



U.S. MAGNET
DEVELOPMENT
PROGRAM

Nb_3Sn SMCT task overview and coil status

Igor Novitski

MDP General Meeting

06/08/2022

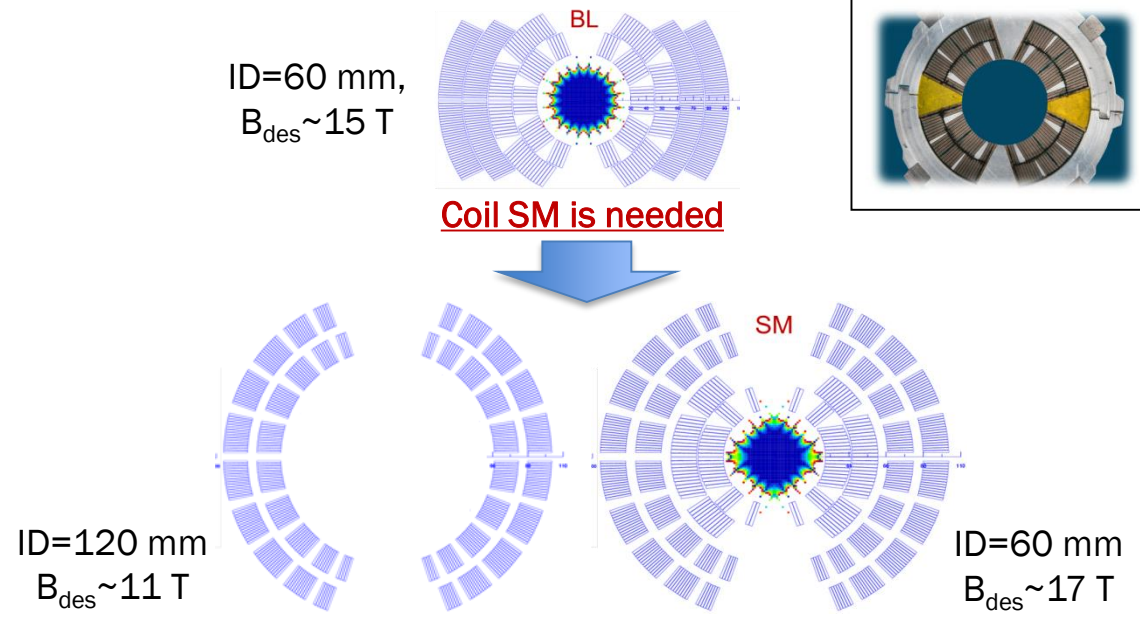


- MDP Nb₃Sn Stress-Managed Cos-Theta (SMCT) magnet task goals, plan and milestones
- SMCT coil development and fabrication status
- Mirror magnet assembly and test plan
- Summary

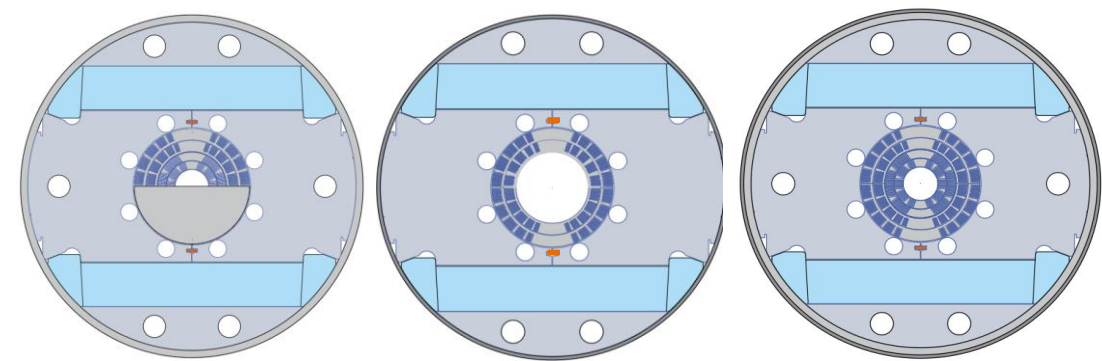


The SMCT R&D goals:

- a) develop and demonstrate a new approach to manage radial and azimuthal stresses in brittle cos-theta coils, through the study and reduction of magnet training
- b) demonstrate a bore field up to 11 T at 1.9 K with 120-mm aperture in 2-layer Nb₃Sn dipole magnets with stress-managed coils
- c) demonstrate up to 17 T at 1.9 K with a 60-mm aperture in a 4-layer Nb₃Sn dipole magnet with stress-managed outer coils



Cos-theta dipole coils with stress management



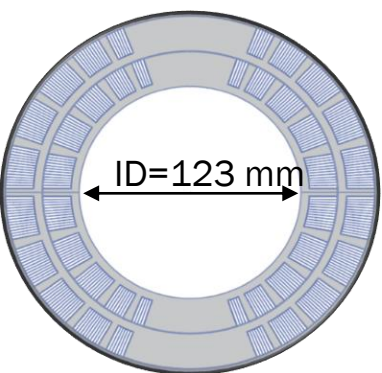
Milestone #	Description	Target
AI-M1a	Development and test of stress management concept using a 2-layer large-aperture and 4-layer small-aperture cos-theta coils and dipole mirror structure	March 2022
AI-M2a	Development, fabrication and test of stress management concept in a 2-layer 120-mm dipole with the field up to 11 T.	April 2023
AI-M3a	Assembly and test of stress-management concept in a 4-layer 60-mm 17 T dipole with stress management.	April 2024



