

From Manufacture to Assembly of the 43 T Grenoble Hybrid Magnet

P. Pugnat

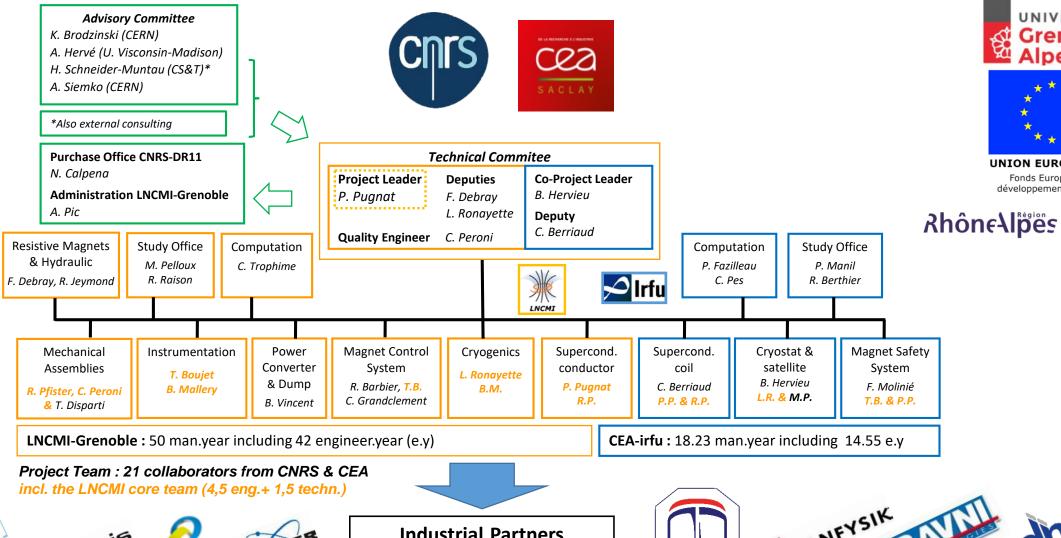








Project Structure & Collaborators











Industrial Partners







Grenoble

UNION EUROPEENNE

Fonds Européen de

développement Régional

Outline

- Introduction
- Superconducting Coil Manufacturing
 - Status of the coil production
 - Connections between DPs
 - Quality control
- Manufacturing & delivery of the cryogenic satellite
- Manufacturing & delivery of the cryostat
- Tests & assembly at LNCMI
- Summary & Outlook



The Challenge of Building Hybrid Magnets

- How to marry a non-reliable technology, *i.e.* resistive inserts, with a non-robust one, *i.e.* a large bore superconducting "outsert" ?
- Mitigating strategy of the Grenoble Hybride magnet for both, non-reliability & non-robustness aspects
 - Pushing the most robust technologies and less expensive part, *i.e.* the resistive inserts, to their present limit
 - Using the most conservative and validated technology, *i.e.* Nb-Ti/Cu at 1.8 K for the superconducting outsert
 - Reduce the insert/outsert coupling with eddy-current shield
 - Consider disassembly of the overall hybrid magnet for repairing since the design phase
 - ⇒ Segmentation of the SC outsert in interchangeable double-pancakes
 - ▶ 44 DPs produced / 37 needed for the coil, i.e. 7 spare DPs
 - ⇒ Modularity of the experimental platform between high magnetic field/high magnetic flux, **Big** interest for users

The Grenoble Hybrid Magnet: Possible Disassembly & Modularity as key Points of the Design

Modular Plateform for the production of High Magnetic Field & Flux

- 43 T / 34 mm hybrid magnet 24 MW
 - ▶ 8.5 + 9 + 25.5 T / sc. + poly-Bitter + poly-helix
- 38 T / 34 mm hybrid magnet 12 MW
 - ► Energy saving!
- 27 T / 170 mm hybrid magnet 18 MW
- 17 T / 375 mm hybrid magnet 12 MW
- 9 T / 800 mm sc. magnet alone

High Flux Magnets

Under Study

- Upgrade phase of resistive inserts with
 9 T produced by the superconducting outsert
 43 T / 34 mm
 45+ T / 34 mm
- Modular field gradient platform for levitation
- 60 T / 300 ms pulsed field



Cnr





Hydraulics: 300 l/s

Total stored Energy: 108 MJ ~ 23 kg de TNT

55 t in total incl. 22 t @ 1.8 K

P. Pugnat et al., IEEE Trans. Appl. Supercond. 28, 4300607 (2018) [Invited MT25] https://indico.cern.ch/event/445667/contributions/2562521/

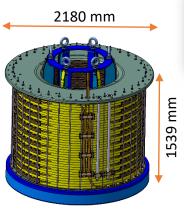
2 m

Hybrid Magnet: SC outsert & Cryogenics



Superconducting coil

17 tons @ 1,8 K Delivery: End 2019 (TBC)



