

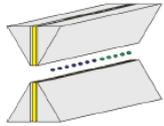
# A powerful cryogenic platform at 0.5 – 1.0 K for SPIN-Qubit quantum processor applications

Ph. Camus<sup>1</sup>, M. Davaine<sup>2</sup>, V. Doebele<sup>2</sup>, T. Meunier<sup>2</sup>, T. Trollier<sup>3</sup>, J. Vessaire<sup>1</sup>, M. Zeman<sup>1</sup>

European Cryogenics Days – University of Twente, 27-30 Oct 2025

- SPIN-Qubit development and roadmap (Quobly / CEA-LETI)
- The QuCUBE cryogenic platform
  - Requirements for 100 SPIN-qubits
  - Performances achieved
- Scale-up challenges for cryogenics
  - A 1000 physical Qubits platform
  - Going to > 1 M Qubits ?
- The Cryonext/P3 Program

## atoms



trapped ions



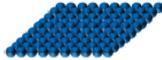
1



2



3



cold atoms



4

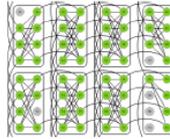


5



6

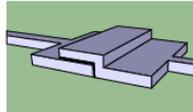
## electrons controlled spin and microwave cavities



annealing



NEC



superconducting

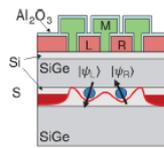


7



8

Z-Axis Quantum



