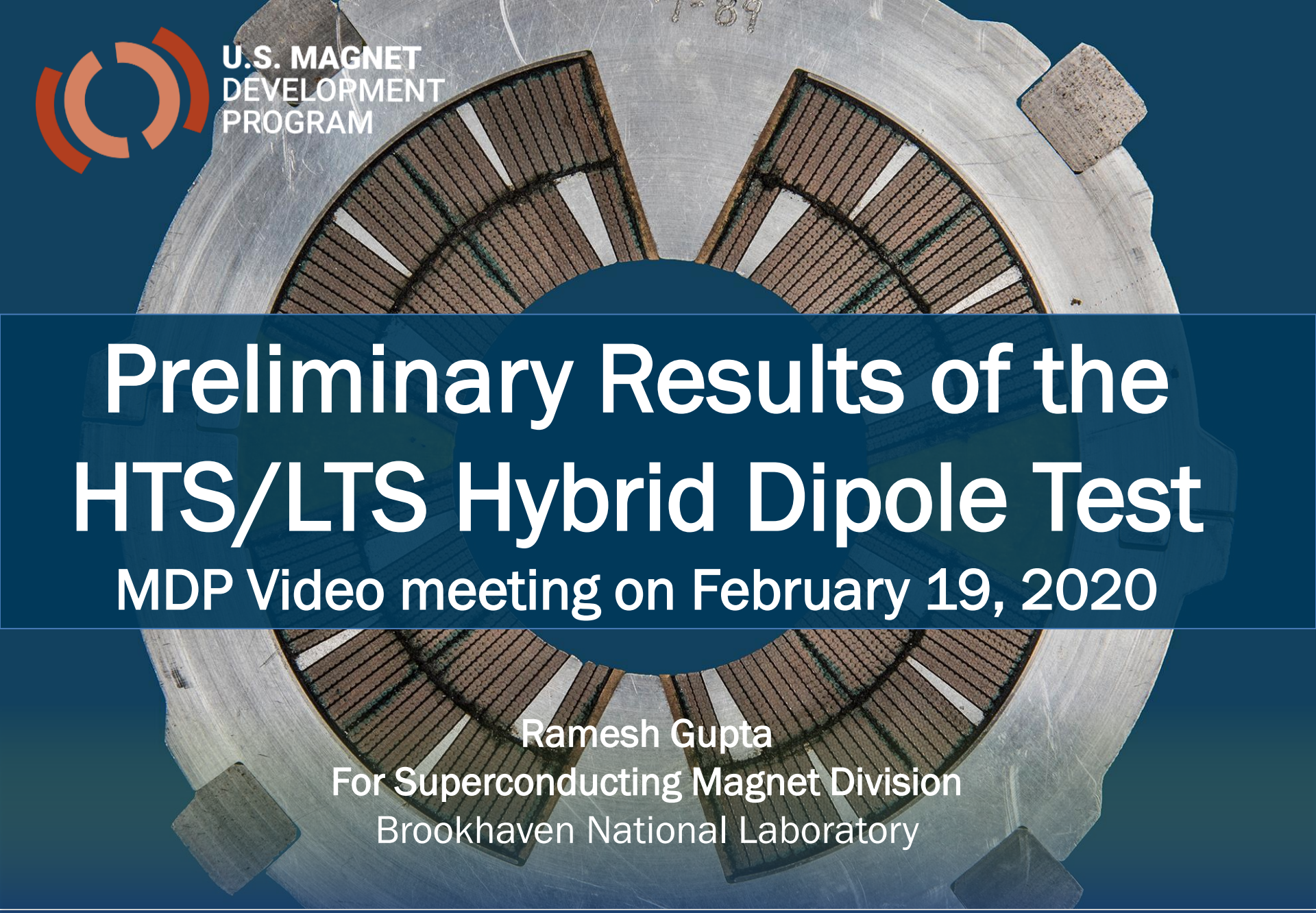

U.S. MAGNET DEVELOPMENT PROGRAM

Preliminary Results of the HTS/LTS Hybrid Dipole Test

MDP Video meeting on February 19, 2020

Ramesh Gupta
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Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

Contributions from

Work presented here and the work being performed now is thanks to many individuals, including:

Bill Sampson, Shresht Joshi, Anis Ben Yahia, Piyush Joshi, Bill McKeon, Sonny Dimaiuta, Denny Sullivan, Peter Galioto, Pat Doutney, Mike Anerella, John Cozzolino, Ray Ceruti, …

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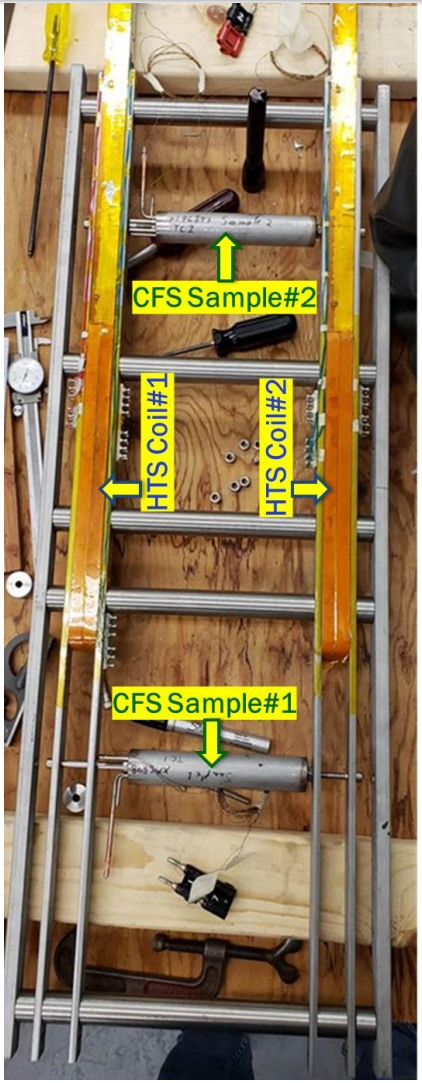
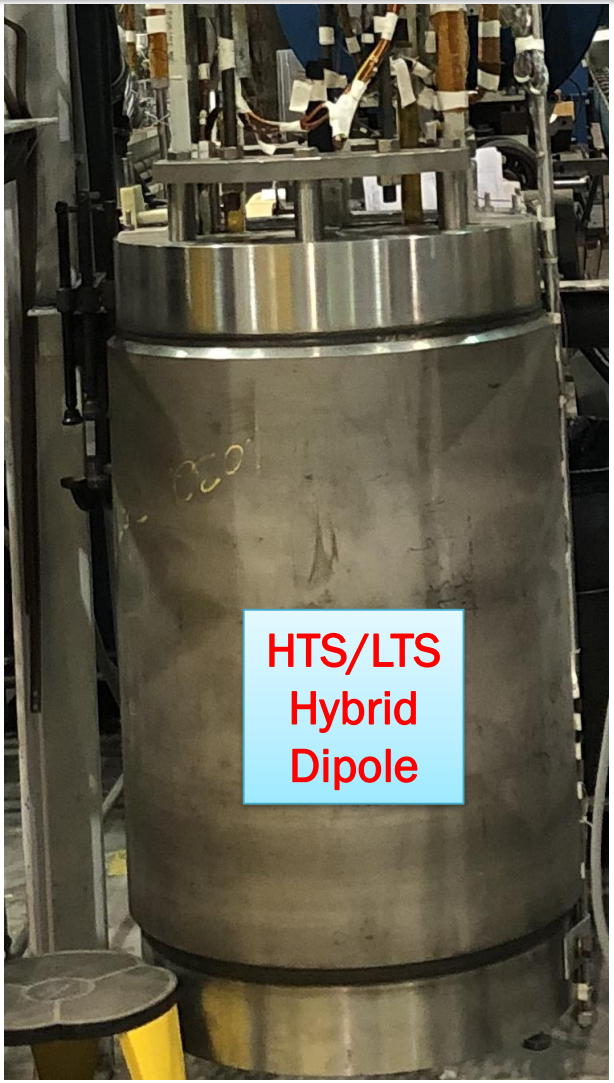
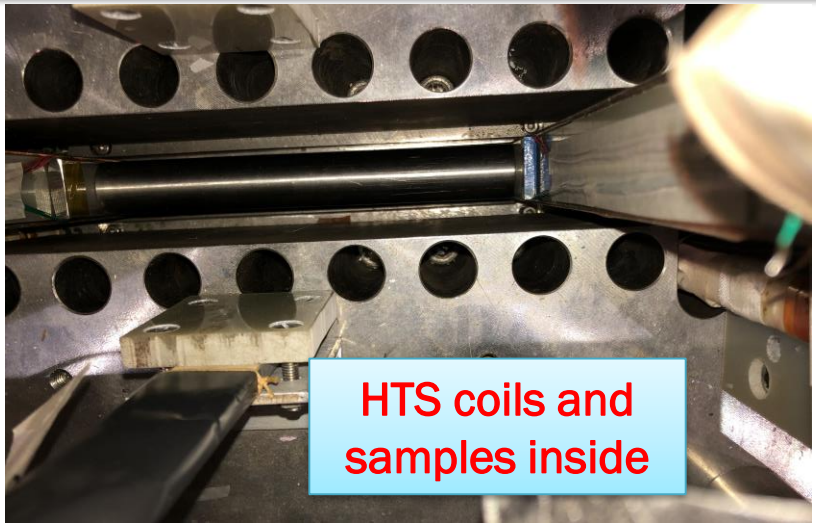
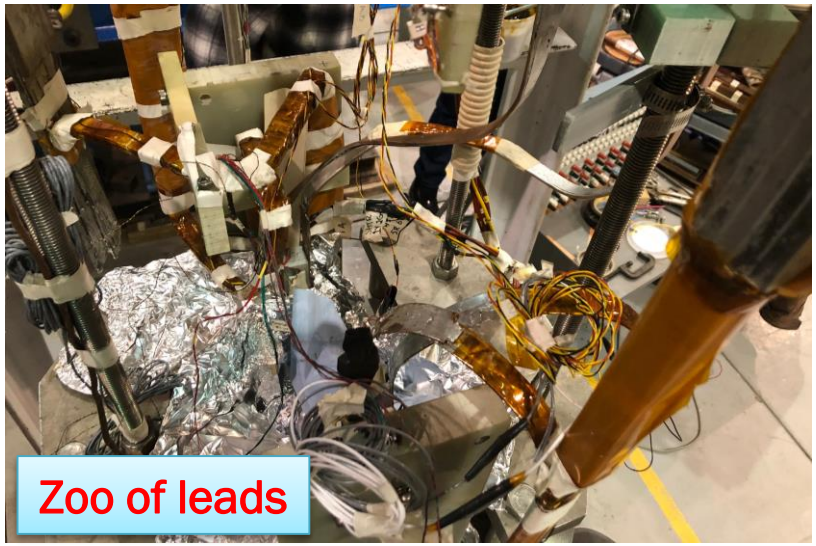
Fixture inside the magnet









