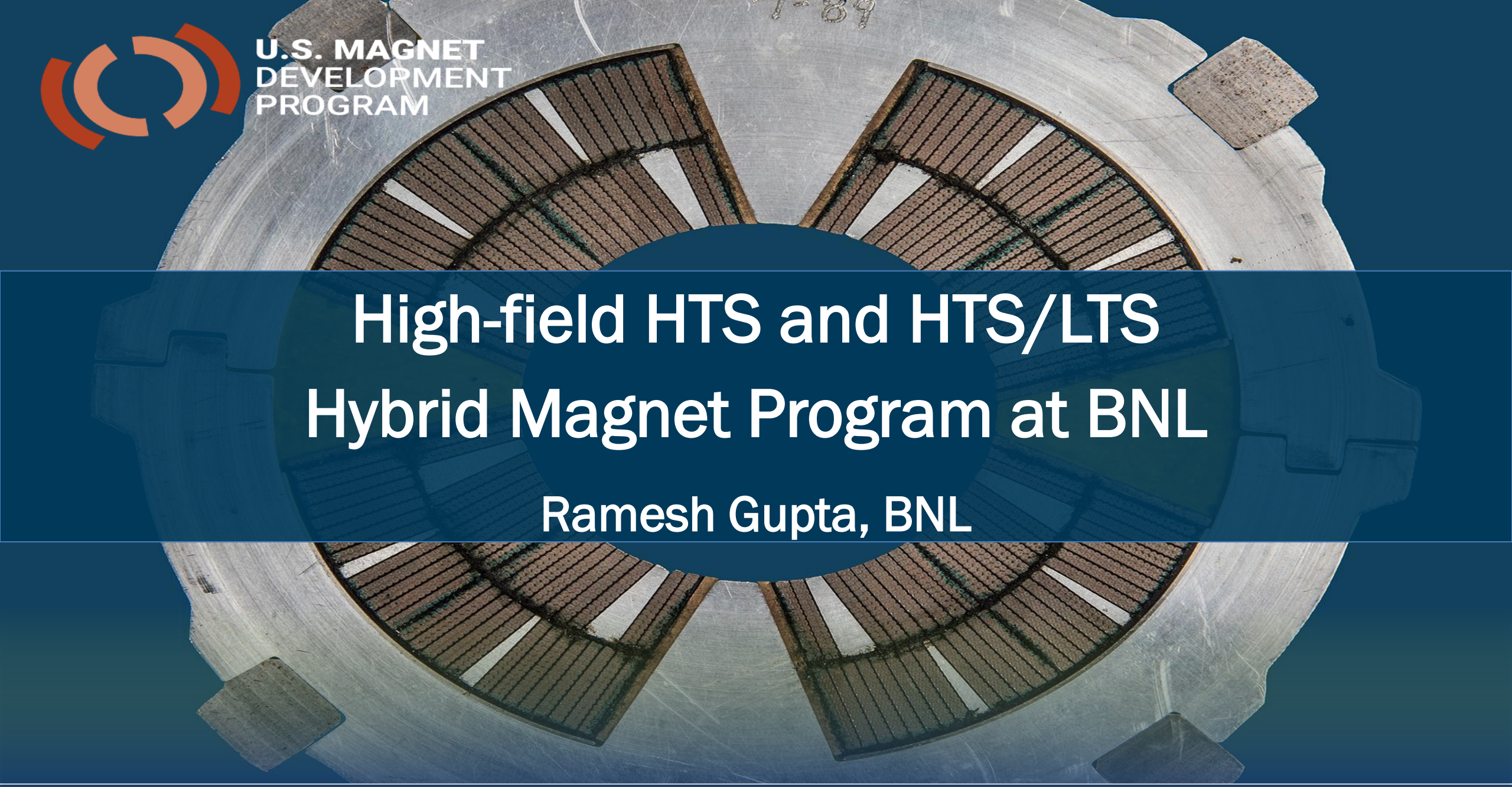


U.S. MAGNET DEVELOPMENT PROGRAM

High-field HTS and HTS/LTS Hybrid Magnet Program at BNL

Ramesh Gupta, BNL

Updated GARD/MDP Plan at BNL

- There has been an intense internal discussion on how BNL can contribute more effectively towards the national program
- It leverages existing hardware and is well aligned to the MDP roadmap
- The program has been presented to DOE. Details and timeline TBD
- Components of the High-field HTS and HTS/LTS hybrid magnet program:
  - ❑ 7-8 T all HTS dipole with 8 large FRIB coils (significant stored energy)
    - ➢ Up to 680X292 mm, stack 40X12 mm (~9km 4mm tape equivalent)
  - ❑ ~14 T HTS/LTS hybrid program with large HTS coils
    - ➢ Will address many technical issues associated with larger magnets
- Next slide: Other components of the program (not covered in this talk)

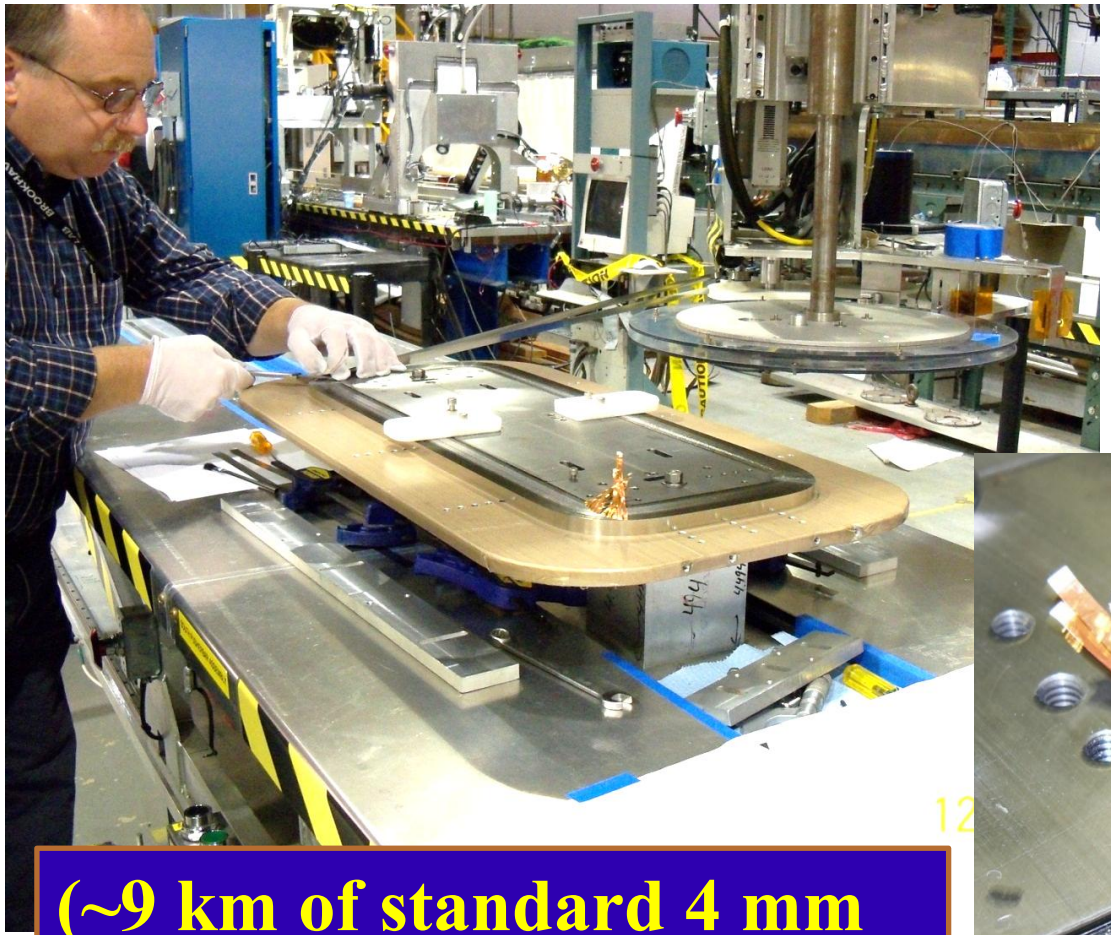
GARD/MDP Plan and Collaboration

Not included in this presentation:

- **Quench protection of HTS magnets (including cold electronics)**
  - A major issue in developing HTS magnet technology for accelerators
- **Field quality measurements in HTS magnets**
  - A major issue in accepting HTS for accelerator quality magnets
- **Study temperature dependent performance of HTS magnets**
  - Significant discussion on reducing cryogenic and operational cost

- ❑ Remains cost-effective, as it is primarily based on the existing hardware
- ❑ Collaborations are welcome; compare models and measurements
- ❑ Next step: Develop specific goals and MDP milestones

Driver: Existing 8 Large HTS Coils of FRIB Quad (up to 680mmX292mm, tape stack 40mmX12mm)

