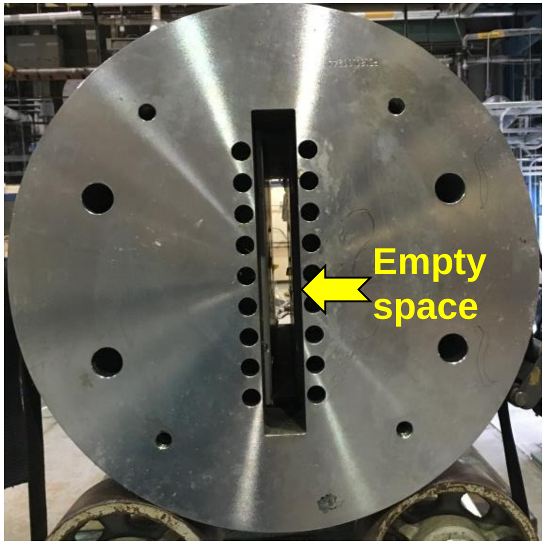
BROOKHAVEN NATIONAL LABORATORY

Superconducting
Magnet Division

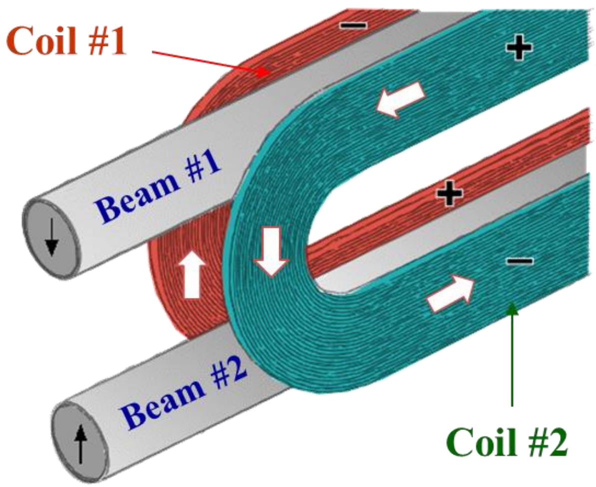
Unique BNL Common Coil Dipole for Cable and Coil Testing at High Fields

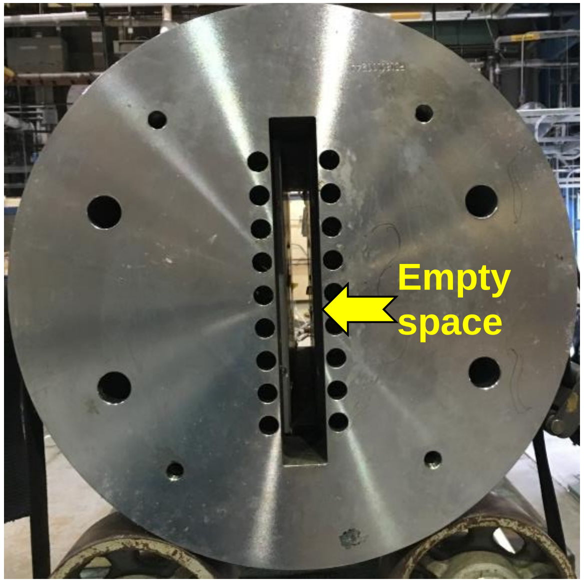


Prepared by Ramesh Gupta for

Superconducting Magnet Division @ BNL

A Unique Background-field Dipole





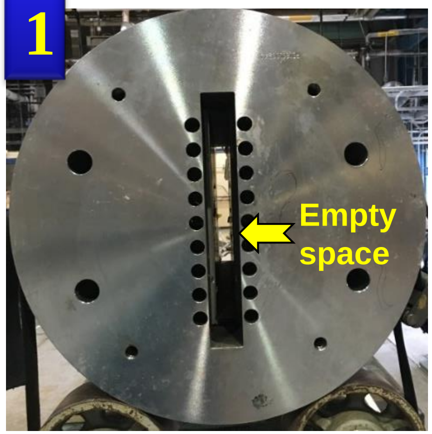
- Nb_3Sn, 2-in-1, common coil dipole
- Structure specifically designed to provide a large open space (30mm wide, 335mm high)
- New racetrack coils can be inserted here for testing them in a background field of ~10 T
- These new insert coils come in direct contact with the existing Nb_3Sn coils and become an integral part of a potential ~16 T dipole
- A new coil test becomes a new magnet test
- Allows a rapid-turn around, low-cost test
- A unique facility for testing HTS cables also

Rapid turn-around, Low cost R&D Approach

Five Simple Steps/Components

1. Magnet (dipole) with a large open space
2. Coil for high field testing
3. Slide coil in the magnet
4. Coils become an integral part of the magnet
5. Magnet with new coil(s) ready for testing

1



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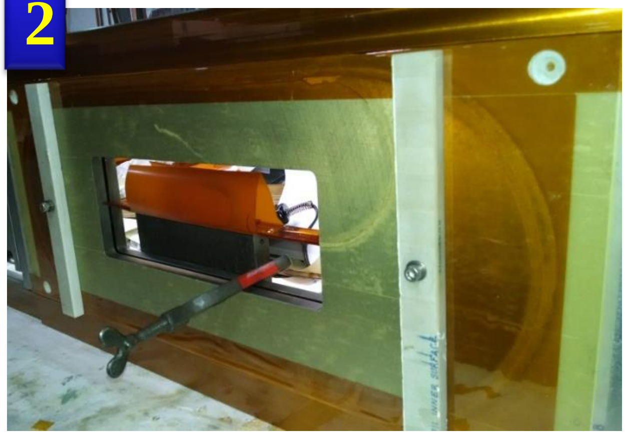

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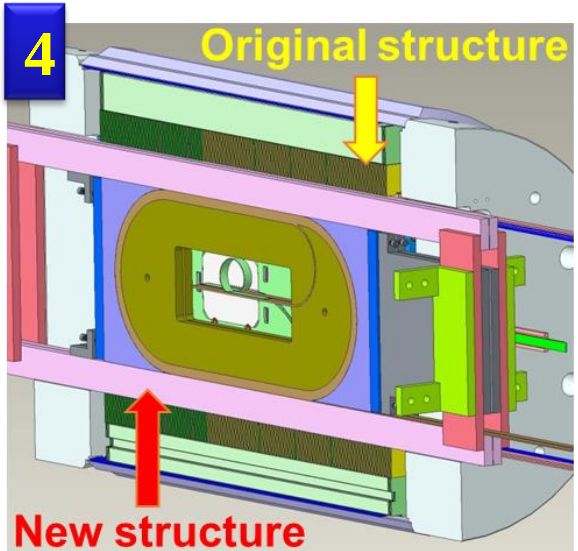
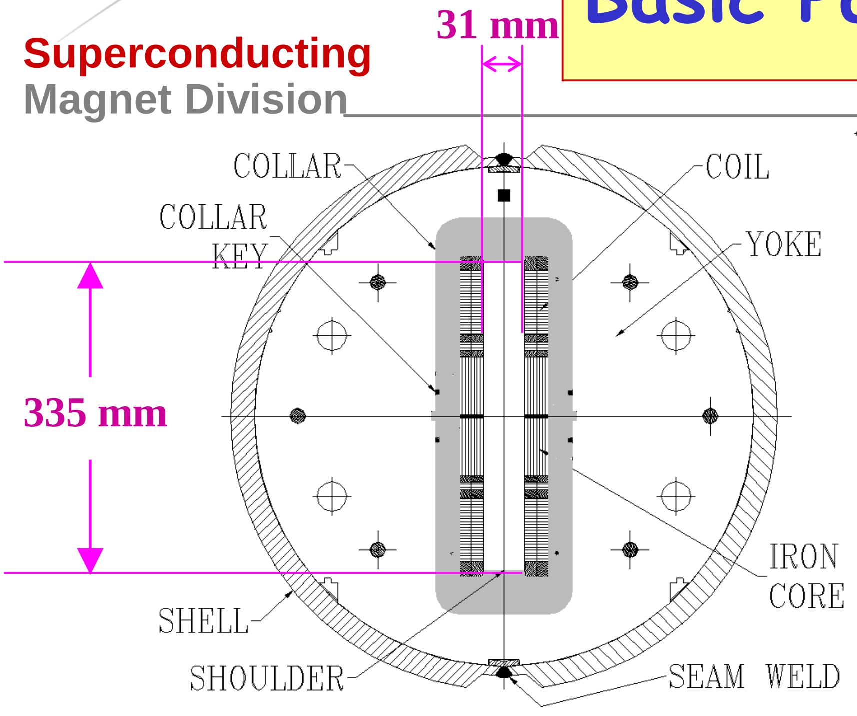
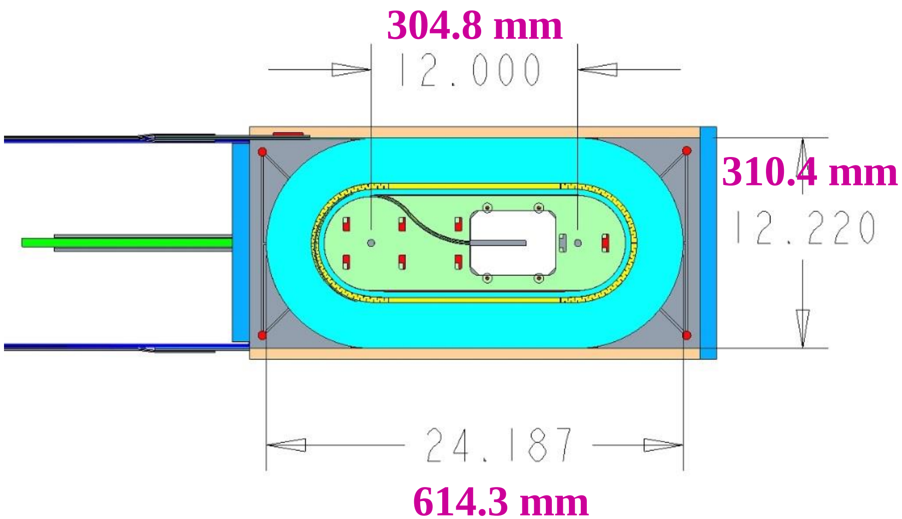


5

Basic Parameters of Dipole DCC017





- Two layer, 2-in-1 common coil design
- 10.2 T bore field, 10.7 T peak field at 10.8 kA short sample current
- **30 mm horizontal aperture**
- **335 mm vertical aperture**
  - **A unique feature for testing insert coils or cables**
- **977 mm magnet length (overall)**
- 0.8 mm, 30 strand Rutherford cable
- 70 mm minimum bend radius
- 85 mm coil height
- 305 mm coil straight section
- 614 mm coil length
- 653 mm yoke length One spacer in body and one in ends
- Iron bobbin
- Stored Energy@Quench ~0.2 MJ

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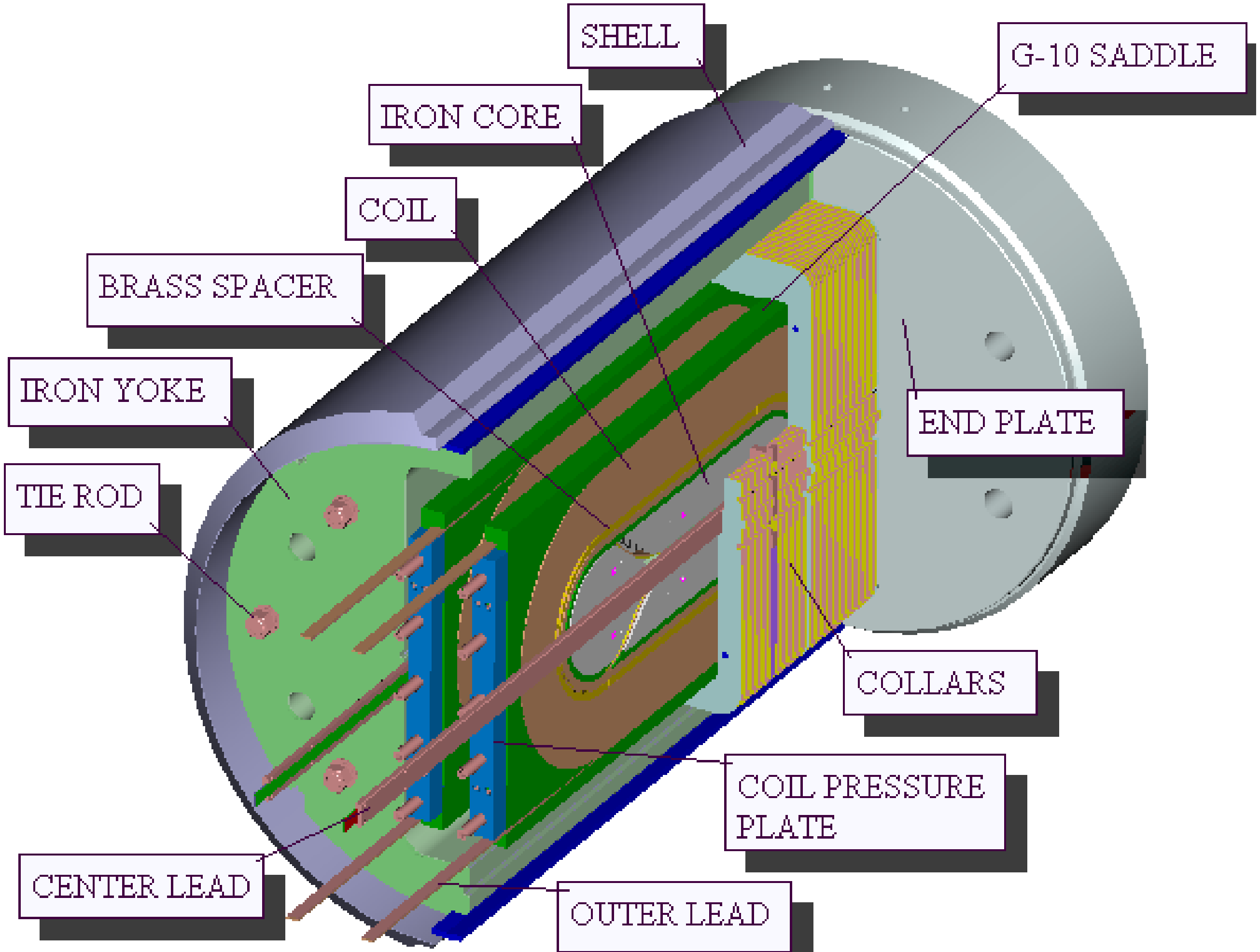
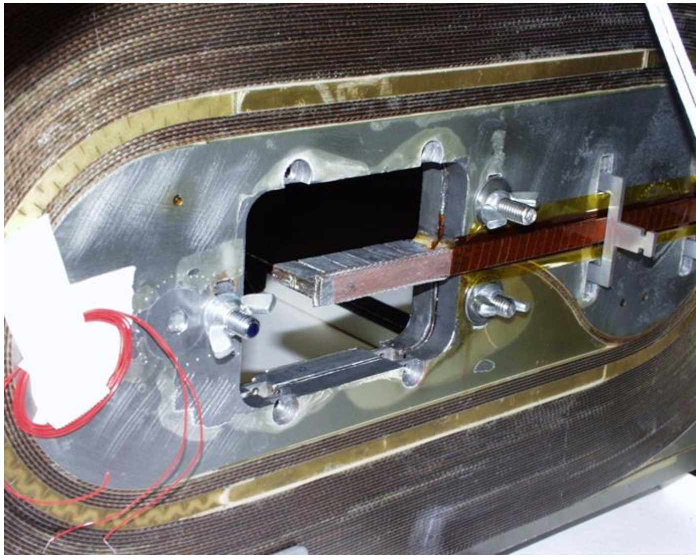
Detailed Design Parameters of DCC017

