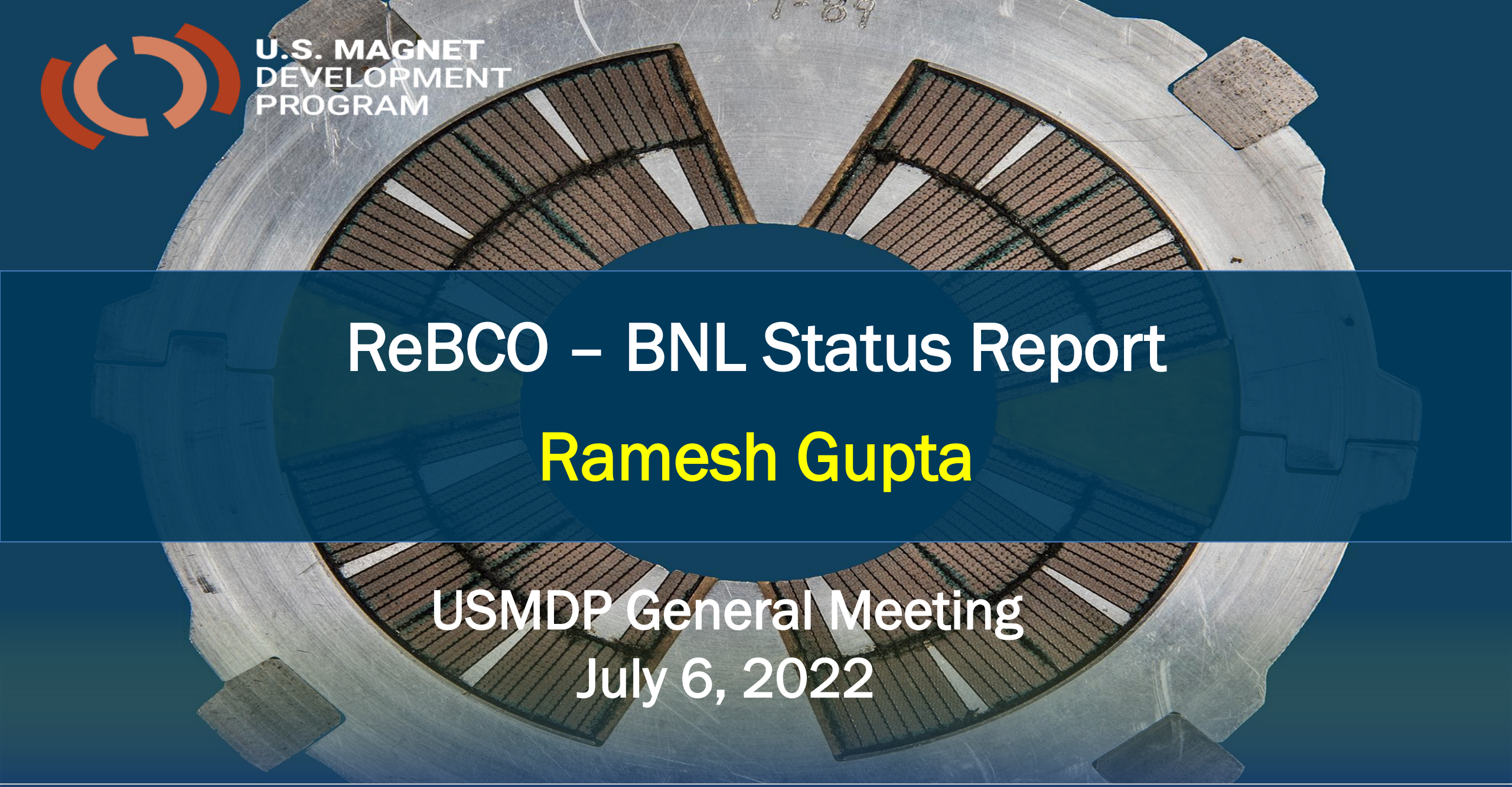


U.S. MAGNET DEVELOPMENT PROGRAM

ReBCO – BNL Status Report

Ramesh Gupta

USMDP General Meeting
July 6, 2022

HTS Coil Tests at various stages (all funded) at the BNL Rapid-turn-around, Low-cost, R&D 10 T Dipole Test Facility

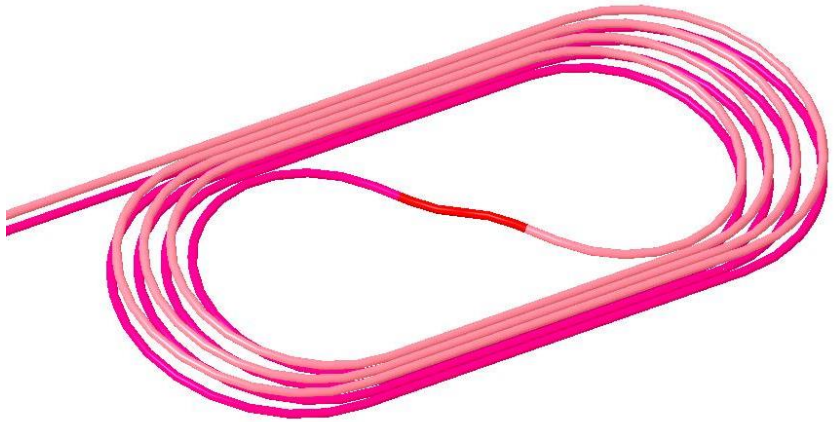
1. CORC coil quench studies (MDP) – Coil wound and tested at 77 K at ACT, to arrive at BNL soon for testing with the 10 T Nb_3Sn common coil dipole
2. CORC coil 13-14 T HTS/LTS hybrid dipole (STTR) – Coils to be wound soon and tested at 77 K; once delivered in support structure will try to meet extended (2+2) 8/22 deadline
3. PSI Nb_3Sn coil and BNL HTS coil for HTS/LTS hybrid test at high field (hopefully >12.3 T) - Both coils wound and are at BNL in their respective support structure
4. VIPER cable in U-shape (arpa-e fusion) – Cable available, working on the details
5. Magnum-NX coil test with SMS (fusion) – Waiting for the coil to be wound
6. CORC cable-in-conduit test with General Atomics (fusion) – Test article ready at GA, waiting for administrative/legal work to be completed
7. HTS coils with ceramic insulation (US-Japan) – likely in FY 2023

Significant investment from BNL for higher current (20 kA with power supply, and 50 kA with SC transformer) and higher temperature testing (20K, 4-40K)

High Level Goals/Plans/Tasks

Two Related R&D programs. Magnet Design Program (MDP) and Small Business Technology Transfer (STTR)

- **MDP: "In-field quench studies of a long CORC cable" in the background field of common coil dipole via one 8-turn HTS coil (S-turn in to flip the polarity)**
- **STTR: "Demonstration of a high field HTS/LTS hybrid dipole" with two sets of double pancake coils made with 6+8 turns (total 28 turns) of CORC cable**

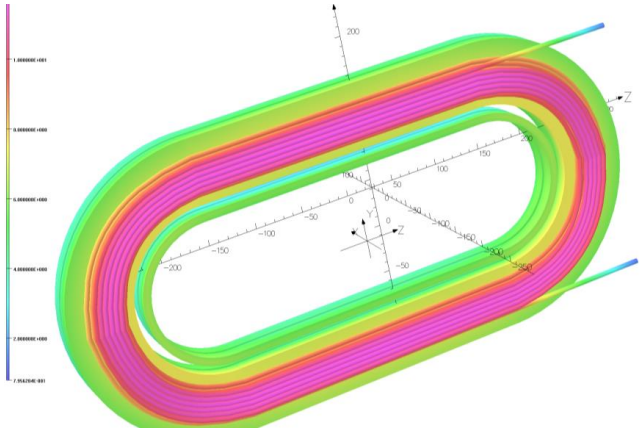


MDP:

Quench studies & technology demo

(10.7 T with

10 T from LTS)



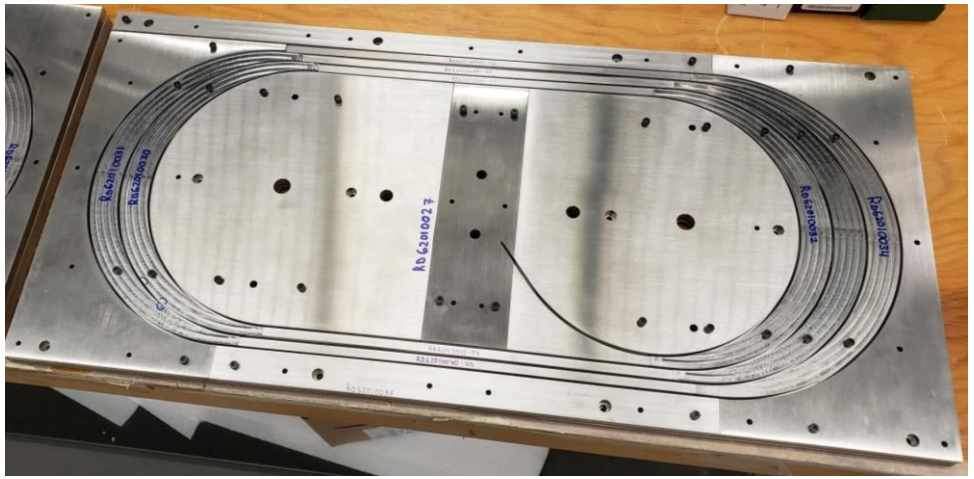
STTR:

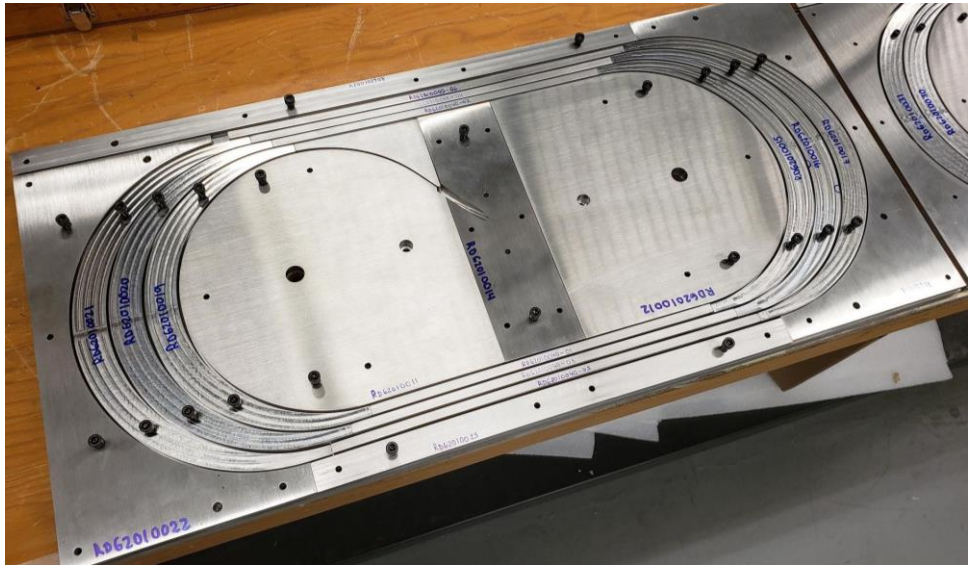
High field Demo

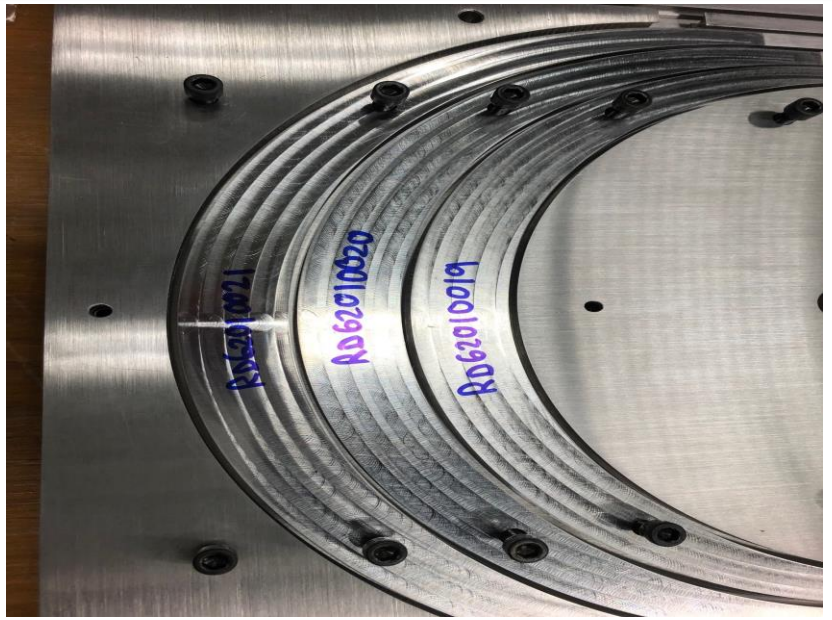
(13-14 T with

10 T from LTS)

A Few Coil Structure Parts Shown Below (all parts for MDP coil test obtained)







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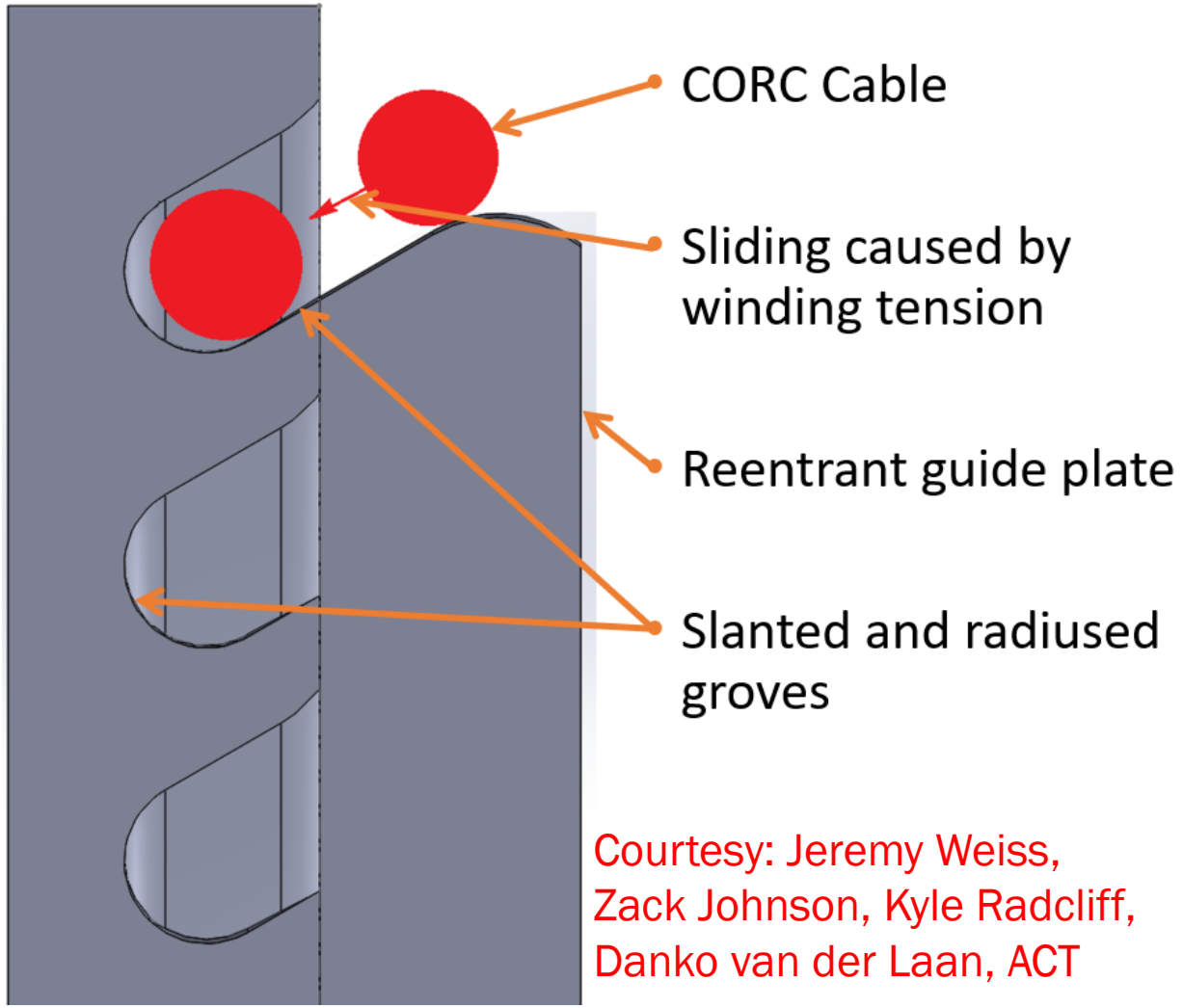
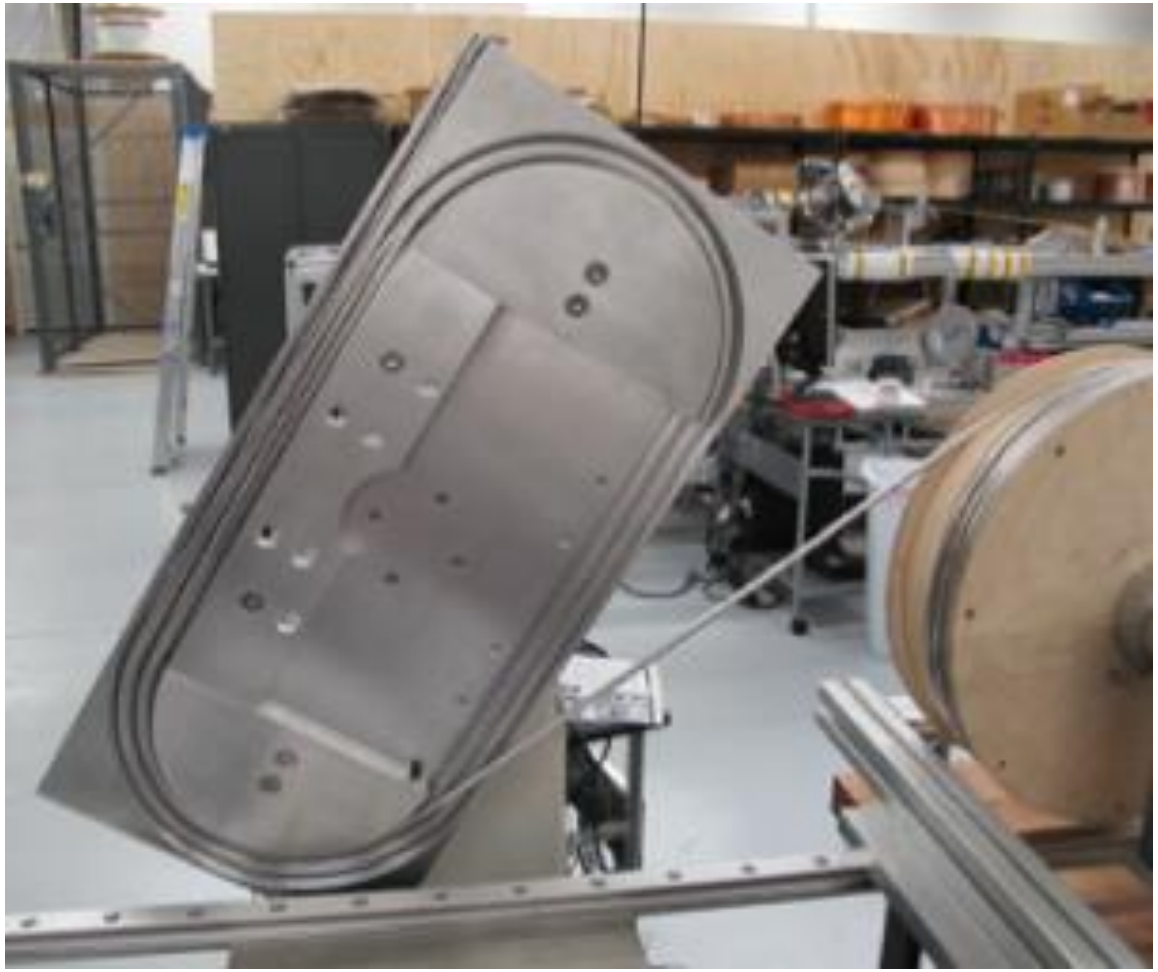
ACT proposed an alternate design and requested to wind the MDP coil as a practice winding for the STTR CORC coil

