Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Magnet R&D Overview

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Overview

- **A walkthrough of a selected magnet R&D initiatives @ BNL**
- **Most were funded from the external sources such as SBIR, arpa-e, MSU/FRIB, international, US-Japan, INFUSE, etc.**
- **Many have the potential for attracting future business**
- **Those opportunities will be the focus of this presentation**

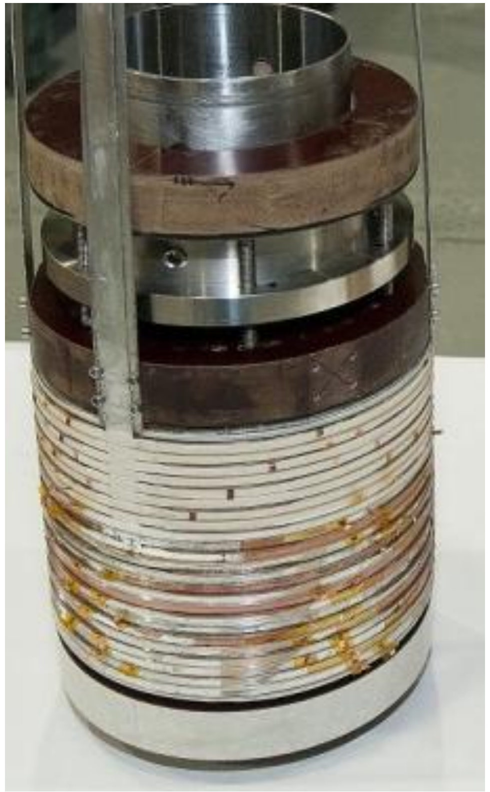
HTS Coil and Magnet R&D

HTS 16 Tesla Solenoid (Record HTS field in 2012)

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

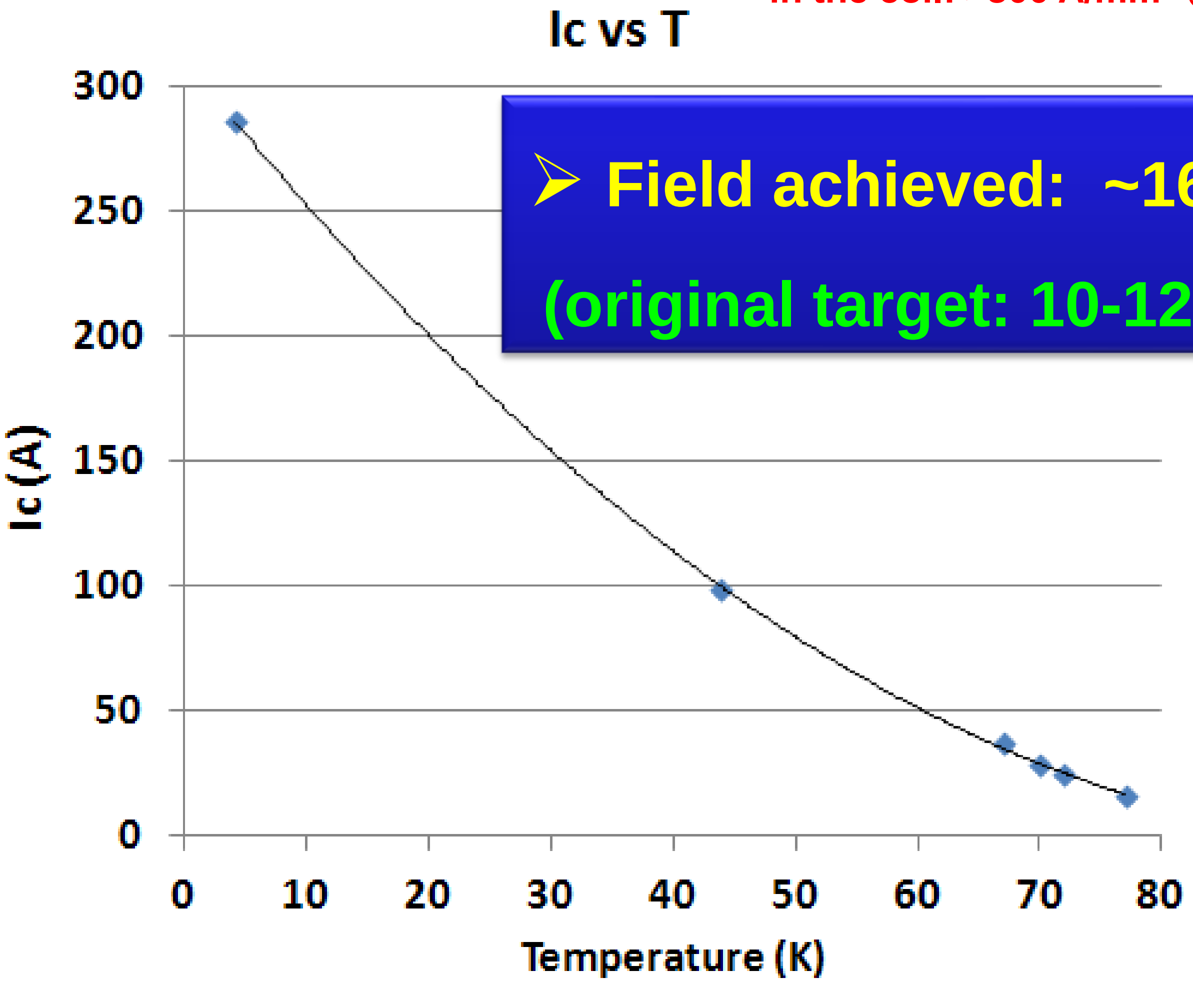
Insert solenoid

Use these coils for quench studies (see next slide)



Outsert solenoid

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



- **Field achieved: ~16 T**

(original target: 10-12T)

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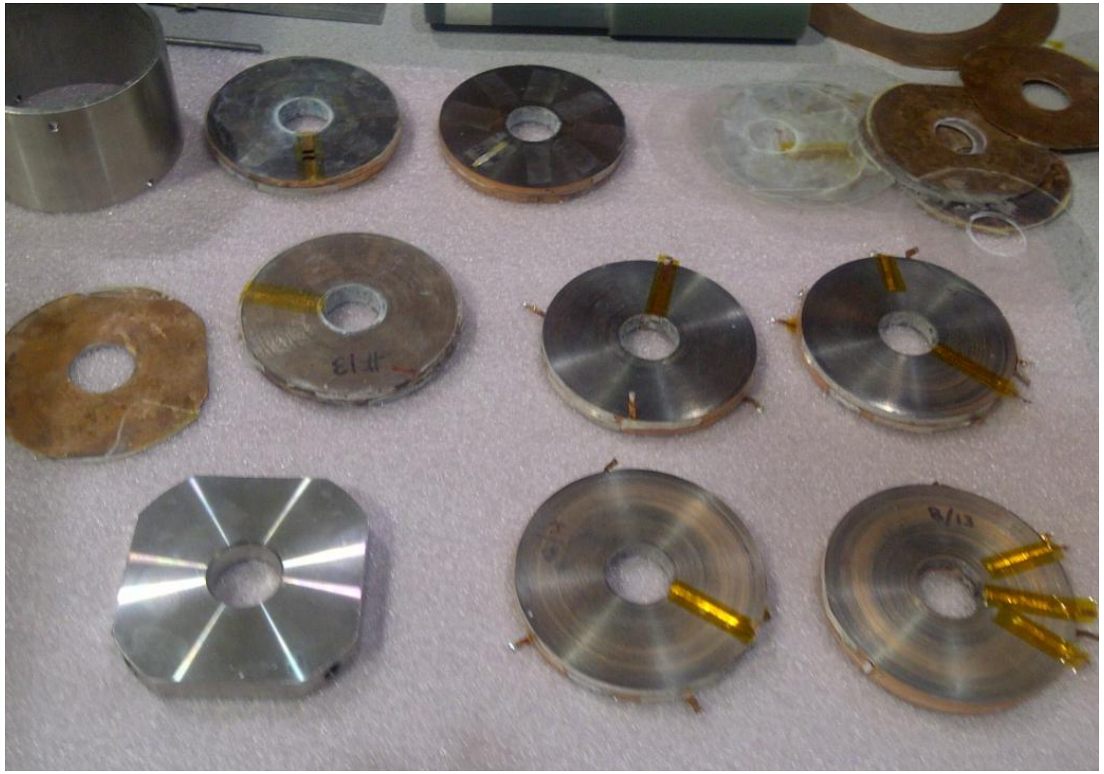
Quench studies with a large number of expensive HTS coils leftover from the previous R&D programs

(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)

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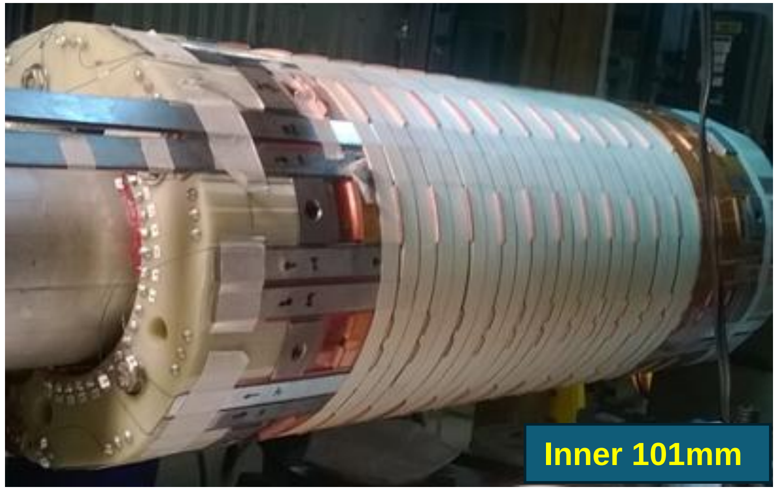
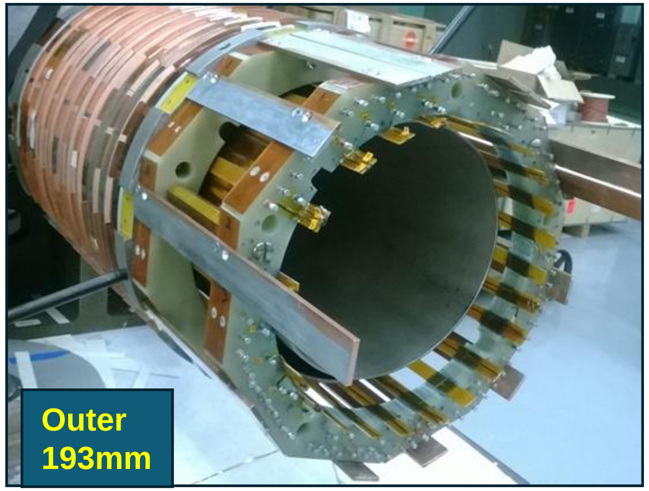
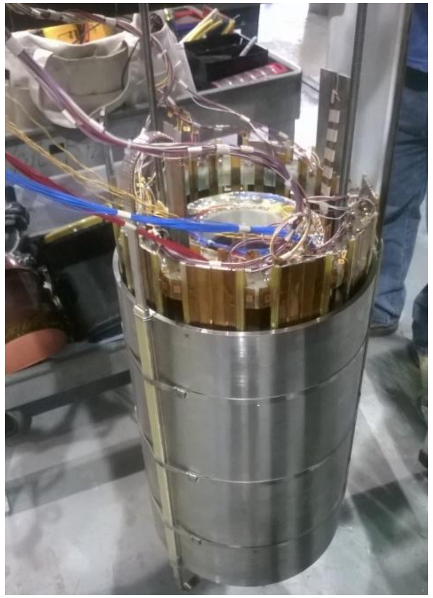
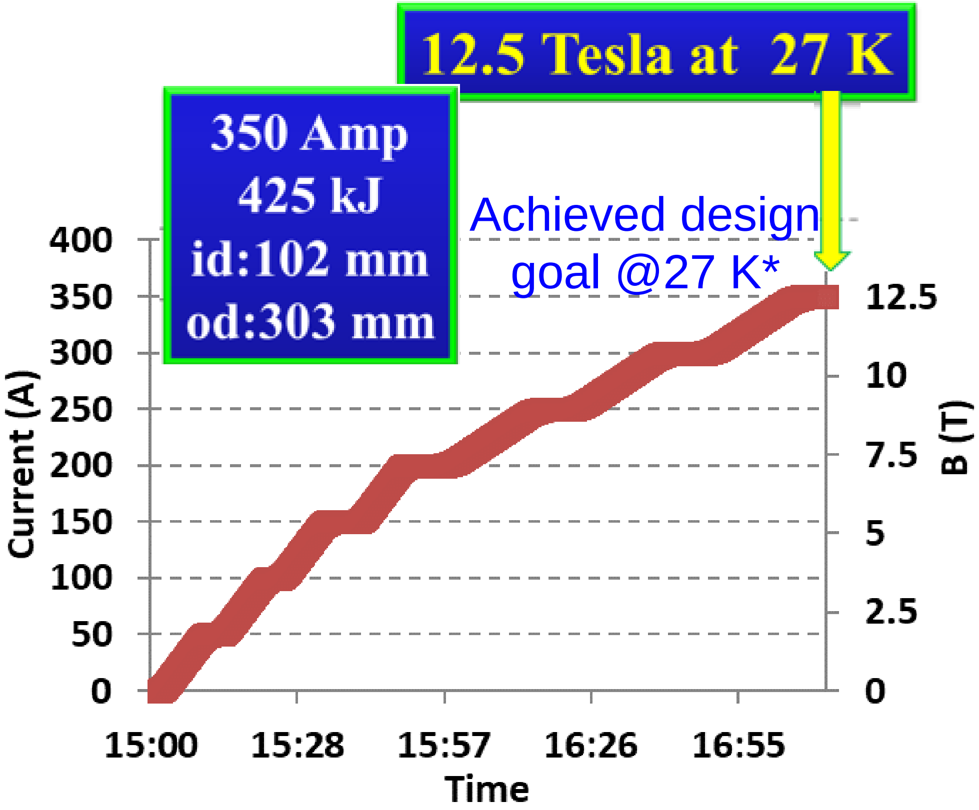
High Field 100 mm HTS Solenoid (SMES ARPA-E, Axion Korea)





