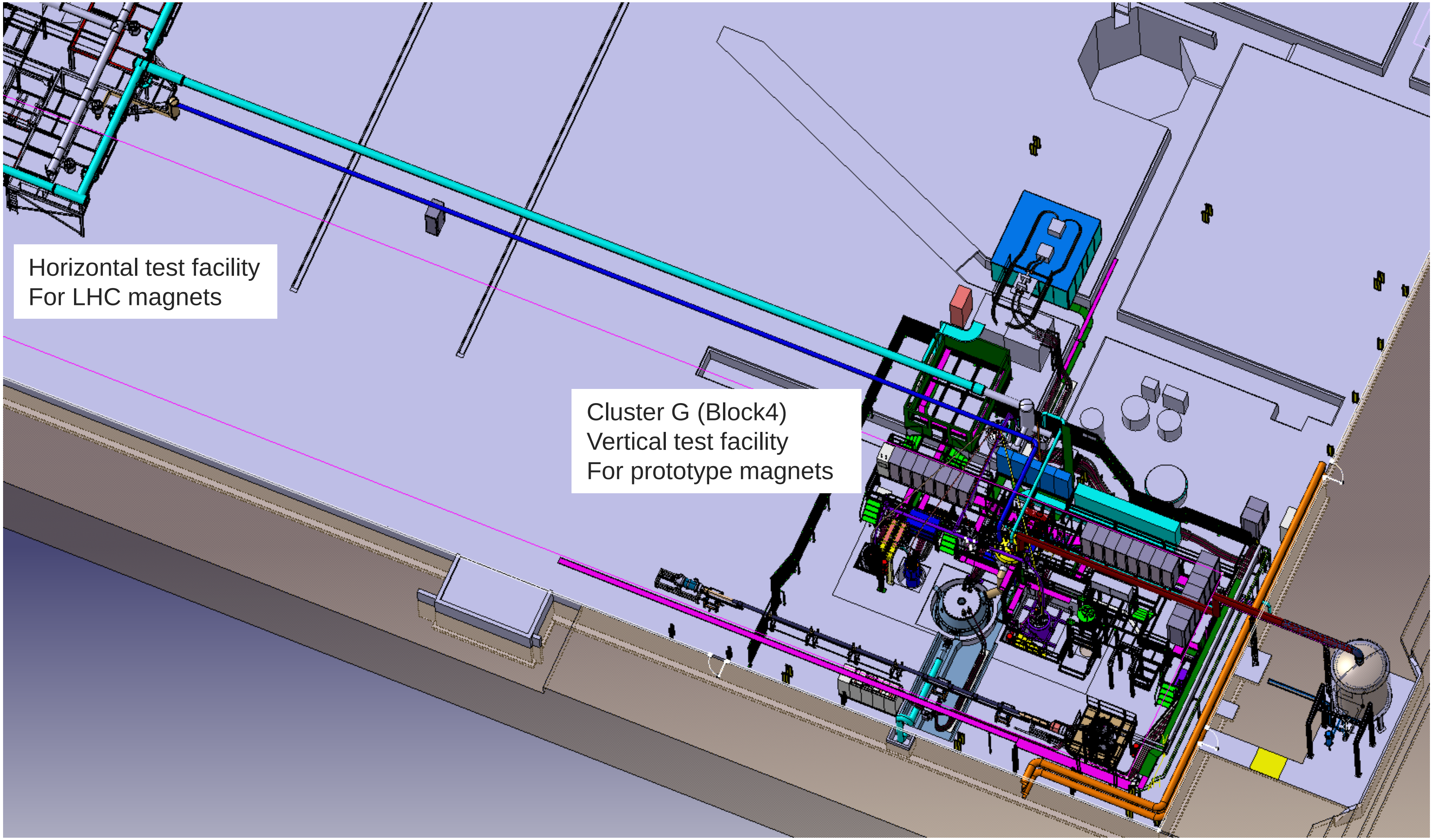
CERN

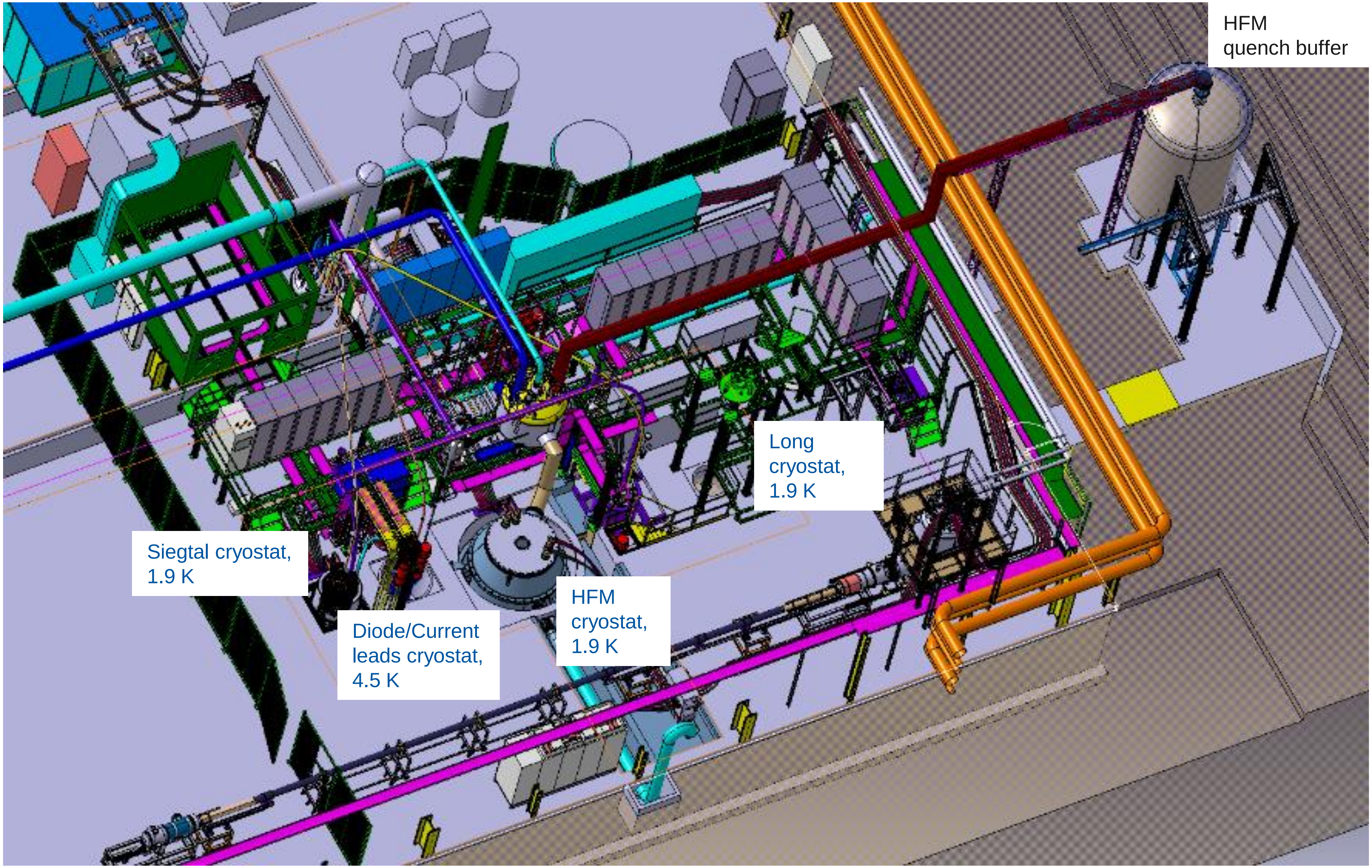
# Block 4 and Cluster D - Safety

V. Benda

# SM 18 overview



# Cluster G layout



# Cluster G cryostats

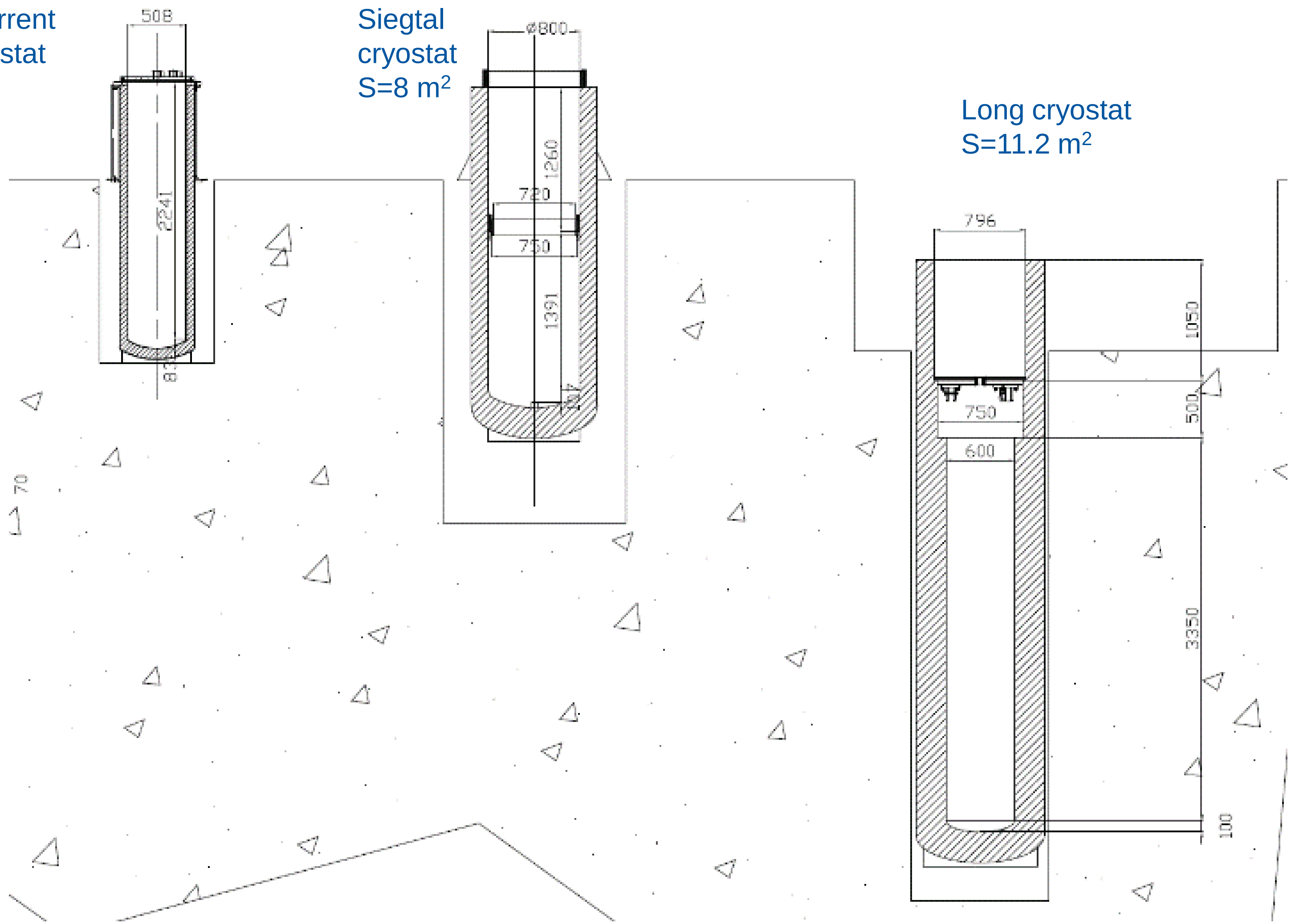
Diode/ Current leads cryostat
S=4 m$^2$

Siegtal cryostat
S=8 m$^2$

Long cryostat
S=11.2 m$^2$

