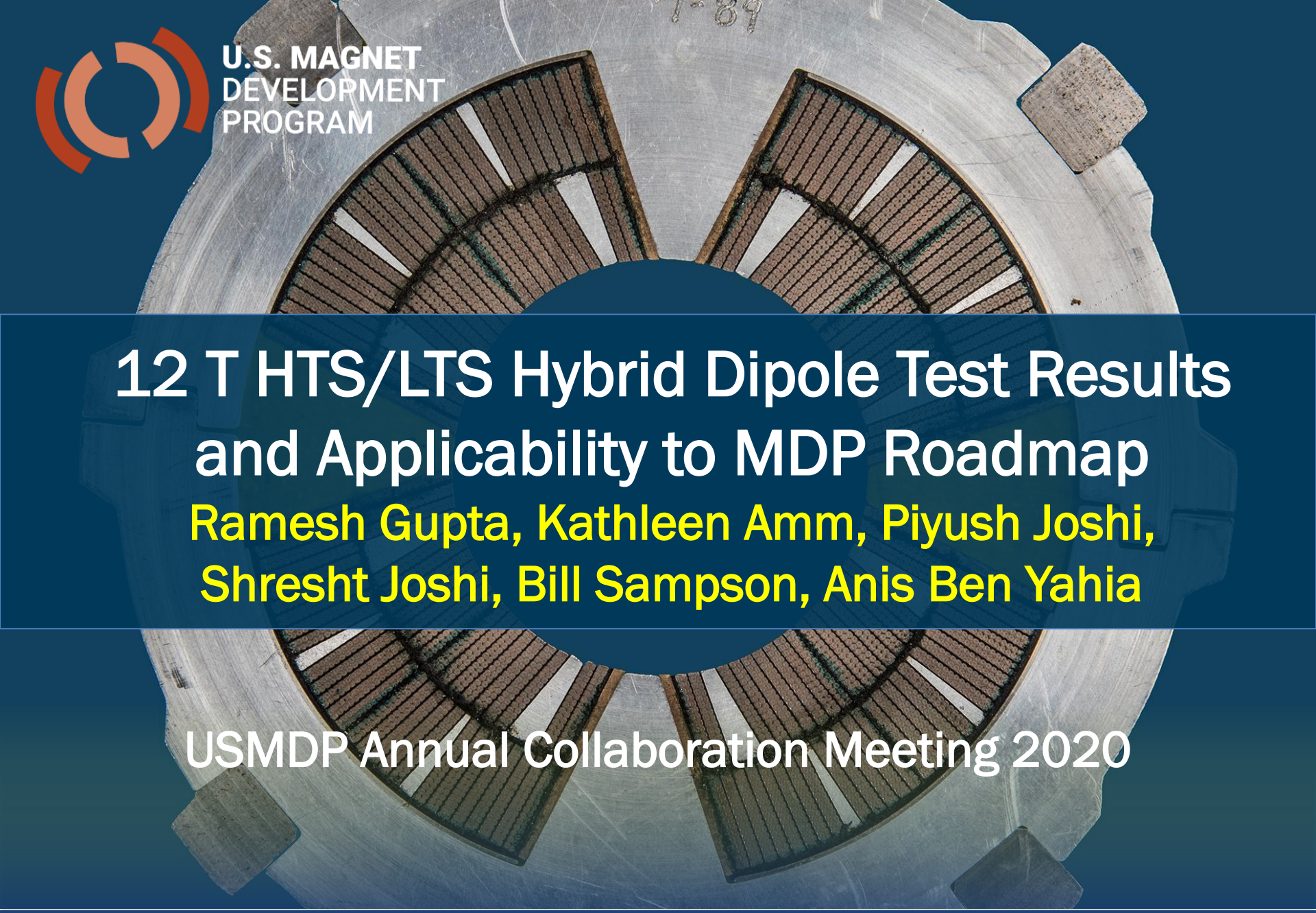

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12 T HTS/LTS Hybrid Dipole Test Results and Applicability to MDP Roadmap

Ramesh Gupta, Kathleen Amm, Piyush Joshi, Shresht Joshi, Bill Sampson, Anis Ben Yahia

USMDP Annual Collaboration Meeting 2020

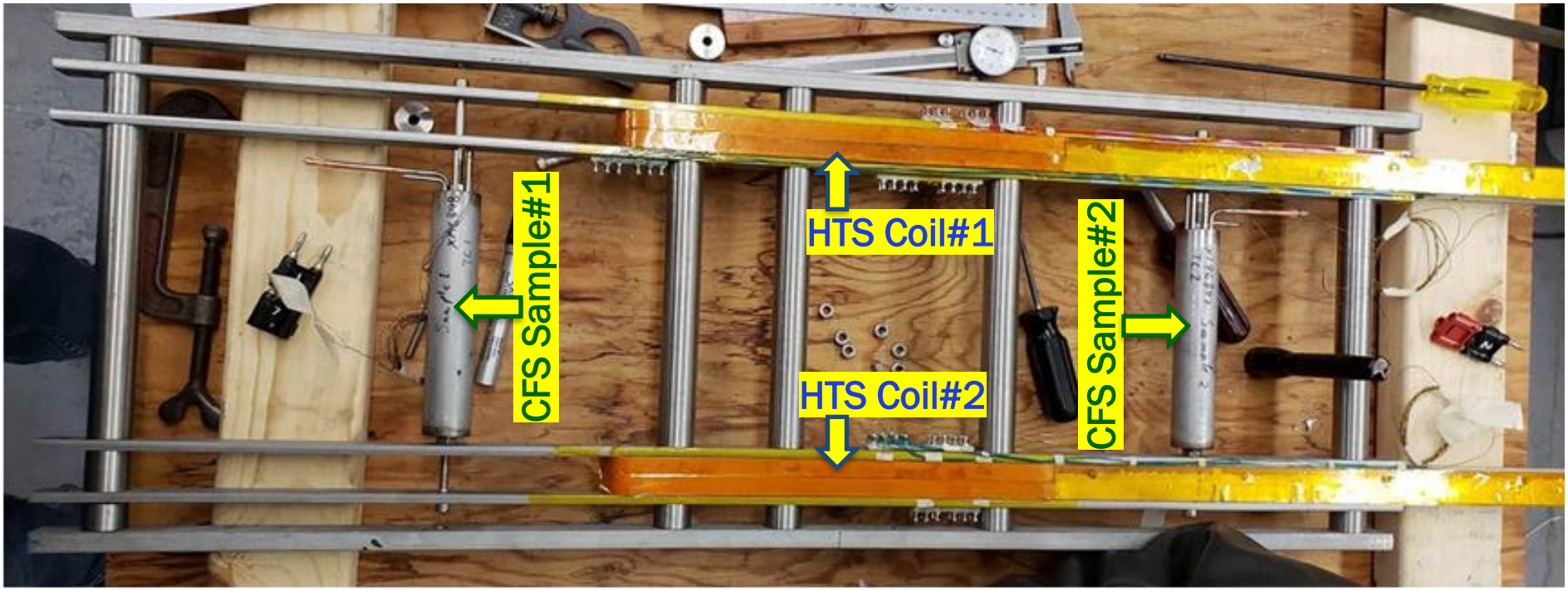
U.S. MAGNET DEVELOPMENT PROGRAM

CONTENTS

- Test Objectives
  - Test entirely supported by MDP with contributions to test facility from BNL internal funding
- Test Results – 12 T HTS/LTS Hybrid Dipole
  - Significant results in <9 months from the 1st funding
  - Only partial results presented, analysis ongoing
- High Field Magnet Technology Development Approach
- Contributions to MDP Roadmap
  - Contributions to roadmap made by this test and future tasks that can be accelerated

