The STAARQ test facility

Station de **T**est d’**A**imants d’**A**ccélérateurs
Supraconducteurs

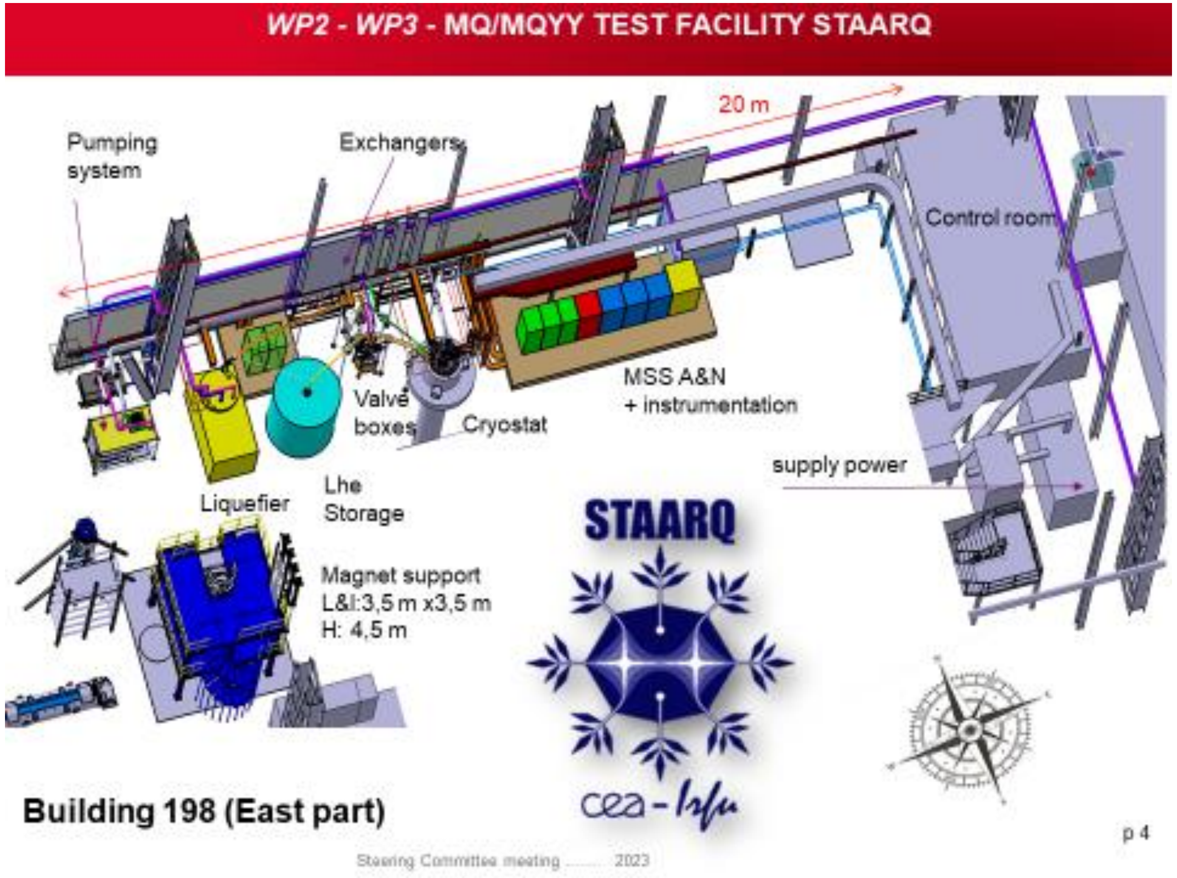
Summary

1. Introduction

Introduction :
The purpose of the facility

- This test facility has been designed to test and characterize quadrupole magnets designed for the LHC accelerator
  - Magnet training to reach nominal current
  - Magnetic characterization
  - Quench survivability
- 2 types of magnets are to be tested:
  - **MQ magnets** designed for the LHC consolidation project
    - Length: 3.45 m
    - OD: 452 mm
    - Apertures diameter: 56 mm
    - I_{max}: 13 kA
    - Mass: 4060 kg
    - Manufacturer: Tesla (x6)

  - **MQYY magnets** designed for the HiLumi project
    - Length: 4.035 m
    - OD: 614 mm
    - Apertures diameter: 90 mm
    - I_{max}: 6 kA
    - Mass: 9000 kg
    - Manufacturer: Elytt (x1) and Sigma-Phi (x1)



WP2 - WP3 - MQ/MQYY TEST FACILITY STAARQ

Building 198 (East part)

Steering Committee meeting 2023

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Introduction:
Main characteristics of the STAARQ facility

- 2 different types of magnets: STAARQ facility has to be versatile: different magnet and conductor supporting systems to accommodate both MQ and MQYY magnet types

- 1.9K pressurized superfluid helium bath
  - Max OD: 750 mm
  - Max length: 6.35 m

- Max current 13kA with appropriate ramp up and ramp down rates for both MQ and MQYY magnets

- Magnetic characterization of the magnets require dual anticryostats in the magnet apertures to house the magnetic probes

