SMCT coil status

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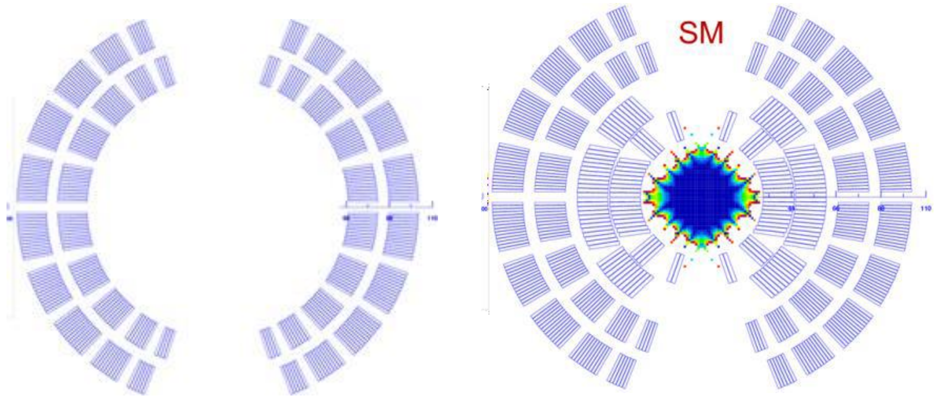
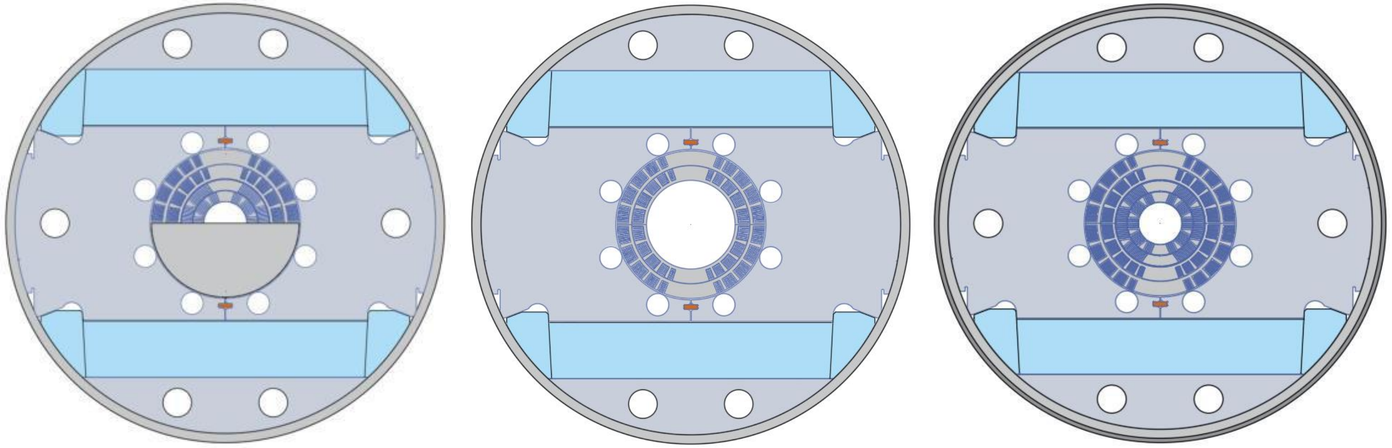
MDP General Meeting

11/9/2022

Introduction – Nb_3Sn SMCT R&D goals and milestones



ID=120 mm, B_{des}~11 T   ID=60 mm, B_{des}~17 T



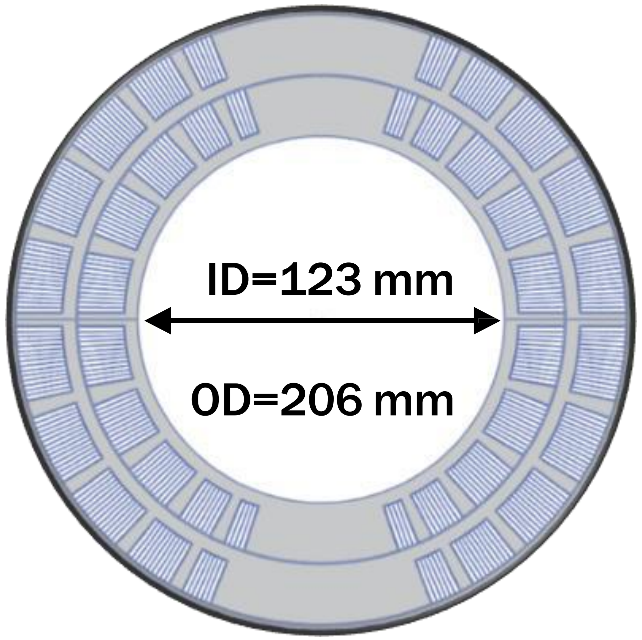
Cos-theta dipole coils with stress management

- **Development and test of stress management concept using a 2-layer large-aperture and 4-layer small-aperture cos-theta coils and dipole mirror structure.**
- **Development, fabrication and test of stress management concept in a 2-layer 120-mm dipole with the field up to 11 T.**
- **Assembly and test of stress-management concept in a 4-layer 60-mm dipole with the field up to 17 T.**

SMCT coil design and parameters

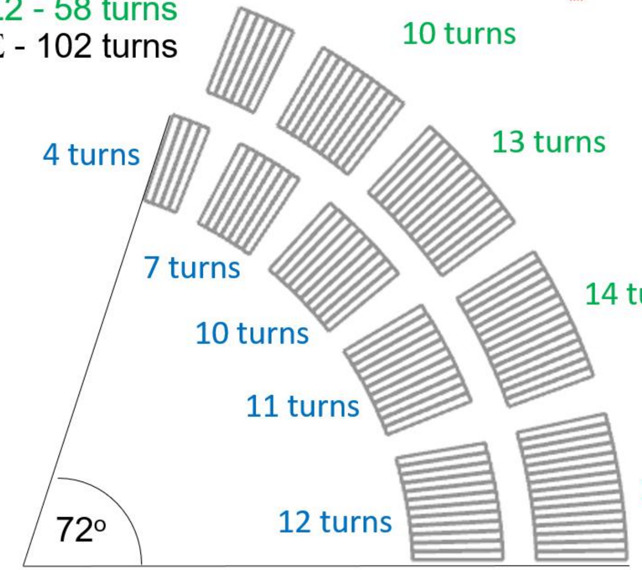
U.S. MAGNET DEVELOPMENT PROGRAM

Large aperture dipole coil



5 block per layer
L1 - 44 turns
L2 - 58 turns
Σ - 102 turns

t_r – 3.2 mm
t_s - 4.5 mm



Insulation thickness per side:
cable - 0.15 mm
groove - 0.36 mm

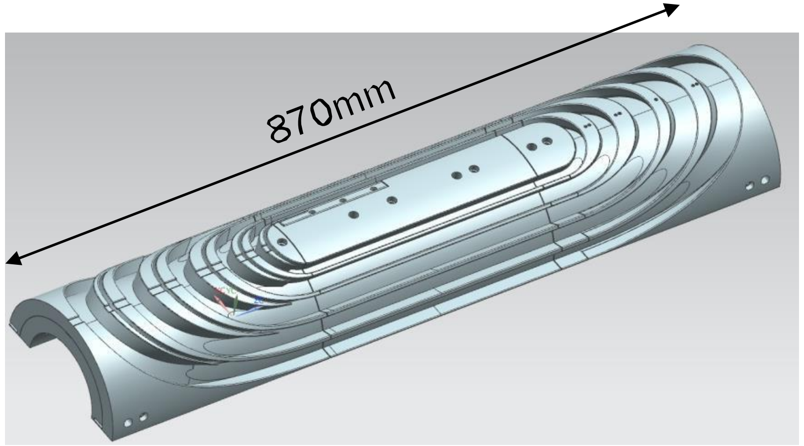
Nb_3Sn Rutherford cable

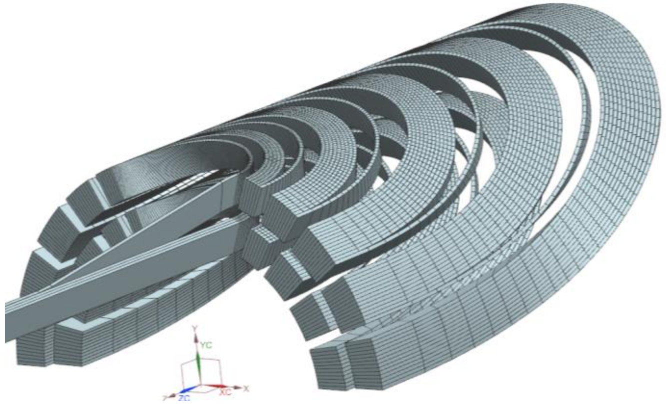
0.7 mm RRP108/127
40-strand cable with SS core

from 11T coils

reacted dimensions: 15.1x1.319 mm
Jc(12T, 4.2K)=2650A/mm^2

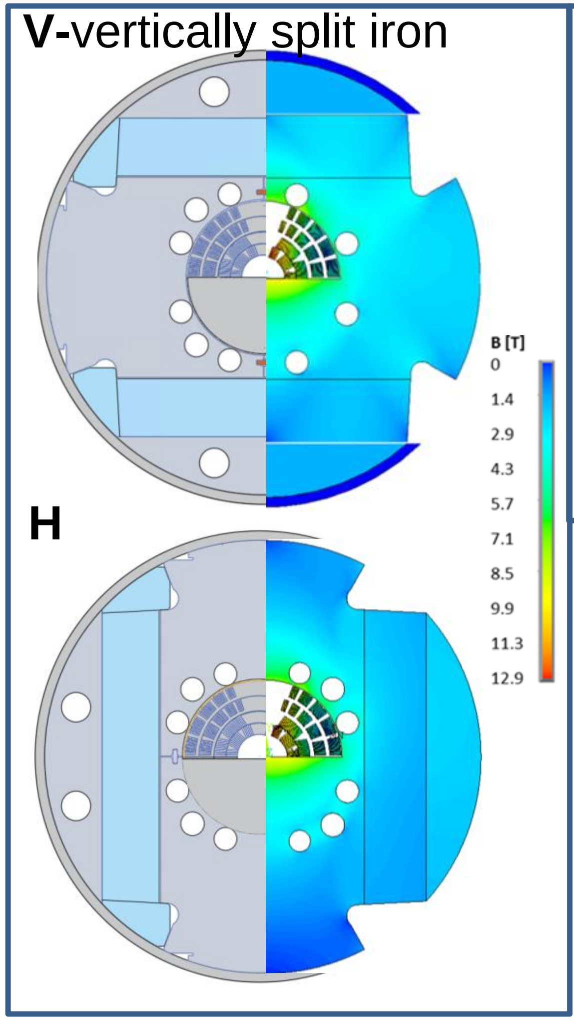
Stress management for whole coil using stainless steel mandrels

