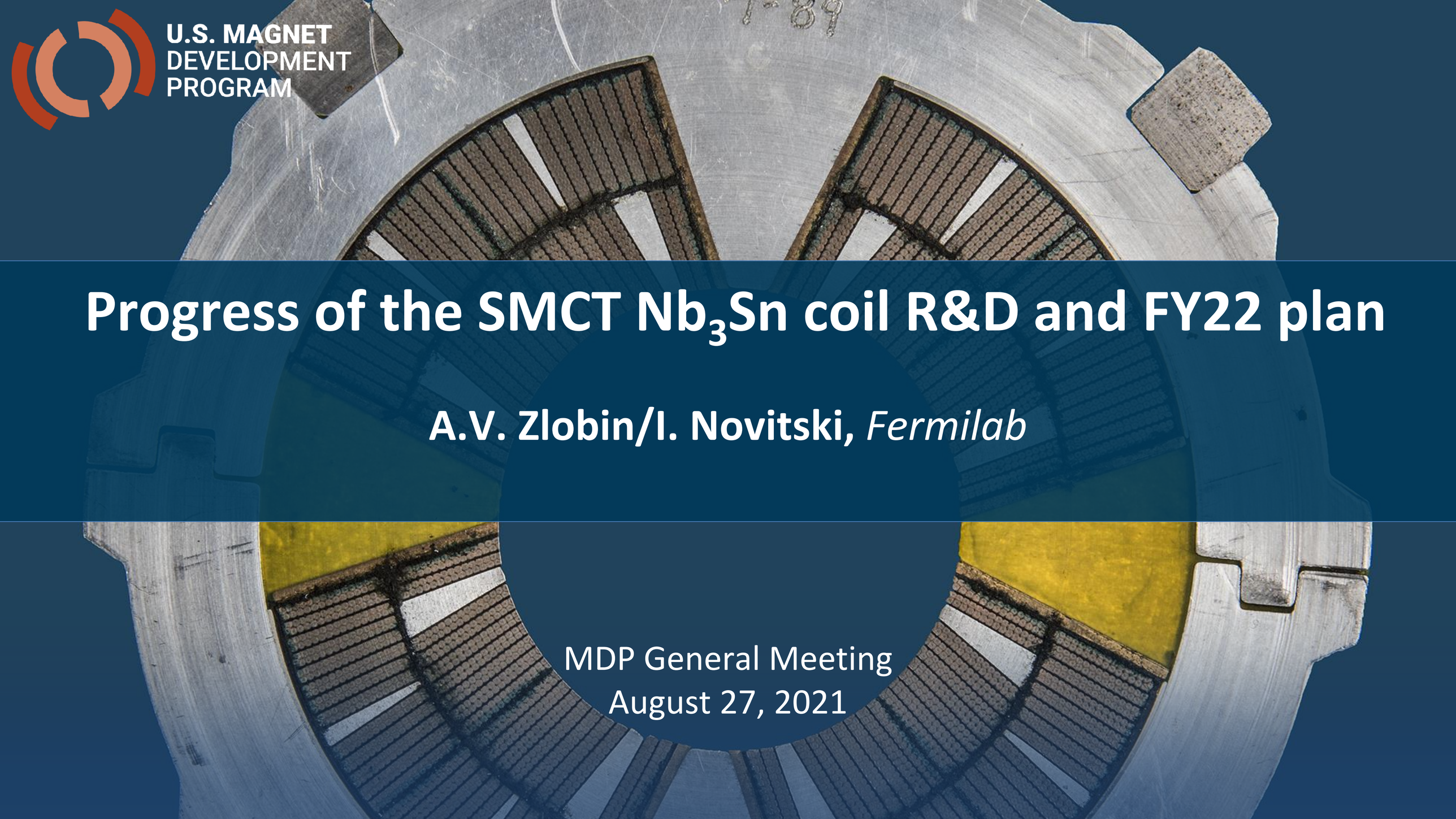


U.S. MAGNET DEVELOPMENT PROGRAM

Progress of the SMCT Nb_3Sn coil R&D and FY22 plan

A.V. Zlobin/I. Novitski, *Fermilab*

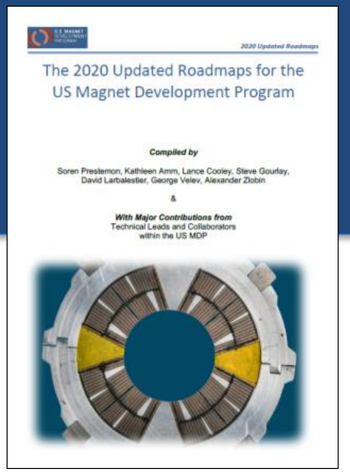
MDP General Meeting
August 27, 2021

Outline

- ✓Nb_3Sn SMCT R&D goals and milestones
- ✓1st SMCT coil design and fabrication status
- ✓2nd SMCT coil design optimization
- ✓Assembly and test schedule and resources

U.S. MAGNET DEVELOPMENT PROGRAM

Nb_3Sn SMCT R&D goals and milestones

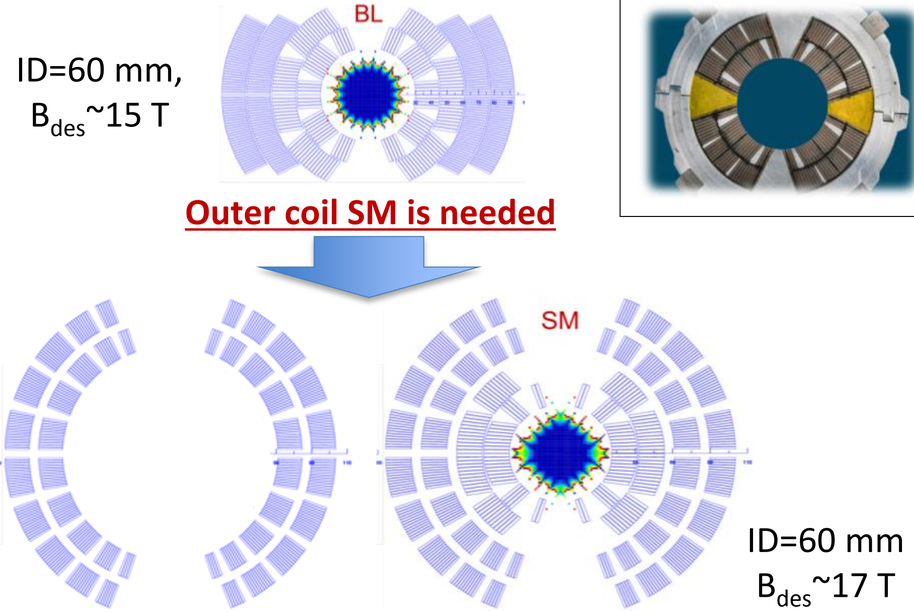


SMCT R&D goals:

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;

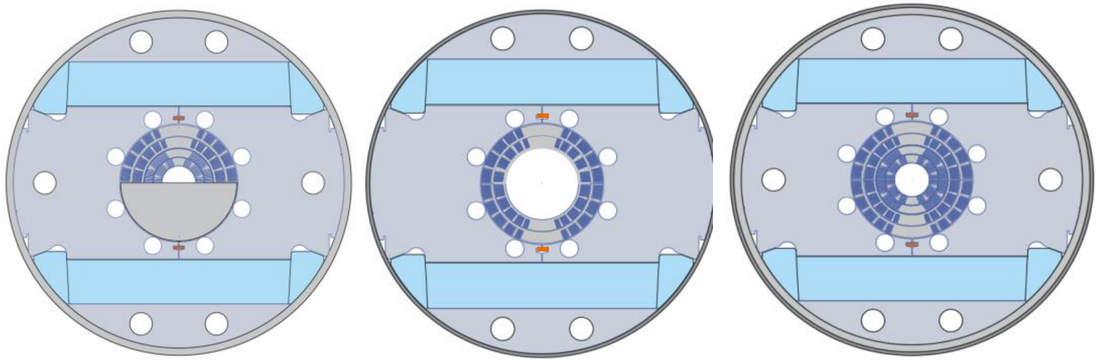
b) demonstrate a bore field up to 11 T at 1.9 K with 120-mm aperture in two-layer Nb3Sn dipole magnets with stress-managed coils;

c) demonstrate up to 17 T at 1.9 K with a 60-mm aperture in a four-layer Nb3Sn dipole magnet with stress-managed outer coils.