New Design from ACT



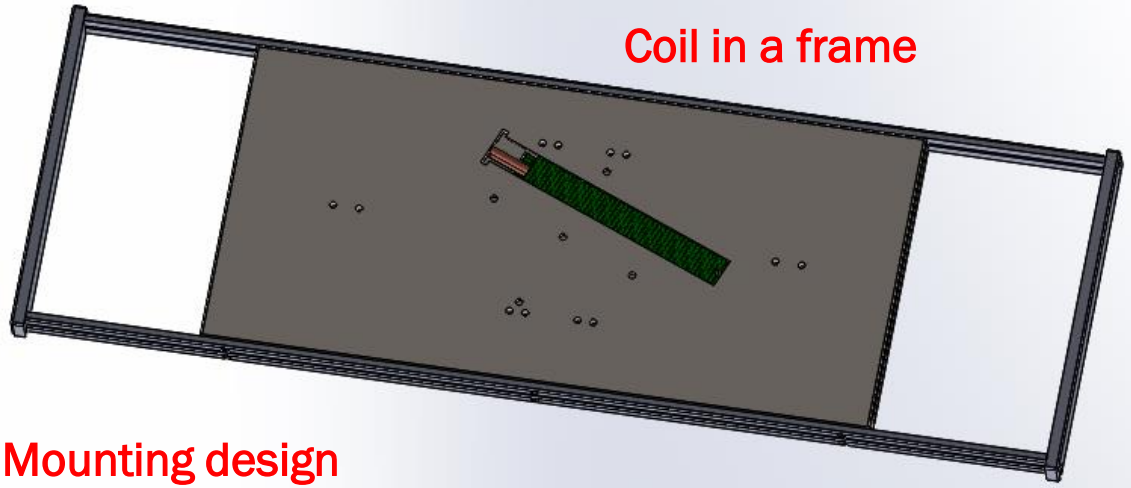
Courtesy: Jeremy Weiss, Zack Johnson, Kyle Radcliff, Danko van der Laan, ACT

