U.S. MAGNET DEVELOPMENT PROGRAM

Feedback from the PSI Stress-managed Insert Test in Common Coil Dipole DCC017

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USMDP 20 T Subgroup Meeting

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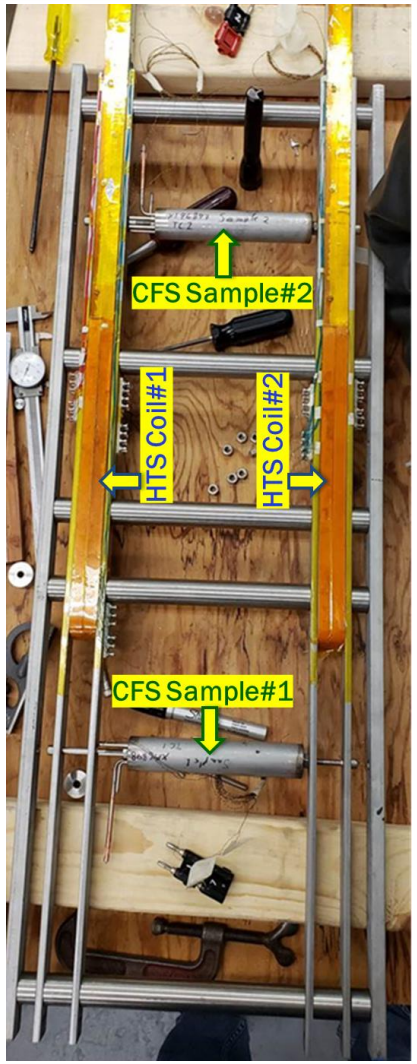
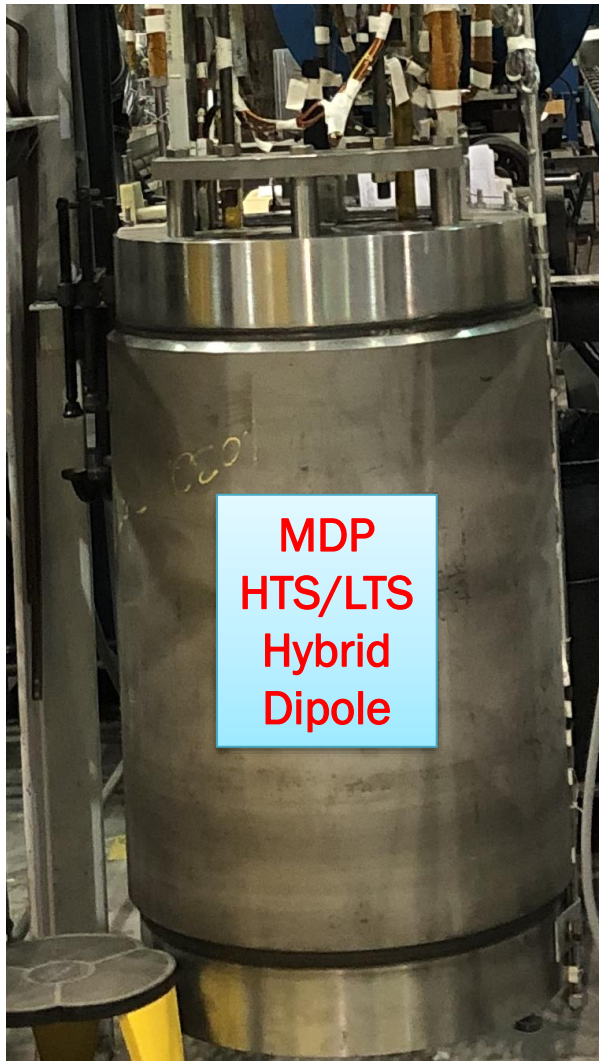
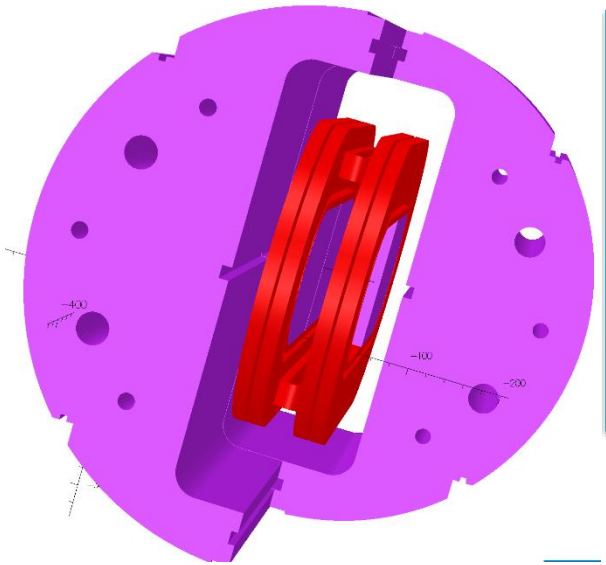
U.S. MAGNET DEVELOPMENT PROGRAM

Impact of the Load from Insert Coil(s) on the Main Nb_3Sn Coils of DCC017

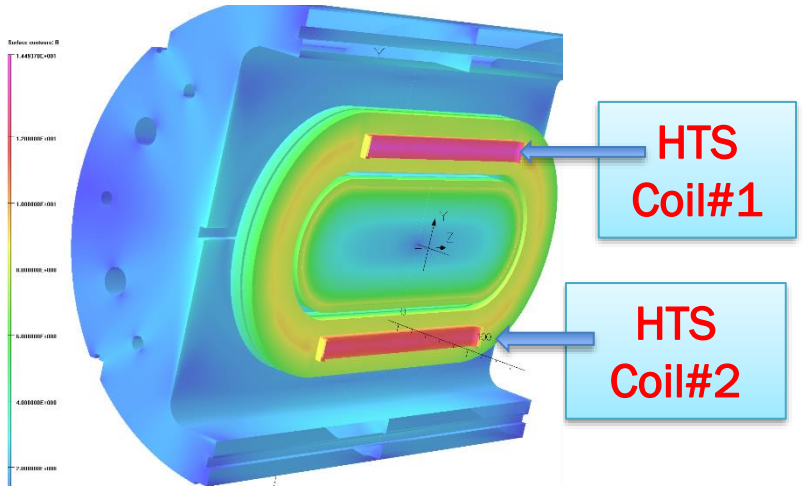


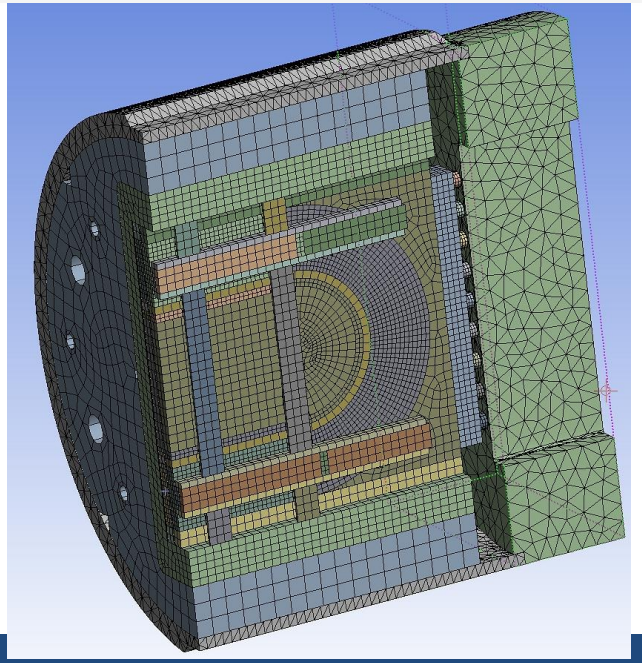




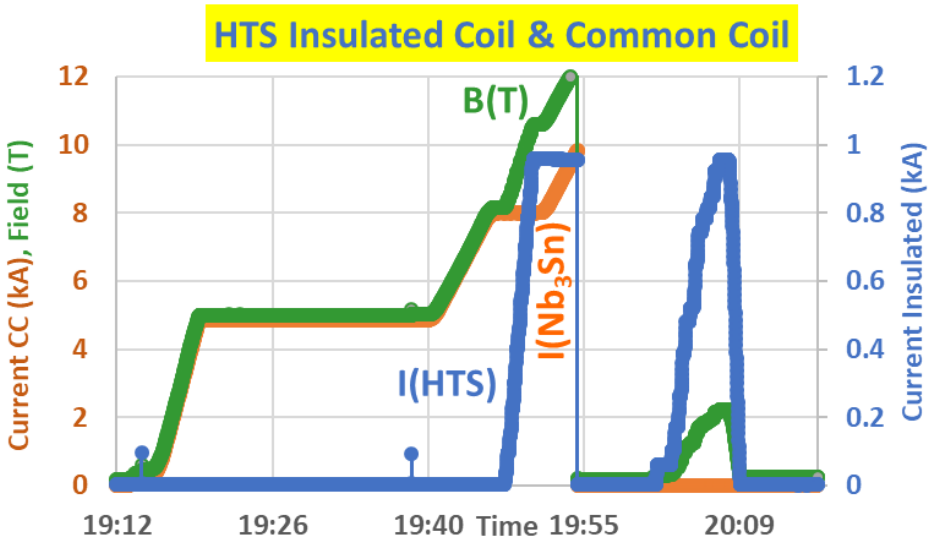
Basic Question:

