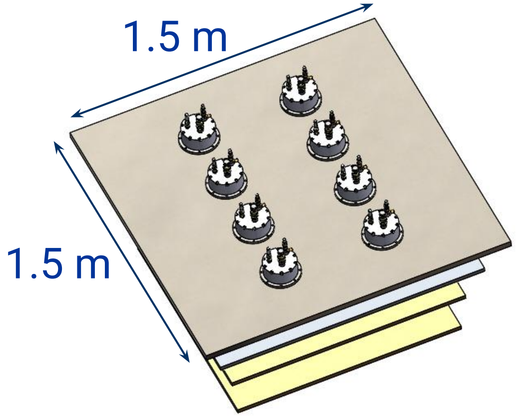
Decreasing error rates reduced the number of required physical Qbits.

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



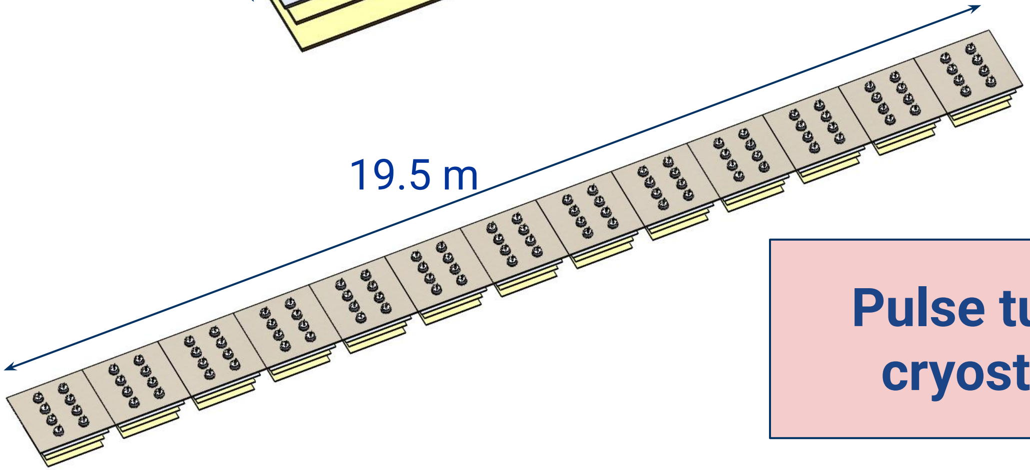
The challenge is to increase the number of physical Qbits and reducing the error rates by 2030 (~100 kQbit to 1 MQbits).

2- Scale-up Challenge for Dilution Refrigerators (DR) : Cryostat size



Example of a DR square design with 8 PT Cryomech 425.

⇒ ~ 22 W@4K + 0.44 kW@45K

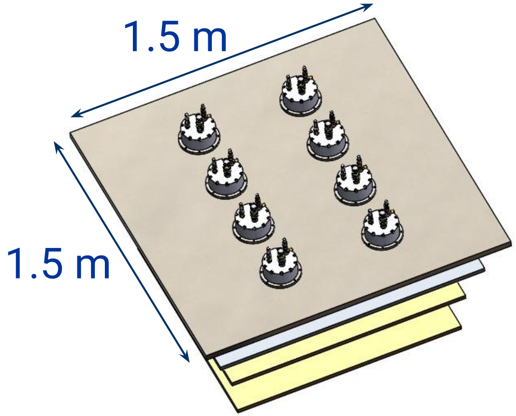


13 modules with **104** PTs in total.

