U.S. MAGNET DEVELOPMENT PROGRAM

FNAL Bi2212 SMCT insert program overview

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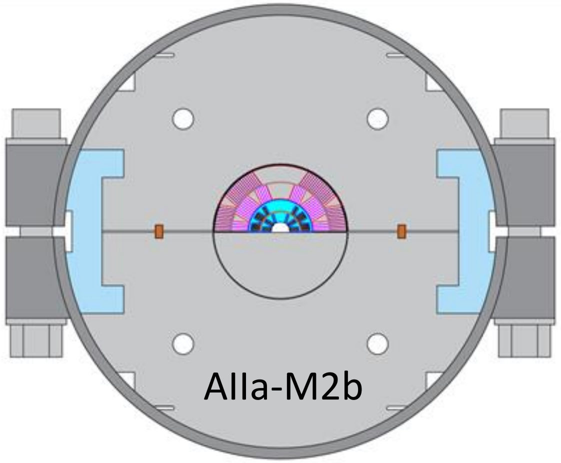
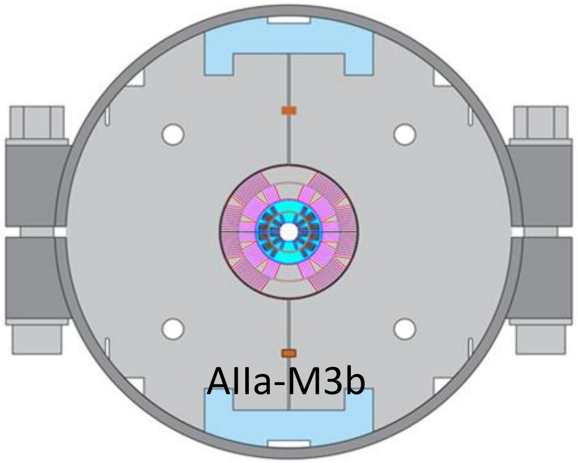
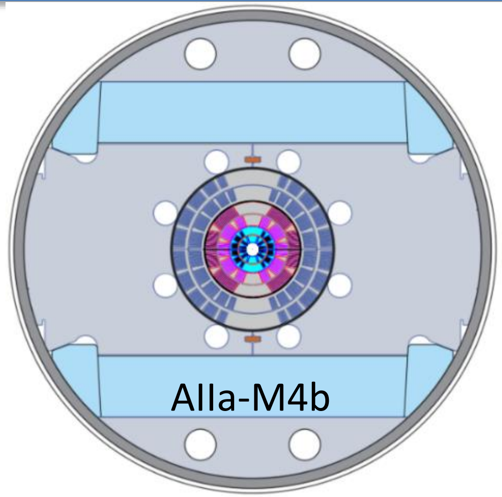
U.S. MDP Collaboration Meeting CM7
03/22/2023

US-MDP Task: Bi2212 SMCT insert goals and milestones

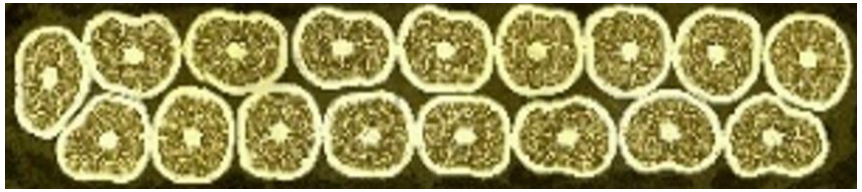






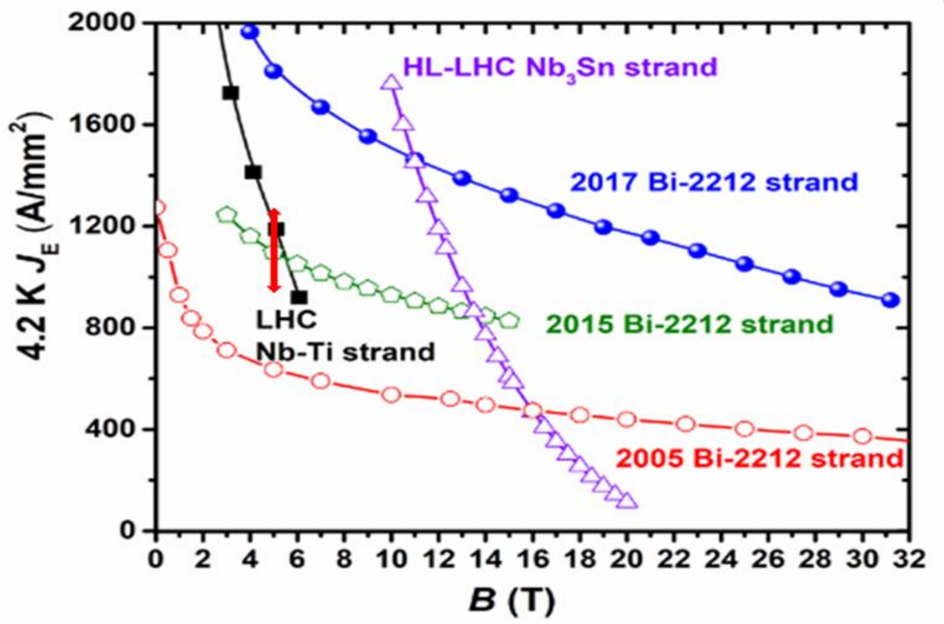
Milestone #	Description	Target
AIIa-M2b	Design and fabricate the first small-aperture Bi-2212 coil using LBNL cable. Coil test independently and inside a 60-mm aperture 2-layer Nb_3Sn dipole coil in mirror configuration.	Aug-23
AIIa-M3b	Design and fabricate the 2nd small-aperture Bi-2212 coil using optimized Bi-2212 cable, coil structure, materials and technologies. Coil test independently and inside a 60-mm aperture 2-layer Nb_3Sn dipole coil in mirror configuration.	Mar-24
AIIa-M4b	Fabricate another small-aperture Bi-2212 coil using optimized Bi-2212 cable and coil structure. Bi-2212 coil test independently and inside a 60-mm aperture 4-layer Nb_3Sn dipole coil.	Sept-24

