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U.S. DEPARTMENT OF ENERGY

BNL activities and vision for the GARD/MDP magnet program

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@BrookhavenLab

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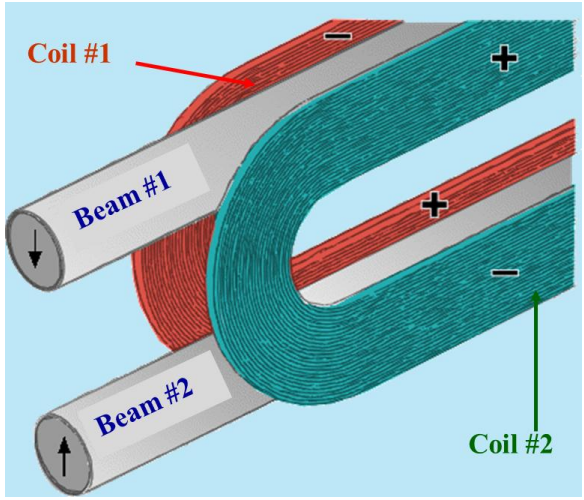
Content

- Unique strength of the BNL program relevant to GARD/MDP
- Significant contributions in recent past
- Deliverable in pipeline for remaining FY25-26
  - ➢After a brief pause in some areas (to respect AUP priorities)
- Programs for coming years with expected timeline
  - ➢Leveraging large HTS coils for “High T/All HTS Sustainability”
- Summary

✓NOTE: BNL program remains well aligned with the MDP

(large number of extra slides if needed during the discussion)

Unique Strength and contribution from BNL (to the ongoing magnet R&D worldwide)



Common Coil Magnet Design for hadron collider

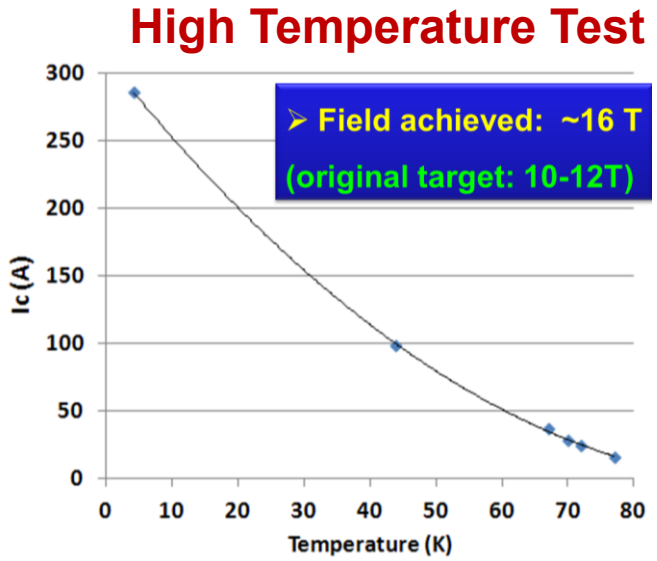
- Being used at CERN, PSI and CIEMAT

Common Coil Test Facility

- Unique lower cost, rapid turn-around R&D

HTS Magnets and Advanced Quench Protection

- All HTS and HTS/LTS hybrid magnet R&D



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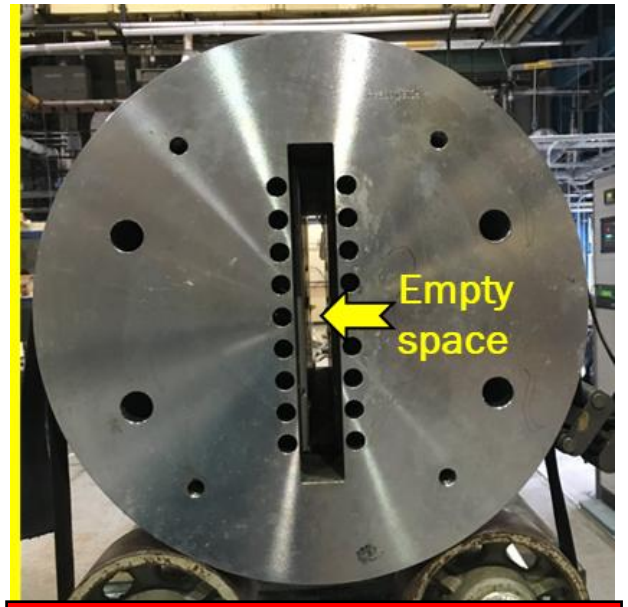
BNL common coil dipole as a test bed for high field magnet R&D

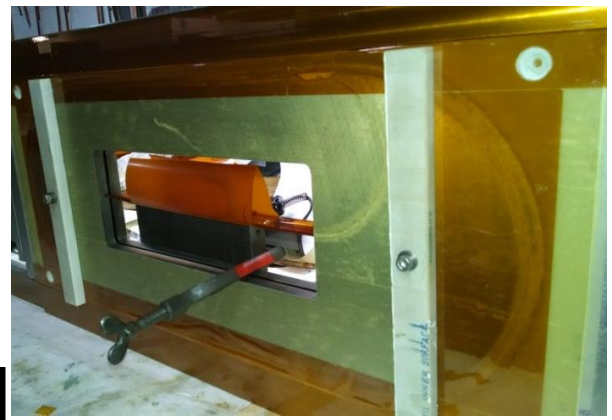
Unique Test Facility @BNL

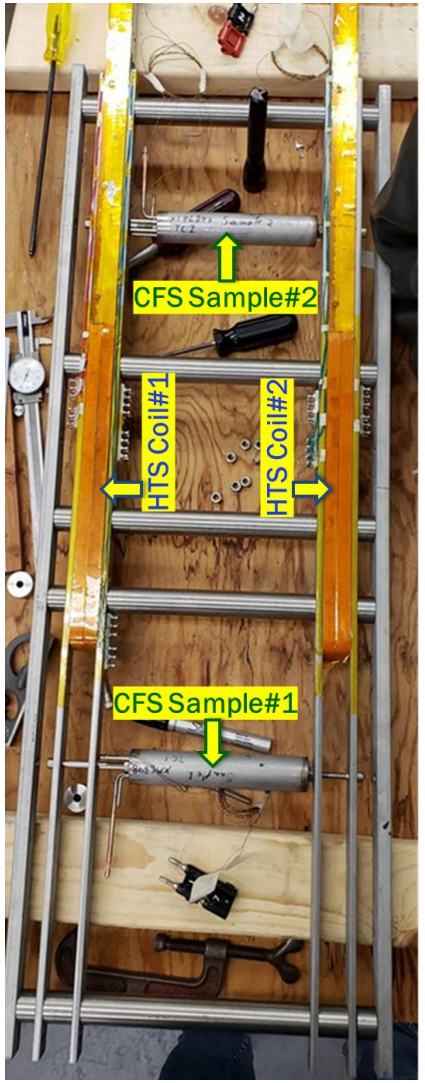
- 10 T, Nb_3Sn R&W dipole with a large open space for high field insert coil testing
- New coil(s) in the magnet without any disassembly
- Coils become an integral part of the dipole magnet
- A new coil test essentially becomes a new magnet test

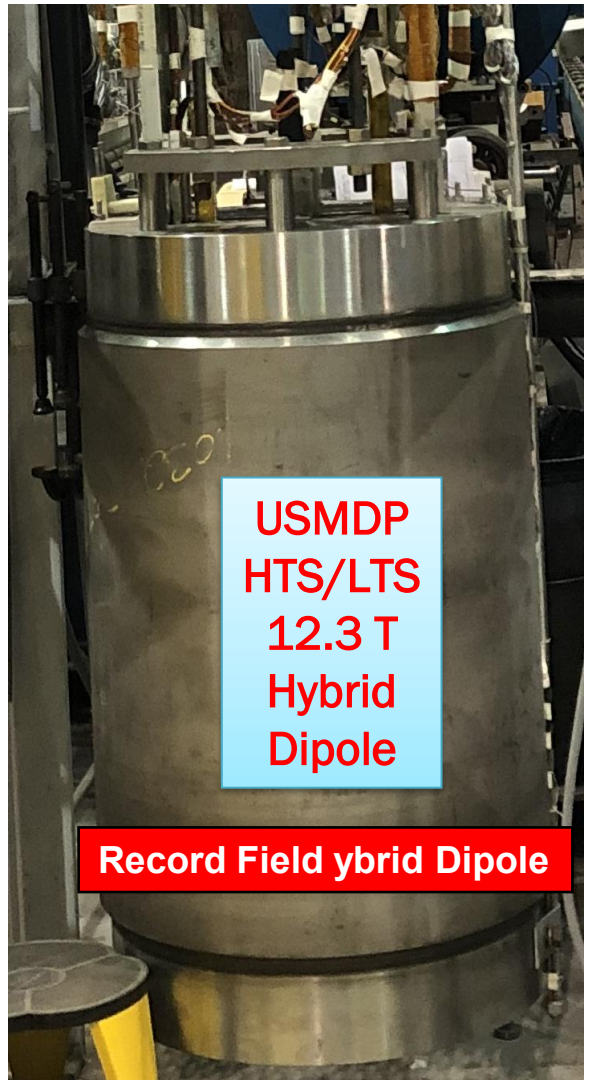
Lower cost, fast-turn-around demo of high field technology



Record Field R&W Nb_3Sn Dipole







Record Field ybrid Dipole

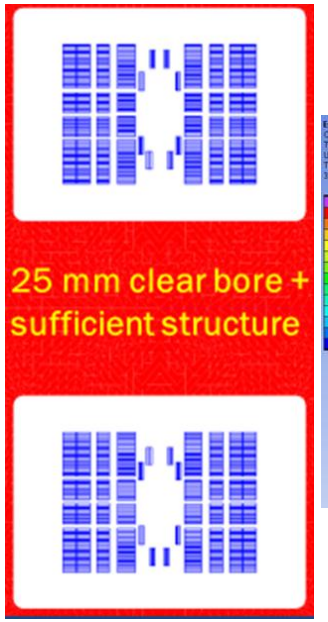
Used in many HEP/FES R&D Tests (US and international)

Activities in Recent Past

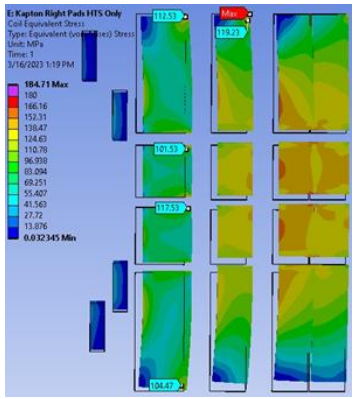
Key Outcome

- **High field common coil design (20 T design)**
- **HTS/LTS hybrid tests (record 12.3 T magnet)**
- **International collaboration (PSI BigBox test)**
- **Advance quench protection**
- **Direct wind technology for HTS**

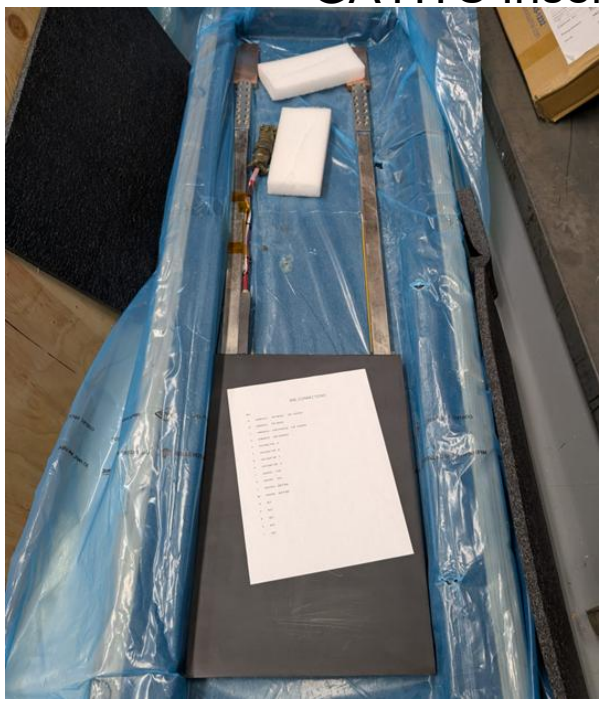
➢ **Related activities: FES, US-Japan, etc.**



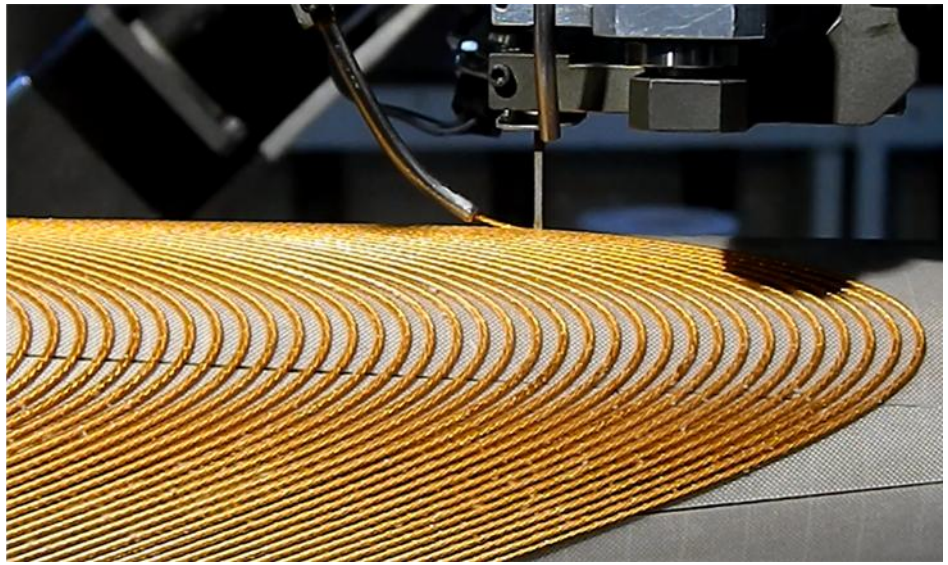
20 T Common Coil Design

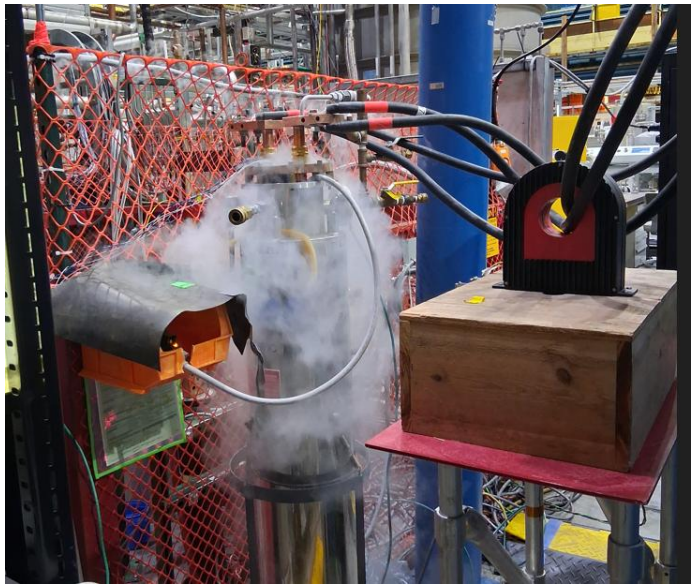


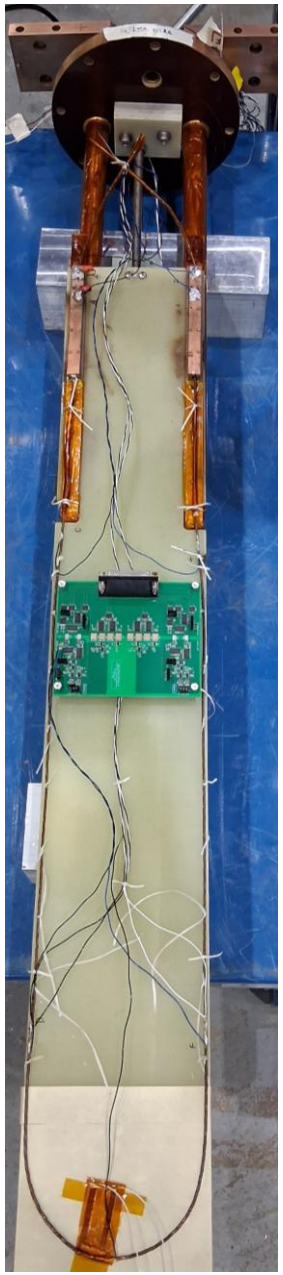
GA HTS Insert

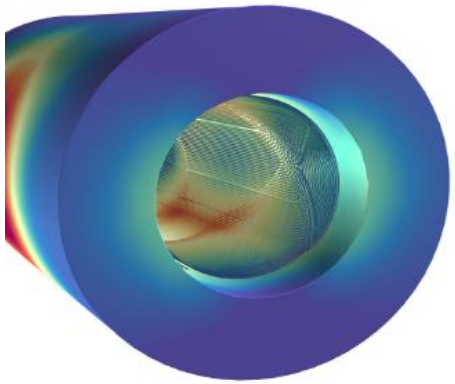


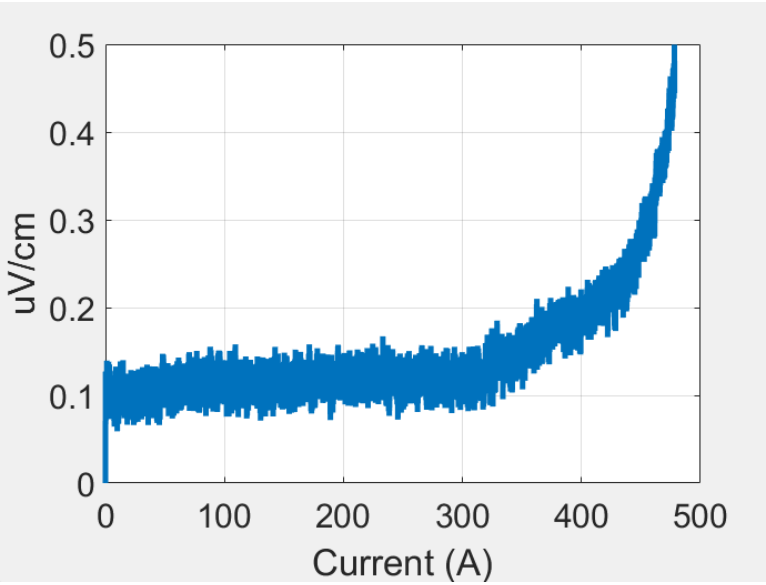
STAR Cable Coil Development with Direct Wind Technology