silicon



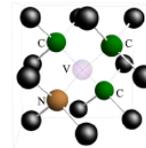
9



10



11



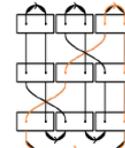
vacancies



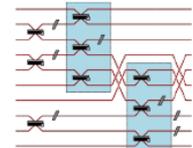
12



13



topological



photons



14



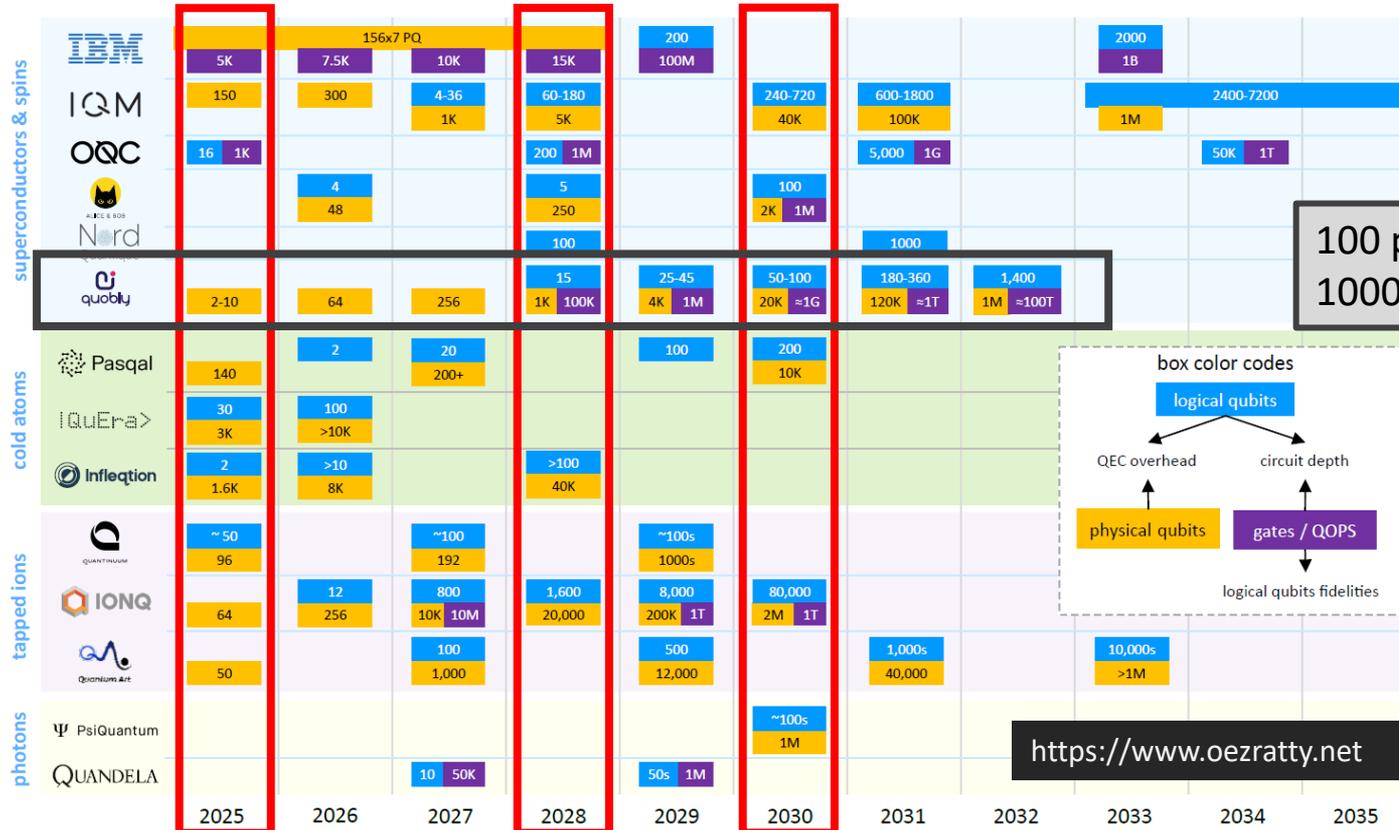
15



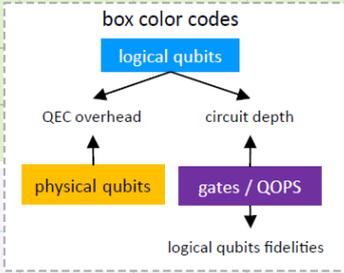
16

<https://www.oezratty.net>

# SPIN-Qubit development and roadmap



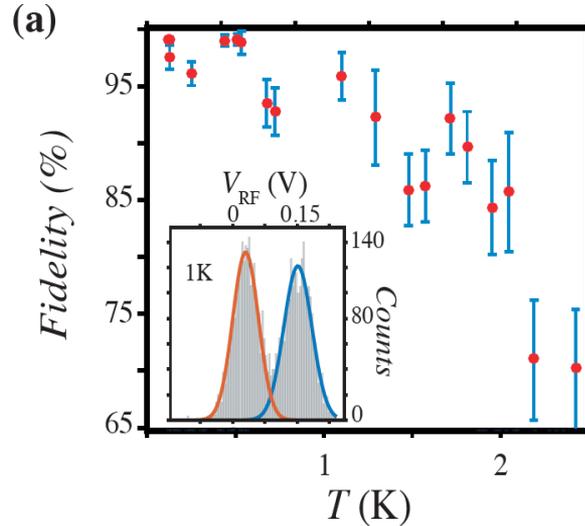
100 phys. Qubits (2025)  
1000 phys. Qubits in (2028)



<https://www.oezratty.net>



Dilution fridge used for spin qubit measurements at Néel Institute (Mathieu Darnas thesis)



M. Urdampilleta et al.,  
Nature nanotechnology (2019)

Qubits are highly susceptible to thermal noise and decoherence.

Temperature requirements :

- **SC Qubits**                    **T < 20 mK**
- **SPIN Qubits**                **T < 1 K ( + B ~1T )**
- **Photonic Qubits**        **T < 3 K**

## Control Chip

- Cryoelectronic development (control chip)
- Quantum Error Correction codes (physical qubits)