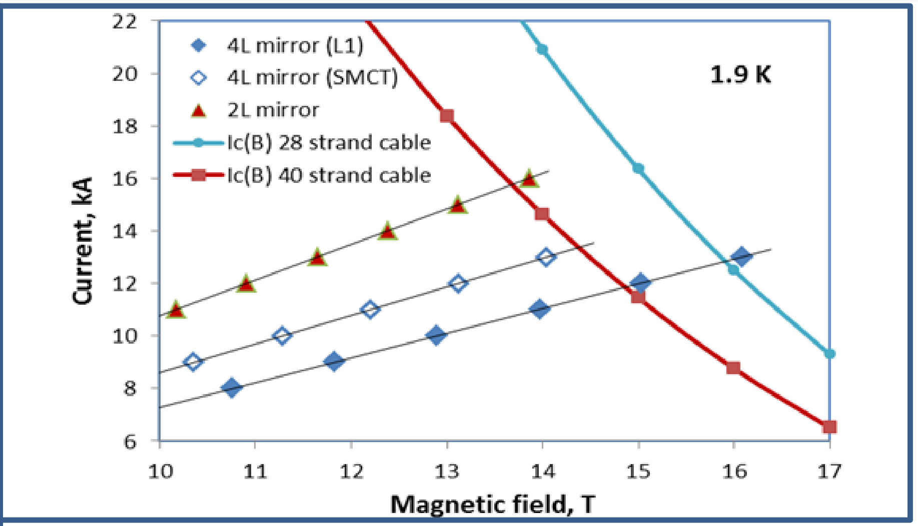


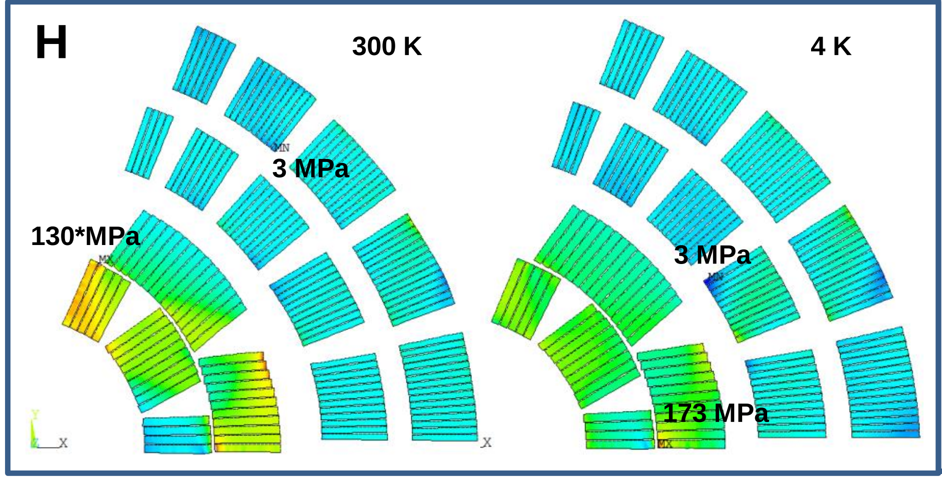


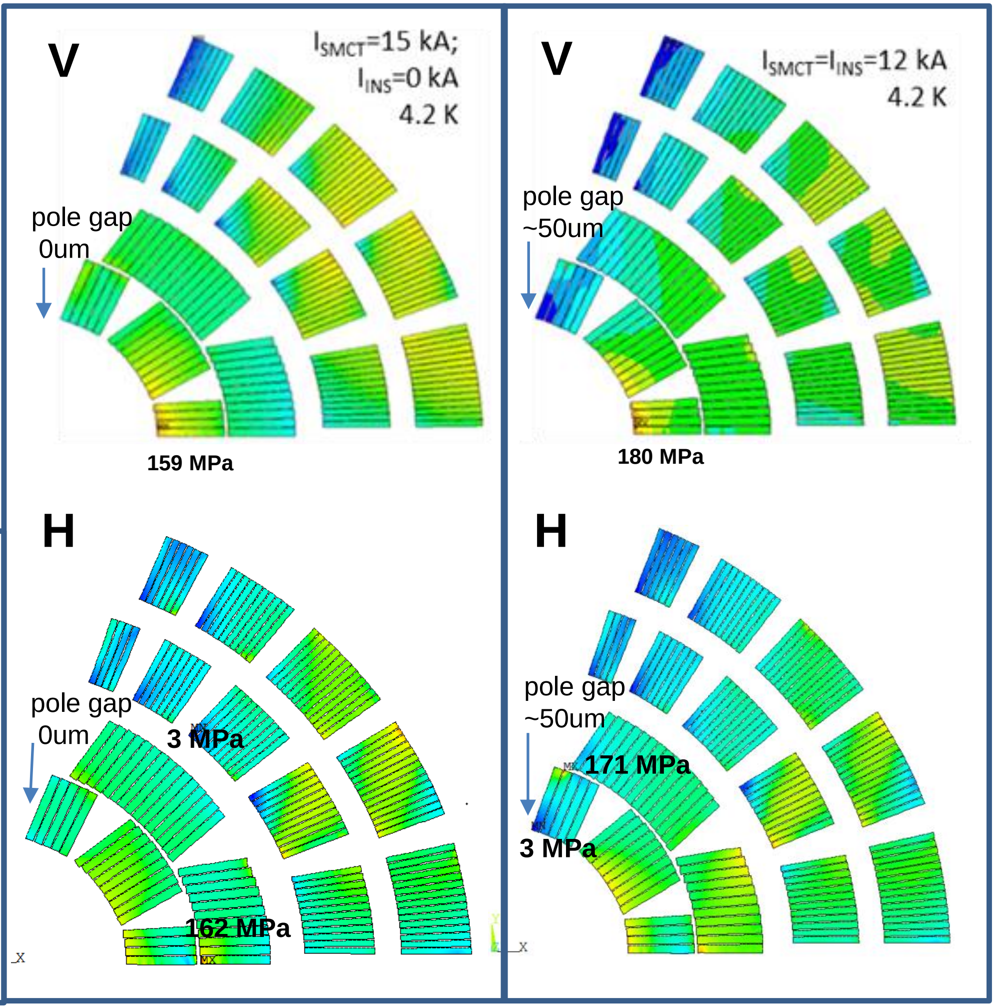
Cable layout at Lead End with ramp

Magnetic and mechanical analysis





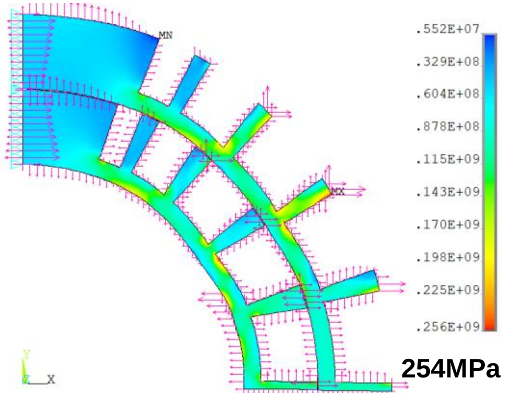




Coil loading with 130MPa (pick) at 300K leads to 180MPa at max current of 12kA for 4-layer case in two designs