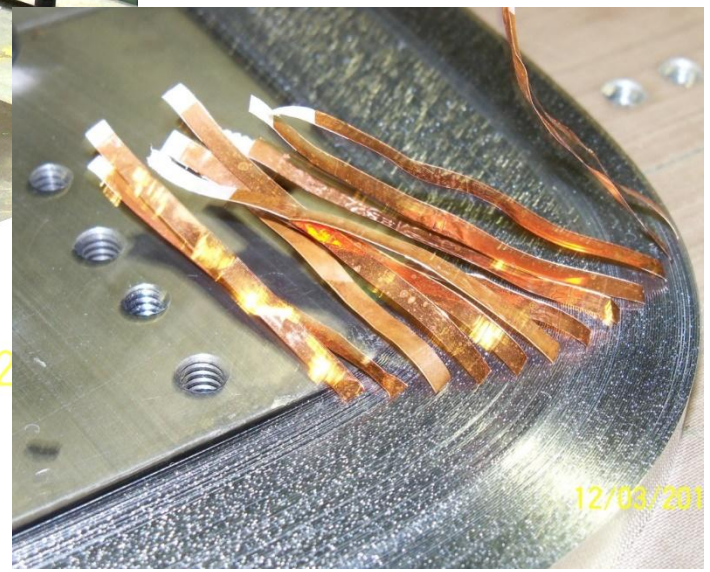


4 coils made with SuperPower Tape

and

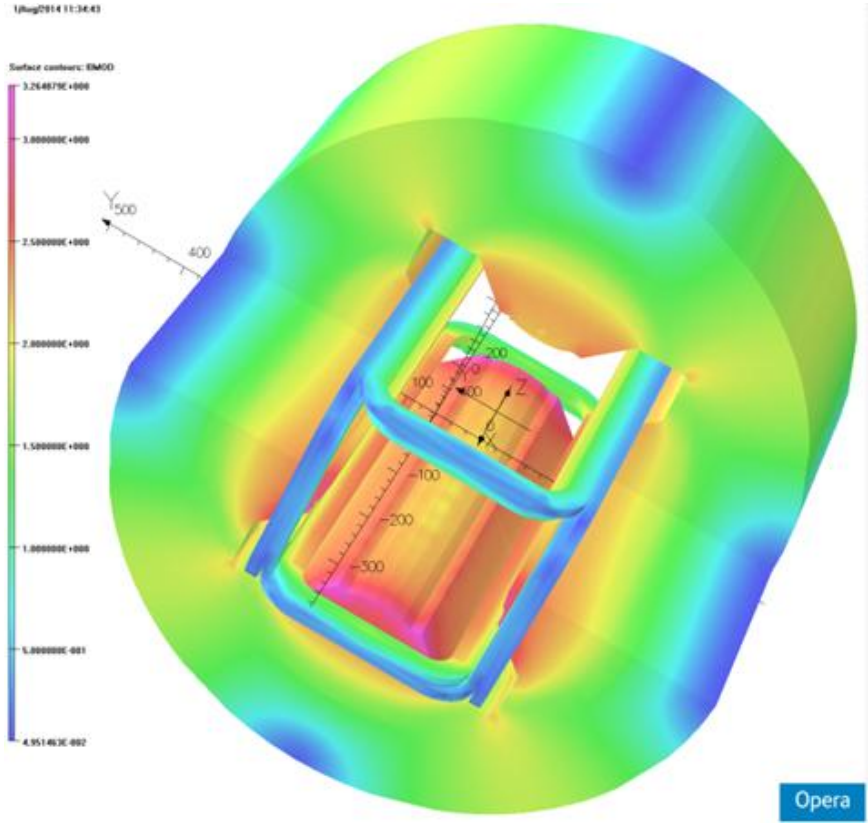
4 coils made with ASC Double Tape

(~9 km of standard 4 mm equivalent HTS tape used)