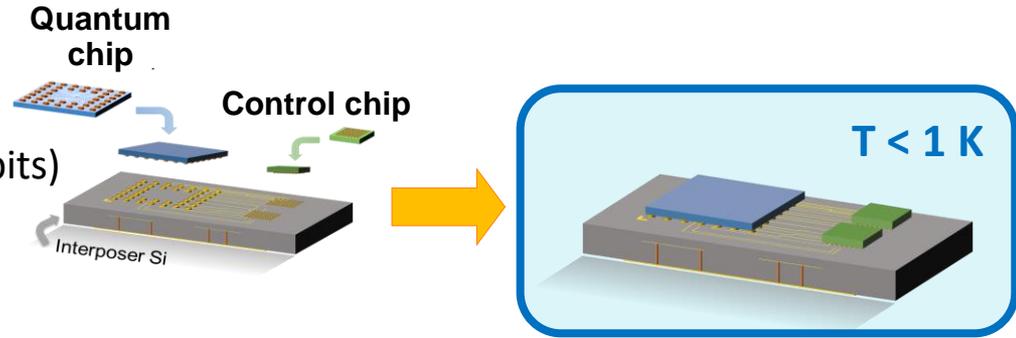
## Advantages

- minimize number of wires in the fridge
- improve process time

## Heat dissipated by the control chip

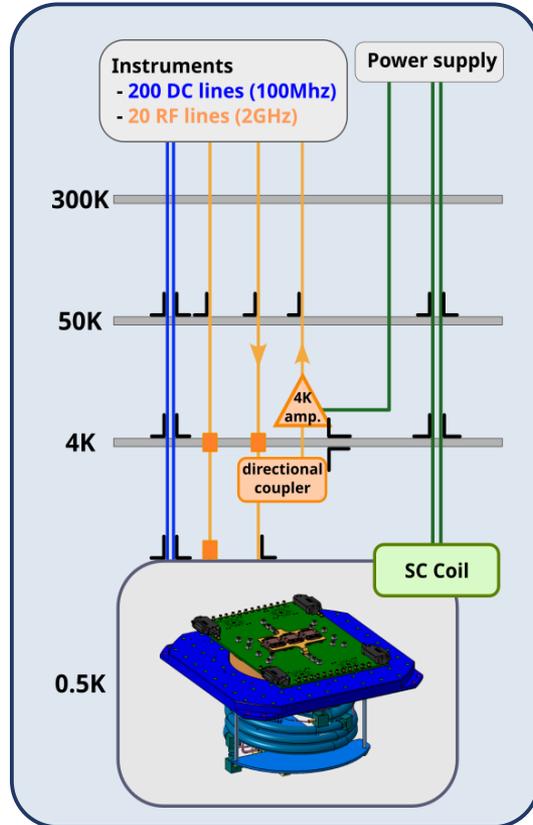
$$\dot{Q}_{tot} \approx \#MOS \times f_{operations} \times C_{load} \cdot V^2$$

$$\approx 1 \text{ mW / Qubit}$$

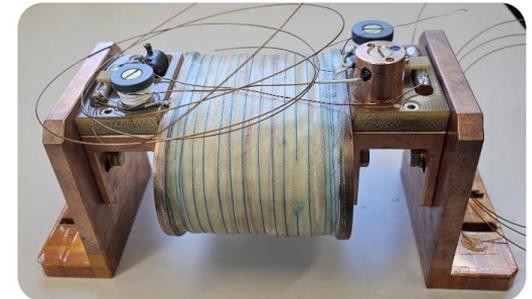
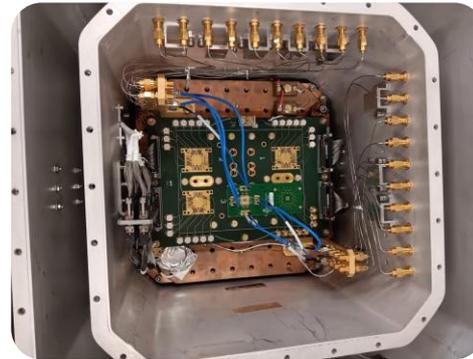


## QuCube-100 Qubits requirements

- 100 qubits  $\Rightarrow \dot{Q}_{tot} \approx 100 \text{ mW}$
- high fidelity  $\Rightarrow T \approx 500 \text{ mK}$



- ❑ **200 DC lines** (low frequency)
  - charge manipulation
- ❑ **100-200 RF lines** (high frequency)
  - spin manipulation
  - spin readout (with DC & 4K amp)
- ❑ **1T superconducting magnet** (Zeeman splitting)
  - 2 x 10 A