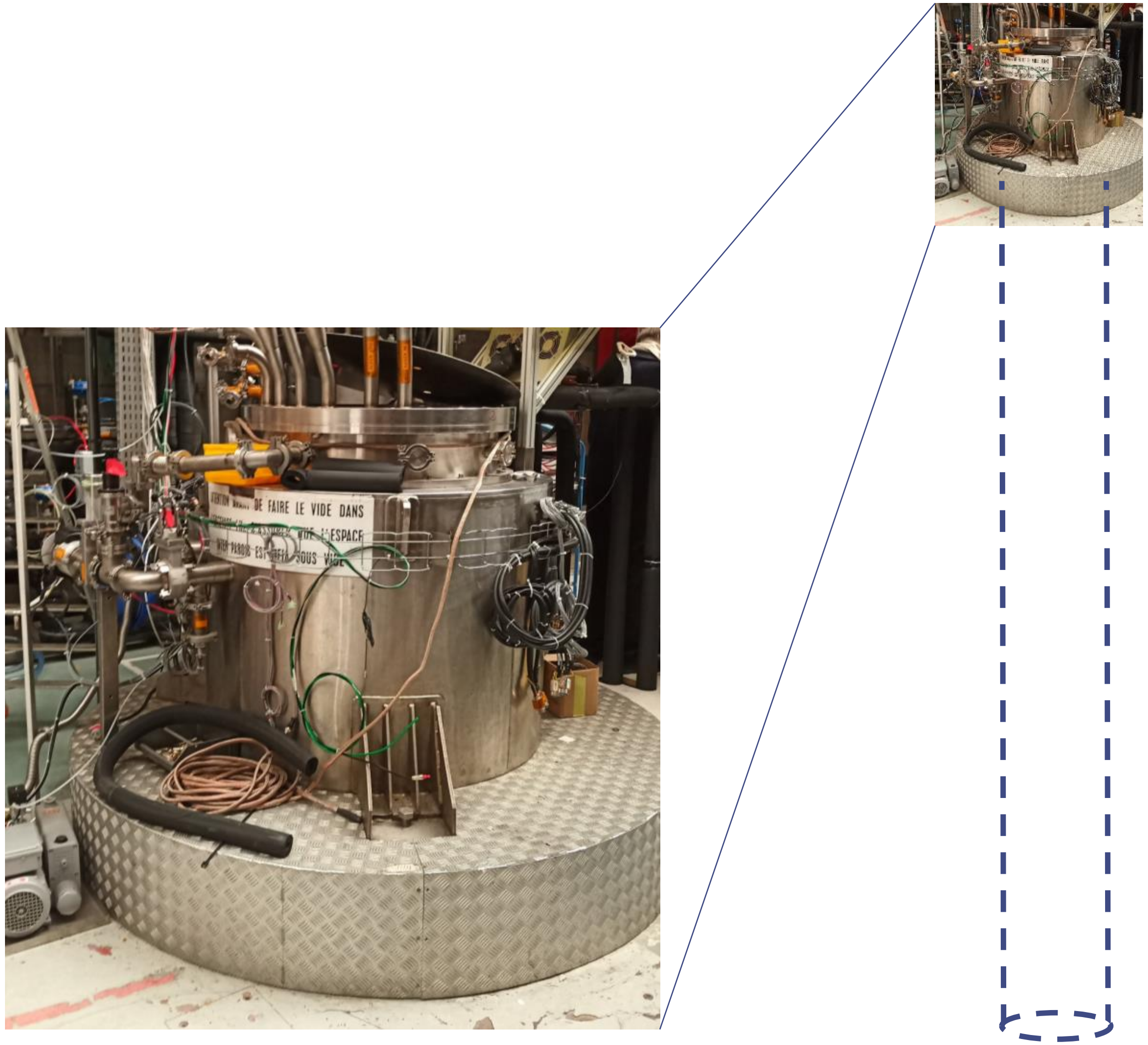
Introduction:
Test cycle of a magnet in the STAARQ facility

- Integration of the magnet in the cryogenic insert:
  - install the magnet in its support
  - Connect the magnet conductor to the current leads
  - Connect magnet instrumentation, quench heaters…
- Cool down the magnet with control of the temperature slope (2K/h) and gradients (<40K between highest and lowest temperature)
- Current tests of the magnet:
  - Training to reach nominal current
  - Magnetic characterization of the magnet at full current
  - Quench test at full current
- Warm the magnet back up with the same precautions regarding temperature slope and gradients (1-2K/h and 40K)
- Remove the magnet from the cryogenic insert and send it back to CERN

