27th International Conference on Magnet Technology (MT27)

Fukuoka, Japan / 2021

[Invited] 43+T Grenoble Hybrid Magnet: From final Assembly to Commissioning of the Superconducting Outsert

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C01 Superconducting and Hybrid High-Field Magnets

ID#382, THU-OR5-301-01

Thursday November 18, 2021

18:30 - 18:45

The Modular Grenoble Hybrid Magnet User Platform

LNCMI

Objectives for the Highest Magnetic Field configuration

- **Baseline @ 24 MW*/2022 : 43 T in 34 mm dia.**
  SC + poly-Bitter + poly-helices = 8.5 + 9 + 25.5 = 43 T

- **Upgrade @ 30/36 MW : 46 T in 34 mm dia. (to validate)**
  SC + poly-Bitter + poly-helices = 9 + 9.5 + 27.5 = 46 T

But also various high magnetic Flux configurations

Field	Warm dia.	Configuration	Electric Power*
43 T	34 mm	14 helices + 2 Bitter + SC	24 + 1 + 0.4 MW
40 T	50 mm	12 helices + 2 Bitter + SC	24 + 1 + 0.4 MW
27 T	170 mm	6 helices + 2 Bitter + SC	18 + 0.75 + 0.4 MW
17.5 T	375 mm	2 Bitter + SC	12 + 0.5 + 0.4 MW
9.5 T	812 mm	SC	0.4 MW**

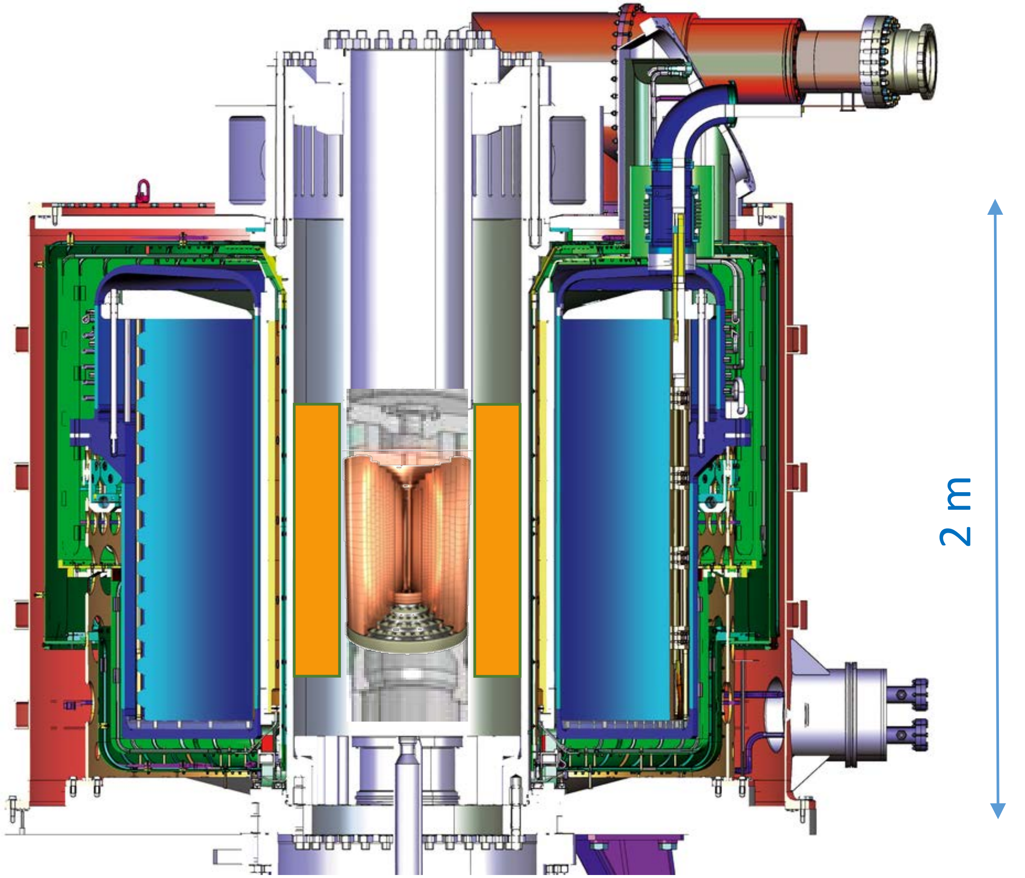
* Magnet powering + water cooling pumps + cryogenics
** He liquefier + 1.8 K pumps + cryoplant ancillaries

**Electricity cost 2020: 95.3 EUR/MWh*

P. Pugnat *et al.*, *IEEE Trans. Appl. Supercond.* 28, 4300907 (2018)
P. Pugnat *et al.*, *IEEE Trans. Appl. Supercond.* 30, 4300605 (2020)

INVESTISSEMENTS D'AVENIR — PROJET LaSUP — Equipex

MINISTÈRE DE L'ENSEIGNEMENT SUPÉRIEUR ET DE LA RECHERCHE
COMMISSARIAT GÉNÉRAL À L'INVESTISSEMENT



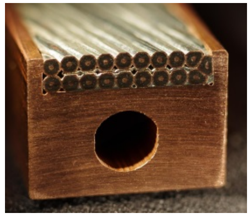
Technologies	*SC Nb-Ti/Cu & superfluid He*
Hydraulics for resistive inserts	*300 l/s*
Total stored energy @ 43 T	*108 MJ (~ 26 kg of TNT explosive)*

Technical choices : "The French Tech."

Nb-Ti/Cu Rutherford Cable On Conduit Conductor (RCOCC) specially developed with in-house assembly

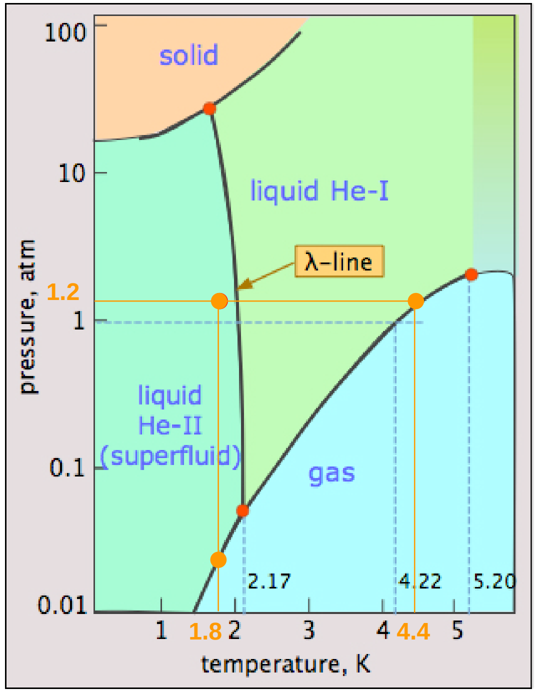
- Internal cooling with stagnant superfluid He in addition to the external bath
- Strict control of AC-losses

