Hybrid Configuration and BNL Activities

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for
PBL/BNL Team and Collaborators

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BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

U.S. MAGNET DEVELOPMENT PROGRAM

BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Latest from BNL

Testing NOW. Magnet at 4K.

- **HTS/LTS hybrid (PBL STTR)**
- **Commissioning of a novel rapid-turn-around, low-cost 10 T background field racetrack coil test facility**

Significant funding for HTS high field (25T) 100mm solenoid based on the SMES work @BNL

- **~4.3 M$ from IBS, Korea**
- **~2.3 M$ is already in house**
- **~1M$ for ReBCO purchase**

Introduction

BNL common coil offers a dual purpose program:

- A unique design for lower cost Nb_3Sn and HTS/LTS Hybrid magnets
  - ✓ It allows a wider use of material and technologies
- A unique low-cost, fast turn-around coil/magnet test facility

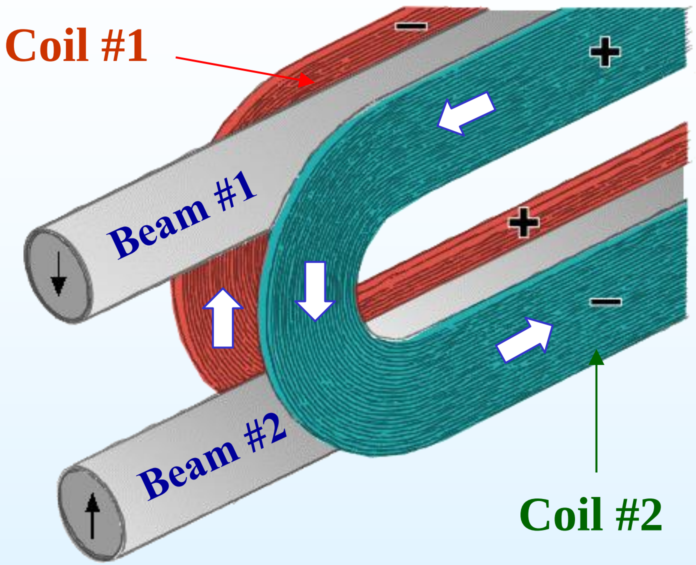
BNL is facilitating technology development through SBIR/STTR programs, as in a lower cost "garage" operation

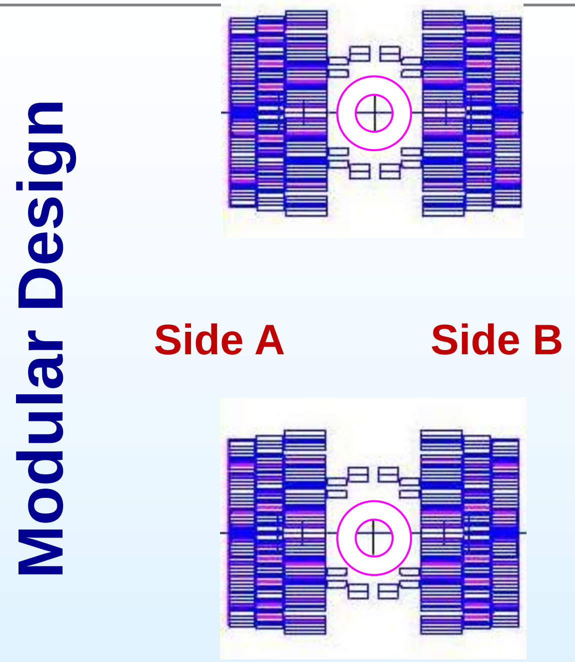
- ✓ R&D programs that can make large impact

(for superconducting magnets, the "garage" needs to have a bit of facilities and skilled persons. BNL and collaborators offer that)

- ❑ This presentation highlights the major contributions of SBIRs

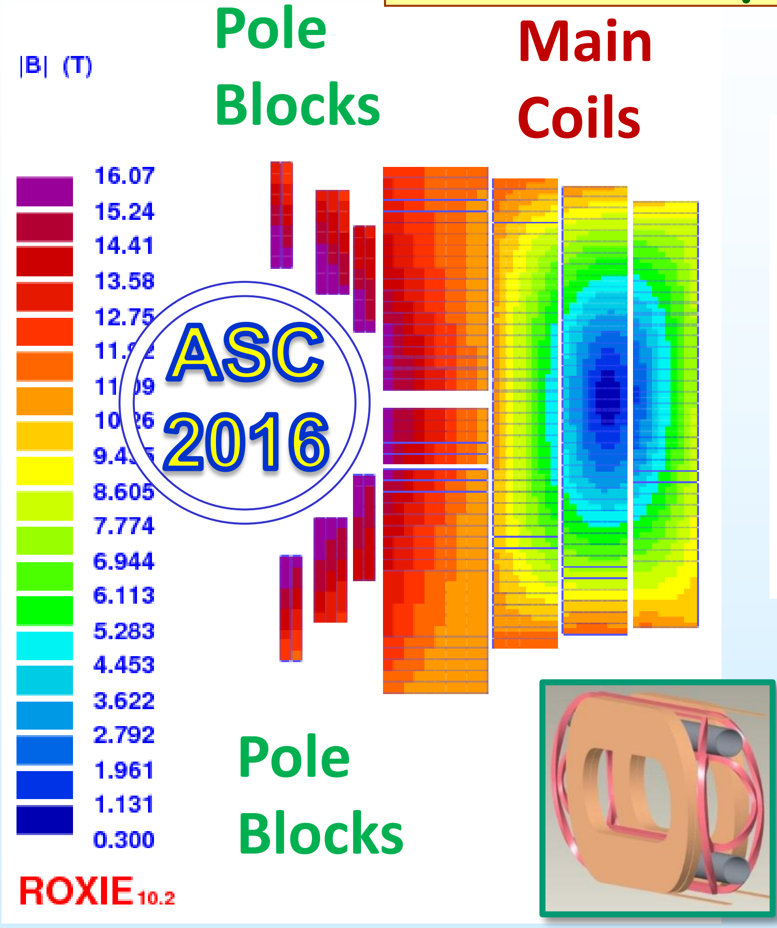
Common Coil Design for Colliders

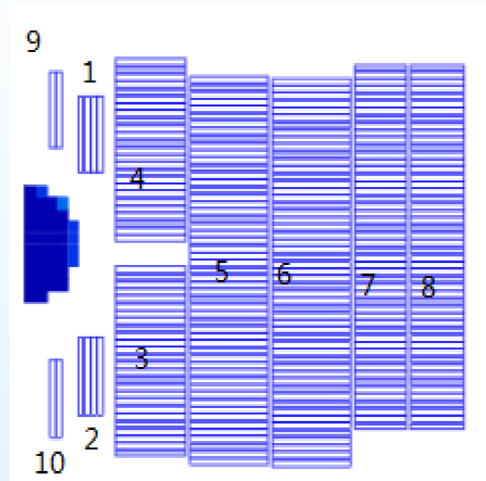




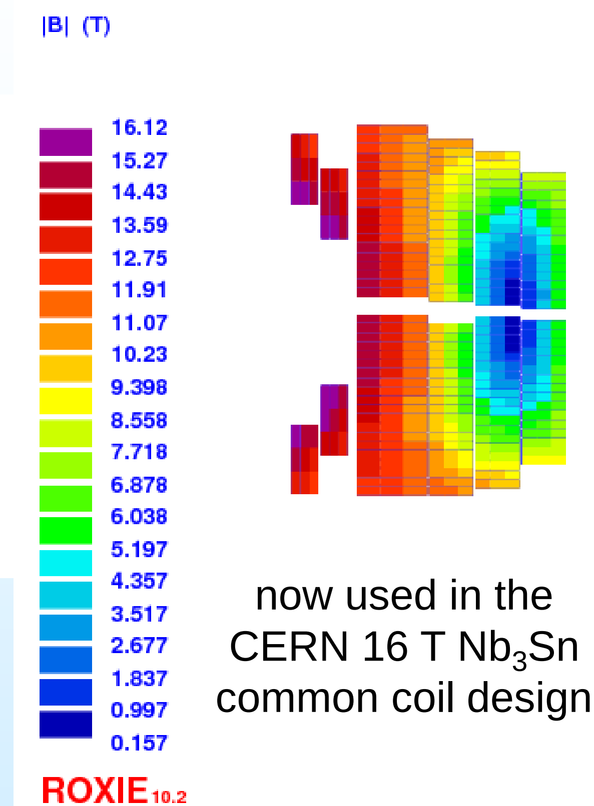
- Simple, large bend radii, conductor friendly design to allow many technologies
- Same coils for two apertures : 2-in-1 design for both iron and coils
- Expected lower cost : Number of coils half, simpler geometry, more automated manufacturing, etc.
- Easier segmentation based on material and easier stress management
- Common coil design is a block coil design with simpler ends where coils move as a whole, allowing large deflections with lower strain in the end region

