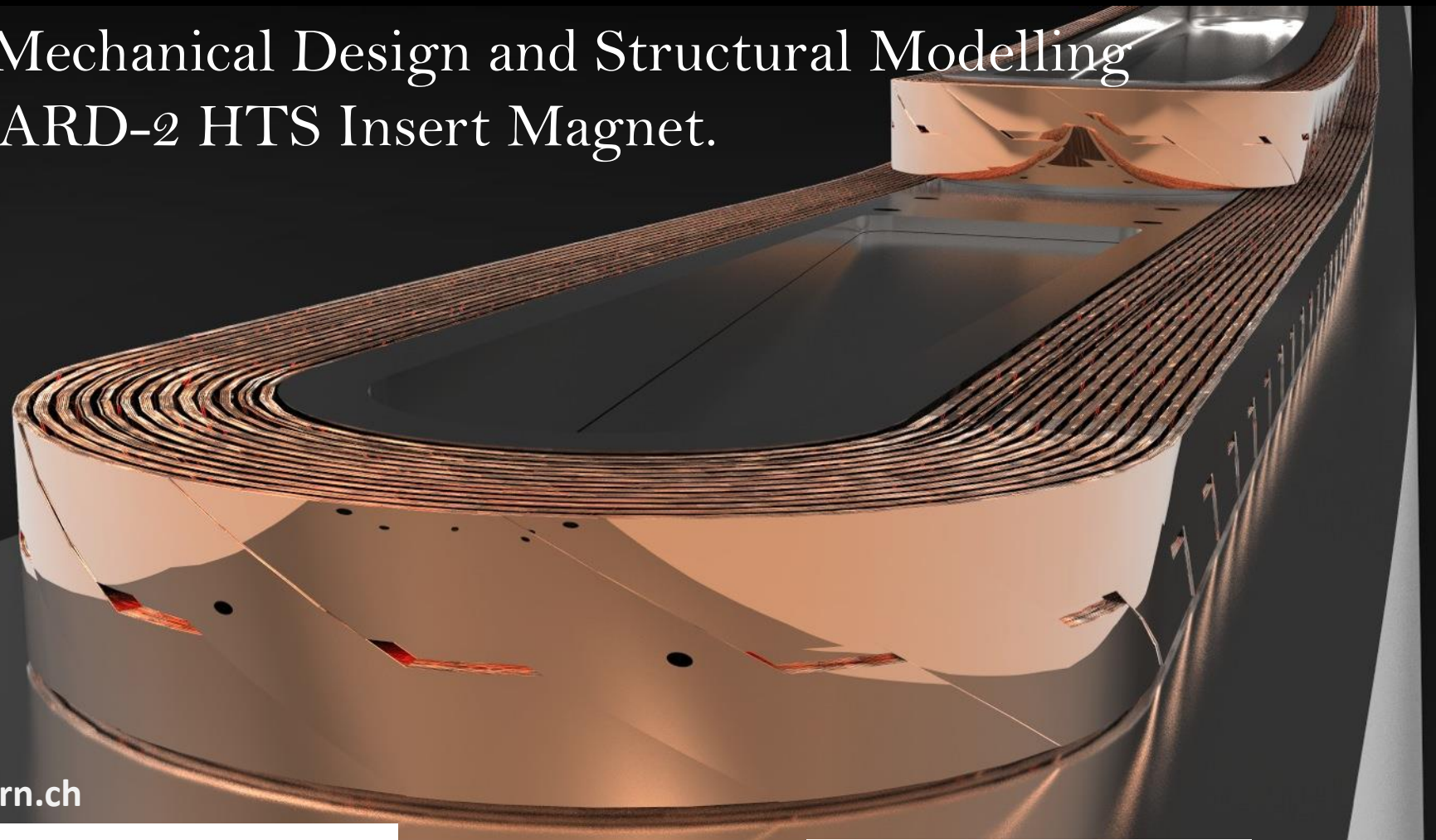
Challenges in Mechanical Design and Structural Modelling of WP10 EuCARD-2 HTS Insert Magnet.



http://eucard2.web.cern.ch

EuCARD-2 is co-funded by the partners and the European Commission
under Capacities 7th Framework Programme, Grant Agreement 312453.

TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

27.4. 2016

Jaakko Murtomäki, G. Kirby, J. van Nugteren

Talk Overview

- EuCARD-2 High Temperature Superconductor (HTS) Project
- WP10 Magnet design: 40 mm Clear-Aperture Accelerator Dipole Demonstrator
  - Cable: so-called “Röbel” wound from ReBCO tapes
  - Conductor: HTS material ReBCO

- Management of electromagnetic forces
- Non-homogenous current distribution

ReBCO Coated Conductor Tape

We wanted to make use of high critical current with the field angular dependency

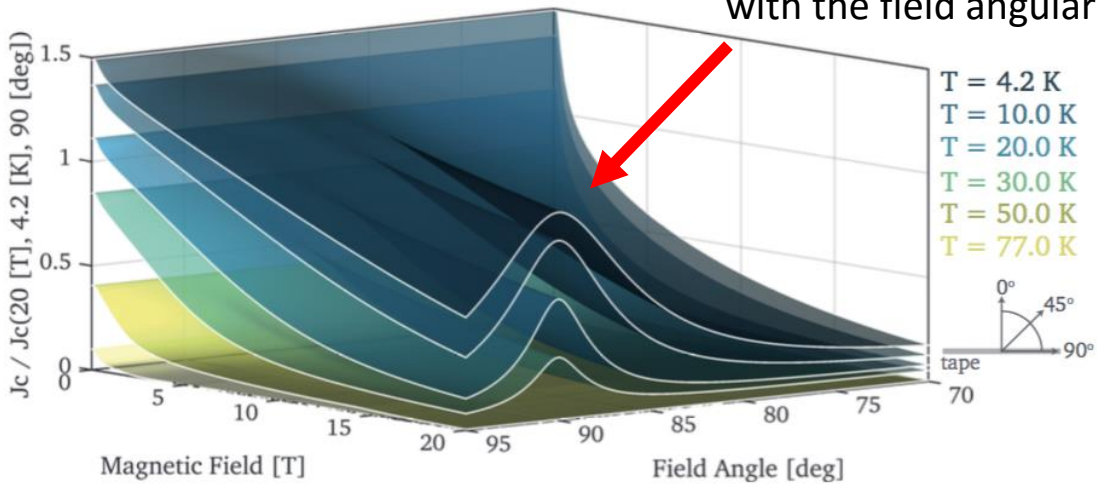


Figure 1.3: *Normalized critical current as function of magnetic field, temperature, and field angle of state of the art ReBCO coated conductor source data [3].*

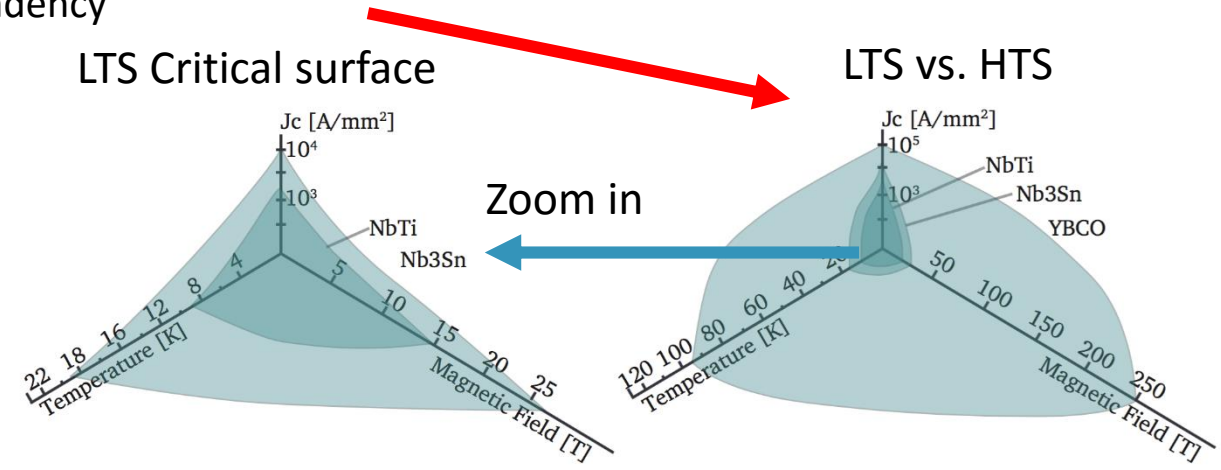


Figure 1.1: *Comparison between the critical surfaces of LTS and HTS.*

YBCO is profoundly different from LTS: The YBCO doesn't have fine filaments that take the current like in LTS, but is a wide tape.

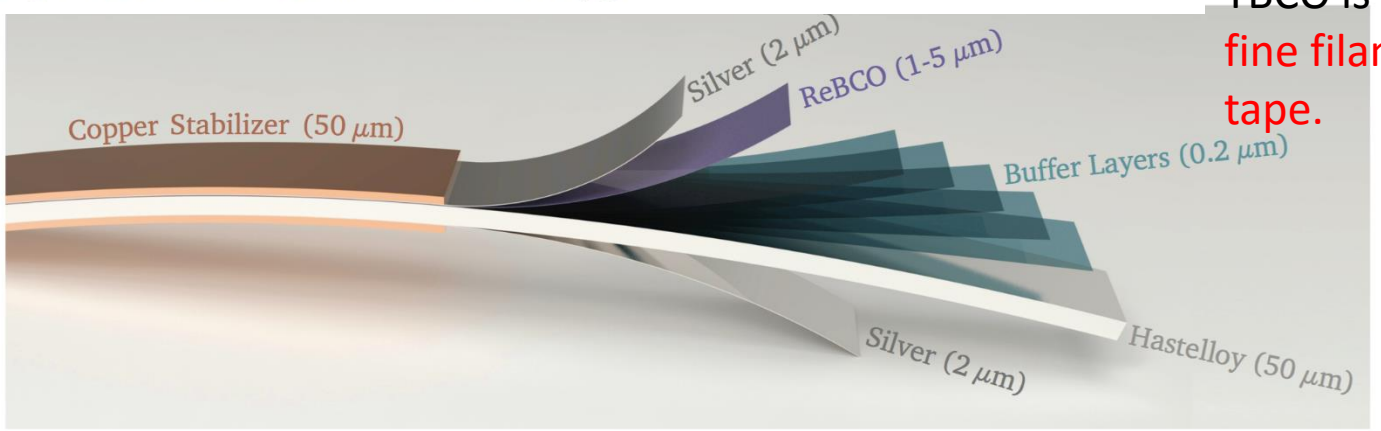
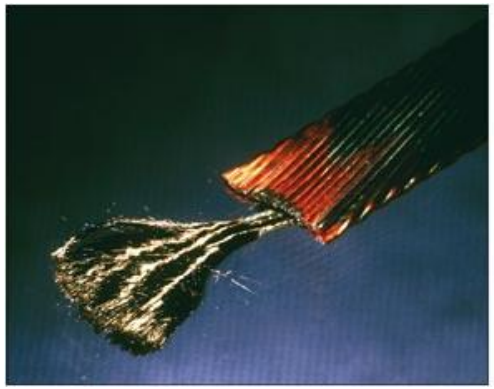


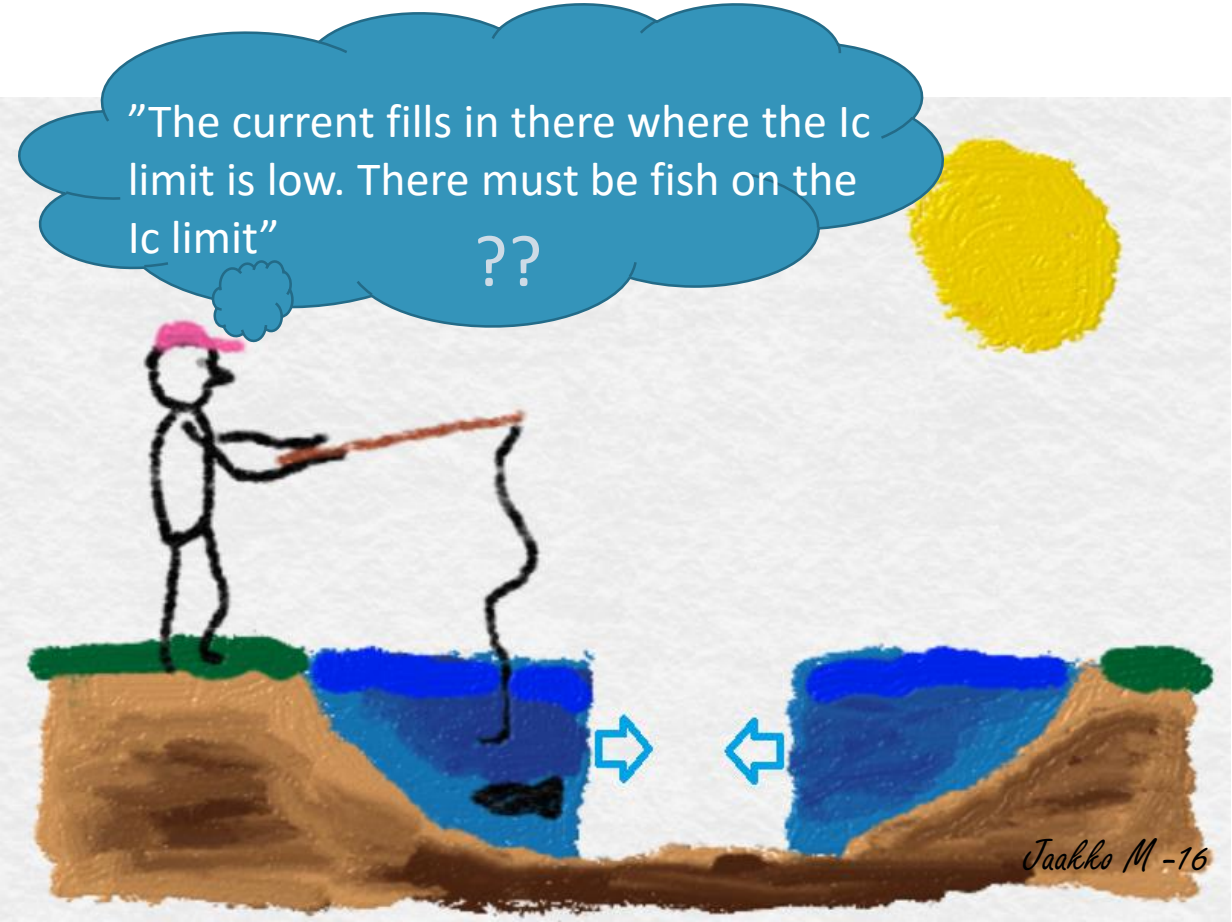
Figure 1.2: *Material composition of ReBCO coated conductor. For visual clearness the tape is cut in half so that the inside becomes visible. In reality the copper and the silver layers fully surround the tape.*



ReBCO Coated Conductor Tape

The HTS is special, current is not running flat in one continuum, but is filling in from the sides of the wide tape!