Bi2212 wire and cable



- 0.8 mm Bi2212 wire (BOST)
- 17-strand cable 7.8×1.44 mm² (LBNL)

Bi2212 round composite wire and Rutherford cable.



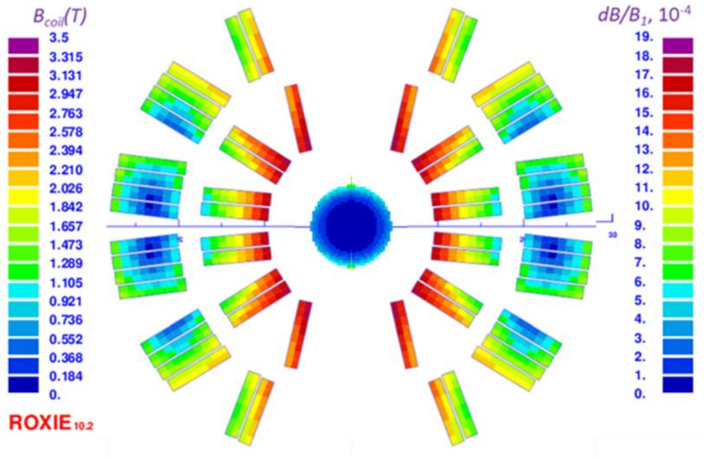
Bi2212 cable and strand parameters.

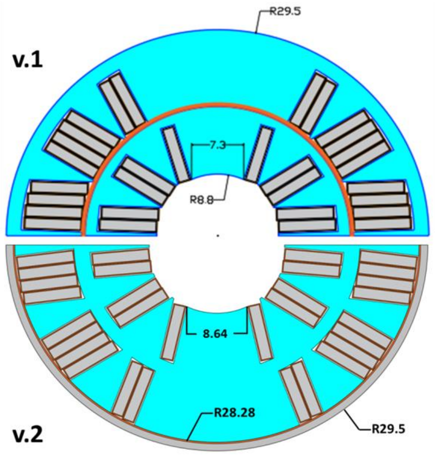
Parameter	Unit	Value
Number of strands		17
Bare cable width	mm	7.8
Bare cable thickness	mm	1.44
Cable transposition pitch	mm	58
Strand diameter before/after reaction	mm	0.8/0.778
Strand twist pitch	mm	25
Strand I_c(4.2K,5T) after NHMFL 50 bar OPHT	A	460-640*

- The target field will be approached gradually using the "old" 2015 and the "new" 2017 Bi2212 wires.
  - Bi2212 cable request has been submitted
- Understanding and solving fundamental problems of Bi2212 wire and cable is critical for this US-MDP direction (*see E. Barzi's talk "Bi-2212 Challenges as a Magnet-Ready Conductor" in this session*)

Bi2212 SMCT coil cross-section evolution

2L 6-block coil





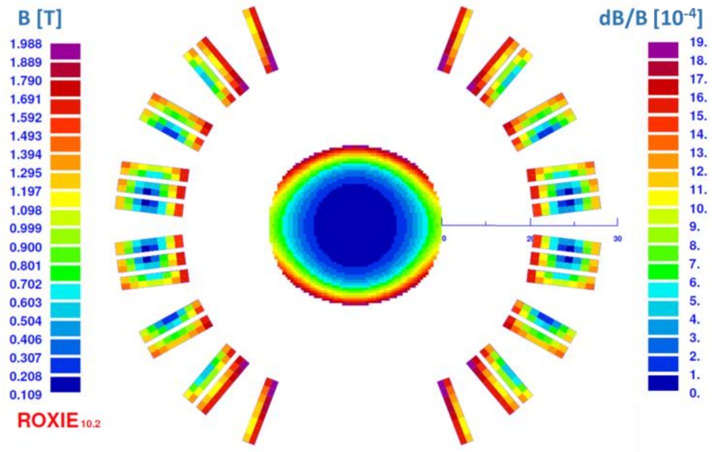
v.1:

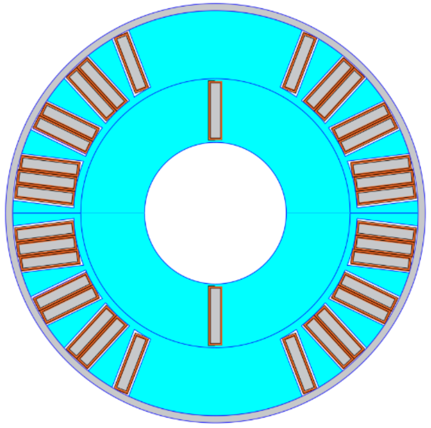
- separate structure for each layer
- both coil winding from inside

v.2:

- one structure for both layers => larger bore
- IL winding from inside
- OL winding from outside

