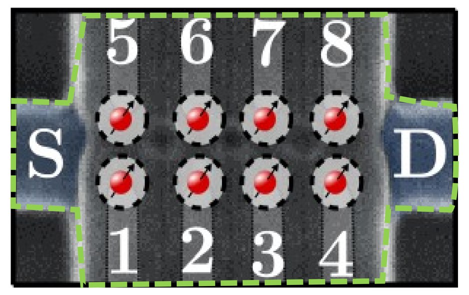
A High-Powered Cryogenic System for Sub Kelvin Electronic Applications

Victor Doebele[1], Vivien Thiney[2], Jérôme Lacipière[1], Olivier Tissot[1], Pierre Mc Cavana[1], Tristan Meunier[1], Philippe Camus[1]
1 CNRS/UGA, Institut Néel, Grenoble (France), 2 CEA, Leti, Grenoble (France)

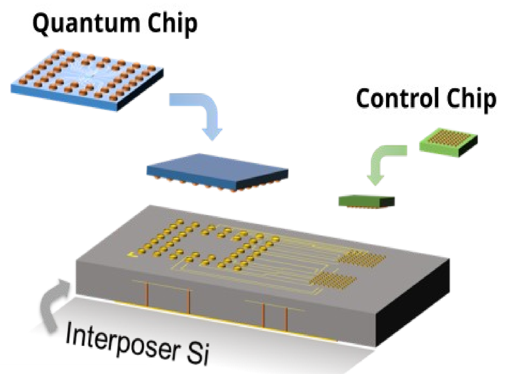
Poster Id:551

CMOS-qubit based quantum processor unit

ERC QuCube Goal: Development of a 100 qubit quantum processor unit based on silicon qubit technology
- fabrication process compatible with existing semiconductor fab
- small footprint (<1µm) favorable to high density integration
- operate at relatively high temperature



Example of 2x4 Qdots array [1]



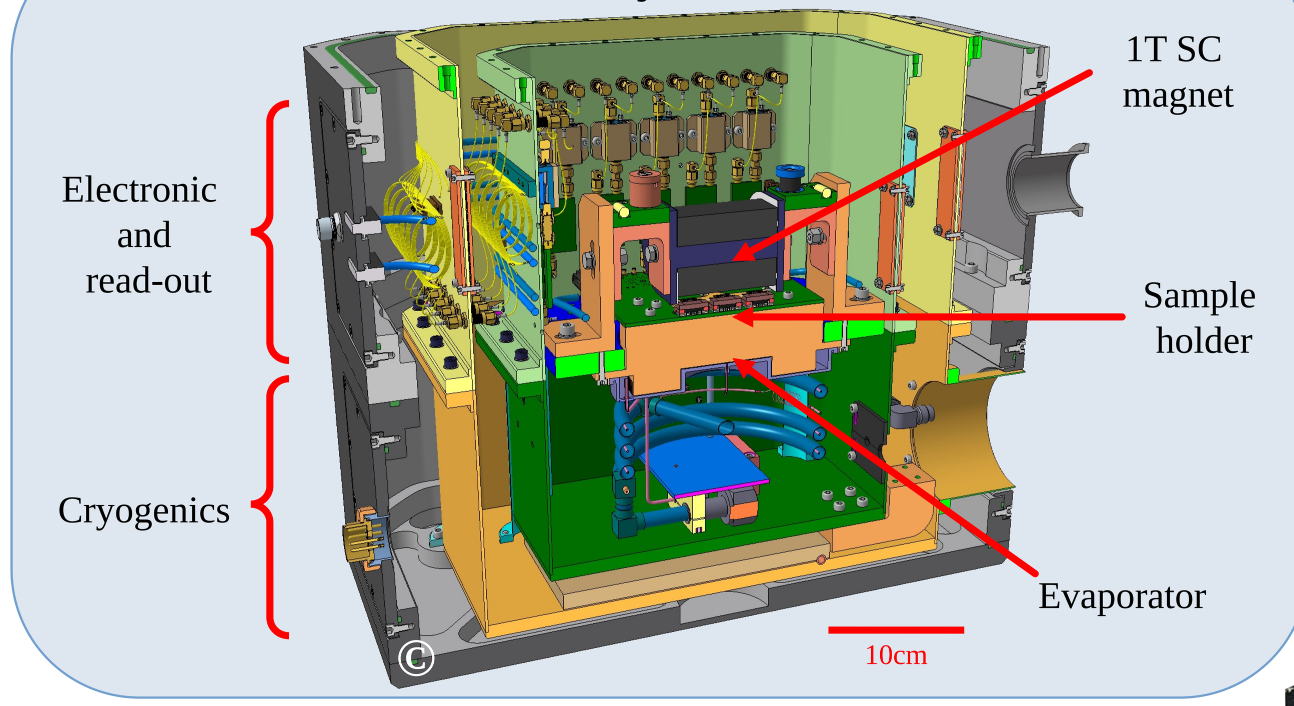
System in package [2]

