U.S. MAGNET DEVELOPMENT PROGRAM

FNAL Bi2212 SMCT insert program update

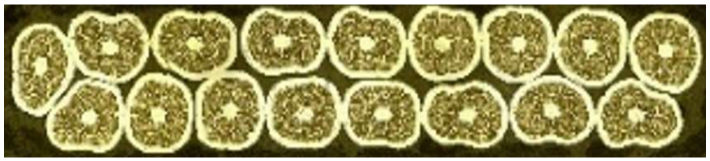
A.V. Zlobin

U.S. MDP General Meeting
06/21/2023

Outline

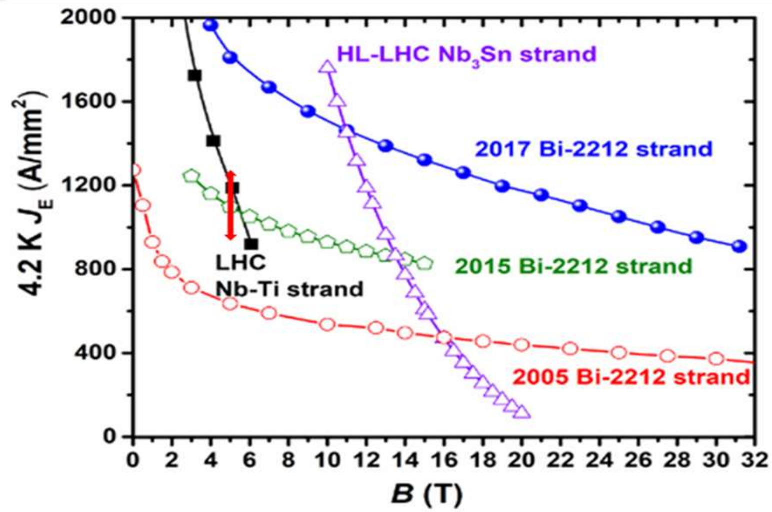
- Bi2212 insert work overview at Fermilab
- Work progress since MDP CM7
- Summary and next steps

Bi2212 wire and cable



- **0.8 mm Bi2212 wire (BOST)**
- **17-strand cable 7.8×1.44 mm^2 (LBNL)**

Bi2212 round composite wire and Rutherford cable.



Bi2212 cable and strand parameters.

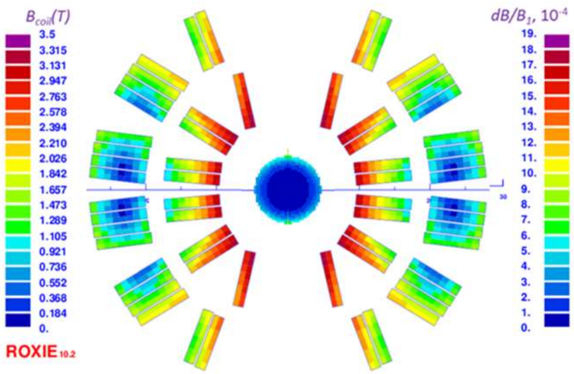
Parameter	Unit	Value
Number of strands		17
Bare cable width	mm	7.8
Bare cable thickness	mm	1.44
Cable transposition pitch	mm	58
Strand diameter before/after reaction	mm	0.8/0.778
Strand twist pitch	mm	25
Strand I_c*(4.2K,5T)* after NHMFL 50 bar OPHT	A	460-640*

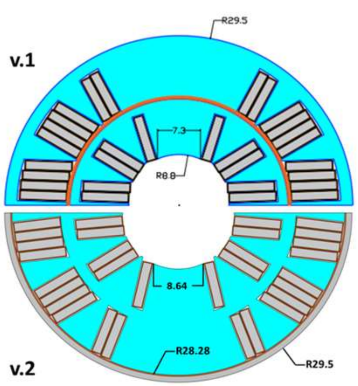
- The target field will be approached gradually using the "old" 2015 and the "new" 2017 Bi2212 wires.
  - Bi2212 cable request has been submitted
- Understanding and solving fundamental problems of Bi2212 wire and cable is critical for this US-MDP direction