All pics: Courtesy ACT

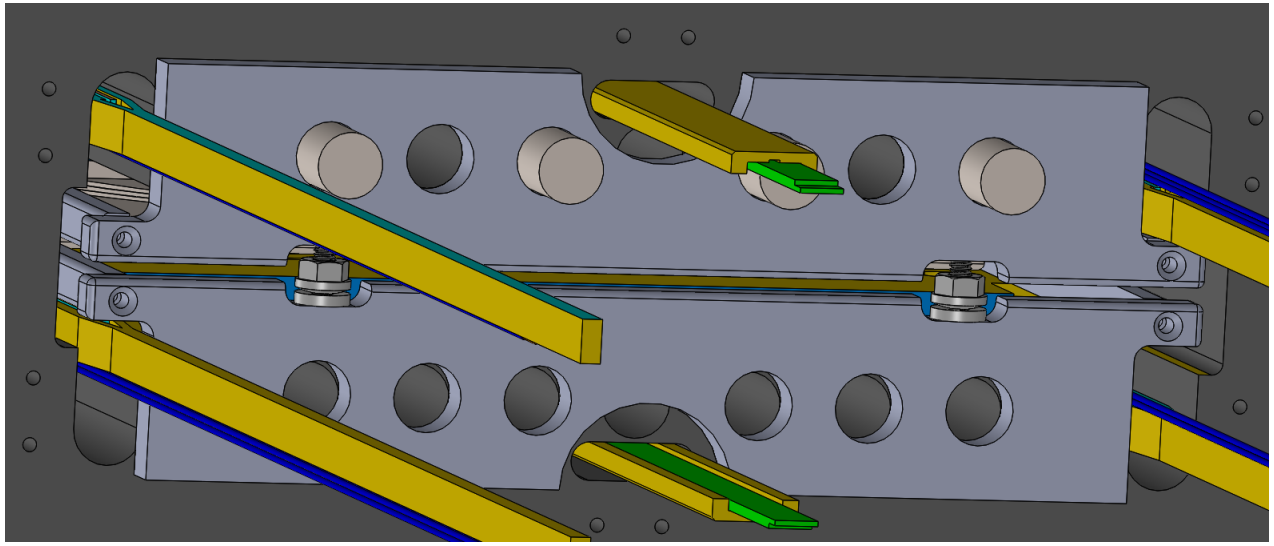


MDP CORC COIL INSERT in DCC017

Coil in a frame

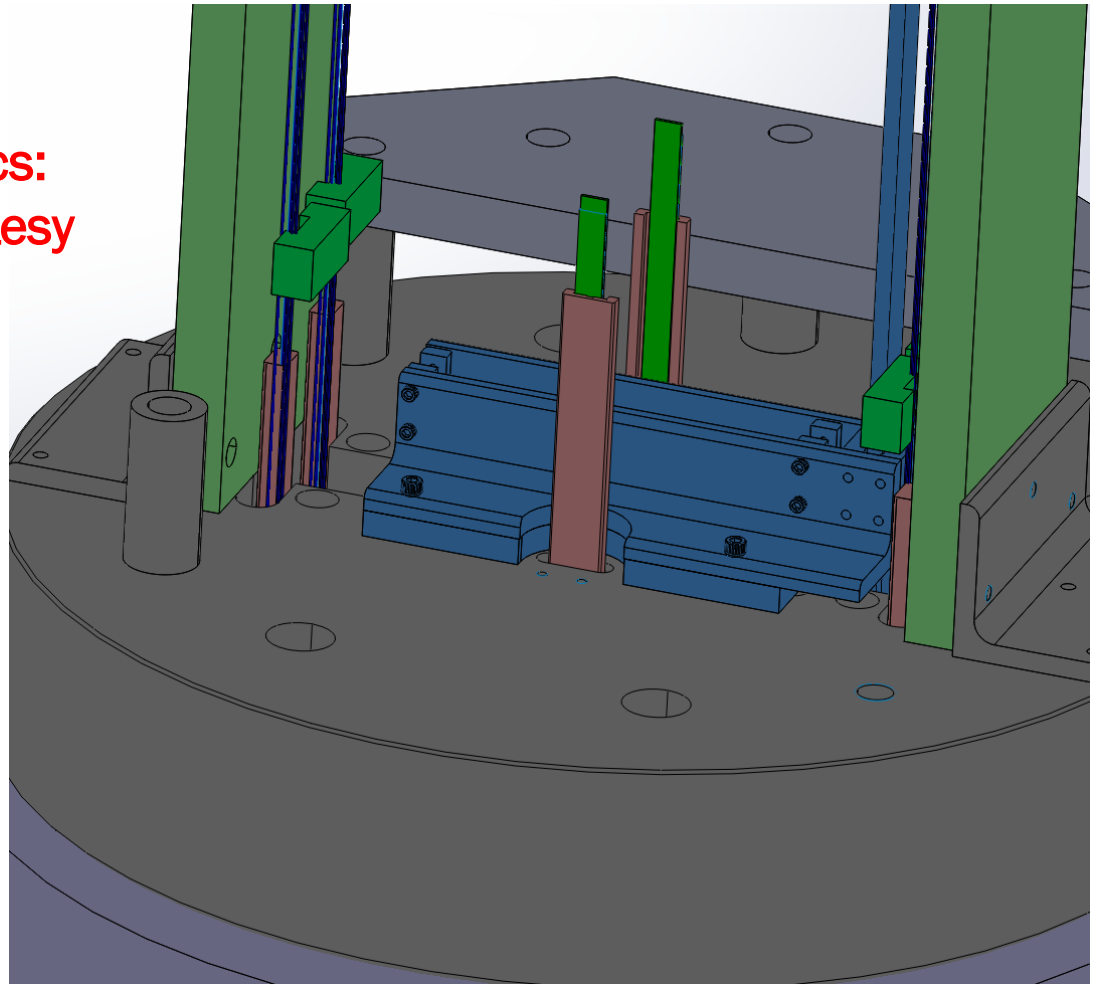


Mounting design



All pics: Courtesy ACT

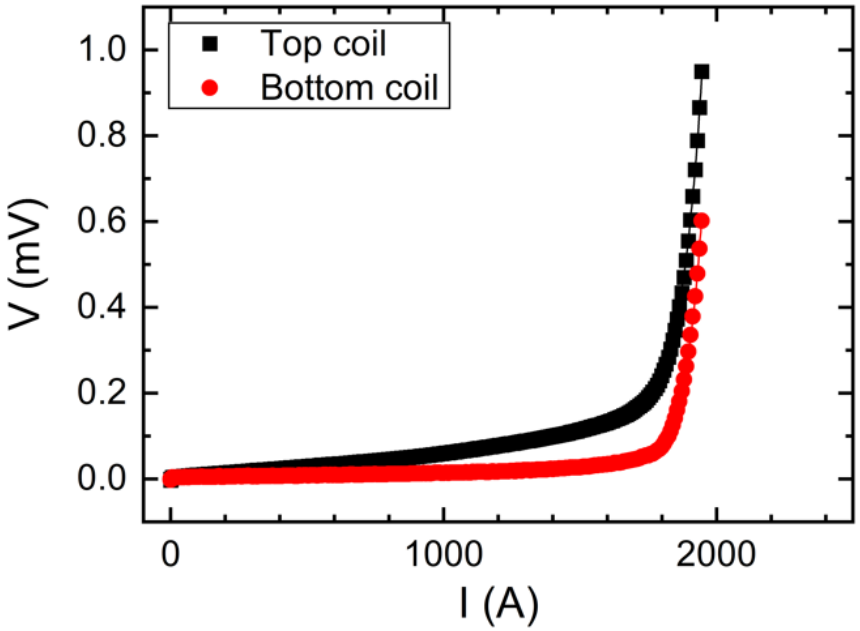
MDP CORC Coil installed in DCC017



Pre-test in Liquid Nitrogen at ACT

Will request ACT to make full presentation in our subgroup meeting

V(I) at 76 K



50 A/s
L = 540 cm

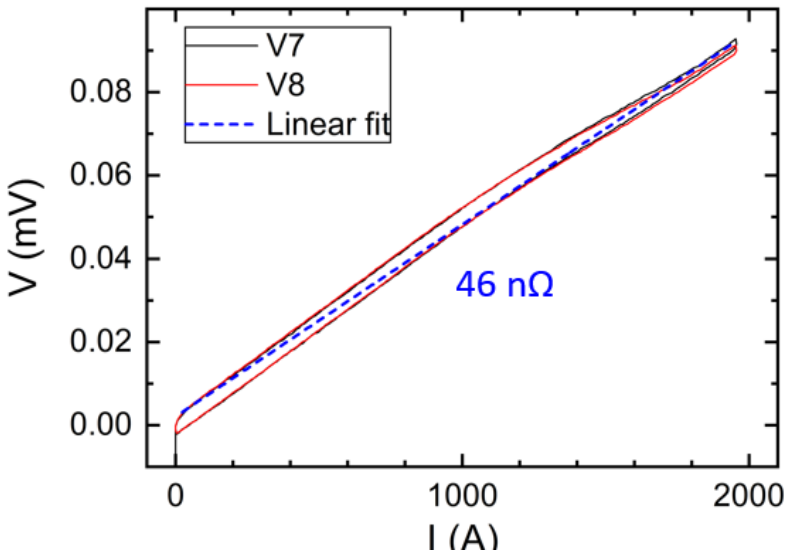
V1-Top coil
I_c = 1915 A
N-value = 25

V6-Bottom coil
I_c = 1942 A
N-value = 31

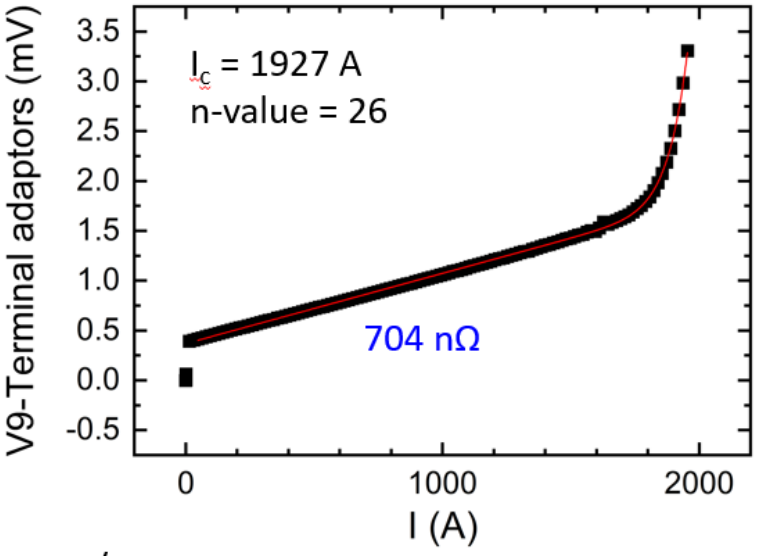
Advanced Conductor Technologies
www.advancedconductor.com

Joint resistances at 76 K

Voltage measured over joint



Voltage measured over terminal adaptors
(includes both coils, terminals, and joint)

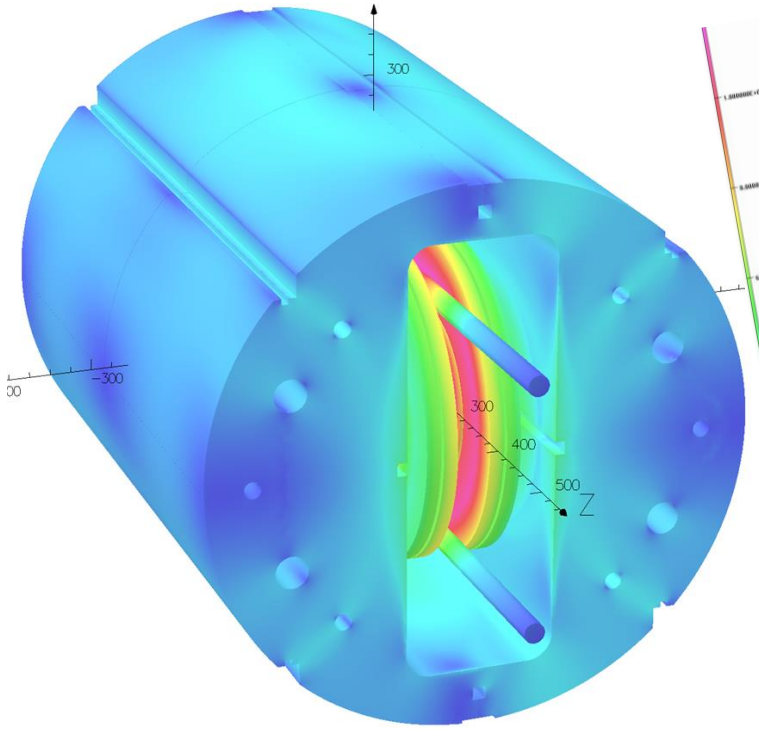


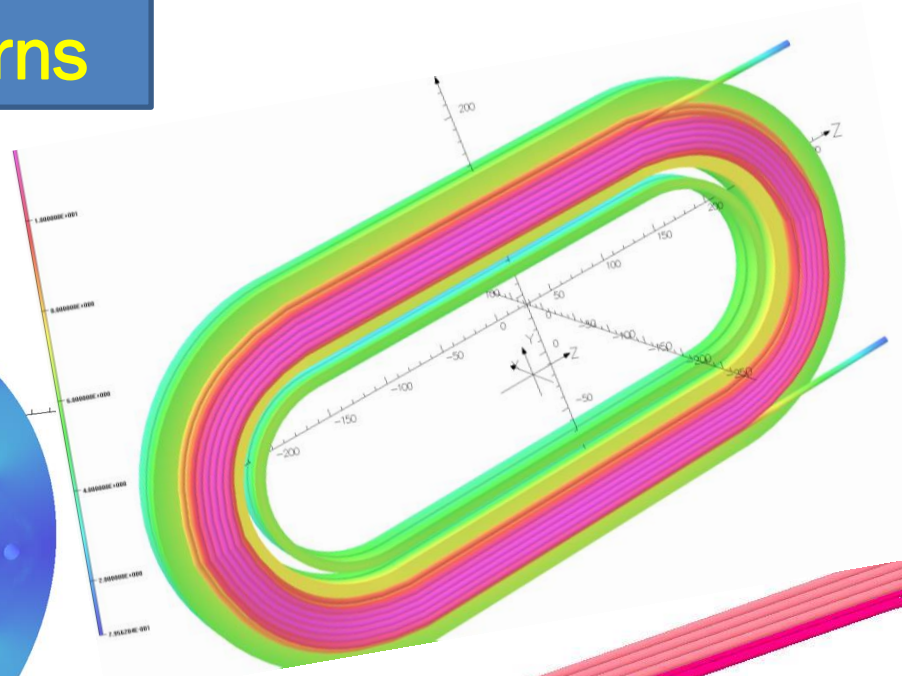
BNL to receive the coil soon for 4K testing with DCC017

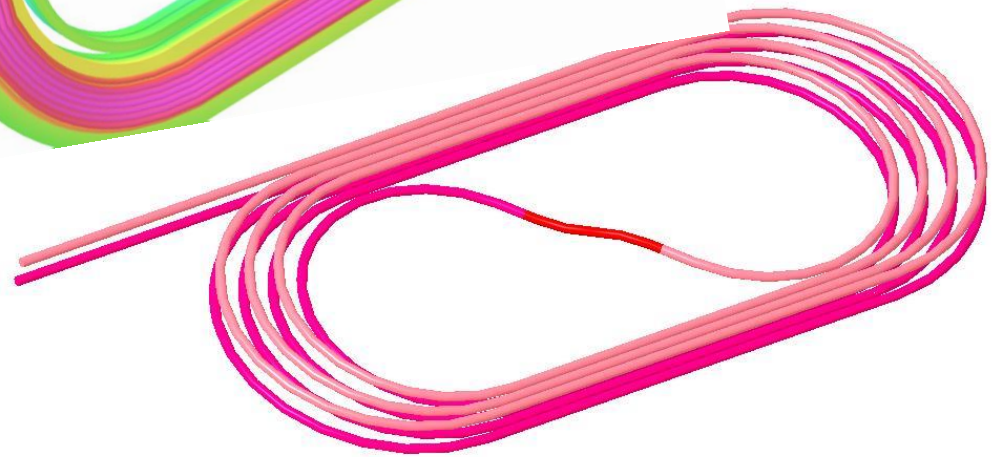
HTS/LTS Hybrid Dipole STTR with CORC coil

Recap: CORC Coils with the Common Coil Dipole

STTR Coils two sets:
Each with 6 and 8 turns







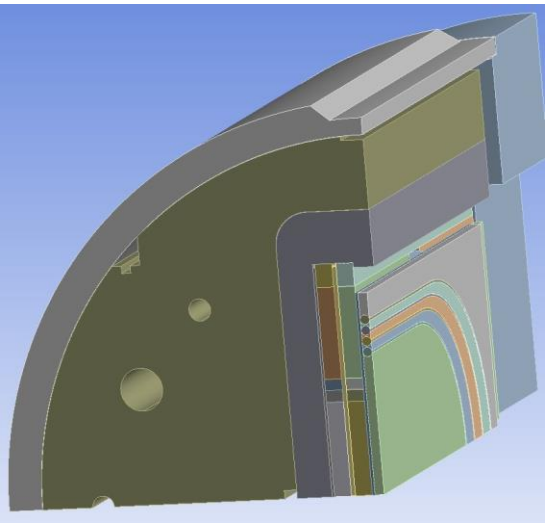
STTR: High field Demo
(13-14 T with 10 T from LTS)

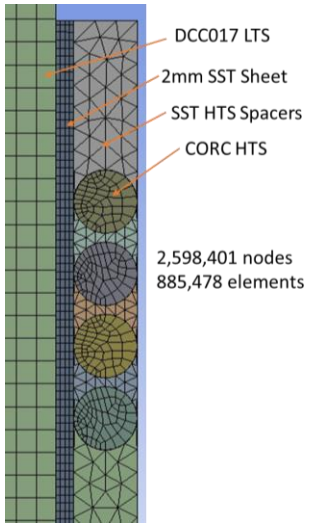
MDP: Quench studies and technology demo
(10.7 T with 10 T from LTS)