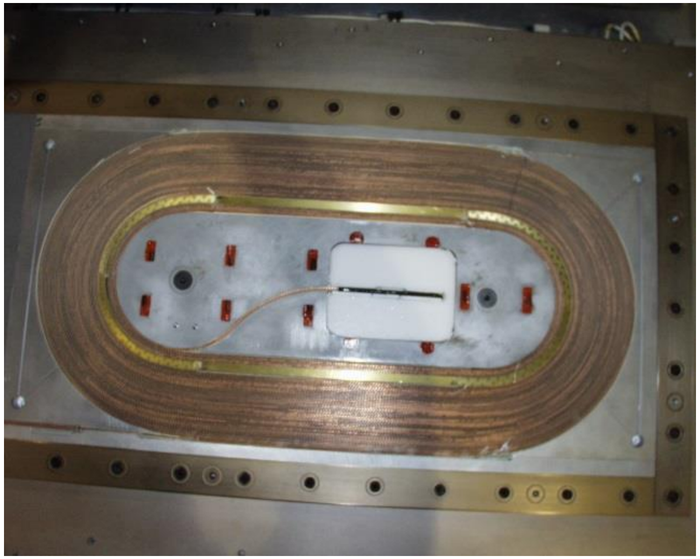
MAJOR PARAMETERS OF REACT & WIND COMMON COIL DIPOLE DCC017

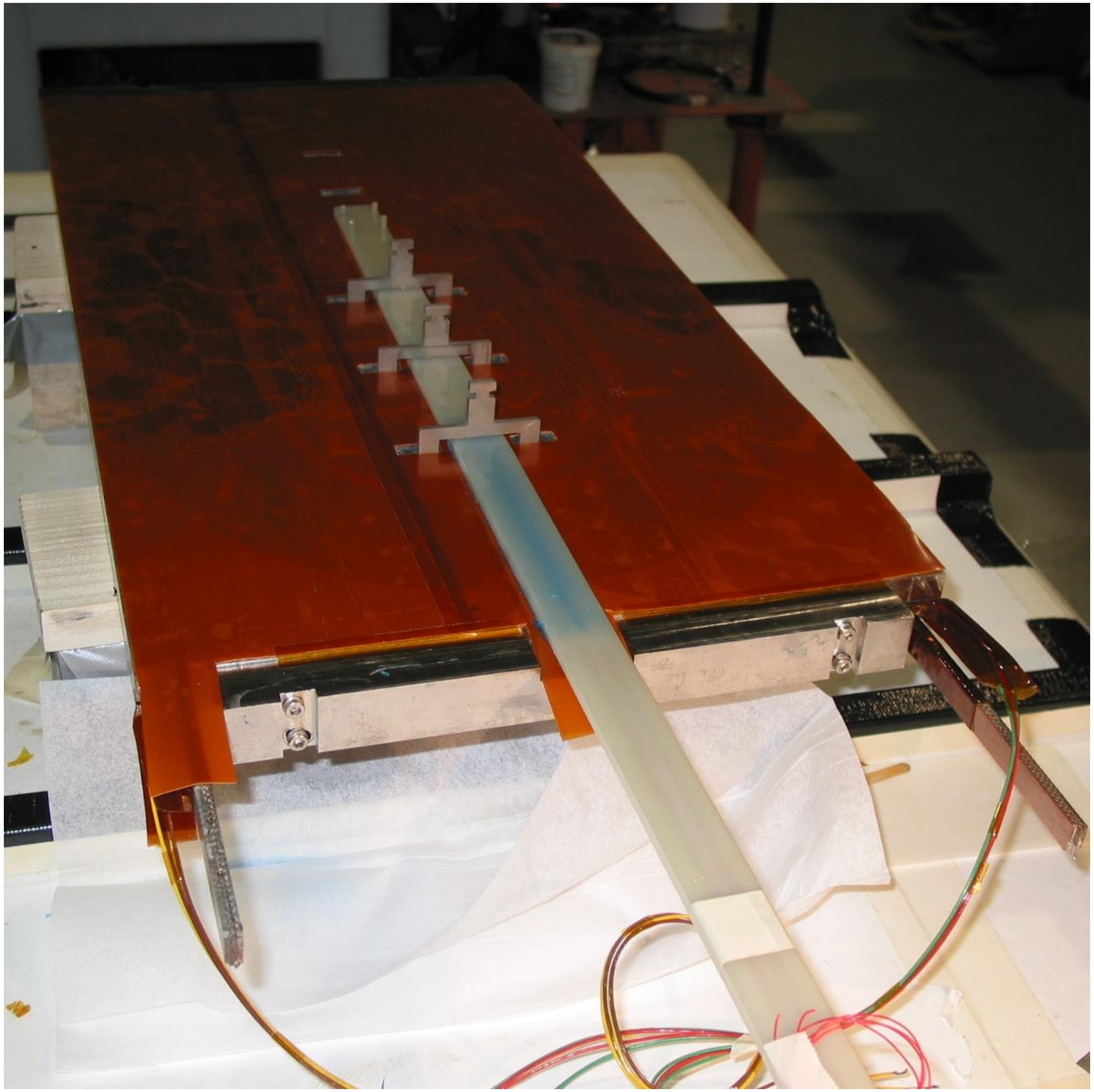
Magnet design	2-in-1 common coil dipole with racetrack coils
Conductor type	Nb_3Sn
Magnet technology	React and wind
Horizontal coil aperture (clear space)	31 mm
Vertical coil aperture (clear space)	335 mm
Separation between the magnetic center of the upper and lower aperture	236 mm
Number of layers	Two
Number of turns per quadrant of single aperture (pole-to-pole)	45 turns in each layer
Coil height (pole-to-pole)	85 mm
Wedge(s) (size and number)	8.5 mm, one in each layer (inner & outer)
End-spacer(s) (size and number)	8.5 mm, one in each layer (inner & outer)
Wire non-Cu J_{sc} (4.2 K, 12 T)	1900 A/mm^2
Strand diameter	0.8 mm
Number of strands in inner and outer cable	30
Cable width (inner and outer layers)	13.13 mm
Cu/Non-Cu ratio in the wire (same for both inner and outer cables)	1.53
Computed quench current (limited by inner)	10.8 kA
Computed quench field @4.2 K	10.2 T
Peak field at quench in inner, outer Layer	10.7 T, 6.1 T
Special electrical feature (not used)	Shunt between layers
Computed stored energy at quench	0.2 MJ
Computed inductance	4.9 mH
Coil bobbin (core) material	Carbon steel
Coil length (overall)	614.3 mm
Coil straight section length	304.8 mm
Coil height (overall)	310.4 mm
Coil inside radius in ends	70 mm
Coil outside radius in ends	155 mm
Coil curing preload - sides	0 N
Coil curing preload – ends	0 N
Insulation thickness between turns	180 μm thick Nomex®
Potting agent	CTD-101K
Thickness of the collar	26.6 mm
Thickness of stainless-steel sheet between inner and outer layers	1.65 mm
Vertical pre-stress applied	17 MPa (low)
Horizontal pre-stress applied	Essentially none
Computed horizontal stress on structure	59 MPa at 10.2 T
Design maximum for horizontal stress	75 MPa
Stainless steel shell thickness	25.4 mm
Thickness of the end plates	127 mm
Yoke outer radius	267 mm
Yoke length	653 mm
Quench protection strip heaters (no energy extraction available during the tests)	25 μm X 38.1 mm, each quadrant, between layers



Nb_3Sn Coil Package of DCC017







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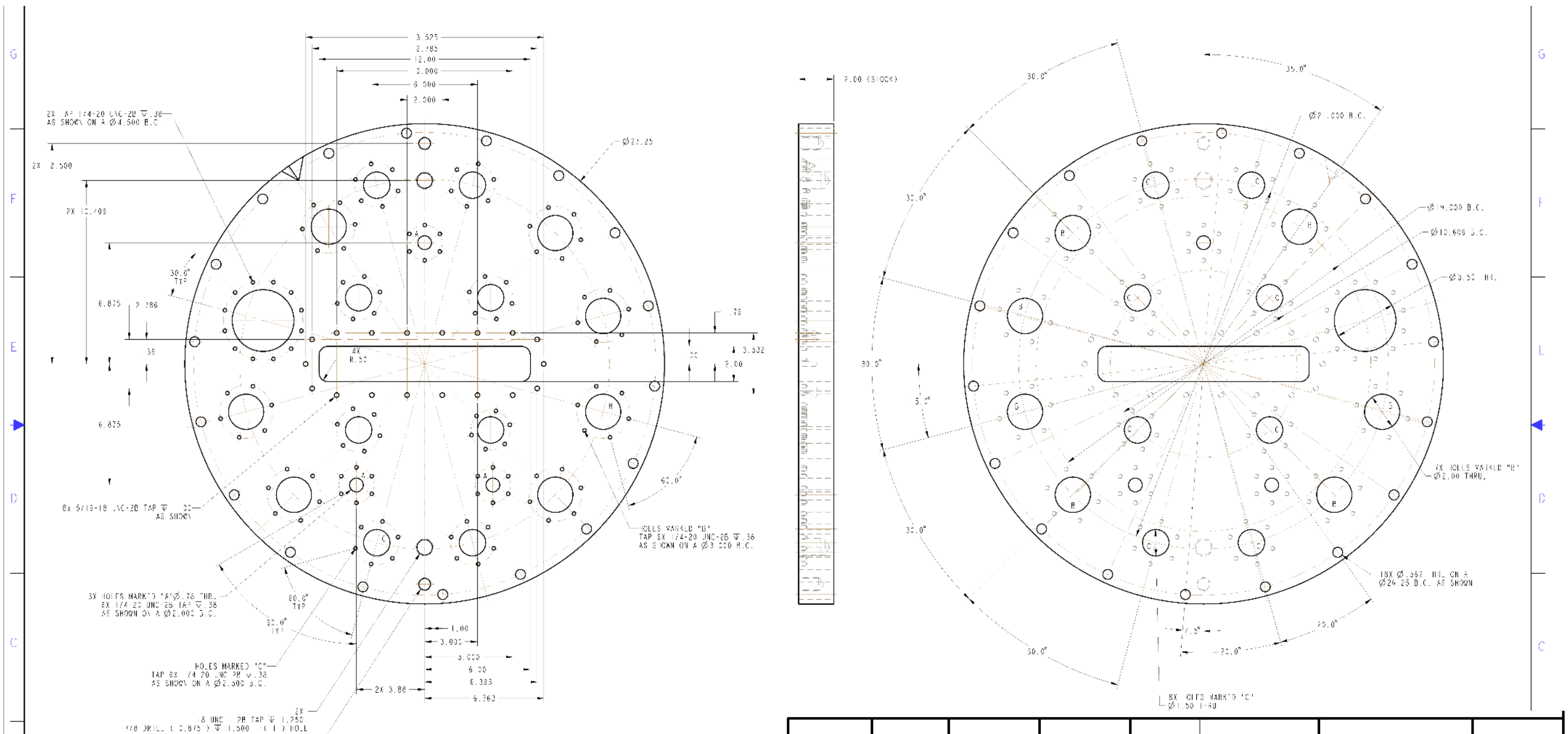
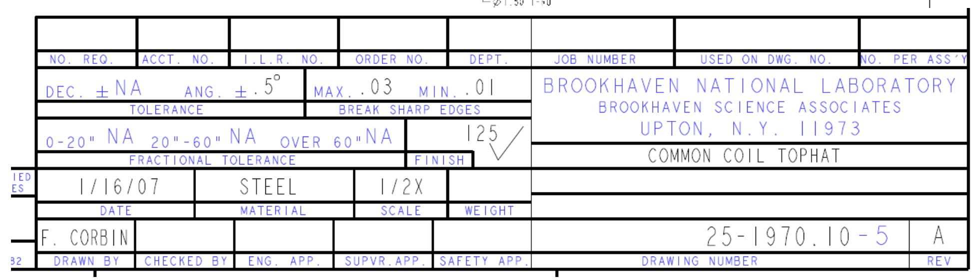
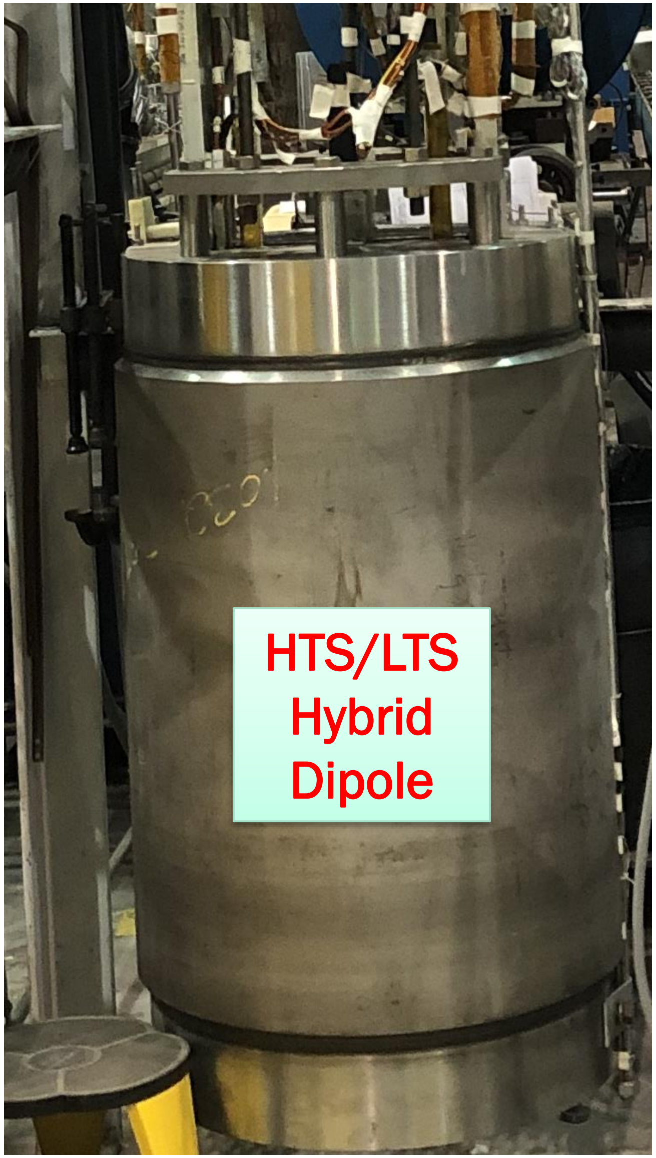
Drawing of the Top-Hat

