Status of ERMC and RMM

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EuroCirCol Review

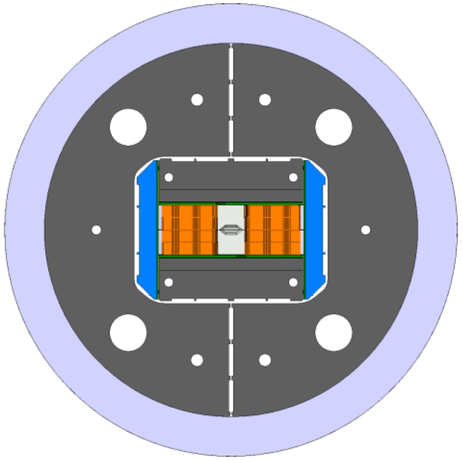
The ERMC and RMM program

ERMC

Enhanced Racetrack Model Coil

16 T midplane field

- Demonstrate field on the conductor
- Coil technology development

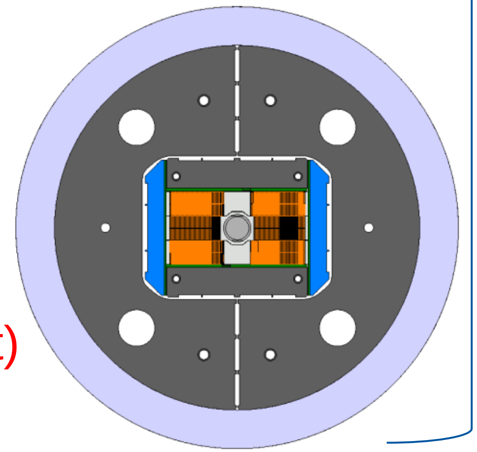


RMM

Racetrack Model Magnet

16 T in a 50 mm cavity

- Demonstrate field on the aperture
- Mechanics (including inner coil support)



Base for the development of the technology needed for the 16 T dipole program

ERMC & RMM design strategy

Stage 1 priorities:

1. Demonstrate the field
   - Design based on the “available” critical current density (~20% lower than FCC target at 18 T, 4.2 K)
   - As field quality is not an objective, profit from the use of an iron pole to decrease the ratio between the field in the aperture and in the coil to ~ 1
2. Study the mechanics

Stage 2 priorities:

1. Coil size → Grading
   - Design based on the target FCC critical current density
   - High Field Nb_3Sn splice development needed
2. Field quality (b_n<10 units, including iron saturation)
   - Still, it will need to be accommodated within the same structure, changing only the collar pack assembly

Non graded design

- Design finished
- Components for the magnet structure under procurement

Graded design

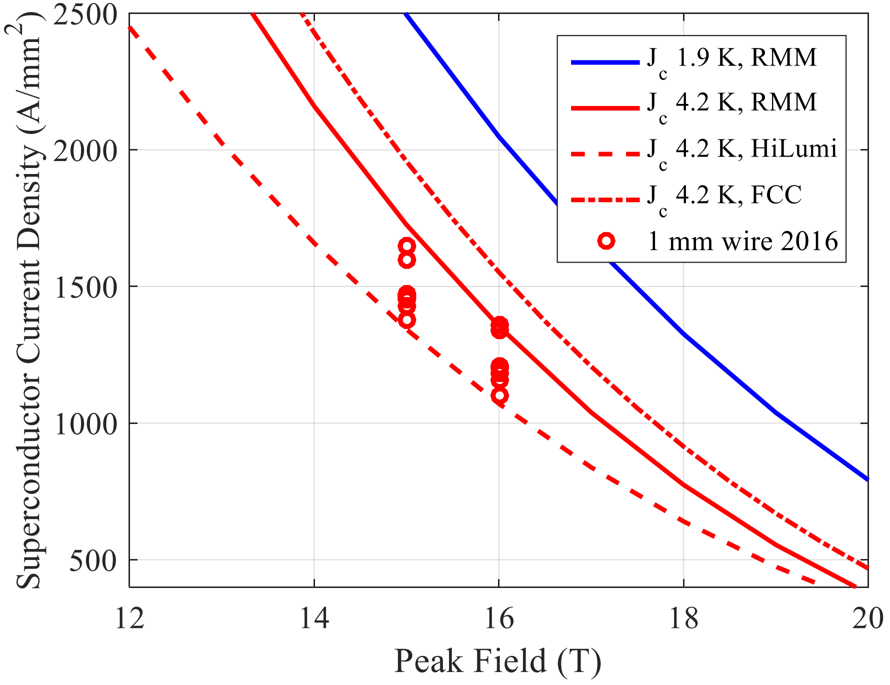
- 2D magnetic and mechanical design done
- Activity launched on splice development, but further feedback needed before starting the engineering design.

