Hi-Lumi LHC Twin Aperture Orbit Correctors Update
Development , Cold Test, Next models

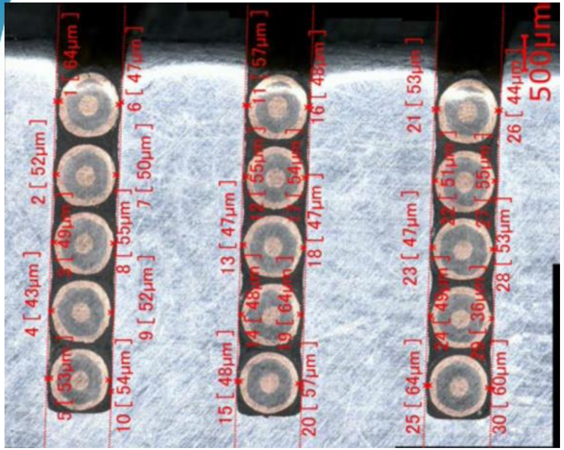
G. A. Kirby

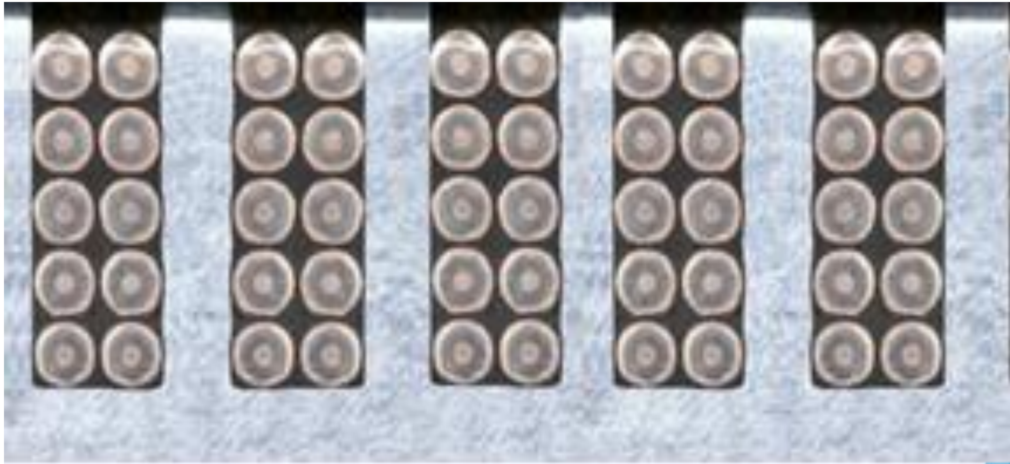
13th Sep 2017

Talk Over View

- CCT aperture development
- Coil and former design
- Impregnation tooling
- Quench analysis
- Heat extraction
- 0.5m coil test over view
- The improved magnet design
- Planning

Machined former development





The 1mm wide x 5mm deep channel could not be machined over the 128 m long 0.5m former!

Moving to a 2 mm wide slot, the cutting tool is much stronger!

The machining time / cost to machine the channel is reduced!

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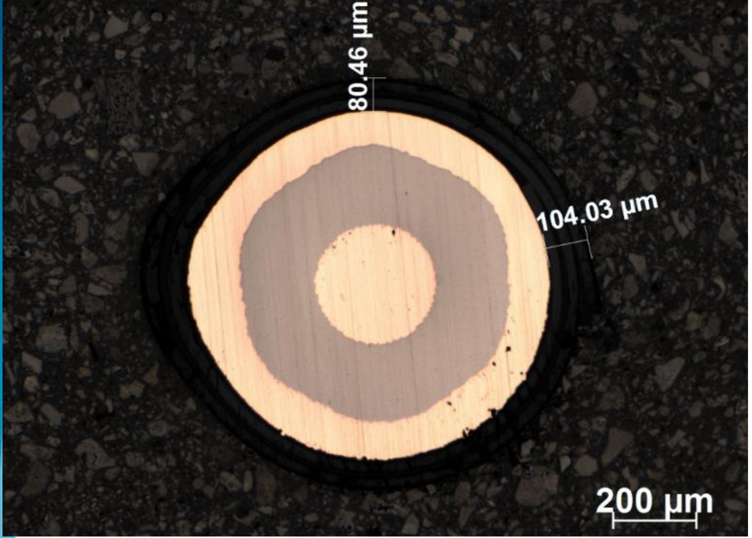
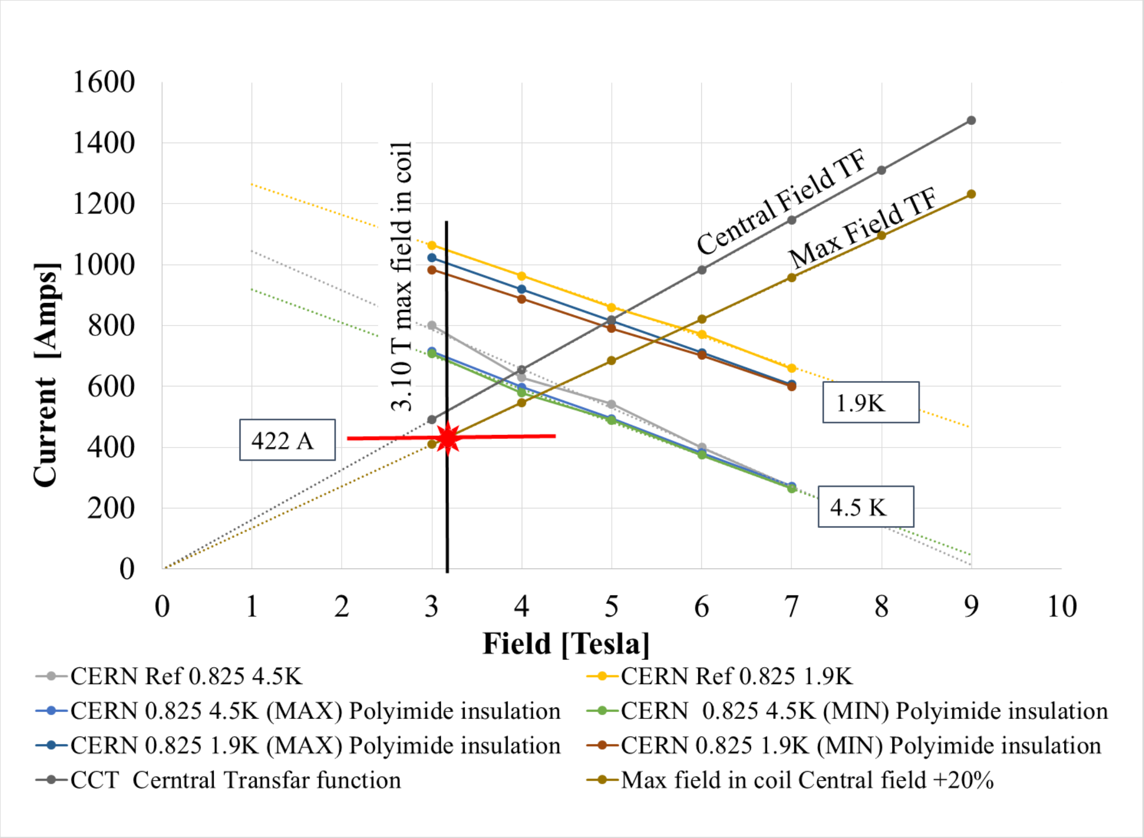
Wire Performance

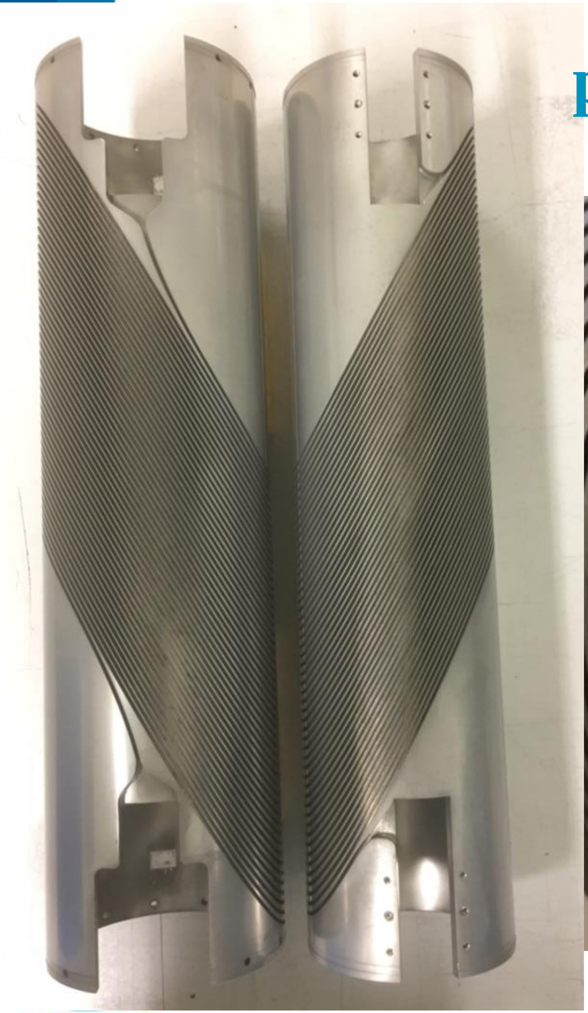


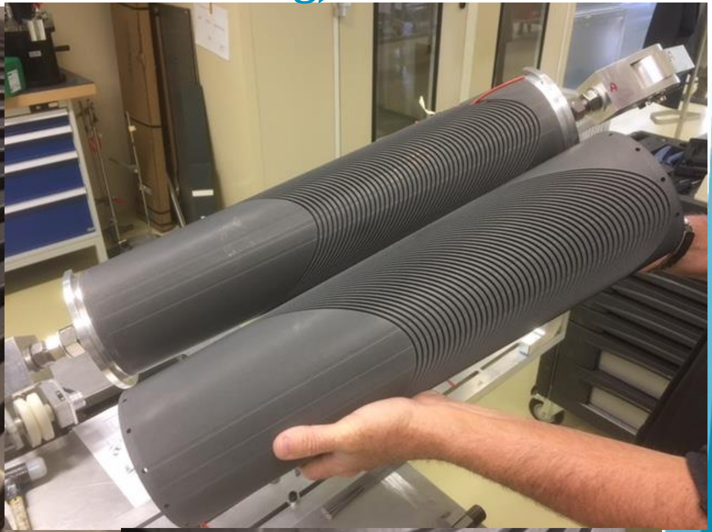
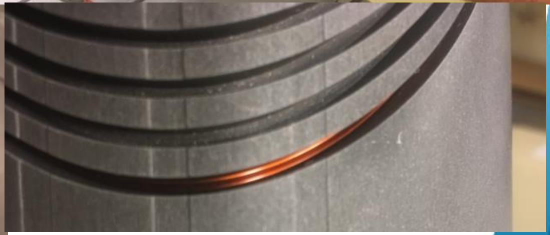
6 mm wide tape 50 to 55 % polyimide wrapped insulation .
Insulation curing temperature 420ºC for 30 sec degraded the wire Ic by 10%.
Magnet merging is still high at 55 % SS

Test insulation 12 kV min



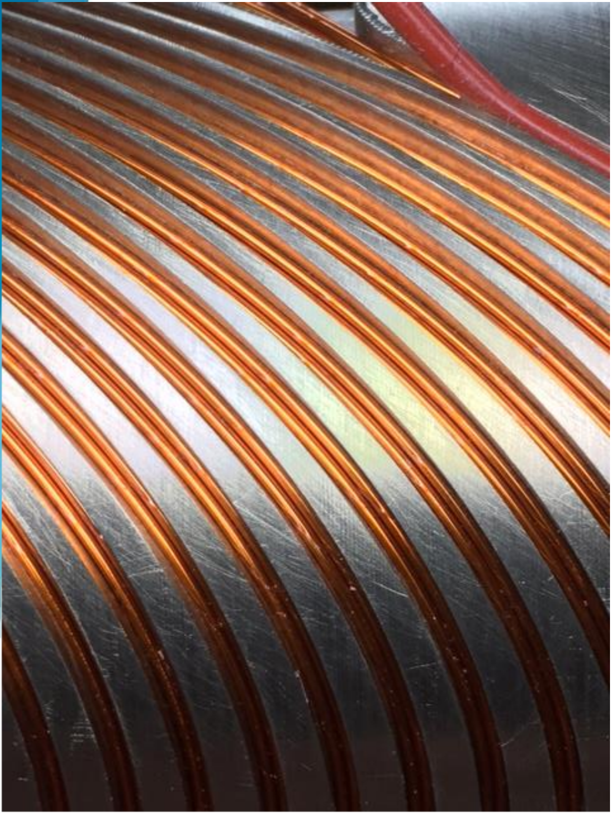
Aluminium formers 6082-T6
polishing test to de-burr? and then Hard Anodization (Micro-Machining)

