Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Overview of GARD Magnet Activities

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August 5, 2024

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Overview

- Magnet programs at each national lab has a few unique things to offer. What is unique at BNL and from BNL?
- Major contributions of the BNL magnet program over the last five years.
- Future programs and vision.

Additional material at SharePoint: Documents >support-documents-gupta

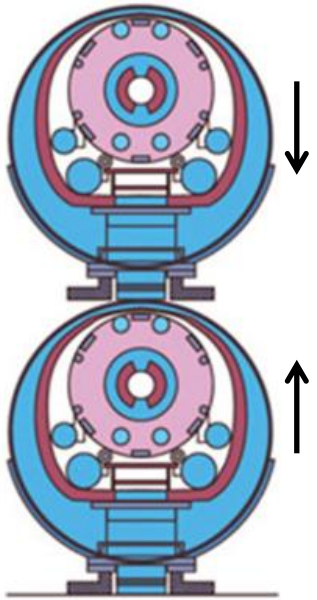
Unique Features and Contributions

- BNL has an operating collider (RHIC) on site and is building another one (EIC).
- The team that built those magnets is doing hands-on knowledge transfer to the next generation now (just as we benefited from the experts before).
- BNL has also invented several new magnet designs and has demonstrated those designs and new technologies.
- They are now being seriously considered for future machines. A few examples follows in next set of slides (most in more details in presentations by others).

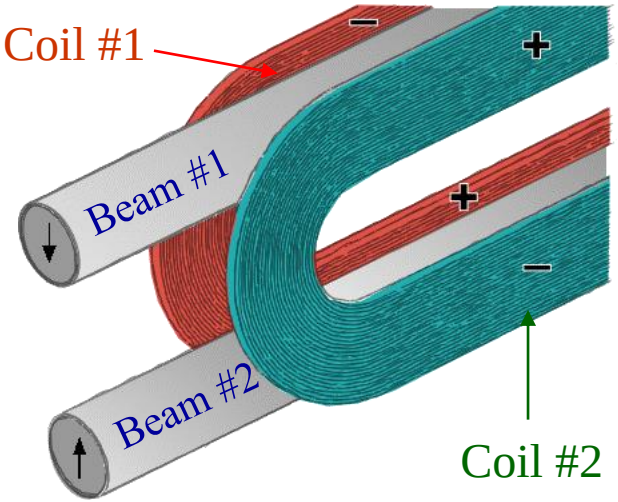
A personal opinion – a good engineering team at BNL that helped built successful machine magnets, is also important in guiding the novel designs and technologies towards the successful implementation.

Common Coil Geometry

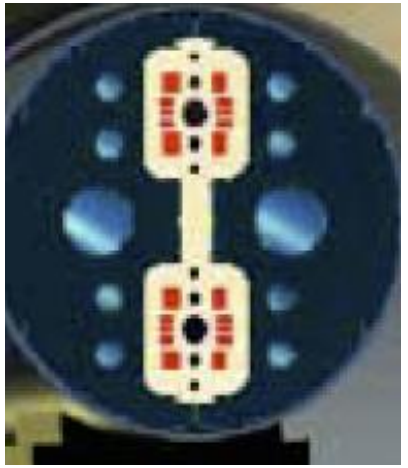
(For collider dipoles and for unique magnet R&D)



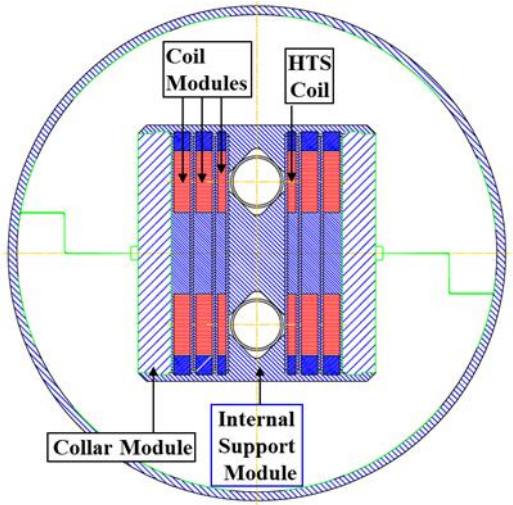
SSC

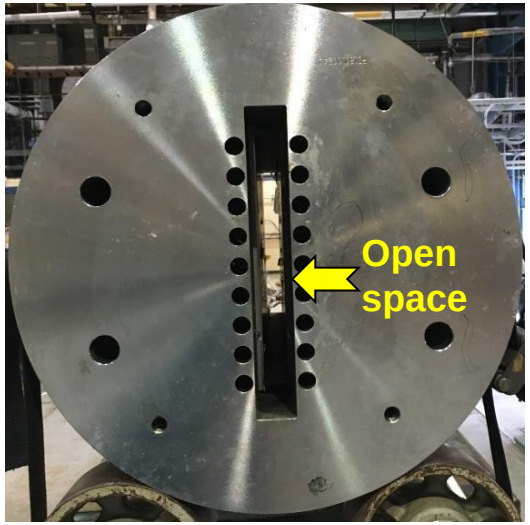


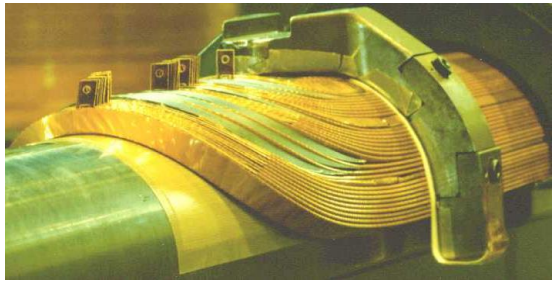
Main Coils of the *Common Coil Design (simple ends)*



vlhc(2001)







Conventional design with complex ends

- Simple racetrack coils, large bend radii (determined by the separation between the apertures rather than the aperture)
- Conductor friendly design for high field brittle conductors (HTS, Nb_3Sn), react & wind, new fusion high current cables
- Modular design: Good for HTS/LTS hybrid designs
- Expected lower manufacturing cost

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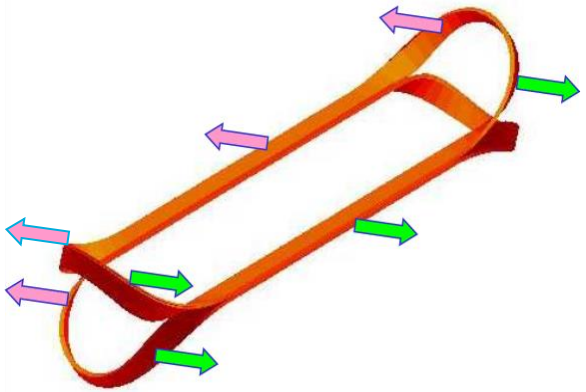
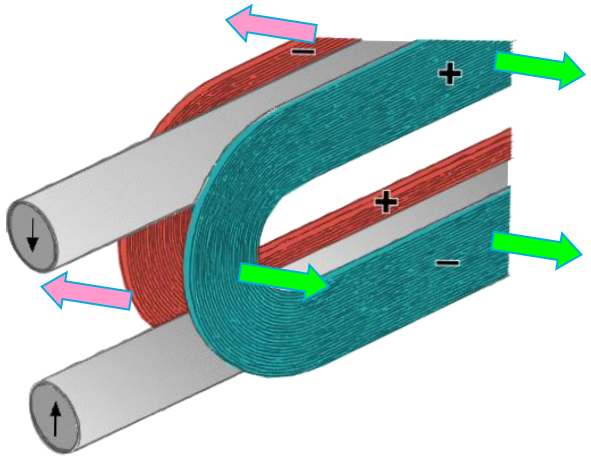
High Field Common Coil 2-in-1 Dipole Designs



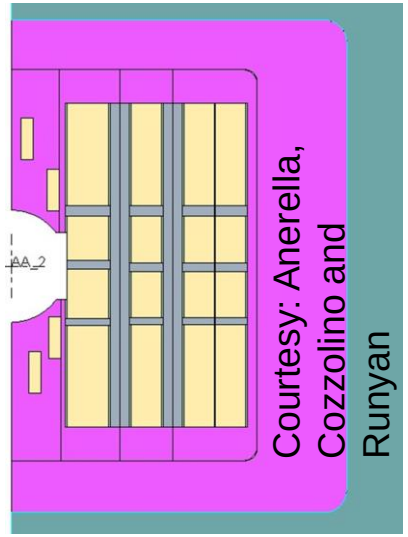
In conventional designs, Lorentz forces put excessive stress/strain on the conductor in the end region

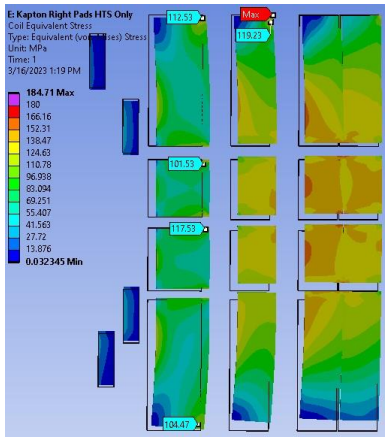


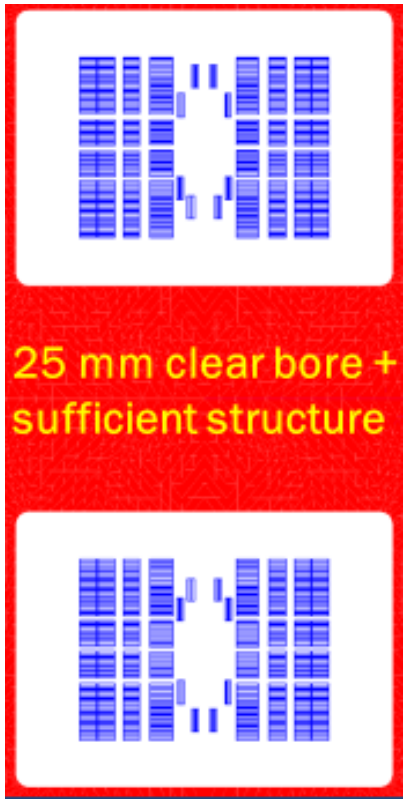
In common coil designs, coils move as a whole - much smaller stress/strain in the end region

20 T HTS/LTS Hybrid Design (MDP)

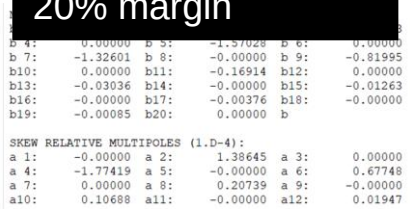
Simpler structure for stress management



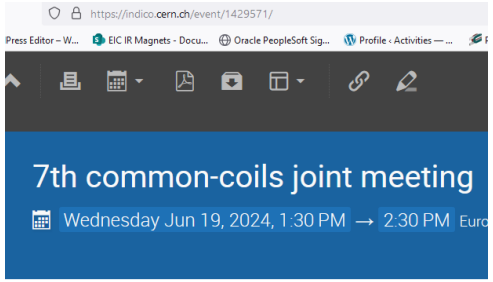




Design with a good field quality with 20% margin



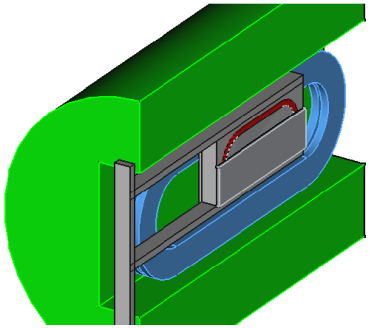
International Collaboration (MDP)