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

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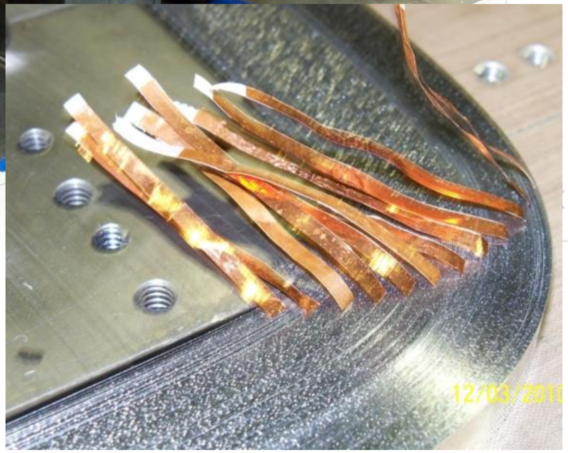
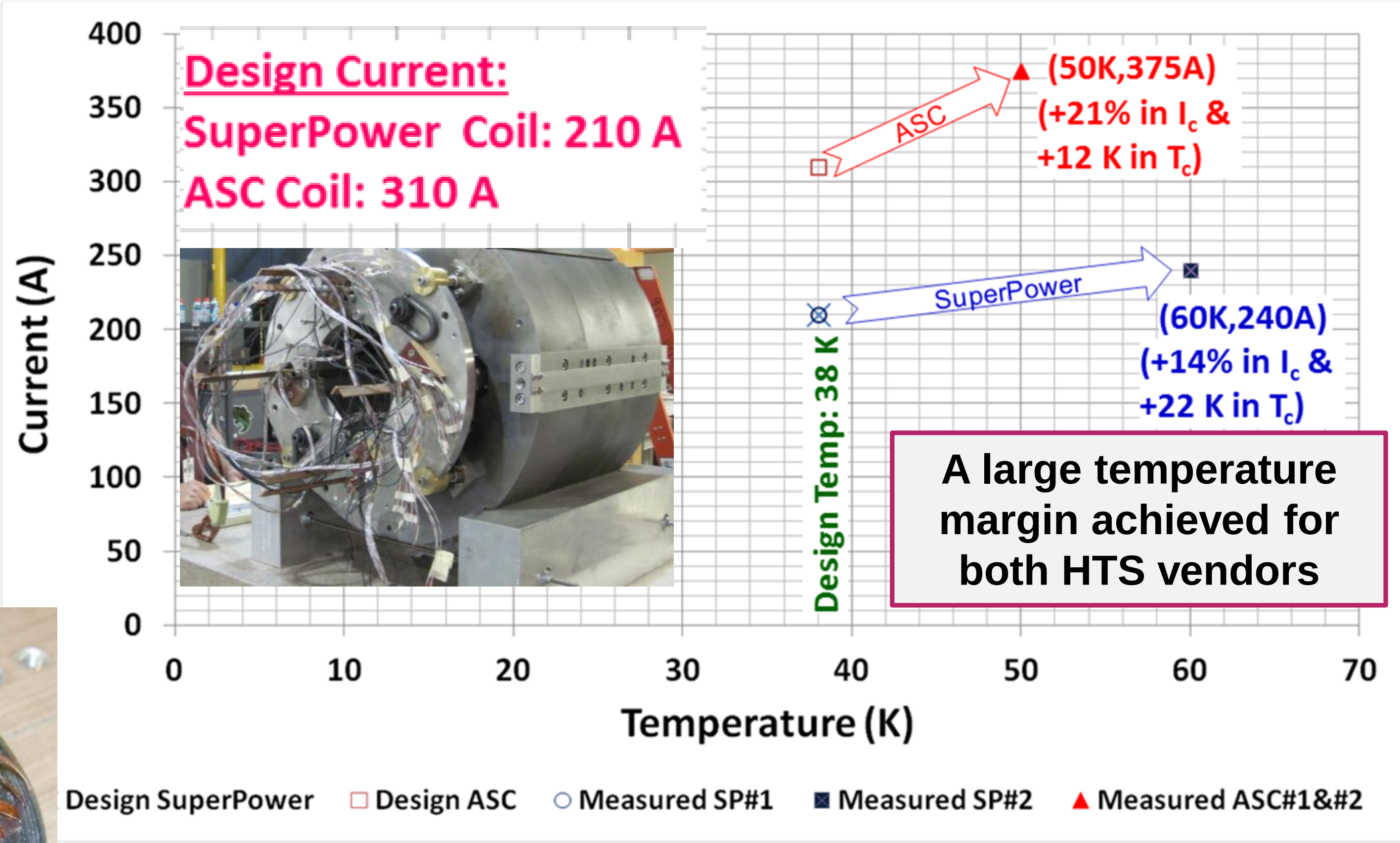
(some coils are available, more may be obtained for future R&D)

High Operating Temperature HTS Quadrupole for FRIB

Four large heavily instrumented coils



~3 km of 12 mm wide HTS tape



A large temperature margin achieved for both HTS vendors

8 large HTS are coils available for future R&D (next slide)

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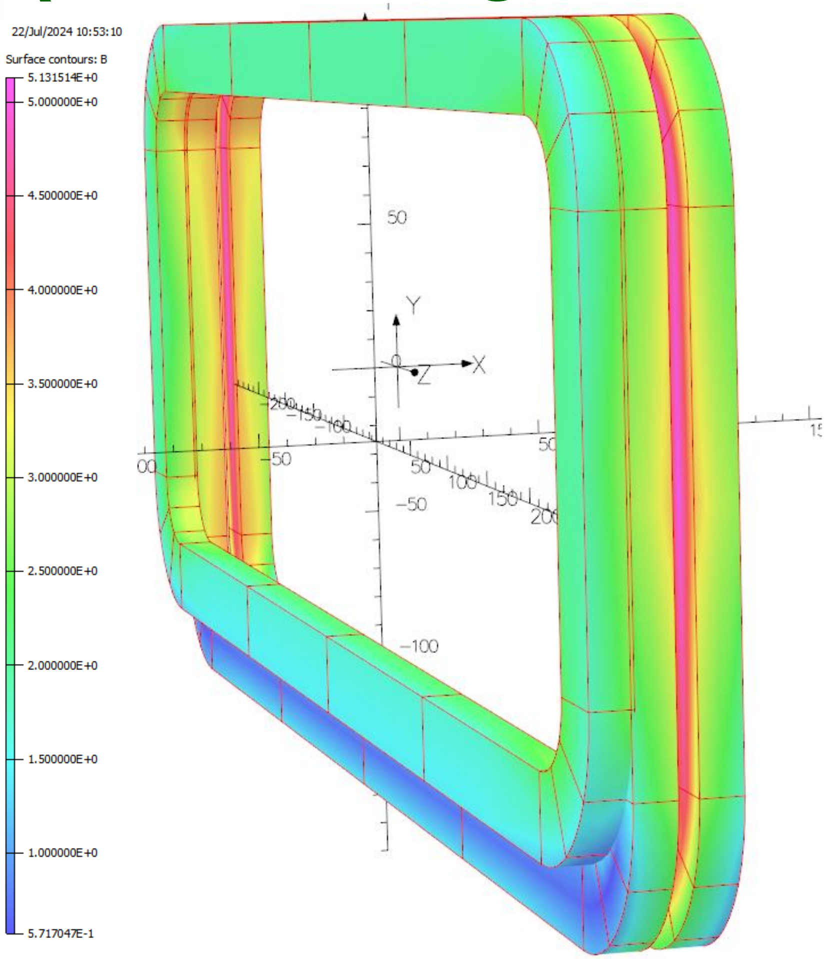
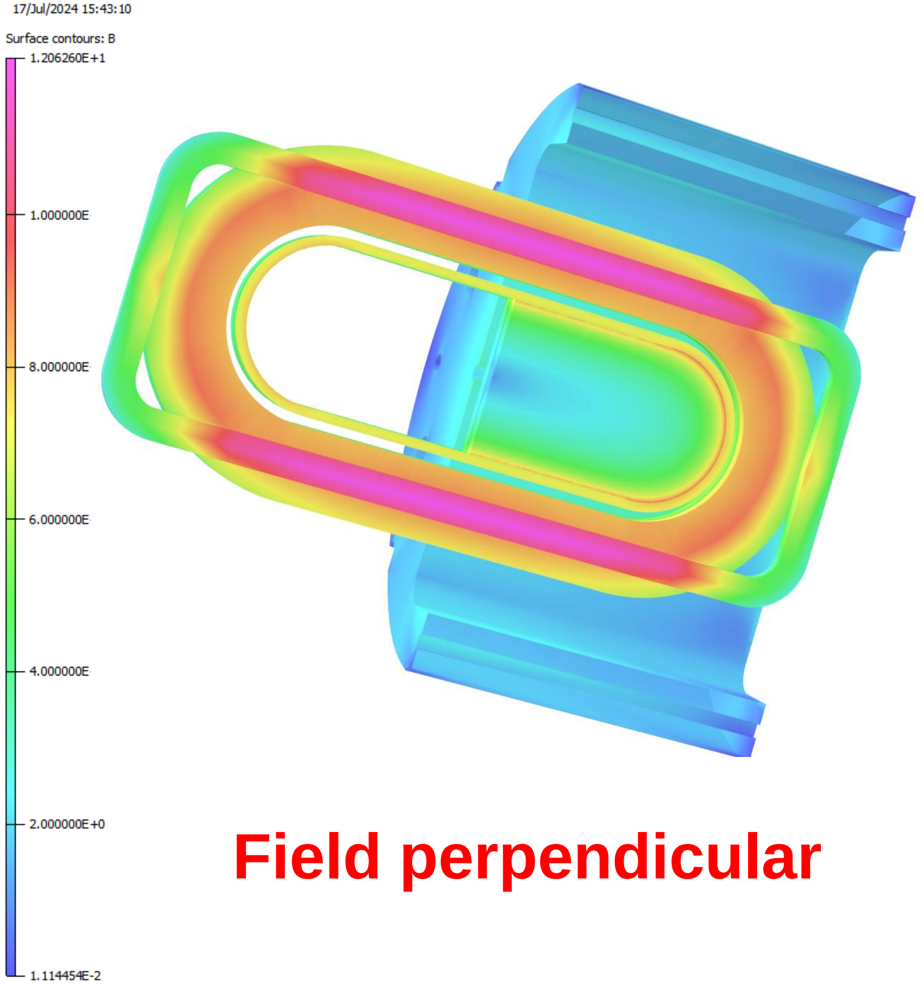
MDP Goal of a 5 T standalone HTS Magnet and Hybrid Demo