Standard river



ReBCO Coated Conductor Tape

CORC, Twisted stack ,and Röbel geometries, we chose Röbel to be able to use high critical current density parallel to the tape

Röbel

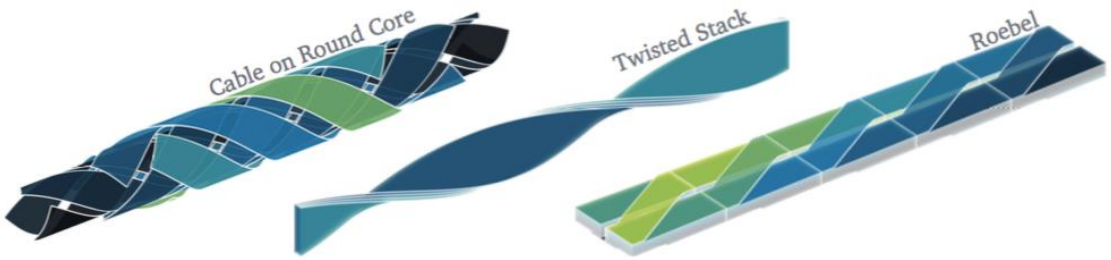
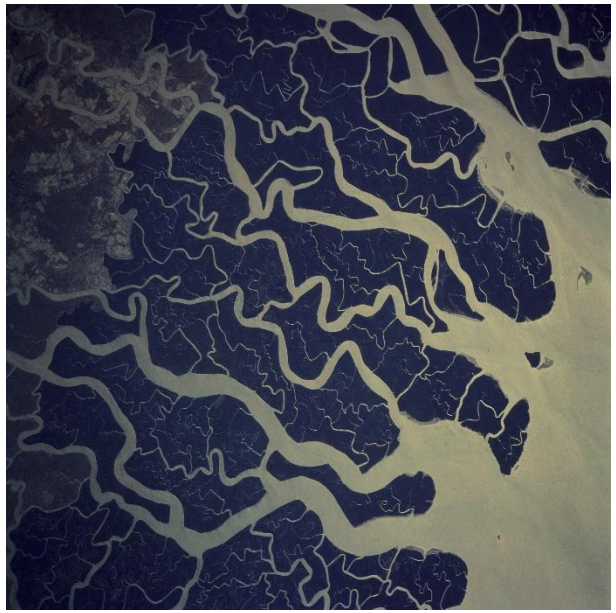


Figure 1.4: *Possible geometries for constructing a cable with ReBCO coated conductor.*



The cable is composed of HTS Rivers…

Actually it's bit like Netherlands, but with bizarre channels where current is filling in from the sides

PUNCH-AND-COAT

- Standard Roebel production sequence
  - Produce Cu-coated tape
  - Punch meanders
  - Assemble cable
- Modified Roebel production sequence
  - Produce Ag-capped tape
  - Punch meanders (less than 5% I_C degradation !)
  - Cu-coat (dog-boning !)
  - Assemble cable

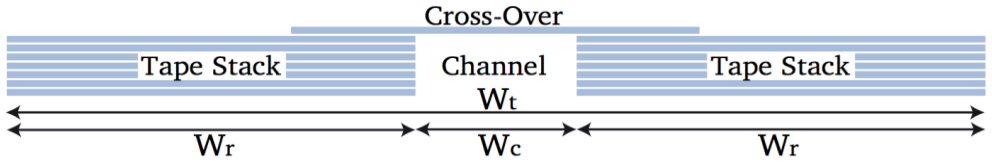
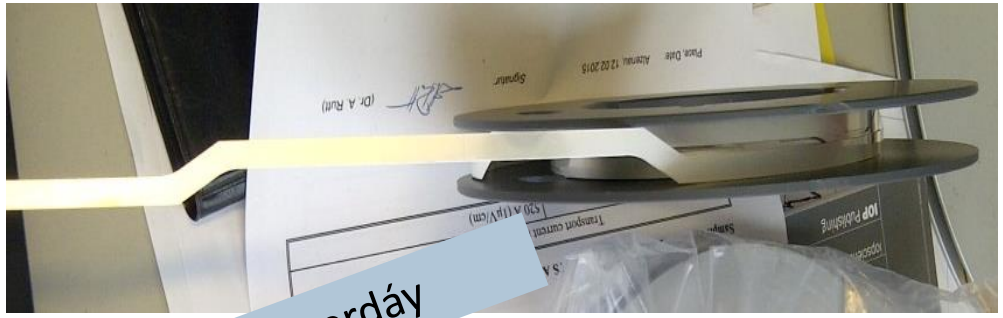


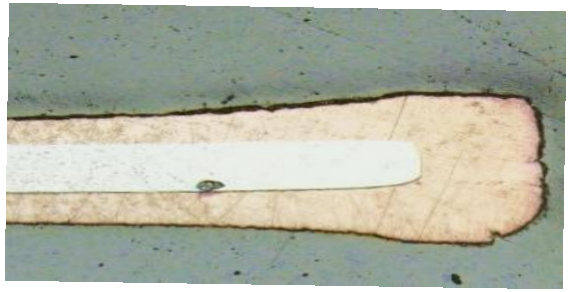
Figure 2.2: *Cross section and definition of parameters for the Roebel cable. The geometry shown is for a cable with an odd number of tapes, resulting in alternating cross-overs along the length of the cable. Therefore in this cross-section the cross-over is only shown on one side.*

Ag capped punched tape

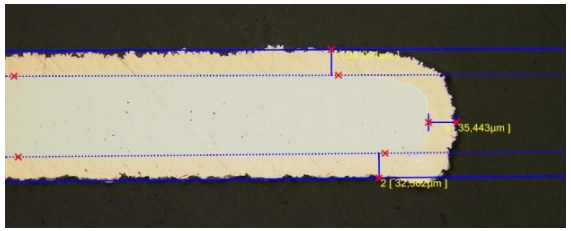


Already covered by Anna Kario from KIT yesterday

2x40 µm coating



2x20 µm coating

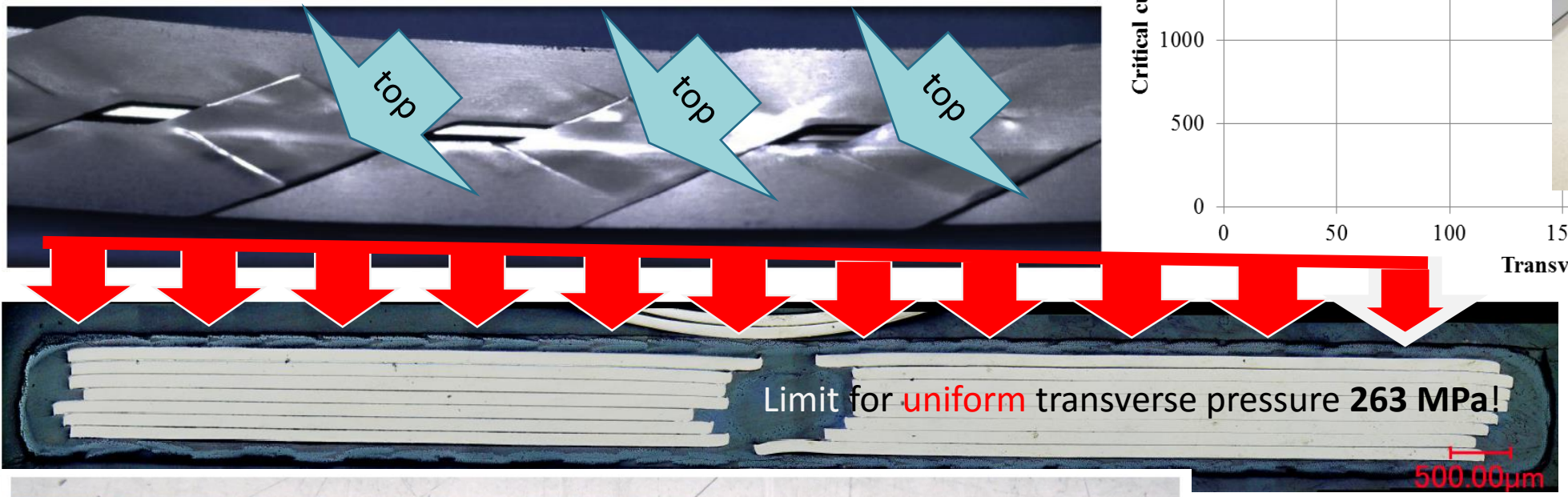


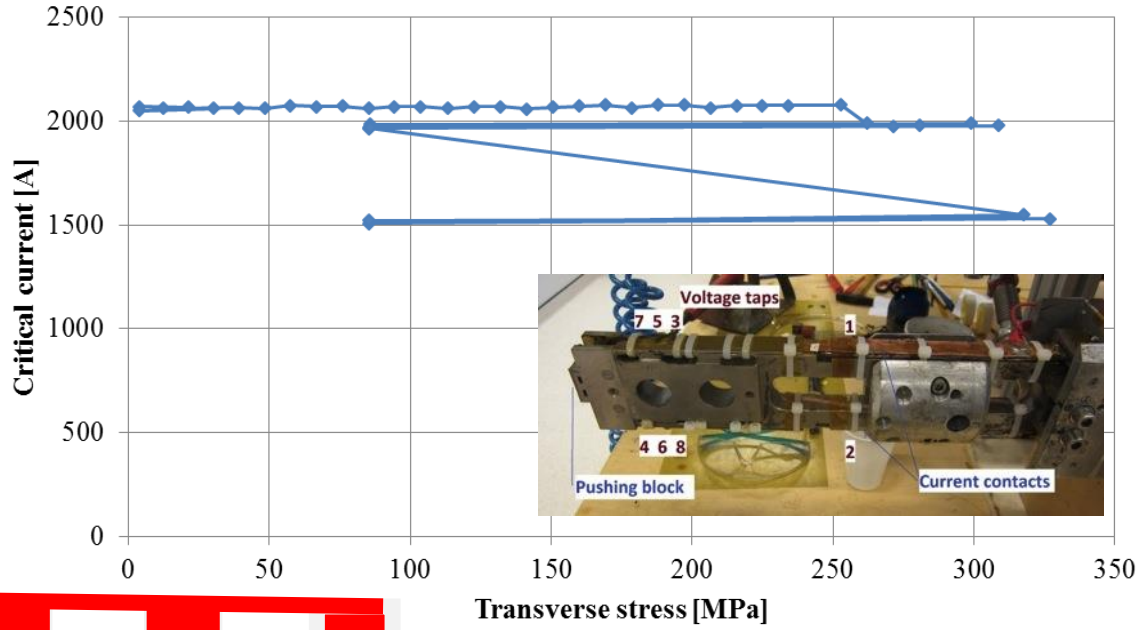
Optimized
2x20 µm coating

Impregnation

UNIVERSITY OF TWENTE.