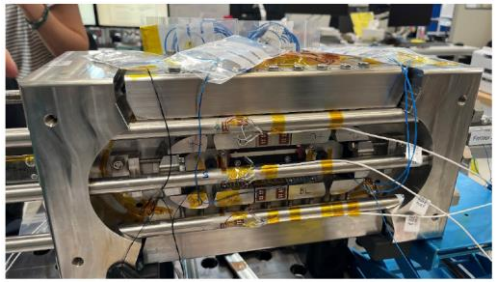


HFM High Field Magnets Programme

CHART Swiss Accelerator Research and Technology

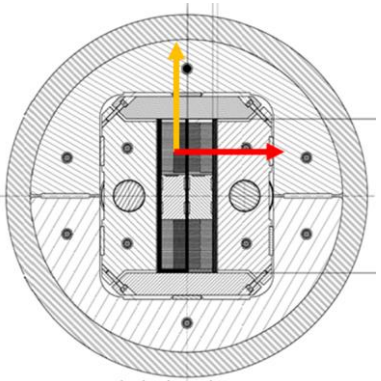
PSI





CIEMAT program using CERN coils

Design of a Common Coil Magnet Using Existing Racetrack Model Coils (RMC)



Rotated Block Coil cross-section

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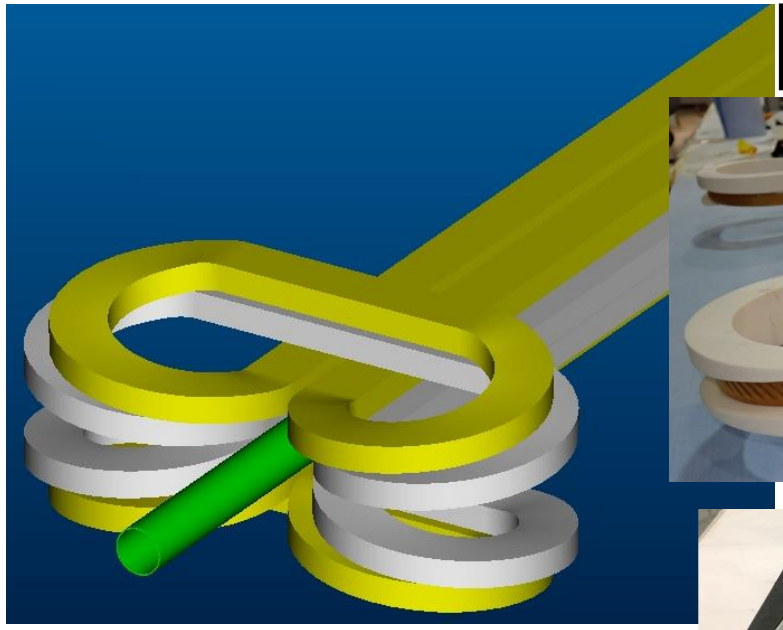
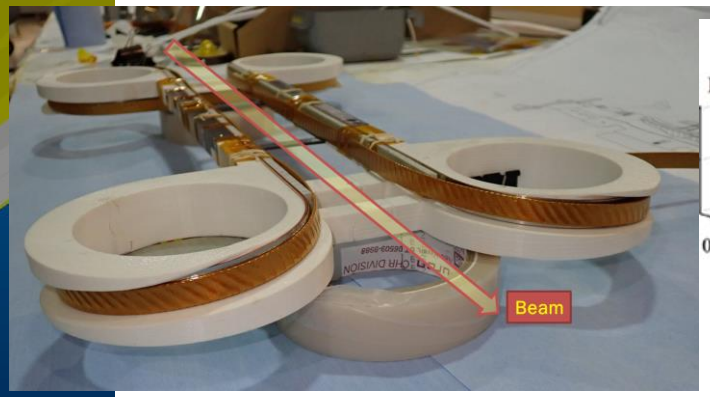
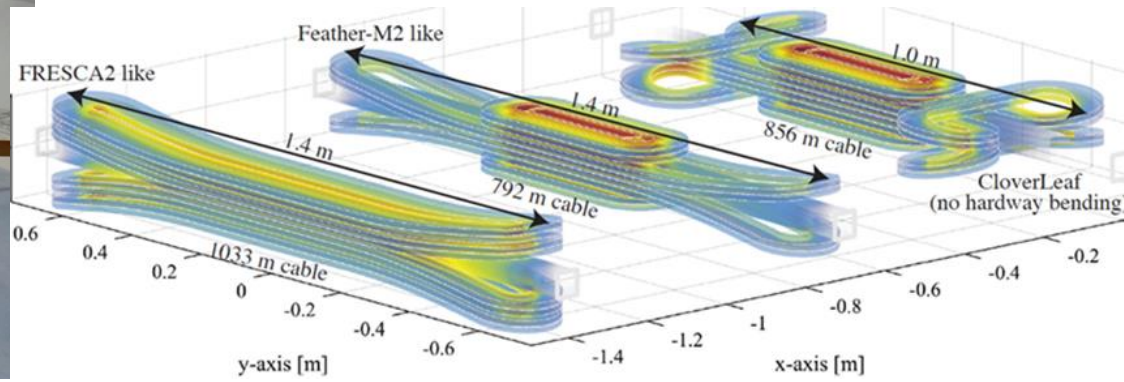
OverPass/UnderPass Design for Single Aperture Magnet



PBL/BNL STTR (2021)



Collaboration with CERN (MDP)



(aka: Clover-leaf design)

Highway Driving

- No lifting of conductor in hard way bend
- Lower strain
- Shorter length of end

Conductor friendly design for high field conductors

Both BNL (SBIR) & CERN built and tested HTS coils based on this design

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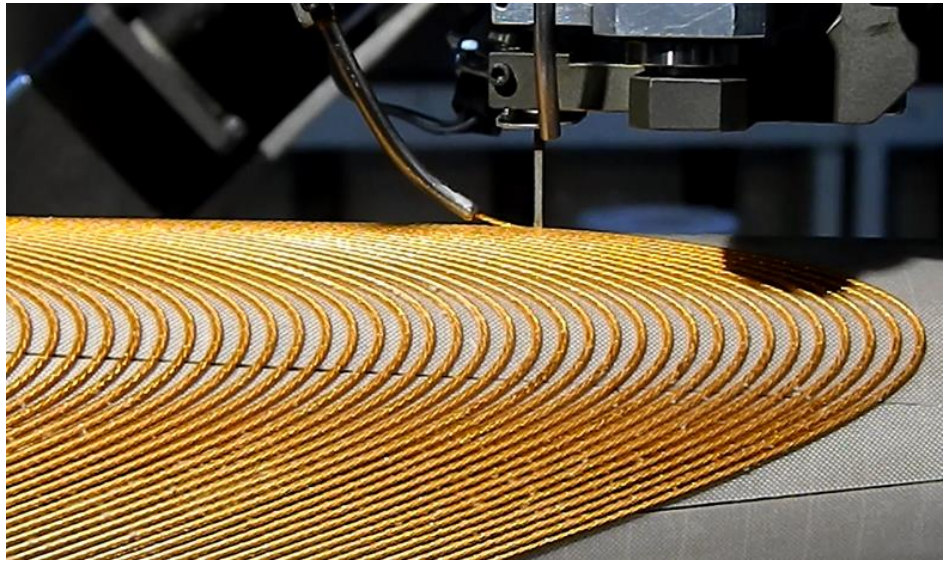
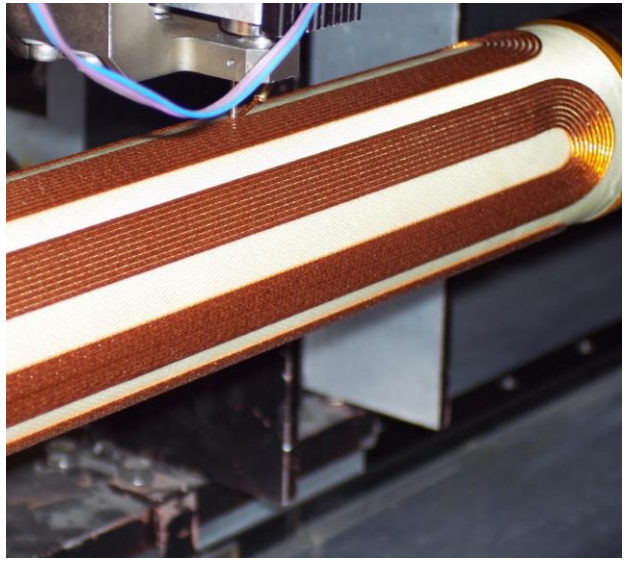
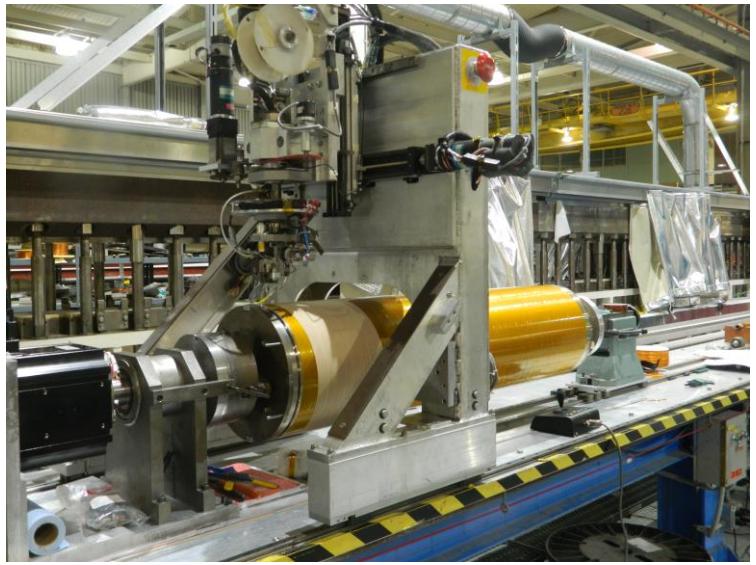
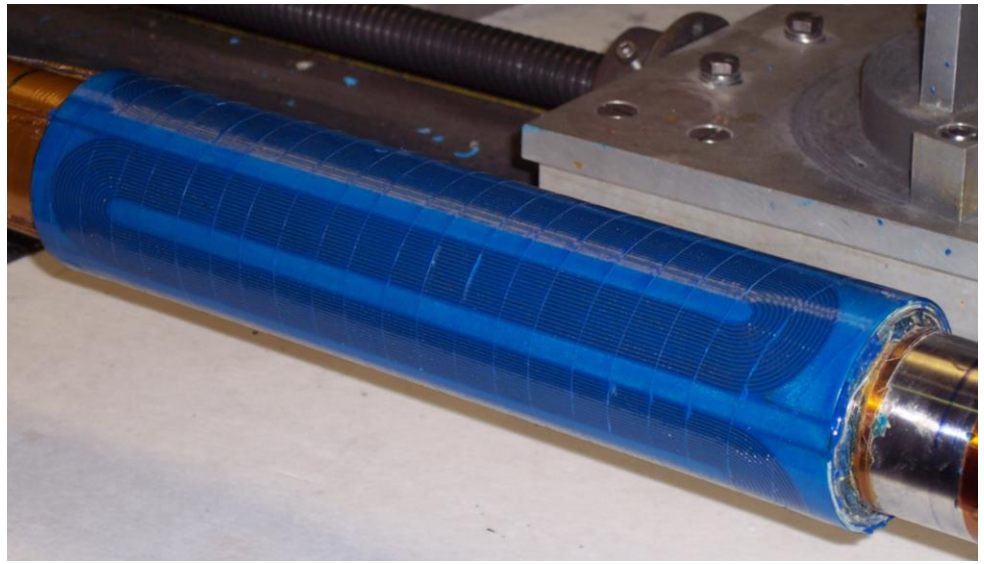
Unique Direct Wind Technology at BNL

