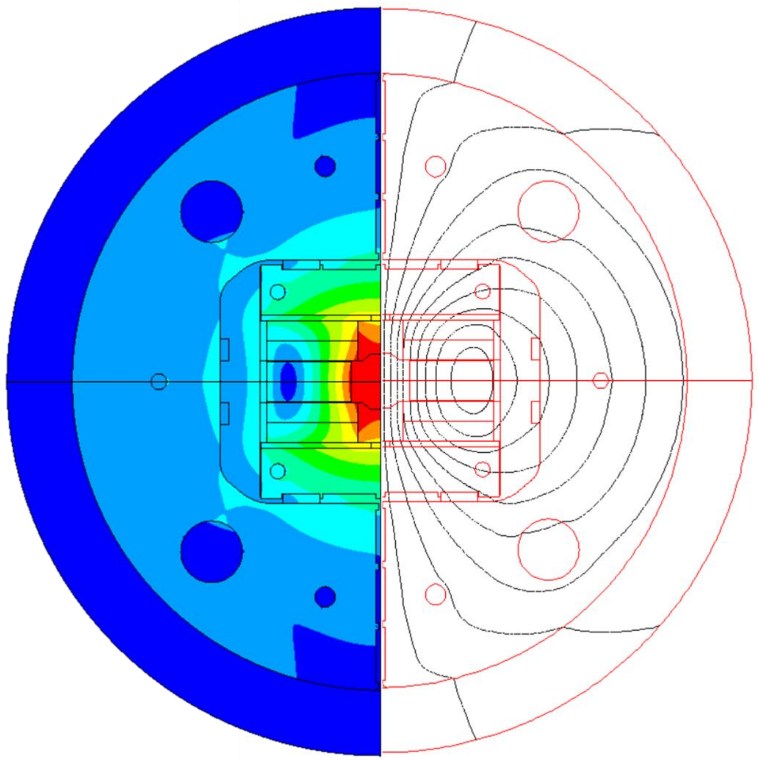
# HFM

High Field Magnets Programme

# RMM magnet with fishbone: Design and extension to BOND



RMM

# HFM Forum

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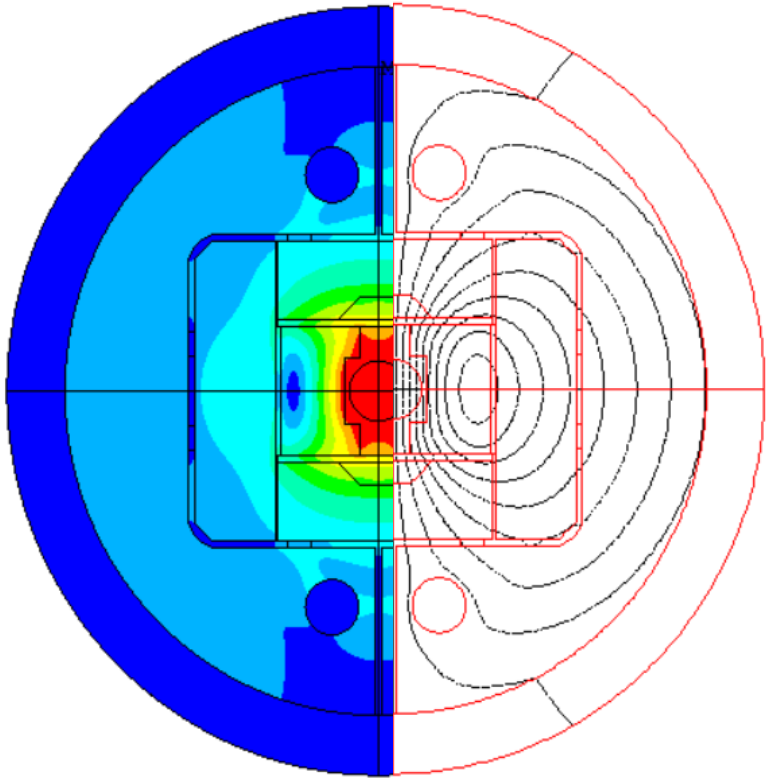
Date: Wednesday 15th January 2026



BOND

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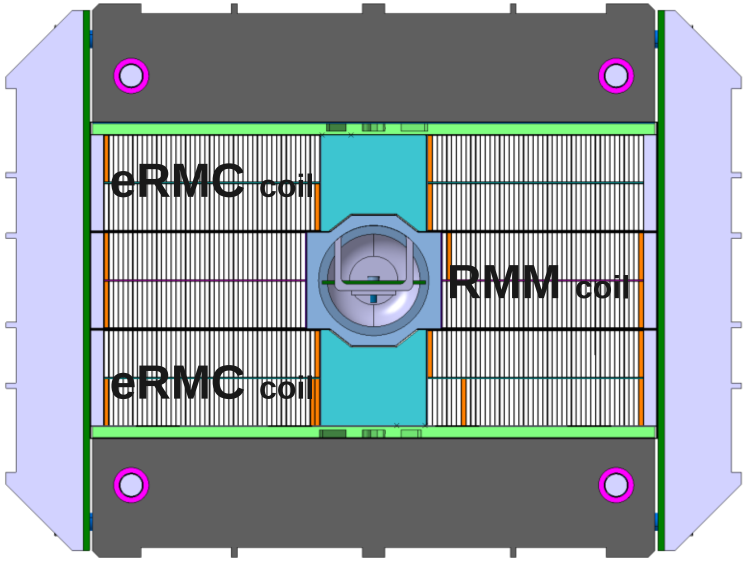
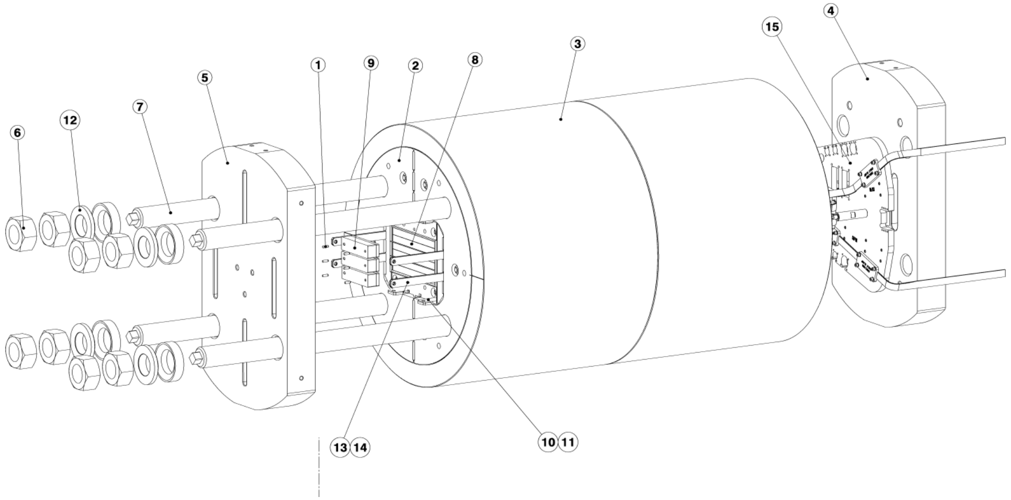
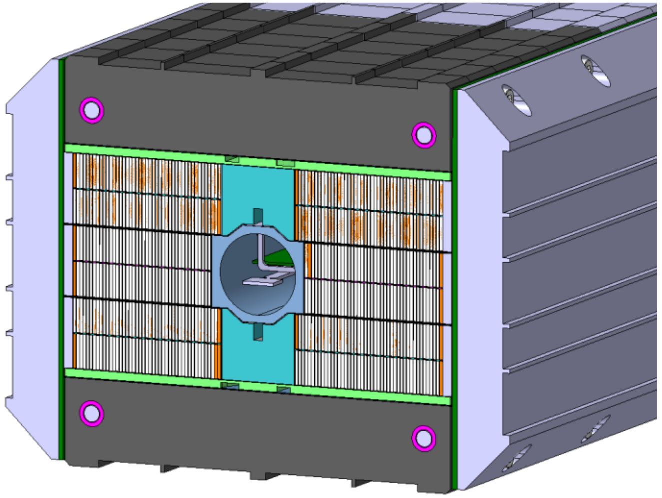
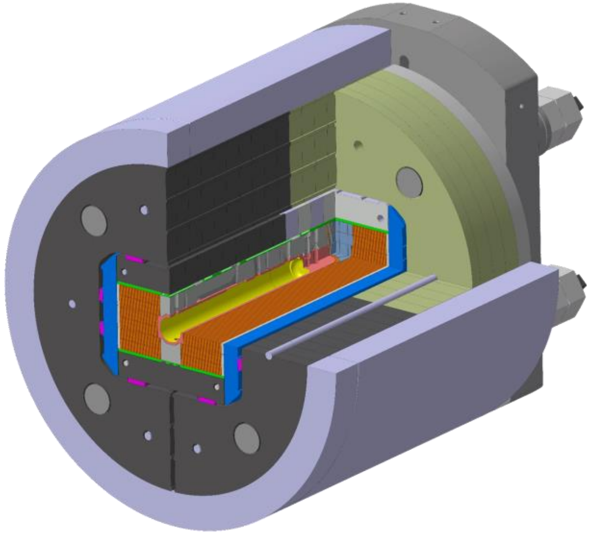
# Introduction to RMM configuration

- The objective of RMM is to explore the $Nb_3Sn$ technology for high field accelerator magnets.
- RMM will explore the high field straight section region of a 16 T dipole, on a block-coil configuration, focussing on mechanical aspects.
- RMM has been designed using the Bladder and Keys technology and stainless-steel rods for longitudinal preload.
- RMM is a Racetrack Model Magnet, with a Ø 50 mm closed cavity, using 2 eRMC coils and 1 RMM coil in the middle.