- **Quantum chip:**
  - qubit information → e^- spin in a quantum dot, under magnetic field
  - below **1.5K** for high fidelity measurements [3]
- **Control chip:**
  - in situ manipulation of qbits, using cryoCMOS
  - generate heat → $\dot{Q} \sim \#_{MOS}$ x freq x $C_{load}V^2$

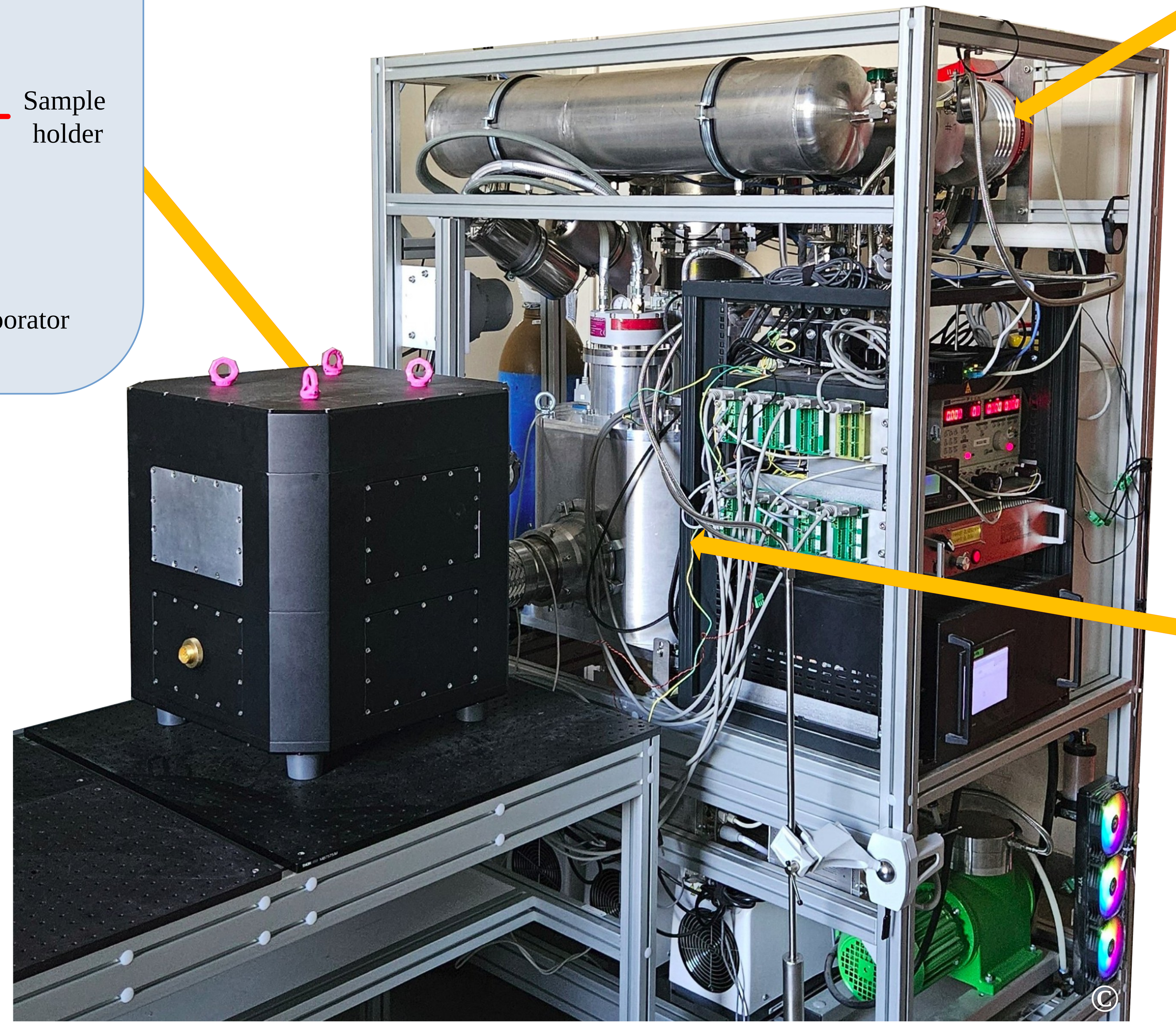
Cryogenic requirements:
- **Temperature ~ 500 mK**
- **Cooling power ~ 100 mW**