- Impregnation is obligatory
- With glass fiber sleeve insulation





TRANSVERSE PRESSURE DEPENDENCE OF THE CRITICAL CURRENT IN EPOXY IMPREGNATED REBCO ROEBEL CABLES

Simon Otten

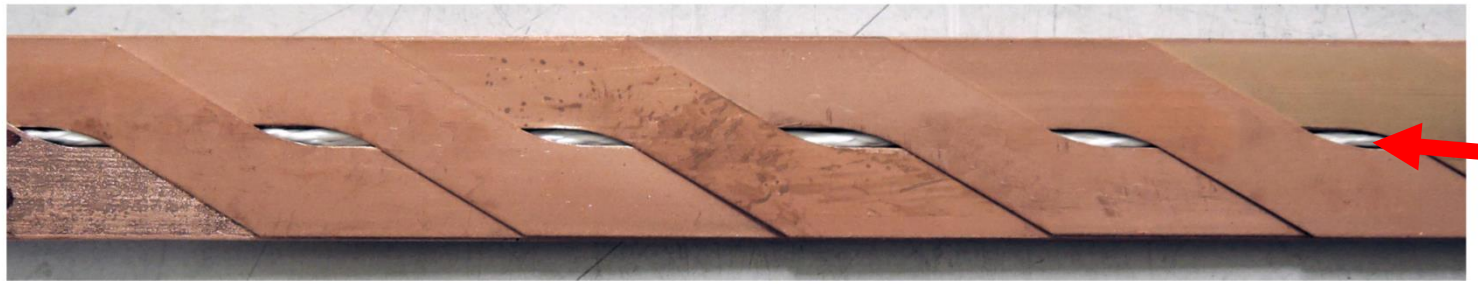


Figure 2.1: *Photograph of a Bruker-HTS Roebel cable used for FM0-4 with rope inserted into the central channel before winding and impregnation.*

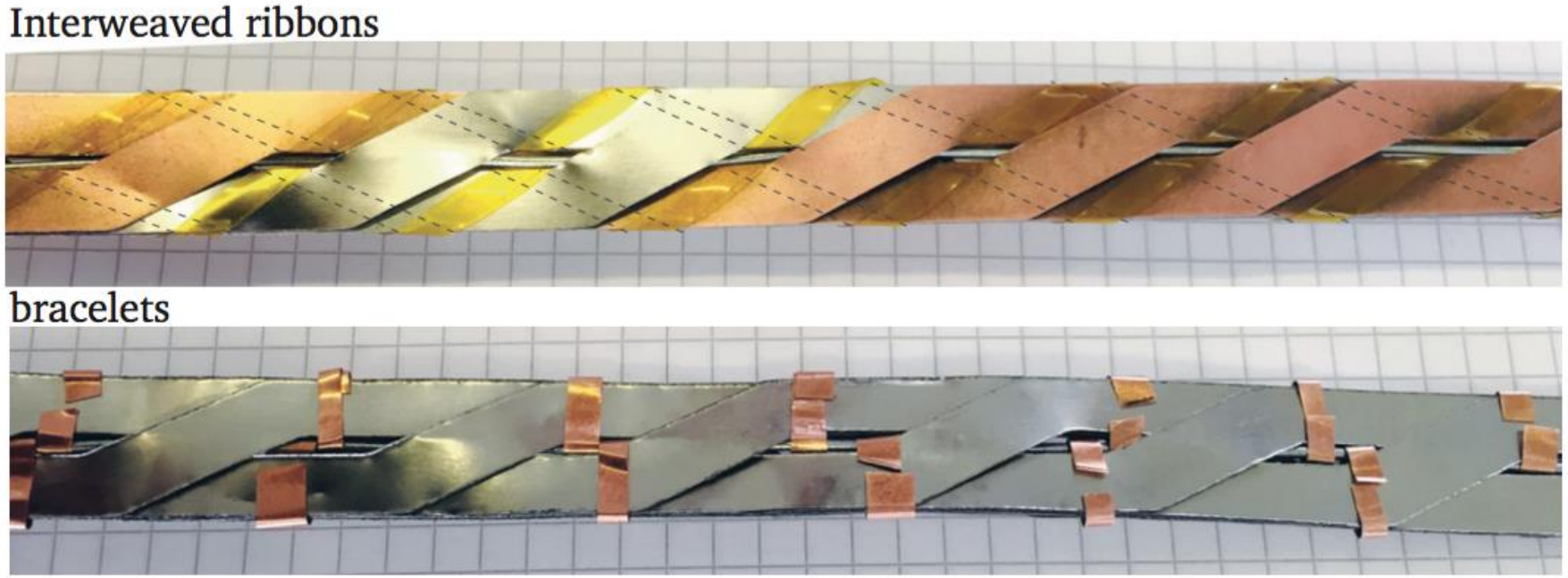


Figure 2.11: *Interweaved ribbons or bracelets to improve stability of the Roebel cable. The dotted lines show how the polyimid ribbons are positioned on the backside of the cable.*

The challenges with the conductor

- With YBCO there are two challenges,
  - quench protection ; we have solutions, but we skip details for your convenience
  - current distribution ;
    - Effect on field quality ; there are solutions for it ; but not explained today
    - Management of the mechanical forces becomes intrique ;

    We are worried about the forces because the current flows at the edge of the tape.

INTRODUCTION TO THE EUCARD2 WP 10 PROJECT

- Racetrack wound around aperture by lifting the central decks; called " flared ends "

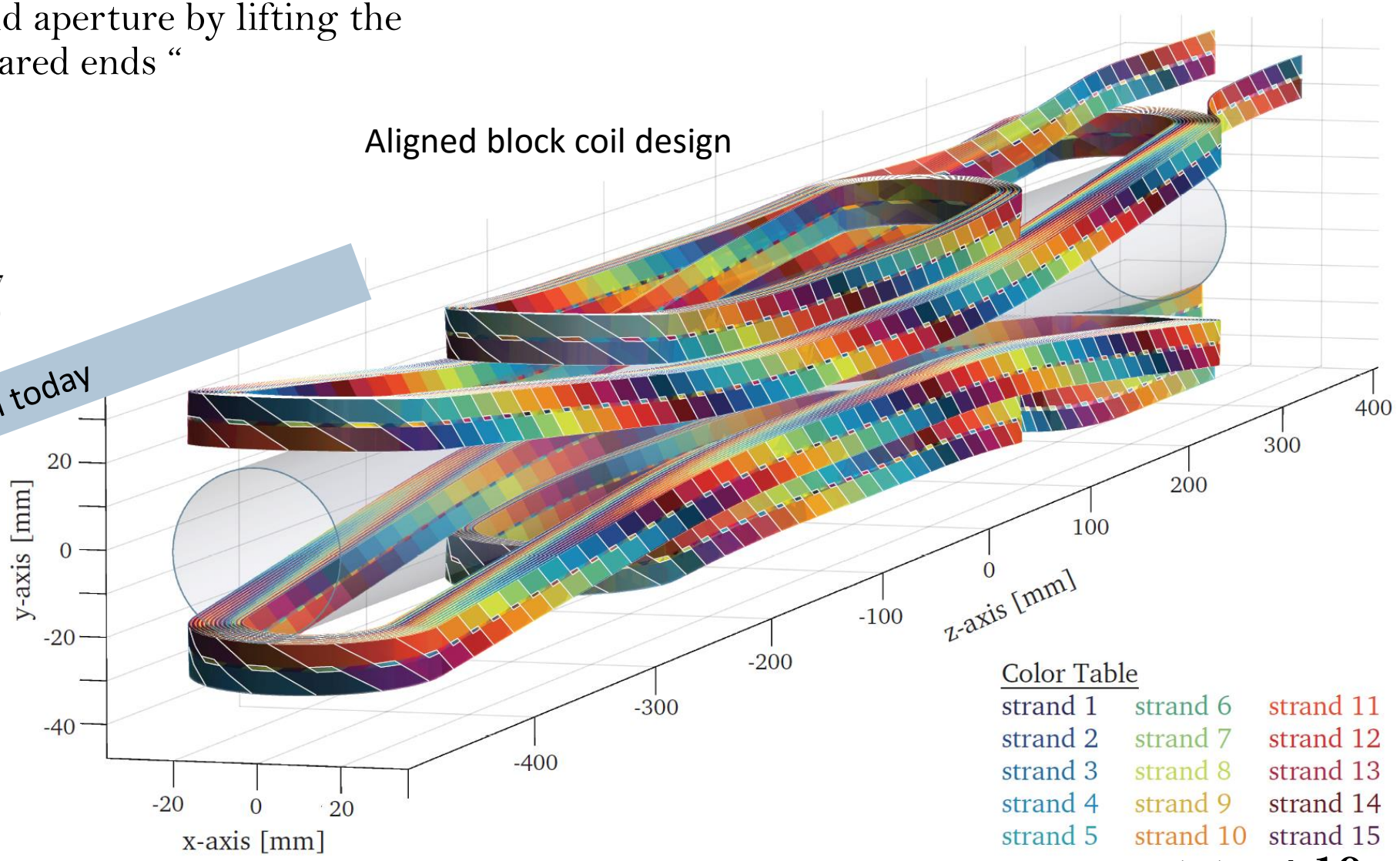
- EuCaRD2 Work package 10 Accelerator dipole
- 5 Tesla stand alone the workpackage requirement

(but we decided to go further for 17 Tesla in 13 Tesla background field)

- 40 mm aperture
- 10 kA class cable
- @ 4.5K

Already covered by Lucio Rossi today

Aligned block coil design



Magnetic field direction and forces

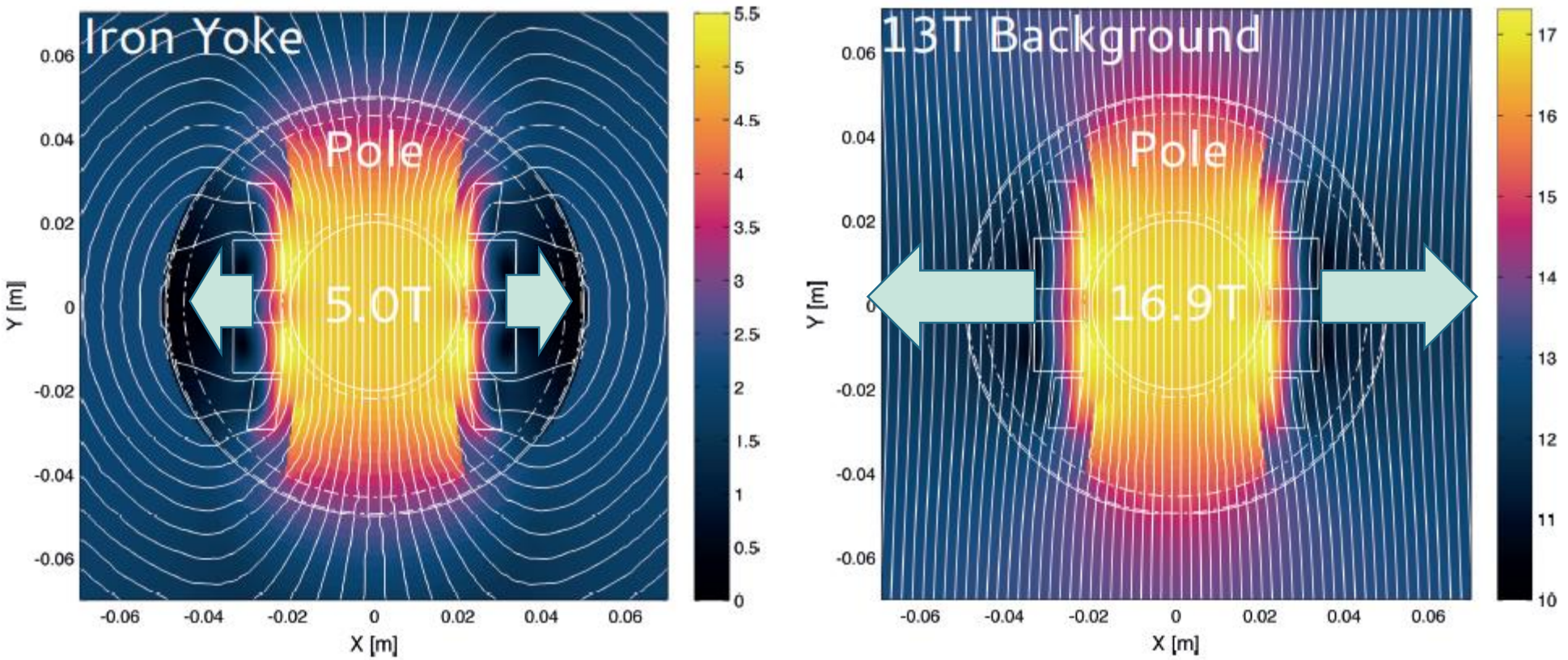
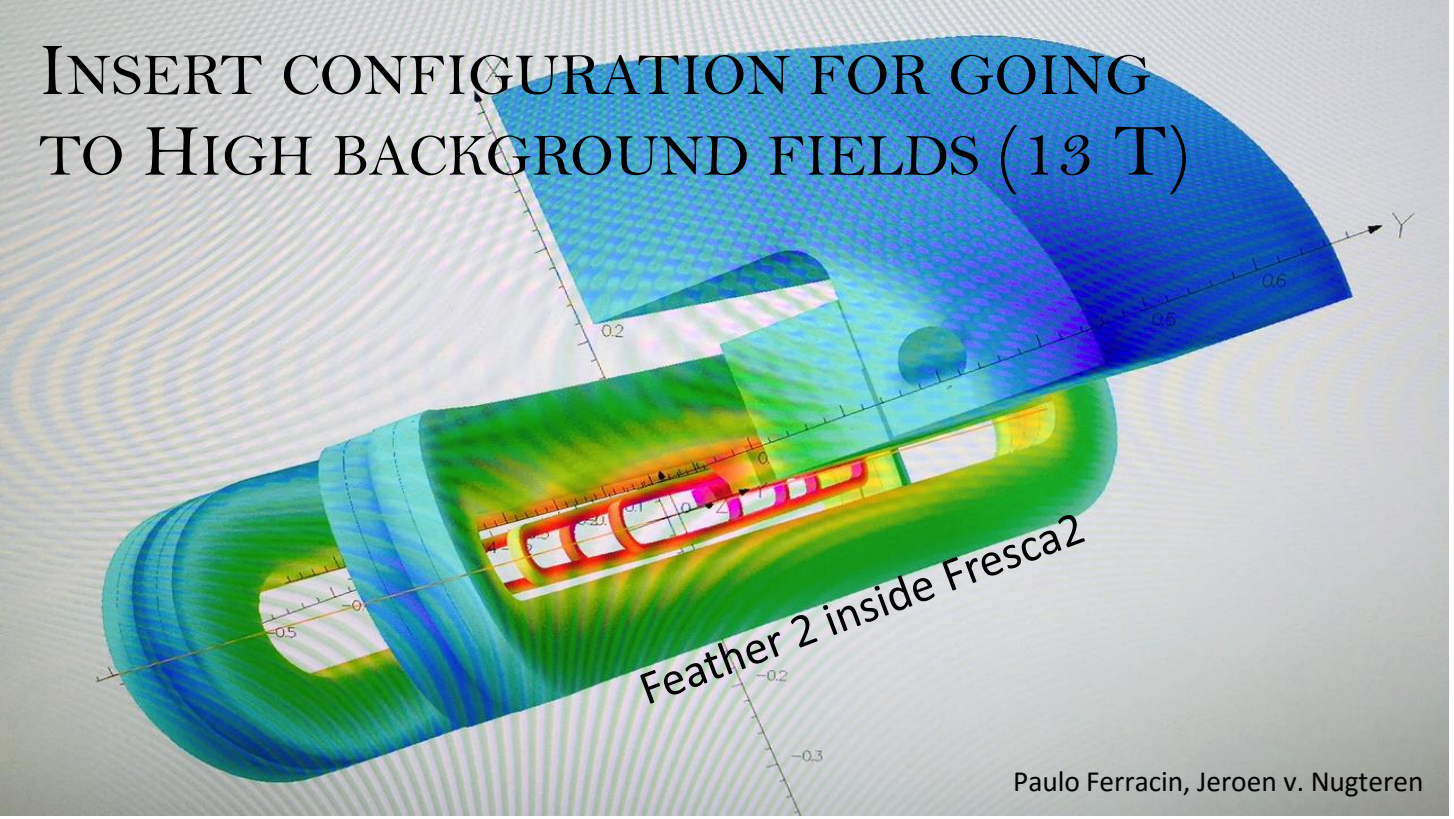
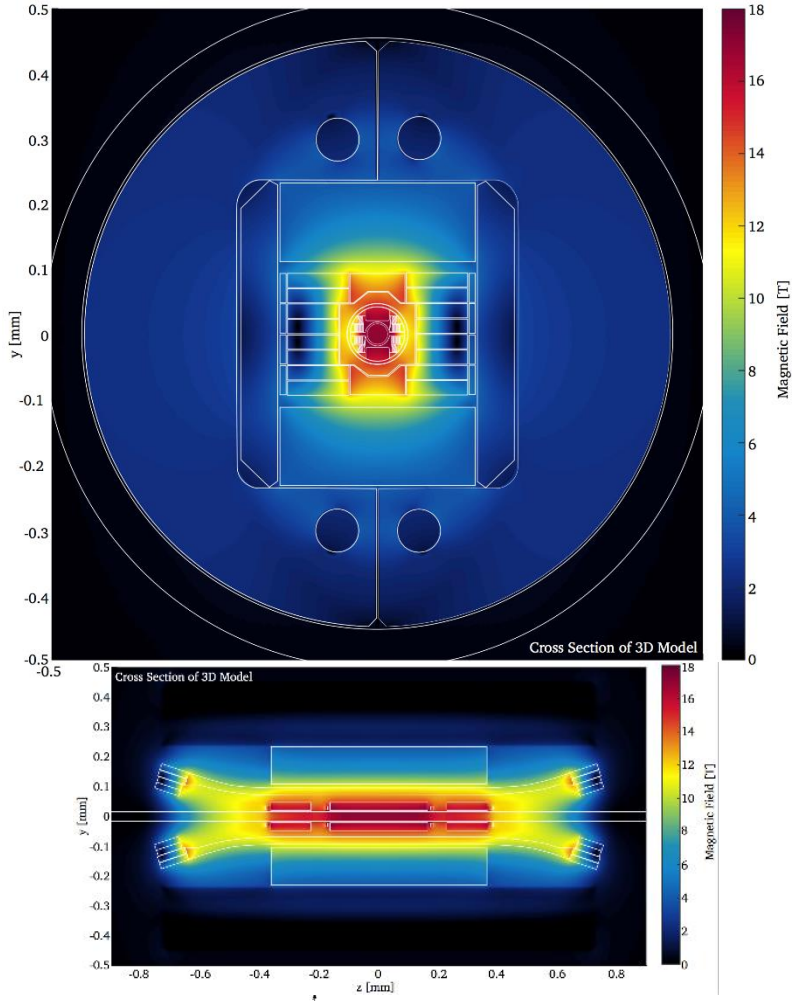