- Wire is laid directly on the tube and bonded with ultrasound onto a substrate.
- Gaps are filled with matched expansion material
- Pre-stress is applied with S-glass pre-peg roving
- This is an inexpensive technology for one-off magnets. It doesn't require tooling, and design work and has been reliable for low field magnets
- Used at many places worldwide and now in EIC









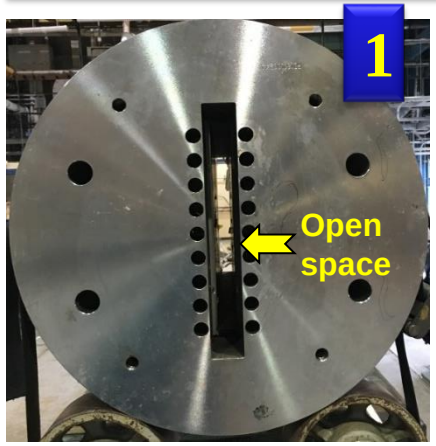
- Much more in the presentation of Brett and Vikas

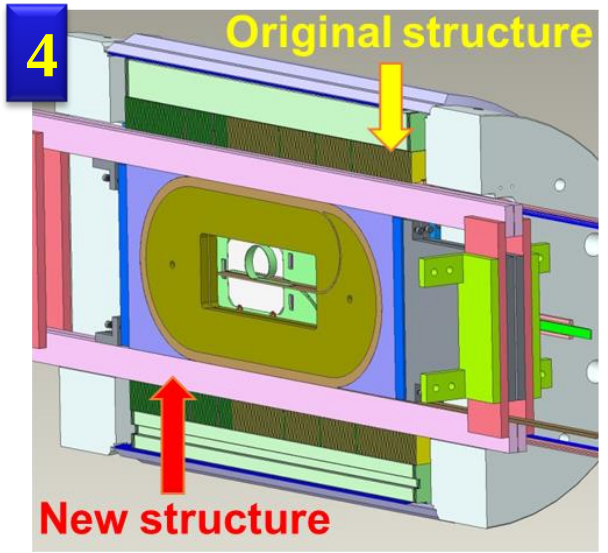
Major R&D activities in last 5 years

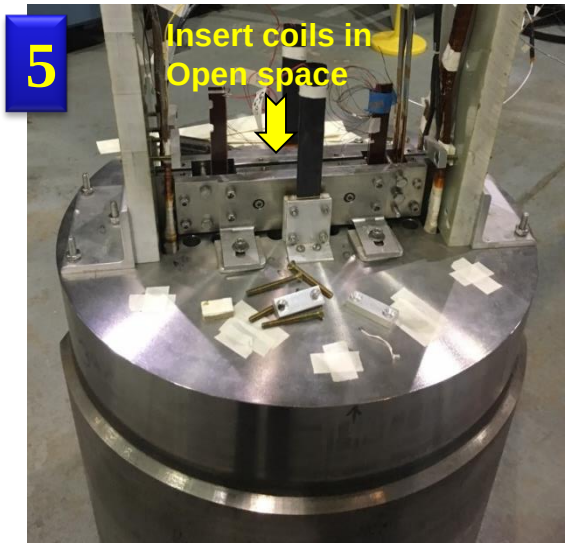
Common Coil Test Facility (CCTF)
(A unique magnet and test facility at BNL)

- A unique magnet with a large open space for insert coil and high field cable test in field
- Unique facility to allow technology demonstrations
- Rapid-turn-around and low-cost R&D=> changes the way we do innovative and systematic R&D

Five steps for testing new design







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. Coil test becomes a magnet test at a lower cost & faster

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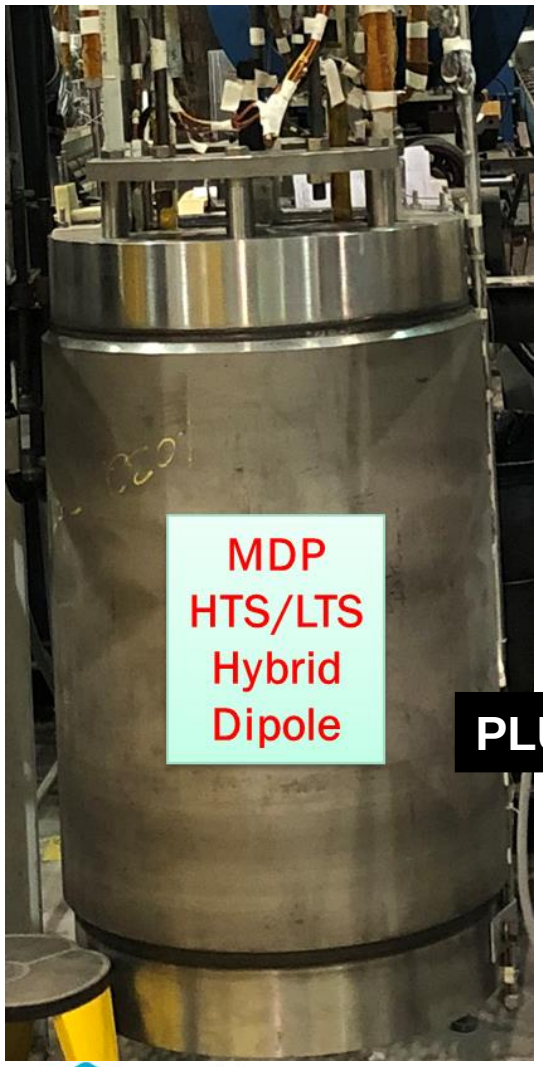
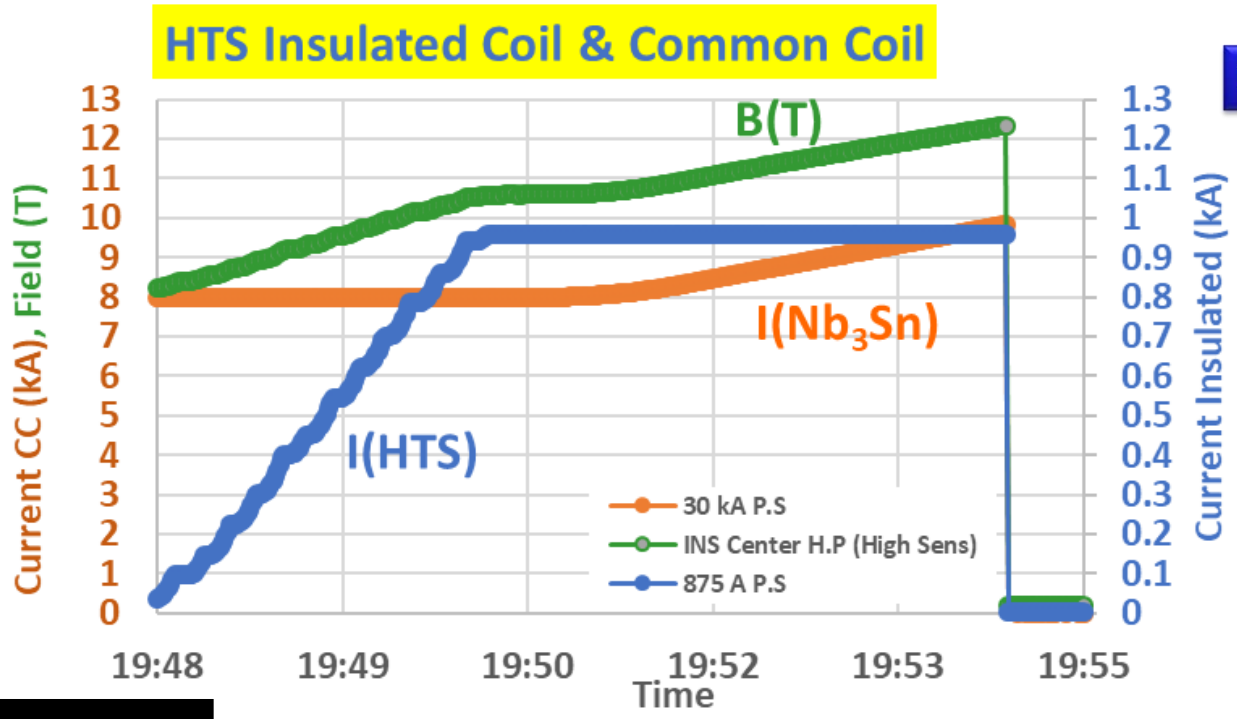
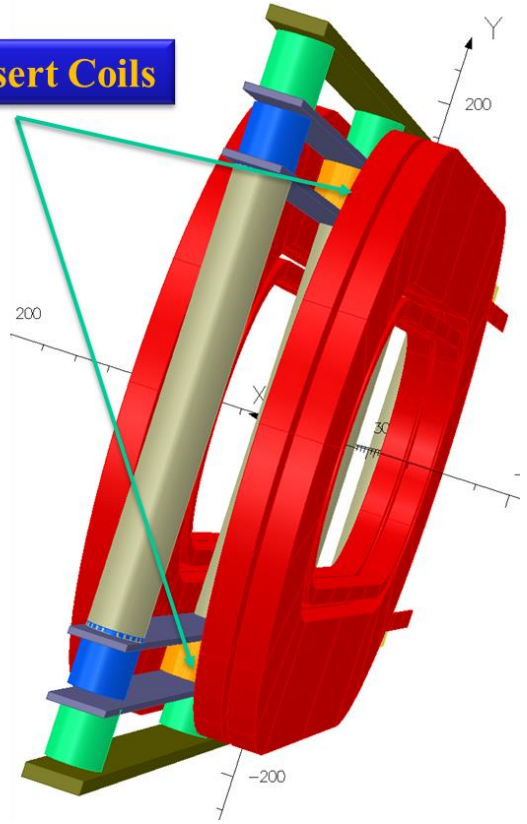
Lower-cost, Rapid-turn-around Approach in Action

(Demonstration of a record 12.3 T HTS/LTS hybrid dipole in <1 year)

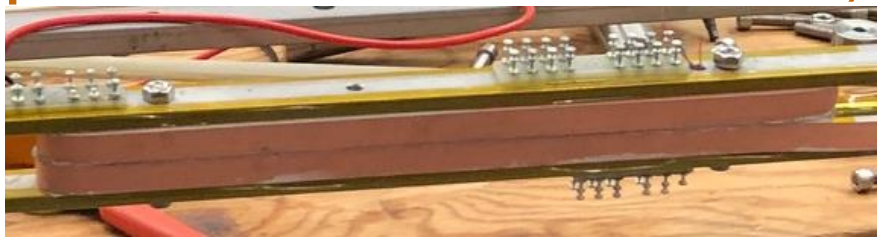






PLUS MORE

One run and two tests - 2 aperture 2 HTS insert coils:
Aperture #1: Coil#1 with insulation; Aperture #2: Coil#2 with NO-insulation



