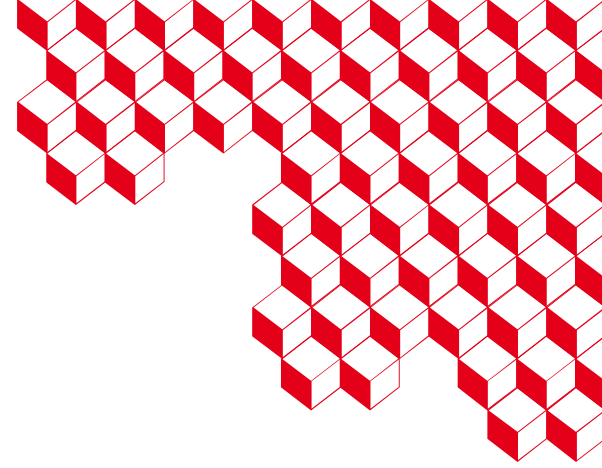




irfu



R2D2 coils insulation : the impact of the sizing

CEA Paris-Saclay

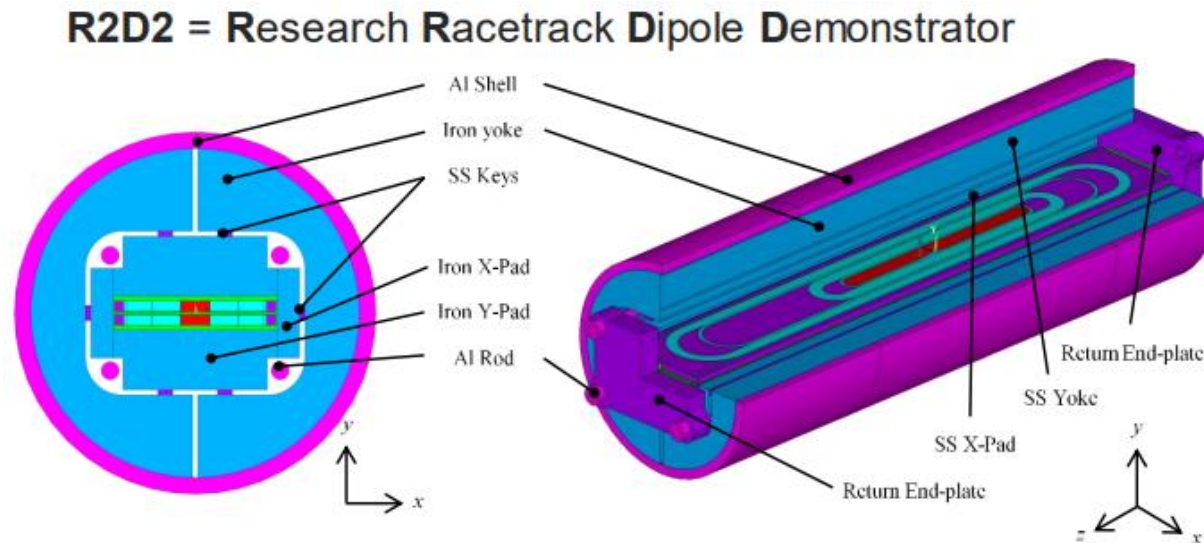
*Jeremy Faucheux, Françoise Rondeaux, Maria Durante, Simon Perraud,
Etienne Rochepault*

CERN HFM Insulation WG#4

January 30th 2025

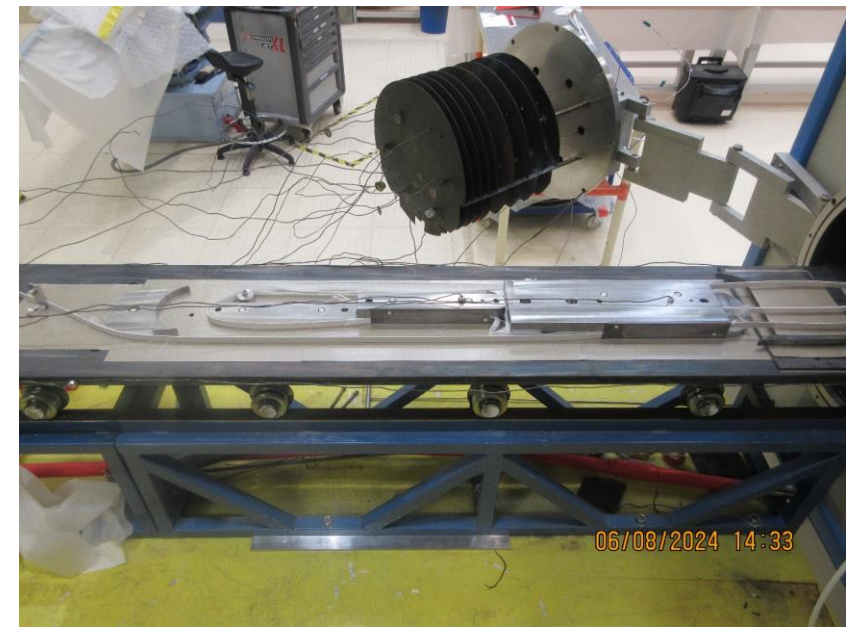
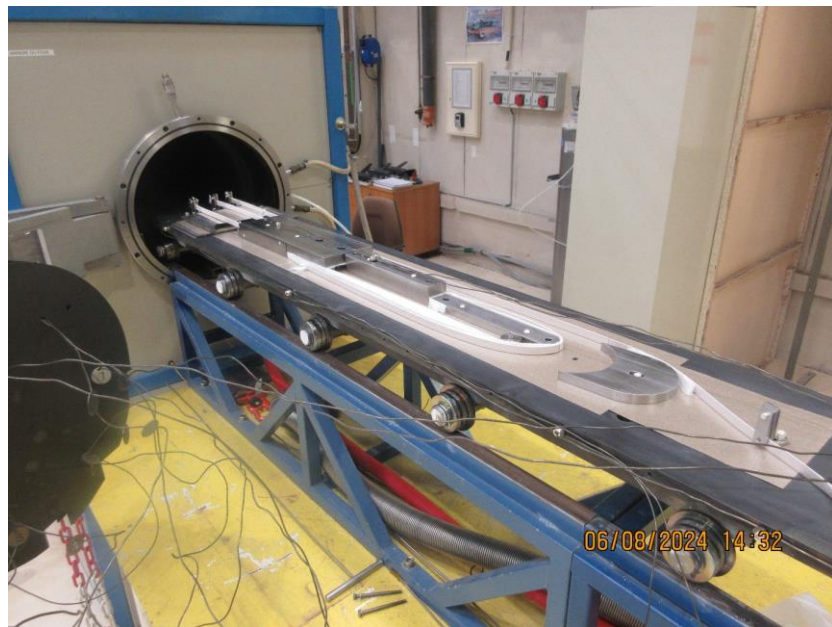
Context and Goal