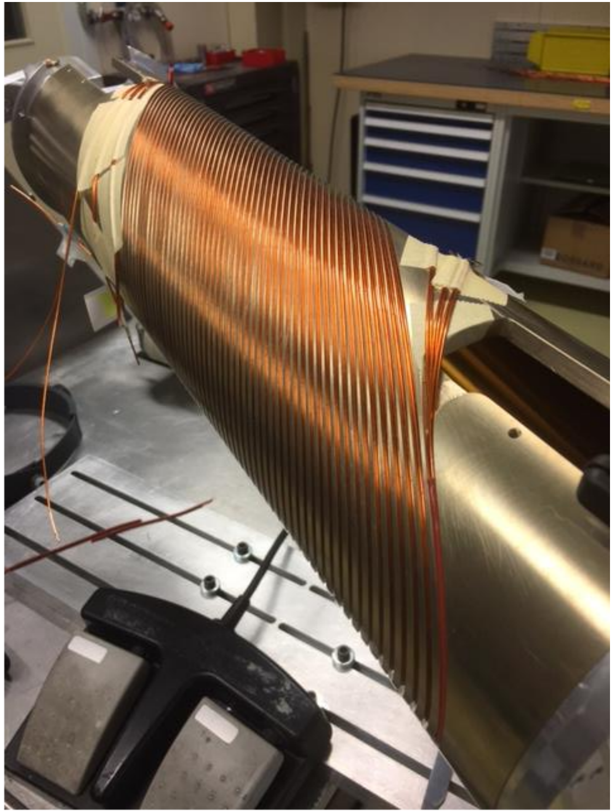


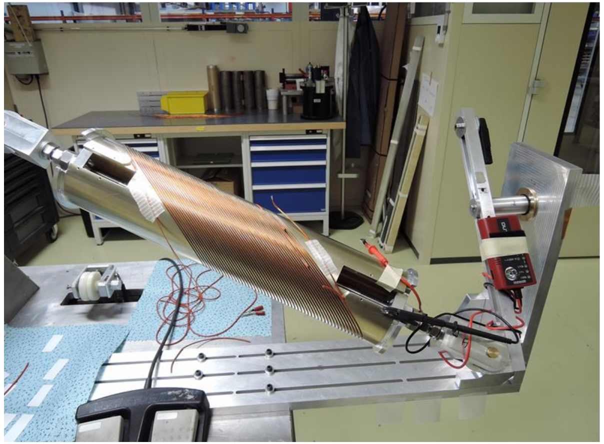



Example of polishing to remove burrs

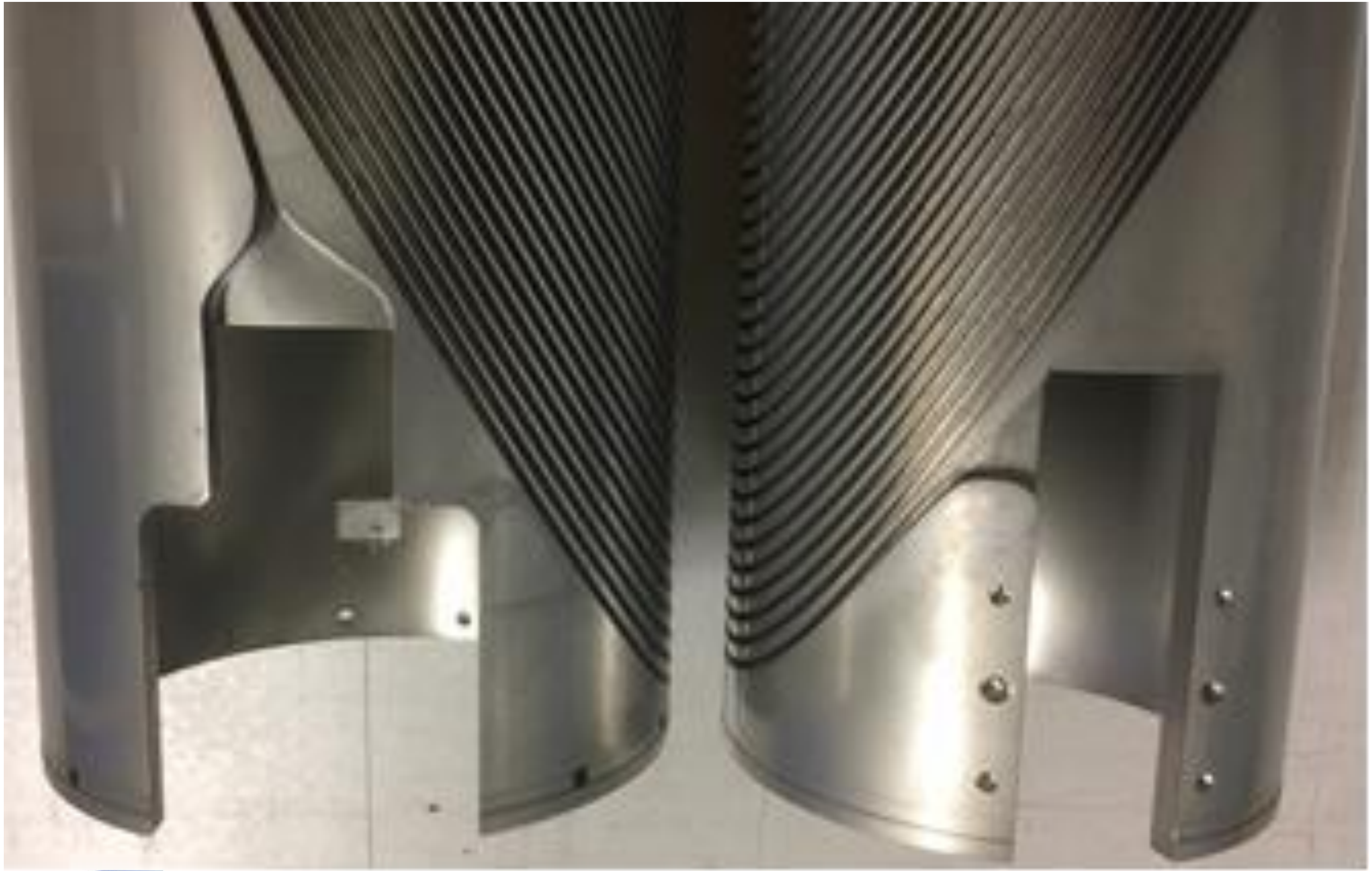
Coil Winding



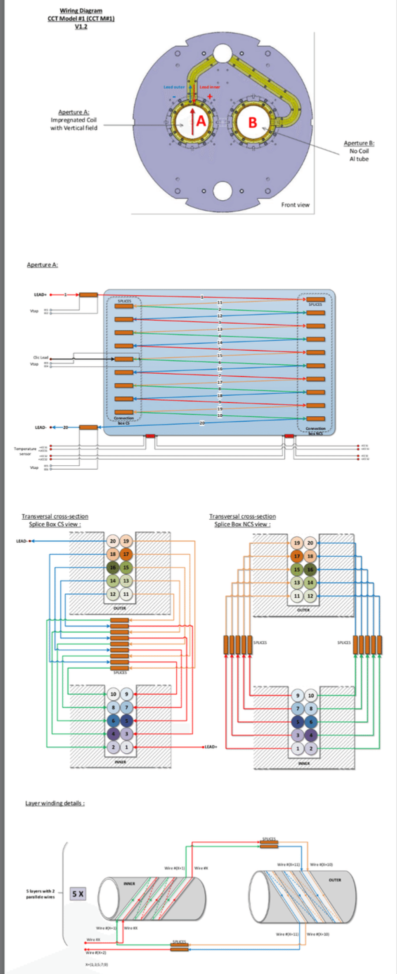




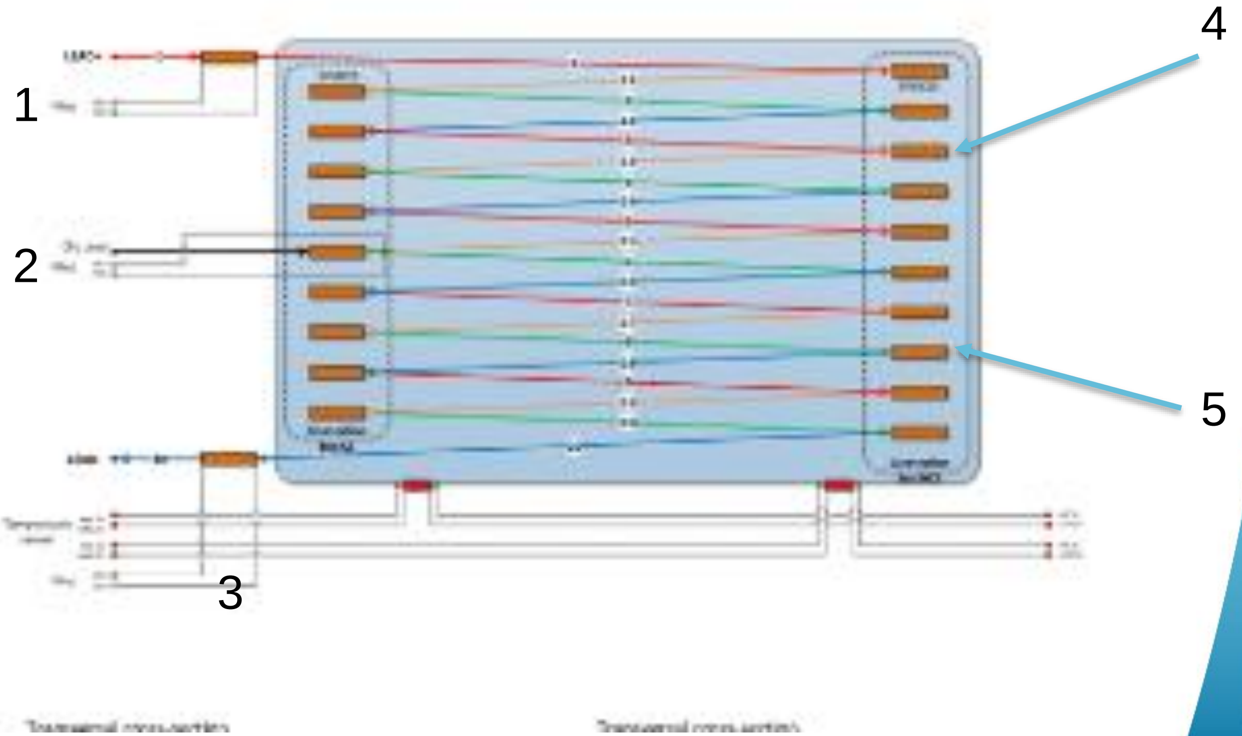
Two wires are wound at the same time, with low tension.
This is repeated until we have the full 2 wide by 5 high coil.



Wiring

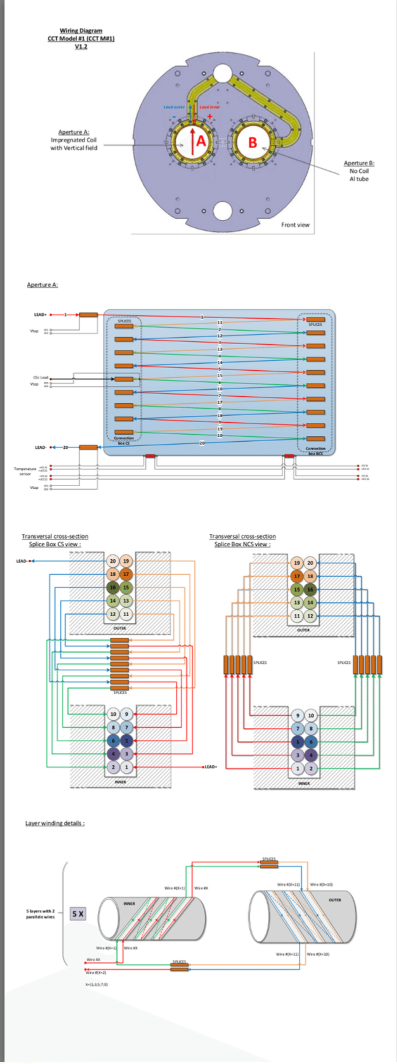


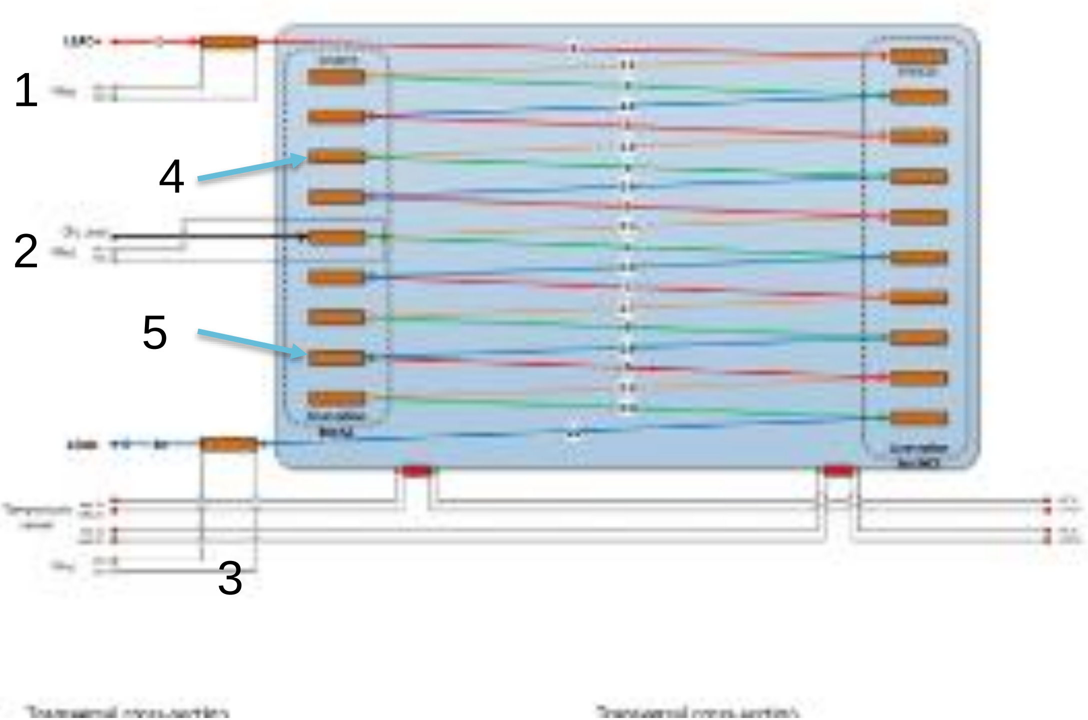
We may need 5 sets of voltage taps on each aperture to be able to see symmetric quenches



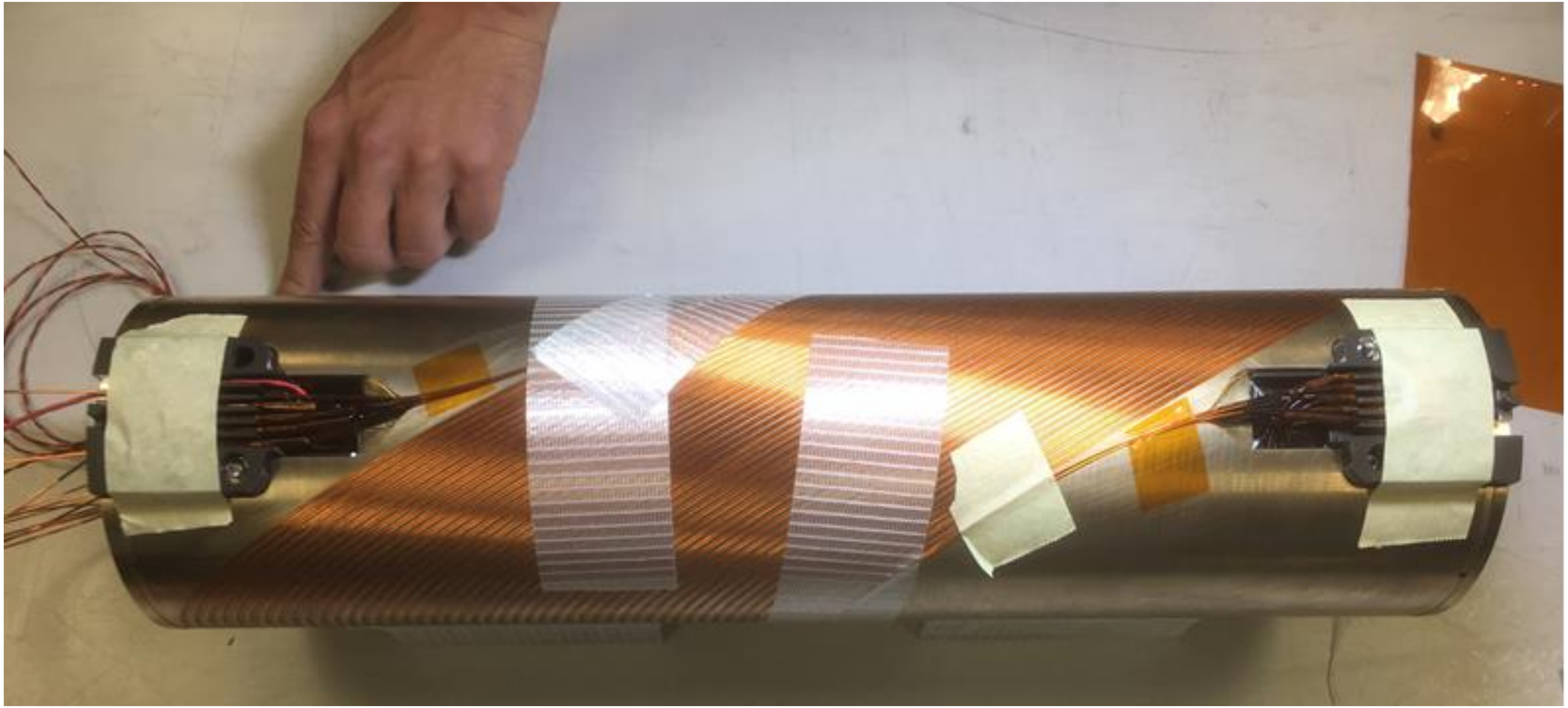
Wiring

Would be better to have all instrumentation exiting at the lead end! So 4&5 should move.





