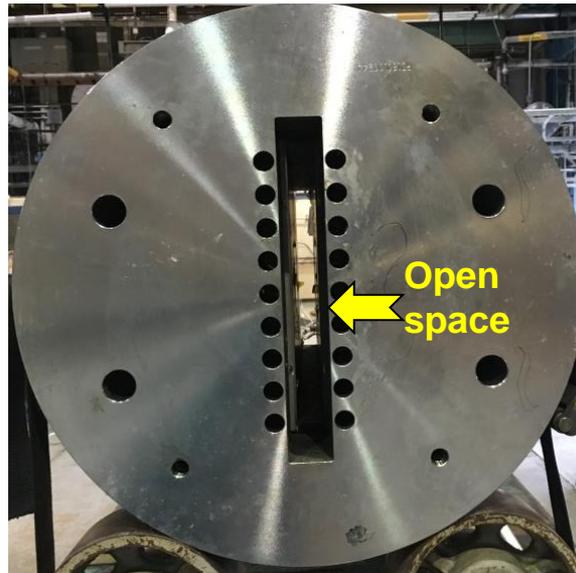
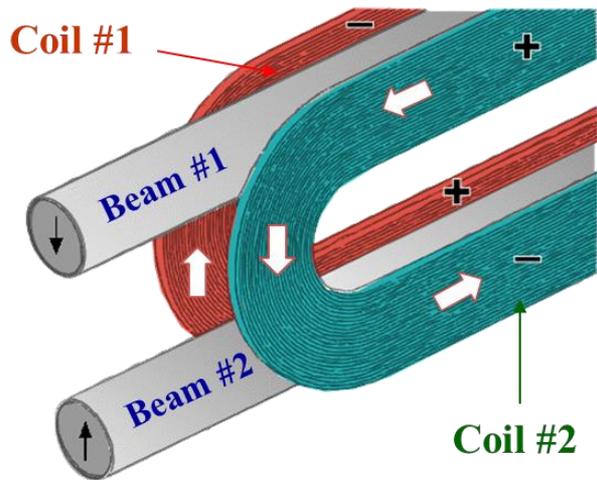


Unique Common Coil Test Facility (CCTF) Based on the BNL Common Coil Dipole for Cable and Coil Testing at High Fields

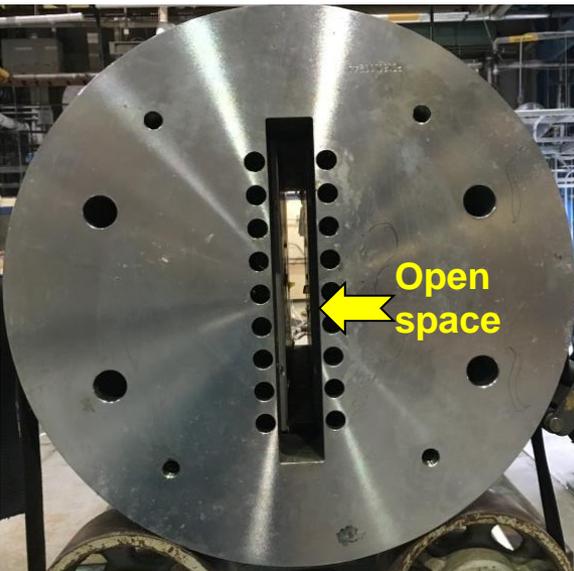


**Prepared by Ramesh Gupta for
Superconducting Magnet Division @ BNL**

A Unique Background-field Dipole



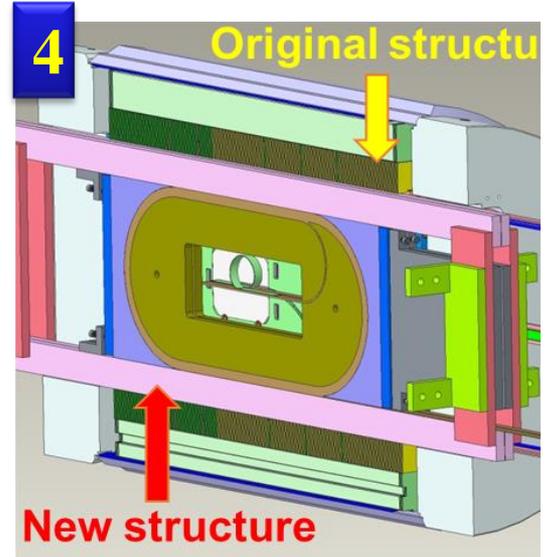
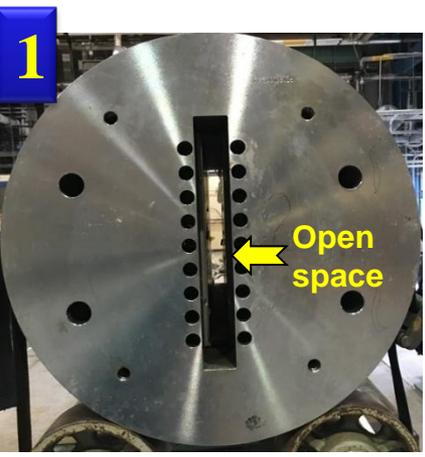
- **Nb₃Sn, 2-in-1, common coil dipole**
- **Structure specifically designed to provide a large open space (31mm wide, 335mm high)**
- **New racetrack coils can be inserted here for testing them in a background field of ~10 T**
- **These new insert coils come in direct contact with the existing Nb₃Sn 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**