Cos-theta dipole coils with stress management (SMCT)

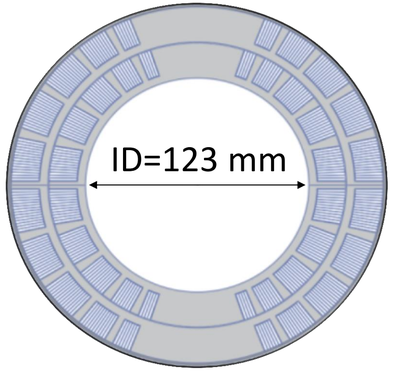
Milestone #	Description	Target
AI-M1a	Development and test of stress management concept using a 2-layer large-aperture and 4-layer small-aperture cos-theta coils and dipole mirror structure	March 2022
AI-M2a	Development, fabrication and test of stress management concept in a 2-layer 120-mm dipole with 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

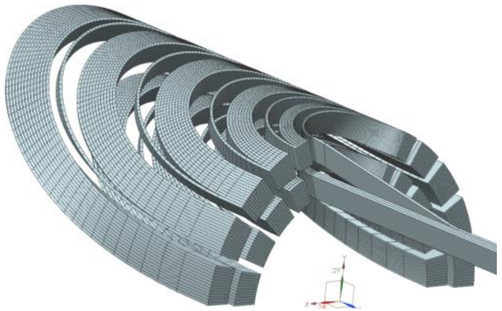


V.V. Kashikhin, I. Novitski, A.V. Zlobin, "Design studies and optimization of a high-field dipole for a future Very High Energy pp Collider," in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, p.3597.

High-Field Nb_3Sn Cos-theta Dipole with Stress Management
Igor Novitski, Justin Carmichael, Vadim V. Kashikhin, Alexander V. Zlobin (Fermilab)
FERMILAB-CONF-17-340-TD

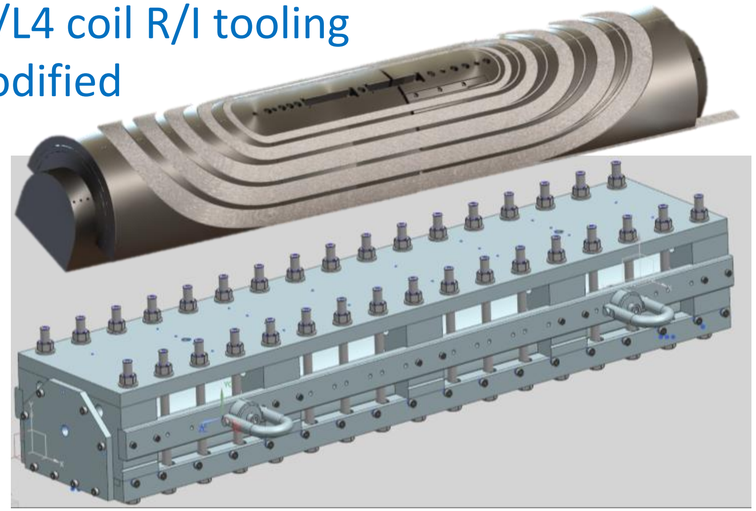
SMCT coil design, W/R/I tooling, practice coil

