Thesis review

TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

15.12.2015, Jaakko Murtomäki

Structure

Structure of the thesis is hidden in the presentation in it's logical context

1. Background of the thesis subject
2. Objectives of the thesis
3. Hypotheses of the thesis
4. How to reach the objectives?
5. Schedule
6. Discussion

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Future high energy accelerators will need much higher magnetic fields in the range of 20 Tesla. The EuCARD-2 work-package-10.3 is a collaborative push to take HTS materials into an accelerator quality demonstrator magnet.

The demonstrator will produce a magnetic field of 5 T in the aperture when operated in standalone and between 17 T and 20 T, when inserted into the 100 mm aperture of Fresca2 high field outsert magnet.

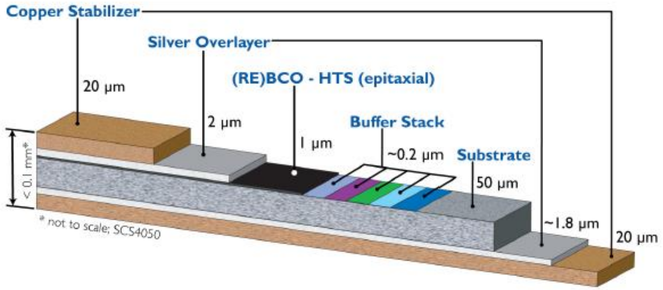


Figure 2.1: Schematic of the cross section of a SCS4050 $YBCO$ coated conductor as provided by SuperPower.

Cable Name	Röbel
photograph	
filling fraction	70 %
transposed	fully
parallel performance	yes
number of tapes range	< 24 (twist pitch)
twist pitch range	$50 - 300\ mm$
soft bending radius	$11\ mm$ [25]
hard bending radius	$2\ m$ (see Appendix A)

This thesis is focusing on two magnets:
Aligned block layout for the YBCO insert magnet for the EuCARD-2 project named Five Tesla HTS Research Magnet (FeaTHeR).

Because of the technical complexity of such a YBCO insert magnet it will be near impossible to successfully manufacture and test the final magnet on the first attempt. Therefore it was decided to start with a series of smaller magnets, in order to provide a playground for testing the necessary novel techniques without risking long lengths of expensive conductor.

This series of YBCO Magnets are numbered as Feather-M0 (FM0) and Feather-M2 (FM2), where FM2 is the final magnet that meets the EuCARD-2 requirements.

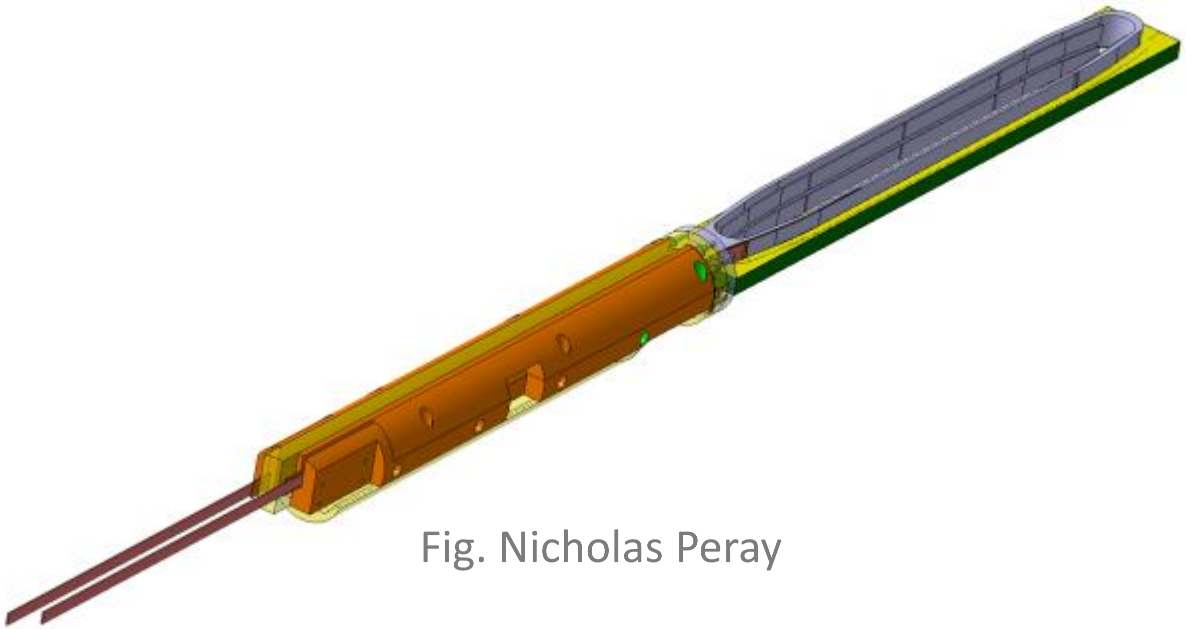
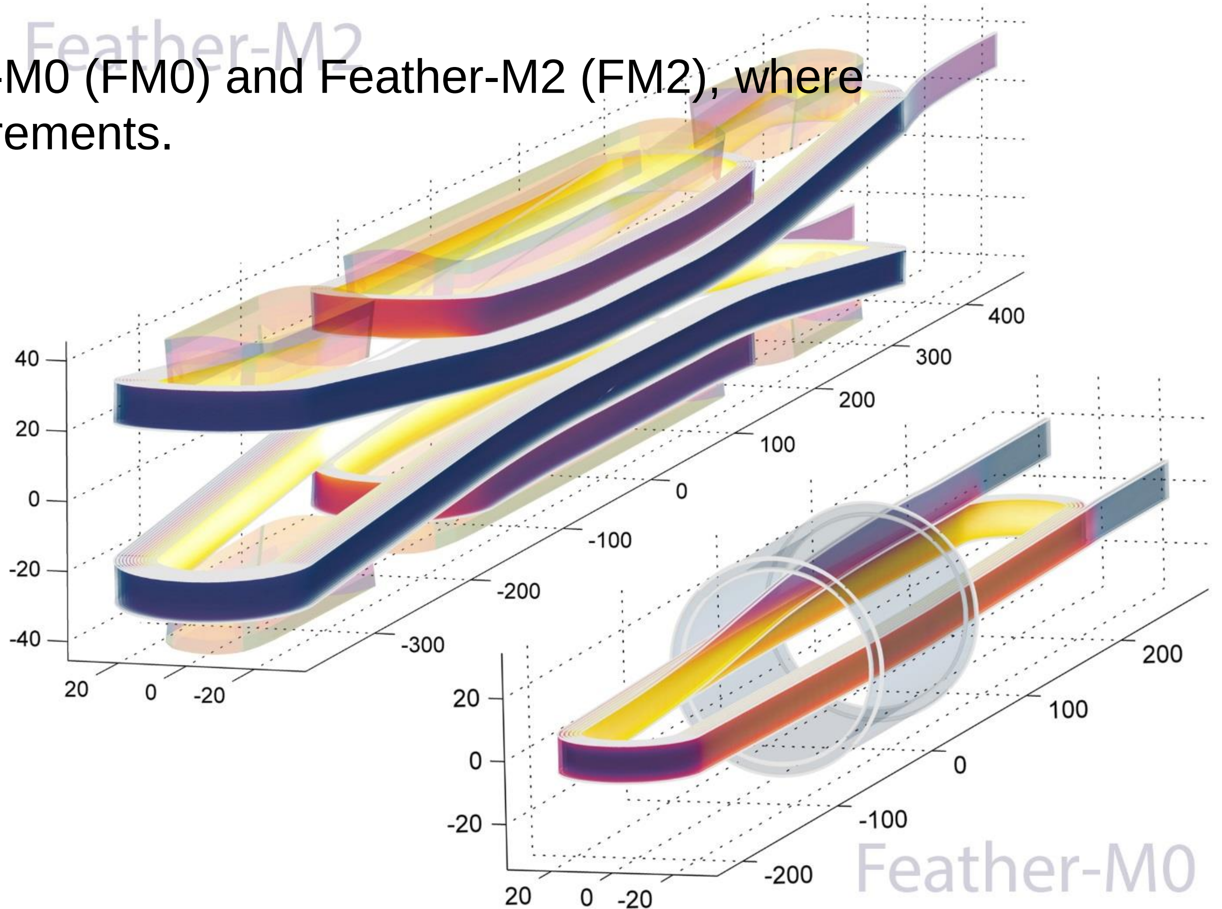
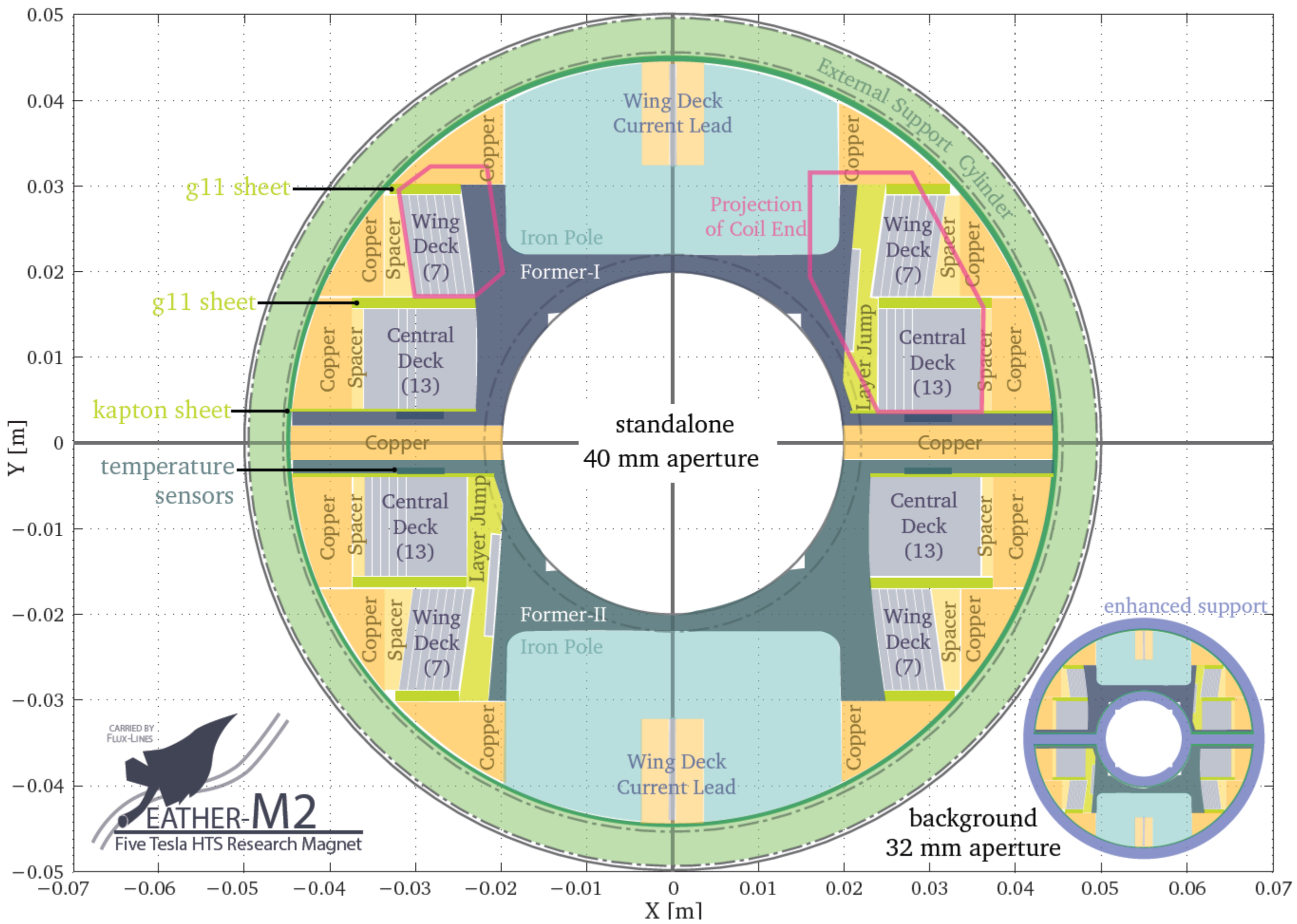
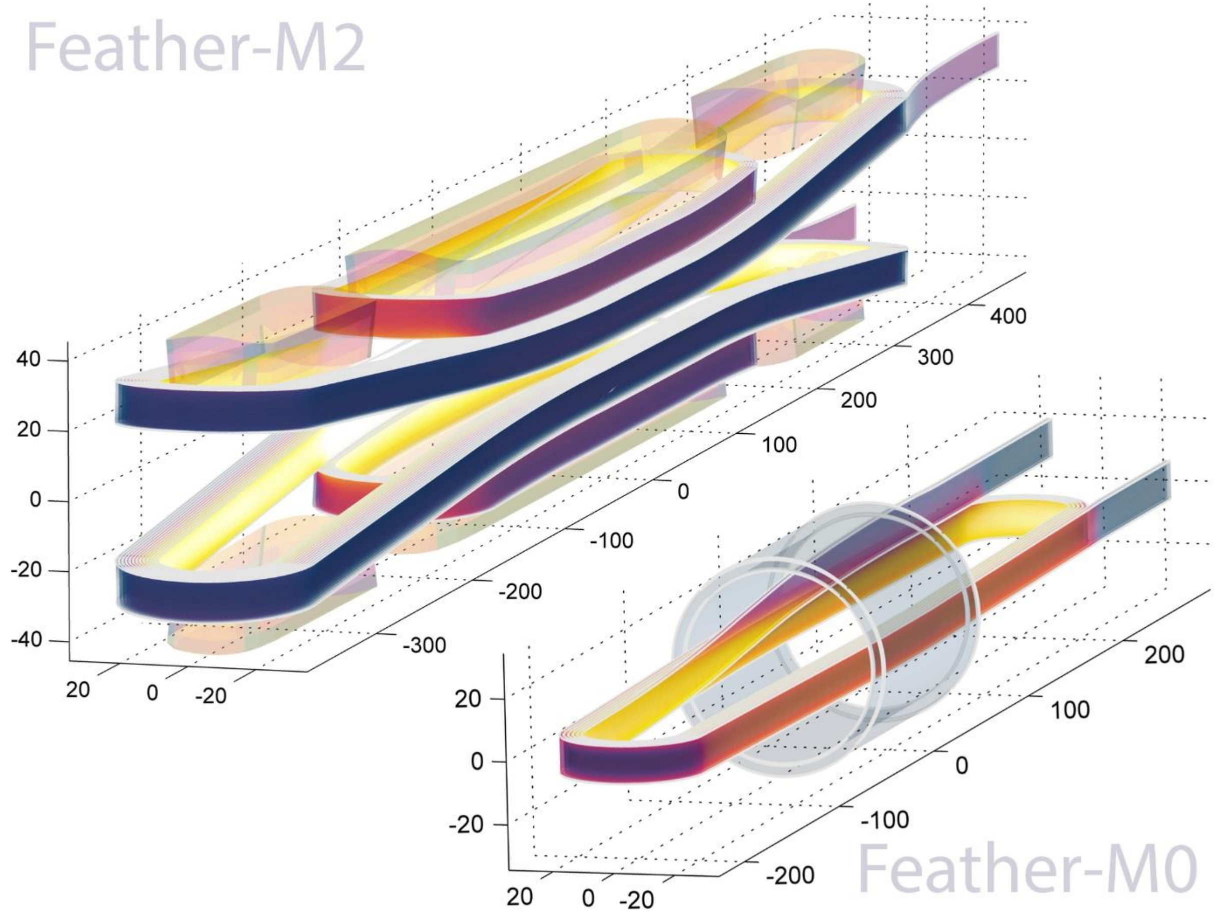


Fig. Nicholas Peray



HTS Development





J. van Nugteren et al., FCC Dipole Layout Study, Magnet Technology Conference, 2015

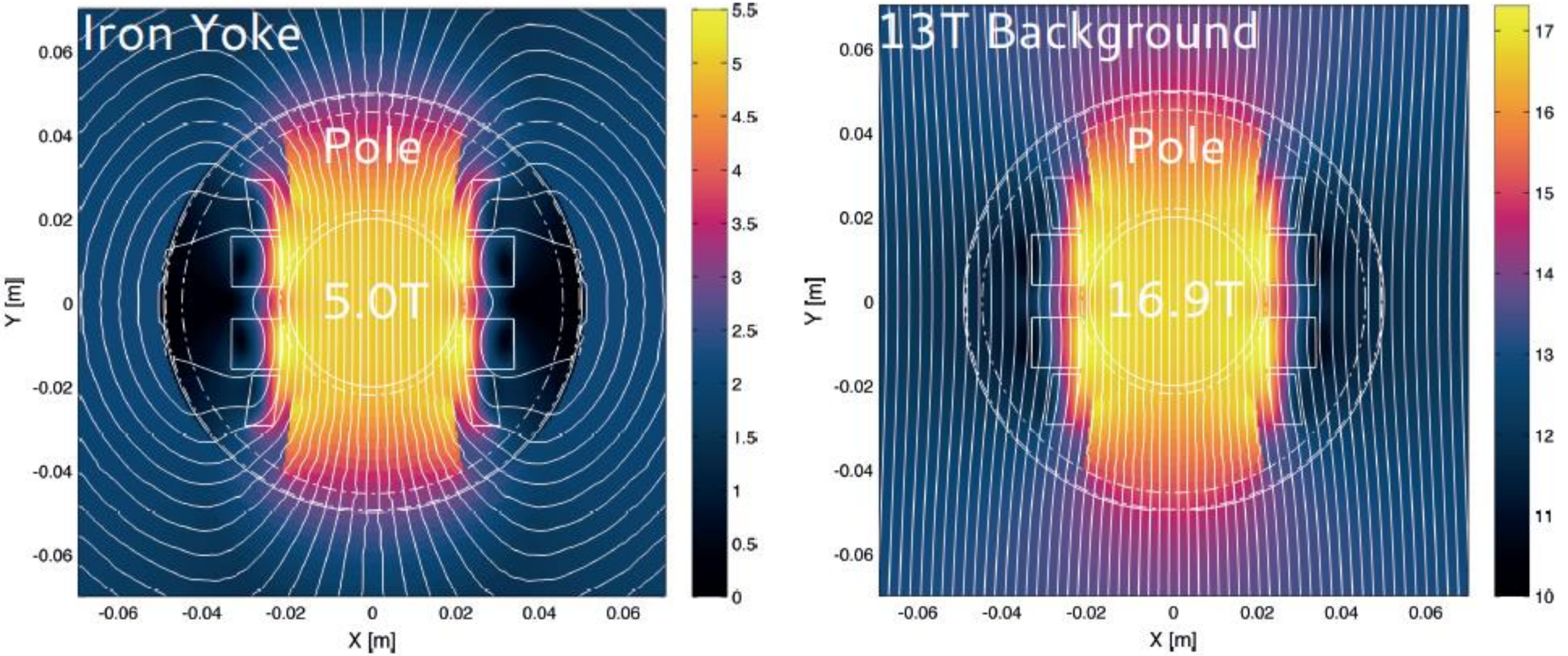


Figure 2.11: Calculated fieldlines for a 2D cross section of the Feather-M2 magnet. On the left side standalone in iron yoke and on the right side in a $13\ T$ background field.

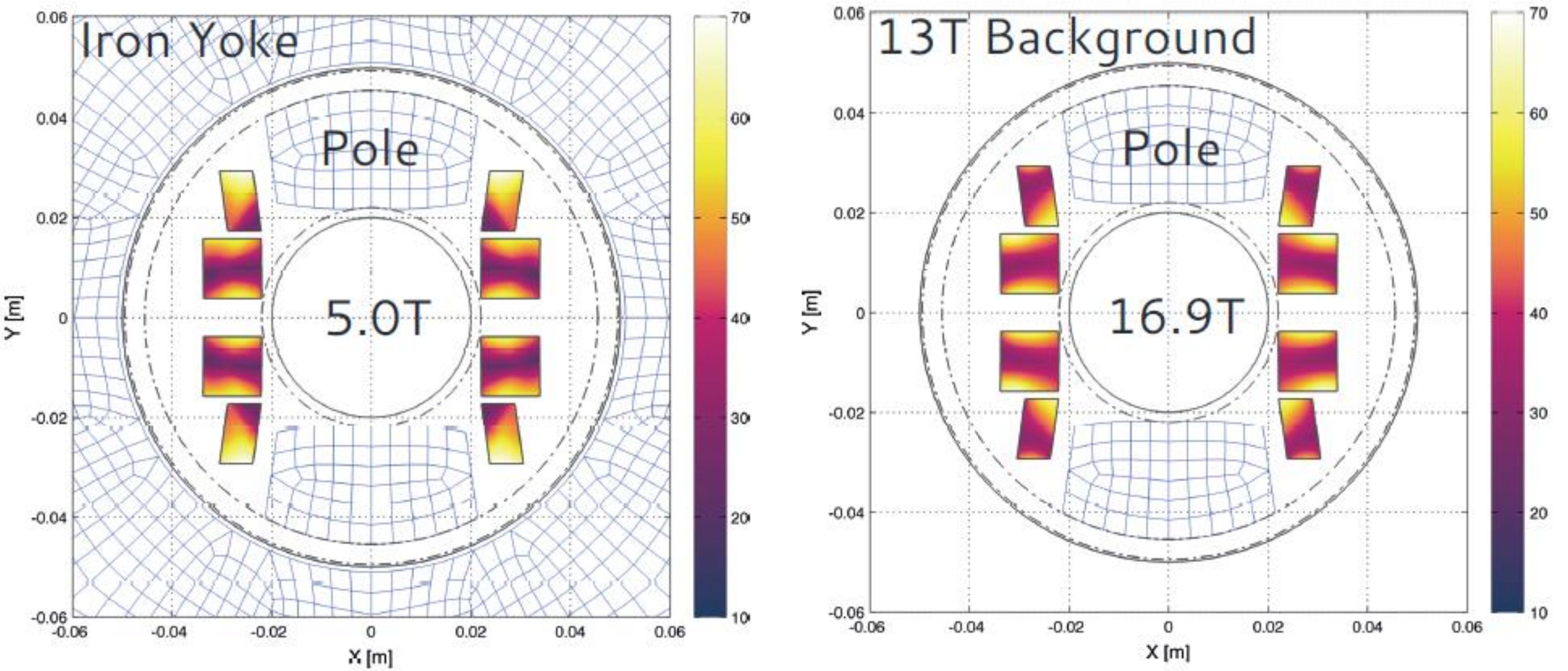


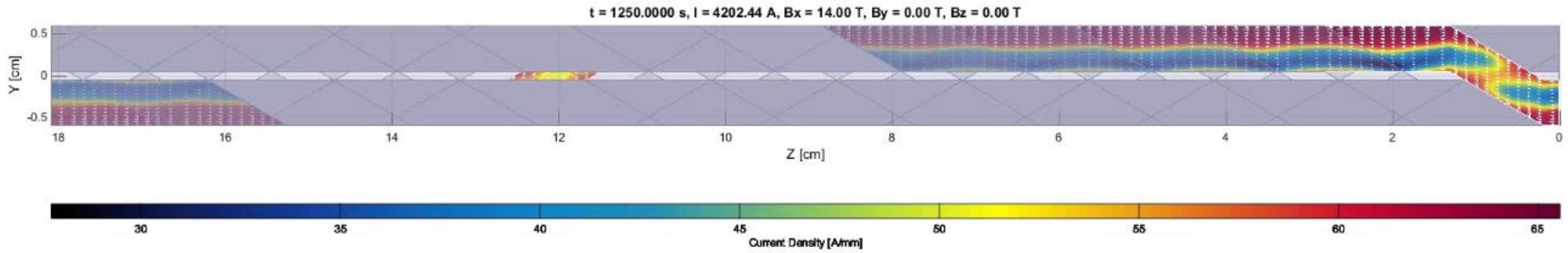
Figure 2.12: Percentage on the loadline for a operating current density of $\sim 650\ A/mm^2$ (homogeneously distributed in the blocks), the required current density to reach $5\ T$ in standalone operation.

- The critical current of REBCO keeps improving
  - Cost per ampere decreases
  - Very high current density wires are already demonstrated on short lengths (Houston University)
  - High current density close to the aperture leads to highly efficient magnets
  - At these current densities classical quench detection and protection no longer work.

Thanks to J. Van Nugteren

- This leads to many questions regarding quench and stability
  - What is the origin of heating and how fast is it deposited?
  - Can we detect thermal drift before the current sharing temperature is reached?
  - What margin would be sufficient in an accelerator?
  - …

Thanks to J. Van Nugteren



If you add current source and sinks on either end of the cable the transport current can be simulated

It flows mainly on the edge of the tapes (screening)

A normal zone can be created by firing a heater (like placing a stone in the river)

What we see is that the current flows around it creating higher current density areas next to the normal zone

This causes the tape to quench very quickly over its width.

Thanks to J. Van Nugteren

Ramp over critical current most likely cause for roasted coil (=

Beam loss (should be caught by beam loss monitors dumping beam immediately)

Cryogenic failure (very slow large time to detect)

Conductor movement (need more than 0.5 cm bad design, should not happen)"

Mechanical failure (bad design, should not happen)

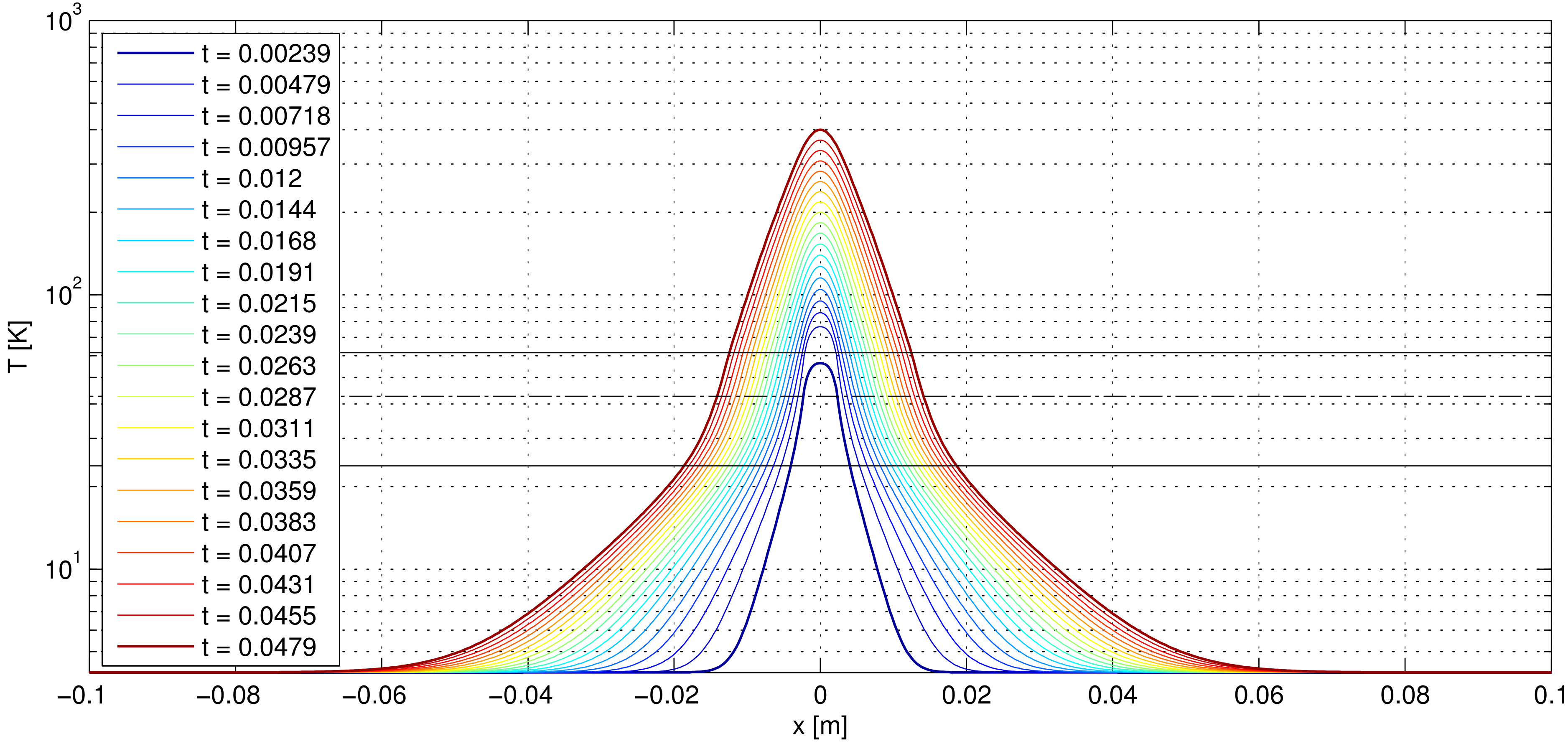
AC-Loss (need to ramp slowly)

...

Can we make the magnets easier to replace?

Thanks to J. Van Nugteren

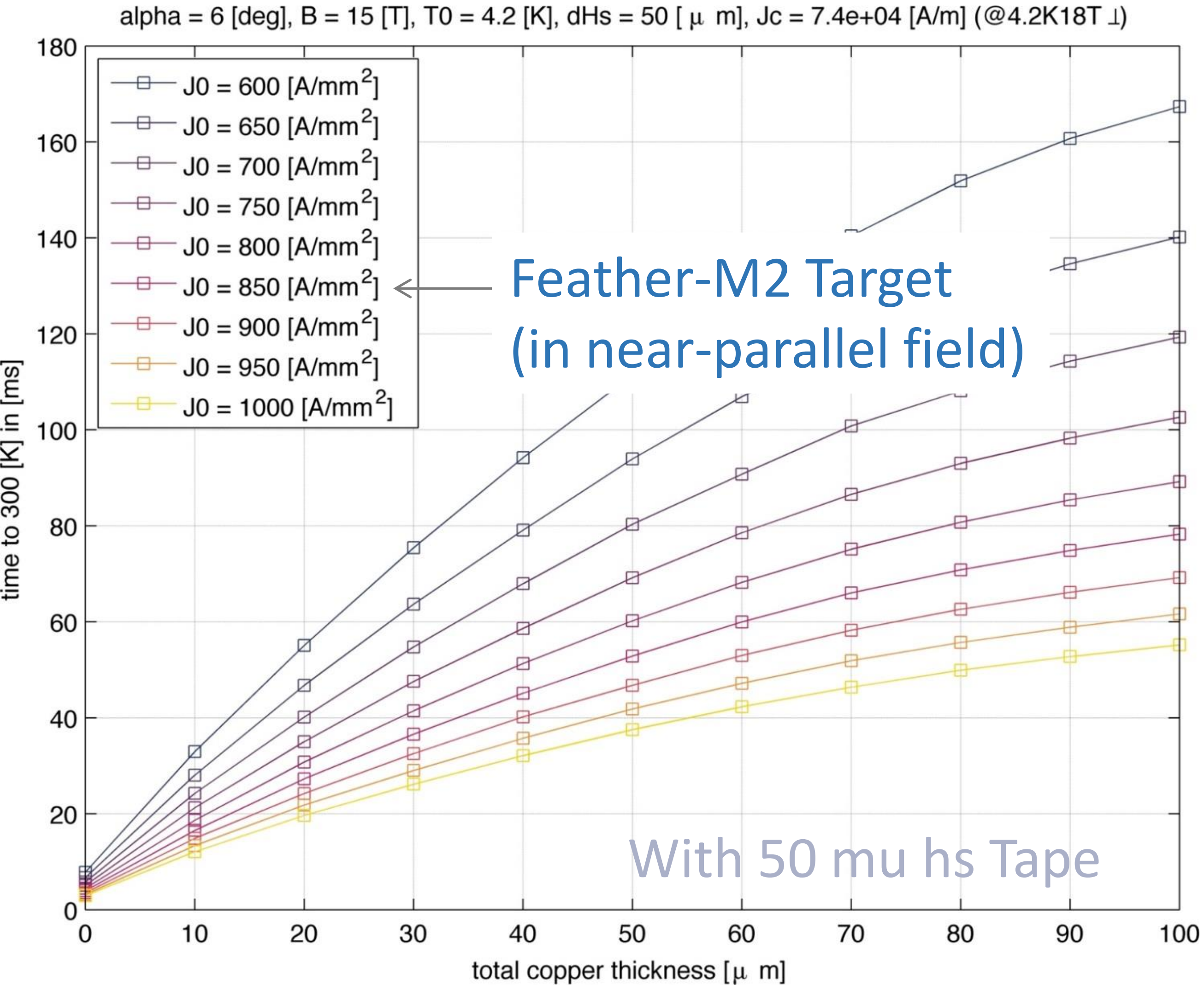
Very local heating

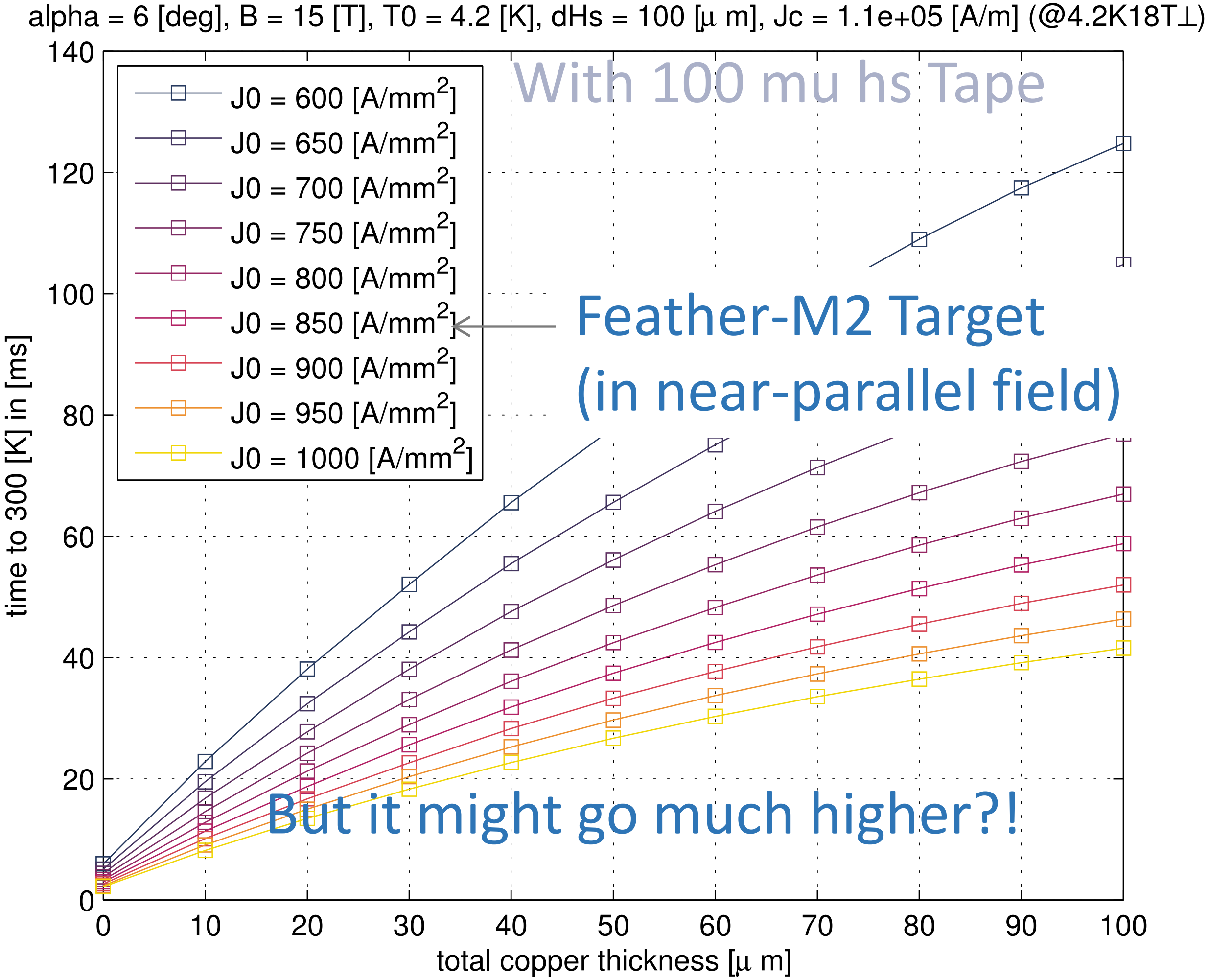


Thanks to J. Van Nugteren

Reaction Time for Feather-M2 Aligned

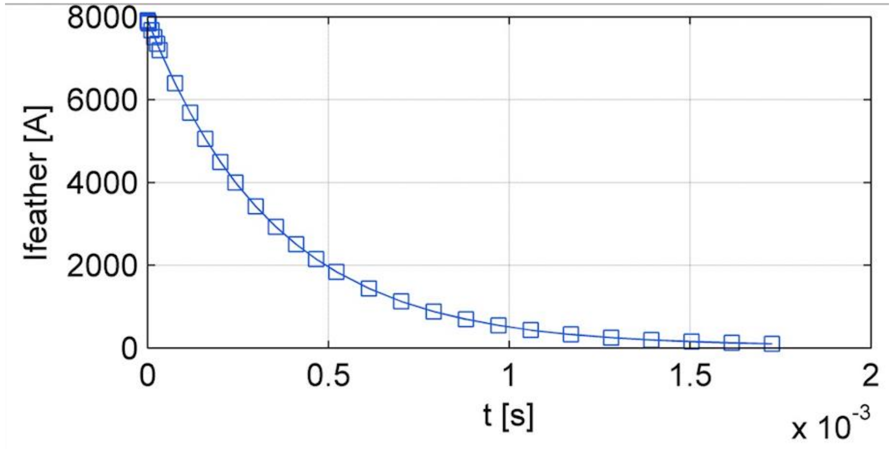
- Jcu is 2100 A/mm² for 50 mu hs and 3100 A/mm² for 100 mu hs tapes
- The time to 300 K is about 30-40 ms
- Variable temperature test should provide us the safety to study the detection-protection system

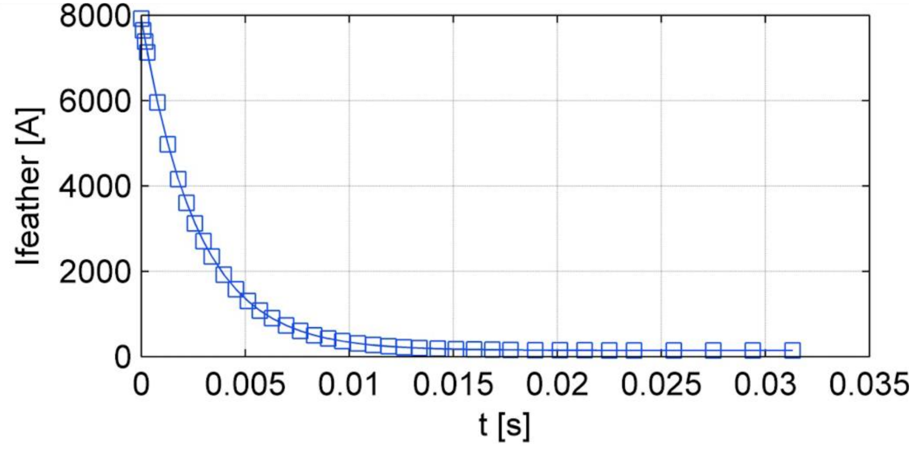


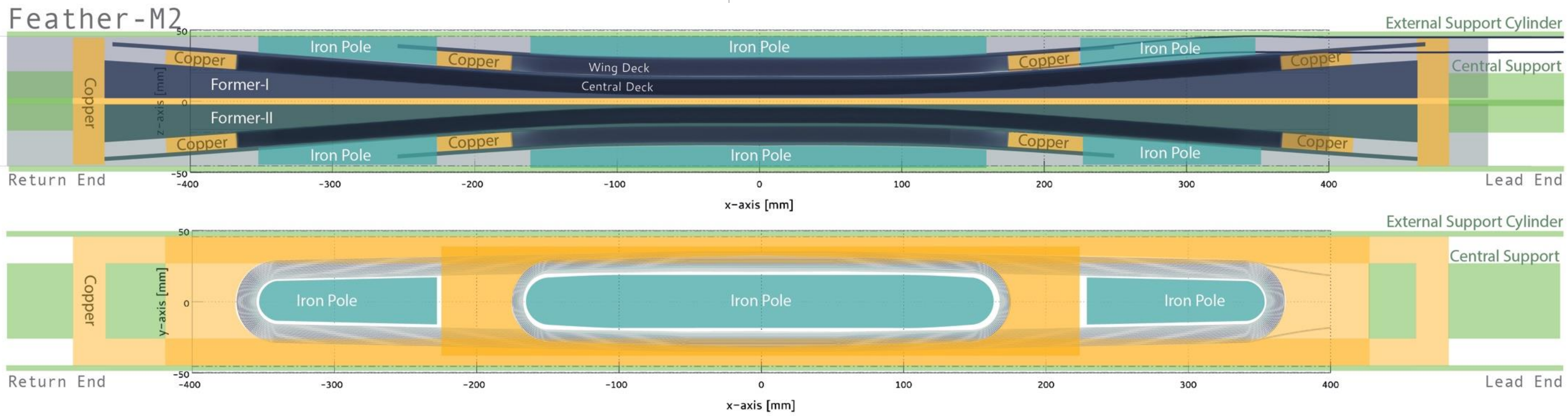


Thanks to J. Van Nugteren

Copper Rings, Some sort of Transformer



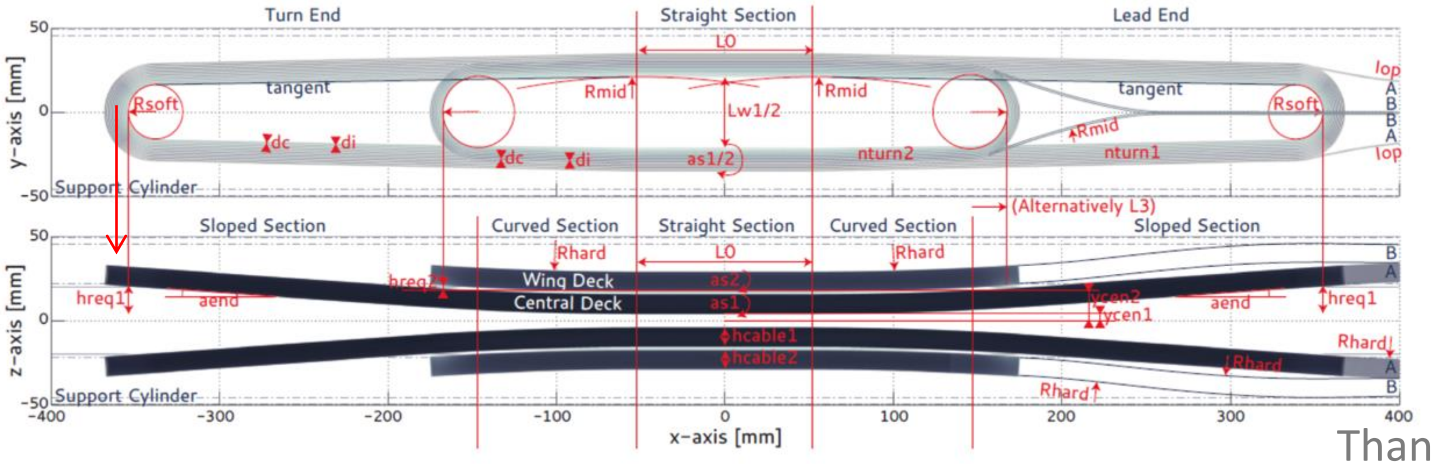


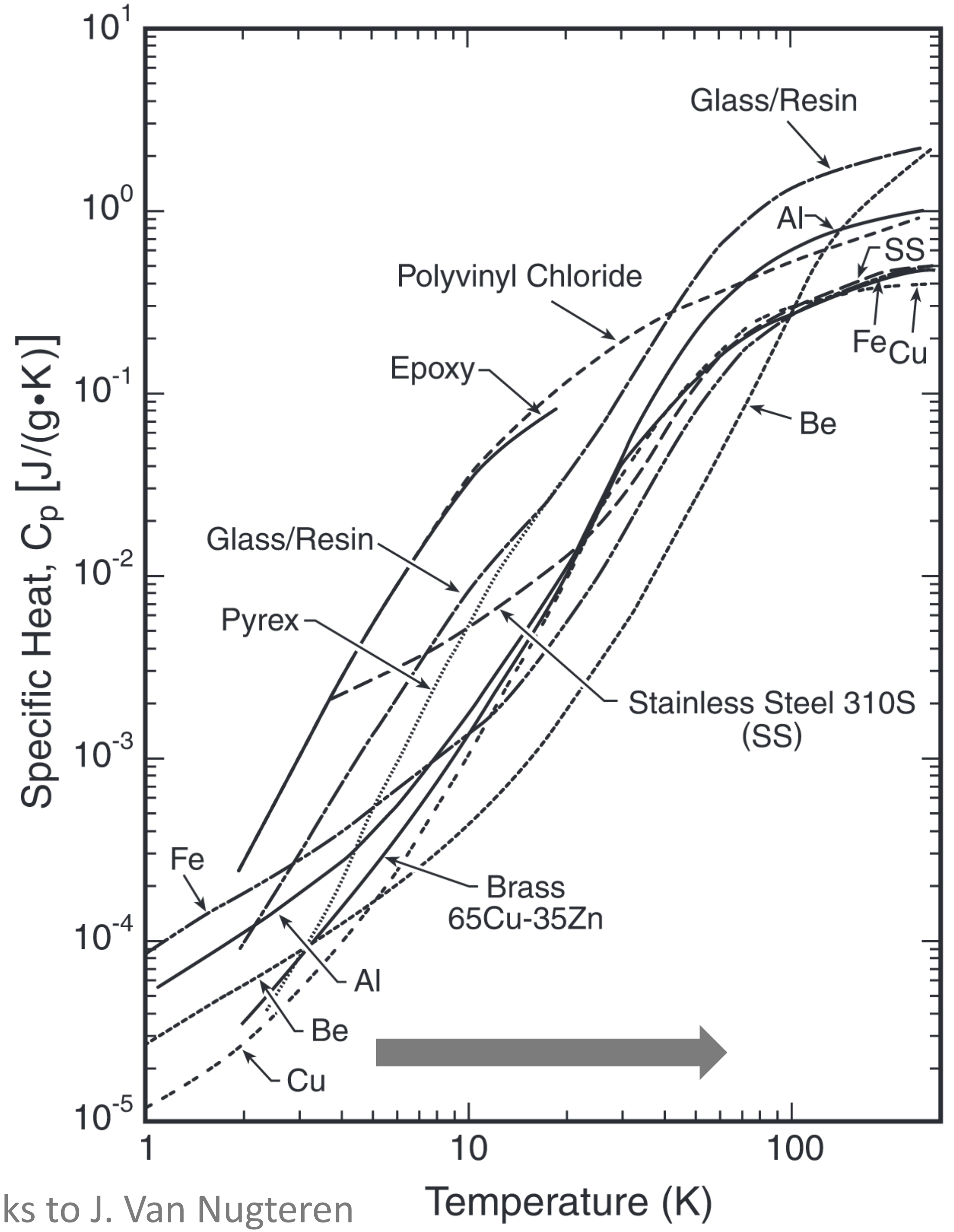


Thanks to J. Van Nugteren

Stability

- The temperature margin on Feather-M2 is ~40 K at worst point (if not better)
- This is excelent news because the heat capacity increases rapidly with temperature
- MQE is estimated to be on the order of 100 mJ per tape
- How well do the strands work together and thus the question on the current sharing?





Thanks to J. Van Nugteren

Thesis objectives

To summarize, the objectives are

- To find via modelling and prototyping optimal Roebel cable structures and coil winding method
- To find via modelling and prototyping adequate magnet design
- To find potential new technologies for quench detection/protection
- To test technologies proven on LTS for quench detection on HTS
- To study if piezoelectric sensors can be used in AE diagnostics of a quench event.
- To learn how to use FBGA for data read-out.

For more info on thesis objectives, read research plan in Indico

Hypotheses

Hypotheses of the objectives are:

- Certain Roebel cable assembly turns out to be better than the others and future coils utilize that. Adequate tooling is innovated for coil winding.
- Such magnet design methods are found that training is reduced and mechanical damages of the superconductor due to stress state are avoided.
- Joint technologies are developed to avoid quenches on the conductor and current leads.
- It is possible to detect quench onsets by electro-magnetic sensors on HTS
- With piezoelectric sensors it is possible to determine their onset and their spatial locations. Moreover, it is possible to follow with them the spreading of the normal zone.

For more info on thesis hypotheses, read research plan in Indico

Tooling development

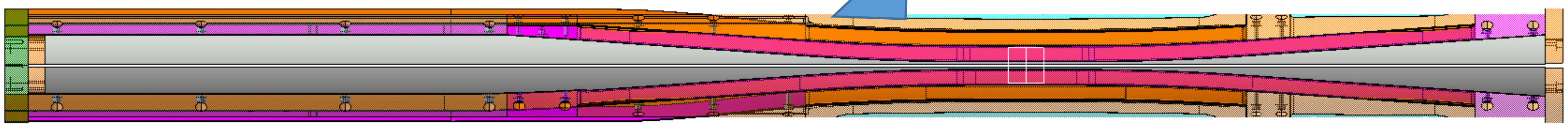
15.12.2015, Jaakko Murtomäki

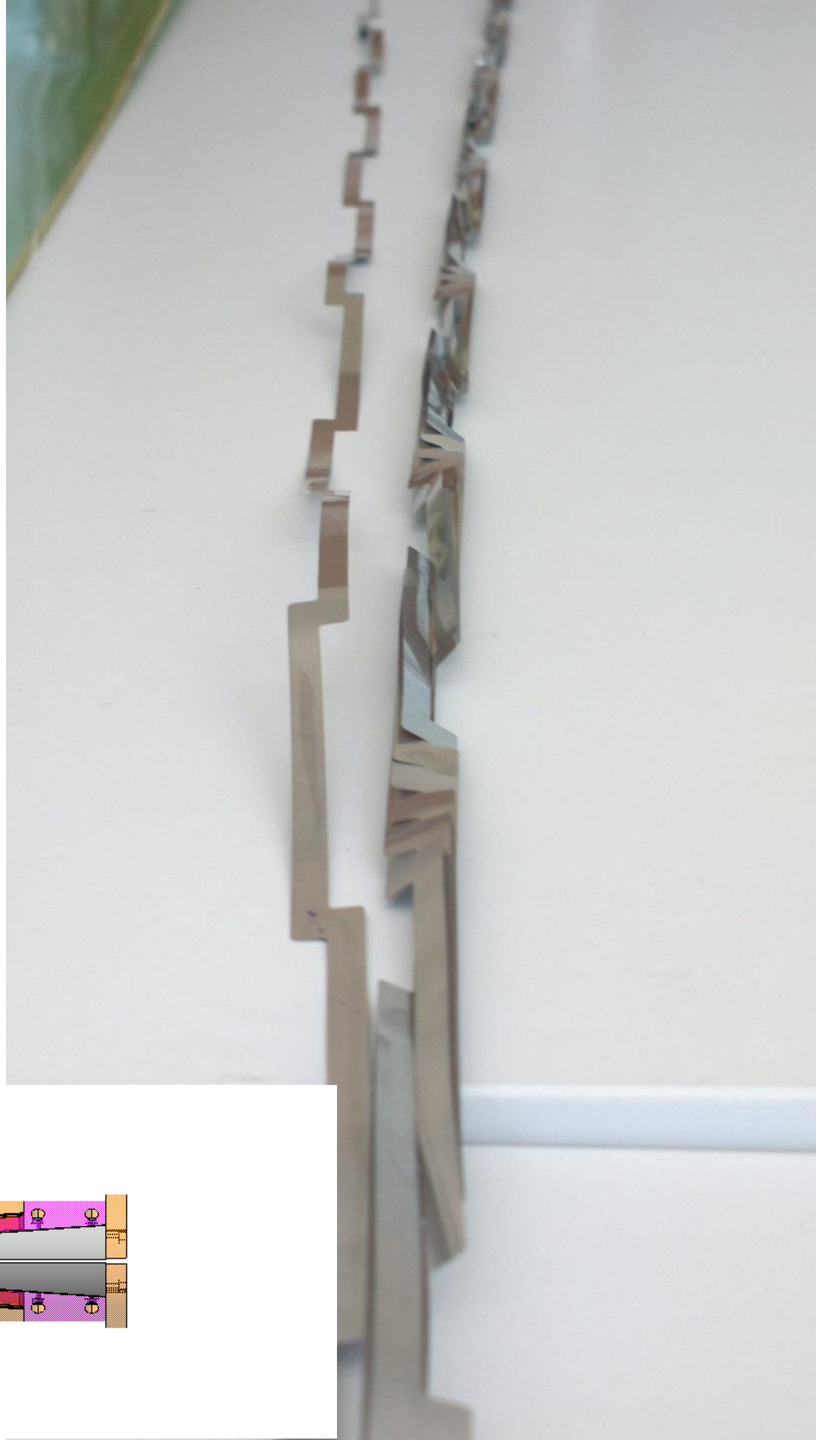
Tooling development

Roebel is challenging to handle in very long lengths.

Manual reassembly takes time and is even risky

soft bending radius	$11\ mm$ [25]
hard bending radius	$2\ m$ (see Appendix A)

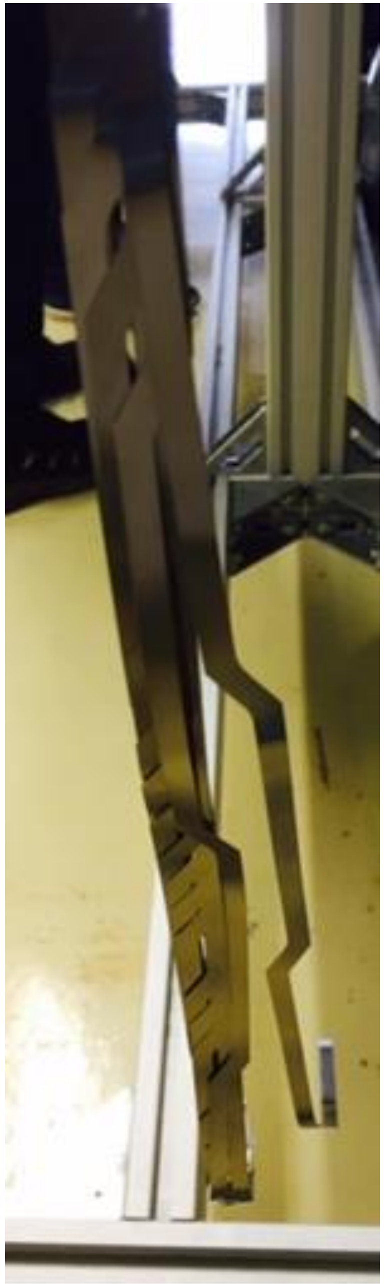


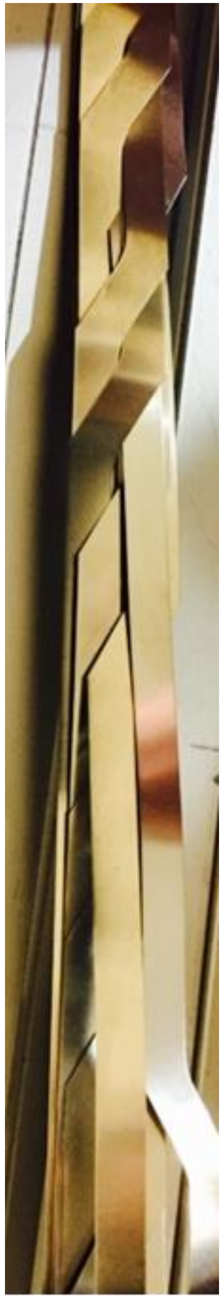


Re-assemble cable

Cable unravelling:
It would be nice to find a way of fixing the cable to stop it from coming apart.   this happens at the ends and occasionally in the straight section..

Tape , clips, ….





Tooling development

Figure 2.6: Illustration of a cross section of a Röbel cable .

Tape misalignment in cross-section

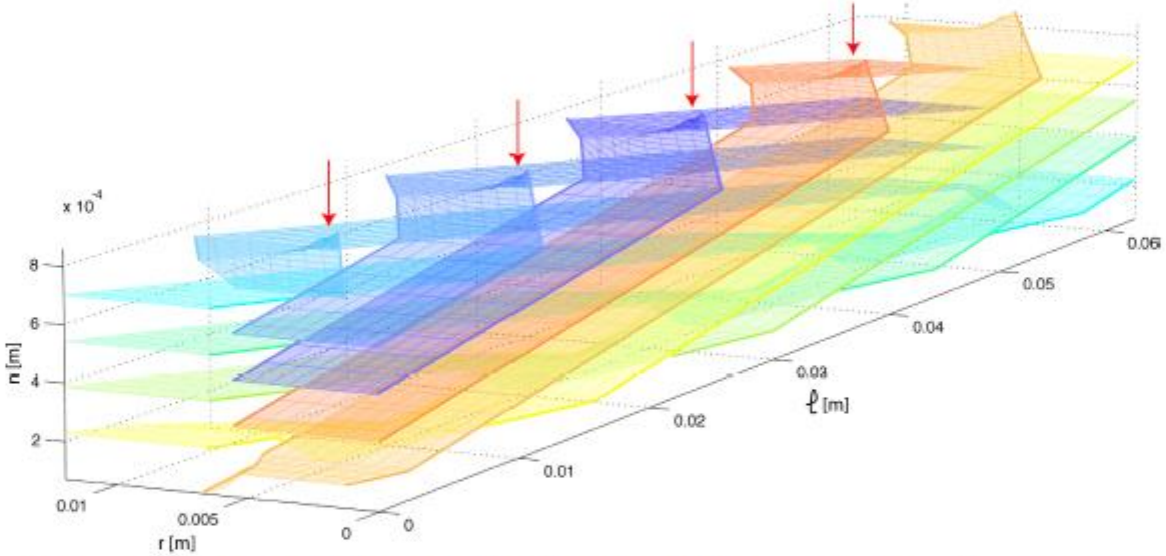
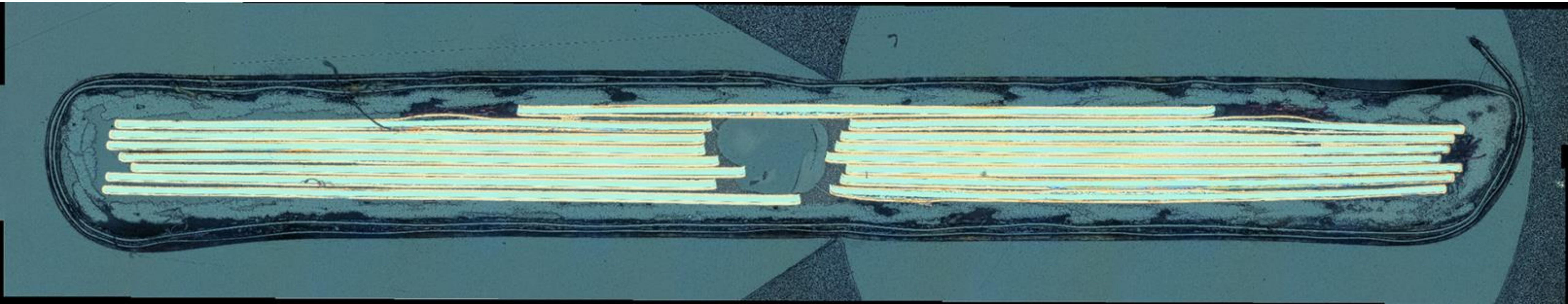
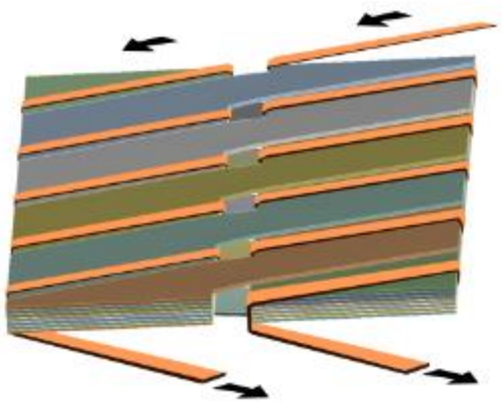


Figure 2.7: Plot of the strand trajectories of a Röbel cable with the KIT layout using 9 strands each strand consisting of a superconducting and a copper tape (only superconducting tapes are shown). Tapes are represented as flat surfaces. Each color represents one of the strands. It can be seen that at the crossovers, denoted with the red arrows, the strand reorients itself. Note that vertical axis is not plotted to scale. Only half a twist pitch (five unit cells) is shown.

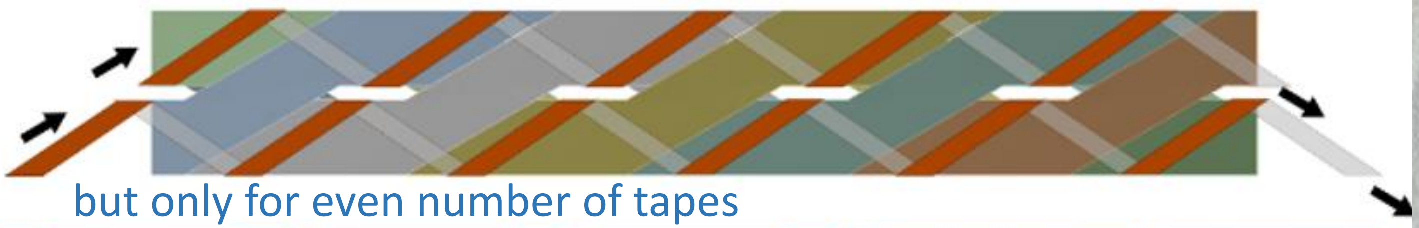


Patent disclosure

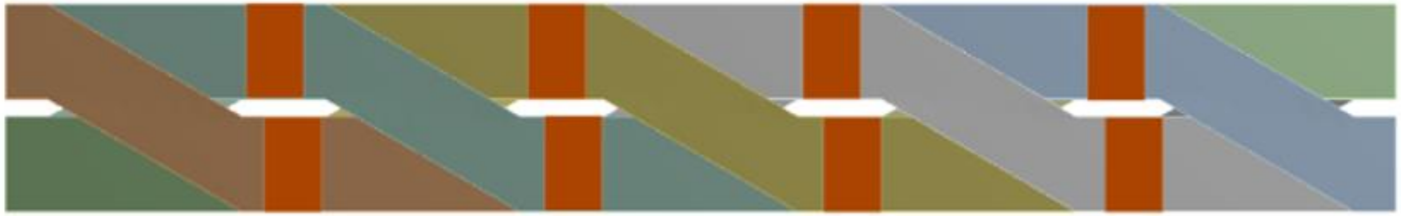


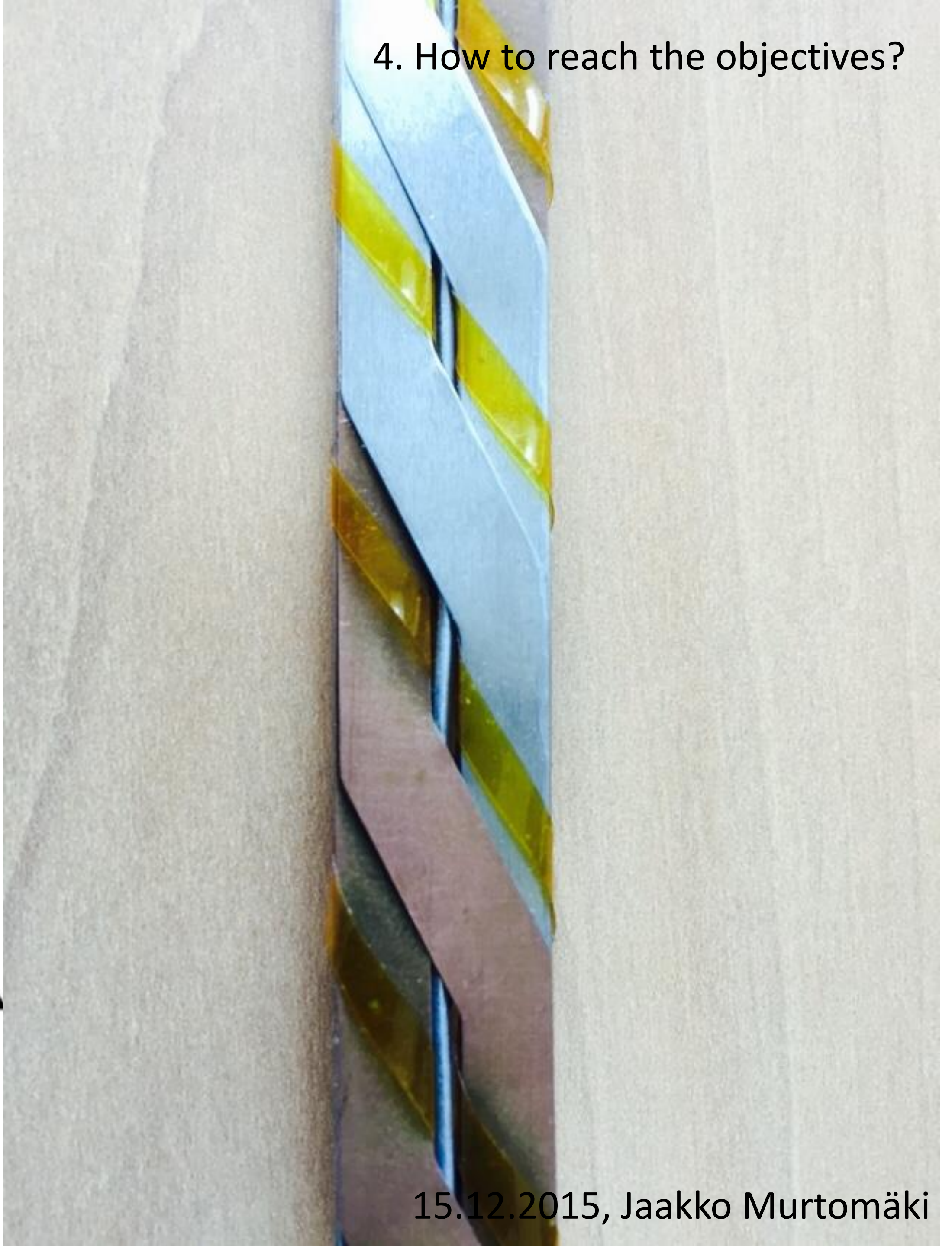
An european patent application invented by the investigator and his closest colleagues Glyn Kirby and Jeroen van Nugteren has been disclosed on 10.8.2015. Braiding and bracelet support configuration on Roebel cable assembly is meant to increase manual handling capabilities of Roebel cable and make assembly of it more secure to avoid cable current carrying capacity degradation during transport and manufacturing procedures. The investigator has produced the main bulk of descriptions and illustrative material for the application. Currently, after 12 months of initial phase the patent is intended to be converted into international patent application.

