U.S. MAGNET DEVELOPMENT PROGRAM

MT27

Integration of Bi-2212 and Nb_3Sn CCT magnets for a hybrid magnet test

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11/19/2021

Outline

- Introduction: Plans for hybrid tests at LBNL
- Preparation for the CCT5-BIN5c hybrid test
- Preparation for the CCT6-BiCCT1 hybrid test

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Plans for hybrid tests at LBNL

Hybrid test plans:

Outsert:

- Nb_3Sn Canted-Cosine-Theta (CCT) dipole magnets (CCT5, CCT6)

Inserts: Focus of this talk

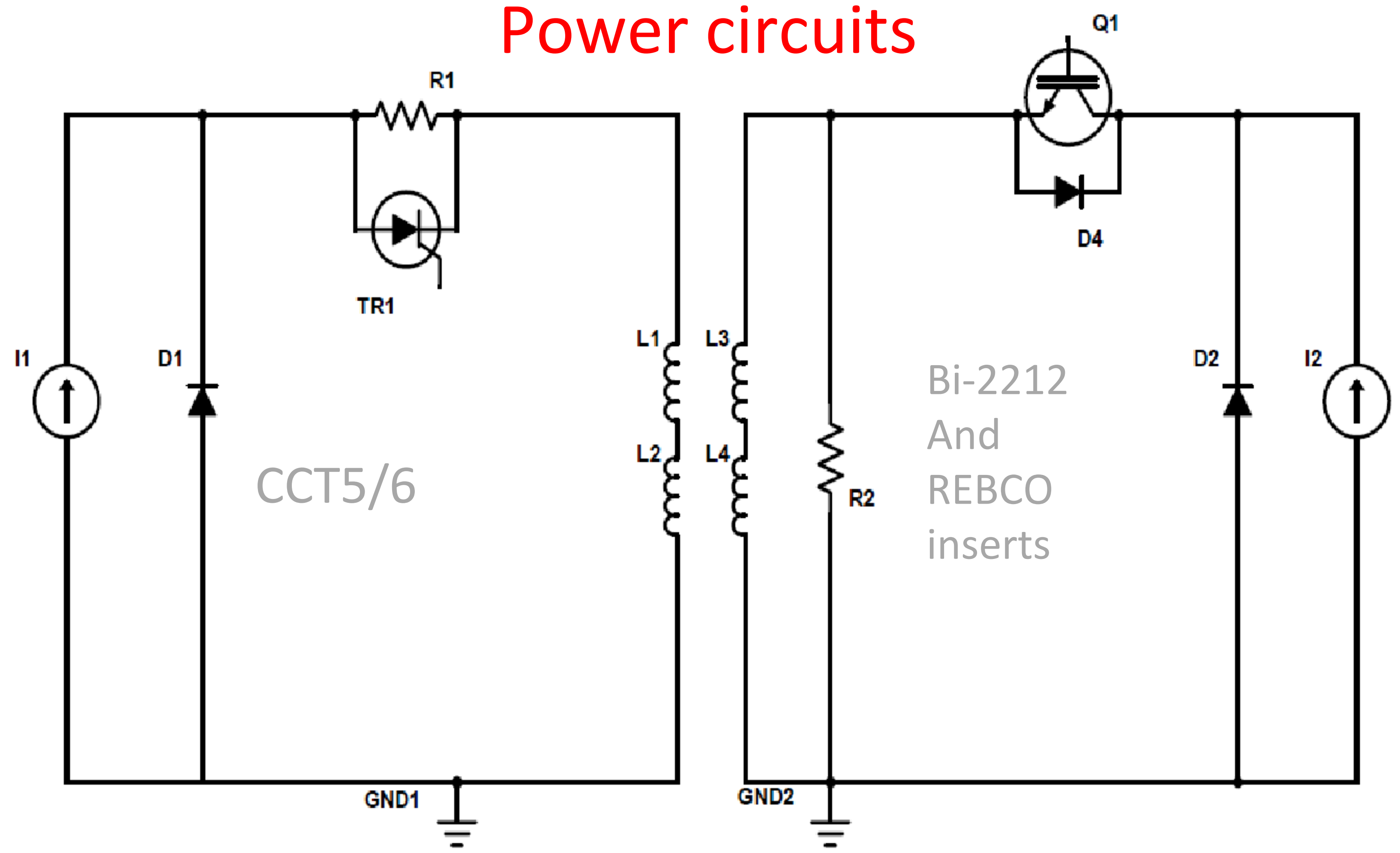
- Bi-2212 CCT dipole magnets (BIN5c, BiCCT1)
- Possibility of testing Rebco (CORC) CCT magnets (CT3 with only 2 layers) (X. Wang)

Necessary upgrades:

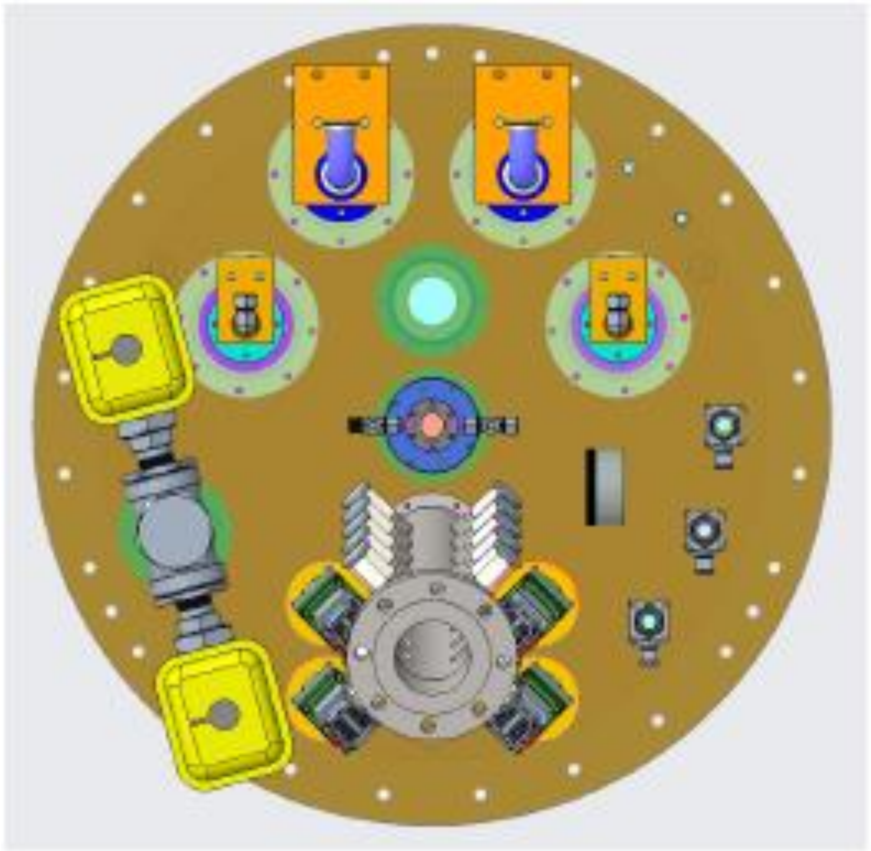
Upgrade the test facility at LBNL for testing LTS-HTS hybrid magnets:

- Two independent power circuits
- A new header

Power circuits



Header



(CAD by Aurelio Hafalia Jr., Regi Lee)

Outline

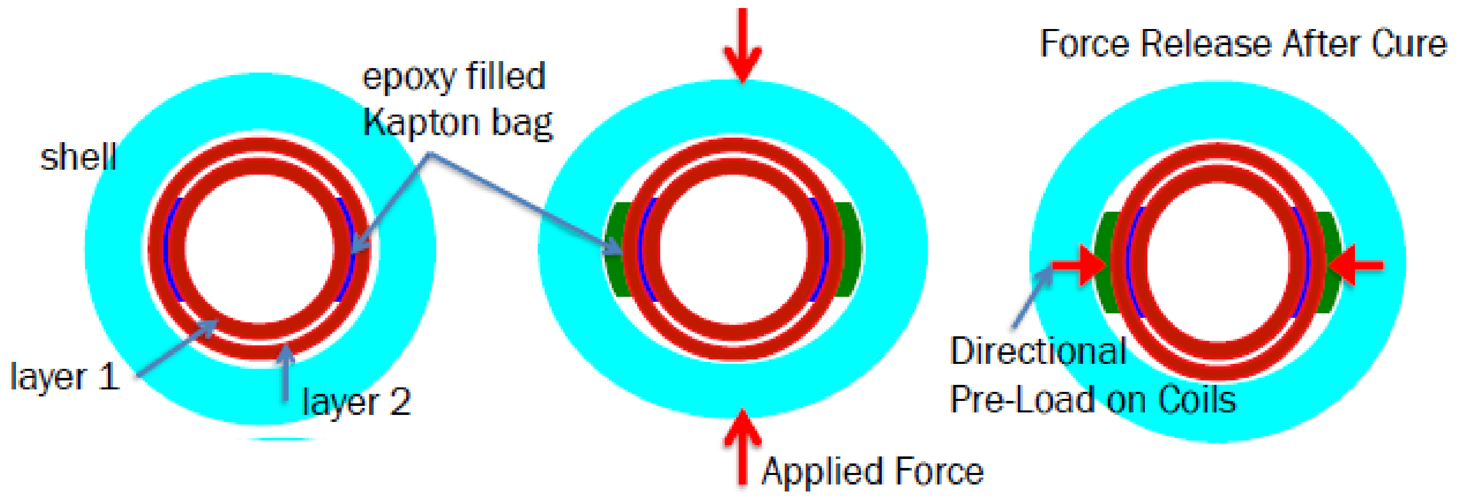
- Introduction: Plans for hybrid tests at LBNL
- **Preparation for the CCT5-BIN5c hybrid test**
- Preparation for the CCT6-BiCCT1 hybrid test

CCT5 and BIN5c main characteristics

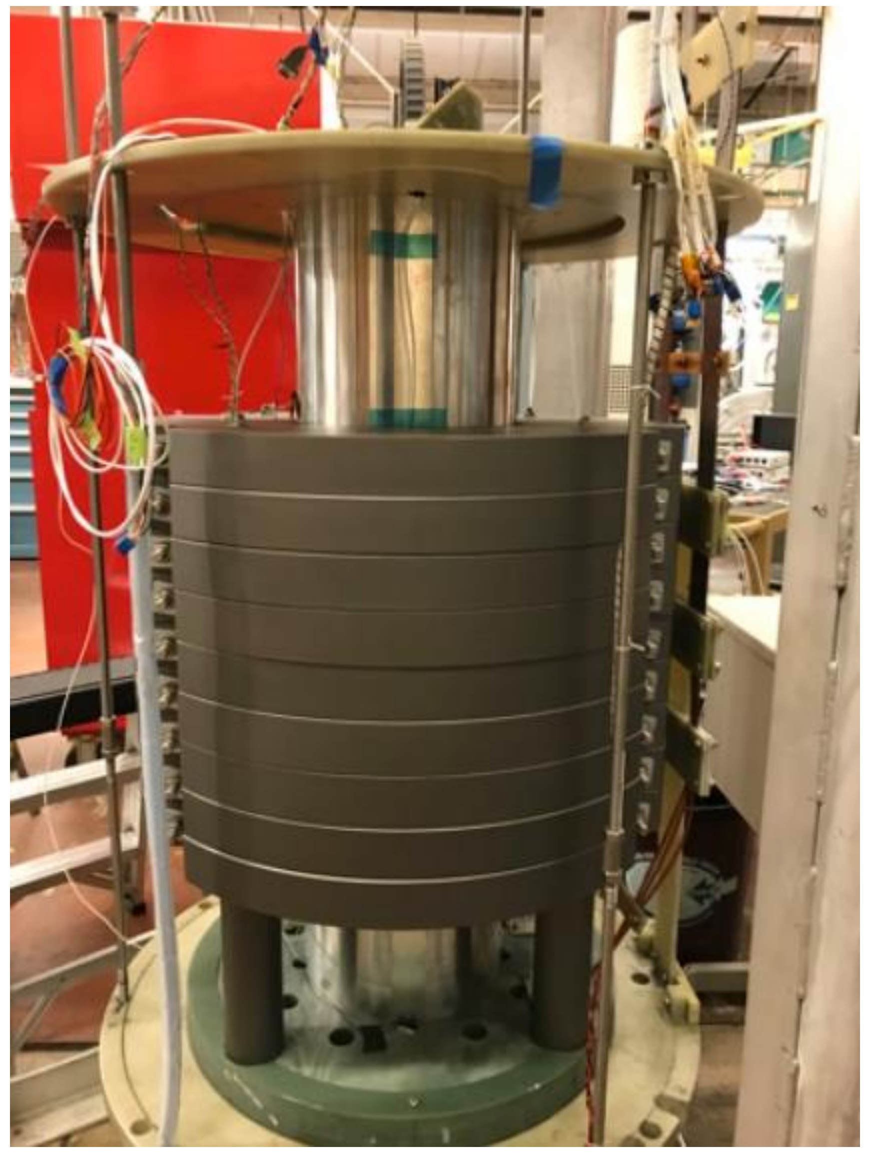
CCT5:

- Nb_3Sn two-layer CCT magnet, 90 mm clear bore, 1 m long
- Layers impregnated individually
- Layers assembled using bend and shim technique
- Tested at LBNL in 10/2018
- Produced ~8 T in standalone configuration at 80% of its short sample limit

Bend and shim technique



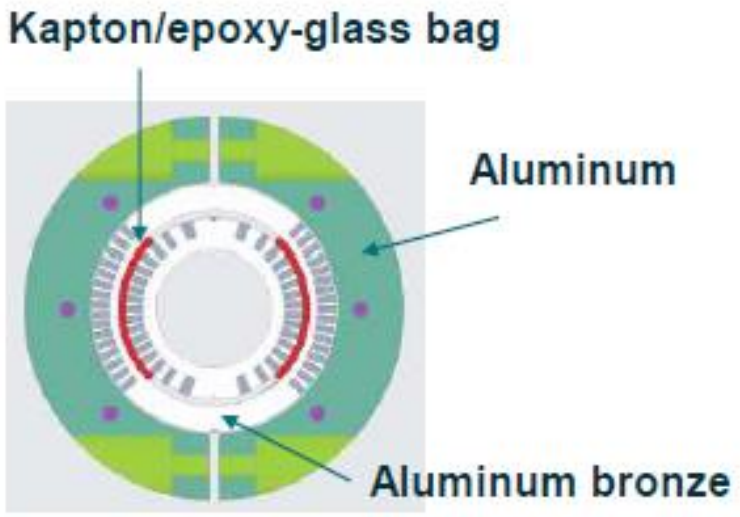
CCT5 on header



BIN5c:

- Bi-2212 two-layer CCT magnet, 30.8 mm clear bore, 39 cm long
- Coils reacted using the Deltech overpressure processing heat treatment furnace at NHMFL
- Layers impregnated independently
- Layers assembled using epoxy-filled Kapton bags
- Tested at LBNL in 06/2021
- Produced 1.64 T in standalone configuration at 65% of its short sample limit

*(see performance details in the poster WED-PO2-111-08)



BIN5c on header

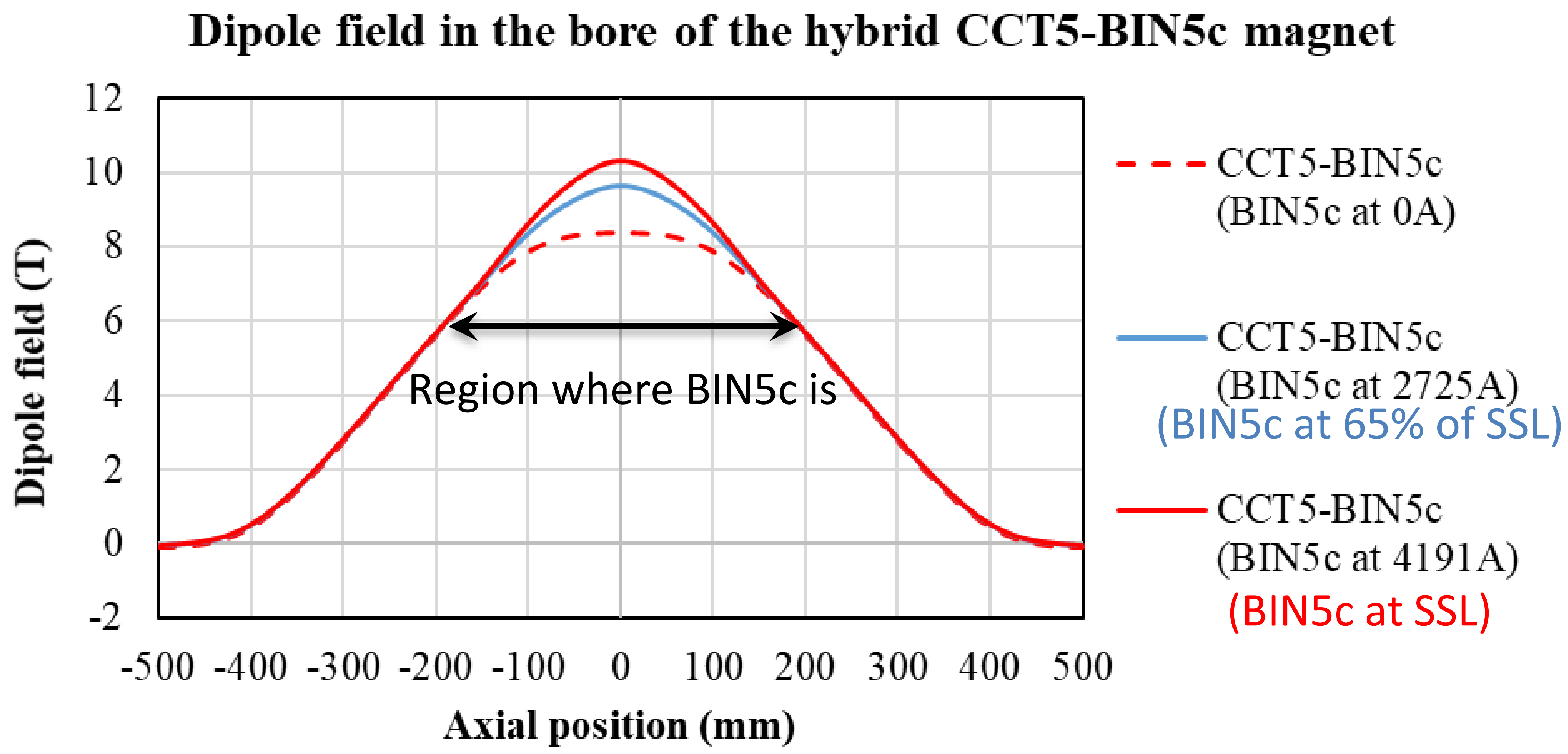
Practical considerations for the CCT5-BIN5c hybrid test

Key points:

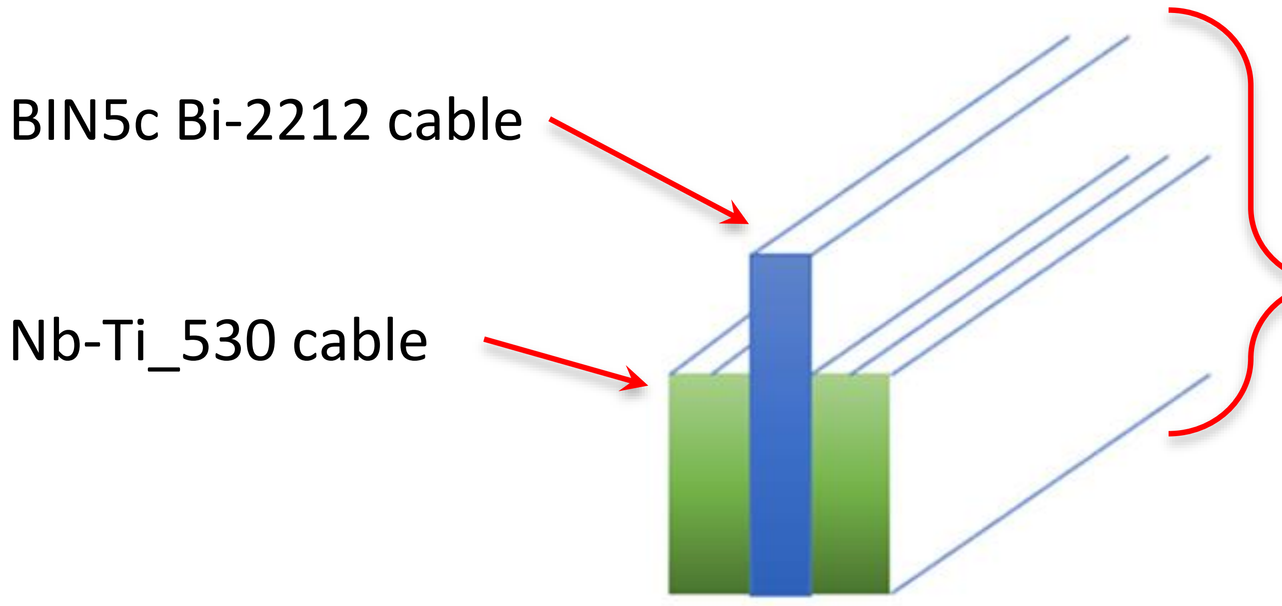
- CCT5 and BIN5c were designed independently
- Their main goal was to prove Nb_3Sn CCT technology and Bi-2212 CCT technology, respectively (not the hybrid test)
- For this reason the structure of BIN5c had to be adapted during the fabrication process to be compatible with CCT5 for the hybrid test

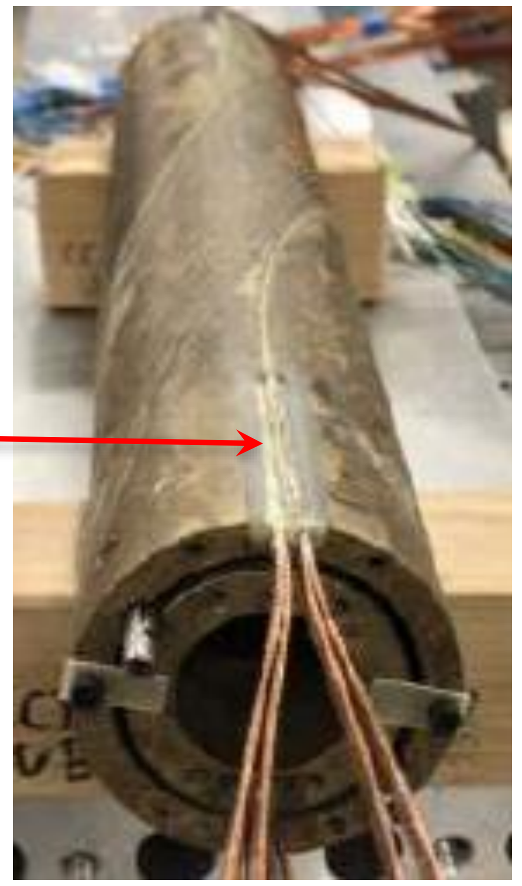
Length mismatch:

- CCT5 is 1 m long and BIN5c is 39 cm long
- Due to the length mismatch, the splices of BIN5c are in the ~6 T region of CCT5
- Therefore, we chose four Nb-Ti_530 cables per joint, in contact with to LHe to ensure good heat dissipation in a 30 cm long region, at 4500 A



Configuration of the BIN5c splices:





Peak field increase in CCT5 in hybrid configuration

The radial distance between the outer coil of BIN5c and the inner coil of CCT5 is 2 cm

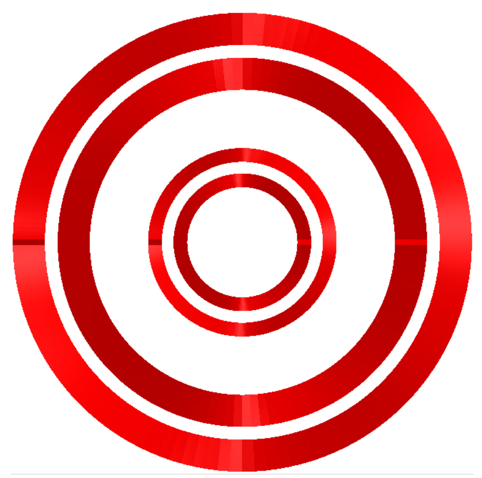
The increase of the peak field in the Layer 1 of CCT5 when working in hybrid configuration is:

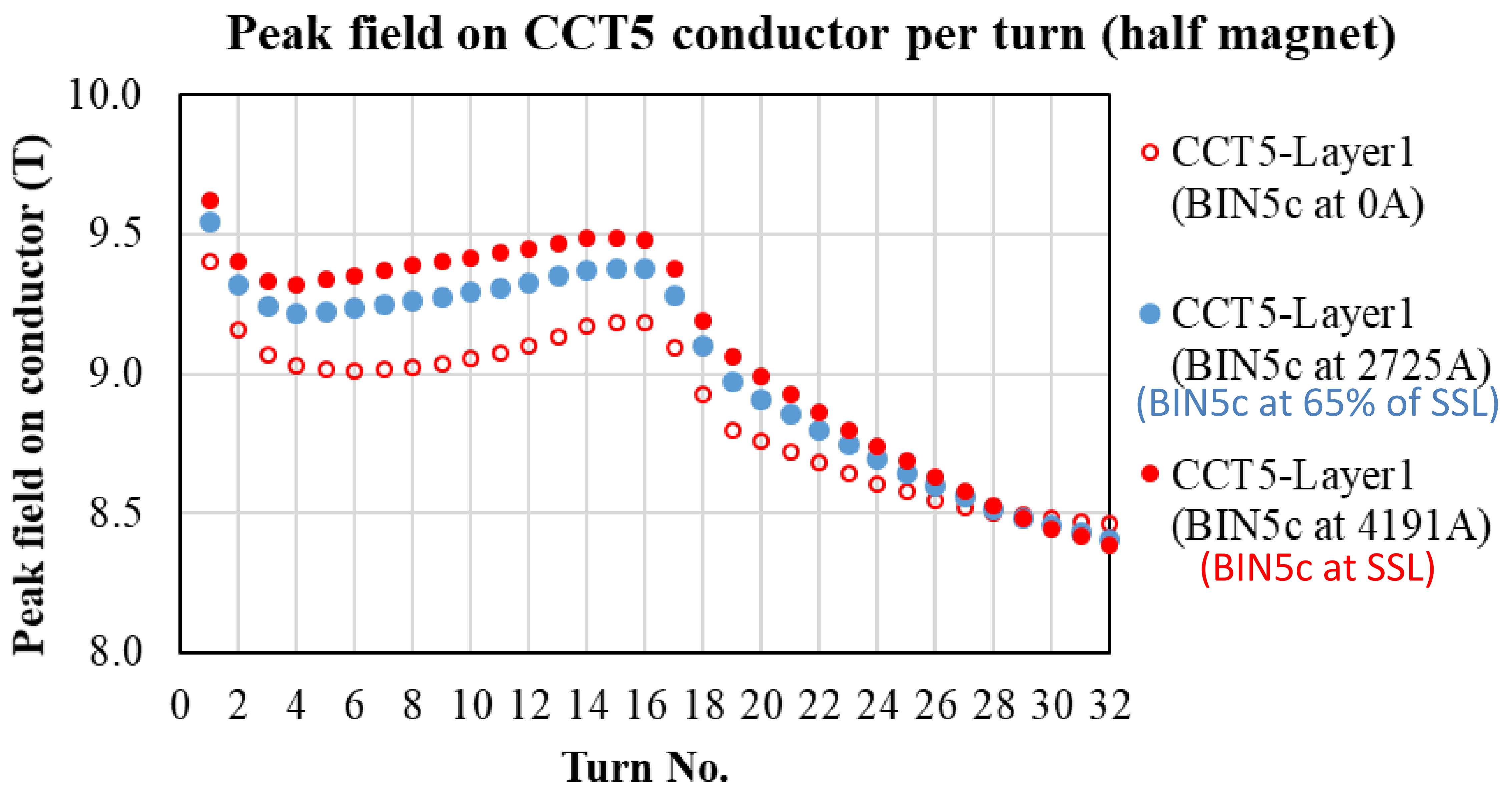
- 0.2 T if BIN5c is powered to its SSL (not feasible)
- 0.15 T if BIN5c is powered to 65% of its SSL (performance reached during test in standalone configuration at 4.2 K)

With this field increase, the margin of CCT5 would be reduced in:

- 0.9% for 0.2 T increase
- 0.7% for 0.15 T increase

The peak field increase in CCT5 is not a concern for working safely





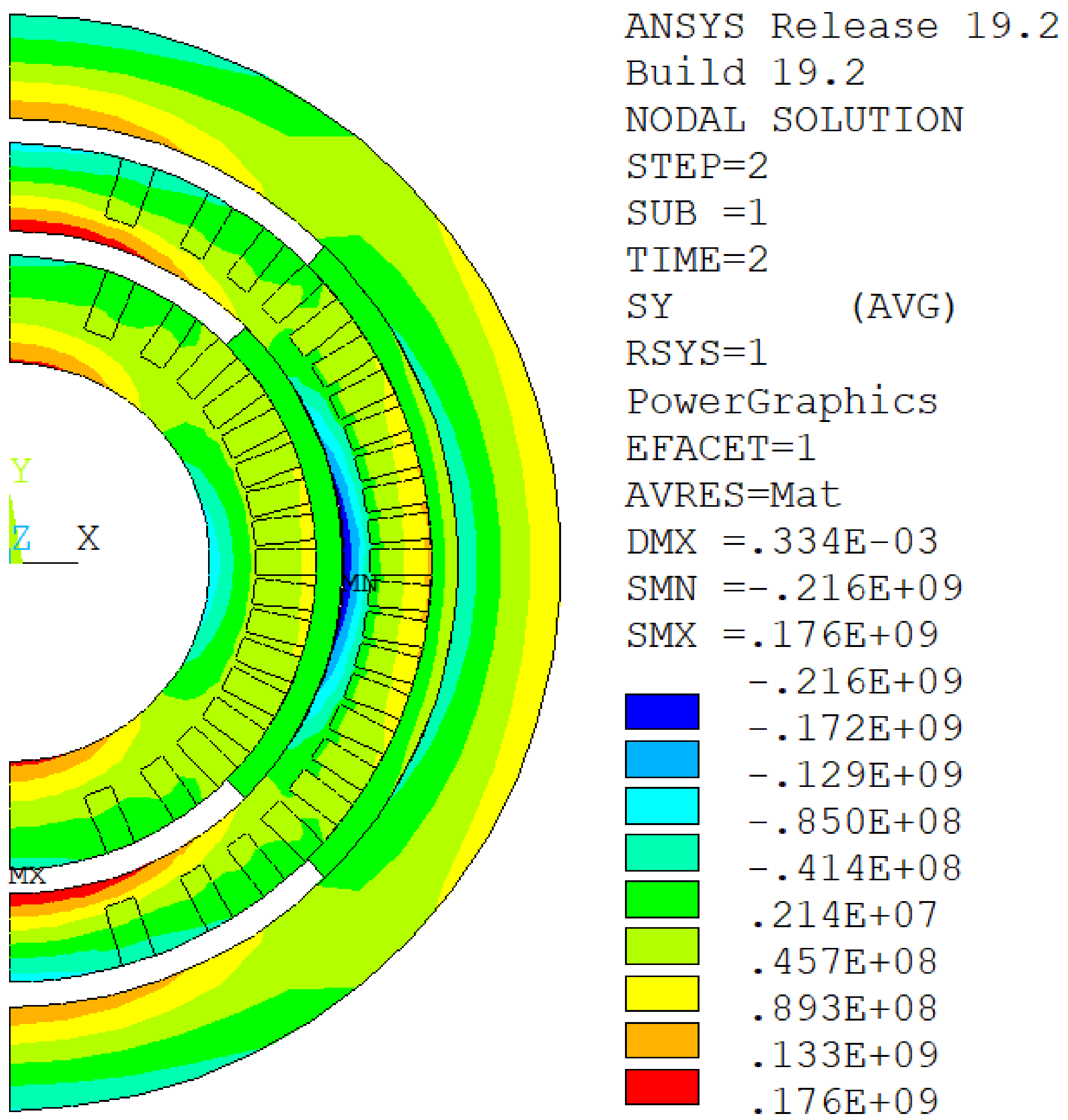
Mechanical behavior of BIN5c inside CCT5

- BIN5c coils are impregnated independently
- The assembly of the magnet consists of Kapton bags filled with epoxy-glass, spanning +/- 45 deg from the midplane, placed between the coils and between the magnet and the aluminum shell
- In hybrid configuration, the outer layer bends such that a gap opens at the midplane
- Still under discussion how the mechanical coupling between BIN5c and CCT5 will take place in order to ensure contact at the midplane during operation

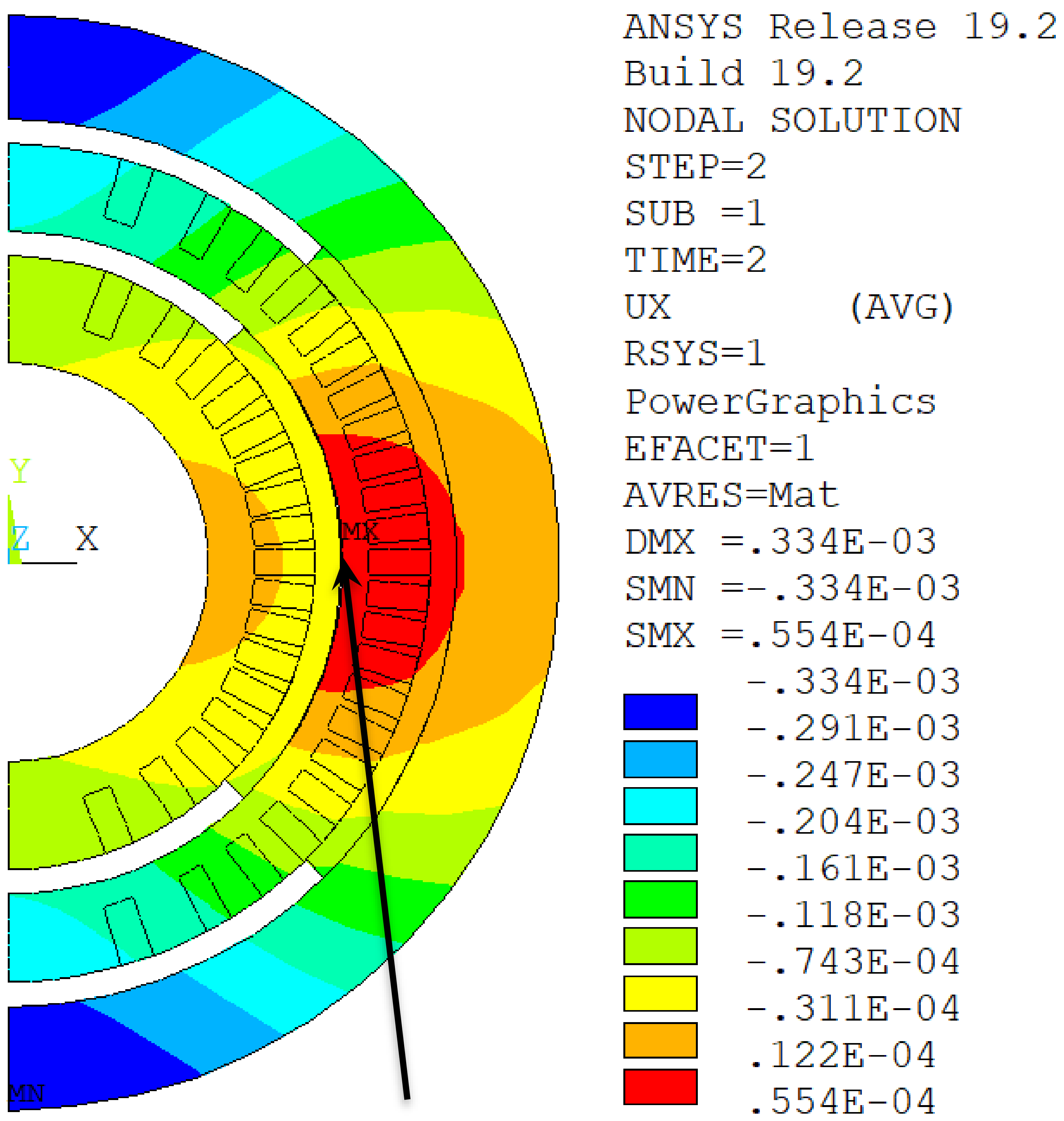
BIN5c under background field of 8T (inside CCT5)

(BIN5c at 65% of SSL and CCT5 at ~81% of SSL)

Azimuthal Stress (Pa)