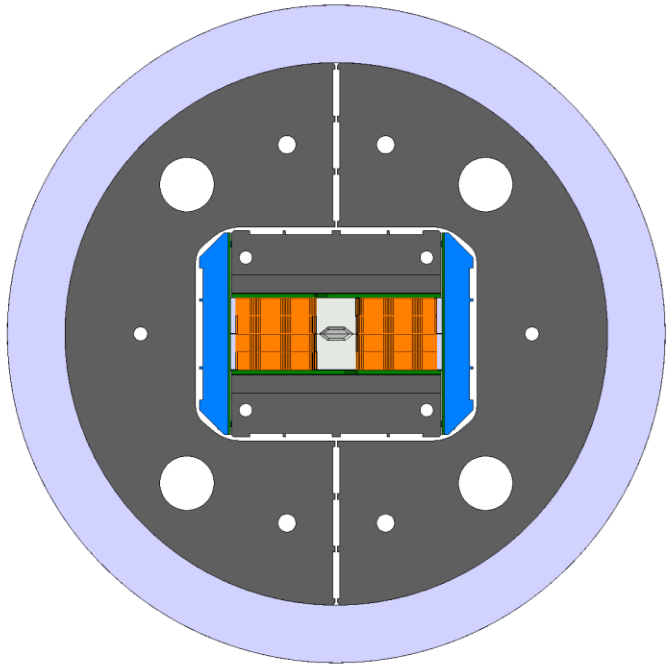


$L_{cavity\_D50}$= 431 mm

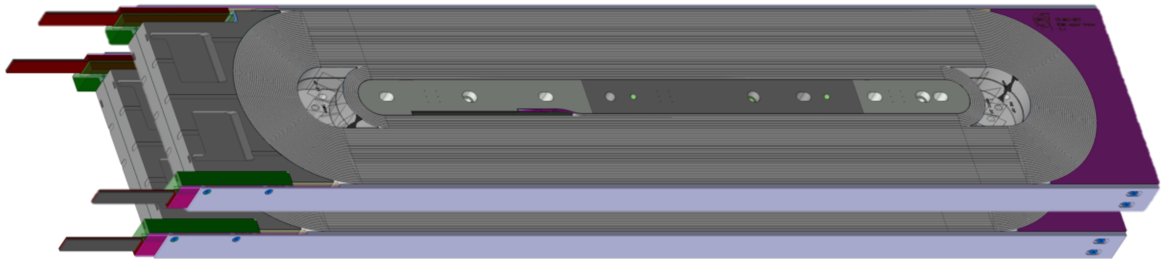
# eRMC

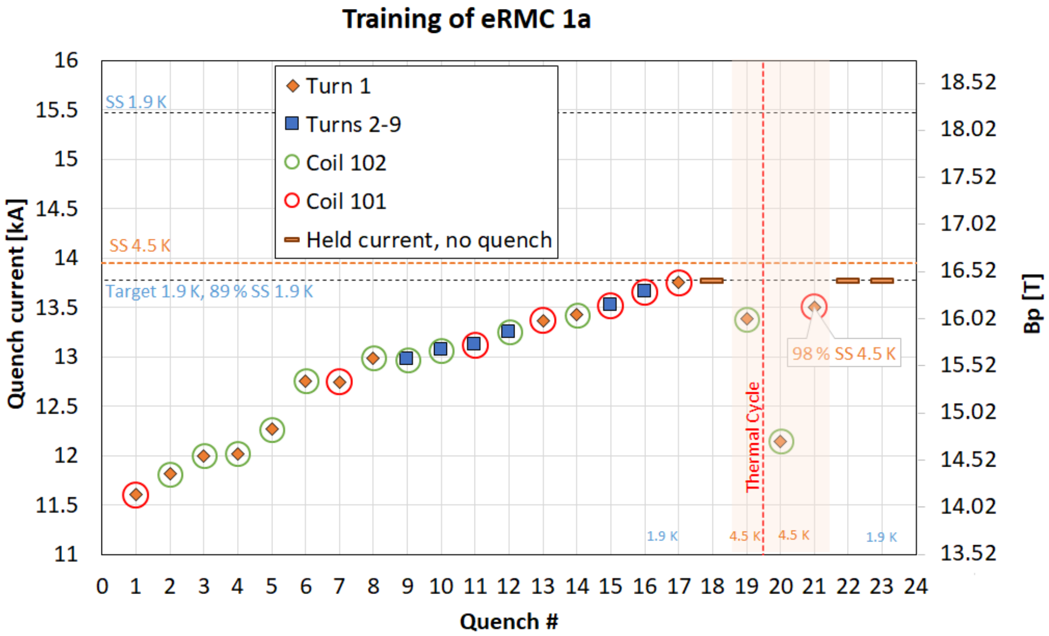
**Enhanced Racetrack Model Coil** with 16 T midplane field

- Demonstrate field on the conductor
- Coil technology development



- eRMC1a was assembled with 2 eRMC coils foreseen to be used in RMM.
- The target field for this preparatory test was set at 16.5 T Bp.
- The magnet reached 13.77 kA corresponding to 98% of SS at 4.5 K.

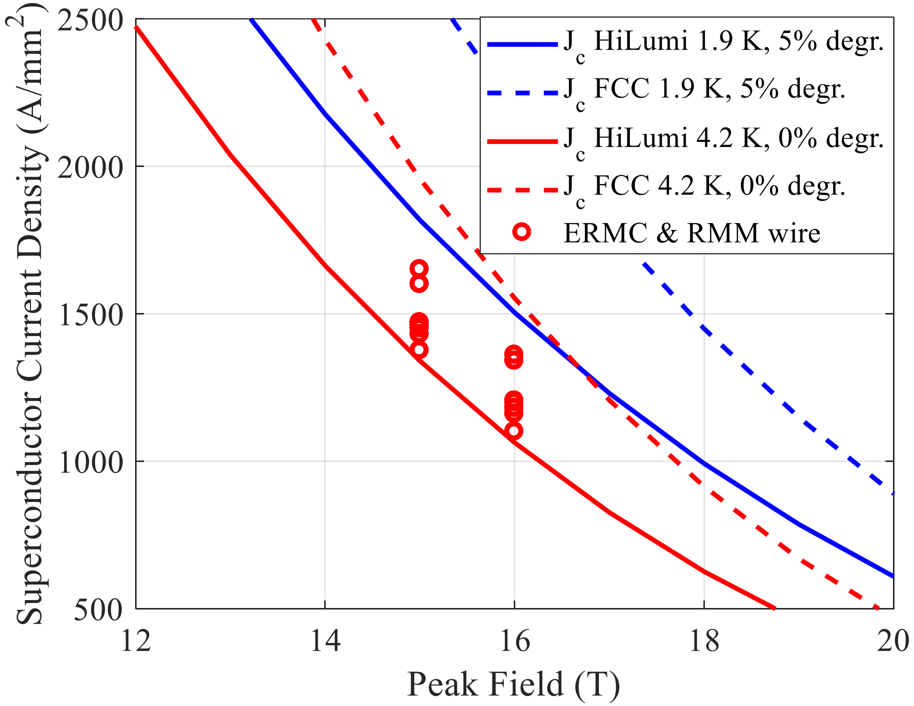




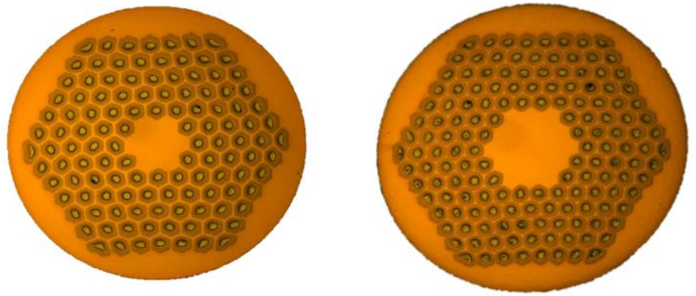
# Strand a cable parameters

| | eRMC #101 | eRMC #102 | RMM #101 |
|---|---|---|---|
| Strand Type | RRP 120/127 | RRP 150/169 | RRP 120/127 |

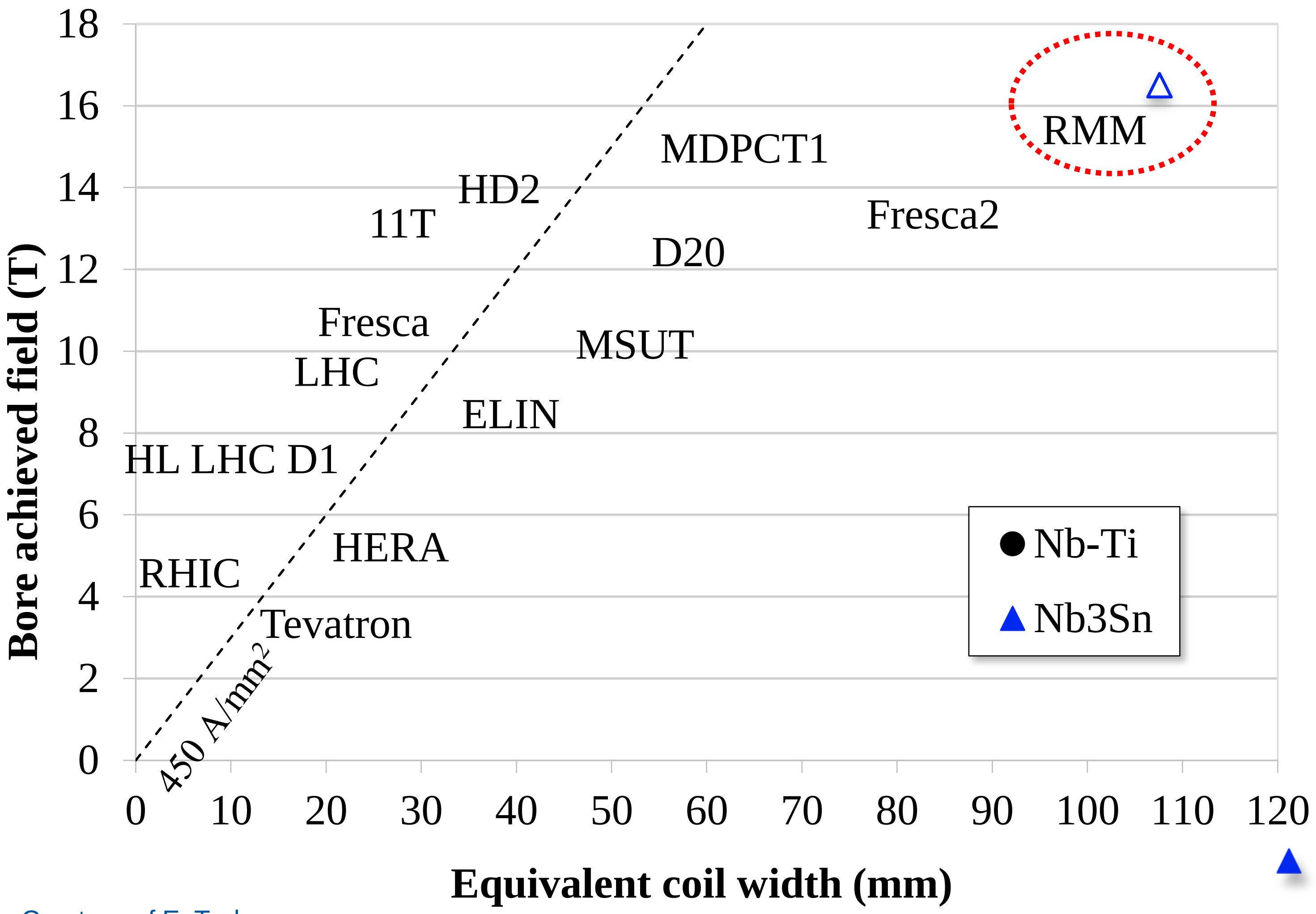
- 1 mm diameter wire, Cu/Sc ~ 1
- 40-strand cable
- Bare cable width x thickness: 20.95 x 1.82 mm
- Assumed growth during HT: 0.8 % (width), 3.6% (thickness)
- SS core 14 mm wide x 25 um thick
- Mica 44 mm + S2 636, Braided, 0.145 mm

