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SACM



saclay

*Annual meeting
CARE07
29-31 October 2007*

Advances in Heat Transfer in High Field Accelerator Magnet



*B. Baudouy
CEA/Saclay - Dapnia/SACM*

- Heat transfer in superconducting magnets for accelerator

- The NED Heat Transfer program
 - Double-bath cryostat for NED
 - Test facilities

- Experimental results
 - Technical solution tests
 - Tests on NED electrical insulations
 - the classical insulation
 - the innovative insulation

- People in and around NED HT program
 - J. Polinski, F. Rondeaux (CEA), S. Canfer (RAL)
 - N. Kimura (KEK)
 - D. Richter (CERN)
 - F. Michel (CEA - Grenoble)

Heat transfer in accelerator magnets (1/2)

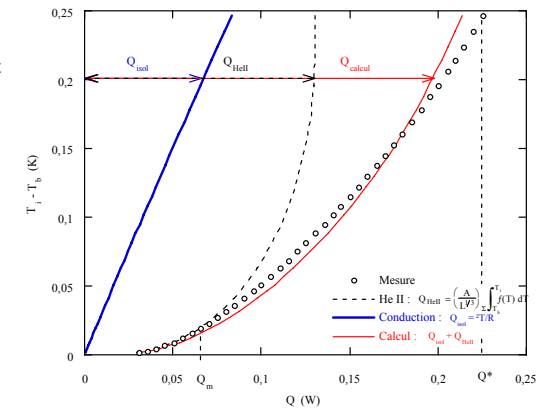
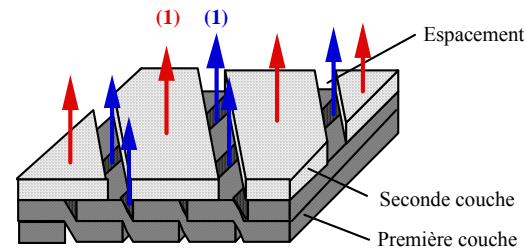
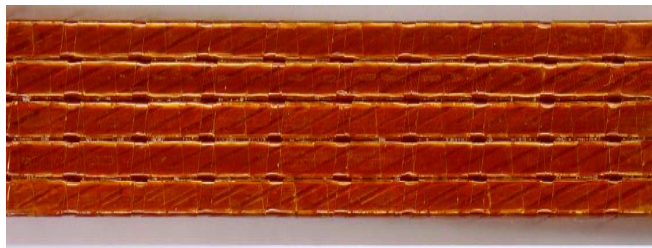
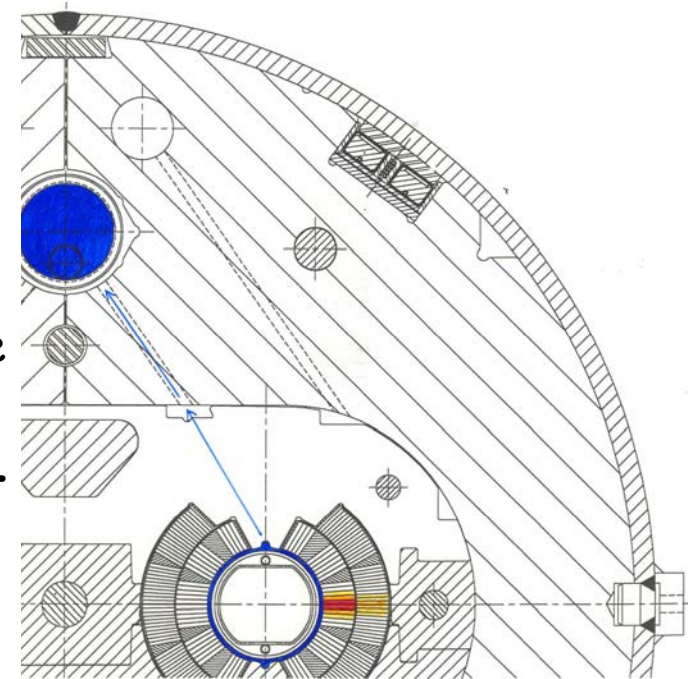
- “Wet” magnets with “heat exchanger”
 - Large internal losses and smaller stored energy
 - Single phase coolant in contact with conductor
 - Cooling Source: Internal tube flow heat exchanger

□ Heat transfer between the conductor and the cooling source determines the temperature margin

□ Electrical insulation constitutes the largest thermal barrier

□ LHC Electrical Insulation : All-polyimid

- 10 mW/cm³ or 0.4 W/m (cable)
- $\Delta T < 0.3$ K with permeable insulation or $\Delta T \sim 4$ K with monolithic insulation
- He II + Conduction

