



8th HL-LHC collaboration meeting, 15 to 18 October 2018

D2 magnet cooling

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With contributions from WP3 : A. Foussat, A. Vande Craen, CERN (TE-MS)

Heat exchanger development* in collaboration with CEA-SBT: F. Millet , B. Rousset, F. Bancel, P. Nivelon, CEA INAC-SBT Grenoble, France

Special acknowledgement to D. Berkowitz

HL-LHC / Work Package 9

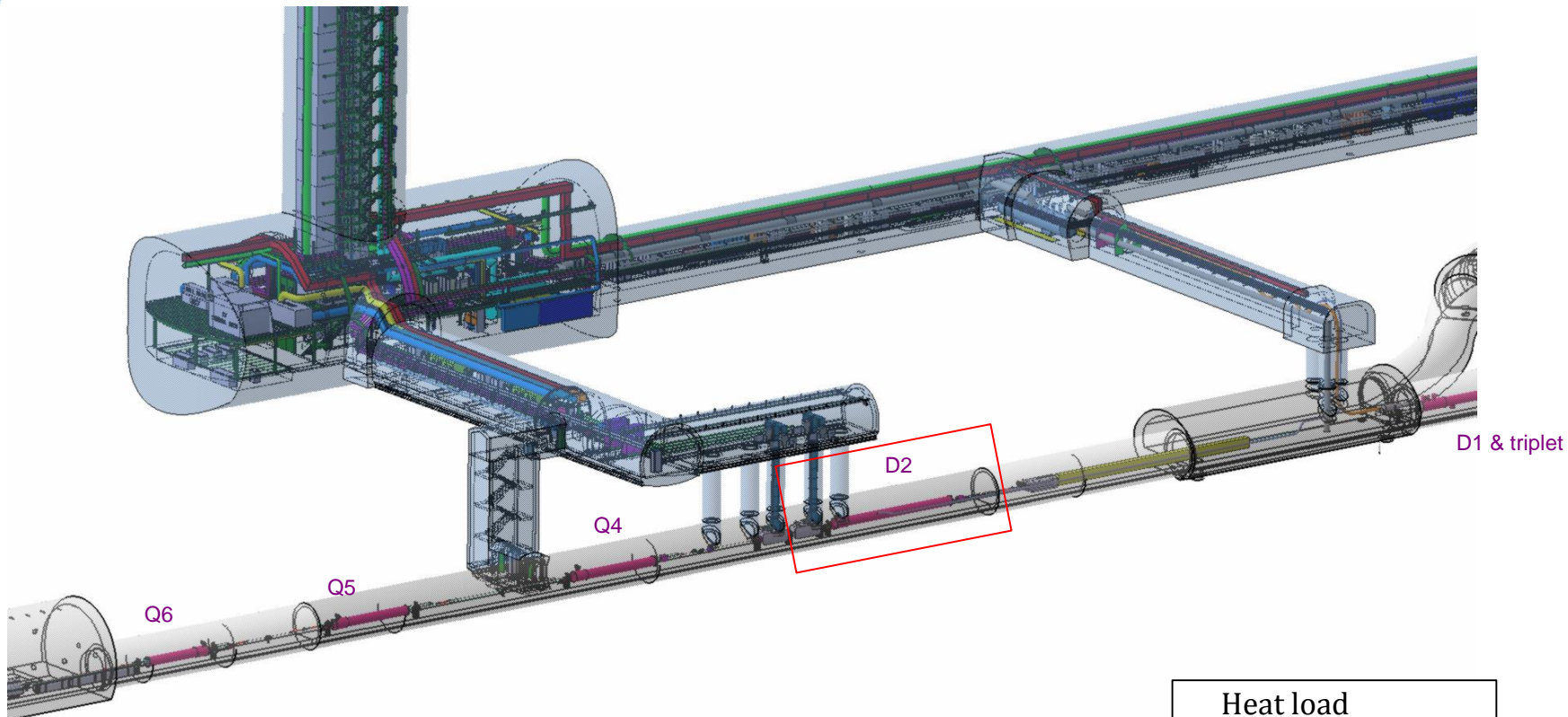
CERN, 17 October 2018, INDICO 742082

* The development of the heat exchanger system is performed in the Framework of the agreement KN3573/GEN between CERN and CEA and Addendum n°2 KE3800

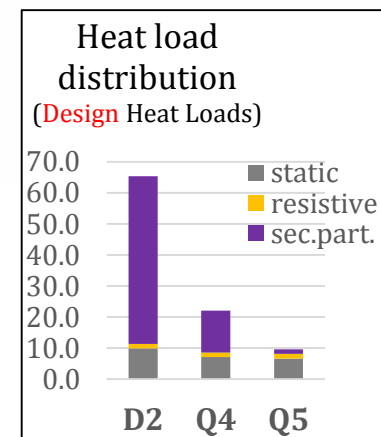
Outline

- The D2 magnet (from cryogenic point of view), its specificities and its heat loads
- Cooling configuration and flow diagram
- Design and validation of the heat exchanger
- Integration into the D2
- Status, next steps and conclusions

Position of D2 magnet

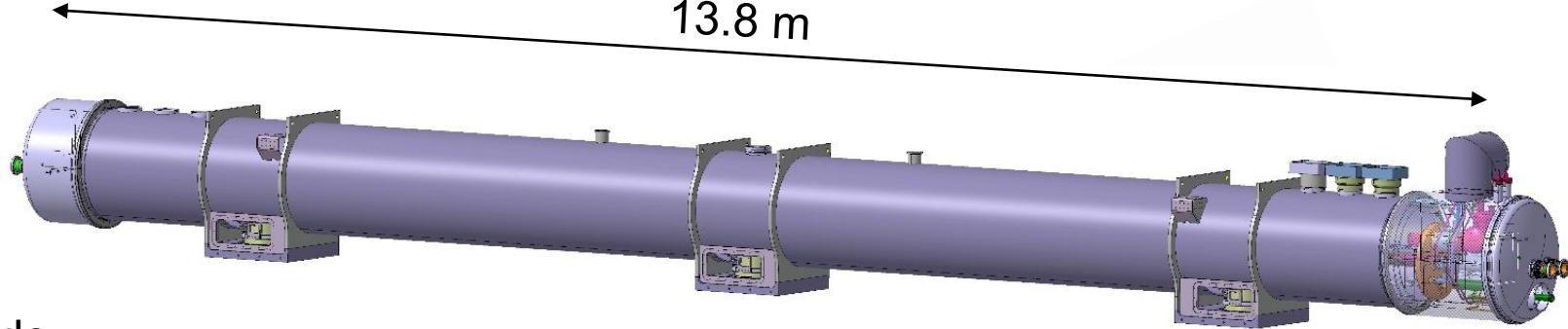


- D2, Q5 and Q4 are at 1.9 K in the baseline. This is being re-evaluated (see. P. Fessia presentation) with only D2 staying at 1.9 K.
- The D2 has the highest heat load but the cooling scheme & technology could be used also for Q5 & Q4). Presentation focuses on D2.
- cooled from new IP cryoplant
- powered from local cavern through SC link

