Improved thermal removal from Nb-Ti SC cables

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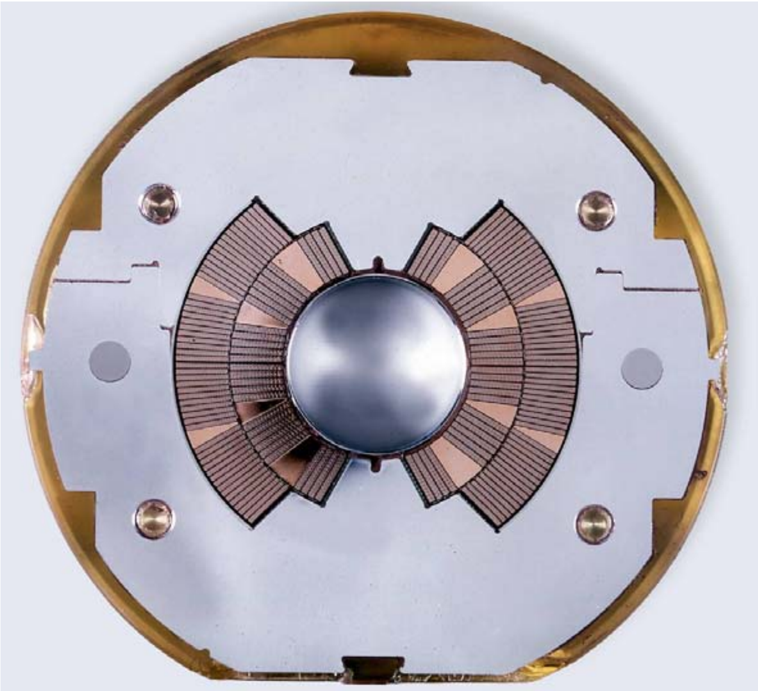
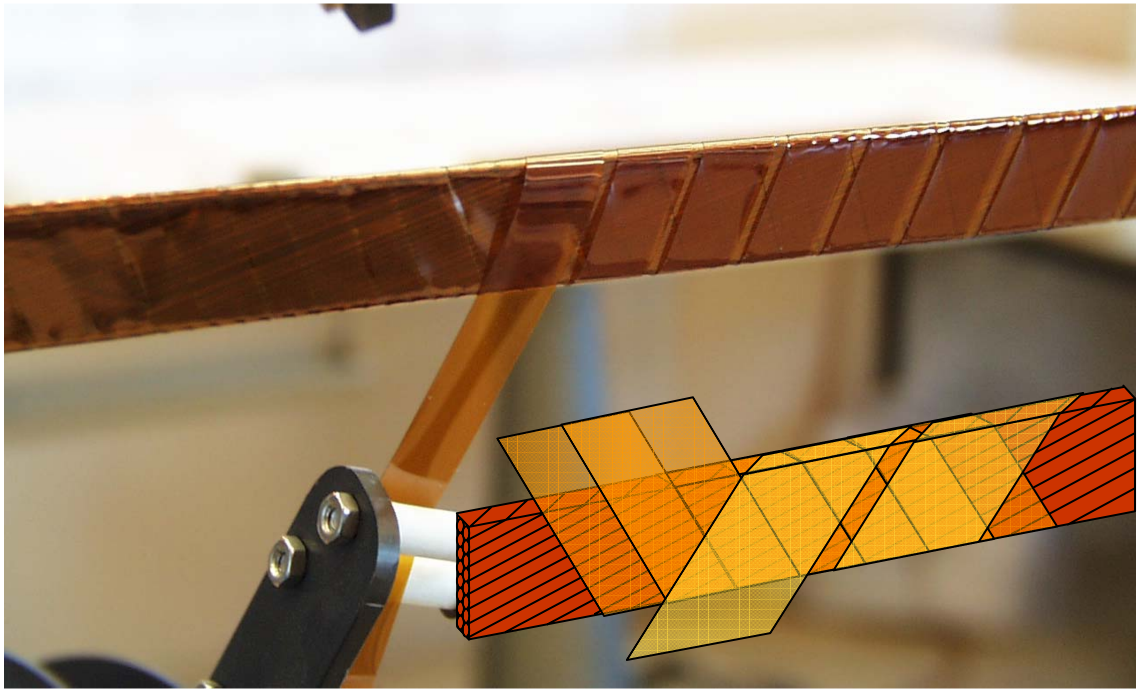
We are modeling *steady-state* heat transfer from SC Rutherford cable to an *isothermal* He II bath.

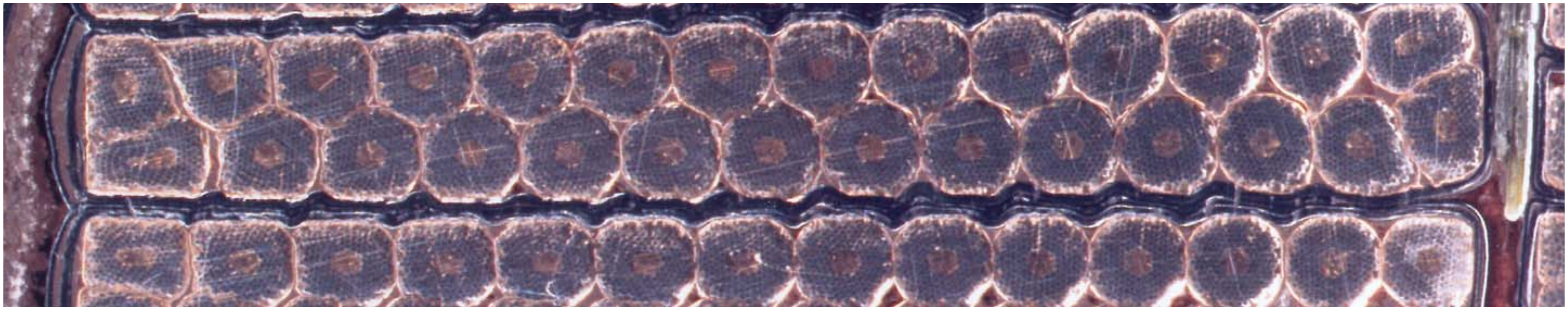
We profit of previous measurements done mostly at CEA-Saclay on different cable insulation schemes.