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

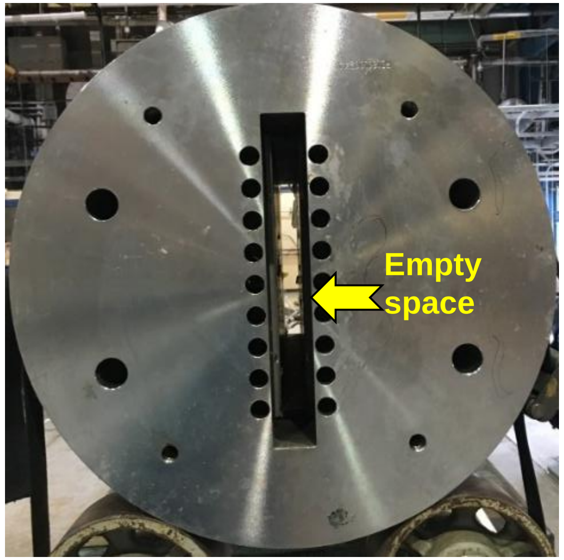


FRIB HTS coils @520 A made with 12 mm HTS tape from SuperPower for 5T standalone



Field perpendicular

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

BNL MDP HTS coil in structure

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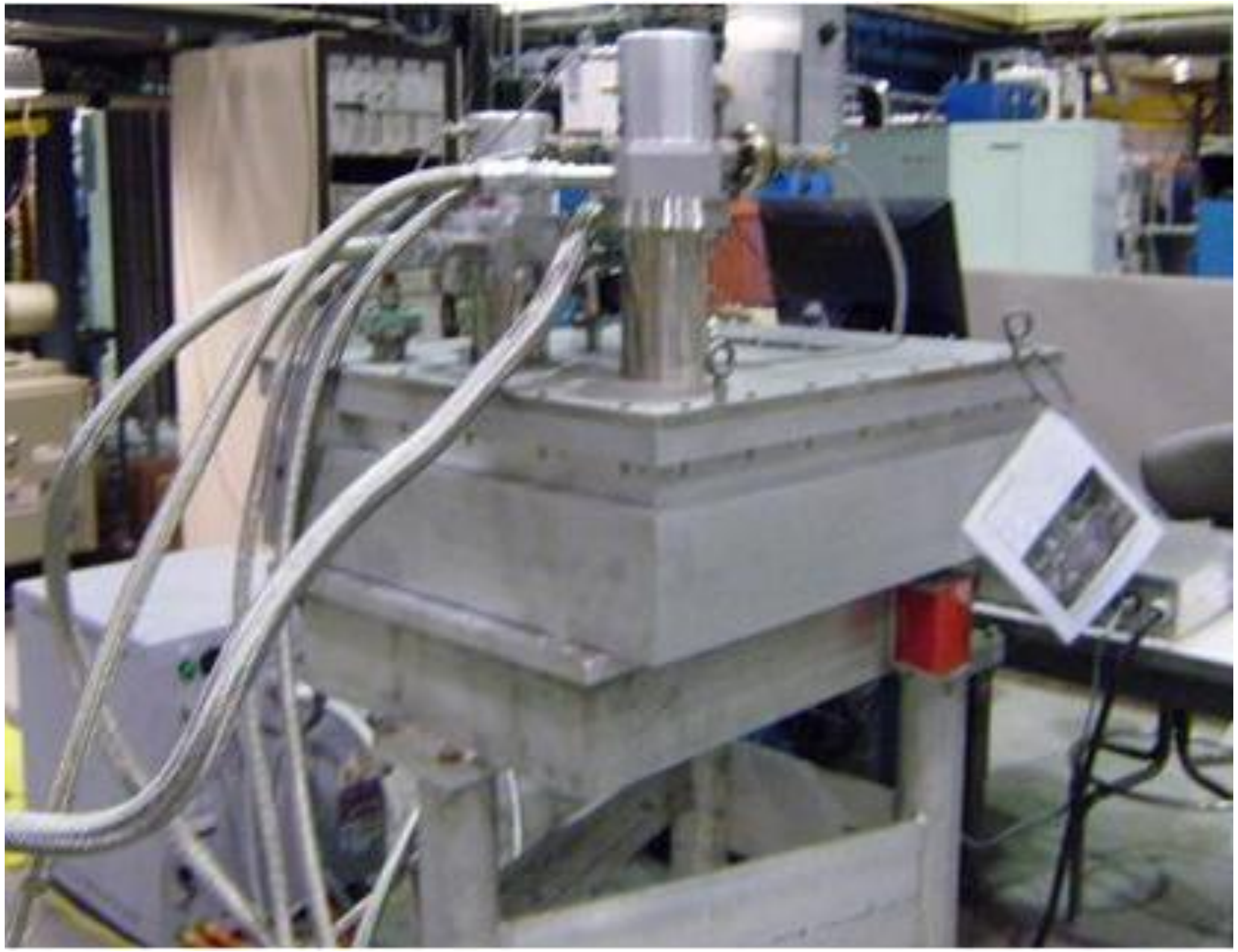
A Facility for HTS Magnet R&D with Cryo-cooler

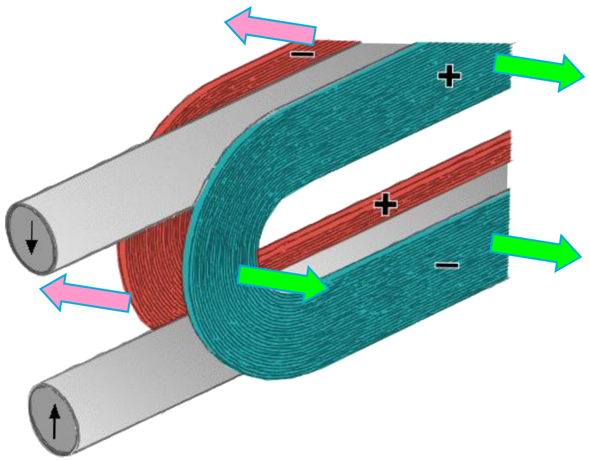


- Good test bed for HTS coil technology (bolted structure)
- No Helium, no personnel
- Turn on cryo-coolers in the evening & start experiment in the morning…

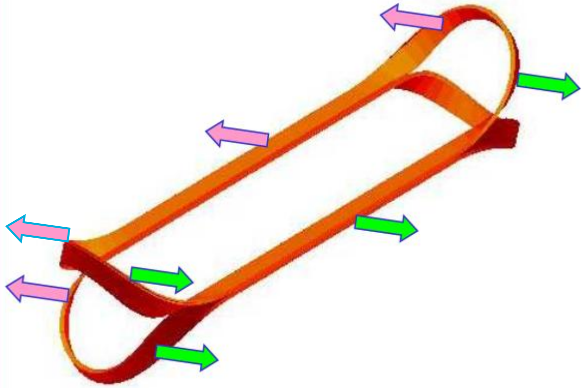
Magnet Designs and Technologies

(we should be able to leverage some of them for future collaboration and possible funding as they were invented/developed at BNL)

High Field Common Coil 2-in-1 Dipole Designs



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



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

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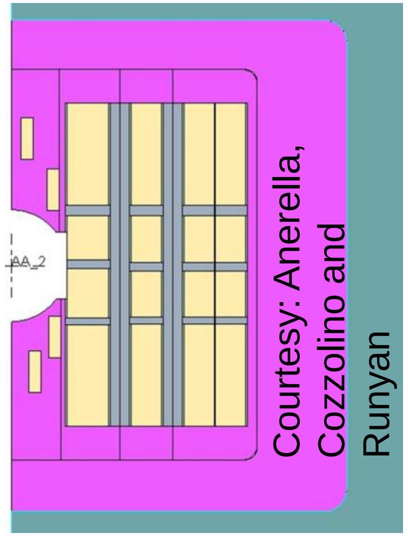
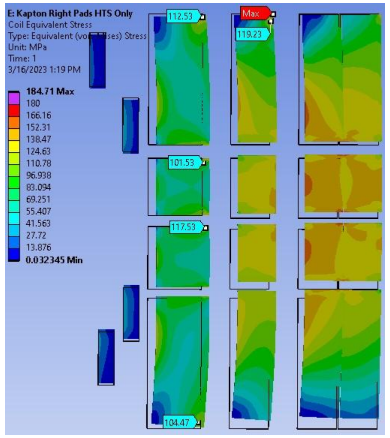
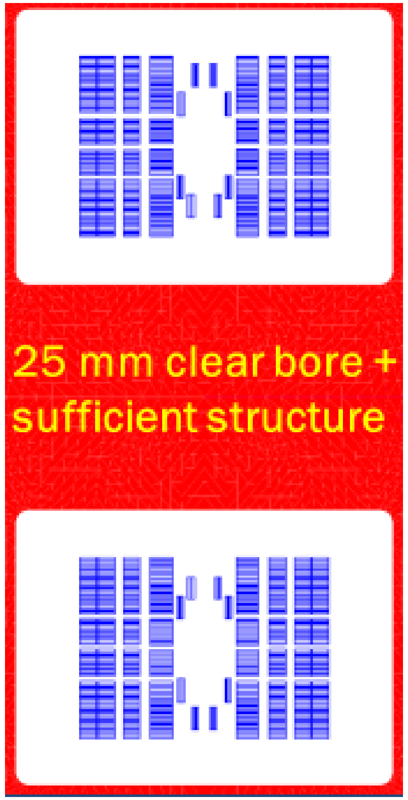
20 T HTS/LTS Hybrid Design (MDP)

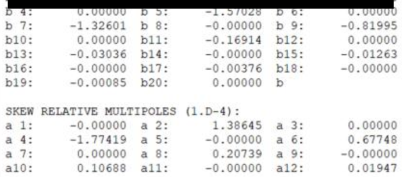
Simpler structure for stress management







Design with a good field quality with 20% margin

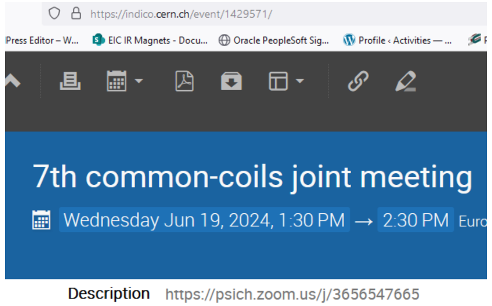


b 4:	0.00000	b 5:	-1.57028	b 6:	0.00000
b 7:	-1.32601	b 8:	-0.00000	b 9:	-0.81995
b10:	0.00000	b11:	-0.16914	b12:	0.00000
b13:	-0.03036	b14:	-0.00000	b15:	-0.01263
b16:	-0.00000	b17:	-0.00376	b18:	-0.00000
b19:	-0.00085	b20:	0.00000	b	

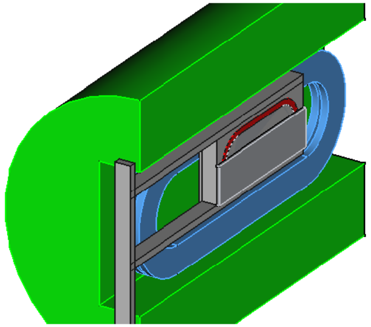
SKEW RELATIVE MULTIPOLES (1.D-4):

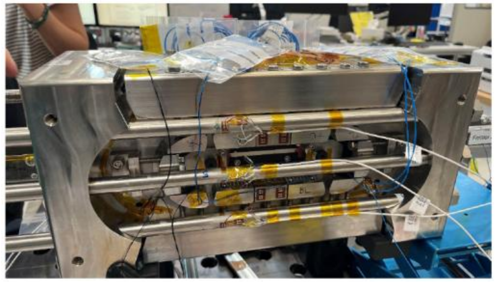
a 1:	-0.00000	a 2:	1.38645	a 3:	0.00000
a 4:	-1.77419	a 5:	-0.00000	a 6:	0.67748
a 7:	0.00000	a 8:	0.20739	a 9:	-0.00000
a10:	0.10688	a11:	-0.00000	a12:	0.01947

International Collaboration (MDP)



