# DFM : Engineering Detailed Design

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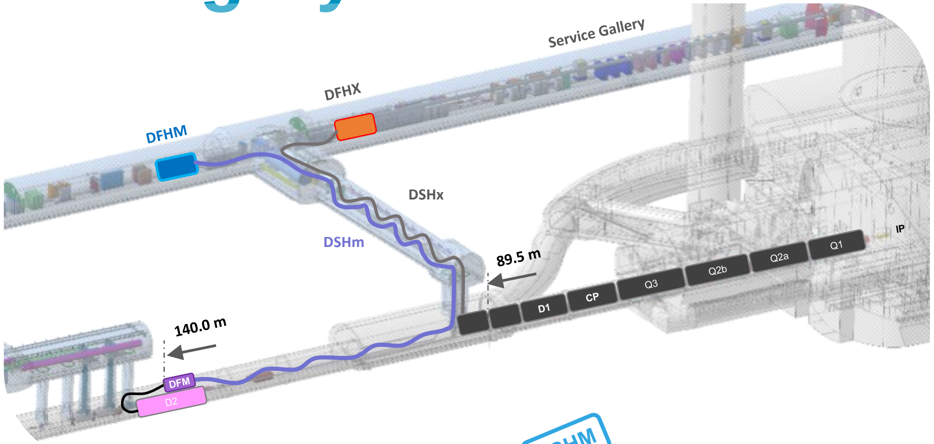
***Engineering Design Review of DFM 18.01.2022***

# DFM in Cold Powering System

## DFM in HL-LHC Layout

- Part of the WP6a Cold Powering chain
  - DFM-DSHM-DFHM
- Installed on either side of ATLAS and CMS
- Interface with DSHM of WP6a, with D2 & QXL of WP3

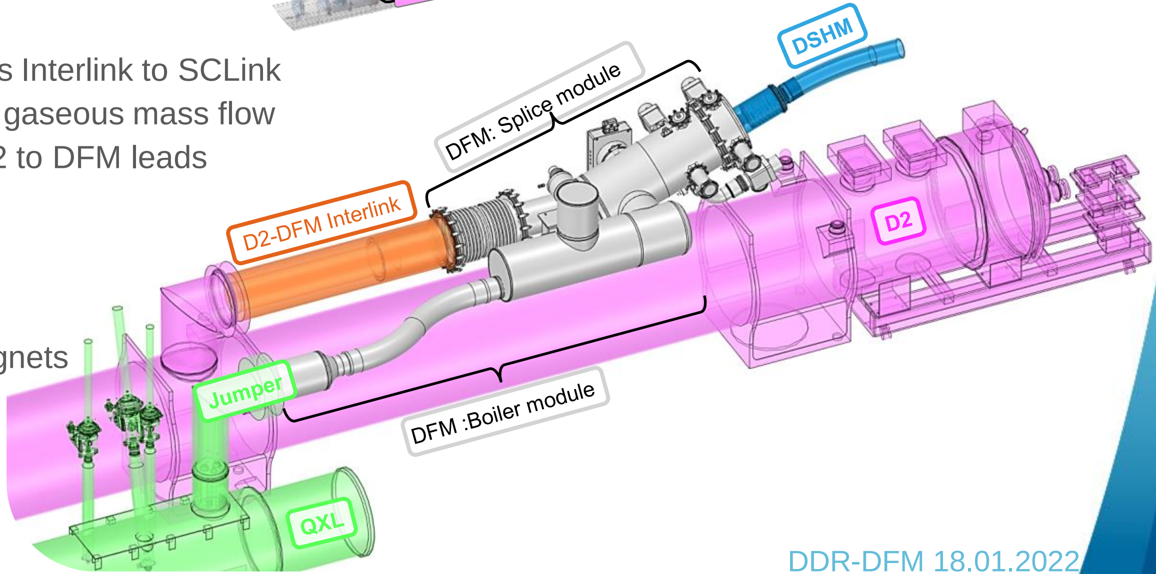



## Components denominations

- **DSHm** (SCLink D2): from DFHM to DFM
- **DFM**
  - **Splice module (SM)**: electrically connects Interlink to SCLink
  - **Boiler module (BM)** : creates the helium gaseous mass flow
- **D2-DFM interlink:** connects leads from D2 to DFM leads
- **DFM Jumper:** connects to cryo-lines

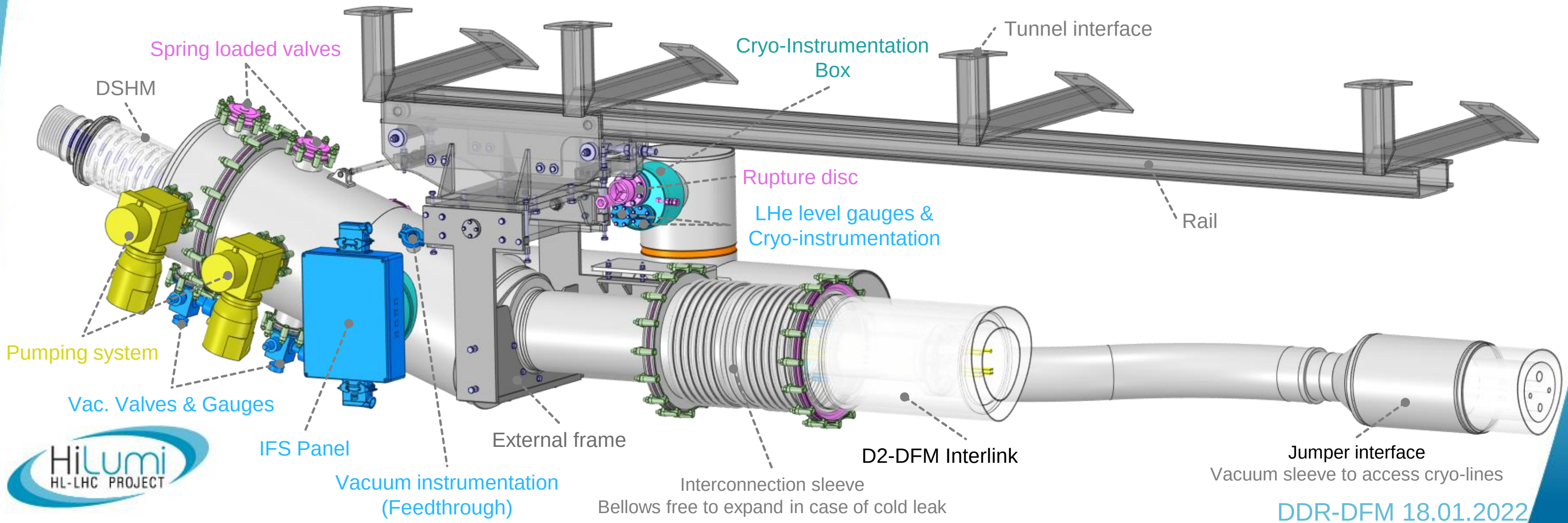
## Key Functions

- Electrical interface between DSHM & magnets
- Supply cryogenics to the DSHM



# External overview & interfaces distribution

- **Tunnel interface**
  - Cryostat suspended from tunnel's roof
- **Services**
  - Vacuum & cryo-instrumentation equipment accessible from transport area
- **DFHM interface**
  - Vacuum & helium jacket flanges fixed to DFM
- **DFM-D2 interlink interface**
  - Vacuum & helium sleeves to access NbTi-NbTi splices
  - Hydraulic barrier (plug) separating LHe (DFM side) from superfluid helium (D2 side)
- **Jumper interface**
  - Flexible cryo-interconnections
  - Vacuum sleeve to access cryo-interconnections