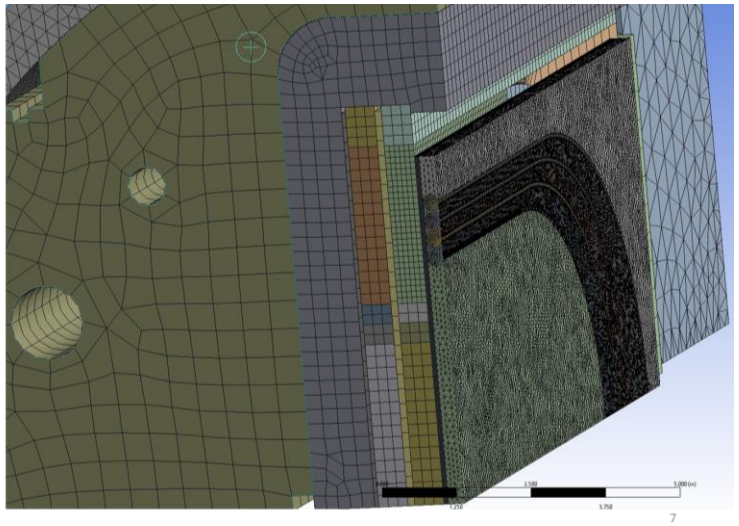
CORC® coils will run in series with the Nb_3Sn coils

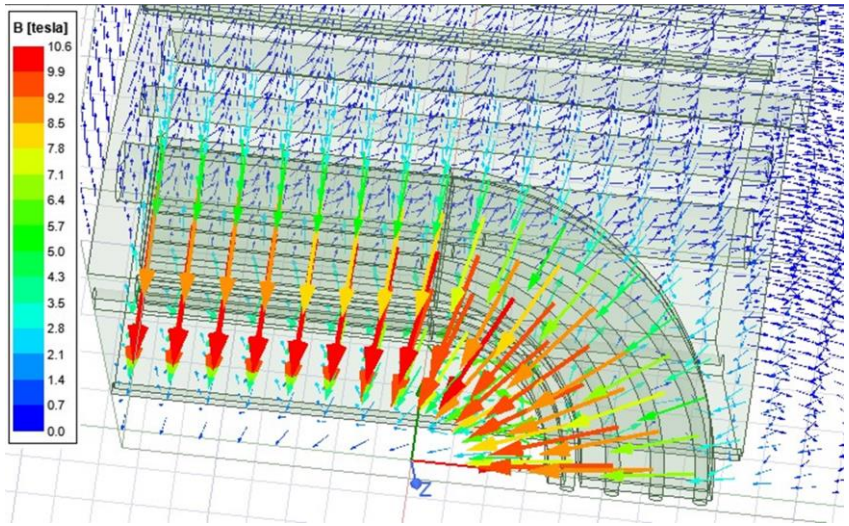
MDP Coil
4+4 turns
with an S-turn

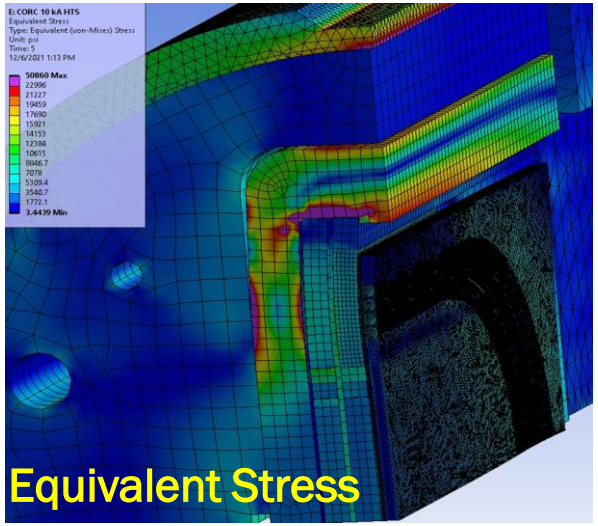
Finite element analysis performed for the CORC coil in a structure @10 kA inside BNL common coil dipole @10 T



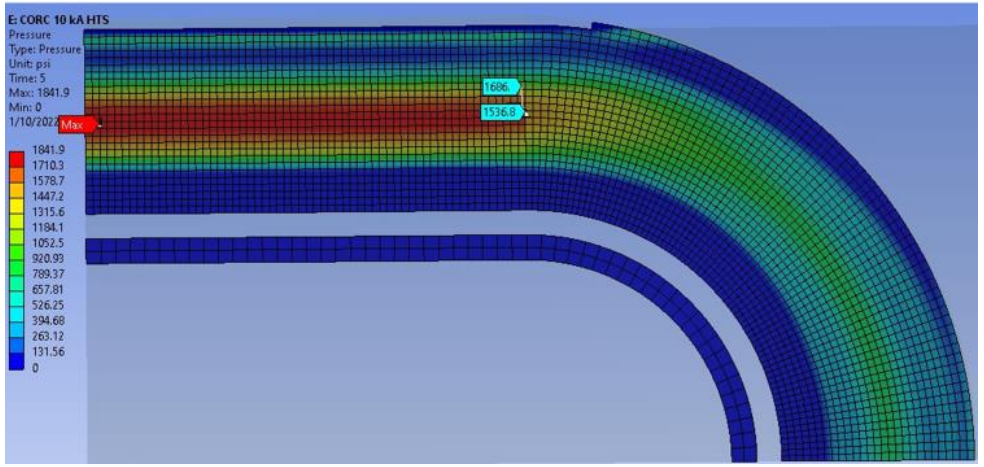




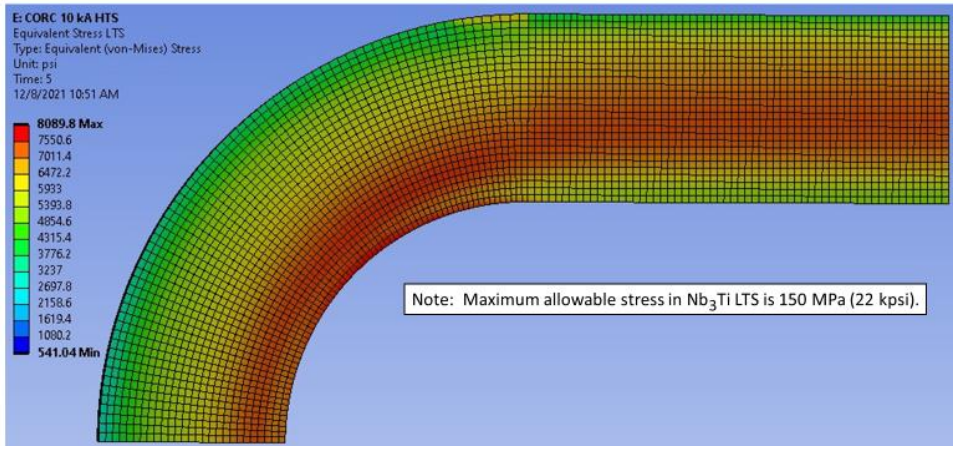




LTS Contact Pressure – 10 kA HTS (Inside/HTS Surface)