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Run Plan for Magnetization Studies

(almost everything planned in this slide done, perhaps not always be in the order planned)

Magnetization Studies Test Program at 4.5 K.

Purpose: To perform magnetization studies of HTS coils first by themselves and then in the background field of the Nb_3Sn common coil magnet.

During the following tests the magnet field should be measured continuously by the Hall probes and recorded.

1. **HTS Nomex Coil Only** (difference voltage between two HTS pancake coils must remain < 2 mV and attempt should be made that the HTS coil doesn't quench)
    - Ramp up to 100 A and down to 0 A
    - Ramp up to 200 A and down to 0 A
    - Ramp up to 400 A and down to 0 A
    - Ramp up to 600 A and down to 0 A
    - Ramp up to 800 A and down to 0 A

2. **HTS No-Insulation Coil Only** (difference voltage between two HTS pancake coils must remain < 10 mV and attempt should be made that the HTS coil doesn't quench)
    - Ramp up to 100 A and down to 0 A
    - Ramp up to 400 A and down to 0 A
    - Ramp up to 800 A and down to 0 A
    - After review of results of above tests, make plan to ramp to higher currents

3. **LTS (Nb3Sn) Coil Only**
    - Ramp gradually in steps to 10000 A (no quench at 10000 A in 2017 test and it reached 10,800 A in 2006).
    - If magnet trains, we will stop at 5 quenches and limit further operation of the LTS magnet to 90% of the current reached at the 5^{th} quench.
    - If the magnet reaches 10000 A without quench, ramp the magnet to quench and limit further operation of the LTS magnet to 90% of the current reached.

4. **HTS/LTS Hybrid Magnetization Tests**
    - Hold LTS magnet at 500 A, 1 kA, 2 kA, 4 kA, 6 kA, and 8 kA, and for each HTS coil ramp up and down to whatever current safely possible without quenching (800 A nominal max).
    - Reduce current in LTS magnet and perform above steps.

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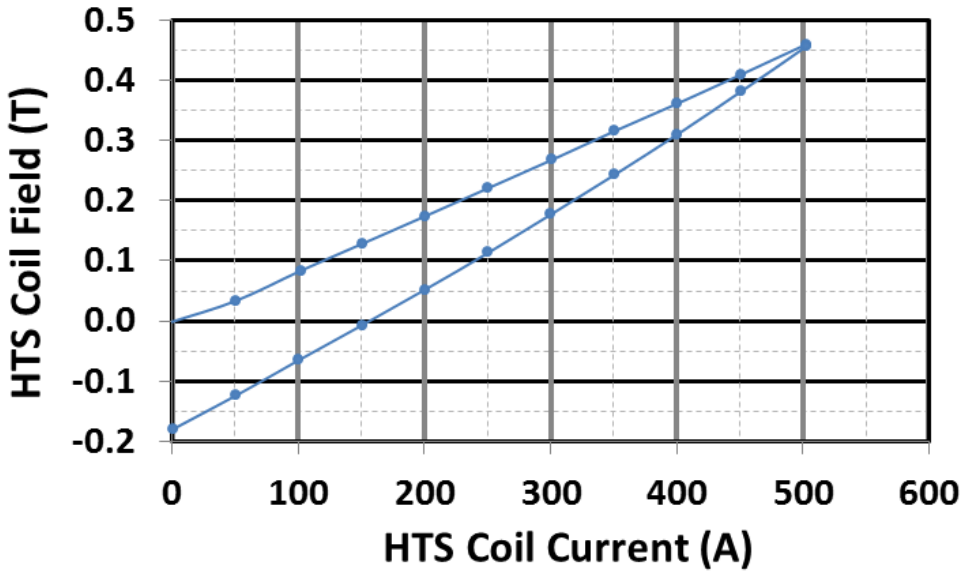
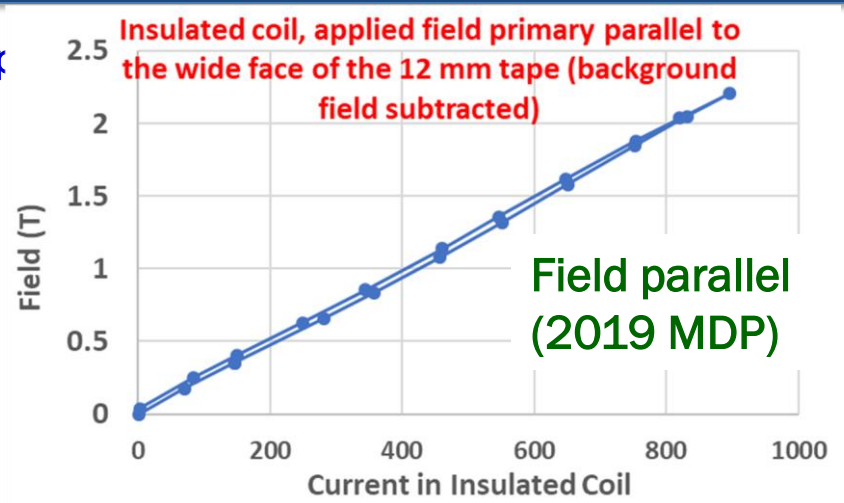
Test Run at 4 K in HTS/LTS Hybrid Dipole (~2 T background field from Nb_3Sn coils)

