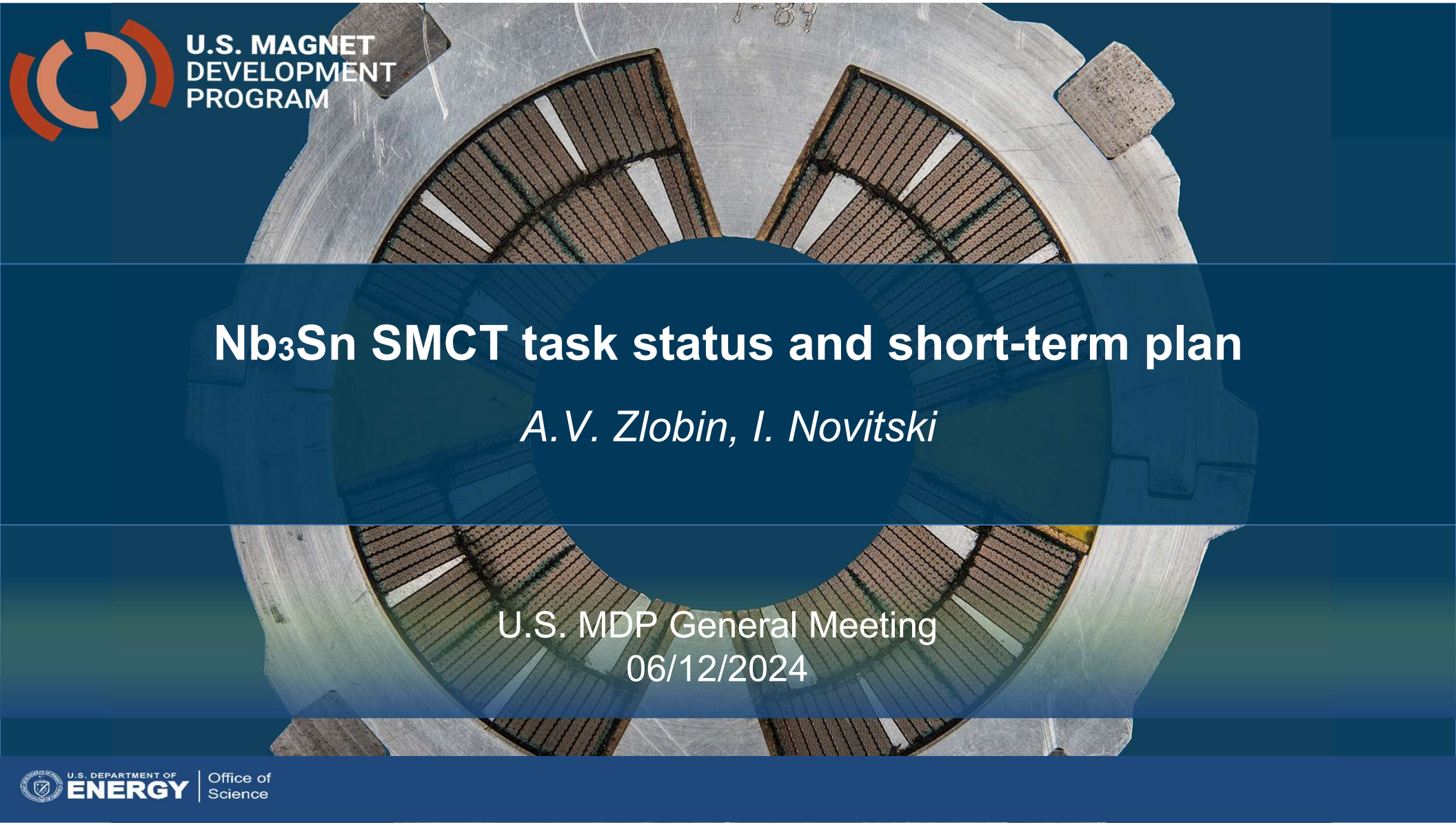


U.S. MAGNET DEVELOPMENT PROGRAM

Nb_3Sn SMCT task status and short-term plan

A.V. Zlobin, I. Novitski

U.S. MDP General Meeting
06/12/2024

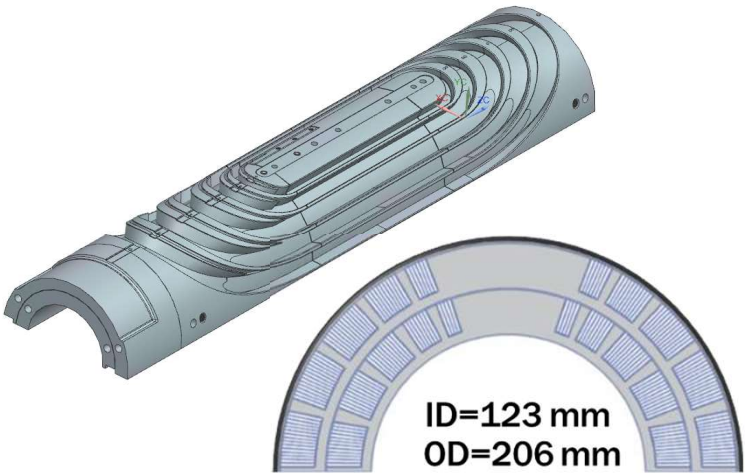
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Nb_3Sn SMCT program goal and milestones
- SMCTD1 design concept and work status
- SMCTD1 updated schedule
- SMCTM1a/b result analysis, discussion and presentation

Stress Management Cos-Theta (SMCT) coil concept

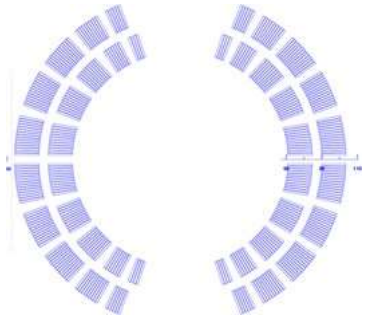
Nb_3Sn Rutherford cable



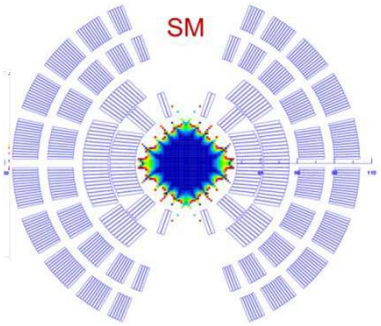
3D stress management using stainless steel mandrel

- The stress-managed cos-theta (SMCT) coil is a new concept being developed at Fermilab for High-Field (HF) and/or Large-Aperture (LA) accelerator magnets based on LTS and HTS.
- The SMCT structure is used to reduce large coil deformations under Lorentz forces and, thus, excessively large strains and stresses in the coil.
- A 123-mm aperture two-layer Nb_3Sn SMCT dipole coil has been developed at Fermilab to demonstrate the SM concept including coil design, fabrication technology and performance.