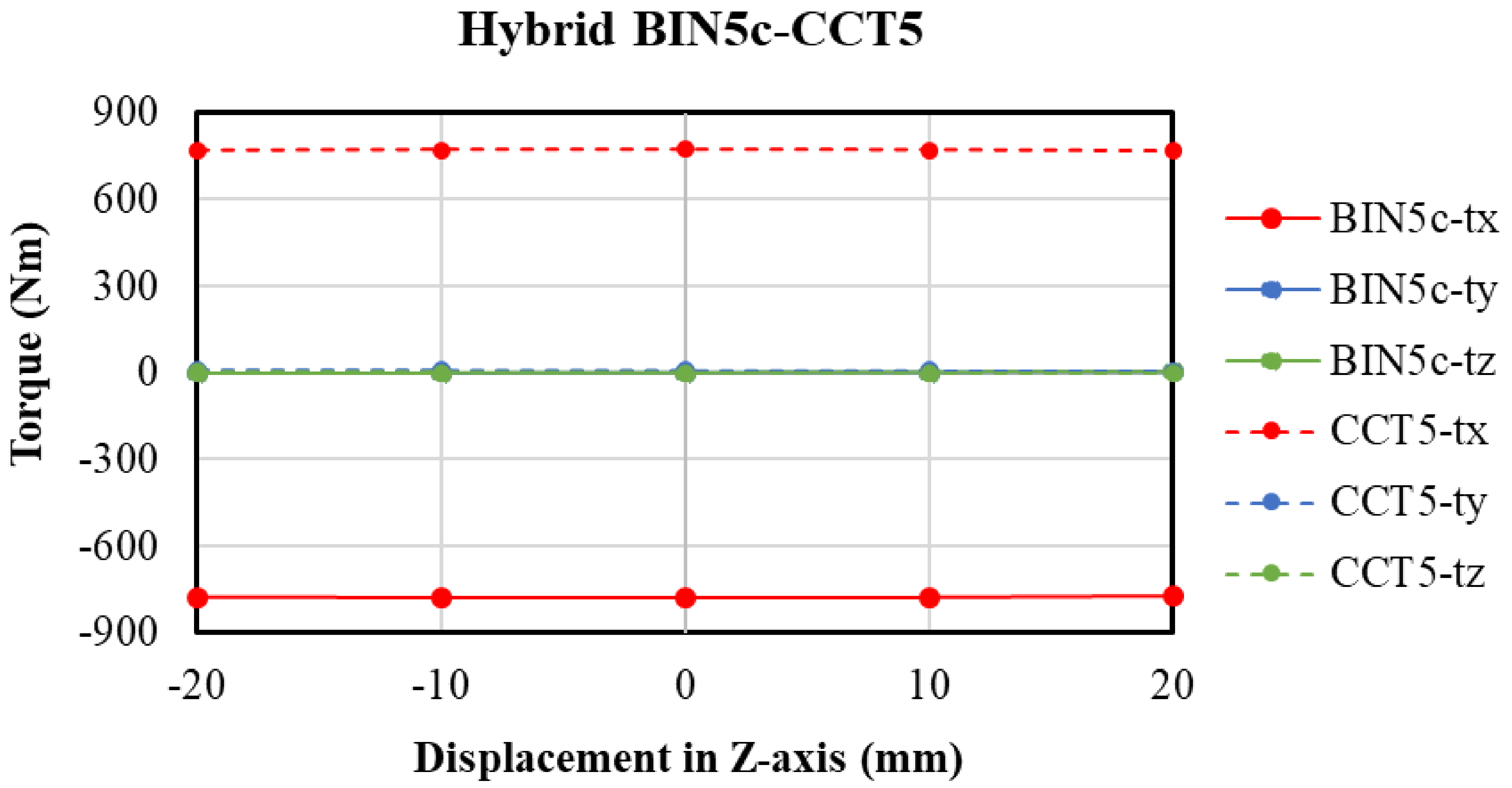


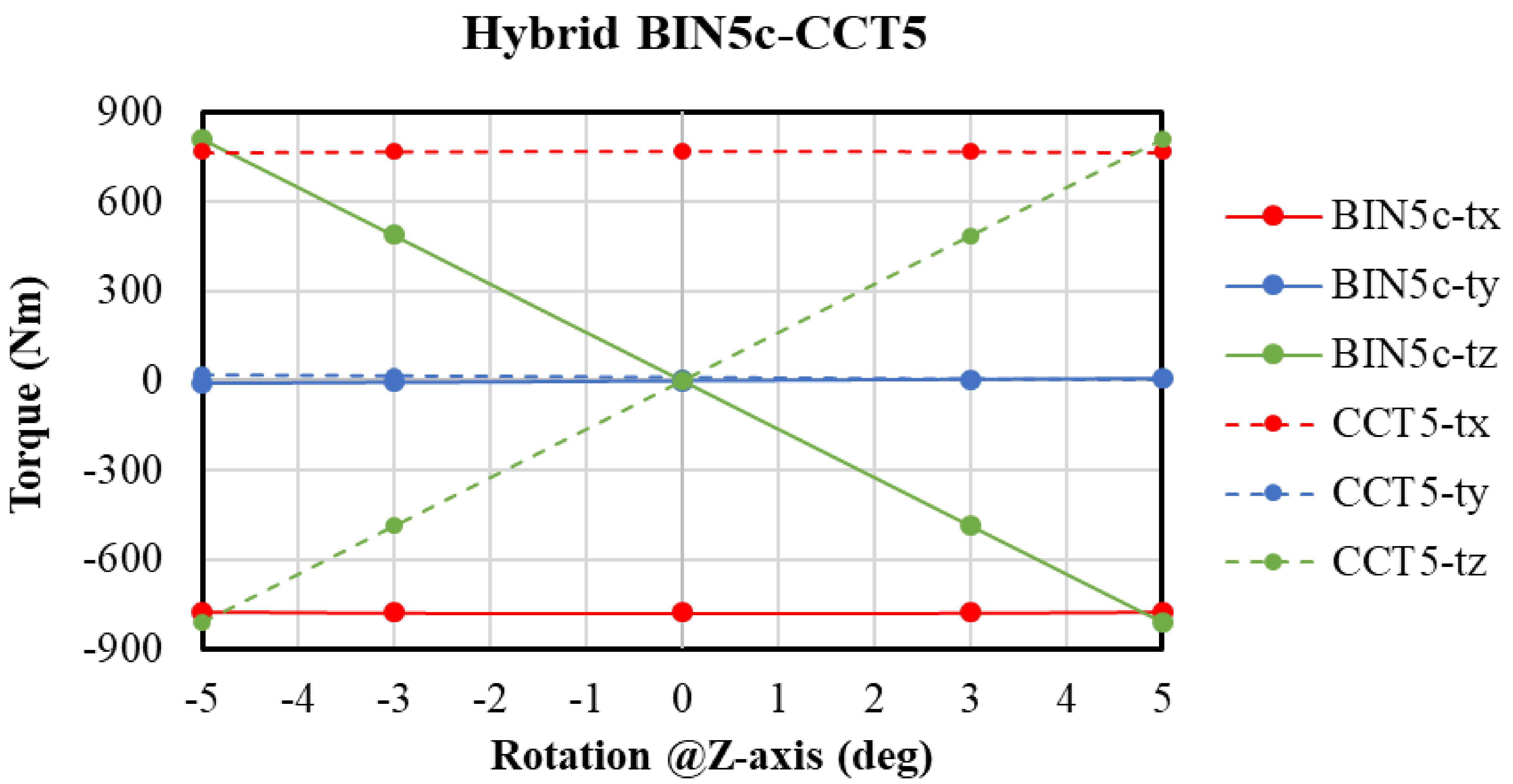
Radial displacement (m)



Gap in BIN5c in hybrid configuration

Torque in the hybrid CCT5-BIN5c magnet



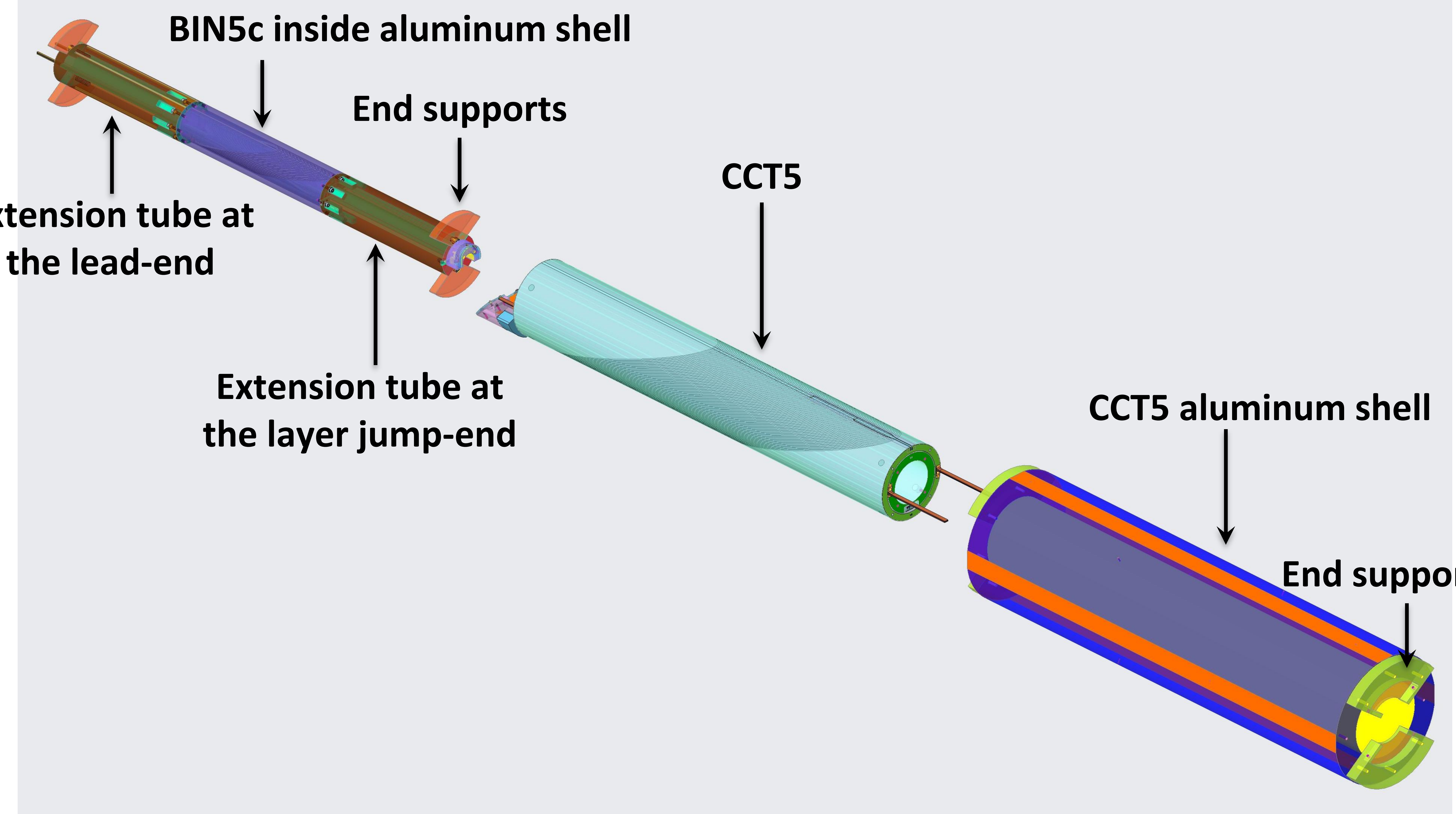


- The only misalignment that influences the torque is the rotation about the z-axis
- There is always a torque about the x-axis between the magnets (even in the perfectly aligned position)
- The torque can be handled by assembling the magnets using end supports (no need for radial contact between the magnets)
- It is desirable to minimize the mechanical coupling between the magnets. However, it is being considered adding shims at the pole region or at the midplane as a redundant measure to handle the torque