Recent Progress in Common Coil Design
(Field Quality Design for Accelerator Magnets with Simpler Pole Coils – SBIR Contribution)





now used in the SppC 20 T hybrid common coil design



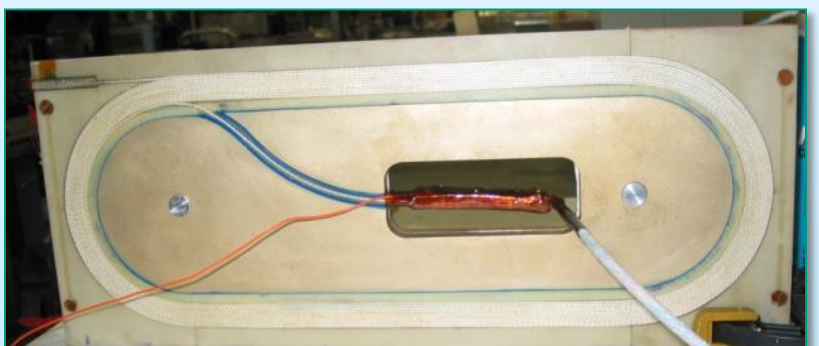
now used in the CERN 16 T Nb_3Sn common coil design

BNL/PBL Nb_3Sn 16 T, 50 mm Design
(Meets FCC specifications on geometric and saturation harmonics with simpler pole coils)

Informal Exchange/Collaboration with CERN and IHEP

A Unique Aspect of the Common Coil Design (allows "React & Wind" option, as well)

BNL "React & Wind" Nb_3Sn Dipole



BNL "React & Wind" Bi2212 coil
8 coils, 5 magnets, 4.3kA (10/03)

- Common coil design allows both "Wind & React" and "React & Wind" technologies
- "React & Wind" technology has many advantages. For example, it allows a wider use of material and construction techniques.
- BNL has made several coils and magnets (Nb_3Sn, Bi2212 & ReBCO)
- "React & Wind" technology is not covered by any other current design and/or program.

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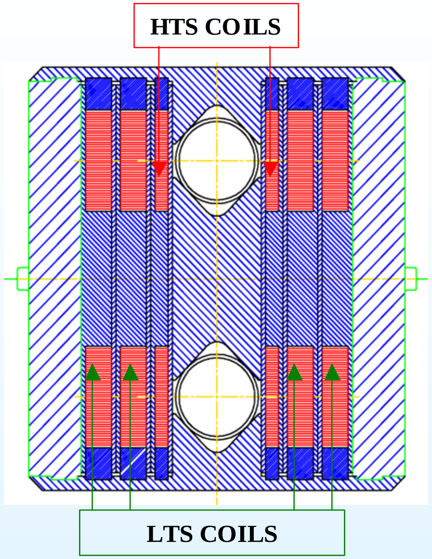
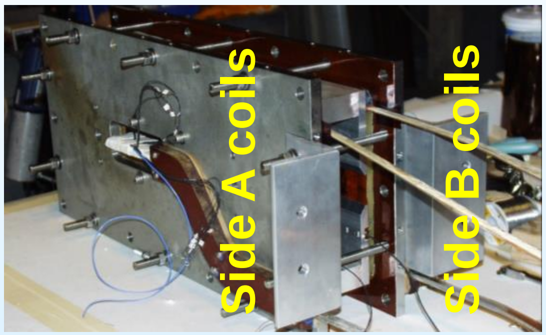
Common Coil Dipole for High Current CORC® Cable

- CORC® cable offers a promising option for high performance, high strength ReBCO tape for making high field magnets
- Partially transposed CORC® cable reduces the field harmonics associated with the tapes
- 6 mm diameter offers a relatively robust CORC® cable with a measured J_e(4.2 K, 17 T) = 344 A/mm^2; I_c = 7,030 A, and is ready for use in common coil with practically no R&D required
- CORC® cable based HTS insert coils running at 10 kA in series with BNL Nb_3Sn common coil DCC017 produces a proof-of-principle 13 T hybrid dipole within the budget of Phase II SBIR
- High current HTS coils running in series with Nb_3Sn coils provides a magnet with easier operation and easier protection
- Larger diameter cable requires magnet designs with large diameter coils – common coil design offers that
- 6 mm CORC® cable is a factor of 2 higher in J_e than the smaller 3 mm diameter cable, has less wastage, lower cost, …
- Phase 2 J_e > 600 A/mm^2 at 20 T in 5-6 mm thick CORC® cables
- CORC® based common coil offers a promising hybrid option

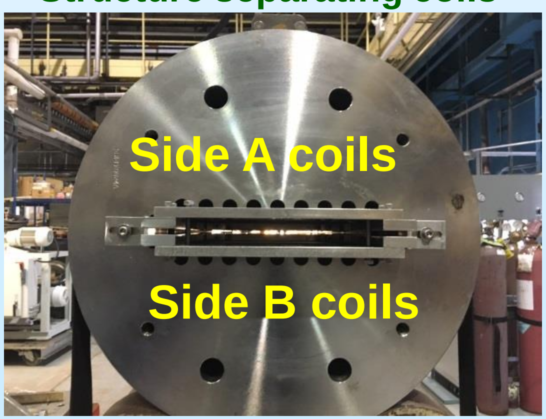


Relevance of Aperture in Magnet R&D

All coils in a single structure



Structure separating coils



Visible space between left and right insert coils inside DCC017

- The modular common coil design offers an option where the aperture can be made smaller to do initial evaluation of high field magnets R&D at a lower cost
- Natural question: what is the applicability of these results in "magnets with real aperture?"
- If a design is such that one side of the coils are independent of the other side of the coils, then how much does it matter that how far they are, as long as the individual set of coils are subjected to the same level of field & stresses.
- Compare this with using the results of magnet R&D between the long magnets and the short magnets
- Yes, long magnets give complete results. But if we were relying only on them then what would have been the cost of developing technology; or examine different options; or how much R&D we would have been able to do?
- Common coil design with an option of doing R&D with smaller aperture takes the value of subscale magnet R&D to the next dimension

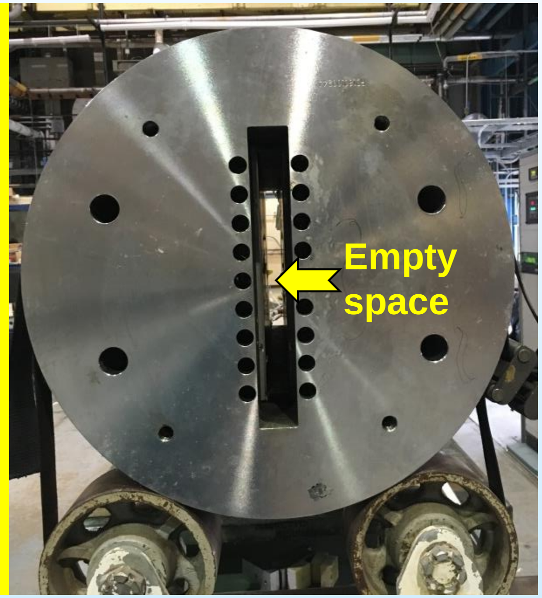
BNL Common Coil - A Dual Purpose Design

(Proof-of-Principle and New Efficient Way of Magnet R&D)