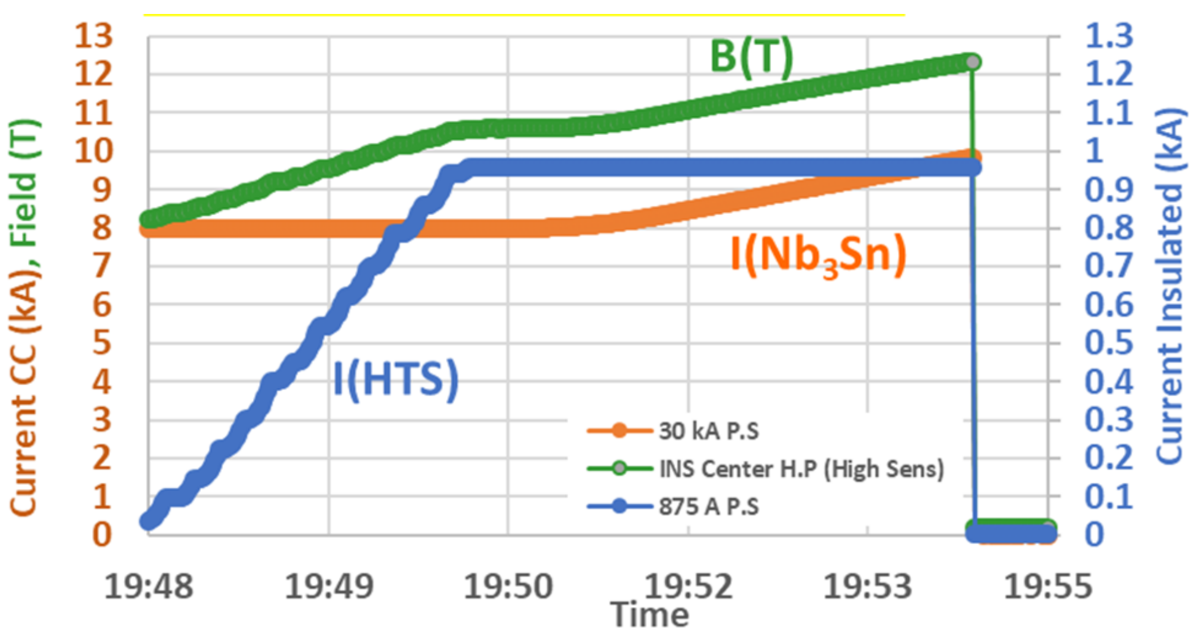


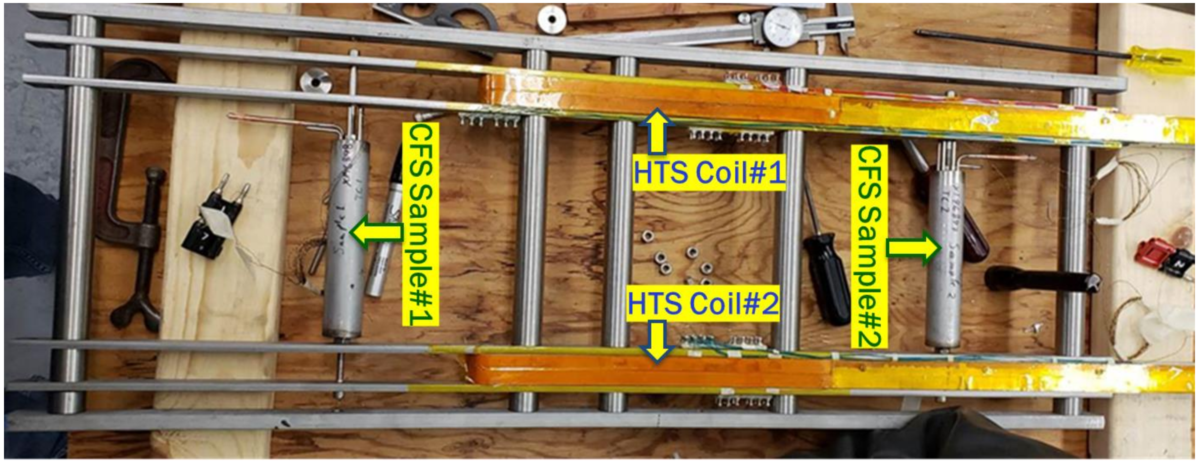
Test structure going inside the magnet can be inserted from the top-hat to the magnet (not preferred, contact us before planning)



HTS/LTS Hybrid Dipole & Cable Test (2019)
(an example of four tests in one run)

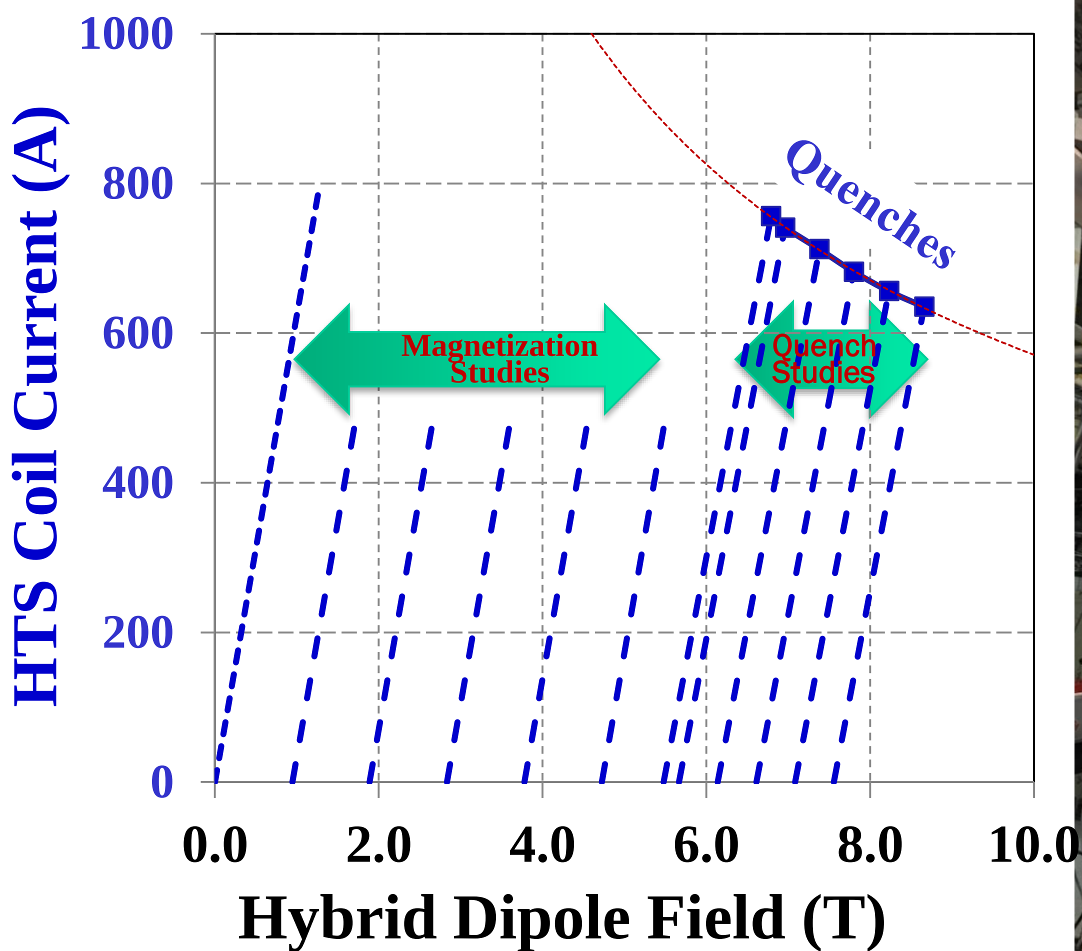




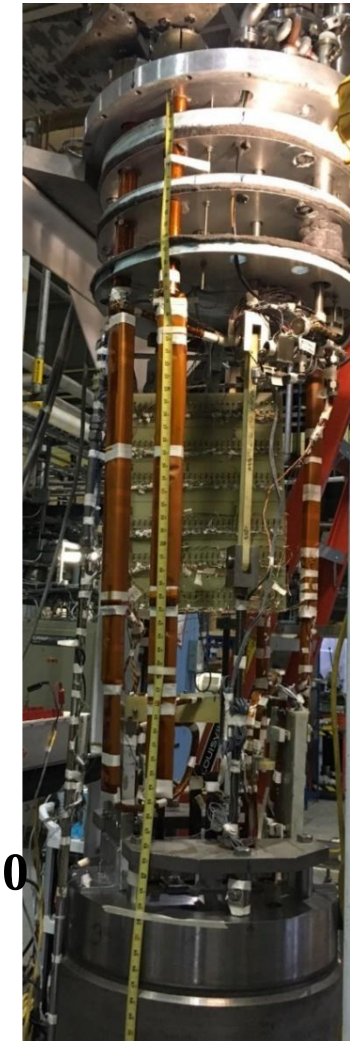


HTS/LTS Hybrid Dipole Test (2016)

(new HTS insert coils with existing Nb_3Sn magnet coil)



(LTS Fixed, HTS ramped)

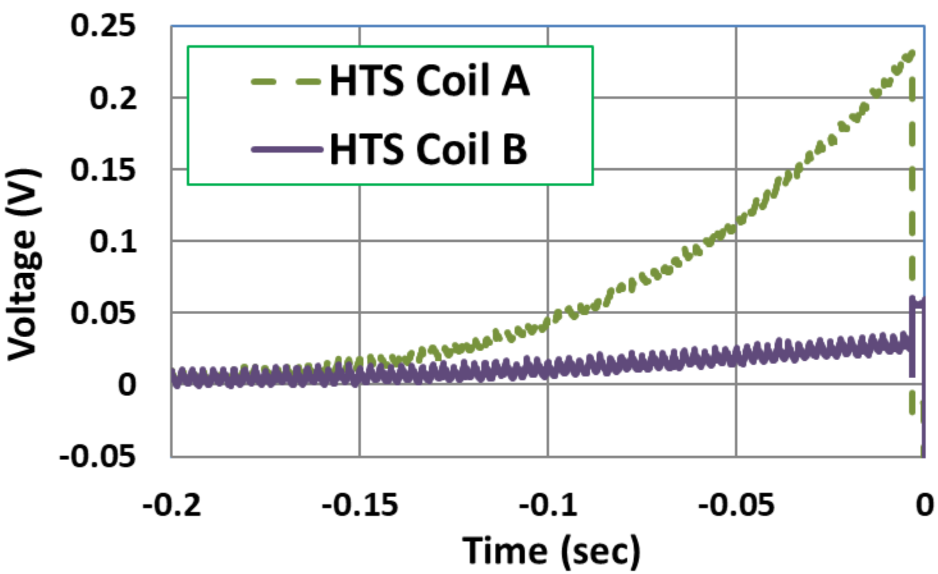


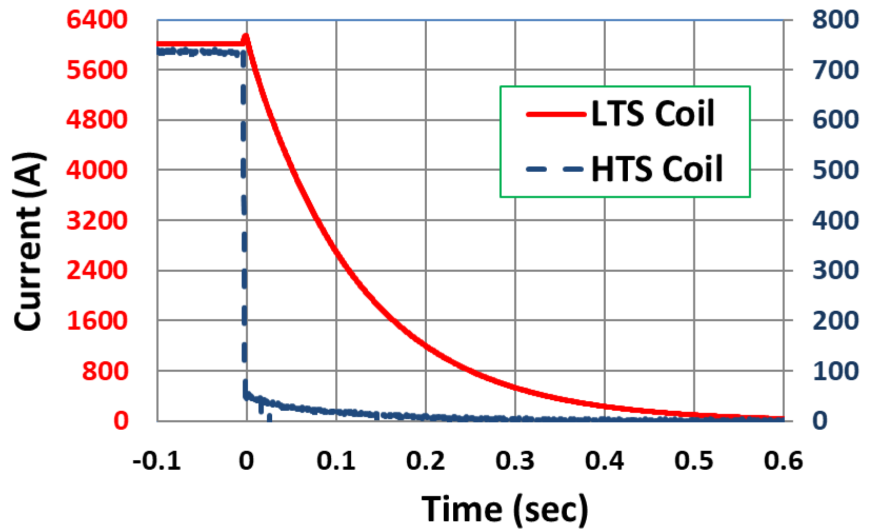
HTS coils were ramped to quench, just like LTS coils

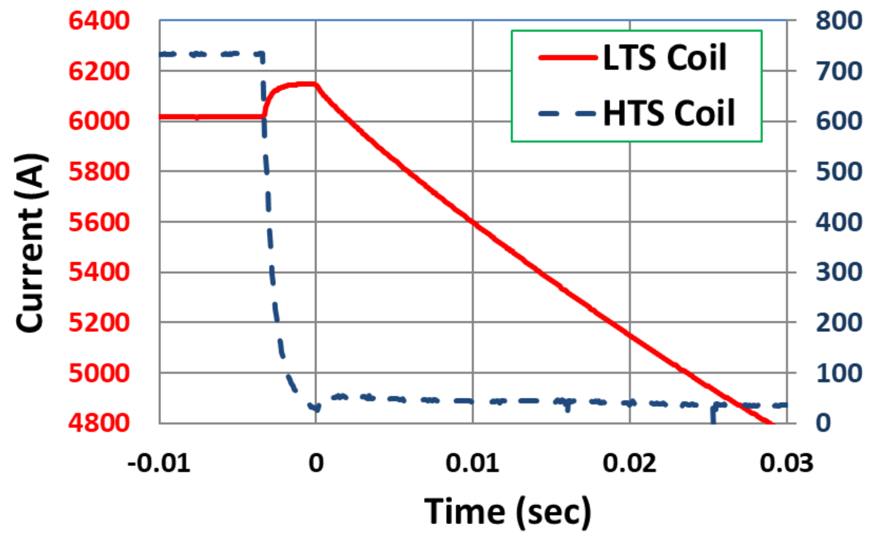
HTS coils exhibited <u>NO</u> training and <u>NO</u> degradation despite a number of quenches

Quench Protection of HTS Coils in HTS/LTS Hybrid Magnet (2016)

HTS coils were operated like the LTS coils
(significant voltages allowed till quench even on the HTS coils)







HTS and LTS coils were operated with different power supplies and had separate energy extraction under a common platform

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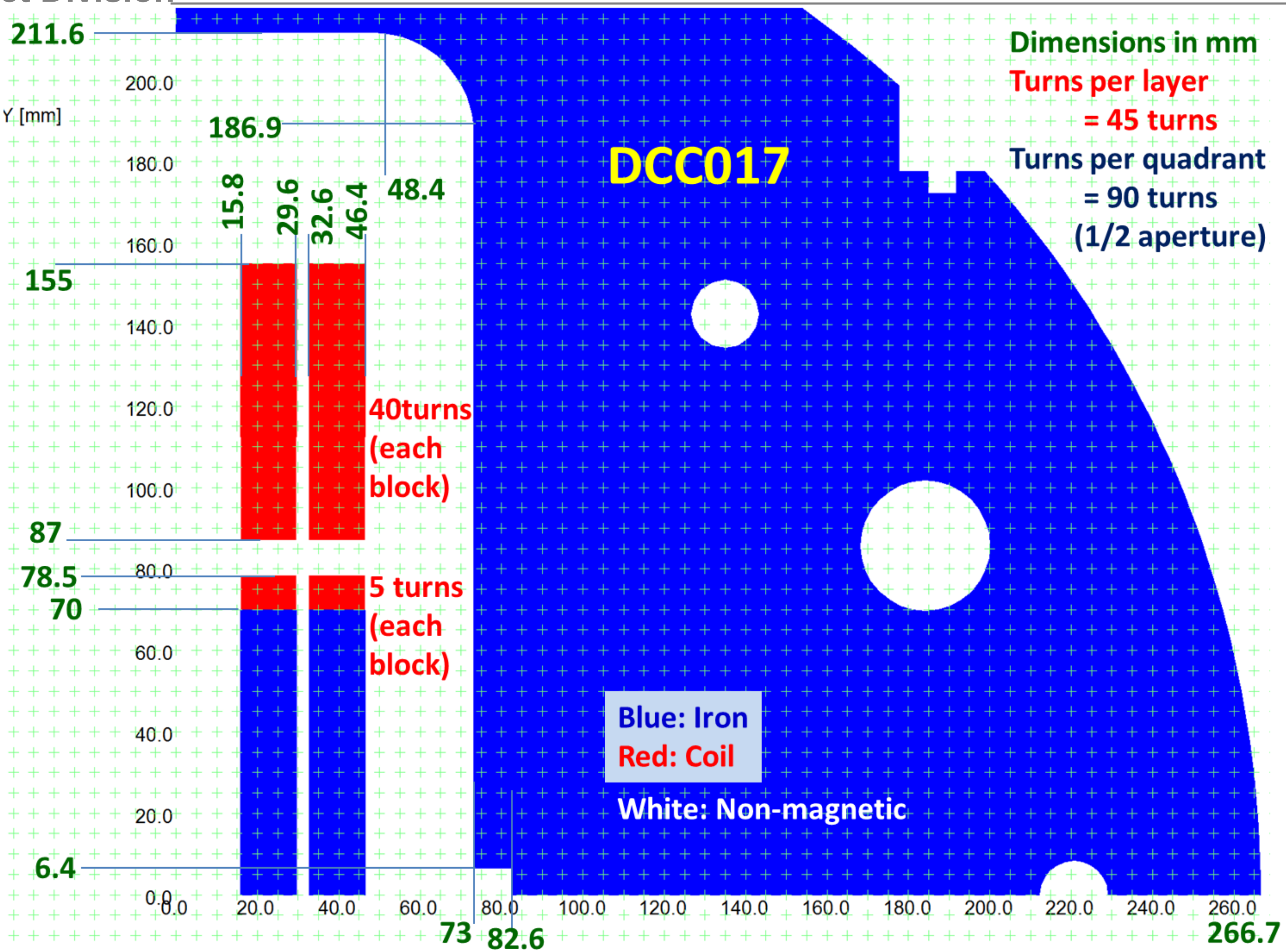
2-d Magnetic Model



