# Design and operation of cryogenic test facilities

Superconductivity: Properties of Superconductors and their application in Science Conference

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# Contents

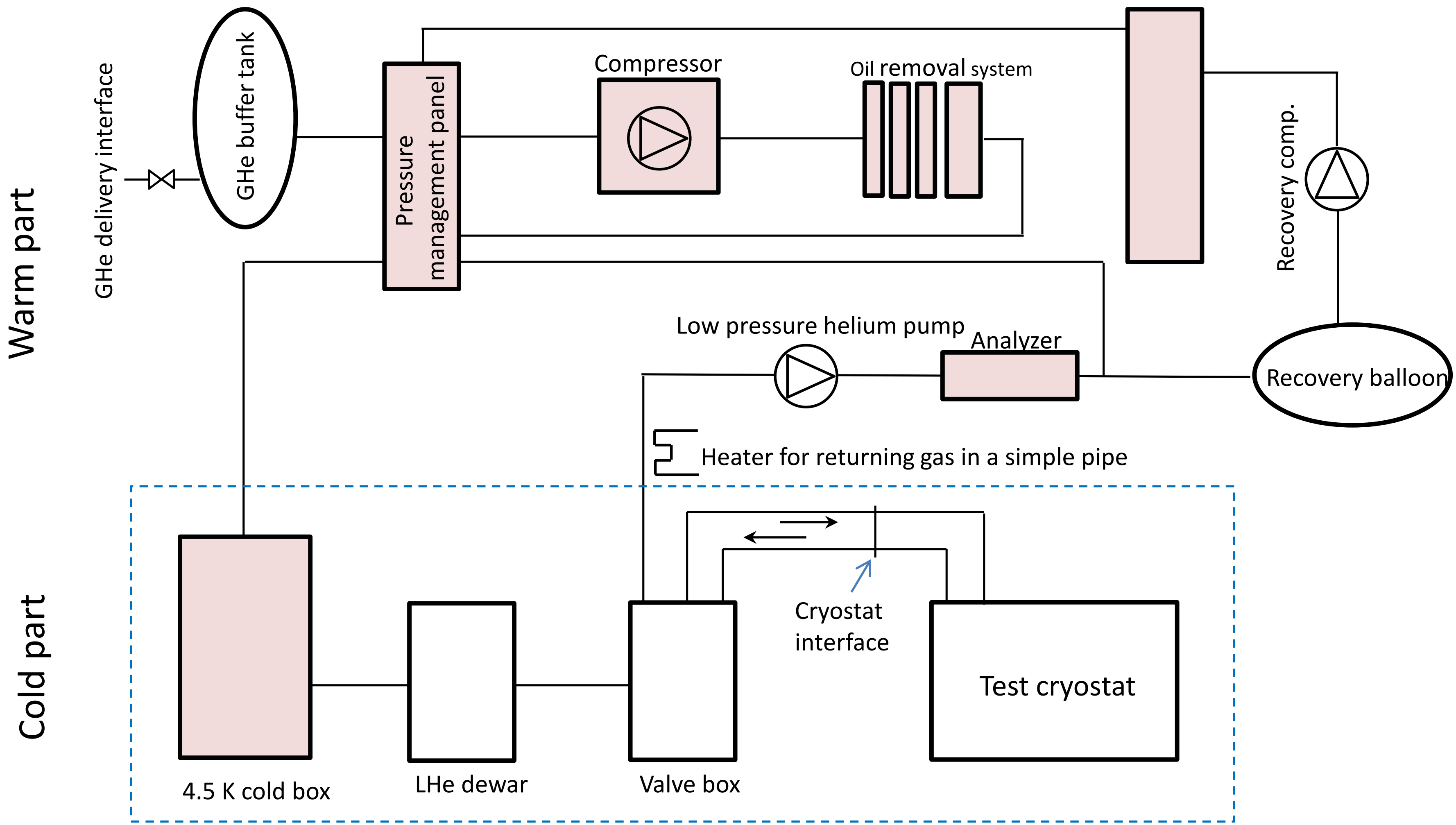
This presentation will cover only some part of the subject related to the design and operation of the cryogenic test facilities. It will focus on helium refrigeration process providing main information about helium properties, helium refrigeration machines, cryogen distribution and cryostat operation for both magnets and cavities testing.




References:

- G.Gistau-Bauger, “Helium refrigeration course, CERN, Geneva, Switzerland 2009
- U. Wagner, “Superconductivity for accelerators”, CAS, Erice, Italy 2002
- L. Tavian, “Les Bains Pressurisés HeI-HeII: Principes et Caractéristiques de Fonctionnement. Éléments de calcul et de dimensionnement ’’
- L. Tavian, “Technology of Superfluid Helium”, CAS, Erice, Italy 2002

# General architecture




Equipment typically sold as one assembly (for small installations as required by IFJ)

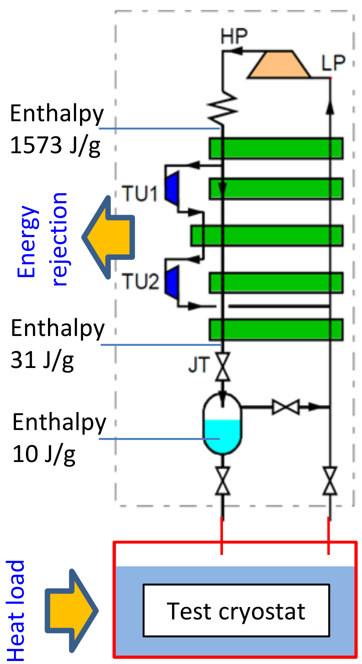
# Nitrogen and Helium

| | | Nitrogen | Helium |
|---|---|---|---|
| Boiling point | K | 77.3 | 4.2 |
| Melting point | K | 63.1 | - |
| Liquid density | kg/m3 | 808 | 125 |
| Vapor density | kg/m3 | 4.59 | 16.7 |
| Normal gas density | Kg/m3 | 1.25 | 0.18 |
| Latent heat | J/g | **200** | **20.9** |
| Sensible heat capacity (sat. vap. to 300 K) | J/g | **234** | **1542** |
| Critical temp. | K | 126 | 5.2 |
| Critical pressure | Bar | 34 | 2.2 |

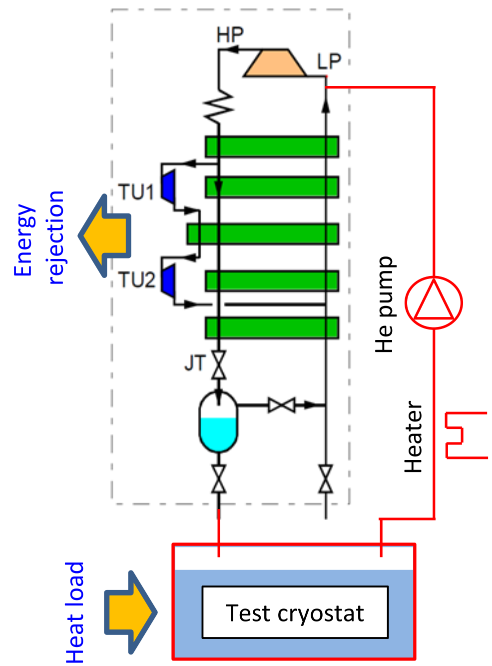
Data are given for 1 bar of pressure

There is an interest to make use of Nitrogen latent heat and Helium thermal capacity.

