U.S. MAGNET DEVELOPMENT PROGRAM

US MDP high-field Nb_3Sn cos-theta dipole magnet with stress management

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EU HFM annual meeting 2023
11/01/2023

Stress/strain management elements in coil designs

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Fermilab in the framework of US-MDP is working on the development and demonstration of Stress Management (SM) concept for accelerator magnets

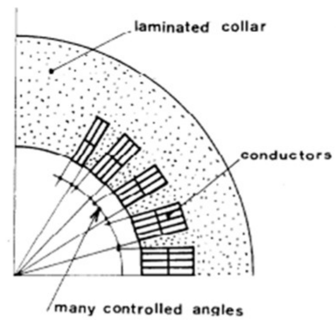
SM concept

- Coil blocks or individual turns are placed in their own compartments inside a strong coil structure
- Lorentz forces in coil blocks are transmitted to the coil structure and magnet external mechanical structure

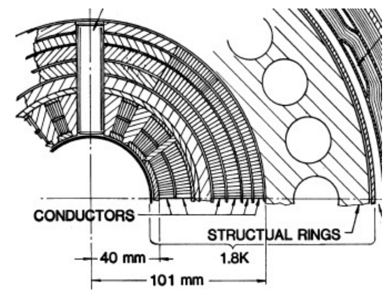
Expected effects

- control of coil geometry deformations => field quality,
- reduction of superconductor I_c degradation => magnet margins,
- improvement of magnet training

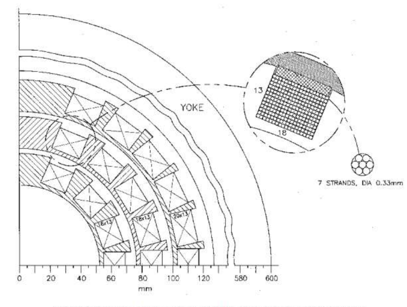
Early designs



A. Patoux, J. Perot
A new accelerator superconducting dipole suitable for high precision field,
IEEE TNS, NS-28, 3, June 1981

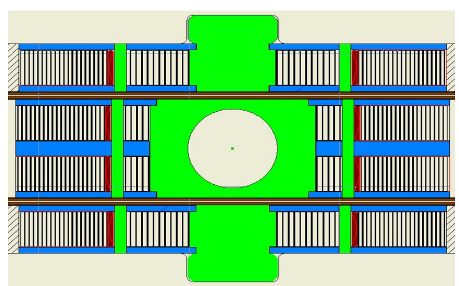


Taylor, C. E.; Meuser, R. B.
Prospects for 10T Accelerator Dipole Magnets, IEEE TNS, 28, 3(2), June1981

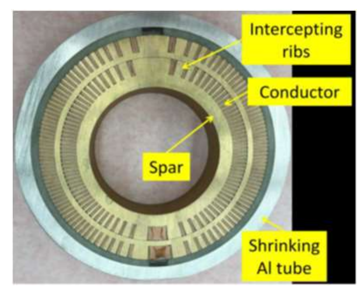


Status of Muon Collider Research and Development and Future Plans
BNL-65623 Fermilab-PUB-98/179 LBNL-41935

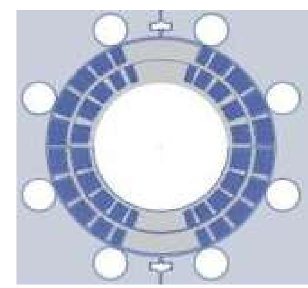
Recent designs



Block-type coil (TAMU)



Canted cos-theta coil (LBNL)



Shell-type coil (FNAL)

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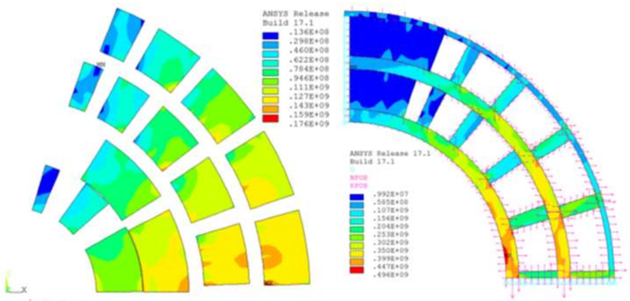
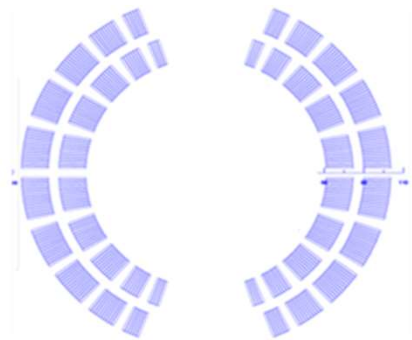
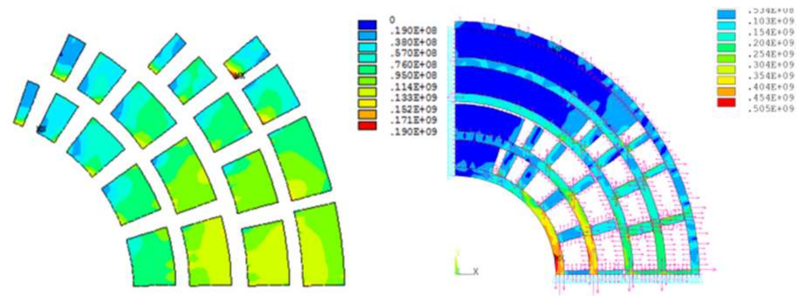
Design studies of SM concept for high-field large-aperture accelerator magnets (IPAC2017, IPAC2018)



Equivalent stress (Pa) in the SM coil and the outer coil structure at the bore field of 16 T.



