Large Bore Axion Magnet

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(with contributions from IBS/BNL colleagues)

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BROOKHAVEN NATIONAL LABORATORY

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Office of Science
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Contents

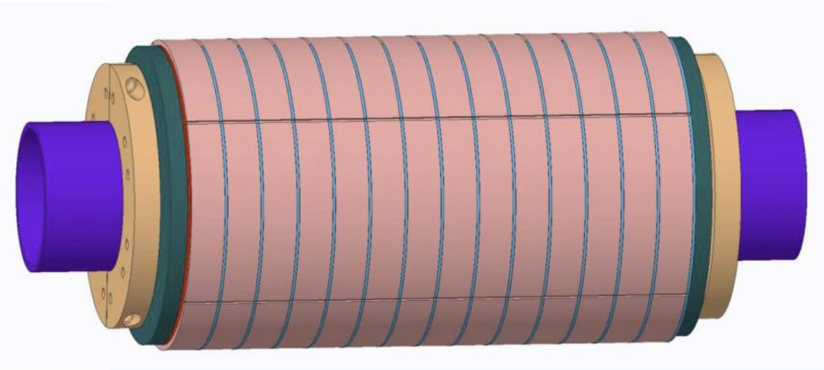
- Status and progress towards large bore solenoid for Axion search
- A brief summary of SBIR on CORC® cable

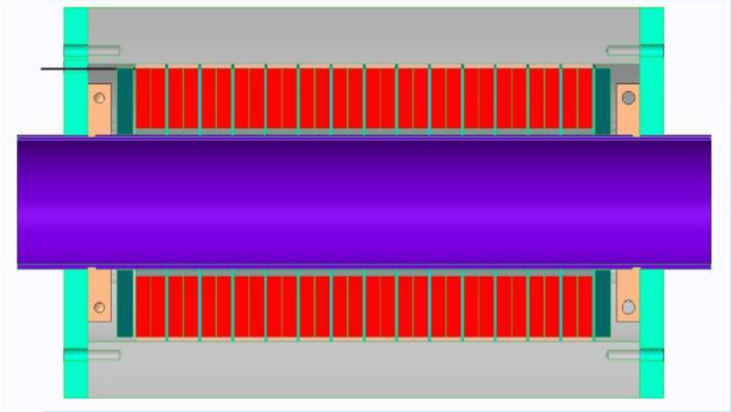
Institute Funding the Construction of High Field, Large Aperture Solenoid

- Center for Axion and Precision Physics Research (CAPP), Institute for Basic Science (IBS), Daejeon, South Korea
- Targeted science goals receive significant funding from Korean government to become major player internationally

Major Parameters of the IBS/BNL HTS Solenoid

- Field: 25 T@4 K
- Single Layer
- Cold Bore: 100 mm
- Coil i.d.: ~118 mm
- Coil o.d.: ~200 mm
- Conductor: 12 mm wide ReBCO
- Current: ~500 A
- Current Density: ~550 A/mm^2
- Stored Energy: ~1.6 MJ
- Max. Hoop Stress: ~500 MPa

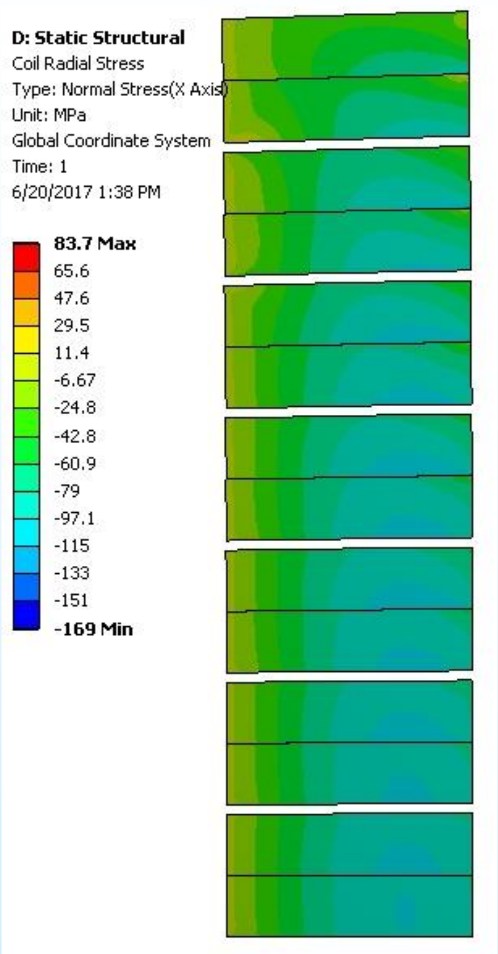


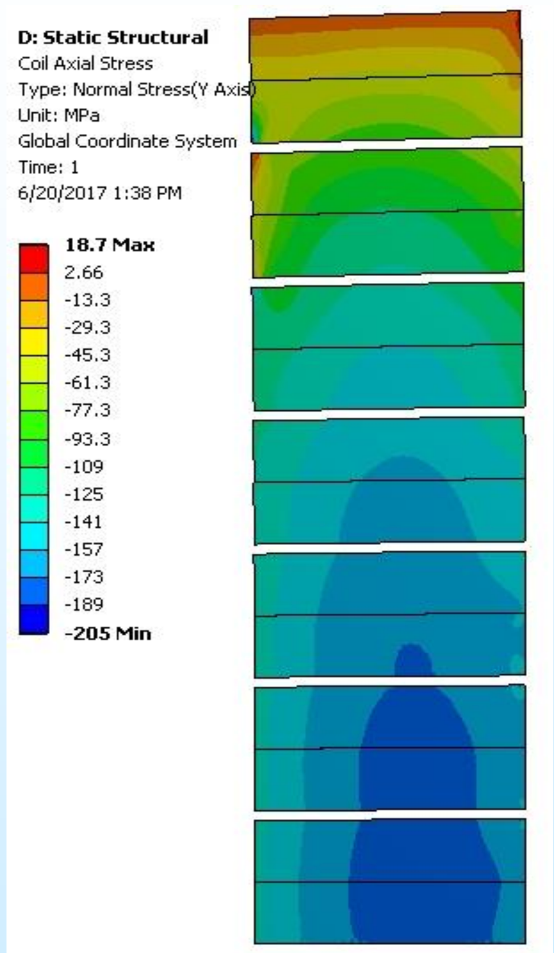


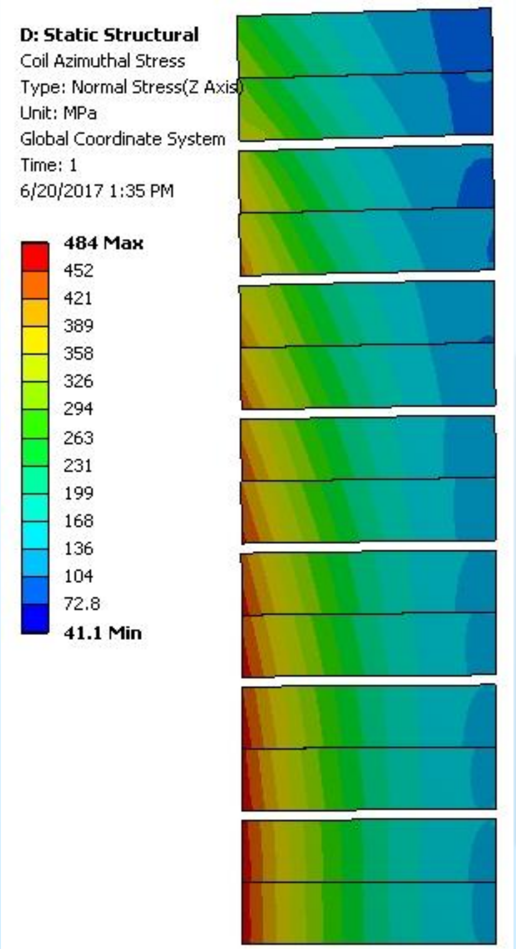
Conductor Requirements and Status

- Need a significant quantity of ReBCO tape
  - ~12 mm wide, 8-10 km (actual amount depends on the design margin, performance and extra desired)
- I_c(8T,4K)>675A (higher current @25T, field parallel)
  - No specs on the minimum performance or on the I_c uniformity
  - Design is limited by the mechanical properties (large hoop/axial stresses) and not by the electrical/magnetic properties
  - Higher I_c, however, gives higher margin and is welcome
  - Performance limited by coils in the end region (sorting helps)
- An order of 5 km tape has been placed with SuperPower