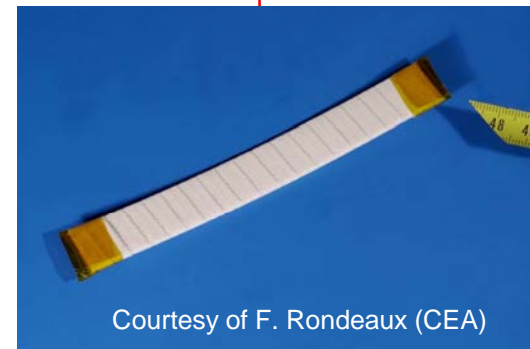
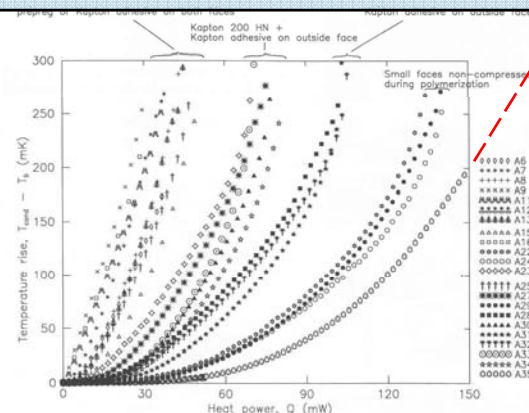


Heat transfer in accelerator magnets (2/2)

- "Beam losses" of LHC upgrade with Nb₃Sn Magnets
 - 50 to 80 mW/cm³ or 2 to 3 W/m (cable) → ΔT~ K with polyimide insulation
 - **Dry insulation for Nb₃Sn Magnets !**

- **Development of "innovative" ceramic insulation**
 - Thermal treatment (insulation+Nb₃Sn, easier and less costly construction)
 - Fiberglass + ceramic precursor (CEA patent)
 - Higher heat transfer rate, larger He volume in the insulation (Cp) and heat exchange surface increase (matrix participation)

	Ceramic	Classic (Polyimid)	Full impregnation
Pore size	d~100 μm (peak)	10 to 100 μm	-
Porosity ε	4.5 to 29 %	~1 %	-
Conductivity	k≈4 10 ⁻² W/Km	k _{kapton} ≈10 ⁻² W/Km @ 2 K	- k _{epoxy} ≈10 ⁻² W/Km



The NED heat transfer program

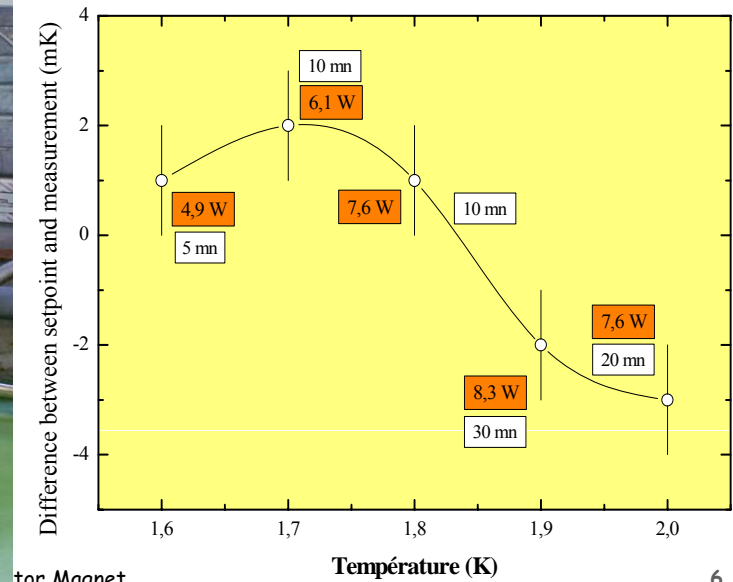
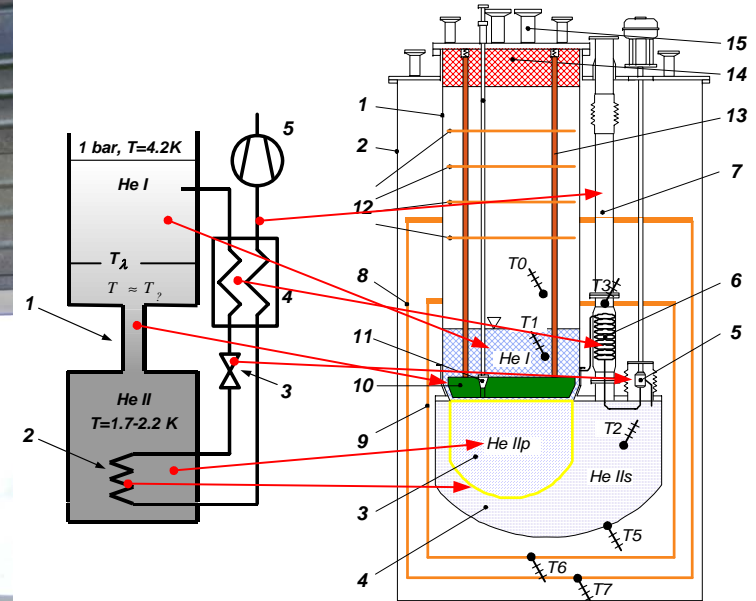