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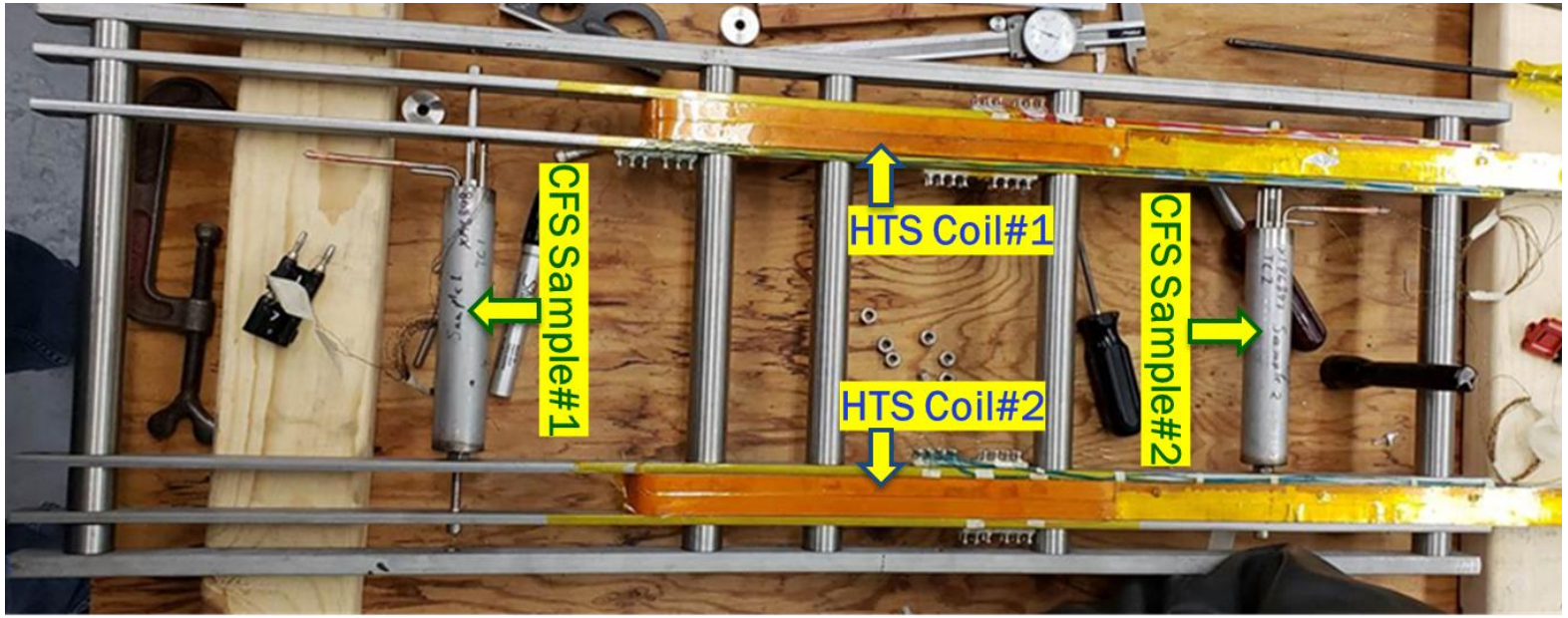
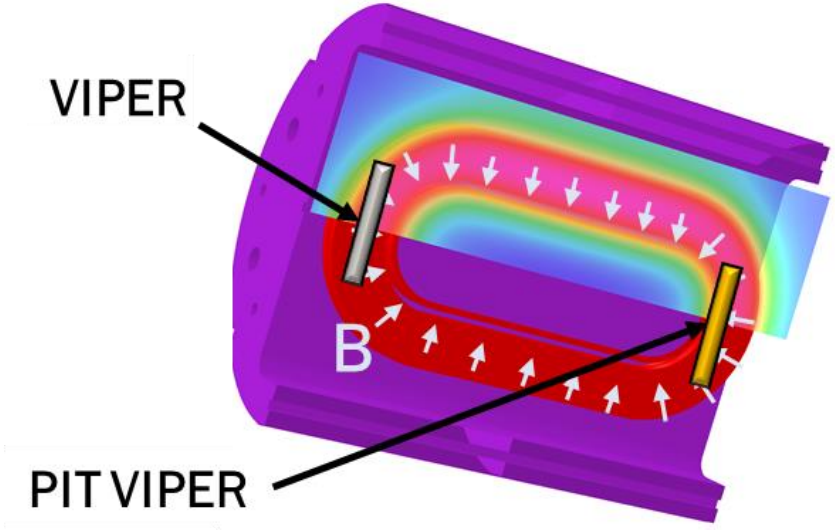
HEP/FES Synergy – 2 HEP Coils and 2 FES Samples (Feb '20)

4 tests in one go: record hybrid field for HEP, crucial cable test for FES





Commonwealth Fusion Systems

CFS SPARC

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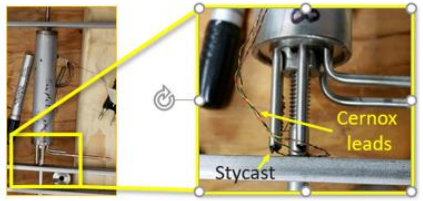
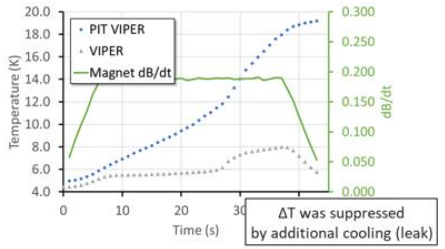
Program goals

1. Characterize PIT VIPER cable AC losses at relevant dB/dt
   Note: induced currents from the changing magnetic field are heating up the sample (AC losses).
2. Characterize and qualify novel quench detection systems.
   Note: quench detection systems are not being qualified with transport current, only heat pulses.



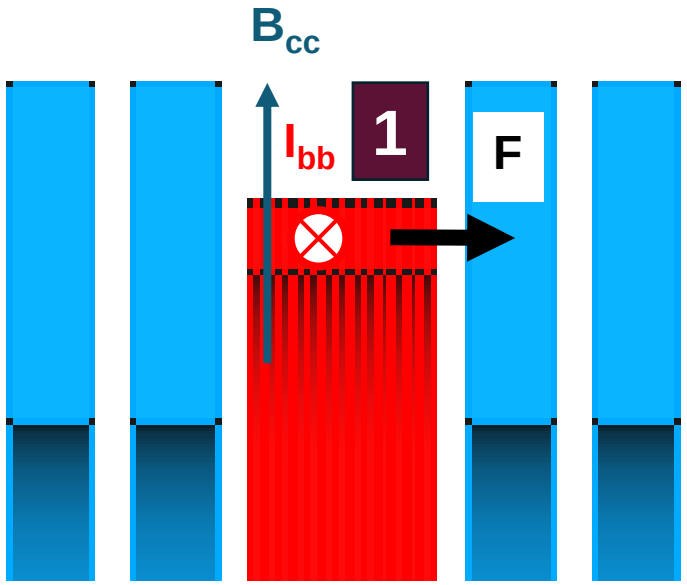
0.183 T/s to 7.49 T



- ✓ **This test successfully demonstrated the design and benefit of the MIT/CFS VIPER cable. successful Crucial test of CFS PIT VIPER Cable.**
- ✓ **A crucial test for fusion**
- ✓ **HTS cables developed for fusion can be used by HEP.**

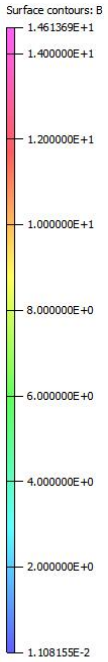
Wax Impregnated Nb_3Sn Coil (BigBOX) under High Magnetic Field

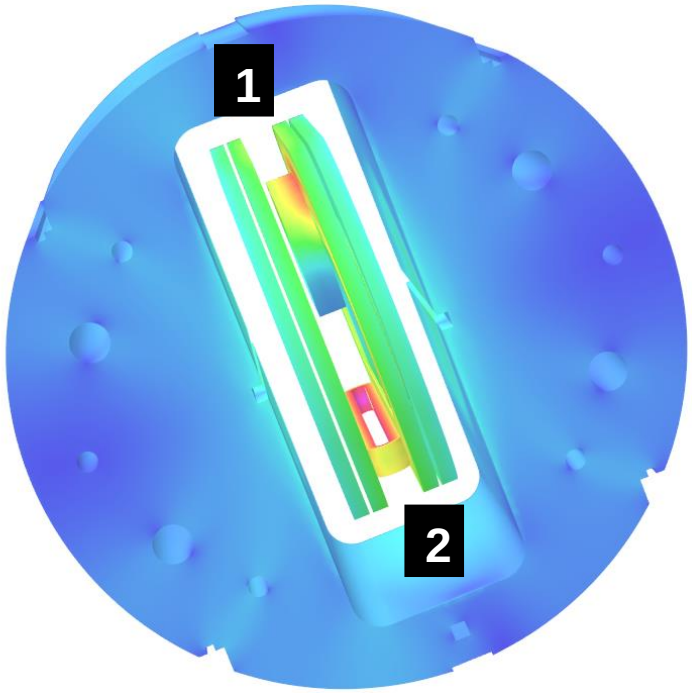
(CCTF for low-cost, fast-turn-around test, and such test not possible elsewhere)



Test goals:

- **Wax to reduce training**
- **Impact of large Lorentz forces and stress management**





1 Hard way bend Nb_3Sn Insert coil

2 HTS insert coil (BNL)

More in the talk of Mithlesh Kumar

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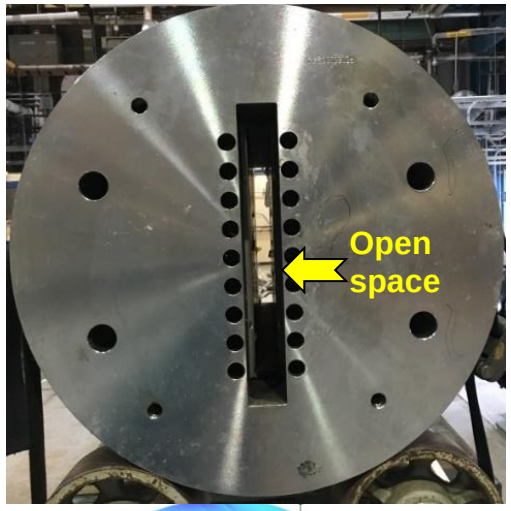
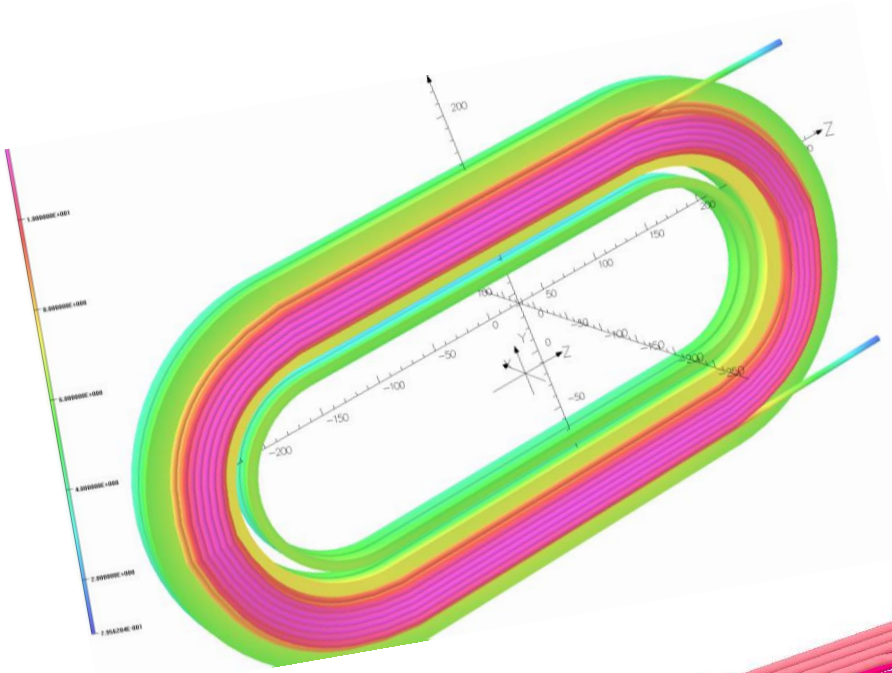
PSI

