U.S. MAGNET DEVELOPMENT PROGRAM

HTS/LTS Hybrid Dipole Test

MDP Video meeting on January 29, 2020

Ramesh Gupta
For Superconducting Magnet Division
Brookhaven National Laboratory

Contributions from

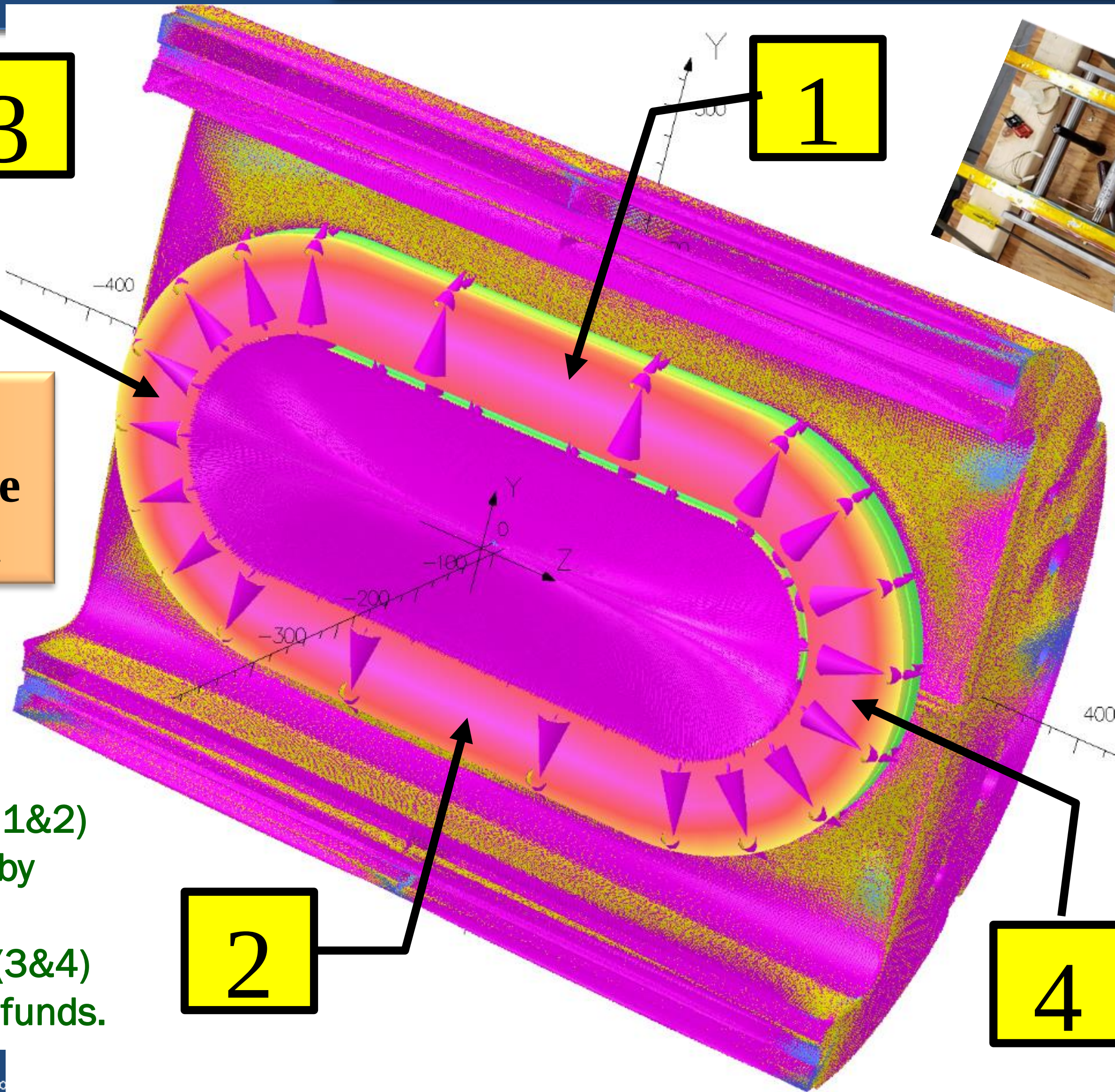
Work presented here and the work being performed now is thanks to many individuals, including:

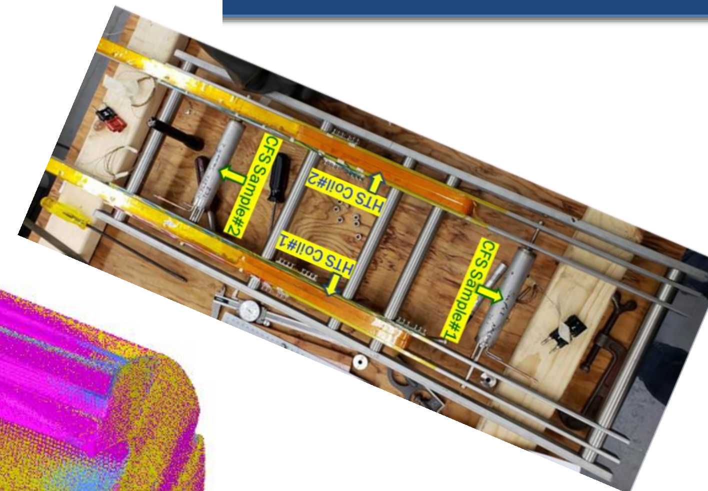
Bill Sampson, Shresht Joshi, Anis Ben Yahia, Piyush Joshi, Bill McKeon, Sonny Dimaiuta, Denny Sullivan, Peter Galioto, Pat Doutney, Mike Anerella, John Cozzolino, Ray Ceruti, ...

Overview

- Main goal of this test is to perform field error measurements of the HTS coils with tape aligned primarily in field parallel direction.
- Another technically important goal is to study high field HTS/LTS hybrid magnet, particularly the quench and mechanical studies
- The program benefits from the unique geometry of DCC017, which allows insert coils to be inserted and become integral part of the magnet without disassembling or assembling magnet
- This particular test should be very productive with four tests in one go (a) two tests for two sets of HTS double-pancake coils (both on two separate power supplies in two high field apertures for *HEP*, and (b) another two independent tests of two HTS cable samples for "*fusion community*" in other two high field region in the end sections, clear of interference from the straight section.

Four easily accessible high field regions for four independent high field tests





|B| at y-z plane @10 kA

Locations 1 and 2 for HTS coils; Locations 3 and 4 for HTS samples

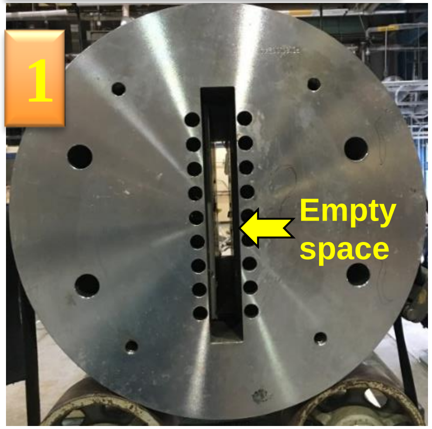
Basic test (1&2) supported by USMDP. Additional (3&4) by internal funds.

Testing of HTS Coil Technology @High Fields (rapid turn-around, low cost)

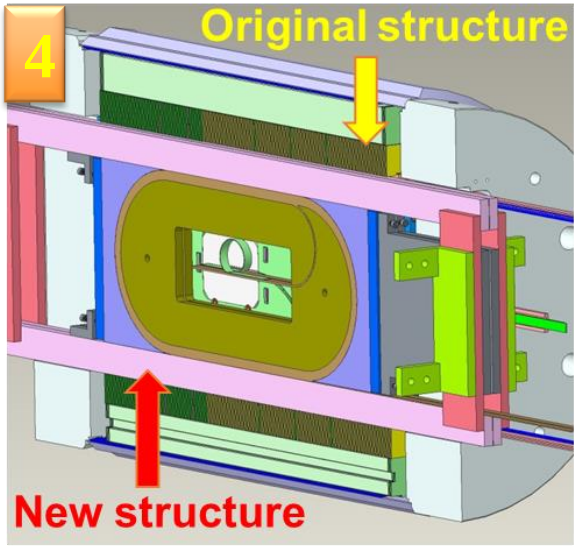
U.S. MAGNET DEVELOPMENT PROGRAM

Five Steps:

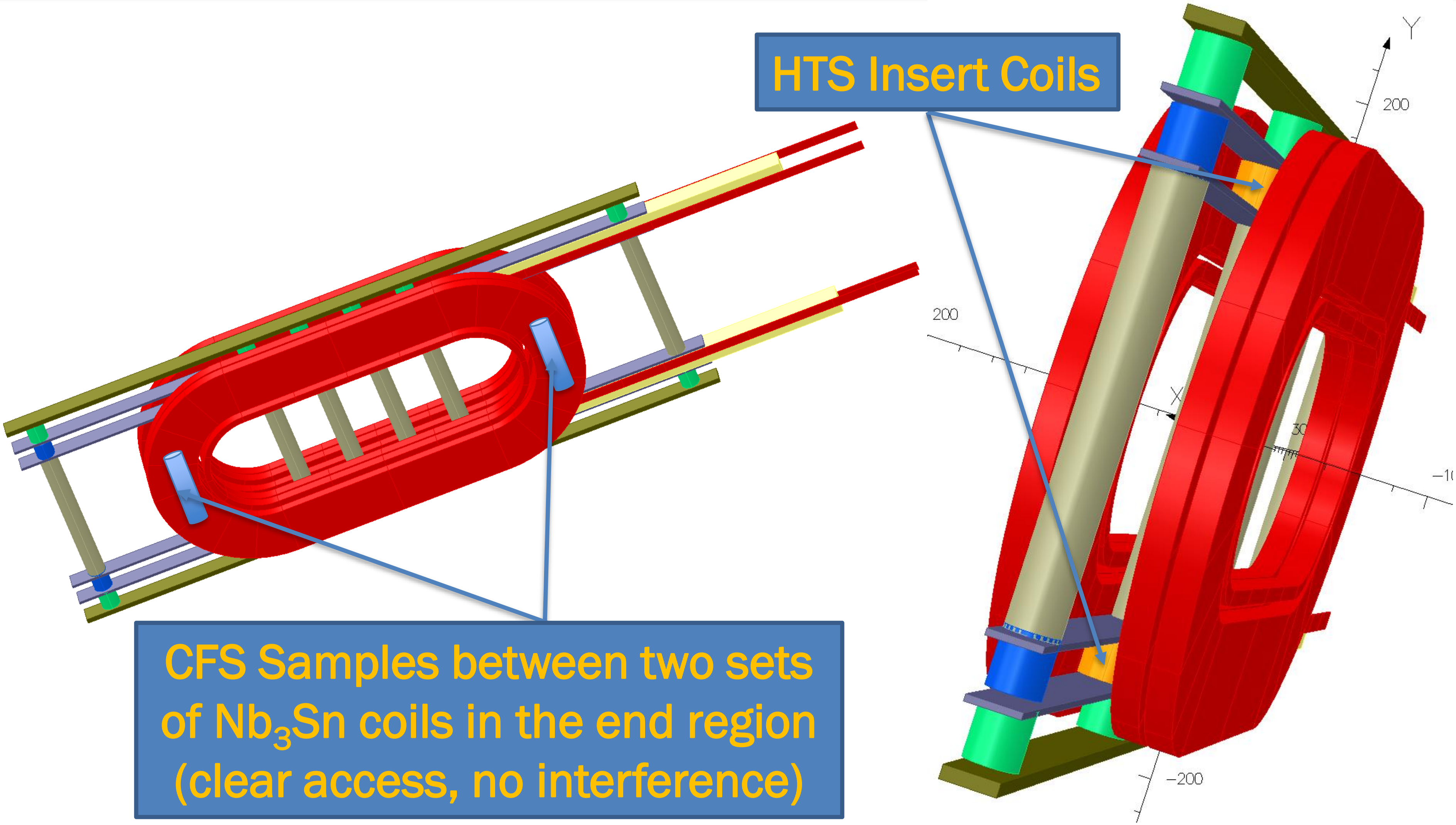
Replaceable R&D Coil(s)



