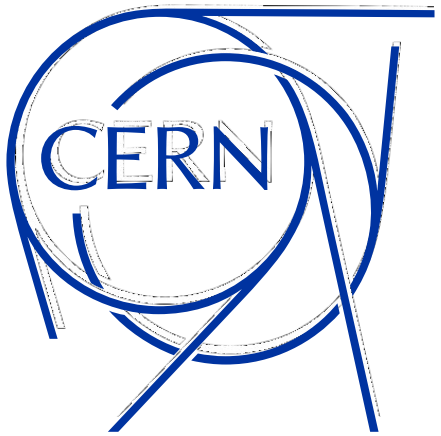
EP R&D

Politechnika Wrocławska



Development of a Cryocooler-Based 3 kA BSCCO-2223 Current Leads for Superconducting Magnets

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Special thanks to Thibaut Coiffet, Philippe Frichot, Marco Garlasche, Laura Hernandez Saurbier, Bahar Karahan, Torsten Koettig, Matej Konopik, Allan Saillet, Michał Sajdak, Patricia Tavares Coutinho Borges De Sousa, Anton Titenkov, Igor Titenkov

Date: 21/10/2026

Cryocoolers for Superconducting Magnets

USE CASE

- Cryocoolers instead of cryo-plants
- Example: BabyIAXO Project

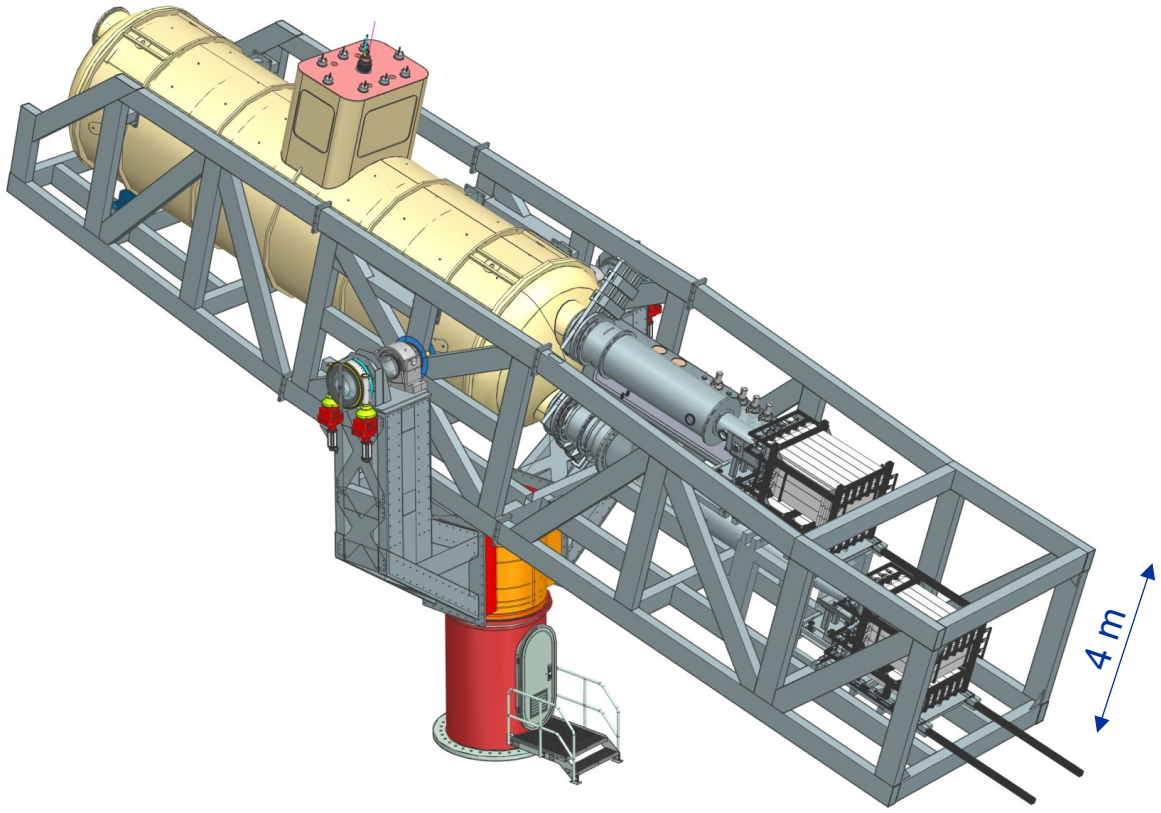
CRYOCOOLER CONSTRAINTS

- Limited cooling power @ 4-5 K
- Magnetic field sensitivity

HEAT LOAD REDUCTION

- Hybrid HTS current leads
- Passive helium circulation

The main benefits are **low helium inventory, compactness and modularity**.



BabyIAXO detector concept

[1] The IAXO collaboration, *Conceptual Design Report of the BabyIAXO Magnet*, work in progress

3 kA Cryocooler-Based HTS Current Leads

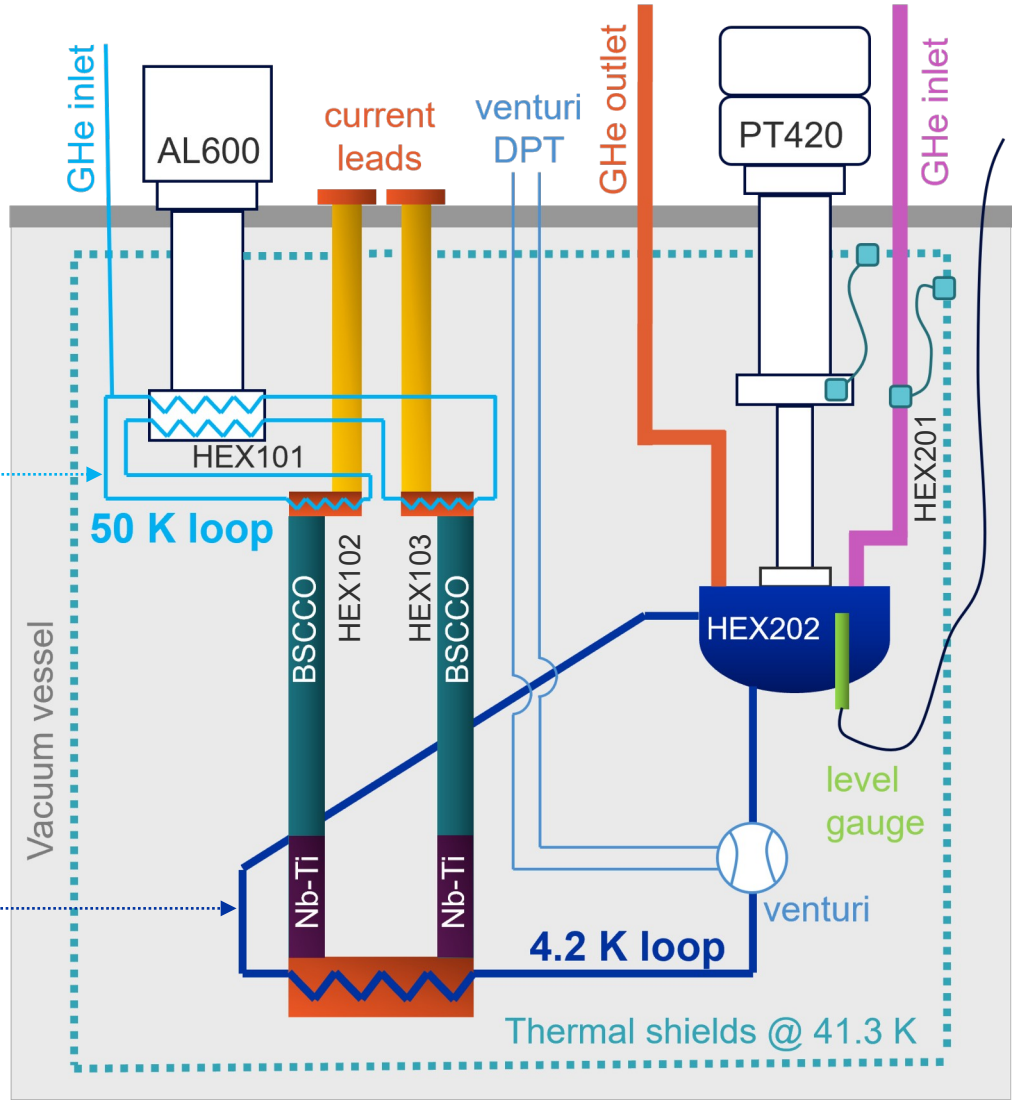
PROJECT GOAL: Development and operation of 3 kA hybrid current leads for LTS magnets and associated cryocooler-based cryogenics.