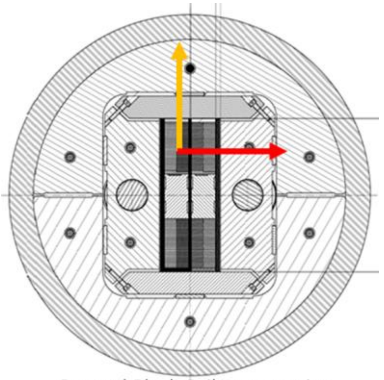
HFM High Field Magnets Programme · CHART Swiss Accelerator Research and Technology · PSI





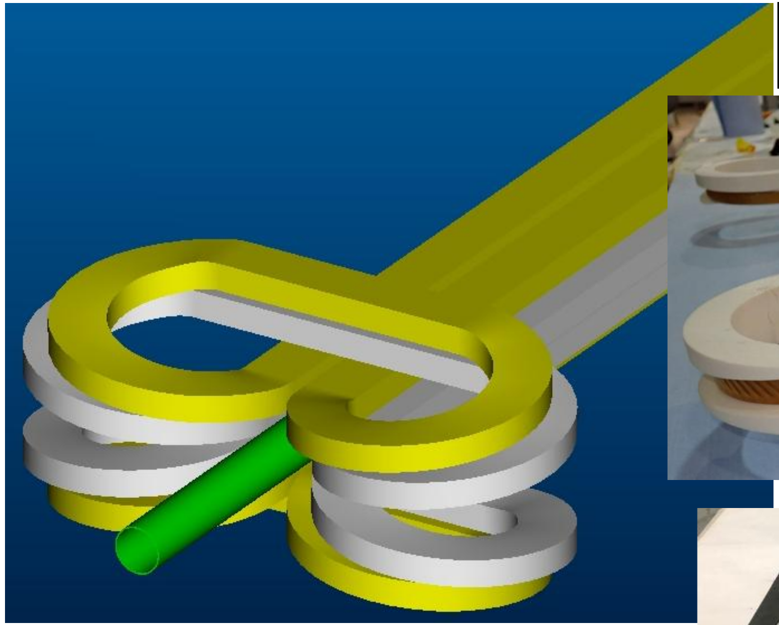
CIEMAT program using CERN coils

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

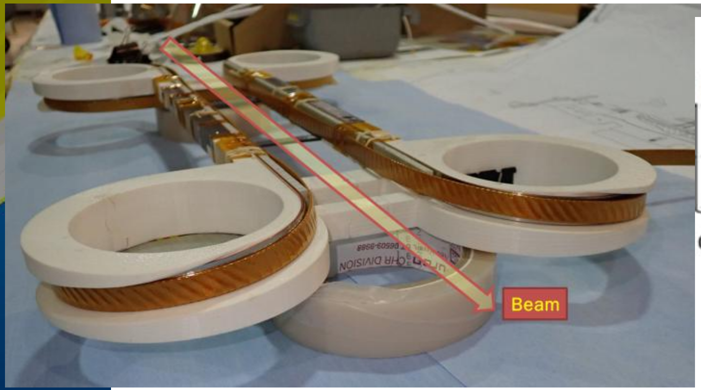


Rotated Block Coil cross-section

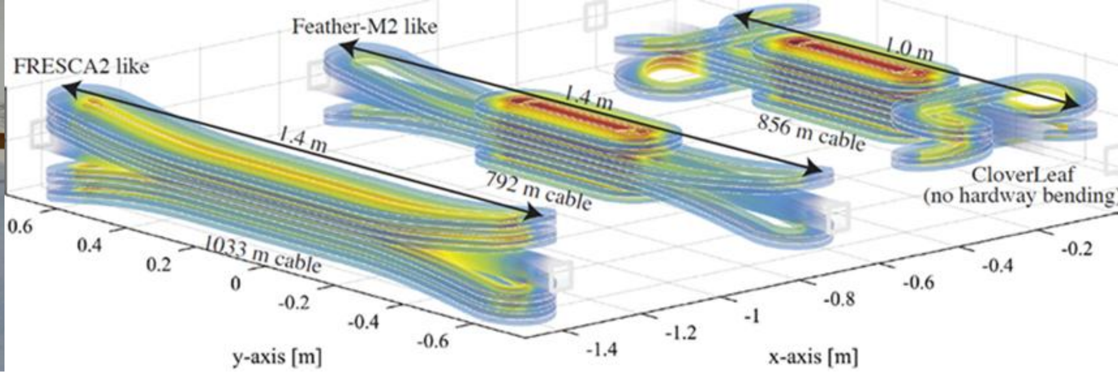
OverPass/UnderPass Design for Single Aperture Magnet



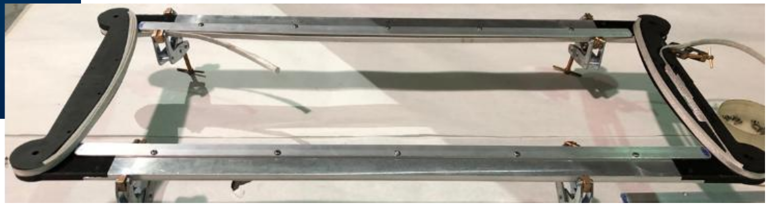
PBL/BNL STTR (2021)



Collaboration with CERN (MDP)



(aka: Clover-leaf design)



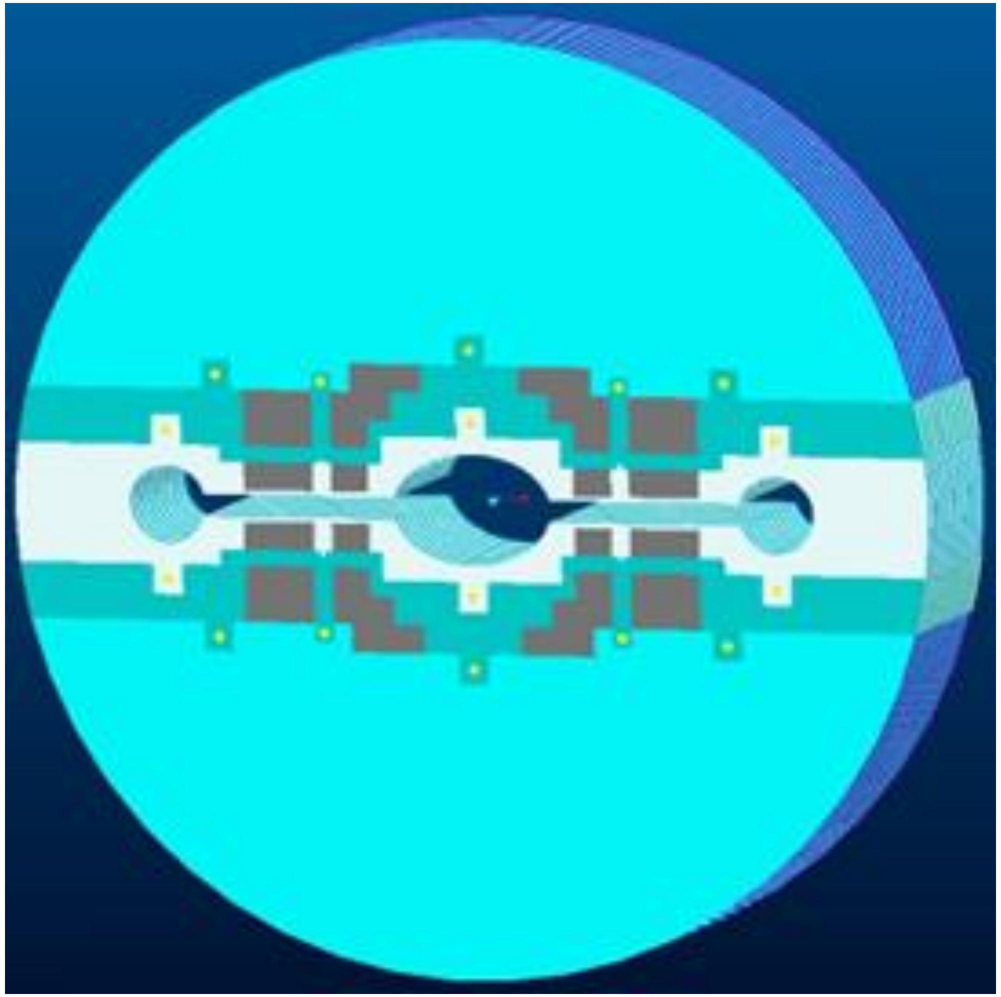
Highway Driving

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

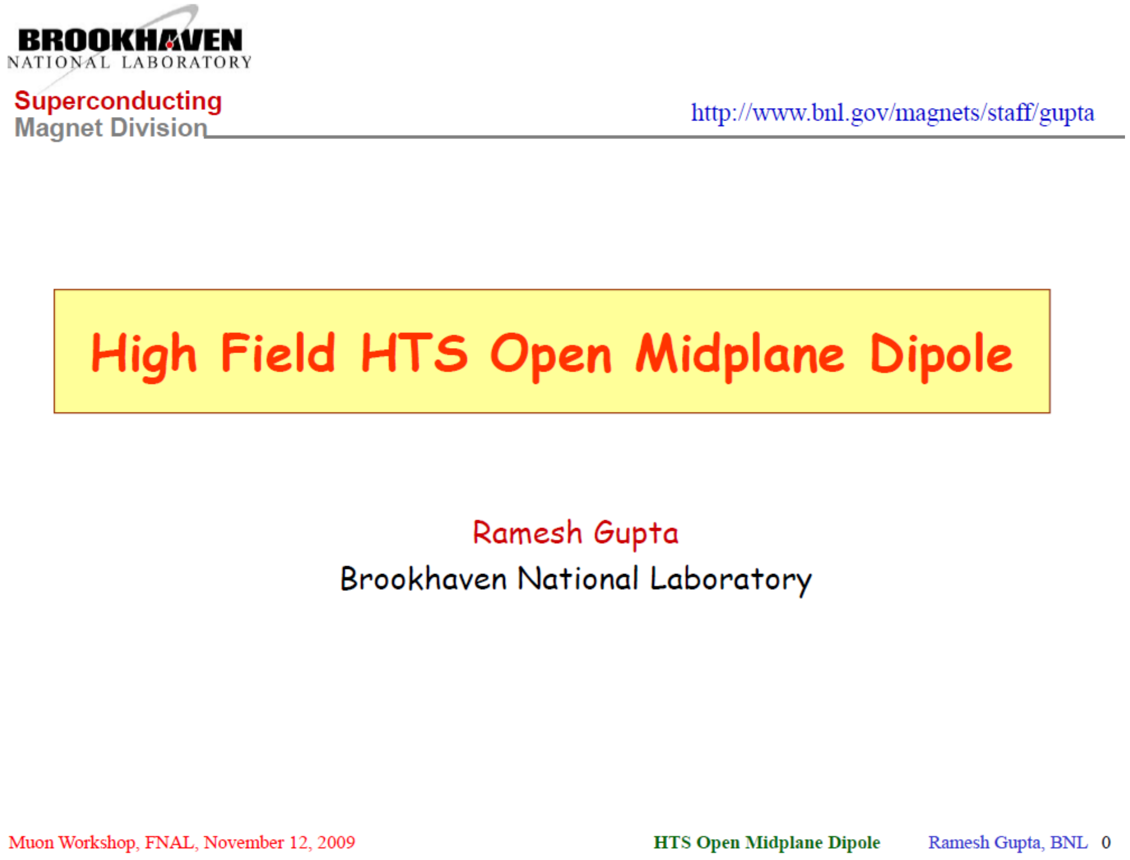
Conductor friendly design for high field conductors

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

Open Midplane Dipole for Muon Collider (truly open)