Figure 2.11: Calculated fieldlines for a 2D cross section of the Feather-M2 magnet. On the left side standalone in iron yoke and on the right side in a $13\,T$ background field.

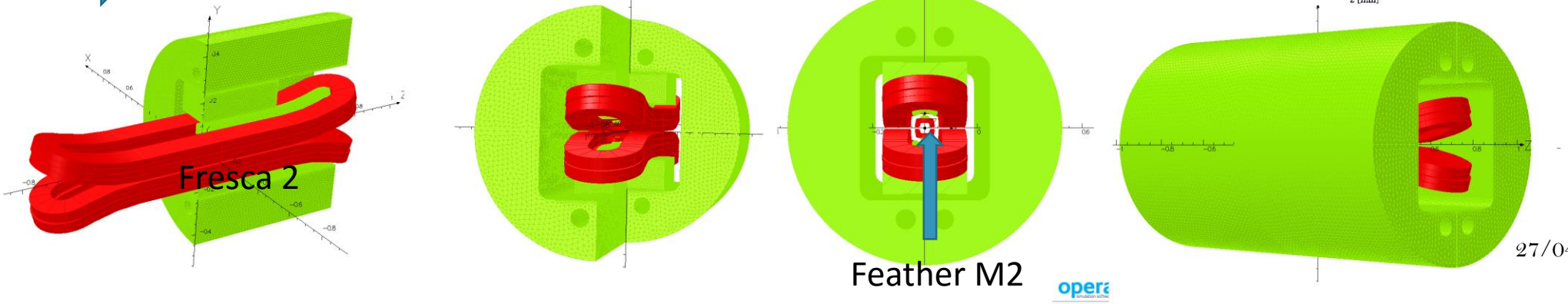
Insert configuration for going to High background fields (13 T)





The main mechanical constraint is that the insert has to be mechanically self-supported and decoupled from the Fresca 2 outsert magnet.

Main constraint for supports of the Feather!



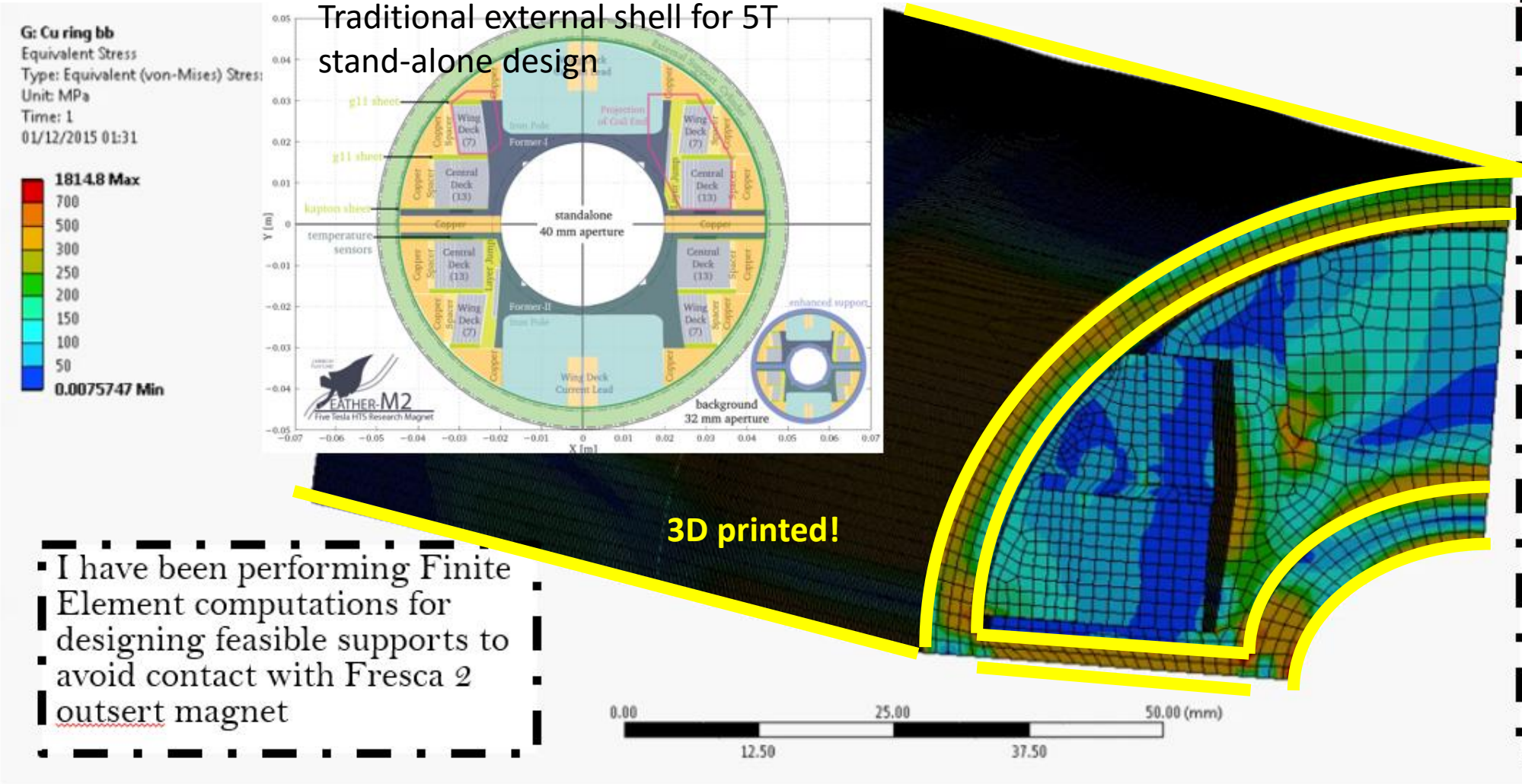
In 17 T, electromagnetic forces are 253 t per one side of the magnet, supported in the 99 mm diameter magnet. (and 340 t/m) like LHC dipole!

What would you do to support this? In 17 to 20 T ?

Image thanks to Jeroen Van Nugteren.

THE MECHANICAL ANALYSIS WITH HOMOGENOUS CURRENT DISTRIBUTION

Computed at 9kA + 12 T background field = 17 T



We cheated a little bit

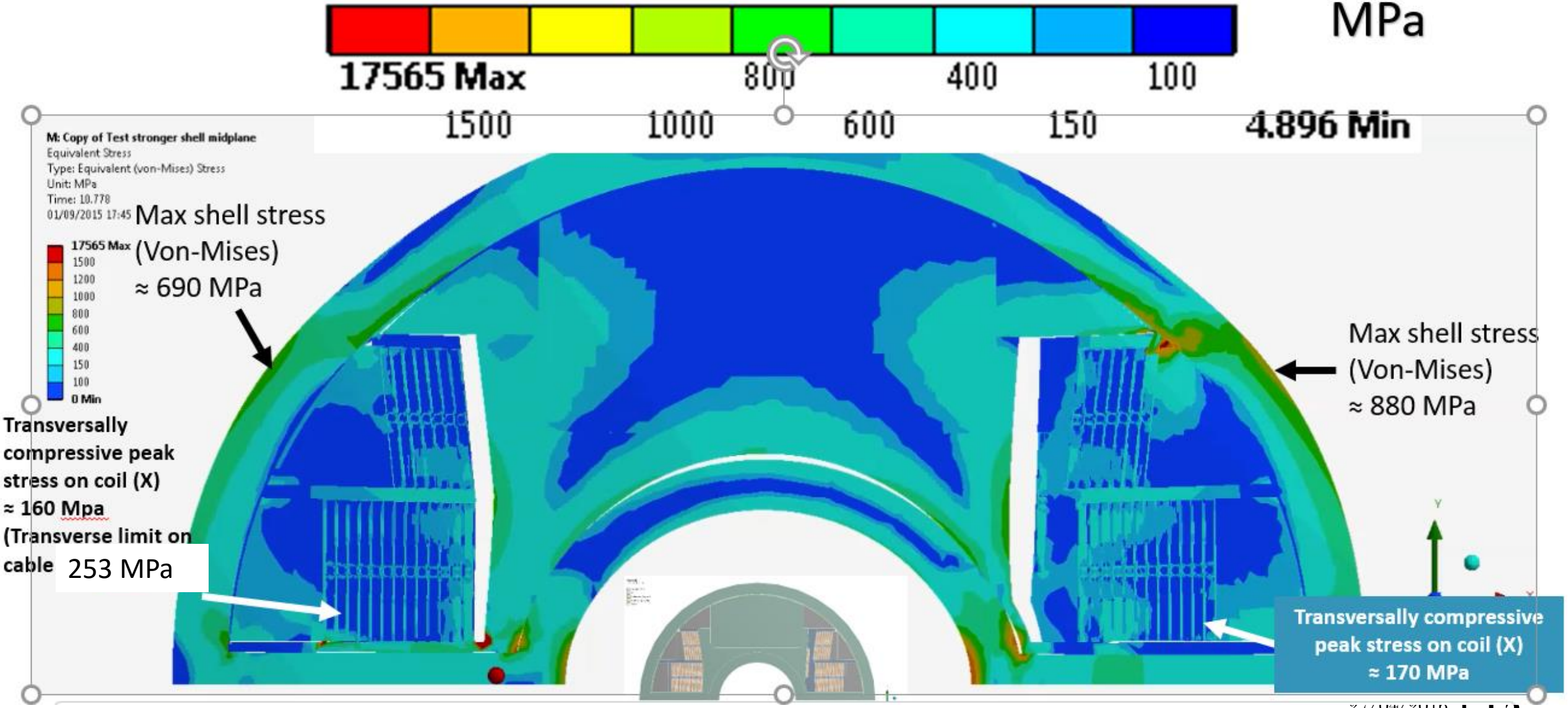
The EuCARD-2 requirement is 40 mm aperture and 5T. for 20T, we change the traditional external shell to a 3D printed integral support comprising of external and internal shell and mid-plane connection between the shells for extra support. But we trade off 4 mm radially from the aperture.