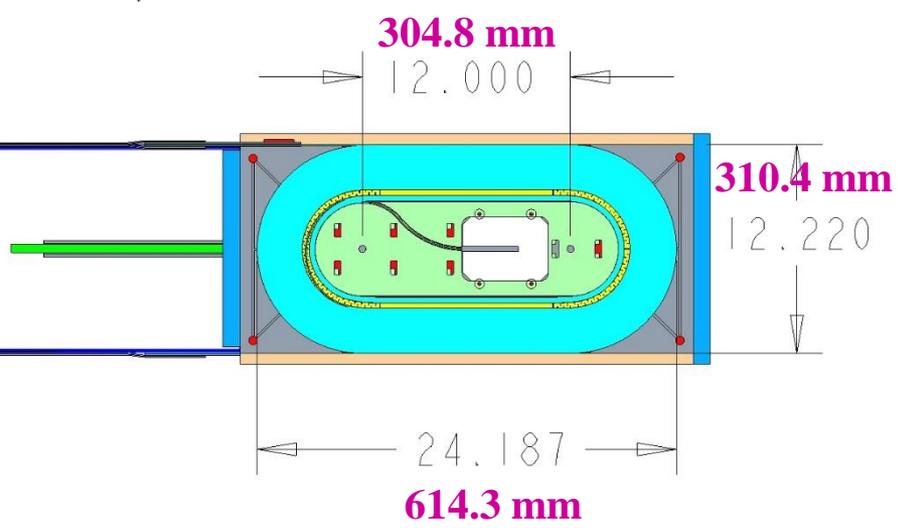
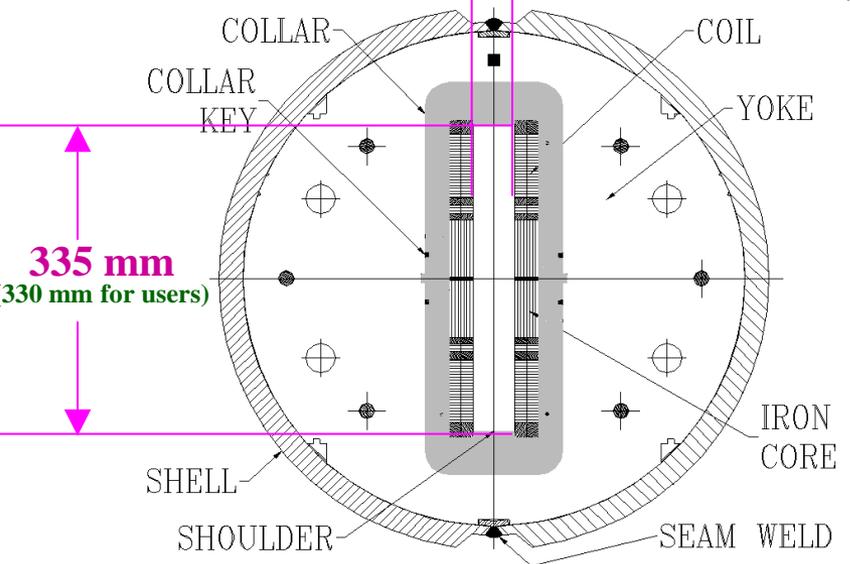
Rapid turn-around, Low cost R&D Approach

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



Basic Parameters of Dipole DCC017



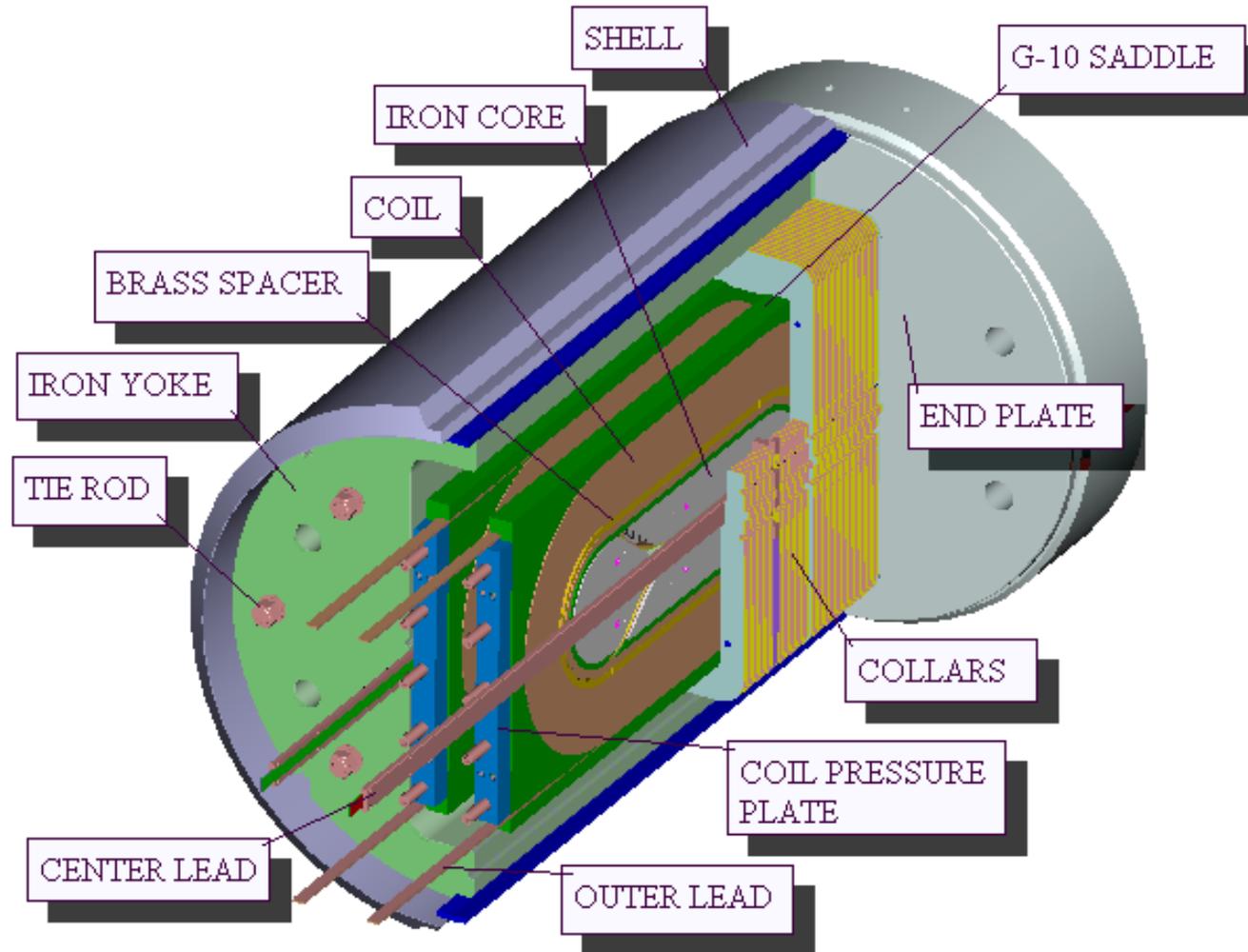
- Two layer, 2-in-1 common coil design
- 10.2 T bore field, 10.7 T peak field at 10.8 kA short sample current
- **31 mm (use 29 mm) horizontal aperture**
- **335 mm (use 330 mm) vertical aperture**
 - **A unique feature for testing insert coils or cables**
- **977 mm magnet length (overall)**
- **305 mm coil straight section**
- 0.8 mm, 30 strand Rutherford cable
- 70 mm minimum bend radius
- 85 mm coil height
- 614 mm coil length
- 653 mm yoke length One spacer in body and one in ends
- Iron bobbin
- Stored Energy@Quench ~0.2 MJ