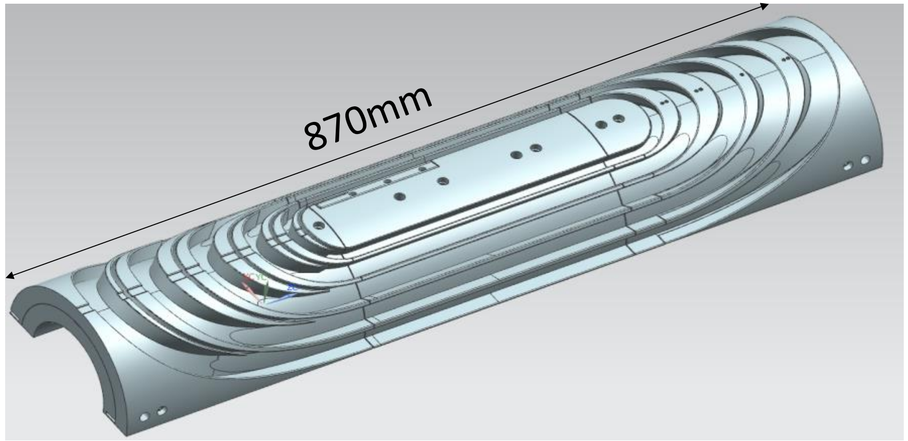




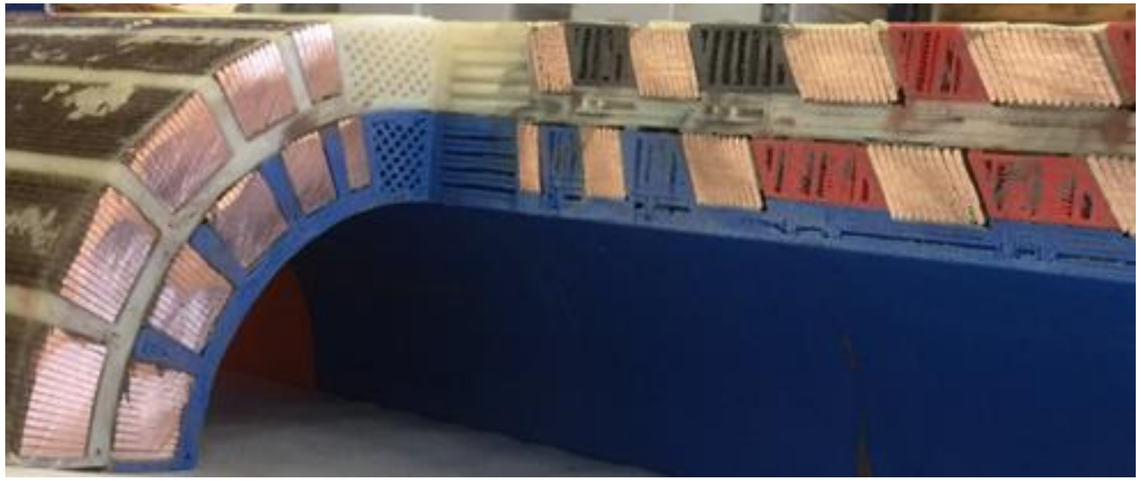
Large aperture dipole coil

L3/L4 coil R/I tooling modified



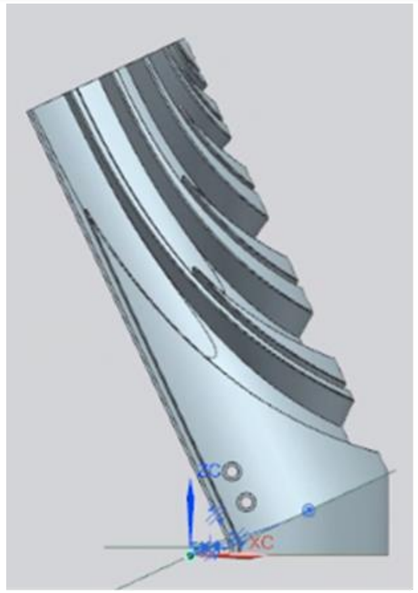


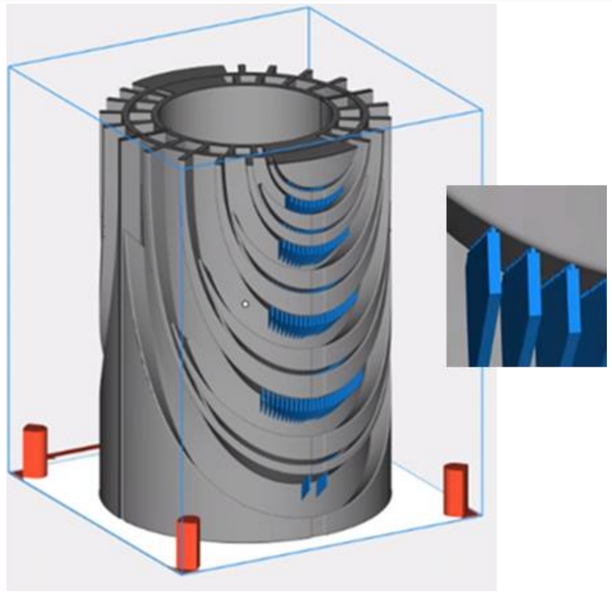
Stress management coil structure

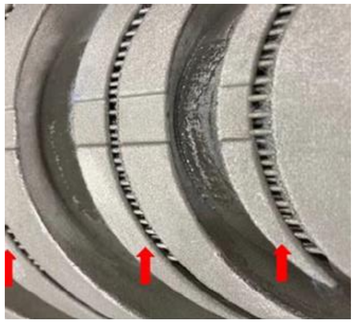


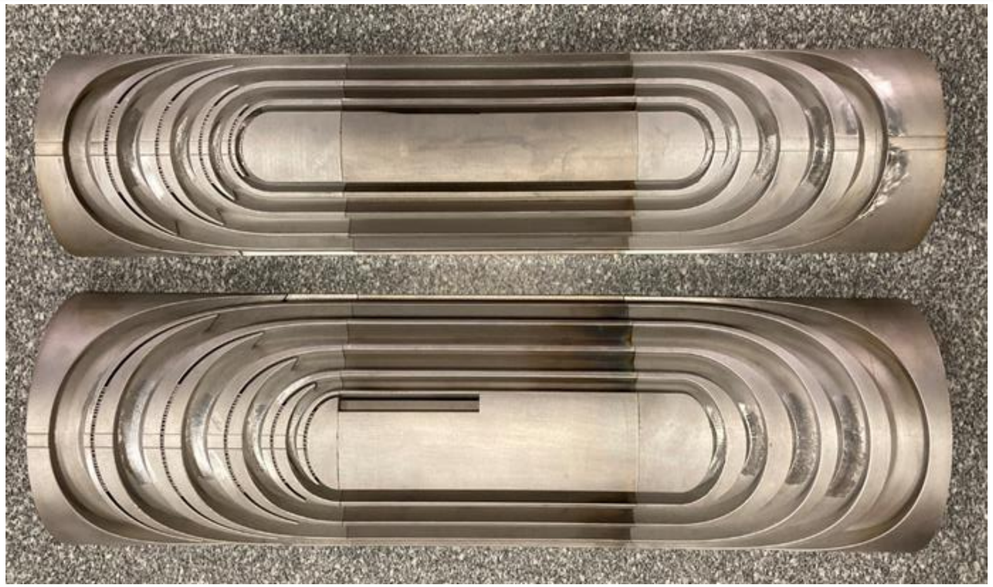
Practice coil winding/impregnation/ QC

SMCT coil part fabrication by GE Additive









Direct Metal Laser Melting (DMLM) technology

- 316L stainless steel powder
- Two orientations of end part printing:
  - 25-degree angle to eliminate support
  - vertical with surface support in blue

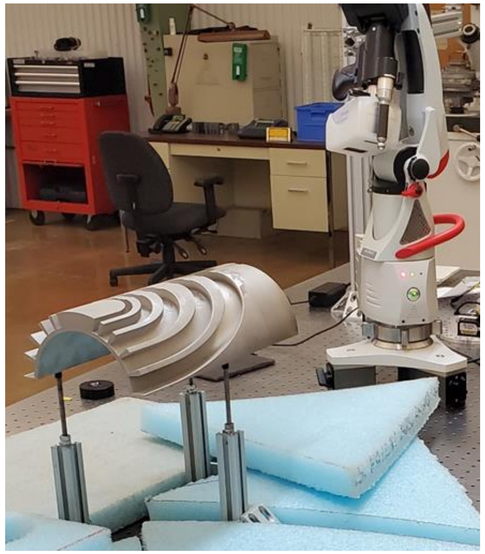
SMCT coil parts printed as two-layer cylinders

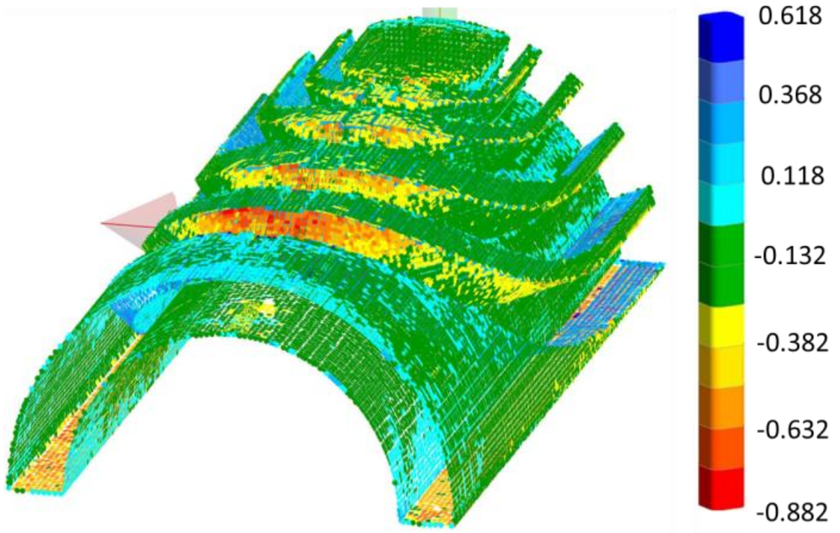
- surface support inside large blocks removed at GE Additive
- narrow inter block channels in LE with surface supports to be removed at Fermilab

Contract signed in December 2020, parts delivered by the end of February 2021

Coil structure size control

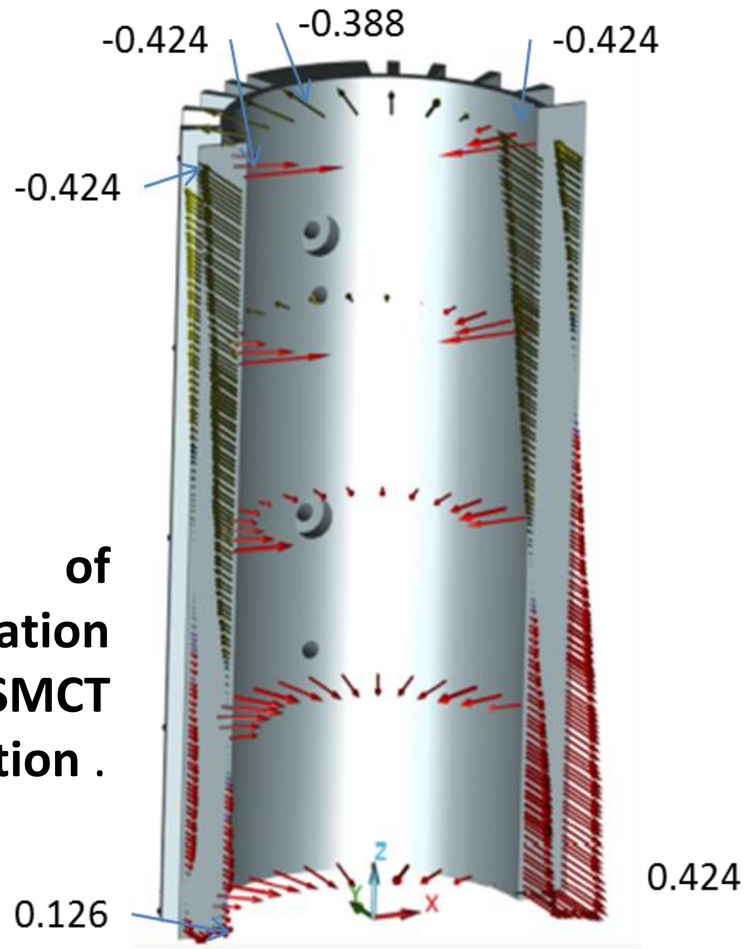
Control of SMCT coil end parts by micrometer on granite table.





