HFML
Science in High Magnetic Fields

FOM

NWO
Netherlands Organisation for Scientific Research

EMFL
European Magnetic Field Laboratory

Design of the resistive insert coils for the HFML 45 T Hybrid Magnet

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Mon-Mo-Or2.04

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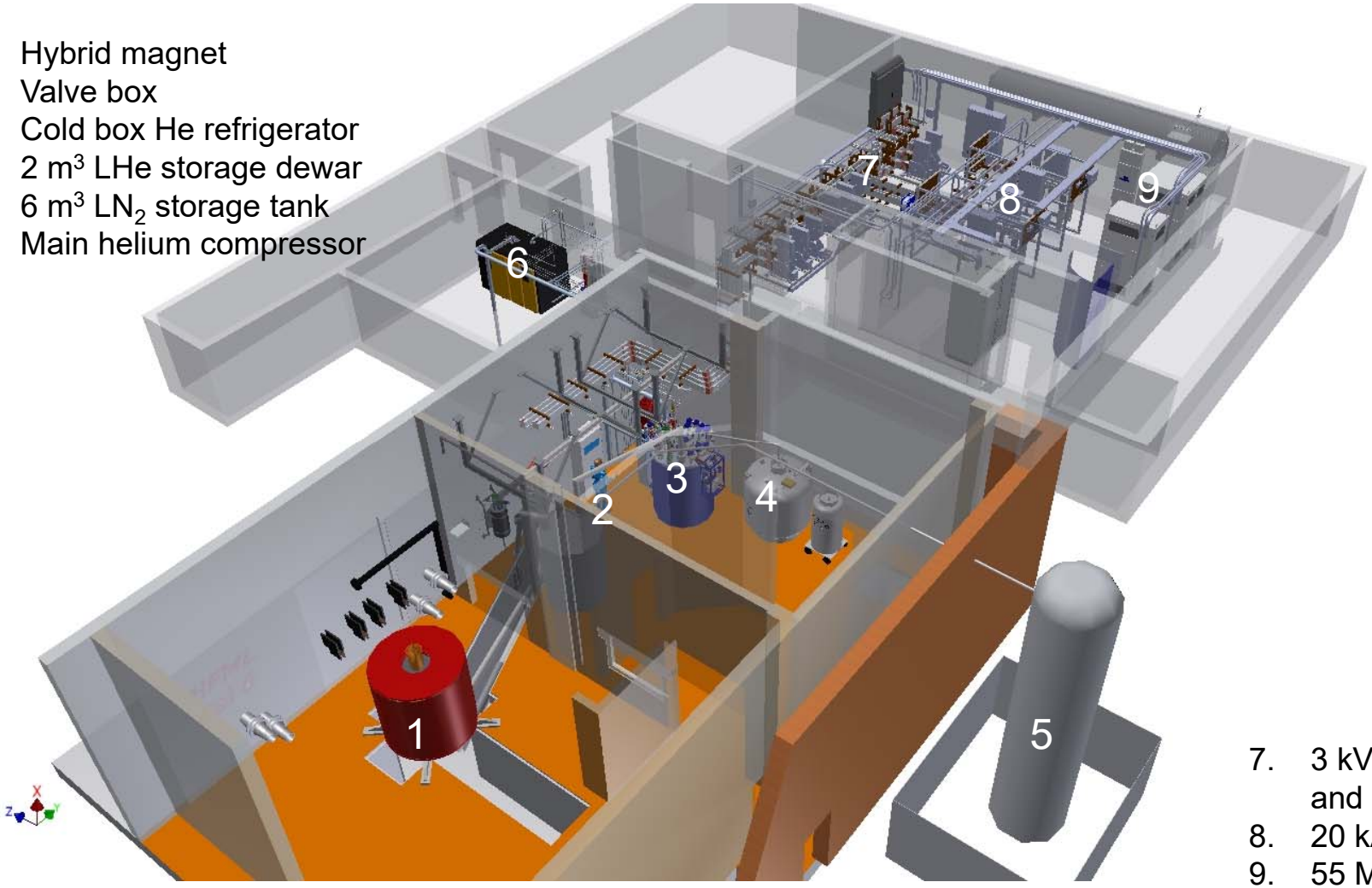
Outline

- Short introduction of the 45 T hybrid magnet in Nijmegen
- Insert design requirements
- Coil design
- Housing design
- Clamping of the coil set

Hybrid System Overview

1. Hybrid magnet
2. Valve box
3. Cold box He refrigerator
4. 2 m^3 LHe storage dewar
5. 6 m^3 LN_2 storage tank
6. Main helium compressor