May be incorporated into an automatic winding machine.

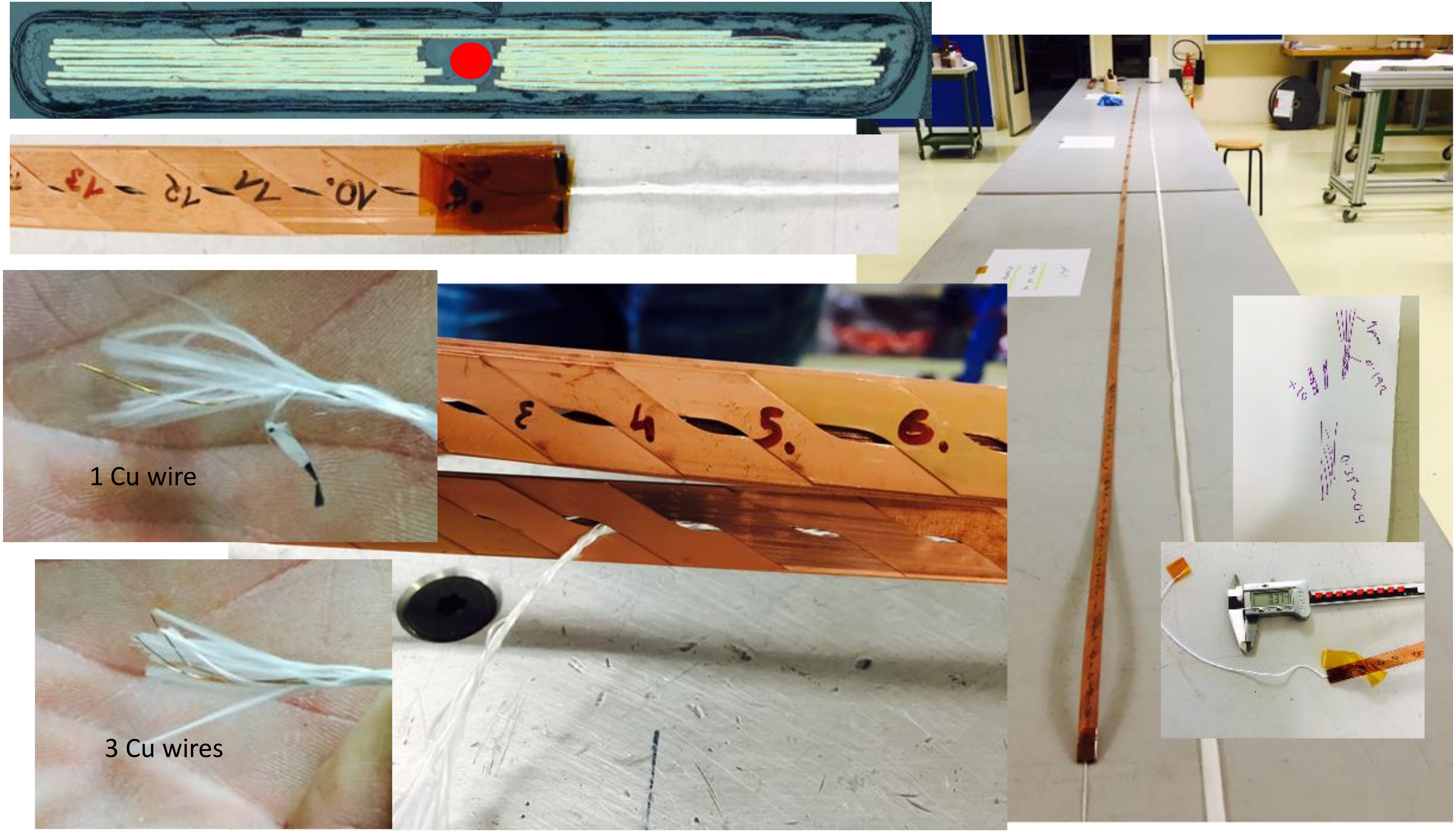


but only for even number of tapes





Roebel sleeve assembly


1 Cu wire
3 Cu wires

Safe axial tension during winding

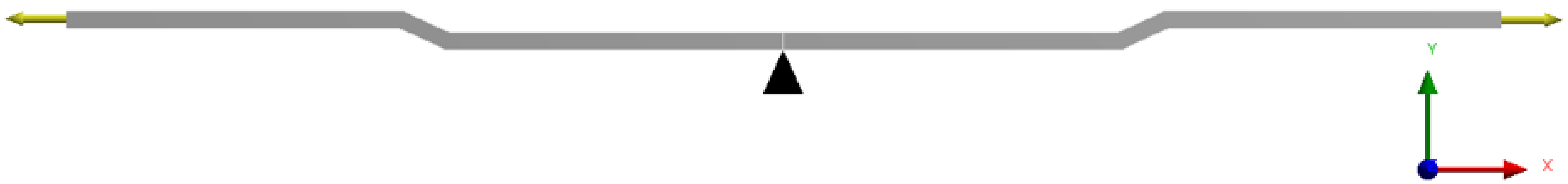


Figure 2 Boundary conditions of the model.

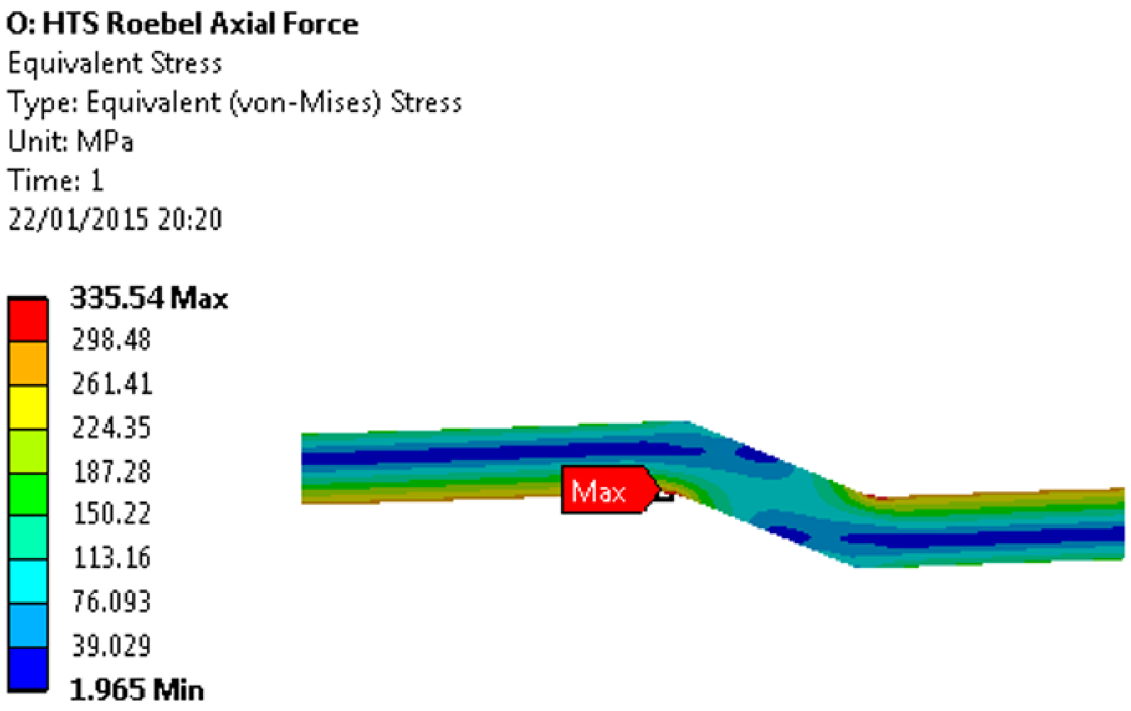


Figure 4 Von-Mises stress distribution of a portion of the model showing the elbow geometry.

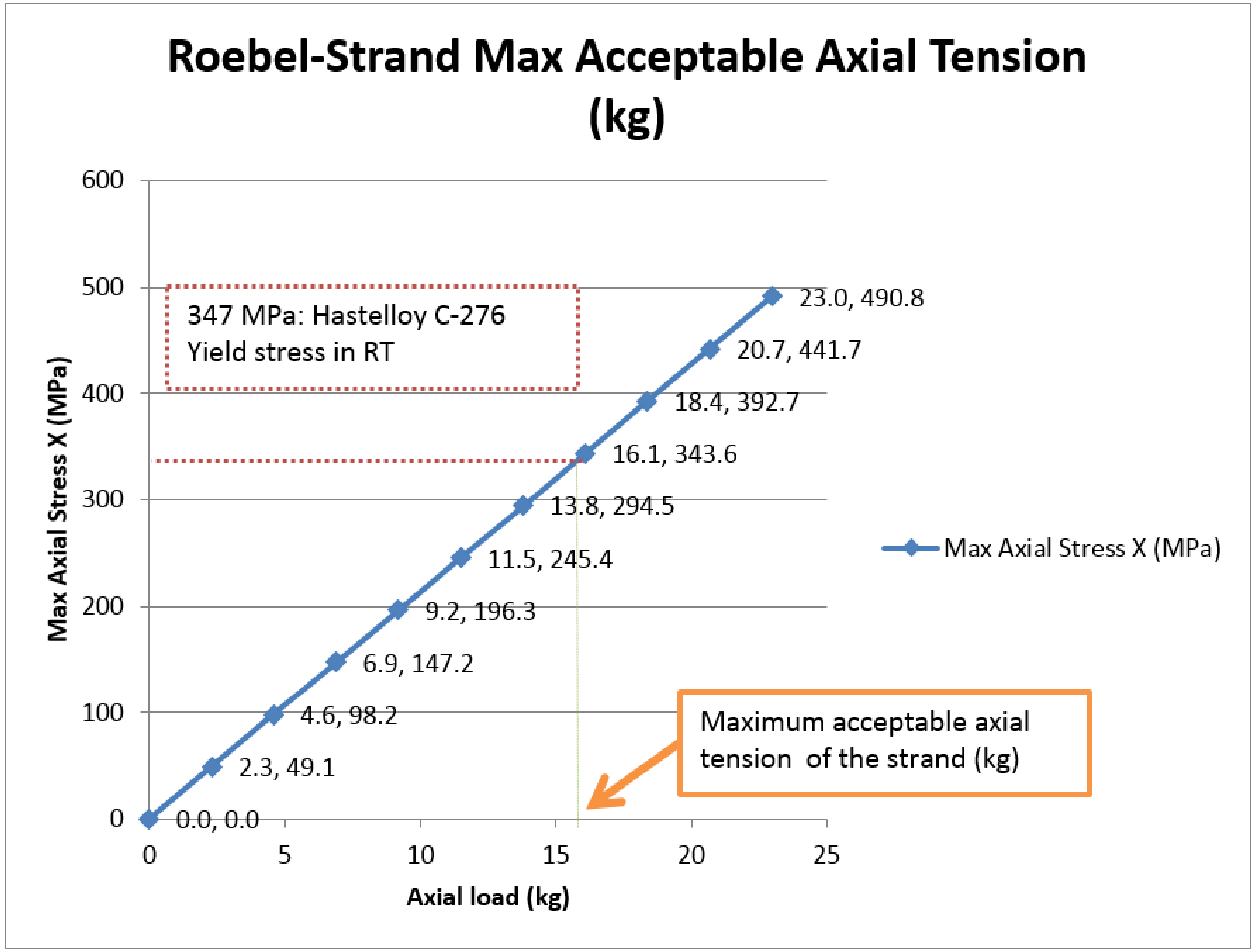


Figure 5 Roebel strand maximum acceptable tension. The limit is shown by the orange arrow.

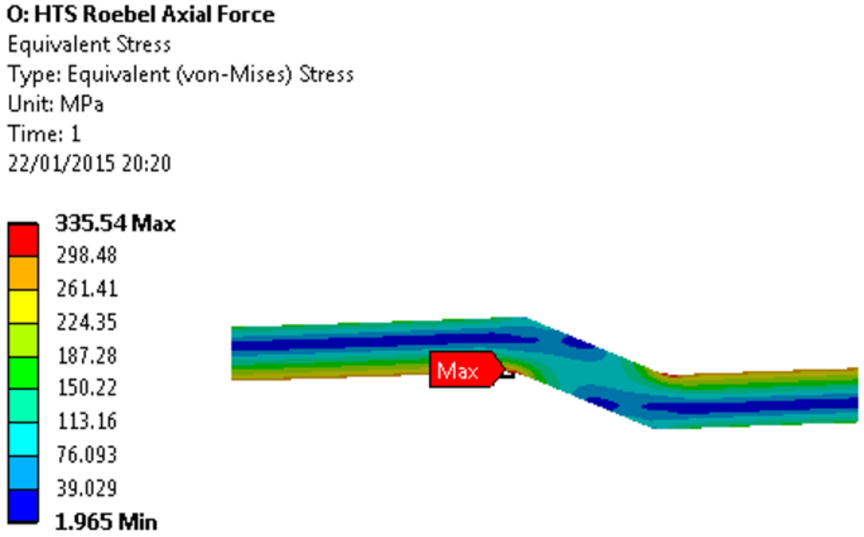
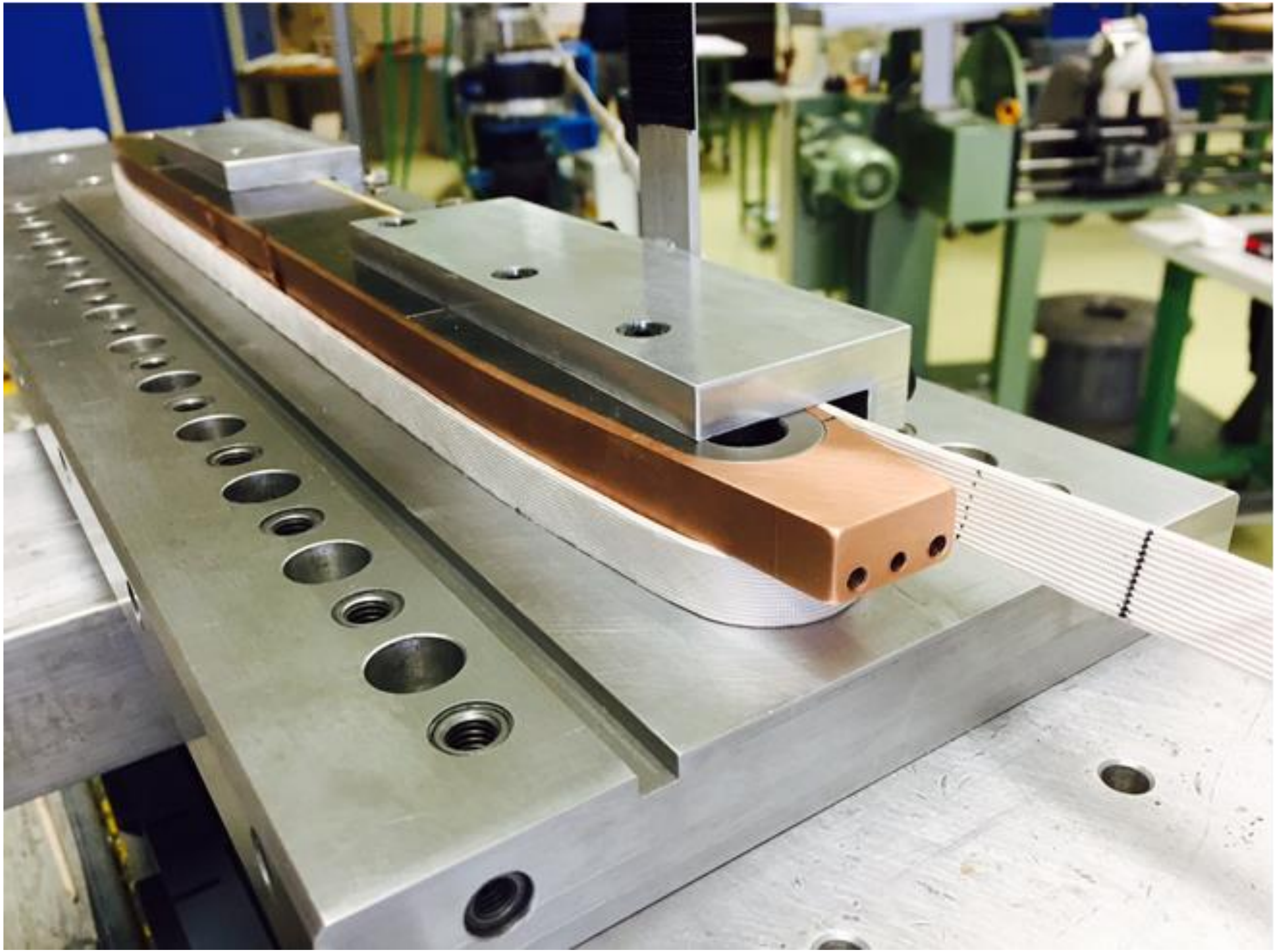
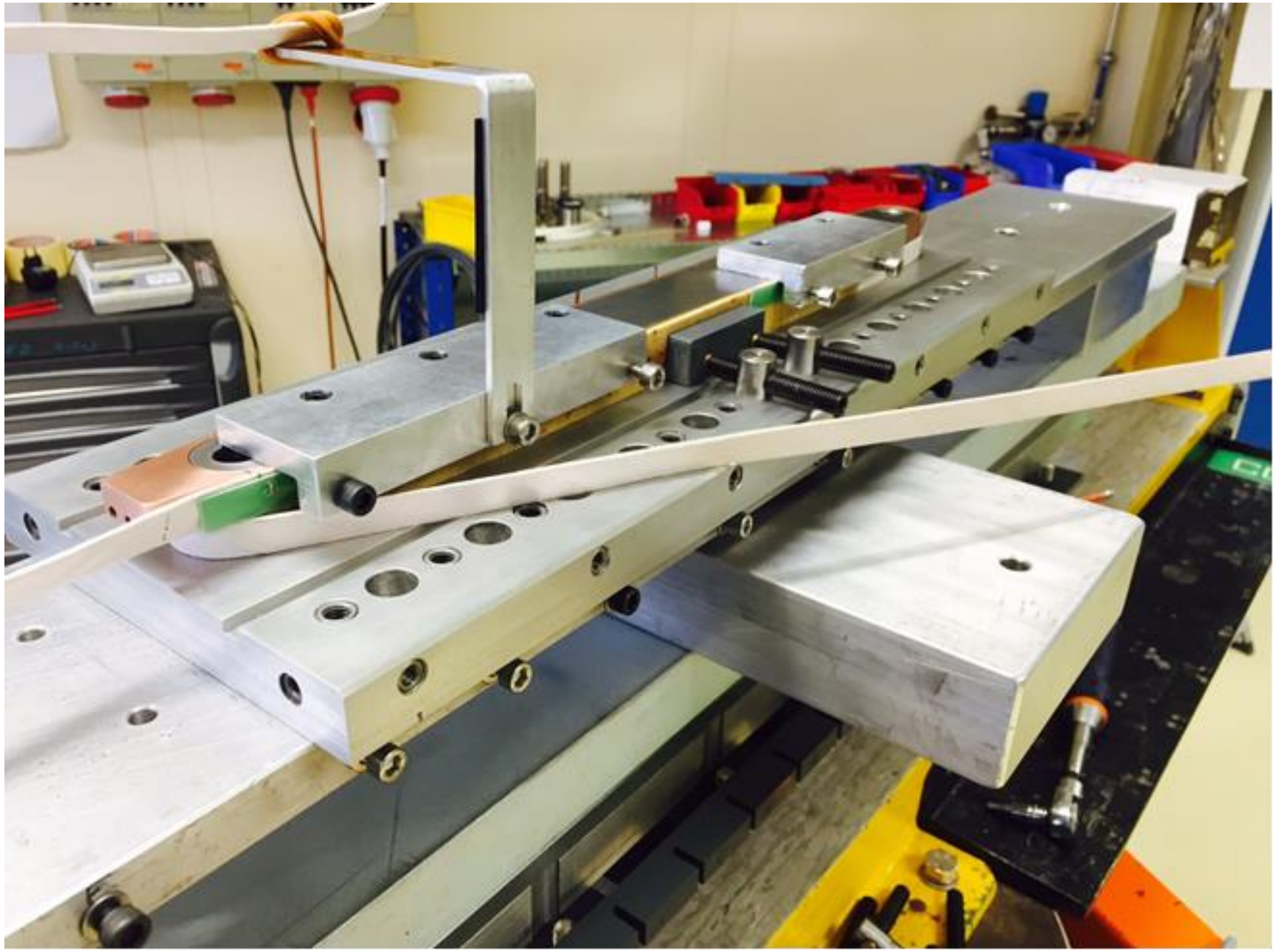


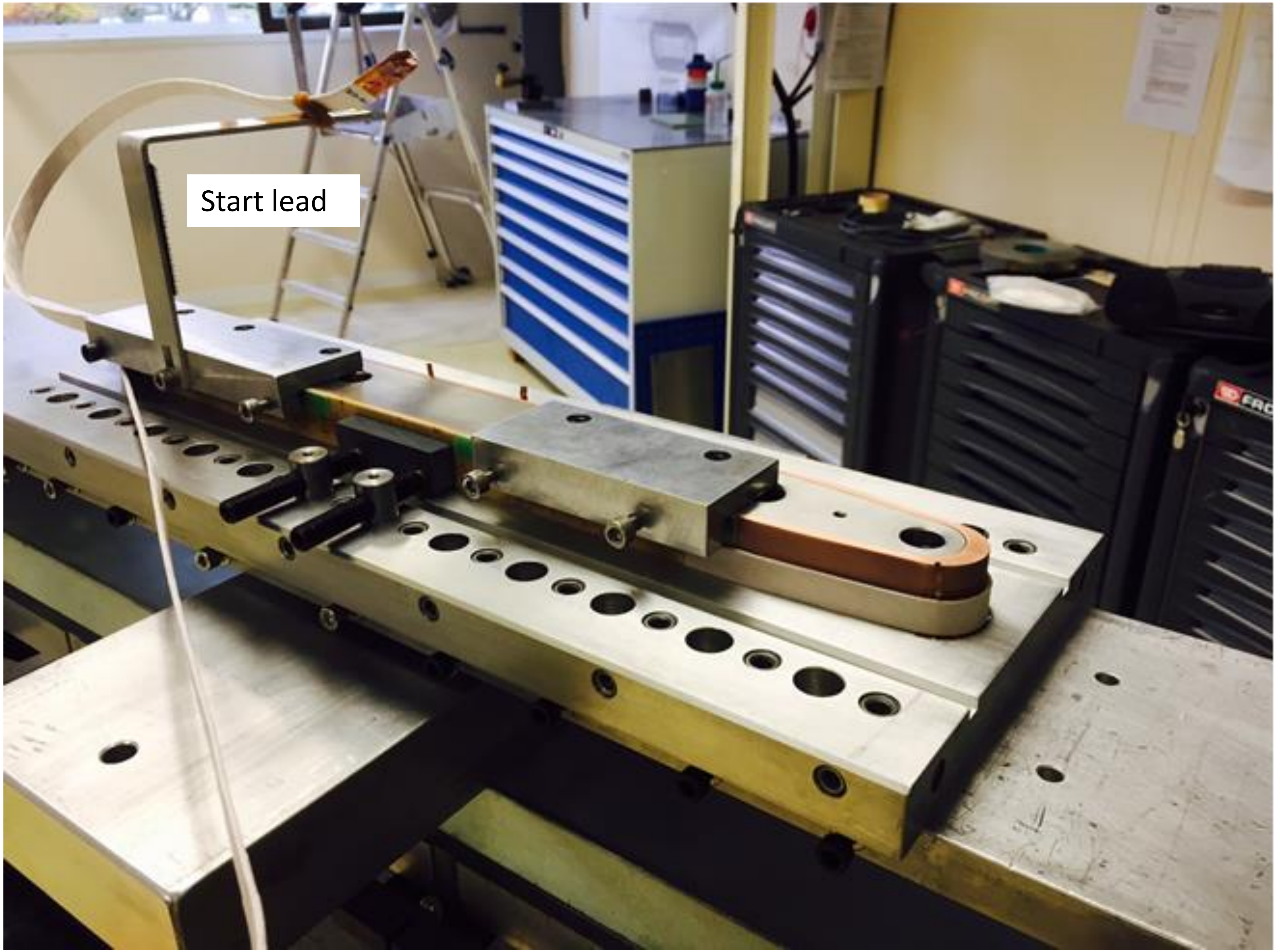
Figure 4 Von-Mises stress distribution of a portion of the model showing the elbow geometry.

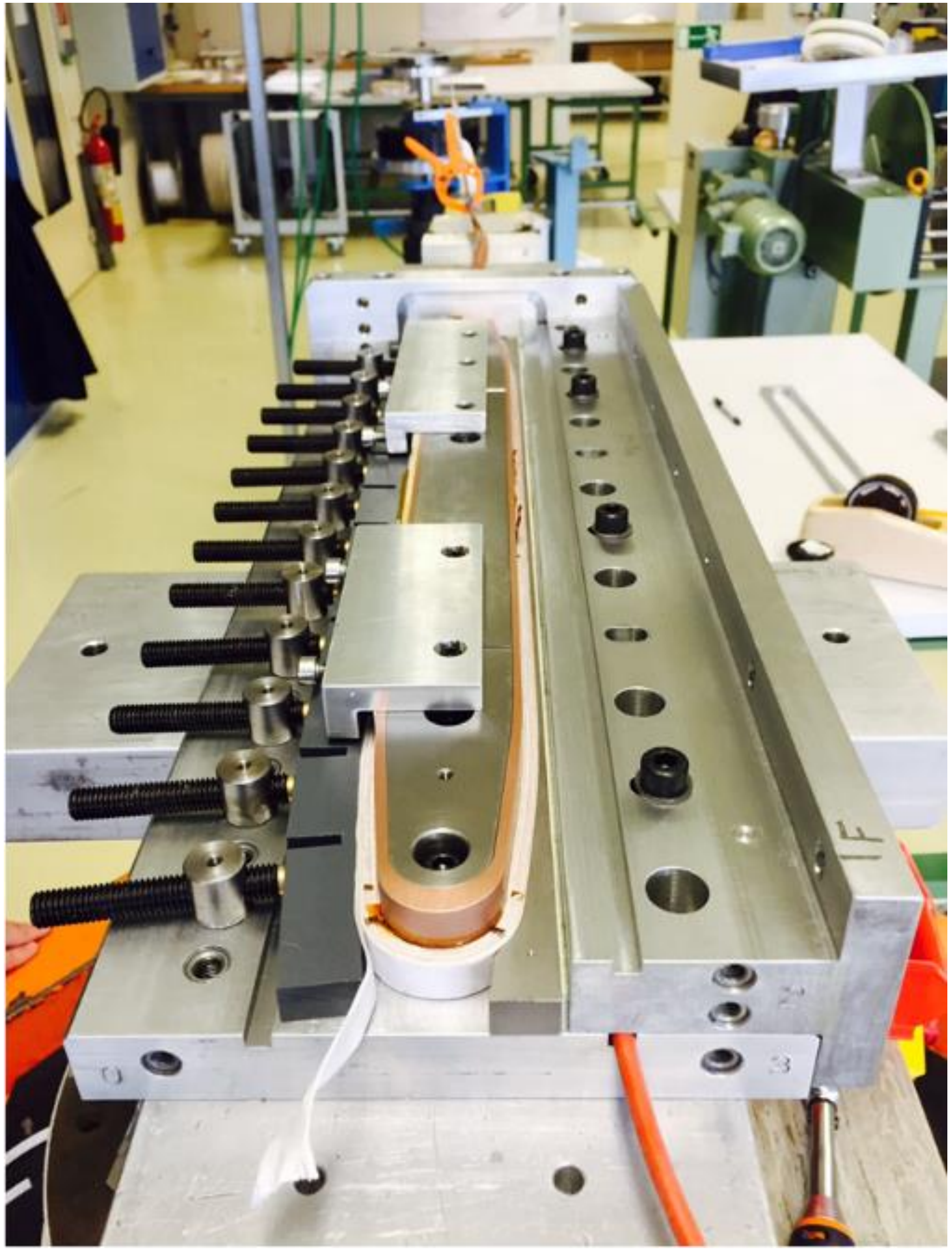

Mold released parts
Spot heater
Spot heater

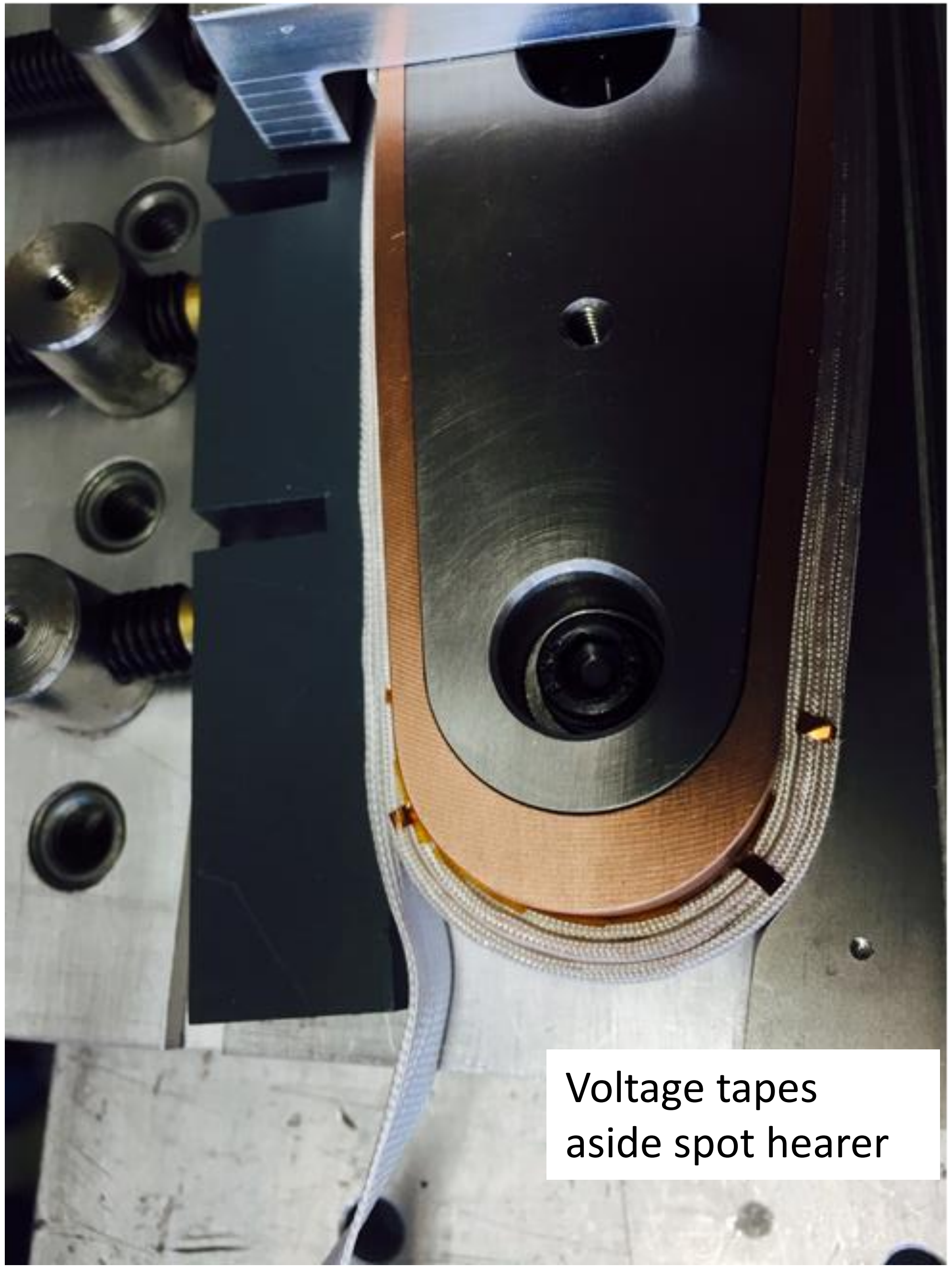


Clamp layer jump box to former & start



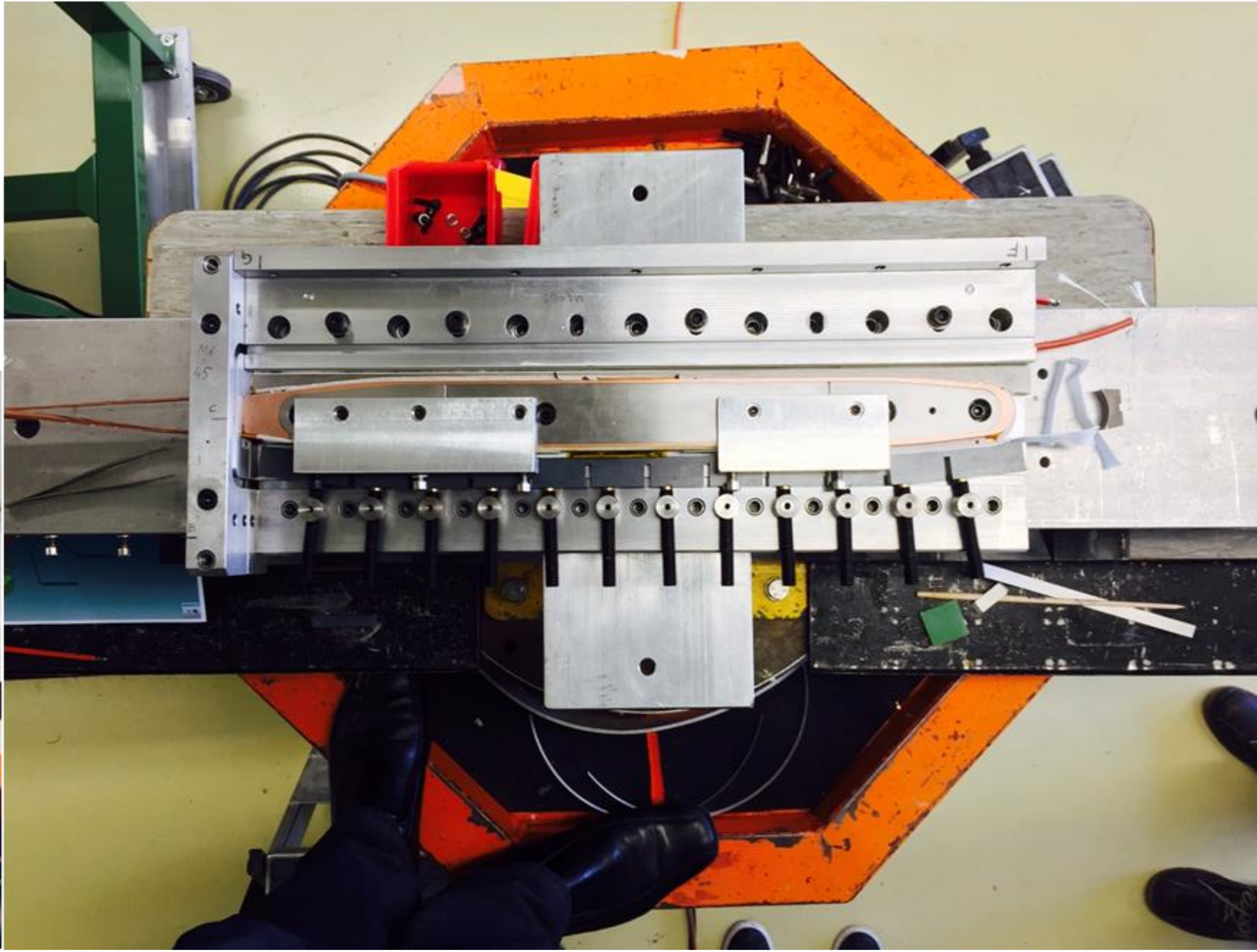

Start lead





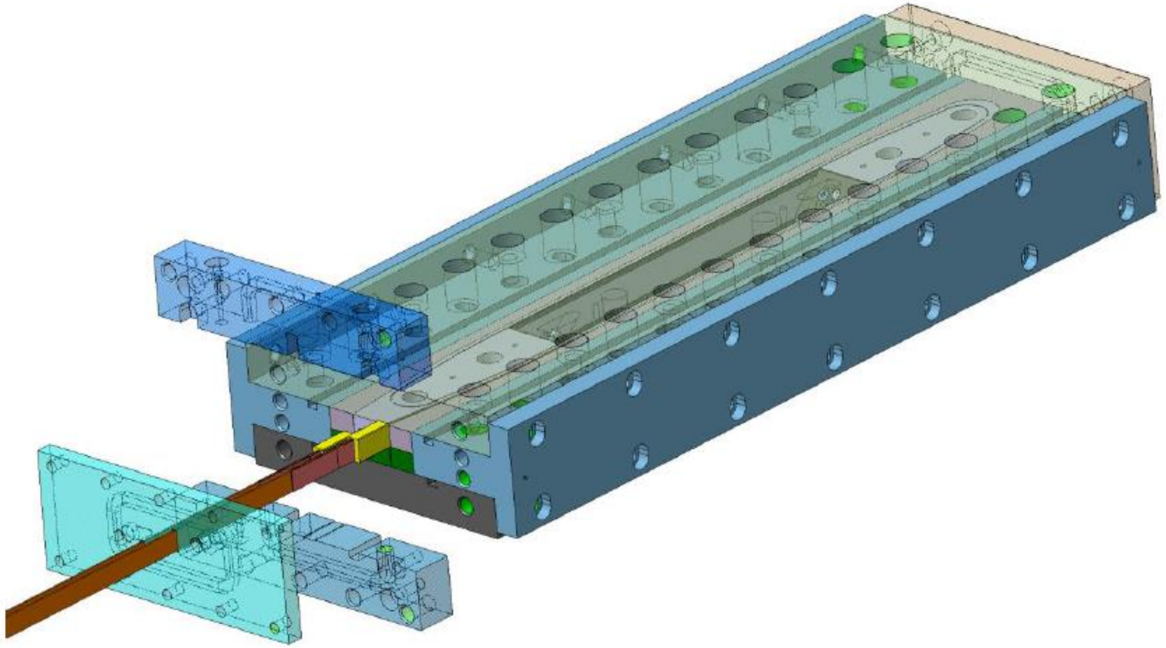
Voltage tapes
aside spot hearer

Top view

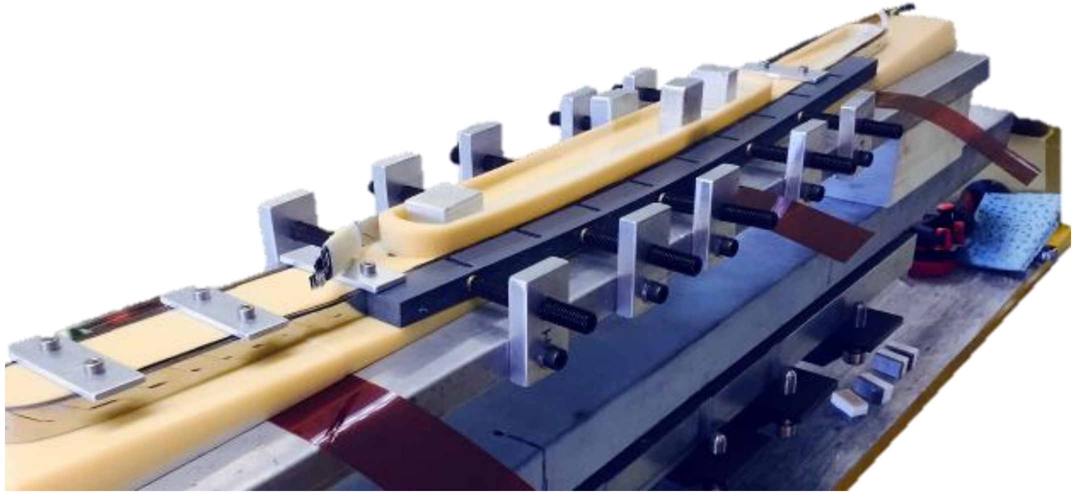


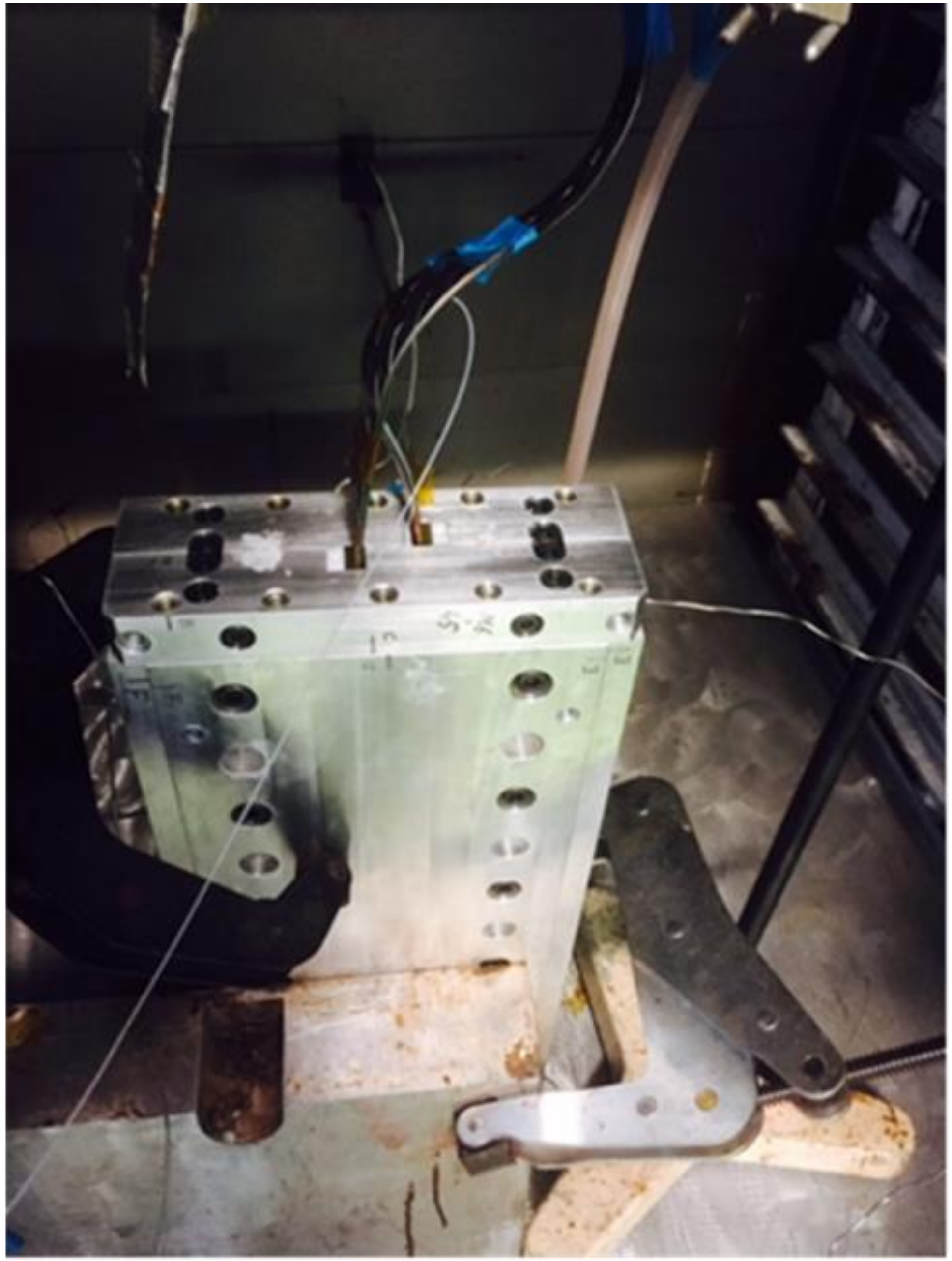
Tooling development

Feather M0 impregnation mold

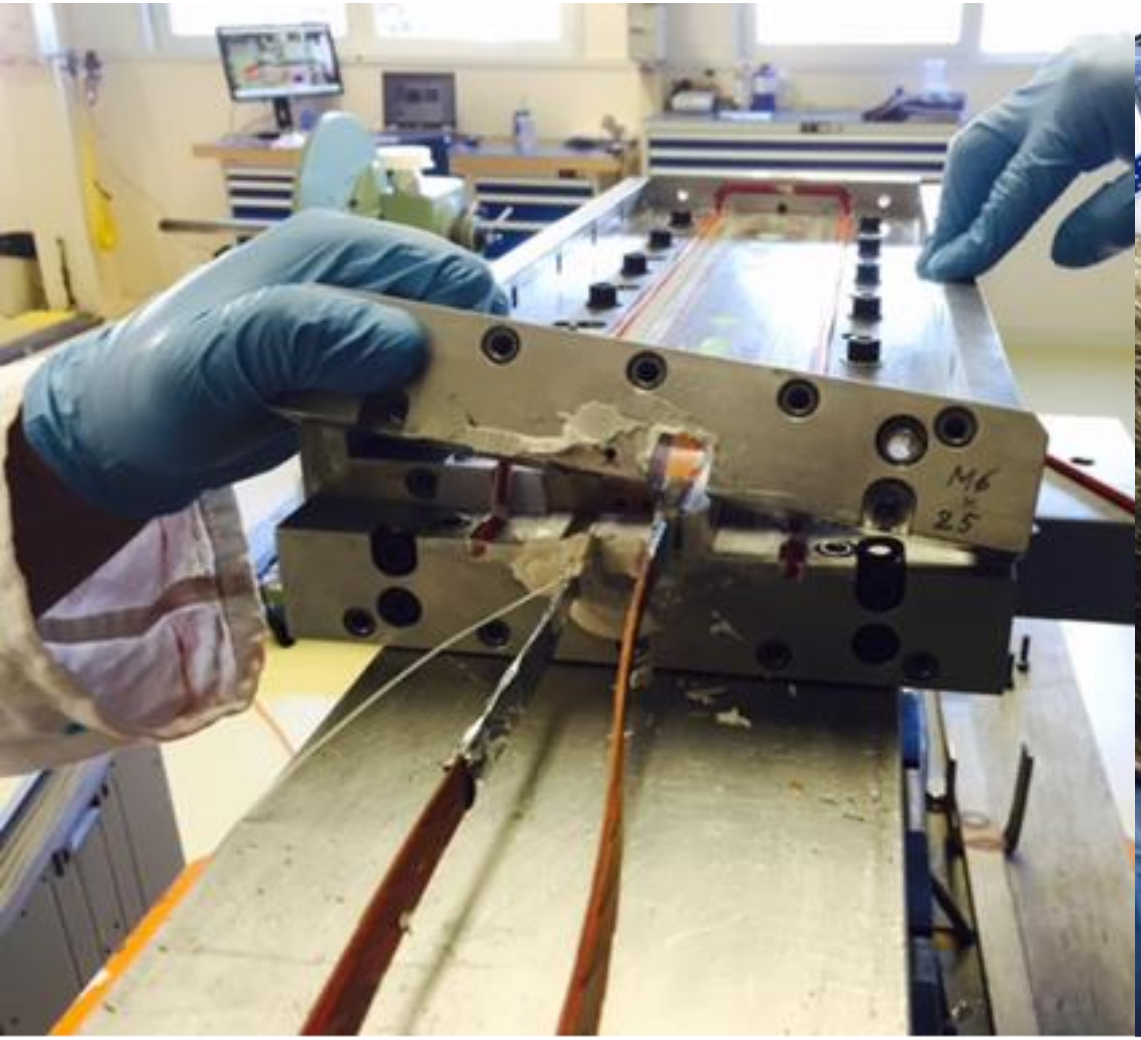


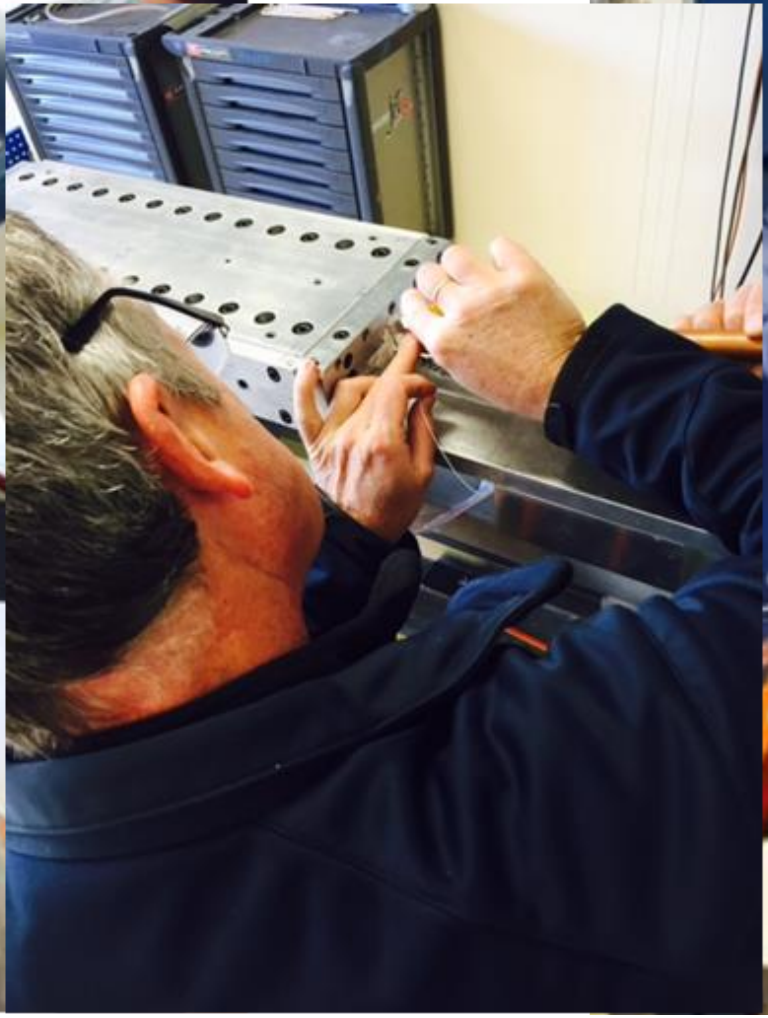
In parallel: Feather M2 winding tooling

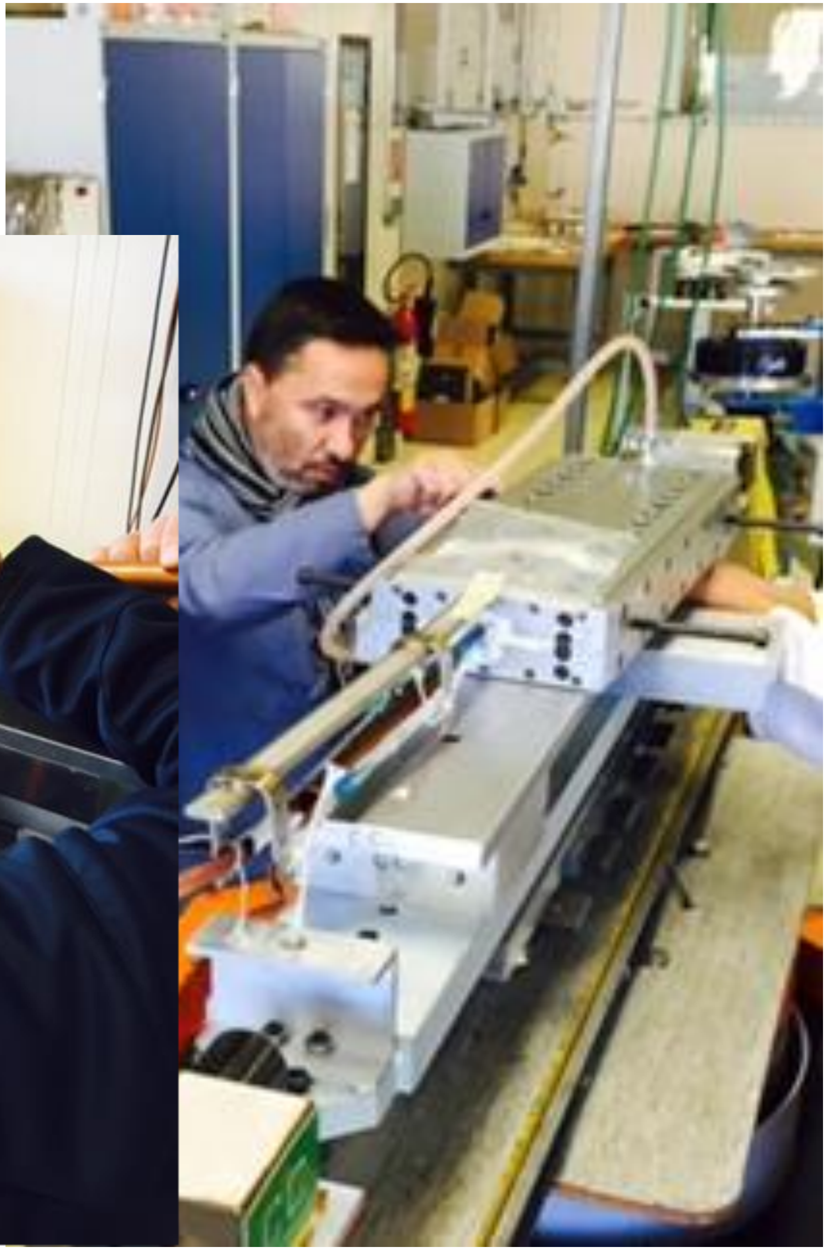


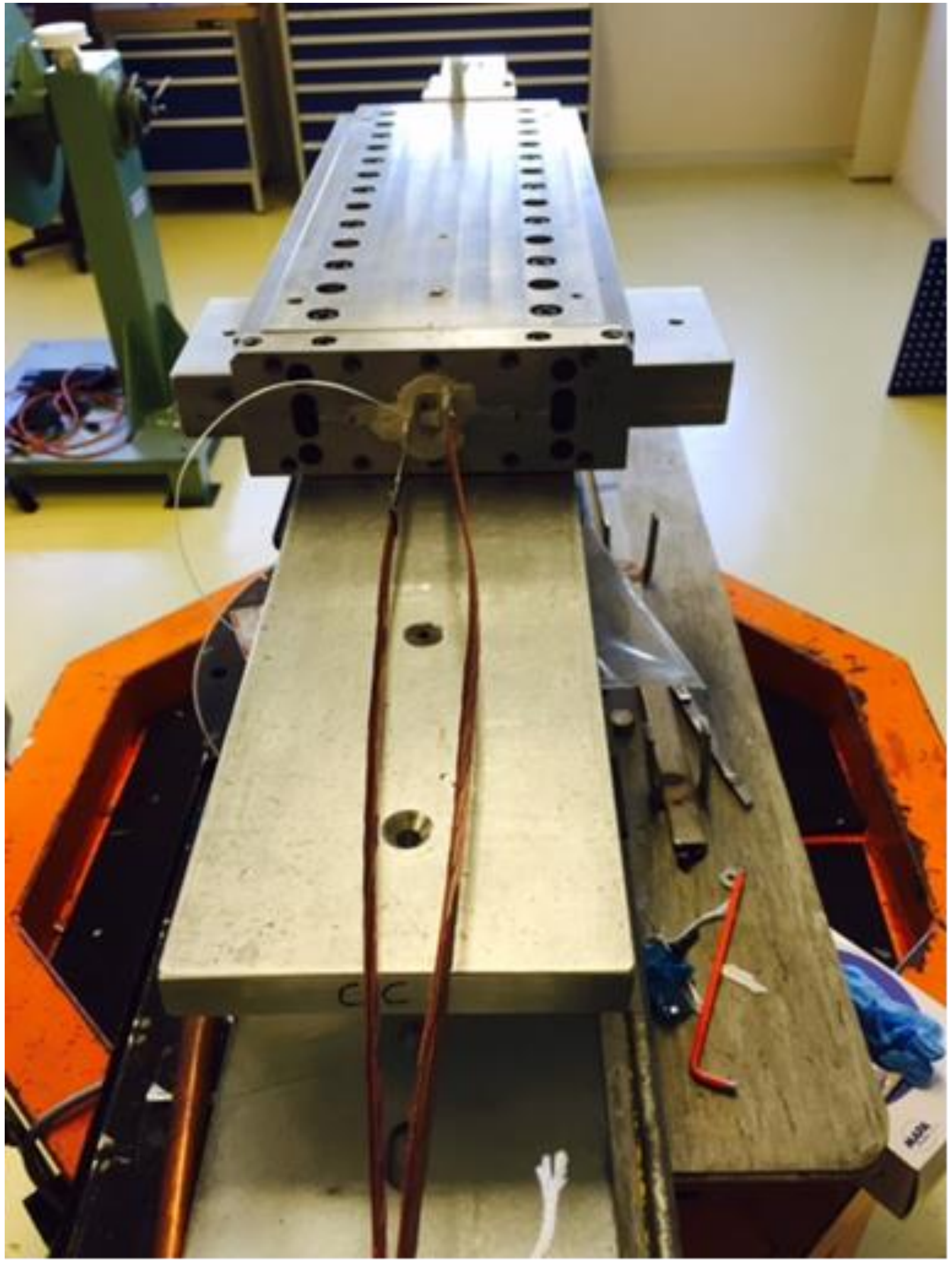


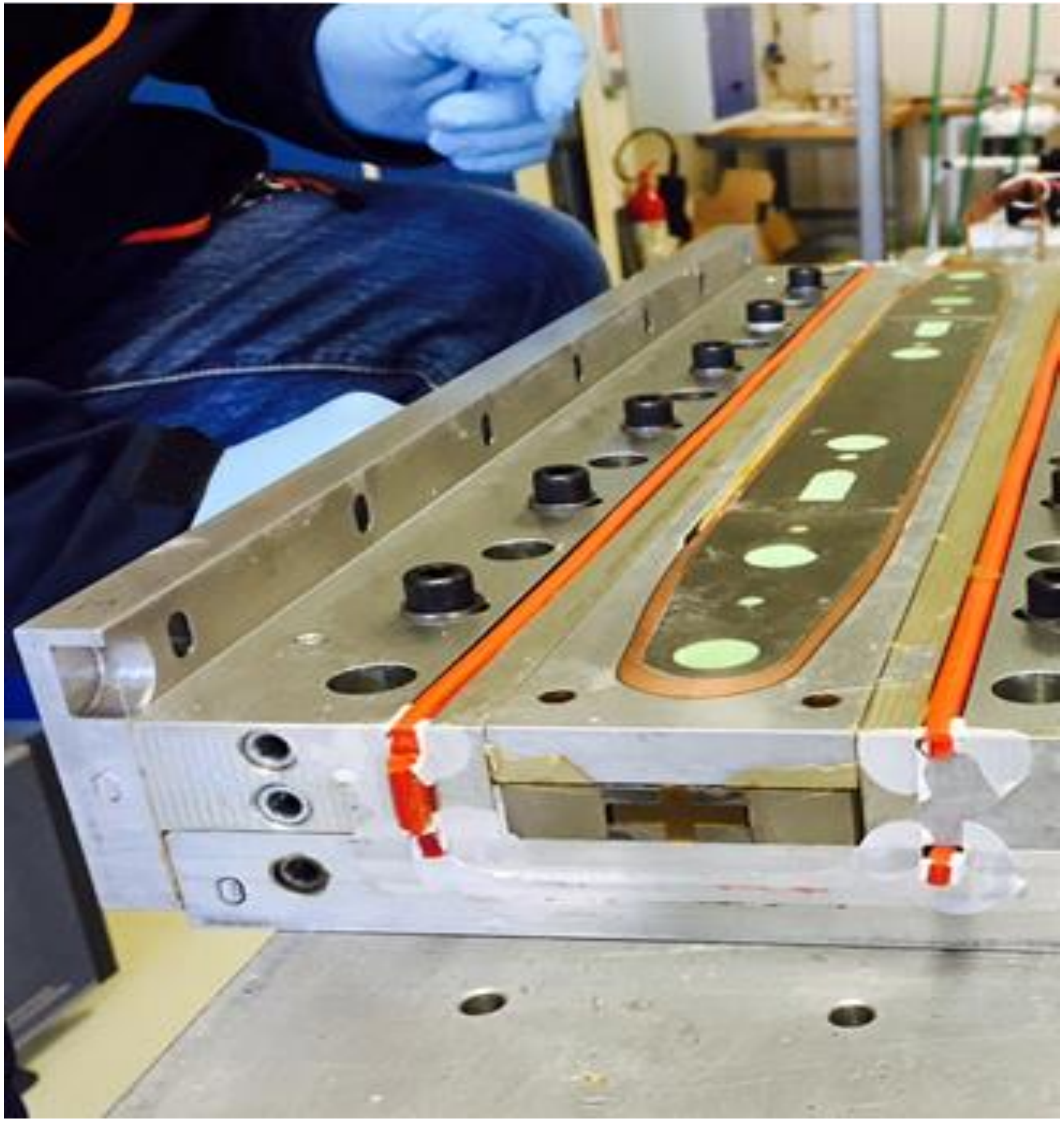
Opening!