*SC magnet above sample holder*

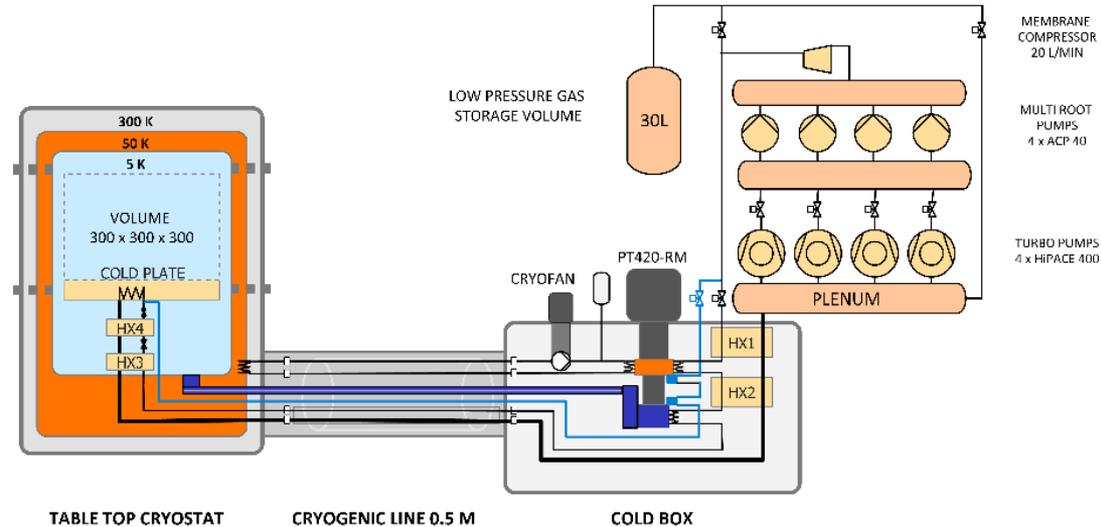
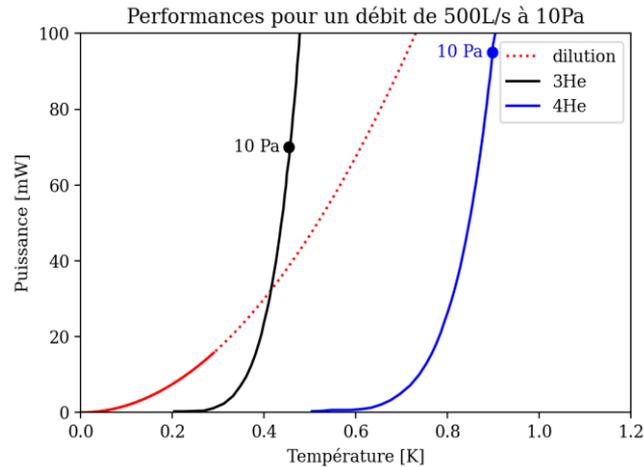
Sources of heat in the readout chain :

- Joule effect & control chip dissipation
- Thermal conductivity of wires

Stage	500 mK	4K	50 K
<b>QPC + Control</b>	100 mW		
<b>4K amplifiers (~20× 10mW)</b>		200 mW	
<b>RF cables DC lines</b>	-	75 mW	2.4 W
<b>SC cables (2×10A)</b>	< 0.1 mW	< 20 mW	1.4 W
<b>Total</b>	<b>100 mW</b>	<b>295 mW</b>	<b>3.8 W</b>

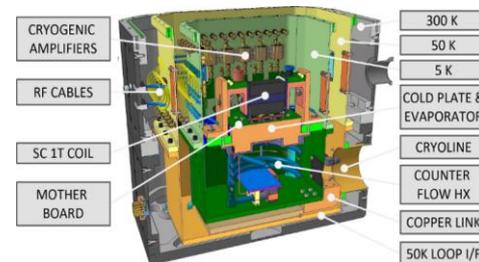
- Requirements @ 4K & 50K => compatible with a **two-stage pulse tube 2 W@4K / 30 W@50K)**
- **100 mW @ 500 mK** => **drives the design choices**

