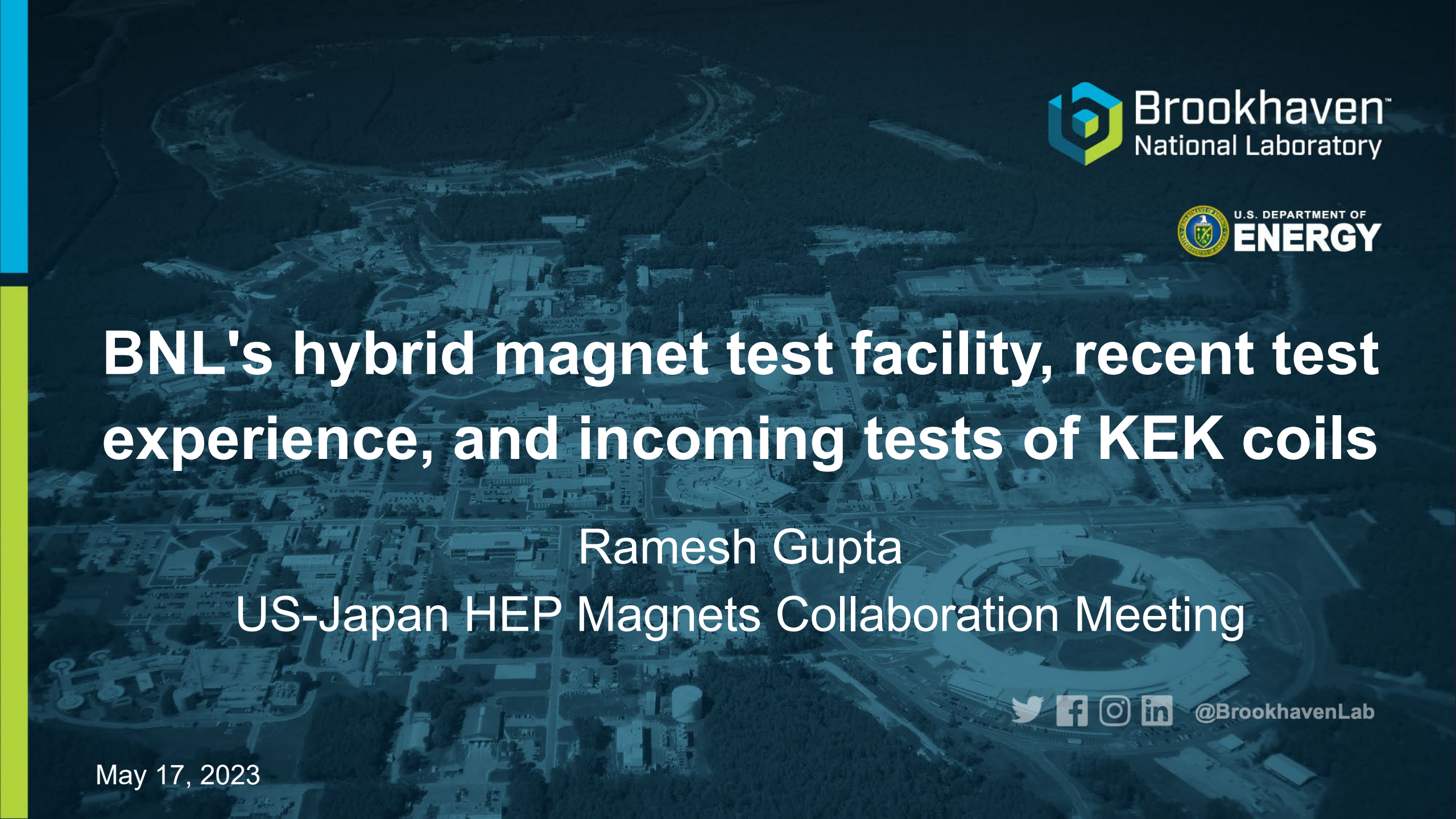


Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

BNL's hybrid magnet test facility, recent test experience, and incoming tests of KEK coils

Ramesh Gupta

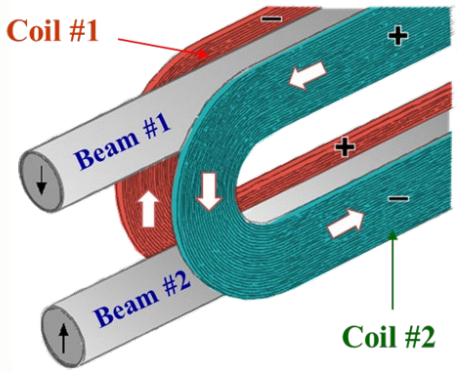
US-Japan HEP Magnets Collaboration Meeting

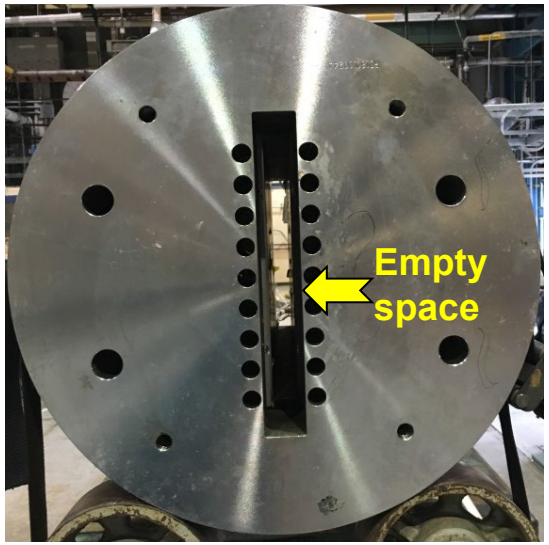
@BrookhavenLab

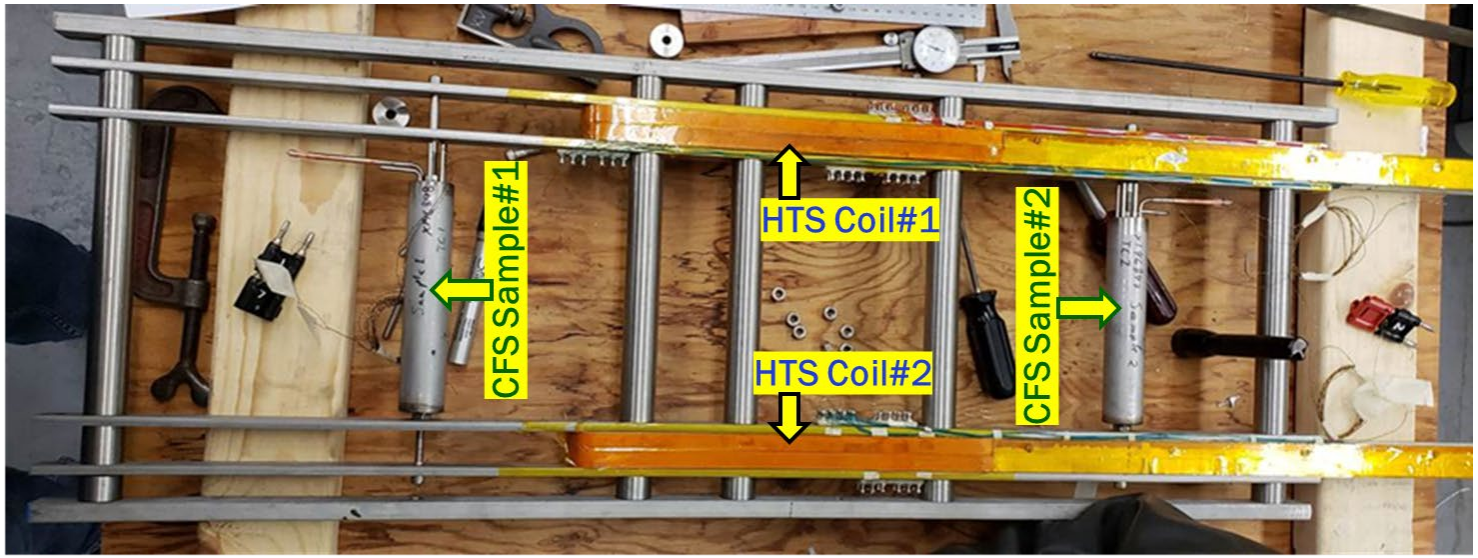
May 17, 2023

A Unique Background-field Dipole for Magnet R&D

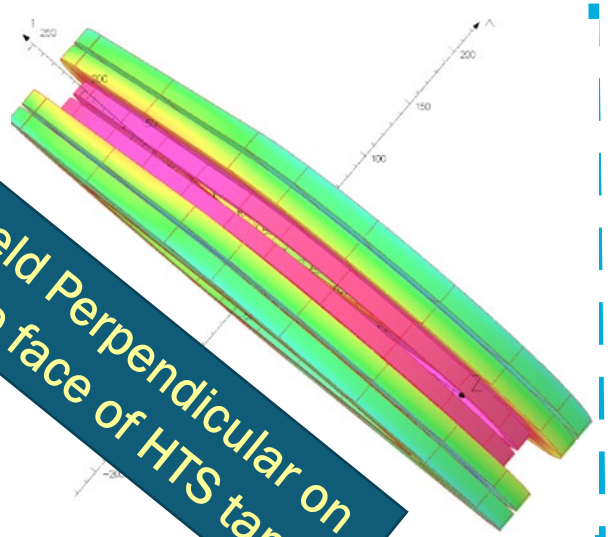
- Nb_3Sn, common coil 2-in-1 dipole that allows two insert coils in two aperture
- Structure is designed to provide a large open space (~30 mm X 335 mm)
- New insert coils can be tested in the background field of up to 10 T (+ self-field)
- The insert coils come in direct contact with the existing Nb_3Sn coils and therefore become an integral part of the magnet (e.g., HTS/LTS hybrid dipole)
- Facilitates a rapid-turn around, low-cost R&D approach for high field magnets
- The approach has already been successfully demonstrated in several tests