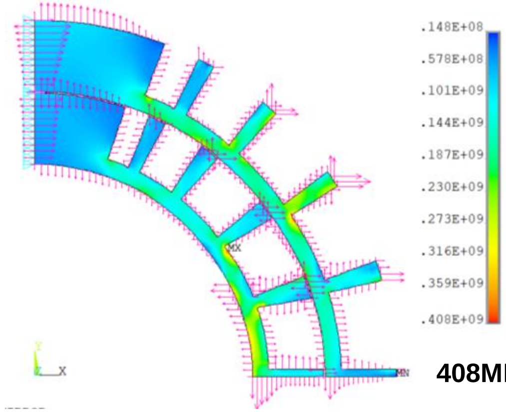
Mechanical analysis

300 K



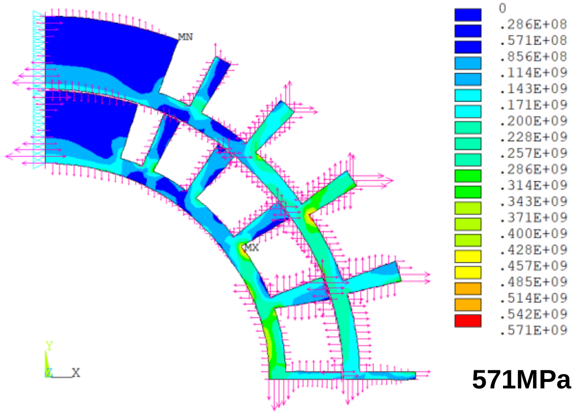
254MPa

4 K

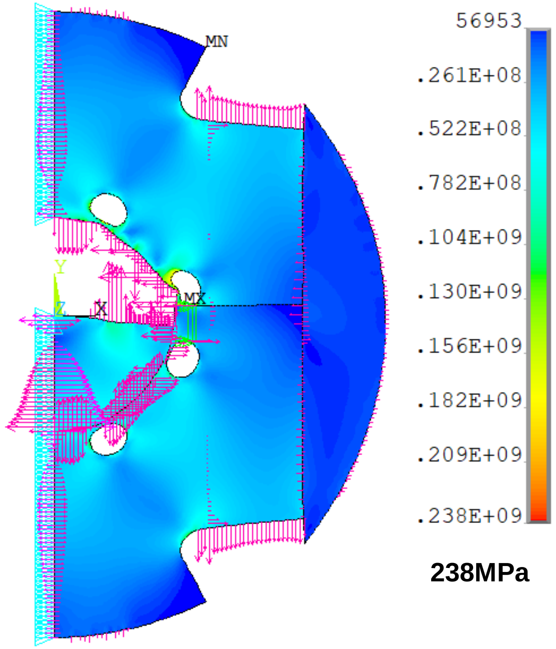


408MPa

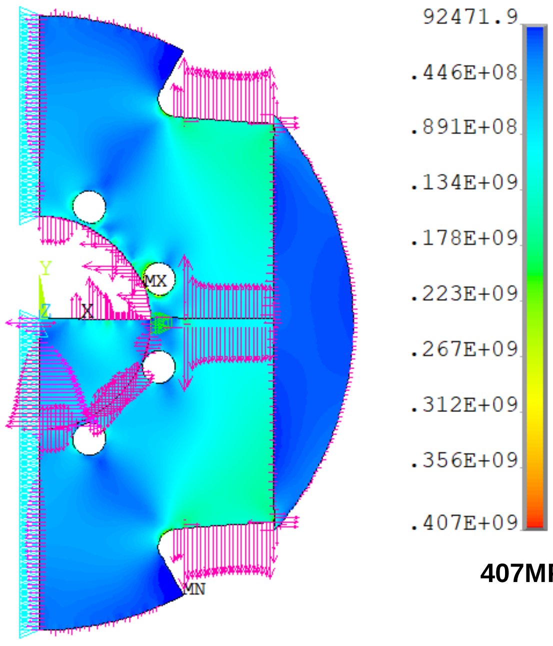
4 K + Bmax



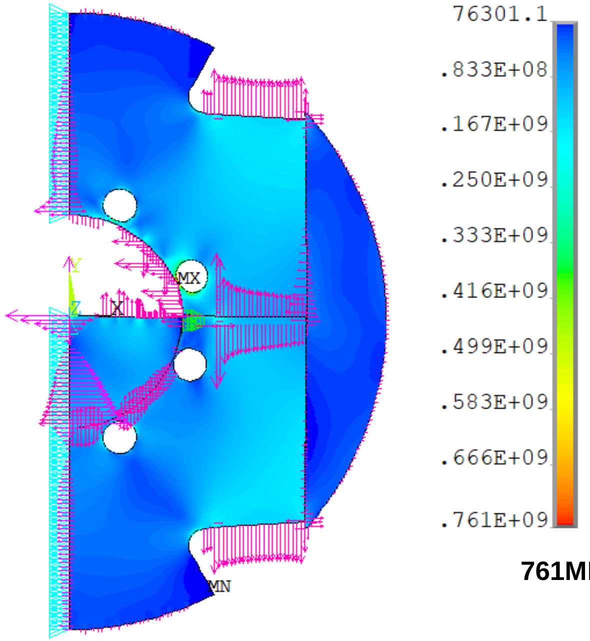
571MPa



238MPa



407MPa



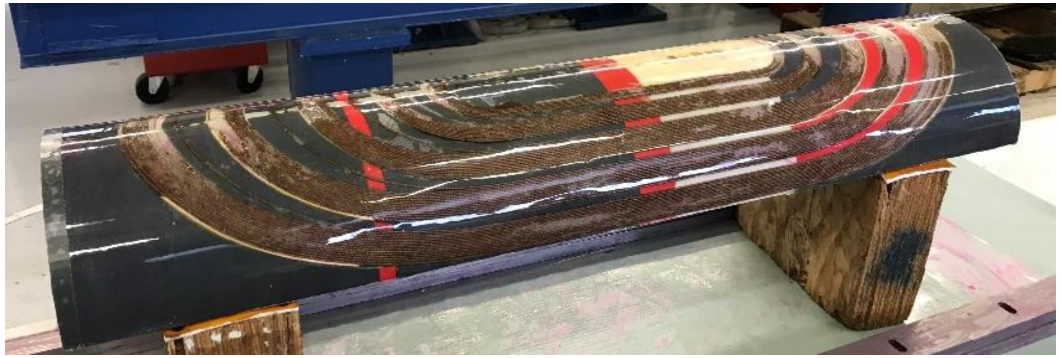
761MPa

Practice coil SM structure

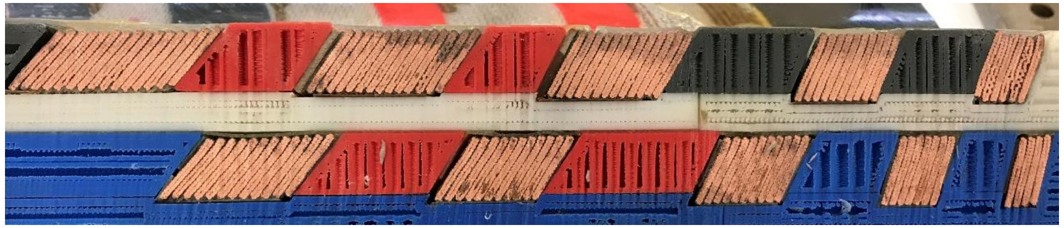
Printed plastic parts for inner and outer layers

Coil winding process

- Plastic coil parts printed on site
- Copper cable with real insulation
- Winding in slot
- Room for cable expansion during reaction



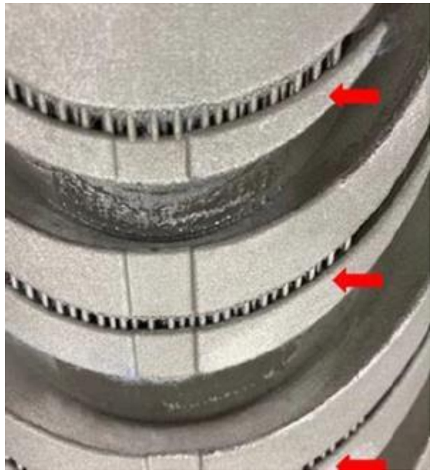
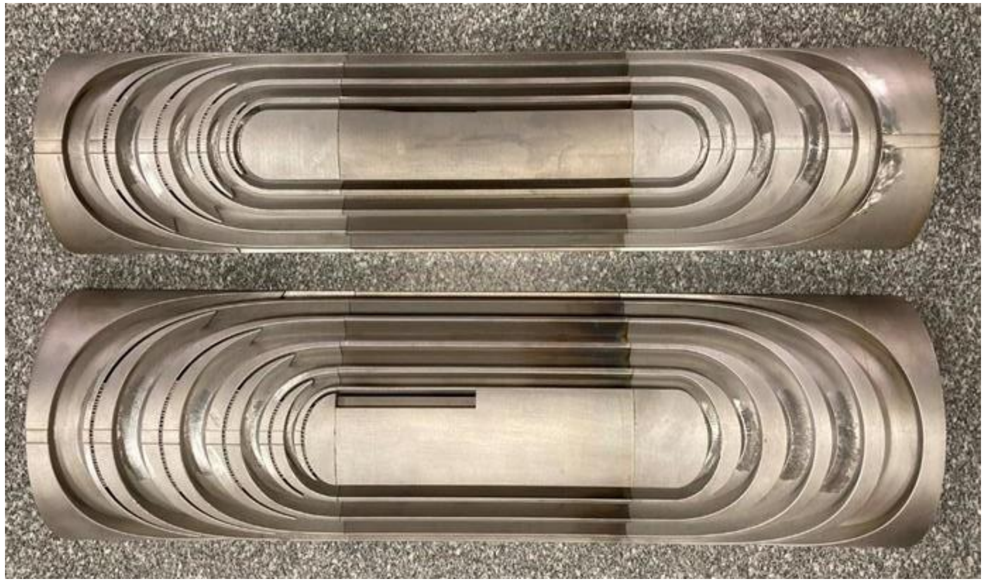
Impregnated coil



Cable turn positioning at the coil return end

SMCT coil part fabrication by GE Additive



Direct Metal Laser Melting (DMLM) technology

- 316L stainless steel powder
- Vertical orientation of end part printing:
  - reduce the number of prints
  - require support of some surfaces (red arrows)

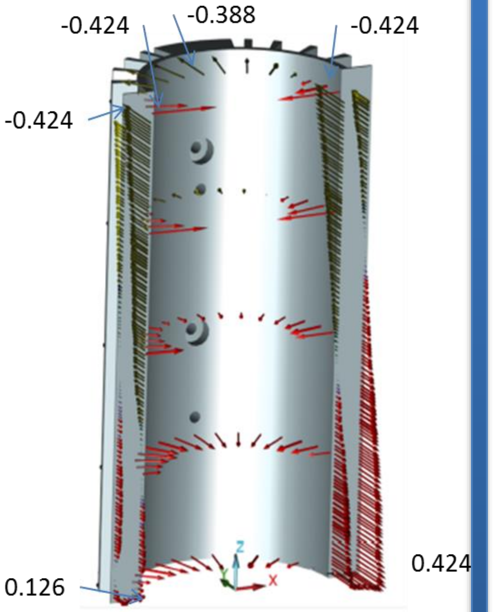
SMCT coil parts printed as two-layer cylinders