Building Collaborations

HEP Working with the Fusion Community



Test results in <3 months from the first mention, thanks to MDP, unique test platform @BNL (*existing*), and the Fusion Business Development funds provided by the BNL management

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Overriding Test Objectives (a view from 30,000 ft)

MDP R&D test is to continue the HTS/LTS hybrid dipole technology work performed under a previous PBL/BNL SBIR

- SBIR test was for the case when the field was primarily perpendicular to the wide face of the tape; MDP test is when it's primarily parallel (expect much lower magnetization)
- SBIR test was for the case when HTS coil survived multiple quenches in itself; MDP test is to find out if HTS coil will survive when LTS coil, with much larger energy, quenches
- SBIR test achieved 8.7 Tesla hybrid field (record at that time), MDP test will find out if it can be increased significantly without destroying the HTS coils in the event of a quench

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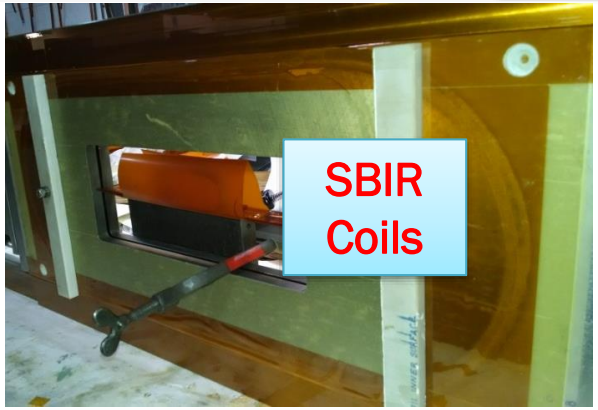
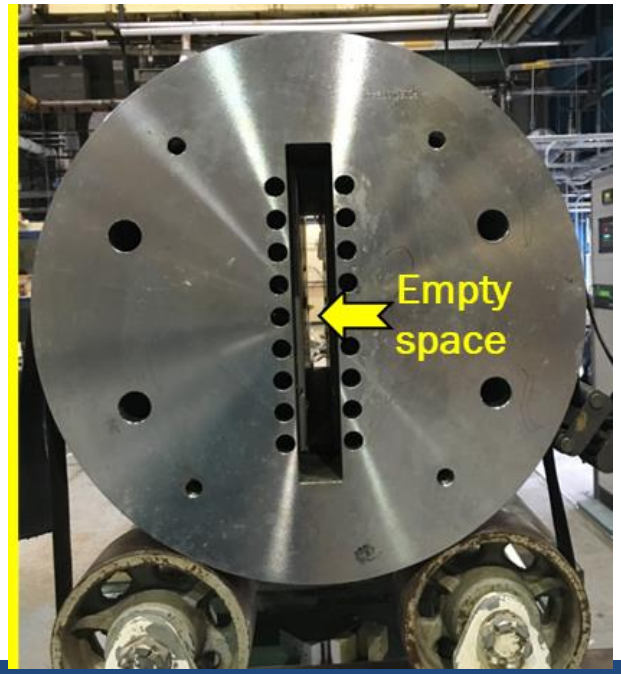
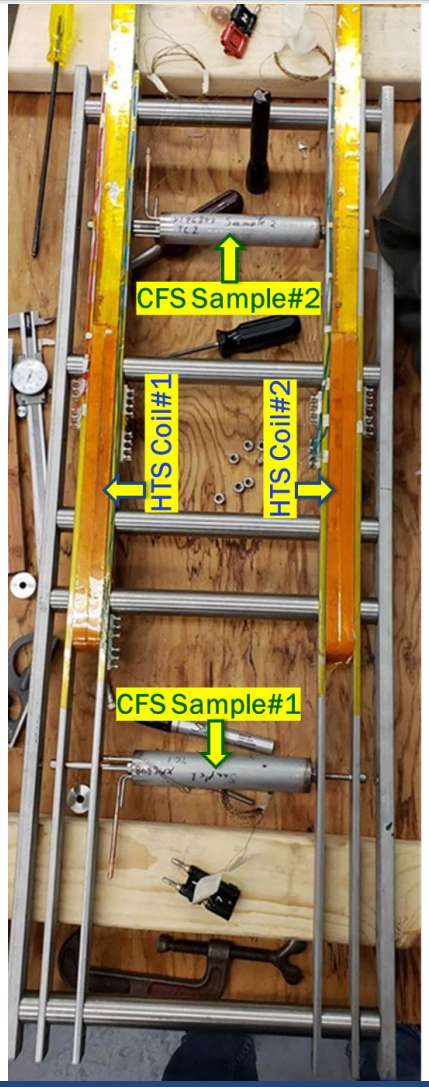
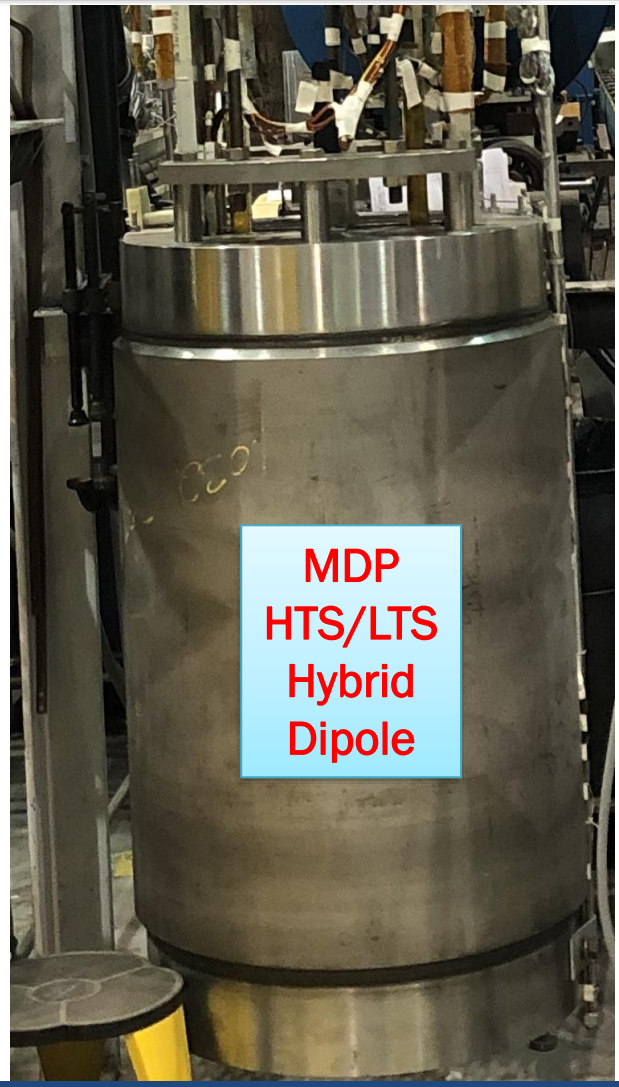
HTS/LTS Hybrid Dipole (1) (SBIR & MDP)