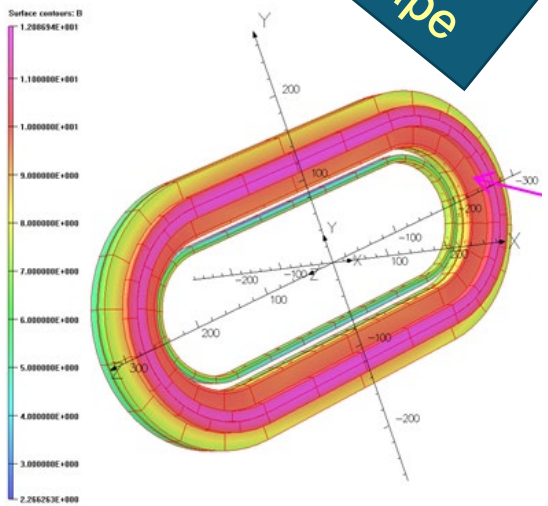




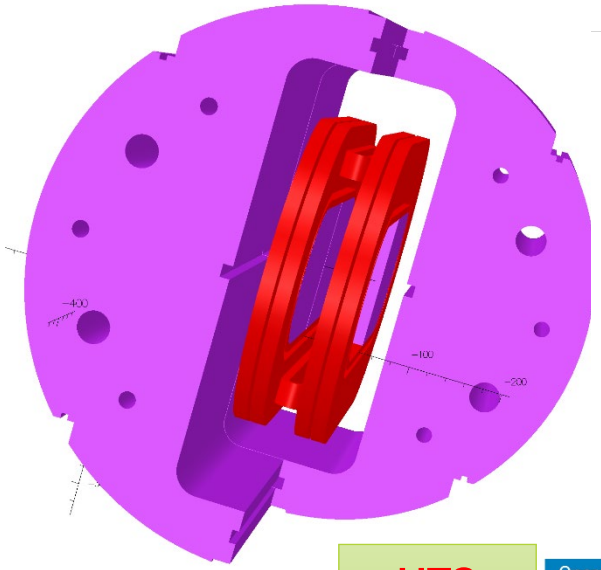
Two Previous HTS/LTS Hybrid Dipole Tests (Either Field Perpendicular or Field Parallel)

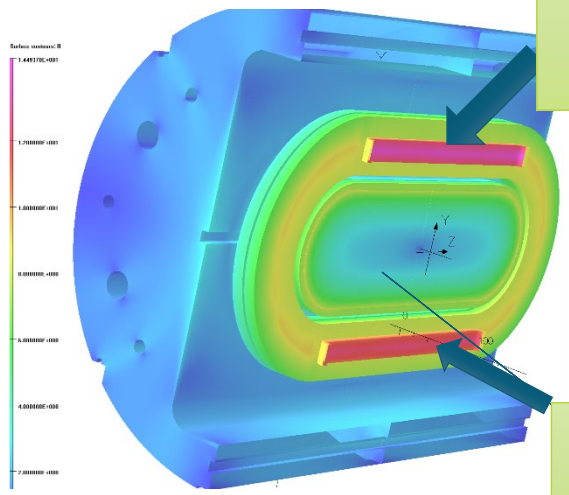


Field Perpendicular on wide face of HTS tape



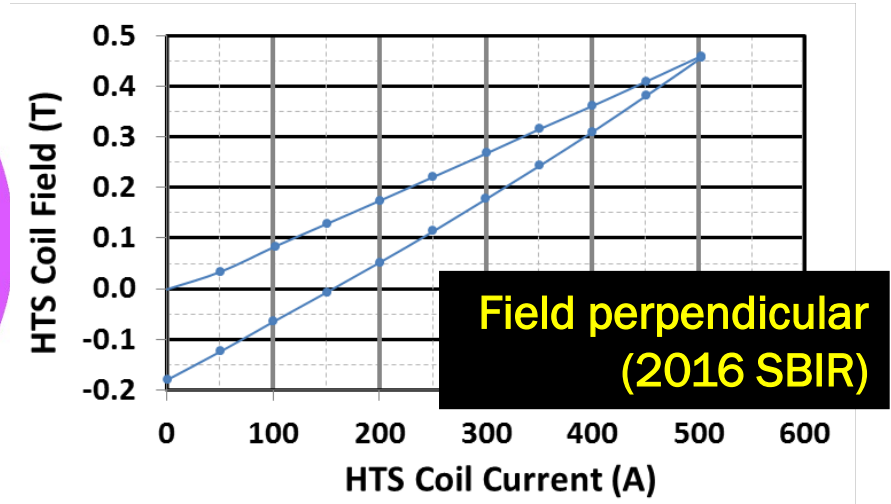
Field Parallel on HTS coils

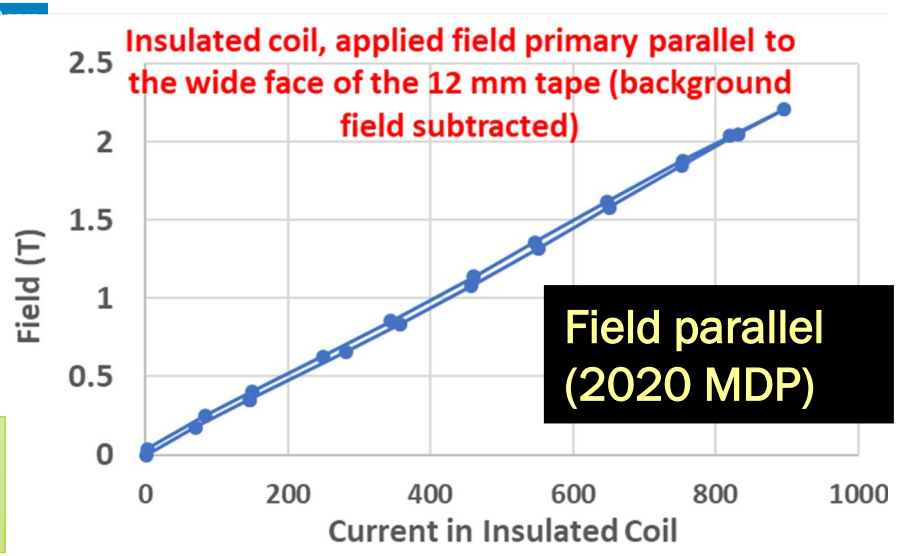




HTS Coil#1

HTS Coil#2

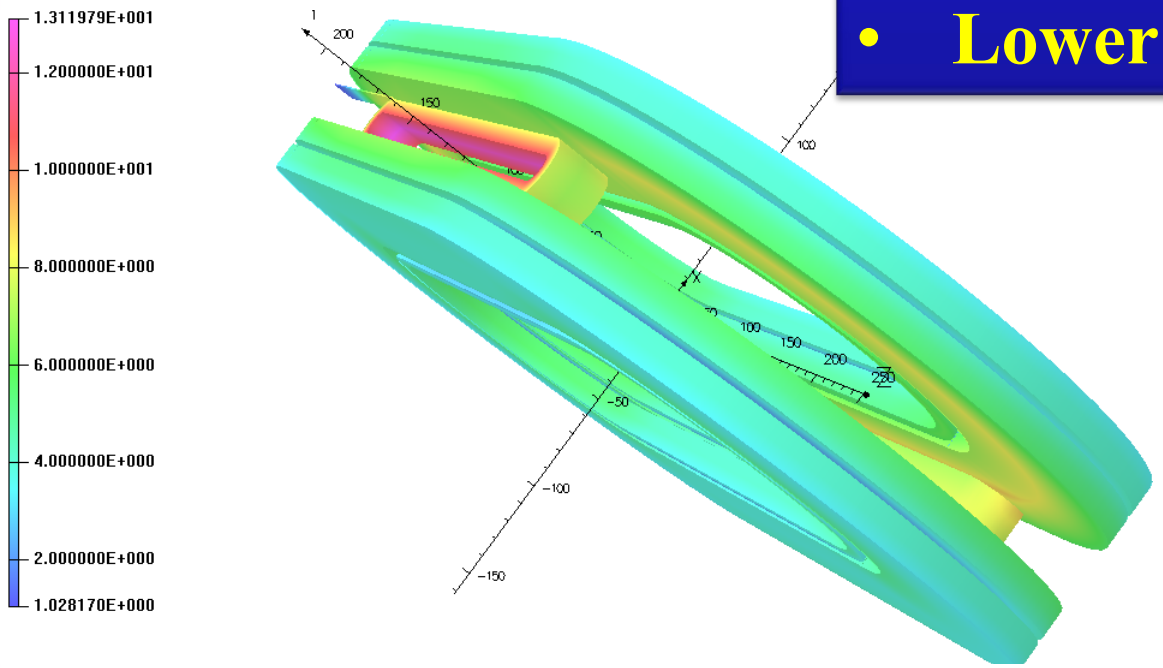




Configuration of US-Japan HTS/LTS Hybrid Test

Two identical HTS insert coils in two apertures of the common coil dipole:

- **Upper Bore: field primarily parallel**
- **Lower bore: field primarily perpendicular**



Systematic and definitive studies:

- Expect significantly lower magnetization and significantly higher current carrying capacity in field parallel case.
- This test will quantify them in high field dipole and provide useful data for designing high field accelerators