- R2D2 1st coil CR01 showed electrical shortcuts after curing ($<200\Omega$)
- Undetectable by employed means before heat treatment
- Coils manufacturing is stopped until we unveiled the defect and fix it





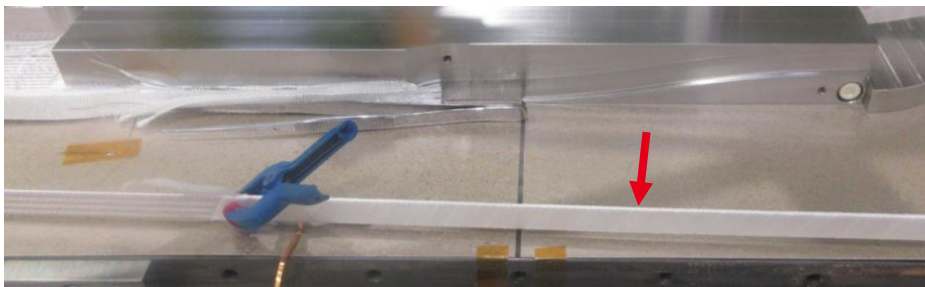
1st hypothesis : worn fiber glass inside layer jumps during heat treatment



R2D2 fibre glass

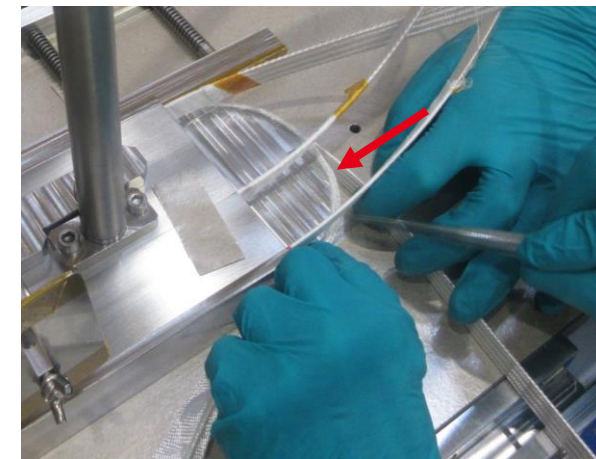
Hiltex 0,1mm thick sizing ?

- S2
- 15mm large
- Used in layer jumps
- 2 layers wrapped around the cable with 2mm gap between each