1. Magnet (dipole) with a large open space
2. R&D Coil for high field testing
3. Slide coil in the magnet
4. Coils become an integral part of the magnet
5. Magnet with new coil(s) ready for testing



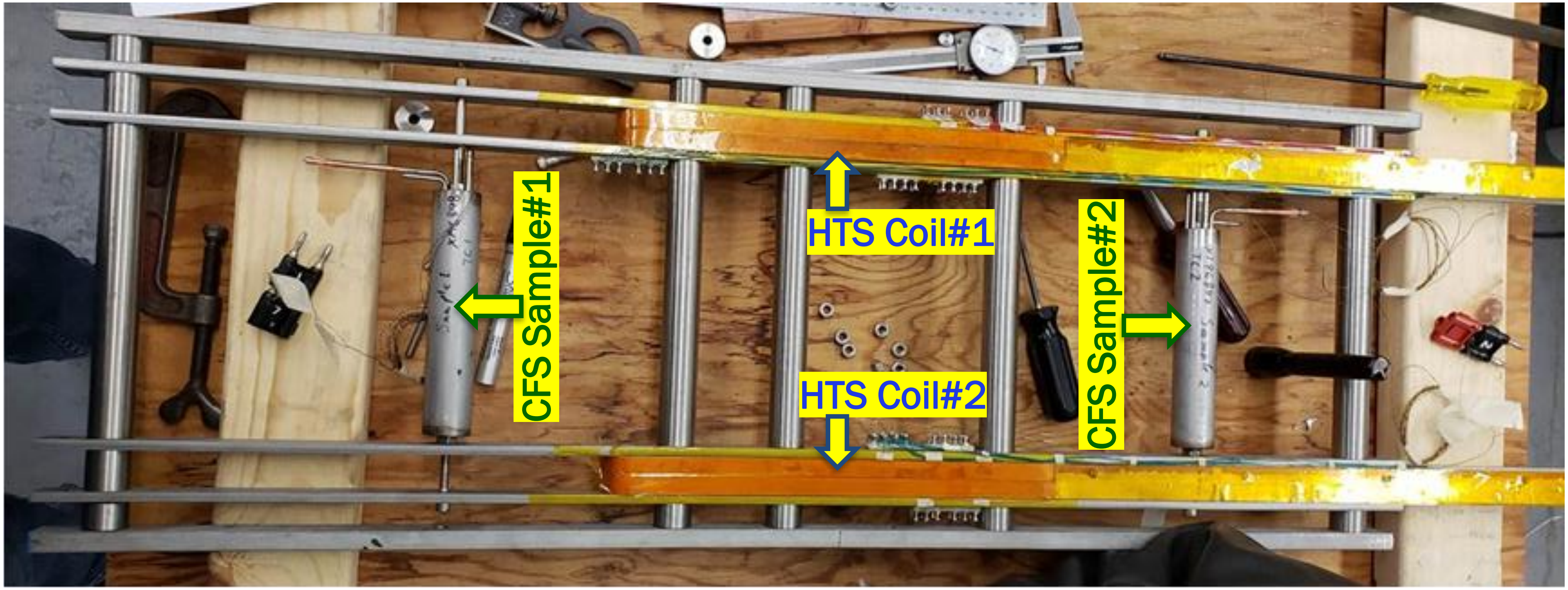
HTS Coils Structure Inserted in Nb_3Sn Coils (addition of CFS samples incorporated later)



USMDP HTS/LTS Hybrid Dipole Test in February 2020 (4 tests in one go)

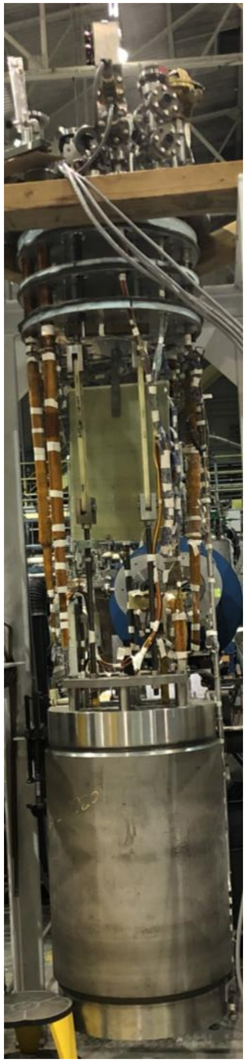
U.S. MAGNET DEVELOPMENT PROGRAM

A simple fixture is inserted inside the BNL Nb_3Sn Common Coil Dipole DCC017 (without disassembling the magnet) to test insert coils, in addition to the cable samples, in a high background field.

