# WP9: Heat Load Review - D2 Heat Loads

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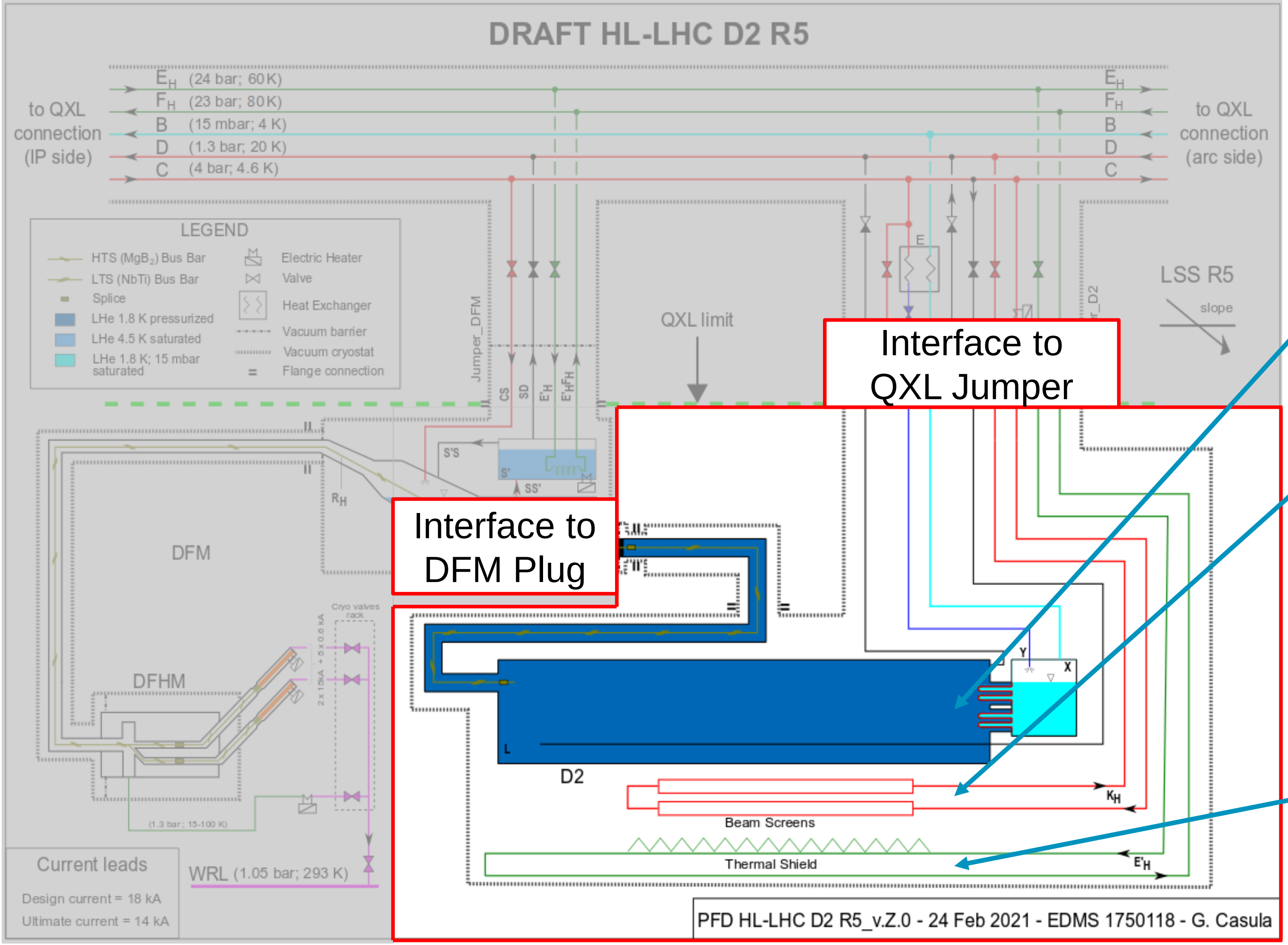
Indico 1019569
EDMS 2563603