Previous SMCT coil development steps

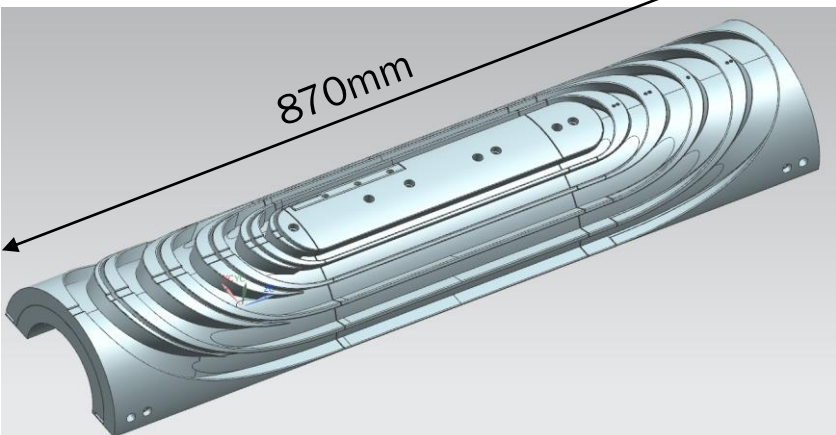
Coil design in FY19

Large aperture dipole
coil

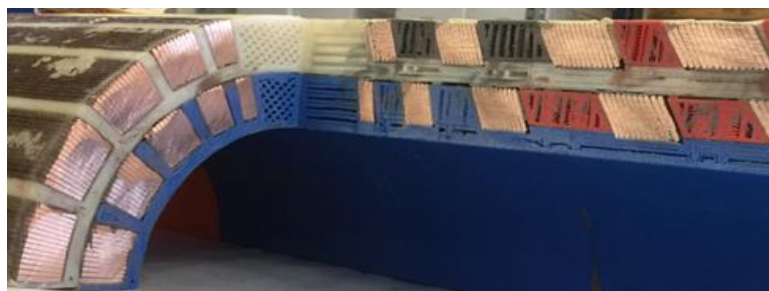


OR=103 mm

Stress management coil structure

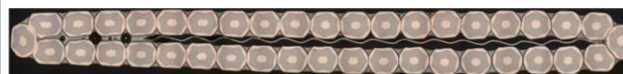


Practice coil SM structure-winding- impregnation-QC in FY19



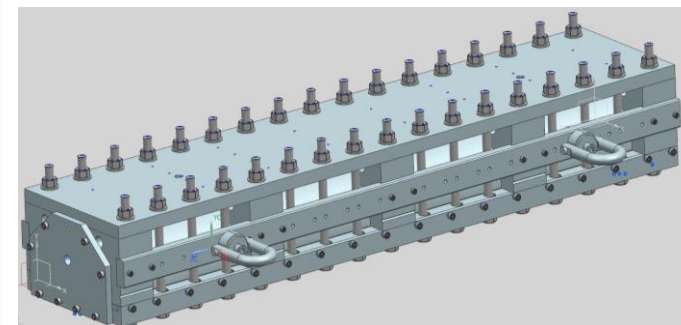
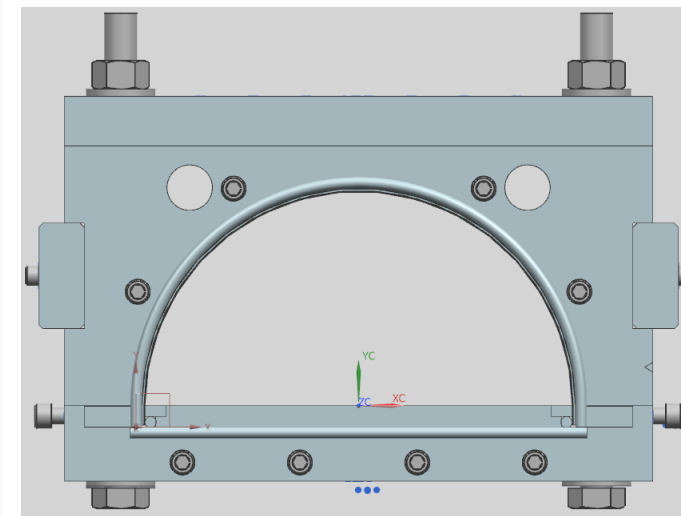
0.7 mm RRP108/127
40-strand cable with SS core

OL coils



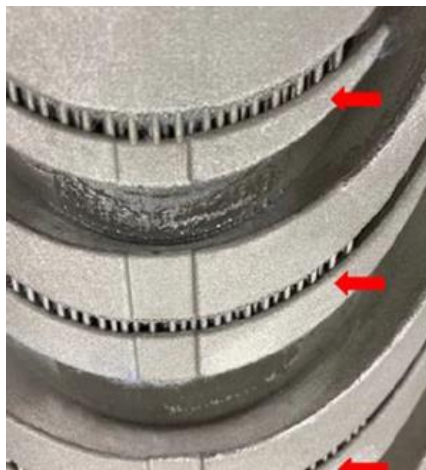
40-strand Nb₃Sn cable is available from
the 11 T dipole program

Coil reaction/impregnation tooling design-fabrication-QC in FY19-20





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 (shown in blue)

SMCT coil parts printed as two-layer cylinders

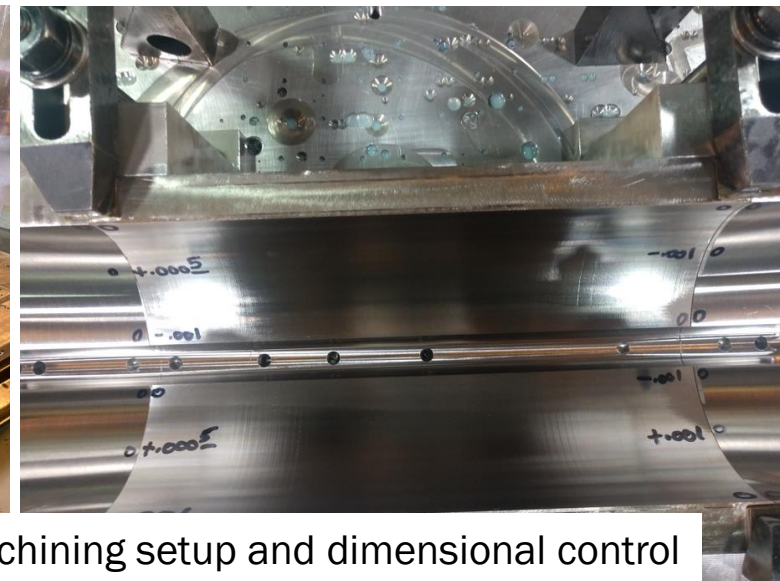
- surface support inside large blocks has been removed at GE Additive
- narrow inter block channels in LE with surface supports were removed at Fermilab

Contact signed in December 2020, parts delivered in February 2021

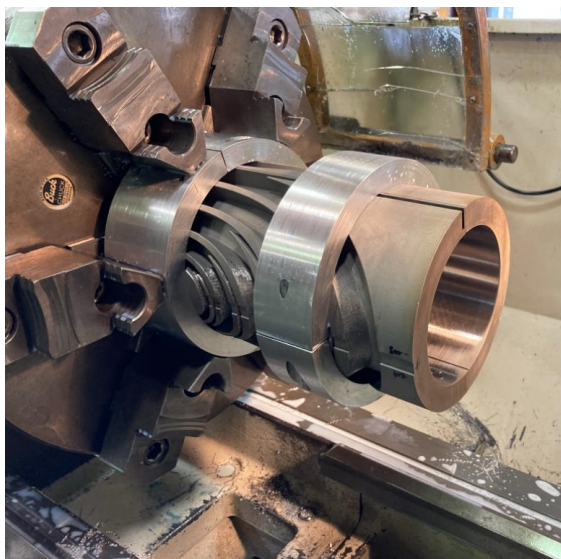


CMST coil parts postprocessing

- obtain uniform ID for two ends
- remove powder reloading marks
- cut ends
- obtain uniform ID for central pieces
- keyway machining and holes drilling
- wire EDM to remove supporting posts in single channels