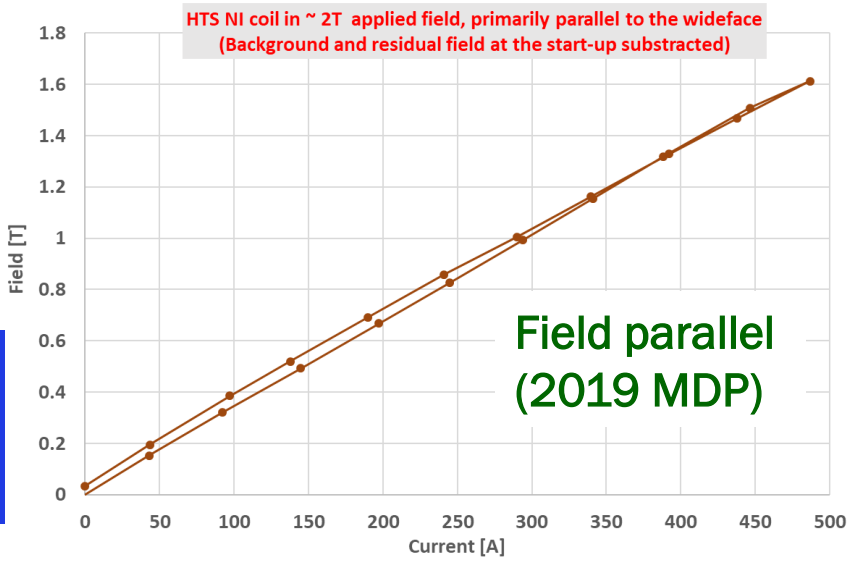
Additional field from the HTS coils in up and down ramp
(offset to start from zero to start up-ramp)

Field perpendicular (2016 SBIR)

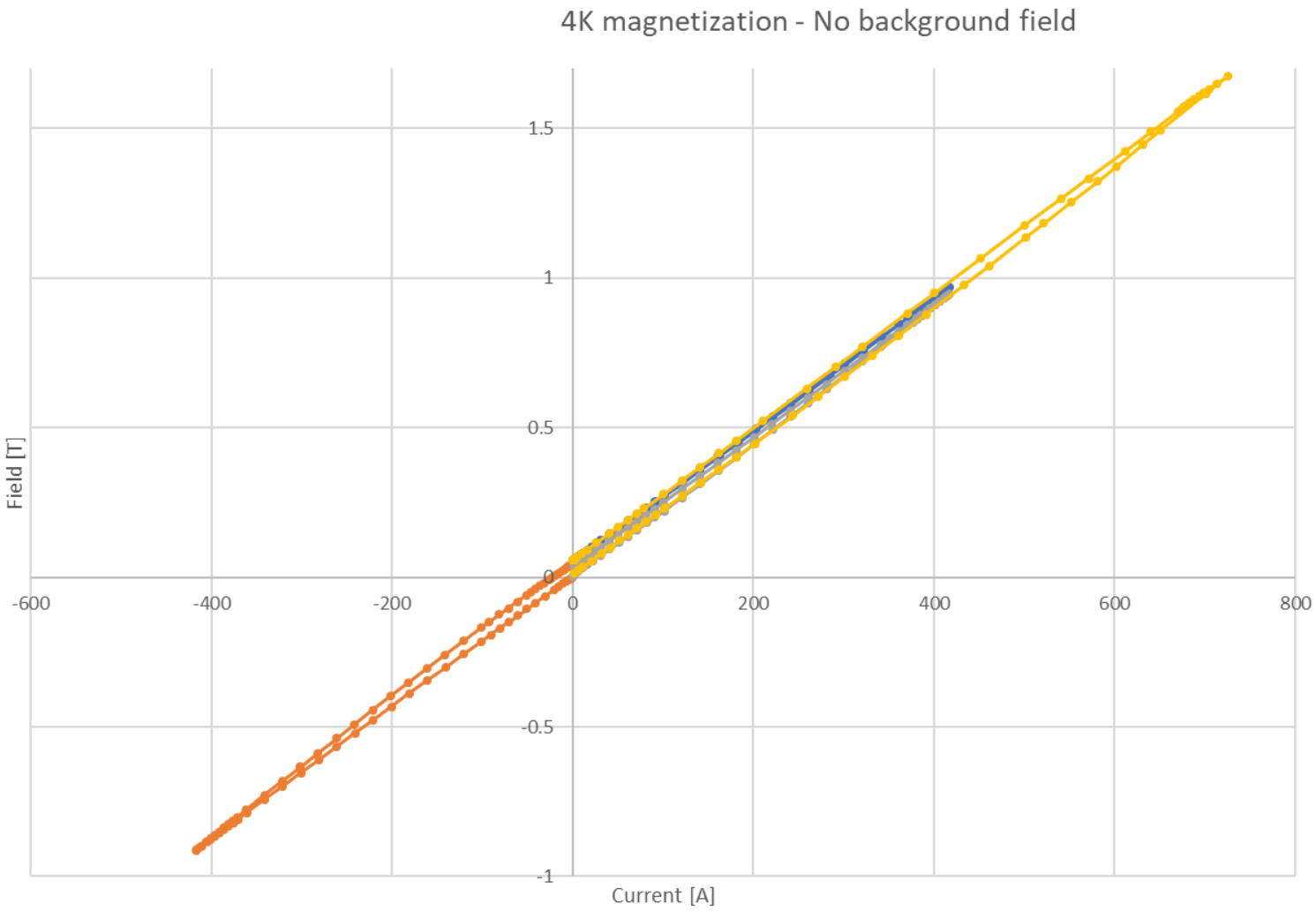


Significant reduction in magnetization from HTS coils when field is primarily parallel to the wide face when compared to primarily perpendicular





4 K run – No background field



Magnetization measurement were done prior to this test up current up to 500A at higher temperatures