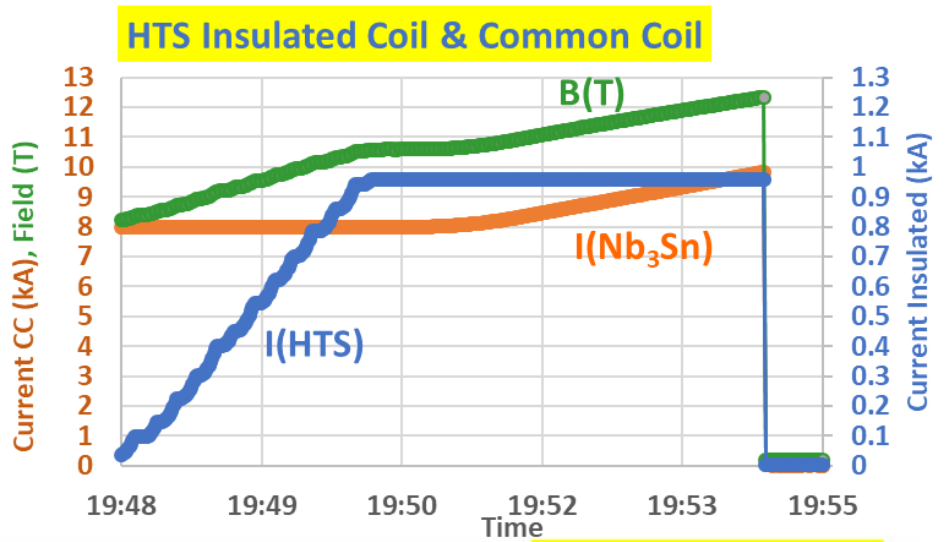
Will the transverse Lorentz load from the insert coil(s) exceed the stress or strain limit of Nb_3Sn coils in DCC017? Could it degrade performance or even cause a permanent damage?

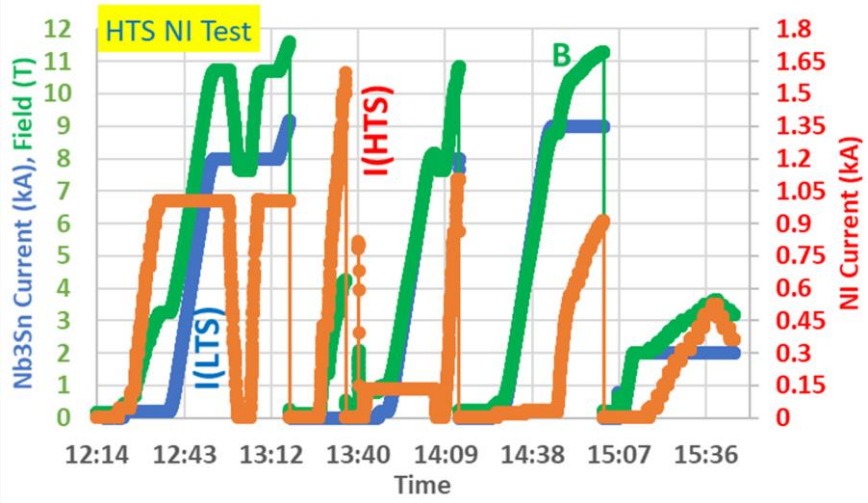


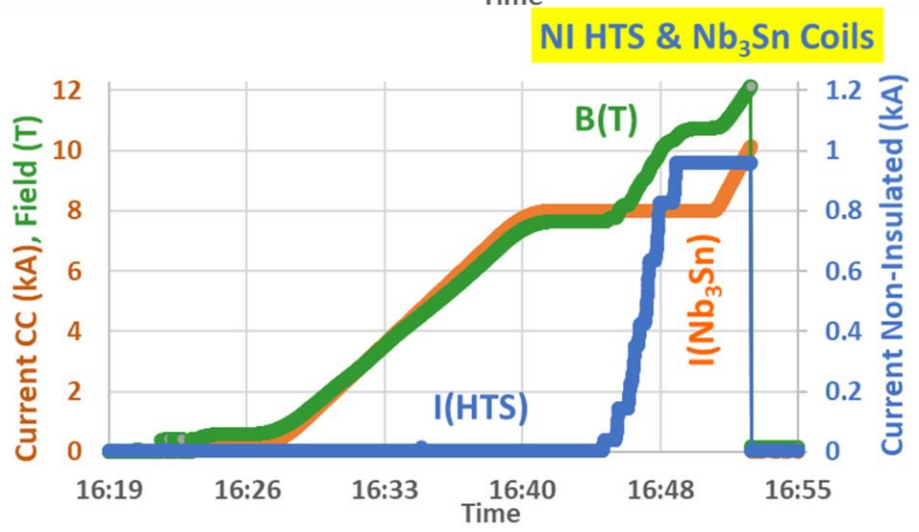


Hybrid Magnet Test Results (1)









Several combinations of currents in the HTS coils and the Nb_3Sn coils were tried.

In all cases, Nb_3Sn coils quenched (a bit before short sample, if no additional strain on Nb_3Sn coil considered).

As such Nb_3Sn coils alone were tested to a higher current

Hybrid Magnet Test Results (2)

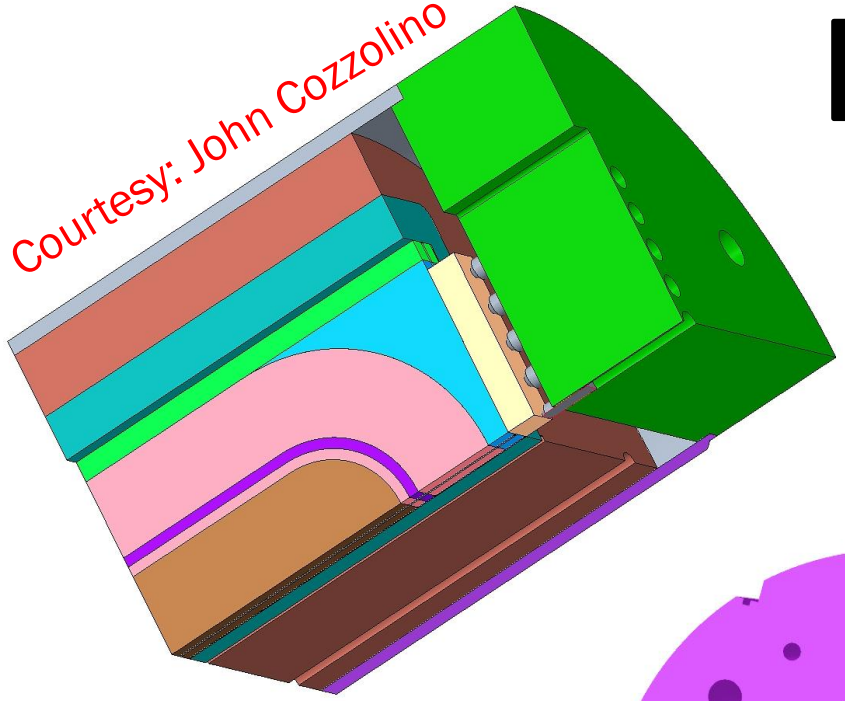
- Several combinations of currents in HTS and LTS coils tried.

The performance of HTS/LTS hybrid was always limited by the Nb_3Sn coil.

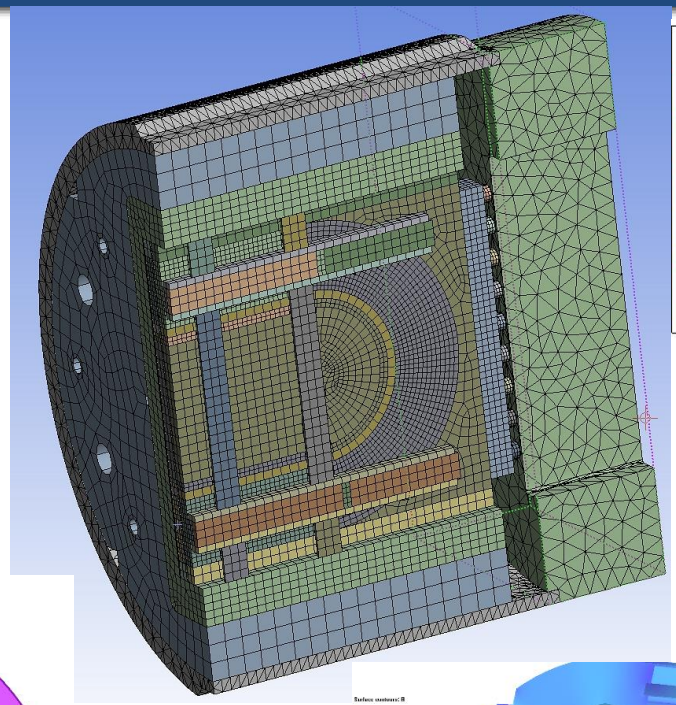
DATE	TIME	HTS COIL	Nb3Sn Coil (A)	HTS Coil (A)	B, hybrid (T)	B, Nb3Sn + trapped
13-Feb-20	1955	Nomex	9830	955	**12.3 Tesla**	**9.39 Tesla**
14-Feb-20	1157	Nomex	9617	955	**11.96 Tesla**	**9.87 Tesla**
14-Feb-20	1652	NI	10120	955	**12.09 Tesla**	**10.37 Tesla**
15-Feb-20	1318	NI	9171	1000	**11.53 Tesla**	**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**

