
# Aimant Hybride 43 T du LNCMI
# Préparation de la mise en froid à 1,8 K du satellite cryogénique

## Journées liquéfacteurs-réfrigérateurs hélium
## 16-18 Septembre 2019
## CERN

L. Ronayette, R. Barbier, T. Boujet, F. Debray, T. Disparti, C. Granclement, K. Juge, B. Mallery, M. Pelloux, R. Pfister, P. Pugnat, R. Raison, C. Trophime, B. Vincent.

C. Berriaud, R. Berthier, P. Bredy, P. Fazilleau, P. Graffin, B. Hervieu, FP. Juster, P. Manil, C. Mayri, F. Molinié, H. Neyrial

# Only 8 high magnetic field ( > 25 T) laboratories

EMFL European Magnetic Field Laboratory

- Pulsed field (B : 60 to 100 T , t ~ 10 ms)
- Stray field (B : 20 to 45 T , t ~ 10 h)

**NHMFL**
Tallahassee
Los Alamos

**LNCMI**
Grenoble
Toulouse

**HFML**
Nijmegen

**HLD**
Dresden

**WHMFC**
Wuhan

**HMFL**
Hefei

**HFLSM**
Sendai

**TML**
Tsukuba

# LNCMI Grenoble electro-magnets

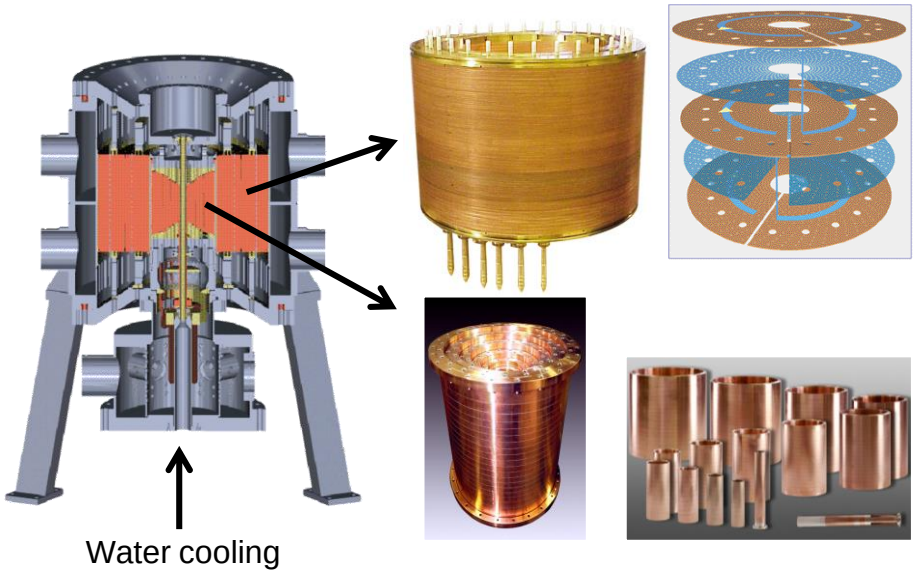
## Existing

**12 Superconducting coils**

- **B : 12 to 20 T**
- **Exp. dia. : 30 to 65 mm @ 4,2 K or 300 K**
- **P elec. : few tens mW**

**6 resistive electro-magnets**

- **B : 13 to 37 T**
- **Exp. dia. : 34 to 376 mm @ 300 K**
- **P elec. : 10 to 24 MW**



Water cooling

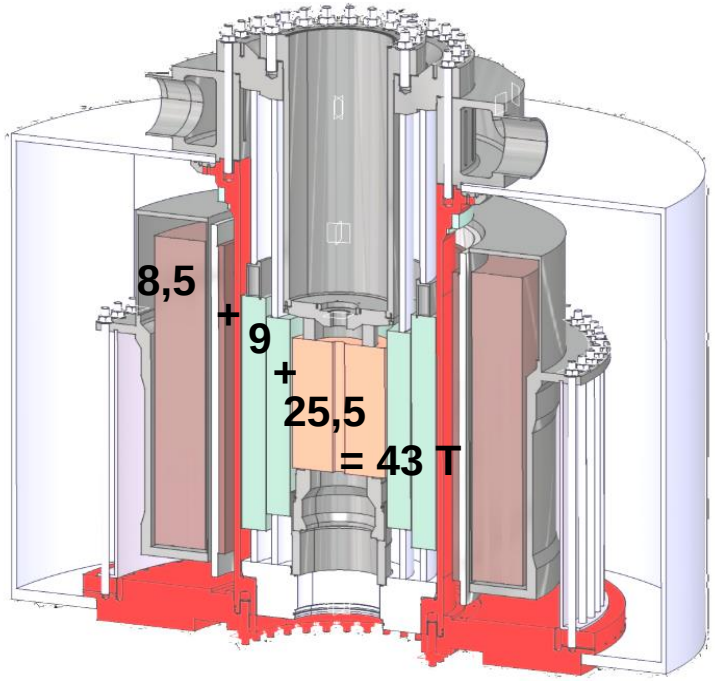
300 l/s , 27 bars , 20 °C

F. Debray et al.
IEEE Trans. Appl. Supercond. vol. 22, 4301804 (2012)

## Under construction

PROJET LaSUP

**LaSUP** : **La**rge **S**uperconducting **U**ser **P**latform
Equipex 2011, convention ANR-10-EQPX-35-01

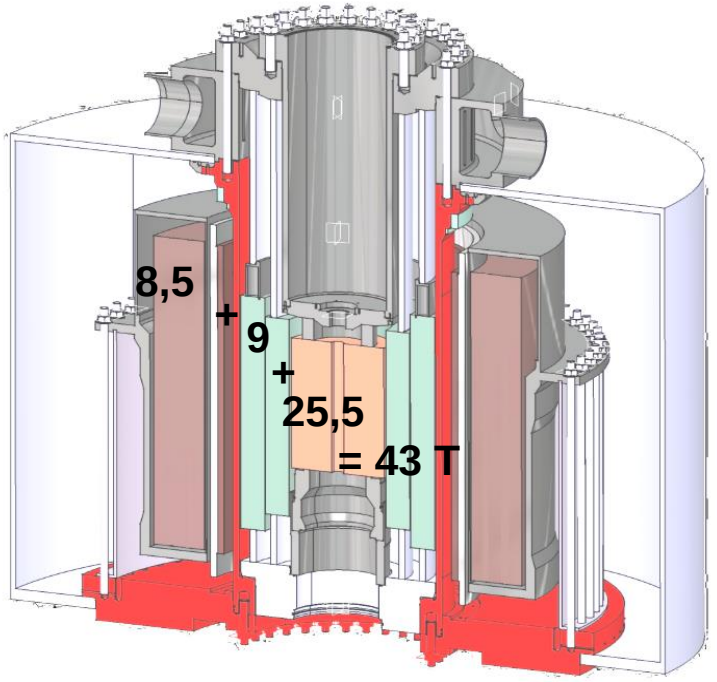



**LaSUP / Hybrid Magnet**
**Modular platform**
**B : 8.5 to 43 T**
**Exp. dia. : 34 to 800 mm @ 300 K**

# The LNCMI Grenoble Hybrid Magnet

## Modular Plateform for the production of High Magnetic Field

- 43 T / 34 mm hybrid magnet 24 MW
  - ► 8.5 + 9 + 25.5 T **/** sc. + poly-Bitter + poly-helix
- 34 T / 34 mm hybrid magnet 12 MW
- 27 T / 170 mm hybrid magnet 18 MW
- 17.5 T / 375 mm hybrid magnet 12 MW
- 8.5 T / 800 mm sc. magnet alone