Coil Stresses (@4 K, 25 T)







~500 MPa Max Stress

-100 MPa Max Stress

-205 MPa Max Stress

Azimuthal

Radial

+

Axial

+

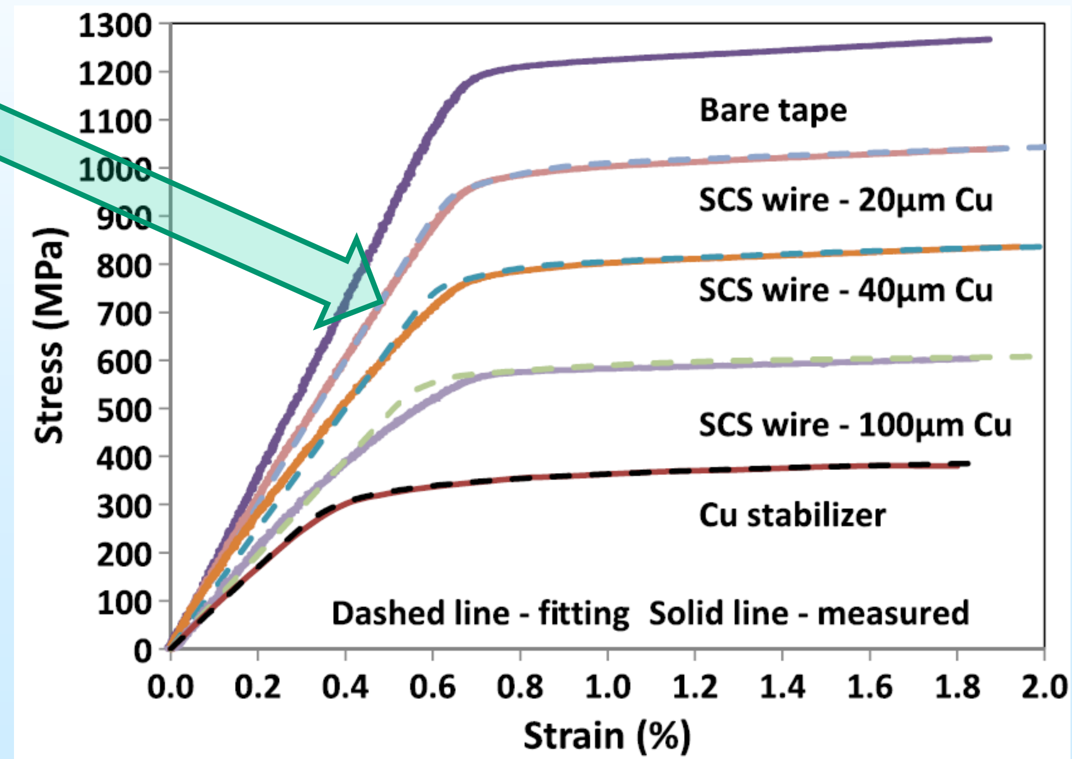
Mechanical Properties of the Conductor

Requirement of Azimuthal stresses of ~500 MPa is met with 2G Tape having 50 micron Hastelloy and 20 micron Copper

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 26, NO. 4, JUNE 2016 8400406

Stress–Strain Relationship, Critical Strain (Stress) and Irreversible Strain (Stress) of IBAD-MOCVD-Based 2G HTS Wires Under Uniaxial Tension

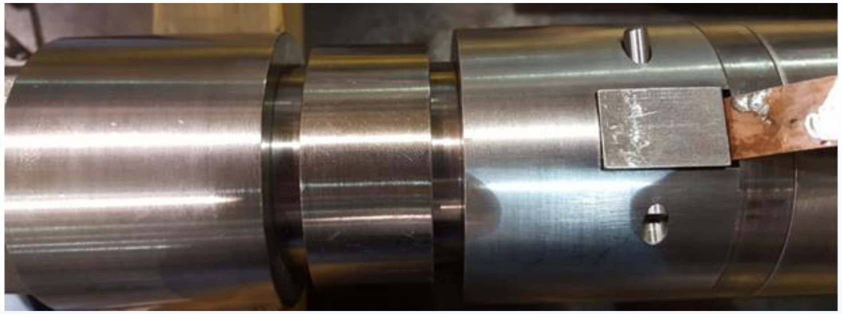
Y. Zhang, D. W. Hazelton, R. Kelley, M. Kasahara, R. Nakasaki, H. Sakamoto, and A. Polyanskii

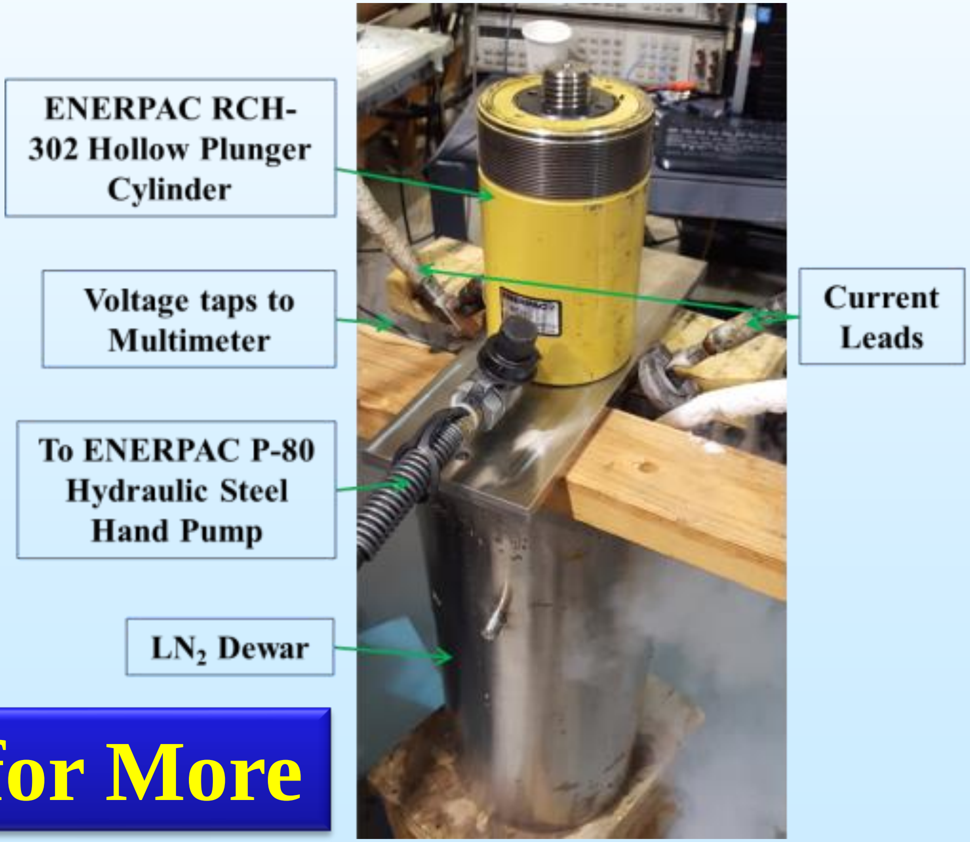


Courtesy: SuperPower

Meeting requirement of ~200 MPa on the narrow side of the tape needs to be checked as no such data is available

Apparatus to Measure High Pressure (300 MPa) on the Narrow Face of the Conductor and Coil





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"No-Insulation" Coil Option

Typical issues with the "no-insulation" coils:

Slow charging time and poor field quality.