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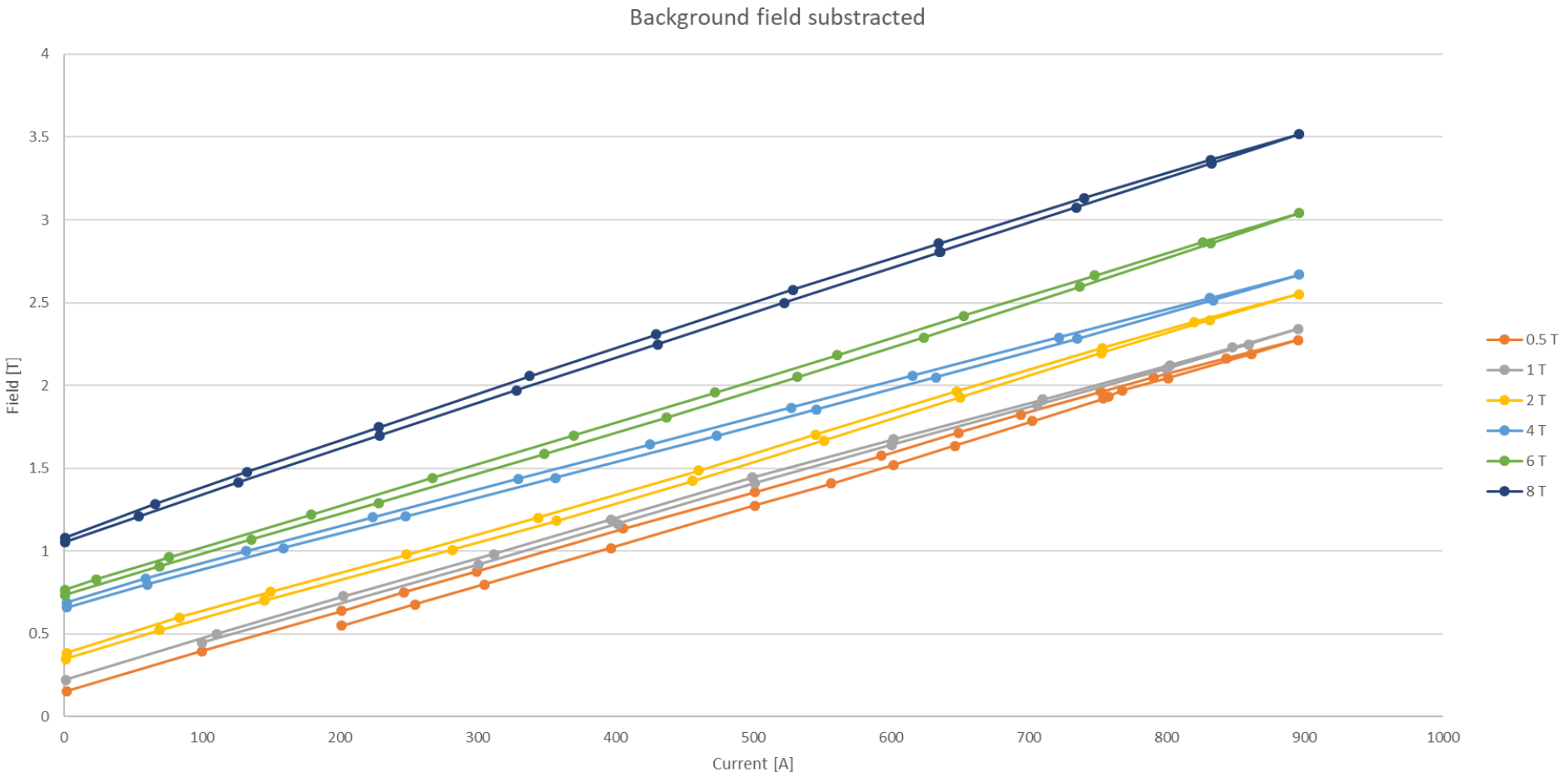
4 K Magnetization Run in Background Field (background field subtracted)



Quench Protection of HTS/LTS Hybrid Dipole

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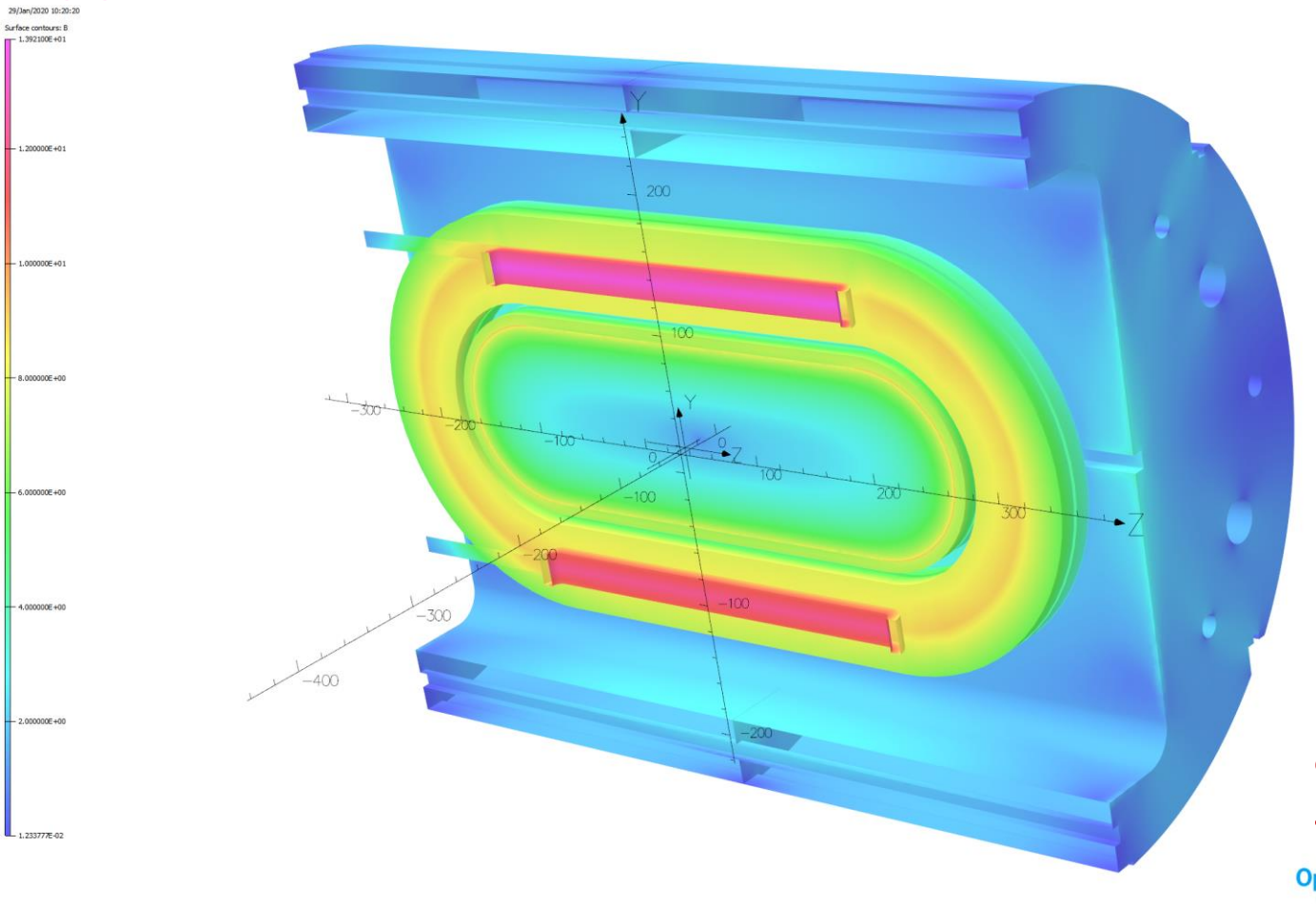
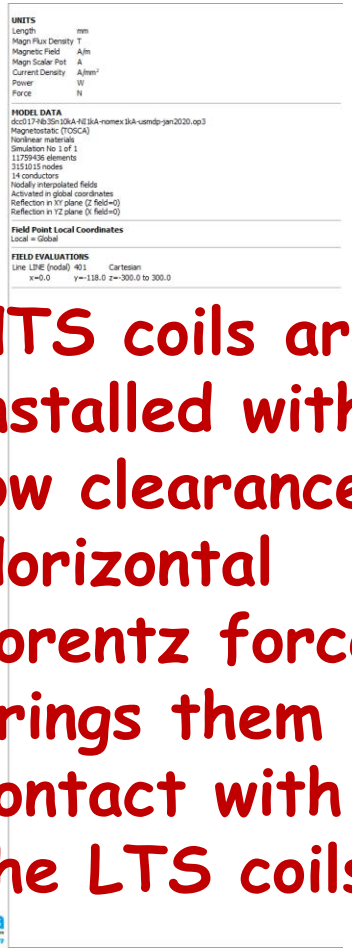
Cutout View for Nb_3Sn coils at 10 kA and HTS coils at 1 kA (with Nomex insulation and No-insulation)

13.9 T





HTS coils are installed with as low clearances. Horizontal Lorentz forces brings them in contact with the LTS coils