Non-Graded Design

B. Bordini & J. Fleiter & A. Bonasia

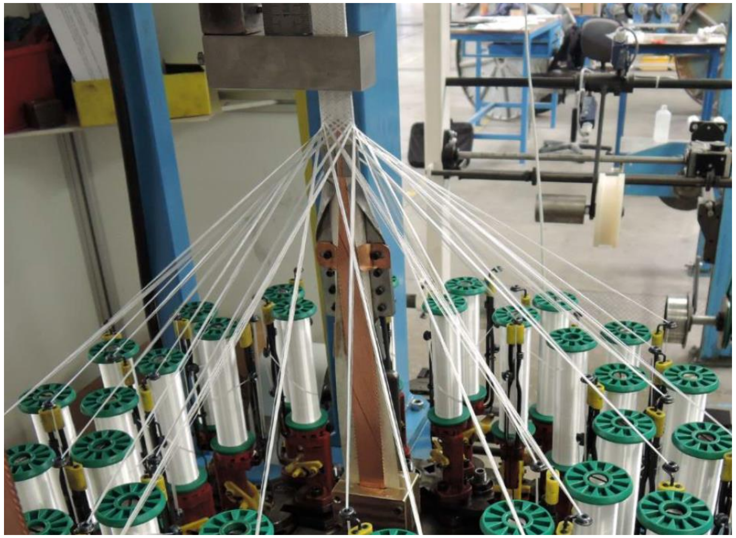
Strand and Cable

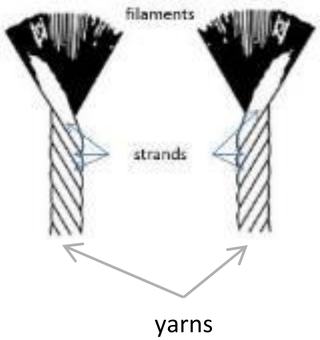
- 1 mm diameter wire, cu/sc =1
- RRP 120/127 (62-64 µm) & RRP 150/169 (54-55 µm)
- 40-strand cable
  - Bare width x thickness: 20.9 x 1.82 mm
  - SS core 14 mm wide and 25 µm thick
- 3 cable unit lengths (220 m x 3) available
- Assumed growth during HT : 3% (thickness), 1% (width)



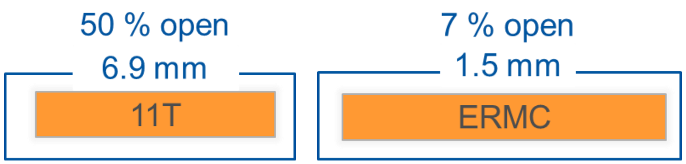
Cable insulation

- Baseline: 0.150 $^{+0.00/-0.02}$ mm Mica-Glass Insulation
- Insulation tests preformed to define the best parameters:
  - S2 glass 636 11 TEX yarn
  - 14 yarns (ply) per bobbin
  - 32 bobbins
  - Speed (angle) set to guarantee full coverage and appropriate thickness





Cable insulation



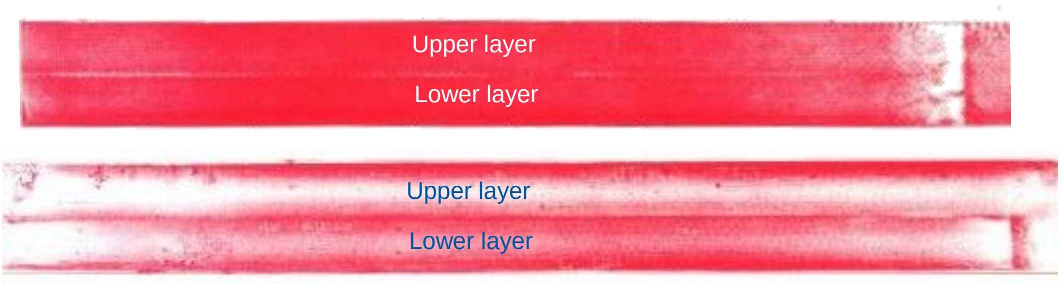
Remark: plots not on scale

- Some evidences on 11 T and SMC 11 T that the C-Shape mica can have a negative impact on the uniformity of the pressure distribution.

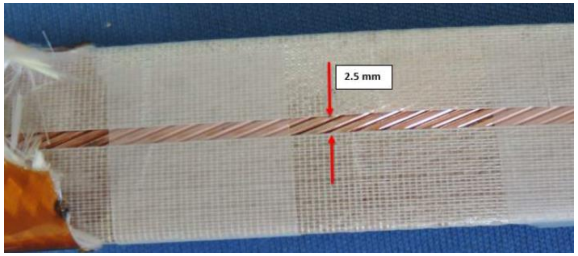
Contact pressure on outer coil turns, SMC11T under 50 MPa compression

SMC11T-1 (no mica)

SMC11T-3 (mica)



- After some iterations, braiding with wider mica tapes (44 mm) feasible.
- One cable unit length insulated, ready to be wound.
- The other two cable unit lengths will be insulated end of October.



https://indico.cern.ch/event/641884/
https://indico.cern.ch/event/659541/contributions/2689641/attachments/1507432/2349396/Visite_CGP_ERMC.pdf

