U.S. MAGNET DEVELOPMENT PROGRAM

FNAL Bi2212 insert status and milestone correction

Alexander Zlobin

US-MDP General Meeting

06/22/2022

Outline

- FNAL Bi2212 program goals and milestones
- Previous work summary
- Work in progress, issues and next steps
- Milestones correction
- Summary

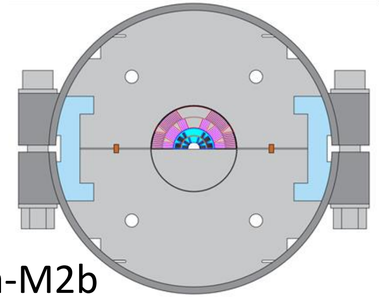
Bi2212 SMCT insert goals and milestones

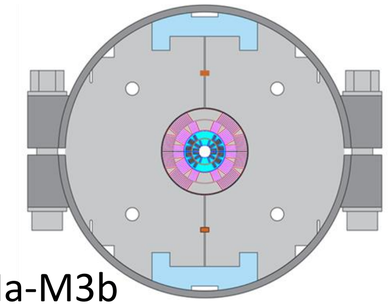
The Bi2212 SMCT insert R&D goals

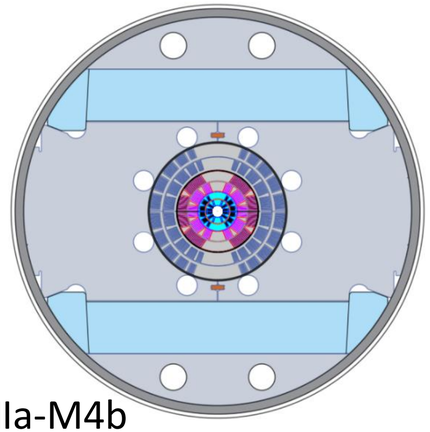
a) Development of the 17-mm aperture 2-layer Bi-2212 SMCT dipole coils with the design self-field of 5.5 T. This target field will be approached gradually by using the old and new generations of Bi-2212 wires.

b) Coil testing in the background fields of Nb_3Sn coils being developed within the MDP to understand key questions related to Bi-2212 magnet design and technology.

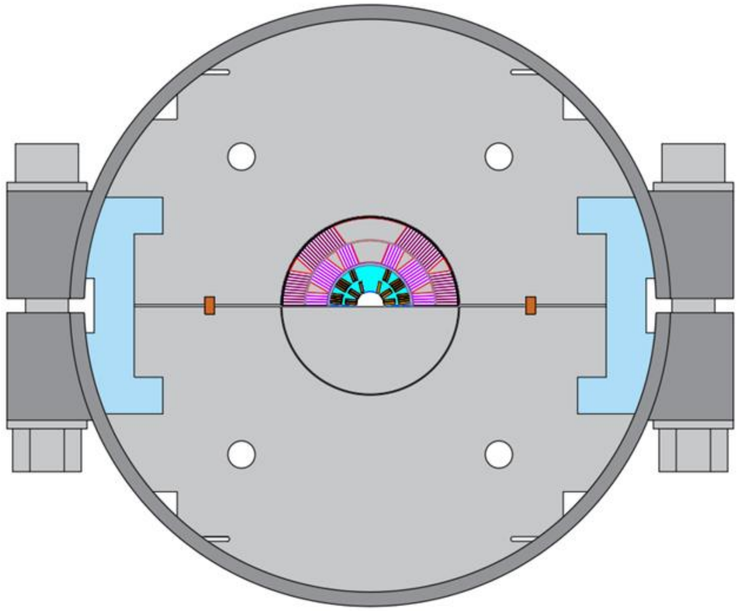
Milestone #	Description	Target
AIIa-M1b	Study strand damages due to cabling, transverse pressure dependence	April 2022
AIIa-M2b	Fabricate the first 2-layer 17-mm aperture Bi-2212 coil using LBNL cable. Coil test independently and inside a 60-mm aperture 2-layer Nb_3Sn dipole coil in mirror configuration.	July 2022
AIIa-M3b	Fabricate the 2nd 2-layer 17-mm aperture Bi-2212 coil using optimized Bi-2212 cable, coil structure, materials and technologies. Coil test independently and inside a 60-mm aperture 4-layer Nb_3Sn dipole coil in mirror configuration.	December 2022
AIIa-M4b	Fabricate another 2-layer Bi-2212 coil using optimized Bi-2212 cable and coil structure. Bi-2212 coil test independently and inside a 60-mm aperture 4-layer Nb3Sn dipole coil.	September 2024