50 K loop

- Helium gas circulation
- Cooling of BSCCO-2223
- Total heat load of 340 W

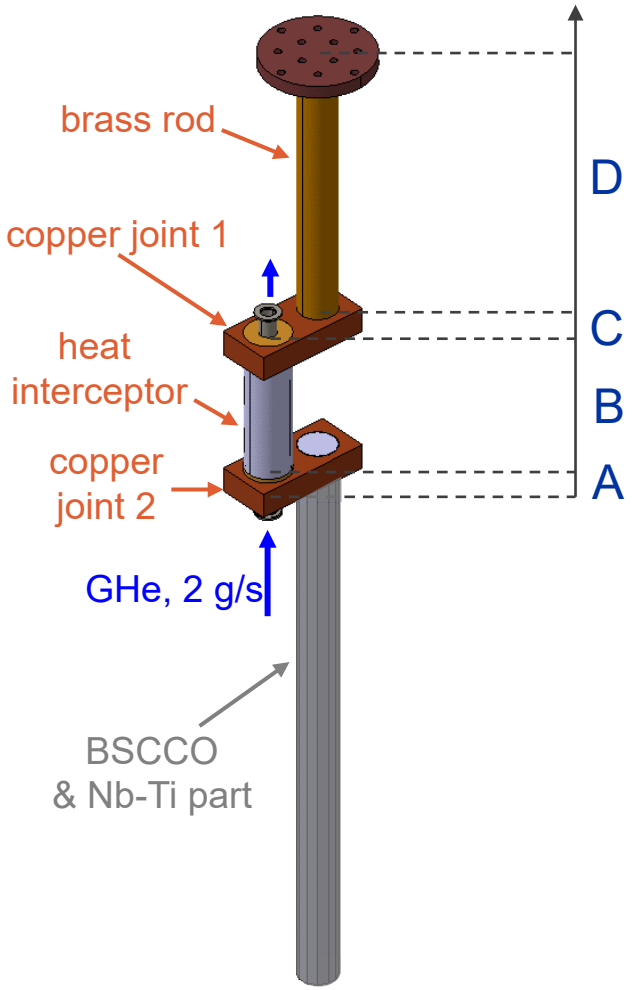
4.2 K loop

- Thermosiphon circulation
- Cooling of Nb-Ti
- Total heat load of 2 W



Normal-conducting Part of the Current Leads

Hybrid current lead



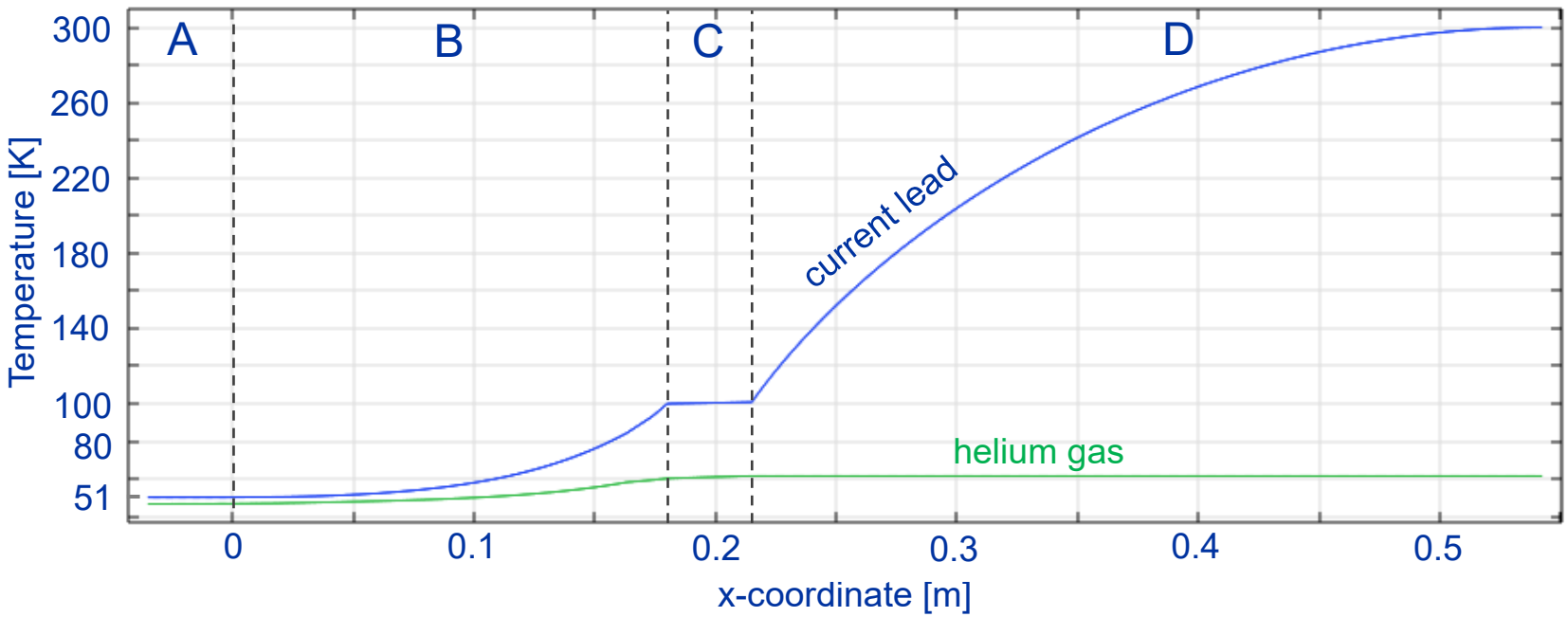
Characteristics of the current leads	
Material:	Brass / Cu joints
Current:	3 kA
Heat intercepted:	151 W
Outer diameter:	40/51/65 mm

Heat balance of the CL element

$$\frac{d}{dx}k(T)A\frac{dT}{dx} + \rho(T)\frac{I^2}{A} - \dot{m}_{He}C_p(T_{He})\frac{dT_{He}}{dx} = 0$$