*Total stored Energy : 108 MJ ~ 23 kg TNT*

**55 tons (including 22 tons @ 1.8 K)**

## 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

**P. Pugnat *et al.*, *IEEE Trans. Appl. Supercond.* 28, 4300607 (2018)**

# LNCMI Grenoble Hybrid Magnet

## *Project Organization - Organigram*

**Monitoring Committee**

| Members | Deputies |
|---|---|
| G. Rikken | C. Simon |
| A.-I. Etienvre | N. Alamanos |
| P. Védrine | J.M. Rifflet |
| J. Paret | I. Dhé |
| J. Prétet | I. Allegret |

**Advisory Committee**
- K. Brodzinski (CERN)
- A. Den Ouden (HFML)
- A. Hervé (U. Visconsin-Madison)
- H. Schneider-Muntau (CS&T)
- A. Siemko (CERN)

**External Consulting**
H. Schneider-Muntau

**Technical Commitee**

| | | |
|---|---|---|
| **Project Leader** P. Pugnat | **Deputies** F. Debray, L. Ronayette | **Co-Project Leader** B. Hervieu |
| **Quality Engineer** C. Peroni | | **Deputy** C. Berriaud |

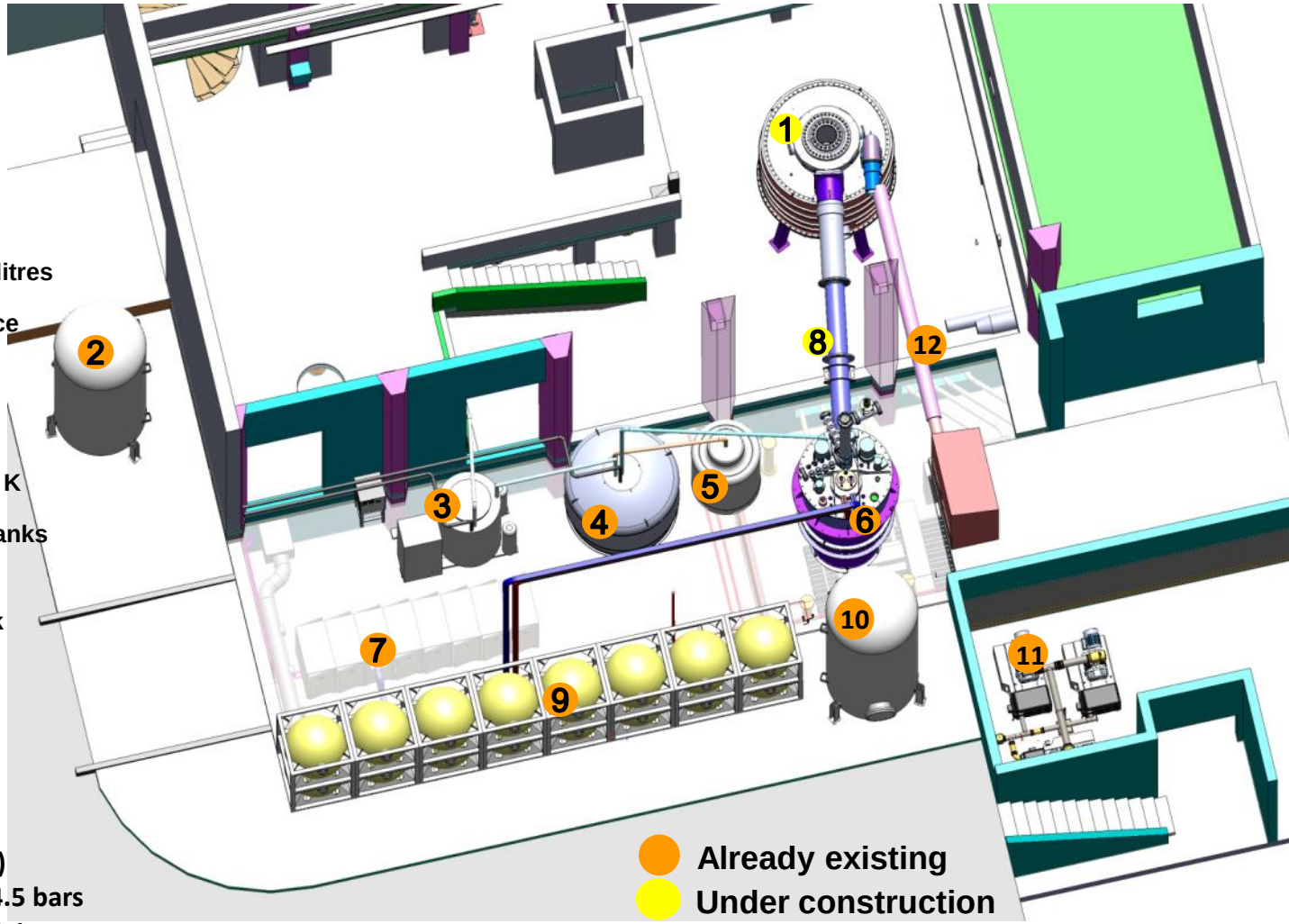
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Integration** C. Peroni | **Study Office** M. Pelloux | **Computation** C. Trophime | | | | | **Computation** P. Fazilleau, C. Pes | **Study Office** P. Manil, P. Graffin, R. Berthier | |
| **Resistive Magnets & Hydraulic** F. Debray | **Mechanical Assemblies** R. Pfister, T. Disparti | **Power Converter & Dump** B. Vincent | **Magnet Control System** R. Barbier, C. Grandclement | **Cryogenics and instrumentation** L. Ronayette, T. Boujet, B. Mallery | **Supercond. coil** P. Pugnat | | **Supercond. coil** C. Berriaud | **Cryostat & satellite** B. Hervieu | **Magnet Safety System** F. Molinié |
| **LNCMI-Grenoble : 60 man.year** | | | | | | | **CEA-irfu : 20 man.year** | | |

*Project Team :*
*20 collaborators*
*from CNRS & CEA*
***Only 6 people full time***