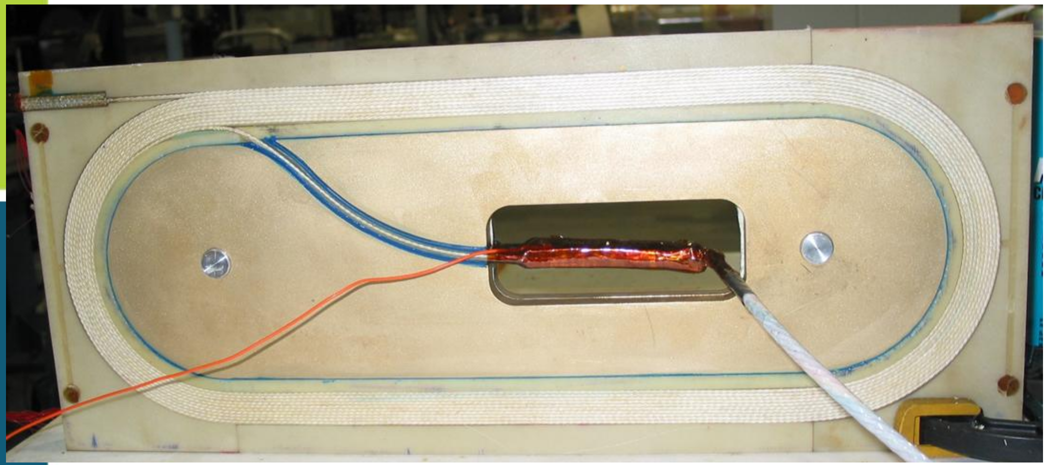


2009

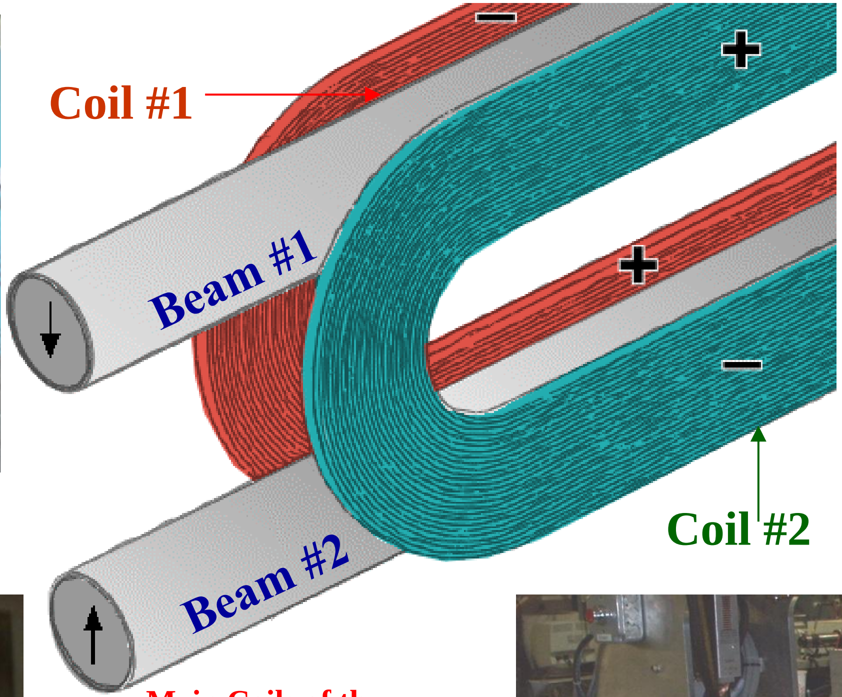


Now being pursued in Europe (BNL has a potential to join)

React & Wind Technology (Nb_3Sn, Bi2212 Cable)

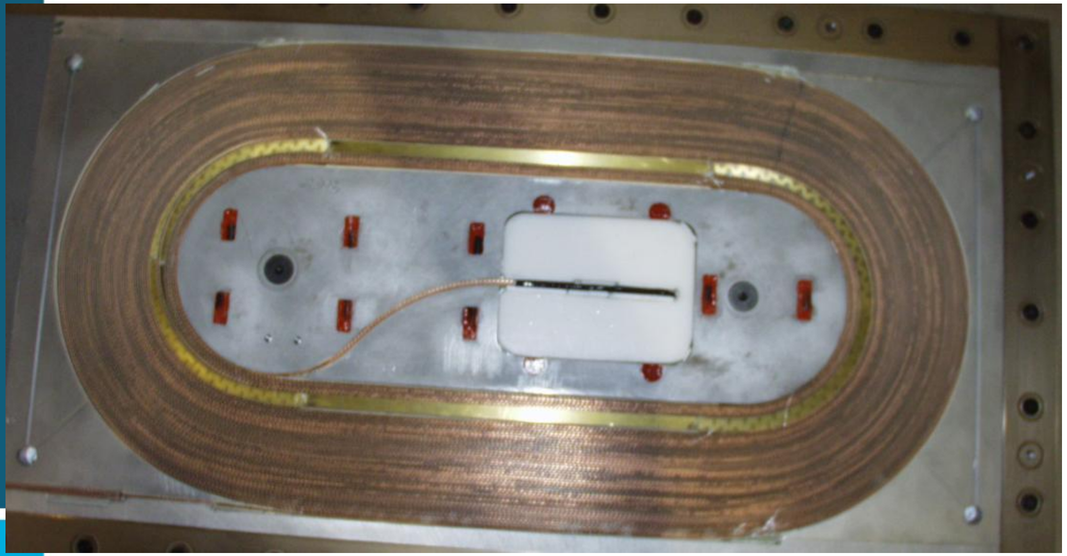


React & Wind Bi2212 Coil

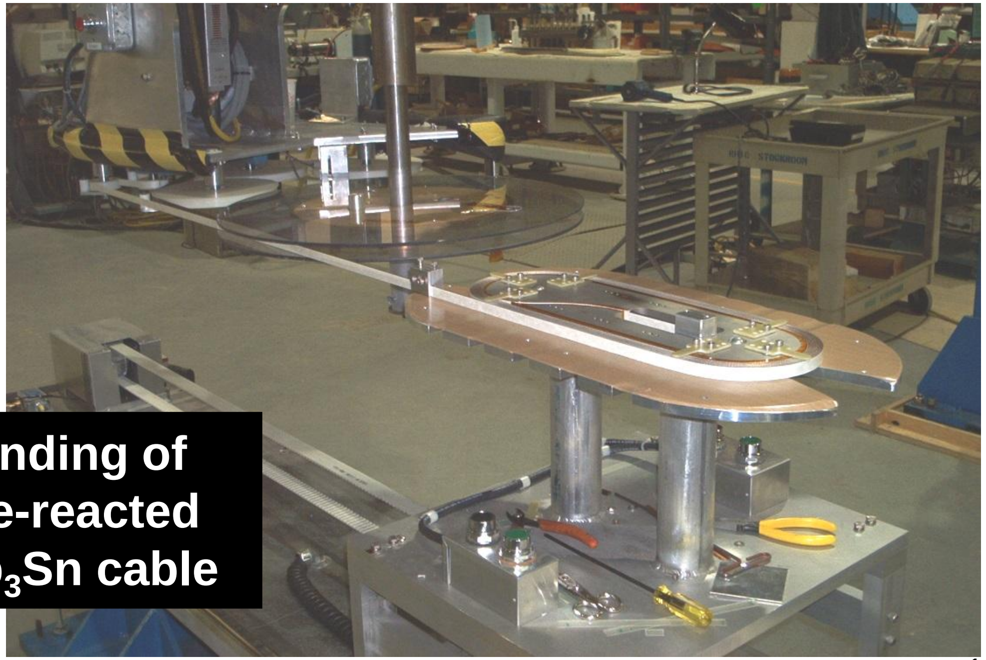


Main Coils of the
Common Coil Concept

- React & Wind technology offers several advantages.
- BNL has successfully developed design and proven technology.
- BNL can collaborate in this area.