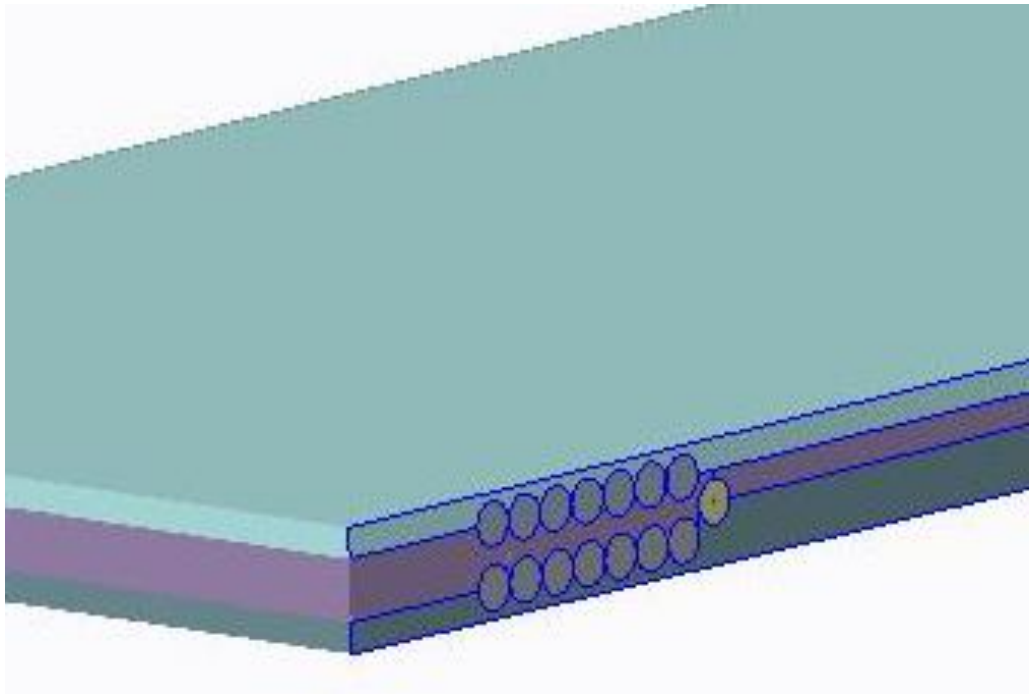


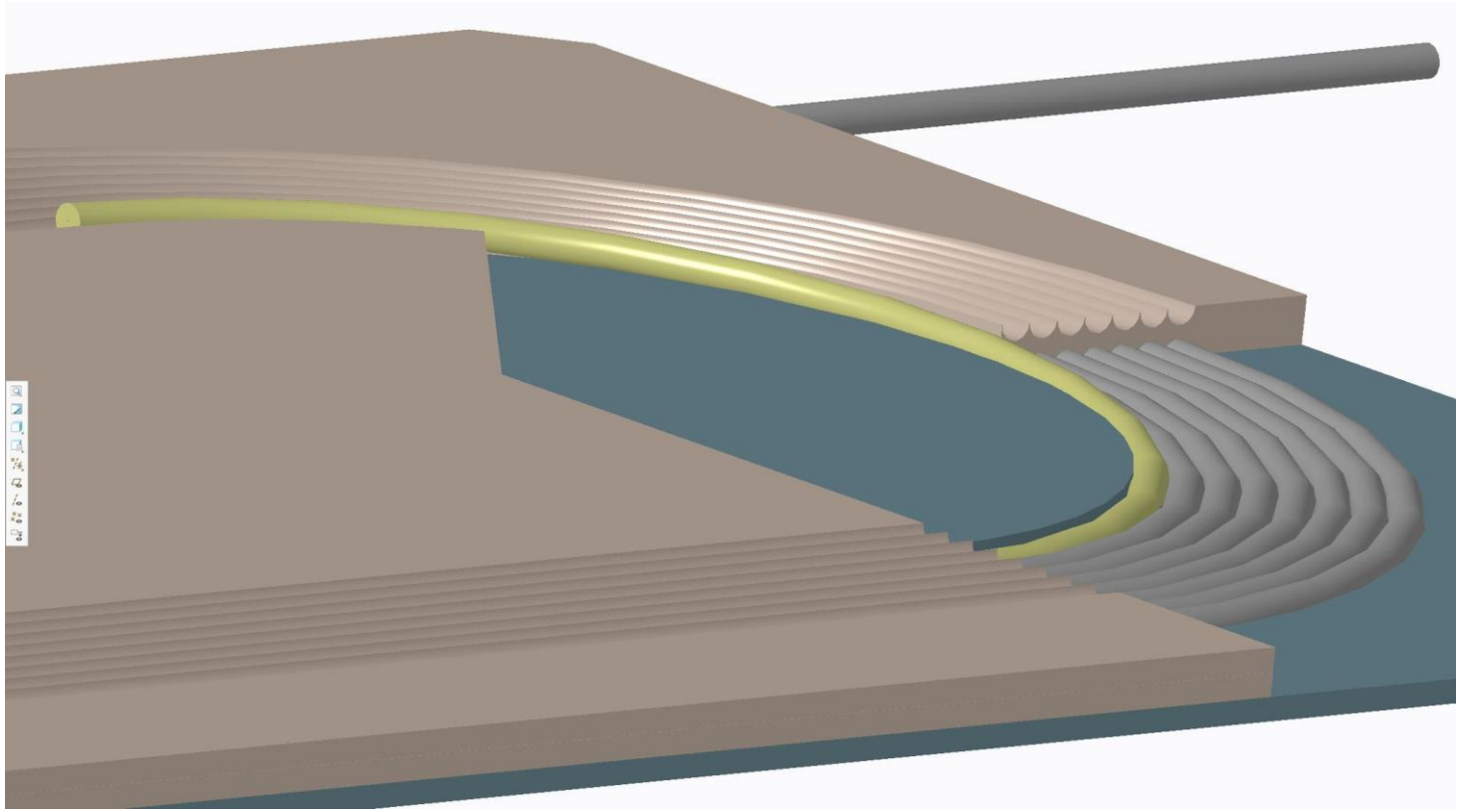
Equivalent Stress LTS – 10 kA HTS (Outside Surface)



Early Design Work at BNL

Conductor fully supported



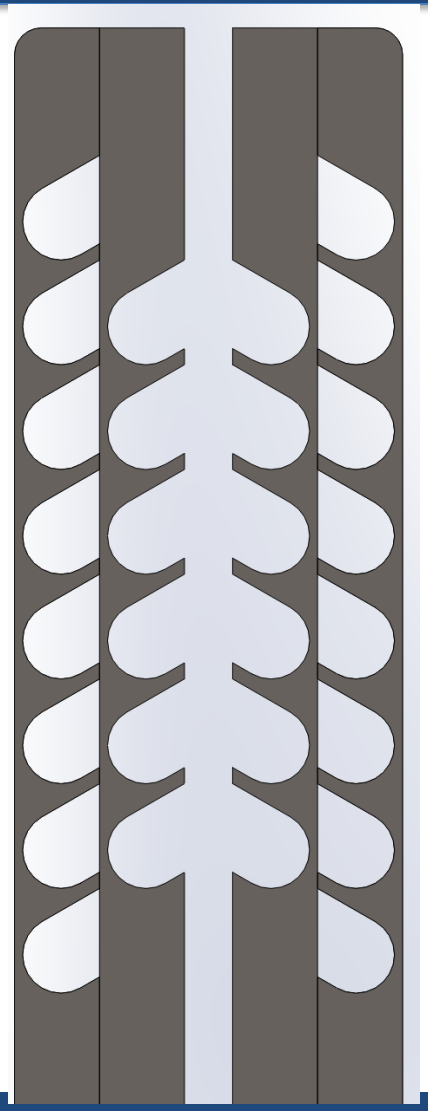


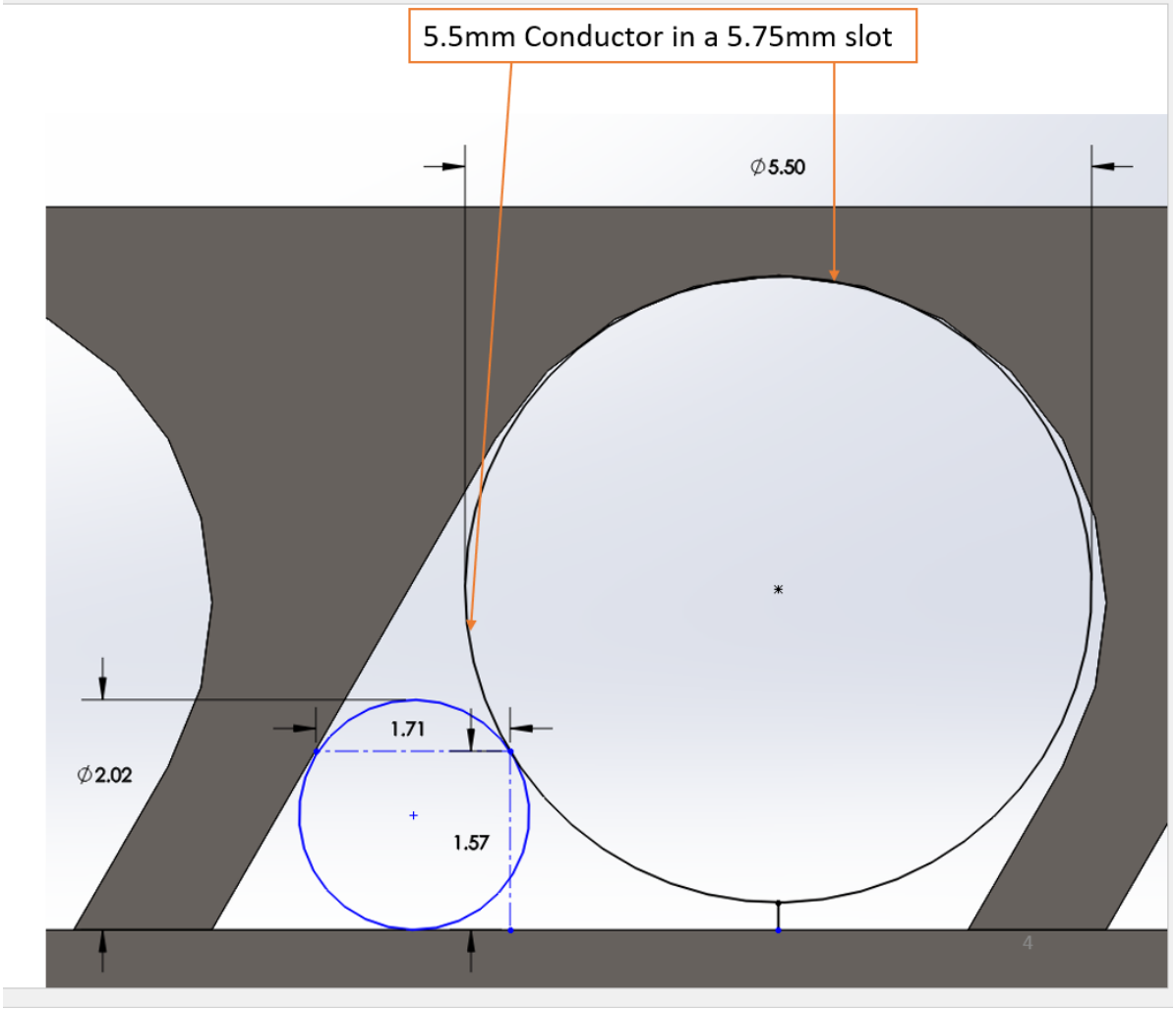
But cable was difficult to put in place

Work Performed at ACT

4 Plate Coil

- Outer plates have 8 turns
- Inner plates have 6 turns
- Coils centered at ± 118mm
- The left-hand and right-hand coils are mirrors of each other





Status of STTR

e-mail from Danko (this morning):

1. Zack, who made the model of the STTR coil is on vacation this week, but I'll have someone else prepare a STEP file of the STTR coil.
2. The current connectors are the same as four the MDP coil. We've sent an overview last week, which is attached. The only difference between the STTR and MDP coils is that the lead position may have shifted by no more than an inch. The STEP file should clarify this. I assume that the lead connectors will interface with flexible Rutherford cables so this should be no problem and the current lead interface blocks could be machined.
3. The cable for the STTR coil will be finished this week, while all remaining parts for the coil should arrive next week. The STTR coil will be wound the week of July 18th, tested in liquid nitrogen the week of July 25th, and shipped top BNL before the end of that week. Assuming shipping freight takes one week, **the coil should arrive at BNL before August 5th**. There is a likelihood that we might speed things up and deliver sooner, but I'll keep you updated.

Ongoing Discussion within MDP Collaborators

- Discussion on the detail instrumentation
- Discussion on the detail test plan

Both will be formalized soon.