**Industrial Partners**

# LNCMI Hybrid complete system overview

1. Hybrid Magnet 43 T
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



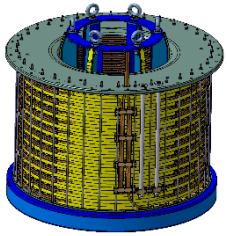

Not shown (located in other areas)

- 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

# Zoom on…

## Superconducting coil

*Delivery : November 2019*



h = 1.8 m

Dia. = 1.9 m

## Cryogenic satellite

10 tons (including 4 tons @ T < 4.5 K)

*Delivered : February 2019*

*Fully assembled : June 2019*

*Partially accepted : September 2019*

*Commissioning tests @ 1.8 K to come…*

h = 9 m

Dia. = 2.9 m

Dia. = 0.65 m

L = 5.3 m

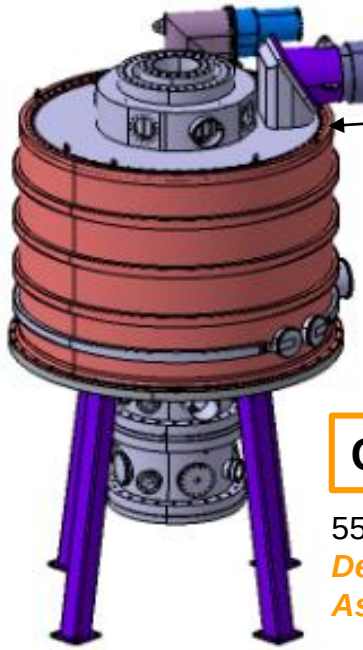
## Cryoline & busbars

2 tons (including 1 ton @ 1.8K)

*Delivery : April 2020*

*Fully connected : June 2020*

h = 5.5 m



## Cryostat

55 tons (including 22 tons @ 1,8 K)

*Delivered : July 2019*

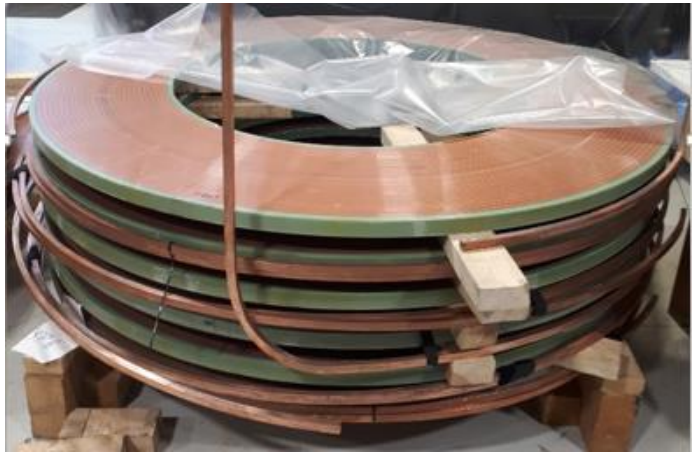
*Assembly : started September 2019*

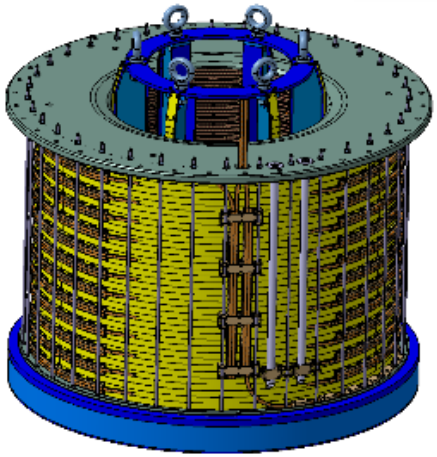
Dia. = 2.2 m

h = 1.7 m

# Superconducting coil

**DP production made 100% , assembly made 50 %**



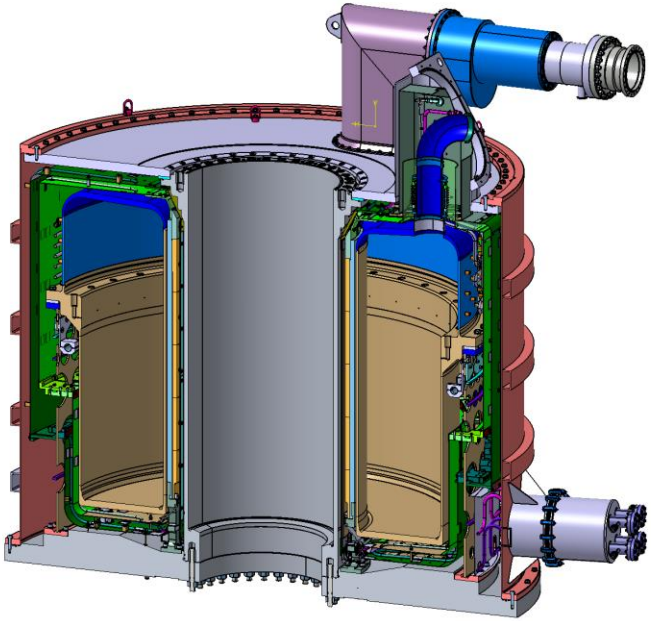


Two first double-pancake assembly test

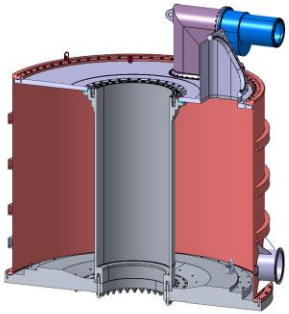
Stacking / lifting tool

# Cryostat

**95 % manufacture made**
**90 % control tests made**

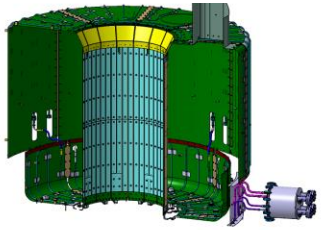


## Outer Vacuum Chamber



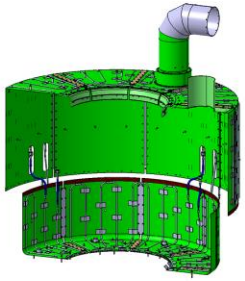
100 %

## Outer 120 K thermal screens



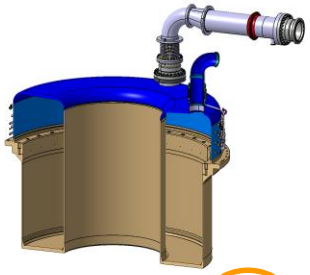
100 %

## Outer 50 K Thermal screens



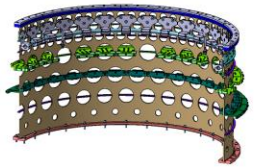
100 %

## Helium vessel



70 %

## Magnet support ferrule



100 %

## Inner 120 K thermal screen

100 %

# Cryostat

Helium vessel bottom part

50 K thermal screens lateral part

Magnet support ferrule

Outer vacuum chamber (on top plate : cryo line and quench line connections)