Laser Scanning measurements of surface deviation from CAD.

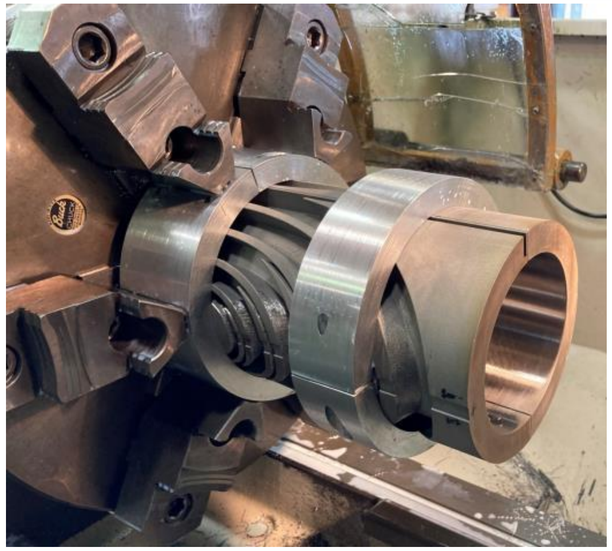
CMM measurements of surface deviation from CAD of SMCT coil straight section .



3 month to perform all the measurements.

I . Novitski et al., “Using Additive Manufacturing technologies in high-field accelerator magnet coils,” CEC-ICMC’21 invited talk and paper

SMCT coil structure post-processing



Completed:

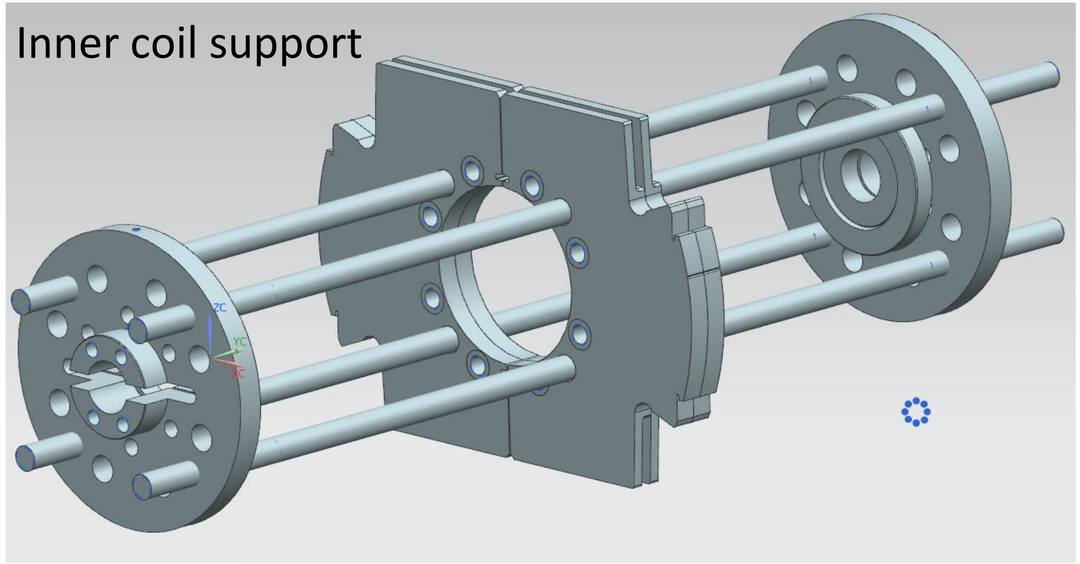
- inner coil ID increased and pole slots added
- Technological holes in coil parts and winding mandrel added

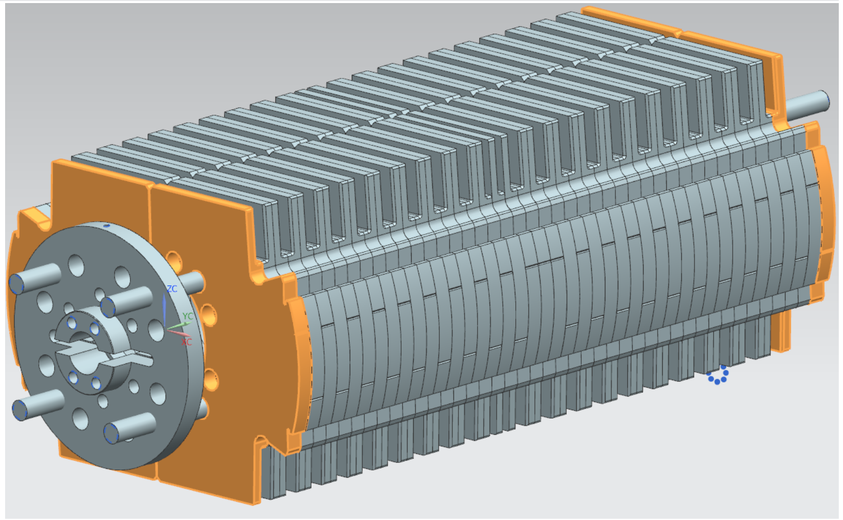
In progress:

- removing support materials in IL cable transition slots
- outer coil OD, pole slot and technological holes