The Paul Scherrer Institute (Switzerland)

Assessment of Training Performance, Degradation and Robustness of Paraffin-Wax Impregnated Nb_3Sn Coil

Common Coil Test Facility (CCTF) to Test the Viability of CORC® Cable in Accelerator Magnets



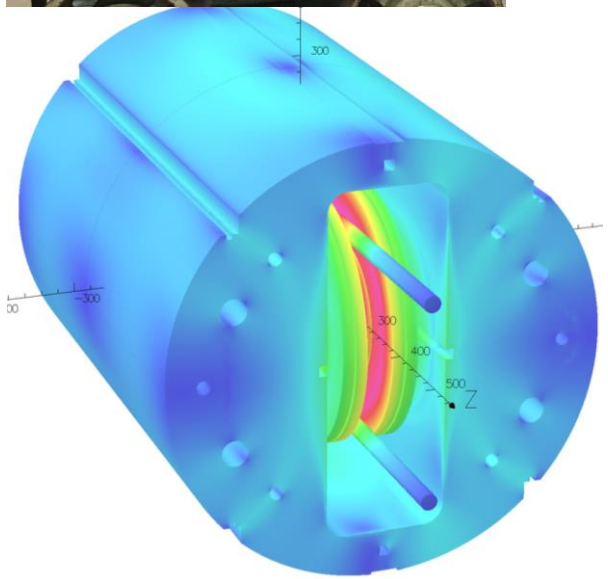


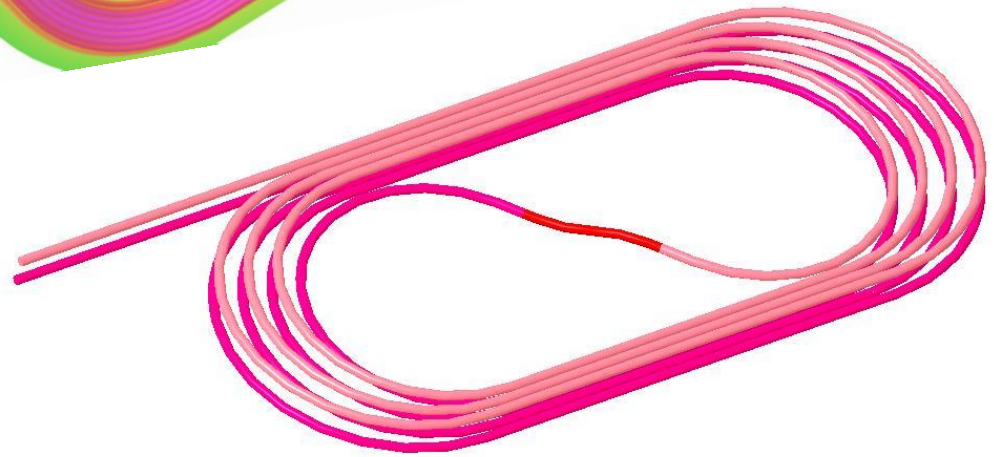
STTR: High field Demo

(~13 T with 10 T from LTS)

MDP: Quench studies and technology demo

(10.7 T with 10 T from LTS)





MDP Coil 4+4 turns with an S-turn

More in the presentation of Mithlesh Kumar

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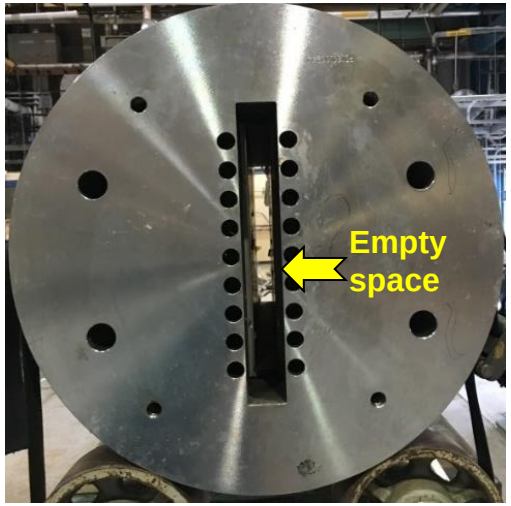
US-Japan HEP Collaboration for Developing HTS Technology

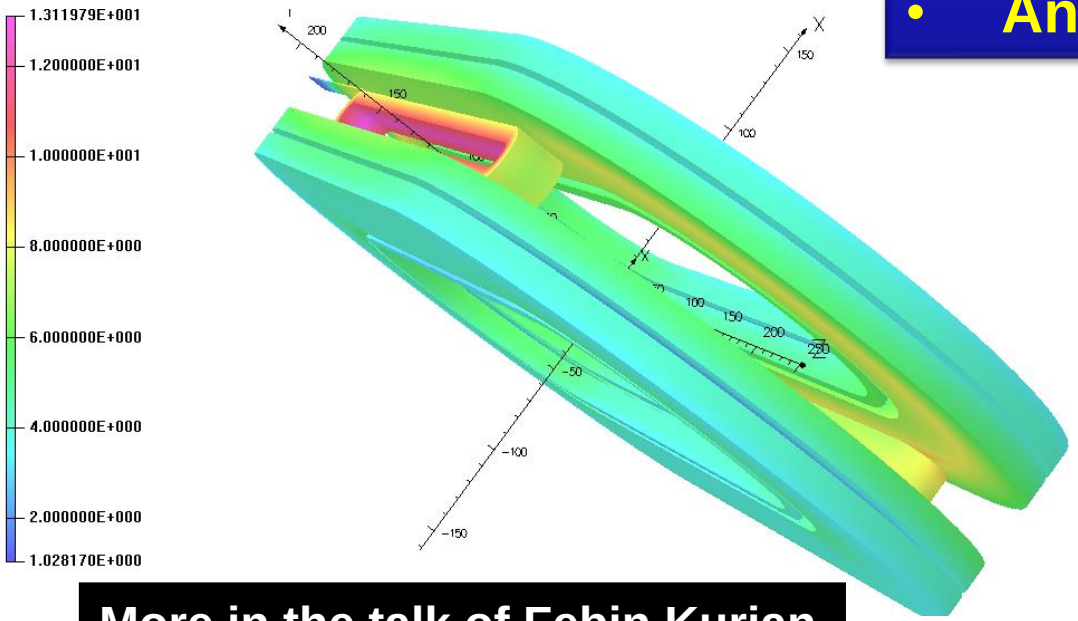


(follows the MDP 12.3 T HTS/LTS hybrid test)

➢ **BNL common coil test facility is uniquely suited for this**

Two identical HTS insert coils from KEK in two apertures of the BNL 2-in-1 common coil dipole:

- **One Bore: field primarily parallel**
- **Another bore: field primarily perpendicular**



More in the talk of Febin Kurian

Test the hypothesis

1. **Expect a significantly higher current in HTS coils for field parallel orientation as compared to the field perpendicular.**
2. **Expect a significantly lower magnetization (field errors in magnets) for field parallel.**

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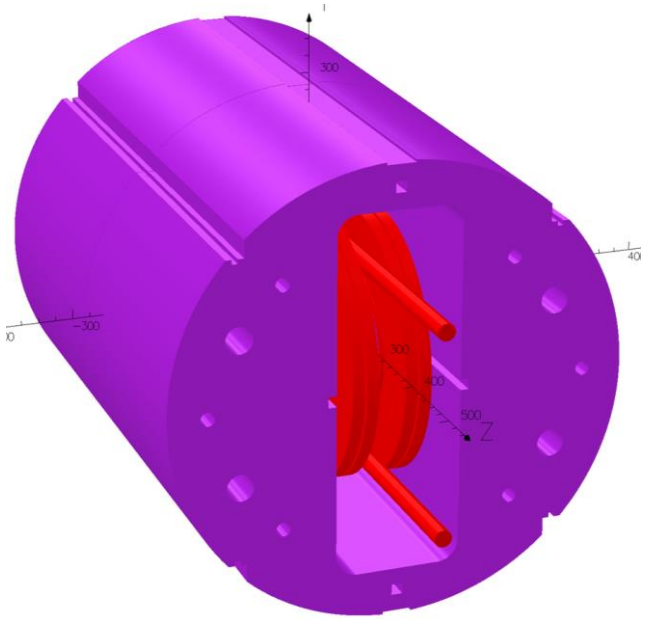
•Program under 3-year US-Japan funding completed; new 2-year funding awarded

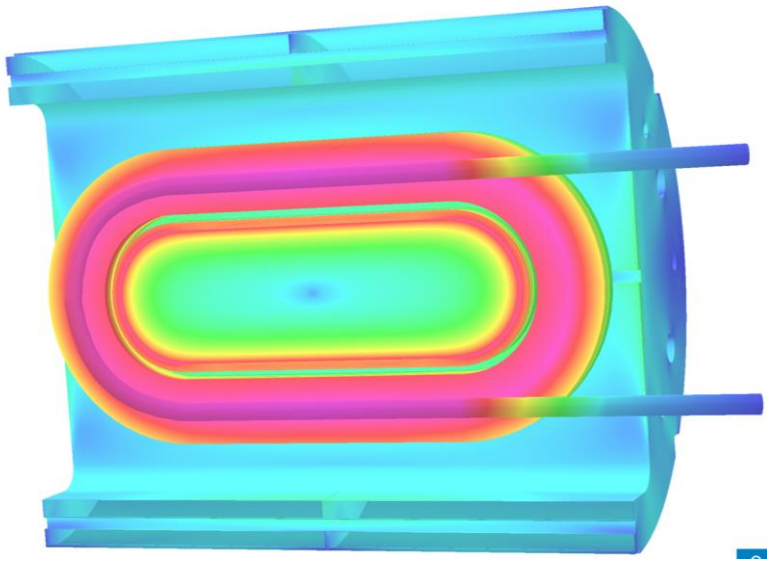
Another Upcoming Test - Only Possible with the BNL CCTF