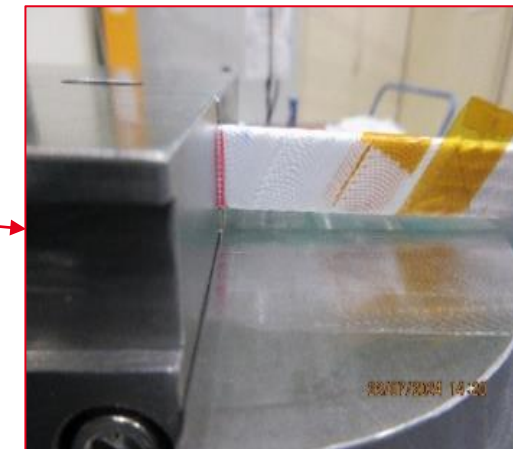
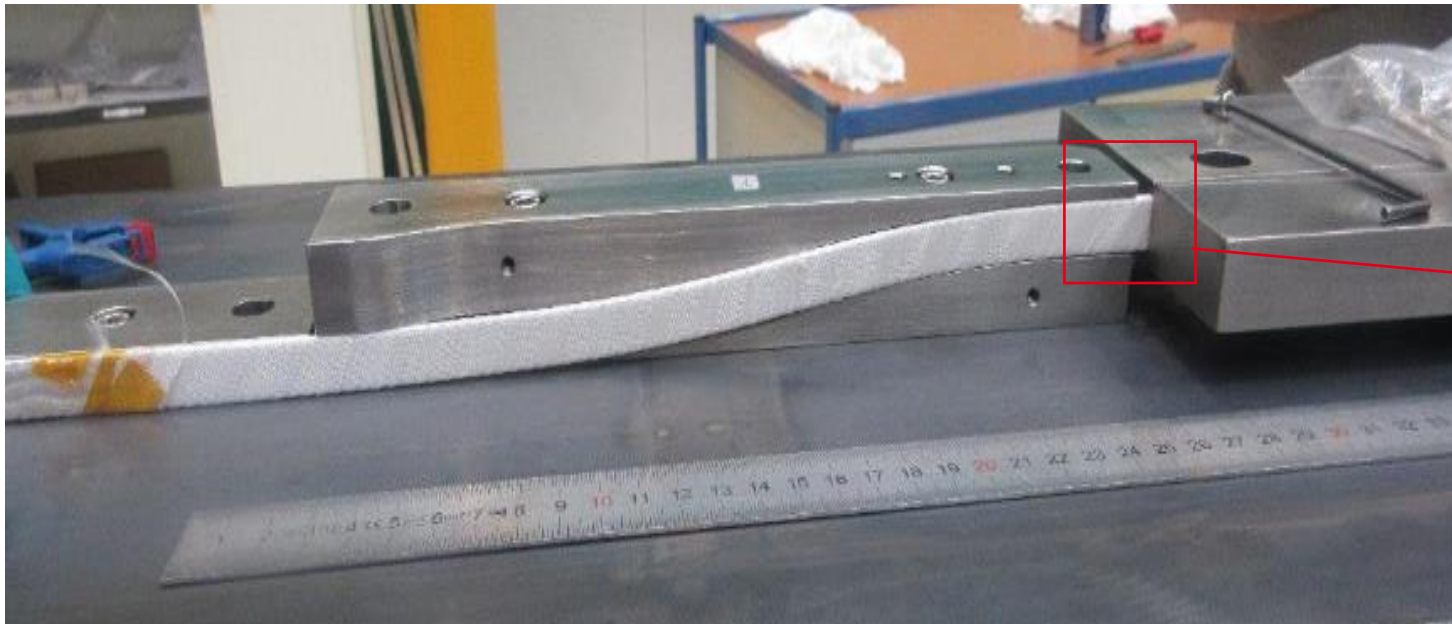
Tisstech 0,2mm thick sizing 493

- S2 66/66-20
- 13mm large
- Used in end shoes
- 3 layers placed between the cable and the stainless steel part



Traction trials

- Quantify which tension is needed to let the cable slide → 2 possibilities
 - Glass fiber wearing (due to the groove design)
 - Cable strain (overconstraint during heat treatment)
- HF Cu conductor wrapped with 2 Hiltex glass fiber layers 0,1mm thick (same conditions as CC01 and CR01)



Traction trials

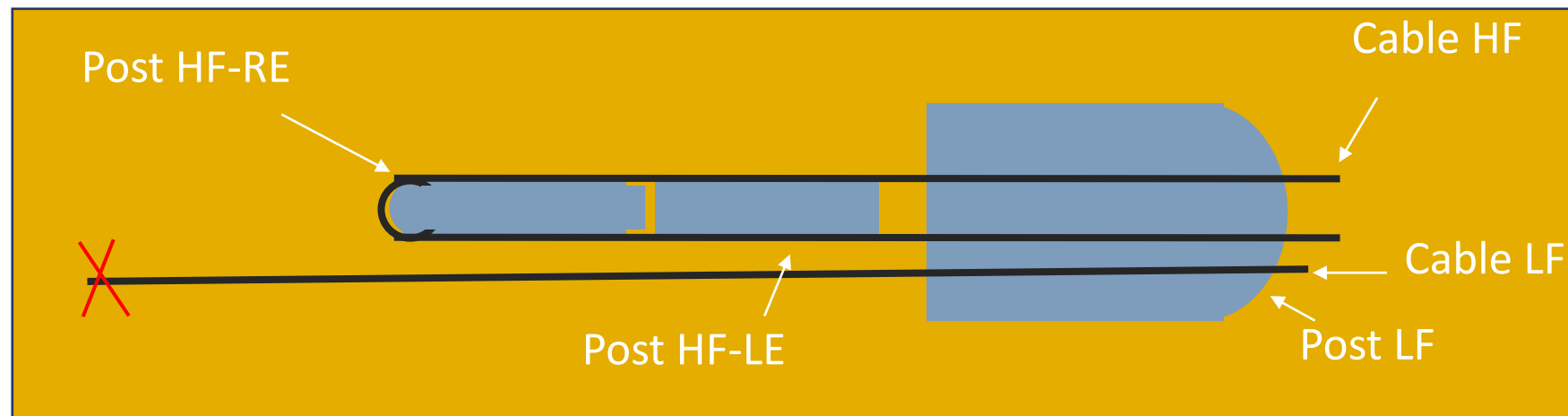
- Trial at 15kg (usual winding conditions) : cable sliding
- Trial at 15kg with 3 Hiltex glass fiber layers 0,1mm thick : no sliding
- Trial > 22kg with 3 Hiltex glass fiber layers 0,1mm thick : no sliding