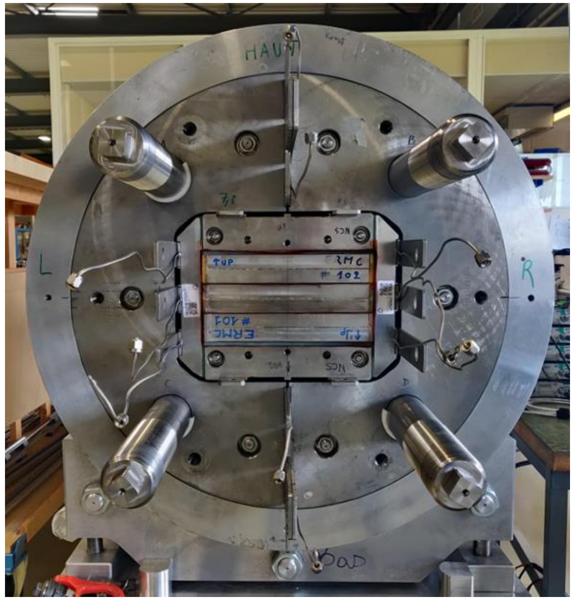


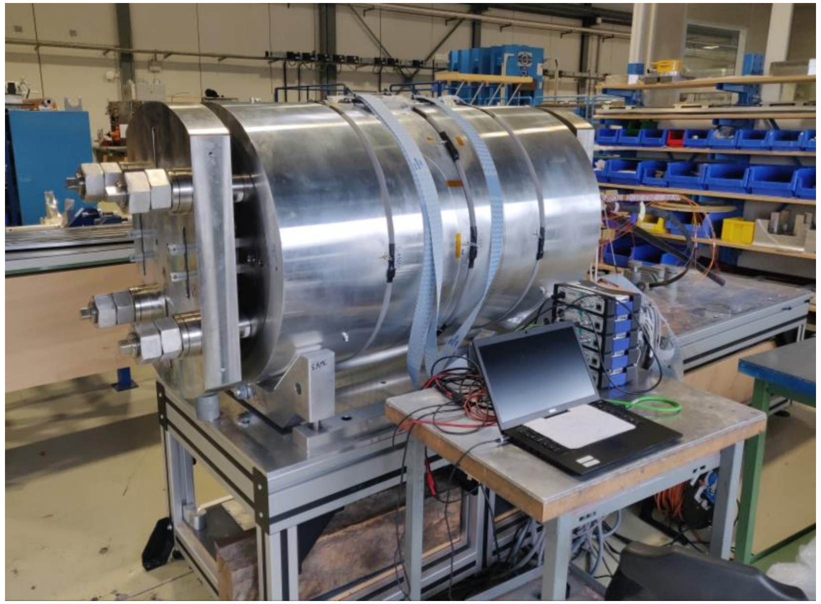

B. Bordini, J. Fleiter & A. Bonasia



# RMM is a big dipole magnet



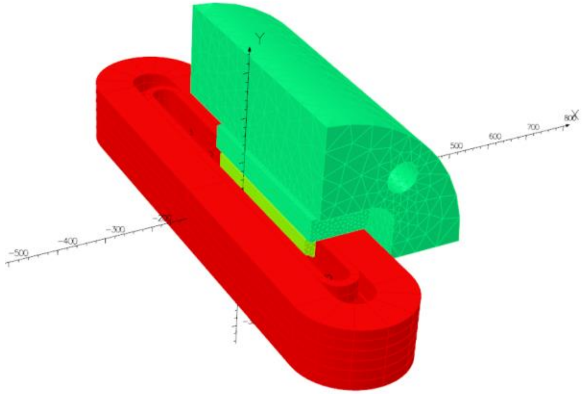



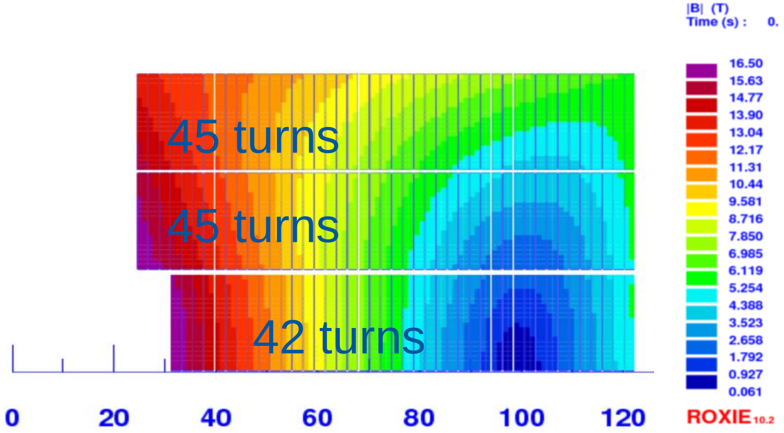


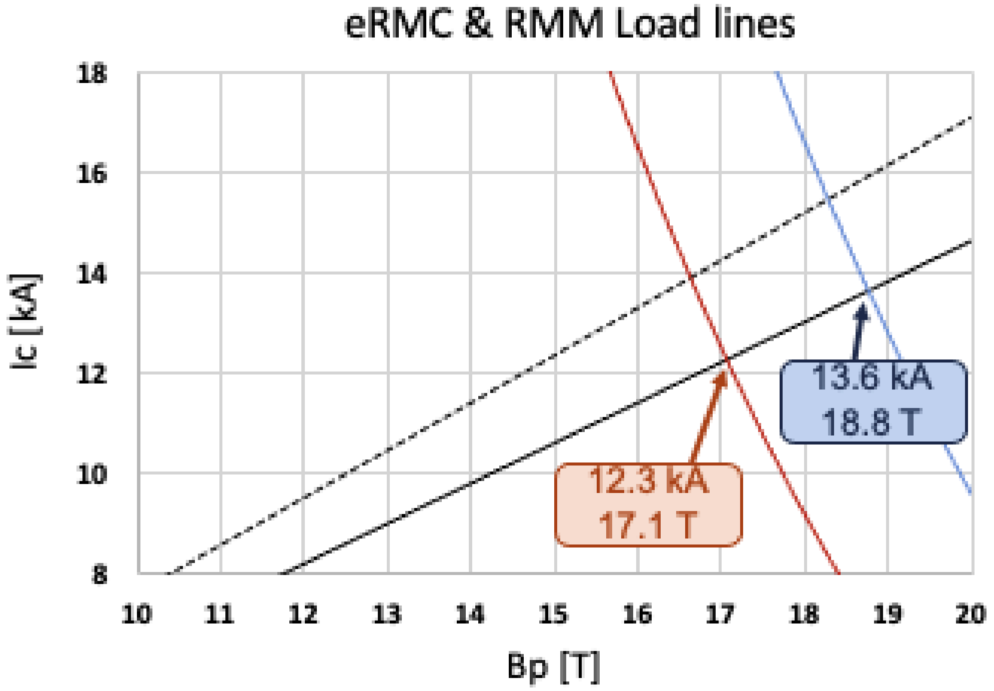
Courtesy of E. Todesco

# Magnetic design

- eRMC coils: titanium pole in the ends & magnetic steel ST430 pole in the middle
- RMM coil: titanium pole with 50 mm closed cavity