These are not issues in this application because of:

- ❑ **Relaxed field quality: few percent is OK**
- ❑ **Slow charging time: ~ 1 day is OK**

"No-insulation" option provides higher reliability since the current can go to next turn bypassing a local defect. This provides extra protection that is desired for a user magnet.

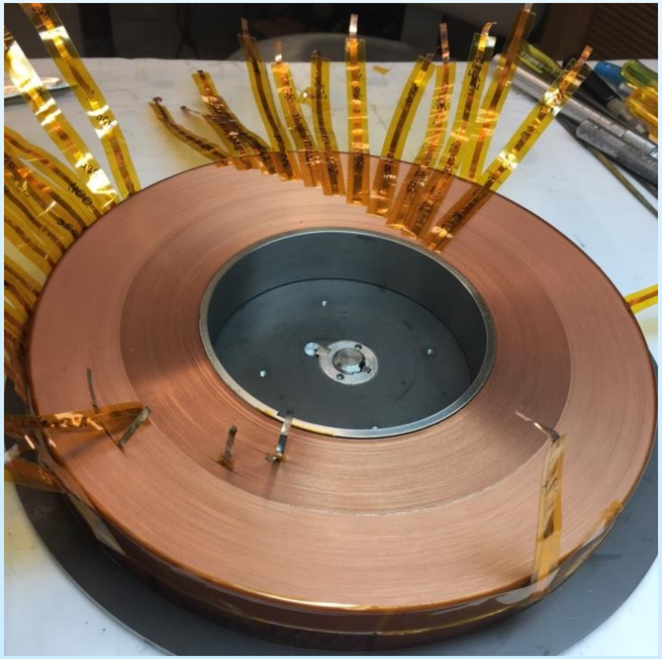
No Insulation Coil Construction and Test Results at 4K-77K

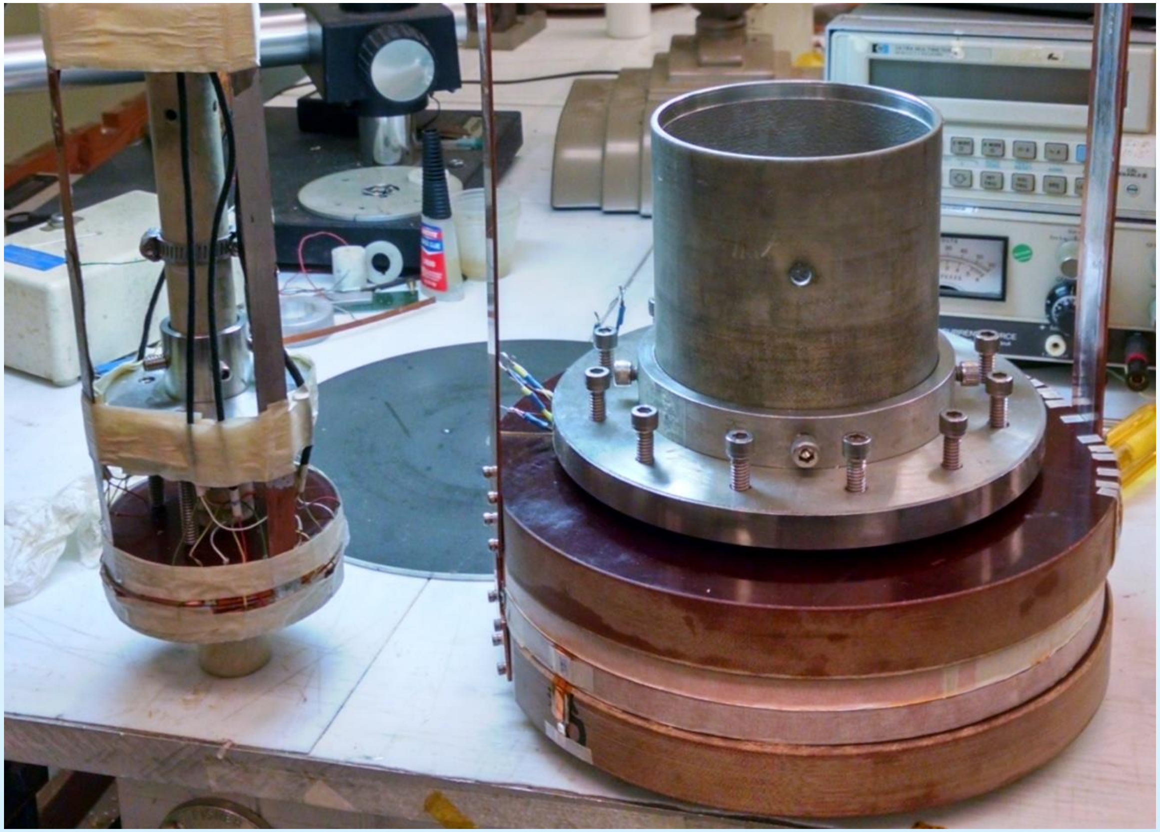
- **No-insulation double pancake coils have been built and tested before but never in such a large size and never using so much conductor.**

No Insulation Double Pancake Coils

To obtain data and 4 K test experience with large "NI" coils early on, a coil wound with over 500 meters of 12 mm wide ReBCO tape