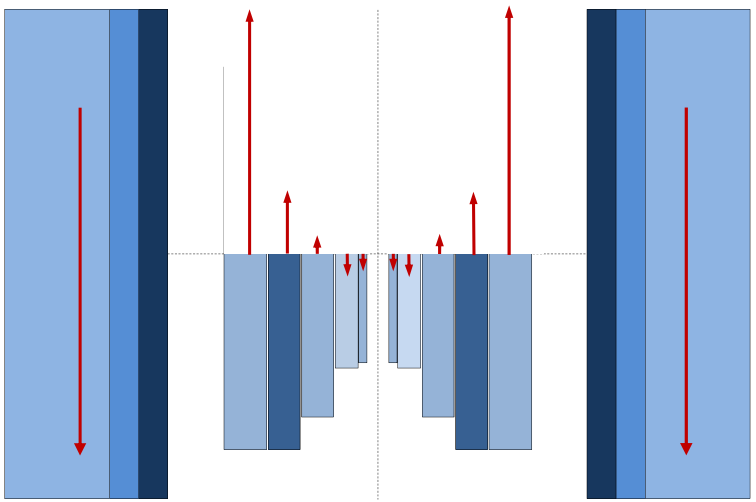


7. 3 kV/20 kA circuit breakers and thyristor switches
8. 20 kA/10 V power convertor
9. 55 MJ fast and slow dump resistor

Hybrid magnet requirements

- Combined on-axis field 45+ T
  - Resistive insert 32.7+ T @ 22 MW
  - Superconducting outsert 12.3+ T
- Free bore
  - Resistive insert: 32 mm
  - Superconducting outsert: 620 mm
- Technically robust design: user magnet

- Design a user magnet
  - Friendly access
  - Clear top side => connections on bottom
  - Reliable performance
  - As quiet as possible (acoustics)
- Fit in outsert bore => Housing OD 618 mm
- Max power 22 MW
- Worst-case fault force ≤ 2.5 MN