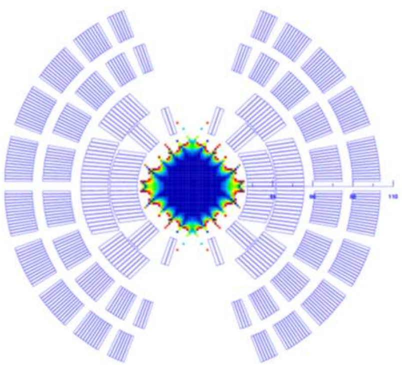
120 mm 11 T

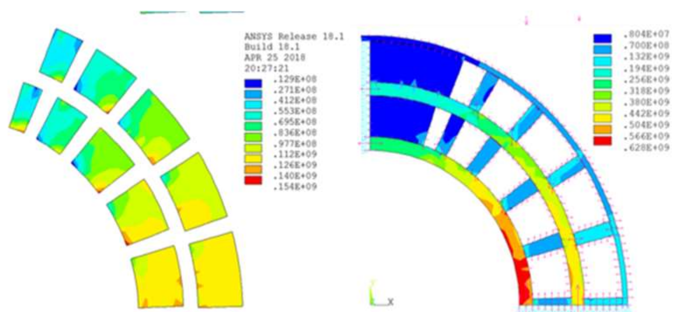


Equivalent stress (Pa) in the SM coil and the outer coil structure at the bore field of 15 T.

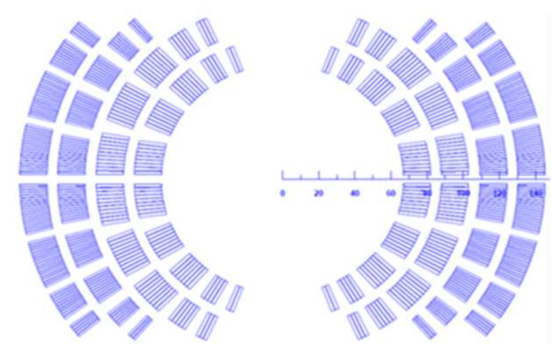
60 mm 16 T

120 mm 15 T





Equivalent stress (Pa) in the SM coil and the outer coil structure at the bore field of 11 T.



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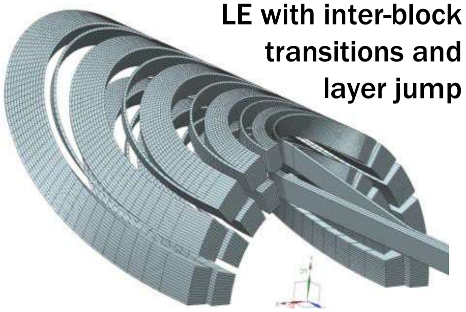
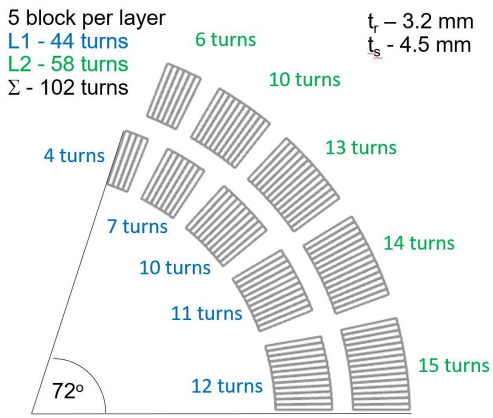
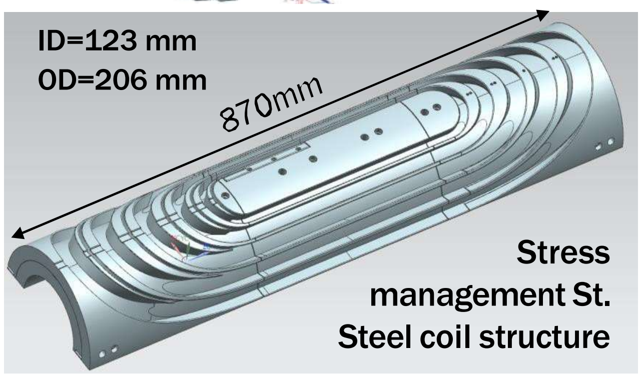
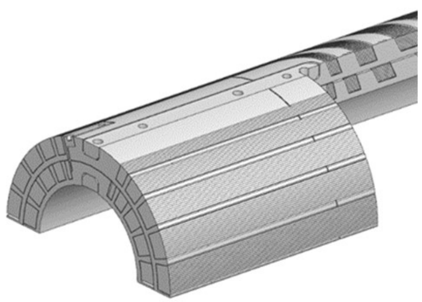
SMCT coil design and technology development

Cable and coil cross-sections

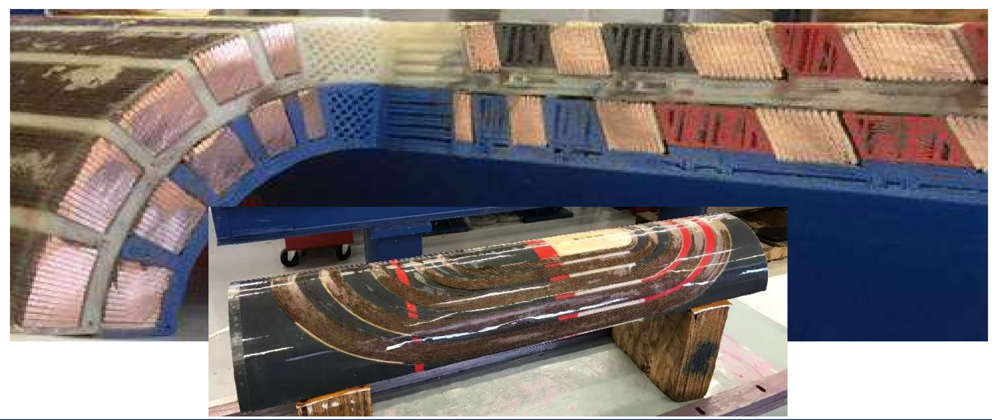








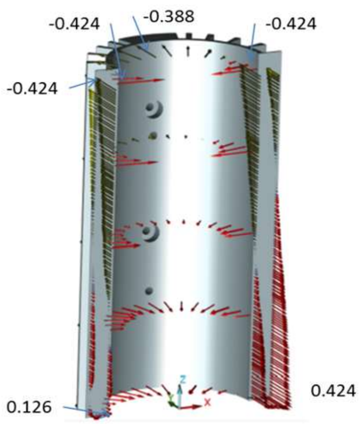
Practice SMCT coil structure-winding- impregnation-QC