- surface support inside large blocks has been removed at GE Additive
- narrow inter block channels in LE with surface supports were removed at Fermilab

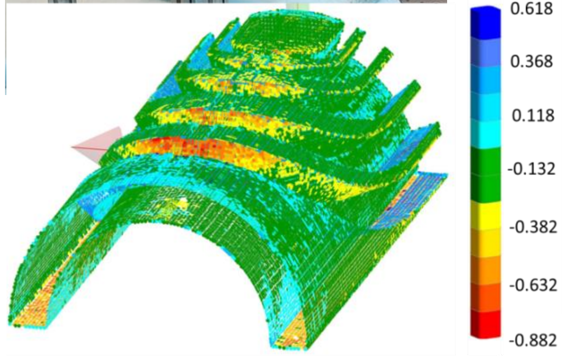
Contact signed in December 2020, parts delivered in February 2021

SMCT Coil structure measurement and postprocessing

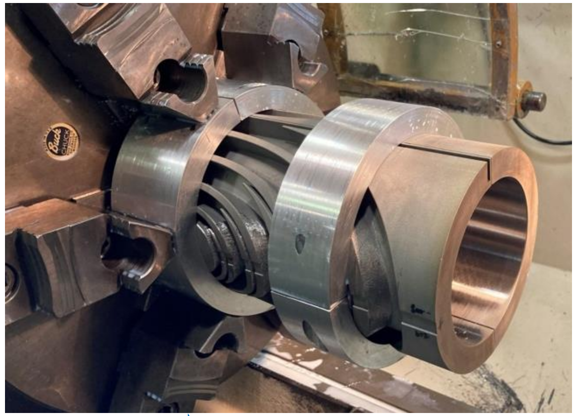
CMM measurements of surface deviation from CAD of SMCT coil straight section.



Laser Scanning measurements of surface deviation from CAD.

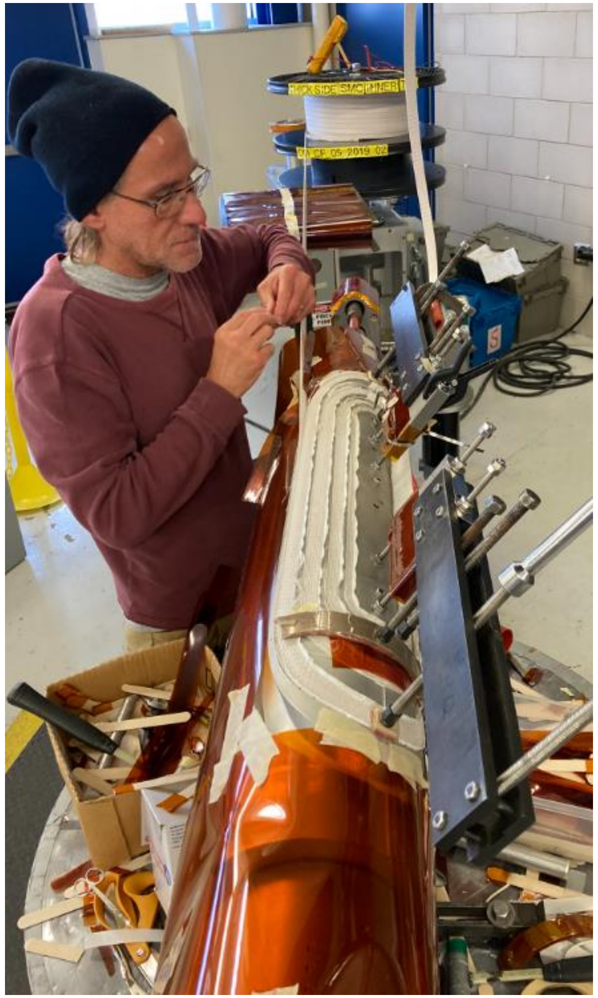


Inner coil ID increase and adding pole slots and technological holes.