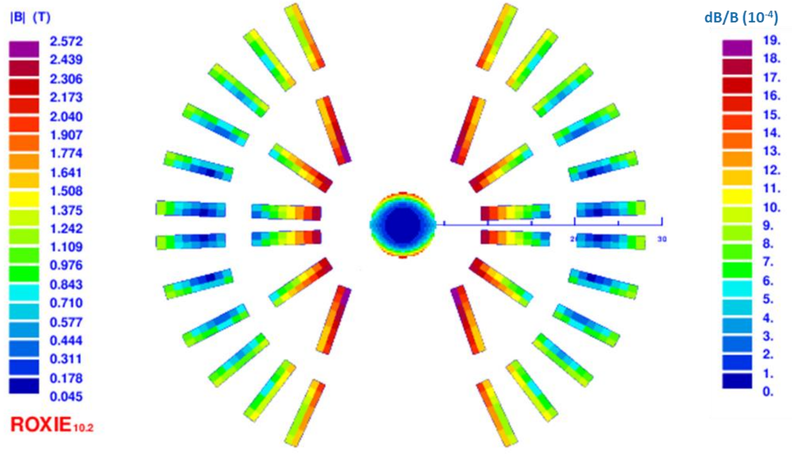
1L 4-block coil

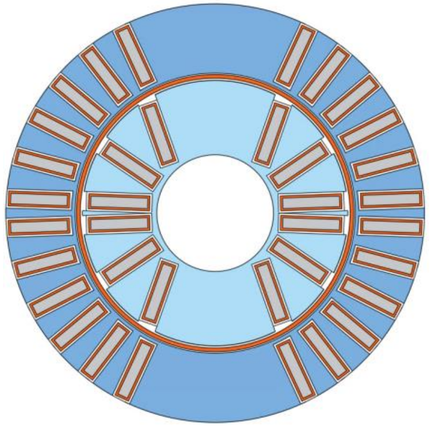




- Coil leads through aperture => reduce bore diameter
- coil winding from inside
- two separate half-coils
- one single coil w/o splice

2L 9-block coil



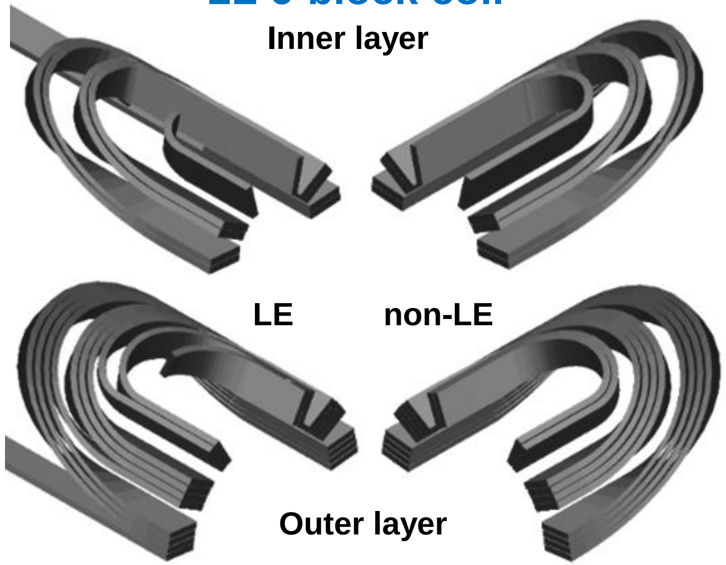


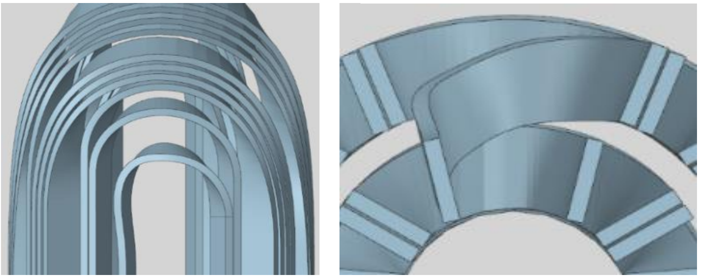
- Separate structure foe each layer
- both coil winding from inside
- two separate half-coils
- one single IL coil w/o splice
- Separate OL half-coils

End design optimization

Coil ends optimized to minimize their length, produce coil blocks acceptable for winding the Bi2212 Rutherford cable, and minimize transitions between coil end blocks.