Detailed Design Parameters of DCC017

Superconducting Magnet Division

MAJOR PARAMETERS OF REACT & WIND COMMON COIL DIPOLE DCC017

Magnet design	2-in-1 common coil dipole with racetrack coils
Conductor type	Nb ₃ Sn
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

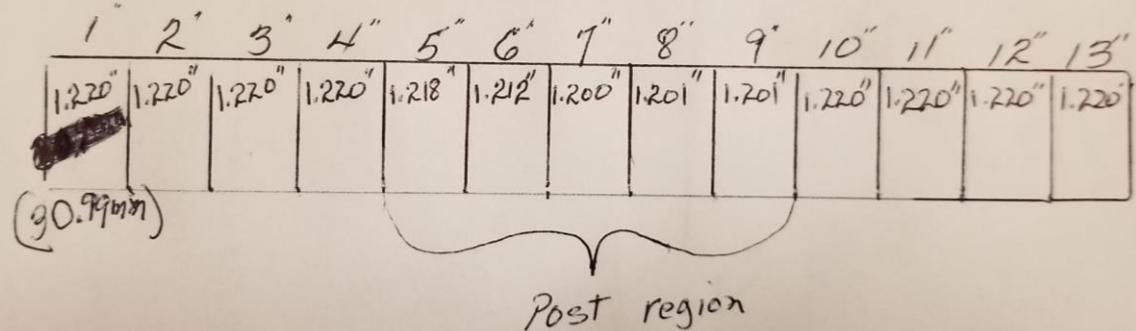


Space Restrictions



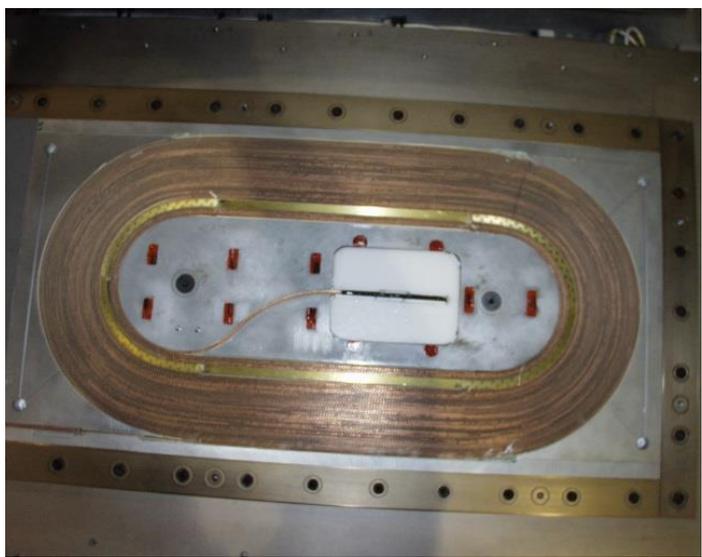
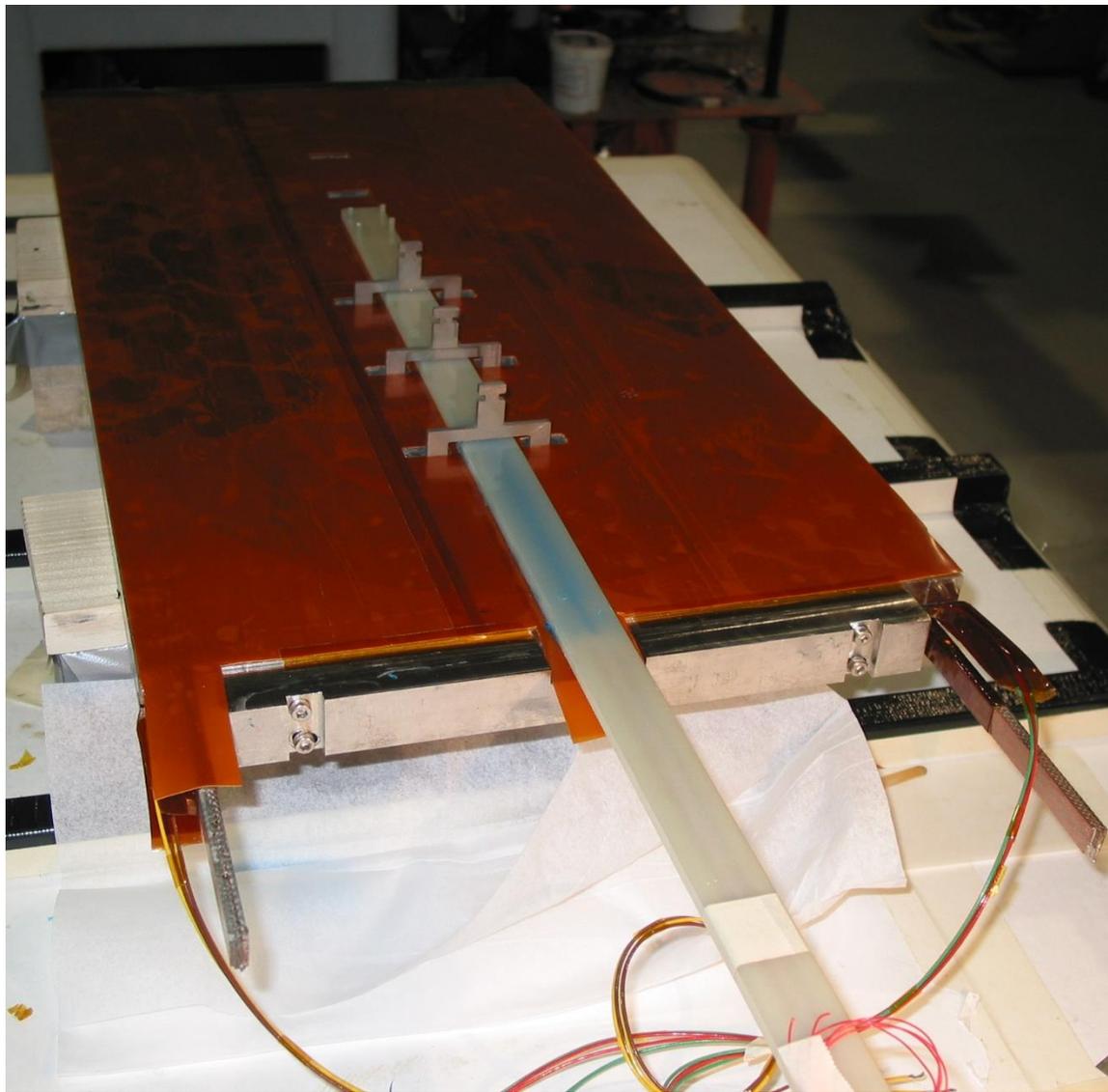
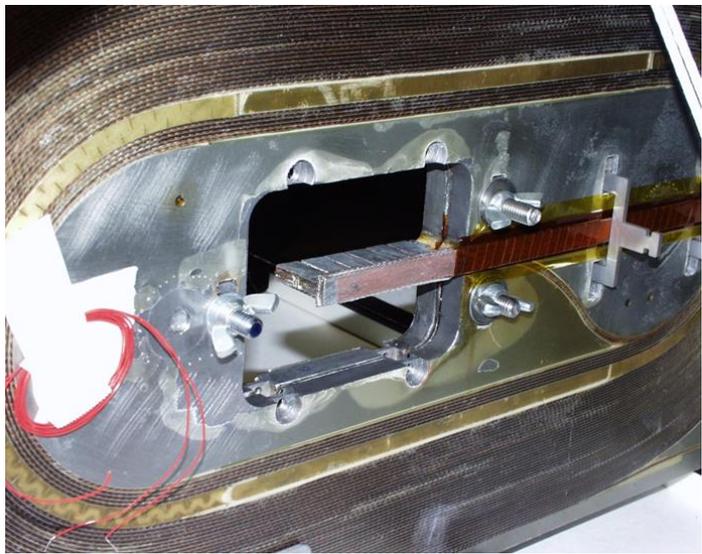
10-18-2021