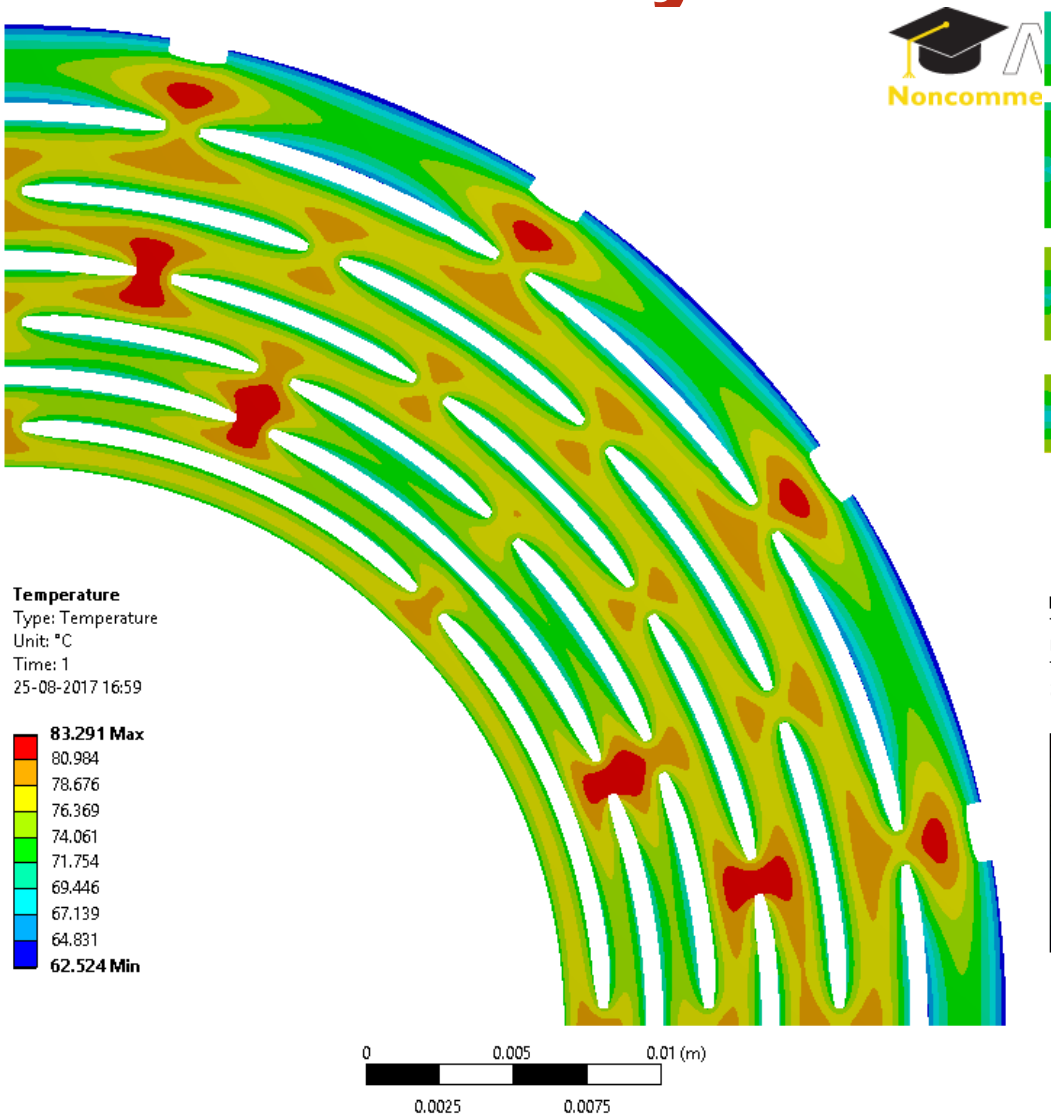
Coil Design – inner coils

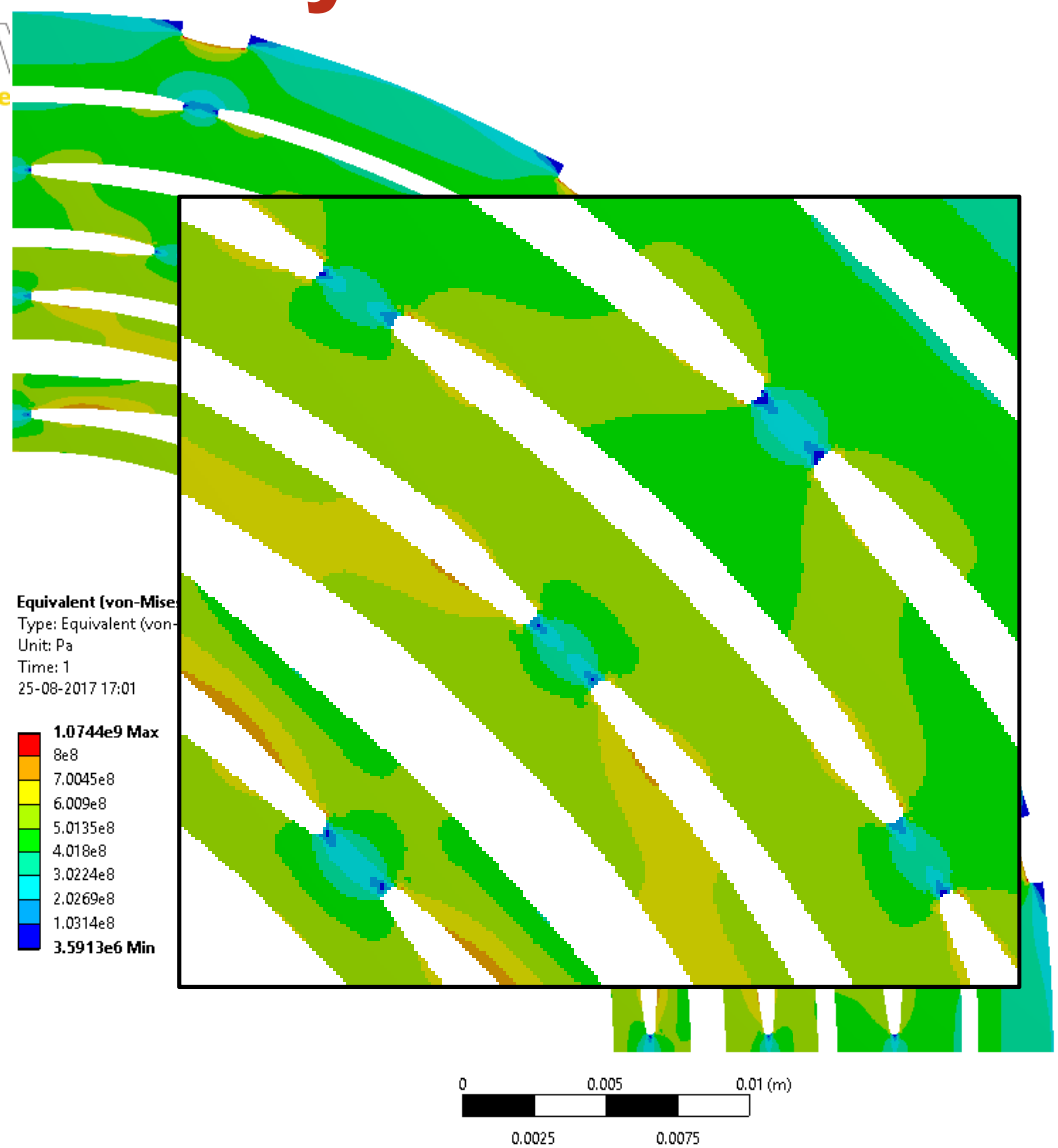
- Used the design of our 38T magnet (commissioned 2014) as starting point