AIIa-M2b


AIIa-M3b

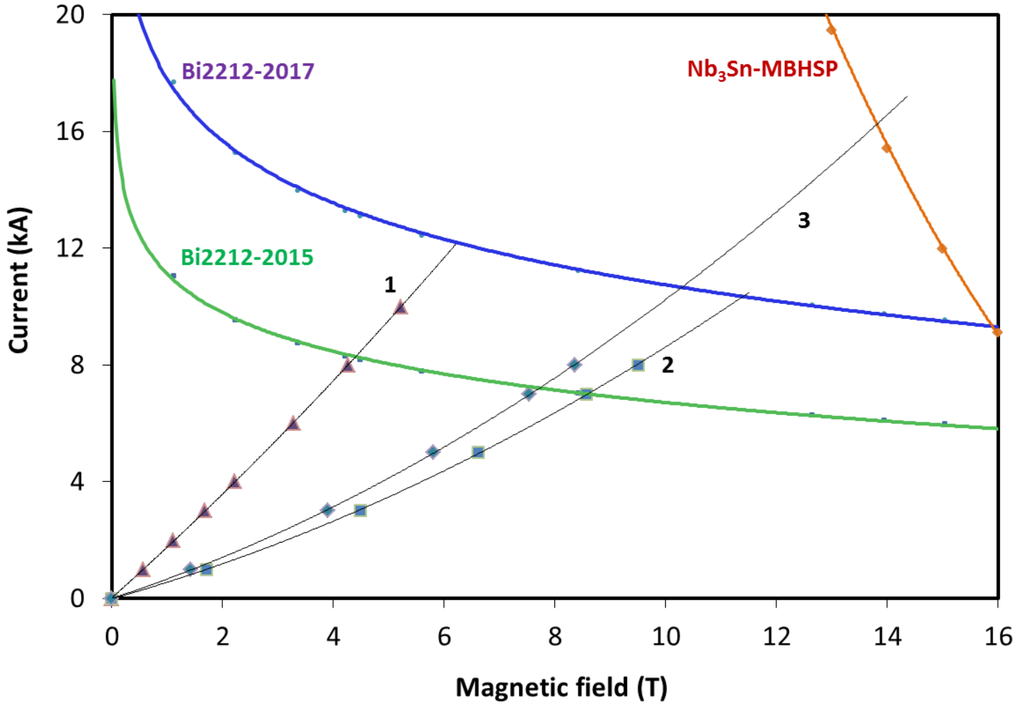

AIIa-M4b

Bi2212 4-layer mirror test parameters



AIIa-M2b

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



***$I_c(B)$* curves and load lines of Bi2212 (1, 2) and Nb_3Sn (3) coils in various test configurations:**

- **1 – single Bi2212 coil in dipole mirror;**
- **2 – Bi2212 coil in 4-layer hybrid mirror;**
- **3 – Nb_3Sn coil in the 4-layer dipole mirror.**

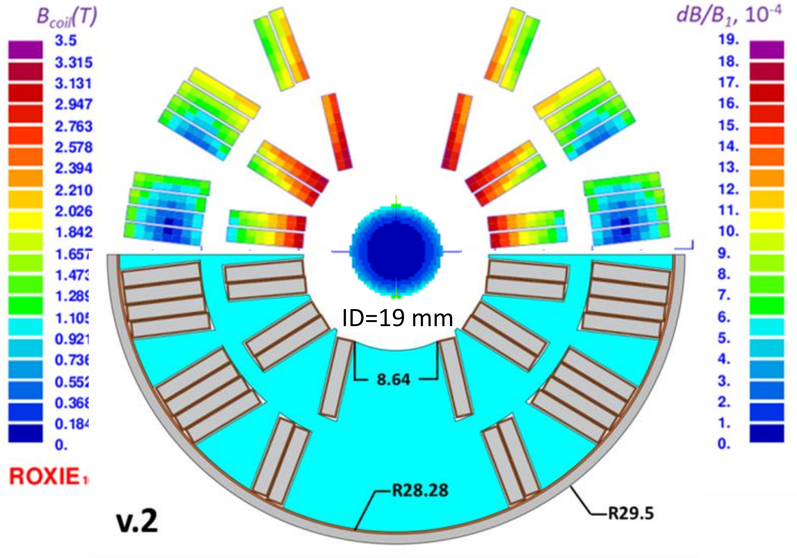
Dipole mirror structure developed at Fermilab and used to test superconducting dipole coils.