I have been performing Finite Element computations for designing feasible supports to avoid contact with Fresca 2 outsert magnet

No pre-stress is applied to the dipole magnet design (compare LHC)! No shrinking shell concept

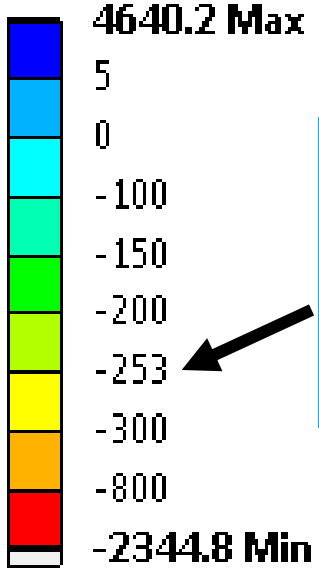
FEATHER M2 2D Von-Mises plot, Cool down to powering 9kA + 15 T background field ≈ 20 T in the bore

Assuming uniform current distribution over the cable

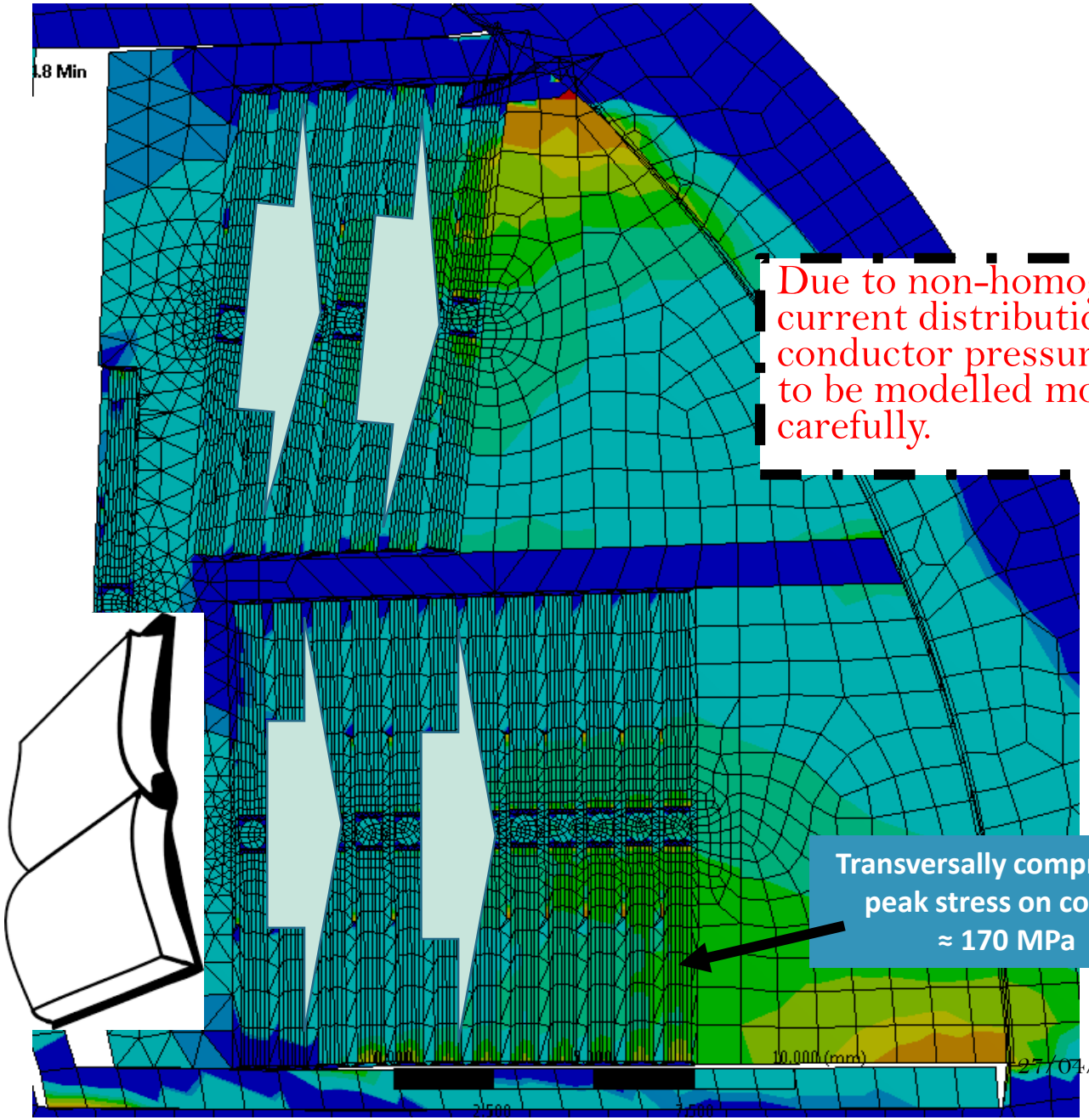


THE COMPRESSION OF THE COILS

M: Copy of Test stronger shell midplane
Normal Stress 3
Type: Normal Stress(X Axis)
Unit: MPa
Global Coordinate System
Time: 11
01/09/2015 20:06



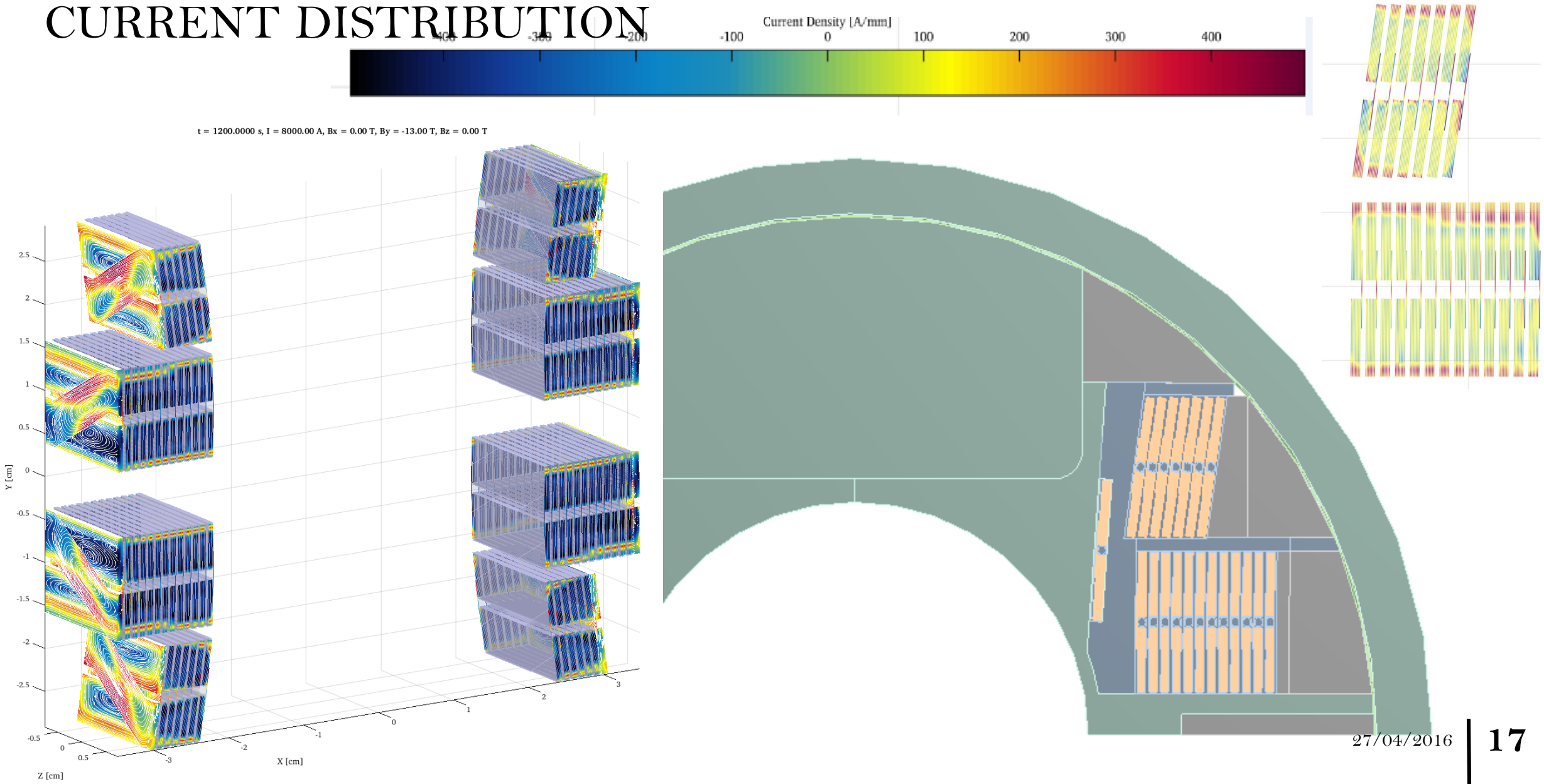
(REMEMBER: uniformly applied Transverse limit on cable 253 Mpa)



Due to non-homogenous current distribution, conductor pressure needs to be modelled more carefully.

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

The mechanical analysis with non-homogenous current distribution



Modeling the Coil pressure

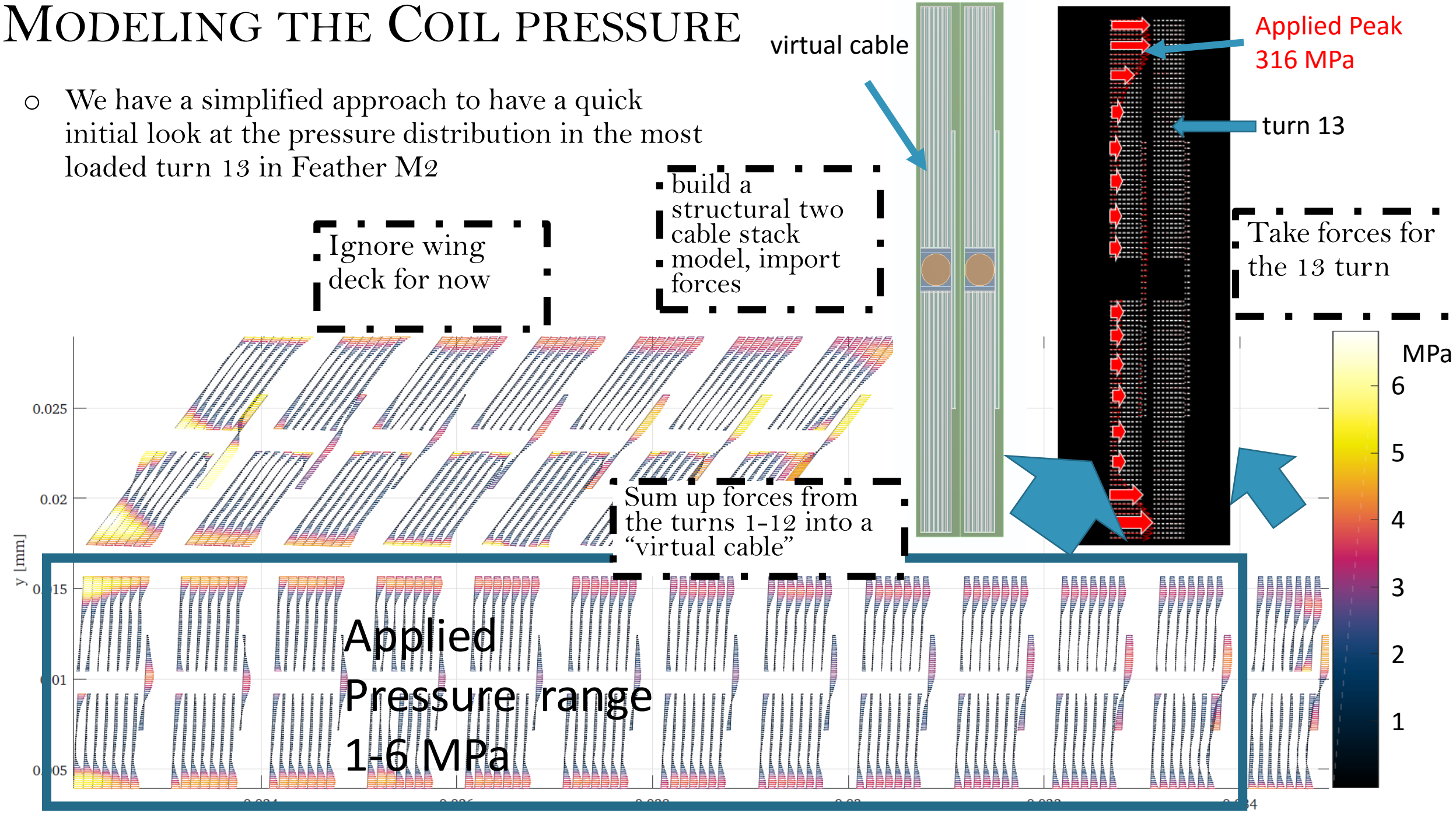
- We have a simplified approach to have a quick initial look at the pressure distribution in the most loaded turn 13 in Feather M2

