Thermo-mechanical aspects of SPL b=1 cavity helium vessel and cryomodule interface

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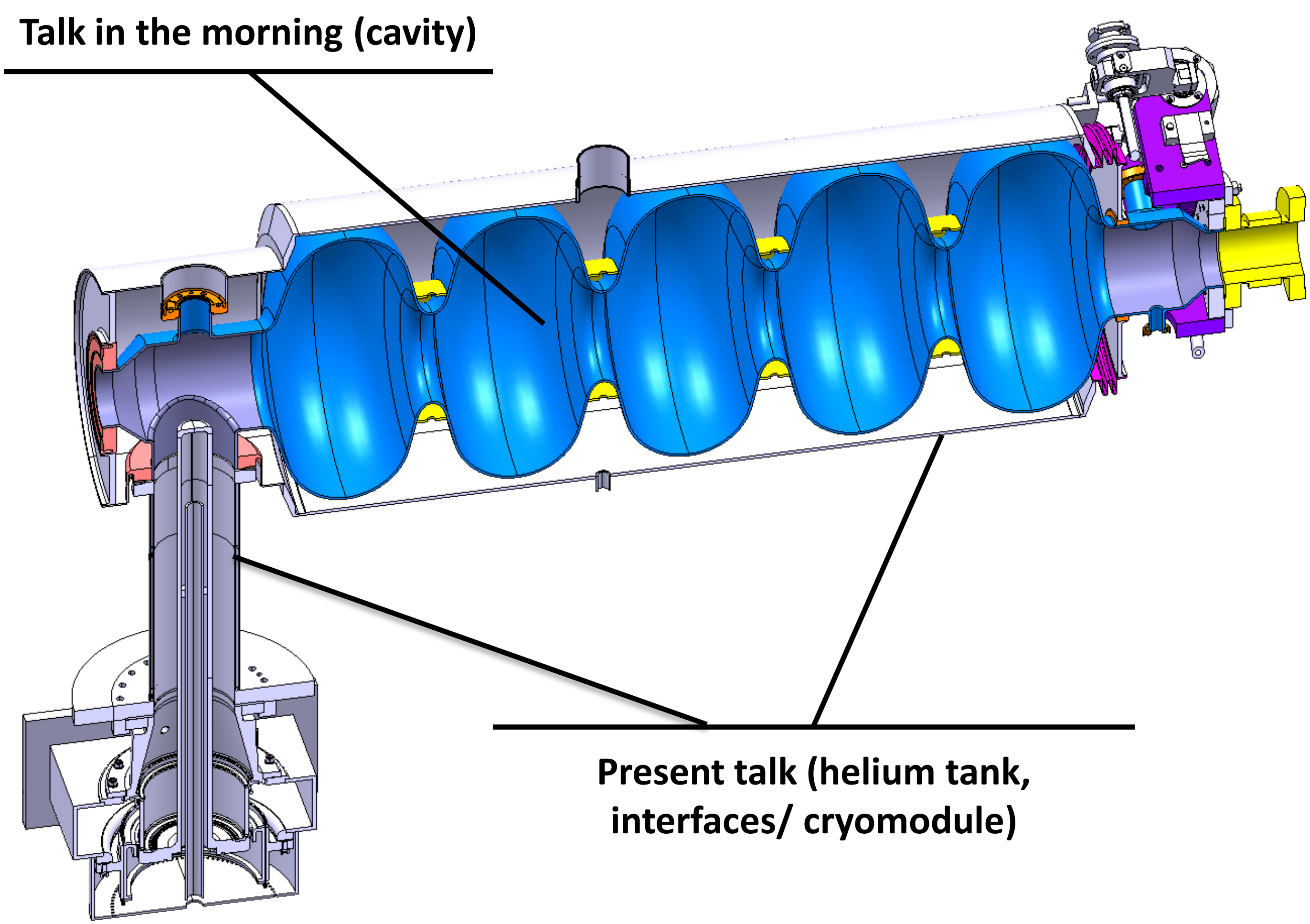
+ discussions and contributions from CEA and
CNRS colleagues

Introduction

- SPL beta = 1 cavity + helium tank + tuner + main coupler + bellow to next cavity

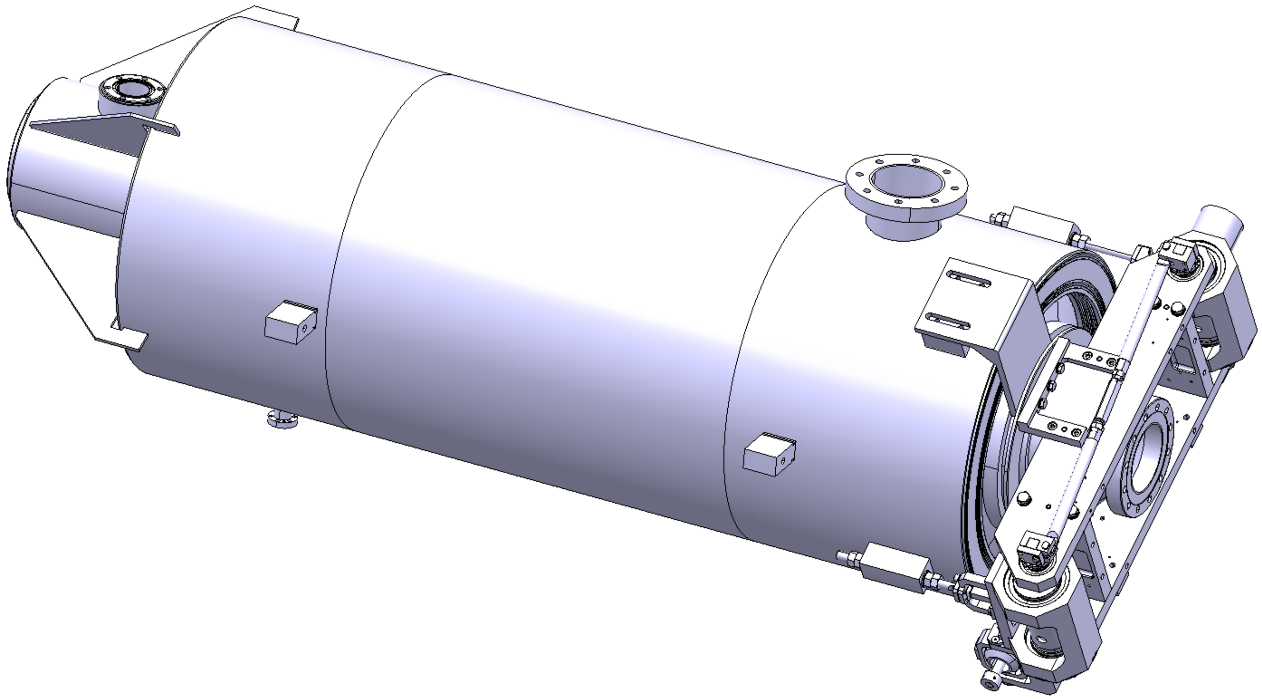


Overview

- Helium tank
- Interface / cryomodule vacuum vessel (main coupler “double wall”)
- Interface / cryomodule cryogenic lines
- Conclusions