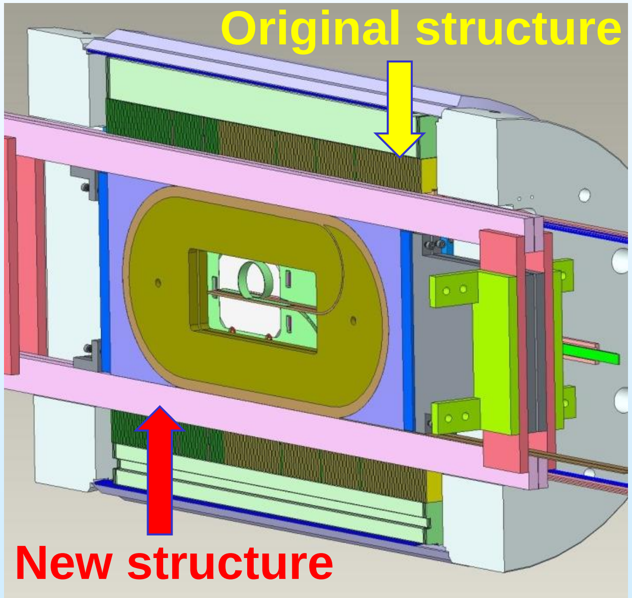
A unique feature of BNL's common coil dipole: large open space for inserting & testing "coils" without any disassembly (rapid around, lower cost)

Examples: **1.** High field HTS/LTS hybrid (STTR Phase II for adding HTS coils)

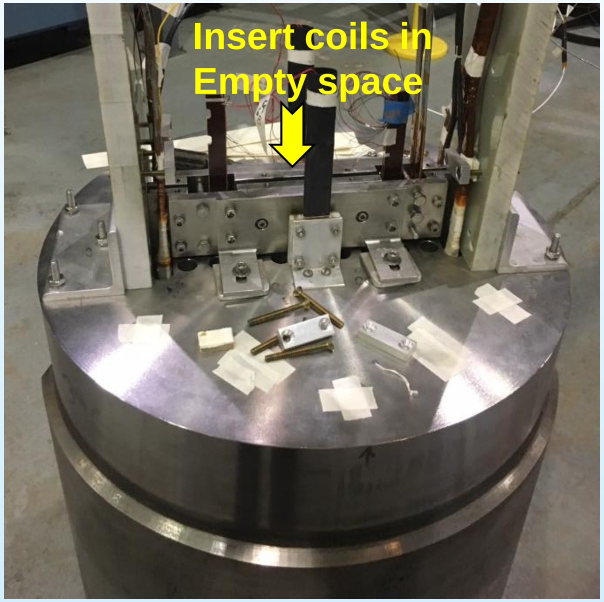
2. Accelerator Type Common Coil Dipole (SBIR for adding Nb_3Sn pole coils)



BNL Nb_3Sn common coil dipole DCC017 without insert coils

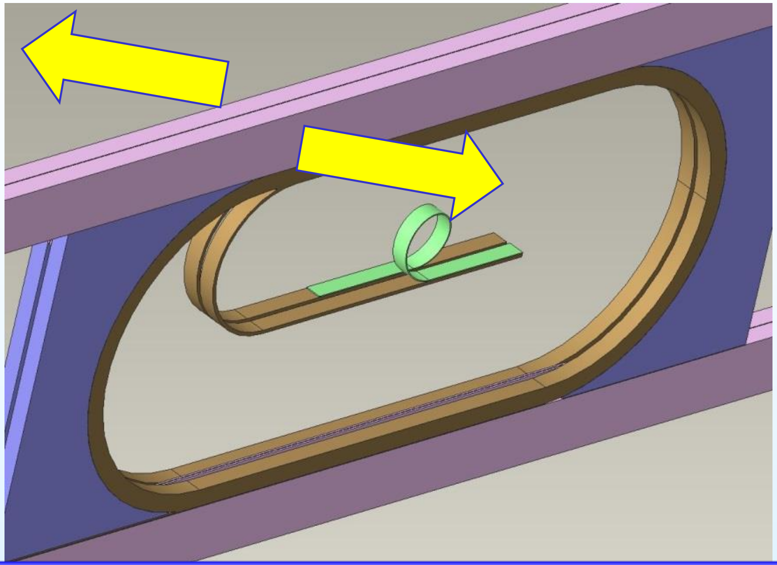


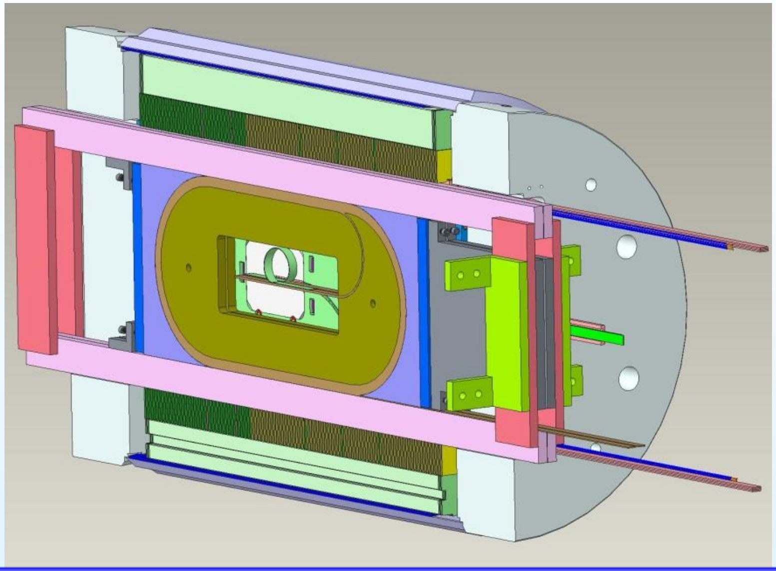
New coils (Nb_3Sn or HTS) slide inside existing Nb_3Sn coils. New coils become part of the magnet



HTS coils inside Nb_3Sn dipole - early experience of HTS/LTS hybrid (STTR)

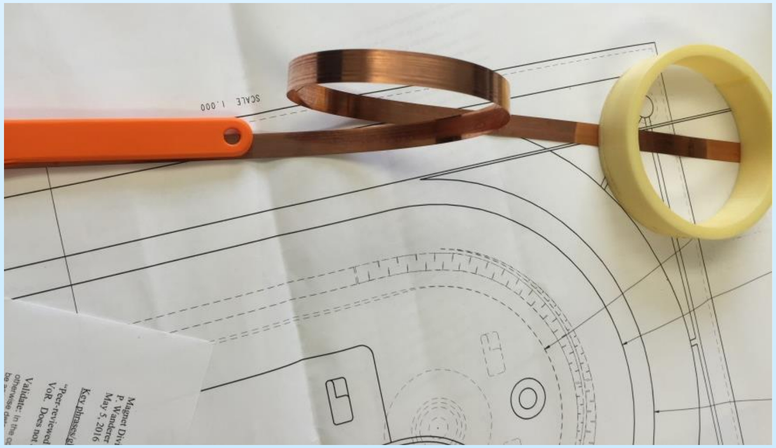
A Key Component - Flexible Splice
(first insert pair of coils together and then separate them out to contact the main coils)