Bipolar Power Supply to Study Hysterics Loop

Picture 5

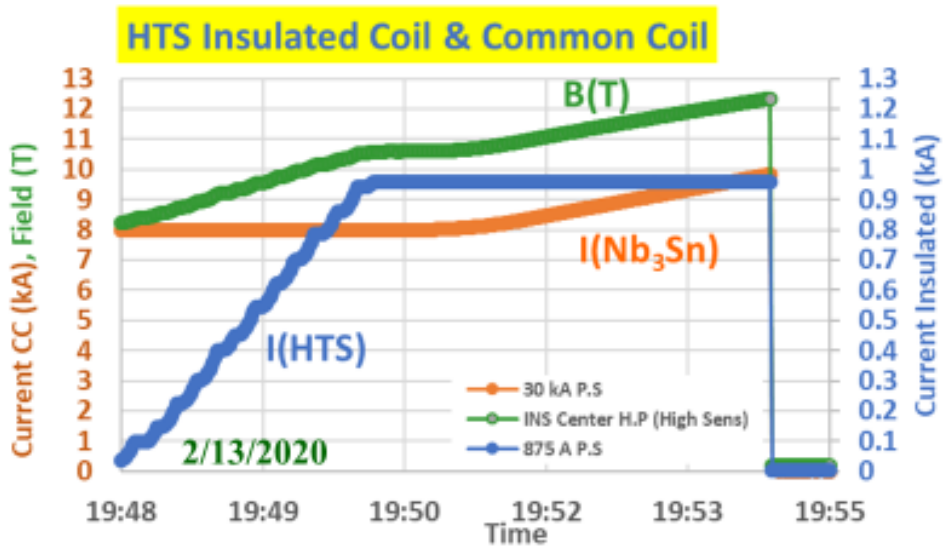
Picture #6

A Lingering Issue until the Recent PSI/BNL Test

BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division

12 T HTS/LTS Hybrid Dipole Test Results

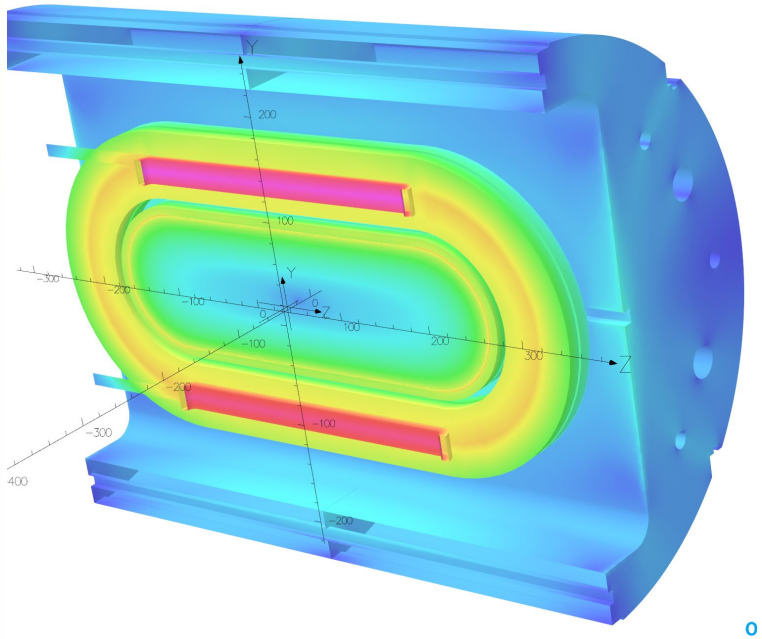
Ramesh Gupta, K. Amm, P. Joshi,
S. Joshi, W. Sampson, A. Ben Yahia
LTSW/HFSW2020, Berkley, CA

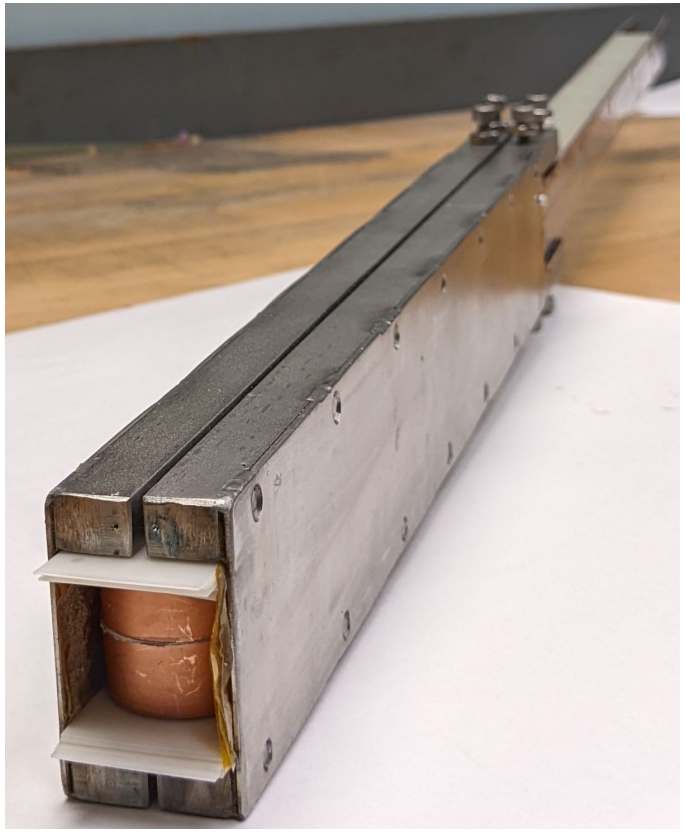


Even though a record 12.3 T hybrid field was obtained, the performance was not limited by HTS coils. It was limited by the Nb_3Sn coils in every HTS/LTS combination.

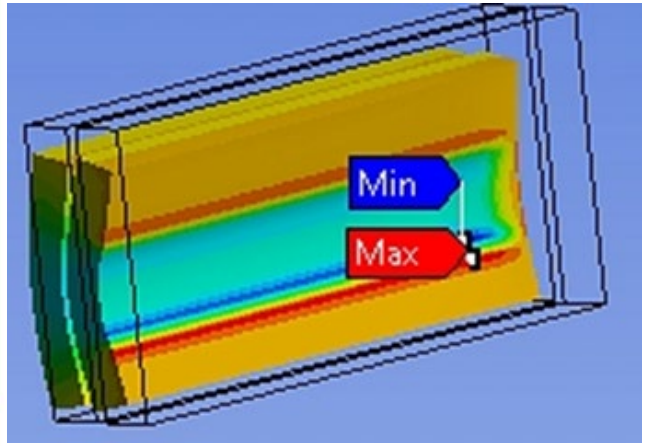
Smaller HTS coils were in direct contact with the larger Nb_3Sn coils with no structure in between. This meant a local discontinuity or stress/strain from the pressure of HTS coils on Nb_3Sn coils.

Stress/Strain Management in Common Coil Structure

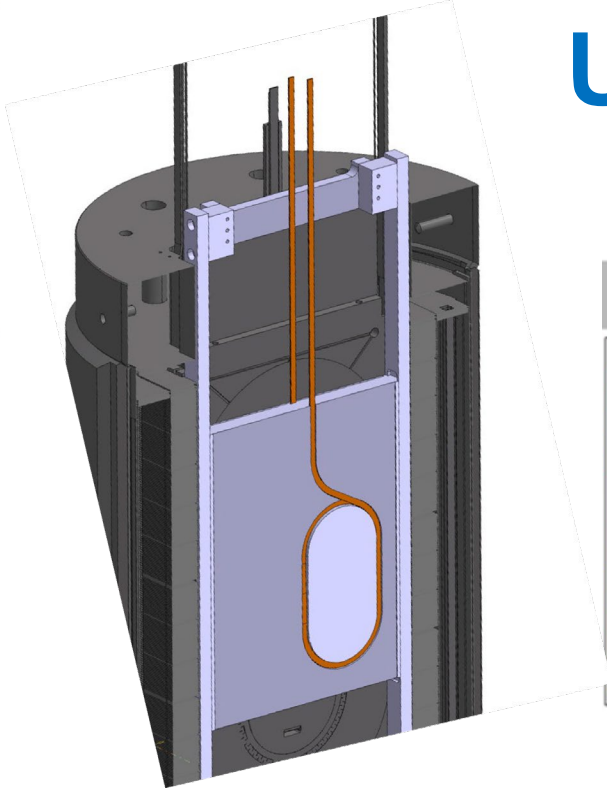


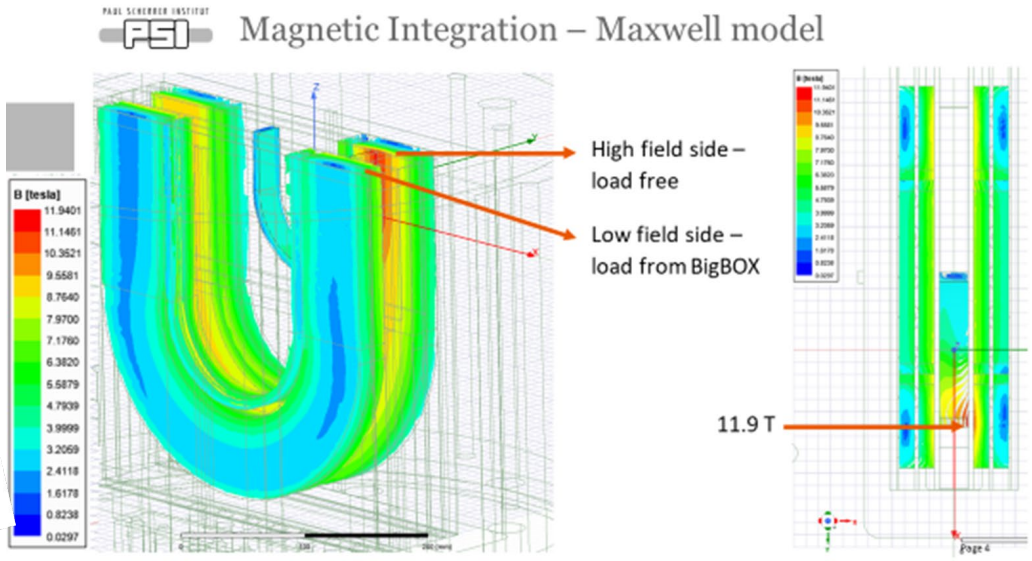


- Intermediate structure removes the local stress/strain concentration on Nb_3Sn coils
- A structure based on this principle was used in the recent PSI insert coil test
- Similar structure is being used in US-Japan collaboration