Additional preparation of BIN5c to account for the hybrid test

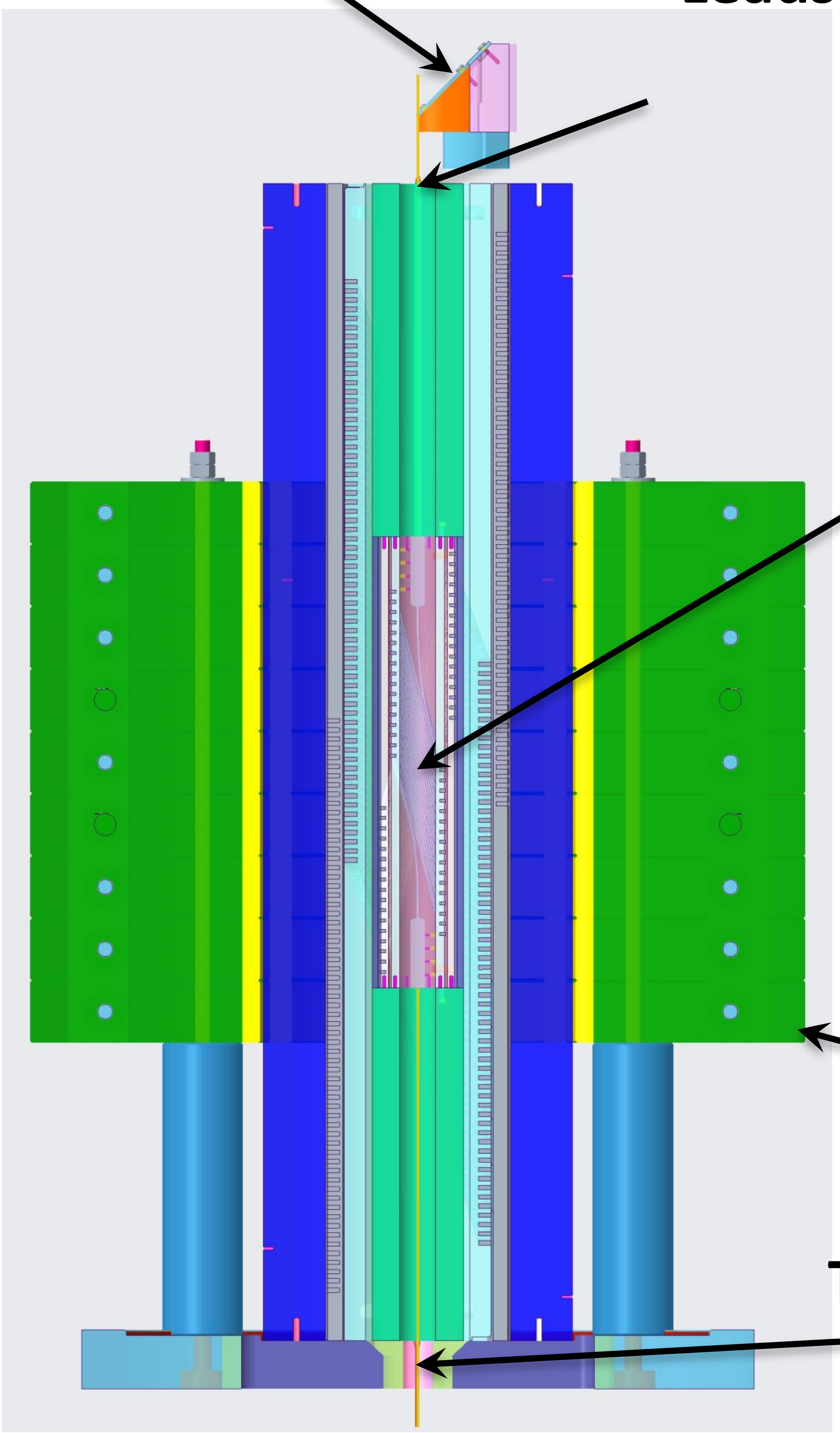
- For the hybrid test, extension tubes will be installed at the ends of BIN5c to match the length of CCT5
- The assembly of BIN5c inside CCT5 will rely on end supports
- The voltage tap wires and Nb-Ti leads will be guided through the lead-end extension tube towards the header of the cryostat
- Nb-Ti cables will also be guided through the other extension tube for the installation of the layer jump

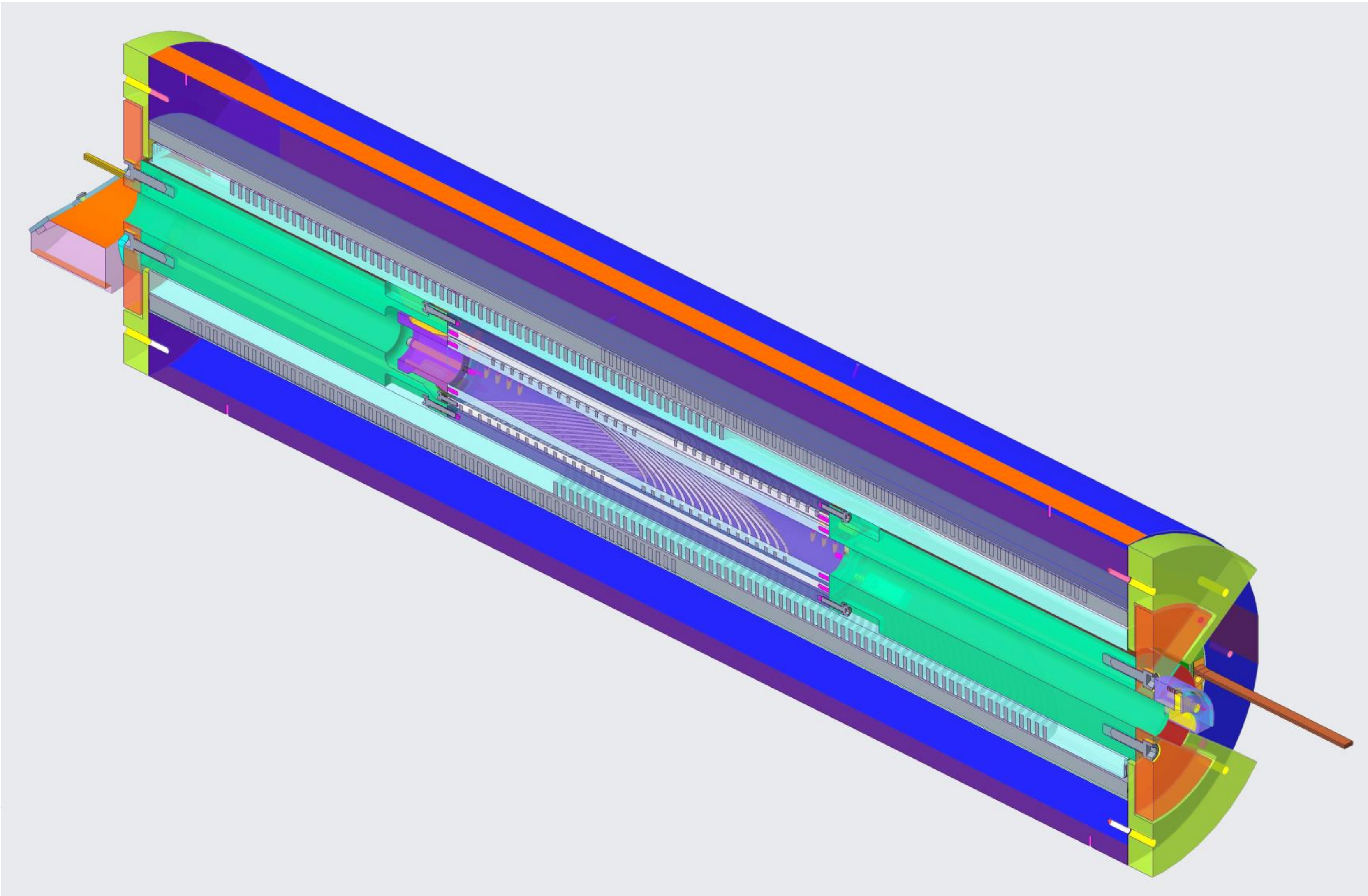
Assembly of BIN5c inside CCT5

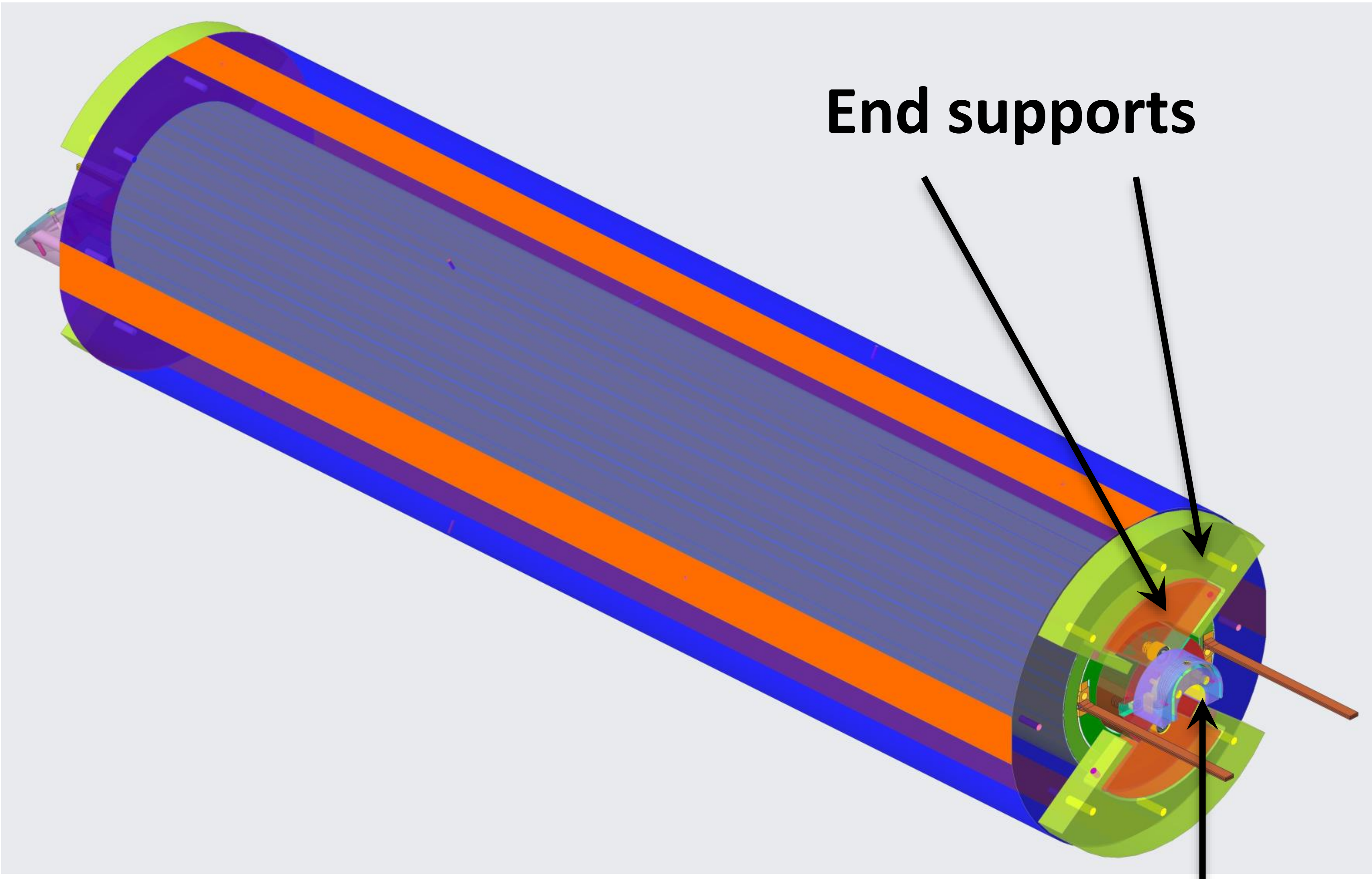


(CADs by Aurelio Hafalia Jr.