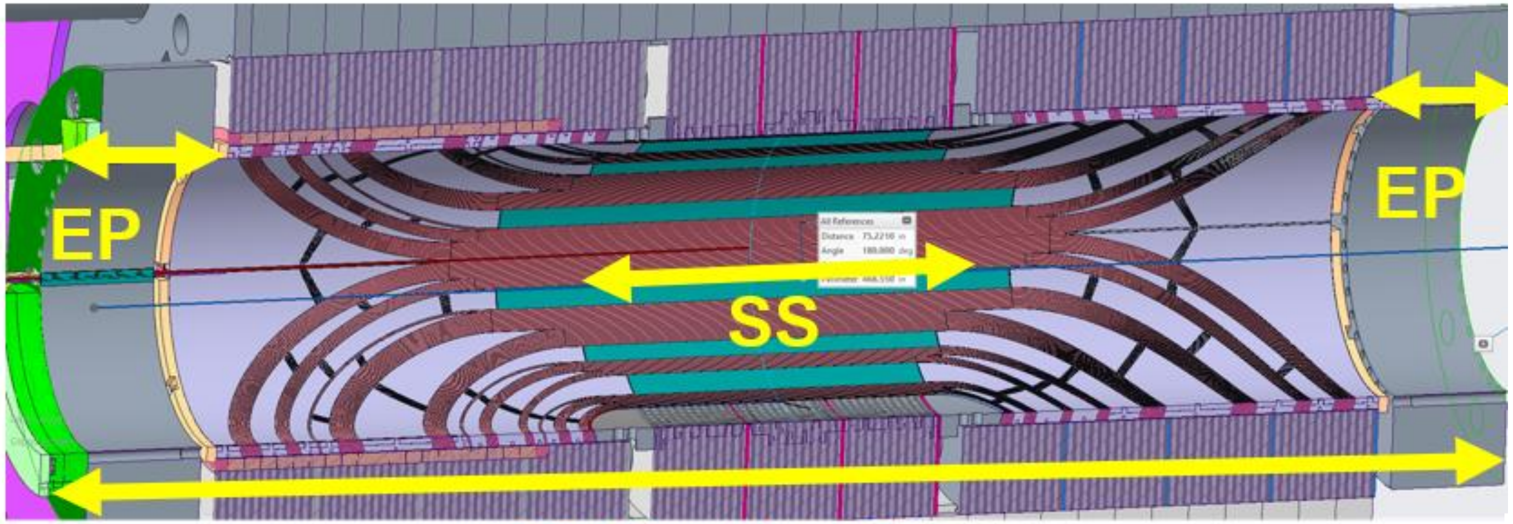
React & Wind Nb_3Sn Coil



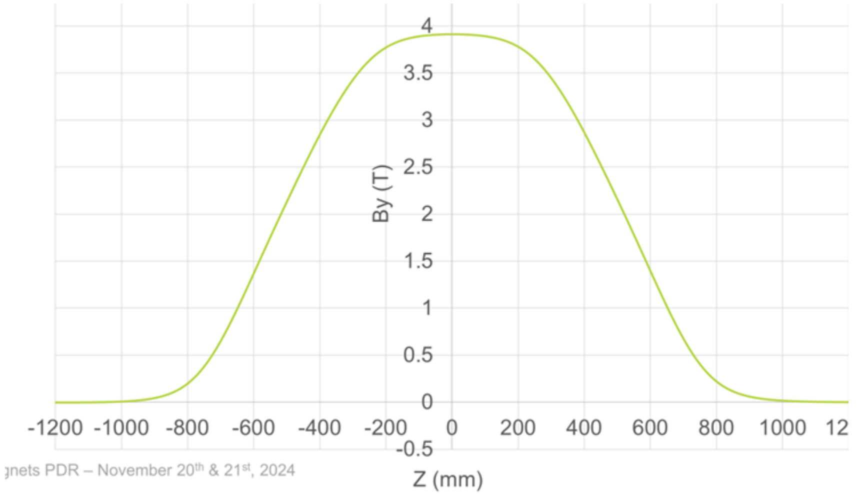
Winding of pre-reacted Nb_3Sn cable

Direct Wind Technology and Optimum Integral Design

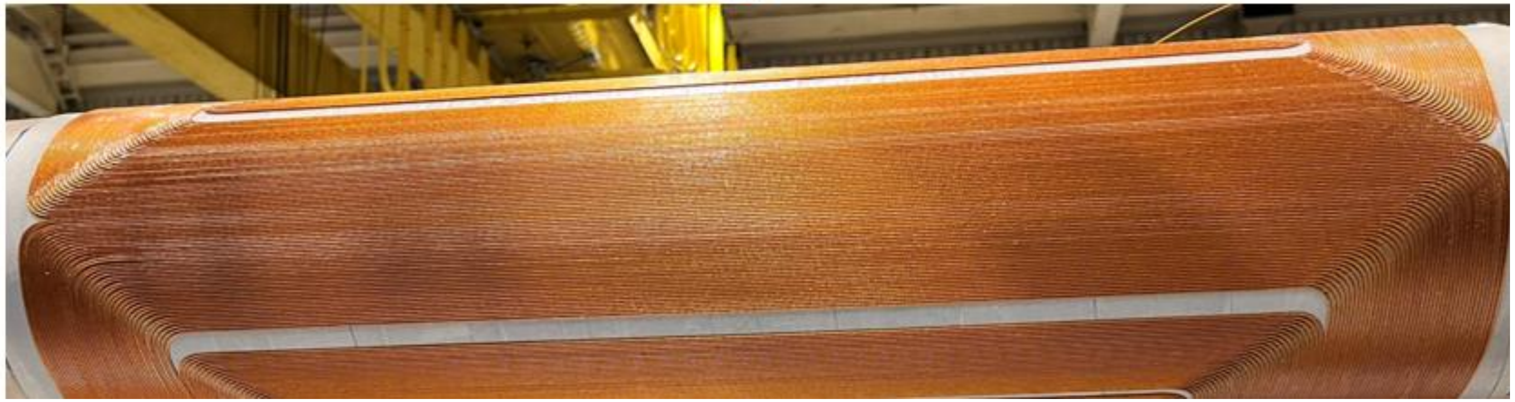
Cable design

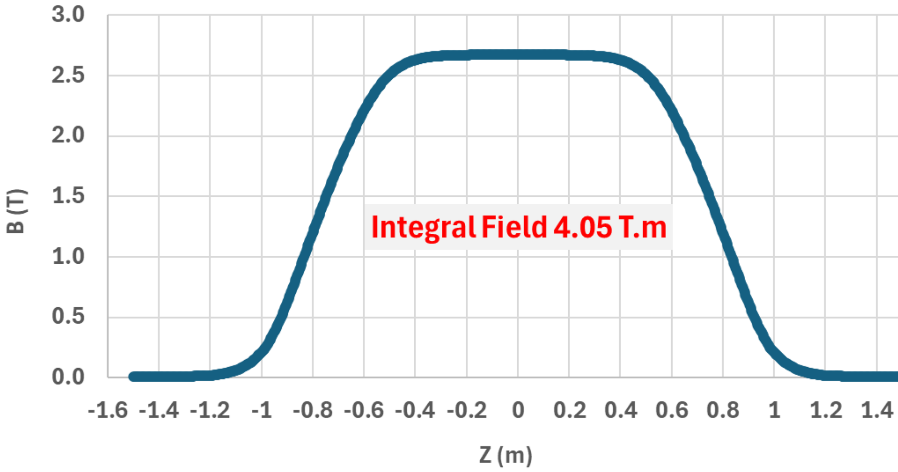


Total Length=1.91 m



Optimum Integral





B_o goes down from ~4 T to ~2.6 T; forces and stresses go down as B^2

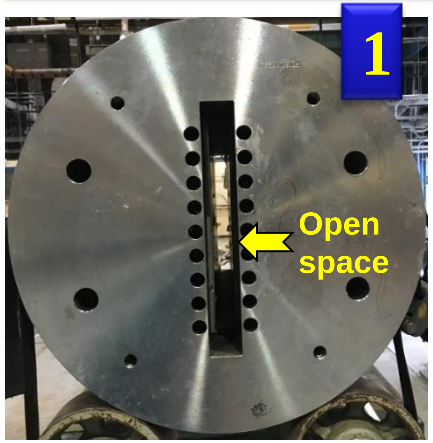
- **Direct wind: cheaper and faster for one-off magnets, as in EIC**

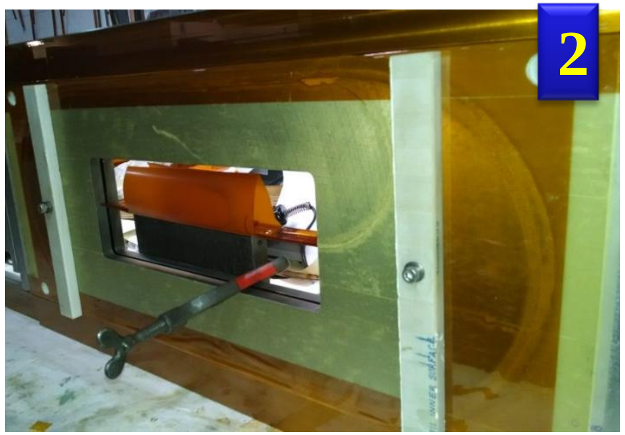
Common Coil Test Facility (CCTF)

Common Coil Test Facility (CCTF) at BNL

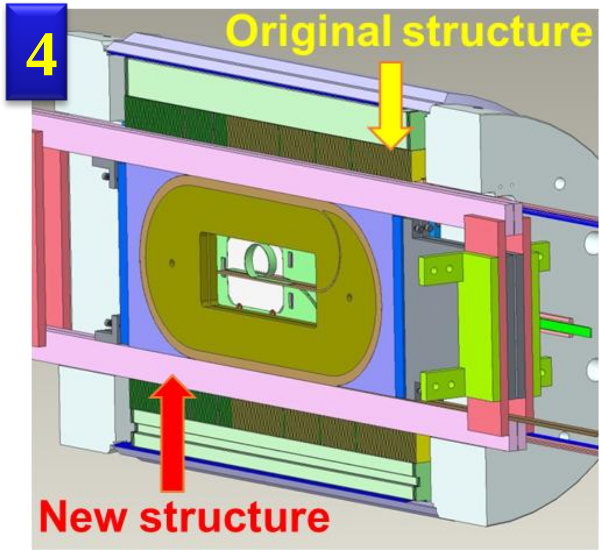
(based on a unique common coil dipole with a large opening)

Five steps for testing new design





1. Magnet (dipole) with a large open space
2. Insert coil or (bent) cable for high field testing
3. Slide module in the magnet
4. Coils become an integral part of the magnet
5. Coil test becomes a magnet test



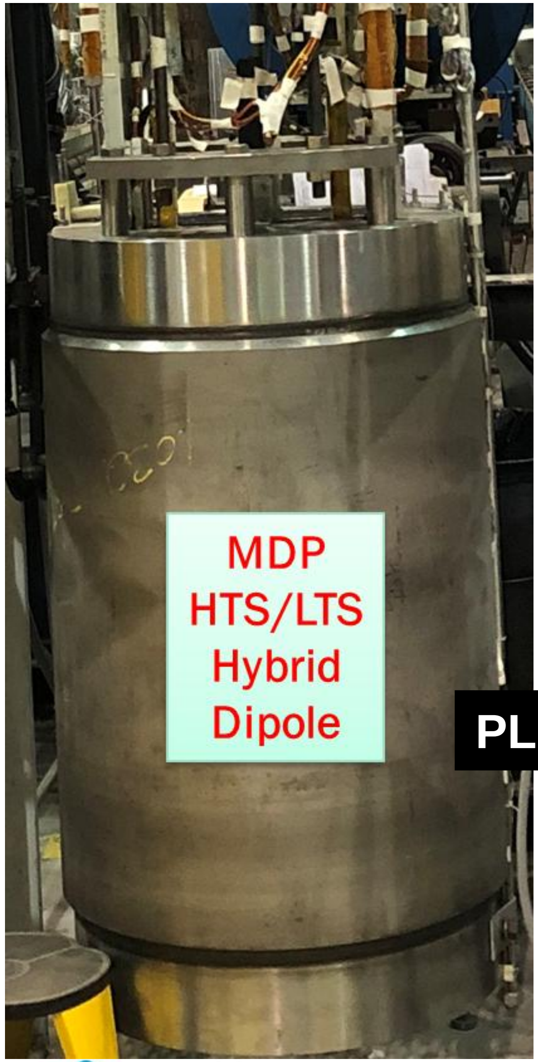
Rapid-turn-around and lower-cost R&D => changes the way we do both the innovative R&D and the systematic R&D

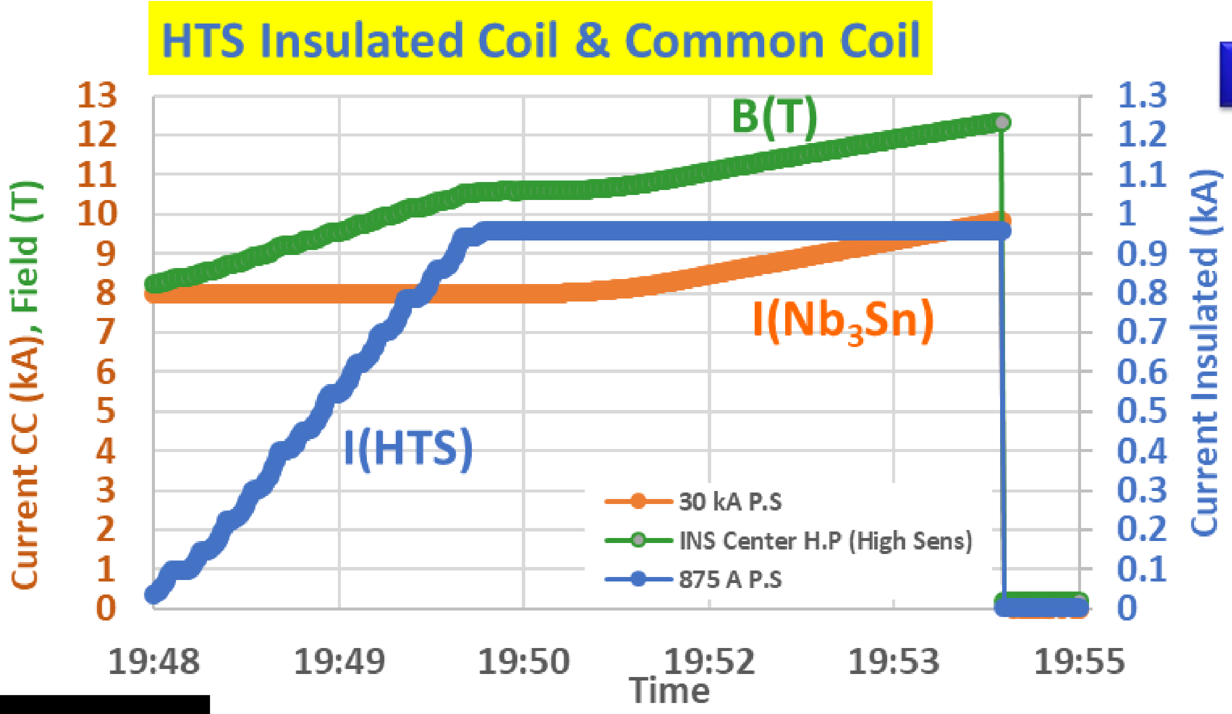
Some funded proposals with the unique Common Coil Dipole

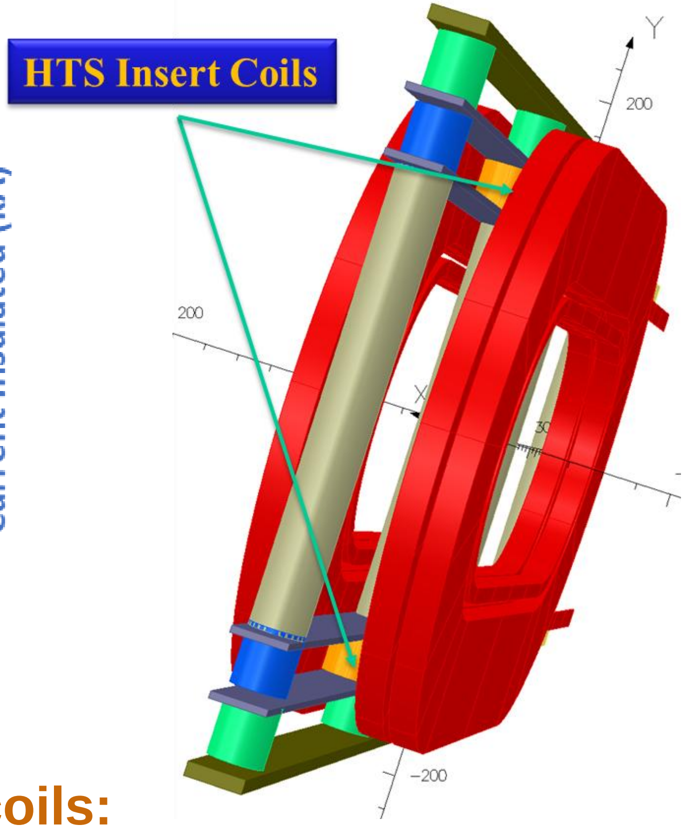
- PBL/BNL HTS/LTS dipole creating record 8.7 T hybrid field - field primarily perpendicular on the HTS coil
- MDP HTS/LTS dipole creating record 12.3 T hybrid field – field primarily parallel on the HTS coil
- CORC®/Nb_3Sn dipole for quench studies (two tests supported by MDP)
- CORC®/Nb_3Sn high field HTS/LTS hybrid dipole (funded by STTR)
- PSI Wax impregnation high tests for reducing training and high stress- one completed, other waiting to be tested (supported by MDP)
- CFS tests of VIPER cable - three tests one each funded by INFUSE, arpa-e, CFS
- US-Japan HEP test (one completed, for other coils are bring made)
- GA INFUSE test (recently completed, another possible)