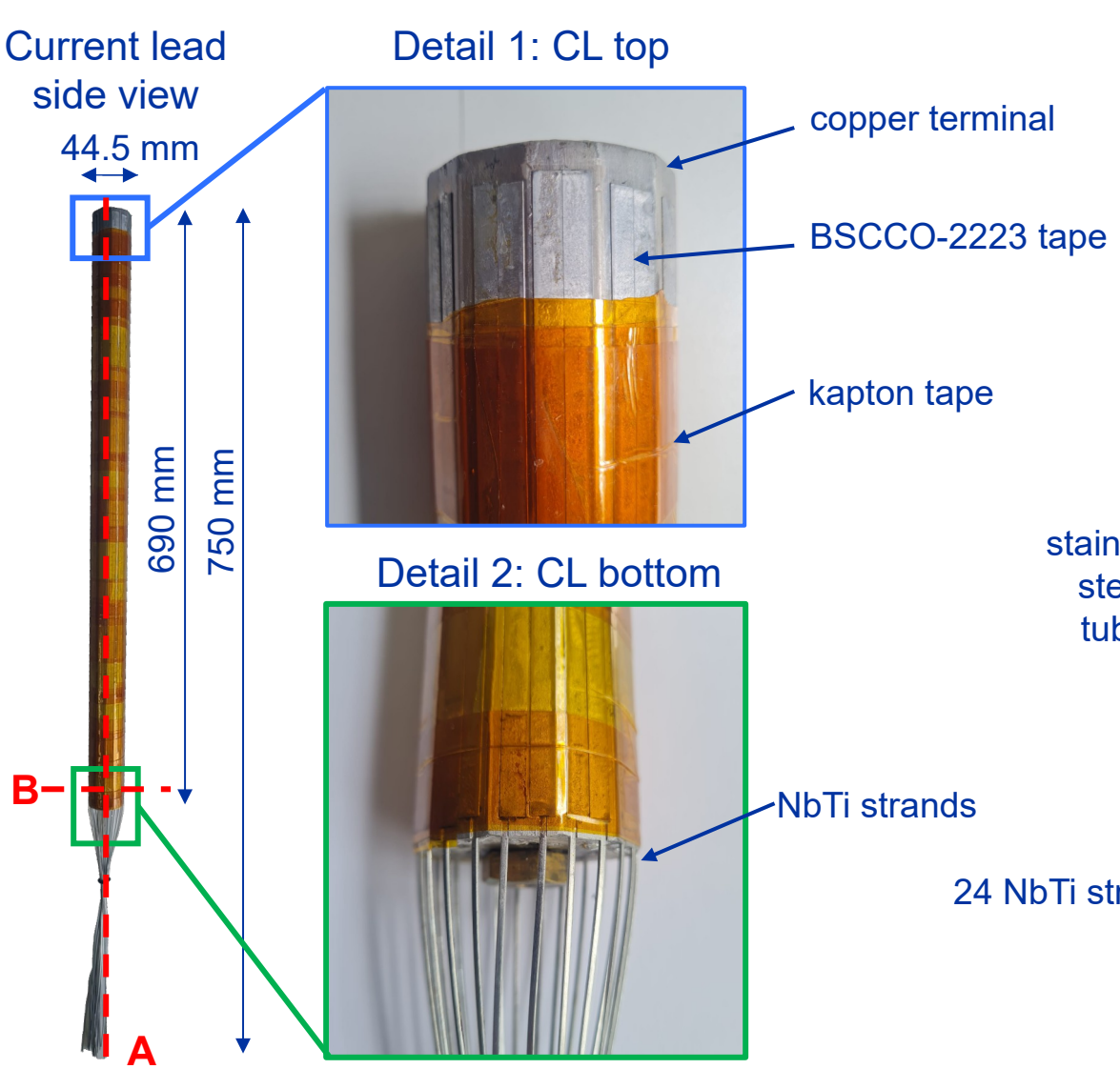
conduction — Joule heating — gas enthalpy

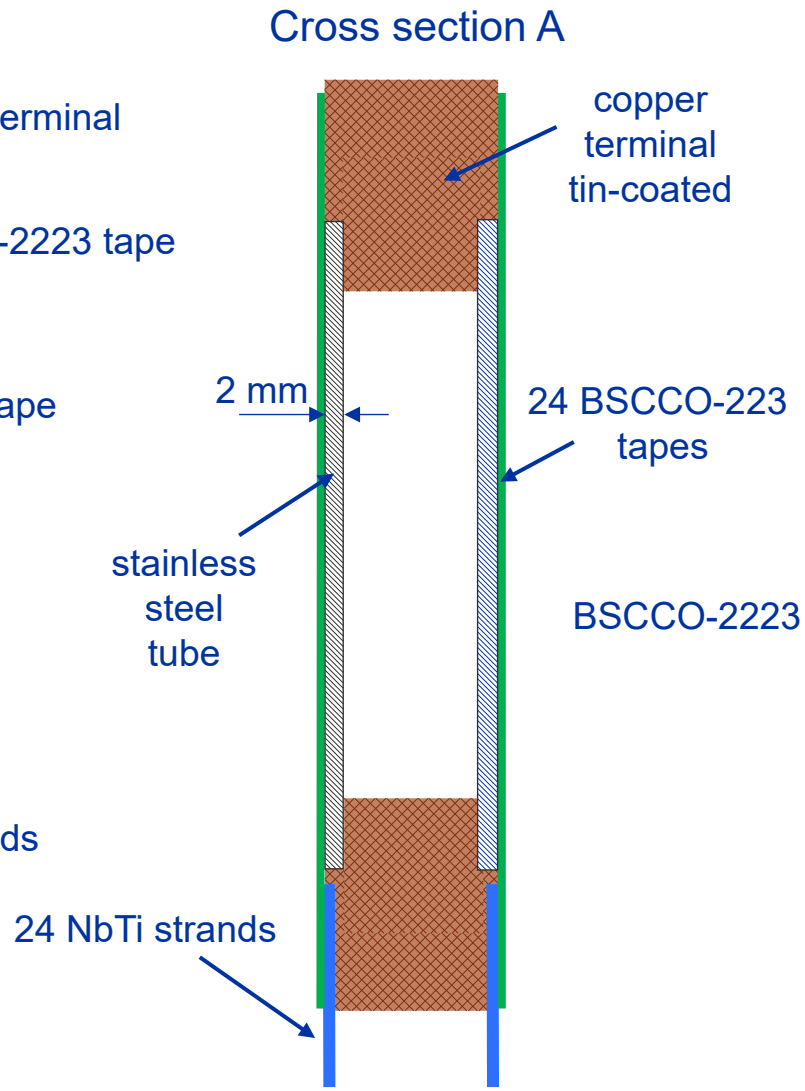
Curent lead temperature over length – conductive part