Helium tank

- Helium tank for short cryo-module cavities (first set)
  - The most recent design proposed by CEA – meeting foreseen today for discussion on this subject



Helium tank

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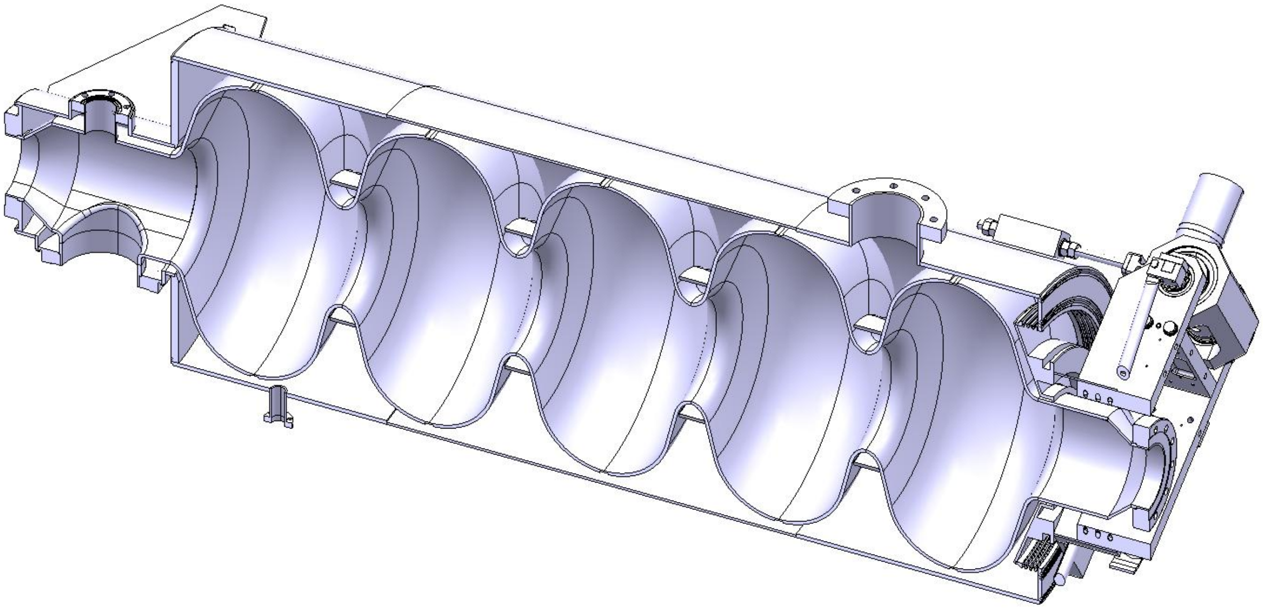
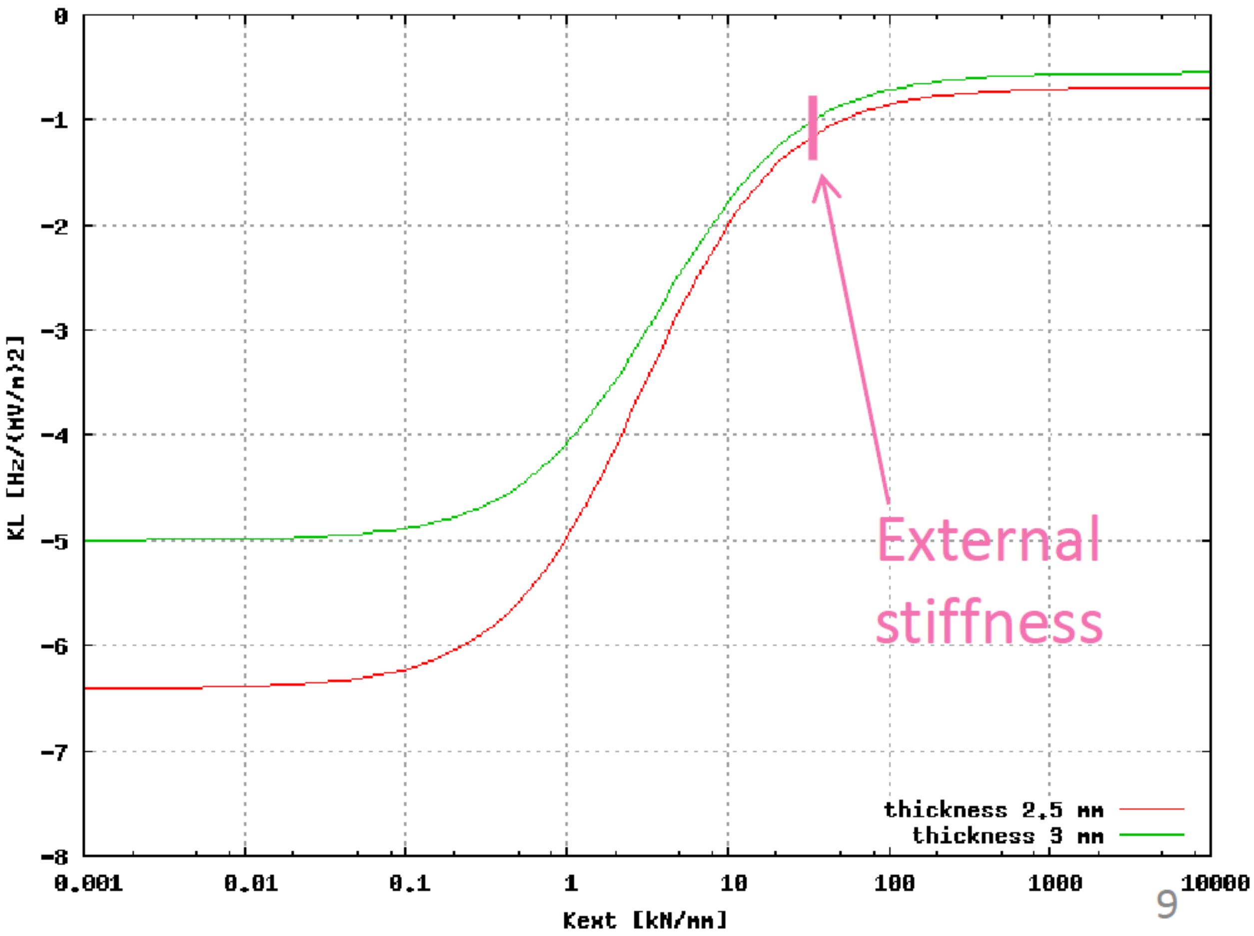


Helium tank

- Helium tank for short cryo-module cavities (first set)
  - Tank in Titanium for thermal contraction compatibility with respect to Niobium
  - Transition between Nb and Ti via NbTi to be EB welded on both sides
  - Flanges for external interfaces: HOM coupler, main coupler, inter-cavities, cryogenic lines in NbTi; alternative transition to cryogenic lines – bimetallic
- At least one stainless steel helium tank will be designed and manufactured in the frame of the 2^{nd} set of cavities (2013) for the long cryo-module