Bi2212 insert coil 2D design and parameters

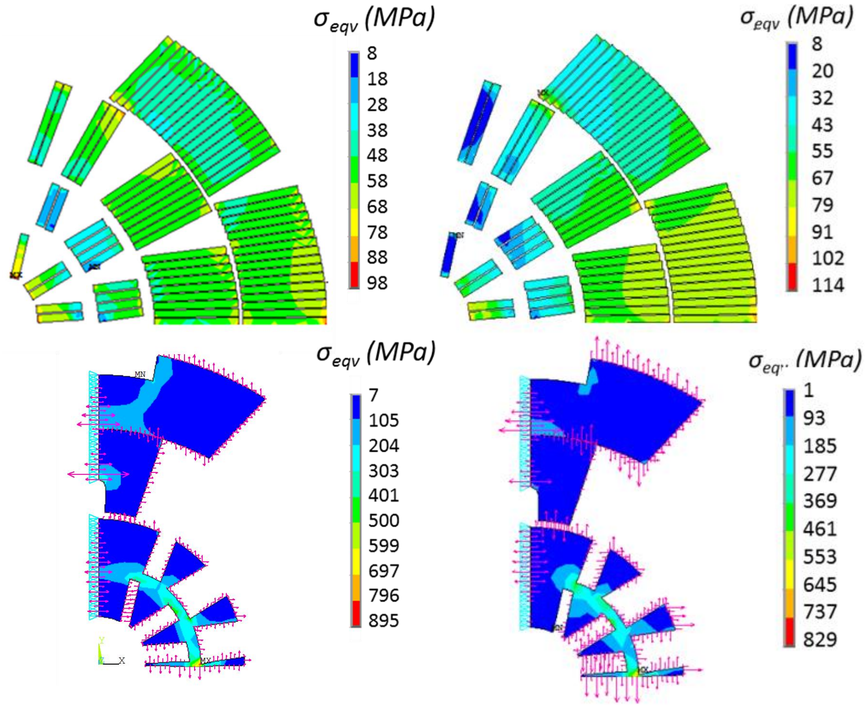
Bi2212 round composite wire and Rutherford cable.

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

The field uniformity in the aperture and the field distribution in the *optimized* coil cross-section at 6 kA.



Stress distribution in Bi2212 and Nb_3Sn coils in a dipole mirror at 0 and 8 kA.



Bi2212 insert parameters

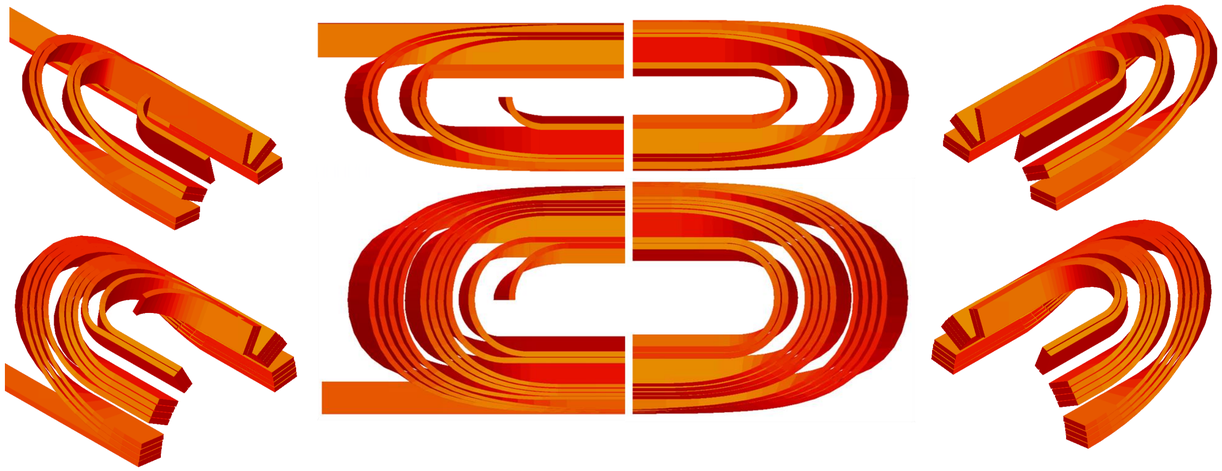
Parameter	Unit	Value
Number of layers		2
Number of turns		15 (5 IL+10 OL)
Coil ID/OD	mm	19/59
Maximum coil $TF=B_{max}/I$	T/kA	0.533
Maximum aperture $TF=B_o/I$	T/kA	0.529
Coil to aperture field ratio B_{max}/B_o		1.008