US-MDP Task: Nb_3Sn SMCT R&D next steps

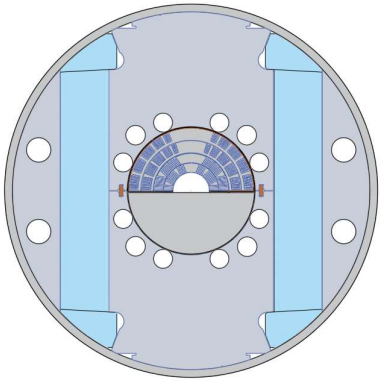


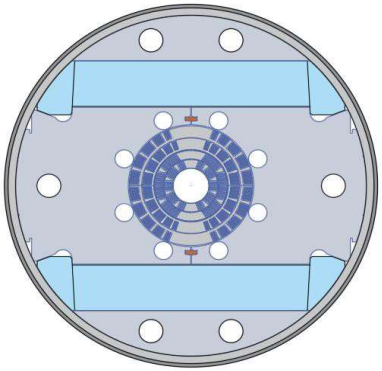
ID=123 mm, B_{des}~11 T



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

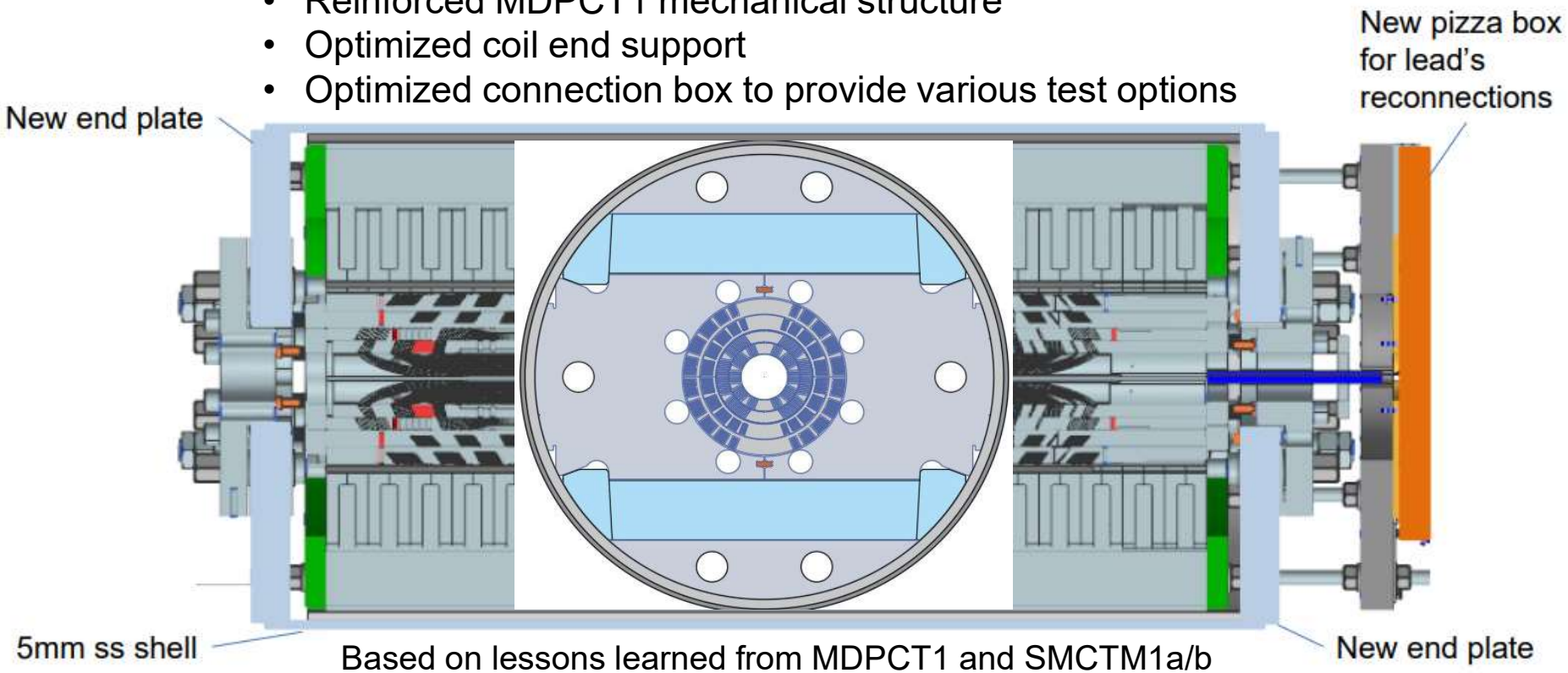
Milestone #	Description	Target
Al-M1a	Development and test of stress management concept using a 2-layer small-aperture and 4-layer small-aperture coils and dipole mirror structure. **Completed**	Jun-23 => Feb 24
Al-M2a	Development, fabrication and test of stress management concept in a 2-layer 120-mm dipole with the field	Jun-24
Al-M3a	Assembly and test of stress management concept in a 4-layer 60-mm 17 T dipole with stress management. **Modified**	Sep-24
Al-M2a +Al-M3a	Development of the SMCT coil technology and test of stress management concept in a 2-layer 120-mm dipole with the field up to 11 T and in a 4-layer 60-mm dipole with the field up to 15 T.	Jan-Jun 2025





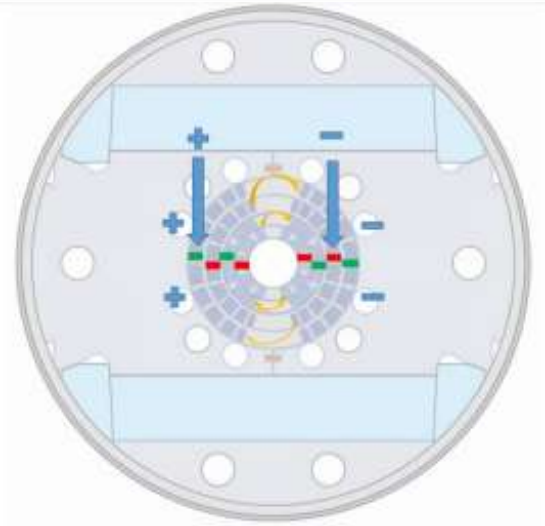
SMCTD1 design concept

- New optimized SMCT2 coil + 2 inner coils from MDPCT1
- Reinforced MDPCT1 mechanical structure
- Optimized coil end support
- Optimized connection box to provide various test options