# Cryoline and busbars

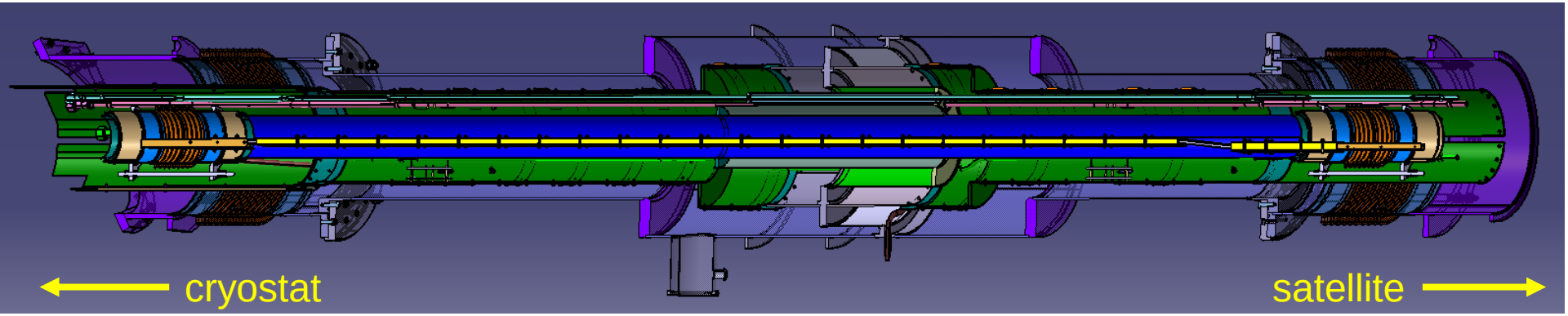
**Cryoline**
**100 % studies made**
**0 % manufacture made**

**Busbars**
**100 % studies made**
**50 % manufacture made**

**Tender made during summer 2019**

**Manufacturer choice : end of September 2019**

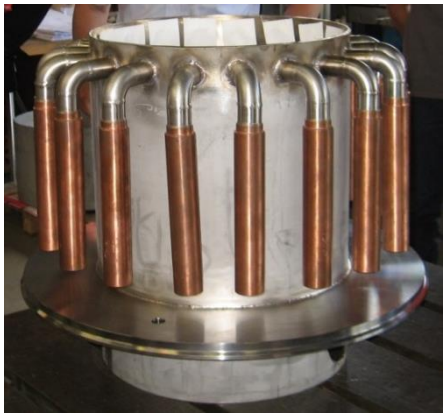
**Delivery : April 2020**



# Cryogenic satellite

**100 % manufacture made**
**100 % assembly made**
**100 % room temp. tests made**

**Cool down and cold temp. tests to come October – November 2019**

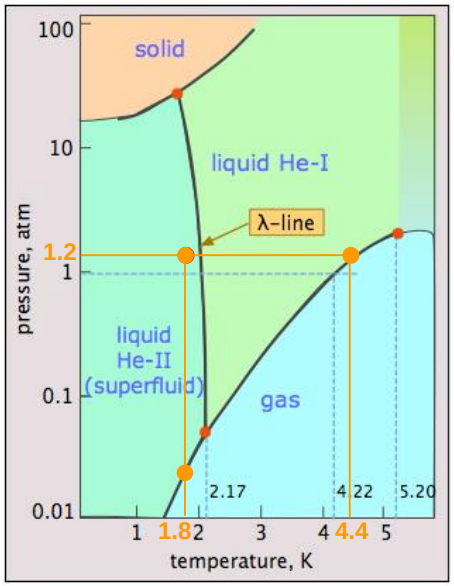


Cold fingers
(i.e. 1.75 - 1.8 K heat exchanger)


Cryo valves
and current leads

Work on the instrumentation
(~ 200 sensors)