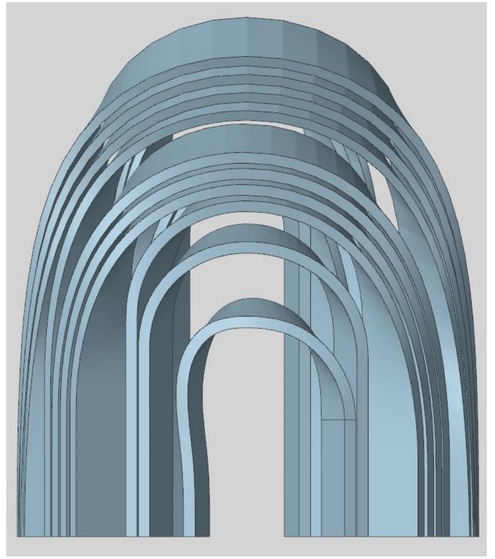
The maximum stress in Bi2212 coil with Inconel 718 structure is achieved at 8 kA

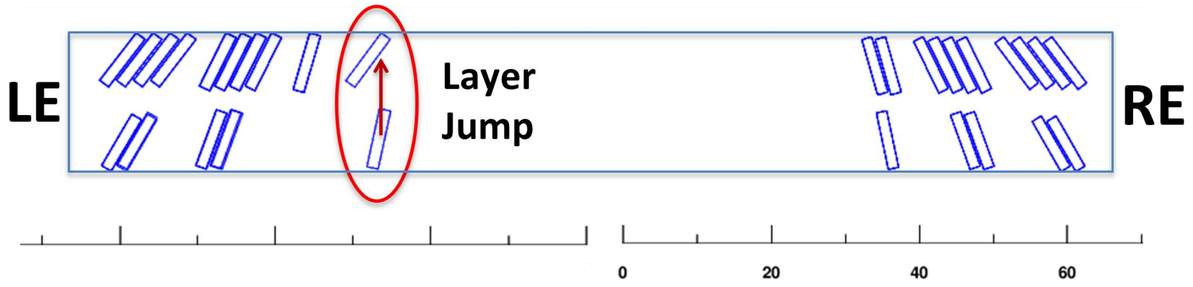
- Von Mises Stress in coil < 105 MPa
- Von Mises Stress in structure < 895 MPa.

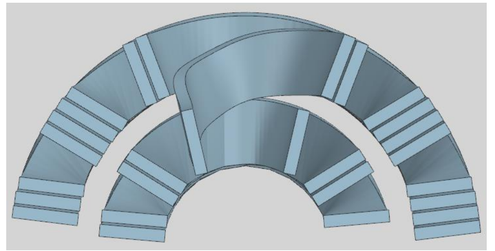
3D coil end design (*ROXIE*)

- Compact ends to provide reasonable length for the coil straight section
- Short block transitions in LE
- Smooth turn bends in both layers (constant perimeter design)
- Short layer jump by 3D cable bending to connect with the outer layer cable
- Coil length ~450 mm - determined by the cable length