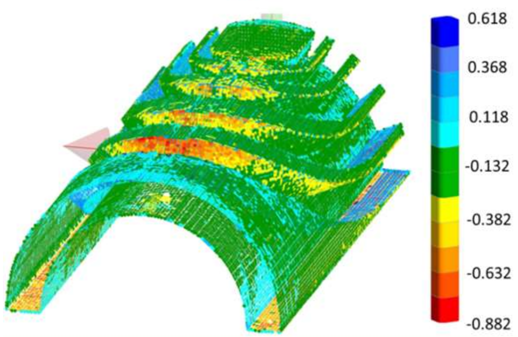


SMCT coil structure fabrication

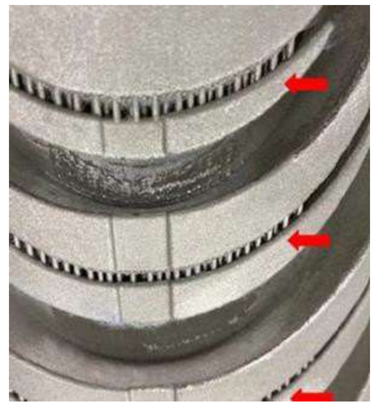
3D printed parts from 316 powder by GE Additive

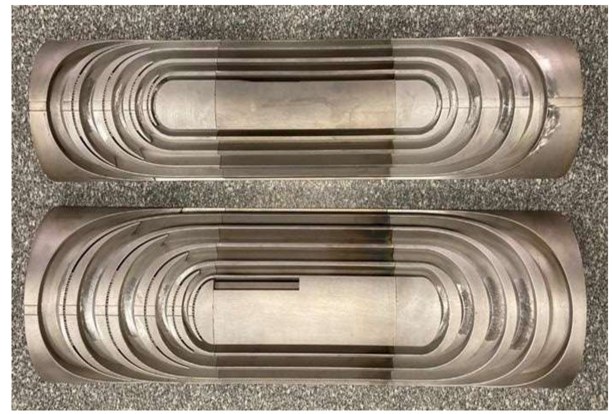
Part QC using CMM and Laser Scanning

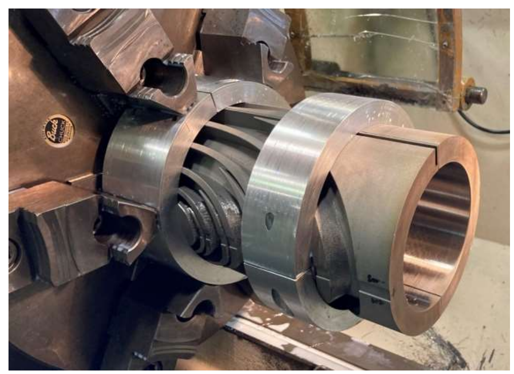




Coil structure post-processing







- wire EDM to remove supporting posts in single channels
- cut ends
- provide uniform ID for ends and central pieces
- add keyway and holes

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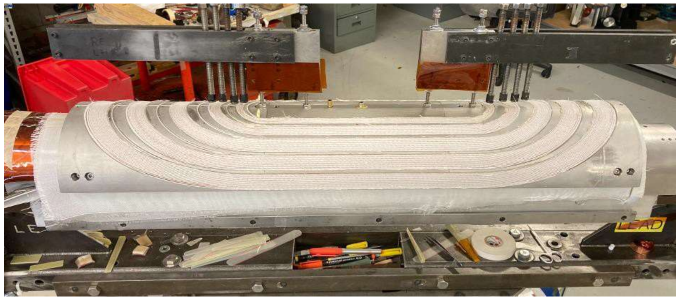
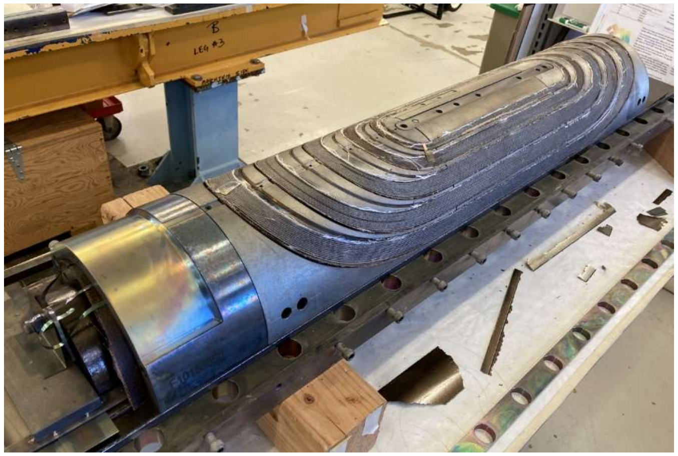
SMCT1 coil fabrication and instrumentation