Helium tank

- The stiffness of the helium tank has a direct impact on the Lorentz detuning (defines the boundary conditions of the cavity)



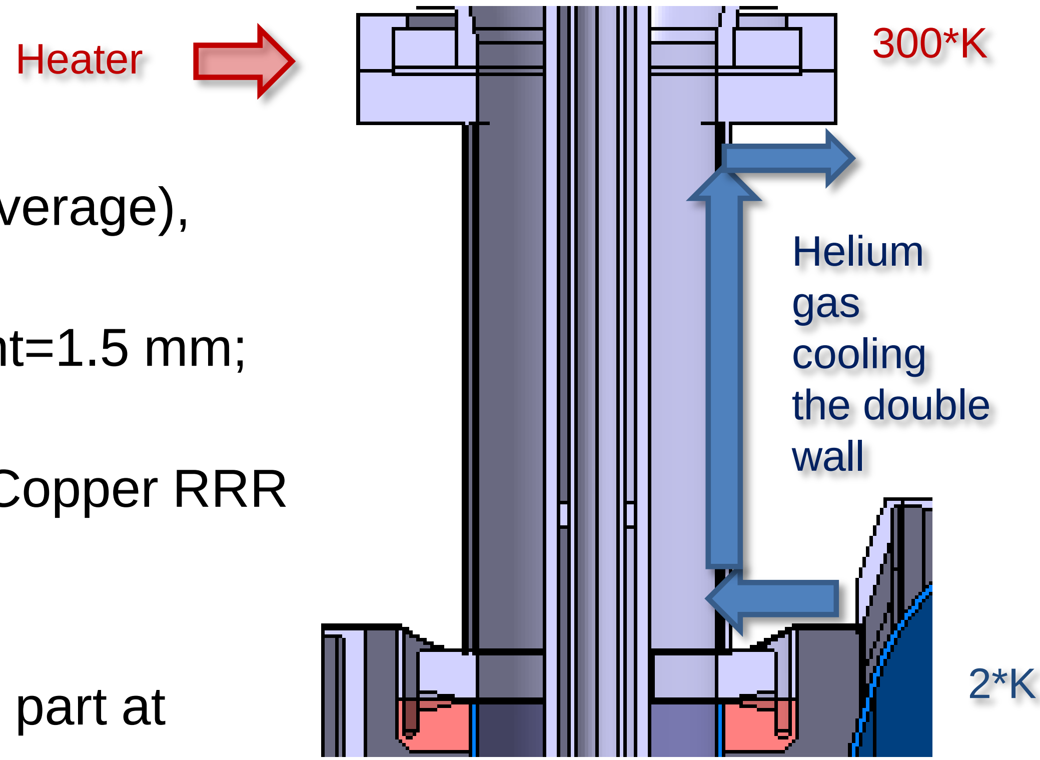
Juliette Plouin
CEA, Saclay

- Helium tank stiffness calculated by CEA

“Double wall” tube of main coupler

- Interface between the helium tank and the cryomodule vacuum vessel

- Parameters
  - 1000 kW pulsed (100 kW average), 704.4 MHz, 50 Ω
  - H=300 mm; D=100 mm; eint=1.5 mm; eext=2 mm
  - Copper on stainless steel; Copper RRR = 30 (Sergio Calatroni)
  - Cooling gas at 4.5 K input
  - Lower part at 2K and upper part at 300K
  - Heater at upper part to insure 30 ºC of flange temperature



“Double wall” tube of main coupler

- Model description (validated / the LHC main coupler)
  - Copper on Stainless steel wall
  - Semi-analitical model taking into account
    - **Conduction** through the tube

$$Q_{cond}(T_a, T_b, i) := \int_{T_b}^{T_a} \frac{\lambda_{ss}(T) \cdot S_{cond\_tube\_coupleur}}{l_i} \, dT$$

    - **Convection** $Q_{cv}(T_{wall}, T_{gas}, h_c, S_{convection}) := h_c(T_{gas}) \cdot S_{convection} \cdot (T_{wall} - T_{gas})$
    - **Radiation** between warm and cold parts

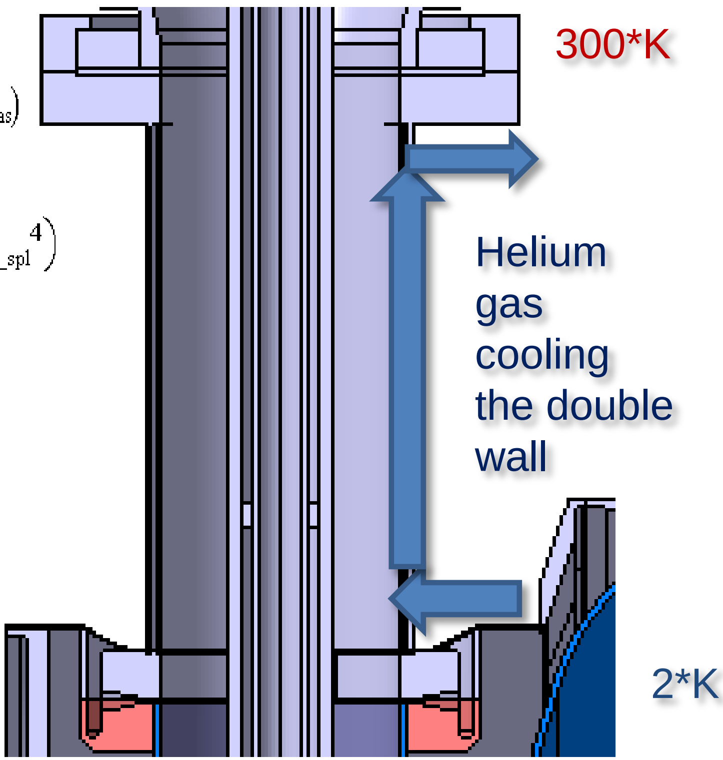
$$Q_{rad\_antenne\_wall} := A_{wall} \cdot \varepsilon_{antenne\_wall}(T_{wall\_spl}) \cdot F_{wall\_antenne} \cdot \sigma_z \cdot \left(T_{antenne}^{\ 4} - T_{wall\_spl}^{\ 4}\right)$$

    - **Power dissipation** (average) in the wall when coupler on

$$P_{diss\_ext} := \int_0^{h_{tube\_coupleur}} \frac{\left(I_{peak\_wall}(x)\right)^2}{2} \cdot R_{ext\_elect}\left(Temp_{tube\_coupleur}(x)\right) dx$$