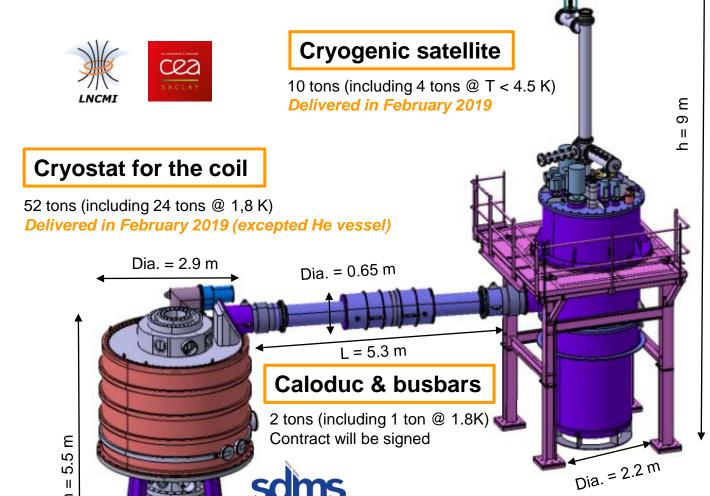




13 x 18 mm²

Project Key Figures

- Collaboration with CEA-Saclay
- 10 years, design & construction
- 15 M€
- Project team
 - . 21 members (LNCMI & CEA)
 - . 70 man.year
- Industrial supports
- . 14 public contracts (0.1 1.5 M€)

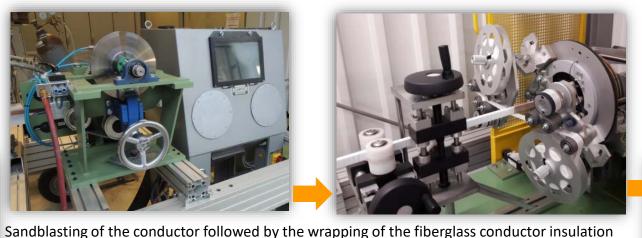




Connected to a fully dedicated cryoplant producing 150 l/h LHe @ 4.5 K

Double-pancake winding production line (2017-18)









Forming the layer jump In the middle of the DP



Mold for the epoxy

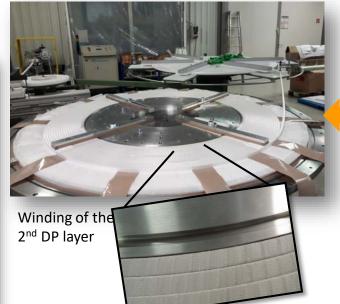
resin impregnation

Dia = $1868 \pm 0.5 \text{ mm}$

Geometry of the double-pancake (DP)

in a clean area







Winding the 1st layer after having stored on the upper part the conductor length for the 2nd layer

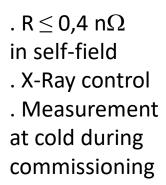


Assembly, gluing and connection of DPs (2018-19)

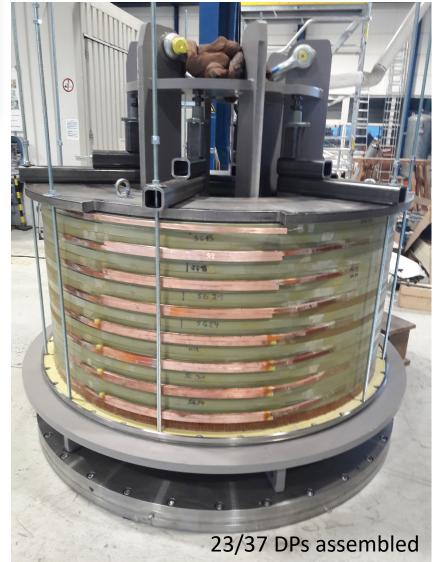












Quality Control of the SC



Dimensional measurements

Measurements	Number & positions of measurements	Averaged results +/- max/min
Internal diameter	6/DP (each 60°)	1101 ± 0.5 mm
External diameter	2/DP(Max/min)	1867.5 ± 0.5 mm
Height of each DP	3/DP (at 120°)	38.25 ± 0.1 mm
Height of the DP stacking ^a	1 at the position of each coil tie rod	1427 mm



^a Not yet measured, the result corresponds to the extrapolated value from the height of the stacking containing currently 24 DPs.