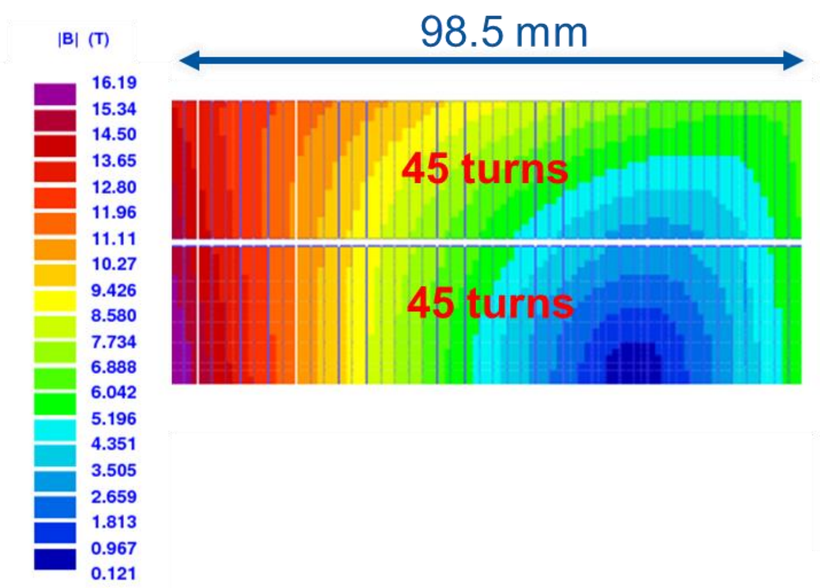
Magnetic design

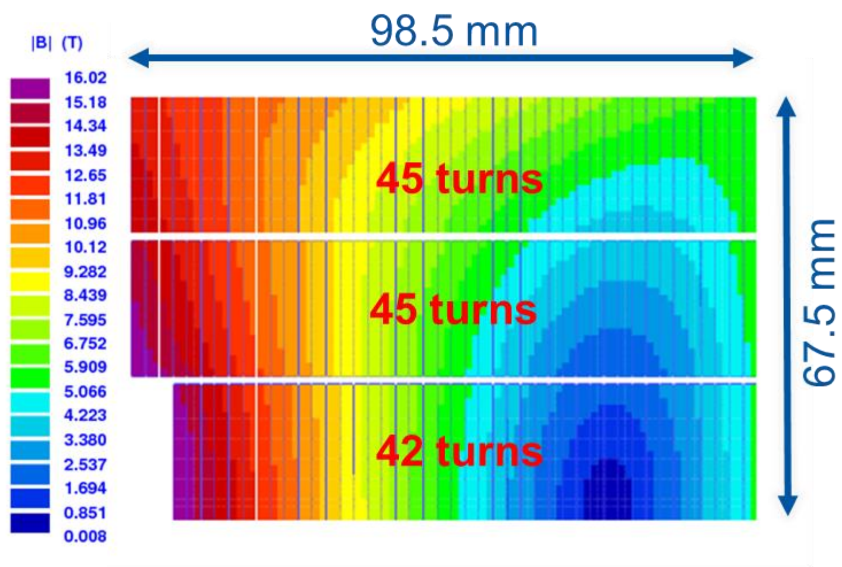
ERMC

- Two double-layers with 45 turns each wounded around a magnetic pole
- B_p/B_o = 1.097

RMM (ERMC double layers +)

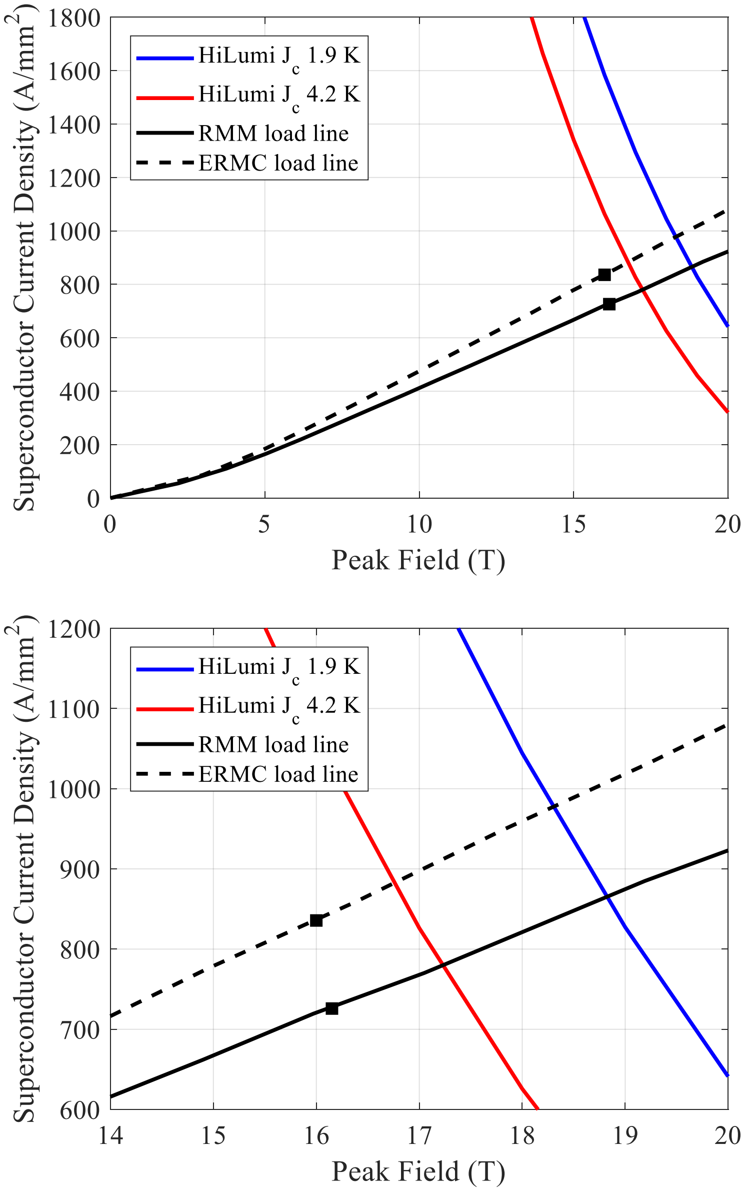
- Middle double layer with 42 turns each wound around a titanium closed cavity
- Coil aperture radius = 31 mm
- Closed aperture radius = 25 mm
- B_p/B_o = 1.097