Joints at both end in the magnet former

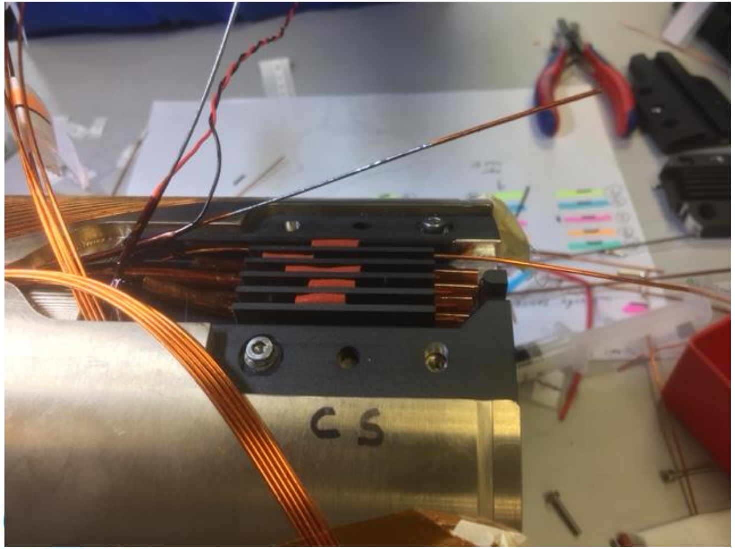


Jointing

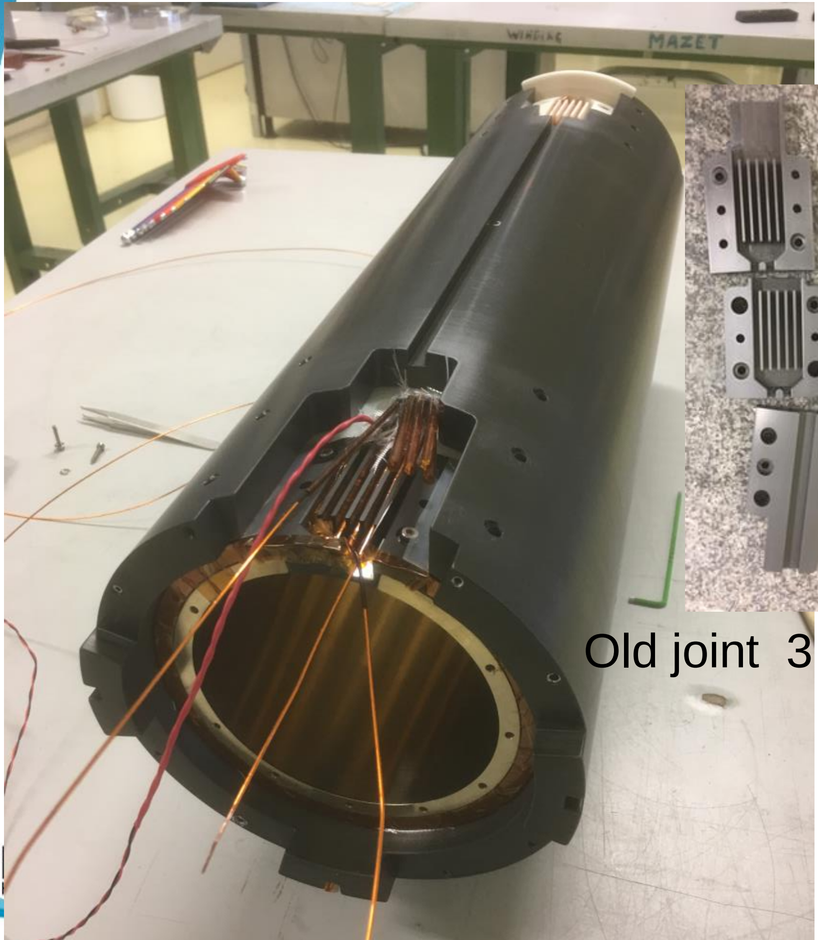
Jointing system:

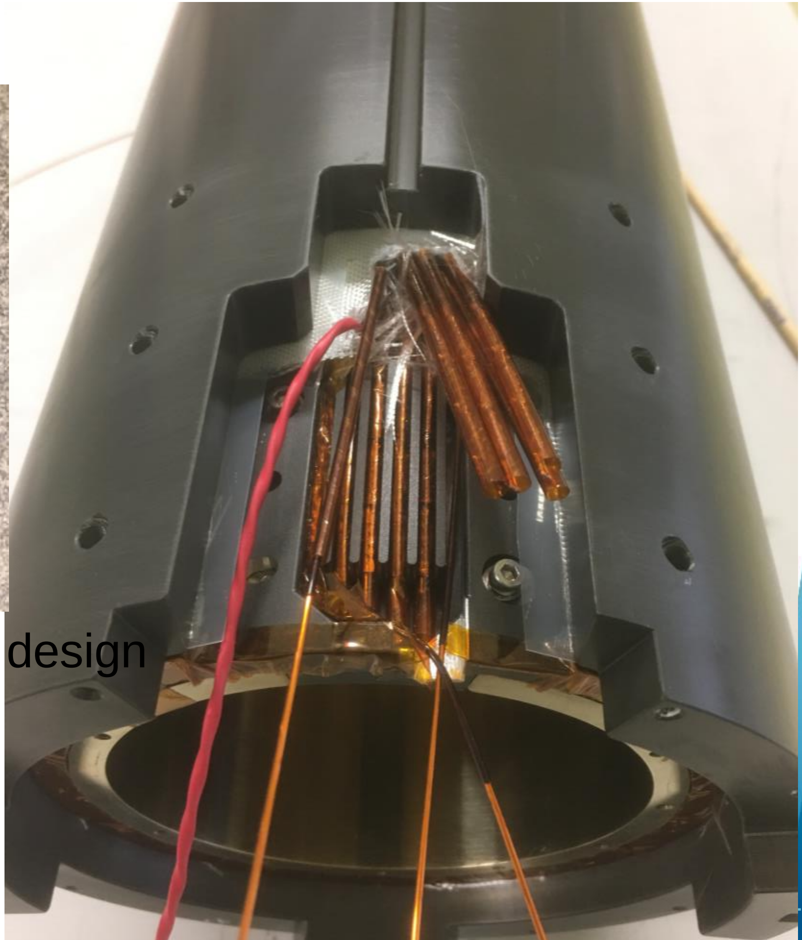
1) Tin wires,
2) Copper tube
3) Crimp for mechanical support
4) Solder
5) Insulation

~6 nOhm’s



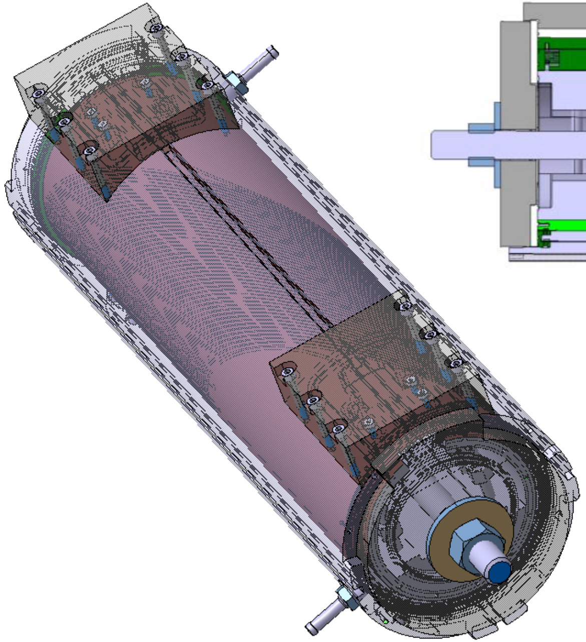
Joint box

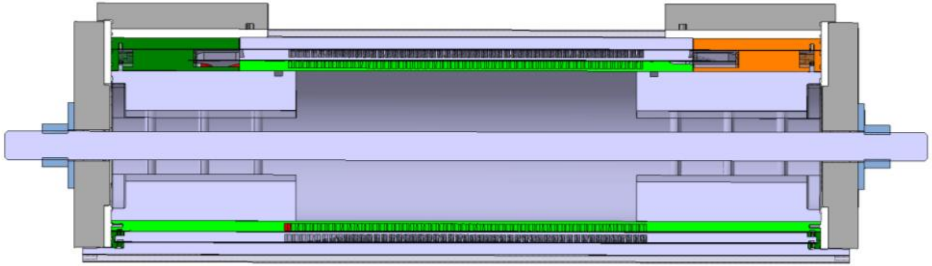




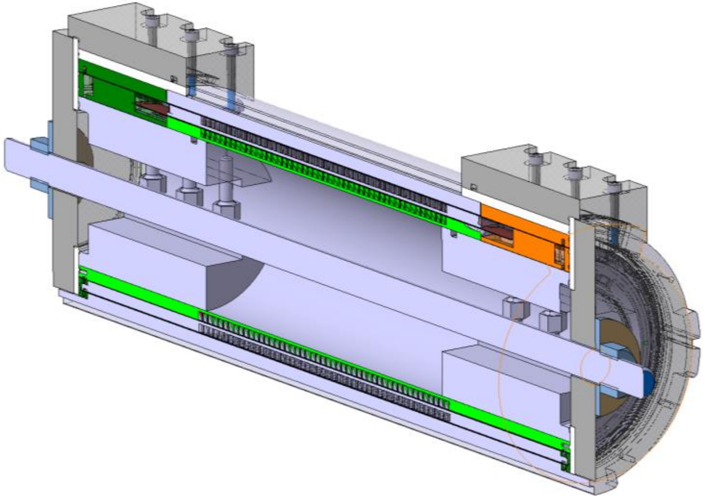
Old joint 3 part box design

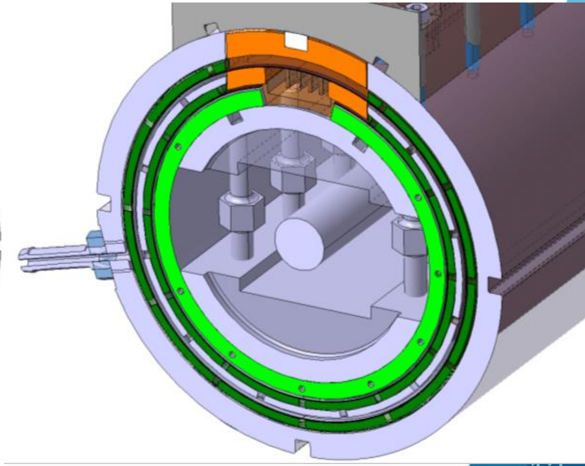
Impregnation



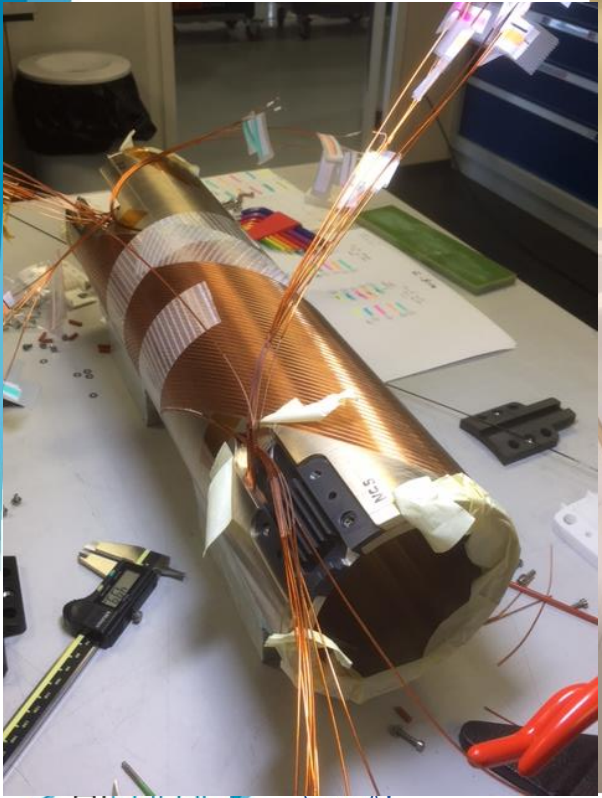


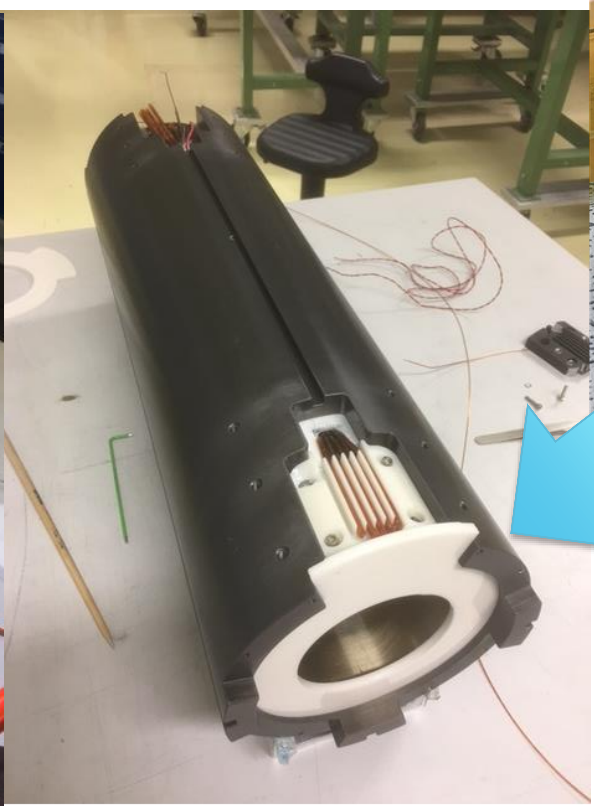
This is the only specialist tooling that is needed to build the magnet, along with the winding machine and impregnation equipment.