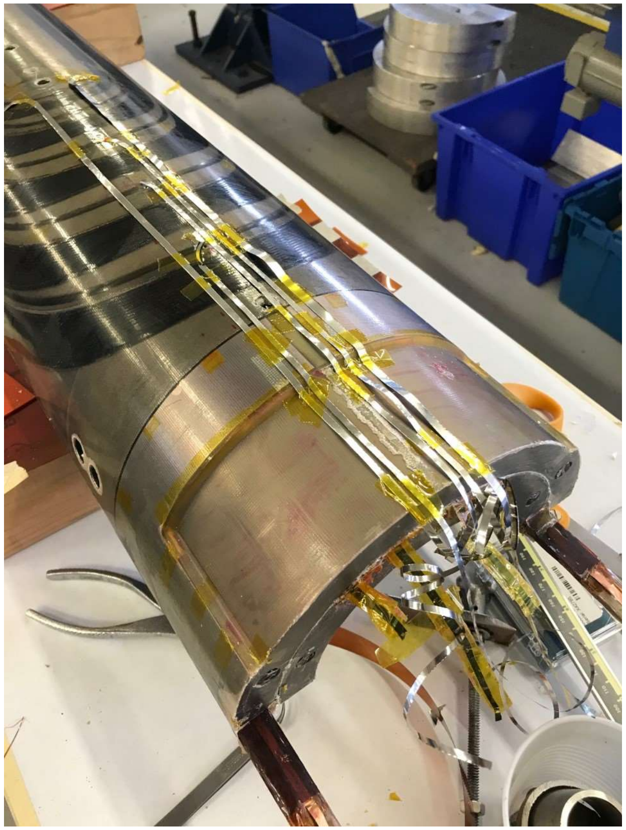


Coil winding



Coil reaction

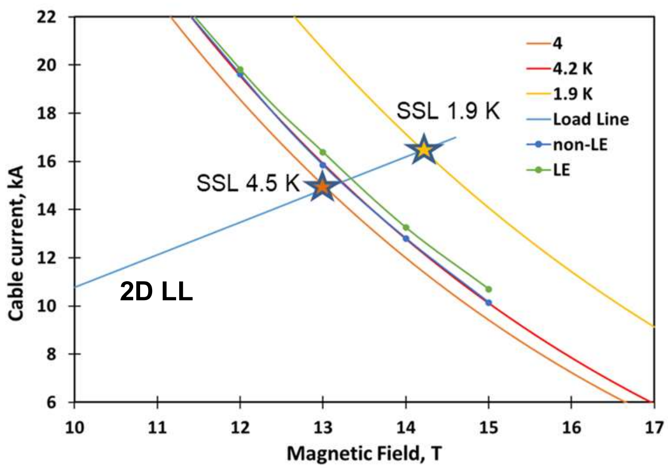
Coil impregnation with epoxy



Coil instrumentation

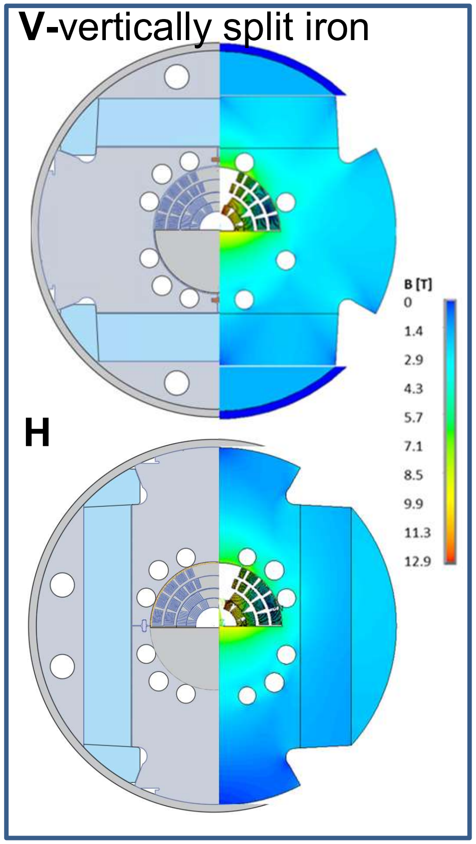
WS test and mechanical analysis

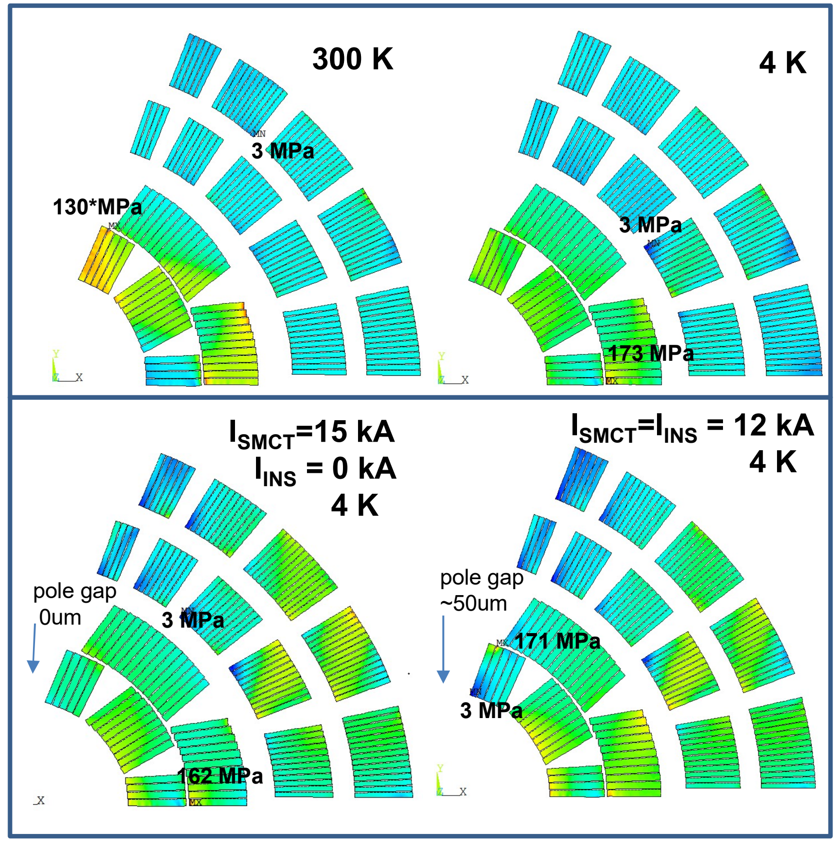
Witness Sample test and SMCTM1a conductor limits



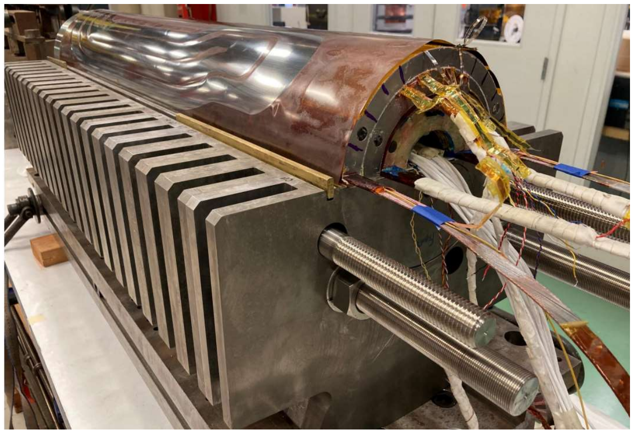
Short sample limits for 2L mirror

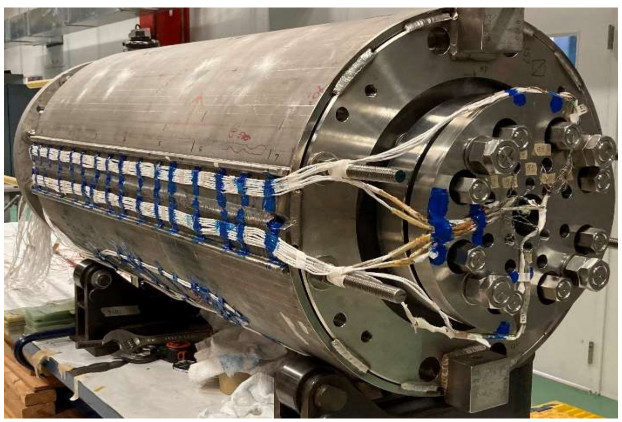
- B_{max}=14.2 T at 16.5 kA at 1.9 K
- B_{max}=13.04 T at 14.89 kA at 4.5 K