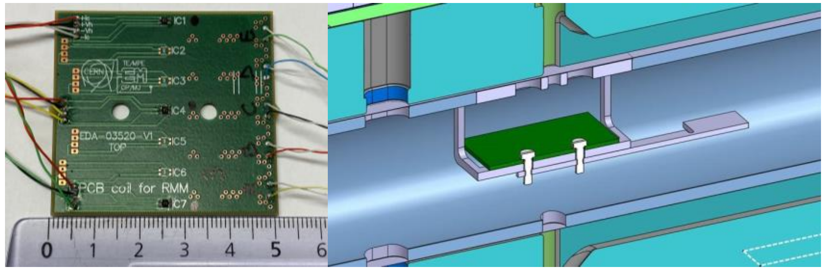



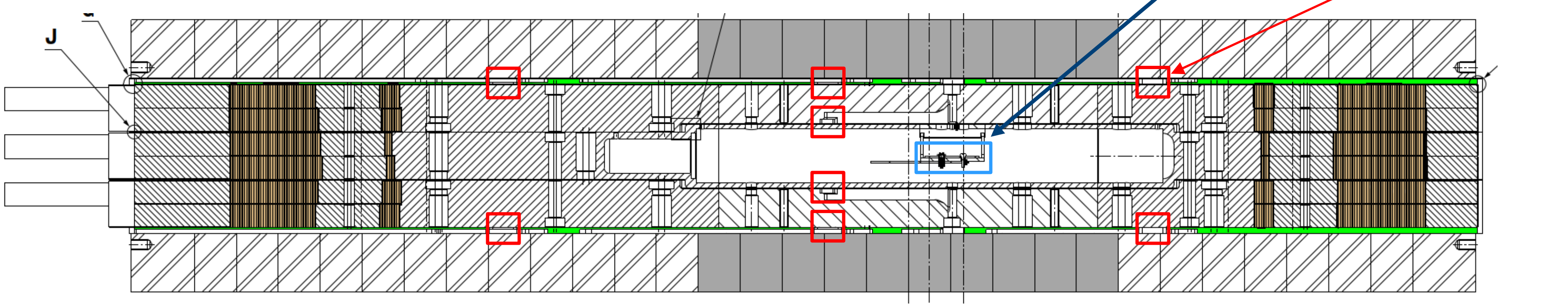

Courtesy E. Gautheron

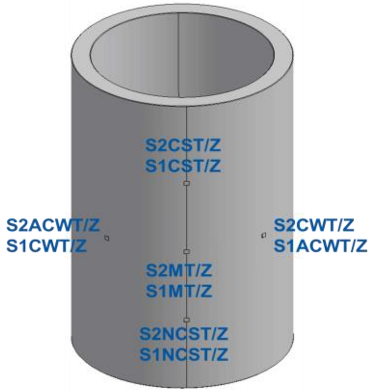
| | I (kA) | Bp (T) | Bo (T) |
|---|---|---|---|
| Short Sample @4.3 K | 12.26 | 17.07 | 16.85 |
| Short Sample @1.9 K | 13.64 | 18.77 | 18.51 |

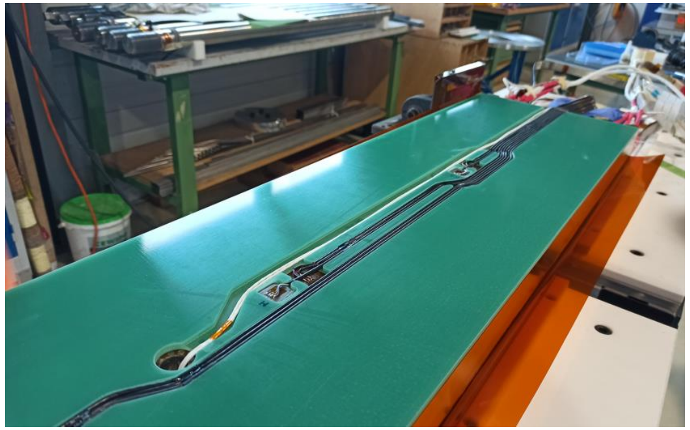
# Measurements

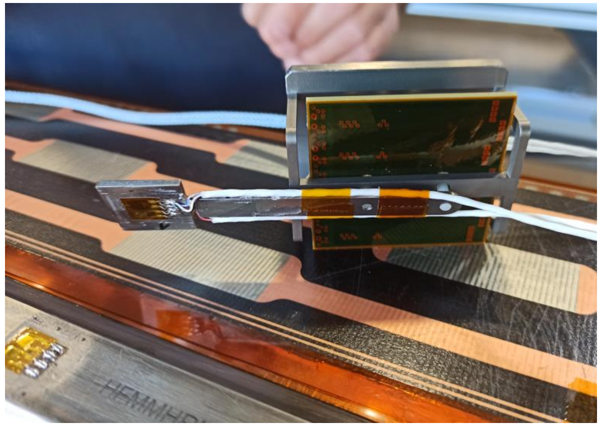
- **Mechanical measurements** using strain gauges on coil poles, shell and rods
- **Magnetic measurements** using dedicated PCB with hall probes and coils