QuCube Cryogenic Architecture

Cryostat



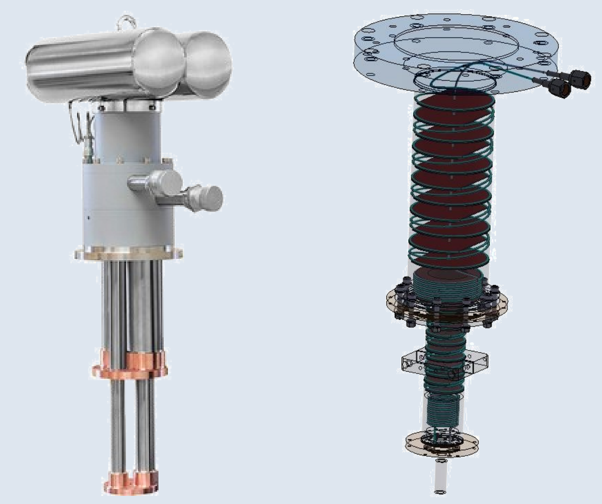
- **Prototype for 100 qubits demonstration:**
  - Joule-Thomson loop
    - using **3He** (temperature req.)
    - using **4 turbo pumps** (cooling power req.)
  - Pulse Tube pre-cooling
  - optimization of heat loads in upper stages
  - ~20L of 3He usage
- **User-friendly system:**
  - table-top cryostat
  - 25x25cm experimental surface
  - pulse tube decoupled from cryostat
  - computational unit separated from cryogenics