Based on lessons learned from MDPCT1 and SMCTM1a/b

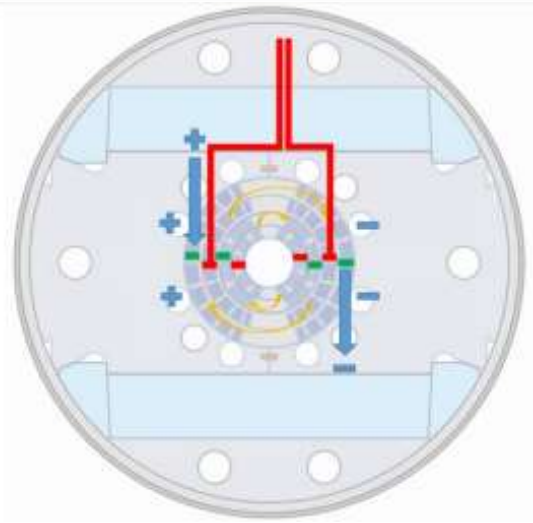
SMCTD1 test configurations and goals



SMCTD1a (SMCT2 coil)

SSL_{nom}	SSL_{deg}
14.0	**12.5**
14.2	12.7

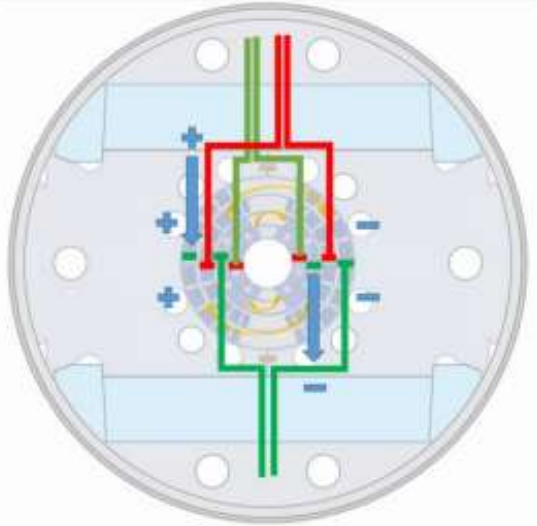
Demonstration of the SMCT coil technology improvement



2L SMCTD1b

B_o, T	B_{max}, T
11.6	**13.3**
12.8	14.8

Demonstration of the SMCT coil technology in 123-mm aperture 2-layer 11+ T dipole