HFM cryostat
S=25 m$^2$

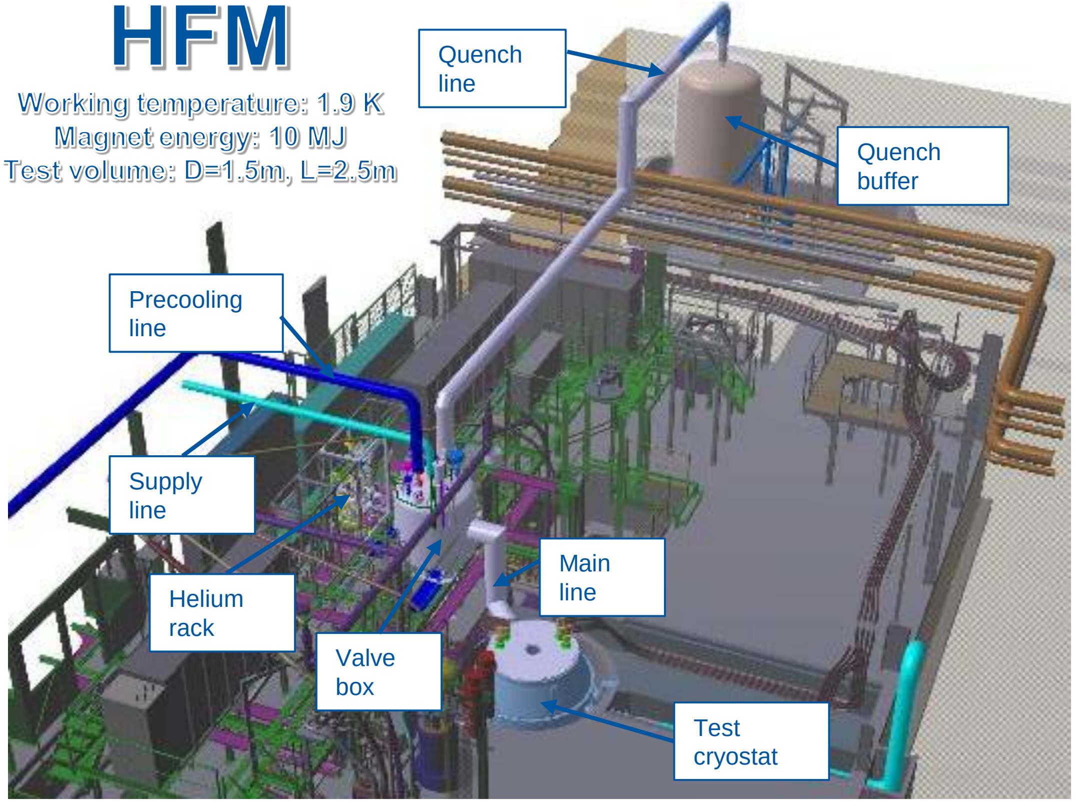
Cluster D cryostat
S=23 m$^2$



# HFM and Cluster D layout

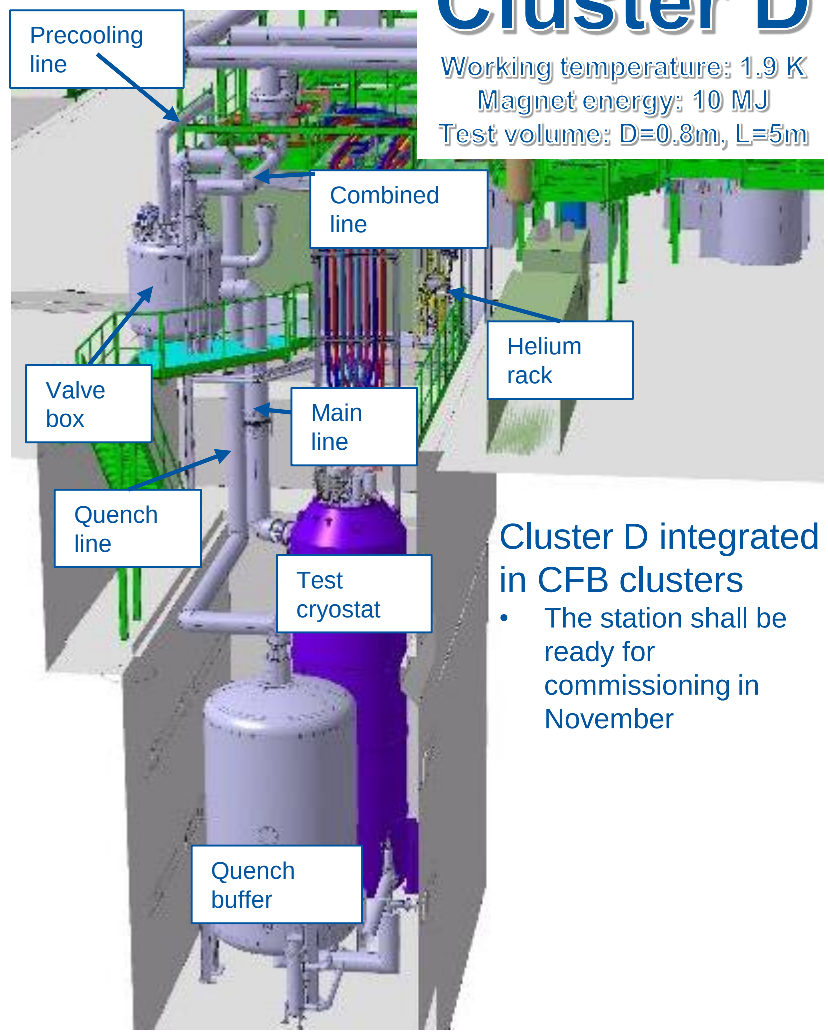
## HFM

Working temperature: 1.9 K
Magnet energy: 10 MJ
Test volume: D=1.5m, L=2.5m




## Cluster D

Working temperature: 1.9 K
Magnet energy: 10 MJ
