U.S. MAGNET DEVELOPMENT PROGRAM

SMCT Magnet Status and Next Steps

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U.S. MDP Collaboration Meeting

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U.S. DEPARTMENT OF ENERGY | Office of Science

Content

- Nb_3Sn Stress-Managed Cos-Theta (SMCT) Magnets goals and milestones
- SMCT design concept
- SMCT coil and mechanical structure analysis and improvement
- SMCT coil and magnet development status and next steps
- 2L/4L Mirror assembly and test plan (MDP milestone)
- Summary

Nb_3Sn SMCT Magnets Goals and Milestones

The SMCT R&D goals are

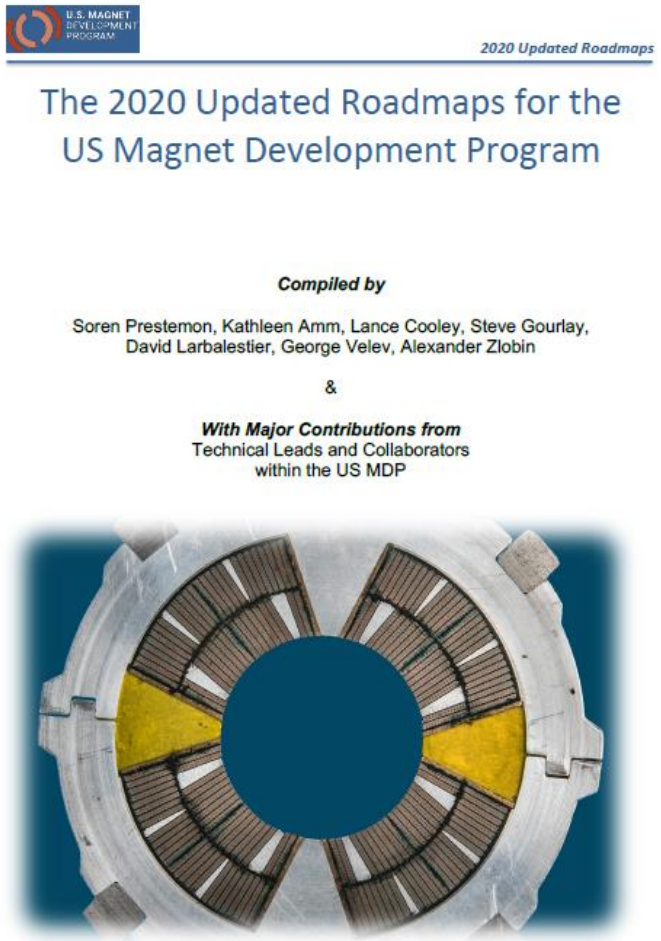
a) to develop and demonstrate a new approach to manage the radial and azimuthal stresses in brittle cos-theta coils, through the study and reduction of magnet training;

b) to 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;

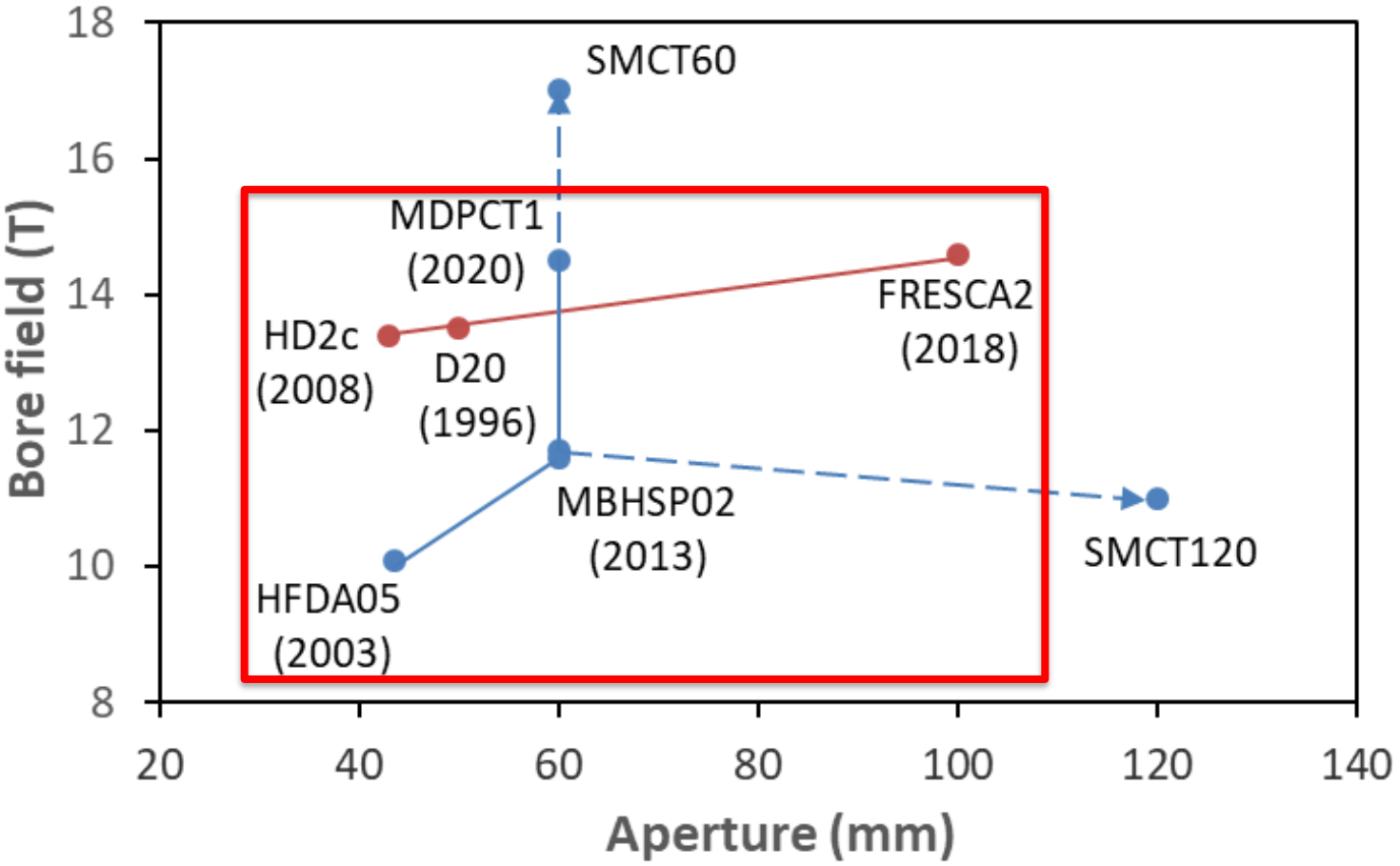
c) to demonstrate up to 17 T at 1.9 K with a 60-mm aperture in a four-layer Nb3Sn dipole magnet with stress-managed outer coils.

Table 2. Milestones for the Stress-Managed Cosine-Theta (SMCT) effort within the Nb_3Sn area of the MDP.