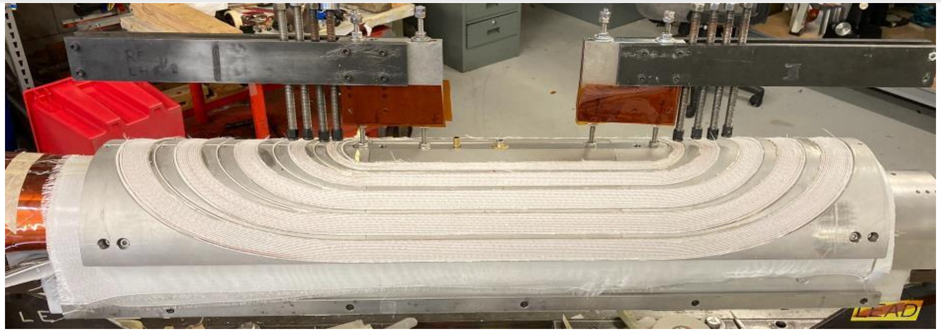


SM part post-processing

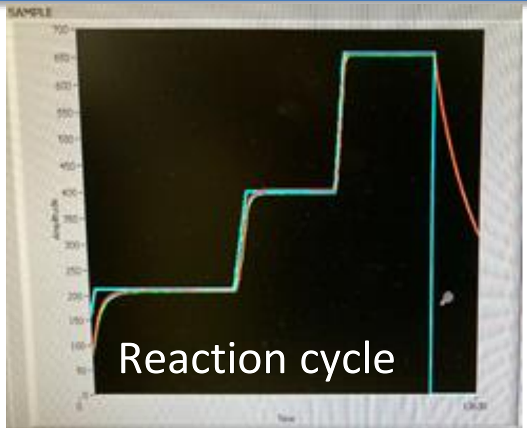
Coil winding and reaction



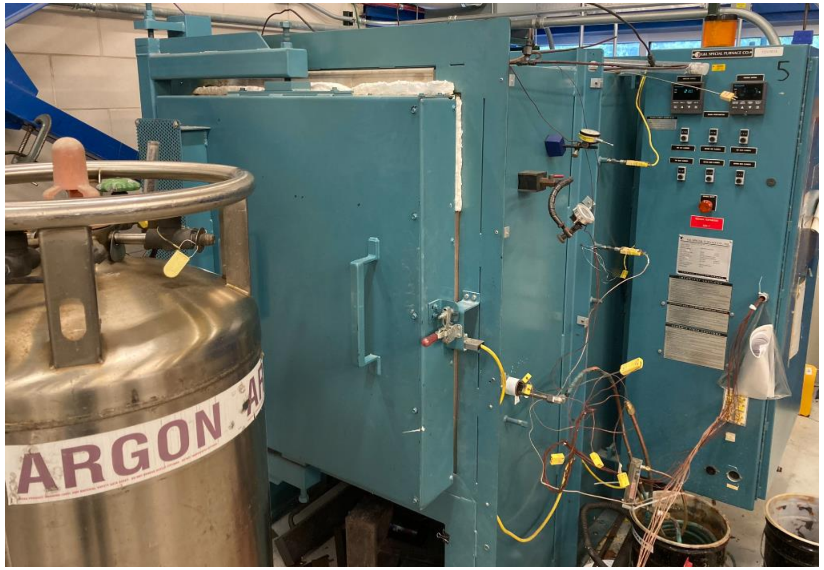
Coil winding process



Completed coil winding



Reaction tooling on the loading cart

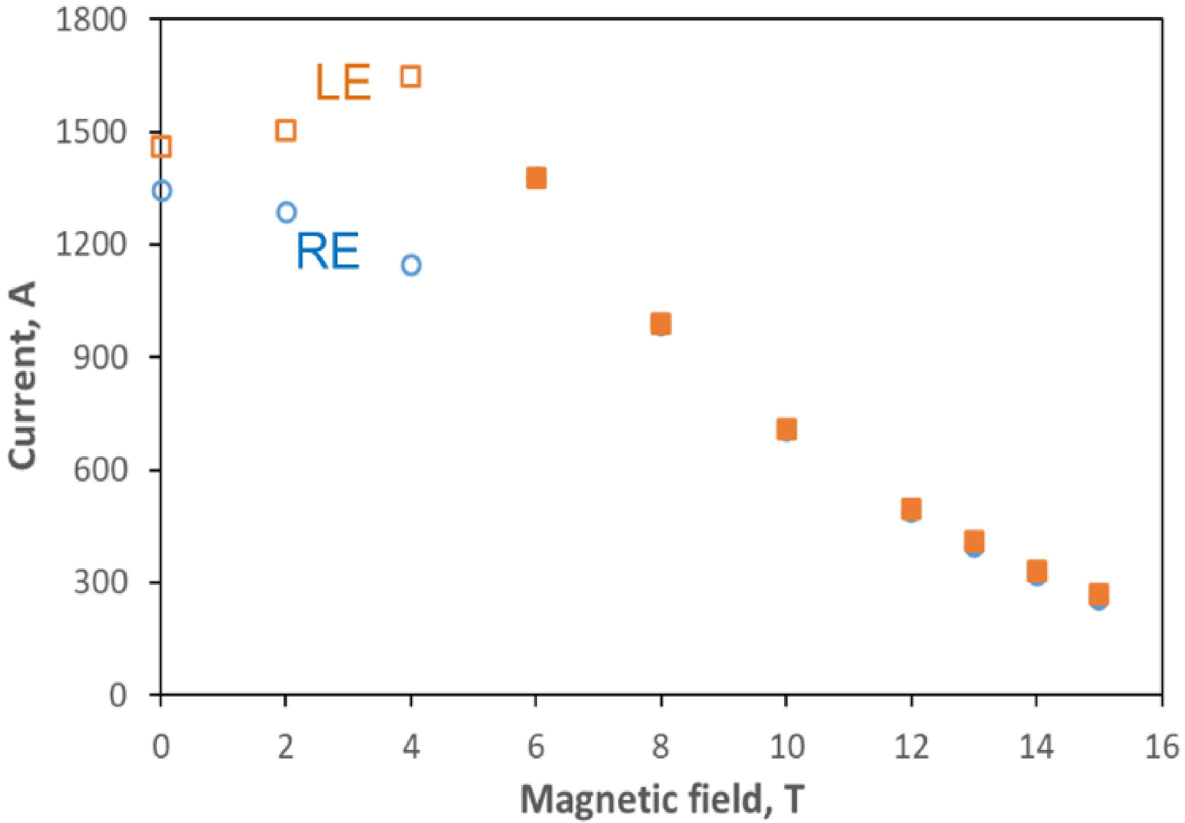


Coil reaction in argon atmosphere

Witness Sample test results

- I_c vs B for two witness samples are shown in Figure
  - SMCT coil I_c at 15 T is 254 A for the RE and 268 A for the LE
  - I_c data are in a good agreement with WS data for the three 15 T dipole outer coils 266 A, 256 A and 258 A which used the same cable and were reacted ~4-5 years ago
- Instabilities are seen at low fields below 6 T. The level of instability currents is well above the coil operation currents.
- The WS RRR values measured at 19 K are 156 and 101 for the LE and 77 and 74 for the RE
  - Measurements for two 15 T outer coils were within 70-100.

Two witness samples at LE and RE in the reaction fixture



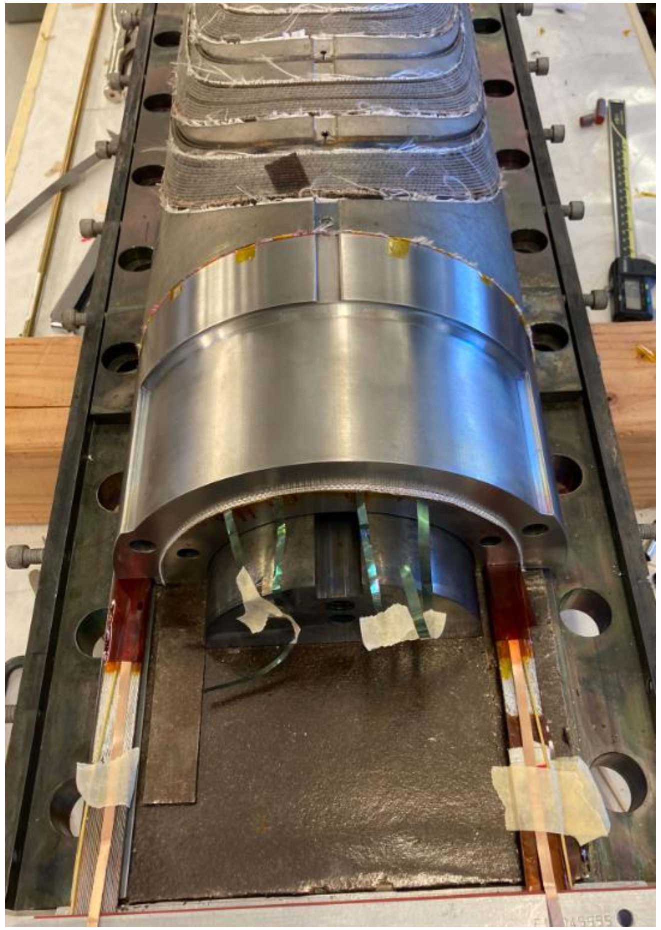
NbTi leads splicing

Nb3Sn cable trimming

Nb3Sn cable pre-tinning

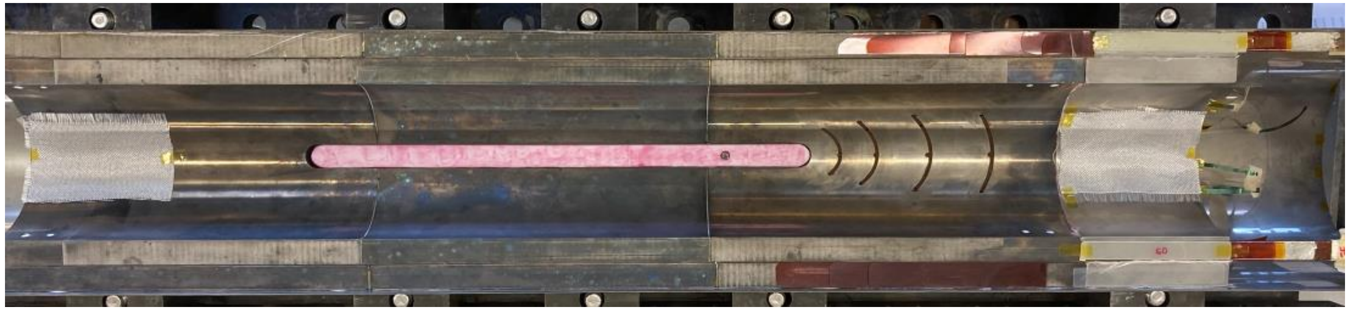
Splicing setup

Splice with VTs

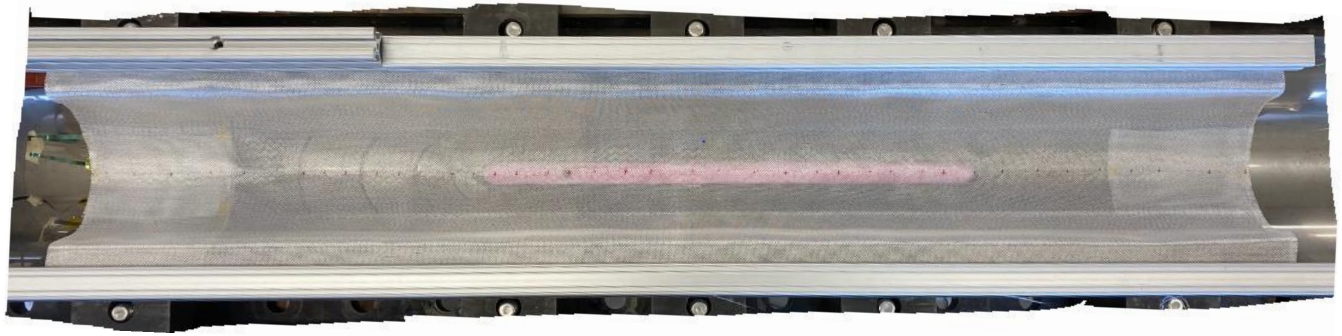


Splice blocks installed

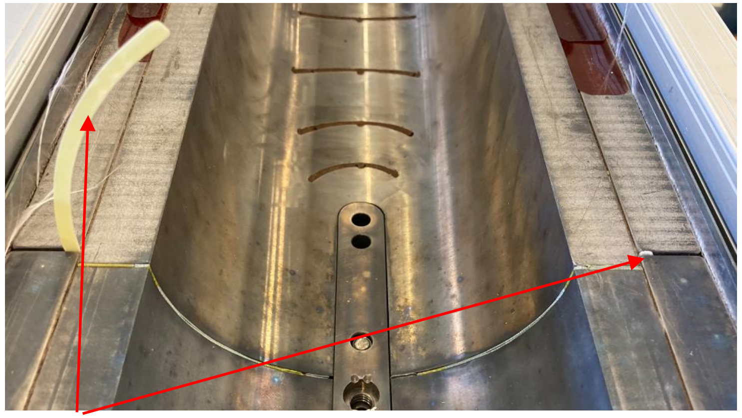
Preparation of surfaces for impregnation



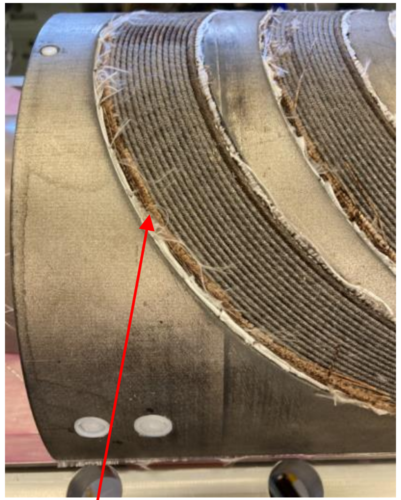
ID view

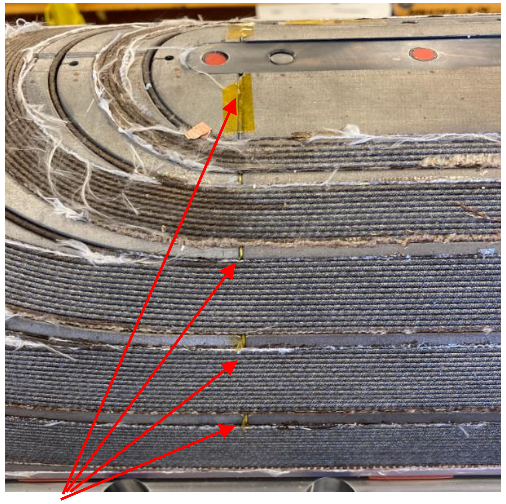


S2 blanket covers inside surface and MPs



G10 filler insertion into interlayer space



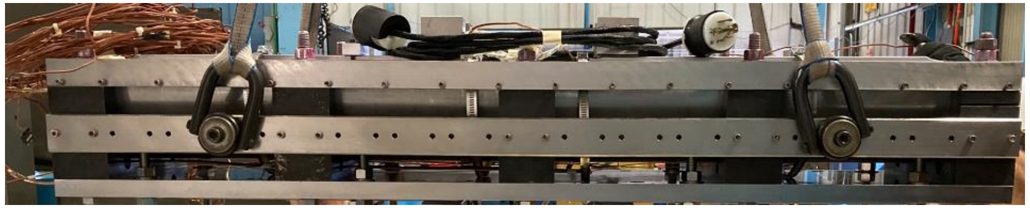


S2 fillers at RE area and G10 between metal parts

All accessible gaps were filed with S2 or G10 plugs

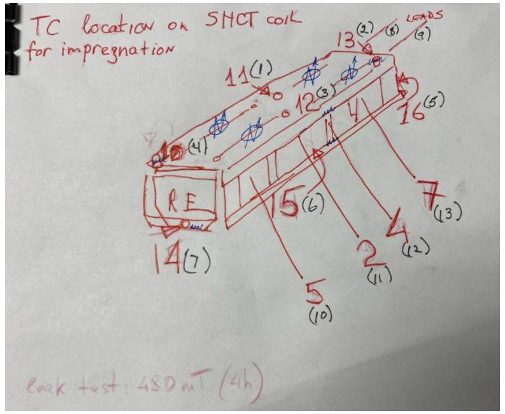
Teflon and silicon fillers protect technological grooves and holes