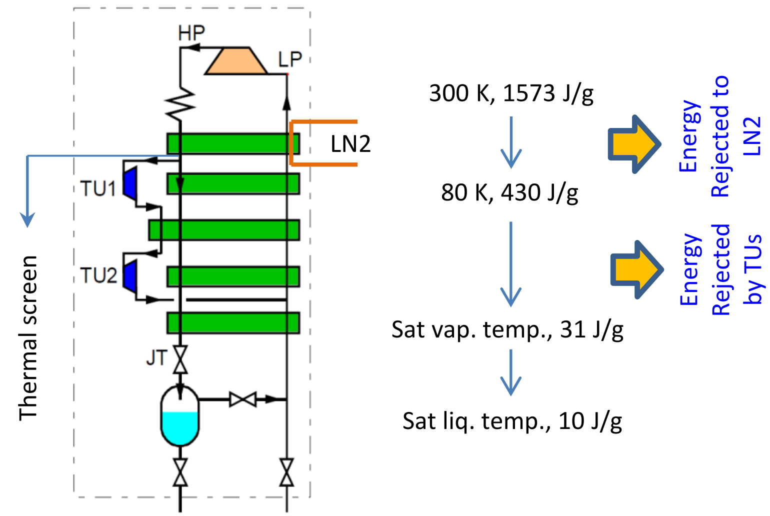
# 4.5 K cold box operation modes




**Refrigeration** @ 4.5 K, 1.3 bara
(e.g. sc coils testing)




**Liquefaction** @ 2 K, 30 mbar
(e.g. sc cavities)




**Refrigerator** makes use of return LP cold flow to precool the gas in HP line via the cold box heat exchangers.

**Liquefier** – heat rejection is done mainly via the turbines since return flow bypasses the cold box heat exchangers.

Most of the cold boxes offer possibility of boost by means of LN2 evaporation ➔ gain on the refrigeration/liquefaction capacity. Typically the capacity can be increased by ~80%

Design of most of the cold boxes allows taking some portion of HP flow at the level of 80 K for thermal screening of the distribution and connected cryostats

# Coefficient Of Performance (COP)

Coefficient of performance calculated for ideal Carnot cycle:

Refrigeration (for 1W@4.2K):

$$\frac{W_{Tw}}{W_{Tc}} = \frac{T_w - T_c}{T_c} \qquad \frac{W_{Tw}}{W_{Tc}} = \frac{300 - 4.2}{4.2} = 70 \ {}^{W}/_{W}$$

Liquefaction (1g@4.2K) :

$$\frac{W_{Tw}}{W_{Tc}} = (T \cdot \Delta S) - \Delta H$$

$$\frac{W_{Tw}}{W_{Tc}} = 300 \cdot (31.61 - 3.56) - (1573.51 - 9.94) = 6852\ W$$

Theoretically, the power needed to liquefy **1 g/s** or deliver **100 W** of refrigeration @ 4.2K are similar.

The above analysis of power consumption refers to ideal Carnot cycle. The real consumption will depend on efficiency of our system with relation to ideal Carnot cycle.

# Coefficient Of Performance (COP)

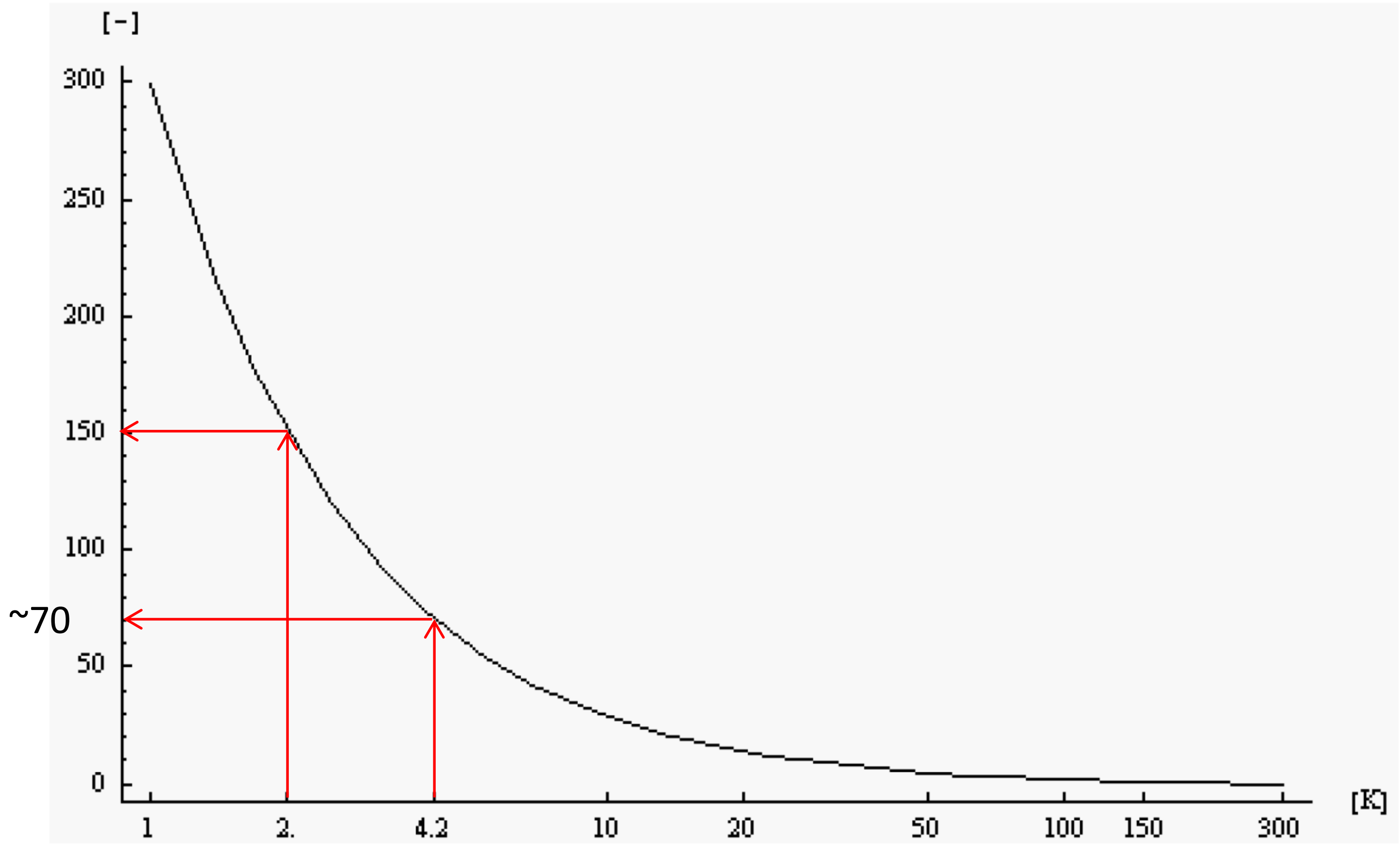
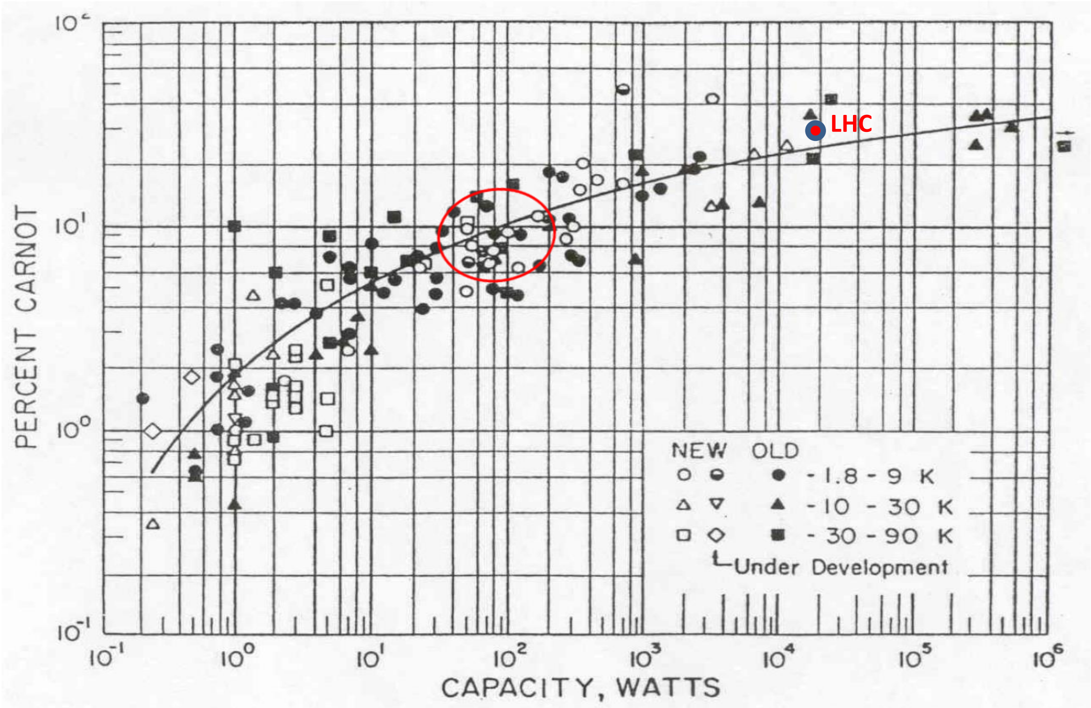