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



SMCT Task Role in MDP and HEP

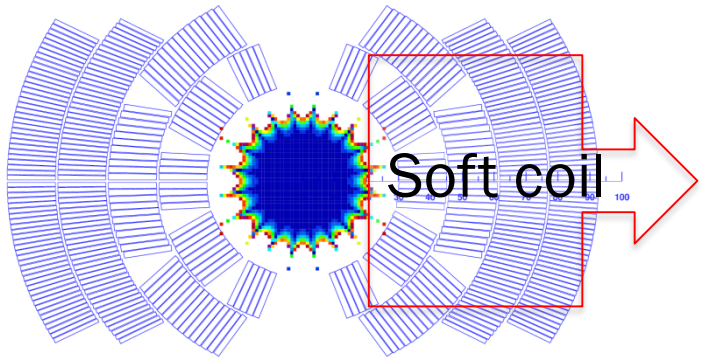


SMCT Dipoles is a key MDP task

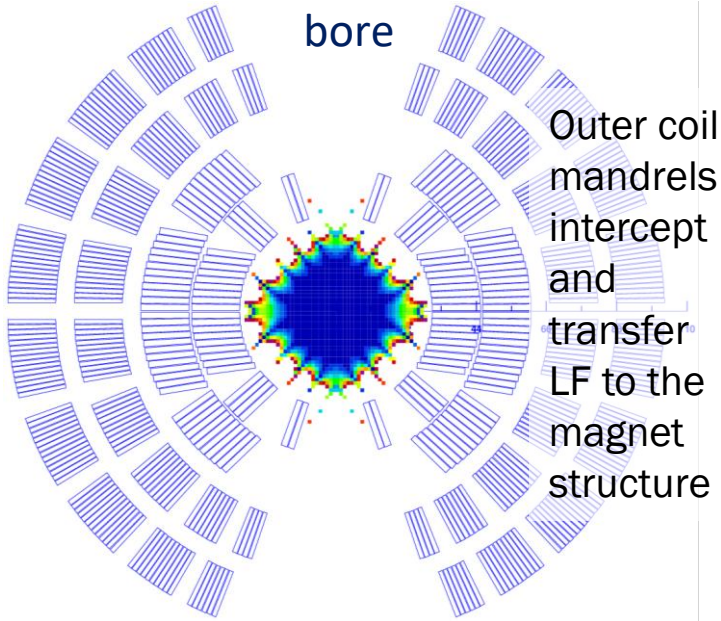
- *innovative* and *challenging* magnet *designs* and technology
- magnet *parameters go beyond* the state-of-the-art
- *complementary task* to CCT Dipoles
- *contributes* to Area II HTS Magnets tasks (both Bi2212 and REBCO magnets)
- *provide input to* Hybrid Magnet task on magnet design and technology
- *address needs* of present and future *HEP accelerators*

Stress Management Concept for Cos-Theta Coil

B_{des}~15 T
60 mm
bore

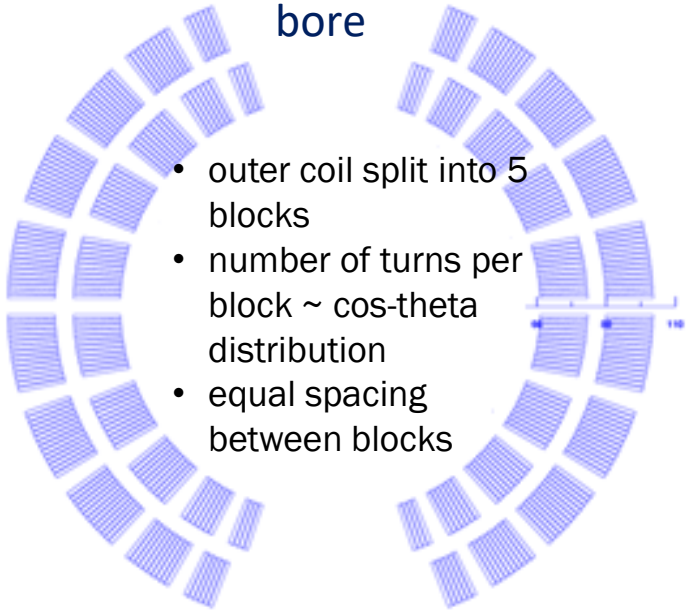


B_{des}~17 T
60 mm
bore



Outer coil mandrels intercept and transfer LF to the magnet structure

B_{des}~11 T
120 mm
bore



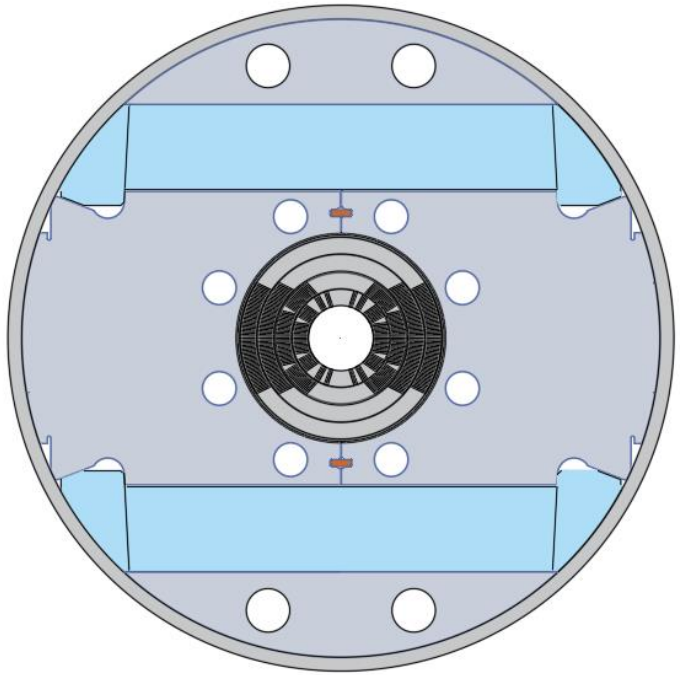
- outer coil split into 5 blocks
- number of turns per block ~ cos-theta distribution
- equal spacing between blocks

- **SMCT concept was proposed in 2018 based on understanding of SM issues in 15 T dipole L3-L4**
- **MDPCT1b tests confirmed those concerns**

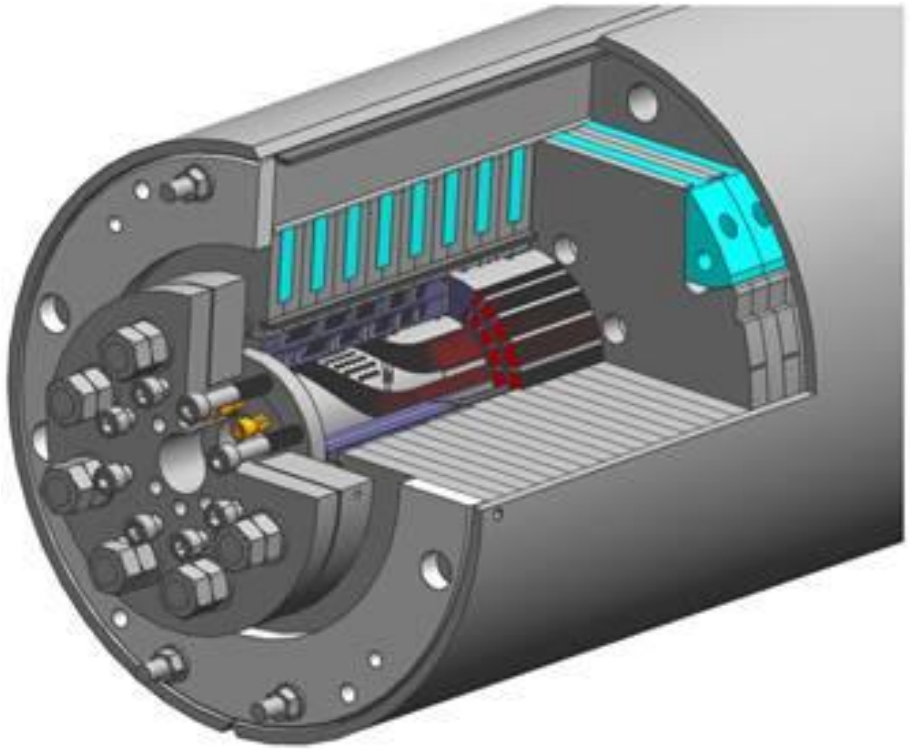
V.V. Kashikhin, I. Novitski, A.V. Zlobin, "Design studies and optimization of a high-field dipole for a future Very High Energy pp Collider," in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, p.3597.