## 3He Joule-Thomson cryocooler



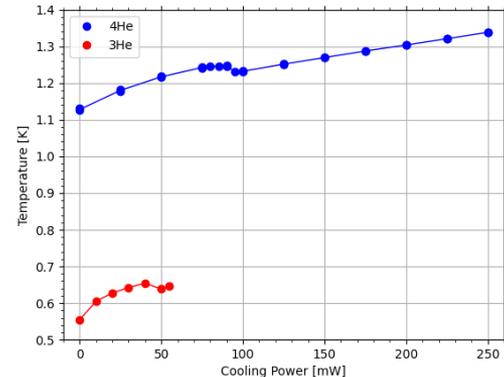
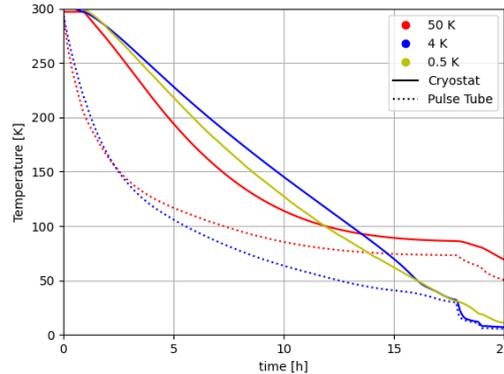
- Identical pumping speed of 500 L/s
- (ideal - whatever is the pressure < 0.1 mbar)
- Advantage to JT <sup>3</sup>He cooler above ~ 450 mK
- Commercial DR are limited to ~300 mK

100 mW @ 500 mK => n > 3.3 mmol/s @ 10 Pa (> 1200 L/s)





*The real life*



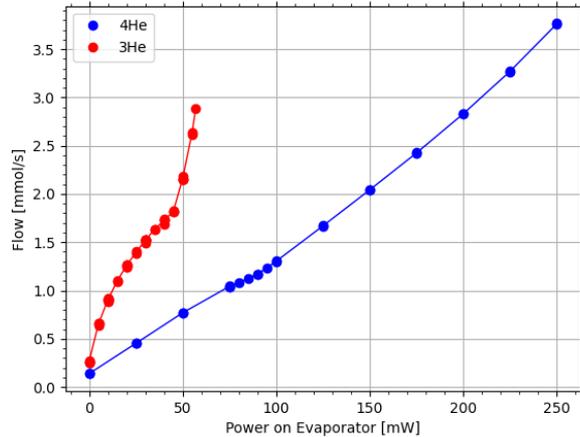
Cooldown controlled by an active cooling loop (bypass of the JT impedance)