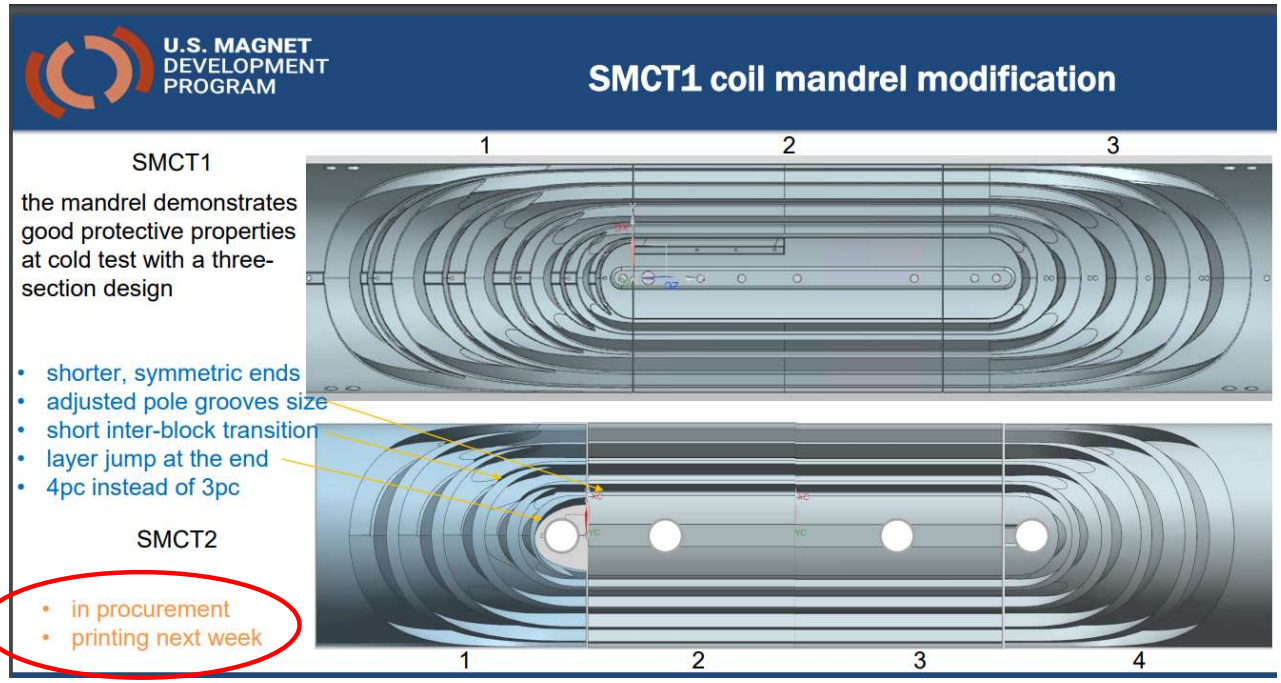
4L SMCTD1c

B_o, T	B_{max}, T
14.2	15.1
17.2	18.4

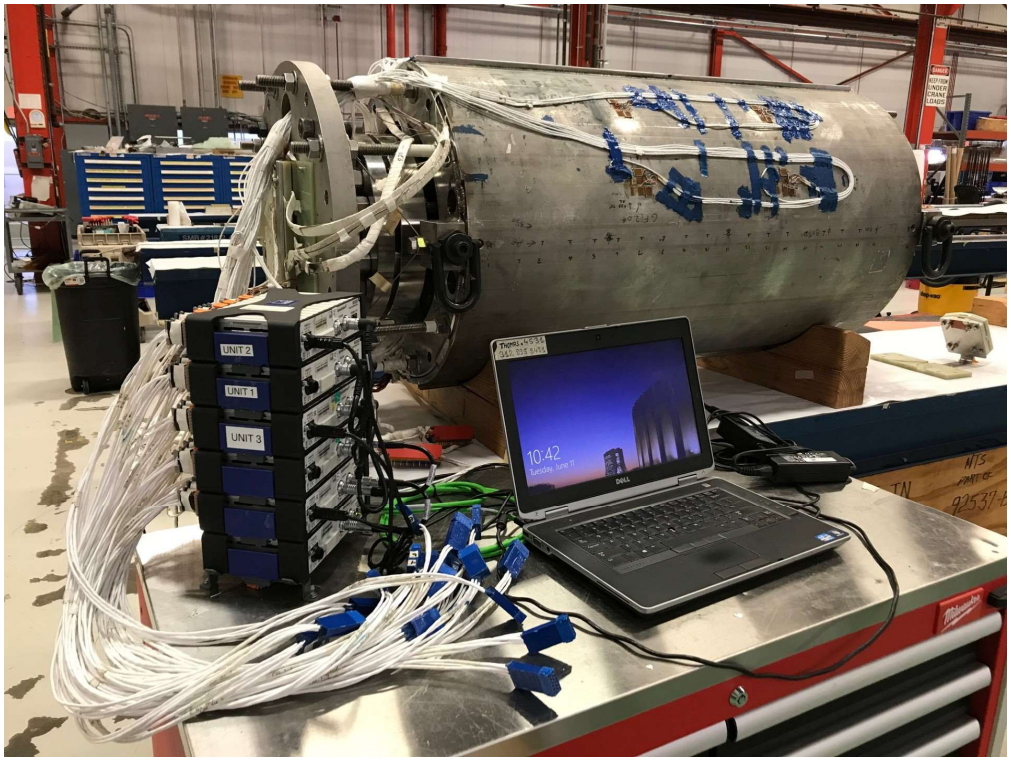
Demonstration of the SMCT coil technology in 60-mm aperture 4-layer 15+ T dipole