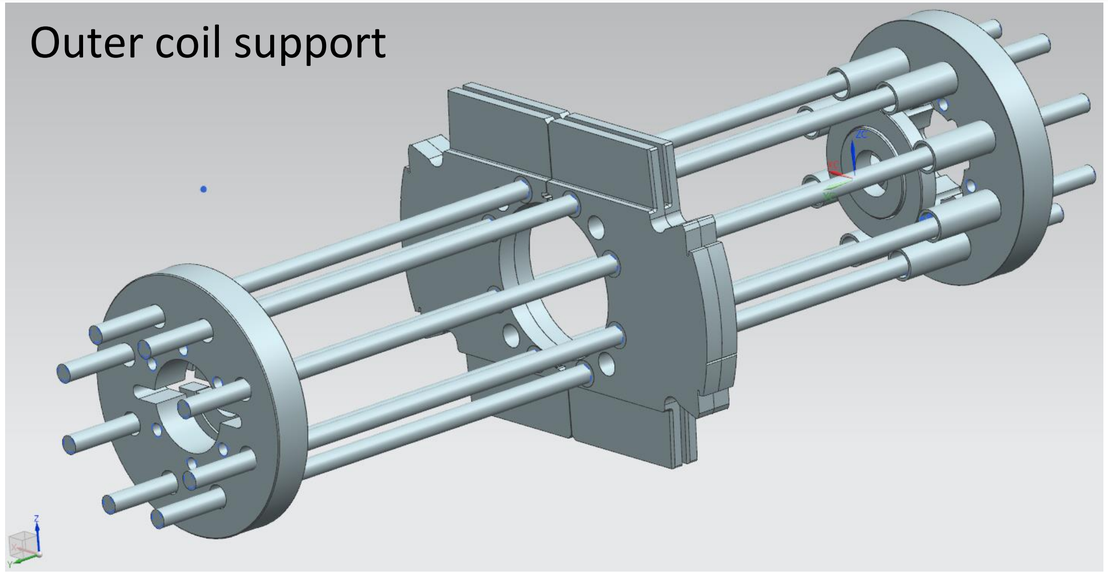
Improvement of coil end support

Inner coil support



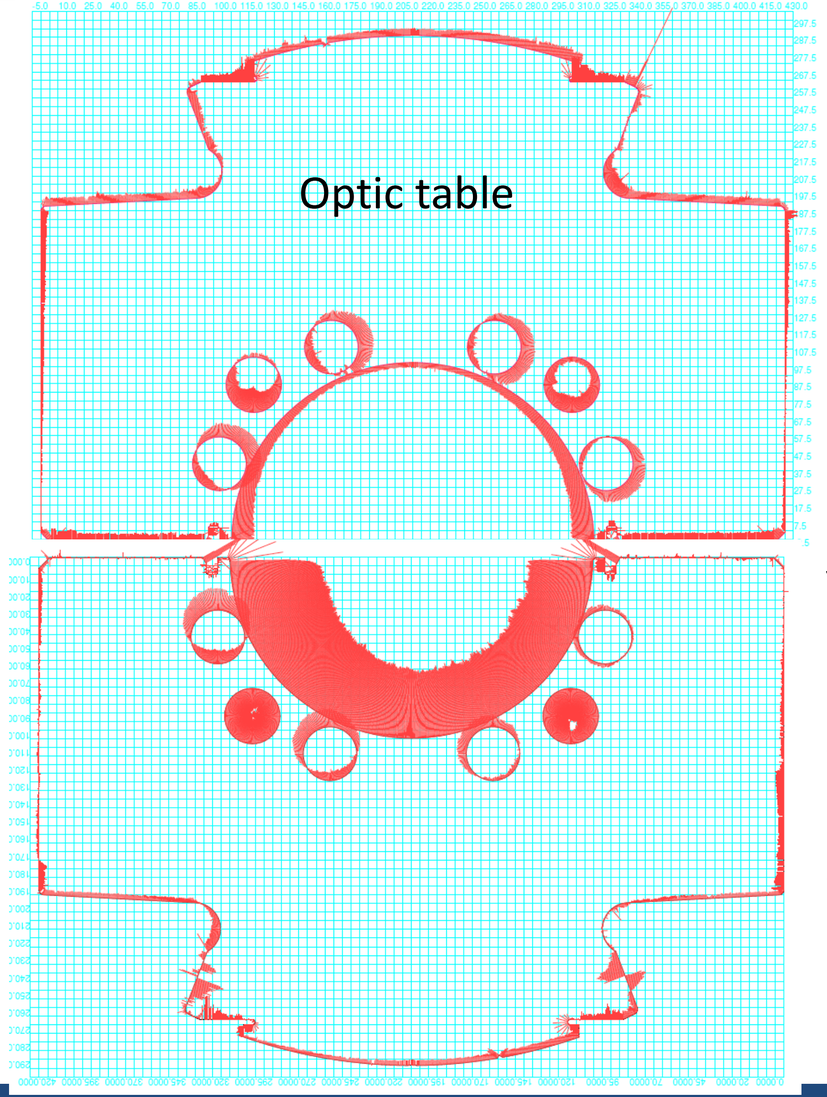


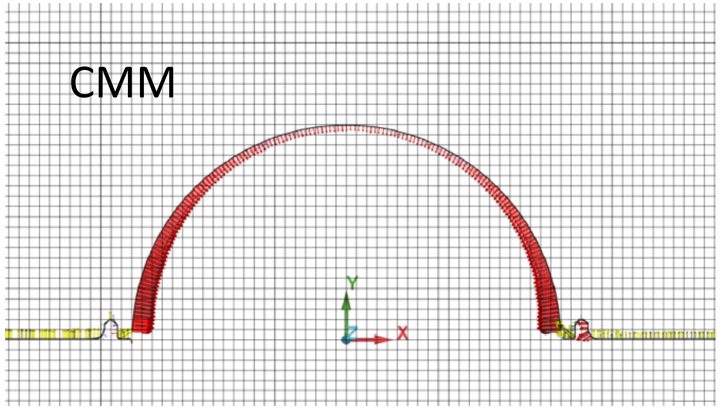
Outer coil support



- Rod system reinforcement
  - 4 new rods for inner coil
  - 6 rods old rods for outer SMCT coil
- SMCT coil rod anchoring
- End contraction control for SMCT coil

Iron yoke modification and measurement

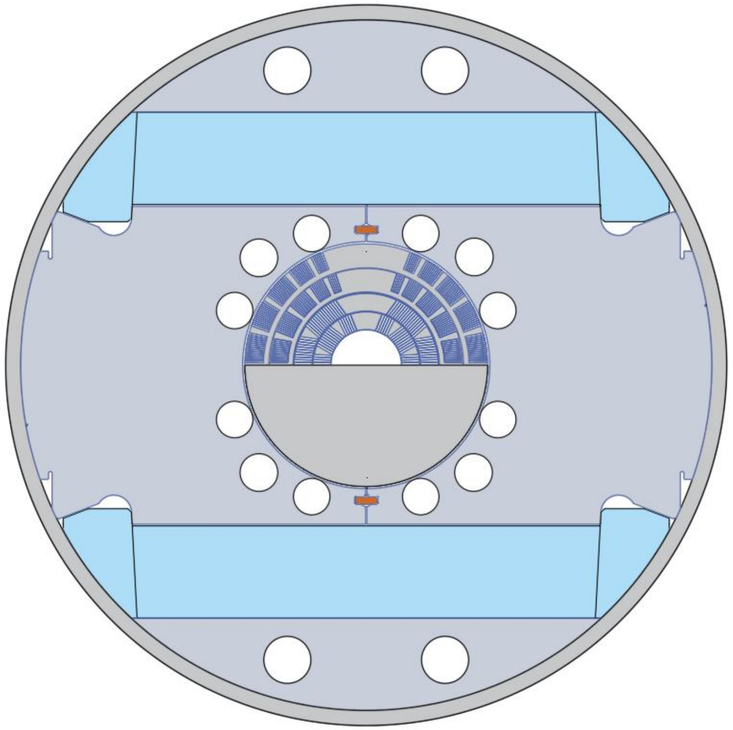




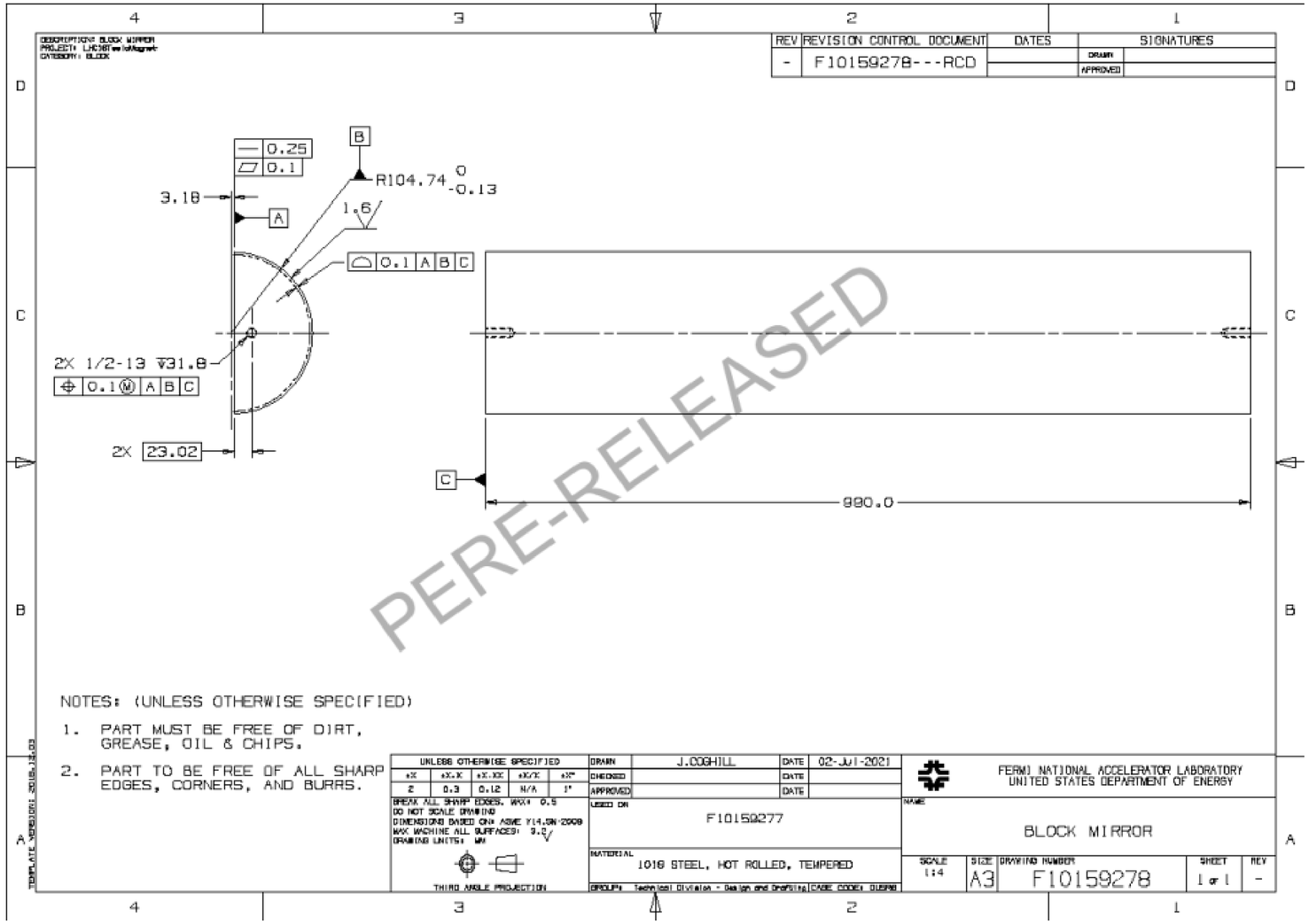
Status:

- Iron yoke ID increased to accommodate SMCT coil
- Two holes added to reinforce coil end support
- Selected laminations measured using CMM and optic table => rework of laminations in progress

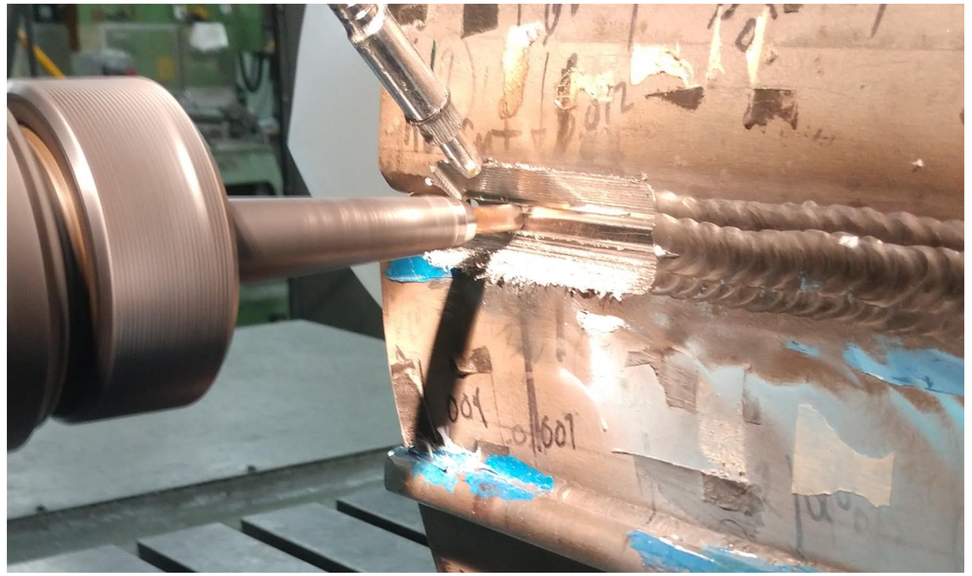
Mirror block design and fabrication

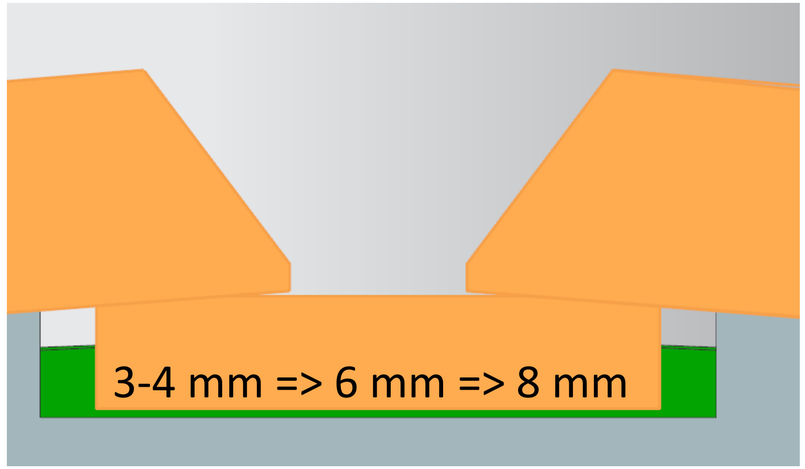


- Single piece for accuracy (similar to the winding mandrel)
- Drawing has been made
- Fabrication starts in October