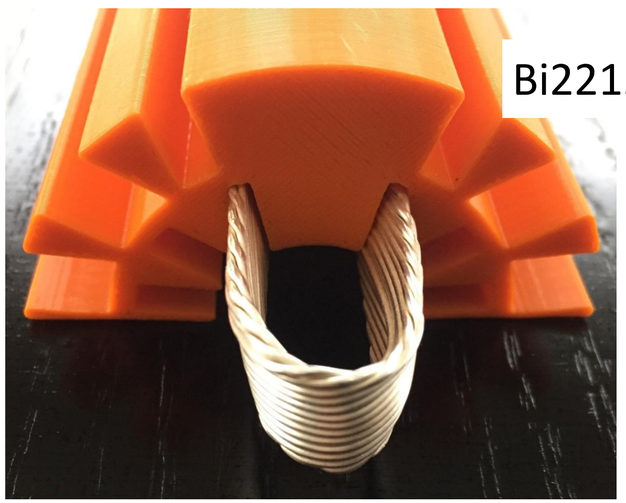




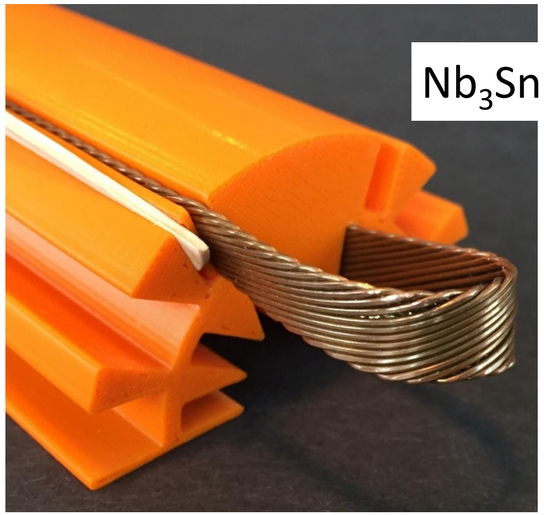
Effect of cable mechanical properties

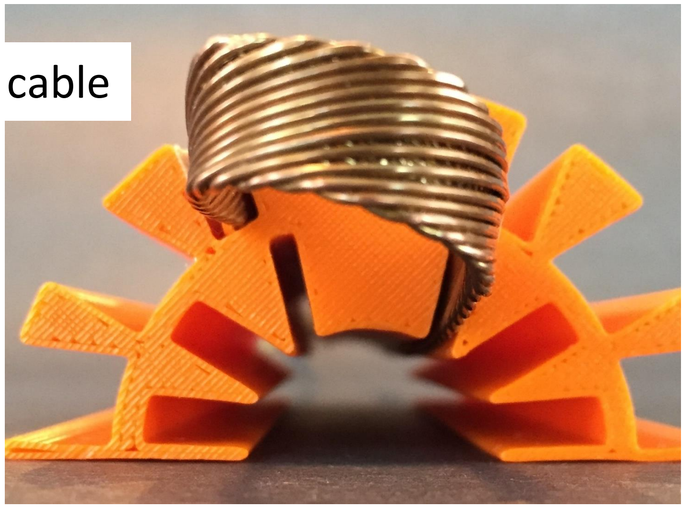
Practice winding of key turns using Bi2212, Nb_3Sn and Cu cables with the same width and slightly smaller thickness to check