# The cryogenic system



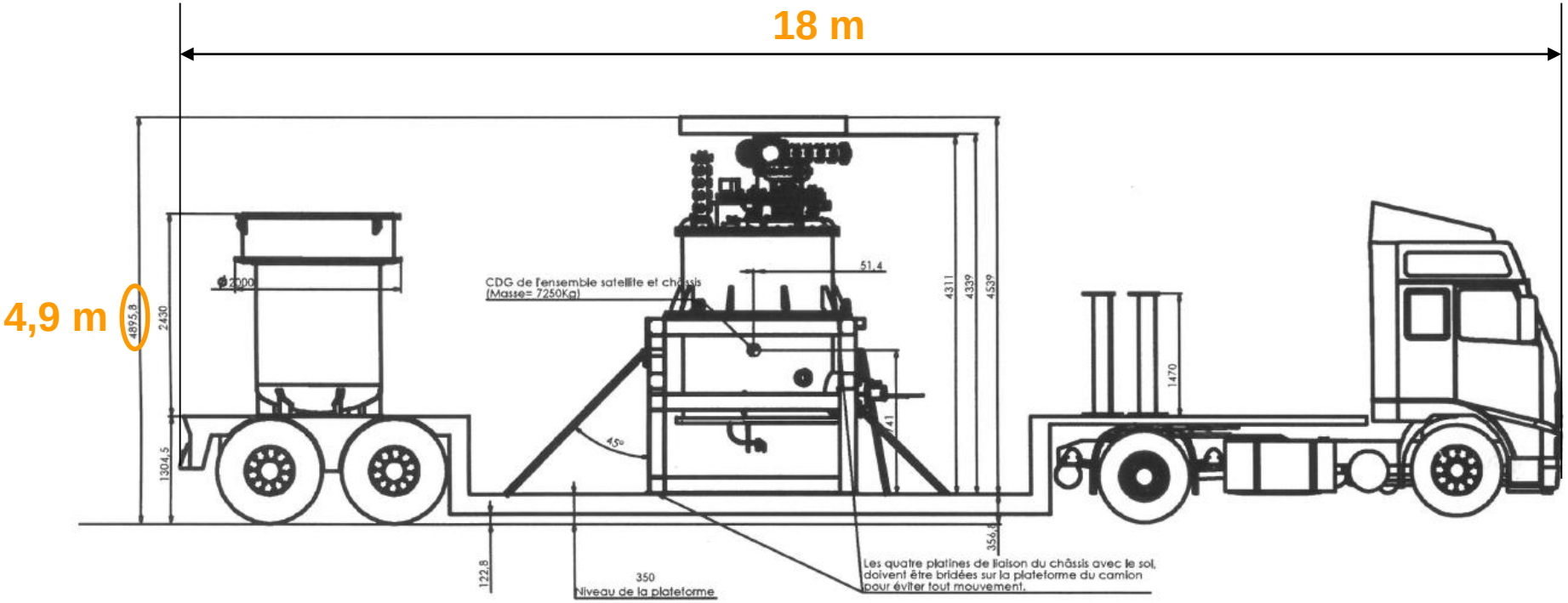

**Superfluid pressurized LHe bath at 1200 hPa , 1.8 K.**

**Principle invented in 1974 :**
**G. Claudet et al. from CEA Grenoble**



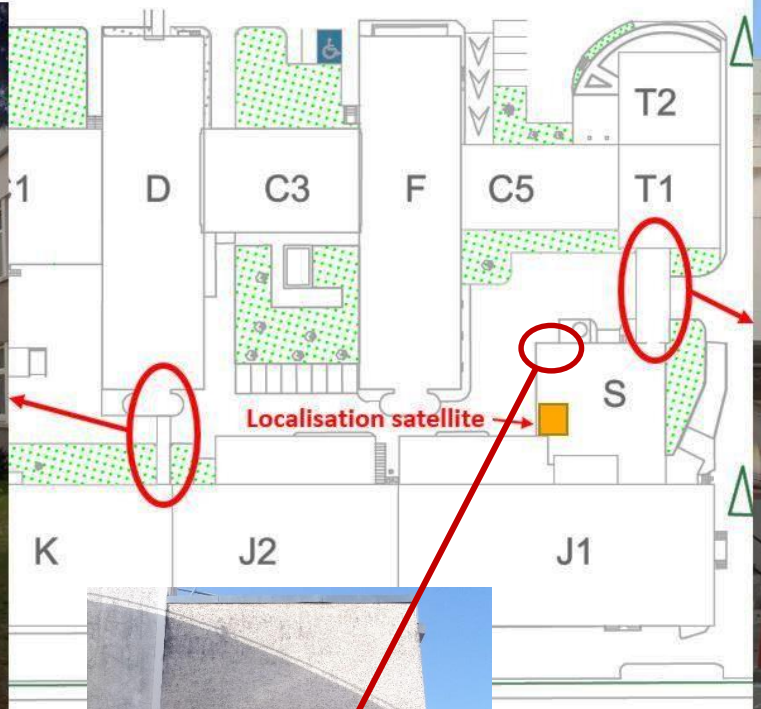

L. Ronayette, et al., "Cryogenic system for the 43 T Hybrid Magnet at LNCMI Grenoble: from the needs to the commissioning."
IOP Conf. Ser. : Mater. Sci. Eng. 171, 012107, (2017)

# Cryogenic satellite : delivery in 2 parts and on site assembly



# Height limitation issues…

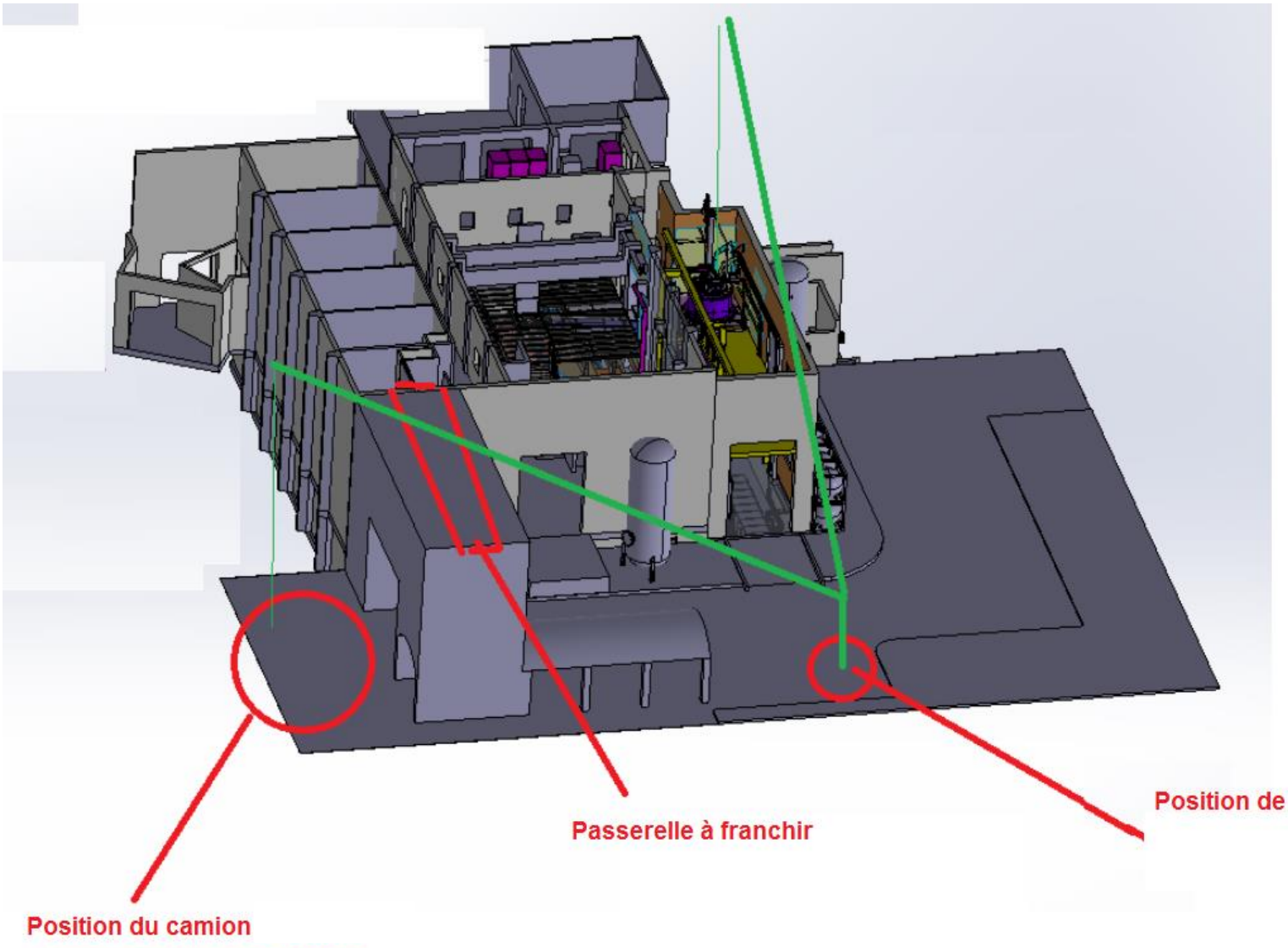

Height limitation #1
3.5 m




Height limitation #2
4 m


Height limitation #3
4.5 m

# Consequence #1: handling over the building



# Consequence #2 : entry from the roof

# February 2019 5th : D day = Delivery day

# Since the D day

- **End of assembly**
  - Internal pipes + test plugs welding
    - Thermal chocks between $LN_2$ and ambient temperature
  - Local leak tests (spec. : < $1.10^{-9}$ mbar.l/s)
  - End of internal instrumentation realization
  - Vacuum chamber closing