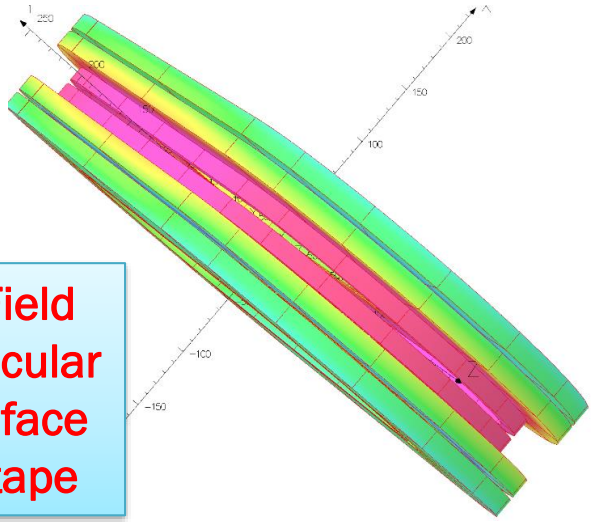




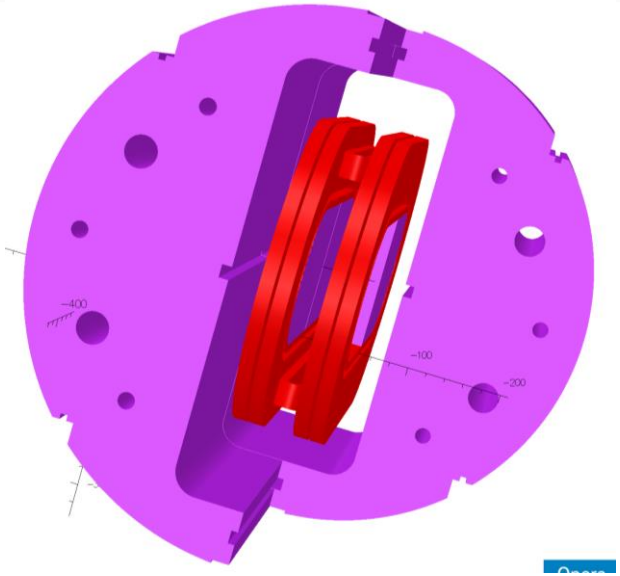




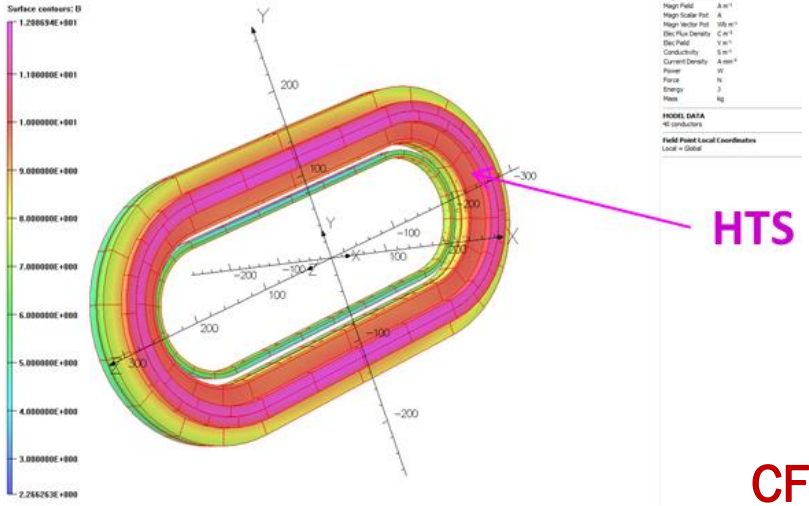
HTS/LTS Hybrid Dipole (2) (SBIR & MDP)



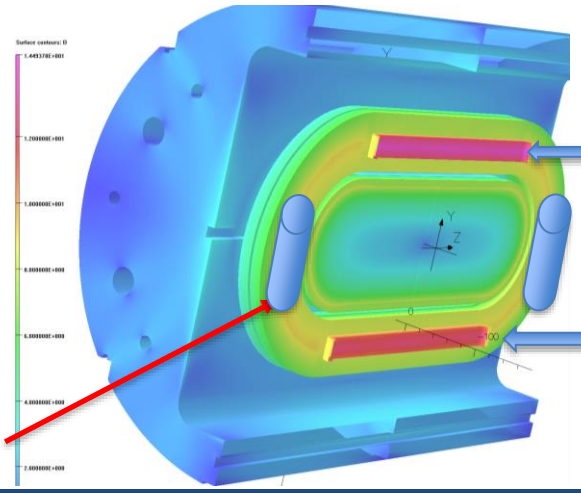
SBIR : Field Perpendicular on wide face of HTS tape