Figure 2: Carnot factor as function of cold temperature for $T_W$ = 300 K

Non linear scale on horizontal axis

# Exercise on real power consumption

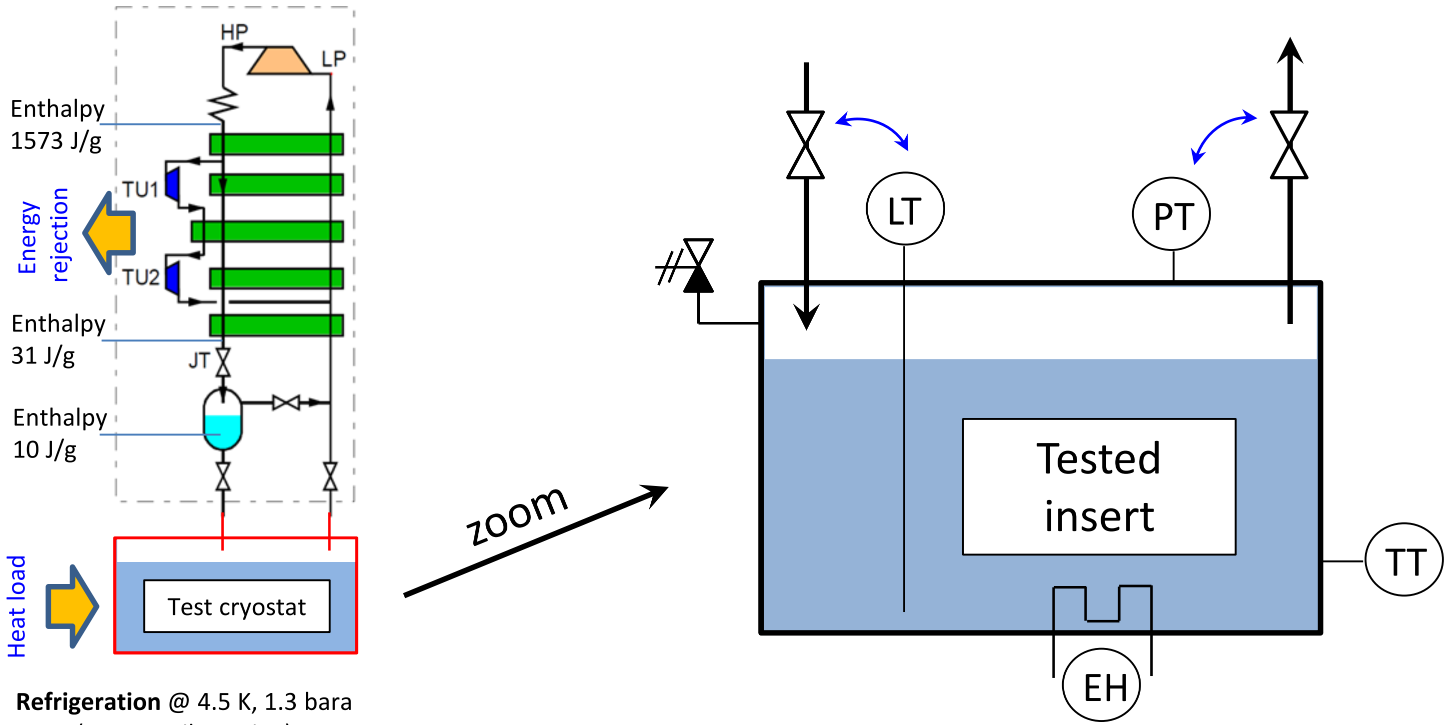
Large number of fabricated refrigeration systems Carnot efficiency vs refrigeration capacity at 4.5 K




Design info:
Carnot efficiency for small refrigeration systems with capacity of ~100 W at 4.5 K is about 10 %
i.e. such small system needs about 70000 W of power delivered at 300 K to cover its cryogenic capacity.
The same reasoning is applicable also for liquefiers.

For 2 K cryogenic systems the ratio taken for design is typically 1000 W/W

# 4.5 K refrigeration – cryostat

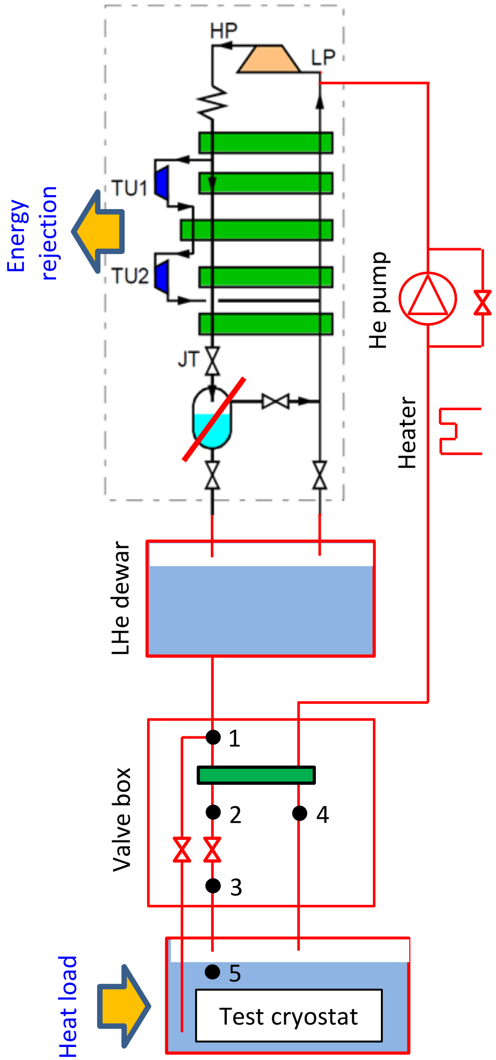



**Refrigeration** @ 4.5 K, 1.3 bara
(e.g. sc coils testing)

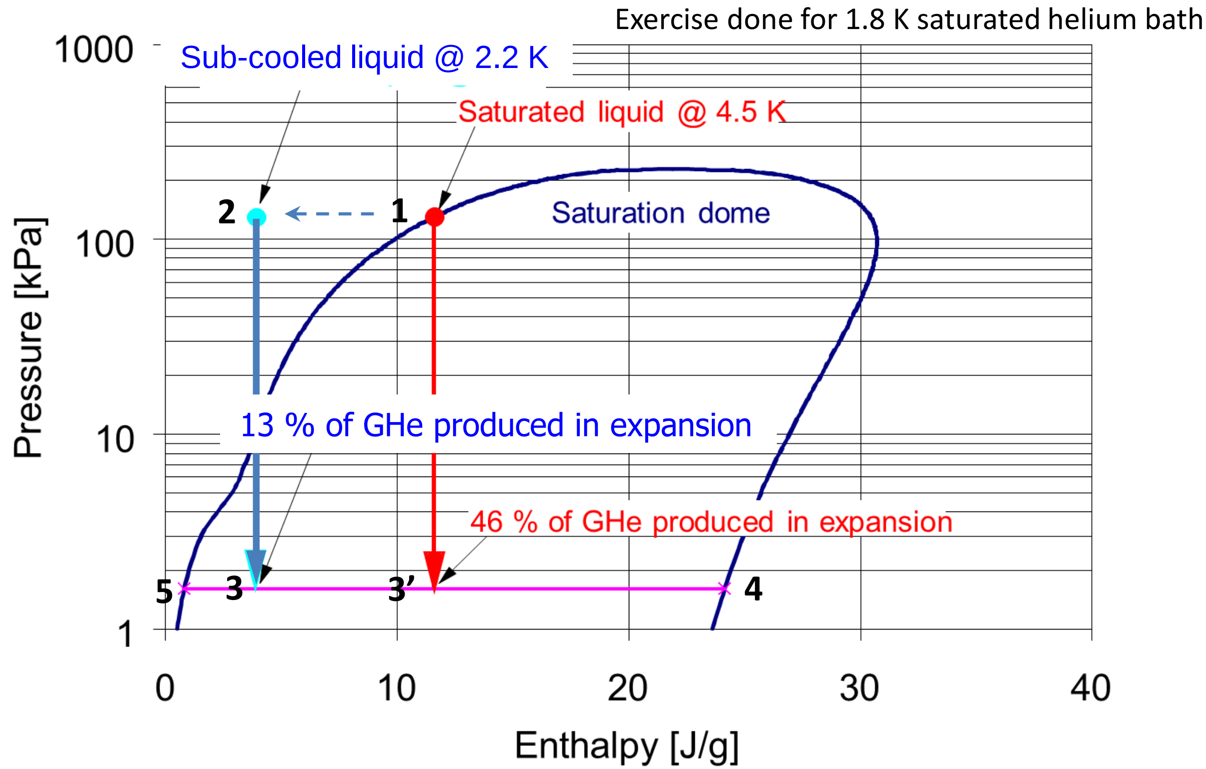
Design Tip – cryostat instrumentation and operation:

- Inlet valve regulates helium level
- Outlet valve regulates pressure inside the cryostat
- Thermometer allows for controlled cool down (not indispensable for normal operation)
- Electrical heater – allows for empting, can stabilize the process during operation
- Safety valve – protect the system from over pressurization

# 1.8 K refrigeration

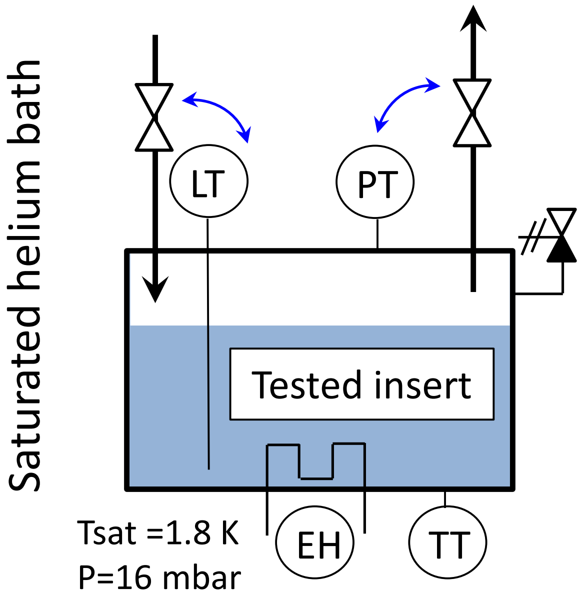


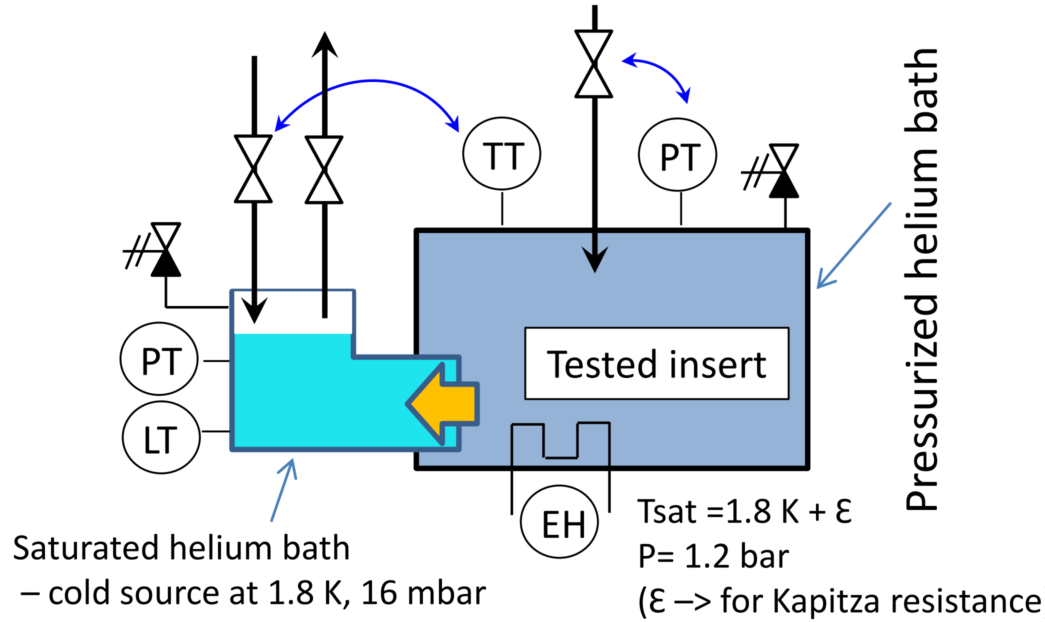

**Liquefaction** @ 1.8 K, 16 mbar
(e.g. sc cavities)




Design info.:
In most of the liquefiers internal phase separator does not exist, external dewar must be installed.
Installation of a valve box with its circuits allows for reliable handling of cool down and normal operation processes.
Additional HX allows to improve LHe/Ghe quality factor

# 1.8 K cryostat (saturated and pressurized)



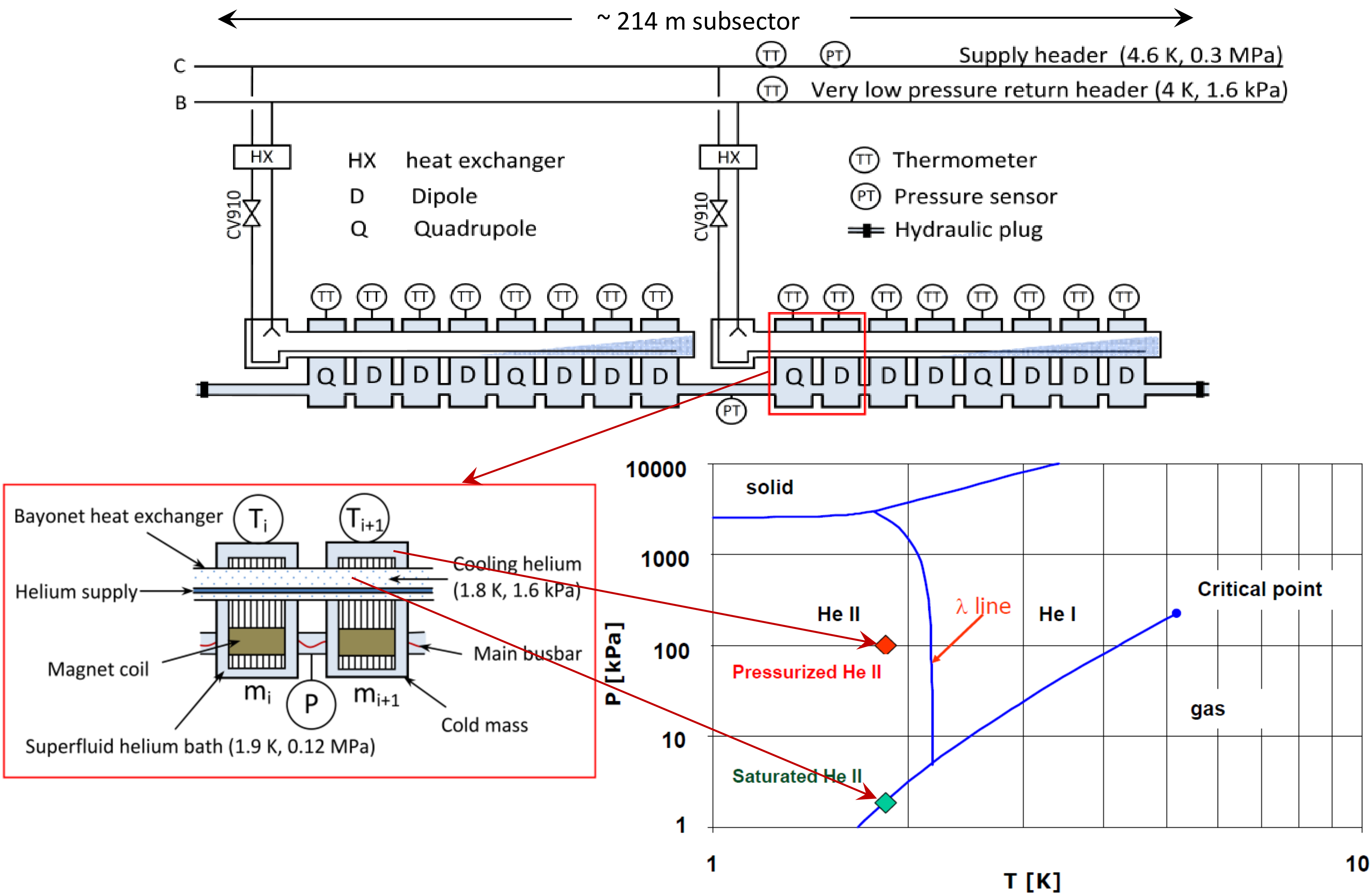

Saturated helium bath:

- operates at sub atm. pressure
- adapted for sc cavity testing
- Technically simple w.r.to pressurized bath
- He guard system to be applied on the cryostat

Pressurized helium bath:

- operates at above atm. pressure
- adapted for sc magnets
- More thermal capacity margin for transients w.r.to saturated bath
- Air inleak prevention to the main cryostat