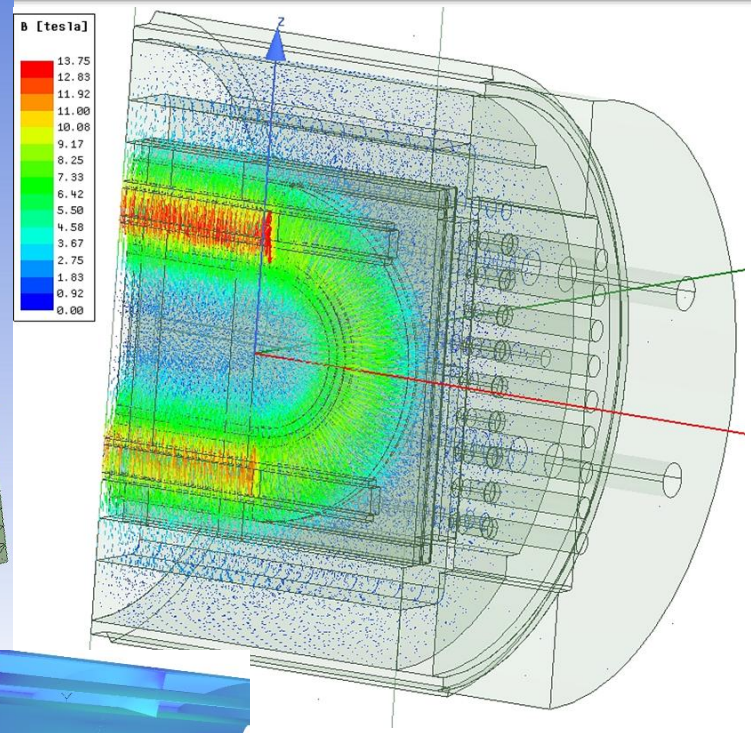
The hypothesis is that the quench in Nb_3Sn coil is caused by the local strain discontinuity from the pinching forces. To reduce this strain either include a structure on the HTS coil to contain the Lorentz forces, or at least include a structure at the interface to distribute the local stress/strain on NB_3Sn coils.