- i.d. = 100 mm
- o.d. = 220 mm
- Turns = 971

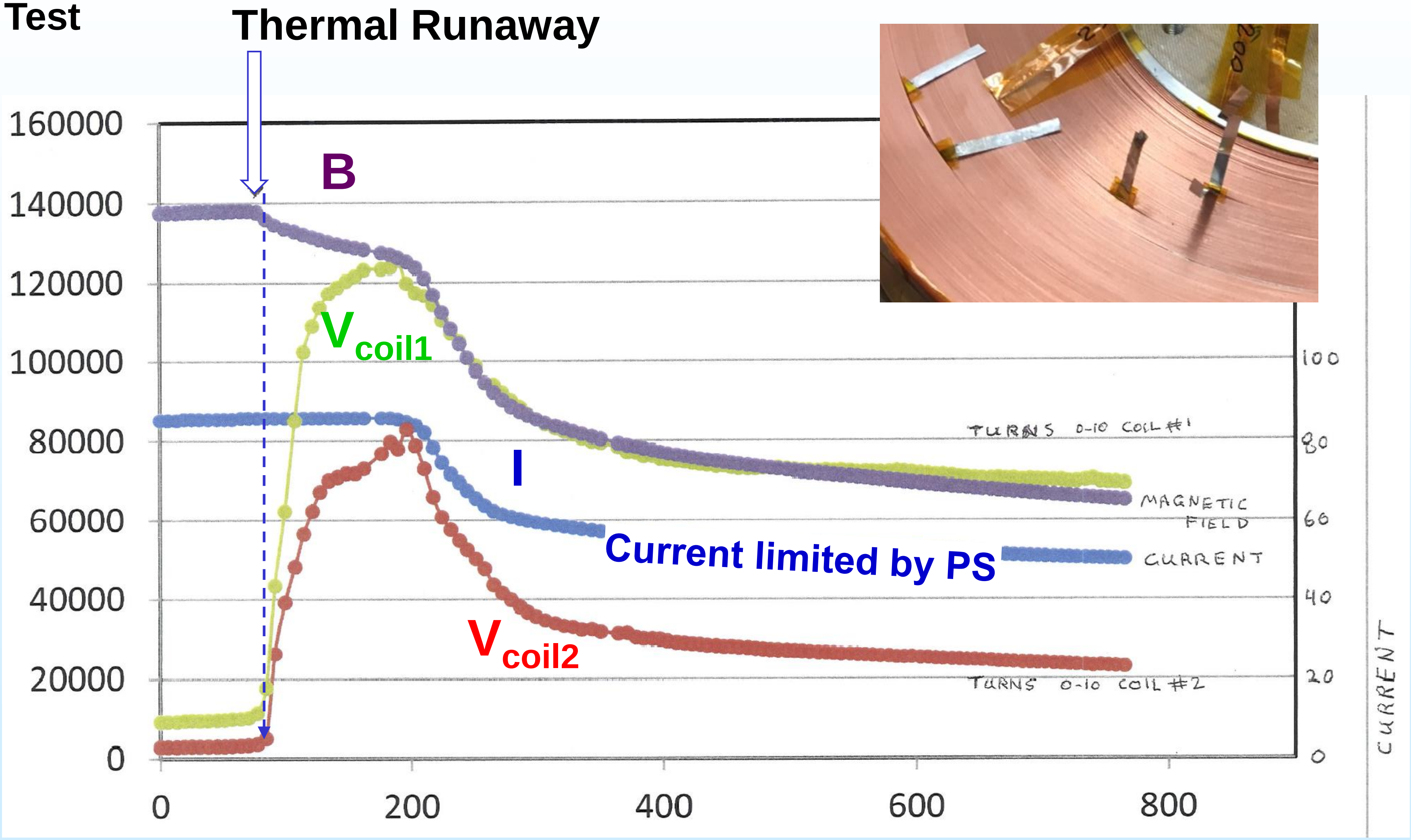




Significant instrumentation (v-taps) and three heaters for simulated defects

B, V and I in No Insulation Coil at Thermal Runaway

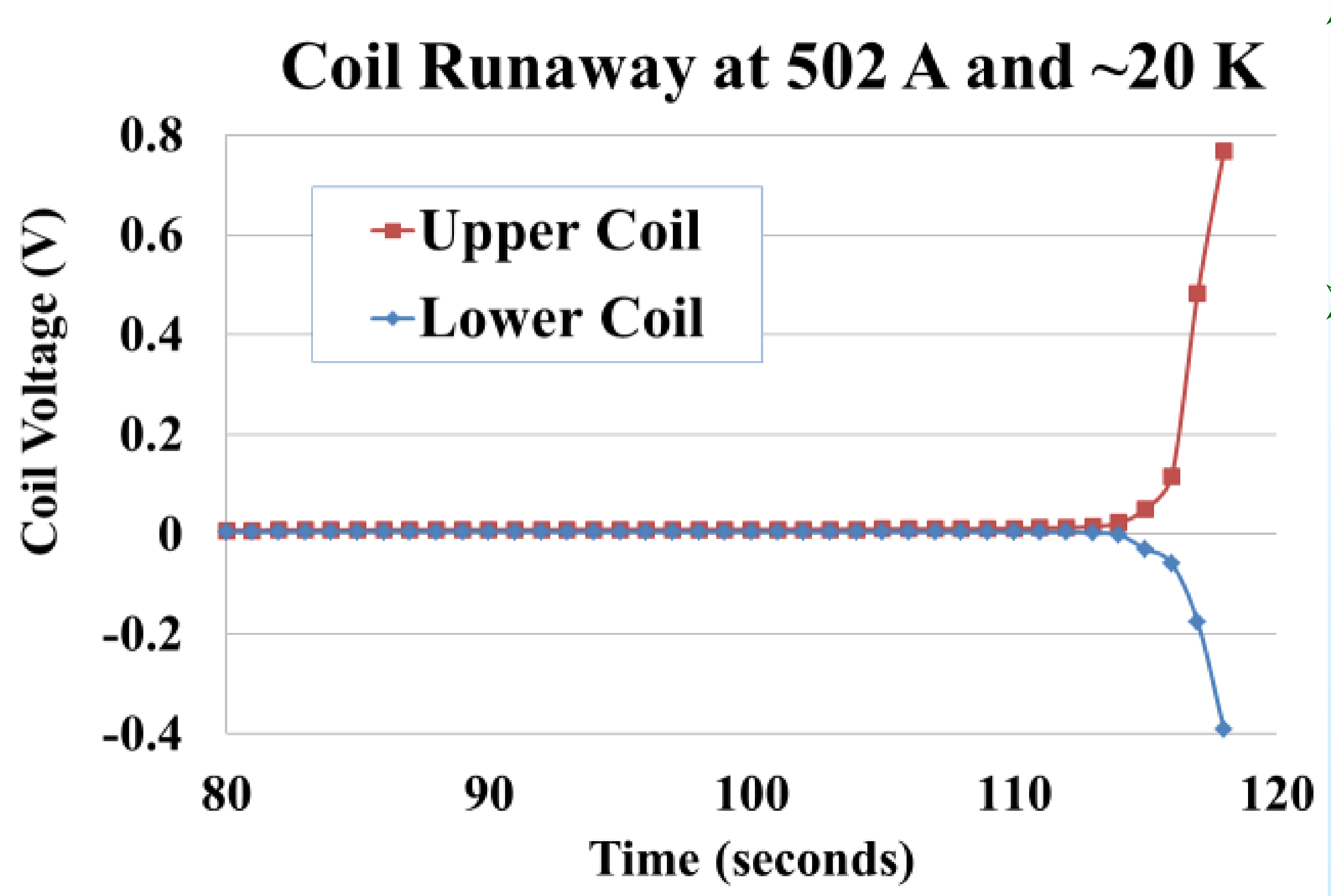
77K Test



Time (seconds)

Low Temperature, High Current Testing at Various Temperatures

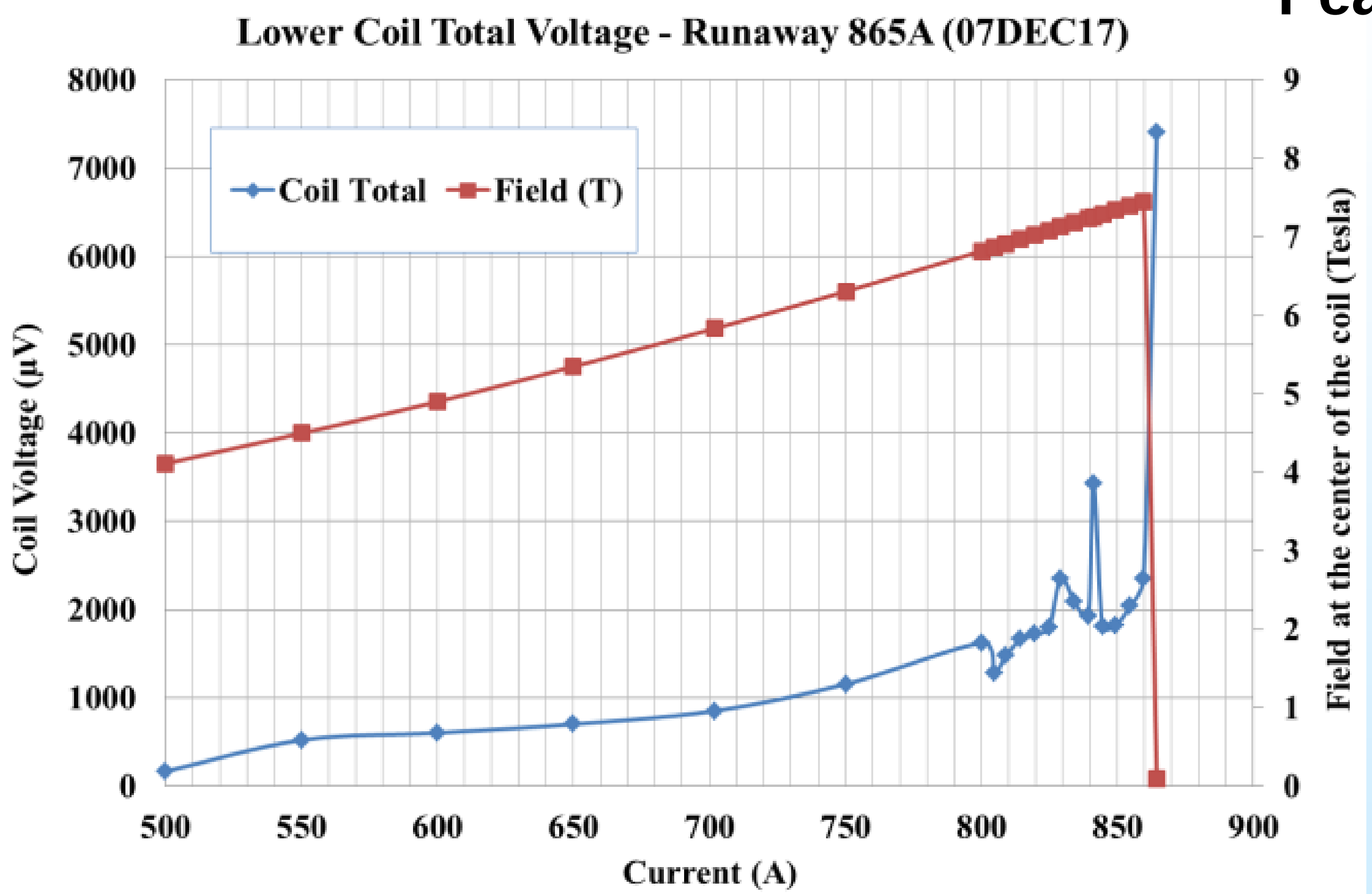
Test at Intermediate Temperature (20 K)