MDP Field Parallel on HTS coils



HTS

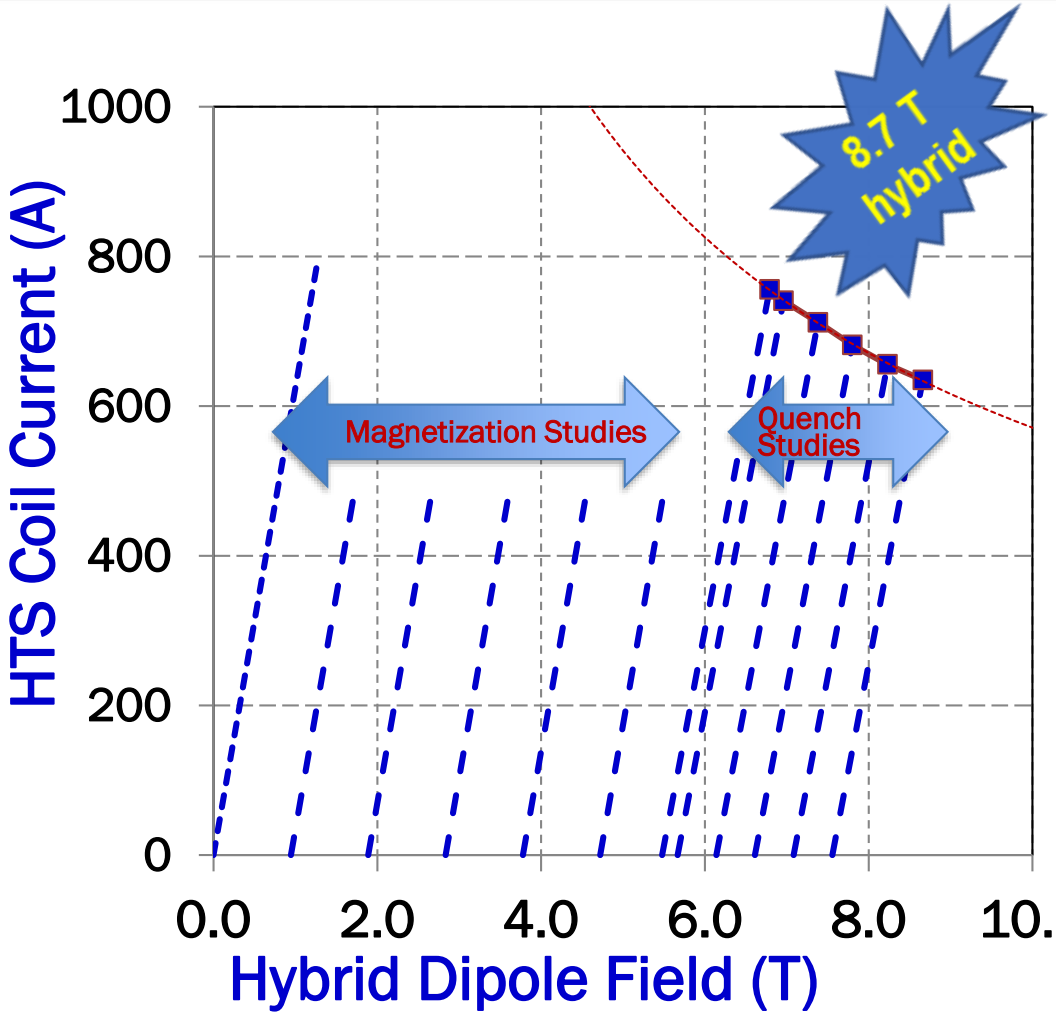


HTS Coil#1

HTS Coil#2

CFS Sample

PBL/BNL SBIR 2016 Test
HTS/LTS Hybrid Dipole Structure



- HTS coils in hybrid dipole were ramped multiple times to quench, just like LTS.
- NO training
- No degradation in HTS coils despite a number of quenches.

- Field due to conductor magnetization estimated by taking difference between up and down ramps.

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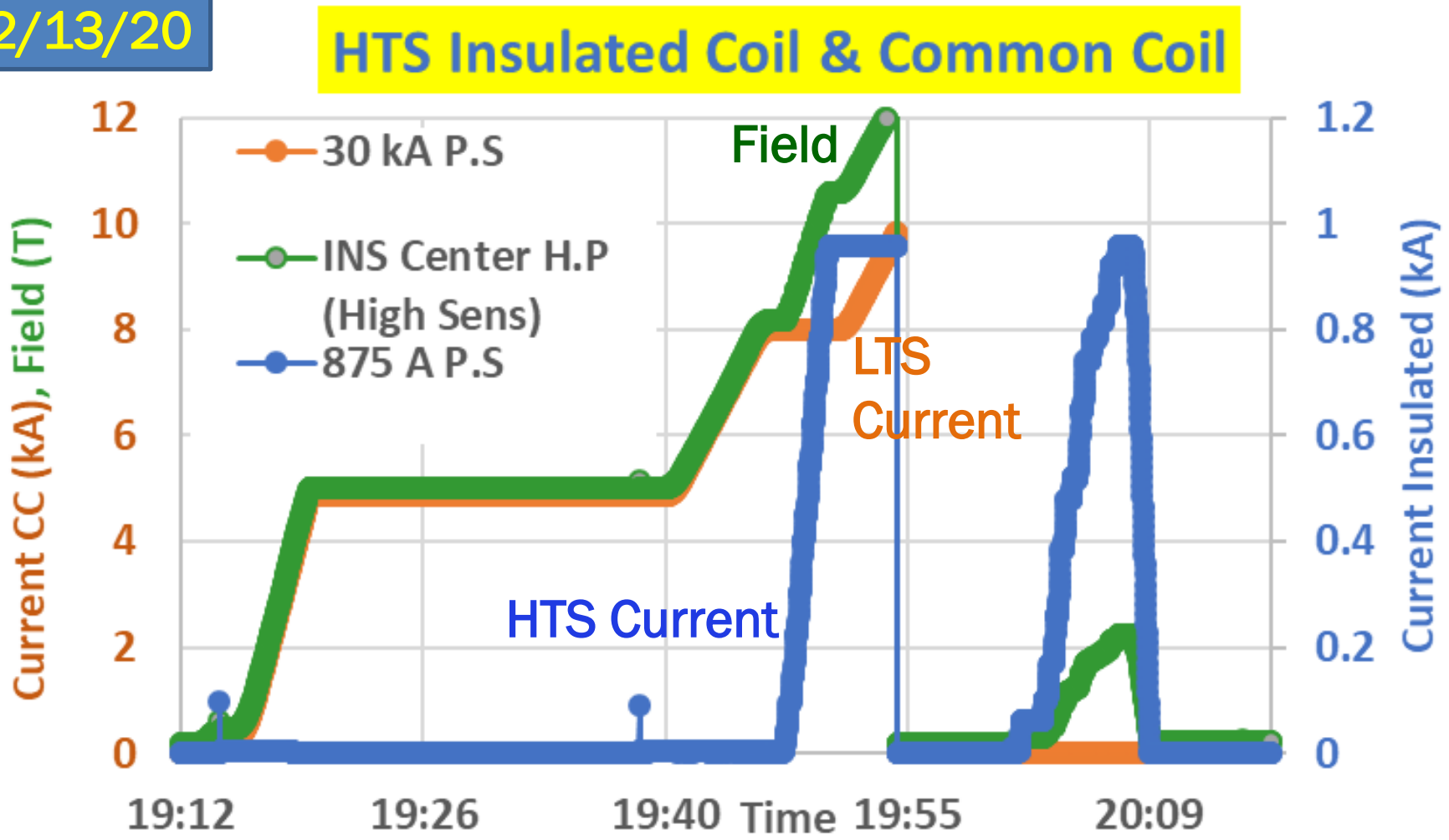
MDP HTS/LTS Hybrid Dipole
(magnet reached 12.2 T, HTS coils survived)