3d-model and the Field Profile inside DCC017

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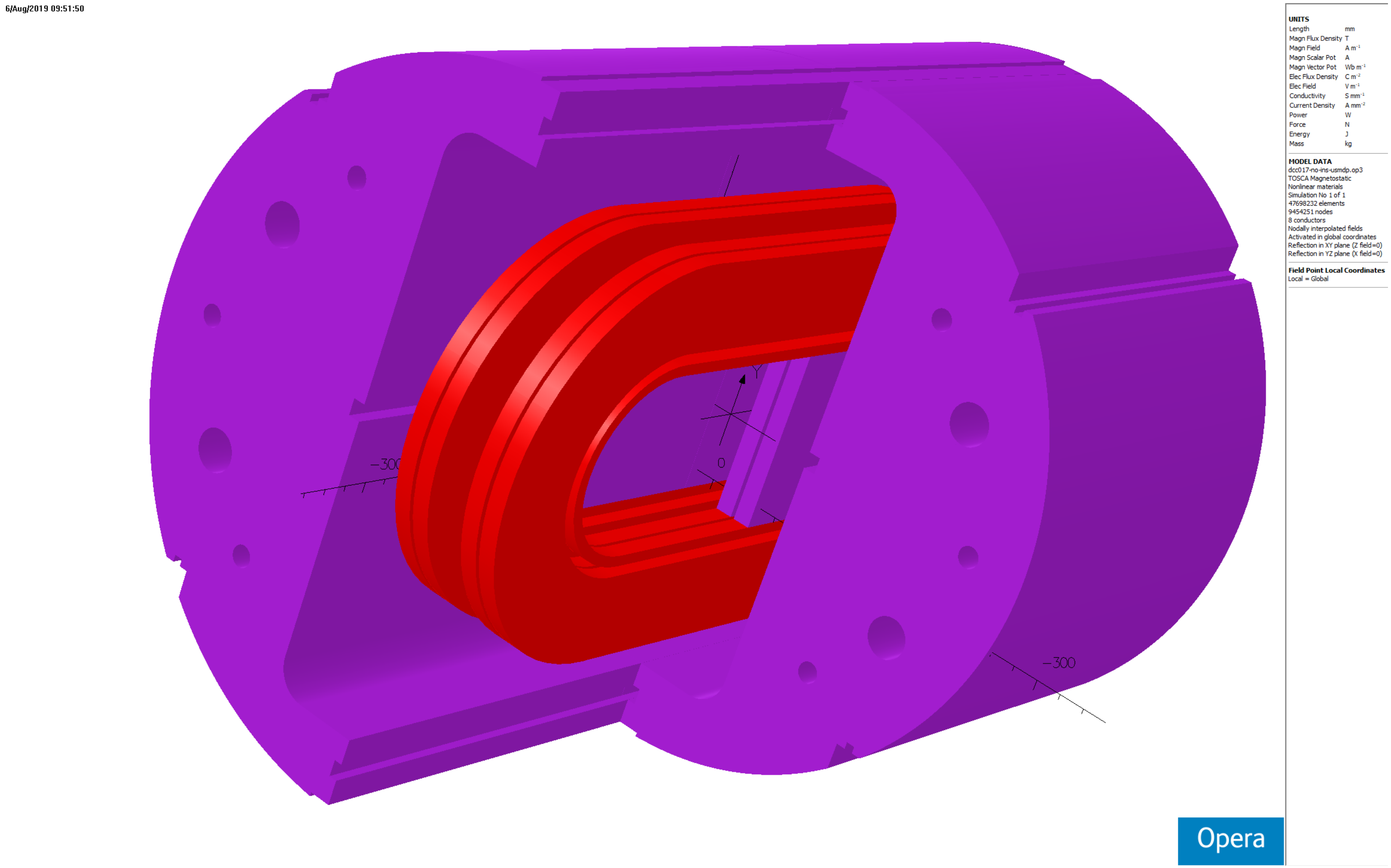
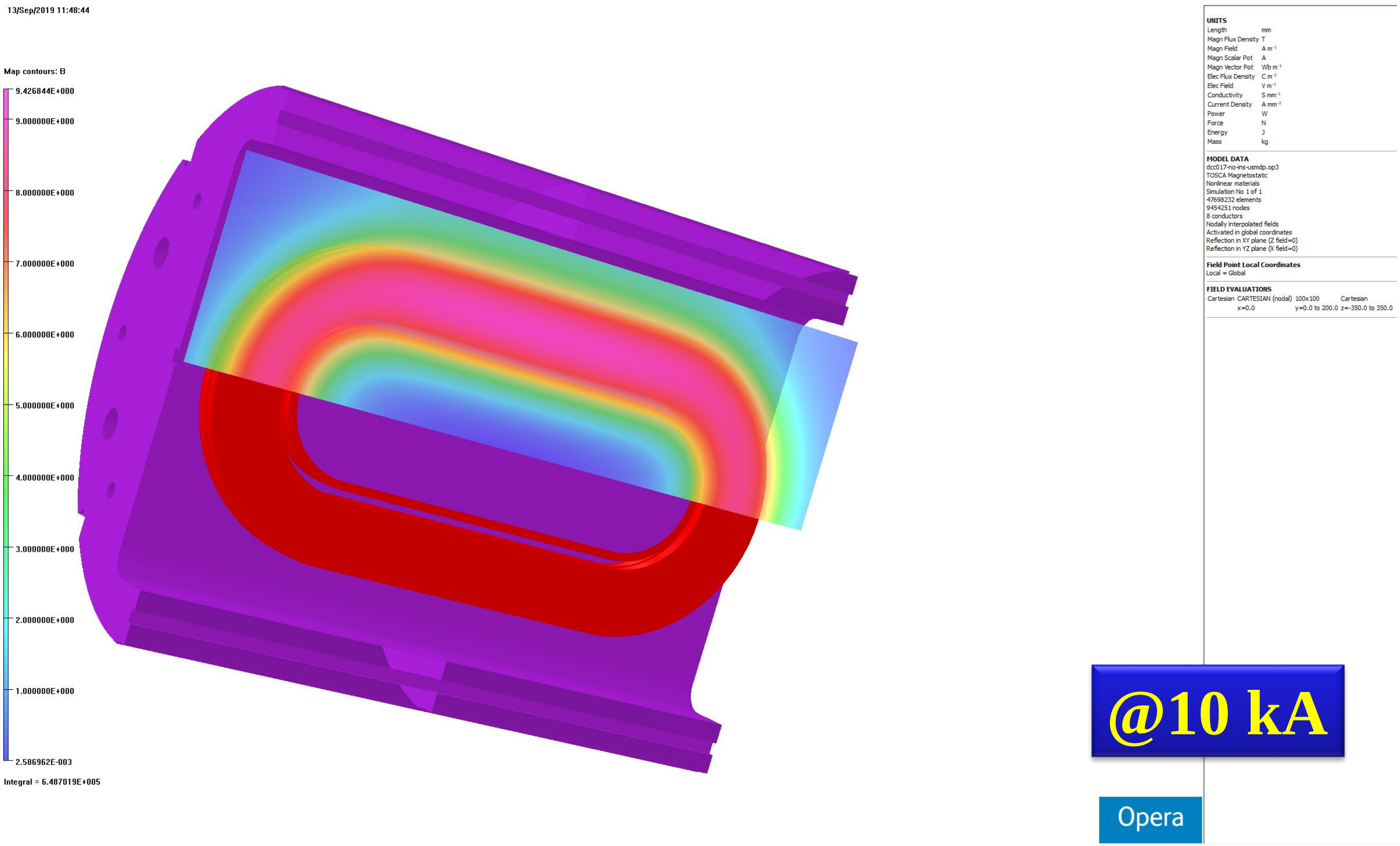
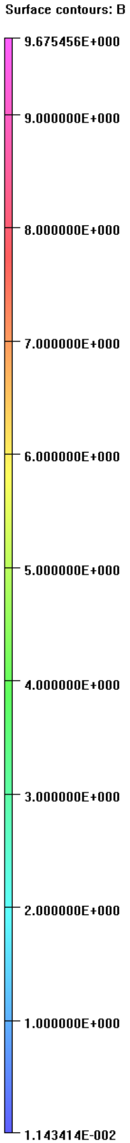
3-d model of the coils with ¾ cut-out of the iron yoke



Magnitude of the Field in DCC017 at x=0 (y-z plane)

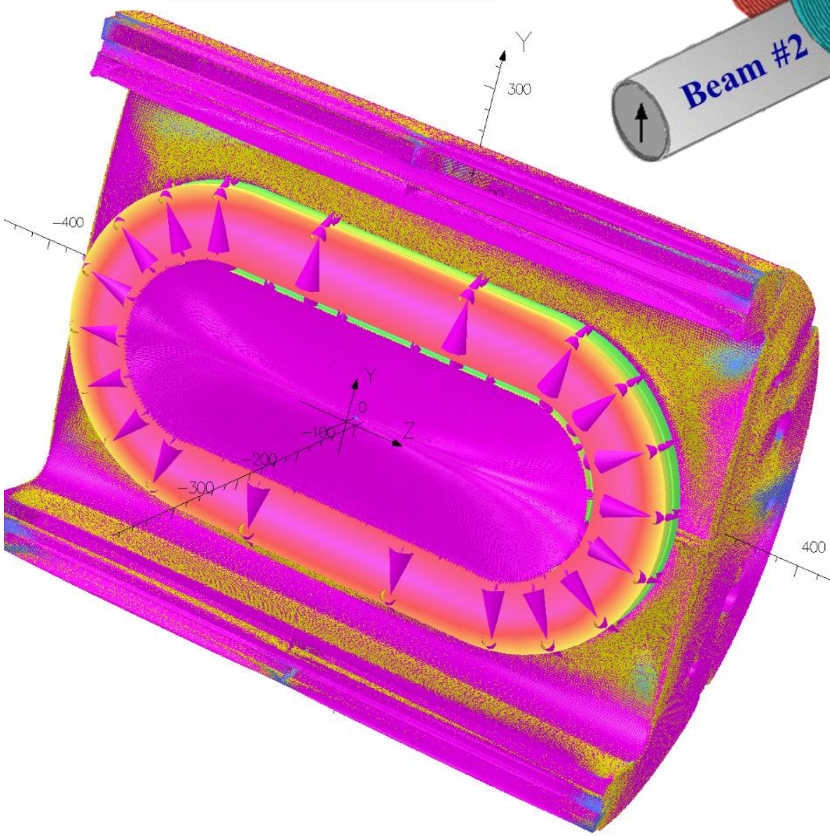


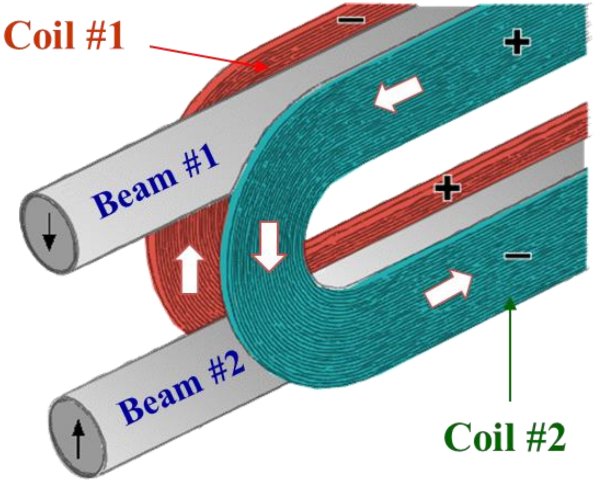
Direction of the Field between the Coils in the Open Space of DCC017



DCC017
(magnet only)