# Key design specifications & constraints

- Design (nominal) GHe mass flow rate → **6.5 (3) g/s**
- Autonomy in case of LHE supply stop → **10 min @ nominal**
- Gas evacuation through SC Link


EDMS NO. 2052614 | REV. 0.2 | VALIDITY DRAFT

REFERENCE : LHC-EQCOD-ES-XXXXX

FUNCTIONAL SPECIFICATION

DFM CRYOSTAT

COLD POWERING WORK PACKAGE – WP6A

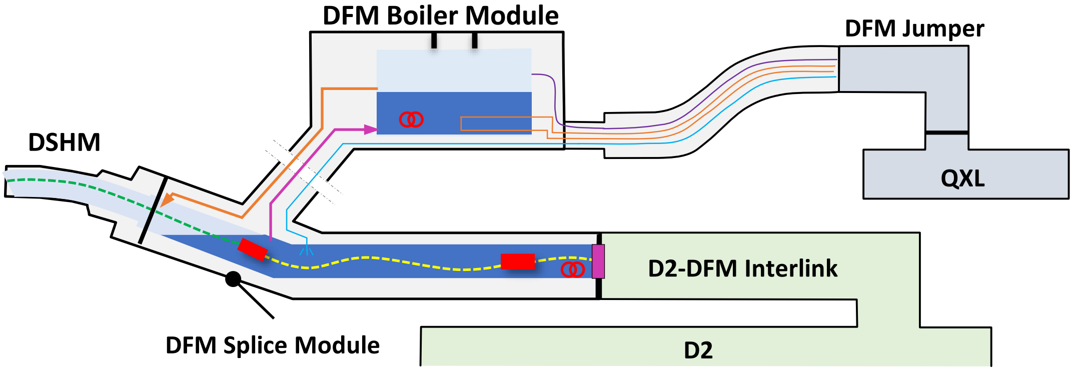
[HL-LHC EQCOD ACCORDING TO CONFIGURATION MANAGEMENT]

- Maximum static heat load to 4.5 K → **25 W**
- Absence of condensation → **Dew point 12°C**

} Compliance demonstrated via numerical analyses

- Helium vessel design pressure → **3.5 $bar_a$**
- PED Category → **II**

} Compliance demonstrated via numerical analyses



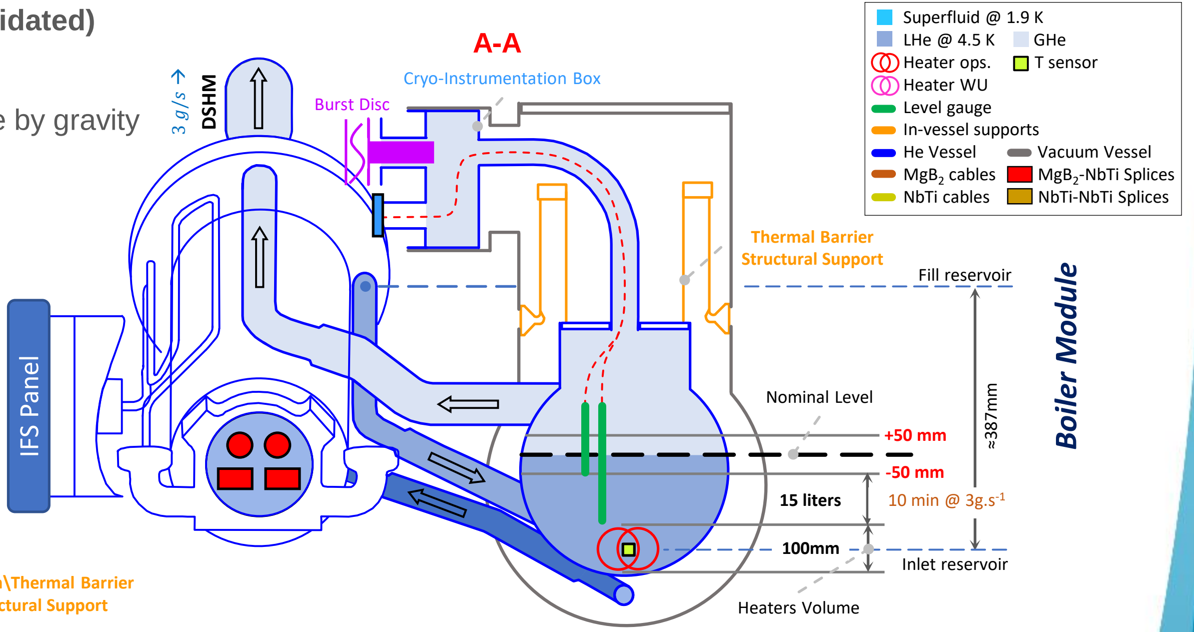
# Principle of fluid flow & LHe buffers

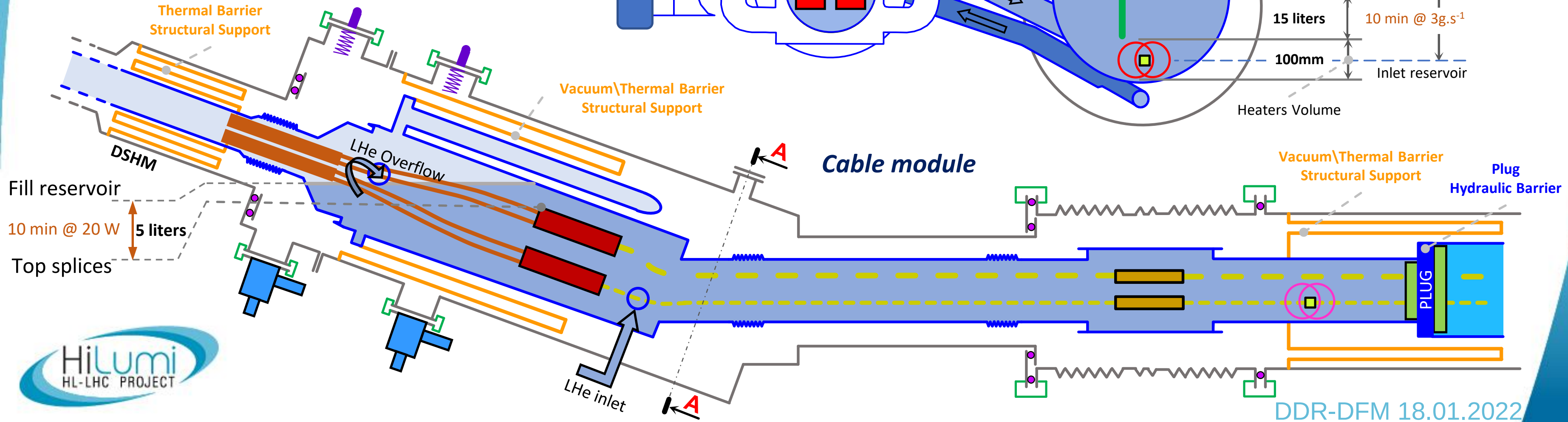
**Principle (same as Demo 2, successfully validated)**