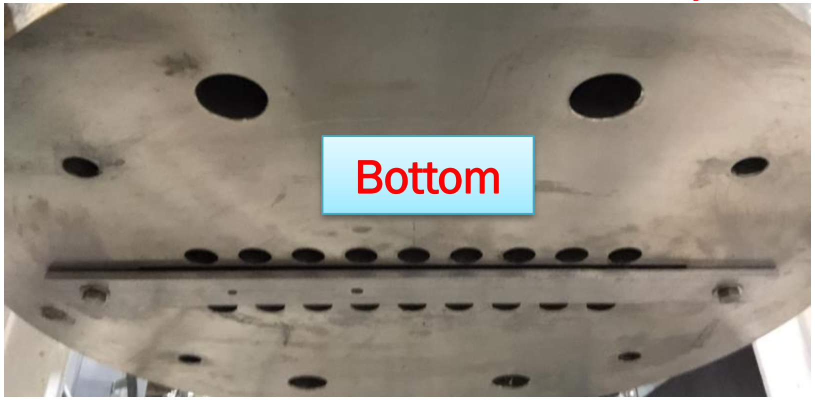


HEP Working with the Fusion Community

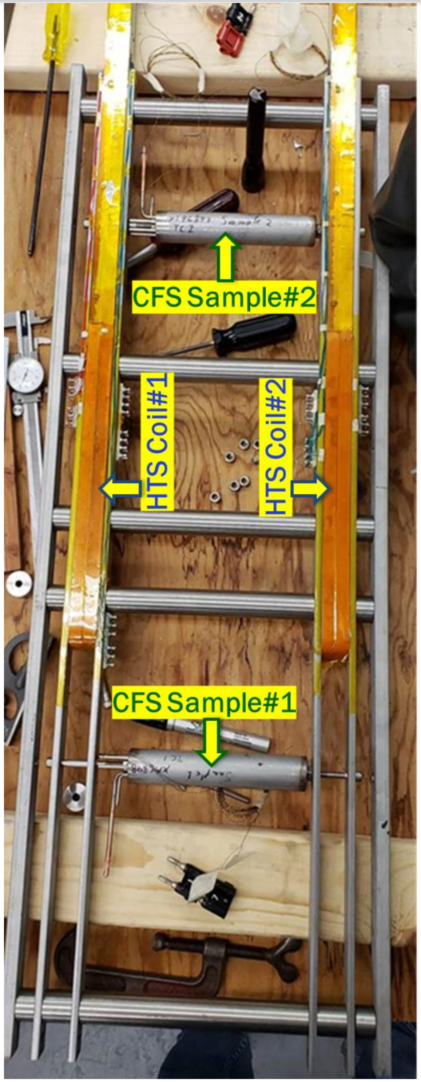
Magnet Test Assembly

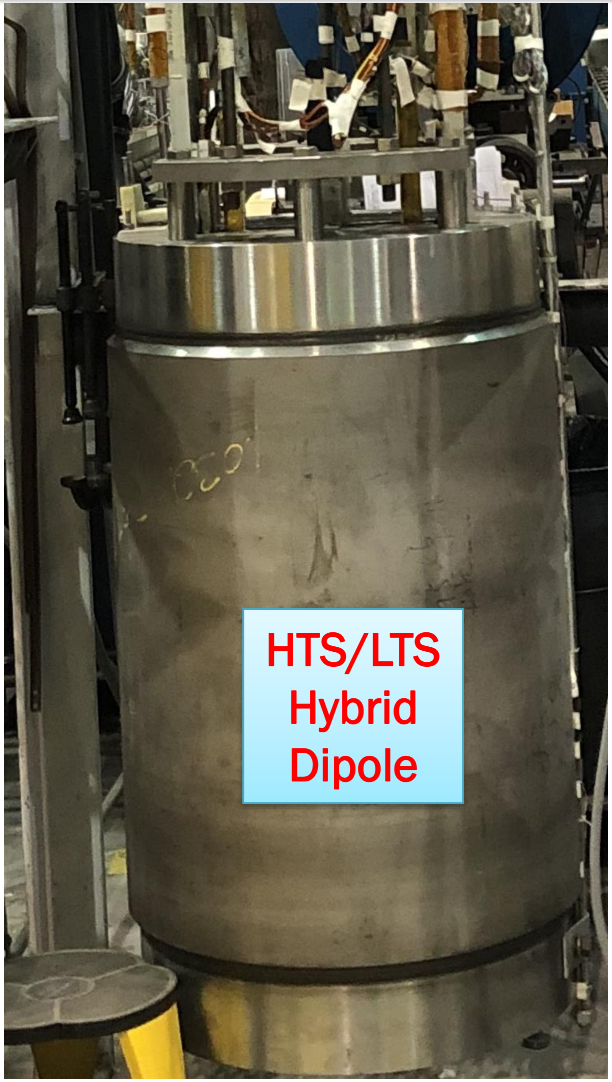


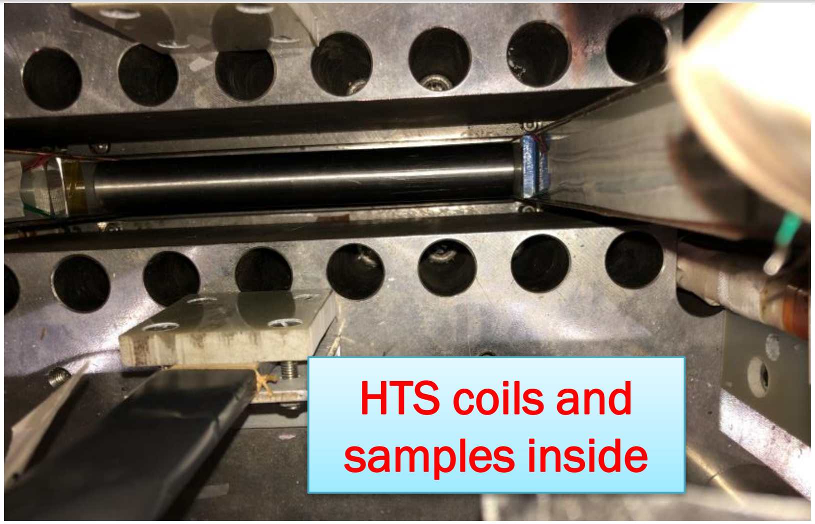
Fixture inside the common coil dipole

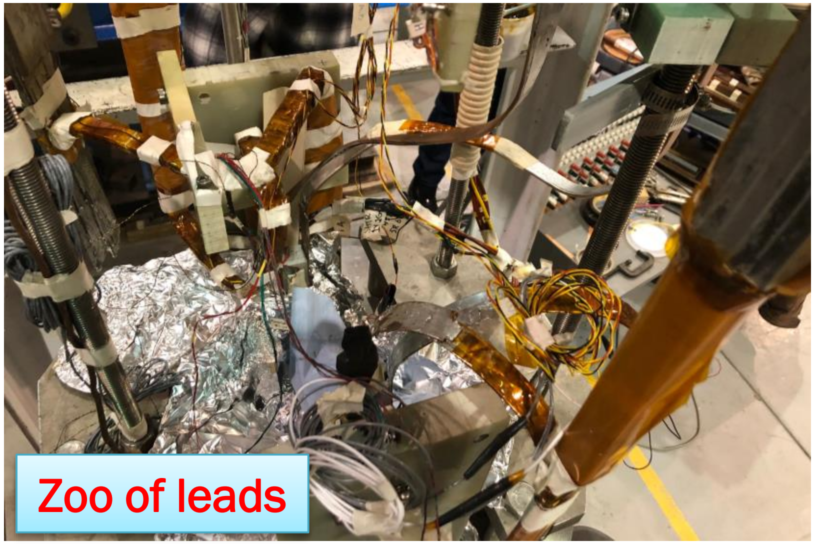


Fixture inside the magnet









Run Plan and Instrumentation

Run Plan for Magnetization Studies

(partly shown earlier and reviewed by BNL/LBL/OSU team)

Magnetization Studies Test Program at 4.5 K.

Purpose: To perform magnetization studies of HTS coils first by themselves and then in the background field of the Nb_3Sn common coil magnet.

During the following tests the magnet field should be measured continuously by the Hall probes and recorded.

1. **HTS Nomex Coil Only** (difference voltage between two HTS pancake coils must remain < 2 mV and attempt should be made that the HTS coil doesn't quench)
   - Ramp up to 100 A and down to 0 A
   - Ramp up to 200 A and down to 0 A
   - Ramp up to 400 A and down to 0 A
   - Ramp up to 600 A and down to 0 A
   - Ramp up to 800 A and down to 0 A

2. **HTS No-Insulation Coil Only** (difference voltage between two HTS pancake coils must remain < 10 mV and attempt should be made that the HTS coil doesn't quench)
   - Ramp up to 100 A and down to 0 A
   - Ramp up to 400 A and down to 0 A
   - Ramp up to 800 A and down to 0 A
   - After review of results of above tests, make plan to ramp to higher currents

3. **LTS (Nb3Sn) Coil Only**
   - Ramp gradually in steps to 10000 A (no quench at 10000 A in 2017 test and it reached 10,800 A in 2006).
   - If magnet trains, we will stop at 5 quenches and limit further operation of the LTS magnet to 90% of the current reached at the 5^{th} quench.
   - If the magnet reaches 10000 A without quench, ramp the magnet to quench and limit further operation of the LTS magnet to 90% of the current reached.

4. **HTS/LTS Hybrid Magnetization Tests**
   - Hold LTS magnet at 500 A, 1 kA, 2 kA, 4 kA, 6 kA, and 8 kA, and for each HTS coil ramp up and down to whatever current safely possible without quenching (800 A nominal max).
   - Reduce current in LTS magnet and perform above steps.

U.S. MAGNET DEVELOPMENT PROGRAM

Hall Probes for Magnetization Measurements

Two Hall probes (redundancy) at the center and one at the edge (at the request of Mike Sumption) in the base coil with turn-to-turn insulation after the BNL/LBL/OSU test planning meeting

Note: planned test is magnetization studies in insulated coil only.
Everything else is exploratory (extra at very small cost).

AVT5-a	Insulated Coil - Center Hall sensor 1
AVT5-b	Insulated Coil - Center Hall sensor 1
AVT5-c	Insulated Coil - Center Hall sensor 1
AVT5-d	Insulated Coil - Center Hall sensor 1
AVT5-e	Insulated Coil - Center Hall sensor 2
AVT5-f	Insulated Coil - Center Hall sensor 2
AVT5-g	Insulated Coil - Center Hall sensor 2
AVT5-h	Insulated Coil - Center Hall sensor 2
AVT5-j	Insulated Coil - Edge Hall sensor
AVT5-k	Insulated Coil - Edge Hall sensor
AVT5-l	Insulated Coil - Edge Hall sensor
AVT5-m	Insulated Coil - Edge Hall sensor

AVT5-n	Non-Insulated Coil - Center Hall sensor 1
AVT5-p	Non-Insulated Coil - Center Hall sensor 1
AVT5-r	Non-Insulated Coil - Center Hall sensor 1
AVT5-s	Non-Insulated Coil - Center Hall sensor 1
AVT6-r	Non-Insulated Coil - Center Hall sensor 2
AVT6-s	Non-Insulated Coil - Center Hall sensor 2
AVT6-t	Non-Insulated Coil - Center Hall sensor 2
AVT6-u	Non-Insulated Coil - Center Hall sensor 2

Two Hall probes (redundancy) at the center only in the No-insulation coil

U.S. MAGNET DEVELOPMENT PROGRAM

Voltage-taps for HTS Quench Protection

A v-tap after every 10 turns in each of four pancake coil

Two “insulated pancake coils” with 16 v-taps and two “No-insulation pancake coils” with 10 v-taps

AVT3-A	Non-Insulated Coils - Coil 1 Turn 71
AVT3-B	Non-Insulated Coils - Coil 1 Turn 60
AVT3-C	Non-Insulated Coils - Coil 1 Turn 50
AVT3-D	Non-Insulated Coils - Coil 1 Turn 40
AVT3-E	Non-Insulated Coils - Coil 1 Turn 30
AVT3-F	Non-Insulated Coils - Coil 1 Turn 20
AVT3-G	Non-Insulated Coils - Coil 1 Turn 10
AVT3-H	Non-Insulated Coils - Coil 1 Turn 0
AVT3-J	Empty
AVT3-K	Insulated Coils - Coil 1 Turn 46
AVT3-L	Insulated Coils - Coil 1 Turn 40
AVT3-M	Insulated Coils - Coil 1 Turn 30
AVT3-N	Insulated Coils - Coil 1 Turn 20
AVT3-P	Insulated Coils - Coil 1 Turn 10
AVT3-R	Insulated Coils - Coil 1 Turn 0

AVT4-A	Non-Insulated Coils - Coil 2 Turn 71
AVT4-B	Non-Insulated Coils - Coil 2 Turn 60
AVT4-C	Non-Insulated Coils - Coil 2 Turn 50
AVT4-D	Non-Insulated Coils - Coil 2 Turn 40
AVT4-E	Non-Insulated Coils - Coil 2 Turn 30
AVT4-F	Non-Insulated Coils - Coil 2 Turn 20
AVT4-G	Non-Insulated Coils - Coil 2 Turn 10
AVT4-H	Non-Insulated Coils - Coil 2 Turn 0
AVT4-J	Empty
AVT4-K	Insulated Coils - Coil 2 Turn 46
AVT4-L	Insulated Coils - Coil 2 Turn 40
AVT4-M	Insulated Coils - Coil 2 Turn 30
AVT4-N	Insulated Coils - Coil 2 Turn 20
AVT4-P	Insulated Coils - Coil 2 Turn 10
AVT4-R	Insulated Coils - Coil 2 Turn 0

More v-taps at leads, etc.