Gas Handling System

with Hipace400 x4

Cold Box

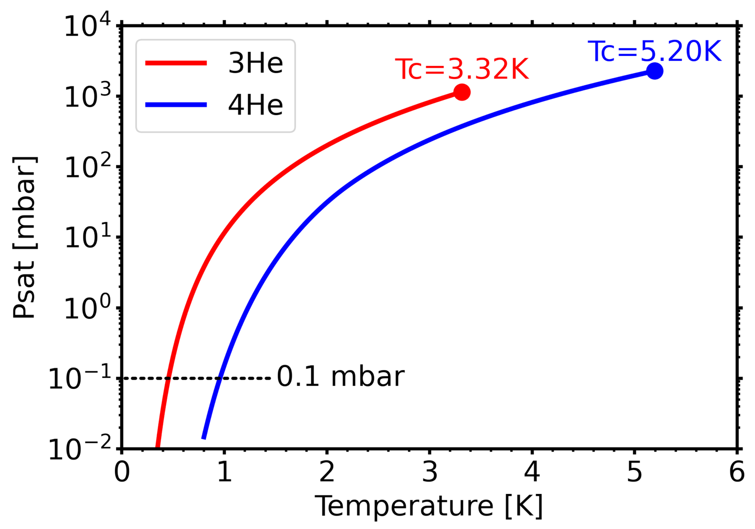


Double stage PT420 Pulse Tube

ABSOLUT SYSTEM

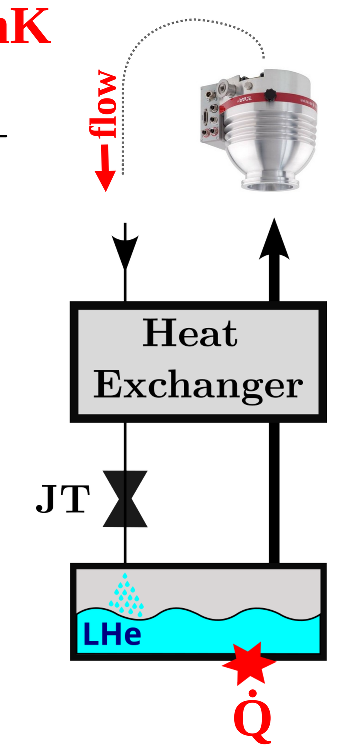
Low Pressure Heat Exchanger (70% efficiency)

How to reach sub-1K temperatures?



- Evaporative cooling by He bath pumping
  - → pressure decrease
  - → temperature decrease
- Turbo pumping (P ~ 0.1 mbar)
  - **4He → T ~ 1K**
  - **3He → T ~ 500mK**

- Continuous pumping using **Joule-Thompson cycle**
  - → bath re-filled through a JT valve