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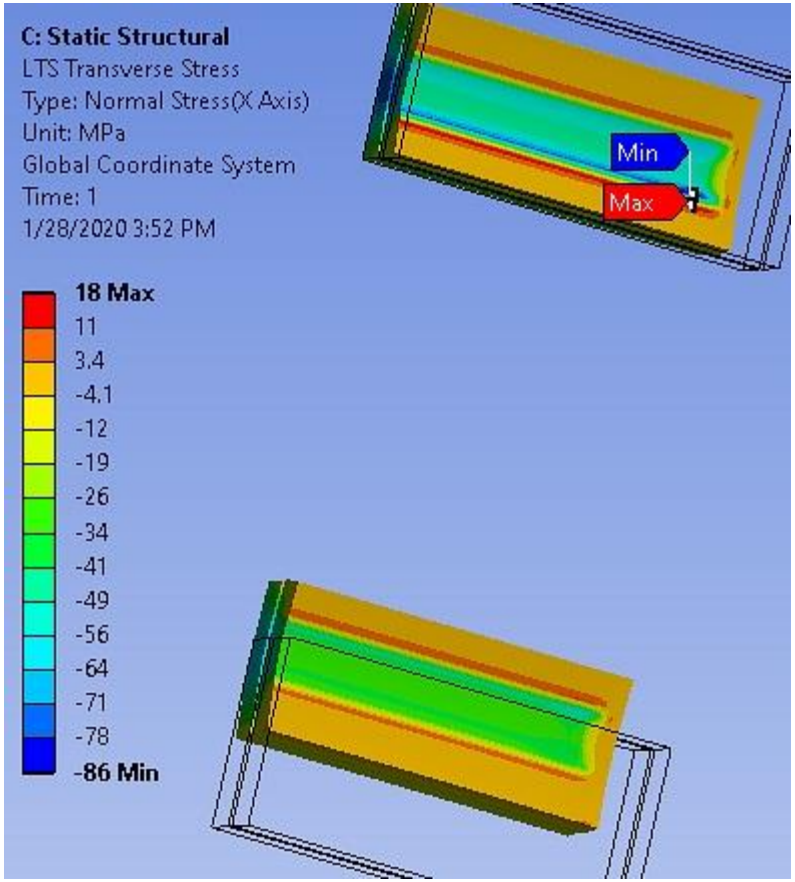
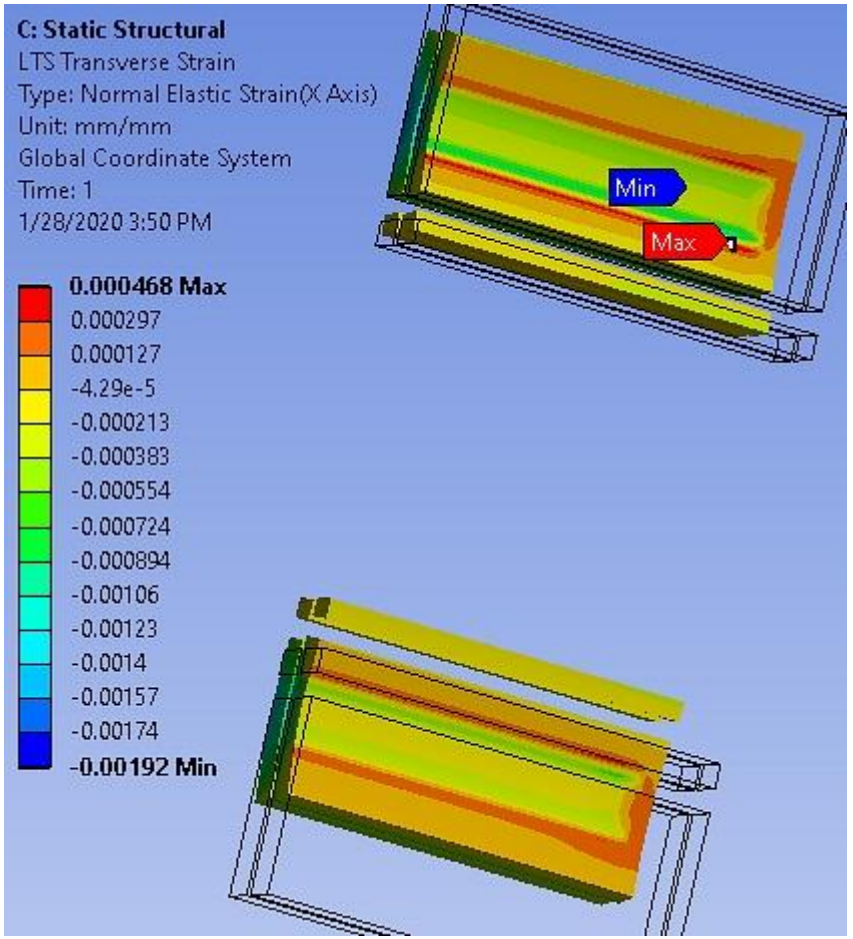
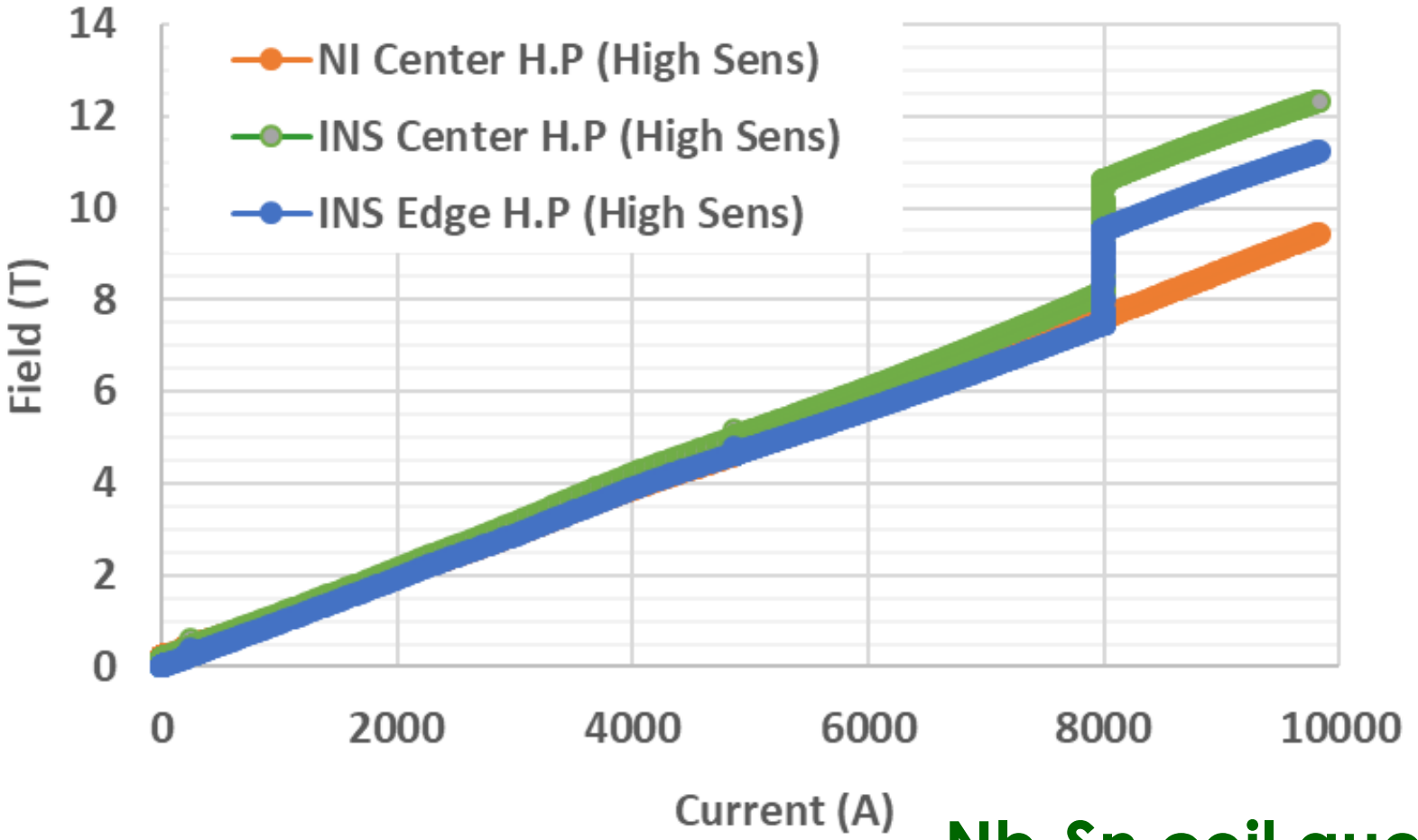
ANSYS Run Transverse Stress and Strain from Nb_3Sn 10 kA, HTS 1 kA