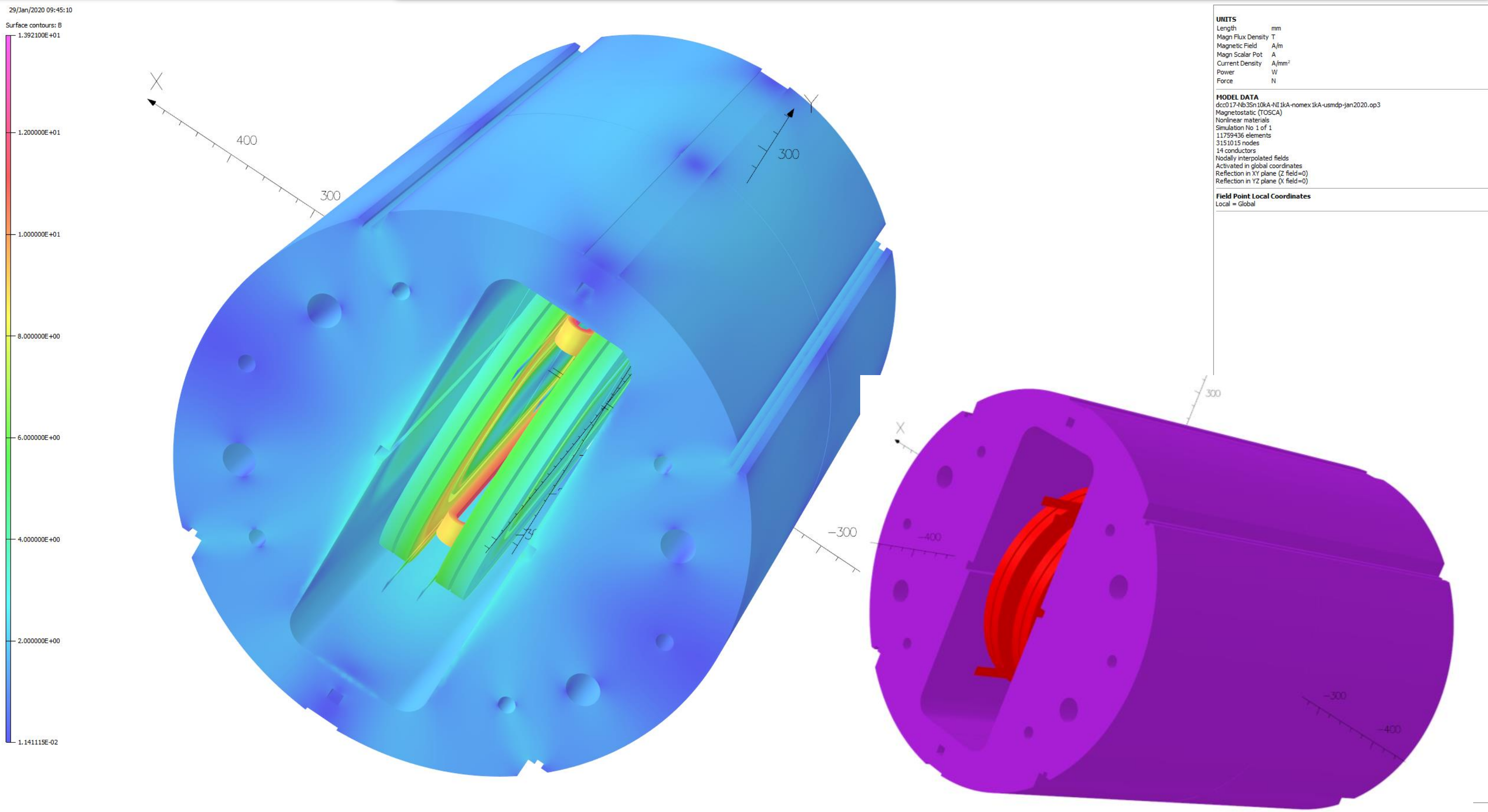
LTS coils have the original v-taps

Magnetic and Mechanical Models

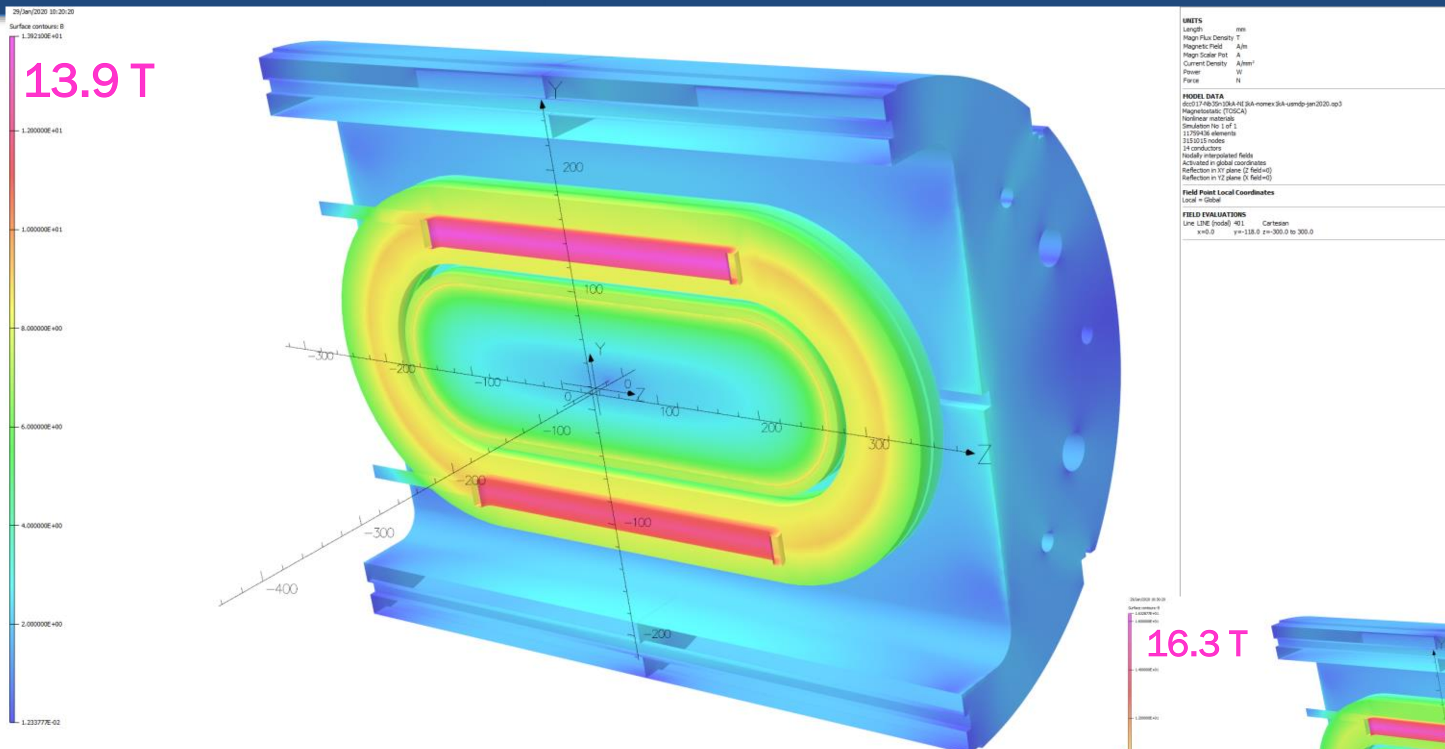
- Maximum for magnetization test: 8 KA in Nb_3Sn coils and 800 A in HTS coils

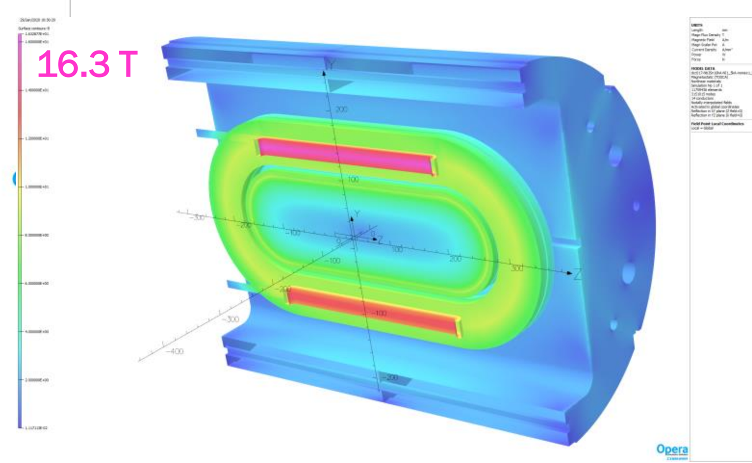
- The baseline models are for 10 kA in the Nb_3Sn coil and 1 kA in two HTS coils
- Also examined HTS coils at 1.5 kA and 2 kA (just in case), for quench studies

Magnetic Model
(Nb3Sn coils @10 kA, HTS coils @1kA)



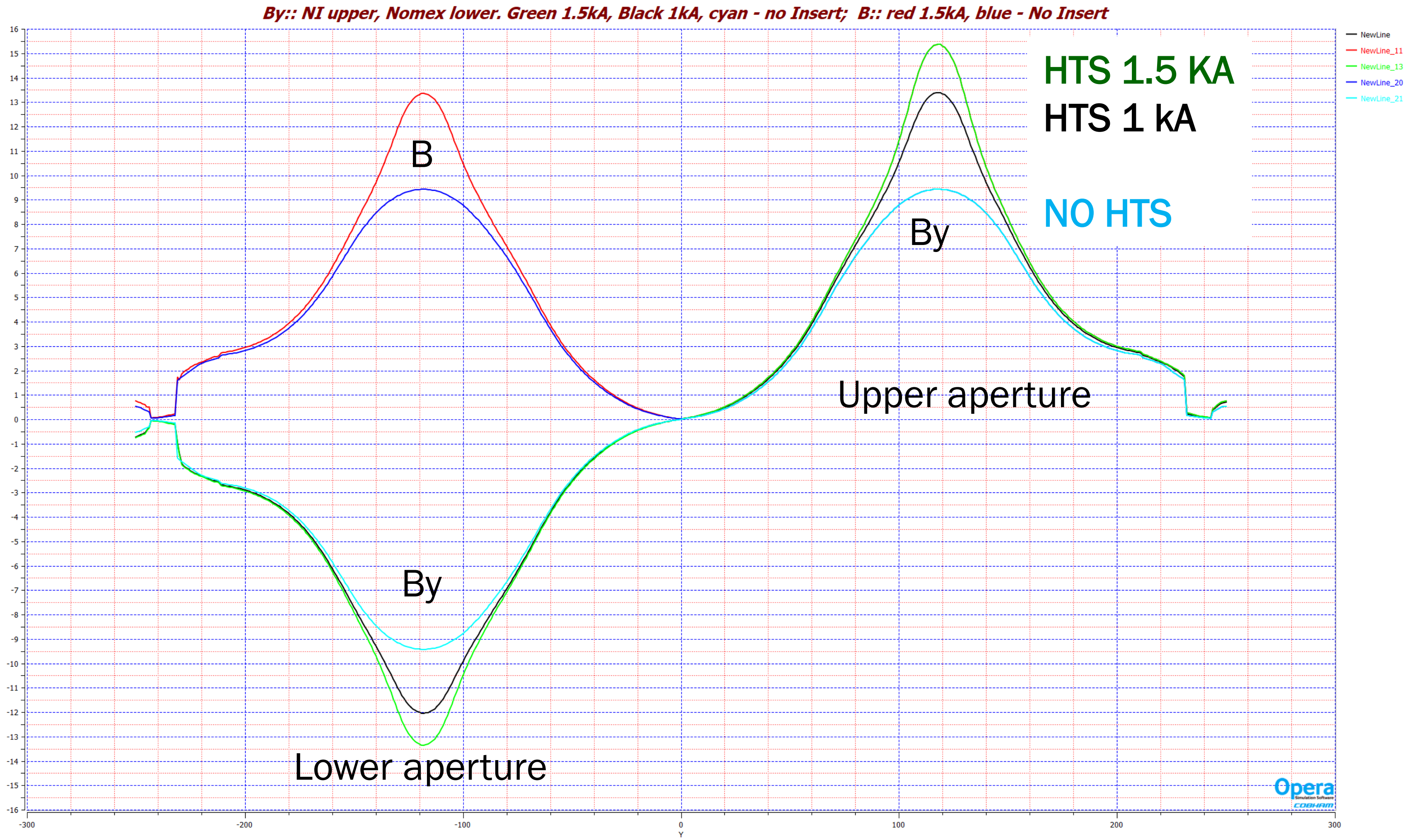
Cutout View for Nb_3Sn coils at 10 kA and HTS coils at 1 KA and 1.5 kA