- Coil was allowed to runaway unprotected
- The coil survived with no noticeable degradation (HTS coil with turn-to-turn insulation would probably have been damaged in such runaway conditions)

Test of Large Double Pancake Coil at 4 K

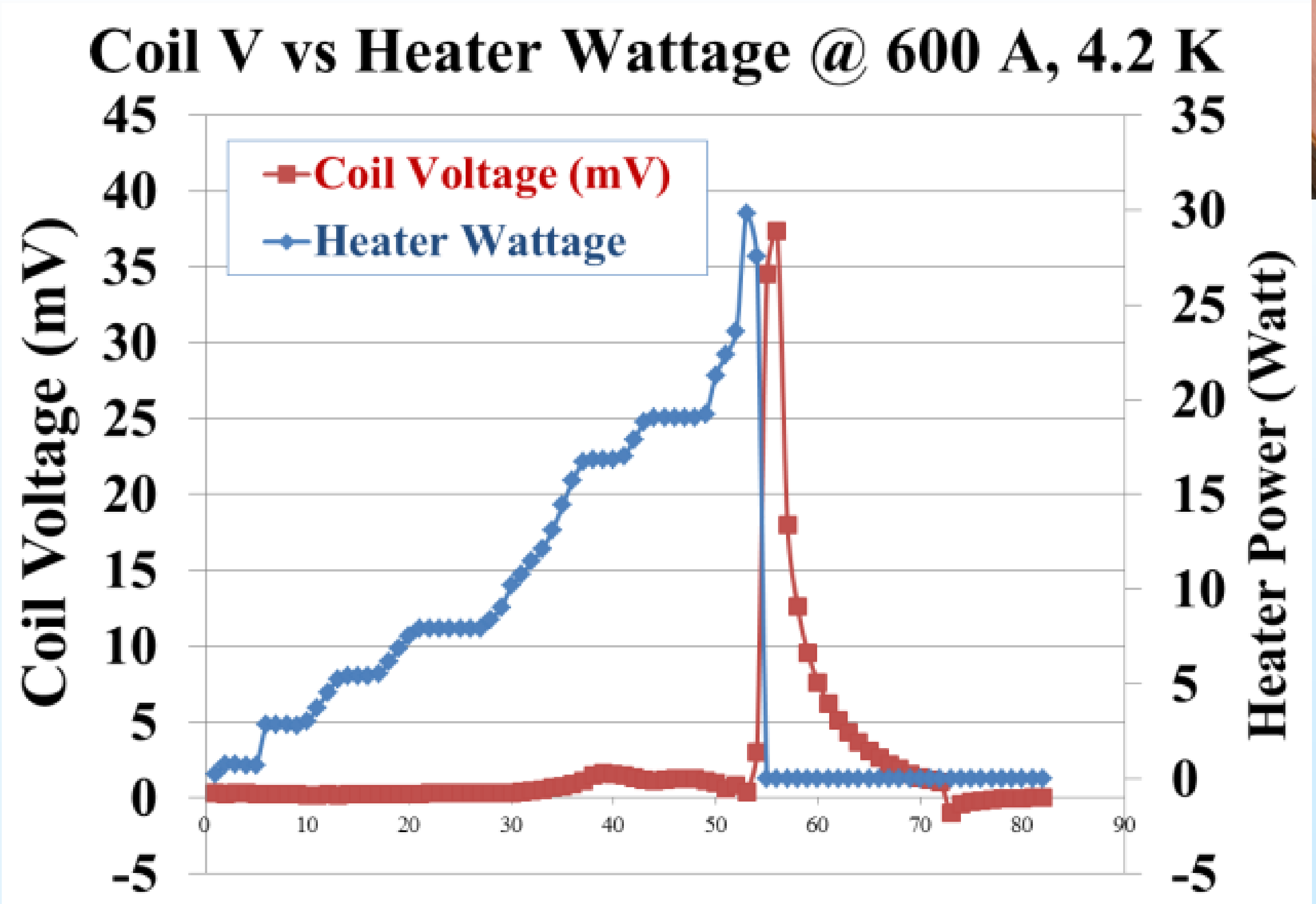
Peak field 11.2 T