Coil impregnation using AUP procedure

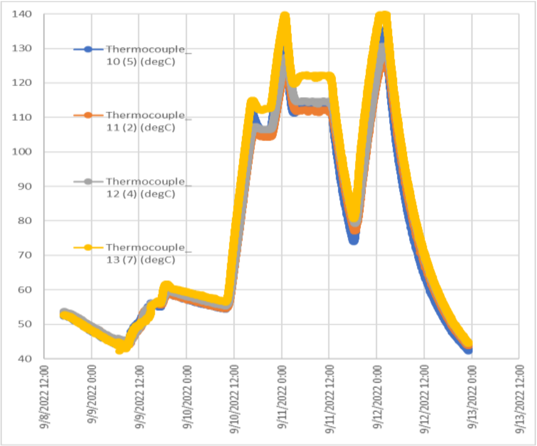


Impregnation fixture

Impregnation setup in the vacuum oven



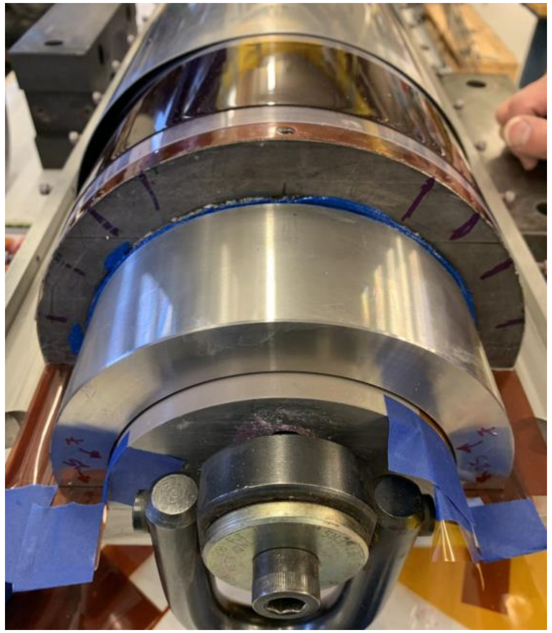
TC's location schematic

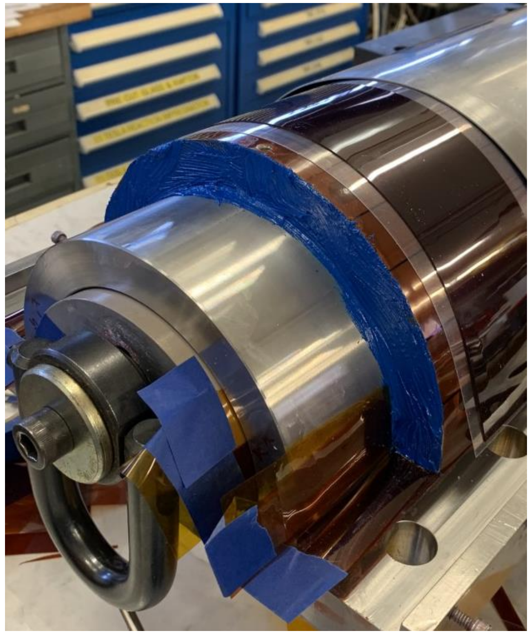


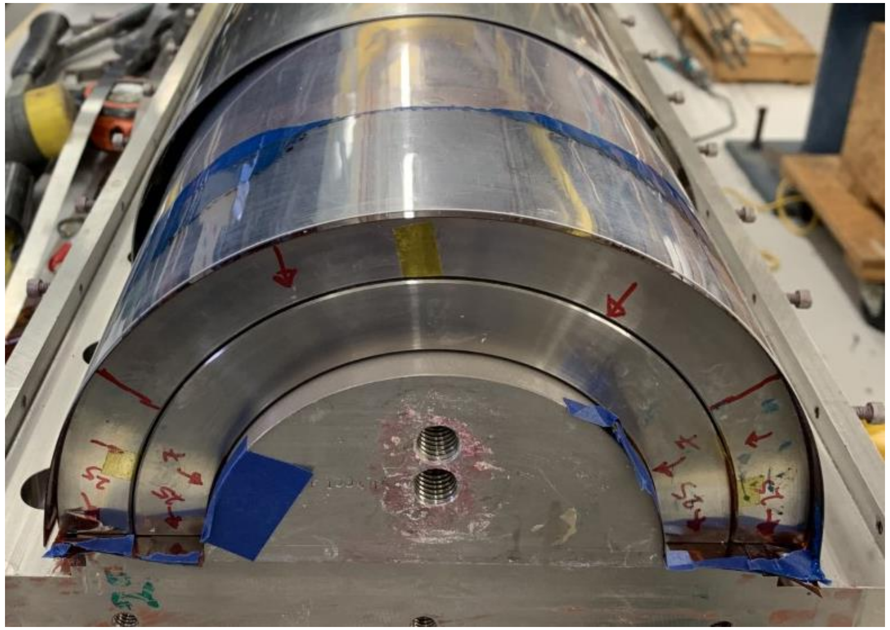
Epoxy curing cycle

Impregnated SMCT coil

Coil RE extension

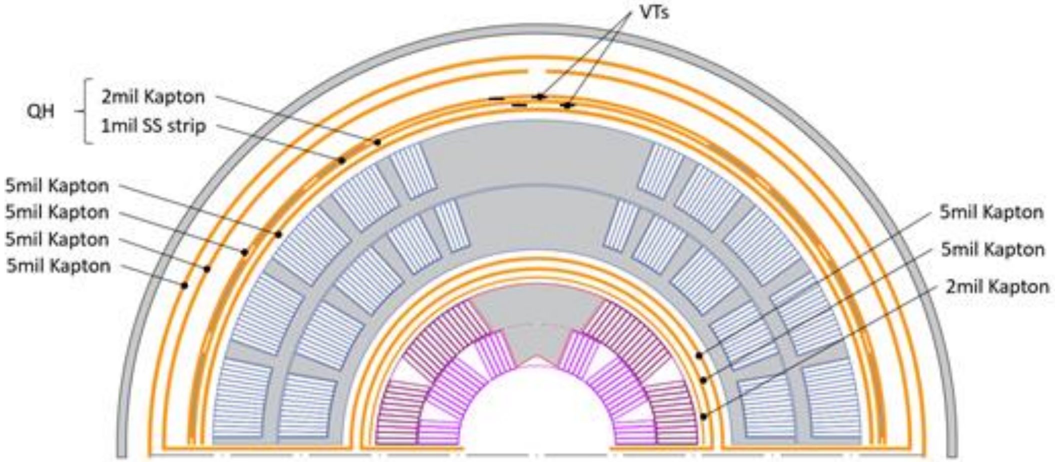




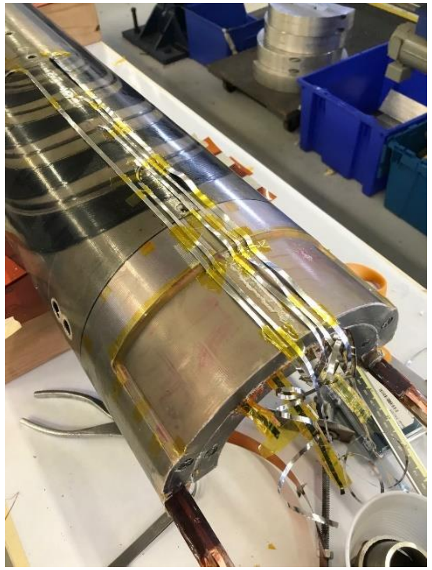


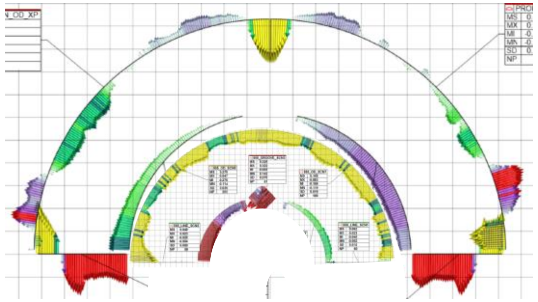
The length of the coil has been increased by two metal extensions on the RE to match the size of the inner coil. The process is carried out in an impregnation fixture using Stycast as an adhesive.