Central part machining setup and dimensional control



L1 end parts turning setup



Wire EDM set up with new rotation head

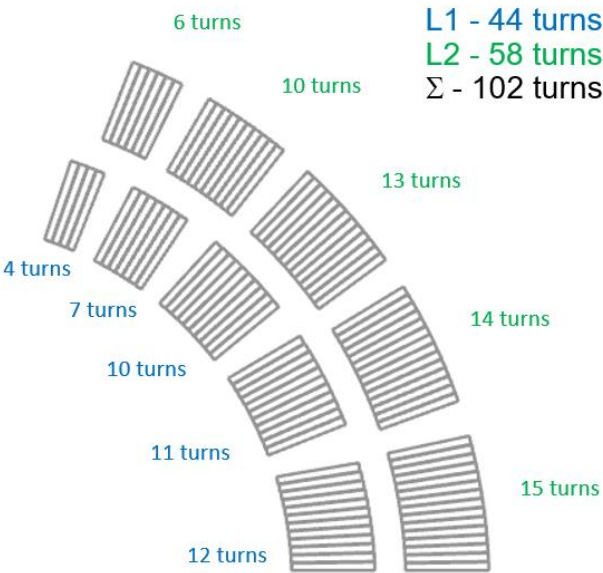


Parts with metal wedges after machining



Coil winding

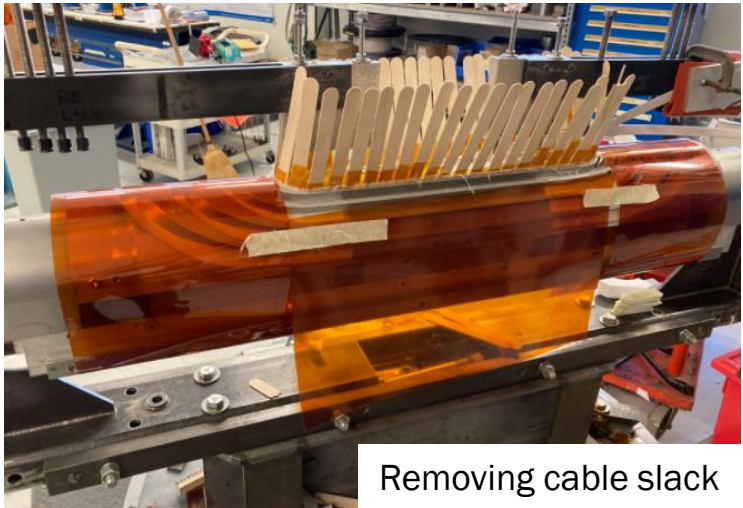
Cable spited for winding



Cable turns layout in 1/4 cross-section



L1 winding setup

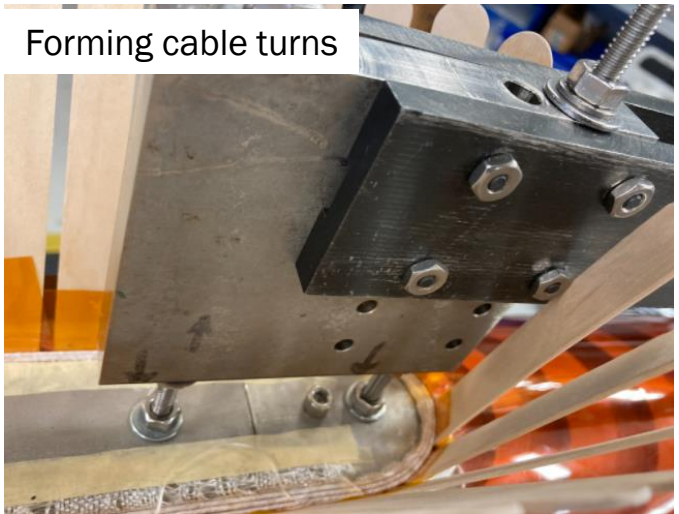


Removing cable slack



Layer jump and first turn

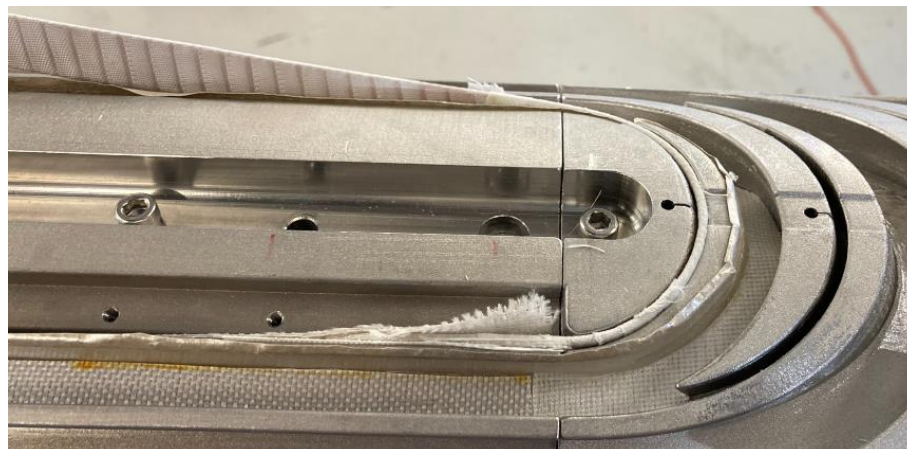
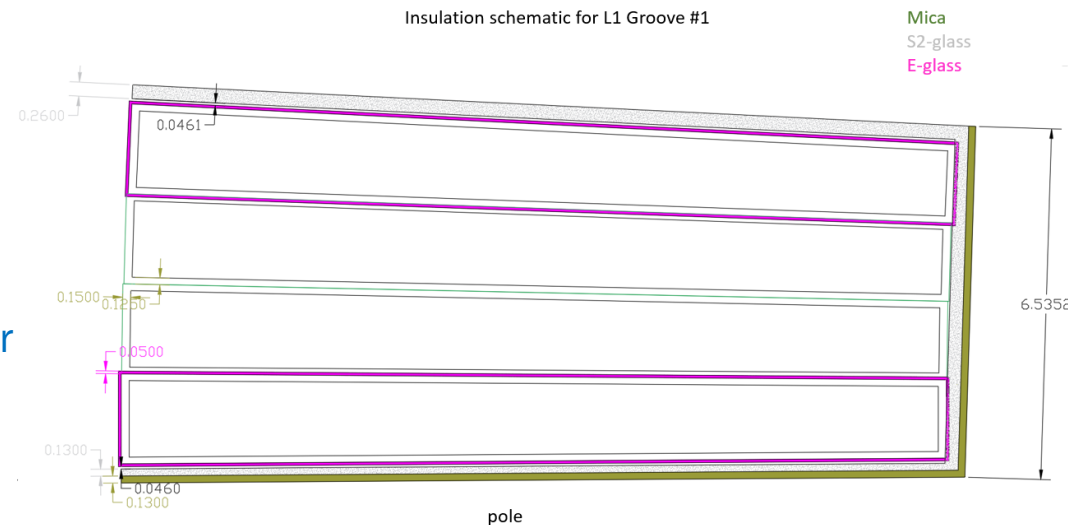
Forming cable turns





SMCT coil ground insulation

- Each cable groove has:
 - 0.35mm extra side-space per design
 - hand-made versions of Mica and S2-glass templates on bottom
 - S2-glass tape and strips on sides
- A single groove has an extra wrap of S2-glass insulation with binder
- Pole groove only in each layers:
 - an extra wrap of E-glass tape for the pole turns force to reduce number of turns in pole block by 1 (3 and 5 instead of 4 and 6 for L1 and L2)
 - cable insulation was modified
- Continuously monitoring and fixing any ground shorts during winding



Mica and S2 glass strips for the groove insulation



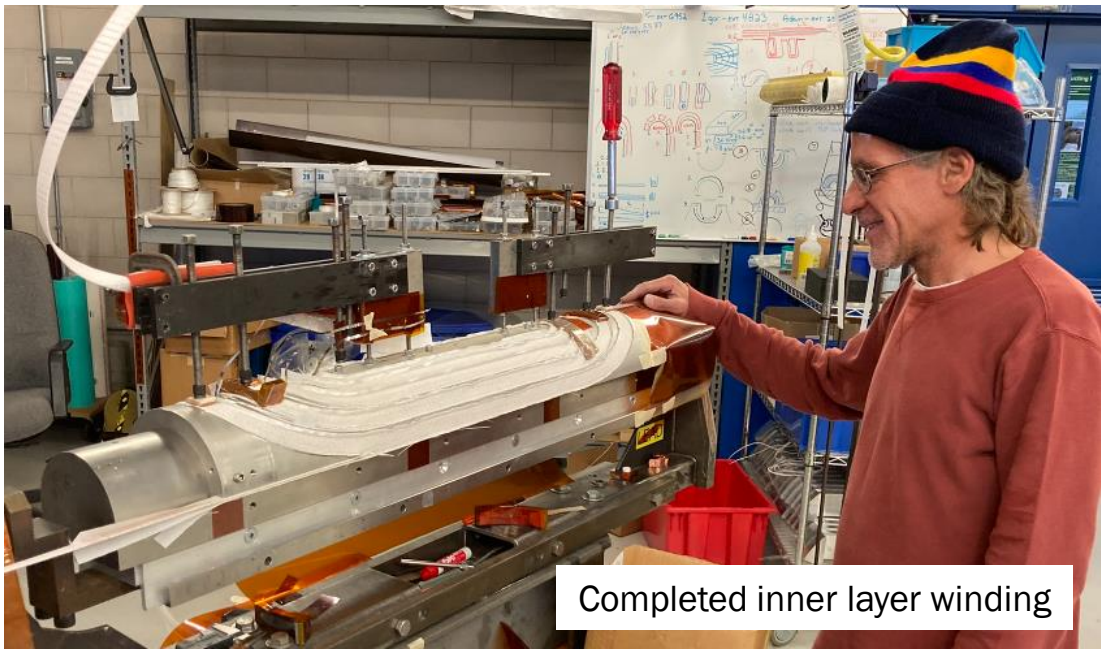
First groove insulation scheme for L1 and real winding of L2