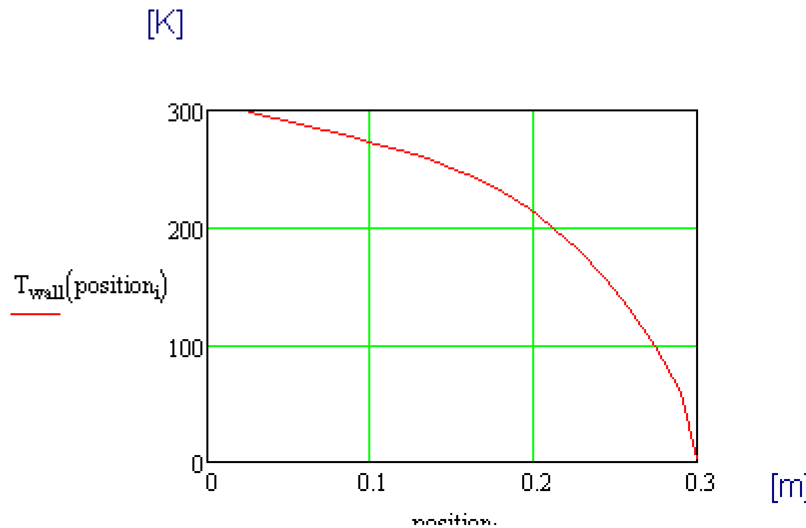
$$I_{peak\_wall}(x) := I_0 \cdot 2 \cdot \sin\left(\frac{\omega_0}{c} \cdot x\right) \qquad I_0 := \sqrt{2 \cdot \frac{P_f}{Z_0}}$$

$$R_{ext\_elect}(T) := \frac{\rho_{CU\_RRR30}(T)}{\delta(\rho_{CU\_RRR30}(T), \omega_0) \cdot \pi \cdot d_{tube\_coupleur\_int}}$$

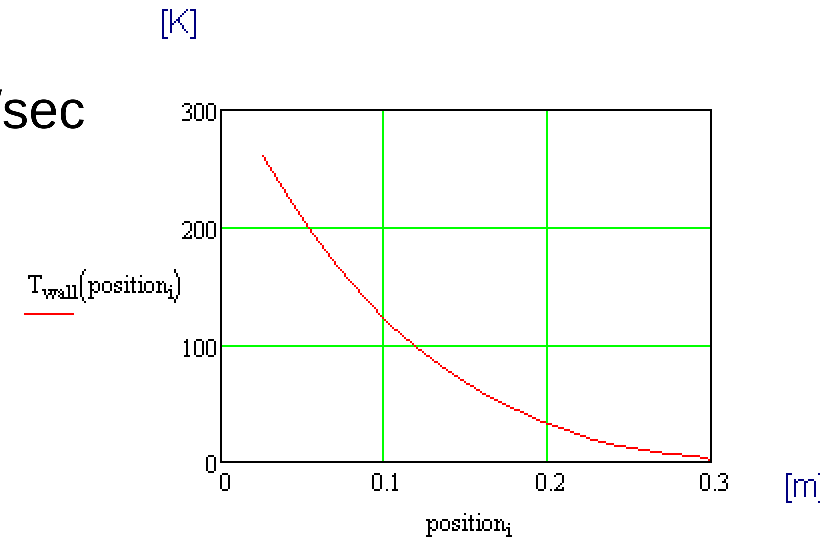


“Double wall” tube of main coupler

- Why cooling the wall?
  - No cooling
    temperature profile
    => Gives 21W to 2K



  - Cooling with 42 mgram/sec
    temperature profile
    => Gives 0.1W to 2K



“Double wall” tube of main coupler

- Why a heater at the top flange?
  - The heater insures 30 ºC of flange temperature
  - If no heater, in order to have the same temperature at the flange when no power on
    for the same thickness => height of more than 1m

“Double wall” tube of main coupler

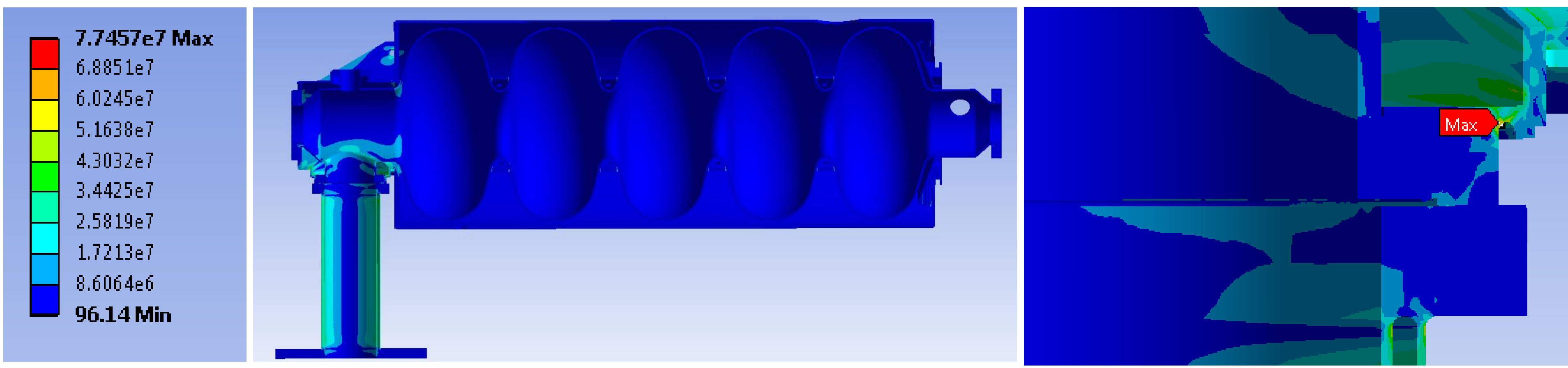
- Some thermal results

Massflow mgram/sec	21		23		28		35		42	
Power	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
Temp. gas out	286 K	277 K	283 K	273 K	271 K	242 K	255 K	205 K	232 K	180 K
Q thermal load to 2K	2.4 W	0.1 W	1.7 W	0.1 W	0.4 W	0.1 W	0.1 W	0.1 W	0.1 W	0.1 W
Q heater	19 W	32 W	21 W	34 W	29 W	38 W	39 W	41 W	46 W	44 W
ΔL	0.1 mm (0.63-0.53)mm				0.05 mm (0.66-0.61)		~ 0 mm (0.67-0.67)			

- Outlet tube for cooling gas inside the cryomodule
- Cryo people wish: remote controlled valve for massflow adjustment