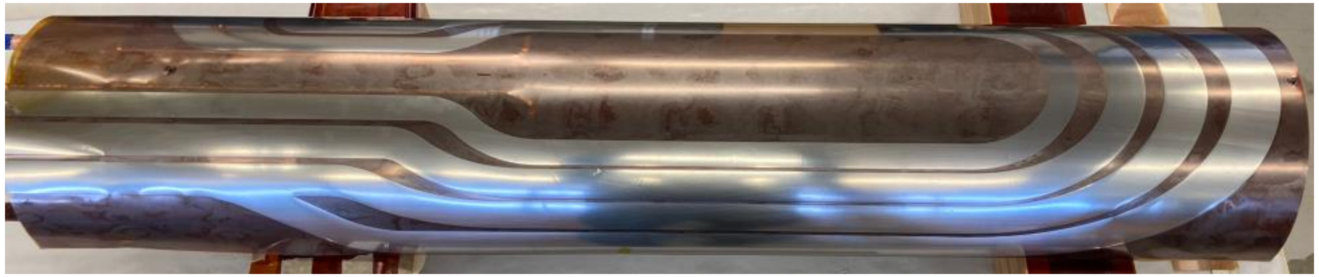
Coil measurements, instrumentation and insulation

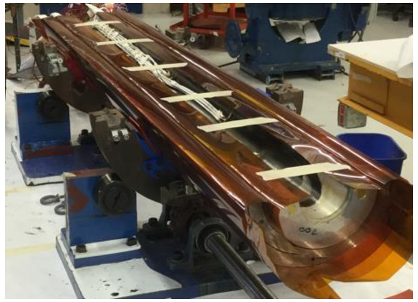


Coil ground insulation and instrumentation schematic

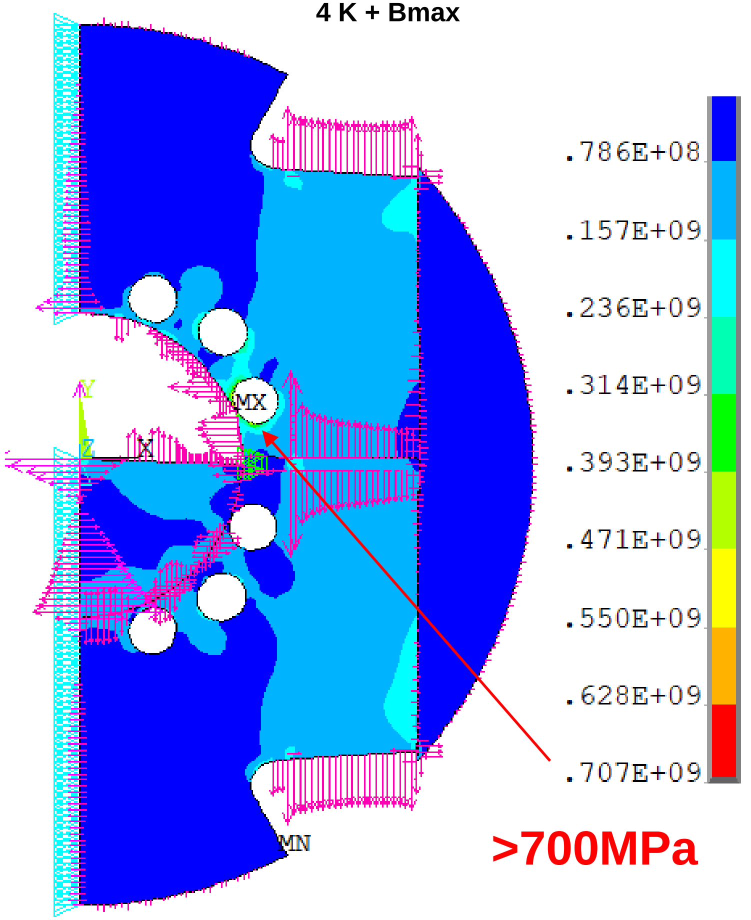

VT's location on OD


CMM of impregnated coils

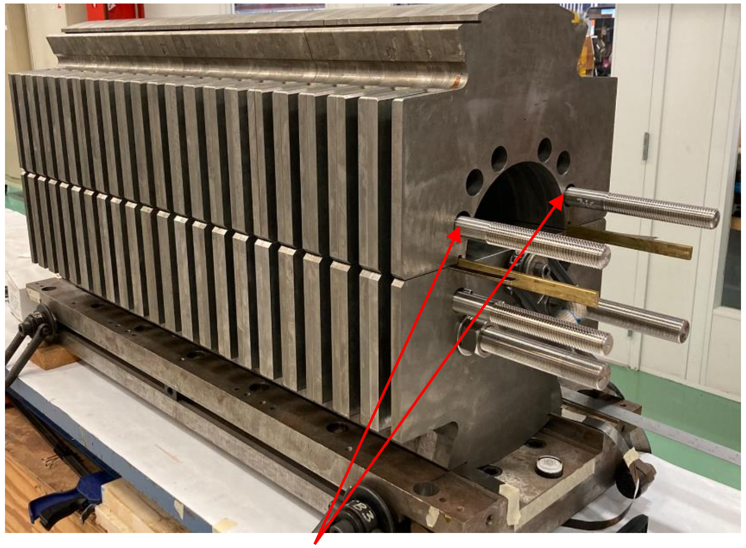

Protection heater for SM coil


Coil block insulation

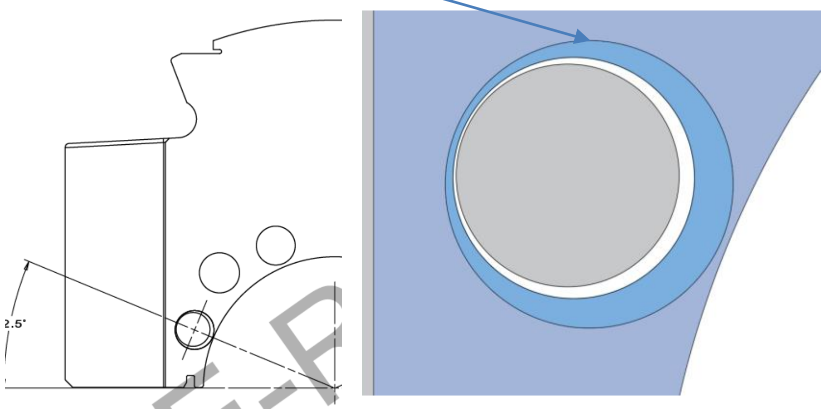
Mechanical analysis – yoke lamination

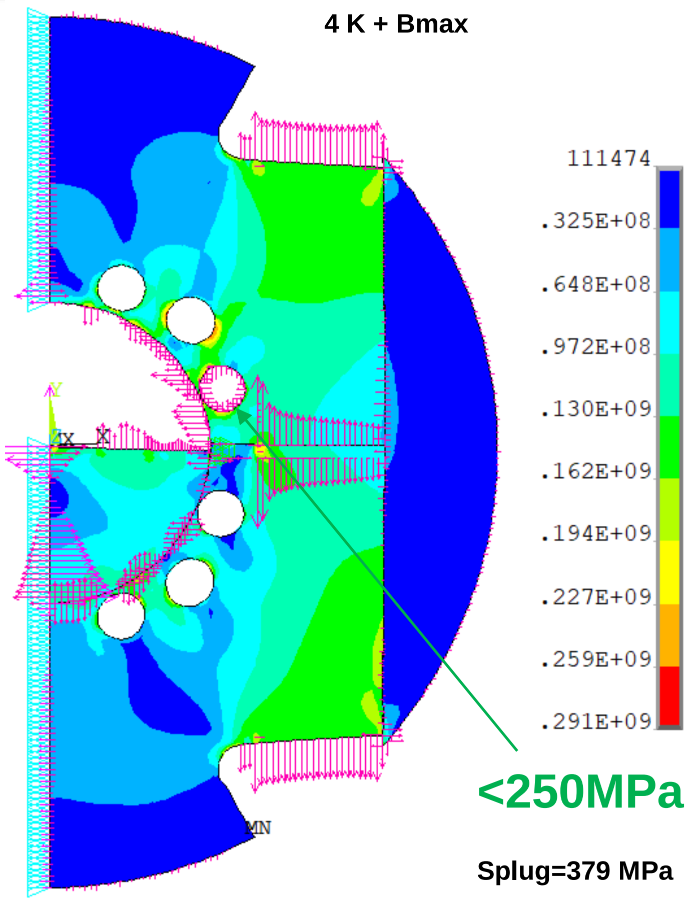


Stresses in iron lamination



Steel plugs for two holes

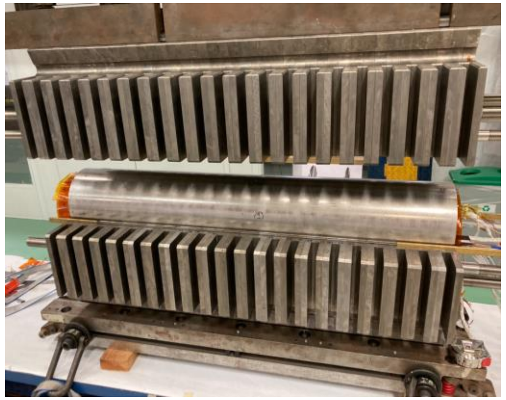




Stresses in iron lamination with steel plug will decrease by ~2.5 times

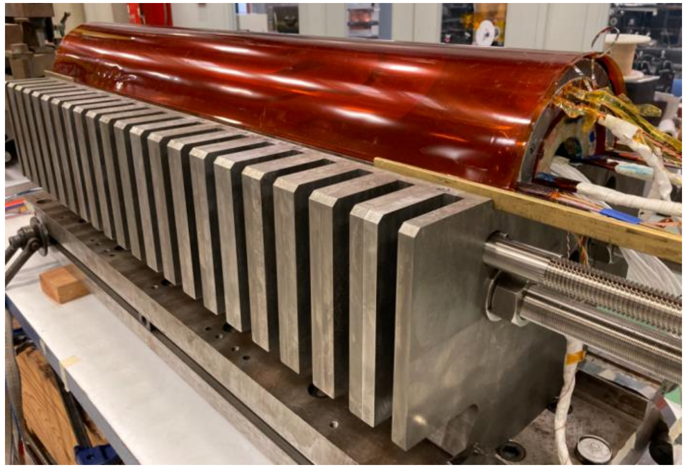
Mirror assembly steps

Mirror insertion into the lower yoke



Iron yoke assembly

Skin welding*



Coil block on the mirror

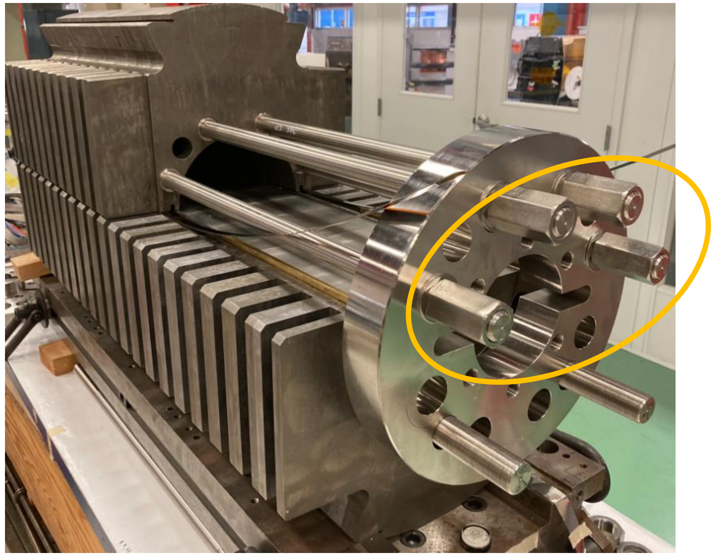
Iron yoke clamping*

Ends loading and electrical connections*

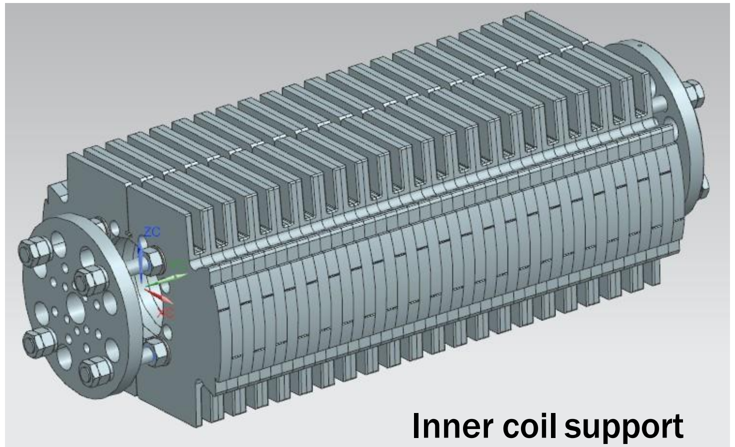
* planned

Structure Status

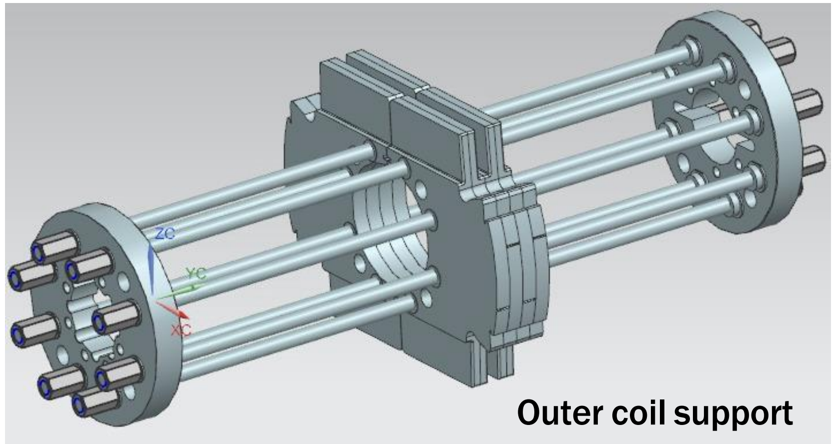
Inner coil support attaching to the iron ends



Outer coil support anchoring in the iron middle



Inner coil support