2. Cryostat

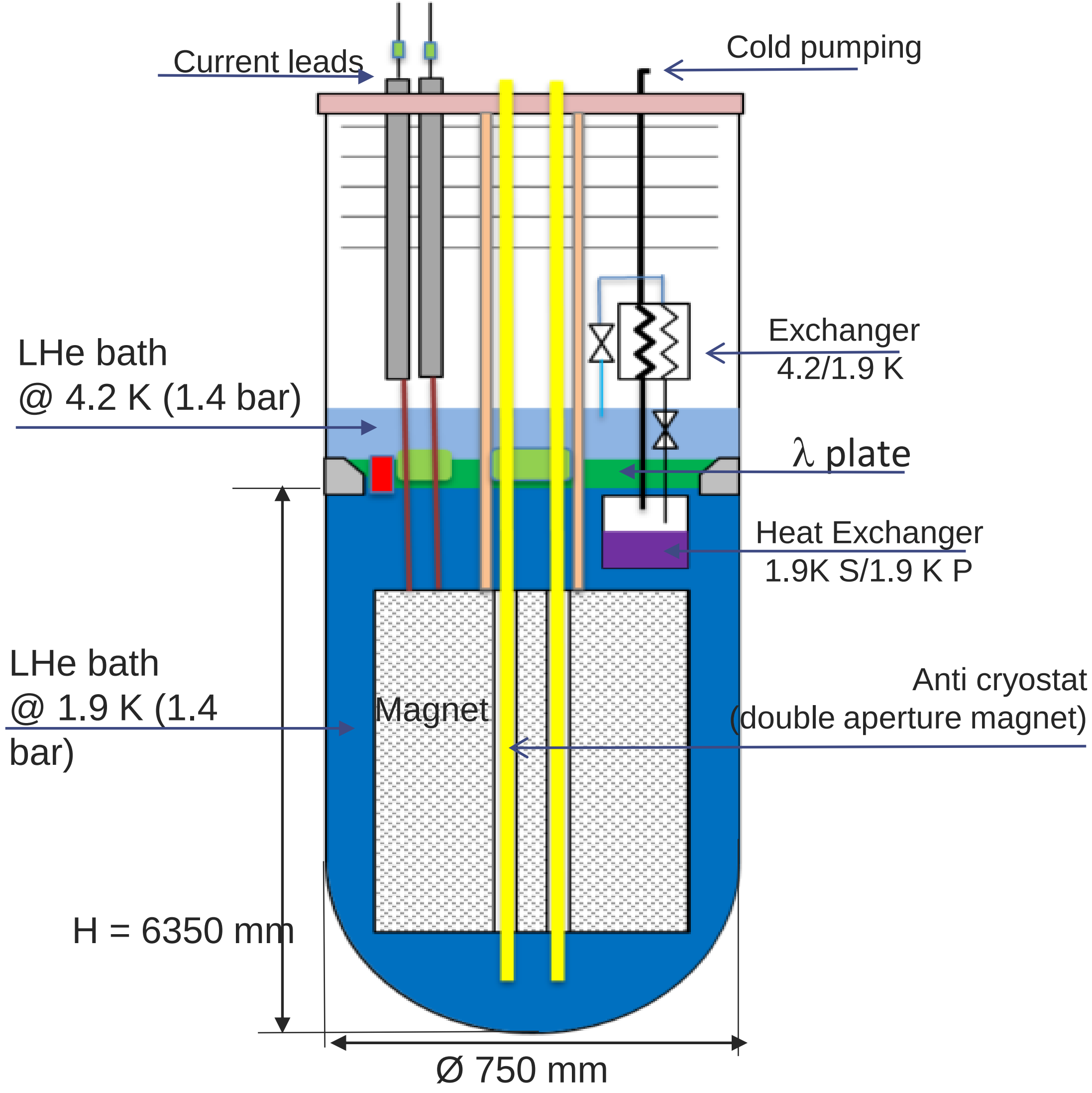
Cryostat :
The outer vessel

- Main constrains:
  - the outer shell of the cryostat is an existing vacuum vessel equipped with a liquid nitrogen cooled ring guard and heat shield set inside a 9m deep pit: no access from the sides of the cryostat
  - Pressurized superfluid helium: requires a lambda plate to mitigate the heat exchange between the 4.2K normal liquid helium and the magnet section at 1.9K as well as heat exchangers
- Every interface to the magnet (cryo, power, instrumentation…) has to come from above through the lambda plate



Cryostat : Conceptual design of the inner helium vessel

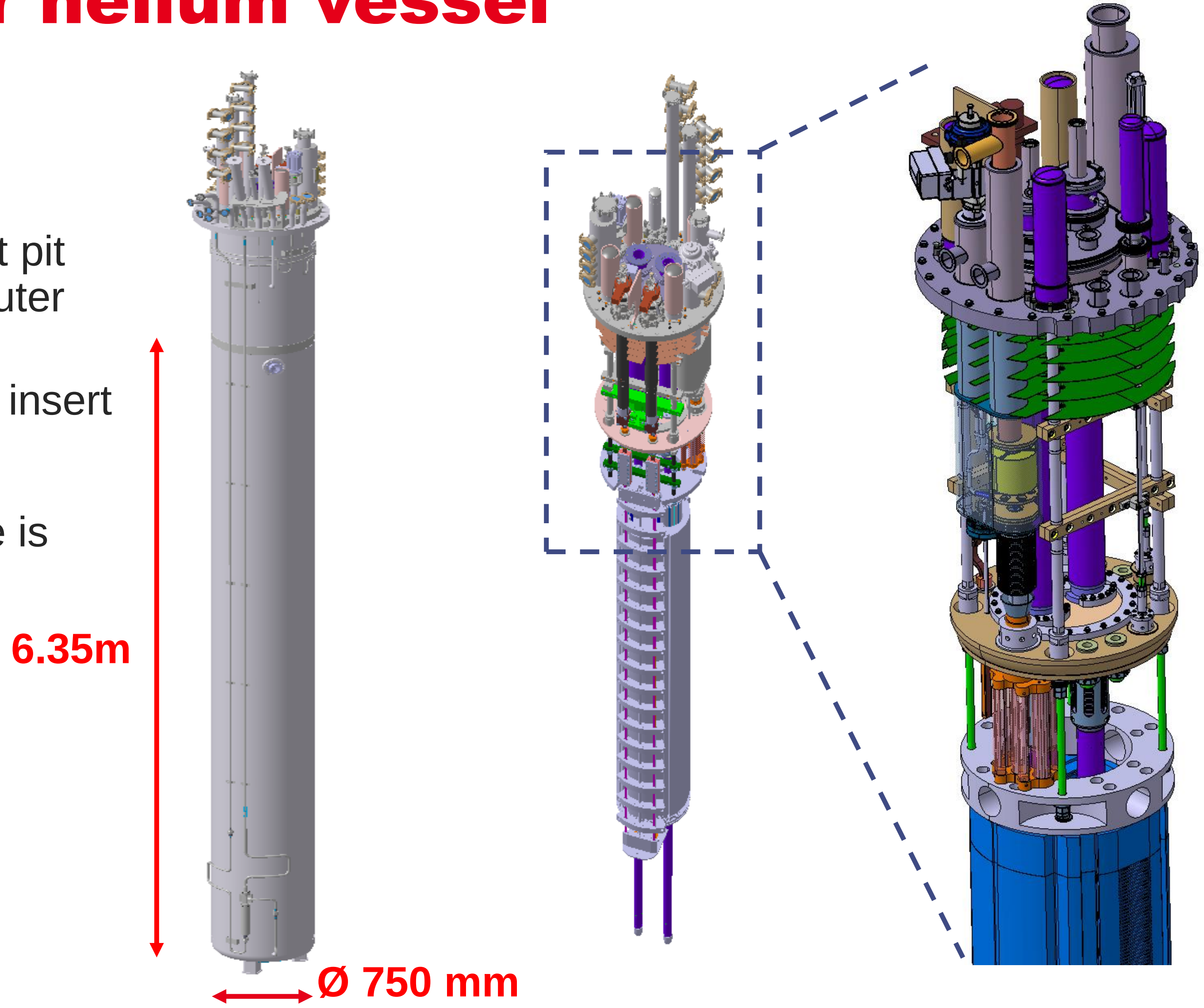
- Contains all the elements of a pressurized superfluid vessel:
  - 4.2K/1.9K heat exchanger
  - Saturated/pressurized 1.9K heat exchanger
  - JT valve
  - Lambda plate
- Vertical layout because of the access constrains
- 8mm thick wall because of the peak quench pressure (up to 2 bars relative)
- G10 lambda plate due to limited cooling power but potential leakage problems between the top 4.2K bath and the bottom 1.9K magnet bath
  - Material makes leak tightness more difficult: no welding
  - Numerous passages through the plate for instrumentation and anticryostats