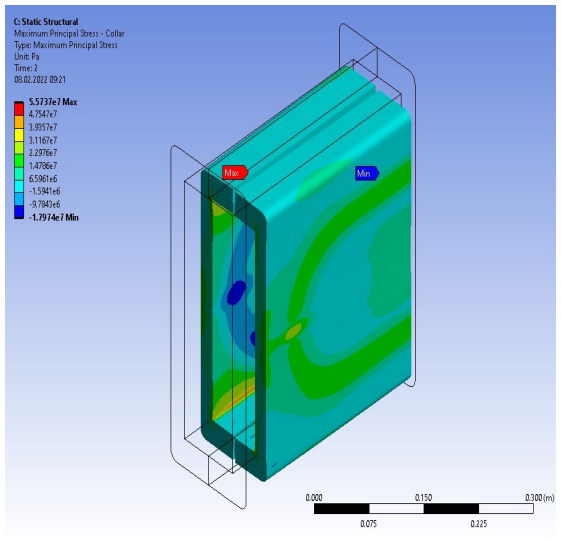
Update from the Recent PSI/BNL Test



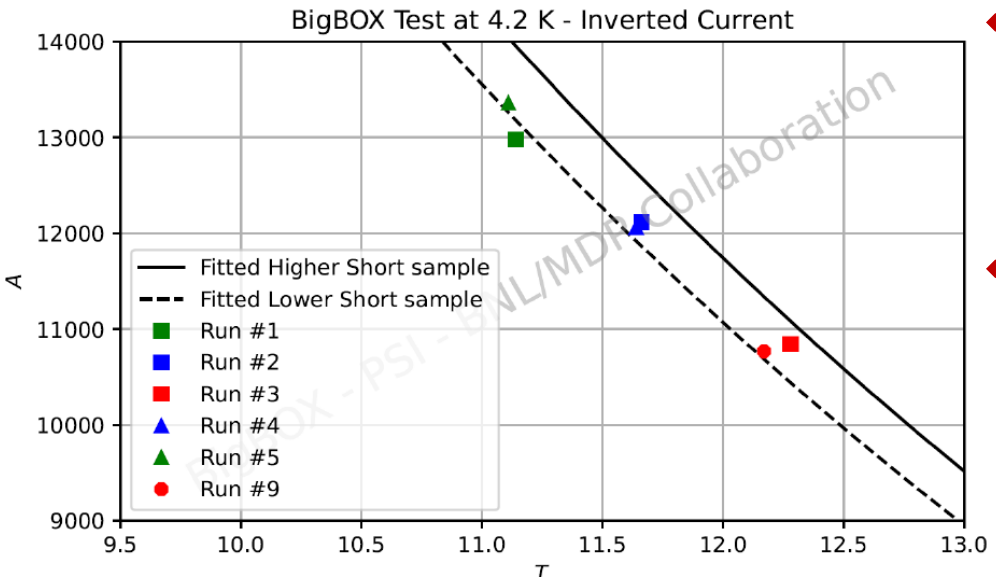


PSI insert coils had a structure to manage stress concentration

- Performance of DCC017 was no longer limited by the stress/ strain limit of Nb_3Sn coils
- DCC017 coil didn't quench as it reached over 12 T field
- This was higher than ever reached in DCC017 (DCC017 coils ran at a lower current – ~9 kA)

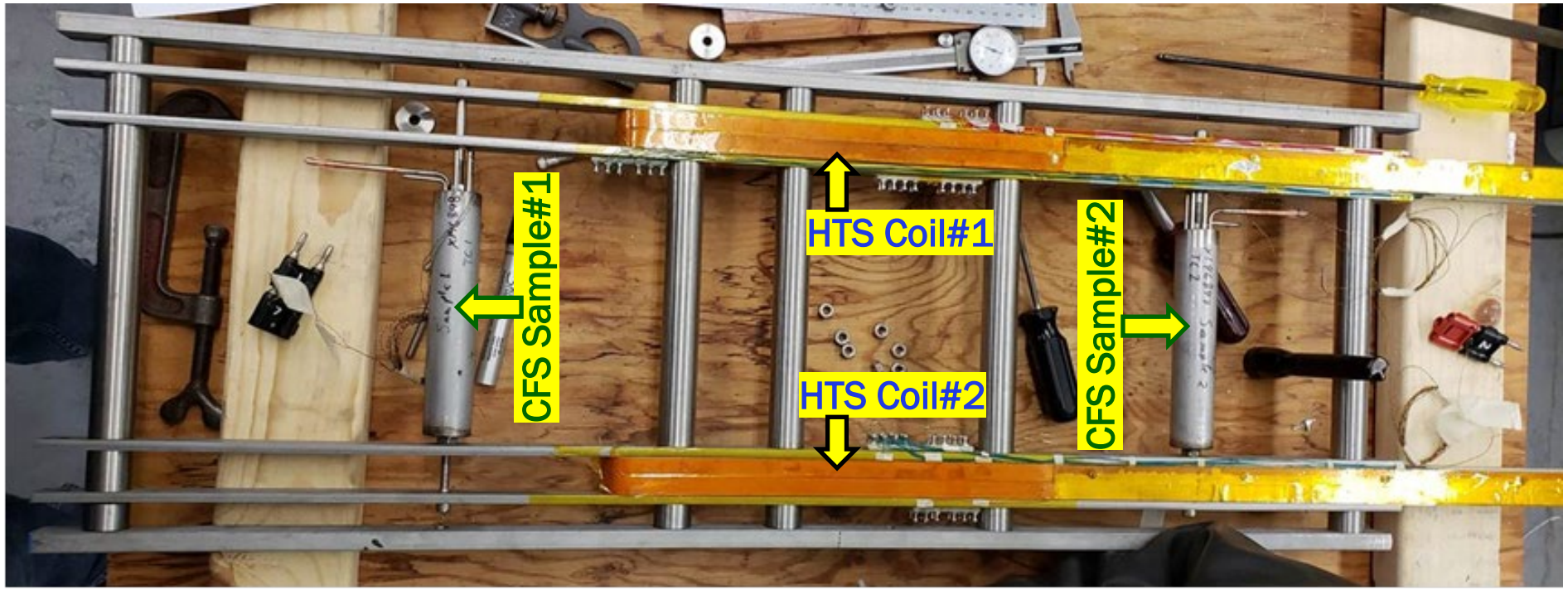


Courtesy: PSI



Frame used in Previous HTS/LTS Hybrid Test

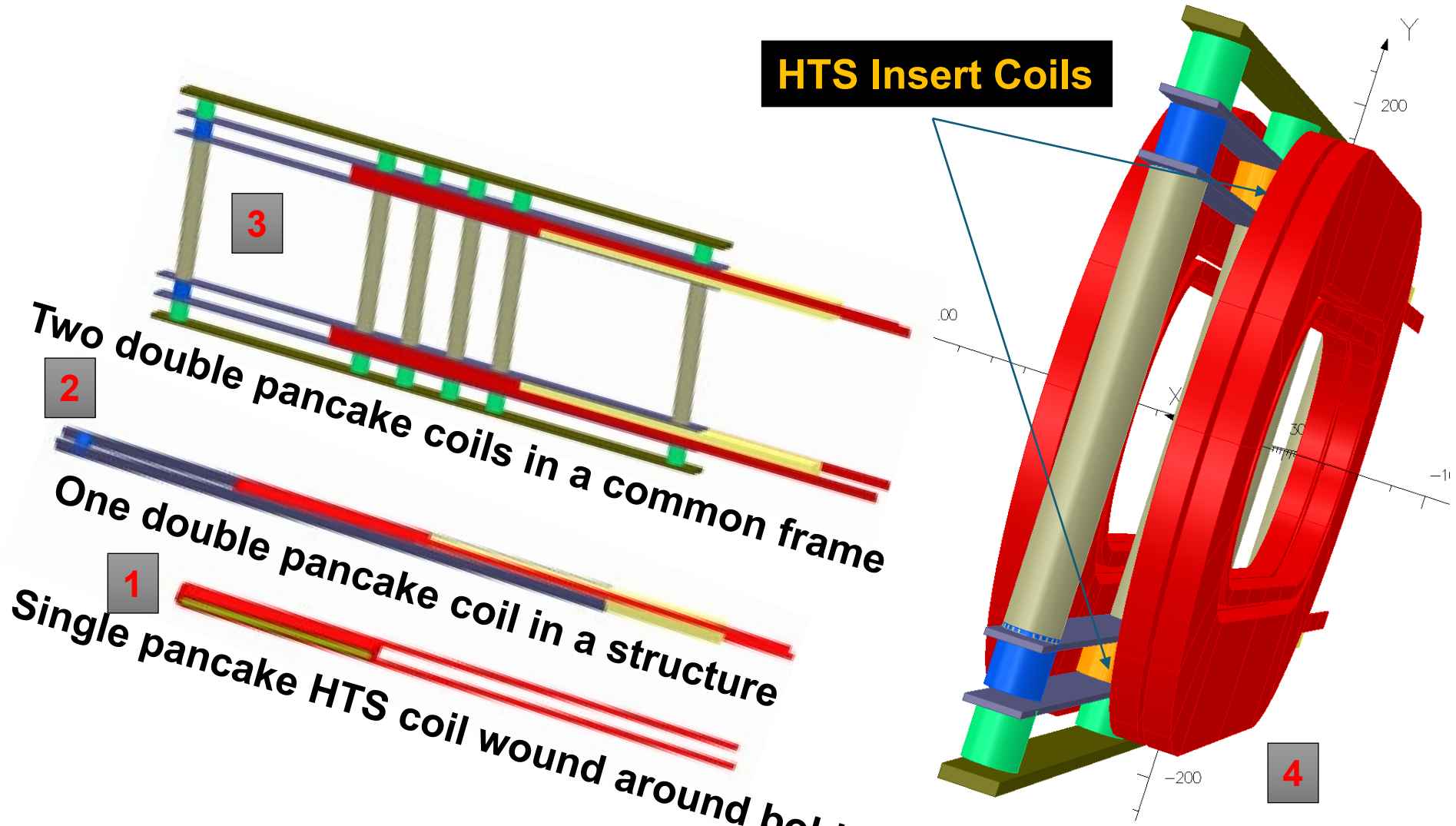
Test holder ready to be inserted in DCC017