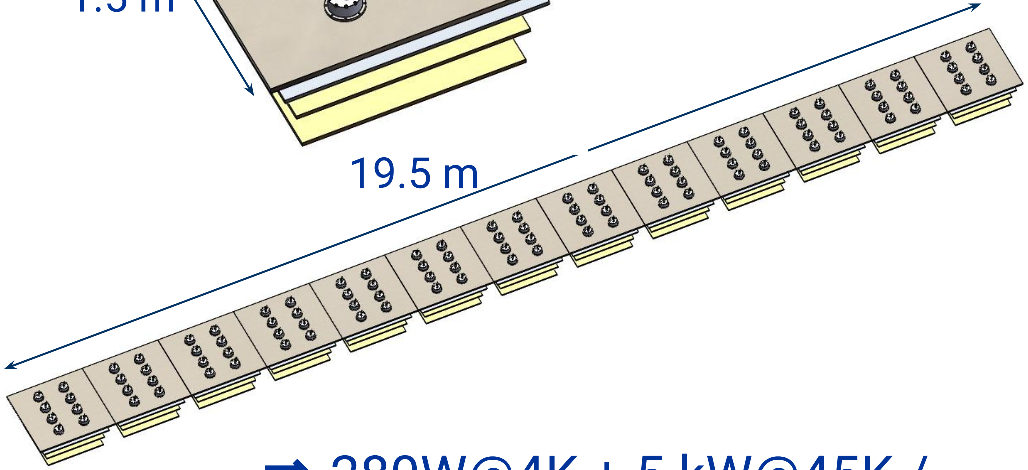
⇒ ~ 280 W@4K + 5 kW@45K

Pulse tubes are very structuring for cryostats (interface and internal)

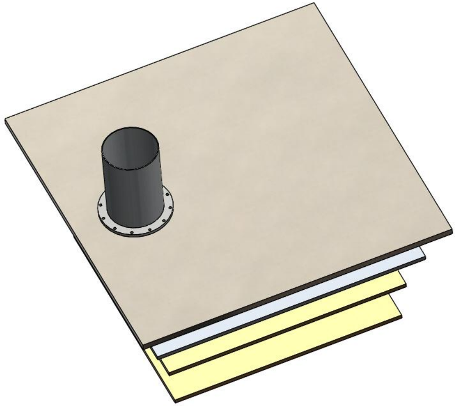
2- Scale-up Challenge for Dilution Refrigerators (DR) : Cryostat size



⇒ 22W@4K + 0.44kW@45K / **108 kW elec.**



⇒ 280W@4K + 5 kW@45K / **1 350 kW elec.**



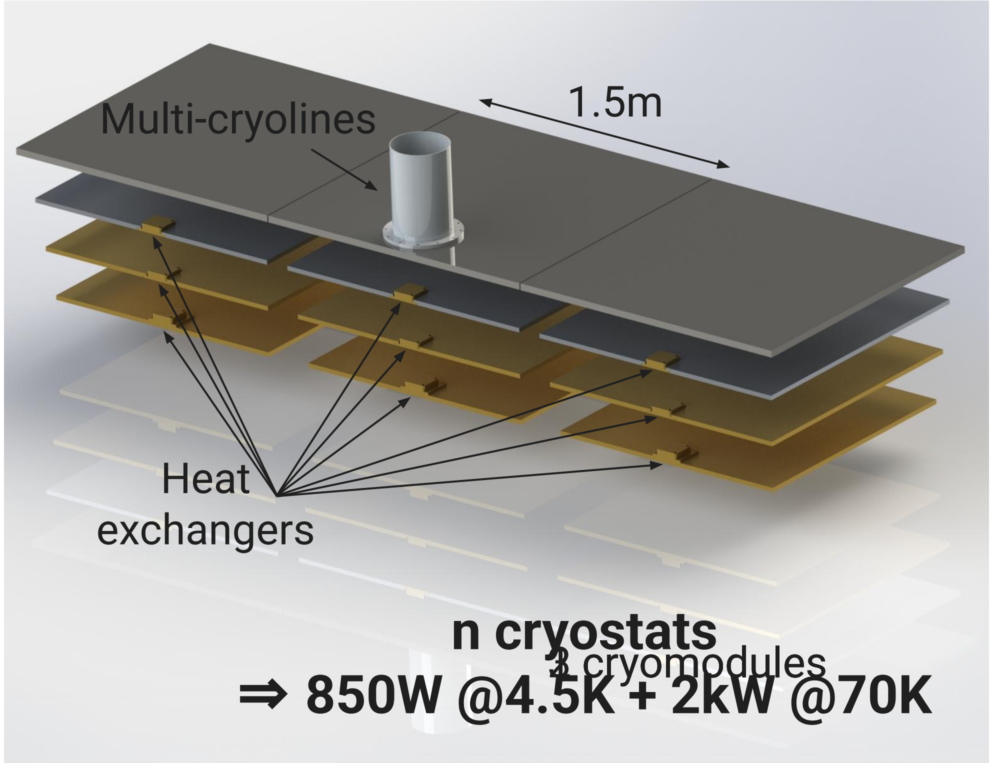
Liq. Helium based architecture with a single cryoline