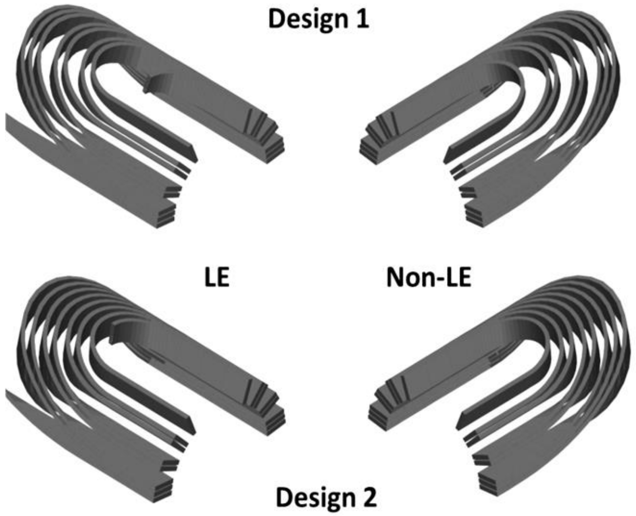
2L 6-block coil

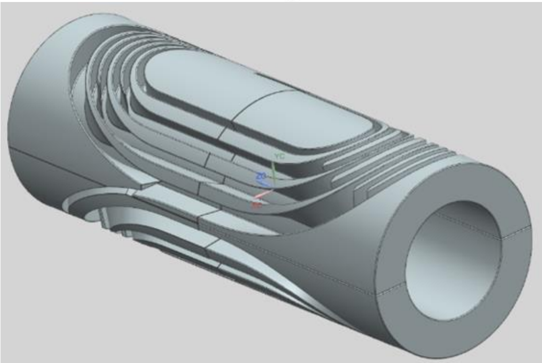




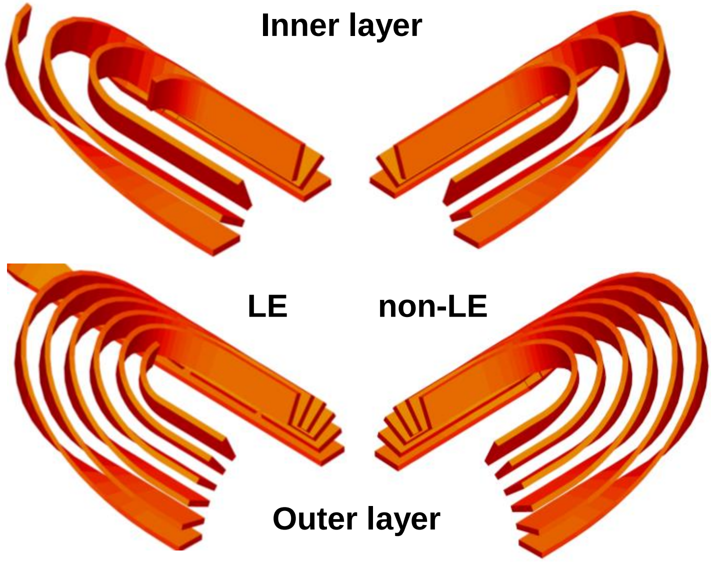
Inner-layer transition

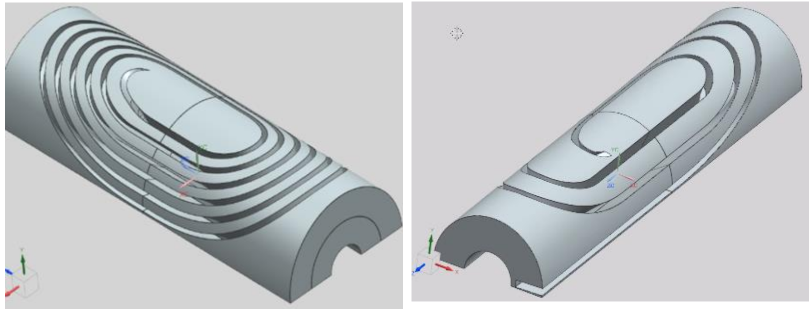
1L 4-block coil



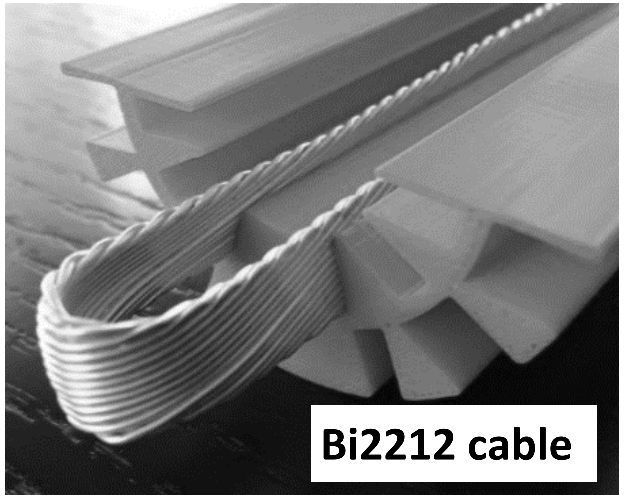


2L 9-block coil

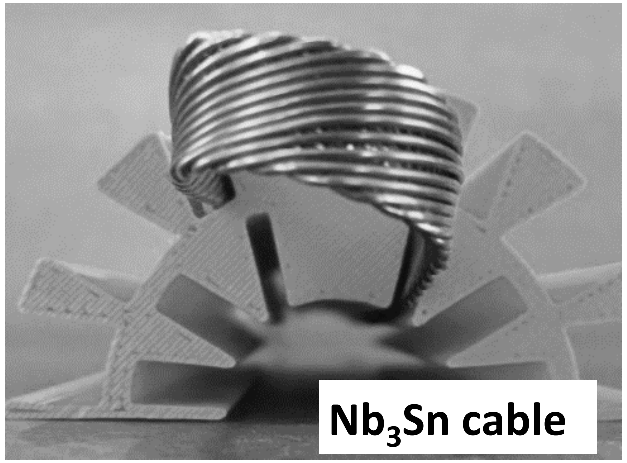


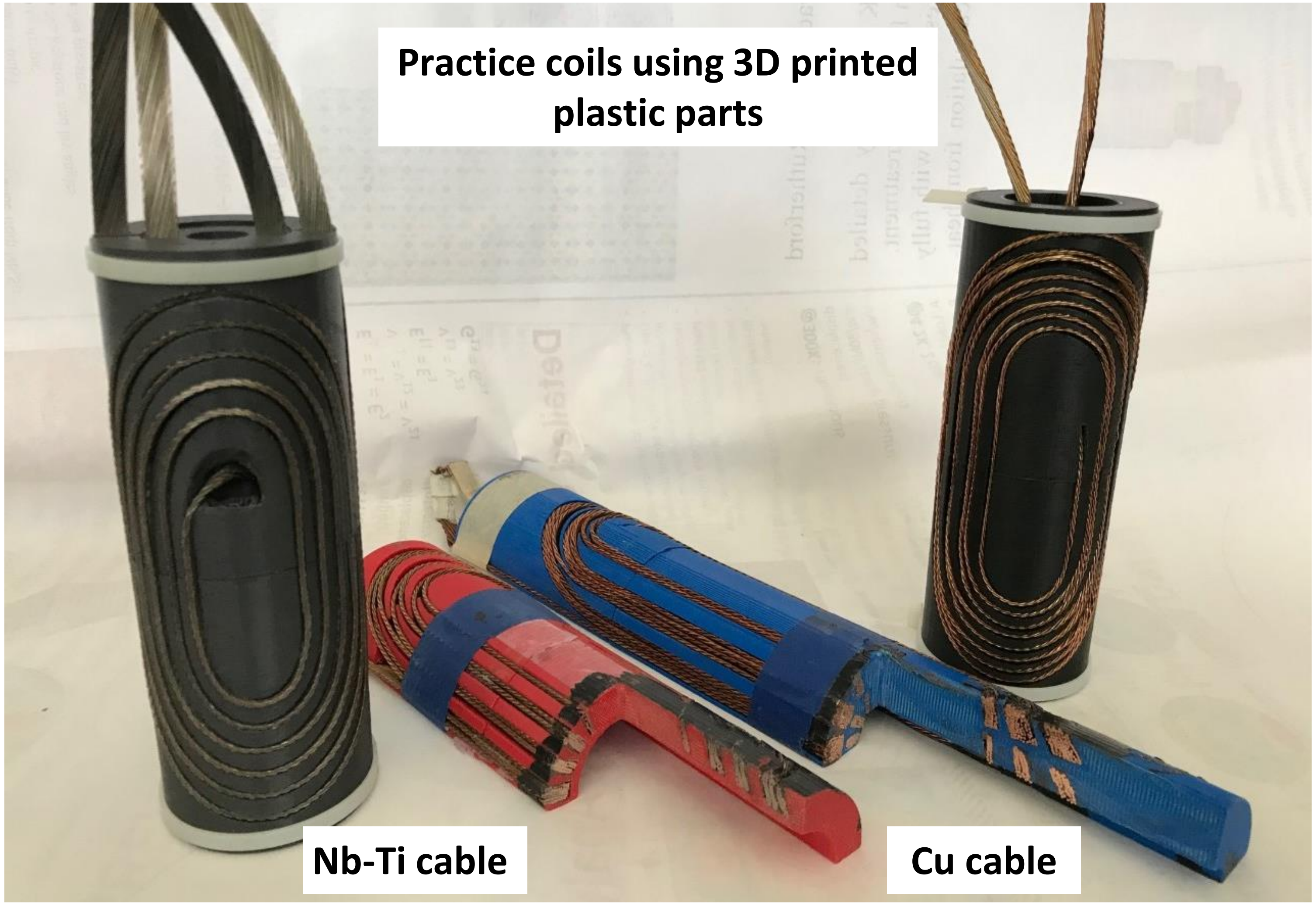


Winding tests and practice coils