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

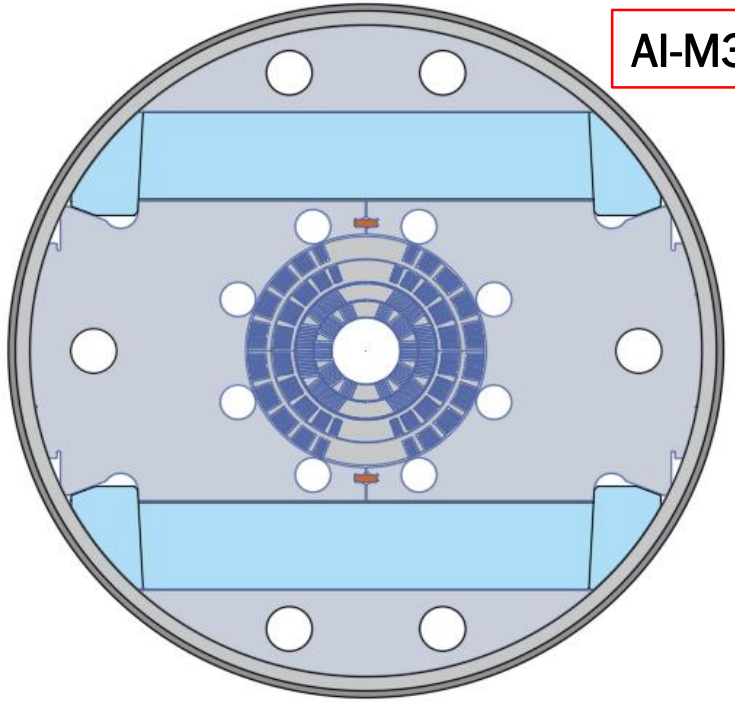
MDPCT Mechanical Structure Modification for VMTF



15T MDPCT1 structure



- Iron ID=210 mm (Modified Yoke Lams)
- Cold mass OD=630 mm
- 19 mm thick stainless-steel shell
- AL or Stainless-Steel clamps
- 2 end plates per end/14 rods