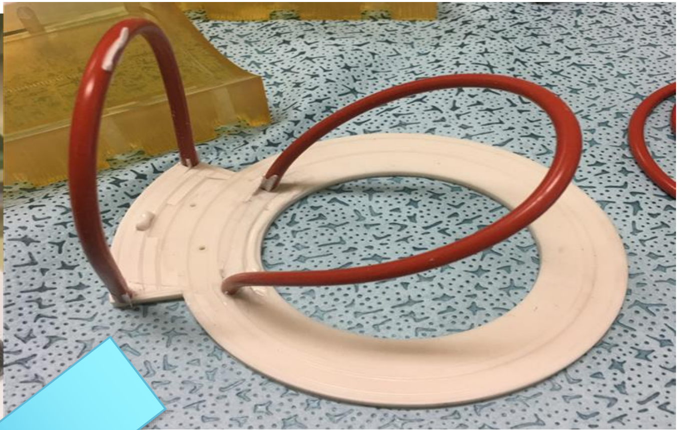




Coils impregnated inside the magnet outer support tube



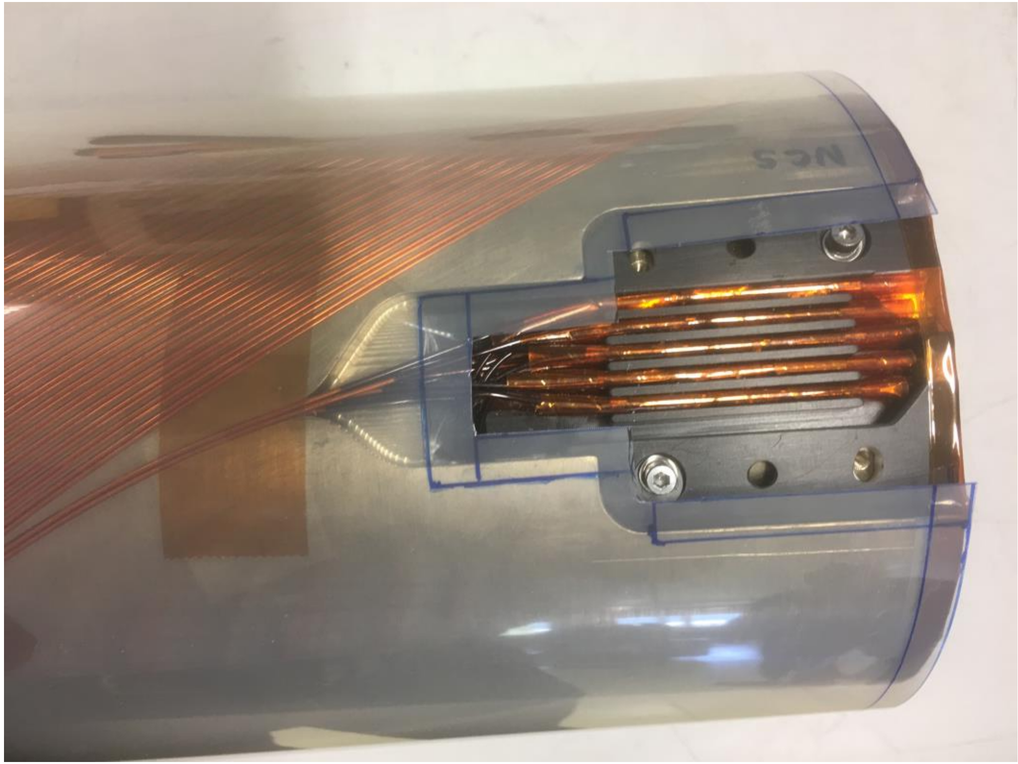


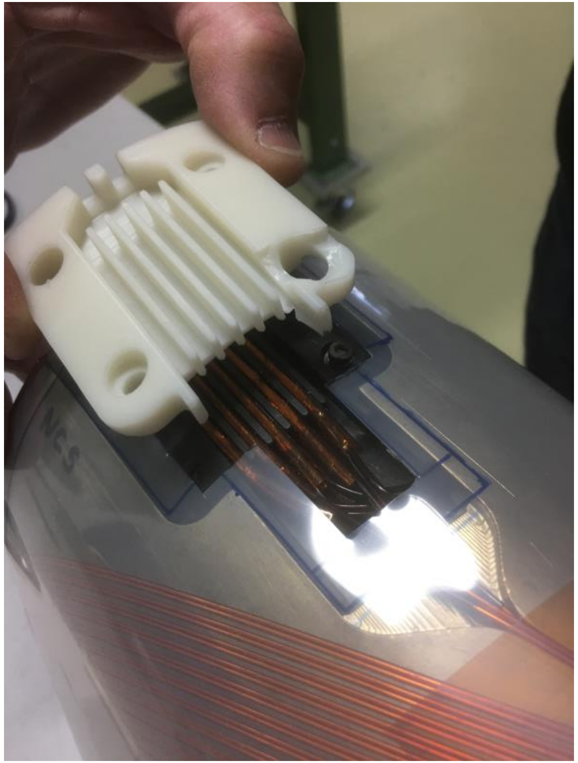


Vacuum / pressure Impregnation seal

Seal mechanical support

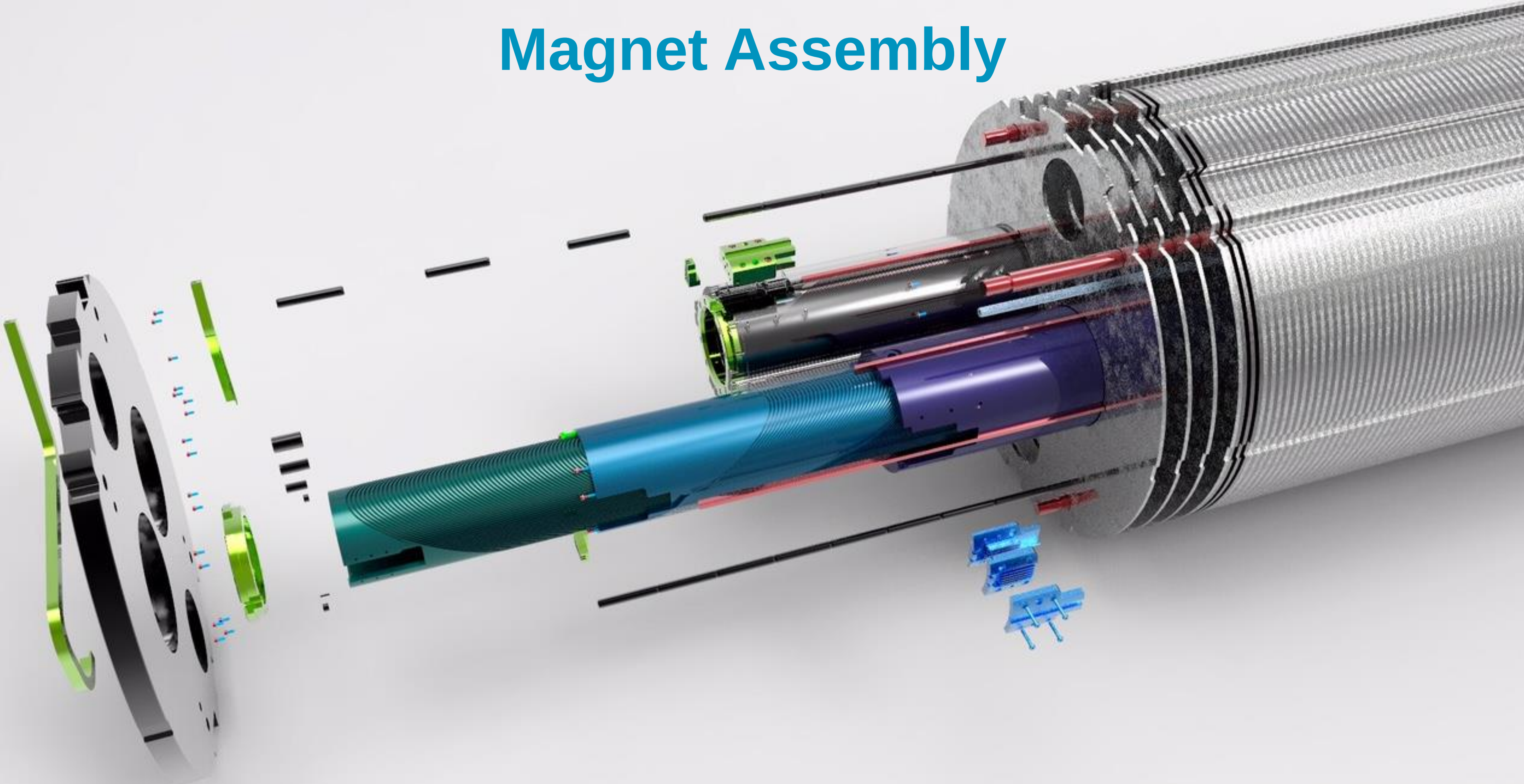
Insulation between the two layers



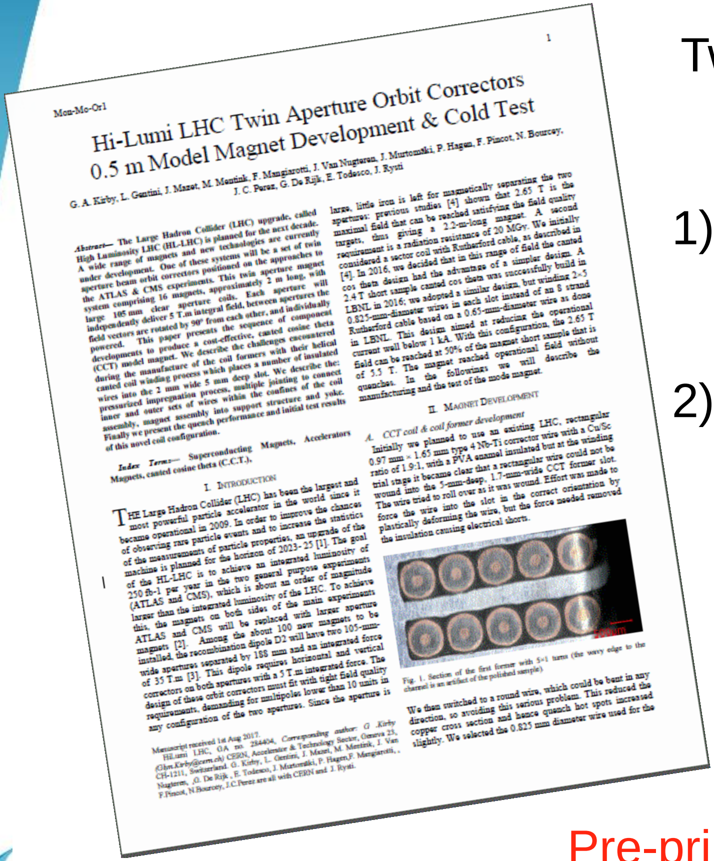


Two layers of insulation with min
4mm brake down distance for

Magnet Assembly



MT25 Papers


Mon-Mo-Or1

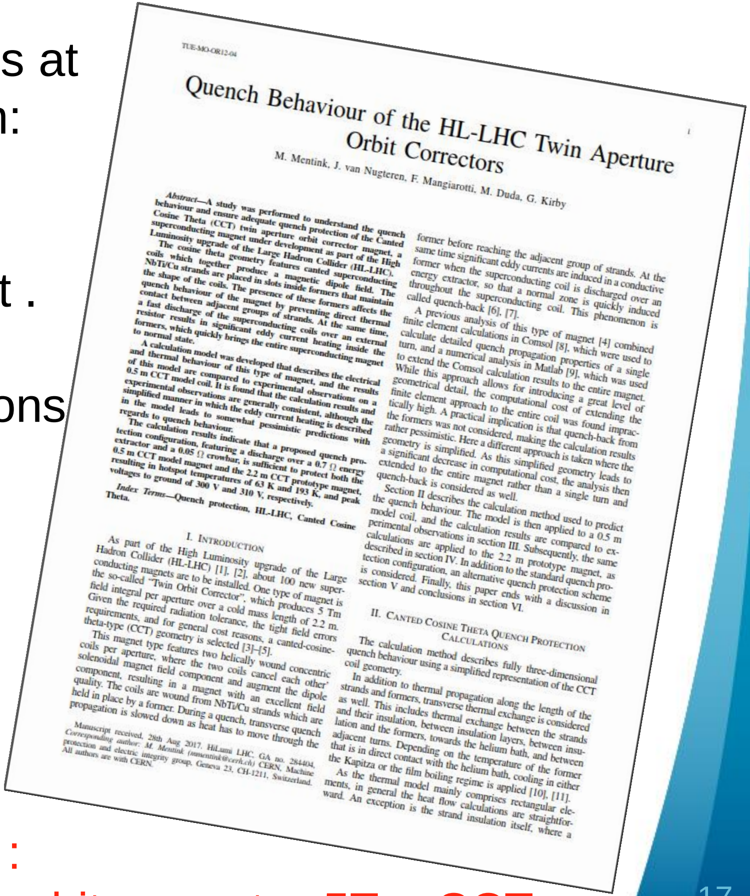
Hi-Lumi LHC Twin Aperture Orbit Correctors 0.5 m Model Magnet Development & Cold Test

G. A. Kirby, L. Gentini, J. Mazet, M. Mentink, F. Mangiarotti, J. Van Nugteren, J. Murtomäki, P. Hagen, F. Pincot, N. Bourcey, J. C. Perez, G. De Rijk, E. Todesco, J. Rysti

Two papers publishes at MT 25 Amsterdam:

1) 0.5 m model assembly and test .

2) Quench Calculations


TUE-MO-OR12-04

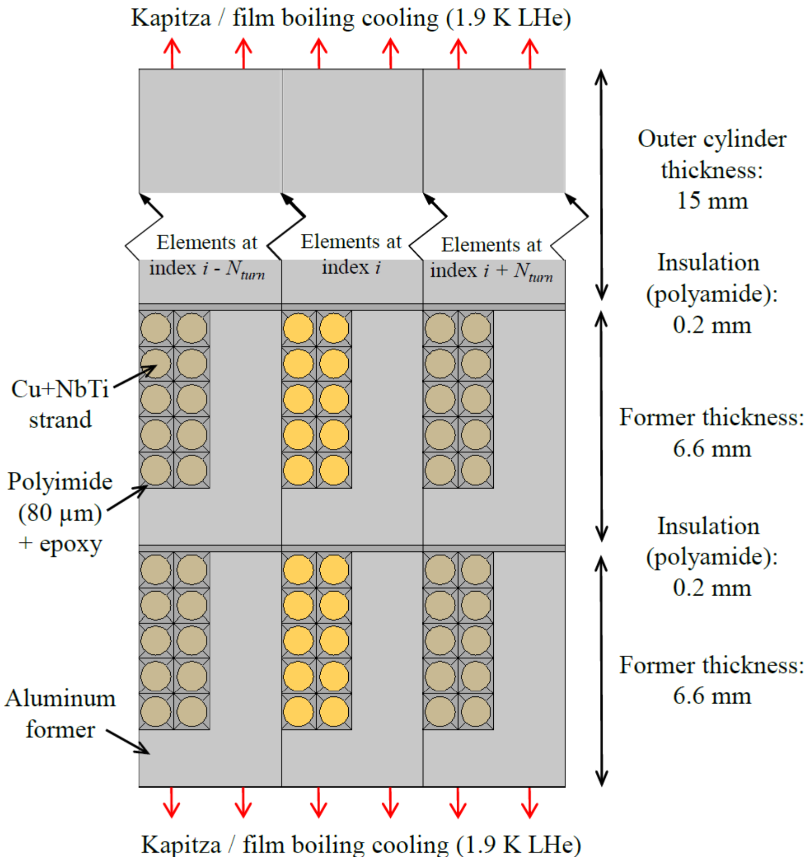
Quench Behaviour of the HL-LHC Twin Aperture Orbit Correctors

M. Mentink, J. van Nugteren, F. Mangiarotti, M. Duda, G. Kirby

Pre-prints are available at :