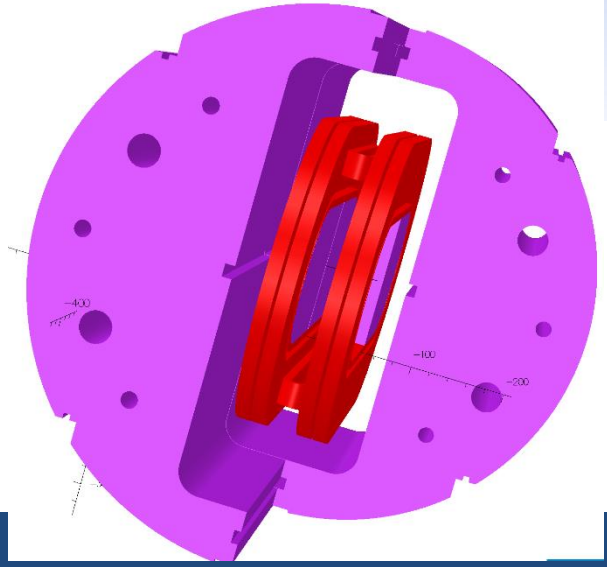
Mechanical Model



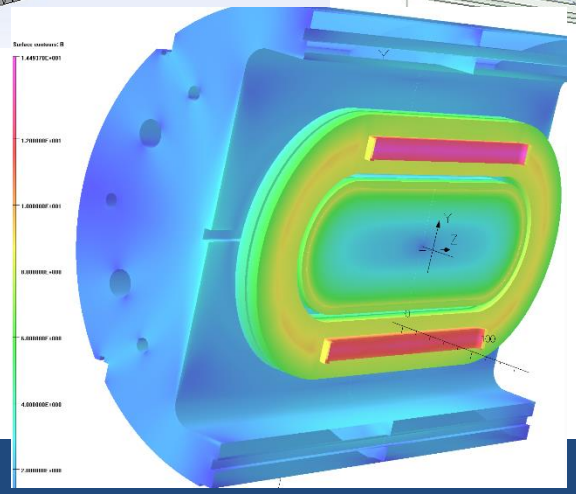
ANSYS







OPERA

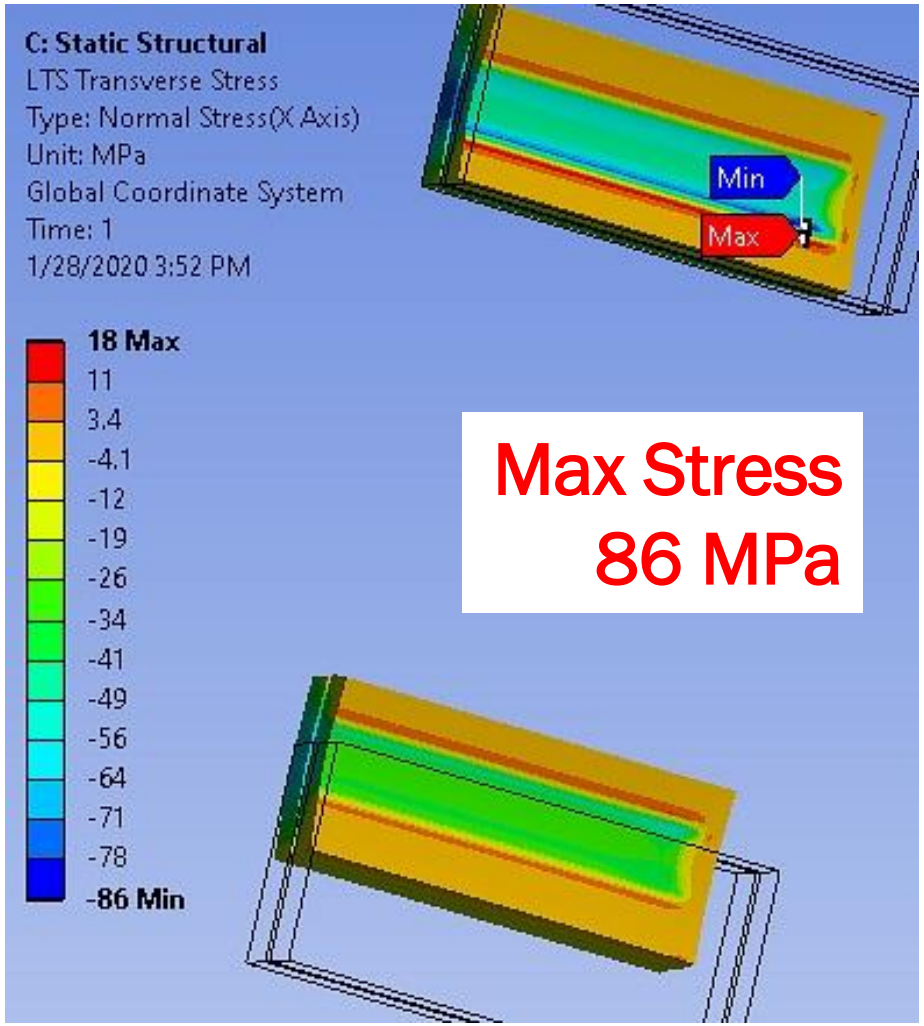


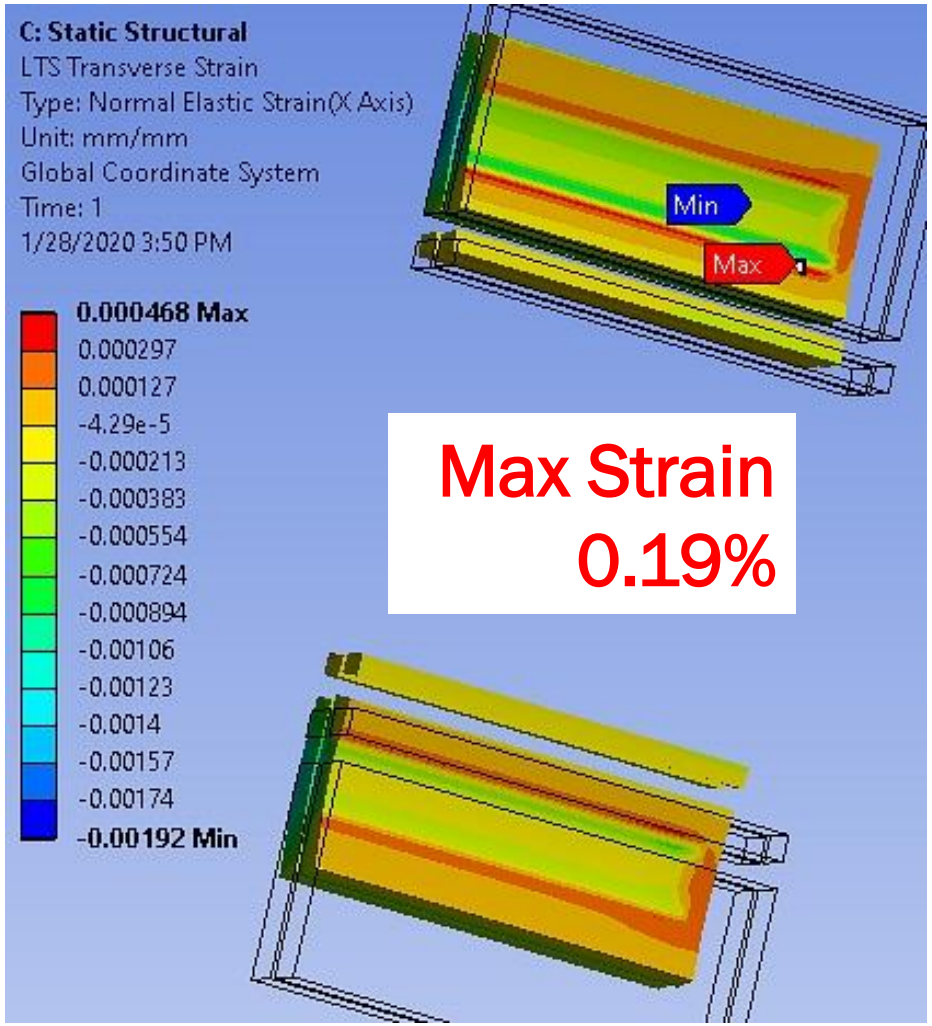
ANSYS Run Transverse Stress and Strain from Nb_3Sn 10 kA, HTS 1 kA

Stress and Strain on the LTS Coils from the HTS.

The magnitude of local stress/strain discontinuity may significantly be influenced on the mesh.

Courtesy: John Cozzolino

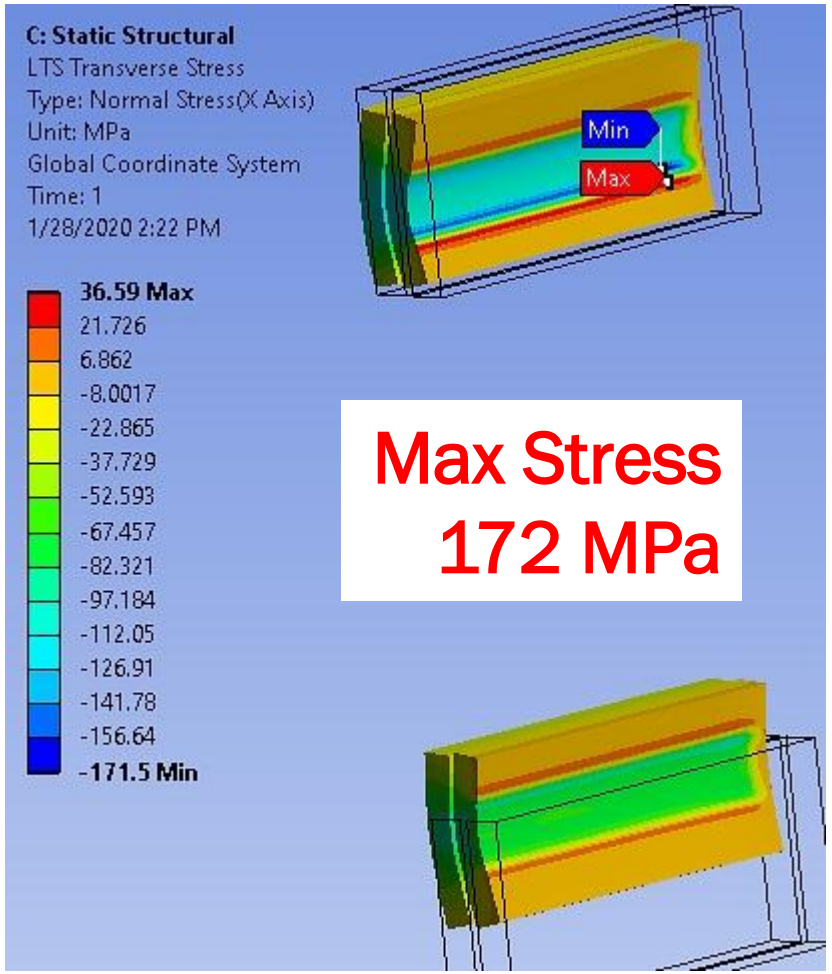




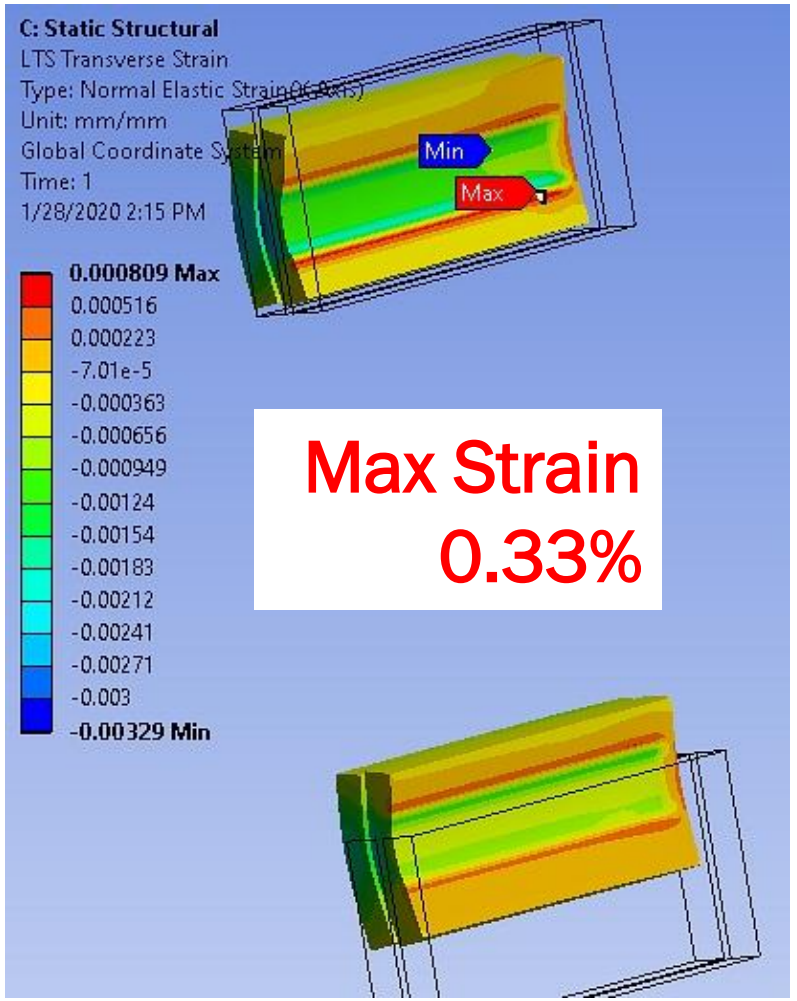
ANSYS Run Transverse Stress and Strain from Nb_3Sn 10 kA, HTS 2 kA

Stress and Strain on the LTS Coils from the HTS.

This seems to be crossing the limit.