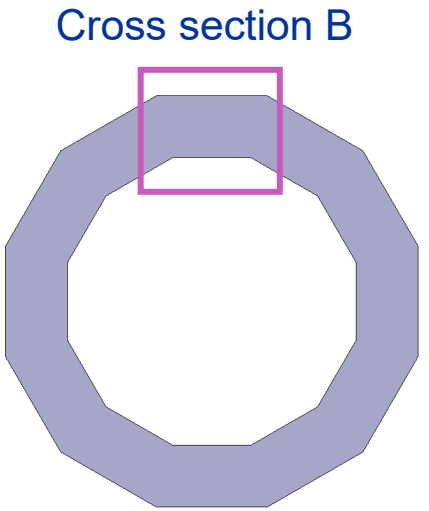


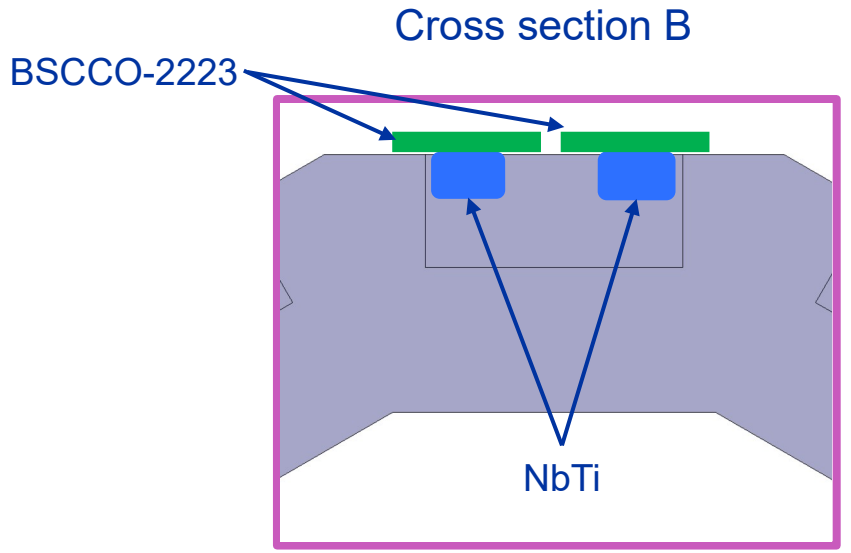
Weronika Głuchowska et al., “Thermalization of 3 kA Current Leads through a Remote Cooling Loop Using a Single- Stage Cryocooler”, In: Cryocoolers 23. Boulder CO: ICC Press, 2024, pp. 445–454.