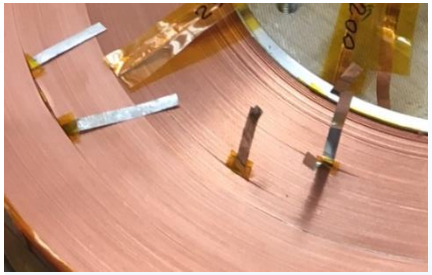


Further tests found no damage in the coil

Design current: ~500 A

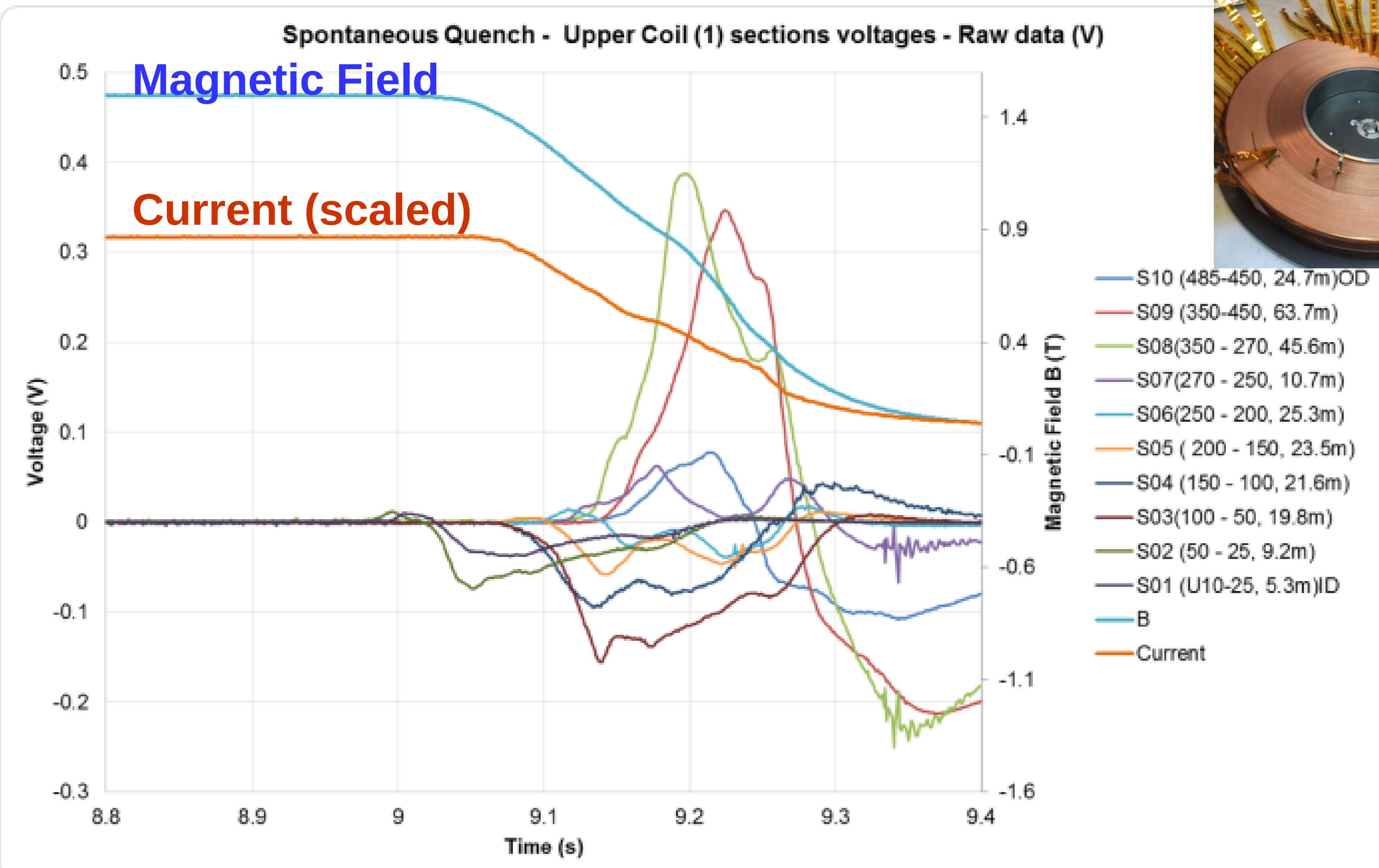
Simulation of Large Local Defects (~30 W)

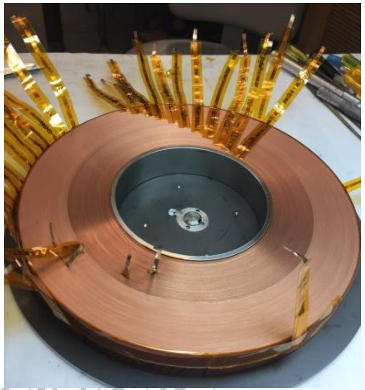




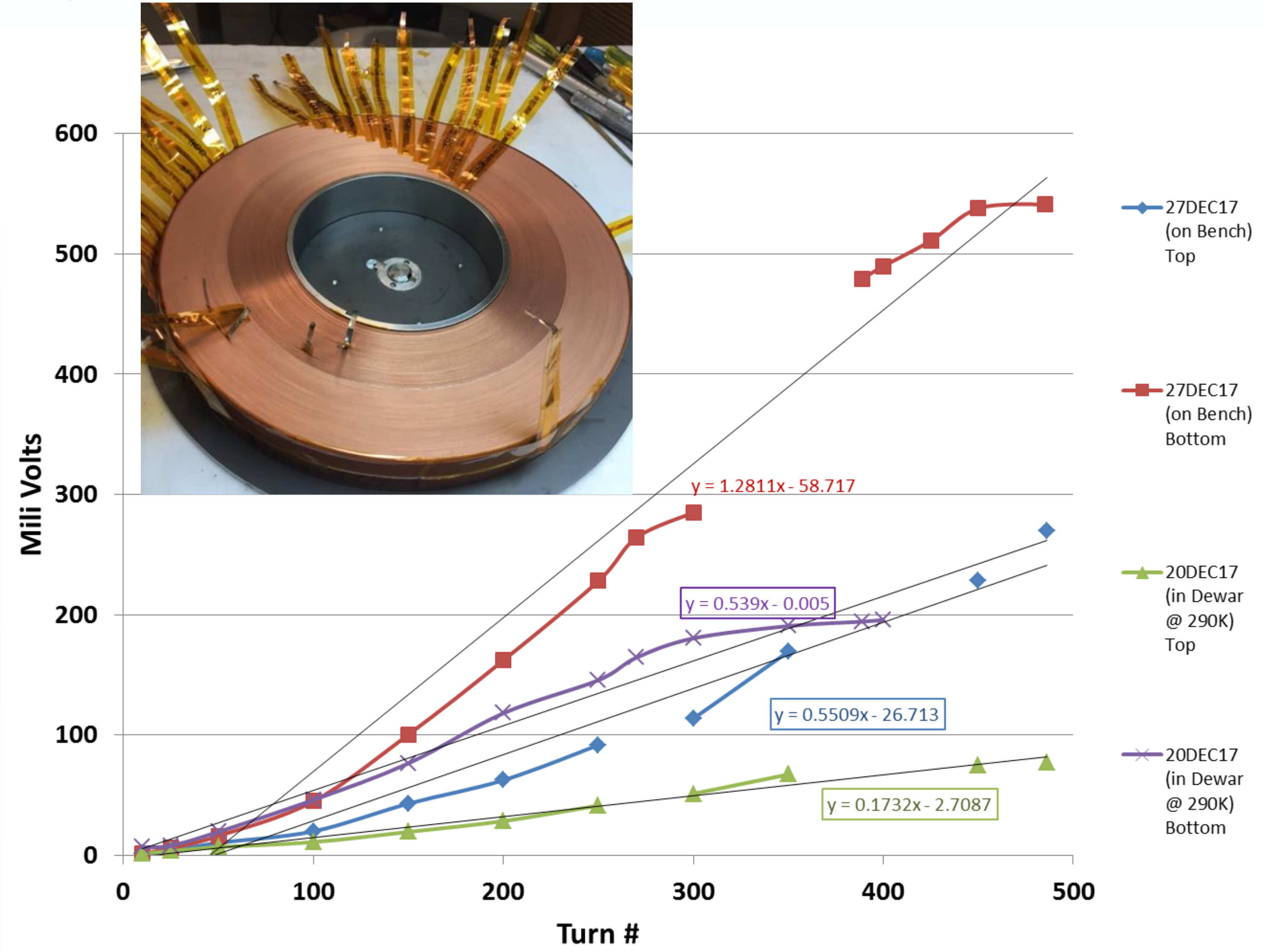
No degradation in the coil performance observed