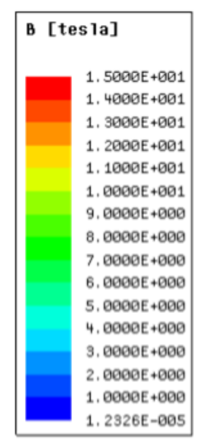
@10 kA

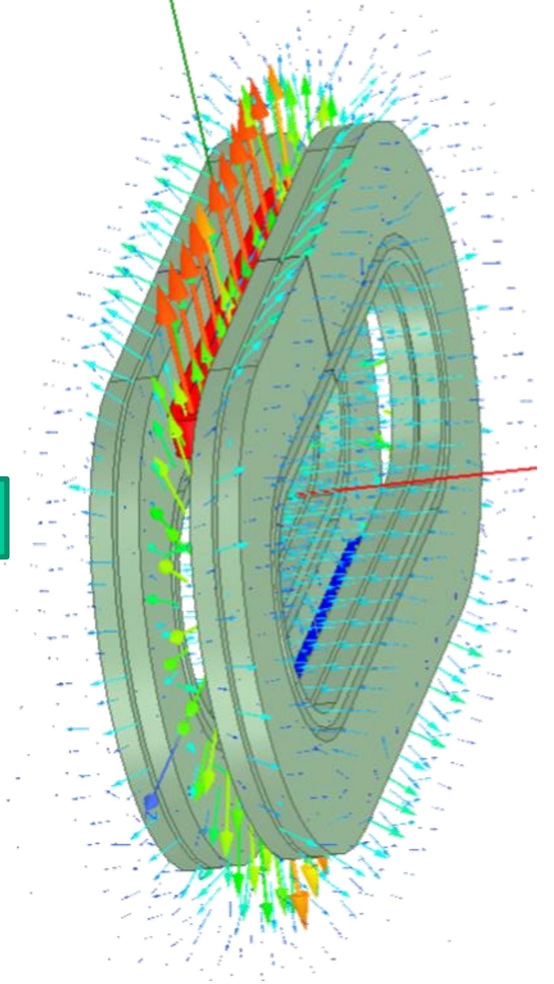




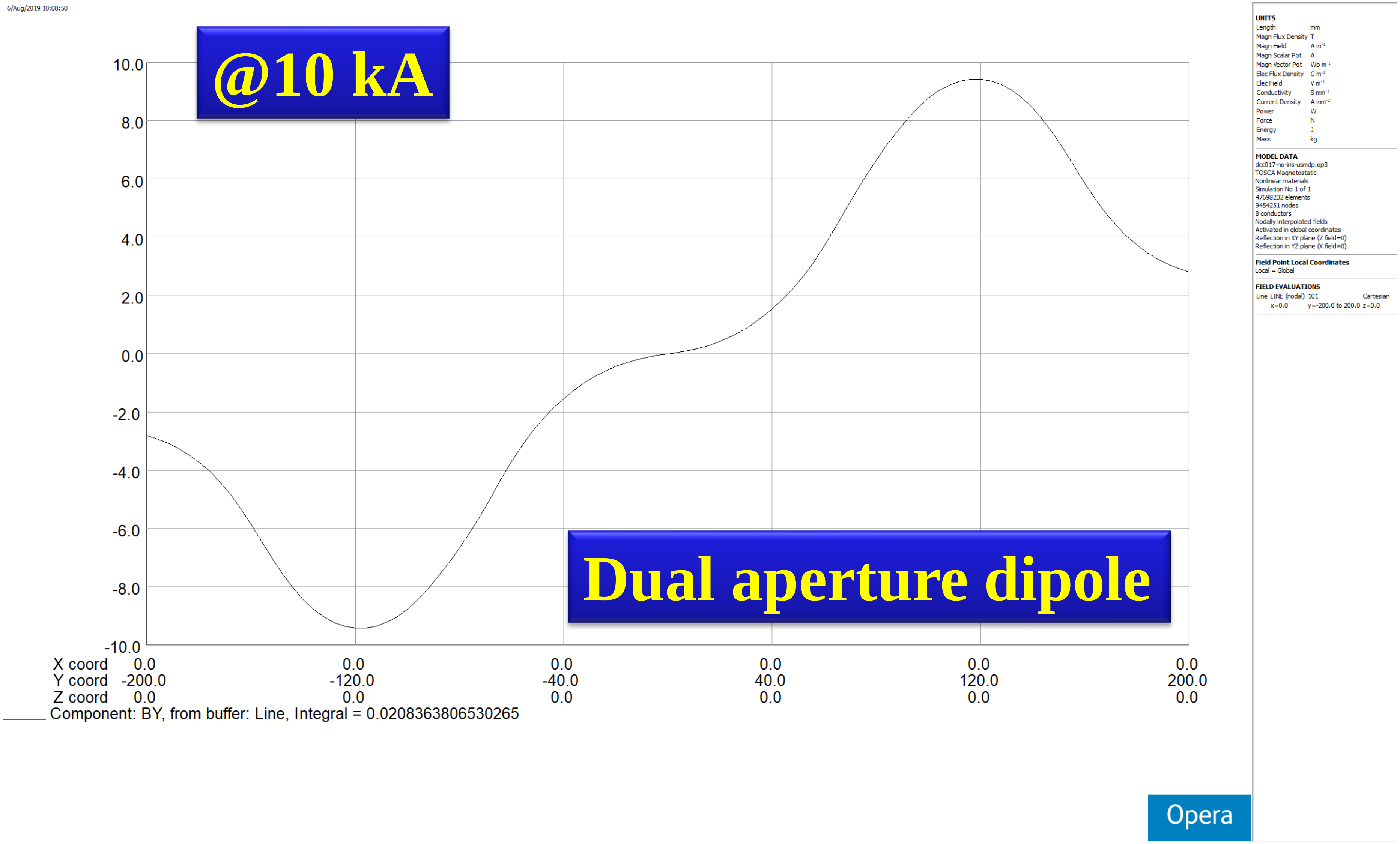
DCC017
(with an insert coil)

COMSOL

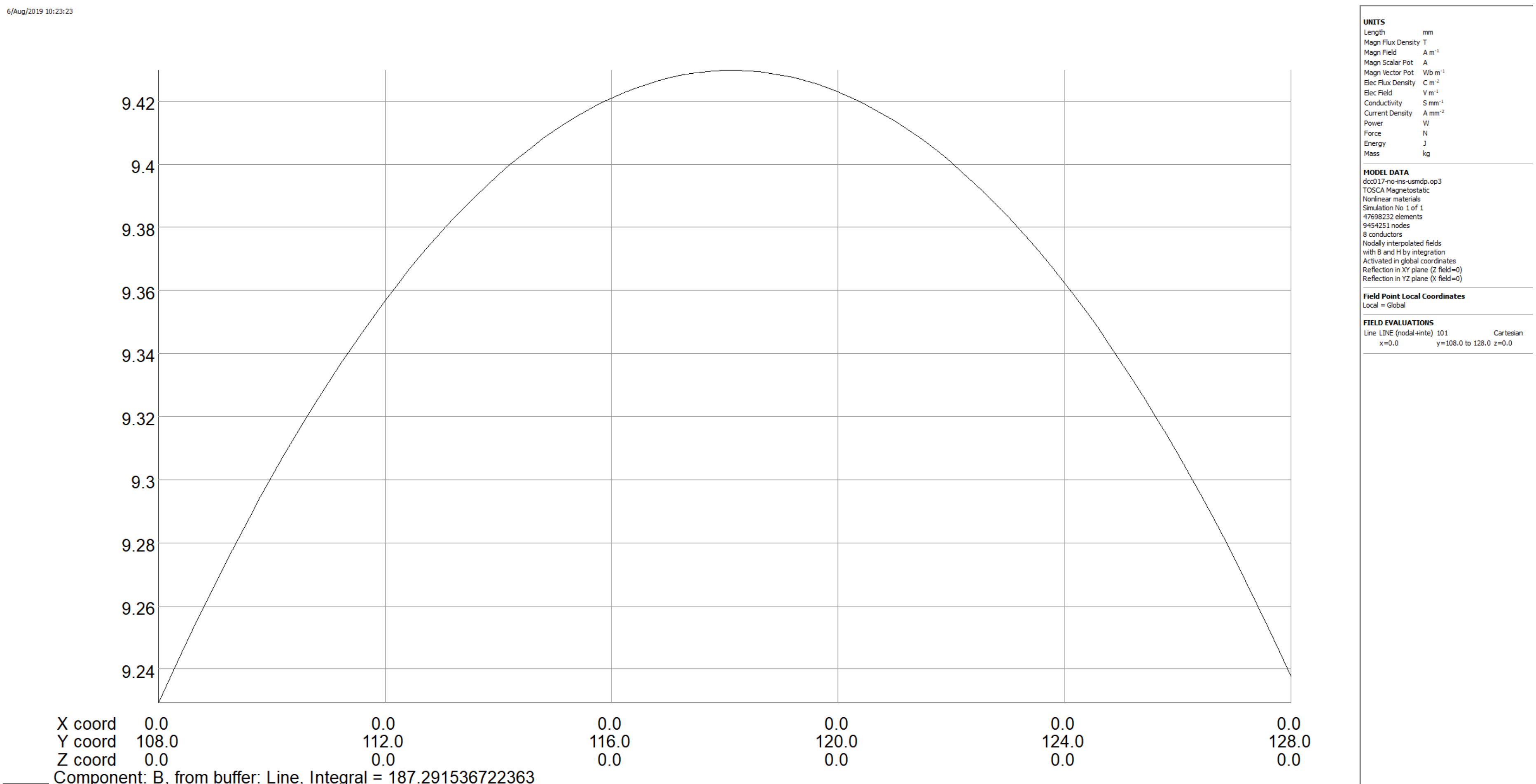




B_y along the Vertical-axis at x=0, z=0



B along the y-axis at x=0, z=0 (upper bore)



@10 kA

Opera

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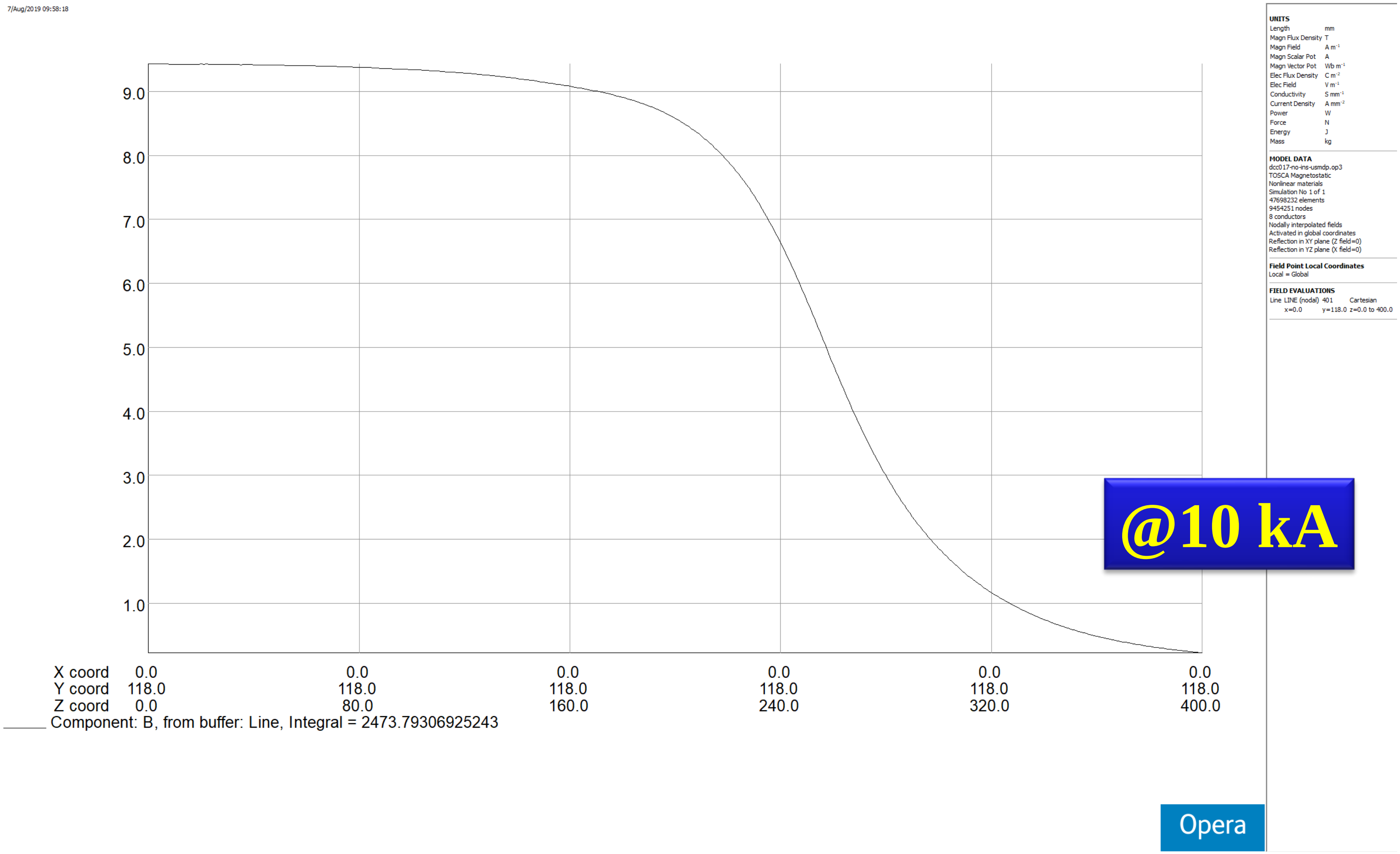
B along the z-axis (center of upper bore)



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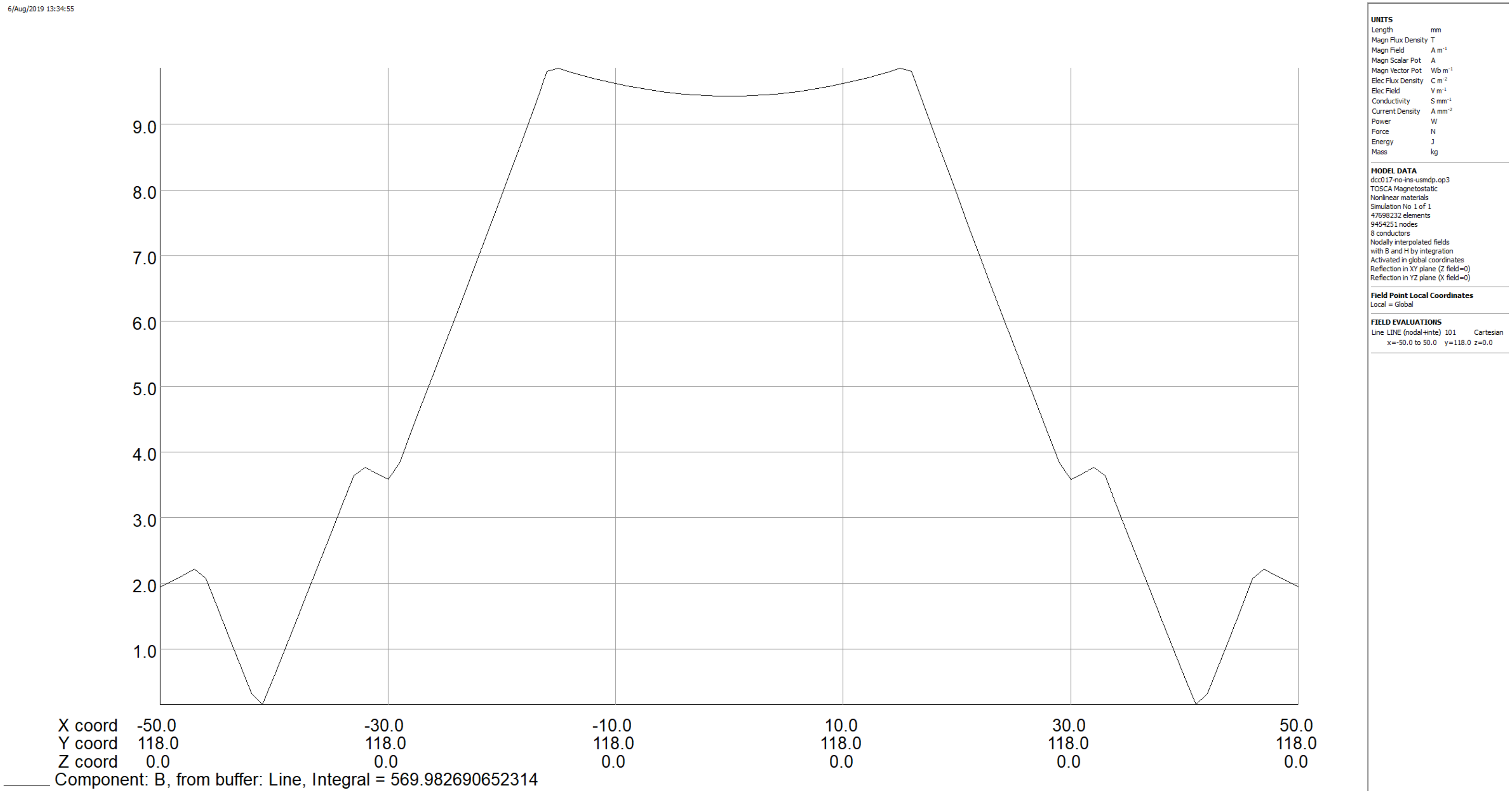
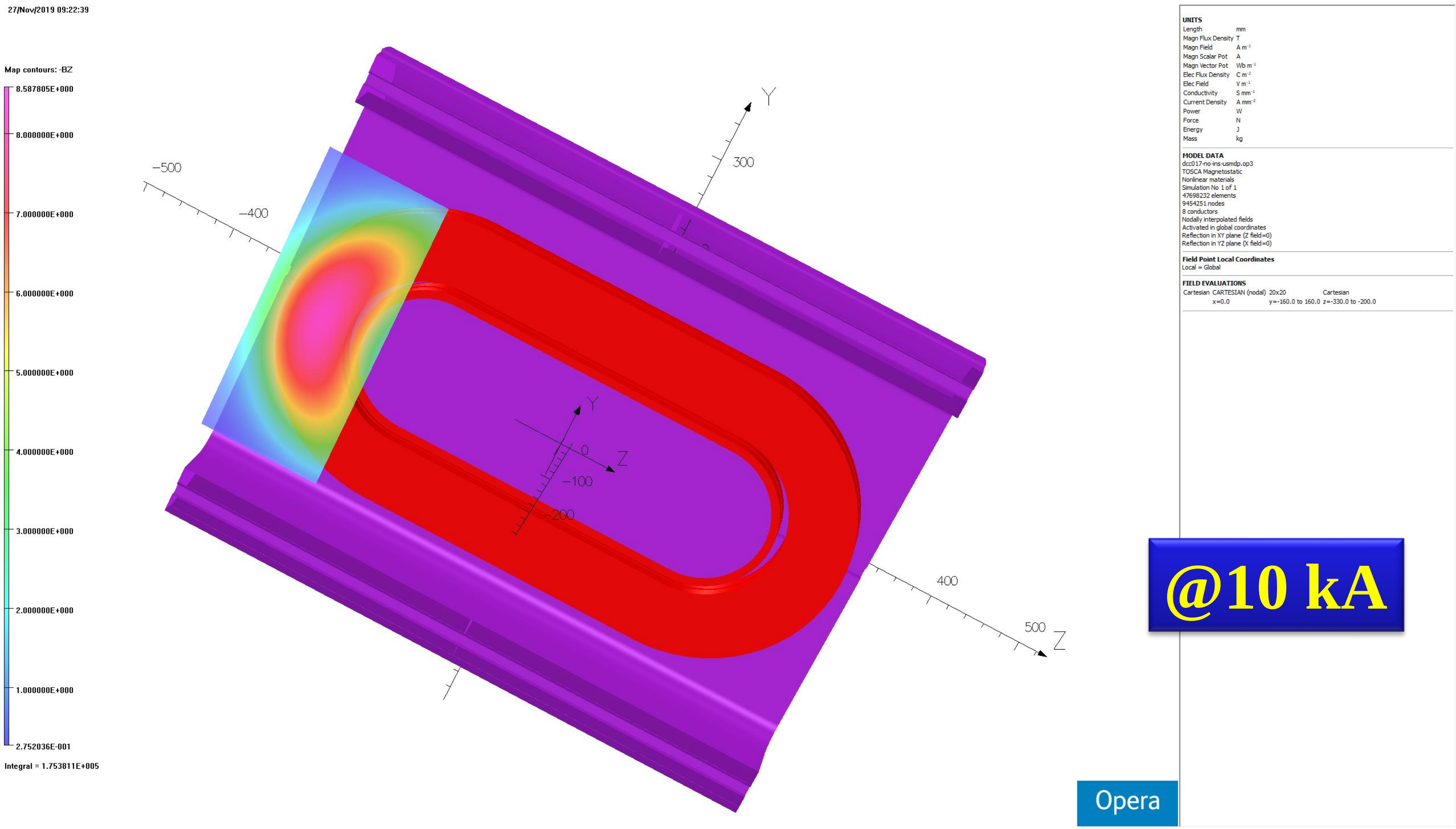
B along the x-axis at z=0 (upper bore)