# LHC 1.9 K cooling circuit



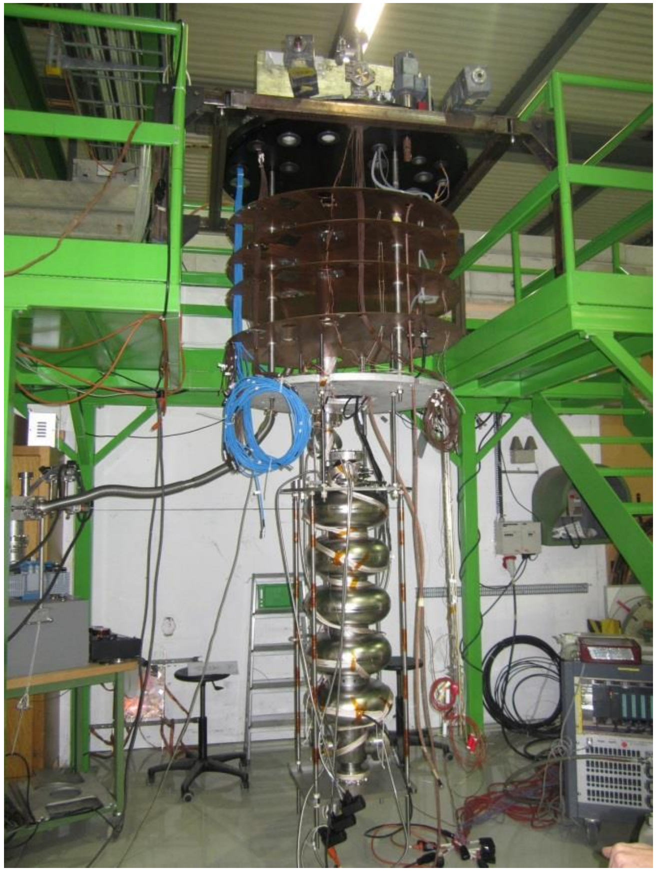
# Transfer lines and cryostats

**Basic design considerations:**

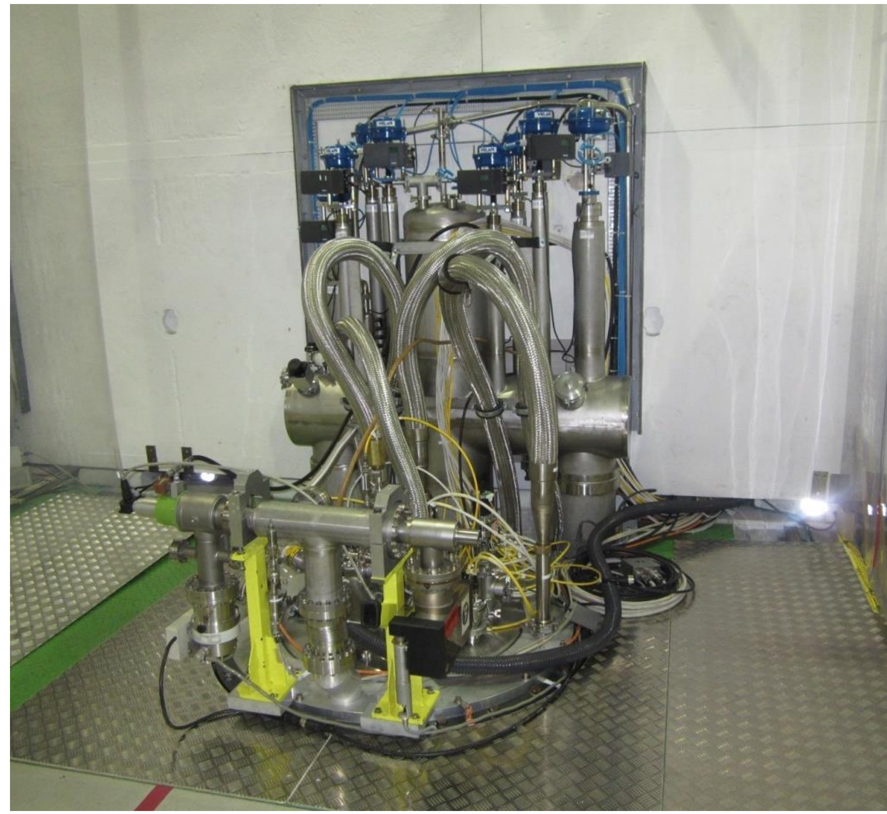
- Size of the transfer lines should be optimized (length and diameter) to minimize the static heat load (typically between 100-300 mWatt/m for a few g/s transfer line)
- Thermo-mechanical optimization of the support system to be performed (geometry of the line routing to be considered)
- Using of actively cooled thermal shield combined with MLI to be applied (typical screening at level of 70-90 K)
  - In some cases it is suitable to use return GHe stream to screen the cryostat or distribution system
- Sectorization of the vacuum insulation system to be optimized
- <u>The most of the problems relates typically to the different interfaces – these areas should be carefully analyzed and designed</u>

# RF cavity vertical test

~ 3m



1.9 K saturated helium bath



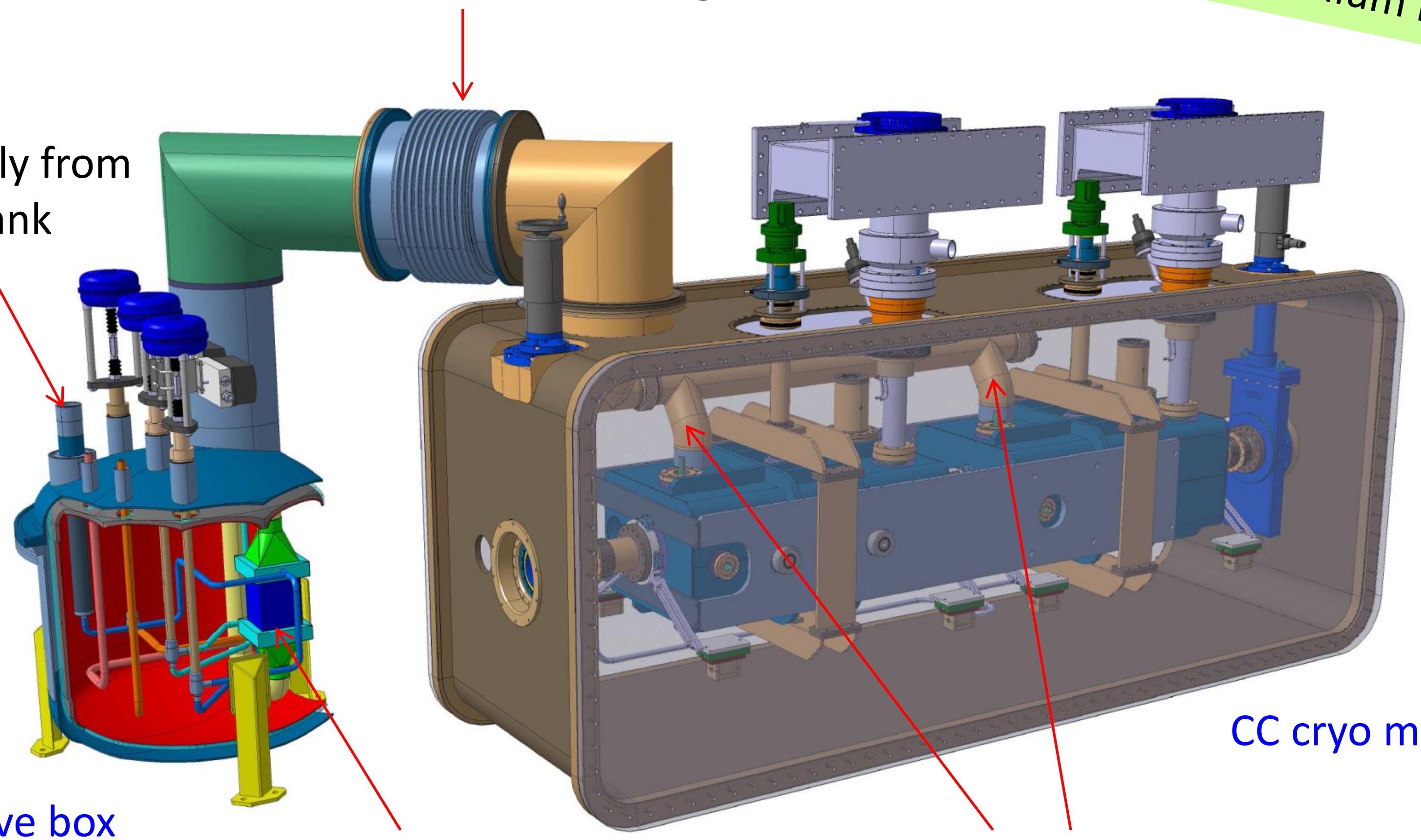
CERN: SM18 vertical cryostat test facility