1. LHe injection in splice module
2. LHe flows downward in beside boiler module by gravity
3. Heating line vaporizes LHe in boiler module
4. GHe flows upward to splice module
5. Level gauges control LHe inlet valve

**Cryogenic**

- Splices are immersed in LHe bath
- 5 liters of LHe in SP for 10 min @ 20 W
- 15 liters of Lhe in BM for 10 min @ 3g·s$^{-1}$



# Coldmass design overview

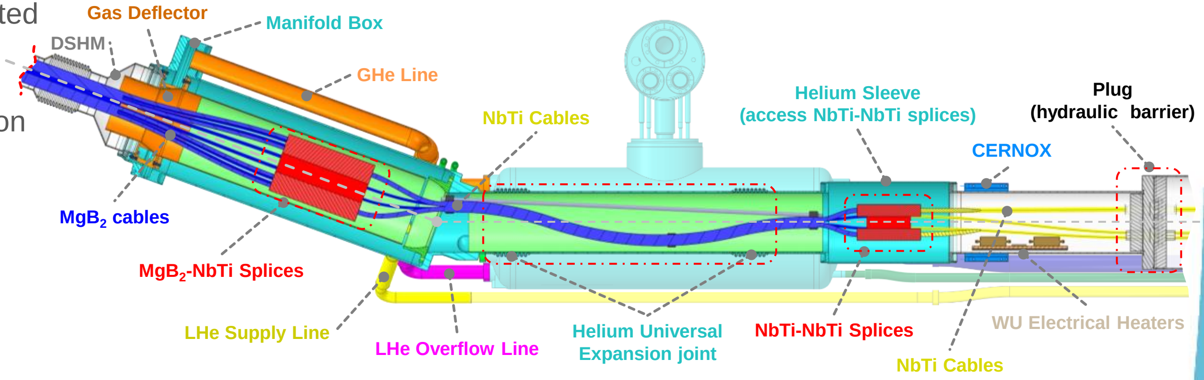
- Two helium vessels hydraulically interconnected

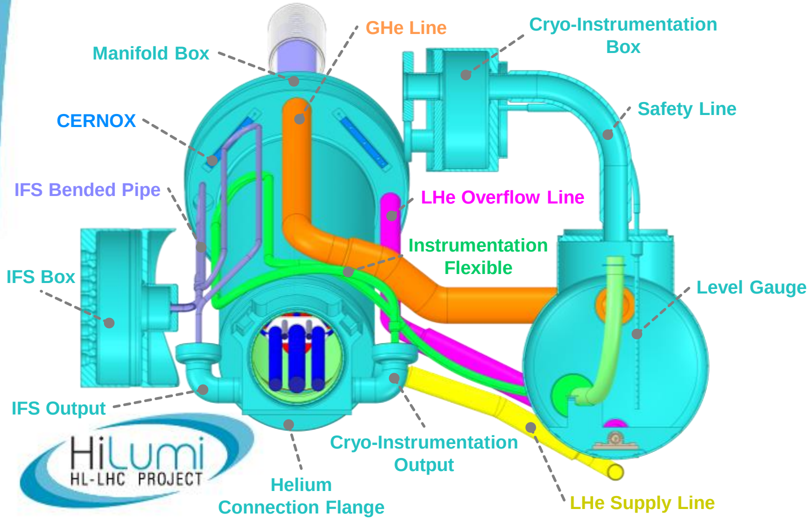
**Splice module (cooling splices)**

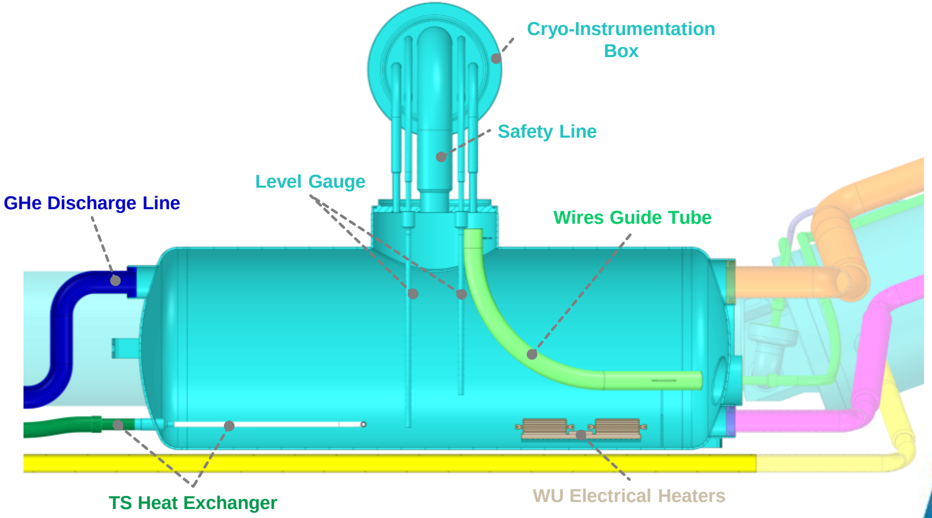
- Inclined design to perform LHe-GHe separation
- Universal expansion joint connection with D2
- He sleeve to access NbTi-NbTi splices
- Hydraulic barrier @ D2

**Boiler module (vaporizing LHe)**

- Horizontal helium tank
- Safety & Cryo-Instrumentation outputs
- Cryo-connection lines to jumper