Test volume: D=0.8m, L=5m




Cluster D integrated in CFB clusters

- The station shall be ready for commissioning in November

HFM integrated in the Cluster G

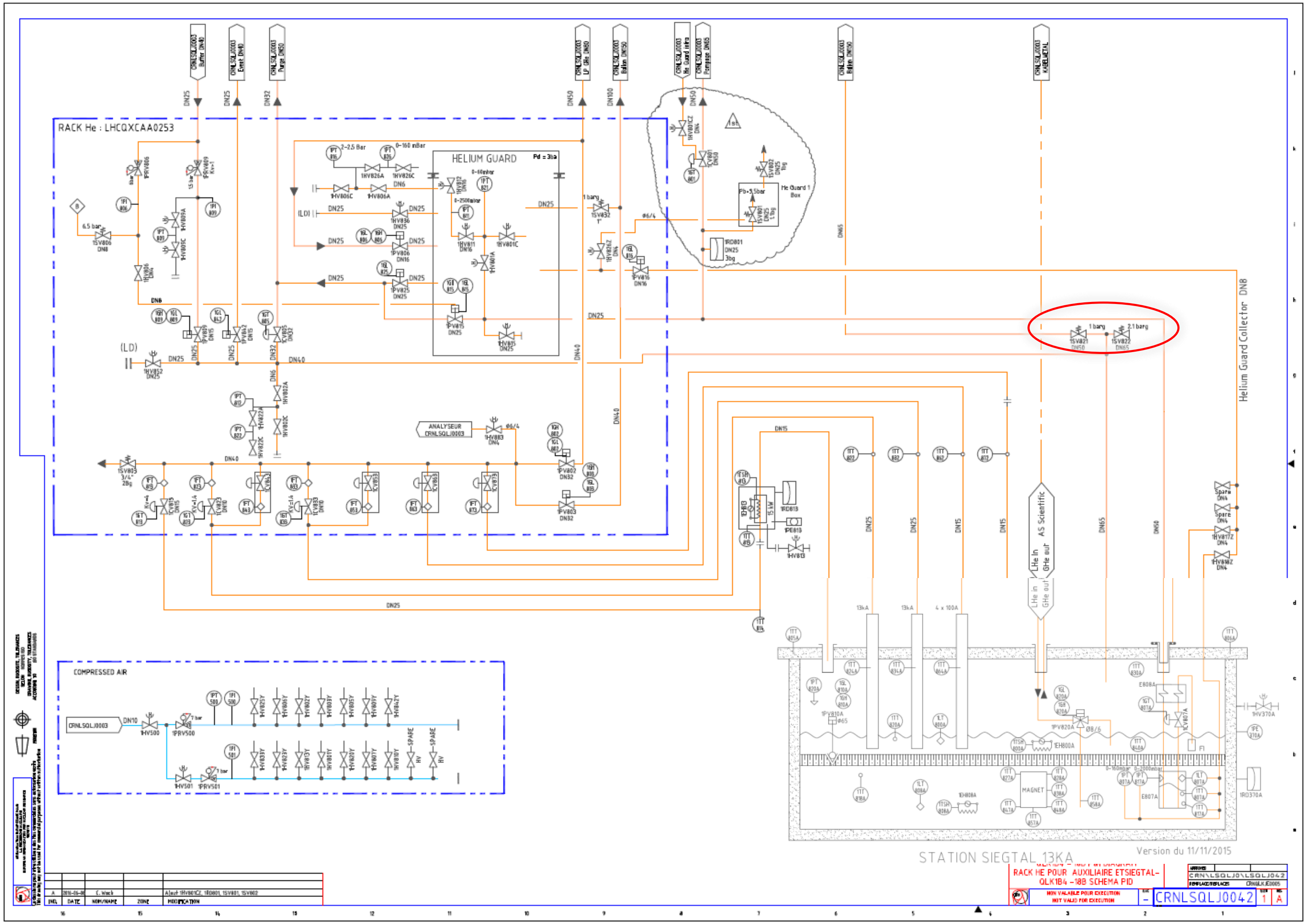
- The first cold test (without magnet) was successfully finished in August
- The first magnet test is foreseen for beginning of October