Common Coil Aperture Size

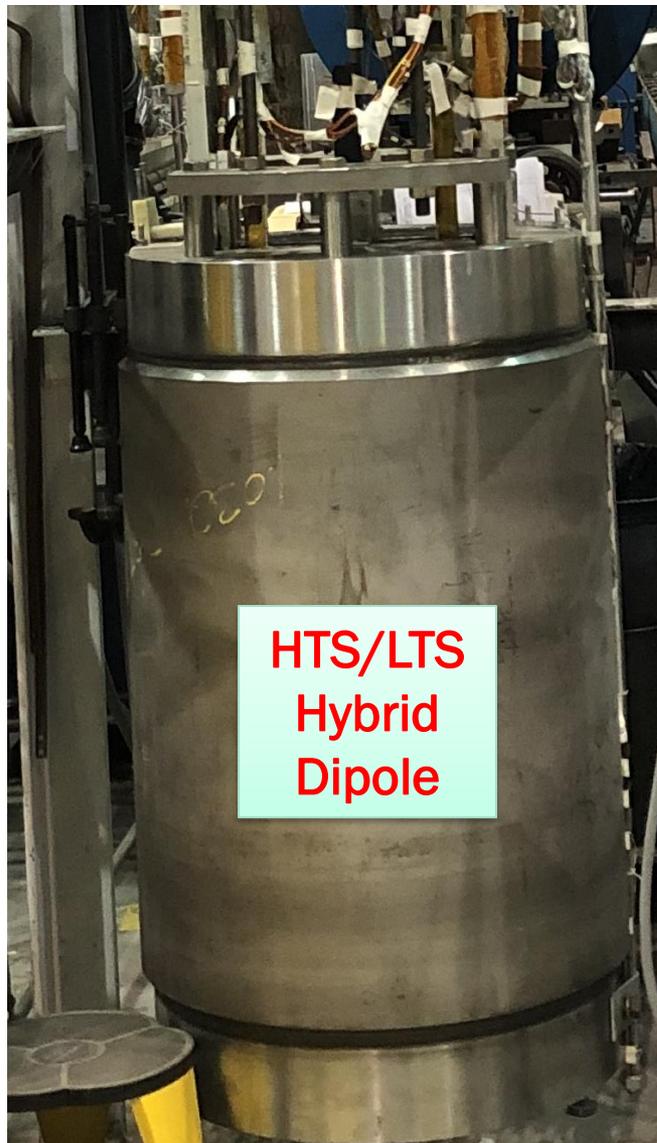


1" to 13" are only accessible from below.