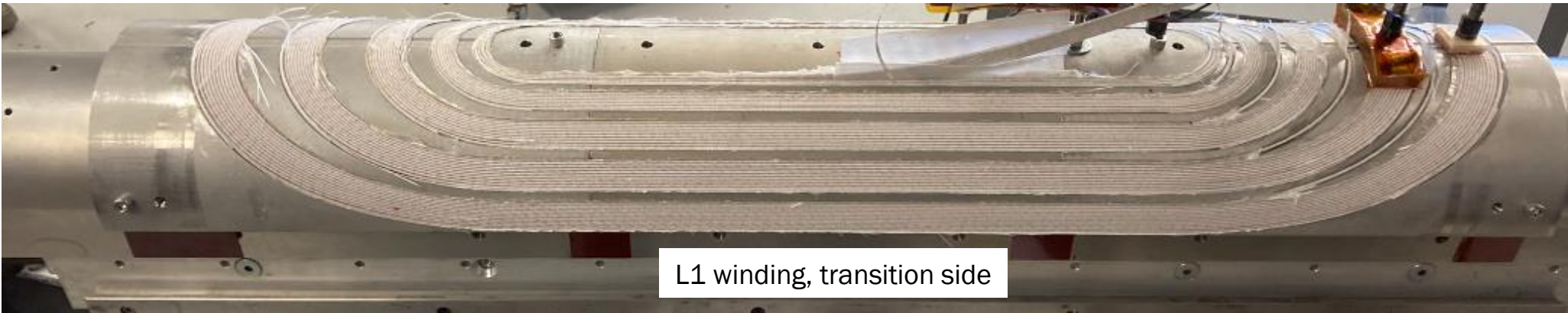
Inner layer winding



Winding of the second groove



Completed inner layer winding



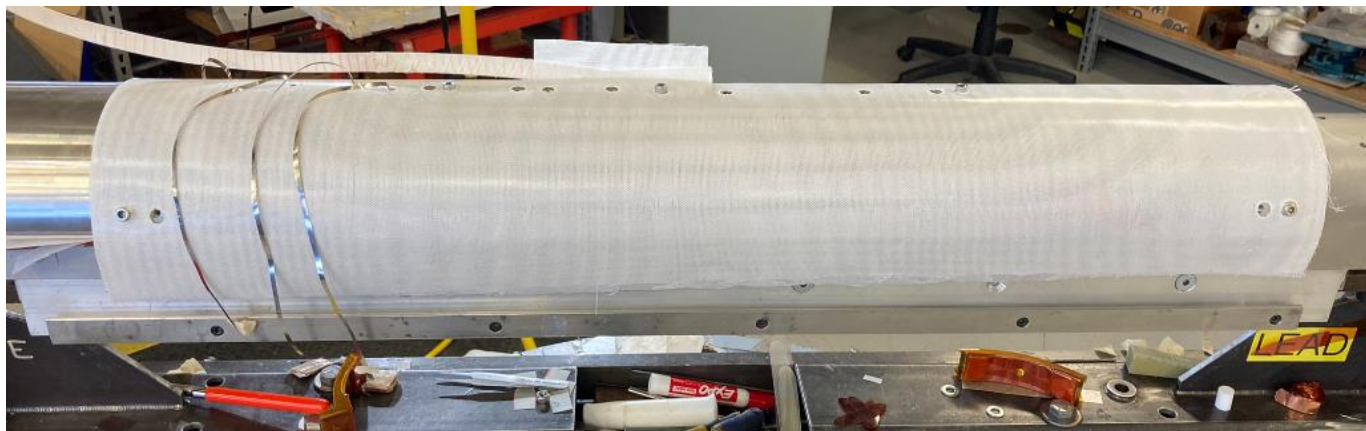
L1 winding, transition side



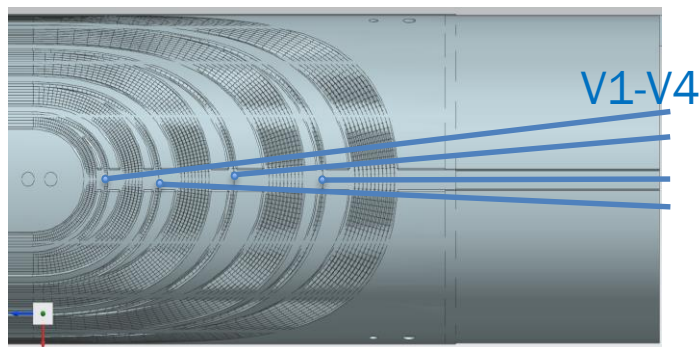
Inter-layer insulation and outer layer mandrel setup