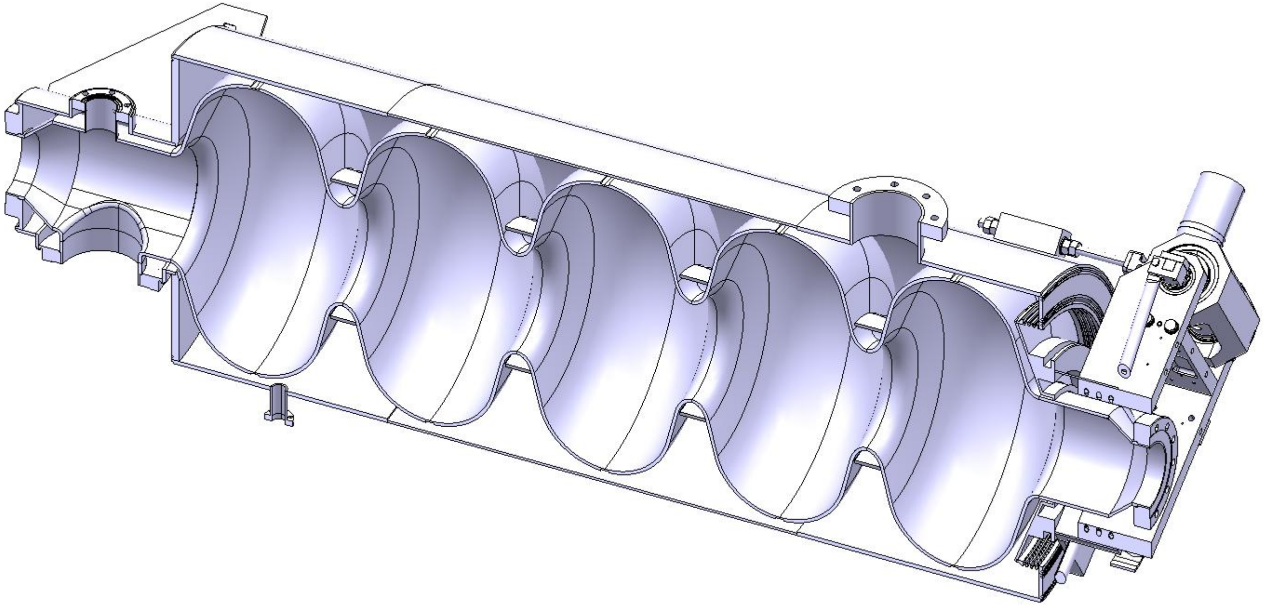
"Double wall" tube of main coupler

- Mechanical considerations
  - Foreseen as supporting system for the cavity inside the cryomodule
  - Worst case: cavity supported in cantilever by the double wall => maximum stress in the double wall below the maximum allowable stress



Interfaces to cryogenic lines

- Helium tank / cryogenic lines
  - Operation at 2K with saturated superfluid helium
  - 2 connections to cryogenic lines
    - For initial fill-in – dimensioned for optimization initial fill time + instrumentation cables if any
    - For continuous cooling – detailed hereafter



Interfaces to cryogenic lines

- Some theory concerning HeII

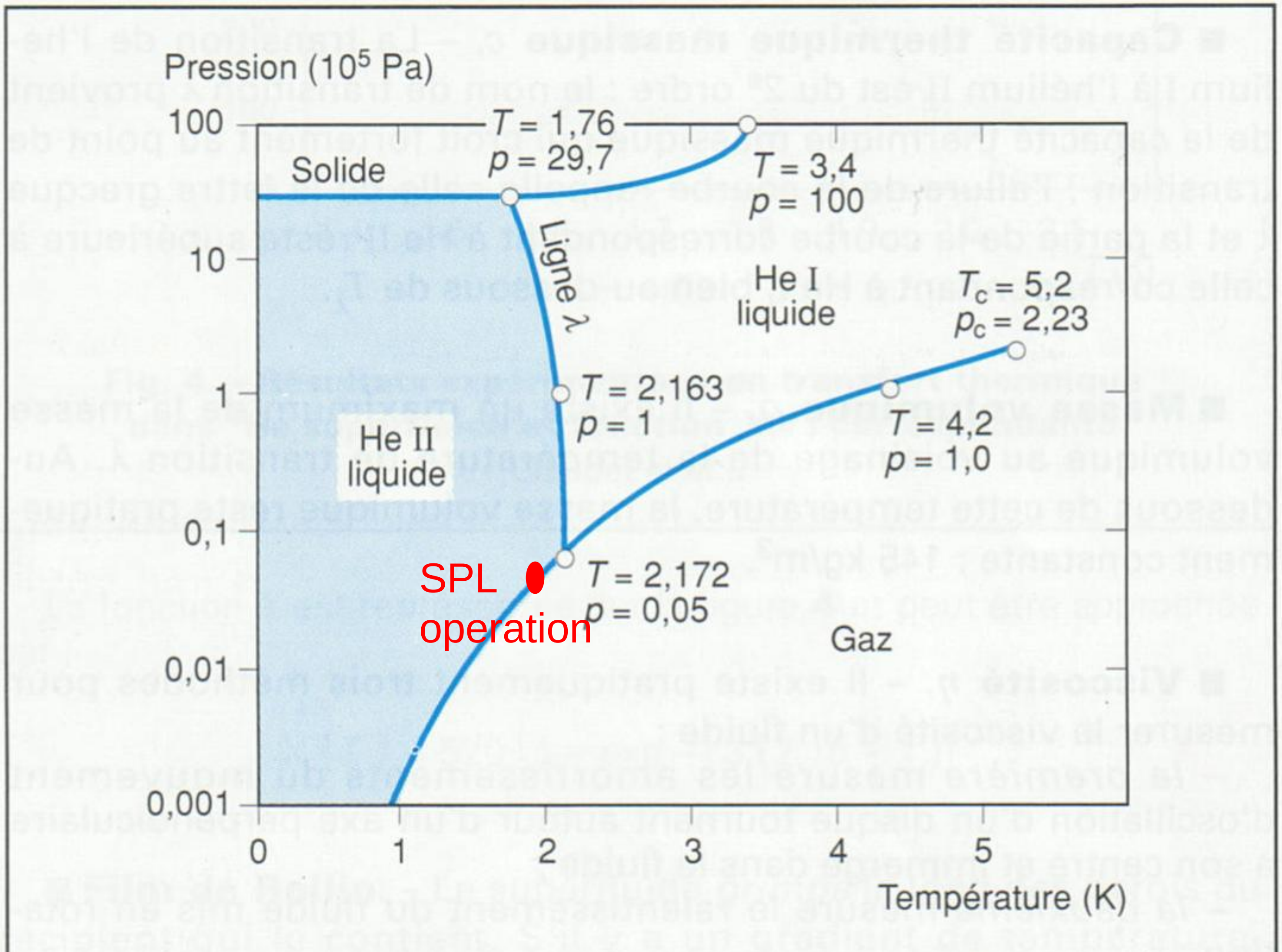
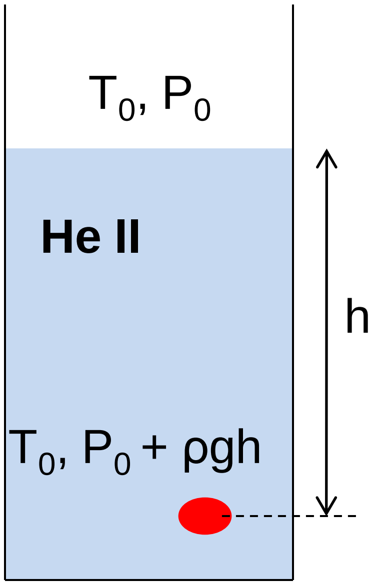
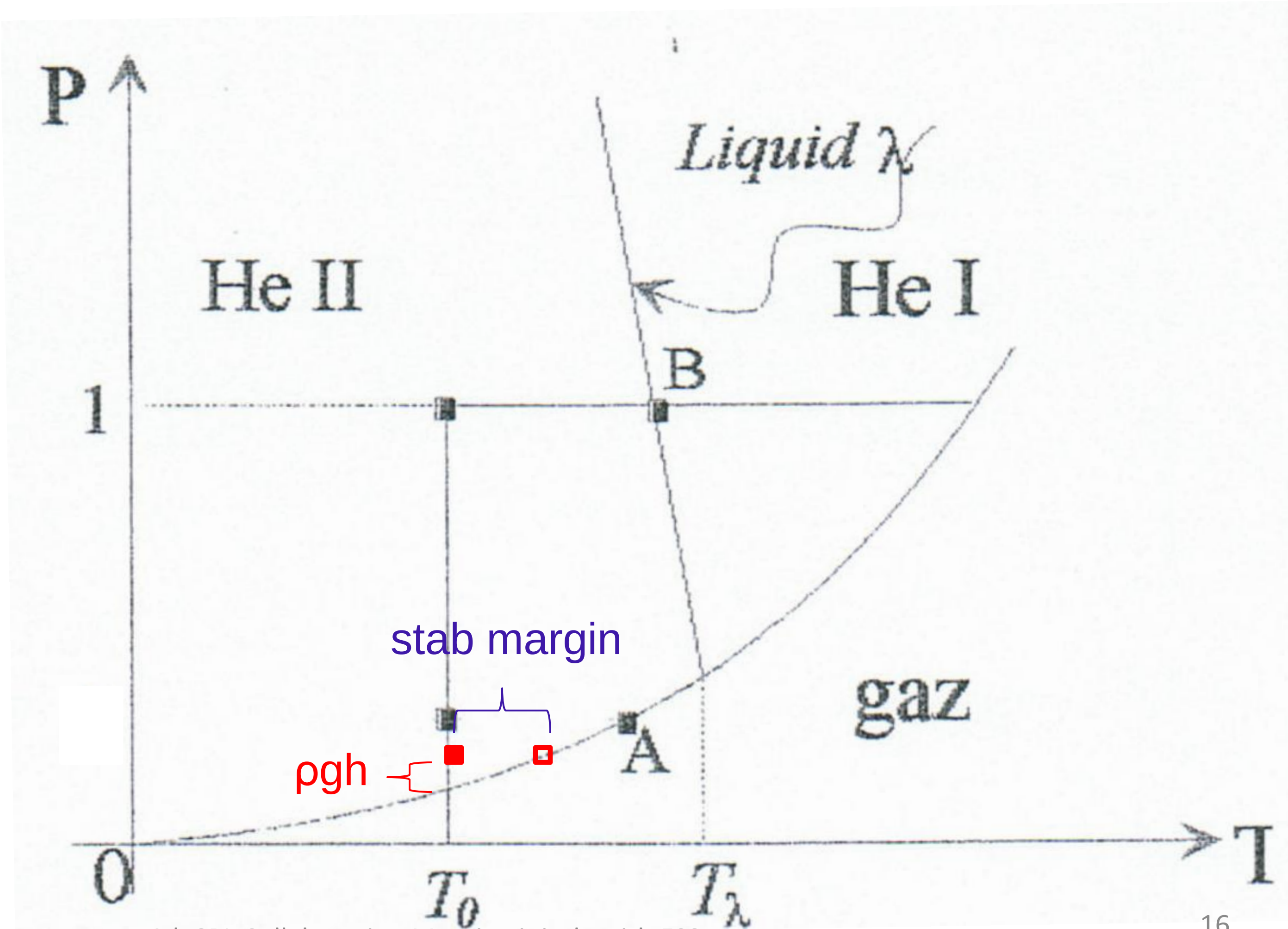