P. Pugnat, R. Pfister, *et al.*, *IEEE Trans. Appl. Supercond.* 28, 4301005 (2018)
https://indico.cern.ch/event/659554/contributions/2714073/



18 x 13 mm^2

LNCMI

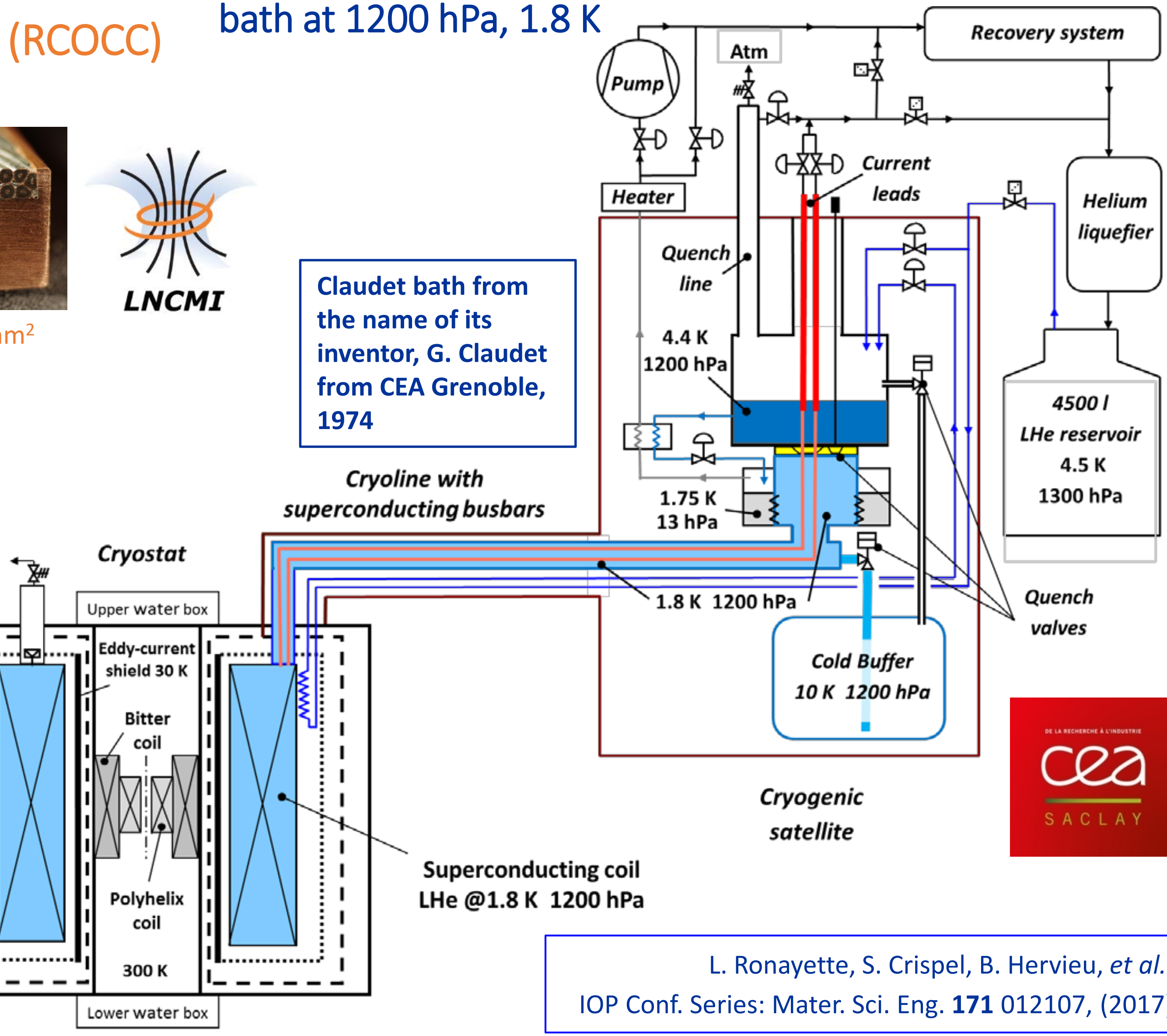


Superfluid pressurized LHe bath @ 1200 hPa , 1.8 K

Cooling of the sc. coil with 1100 l of pressurized superfluid He

The cryogenic system principle: Pressurized superfluid He bath at 1200 hPa, 1.8 K

Claudet bath from the name of its inventor, G. Claudet from CEA Grenoble, 1974



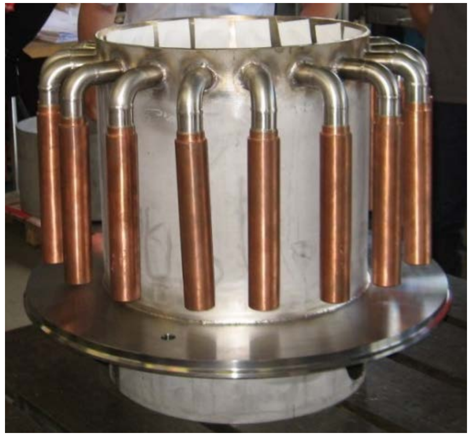
L. Ronayette, S. Crispel, B. Hervieu, *et al.*, IOP Conf. Series: Mater. Sci. Eng. **171** 012107, (2017)

Cryogenic satellite during assembly

Mounting of the current leads and instrumentation wires crossing the λ-plate within the cryogenic satellite before the closure of the 4.2 K reservoir.

Top part of the cryogenic satellite with the warm extremities of the current leads, the cryogenic valves and one of the clarinets for the connectors interfacing 944 instrumentation wires for about 200 sensors.