SMCT2 coil status

- Mandrel
  - 3D printing contract finalized in early June
  - part delivery - end of July
  - part measurements and post-processing – August
- Nb_3Sn cable – available
- Nb-Ti cable for leads - ?
- Coil ground insulation design and fabrication – July-Aug
- 2 new IL coils from MDPCT1 are available –
  - coil instrumentation – Oct-Nov



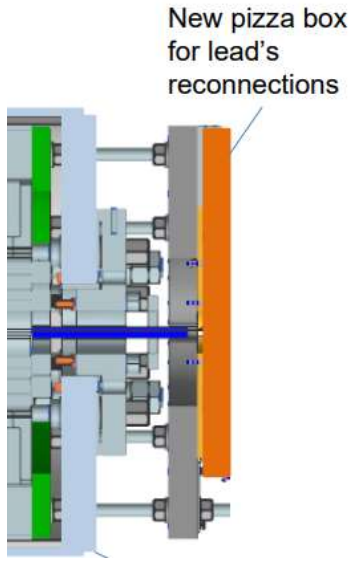
SMCTD1 structure



Cold mass is in IB3

Work in progress

- structure mechanical measurements
- strain gauge “0” reading
- instrumentation check out



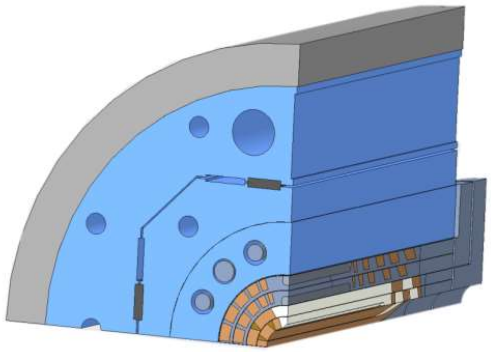
Next steps

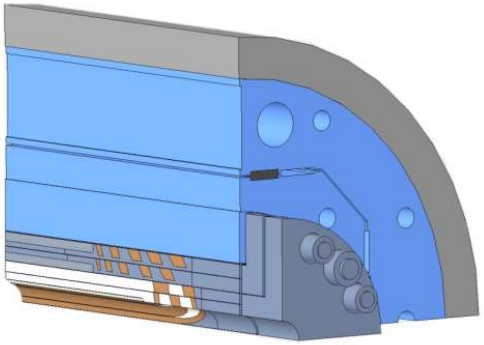
- Structure disassembly – June-July
- Additional skin design and procurement – Oct-Nov
- End support upgrade
  - 3D model and analysis – June-Aug
  - Design and procurement – Sept-Dec
- New connection (“pizza”) box – Oct-Nov

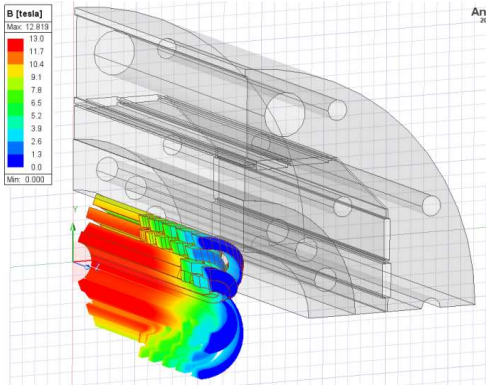
U.S. MAGNET DEVELOPMENT PROGRAM

3D Mechanical models and analysis (FNAL/LBNL)