Cryostat :
Final design of the inner helium vessel

- The top plate of the cryostat is in 2 parts:
  - A stationary part holding the vessel in the cryostat pit with the helium connections to the process and outer instrumentation
  - A mobile part that supports the magnet cryogenic insert

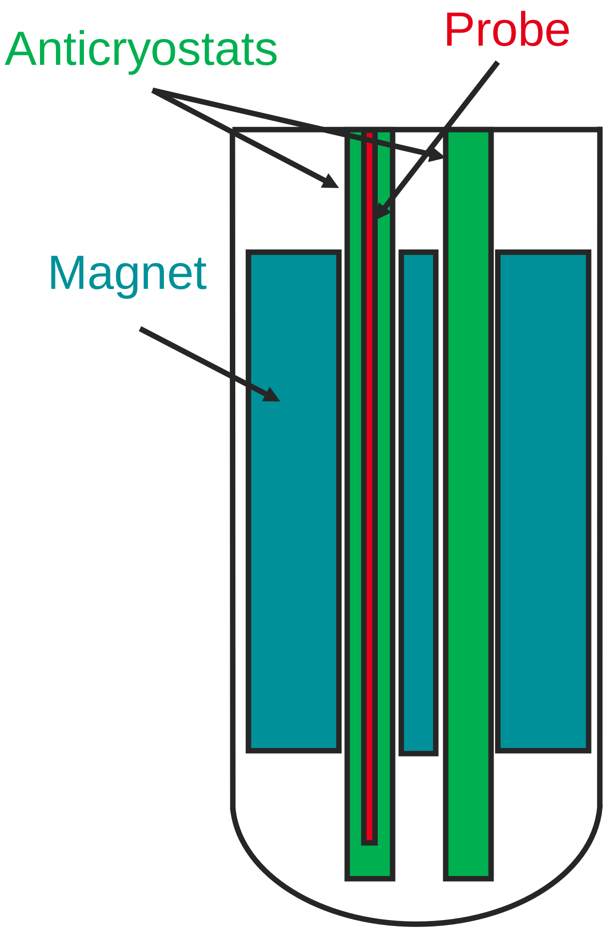
- The magnet insert supported by the mobile top plate is constituted of:
  - The magnet to be tested
  - The 1,9K heat exchangers
  - The lambda plate
  - The anticryostats
  - …/…