- Copper-Silver inner coils A1-A2 and B
  - OD limited to 240 mm (material manufacturing)
  - Radial division of space of the 38T is unsuitable for hybrid insert

	A1	A2	B		38A1	38A2	38B
ID [mm]	38	70	140		38	68	152
OD [mm]	68	134	238		66	146	238
Length [mm]	352	353	519		242	243	385
J_0 [A/mm²]	600	402	260		653	477	337
B_{self} [T]	5.8	7.8	8.7		5.9	9.9	7.7
Stress [MPa]	700	720	700		620	660	650

Preliminary ANSYS Analysis – A1





Coil design – outer coils

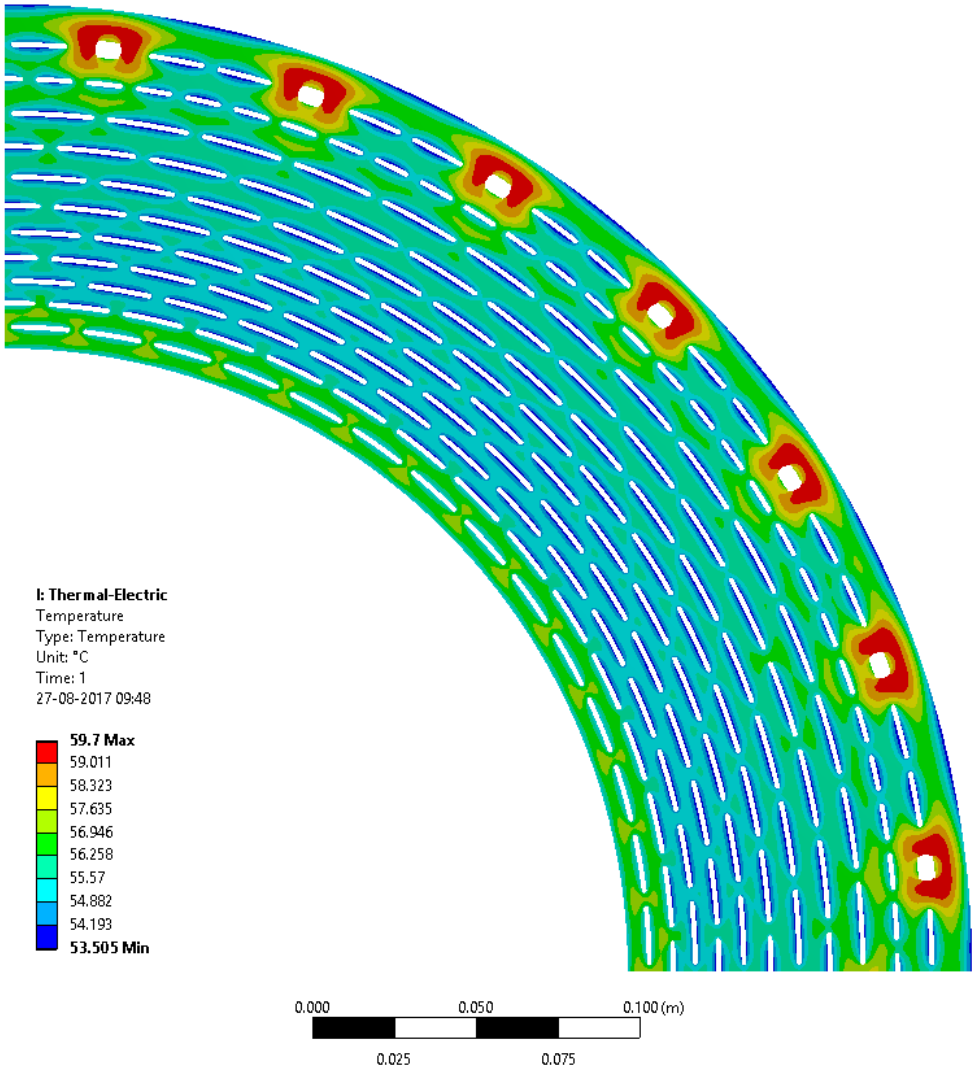
- Initial design based on a double hull housing, i.e. return path for water in a separate channel.
  - Consumes space that does not contribute to field generation