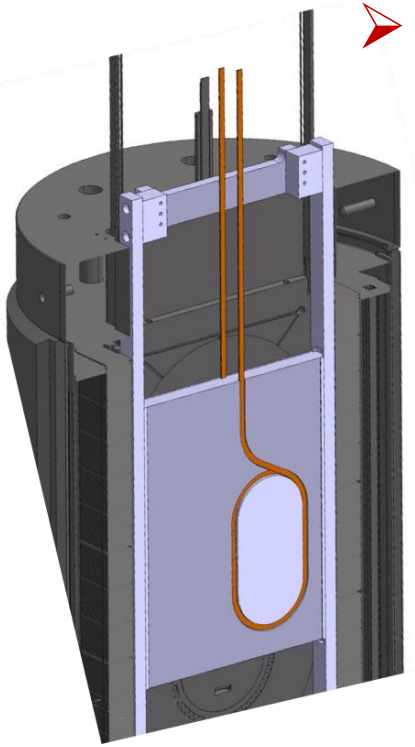
Max Stress 172 MPa



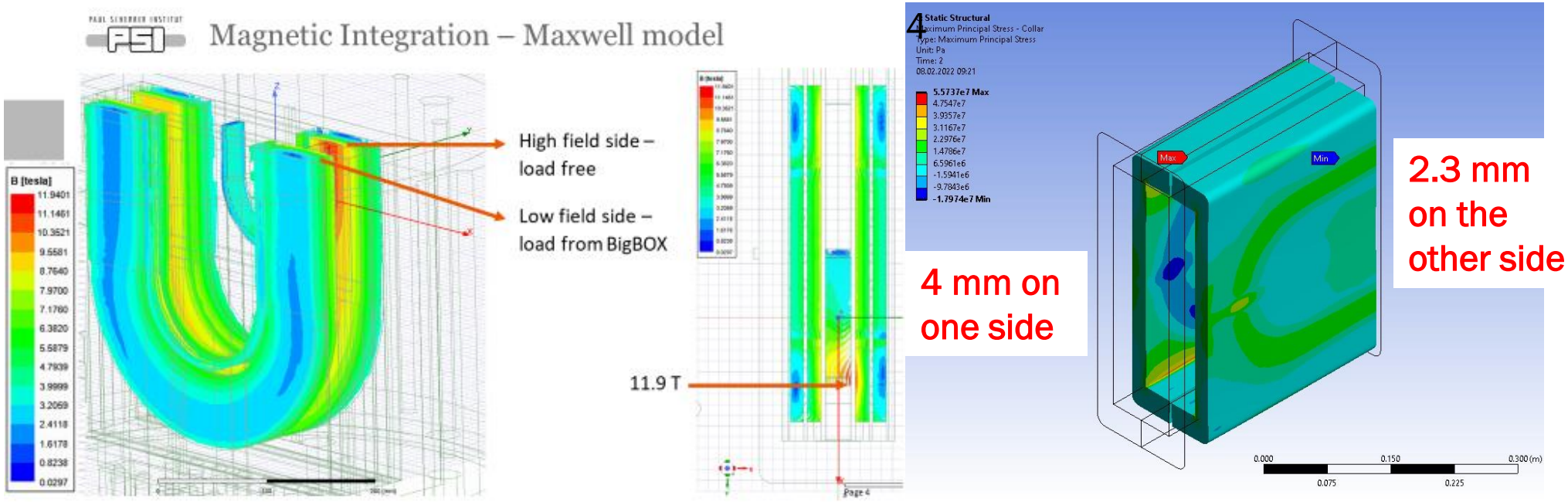
Max Strain 0.33%

Courtesy: John Cozzolino

Powering of PSI Coils IN DCC017 (ok despite energizing with wrong polarity)



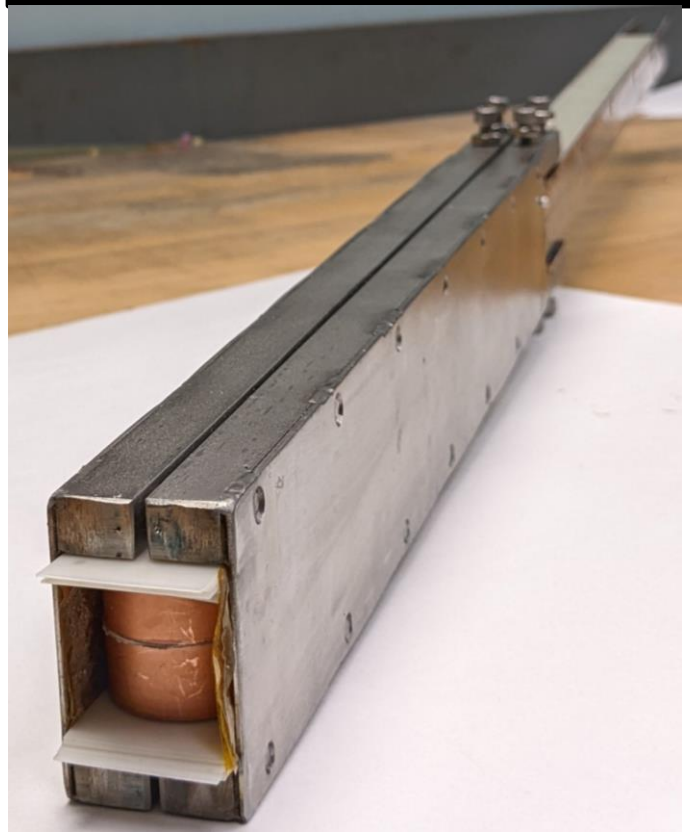
- PSI coils moved significantly under Lorentz forces to close-in the ~2 mm gap



- No quenches in Nb_3Sn coils, means that the gap tolerances can be relaxed in such structures (though a large variation in the gap should perhaps be avoided)
- Structure of ~2.3 mm rather than ~4 mm was sufficient
- Stress diffusion – avoiding local stress/strain to spreading the stress worked

MDP HTS Coil in a Support Structure

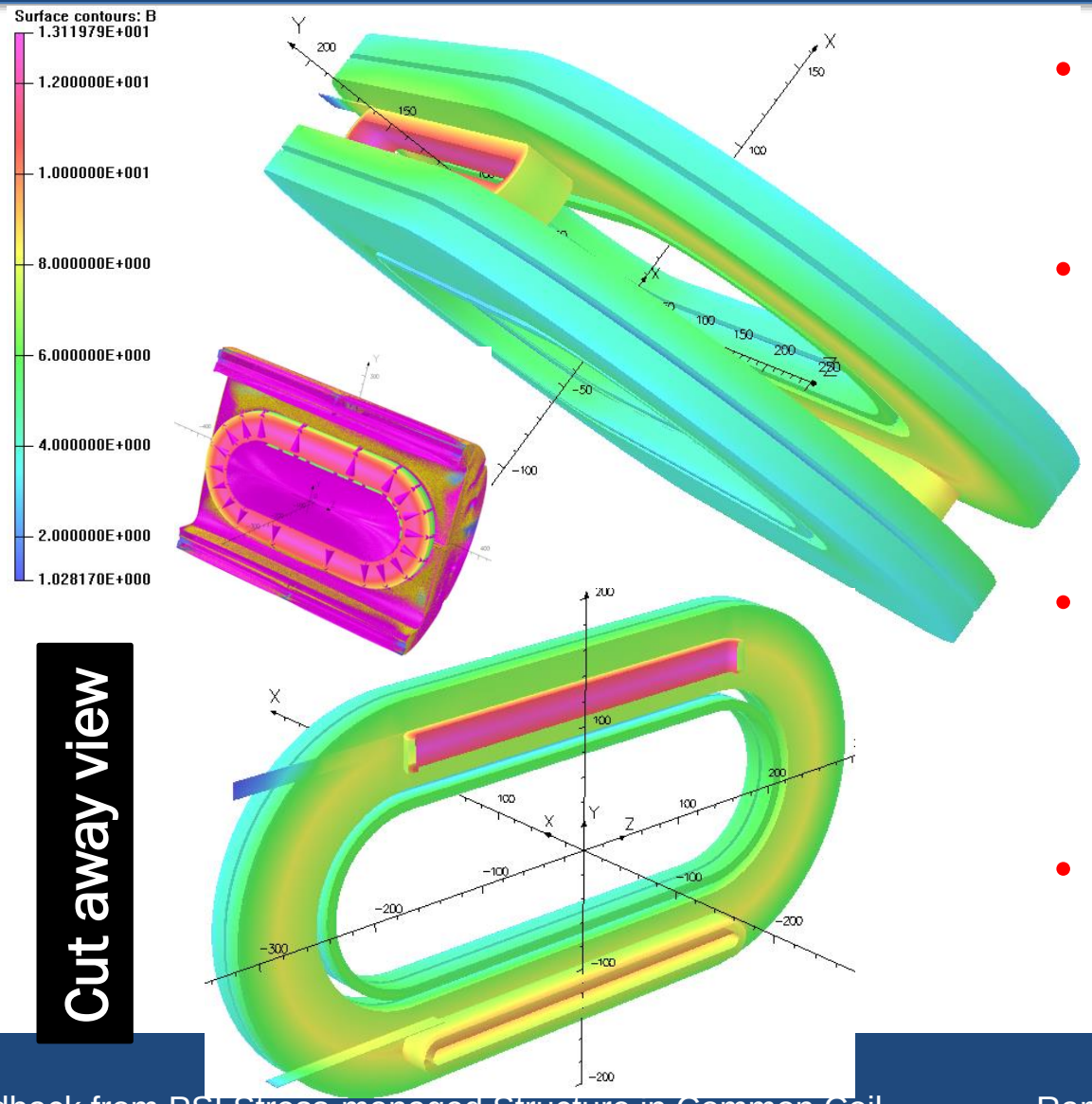
Question: Can a higher hybrid field be reached with some intermediate structure on HTS coil (stress management) ?



- HTS coils with leftover conductor.
- Coils tested at 77 K in the structure
- Intermediate structure provides stress management
- This structure was inserted in the second aperture
- Similar structure is being used in US-Japan collaboration

Test Configuration for US- Japan Test - Both (field parallel & field perpendicular) Tested Together

Two HTS insert coils in two bores of the common coil dipole
(a) Upper bore: field primarily parallel
(b) Lower bore: field primarily perpendicular



- Mechanical structure included individually over the two HTS insert coil.
- Upper coils (field parallel) could create ~14 T hybrid field, depending on the actual performance of the conductor.
- Lower coils creates a torque with a discontinuity on the two diagonally opposite sides.
- Surface rounded to reduce discontinuity.