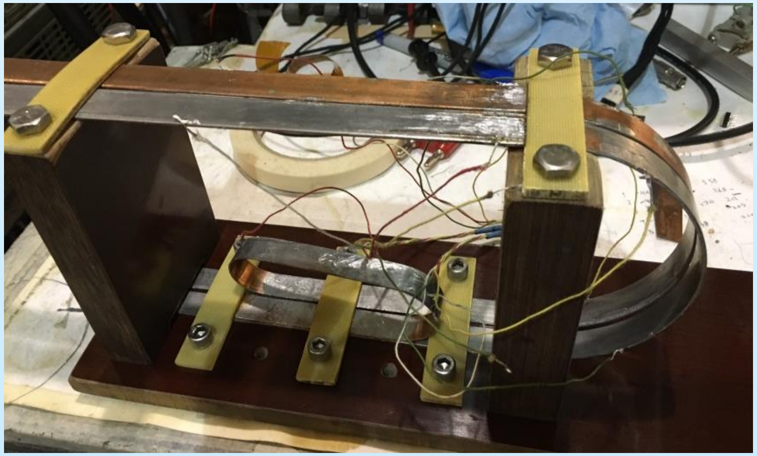




Splice is in low field region

Insert coils become an integral part of the magnet. Drawing board to test demo.





Tests show <u>NO</u> degradation

PBL/BNL STTR on HTS/LTS Hybrid

Goals of this STTR:

- Study HTS tape magnetization in real coils for field parallel and field perpendicular configurations

- Perform HTS/LTS (ReBCO/Nb_3Sn) Hybrid Test at 4K
  - ✓ Yes we can plan to do it under SBIR/STTR funding

High Speed Pictorial Tour Follows

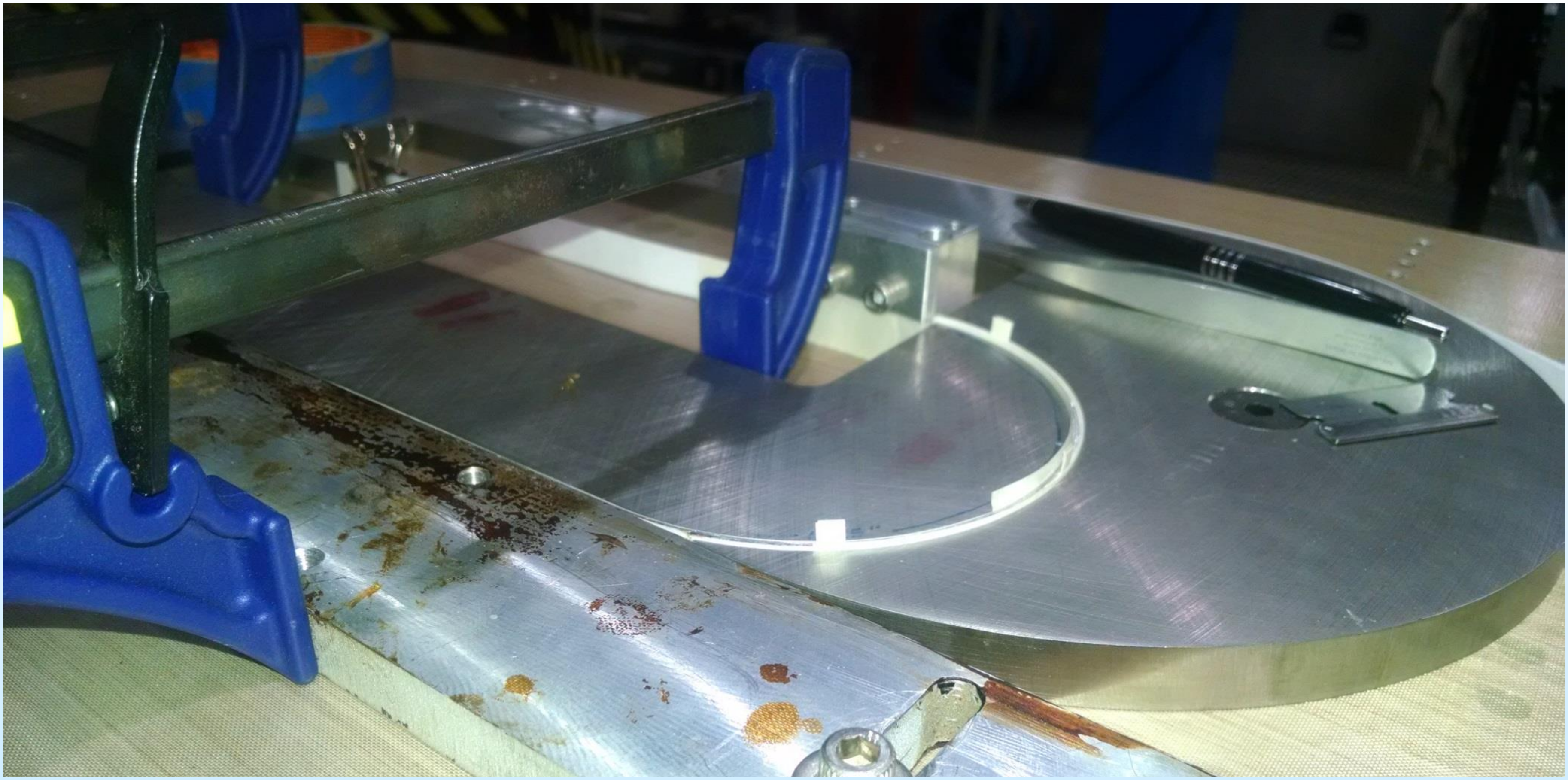
Making Special Splice (1)

First of the two step process with spliced conductor inside the groove (the outside piece is for display only)

Making Special Splice (2)

Soldering Fixture for making the first part (HTS with Cu backing)

Making Special Splice (3)



Second of the two step process with spliced conductor inside the groove and the coil conductor getting spliced

HTS Coil Winding (1)