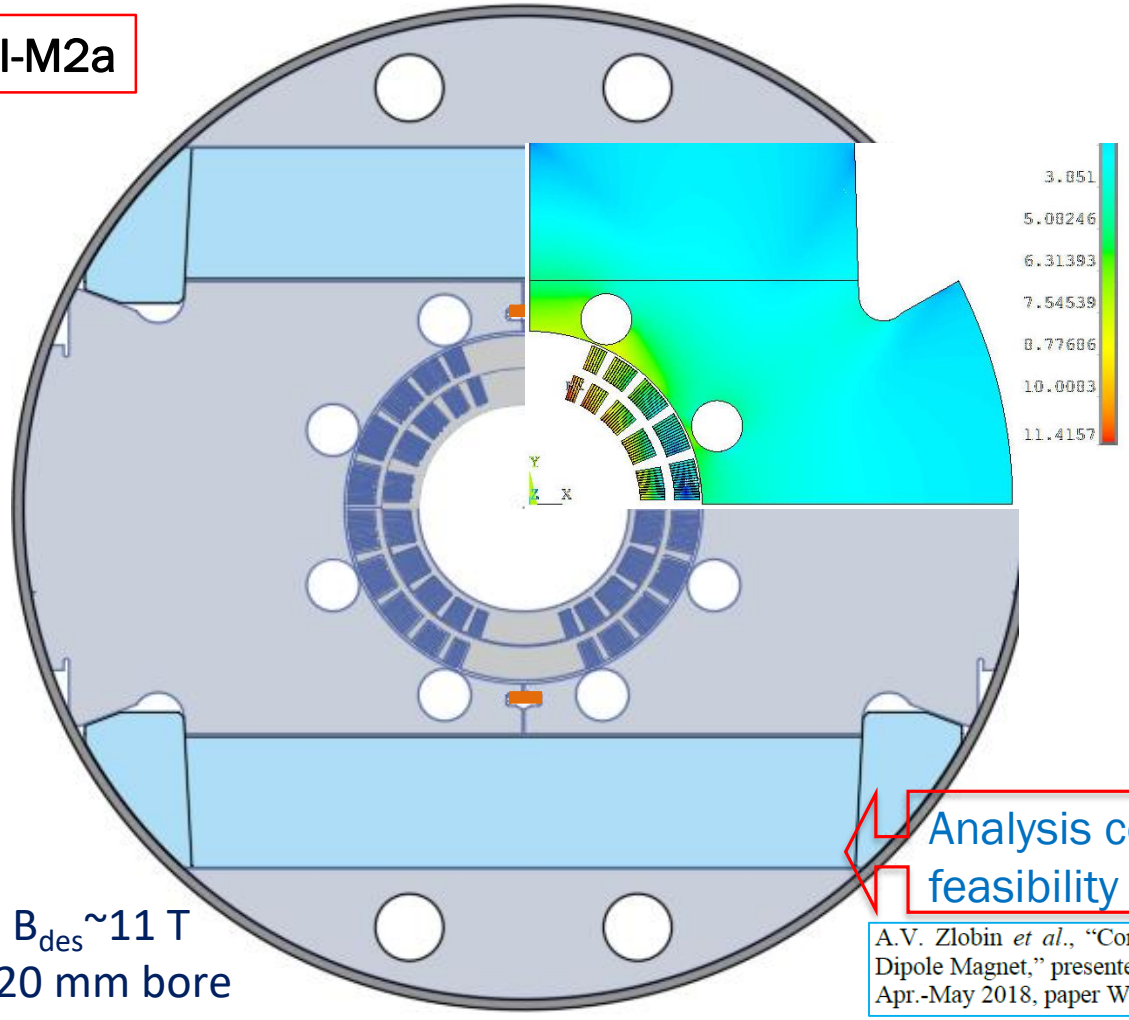
Al-M3a

17T SMCT Dipole structure

Magnetic and Mechanical Design Concepts for Dipoles

15T Dipole Magnet structure w MYL

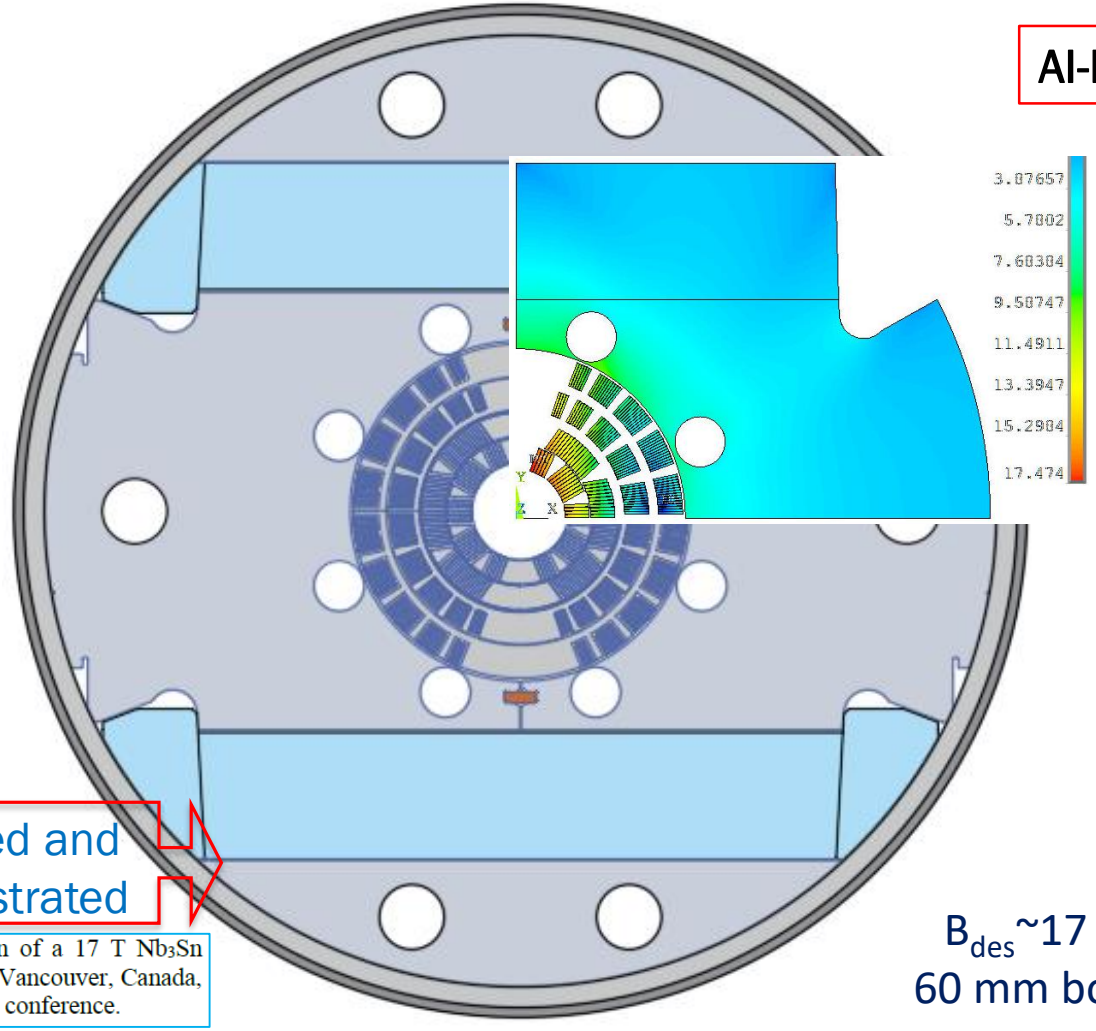
Al-M2a



B_{des}~11 T
120 mm bore

17T Dipole Magnet structure

Al-M3a



B_{des}~17 T
60 mm bore

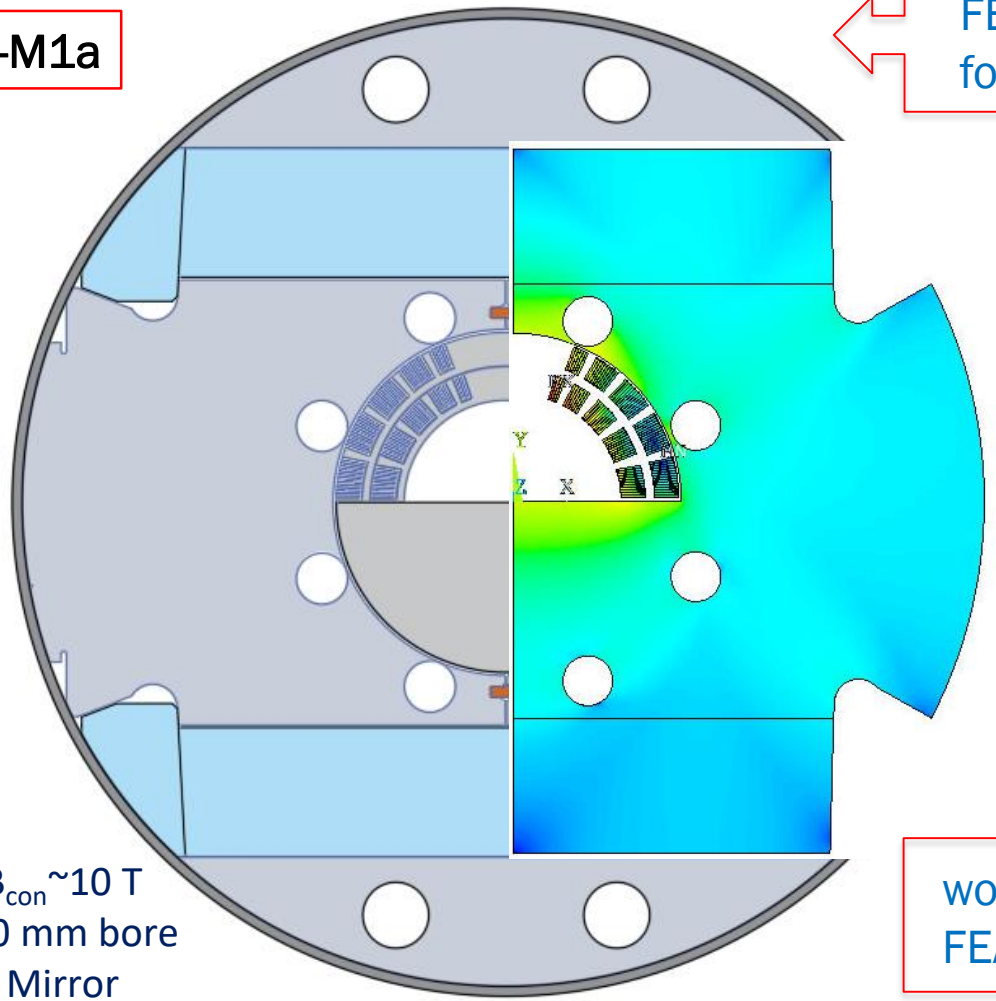
Analysis completed and feasibility demonstrated

A.V. Zlobin *et al.*, "Conceptual Design of a 17 T Nb_3Sn Dipole Magnet," presented at IPAC'18, Vancouver, Canada, Apr.-May 2018, paper WEPML027, this conference.