- cable bending around poles
- layer jump

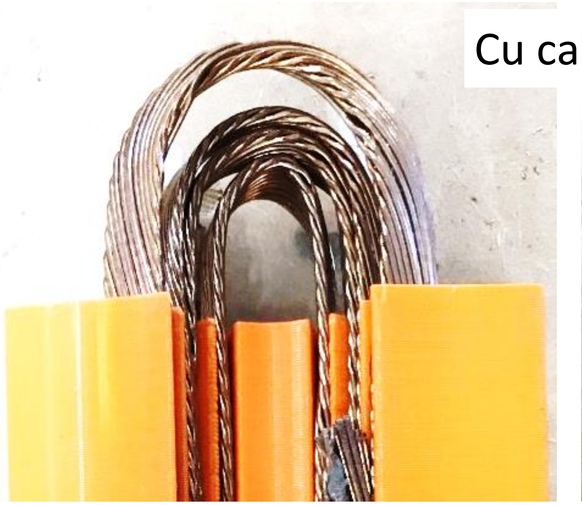


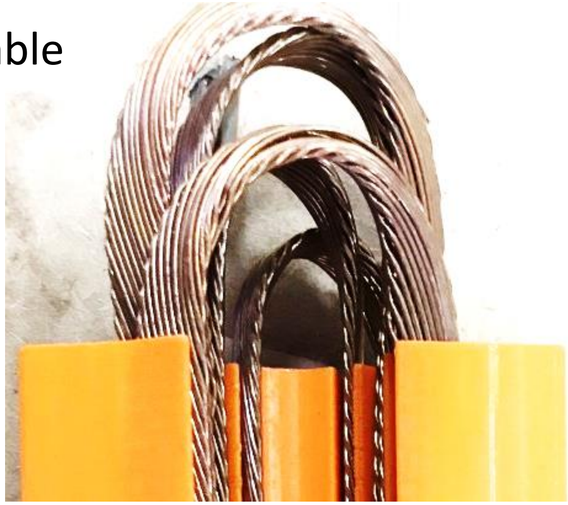
Bi2212 cable





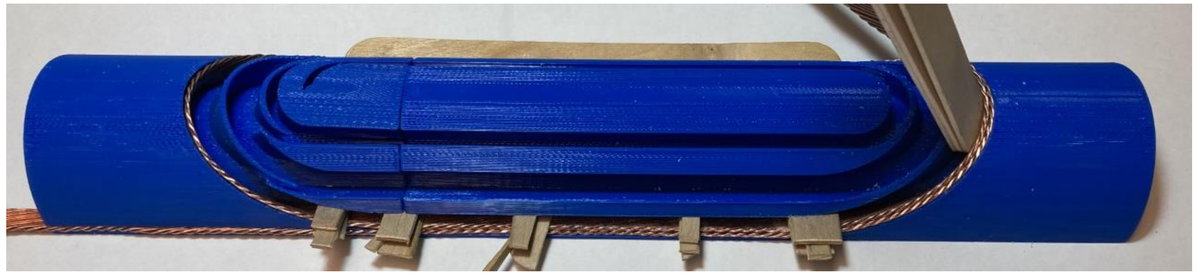
Nb_3Sn cable

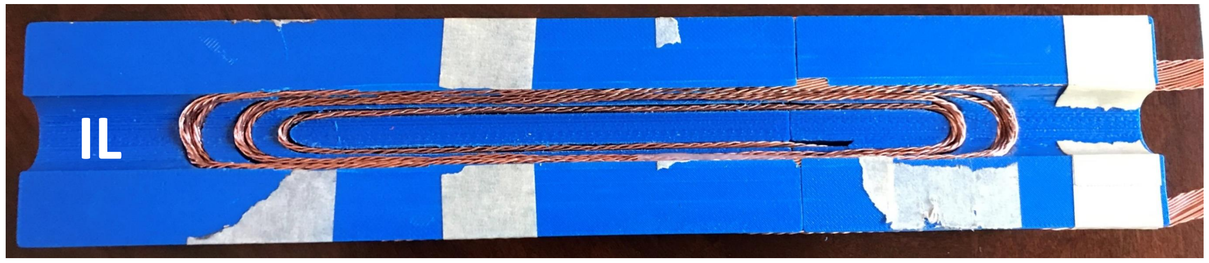


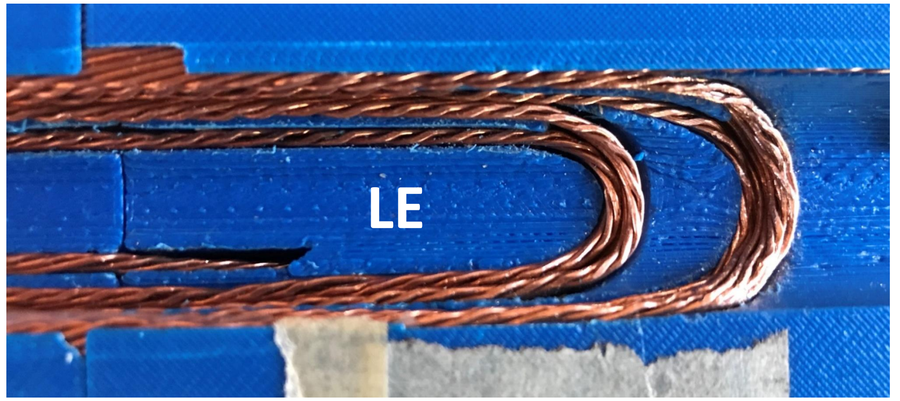


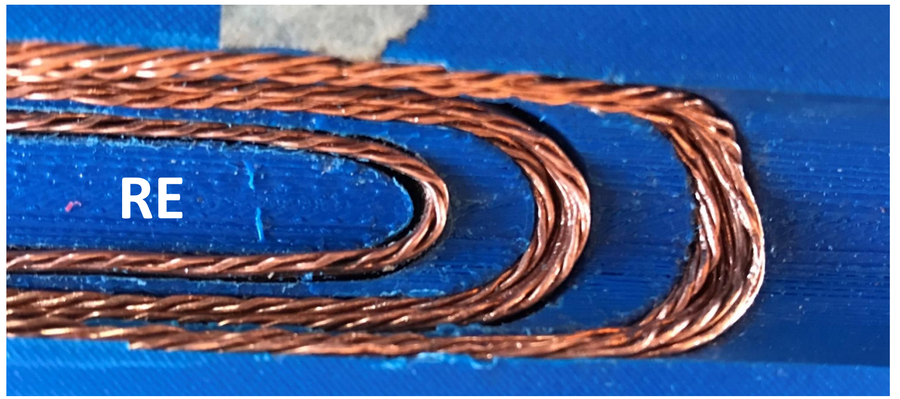
Cu cable

3D Practice coil winding









- 3D printed 3-piece part
- RE + straight section
- LE (short block transitions)
- Layer jump cap

- Several attempts with various cables – the best result with Cu cable
- OL: winding was OK (will be easier with Bi2212 cable)
- IL: mid-plain turns lost stability (popped-up strands) in both end
  - not mechanically stable cable, no-insulation

IL practice winding with removable end spacers

Better but still hard to preserve cable stability in coil ends