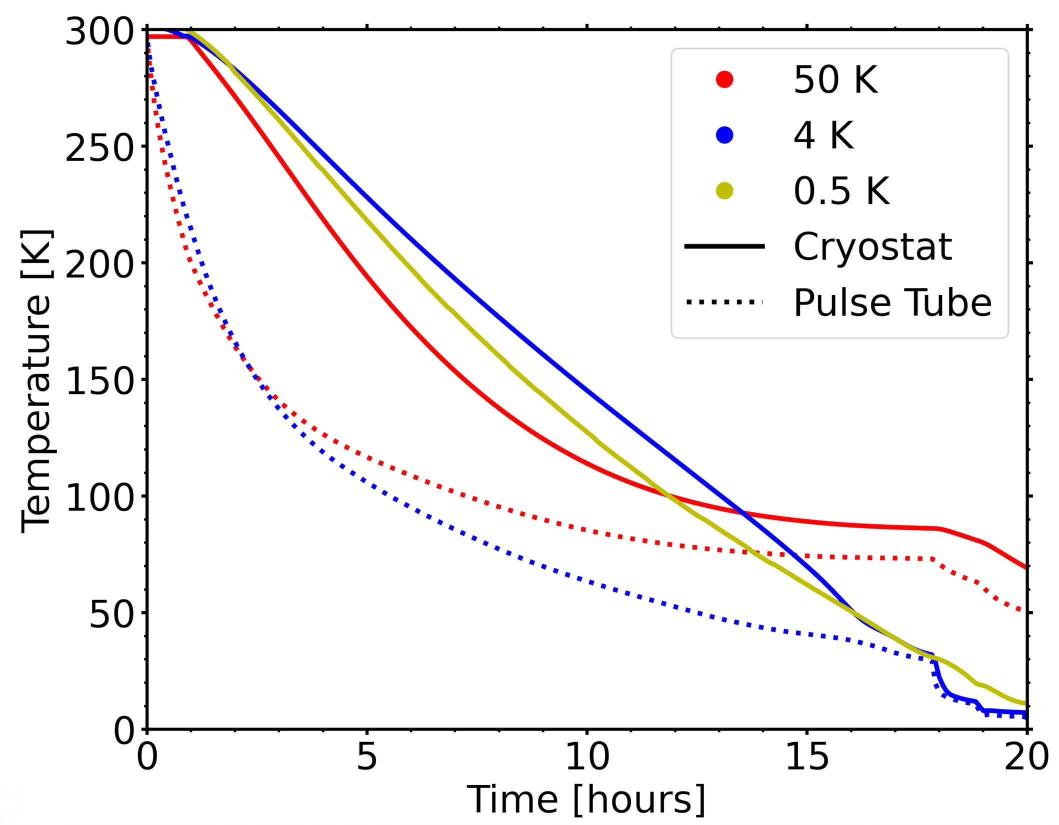


Cooling Power ~ flow x Latent heat

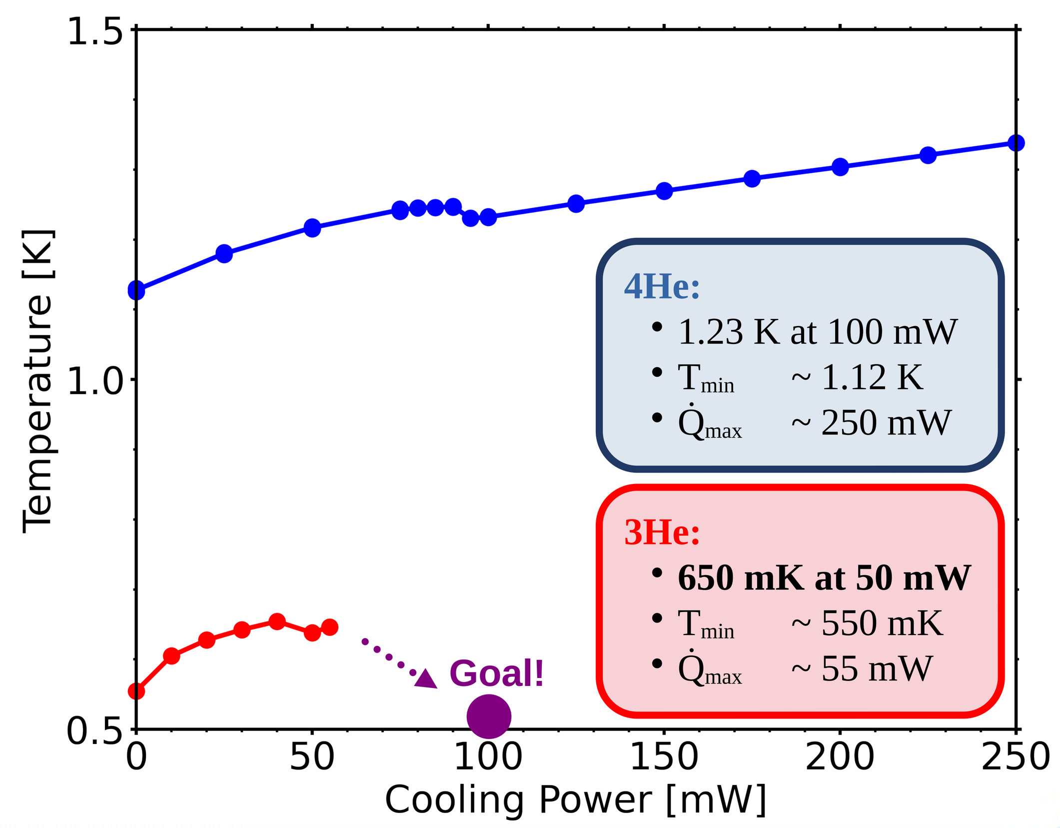
more flow, more cooling power!

Initial results

Cooling down time { pre-cooling → 20h; condensation → 1h }



- **Power Curves** using 4He and 3He



Conclusions

- Our first measurements are very promising using 3He, with available cooling power of 50mW at 650mK.
- To reach the 100mW at 500mK, setup has to be improved:

Reduce Temperature
→ lower pressure drop along the pumping line (new Cold Box needed).

Increase Cooling Power
→ enhance maximum flow (replace primary pumps, add more turbo pumps).
→ increase 3He liquid fraction in the evaporator by adding a second JT valve.

References
1. Chanrion et al., Physical Review Applied (2020)
2. Thomas et al., Mater. Quantum. Technol (2022)
3. Urdampilleta et al., Nature nanotechnology (2019)

Contacts
victor.doebele@neel.cnrs.fr
philippe.camus@neel.cnrs.fr

This work is supported by ERC QuCube Synergy Grant (ID: 810504)

29th International Cryogenic Engineering Conference, International Cryogenic Material Conference 2024, July 22-26, 2024, Geneva, Switzerland