Superconducting Part of the Current Leads

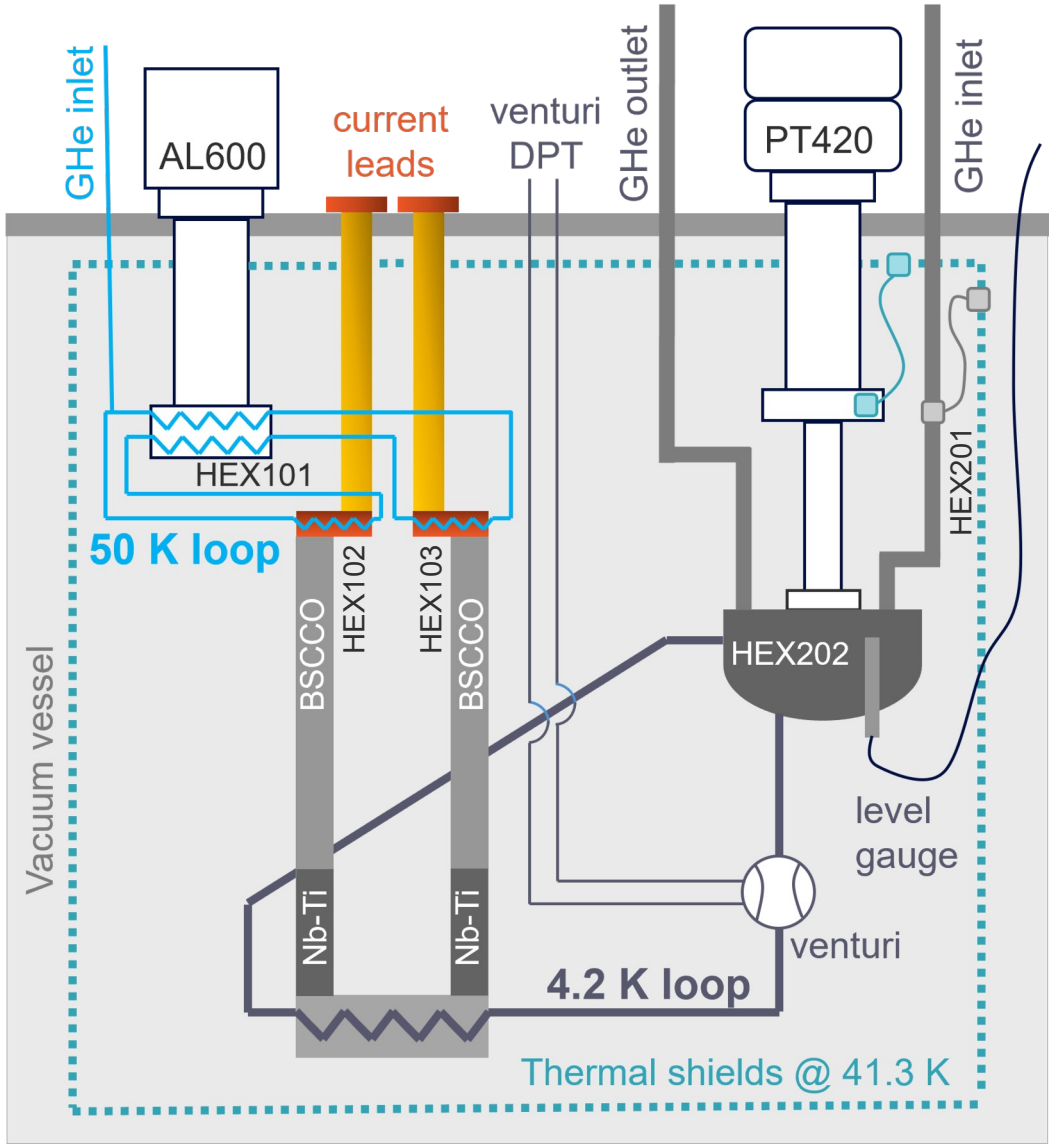








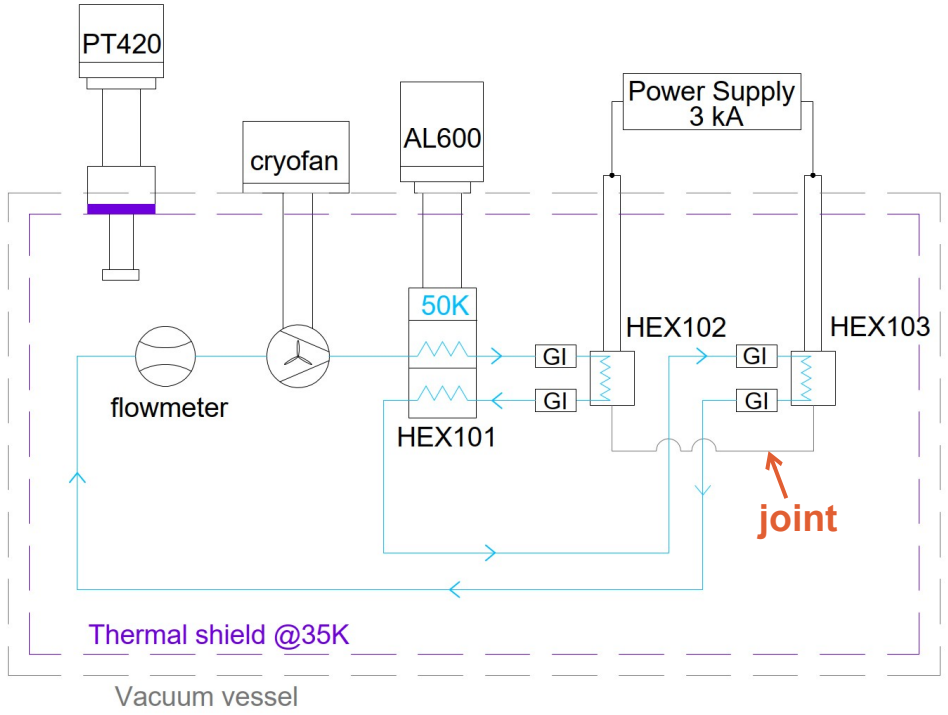
50 K Cooling Loop



50 K Loop Testing

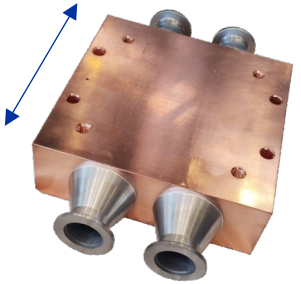
TEST GOAL

- Current leads temperature distribution
- **Joint temperature < 60 K**



50 K loop test schematic

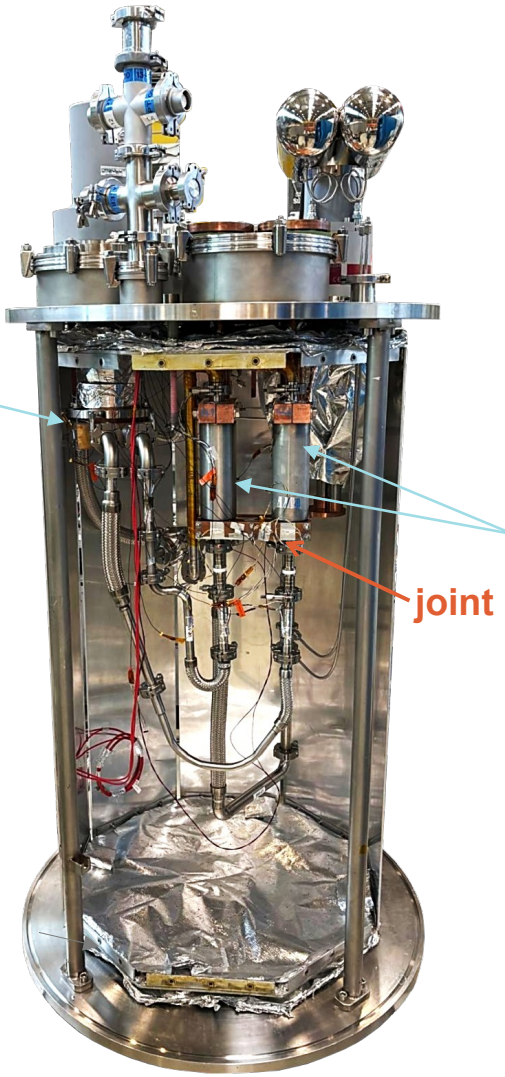
16 cm HEX101



104 cooling channels

≥ 150 W per section

He outlet T ≤ 50 K



HEX102/3

25 cm



60 cooling channels

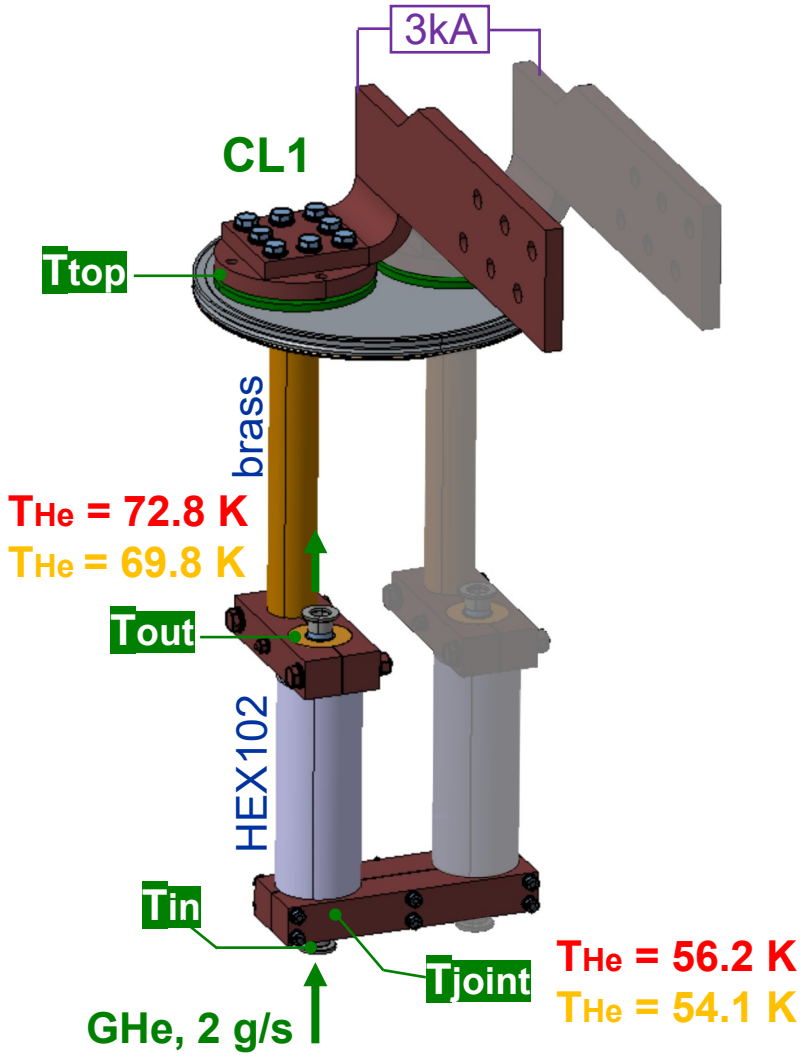
151 W intercepted

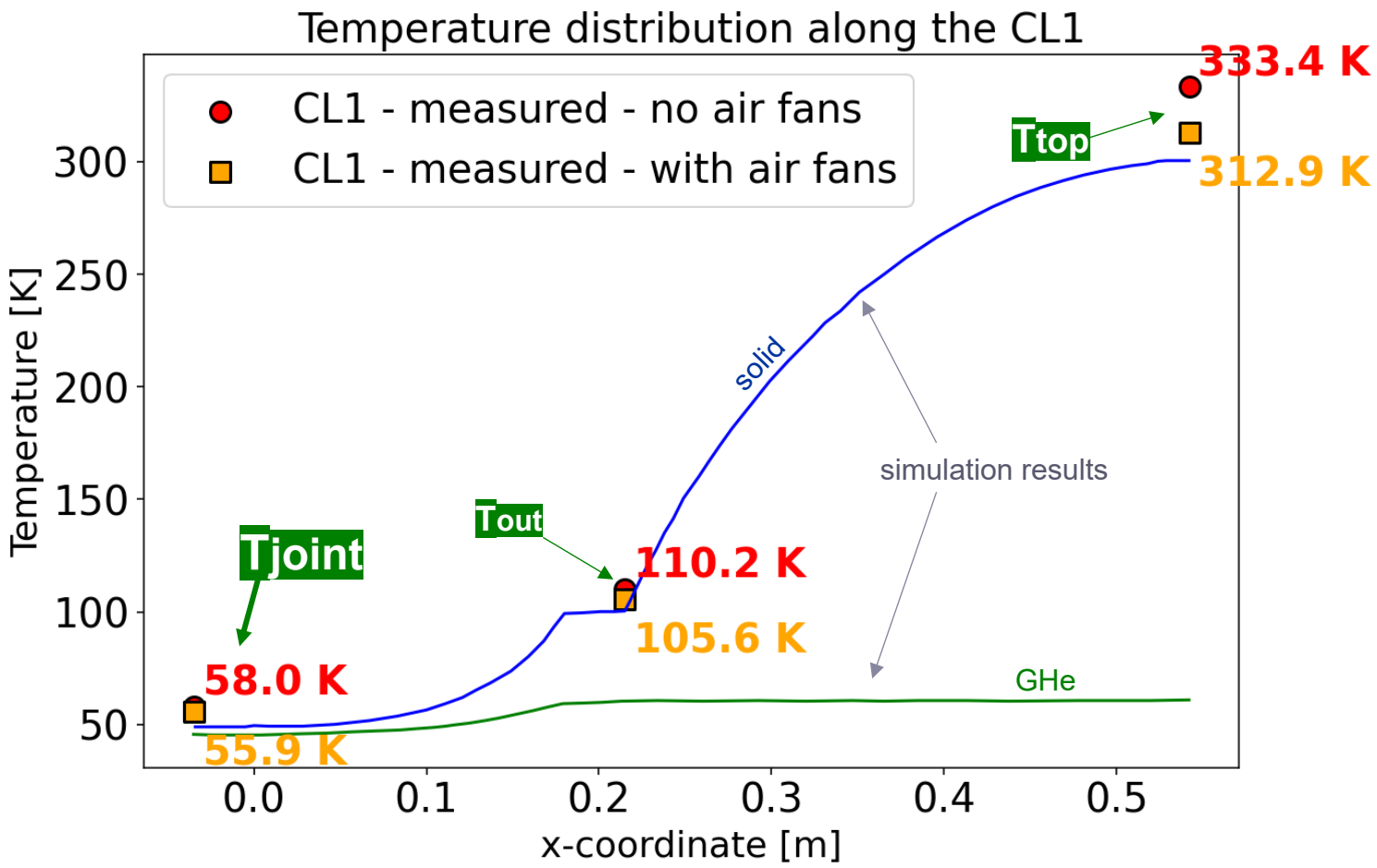
Brass T : 52.5 K