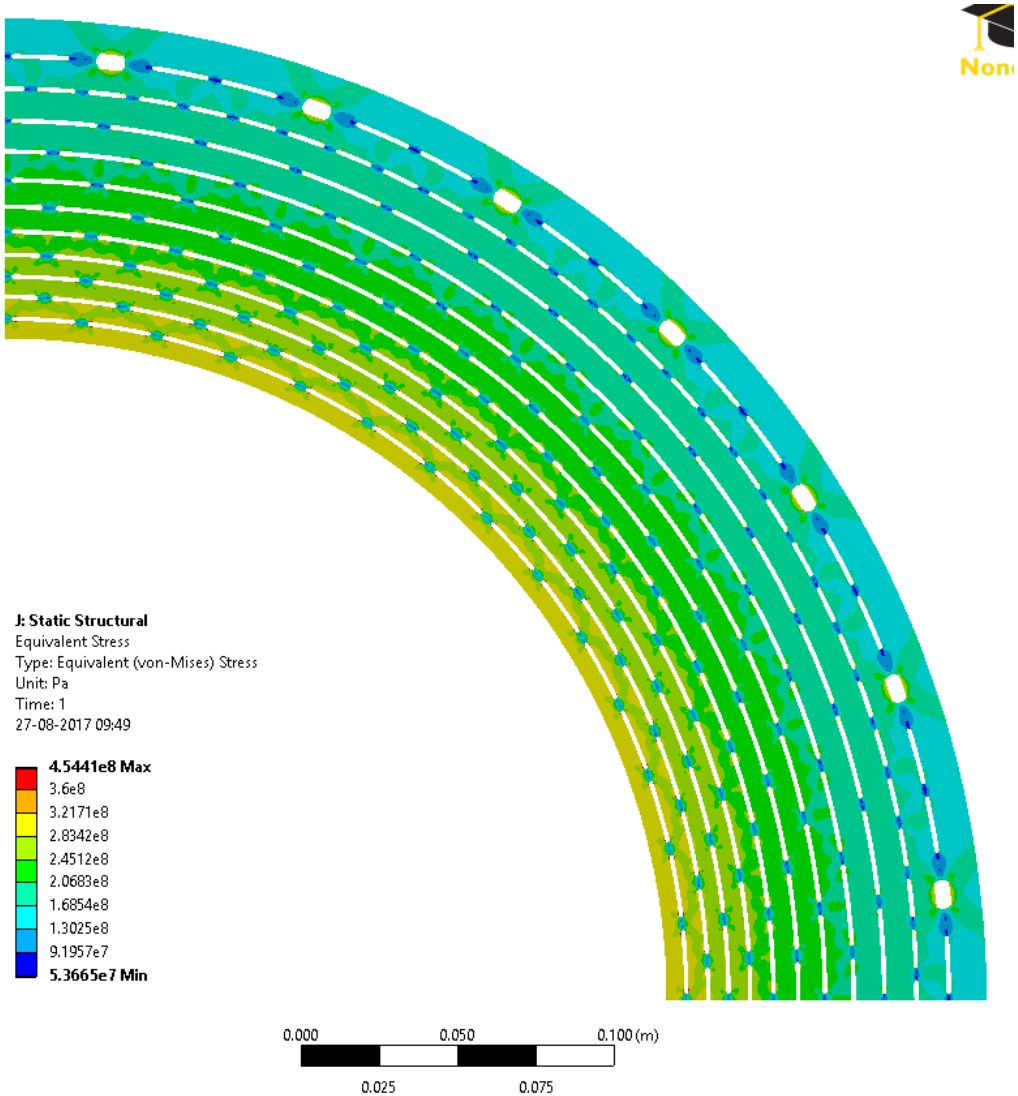
- Investigated the possibility of alternative hydraulic path
  - Inner coils A-B-C in parallel, water flowing up
  - In series with coil D, water flowing down

- Benefits:
  - OD of the largest coil grows from 520 to 590 mm
  - More space to generate field
  - Larger coils are more efficient