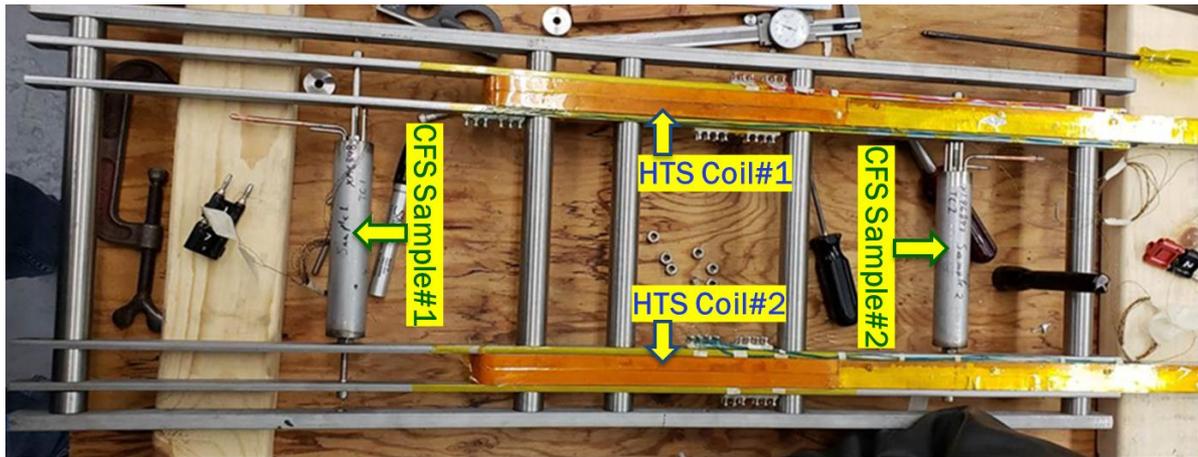
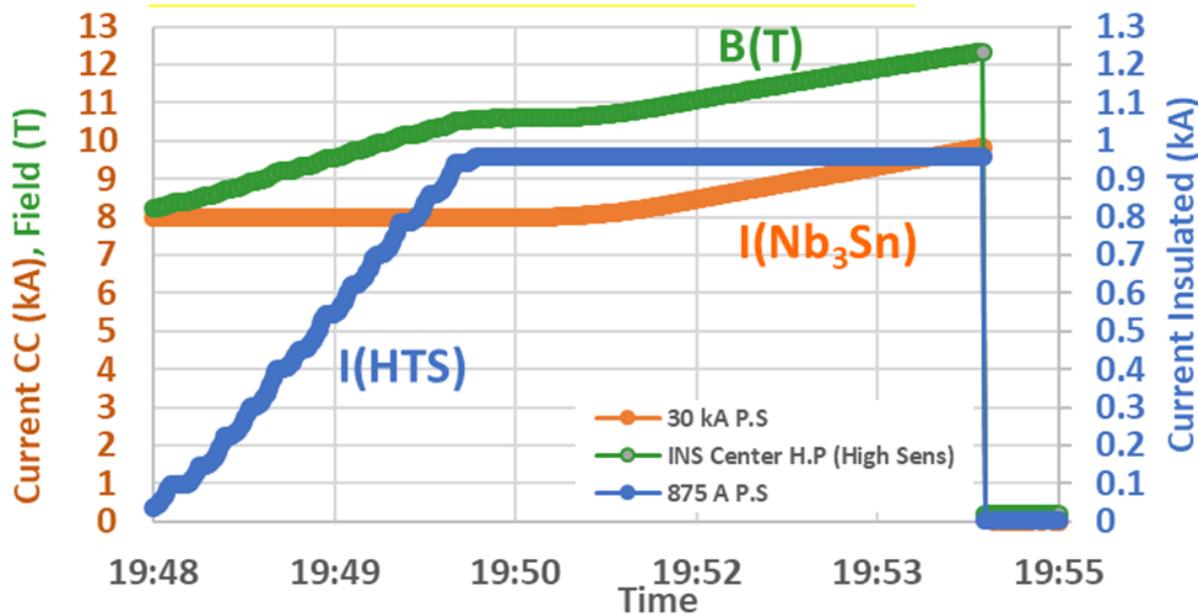
Nb₃Sn Coil Package of DCC017