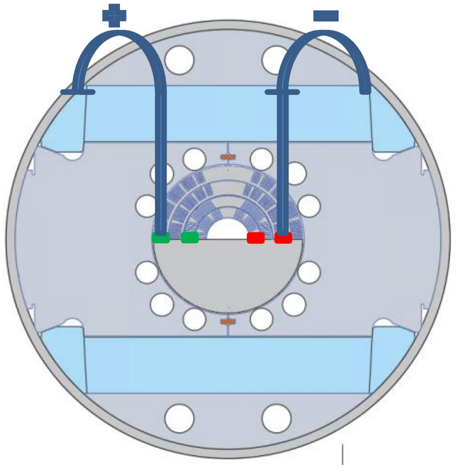


Outer coil support

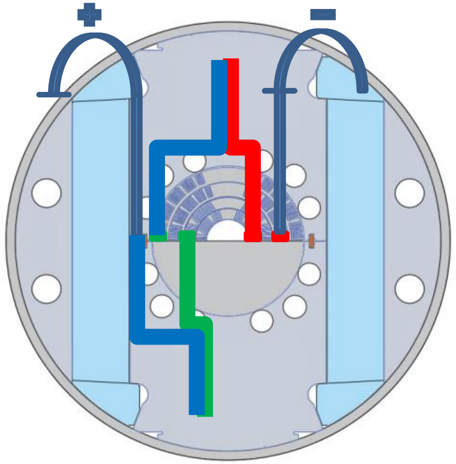
- End support parts in house
- Assembly prechecked
- All parts will be reused from the 15T magnet structure

End plates

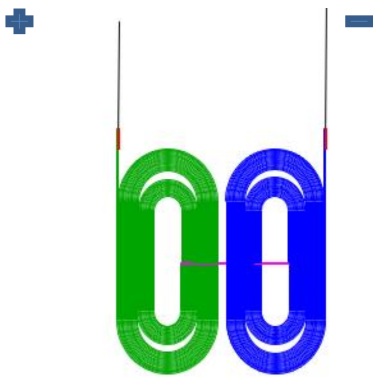
Leads connections for two tests

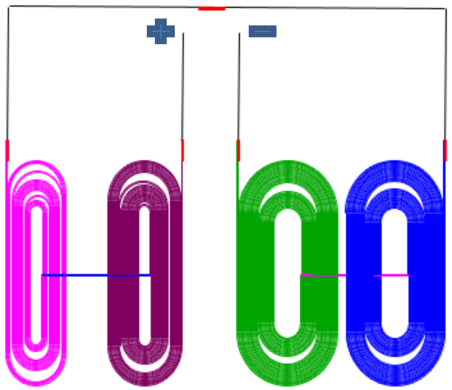


Test 1:
Only SMCT (outer) coil powered

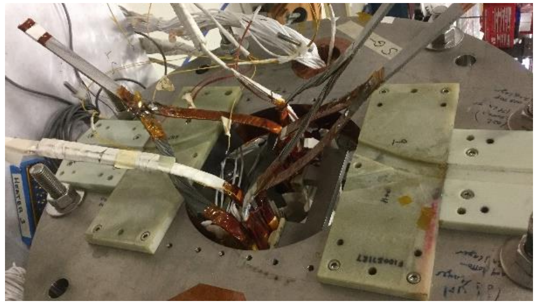


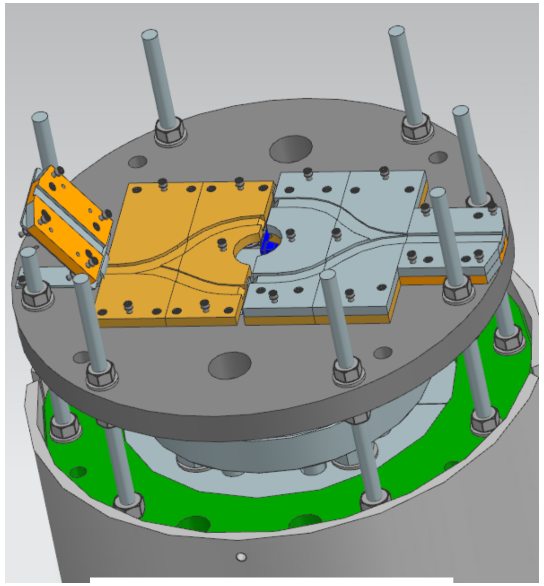
Test 2:
15T inner and SMCT (outer) coils powered



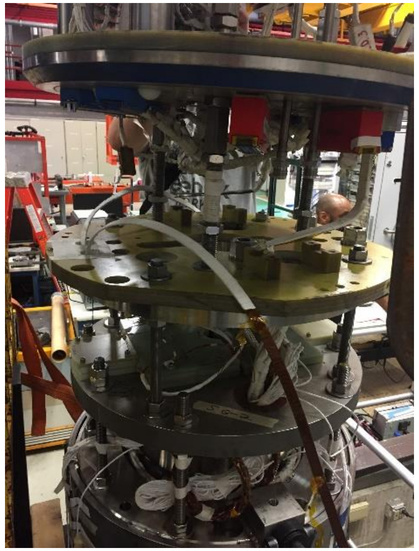


Magnet leads and G10 insulators





Modified “pizza box”



Magnet current leads connection area

Working space for leads reconnection

Summary

- SMCT concept R&D is a key part of the updated MDP plan
- Noticeable progress has been made since last year:
  - SMCT 2L and 4L Mirror 2D magnetic and mechanical analysis is complete
  - MDPCT1 structure for the SMCT 4L Mirror and 4L Dipole has been modified
  - SMCT coil parts were built, checked and post-processed
  - Reaction and impregnation tooling were modified and are ready for a coil fabrication
  - SMCT coil fabrication is complete
  - Mirror assembly is in progress