Fig. 1. – Diagramme de phase de ^{4}He.

Interfaces to cryogenic lines

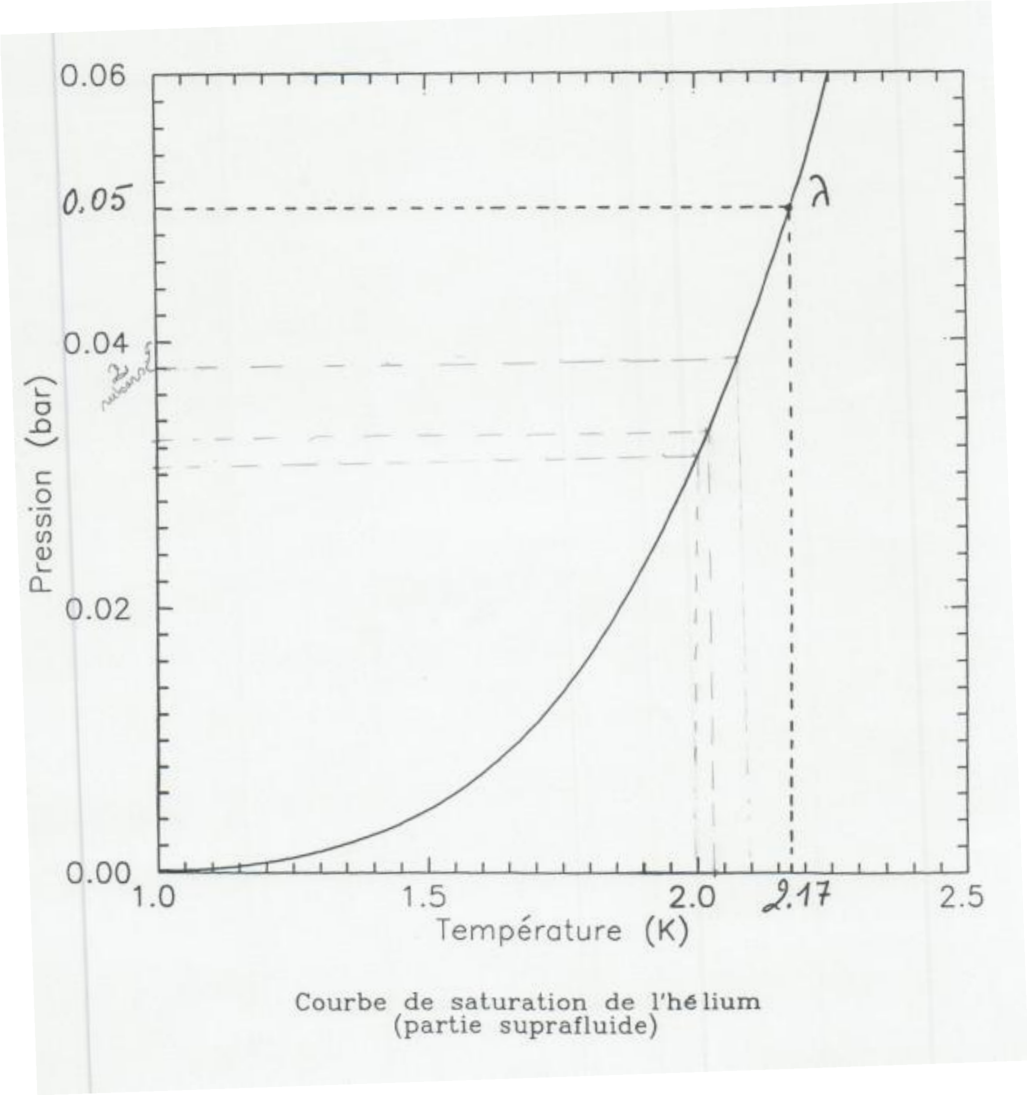
- HeII pressurized better stabilizer than HeII saturated
- Stabilization margin for saturated HeII due to hydrostatic pressure