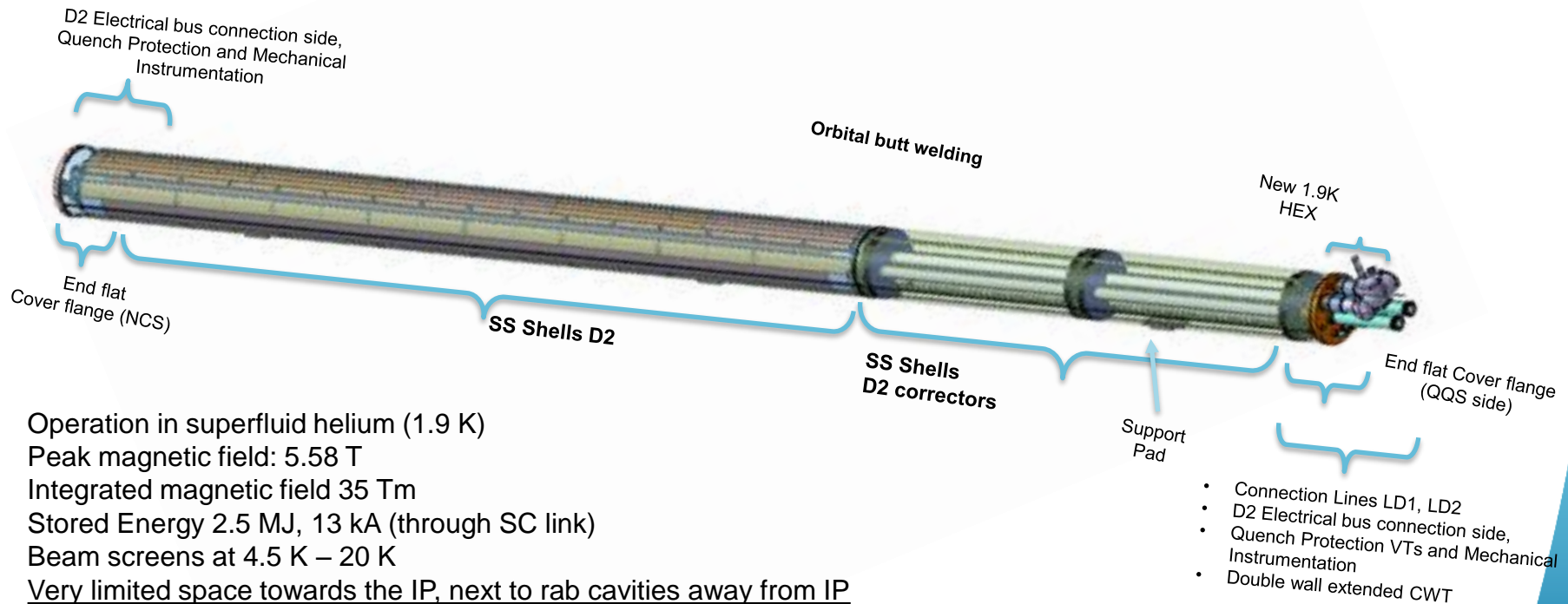


The D2 magnet

13.8 m



IP side



Operation in superfluid helium (1.9 K)

Peak magnetic field: 5.58 T

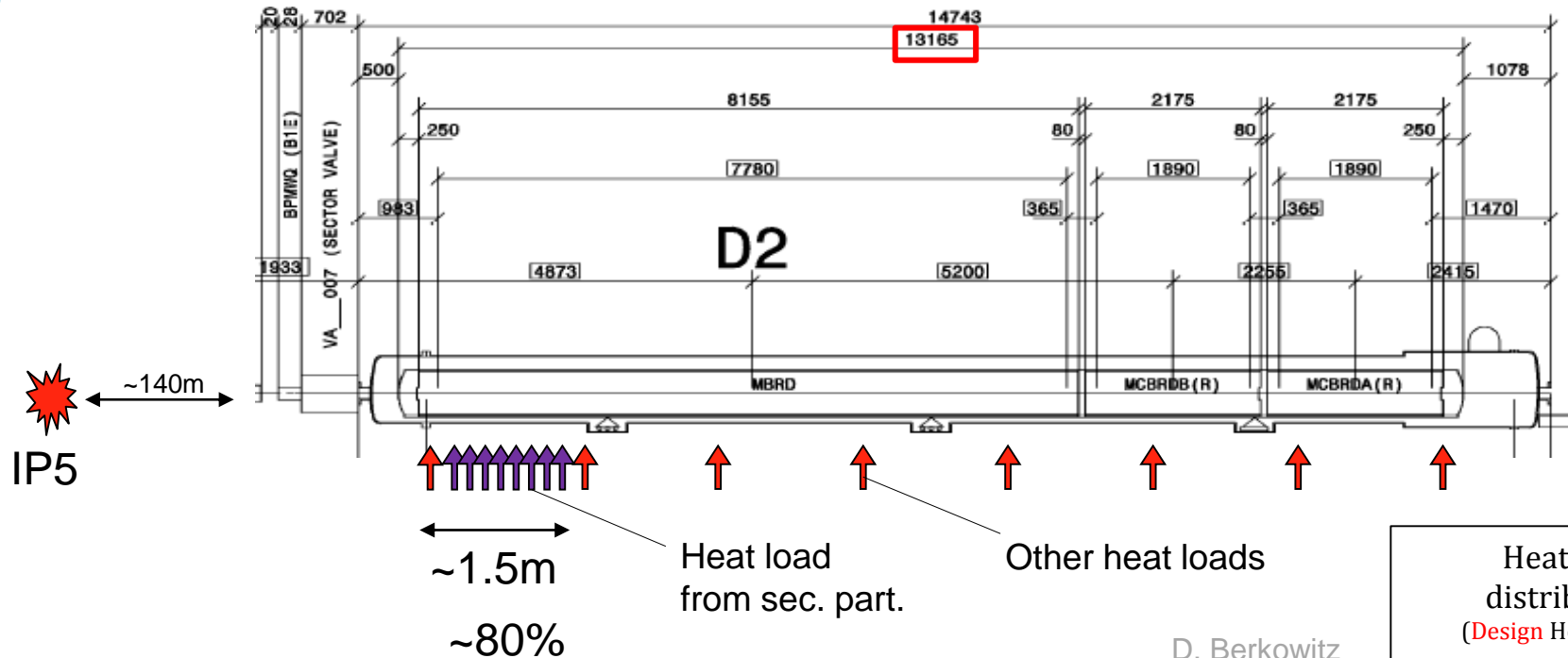
Integrated magnetic field 35 Tm

Stored Energy 2.5 MJ, 13 kA (through SC link)