- Characterization of the thermal performance of the magnet insulation
 - **Classical** insulation and **Innovative** insulation
 - "real situation" (coil) and on the insulation itself
- Construction of a pressurized He II double bath cryostat
- The drum experiment
 - Determination of the thermal conductivity and Kapitza resistance
- The stack experiment
 - Test on a stack of conductors closed to the coil mechanical, geometrical and heat transfer configurations
- Collaboration CEA-Saclay, KEK, CERN and RAL
 - Tests in He II at CERN and Saclay, Tests in SHe at KEK (**N. Kimura**)
 - Construction of a Double bath Cryostat (WUT and CEA-Saclay) (**J. Polinski**)
 - Construction of molds by KEK (**N. Kimura**)
 - Collaboration with **D. Richter** at CERN

The NED Double bath Cryostat



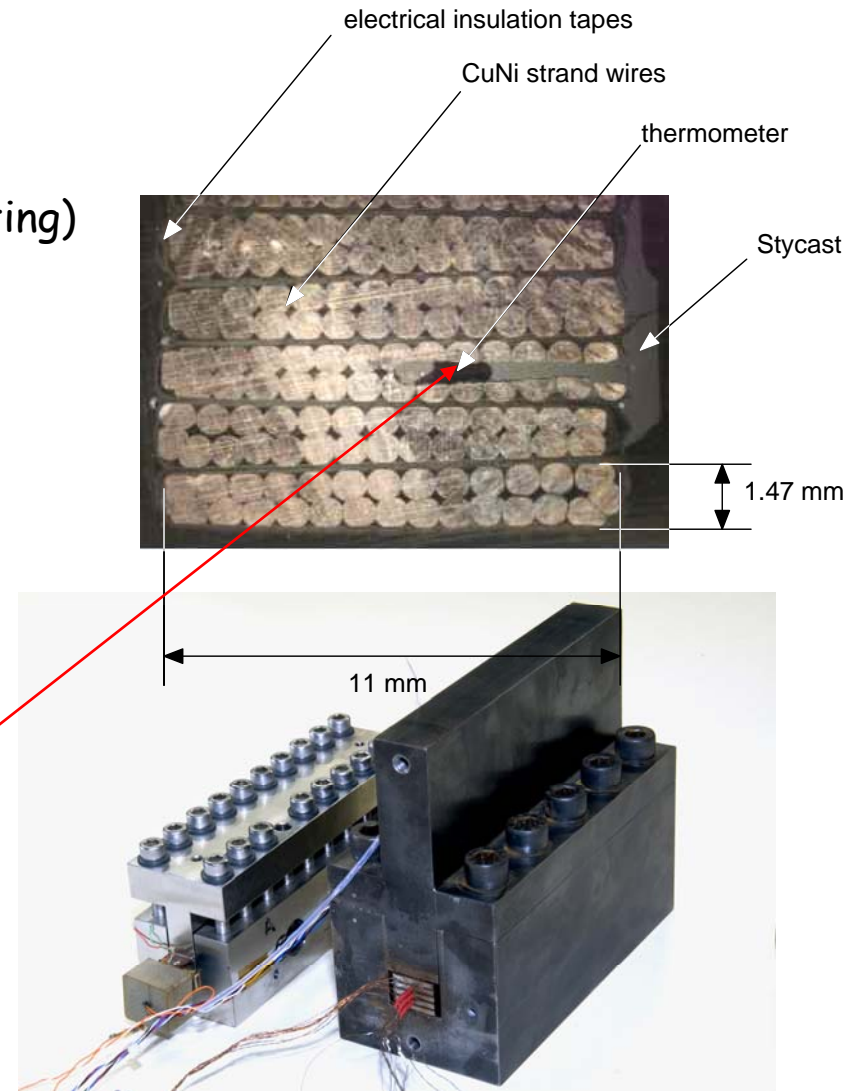
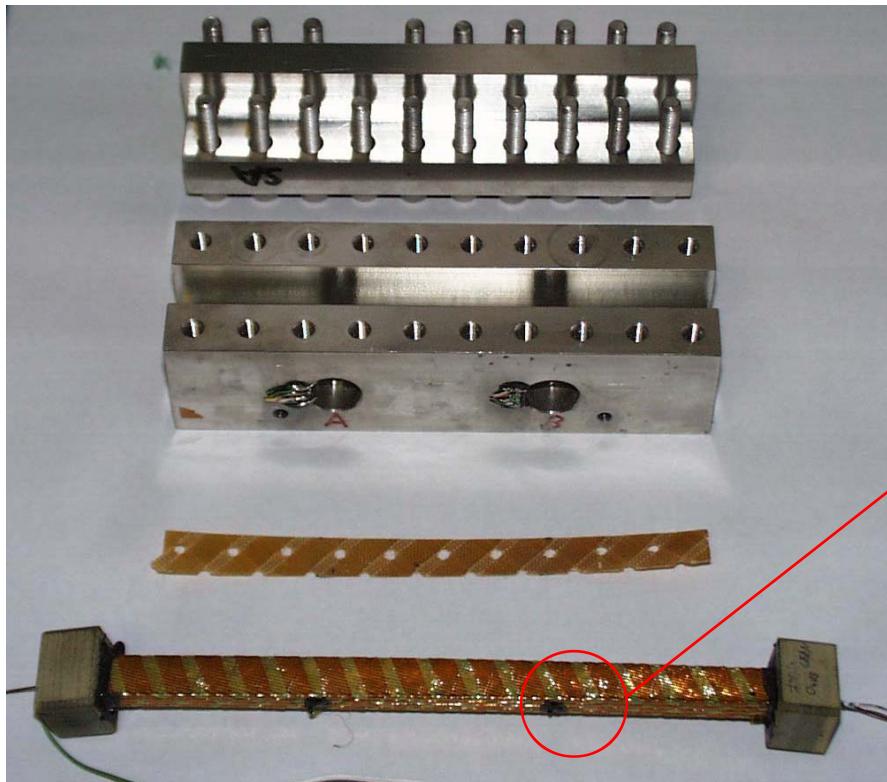
CEA Saclay and WUT