RE view of inner layer



A sheet of S2-glass inter-layer insulation blanket with L1 VT strips



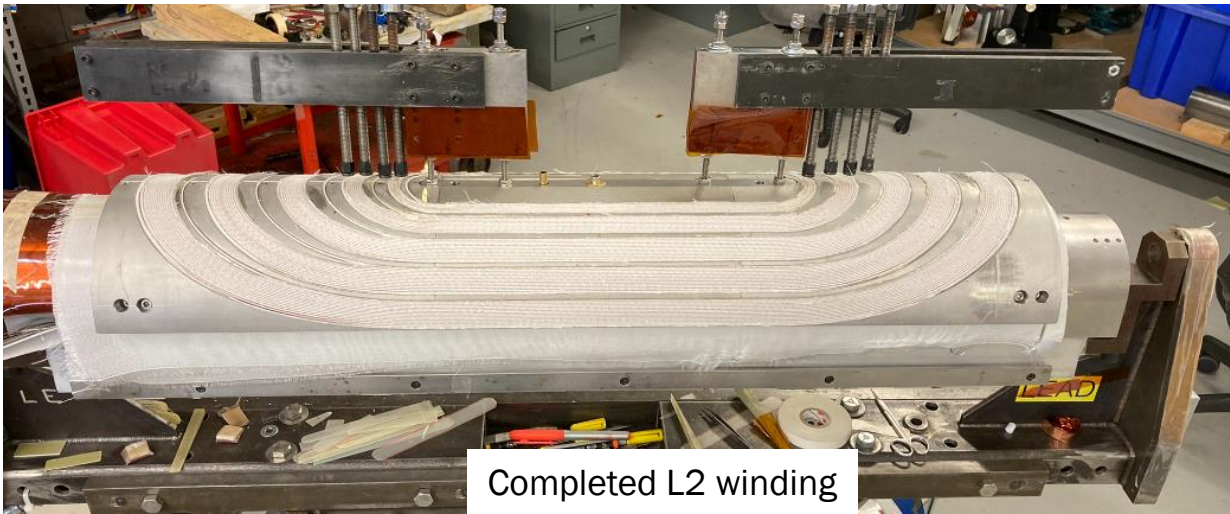
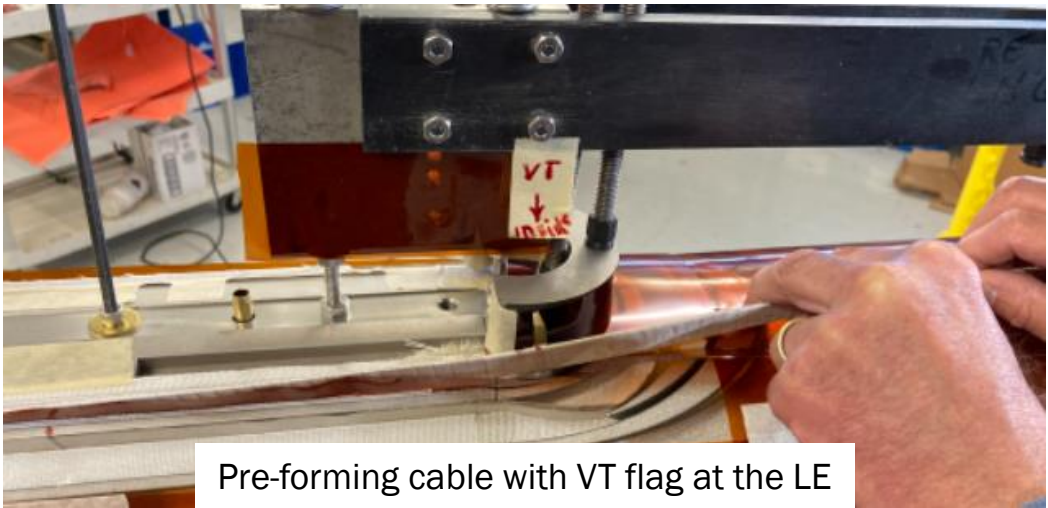
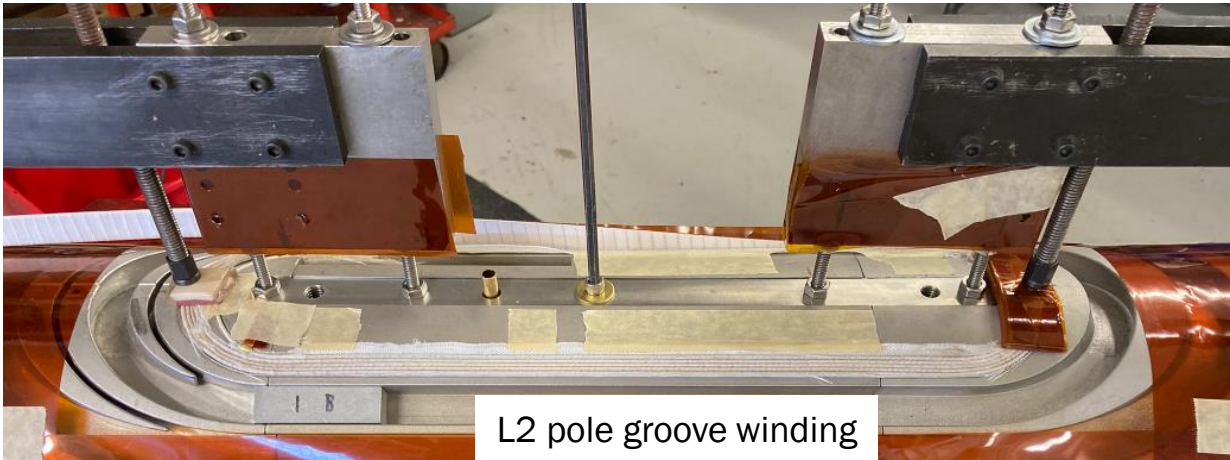
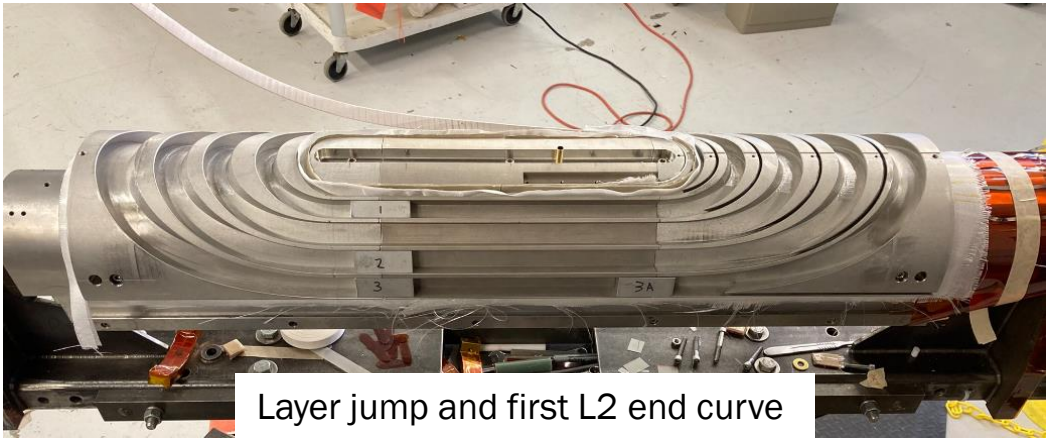
L1 VT strips located between two inter-layer blankets



Installation of the outer layer parts



Outer layer winding



Post winding



Post winding :

- End gaps measurements and patching
- Outer surface preparation
- Cable insulation repair
- Coil electrical measurements



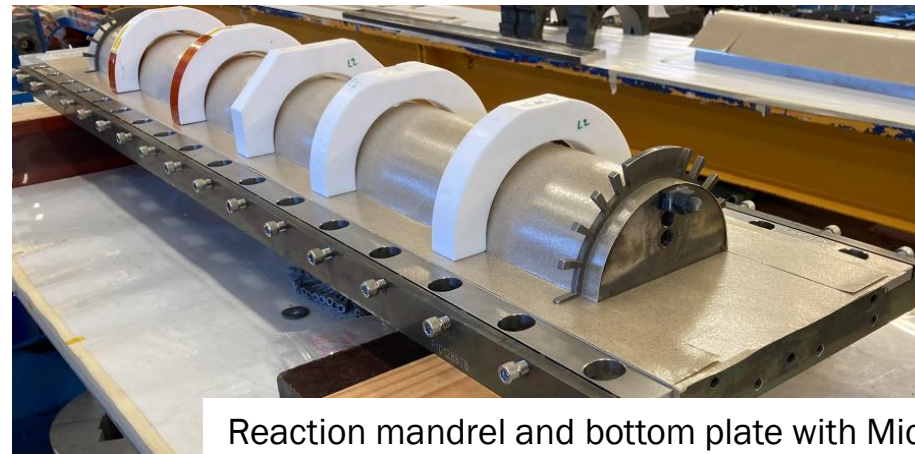
Coil winding completed



Coil lifting and transferring to the reaction fixture



Lifting coil up from the winding table



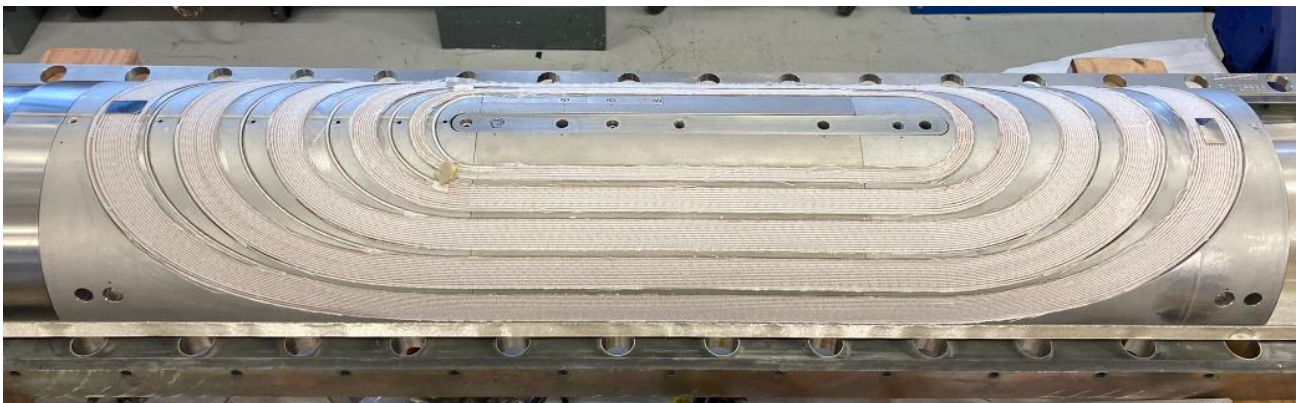
Reaction mandrel and bottom plate with Mica insulations