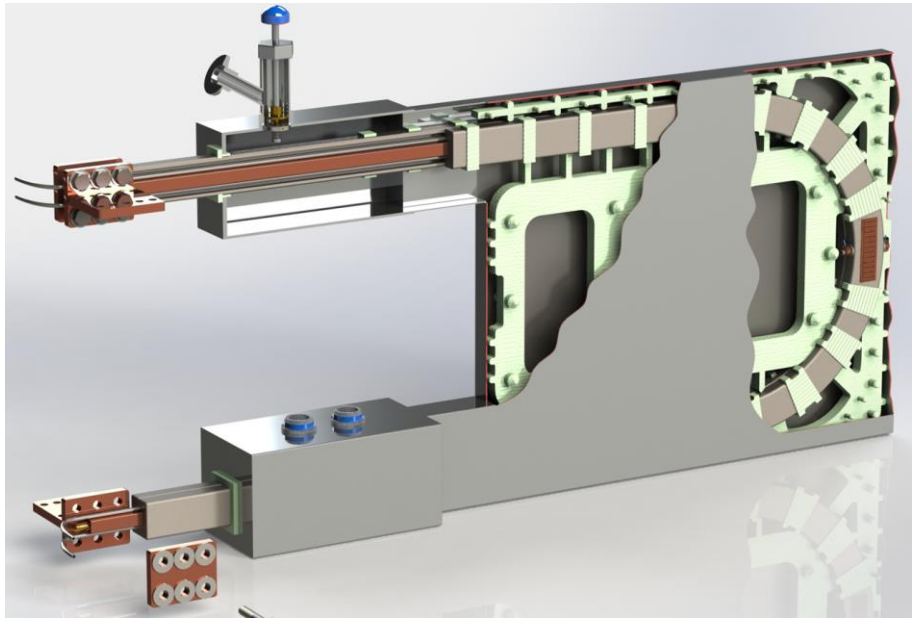
(GA's test is funded by the FES under the INFUSE program)

- Test of a bent fusion cable in CCTF's dipole field (field can be varied). Cryo-module delivered for test at 20 K (temperature can be varied).

HTS magnets operating at higher temperature is of interest to muon collider







Cable in a cryo-module already delivered by GA
Now waiting for the availability of the test facility

HTS Coil and Magnet R&D at BNL

(5-20 years ago, results and coils are useful for future)

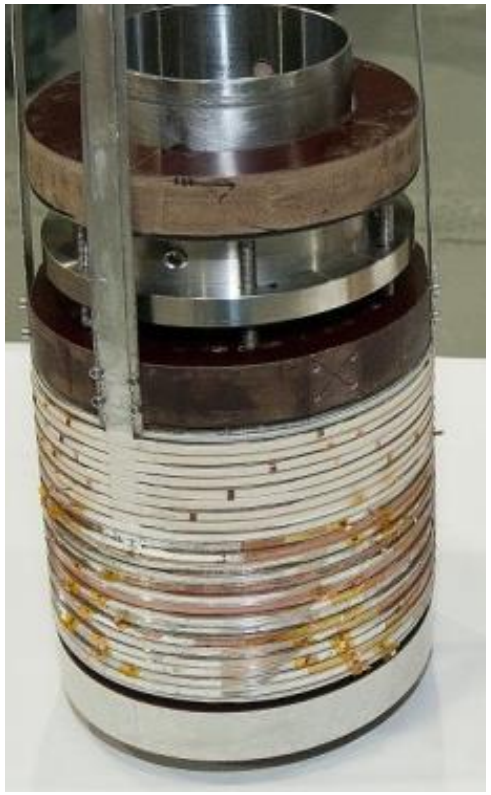
Highlights of the HTS Magnet Program at BNL

- First US national lab to start HTS magnet R&D (over 20 years ago)
- A wide ranging HTS magnet R&D at BNL
  - High field, high temperature, medium field @medium temperature
  - Solenoid, racetrack, cosine θ, curve coils, clover-leaves, ...
- Well over 150 HTS coils and well over 15 HTS magnets designed, built and tested. We have used a large amount of HTS – wires, tapes, cables, 60 km of 4 mm tape equivalent)

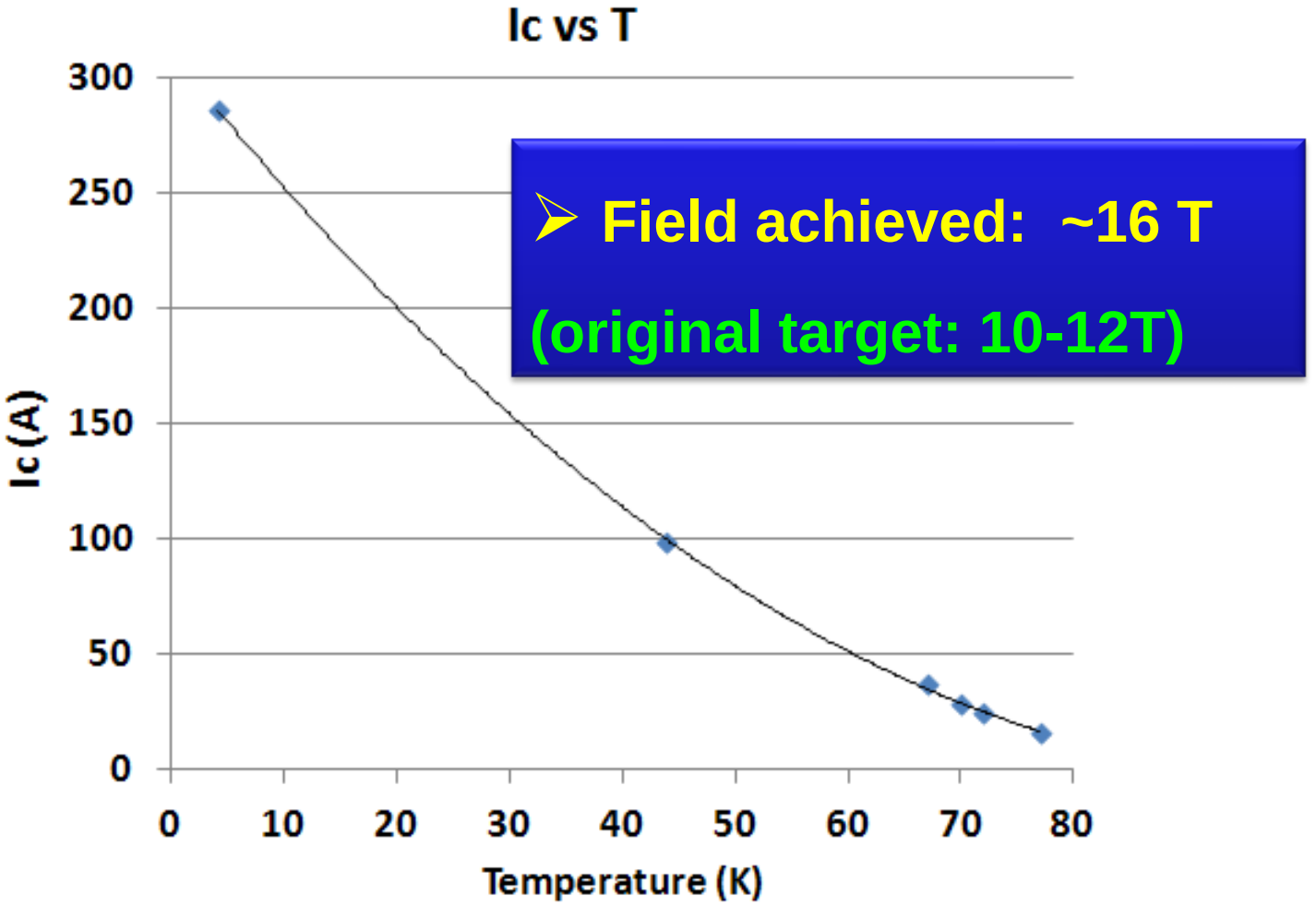
HTS 16 Tesla Solenoid (Record HTS field in 2012)

(Testing at higher operating temperature is important to muon collider)

Insert solenoid



Outsert solenoid

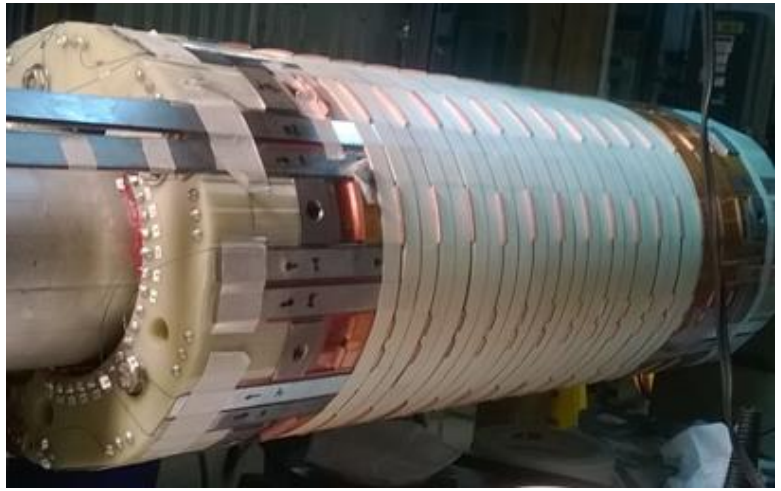


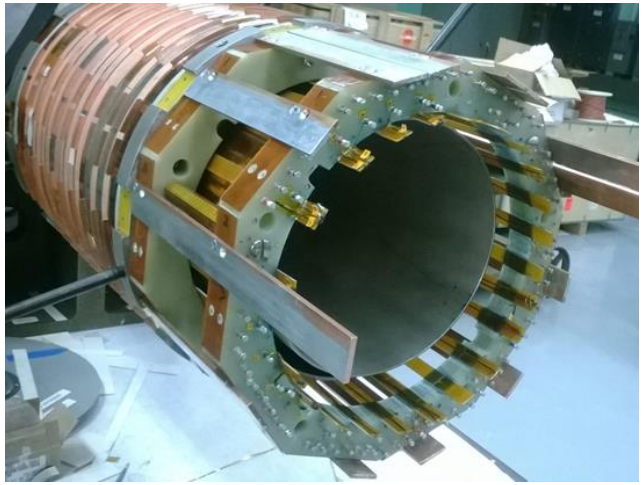
- **Field achieved: ~16 T**

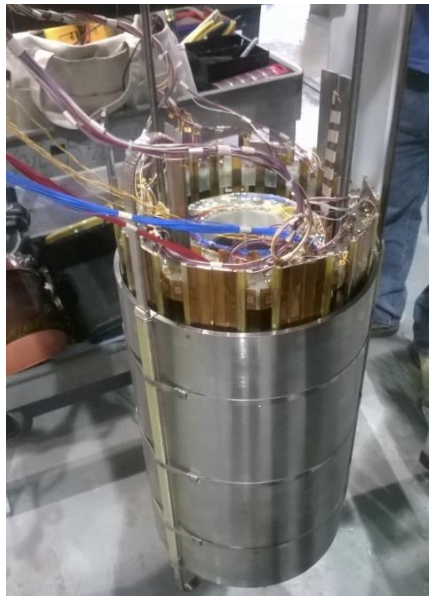
(original target: 10-12T)