for Magnet

The Stack Experiment

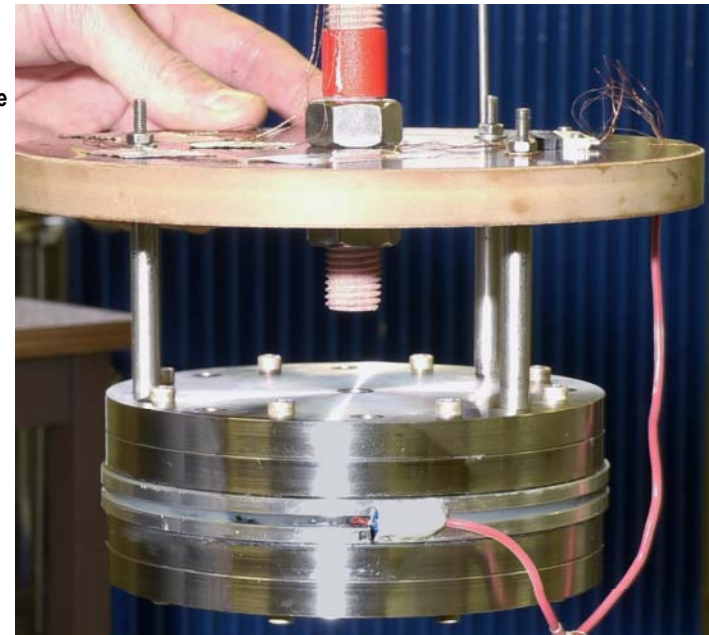
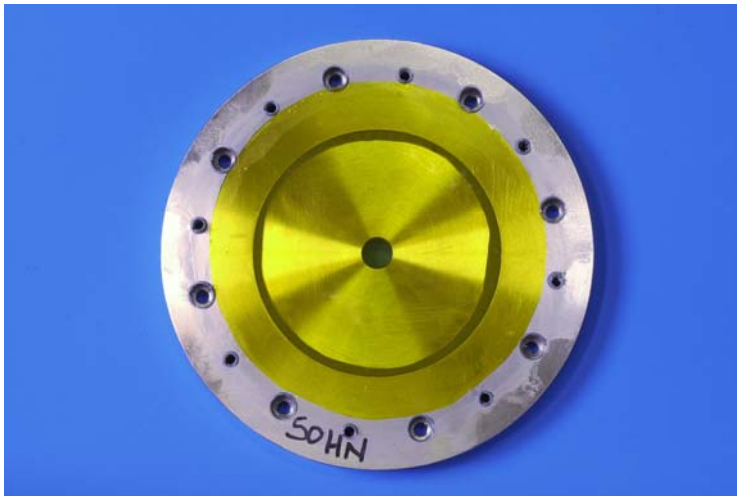
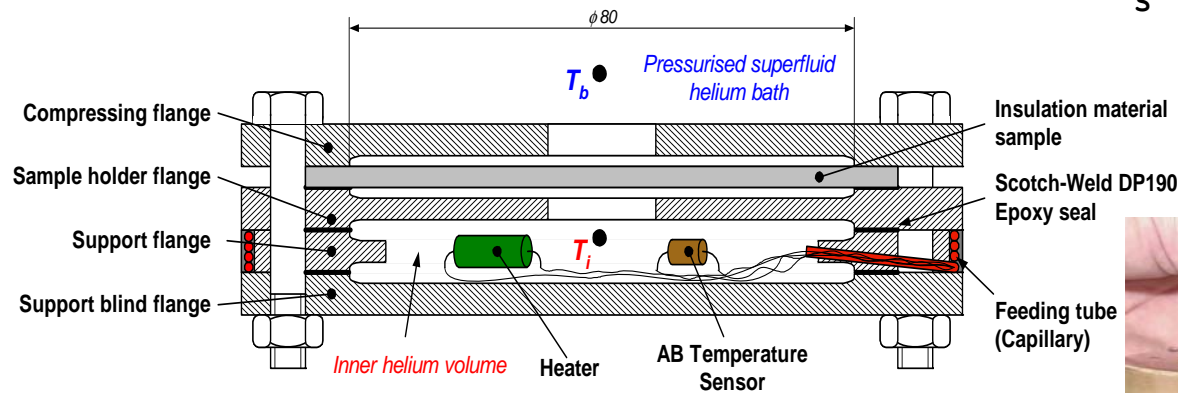
- Characterization of the thermal performance of the magnet insulation
 - "real cable" geometry (CuNi cable)
 - Real electrical insulation
 - Mechanical constraints (compression)
 - Heat transfer configuration (Joule heating)