# Safety strategy and pressure parameters

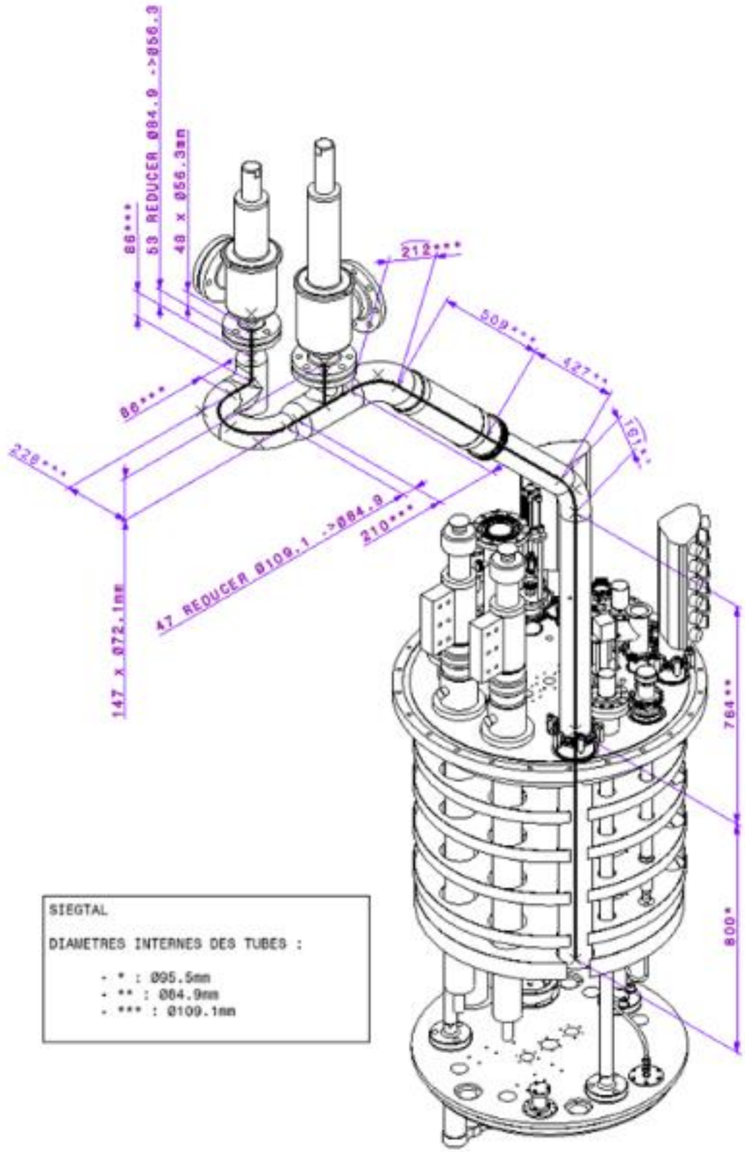
## Siegtal cryostat, Long cryostat and Diode/Current leads cryostat

- Main safety valve protects the cryostat against lost of insulating vacuum and quench in the same time
  - Very low probability, GHe to atmosphere in SM18
- Quench relief valve
  - Nominal operation, GHe to balloon (recuperation)
- Set pressure for Siegtal and Long cryostat
  - Main safety valve: 2.1 bar gauge
    - Full safety valve opening: 2.31 bar gauge ( 10% more)
    - dP of inlet < 3% and outlet line < 7% has to be respected
  - Set pressure of quench relief valve (only for quench): 1 bar gauge
  - Full opening at 1.1 bar gauge
- Set pressure for Diode/Current lead cryostat
  - Setting of the main safety valve is: 1.4 bar gauge
  - Only the main safety valve as there is no possibility of quench
- On a basis of risk analysis it was decided not to install a rupture disk in parallel with the safety valve.