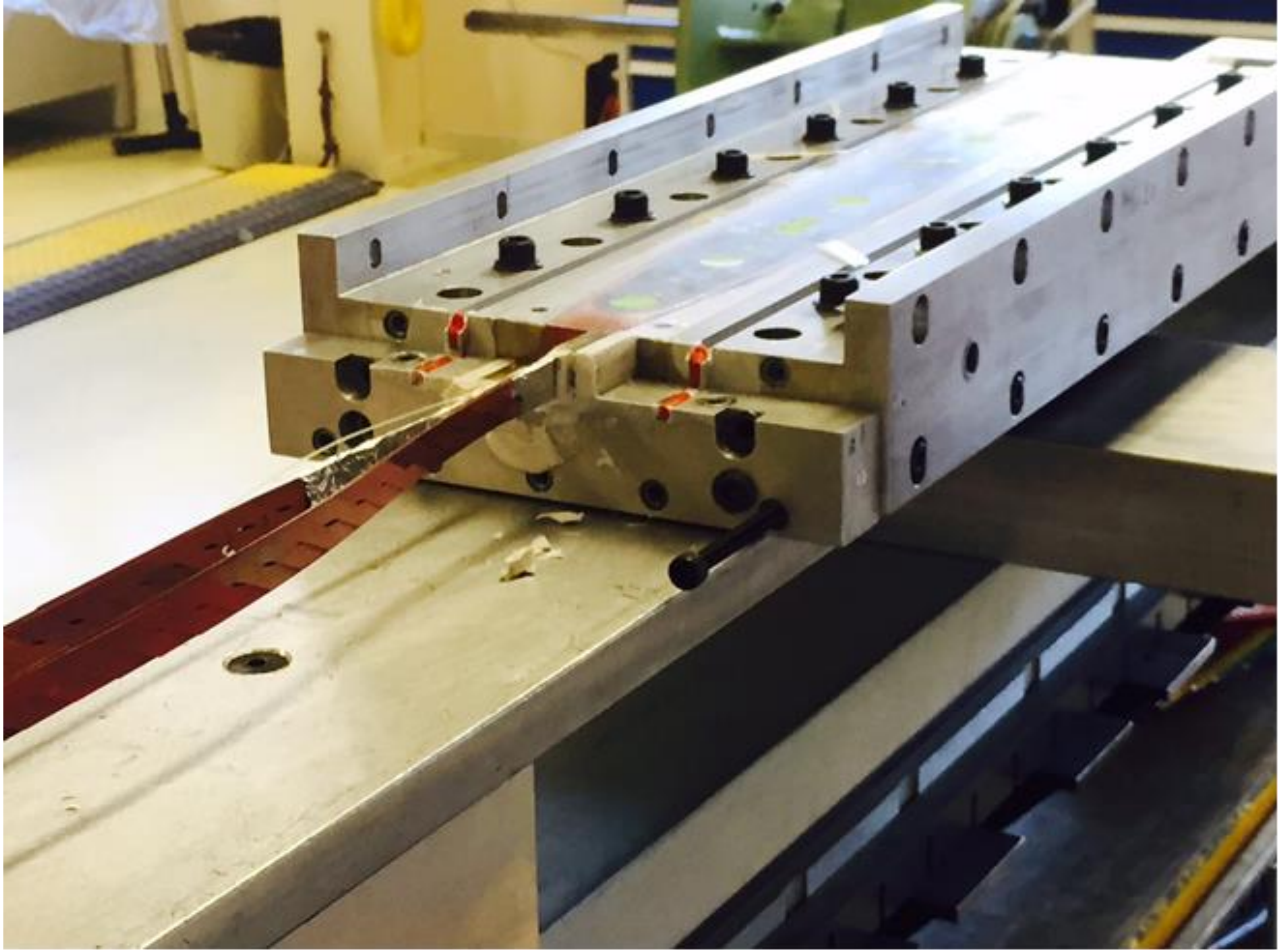


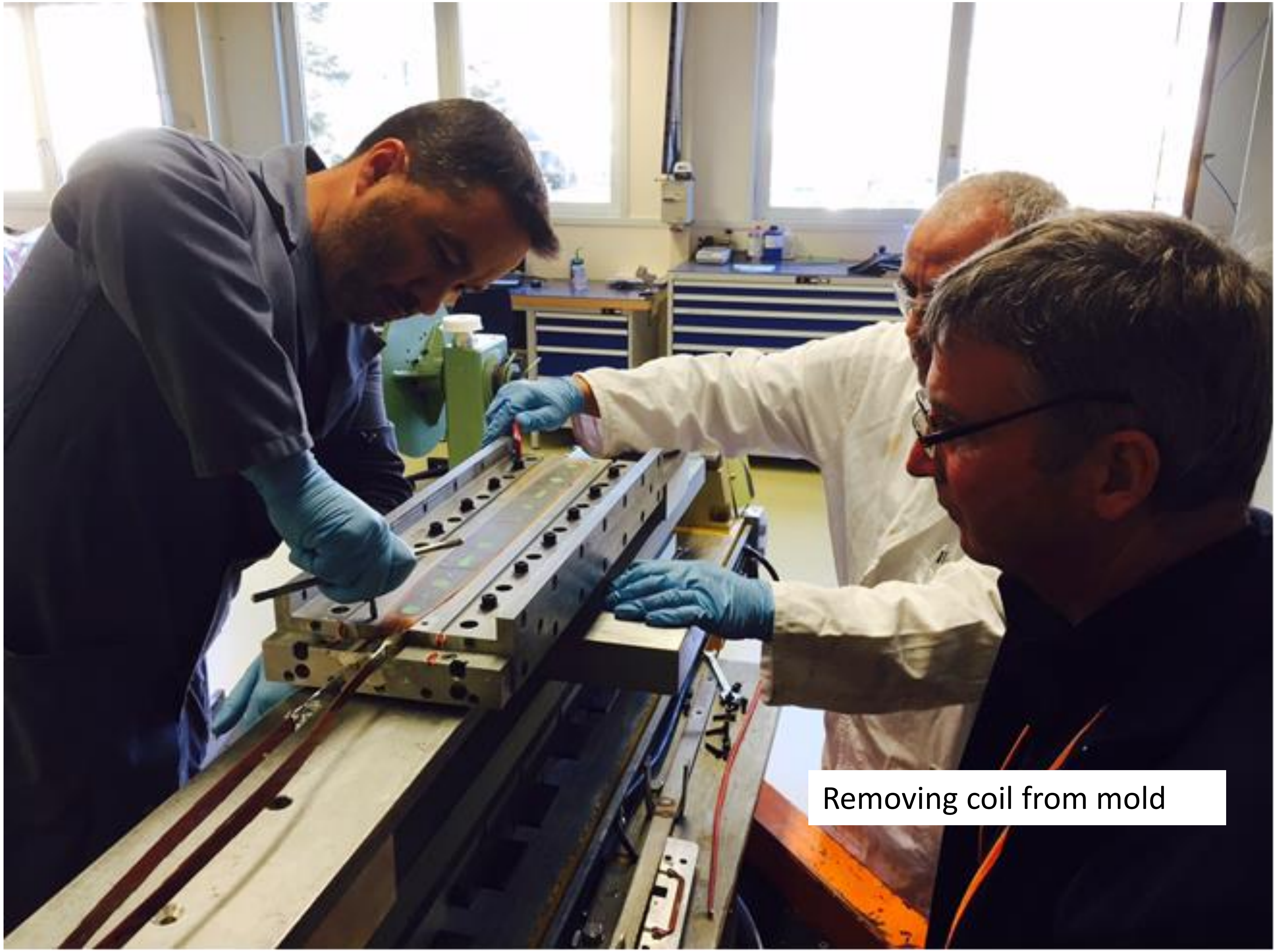




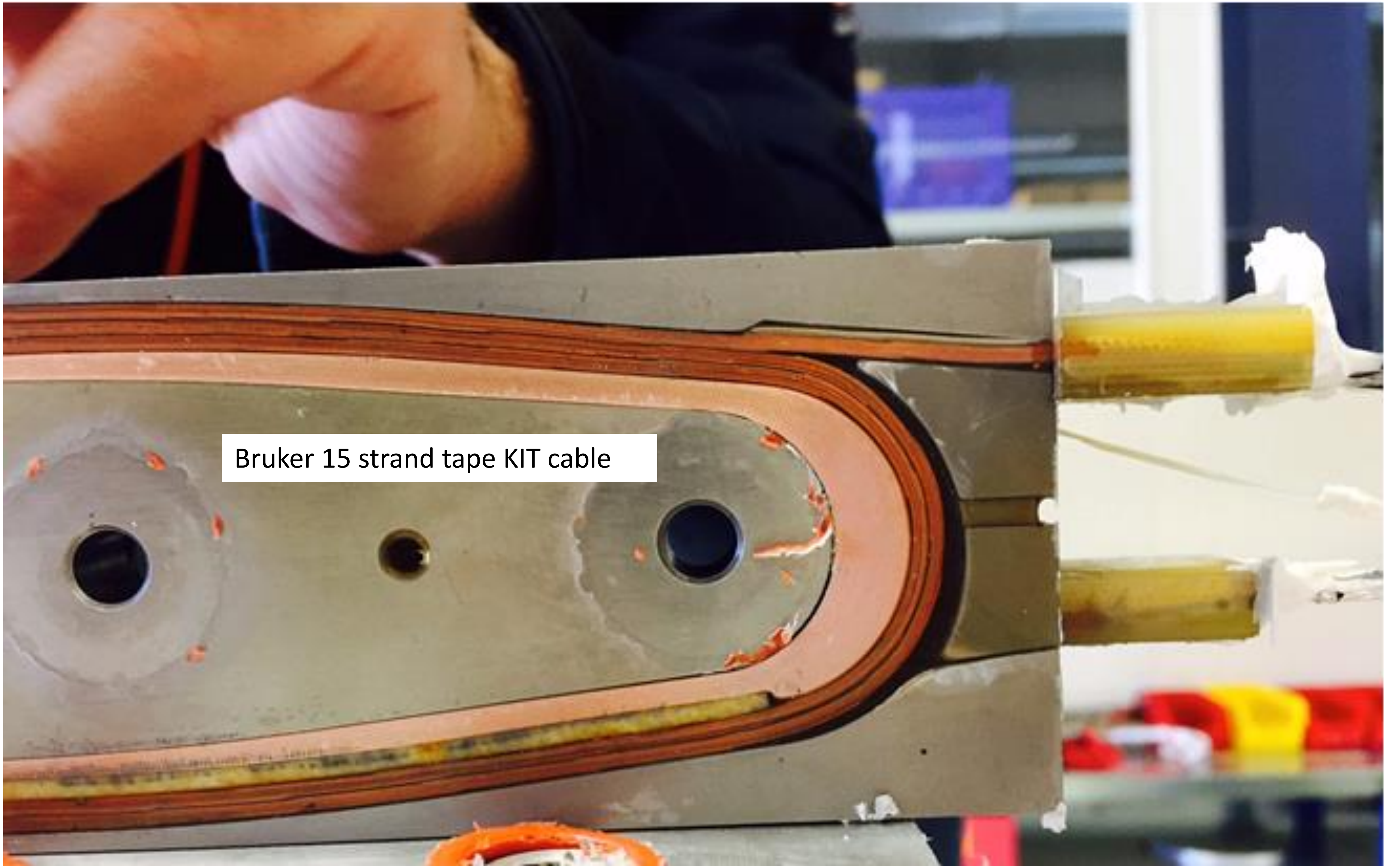


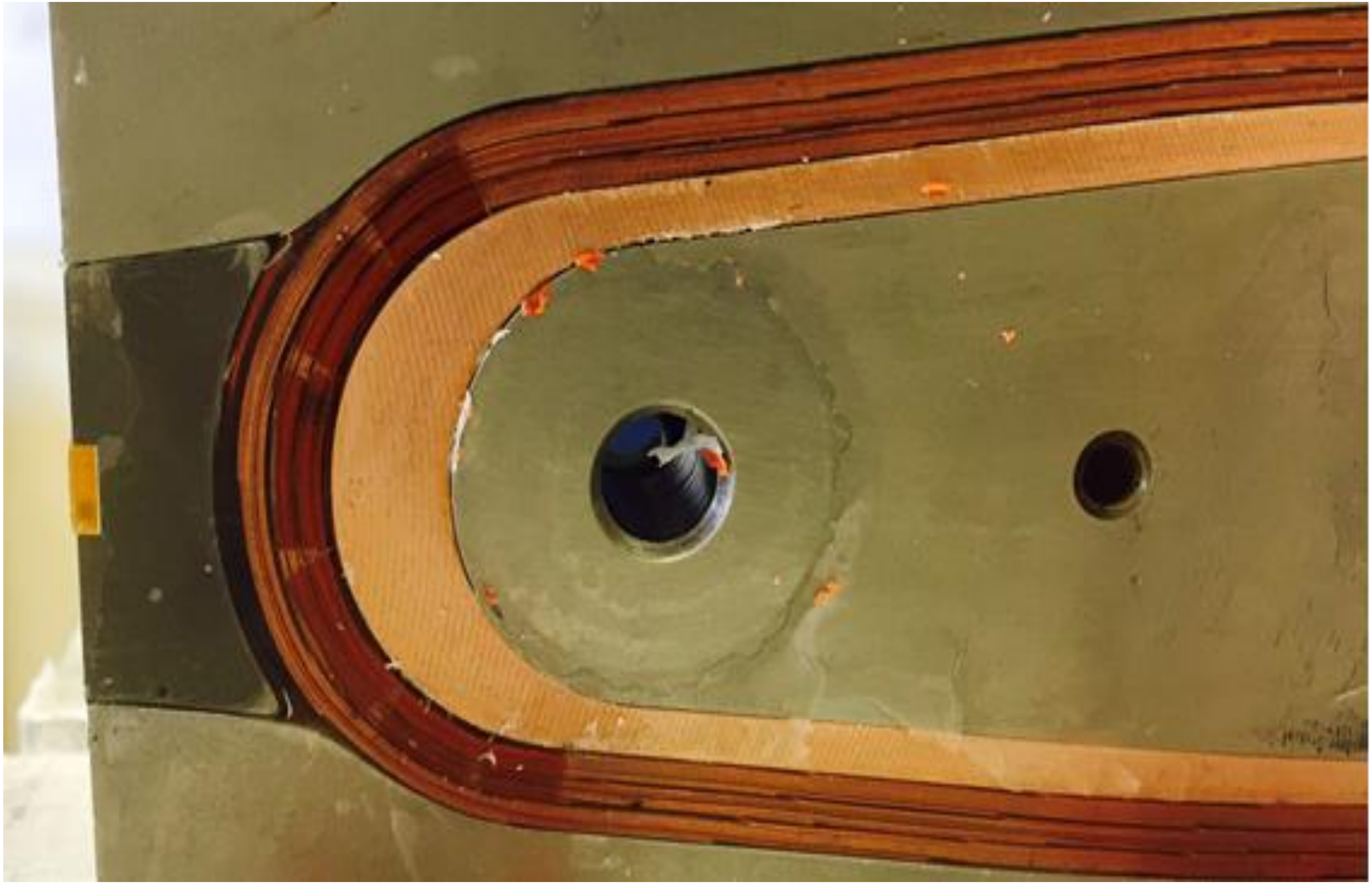




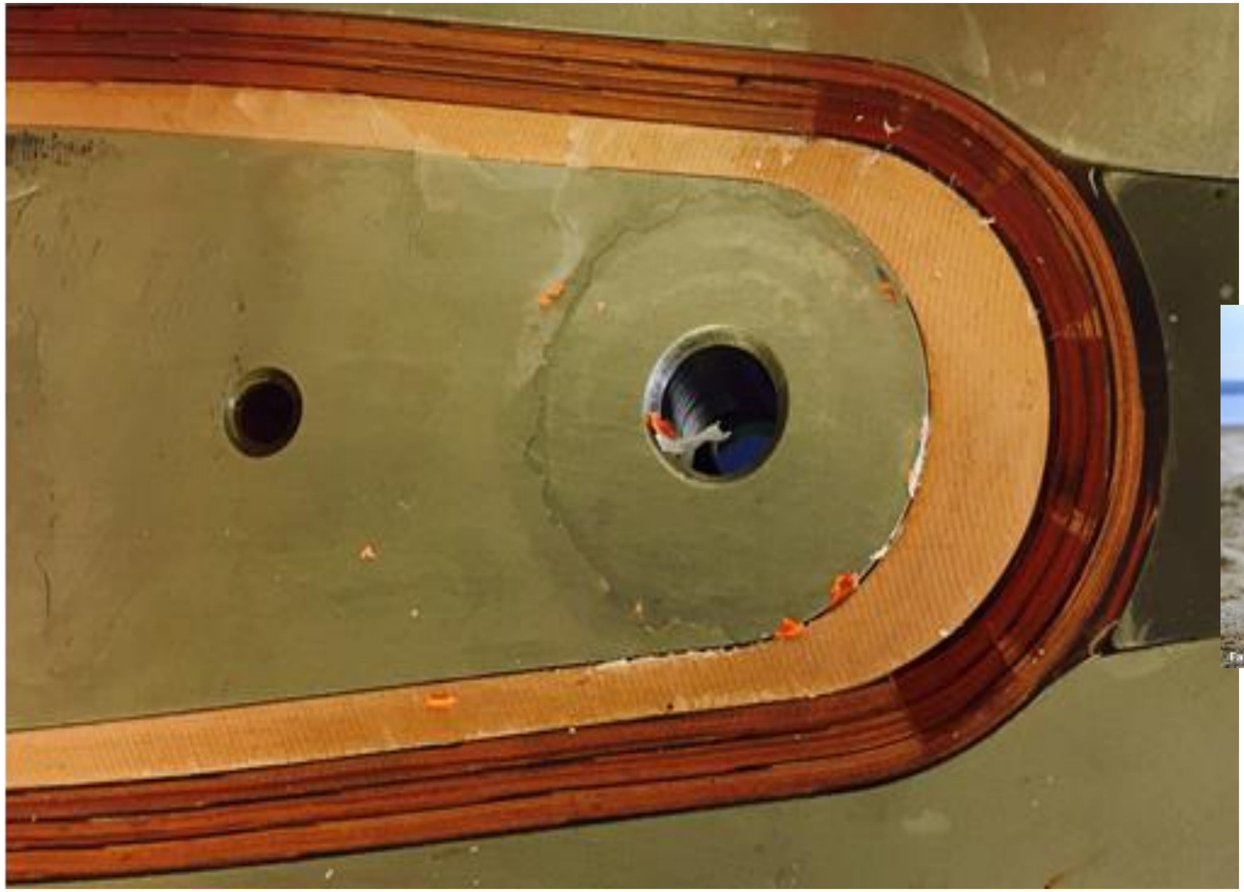


Removing coil from mold


Bruker 15 strand tape KIT cable

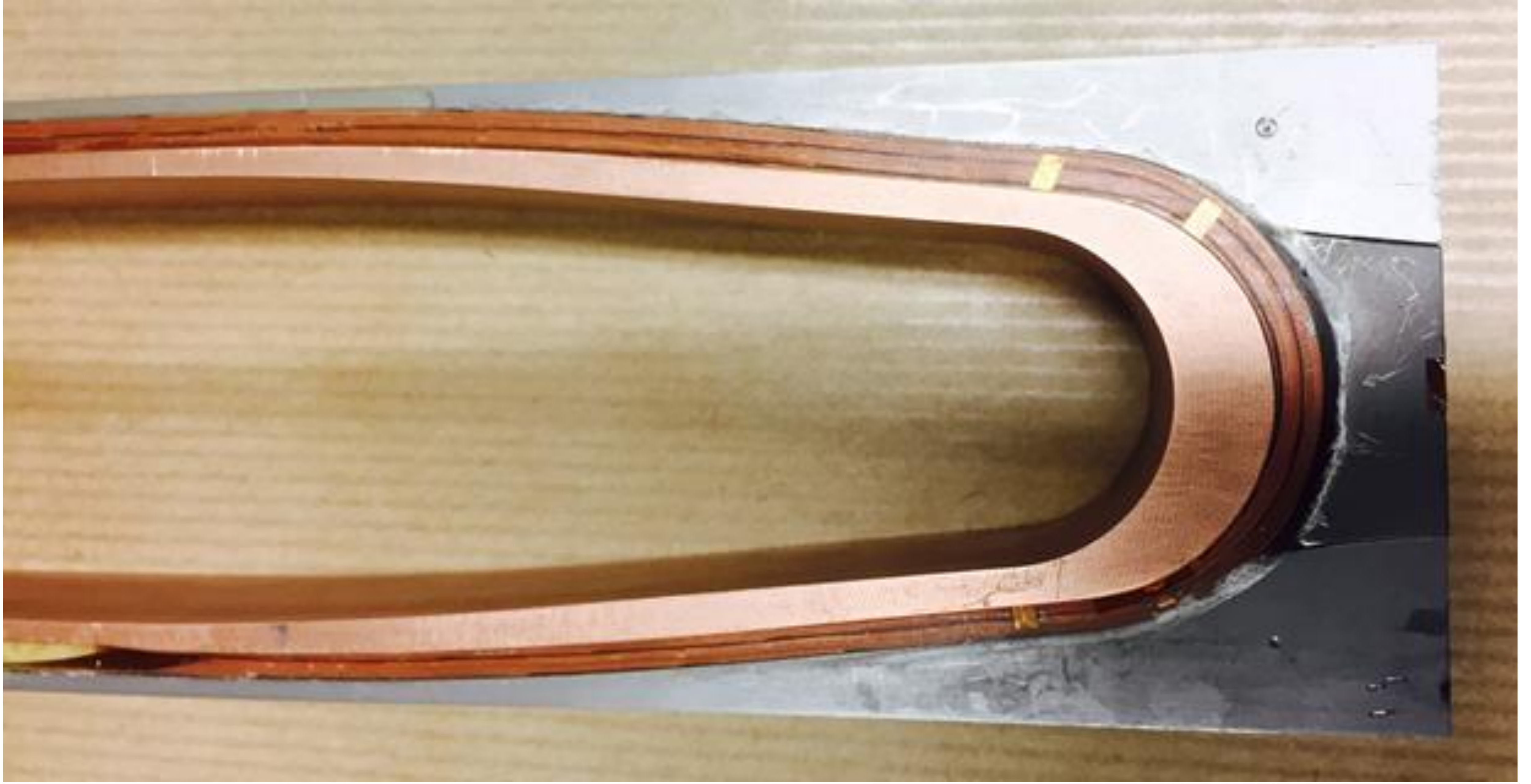


Adjusting the number of turns so that the cable fits the space available in the coil cavity



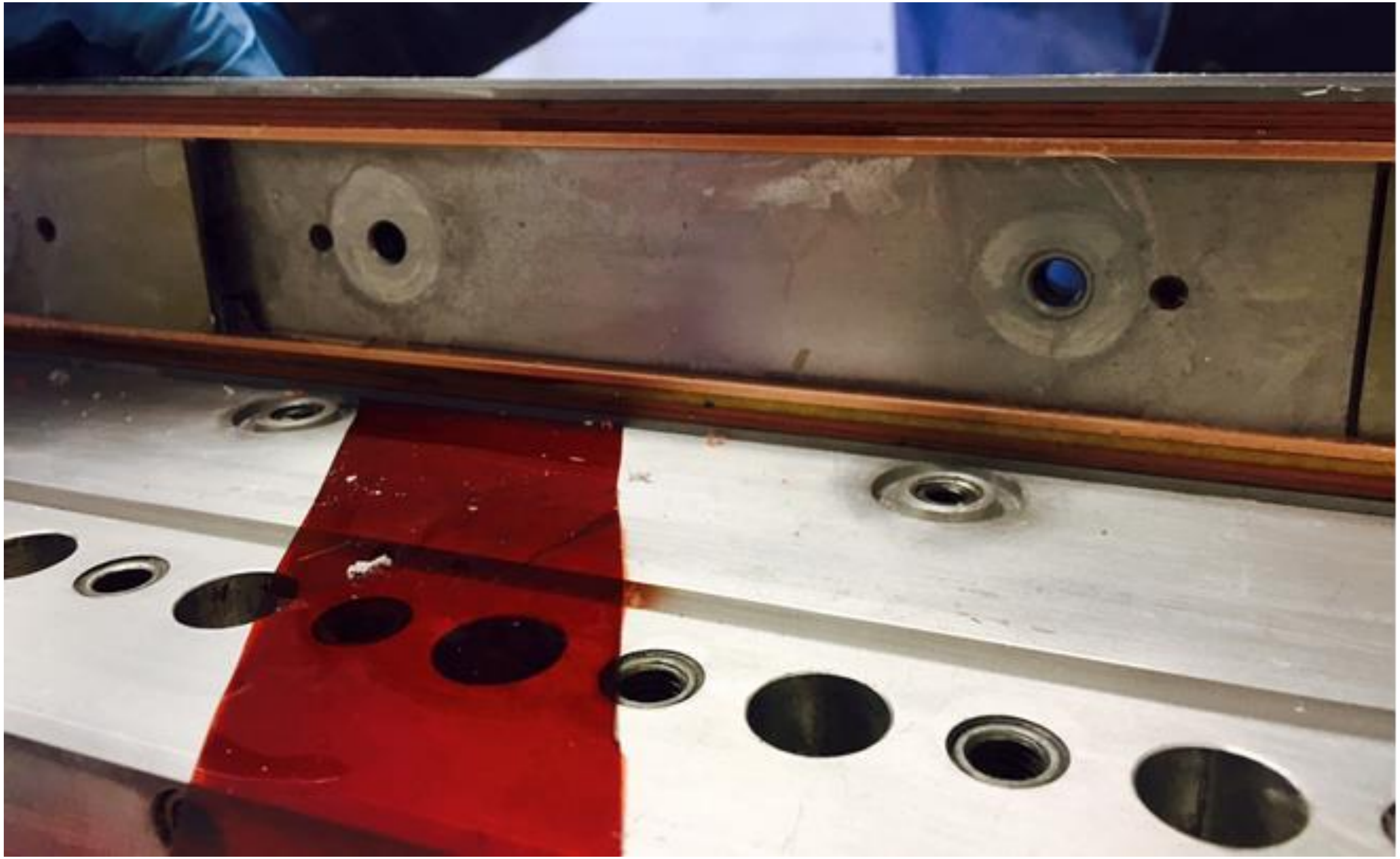
3 turns 0.2mm tape
15 strand cable higher winding tension

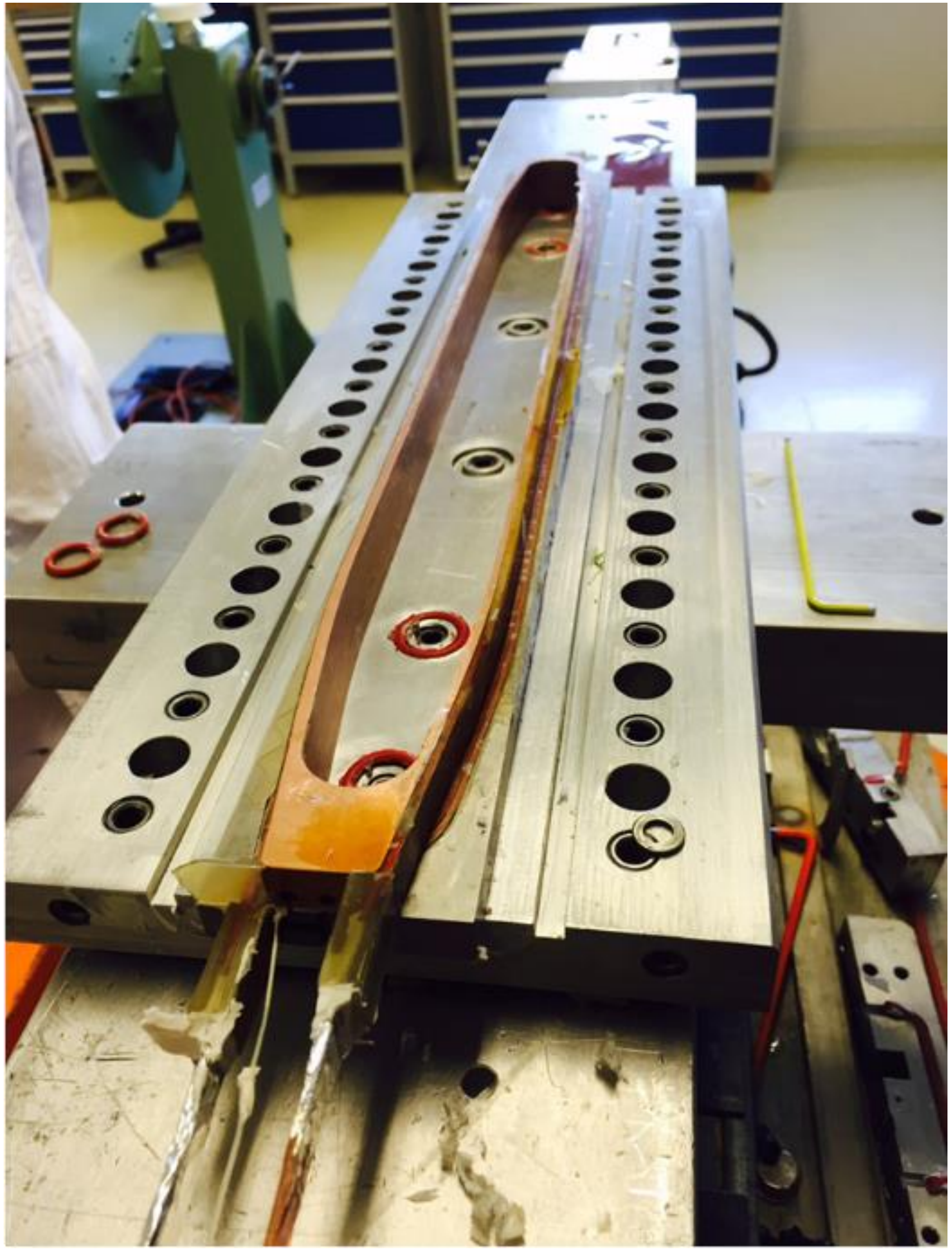
5 turns , 0.1 mm tape
15 strand cable



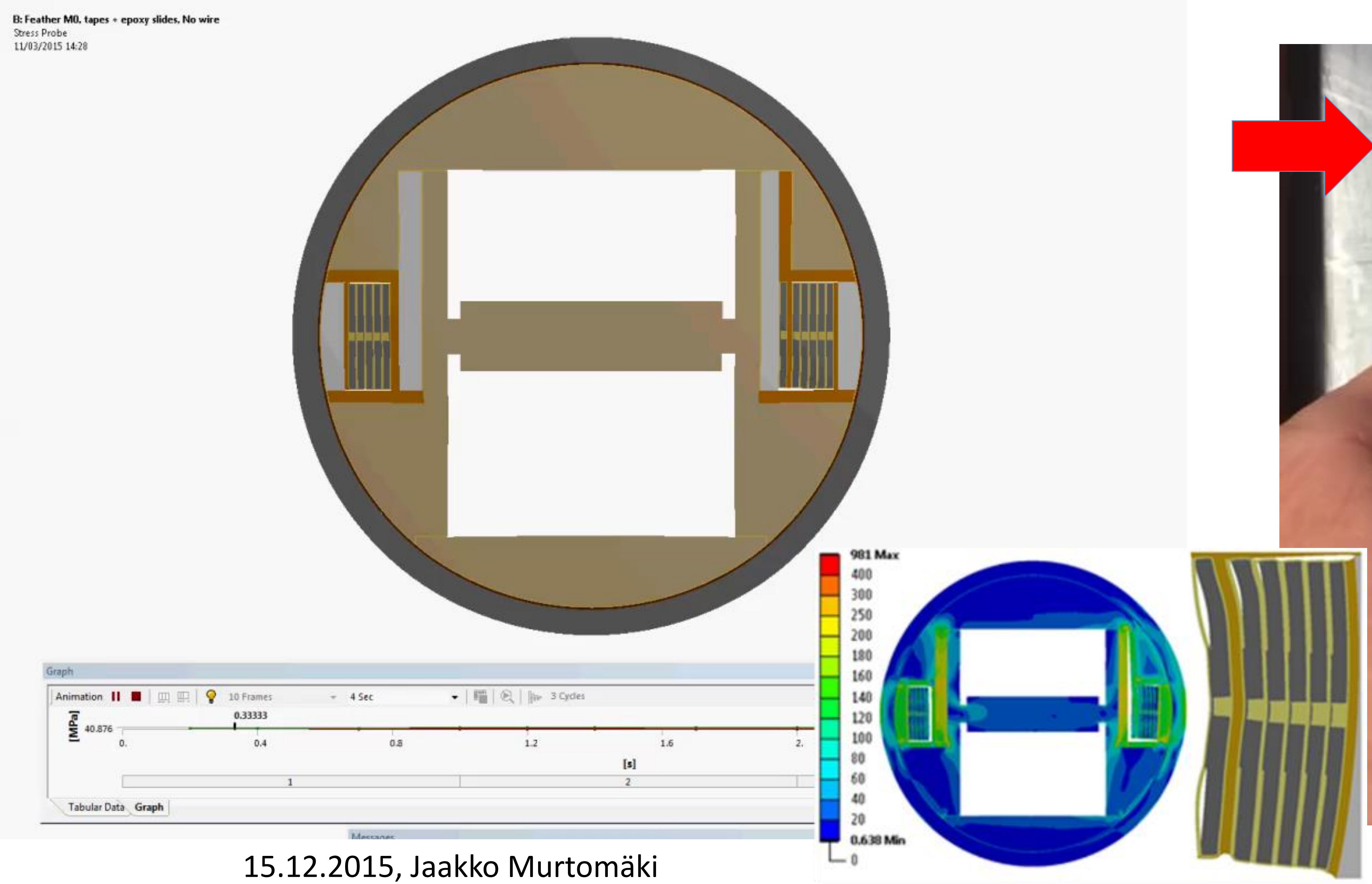
Voltage taps

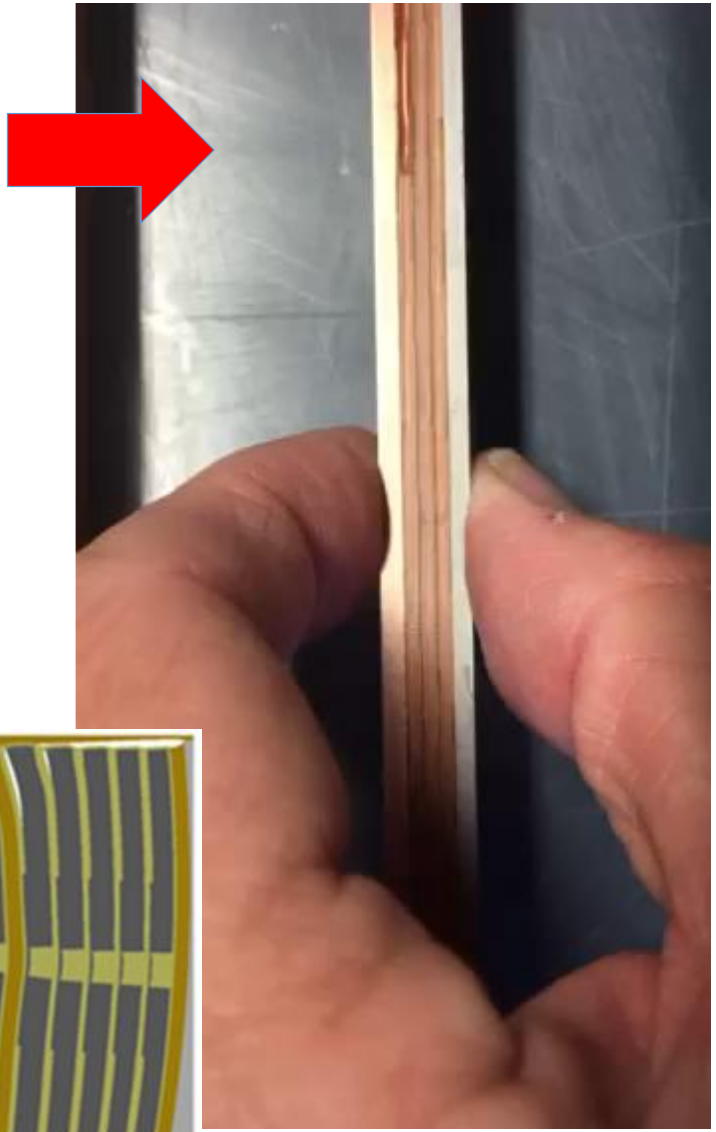
Removing the central section of mold





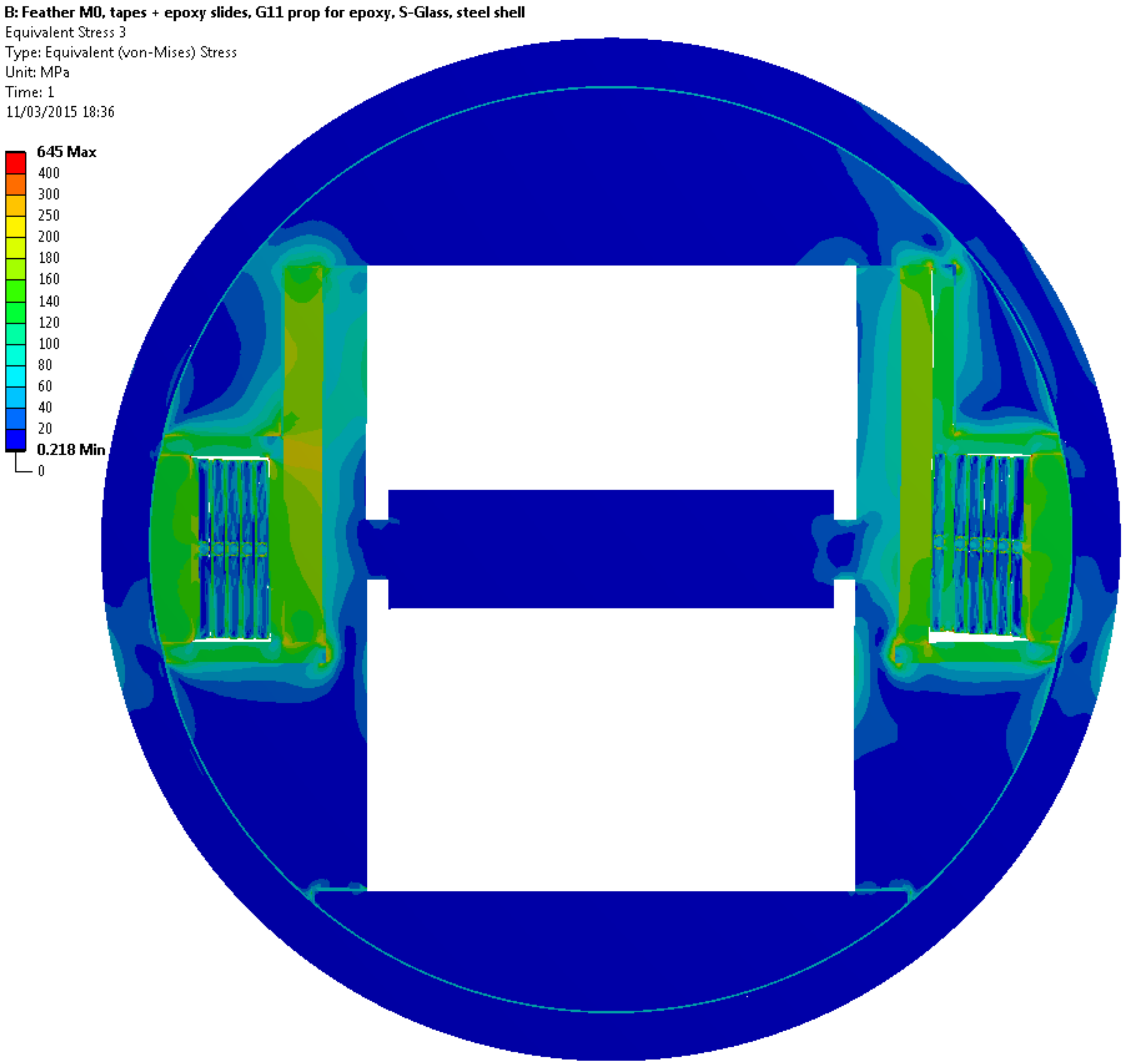
Mould release on coil former





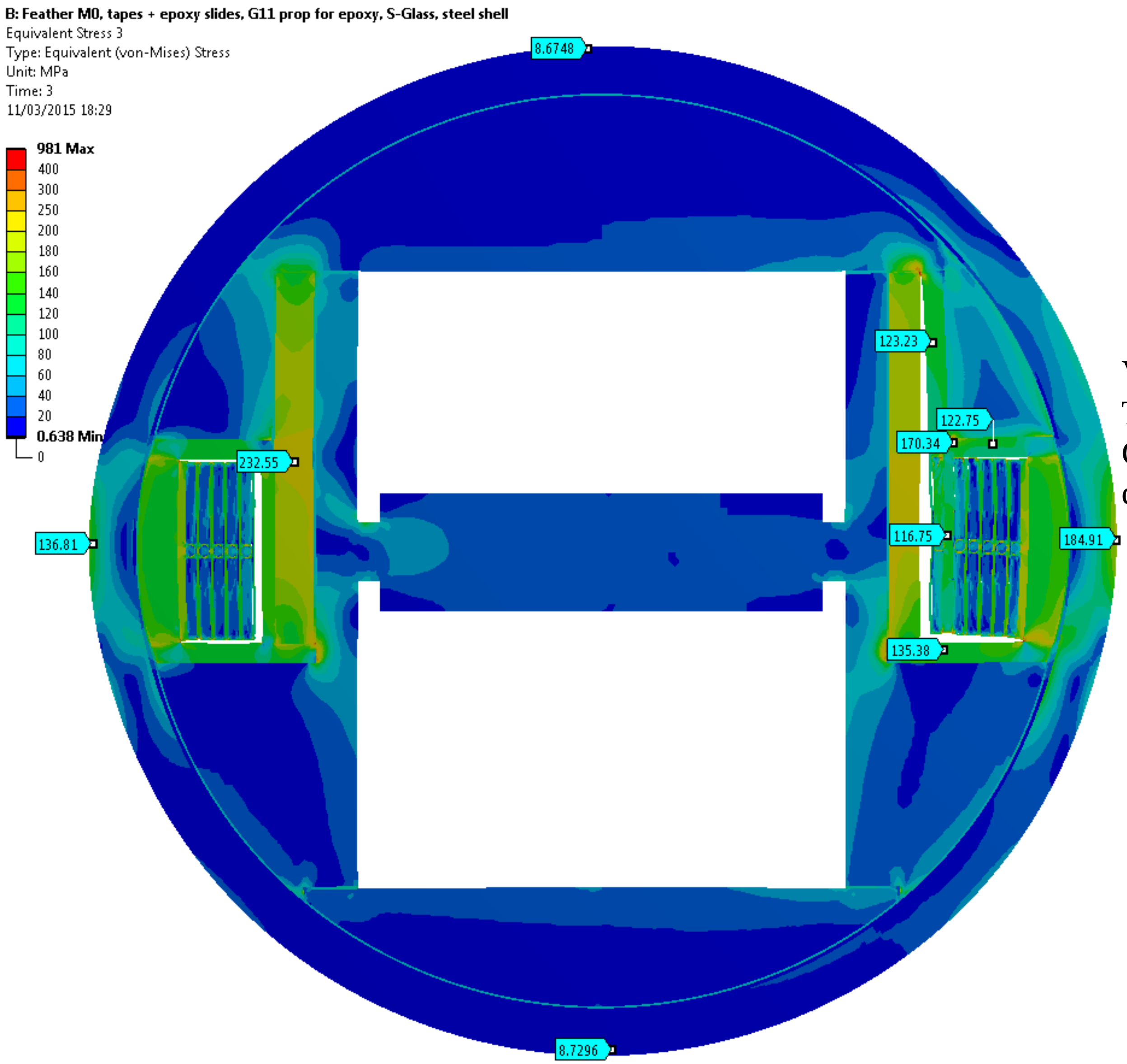
Feather M0 2D-cross section

-to assist in shell material selection, to understand how to model coils
-Cooling, standalone, background field



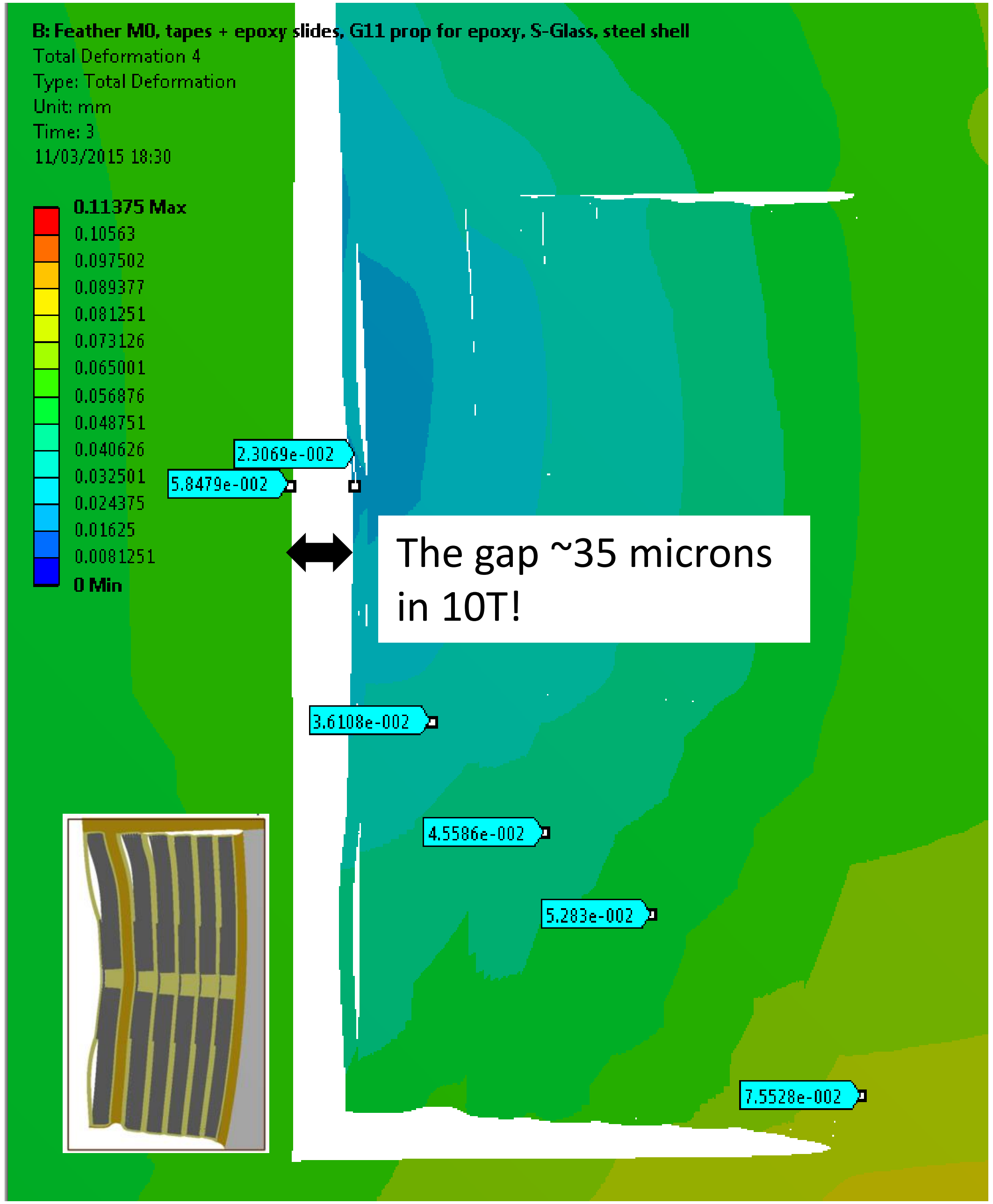
Von Mises stress after cool down. Assumptions: Tapes+epoxy interfaces frictional, S-Glass core inside the gap of the cable, G11 prop. Assigned for glass-sock+epoxy, steel shell. One can see that the shell doesn’t provide compression. 18 X scaling for the deformed geometry.

Feather M0 2D-cross section

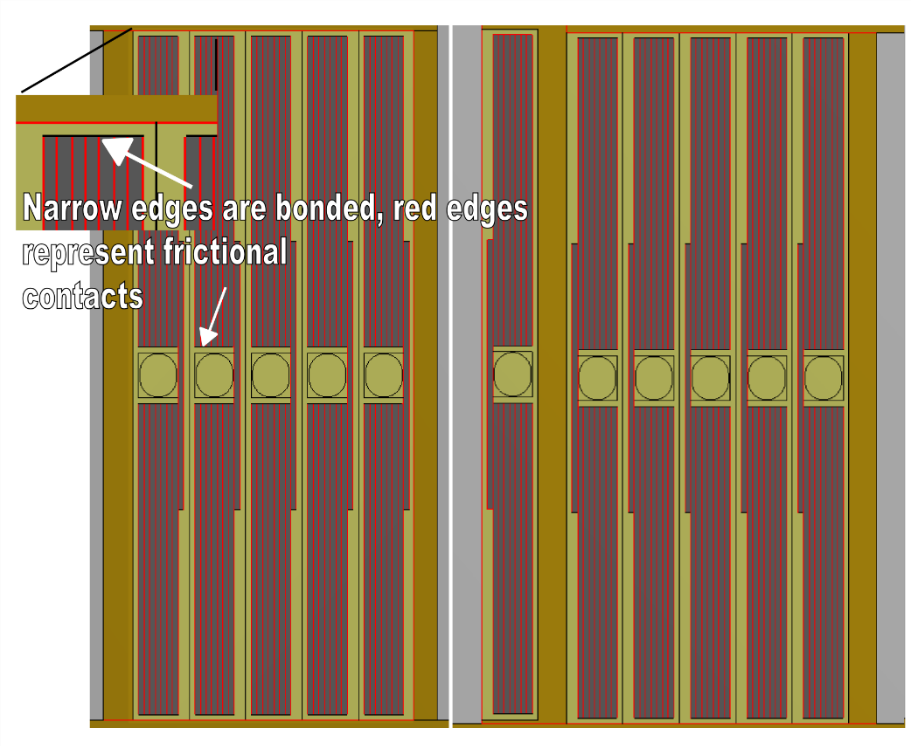


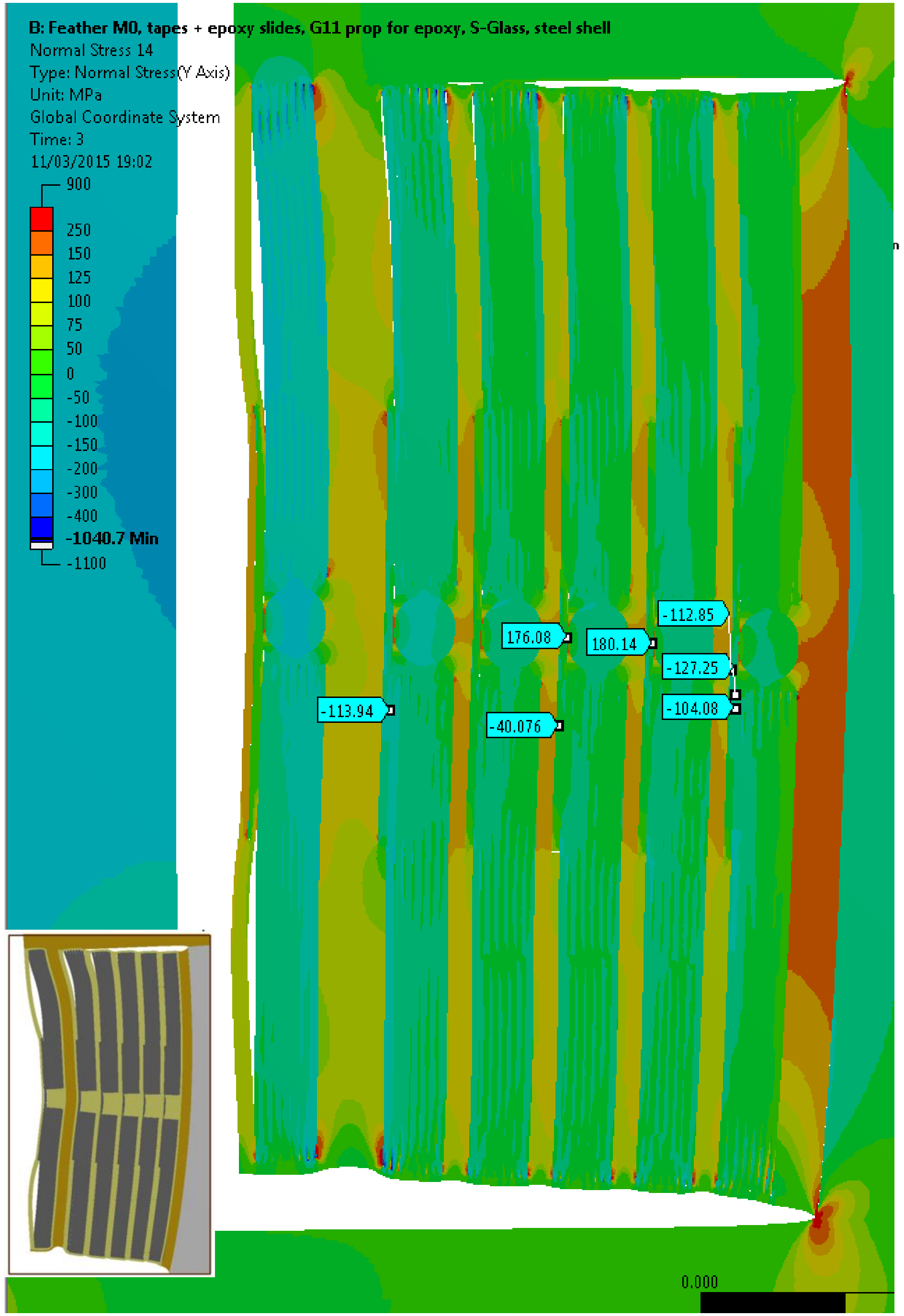
Von Mises stress after cool down + powering to 10T. Assumptions: Tapes+epoxy interfaces frictional, S-Glass core inside the gap of the cable, G11 prop. for glass fiber sock + epoxy, steel shell. 18 X scaling for deformed geometry.

Feather M0 2D-cross section

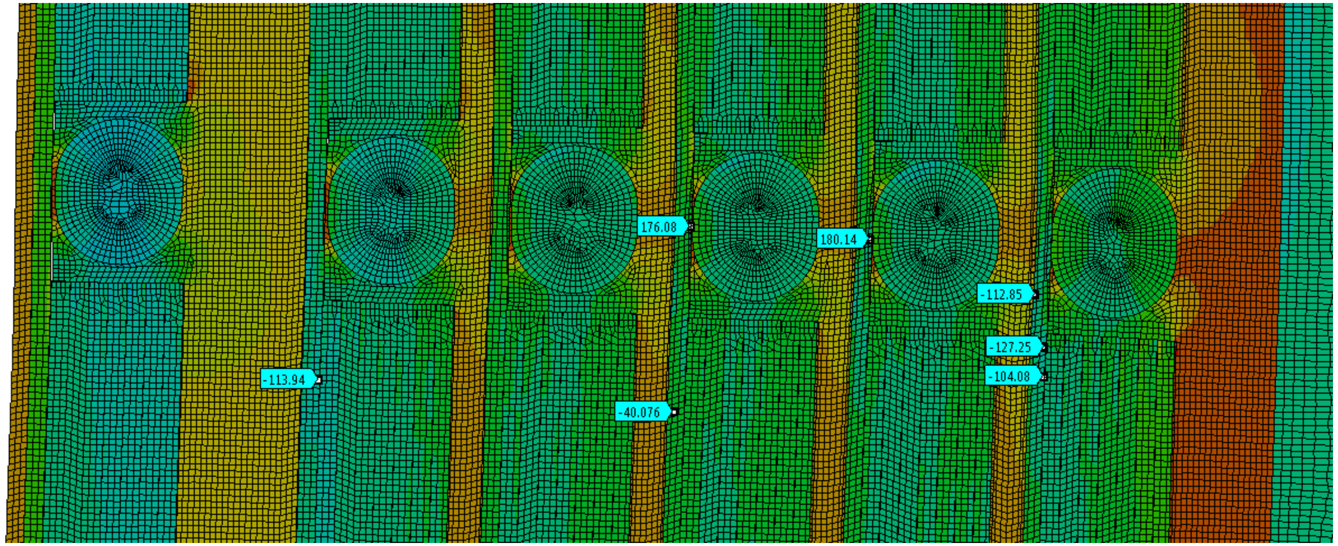


Total displacement after cool down + powering to 10T. Assumptions: Tapes+epoxy interfaces frictional f=0.8, S-Glass core in the gap, G11 prop. for glass fiber sock + epoxy, steel shell. 18 X scaling for the deformed geometry.

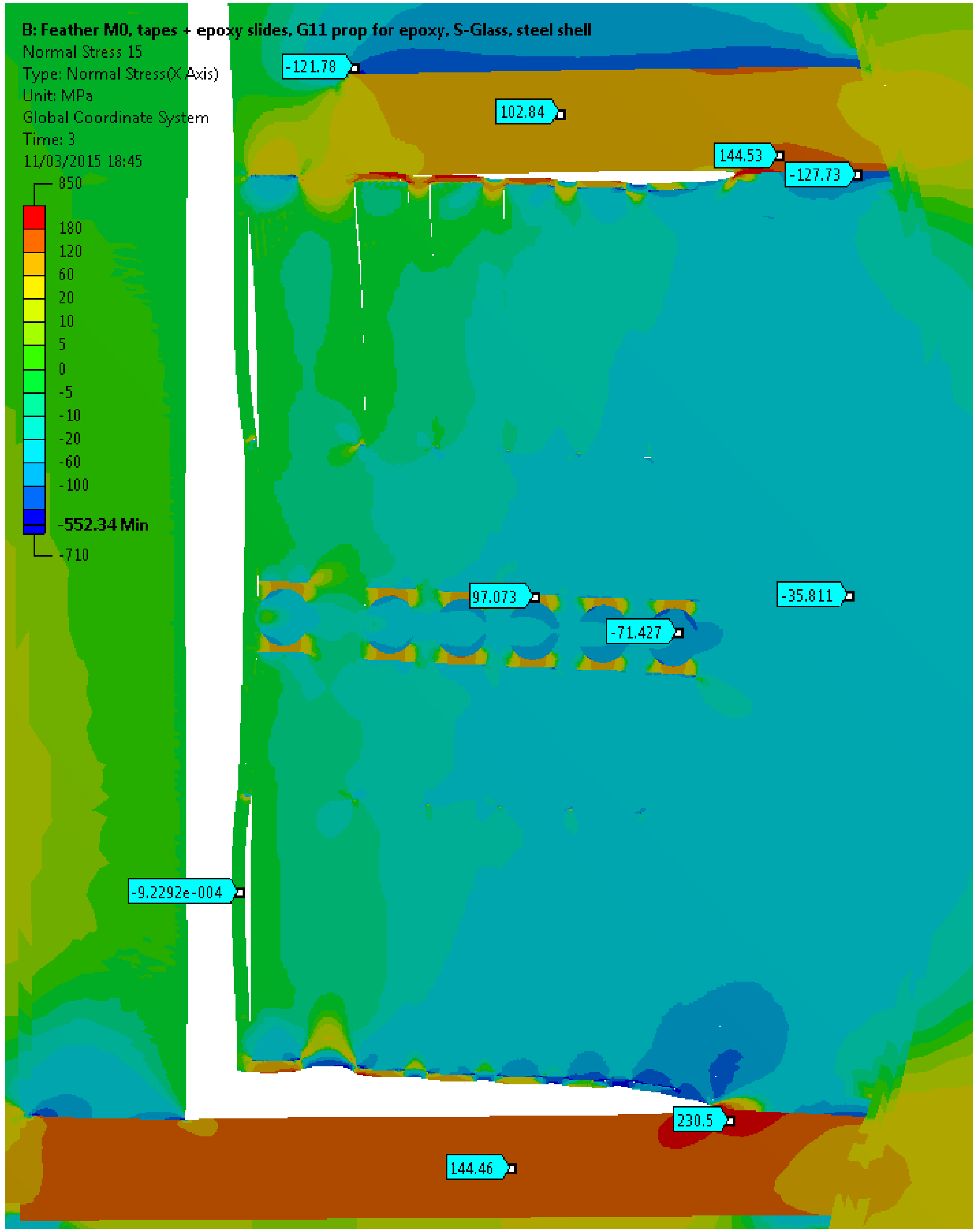




Feather M0 2D-cross section



Stress component parallel to y-axis after cool down + powering to 10T. Assumptions: Tapes+epoxy interfaces frictional f=0.8, S-Glass core in the gap, G11 prop. for glass fiber sock + epoxy, steel shell. 18 X scaling for the deformed geometry.



Stress component parallel to x-axis after cool down + powering to 10T. Assumptions: Tapes+epoxy interfaces frictional f=0.8, S-Glass core in the gap, G11 prop. for glass fiber sock + epoxy, steel shell. 18 X scaling for the deformed geometry.

Possible paper topics

At Tampere University of Technology needed three papers as a main author:

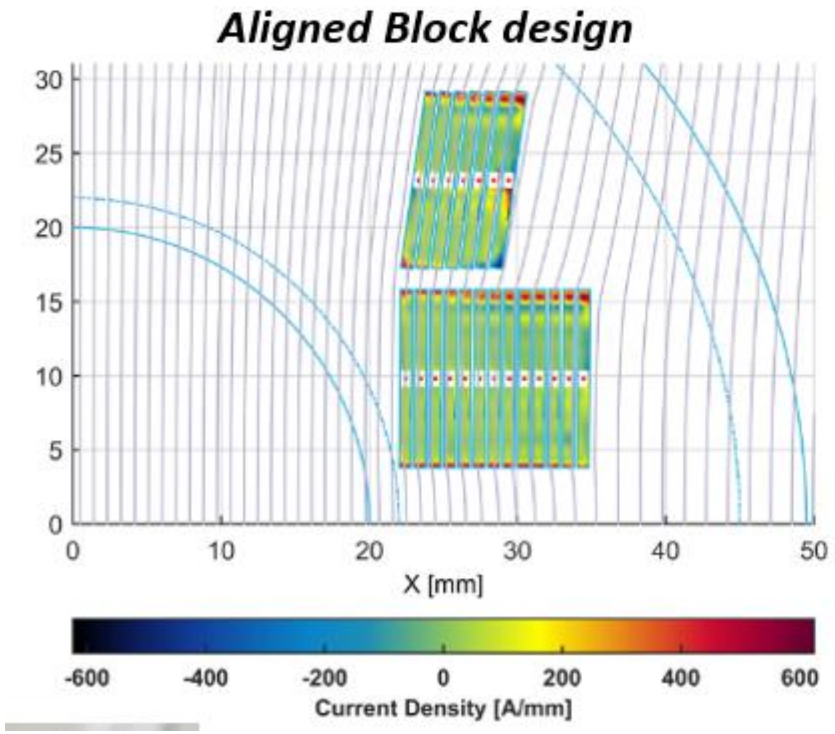
1. Cross-sectional 2D modelling of HTS magnets (conference?)

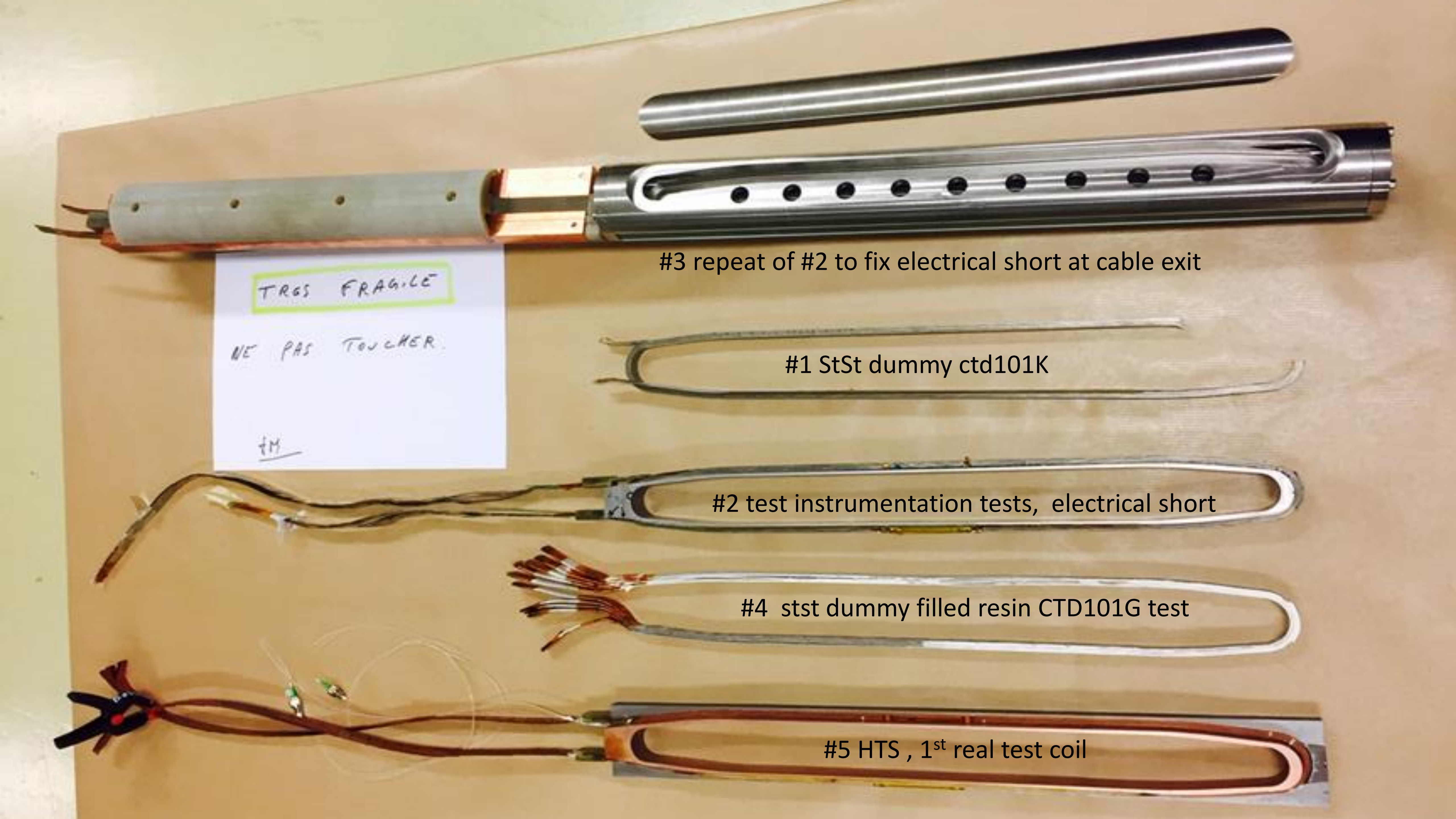
Currently, homogenous current distribution is assumed over the tapes in electro-magnetic models. But in reality, current is on the edges.

Later the plan is to develop models in such way that they can use input from:

1.) J. van Nugteren's current distribution model

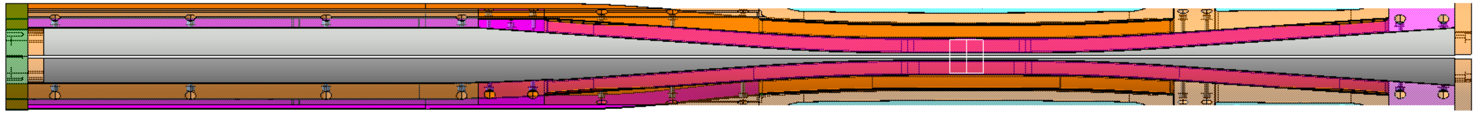
2.) or a model to be developed at Tampere university of technology (TUT) by doctoral student Janne Ruuskanen. The aim is to investigate the matter how the current distributes on the edges of the tapes and see how the forces are redistributed.