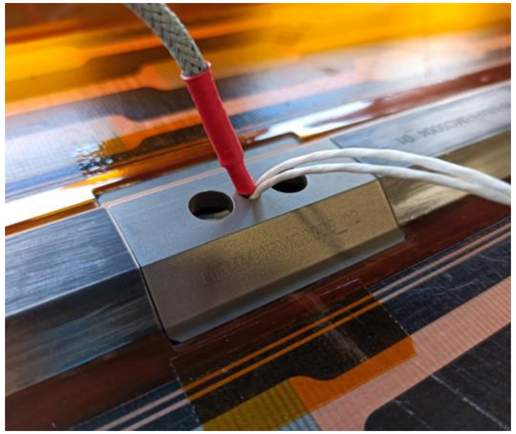




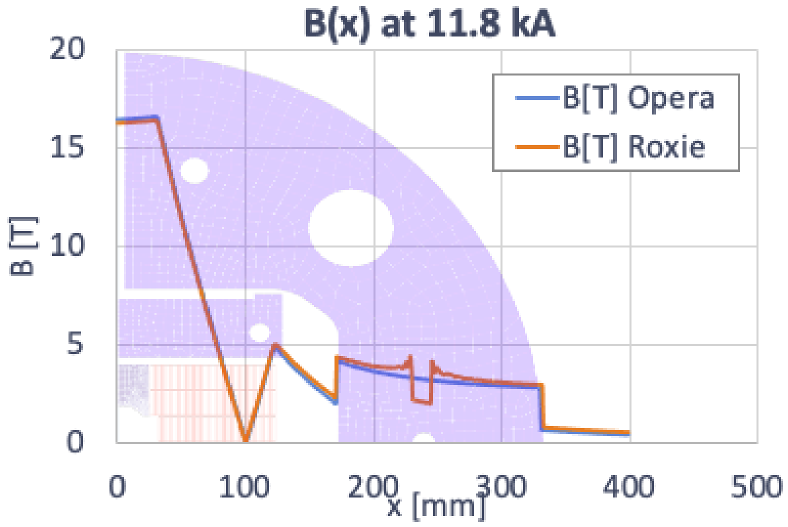



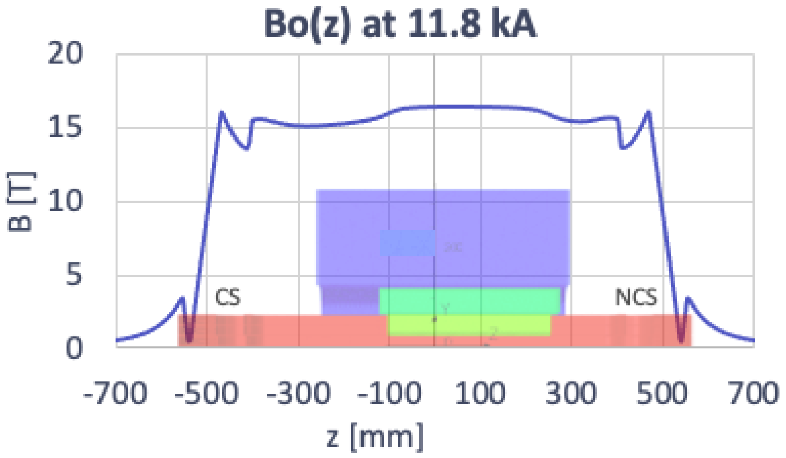



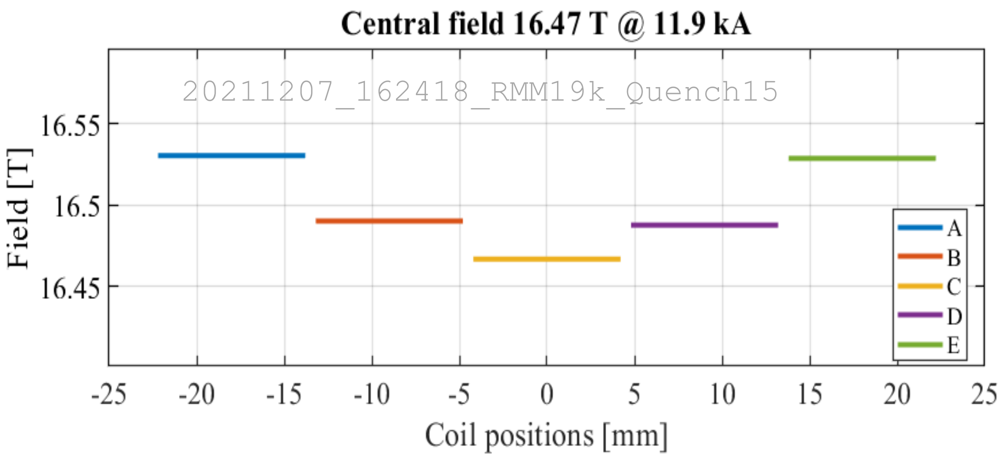


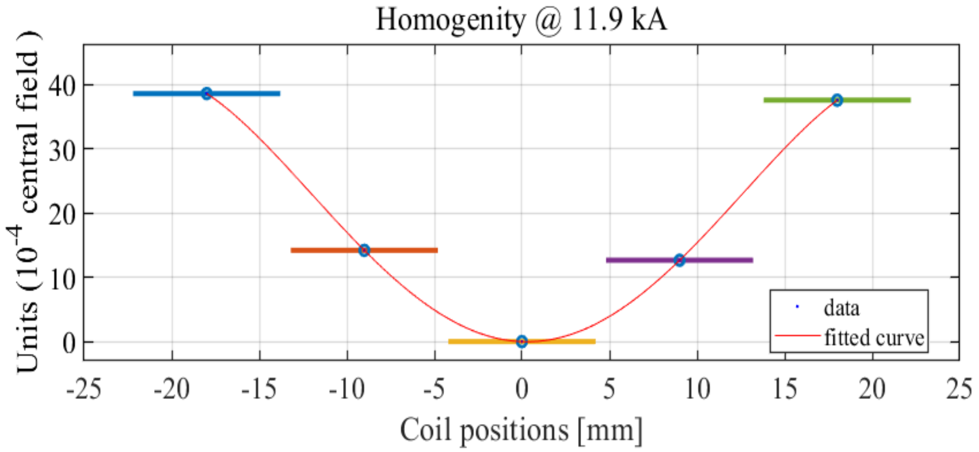


# Magnetic design



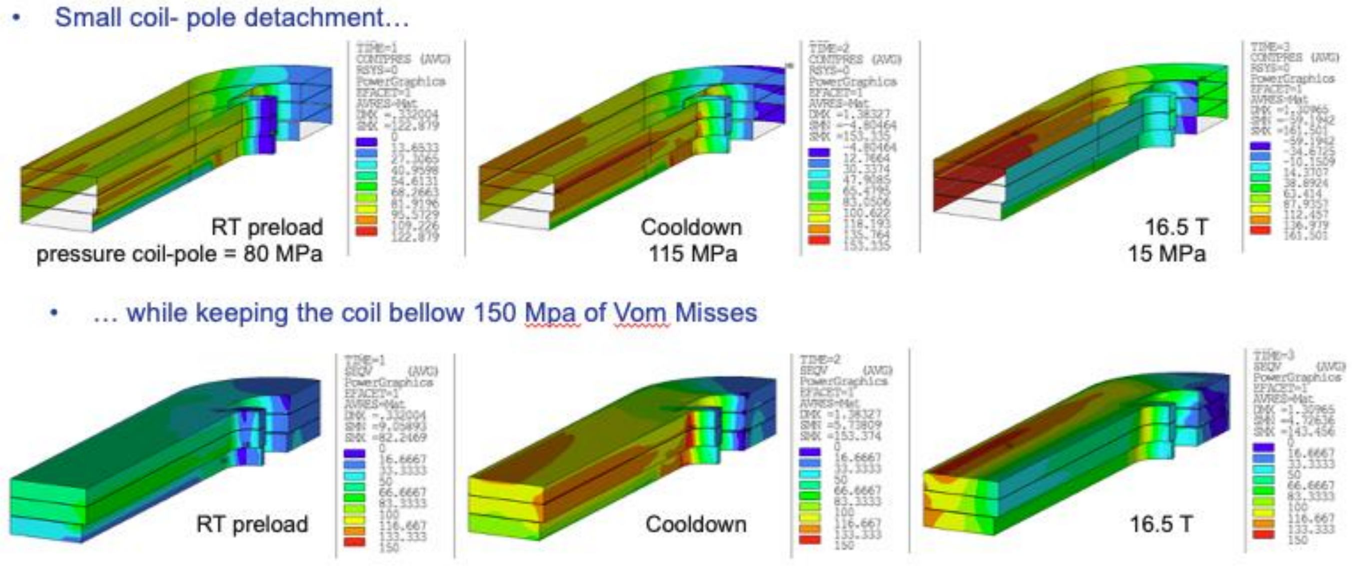




Courtesy of C. Petrone

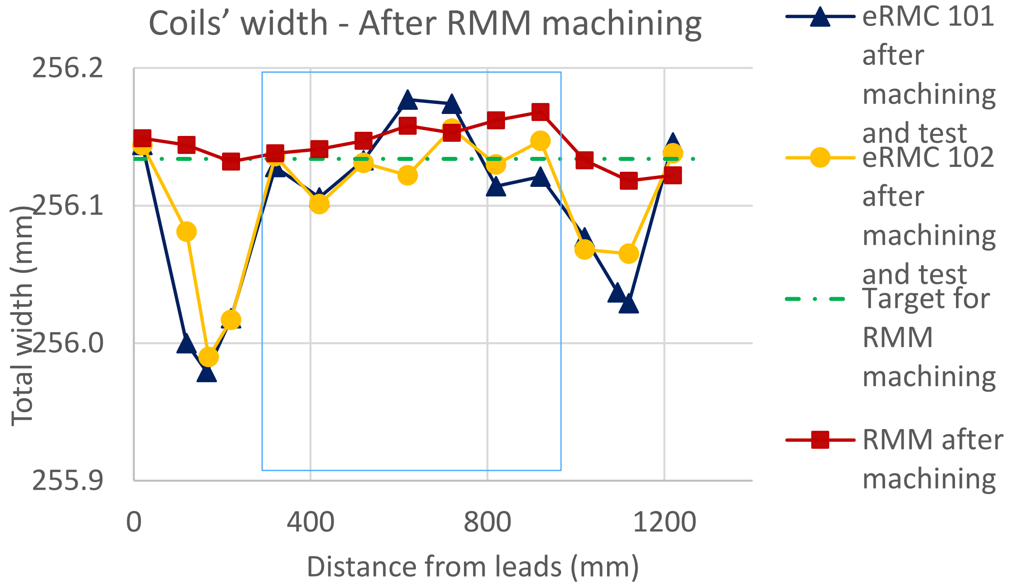
# Mechanical design

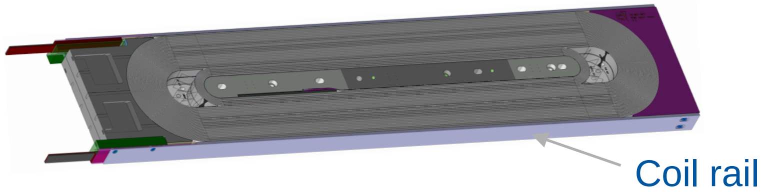
- Preload for 11.8 kA, i.e. 16.3 T bore field and 16.5 T target peak field in conductors
- With 1200 microns of lateral interference and rods at 350 kN* (each) at RT preload (80% of the Lorentz forces in the rods at cold)
- Upper stress limit: 150 MPa Von Misses in the coil blocks



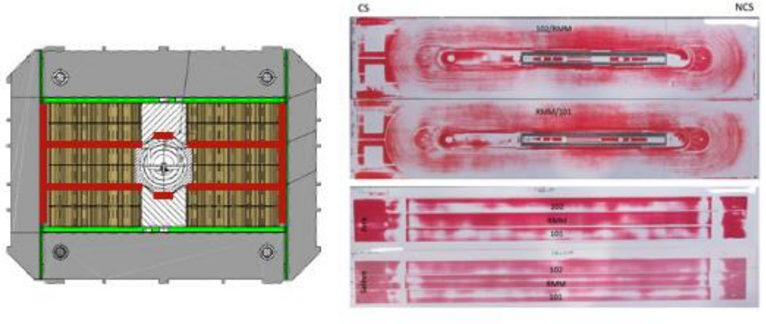

Courtesy E. Gautheron

## Machining of coil rails




## Shimming of the coil rails & intercoils

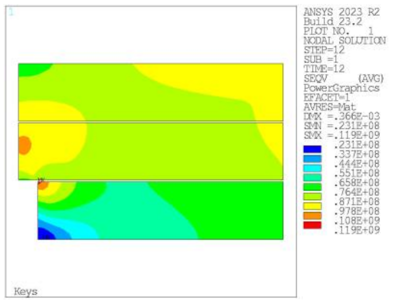


# RMM1d 2D Model

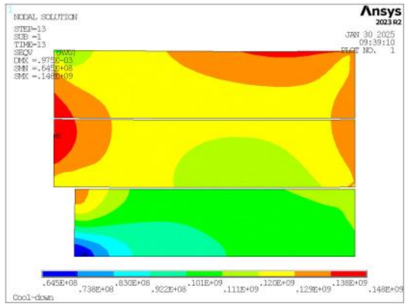
| | ANSYS 2D Magn. model |
|---|---|
| Magnet current | 12. 35 kA |
| Bore field | 16.9 T |
| Conductor peak field | 17.0 T |

| | Shell strain 0 Deg (2D Model) | Shell strain MI 0 Deg (Abs. value measured) |
|---|---|---|
| After room-temperature assembly | 1081 μstr | Avg = 970 (Avg of 928 & 1014) |
| At 1.9 K | 2028 μstr | Avg = 1580 (Avg of 1600 & 1562) |
| Delta CD | 947 | 610 |

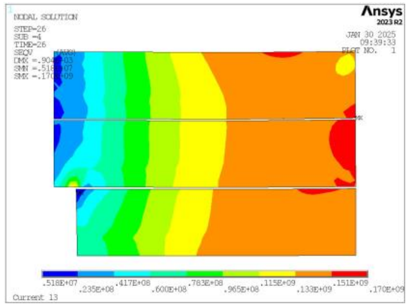
## VM Seq



After loading



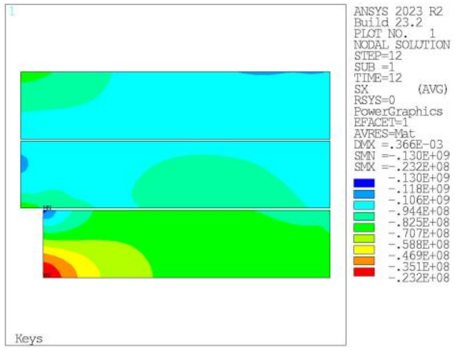
At 1.9 K



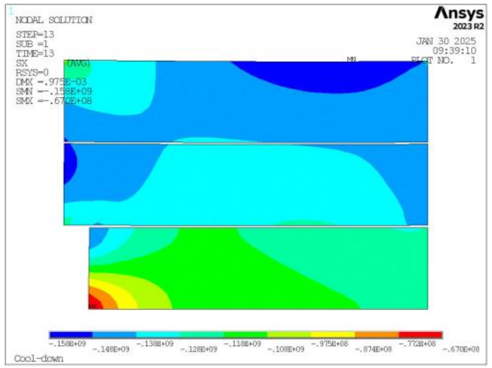
At 17 T

| | After loading | At 1.9 K | At 17 T |
|---|---|---|---|
| E-RMC peak VM Seqv | 99 MPa | 148 MPa | 170 MPa |
| E-RMC peak Sx | -108 MPa | -159 MPa | -180 MPa |
| RMM peak VM Seqv | 120 MPa | 134 MPa | 152 MPa |
| RMM peak Sx | -130 MPa | -146 MPa | -175 MPa |