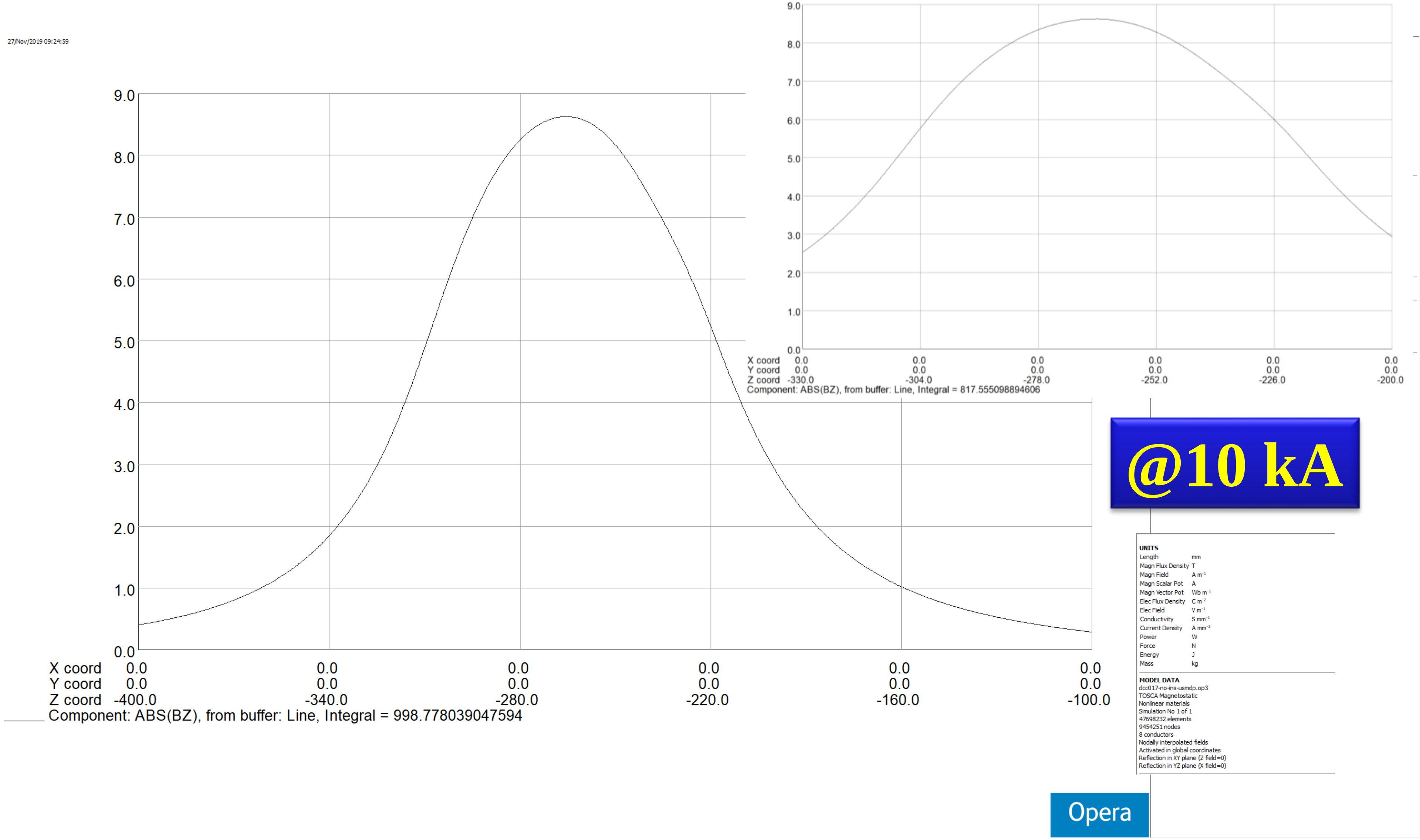
@10 kA

Opera

Magnitude of the Axial Field (Bz) Map in DCC017 in the End Region



Magnitude of the Axial Field (Bz) along the z-axis in DCC017 in the End Region



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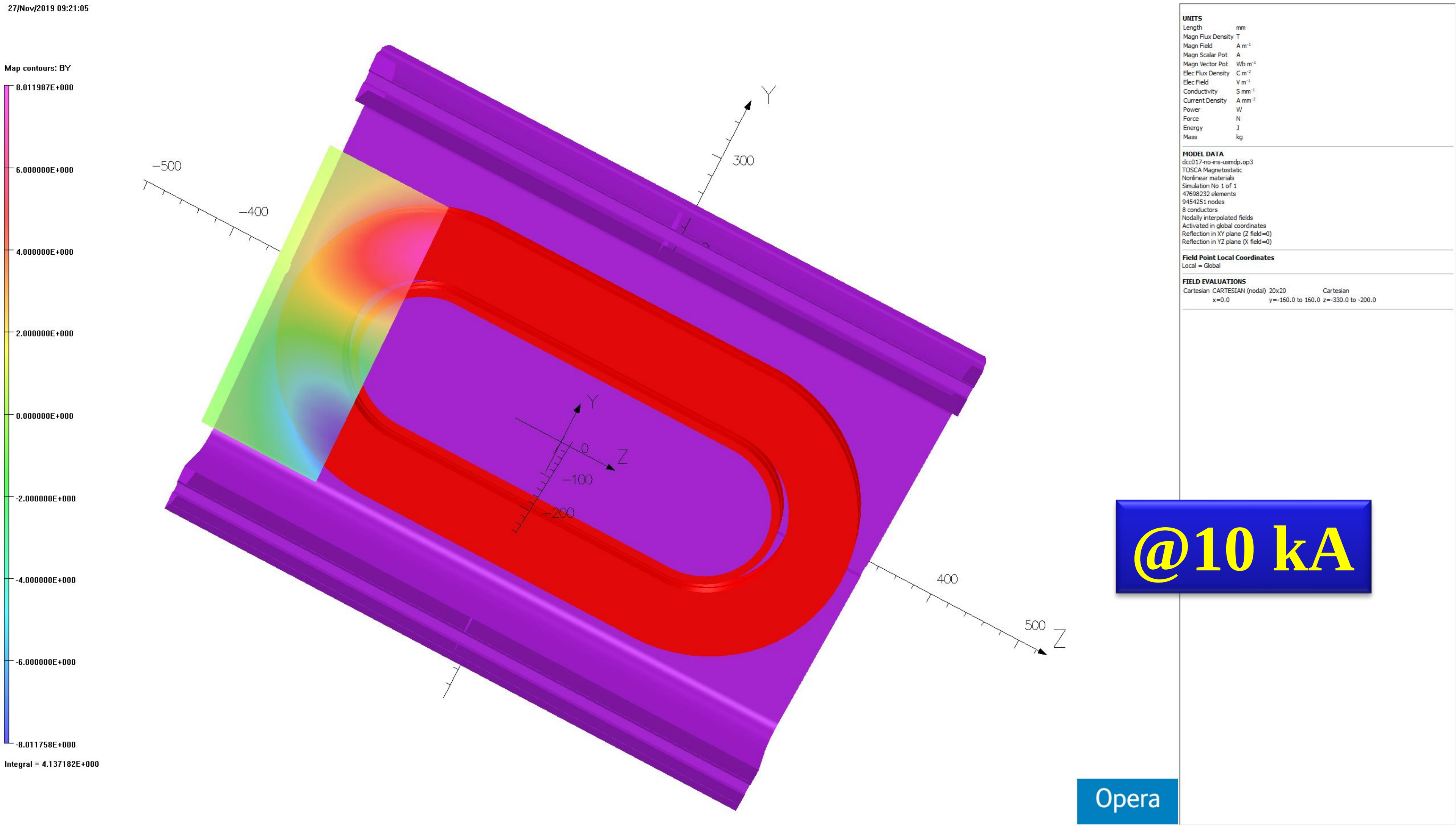
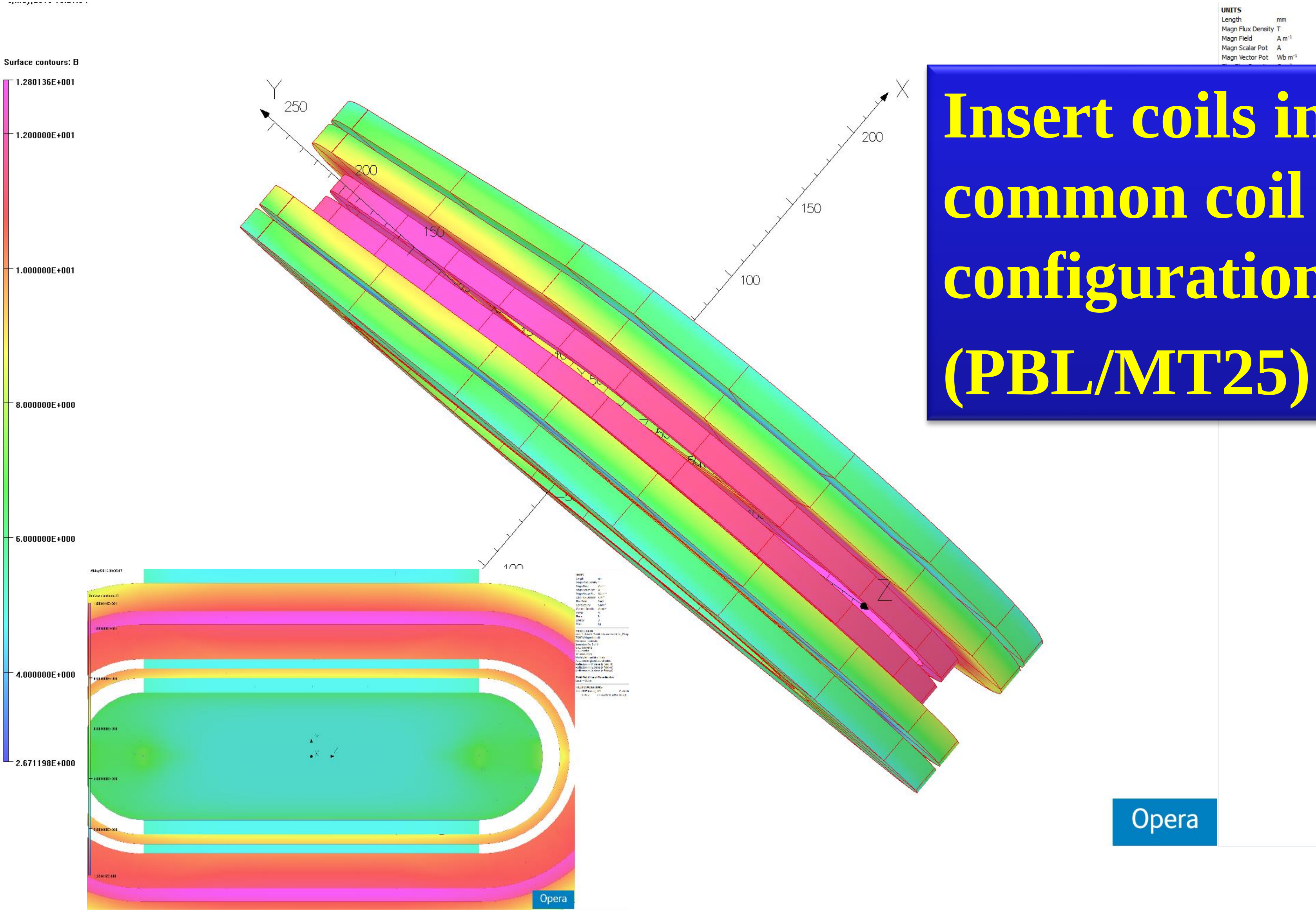
Vertical Field (By) Map in DCC017 in the End Region



@10 kA

Models of Insert Coil Testing in DCC017

Insert Coil Test Configuration #1



Insert coils in common coil configuration (PBL/MT25)