We show there is a potential for a large margin of improvement of heat removal with respect to present LHC schemes

Cable insulation

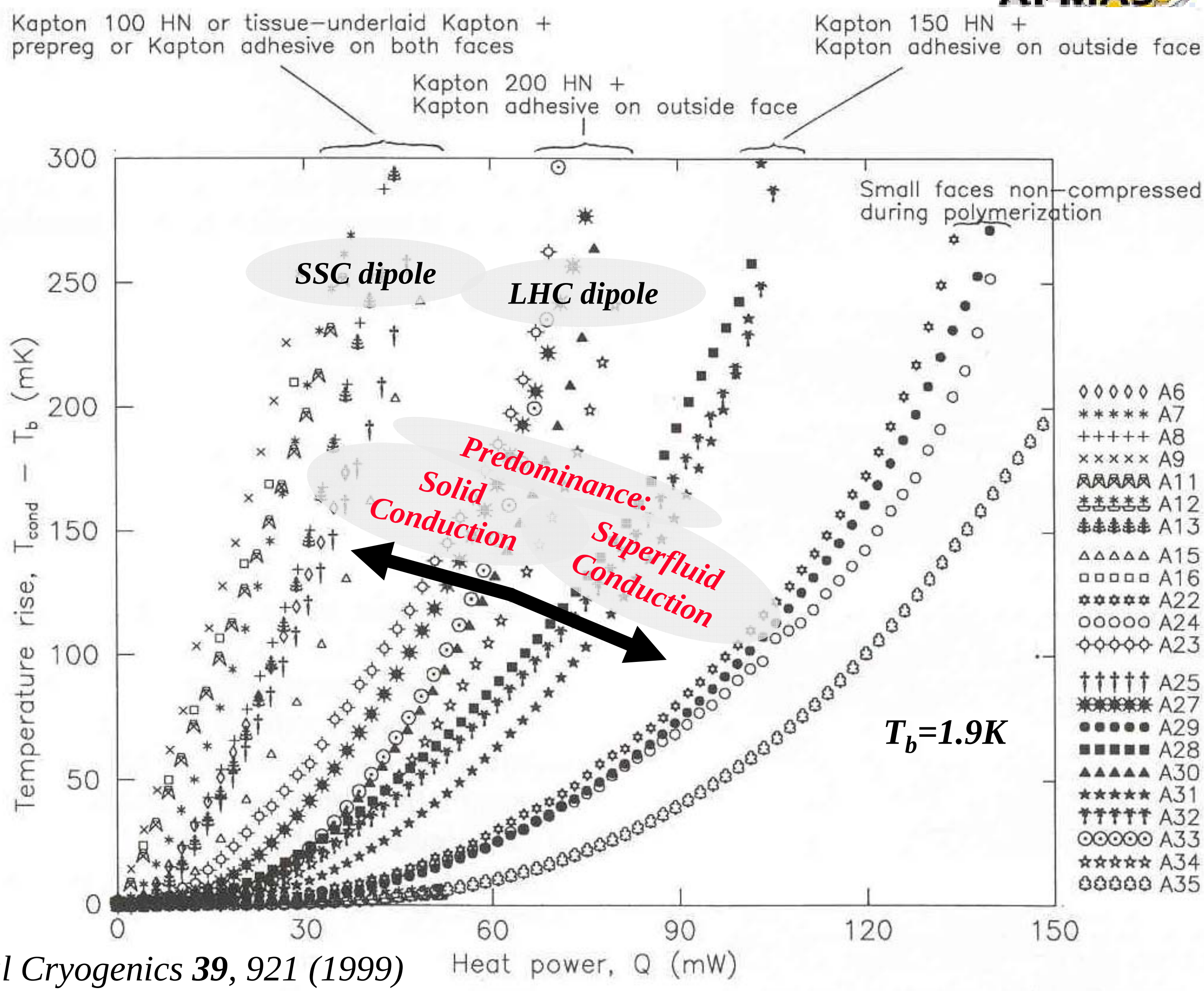






Heat transfer

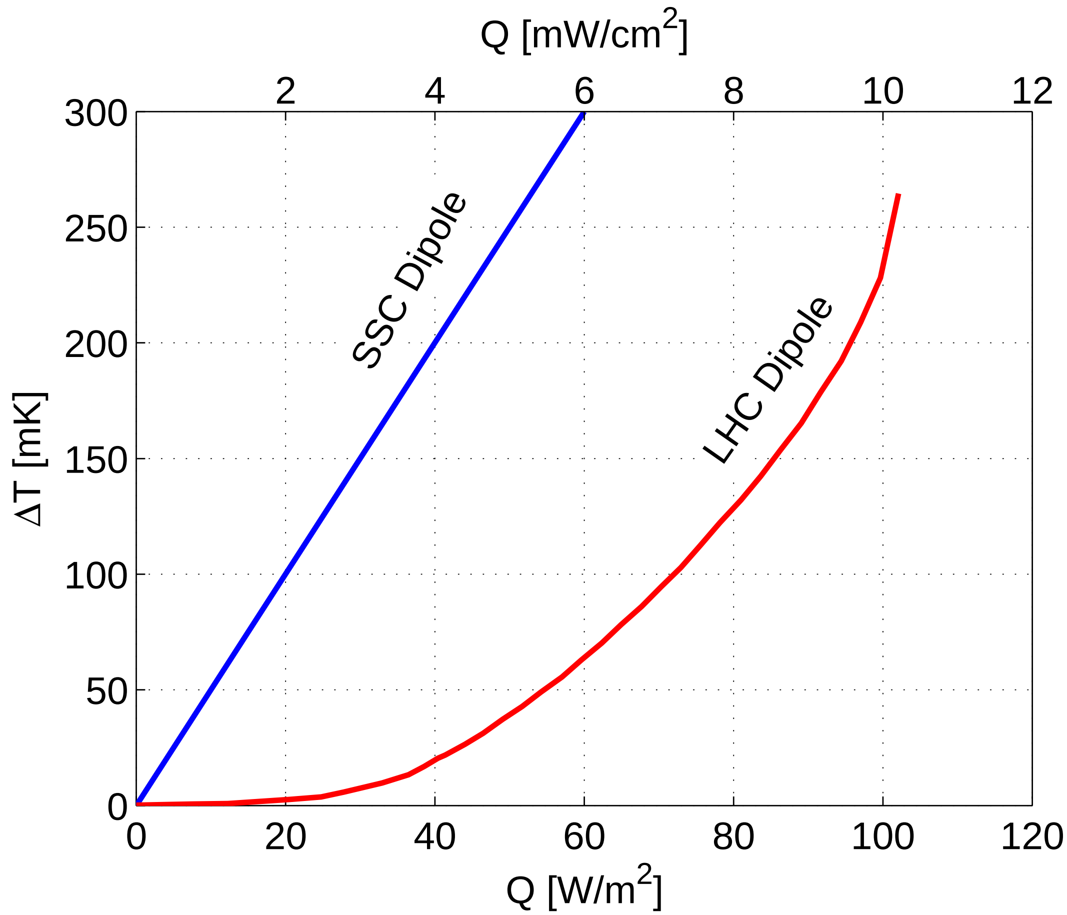
- Nb-Ti pourous insulations
- Insulations are wrapped around a steel cable mock-up, 150 mm long.
- Conductor is always wet by He II
- He II Channels saturate $T_c = T_\lambda$



From B. Baudouy et al Cryogenics **39**, *921 (1999)*

Q (mW/cm^3)

Heat transfer



Elaborated from B. Baudouy et al Cryogenics 39, 921 (1999)

For a LHC main dipole :