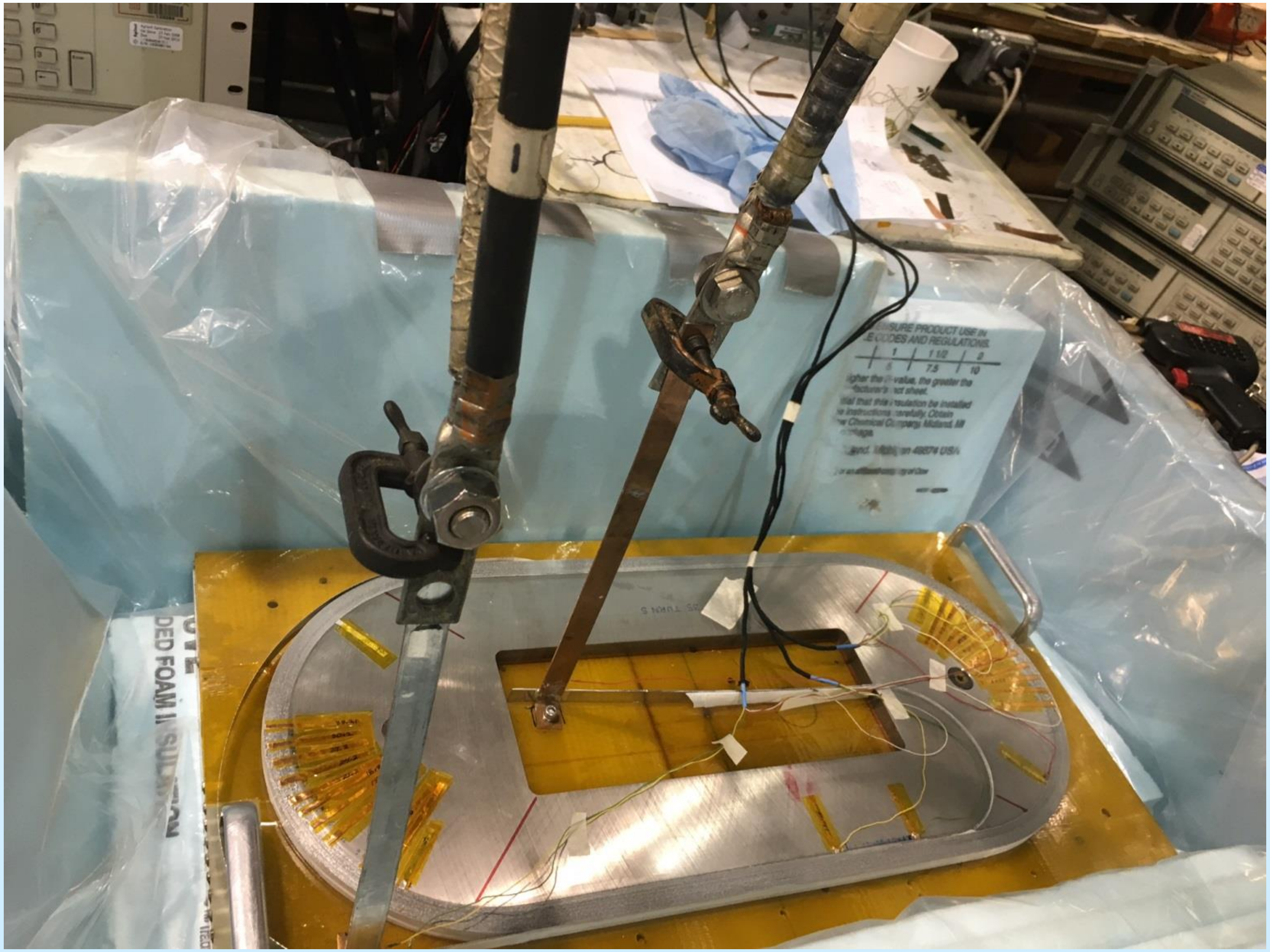
Coil wound with the 4-ply ASC tape and Nomex insulation

HTS Coil Winding (2)

Many v-taps for detailed 77 K test study and diagnostics

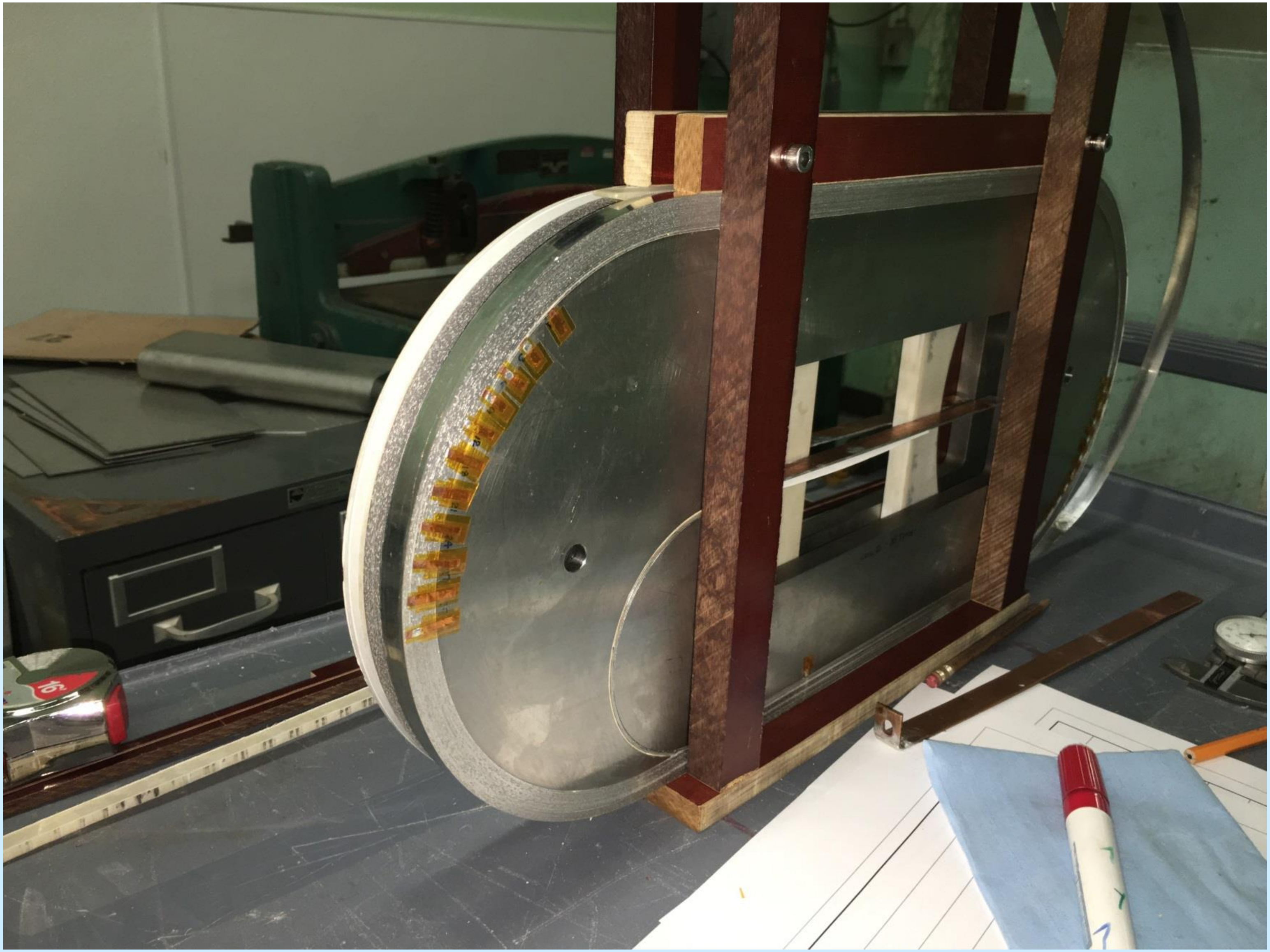
Everything looks OK under the microscope

Single Pancake HTS Coils (2) Testing



In HTS coils, low cost 77 K testing with a large number of v-taps, reveals a lot

Two HTS Coils Assembled in Common Coil Configuration



½ inch aperture

All Cleared by a Young Scientist

Hall probe installed for magnetization measurements at 77 K

Common coil configuration to study field perpendicular case

HTS Common Coil Magnet (just out after 77 K test)

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Superconducting Magnet Division