→ Add more insulated layers to avoid sliding and fiber glass wearing

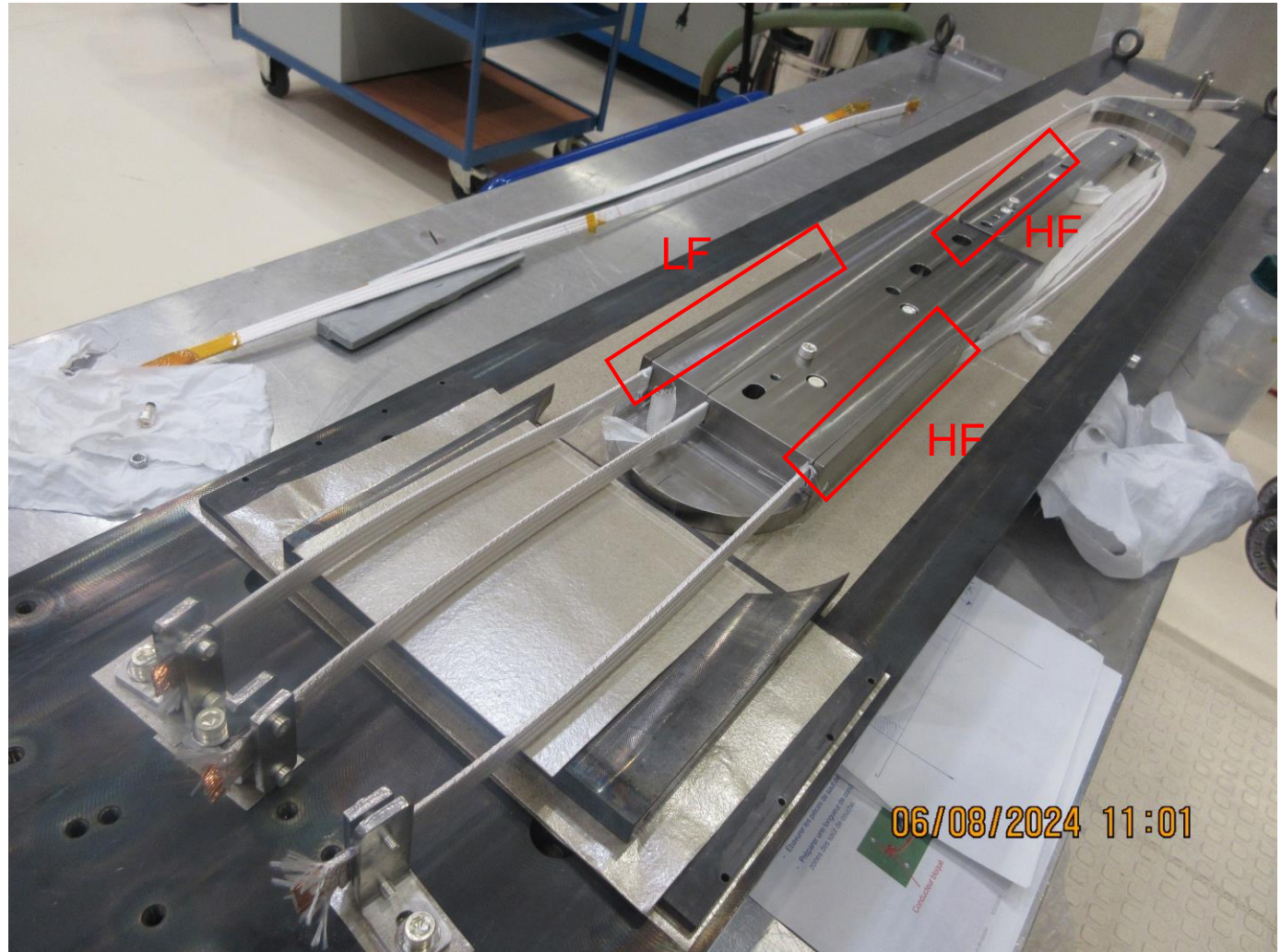
Heat treatment 1 – CR01 conditions

SETTINGS

- Heat treatment set for 50h at 650°C
- Samples :
 - Nb₃Sn HF cable wrapped with 2 Hiltex glass fiber layers 0,1mm thick in 2 layer jumps
 - Nb₃Sn LF cable wrapped with 2 Hiltex glass fiber layers 0,1mm thick in 1 layer jump



Heat treatment 1 – CR01 conditions



Heat treatment 1 – CR01 conditions

RESULTS

- 8mm sliding from layer jumps, no worn fibre glass
- Electrical tests
 - Continuity OK
 - 0,5 Ω cable resistance
 - Localized defaults with 4 wires measurements (+-12mm precision)
 - Insulation measurements
 - >1G Ω before treatment
 - \approx 10k Ω after



→ Increase number of layers to avoid sliding and keep a suitable insulation

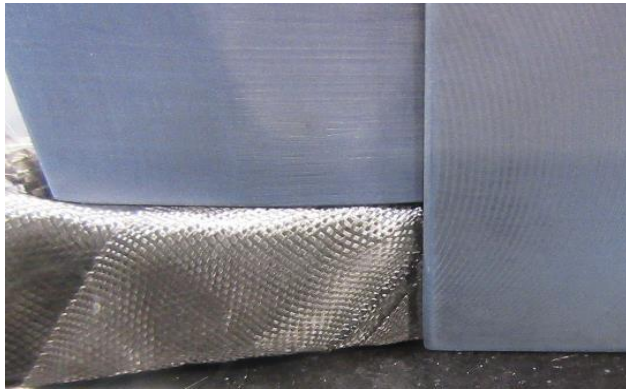
Heat treatment 2 – 5 fibre glass layers

SETTINGS

- Same as previously with 5 Hiltex glass fiber layers 0,1mm thick (2mm gap between each) in each layer jump