Two HTS coils for testing in field parallel configuration

(also included, two HTS cable samples from the fusion community)

HTS Insert Coil Structure in Frame Concept for US-Japan Test (two HTS coils in the 2-in-1 Nb_3Sn common coil dipole)



Summary and Discussion

- A unique structure of the DCC017 common coil dipole with large open space is beginning to show its utility to carry out systematic, rapid-turn-around, low-cost magnet R&D such as the one being performed under this US-Japan collaboration.
- The facility provides a vehicle for accelerator magnet R&D based on the racetrack coil. The general principle should be applicable to all designs, such as the use of mineral insulation and HTS/LTS hybrid R&D that is being performed under US-Japan collaboration.
- The basic design and most components are ready to perform this test in a few months. A regular discussion between the team member will ensure that the test goes smoothly.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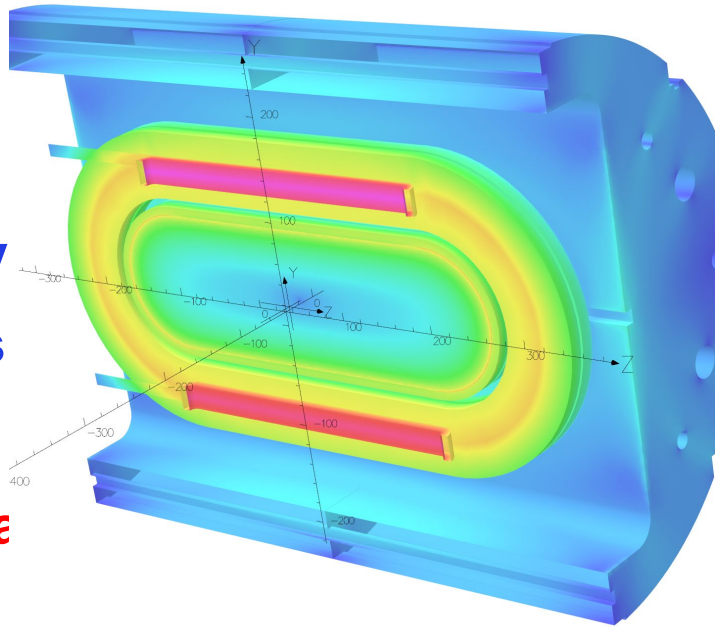
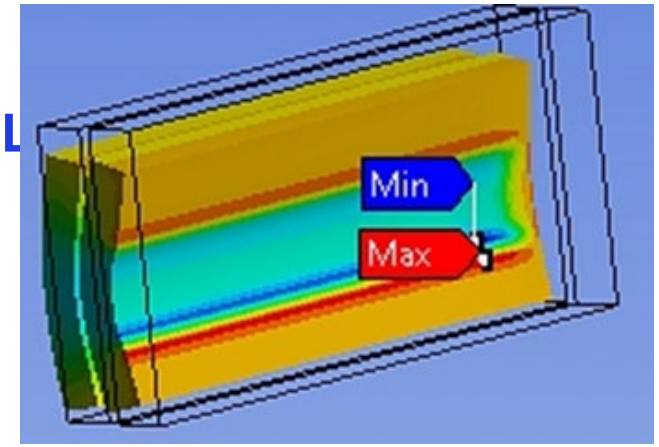
EXTRA SLIDES
@BrookhavenLab
May 17, 2023

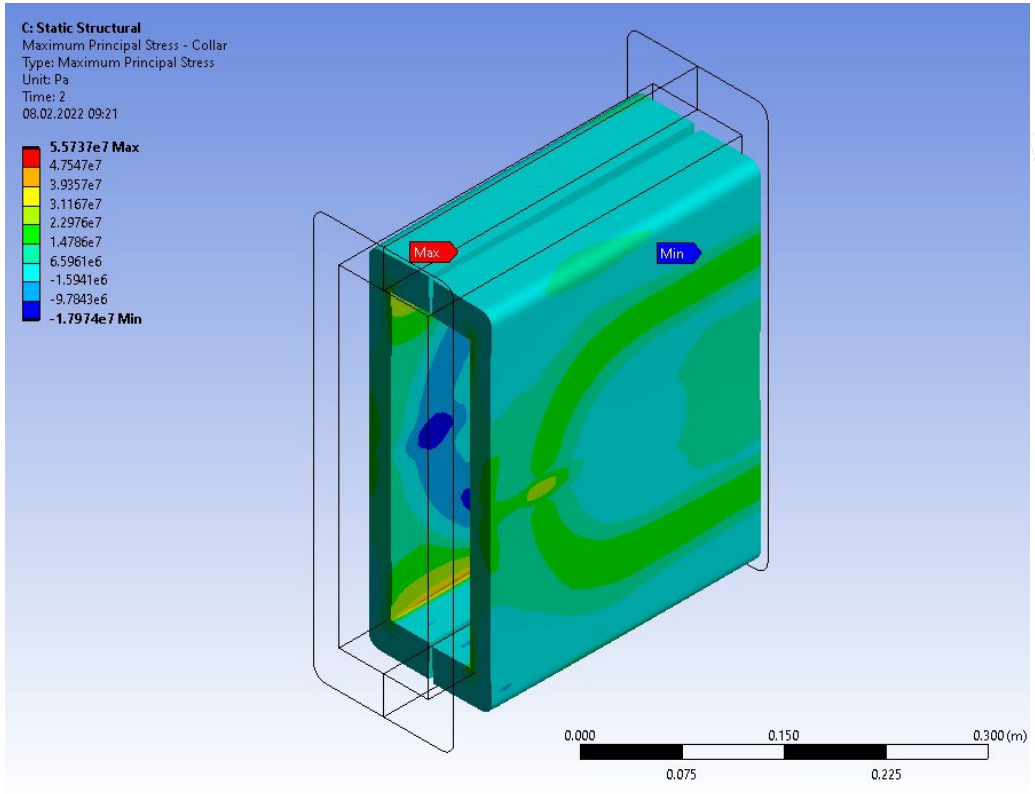
Slides from presentations made earlier

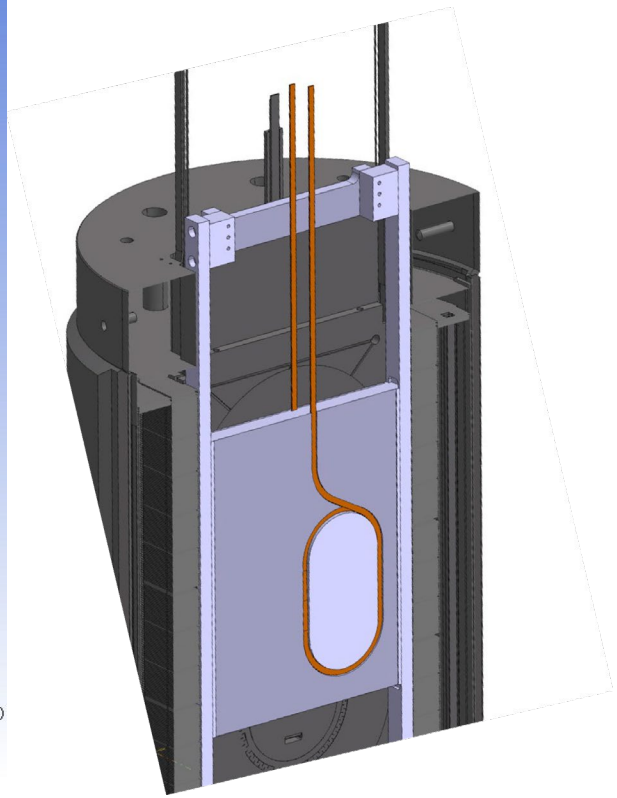
- During the last HTS/LTS hybrid test, the maximum performance of 12.3 T was limited by the LTS coils, and not by the HTS coils.
- Moreover, it was NOT limited by Nb_3Sn coils themselves, as they by themselves worked well. Performance got limited when Nb_3Sn coils were energized together with the HTS insert coils.
- Theory: Nb_3Sn coils were stress/strain limited locally (no intermedia structure to manage or distribute the stresses).
- This question/issue is important in all high field Nb_3Sn magnets.
- All new inserts are planned with intermediate structures. This PSI/BNL test was became a test to overcome the stress limit.
- It allowed higher peak field in DCC017 coils (10.7 T => ~12 T)
- More interesting what was observed accidently (magnet survived).