## Helium-4 performances

- 1.23 K @ 100 mW
- $T_{min} \sim 1.12$  K
- $\dot{Q}_{max} \sim 250$  mW

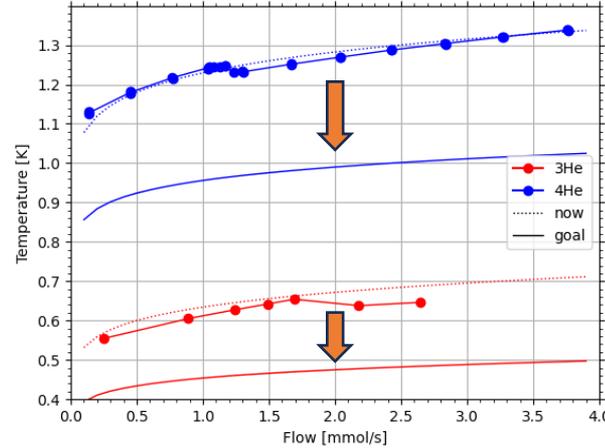
## Helium-3 performances

- 650 mK @ 50 mW
- $T_{min} \sim 550$  mK
- $\dot{Q}_{max} \sim 55$  mW

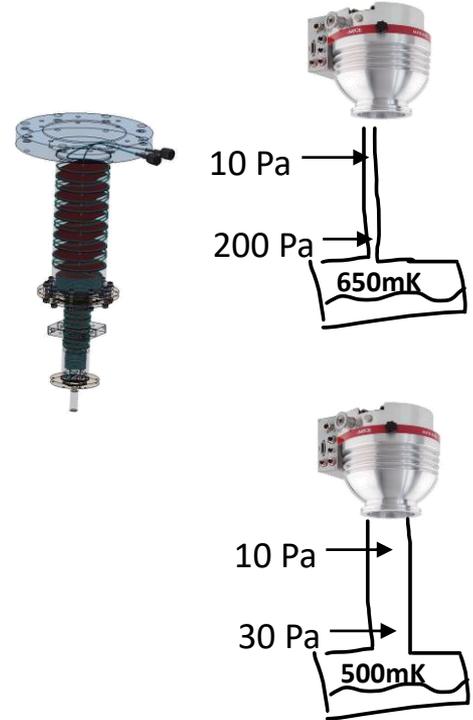


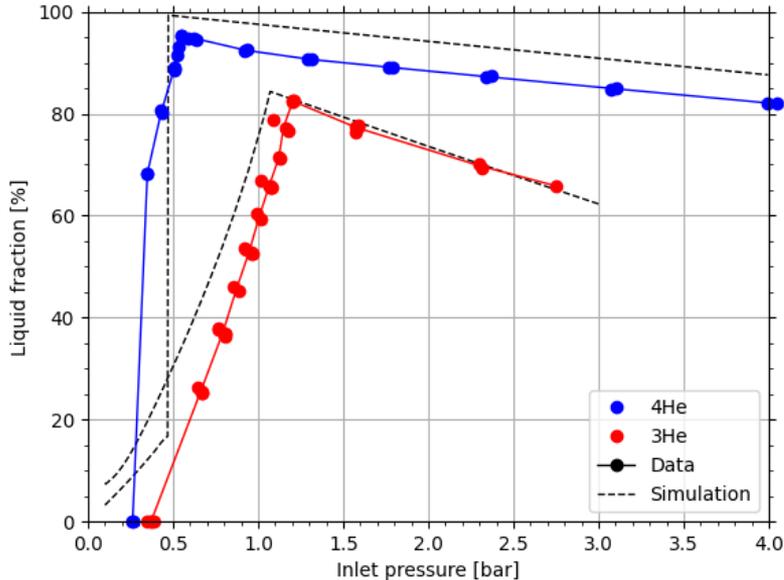
**$^4\text{He}$**   $\dot{n} \sim 3.7 \text{ mmol/s}$   
 **$^3\text{He}$**   $\dot{n} \sim 2.9 \text{ mmol/s}$

- Turbopumps power limit
- **Primary pumps conductance in  $^3\text{He}$**



Pressure loss in the low pressure recuperative HX





$$\text{Liquid Fraction} = \frac{\text{Specific Cooling power}}{\text{Latent heat}}$$

**<sup>4</sup>He:** ~95% of liquid after JT

**<sup>3</sup>He:** ~85% of liquid after JT

Coherent Results with JT loop simulations

**Liquefaction on the cold stage (inlet pressure)**

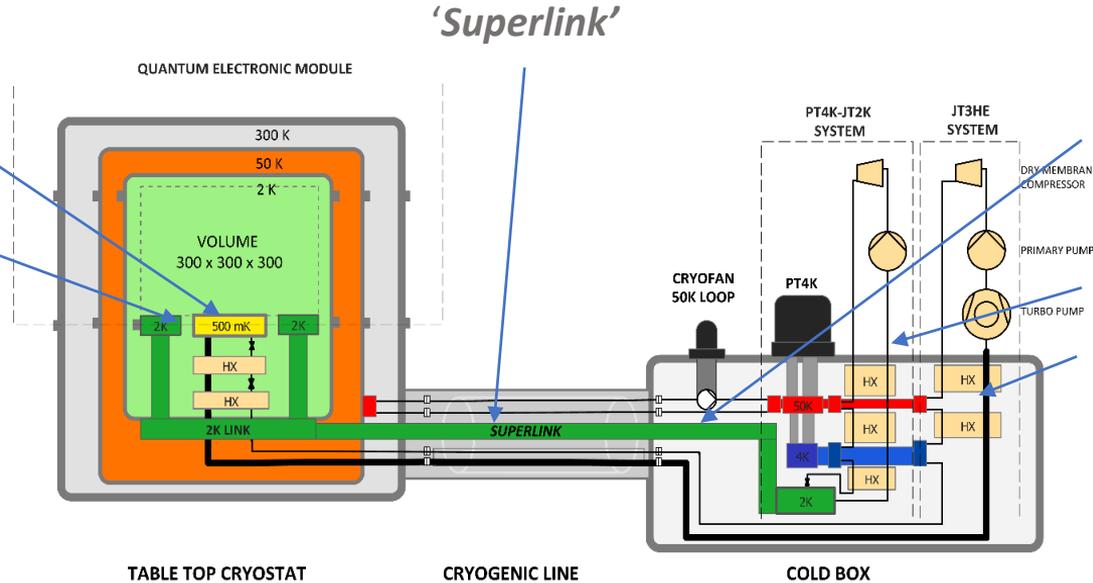
=> Use a variable throttle JT valve ?