Magnetic and Mechanical Design Concepts for Mirrors

15T Dipole Magnet structure w MYL

Al-M1a



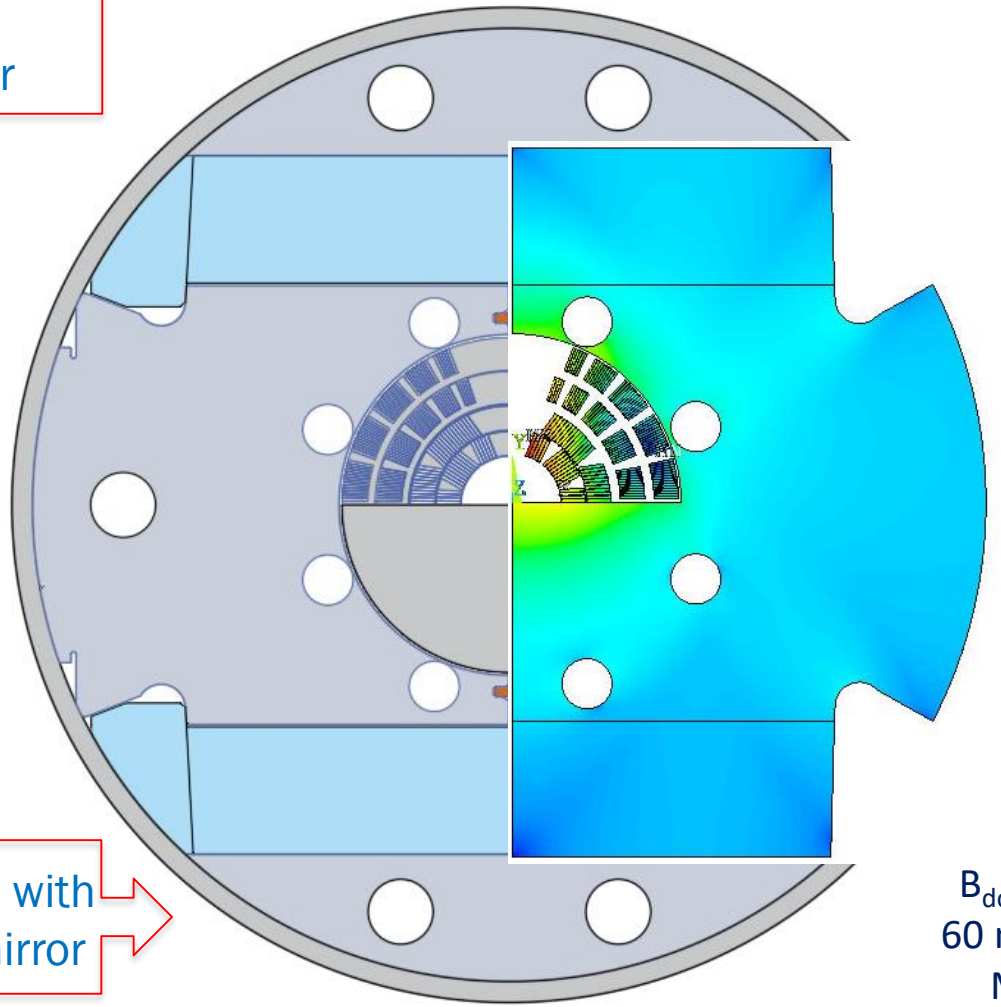
B_{con}~10 T
120 mm bore
Mirror

FEA completed
for the 2L mirror

work in progress with
FEA for the 4L mirror

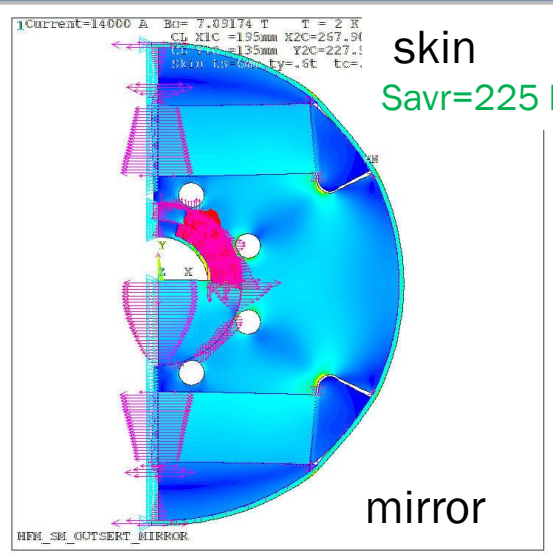
15T Dipole Magnet structure w MYL

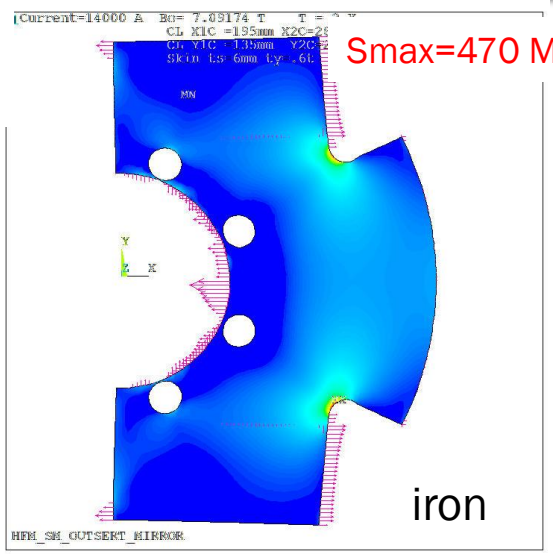
Al-M1a

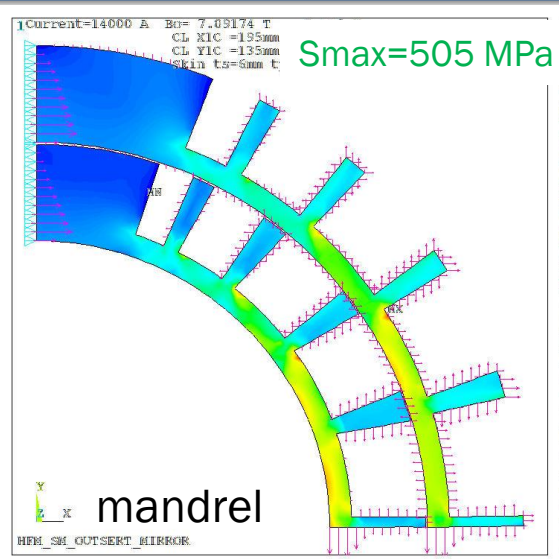


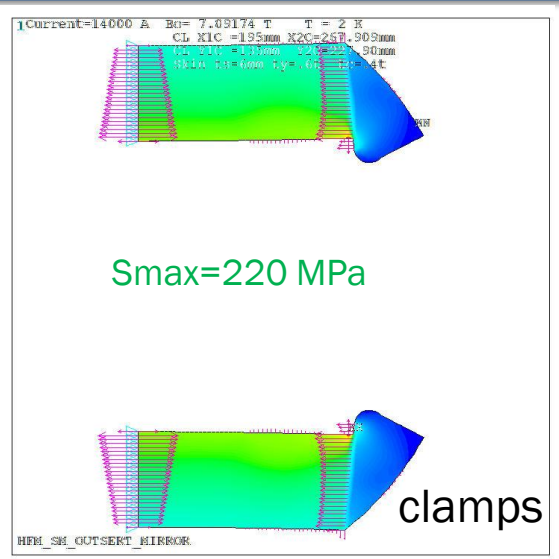
B_{dcon}~14 T
60 mm bore
Mirror

FEA Results for 120-mm Mirror

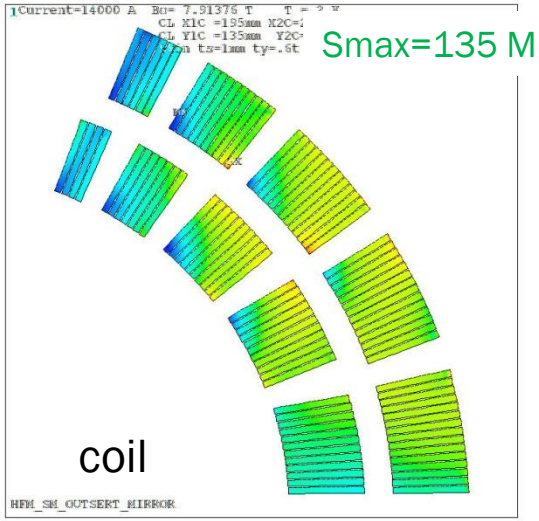


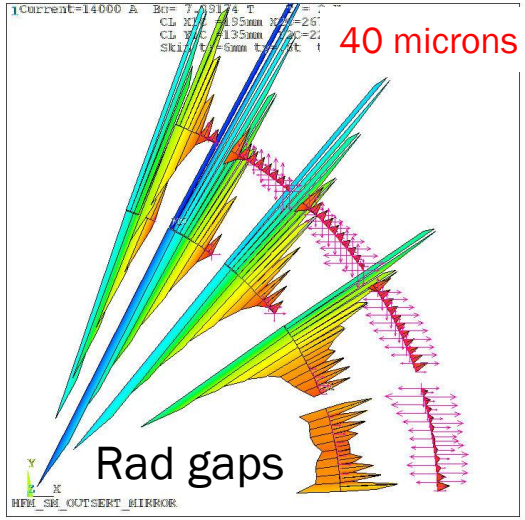


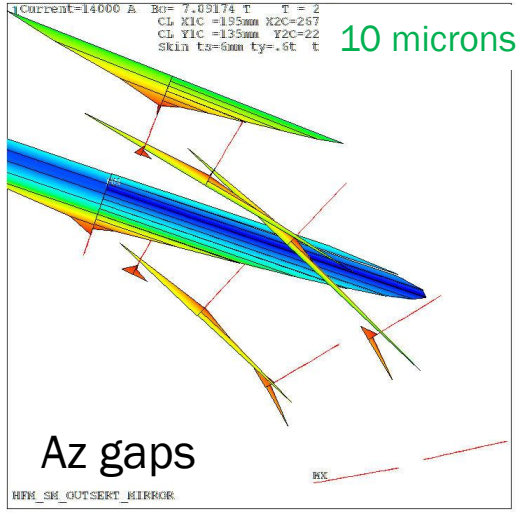