Inner cable perimeter ~ 12 cm

For ΔT = 150 mK $\Rightarrow$ Q = 85 W/m²

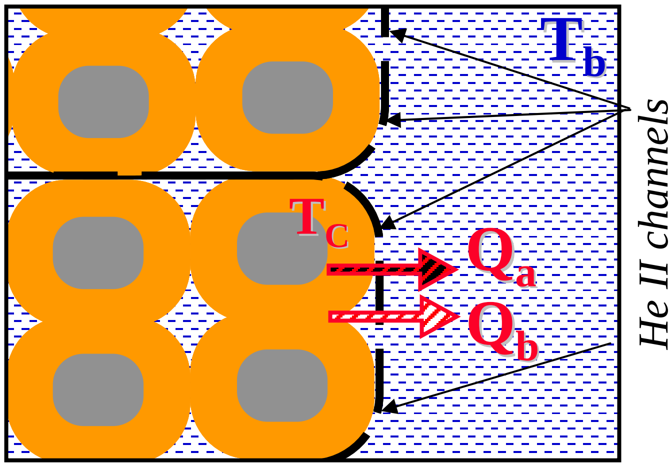
$\Downarrow$

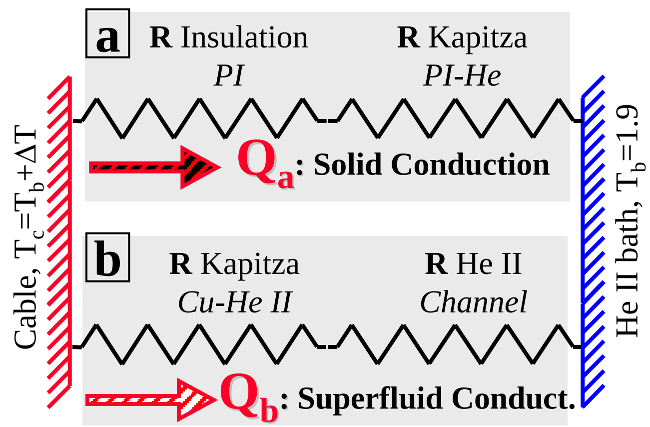
Heat transfer ~ 165 mW/m per turn

IF UNIFORMELY DISTRIBUTED