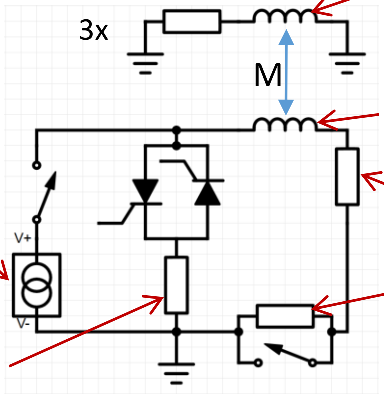
https://www.researchgate.net/project/LHC-hi-Lumi-orbit-corrector-5Tm-CCT

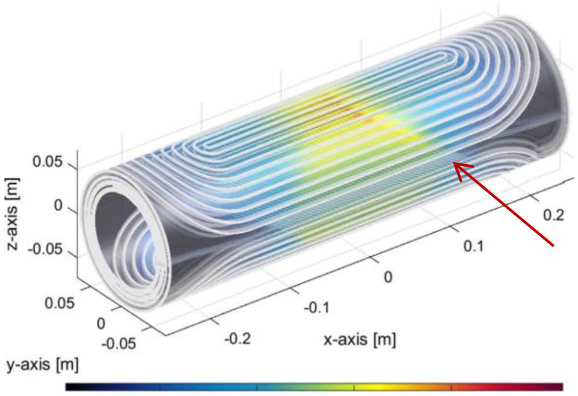
Simulation model: Thermal aspects



- Incorporates a simplified three-dimensional thermal layout
- Longitudinal thermal exchange along strands and formers
- Transverse thermal exchange
  - Between strands, insulation, formers, former insulation, and outer support cylinder
  - Between adjacent turns
  - To 1.9 K helium bath (Kapitza / film boiling)

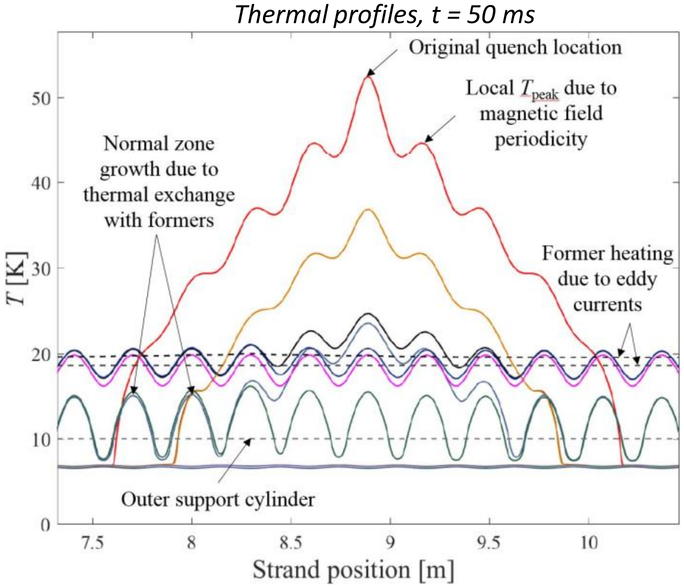
Simulation model: Electro-magnetic aspects

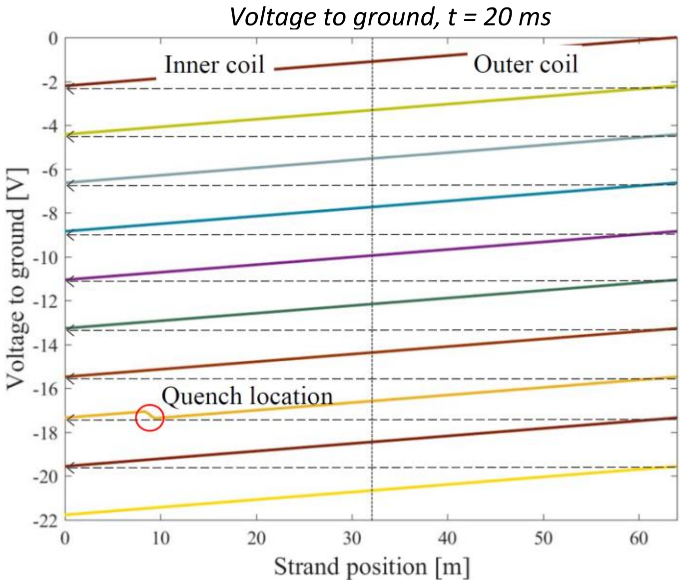




- Magnet assumed to be powered by a typical LHC 600 A circuit, including a crowbar and an energy extractor
- Eddy currents in the formers and outer support cylinder: Assumed to follow specific path with homogeneous current density (= simplified assumption)
- Inductances and magnetic field distributions calculated with Field simulation package

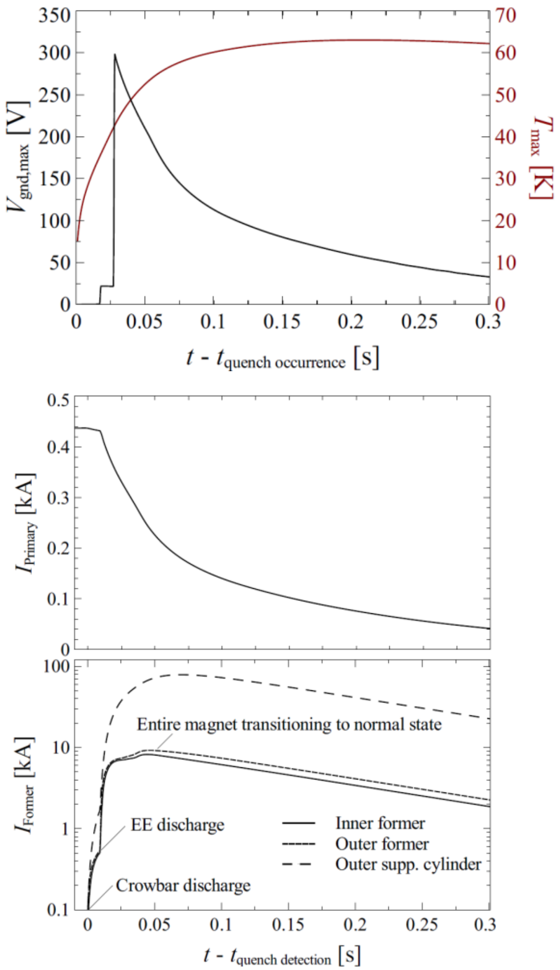
0.5 m CCT model magnet, calculation results 1/2

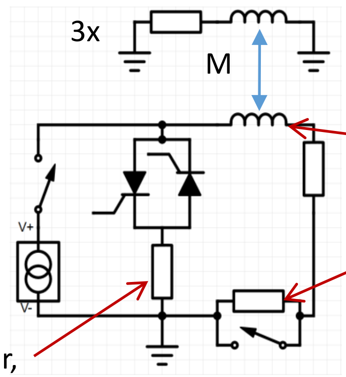




- Initial operating current: 438 A
- After quench detection and validation, magnet is discharged over 0.05 Ω crowbar + 0.7 Ω energy extractor (10 ms after quench detection + validation)
- Eddy current heating --> Normal zone spreads throughout magnet
- Peak voltage to ground dominated by external resistors

0.5 m CCT model magnet, calculation results 2/2

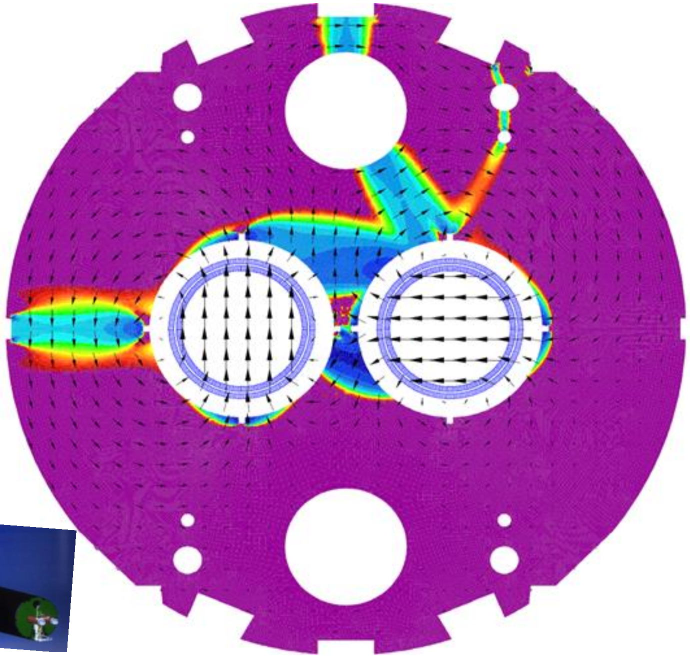


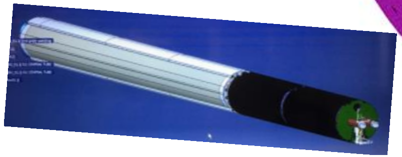


- Quench detection (0.1 V threshold) + 10 ms validation --> 17 ms in total
- Initial discharge over crowbar, followed by discharge over energy extractor (10ms later)
- Peak temperature: 63 K
- Peak voltage to ground: 300 Volts

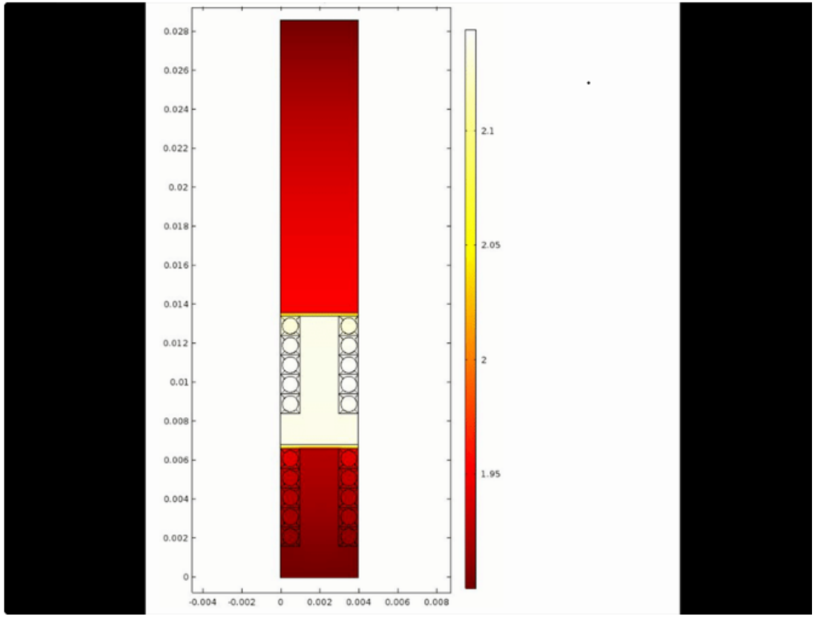
- For the 2.2m coils, extrapolating from the test results we expect:
- Hot spot 193 K
- Max voltage 330 Volts

Beam heating calculations and heat extraction through cold mass





Large holes to extract heat from D2 through the corrector to the cold point 225 cm^2



Heat load from radiation. 1 mW/cm^3 (1000 W/m^3) was applied to the full cross section? and fixed the former boundaries (i.e. the interface with the helium) at 1.9 K.

The result of this calculation is that the peak temperature is 2.15 K. This number is mainly determined by the thickness of the polyimide insulation separating the middle former from the innermost and outermost former. Here I assume a polyimide insulation thickness of 0.2 mm and a thermal conductivity of 0.0037 W/(m*K).

The heat load towards the helium is rather low; I find an average load of 14 W/m2, well below the Kapitza limit of 35000 W/m2.

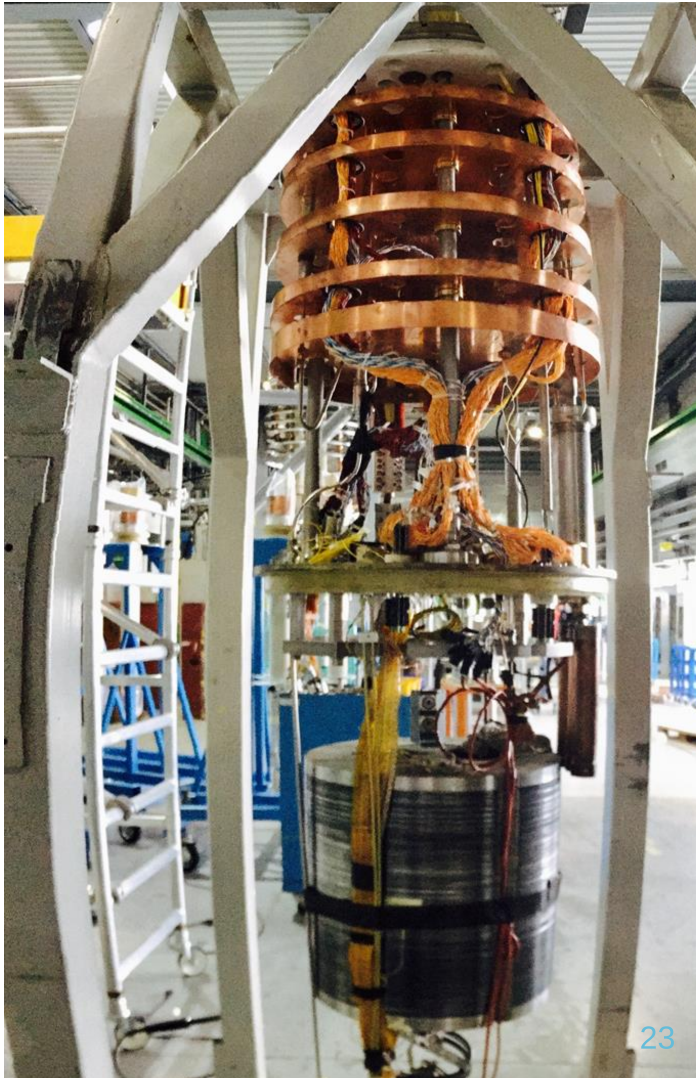
to conclude the temperature in the coil will not increase above the lambda point. However boundaries are in perfect contact this may not be the case in the magnet.