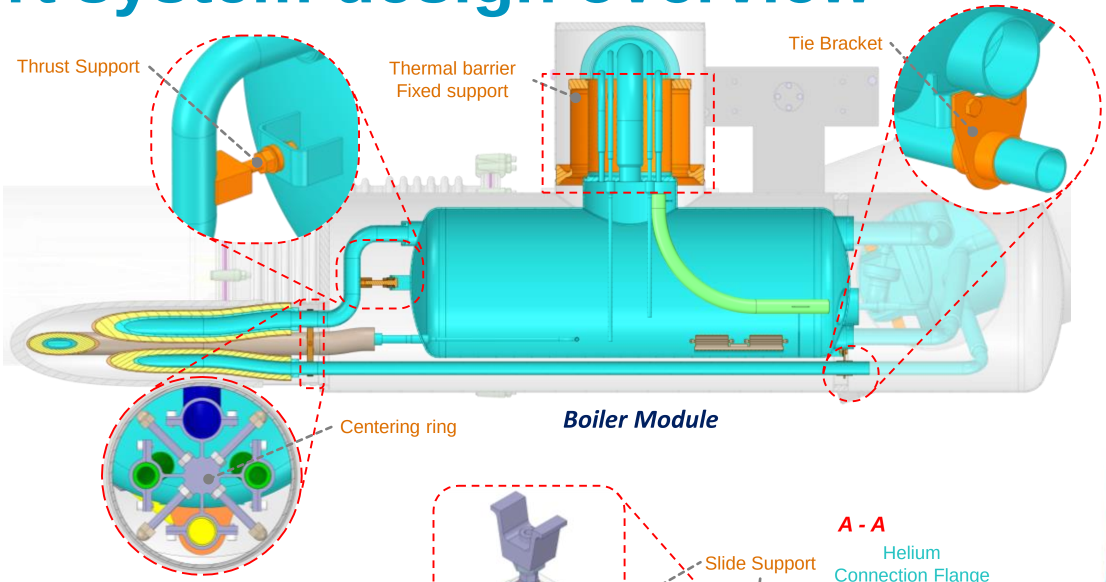



# In-vessel support system design overview

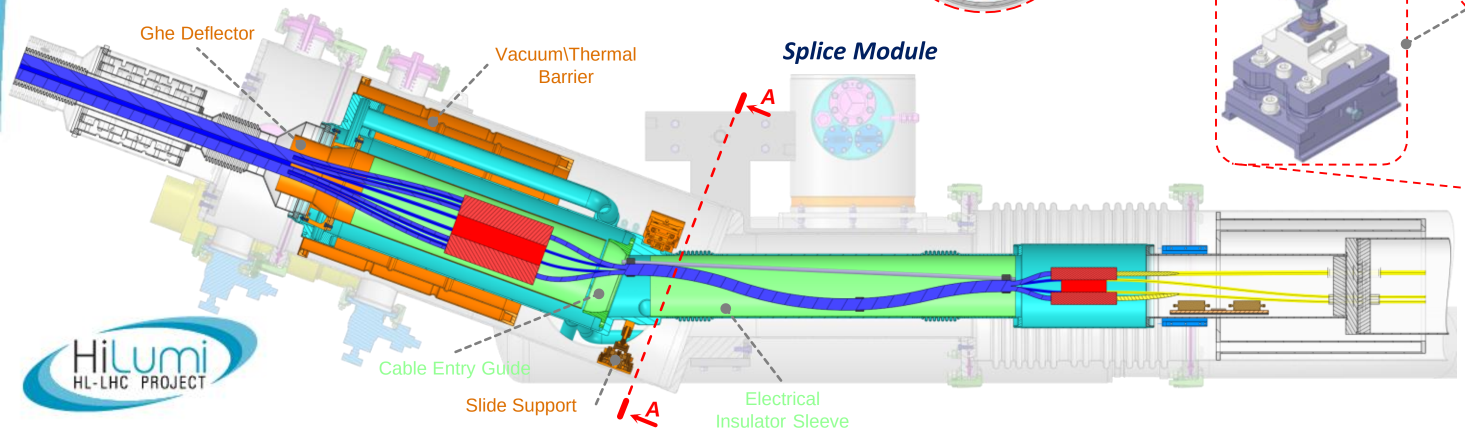
**Boiler module**

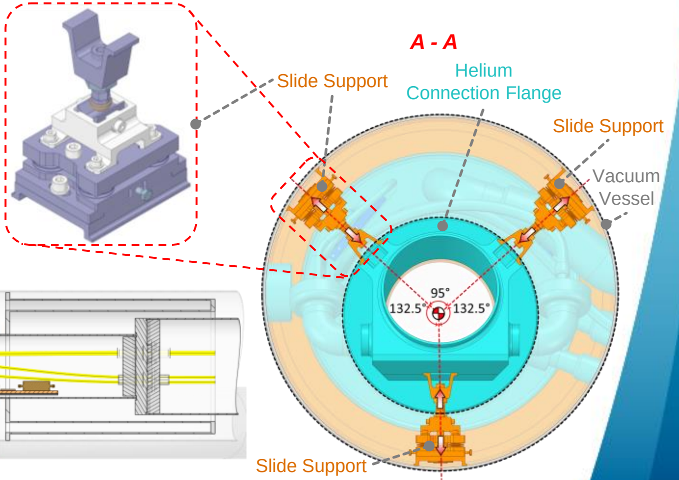
- One point constraint layout
  - Fixation point @ the top (suspension layout)
  - Dedicated fixtures for supporting cryo-lines




**Splice module**

- Two points constraint layout
  - Fixation point @ vacuum\thermal barrier
  - Slide connection @ helium connection flange



# Cryogenic : thermal contraction

## Splice Module

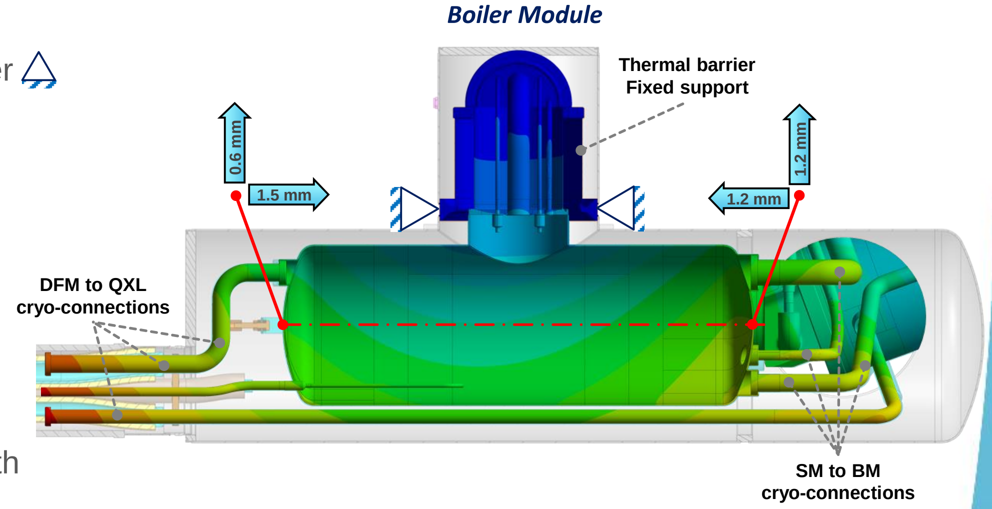
- Fixed point @ **SM** vacuum barrier & **D2** vacuum barrier
- Sliding point @ helium connection flange
- Universal expansion joint between **SM** & **D2**
  - Structurally "decoupling" **D2** from **DFM**