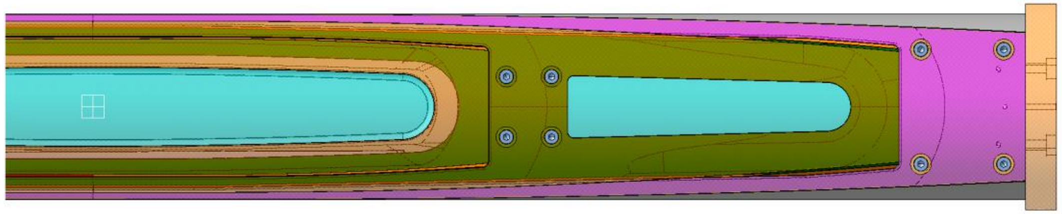


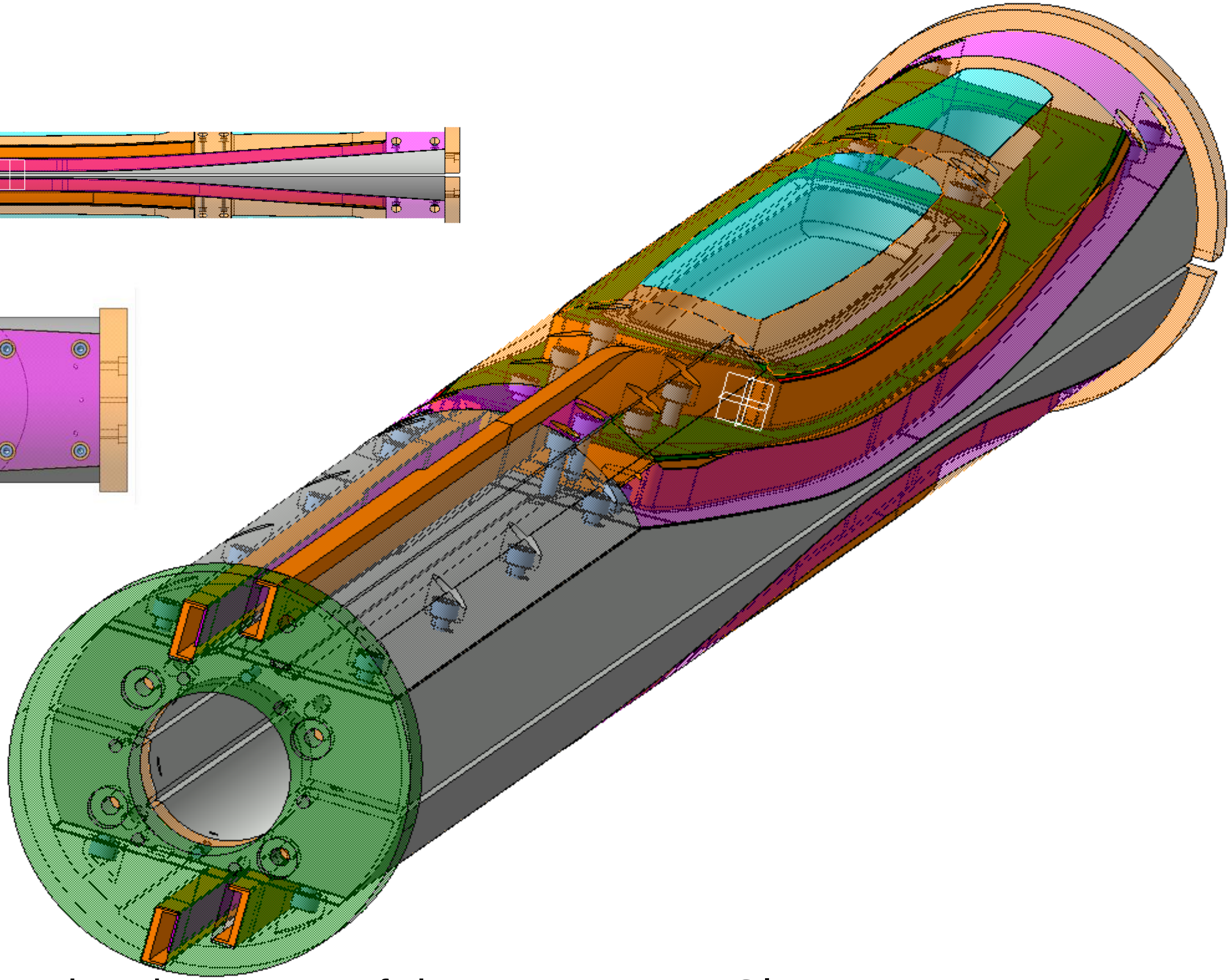

#3 repeat of #2 to fix electrical short at cable exit
TRES FRAGILE
NE PAS TOUCHER
#1 StSt dummy ctd101K
#2 test instrumentation tests, electrical short
#4 stst dummy filled resin CTD101G test
#5 HTS , 1st real test coil

Feather M2 assembly

“Swiss watch” assembly



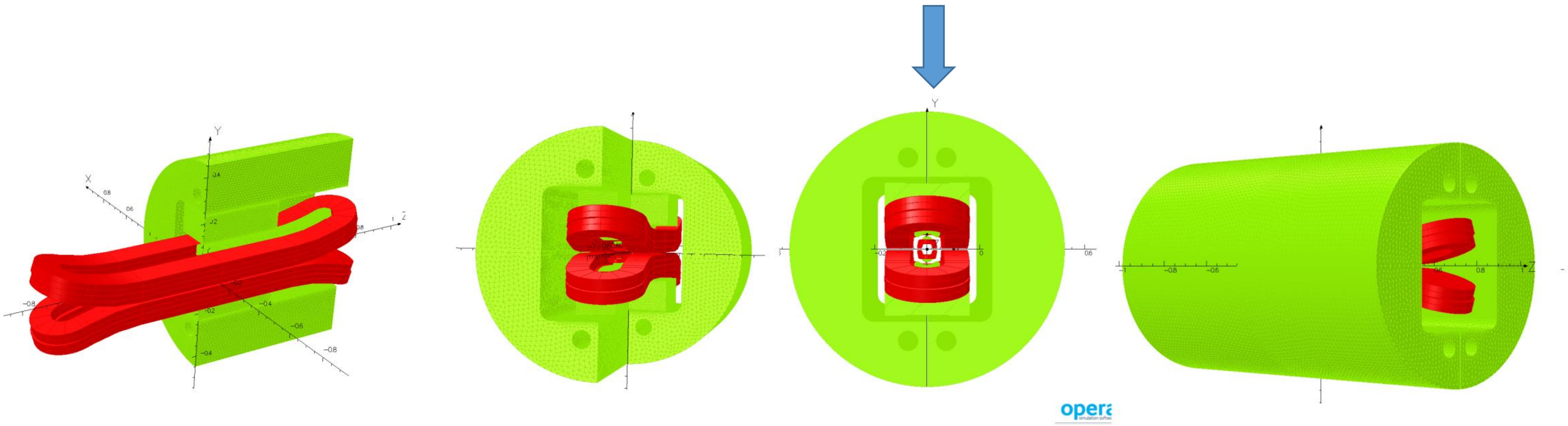




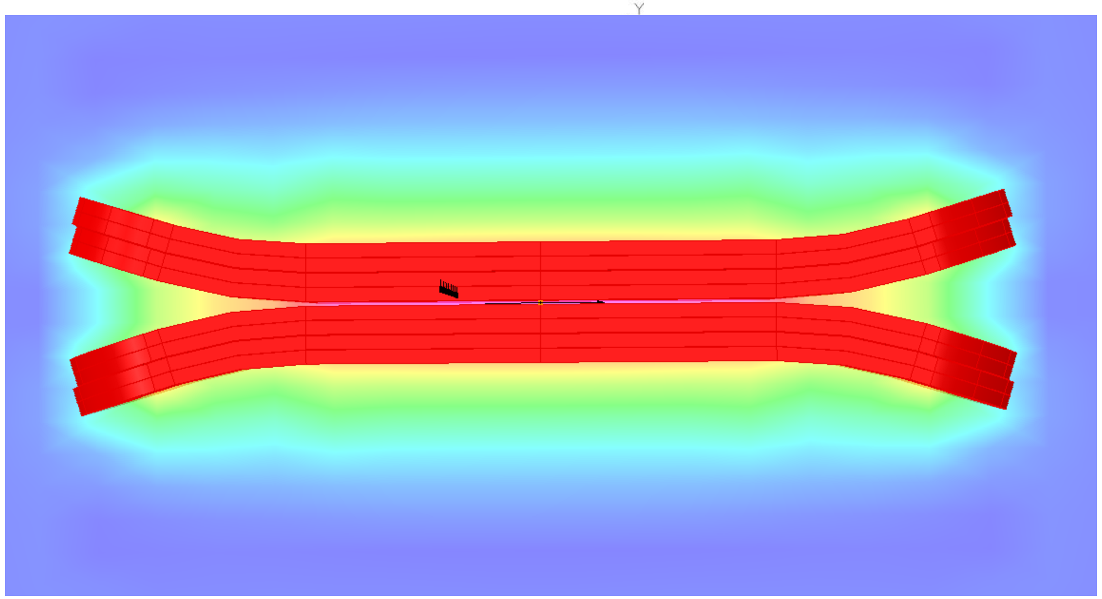
During the last year the principal investigator has been part of the core team – Glyn Kirby, Jeroen van Nugteren, Matthieu Canale and Luca Gentini – to engineer the Feather M2 assembly.

CAD Model by Matthieu Canale

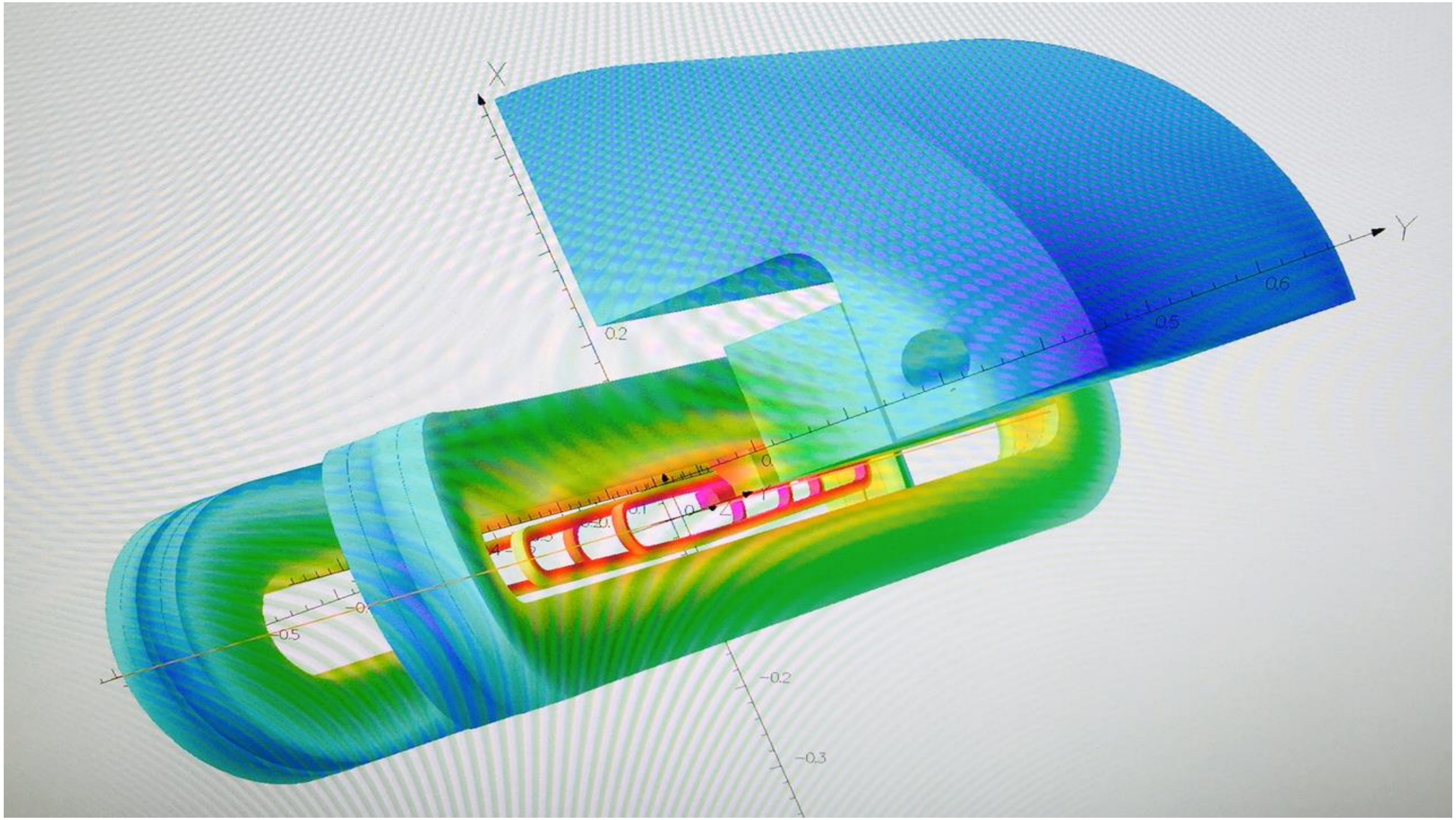
Feather M2



Fresca 2



Thanks to Jeroen van Nugteren for cooperation (coil geometries etc.)


X
Y
0.2
0.5
0.6
-0.2
-0.3
-0.5

17 T

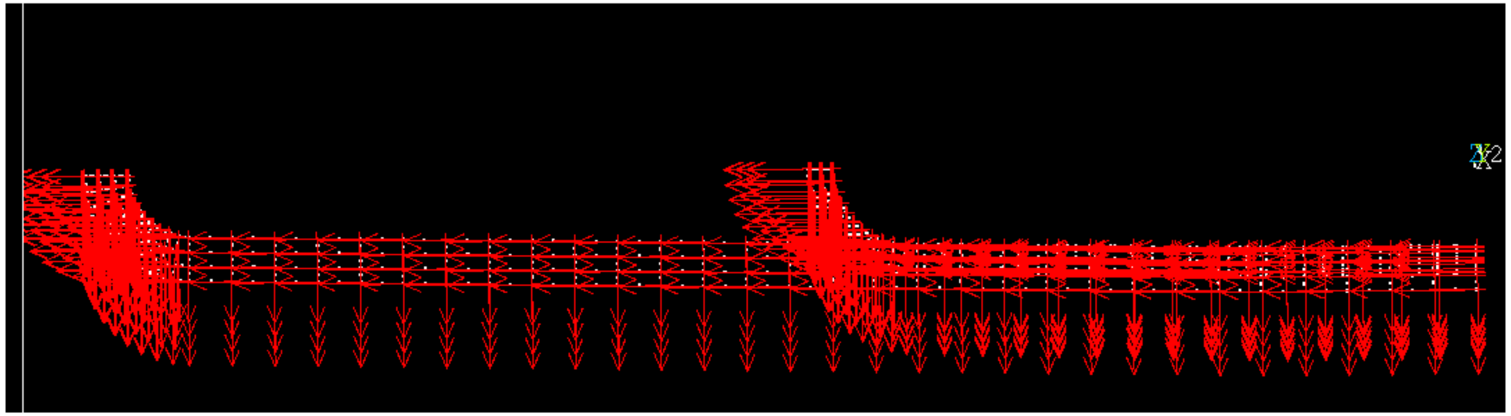
Forces for quarter of a Coil

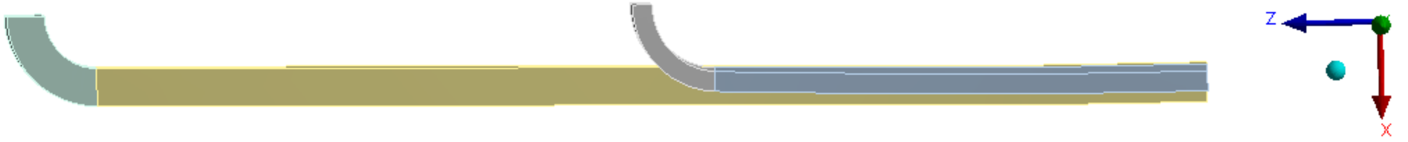
FX_tot (lateral) = 6.2015 *1.0e+05 N = 620 kN = 63 tonnes

FY_tot (vertical)= -0.2281 *1.0e+05 N = -22 kN = -2 tonnes (poles attract each other)

FZ_tot (conductor axial)= 0.5778 *1.0e+05 N = 58 kN = 6 tonnes

Length 380 mm





In 17 T, This means 253 t per one side of the magnet, (and 340 t/m)

Force transfer method by Attilio Milanese: A method to transfer distributed Lorentz forces in 3D to a finite element mechanical model
http://cds.cern.ch/record/1325572/files/OPERA_ANSYS_v2.pdf?version=2

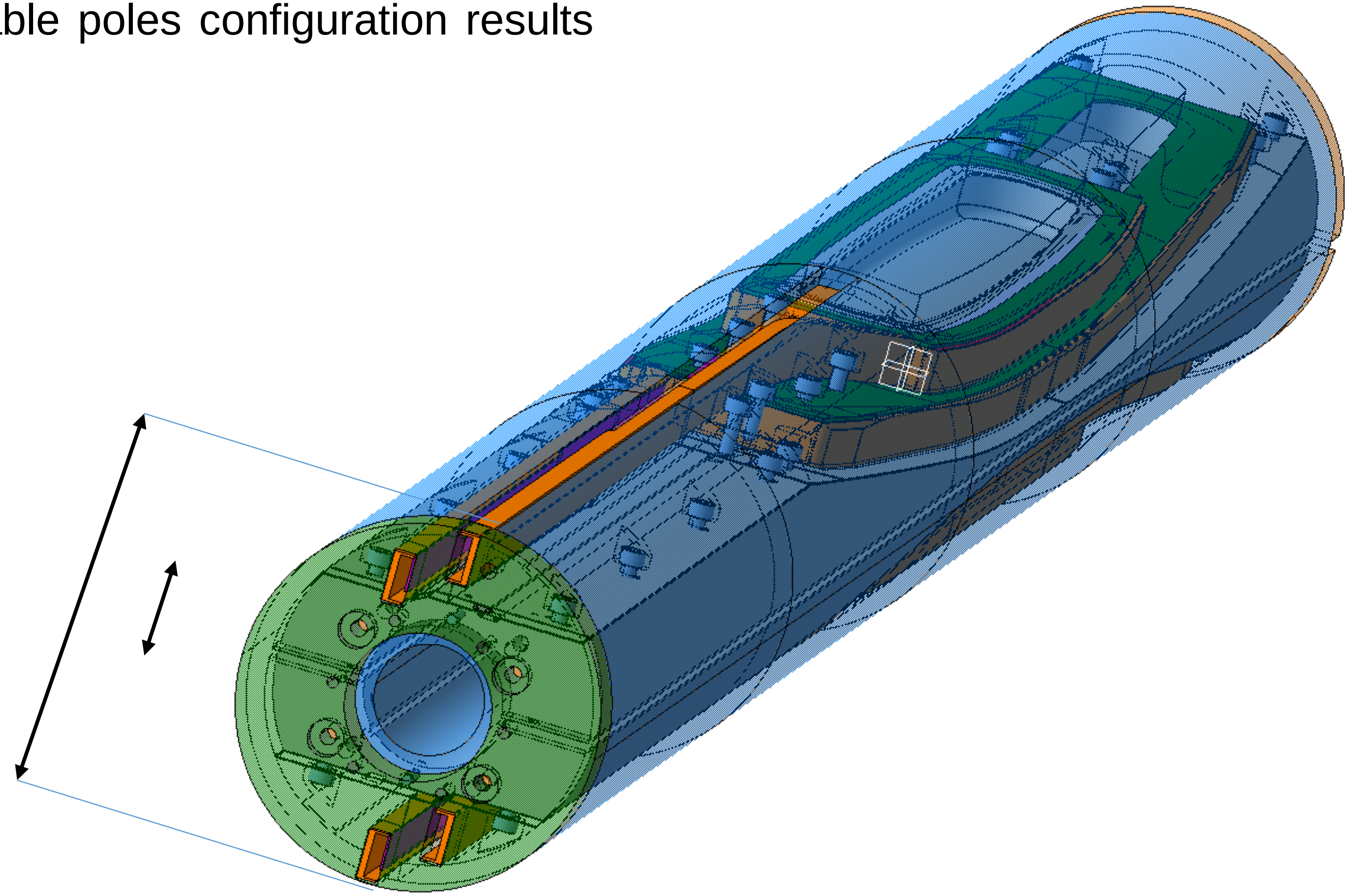
Limited space, the requirement of mechanical clearance to Fresca 2 aperture, and replaceable poles configuration results in real “Swiss watch” assembly.

In 17 T configuration

bore of D=30 mm

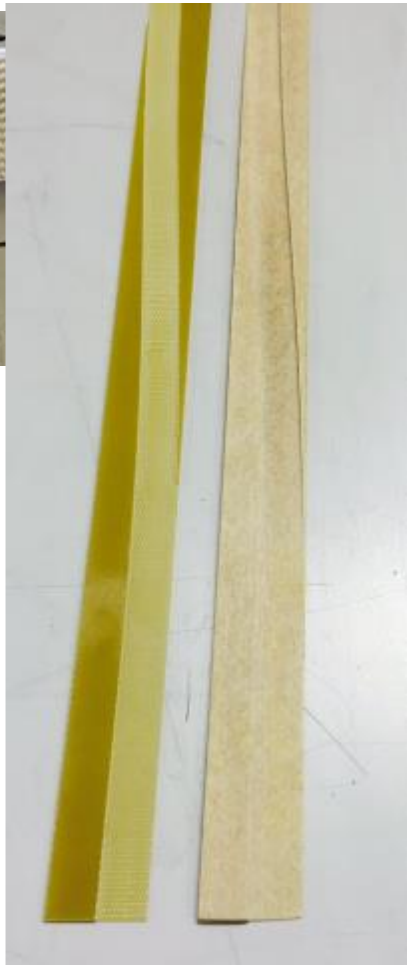
In only D=100 mm

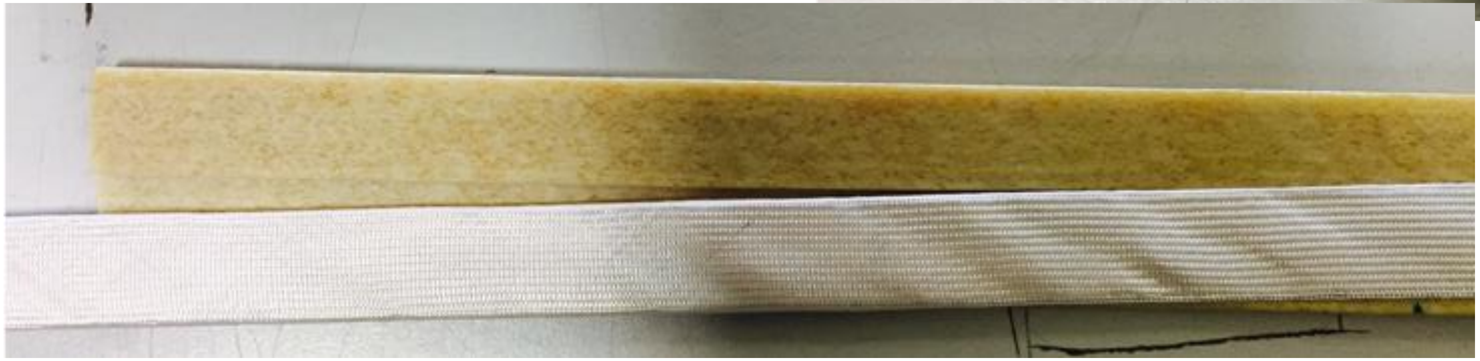
Fresca 2 aperture.



CAD Model by Matthieu Canale

Layer Jump mod

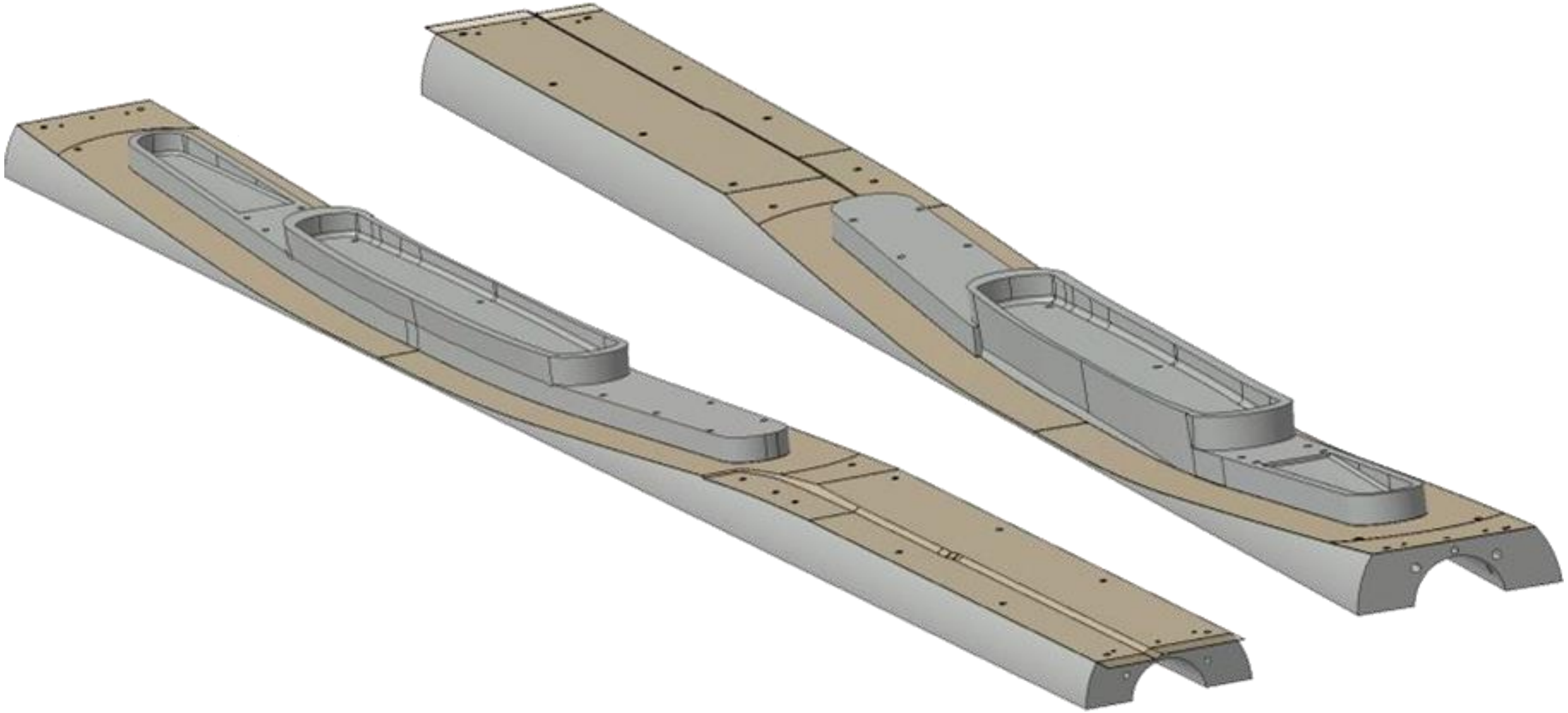




Modification to layer jump box to accommodate the Bruker tape cable

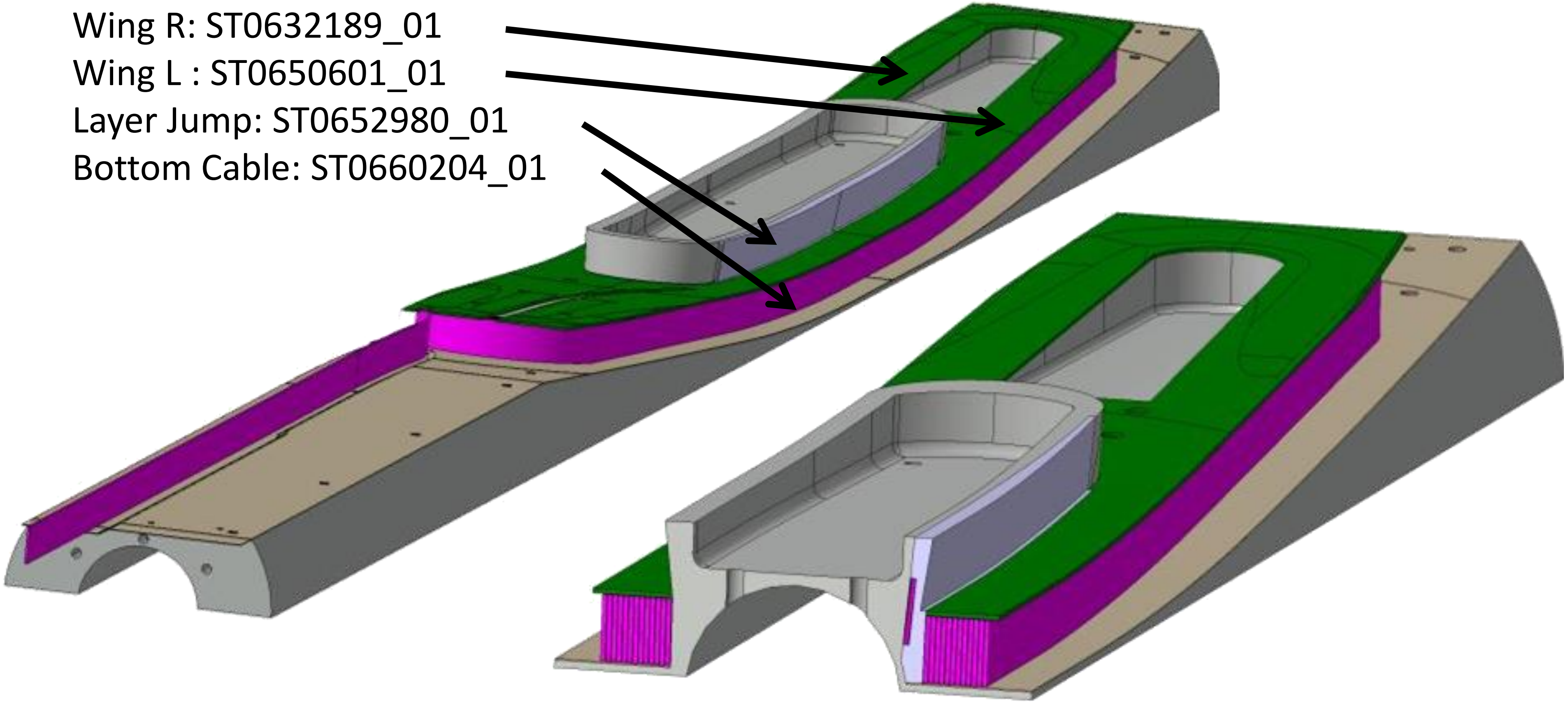
Mounting Range Magnet HTS

- ***Step n°1:*** Kapton Layer



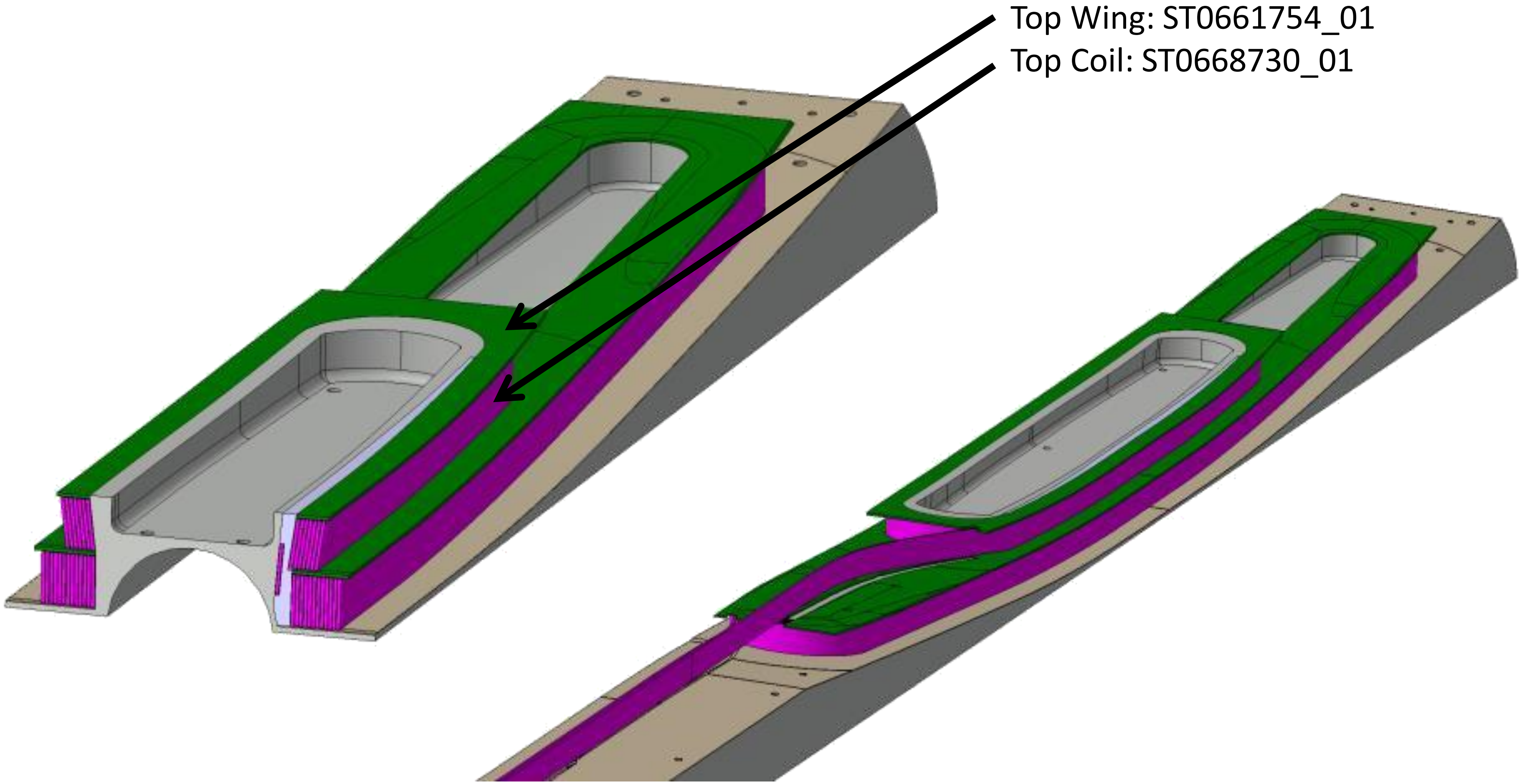
Mounting Range Magnet HTS

- *Step n°2:* Bottom Cable



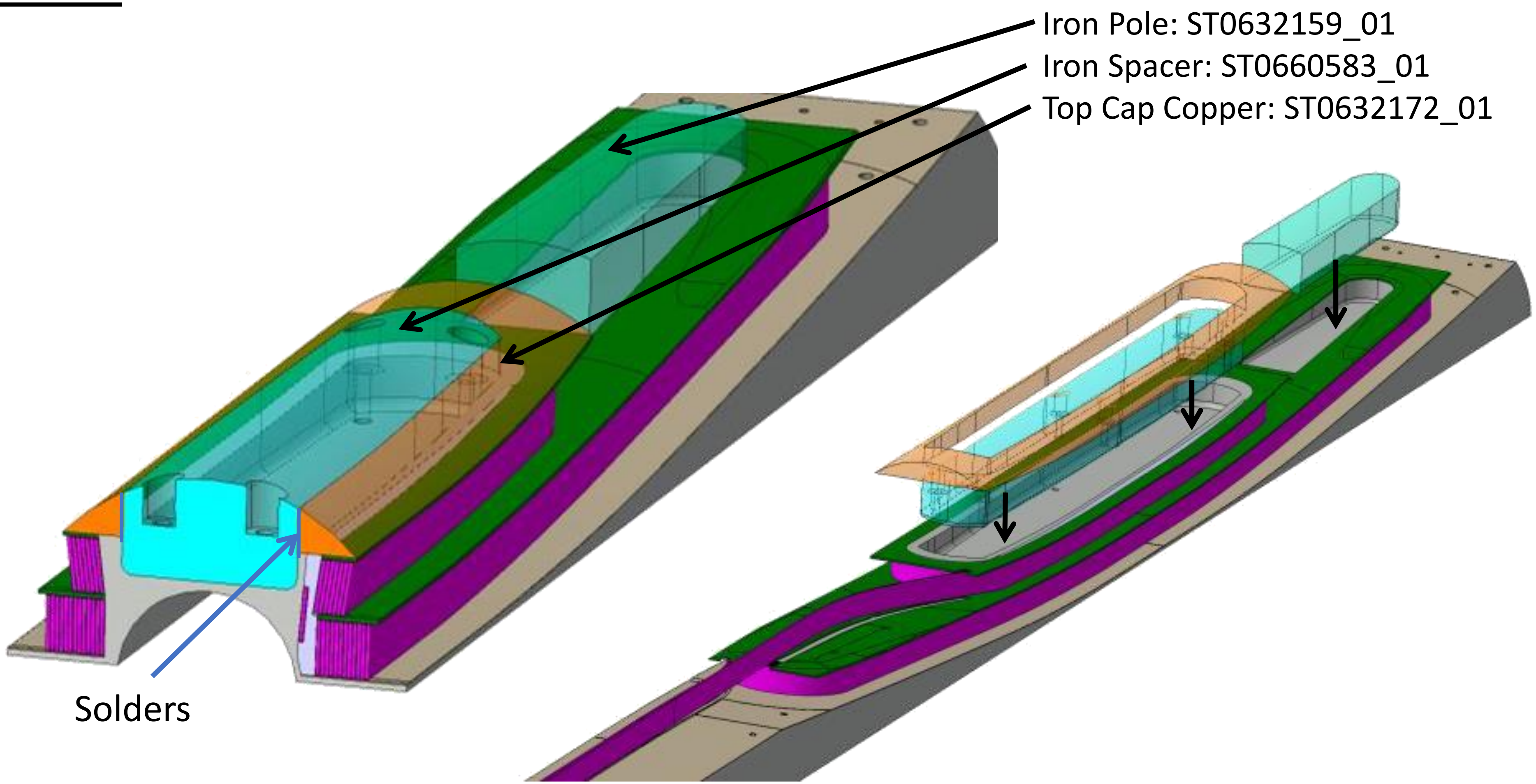
Mounting Range Magnet HTS

- ***Step n°3:*** Top Cable



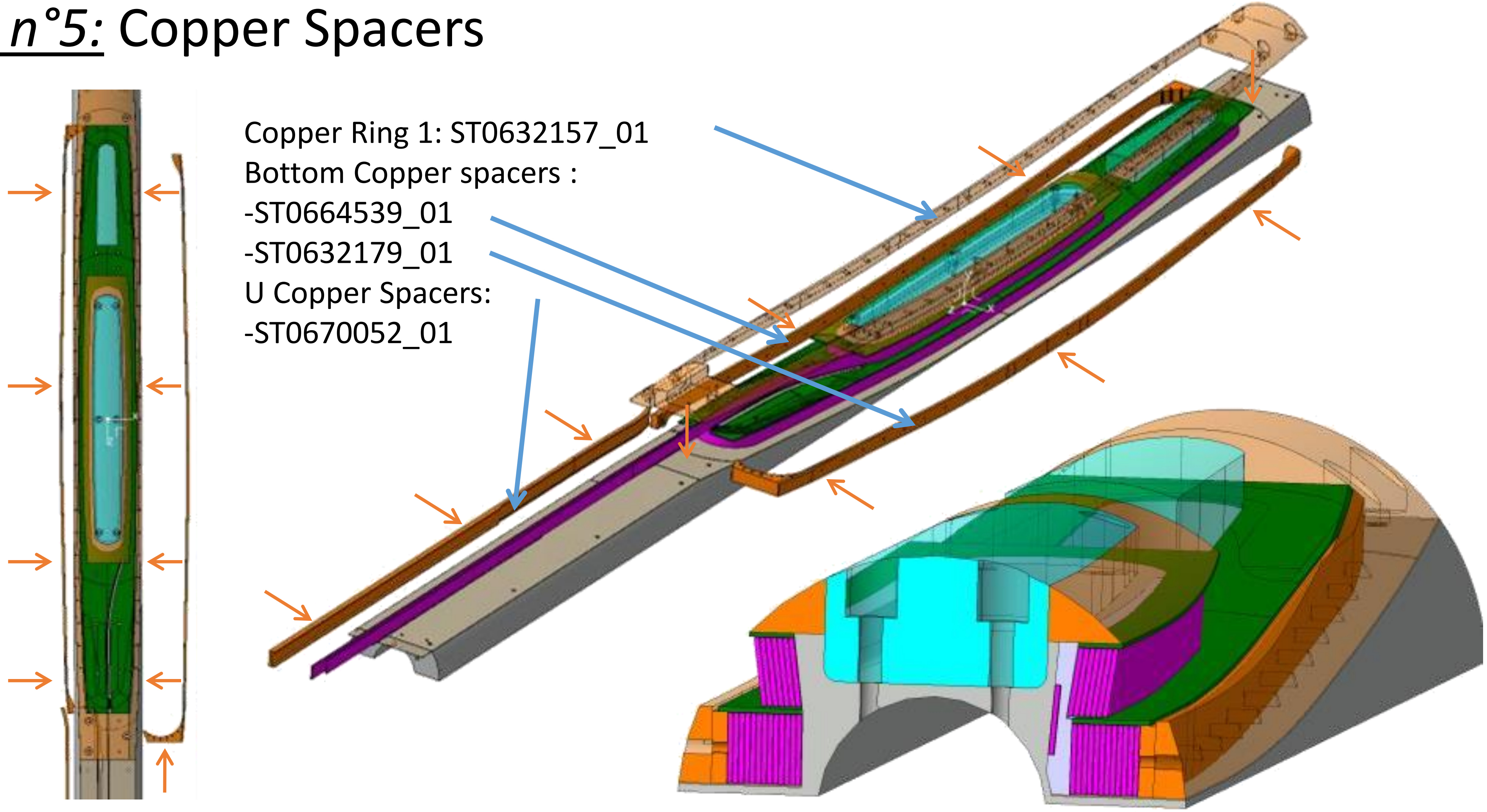
Mounting Range Magnet HTS

- *Step n°4:* Iron Poles



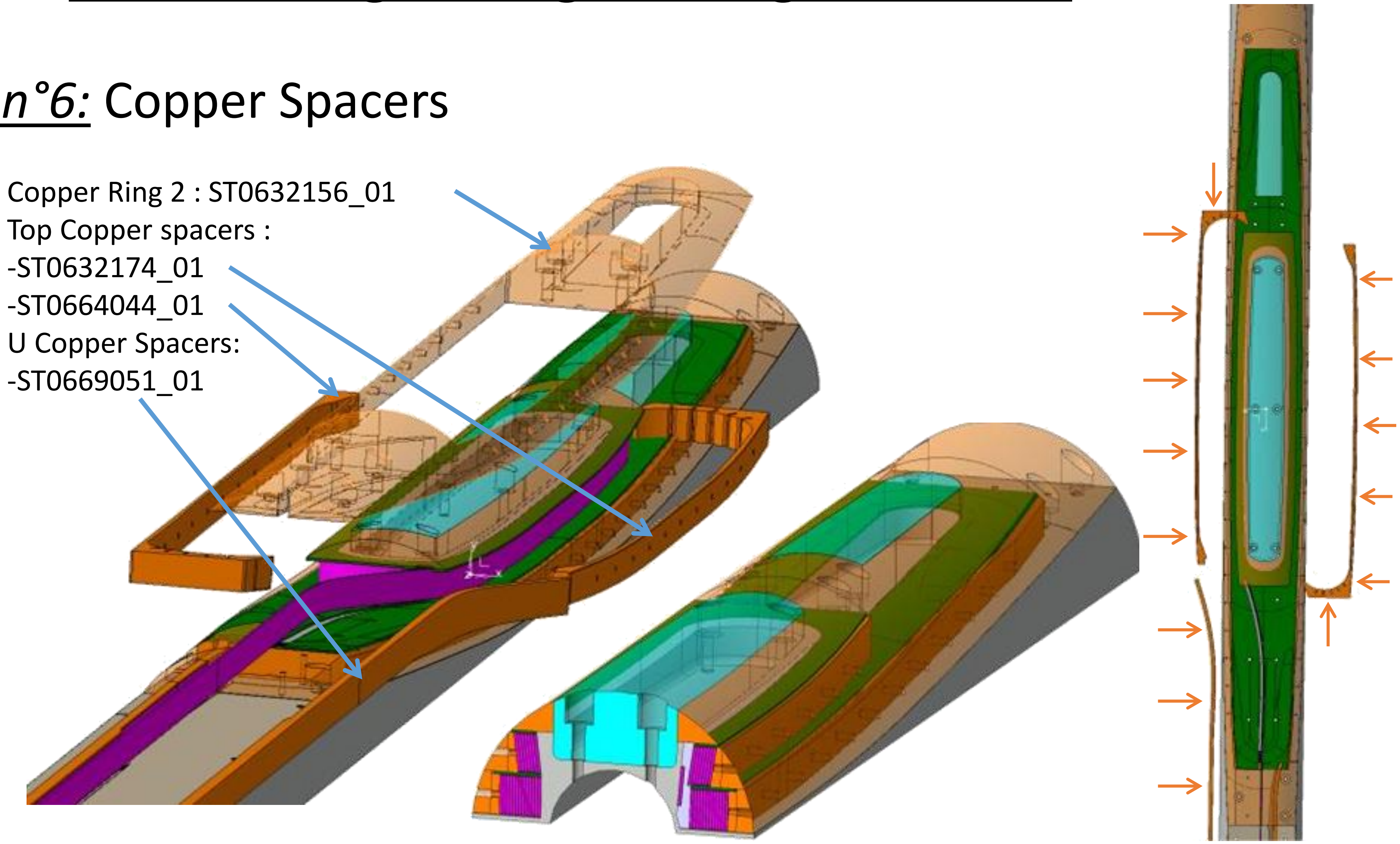
Mounting Range Magnet HTS

- ***Step n°5:*** Copper Spacers



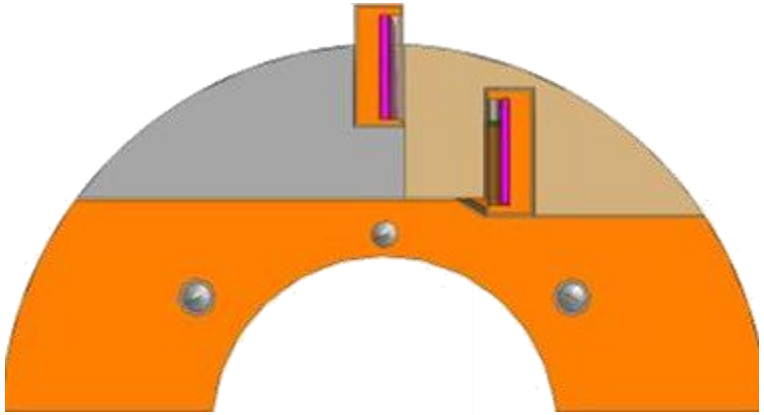
Mounting Range Magnet HTS

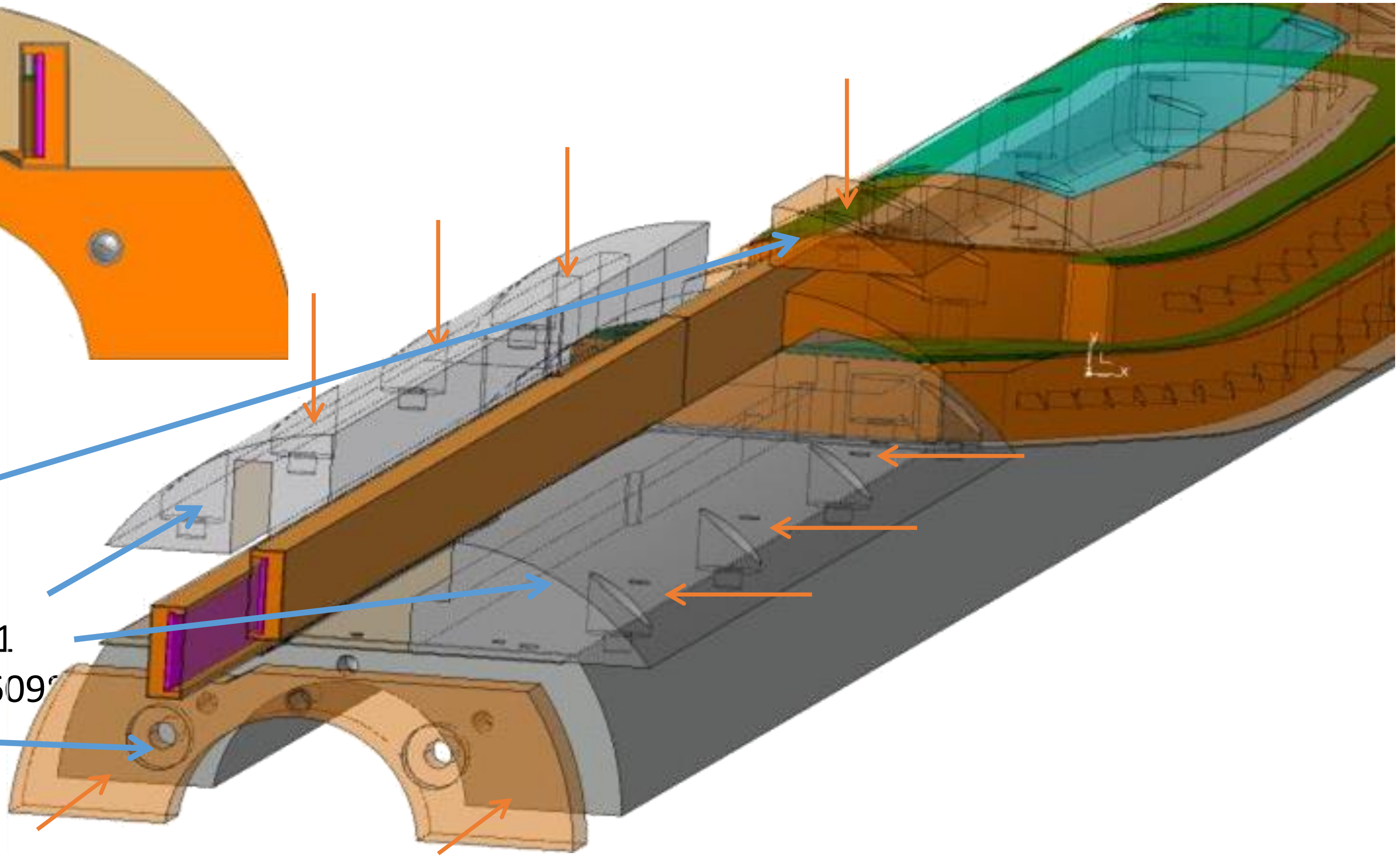
- ***Step n°6:*** Copper Spacers



Mounting Range Magnet HTS

- *Step n°7:* Top Copper Spacers

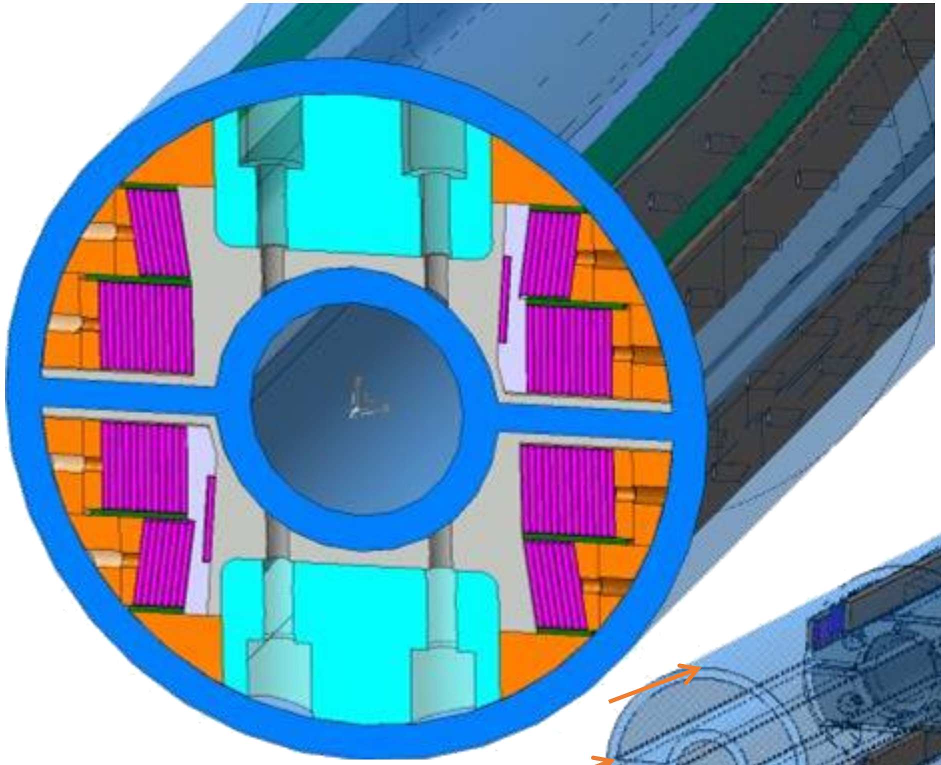


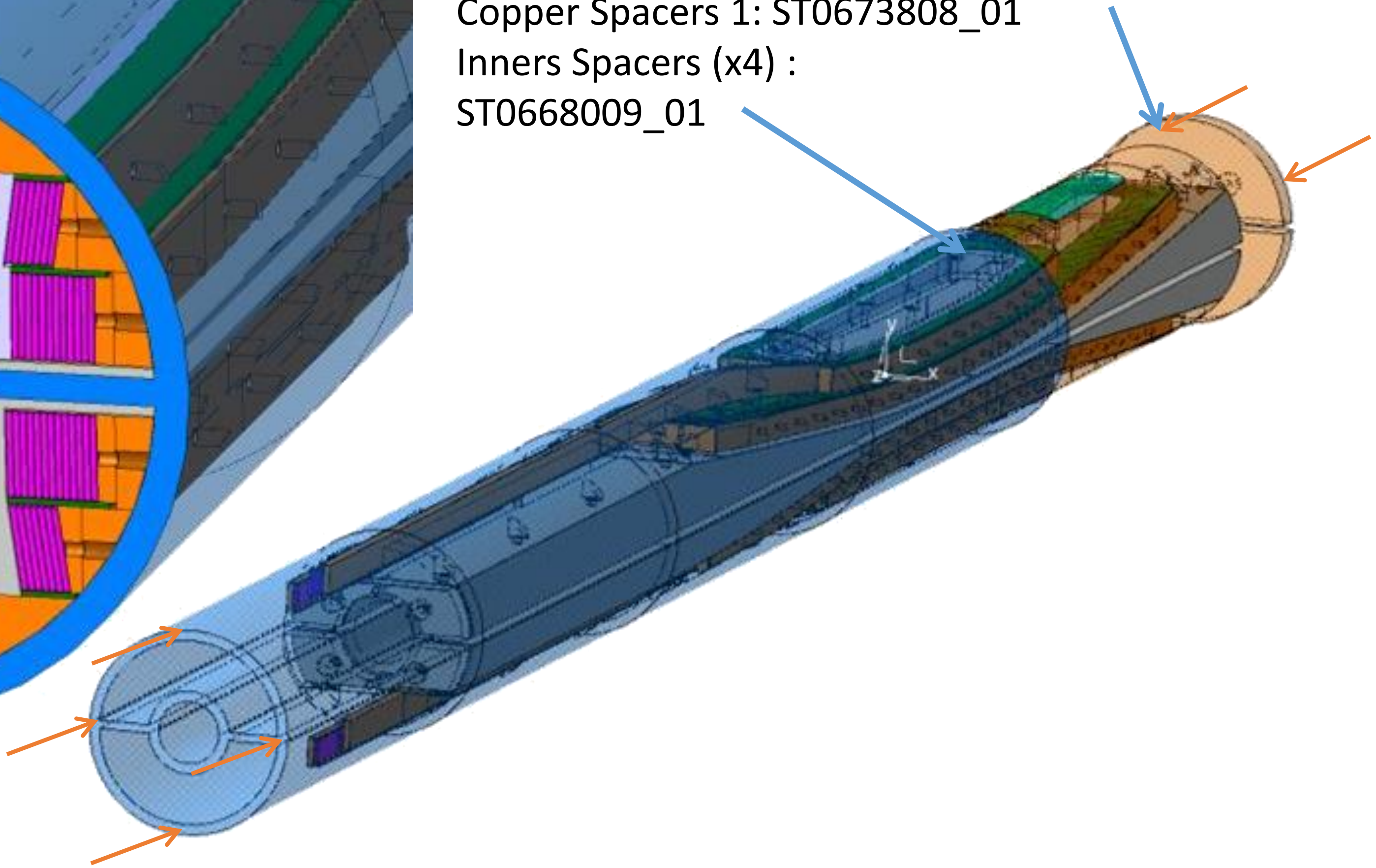


Triangular Spacers :
ST0668009_01
Top Cap : ST0673808_01
Spacer 10 : ST0655445_01
Copper Spacers 2 : ST06609?