Propagation of Quench Voltage





Observed Change in Contact Resistance

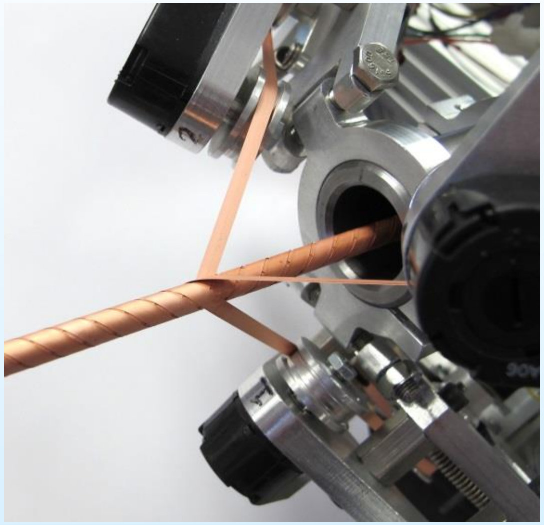


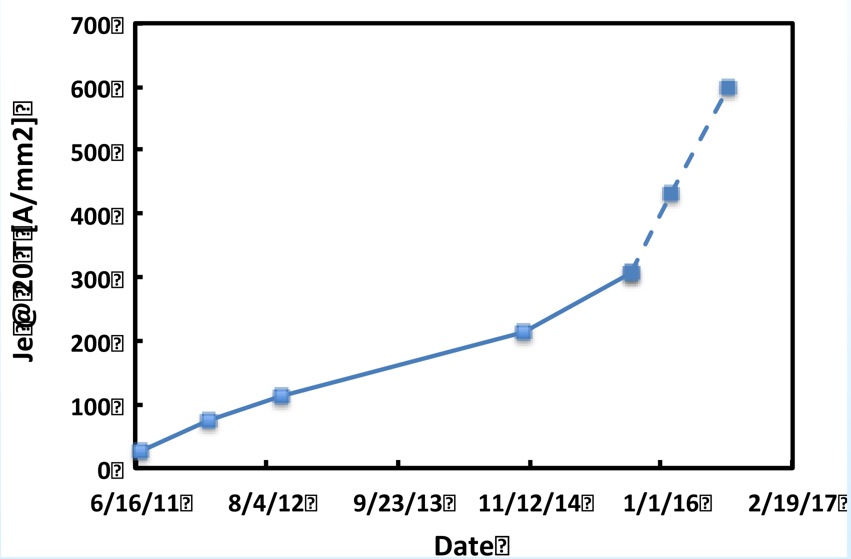
- Large coil (100 mm id, 220 mm od, using >500 m 12 mm tape)
- No epoxy painted on the surface
- Coil is being rewound at higher (3X) tension

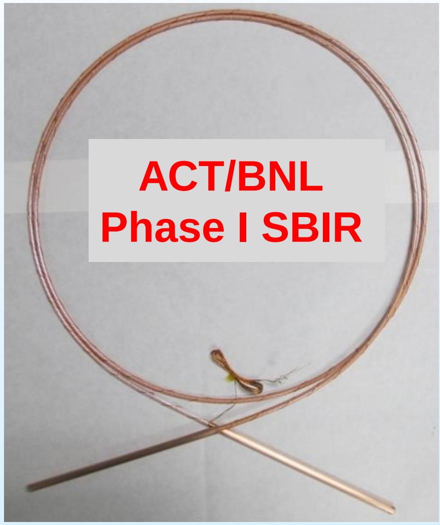
SBIR on High Field Hybrid Dipole Magnet with High Current CORC® Cable with the Advanced Conductor Technology (ACT)

Conductor on Round Core (CORC)

CORC® Cable for Accelerator Magnets
High J_e and High I_c Cable from ACT



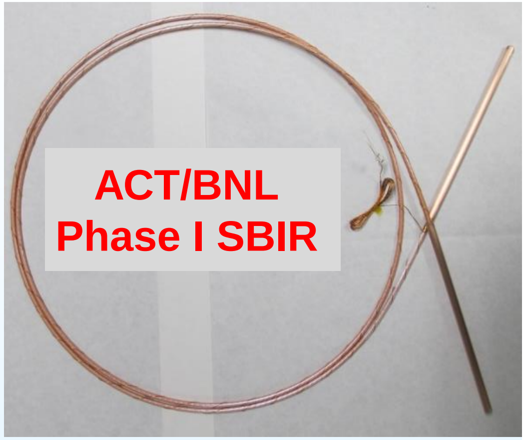




Larger diameter allows a higer J_e and a more economical use of ReBCO

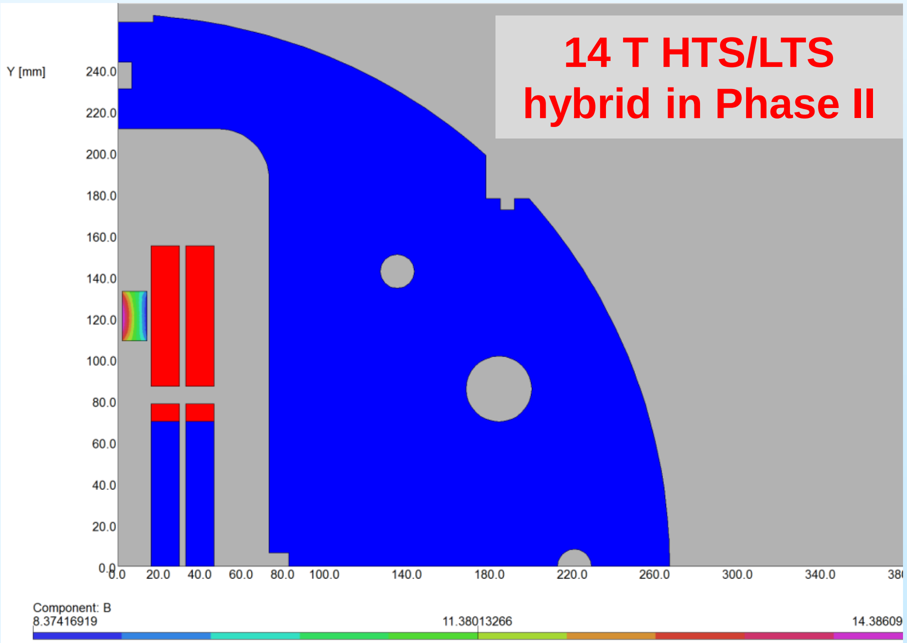
- **J_e of ~530 A/mm² @20 T for ~10 kA is already available for common coil cable**
  - **developed as a part of this SBIR (promised target was 400-500 A/mm²)**
- **J_e of ~1000 A/mm² at 20⁺ T for 10-20 kA such cable in a few/several years?**

SBIR Main Tasks and Plans on the Demonstration of HTS/LTS Hybrid Dipole with the CORC® Cable



Phase I (funded)

- Make high cable suitable for Phase II (completed)
- ~77K Test of CORC cable/coil at ACT and at BNL
- Test ~2 turn CORC coil with flat and lifted ends
- Develop Phase II design for HTS/LTS hybrid



Phase II (if funded)

- Make CORC cable for two coils
- Wind two double pancake coils
- Assemble HTS/LTS hybrid dipole
- Test 14 T HTS/LTS hybrid dipole
- Develop 20 T HTS/LTS design