CERN - 27/04/2021

# D2 Magnet Configuration



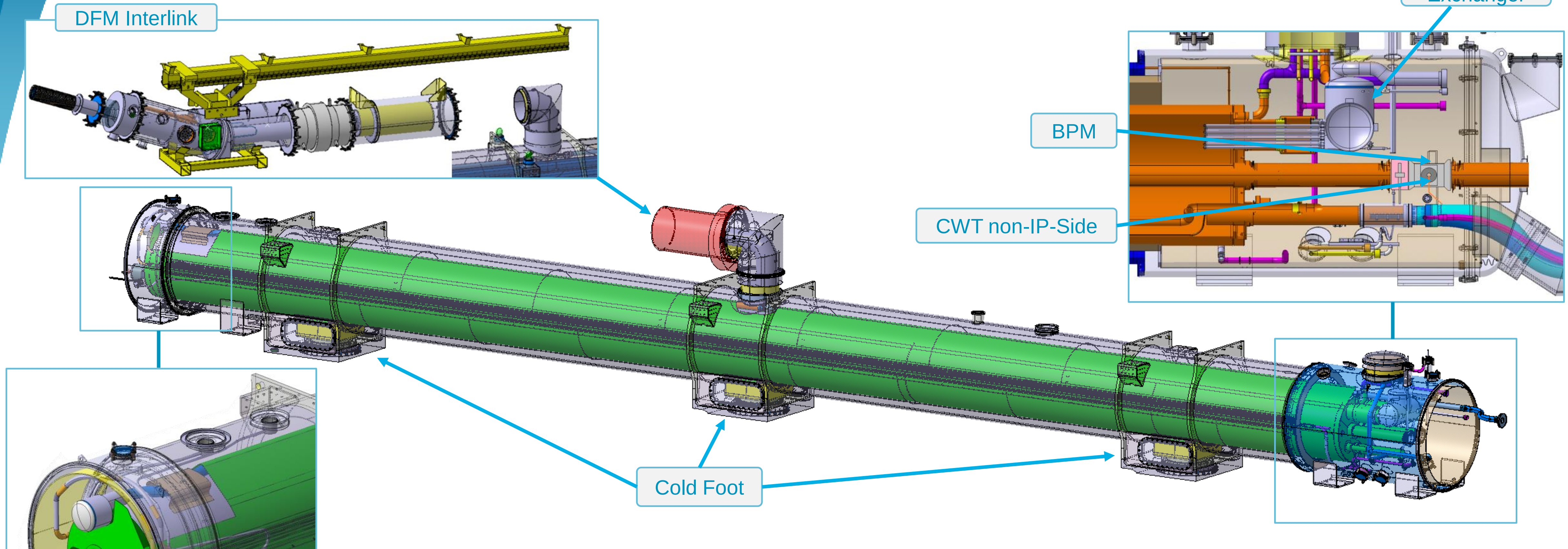

## Cooling During Operation

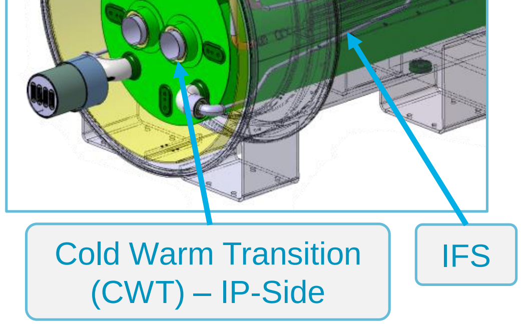
**Coldmass and HX:**
- 1.9 K

**Beam Screen:**
- 4.5 K in / 20 K out
- Calculation:
  - IP side 20 K
  - Non-IP side 4.5 K
  - Radiation at 20 K

**Thermal Shield:**
- 60 K in / 80 K out
- Calculation at 70 K

# Sources of Static Heat Loads




- Previous static heat load estimate by Marco Spitoni (EDMS 1610730, 05/2020) Compiled by scaling from LHC or Inner HL-LHC Triplets.
- New study to find most recent and accurate reference, then verify with hand calculation (Reference CAD model for estimations - ST1371245/ST1237123).