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

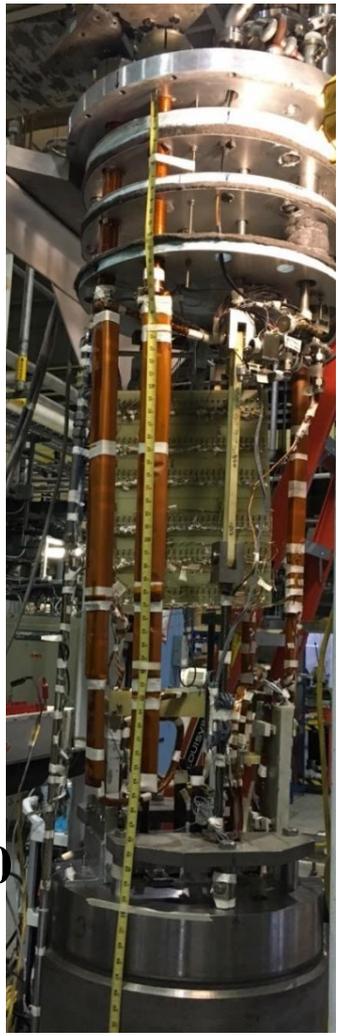
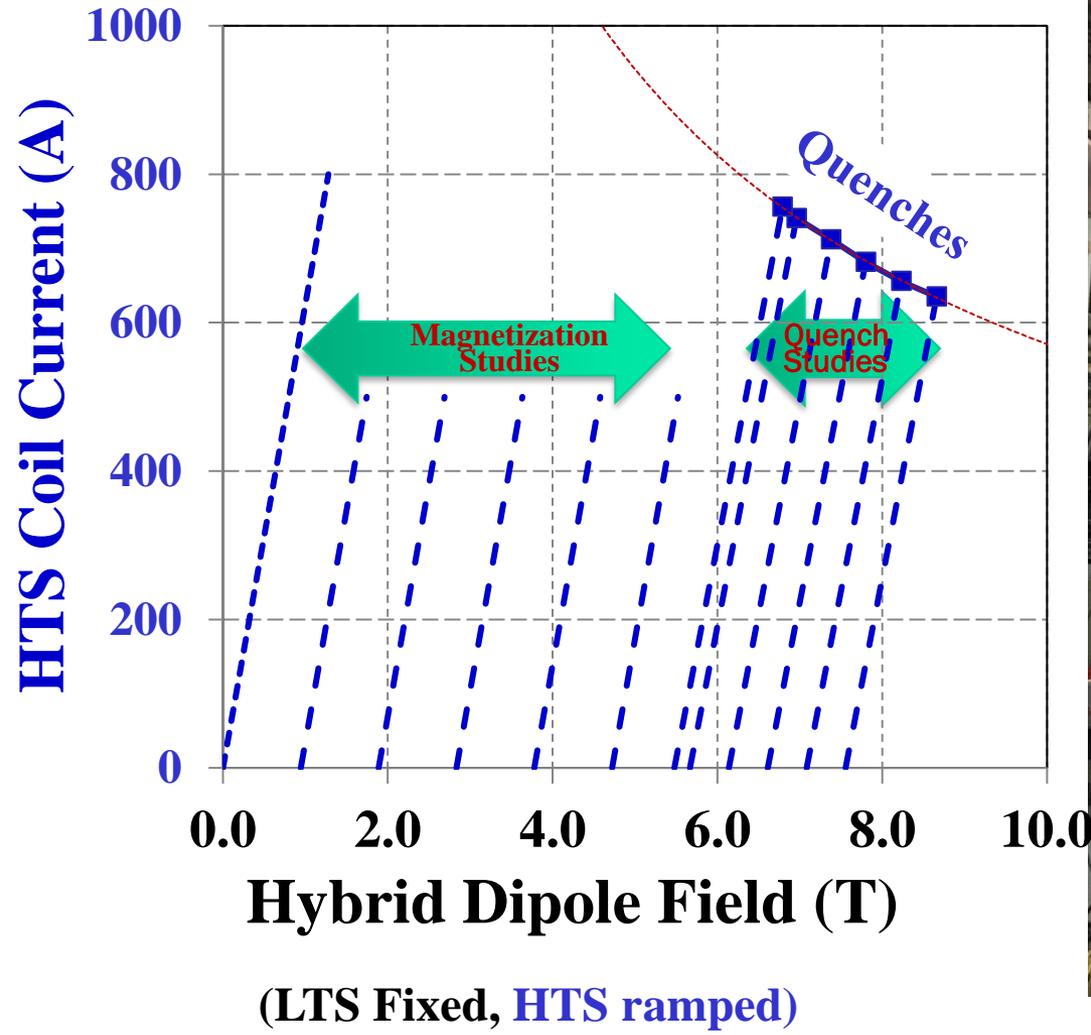


HTS/LTS
Hybrid
Dipole



HTS/LTS Hybrid Dipole Test (2016)

(new HTS insert coils with existing Nb₃Sn magnet coil)