The cryogenic satellite of about 6 m high assembled at SDMS for pressure tests



Cold fingers of the pressurized and saturated superfluid He bath heat exchanger

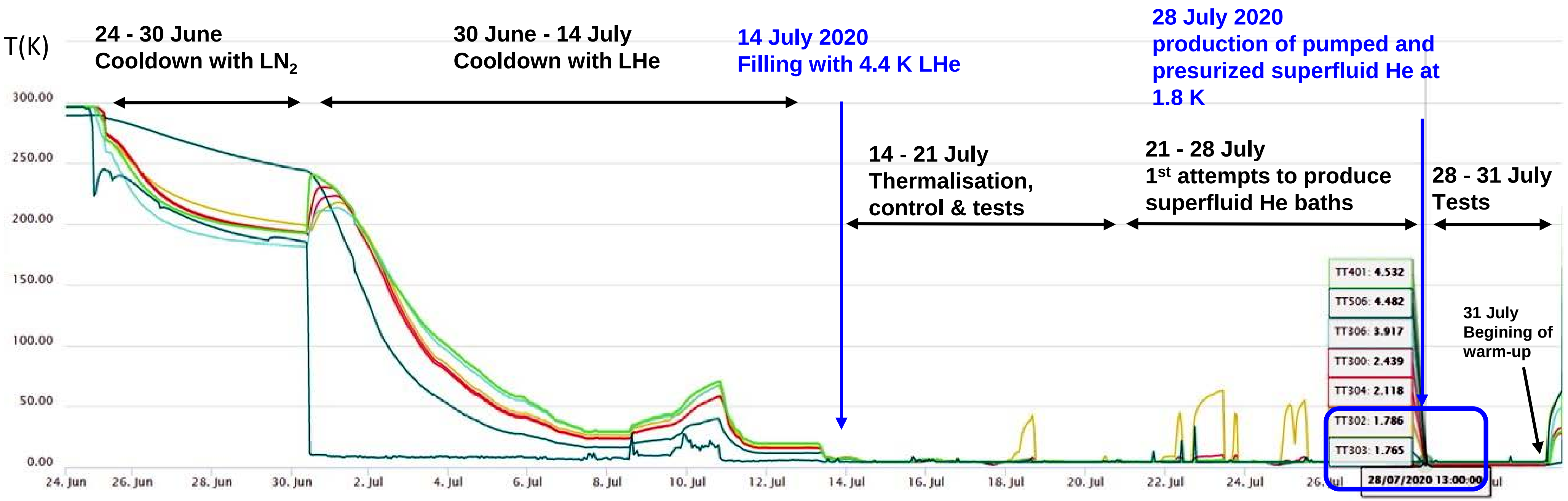
sdms la chaudronnerie blanche

LNCMI

cea SACLAY

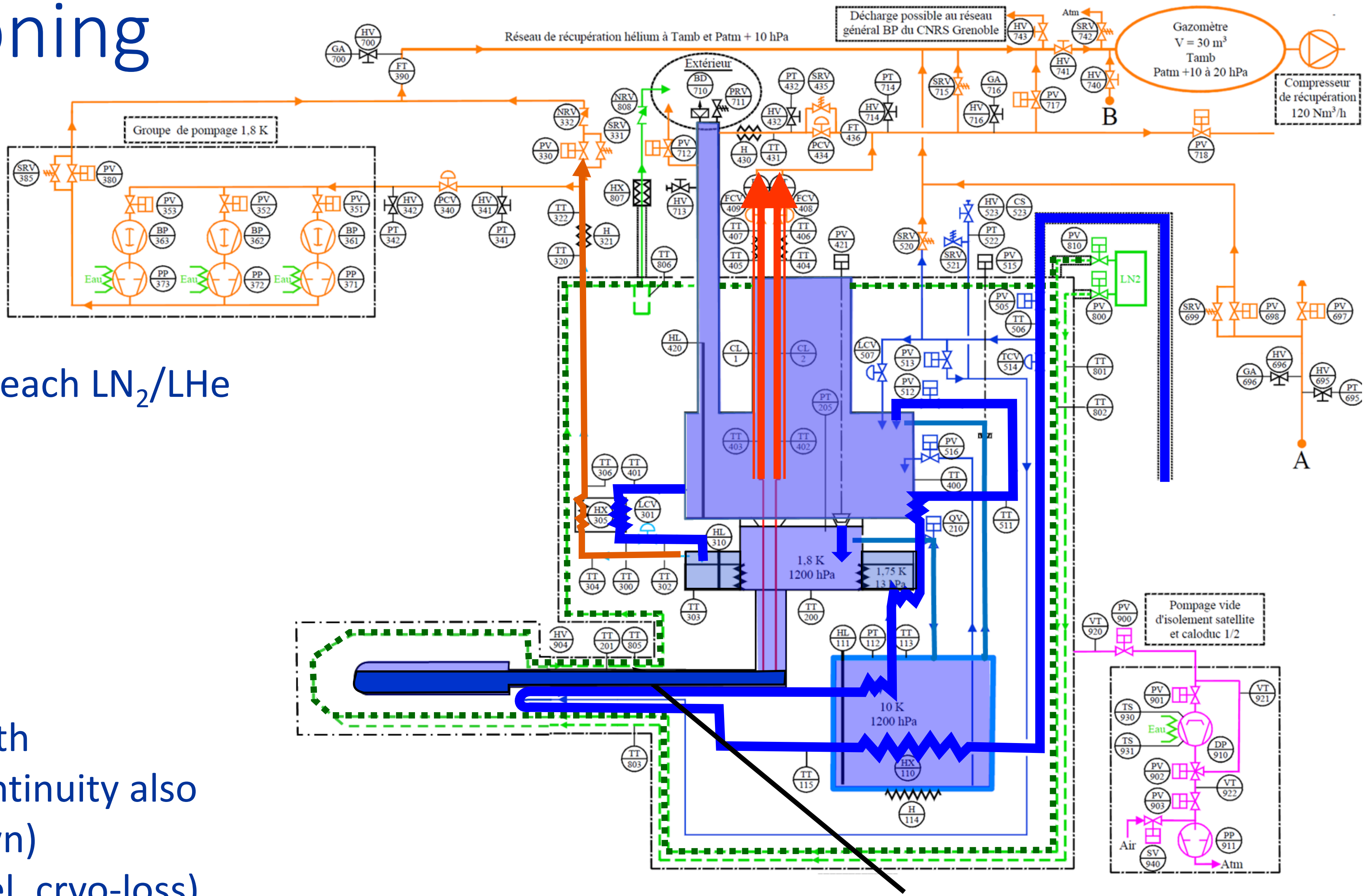
Installation of the Cryogenic Satellite & Commissioning overview

5 Feb. 2019	Delivery of the cryogenic satellite in 2 parts
30 Sept. 2019	End of the assembly
20 Feb. 2020	End of the 1st part of the control system
24 Feb. 2020	Begining of the 1st cooldown
16 March 2020	Stop of the cooling at 25 K and warm-up (French Covid lockdown for 13 weeks)
24 June 2020	Begining of the 2nd cooldown
28 July 2020	The pumped & pressurized superfluid He baths obtained & stabilized
28 - 31 July 2020	Cryogenic & Electrical tests of the current leads