Ignore wing deck for now

build a structural two cable stack model, import forces

Take forces for the 13 turn

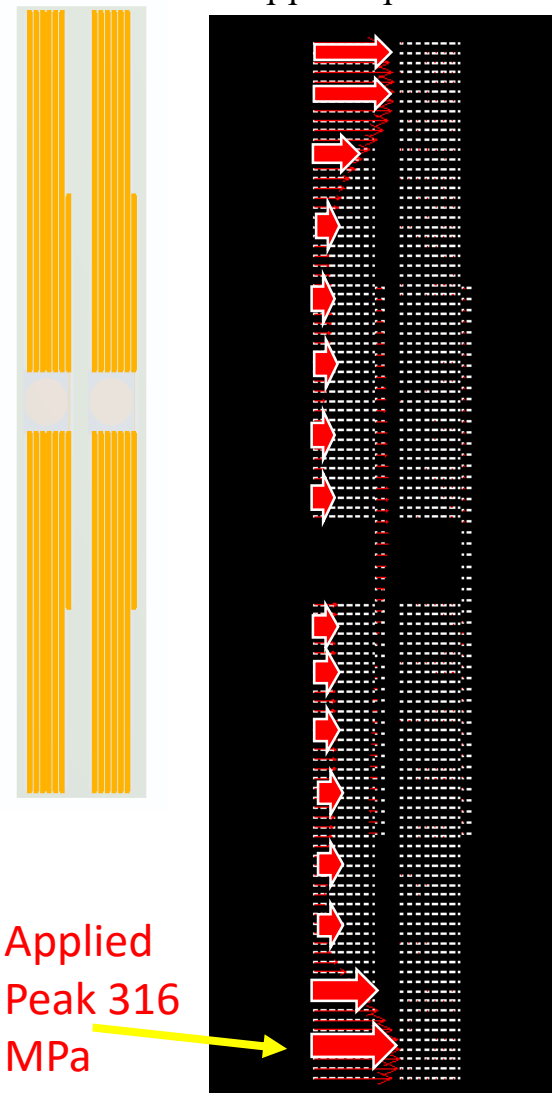
Sum up forces from the turns 1-12 into a "virtual cable"

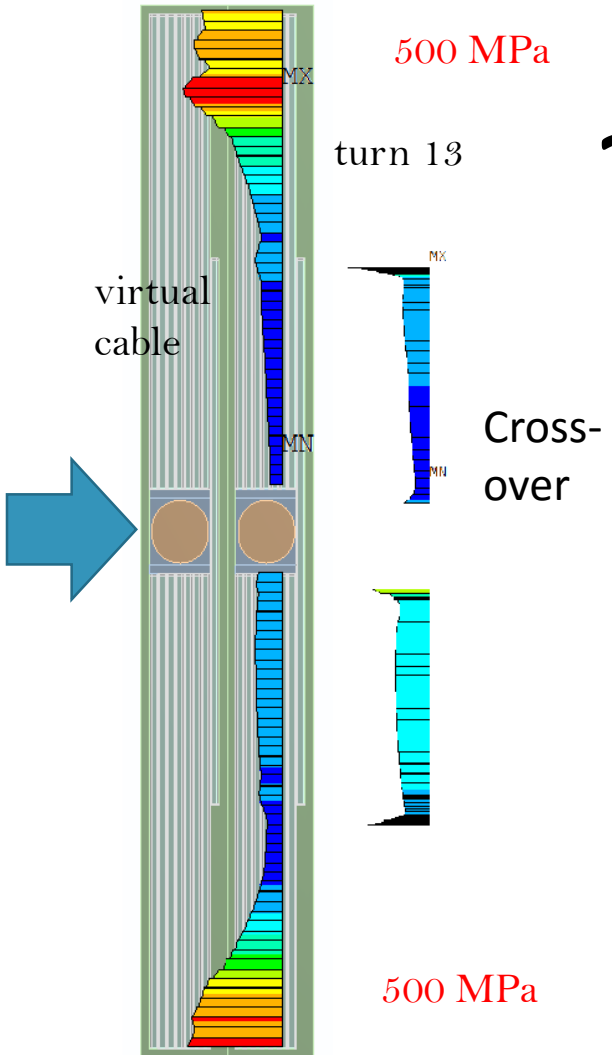


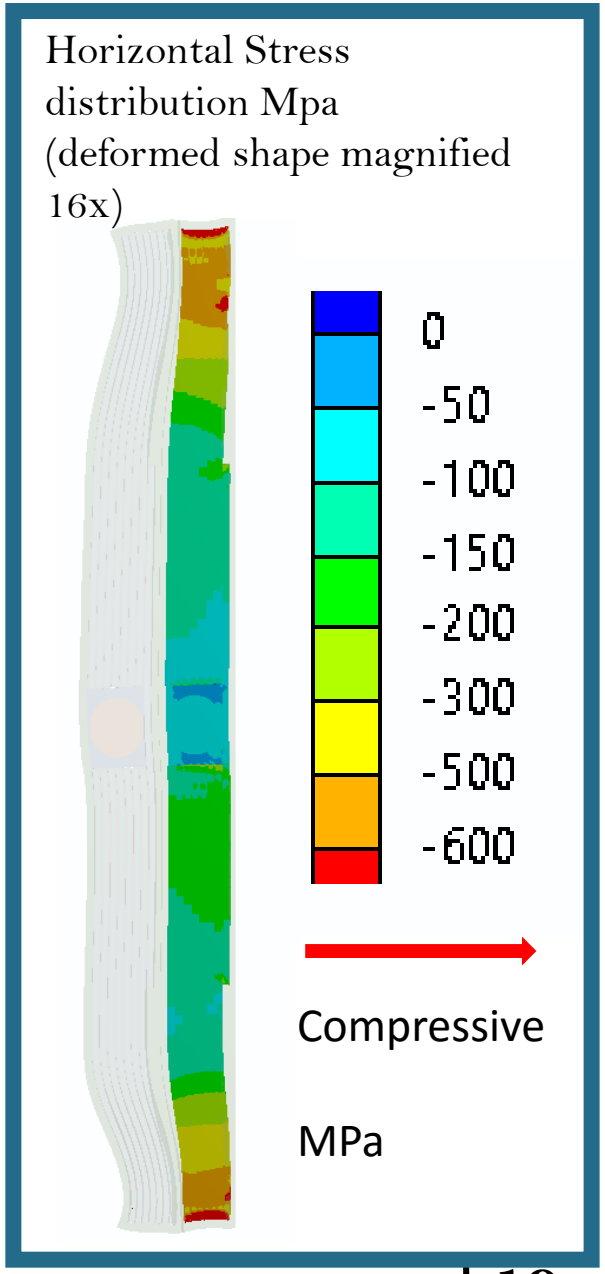
Modeling the Roebel Contact

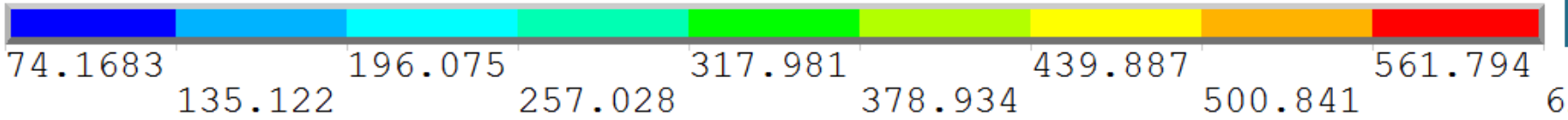
- Frictional sliding contacts assumed between tapes, realistic approach, since they are free to slide
- Increases stresses by 1/3 compared to fully glued tapes!

(REMEMBER: uniformly applied Transverse limit on cable 253 Mpa)









Conclusions

- The non-homogenous current distribution property for HTS was described
- Solutions for cable stress management and handling during assembly were presented.
- In 5 T, can be supported with traditional external shell
- The high field forces in 17-20 T in constrained space imply non-conventional supports for the demonstrator magnet
- The effect of non-homogenous transverse pressure need to be studied more carefully for the Feather M2 aligned block design, but for the cosinus theta as well!

Thank you!

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Back ups

Persistent current shim coils for accelerator Magnets

J. van Nugteren, J. Murtomäki, G. Kirby, G. de Rijk, L. Rossi and H. ten Kate

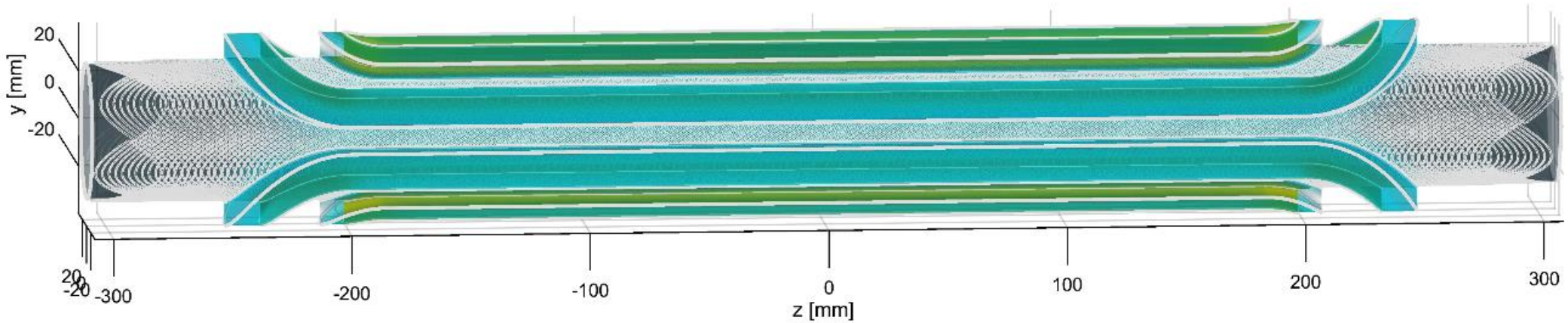


Fig. 3. The geometry of the dipole used for the calculations. The dipole consists of two racetracks, bend over the z-axis, per pole. For demonstration purposes, inside the aperture a sextupole shim coil is shown.

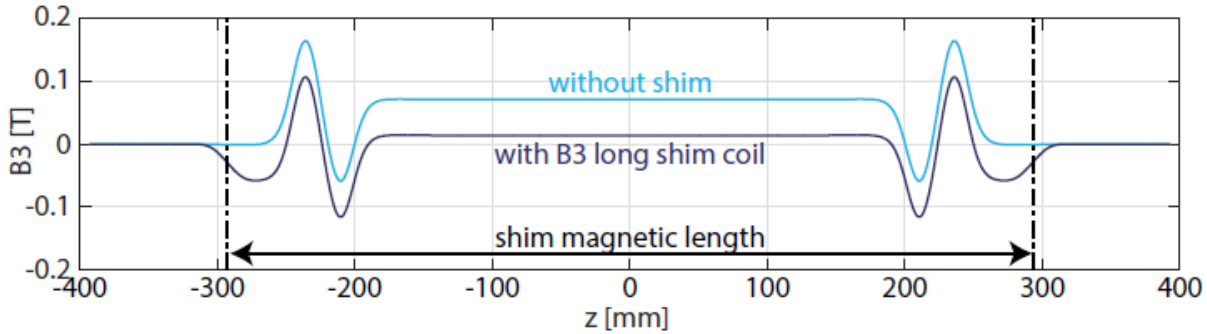
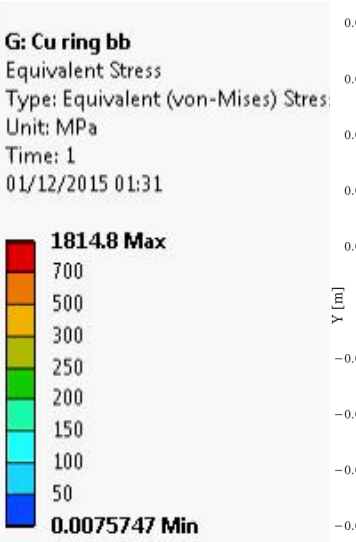
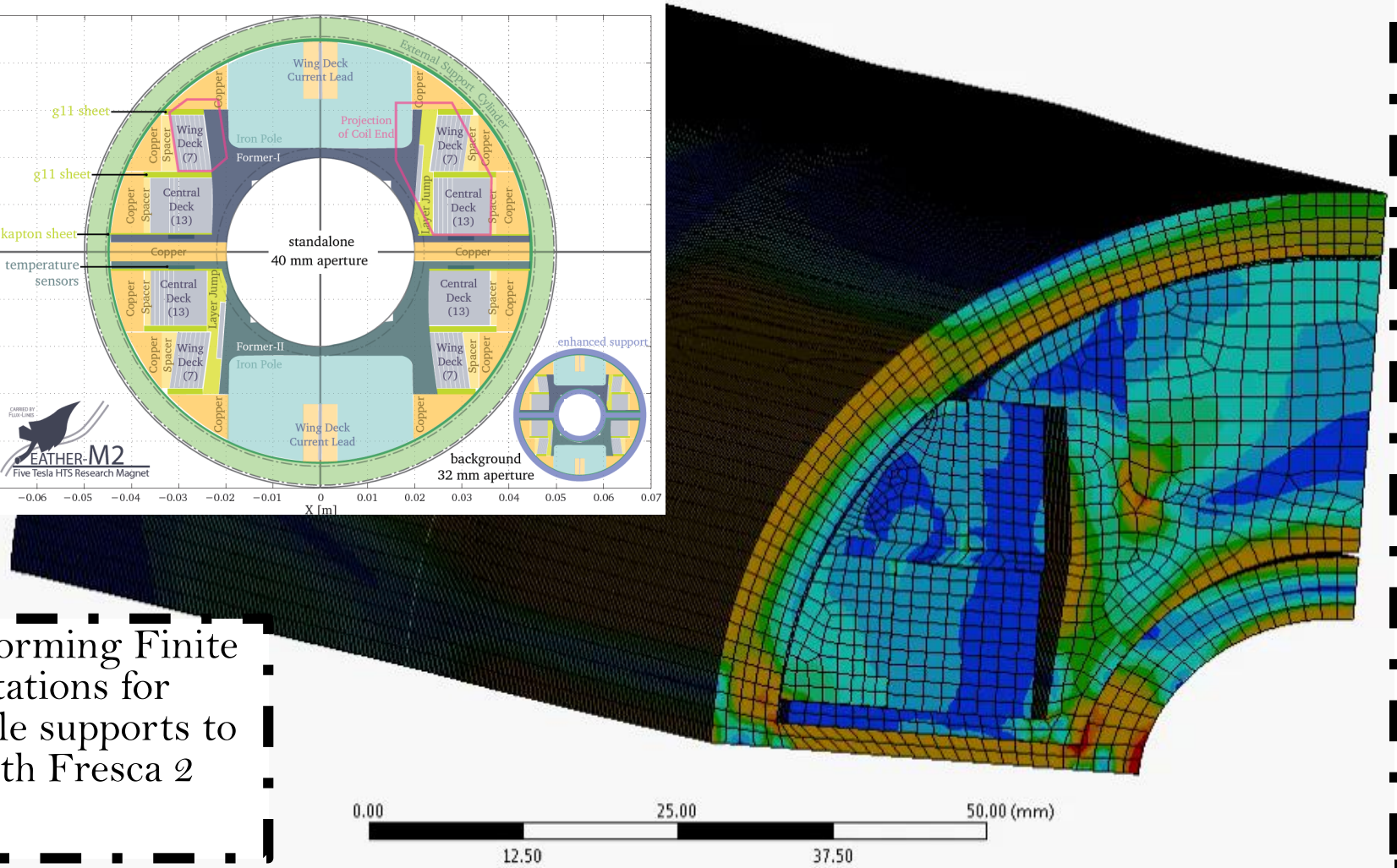