- **PI: Vikas Teotia**

Other HTS coils were also tested as a part of tech transfer to the next generation

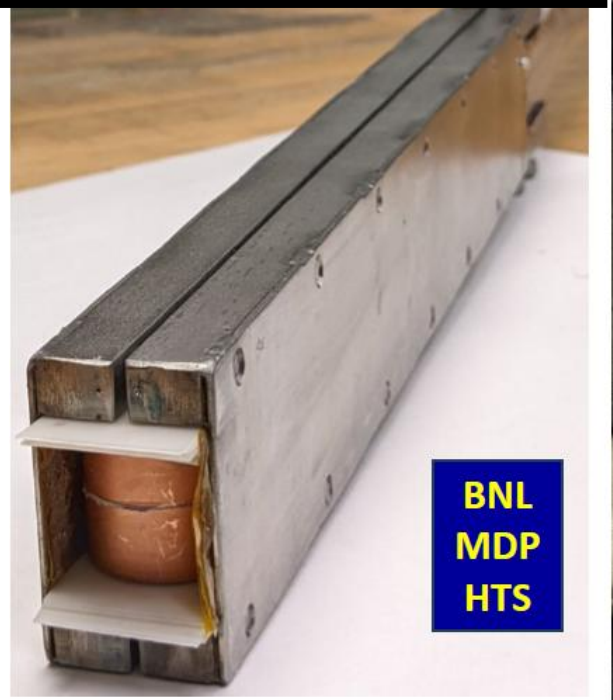
Expected Results in FY26

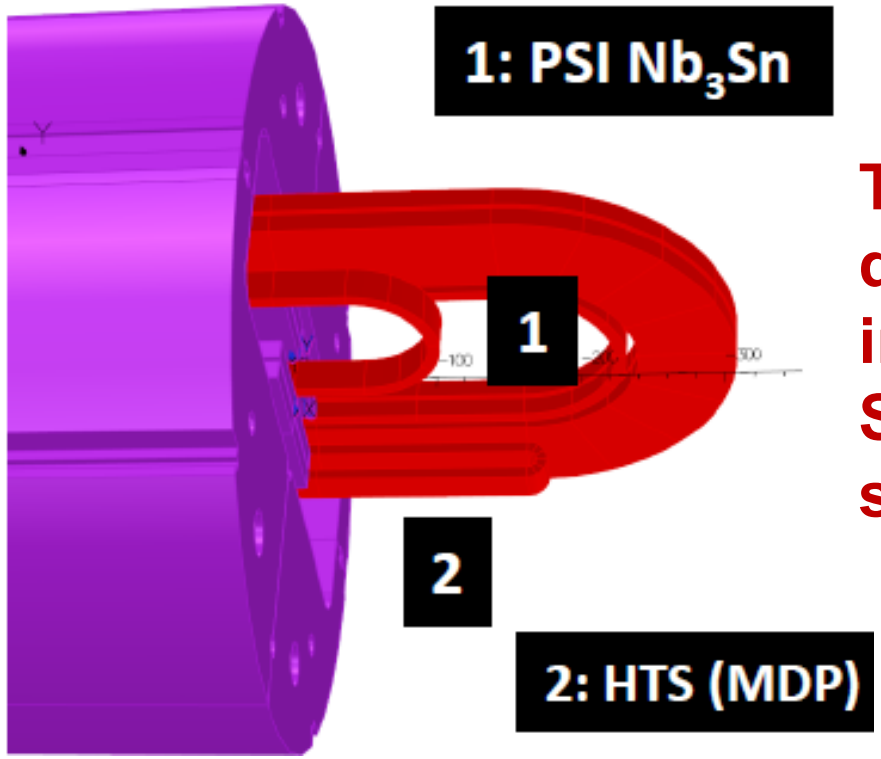
(continuing from the activities started earlier)

PSI and BNL Tests under MDP at CCTF in FY26 (BNL Person Responsible: Mithlesh Kumar)

- PSI: Wax impregnated Nb3Sn coil to study improvement in training performance
- BNL: HTS coil to study magnetization and to reach higher HTS/LTS hybrid field

BigBox 1 test completed
BigBox 2 testing soon

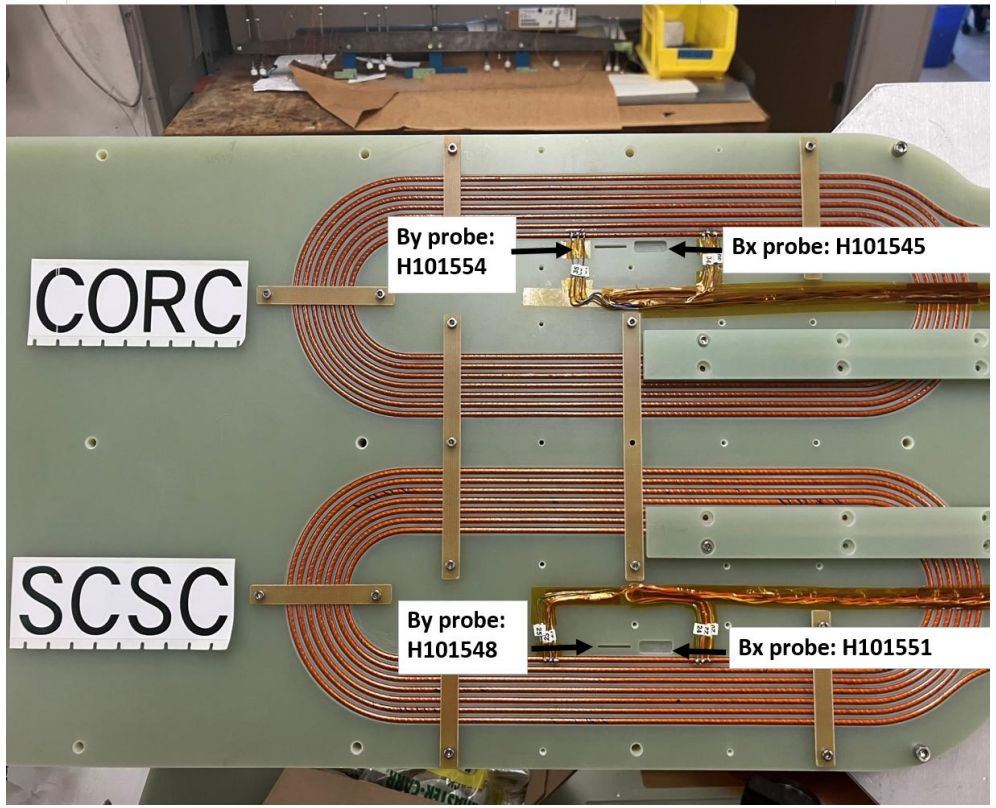




Two very different tests in one go. Significant savings.

➢ **Mithlesh manages all tests at the common coil test facility.**

US-Japan HEP and MDP Tests at CCTF in FY26



Testing in next few months

MDP will leverage this for high temperature HTS test

BNL Person Responsible: Febin Kurian

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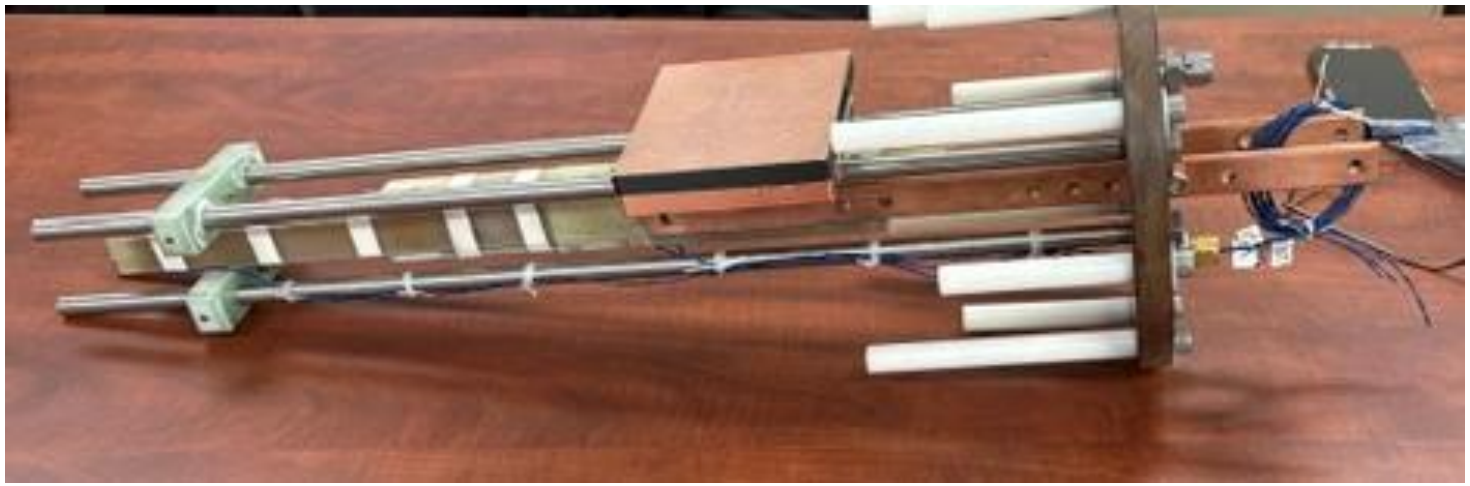
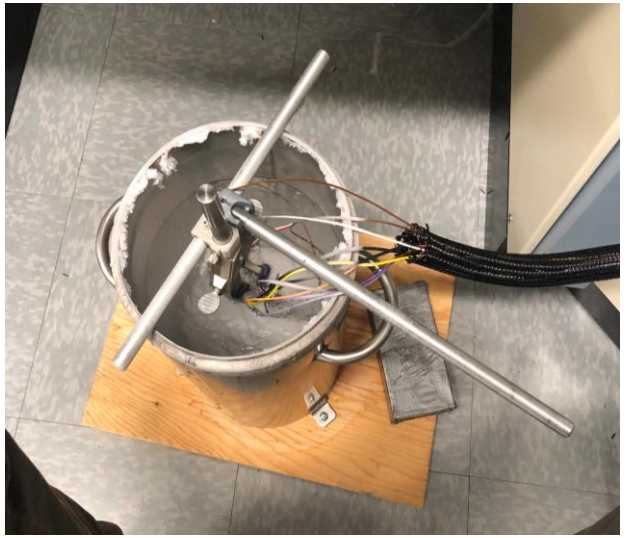
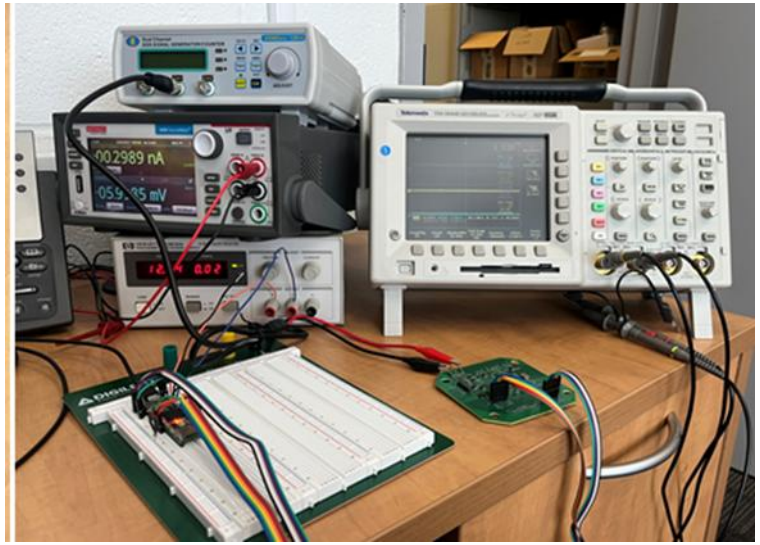
Advanced HTS QP and Cryo-electronics Demo in FY26

(a key area of HTS magnet technology development is quench protection)







- Low noise (μV) and high isolation (kV) voltage
- Major QP components stay in Dewar

- PI: Piyush Joshi with tech transfer to Mithlesh Kumar

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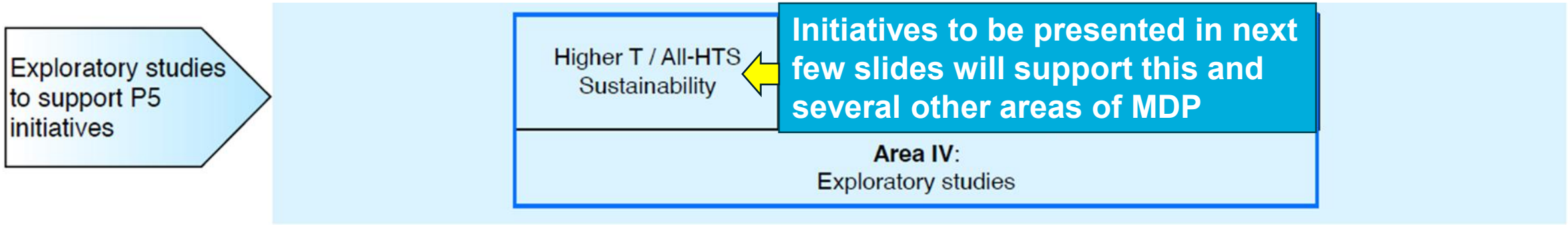
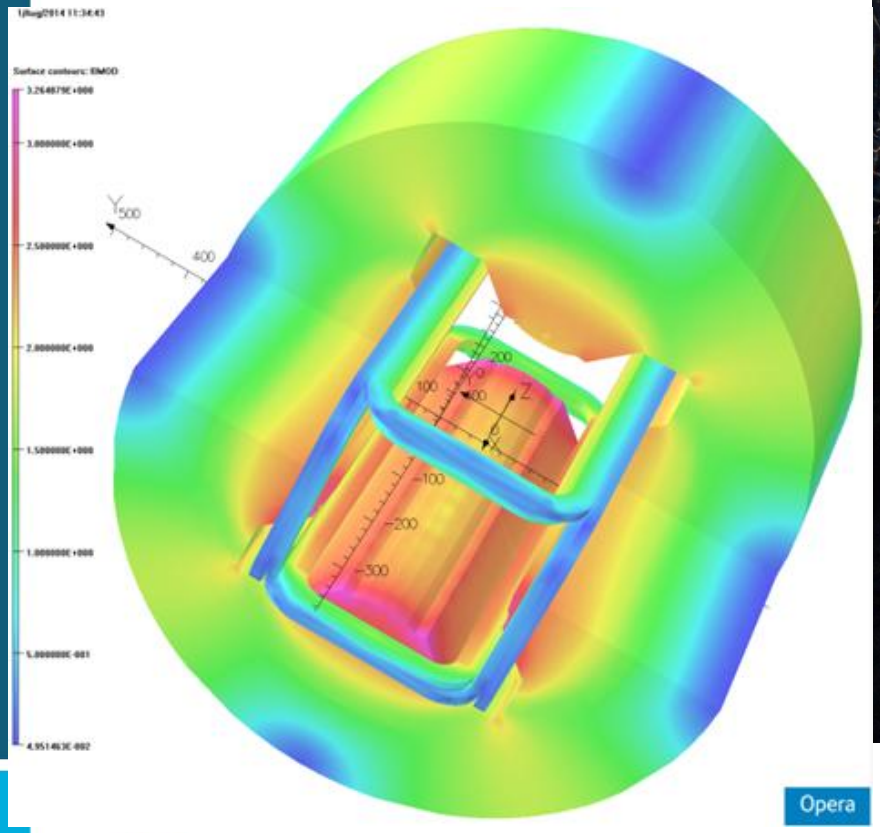
Expected Results in FY26-FY28