Additional preparation of BIN5c to account for the hybrid test





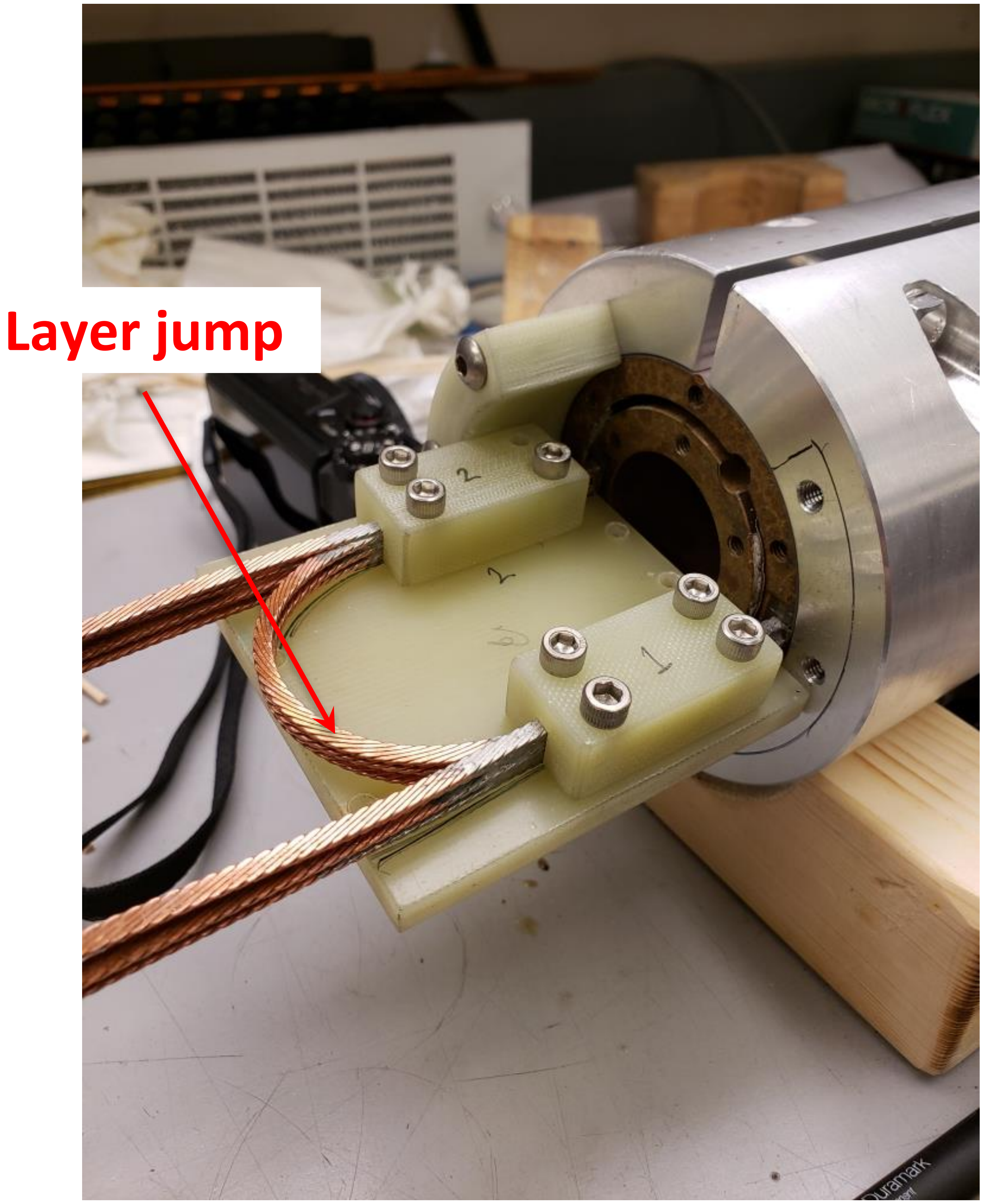


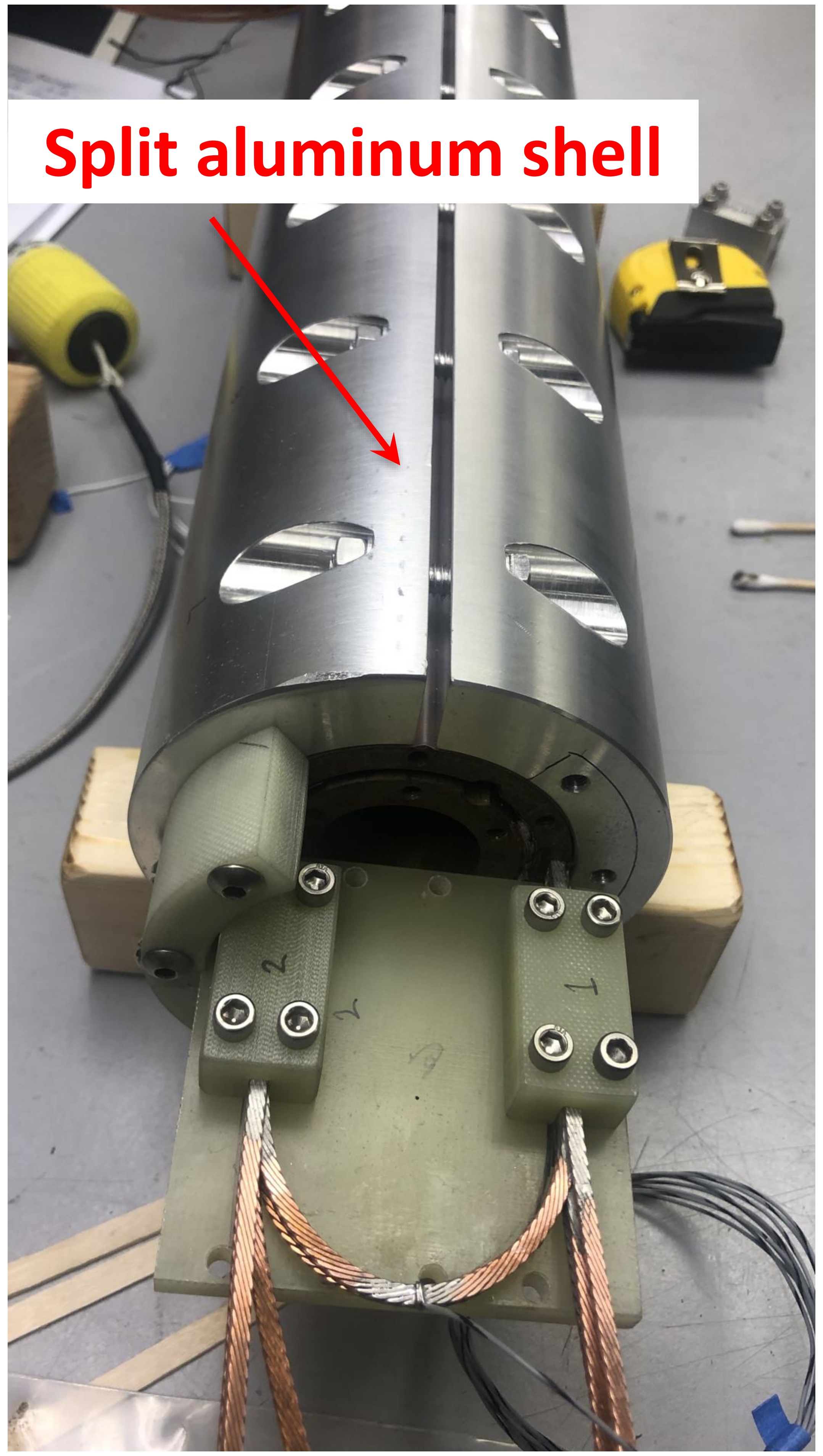
(CADs by Aurelio Hafalia Jr.

Note: Setup adaptation for the standalone test of BIN5c

- Since the standalone test of BIN5c was done in a small cryostat, the extension tubes were not be used (because the whole setup would not fit). Therefore, the layer jump will be dismounted and re-soldered for the hybrid test

- In addition, a split shell was used for easier assembly and the installation of the instrumentation





Outline

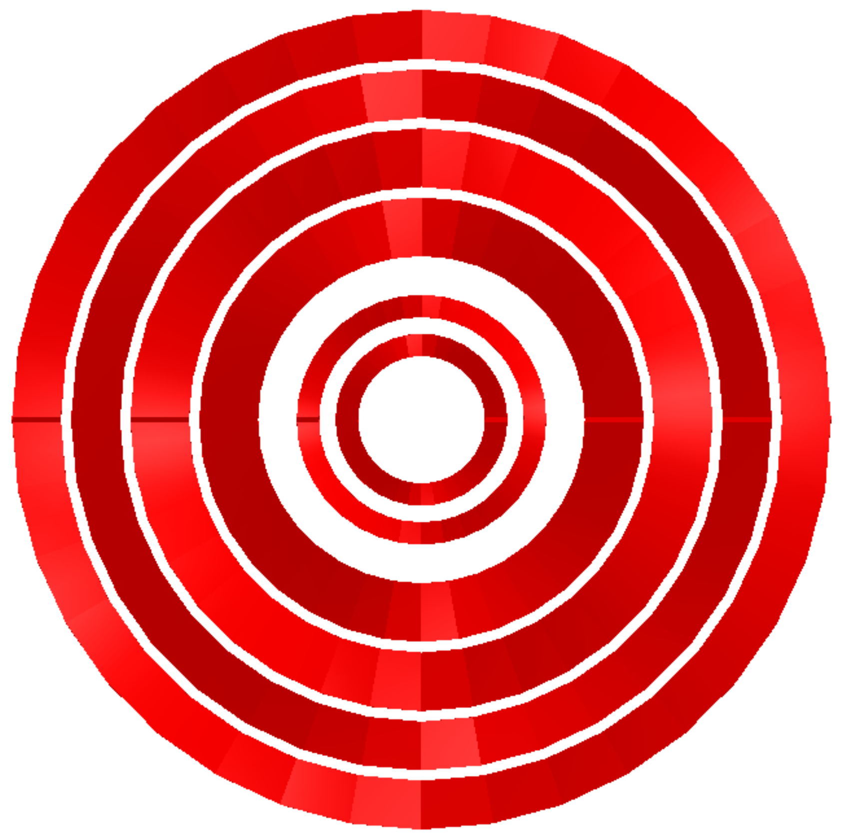
- Introduction: Plans for hybrid tests at LBNL
- Preparation for the CCT5-BIN5c hybrid test
- **Preparation for the CCT6-BiCCT1 hybrid test**

CCT6 and BiCCT1 main characteristics

CCT6:

- Nb_3Sn four-layer CCT magnet, 120 mm clear bore, 1.5 m long
- Will use LD1 cable in layers 1 and 2, and MQXF cable in layers 3 and 4. Not the most optimum design but the most practical from the conductor availability point of view
- Support structure still under optimization
- Should produce 12 T in standalone configuration at 75% of its short sample limit

CCT6-BiCCT1



BiCCT1:

- BiCCT1 two-layer CCT magnet, 40 mm clear bore, **85 cm long**
- Mandrels are under fabrication
- Coils will be reacted using the **RENEGADE** overpressure processing heat treatment furnace at NHMFL

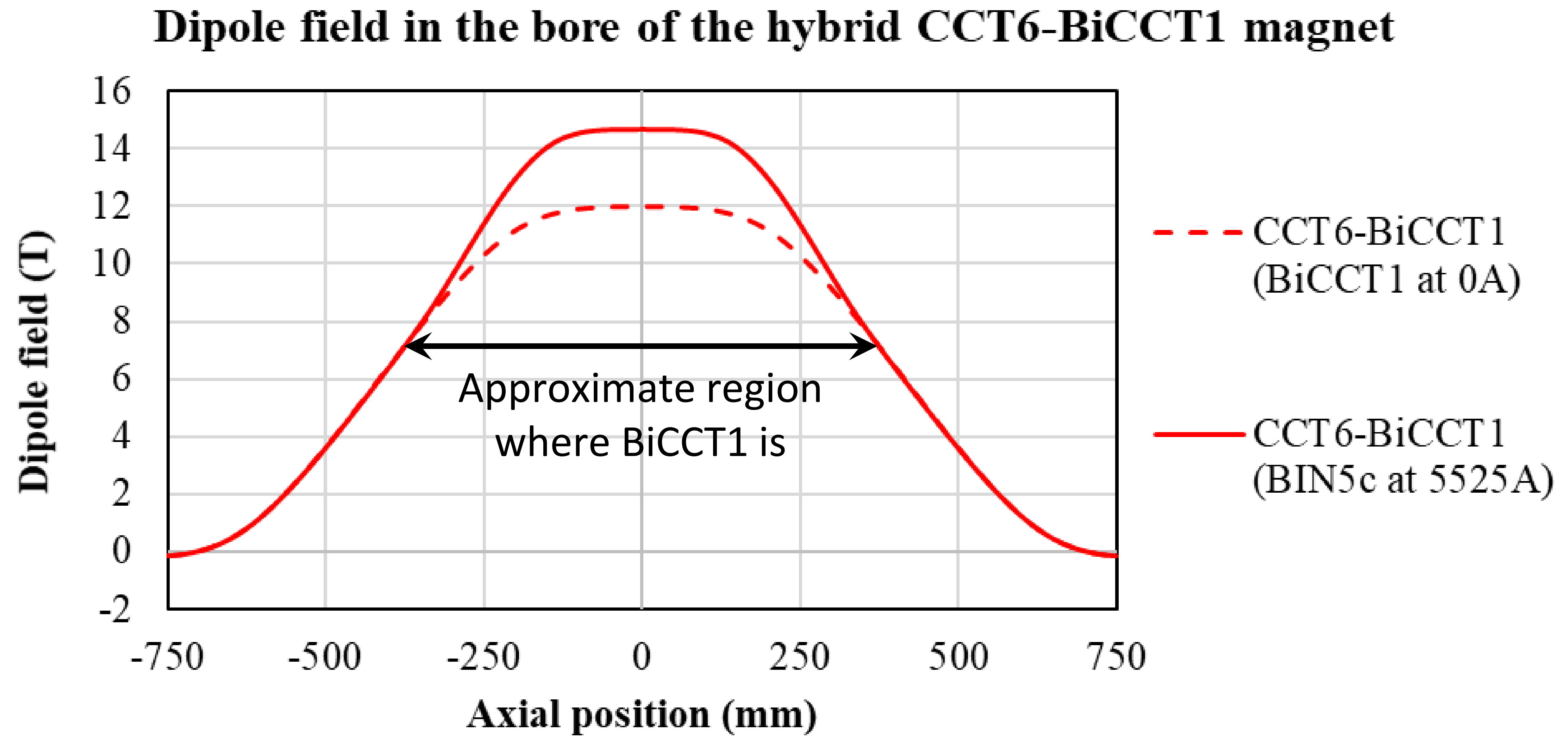
Practical considerations for the CCT6-BiCCT1 hybrid test