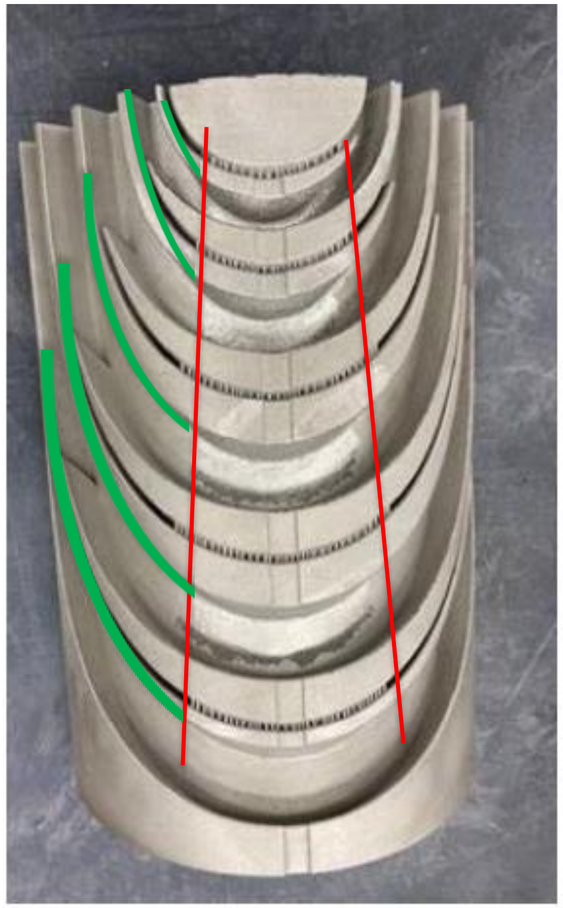
Skin preparation

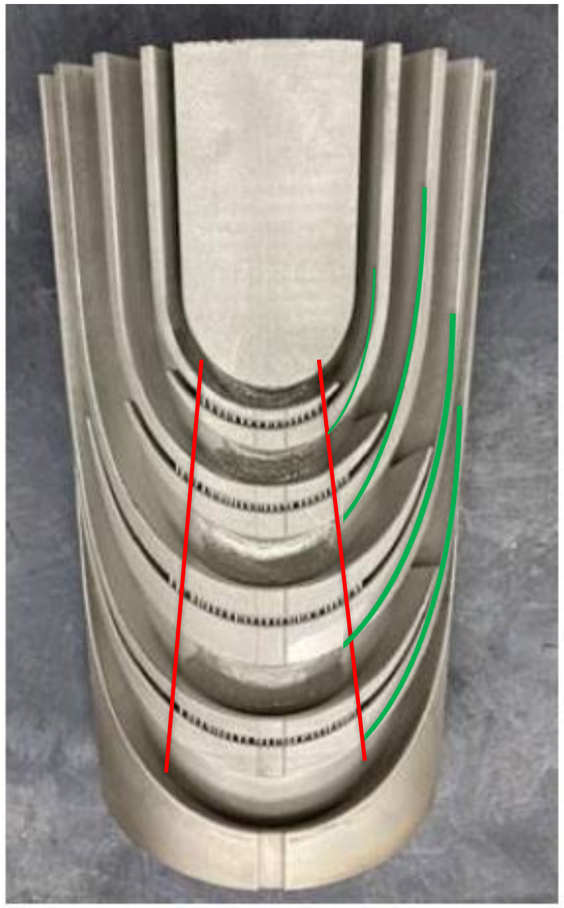


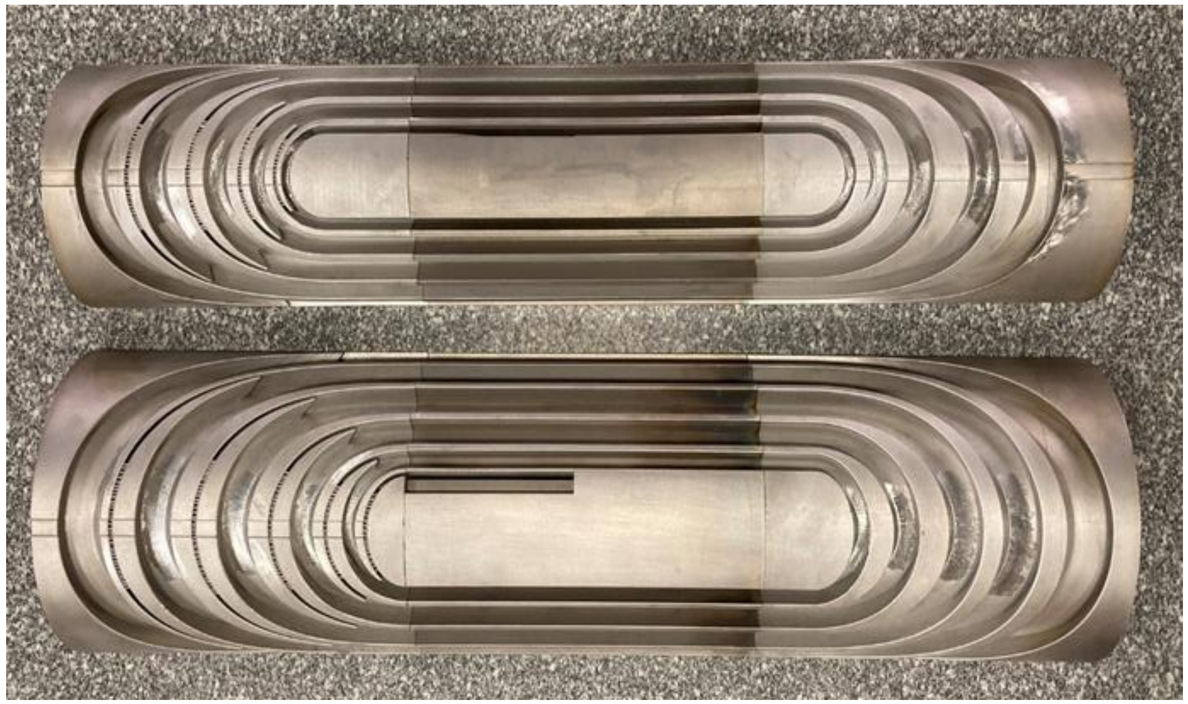


- 3rd time skin re-using
- Welding groove machined and prepared for welding
- Larger groove size => control welding to optimize shrinkage was discussed with welder

SMCT coil design optimization

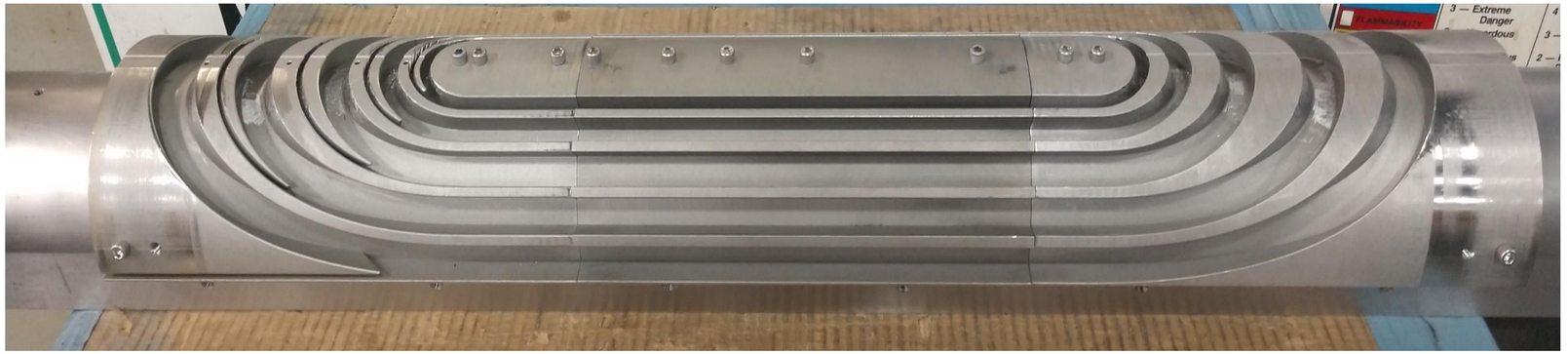


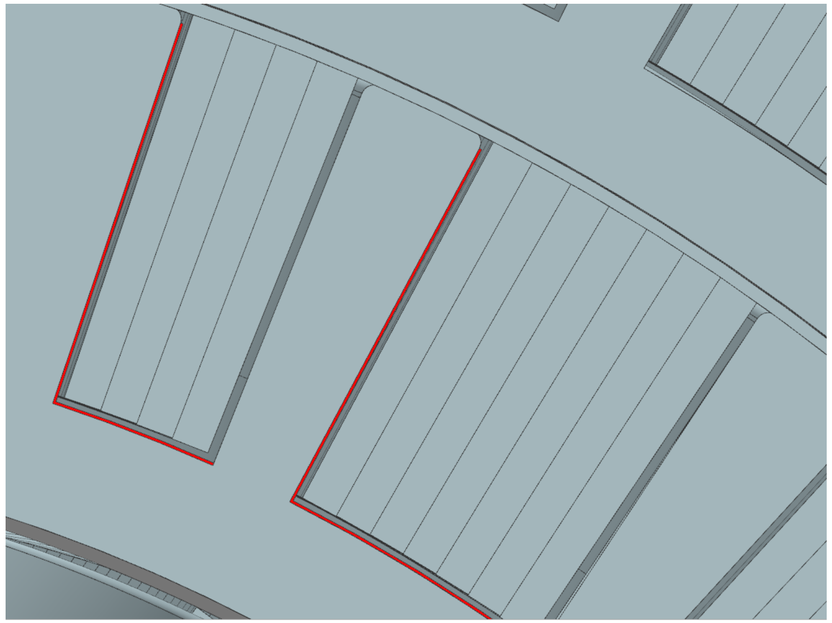




- Short interlayer transition to avoid support elements in transition channels
- More compact LE and RE
- Split straight section in two equal pieces for printing
- Design work starts after finishing 1st mirror design