⇒ **850 W@4K + 2 kW@70K / 350 kW elec.**

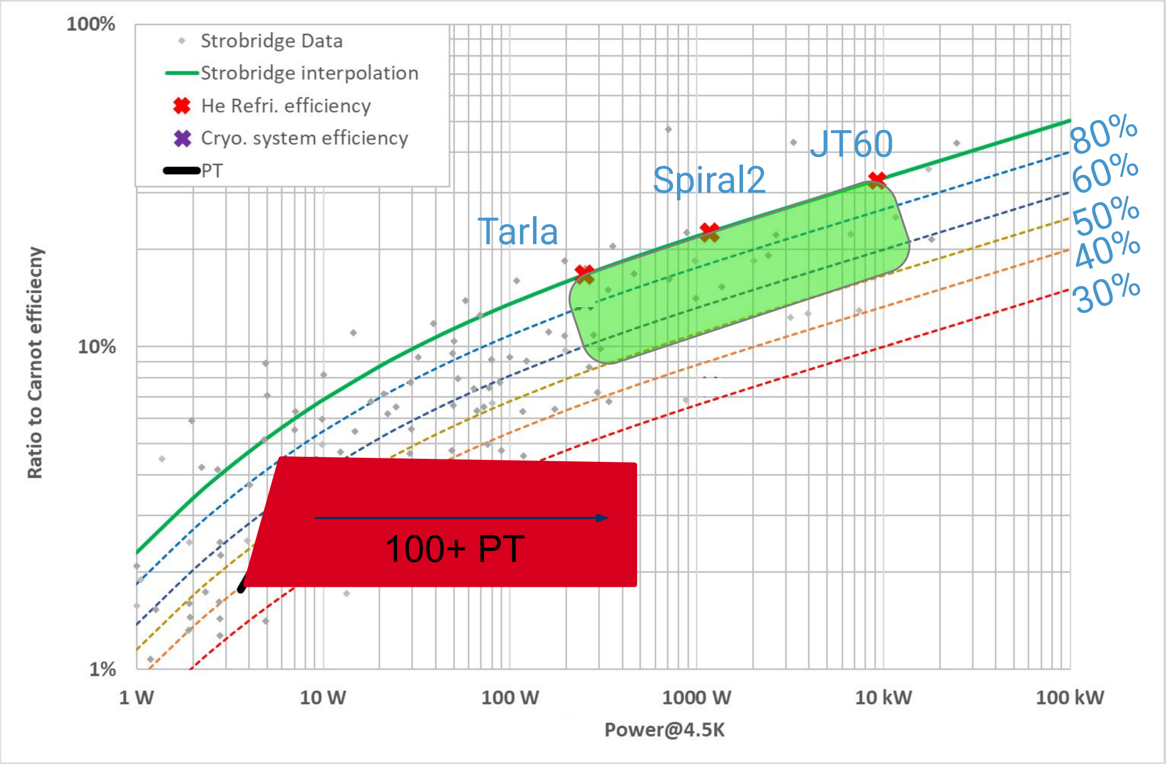
2- Scale-up Challenge for Dilution Refrigerators (DR) : Internal distribution

AL-aT is developing Interface Heat exchangers to provide required cooling powers at required temperatures with a very reduced footprint.