Fig. 7. The sextupole component at 18 mm as function of the axial position, with and without shim coil, for the case-III, in which a single shim coil is covering the full length of the dipole.

The mechanical analysis with homogenous current distribution

Computed at 9kA + 12 T background field = 17 T





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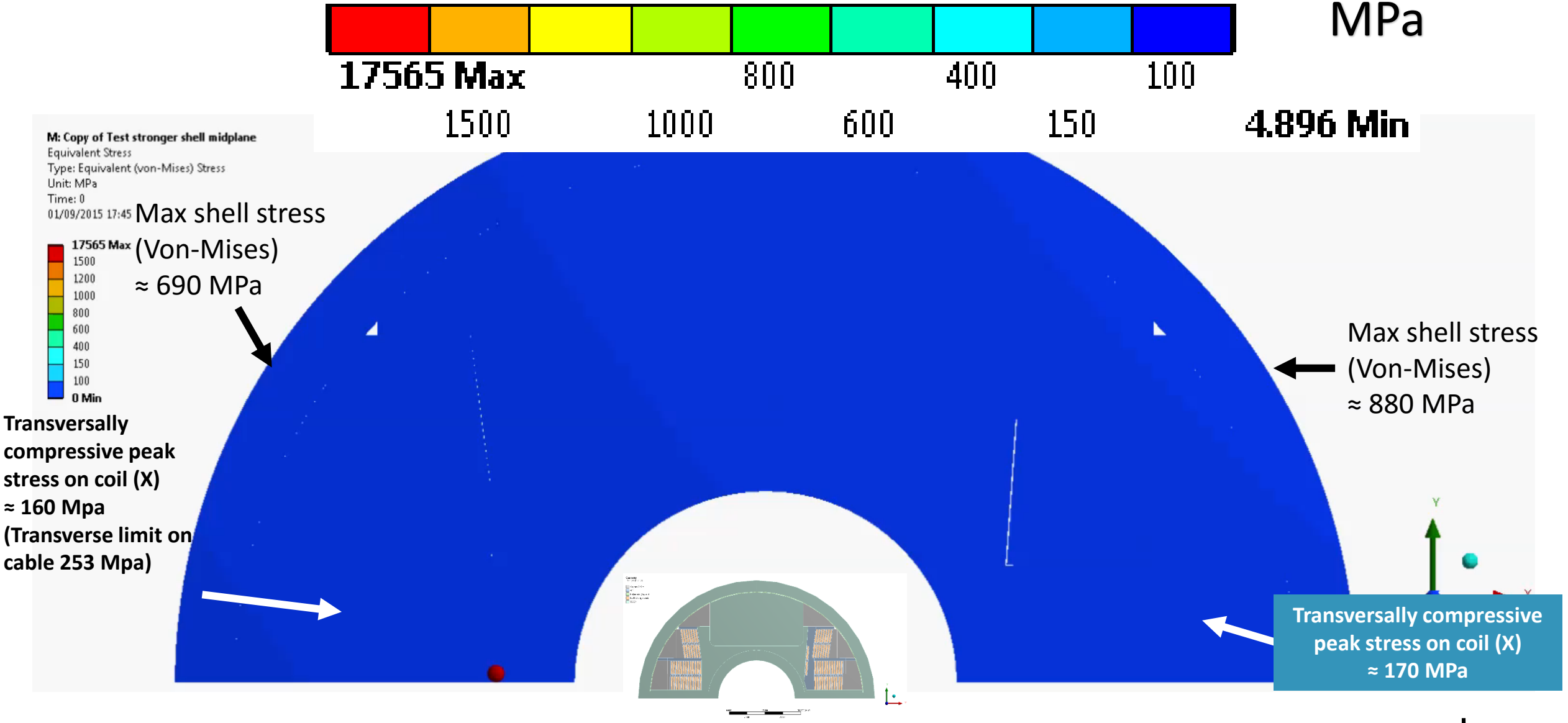
FEATHER M2 2D Von-Mises plot, Cool down to powering 9kA + 15 T background field ≈ 20 T in the bore

Assuming uniform current distribution over the cable



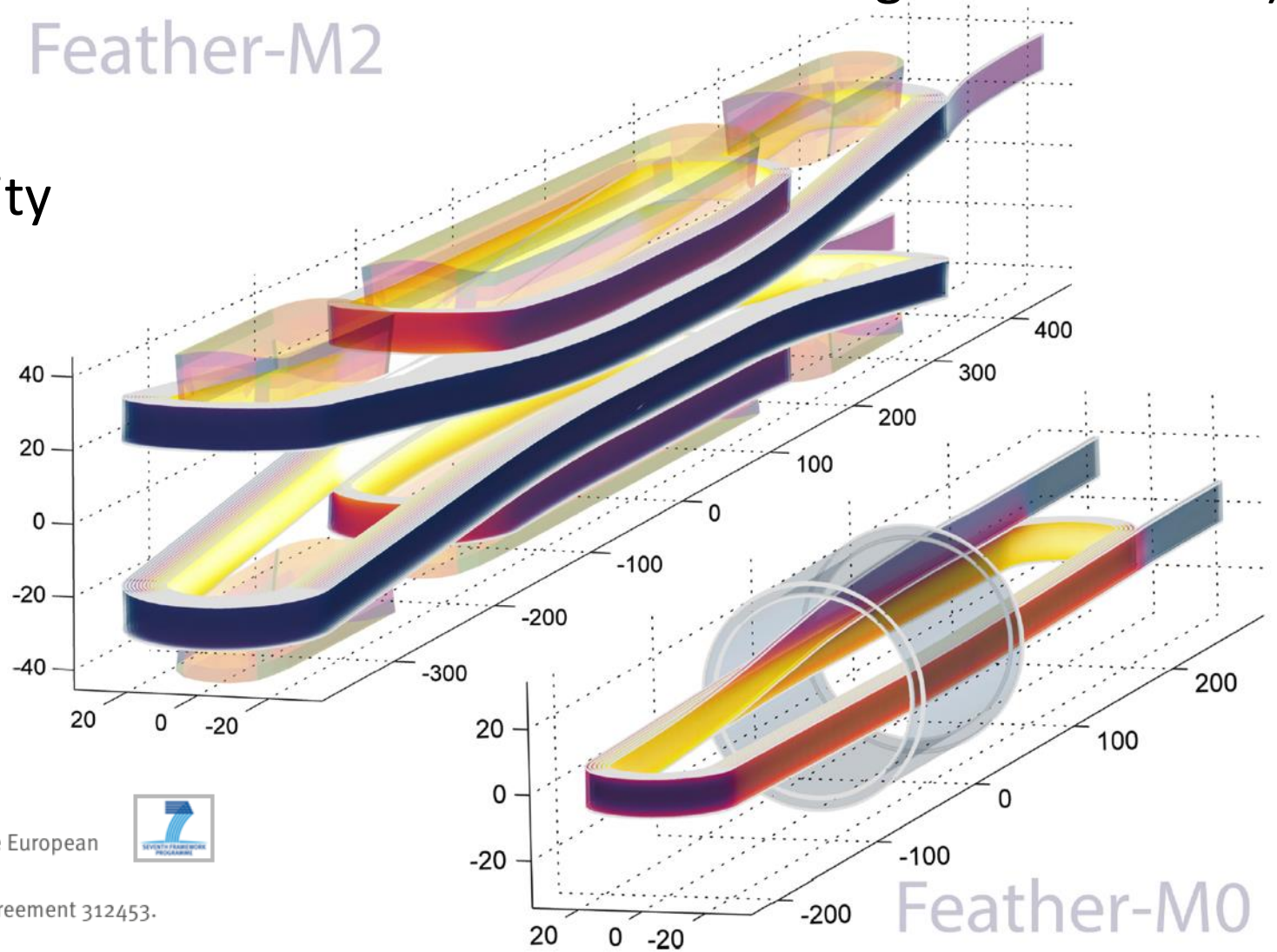
CLICK TO PLAY

Introduction to the EuCARD2 WP 10 project

- 5 Tesla stand alone, (18 Tesla to 20+ Tesla in 13 Tesla background or other)
- 40 mm aperture
- 10 kA class cable
- Accelerator Field quality
- @ 4.5K

- WP 10 Magnets
  - 10.1 Communication
  - 10.2 Cable 10kA 20T
  - 10.3 Magnet
  - 10.4 Test

http://eucard2.web.cern.ch/



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17 T

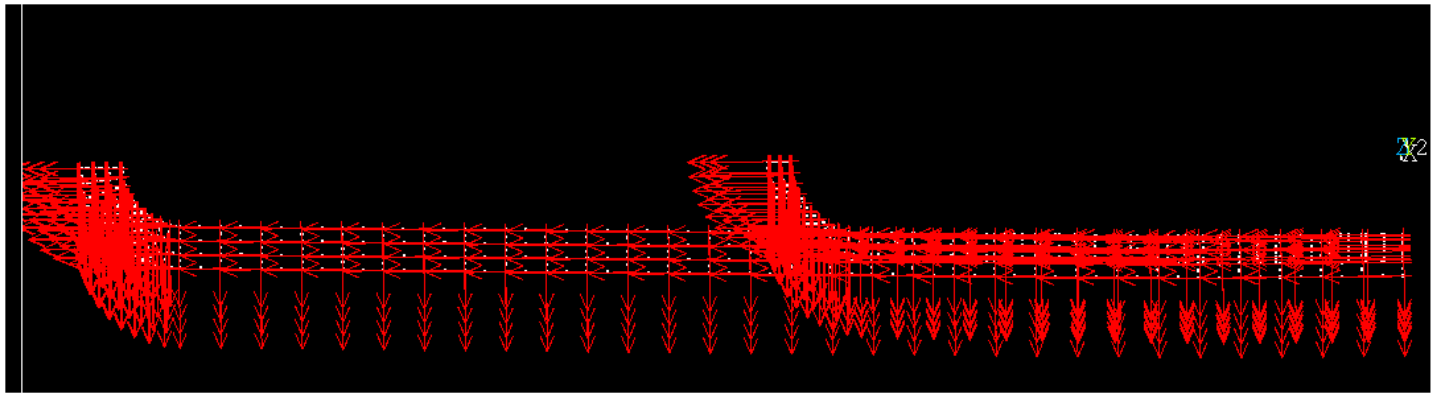
Forces for quarter of a Coil

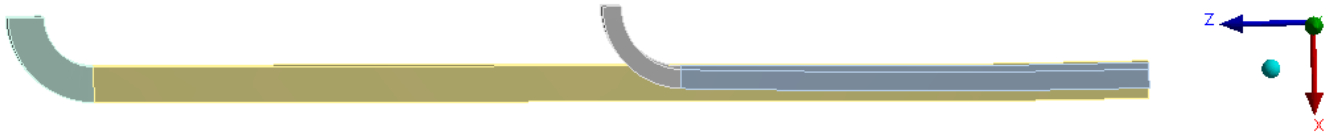
FX_tot (lateral) = 6.2015 *1.0e+05 N = 620 kN = 63 tonnes