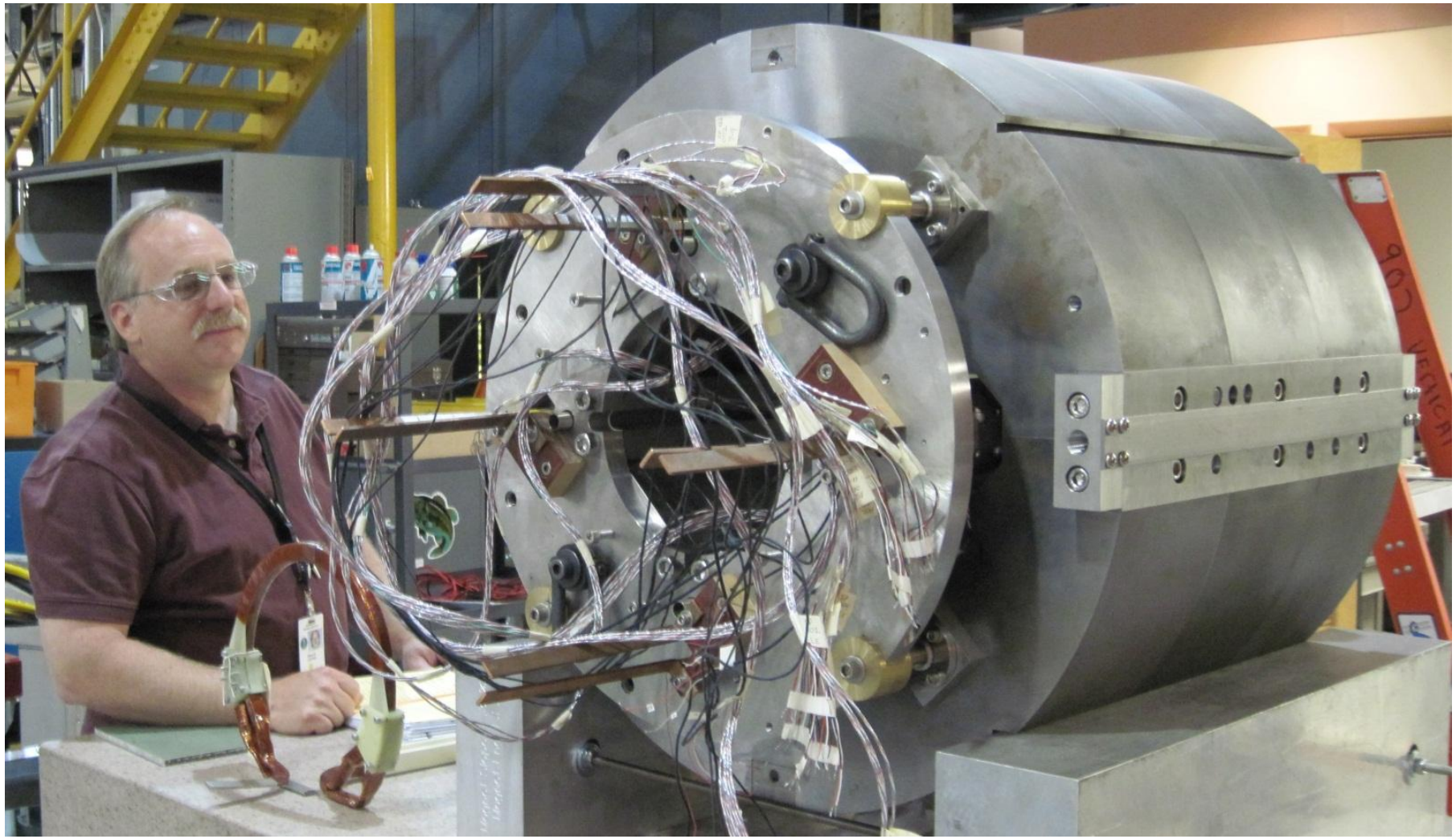


Well-instrumented with v-taps

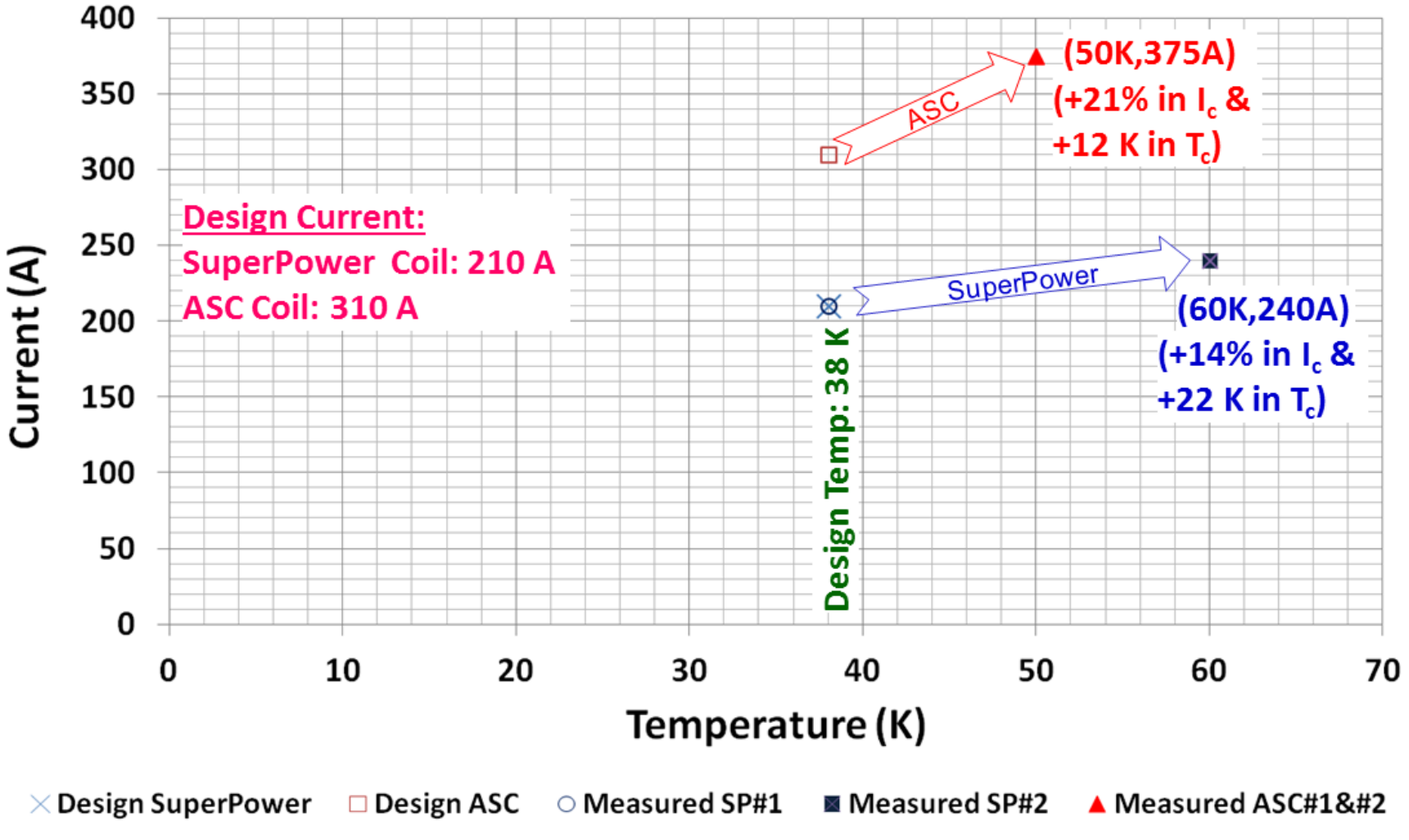
Magnetic Model of the HTS FRIB Quad



Large FRIB R&D Quad (HTS coils from this to play major role)



Performance of the FRIB HTS Quad



Designed for high temperature operation with large temperature margin.

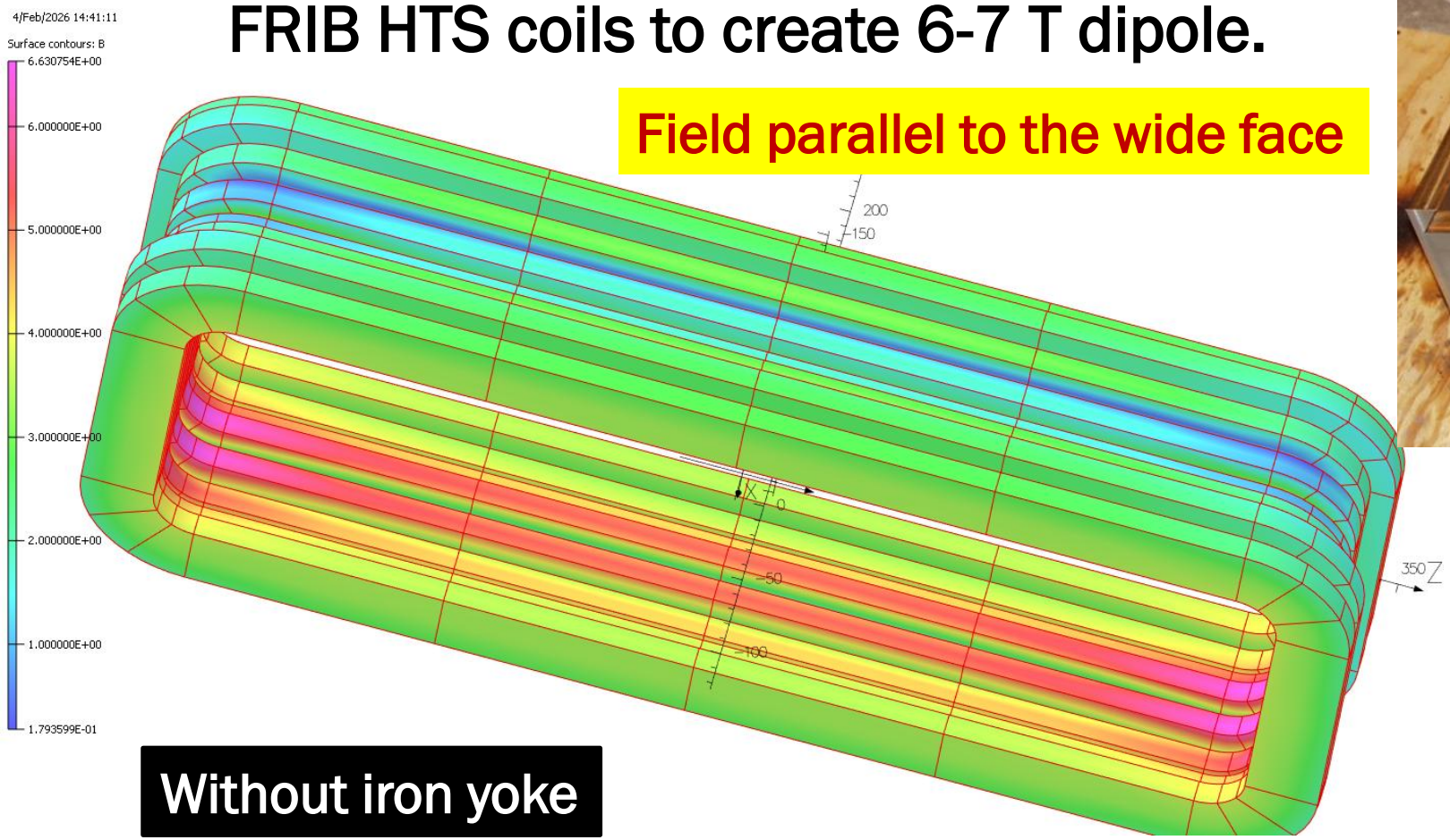
Demonstrated for robust operation against local and global heat loads.

FRIB QUAD Parameters and Recent Retest (all eight large HTS coils are still good)

Parameter	Value
Pole Radius	110 mm
Design Gradient	15 T/m
Magnetic Length	600 mm
Coil Overall Length	680 mm
Yoke Length	~550 mm
Yoke Outer Diameter	720 mm
Overall Magnet Length(including cryostat)	~880 mm
Number of Layers	2 per coil
Coil Width (for each layer)	12.5 mm
Coil Height (small, large)	27 mm, 40 mm
Number of Turns (nominal)	125 (ASC for 40 mm), 220 (SP for 27 mm)
Conductor (2G) width, SuperPower	12.1 mm ± 0.1 mm
Conductor thickness, SuperPower	0.1 mm ± 0.015 mm
Cu stabilizer thickness SuperPower	~0.04 mm
Conductor (2G) width, ASC	12.1 mm ± 0.2 mm
Conductor (2G) thickness, ASC	0.28 mm ± 0.02 mm
Cu stabilizer thickness ASC	~0.1 mm
Stainless Steel Insulation Size	12.4 mm X 0.025 mm
Field parallel @design (maximum)	~1.9 T
Field perpendicular @design (max)	~1.6 T
Minimum I_c @2T, 40 K (spec)	400 A (in any direction)
Minimum I_c @2T, 50 K (expected)	280 A (in any direction)
Nominal Operating Current	~140 A (SuperPower), ~370 A (ASC)
Stored Energy	37 kJ
Inductance	~1 H
Operating Temperature	50 K (nominal)
Design Heat Load on HTS coils	5 kW/m^3

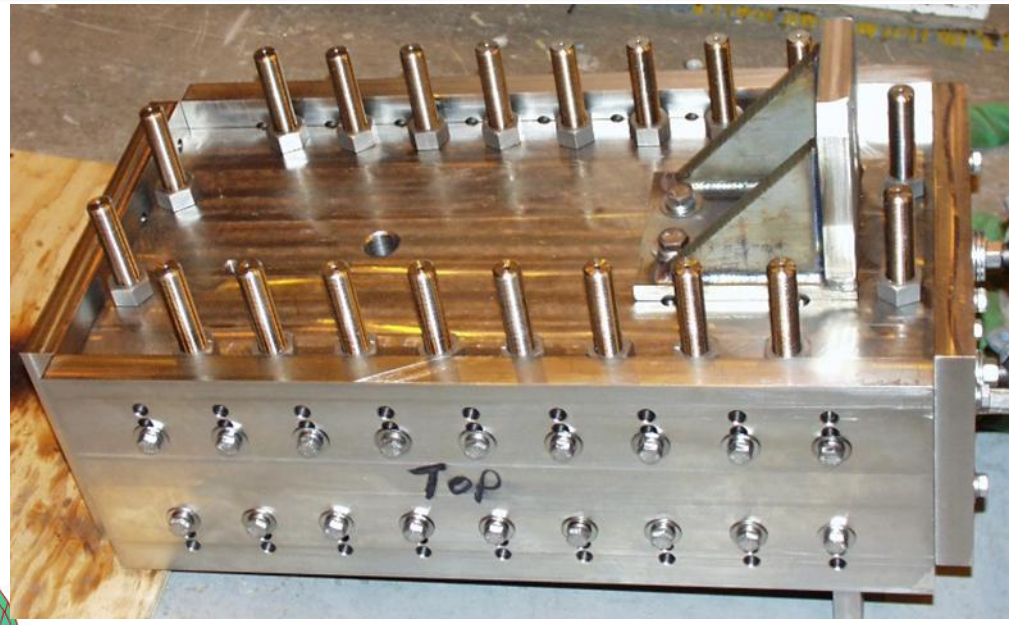
FRIB Coils in Dipole Configuration to create 6-7 T Field (Single aperture dipole configuration)

Reconfigure and assemble the large FRIB HTS coils to create 6-7 T dipole.