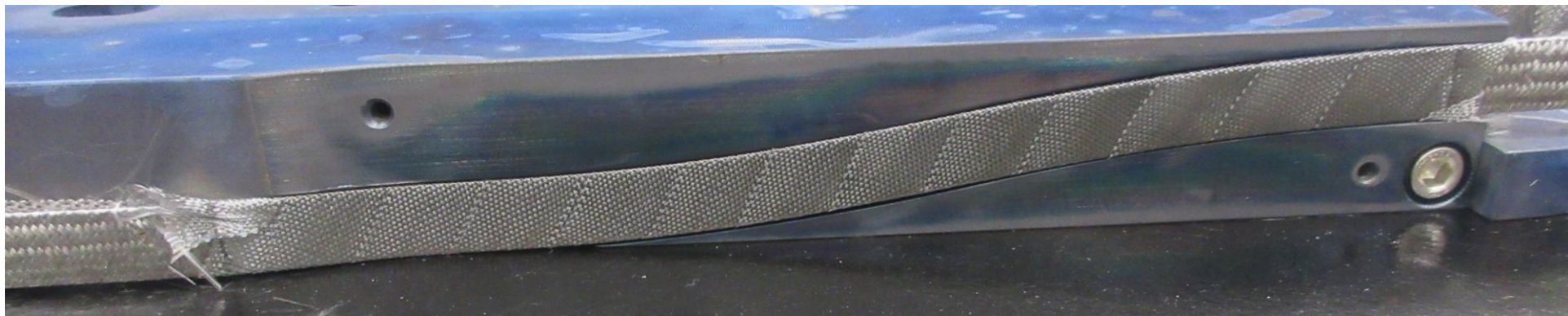
RESULTS

- No sliding, no worn fibre glass
- Electrical tests
 - Continuity $<1\text{k}\Omega$
 - $0,5\Omega$ cable resistance
 - Same localized defaults with 4 wires measurements
 - Insulation measurements
 - $0,6 < x < 2,5\text{G}\Omega$ before treatment
 - $150 < x < 460\Omega$ after
- Bonus tests
 - Shims removed from layer jumps : $<10\text{k}\Omega$ / 5 fiber glass removed from conductor : $24,6\text{k}\Omega$ / 2 new unreacted 0,1mm Hiltex fibre glass added : $108\text{M}\Omega$ / 2 new 0,2mm reacted Tisstech fibre glass added : $100\text{M}\Omega$
 - Darker visual aspect in layer jumps than previous treatment → **sizing reaction during heat treatment**





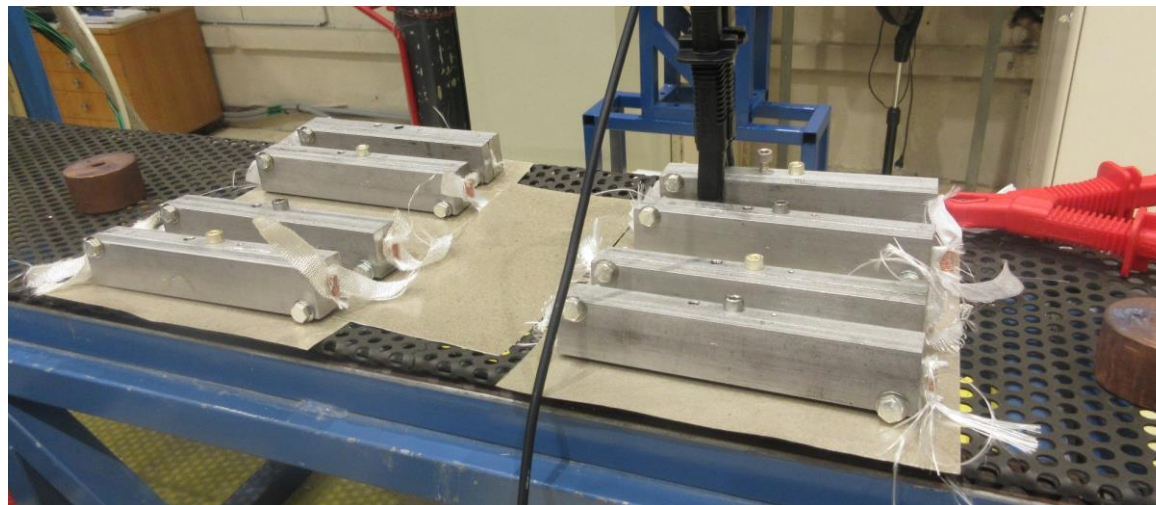
2nd hypothesis : differences in Hiltex and Tisstech fibre glass desizing



Heat treatment 3 – mini layer jumps

SETTINGS

- Test multiple configurations (increase trials statistics) with 8 mini straight layer jumps manufactured (180mm long, reacted HF Cu cable used, 2 layers per configuration)
 - 2 desized Hiltex 0,1mm thick layers
 - 2 sized Hiltex 0,1mm thick layers
 - 2 desized Tisstech 0,2mm thick layers
 - 2 sized Tisstech 0,2mm thick layers