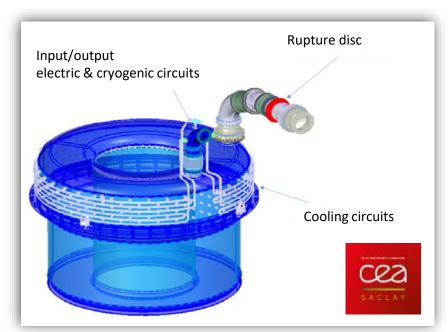
Electrical Tests & Measurements

Assembling sequence	Test type	Voltage	Results
Each DP separately	R@ 293 K L CDT in air HV/ground	~ 0 V ~ 0 V 500 V 3 kV	22.95 \pm 0.07 m Ω 5.42 \pm 0.09 mH No difference R _{insulation} > 1G Ω
First pair of inter- connected DPs assembled between flanges in 1 bar of He	HV/ground	3 kV	$R_{insulation} > 1G\Omega$
After stacking of each DP (under compression)	HV between DPs in contact	3 kV	$R_{insulation} > 1G\Omega$
After assembly and connection of 37 DPs ^a	R@ 293 K L CDT air/He HV/ground air/He (1 bar)	~ 0 V ~ 0 V 3 kV 3 kV	$849\pm2.6~\text{m}\Omega$ $3.05\pm0.1~\text{H}$ To be done $R_{\text{insulation}} > 1G\Omega$

R = resistance measurements, L = inductance measurements @ 100 Hz, CDT = Capacitor Discharge Tests, HV = High Voltage Tests & measurements.

^a Operation not yet completed, results are specified values.

Production of the cryostat (2018)



Trial assembly in industry of the magnet ferule with thermal screens







Ferule in TA6V for the Eddy current shield

Cooling circuits

- . 5 K
- . 50 K
- . 120 K





Trial assembly in industry of the OVC with thermal shields

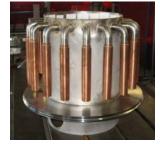
The cryogenic satellite (2018)







Mounting of the current leads crossing the λ -plate













Feedthrough for the 212 instr. wires (vacuum side)

Upper part of the satellite with valves, connectors and current leads

1.8 K cold finger heat exchanger (350 mm dia.)

Delivery of the cryogenic Satelite (D-Day: 5 February 2019)













Integration & dummy assembly at LNCMI-Grenoble













In house trial assembly without thermal shields nor the superconducting coil for leak tests

► A leak was detected and repaired

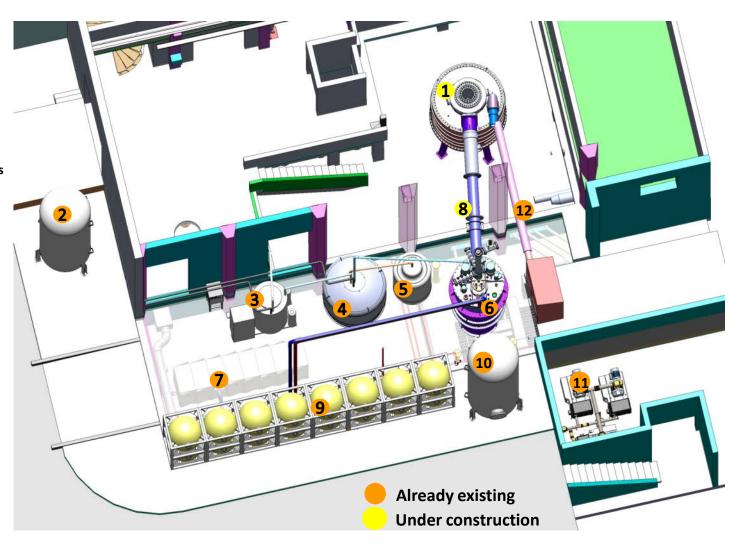
Grenoble Hybrid complete system overview



- 1 Hybrid Magnet 43 T
- 2 LN₂ tank 27 000 litres.
- 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
- High pressure gaseous He tanks 16 x 1 m³ @ 200 bars
- Liquefier pure He buffer tank 15 m³ @ 20 bars
- Helium pumping system 6000 m³/h @ 10 mbar, 20 °C
- 12 Quench line

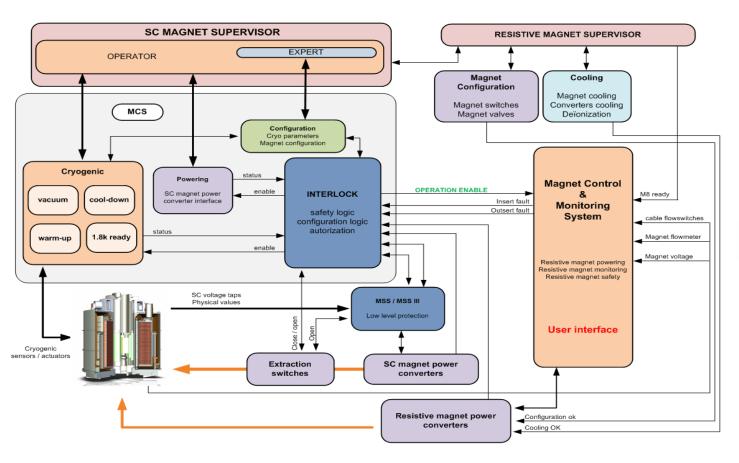
Not shown (located in other areas)