Acknowledgement

This test was made possible by the heroic effort of several magnet division staff and close collaboration between PSI and BNL staff, together with the discussion and contributions of other US labs

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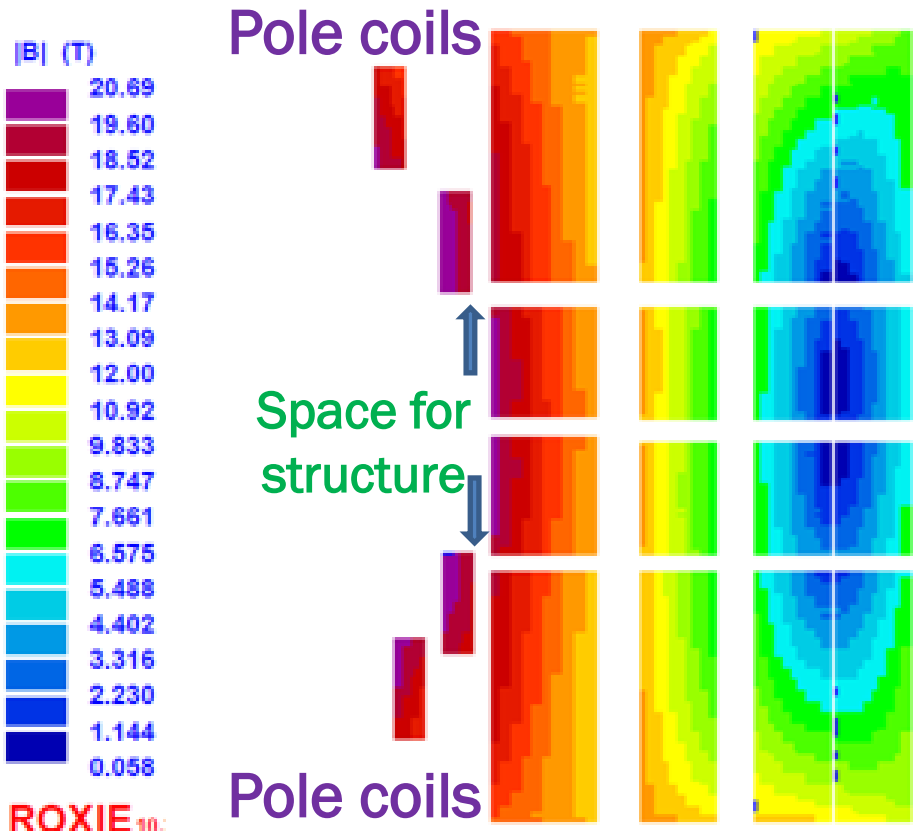
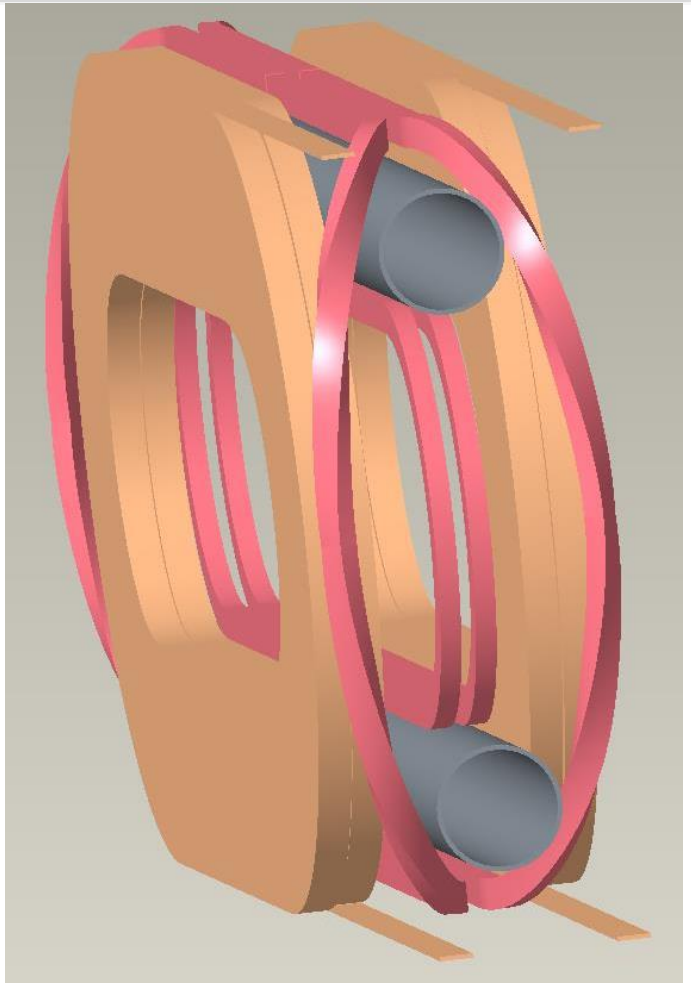
EXTRA Slides

Proof-of-Principle Test of Field Quality Pole Coils in the Common Coil Design



20 T MDP Hybrid Design

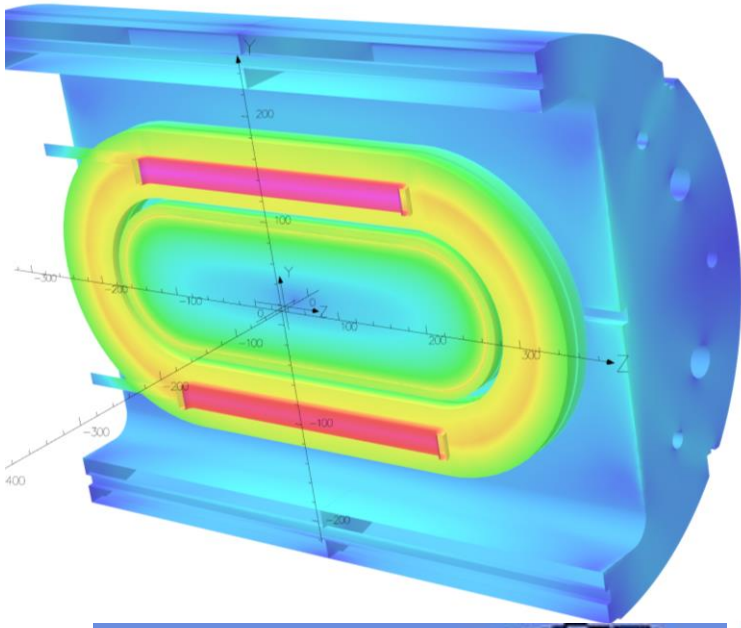
- In this case pole coils are oriented differently (hard way bend) from the main coils (soft way bend), same as in the PSI test.
- Pole coils are inserted in an intermediate structure inside the mail coils, same as in the PSI test.
- Therefore, in a way PSI test was the proof-of-principle test of the incorporation of the field quality pole coils in the common coil design

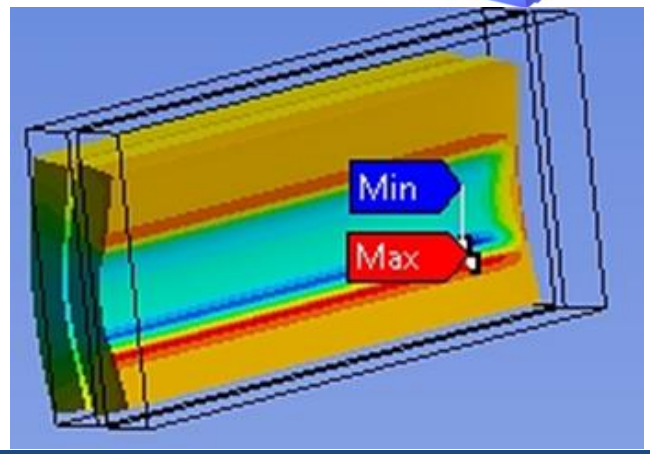


Concept from: PBL/BNL SBIR

Background

- During the last HTS/LTS hybrid test, the maximum performance of 12.3 T was limited by the LTS coils, and not by the HTS coils.
- Moreover, it was NOT limited by Nb_3Sn coils themselves, as they by themselves worked well. Performance got limited when Nb_3Sn coils were energized together with the HTS insert coils.
- Theory: Nb_3Sn coils were stress/strain limited locally (no intermediate structure to manage or distribute the stresses).
- This question/issue is important in all high field Nb_3Sn magnets.
- All new inserts are planned with intermediate structures. This PSI/BNL test was became a test to overcome the stress limit.
- It allowed higher peak field in DCC017 coils (10.7 T => ~12 T)
- More interesting what was observed accidently (magnet survived).