Field parallel to the wide face

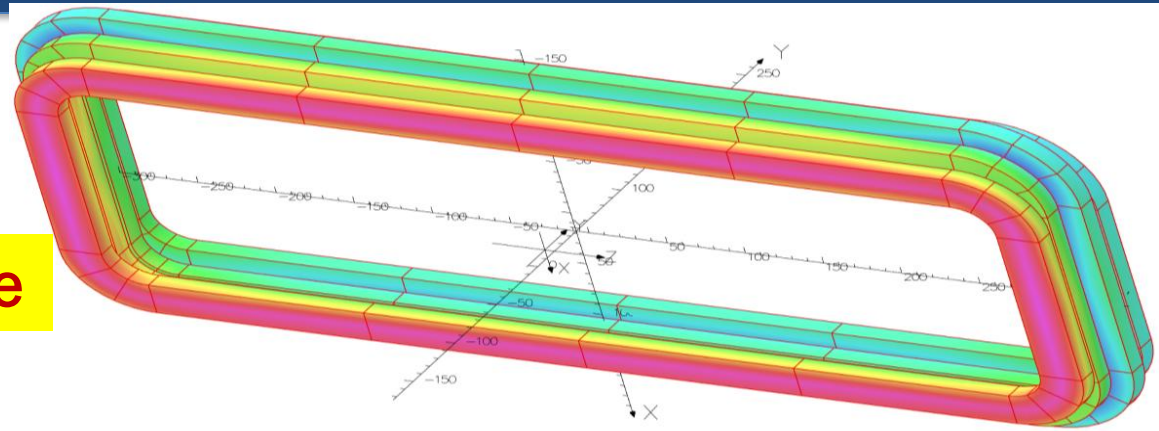
Without iron yoke

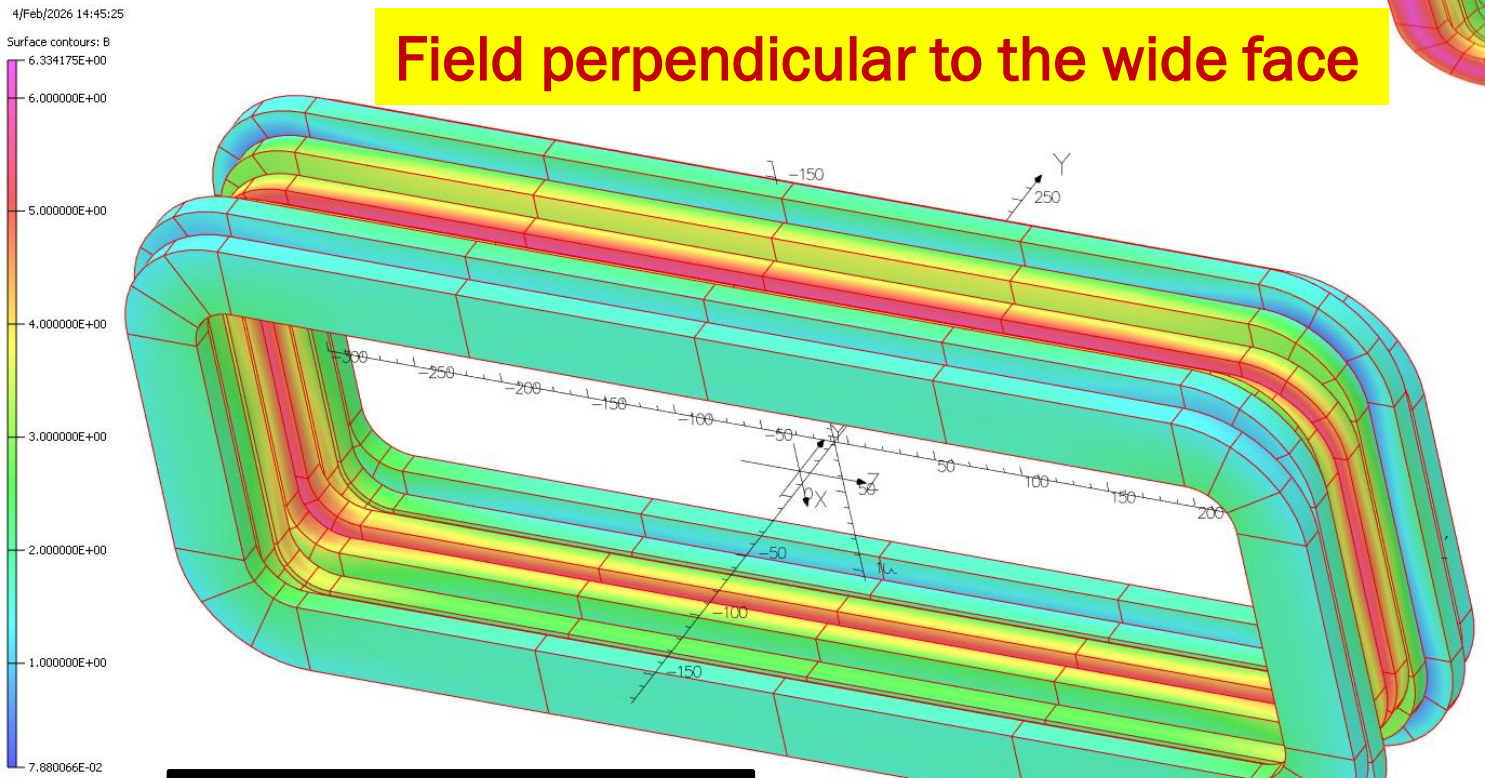


Simple, low-cost, flexible structure, at least for 77 K tests (as used in earlier BNL HTS magnets)

Another Configuration for FRIB Coils to create 6-7 T (2-in-1 Common Coil Dipole Configuration)

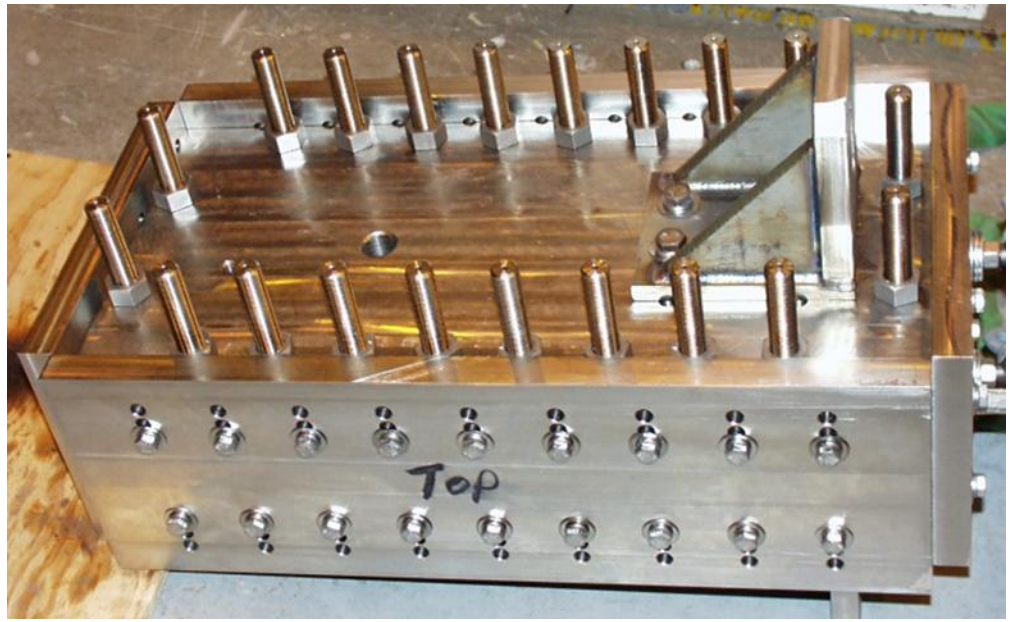
Reconfigure and assemble the large HTS coils to create 6-7 T common coil dipole.