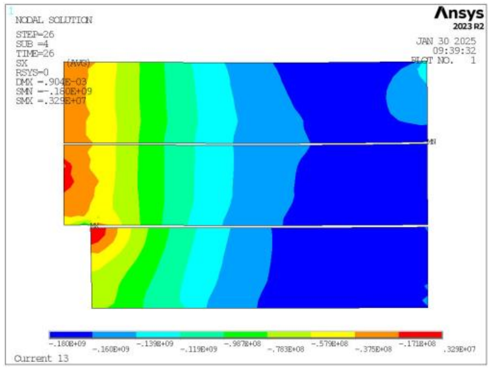
## VM Sx



After loading



At 1.9 K



At 17 T

Courtesy of J. Ferradas

# RMM1 timeline

**2018**

**Dummy Assembly**

*Characterisation of the mechanical structure*

**2019**

**eRMC1a**

*2 eRMC coils assembled*
*Coil pack and contacts optimisation*
*Target during powering tests limited to 16.5 T Bp*

**2020**

**2021**

**RMM1a**

*Coil pack and contacts optimisation*
*Fuji assemblies*
*Magnet loaded for 16.5 T Bo and rods for 70-80% of LF at cold*

**2022**

**RMM1b**

*Modification of rods diameter to prevent interference with the yoke*

**2023**

**RMM1c**

*Increase of lateral shimming on eRMC coils*
*Most of the quenches are located in eRMC coils*

**2024**

**RMM1d**

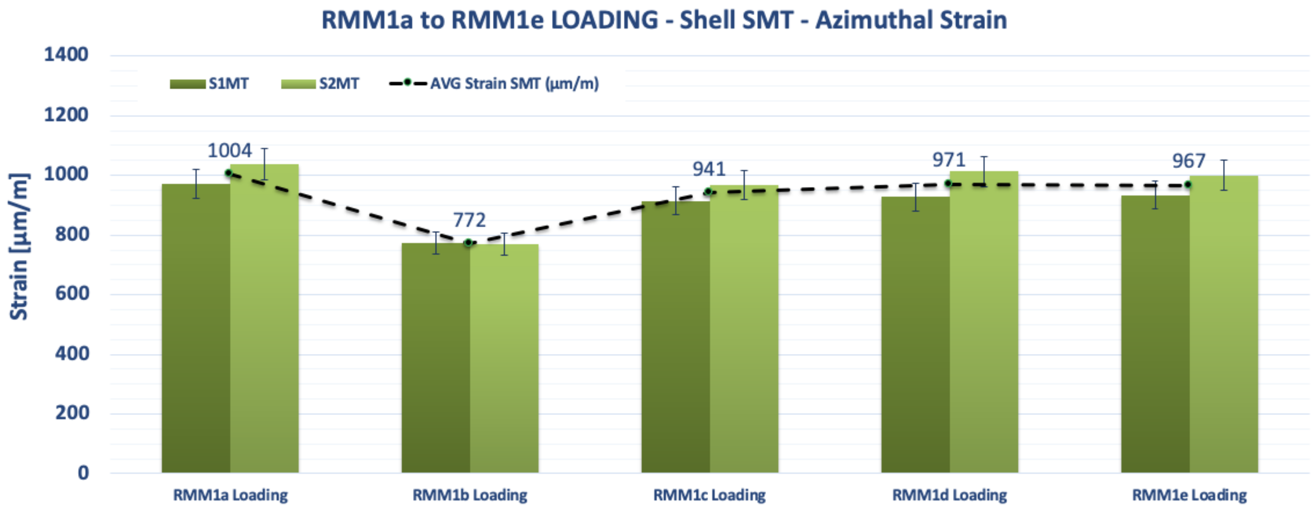
*Coils precompression increased by 10 MPa*

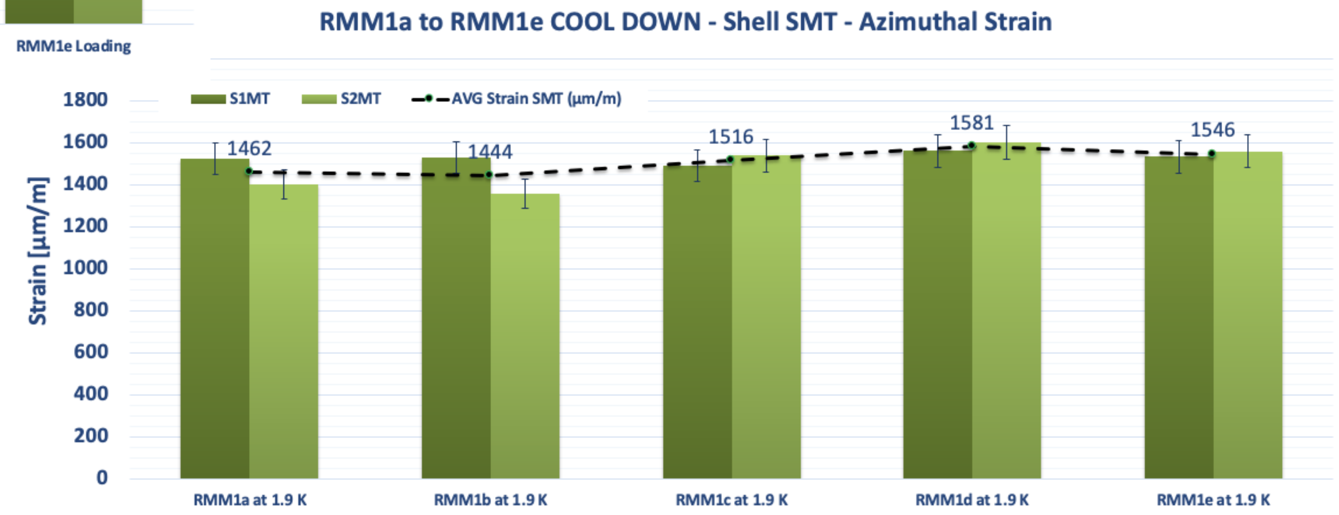
**2025**

**RMM1e**

*Fishbones added to improve cooling*

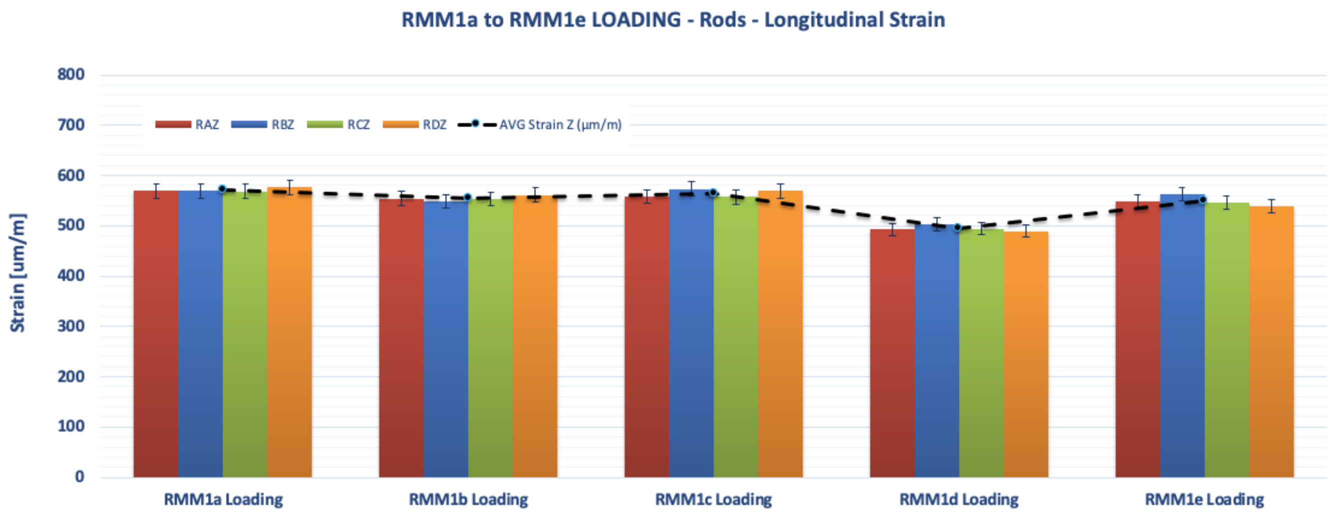
# RMM1 mechanical measurements (Azimuthal strain)