(includes higher temperature operation)



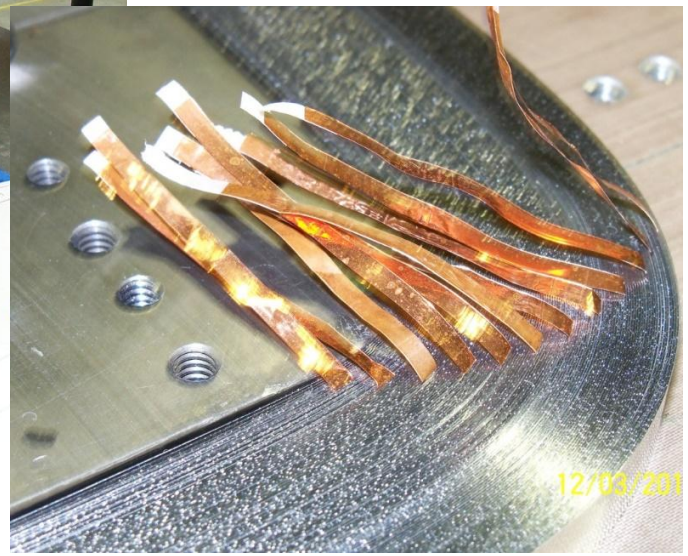
A proposed program leveraging existing hardware
(eight large expensive HTS coils made for FRIB R&D quad)

Magnetic Model of the HTS FRIB Quad



~9 km of 4 mm equivalent HTS tape used

Designed to operate at 30 K – 40 K



Well-instrumented with v-taps

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GARD HTS Magnet Development Programs using Large FRIB R&D Coils

➢ Start by measuring performance @77K and then field harmonics measurements

With yoke testing in ~2 months

Harmonic measurements without yoke in ~6 months

✓ Vikas Teotia and Andy Marone will lead the task of harmonic measurements

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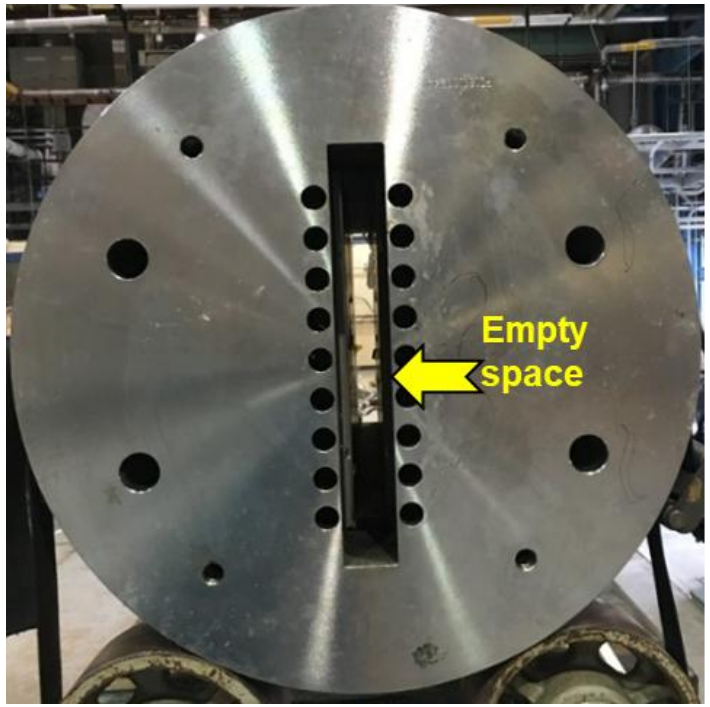
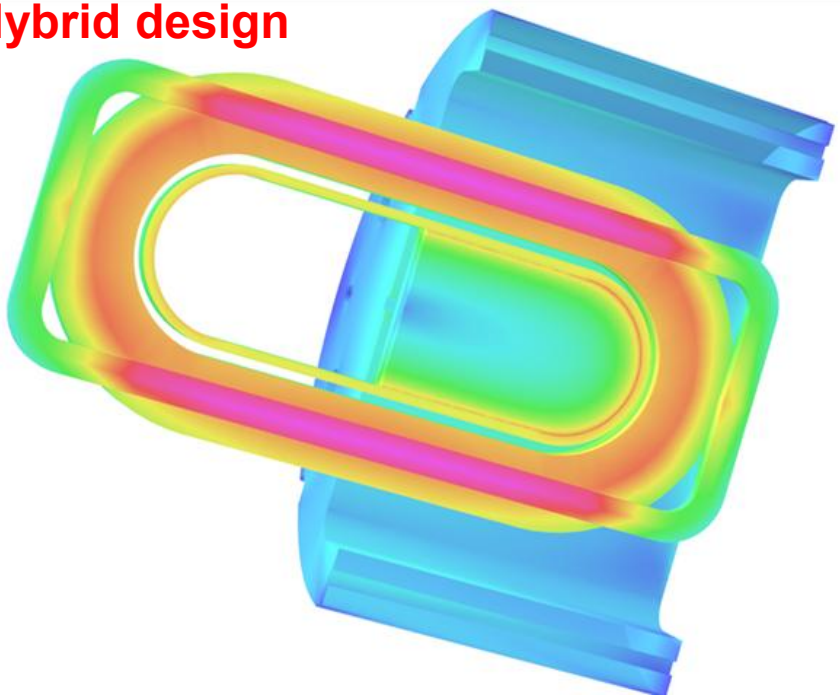
HTS/LTS Hybrid and Stand alone HTS Test with Large FRIB Coils

- ~14 T HTS/LTS Hybrid configuration
- ~7 T all HTS (initial MDP target: 5 T)

- High temperature operation to be performed
- Cold electronics to be tested in real magnets

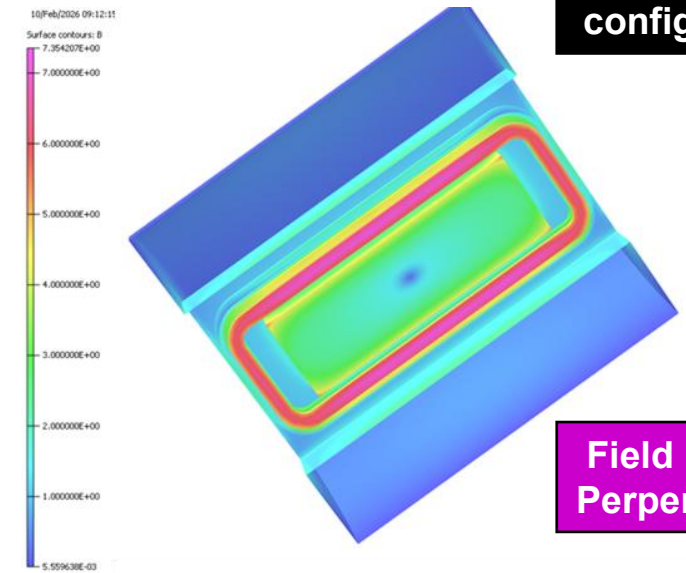


Hybrid design



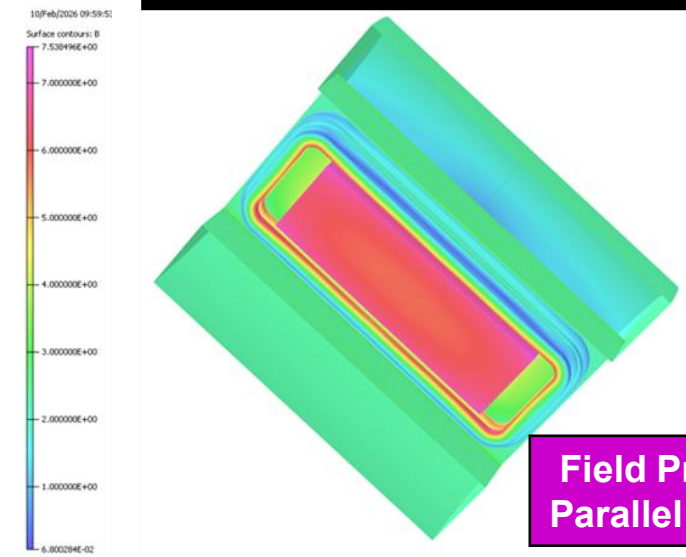
Stand alone designs

common coil configuration



Field Perpendicular

Single aperture dipole configuration



Field Primarily Parallel

This will involve significant design, engineering and construction with many people participating.

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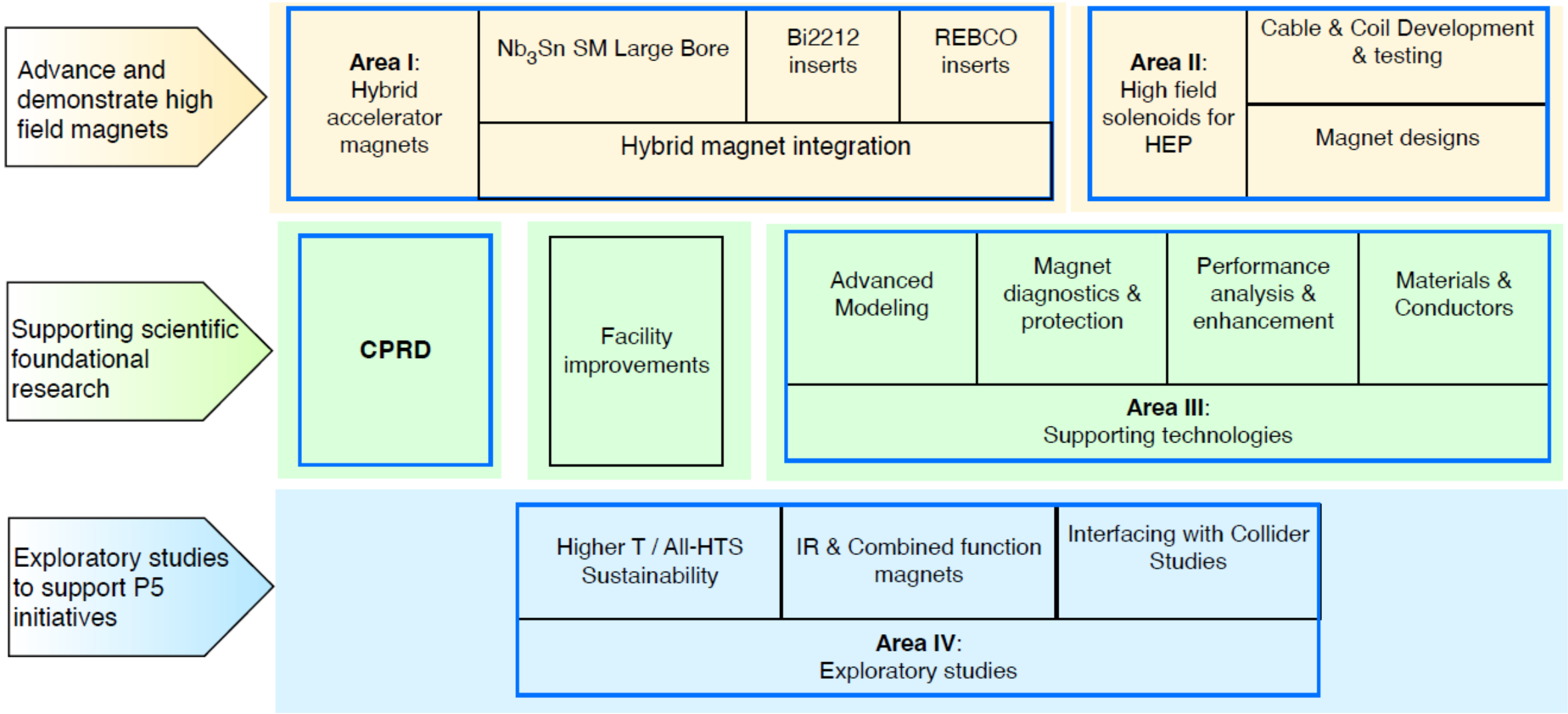
SUMMARY

- BNL has made many contributions that are relevant to the ongoing R&D. A few mentioned in this presentation (common coil, HTS technology).
- A plan and vision was presented that leverages unique BNL strengths and existing hardware to start making important contributions soon.
- Specific key deliverable have been mentioned to measure progress in short run, along with a vision for longer term.
- The program is well aligned with MDP and its stated initiatives.
- Plan to transfer IP and the technology to the next generation is in place.

Extra Slides

Figure 3. Program structure with four dedicated areas.



BNL is participating in all four areas of the MDP roadmap

Other key technologies (with persons expected to lead them)

- **Direct wind HTS cable magnets and field quality measurements**
  - ➢**Vikas Teotia (with guidance from Brett Parker)**
- **Advance quench protection (including cold electronics)**
  - ➢**Mithlesh Kumar (with guidance from Piyush Joshi)**
- **High temperature operation of HTS magnets (US-Japan)**
  - ➢**Febin Kurian (with guidance from Ramesh Gupta)**
- **Magnet engineering**
  - ➢**New engineers (with guidance from Mike Anerella)**
- **….**

HTS Coil and Magnet Technology

- **Apart from several major contributions to the HTS magnet technology, BNL has a valuable inventory of large HTS coils.**
- **They can be repurposed for a lower cost, high impact R&D program in a relatively short period of time.**
- **One major area of interest is higher temperature operation.**
- **Following slides presents a program that leverages the existing hardware (particularly large HTS coils, expensive and take time to make), expertise in quench protection and unique facility.**

Increasing BNL Visibility and Participation

➢ More regular communication with stakeholders

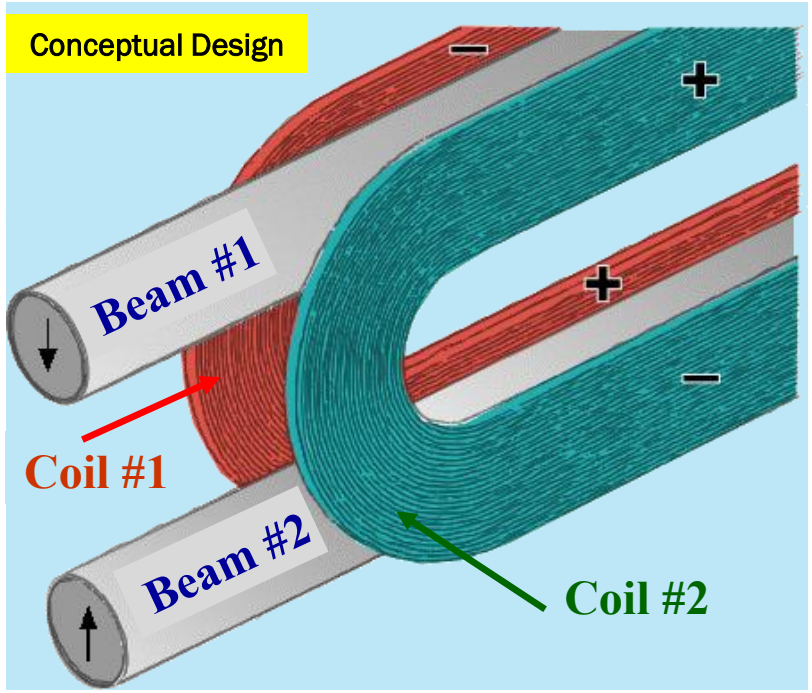
Several papers/presentations at:

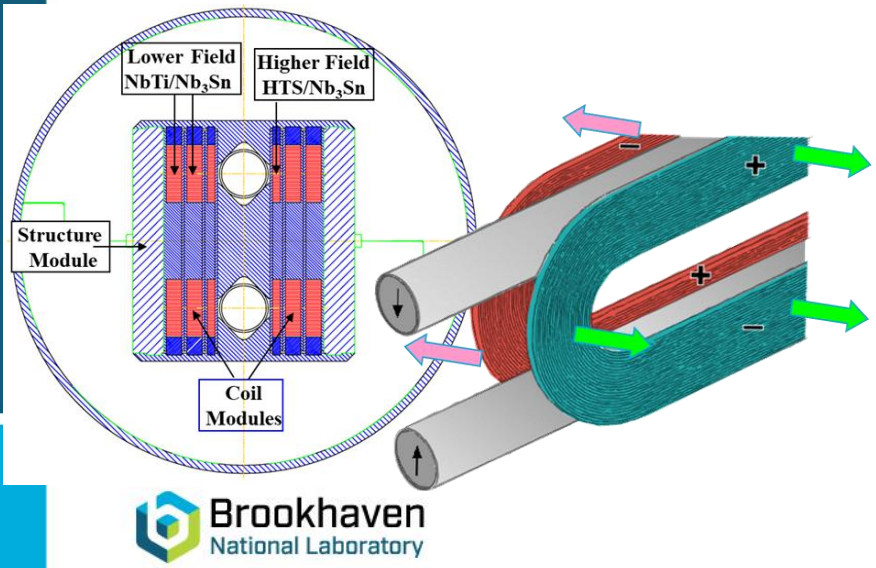
- MDP annual meeting: May 27-29, 2026, at Fermilab
- 2026 Applied Superconducting Conference: Pittsburg Sept 6-11, 2026