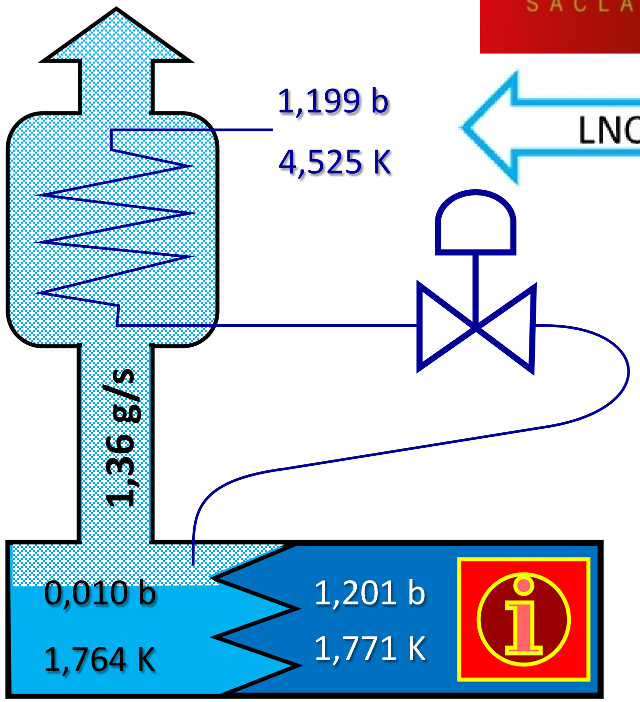
Main commissioning steps

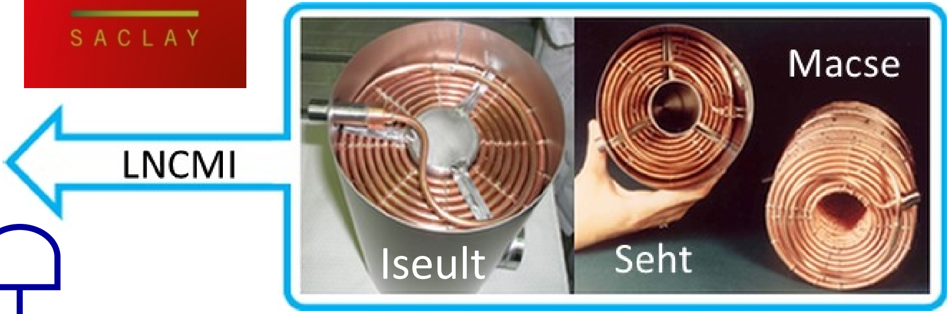
- Pumping & leak detection each LN_2/LHe circuit & global
- 3 purging cycles with GHe
- Cooldown with LN_2
- Cooldown with LHe
  . Precooling
  . LHe transfer
  . Pumping on the LHe bath
- Electrical checks (HV & continuity also at warm & during cooldown)
- Cryogenic Tests (filling level, cryo-loss)
- Tests of Current leads

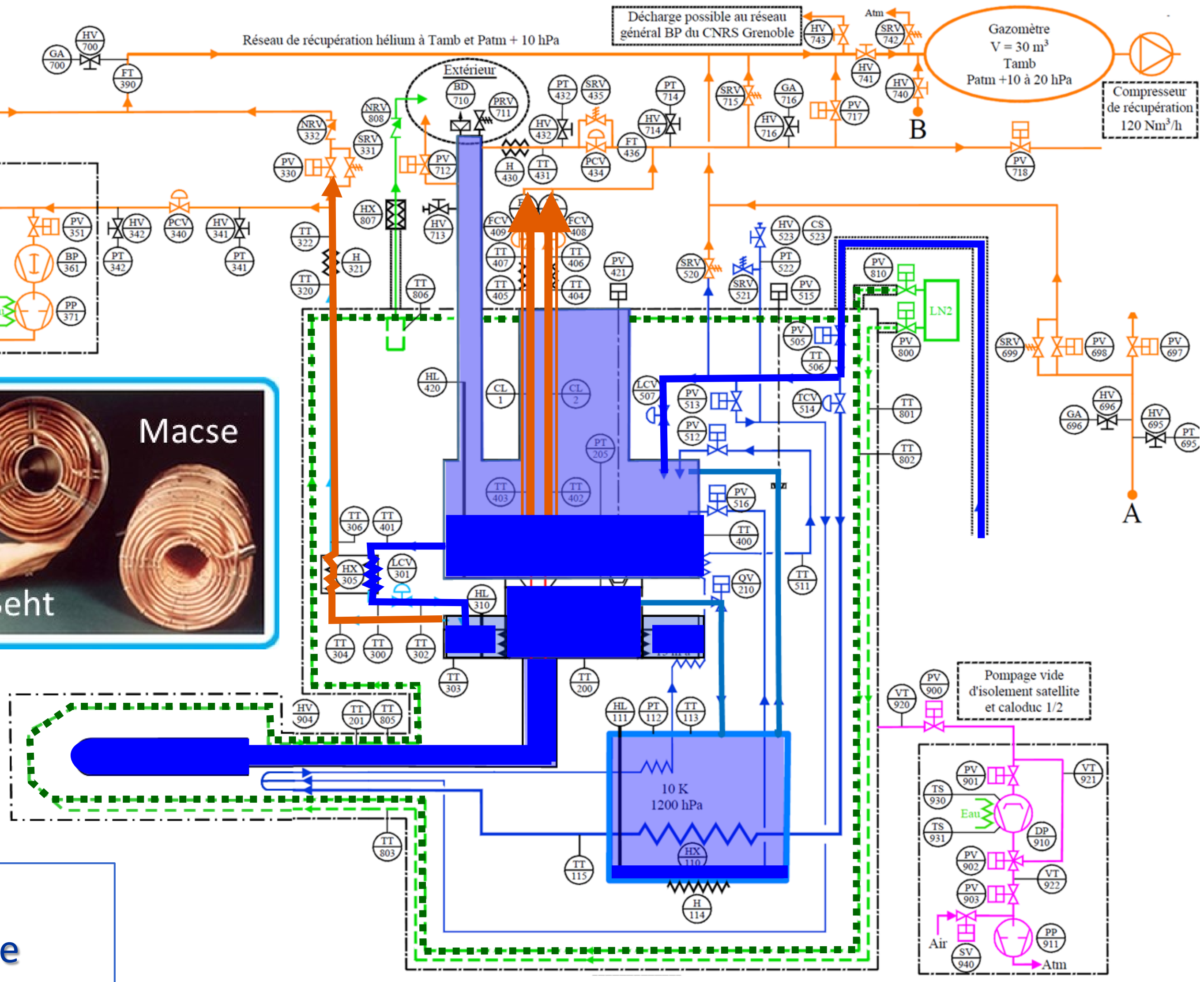


Precooling step with LHe : Stopped when TT 201 stable at 4.5 K, i.e. with minimum of liquid

Cryogenic Loss Measurements







Measured extracted power at 1.8 K for the cryogenic satellite > 40 W

Focus on the specially developed current leads – Not commercially available / requests on fiability & robustness