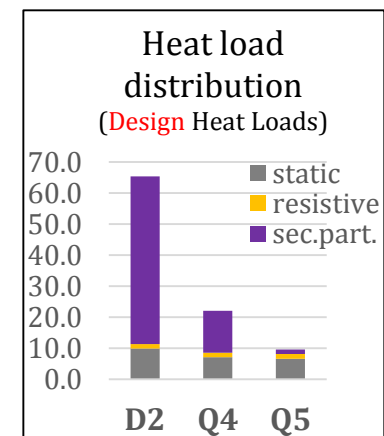
Beam screens at 4.5 K – 20 K

Very limited space towards the IP, next to rabs cavities away from IP

Profile of heat power deposition on the cold mass at 1.8 K



Design heat load to the cold mass: 70 W
Mostly on the IP side

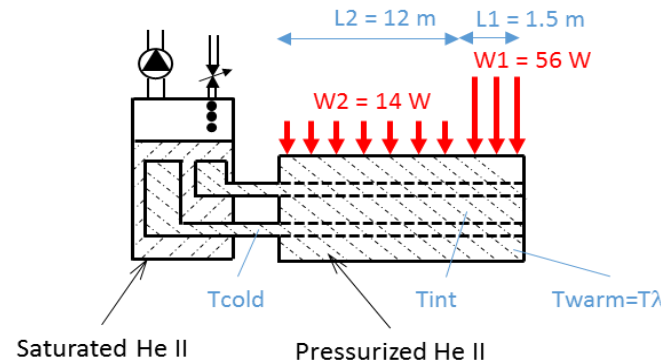


Configurations to extract the heat

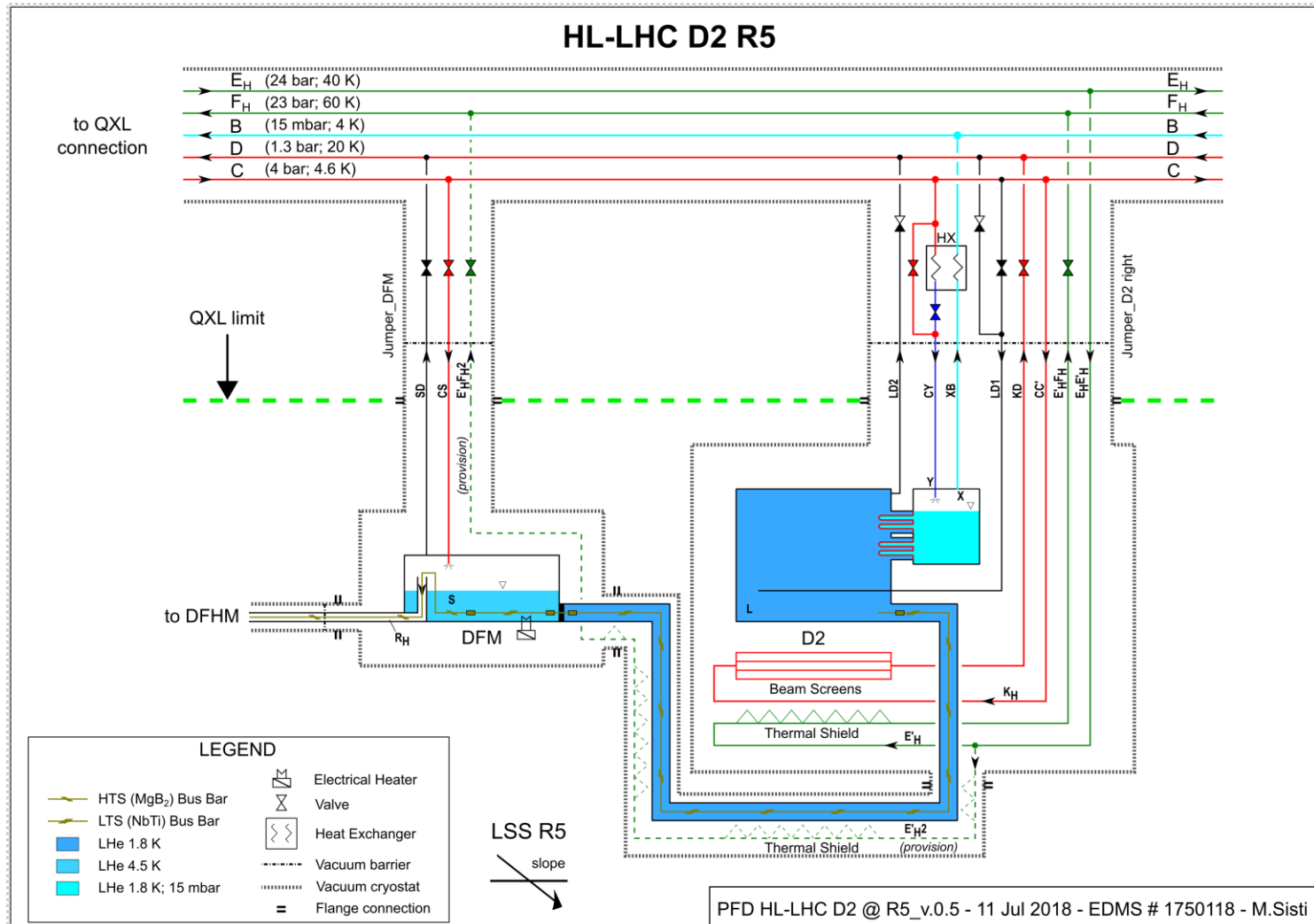
Operation in pressurized (1.3 bar) superfluid helium: pumping on saturated helium batch and heat exchange through copper Heat Exchanger.

Two possibilities have been studied:

- Distributed heat exchanger (bayonet) (like triplets).
 - + no need to carry heat on long distance for pressurized helium
 - + could require smaller cross section in the cold mass
 - Could be difficult to control for such a short HX in particular for fast varying heat loads
 - requires phase separator on low point. Space very limited on IP sides.
 - 4 different configuration needed for the cryostat
- Localized heat extraction (at non-IP side) + conduction along magnet: selected one
 - + cryogenic configuration does not depend on slope (4 times the same)
 - + easier to regulate (only level)
 - Requires larger cross section for conduction
 - Heat exchanger needs a large area while being compact to fit in the cryostat.



Process Flow Diagram for D2 magnets for the HL-LHC



Cold mass, heat screen, beam screen and SC link cooling & protection in case of quench

Sizing the heat exchange key parameters

Parameters

He II bath:

- Cold-mass length L_{CM} [m]
- Bath length L [m]
- Free cross section A_{CM} [cm²]
- Heat flux \dot{q} [W/cm²]

Heat exchanger:

- Wall thickness a [mm]
- Heat exchange area A_{HX} [m²]
- Heat power \dot{Q} [W]

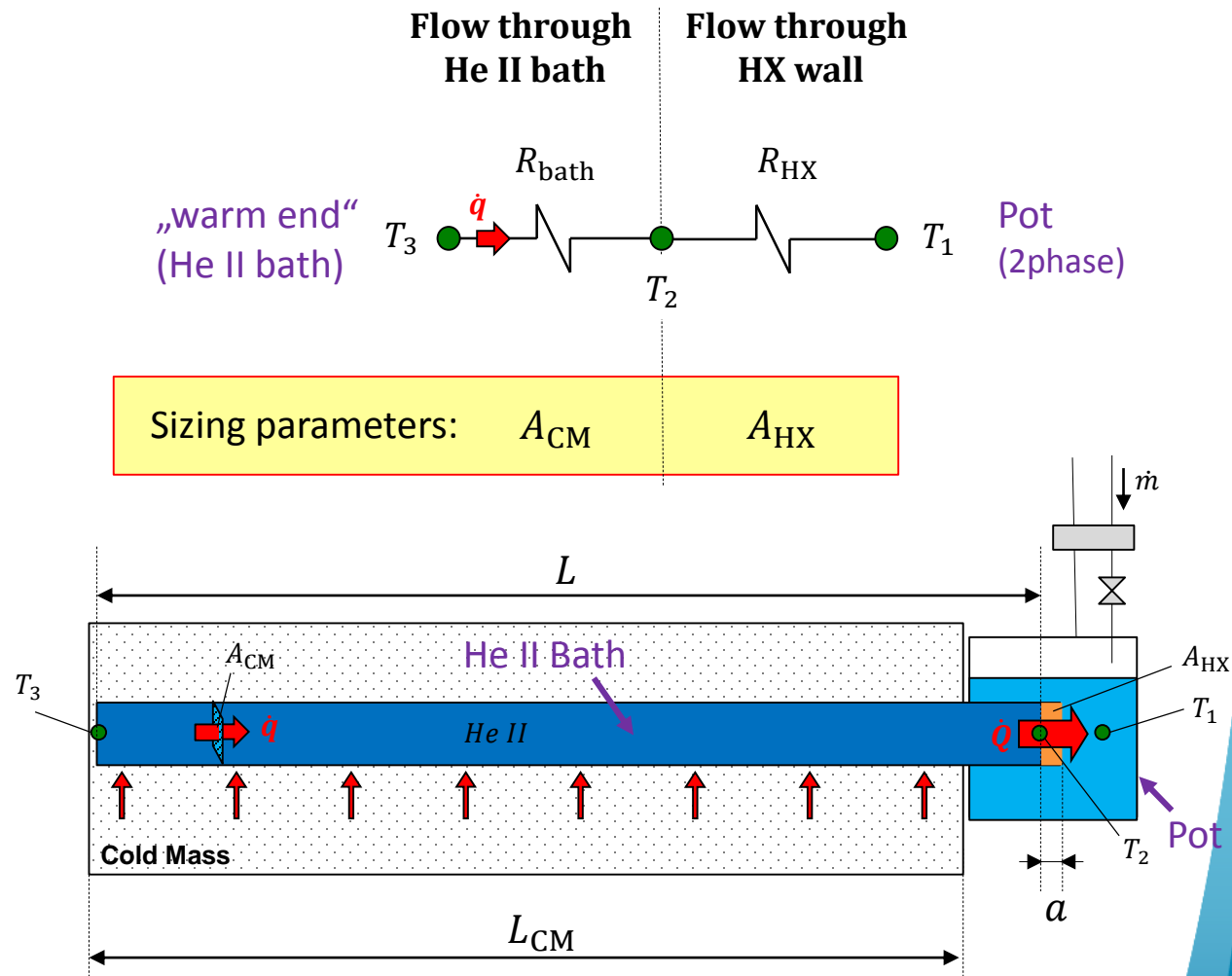
Assumptions for D2:

- $Q = 70 \text{ W@1.8K}$
- $L = 13.5 \text{ m}$
- Subcooled HeII-bath at 1.3bar
- $T_1 = 2 \text{ K}$
- HX made of Cu (RRR50)
- $a = 3 \text{ mm}$

$A_{CM} \geq 207 \text{ cm}^2$ **ok taken into account in the magnet design (see A. Foussat presentation)**

$A_{HX} \geq 1 \text{ m}^2$

(see EDMS 1792675 for details)



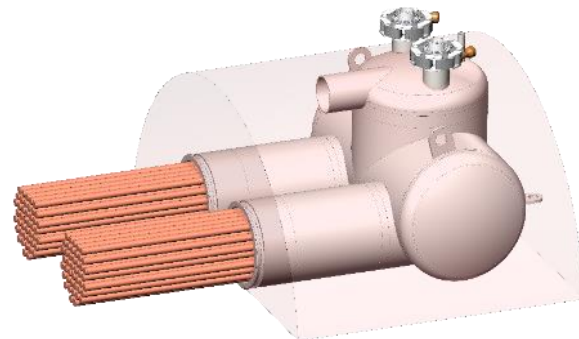
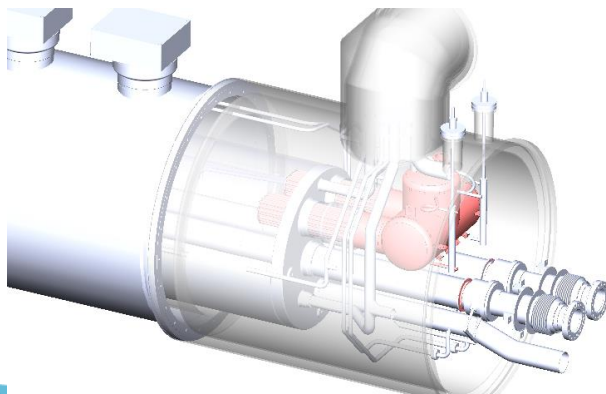
Development of the heat exchanger

The cooling system (saturated bath + heat exchanger) characteristics were defined in the first half of 2017. (We use in fact heat exchanger for naming the whole system)

After the first estimations, a collaboration agreement was established in summer 2017 with CEA INAC-SBT institute in Grenoble, France with the aim to:

- On the basis of CERN study, perform a detailed study of possible practical heat exchangers taking into account the required performance and the design constraints.
- Select a configuration and perform a study on its performance
- Produce a fully functional prototype compatible with the integration into a D2 prototype
- Validate the prototype heat exchanger by performing a full scale cryogenic test on the unique superfluid helium testing facilities available at CEA-SBT.