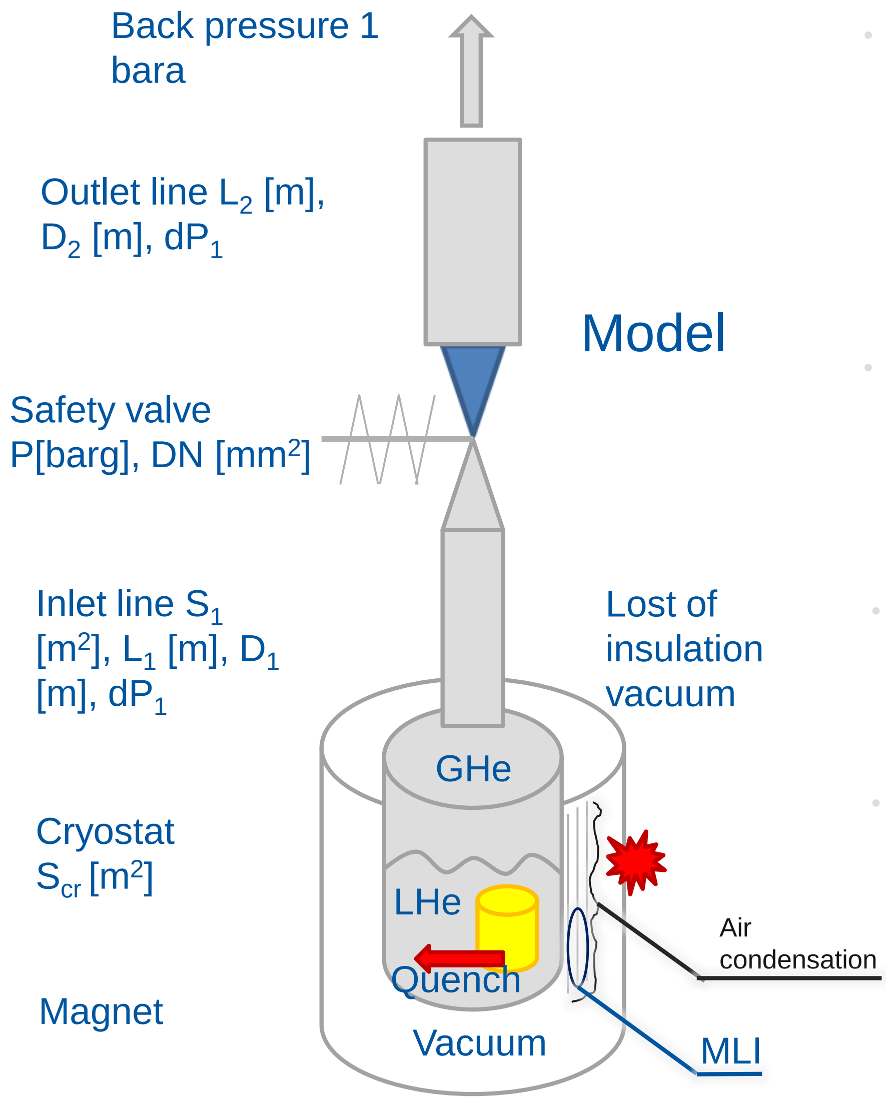
# Siegtal process and instrumentation diagram



# Siegtal cryostat geometry for inlet pipe dP calculation



# Strategy of SV/RD calculation adopted for Cluster G and D




- Risks taken into account
  a. Lost of vacuum
     - If insulated by 10 layers of MLI $Q_{vac}$=6 kW/$m^2$
     - If not isolated (line between the cryostat and the safety valve ) $Q_{line}$=38 kW/$m^2$
  b. Quench
     - Estimation based on LHC dipole $Q_q$=1 kW/m to LHe
  c. Total heat in-leak $Q_T = Q_{vac} + Q_{line} + Q_q$

- Calculation principle
  - $m_v=Q_T/L_v$ total vaporized
  - $m_o=m_v(1-\rho_g/\rho_l)$ out of cryostat
  - $m_o/A=K_{dr}\ P\ C\ (M/Z\ T)^{1/2}$ (ISO4126)
  - A is the required surface of the safety valve

- Requirements on the pipes connected to SV:
  a. Inlet line
     - $dP_{in}$ < 3% of P
  b. Outlet pipe
     - $dP_{out}$ <7% of P

- Note
  - If the non isolated line between the cryostat and the safety valve is too long the calculation will not converge
    - To reduce $dP_{in}$ diameter of inlet line shall be increased
    - If the diameter is increased: $Q_{line}$ is larger > $Q_T$ is larger >$m_o$ is larger>dP is larger
  - Non insulate part of the inlet line shall be as short as possible

# Siegtal, dimensioning of safety valve

- SV calculation for the following parameters
- $Q_{vac}$ heat in-leak in case of a cryostat vacuum lost
  - $Q_{vac}=S_{cr} \times q_{vac} = 8 \times 6 = 48$ kW
- $Q_q$ heat coming into LHe during magnet quench
  - On a basis of LHC magnet measurement it is estimated to 5 kW
- $Q_{line}$ heat in-leak into the insulated line
  - $Q_{line}=S_{line} \times q_{line} = 1 \times 38 = 38$ kW
- $Q_T=Q_{vac}+Q_q+Q_{line}= 91$ kW
- Set pressure 2.1 barg
  - For calculation $P_c$=3.31 bar absolute
- For $Q_T$ and $P_c$ the following parameters of the safety valve were found
  - $m_o$=4.97 kg/s, S=2358 mm$^2$, di=54.8 mm
  - dP of the inlet line base of its geometry is 2 % < 3%
  - Outlet pipe directly to atmosphere
- Safety valve LESER DN65, P=2.1 barg (S=2830 mm$^2$) was chosen

# Safety valve for Siegtal cryostat by Kryolize

**Kryolize® Sizing Report**

## Setup Properties

| | | | | | |
|---|---|---|---|---|---|
| Fluid | Helium | | Maximum Allowable Pressure | 2.10 | barg |
| Working Phase | Gas | | Relief Pressure | 3.31 | bar |
| Working Pressure | 1.30 | bar | Back Pressure | 1.00 | bar |
| Working Temperature | 4.50 | K | Pressure at Critical Point | 2.27 | bar |
| Set Pressure | 2.10 | barg | Temperature at Critical Point | 5.19 | K |

## Cryostat Properties

| | | |
|---|---|---|
| Surface Area | 8.00 | m² |
| Ullage | 0 | % |
| Inlet Piping Length | 2.00 | m |
| Outlet Piping Length | 0.30 | m |

## Heat Load Events

| | | |
|---|---|---|
| Loss of Insulation Vacuum | 48.00 | kW |
| Quench & inlet line | 43.00 | kW |
| Total Event Heat Load | 91.00 | kW |
| Safety Margin | 0 | % |
| Total Heat Load | 91.00 | kW |

## Mass Flow

| | | |
|---|---|---|
| Pressure Ratio | 1.45 | |
| Fluid State | Supercritical | |
| Specific Heat Input | 18.29 | kJ/kg |
| Mass Flow | 4.97 | kg/s |