Warm part

	Spec.	As built	% Change
Ø CuP*/strand [mm]	0.5	0.5	0 %
Number of strands (N_s)	4250	3392	- 20 %
Cross section [mm^2]	834	666	- 20 %
Length [m]	1	1	0 %
Tortuosity (N_s R_b/R_s)	1.12	1.3	16 %
Void fraction	45 %	65 %	44 %
RRR (273 K/4 K)	10	7.4	- 26 %
I_{max} [kA]	8	7.5	- 6 %
Voltage [mV]	75	100	33 %
Flow He [ℓ/h]	12	15	25 %

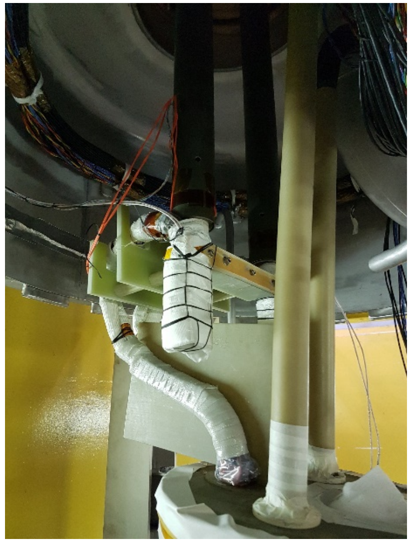
*235 g/ton

► Departure from optimized design $\Rightarrow$ consumption + 30% with respect 1 W/kA

Cold part : Coil overlengths of Nb-Ti/Cu Rutherford cable of 19 strands ϕ1.6 mm, 6264 filaments/strands ϕ14 μm

inside

Optimized compacted braid for GHe flow within insulated AISI 304 L tube



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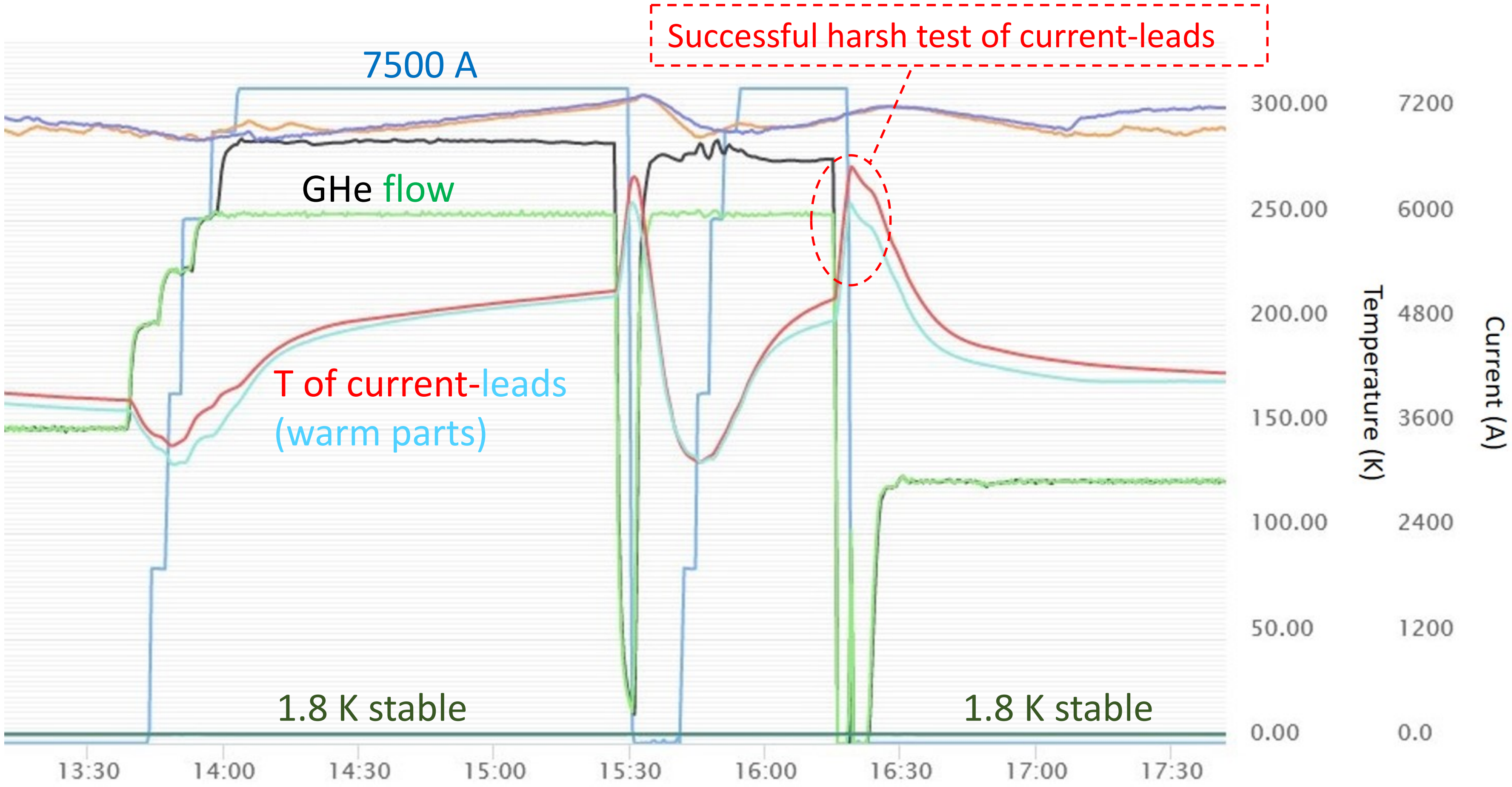
Cryogenic system for pressurized superfluid He fully commissioned together with current leads powered at ultimate current in July 2020