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

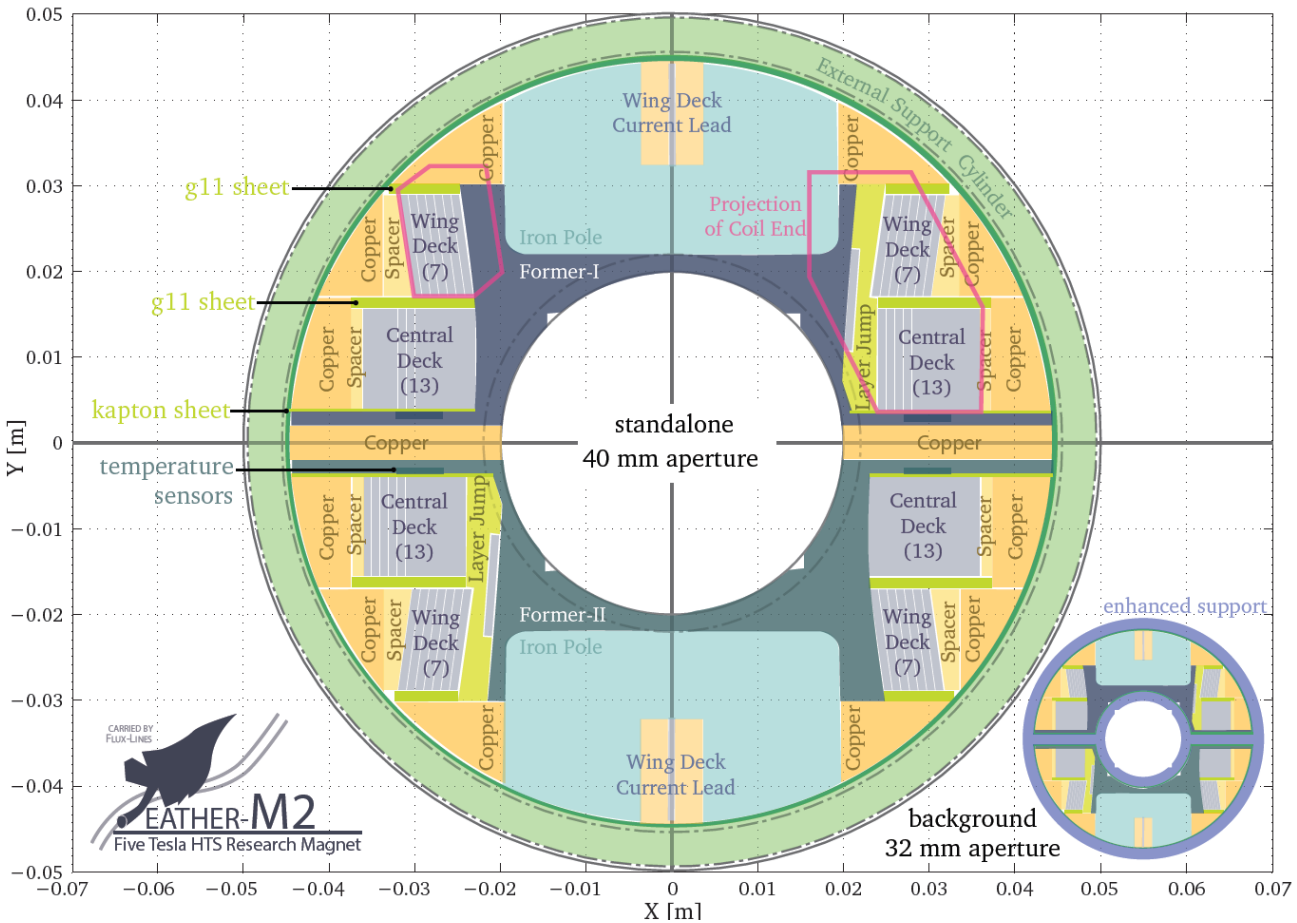


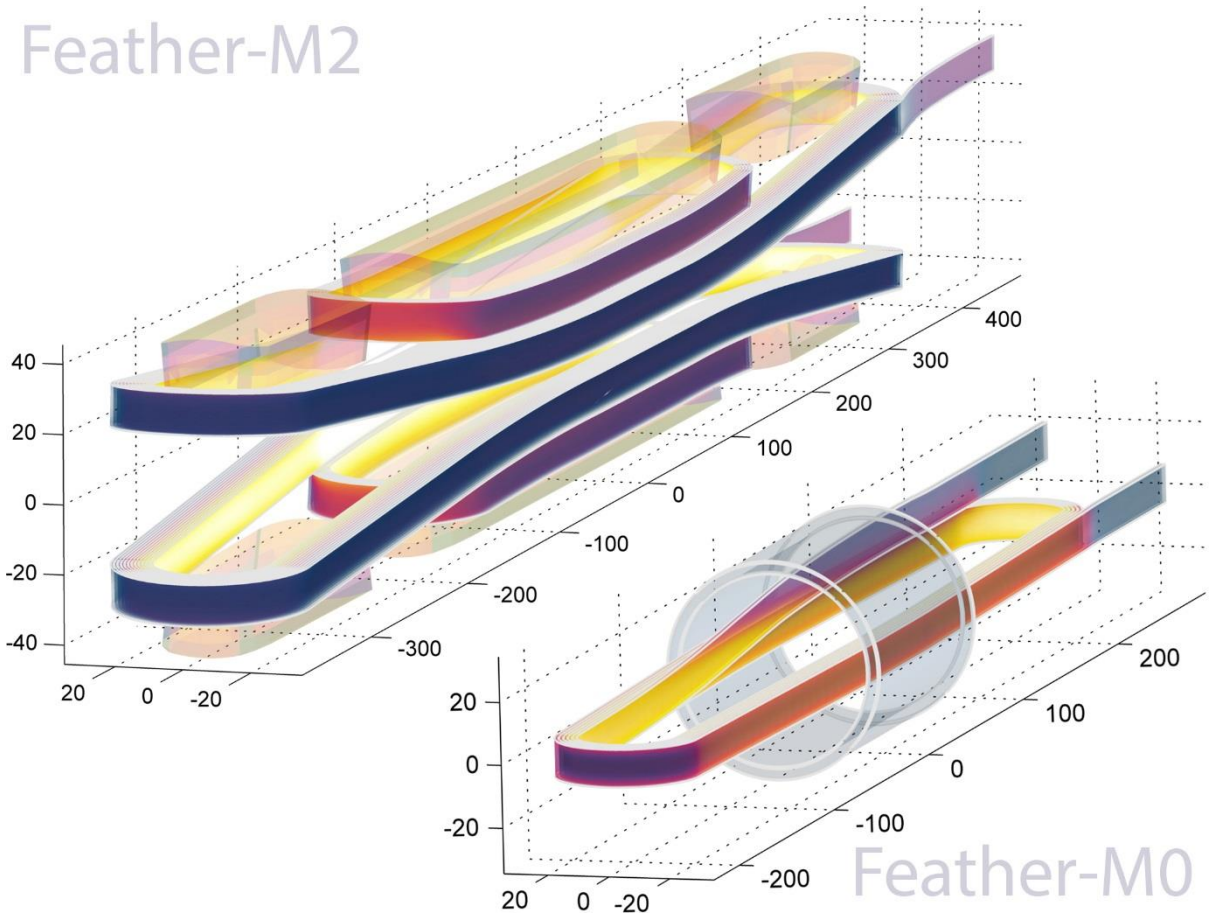


In 17 T, This means 253 t per one side of the magnet, (and 340 t/m) like LHC!

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

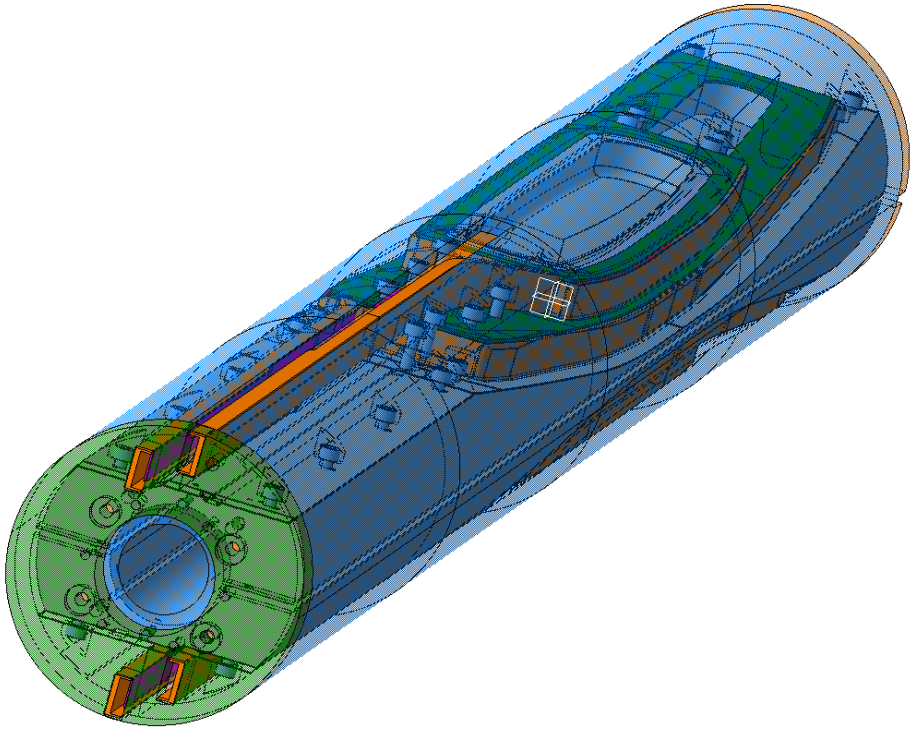
HTS Development



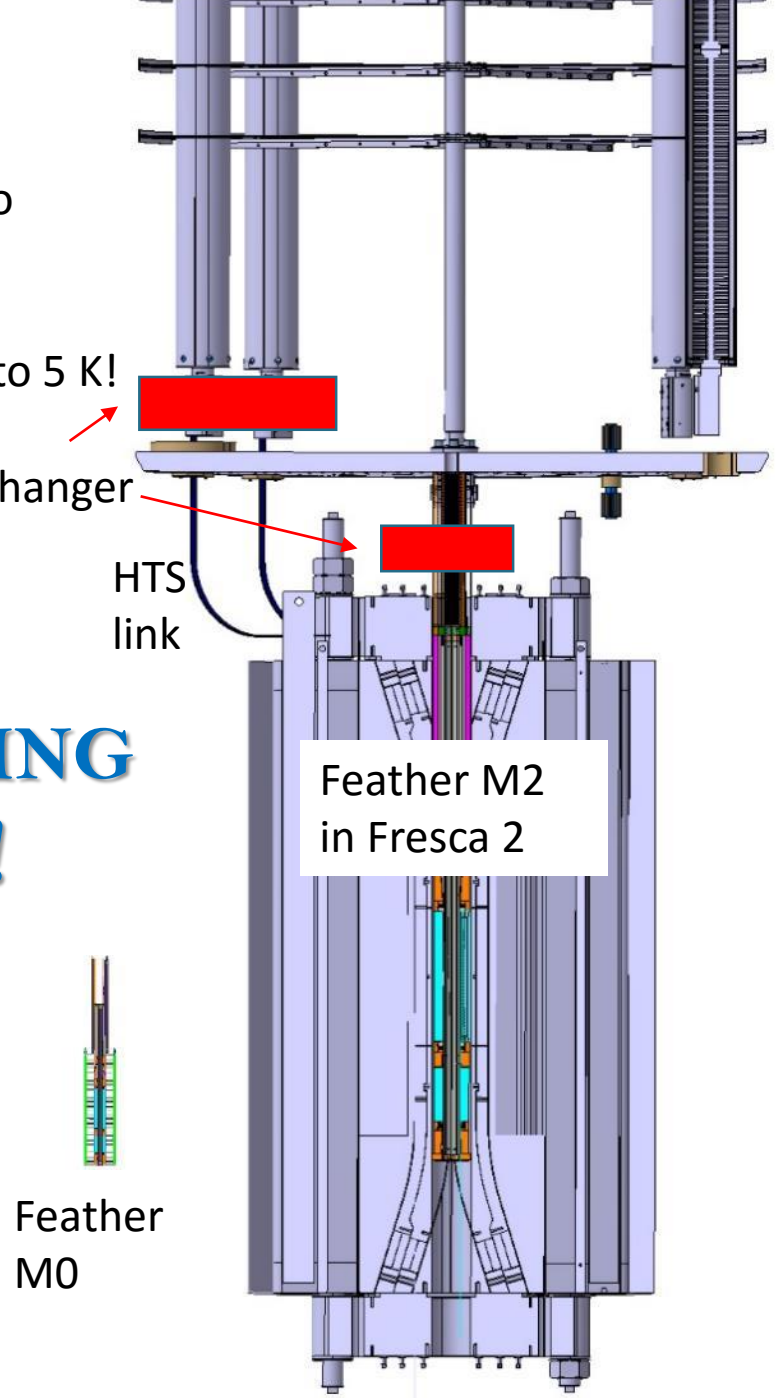


J. van Nugteren et al., FCC Dipole Layout Study, Magnet Technology Conference, 2015

Feather M2
assembly



COLD TESTING IN GAS !



SM18, INFN, AND FRESCA2 CRYOSTATS .

Planned Testing 70K to 4K ,

Fresca 2 test station due 2016

SM18 Super critical helium supplied at a wide range of temperature

Feather M0

INFN test station