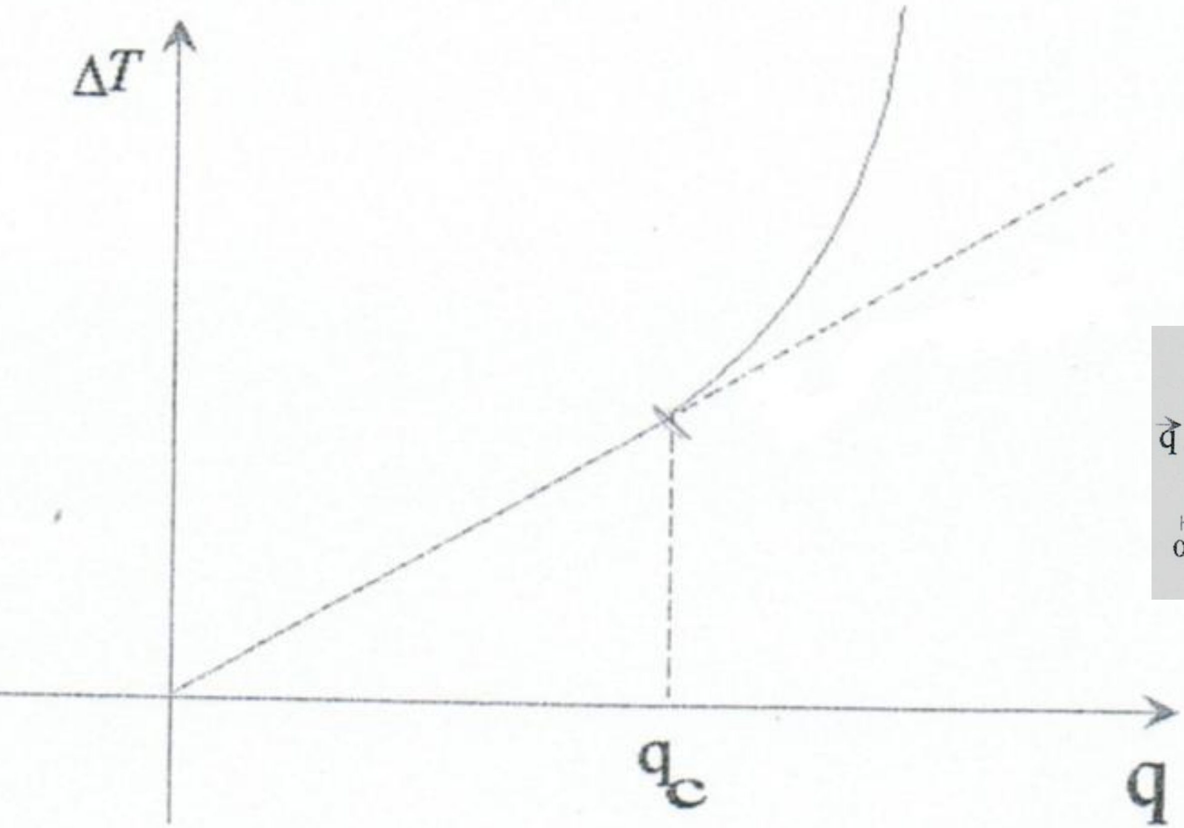
Interfaces to cryogenic lines

- For example, in saturated HeII, for a channel of L=10 cm height, Δp = 1.4 mbar, margin from 2K to ~2.025K

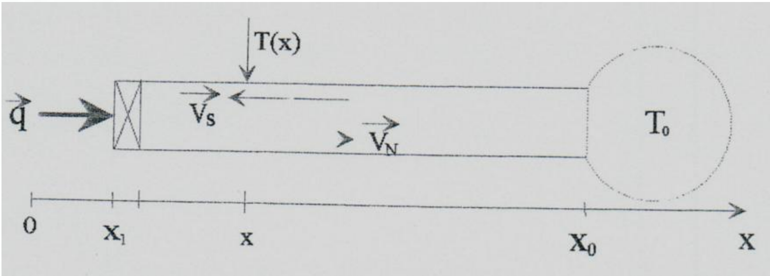


Interfaces to cryogenic lines

- HeII is an excellent thermal conductor; A typical value of "thermal conductivity" at 2K is 2kW/mK for a channel of cross section of 1 cm^2 and length 10cm (one order of magnitude higher than pure copper).
- However, this relationship is true only for small heat fluxes!!! Above a critical heat flux, the temperature increases drastically and eventually the superfluidity is lost.