# RF cavity cryo module test

Valve box to cavities cryo module interface:

- Welded internal lines, equipped with flexible hoses
- Bolted external bellow with vacuum sealing

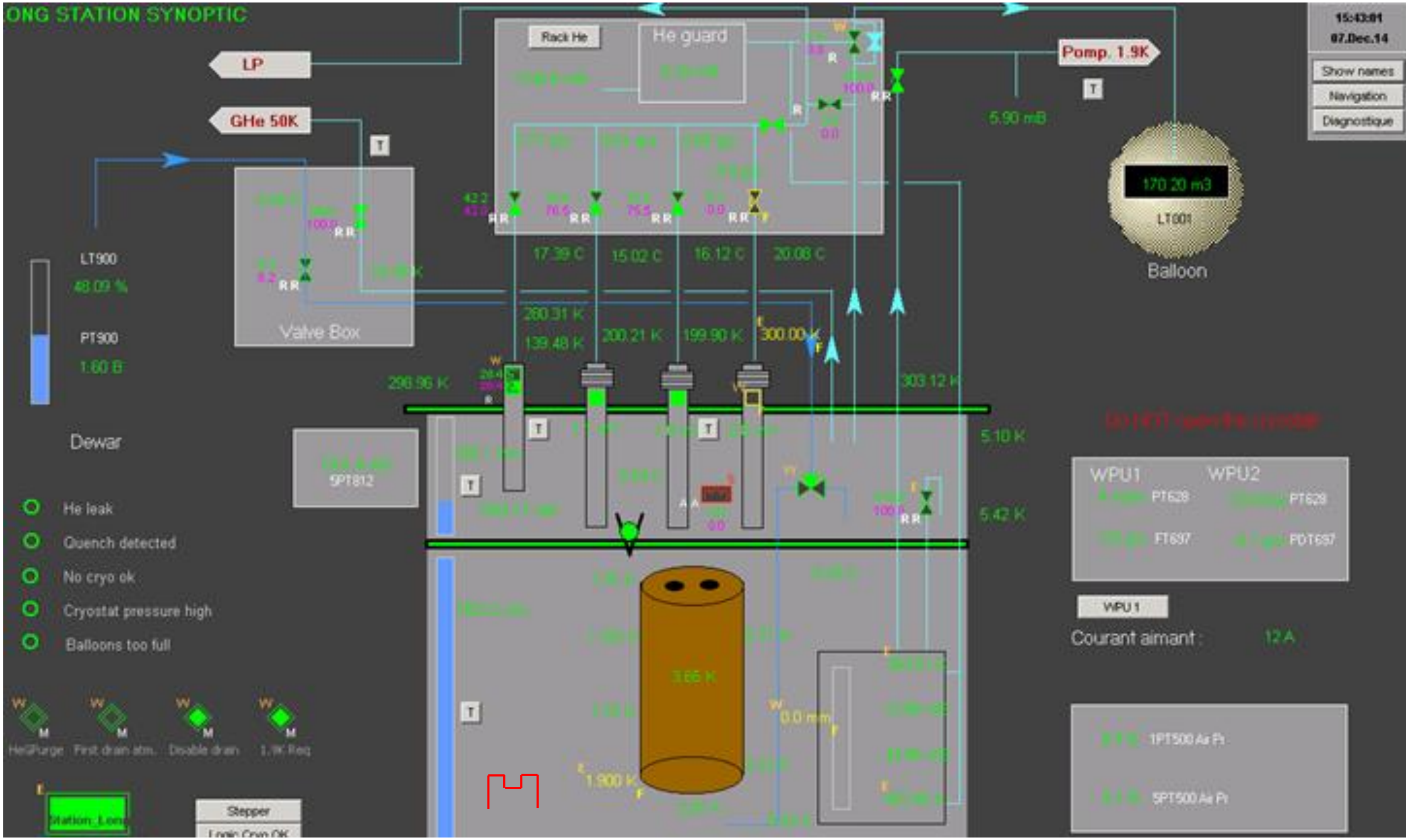
Crab Cavities cryo module
(2 K saturated helium bath)



# RF cavity cryo module test facility

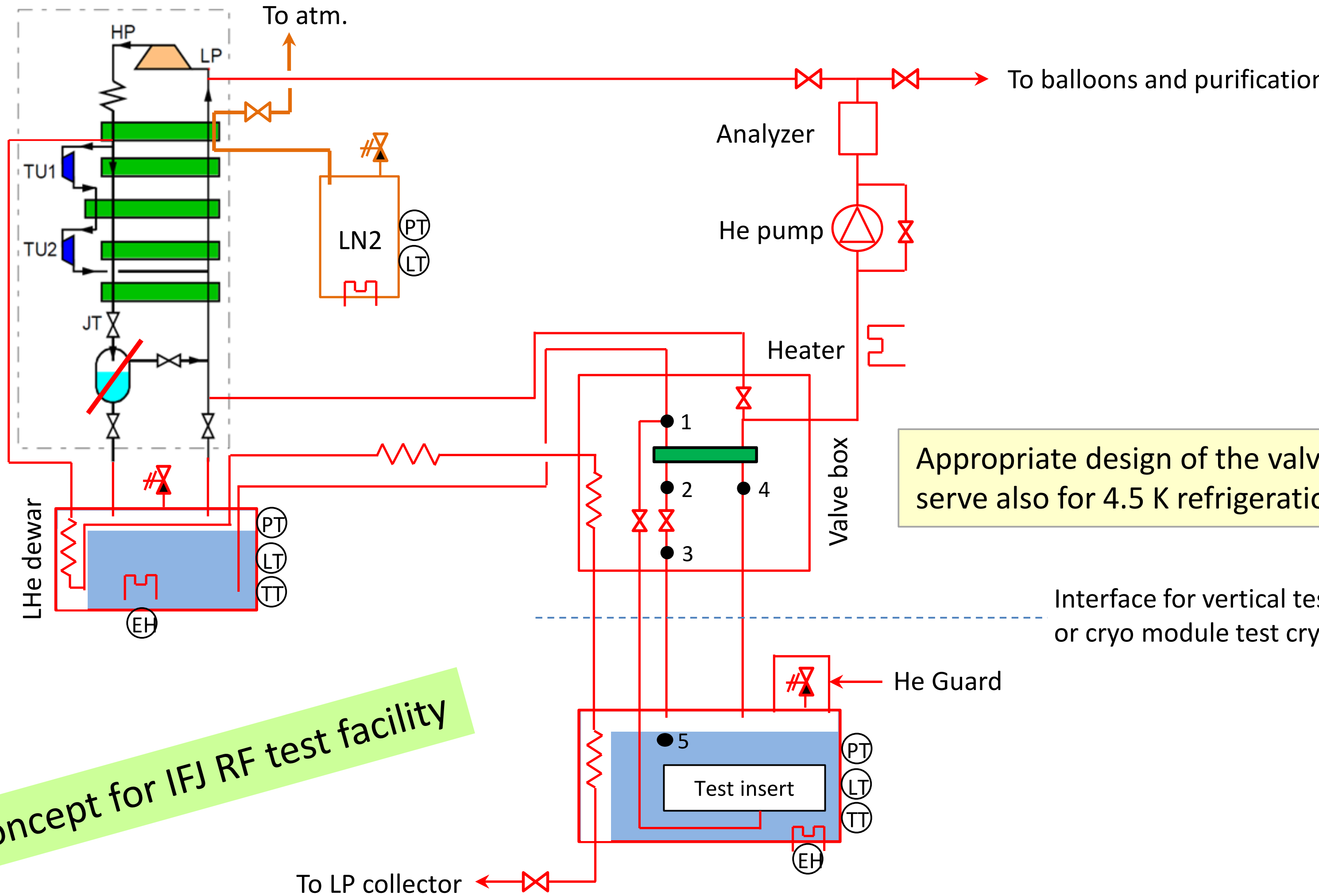
CERN: SM18 test facility for horizontal RF cryo module test

# 1.9 K pressurized He bath




CERN: SM18 magnet coils samples testing

# Exercise – 2 K infrastructure, saturated He bath




Appropriate design of the valve box can serve also for 4.5 K refrigeration

Concept for IFJ RF test facility

**Liquefaction** @ 1.8 K, 16 mbar (e.g. sc cavities)
**Refrigeration** @ 4.5 K (e.g. sc cables, magnet samples)

# Project strategy and conclusions 1/2

1. Answer to question: What will be application of built cryogenic infrastructure ?
2. What capacity should be delivered at required refrigeration level?
3. Define required distribution transfer lines with functionality of the valve box.
4. Size the capacity of the main refrigerator and pumping units (for 2 K cooling)
5. Size necessary utilities capacity in area of the infrastructure: electrical power, cooling water, compressed air, Ethernet …)

All above should be integrated on available space and optimize for power consumption …

# Project strategy and conclusions 2/2

What about the future …?