# Static Heat Loads to 1.9 K

| Source | | | Raw Heat Load (W) | Uncertainty Margin | Raw x Margin (W) | Comment |
|---|---|---|---|---|---|---|
| **Radiation** | From 70 K (Thermal Shield, CWT, HX, Interlink, Pipes and IFS)<br>From 20 K (Beam Screen) | | 4.31 | 1.50 | 6.46 | From TS: q = 0.1 W/m2 (EDMS 890590 = 3.91 W).<br>From BS: Radiation between cylinders, assuming BS at 20K. |
| **Conduction** | CWT | IP Side | 0.01 | 1.25 | 0.02 | TE-VSC, J. Harray, D2 CWT - Thermal Study, EDMS 2458882, and email 14/04/2021. |
| | | Non-IP side | 1.61 | 1.50 | 2.10 | |
| | Beam Screen Springs | | 1.26 | 1.50 | 1.89 | Same as LHC support system. 0.05 W/m |
| | Supports | Cold Foot | 3.00 | 1.25 | 3.75 | TE-MSC, New value provided by Delio. |
| | | Interlink | 0.05 | 2.00 | 0.11 | Design TBC - Value based on preliminary concept |
| | | Jumper QRL | 0.02 | 2.00 | 0.04 | Design TBC - Value based on preliminary concept |
| | HX | Level Sensor Piping | 0.06 | 2.00 | 0.11 | Design TBC - Value based on preliminary concept |
| | | TT Cable | 0.05 | 2.00 | 0.10 | Design TBC - Value based on preliminary concept |
| | | LT Cable | 0.48 | 2.00 | 0.96 | Copper X-sect area provided by J. Casas-Cubillos, based on preliminary concept. |
| | | HX - LT Powering | 0.50 | 1.25 | 0.63 | Value provided by J. Casas-Cubillos |
| | IFS | | 1.56 | 1.50 | 2.34 | Same as triplet, EDMS 1690235 ( LHC value of 0.53 W x 1.5 factor = 0.78 W, x2 so 1.56 W). |
| | Interlink Vacuum Barrier | | 1.27 | 2.00 | 2.53 | Design TBC - Value based on preliminary concept |
| | Lambda Plate | | 6.00 | 1.25 | 7.50 | Value provided by Y. Leclerq |
| **Total** | | | **19.97** | **1.43** | **28.54** | **Raw Heat Load = 1.6 W/m**<br>**Increased from 0.6 W/m (EDMS 1610730, 05/2020)** |

# Static Heat Loads to 20 K

| Source | | | Raw Heat Load (W) | Uncertainty Margin | Raw x Margin (W) | Comment |
|---|---|---|---|---|---|---|
| **Conduction** | CWT | IP Side | 16.42 | 1.50 | 24.63 | TE-VSC, J. Harray, D2 CWT - Thermal Study, EDMS 2458882, and email 14/04/2021. |
| | | Non-IP side | 5.24 | 1.50 | 7.86 | |
| | BPM Cables | | 0.93 | 1.50 | 1.39 | Same as triplet, EDMS 1690235 (0.464 per BPM) |
| **Total** | | | **22.59** | **1.50** | **33.88** | **Raw Heat Load = 1.7 W/m**<br>**Increased from 0 W/m (EDMS 1610730, 05/2020)** |