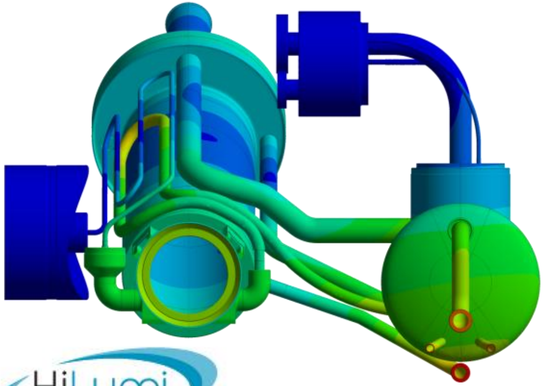
## Boiler Module

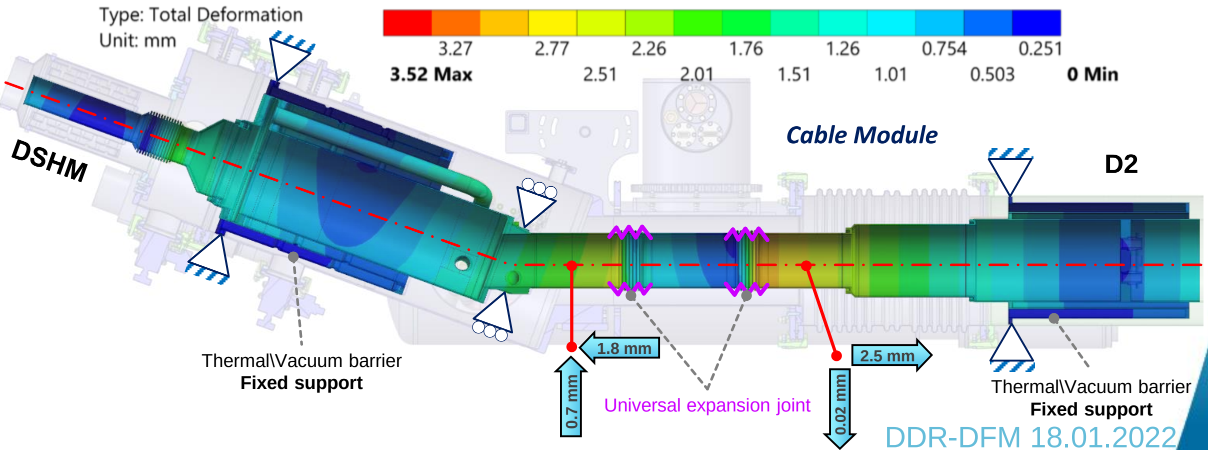
- Fixed point @ thermal barrier

## Cryo-Connections

- Flexibles in between **SM** & **BM** containing extra-length
- Flexibles in between **BM** & **QXL** containing extra-length





# DFM Splice Module : Slide Support Design

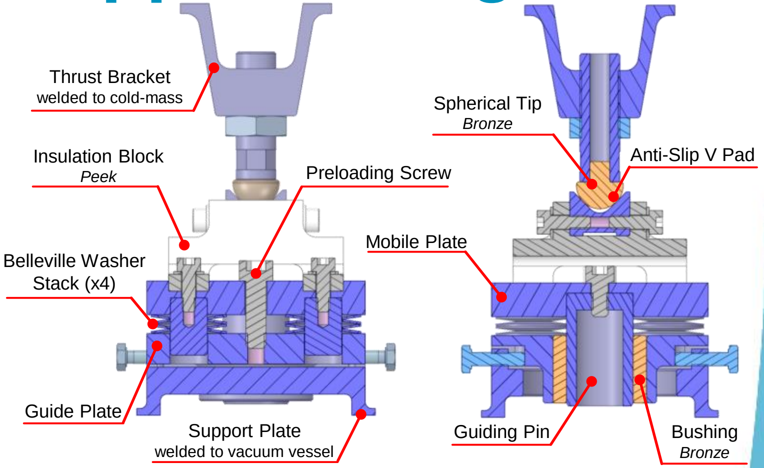
**Scope : rigidify cold-mass & avoid overstressing the vacuum barrier**

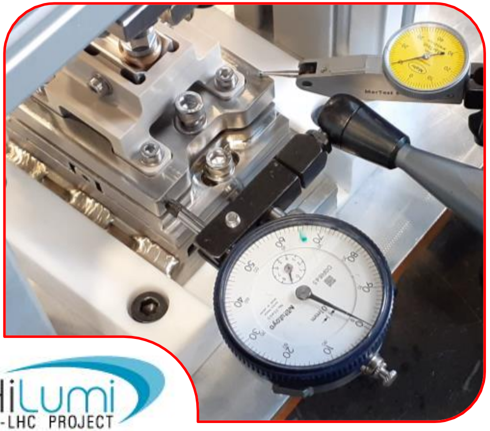
## Key design features

- Three independent slide supports distributed around CM circumference
- Slide support
  - Spring-preloading system to compensate CM thermal contraction
  - PEEK block to insulate CM

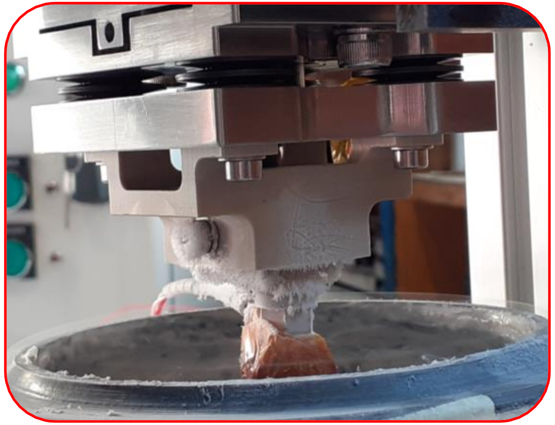
## Design validation

- Measured of PEEK deformation @ warm under design load
- Verified sliding principle under design load
- Verified mechanical strength of PEEK @ cold under design load

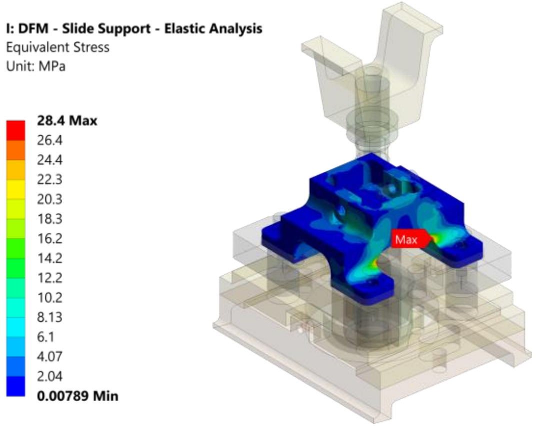


*Test @ warm*



*Test @ cold*




*Dedicated FEM analysis of the slide support*

# Insulation Vacuum & External Interfaces

## Insulation vacuum

- Two insulation vacuum volumes
  - One in common with DSHM
  - One in common with jumper
- Vacuum Barrier with DSHM & D2
- Vacuum equipment
  - Ports for installing pumping system & vacuum gauges
  - Ports for installing pressure relief devices
  - Port for installing vacuum instrumentation (feedthrough)