~10 W/m per aperture

Heat Transfer Model





1) Q_a vs Q_b *depends on insulation porosity*

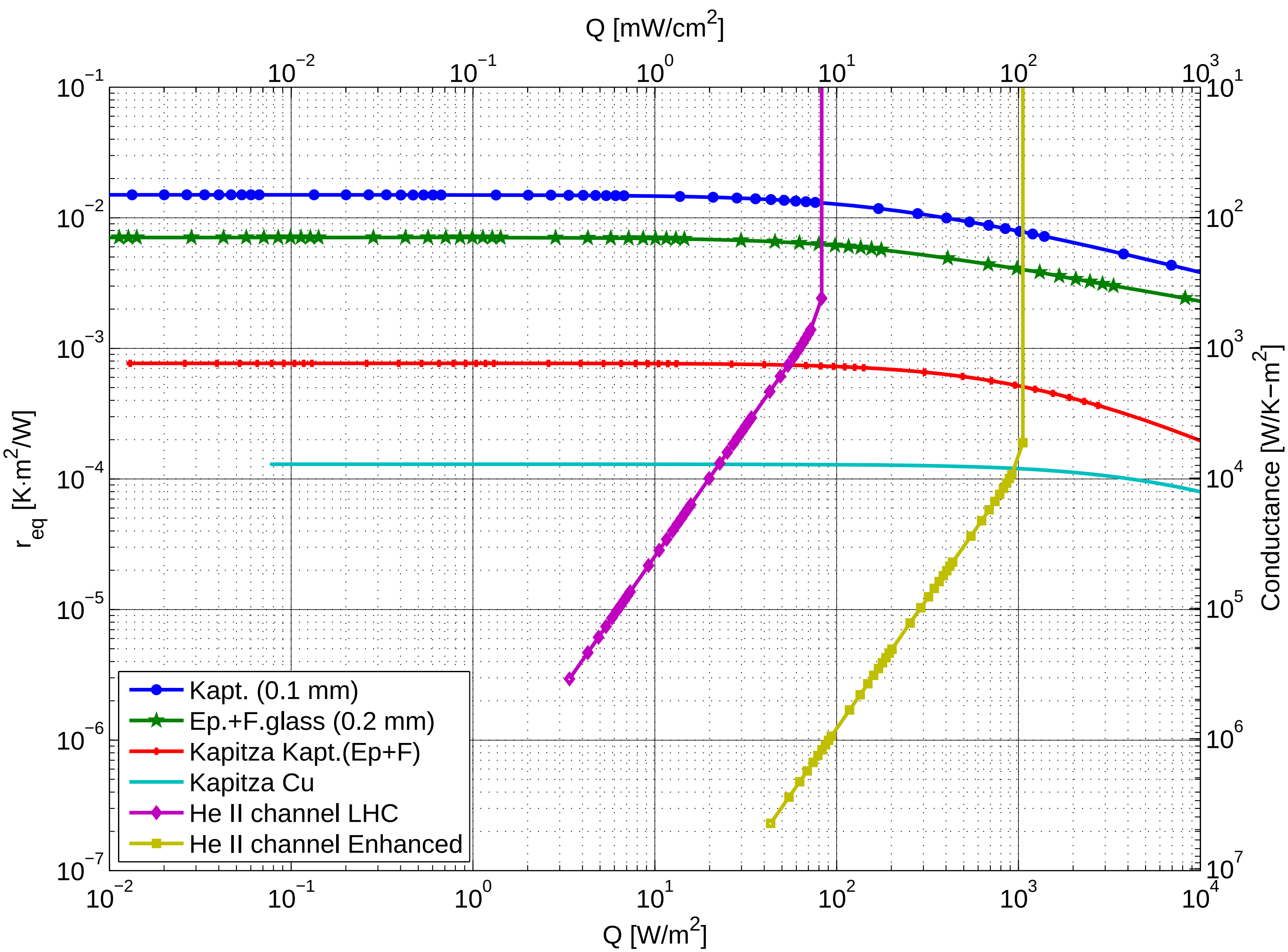
2) Q_a & Q_b *are non linear*

3) Q_b *has saturation level*

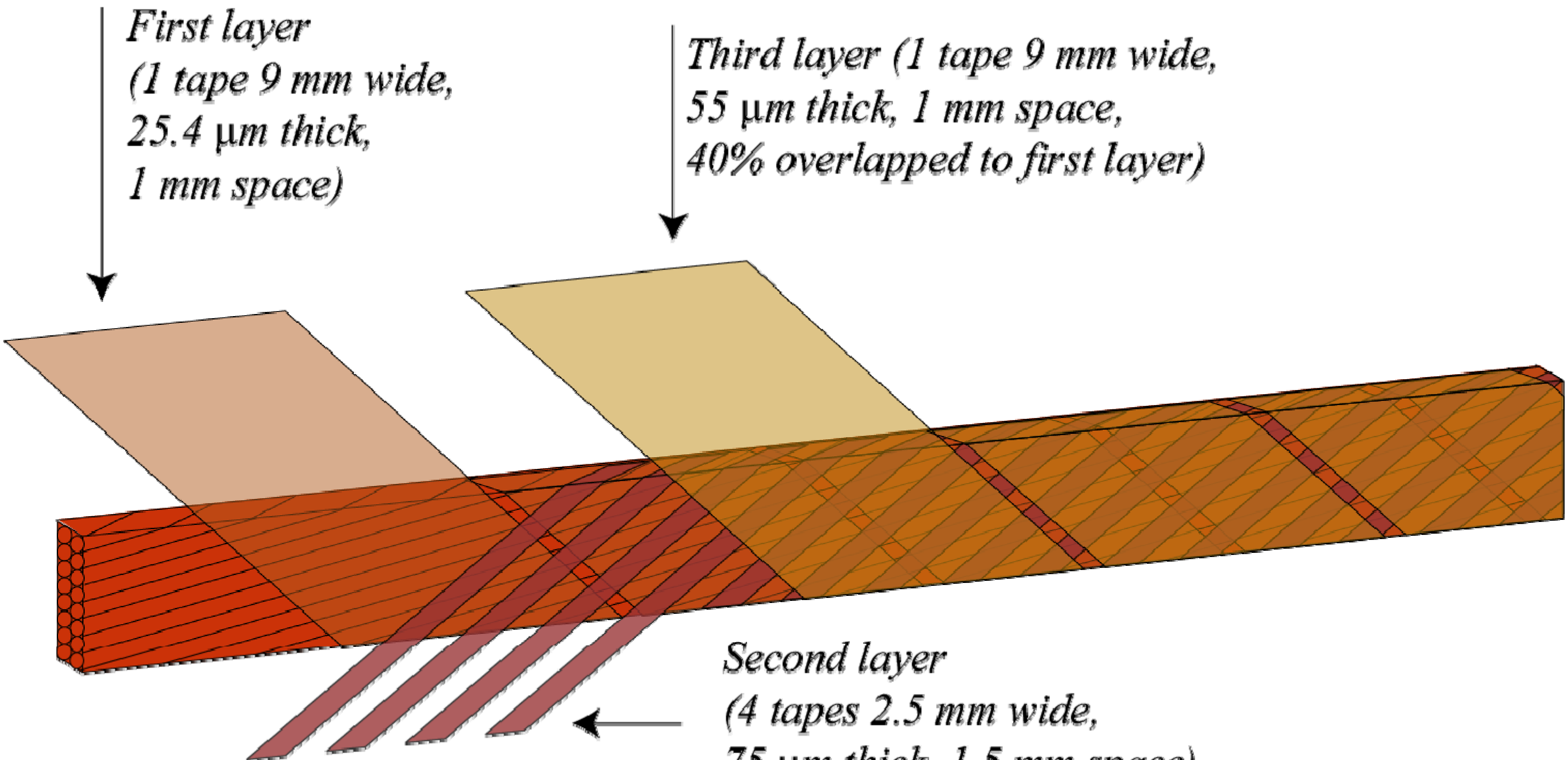
Assumptions:

- Negligible thermal boundary resistance at the strand-insulation interface [3,4]
- Parallel paths are decoupled
- Conductor and He II bath are isothermal
- He II heat transfer regime is Gorter-Mellink [5] (may lead to under-estimate [6]).

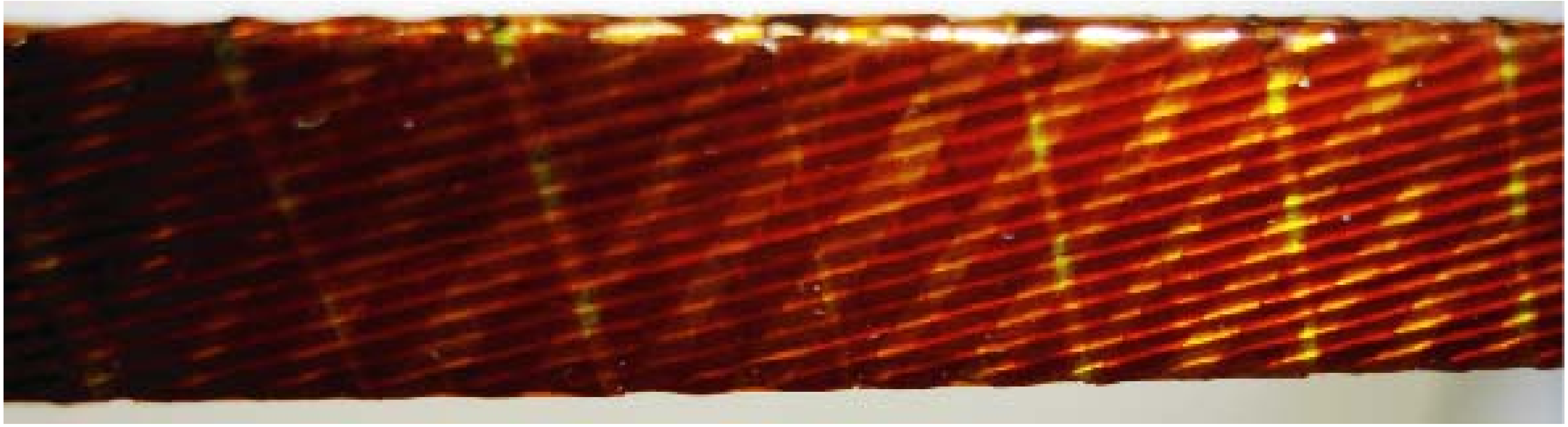
Comparison of Equivalent Thermal Resistances in an Insulated Cable