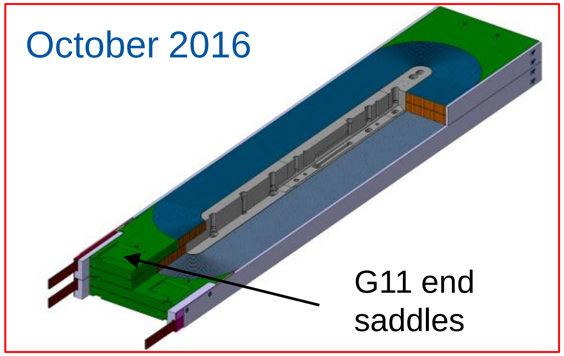
Magnet parameters

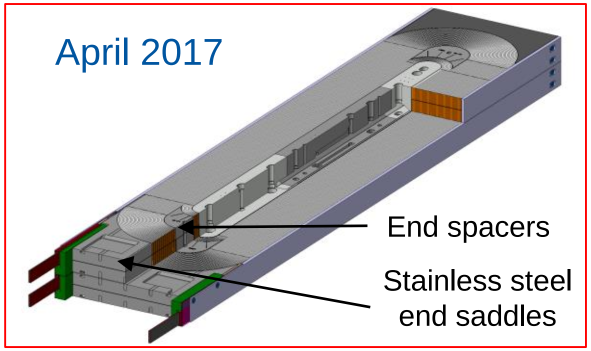
	Units	ERMC	RMM
Nominal current (I_{nom})	**kA**	13.1	11.4
Overall current density	**A/mm²**	282	245
Bore field	**T**	15.7	16.0
Peak field at I_{nom}	**T**	16.0	16.2
Stored energy at I_{nom}	**MJ/m**	1.5	2.1
Differential inductance at I_{nom}	**mH/m**	16.6	31.1
Assuming Hi-Lumi Jc			
Short sample field at 4.2 K	**T**	16.7	17.2
Short sample field at 1.9 K	**T**	18.3	18.8
($1-B/B_{ss}$) at 1.9 K	**%**	13	14



Evolution of the coil design

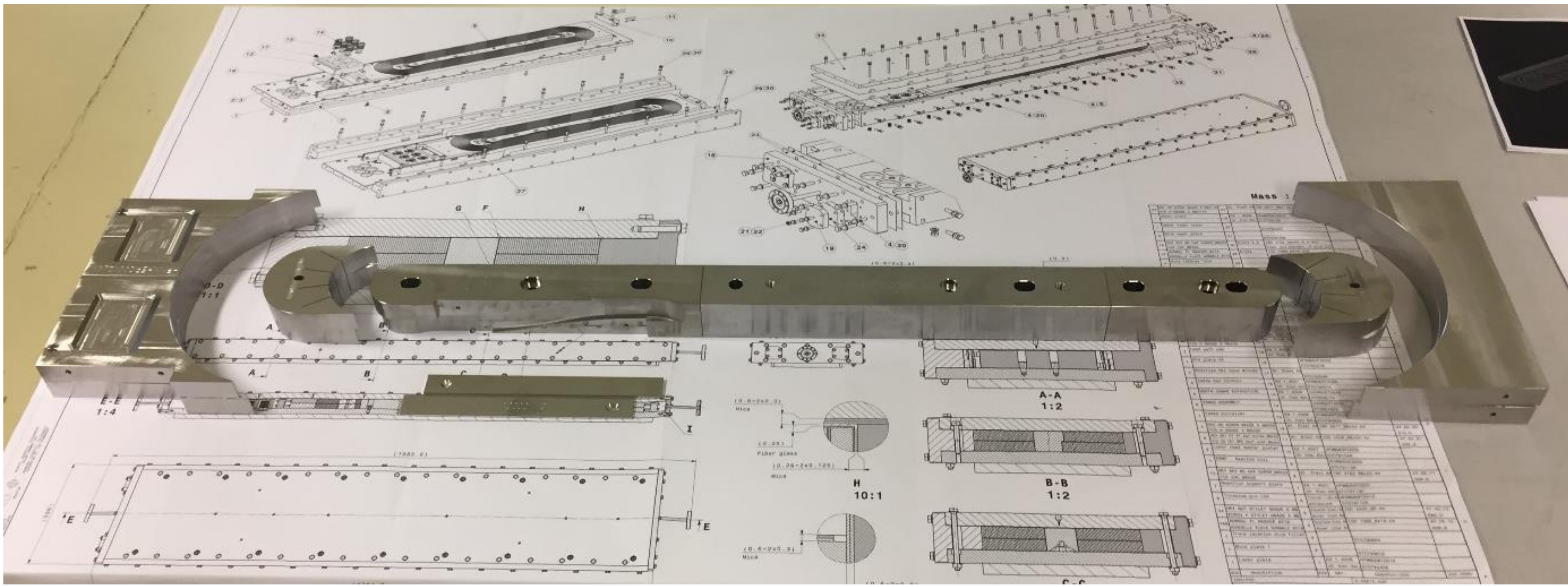
- End spacers introduced on the coil ends
    - Larger peak field for the same amount of conductor, but more favourable from the mechanical point of view.
- End-saddles on stainless steel instead of G11.
    - Limit the displacement on the coil ends.
- Design of the instrumentation and quench heaters finalized.