Chosen configuration: multiple (2x 52) cylindrical HX channels protruding into the D2 cold mass (presented at ICEC-ICM 2018 conference, Oxford)

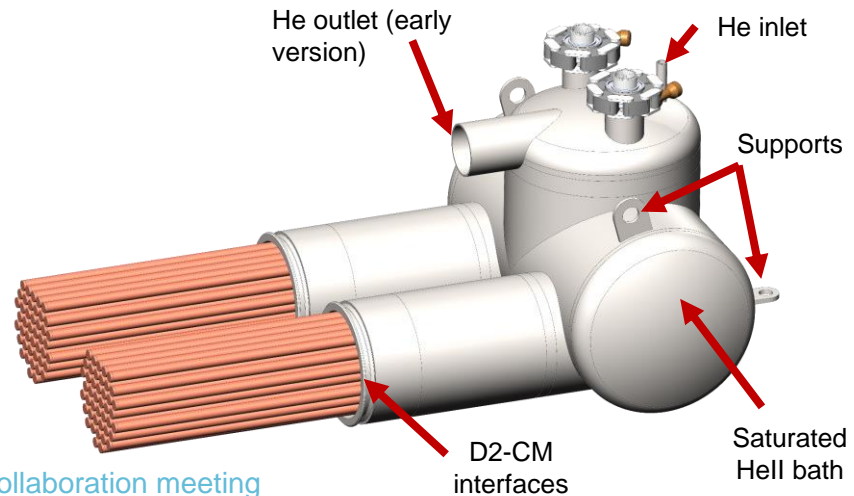
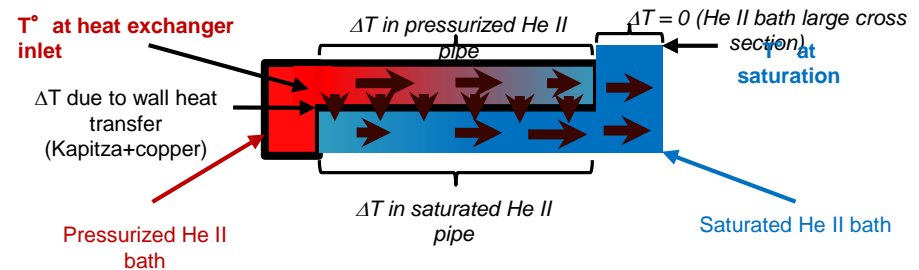
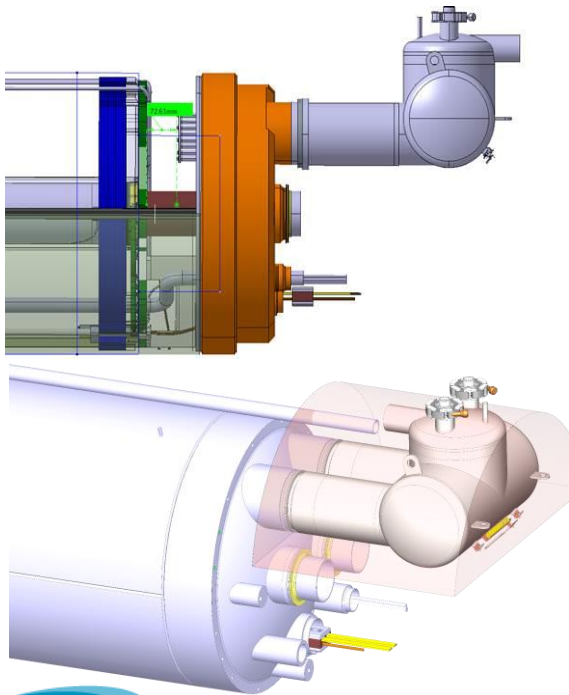


Characteristics of the heat exchanger

Main design constraints:

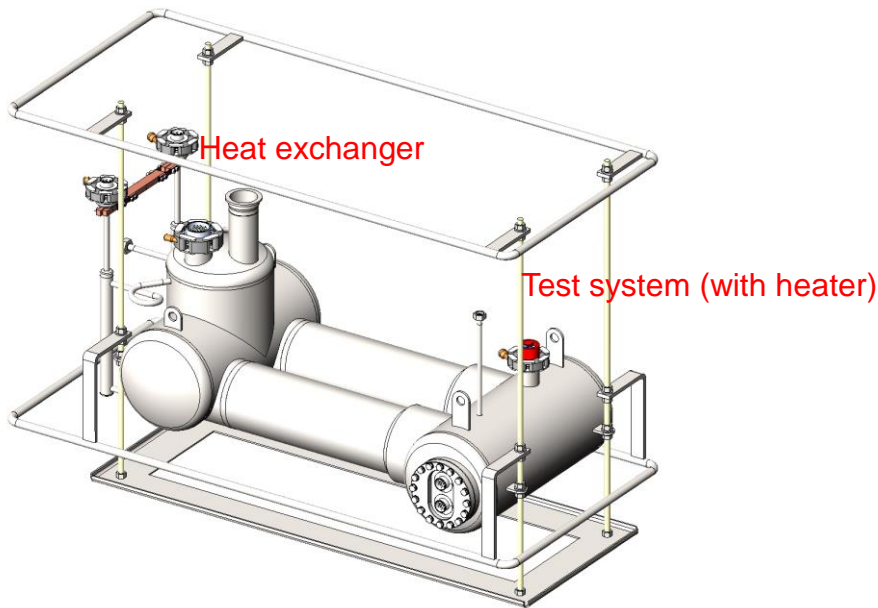
- Extraction of 70 W, T of pressurized He max 2.044 K, T of saturated He 2 K
- Fit at the end of the D2 cold mass (2 holes diam. 135 mm) and in the volume above the beam pipes
- One configuration for all 4 D2 magnets, robust design based on conservative values for Kapitza conductivity (600.T3 (W/m²/K)), Cu RRR (50), and known design principles.
- Proposal: 2x 52 (diam 10mm) Cu tubes in two set of diameter max. 136 mm, with 129 mm penetration into cold mass.

Calculations involved the optimization of the heat exchangers tubes: number, arrangement, lengths, cross section, etc. (presented at ICEC 2018 Conference)



Validation of the heat exchanger

- A full scale prototype heat exchanger will be tested at CEA-SBT in March 2019. The prototype fulfills all the requirements for a possible final design. Production of the prototype will start in November 2018 (procurement already signed).
- The test will validate the design of the heat exchanger up to ultimate performance
- The prototype will then be conditioned and shipped to CERN for installation in the D2 prototype.