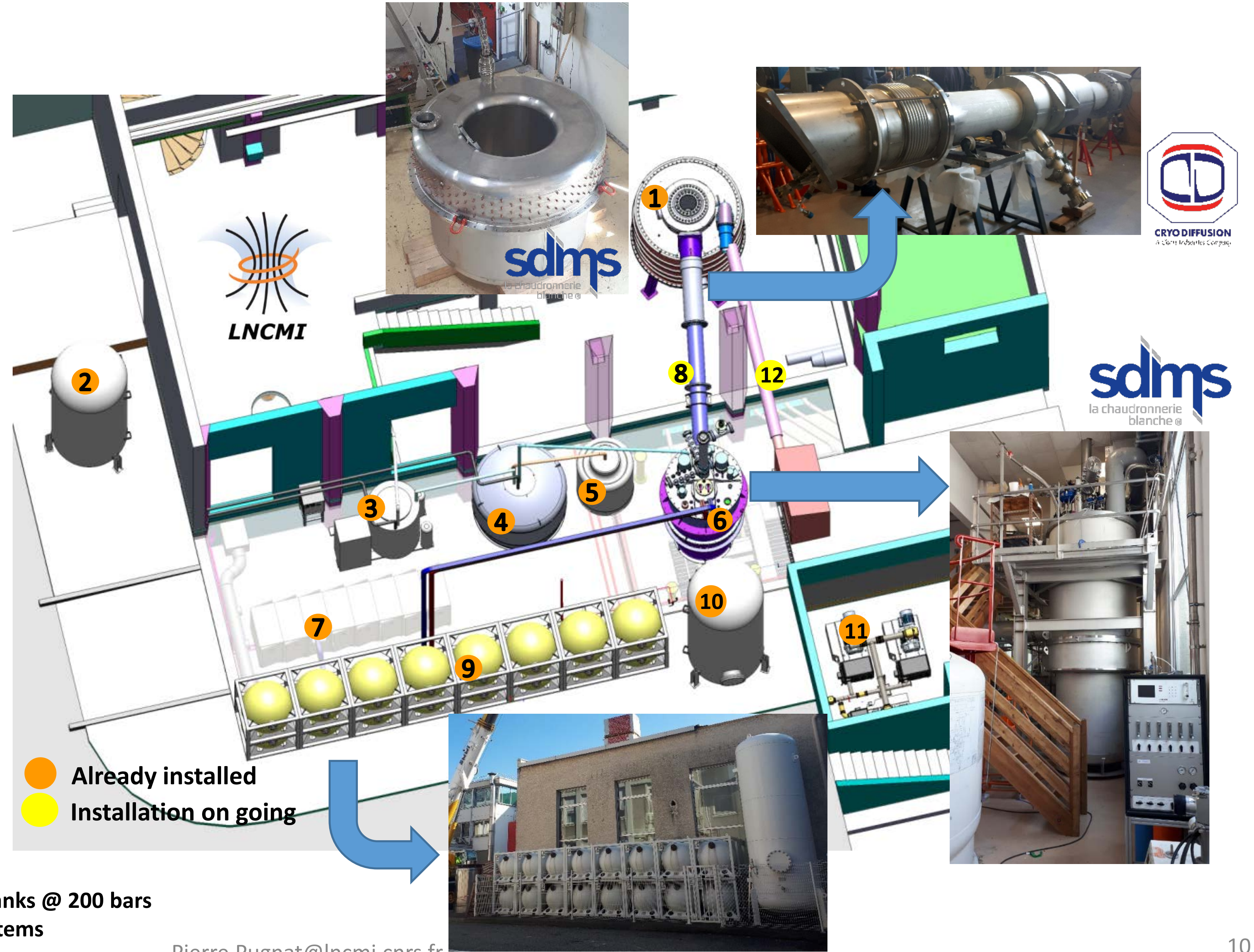
More information p. 90-93 @ http://lncmi.cnrs.fr/wp-content/uploads/2021/02/LNCMI_AR2020vwBD.pdf

Cryogenics is operational for the magnet cooldown and its powering planned first half of 2022

Status of the Construction & Assembly of the Grenoble Hybrid magnet

All equipment built, Final Assembly & Integration are close to completion

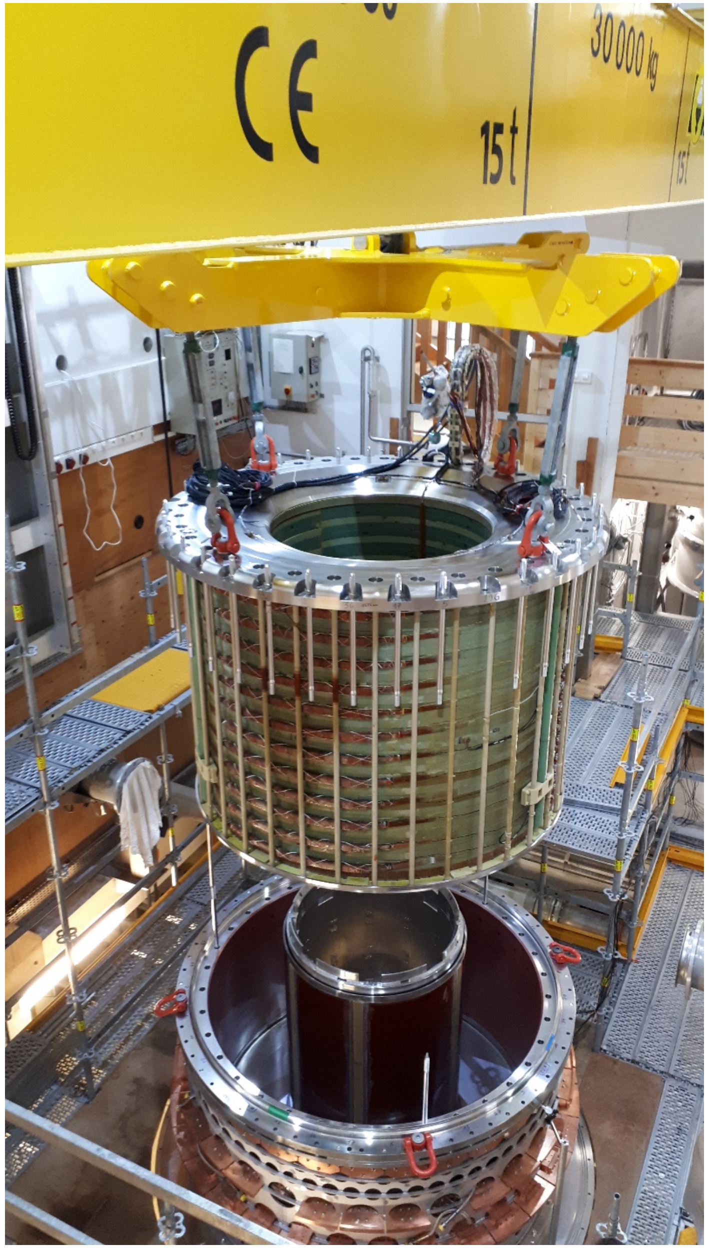
1. Superconducting Magnet
2. LN_2 tank 27 000 litres.
3. He liquefier coldbox
   150 l/h @ 4.5 K , 1.3 bar
4. Main LHe Dewar 4500 litres
5. Secondary LHe Dewar 1700 litres
6. Cryogenic satellite to produce the 1.8 K LHe bath
7. DC power converter
   7500 A , 30 V (underground)
8. Cryoline with busbars @ 1,8 K
9. High pressure gaseous He tanks
   16 x 1 m^3 @ 200 bars
10. Liquefier pure He buffer tank
    15 m^3 @ 20 bars
11. Helium pumping system
    6000 m^3/h @ 10 mbar, 20 °C
12. Quench line