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

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



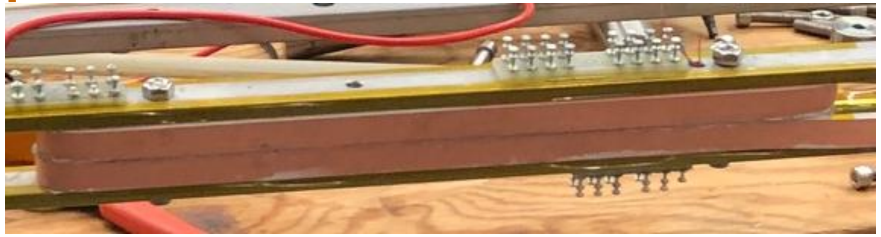




PLUS MORE

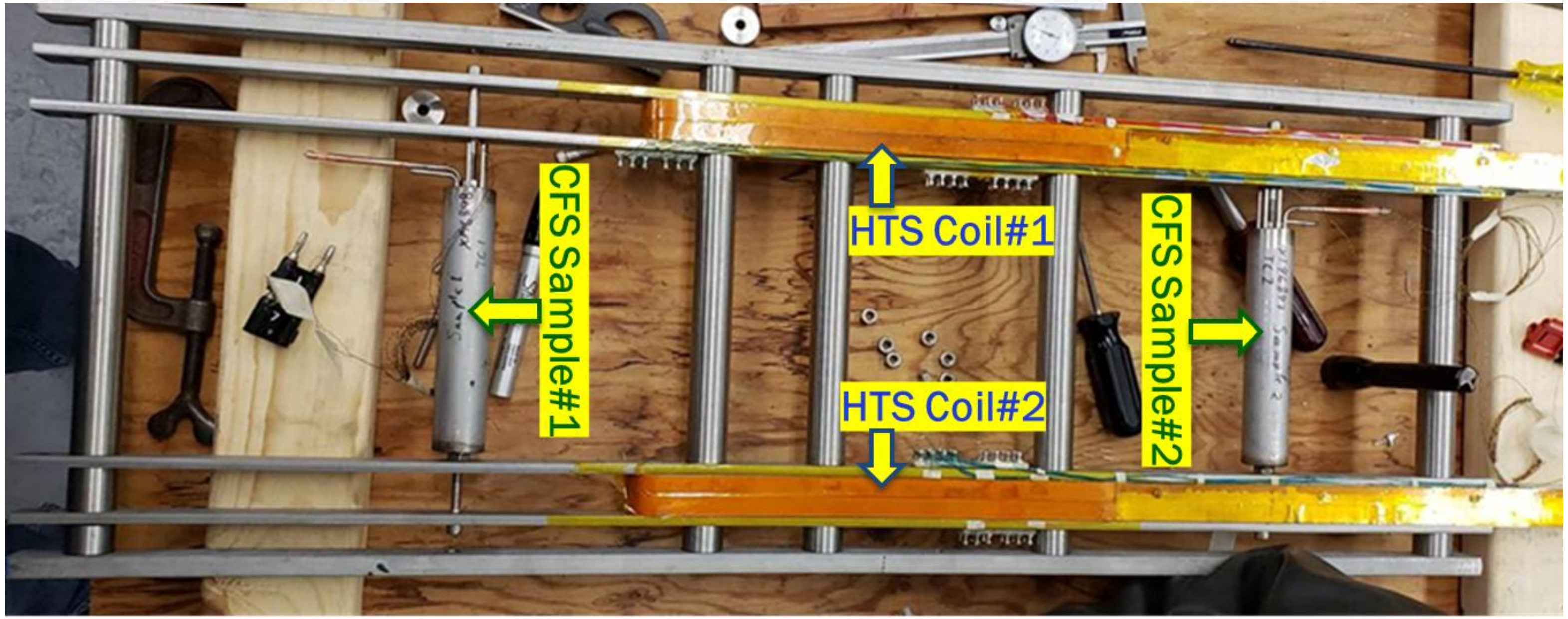
One run and two tests - 2 aperture 2 HTS insert coils:

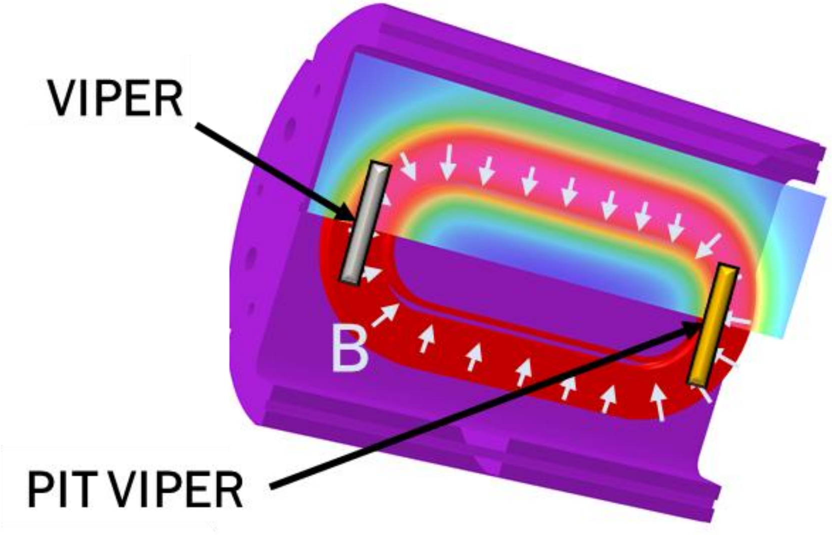
Aperture #1: Coil#1 with insulation; Aperture #2: Coil#2 with NO-insulation



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

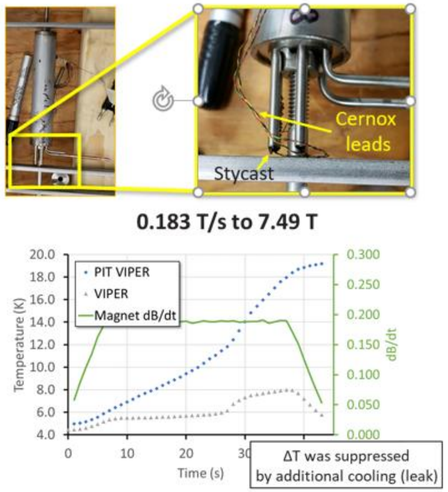
CFS

SPARC

Brookhaven National Laboratory

Program goals

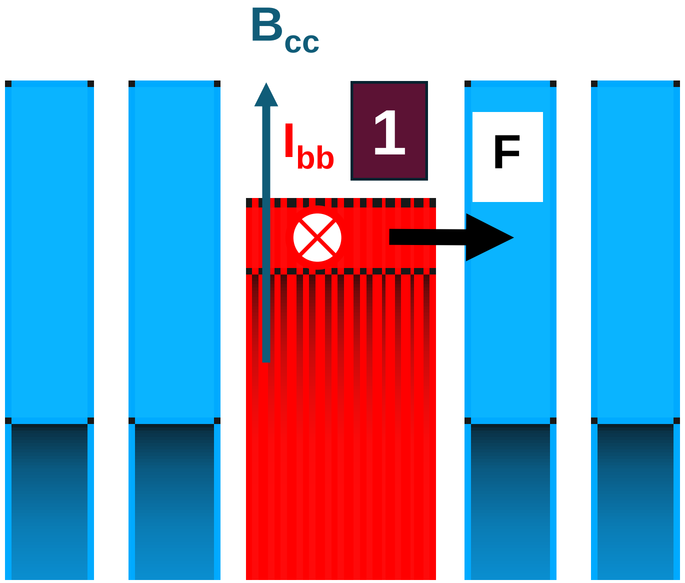
1. Characterize PIT VIPER cable AC losses at relevant dB/dt
   Note: induced currents from the changing magnetic field are heating up the sample (AC losses).
2. Characterize and qualify novel quench detection systems.
   Note: quench detection systems are not being qualified with transport current, only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

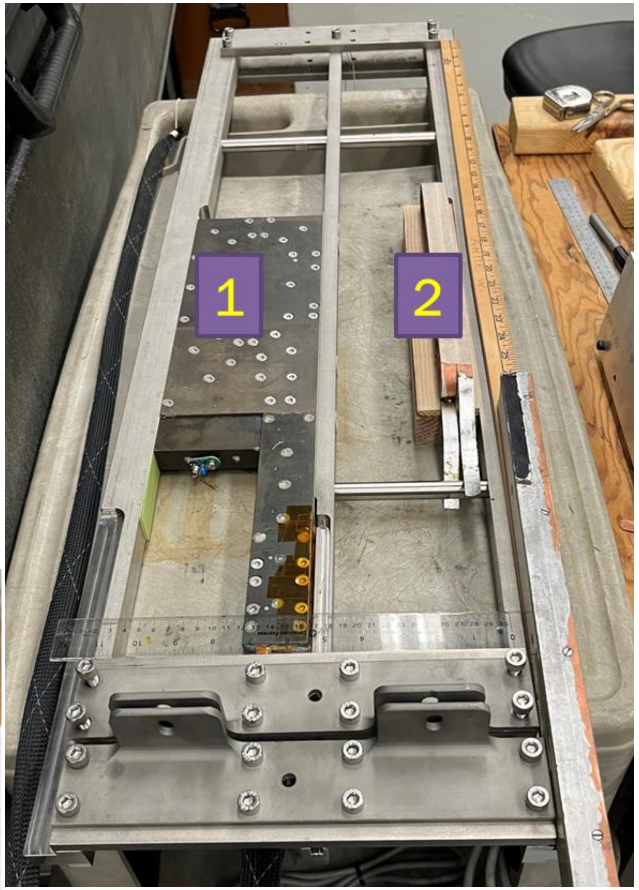


- ✓ **This test successfully demonstrated the design and benefit of the MIT/CFS VIPER cable. successful Crucial test of CFS PIT VIPER Cable.**
- ✓ **A crucial test for fusion**
- ✓ **HTS cables developed for fusion can be used by HEP.**

Wax Impregnated Nb_3Sn Coil (BigBOX) under High Magnetic Field

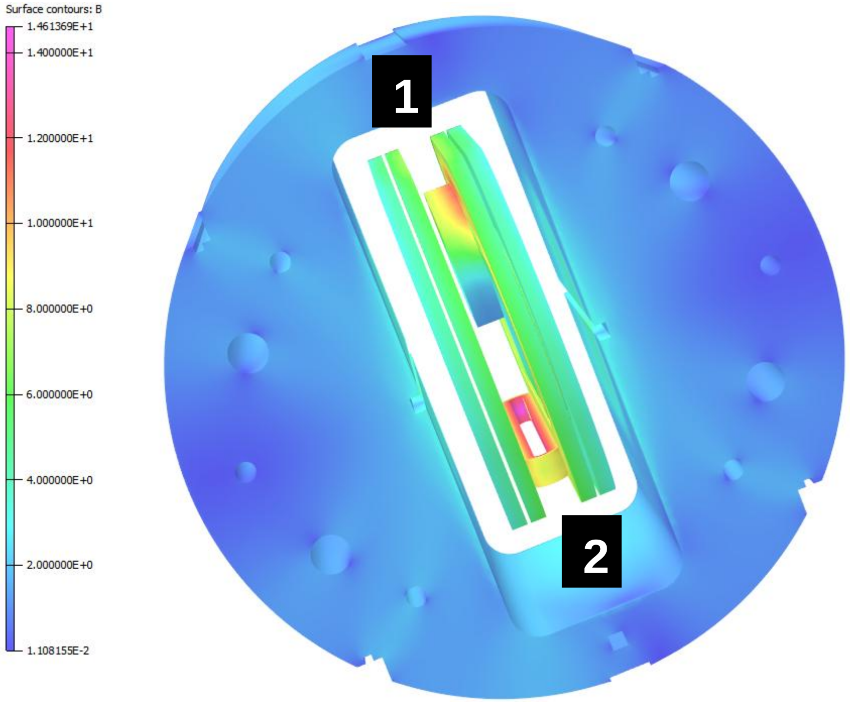
(CCTF for low-cost, fast-turn-around test, and such test not possible elsewhere)