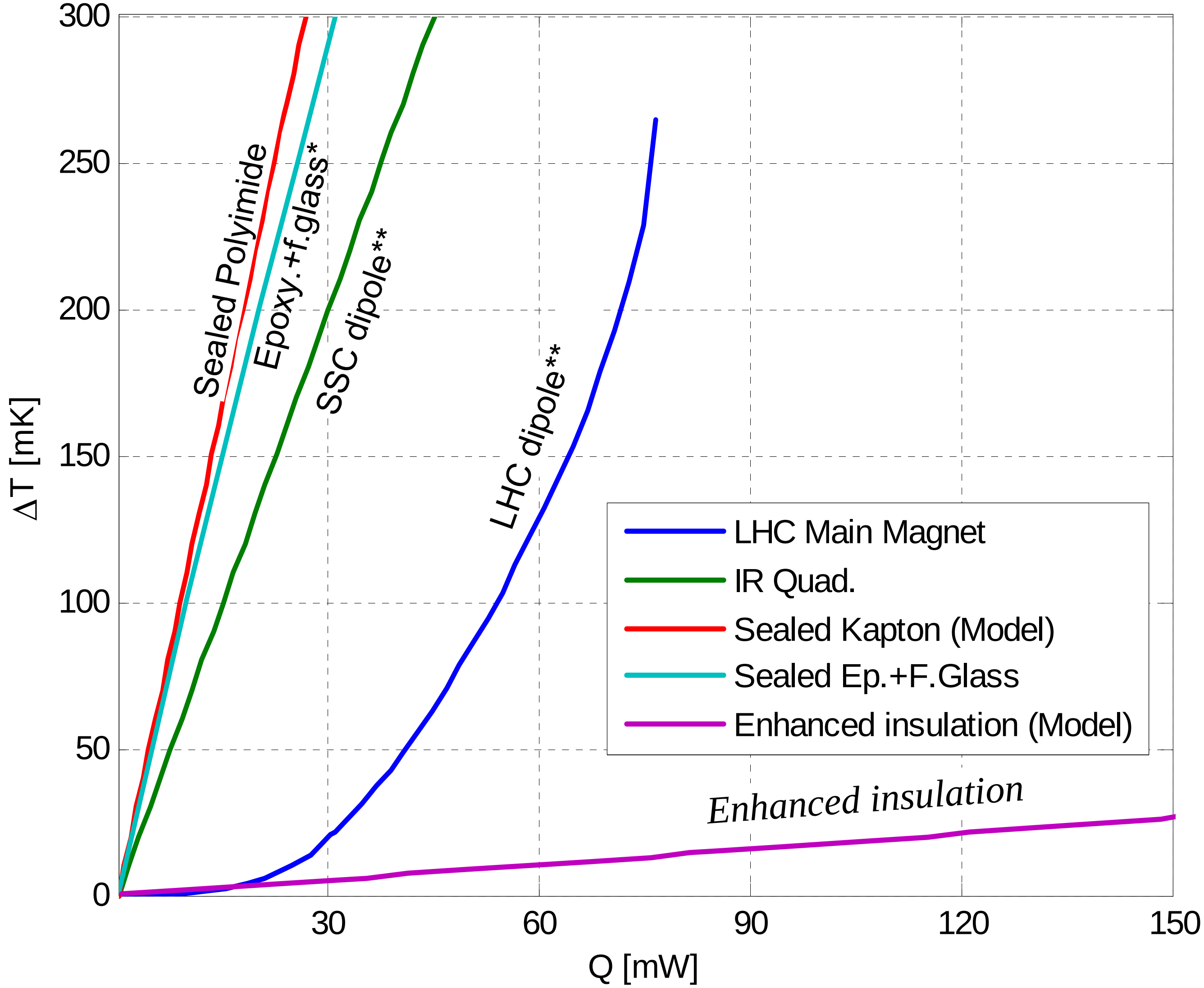
Enhanced Porosity



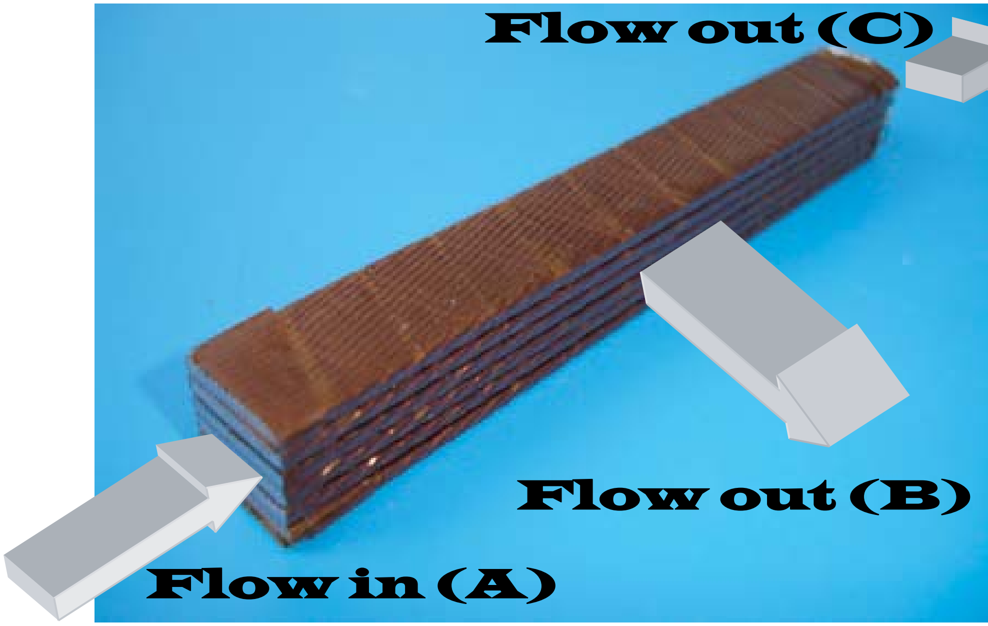
Enhanced Porosity

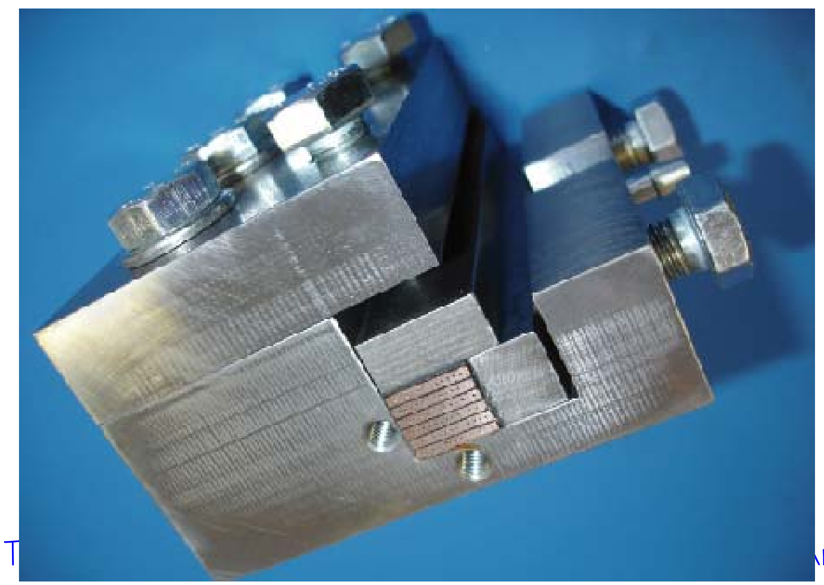


Summary of thermal transfer



Porosity tests

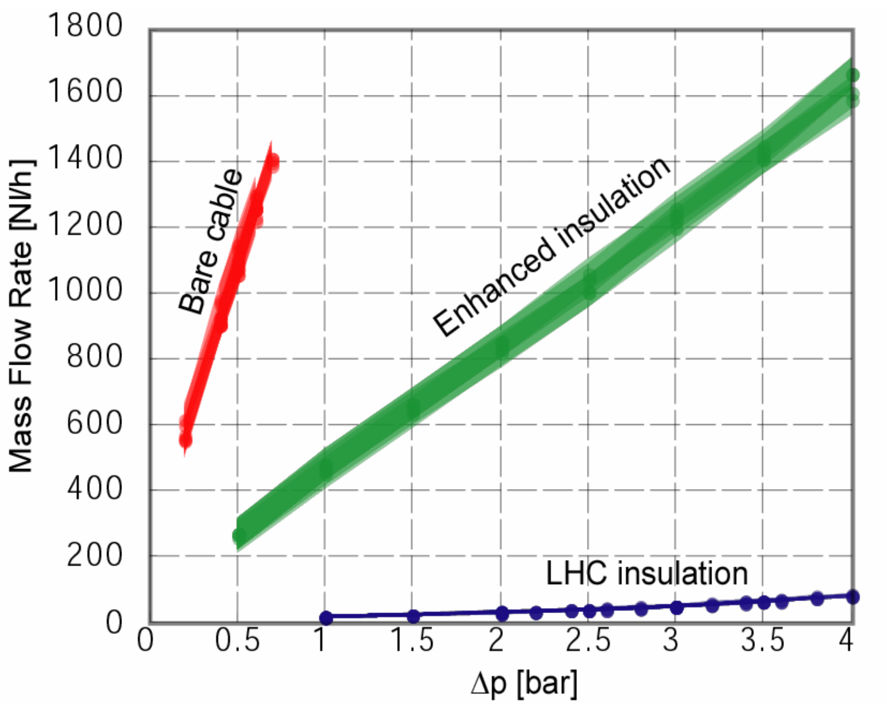