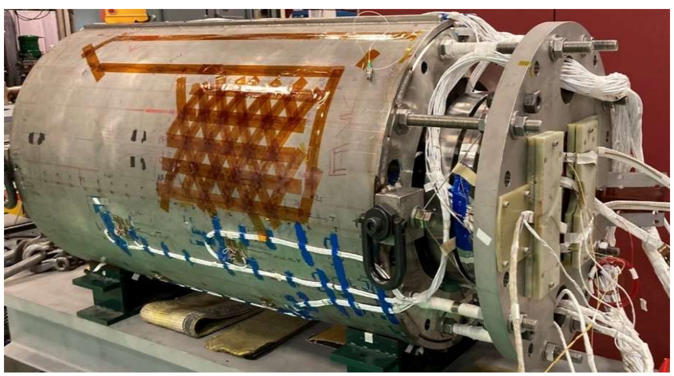
SMCTM1 assembly



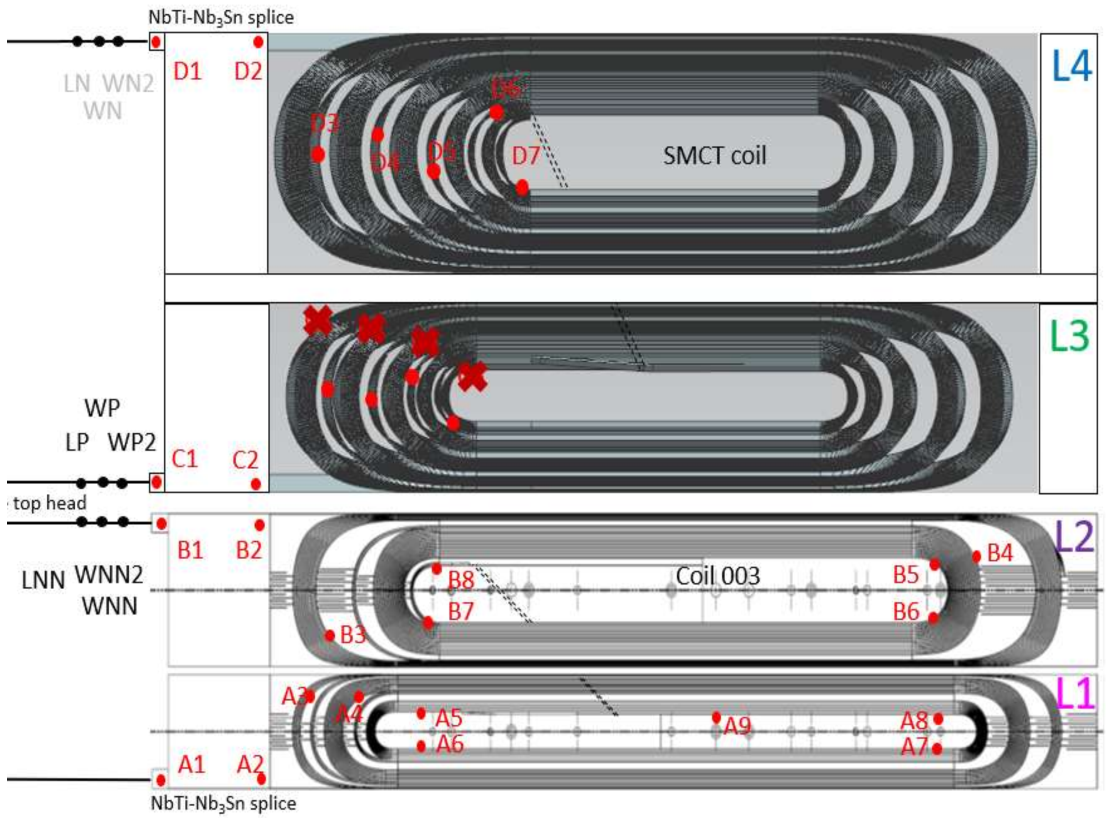


SMCTM1 Instrumentation

Acoustic sensor locations on shell and rods



SGs and a fiber optics grid on the magnet shell



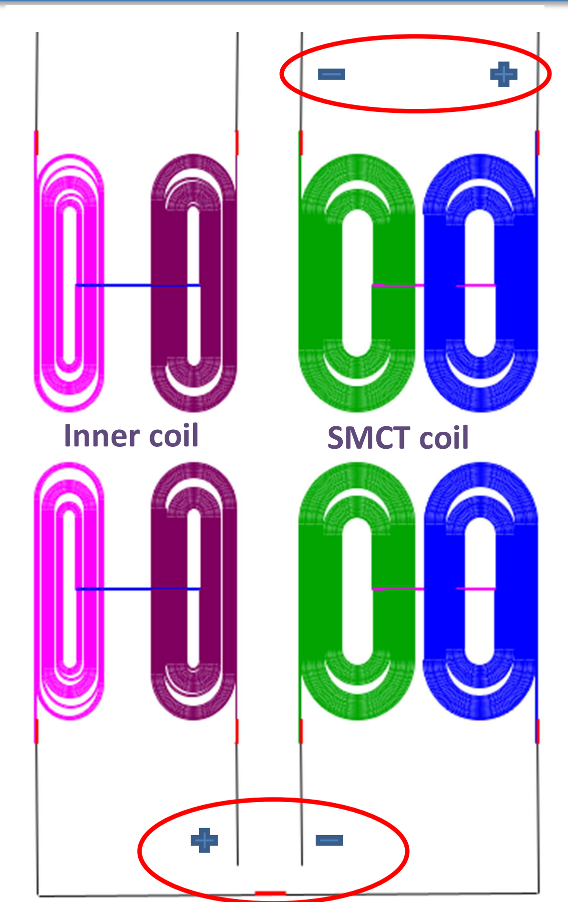
SMCT coil and 15 T D coil 003 schematic with VTs location