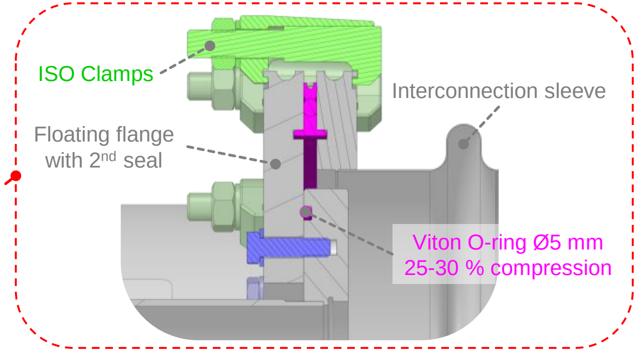
| Insulation vacuum specifications | Unit | Value |
| --- | --- | --- |
| Nominal pressure | [mbar] | $1.10^{-6}$ |
| Design pressure | [bara] | 1.49 |
| Maximum allowed leak rate at RT acc. to [19] | $[mbar.l.s^{-1}]$ | |
| *Liquid Helium volume to insulation vacuum* | | $1.10^{-9}$ |
| *Air to insulation vacuum* | | $1.10^{-8}$ |
| *Through DFM-DSHM vacuum barrier* | | $1.10^{-8}$ |

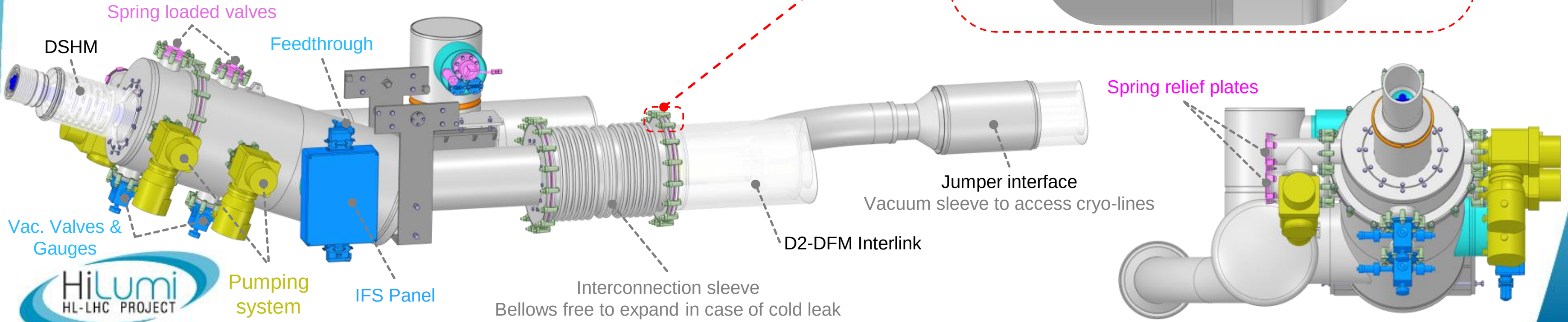
## Leak tightness

- O-ring Viton seal compressed to 25% to 30%
- Standard commercial solutions where possible

## Mechanical design approach

- Vacuum vessel according to EN 13445-3
- Bellows according to EN 14917+A1

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# External frame design overview

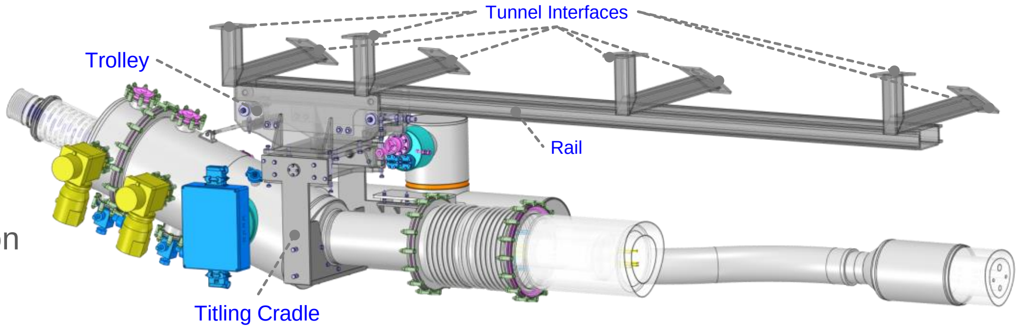
- **Design 90% for location 5R**

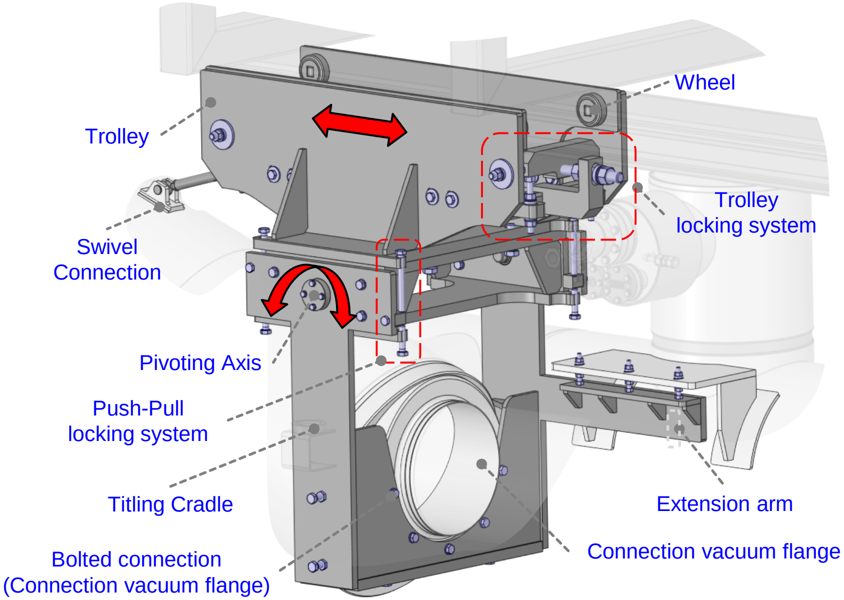
- **Key design features**
  - Cryostat suspended from tunnel's surface
  - 2 DOFs kinematic requirement for DSHM installation

- **Support system composed of three units**
  - **Rail** : Fastened to tunnel surface
    - Aligned wrt referential during fixation to tunnel roof

  - **Trolley** : sliding over the rail by means of wheels
    - Locking system to hold the cryostat in position along the rail
    - Swivel connection (tie rod end) with SM vacuum vessel

  - **Tilting cradle** : connected to cryostat & trolley
    - Primary bolted interface at vacuum connection flange of SM
    - Bolted interface with the BM through dedicated extension arm
    - Rotatable connection with trolley + push-pull locking system