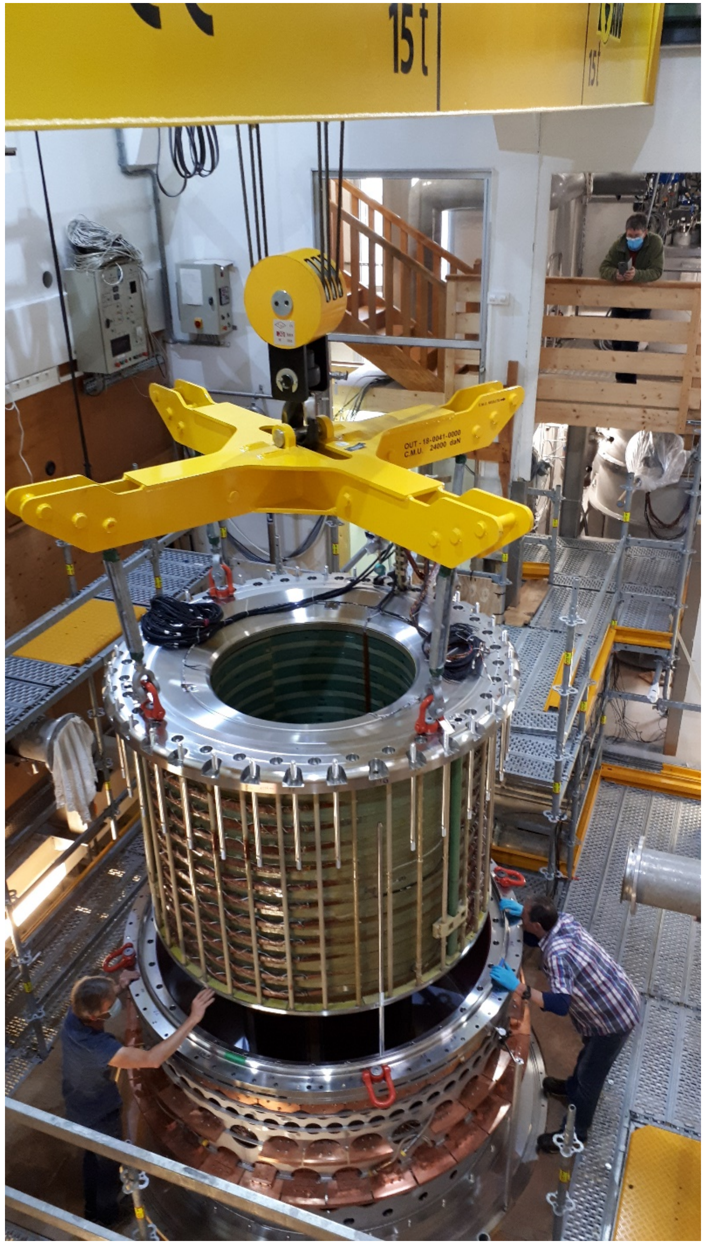


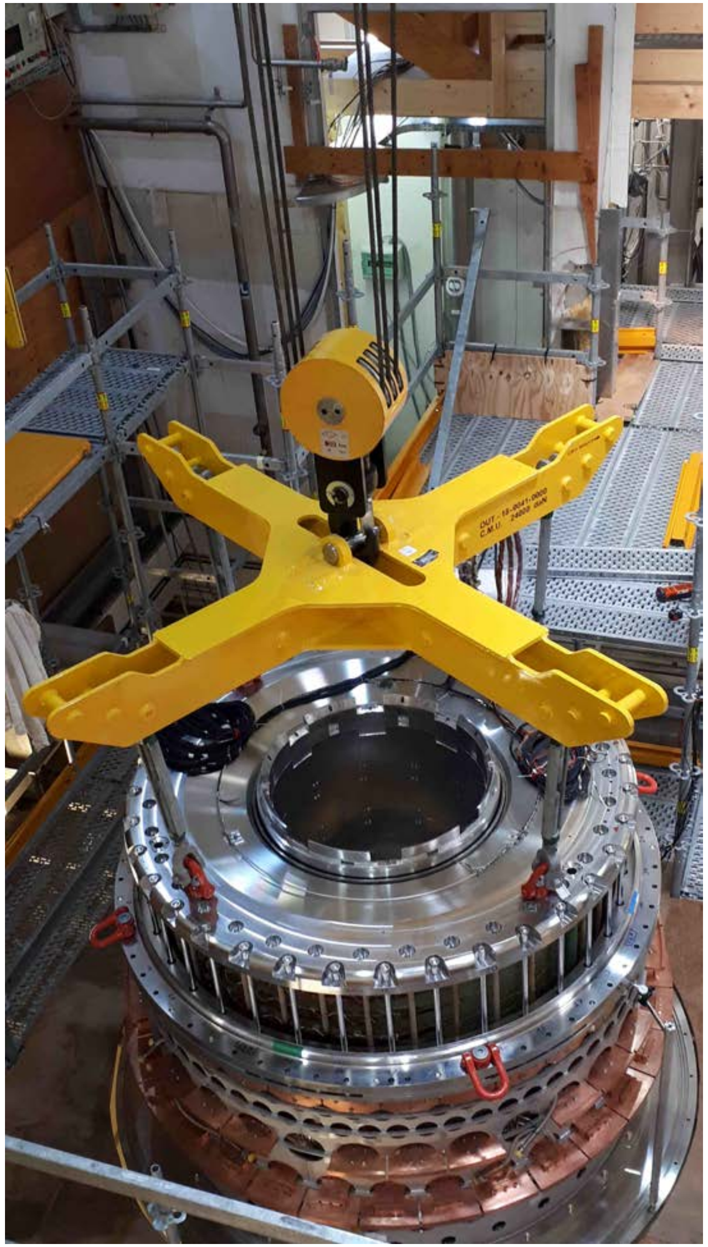
Not shown (located in other areas)

- Liquefier cycle compressor @ 14.5 bars
- He recovery balloon : 30 m^3 @ Patm
- He recovery compressor @ 200 bars
- 32 x 0.5 m^3 high pressure gaseous He tanks @ 200 bars
- Magnet Safety and Magnet Control Systems

Successful insertion of the superconducting coil* (May 5, 2021)







R. Pfister, E. Verney, M. Kamke & M. Pelloux

* Minimum clearance of 0.2-0.3 mm/radius

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Welding of the LHe Vessel & Tests

Cf. p.9 https://emfl.eu/emflwebsite/wp-content/uploads/2021/11/emfl_newsletter_n3_21_web.pdf

► No damage of the superconducting coil inside was detected

► Penetrant testing of weldings was Ok
► Instrumentation & electrical insulation checks are OK
► Pressure test was OK

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R. Pfister, E. Verney, M. Kamke & L. Ronayette