Magnet Test

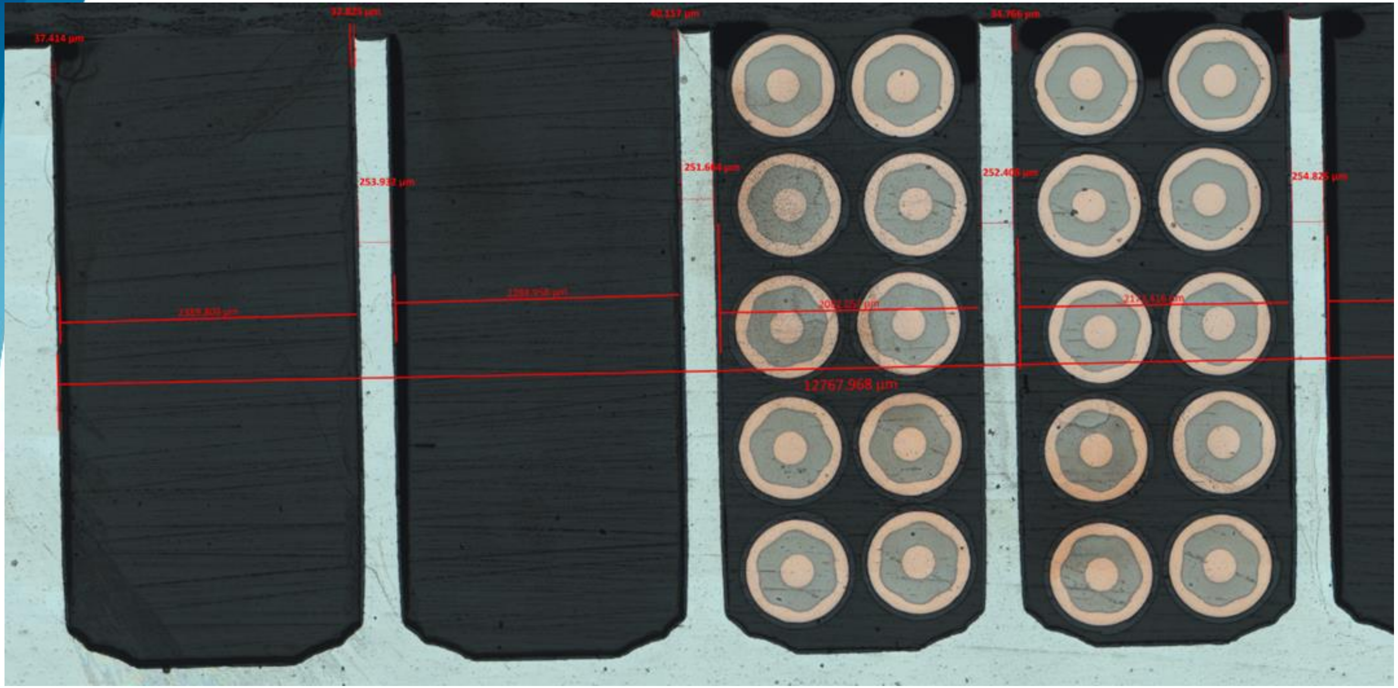
Tested to 1.9K
RRR of wire measured at 253, high!
No quench up to 422 A nominal
One quench at 438 A (hot spot 57K)
Then No quench up to 460 A ultimate design value
Thermal cycle no quench.
Nominal ramp rate 4.2 A/s.
Max tested ramp rate with no quench 40 A/s

Joint resistances: Average 5.7 nOhm's
120 +/- 20 nΩ over one aperture.

Energy distribution during quench : with 0.7 Ω dump:
Coil 13%, Dump 59%,aluminium support tube and formers 28%



- Next model



Channel width machining test.

A number of different channel widths were machined

(2.1, 2.2, 2.3, 2.4 mm)

The aluminium block was then hard-anodized with a 0.02 mm build-up of anodization layer. The insulated wires were then impregnated into the channels

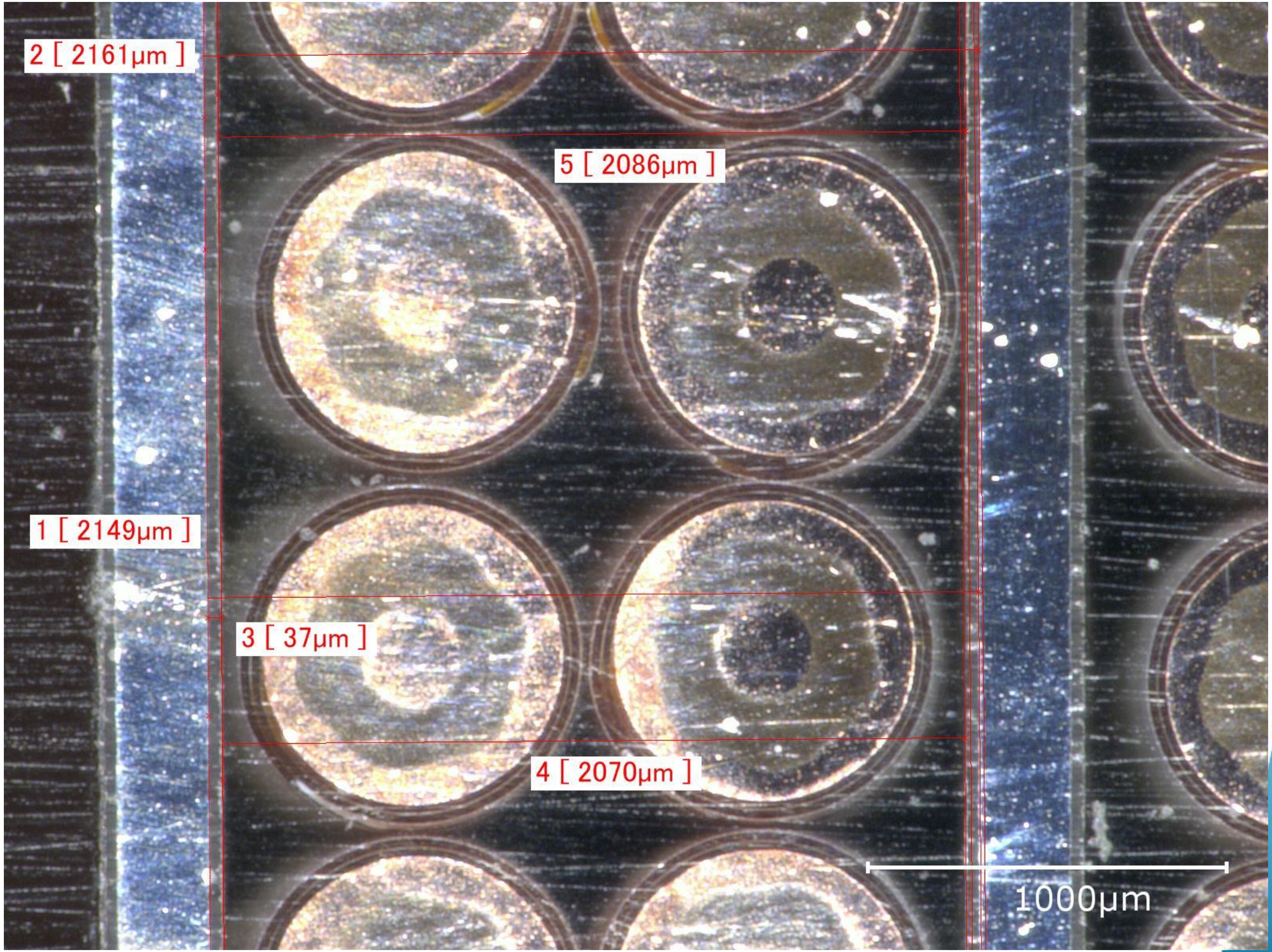
Channel Width Test

We see the:

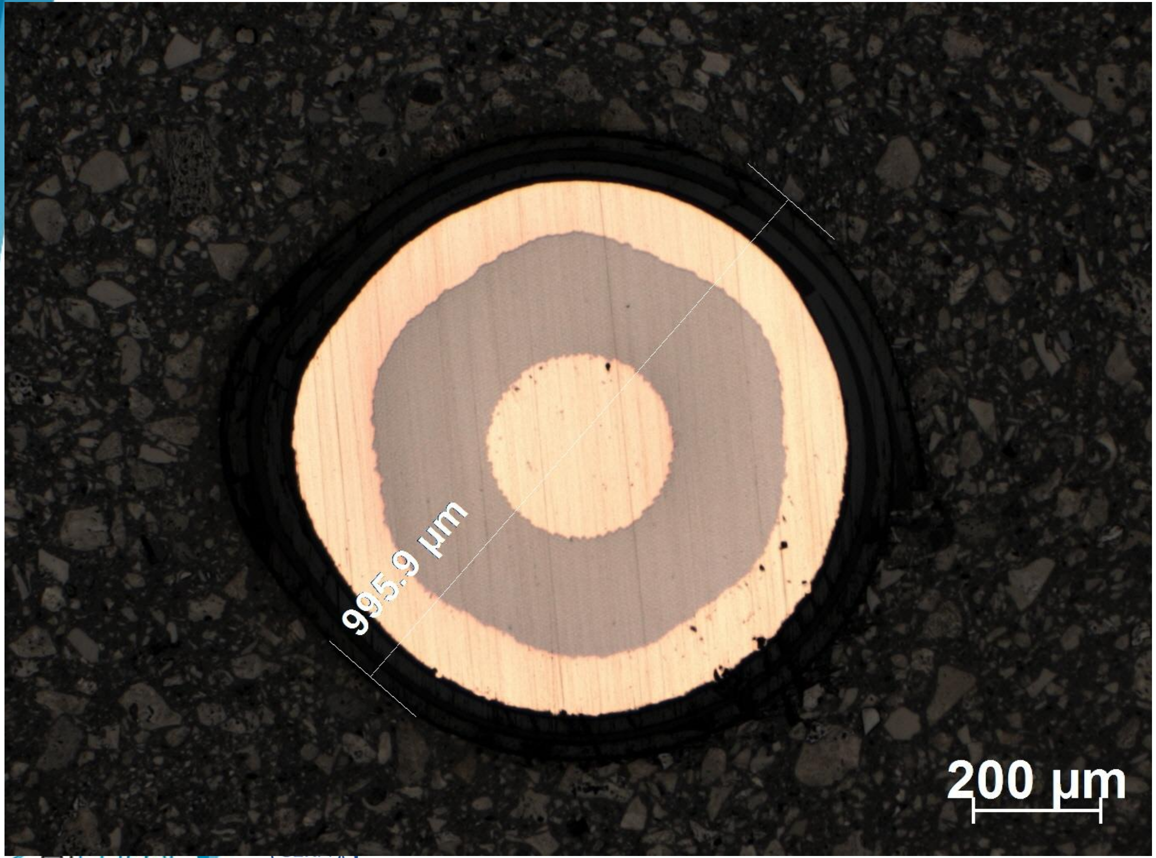
Anodized later on the aluminium former,

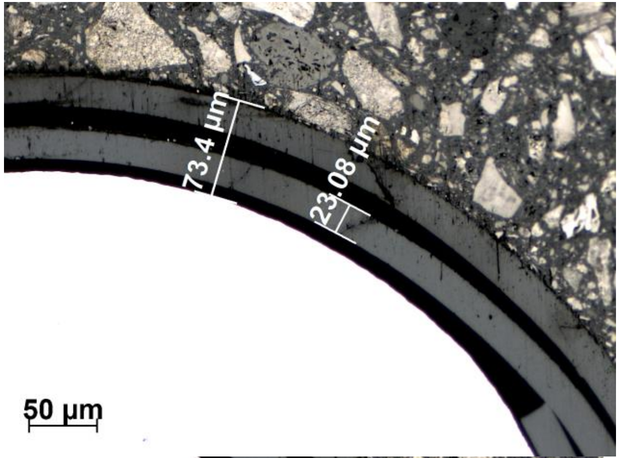
Insulated wires,

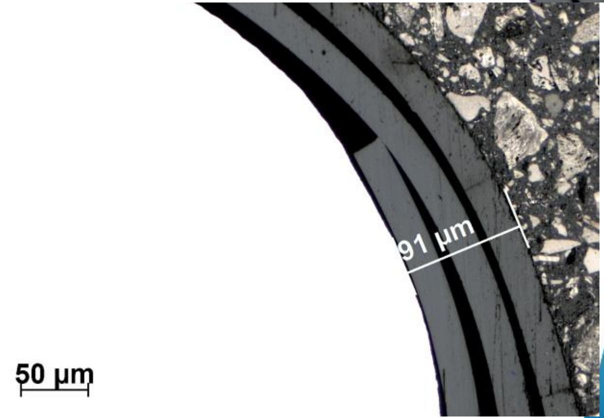
Resin filling the space between wires and former.