- Building a 1000 SPIN-Qubits platform (1W @ 500 mK ?)
- Heat intercept of the control electronics @ 2K – use of a Superfluid link

Application  
cryostat

3He evaporator

JT 3He HX



GHS

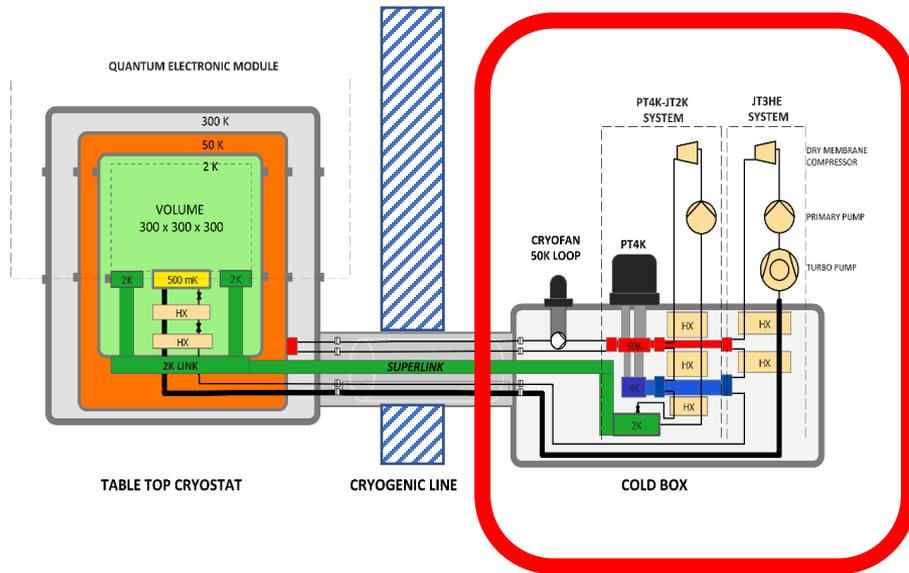
Cryogenic loop @50 K

2 stage cryocooler (one ?)

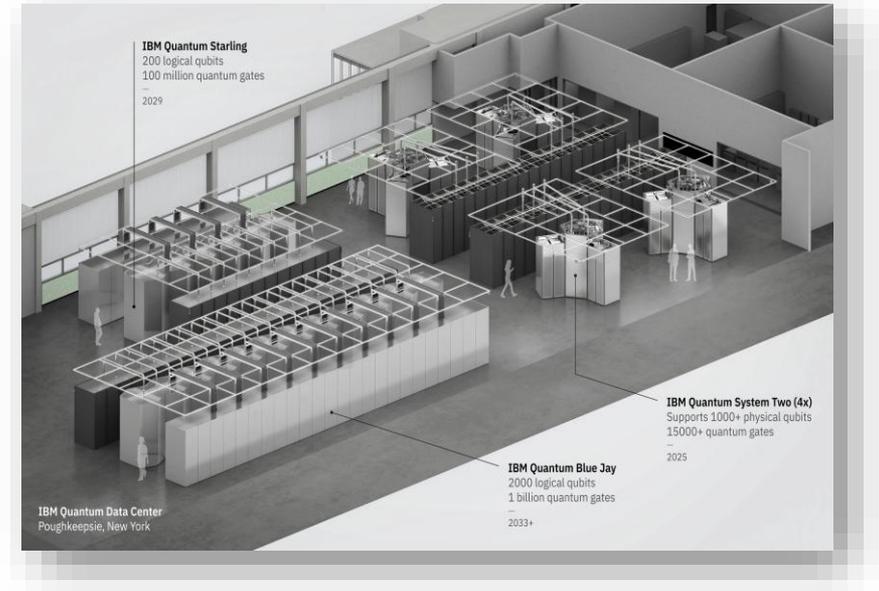
JT 4He (> 2 W @ 2K)

JT 3He (100 mW @ 500 mK)

- 1 kW @ 2 K ? (we hope a best solution from the control chip)
- Compatibility with a centralized cryogenics facility (Quantum data-centers)



**Central cryoplant interface**



*Crédit: IBM*

## Consortium Project P3 500 mK Platform

- Absolut System
- Quobly
- Radiall
- Viqthor

R&D Phase 2026-2027

Prototyping phase 2028-2029

- ✓ 100 Qubit platform in 2028
- ✓ 1000 Qubit platform in 2030