3D model with 4-layer coil in Utility structure



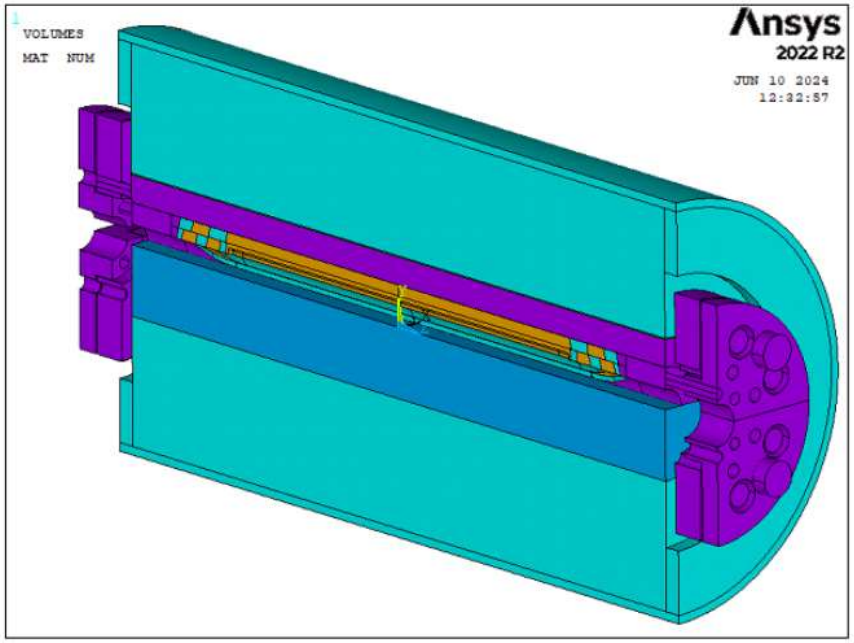




Goal – investigate SMCT coil preload in the MDP Utility structure

- magnetic model in Maxwell is operational
- next step is to set-up the mechanical analysis in Workbench

3D model with 4-layer coil in SMCTM/D structure



Goal – understand SMCTM1 end performance and optimize/design SMCTD1 end support structure

FY24-25: SMCT R&D Plan and Schedule

Task	FY24												FY25											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
SMCTM1b																								
test	VMTF			x	x																			
SMCTD1																								
design										x	x	x	x											
procurement					x	x	x	x	x	x														
coil fabrication					M-PP	W	R	Pot-In			x	x	x	x										
structure upgrade										x	x	x	x	x	x									
magnet assembly									IB3						x	x								
test									WS			VMTF		VMTF			x-a	x	x-b	x	x-c			

Original schedule – October 11, 2023
Updated schedule – June 12, 2024

Task schedule extension to FY25

U.S. MAGNET DEVELOPMENT PROGRAM

SMCTM1a/b result analysis and presentation

IPAC'2024:

DEVELOPMENT AND TEST OF A LARGE-APERTURE Nb_3Sn COS-THETA DIPOLE COIL WITH STRESS MANAGEMENT*

IPAC24

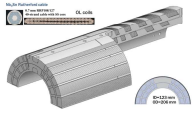
A.V. Zlobin, M. Baldini, I. Novitski, D. Turrioni, E. Barzi, Fermilab, Batavia, IL 60510, USA

FERMILAB-POSTER-24-0040-TD

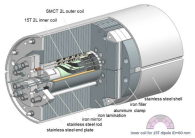
Introduction

An innovative stress-management (SM) concept for cos-theta (CT) coils (SMCT coil concept) has been proposed at Fermilab. A large-aperture two-layer Nb_3Sn SMCT dipole coil was designed and manufactured to validate and test the SM concept including coil design, fabrication technology, and performance. The first large-aperture SMCT coil (SMCT1) was fabricated and assembled with a small-aperture Nb_3Sn coil inside a dipole mirror magnet. SMCT1 coil tests in a dipole mirror structure was performed in two configurations - SMCTM1a with only powered two-layer SMCT1 coil and SMCTM1b with the SMCT coil connected in series with an inner two-layer dipole coil. The test goals are to prove the SMCT coil concept in two-layer and four-layer mirror configurations; demonstrate that the magnet can reach the targeted quench current at the established preload; study magnet training, training memory after thermal cycle, ramp rate and temperature dependences of the magnet quench current; and test the SMCT1 coil quench protection parameters. This paper summarizes the SMCT1 coil design and parameters, the coil main fabrication steps, its assembly in the dipole mirror structure. The results of the SMCTM1a/b mirror test are presented and discussed.

SMCT COIL & MIRROR DESIGNS

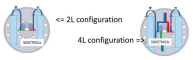


Nb_3Sn cable and SMCT coil parameters.



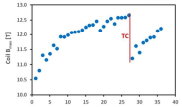
3D view of the 4L dipole mirror magnet.

TEST CONFIGURATIONS

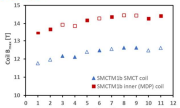


SMCT coil test configurations.

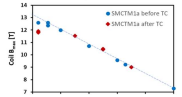
SMCT1 COIL TEST



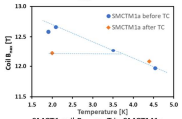
SMCT1 coil B_{max} vs. quench number at 20 A/s and 1.9 K.