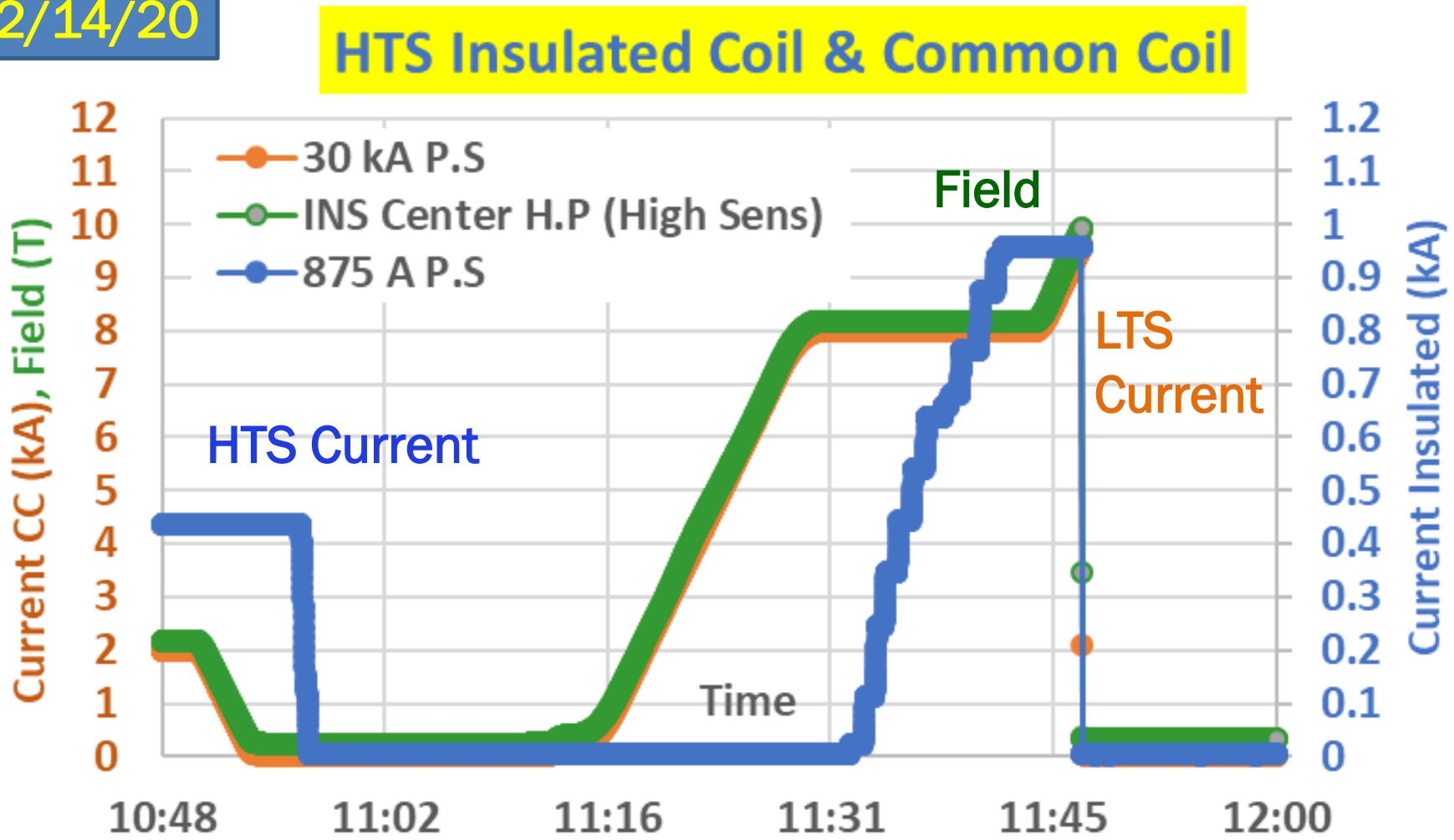
2/13/20



MDP HTS/LTS Hybrid Dipole Test

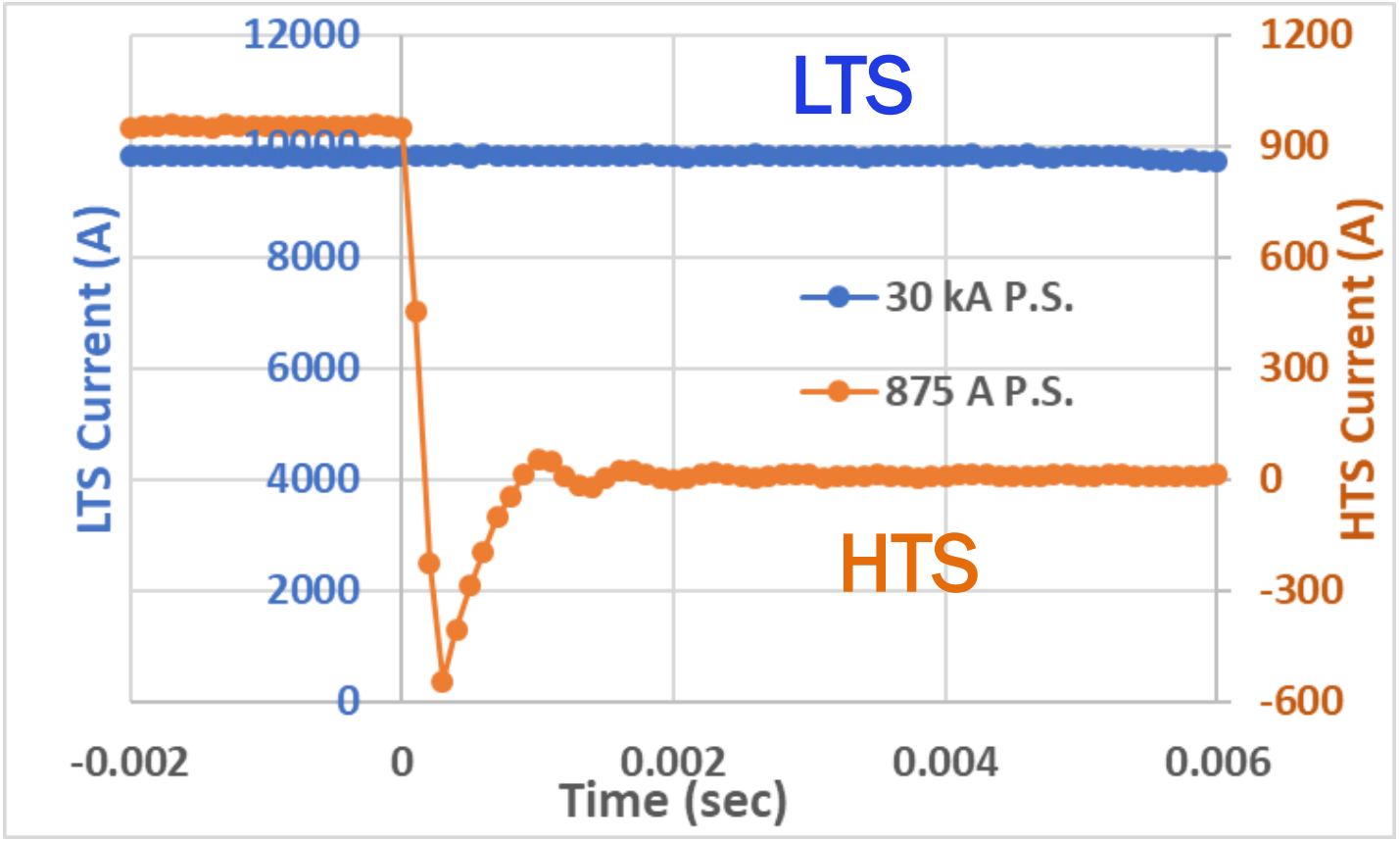
(test repeated next morning, hybrid survived)