LTS Coils





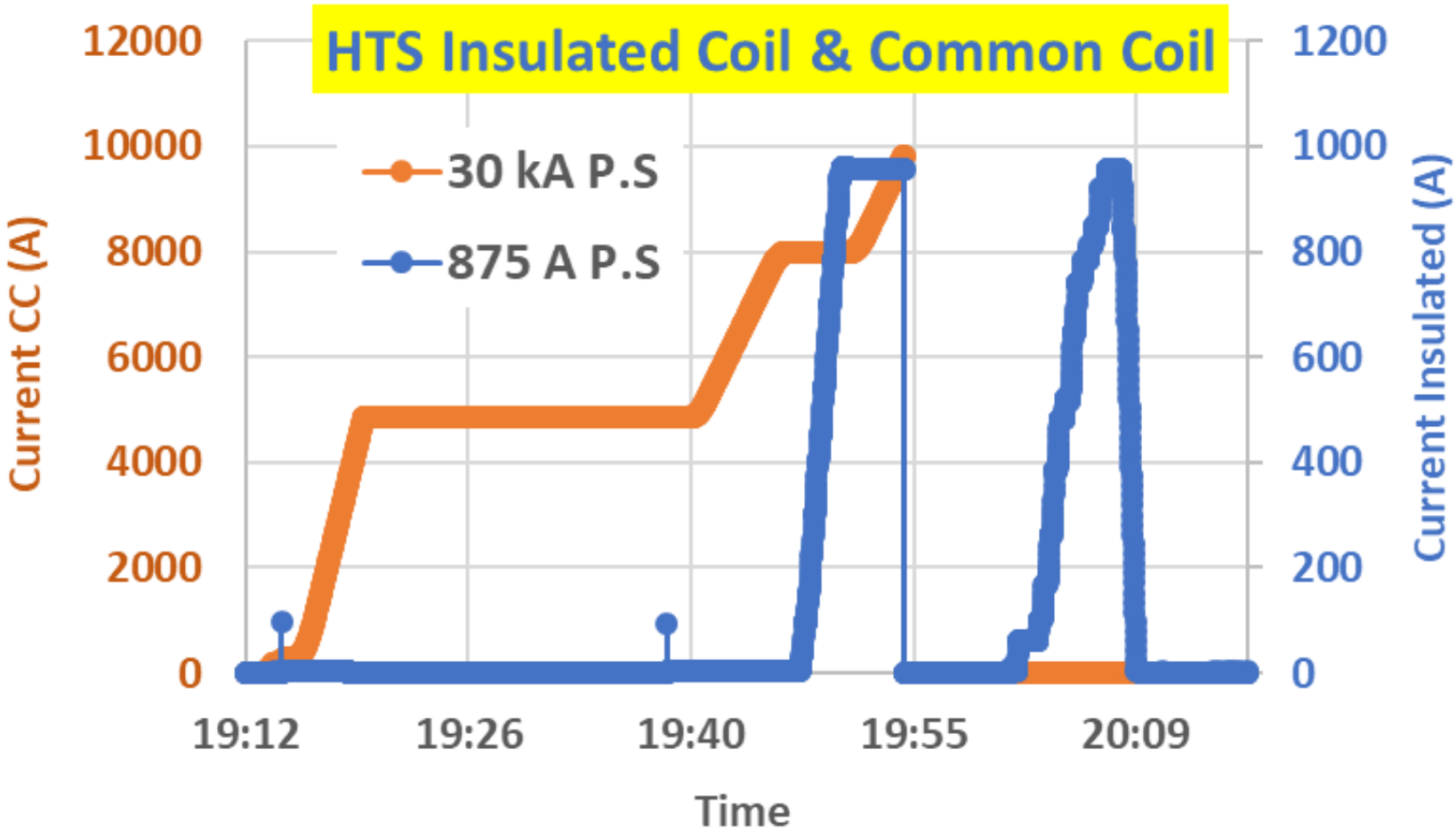
Insulated Coil Powered with the common coil (field in NI coil: Nb3Sn field + trapped field)



Nb_3Sn coil quenched

HTS Coil was ramped to the maximum of PS after the quench to check damage from the quench

Nb_3Sn coil quenched



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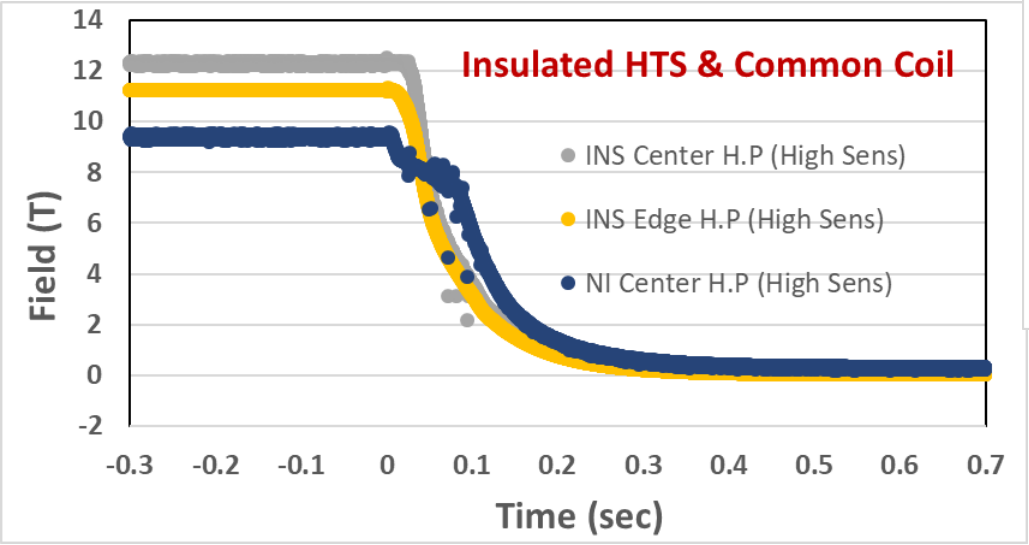
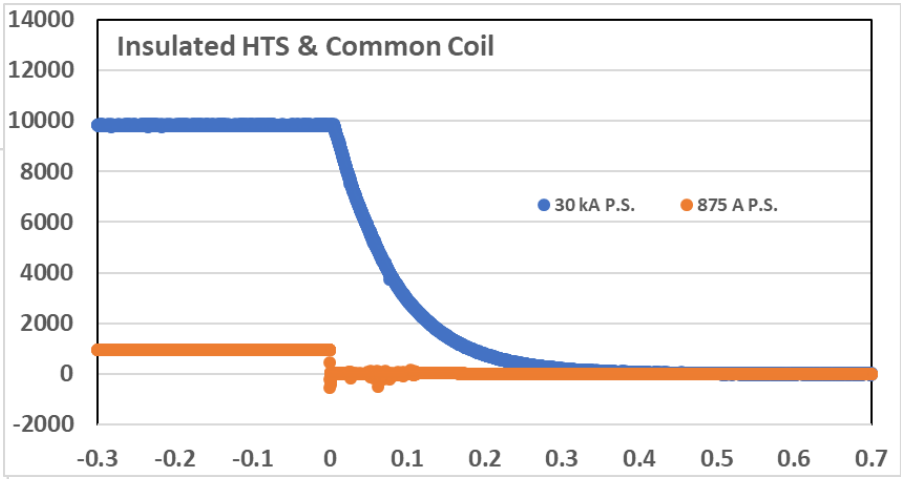
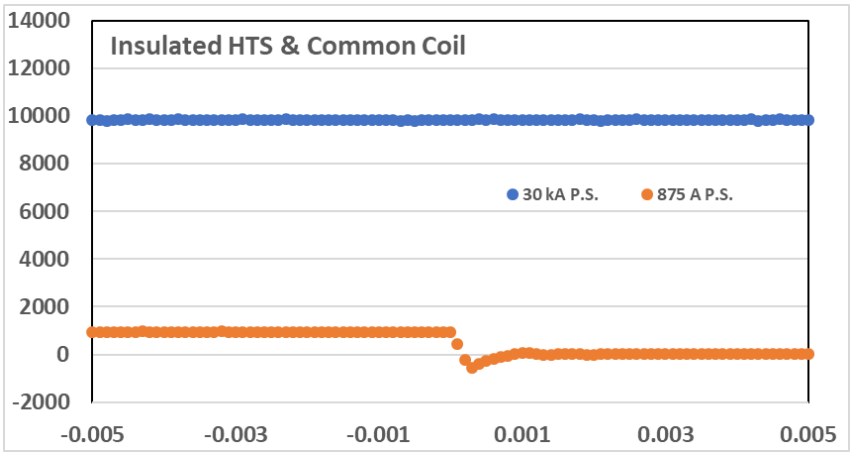
Field and Current Decay (coupling studies)