Mounting Range Magnet HTS

- *Step n°8:* Inner Spacers (version 20T)

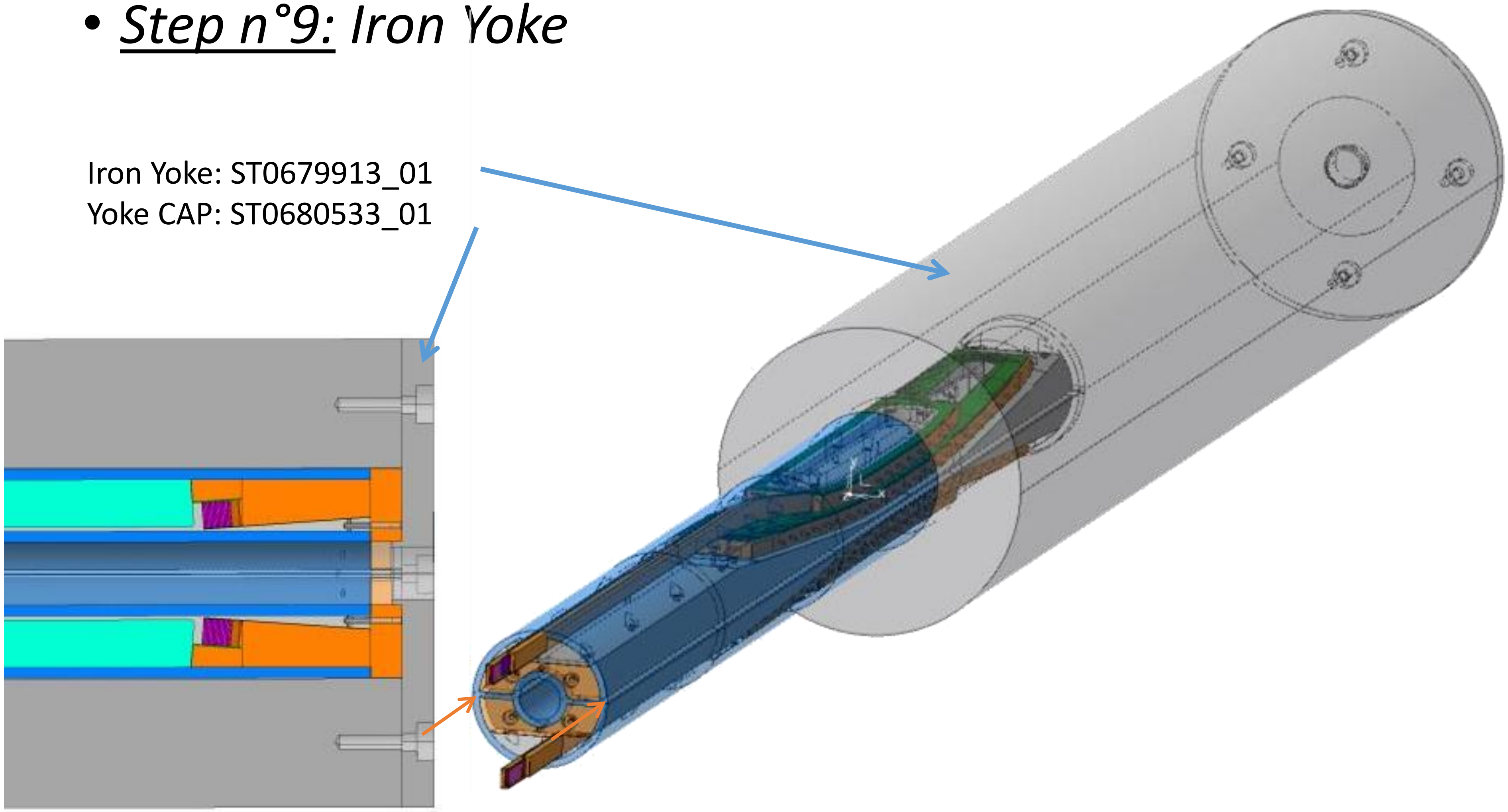




Mounting Range Magnet HTS

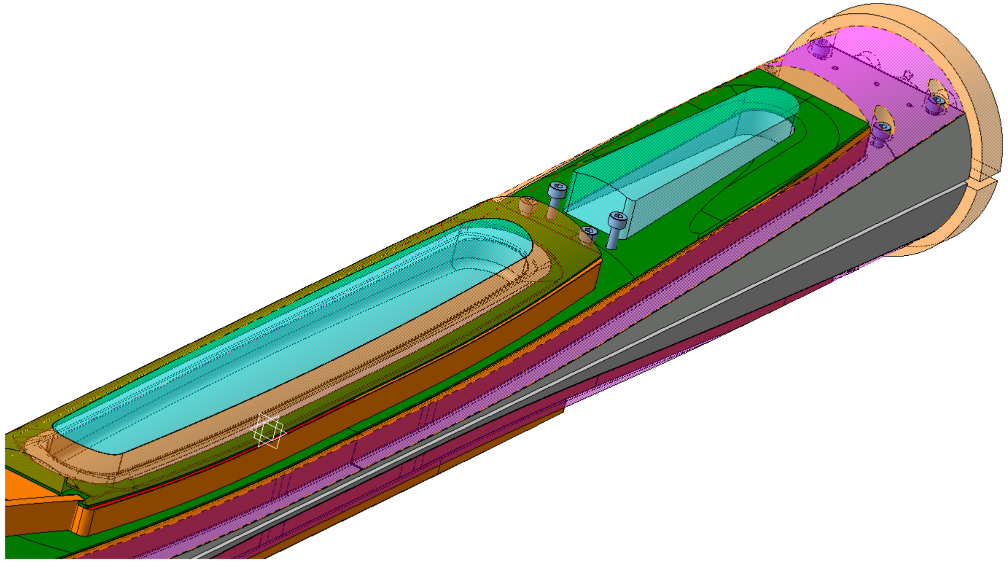
- *Step n°9:* *Iron Yoke*

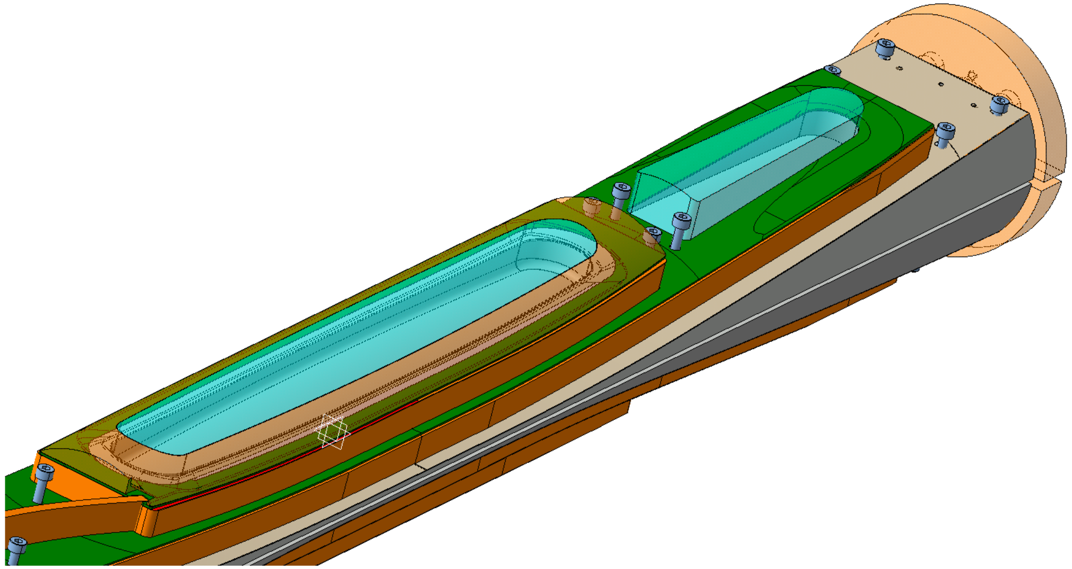
Iron Yoke: ST0679913_01
Yoke CAP: ST0680533_01



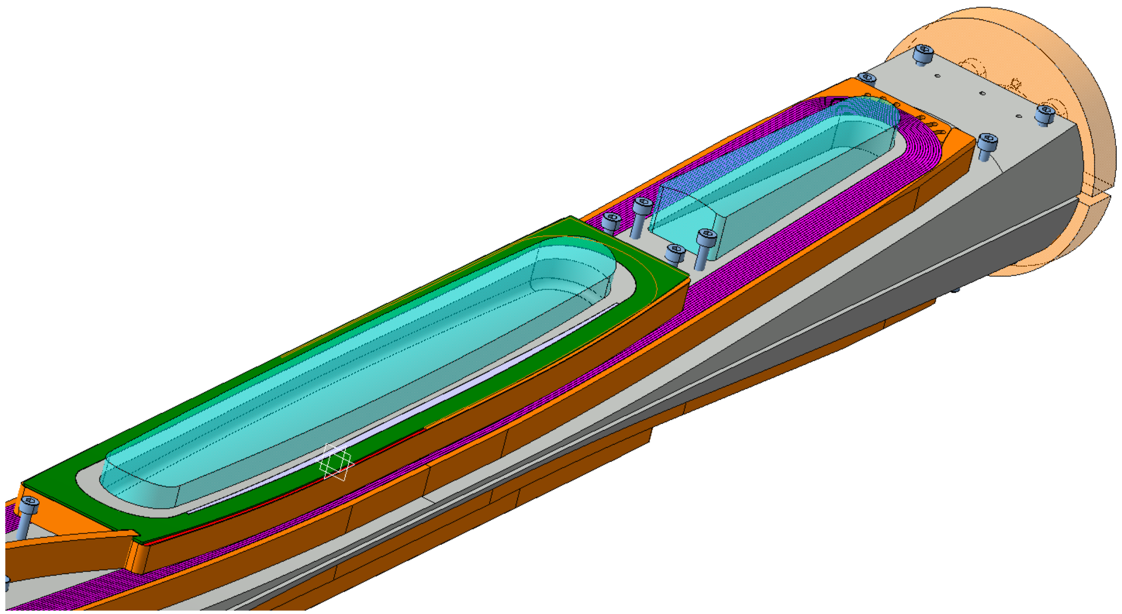
Especially challenging due to huge forces and limited space

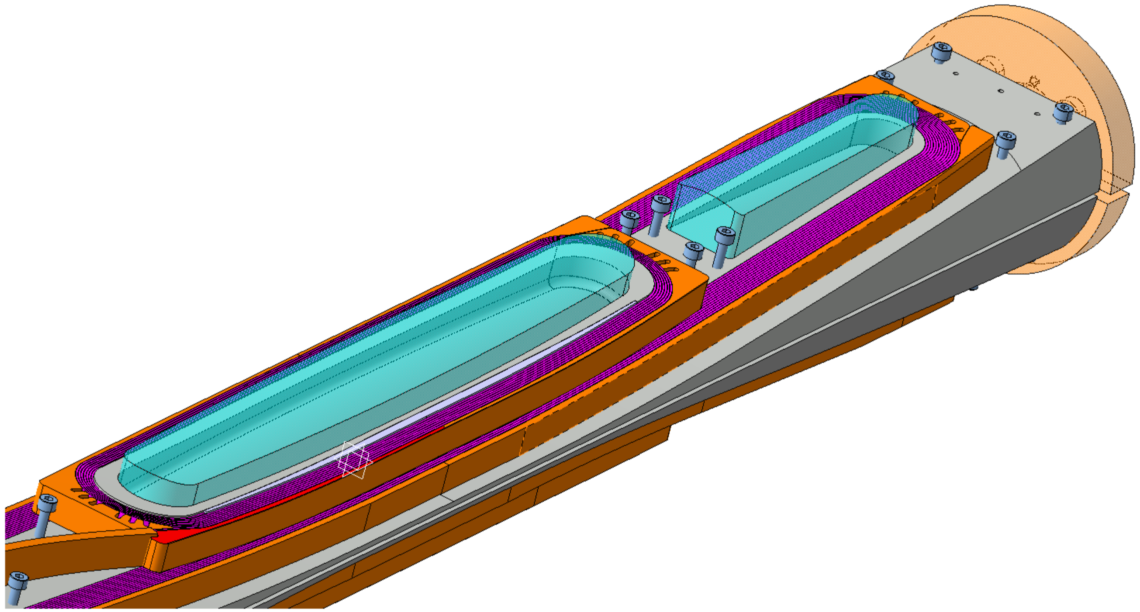
(three to four copper rings per pole, iron poles, adapted for various thicknesses of Roebel)





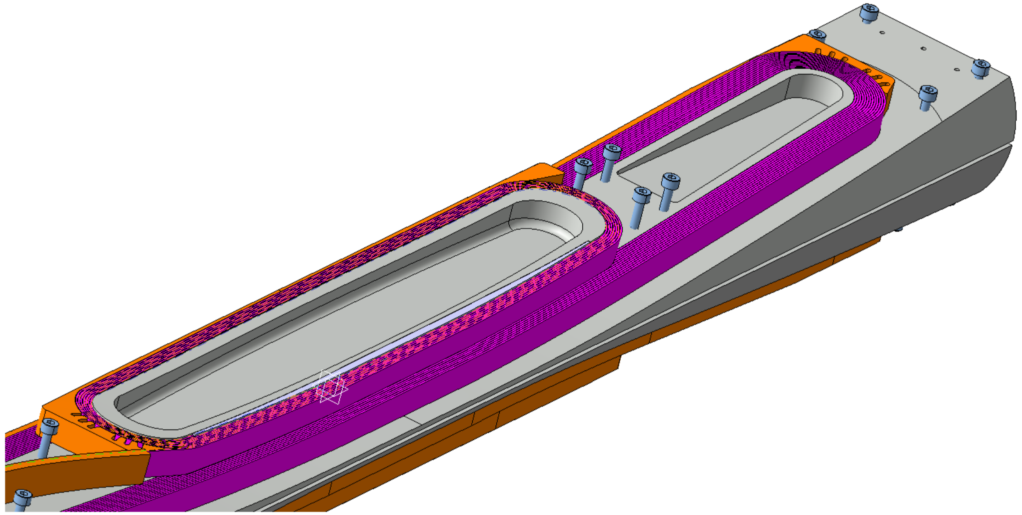
CAD Model by Matthieu Canale

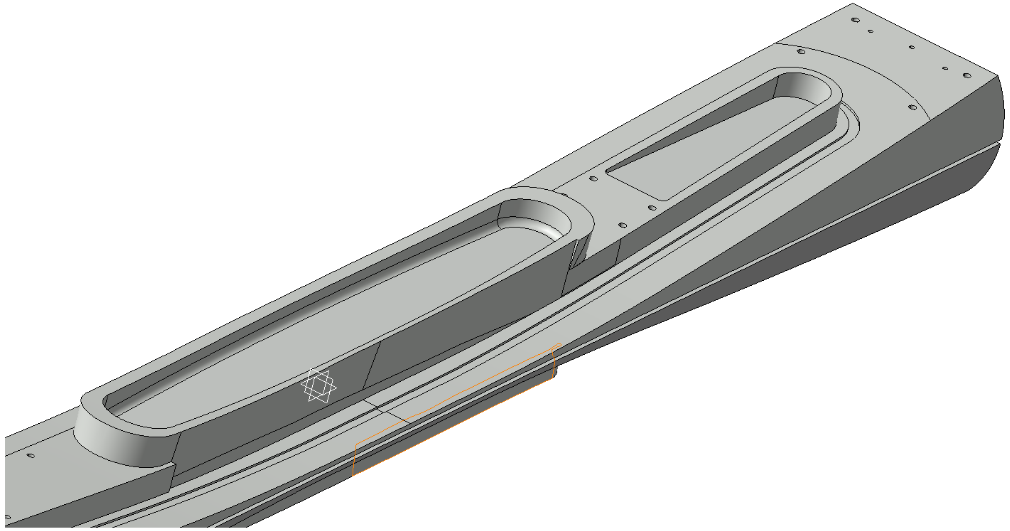




CAD Model by Matthieu Canale

1.12.2015, Jaakko Murtomäki





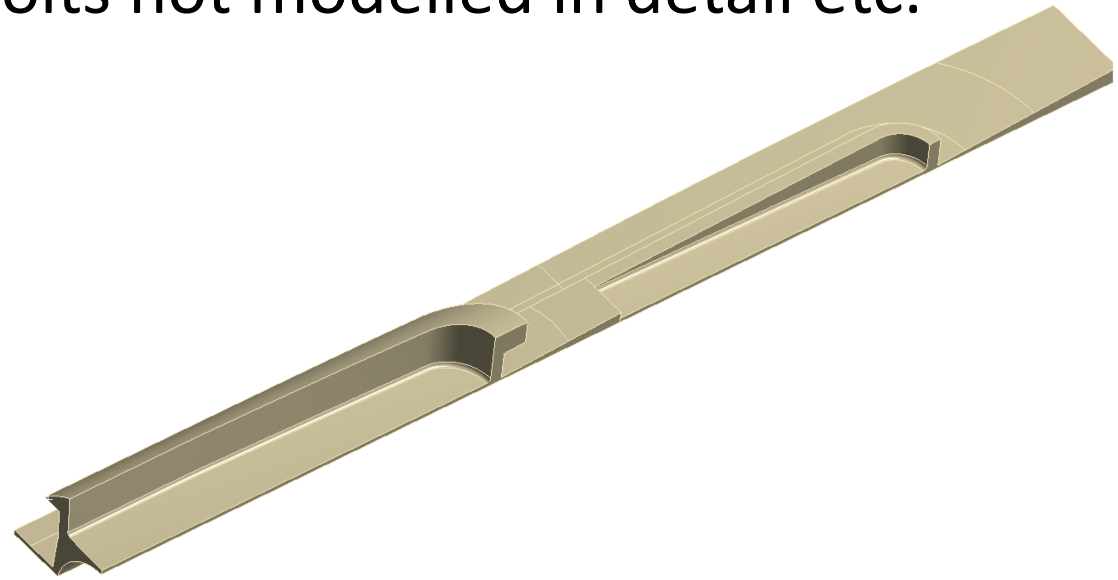
CAD Model by Matthieu Canale

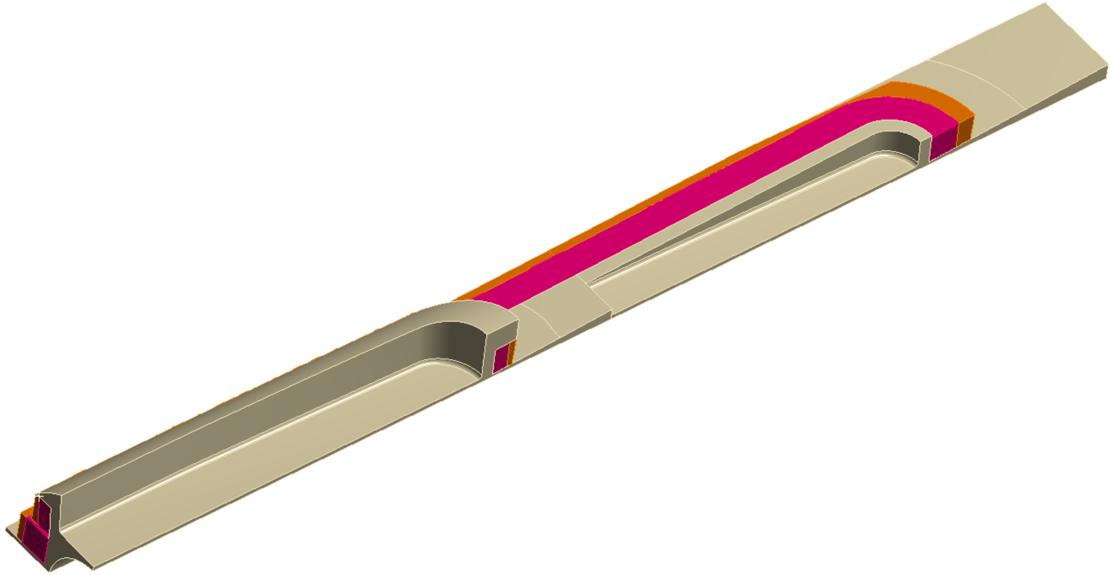
1.12.2015, Jaakko Murtomäki

Assume quarter symmetry

Simplify all the parts to minimum detail keeping the functionality.

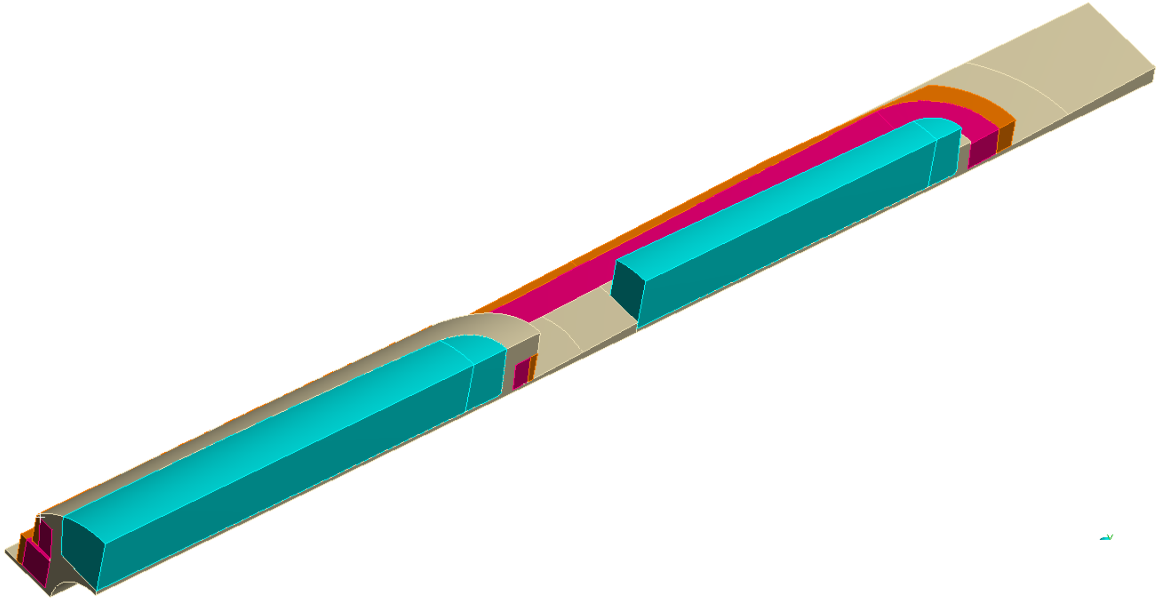
Bolts not modelled in detail etc.

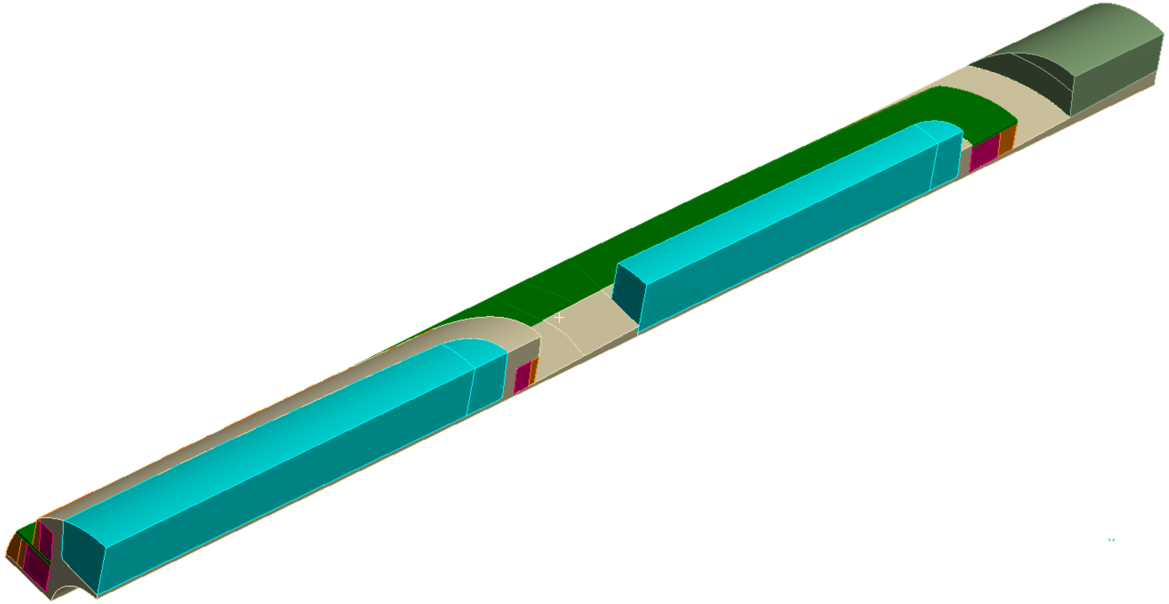




CAD geometry by Jeroen van Nugteren

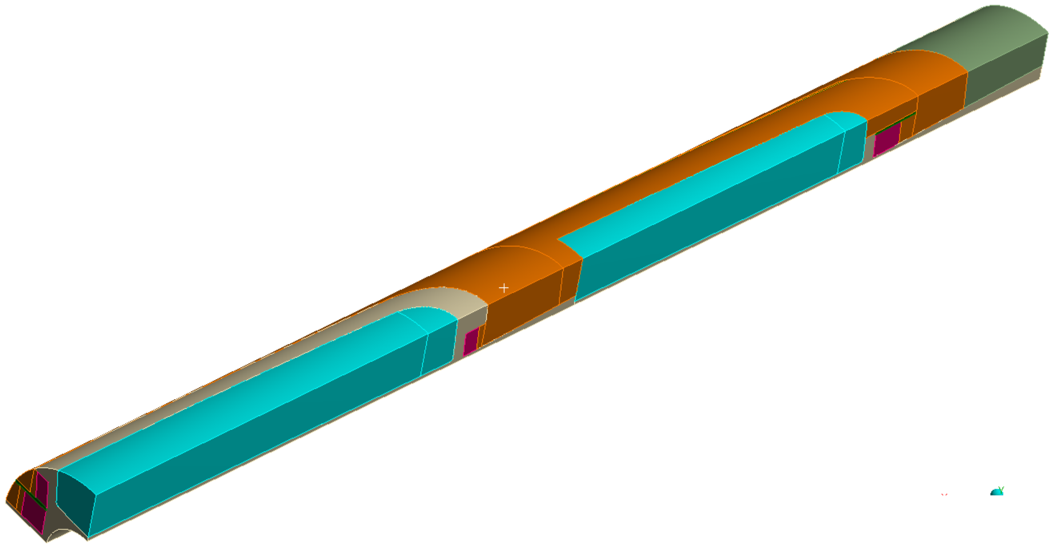
4. How to reach the objectives?

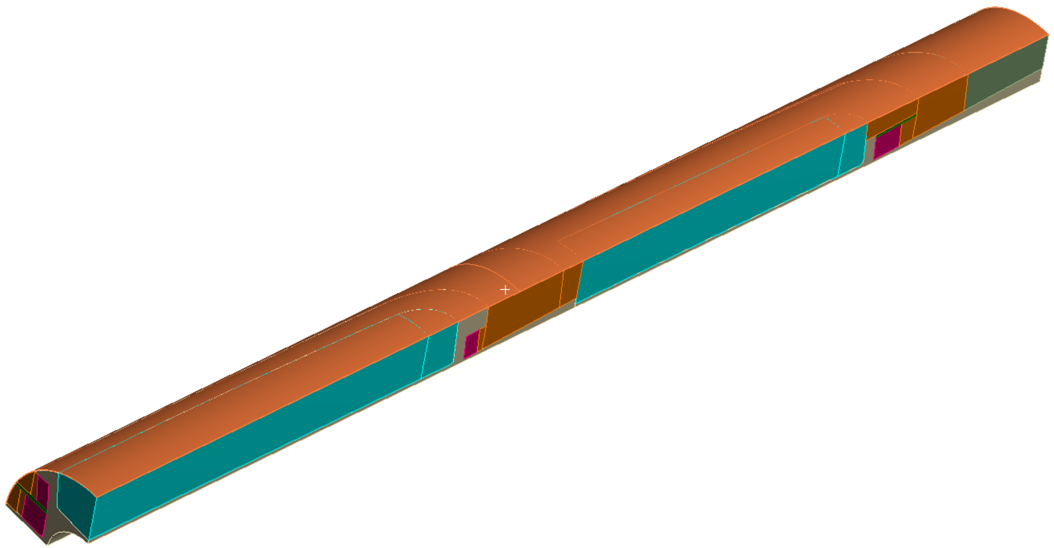




CAD geometry by Jeroen van Nugteren

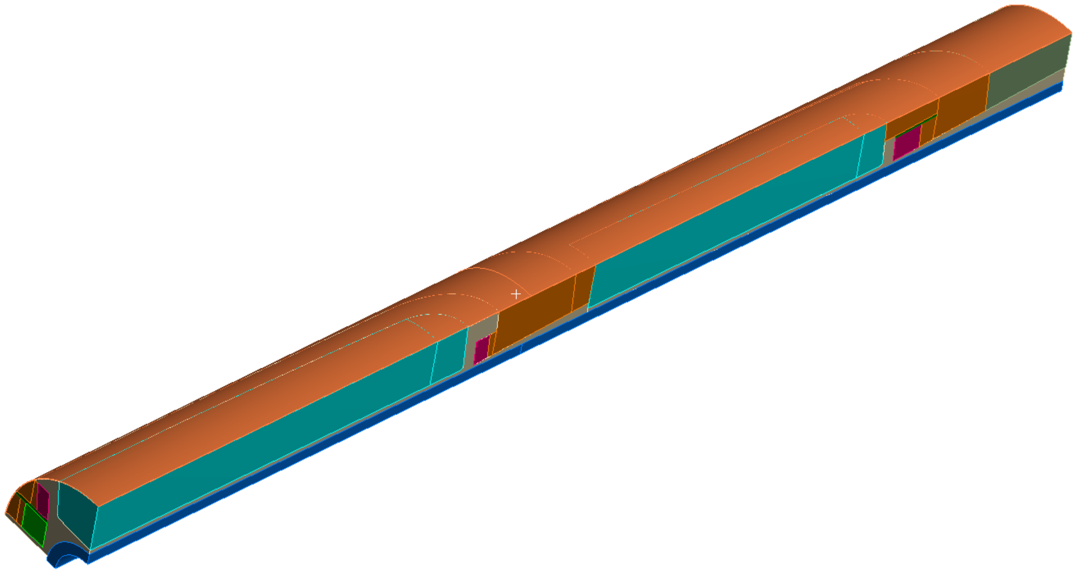
4. How to reach the objectives?

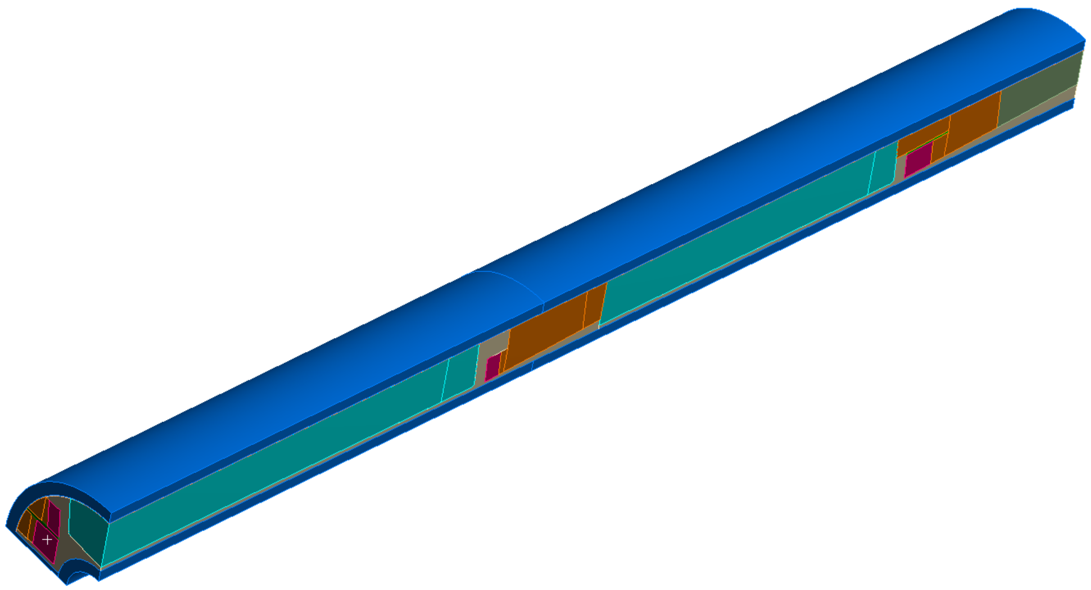




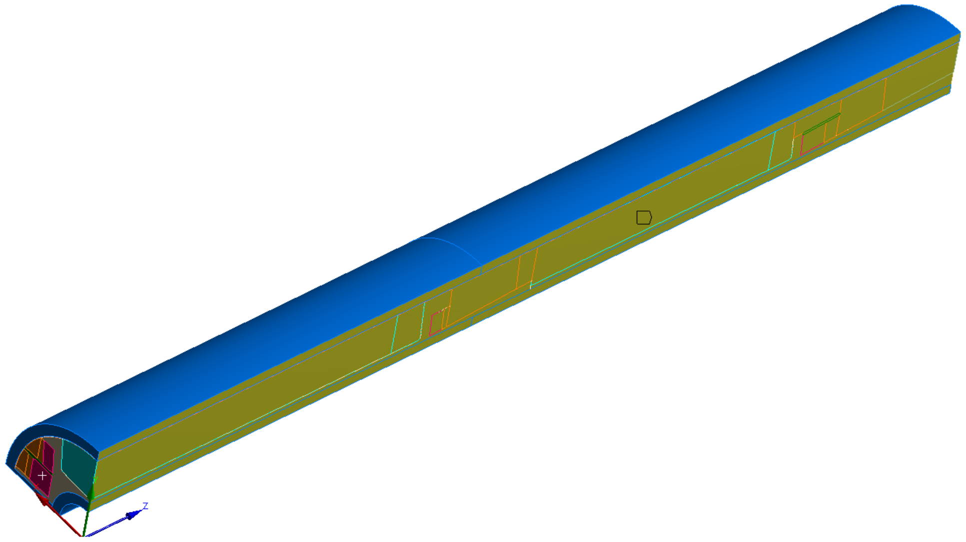
CAD geometry by Jeroen van Nugteren

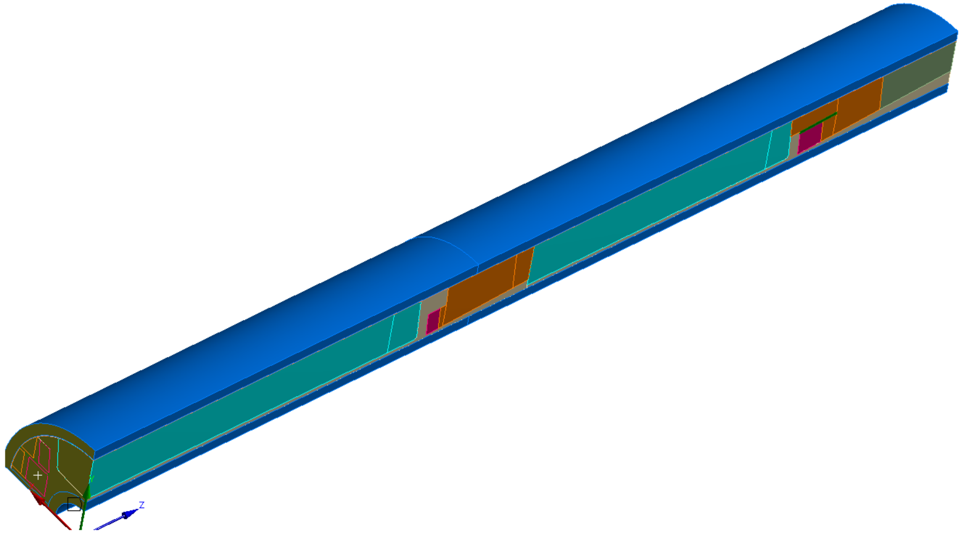
Ground insulation (Kapton) and shell



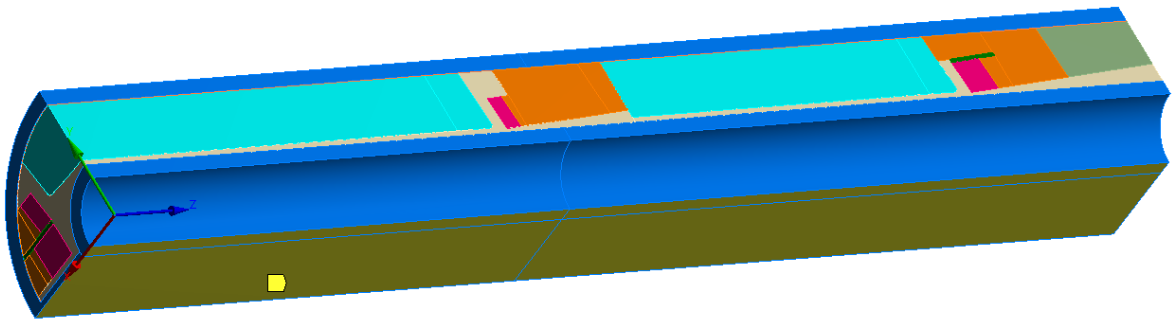


Restrain symmetries to be moving on the plane

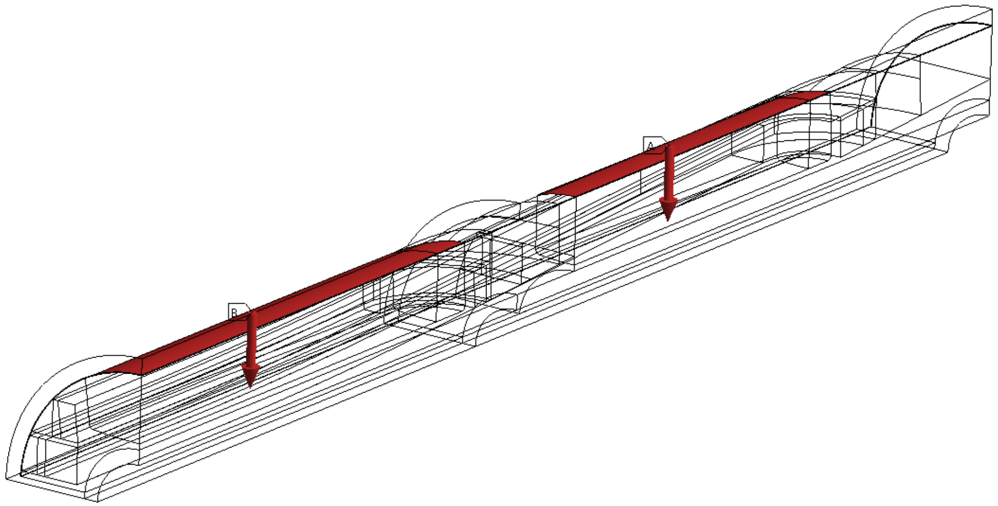




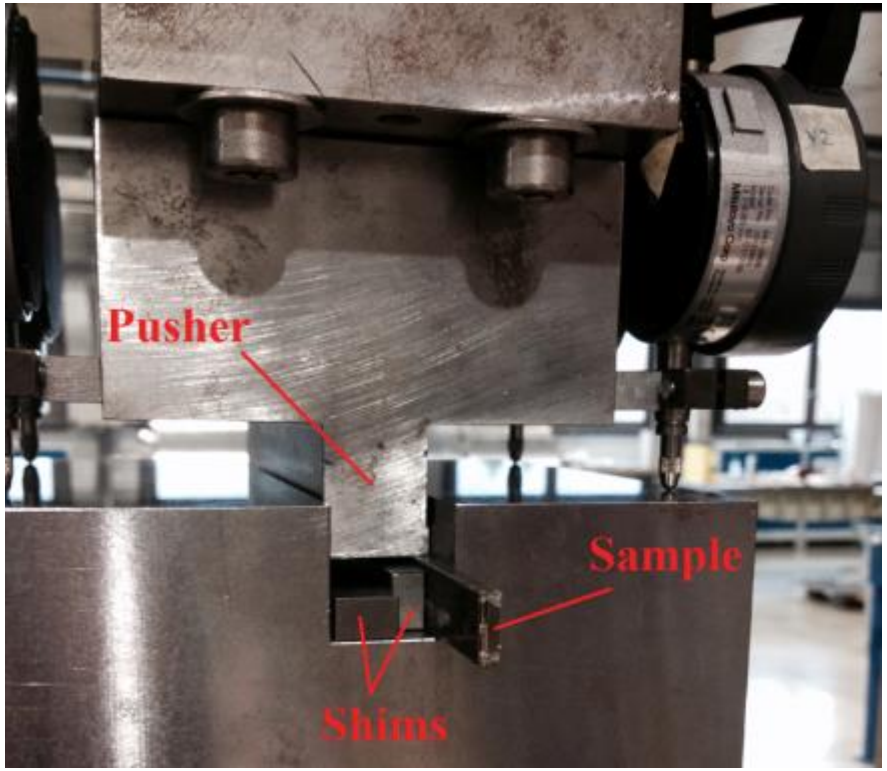
Restrain symmetries on plane

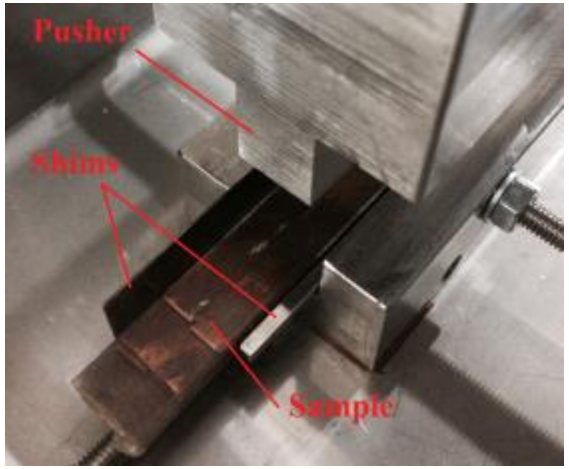


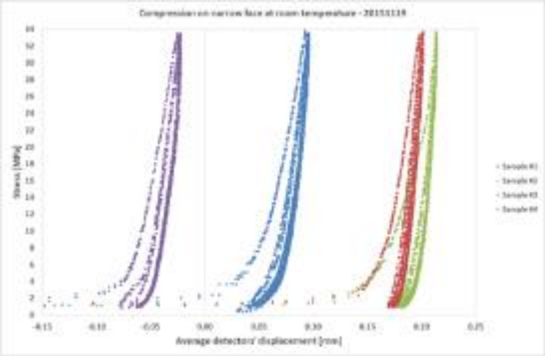
Loading iron poles from the top surface

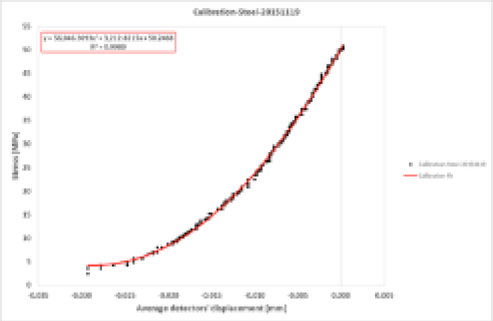


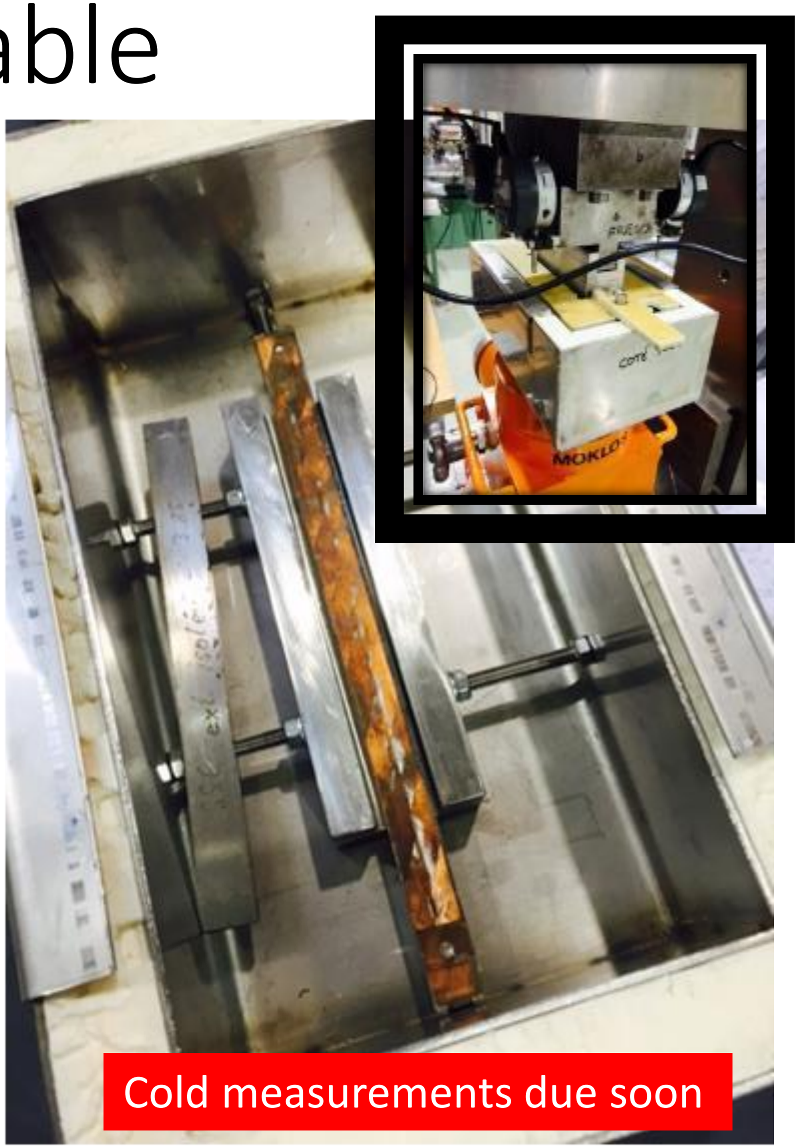
E modulus test on impregnated cable











Young modulus [GPa]	Pressing on the wide face				Pressing on the narrow face			
Sample	#1	#2	#3	#4	#1	#2	#3	#4
1st Compression	18	19	15	16	13	12	19	14
1st Spring back	30	29	25	27	45	112	82	51
2nd Compression	20	21	17	19	19	47	34	22
2nd Spring back	29	29	24	26	46	104	93	48
3rd Compression	20	20	17	20	22	59	38	23
3rd Spring back	29	-	25	26	48	117	87	50

Thanks to Laura Garcia Fajardo
Full report available.

4. How to reach the objectives?

Axial E-modulus measurement

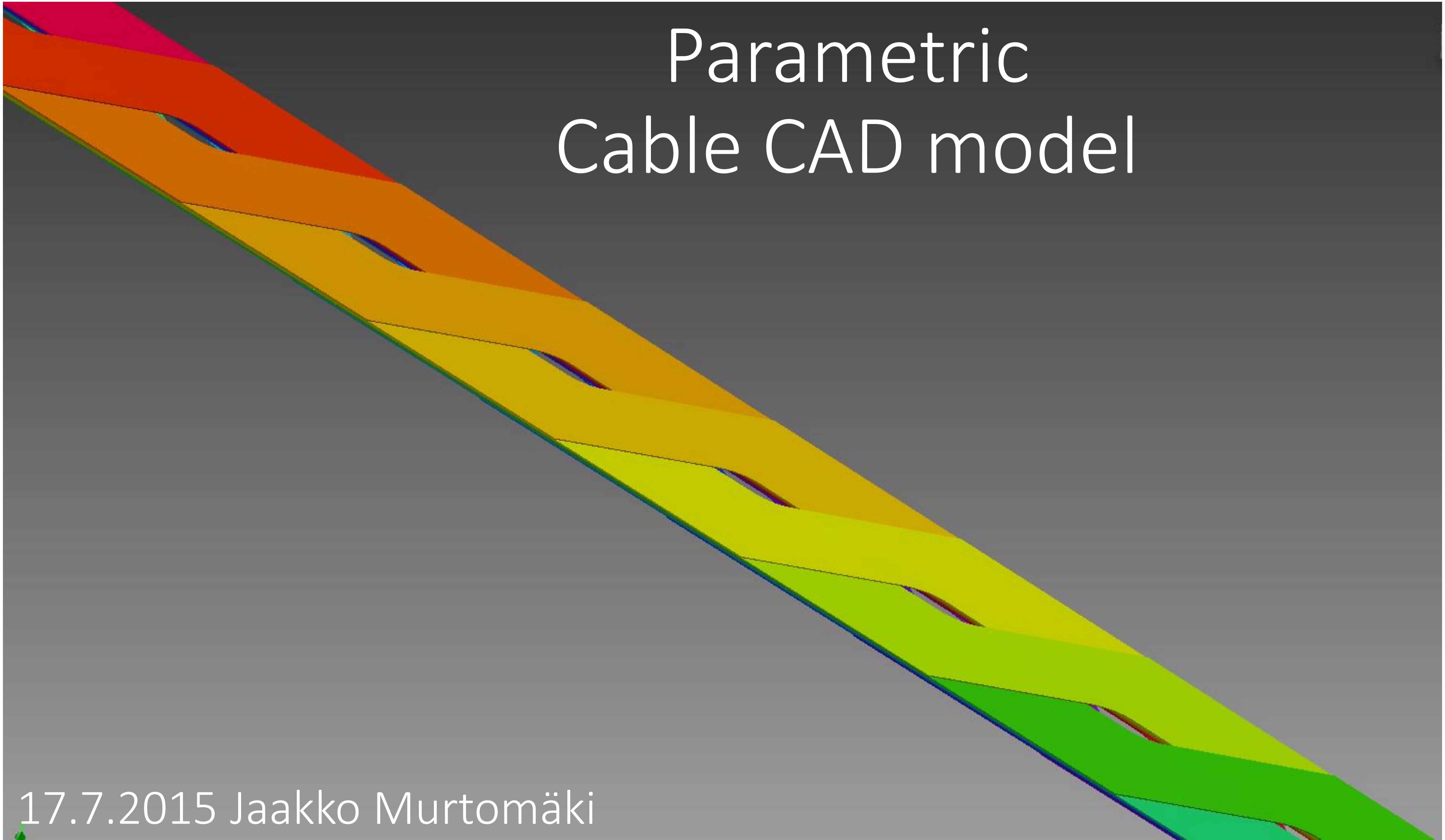
still missing

to be done by me.

Can we also make a cold powered Test for max strain to find engineering limits for the cable?

Aids for future coil design – may be paper???

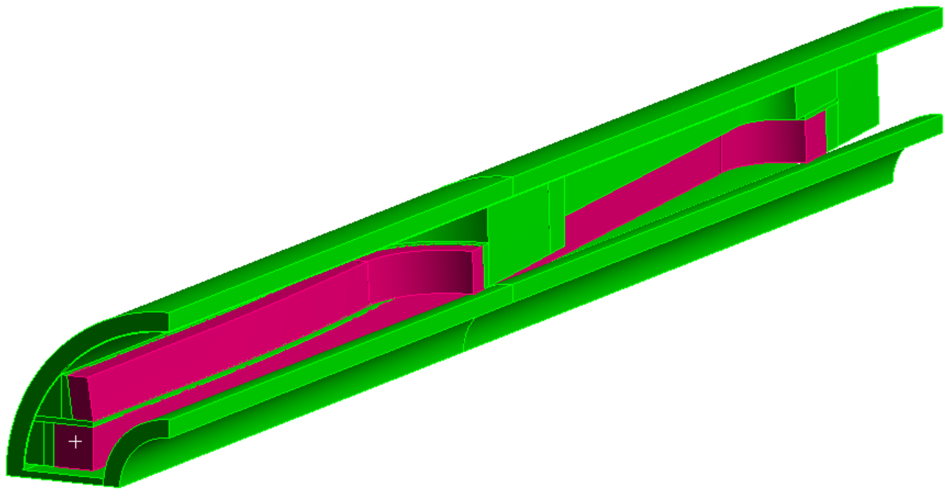
Parametric Cable CAD model

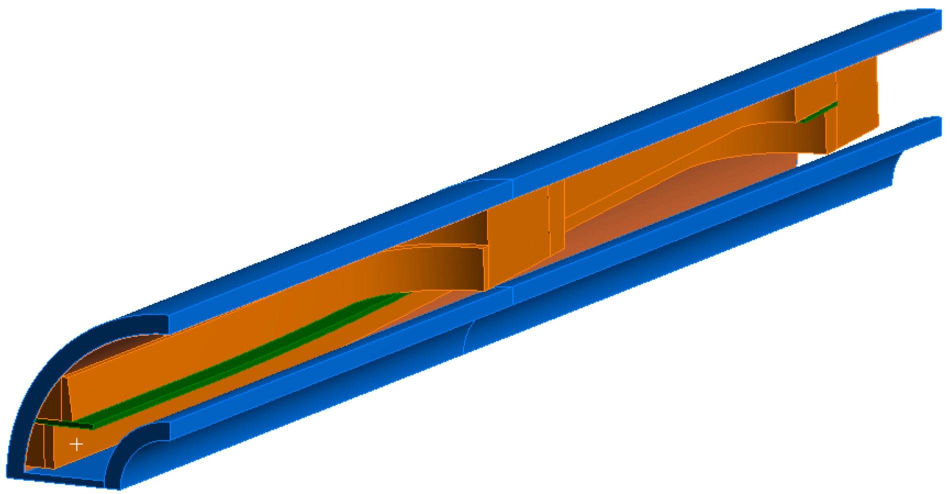


17.7.2015 Jaakko Murtomäki

Ordering of element coordinate systems to be able to input Orthotropic material property data.

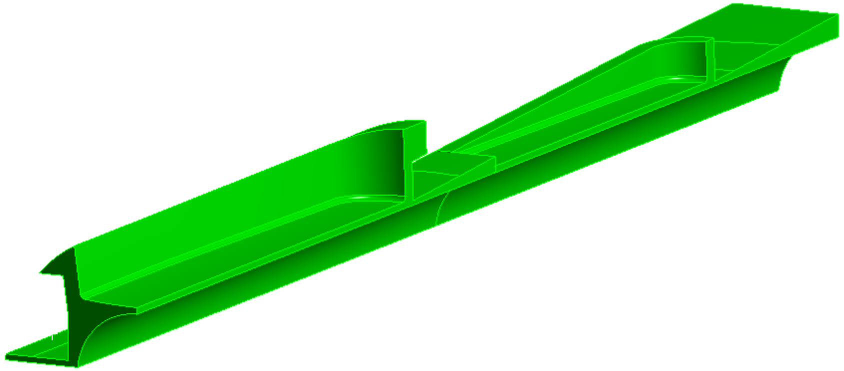
Allow coil to move with respect to copper spacers.

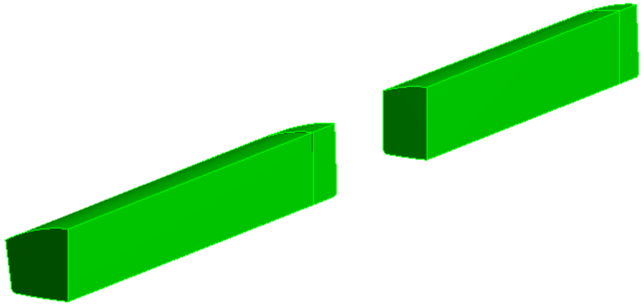


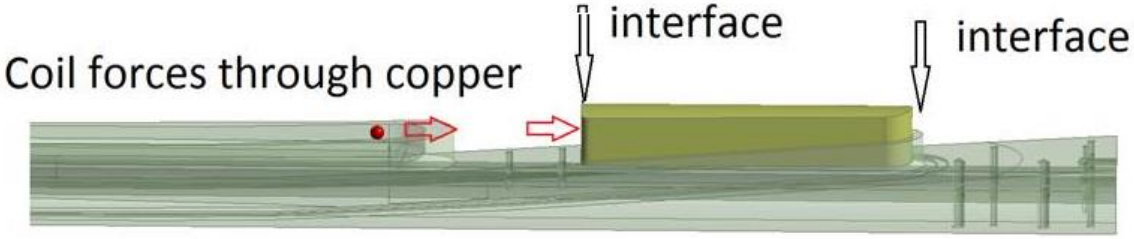


Impregnation and mould release

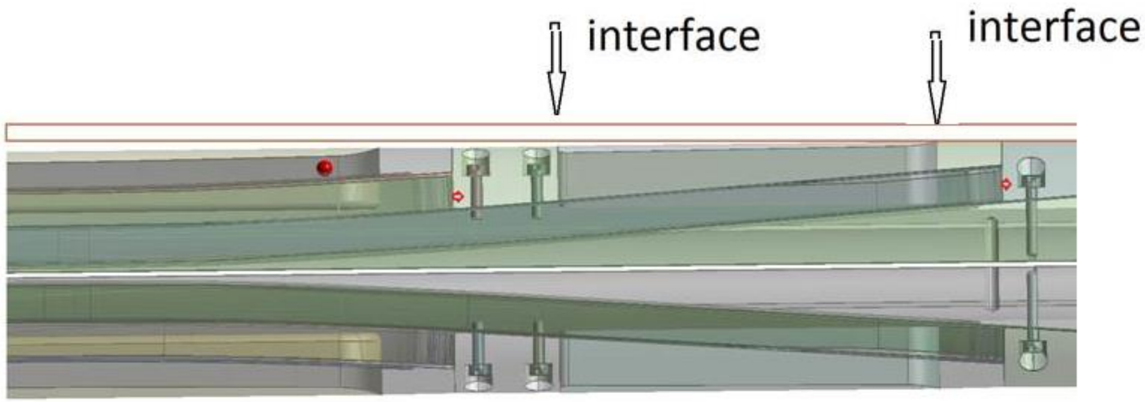
Kapton is allowed to extend longitudinally and azimuthally
Radially has the normal E modulus

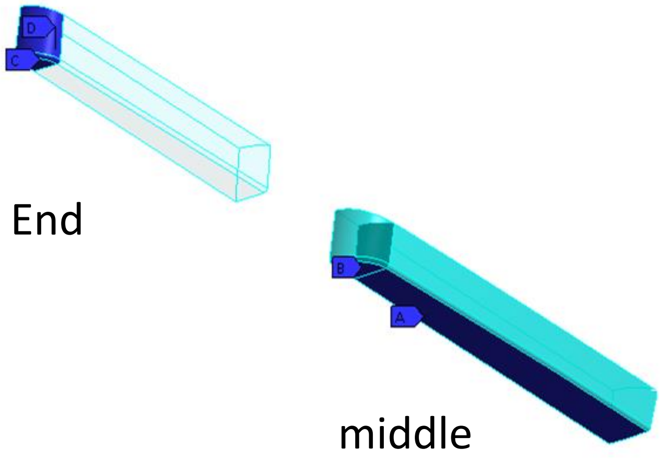


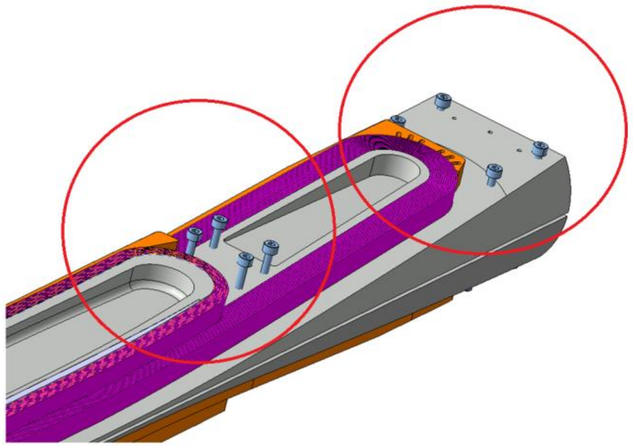


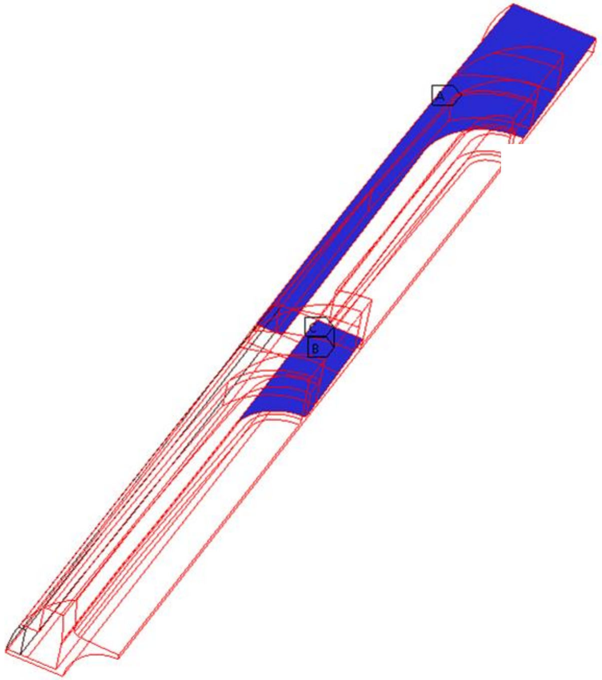


restriction: it only works if the parts fit tightly together!





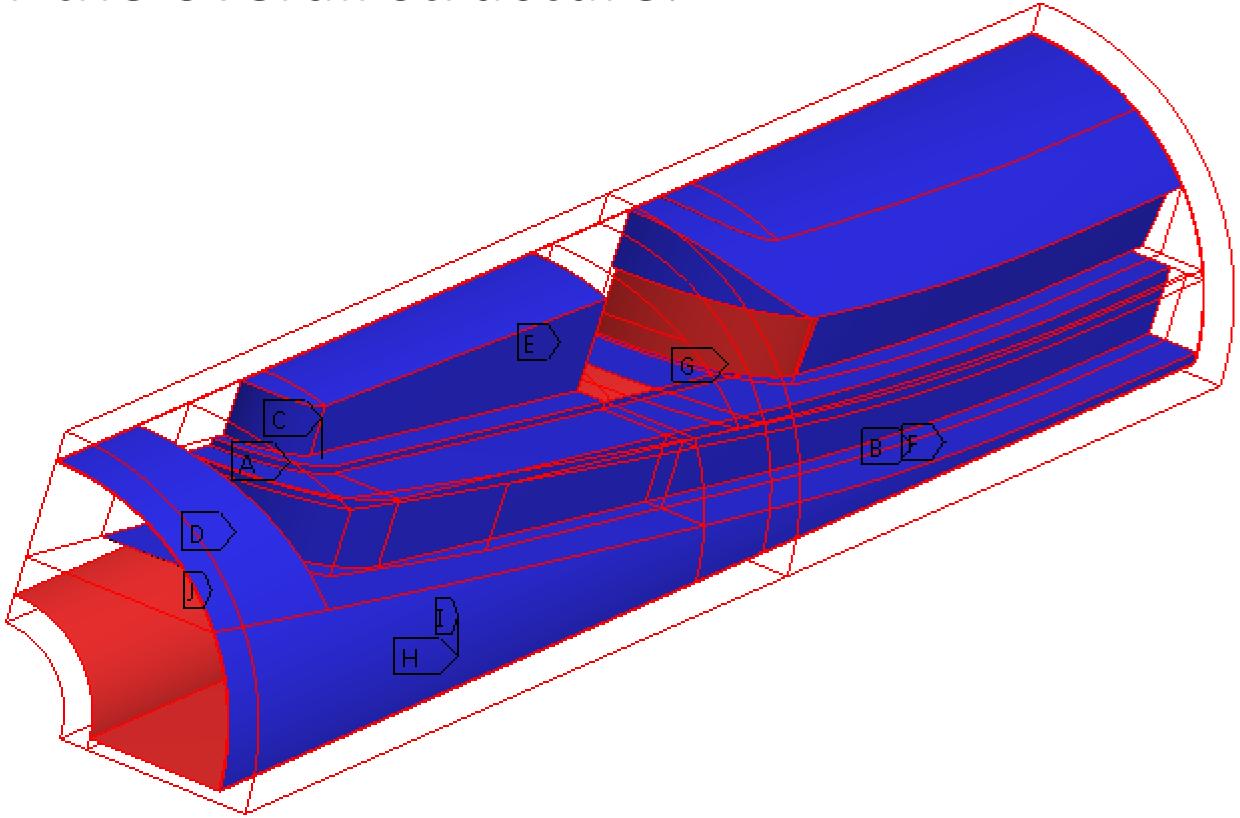




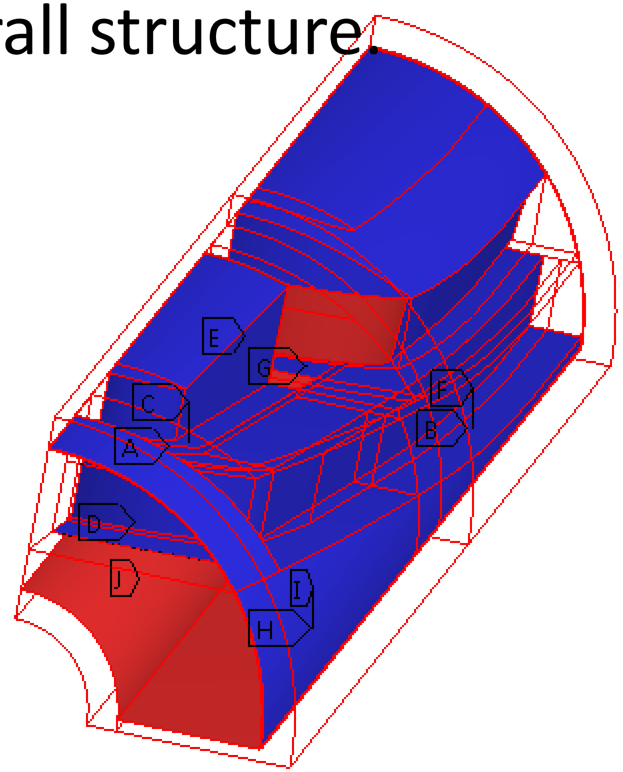
Screws assumed to provide enough friction

And one G11 layer forgotten away between
Copper and former on purpose

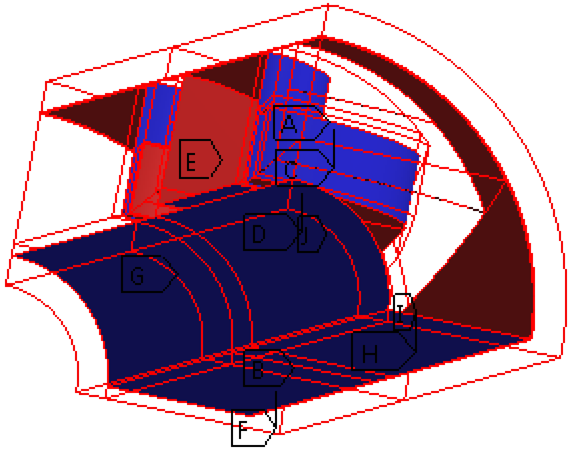
mould release and iron poles not giving more rigidity for the overall structure.



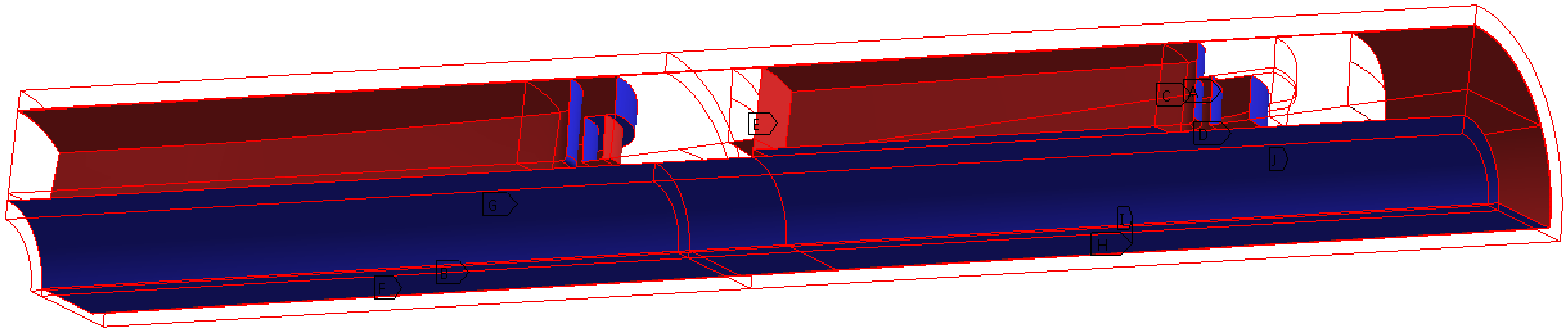
mould release and iron poles not giving more rigidity for the overall structure.



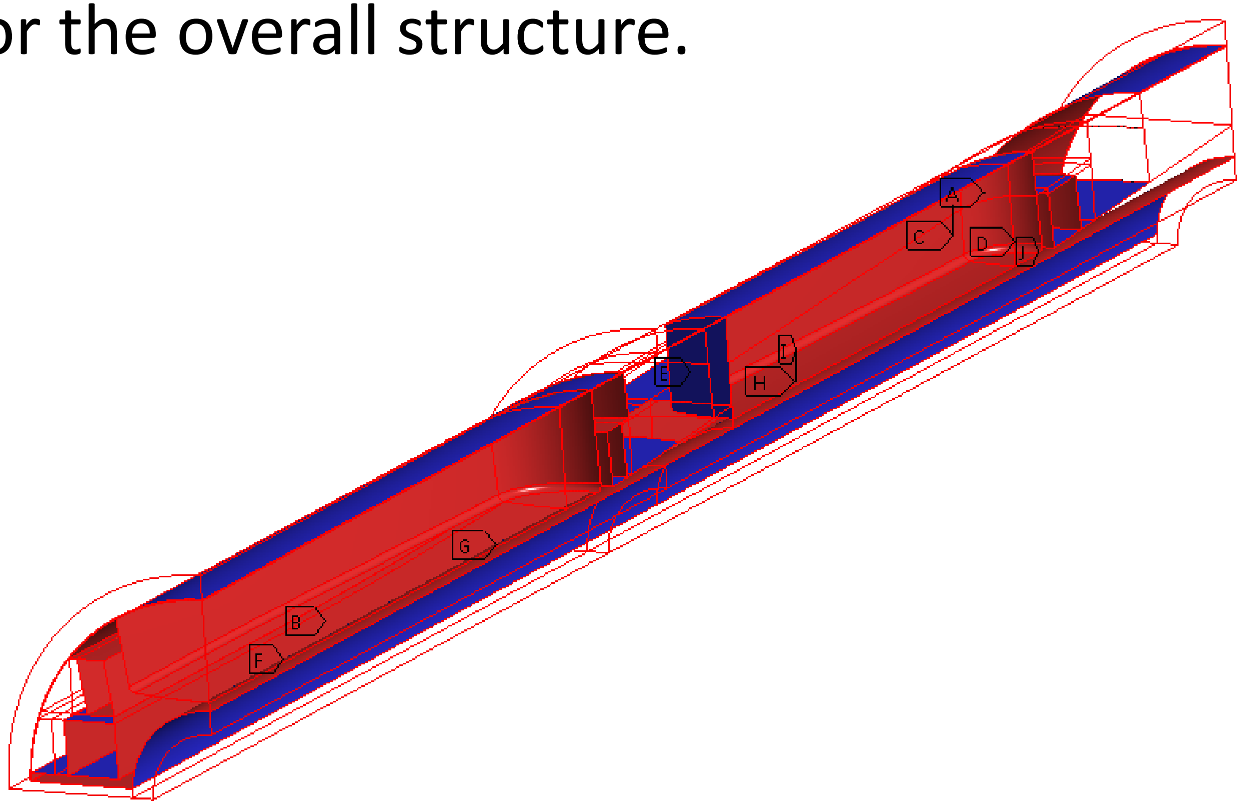
mould release and iron poles not giving more rigidity for the overall structure.



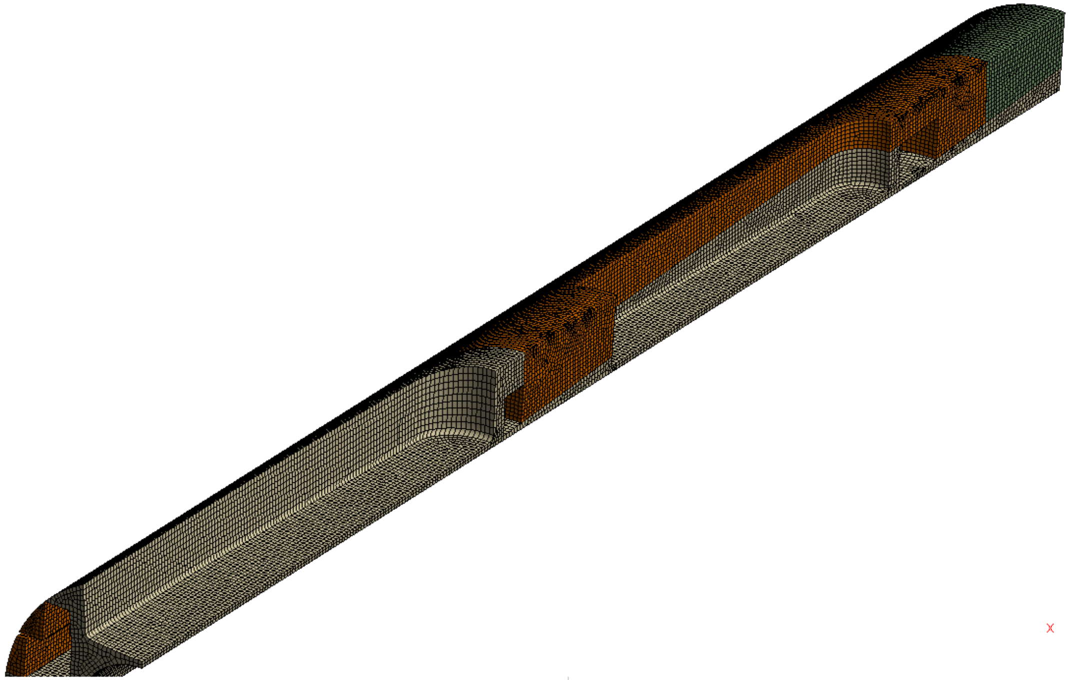
mould release and iron poles not giving more rigidity for the overall structure.