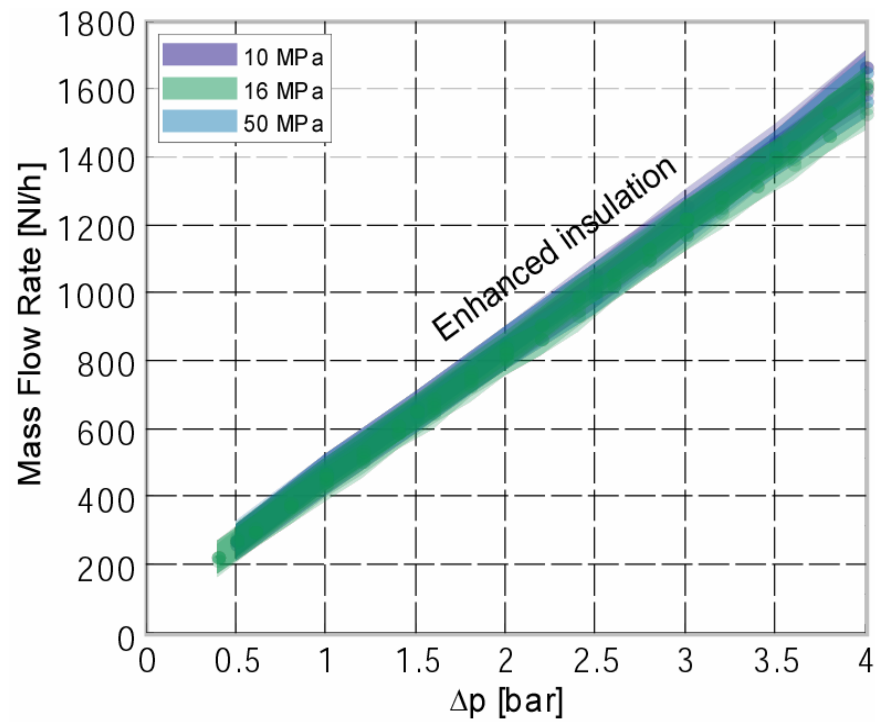
Tests Results: Radial flow

- We show the radial flow rate versus the imposed pressure difference ($\Delta P = P_{inlet} - P_{outlet}$).
- Porosity of enhanced insulation is one order of magnitude larger both at 10 and at 50 MPa vertical compression