Desizing process : 16h at
350°C under atmospheric
conditions

Heat treatment 3 – mini layer jumps

RESULTS

Sample	Insulation before reaction (Ω)	Insulation after reaction (Ω)
Conditions	15,9°C/82,4%	17°C/82,1%
Desized Hiltex DH1	45,5M	363M
Desized Hiltex DH2	79,4M	43,7G
Desized Tisstech DT1	28,6M	>150G
Desized Tisstech DT2	40,2M	>150G
Hiltex H1	523M	757k
Hiltex H2	312M	1,25M
Tisstech T1	34,3M	11G
Tisstech T2	35,1M	9G

→ Desizing shows good insulation measurements that will be confirmed (or not) with impregnation

Impregnation and dielectric – mini layer jumps

RESULTS

Sample	Insulation before reaction (Ω)	Insulation after reaction (Ω)	Insulation before impregnation (Ω)	Insulation after impregnation (Ω)
Conditions	15,9°C/82,4%	17°C/82,1%	17,4°C/81,7%	18,1°C/73,8%
DH1	45,5M	363M	185,9M	1,133G
DH2	79,4M	43,7G	506M	>150G
DT1	28,6M	>150G	128,8M	>150G
DT2	40,2M	>150G	169,7M	>150G
H1	523M	757k	3,32M	935k
H2	312M	1,25M	2,97M	2,04M
T1	34,3M	11G	109,1M	42,1G
T2	35,1M	9G	253M	40,4G

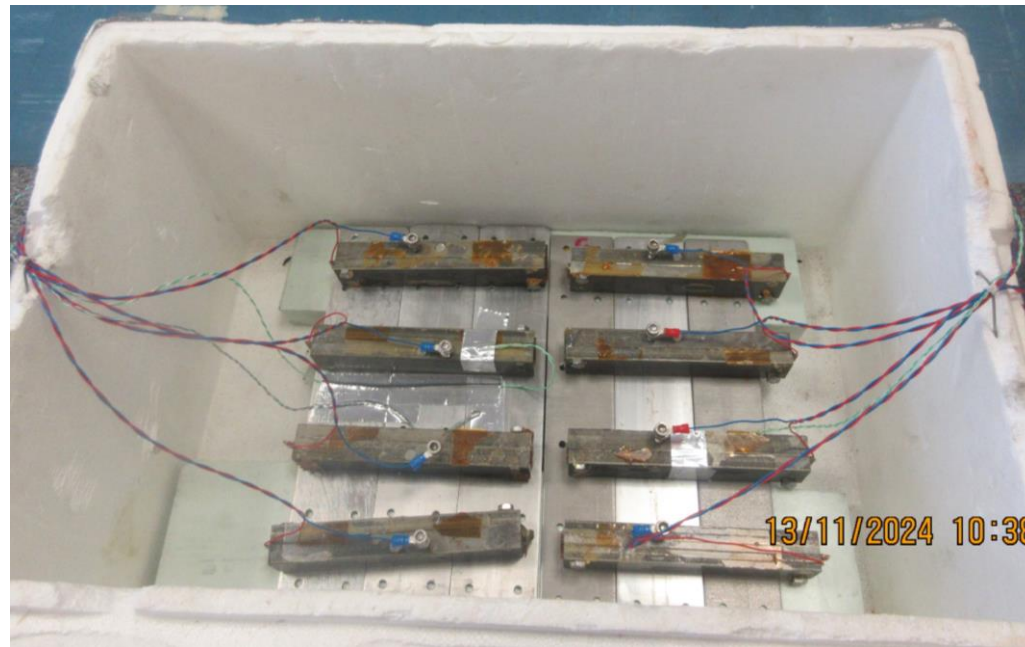
- Room's hygrometry has an influence on insulation measurements