Coil components

- Coil parts for 3 ERMC coils in house.

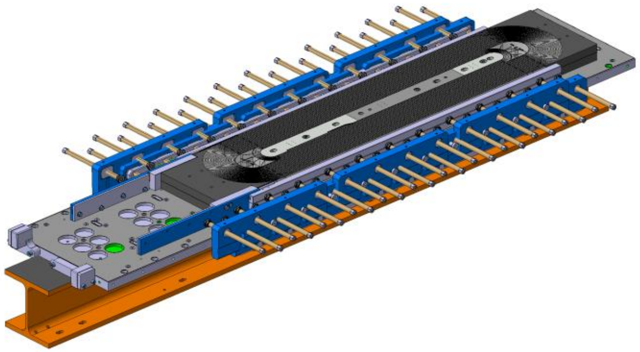


- Traces under procurement, expected to be delivered mid-November.

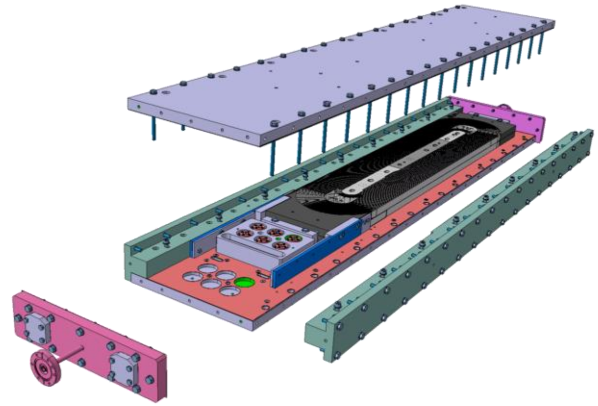
Coil fabrication

Expected to be delivered Oct-2017

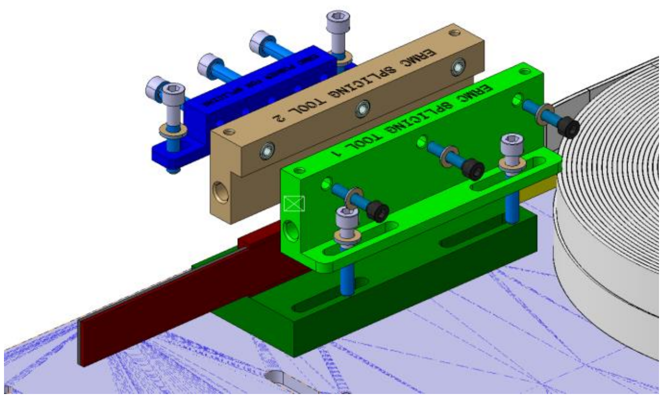
ERMC10 – Winding



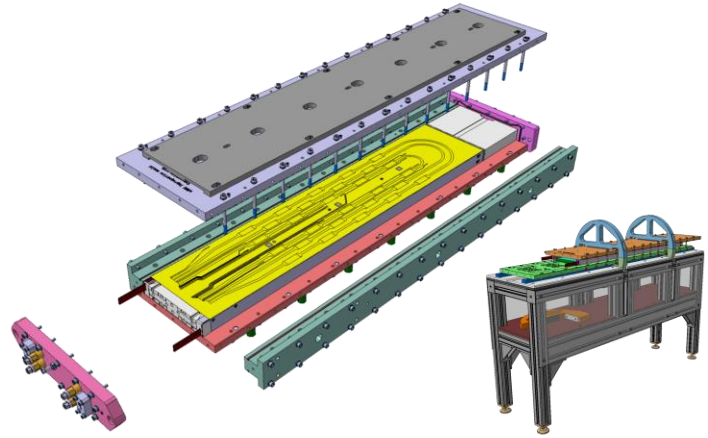
ERMC20 – Reaction



ERMC30 – Splicing

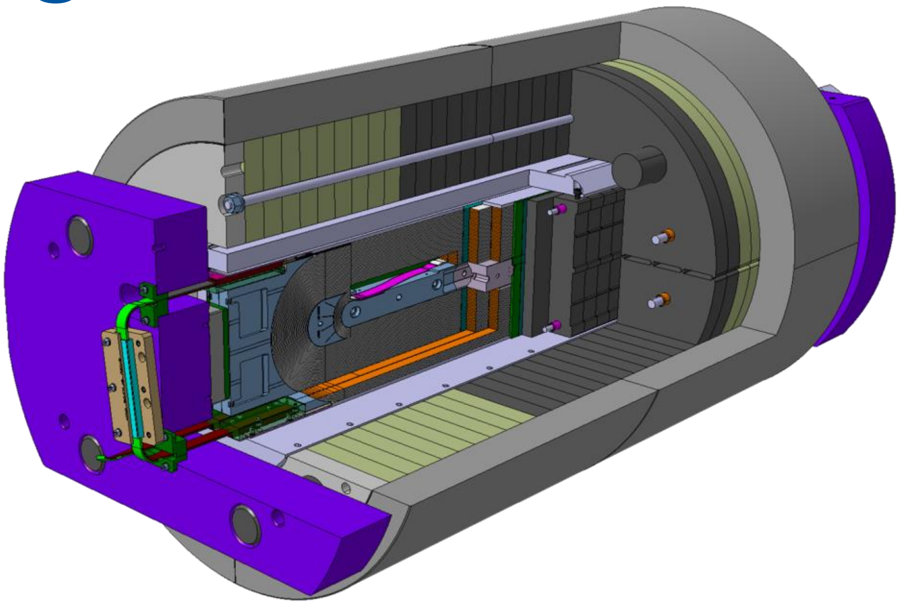


ERMC40 – Impregnation



Mechanical design

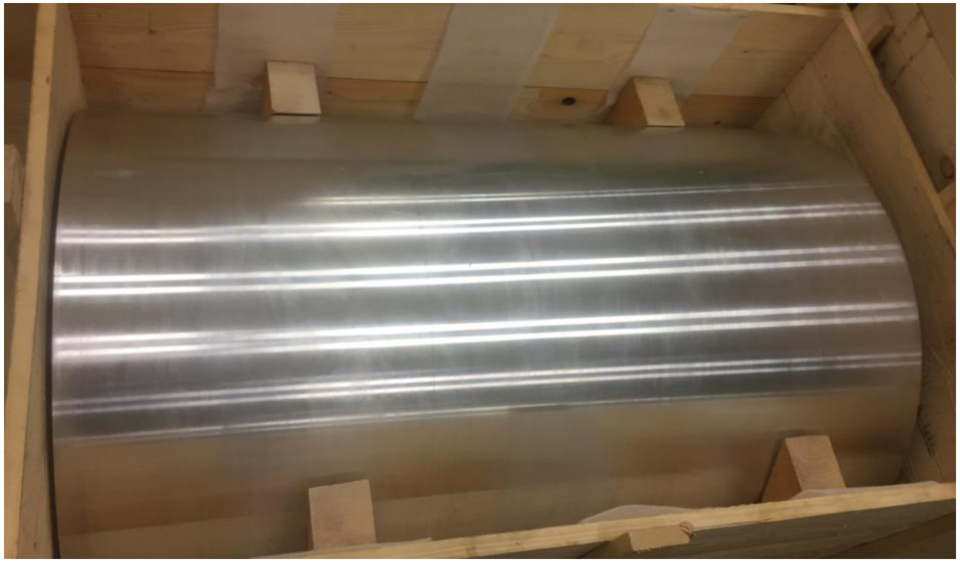
Mechanical structure capable to load the magnet up to 18 T, with enough margin to perform an experimental exploration of the different parameters relevant to magnet performance.



- To allow a further exploration of the assembly parameters:
  - Two different sets of shells have been procured:
    - One shell, full length
    - Two shells, central split
  - Aluminum rods and stainless steel rods are under procurement.

Magnet components

- Shells delivered to CERN, under metrology control.