Key Deliverable of the Proposed GARD Initiative

- **~7 T all HTS dipole and ~14 T HTS/LTS Hybrid Dipole**
  - Surpass near term MDP goals of 5 T (that too with large coils)
- **Different configurations (including high field hybrid dipole demo)**
  - 2-in-1 common coil & single aperture (field parallel vs perpendicular)
- **Field quality measurements in HTS magnets**
  - Important for considering HTS for accelerator quality magnets
- **Quench Protection of HTS Magnets**
  - A major issue for HTS Magnets
- **HTS magnets operating at higher temperature (FES and HEP/NP)**
  - Significant discussion on reducing cryogenic and operational cost

Appeal of 2-in-1 Common Coil Design for High Field Collider Dipoles





- **Simple 2-d geometry for 2-in-1 collider dipoles**
- **Large bend radii, determined by the separation between the two borees rather than the bore itself**
- **Allows use of most HTS cables, including high current fusion cables requiring large bend radii**
- **Allows both "React & Wind" and "Wind & React" Technologies for Nb_3Sn and HTS**
- **Easier incorporation of stress-managed structure**
- **Allows large horizontal displacement of the entire coil as a whole, without much internal strain**
- **Modular design for mixing HTS, Nb_3Sn NbTi in hybrids, and for lower cost, rapid-turn-around R&D**

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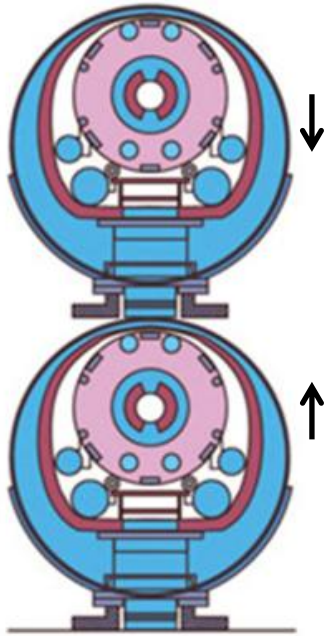
Notable BNL Contributions to HEP Magnet Program
(select designs and technologies still playing a major role)

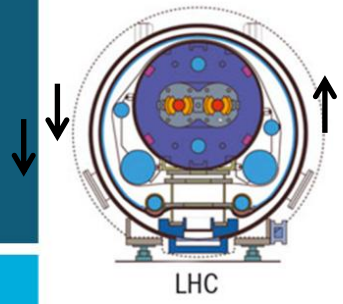
1. **Common coil 2-in-1 design for collider magnets**
   - **Invented at BNL. Used in US vlhc proposal for 100 TeV X 100 TeV collider**
   - **Magnets based on this design built at BNL, LBNL and FNAL soon after**
     - ✓ **BNL: Many HTS & Nb_3Sn dipoles (highest field ever in "React & Wind")**
   - **Baseline for SppC proposal at IHEP (many magnets built and tested)**
   - **Being used at CIEMAT, PSI and CERN magnet R&D for FCC-hh in Europe**
2. **Common Coil Test Facility: Unique facility for HEP and FES high field R&D**
3. **HTS coils and technologies**
   - **BNL- first lab to carry out major HTS magnet R&D with multiple programs**
   - **Created several records at that time: solenoid 16 T@4K (proposal was for 12 T), SMES 12.5T @ 27 K, HTS/LTS hybrid dipole 12.3 T, FRIB HTS Quad**
   - **Advanced quench protection technology (now cold electronics, as well)**

Common Coil Design for Collider Magnets

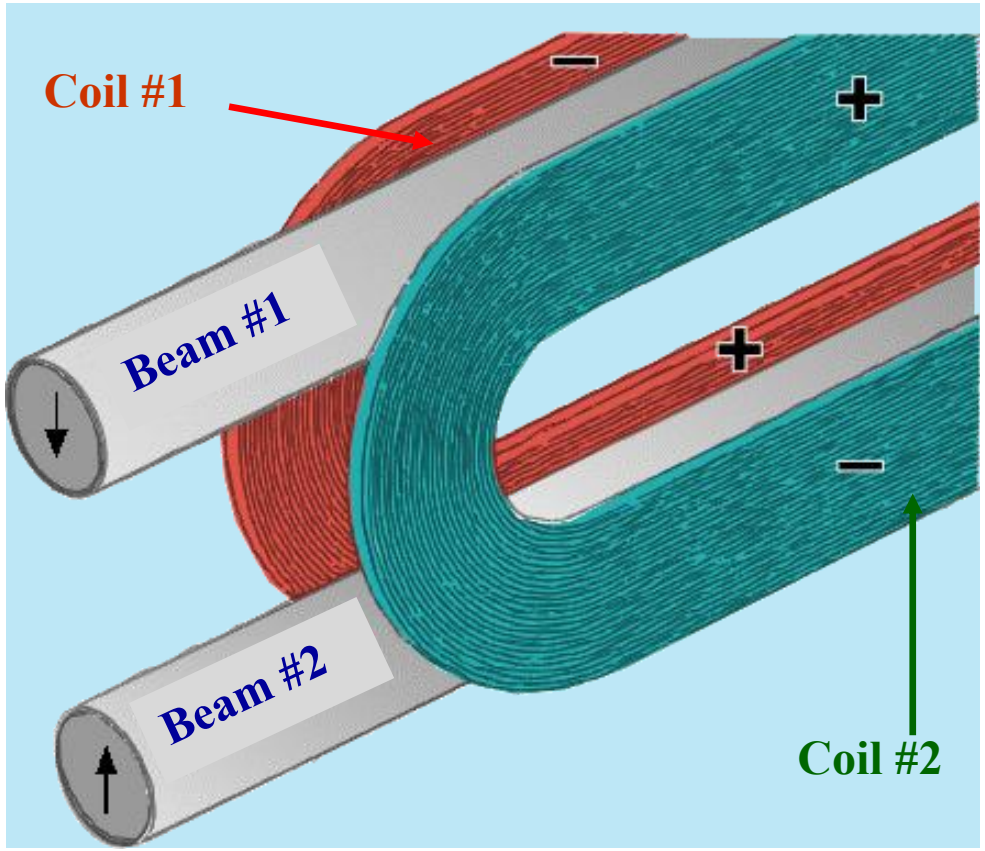
(invented @BNL,used worldwide; European labs in next slide)



SSC



LHC



Main Coils of the *2-in-1* *Common Coil Design*

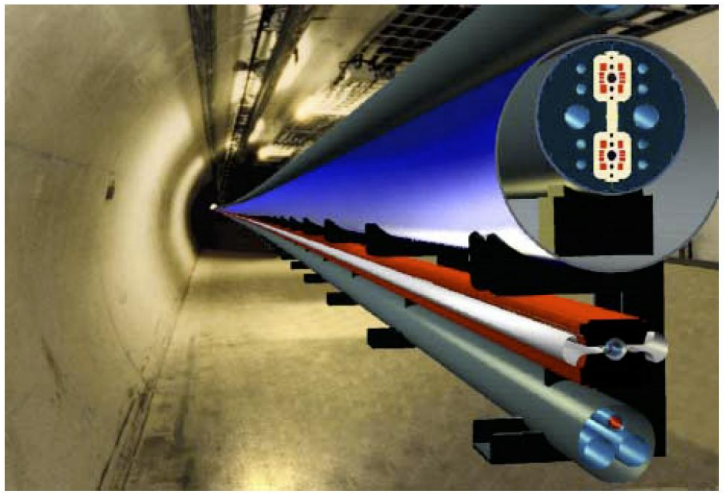
Very Large Hadron Collider

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

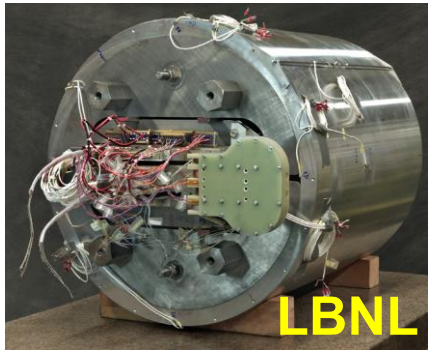
Design Study for a Staged Very Large Hadron Collider

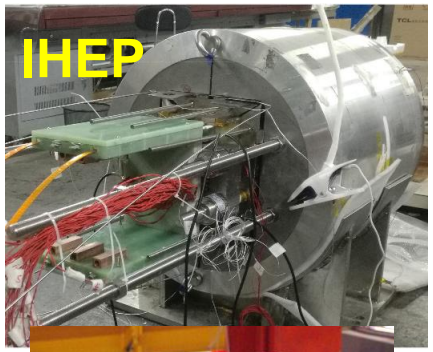
Report by the collaborators of
The VLHC Design Study Group:

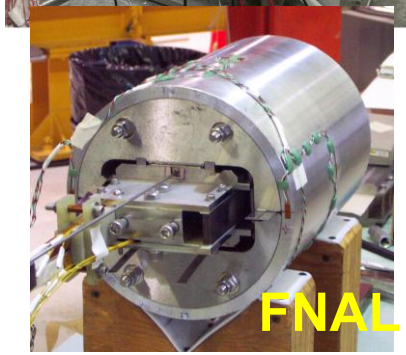
Brookhaven National Laboratory
Fermi National Accelerator Laboratory
Laboratory of Nuclear Studies, Cornell University
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
Stanford University, Stanford, CA, 94309



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







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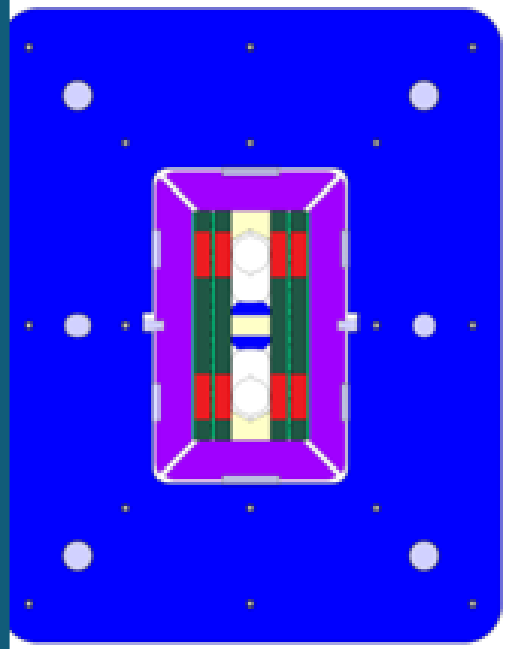
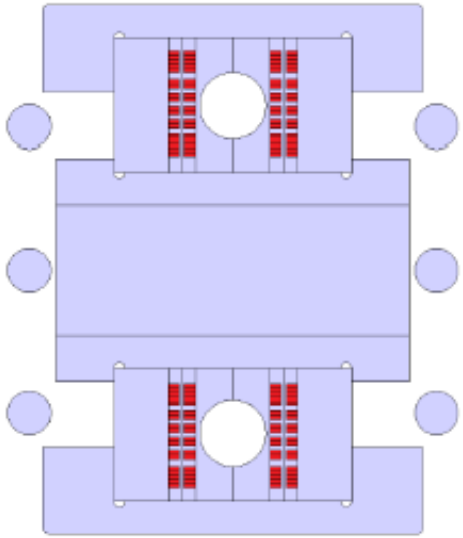
Common Coil Magnet Programs in Europe
(in addition to the R&D programs in US and Asia)