Cost-effective Sign of Our Sponsors Carved

Coils Placed Side-by-Side for 77 K Test

This configuration allows Field Parallel Magnetization Measurements

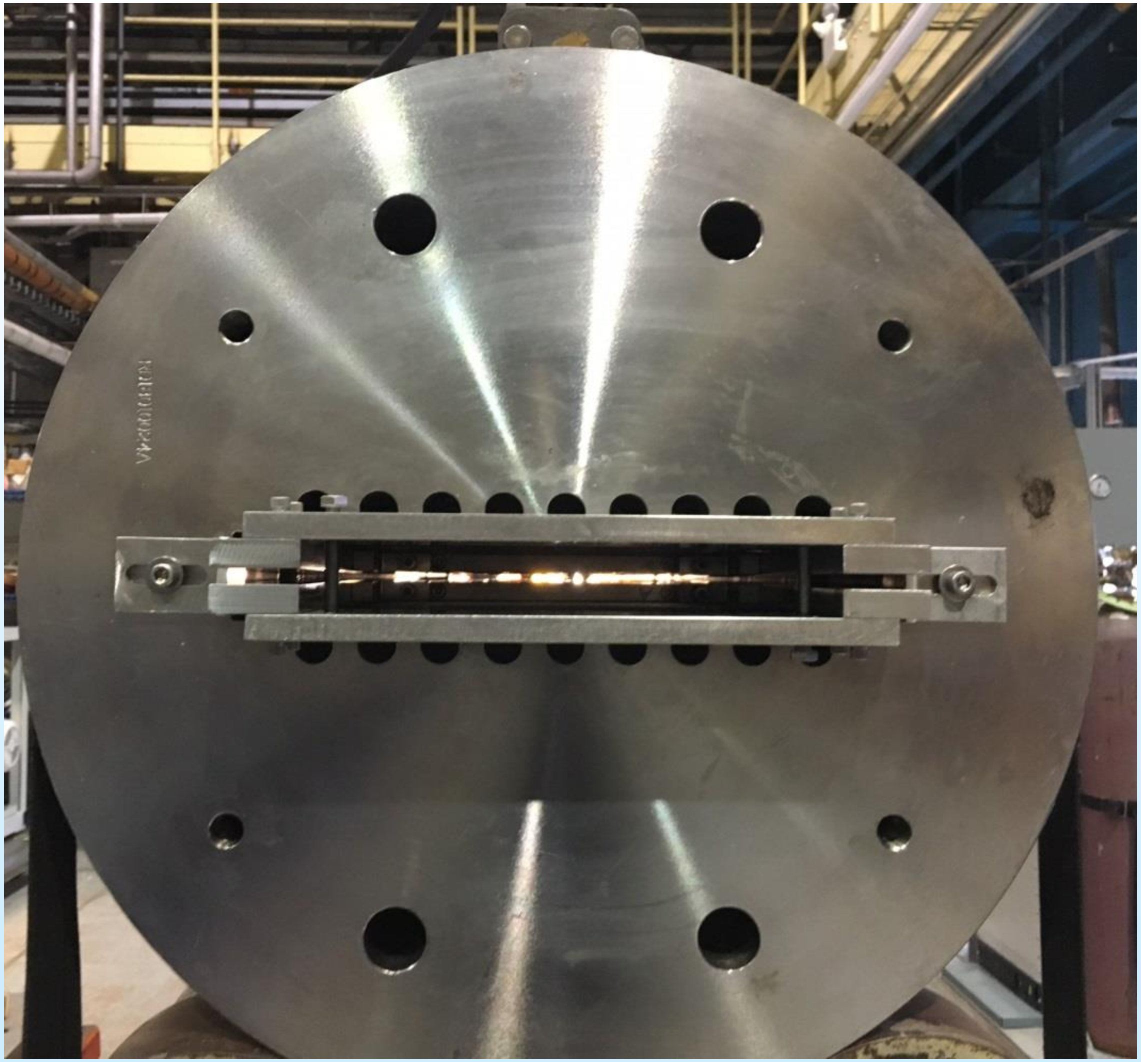
Coil cross-section was made square to compare similar geometries for field parallel (this case) and field perpendicular (previous case)

Dry Run for Final Assembly

Dry run to see that the metal frame structure will fit inside the common coil magnet opening

Metal part fabrication was coordinated and purchased by PBL (saves on overhead)

Metal Structure Inserted



Further check to see that the two pancake coils can be separated out by ~1/16" after the installation

(now you can see light at the end of the tunnel)

Two HTS Coils Getting Assembled in the Metal Frame

Internal Splice Made (flexible to allow separation)

Close-up of Flexible Splice

In common coil design, this splice goes in low-field, low Lorentz force region (requires only moderate support)

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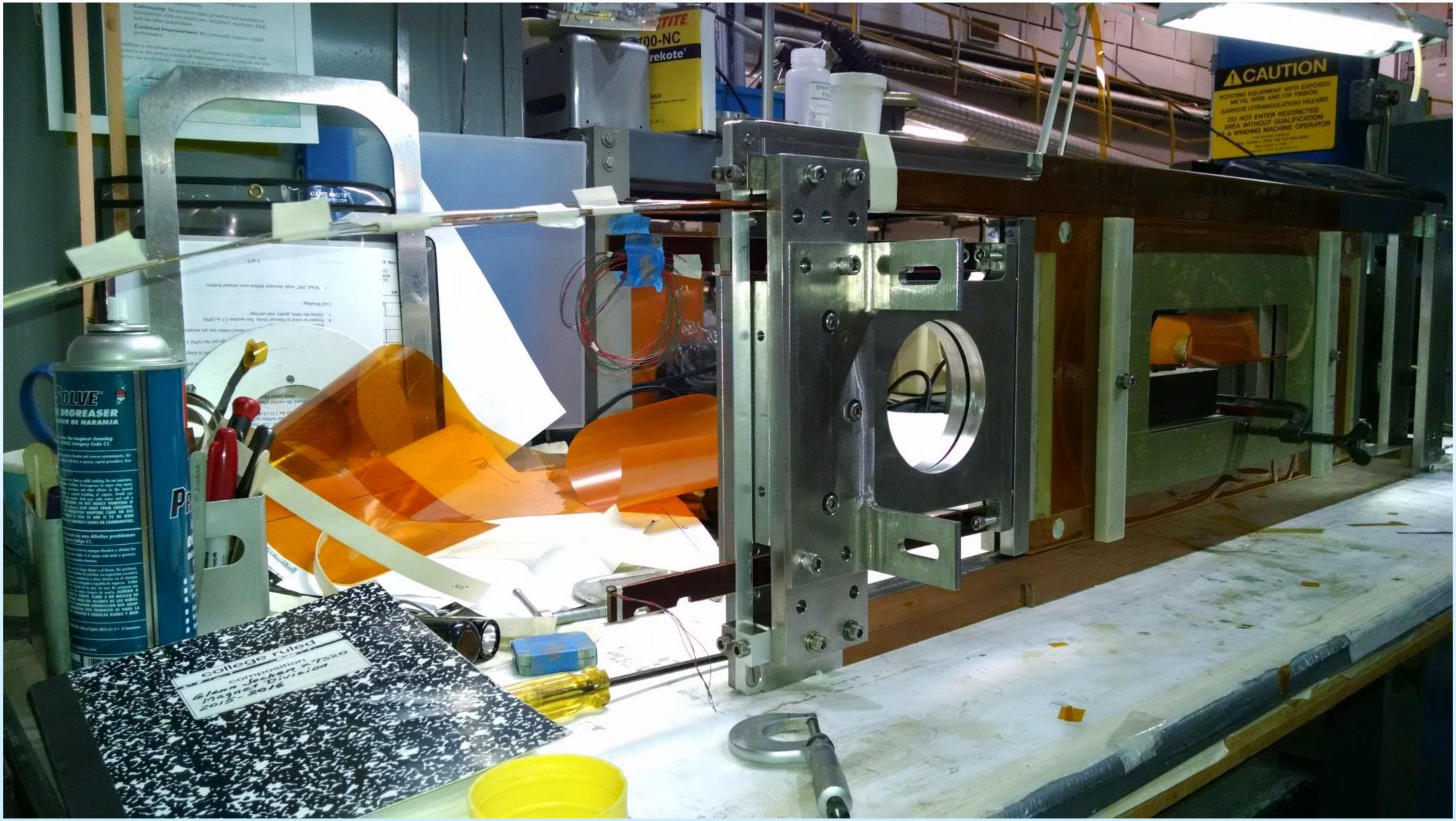
HTS Common Coil Assembly Ready with Current Leads Installed



Here Comes Our Latest and Longest Cryostat

(generously sized to serve whole assembly)