Variant	Field Factor	Power Efficiency	Space Factor
Classical	0.2587	0.1268	0.964
Return flow through D-coil	0.3558	0.1462	0.854
Change	+ 37 %	+ 15 %	-11 %

Preliminary ANSYS Analysis – D

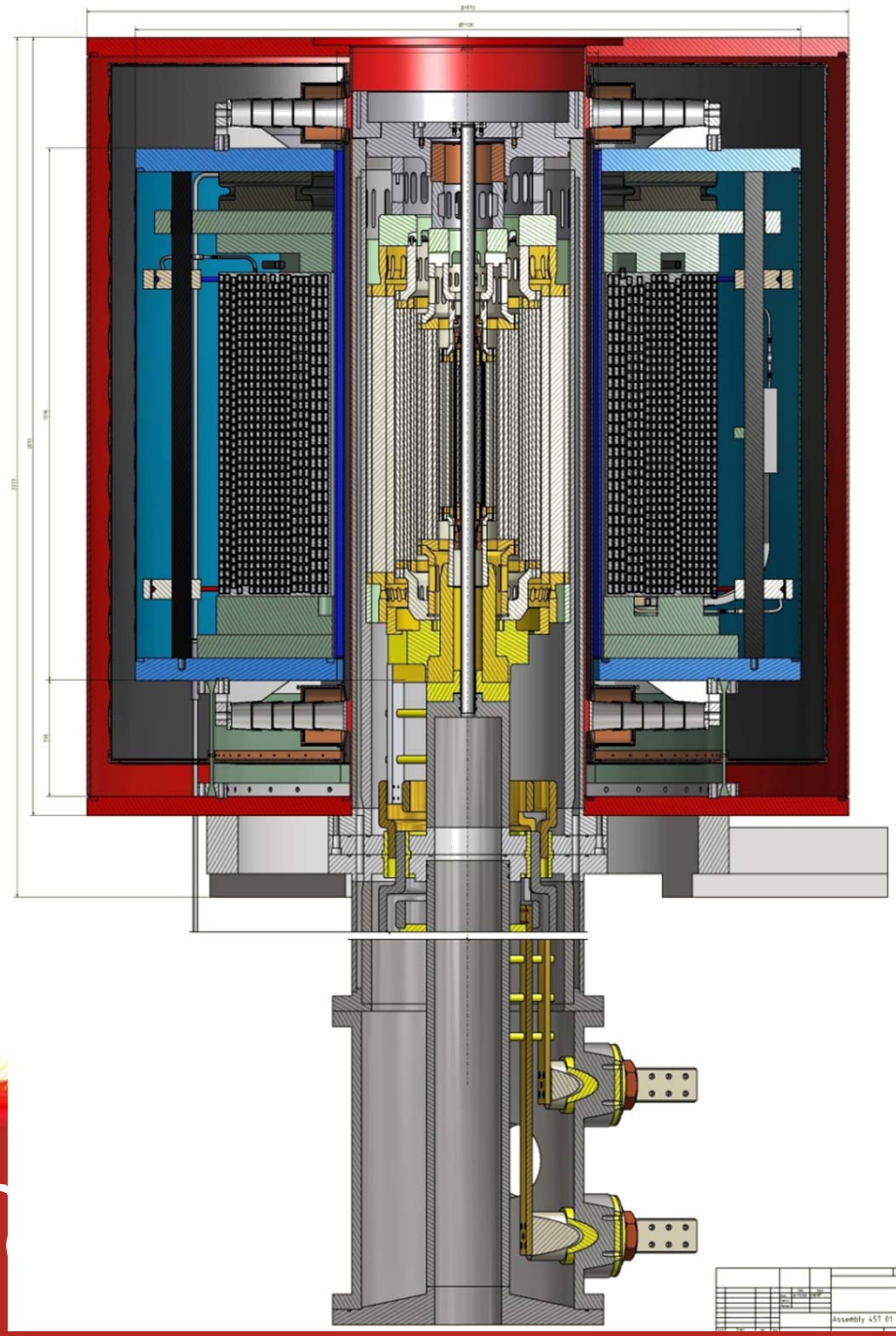




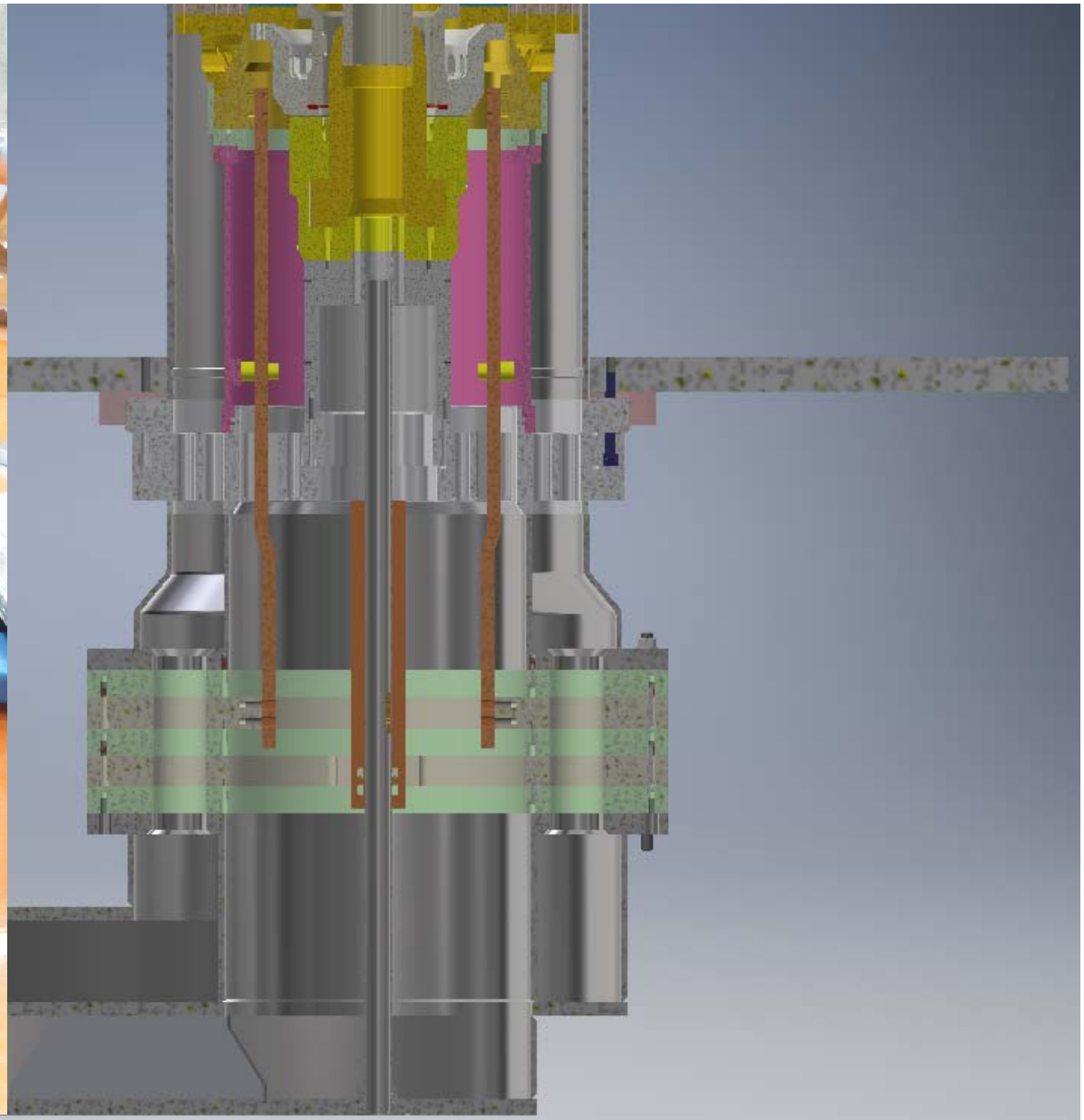
Design of the housing

- Housing split into two segments
  - Top contains coils
  - Bottom for services
  - Both connect to bottom outsert
    - Keeps fault force path as short as can be

- Double hull housing
  - Return water flows around coil
  - Reynolds number: $N_R \sim 10^5$
    - on-set turbulence: 4×10^3
    - typical N_R coil cooling: 4×10^4