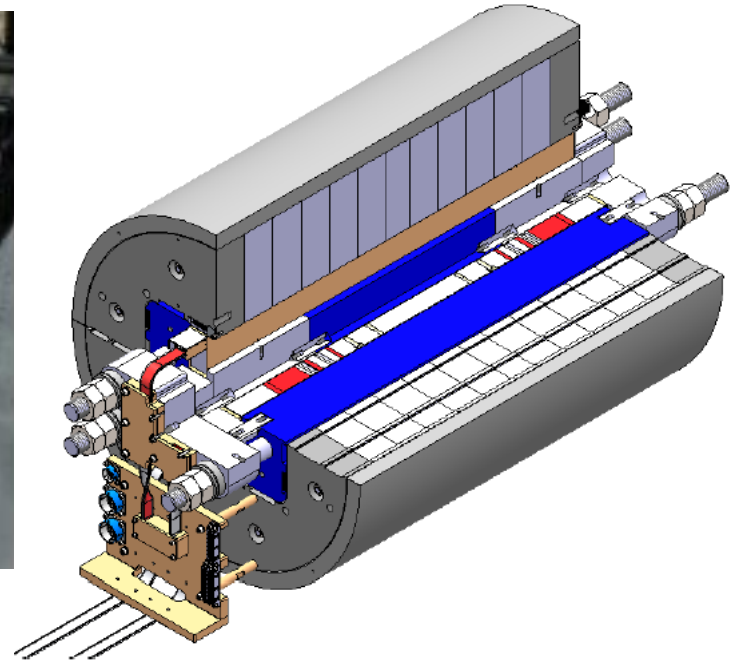
CERN - ROCCO



PSI - SMCC

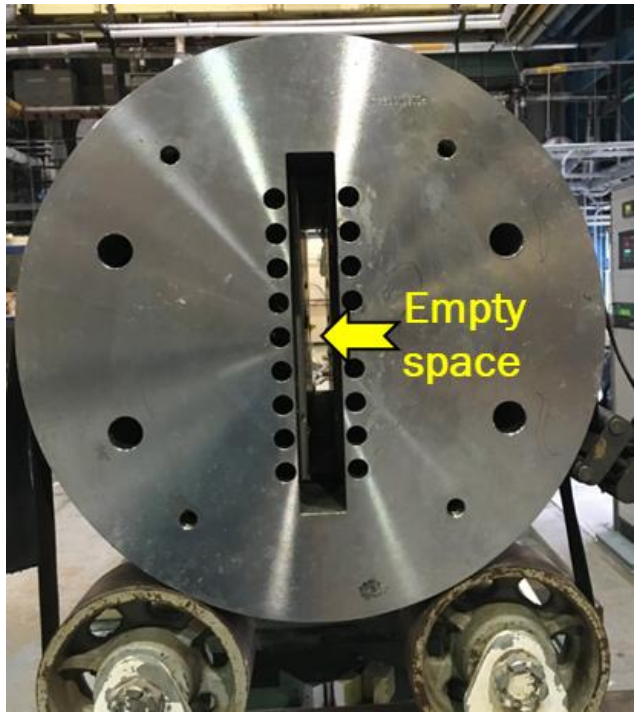


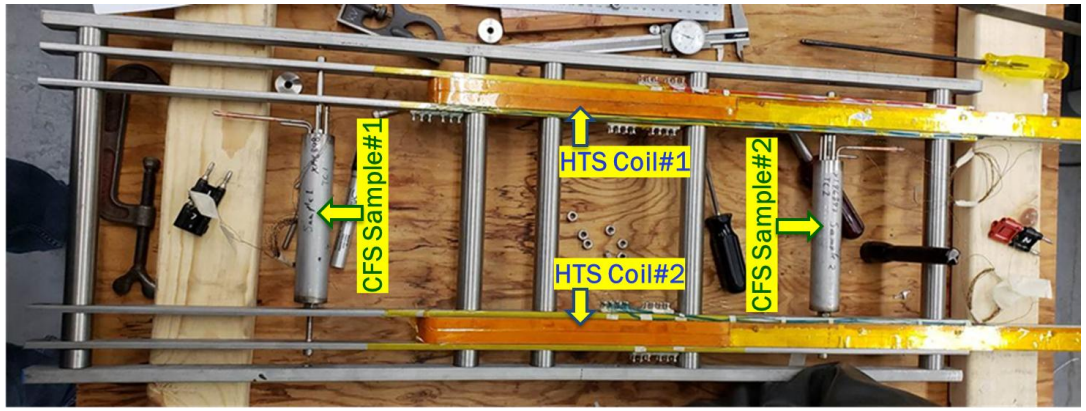
CIEMAT
ISSAC & DAISY

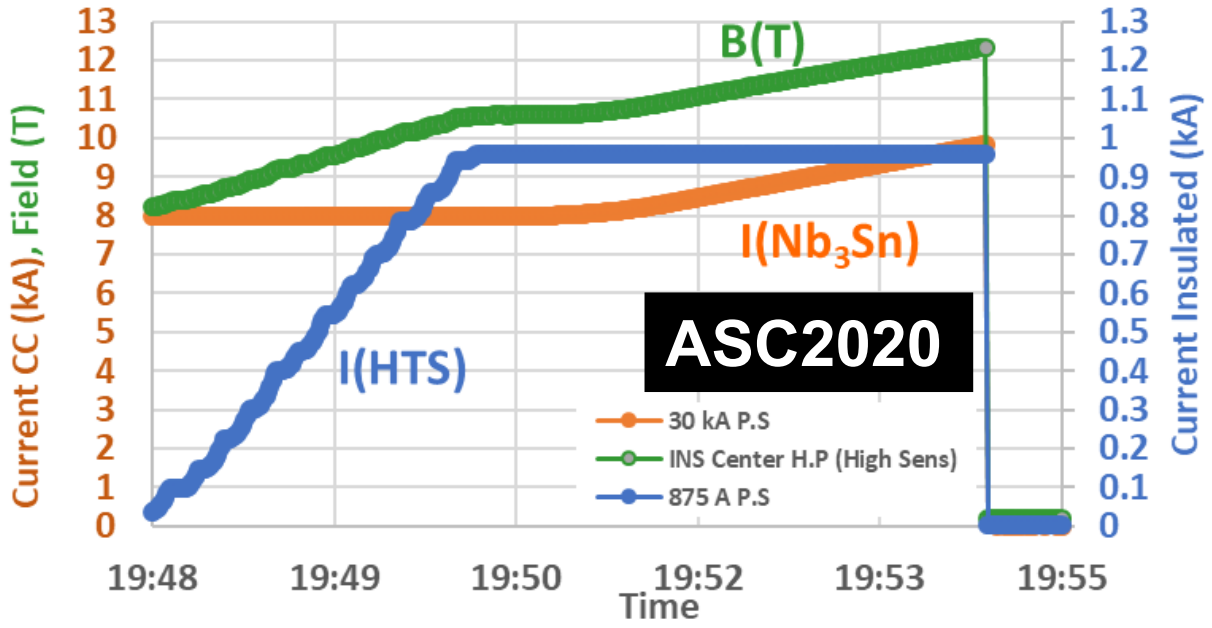


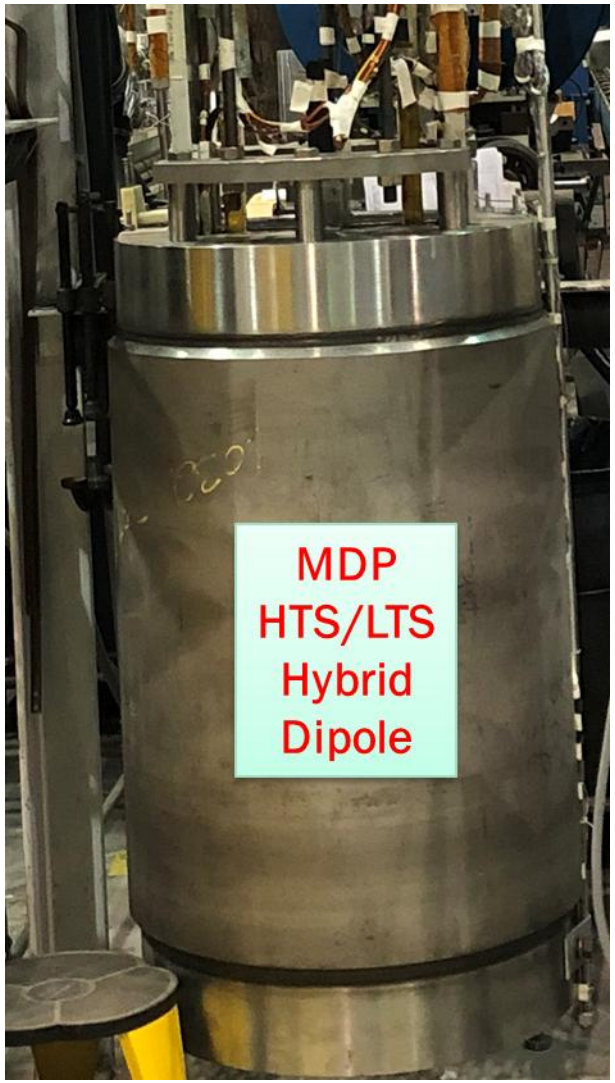
BNL has and can continue to play in the common coil design and guidance

A Record 12.3 T HTS/LTS Hybrid Dipole (still a record)









Common coil Nb_3Sn dipole with large open space to insert HTS coils

HTS: (~3 T) + LTS: (9.3 T)
Total Hybrid: 12.3 T

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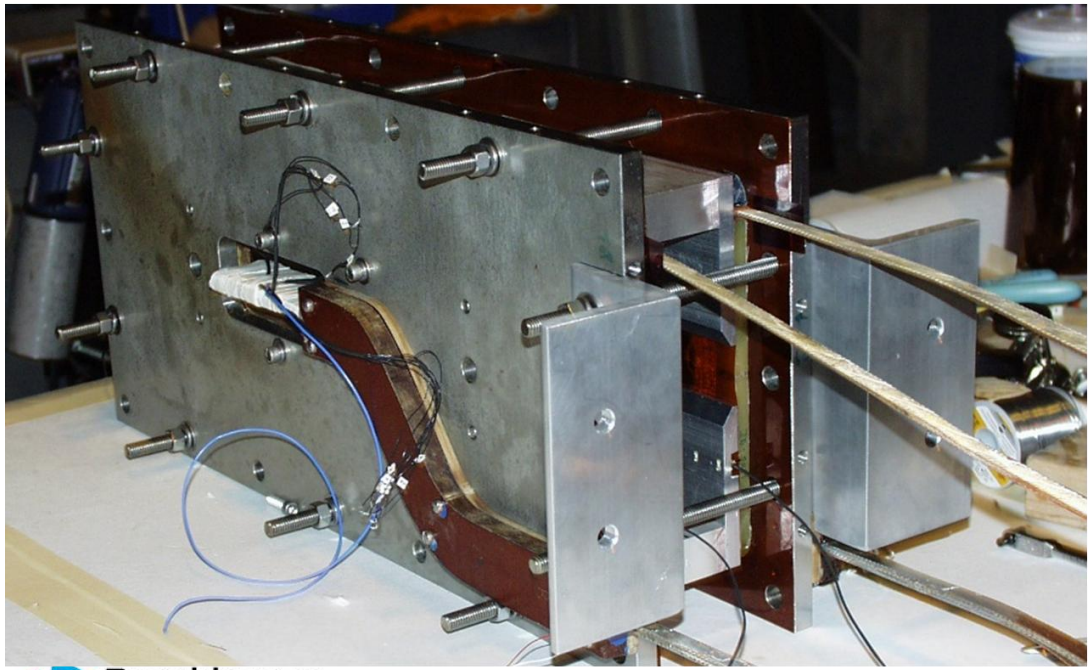
Common Coil Magnet Program at BNL

- **BNL has made a series of LTS (NbTi and Nb_3Sn), HTS (Bi2223, Bi2212 and ReBCO) and HTS/LTS hybrid common coil dipoles.**
- **BNL still holds records for the highest field (10.2 T) "React & Wind" Nb_3Sn and HTS/LTS hybrid (12.3) dipoles based on any design.**

✓ **BNL can continue to contribute and collaborate with CERN/Europe.**



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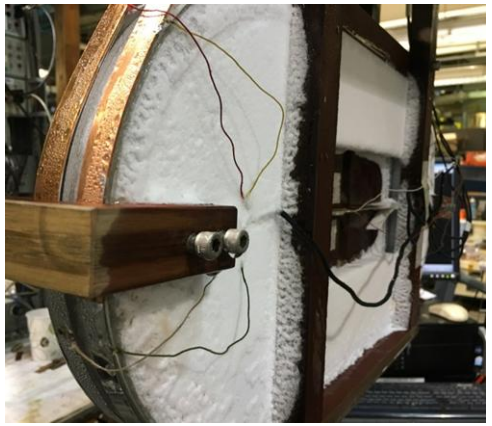
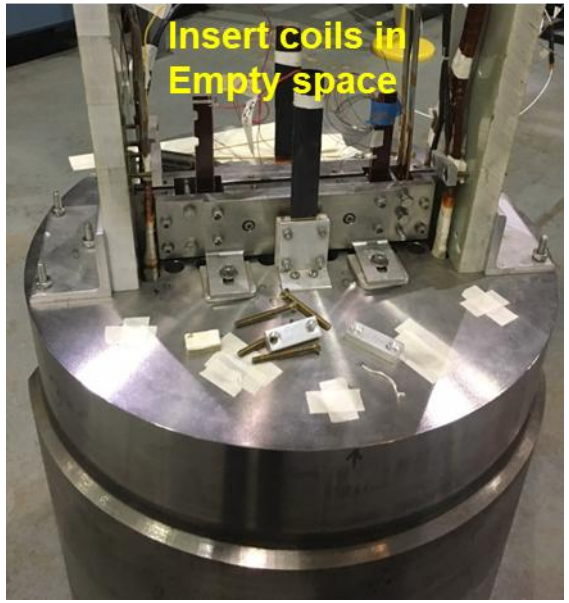
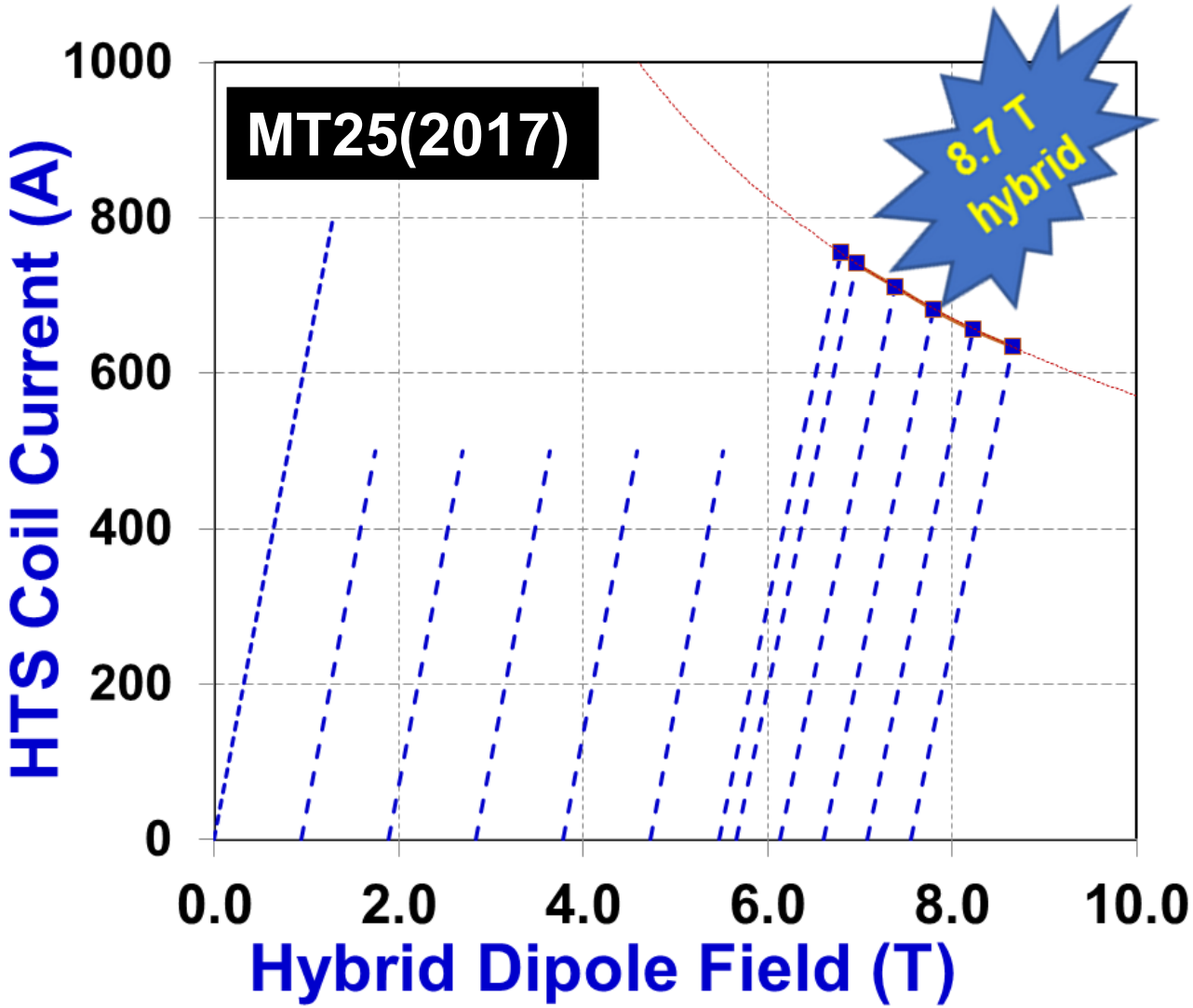
Record HTS/LTS Hybrid Dipole (2016)





REBCO (HTS) and Nb3Sn (LTS) Coils



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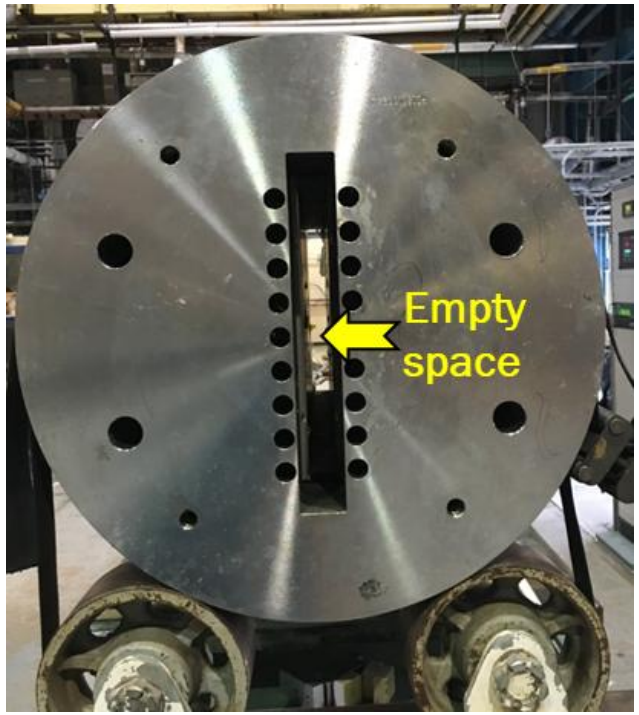
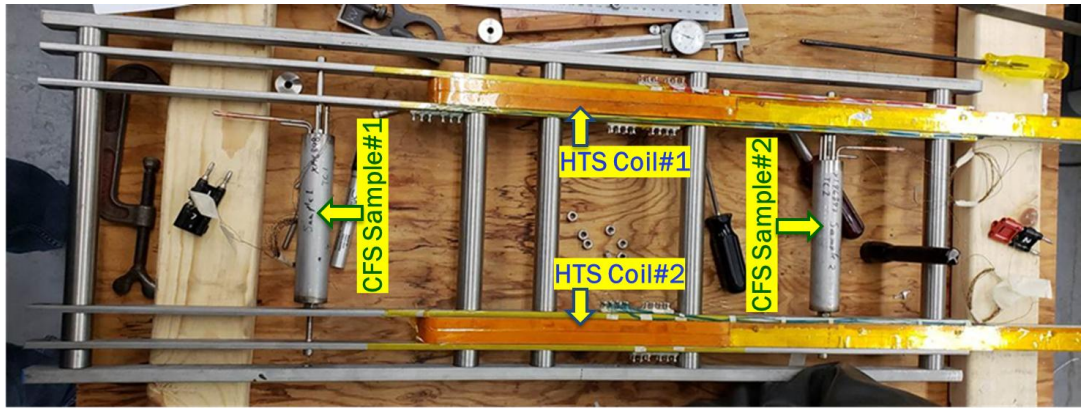
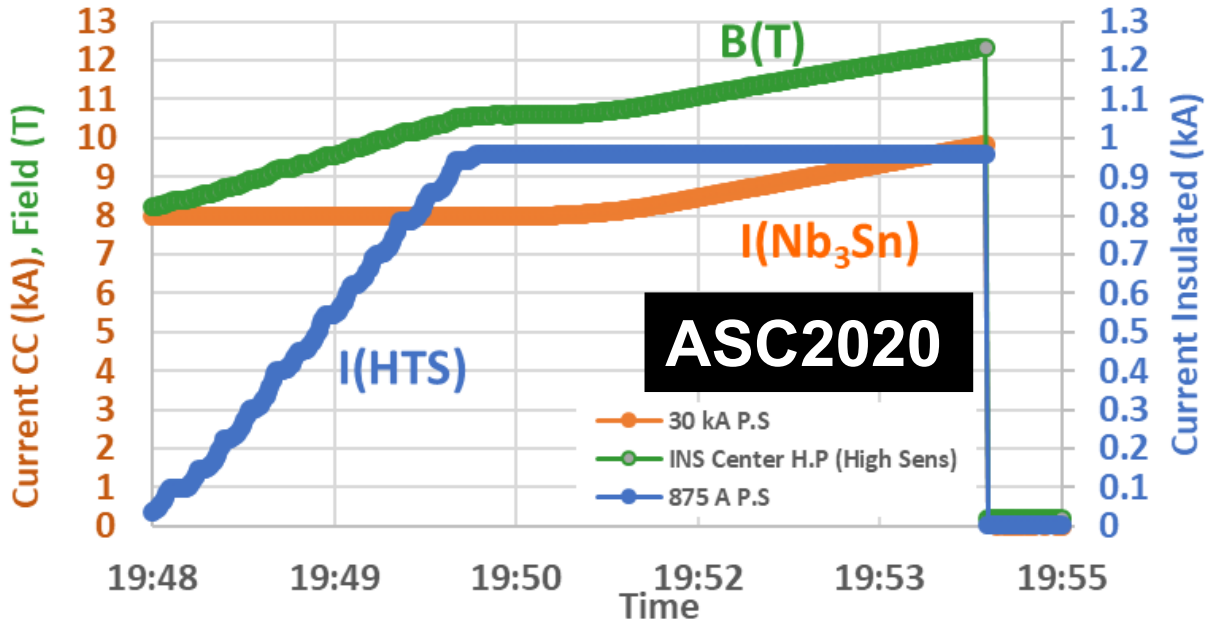
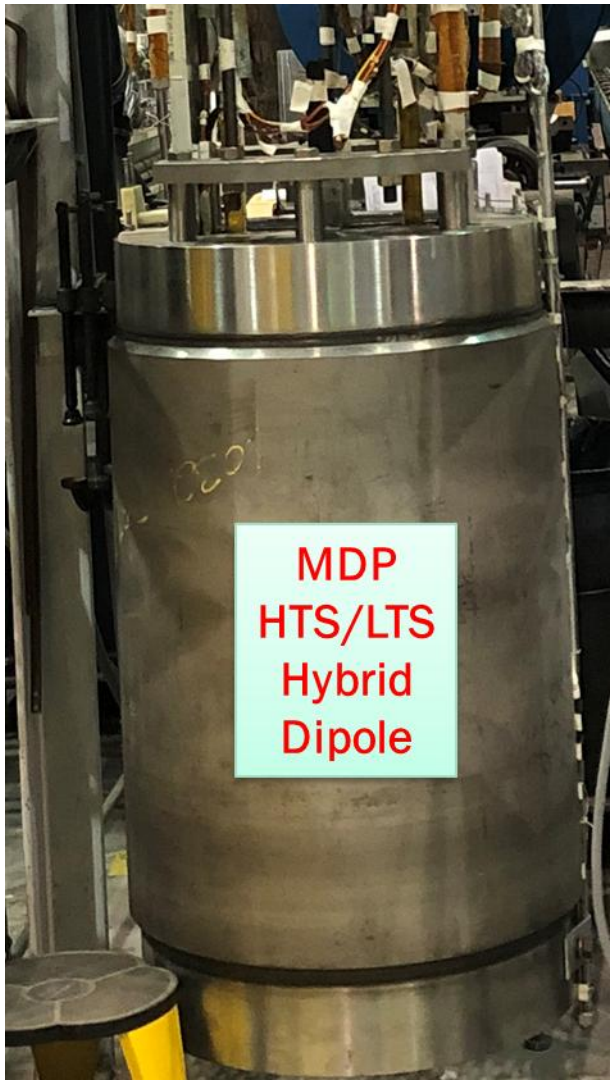
A Record 12.3 T HTS/LTS Hybrid Dipole (still a record)