Insulation design in the magnet that was tested







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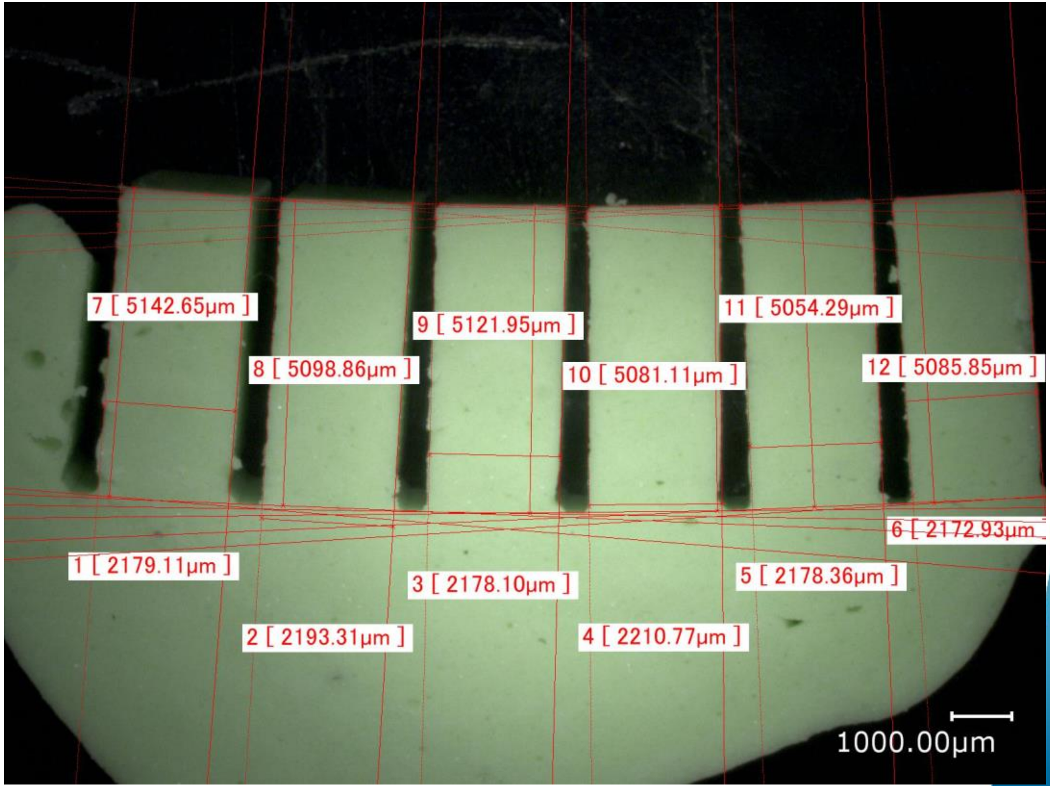
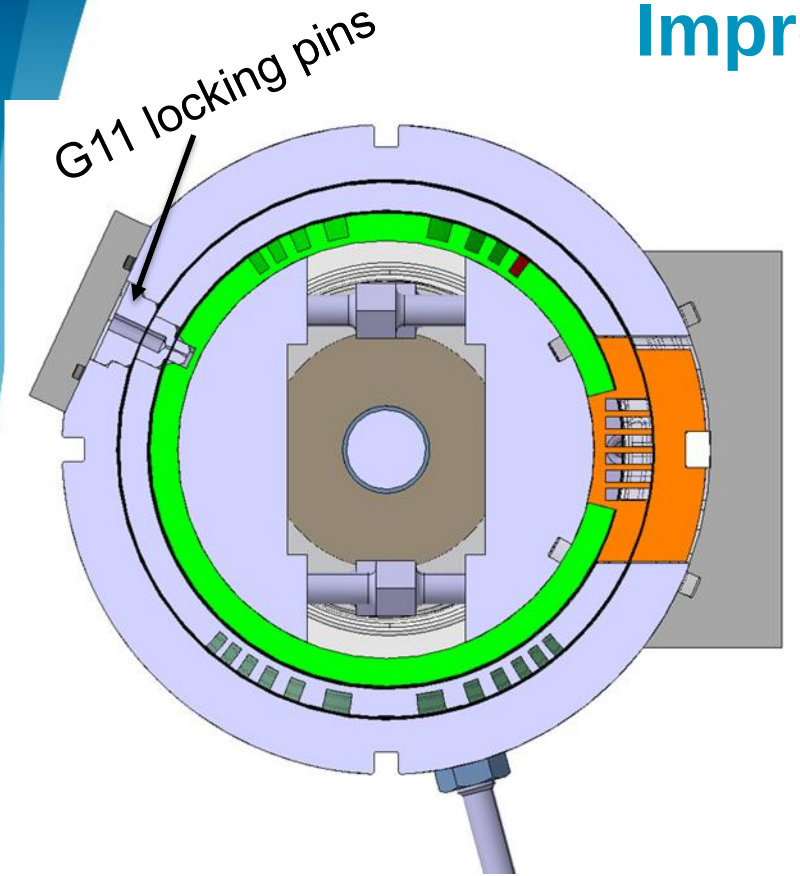
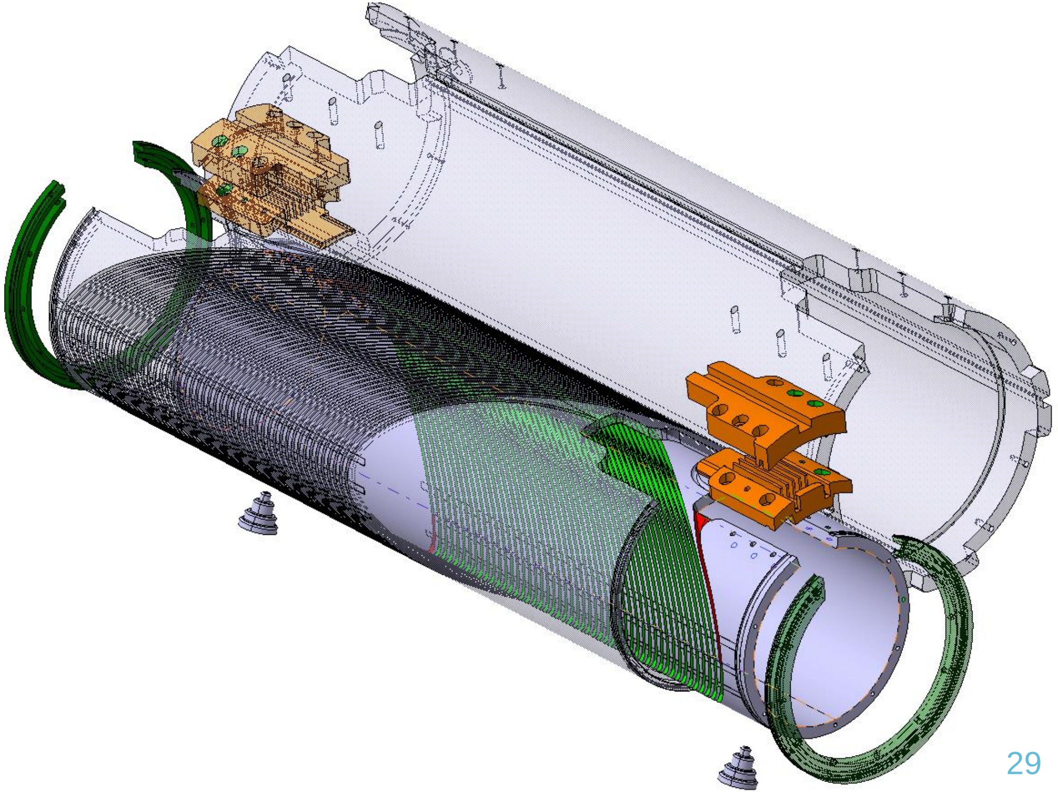
Test cut for firm that will machine the 2.2 m formers



Improved design



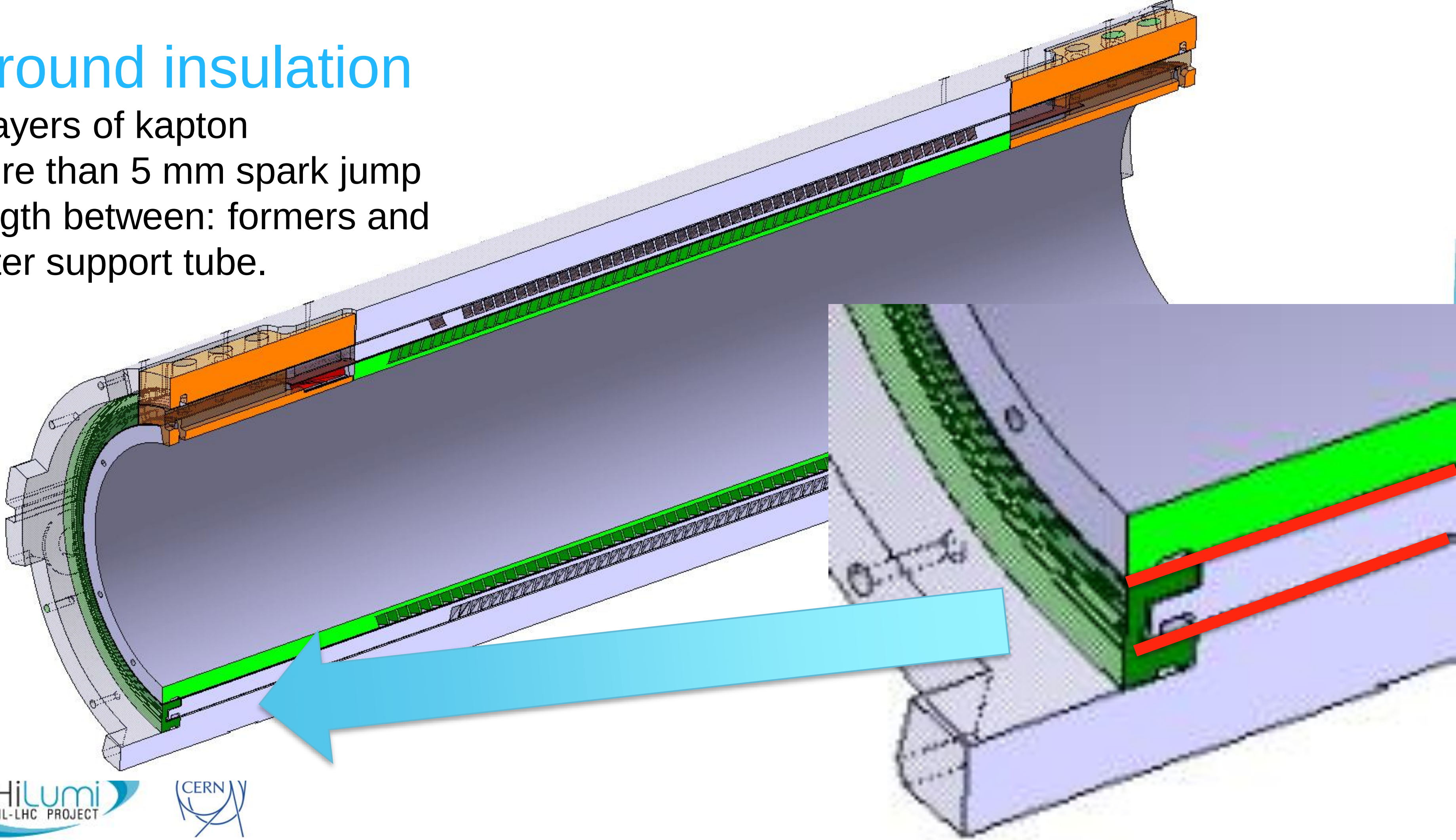
Less components
Improved access for impregnation



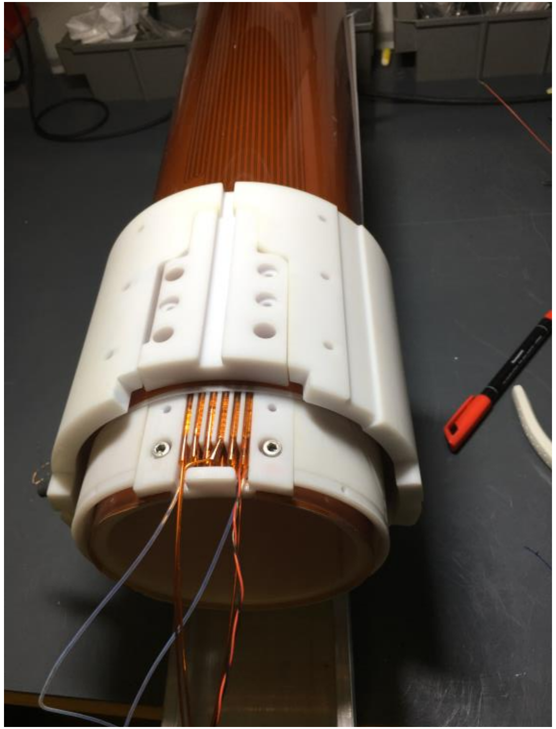
Ground insulation

2 layers of kapton

More than 5 mm spark jump length between: formers and outer support tube.

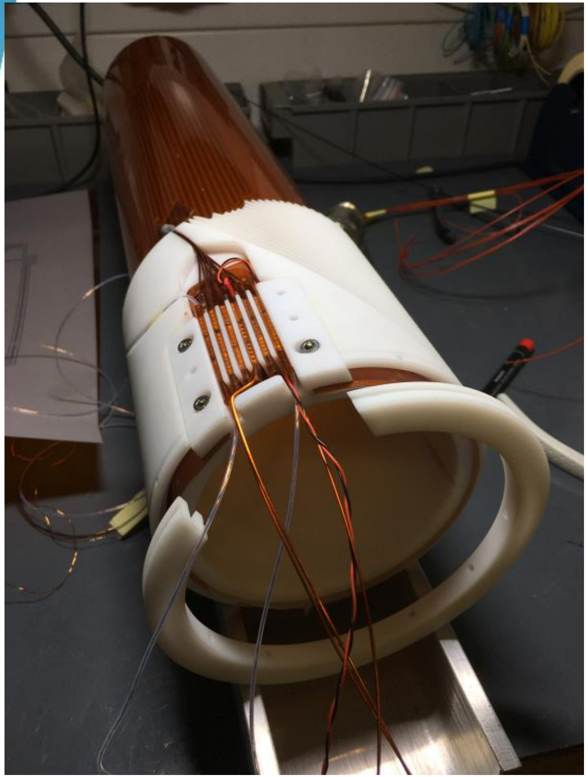


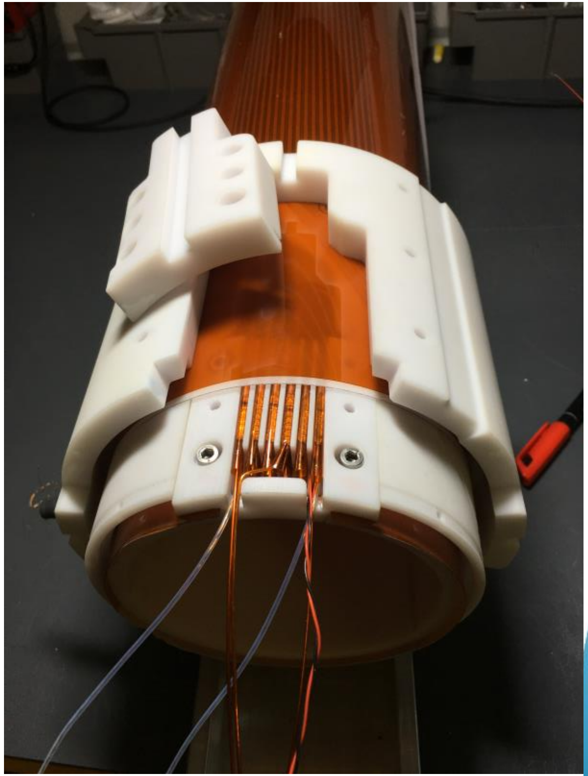
New design: less parts, improved ground insulation, channels for instrumentation



The joint box, joint support plate was simplified from two parts to one, channels for voltage taps and temperature sensor wiring was improved. We are now considering deleting the joint box cover plate.

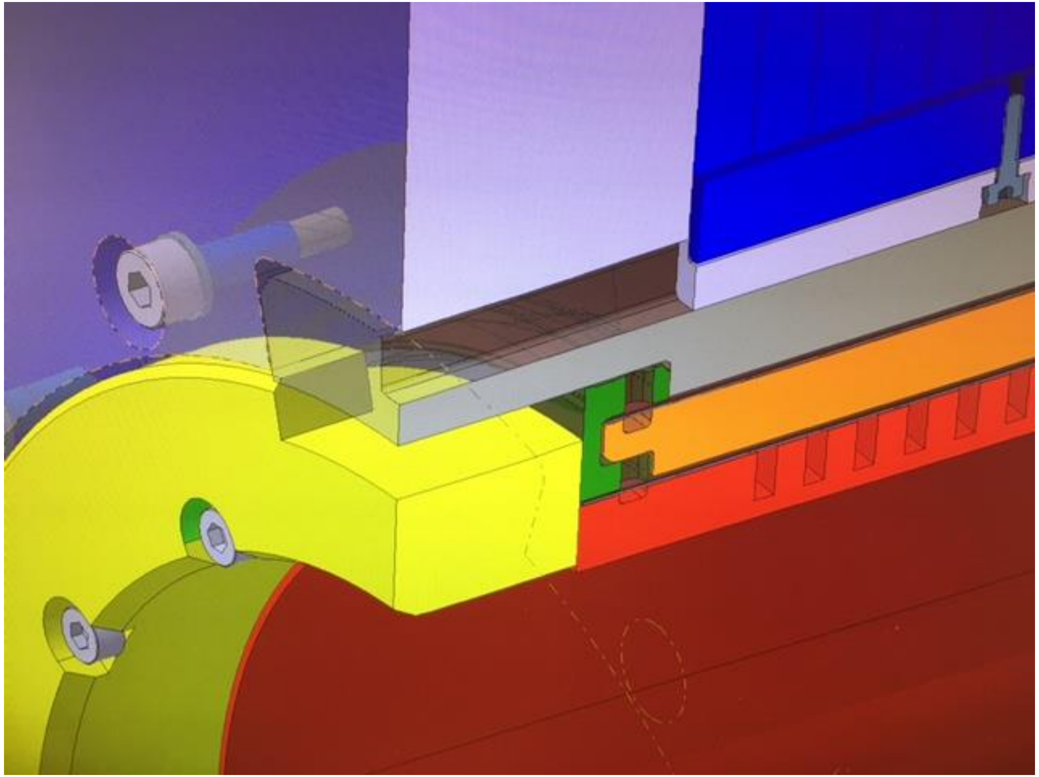
Beam simulation heaters in trace part of insulation.