Field Decay (quench @ t=0)



Current Decay





Planned Quenches

DATE	TIME	HTS COIL	Nb3Sn Coil (A)	HTS Coil (A)	B, hybrid (T)	B, Nb3Sn + trapped
13-Feb-20	1955	Nomex	9830	955	**12.3 Tesla**	**9.39 Tesla**
14-Feb-20	1157	Nomex	9617	955	**11.96 Tesla**	**9.87 Tesla**
14-Feb-20	1652	NI	10120	955	**12.09 Tesla**	**10.37 Tesla**
15-Feb-20	1318	NI	9171	1000	**11.53 Tesla**	**9.34 Tesla**
15-Feb-20	1336	NI	-	1590	**4.23 Tesla**	**0.27 Tesla**
15-Feb-20	1414	NI	8000	1110	**10.74 Tesla**	**8.1 Tesla**
15-Feb-20	1502	NI	9000	910	**11.23 Tesla**	**9.2 Tesla**

All quenches in LTS coils.

HTS coils seems to tolerate quenches from Nb3Sn coils (large energy transfer)

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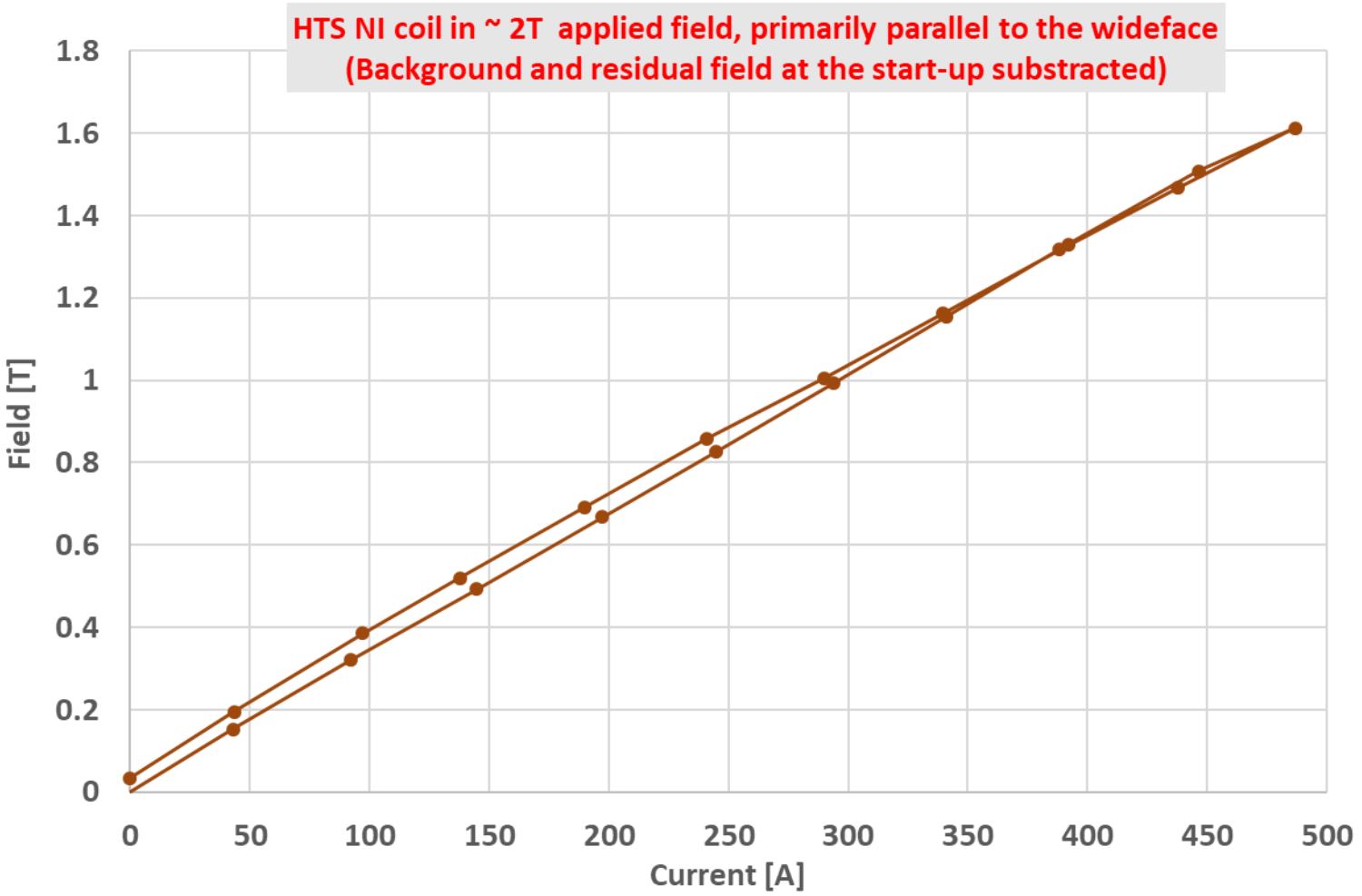
Extra slides

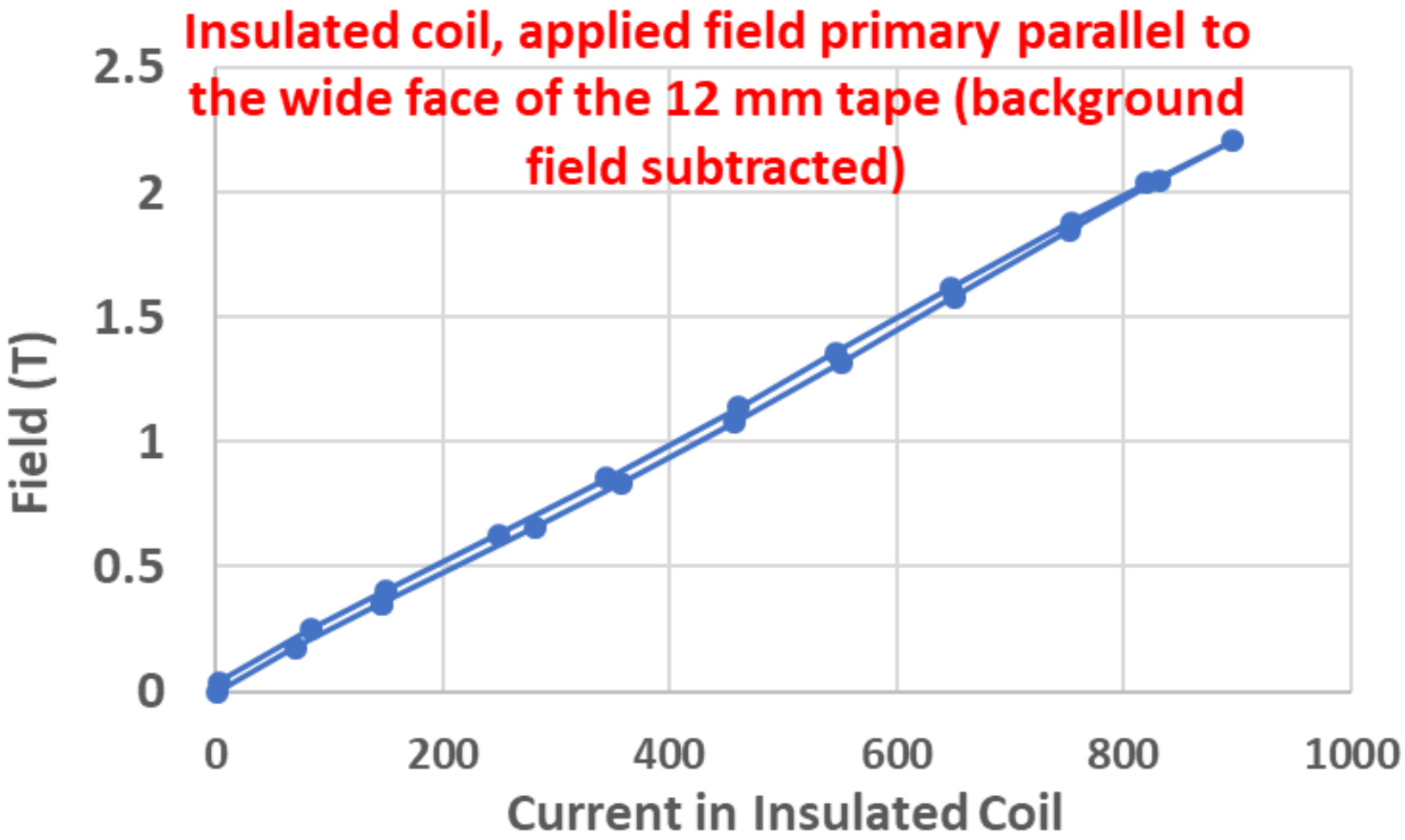
HTS Coil in 2 T Field (primarily parallel to the wide face)