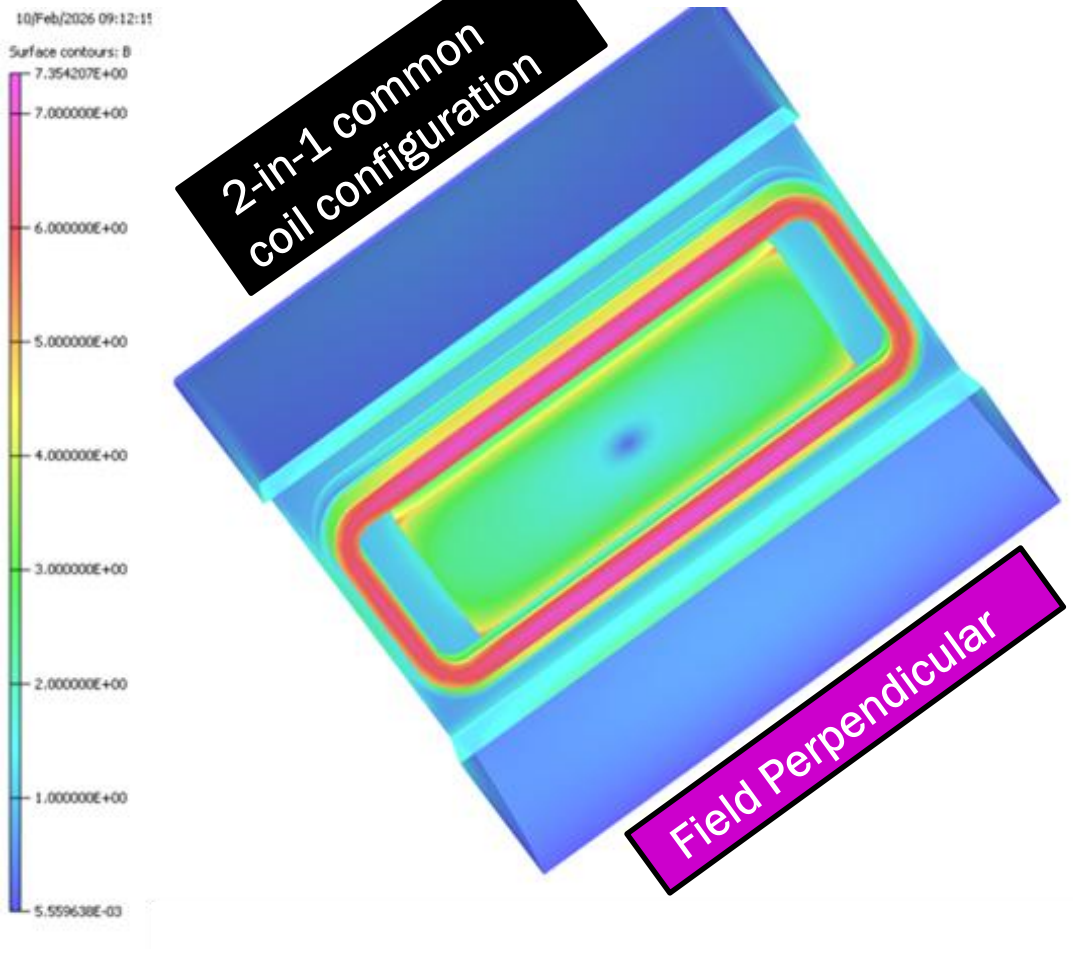
Field perpendicular to the wide face

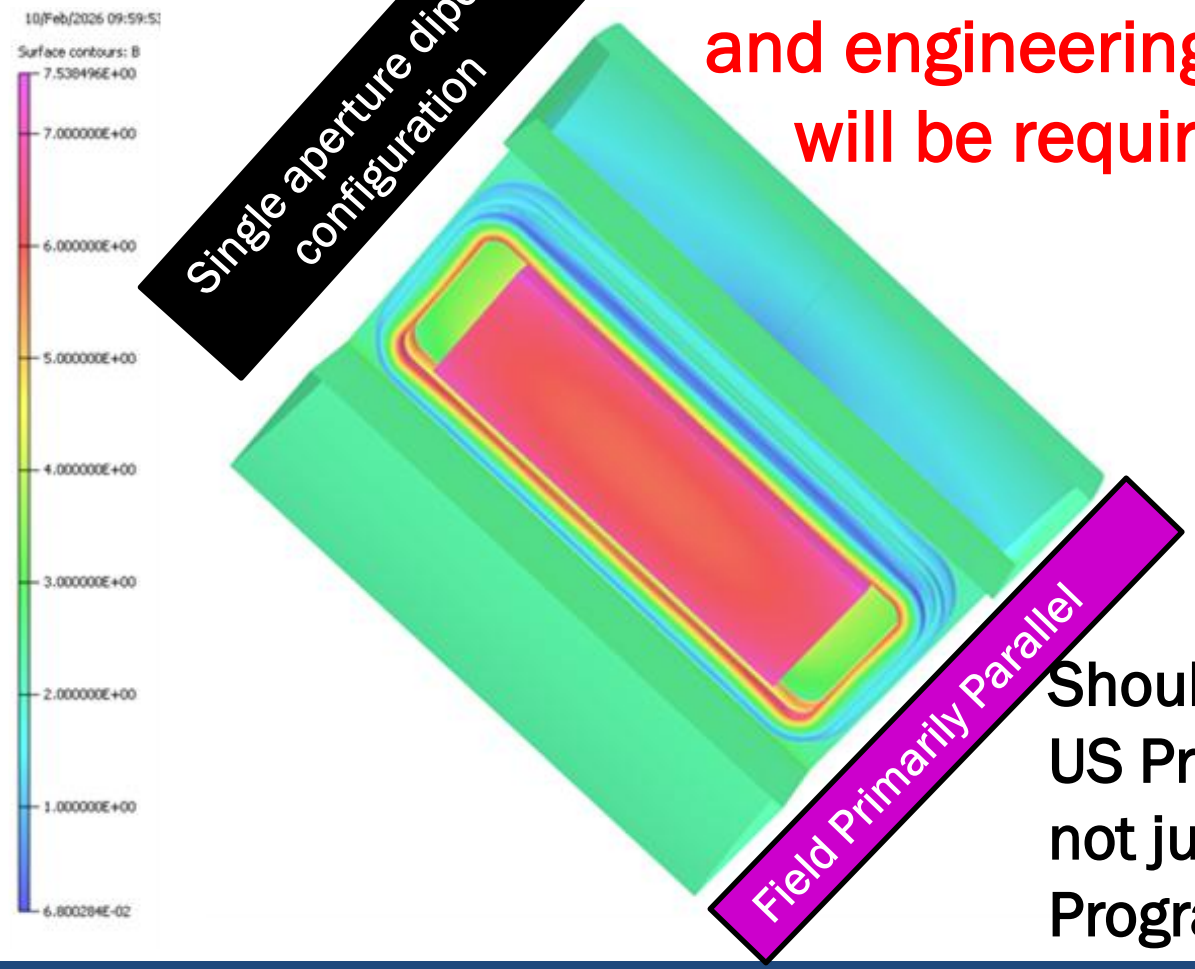
Without iron yoke



Large FRIB Coils with Yoke in Two Configuration (Program TBD: HTS coil tests with/without yoke)

A high value program





Significant design and engineering work will be required.

Should be a US Program, not just BNL Program

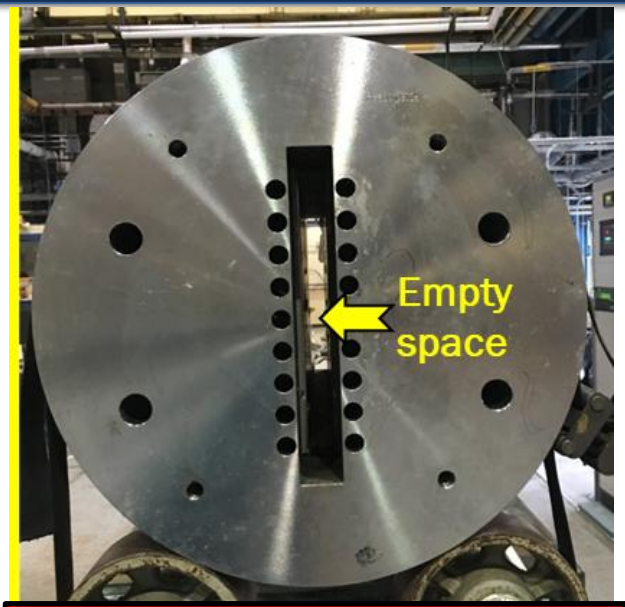
HTS/LTS Hybrid Magnet Program

Common Coil Test Facility (CCTF) for high field magnet R&D

A GARD/MDP Facility in use by HEP and Fusion Community

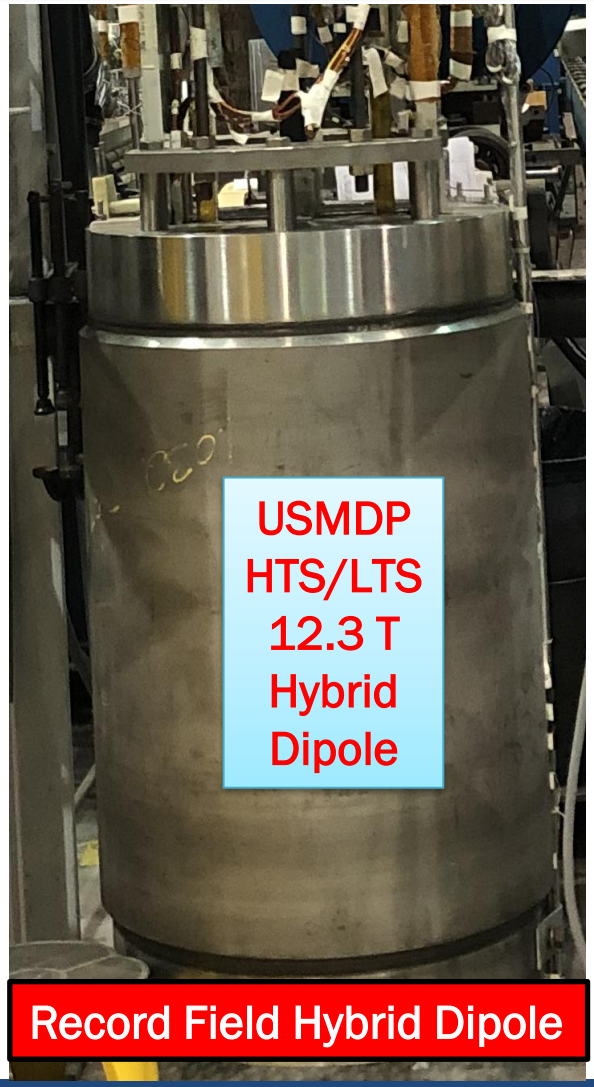
- 10 T, Nb_3Sn R&W dipole with a large open space for high field insert coil testing
- New coil(s) in the magnet without any disassembly
- Coils become an integral part of the dipole magnet
- A new coil test essentially becomes a new magnet test