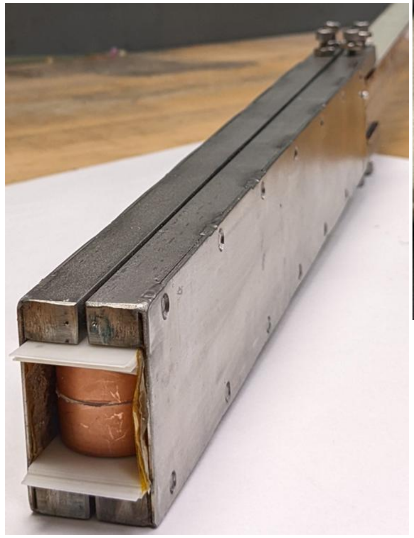
Test goals:

- 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)



PSI

The Paul Scherrer Institute (Switzerland)

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

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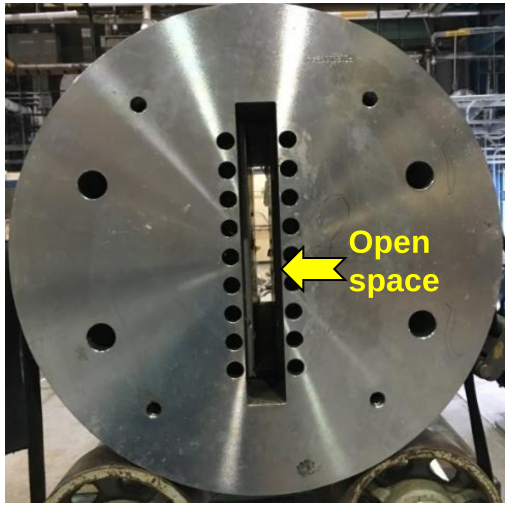
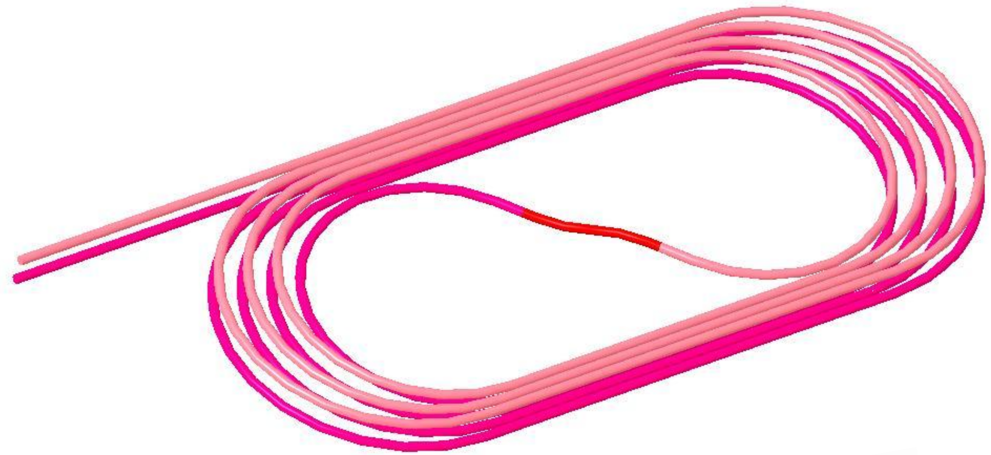
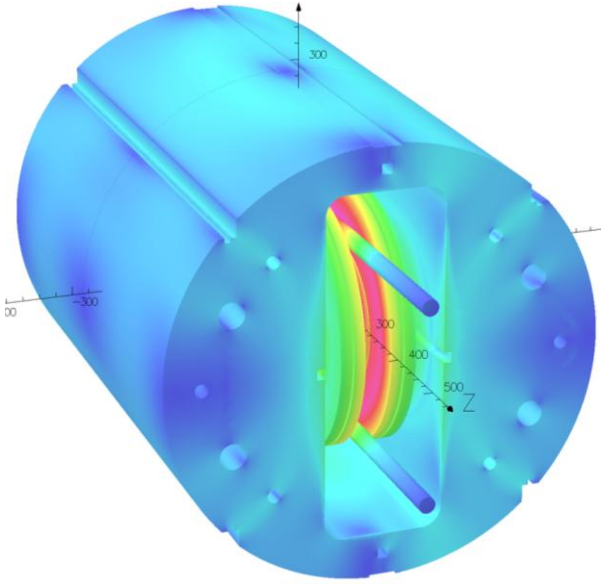
Common Coil Test Facility (CCTF) to Test the Viability of CORC® Cable in Accelerator Magnets

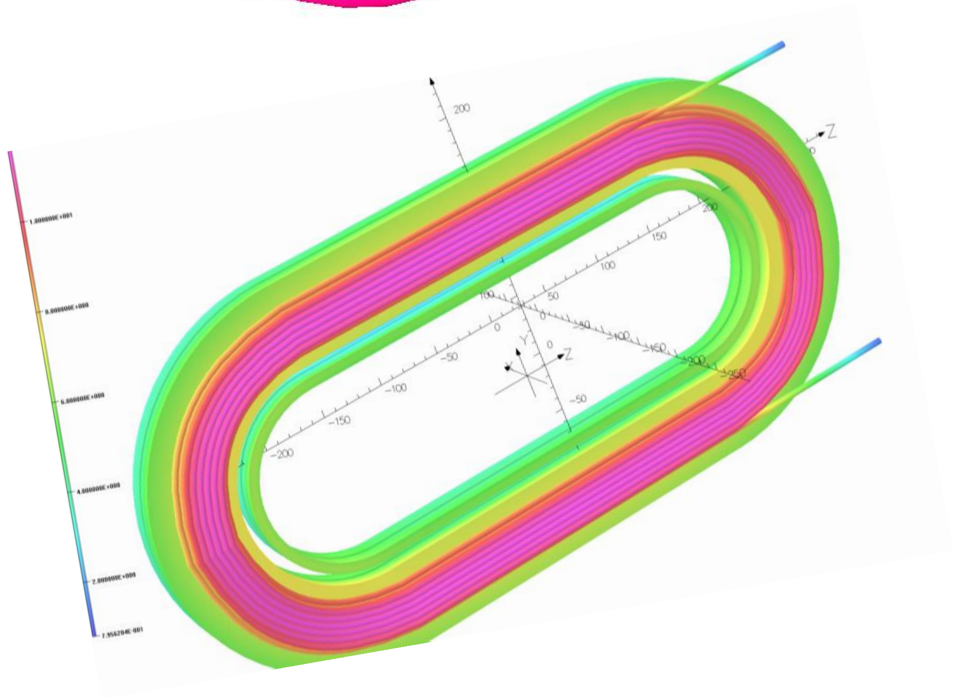




MDP:

Quench studies and technology demo





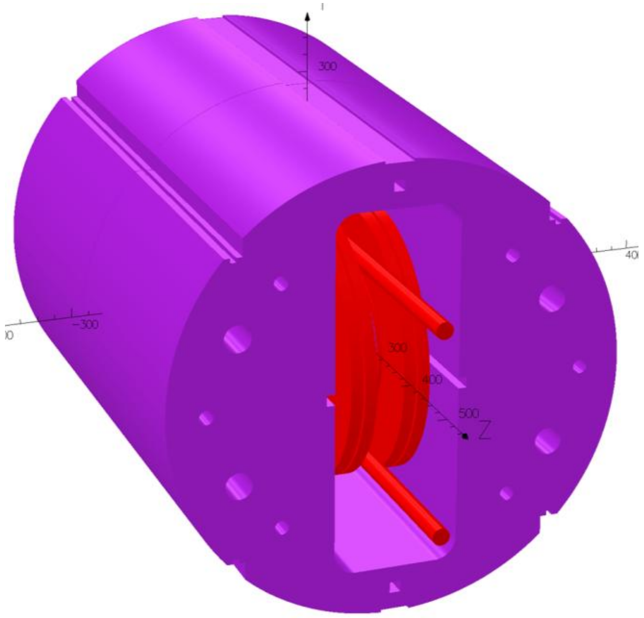
STTR:

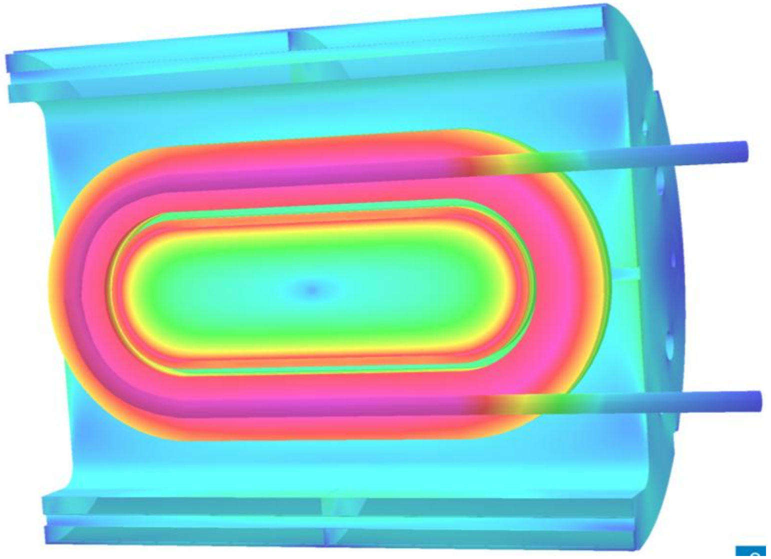
High field Demo

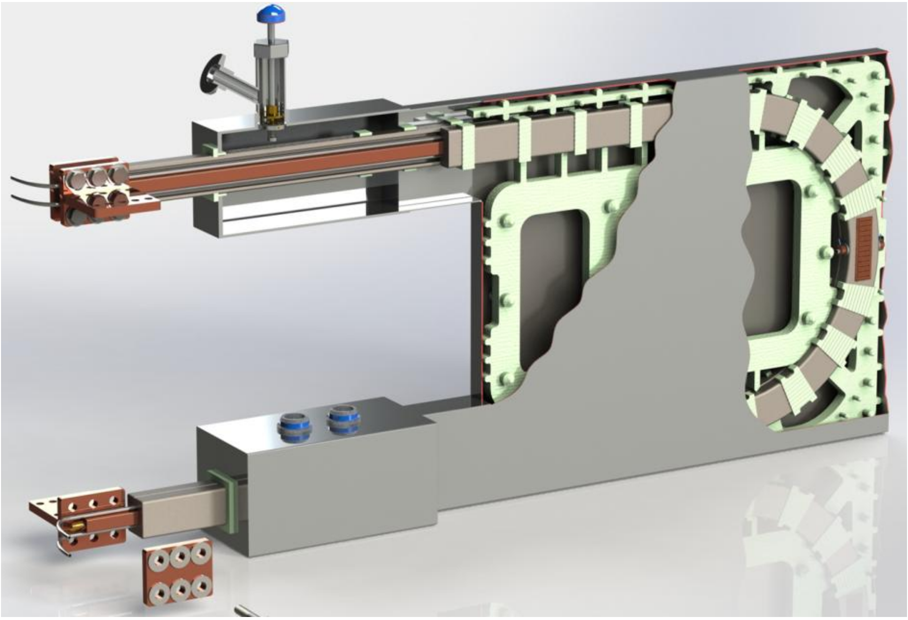
Test of a High Current Cable (straight and bent)

✓ **Test of a high current bent fusion cable in CCTF's dipole field**

- GA bent cable was funded via INFUSE
- Additional MIT/CFS cable was not tested as funds at hand couldn't be rechanneled







SC transformer and cryostat to adjust the temperature should help

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Summary

- BNL produced several unique designs, technologies, hardware (HTS coils). This "unfair competitive advantage" can/should be leveraged.
- In particular, 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 has been high. It has produced several record and high visibility output. This should become more useful with some updates.
- However, all funded proposals were initiated a while ago (~ 5 years?), and nothing new is in the works. It takes about two year from the proposal to get things in action. So, we have some work to do.

Extra Slides

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.**

New Designs and Technologies (https://wpw.bnl.gov/rgupta/)

- HTS Magnet R&D at BNL
- Common Coil Design (The DCC017 Story)
- Common Coil Test Facility (CCTF), Informative Slides
  – a unique facility for testing insert coils and cables in high dipole fields
- Overpass/Underpass (Cloverleaf) Design
- Open Midplane Dipole Design
- Optimum Integral Design