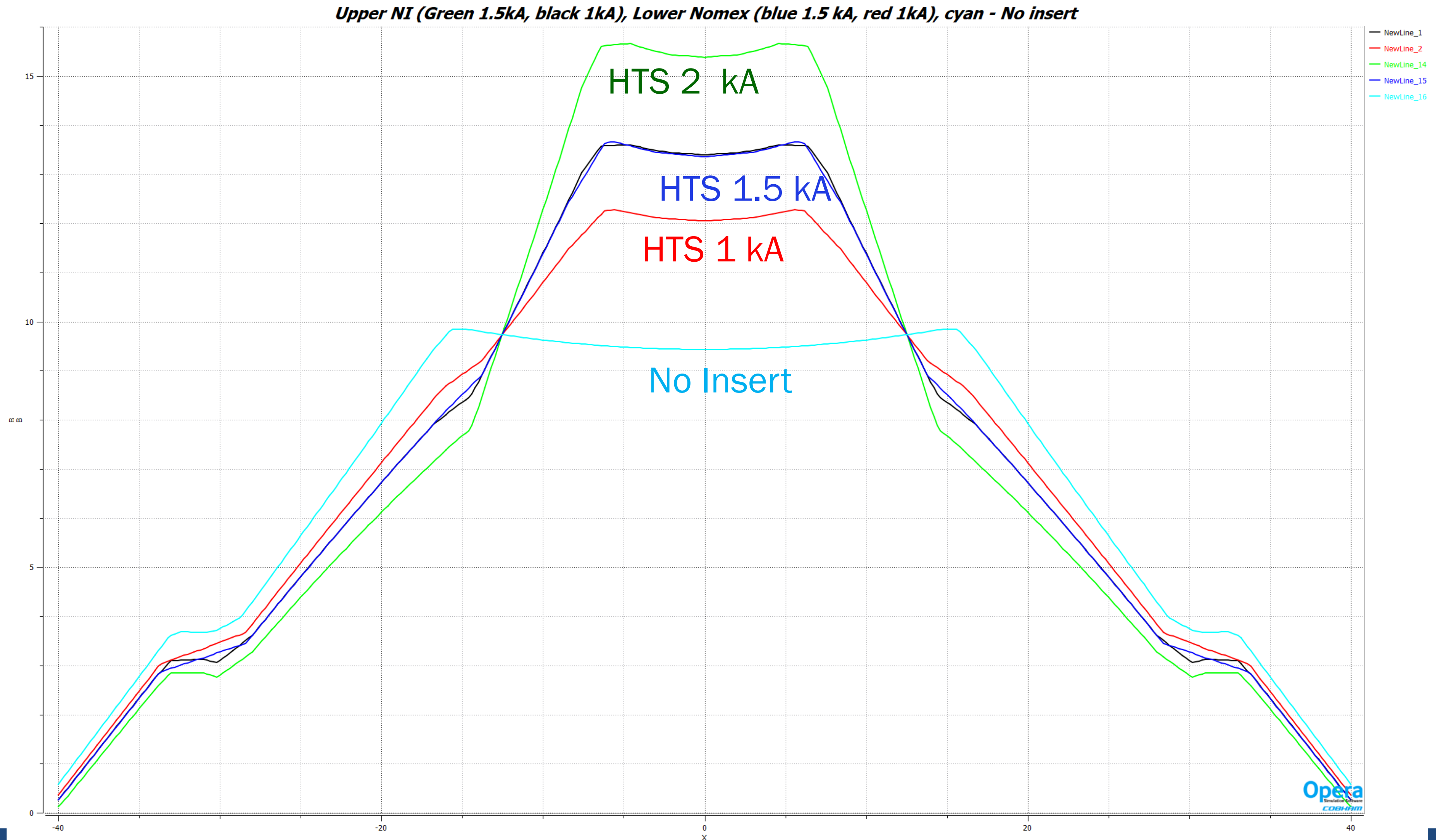


HTS coils are installed with as low clearance as possible. Horizontal Lorentz forces will bring them in contact with the LTS coils