Photo of experimental setup

Weronika Głuchowska et al., “Experimental evaluation of a thermal interface and a cold circulator used in remote cooling loop driven by a cryocooler”, Cryogenics, Volume 152, 2025, https://doi.org/10.1016/j.cryogenics.2025.104199.

Successful Test of 50 K Loop

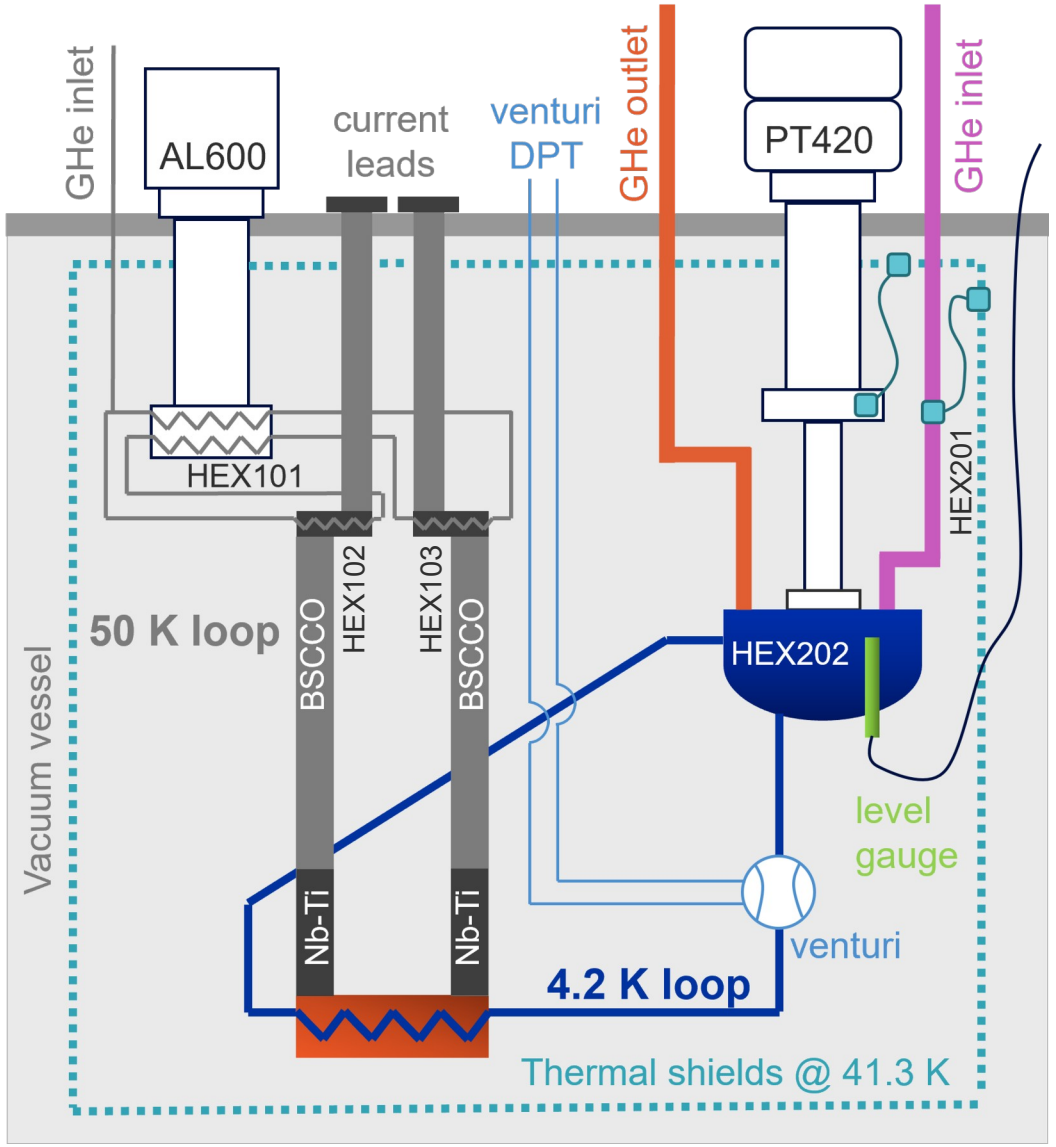




Requirement met: T_{joint} < 60 K

Lesson learned: Joint resistances to be improved

4.2 K Cooling Loop



4.2 K Loop Design

- GHe precooled in HEX201: 300 → 41 K
- Circulation driven by heat load (current leads)
- Custom-made Nb-Ti level gauge monitors the helium level