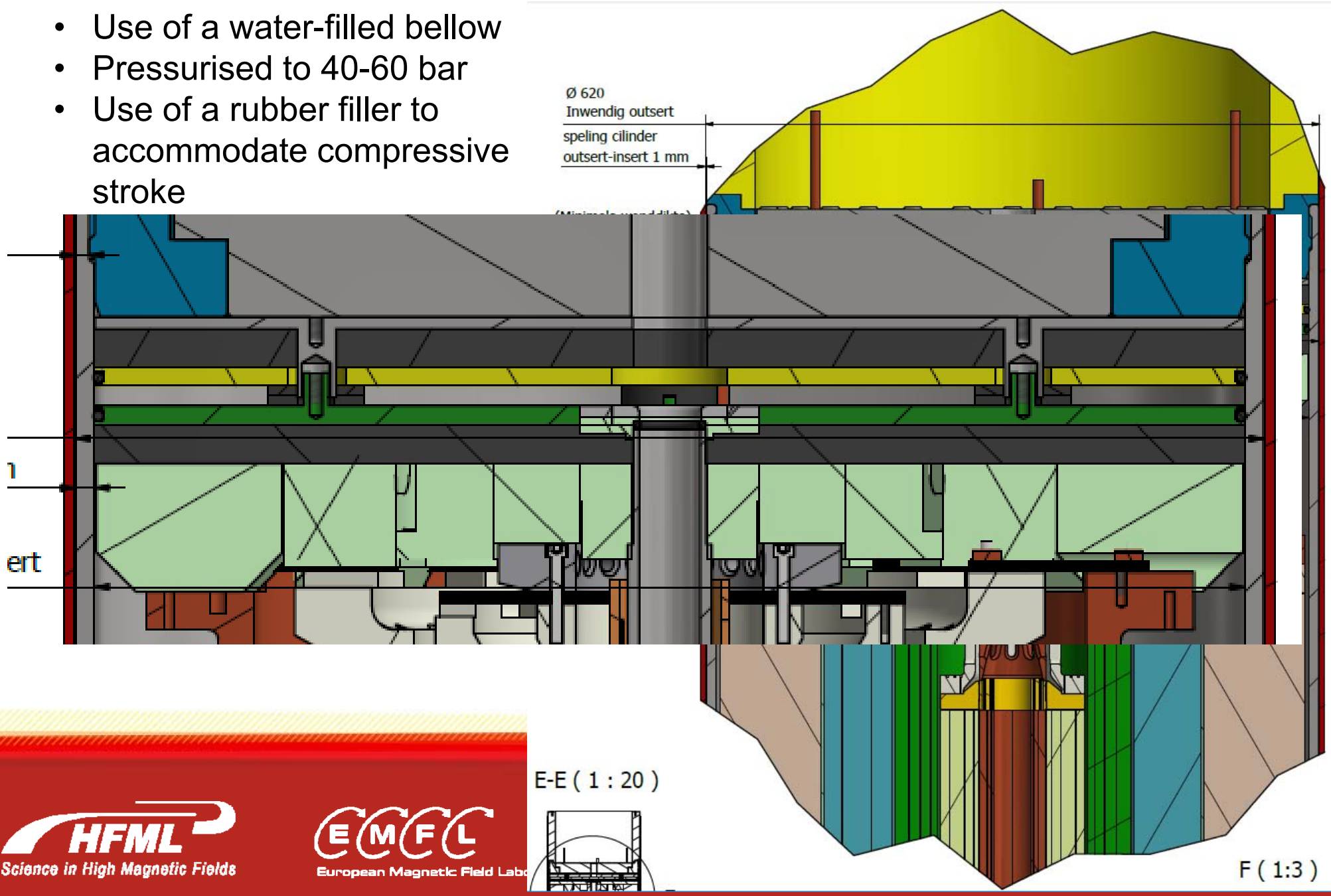


Connections for power & cooling



Improving clamping conditions

- Use of a water-filled bellow
- Pressurised to 40-60 bar
- Use of a rubber filler to accommodate compressive stroke



More information Tue-Af-Po2.04:

SPECIAL ED. - HFML POSTER

no.203.078 FROM THE HIGH FIELD MAGNET LABORATORY - NIJMEGEN Tue-Af-Po2.04

A novel clamping method for resistive magnets

C.W. Wulffers, F.J.P. Wijnen, A. Engels, J.M.H. van Velsen, J.A.A.J. Perenboom, A. den Ouden, N.E. Hussey

HFML Science in High Magnetic Fields

EMFL European Magnetic Field Laboratory

Radboud University Nijmegen

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Introduction

Bitter magnets are constructed by stacking hundreds of individual Bitter plates together in a coil. This loose stack of disks needs to be clamped together with tie rods that are pretensioned for several reasons:

1. the coil should be a 'rigid' object that can be handled
2. the coil should have a stiffness against internal rotations
3. to keep the end turn disks in position despite the large forces on these turns

Summary

- Mechanical design of the insert is well on track
  - Validation of the bellow within a month
  - When successful it should improve stability & lifetime of the coils
  - Bellow can help in the end turn issue

- Preliminary Bitter disk design done
  - We have developed a self-consistent set of design tools
  - Final tuning of cooling hole distribution still needed
  - End turn analysis to be completed