U.S. MAGNET DEVELOPMENT PROGRAM

Bi2212 SMCT coil cross-section evolution

2L 6-block coil

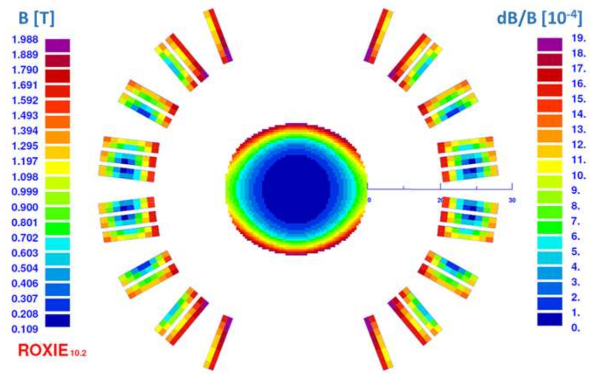


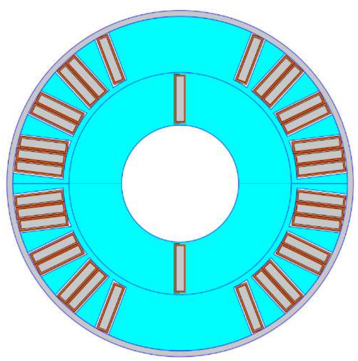


v.1:
- separate structure for each layer
- both coil winding from inside

v.2:
- one structure for both layers => larger bore
- IL winding from inside
- OL winding from outside

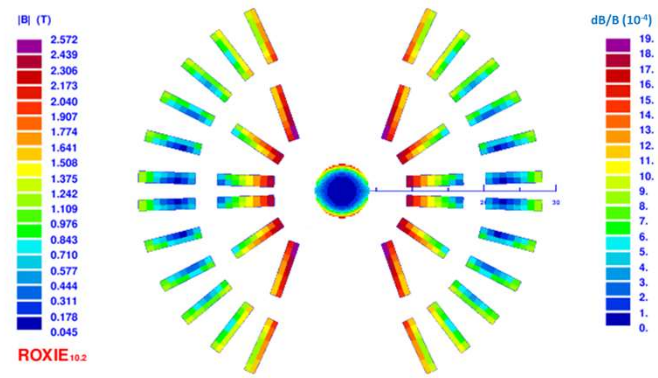
1L 4-block coil

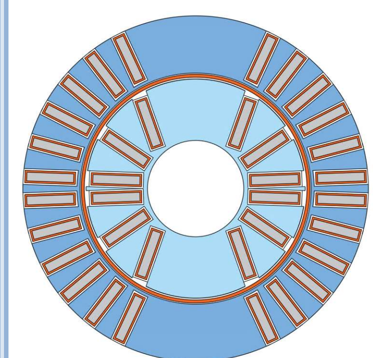




- Coil leads through aperture => reduce bore diameter
- coil winding from inside
- two separate half-coils
- one single coil w/o splice

2L 9-block coil





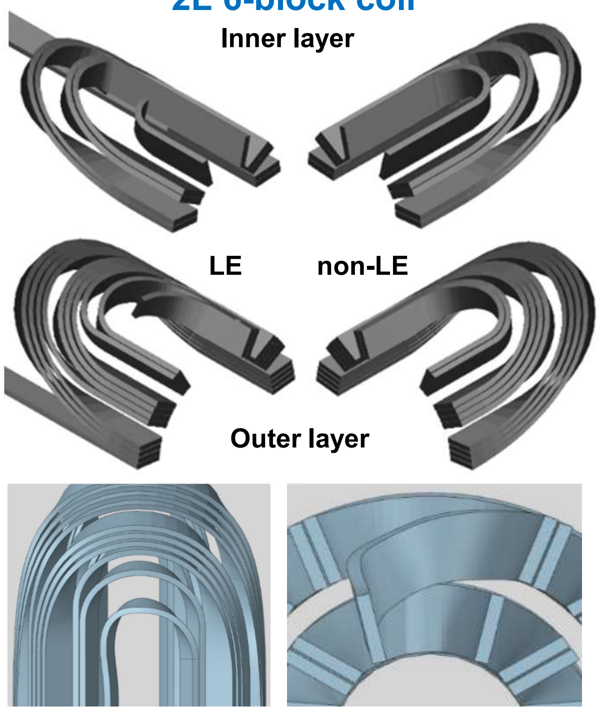
- Separate structure foe each layer
- both coil winding from inside
- two separate half-coils
- one single IL coil w/o splice
- Separate OL half-coils