Coil transferred to the reaction tooling



Coil outer surface packaging for reaction



Coil outer surface before packaging



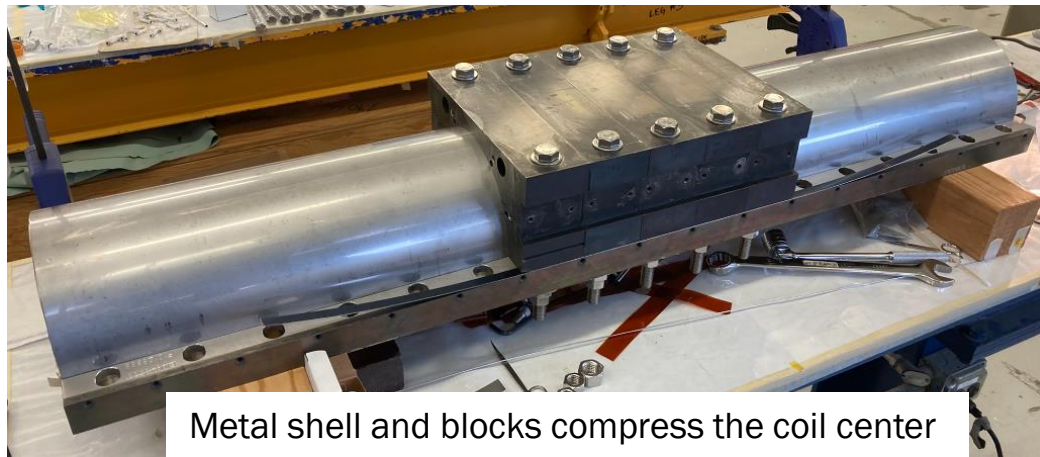
S2-glass blanket



Mica insulation



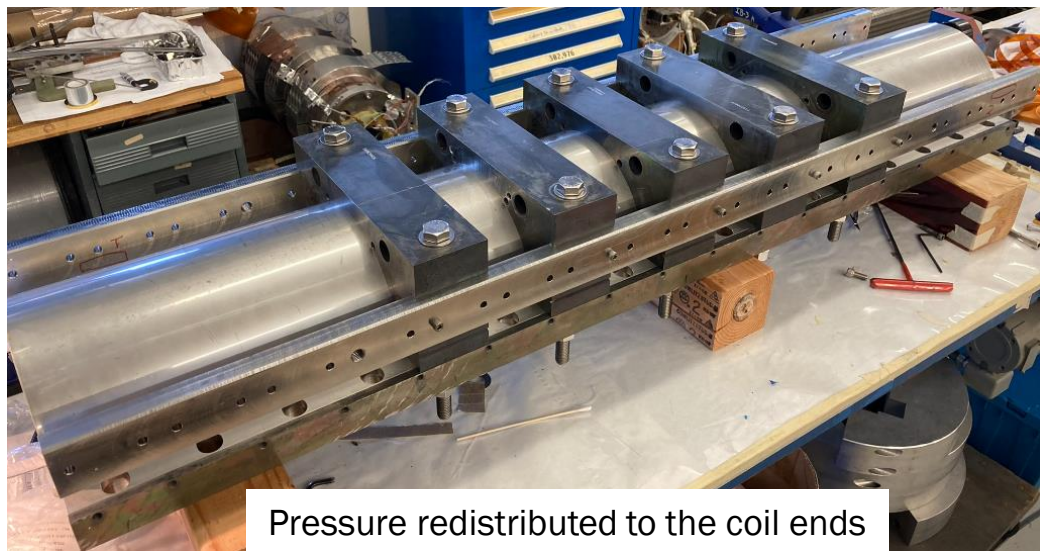
Reaction tooling assembly



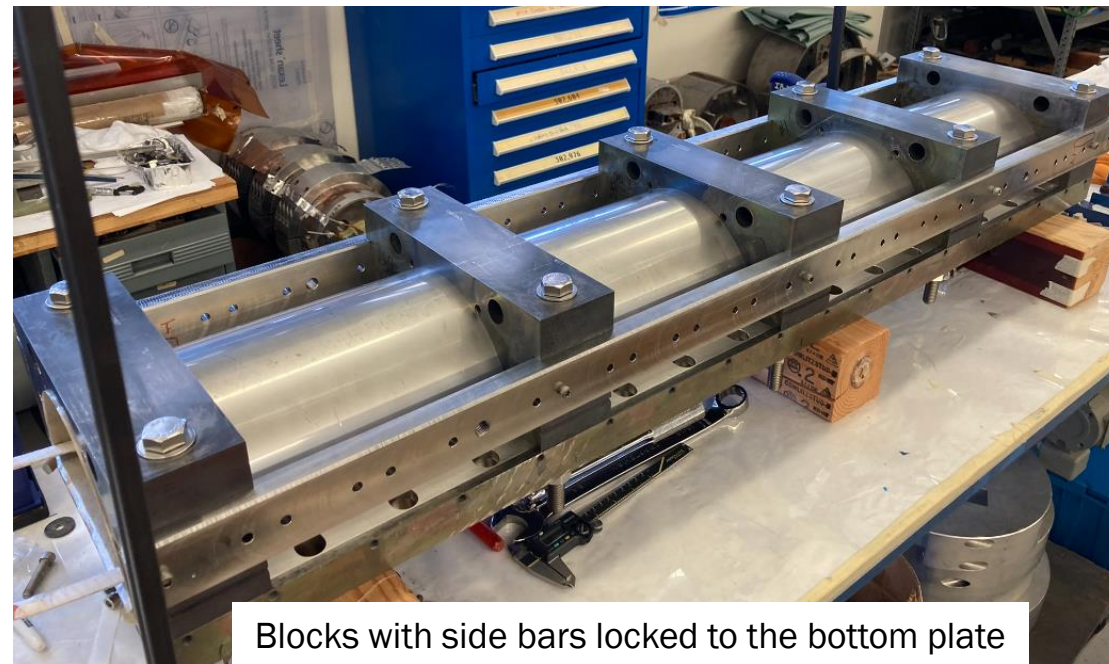
Metal shell and blocks compress the coil center



Blocks in final location



Pressure redistributed to the coil ends



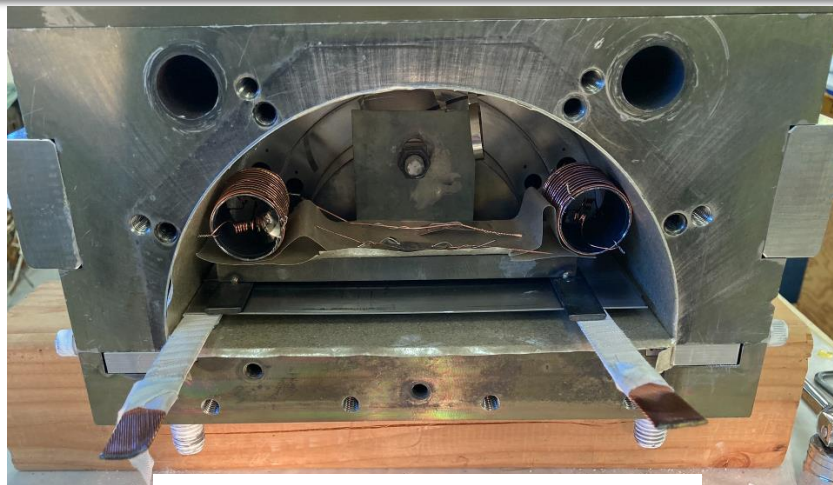
Blocks with side bars locked to the bottom plate