Lessons learned and next steps

Lessons learned:

- Coil winding into structure is possible **but not trivial**
  - winding of OL turns and the layer jump is **OK**
  - winding of IL pole turn (*small radius – possible large cable degradation*) and mid-plain turns (*3D bending – cable stability*) is **challenging**
- Cable mechanical properties and stability are critical

Work in progress:

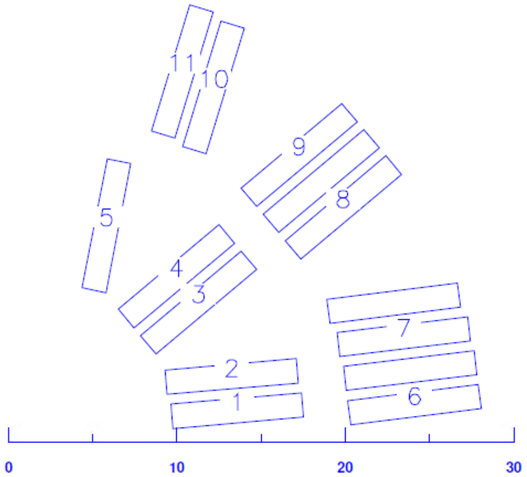
- Coil design optimization wrt winding and thicker ground insulation
- Winding plastic models to finalize the coil winding procedure
  - focus on the inner layer

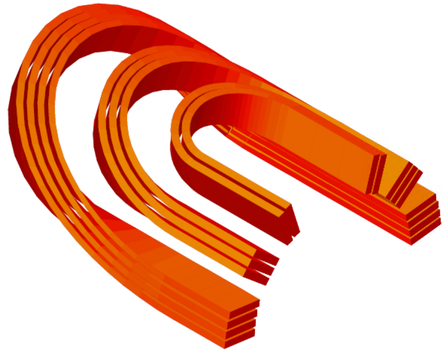
Coil design optimization

Design modifications:

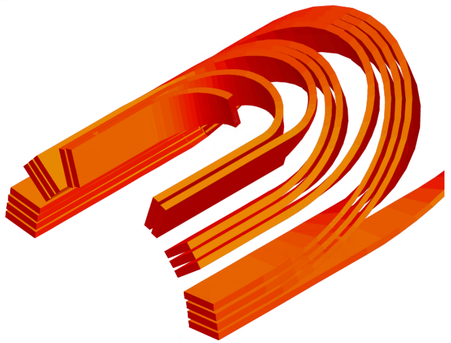
- **Thicker turn insulation**
- **Same OL design – 9 vs. 10 turns**
- **IL end turns in *separate longer* channels**