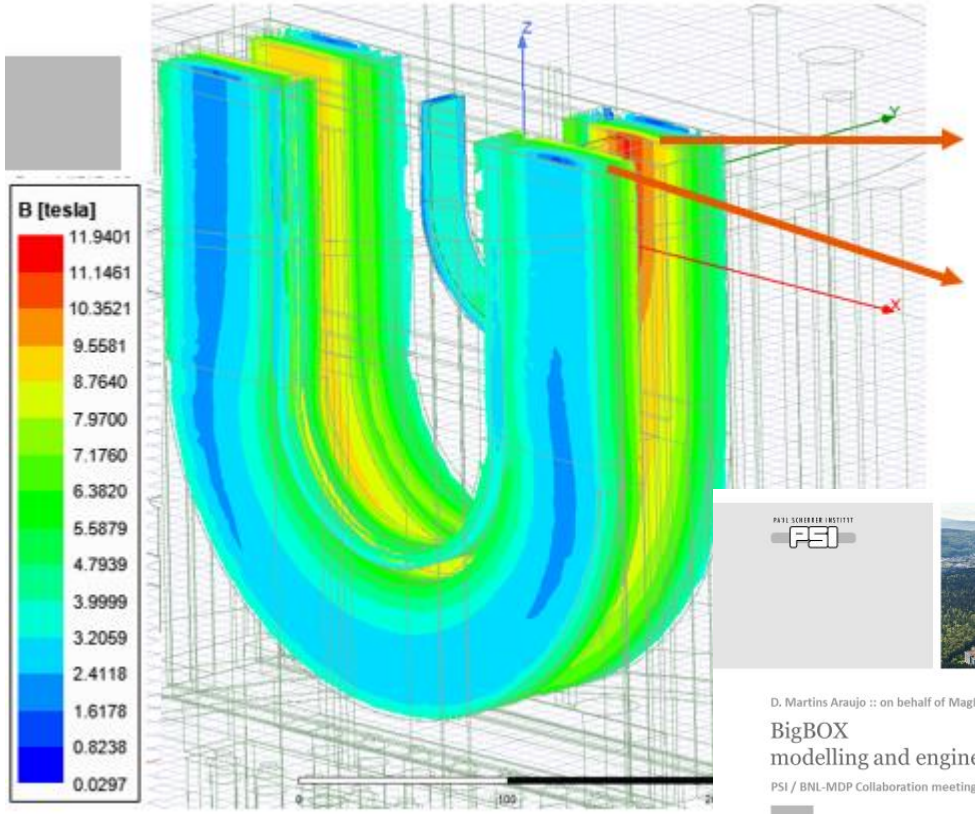
PSI Nb_3Sn coil Test and HTS/LTS High Field Hybrid Dipole Test

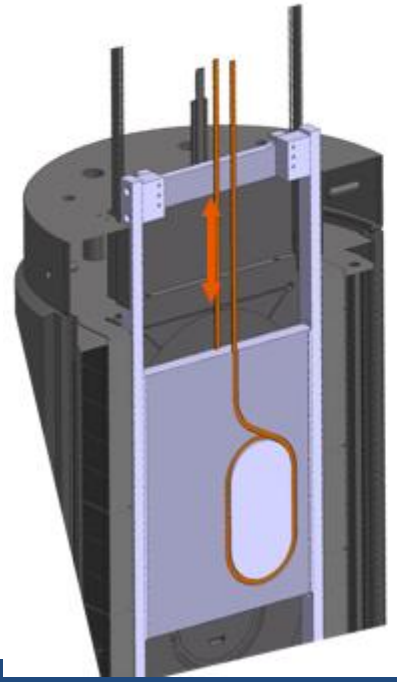
MDP BigBoX Test Nb_3Sn Coil Test with PSI

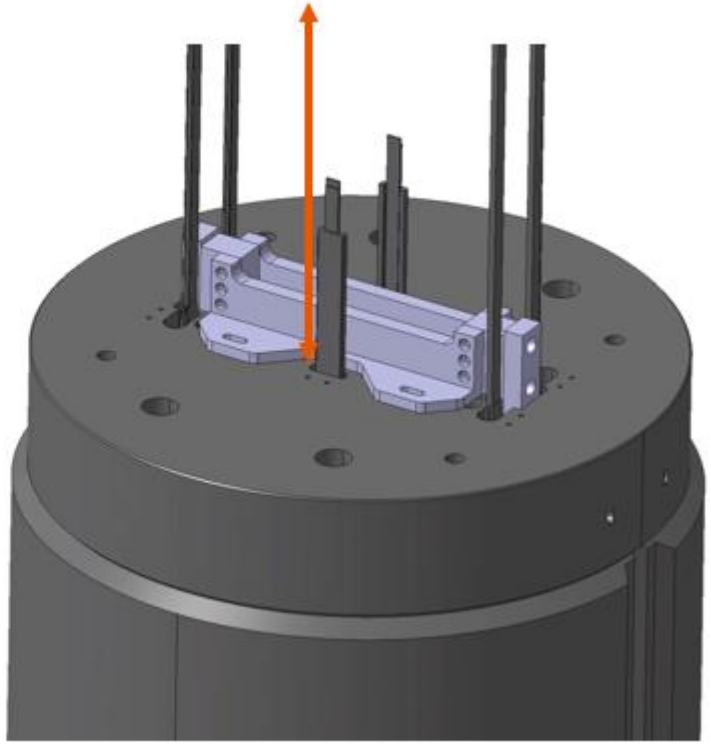
PAUL SCHERRER INSTITUT

PSI

- Coil in support structure received
- Suggest a separate presentation from PSI
- As such one aperture is available, use this
- Taking advantage and testing an HTS coil

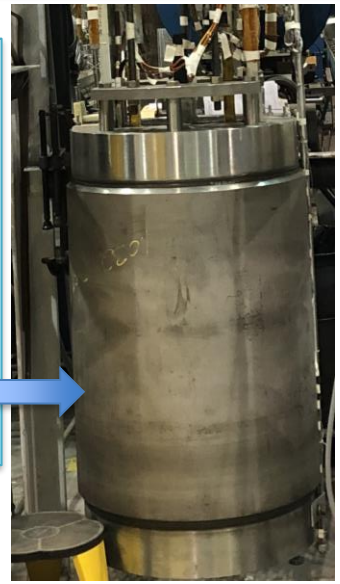




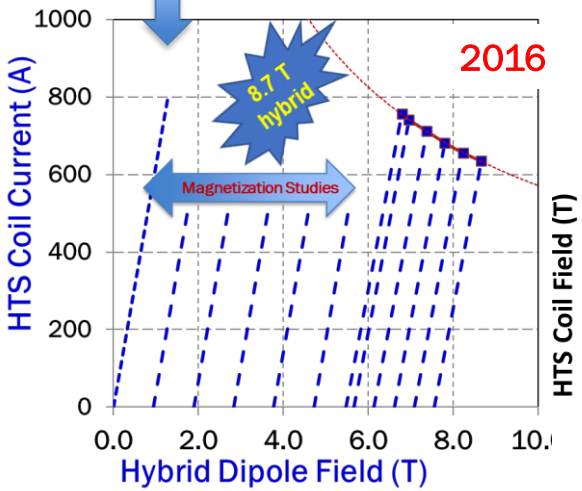


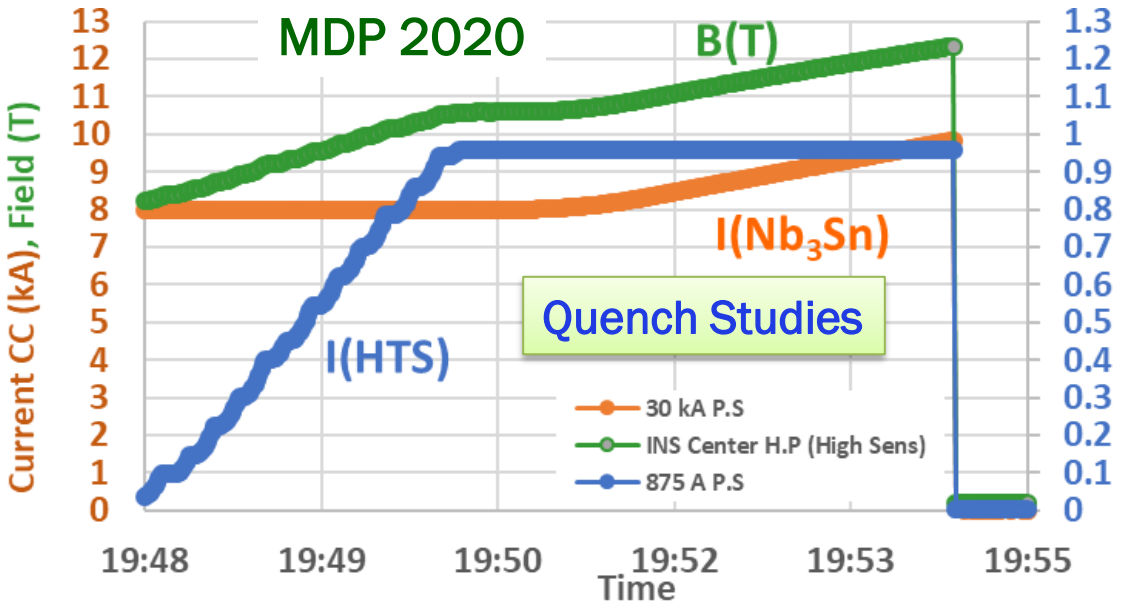
Room for Improvement in Previous MDP Test of 12.3 T HTS/LTS Dipole

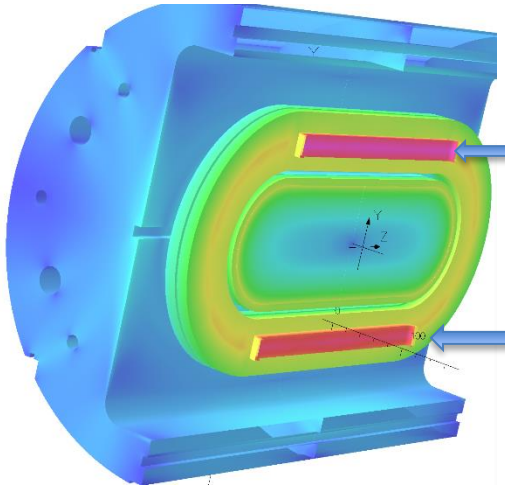
USMDP *"Record"* HTS/LTS 12.3 T Hybrid Dipole (2020)