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



Record Field R&W Nb_3Sn Dipole

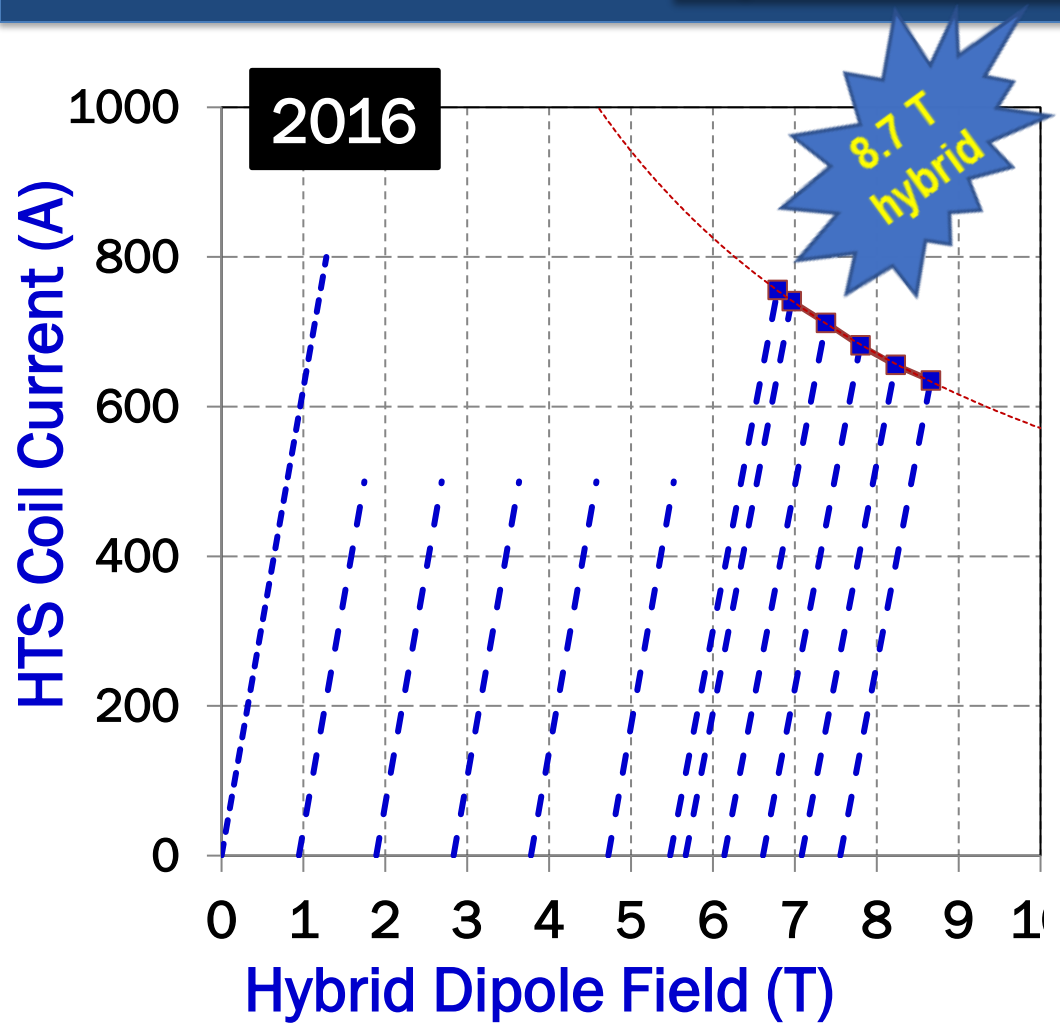
1st Test for FES at a HEP Facility



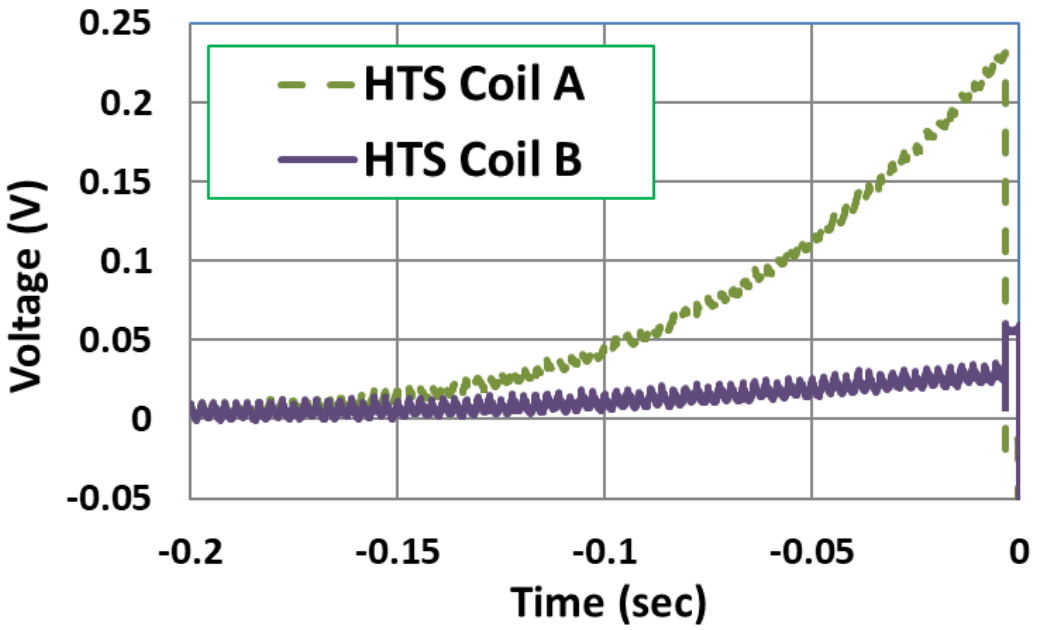
Record Field Hybrid Dipole

Field perpendicular & Field parallel tests

HTS/LTS Hybrid Dipole Test with ASC Double-tape (common coil configuration, field perpendicular)



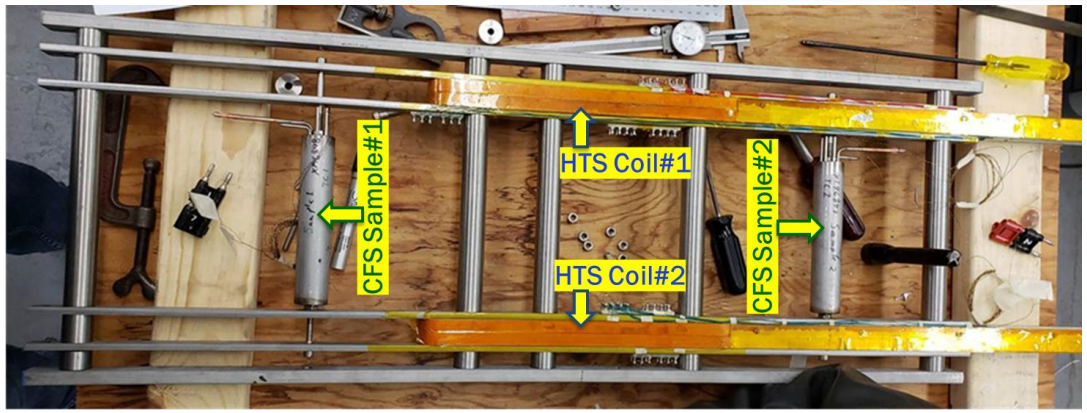
- HTS coils had no training, no degradation despite "**several quenches**", Also, I(B) curve.
- HTS coils were ramped to quench in LTS coils type environment (200 mV, 200 msec).