This first version will be tested at low temperature in CEA Test infrastructure in configuration similar to quantum cryostats.



3- Scale-up Challenge : Efficient Cryogenic Distribution



Distribution can lower significantly the Carnot efficiency of the system

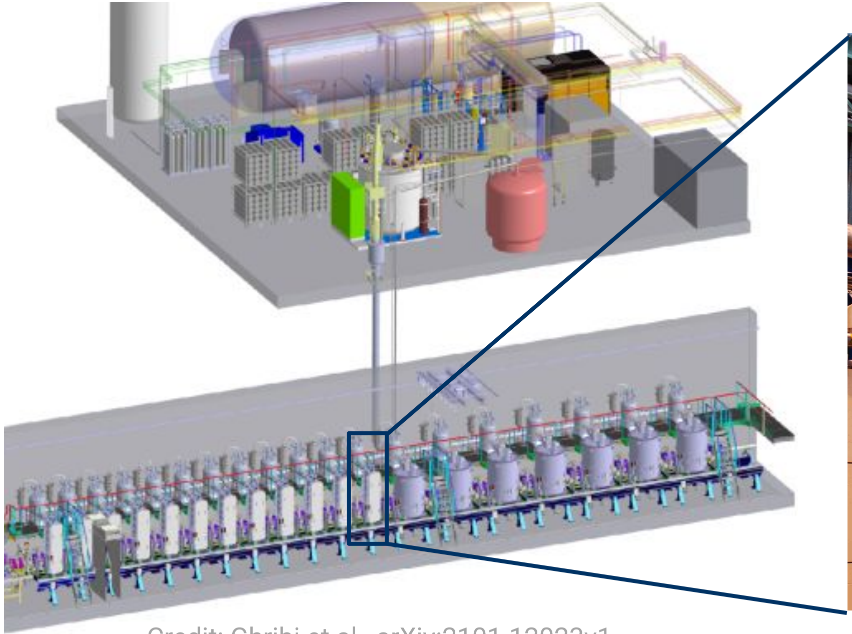
Distribution efficiency

Standard Pulse tube have distrib. efficiency ~100%

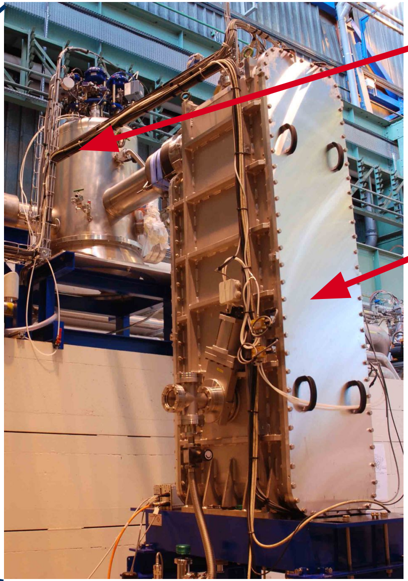
but with the upscale a **Helium Fridge** with a distribution is **more efficient**

3- Scale-up Challenge : Distribution to multiple cryostat

Example of **Linear distribution system** with LHe : Spiral2 (GANIL) with 19 cryostats with 19 Distribution Boxes (DB) and a single Multi-Cryoline