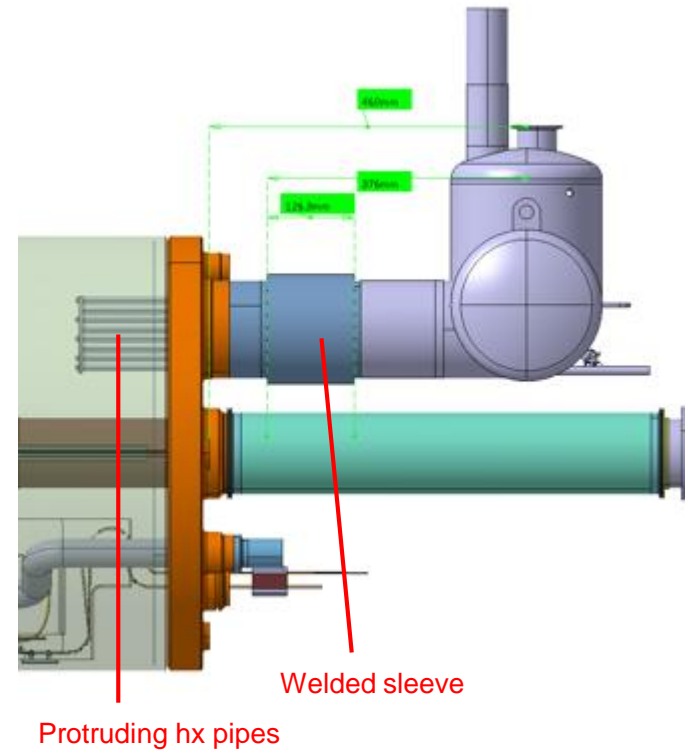
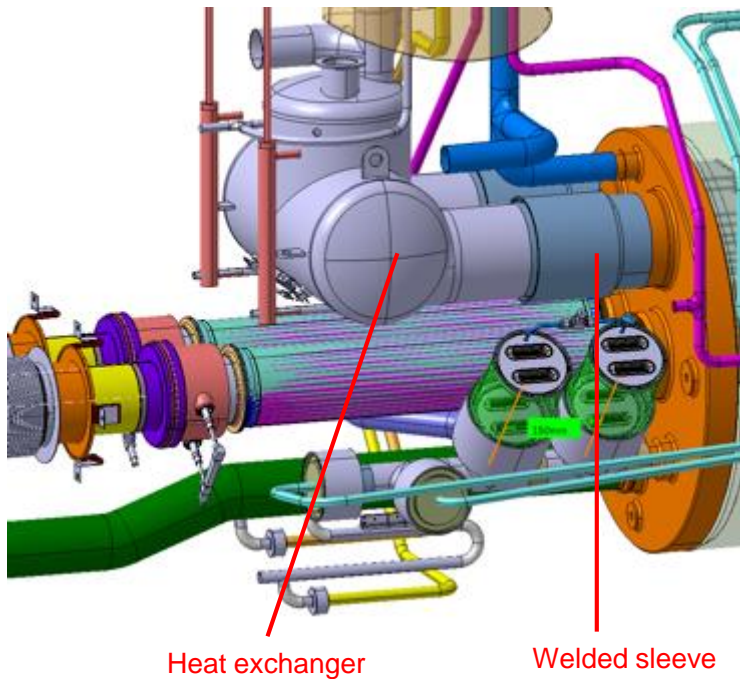
View of the test configuration (courtesy CEA - SBT)



Test station at CEA-SBT (courtesy CEA - SBT)

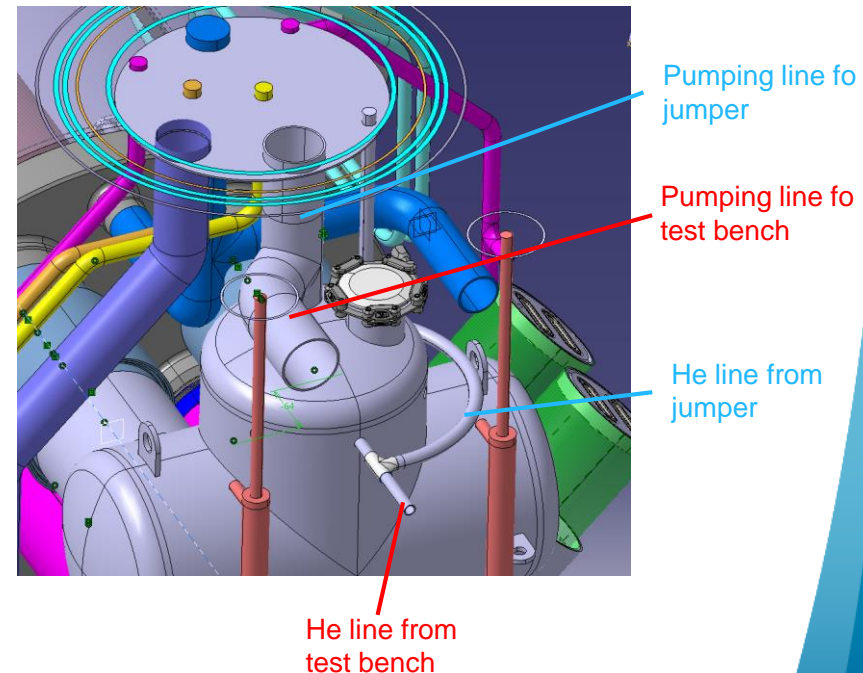
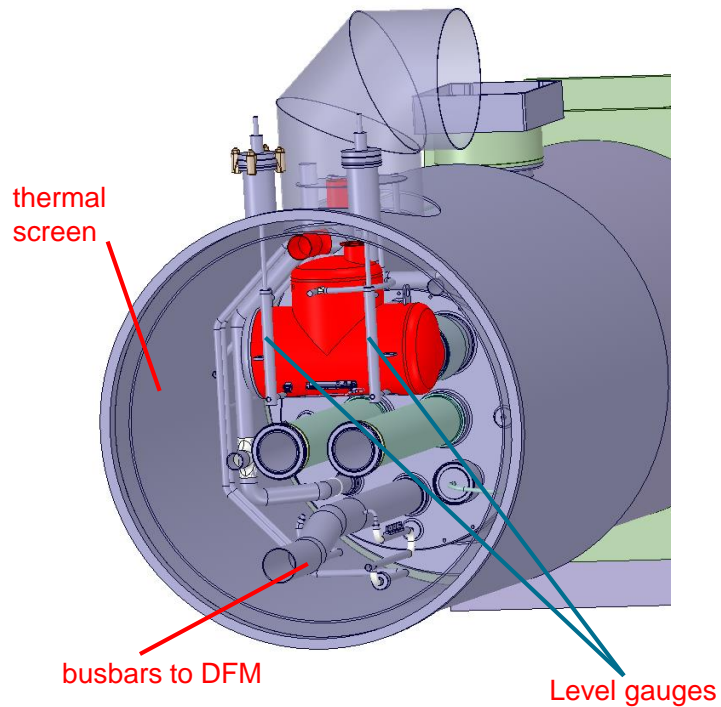
Integration of the heat exchanger into D2 magnet: interface to cold mass

- The interface between the D2 and the heat exchanger has been defined. The interface specifications are being prepared.
- The HX connects to the cold mass with two diam. 136 orifices.
- The heat exchanger Cu tubes protrude into the cold mass by about 129 mm
- The connection will be made with sleeves to compensate for small misalignments.



Integration of the heat exchanger into D2 magnet: cryostat

- The cooling heat exchanger fits in the allocated space
- Interfaces are defined for HL-LHC and for tests in SM18 test bench (closed after tests)
- Cryogenic fluids: pumping line, He supply line
- Instrumentation: exchangeable He level gauges fixed to vacuum tank (with He guard), thermometers



Conclusions (1/2)

- The parameters for cooling the D2 magnet have been established. A cryogenic flow diagram enabling the ultimate operation of the D2 magnet has been defined. The functional cryogenic interfaces have been defined.
- A cooling scheme, with a heat exchanger localized at the side opposite to the IP has been chosen. This provides significant advantages over a bayonet heat exchanger in terms of ease of control and magnet integration. Following an initial study the main cryogenic parameters and required sizes have also been defined.
- A detailed study, performed in collaboration with CEA-SBT in Grenoble, France, has allowed the definition of the detailed design of the heat exchanger. The proposed design fulfills all the functional requirements and fits in the allocated space.

Conclusions (2/2)

- The interfaces between the prototype cooling system and the prototype D2 cold mass and cryostat have been defined.
- A prototype heat exchanger is currently in production and will be tested in March 2019 at CEA-SBT. The prototype will be delivered to CERN for integration into the prototype D2 magnet in summer 2019.
- With limited number of units (4 + 2) for series, the procurement used for the prototype could potentially be used.