# Since the D day

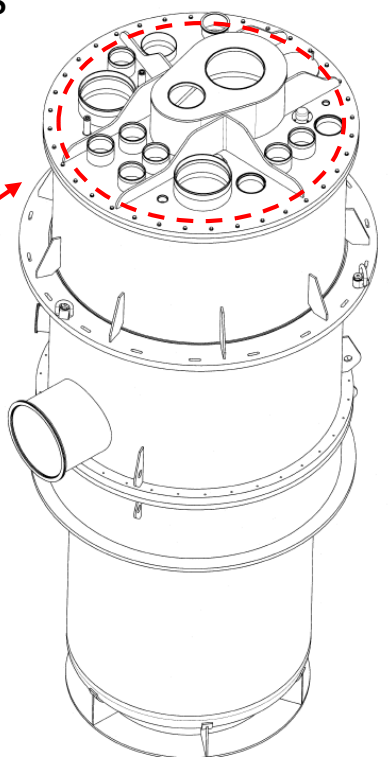
- **Pumping the vacuum chamber**
  - 5 purges between 1 and 1000 mbar with dry gaseous $N_2$ before starting pumping
  - Lowering the pressure down in the $10^{-5}$ mbar range

- **Global leak tests of cold and hot parts vs vacuum**
  - Cold parts : internal volumes and piping : spec. < $5.10^{-9}$ mbar.l/s

    → Test result : $8,5,10^{-10}$ mbar.l/s : ☺

  - Hot part : outer vacuum chamber : spec. < $5.10^{-8}$ mbar.l/s

    → Test result : $8,2.10^{-8}$ mbar.l/s : 😐
    - Problem understood after few days…
    - Top plate o'ring porosity (20 min. delay after He injection)
      - not possible to re-open the OVC at this stage to inspect the seal ☹
    - But…
    - We can survive : $8,2.10^{-8}$ mbar.l/s = 1 liter air at ambient pressure and temperature entering the OVC in ~ 380 years