77 K Pre-test of Two HTS Coils Assembled as in Common Coil

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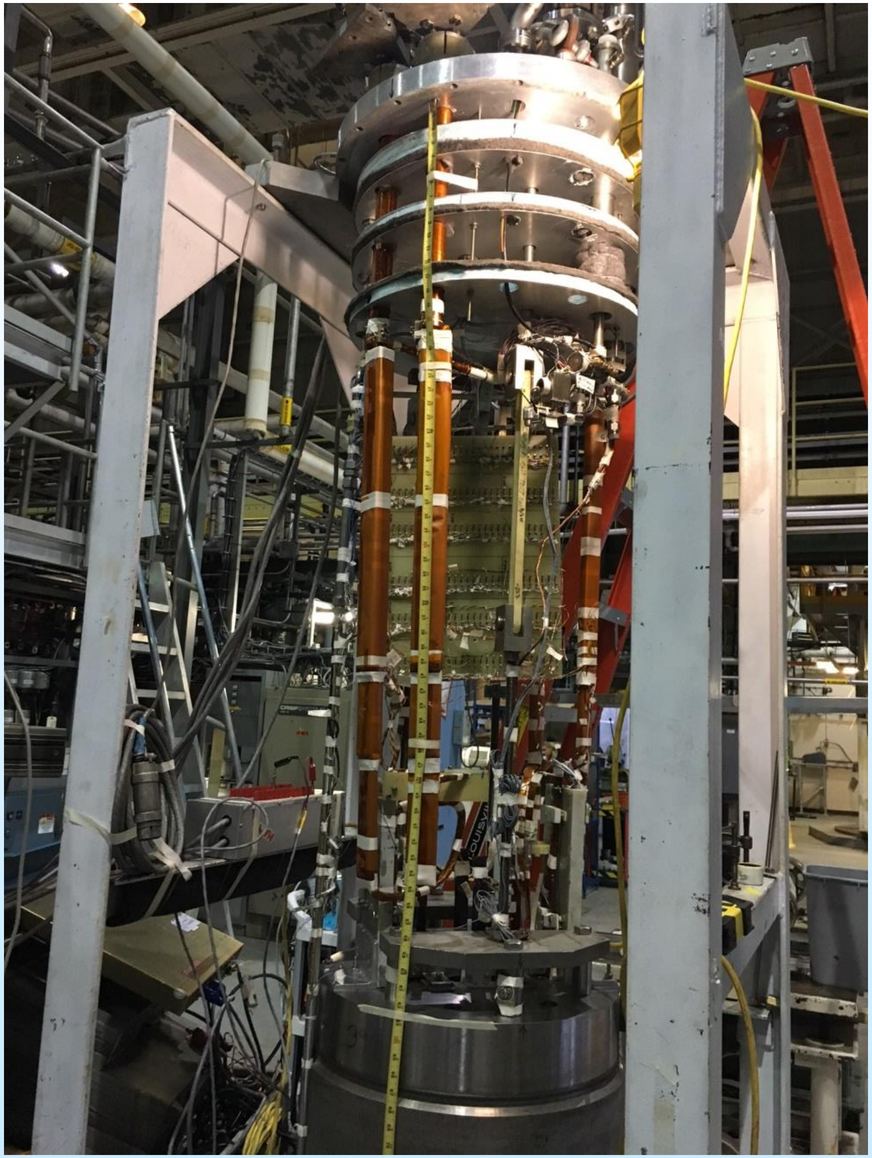
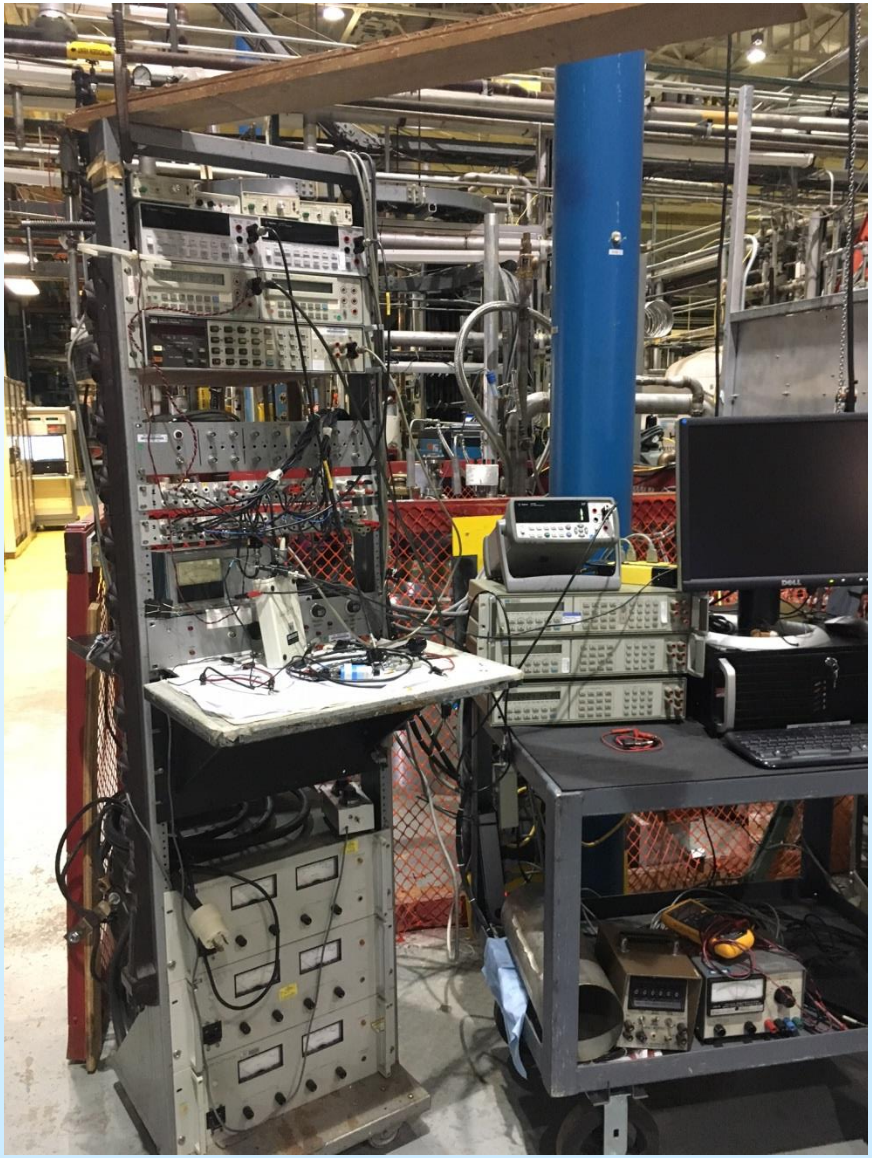
HTS allows such pre-tests before the more expensive 4 K Tests