Additional slides

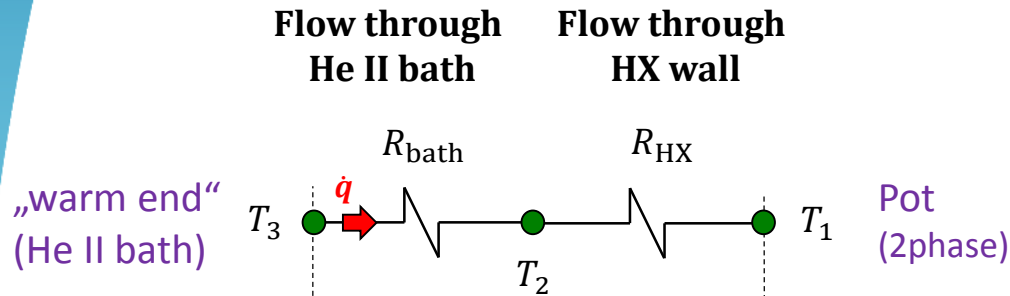
D2 cooling, boundary conditions

- Cooling capacity:
 - The maximum expected capacity for “nominal” is: 50W
 - Considering usual engineering factors, the design value for “ultimate” is defined for 70W
- Pressure range for pressurised Hell:
 - Volume Supplied by line C (4 bar) and protected by quench valve to line D (1.25 bar)
 - Nominal P: 1.3 bar, with a range 1.25-4.0 if leaky valves
- Pressure for cold source (and corresponding temp.)
 - Line B is pumped by cold compressors (CC) at 15mbar
 - In case of clogging of CC inlet filter, operation is envisaged up to 25mbar (1.95K) with an ultimate value at 30mbar (2.0K)

=> For design consideration, only 2 out of the 3 conditions shall be fulfilled.
For completeness, the maximum excursion of the 3rd value could be quoted.

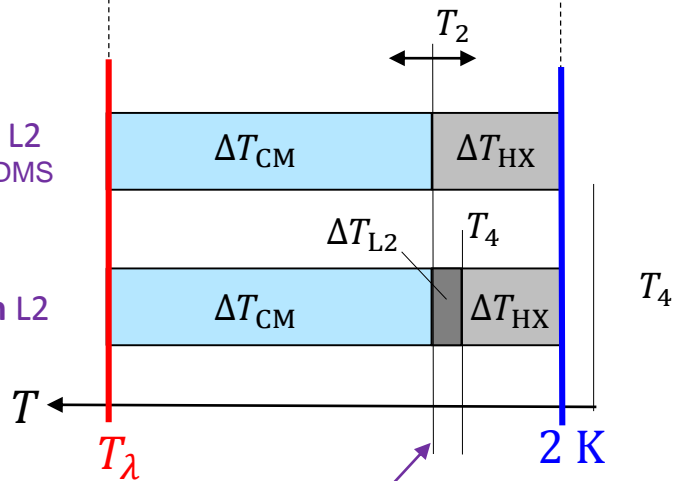
Model Assumptions (boundary conditions)

For more calculation details see presentation on 13APR2017

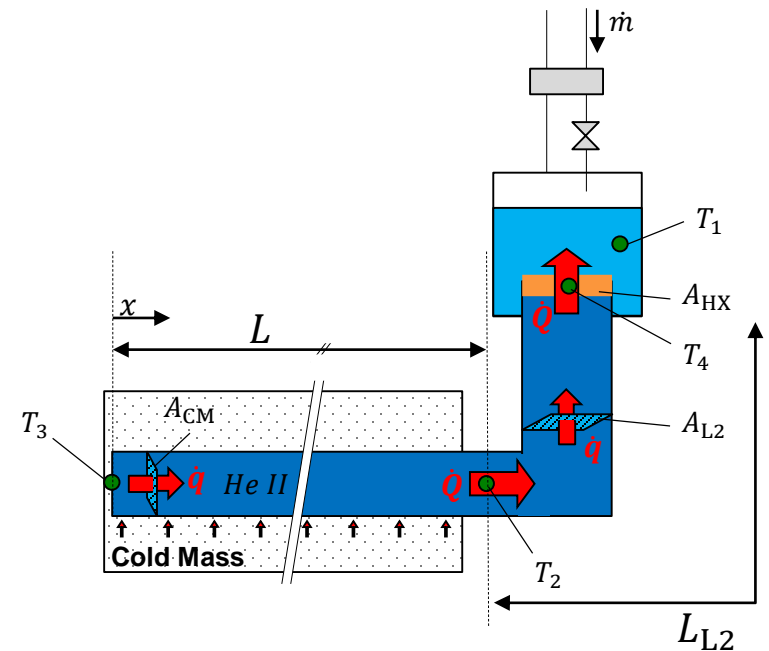


Model w/o L2
(as used in EDMS
[1792675 v1](#))

Model with L2



$T_2 = 2.04$ K for current D2 design ($A_{\text{CM}} = 207$ cm²)



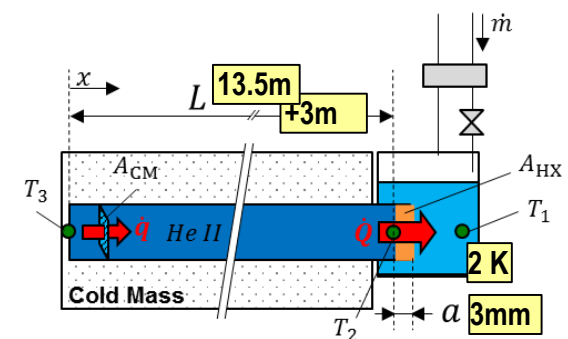
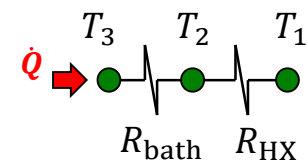
Trade-off

A_{CM} vs A_{HX}

For D2

Assumptions for D2:

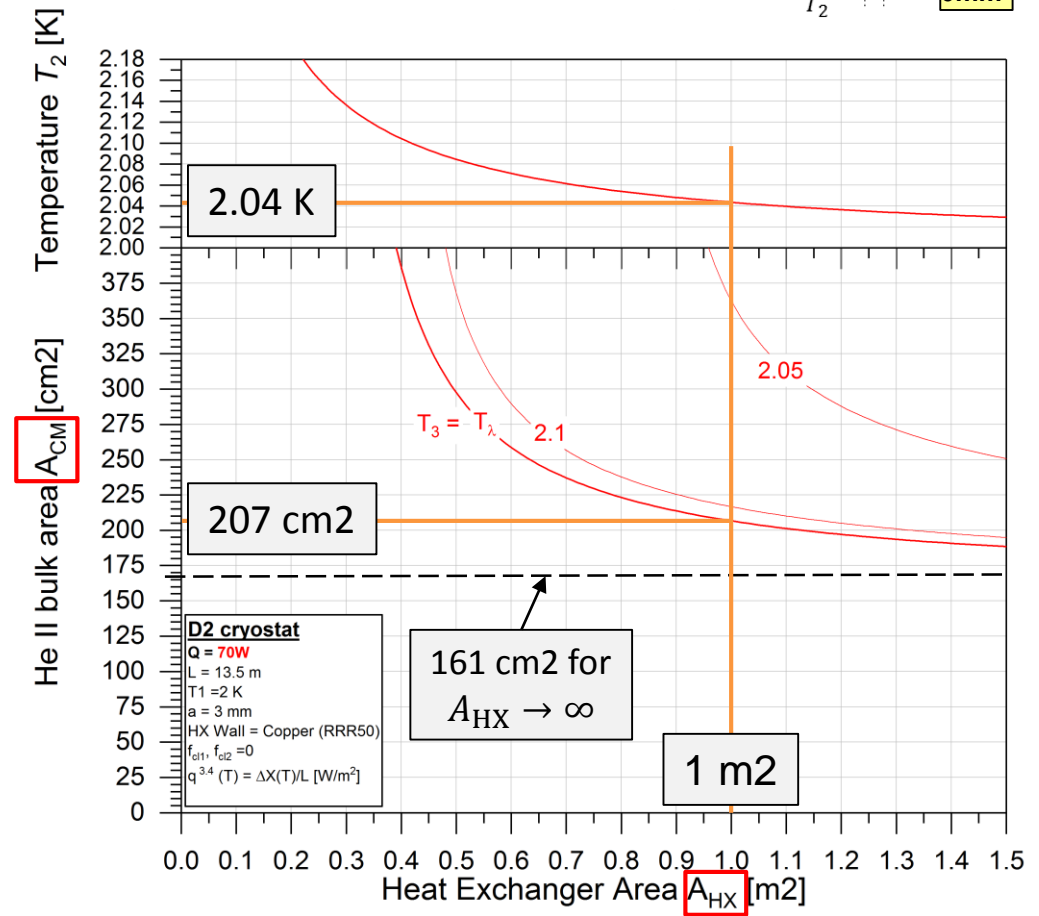
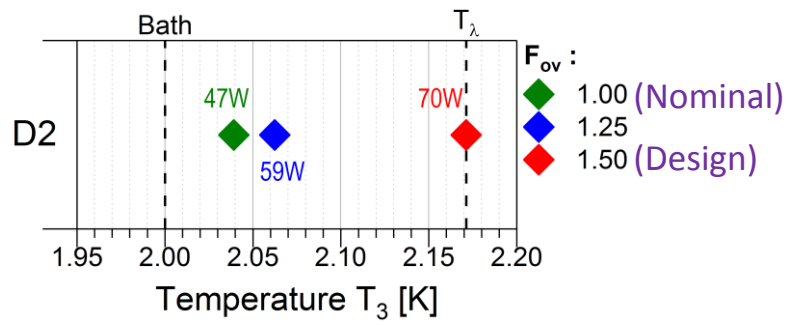
- $Q = 70 \text{ W@1.8K}$
- $L = 13.5 \text{ m}$
- Subcooled Hell-bath at 1.3bar
- $T_1 = 2 \text{ K}$
- $f_{cl1,2} = 0$ („dirty“ surface)
- HX made of Cu (RRR50)
- $a = 3 \text{ mm}$