# Since the D day

Room temp. + cryo piping made

Warm valves + instrumentation manifold made

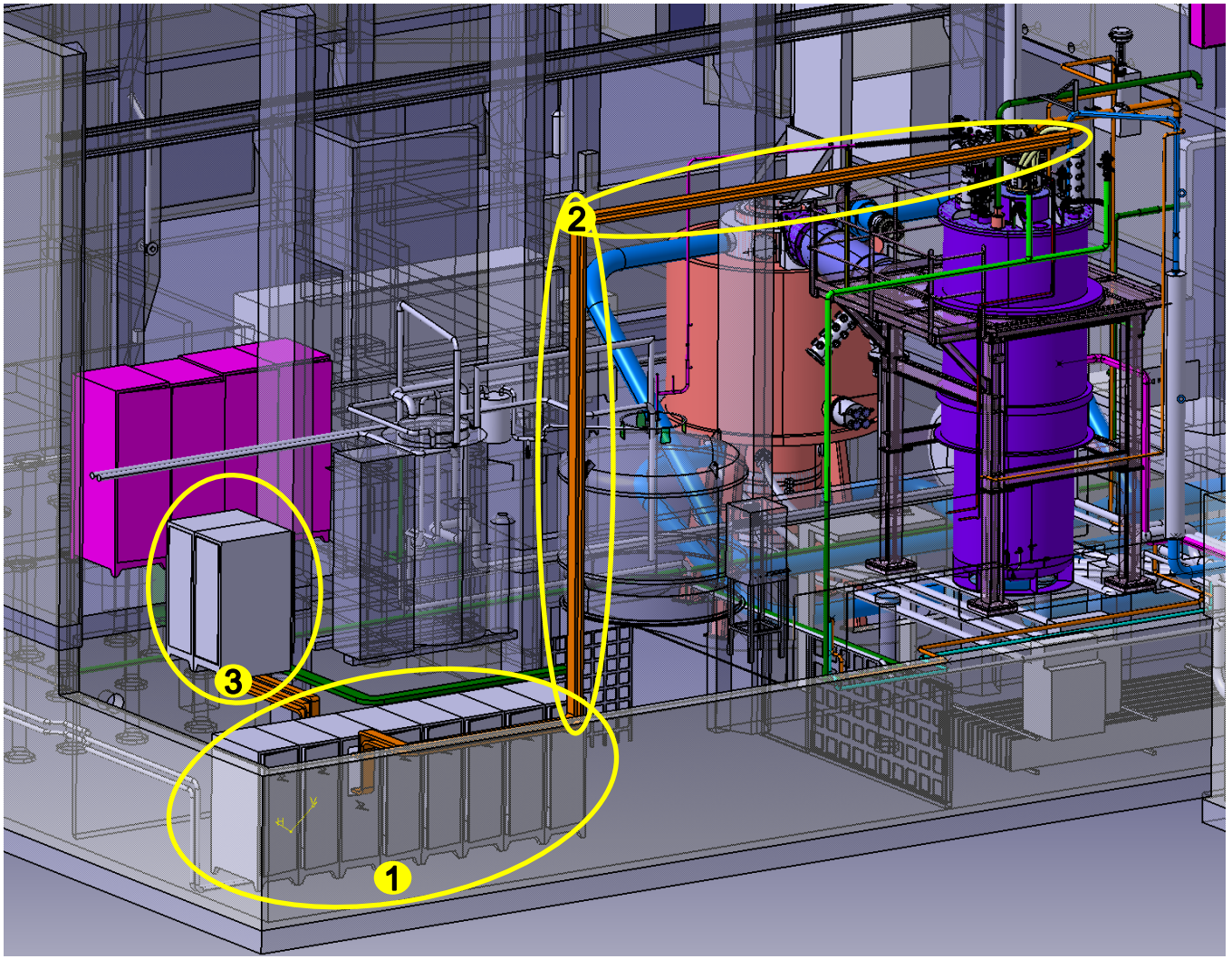
Busbars connected to current leads

# Since the D day

## Commissioning of DC power converter and ancillaries

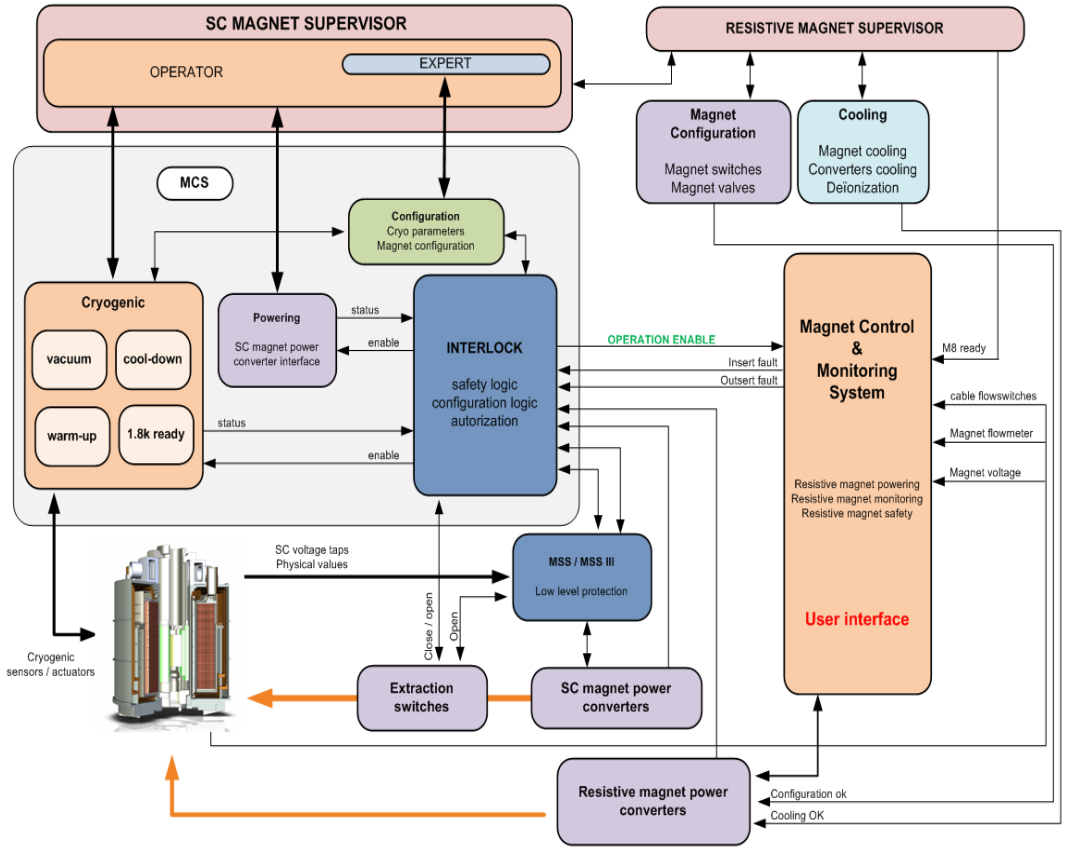
1. **DC power converter 8000 A ; ± 50 V**
2. **Bus-bars**
3. **Dump resistors**

**Commissioning made on a short June 2019**



# Since the D day : Magnet Control System

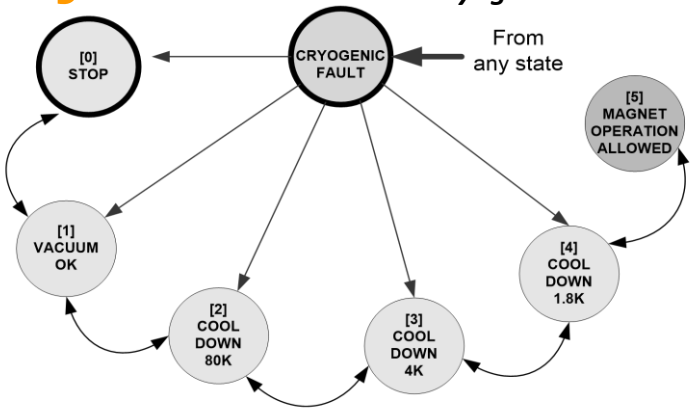
**70 % made (partial delivery for satellite cooldown test : October 2019)**

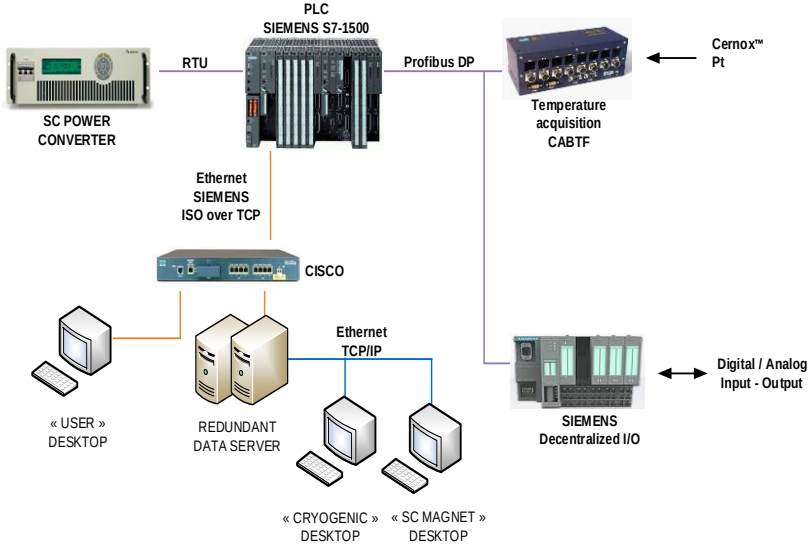



***HMI level***

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

***State chart of the cryogenics***



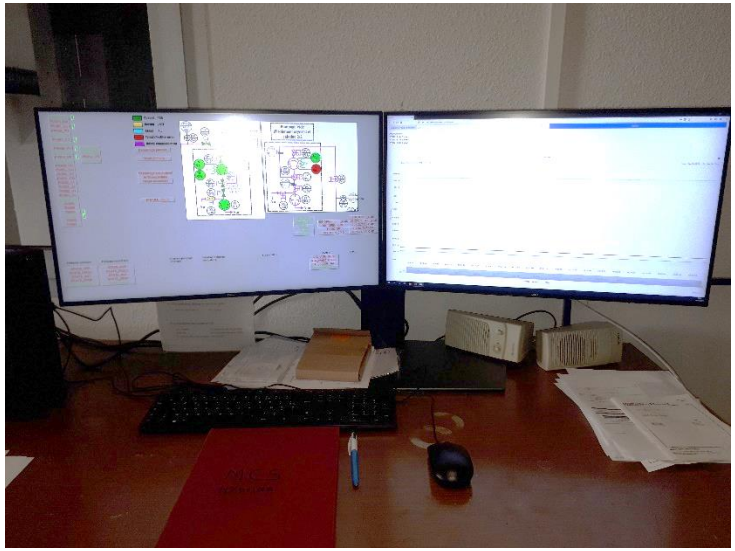



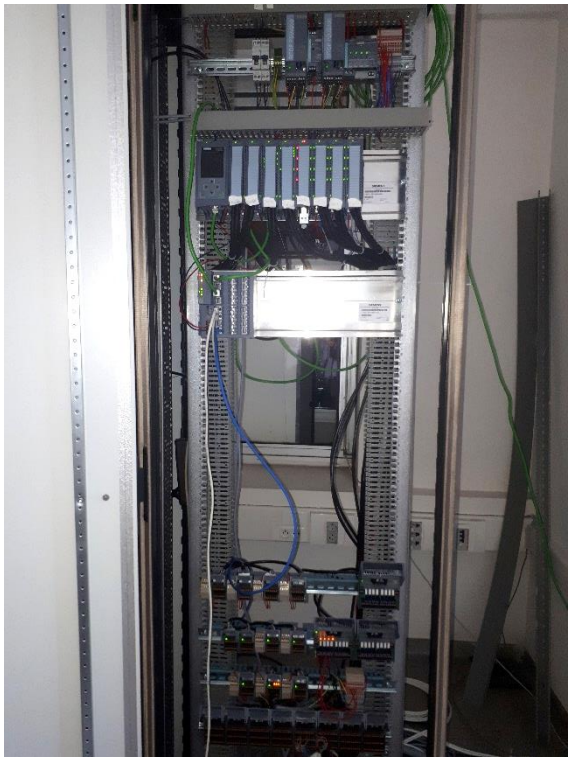

***Flexible hardware architecture of the MCS***

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.