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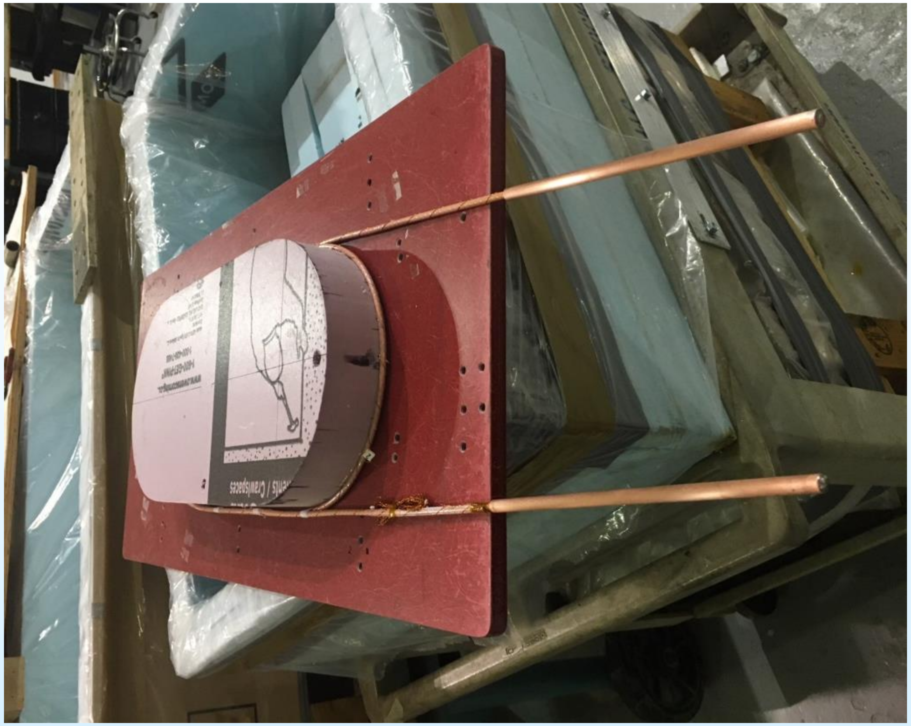
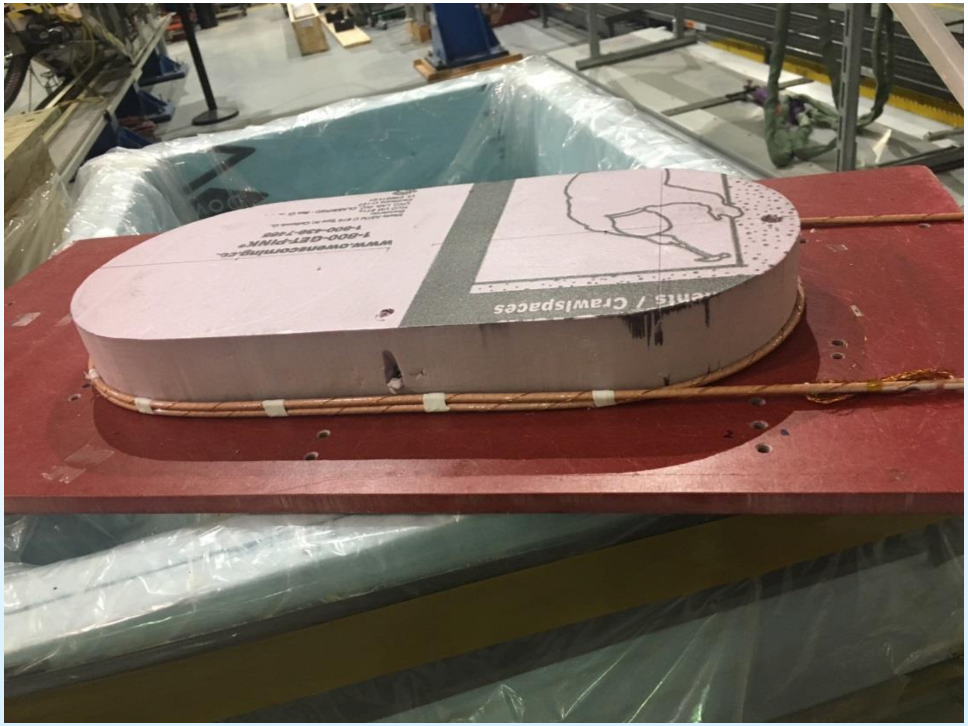
CORC® at BNL as a part of SBIR





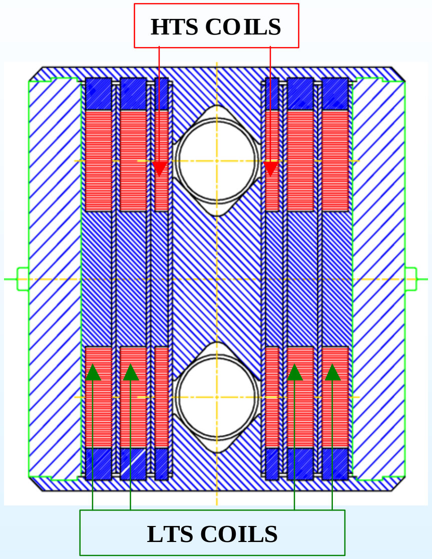
Just received from ACT

Will be put in a fixture for 77 K Tests for

- **Flat geometry**
- **Lifted end geometry**

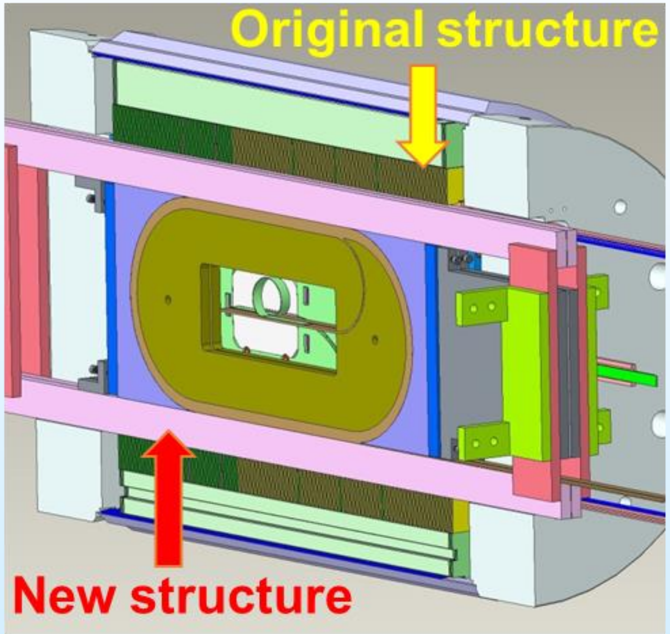
Phase I SBIR (funded) on High Current CORC® Cable in Accelerator Magnets

- High I_c, high J_e CORC® cable requires large bend radii - common coil design allows that
- HTS CORC® cable coil can be powered in series with LTS Rutherford cable coil
- Same high current in both HTS and LTS provides easier operation and easier quench protection
- Partially transposed CORC® cable also helps in reducing magnetization-induced field errors associated with the high strength ReBCO tape
- Demonstration of a proof-of-principle dipole with insert coil CORC® cable coil running in series made with Nb_3Sn BNL common coil dipole is possible within the budget of Phase II

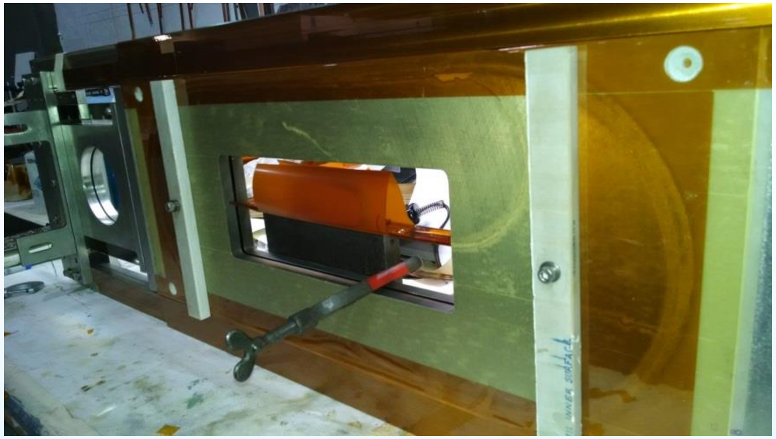


HTS/LTS Hybrid Structure for Phase II

Design



New HTS coils slide inside the existing Nb_3Sn coils and become an integral part of the structure



A pair of HTS insert coils

Summary

- **100 mm, 25 T HTS solenoid will be a significant HTS magnet project for the next two years at BNL**
- **With required validation tests behind us and with conductor coming in few months, we expect to start construction and series of intermediate coil tests soon**
- **Large diameter CORC® cable with higher current density and a relatively more economical use of HTS can be used in common coil design**
- **Phase II SBIR could demonstrate a ~14 T hybrid dipole with CORC® coils running in series with Nb_3Sn coils**