Design Values :

	D2	Q4	Q5
$A_{CM} [\text{cm}^2]$	207		
$A_{HX} [\text{m}^2]$	1.0		

Temperature T_3 on D2:



Trade-off

A_{L2} vs A_{HX}

For D2 with
HX on QXL

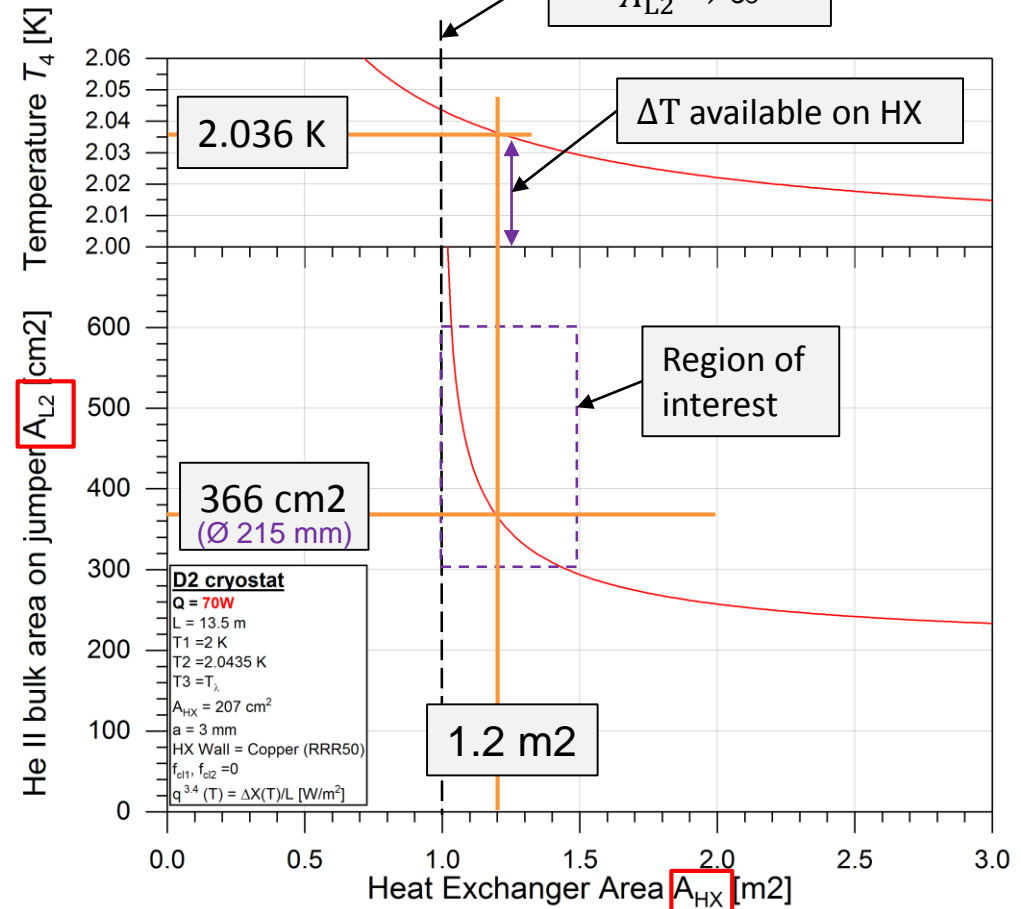
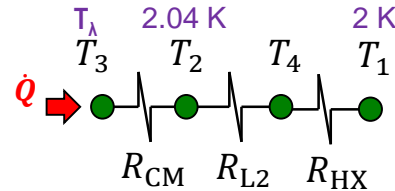
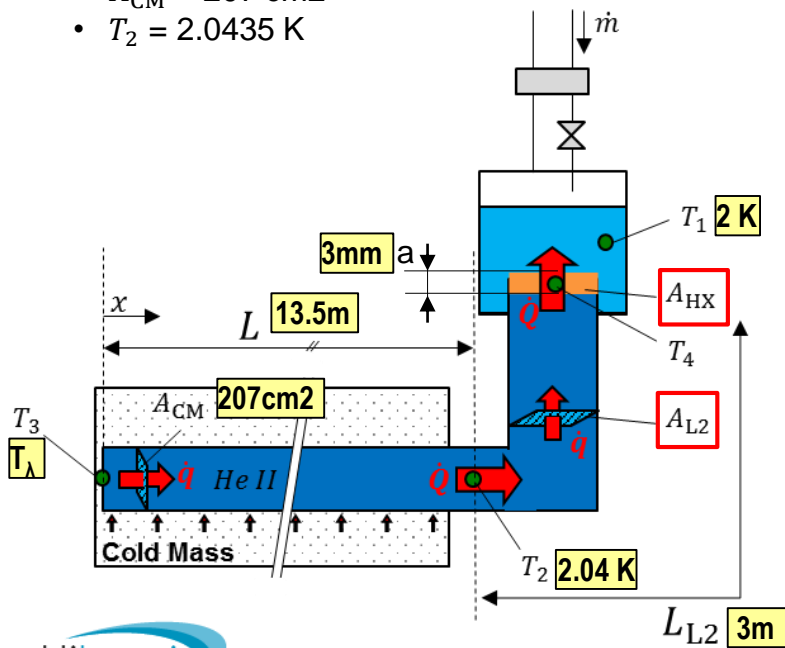
Assumptions for D2

As before:

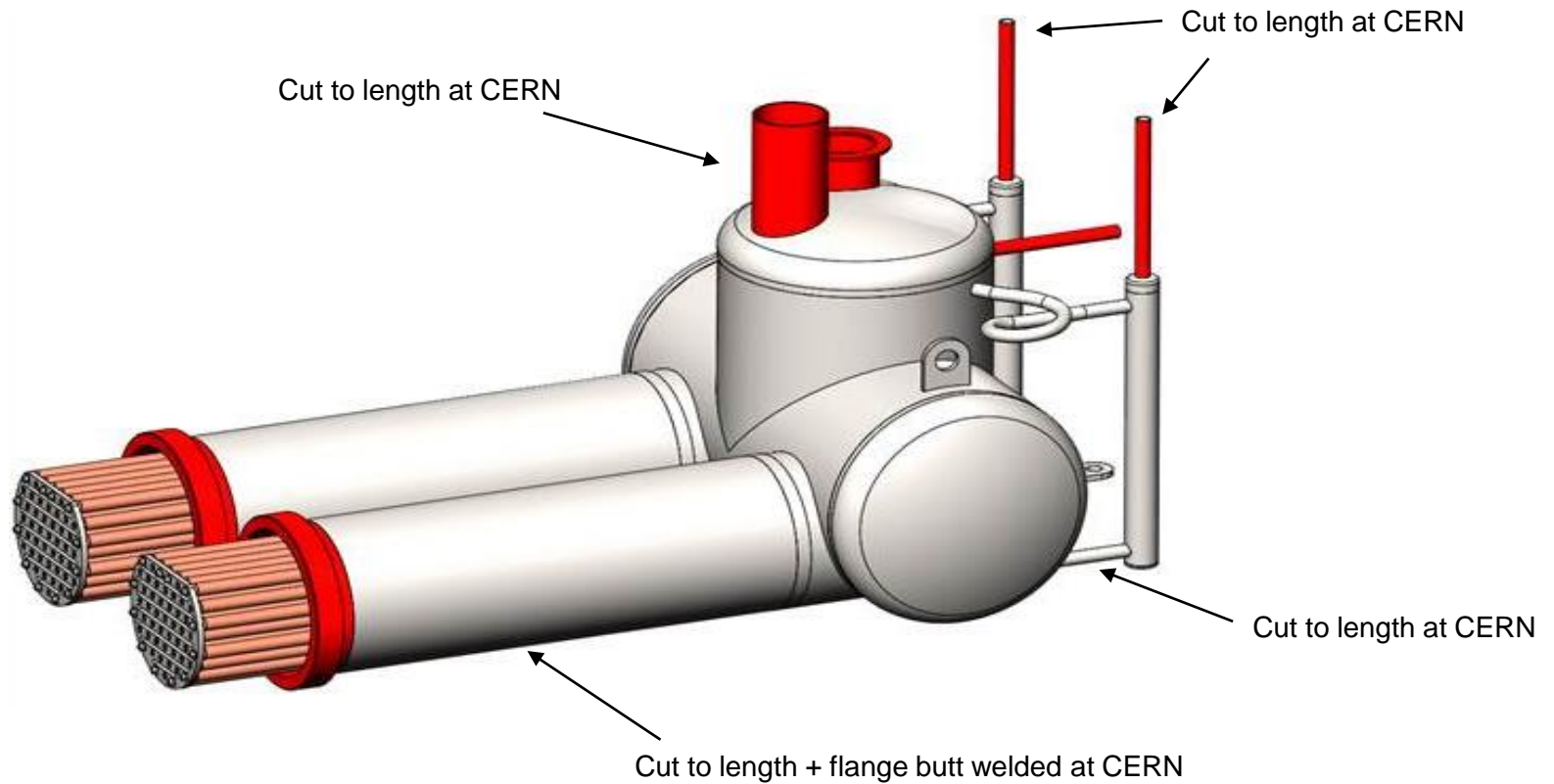
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- $T_1 = 2 \text{ K}$
- $f_{cl1,2} = 0$ („dirty“ surface)
- HX made of Cu (RRR50)
- $a = 3 \text{ mm}$