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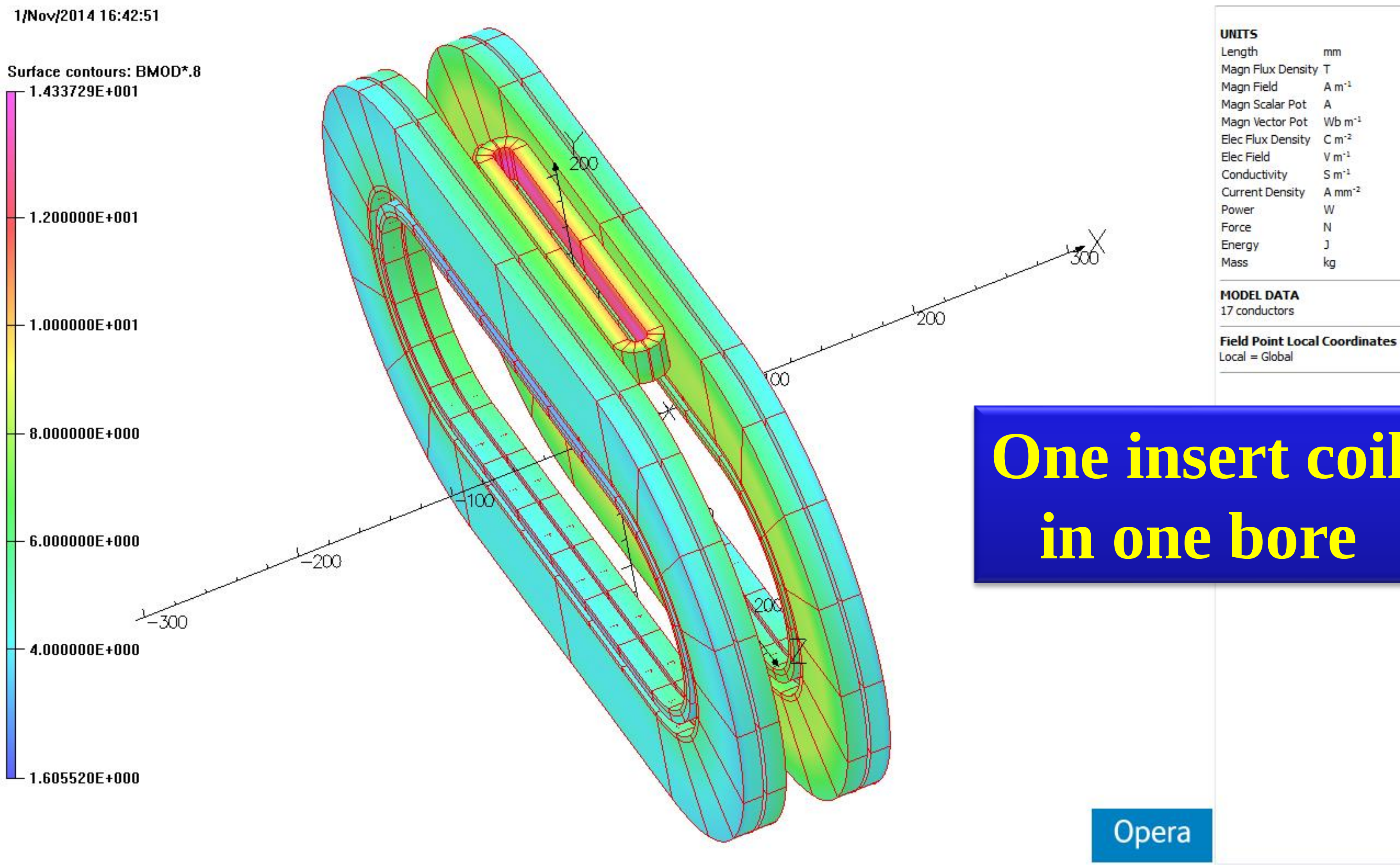
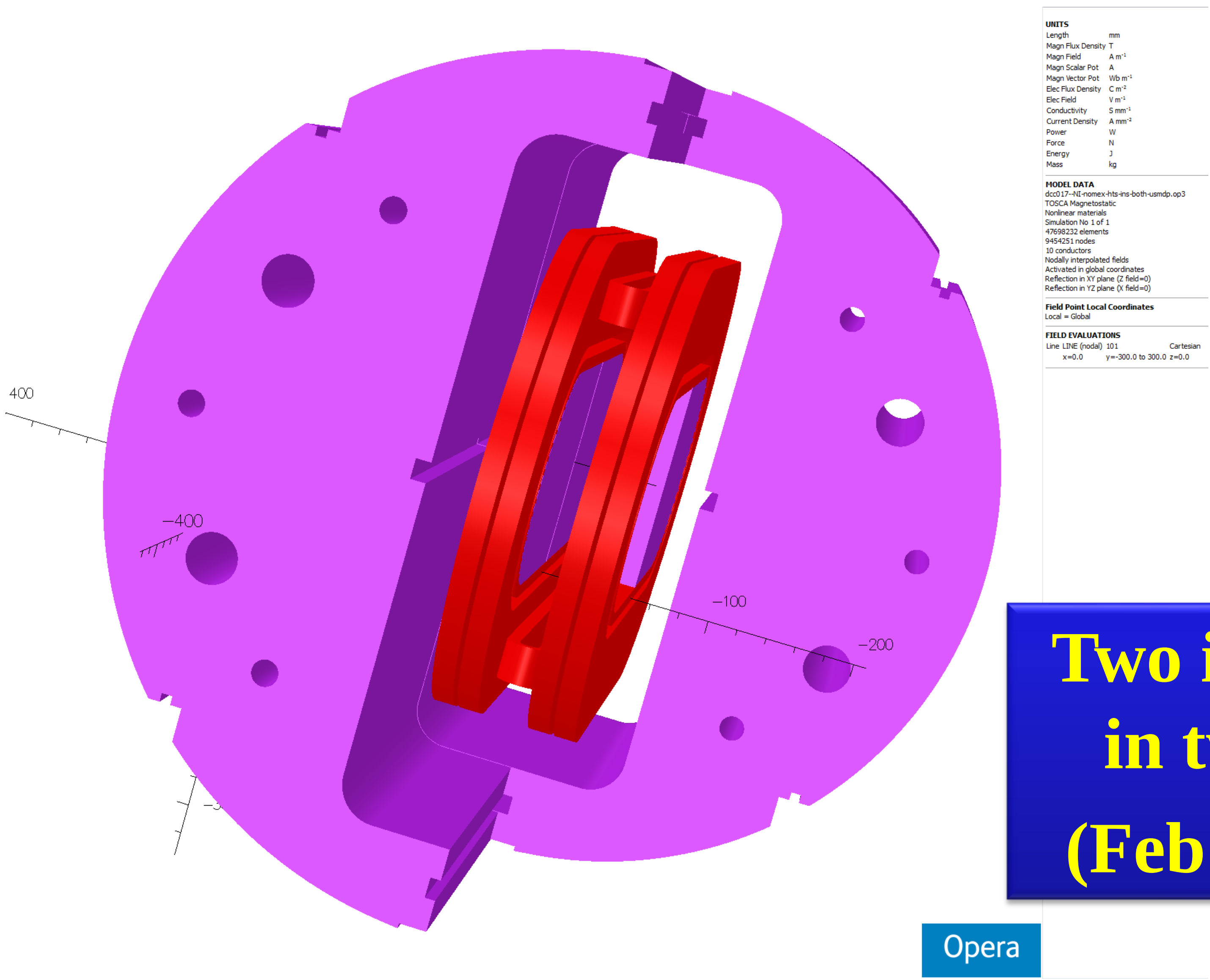
Insert Coil Test Configuration #2



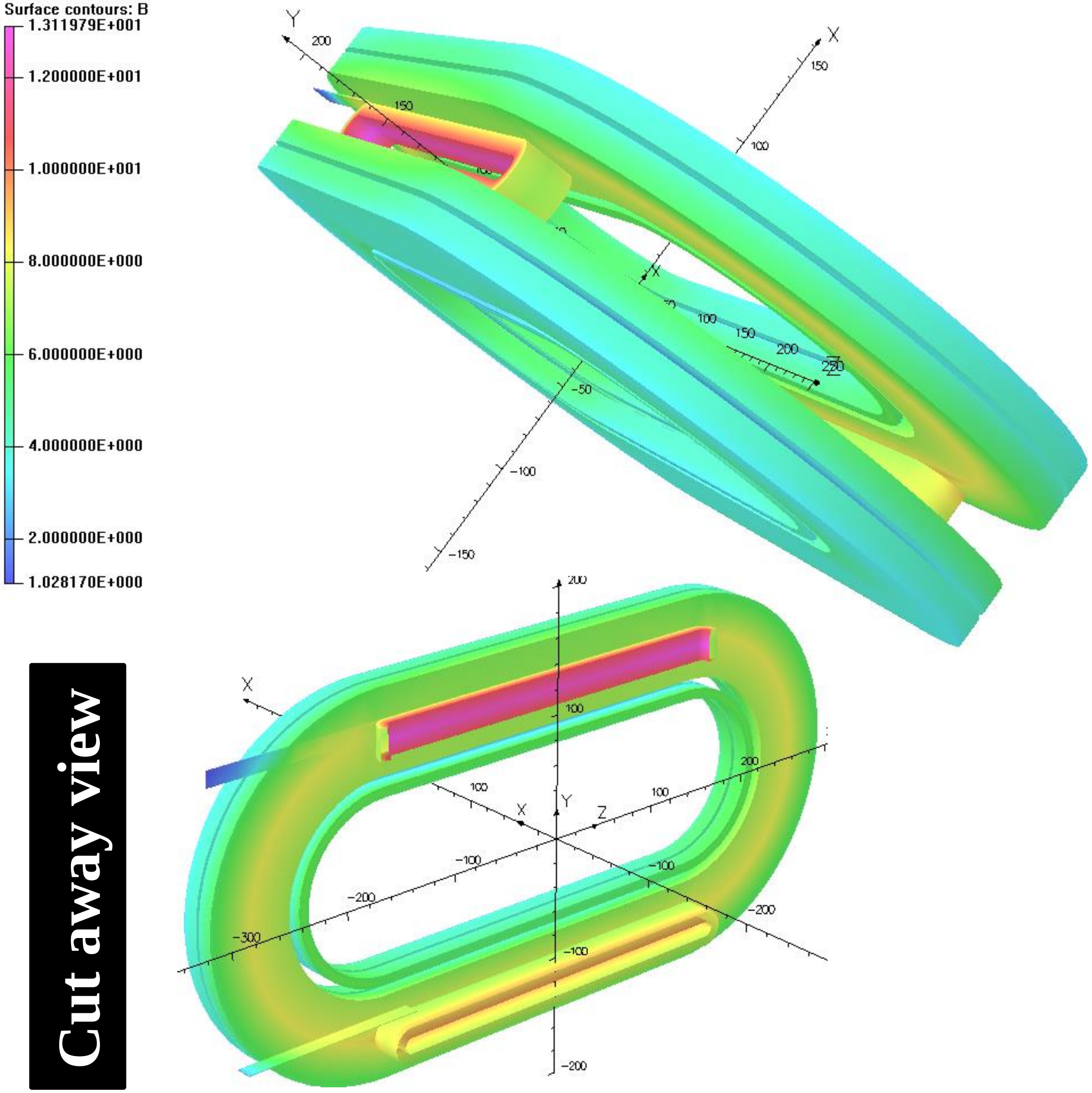
One insert coil in one bore

Insert Coils Test Configuration#3



Two insert coils in two bores (Feb 2020 test)

Insert Coils Test Configuration#4



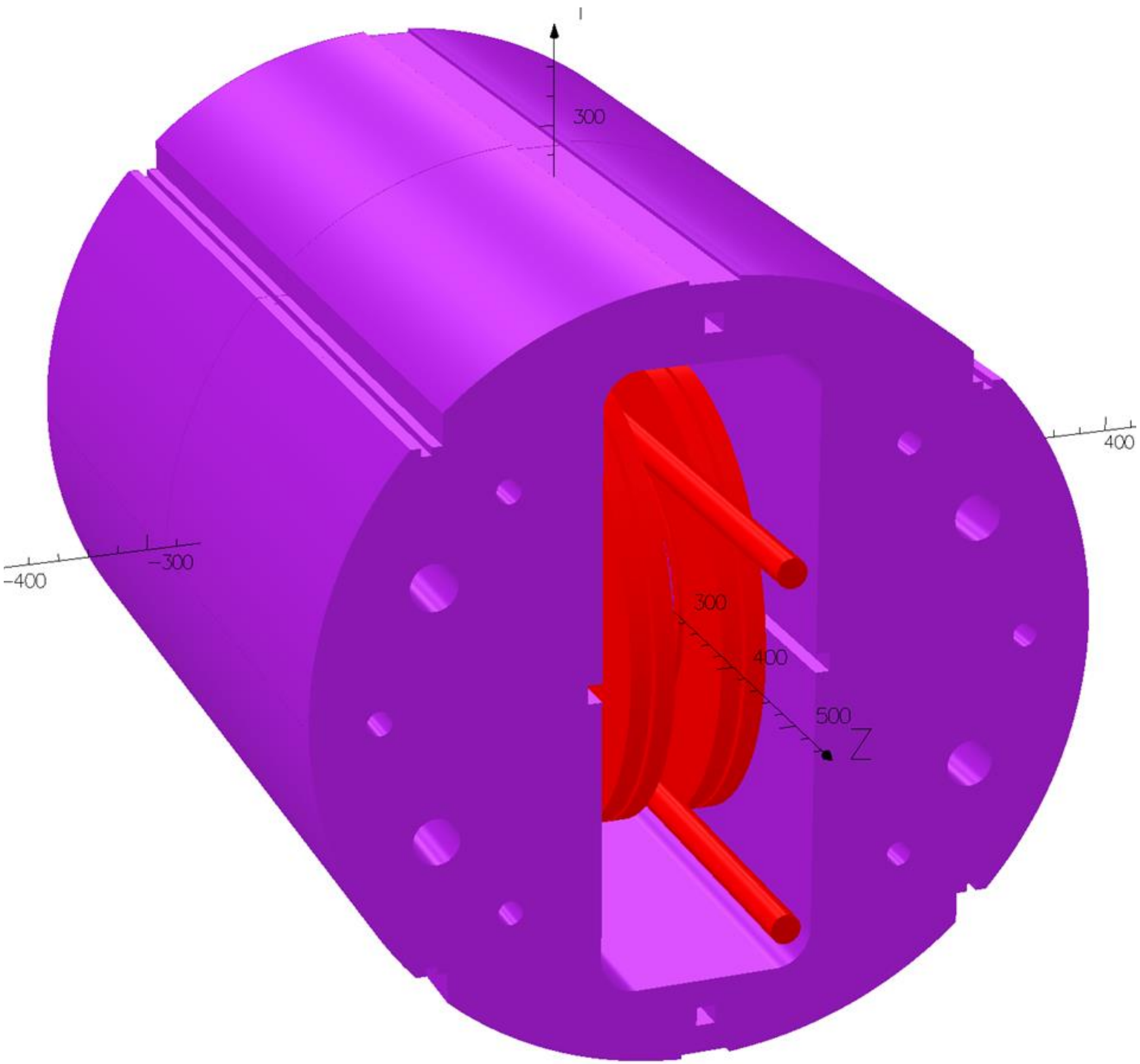
Two HTS insert coils in two bores (apertures) of the common coil dipole