Field along vertical axis

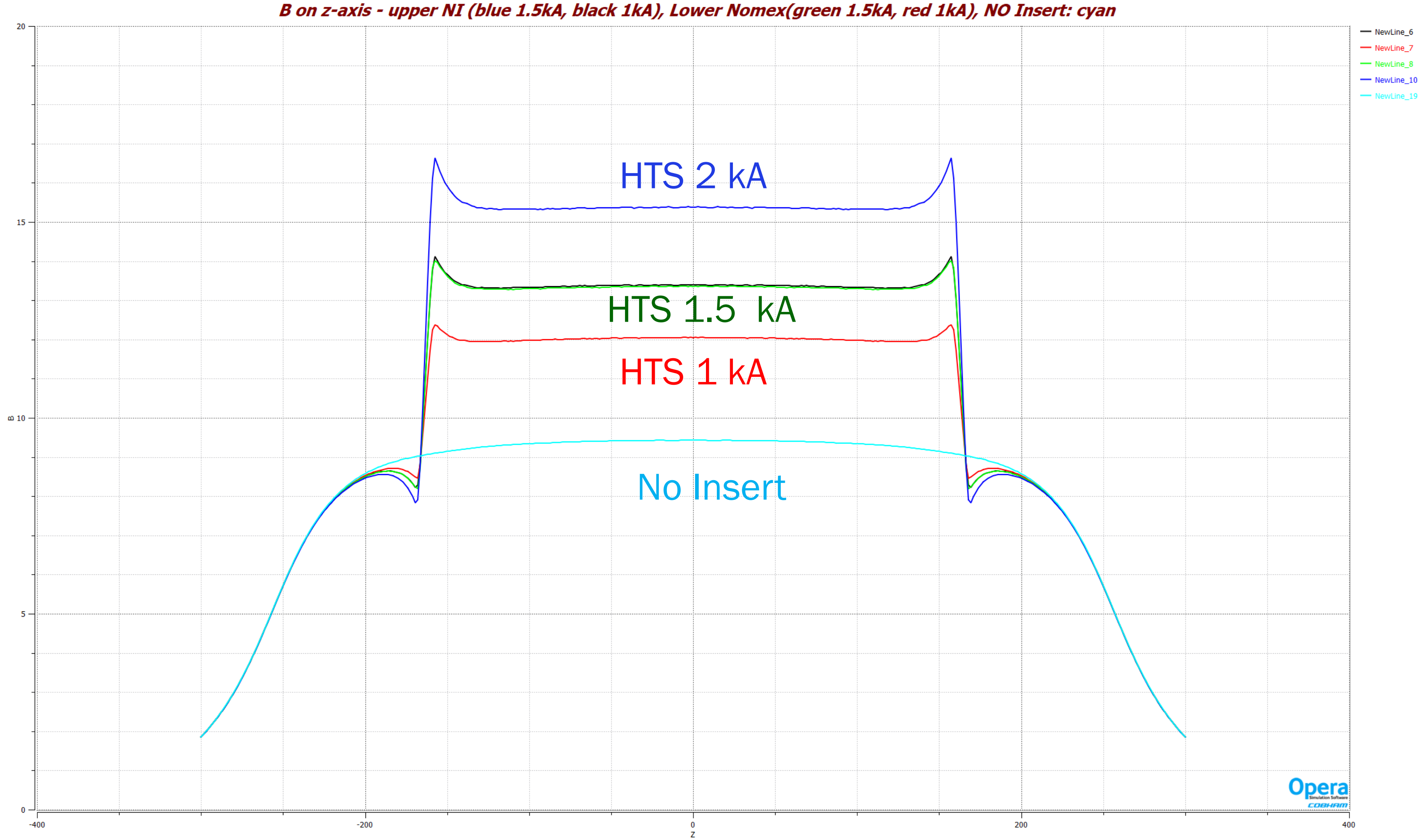


B along x-axis in the aperture



U.S. MAGNET DEVELOPMENT PROGRAM

B along z-axis



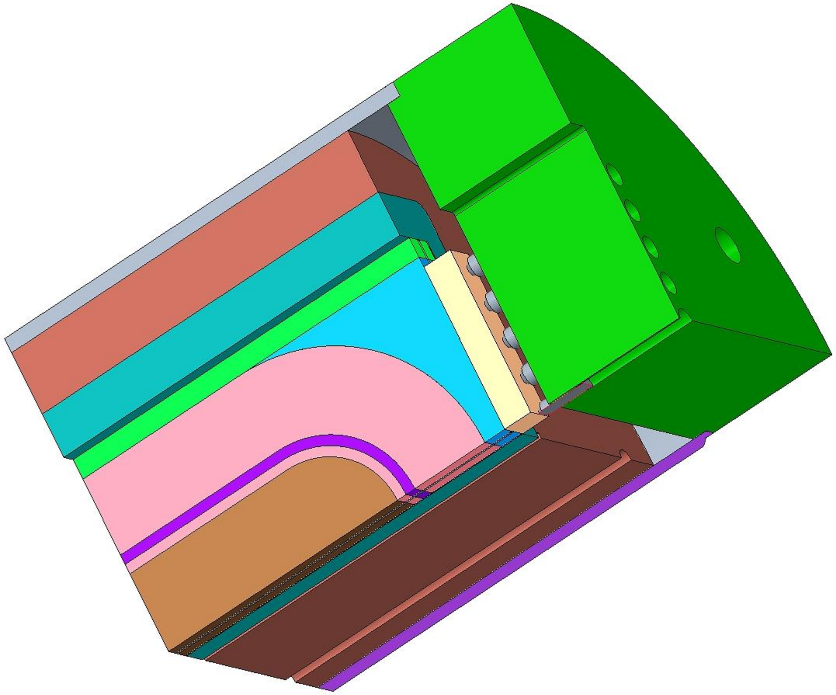
Mechanical Models

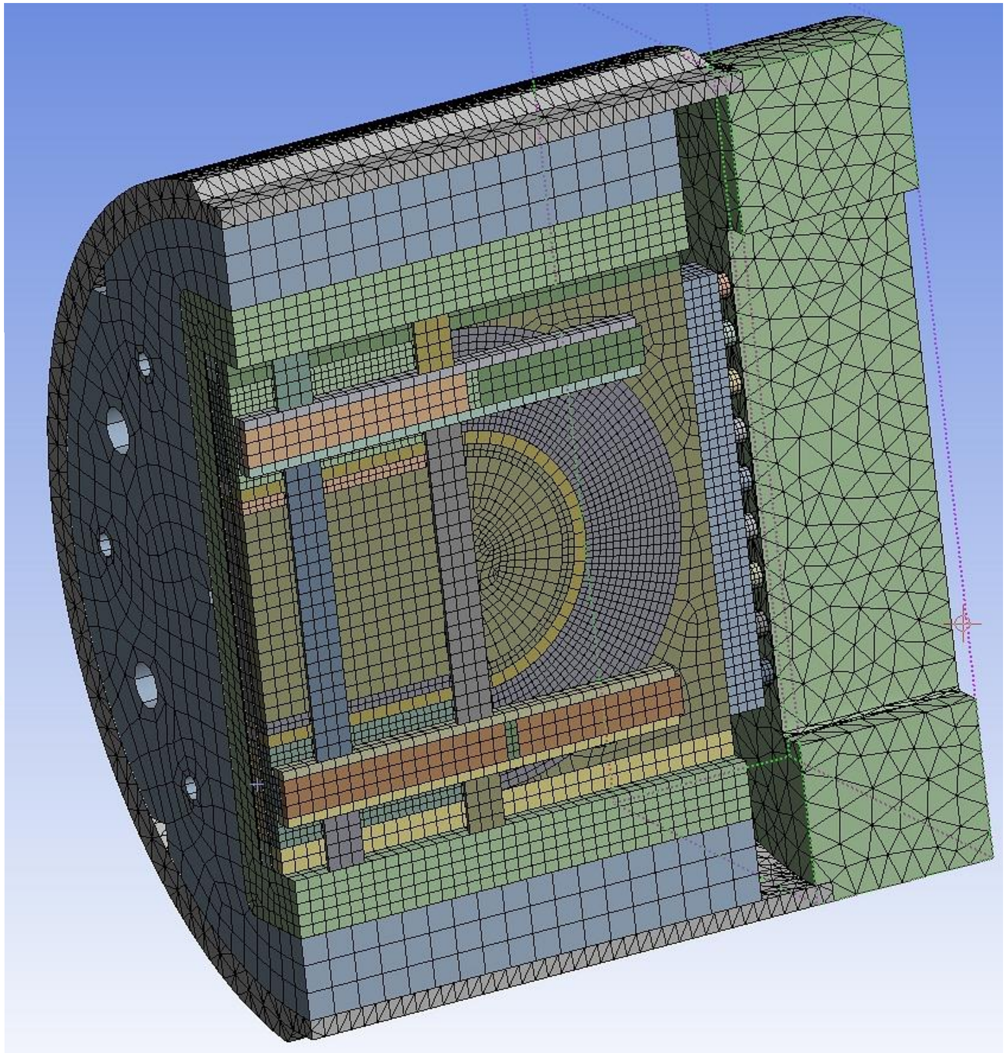
- The baseline models are for 10 kA in the Nb_3Sn coil and 1 kA in two HTS coils
- Also examined HTS coils at 1.5 kA and 2 kA (just in case), for quench studies

ANSYS Model
(Nb3Sn coil and Two different HTS coils)

<u>Main Question</u>

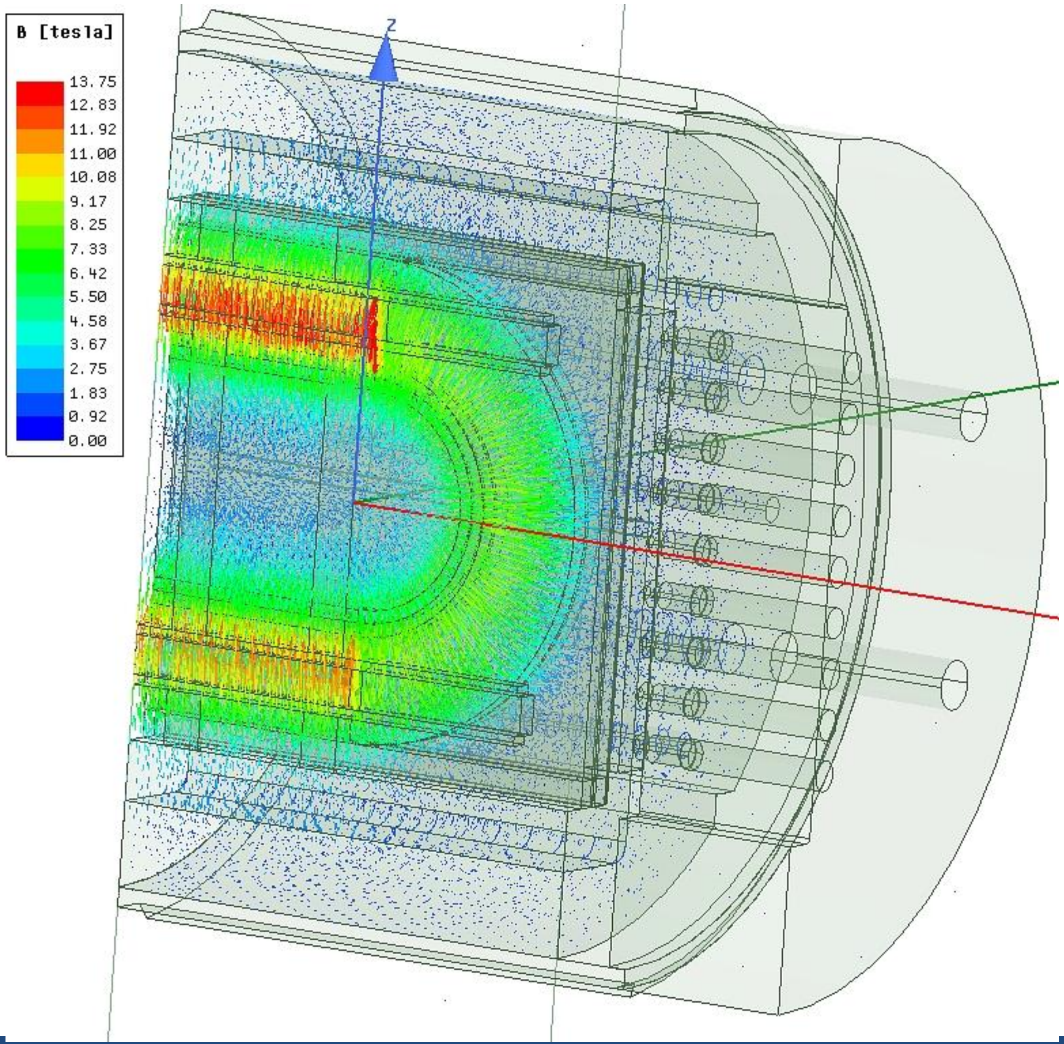
Can Nb3Sn coils and structure take the transverse Lorentz load (x-axis) coming from the HTS coils powered at high current





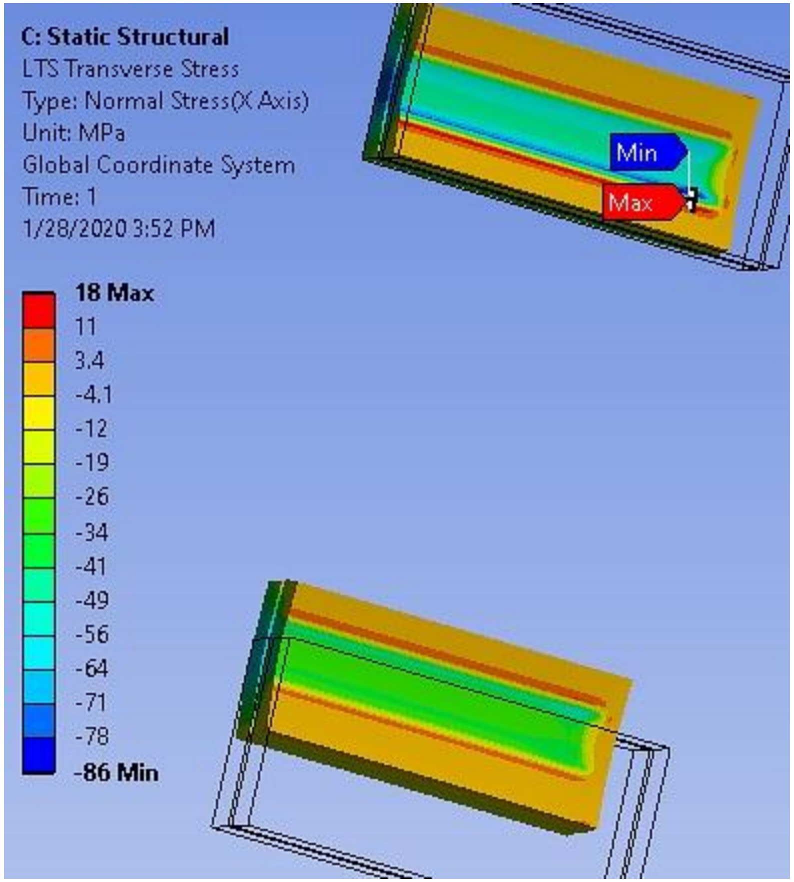
U.S. MAGNET DEVELOPMENT PROGRAM

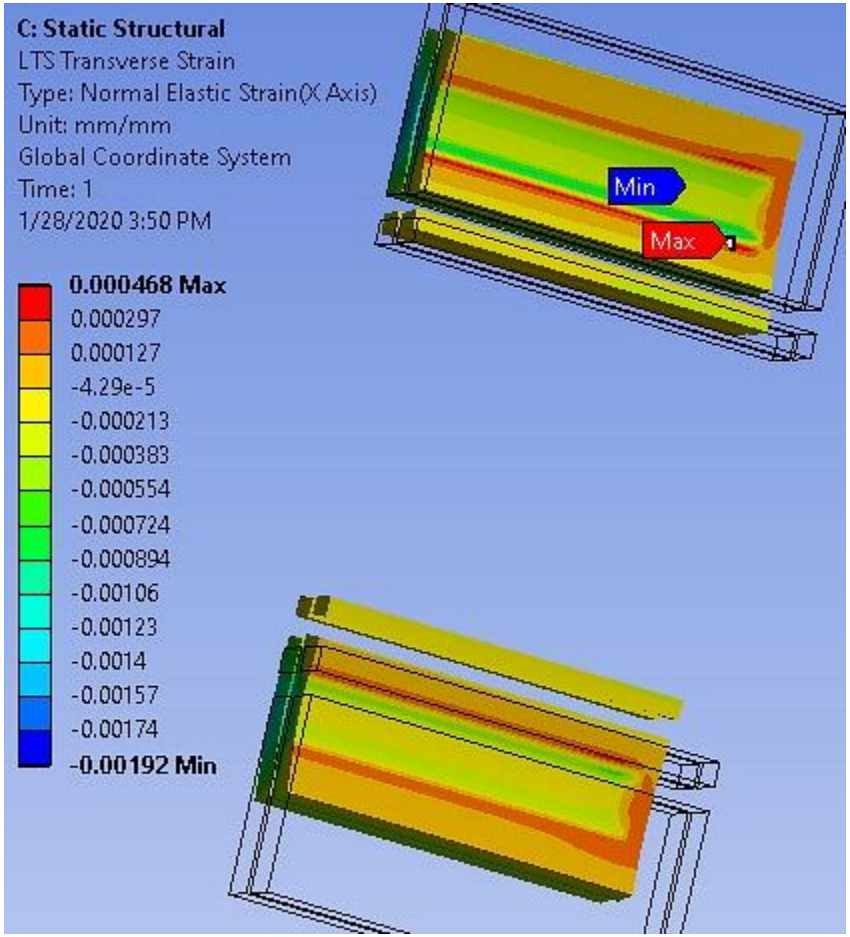
ANSYS Run Field from Nb_3Sn 10 kA, HTS 1 kA