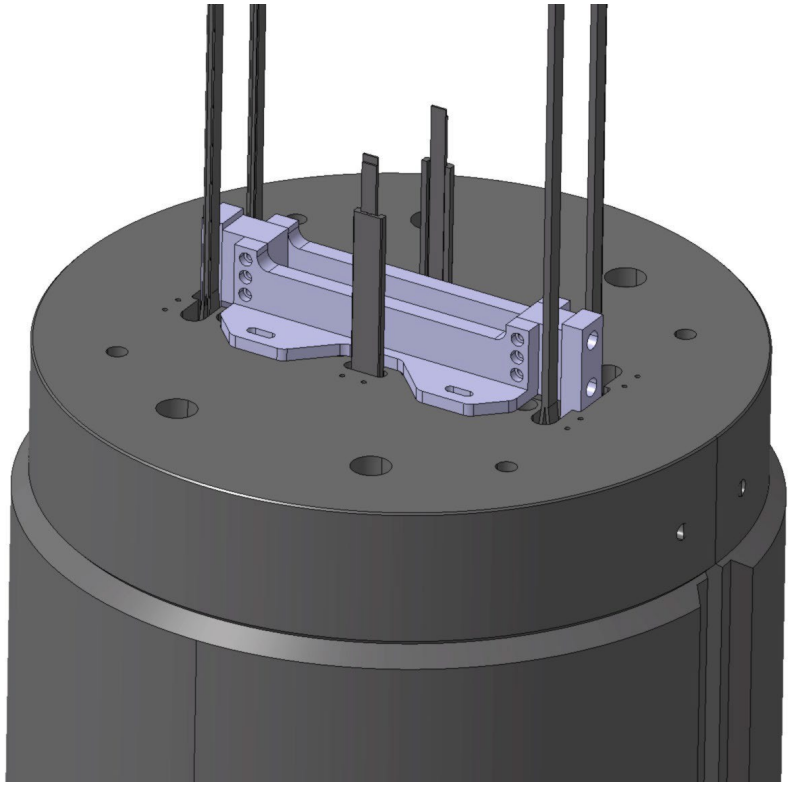




BigBox Structure for Stress Management (analysis to be discussed by PSI)

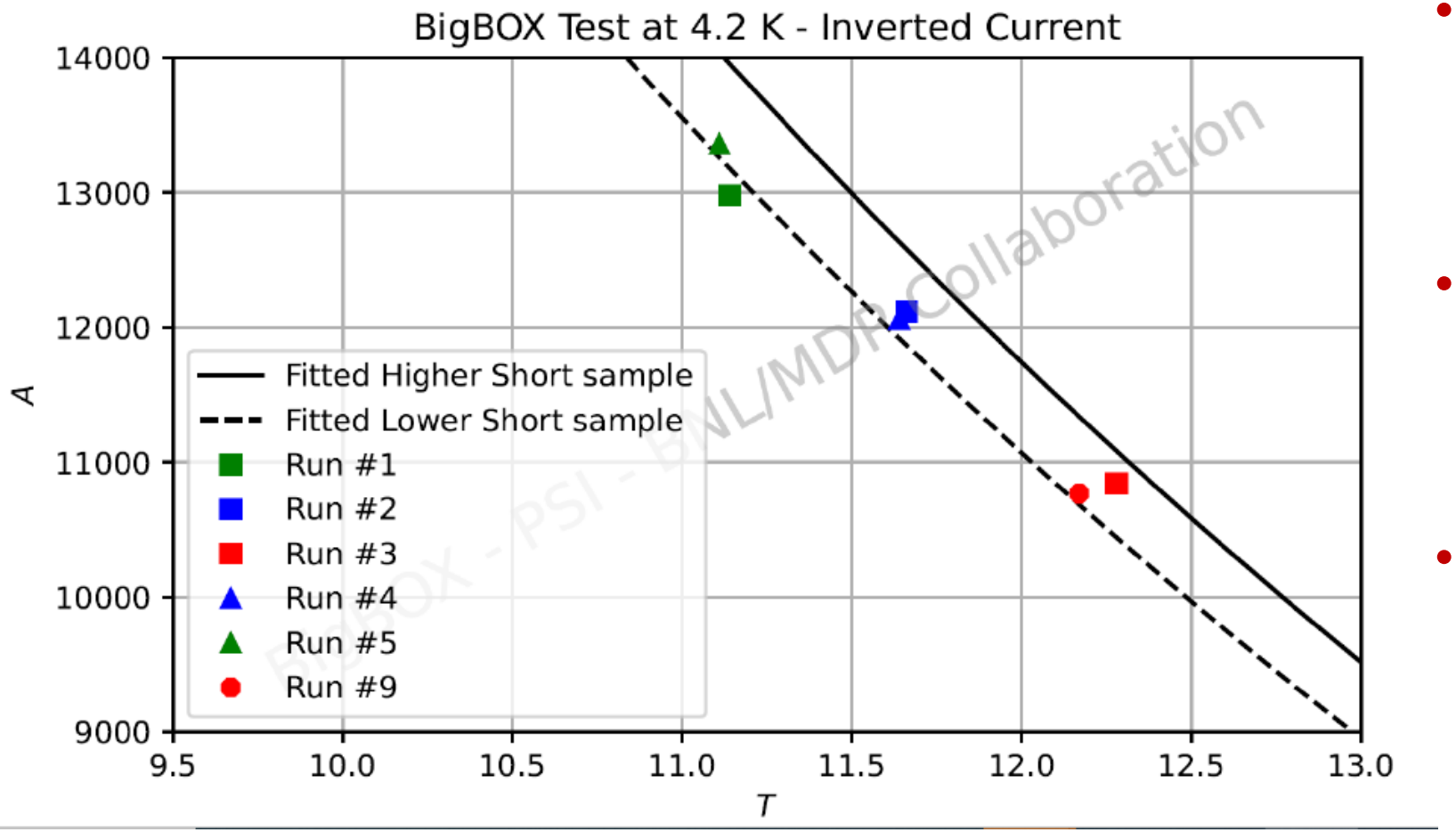






- This brings stress/strain on Nb_3Sn coil of DCC017 below the limit
- Due to the space limitation, the plates were made thicker on the high stress side and thinner on the high field side, with ~2 mm gap at most places.

Expected and Observed Test Results

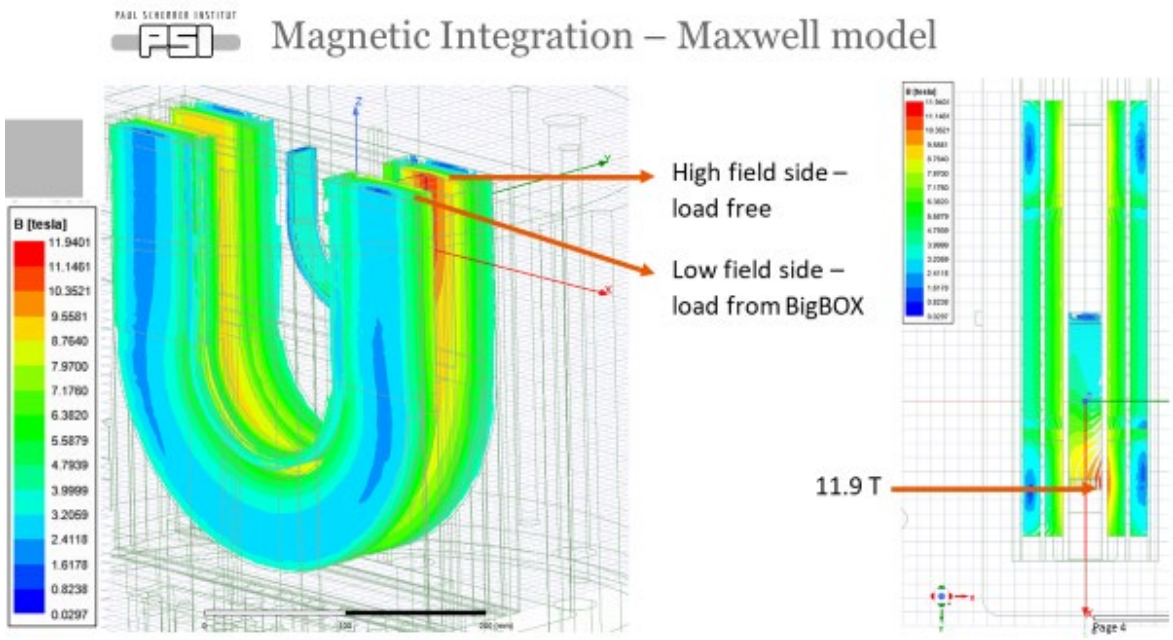


- **Field of DCC017 Nb_3Sn coils was not limited by their stress/strain limit**
- **DCC017 coil didn't quench as it reached ~12 T field (BigBox quenched)**
- **This was higher than ever reached in DCC017 (DCC017 coils ran at a lower current – ~9 kA)**

Courtesy: PSI
(results to be discussed by them

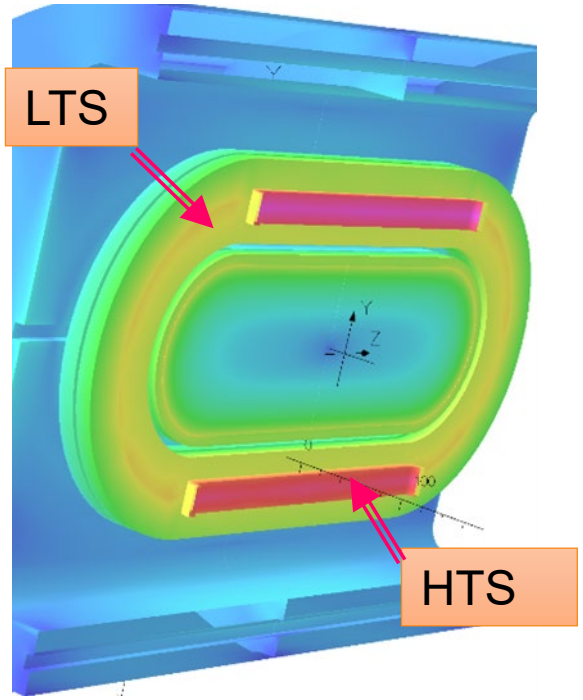
Interesting Oservations

- **PSI insert coil was powered in opposite direction then originally intended.**
- **This means that the coils moved significantly under Lorentz forces to close-in the 2 mm gap**
- **Many good discovery in science have come unintentionally (or accidently). Here is another one, even though not close to other spectacular discoveries**