Summary & Next Steps

- The cryogenic satellite for cooling the superconducting outsert has been successfully commissioned
  - Stable pressurized superfluid He bath (1.8 K, 1200 hPa) maintained during ~ 72 h
  - More than 40 W cooling power measured @ 1.8 K / expected heat load in the range 16-20 W
- Current leads (CuP/LTS) also successfully commissioned
  - 3 powering cycles up to the ultimate current of 7500 A (~ 4 h at the fat top)
  - GHe flow stopped during simulated magnet current discharge (10^4 MA^2s), $\Delta T_{max} < 80$ K
  - Slight dissymmetry between current leads (consumption 10.1 vs. 11.5 Nm^3/h, R ≈ 11.5 vs. 13.5 $\mu\Omega$)
- The final assembly is close to completion with as the sole remaining part the connections of the cryoline
- Next steps & timeline (tbc)
  - Dec. 2021 — End of assembly
  - Jan. 2022 — Start of vacuum pumping for cryostat & satellite
  - March/Apr. — Start of the cooldown
  - May/June — Start of the superconducting magnet powering tests
  - Sept./Oct. — Start of the tests in hybrid mode : **1st target at 42-43 T**

And After ?

As an example of Experiment

GrAHal

Grenoble Axion Haloscopes

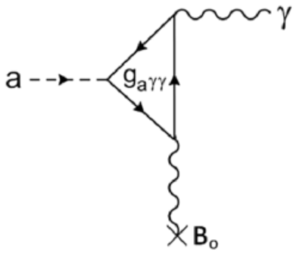
The hybrid magnet project is supported by Université Grenoble-Alpes, CNRS, French Ministry of Higher Education and Research in the framework of "Investissements pour l'avenir" Equipex LaSUP (Large Superconducting User Platform), European Funds for Regional Development (FEDER) and Rhône-Alpes region.

GrAHal : Grenoble Axion Haloscopes for Dark Matter search & Explore the ultra-low energy frontier of cosmic particles (1-100 μeV)

R. Ballou, P. Camus, T. Grenet, S. Kramer, P. Pugnat, J. Quevillon, N. Roch, C. Smith, *CNRS-Grenoble & Univ. Grenoble-Alpes*

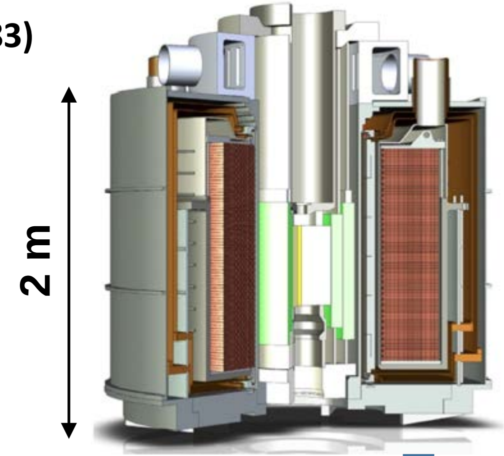
Axion & ALPs Haloscope (Sikivie 1983)

Primakoff Effect



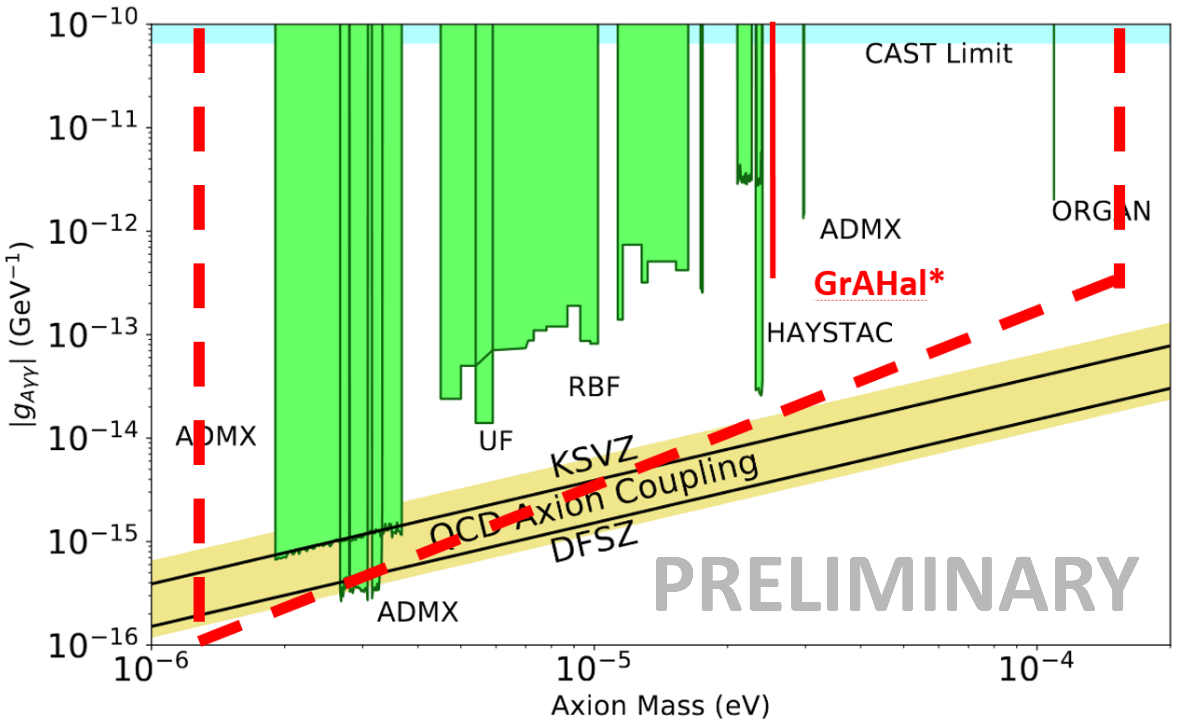
$P \;\alpha\; g_{a\gamma\gamma}^2 \; B_0^2 \, V < 10^{-21}$ W

⇒ **RF cavities (0.3-30 GHz) at 20 mK & quantum amplifiers SQUID & JPA (IN) in strong magnetic field (LNCMI)**



Small & large scale dilution fridges needed

- **Grenoble Hybride Magnet** (Equipex LaSUP, LNCMI)
  43 T/34 mm, 40 T/50 mm, 27 T/170 mm, 9.5 T/800 mm
  https://indico.desy.de/indico/event/13889/contribution/11/material/slides/0.pdf
  http://cds.cern.ch/record/2315130/files/fulltext.pdf
  https://grahal.neel.cnrs.fr/
- **2021-2024: 1st experimental runs down to 20 mK in smaller bore existing superconducting magnets (LANEF, IN)** in 16-20 T/50 mm & 14 T/70 mm
  ***First results** https://arxiv.org/pdf/2110.14406.pdf



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