End design optimization

U.S. MAGNET DEVELOPMENT PROGRAM

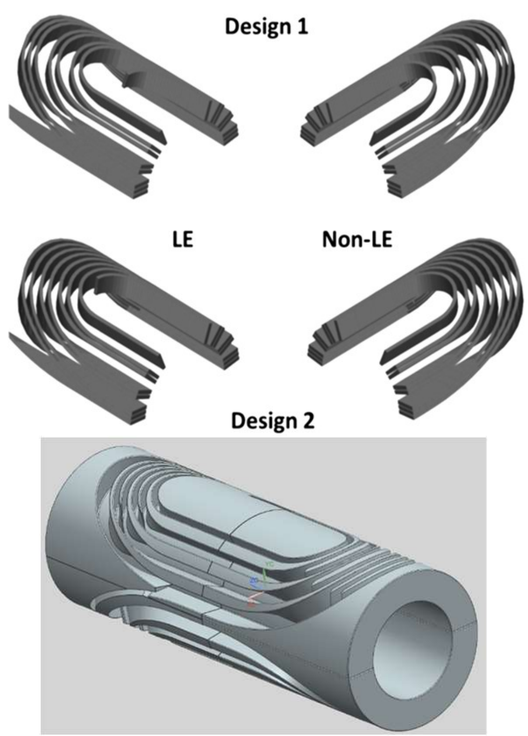
Coil ends optimized to minimize their length, produce coil blocks acceptable for winding the Bi2212 Rutherford cable, and minimize transitions between coil end blocks.