→ Desized Hiltex fibre glass is chosen for next step with R2D2 layer jumps

Dielectric at 77K – mini layer jumps

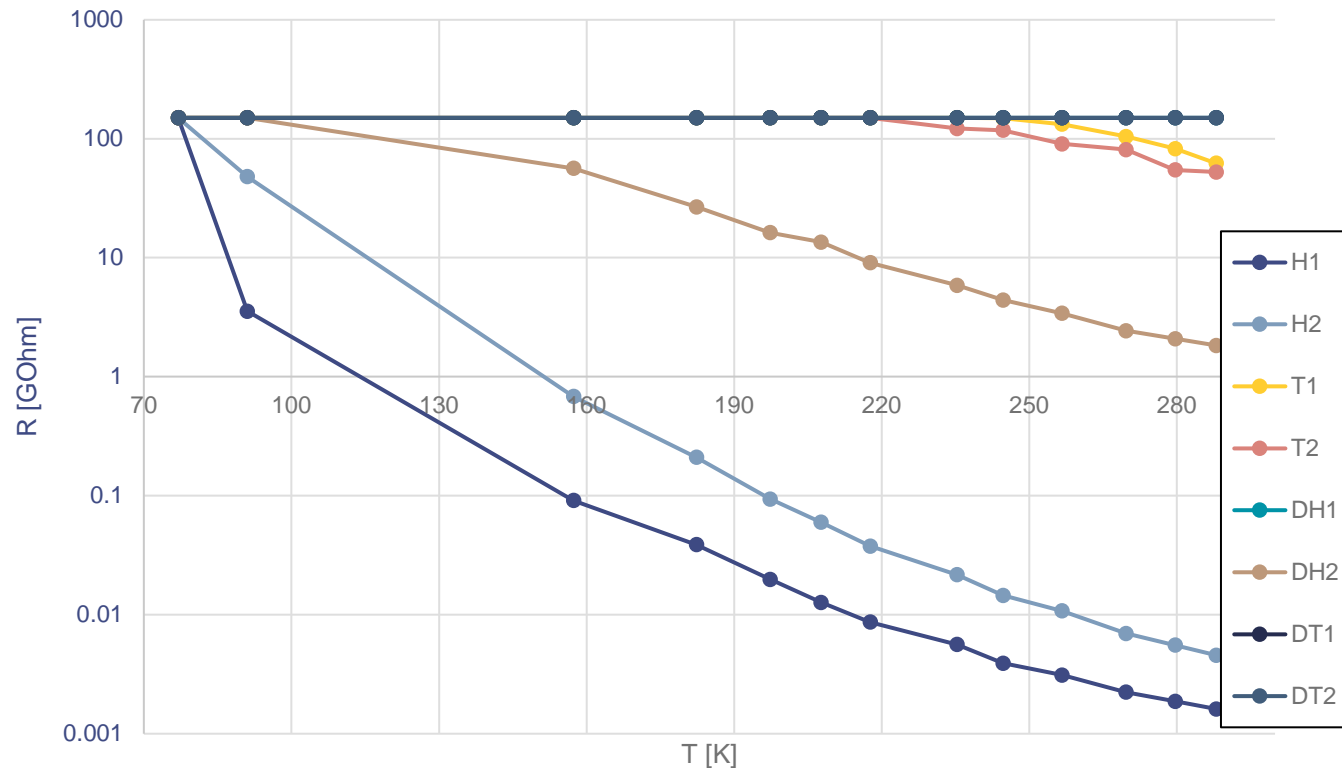
SETTINGS

- Samples placed into a polystyrene box
- Temperature monitoring for a smooth cooldown
- Measurements taken every 20min until 77K



Dielectric at 77K – mini layer jumps

RESULTS



- Tisstech fibre gives $G\Omega$ results, desized or not
- 1 Hiltex sample out of 4 $>1G\Omega$ at 288K
- Each sample ends up $>150G\Omega$ at 77K

→ Next step is to do the same test on CR01

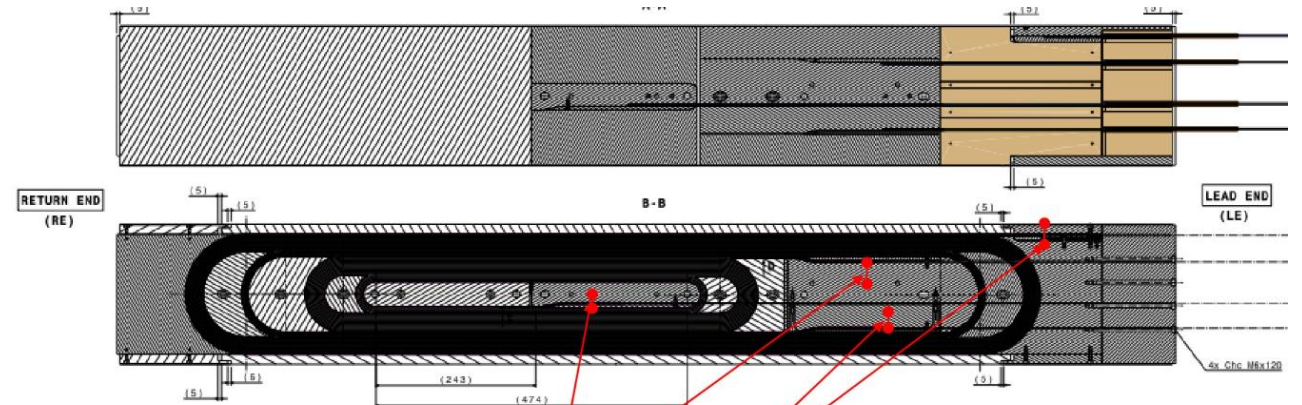
Dielectric at 77K – CR01

CONTEXT

- 3 exit jumps shortcuts out of 4
- 2 Hiltex 0,1mm thickness layers per exit jump used

SETTINGS

- Same conditions as for mini layer jumps
 - Coil placed into an isolated box
 - Temperature monitoring for a smooth cooldown
 - Measurements taken every 20min until 77K