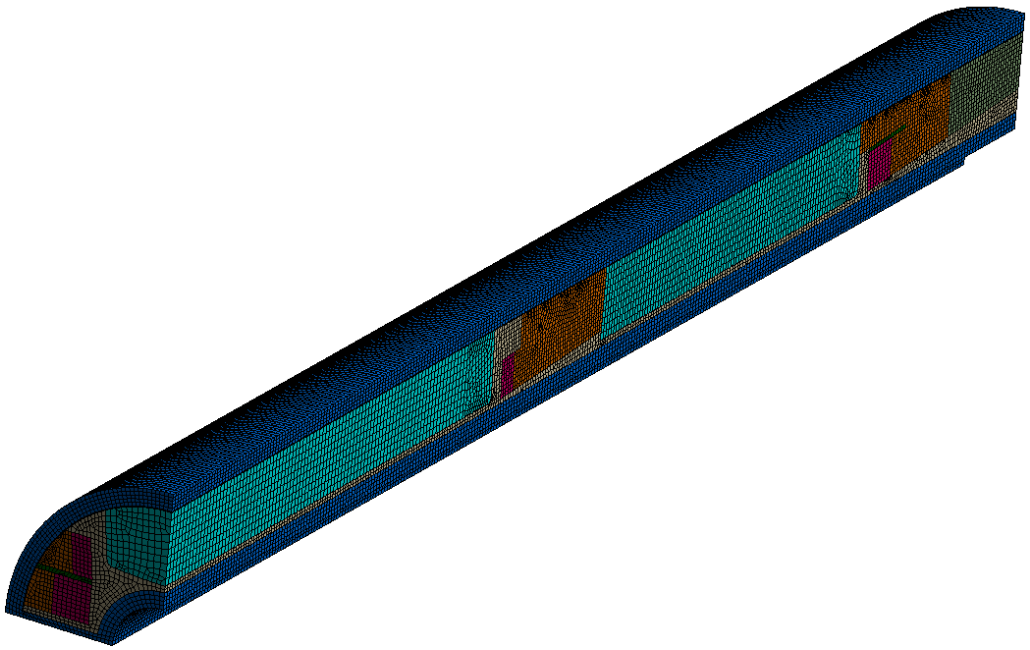


mould release and iron poles not giving more rigidity for the overall structure.

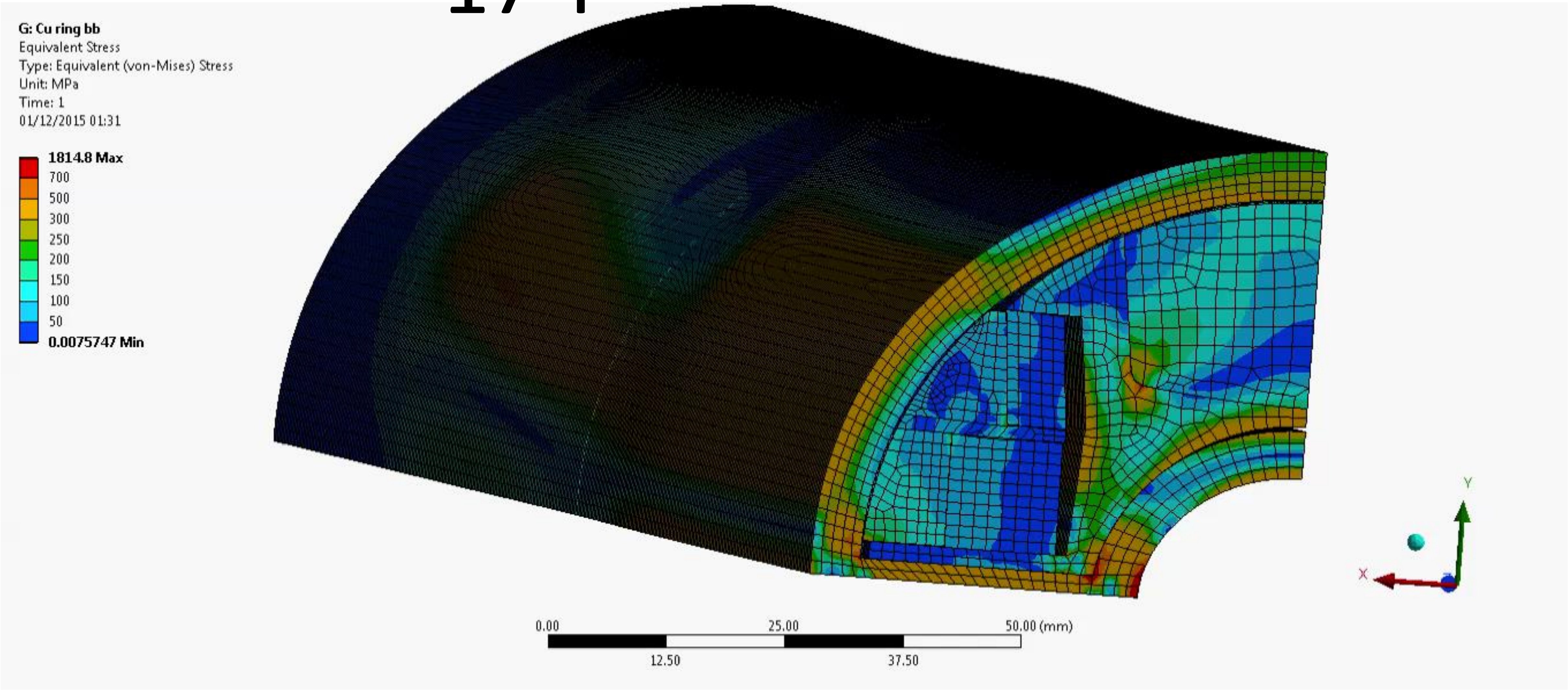


Heavy meshing required, in order of few millions of nodes



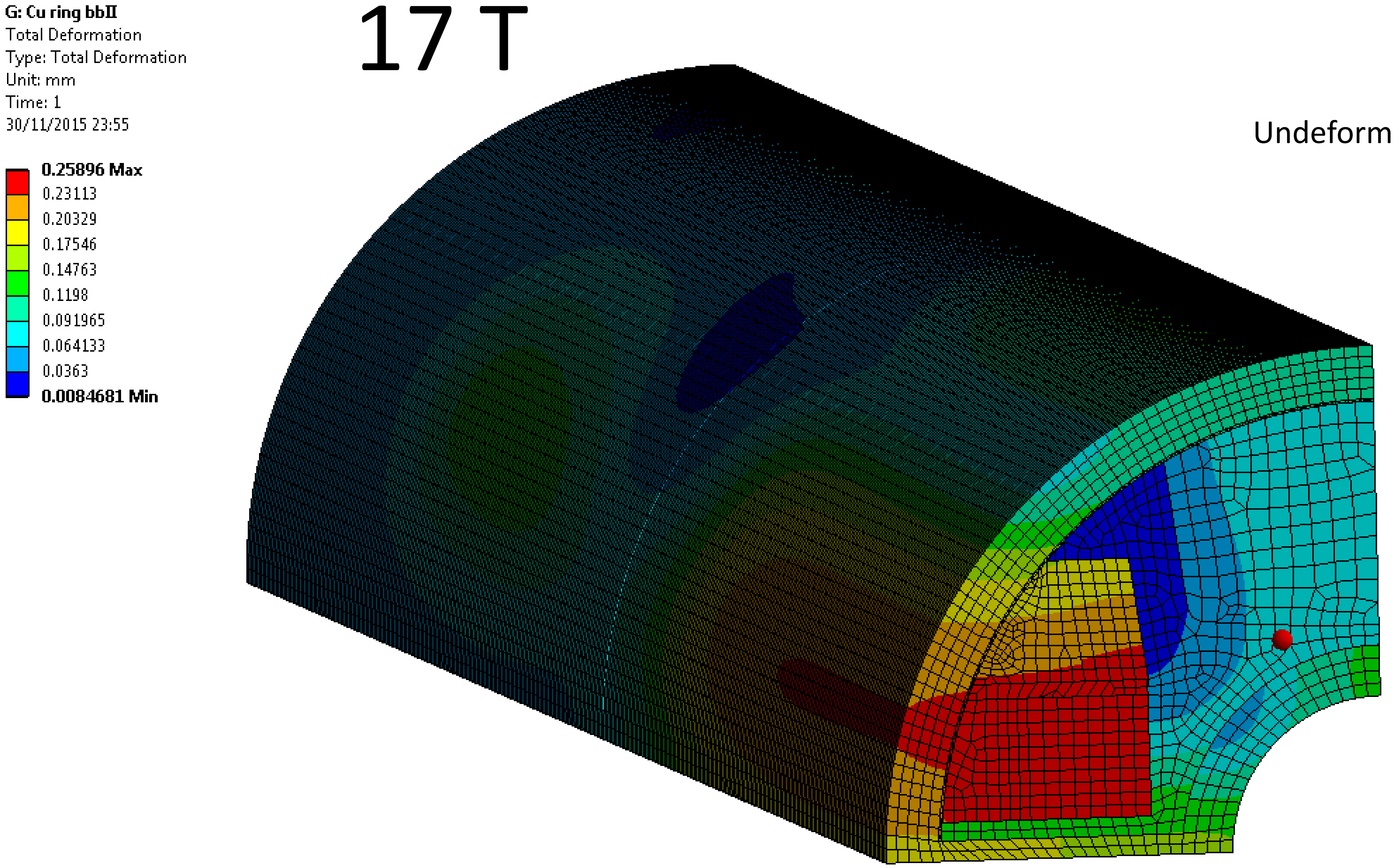


17 T

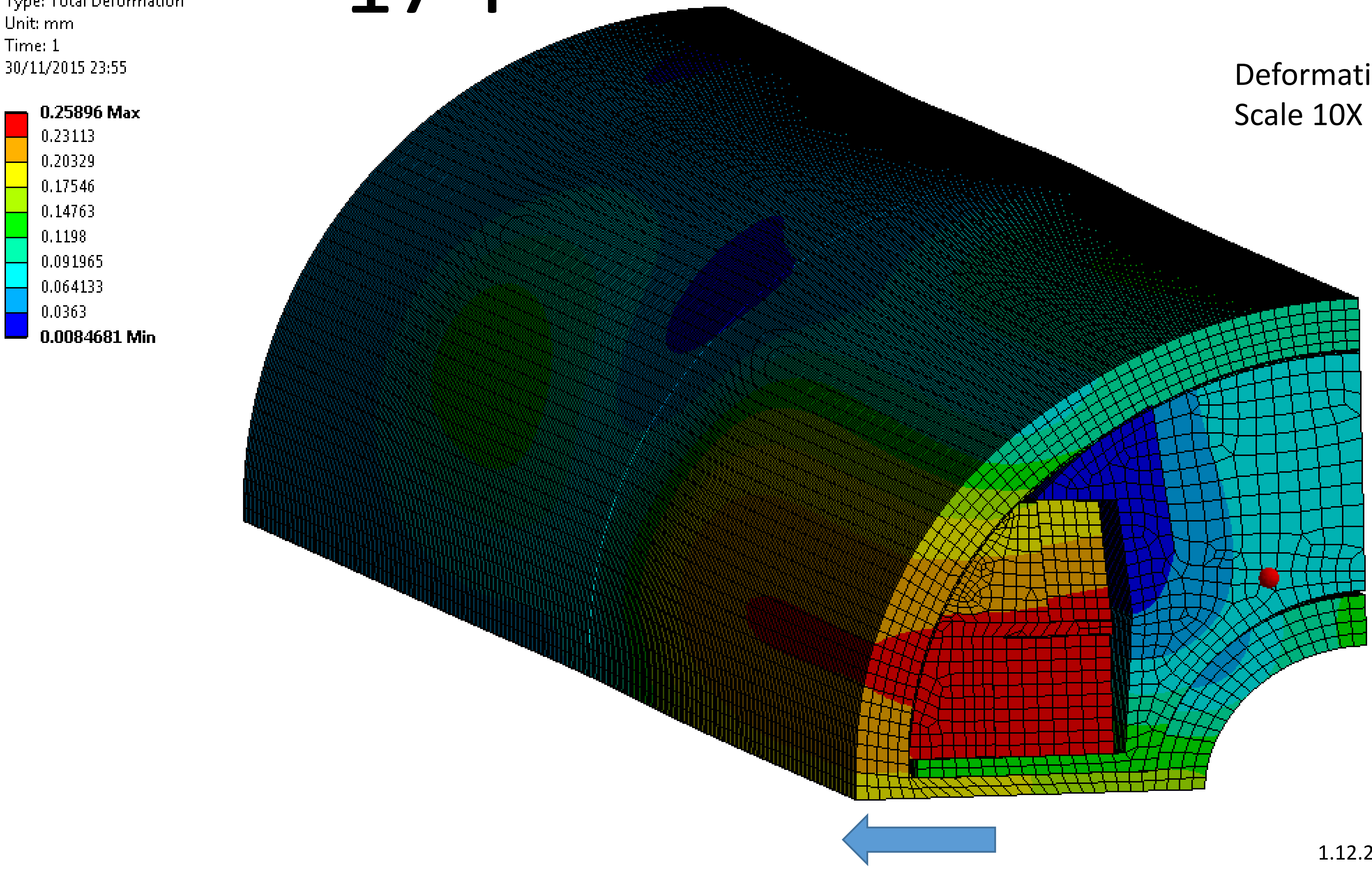

G: Cu ring bb
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
01/12/2015 01:31
1814.8 Max
700
500
300
250
200
150
100
50
0.0075747 Min
0.00
25.00
50.00 (mm)
12.50
37.50
Y
X

17 T

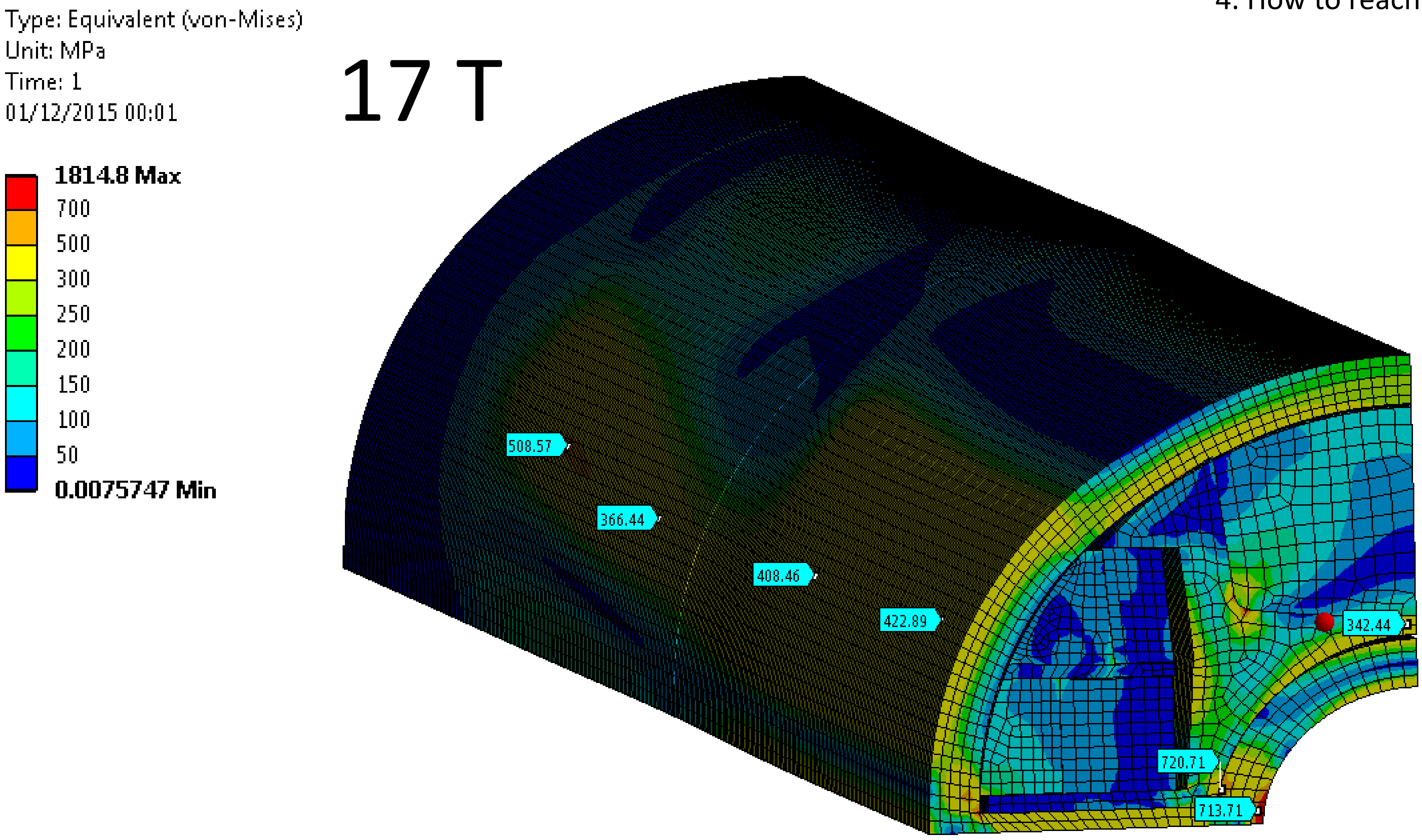
Undeformed

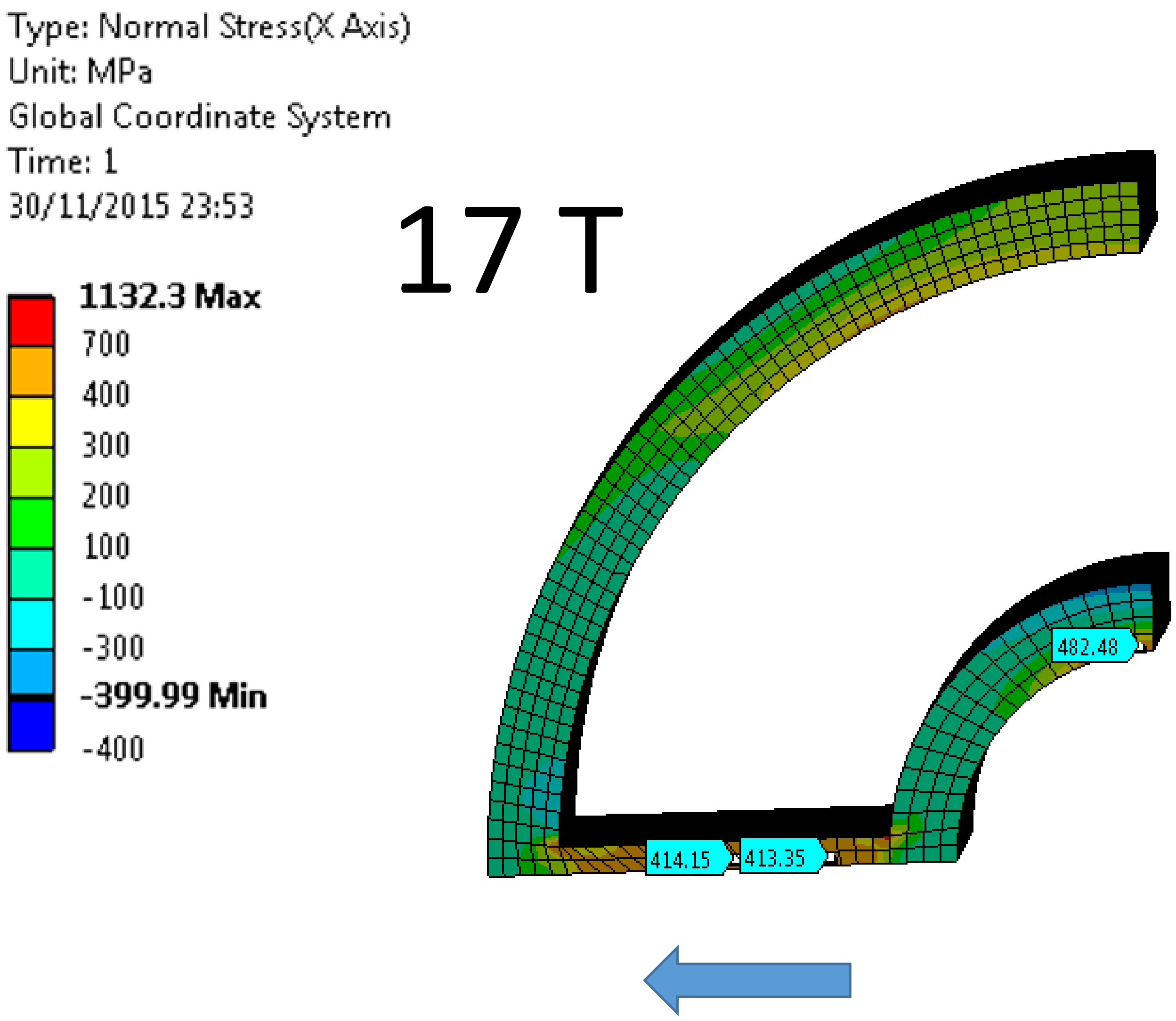


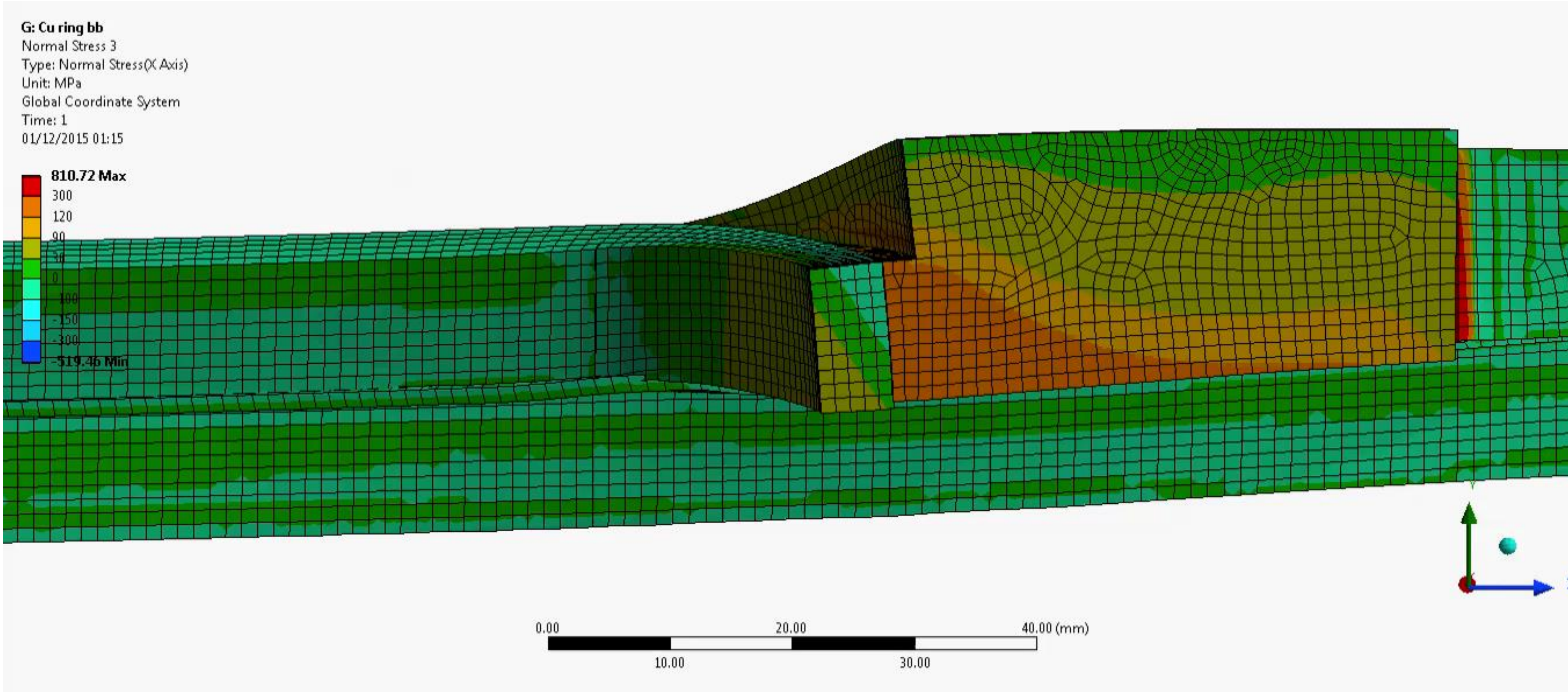
17 T



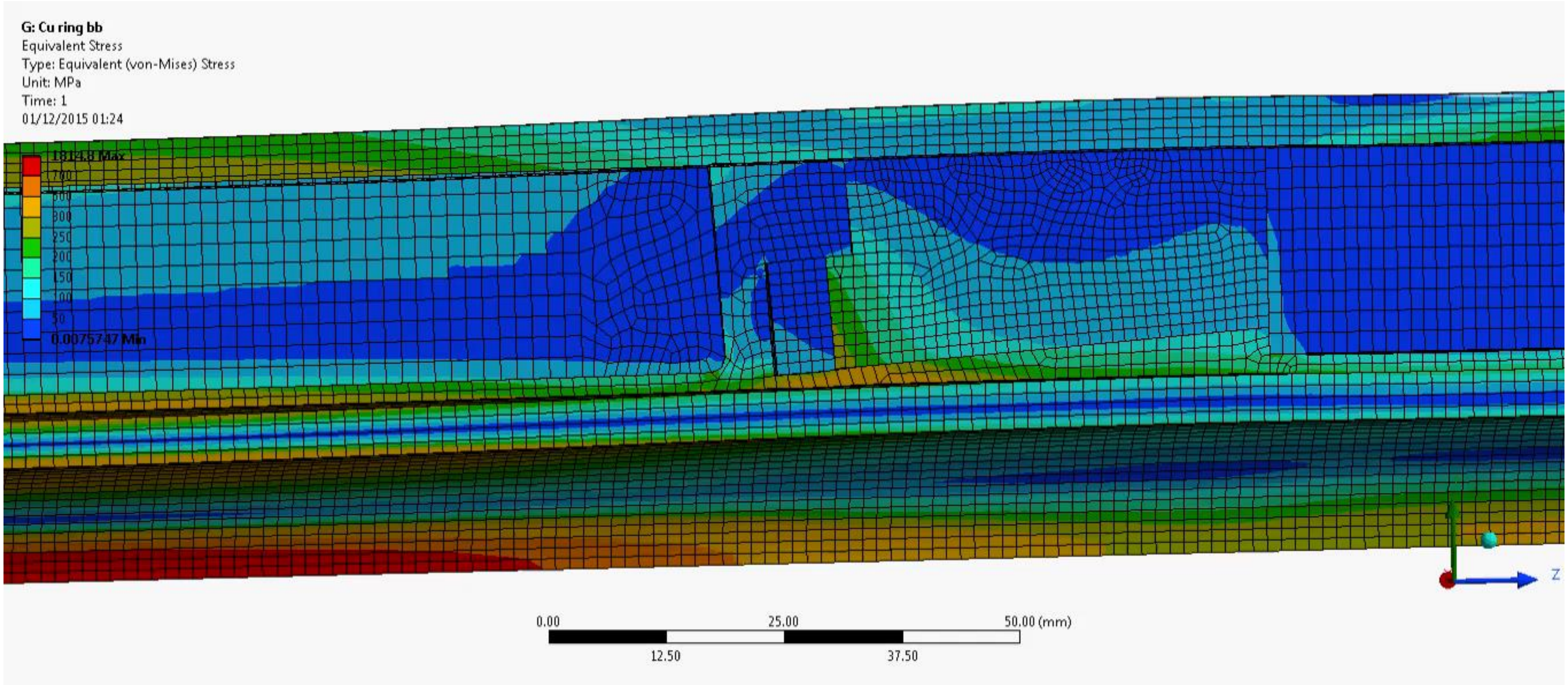
Deformation
Scale 10X


Type: Equivalent (von-Mises)
Unit: MPa
Time: 1
01/12/2015 00:01
17 T
1814.8 Max
700
500
300
250
200
150
100
50
0.0075747 Min
508.57
366.44
408.46
422.89
342.44
720.71
713.71

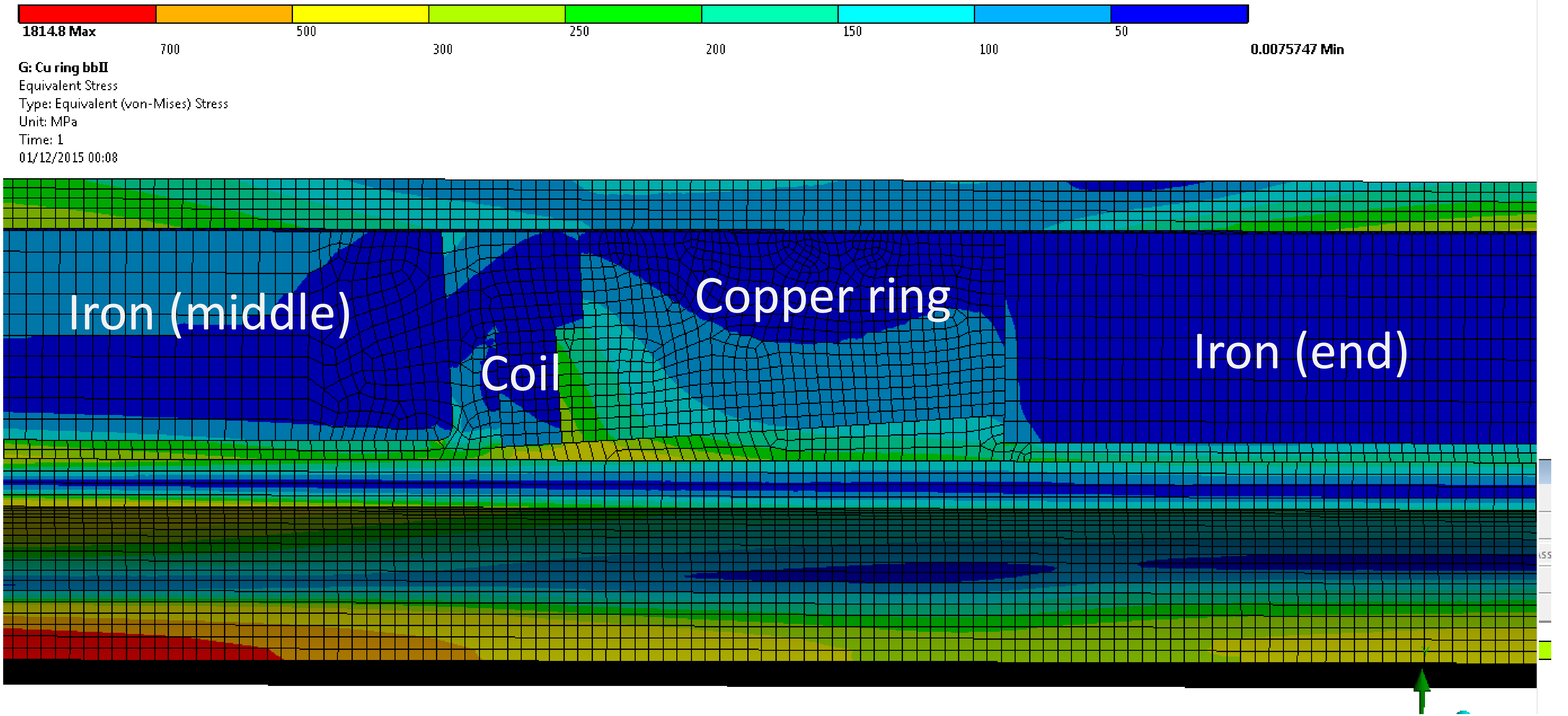

Type: Normal Stress(X Axis)
Unit: MPa
Global Coordinate System
Time: 1
30/11/2015 23:53
1132.3 Max
700
400
300
200
100
-100
-300
-399.99 Min
-400
17 T
482.48
414.15
413.35



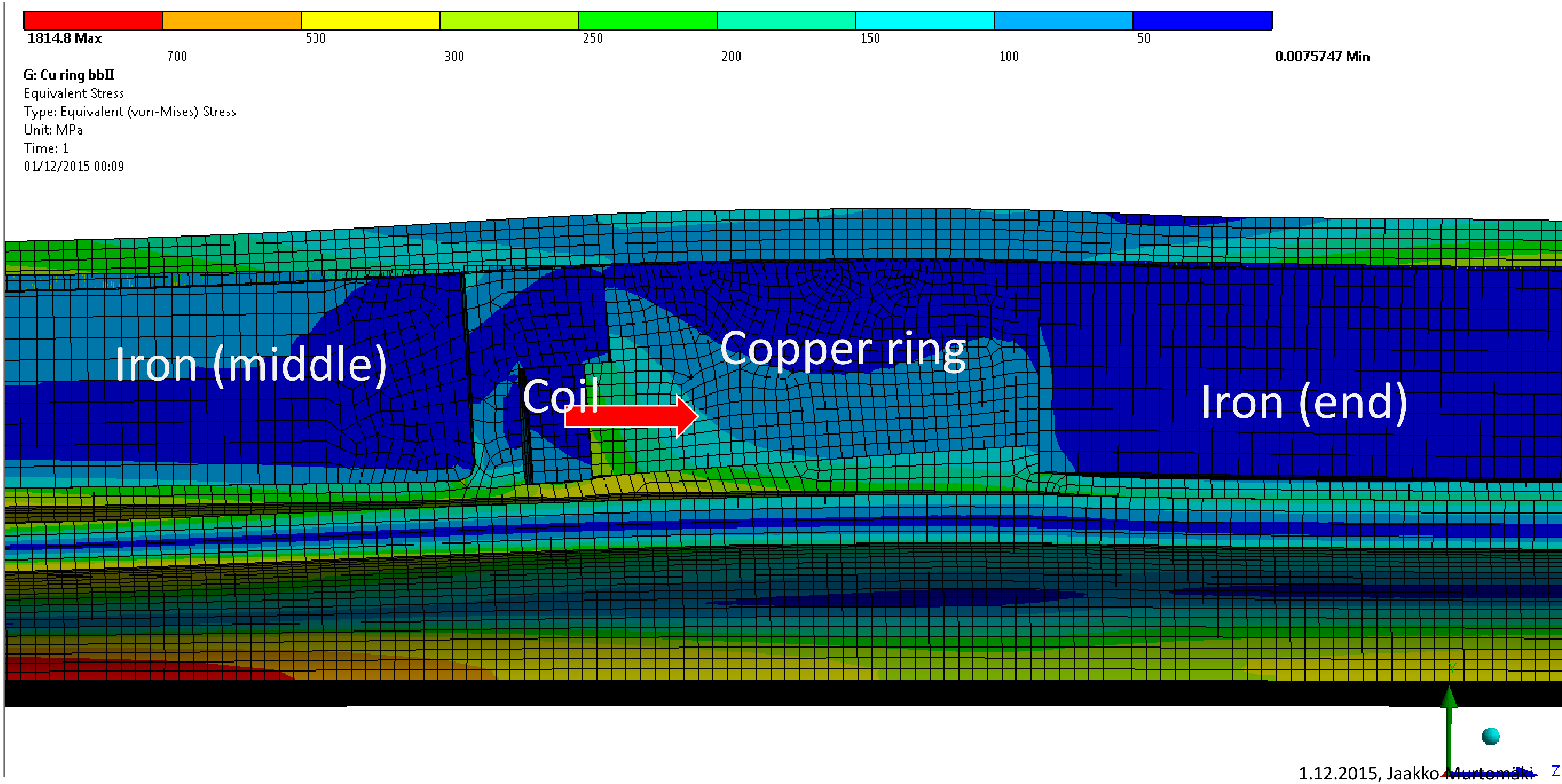
1.12.2015, Jaakko Murtomäki



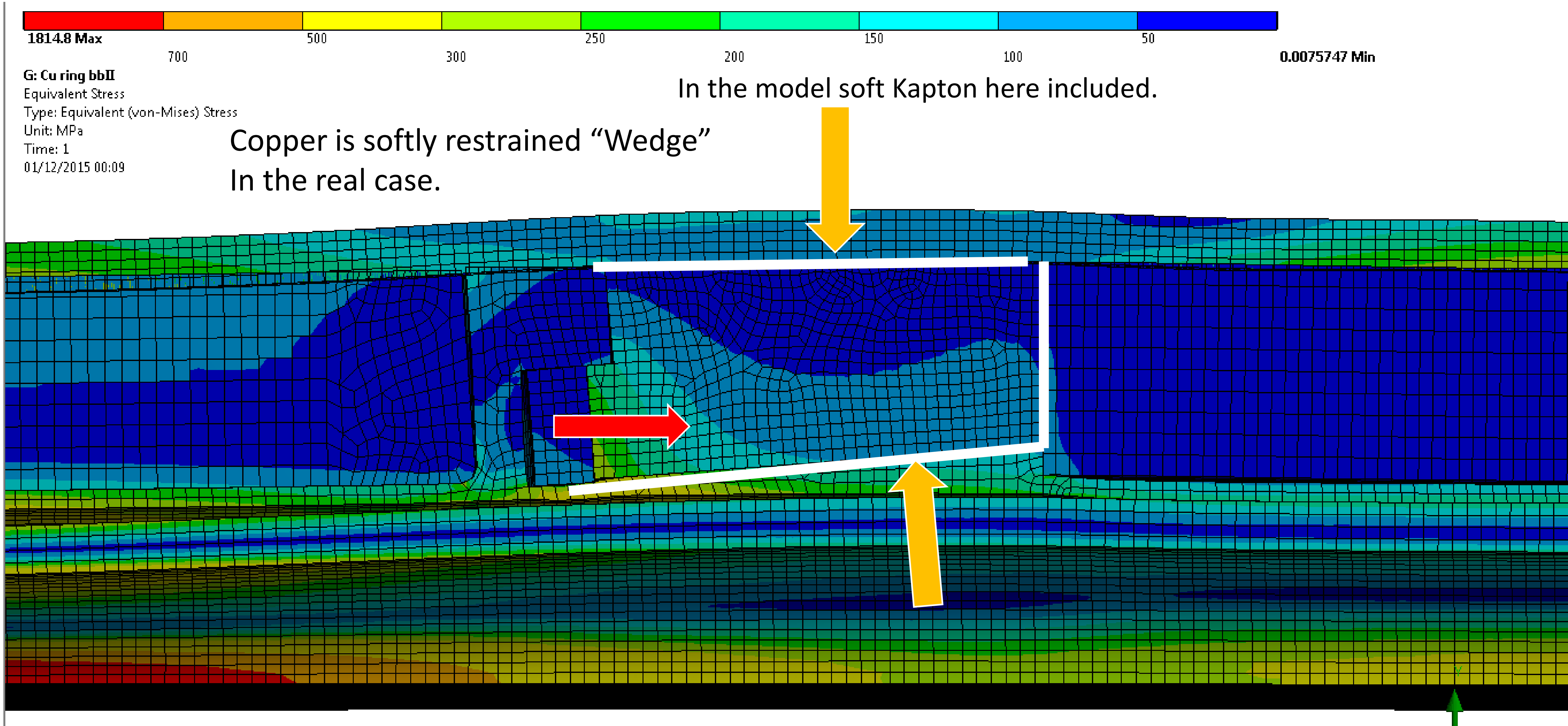
1.12.2015, Jaakko Murtomäki



1814.8 Max
700
500
300
250
200
150
100
50
0.0075747 Min
G: Cu ring bbII
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
01/12/2015 00:08
Iron (middle)
Coil
Copper ring
Iron (end)

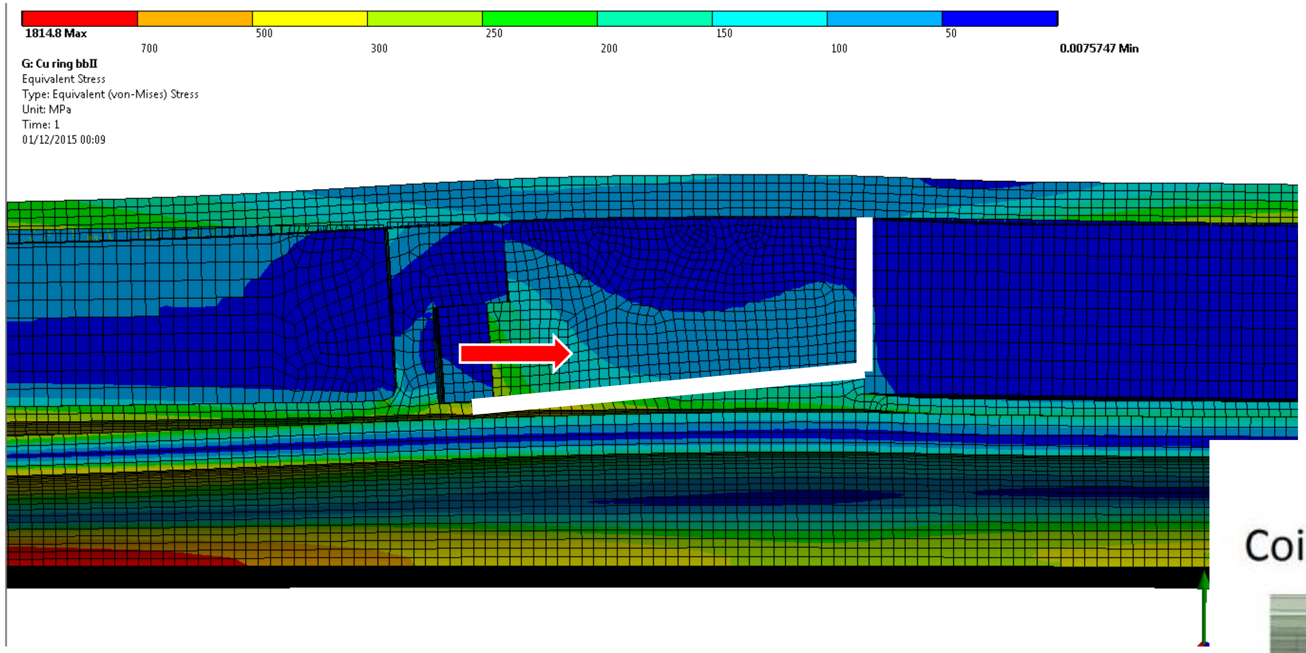


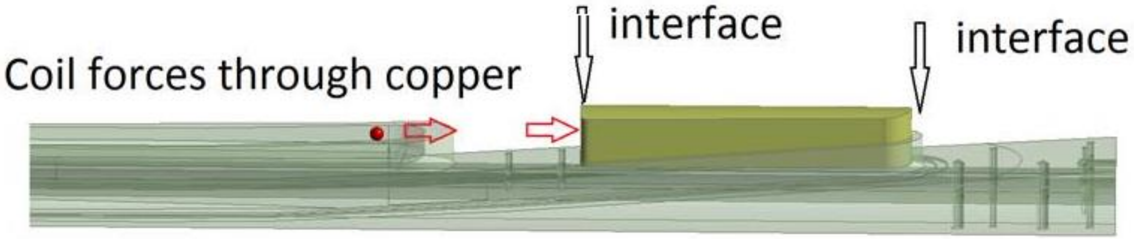
1814.8 Max
700
500
300
250
200
150
100
50
0.0075747 Min
G: Cu ring bbII
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
01/12/2015 00:09
Iron (middle)
Coil
Copper ring
Iron (end)



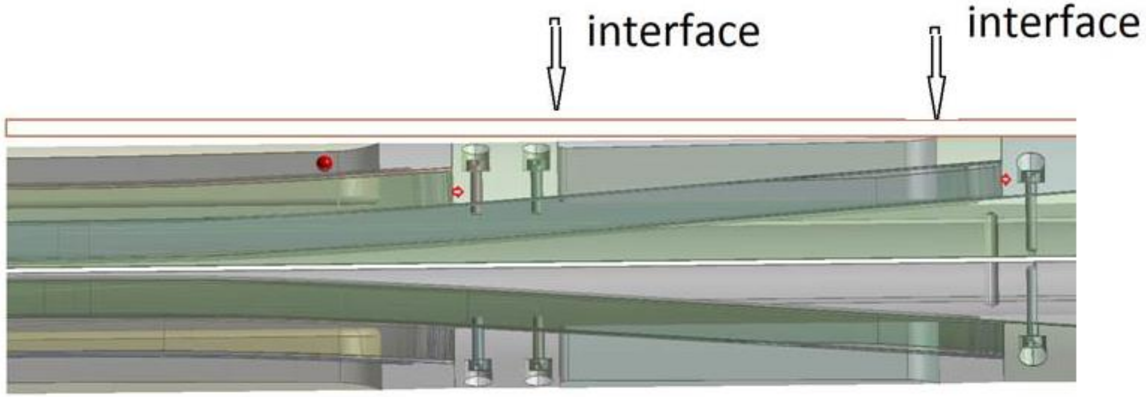
1.12.2015, Jaakko Murtomäki

How to support coil ends



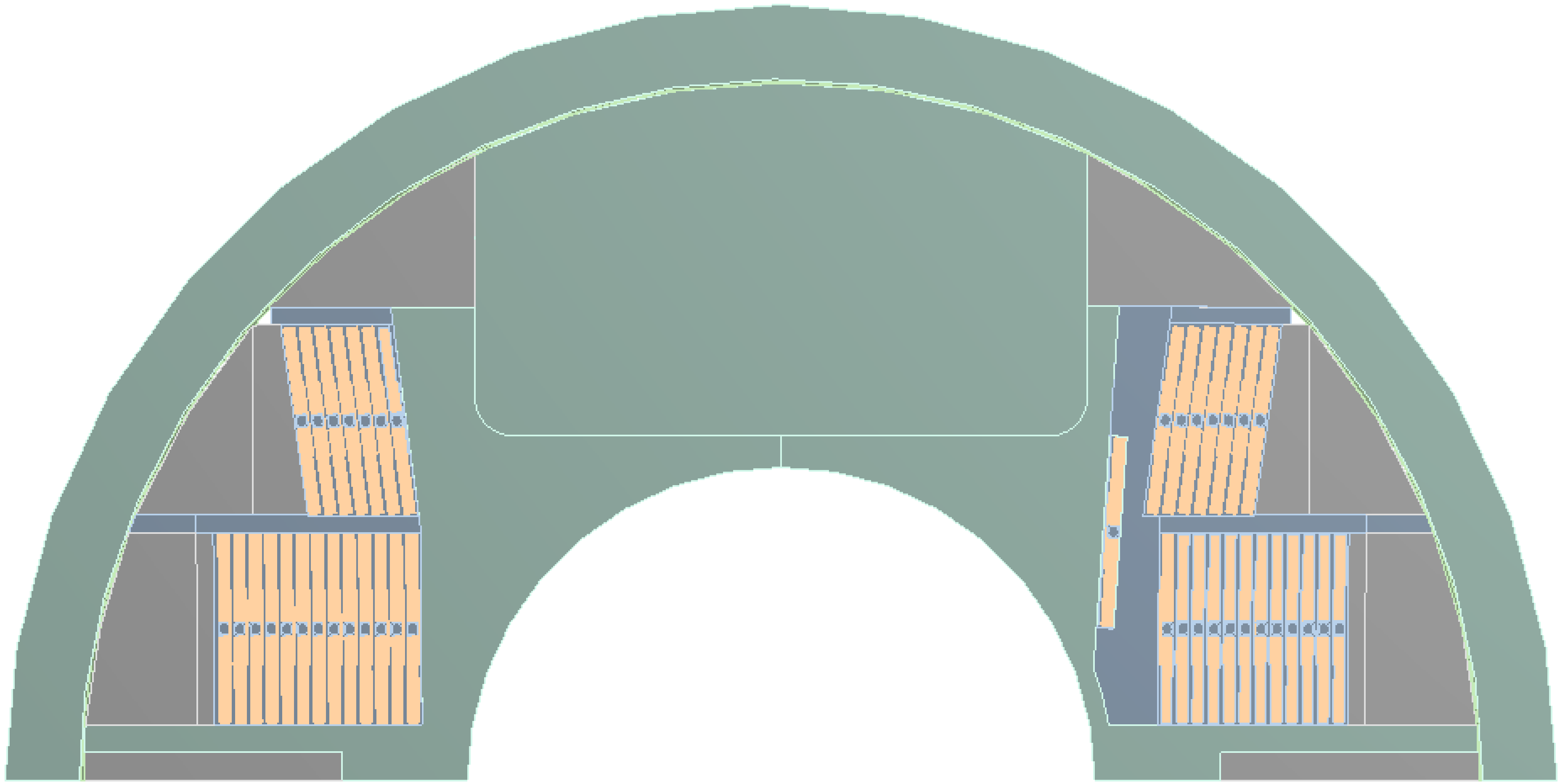


restriction: it only works if the parts fit tightly together!

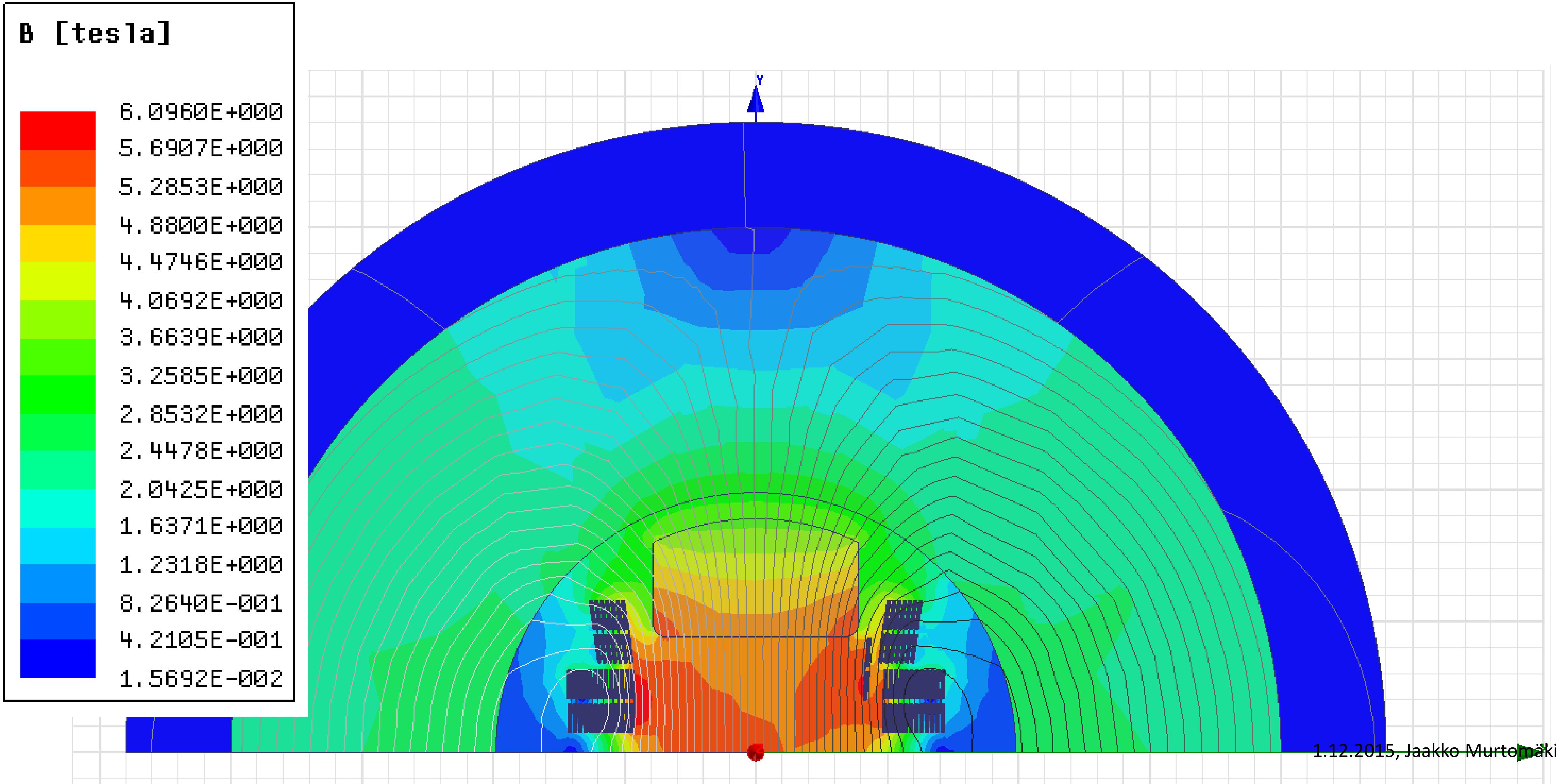


Take the forces to former through iron. Rigid metal to metal contact.

FEATHER M2 2D Configuration, Stand-alone, 9kA ≈ 5 T in the bore

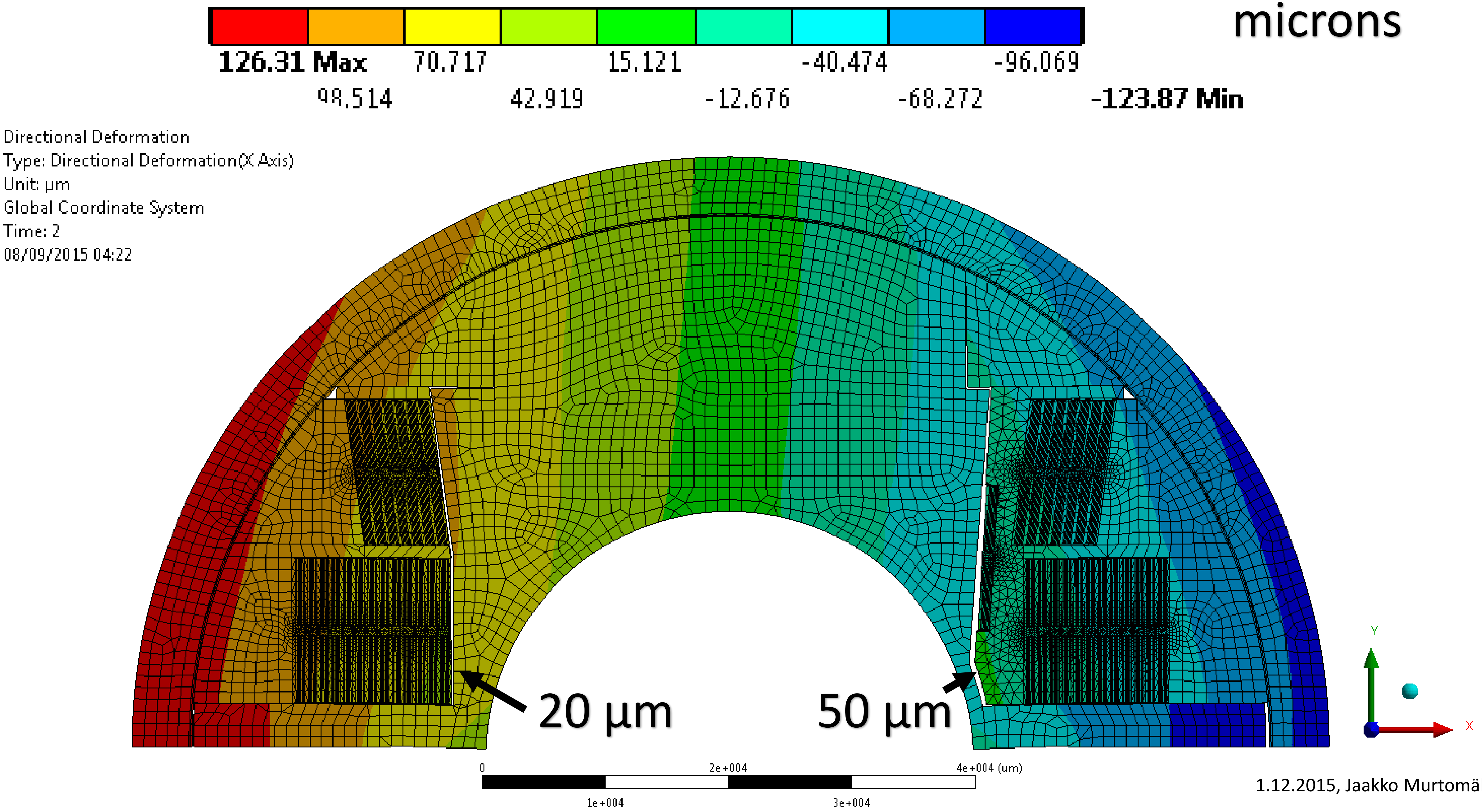


FEATHER M2 2D B-Field, Stand-alone, 9kA ≈ 5 T in the bore

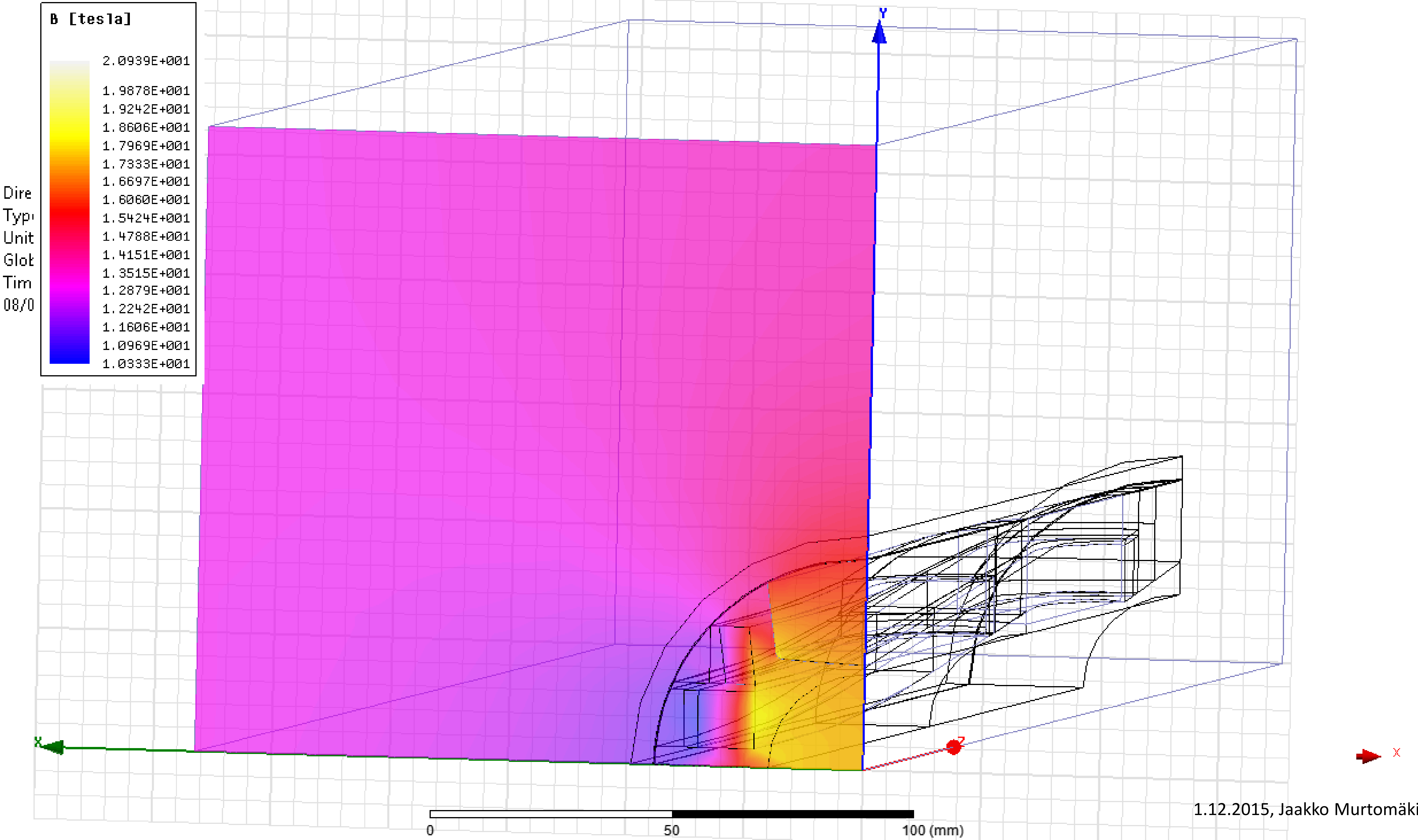


1.12.2015, Jaakko Murtomäki

FEATHER M2 2D deformation X-axis, Stand-alone, Cool down to powering 9kA ≈ 5 T in the bore

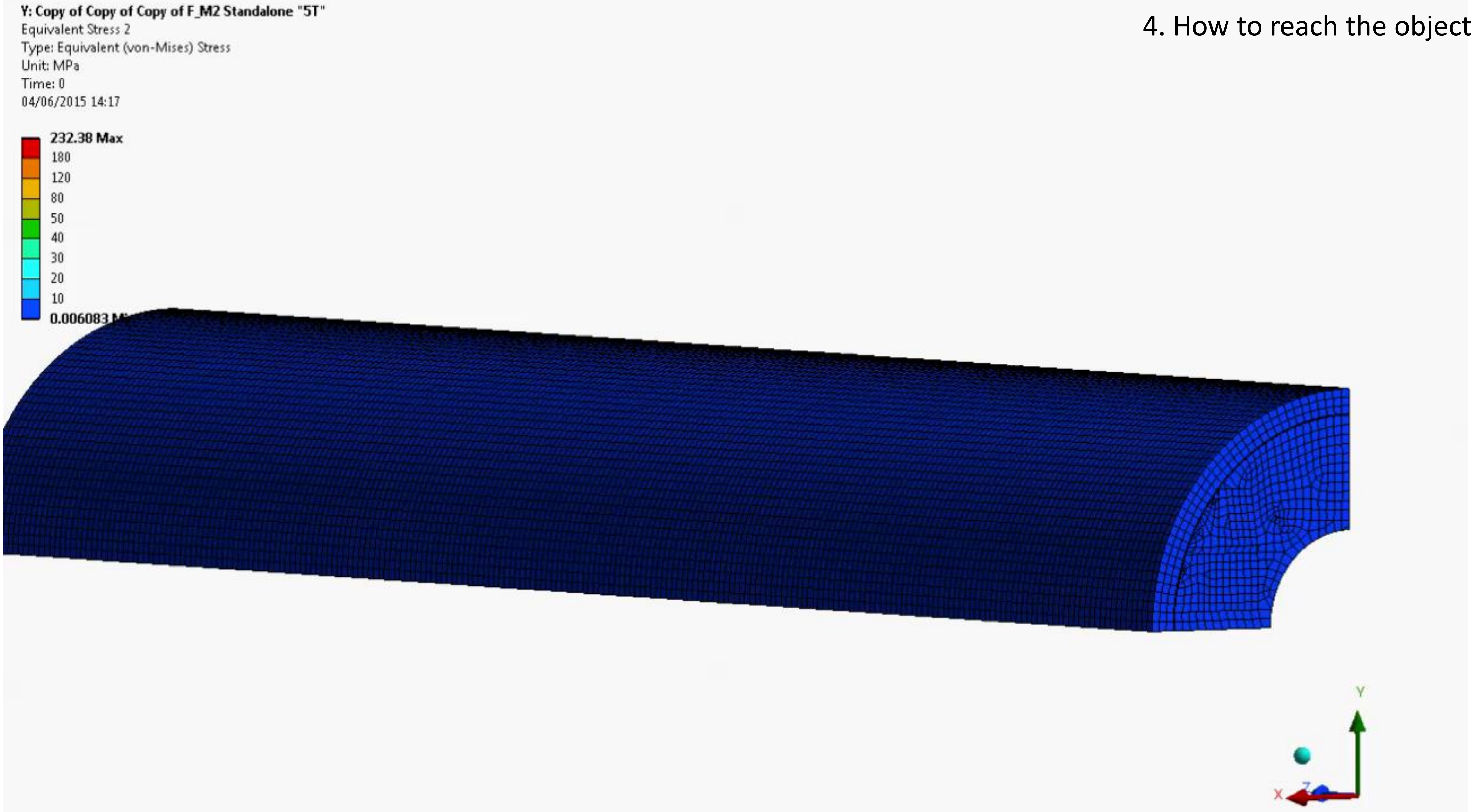


1.12.2015, Jaakko Murtomäki

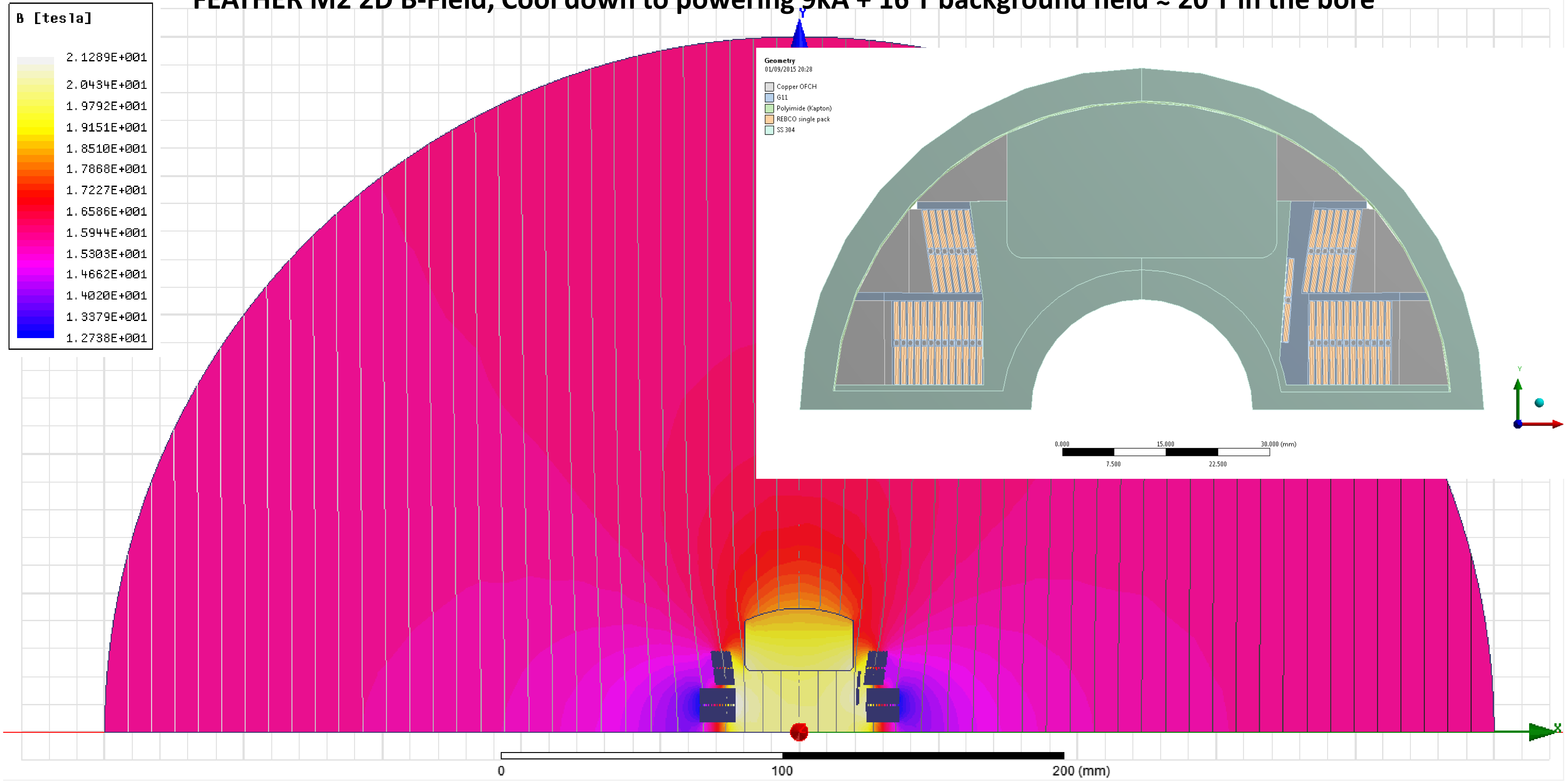


1.12.2015, Jaakko Murtomäki

4. How to reach the objectives?

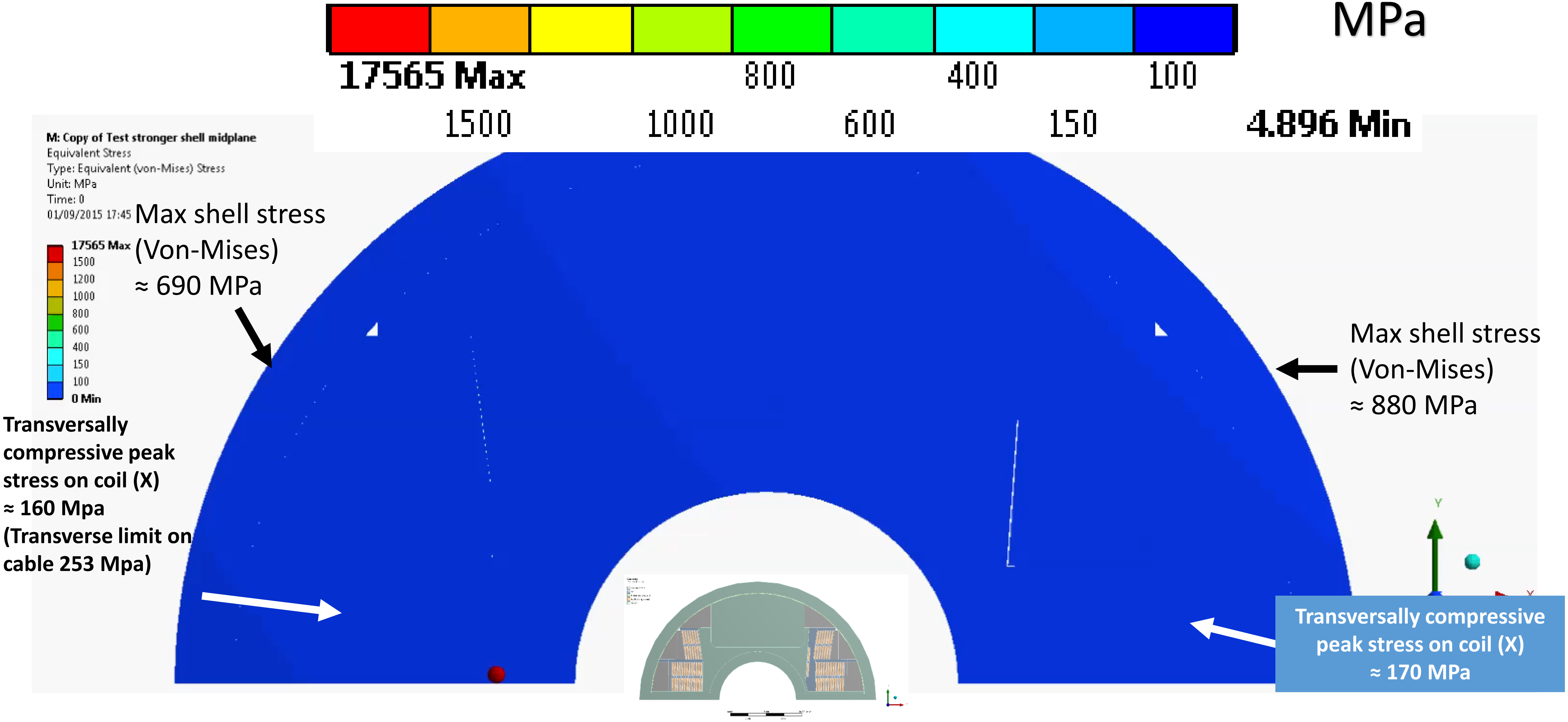


FEATHER M2 2D B-Field, Cool down to powering 9kA + 16 T background field ≈ 20 T in the bore



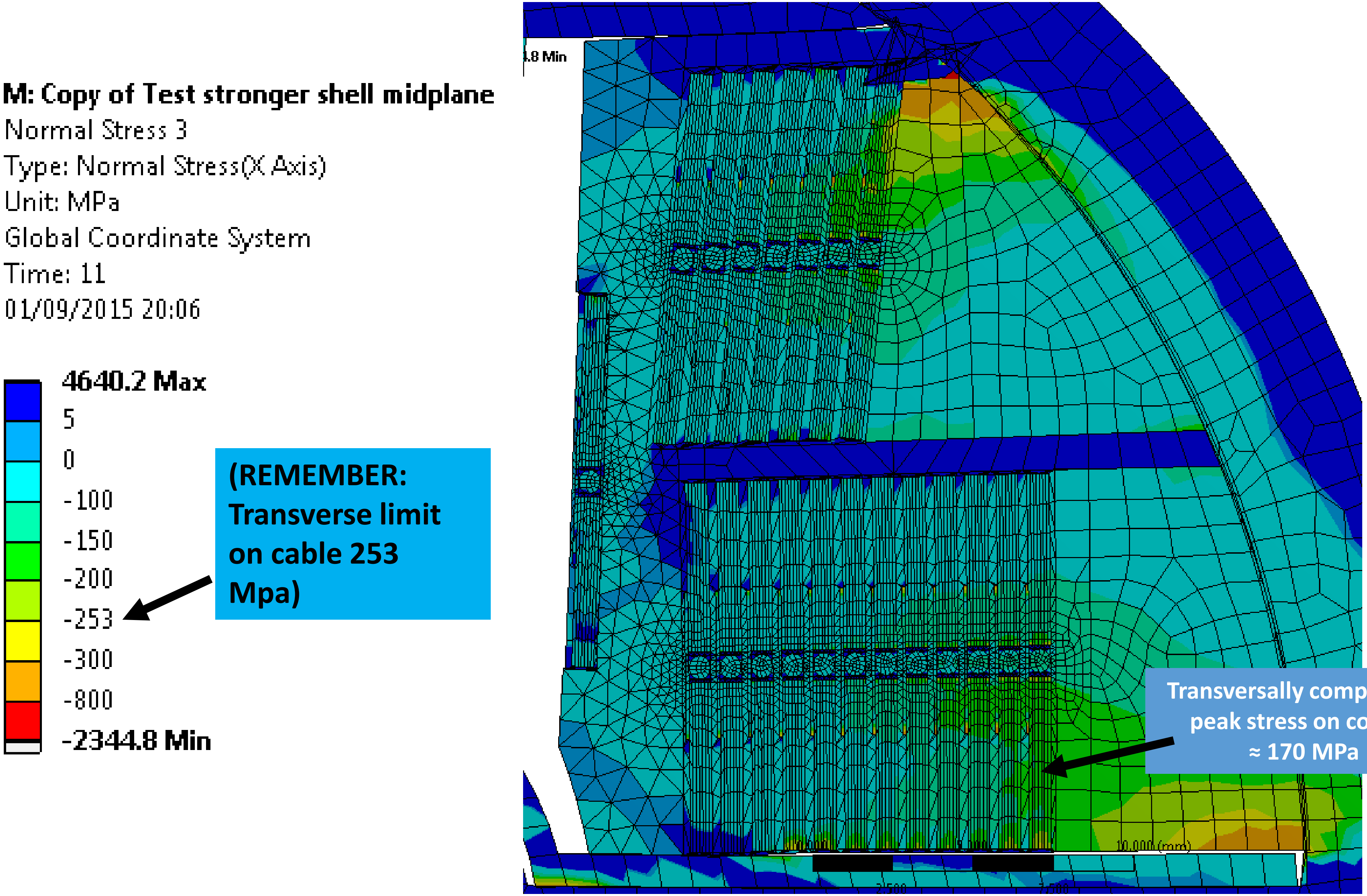
1.12.2015, Jaakko Murtomäki

FEATHER M2 2D Von-Mises video plot, Cool down to powering 9kA + 16 T background field ≈ 20 T in the bore



CLICK TO PLAY

THE COMPRESSION OF THE COILS IF NEEDED, FOR CHECKING, ALL SHOULD BE OK BY THE WAY!