- **No quenches in Nb_3Sn coils, means that the gap tolerances can be relaxed in such structures (though a large variation in the gap should perhaps be avoided)**
- **Structure of ~2.3 mm rather than ~4 mm was sufficient**
- **Stress diffusion – avoiding local stress/strain to spreading the stress worked**

Summary and Observations from the Quench Tests

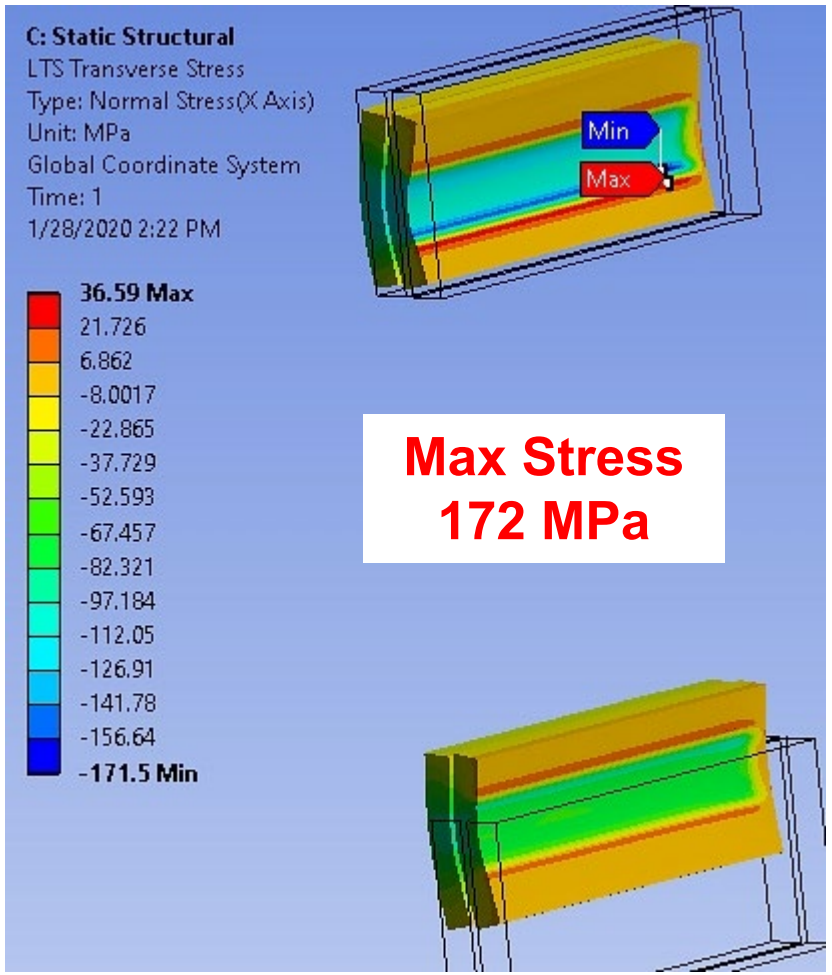


- Note that the HTS coils didn't have their own independent support structure. When they were energized, they leaned on the LTS coils for support. It creates a pinching stress on the LTS coils at the corners where HTS coils rest.
- Several combinations of currents in the HTS coils and the LTS coils were tried. In all cases, LTS coils quenched (sometimes a little before short sample).

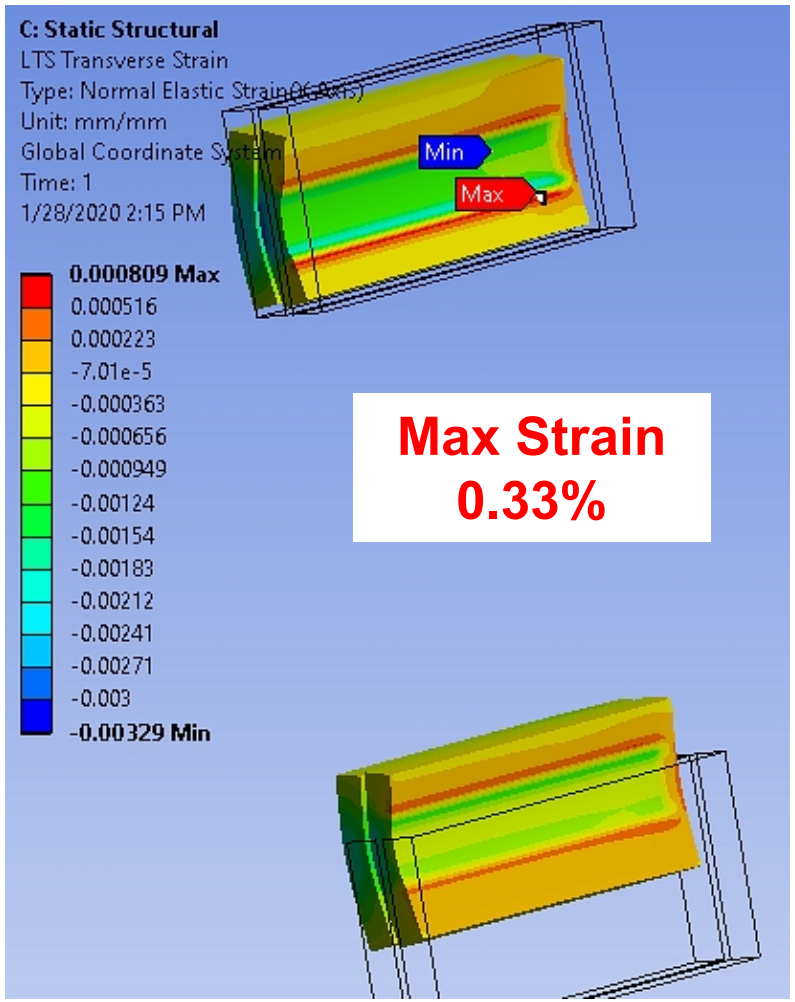
The hypothesis is that the quench is caused by the strain from the pinching forces. To minimize that either include a relatively thicker structure on the HTS coil to contain the Lorentz forces, or at least a thinner structure on the HTS to distribute/dilute the local stress/strain.

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

Stress and Strain on the LTS Coils from the HTS



Max Stress 172 MPa



Max Strain 0.33%

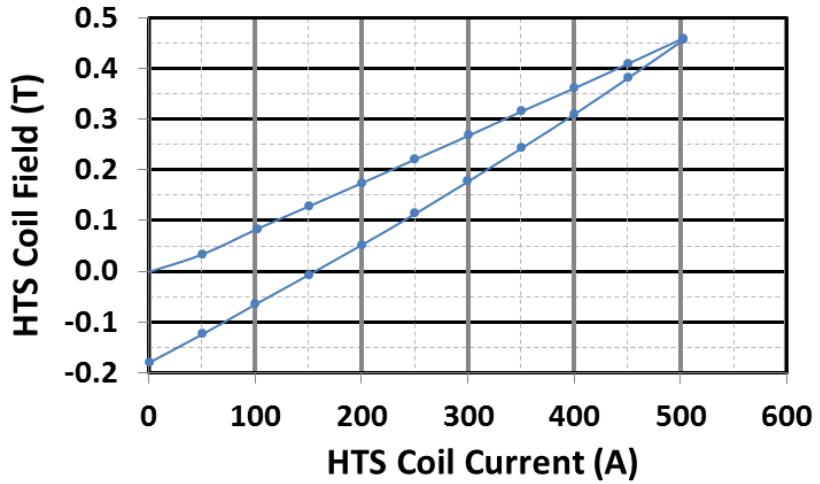
Hybrid Magnet Test Results HTS Coil Magnetization

- Expect smaller conductor magnetization and hence field errors in a configuration when the background field is primarily parallel to the wide face of the HTS tape rather than perpendicular

Comparison between Field Perpendicular and Field Parallel Magnetization @2T Dipole Field

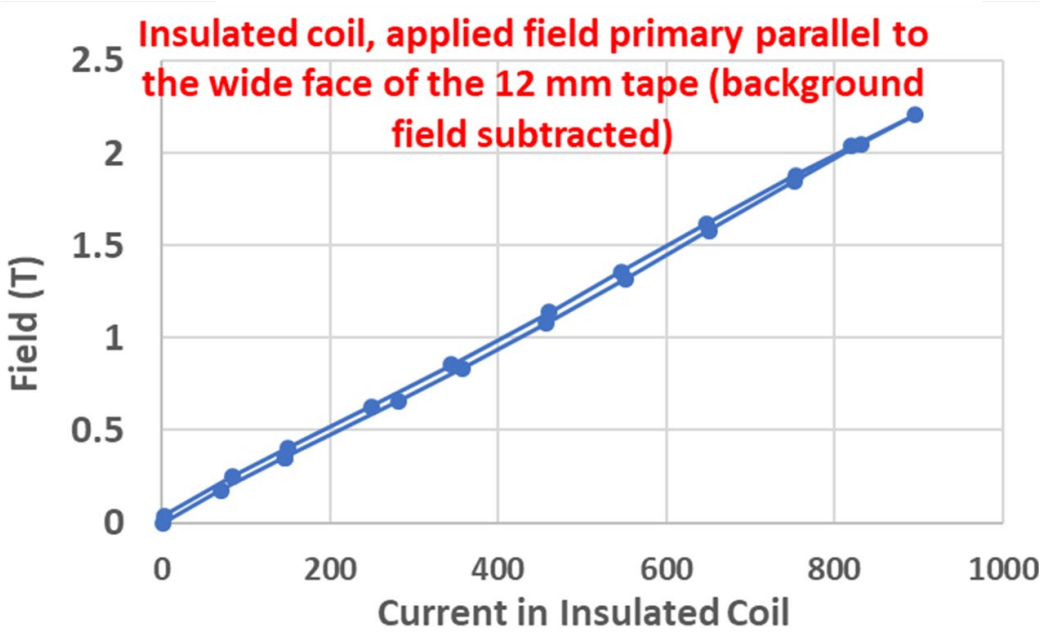
Field perpendicular (2016)