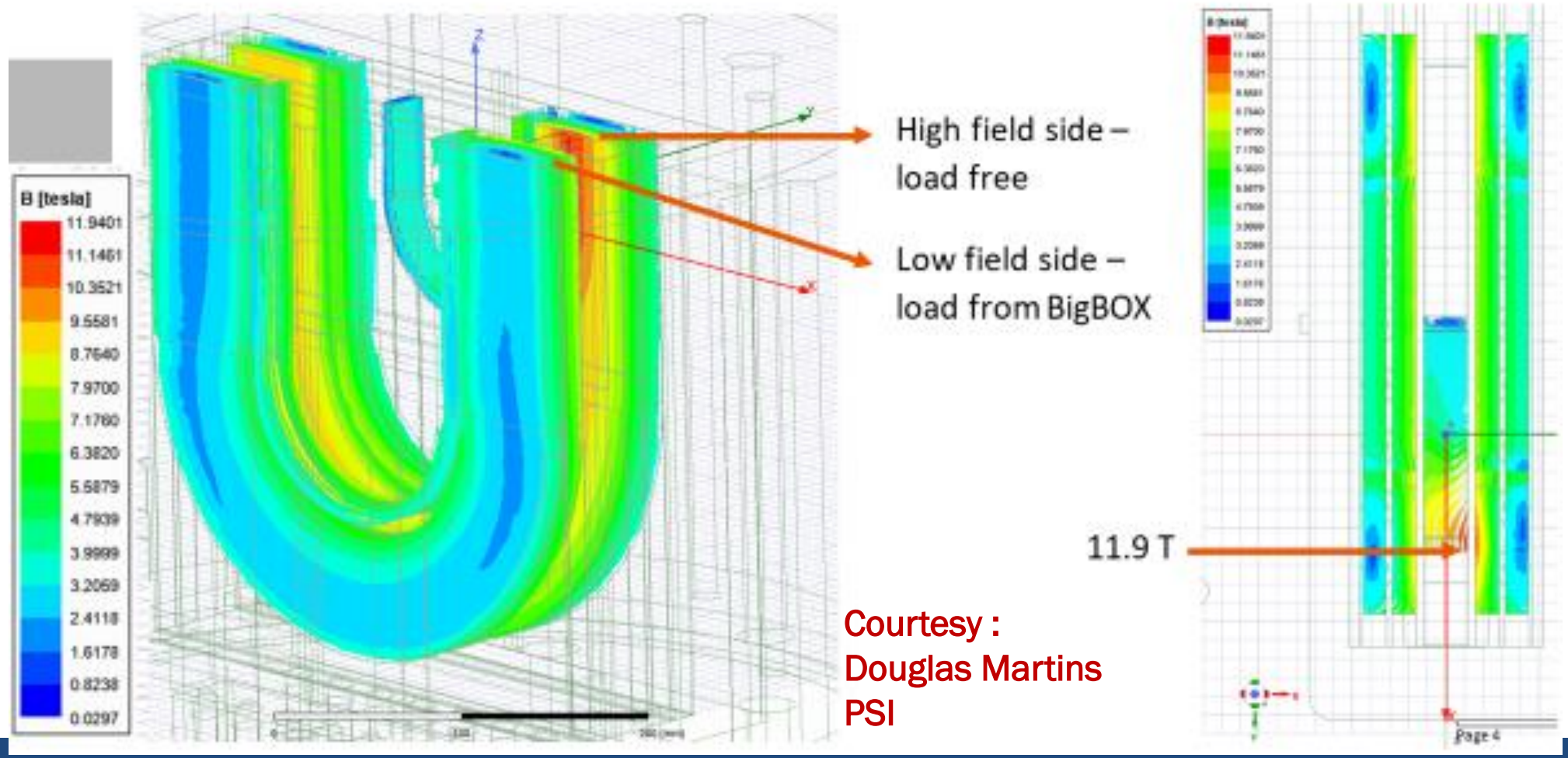


BigBox Coil in DCC017

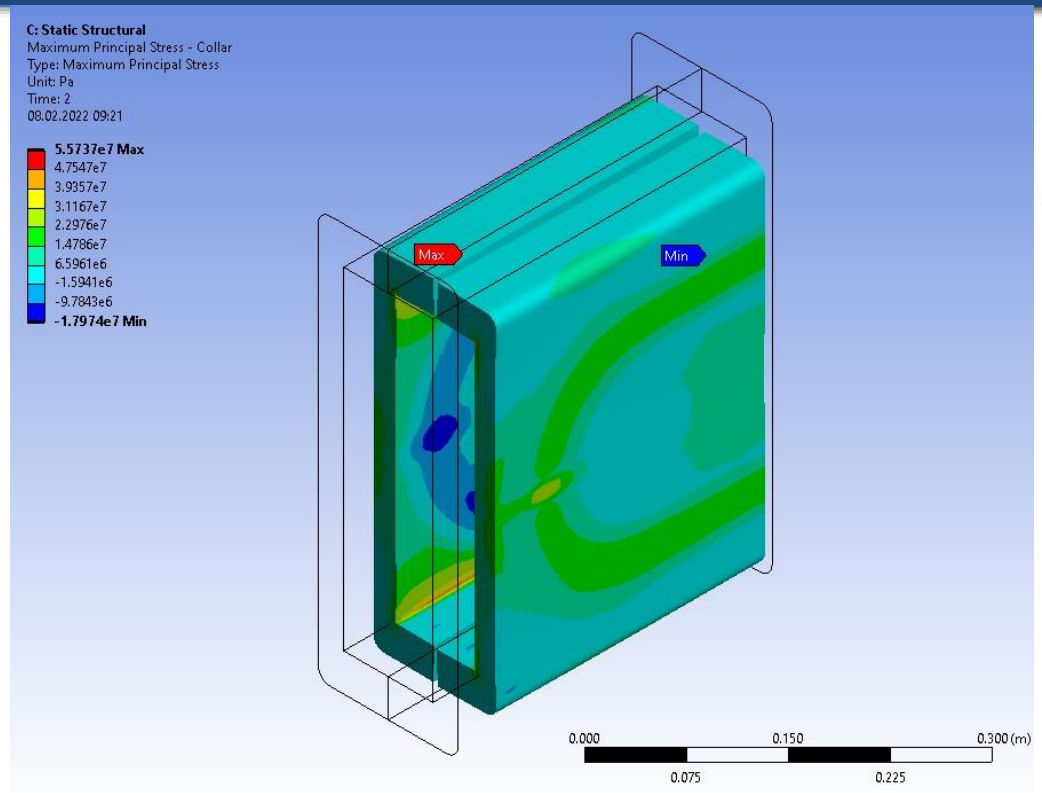
PSI Nb_3SN insert coils are wound with hard way bend.

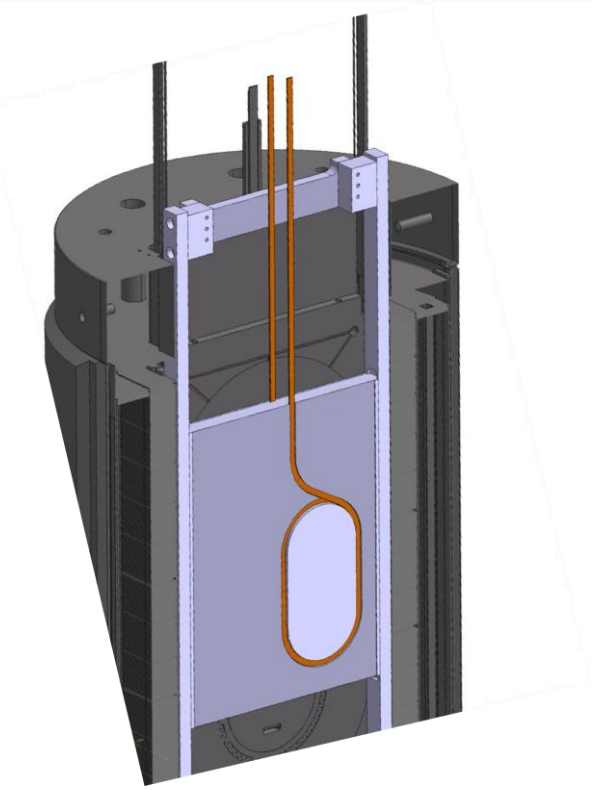
BNL Nb_3Sn coils are wound with easy way bend, as typical in the common coil.

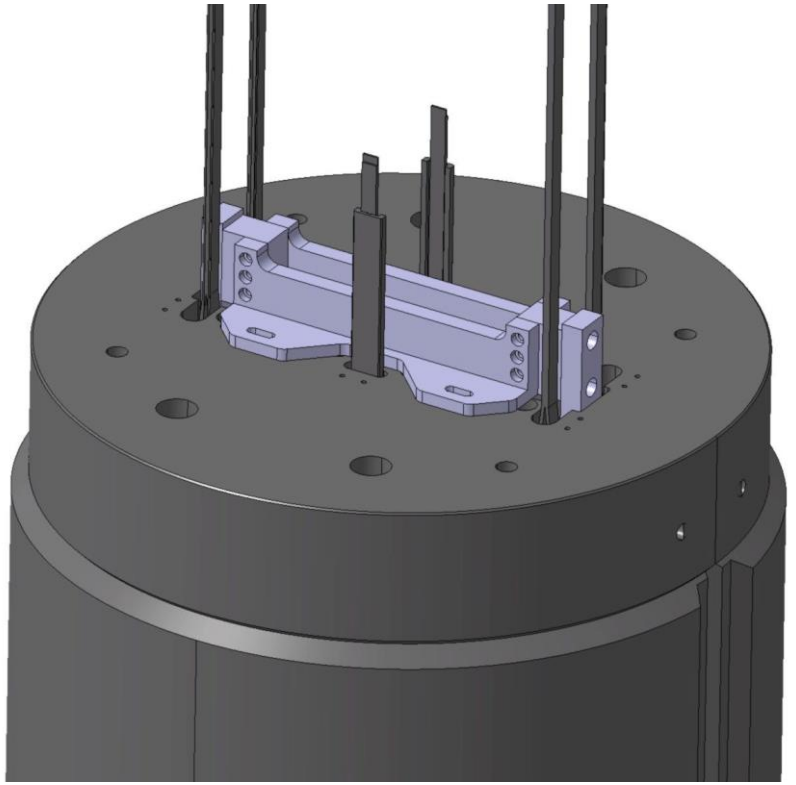
Magnetic Integration – Maxwell model



BigBox Structure for Stress Management (analysis to be discussed by PSI)