The heat flux in HeII depends on temperature and channel dimension

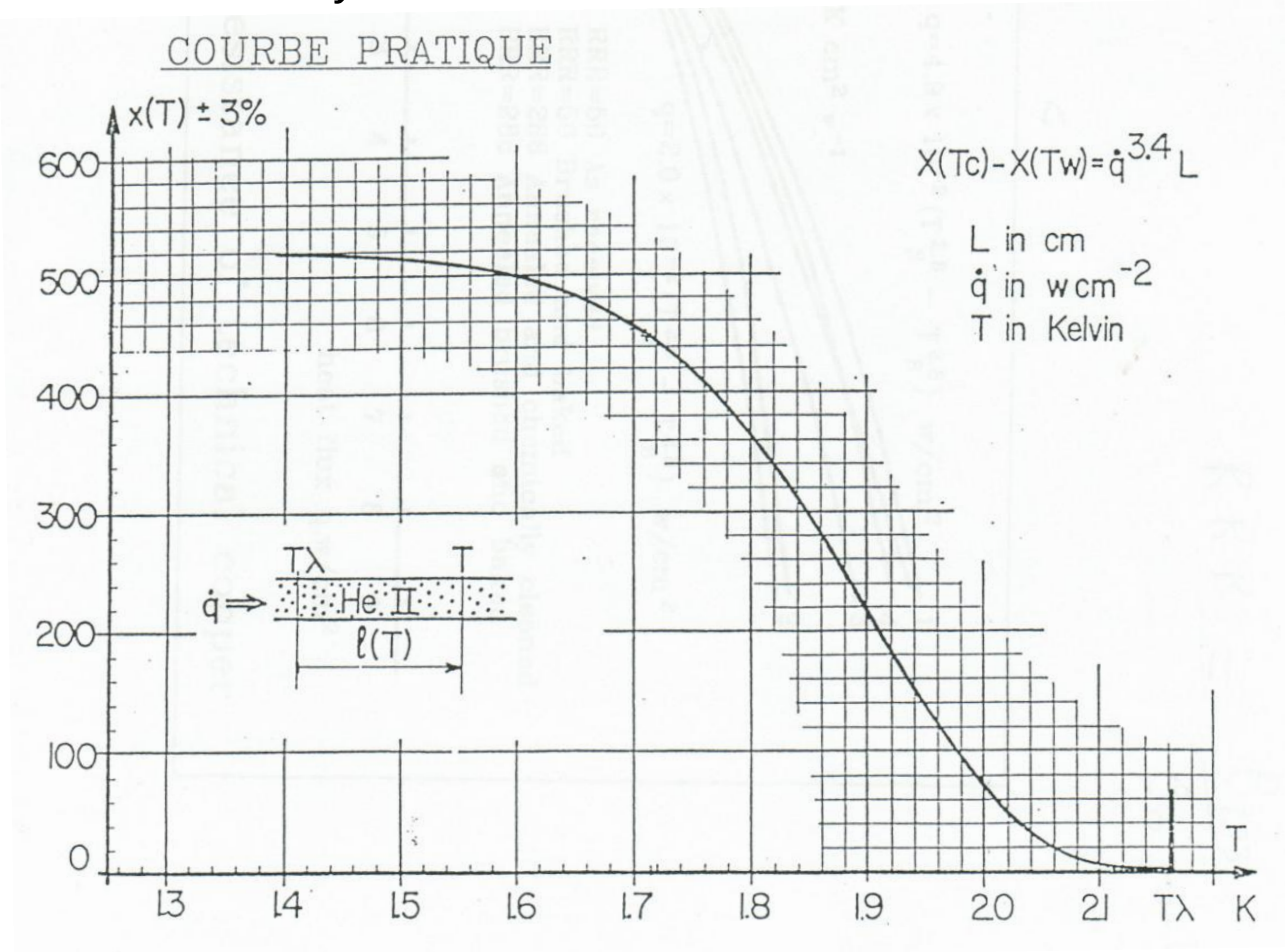


Interfaces to cryogenic lines

- Gorter and Mellinck have shown the dependence of the heat flux density / externally applied temperature
- Claudet et al. gave experimental values of heat transfer by HeII

$$\frac{\dot{Q}}{s} = \left[\frac{X(T_f) - X(T_c)}{l'}\right]^{0,29} \quad \text{(en W/cm}^2\text{)}$$

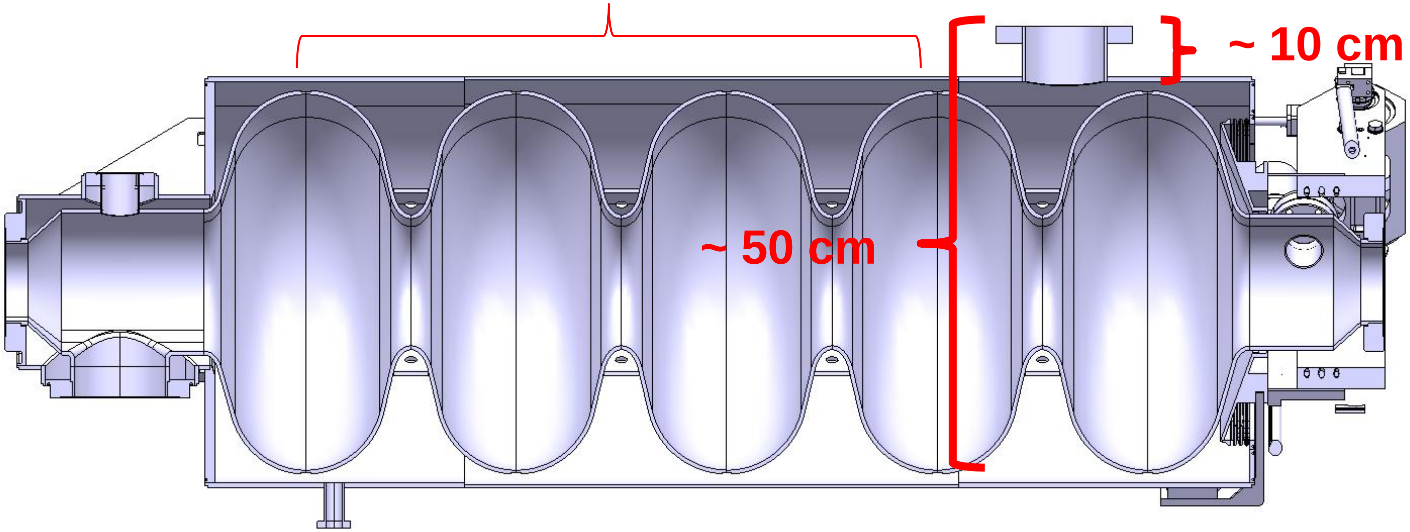
T_f et T_c (K) températures aux bouts froid et chaud d'un canal de section s (cm²) et de longueur l' (cm).



In our case:
Tc = 2K
Tw = temp stability margin (precedent example 2.025K)

Interfaces to cryogenic lines

- Application to our helium tank – some preliminary estimations
  - Heat dissipation mainly at the equator



  - For the upper part Qc= $[[X(2K)-X(2.025K)]/10]^{1/3.4}$
    - Qc_up ≈ 1.5 W/cm^2
  - For the lower part Qc= $[[X(2K)-X(2.1K)]/73]^{1/3.4}$
    - Qc_down ≈ 0.95 W/cm^2
  - Left Qc_left ≈ 0.8 W/cm^2

Interfaces to cryogenic lines

- Application to our helium tank – <u>some preliminary estimations</u>
  - Heat load per cavity, <u>average</u>: **16 W + static load from cryomodule + ? HOM discussed by Wolfgang**
  - Cryo duty cycle: 8.2 % => peak heat load **195 W + … idem**
  - Dimensioning of the piping depending on the cavity test program:
    - To be able to extract 195 W continuously => cross section > 130 cm^2 + optimization of space between cavity and helium tank
    - To be able to extract 25 W (margin as Vittorio) continuously => cross section > 17 cm^2
    - *<u>Rmq</u>* The total tank HeII temperature increase due to 195 W during 1.6 ms is only 10^-5 K !!

Conclusions

- Conclusions
  - Main coupler double wall optimized to withstand the induced mechanical loads and low thermal losses to the helium bath;
    More details at
    http://indico.cern.ch/materialDisplay.py?contribId=3&materialId=slides&confId=86123
  - Interfaces of helium tank with the cryogenic lines to be dimensioned according to the maximum average heat load experienced by the cavity during its lifetime
  - Details of the helium tank will be discussed in a dedicated meeting