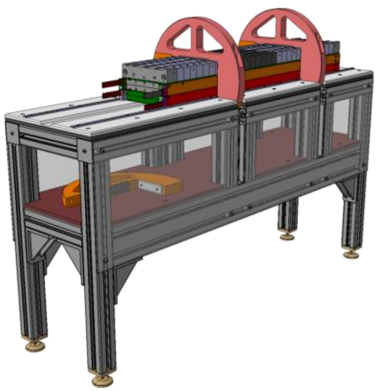


- Rest of the magnet components under procurement
  - Yoke and pads expected to be delivered January 2018
  - End plate in the critical path (procurement launched Sep - 2017)

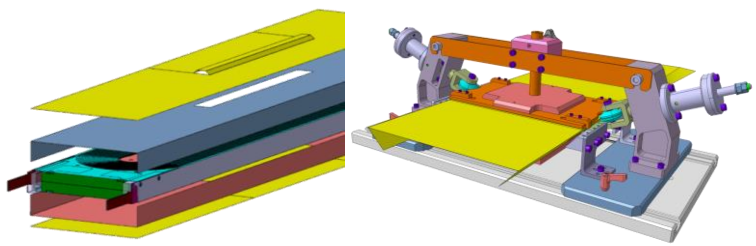
Magnet assembly

Under procurement.
Expected delivery
January 2017

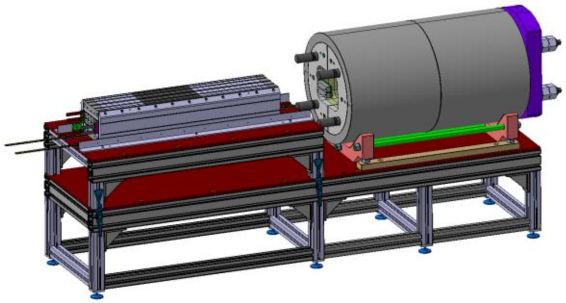
ERMC50
Coil Pack Assembly



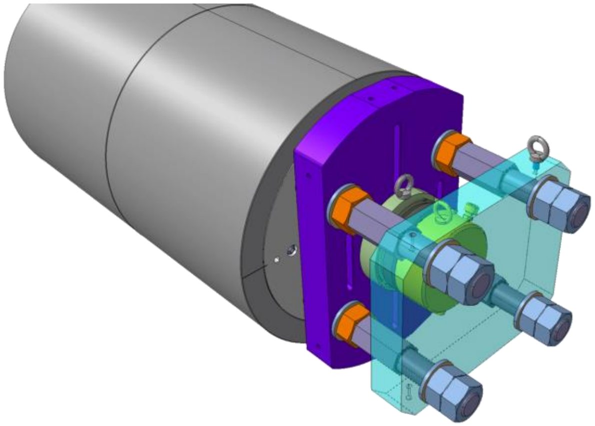
ERMC60
Ground Insulation



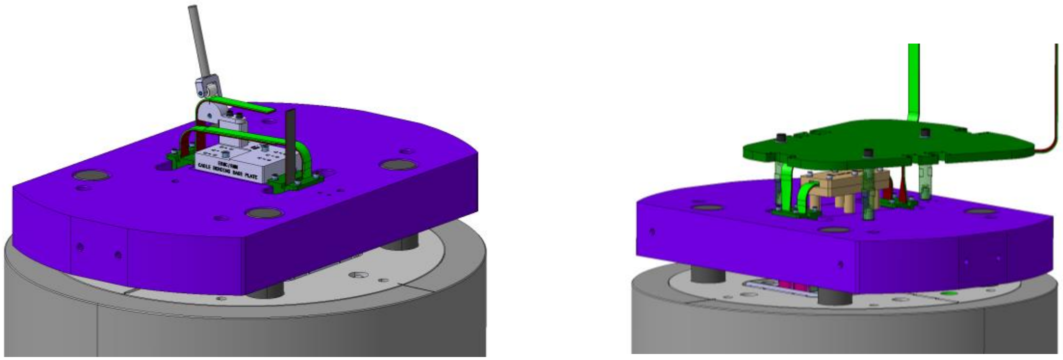
ERMC70
Insertion



ERMC80
Axial loading

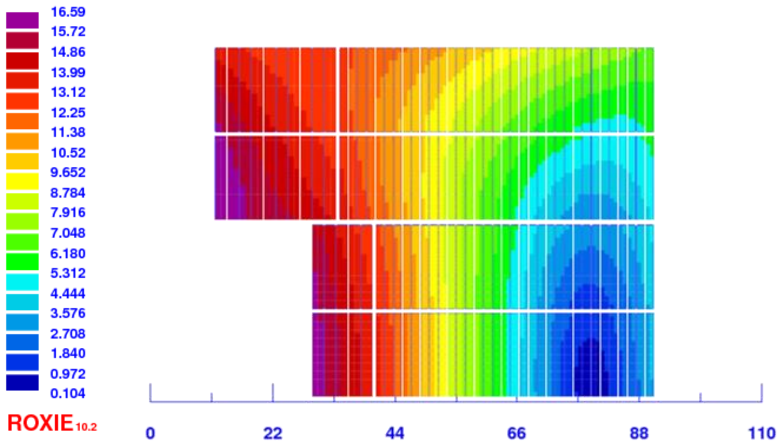


ERMC90
Splicing and Connection box



Graded Design

Magnetic Design

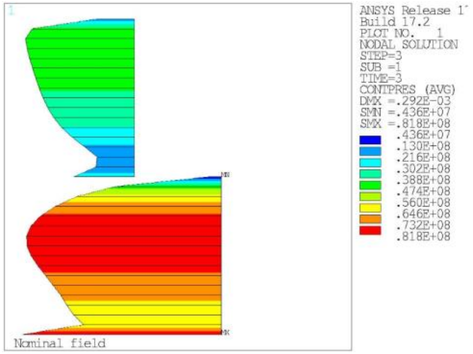


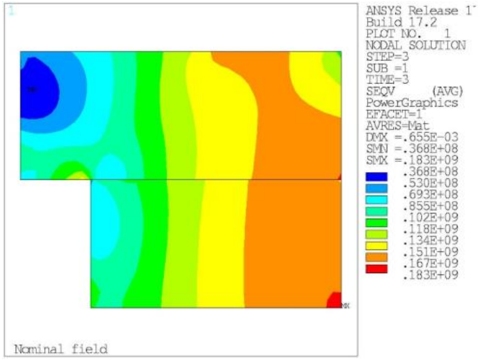
- Strong synergy with the EuroCirCol Block design option, slightly more conservative in some aspects:
  - 16 T bore field, with 14 % margin, using “available” critical current density (RMM critical current density, assuming 5 % cabling degradation)
  - 20 % margin in the low field region, as the impact on coil size is relatively small.
  - Inner support thickness of 4 mm. In a later stage, coil with 2 mm inner support can be produced to study the impact of the inner support on the performance.
  - Minimum available copper to superconductor ration 1 instead of 0.8

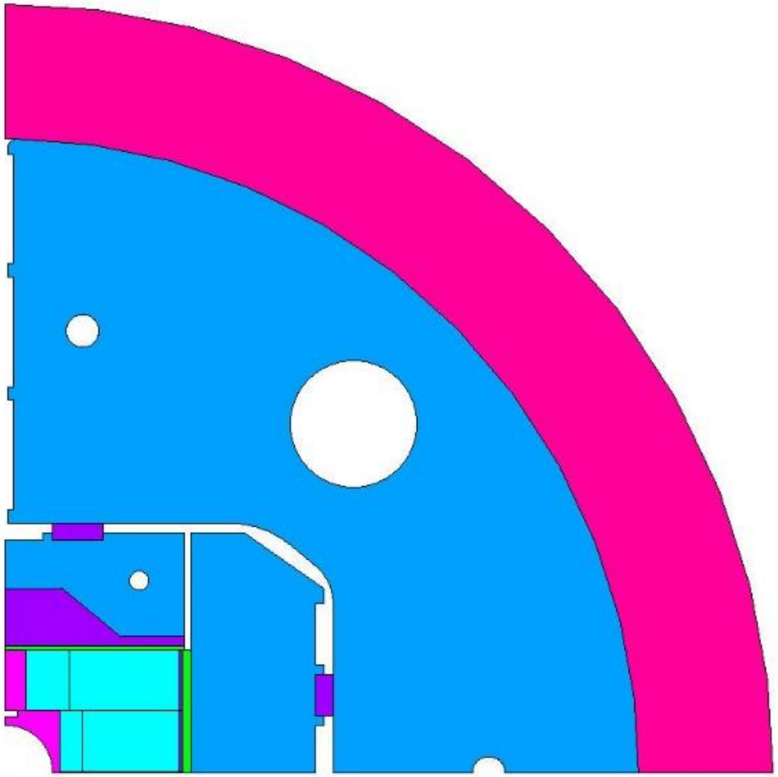
Parameter	Unit	Non Graded	Graded	
			HF	LF