Mirror at:
T=4 K
I=14 kA
B_{cond}=12.4 T



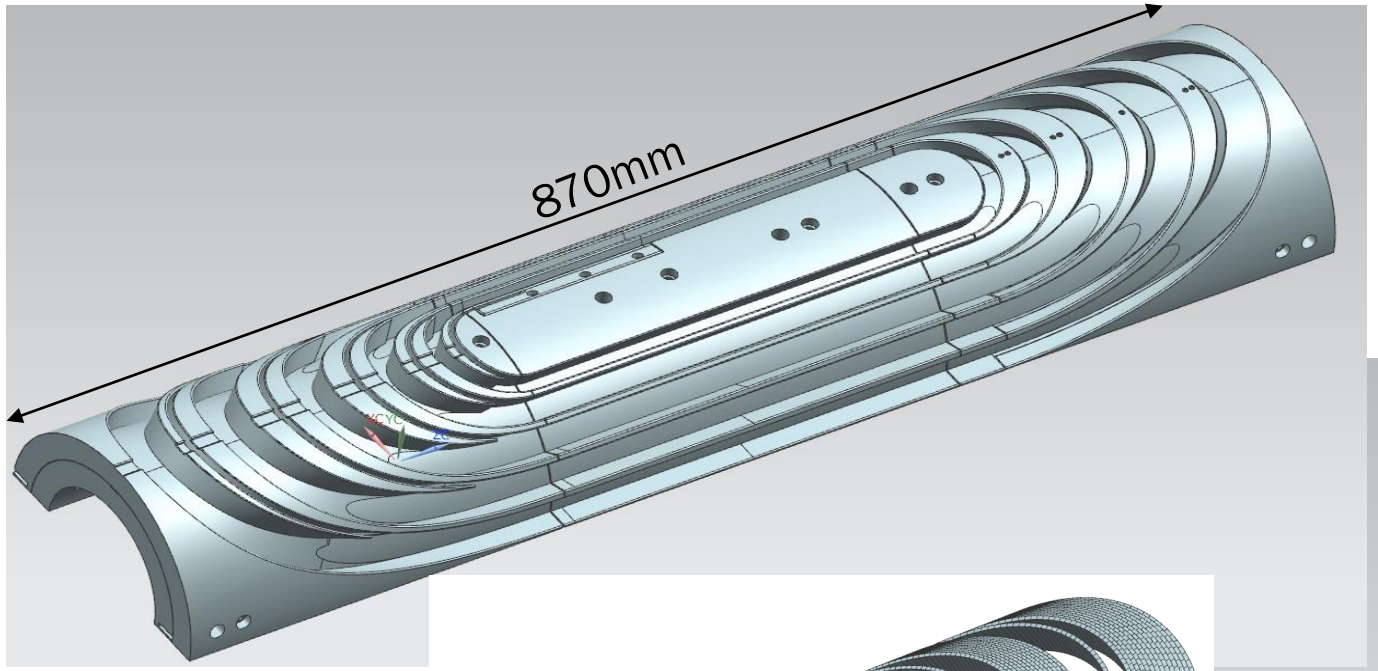


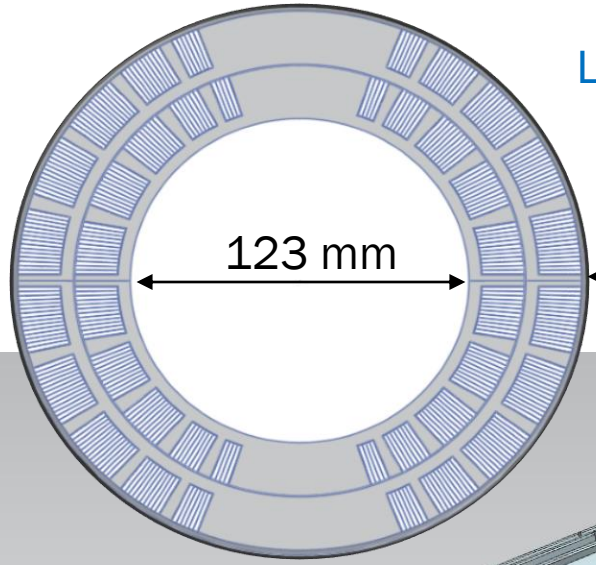


SMCT Coil Development Status

- coil design completed in October 2018 – (FY19)
- plastic model completed in January 2019 – (FY19)
- coil reaction/impregnation tooling design and fabrication completed – (FY19-20)
  - vendor search for the coil mandrel parts completed in October 2019 – (FY20)
  - REQ processing completed in December 2020 - (FY21)
  - PO granted in December 2020 - (FY21)
  - mandrels fabrication COMPLETED by GE Additives (Cincinnati site) in February 2021
- cable available from the 11 T dipole program