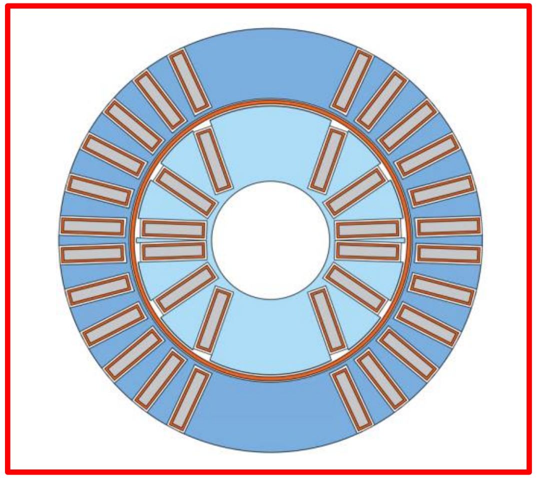


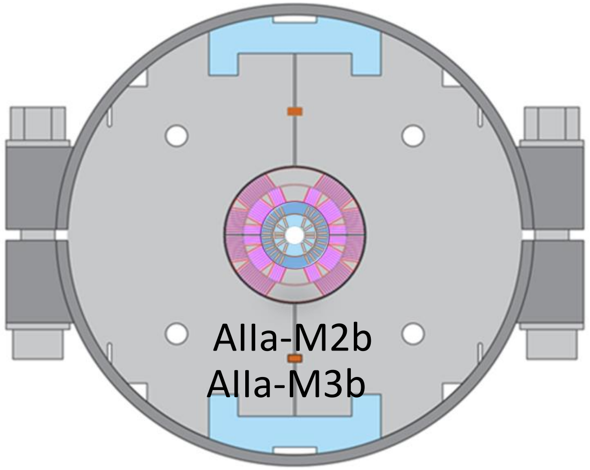
Cable winding test

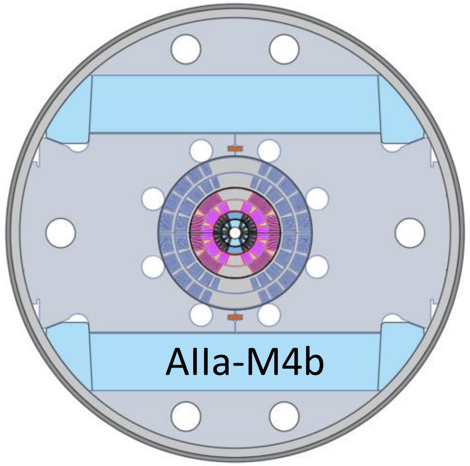




Bi2212 SMCT insert coil final design and goal correction







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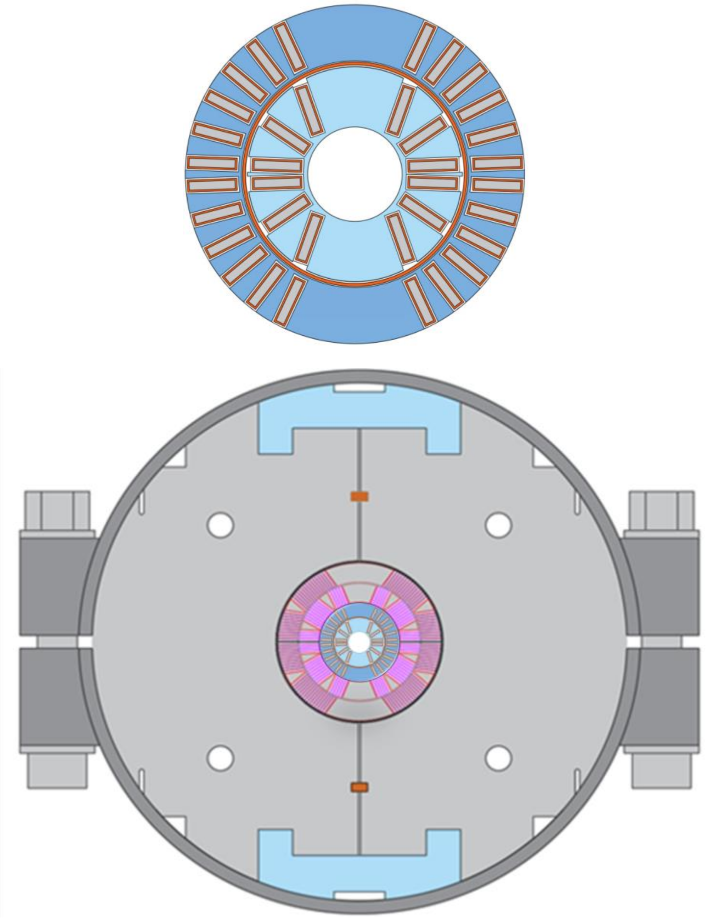
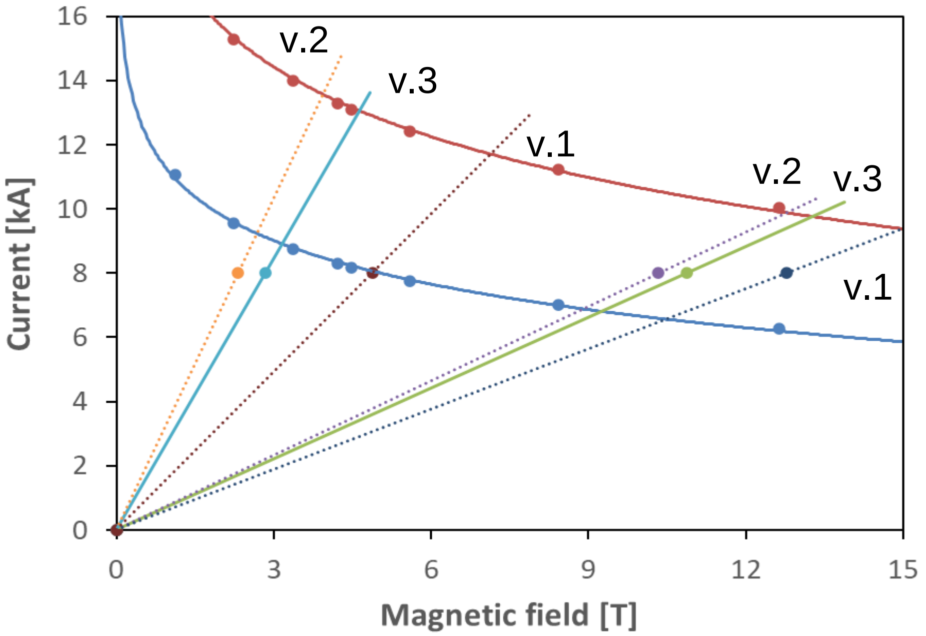
Bi2212 coil test parameters



Bi2212 coil in the dipole mirror configuration with 11 T dipole coil.



Parameter	v.1	v.2	v.3
Number of layers	2	1	2
Number of blocks	6 (3+3)	4	9 (3+6)
Number of turns	15 (5 IL+10 OL)	8	9 (3 IL+6 OL)
Coil ID/OD, mm	19/59	40/58	19/59
Coil B_{max}/I, T/kA	0.61/1.60	0.29/1.29	0.355/1.36
B_{max}/B_o	1.006/1.019	1.027/1.143	1.008/1.033

Dipole structure developed at Fermilab and used to test superconducting dipole coils.