Most probably the requirements for the cryogenic power in the future in IFJ will increase.

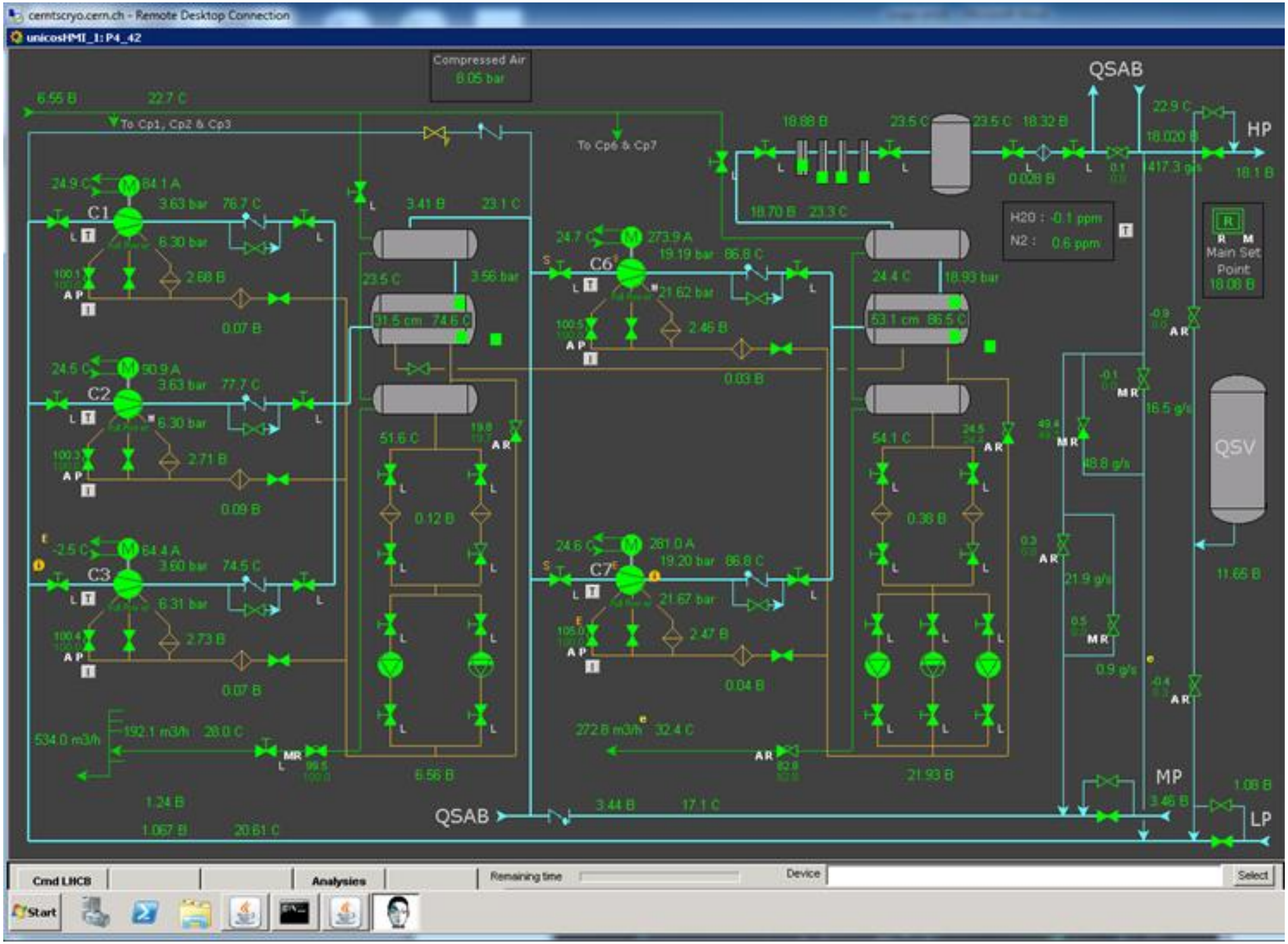
It would be good to divide the cryogenic infrastructure project into a few construction stages, projecting it also with long future extension scenarios, i.e.:

- foresee place and possibility for electrical power distribution increase,
- available space should be reserved for future extensions of the cryo infrastructure
- transportation routing within IFJ and accesses to test buildings should take into consideration future upgrades

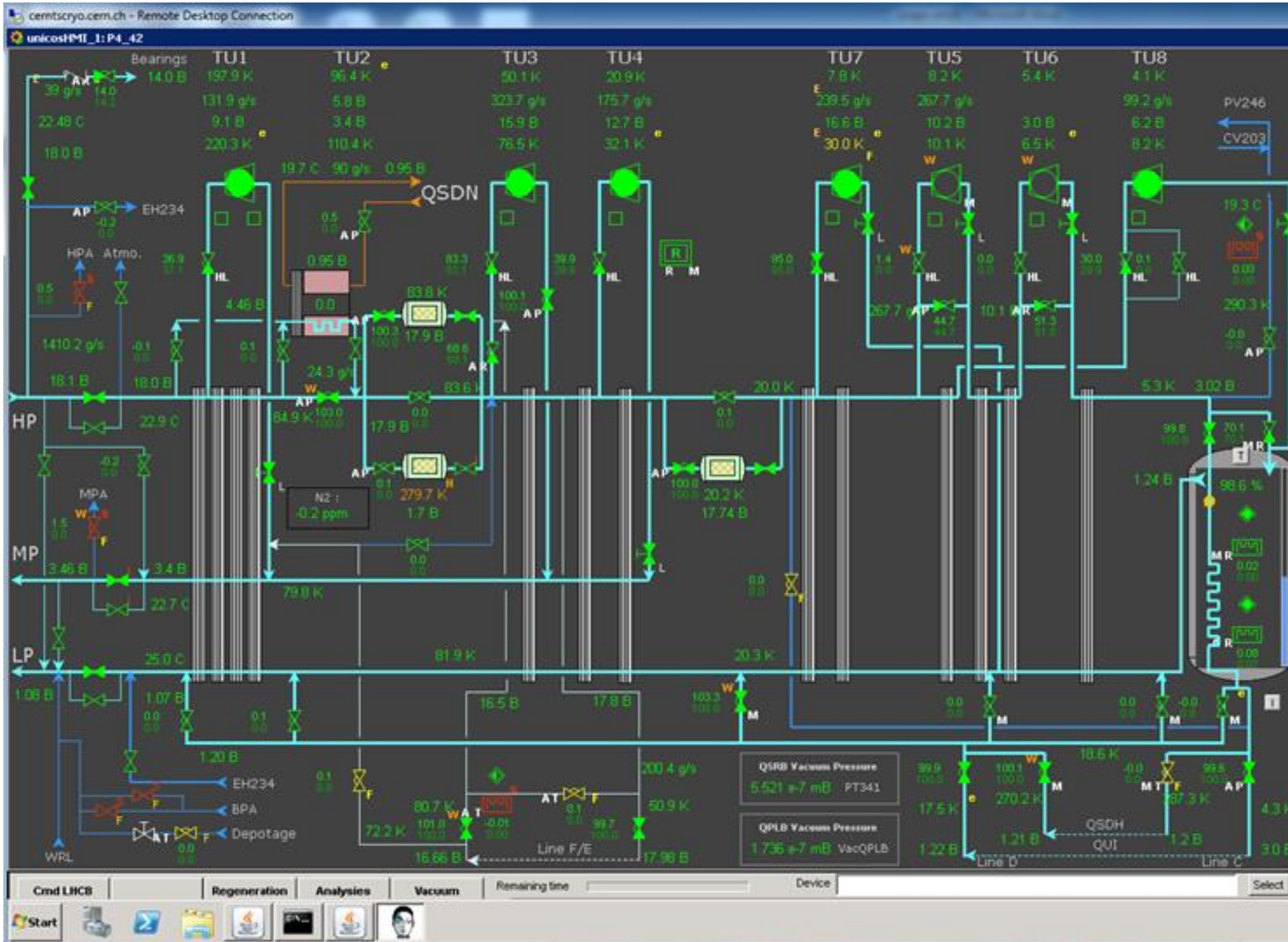
All above should be integrated on available space and optimize for power consumption … <u>and for the future upgrades.</u>