2/14/20



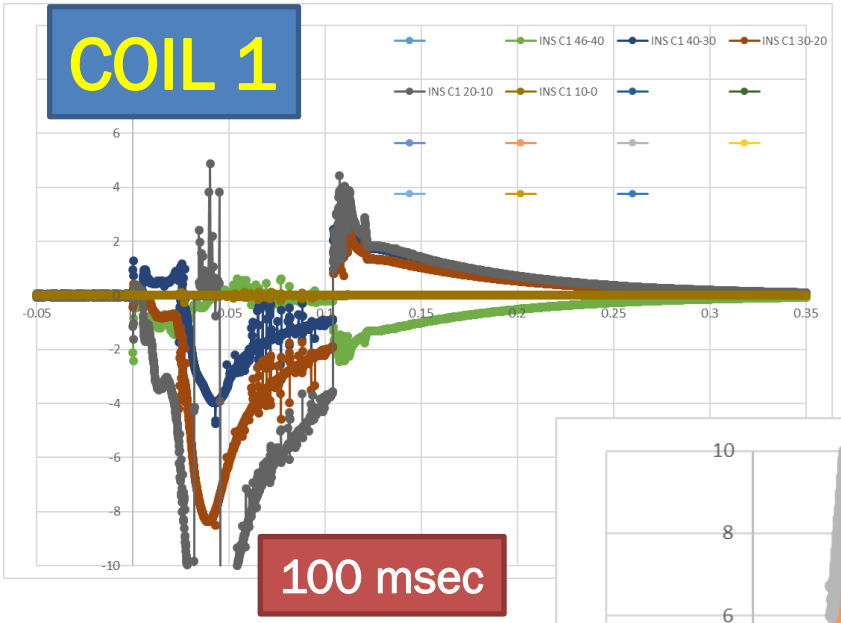
MDP Quenches
(No quench in HTS; LTS quenched)

Major concern: What happens if LTS quenches and it dumps large energy in HTS. Can HTS coil survive?



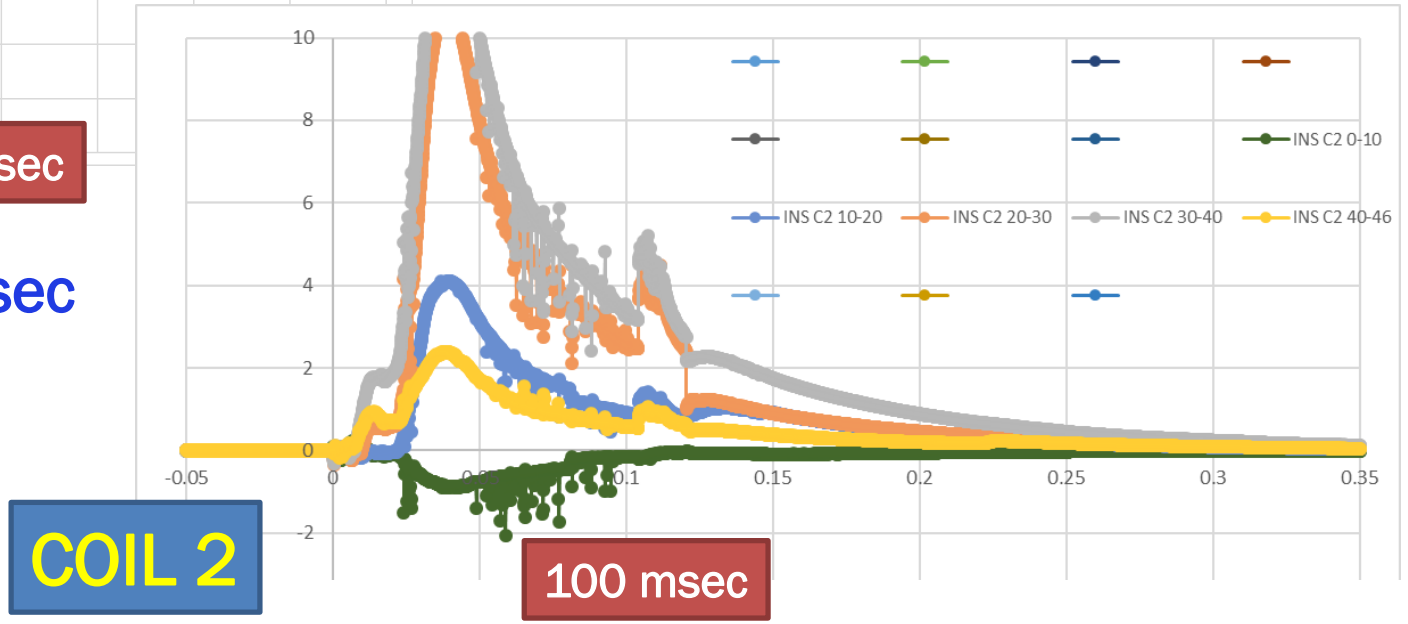
Energy extracted form LTS in 300 msec.
LTS energy extraction starts 4 msec after HTS has been powered down
(P. Joshi)

MDP Quenches (2) (internal turn-to-turn voltage during LTS energy extraction – coil 1 & coil 2)



Transport current zero after 4 msec.
Coil 1 voltage may be inductive but
Coil 2 voltage may be real resistive,
thanks to screening currents...
(preliminary but very interesting)