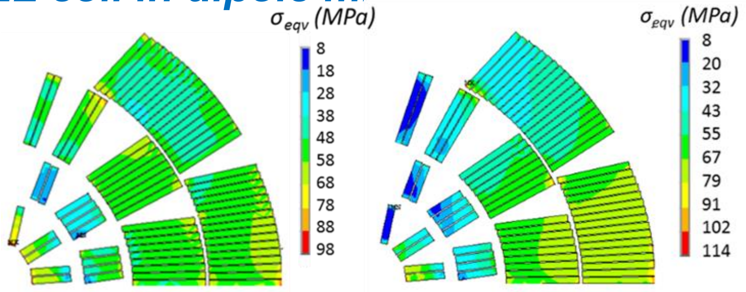
Stress analysis

- Stresses in Bi2212 and Nb_3Sn coils, Bi2212 SMCT coil Inconel-718 structure, and in the main elements of magnet structure.

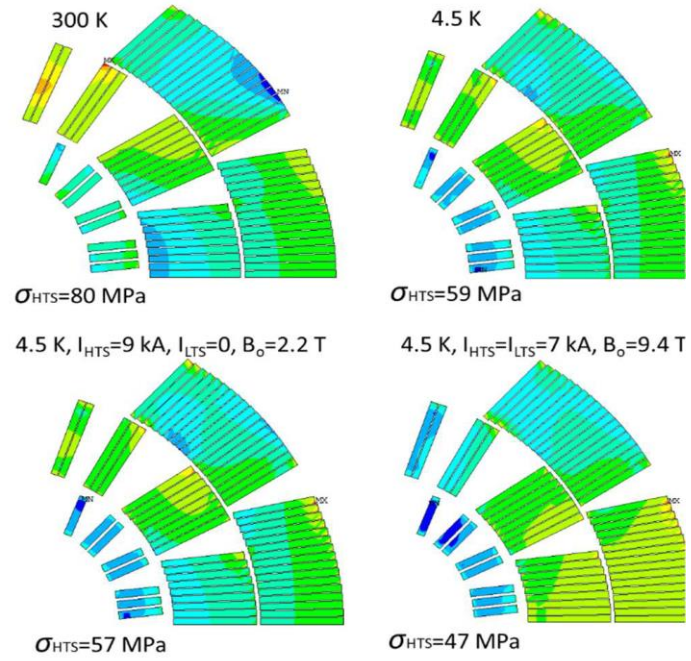
- The calculations after
  - a) magnet assembly
  - b) magnet cool down to liquid He
  - c) at zero and I=9 kA only in Bi2212 coil
  - d) at I=7 kA in both Bi2212 and Nb_3Sn coils powered in series.

- The σ_{max} in the Bi2212 coil, coil structure and other elements of the magnet structure are relatively low in both cases.