# Magnet Control System

Work in progress…





# Since the D day : Magnet Safety System

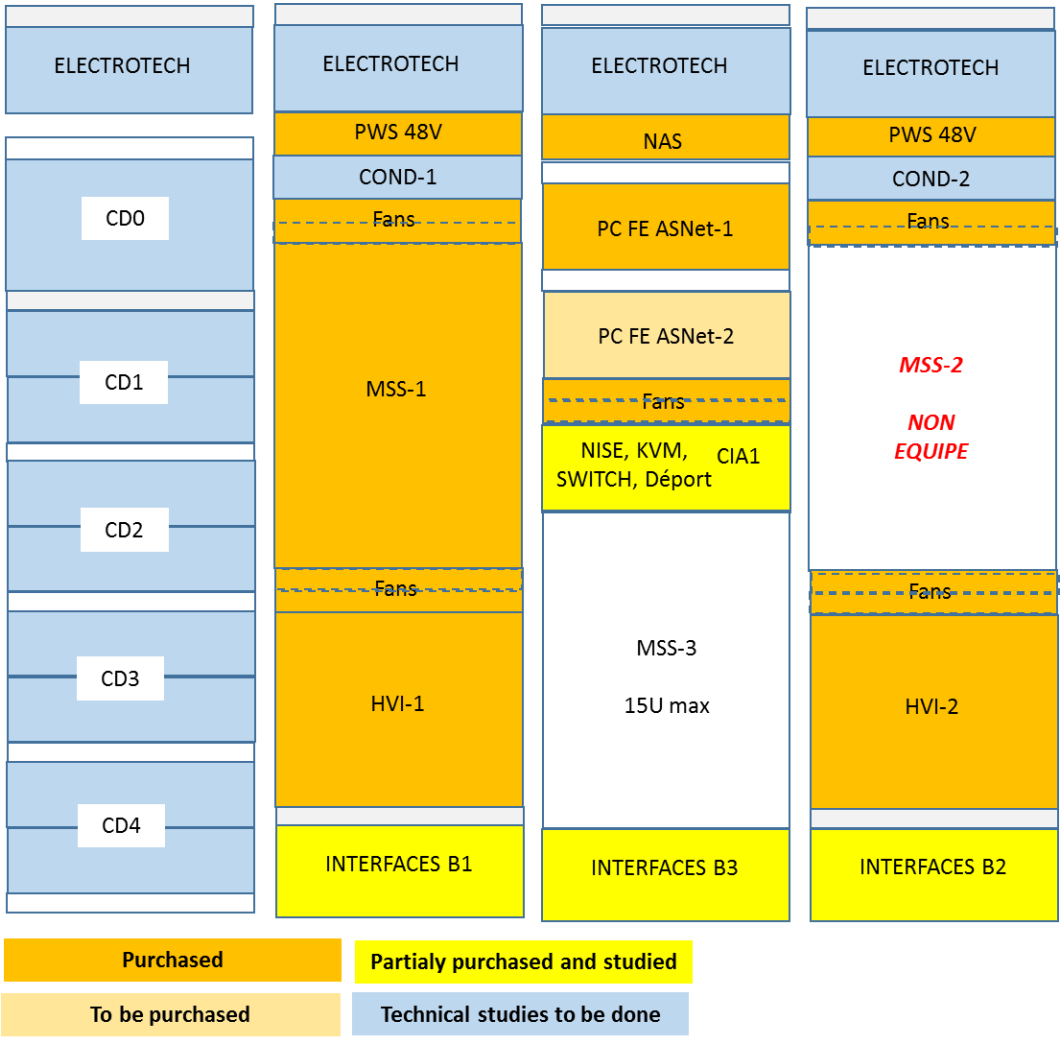
**60 % made (partial delivery for current leads tests at cold temp. in satellite : November 2019)**

**Done :**

- Detection boards manufactured
- 4 cabinets purchased
- Signals dispatching studied
- Hardware/software chosen

**To be done :**

- Functional tests of detection boards
- Hardware integration in the 4 cabinets
- All cables
- Final tests



# In parallel :

Reception and test of the low pressure cold vapors heater

Dummy assembly of the cryostat

# What's next now before end of 2019 ?

- **MCS (Magnet and Cryogenics Control System) to finish**
  - Hardware (still a bit of wiring to do…) + software (PLC and HMI programs)
  - Tests
- **System purging, flushing, conditioning under pure helium**
  - < 10 ppm air and moisture
- **Supply of ~3000 m³ (500 kg) Helium (actual stock : ~ 2100 m³ i.e. 350 kg)**
  - Dependence of the CNRS Grenoble liquefier service and He market
- **Cross fingers and…**
- **Perform the cool down in 3 phases**
  - 300 K → 80 K (intermediate contractual leak test control)
  - 80 K → 4 K
  - 4 K → 1.8 K (final contractual leak test → final reception of the satellite)
- **Test the current leads and the internal bus-bars + MSS up to 7500 A**
  - Superconducting short located in the test plugs
- **Finish the cryostat dummy assembly and start the final assembly**
  - Superconducting coil delivery planned for end of November

# More informations on the LNCMI Grenoble 43 T Hybrid magnet

- **Last presentations**
  - [Invited MT25] https://indico.cern.ch/event/445667/contributions/2562521/
  - [Oral MT25] https://indico.cern.ch/event/445667/contributions/2562535/
  - [Poster EUCAS2017] https://indico.cern.ch/event/659554/contributions/2714073/
  - [Oral ICEC26 - ICMC2016] http://icec26-icmc2016.org/9-O-3A-4.pdf

- **Last publications**
  - P. Pugnat *et al.,* "Progress in the Construction of the 43 T Hybrid Magnet at LNCMI-Grenoble", *IEEE Trans. on Appl. Supercond.* **28**, 4300607 (2018) https://snf.ieeecsc.org/sites/ieeecsc.org/files/documents/snf/abstracts/hdrPugnat-MT25-MoOr2-01.pdf
  - L. Ronayette *et al., "Cryogenic system for the 43 T Hybrid Magnet at LNCMI Grenoble: from the needs to the commissioning", IOP Conf. Ser.: Mater. Sci. Eng.***171** 012107 (2017) https://iopscience.iop.org/article/10.1088/1757-899X/171/1/012107/pdf