# Cryogenic : Thermal Performances

## Thermal analysis

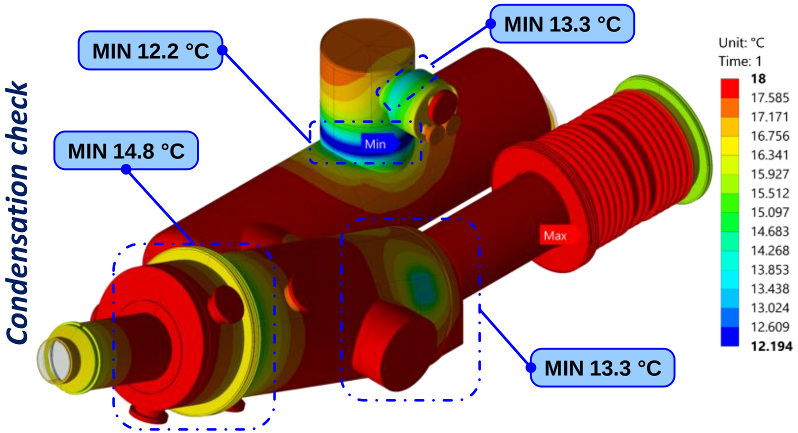
- Convection over surfaces exposed to atmosphere
- Forced T 4.5 K over surfaces exposed to LHe & cold GHe
- Conservative assumptions
  - Perfect thermal conductance between parts
  - Conservative convective coefficient 5 $W/m^2K$, bulk temperature 18°C
  - Heat load through lambda plate neglected (EDMS 2642887)

→ **No condensation on surfaces facing atmosphere**

→ **Heat in-leaks within budget < 25 W**

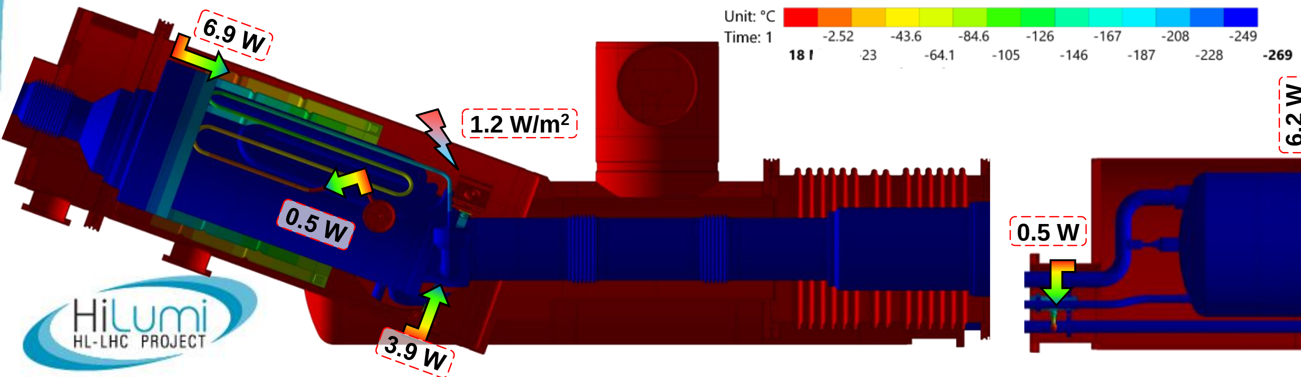
- Extracted conductive resultant heat load ≈18.5 W
- Estimated radiative heat load ≈ 4.8 W (cold surfaces ≈4 $m^2$)

*Operating temperature distribution of the vacuum vessel envelope*

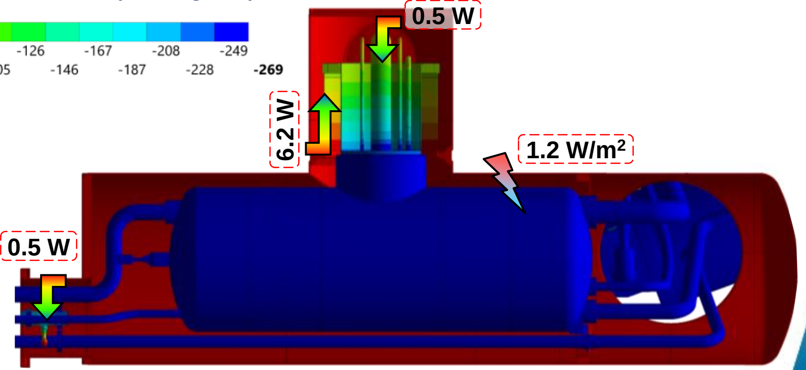



*Heat in-leak loads*

*Operating temperature distribution of the Cable Module*




*Operating temperature distribution of the Boiler Module*

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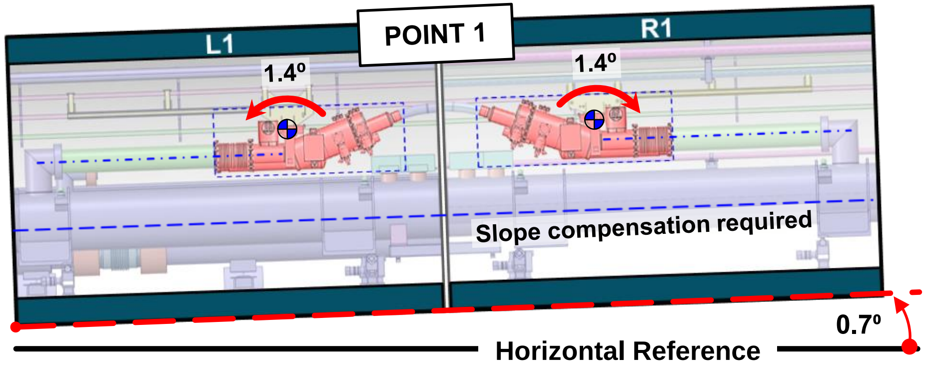
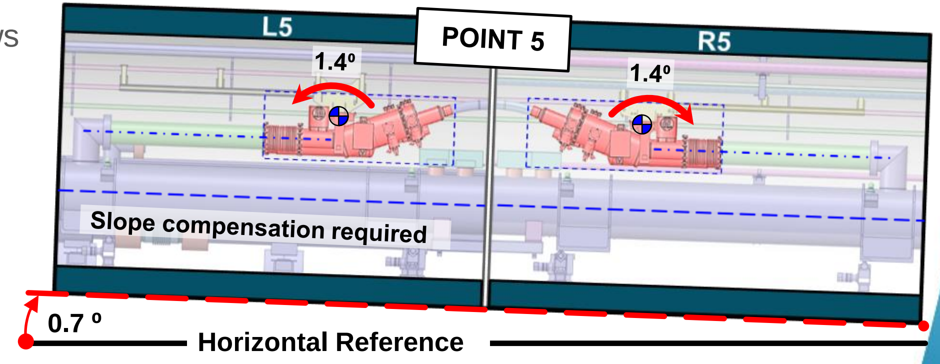
# Cryogenic : Gas evacuation