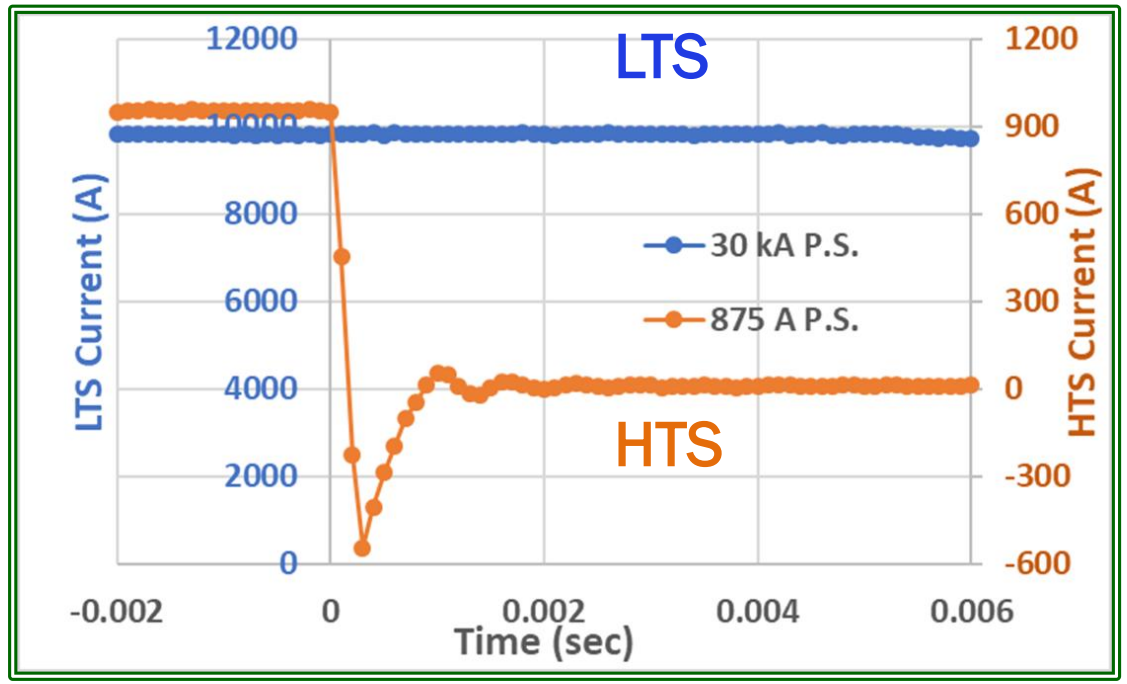
Does two HTS tapes soldered together makes a difference?

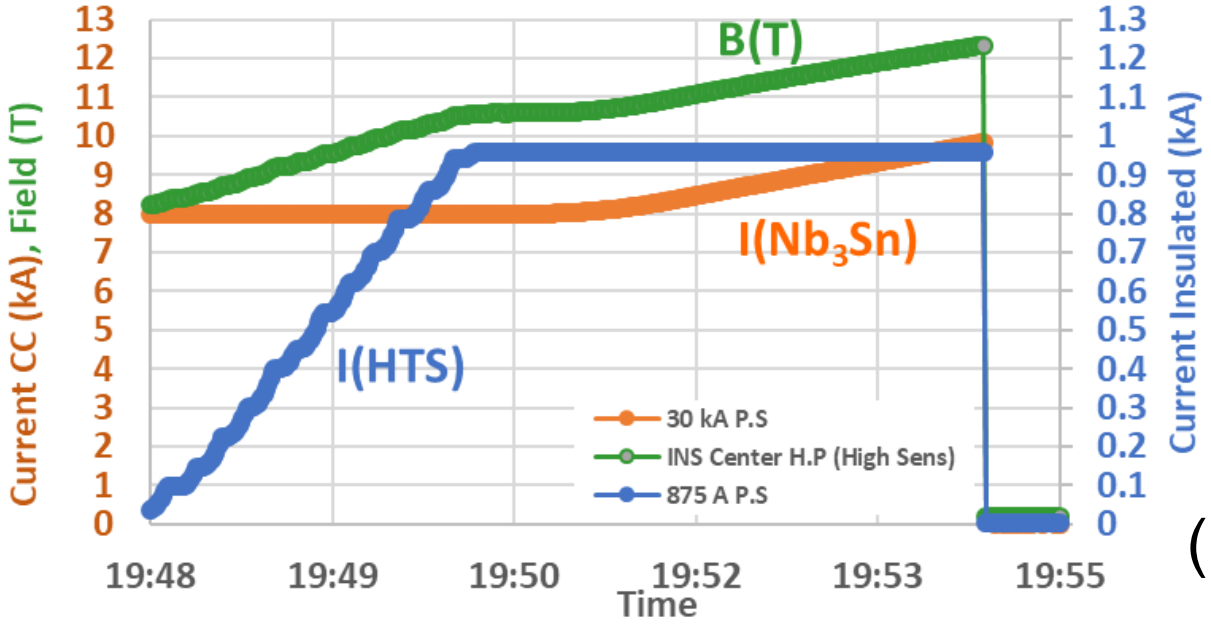
➢ **Limited by energizing the LTS coils**

HTS/LTS Hybrid Dipole Test with SP single-tape coil (2 HTS coils, field parallel; + 2 CFS/FES samples)



2020

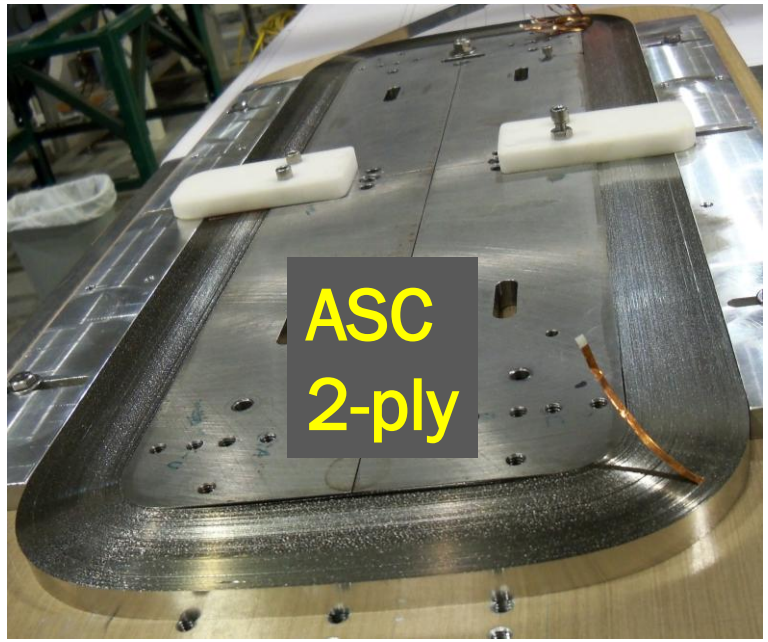


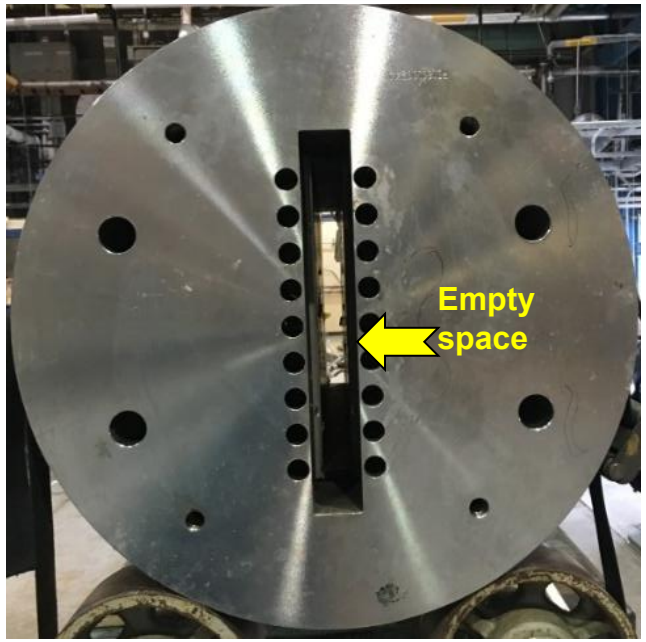


HTS: (~3 T) + LTS: (9.3 T)
Hybrid: 12.3 T (still a record)
(limited by LTS coil, likely from HTS pinching it)

HTS/LTS Hybrid Dipole with Large FRIB Coils

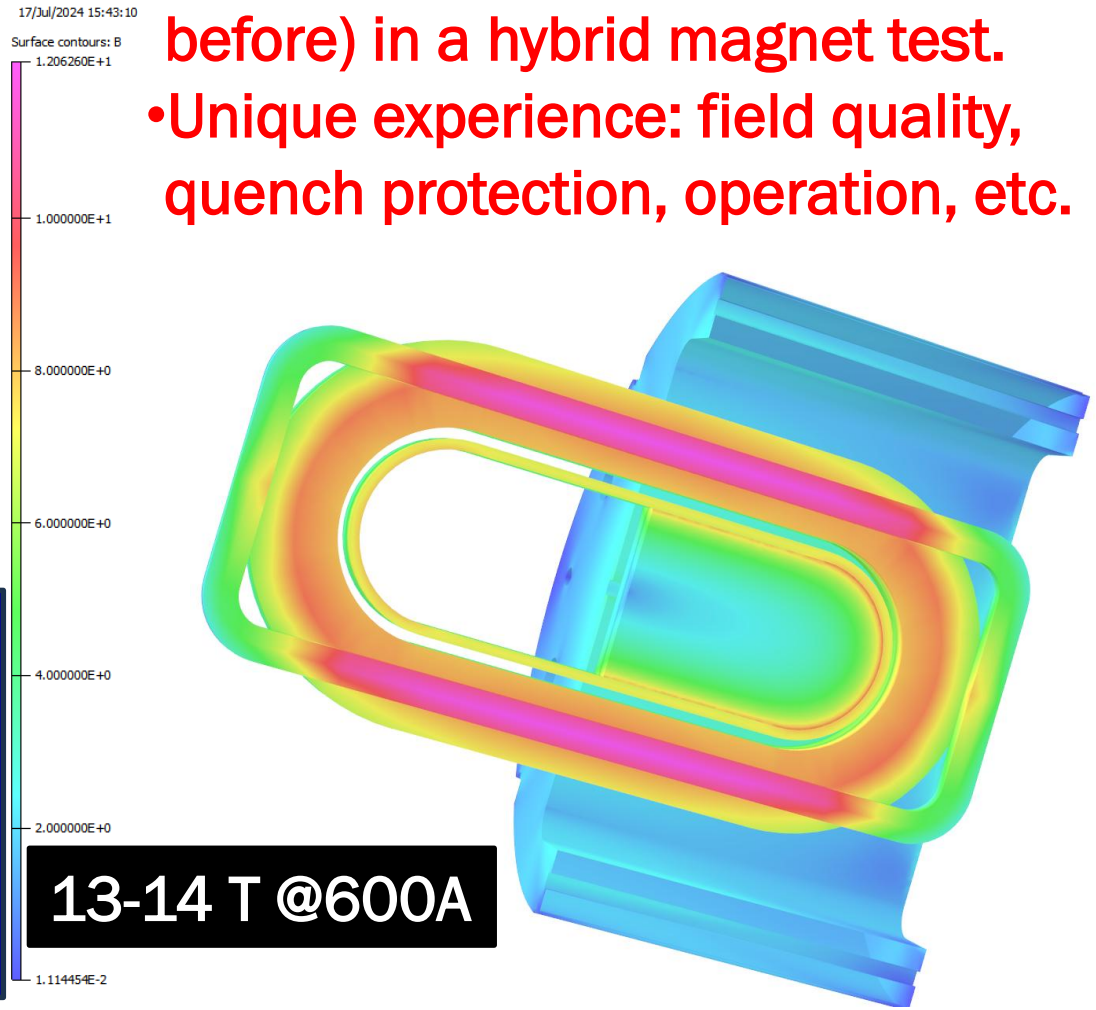
(Schedule : TBD, depends on resources, collaboration)