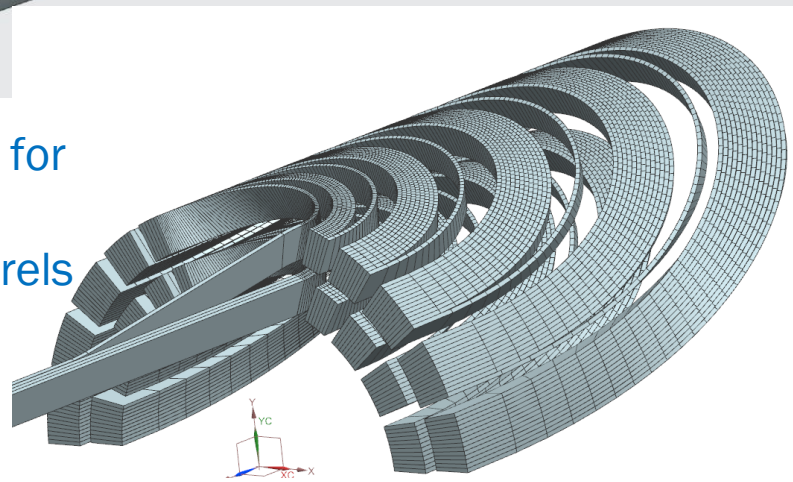
SMCT Coil Design

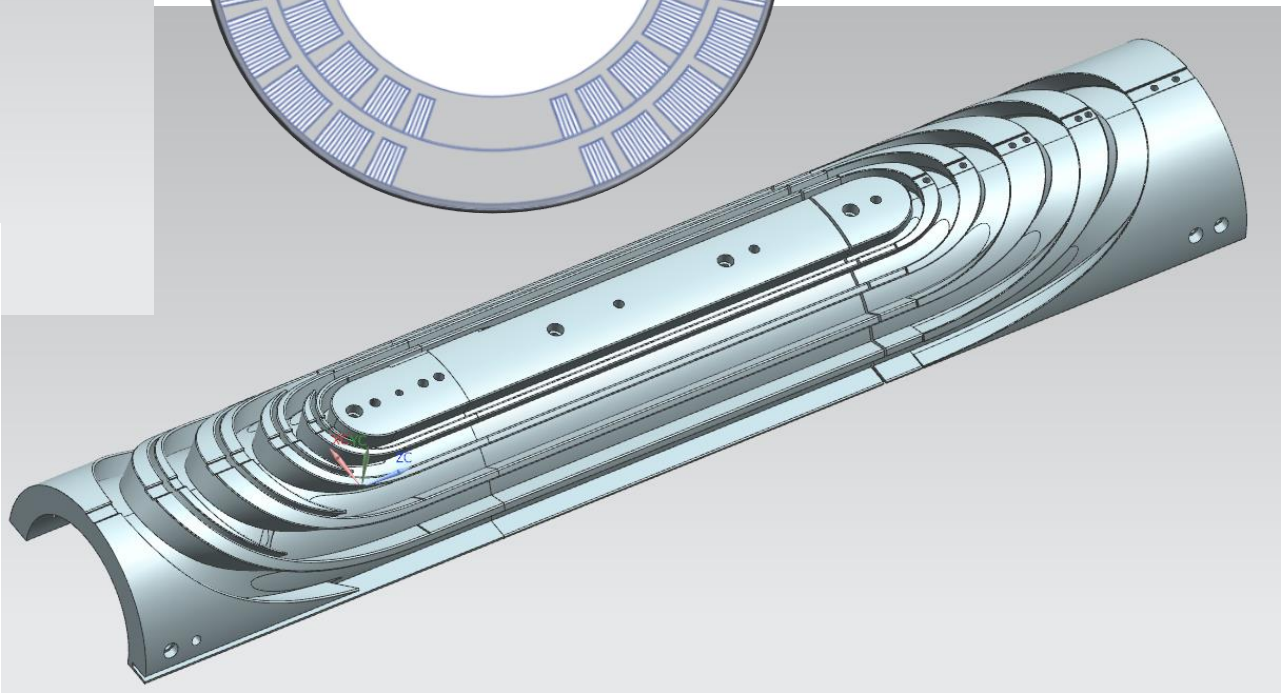




Large aperture dipole

Stress management for whole coil using stainless steel mandrels





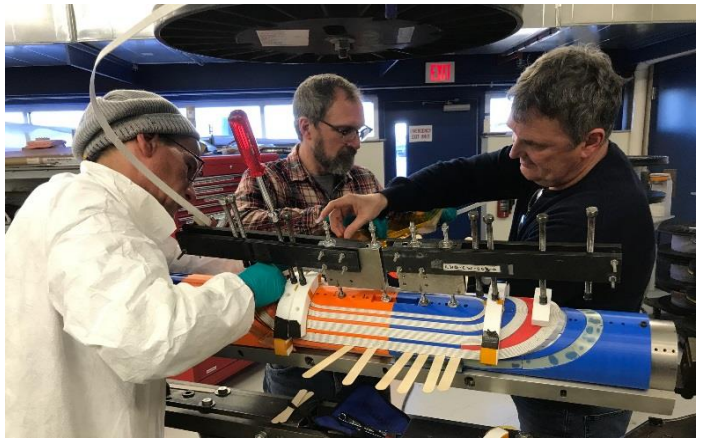
SMCT Coil Design and Technology Demonstration

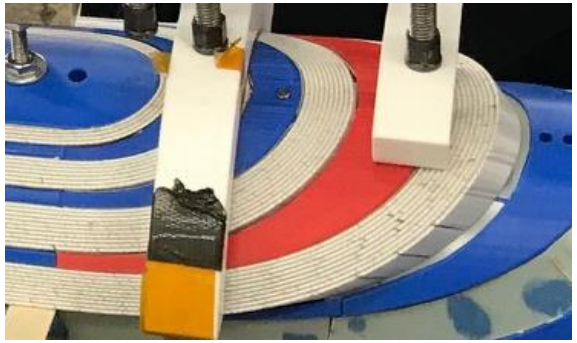
All mandrel plastic parts printed on site

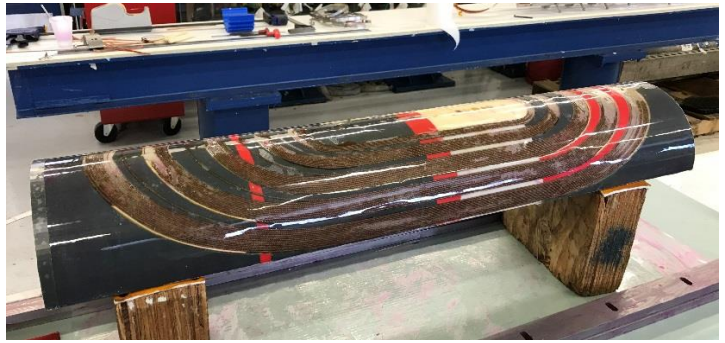
Winding in slots

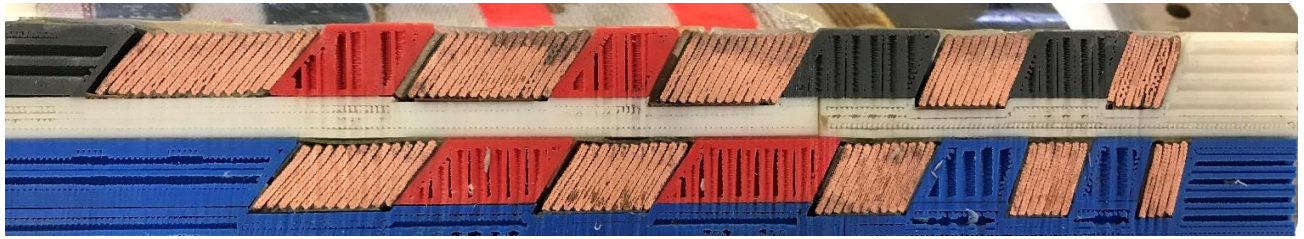
Room for cable expansion during reaction