Timescale <1 sec



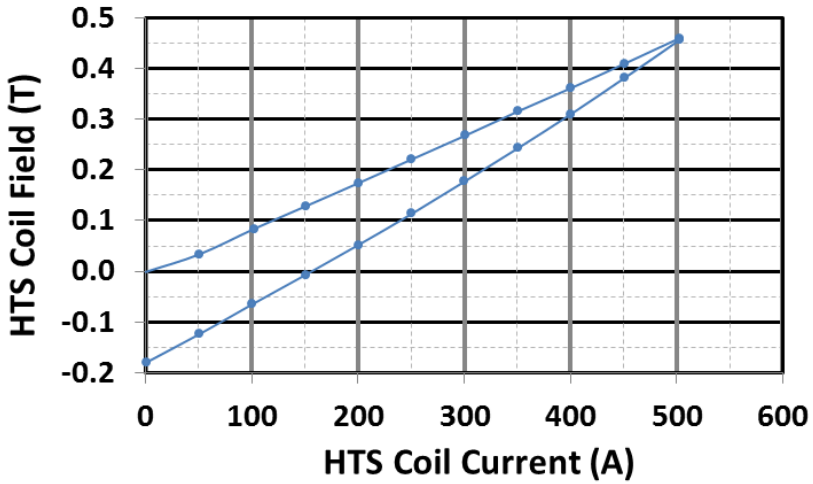
Magnetization Studies @2T Dipole Field

SBIR: Field Perpendicular, MDP: Field Parallel

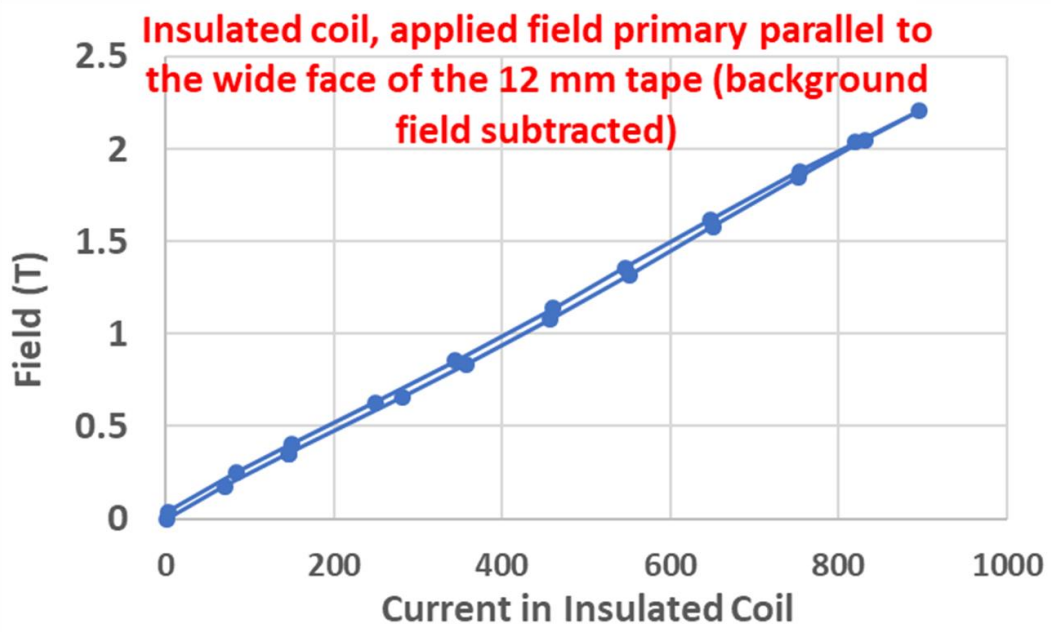
Additional field from the HTS coils in up and down ramp (offset to start from zero to start up-ramp)

Significant reduction in magnetization from HTS coils when field is primarily parallel to the wide face when compared to primarily perpendicular

Field perpendicular (2016 SBIR)



Field parallel (2020 MDP)



An Alternate Approach to Magnet Technology Development

When there were more funds to develop and demonstrate magnet technology (SSC and RHIC days), we used to argue about the applicability of short magnet test results in building long magnets

- We accepted the benefits of short magnet R&D as they could be built and tested cheaper and faster (relatively speaking) and we could afford to change one or fewer parameters at a time to identify issues and to develop magnet technology
- Now short high field R&D magnets take so long and are so expensive to build (relatively speaking) that we can't afford even them. Then we have to find an alternate R&D approach

The results of the alternate approach should be largely (even if not completely) applicable to real magnets and the test vehicle be robust

Alternate R&D Approach for MDP (how new?)

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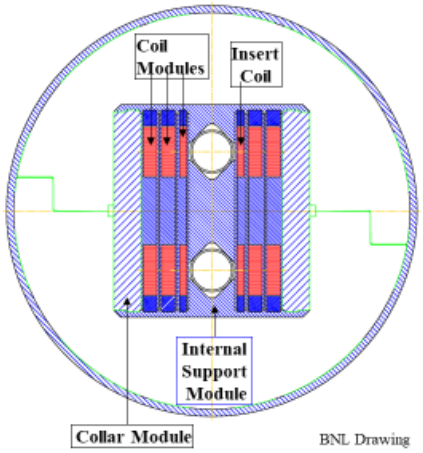
BERKELEY LAB

A Modular Design for a New R&D Approach

(Slide from LBL, 1998)



BNL Drawing

- Replaceable coil module
- Change cable width or type
- Combined function magnets
- Vary magnet aperture
- Study support structure

- Traditionally such changes required building a new magnet
- Also can test modules off-line

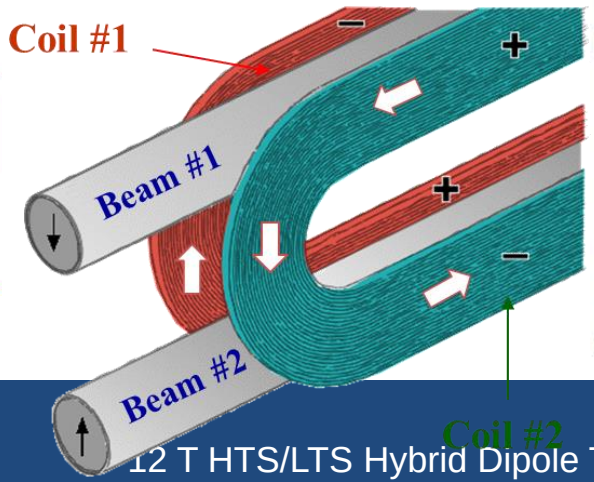
This is our Magnet R&D Factory

Accelerator and Fusion Research Division — BERKELEY LAB — Magnet Design Approach and Strategy
Superconducting Magnet Program — Slide No. 6 — Ramesh Gupta; August 12, 1998

Common Coil Magnet
As a Facility for Conductor and Magnet Development

Ramesh Gupta, LBNL

High Field Materials Low Temperature Superconductor Workshop
Santa Rosa, California
November 1-3, 1999



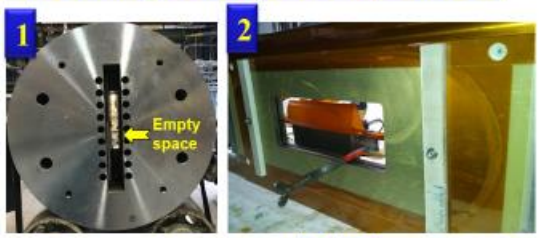
(Slide from BNL, 2019)