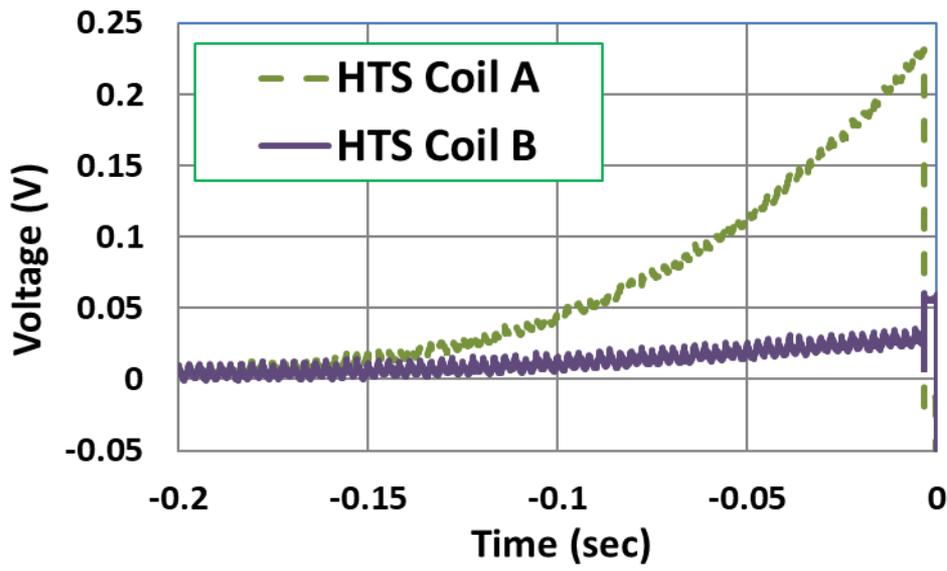


HTS coils were ramped to quench, just like LTS coils

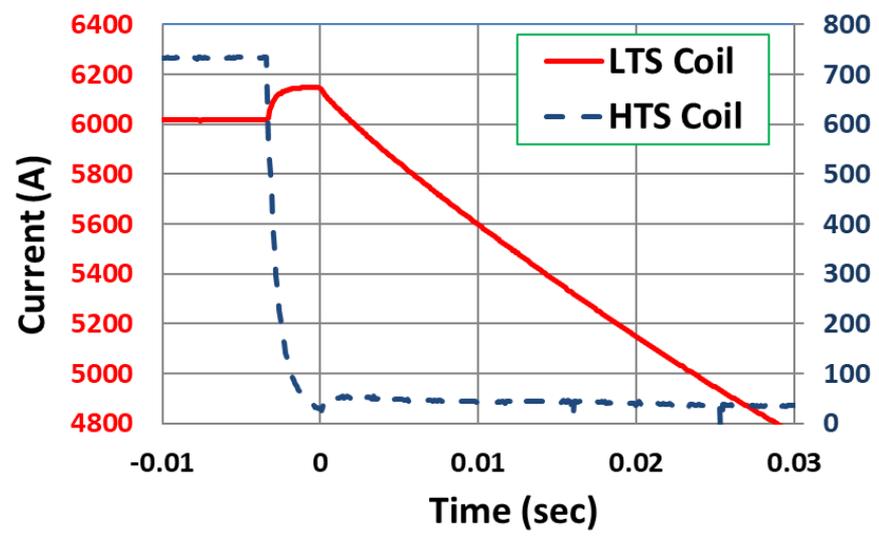
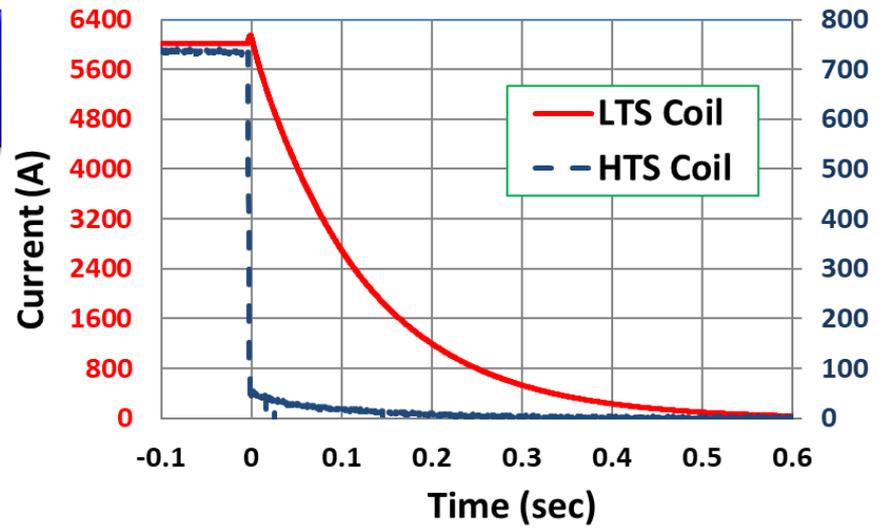
HTS coils exhibited NO training and NO degradation despite a number of quenches

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)

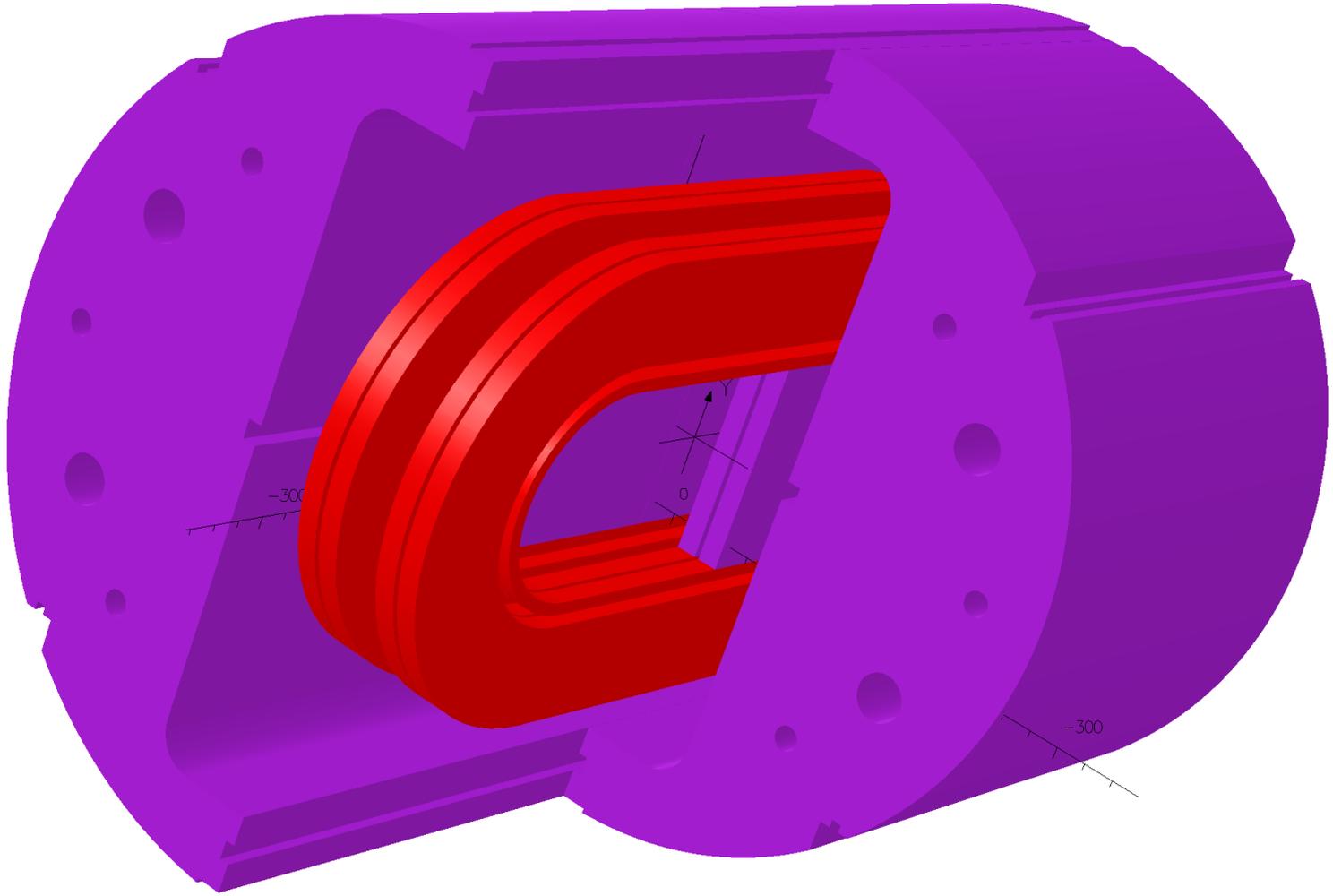


HTS and LTS coils were operated with different power supplies and had separate energy extraction under a common platform



3d-model and the Field Profile inside DCC017

3-d model of the coils with $\frac{3}{4}$ cut-out of the iron yoke



UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot.	A
Magn Vector Pot.	Wb m ⁻¹
Elec Flux Density	Cm ⁻¹
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