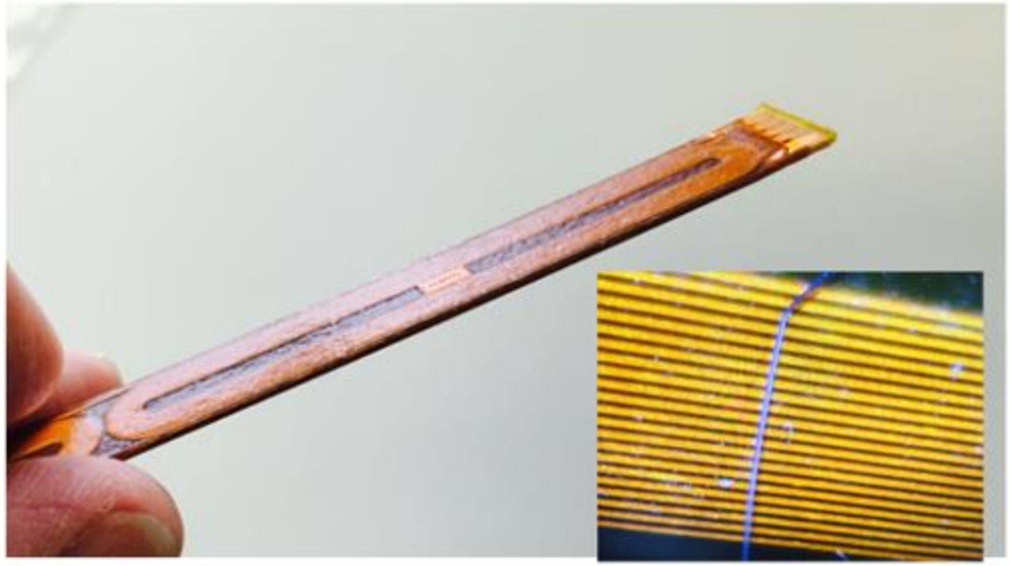


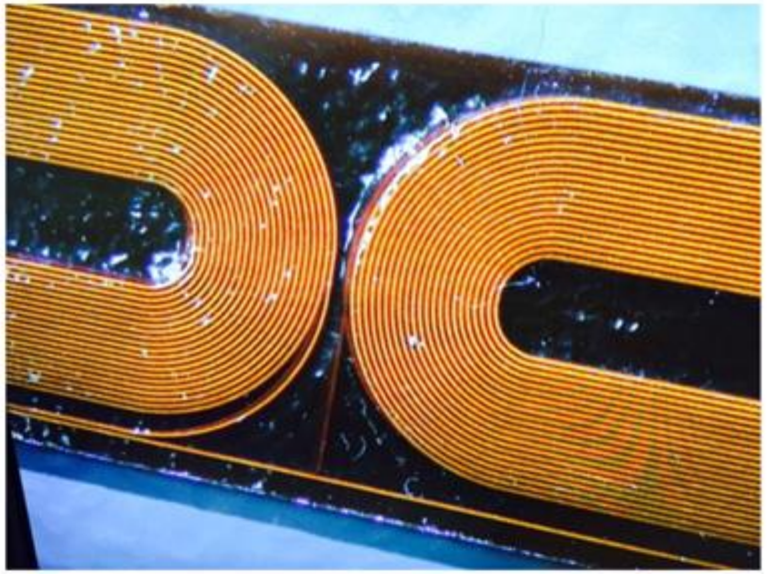
(REMEMBER: Transverse limit on cable 253 Mpa)

Transversally compressive peak stress on coil (X) ≈ 170 MPa

Implementation of the quench detection methods

Pick-up coils have been already manufactured for the Feather magnets (Figure 1, Figure 2). They are based on flexible printed circuit board technology. They are to be installed in the Feather M0 magnet initially and will be tested in January in the first test.





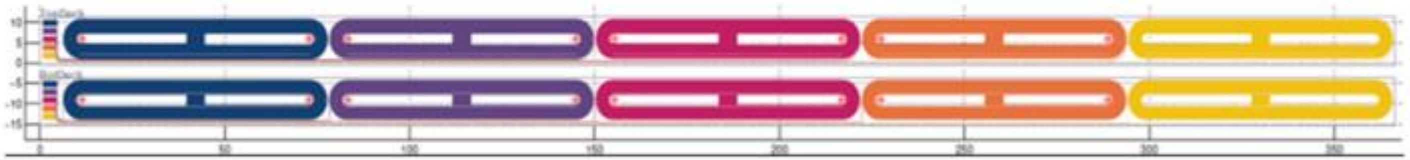


Figure 1 Magnetic pick-up loop array.

Implementation of the quench detection methods

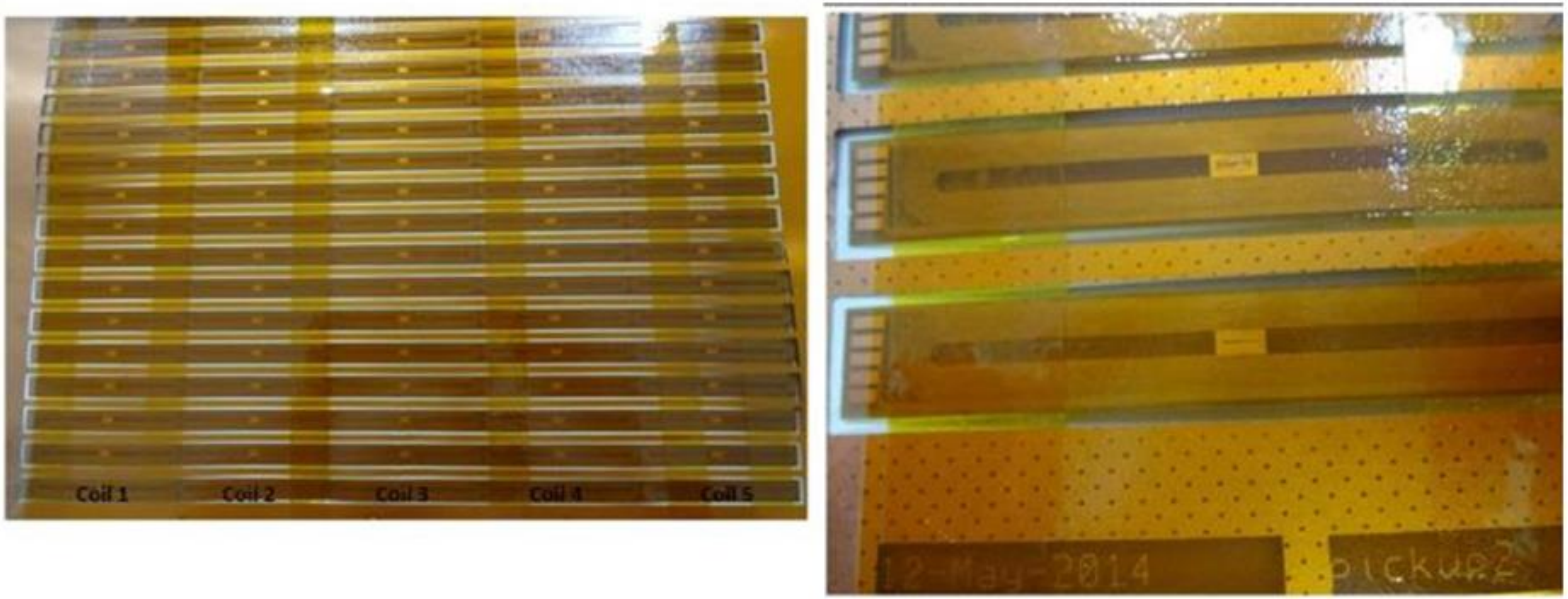
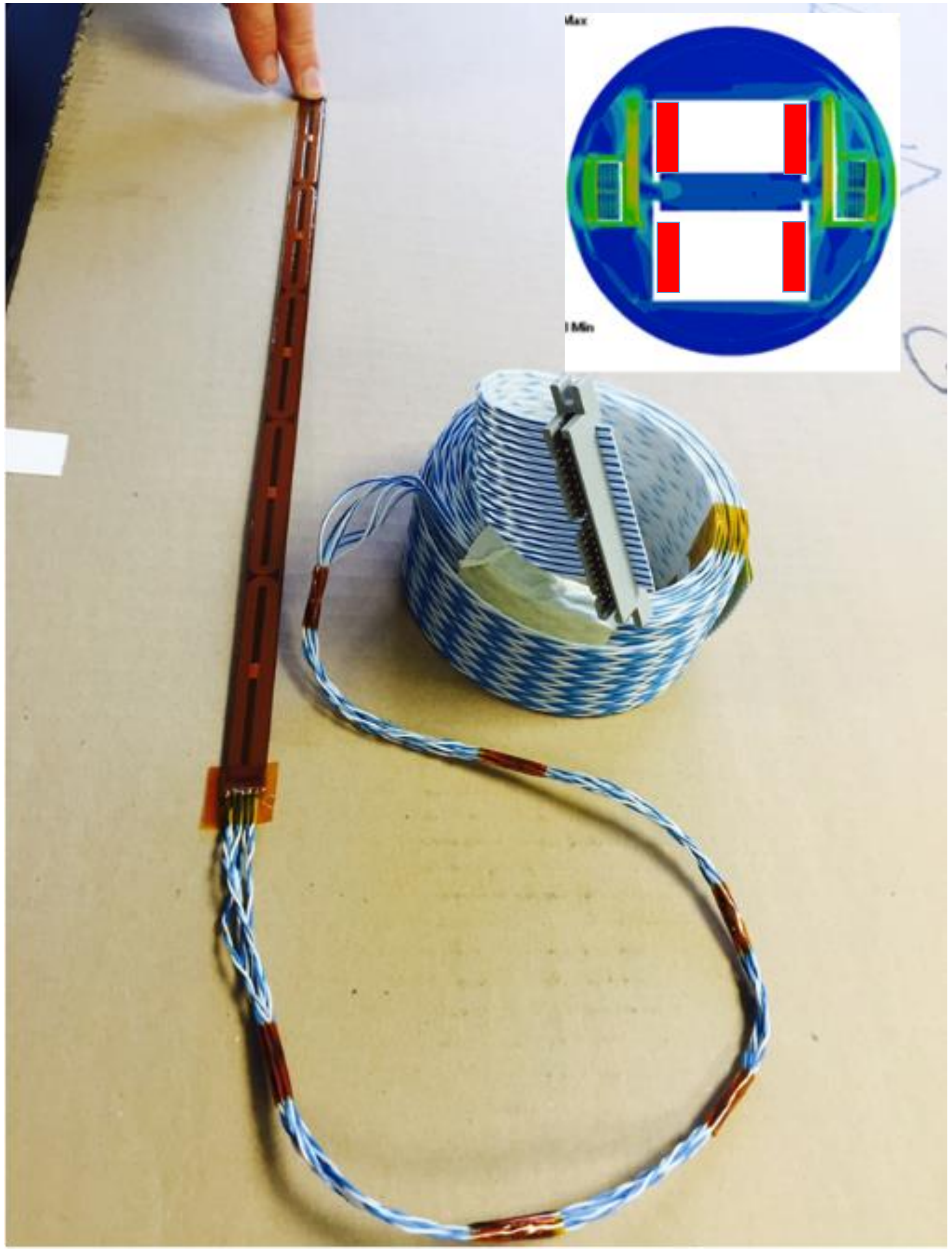
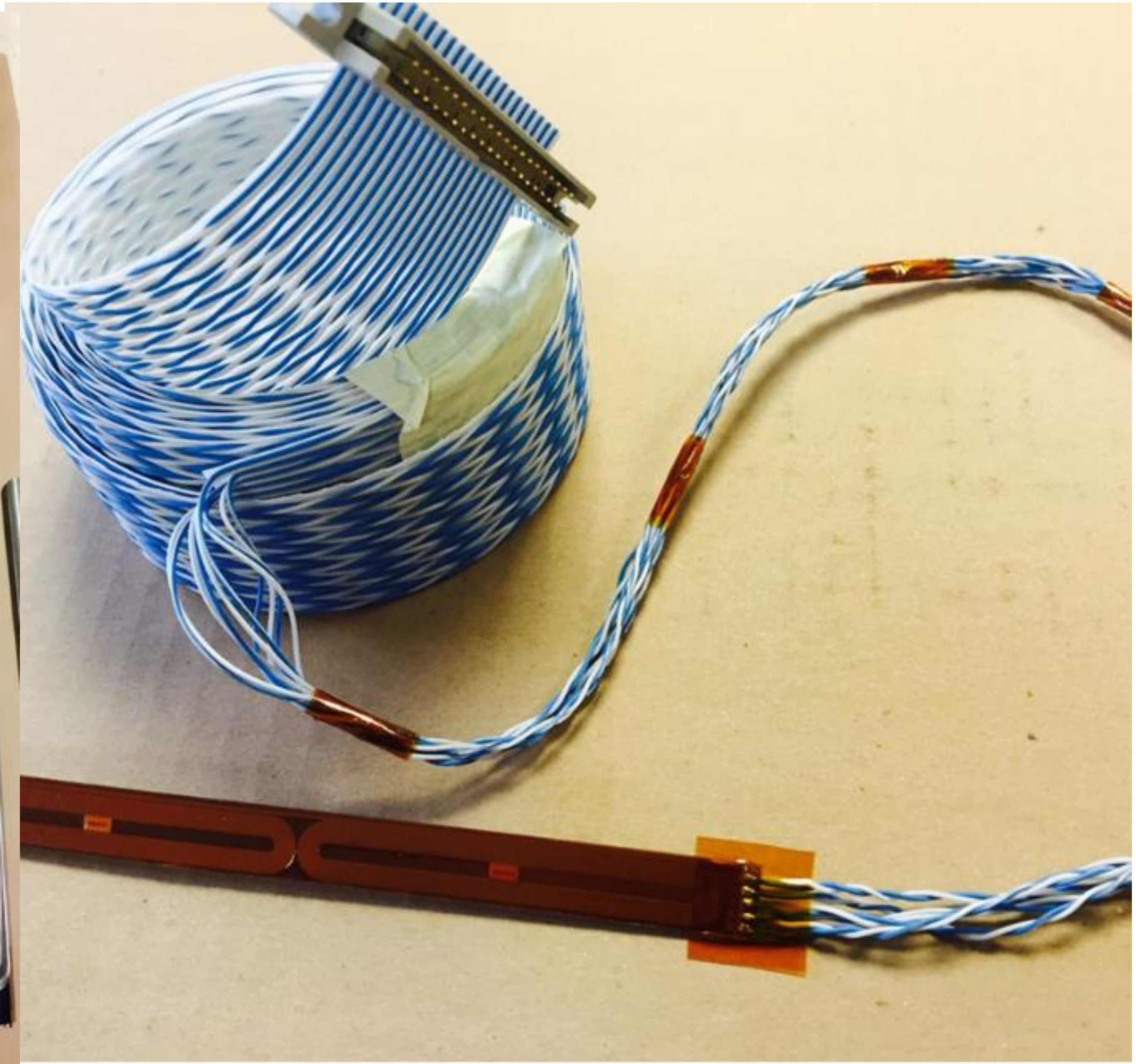


Figure 2 Magnetic pick-up loop array.





Thanks to Francois-Olivier Pincot

Implementation of the quench detection methods

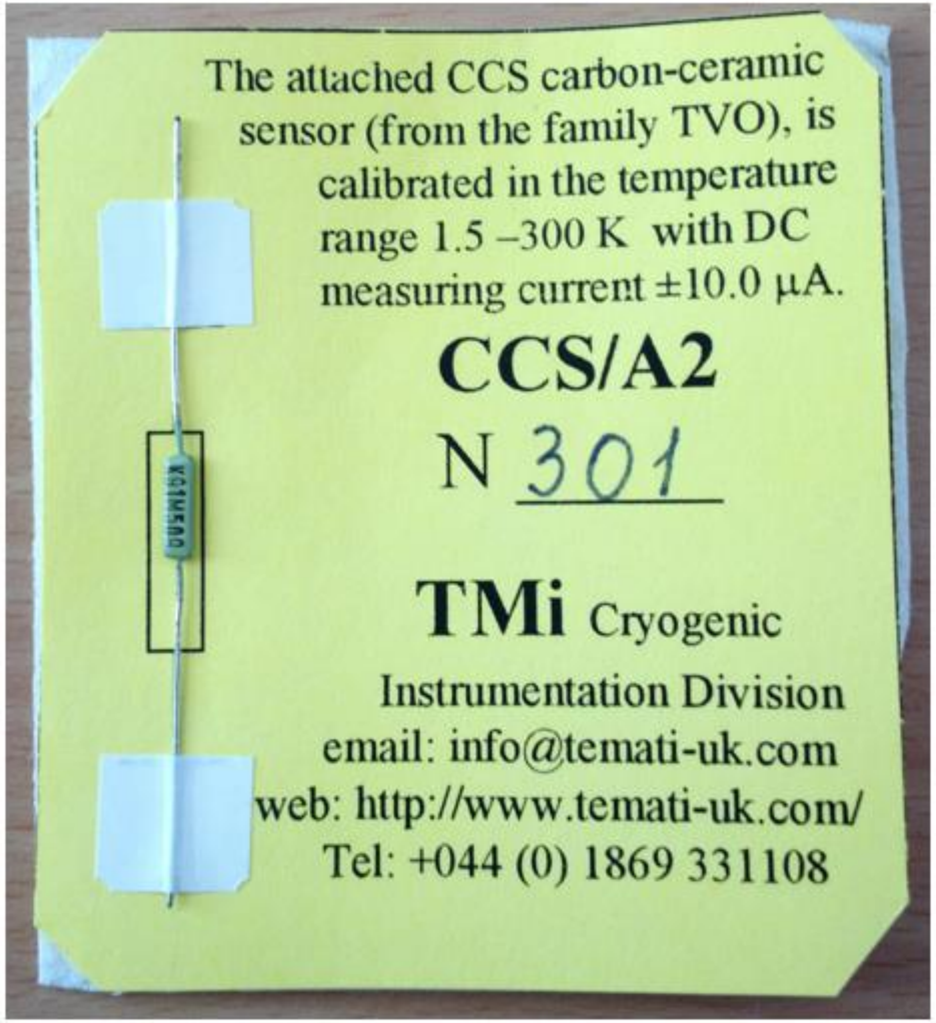


Figure 3 CCS temperature sensor.

First sensibility tests in liquid nitrogen with a Feather M0 dummy coil are done. Thanks to Francois Olivier Pincot. The report is attached.

We will continue with the study in real coil in cryostat.

Implementation of the quench detection methods

Data read-out will be conducted through FPQA system (Figure 4) and systems will be coupled with software Labview.

HTS Quench DAQ FPGA

NI-CompactRIO

Processor:
- 667 MHz dual-core ARM
- 512 MB RAM
- 1 external GB storage
- + Additional 3 TB Ext.Storage
- NI Linux Real-Time OS

FPGA:
- Xilinx Artix-7
- 2 M cells

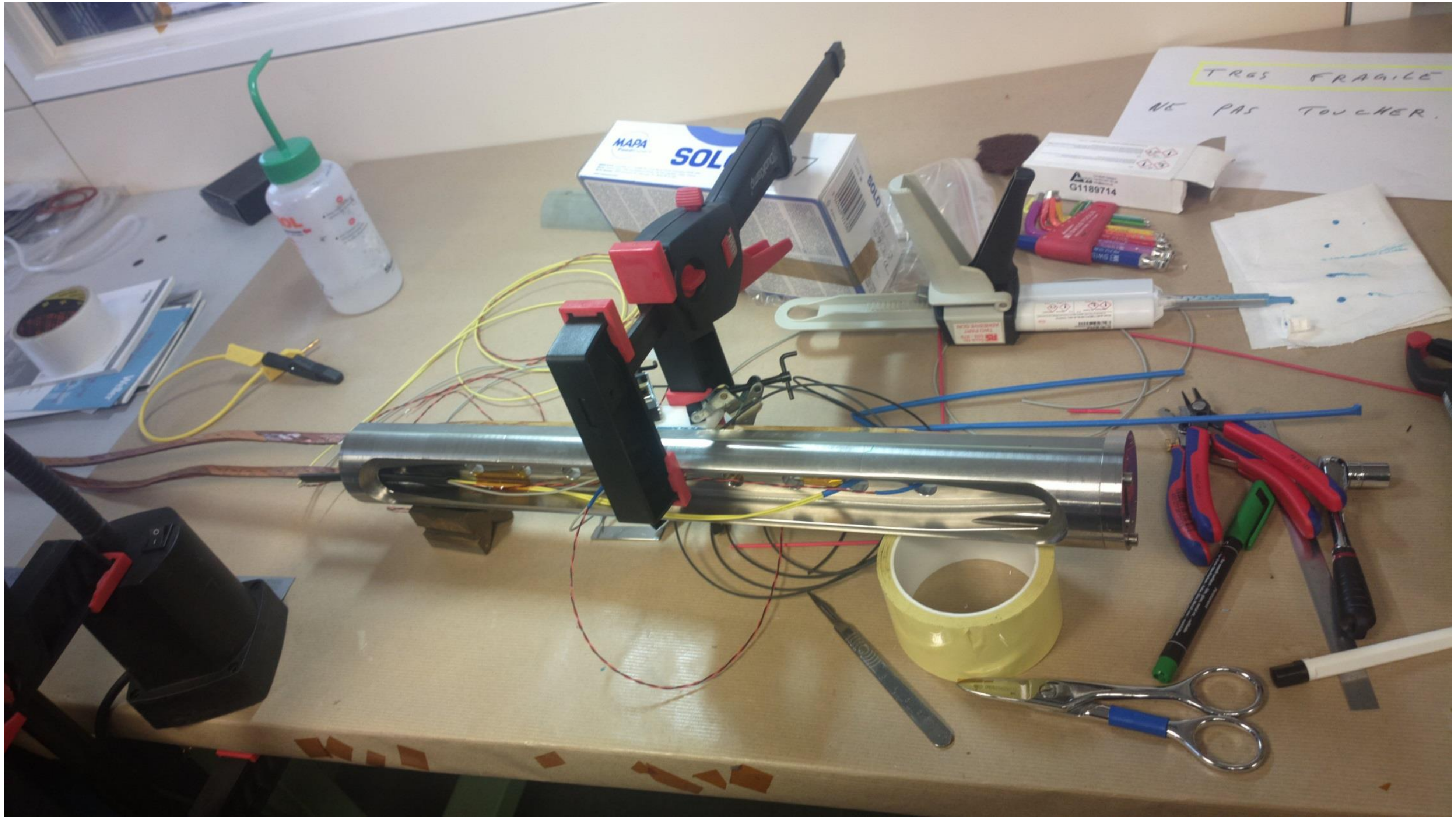
Channels 224 total

7 modules: 16 differential analogue inputs each
- +/- 200 mV till +/- 10 V input range
- 16 bits
- 7.8 kS/s per channel

1 module: 32 digital outputs
- 5 V TTL
- 7 µs response time

Also available: **high speed module**
- 4 differential analogue inputs
- 16 bits
- 1 MS/s, simultaneous sampling

A similar system is used by the EL group to capture voltage transients on the electrical network caused by EDF switching, thunderstorms and internal load changes



Thanks to Francois-Olivier Pincot


Press CTRL + ALT + DELETE to unlock this computer
Windows 7 Enterprise

The plan of my thesis is tied to the plan of the Fresca-2 magnet test station and Feather magnets. In the next year, the plan should follow the plan in Figure 1. [6] The next step is to take the Feather M0 to diode cryostat test station in SM 18 before closure of the facility in February.

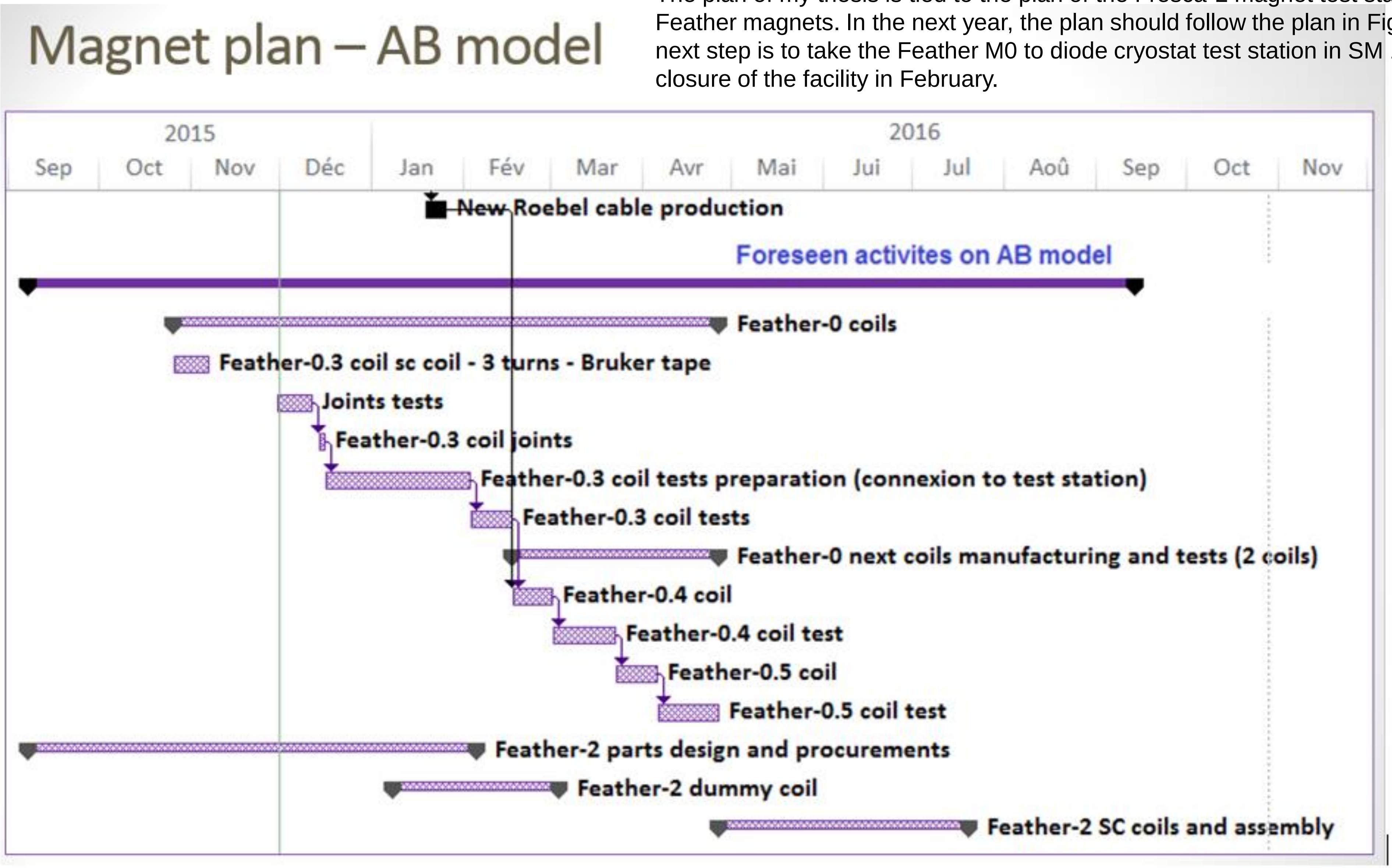


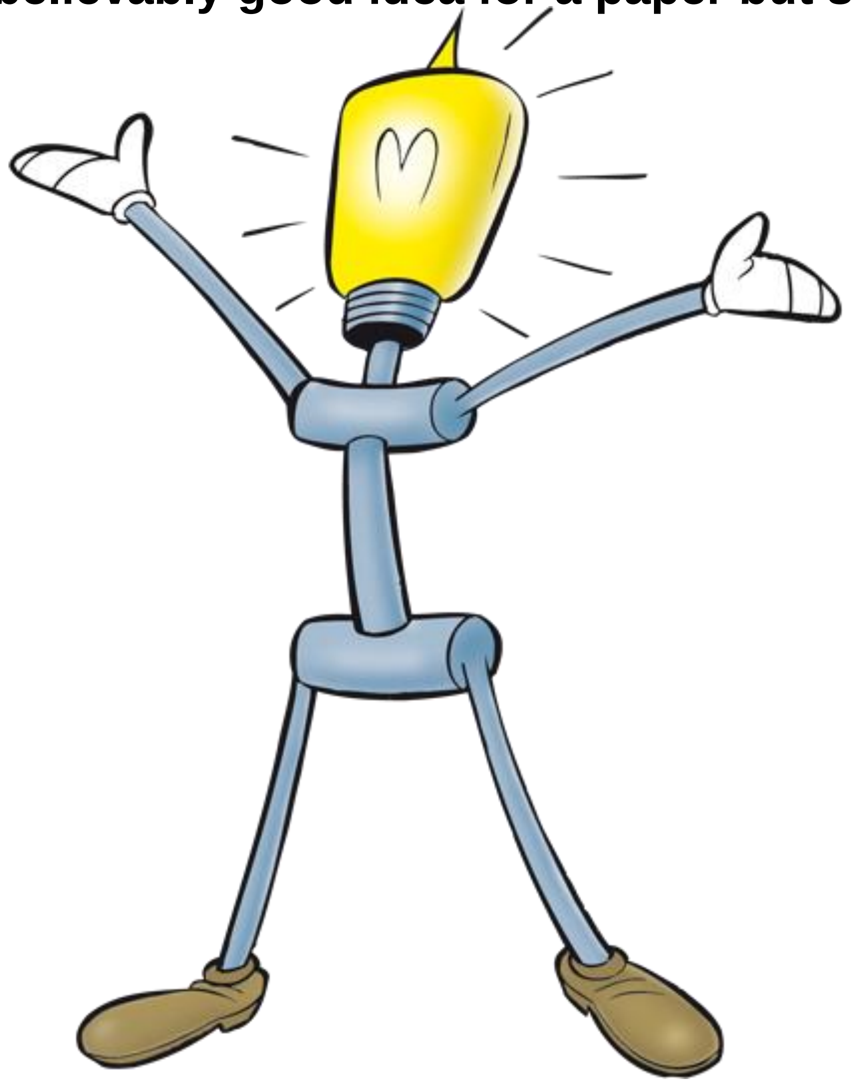
Figure 6 The planned schedule for the Aligned block designs (Feather M0 and M2).[6]

5. Schedule

Figure 7 A plan for manufacturing, assembly and instrumentation. [5]

Possible paper topics

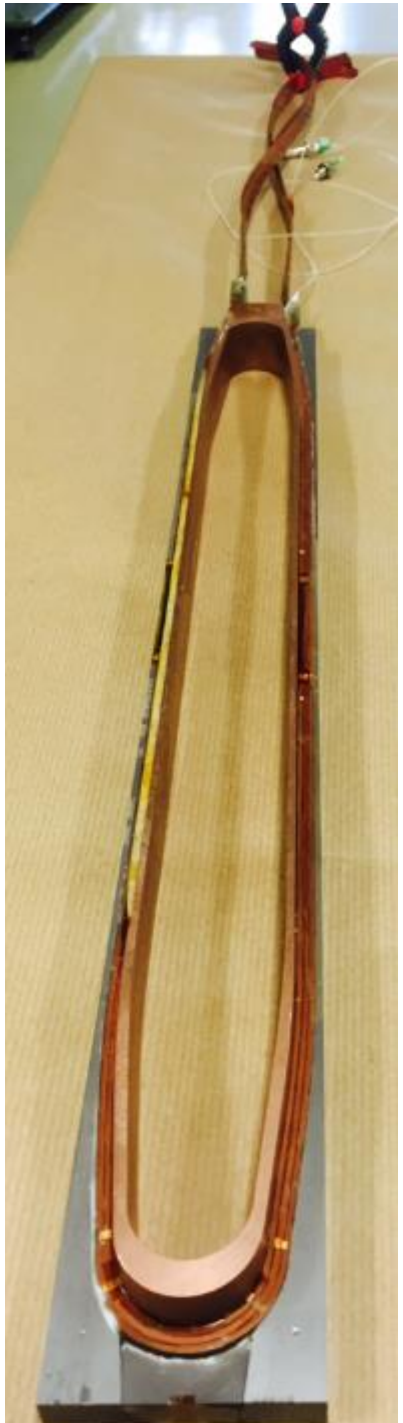
2. Unbelievably good idea for a paper but still secret (planned for journal)



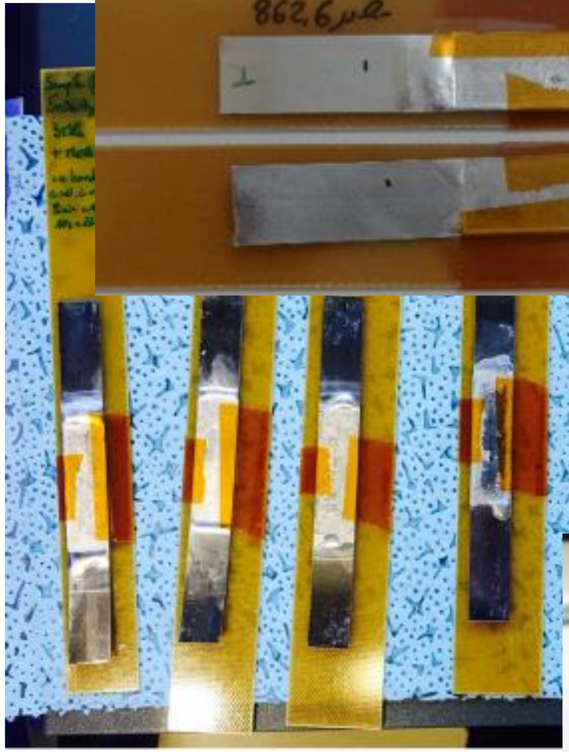
3. Not yet invented (conference paper?)

Feather ZERO project. Where are we?

- 1st HTS coil wound and impregnated.
- We are working on instrumentation.
  - Voltage, temp sensors array, accurate temp sensors, fiber optic, Hall probe………. Lots of work!!
- We need current lead link from magnet to cryostat leads! Need a test in gas to check heating at temperature and current values is acceptable.
- Target for first powering test Febuary 2016, before the CERN test station is closed for 7 weeks end of feb 2016.



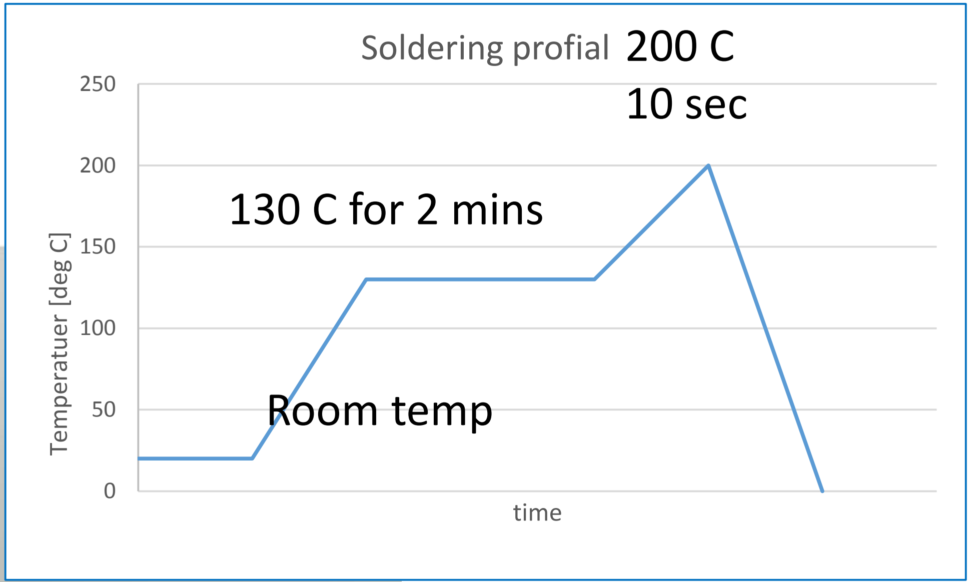
Soldered Joints development

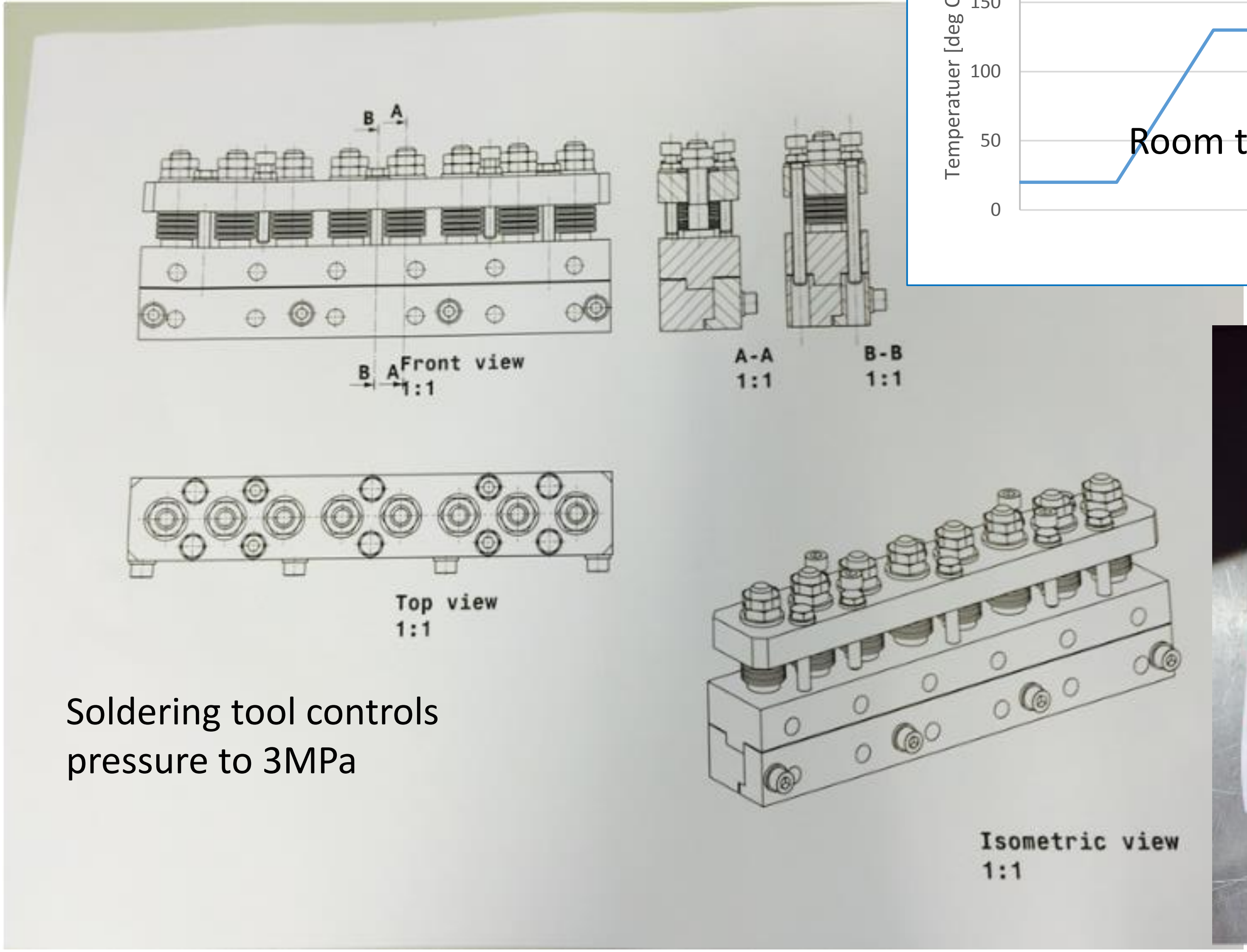


We have selected a low melting point solder with tin – bismuth alloy. It comes in a liquid form, so a thin layer can be applied to the tape. The flus is incorporated in the liquid so a very think, we

Thanks to Francois-Olivier Pincot

Soldering tooling

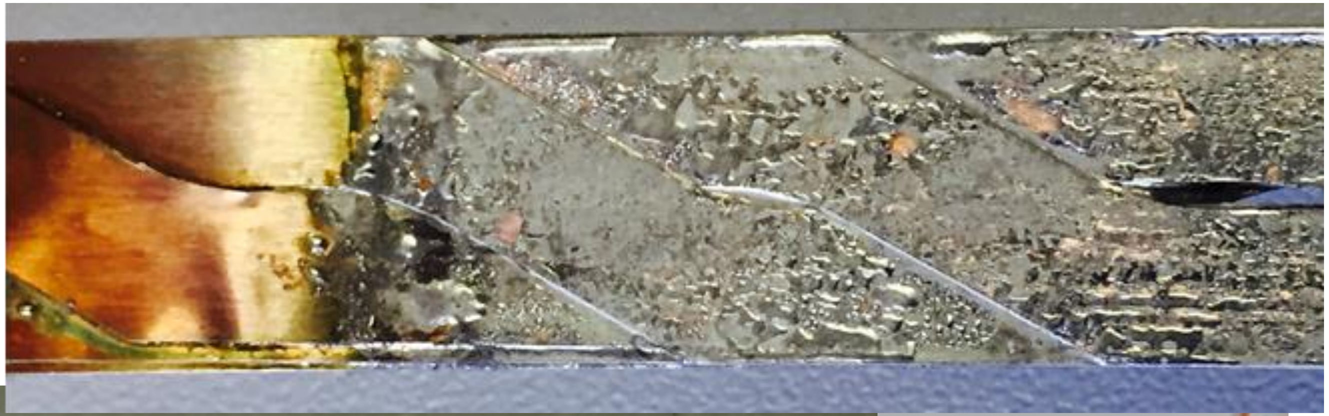


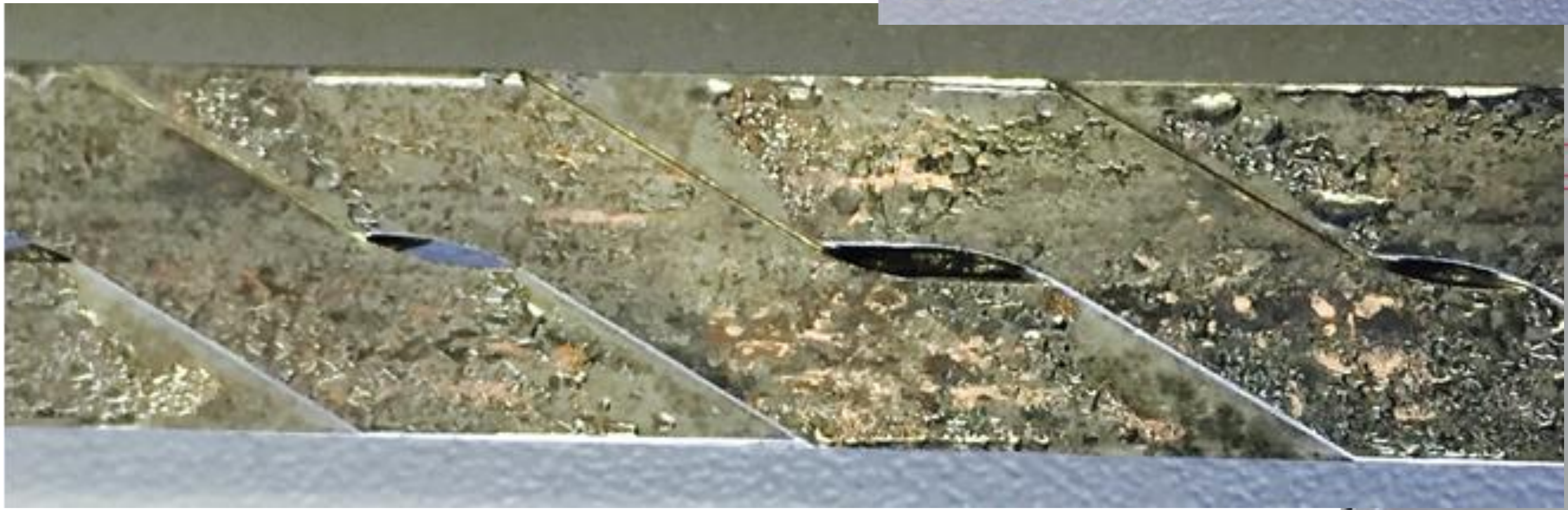


Soldering tool controls pressure to 3MPa

Thanks to Francois-Olivier Pincot

Roebel soldered





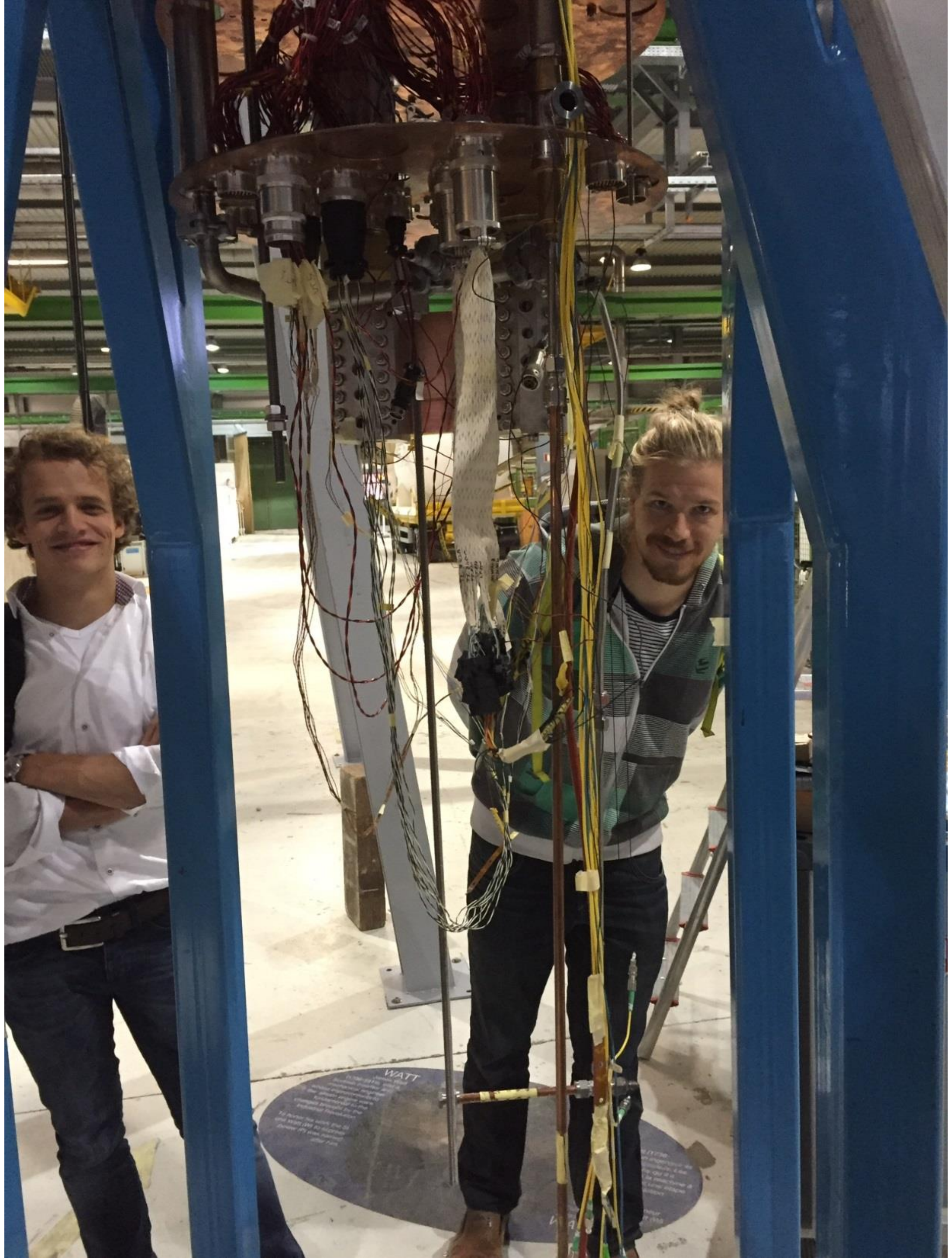
We like!

- The thin layer of solder [solder thermal contraction 6 mm/m].
- Fully soldered surface between the tapes.
- Very low 3 MPa pressure during soldering

4. How to reach the objectives?

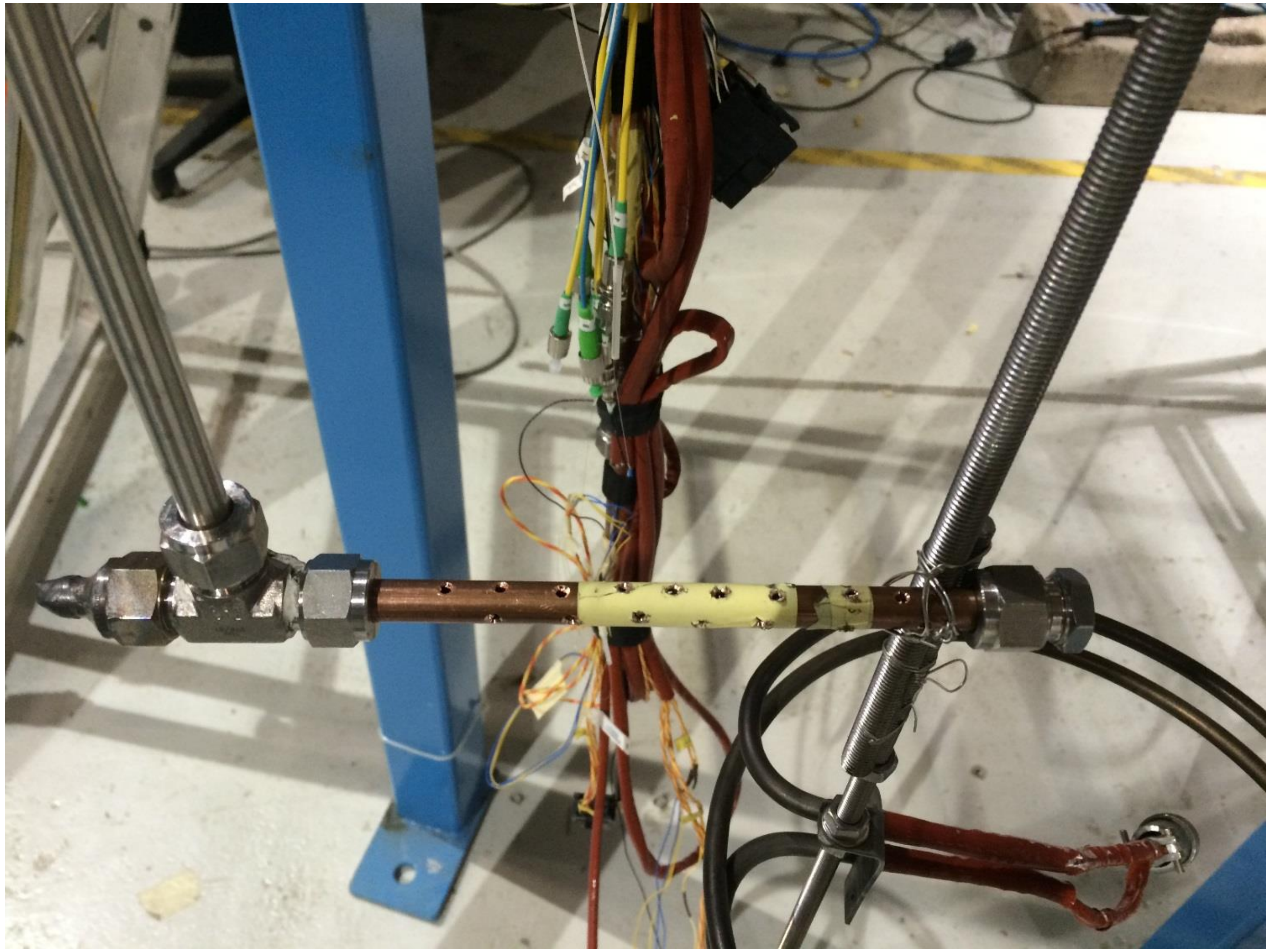
Feather ZERO project.