Simplified reaction and impregnation tooling

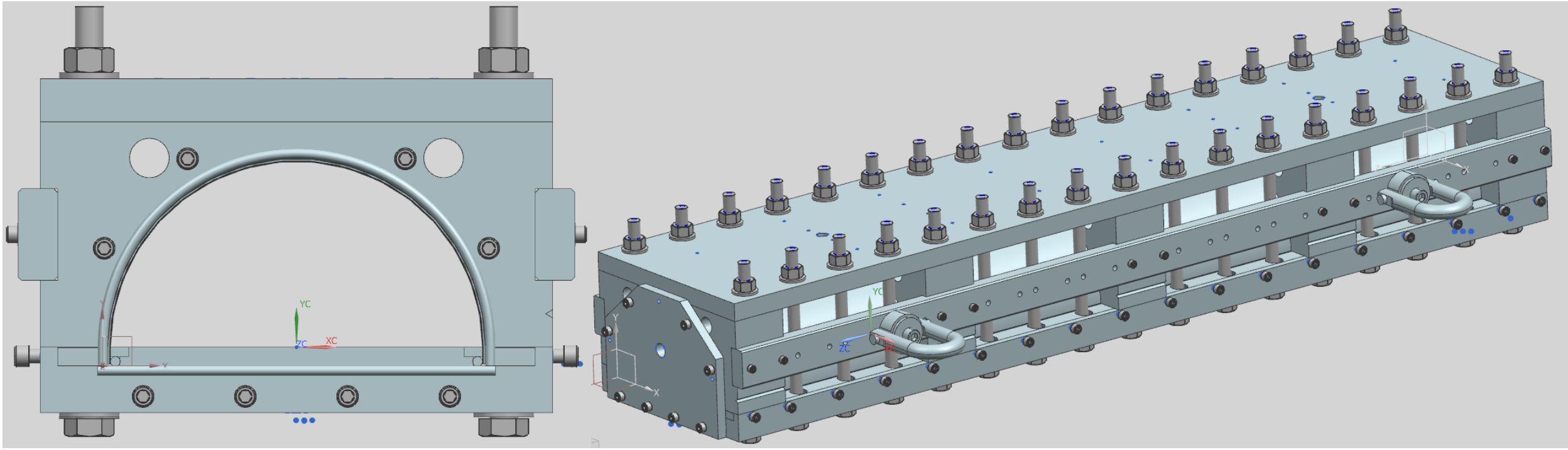








SMCT Coil Reaction and Impregnation Tooling

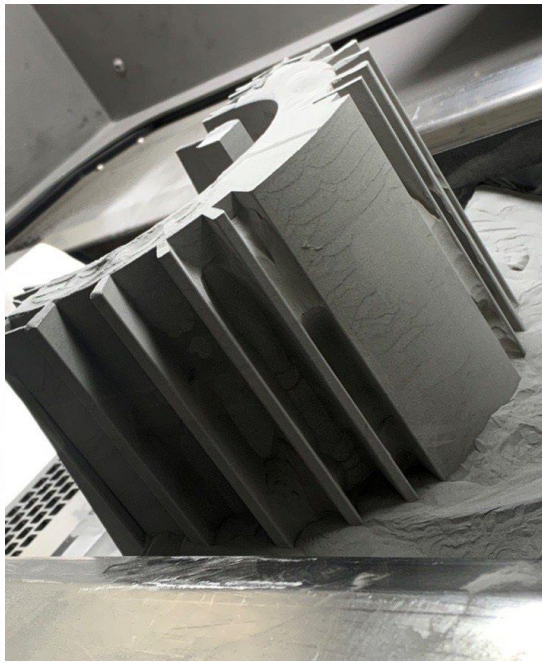
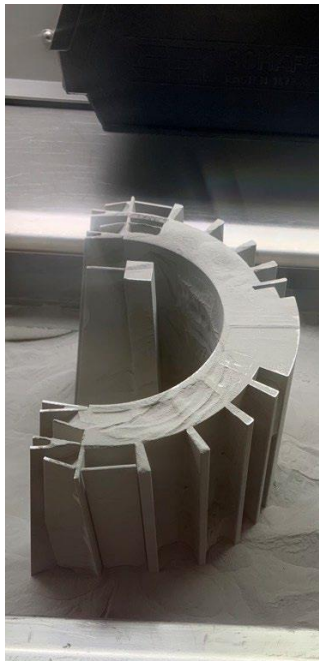
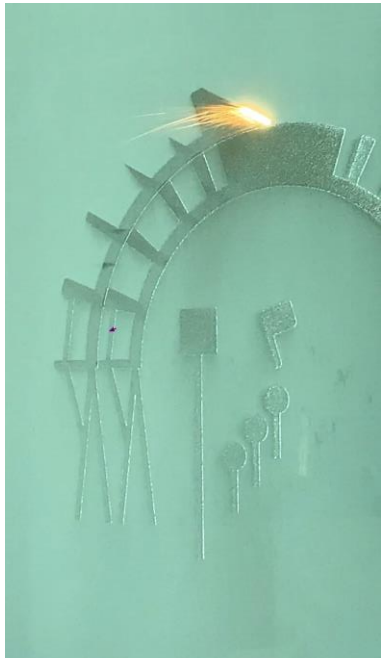


- The MDPCT1 L3/L4 coil tooling for reaction and impregnation have been modified
- The number of blocks and modifications were optimized to reduce cost

SMCT Coil Parts build by GE Additive using Direct Metal Laser Melting (DMLM) technology



Lead End L3-L4 and Return End L4 parts

Straight section L3-L4 parts printing process used 316L stainless steel powder

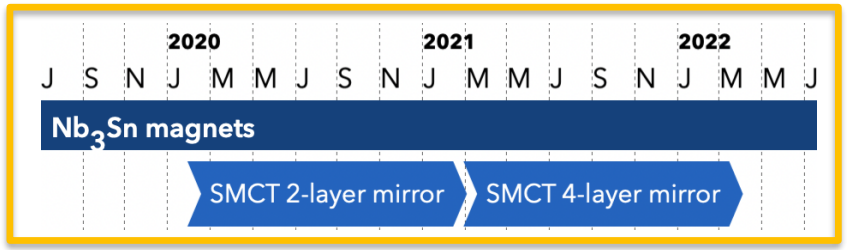
Thanks to Justin Carmichael, Jodi Coghill, Carrie Lawless, Terry Cross, James Hohbein for the big effort and to Joseph Bergeron with entire GE Additive team for the great patience and productive collaboration.

All coil's parts had been delivered to Fermilab site.

SMCT Task - Next Steps

FY21:

- MDPCT1 disassembly and inspection (March-April 2021)
- SMCT coil part inspection and modification (March-April 2021)
- SMCT coil winding/reaction/impregnation/instrumentation (May-July 2021),
- magnet structure design analysis and optimization (March-April 2021)
- mirror block fabrication and structure part modification/inspection/instrumentation (May-July 2021)
- mirror magnet assembly and test preparation (August-September 2021)
  - 4L mirror will be assembled

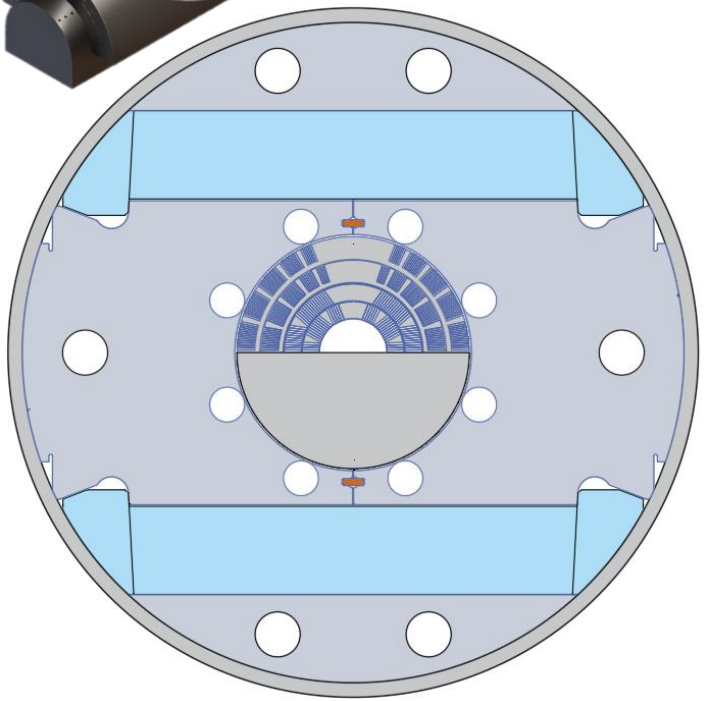


FY22:

- Magnet test (October-December 2021)
  - first, 120-mm SM coil will be connected to power leads and tested
  - next, both 60-mm and 120-mm will be connected in series and tested

SMCT coil after winding

Al-M1a



60 mm bore 4-layers Mirror Magnet

Summary

- SMCT concept R&D is a key part of the updated MDP plan
- SMCT concept is a 15 T Dipole design evolution proposed in 2018 based on understanding of SM issues in L3-L4
- MDPCT1 structure for the SMCT 4L Mirror and 4L Dipole needs to be modified
- SMCT coil parts were designed and verified on the practice coil
- SMCT coil parts were built in the US by GE Additive
- Cable for SMCT coil as well as reaction and impregnation tooling are ready for a coil production
- SMCT coil production expected to start in the later spring and depends on available resources
- 2L/4L Mirror magnet tests in Fall 2021 (milestone March 2022)