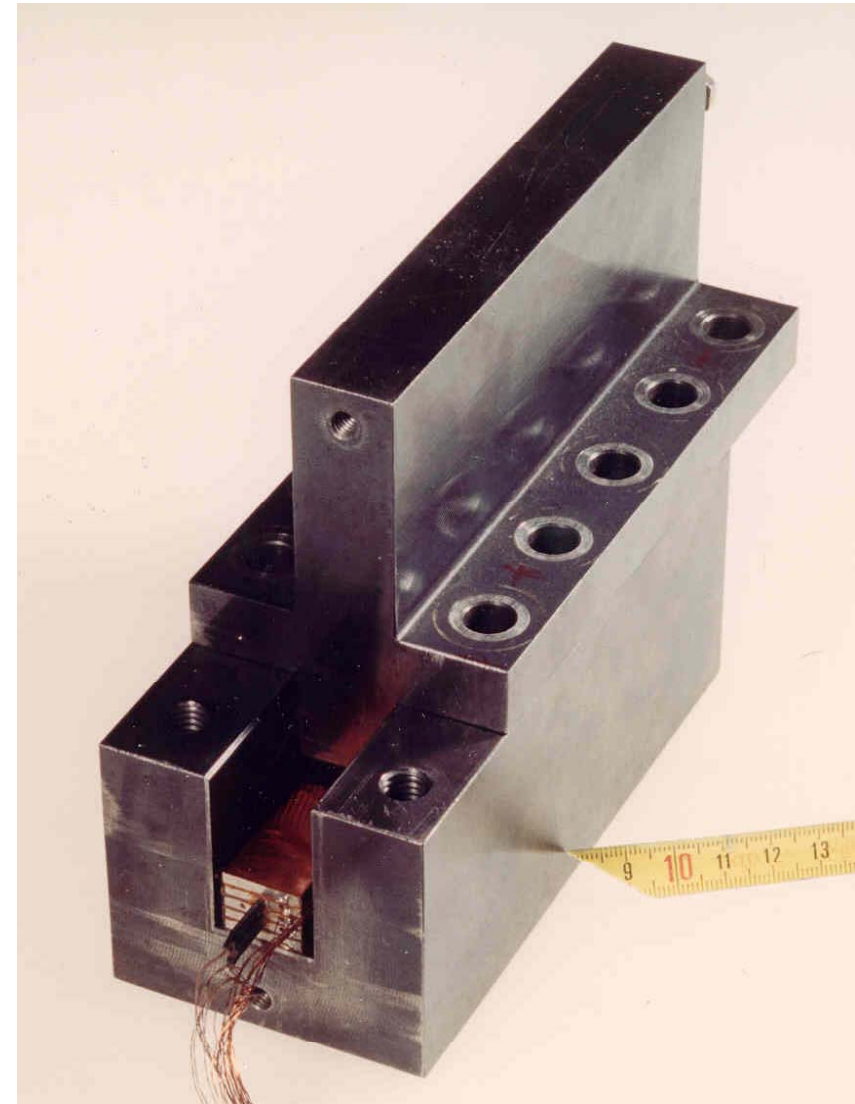
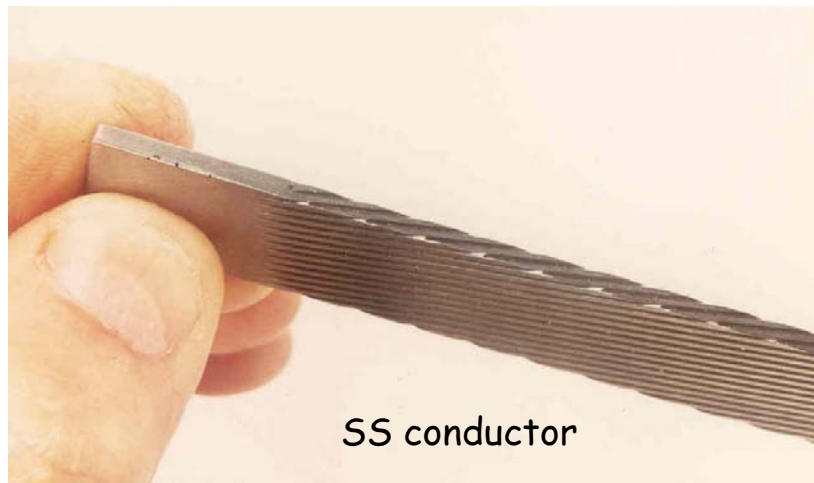
The Drum experiment