ANSYS Run Transverse Stress and Strain from Nb_3Sn 10 kA, HTS 1 kA

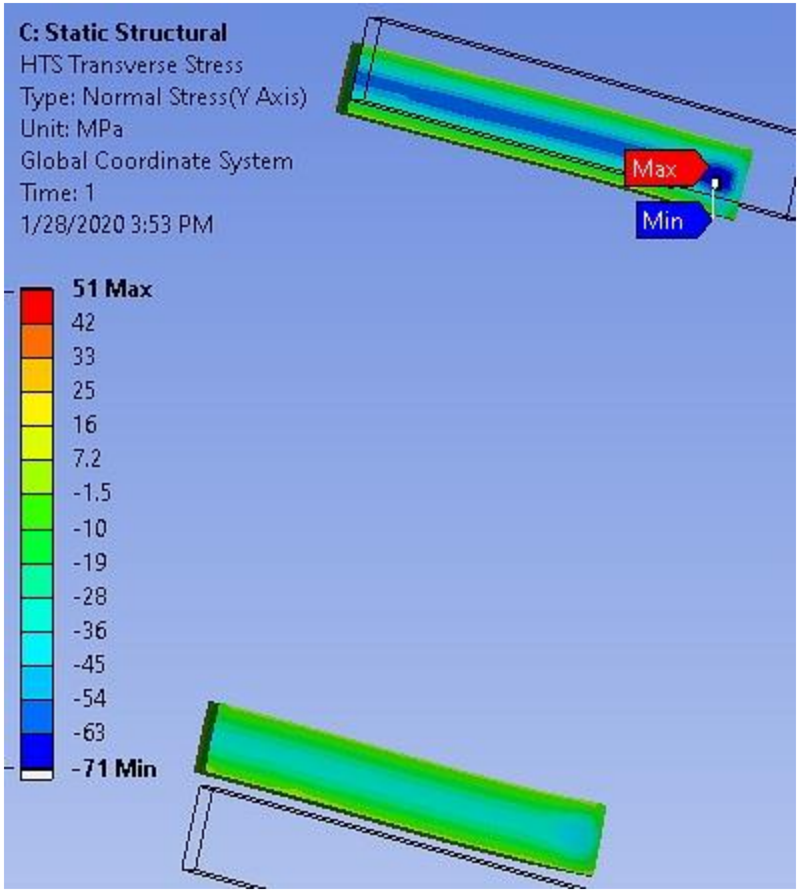
LTS Coils

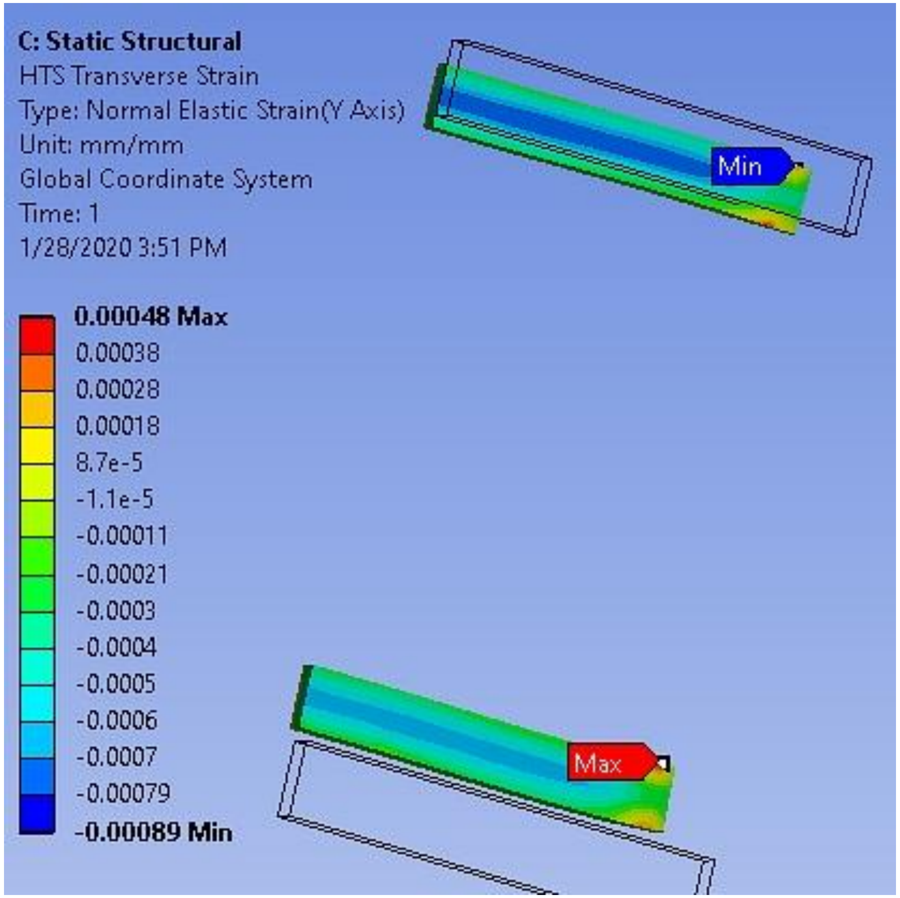




ANSYS Run Transverse Stress and Strain from Nb_3Sn 10 kA, HTS 1 kA

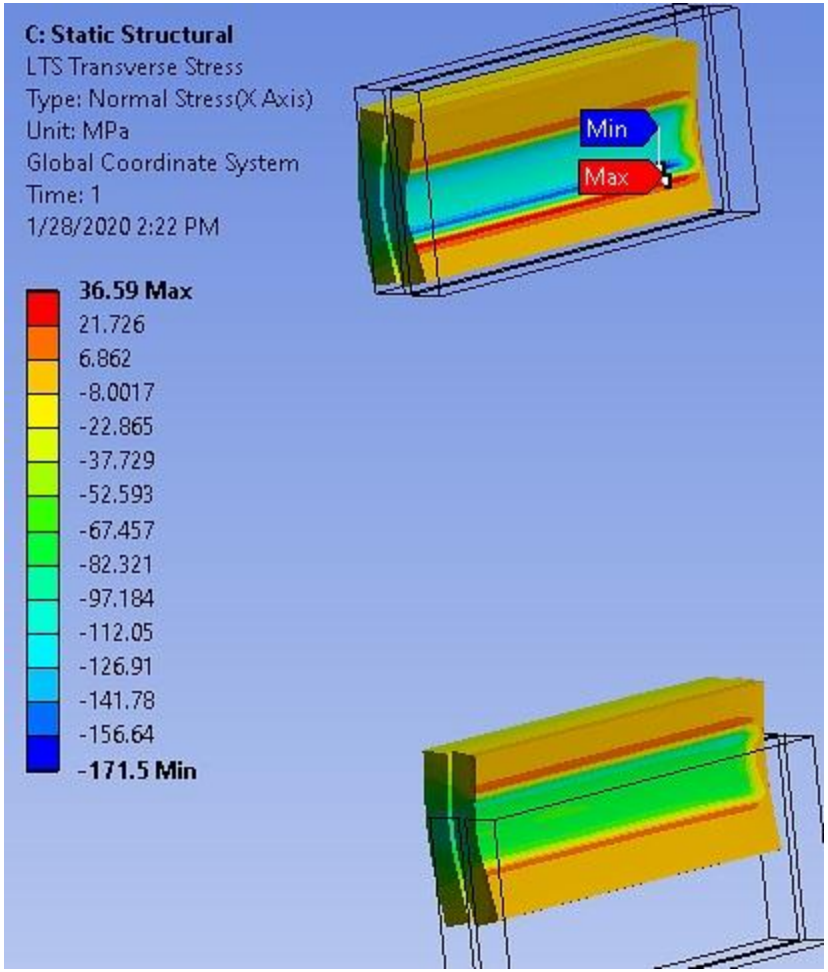
HTS Coils

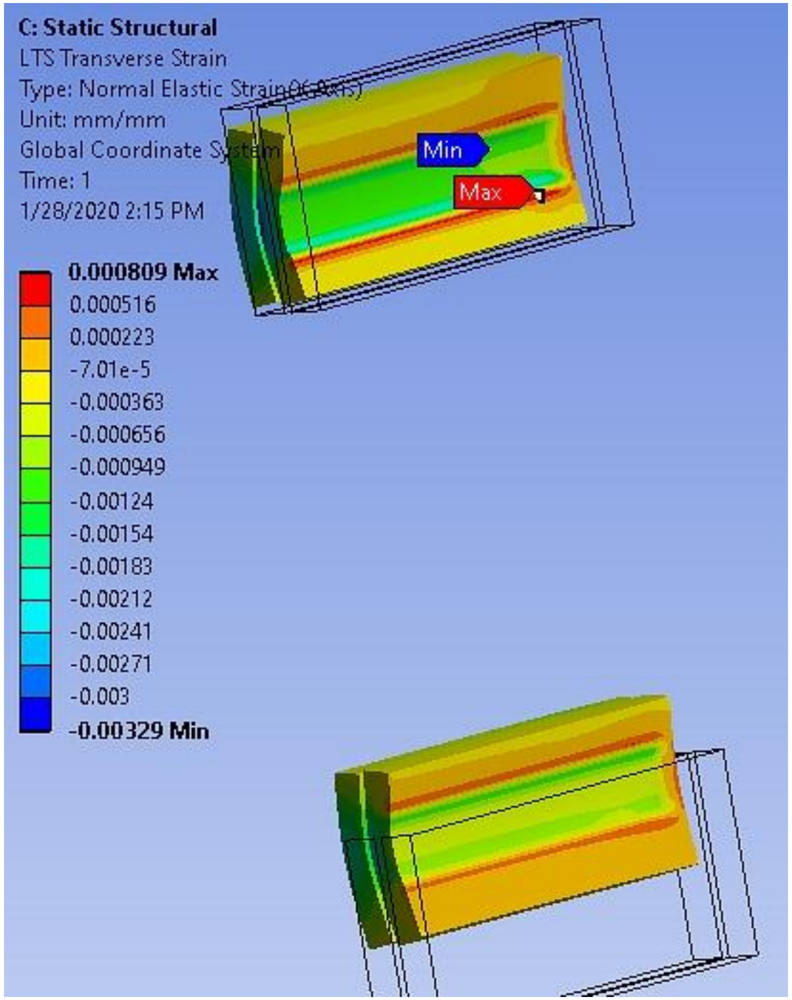




ANSYS Run Transverse Stress and Strain from Nb_3Sn 10 kA, HTS 2 kA

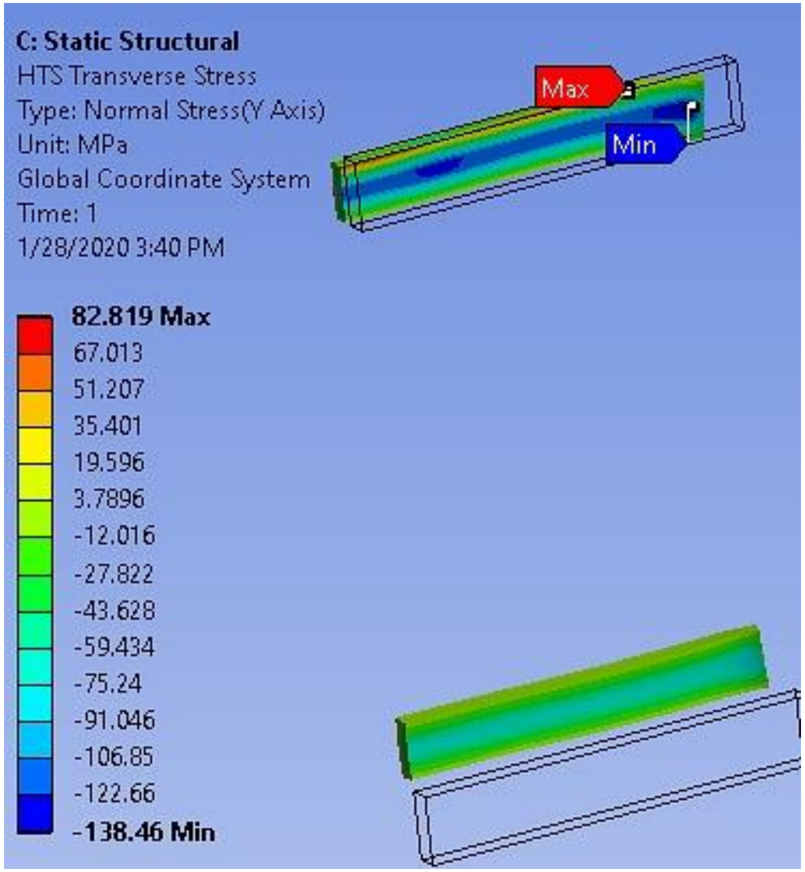
LTS Coils

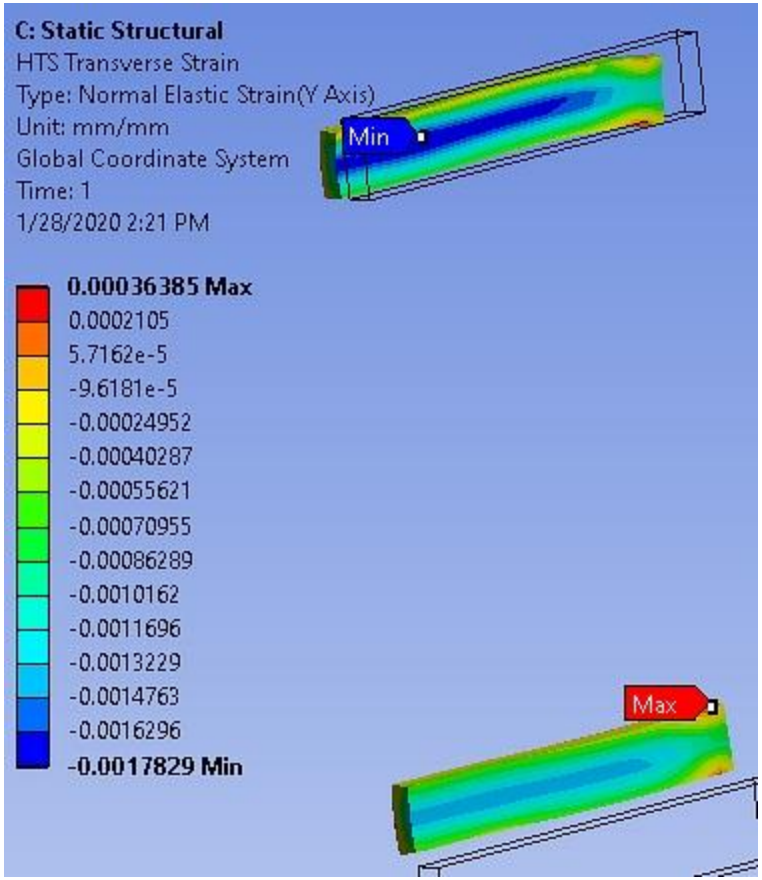




ANSYS Run Transverse Stress and Strain from Nb_3Sn 10 kA, HTS 2 kA

HTS Coils

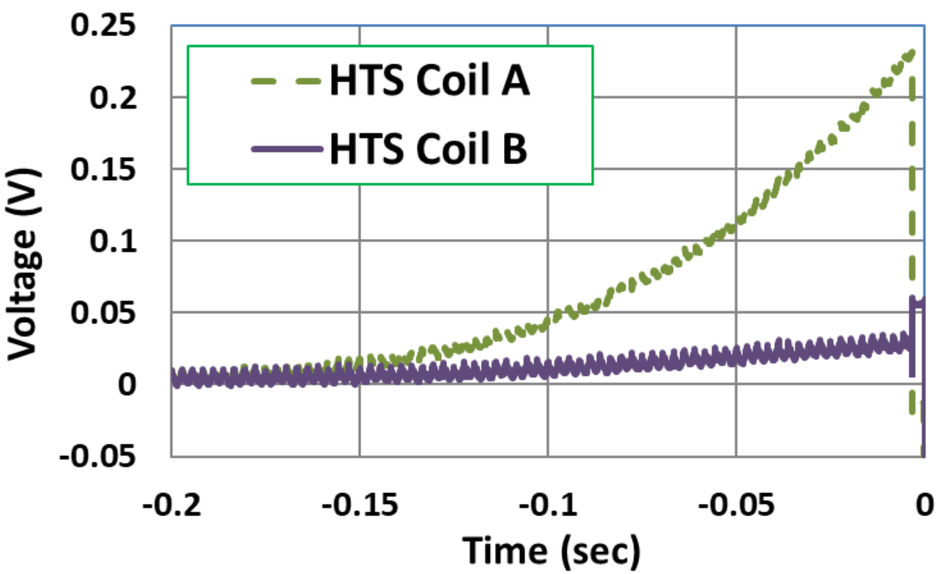


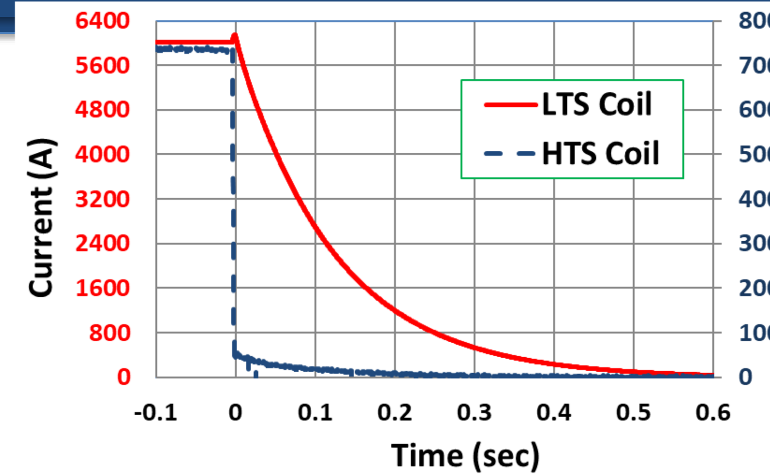


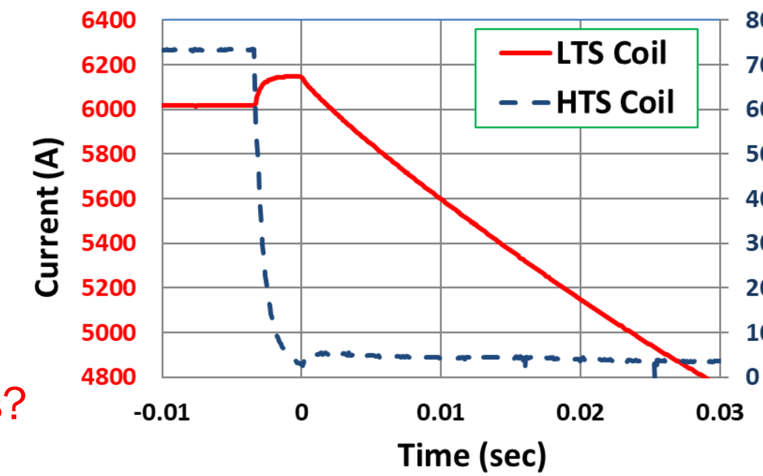
Quench Protection of HTS/LTS Hybrid Dipole

Feedback of Quenching of HTS Coils on LTS Coils in HTS/LTS Hybrid Magnet

- HTS coils operated like HTS coils
- Significant voltage in HTS coils







What happens when the energy of HTS coil increases?
Or what happens to HTS coils if LTS coil quenches?

Study of coupling between HTS & LTS coils can be a major part of MDP

From Piyush Joshi

Summary

- **The magnet has been assembled with HTS coils and CFS samples inserted in the common coil dipole DCC017.**
- **We are on track for performing the test before the MDP collaboration meeting at Berkeley.**
- **The main purpose of this test is to measure the magnetization on HTS coils with HTS tape primary in field parallel direction (earlier studies under SBIR program was for field perpendicular direction).**
- **We will also study the performance HTS/LTS hybrid magnet at high fields (>10 T).**
- **A unique BNL common coil structure allows four simultaneous tests – two HTS coils and two HTS samples. It should score well with the fusion community in terms of MDP/FES collaboration.**