Common coil Nb_3Sn dipole with large open space to insert HTS coils

HTS: (~3 T) + LTS: (9.3 T)
Total Hybrid: 12.3 T

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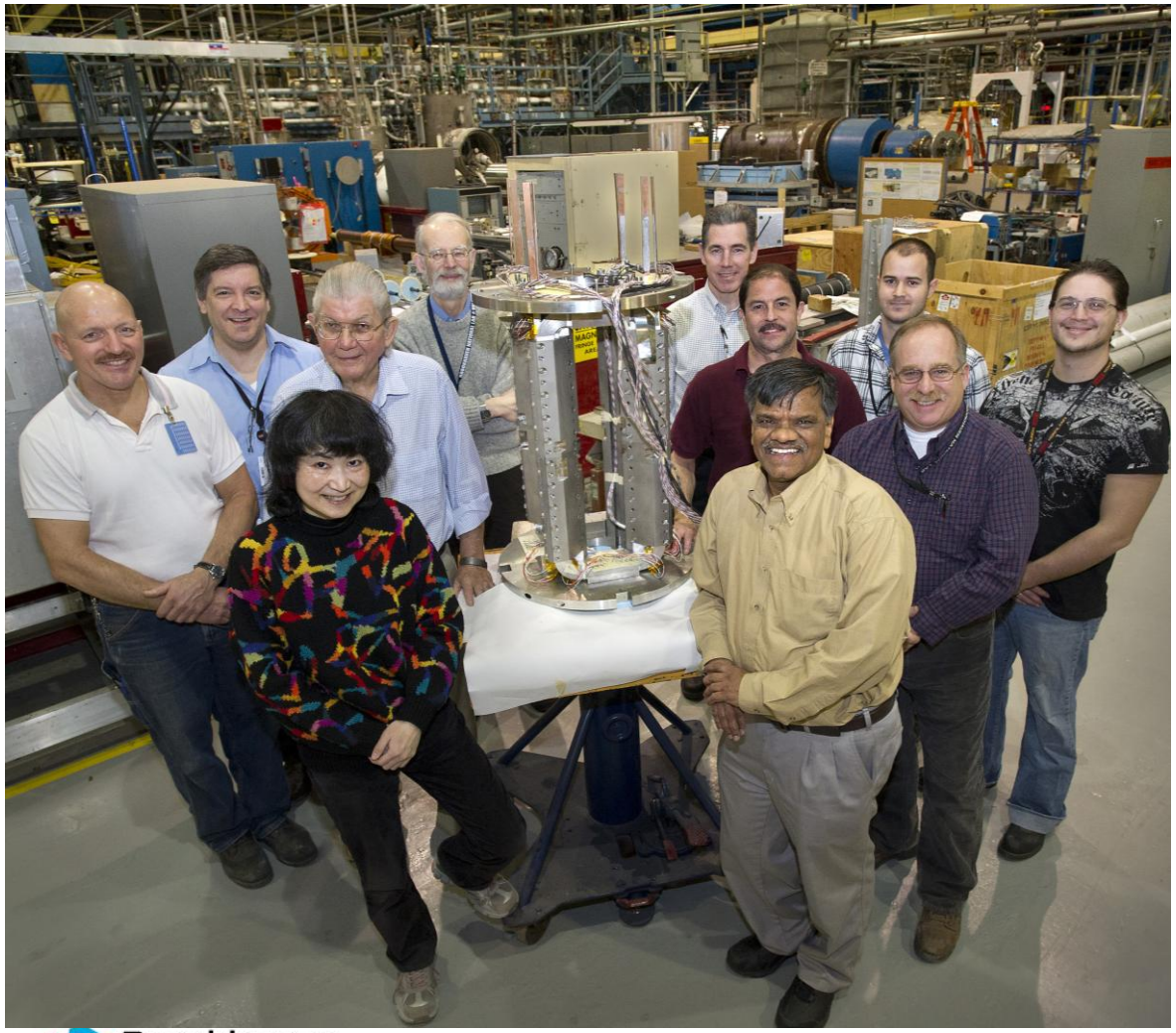
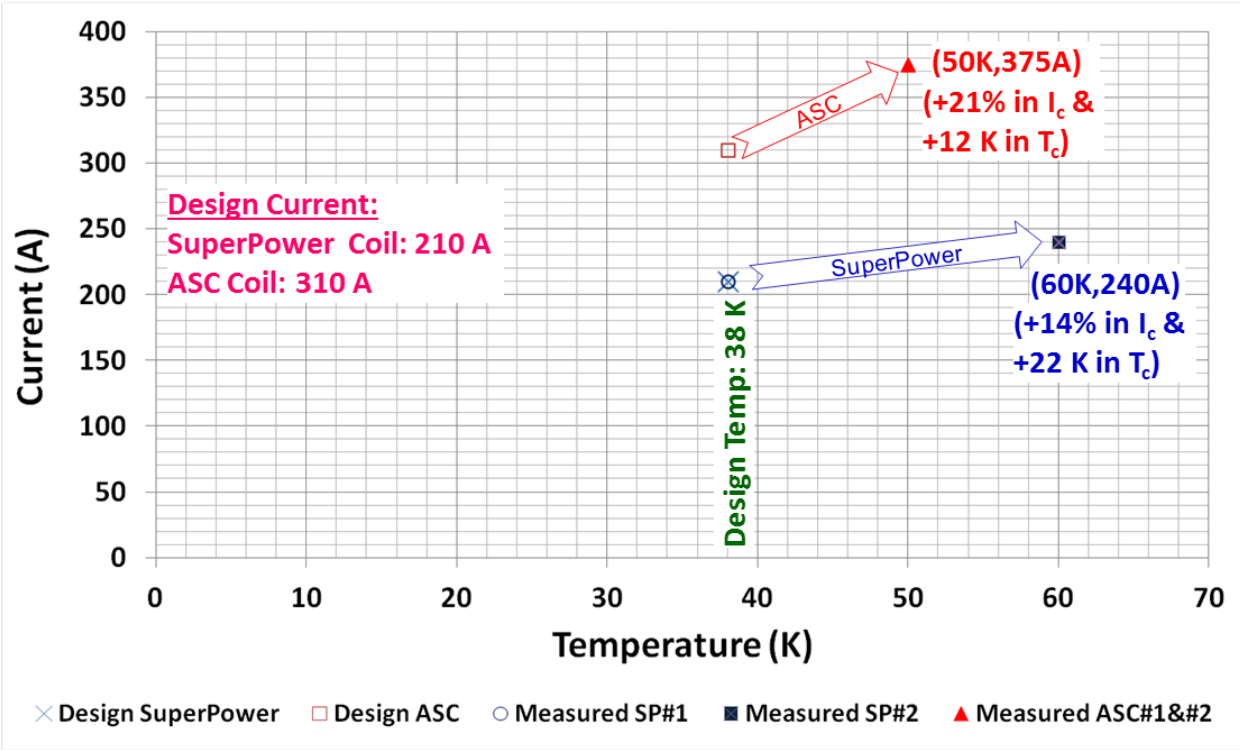
2nd Generation FRIB HTS Quad with ReBCO Tape

(a record gradient HTS quadrupole for high temperature operation)



Large Temperature Margins (only possible with HTS)



FRIB: Facility for Rare Isotope Beams

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High Field Common Coil Design Collaboration

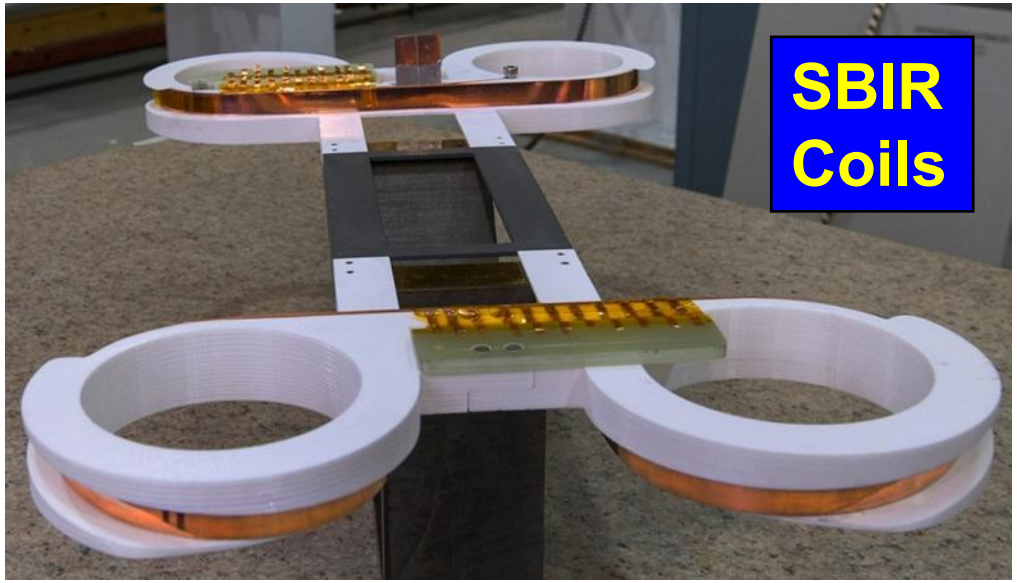
- As a part of MDP program on comparative studies of various design options on 20 T dipole, BNL led the effort on the common coil design.
- BNL developed a high field quality EM design with a stress-managed structure. BNL also started work on the preliminary engineering design.
- BNL joined the international collaboration on the common coil design. Now CERN is managing High Field Magnet (HFM) program in Europe.

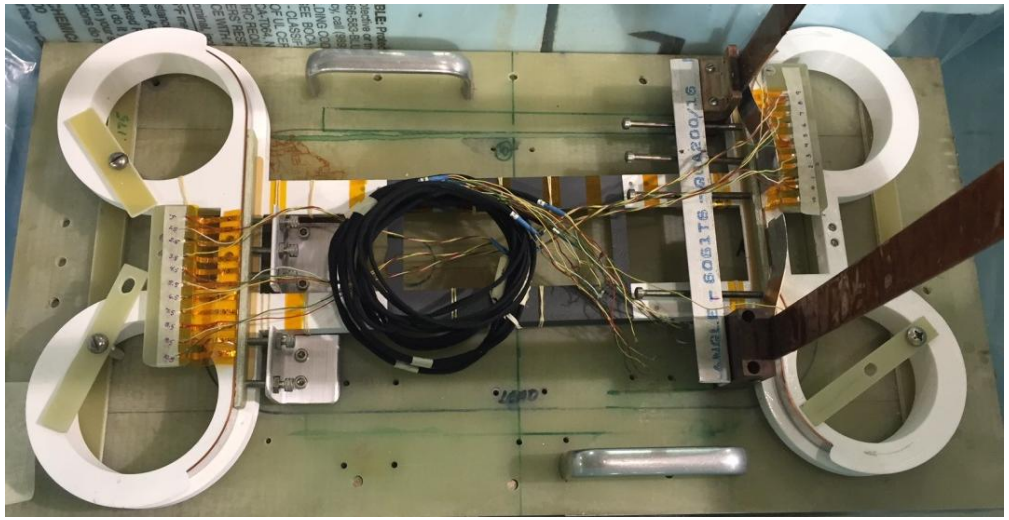
➢ **Leveraging our expertise and past contributions to the common coil design, we can and should play a significant role in the development of the common coil design as a part of the GARD program and join the collaboration with our European colleagues.**

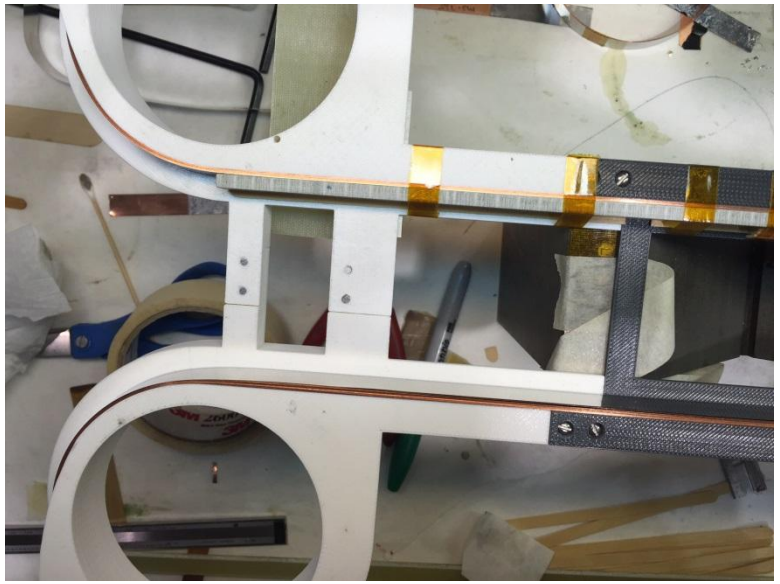
Overpass/Underpass Design with HTS Coils

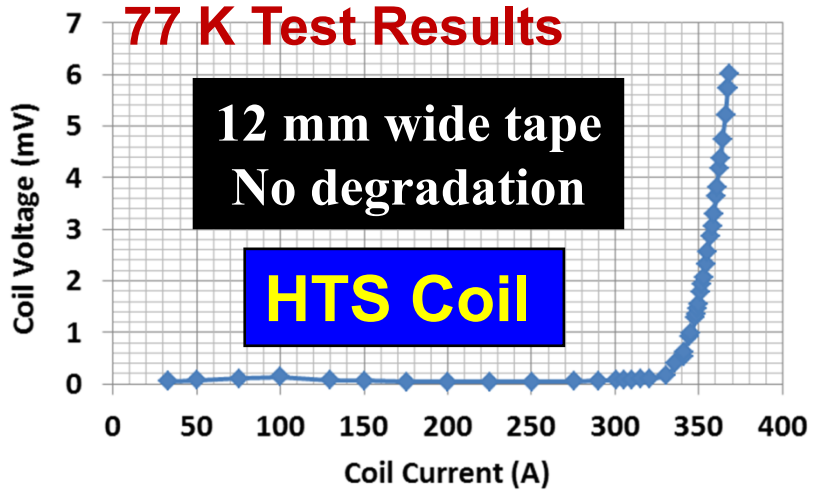
Another Innovative Design from BNL developed at BNL under previous GARD program. Followed by two SBIRs- e2P & PBL