- Heat transfer measurement perpendicular to the insulation (1 D)
 - Determination of the thermal conductivity
 - Determination of the Kapitza resistance

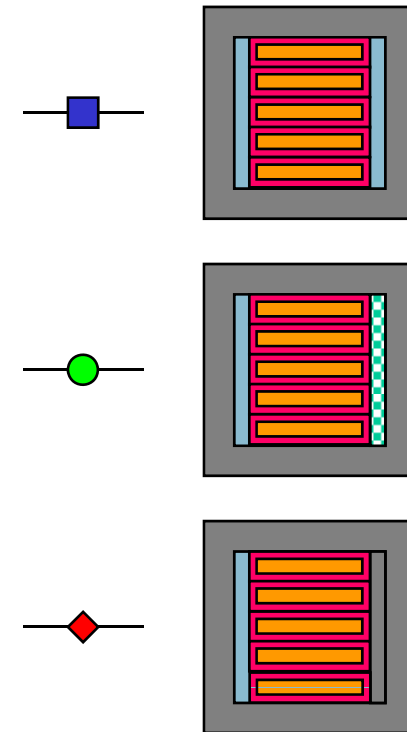
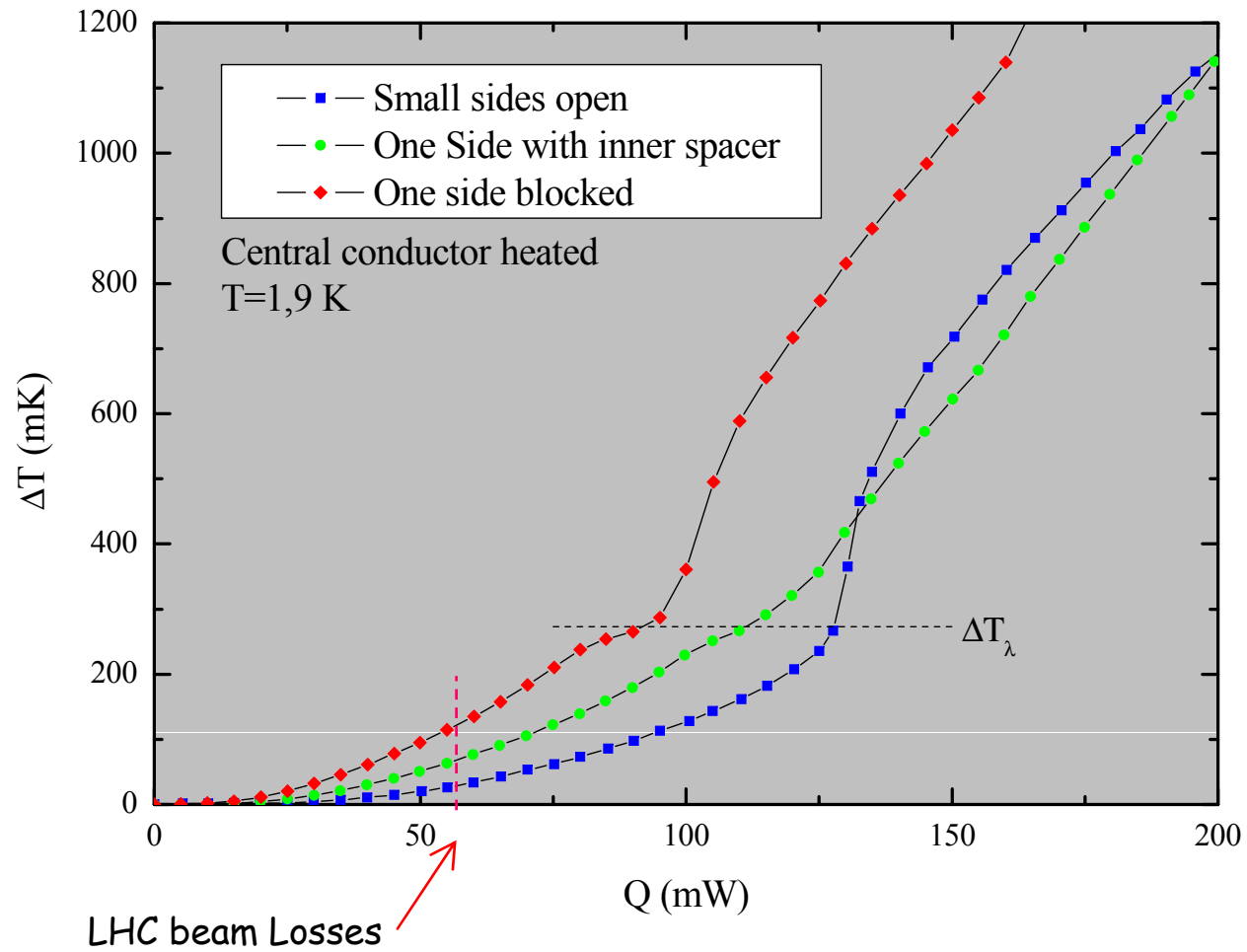
$$R_s = \frac{A\Delta T}{Q_s} = \frac{2}{n \cdot h_K \cdot T_b^{n-1}} + \frac{e}{\lambda}$$