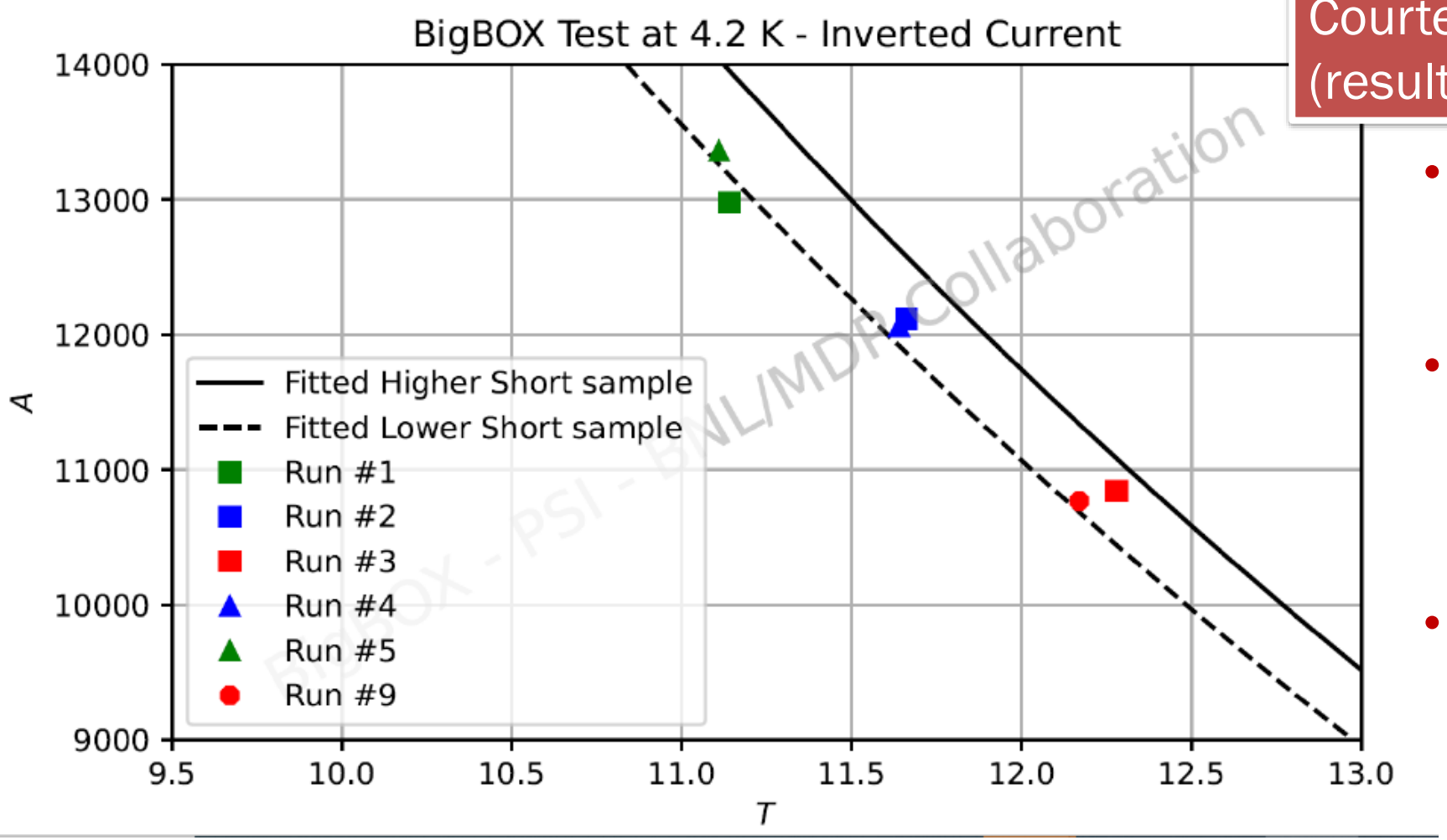






- This brings stress/strain on Nb_3Sn coil of DCC017 below the limit
- Due to the space limitation, the plates were made thicker on the high stress side and thinner on the high field side, with ~2 mm gap at most places.

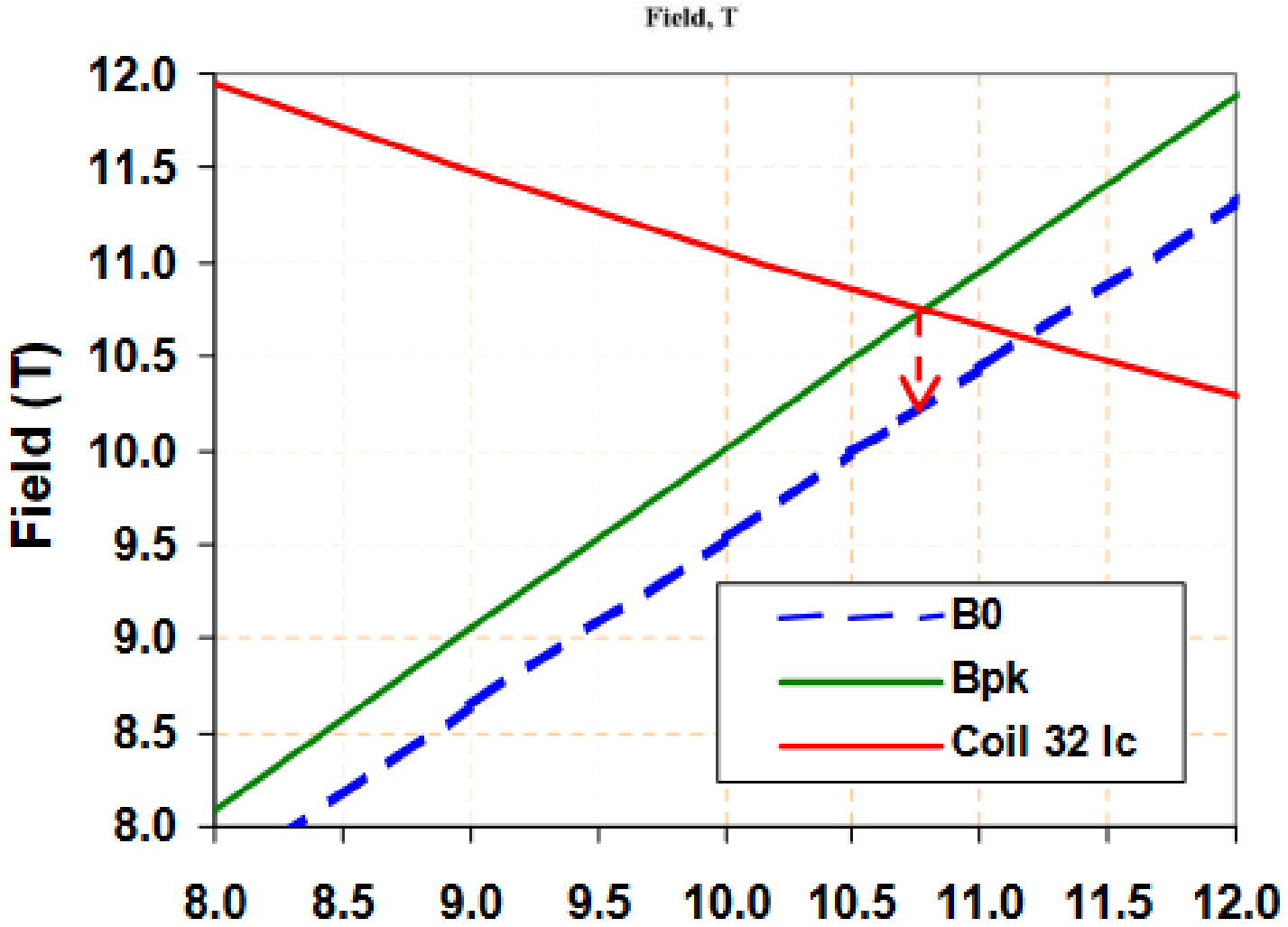
Expected and Observed Test Results



Courtesy: PSI
(results to be discussed by them)

- Field of DCC017 Nb_3Sn coils was not limited by their stress/strain limit
- DCC017 coil didn't quench as it reached ~12 T field (BigBox quenched)
- This was higher than ever reached in DCC017 (DCC017 coils ran at a lower current – ~9 kA)

From ASC2006 Paper on DCC017



High field Nb_3Sn coils should include strain as a parameter in such plots