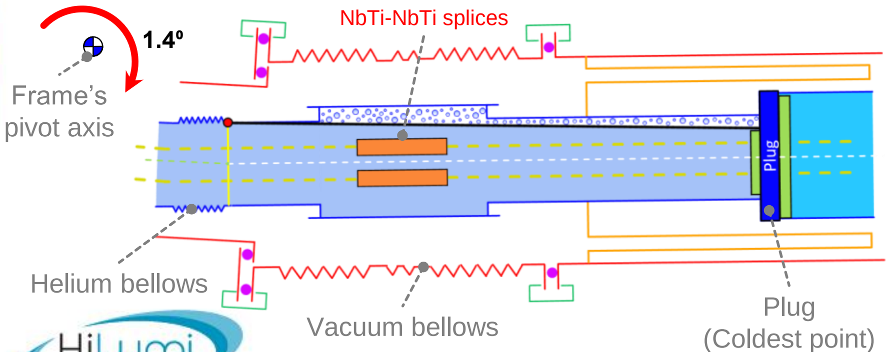
**Requirement : gas evacuation towards DSHM**

**Approach (same as for DFX) :**

- Cryostat rotated around frame's pivot axis ⊕
- Rotation of 1.4º @ all the installation's locations
  - Same installation procedure @ all installation's locations
- Looking from transport area towards DFM
  - Clockwise rotation @ locations R1 & R5
  - Counterclockwise rotation @ locations L1 & L5
- Resulting slope wrt horizontal reference
  - 0.7º positive slope @ locations R1 & L5
  - 2.1º positive slope @ locations L1 & R5
- Relative inclination absorbed by helium\vacuum bellows



# Design compliance with PED

- **Identification of PED Category → II**
  - Calculation report in progress
- **Applicable standard → EN 13445-3**
- **Definition of P-T configurations**
  - Derivation of load case scenarios
- **Identifications of design checks according to EN 13445-3**
  - Thermo-mechanical cycles < 500 (threshold) → not fatigue assessment
  - Pre-qualification of non-standard pressure-retaining welds – Annex C
  - Verification of structural stability (I-DC) – Annex B
- **Thermo-structural analyses through FEM**
  - Methods, safety factors & acceptance criteria according to EN 13445-3
  - Application of Finite Element Sub-modeling Technique
    - Global model for thermal, buckling & displacement field
    - Sub-models for stress distribution at welded connections

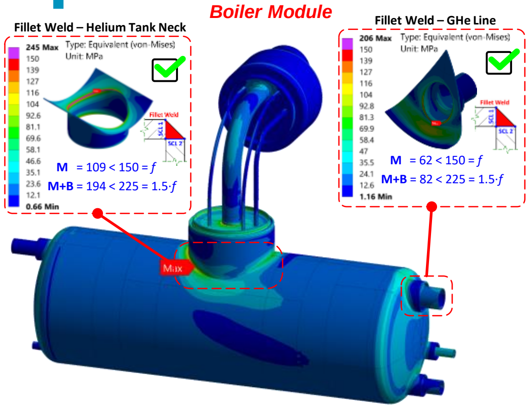
| P-T Configurations |
|---|
| **Transport** |
| **Pumping** |
| *Pumping insulation vacuum SC Link* |
| *Pumping insulation vacuum DFH* |
| **Cryogenic circuit purging** |
| *Purge of cryogenic circuit without vacuum* |
| *Purge of cryogenic circuit with DSHM vacuum* |
| *Purge of cryogenic circuit with DFM vacuum* |
| **Pressure test** |
| **Thermal cycle** |
| *Nominal* |
| *DESIGN* |
| *DFM Cool down* |
| *DFM warm up* |
| **Non nominal events** |
| *Vacuum break DSHM* |
| *Vacuum break DFM* |
| Helium break DFM |

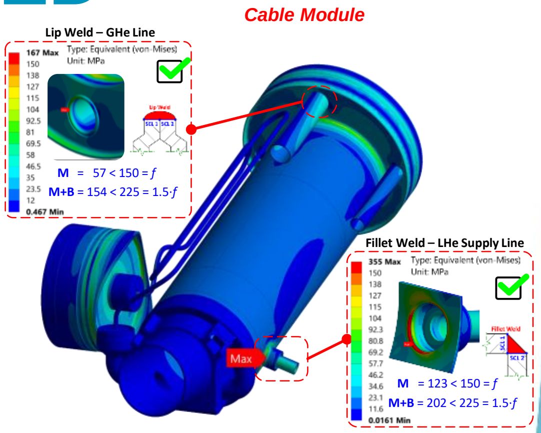
# Design compliance with PED

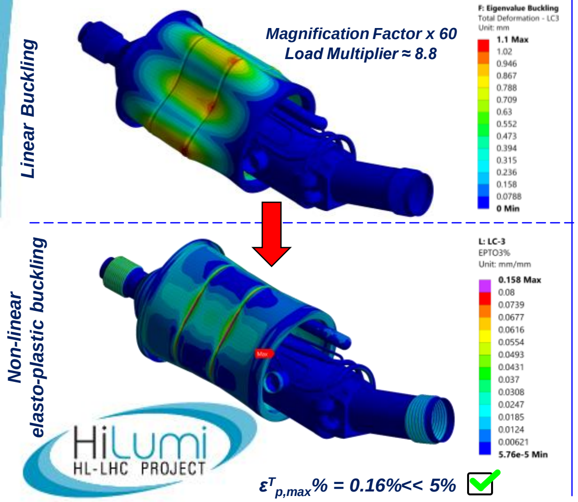
## Stress linearization – EN 13445-3 – Annex C

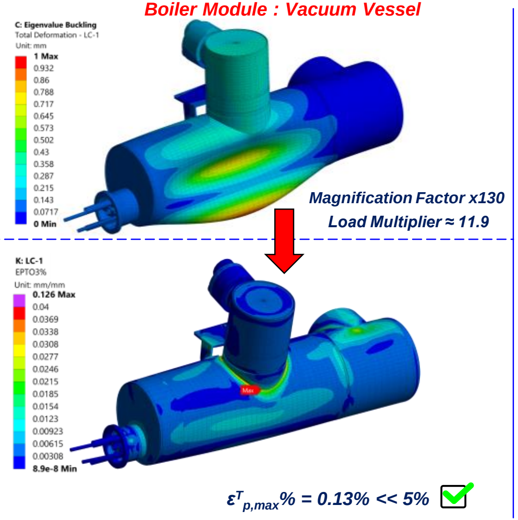
1. Sub-models @ welded connections
2. Identification of weld's critical point
3. Stress linearization & decomposition
4. Verification of prescribed material stress limits

➔ **All pressure-retaining welds verified** ✓




## Instability design check - EN 13445-3 – Annex B

1. Determination of linear buckling modes
2. Mesh pre-deformation according to buckling modes
3. Assessment of non-linear elastoplastic buckling
4. Verification of prescribed material strain limit

➔ **Instability verified for all loading scenarios** ✓

# Conclusions

- Functional and technical requirements have been studied and associated technical solutions were developed in the detailed design
- The design principle is similar to the one of the Demonstrator DFX of Demo2
- 3D detailed model is ready to start producing manufacturing drawings
- Structural calculations required by the PED are completed, report in progress
- The detailed design of the supporting frame needs to be finalized and adapted to the four locations

***Thank you for your attention***