Adapted at CERN for its earlier 20 T HTS program. Coils built & tested CERN









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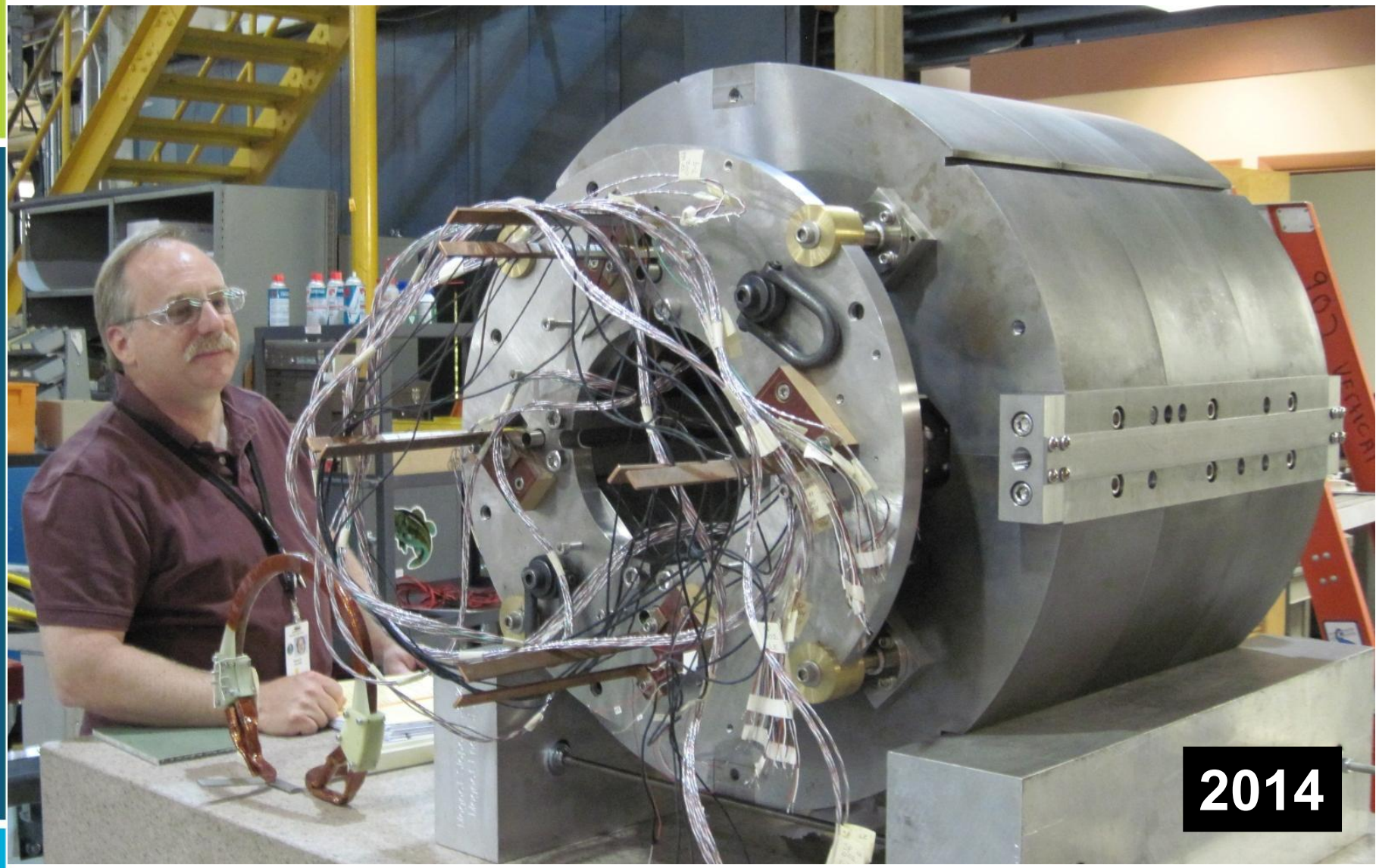
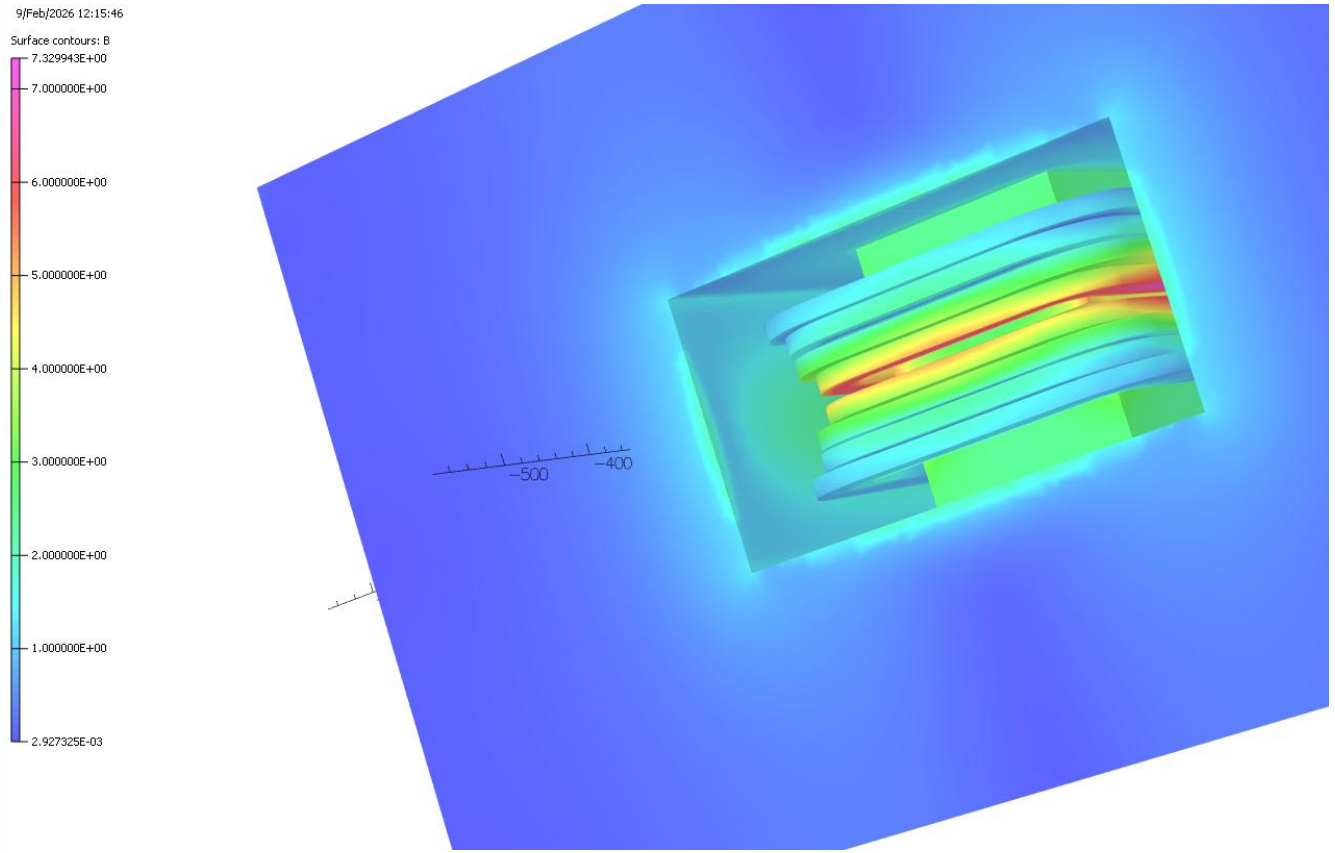
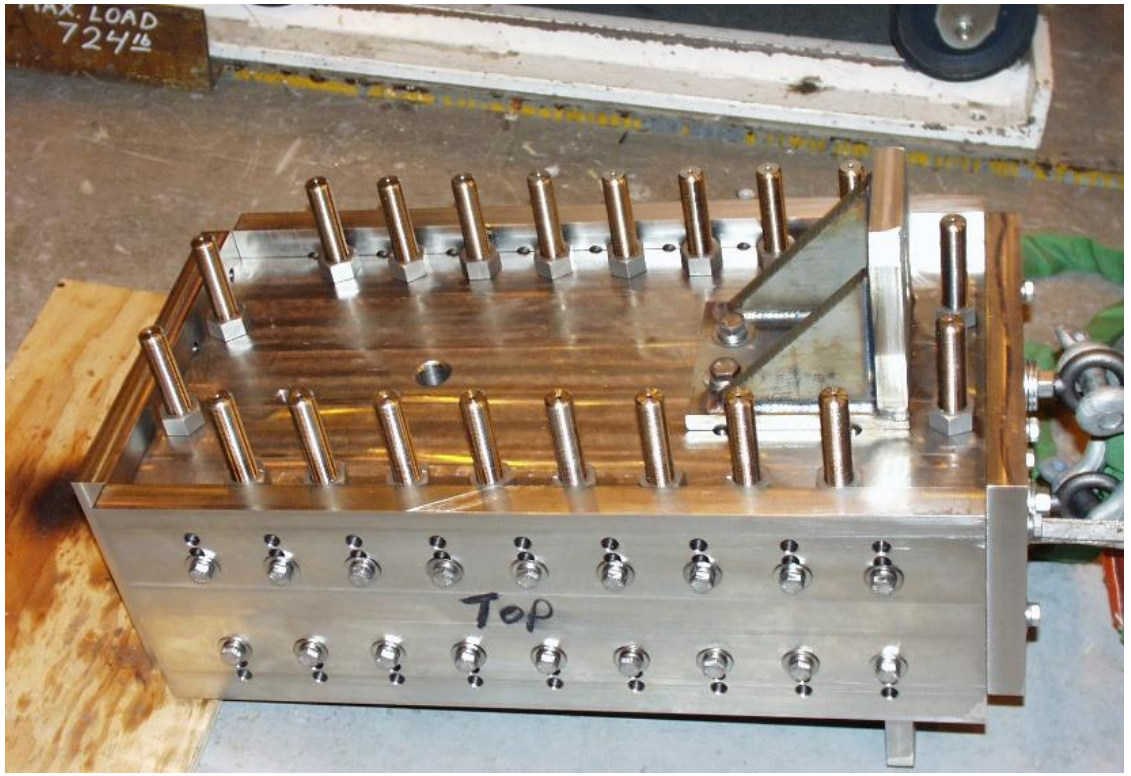
Large HTS Coils from FRIB R&D Quad can be used for GARD



Low-cost, Flexible Structure for Different Configurations

Design using FRIB coils

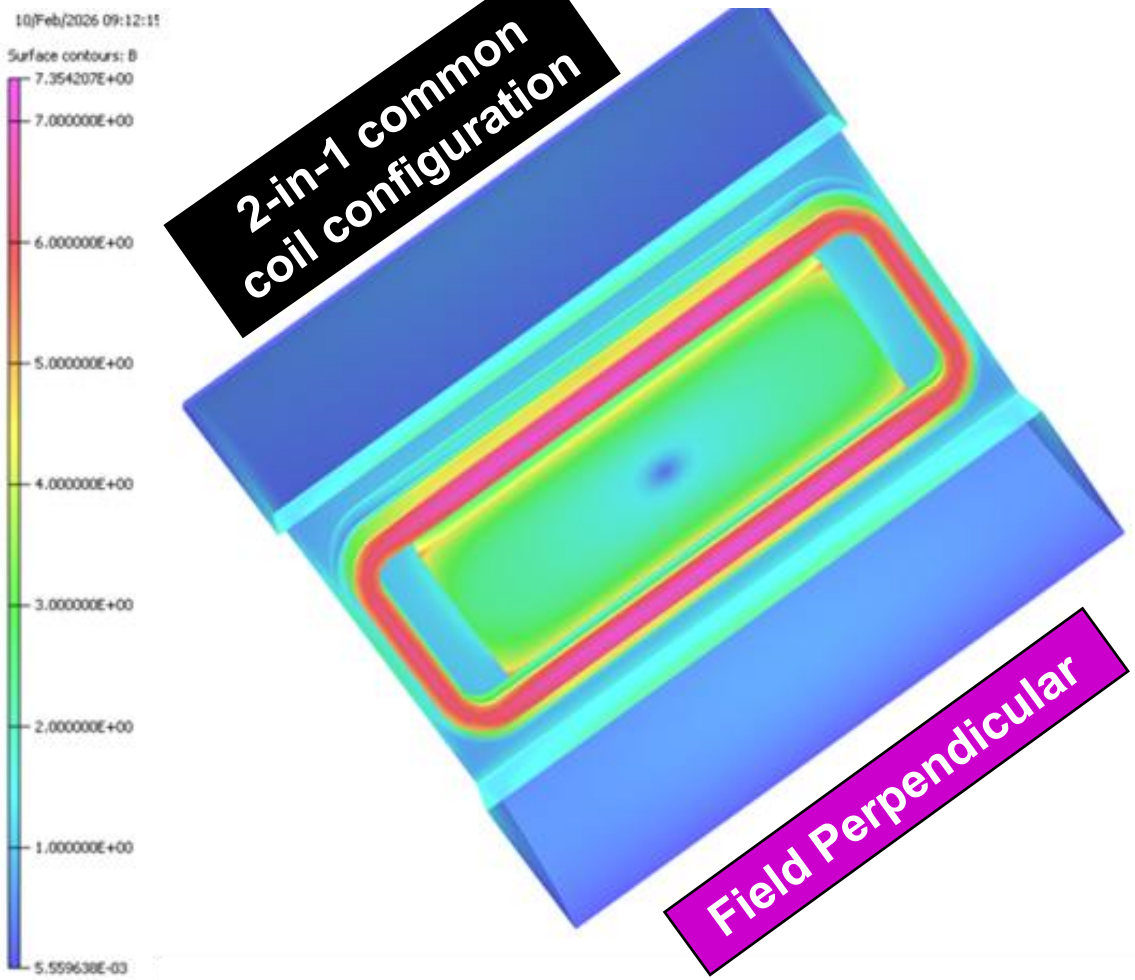


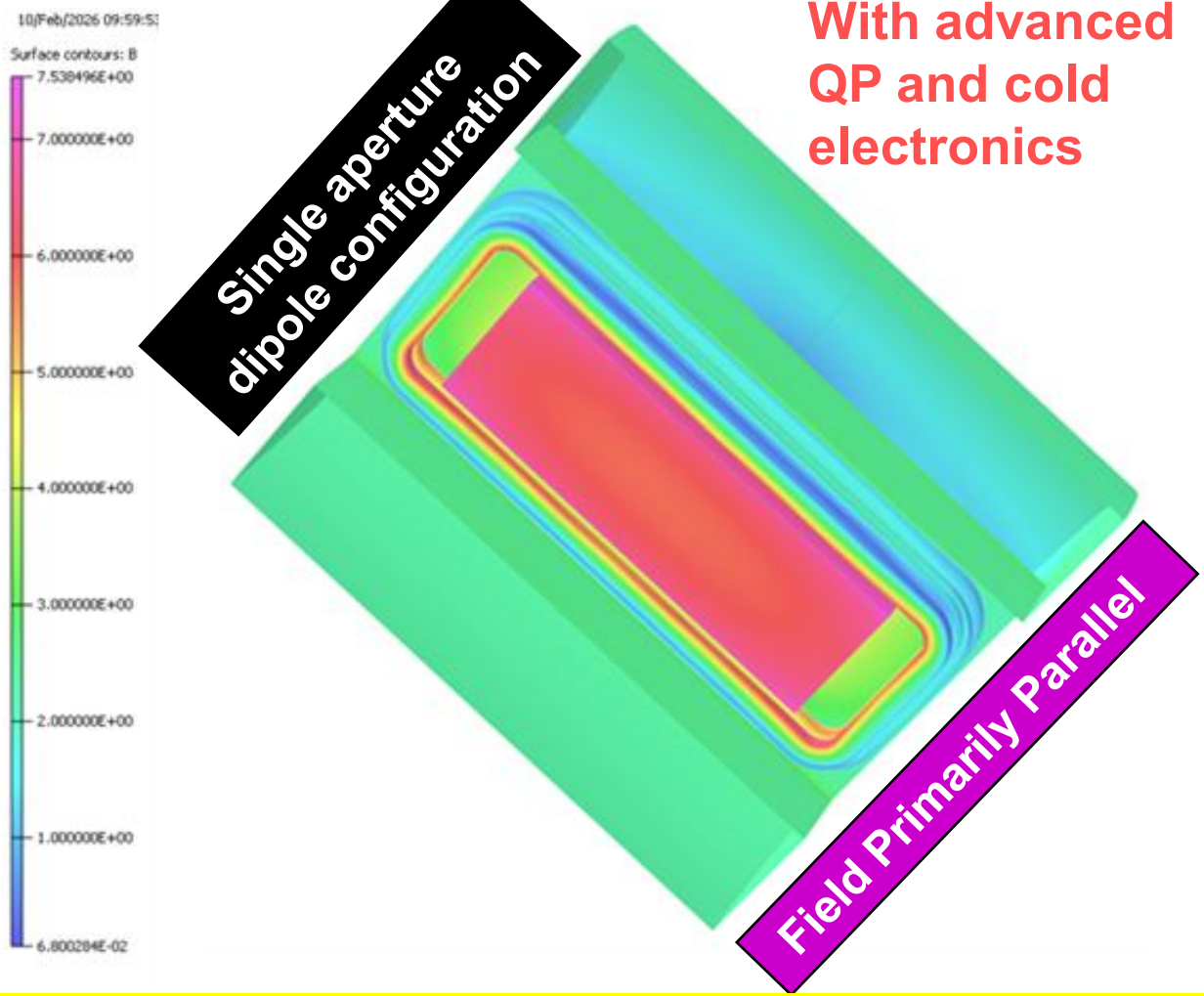


- Mechanical structure work is likely to be led by a new engineer with guidance from Jesse Schmalzle and Mike Anerella.