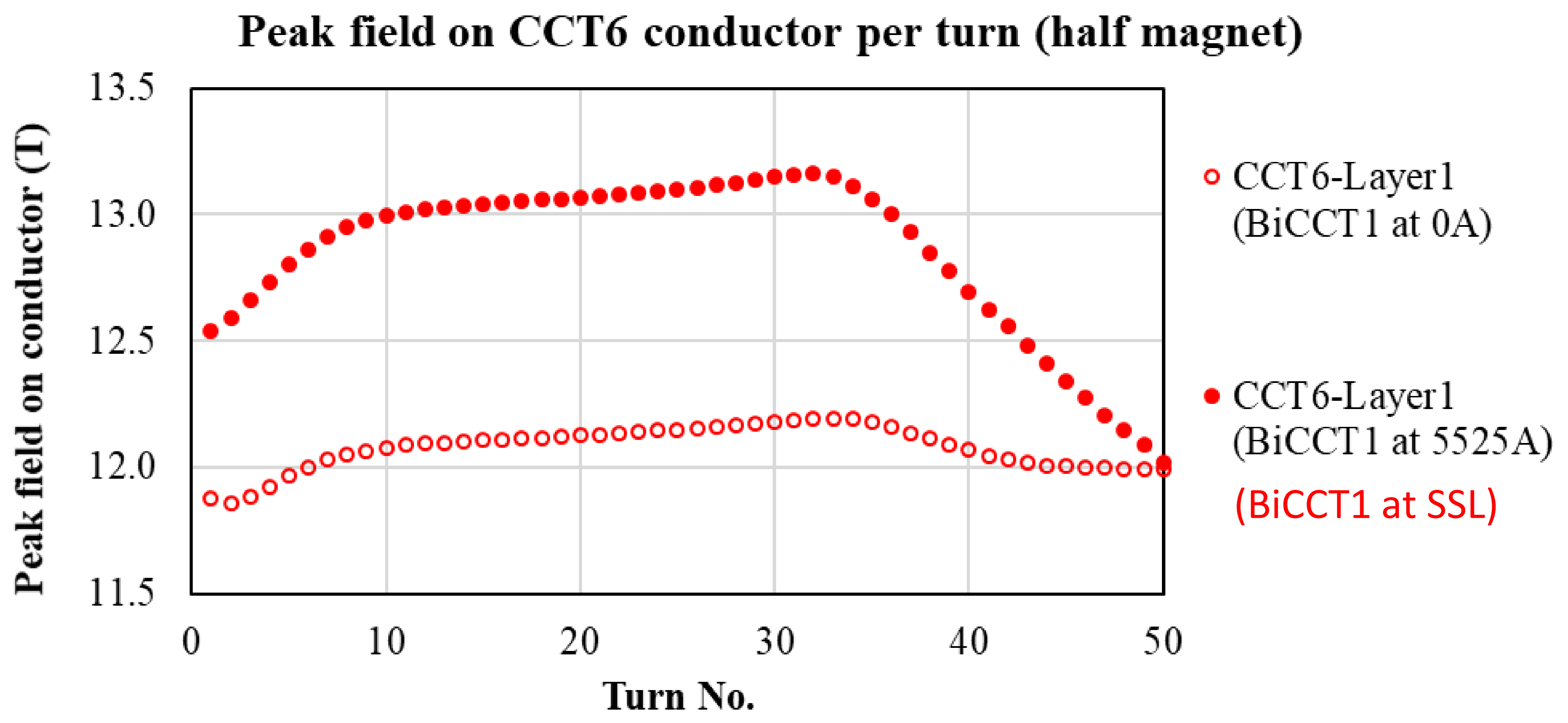
Length mismatch:

- CCT6 is 1.5 m long and BiCCT1 is 85 cm long
- The splices of BiCCT1 are 9 cm long and under 6-8 T background field
- Therefore, Nb_3Sn splices are under consideration for the 6-8 T region, followed by Nb-Ti splices for <6 T region

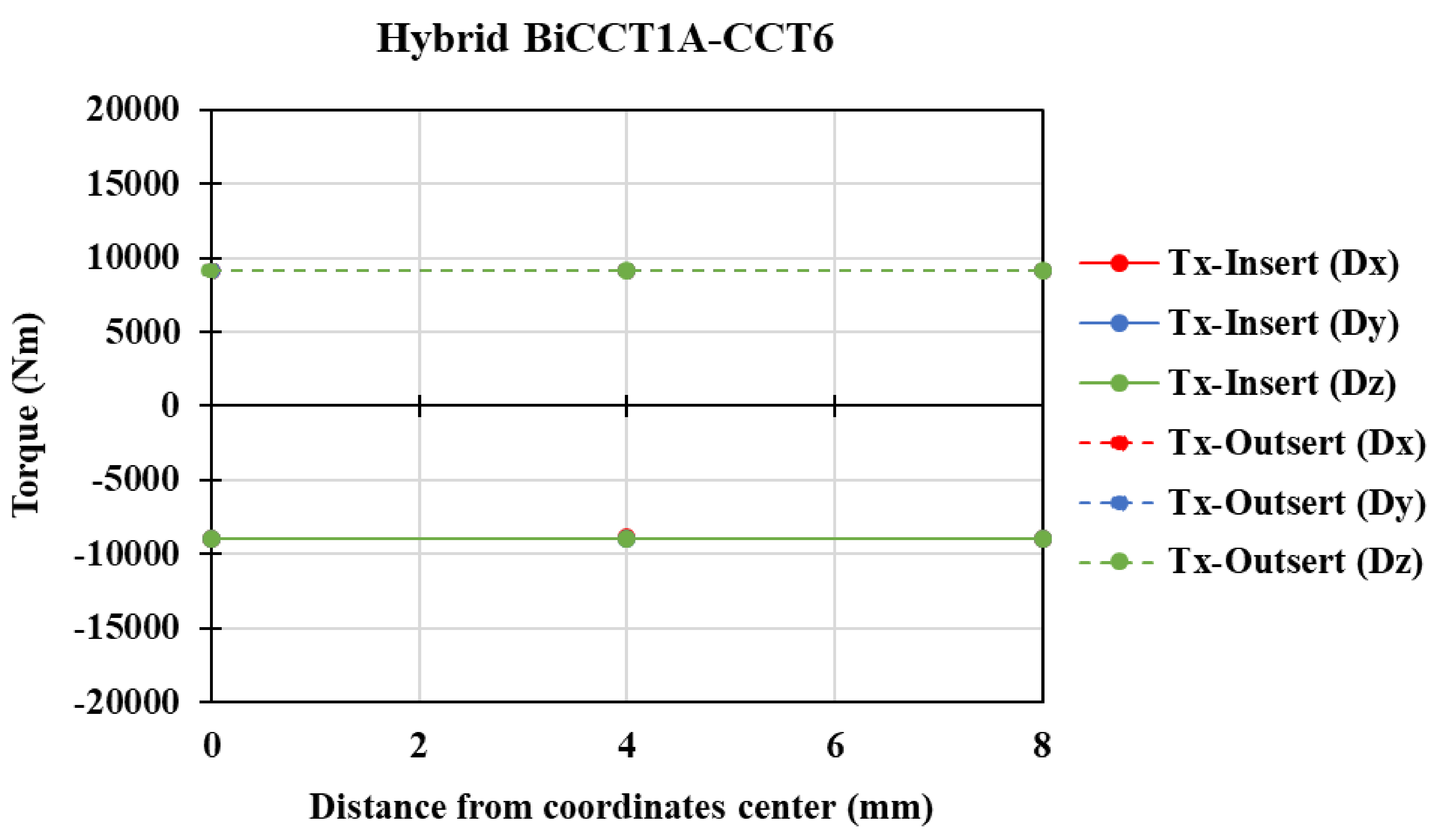
Peak field increase in CCT6:

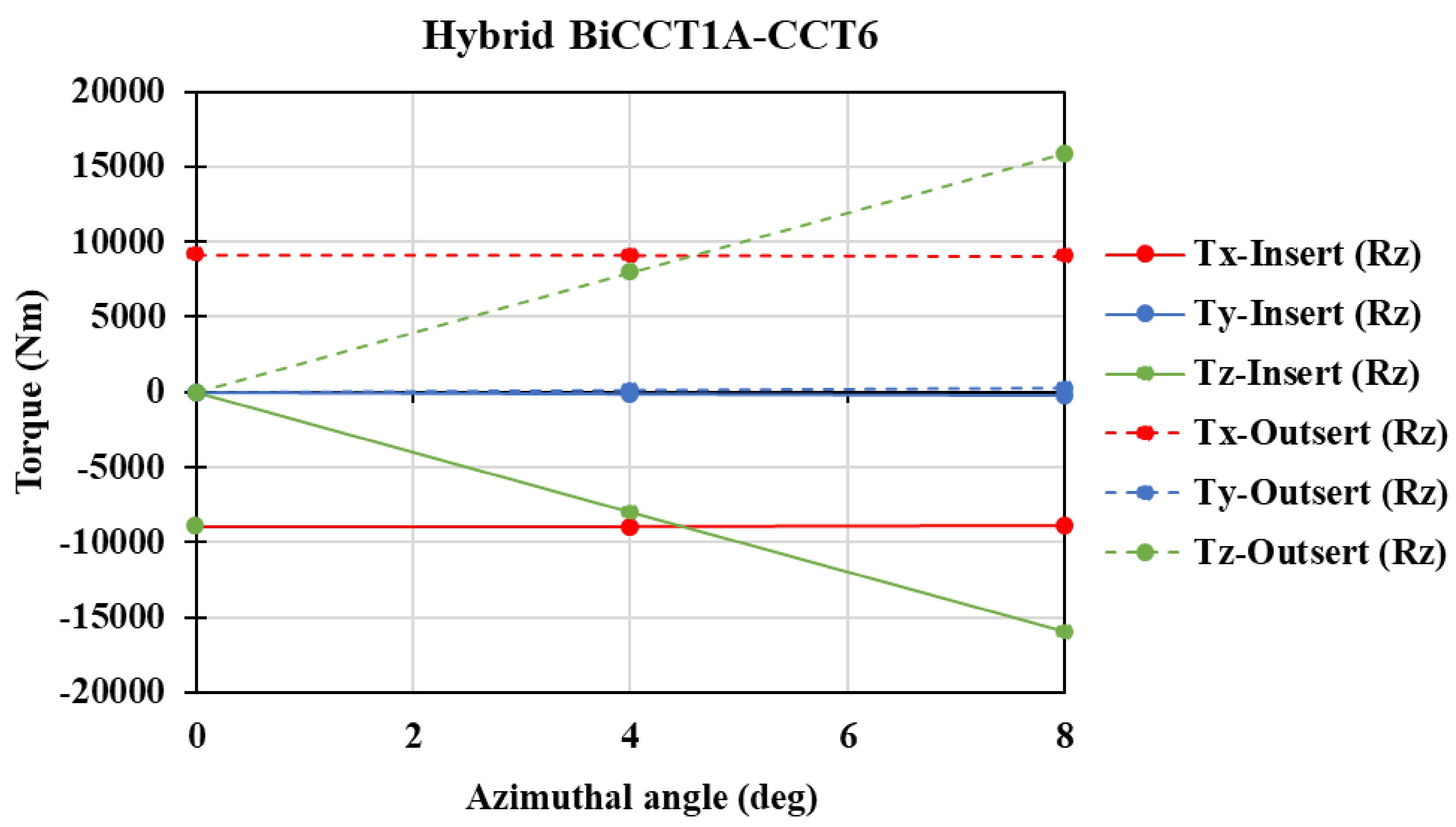
- The radial distance between the outer coil of BiCCT1 and the inner coil of CCT6 is 1.5 cm
- The peak field increase in CCT6 in hybrid configuration is 0.9 T, corresponding to a decrease in margin of 4.2%
- Considering that CCT6 should produce 12 T with 25% SSL margin, a decrease of 4.2% should not be a concern (still under discussion)