5-block, 11-turn design

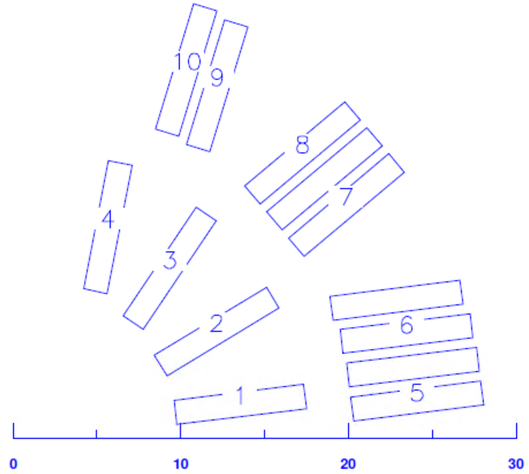


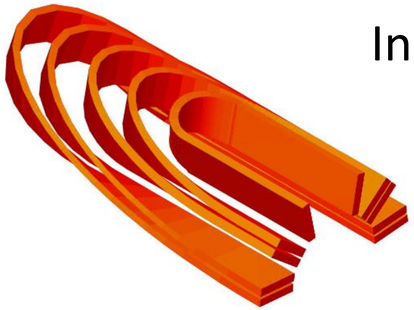


Outer layer

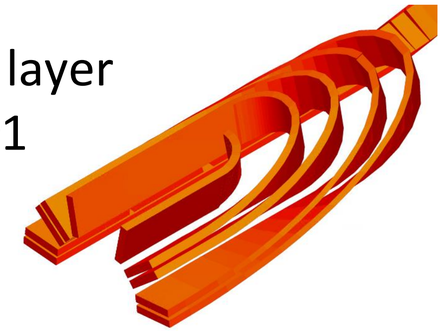


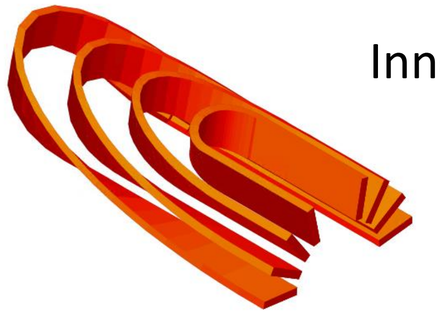
7-block, 10-turn design



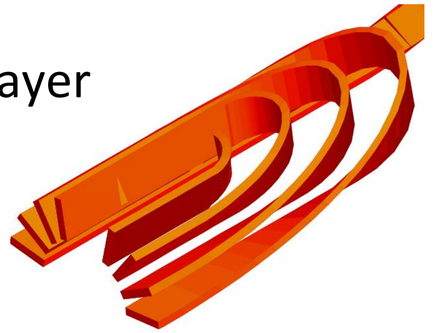


Inner layer v1





Inner layer v2



Coil part design and 3D model is in progress, practice coil winding is next

Summary

- The work on the Bi2212 insert coil design and technology continues
- Two new Bi2212 coil designs have been generated and will be studied using plastic models
  - focus on the coil inner layer
  - the goal is to select coil design by the end of August 2022 (*single OL is considered as a backup*)
- The development of the Bi2212 coil engineering design and fabrication tooling is in progress
  - coil ground insulation design
  - coil winding-reaction-impregnation tooling
- Bi2212 cable degradation study due to bending will start
- Coil fabrication and mirror assembly are planned in October-December 2022
- Tests of the first Bi2212 coil in dipole mirror configuration could start in January 2023
- Delay with respect to the present MDP task milestone is mainly due to the issues related to the coil winding technology and limited men-power – ***milestones to be corrected***

Milestone update

Milestones for the Stress-Managed Cosine-Theta (SMCT) effort within the Bi-2212 area of the MDP

Milestone #	Description	Target	Status	Updated Target	Requestor	Comments
AIIa-M1b	Study strand damages due to cabling, transverse pressure dependence	Apr-22	Not started	**n/a**	A. Zlobin, E. Barzi	Remove
AIIa-M2b	Fabricate the first 2-layer 17-mm 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.	Jul-22	In progress	**Apr-23**	A. Zlobin	Modify to: "Design and fabricate the first ~~2-layer 17-mm~~ 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."
AIIa-M3b	Fabricate the 2nd 2-layer 17-mm aperture Bi-2212 coil using optimized Bi-2212 cable, coil structure, materials and technologies. Coil test independently and inside a 60-mm aperture 4-layer Nb_3Sn dipole coil in mirror configuration.	Dec-22	Not started	**Dec-23**	A. Zlobin	Modify to: "Design and fabricate the 2nd ~~2-layer 17-mm~~ small-aperture Bi-2212 coil using optimized Bi-2212 cable, coil structure, materials and technologies. Coil test independently and inside a 60-mm aperture 4-layer Nb_3Sn dipole coil in mirror configuration. "
AIIa-M4b	Fabricate another 2-layer 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.	Sep-24	Not started	**Dec-24**	A. Zlobin	Modify to: "Fabricate another ~~2-layer~~ 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.