2L 6-block coil

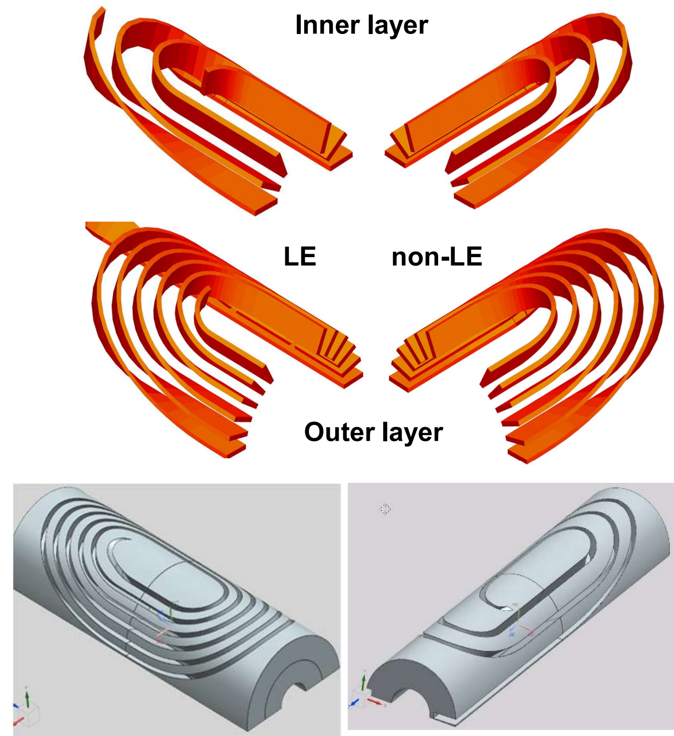


Inner-layer transition

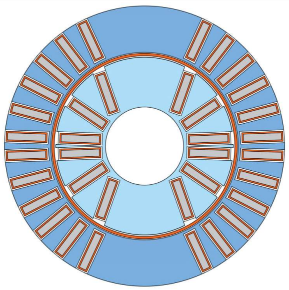
1L 4-block coil

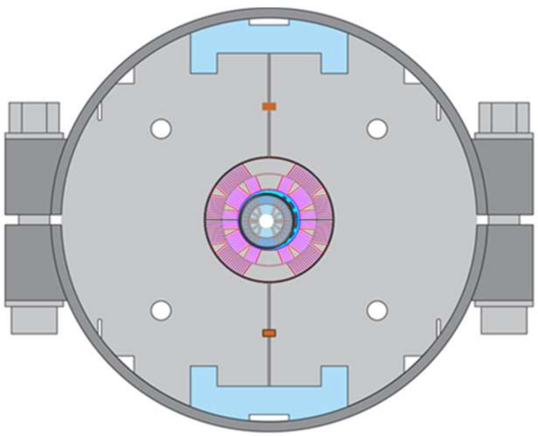


2L 9-block coil

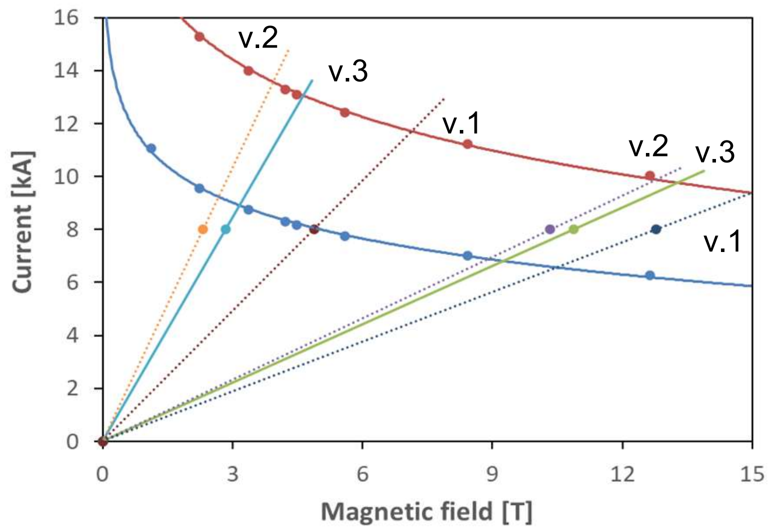


Bi2212 coil test parameters





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

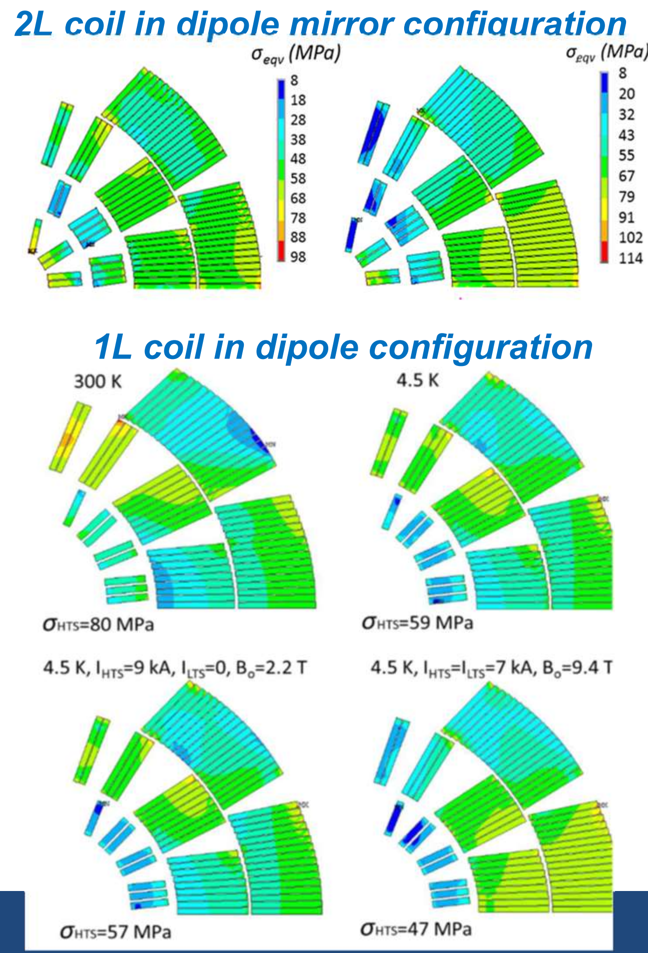


Parameter	v.1	v.2	v.3
Number of layers	2	1	2
Number of blocks	6 (3+3)	4	9 (3+6)
Number of turns	15 (5 IL+10 OL)	8	9 (3 IL+6 OL)
Coil ID/OD, mm	19/59	40/58	19/59
Coil B_{max}/I, T/kA	0.61/1.60	0.29/1.29	0.355/1.36
B_{max}/B_o	1.006/1.019	1.027/1.143	1.008/1.033

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.
- ANSYS analysis for the final insert coil is in progress.