Additional field from the HTS coils in up and down ramp (Field from LTS coil subtracted)



A large remnant field (-0.2 T) due to magnetization in tape

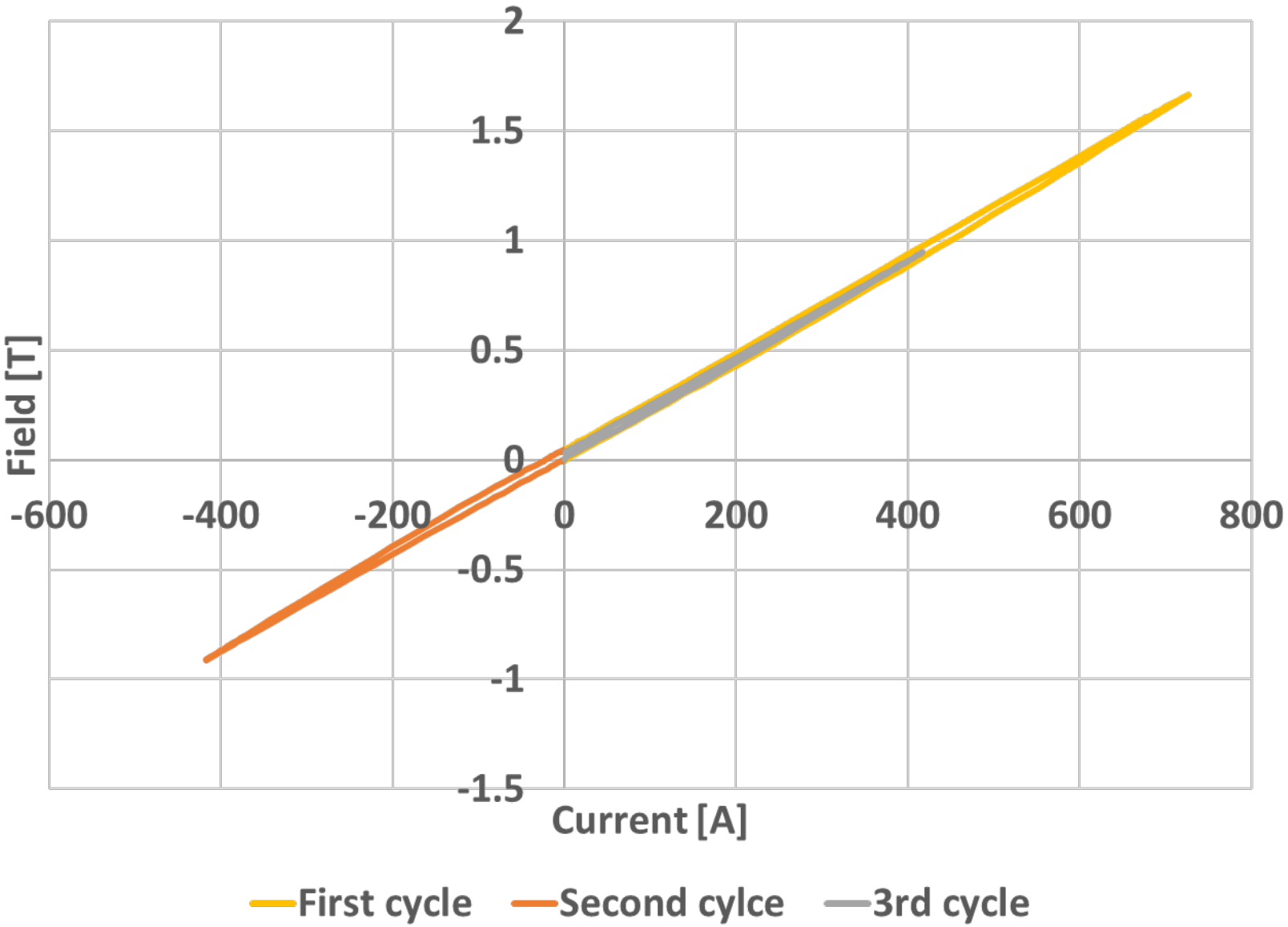
Field parallel (2020)



Order of magnitude reduction in the magnetization when the field is primarily parallel to the HTS tape

Both coils have the same Nomax insulation but 12 mm wide tape from different sources

HTS Magnetization Studies (with no background field)



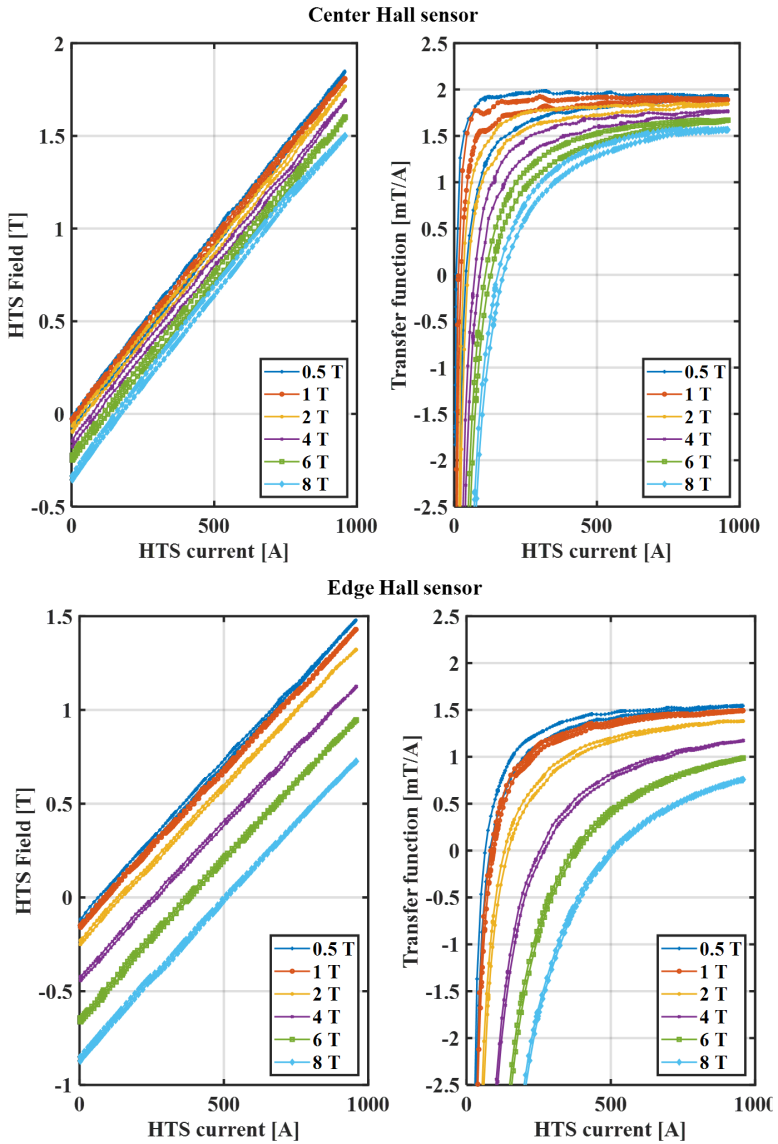
- First ramp from 0 to 726A and back to 0
- Second, reverse polarity and ramp up and down to -417A
- Third, ramp to 417A and back to 0

HTS Magnetization Studies (background field primarily parallel)

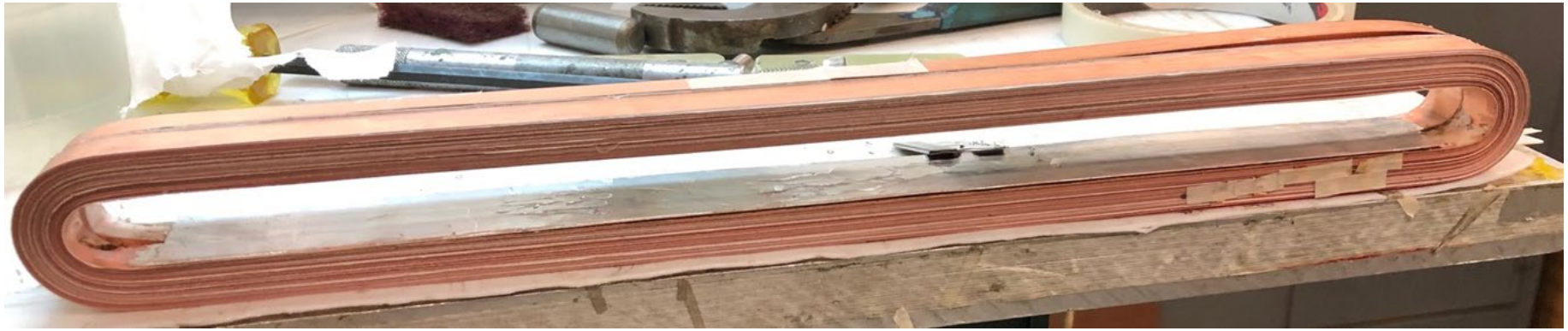
HTS/LTS Hybrid Tests:

- Hold LTS coils at 500 A, 1 kA, 2 kA, 4 kA, 6 kA, and 8 kA. For each background field from LTS, HTS coil is ramped up to 950 A and then back to 0

- The field is measured at two locations: at the center and also at the edge of the double pancake of the insulated coil



Suggested Location of Hall Probes in US-Japan HTS Coils (double pancake)



Possible Locations (marked by X) of Hall probes: at the center, and at two edges of each pancake (5 locations) in SS, and one at the end