**Kryolize® Sizing Report**

## Verification Inlet Piping

| | | |
|---|---|---|
| Release Temperature | 6.10 | K |
| Relief Pressure | 3.31 | bar |
| Allowable Pressure Drop | 3.00 | % |
| Maximum Pressure Drop | 0.09 | bar |
| Initial Piping Diameter | 54.79 | mm |
| Piping Length | 2.00 | m |
| Piping Insulation | No LIV | |
| Surface Roughness | 0.01 | mm |
| Fittings Coefficient | 0.20 | |
| Total Pressure Drop | 0.32 | bar |
| Additional Piping Heat Load | 0.00 | kW |
| Total Heat Load | 91.00 | kW |
| New Mass Flow | 4.97 | kg/s |
| New Total Pressure Drop | 0.04 | bar |
| Minimum Diameter (approximation) | 71.67 | mm |
| New Diameter | 85.00 | mm |
| New Area | 5674.50 | mm² |
| DN as per ISO 6708 | DN 100 | |
| Pressure Drop Verification | VALID | |

## Verification Outlet Piping

| | | |
|---|---|---|
| Release Temperature | 6.10 | K |
| Relief Pressure | 3.31 | bar |
| Allowable Pressure Drop | 7.00 | % |
| Maximum Pressure Drop | 0.23 | bar |
| Initial Piping Diameter | 54.79 | mm |
| Piping Length | 0.30 | m |
| | - | |
| Surface Roughness | 0.01 | mm |
| Fittings Coefficient | 0.10 | |
| Total Pressure Drop | 0.08 | bar |
| | - | |
| | - | |
| | - | |
| New Total Pressure Drop | 0.00 | bar |
| Minimum Diameter (approximation) | 54.79 | mm |
| New Diameter | 110.30 | mm |
| New Area | 9555.22 | mm² |
| DN as per ISO 6708 | DN 125 | |
| Pressure Drop Verification | VALID | |

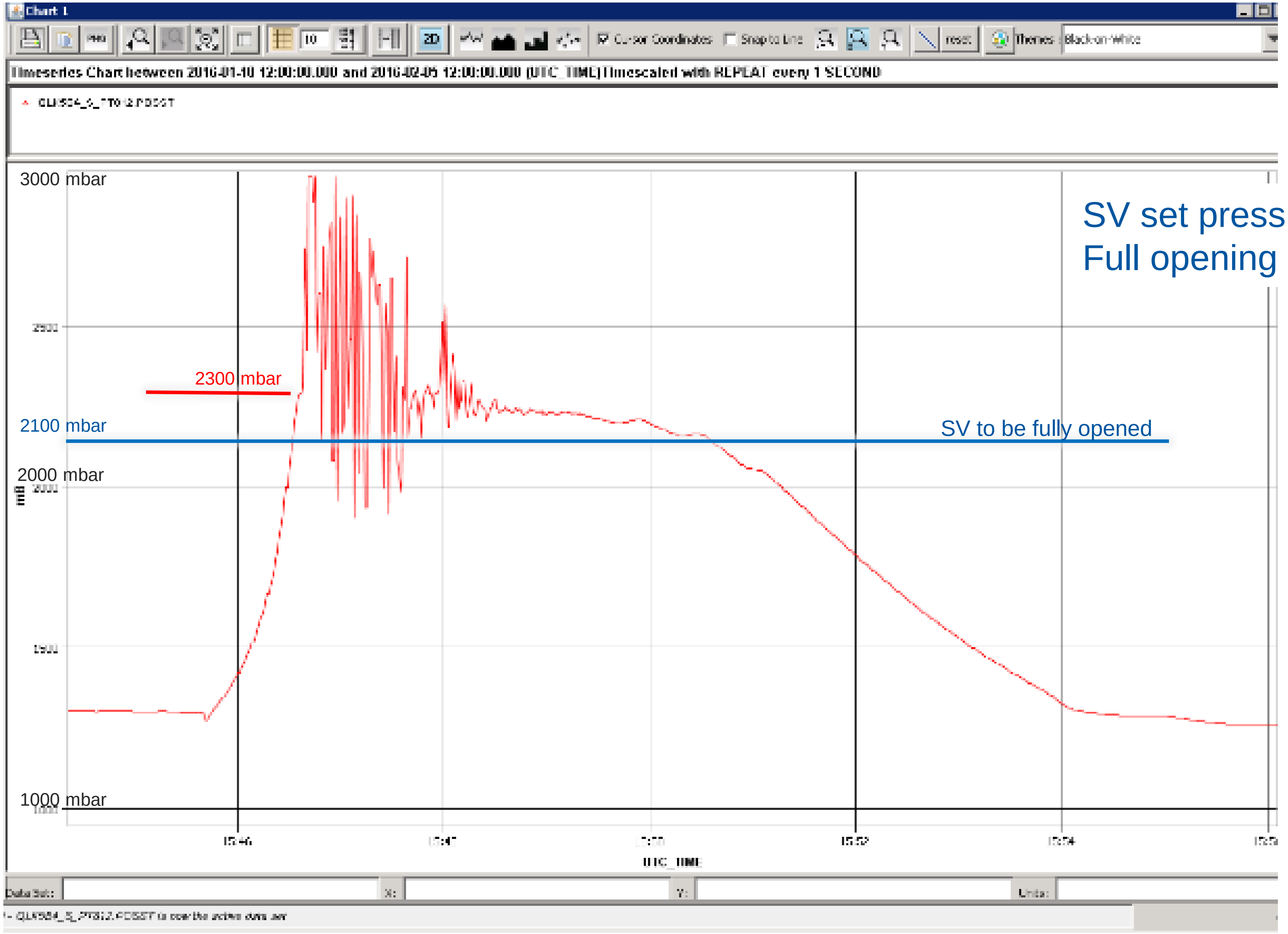
## Discharge Area - Safety Device

| | | |
|---|---|---|
| Safety Device | Safety Valve | |
| Fluid Phase at Release Conditions | Gas | |
| Discharge Coefficient | 0.75 | |
| Release Temperature | 6.1 | K |
| Area | 2358.34 | mm² |
| Diameter | 54.79 | mm |
| Nominal Diameter | DN 50 | |
| Inlet Pipe Diameter | 85.00 | mm |
| Outlet Pipe Diameter | 110.30 | mm |