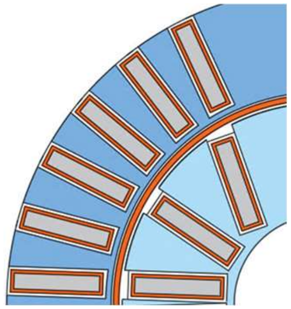
Courtesy Igor Novitski

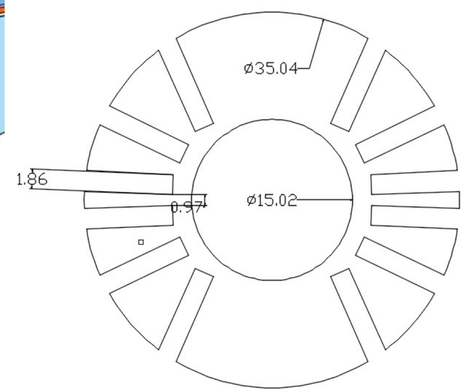
Final design optimization

ROXIE model update with larger cable cross-section

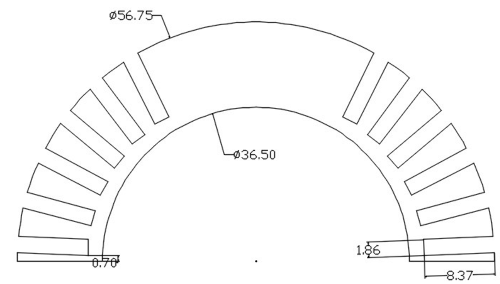
New solid model

- Cable grove size increase
- Layer jump optimization
- Coil length optimization based on the 12 m long cable piece
- Splice block
- Plastic model of coil structure

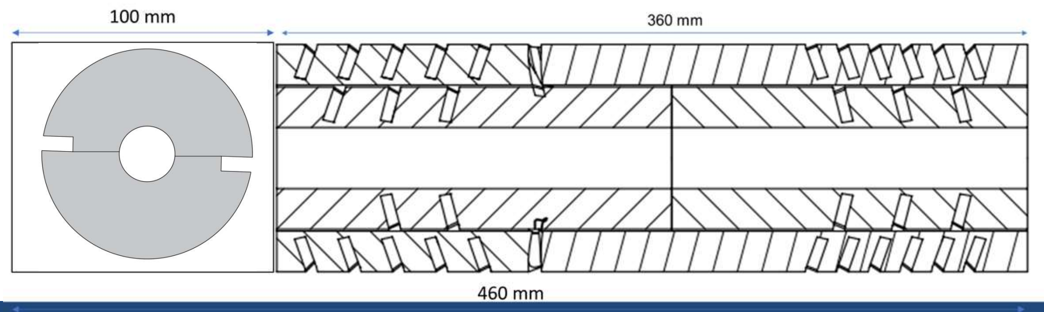


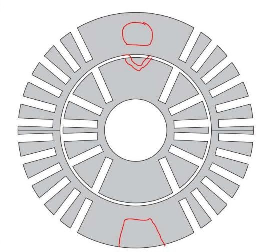


Courtesy Igor Novitski and Jodi Coghill



Courtesy Igor Novitski





Coil structure technologies, materials, procurement

Two technology:
- Laser Powder Bed Fusion (L-PBF)
- Laser Powder Directed Energy Deposition (LP-DED)

Two companies:
- GE Additive – L-PBF
  - GEA produced 316 parts for the Nb3Sn SMCT coil
- Velo3D – LP-DED

Discussion issues:
- part material, printing quality and postprocessing
- cost and schedule

TABLE 3.2 SELECTION OF ALLOYS THAT HAVE BEEN STUDIED TO SOME DEGREE WITH AM PROCESSES[a]

Ni-Based: Inconel 625, Inconel 713, Inconel 718, Inconel 738, Inconel 939, Hastelloy-X, Haynes 214, Haynes 230, Haynes 233, Haynes 282, Monel K-500, C276, Rene 80, Rene 142, Waspalloy

Fe-Based: SS 17-4PH, SS 15-5 GP1, SS 304, SS 316L, SS 410, SS 420, SS 440, 4140/4340, Invar 36, SS347, JBK-75, NASA HR-1

Cu-Based: Pure Cu, GRCop-84, GRCop-42, C18150, C18200, Glidcop, CU110, Monel K500