Reaction tooling assembly, continue



Coil outer surface reinforcement at the middle



Witness sample's location at LE



Top plate installation and shell sealing

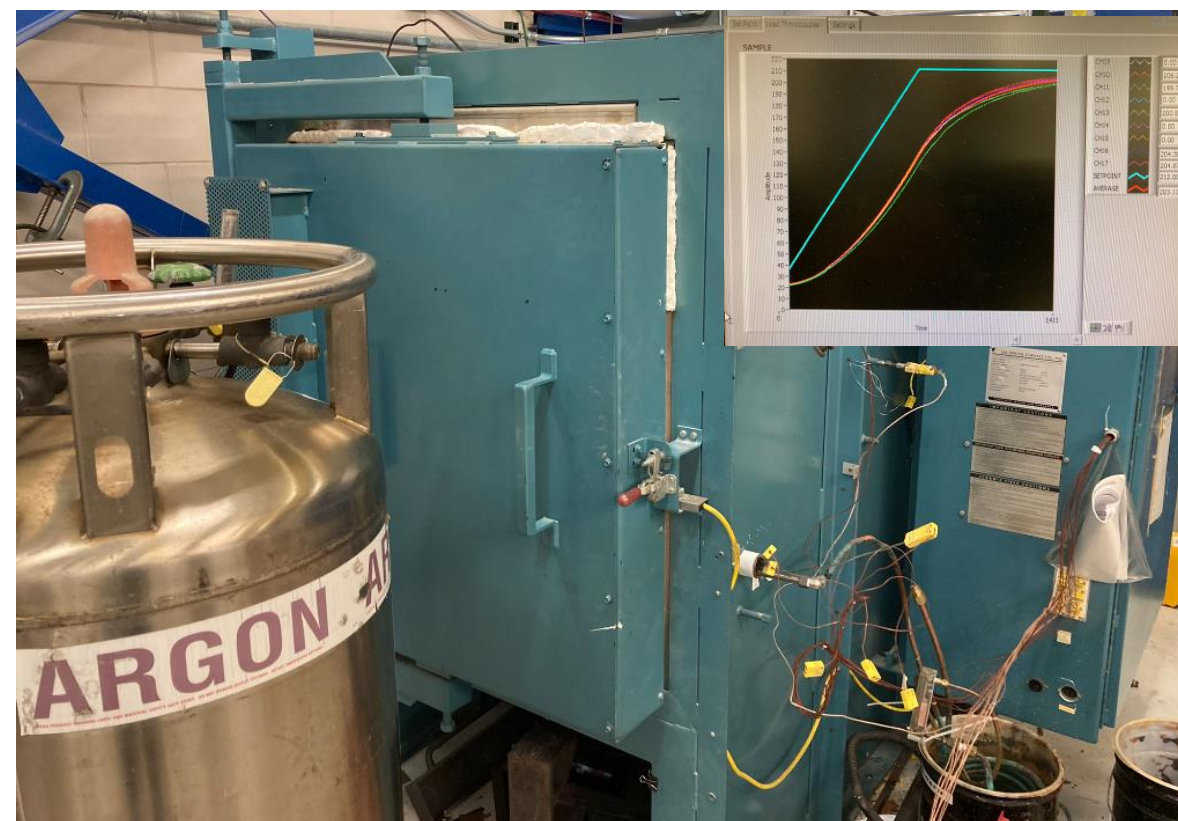


Witness sample's location at RE



Reaction tooling lifting

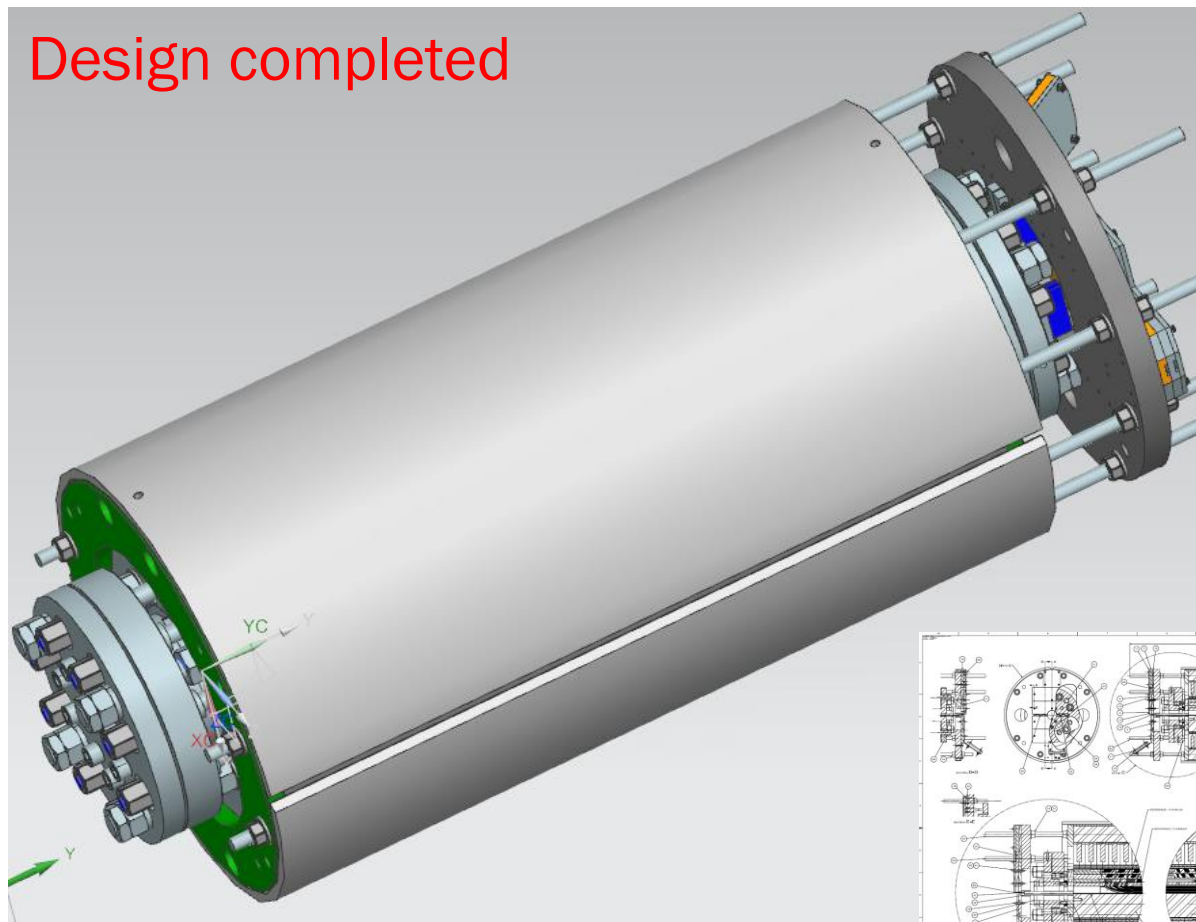
Loading the reaction tooling into oven retort