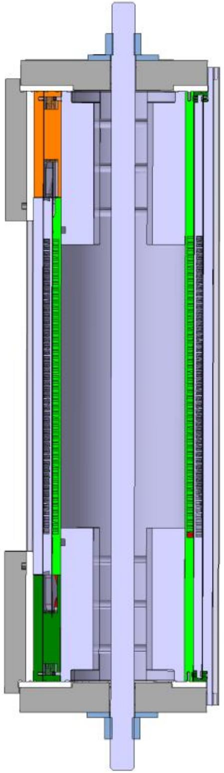


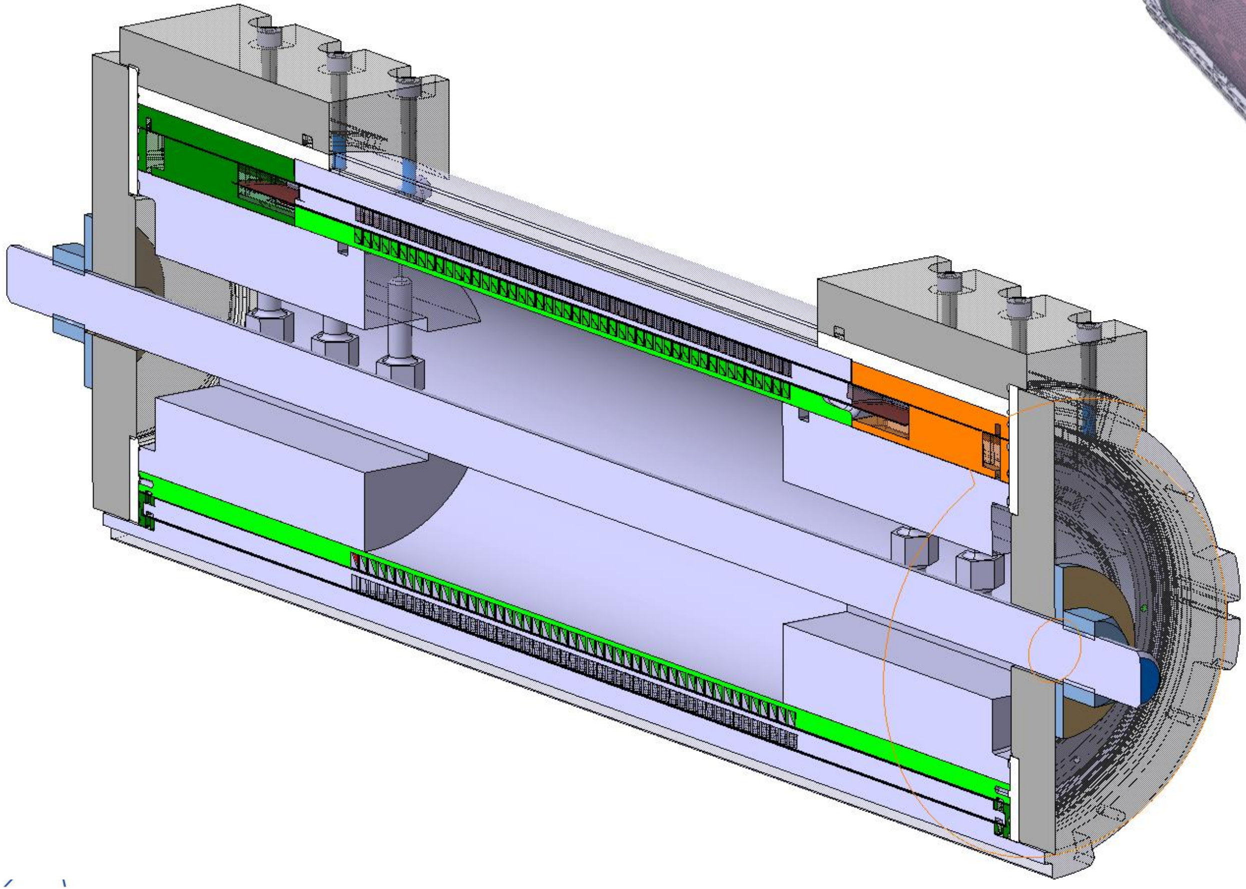
Beam simulation heaters cover inner and outer former, over low field volume where beam heating will be distributed. Only mounted on models

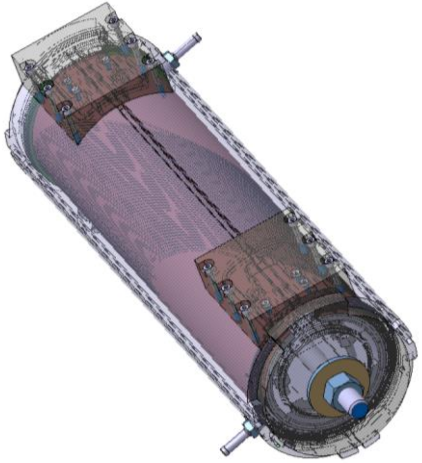
Ongoing development / improvements



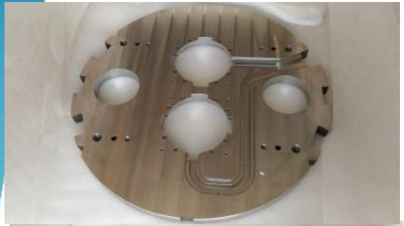
Impregnation tooling

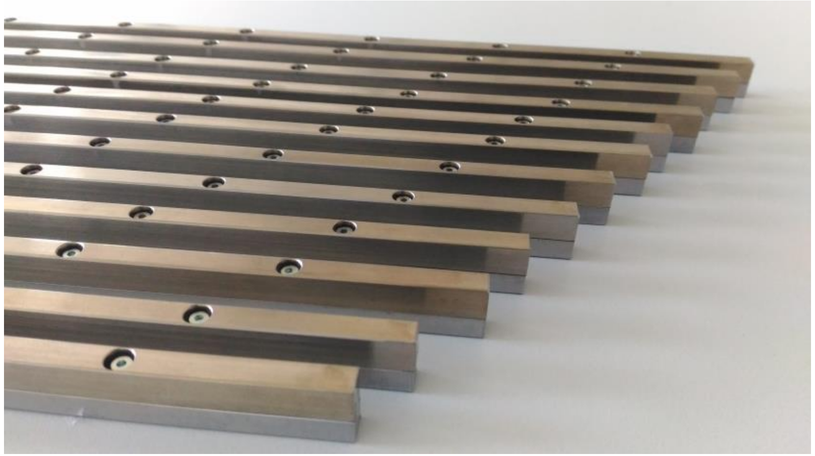




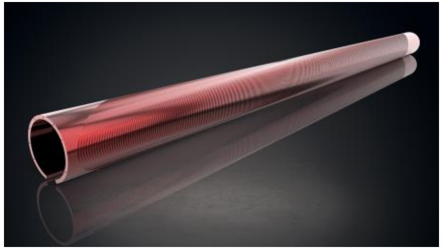


2.2m prototype components arriving





All other components are CERN



We have just finished the new long coil design: formers , outer support tube and joint boxes and hope to order soon

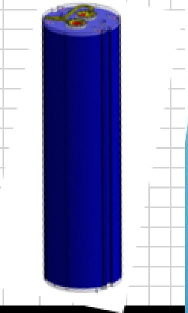
Model planning

2017: August (w32 w33 w34 w35, MT), September (w36 w37 w38 w39, EUCAS), October (w40 w41 w42 w43 w44), November (w45 w46 w47 w48), December (w49 w50 w51 w52); 2018: January (w1 w2 w3 w4 w5), Febuary (w6 w7 w8 w9), March (w10 w11 w12 w13), w14 w15 w16 w17 w18 w19 w20 w21 w22 w23 w24

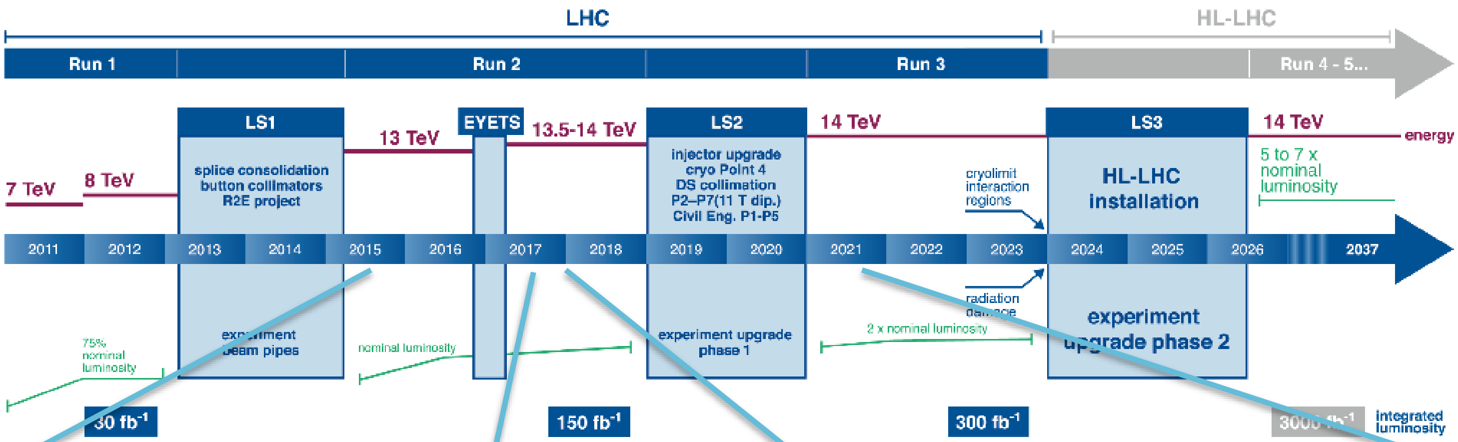
2nd CCT apertuer v2 design 0.5m long	
New former design	
CNC m/c 0.5m formers	?
Polish formers ?	
Hard anodize	
joint box manufactuer	
Winding 0.5 m inner former	
Winding 0.5 m outer former	
Coil assembly , jointing,	
impregnation	
yoke assembly	
Cold test !	Test 500mm

August (w32 w33 w34 w35), September (w36 w37 w38 w39), October (w40 w41 w42 w43 w44), November (w45 w46 w47 w48), December (w49 w50 w51 w52), January (w1 w2 w3 w4 w5), Febuary (w6 w7 w8 w9), March (w10 w11 w12 w13), April (w14 w15 w16 w17 w18), w19 w20 w21 w22 w23 w24

2.2m full lengh model	
component manufactuer	just Joint boxes needed
former manufactuer	Formers and outer suport tube m/c
develop long polishing tool + Anodization	Develop 2.2m polishing tool ?
CERN 0.825 wire insulation (430 c for 30 sec?	b
CERN 0.825 wire insulation (200 c)	
modify 927 coil winding m/c	
coil winding aperture 1	
coil assembly / jointing	
impregnation	
coil winding aperture 2	
coil assembly / jointing	
impregnation	
Magnet assembly into yoke	
Wiring and prep for text	
cold test	Test 2.2m twin; Test 2.2m twin

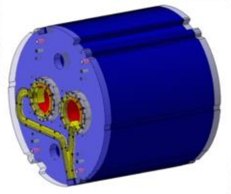


LHC / HL-LHC Plan

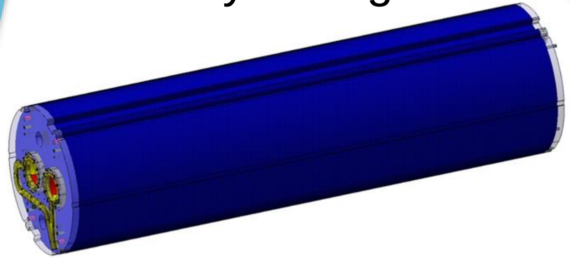


LHC/ HL-LHC Plan (last update 22.02.2016)

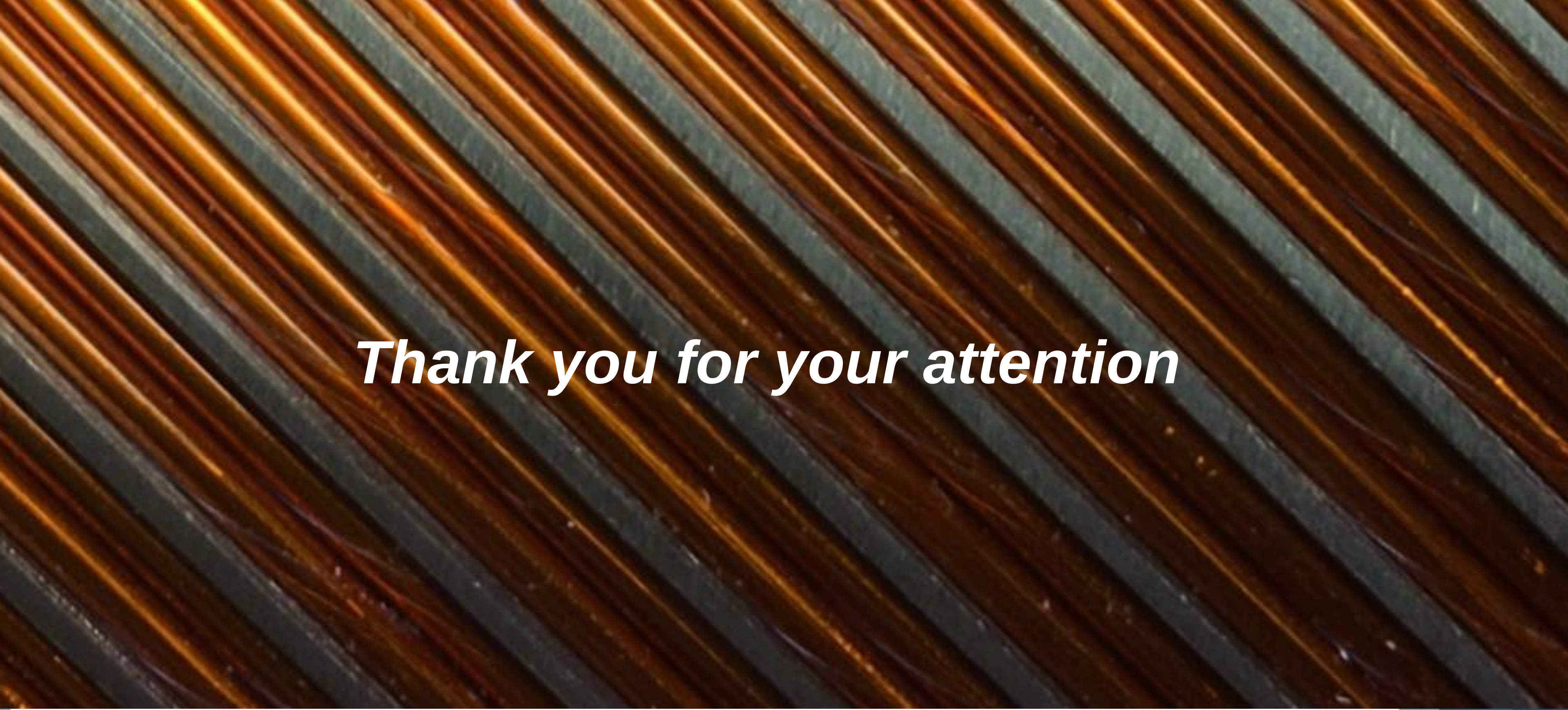
0.5m model tested
Summer 2017



Full size prototype
Assembly during 2018



18 - 20 off twin aperture
magnets production
delivery ~ 2020



Thank you for your attention

https://www.researchgate.net/project/LHC-hi-Lumi-orbit-corrector-5Tm-CCT