# Static Heat Loads to 70 K

| Source | | | Raw Heat Load (W) | Uncertainty Margin | Raw x Margin (W) | Comment |
|---|---|---|---|---|---|---|
| **Radiation** | From 300 K | | 59.87 | 1.25 | 74.84 | EDMS 890590: Equivalent to q = 1.3 W/m2 |
| **Conduction** | CWT | IP Side | 1.50 | 1.50 | 2.25 | TE-VSC, J. Harray, D2 CWT - Thermal Study, EDMS 2458882, and email 14/04/2021. |
| | | Non-IP side | 9.36 | 1.50 | 14.04 | |
| | Supports | Cold Foot | 40.50 | 1.25 | 50.63 | TE-MSC, New value provided by Delio. |
| | | QRL Jumper Spacer | 1.00 | 2.00 | 2.00 | Design TBC - Value based on preliminary concept |
| | | DFM Jumper Spacer | 1.00 | 2.00 | 2.00 | Design TBC - Value based on preliminary concept |
| | HX | Level Sensor Piping | 0.50 | 2.00 | 1.00 | Design TBC - Value based on preliminary concept |
| | | TT Cable | 0.09 | 2.00 | 0.19 | Design TBC - Value based on preliminary concept |
| | IFS | | 5.00 | 2.00 | 10.00 | Design TBC - Value based on preliminary concept |
| | Interlink Vacuum Barrier | | 12.59 | 2.00 | 25.19 | Design TBC - Value based on preliminary concept |
| | BPM Cables | | 2.80 | 1.50 | 4.20 | Same as triplet, EDMS 1690235 ( 1.4 W per BPM). |
| **Total** | | | **134.22** | **1.39** | **186.33** | **Raw Heat Load = 9.8 W/m**<br>**No change from (EDMS 1610730, 05/2020)** |

# Nominal Dynamic Heat Loads

| Source | Design Value (W) | Temperature Level | Reference |
|---|---|---|---|
| Resistive | 1 | 1.9 K (Coldmass) | Nominal Current = 12.33 kA, Ultimate Current = 13.34 kA<br>Splice resistance = 1 nohm per splice<br>Number of splices: 600 A Circuit = 16 / 13 kA Circuit = 5 |
| Beam Induced | 49.9 | 20 K (Beam Screen) | CERN-ACC-2016-0112, G. Iadarola, E. Metral, G. Rumolo, *Beam induced heat loads on the beam-screens of the twin-bore magnets in the IRs of the HL-LHC, September 2016.* |
| Collision | 20 | 1.9 K (Coldmass) | 78th HL-LHC TCC Meeting , M. Sabaté-Gilarte, F. Cerutti, IT orbit corrector preferable orientation<br>and TAXN aperture, July 2019. |

# Conclusion: Combined Heat Loads on D2

<table>
<tr><th rowspan="2">Temperature Level</th><th rowspan="2" colspan="2">Source</th><th colspan="3">Total Heat Load (W)</th><th rowspan="2">Installed Local Capacity</th></tr>
<tr><th colspan="2">Nominal</th><th>With Overcapacity</th></tr>
<tr><td rowspan="3">1.9 K</td><td colspan="2">Static</td><td>28.5</td><td rowspan="3">49.5</td><td rowspan="3">74.25</td><td rowspan="3">Cooling at 1.9 K designed for 70 W:<br>⇨ He-II HX – Verified OK for 80 W.<br>⇨ D2 Coldmass – He-II X-sect at design limit !<br>⇨ Significant increase in static heat load, main contributors:<br>– Lambda plate 27%<br>– Radiation 23%<br>– Cold foot 12%</td></tr>
<tr><td rowspan="2">Dynamic</td><td>Collision</td><td>20</td></tr>
<tr><td>Resistive</td><td>1</td></tr>
<tr><td rowspan="2">20 K</td><td colspan="2">Static</td><td>34</td><td rowspan="2">82</td><td rowspan="2">123</td><td rowspan="2">To be met by LHe supply - OK</td></tr>
<tr><td>Dynamic</td><td>Beam Induced</td><td>50</td></tr>
<tr><td>70 K</td><td colspan="2">Static</td><td colspan="2">187</td><td>280</td><td>To be met by GHe supply - OK</td></tr>
</table>