SOURCES OF HEAT LOAD at 3 kA

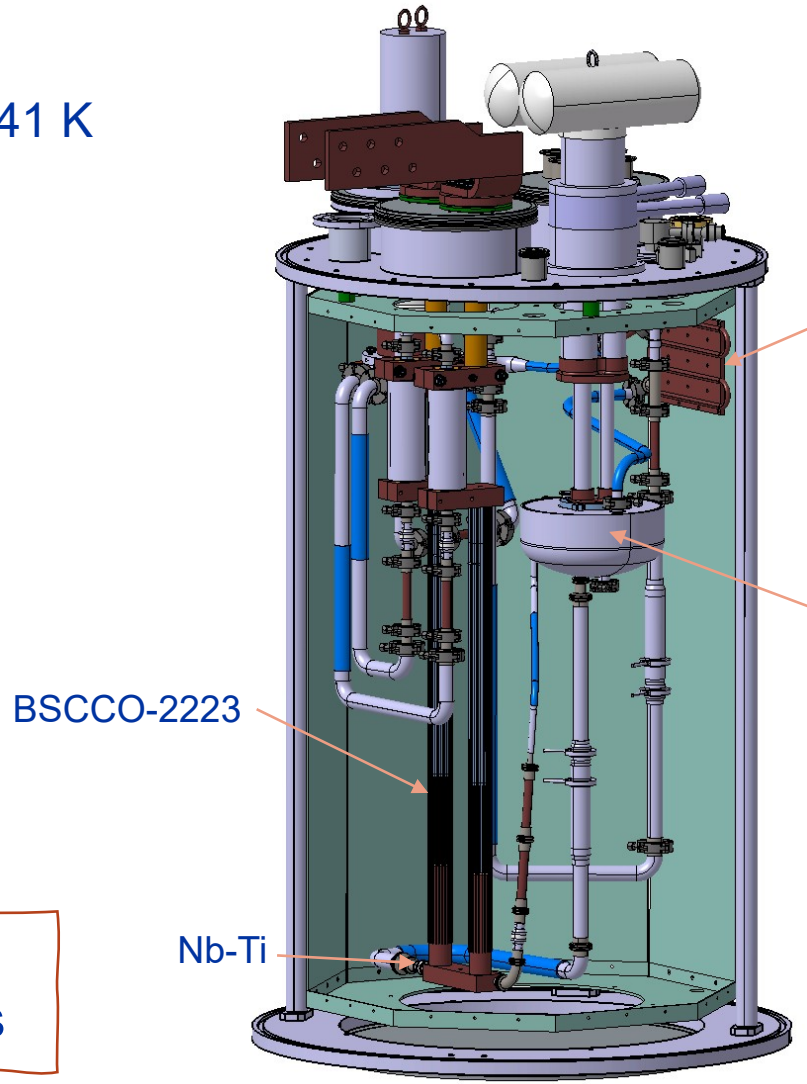
Current leads - 1826 mW

Radiation - 22 mW

Level gauge - 21 mW

Other - 24 mW

Total heat load: 1.89 W
→ dominated by current leads



Final demonstrator – 3D model

GHe precooler HEX201

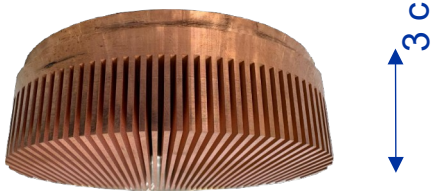


12 W intercepted

Mass flow : 9 mg / s

GHe temp: 41.4 K

Condensing unit in HEX202

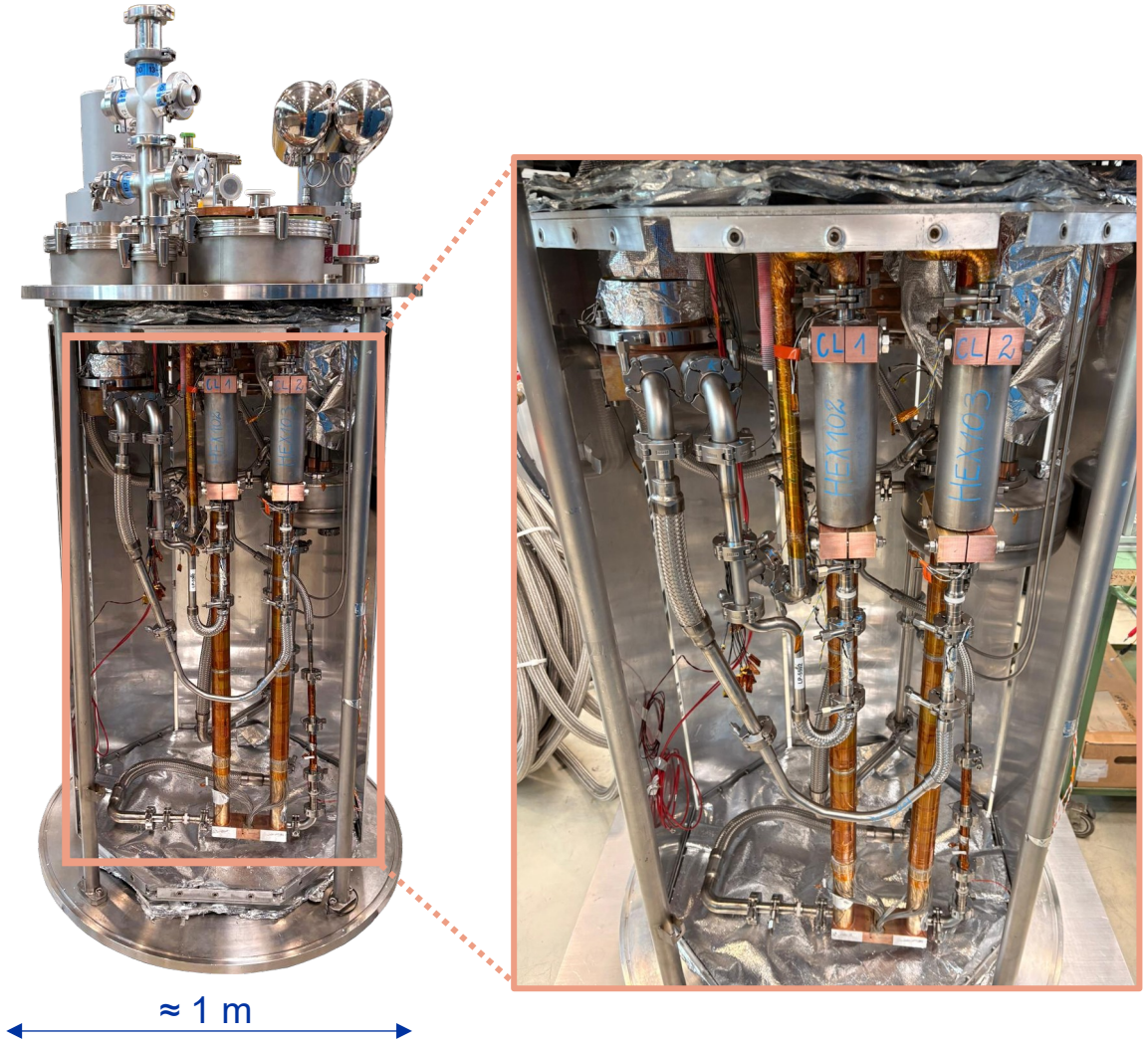


41 copper fins

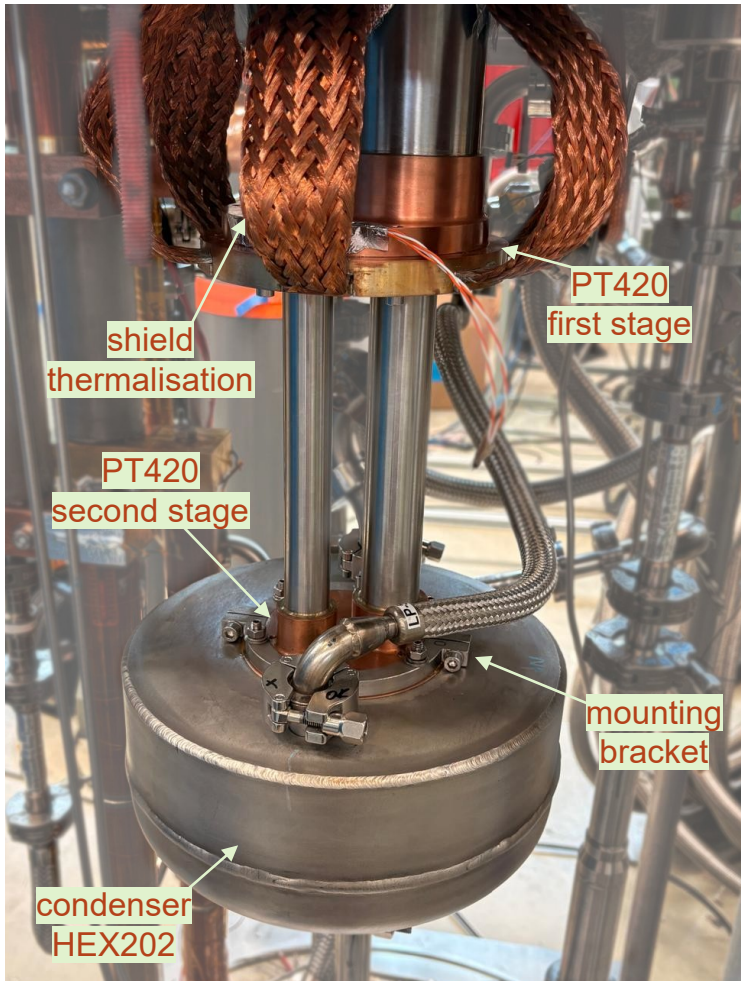
1.5 mm x 19 mm

2 W intercepted @ 4 K

4.2 K and 50 K Loop Integration



Integration of the inner cooling circuit



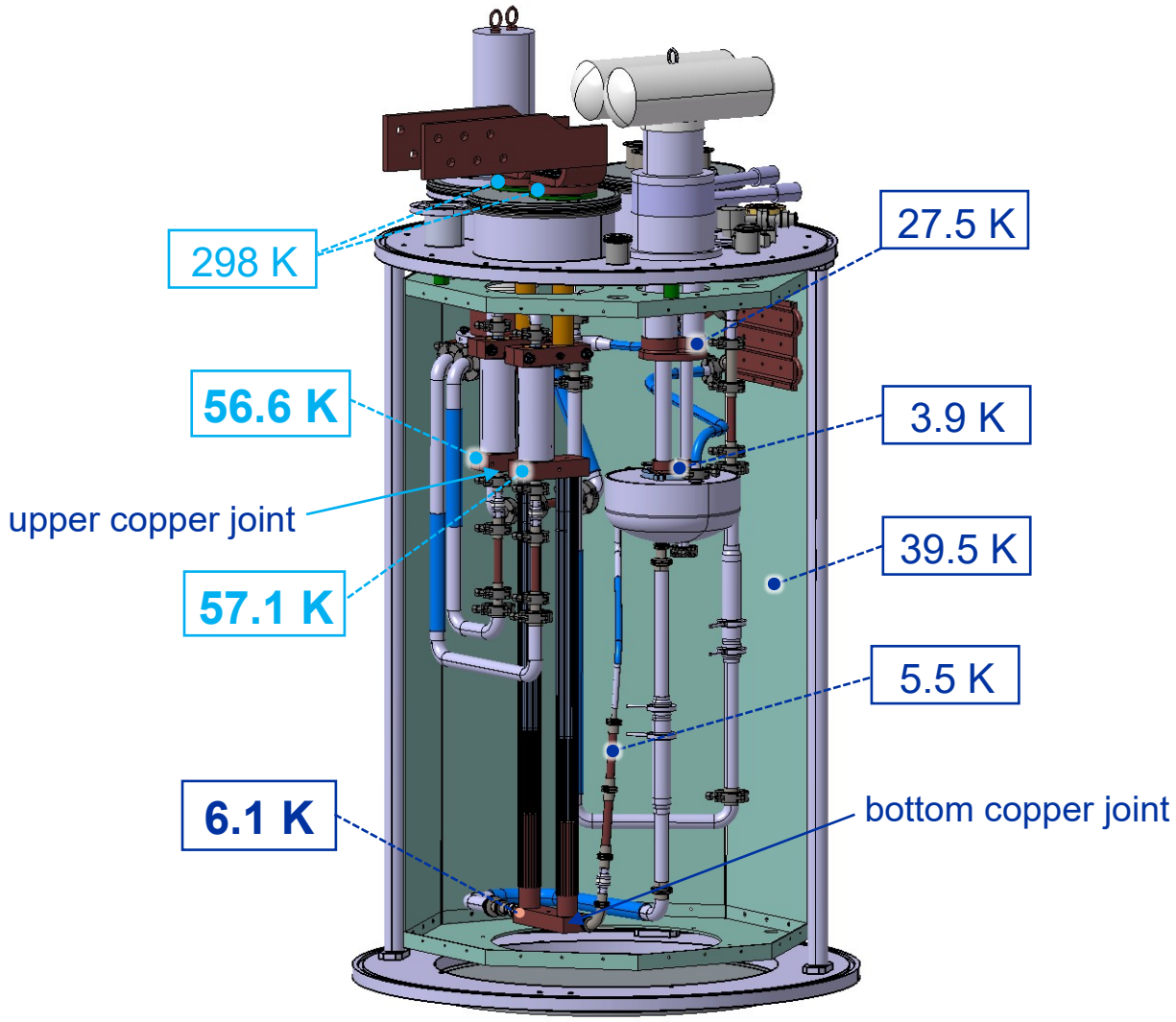
Integration of the condenser and shield cooling

Remote Cooling System: Thermal Behaviour @ 3 kA

Summary of the first test

- Saturated He **liquid produced @ 2 barA** with no current applied;
- 50 K loop operating at 5 barA: upper **BSCCO joints below 60 K**;
- **Bottom copper joint @ 6.1 K**, at nominal current;
- **Fully superconducting leads (BSCCO-223 and NbTi) at 3 kA;**

Key challenge: reaching and maintaining saturation conditions at the bottom copper joint



Temperature distribution @ 3 kA

Conclusions

3 kA cryocooler-based HTS current leads integrated into the remote cooling system, fully operational at 3 kA.

- 50 K loop cools down the **upper BSSCO copper joint below 60 K;**
- 3 kA current sustained in fully superconducting operation;
- Thermosyphon circulation to be verified during final testing.