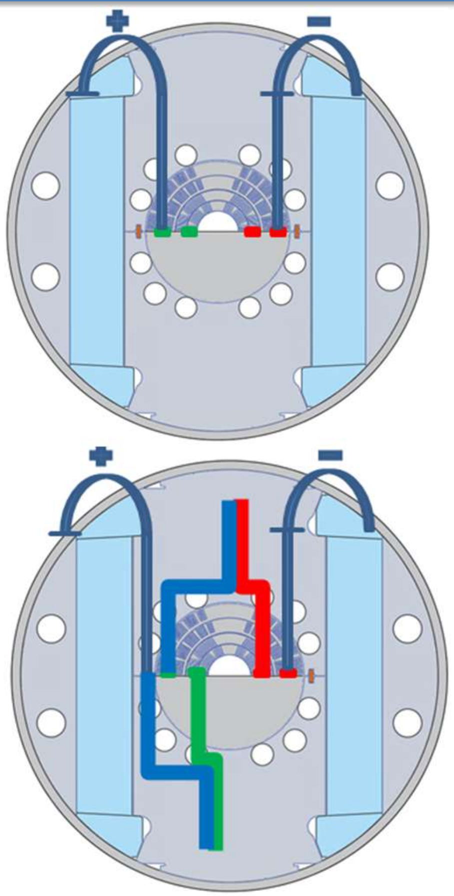
QP heaters

SMCTM1 test configurations

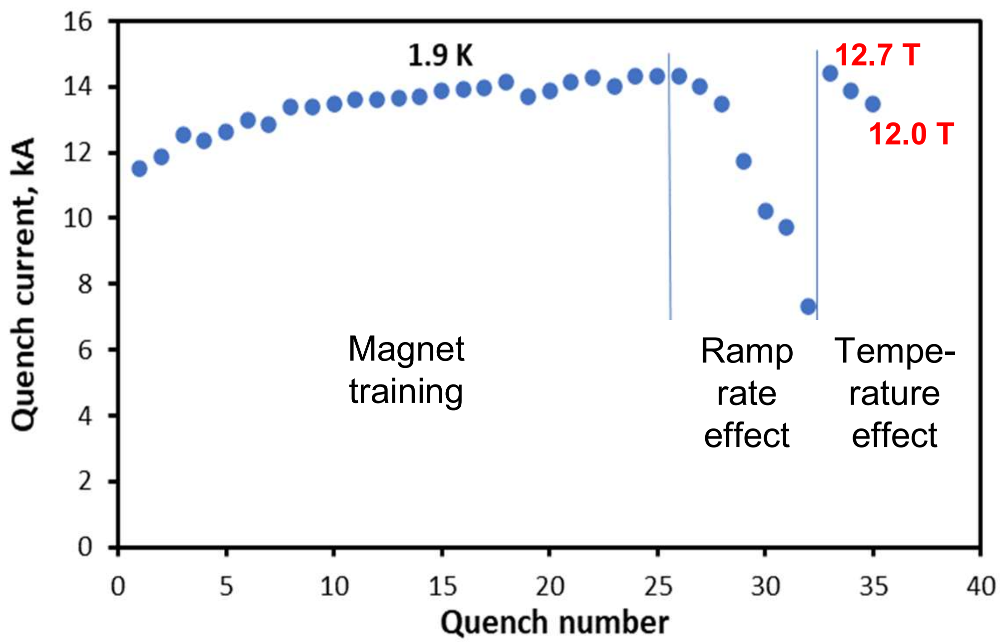
SMCTM1a Test 1:

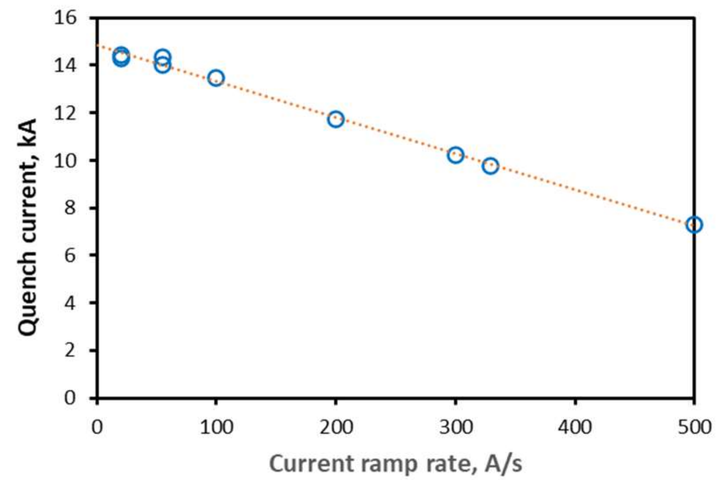
SMCTM1b Test 2:

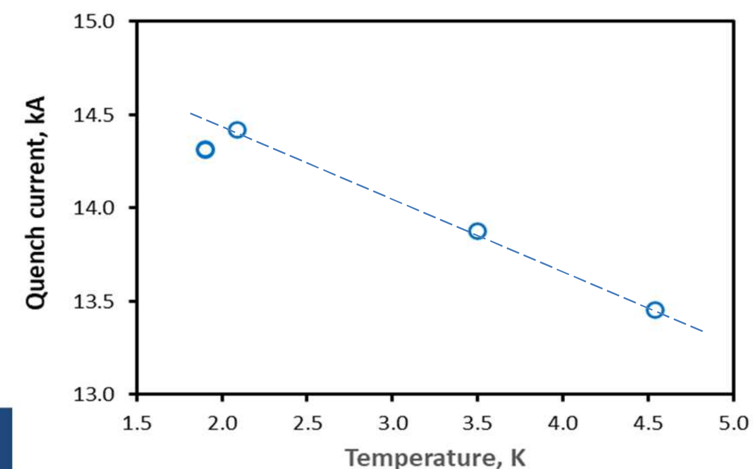




SMCTM1a quench summary

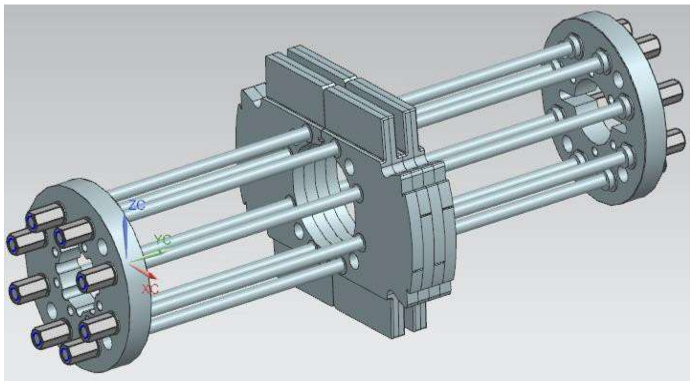




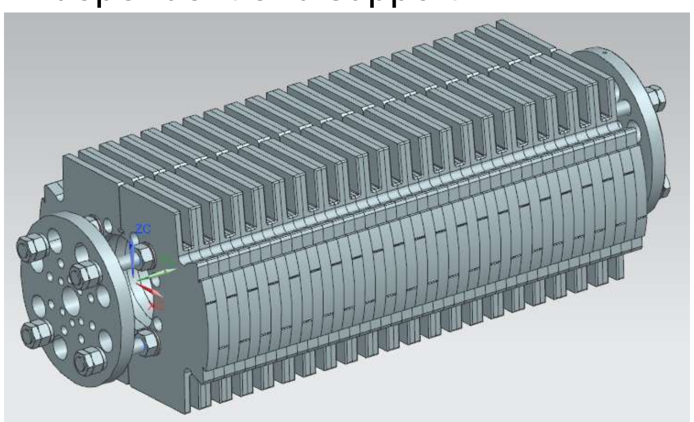


- 4 OL quenches - #1, #11, #19 and #26
- B_{max}=12.7 T at ~2 K or 89% of SSL
- B_{max}=12.0 T at 4.5 K or 90% of SSL
- SMCT1 coil reached conductor limit

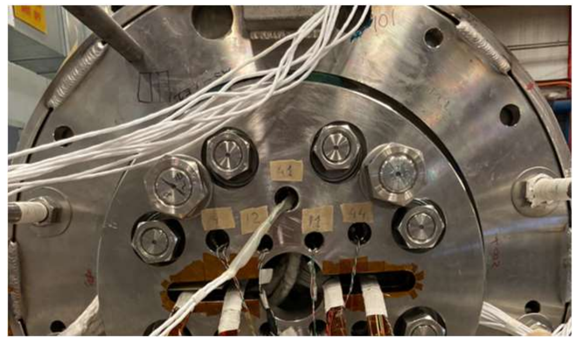
SMCTM1a end force measurement



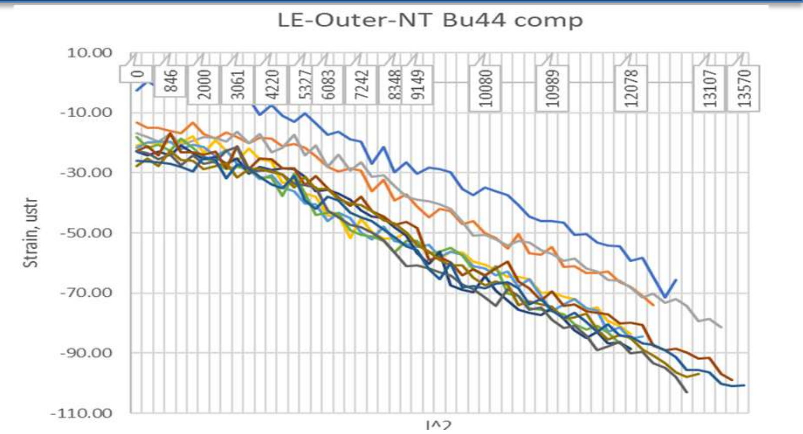
Independent end support

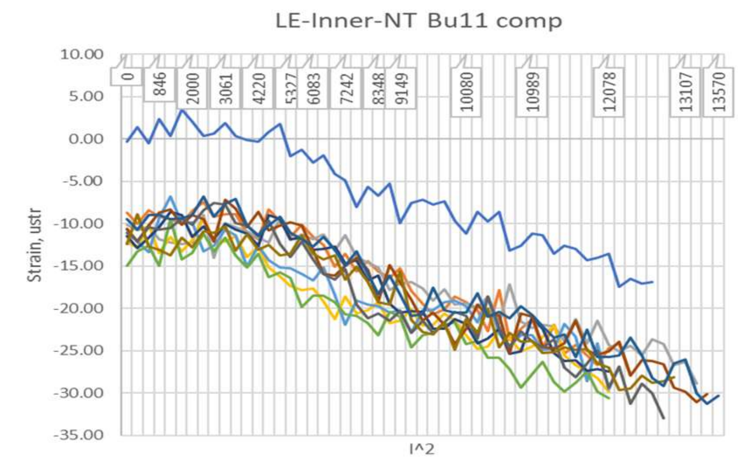


LE SM coil bullets



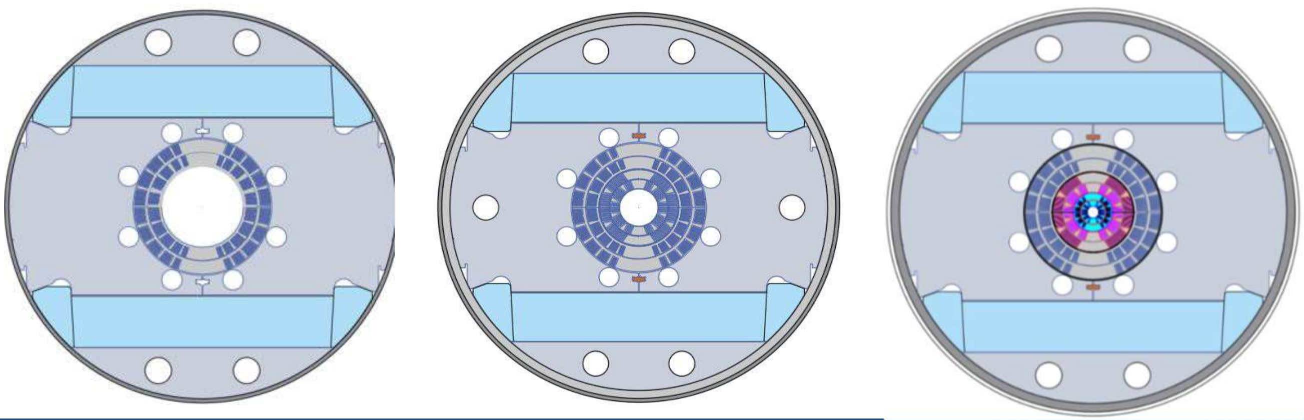
LE inn-coil bullets





SMCT coil R&D - next steps

- **SMCTM1 coil test**
  - SMCTM1a 2L configuration – TC2
  - SMCTM1b 4L configuration – TC1 and TC2
- **SMCT2 coil design, tooling and structure optimization**
  - shorten inter-block transitions, reduce inter-block space, move interlayer transition to LE block
  - additional shell to reinforce structure radial strength
- **SMCT1 and SMCT2 coil assembly with 15 T IL coils (SMCTD1) and test in 2L and 4L dipole configurations and in 6L configuration with small-aperture HTS (Bi2212 and REBCO) inserts**
  - 11 T 2L 120-mm dipole
  - 16 T 4L 60-mm dipole
  - ~18 T 6L 20-35 mm dipole