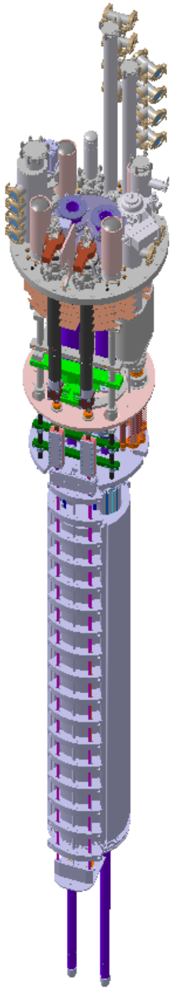


3. Anticryostats

Anticryostat : Ensure room temperature for magnetic probes

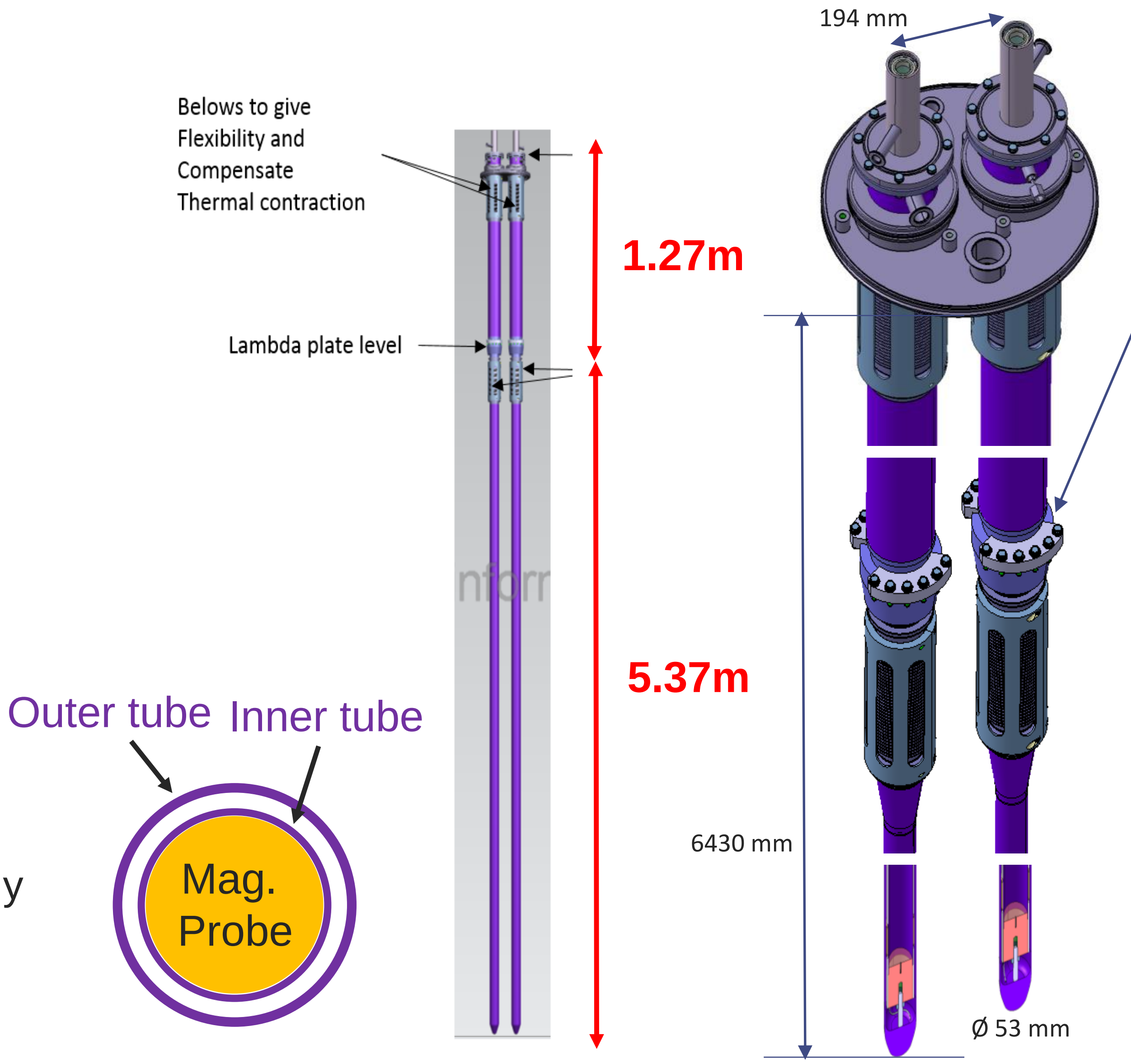
- Magnetic probe system used on STAARQ operates at room temperature but must be inside magnet apertures
- Necessary to protect the probe with an anticryostats ensuring room temperature inside while temperature at 1.9K outside
- Very limited room inside magnet apertures: has to fit within smallest magnet aperture. OD < 56mm
- Bulk of magnetic probe makes insulation problematic





Anticryostat : Challenging design

- Resulting anticryostats have an OD of 53mm
- For the probe to map the entire magnet they run down past the magnet : resulting length of 6.64m
- Only 4mm of insulation available for vacuum jacket and superinsulation:
- Heaters inside the anticryostats required to prevent frosting
- Flow of warm gaseous helium to prevent stratification
- Very delicate objects : have to be stored and handled vertically at all times