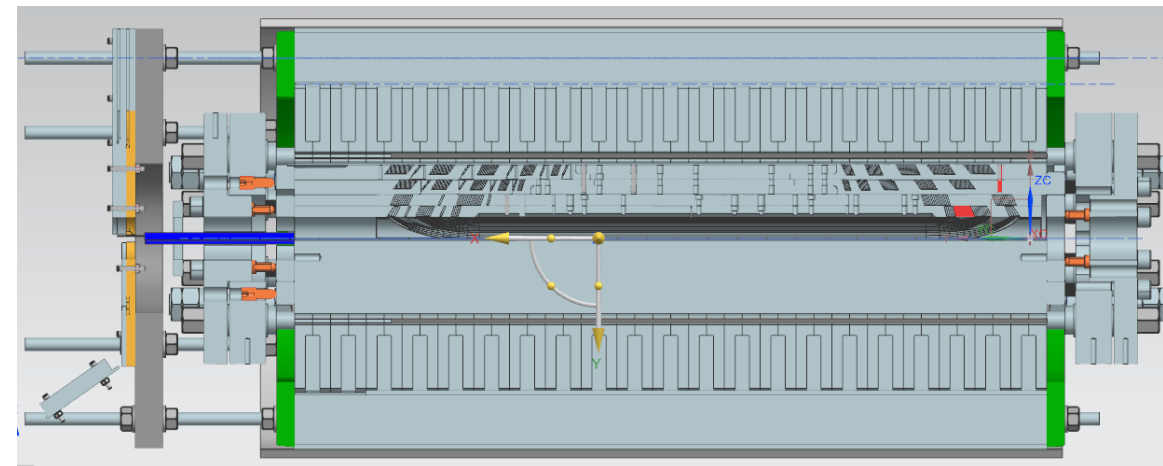
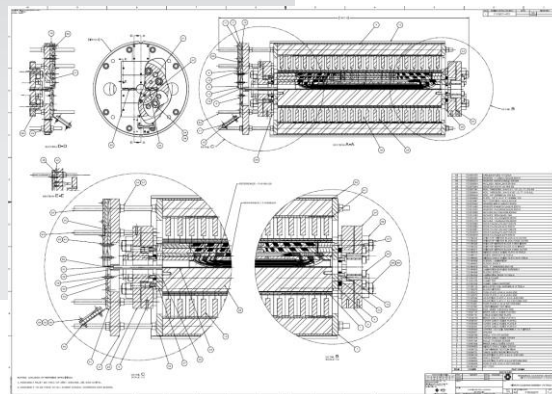


4-layer mirror magnet design

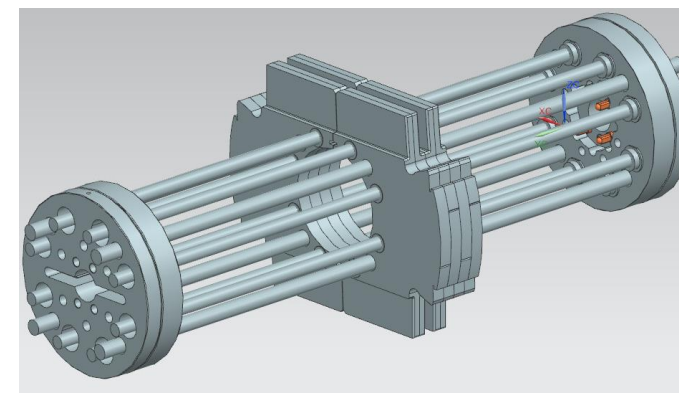
Design completed



Mirror magnet CAD model and drawing



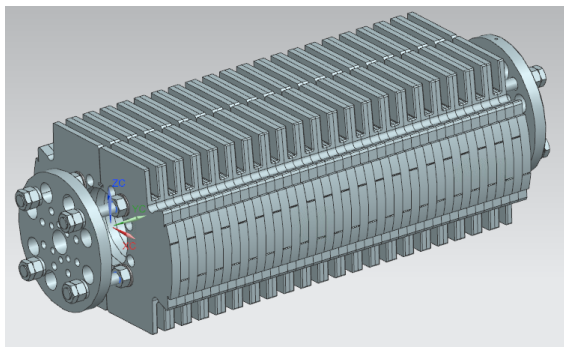
Mirror magnet longitudinal cross-section



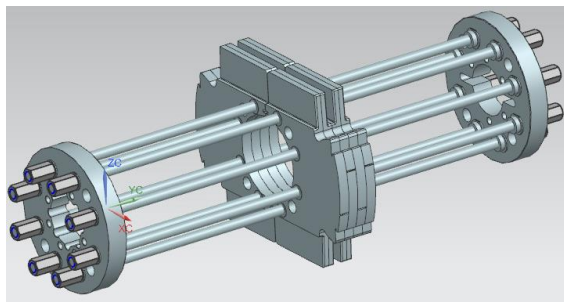
Mirror magnet axial support for inner and outer coils
with central anchoring location



Coil end support modification



Inner coil support



Outer coil support



Anchoring lamination



End plates



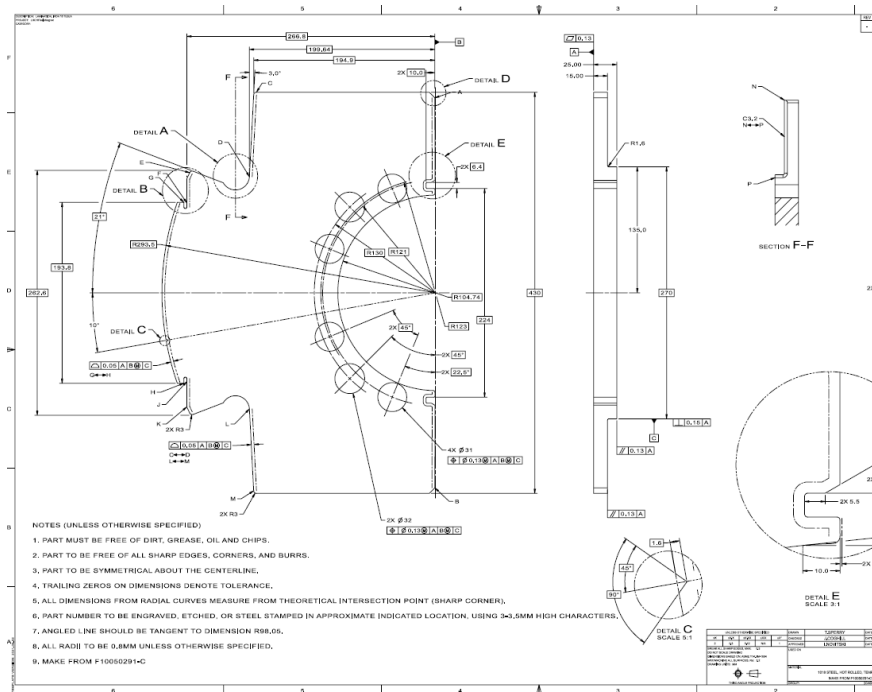
Rod with bushing

Parts in house



Iron yoke modification

Iron yoke ID increased and two holes added to reinforce end support.



Iron laminations drawing



Iron laminations after modification



Parts in house

Next steps

- SMCT coil reaction-impregnation-instrumentation - Jun-Jul 2022
- Mirror magnet assembly and test preparation - Aug-Sep 2022
 - 4L mirror will be assembled
 - Mirror instrumentation – fiber optics, acoustics – ?
 - 2D/3D magnetic analysis update, SS calculation
 - 2D mechanical analysis update
- Mirror magnet test - Oct-Dec 2022
 - 1st test: 120-mm SM coil will be powered
 - 2nd test: both 60-mm and 120-mm will be connected in series and tested

SMCT task milestone update

Milestones for the Stress-Managed Cosine-Theta (SMCT) effort within the Nb3Sn area of the MDP

Milestone #	Description	Target	Status *	Updated Target	Requestor	Comments
AI-M1a	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.	Mar-22	In progress	Dec-22	A. Zlobin	
AI-M2a	Development, fabrication and test of stress management concept in a 2-layer 120-mm dipole with the field up to 11 T.	Apr-23	In progress	Dec-23	A. Zlobin	
AI-M3a	Assembly and test of stress-management concept in a 4-layer 60-mm 17 T dipole with stress management.	Apr-24	Not started	Dec-24	A. Zlobin	

- SMCT concept R&D is a key part of the updated MDP plan
- Even with limited resources (techs) the task is progressing towards the goal
 - 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 was modified
 - SMCT coil winding is complete, coil reaction has started
- Next steps
 - SMCT coil splicing, impregnation and instrumentation
 - 4L mirror assembly and test
 - SMCT mirror magnetic and mechanical analysis update
- SMCT coil test in 2L/4L dipole mirror is now planned for the end of 2022
- SMCT task milestone dates have been updated based on the task progress with limited resources