(a) Upper bore: Field primarily parallel

(b) Lower bore: Field primarily perpendicular

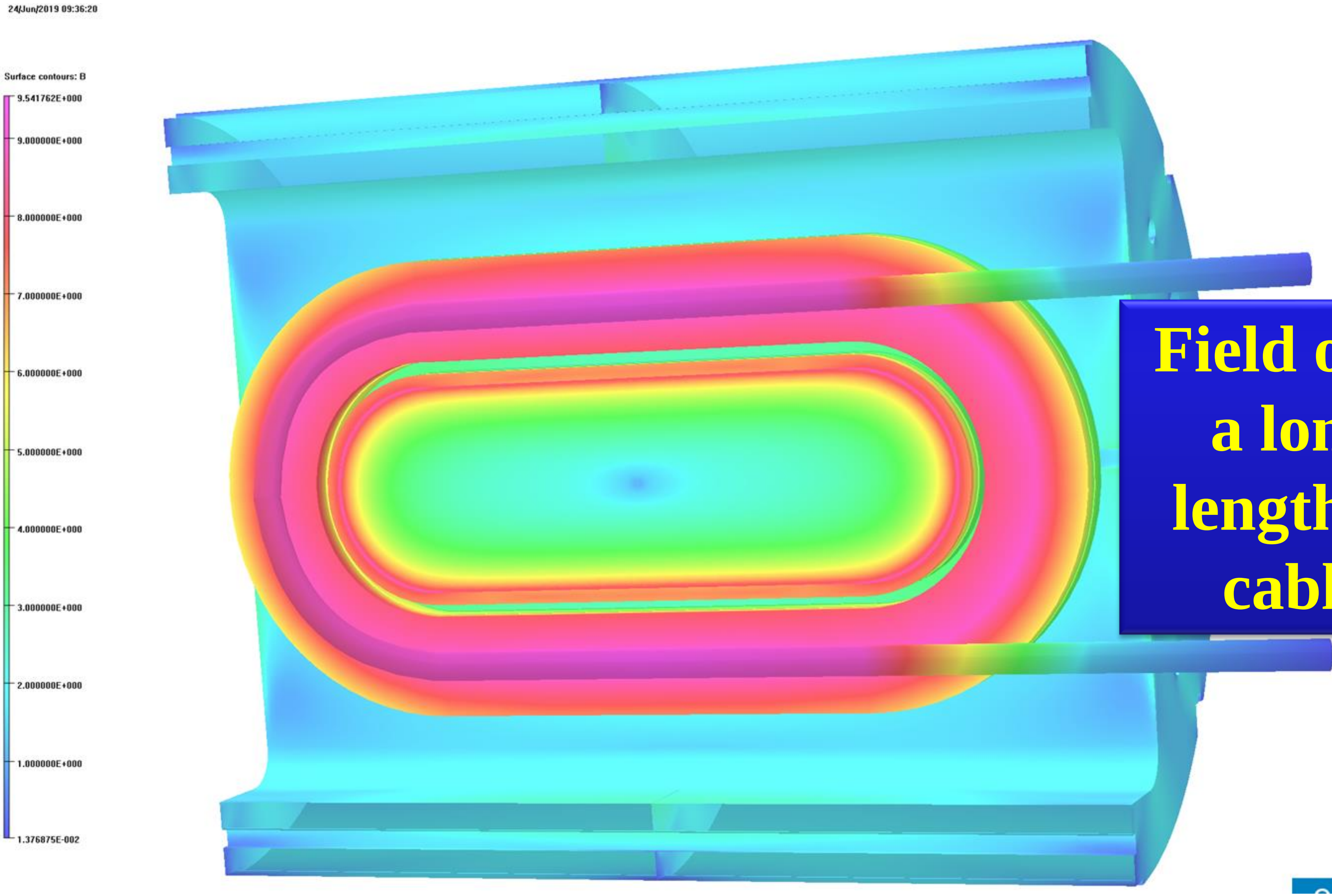
Models of Cable Testing in DCC017

Cable Testing Model – View 1



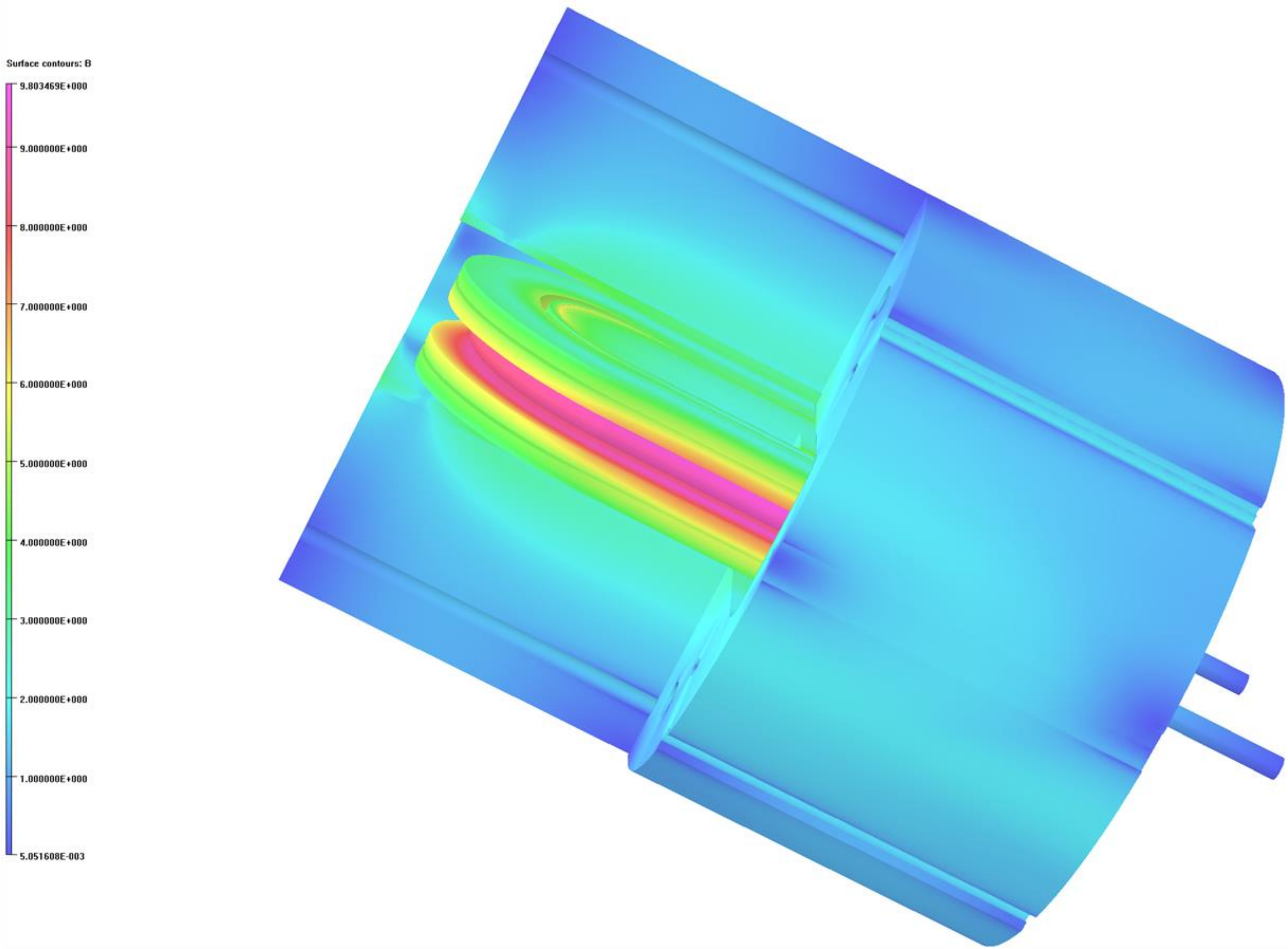
Single turn cable test

Cable Testing Model – View 2

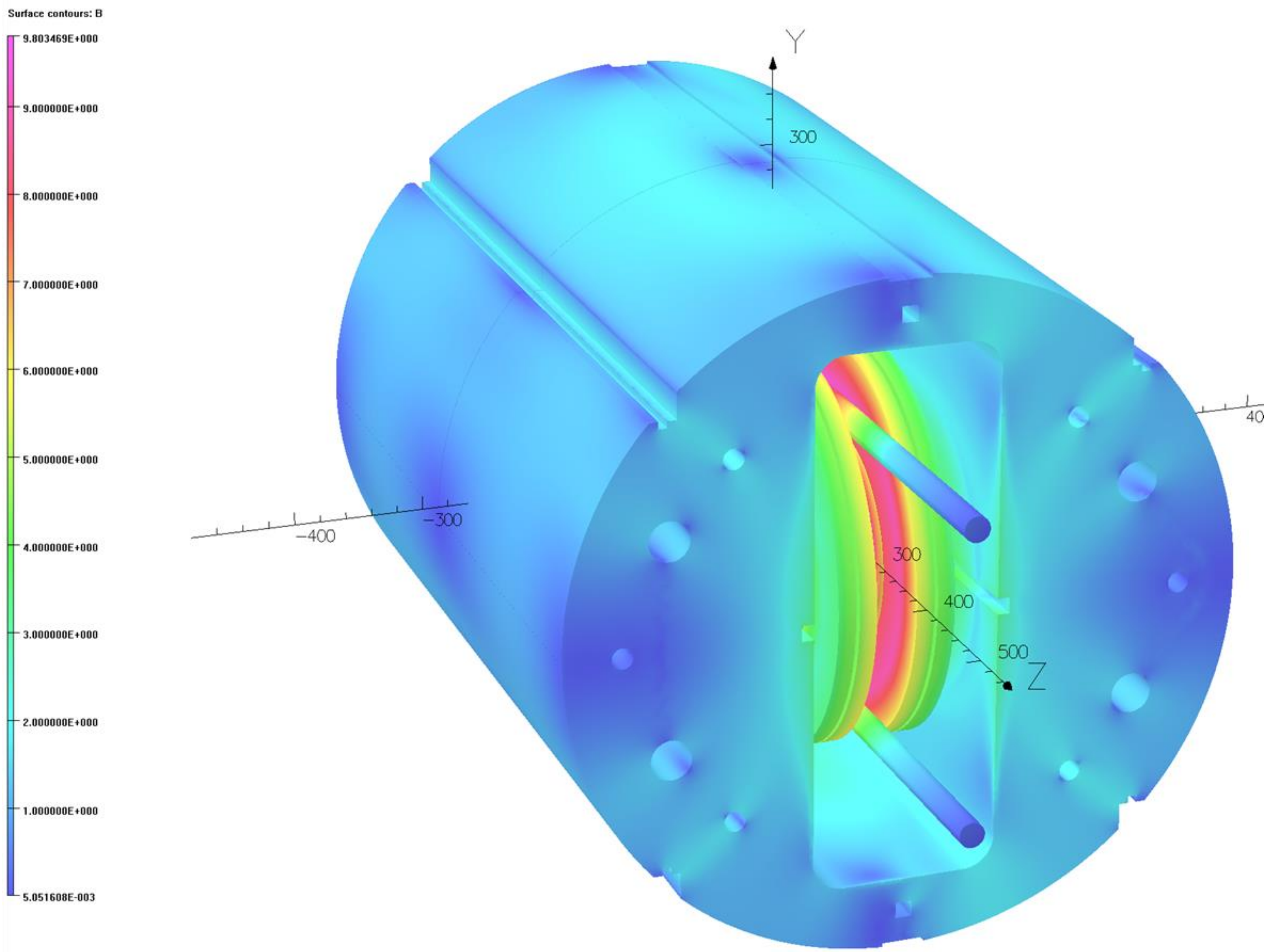


Field over a long length of cable

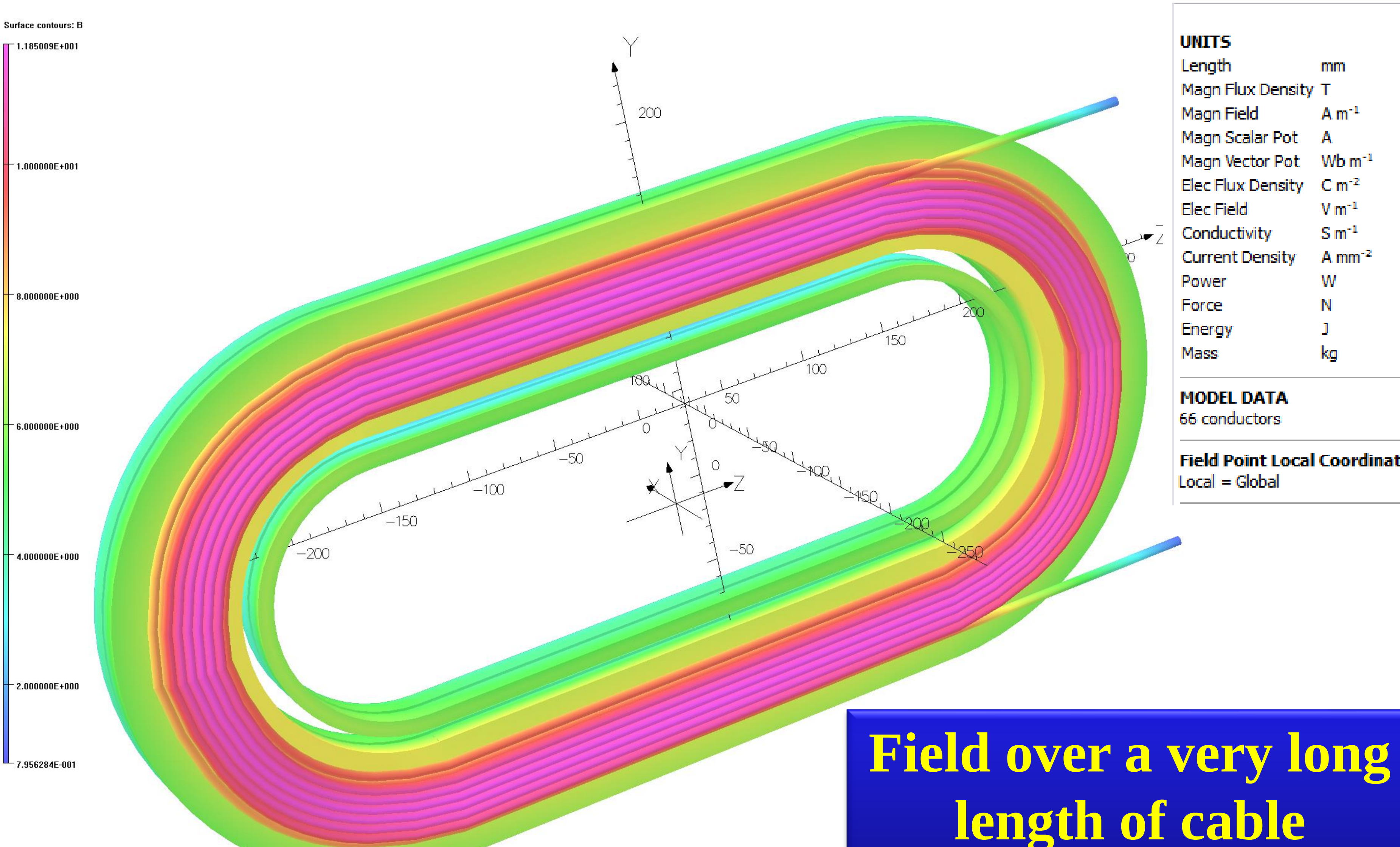
Cable Testing Model - View 3



Cable Testing Model – View 4



Multi-turn Cable Test



Field over a very long length of cable

Upgrades Under Consideration

Current setup is for

- ✓ Insert coil/cable up to 4.5 kA for any background field up to 10 T
- ✓ Insert coil/cable up 10 kA, if in series with common coil

Future upgrades planned for

- ➢ Setup for 20 K testing of cables and insert coils
- ➢ Quench detection upgrades, including fiber optics and acoustics
- ➢ Insert coil/cable to 7.5 kA for any background field up to 10 T
- ➢ Insert coil/cable up to 15 kA, if in series with common coil with added shunt allowing variation in current in insert coil/cable
- ➢ Configuring existing power supplies at BNL for 30 kA insert coil or cable testing with upgrade to top-hat
- ➢ Transformer inside cryostat allowing up to 100 kA for cable test with any background up to 10 T