Joints & Leads & Integration

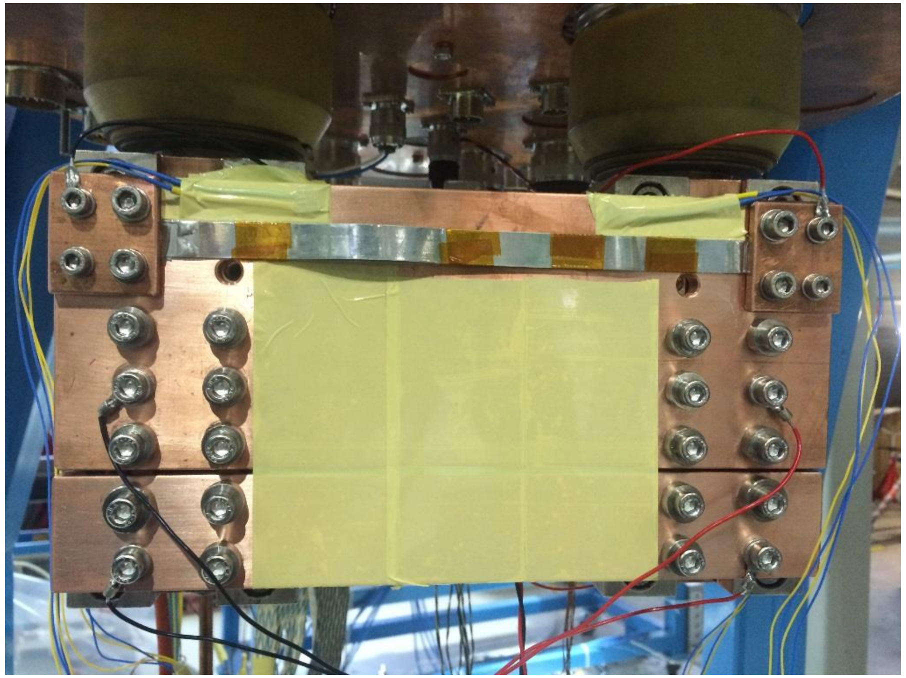


Global view

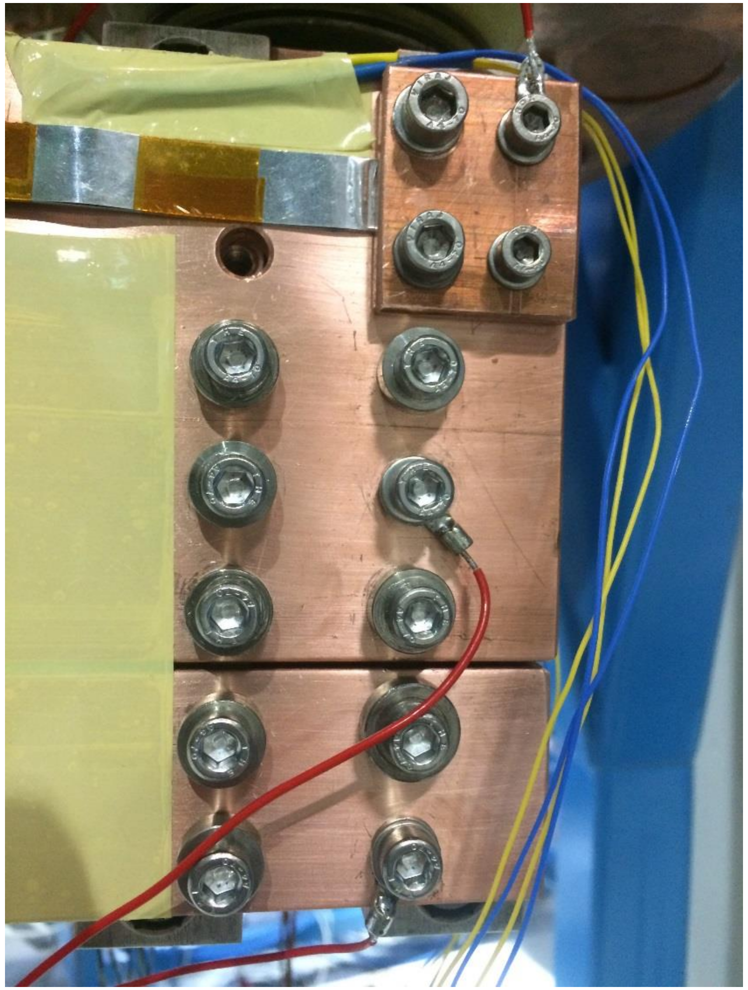
Helium Gas inlet



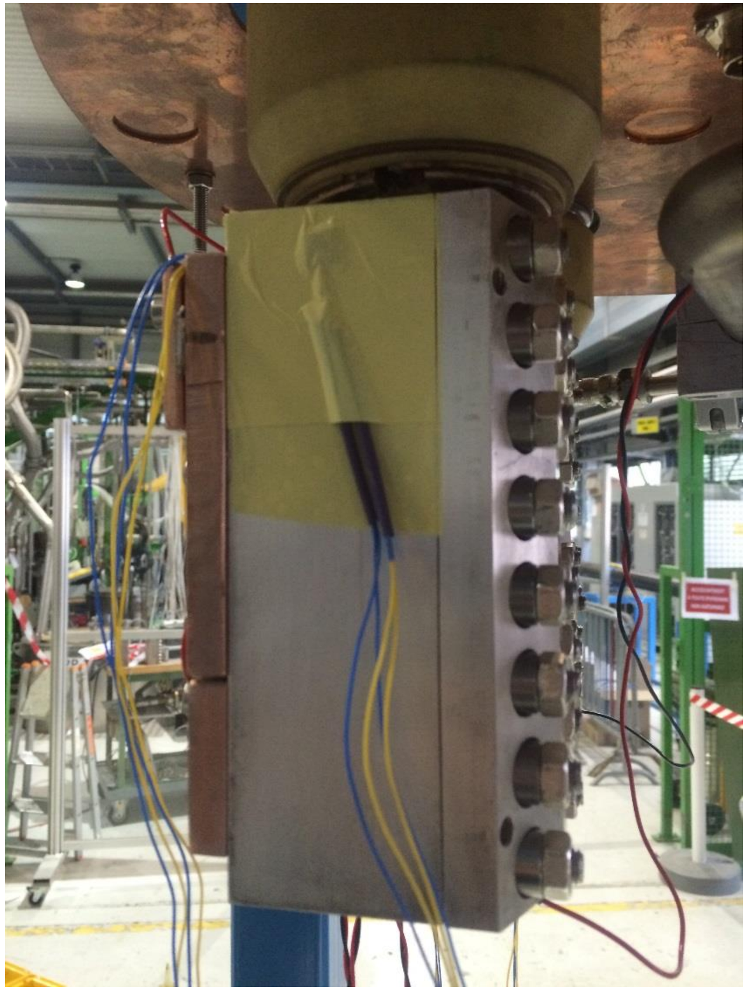
Thanks to Hugo Bajas



Copper bar and 5/tape YBaCuO (Superox)

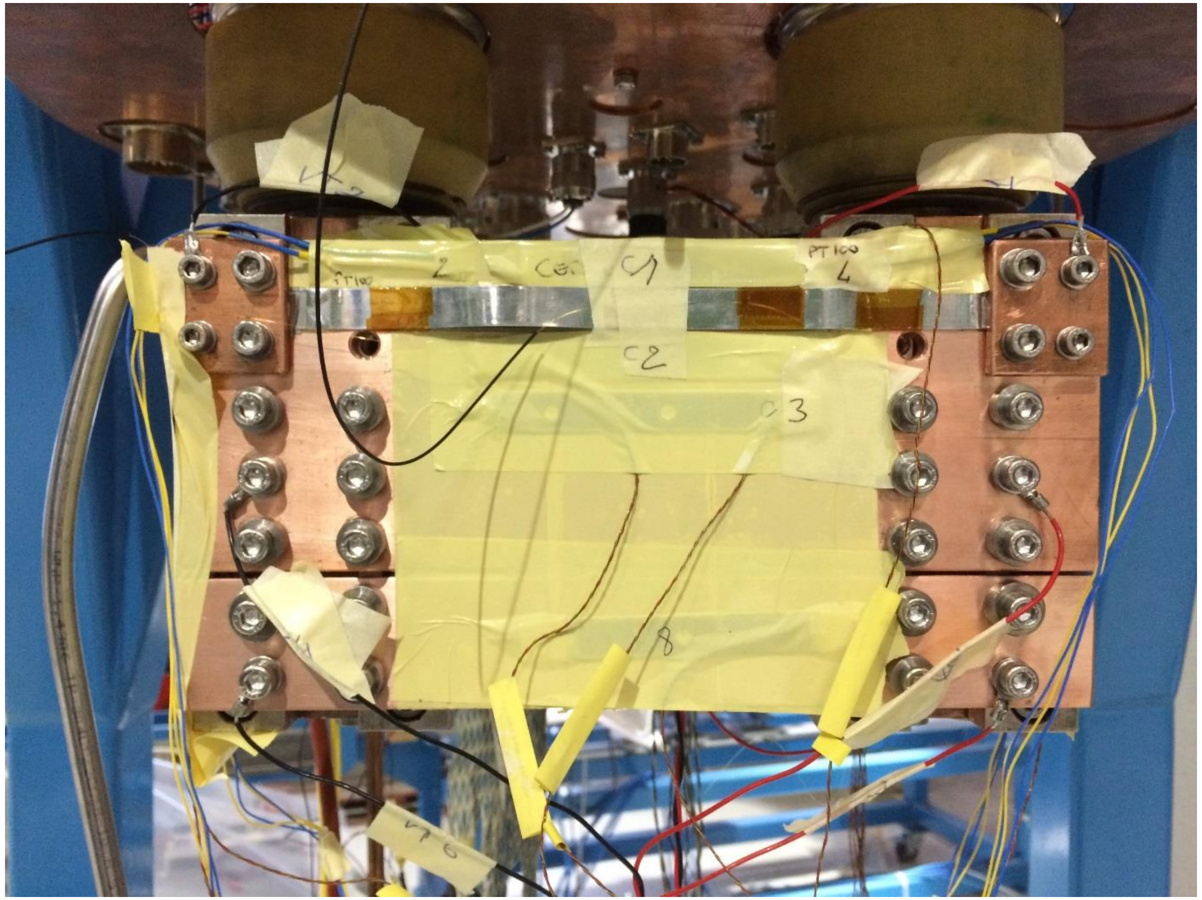


Detail view of the clamp
(between 2 Indium sheet)



Side view of the current
lead connection.

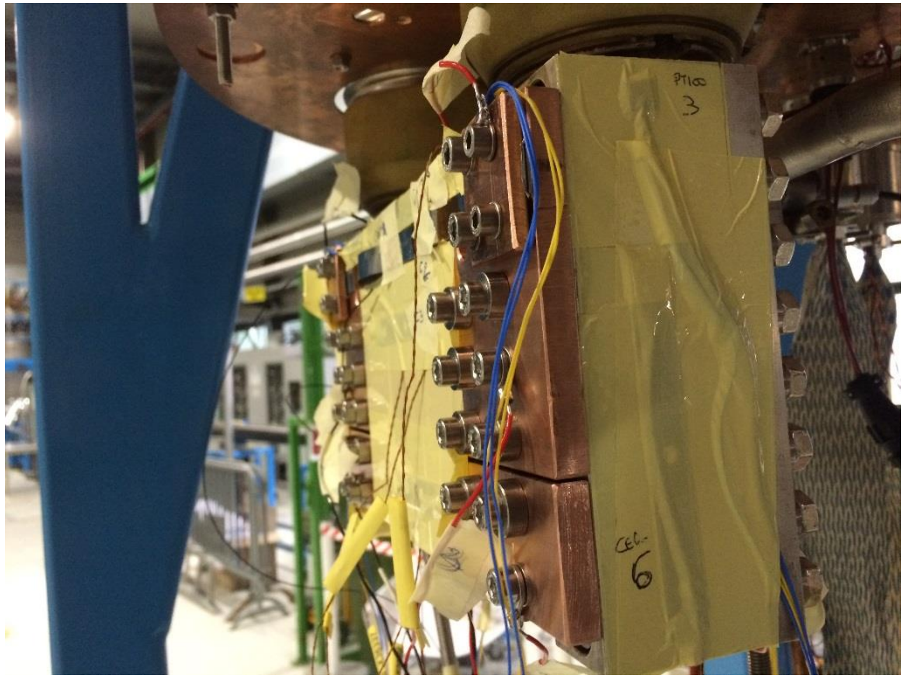
Thanks to Hugo Bajas



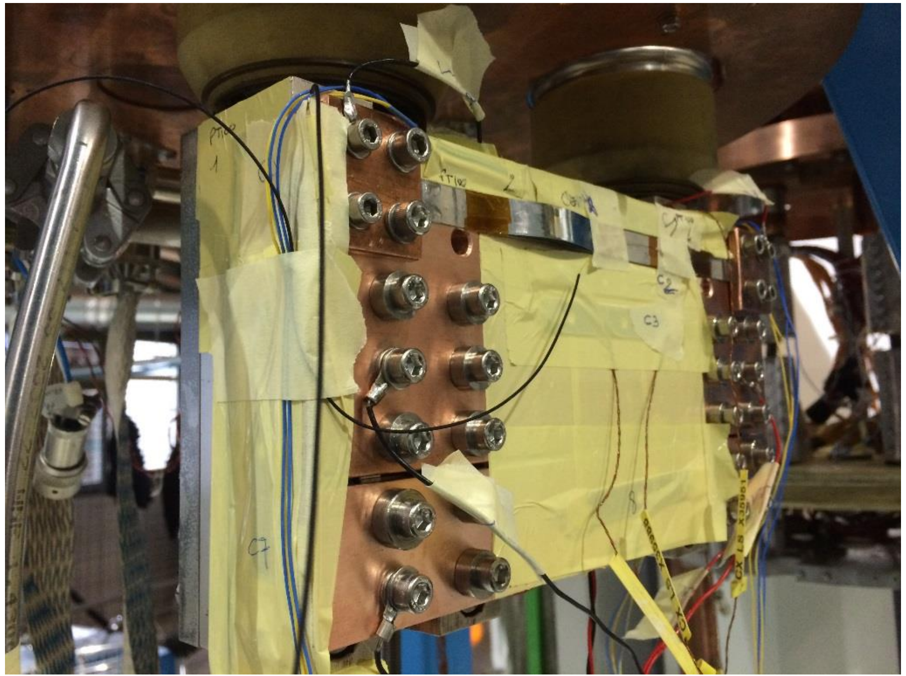
Copper bar and 5/tape YBaCuO (Superox)
after instrumentation

8 Cernox (6 alive, 2 dead)
4 FBG (alive)
4 pair of V_taps

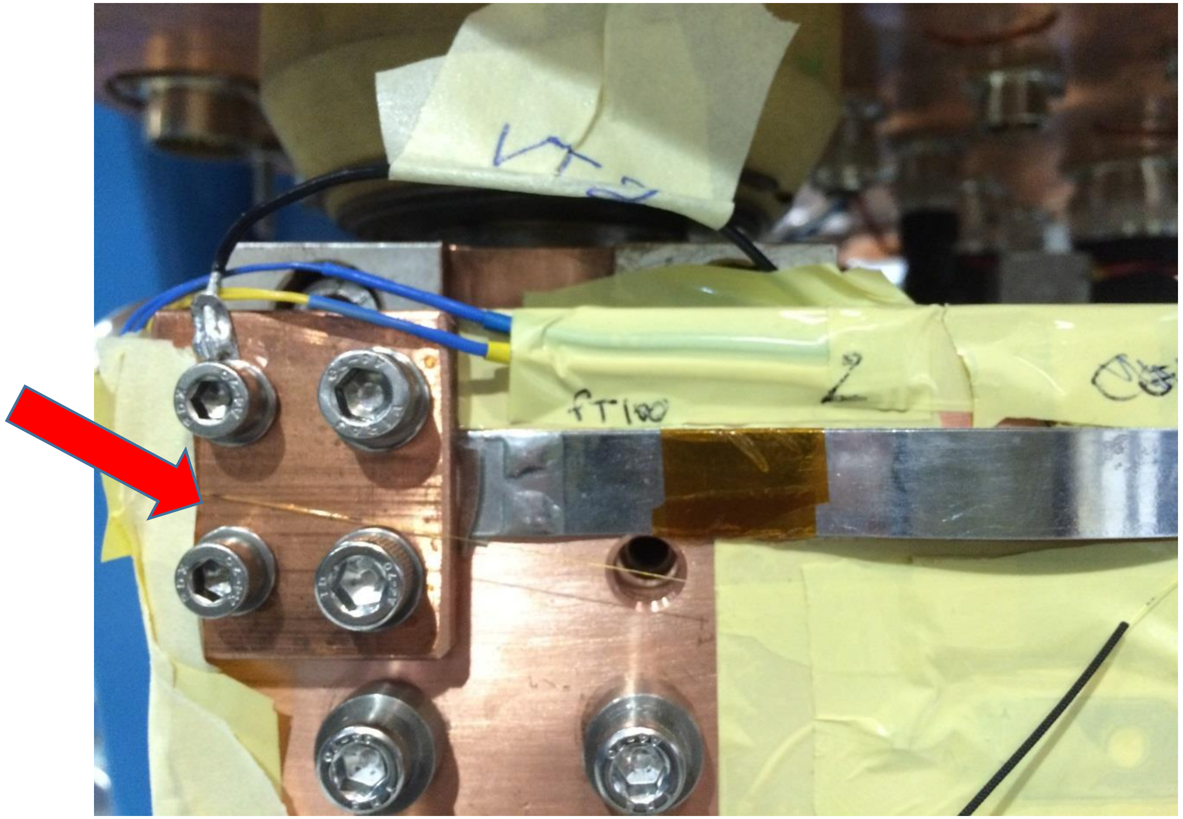
Thanks to Hugo Bajas

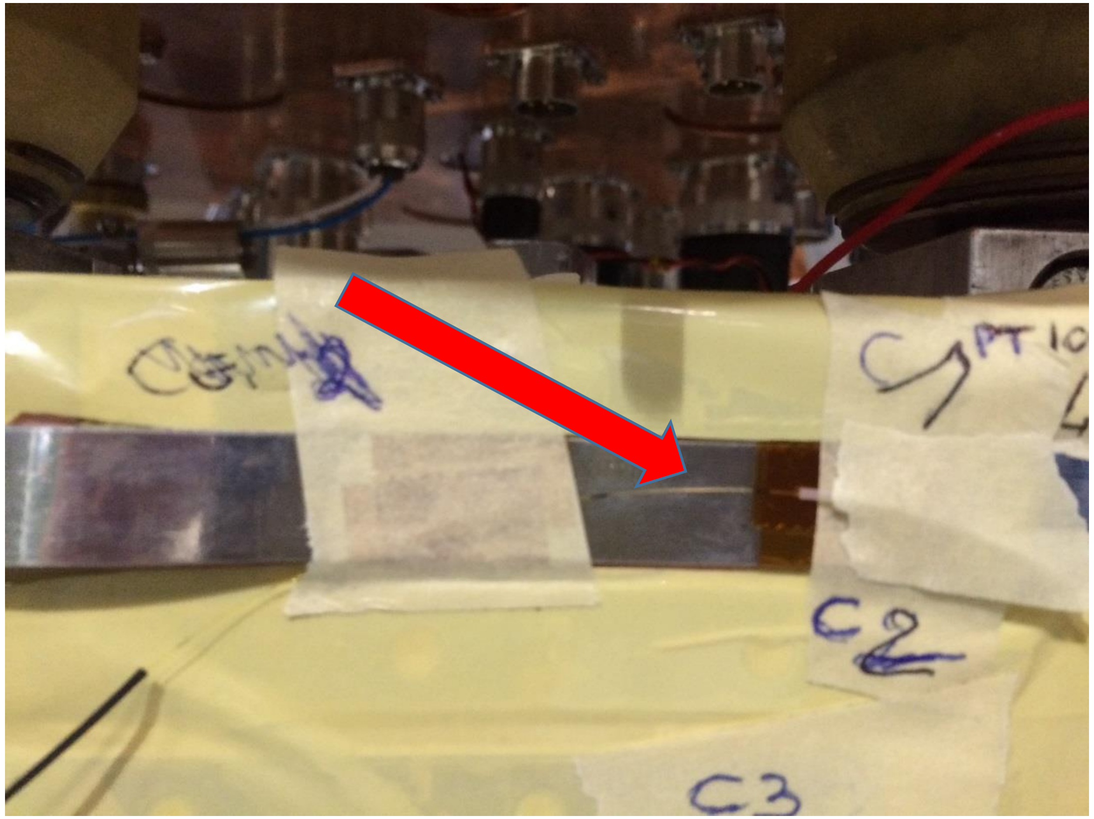


Instrumented side view

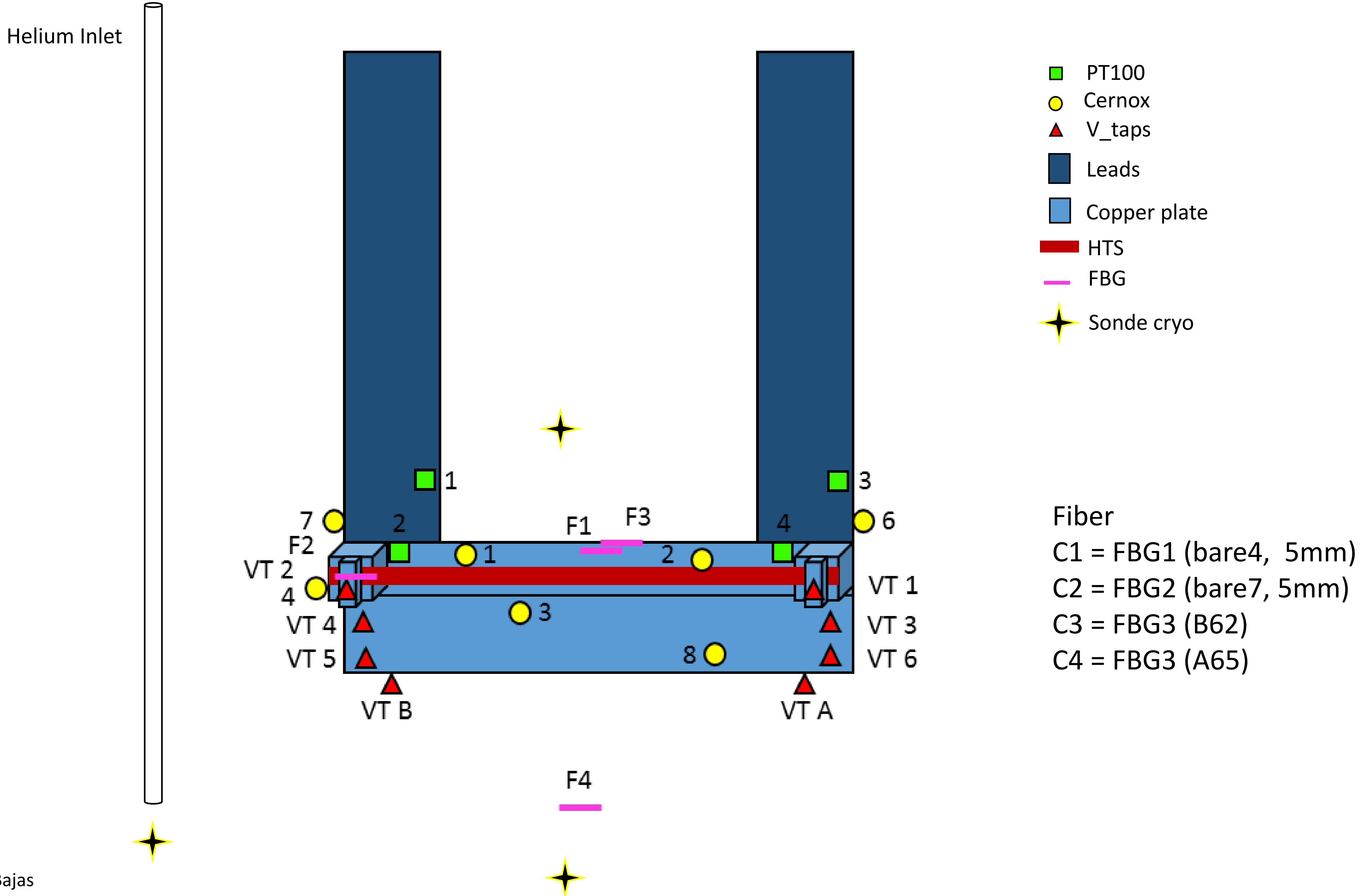


Fiber Optic Sensor





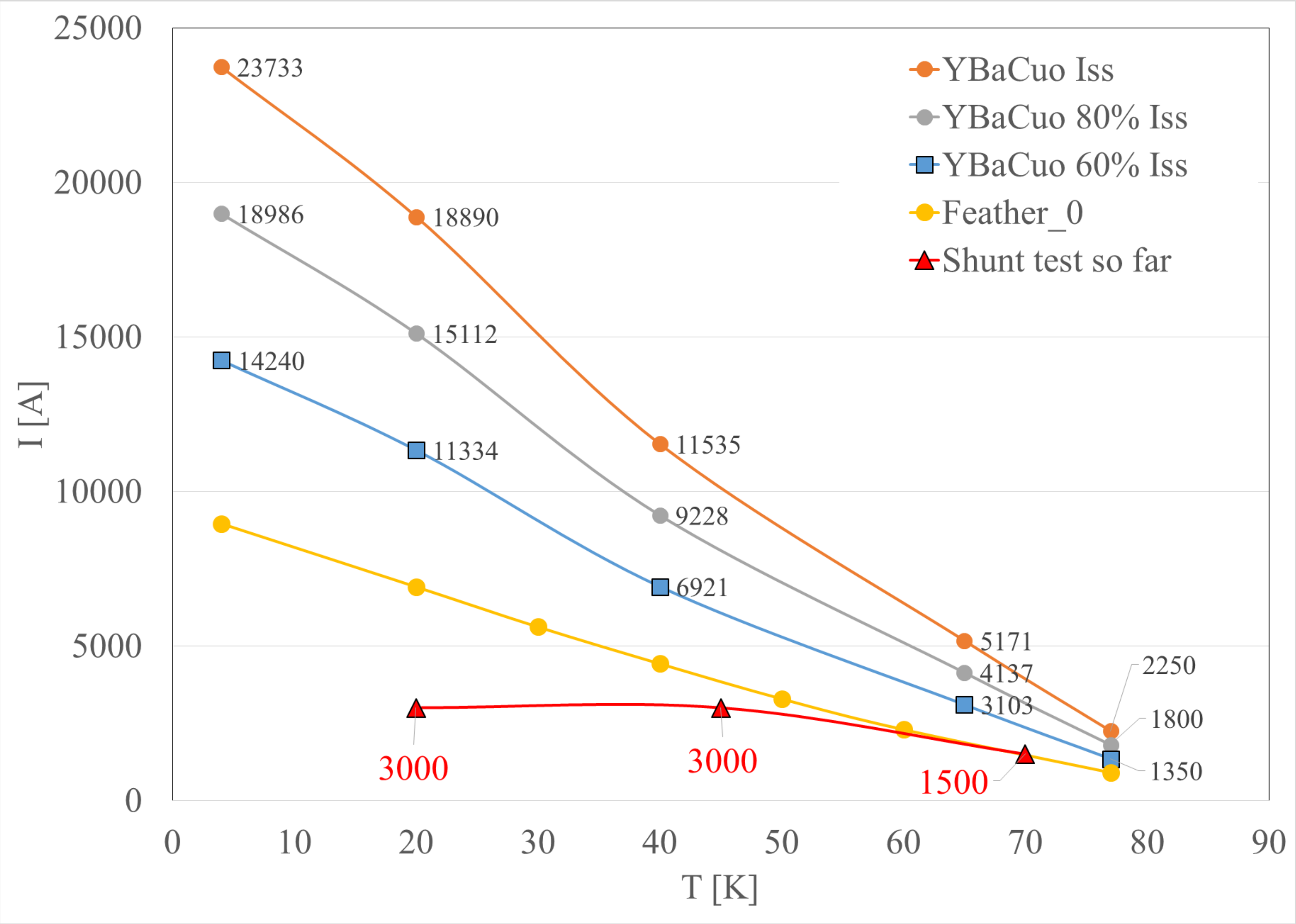
Thanks to Hugo Bajas



Thanks to Hugo Bajas

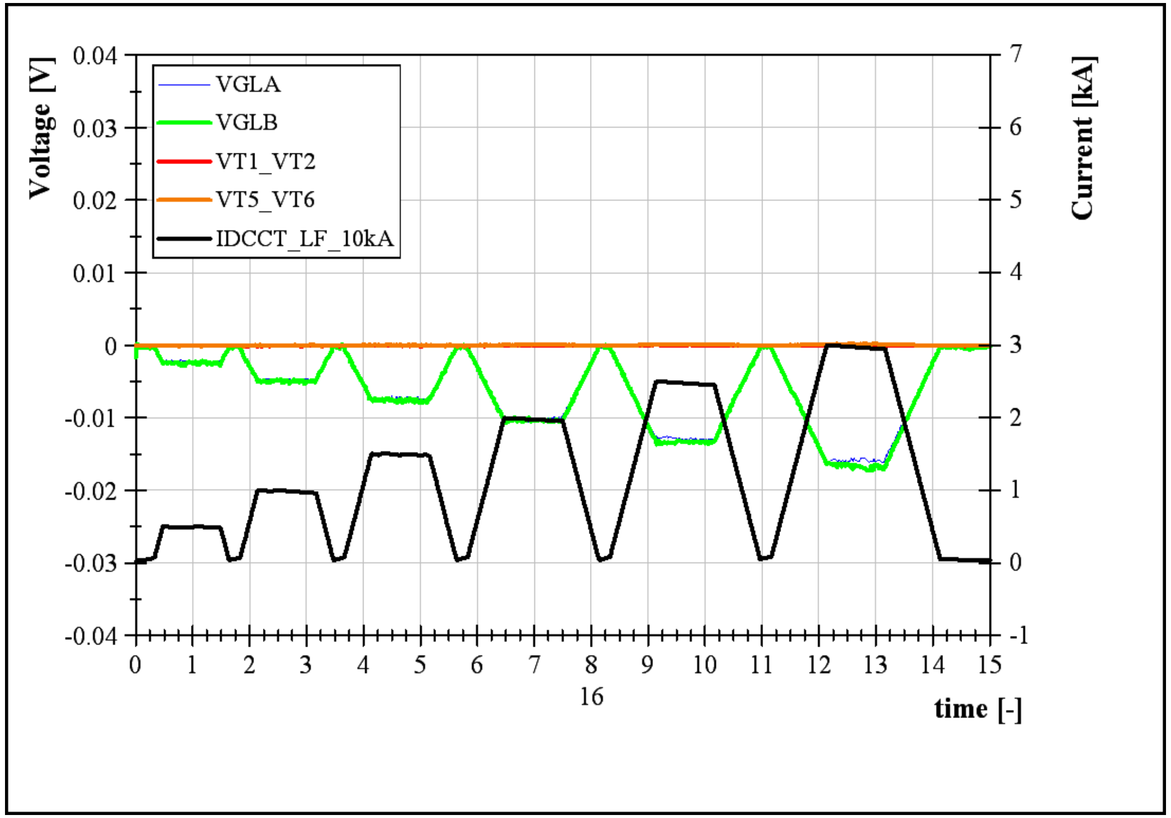
Status so far

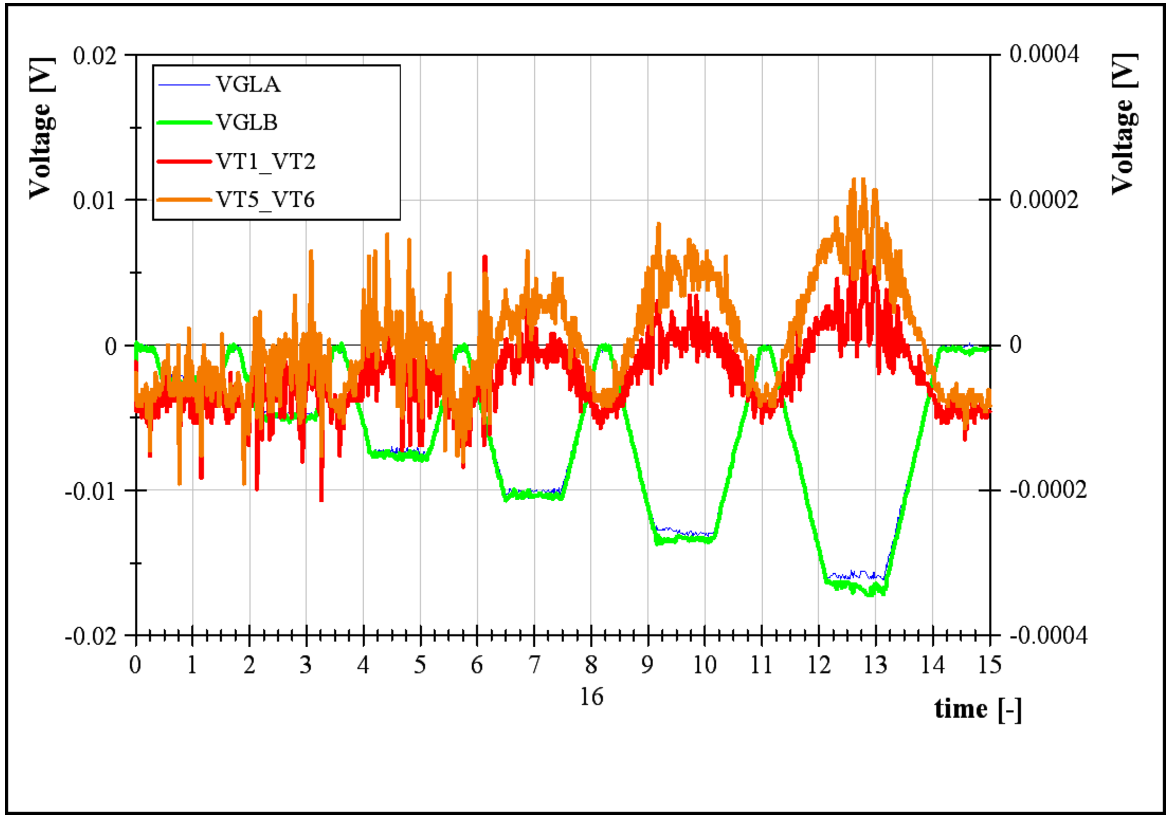
- 20 K, I = 100, 200, 500, 1000, 1500, 2000, 2500, 3000 **OK**
- 45 K, I = 100, 200, 500, 1000, 1500, 2000, 2500, 3000 **OK**
- 70 K, I = 100, 200, 500, 1000, 1500 **OK**



Thanks to Hugo Bajas

Measurement example at 40 K

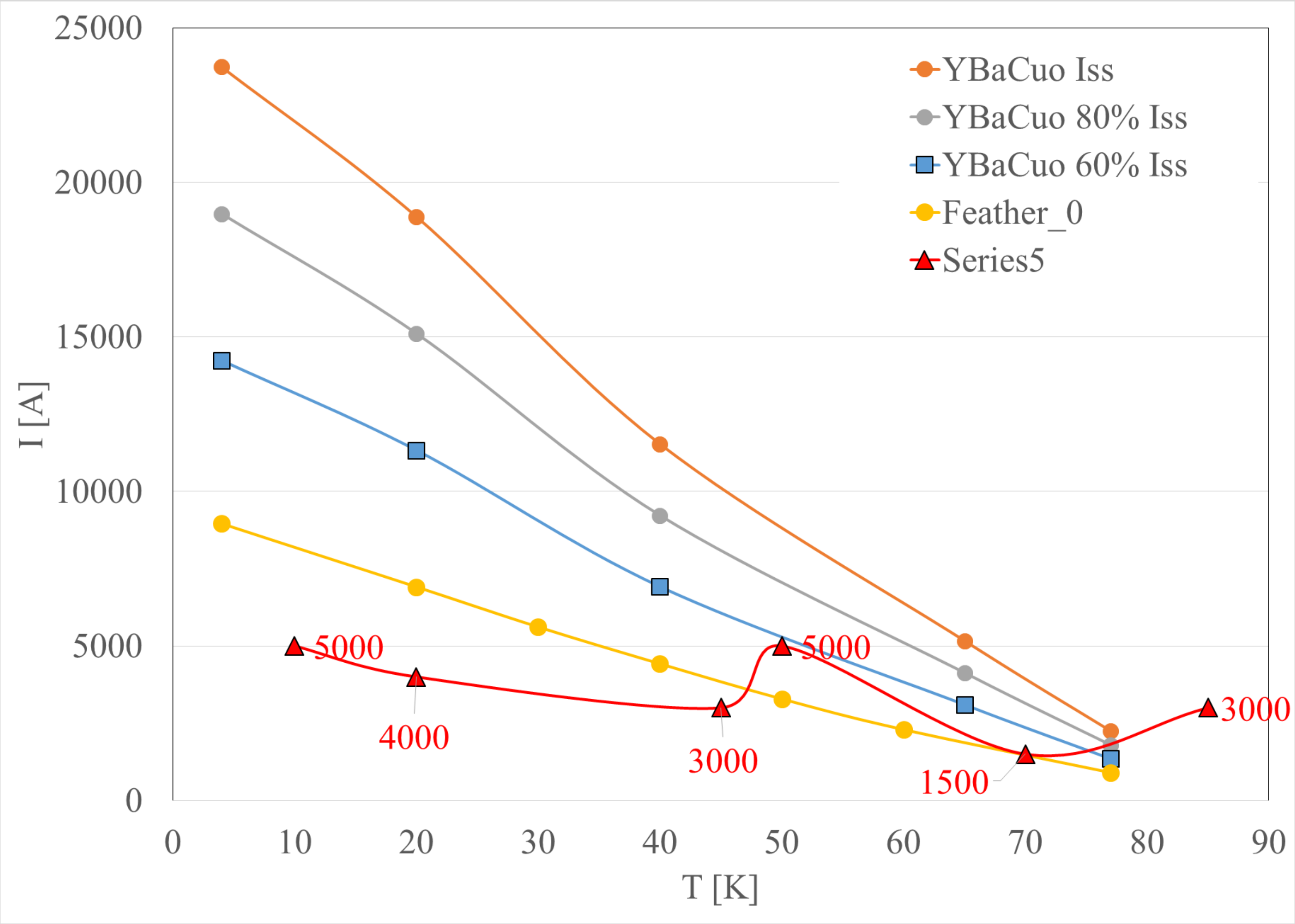




Thanks to Hugo Bajas

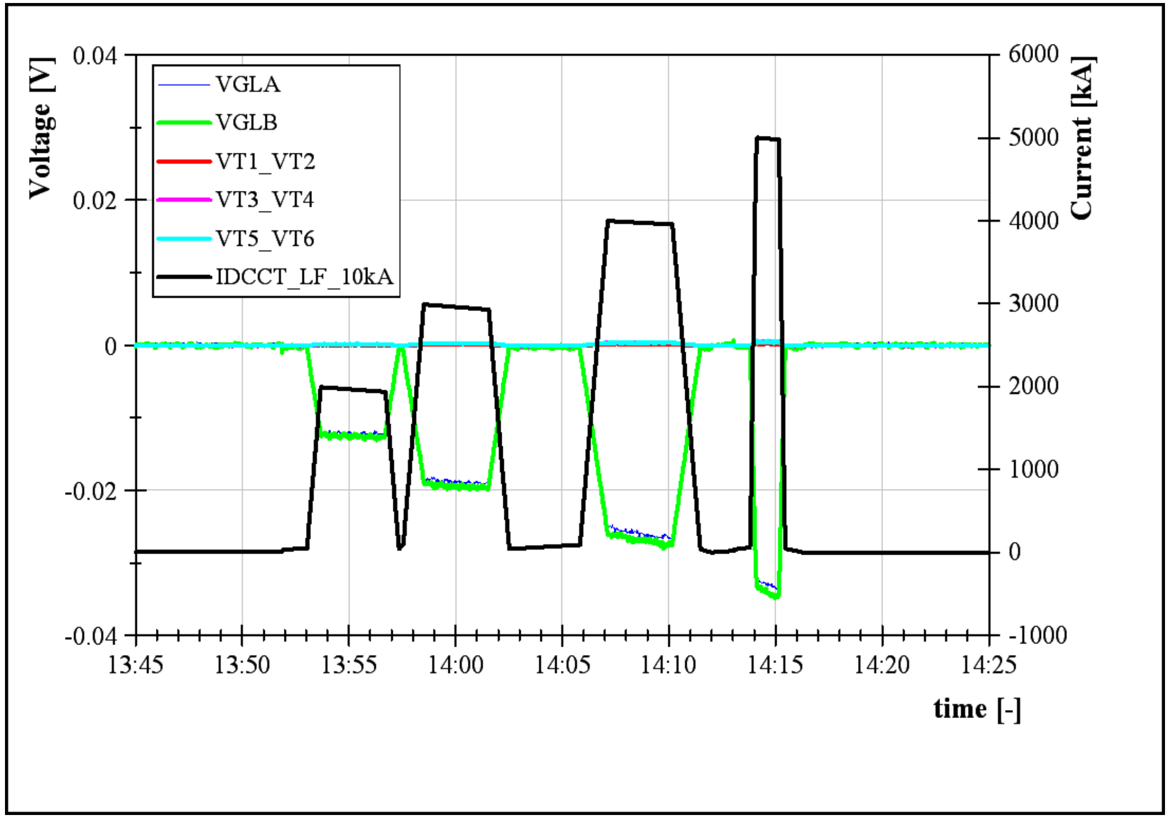
Status so far

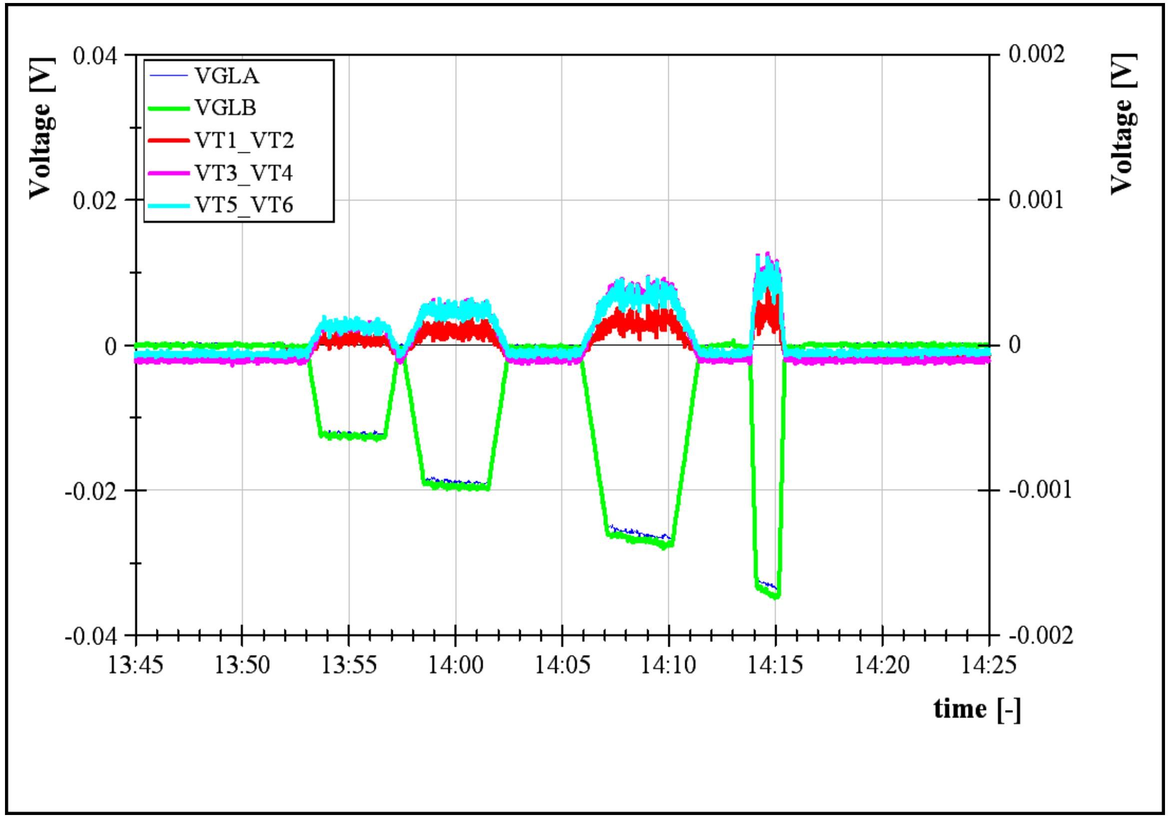
- 10 K, I = 1000, 2000, 3000, 4000, 5000 **OK**
- 20 K, I = 1000, 2000, 3000, 4000 **OK**
- 50 K, I = 1000, 2000, 3000, 4000, 5000 **OK**
- 85 K, I = 1500, 1800, 2000, 2200, 2500, 3000 **OK**



Thanks to Hugo Bajas

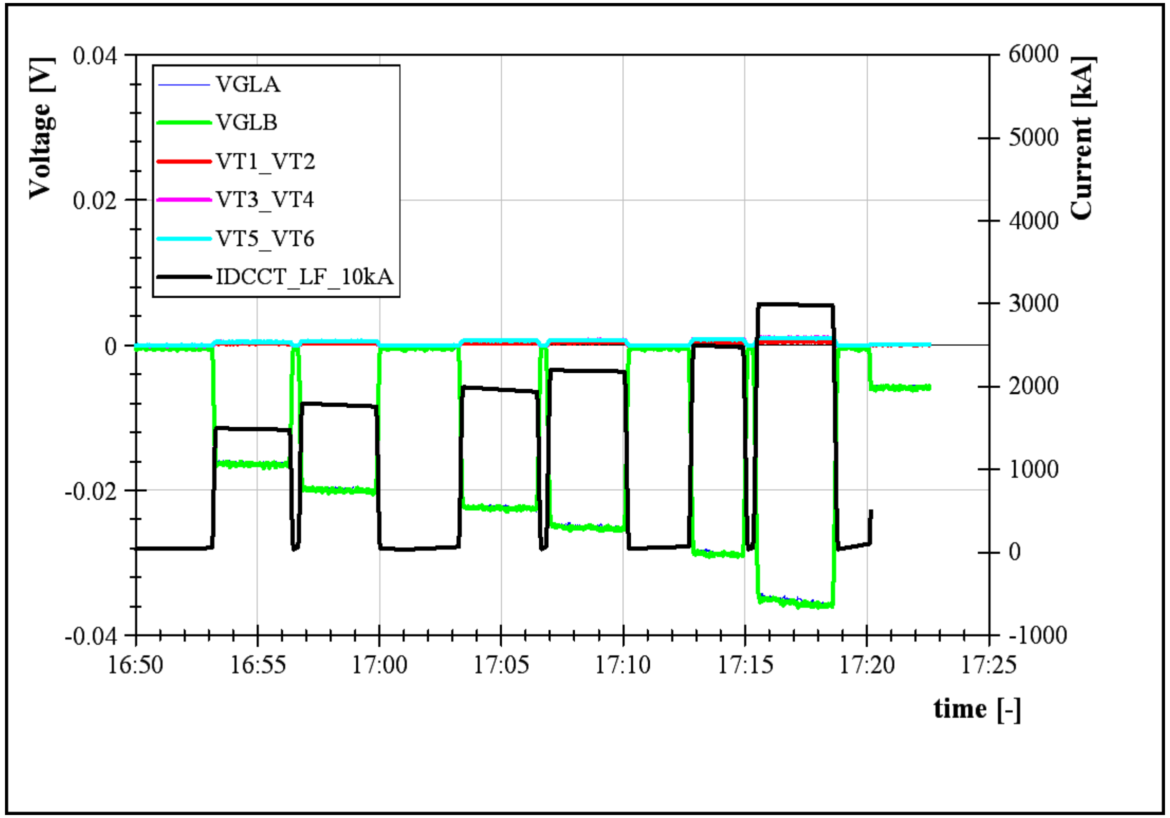
Measurement example at 50 K

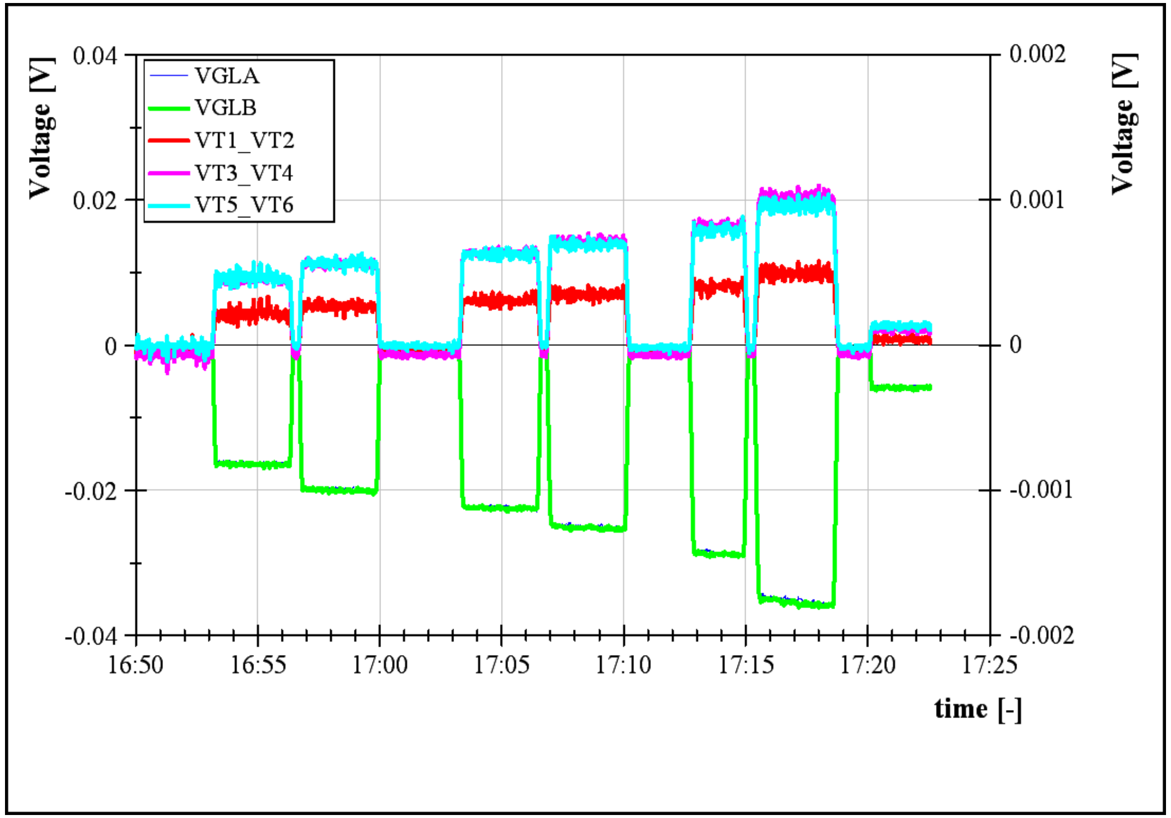




Thanks to Hugo Bajas

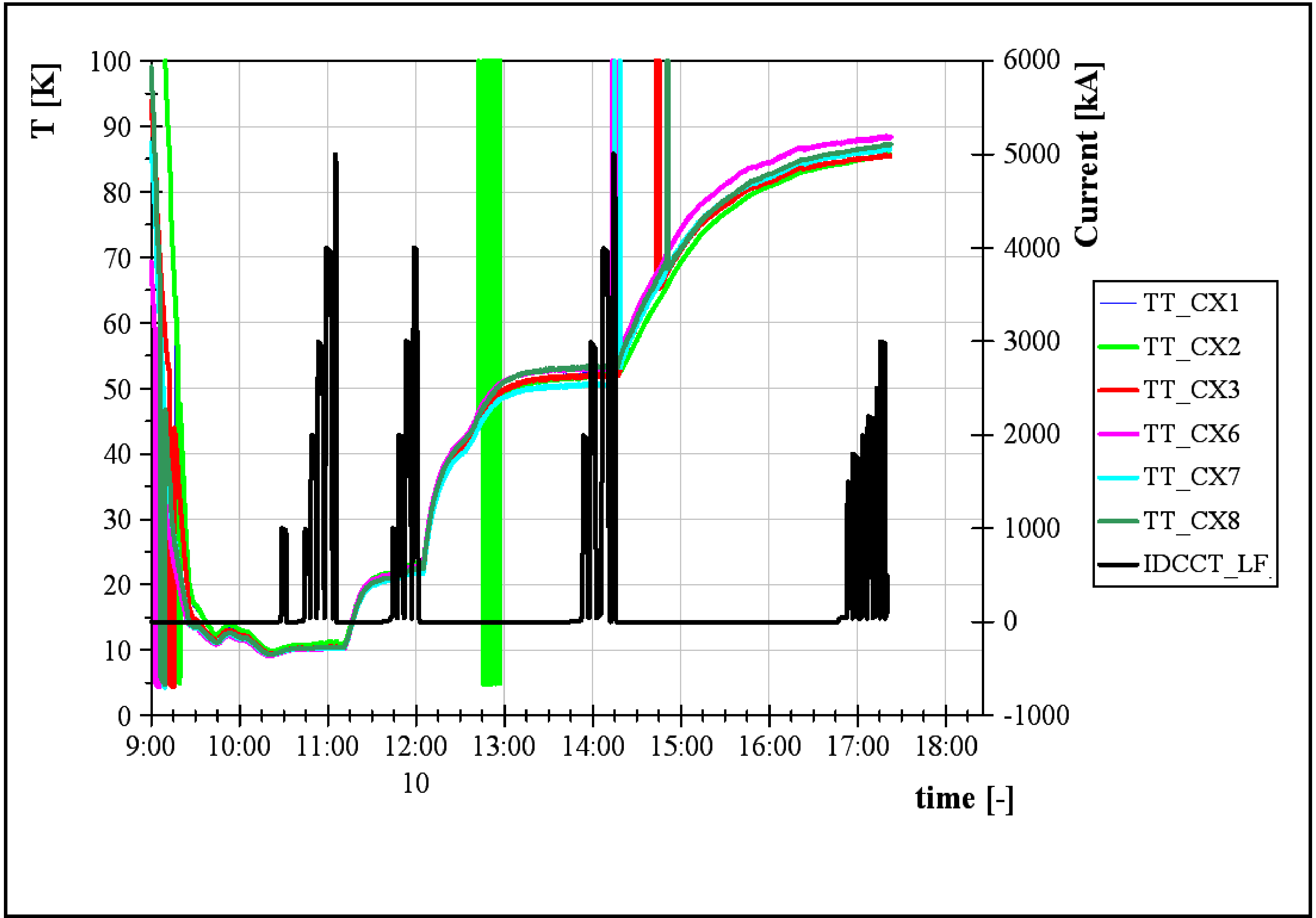
Measurement example at 85 K





Thanks to Hugo Bajas

Temperature measurements



Thanks to Hugo Bajas

After discussions with Jerome Fleiter 10.12, we had the following remarks from him:

The voltage signals see a lot of noise, around 50 micro Ohms just for noise.

All the sensors wires need to be twisted to be able to see something. It is also important for the protection thresholds.

We want to see the “kink” in the voltage-current curve when the HTS gets filled and copper takes the rest and heats up.

The voltage tap on top of the HTS stack does not see current. We need to change the location a little bit.

Next steps 1

We learned more from Jerome

We have relatively big cross-section in the shunt of copper. This means we arrive to lower or comparable overall resistance of the copper shunt compared to the HTS stack. So the proportion of current sharing might be 20% through HTS and 80% through Copper at 77 at 5kA (roughly speaking).

So the decision was made to drive the current to much higher towards 8-10 kA at 77 K depending what Hugo gets through with his set up. This was intended to push to higher current to force HTS run on the Ic and fill it. After we can see if a lot of the current then starts going through the copper and heat it up.

The second step is to take the HTS away and do the same Current-Temp curves for the copper. Then it’s possible to estimate the current through the HTS.

Next steps 2

Remove the Voltage tap on the small copper clamp.

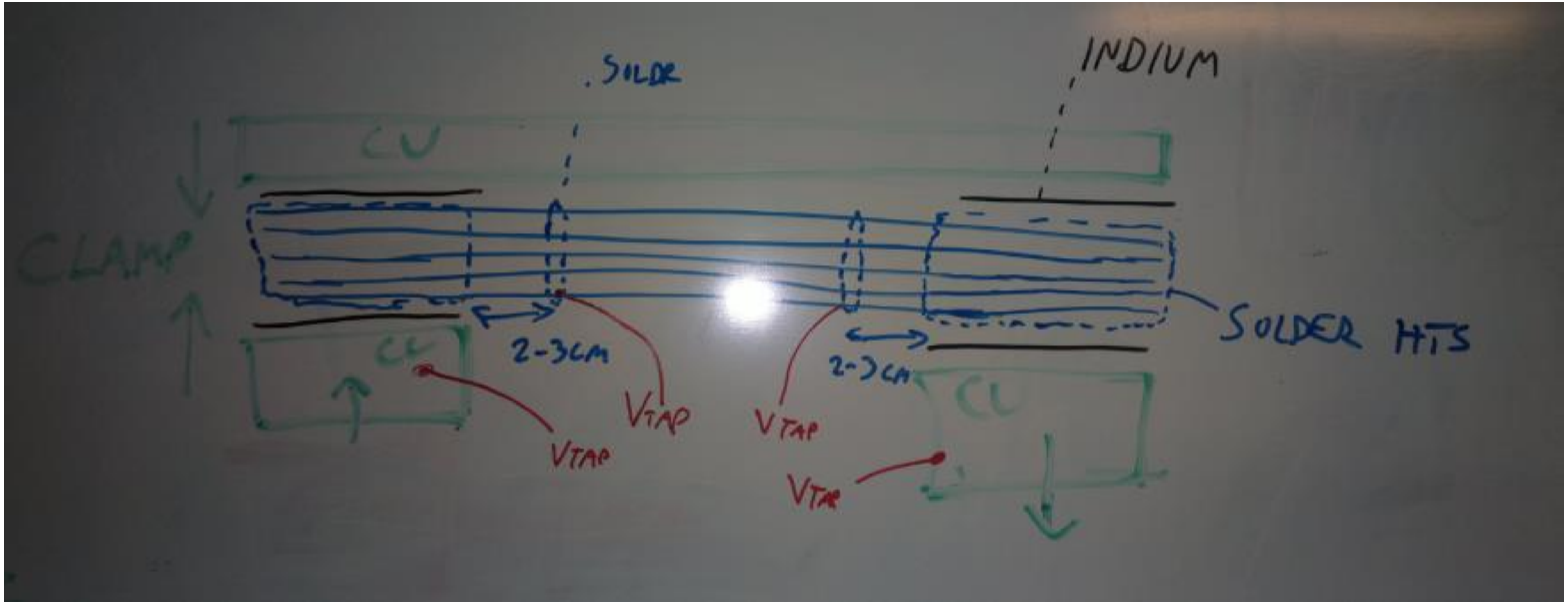
We solder a voltage tap 2-3 cm from the soldered ends with a ring of solder around the HTS to make sure we can measure the COPPER to HTS joint resistance (Picture next slide).

Twist all the sensor wires to avoid current pick-up loops on the self-field of the conductor or shunt.

Decrease the copper section a lot. Put a copper shunt on top of HTS instead of below compared to the current leads (Picture next slide).

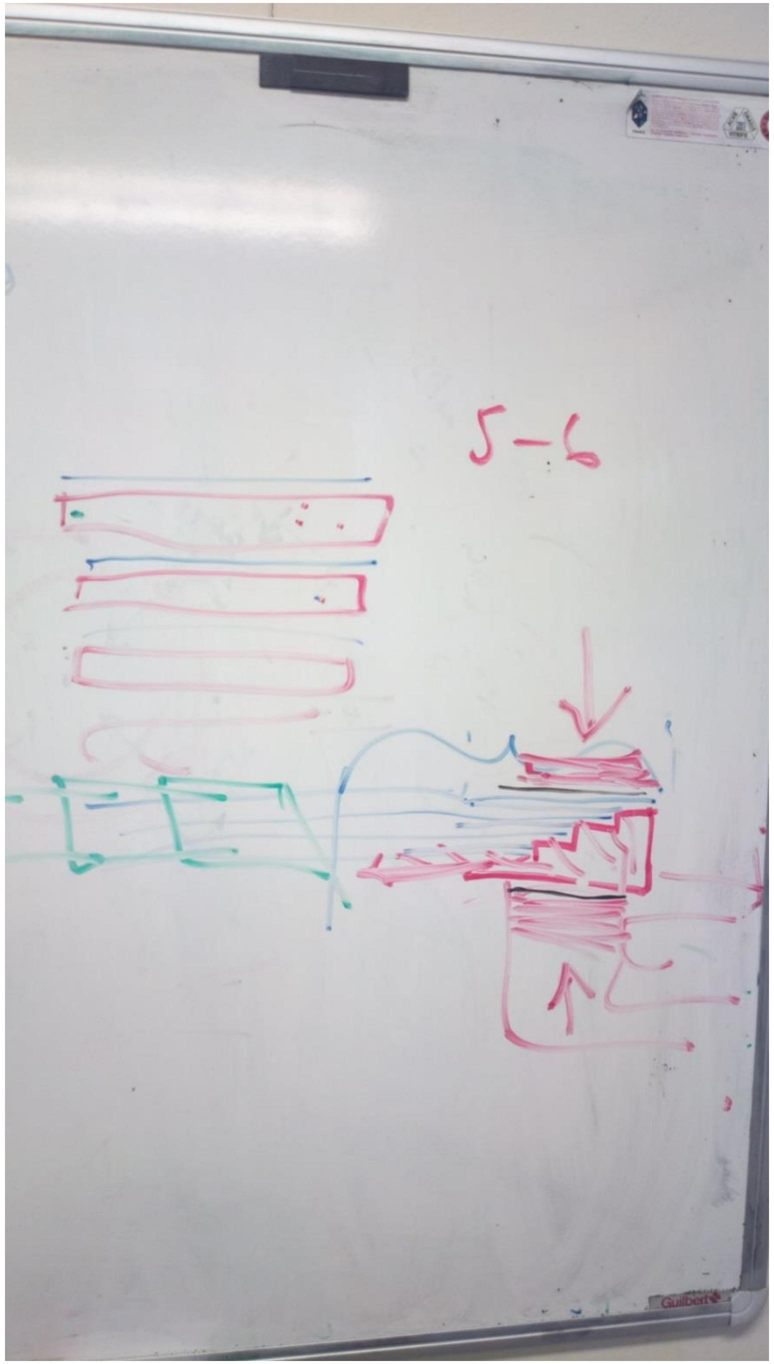
We measure again and push the current as much as we need to see the small “kink” on the voltage when the HTS is fully saturated with current and the copper starts heating up.

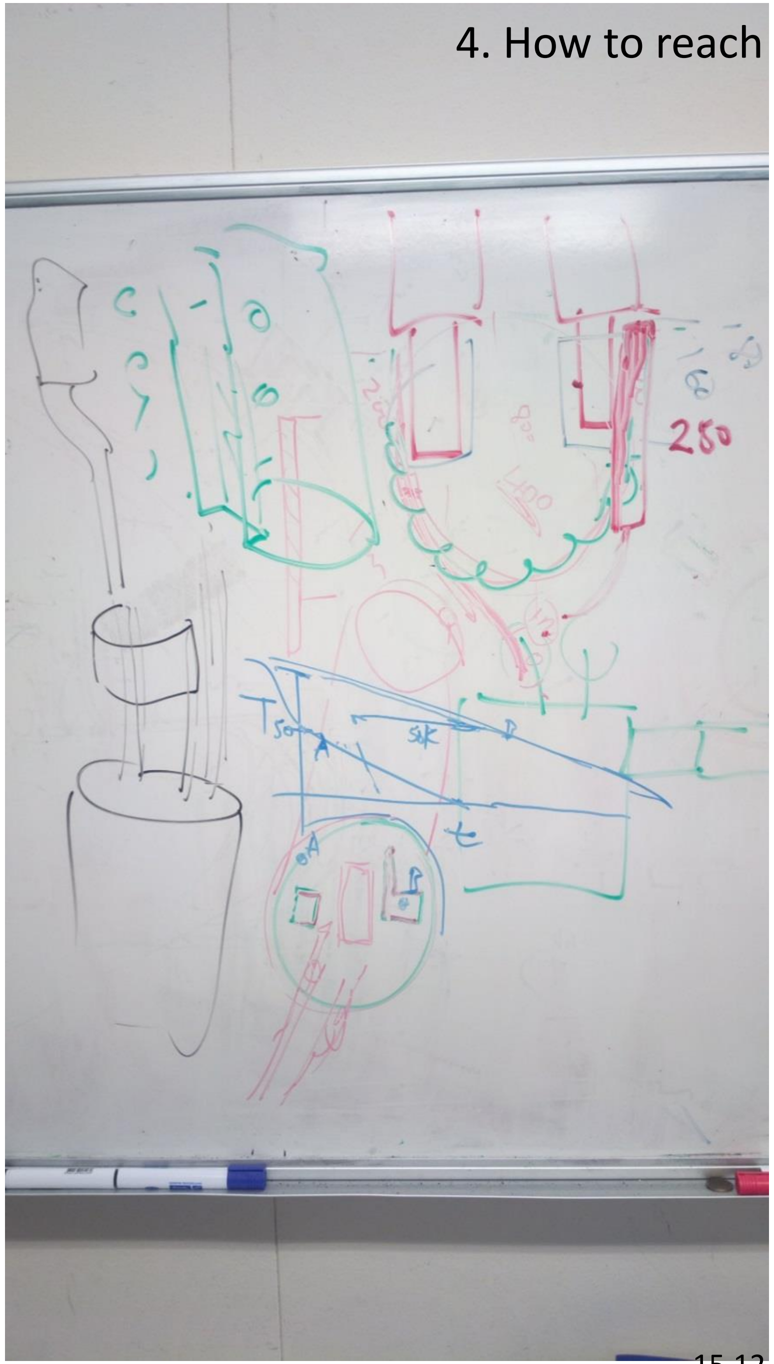
We build a small current network model to counter check with the measurements.



Current coming in from the bottom

4. How to reach the objectives?





Summary

Finite Element Analysis

FEA Status 14.12.2015 (completed or almost, in progress, planned)

Object	configuration		Type of FEA	Motivation	Stage	Software
FM0	stand-alone	2D	electro-mag.-mech. analysis	strength and deformation		Ansys / Maxwell
	insert	2D	electro-mag.-mech. analysis	strength and deformation		Ansys / Maxwell
FM0	stand-alone	3D	electro-mag.-mech. analysis	strength and deformation		Ansys / Opera
	insert	3D	electro-mag.-mech. analysis	strength and deformation		Ansys / Opera
FM2	stand-alone	2D	electro-mag.-mech. analysis	strength and deformation		Ansys / Maxwell
	insert	2D	electro-mag.-mech. analysis	strength and deformation		Ansys / Maxwell
FM2	stand-alone	3D	electro-mag.-mech. analysis	strength and deformation		Ansys / Opera
	insert	3D	electro-mag.-mech. analysis	strength and deformation		Ansys / Opera

Summary

Finite Element Analysis

Object	configuration		Type of FEA	Motivation	Stage	Software
FM0	stand-alone	2D	Thermal analysis	cool-down RT to 4 K		Ansys
FM2	stand-alone	2D	Thermal analysis	cool-down RT to 4 K		Ansys
	insert	2D	Thermal analysis	cool-down RT to 4 K		Ansys
FM0 coil	powering	3D	Thermal analysis	Temperature sensors		Ansys
FM0	stand-alone	3D	Modal analysis	resonance frequency		Ansys
	insert	3D	Modal analysis	resonance frequency		Ansys
FM2	stand-alone	3D	Modal analysis	resonance frequency		Ansys
	insert	3D	Modal analysis	resonance frequency		Ansys
HTS tape in Roebel	winding	2D	mechanical	strength and deformation		Ansys
Roebel	powering	3D	mechanical	axial E-modulus		Ansys
Roebel	powering	3D	mechanical	transverse E-modulus		Ansys

Summary Measurements / tests

Object	Load step	Motivation	Note	Stage	Location
Impregnated Roebel	powering	axial E-modulus			927
Impregnated Roebel	powering	transverse E-modulus	Wide and narrow face		927
SuperOx 12 mm tape	cool-down	Coeff. of thermal exp.			927
Other necessary materials	cool-down	Coeff. of thermal exp.			927
HTS tape	cool-down	delamination	peeling-off edge		???
	cool-down	delamination	peeling-off middle		???
HTS tape	powering	delamination	peeling-off edge		???
	powering	delamination	peeling-off middle		???
Impregnated Roebel	powering	axial strain + current	liquid nitrogen		???
Optical fibers / quench	powering	to detect quench	Feather M0		SM18
Quench antennas	powering	to detect quench	Feather M0		SM18
Acoustic sensors	powering	to detect quench	Feather M0		SM18
Temperature sensors	powering	to detect quench	Feather M0		SM18
Current leads /HTS	powering	to ensure stability			SM18

To do list

- I need to start with FBGA data read-out
- I need to learn LabView
- Feather M0 and M2 wiring
- Especially lack of space in Feather M2 (needs careful thoughts for fitting twisted wire pairs)
- Wiring diagram
- Etc…


Grazie, kiitos danke schön!
Onnellista Joulua ja hyvää
uutta vuotta!
Tanti auguri di buon Natale
e felice anno nuovo!
Frohe Weichnacten und
guten Rutsch ins neues
Jahr!!
15.12.2015, Jaakko Murtomäki