Specific for HX placed at QXL:

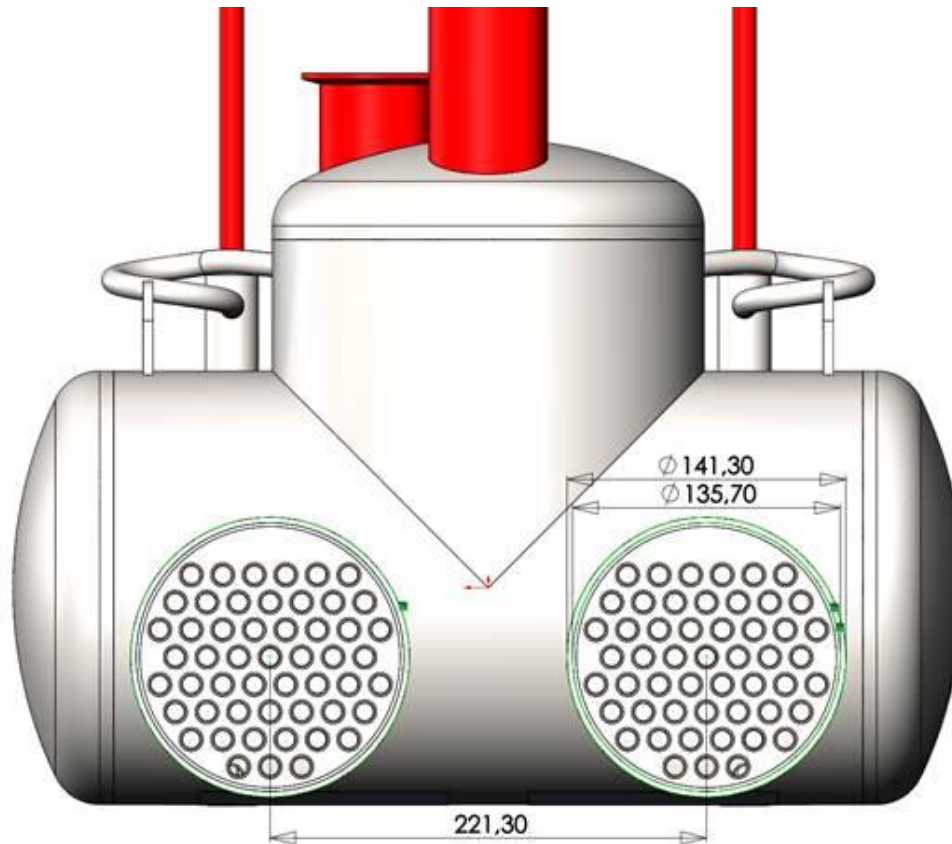
- $L_{L2} = 3 \text{ m}$
- $A_{CM} = 207 \text{ cm}^2$
- $T_2 = 2.0435 \text{ K}$



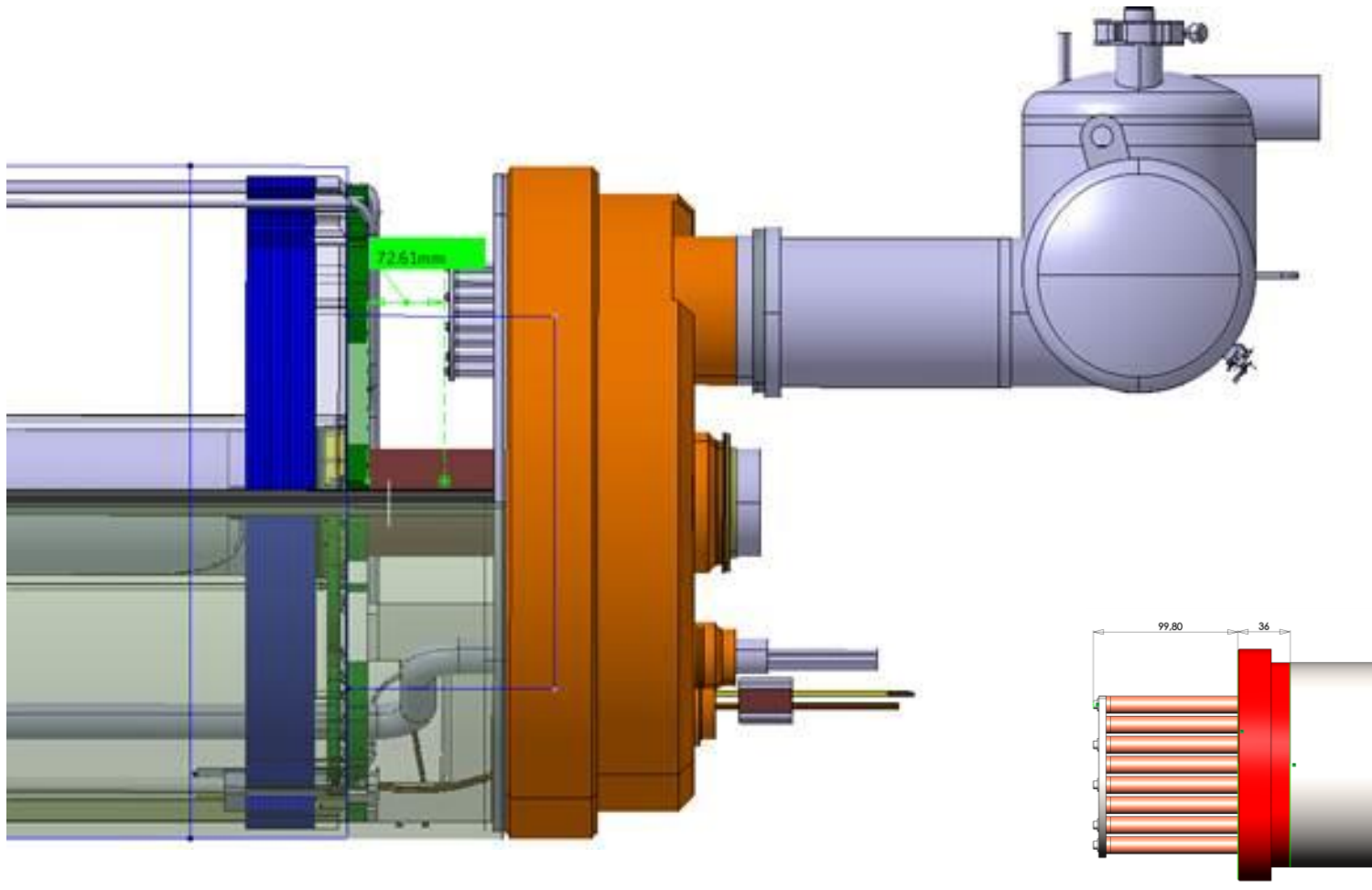
Interfaces of HX with D2 (prototype)



Dimensions of HX with D2 (prototype)



Dimensions of HX with D2 (prototype)



Minimal distance into cold mass to be defined!