SMCT1 and MDP coil B_{max} vs. quench number at 20 A/s in SMCTM1b at 1.9 K.



SMCT1 coil B_{max} vs. dT/dt at 1.9 K.



SMCT1 coil B_{max} vs. T in SMCTM1a.

SMCT1 COIL TEST SUMMARY

SMCTM1a test with TC:
- relatively short training
- poor training memory
- Iq degradation ~9%
- no degradation after TC
- B_{max} at 1.9 K in the SMCT1 coil - 12.7 T

SMCTM1b test:
- current and voltage spikes
- B_{max} in the SMCT1/inner coils - 12.6/14.5 T
- performance limitation by the inner coil

CONCLUSION

The first large-aperture Nb3Sn SMCT1 dipole coil was designed and built at Fermilab to validate and study the SM coil concept. The SMCT1 coil was tested in two dipole mirror configurations. In the first test, after a relatively short training, the SMCTM1a mirror magnet with the SMCT1 coil powered individually, has reached a B_{max} in the coil of 12.7 T at 1.9 K and 12.0 T at 4.5 K which corresponds to ~90% of its SSL. After TC the magnet re-training started at 11.2 T showing some loss of its training memory. However, no con-ductor degradation was found after TC. The possible causes of magnet re-training are being studied and effort will be made to improve the situation in the next coils. In the four-layer SMCTM1b configuration, the B_{max} reached in the SMCT1 coil at 1.9 K was 12.6 T at the B_{max} in the inner MDP coils of 14.5 T. The SMCTM1b magnet performance was limited by the inner coil. Successful demonstration of SMCT coil shows that this design approach open possibilities of large-aperture high-field dipole and quadrupole magnets for Muon Collider and other applications such as 2nd IR for EIC.

*Work supported by Fermi Research Alliance, LLC, under contract No. DE-AC02-07CH11359 with the U.S. DOE and by Jefferson Science Associates, LLC under contract No. DE-AC05-06OR23177

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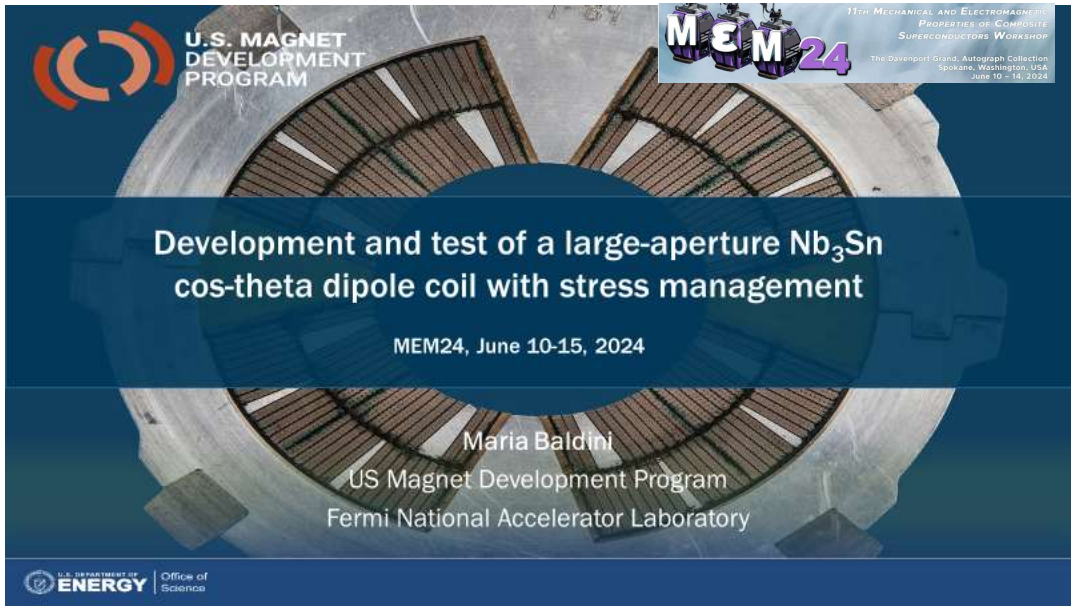
11th Mechanical and Electromagnetic Properties of Composite Superconductors Workshop - MEM'2024:



ASC'2024:

- A.V. Zlobin et al., "Test of a 4-layer Nb_3Sn cos-theta dipole coil with stress management," invited talk