Torque in the hybrid CCT6-BiCCT1 magnet



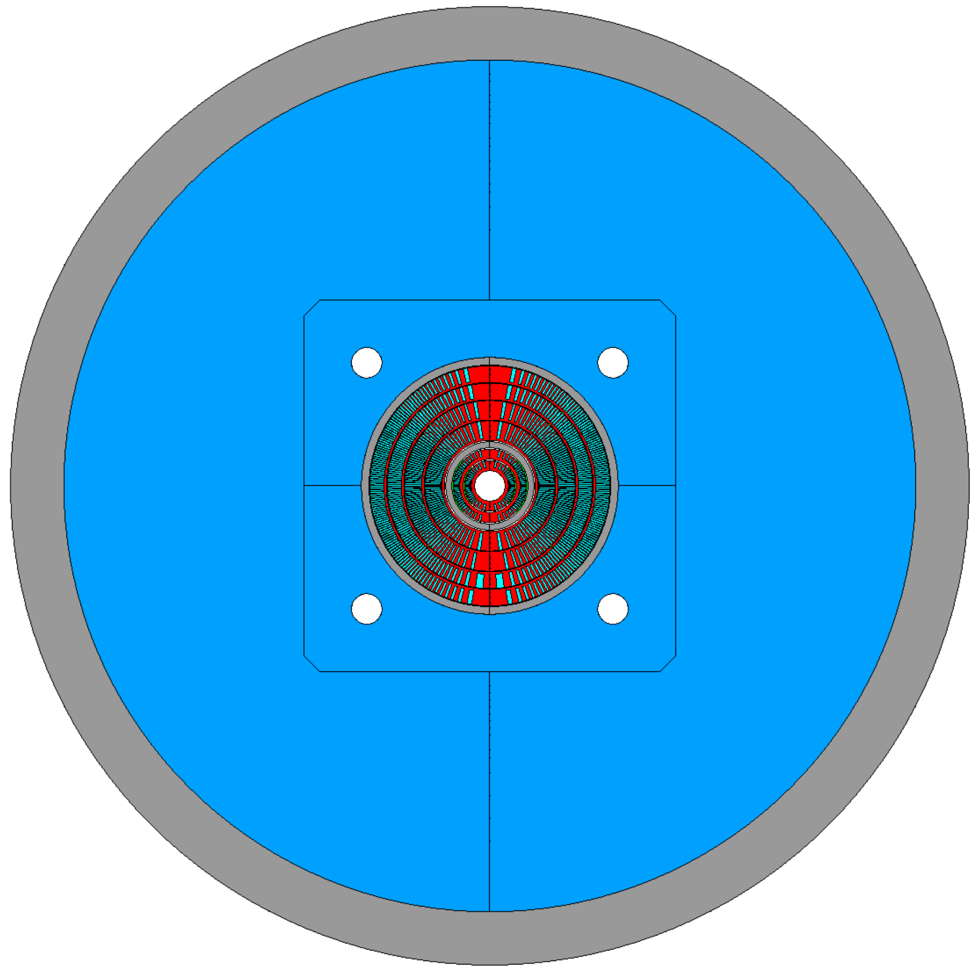


- Like in the CCT5-BIN5c hybrid, the only misalignment that influences the torque is the rotation about the z-axis
- Like in the CCT5-BIN5c hybrid, there is always a torque about the x-axis between the magnets (even in the perfectly aligned position)
- In the BiCCT1A-CCT6 hybrid, Tx is more than 10 times larger than in the CCT5-BiCCT1 hybrid

Mechanical behavior of BiCCT1 inside CCT6

CCT6+BiCCT1 inside support structure

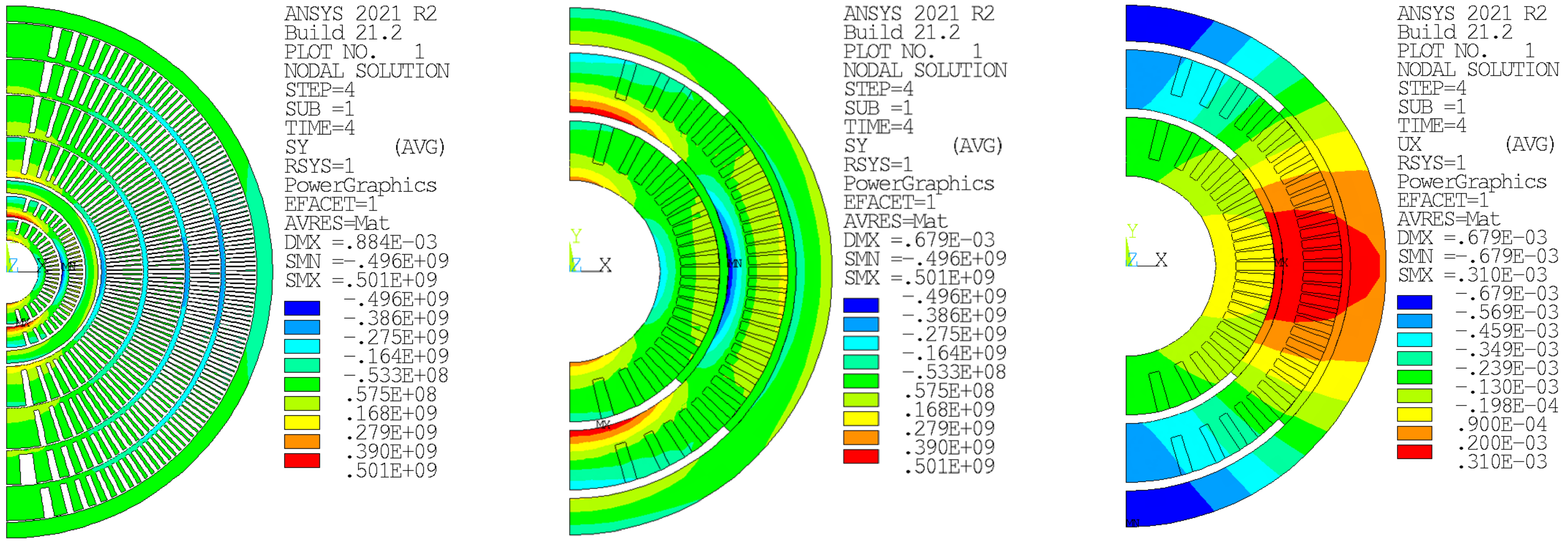
(Structure under optimization by M. Juchno)



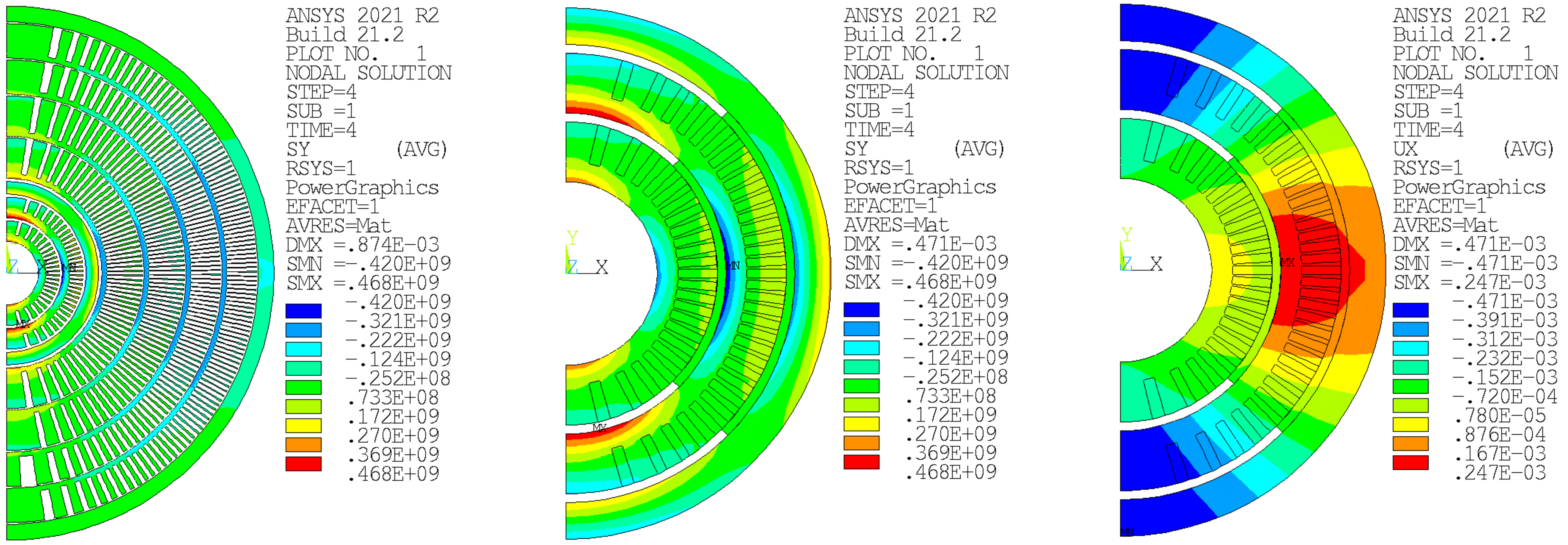
- Very high stress on the BiCCT1 mandrels
- Gap opening between BiCCT1 layers (like in BIN5c)
- Stainless steel (stiffer) shell helps decrease the stress and the gap, but is not enough
- Mechanical coupling between the magnets will be needed to handle the torque and the gap
- Optimization of the shims' spanning angle is under consideration to reduce the bending of the layers

CCT6+BiCCT1 Azimuthal stress (Pa)	BiCCT1 Azimuthal stress (Pa)	BiCCT1 Radial displacement (m)

BiCCT1 with aluminum shell



BiCCT1 with stainless steel shell



Summary of key points for hybrid magnet test preparation

- The design and preparation of magnets for a hybrid test require extensive teamwork and continuous optimization
- There is a length mismatch between the Bi-2212 inserts and the Nb_3Sn outserts (the length of Bi-2212 magnets is limited by the size of the heat treatment furnace). This carries assembly/alignment challenges and special considerations for the splices of the insert. Extension tubes and end supports have been identified as a solution for the assembly/alignment concerns.
- The magnetic field from the insert increases the peak field in the outsert and affects its working margin (0.7% for 0.15 T increase in CCT5, and 4.2% for 0.9 T increase in CCT6). The selection of the working point for the hybrid tests is under discussion.
- There is an intrinsic torque (Tx) between the magnets (~800 Nm for CCT5-BIN5c and ~8000 for BBT6-BiCCT1). End supports and shims at the pole region are under consideration to handle the torque.
- The mechanical behavior of the inserts and the outserts is very different in standalone configuration and in hybrid configuration. Loss of contact was detected in the midplane of the inserts in hybrid configuration. Modification of the spanning angle of the shims, modification of the shell material of the insert and mechanical coupling between the magnets are being considered to eliminate the gap.
- The first hybrid test (CCT5-BIN5c) will provide practical experience on the application of the proposed solutions.

Related work:

- **Poster WED-PO2-111-08**. Tengming Shen. *First canted cosine theta Bi-2212 accelerator magnets: Fabrication, performance, and prospects*.
- **Poster TUE-PO1-110-04**. Lucas Brouwer. *Design of CCT6: a large-aperture, 12 T, Nb3Sn Dipole Magnet*.
- **Poster THU-PO3-707-10**. Christopher Reis. *Quench detection and protection of high-temperature superconducting magnets: The case of a Bi-2212 Rutherford cable canted-cosine-theta dipole magnet*.