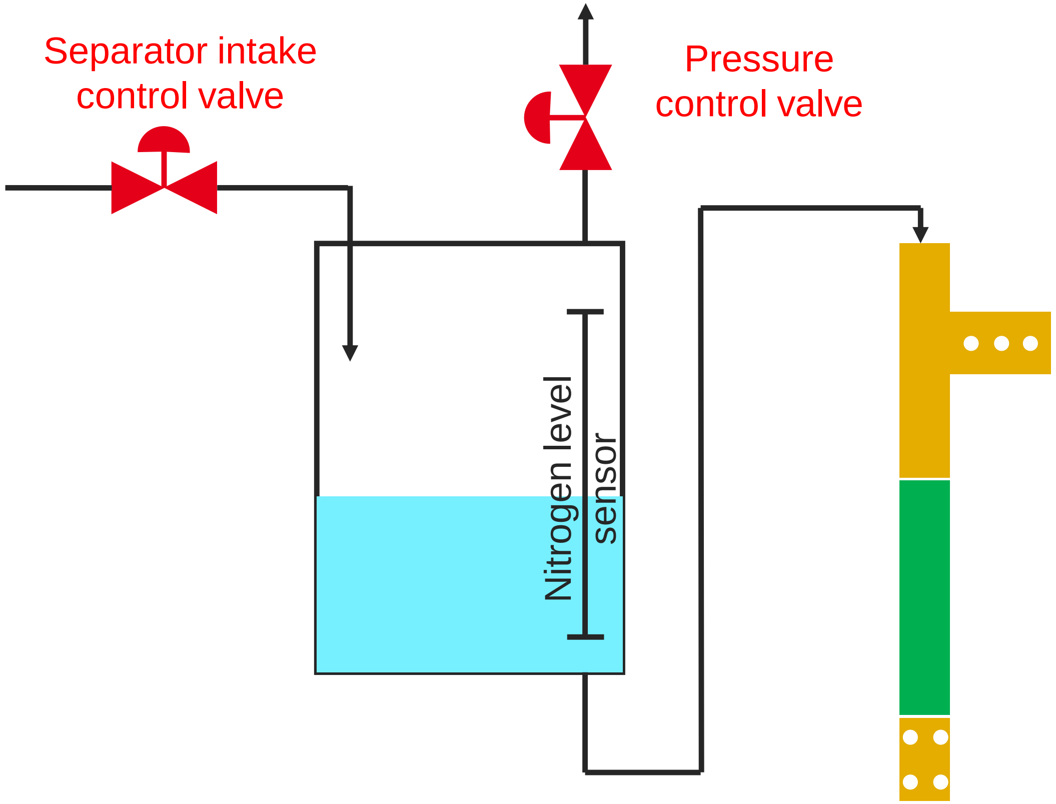
4. Superconducting current leads

Superconducting current leads: A necessity to control helium costs

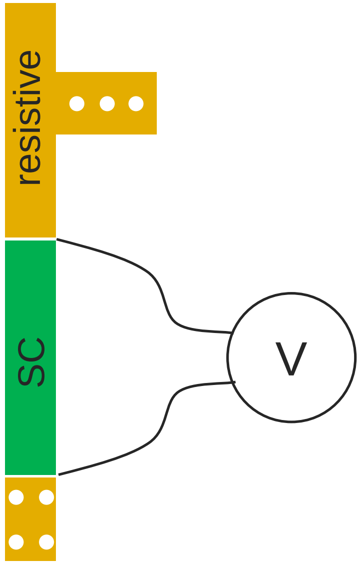
- The liquefier is expected to have to absorb ~45W in hybrid operations not taking into account the current leads:
  - 25W of refrigeration
  - 20W of liquefaction (1 g/s)
- Standard copper current leads would add another ~40W of liquefaction power (2 g/s) at 13kA which is beyond the capabilities of our liquefier
- Necessary to use hybrid superconducting current leads but no 50K helium gas available to cool the junction between resistive and superconductive sections
- CEA partnered with Mark&Wedell to design superconducting current leads using liquid nitrogen to cool the junction and liquid helium for the cold terminals

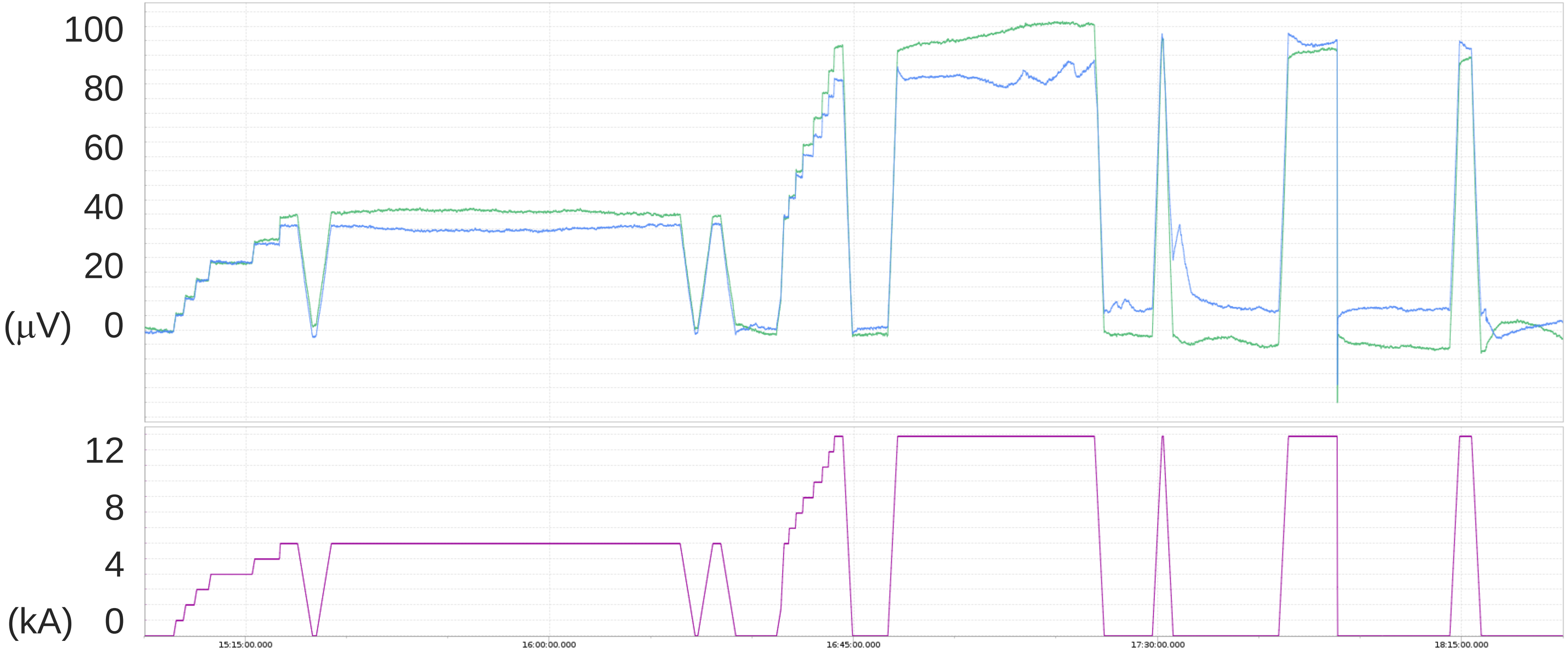
Superconducting current leads: Operations of the current leads

- The superconducting current leads require 1-2 g/s of liquid nitrogen (with very low vapor quality required)
- This required adding a phase separator for each current lead in order to lower the vapor quality of the nitrogen
- The cryogenic operations of each current lead is thus controlled through 2 valves:
  - The liquid level in the separator is controlled by the separator intake valve
  - the liquid nitrogen flow to the current lead is controlled by the pressure control valve