Overall Current Density (J_o) in the coil: >500 A/mm^2 @16 T

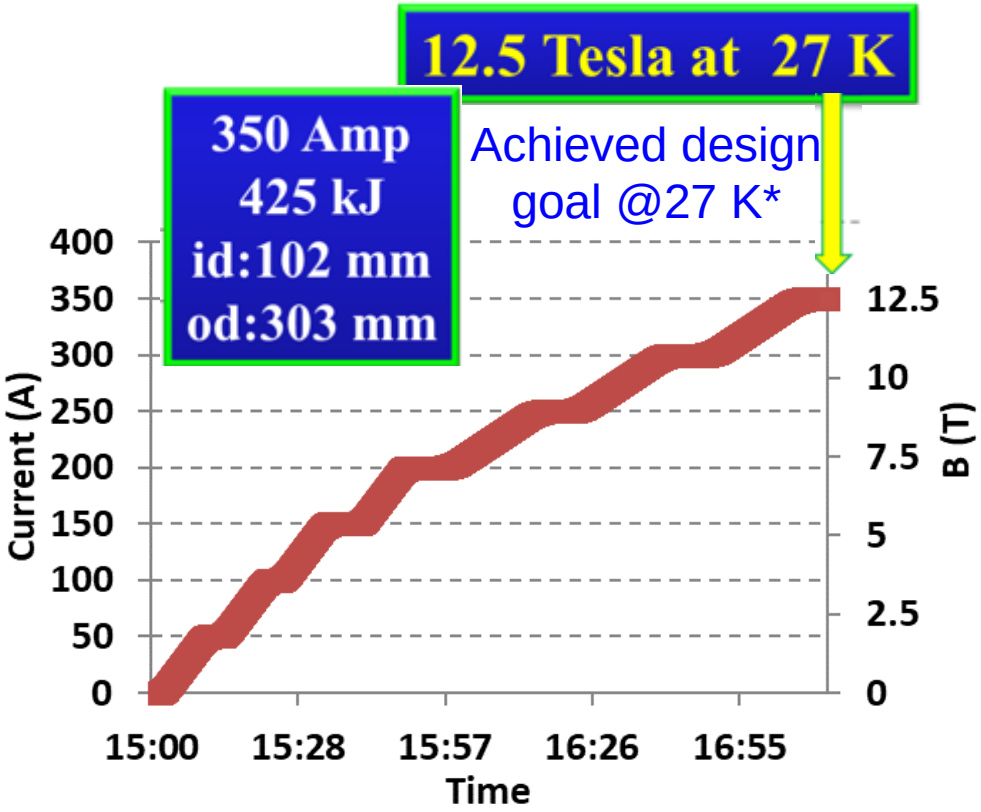
High Field 100 mm HTS Solenoid for SMES (funded by ARPA-E)







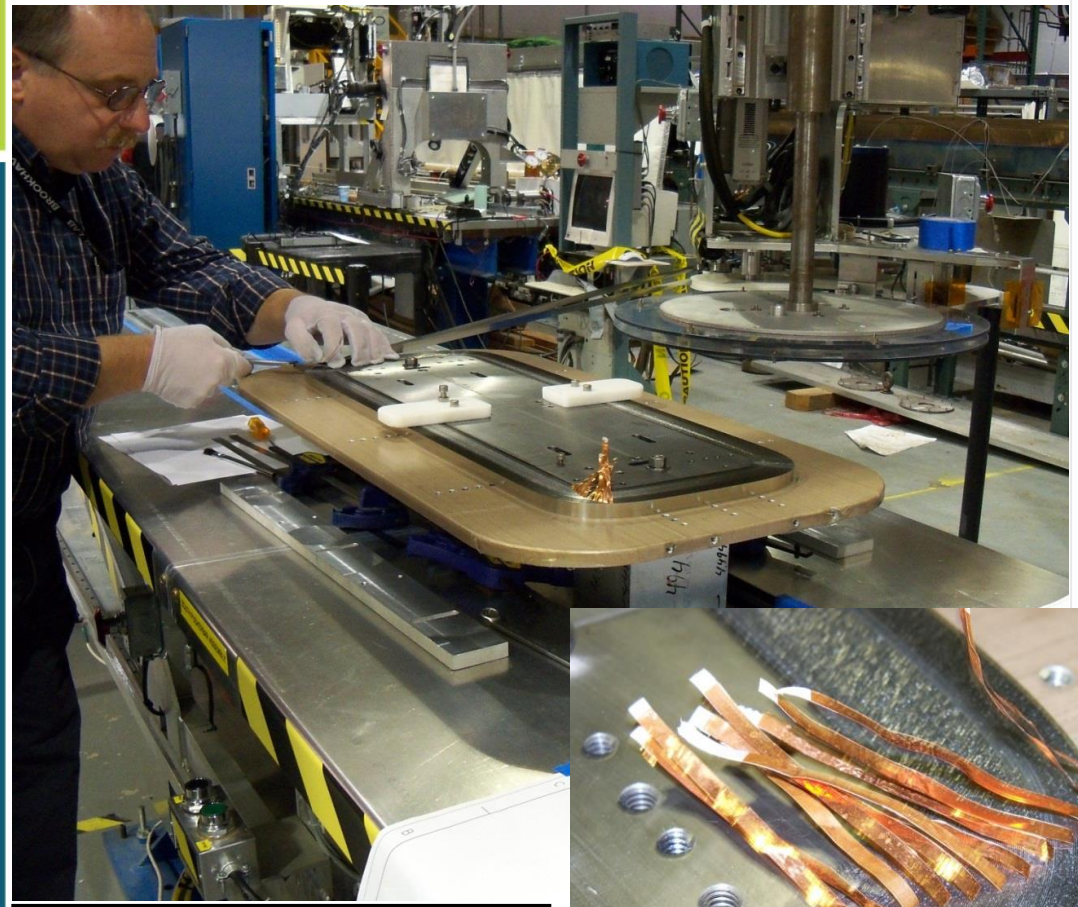
Record field/energy at 10 K or higher
(referenced in fusion proposals)



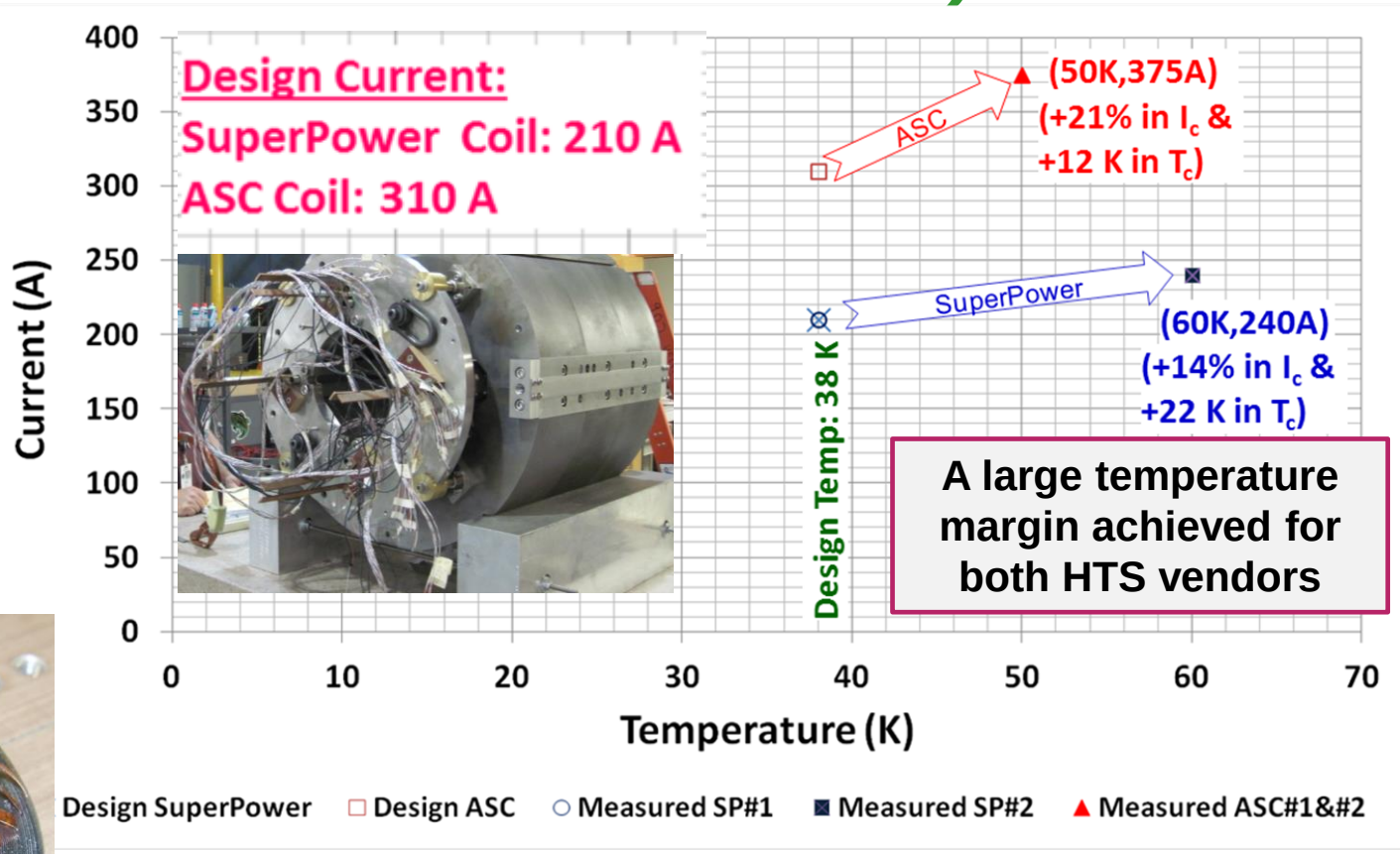
*4 K test couldn't be carried out because of the issues with the leads placed at the coil od

High Operating Temperature HTS Quadrupole for FRIB

(High temperature operation relevant to muon collider)



Four large heavily instrumented coils



A large temperature margin achieved for both HTS vendors

~3 km of 12 mm wide HTS tape
(3X the width of most commonly used 4 mm)
➢ 8 Large HTS coils are available for R&D

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Future Vision and Plan

Future Vision and Plans

Common Coil Design:

- **Multiple laboratories in Europe are designing and building high field common coil dipoles. With our unique insight, we will continue to play a role of major collaborator, both in the design and in the technology (HTS, React & Wind).**

Conductor, Coil, and Magnet R&D at the Common Coil Test Facility (CCTF):

- **CCTF has shown its unique value across many platform around the world. Many experiments are already lined up and the demand is expected to grow significantly.**

Magnet R&D for muon colliders:

- **BNL has been involved with the muon collider and related R&D (HTS solenoids, open midplane dipole, etc.). Participation in that program will increase.**