# Additional Slide

# D2 Cooling limitation at 1.9 K

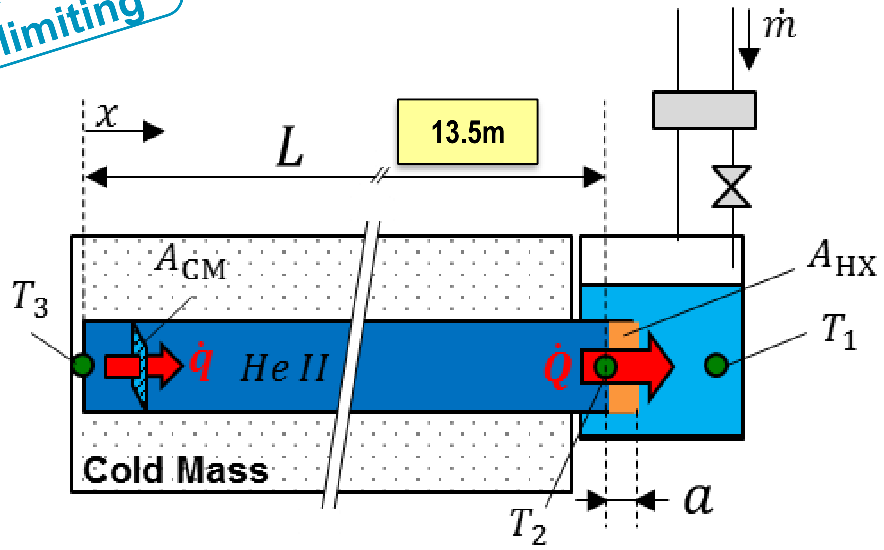
Two limitations to 1.9 K cooling capacity

## Coldmass He-II Cross-section

To ensure He-II conditions over the 13.5 m length of the D2 Coldmass:

- ⇨ Min. 207 cm² He-II cross section to transfer heat.

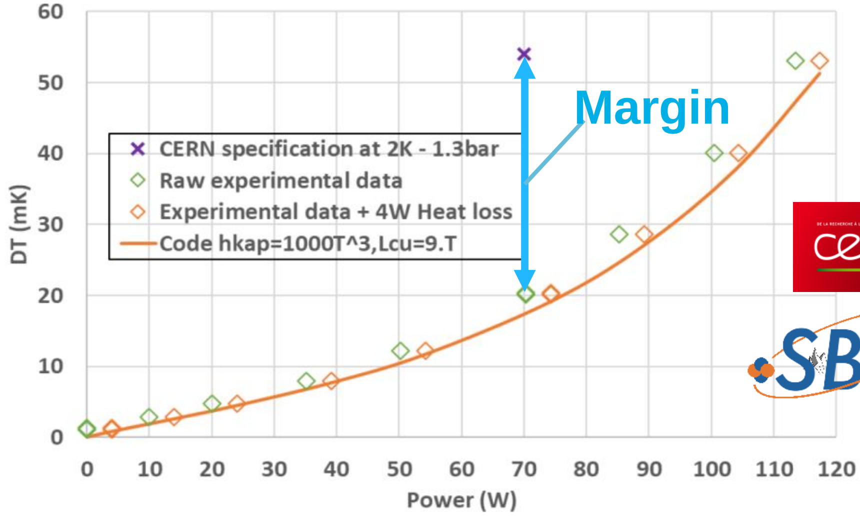
He-II Cross-section is most limiting




## He-II Heat Exchanger

HX Testing - Prototype Performance Margin:

- ⇨ Required to account for variation in Kapitza resistance of copper.
- ⇨ Margin will allow some increase in cooling capacity, so 74.25 W is acceptable.