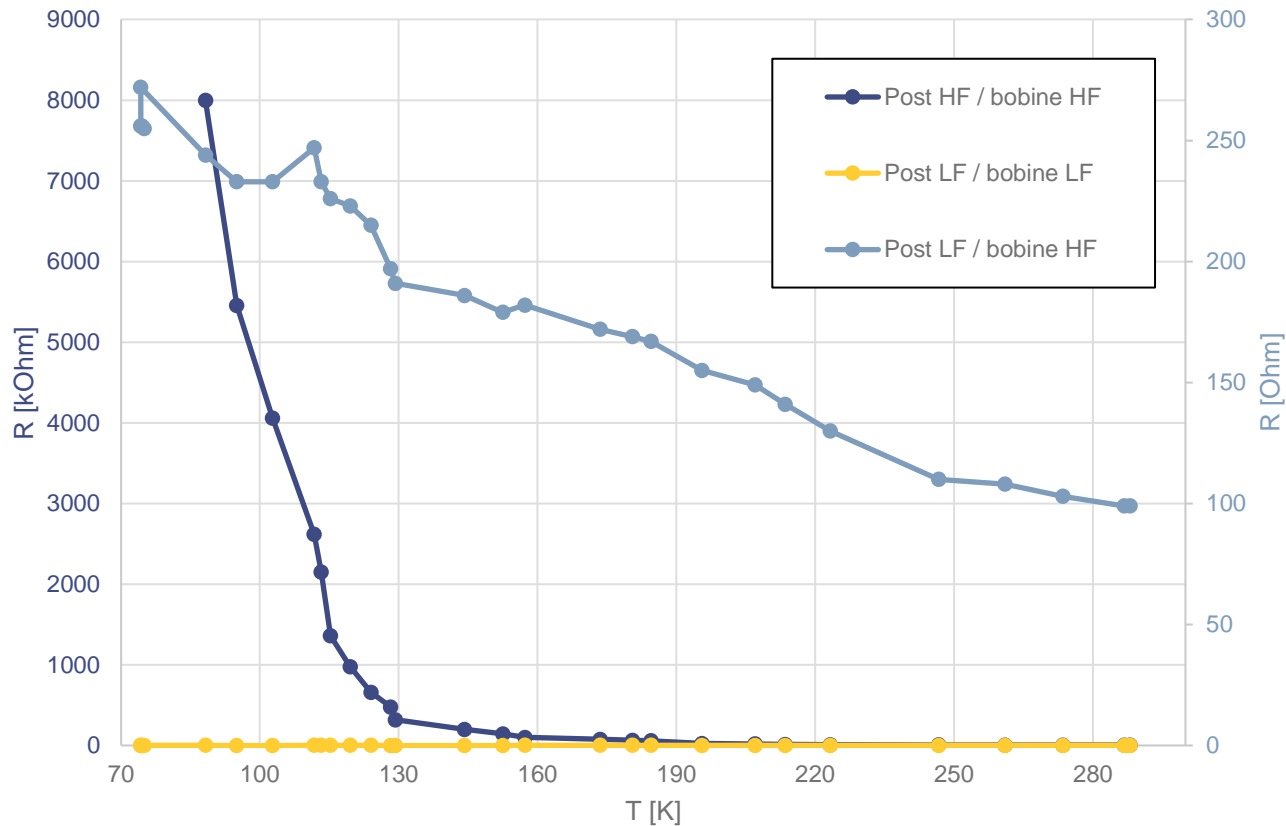


4.34	kOhm	Default n°3
1.3	kOhm	Default n°3
1.2	kOhm	Default n°3
3.33	kOhm	Default n°2
142	Ohm	Default n°1
82	Ohm	Default n°4
61	Ohm	Defaults n°1 and n°3
1.2	kOhm	Defaults n°3 and n°4

→ Systematic electrical defaults in exit jumps

Dielectric at 77K – CR01

RESULTS



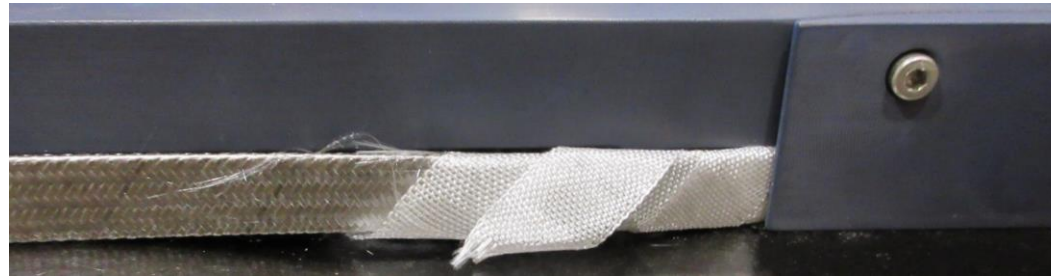
- Only post HF / bobine HF shortcut follow the same trend as the mini layer jumps results
- Post LF / bobine LF insulation increase up to 2,8k Ω until 160K where it plummets down to 200 Ω
- Post LF / bobine HF never reaches 1k Ω

→ **Thermal shrinkage do have an influence on insulation value**

Heat treatment 4 – CR01 conditions with desized Hiltex fibre glass

SETTINGS

- 3 desized Hiltex glass fiber layers 0,1mm thick (2mm gap between each) in each layer jump



RESULTS

- No sliding, no wearing fibre glass
- Electrical tests
 - Continuity OK
 - 0,5Ω cable resistance
 - Insulation measurements average at 4GΩ
- Whiter visual aspect in layer jumps than last reaction → **influence of desizing**



Decision taken for R2D2 magnet

CR02

- Option chosen : 3 Hiltex 0,1mm thick desized layers for each layer jump → keep gaps into the jumps
- No difficulties during CR02 coil manufacturing



CR01

- Coil cutting in progress to check shortcuts visual aspects



Conclusions and future work

Conclusions

Fibre glass	Hiltex ?	Desized Hiltex	Tisstech 493	Desized Tisstech
Results	Dark and oily aspect	White and dry aspect, poor mechanical robustness when wrapped around cable	Grey aspect	White and dry aspect
Insulation				

Trials to come on mini layer jumps

- Tisstech 0,12mm thick fiber glass delivered to CEA
 - Sized and desized samples manufacturing to come
 - Same insulation tests before/after heat treatment
 - Same insulation dielectric tests after impregnation at ambient and 77K

Perspectives

- Elements identification from sized and desized fiber glass