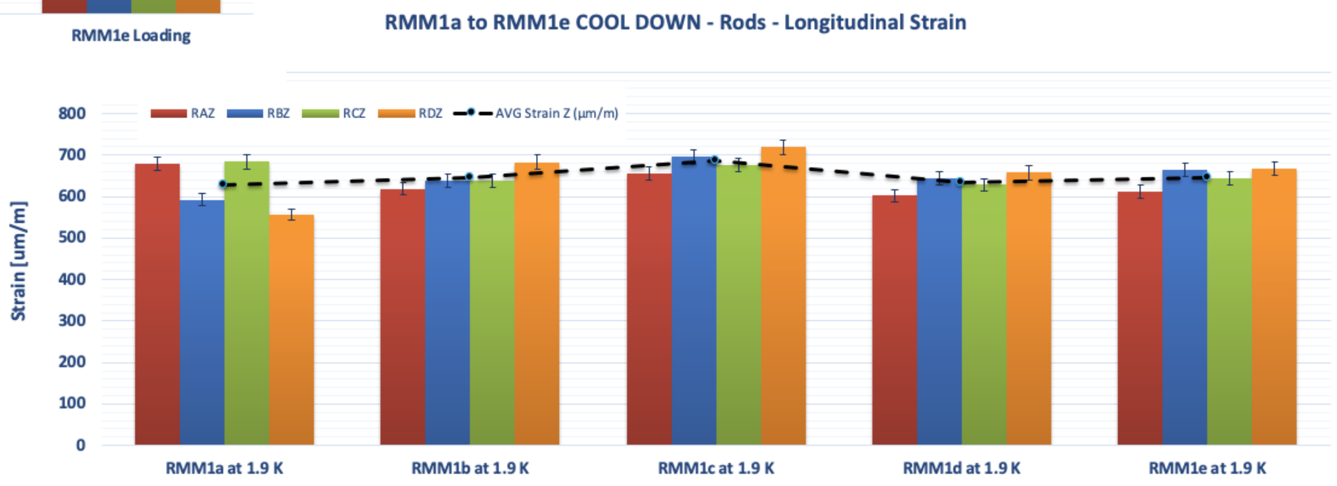



Courtesy of Sylvain Mugnier

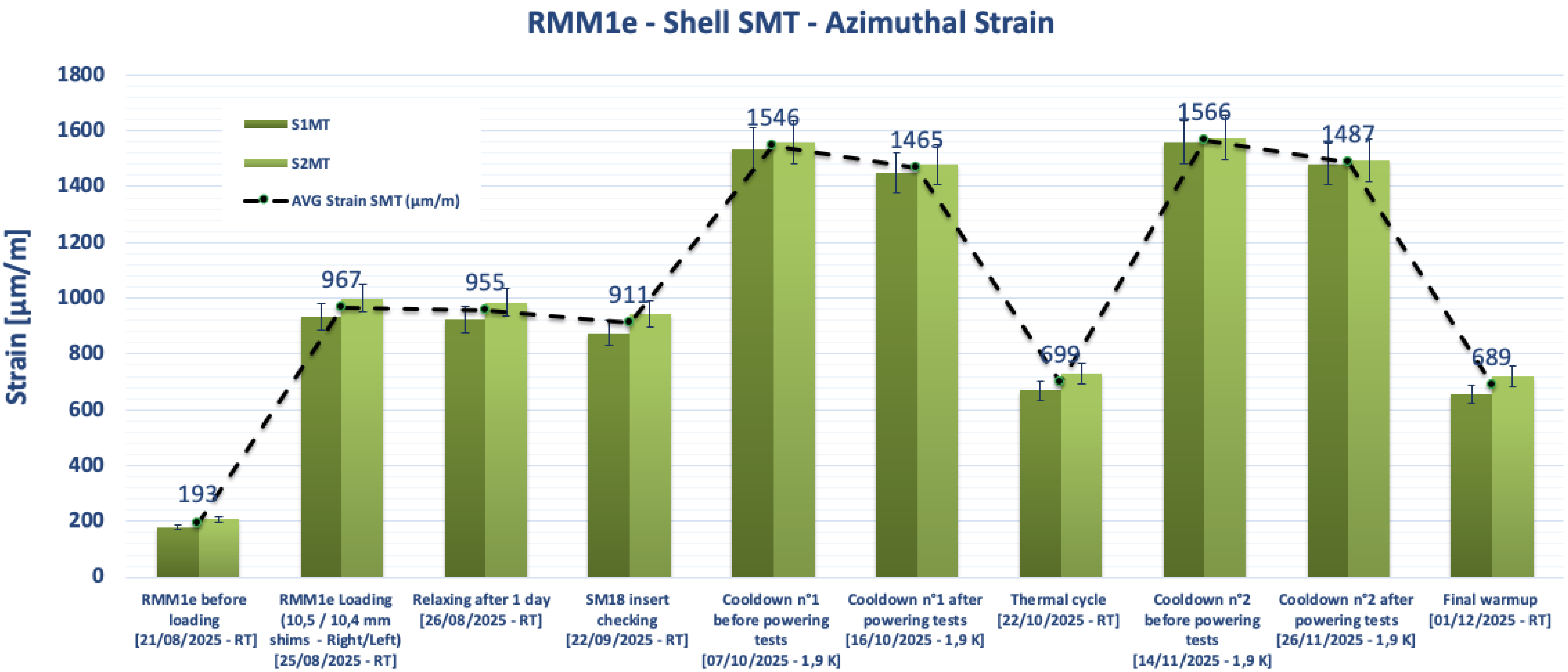
# RMM1 mechanical measurements (Rods longitudinal strain)




Courtesy of Sylvain Mugnier

# RMM1e Shell azimuthal behaviour



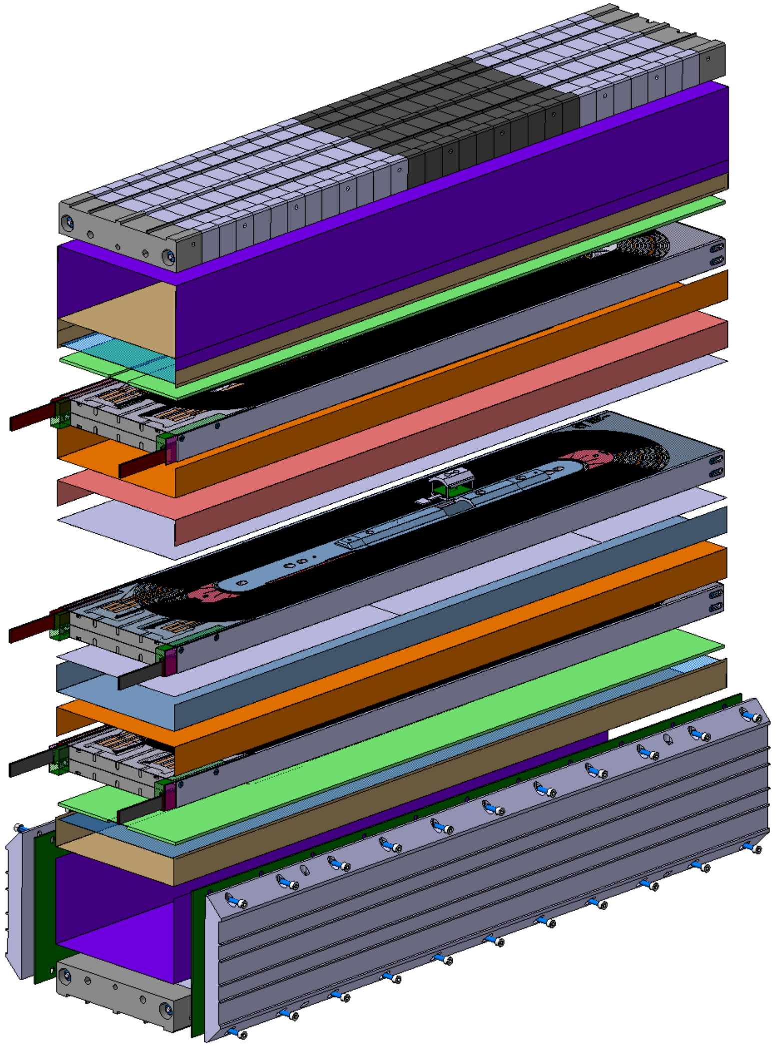

Courtesy of Sylvain Mugnier

# Coil-pack configuration

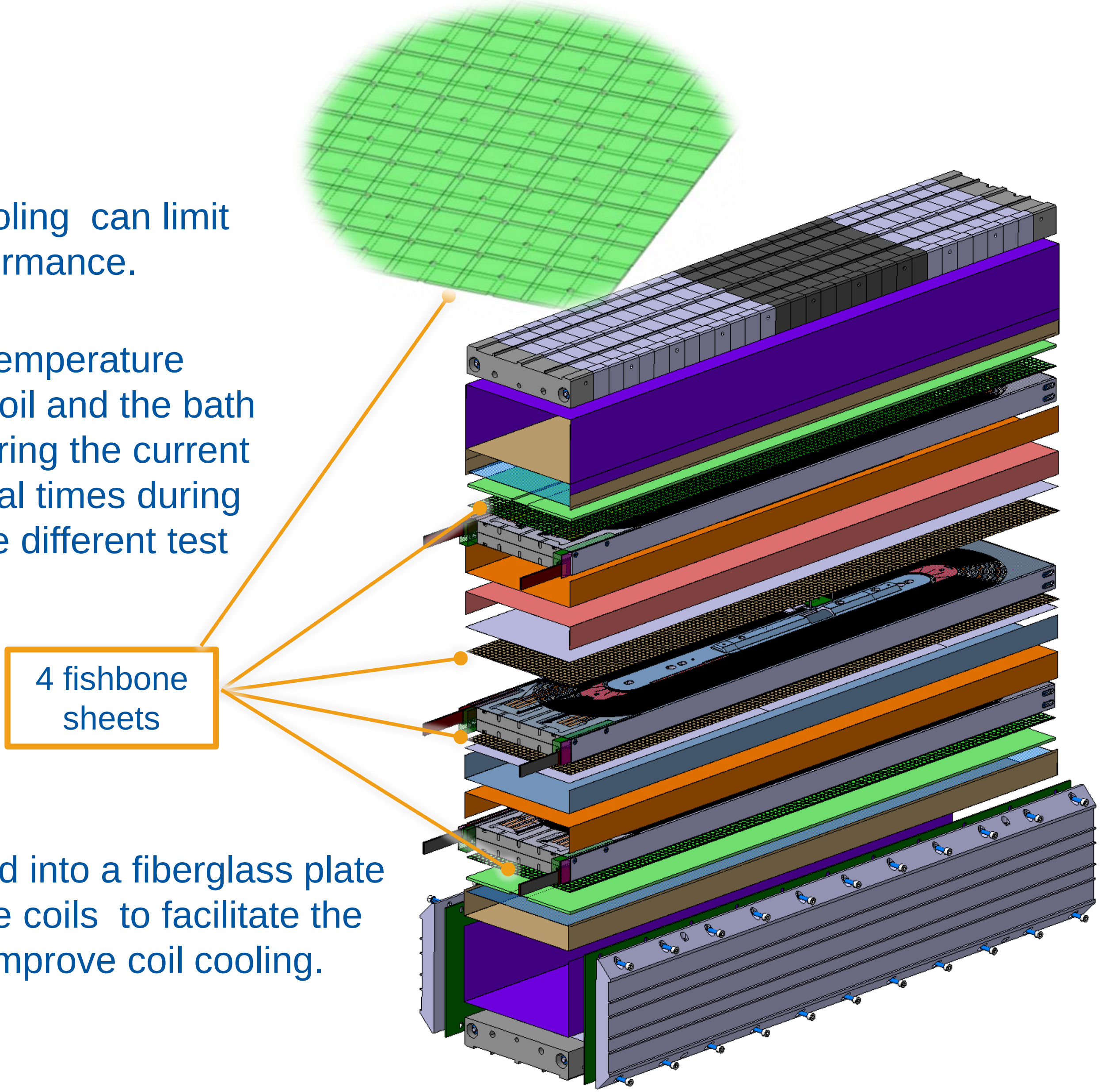
Magnet losses and cooling can limit the magnet performance.