Superconducting current leads: Successfully tested in January 2023



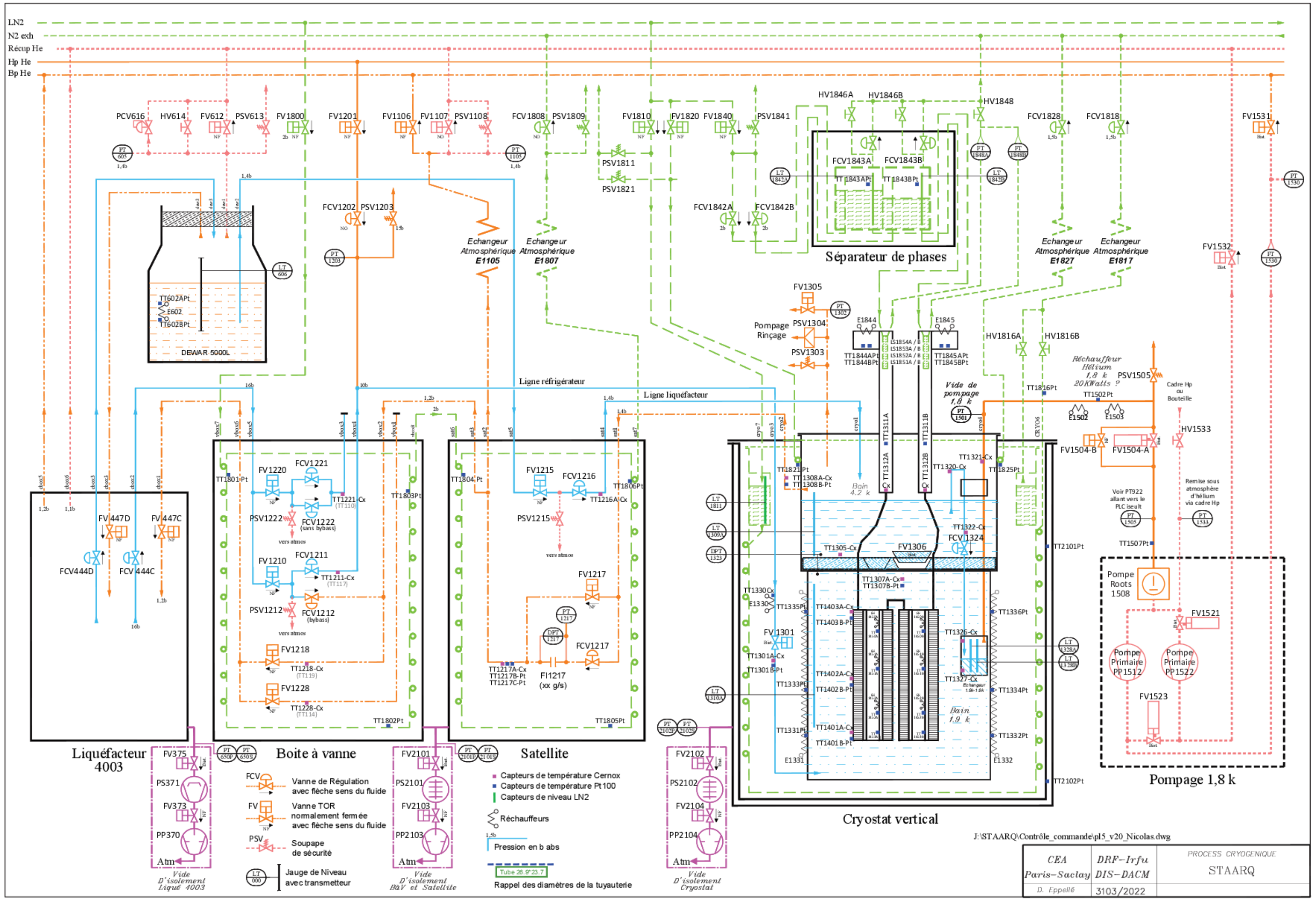


- The superconducting current leads were tested at full current in January this year
- The test was carried out using liquid helium dewars since our liquefier is not fully online
- The test was successful: the current leads conducted heat load to the helium was only 2-3W (instead of 40W for regular current leads)
- The voltages measured by the protection system (~100µV for the superconducting section) were stable and well below the design limits