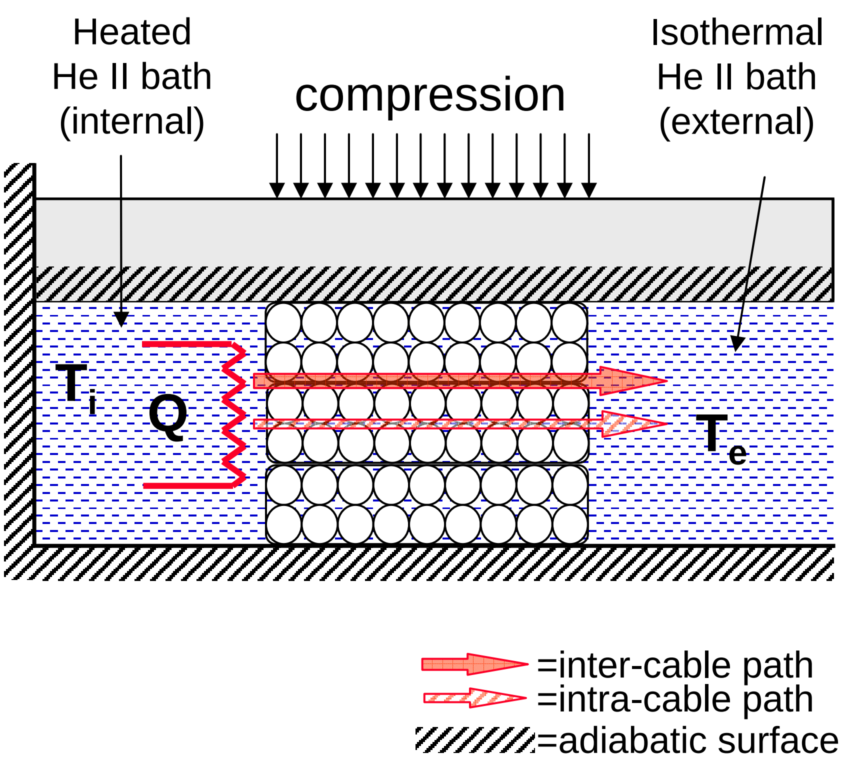
Vertical compression: 10 MPa

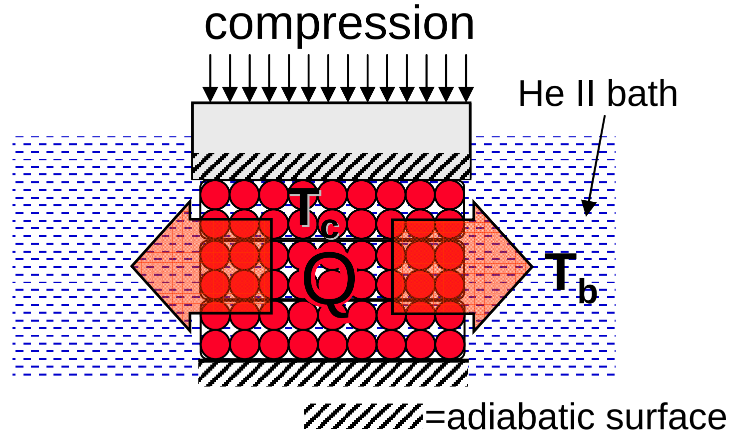


Vertical compression: 10-16-50 MPa

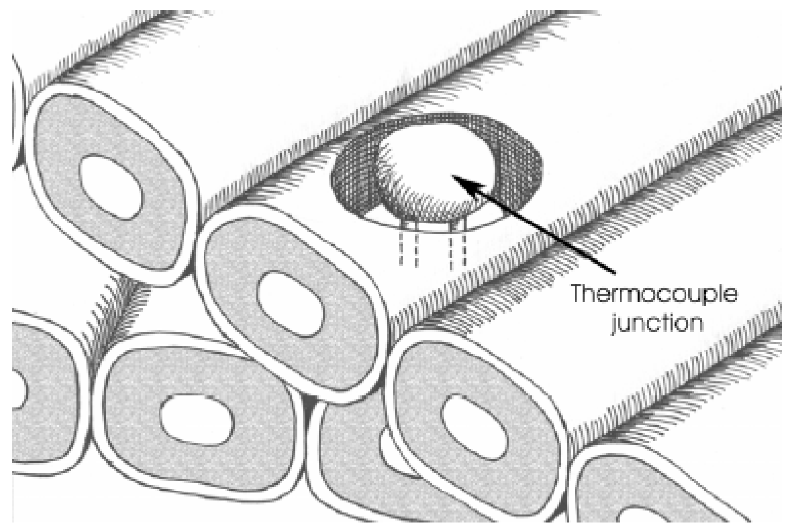


Heat Transfer Tests





Under way : at Cracow University and at CERN



Courtesy of D. Richter (CERN)

Summary

- The present limitation of heat removal from state of the art insulated NbTi Rutherford cables at 1.9 K is about 85 W/m^2 , corresponding to about 165 mW/m for a LHC main dipole turn.

- There is a large potential to increase the dimension of the cooling channels thus moving their saturation at higher heat fluxes

- This opens new opportunities for using NbTi rutherford cables in costeta structures operating at 1.9 K in presence of heat loads

Thermal Resistances Review

- Thermal boundary resistance at interfaces between different materials (Kapitza):

  We use empirical fits q [W/m^2] ,T [K],

  - Cu-He II: $q = 460(T_{Cu}^{3.46} - T_{He}^{3.46})$, [7]
  - Kapton-He II: $q = 47.43(T_{Kap}^{4} - T_{He}^{4})$, [8] verified for small ΔT, we use it also for epoxy
  - Cu-epoxy: $q = 1300_{2K} \div 3600_{6K}(T_{Cu} - T_{Ep})$, [2] consistent with [3]

- Conduction in solids:

  - Kapton: K=4.638e-3*T.^0.5678 [8] verified for 0.5<T<5K
  - Epoxy+fiberglass: $K = 0.6 * K_{Ep} + 0.4 * K_{G10}$, ($K_{Ep}$ & K_{G10} from [9] consistent with [3] and [10])

- He II thermal conductivity

  We consider a fully developed Gorter-Mellink regime [4] (conservative hypotheses [5])

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