strand diameter	mm	1	1	0.7
Cu/SC	--	1	1	1.15
# of strands/cable	--	40	28	40
# turns/quadrant	--	132	30	132
coil width	mm	86	69	
I_{nom}	A	11546	8695	
$J_{overall}$	A/mm²	248	264	357
Ratio LF/JF	--	n.a.	1.35	
B_0 at I_{nom}	T	16.0	16.0	
B_p at I_{nom}	T	16.1	16.6	13.6
$1-B_p(I_{nom})/B_{ss}(1.9\ K)$	%	18.5	14	23
F_x/h at I_{nom}	MPa	141	145	
F_y/w at I_{nom}	MPa	-49	-55	

Mechanical design

- Fulfills EuroCirCol Criteria.
  - Max. Coil stress = 150 MPa at RT
  - Max. Coil stress = 200 MPa at 1.9 K







Summary

- Conductor and cable
  - *Non-graded*: Strand, cable and insulation parameters defined. Three cable unit lengths have been produced.
  - *Graded*: Strand parameters defined; cable and insulation parameters to be defined.
- Non-graded coils
  - Cross section and end design defined for ERMC and RMM.
  - Coil parts for three coils received.
  - ERMC coil fabrication starts in October 2017.
- Graded coils
  - 2D Mechanical and Magnetic design done for the graded design.
  - Activity on High Field Nb_3Sn splice development launched, but further progress is required before launching the detailed graded coil design.
    - Relaying on EPFL program for the high field splice development.
- Structure
  - Baseline design completed.
  - Aluminium shells received, yokes and pads expected to be delivered in January 2018
  - End plate is in the critical path, but hopefully available February 2018.