Credit: Ghribi et al., arXiv:2101.12023v1



Distribution Boxes (DB) with valves, PSV, Pressure, Temperatures

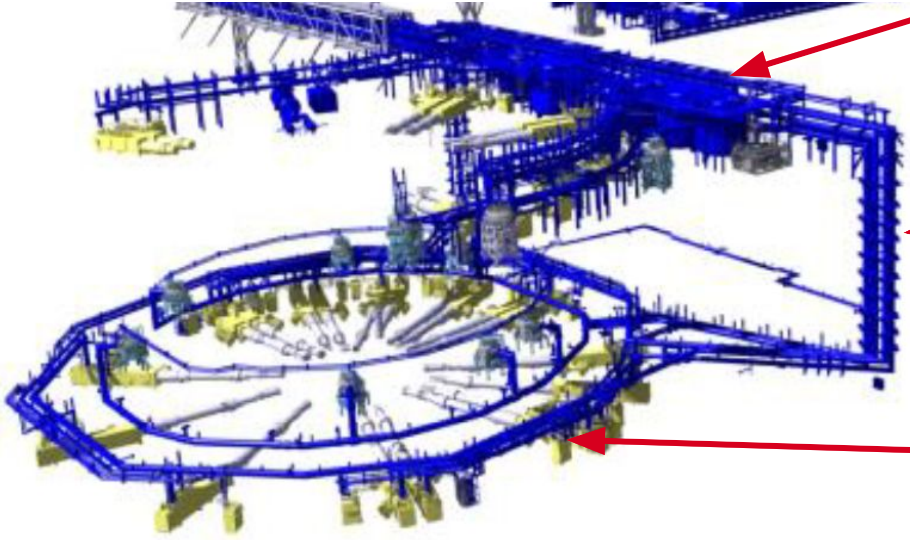
Application Cryostats :

Single or multiple Cryostat for Cavities, Magnets or **Quantum Computers**

see **C2Po3C-03** & **C1Or2C-02**

3- Scale-up Challenge : Distribution to multiple cryostat

Example of **Circular distribution system** with SHe : JT60 (10 kW@4.5K) or ITER (75 kW@4.5K) distribution with ACBs and many Multi-Cryolines



Auxiliary Cold Boxes (ACB) with **Helium circulators**, valves, PSV, Pressure, Temperatures

Multi-Cryoline for transfert and distribution

Application Cryostats :

Single or multiple Cryostat for Feeders, Cryopumps, Magnets

4- Development pathways : Scale up and make cryogenics operational for quantum technologies

Low Temperature Cryogenics :

- Key for quantum technologies
- Mostly Lab level
- No real integration effort
- Energy intensive

I. Integration of proximity cryogenics of quantum computer

II. Architecture and overall efficiency

III. Smart Operation

Development of smart Exchanger to bring cold at the user

Co-dev with cabling, cold electronics specialist and chip integrator

Smart refrigeration processes (Transient, stable and degraded modes)

Efficient machines

Systemic approach

Ultra-efficient Transfer lines

Co-dev with end user (plug and play, coupling, control software)

Cold as a Service

Thanks to :

- **Cryonext French Program**
- Partnerships with other enabling technologies
- End-users

4- Development pathways : CRYONEXT French Reasearch Program

⇒ CRYONEXT Program - 34 M€ during 6 years involving 16 academic partners and 14 industrial stakeholders

Sub-Project 1 - Cryostat Farm and new cryogenic architectures

Distribution presents a significant challenge. Therefore, it's crucial to:

- Select the **most efficient architecture** to deliver the fluid in adequate conditions to the user crysostats.
- Meticulously **manage the interfaces between distribution and usage points** (connections, thermal links, etc.), considering operational and integration requirements of the cryostats.
- **Incorporate cabling solutions** specifically designed for quantum applications.
- Consider **usage and lay-out constraints** of computing world.

⟹ A novel cryogenic architecture tailored to the unique demands of quantum computing is necessary.

Conclusion

- ★ **High interest to envision He cryogenic system for scale-up**
  - → Efficiency
  - → Compactness
  - → Reliability

- ★ **Development program (Cryonext in France) in place to address key scale-up challenges collaboratively : interface cryogenics definition and optimised architecture**

- ★ **Results of these developments will serve also other fields (Science, Fusion, Electricity transport, HPC Data Centers)**

Q&A