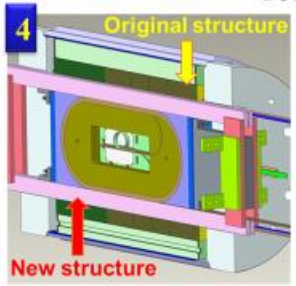
BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division

New R&D Approach Concept (rapid turn-around, low cost)

Five Simple Steps/Components

1. Magnet (dipole) with a large open space
2. 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



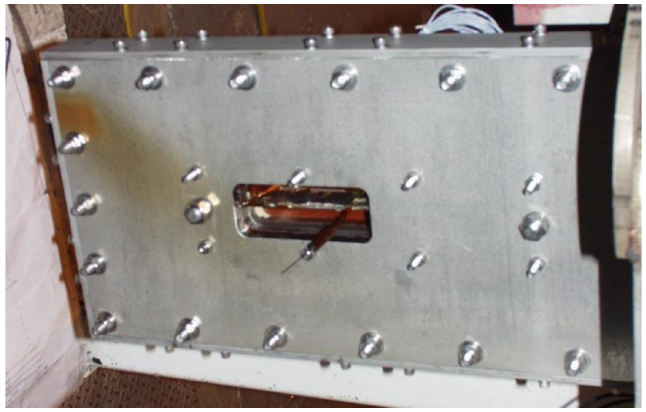


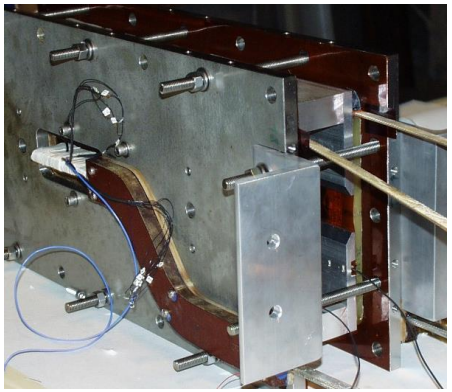
A New Magnet R&D Approach and Test Facility for High Field Magnets -Ramesh Gupta,... Sept 25, 2019 5

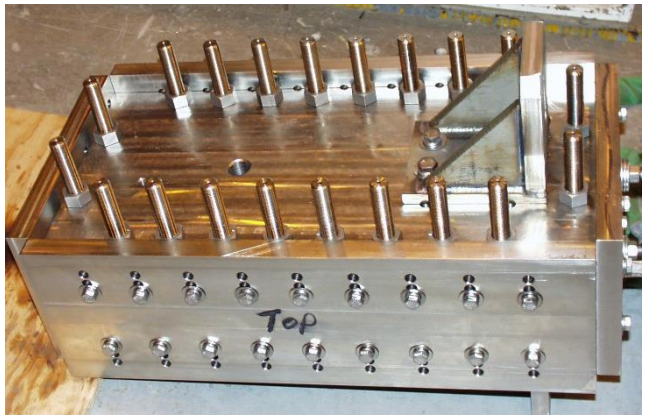
Test of the Magnet Technology: Where does the Size of Aperture Matters and Where it Matters Less?

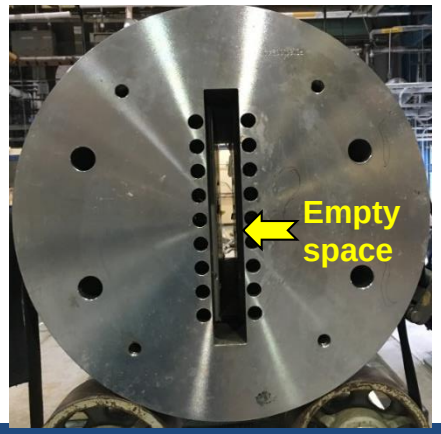
NOT VALID (structure relies on clamping two sides)

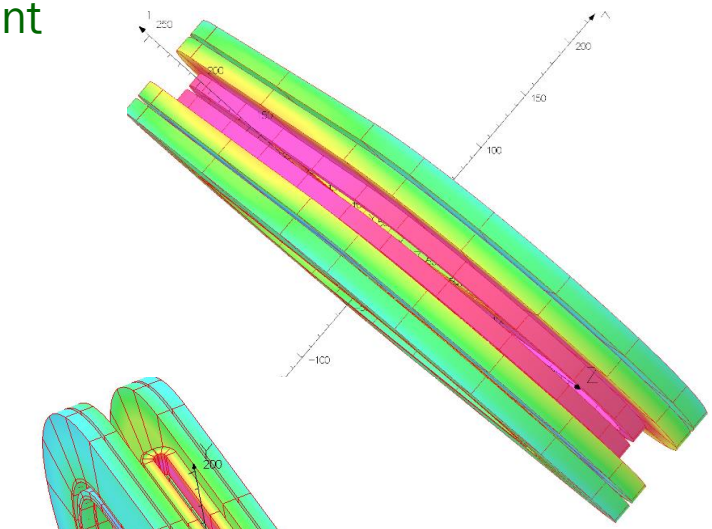
Two sides of the coils are free to move independently. If stresses and fields on the insert coil of small aperture can simulate that of larger aperture, results should be valid for technology development

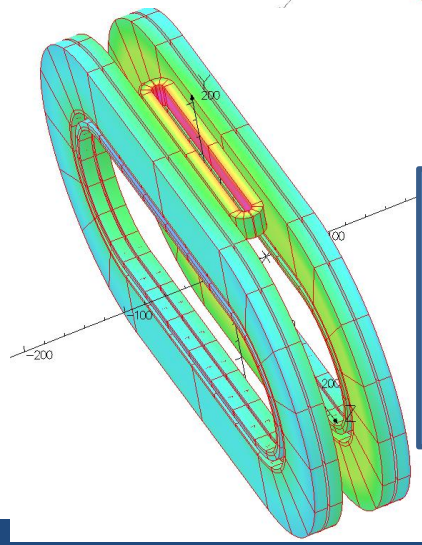












Left side doesn't know how far the right side is?

Thanks to our staff at BNL

Work presented here was the result of many people working very hard - late hours day after day.

They came over weekend, worked late hours for weekdays continuously (usually till 10 pm) and were back early morning next day.

Thank you for this opportunity to present their hard work…

Last Slide
Contribution to Roadmap

- We have a lot of data available from this test then presented here. We will be glad to share.
- They contribute to several parts of the roadmap (that will be specifically mapped in coming days)
- May be we can have a several day workshop.

Run Plan for Magnetization Studies

(almost everything planned in this slide done, perhaps not always be in the order planned)

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.

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More Details of the 12.2 T HTS/LTS Hybrid Dipole Test