The possibility of a temperature difference between the coil and the bath caused by AC losses during the current ramp were raised several times during the presentations of the different test results.

Channels were machined into a fiberglass plate and mounted facing the coils to facilitate the passage of He and improve coil cooling.

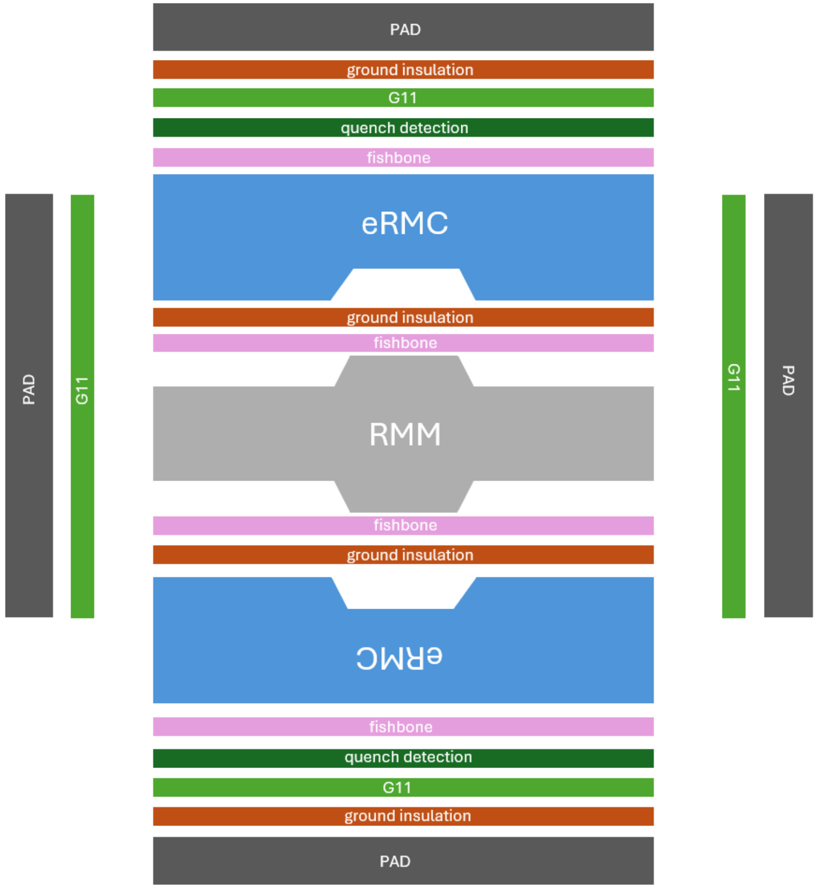


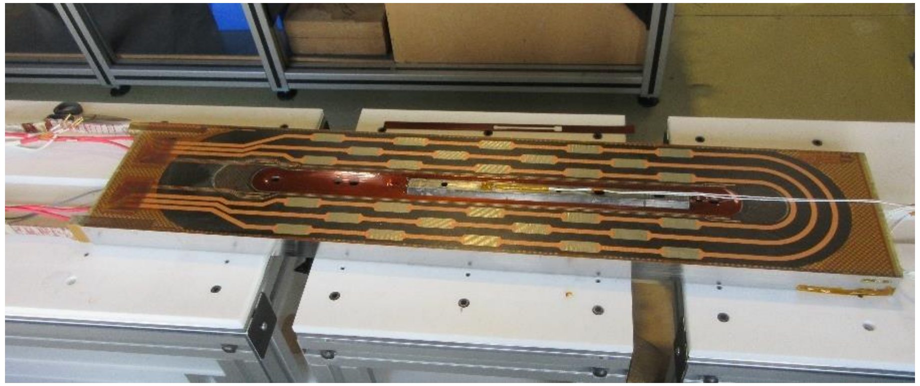
Coil-pack configuration of RMM1a to RMM1d

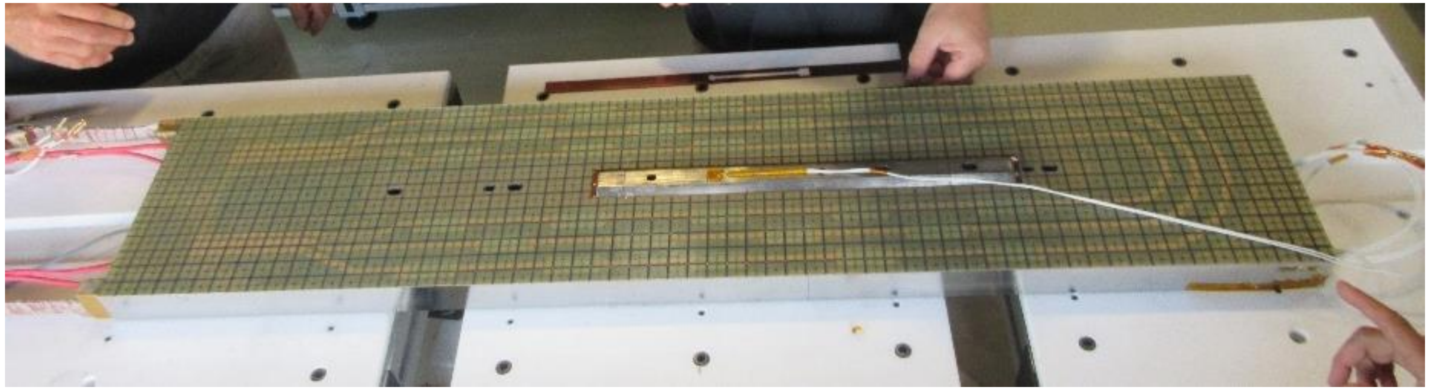



Coil-pack configuration of RMM1e

# Fishbone assembly in RMM1e

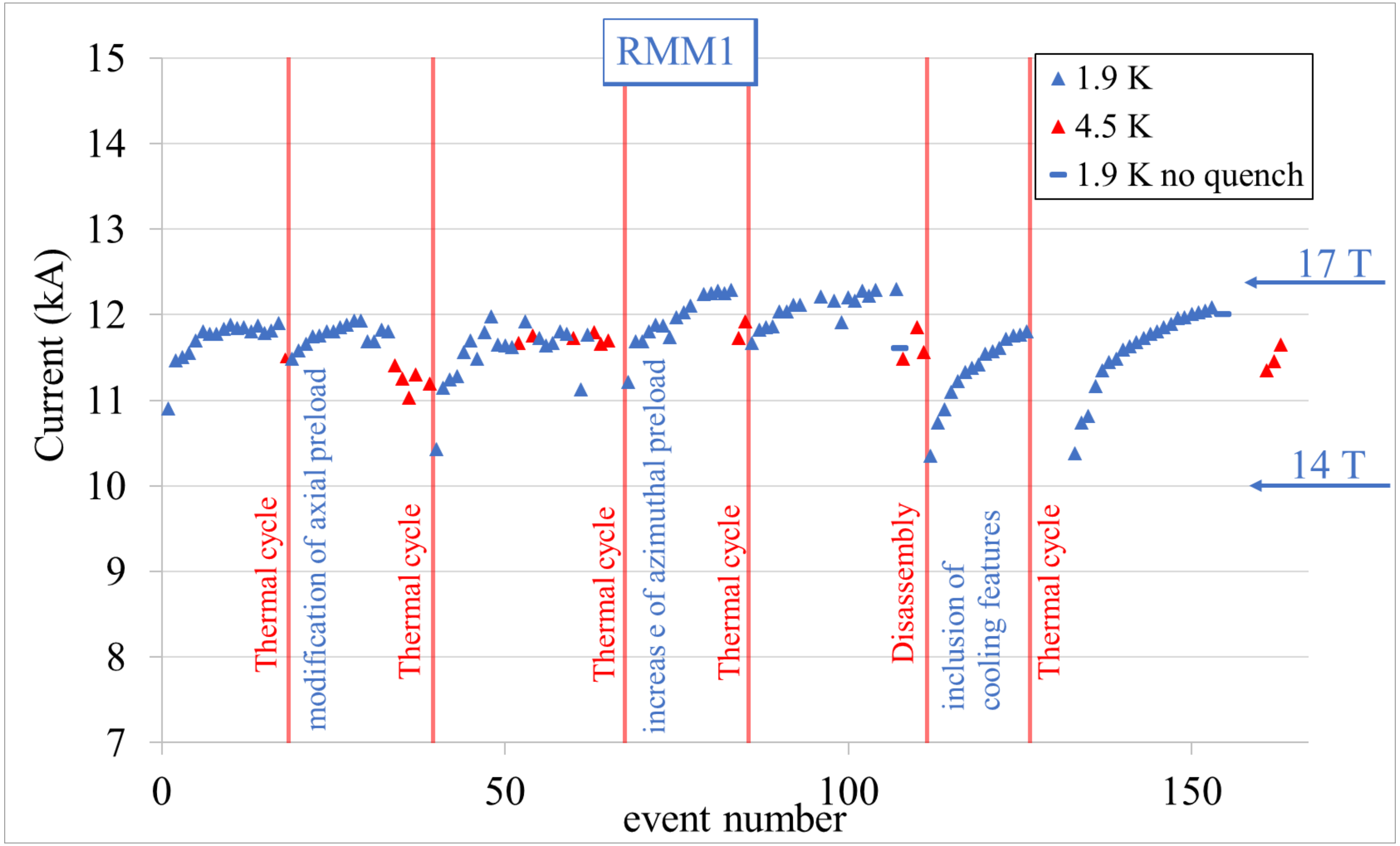




# RMM1 global performance

- Lowest first training Quench at 10.38 kA ($B_0$ : 14.5 T) corresponding to 76% of Iss
- Highest $B_0$ (T) of 16.95 T reached with RMM1d configuration equivalent to 91.6 % of Iss
- RMM1e reached a maximum $B_0$ (T) of 16.6 T corresponding to 89 % of Iss



# Thank you for your attention

HFM

High Field Magnets

Programme