Co-Based: CoCr/CoCrMo, Haynes 188, Stellite 6, 21, 31

Platinum Group: Ir, Pt, Rh, Ru, Pd, Au, Ag

Refractory: W, WRe, Mo, MoW, MoRe, Ta, TaW, Re, Nb, C103, FS85, High Entropy

Ti-Based: Ti6Al4V, γ-TiAl, Ti-6-2-4-2

Al-Based: AlSi10Mg, A205, F357, 1000*, 6061*, 2024*, 7075*, 7050*, Scalmalloy*, 7A77*

*Reactive-based AM

Laser Powder Bed Fusion (L-PBF)

Laser Powder Bed Fusion (L-PBF)

Courtesy Igor Novitski

Coil winding technology, tooling

New plastic models (Alessio d’Agliano):

- 1st winding with bare Nb-Ti bare cable
- 2nd winding with insulated cable, gap control wire and TiO_2 gap filler

Coil tooling and fabrication technologies

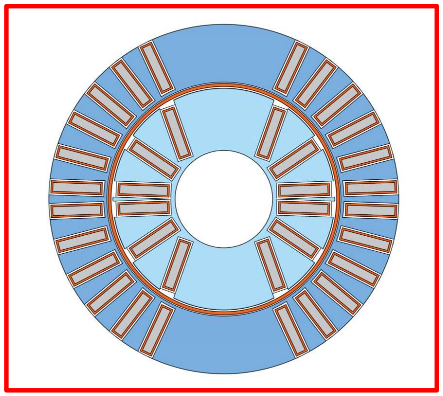
Coil tooling

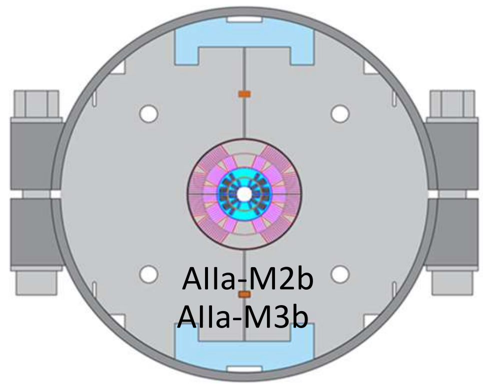
- winding
- reaction/transportation
- epoxy impregnation

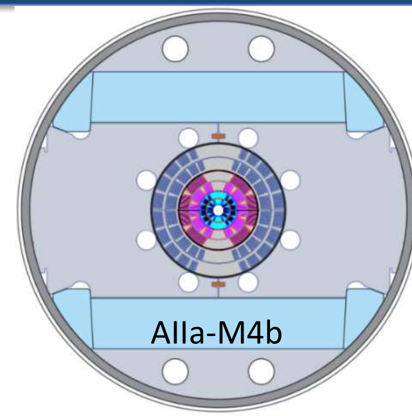
Trips to LBNL and NHMFL for technology learning and discussions (Alessio d'Agliano)

U.S. MAGNET DEVELOPMENT PROGRAM

Bi2212 SMCT insert goal correction







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

U.S. MAGNET DEVELOPMENT PROGRAM

Draft plan

FY23 Progress and Achievements:

1. Final Bi2212 coil design has been selected, the coil engineering design is complete, plastic parts printed.

FY23 next steps:

1. Bi2212 coil structure procurement, measurement and postprocessing – Aug 15, 2023
2. Coil plastic model winding and test – June 30, 2023
3. Coil tooling design, procurement and measurement – Aug 15, 2023
4. Bi2212 coil winding – Sep 1, 2023
5. Bi2212 coil reaction at NHMFL – Sep 30, 2023

FY24 Plan and milestones:

1. Bi2212 coil impregnation, measurement, instrumentation – Oct 30, 2023
2. 4L hybrid dipole assembly and instrumentation – Jan 30, 2024
3. 4L hybrid dipole test and data analysis – Mar 15, 2024
4. 2nd Bi2212 coil structure procurement, measurement and postprocessing – May 1, 2024
5. 2nd Bi2212 coil winding – Jun 1, 2024
6. 2nd Bi2212 coil reaction at NHMFL – Jul 1, 2024
7. 2nd Bi2212 coil impregnation, measurement, instrumentation – Jul 15, 2024
8. 2nd 4L or 6L hybrid dipole assembly and instrumentation – Aug 30, 2024
9. 2nd 4L or 6L hybrid dipole test and data analysis – Sept 30, 2024