High Field Magnet with Large FRIB HTS Coils in Two Configurations

(ongoing step-by-step R&D program FY26-FY28: 7 T all HTS dipoles)





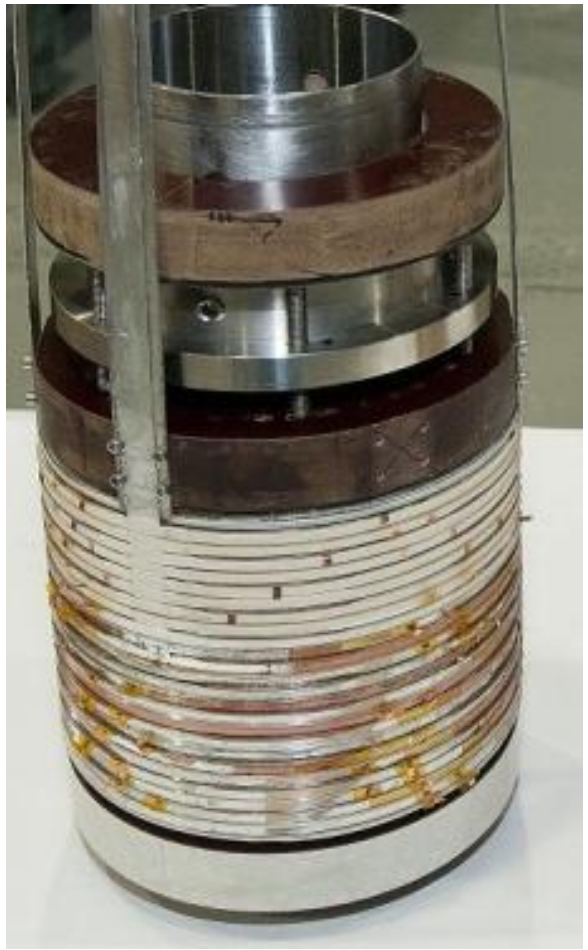
With advanced QP and cold electronics

Magnet will be tested as a function of temperature

HTS 16 Tesla Solenoid (Record HTS field in 2012)

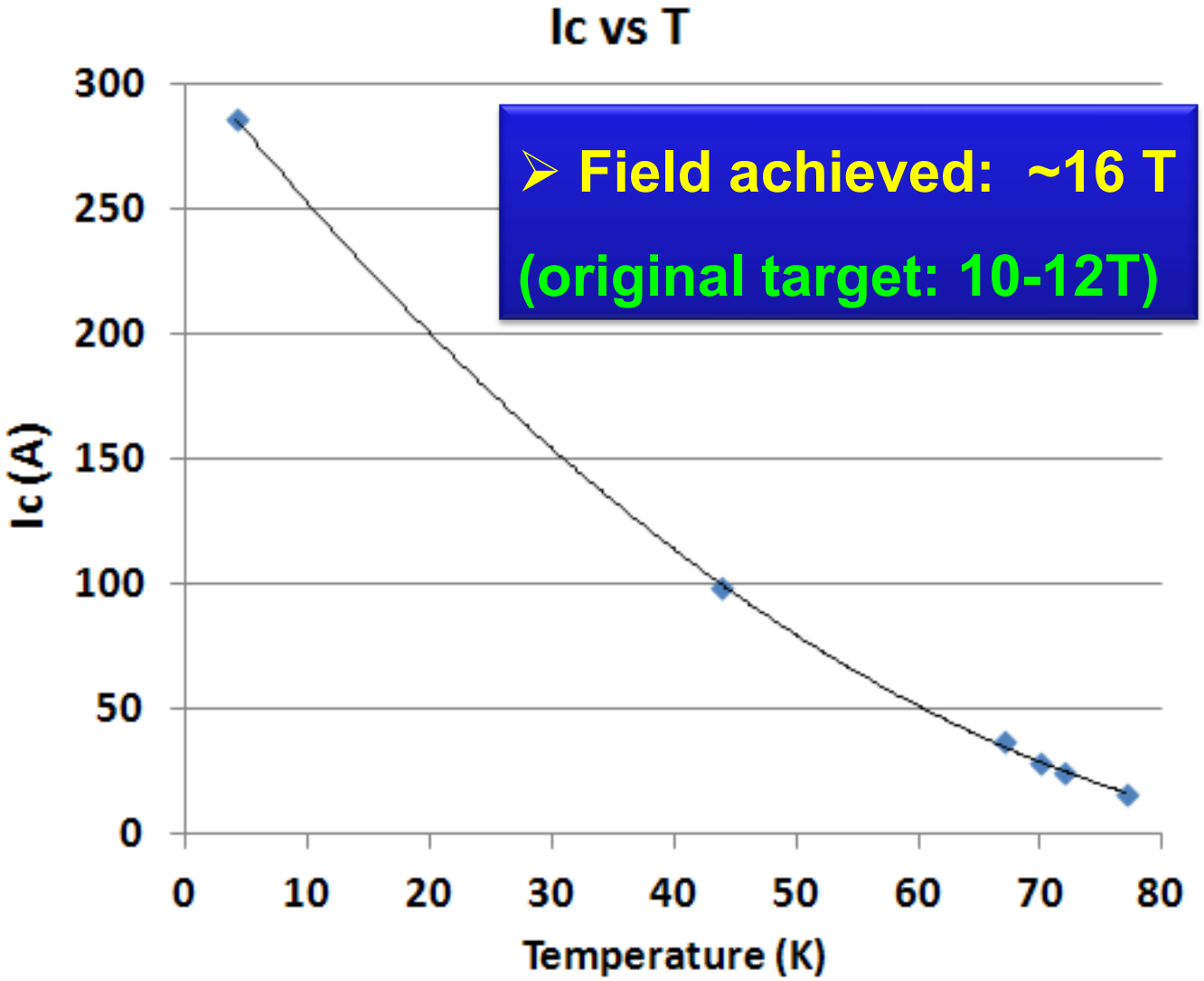
(also BNL program on high temperature operation of HTS)

Insert coil



Outsert coil

MT23 2013)



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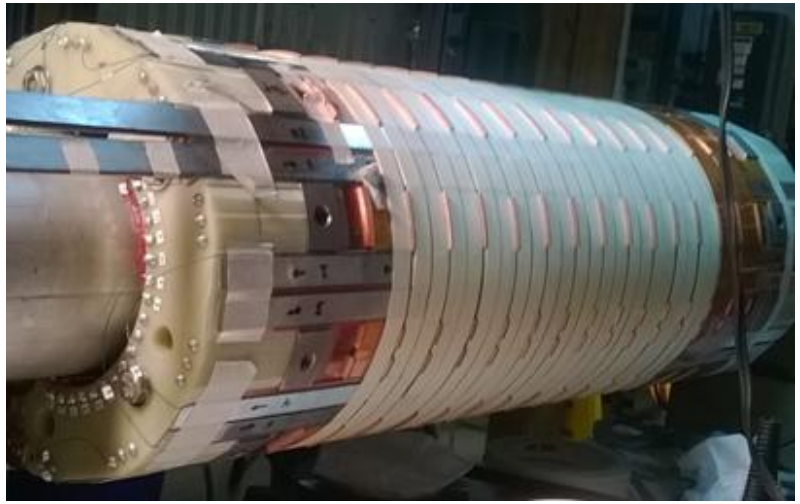
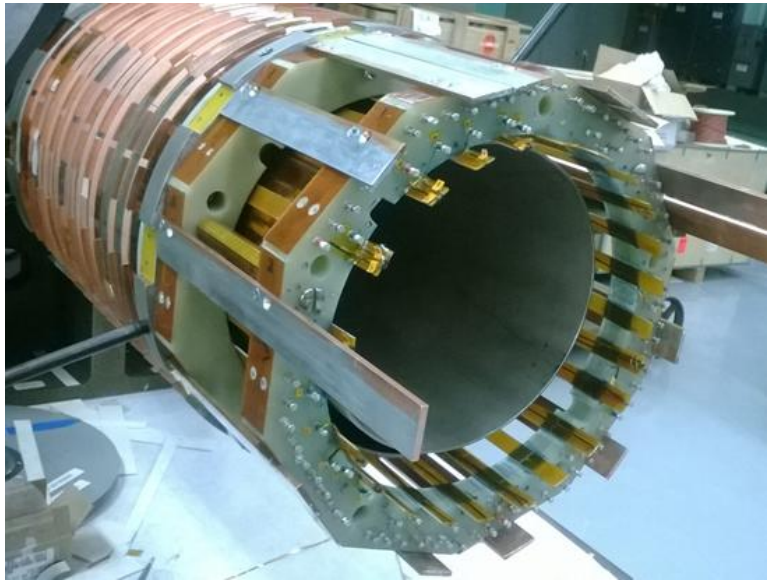
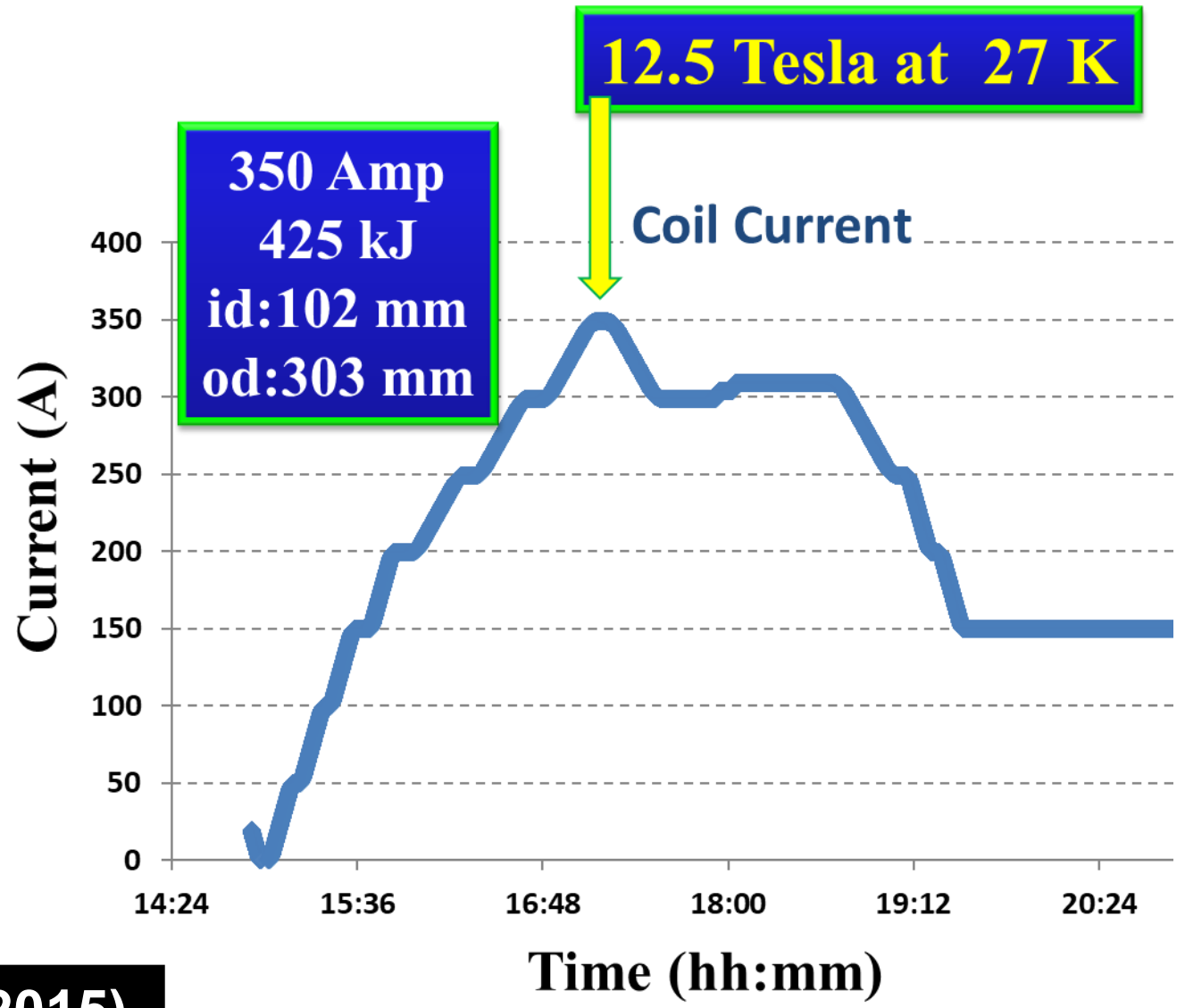
Record field (12.5T) HTS SMES at high temperature (27K)

Inner Coil
28 pancakes





Outer Coil
18 pancakes



MT24 (2015)

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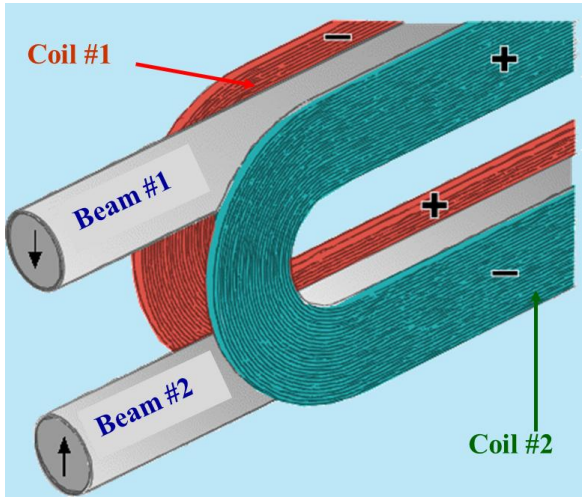
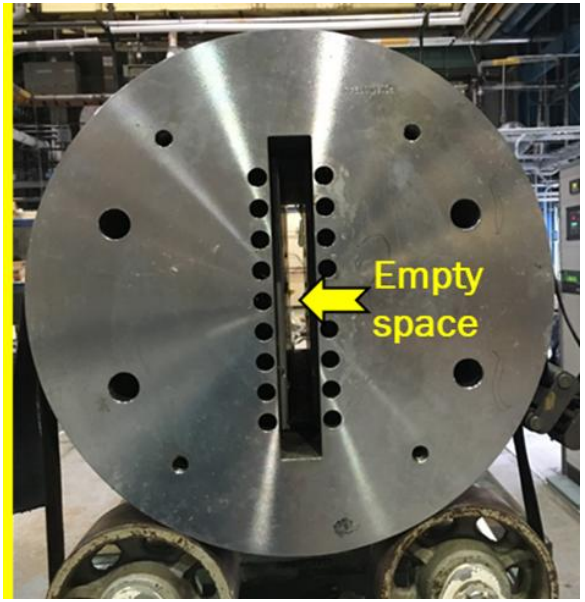
Unique Strength and contribution from BNL (to the ongoing magnet R&D worldwide)

- Common Coil Magnet Design for hadron collider
  - Being used at CERN, PSI and CIEMAT in Europe
  - Also used in vlhc, BNL, FNAL, LBL and IHEP
- Common Coil Test Facility
  - Unique lower cost, rapid turn-around R&D
  - Being used by HEP, FES, international partners
- HTS Magnets and Advanced Quench Protection
  - All HTS and HTS/LTS hybrid magnet R&D
  - Advanced quench protection (cold electronics)





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More background information at:

- https://wpw.bnl.gov/rgupta/hts-magnet-program/
- https://wpw.bnl.gov/rgupta/common-coil-design/
- https://wpw.bnl.gov/rgupta/cctf/