Insert FRIB HTS coils in Nb_3Sn common coil dipole for hybrid test

- A pair of HTS coils, (larger than before) in a hybrid magnet test.
- Unique experience: field quality, quench protection, operation, etc.



SUMMARY

- A cost-effective program for developing high field HTS and high field HTS/LTS hybrid magnet technology leverages existing large FRIB R&D coils.
- Larger HTS coils (with large stored energy, etc.) takes us to the next level. Now is the time to know if there are issues in scaling before going too far.
- The program, as outlined, is well aligned to MDP and its stated initiatives.
- Given the scale of the program and key technical learning involved, this should be a national program, not just BNL program.
- Collaborations and contributions welcome from early-on, including in shaping the program and technical goals. This will make it go faster as well,
- MDP milestones, etc. to be developed based on the resources available.

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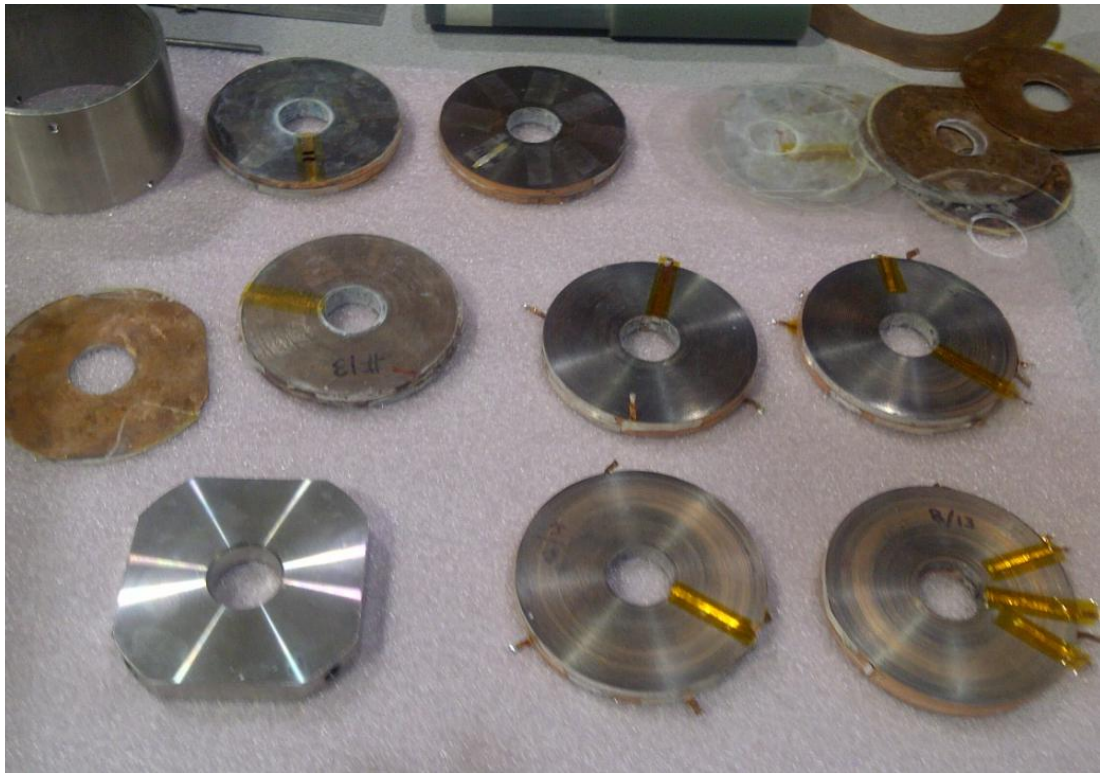
Extra Slides

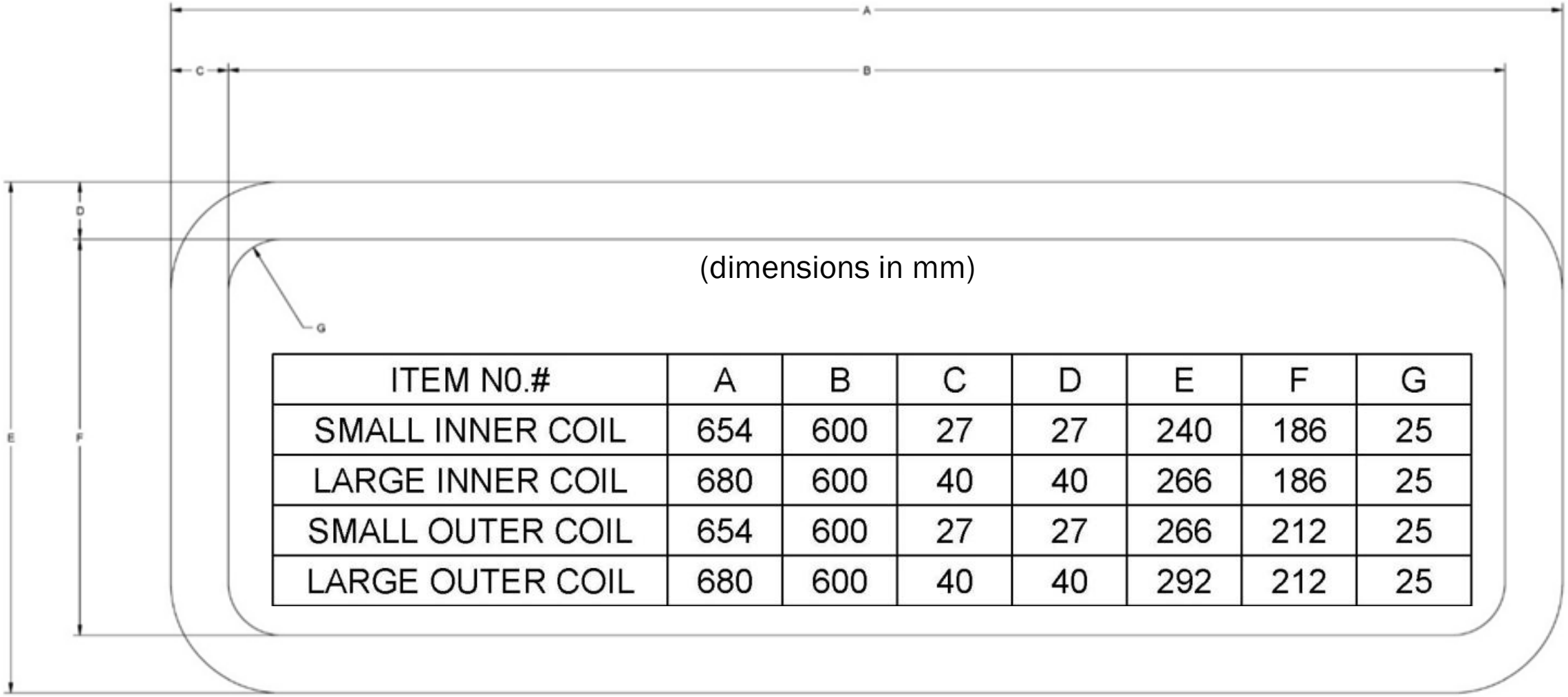
Quench studies with a large number (100+) of HTS coils from the previous R&D programs

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



Example: Development of advanced quench detection/protection and cold electronics

FRIB COILS (four types)



(dimensions in mm)

ITEM N0.#	A	B	C	D	E	F	G
SMALL INNER COIL	654	600	27	27	240	186	25
LARGE INNER COIL	680	600	40	40	266	186	25
SMALL OUTER COIL	654	600	27	27	266	212	25
LARGE OUTER COIL	680	600	40	40	292	212	25

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/