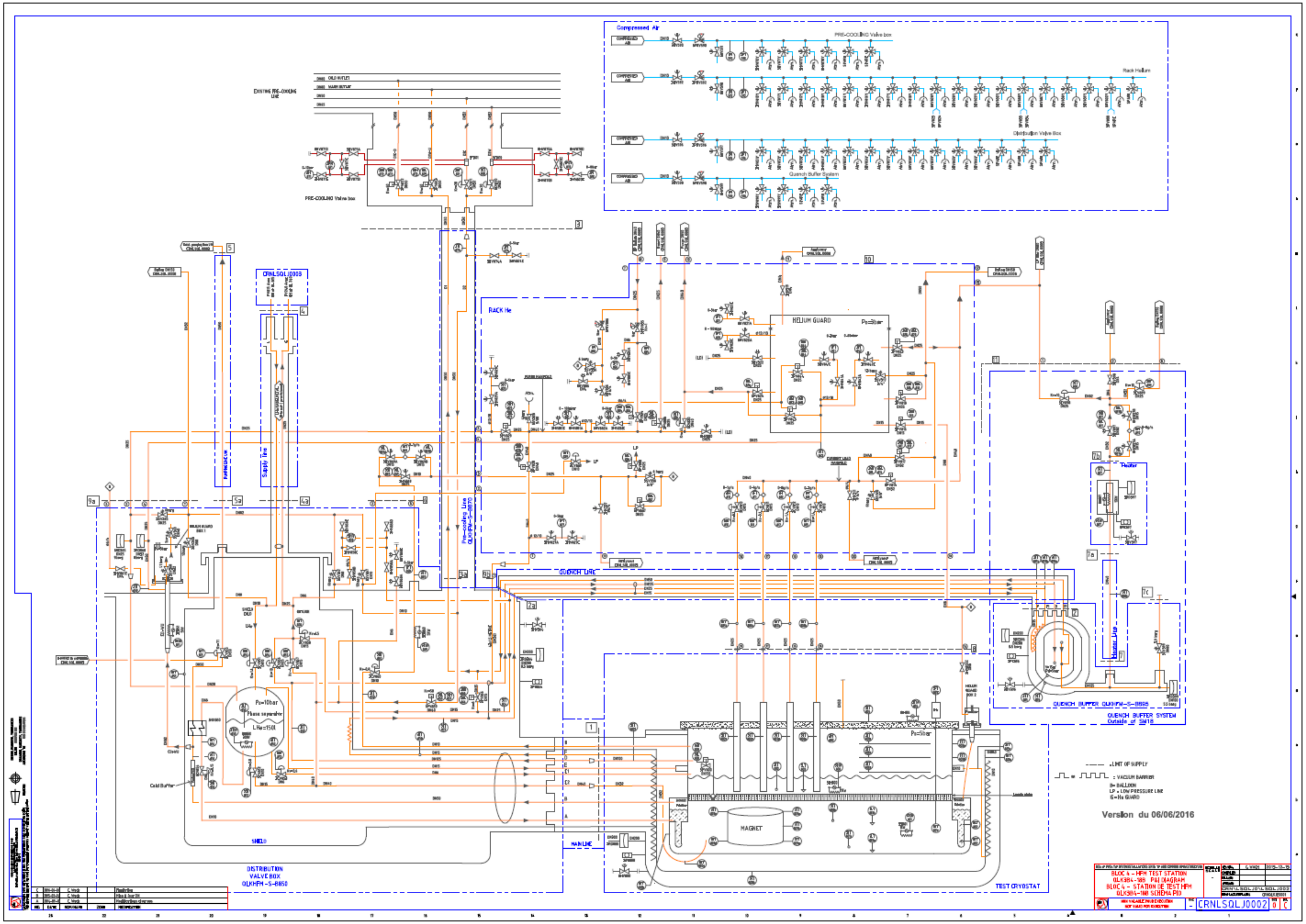
# Siegtal, dimensioning of quench relief valve

- $Q_T = Q_q + Q_{line} = 50$ kW
- Set pressure 1 barg
  - For calculation $P_c$=2.1 bar absolute
- For $Q_T$ and $P_c$ the following parameters of the quench relief valve were found
  - $m_o$=2.73 kg/s, S=1652 $mm^2$, di=45.9 mm
  - dP of the inlet and outlet pipe is not strictly restricted as the quench relief valve is not considered as the safety valve
    - In any case dp in the inlet line is lower that 3% and in outlet line lower that 7%
- Safety valve LESER DN50, P=1 barg (S=1662 $mm^2$)