HTS Coils Installed inside the Magnet

Magnet with the Top-hat



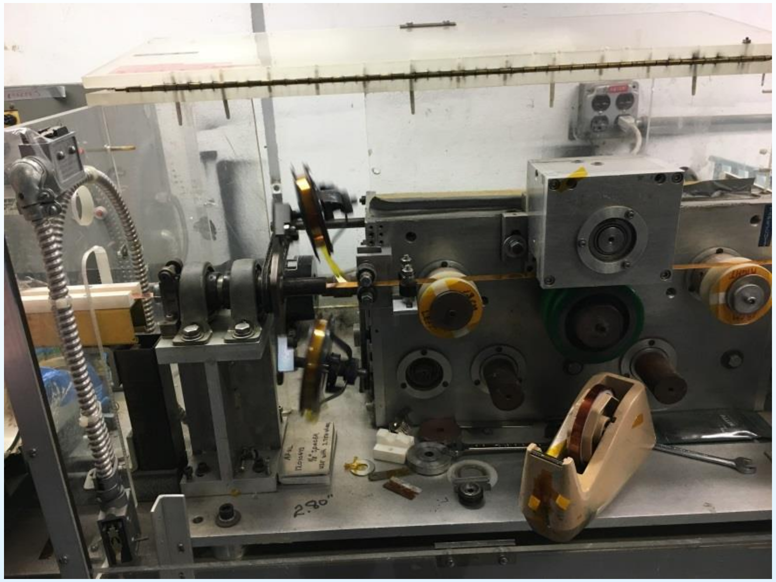
HTS Quench Protection

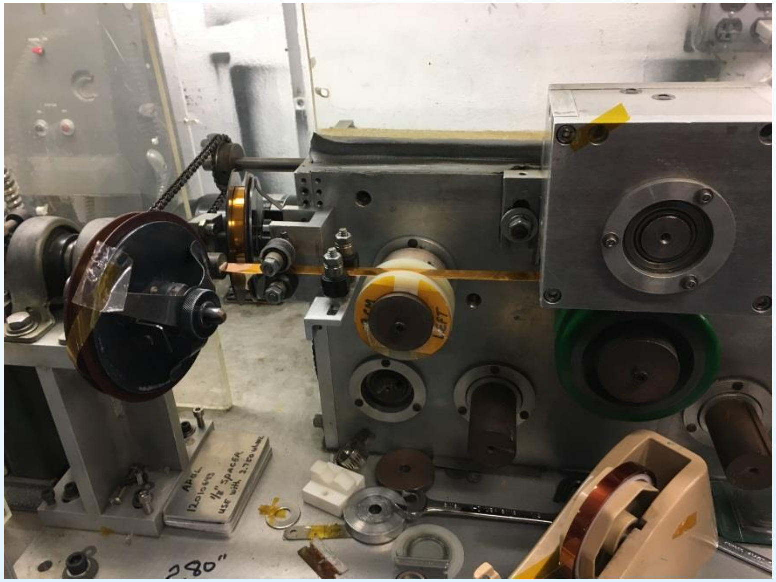


Magnet Status

- HTS/LTS Hybrid Magnet at 4K
- Initial low current test on LTS/HTS coupling is starting (for quench protection)

Kapton-Ci Insulation on ReBCO Tape (and Making a NbTi Type Cured Coil)





Part of the same STTR

77 K tests show no degradation in conductor performance

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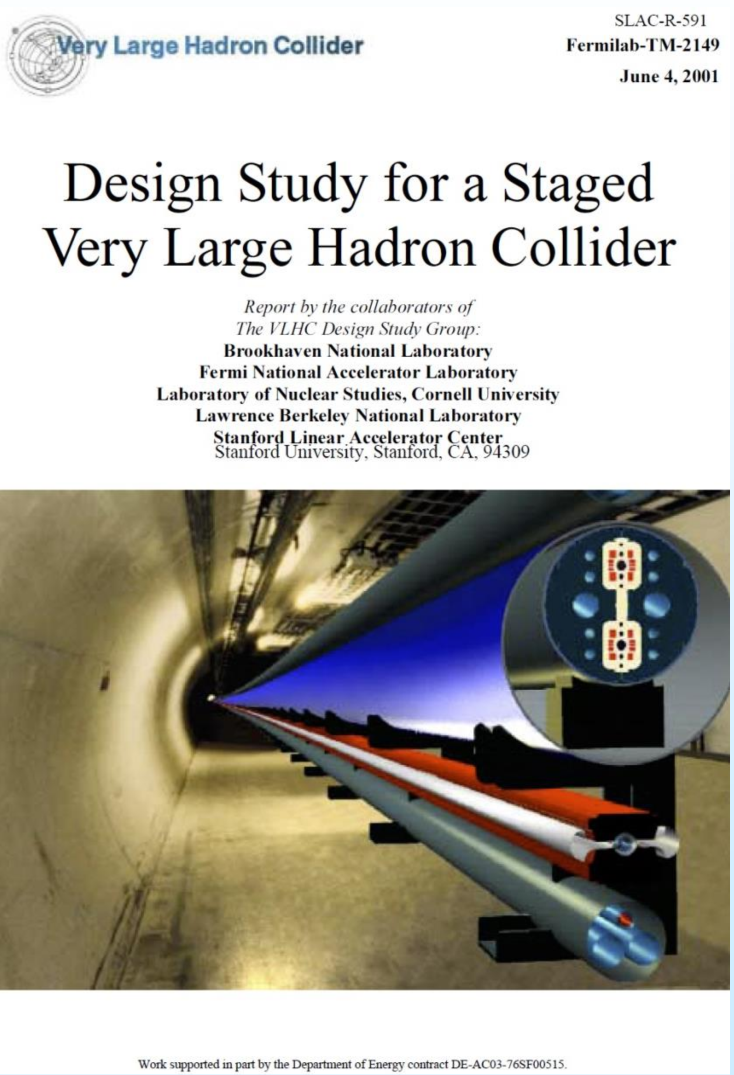
Magnets, Proposals and Programs Based on the Common Coil Design


SLAC-R-591
Fermilab-TM-2149
June 4, 2001

Very Large Hadron Collider

Design Study for a Staged Very Large Hadron Collider

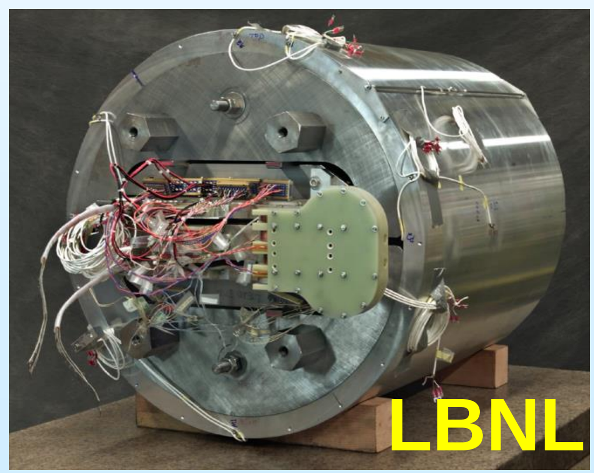
Report by the collaborators of The VLHC Design Study Group:

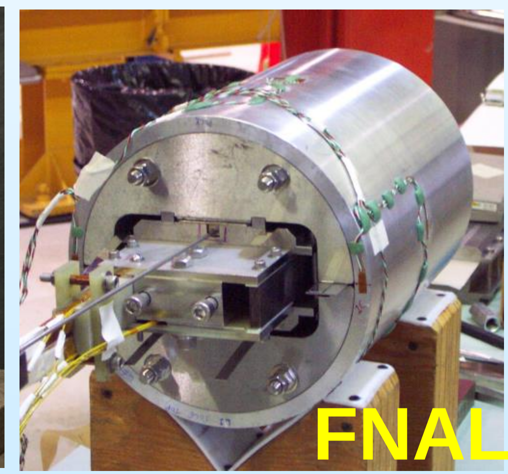
Brookhaven National Laboratory
Fermi National Accelerator Laboratory
Laboratory of Nuclear Studies, Cornell University
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
Stanford University, Stanford, CA, 94309

Work supported in part by the Department of Energy contract DE-AC03-76SF00515.

- R&D magnets built at LBL, BNL and FNAL
- Started the culture of fast turn-around R&D
- Base line design for VLHC; also for SppC

Work stopped for reasons other than failure





LBL sub-scale magnet program is based on the above design and philosophy

CONCLUSION

- The program vision outlined here is based on the "common coil geometry". The program has two significant components:
  - A unique design to produce lower cost, accelerator quality Nb_3Sn (ongoing Phase I, Phase II to be submitted) and HTS/LTS Hybrid (ongoing Phase II) dipoles for collider
  - A unique low-cost, fast turn-around coil/magnet test facility
- Progress made on SBIR funding continues to be impressive. It needs to be integrated with the base program.
- Including BNL, the home of only US superconducting collider and a team with a proven record and unique expertise, should be an asset to program. Leaving BNL out is unimaginable and may be counter-productive in long run.
- Commissioning of the rapid turn-around, lower-cost test facility for racetrack coils should be useful to everyone around the word.