- Liquefier cycle compressor @ 14.5 bars
- He recovery balloon: 30 m³ @ Patm
- He recovery compressor @ 200 bars
- 32 x 0.5 m³ high pressure gaseous He tanks @ 200 bars
- Magnet Safety and Magnet Control Systems



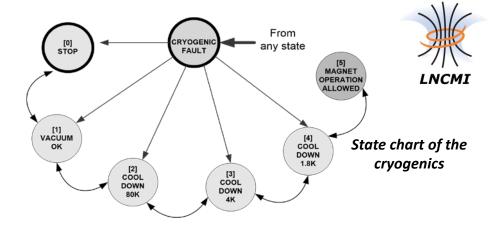
Magnet Control & Protection Systems

70 % made (partial delivery for satellite cooldown test : October 2019)



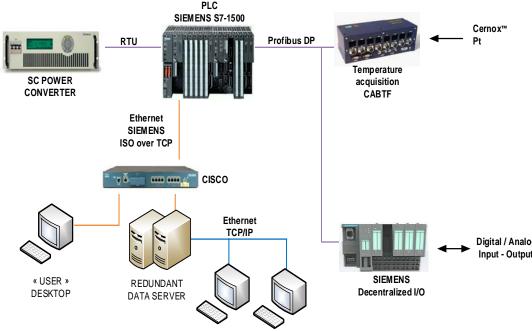
HMI level

System Control And Data Acquisition software: Cimplicity (from G.E.)



Flexible hardware architecture of the MCS

Programmable Logic Controller (PLC) Siemens S7-1500 dispatched on several modules depending on the localization of the sensors and actuators → reduces wiring and offers a better efficiency of the analog measurement.



DESKTOP

DESKTOP

Summary



- Most of the major equipment have been delivered or are close to completion
 - The last contract for the cryogenic line has been signed for a delivery end of April 2020
- On going
 - Commissioning of the cryogenic satellite to produce superfluid He. This will be followed by the full powering of non-sc current leads in short-circuit in normal and extreme conditions
 - Assembly & leak tests of the cryostat
 - Cabling of the magnet safety & control systems
 - Developments of resistive inserts, cf. Mon-Af-Or4-05, Mon-Af-Or4-06
- Commissioning of the overall hybrid magnet system end of 2020 and & 1st operation end of 2021
- Upgrade to 45+T is being studied to be implemented in \sim 2025
- For the road toward 60 T hybrid, cf. H. Schneider-Muntau & P. Pugnat, Mon-Af-Or4-01

Outlook

A practical example of Science that can/will* be done with this unique <u>modular</u> Grenoble hybrid magnet platform...



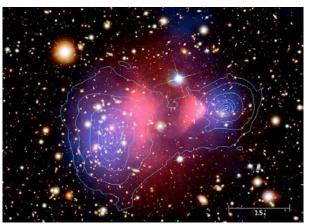
^{*} Disclaimer: The view presented here does not represent necessary the view of CNRS management.



GrAHal: <u>Grenoble Axion Haloscope</u> for Dark Matter search & explore the ultra-low energy frontier of cosmic particles (1-100 μeV/c²)



R. Ballou, P. Camus, T. Grenet, S. Kramer, P. Pugnat, N. Roch, CNRS-Grenoble, Univ. Grenoble-Alpes



Collision of two galaxy clusters (Bullet cluster) one of the strongest arguments in favor of dark matter



https://indico.desy.de/indico/event/13889/contribution/11/material/slides/0.pdf

http://cds.cern.ch/record/2315130/files/full text.pdf

 $m_A c^2 \approx h v$





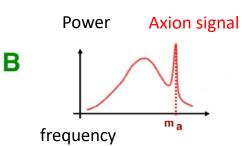
Axion & ALPs Haloscope (Sikivie 1983)

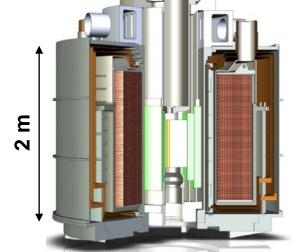
Primakoff Effect

 $P \alpha g_{\alpha\gamma\gamma}^{2} B_{0}^{2} V < 10^{-21} W$

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







- Grenoble Hybride Magnet (Equipex LaSUP, LNCMI)
 43 T/34 mm, 40 T/50 mm, 27 T/170 mm,
 9 T/800 mm
- 1st experimental runs at 20 mK in smaller superconducting magnets (LANEF, Néel)
 - . 16-20 T/50 mm, 14 T/70 mm