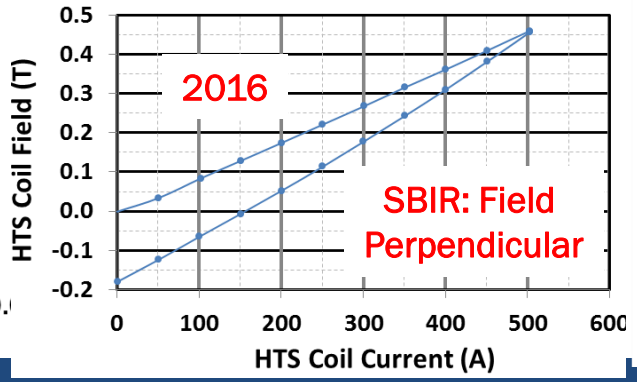
PBL/BNL STTR

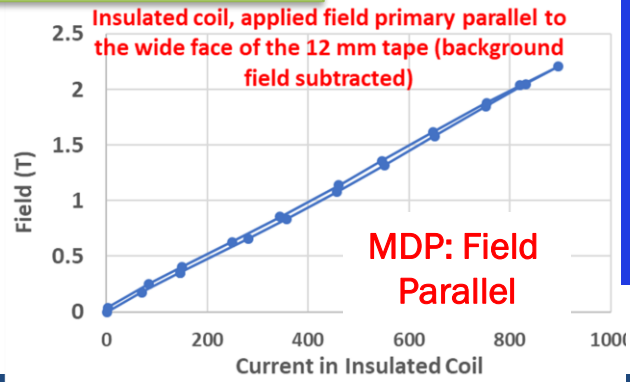






Magnetization Studies





Maximum field was not limited by HTS coil. It was by LTS coil.

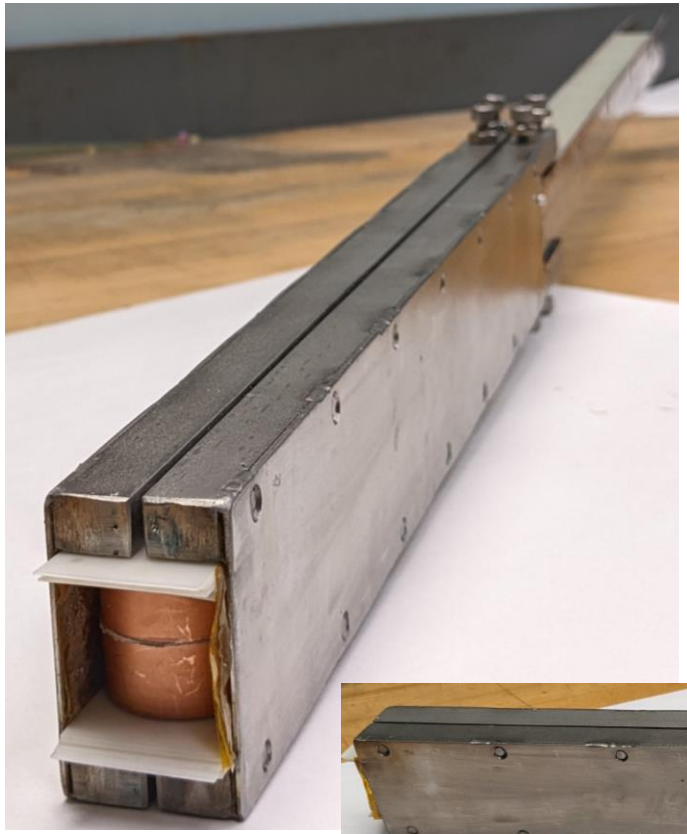
Theory: HTS coil was pinching on the Nb_3Sn making it quench

NEXT: Intermediate structure

Also, to find why coils got damaged

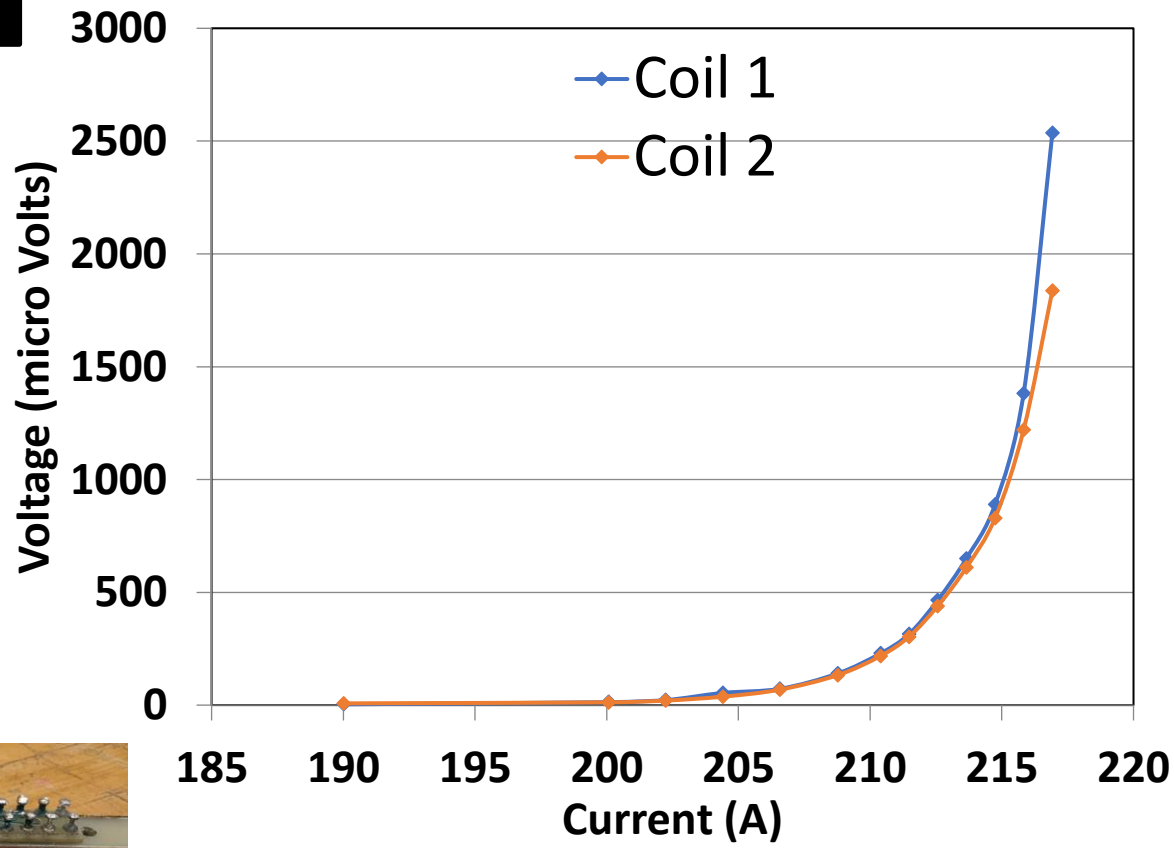
New MDP HTS Coil in a Support Structure

Question: Can a higher hybrid field be reached with some intermediate structure on HTS coil (stress management) ?



- A simple, low-cost, versatile structure made
- Recently wound coil with leftover conductor tested at 77 K in the structure

77 K Test Results



Future Possibilities

We need high current cables with many wires/tapes- for accelerator magnets

- Insert coil made with high current STAR cable (request to MDP made)
  - This is high current cable different from the cable limited by bend radius restriction
- Insert coil made with VIPER cable (in discussion with CFS)
- Insert coil made with Magnum (Alex Otto) Cable

Conductor friendly designs offer many benefits, such as they allow wide range of cables to their potential

BNL Milestones

Table 5. Milestones for the REBCO effort within the HTS area of the MDP.

Milestone #	Description	Target
	Magnet technology development	
AIIb-M1	Demonstrate first COMB (Conductor on Molded Barrel) technology	May 2021
AIIb-M2	Test of CORC® subscale common coil in 10 T background field	June 2021
AIIb-M3	CORC® CCT to reach 5 T dipole field	December 2021
AIIb-M4	Complete COMB insert test	May 2022
AIIb-M5	Complete design study of a 8 T REBCO dipole magnet	December 2021
AIIb-M6	Generate 1 T with REBCO insert in a background field of 8 T from Nb_3Sn CCT5	June 2022
AIIb-M7	COMB performance demonstration	March 2023
AIIb-M8	REBCO magnet generate a 8 T dipole field stand-alone	March 2023
	Conductor characterization	
AIIb-M9	CORC® wire quench study at BNL 10 T common coil magnet	December 2020
AIIb-M10	Impact of Lorentz load on CORC® wires using ASC 14 T solenoid	June 2021
	Key assumptions: infrastructure availability	
AIIb-M11	Commission Nb_3Sn CCT5 test platform	June 2021
AIIb-M12	Hybrid test platform with outsert magnet available at FNAL	June 2021
AIIb-M13	120 mm aperture 10 – 12 T Nb_3Sn magnet	June 2022

ACT/BNL STTR →

← 08/22

Completion date depends on the delivery of the coils (if STTR coil doesn't arrive in time, then MDP coil can be tested sooner)

BNL/LBL MDP →

← 12/22

Acknowledgement

This presentation benefited from the discussions with and direct contributions from the following colleagues:

ACT: Danko van der Laan, Jeremy Weiss, Zachary Johnson
BNL: Anis Ben Yahia, Michael Anerella, Jesse Schmalzle, Piyush Joshi, Mithlesh Kumar,...
FNAL: Vadim Kashikhin, Vito Lomardo
LBNL: Xiaorong Wang, Maxim Martchevsky, Reed Teyber,...

... and more

Summary

- HTS/LTS program at BNL is primarily based on a Common coil dipole with a large opening which provides a rapid-turn-around and low-cost R&D option for developing and testing technologies and instrumentation and for addressing specific questions - one at a time.
- This is alternate and complimentary to developing and demonstrating technology by building magnets which takes much longer time and uses much larger budget.
- Several tests with several collaborators (domestic and international; research institutions and industries) are planned within MDP and with others (SBIR, fusion, international, etc.) to develop and tests various aspects of designs and technologies at ~10 T or above.
- Specific questions to be addressed: HTS/LTS hybrid magnets, quench, magnetization, high current HTS cables, joints, high ramp rates, insulation, instrumentation, etc..
- More synergistic programs are invited. Please evaluate and see what and how to do it.