# Long cryostat, "SV" behaviour during a magnet quench

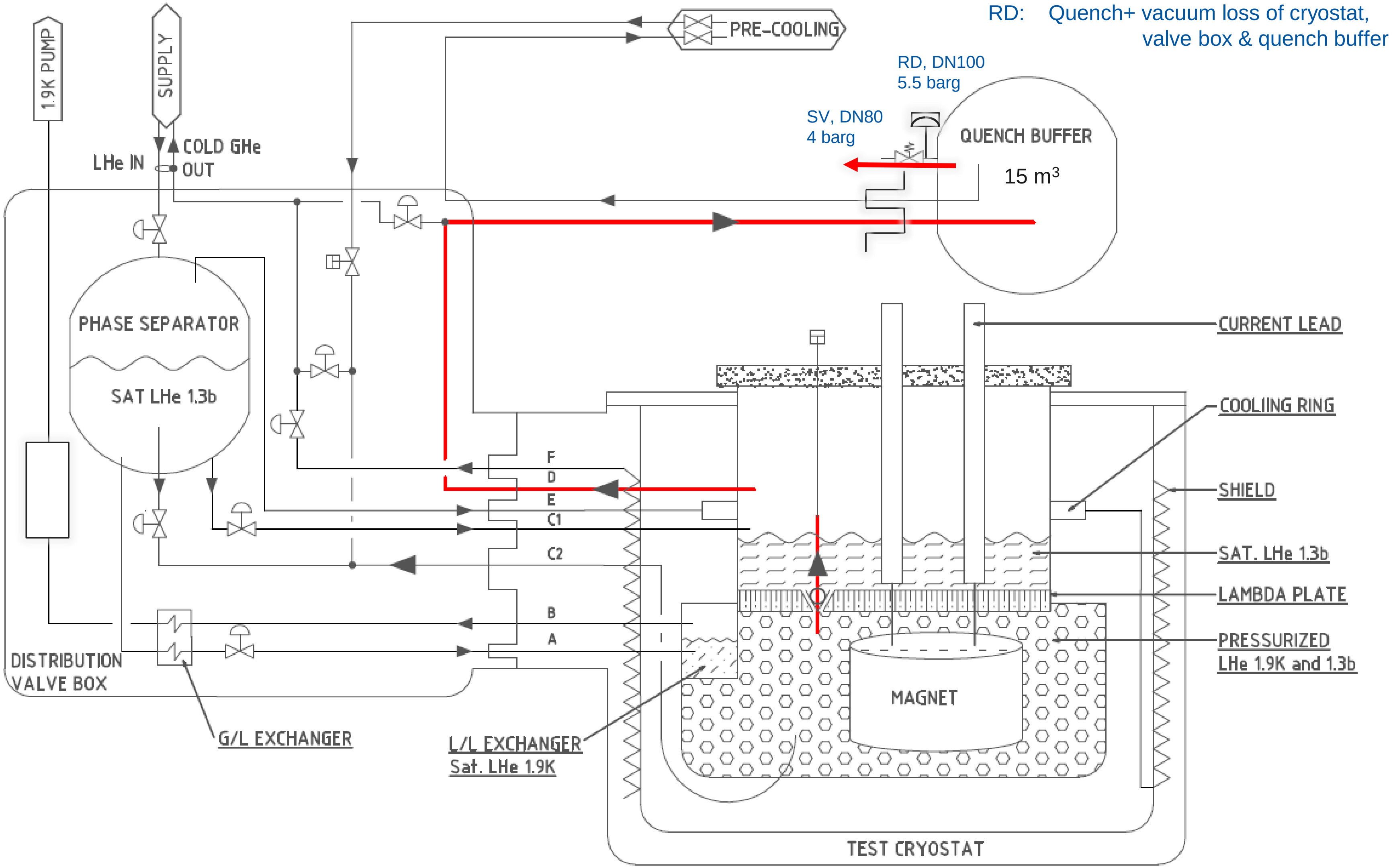


# HFM   P&I diagram



# HFM quench & catastrophic scenario

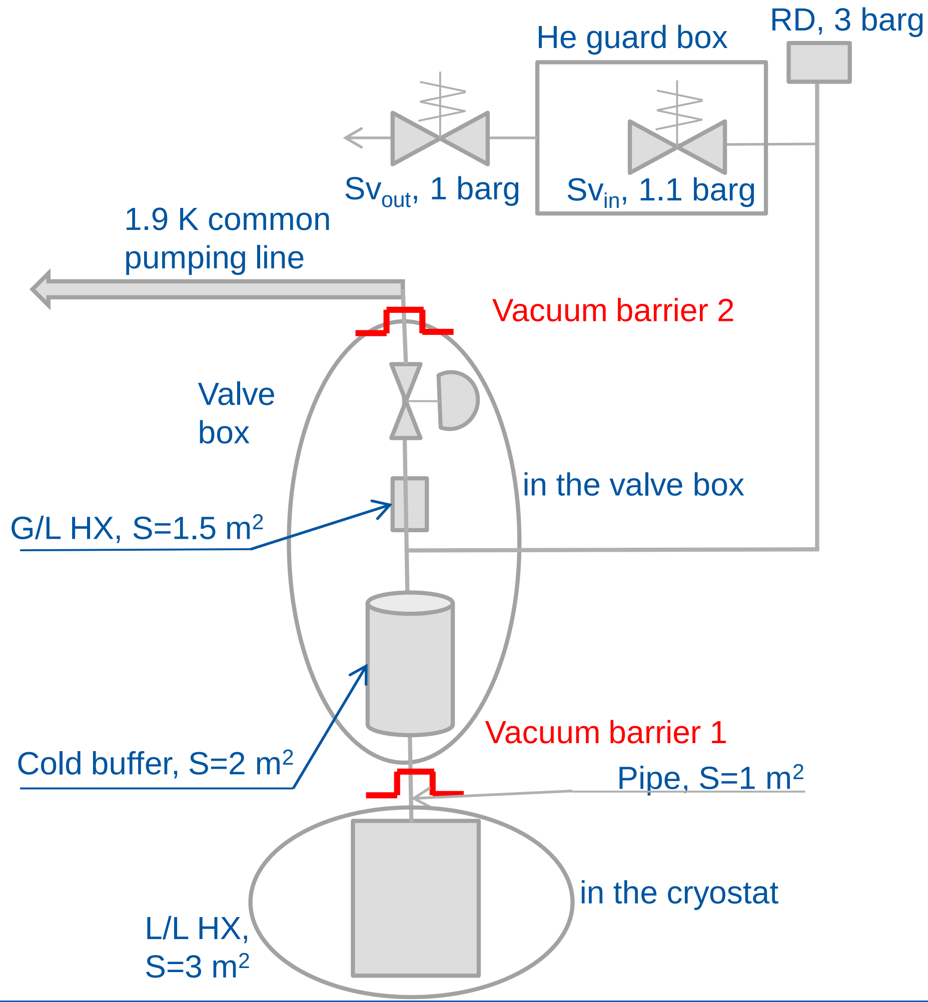
SV: Quench + cryostat vacuum loss
RD: Quench+ vacuum loss of cryostat, valve box & quench buffer



# Protection of 1.9 K pumping circuit of HFM

Similar system is applied for Cluster D, other cryostats of Cluster G including 1.9 K common line

- SV: only L/L HX is full of LHe
  - $SV_{in}$: $Q_T$=24 kW, $P_b$=2.1 bara, $P_r$=3.31 bara, q=6 kW/m$^2$, $S_T$=4 m$^2$
    - Result: S=641 mm$^2$, (d=28.6 mm), m=1.276 kg/s
    - **Safety valve: DN32, P=1.1 bar gauge**
  - $SV_{out}$: $P_b$=1 bara, $P_r$=2.1 bara, m=1.276 kg/s
    - Result: S=777 mm$^2$, (d=31.4 mm)
    - **Safety valve: DN40, P=1 bar gauge**
- RD for case that also the pumping line including the cold buffer and G/L HX is full of LHe and vacuum barrier 1 is broken
  - $Q_T$=45 kW, $P_b$=1 bara, $P_r$=4 bara, q=6 kW/m$^2$, $S_T$=7.5 m$^2$
  - Result: S=777 mm$^2$, (d=31.2 mm), m=2.1 kg/s
  - **Rupture disk: DN32, P=3 bar gauge**



# Cryogenic pipe with cold GHe

## Strategy for SV calculation

- Heat in-leak for determination of a SV is for no moving gas in a pipe low
  - Typically 700 $W/m^2$
- For long pipe during relieving a speed of leaving gas grows and heat exchange improves accordingly. At some speed the heat exchange inside the pipe is better than outside. In this case the limitation of heat exchange is the same as for pipe/vessel with LHe
  - Typically 6 $kW/m^2$
- Detail study of this dynamic process would be appreciated

# Recommendation/Notes

- Risk analysis of each concrete case to be done
  - Especially for more complex systems
    - Additional heat in-leak (quench), divided vacuum space
    - Installation of RD in parallel with SV if justified
- Heat in-leak determination
  - Vacuum loss, number of MLI layers, extra heat in-leak
- Pressure drop of the inlet and outlet pipe
  - Shortest pipes are the best
- Non insulated inlet pipe to be as short as possible
  - Very high extra heat in-leak, typically 38 $kW/m^2$
    - System is not converging
- If SV and RD are installed in parallel the inlet pipe has to be calculated for the worse possible case concerning dP
  - If a hose is used; its dP is about 4x larger than for a smooth pipe…

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