## Thank you! Questions?

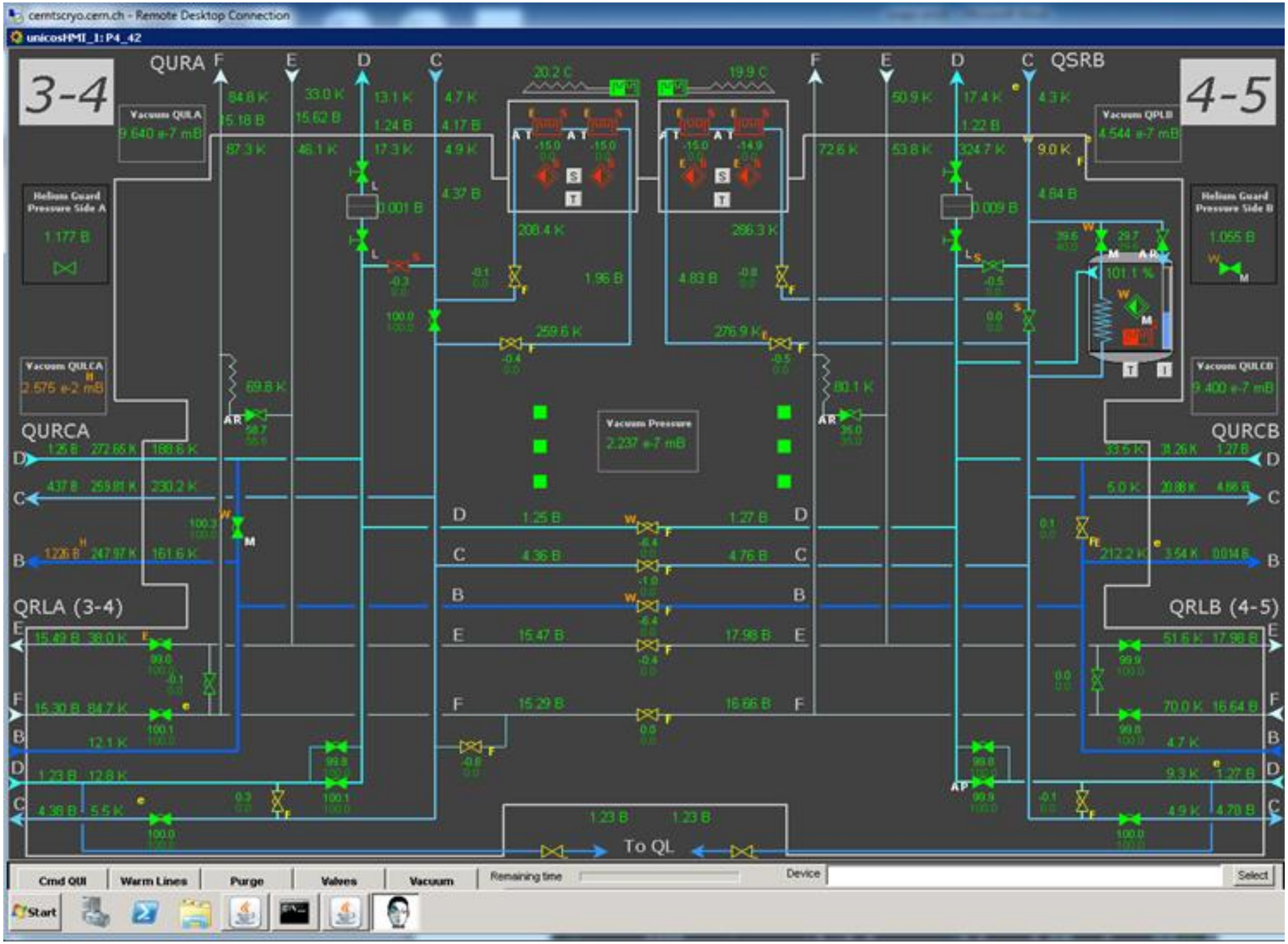
# LHC compressor station



# LHC 4.5 K refrigerator

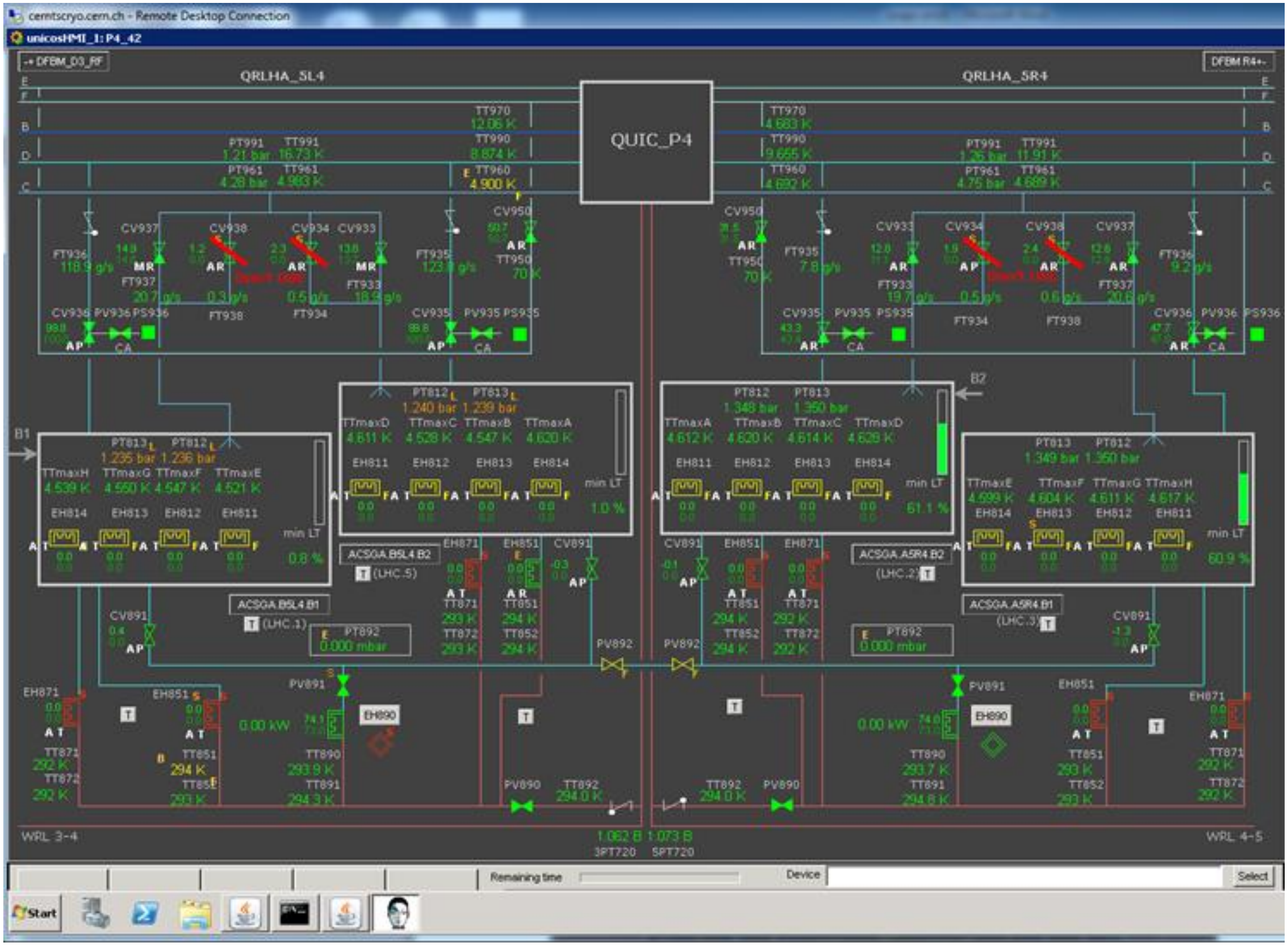


# Valve box



cerntscryo.cern.ch - Remote Desktop Connection
unicosHMI_1: P4_42
3-4
QURA
4-5
QSRB
Vacuum QULA
9.640 e-7 mB
Vacuum QPLB
4.544 e-7 mB
Helium Guard Pressure Side A
1.177 B
Helium Guard Pressure Side B
1.055 B
Vacuum QULCA
2.575 e-2 mB
Vacuum QULCB
9.400 e-7 mB
Vacuum Pressure
2.237 e-7 mB
QURCA
QURCB
QRLA (3-4)
QRLB (4-5)
To QL
Cmd QUI
Warm Lines
Purge
Valves
Vacuum
Remaining time
Device
Select
Start

# LHC 4.5 K cavities



# LHC 1.9 K cooling