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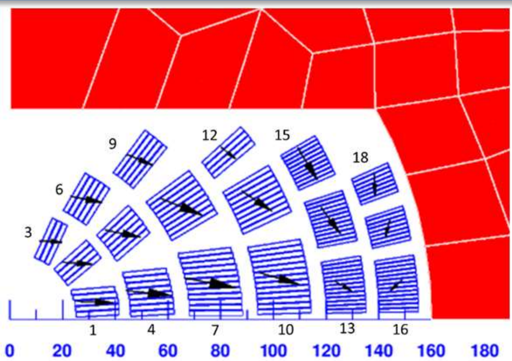
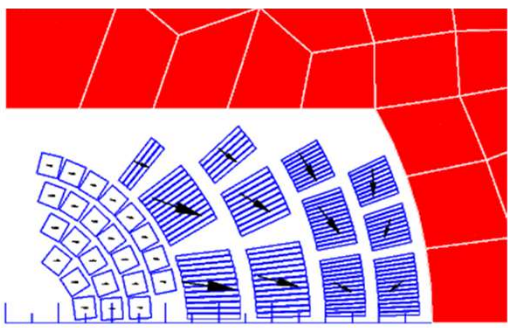
20 T hybrid dipoles with Bi2212 and REBCO coils and SMCT coils

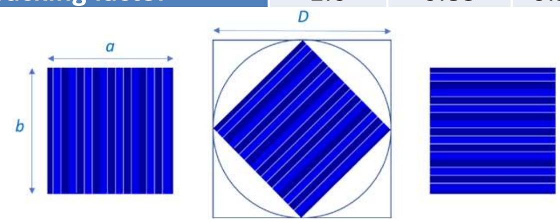


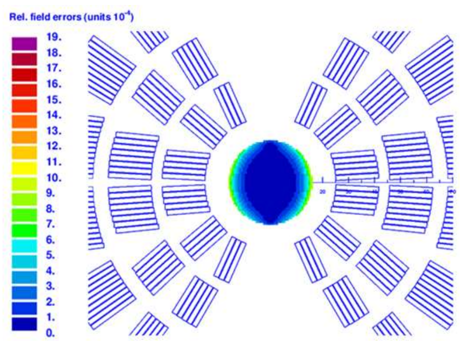
IPAC2023

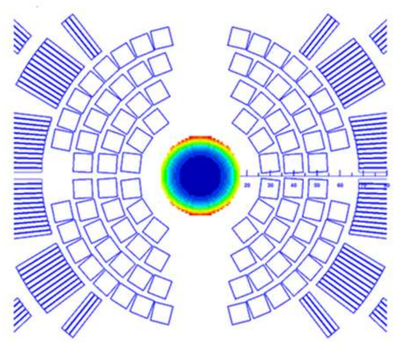


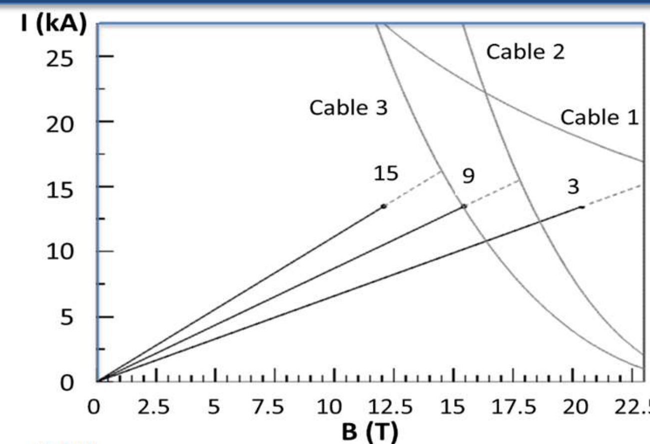
FERMILAB-TM-2807-TD
(in preparation)

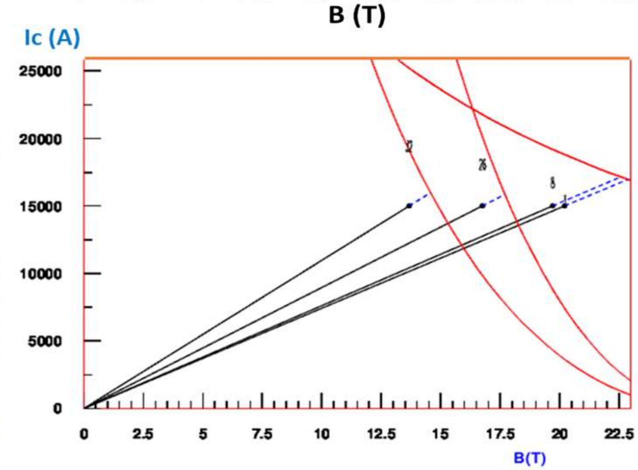
Parameter	REBCO	Bi2212	Nb_3Sn	Nb_3Sn
Strand size, mm	5×0.1	1.0	1.0	0.7
Number of strands	50	32	40	40
Cable width, mm	8	16.5	20.1	15.0
Cable small edge, mm	8	1.85	1.70	1.22
Cable large edge, mm	8	1.95	1.90	1.38
Cable packing factor	1.0	0.83	0.90	0.81











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Summary

- A 120 mm aperture Nb_3Sn dipole coil SMCT1 was designed and built at Fermilab to validate and study the cos-theta coil SM concept
- The SMCT1 coil is being tested in dipole mirror configuration
  - In the first test, after a relatively short training, the SMCTM1a mirror magnet with the SMCT coil powered individually, has reached conductor limit with 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
  - SMCT1 coil test in 4-layer mirror configuration will follow
- SMCT2 coil design, tooling and structure optimization
- SMCT1 and SMCT2 coils will be assembled with 15 T IL coils and tested in 2L and 4L dipole configurations
- SM concept is being also studied using small aperture HTS inserts based on Bi2212 Rutherford cable and REBCO CORC, STAR and TST cables