2L coil in dipole mirror configuration

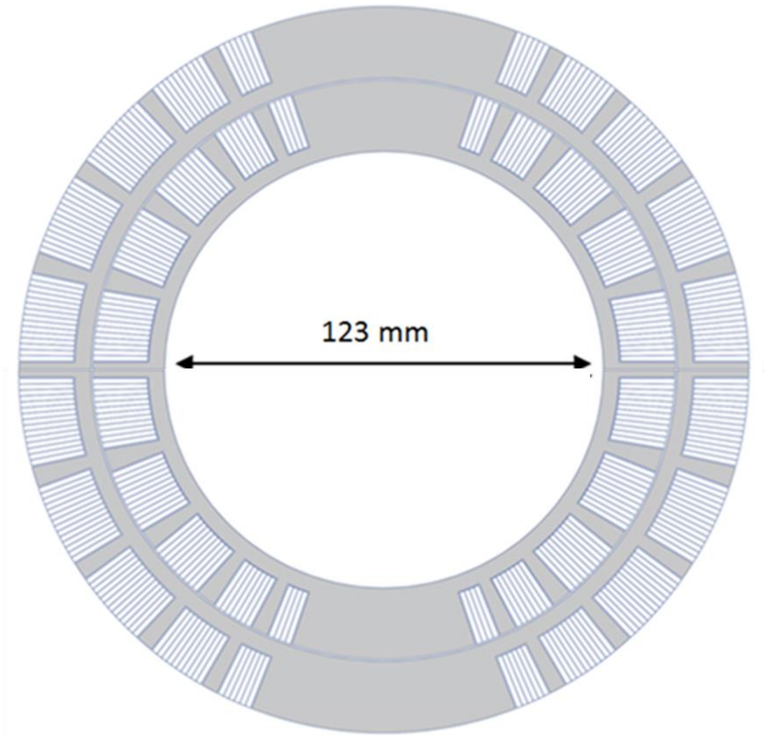


1L coil in dipole configuration

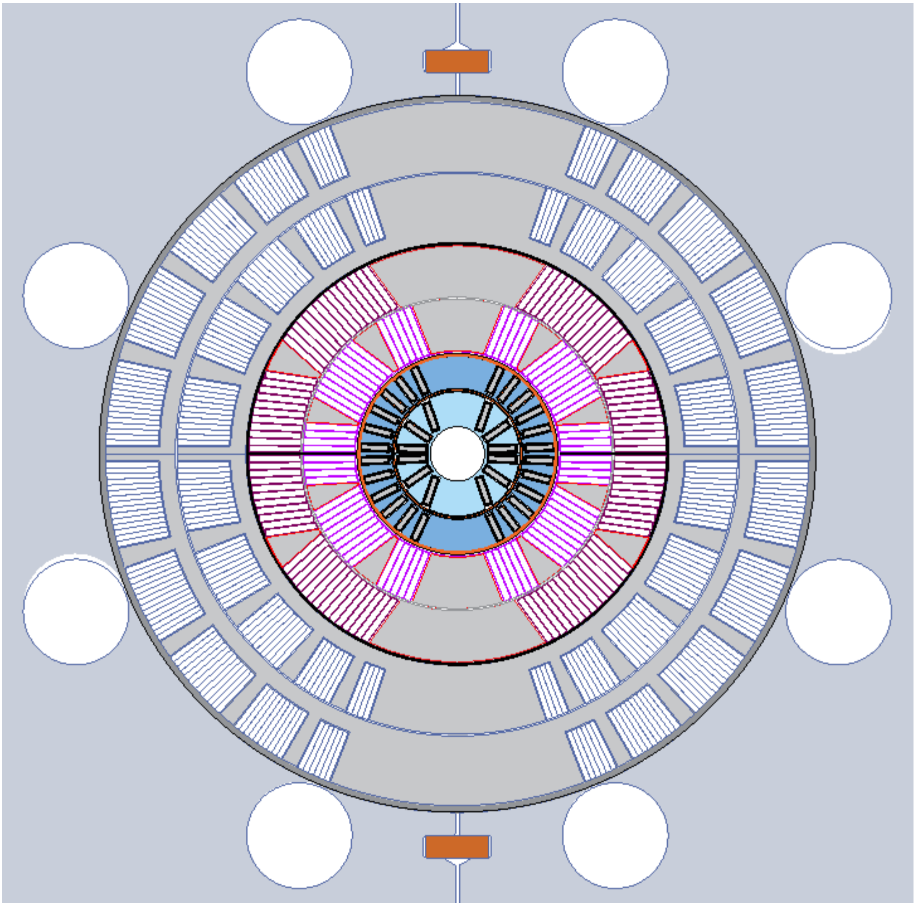


Towards 6L Hybrid HTS/LTS Dipole

123-mm ID 2-layer Nb_3Sn SMCT coil

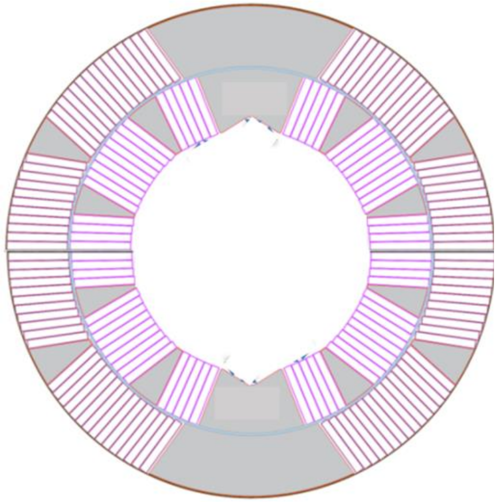


Multilayer (6L) hybrid dipole coil

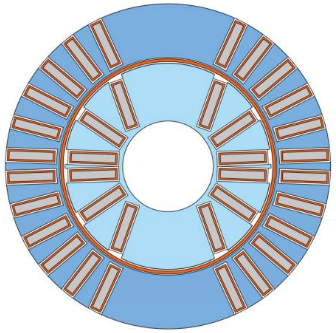


Expected conductor limit ~17-18 T

60-mm ID 2-layer Nb_3Sn coil (MDPCT1 inner coil)



19 mm ID 2-layer Bi2212 SMCT coil



Summary

- 1L and 2L designs of Bi2212 insert coil and SMCT coil support structure have been developed
  - the calculated conductor limit of the individually powered Bi2212 dipole coil (final design) is ~3-5 T
  - the conductor limit of the 4-layer hybrid dipole with Bi2212 coil (final design) is ~9-13 T
  - the maximum stresses in the Bi2212 coils and coil support structures are within the acceptable limits for Bi2212 cable and for a support structure made of Inconel 718
- Several plastic models of the coil support structure were made using 3D printing technology to optimize the coil design and winding process (*see Igor's talk*)
- Bi2212 coil engineering design is almost done, coil part procurement starts in April 2023
- Development towards 6L Hybrid HTS/LTS Dipole continues
  - combining the results of Bi2212 insert with Nb_3Sn SMCT coil
- Bi2212 SMCT insert coil R&D plan has been reviewed and updated
- For the Bi2212 SMCT insert we will need 30-m single piece of high-J_c 17-strand cable in January of 2024. Another such piece we may need in early 2025.
- The work progress and results are being presented and discussed at various meetings and conferences and published (*see next slide*)

Result discussion and publication

Presentations (since CM6):

1. A.V. Zlobin, “FNAL Bi2212 insert status and milestone correction,” MDP general meeting, 06/22/2022.
2. A.V. Zlobin et al., “Development of a Bi2212 dipole insert at Fermilab,” ASC2022, October 27, 2022.

Publications:

1. A.V. Zlobin, I. Novitski, E. Barzi, D. Turrioni, “Development of a Bi2212 dipole insert at Fermilab,” IEEE Trans. on Appl. Supercond., Vol. 3x, Issue x, 2023.

MT-28 abstracts:

1. A.V. Zlobin, I. Novitski, E. Barzi, M. Baldini, A. D’Agliano, D. Turrioni, “Development and test of a two-layer dipole coil made of Bi2212 Rutherford cable”
2. A. D’Agliano, I. Novitski, A.V. Zlobin, S. Donati, D. Turrioni, V. Giusti and E. Barzi, “Modeling of Bi2212 strand and Rutherford cable for dipole coil insert”