5. Cryogenic process

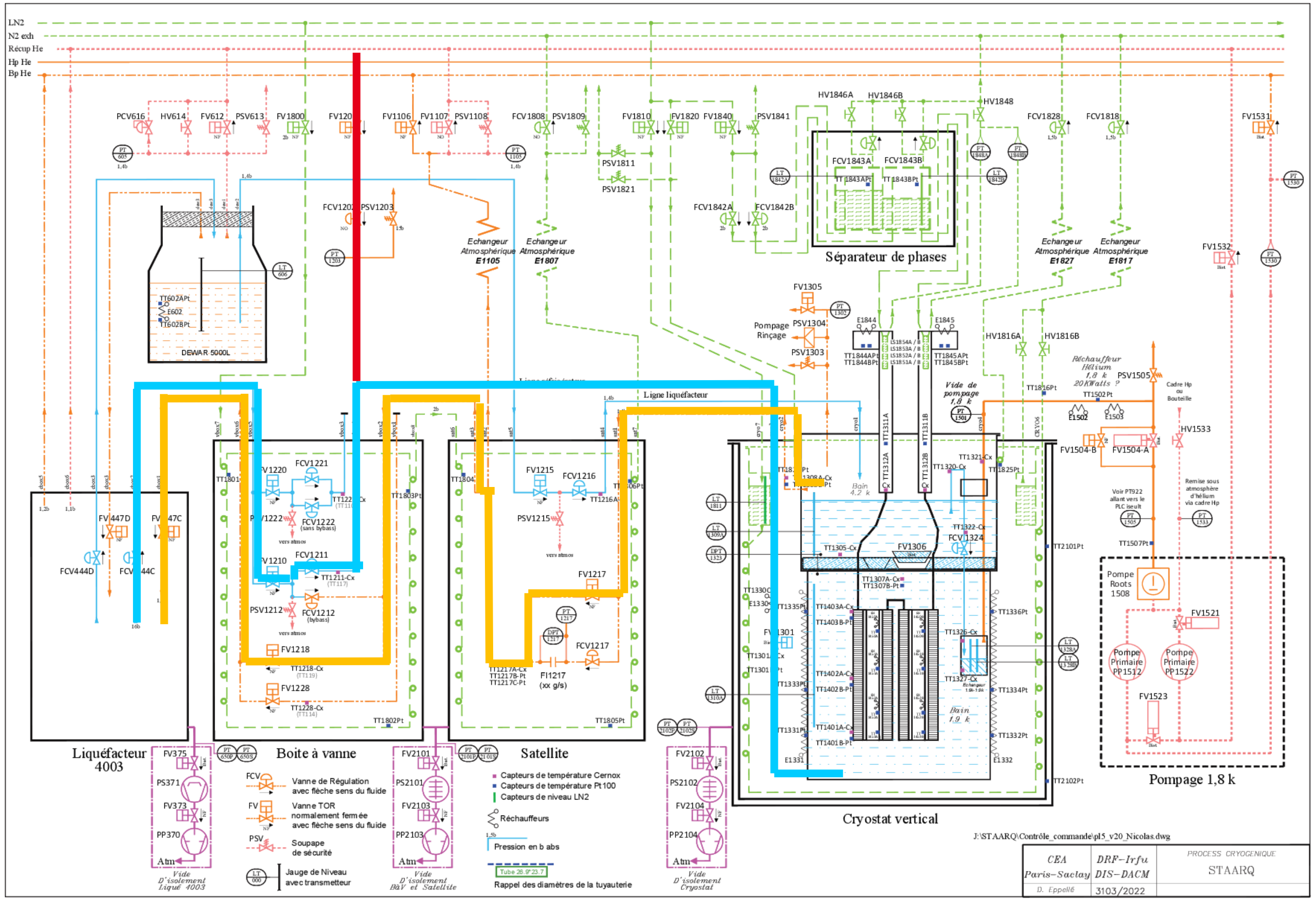
Cryogenic process: Main characteristics

- The cryogenic process has to provide high flow (~10g/s) of temperature regulated helium to ensure safe cooldown of the magnet to operating temperatures
- Provide enough liquid helium once at operating temperature to feed the 1,9K cold pumping system
- Limit the amount of helium losses to the recovery system to keep operating costs down
- Optimize cooling power by using as much as possible refrigeration instead of liquefaction



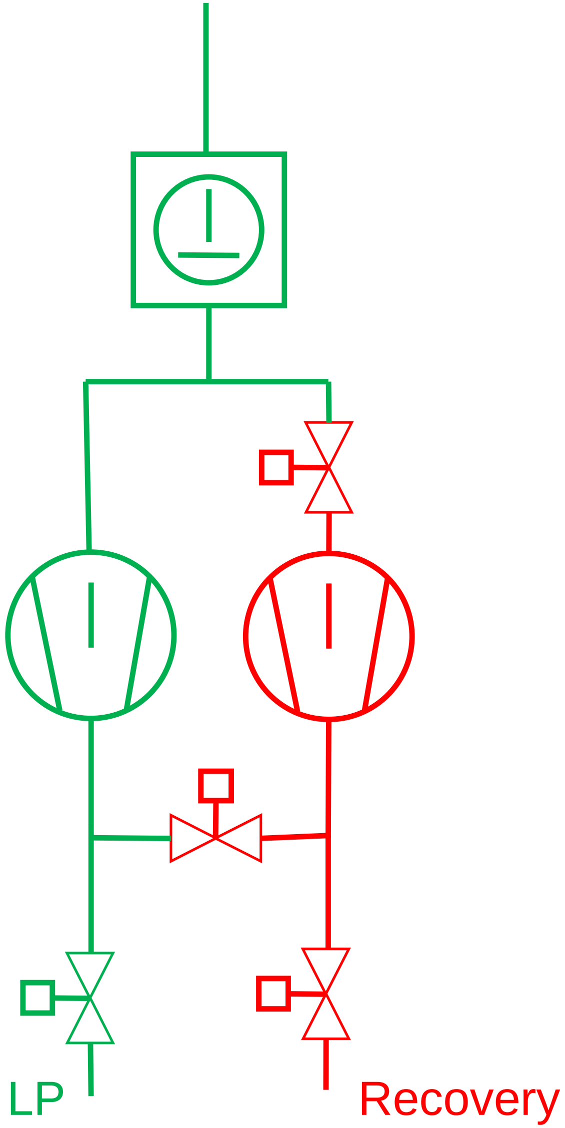
Cryogenic process:
Magnet Cooldown temperature control

- The temperature of the magnet has to be controlled carefully to prevent damage from thermal stress
- Injecting gas in the cryostat with temperature controlled by mixing cold gas from refrigerator and room temperature gas from HP
- Cryostat Intake gas temperature at maximum 40K below magnet temperature.
- Ramp down rate fixed at 2K/h
- If magnet temperature gradients >40K, temperature ramp down freezes: intake temperature constant until magnet temperature gradients drop below 40K



Cryogenic process:
The cold pumping system

- This system is used to drop the temperature of the helium inside the saturated/pressurized heat exchanger to cool the magnet pressurized bath
- Usual pumping systems pollute the gas too much to recycle it in the main liquefier cycle
- STAARQ uses a new hermetic pumping system (root + rotary vane pump) to be able to exhaust the helium directly in the LP part of the liquefier helium cycle: no need for additional purification
- Pumping speed is adjusted with a variable frequency drive instead of regulation valves (more power efficient)
- Additional non hermetic pump to assist the main hermetic pump for short periods of time during high pumping loads (crossing Tλ threshold)



6. Conclusion

Conclusion:
STAARQ is almost ready

- The STAARQ station has to face many design challenges due to the constrains related to the current helium and power costs as well as using older pieces of equipment (liquefier, outer cryostat…)

- Despite that, the STAARQ team is confident that the design of the station will enable the test of CERN quadrupole magnets as well as future magnet designs such as the ASTERIX project

- The STAARQ test station is in its commissioning phase:
  - One of the most critical aspects: the current leads has been successfully tested
  - The commissioning of the liquefier is about to begin after multiple repairs and upgrades to its control system and compressor
  - The commissioning of the full test station with a magnet is expected to begin in September 2023

7. Backups

The integration platform

- Its role is to support the magnet while it is integrated in the cryogenic insert
- It is designed to support magnets up to 15t in weight
- Enables technicians to work around the magnet at 3 levels to perform tasks on different parts of the magnet:
  - Connect power to the magnet
  - Install temperature sensors
  - Connect strain gauges and voltage taps monitoring and protection of the magnet
  - Insert the anticryostats inside the magnet apertures