NI COIL



HTS Coil in 2 T Field (primarily parallel to the wide face)

INSULATED COIL



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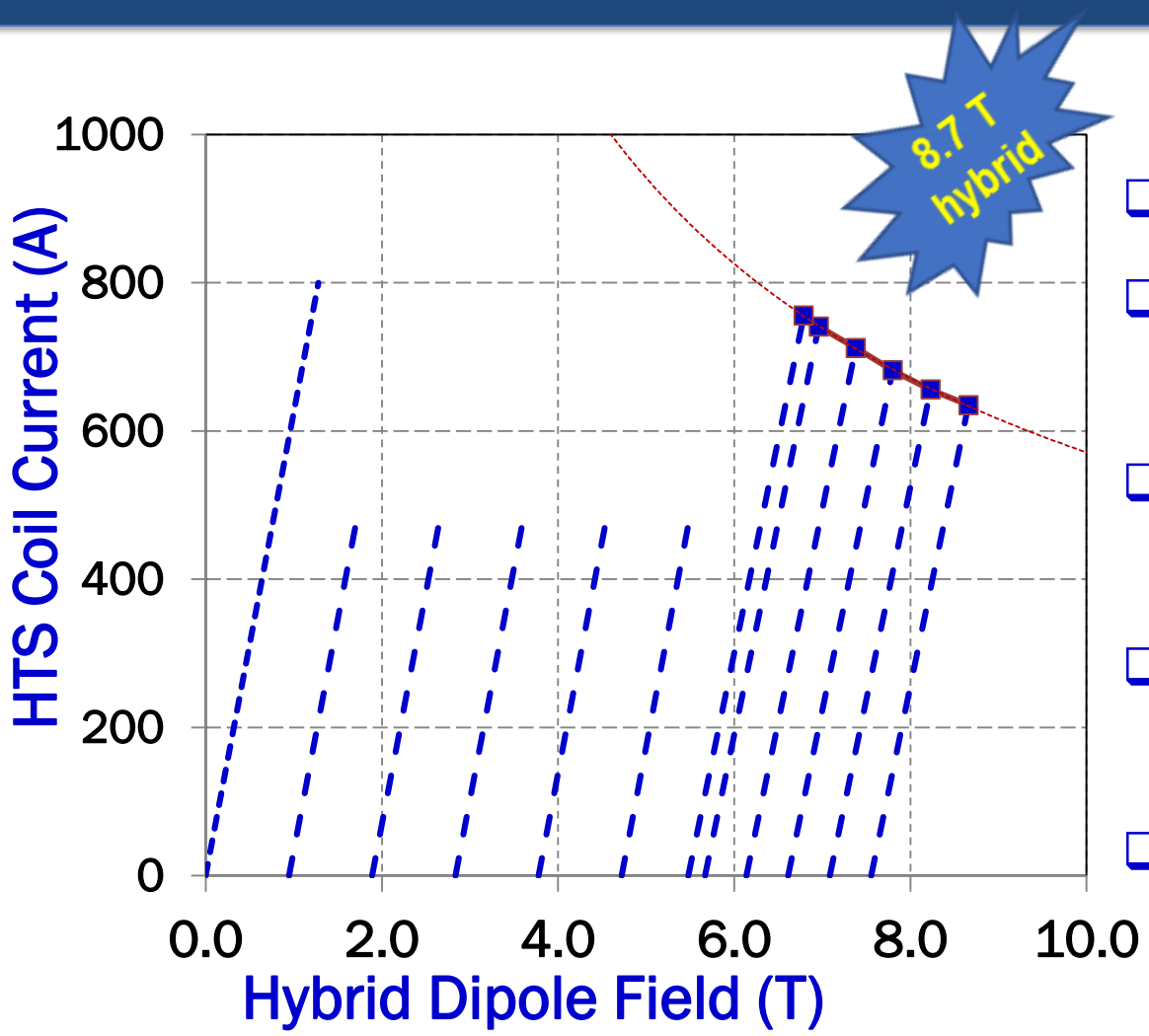
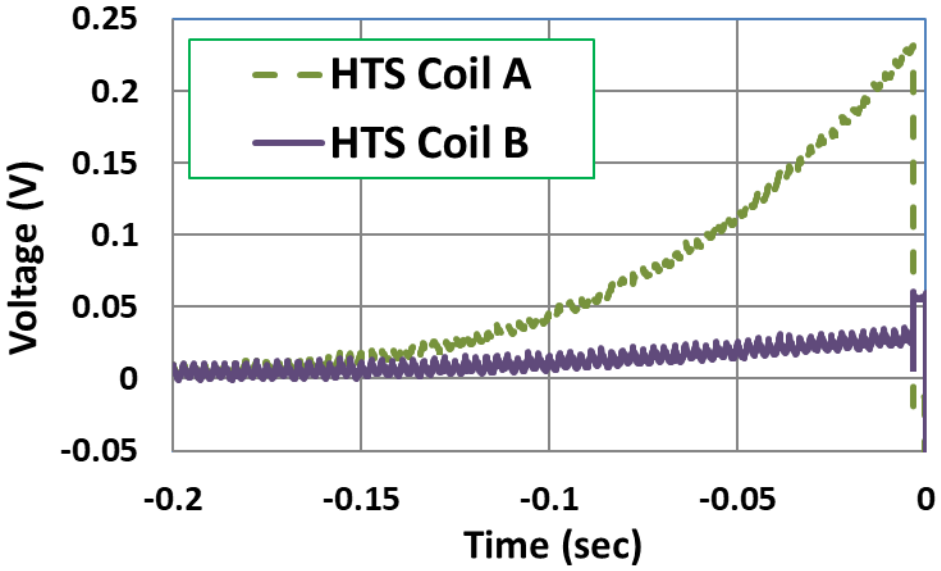
2016 Test (Field Perpendicular)



- HTS coils with ASC tape
- Field primarily perpendicular to the wide side of the tape
- HTS coils were ramped to quench, just like LTS coils
- No measurable degradation found
- Test limited by the current leads of LTS coil

Feedback of Quenching of HTS Coils on LTS Coils in HTS/LTS Hybrid Magnet (2016)



What happens to HTS coils if LTS coil quench?

Coupling between the HTS & LTS coils