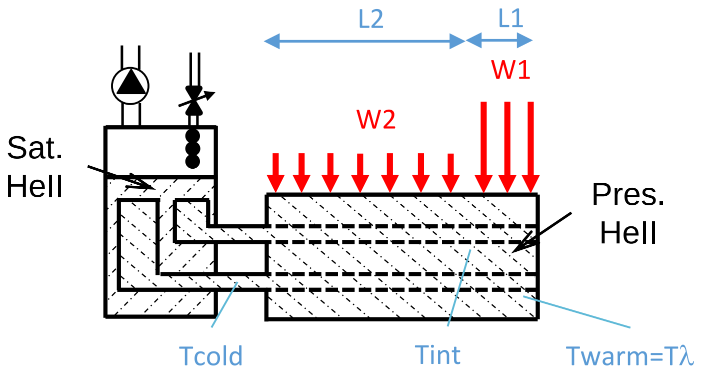



*Comparison between model and experimental results performed at 2K and 1.3bar*

# 2. CERN Specifications (*inputs SC*)

**Maximal magnet temperature and heat load distribution in D2 Cold Mass (CM)**

- Maximal temperature in D2 Cold Mass **< Tλ** in all operating conditions
- D2 CM length = **13.5 m** and internal cross section for pressurized HeII = **0,021 m²**
- Heat loads distributed with **80%** in the first 1.5 m and **20%** in the remaining 12 m




**D2-HX Cooling capacity:**

- Cooling capacity for "nominal" case = 50 W
- Design value for "ultimate" case = 70 W

**D2-HX Pressure range for pressurized HeII:**

- Pressure in "nominal" case = 1.3 bar
- Pressure in "ultimate" case = 4 bar with Line C leaky valves
- *Mechanical Design pressure = 20 bar with Quench Valve set at 20 bar*

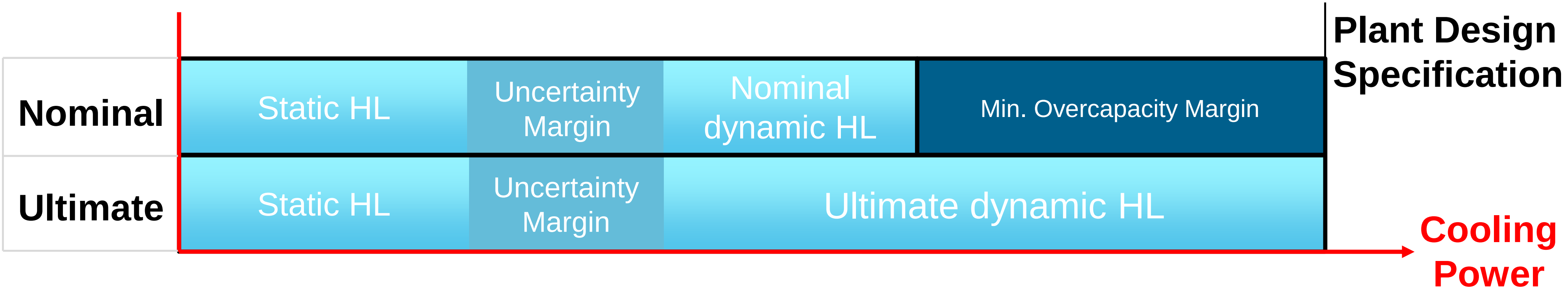
**D2-HX Pressure for cold source (and corresponding temperature)**

- Pressure in "nominal" case = 16 mbar (1.8 K)
- Pressure in "ultimate" case = 30 mbar (2.0 K) with CC filter clogging
- *Mechanical Design pressure = 4 bar with line C safety valve set at 4 bar*

**=> For HX-D2 design, only 2 out of the 3 "ultimate" conditions shall be fulfilled and the 3rd value evaluated.**

Excerpt from D2 HX Concept study. Courtesy of:

# Application of Margin to Heat Load




## Overcapacity Margin:

- ⇨ Factor of 1.5 applied to Nominal Requirement.
- ⇨ Provides for future increases in Luminosity and power.

## Uncertainty Margin :

- ⇨ Applied to reference values of static heat load.
- ⇨ Dependent on current design status.

| Uncertainty Margin | Design status |
|---|---|
| 1.25 | Final design with measured heat load. |
| 1.5 | Detailed design. |
| 2 | Preliminary Concept. |