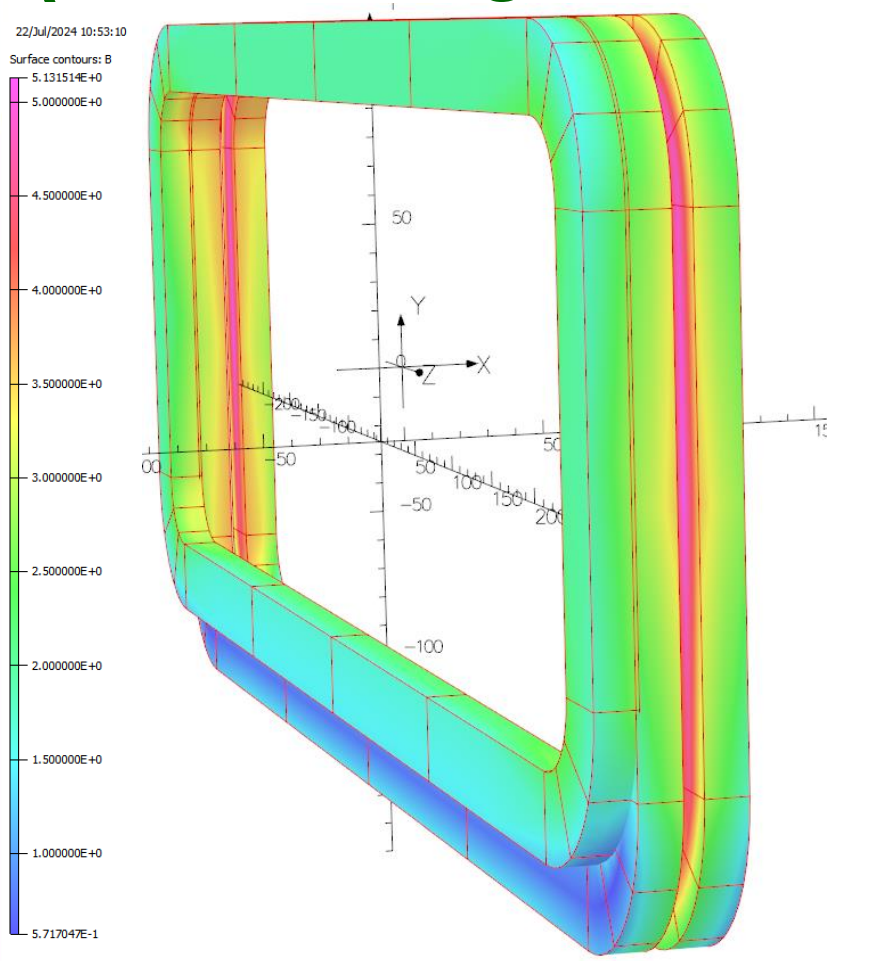
HTS magnet R&D:

- **BNL has a vast experience and many HTS coils at hand. We can leverage them to boost the disruptive HTS magnet R&D at a lower cost and at a shorter time frame.**

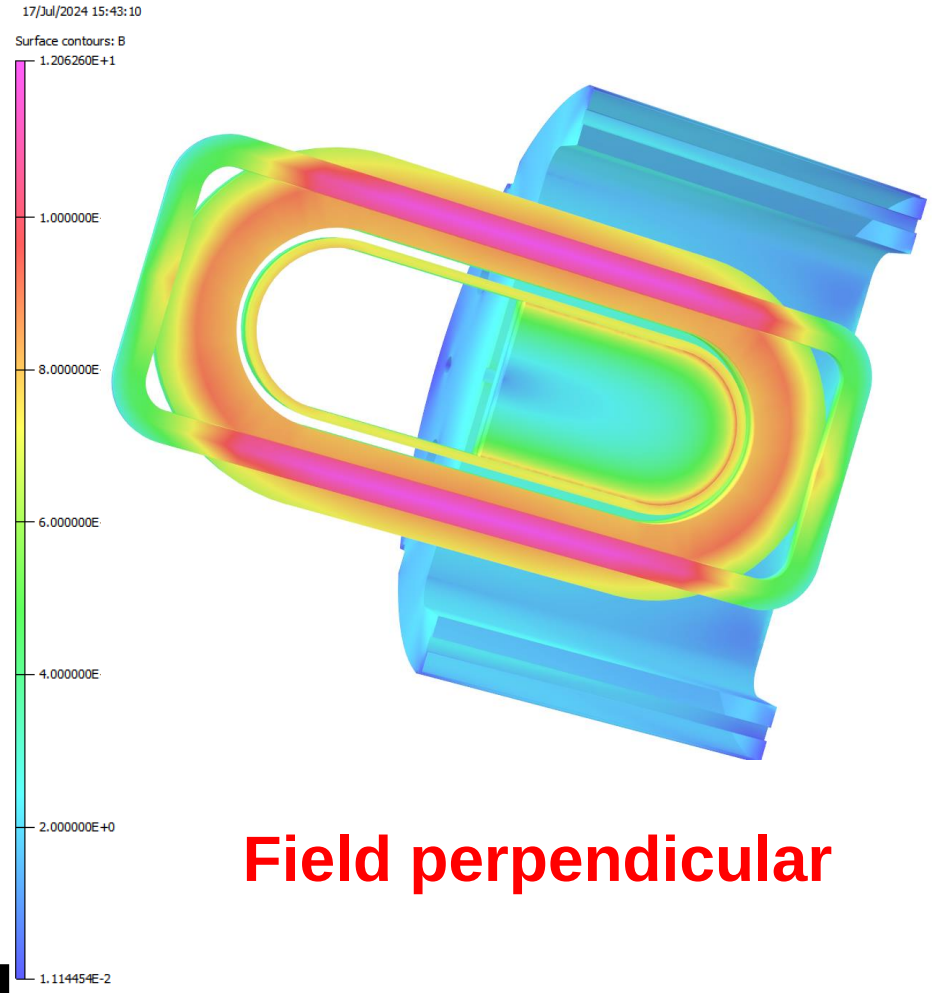
A couple of specific examples on future potential follows

MDP Goal of a 5 T standalone HTS Magnet and Hybrid Demo

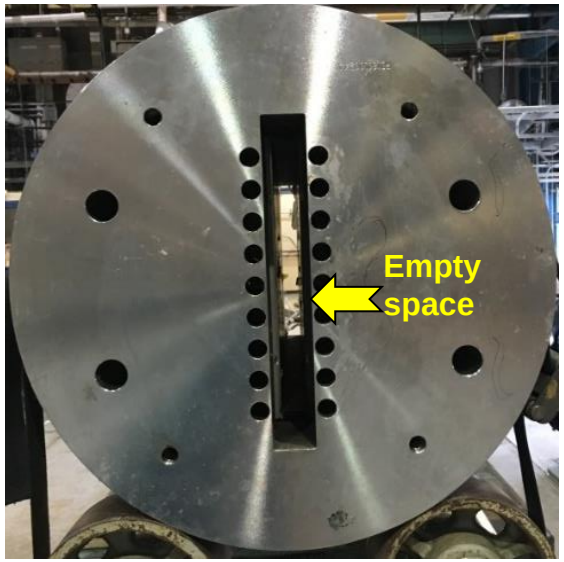
(Use existing FRIB and MDP coils for cost-effective programs)



FRIB HTS coils @520 A made with 12 mm HTS tape from SuperPower for 5T standalone



FRIB HTS coils made with 12 mm HTS tape from SuperPower in the background field of DCC017 @420 A for HTS/LTS hybrid test



Field parallel

Field perpendicular

BNL MDP HTS coil in structure

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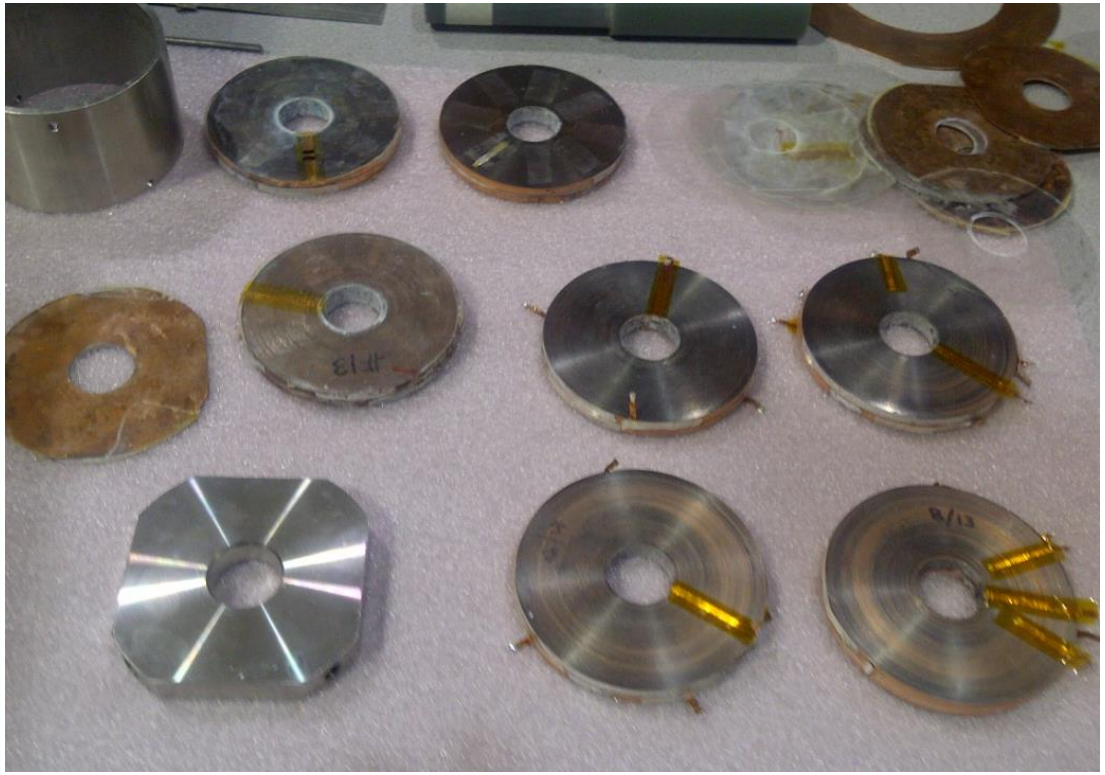
Quench studies with a large number of expensive HTS coils leftover from the previous R&D programs

(No fear of destroying them for a "burn to learn" approach)



Continue development of BNL's Advanced Quench Protection Electronics
Also, future potential of cryo-electronics (Piyush Joshi's presentation)

Summary

- **With an operating collider on site and another being built, BNL is a unique place for knowledge transfer to new generation.**
- **The team also has a culture for inventing new designs (for example, common coil, overpass/underpass, etc.), and then demonstrate them along with alternate technologies (HTS, React & Wind).**
- **The unique common coil test facility (CCTF) offers a new lower-cost, rapid-turn-around R&D approach for cable, coil and magnet R&D (both innovative and systematic). The demand is already high, and with some updates it is expected to grow substantially.**
- **A continued and enhanced support is critical for utilizing above.**

Extra Slides

List of Awards and Related Websites

https://wpw.bnl.gov/rgupta/

https://wpw.bnl.gov/rgupta/about/

Contributions and Collaborations – Technical

https://wpw.bnl.gov/rgupta/wp-content/uploads/sites/9/2024/03/Ramesh-Gupta-collaborations-2022-technical.pdf

Contributions and Collaborations – Managerial

https://wpw.bnl.gov/rgupta/wp-content/uploads/sites/9/2024/03/Ramesh-Gupta-collaborations-2022-manage.pdf

Upcoming funded experiments at CCTF

Magnet R&D using the unique common coil test facility:

- **This dipole has shown its unique value in performing valuable rapid-turn-around, lower cost magnet R&D (both innovative and systematic) for a variety of program and applications. Several are already lined up, a few examples:**
- **CFS is getting ready to test 6 cables in one go while paying with its own fund. CFS is also setting Strategic Partnership Program (SPP) for future tests.**
- **US-Japan HEP R&D funded for another two years**
- **PSI is getting ready for more BigBox experiments**