- Test with a "Saclay stack"
- Central conductor heated
- Insulation all polyimide (Kapton)
 - 1st layer : Kapton 200 HN 50 μm x 11 mm
2 wrappings (no overlap)
 - 2nd layer Kapton 270 LCI 71 μm x 11 mm
2 mm gap
- 60 MPa



Technical solution tests (2/2)



Tests on the classical insulation

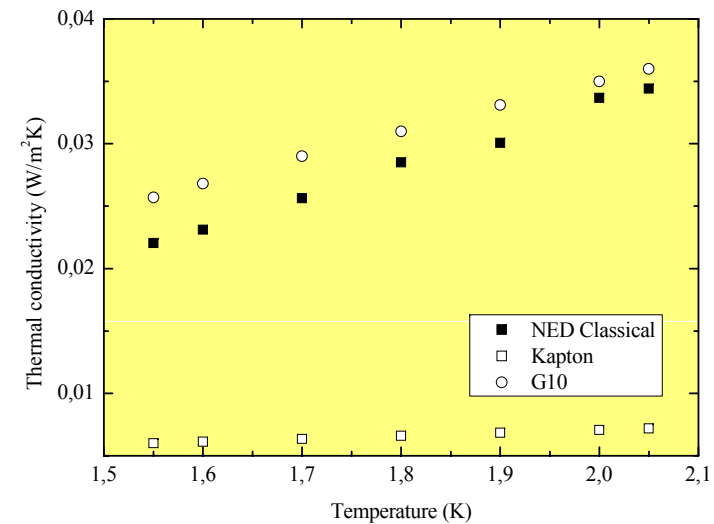
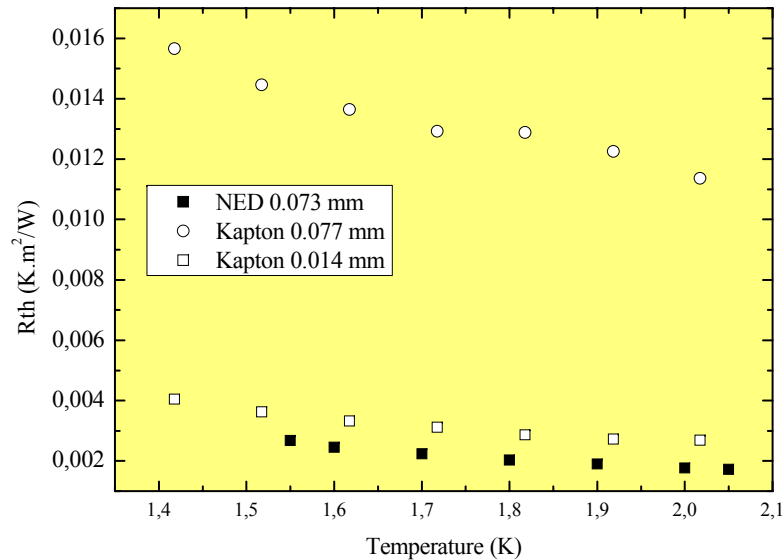
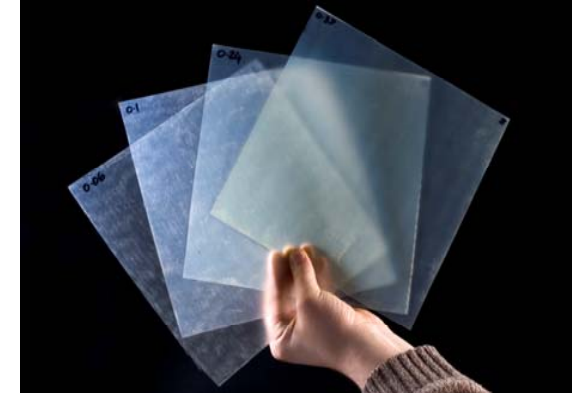
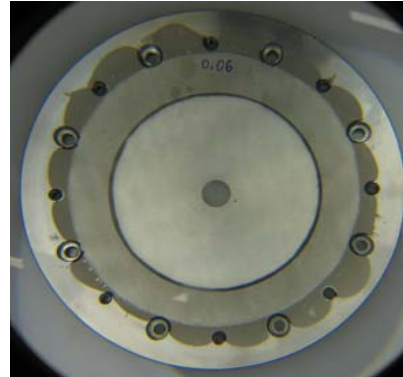
- Glass-fibre epoxy insulation