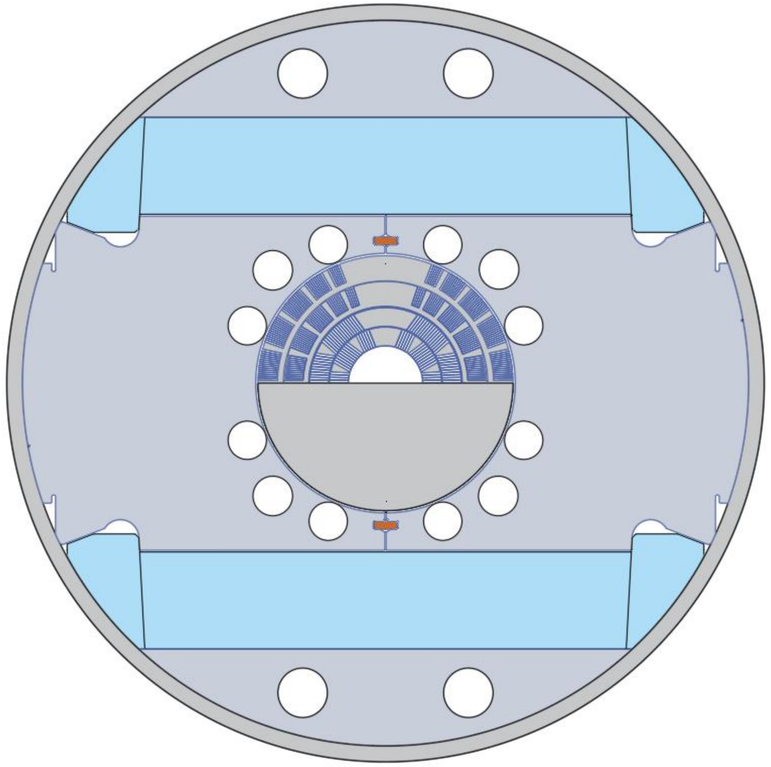
Coil winding preparation



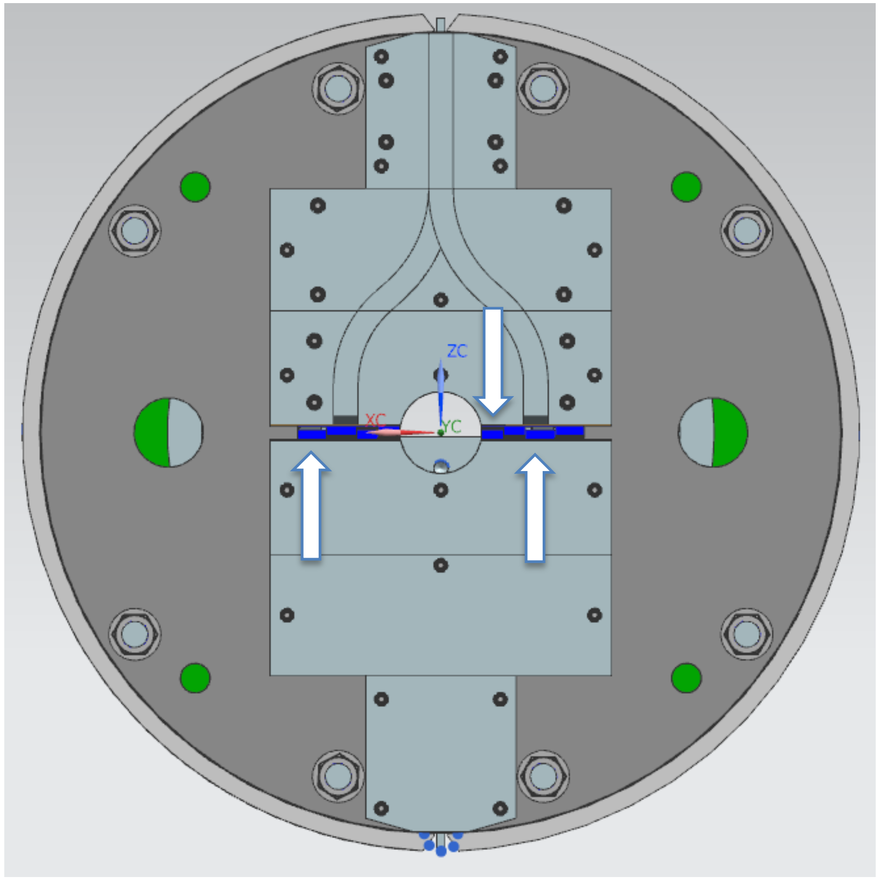


- Cable insulation
- Ultrasonic part cleaning
- Part assembly and surface adjustment
- Adding coil ground insulation
- We may need practice winding of first 1-2 blocks
  - Winding procedure
  - Reduce risk of shorts

Magnet assembly and test

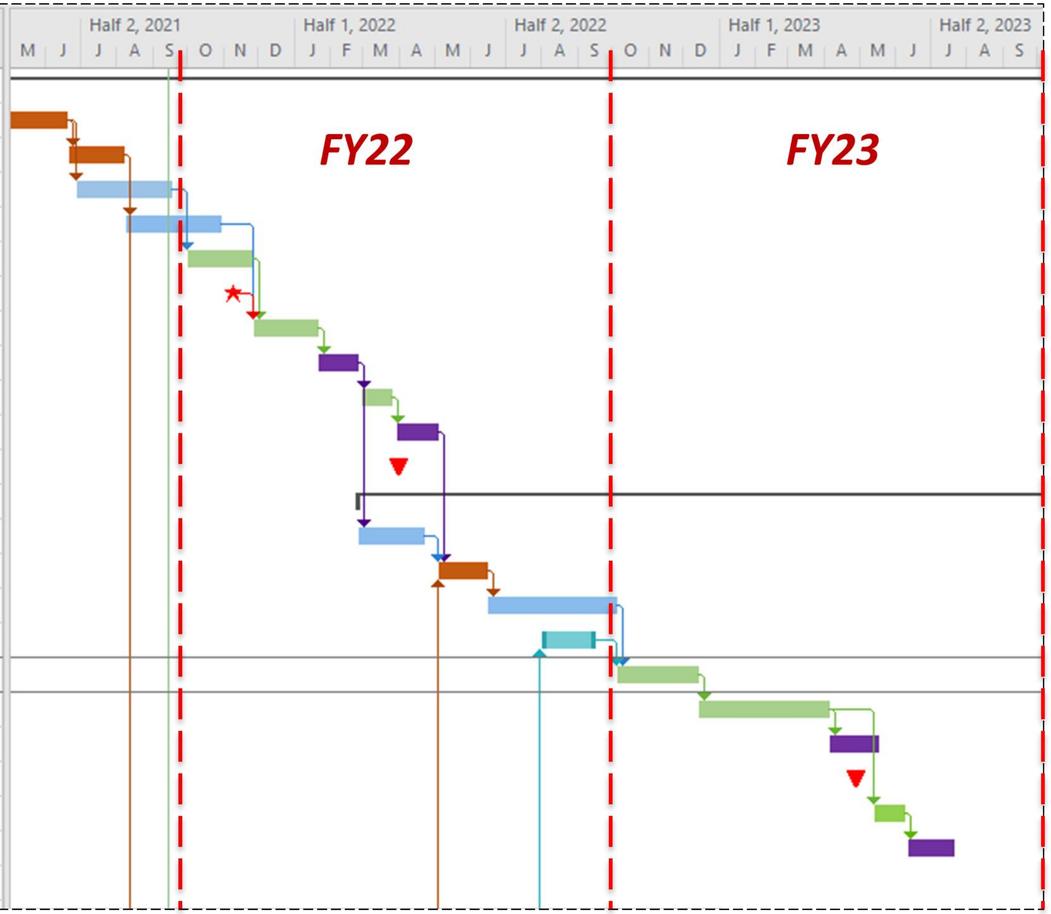


- Mirror assembly with both inner and outer (SMCT) coils
- Two-step test
  - 1st test: only SMCT coil connected
  - 2nd test: both coils connected in series
- Only small splice box modification is needed



Nb_3Sn SMCT coil assembly and test schedule

	Task Mod	Task Name	Duration
1		**Task 1. 1st SM coil fabrication and mirror test**	**797 days**
2		1st coil part design modification	10 wks
3		yoke and end suport design modification	7 wks
4		1st coil part rework at VMS	12 wks
5		HFDM mirror yoke modification	12 wks
6		1st SM coil fabrication/instrumentation	8 wks
7		mirror assembly and test review	1 day
8		SMCTM1 mirror assembly	8 wks
9		SMCT1a mirror 1st test with 120-mm coil	5 wks
10		mirror warm-up and coil reconnection	4 wks
11		SMCT1b test with 4L coil	5 wks
12		USMDP milestone	1 day
13		**Task 1-2. 2nd SM coil design and fabrication**	**568 days**
14		SMCT coil 3D design optimization	8 wks
15		2nd SMCT coil design	6 wks
16		2nd SMCT coil procurement/inspection	16 wks
17		high-Cp cable fabrication and test	6 wks
18		SMCT coil fabrication/instrumentation	10 wks
19		4L SMCT dipole assembly	16 wks
20		120-mm SMCT dipole test	6 wks
21		USMDP milestone	1 day
22		magnet warm up and reconnection	4 wks
23		4L 60-mm SMCT dipole test	6 wks
24		USMDP milestone	1 day



- 1st test in Jan-Apr 2022
  - ✓ milestone - March 31
- 2nd coil design, part procurement and coil fabrication start in February 2022
  - ✓ Resources need to be planned
- Possible delay due to limited availability of techs due to
  - ➢ COVID-19
  - ➢ Al Rusy last working day - end of October