- Developed by RAL

Insulation Development for the Next European Dipole, S. Canfer et al., MT20, Philadelphia, USA, 2007

- Determination of λ and R_{Kapiza}

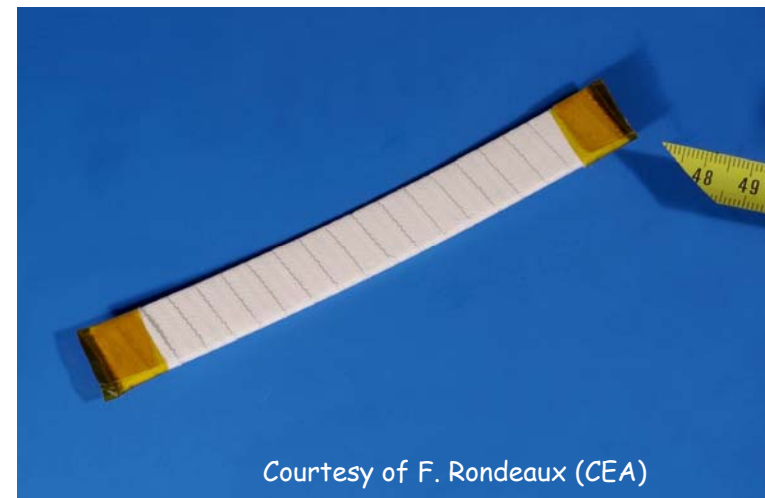
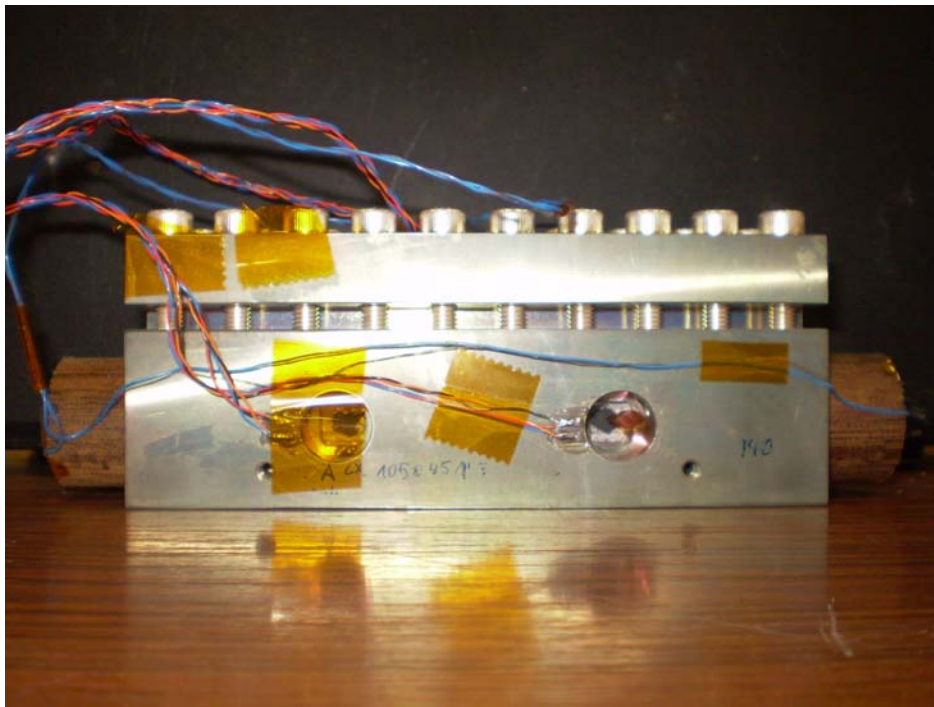
- To be published



Low temperature heat transfer properties of conventional electrical insulation for the Next European Dipole, J. Polinski et al., CEC 2007, Chattanooga, USA, 2007

Tests on the Innovative insulation (1/2)

- One wrapping with 50% overlap
- Heat treatment of 100 h at 660 °C
- **10 MPa compression only !**
- 5 conductors heated



Courtesy of F. Rondeaux (CEA)

Tests on the Innovative insulation (2/2)

- Very small ΔT , at least **one order of magnitude smaller** than for the LHC insulation tests