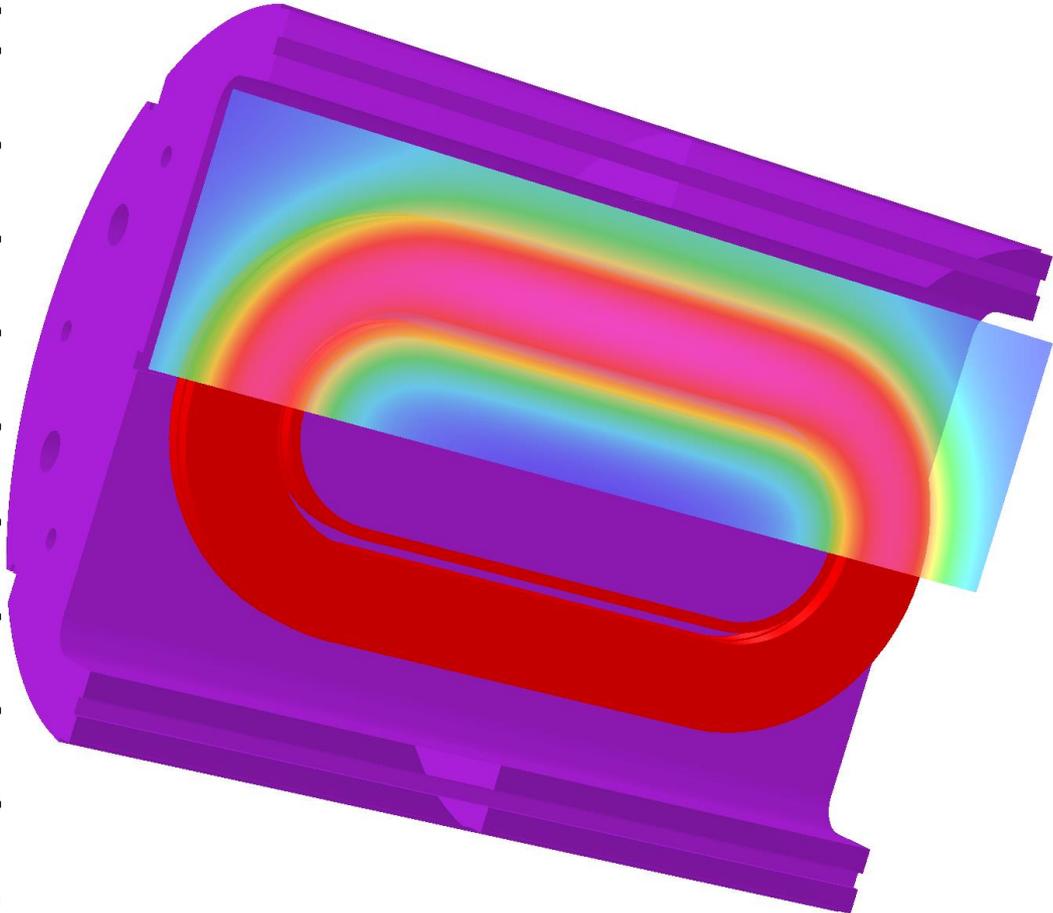
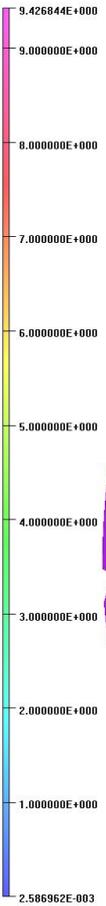
MODEL DATA	
dc017-no-ns-usmdp.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
47698232 elements	
9484251 nodes	
8 conductors	
Nodally interpolated fields	
Activated in global coordinates	
Reflection in XZ plane (Z field=0)	
Reflection in YZ plane (X field=0)	

Field Point Local Coordinates	
Local	= global

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

13/Sep/2019 11:48:44

Map contours: B



Integral = 6.487019E+005

UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
dcc017-no-ins-usmdp.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
47698232 elements	
9454251 nodes	
8 conductors	
Nodally interpolated fields	
Activated in global coordinates	
Reflection in XY plane (Z field=0)	
Reflection in YZ plane (X field=0)	

FIELD POINT Local Coordinates	
Local = Global	

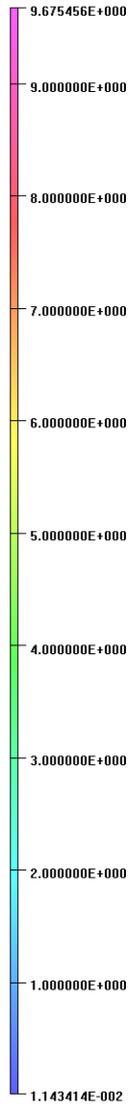
FIELD EVALUATIONS		
Cartesian CARTESIAN (nodal)	100x100	Cartesian
x=0.0	y=0.0 to 200.0	z=-350.0 to 350.0

@10 kA

Opera

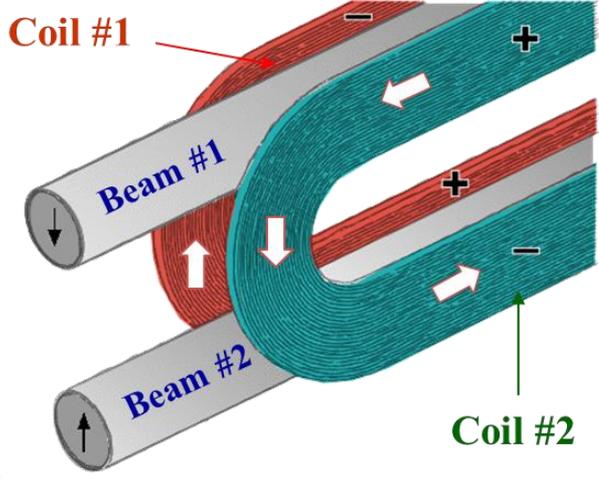
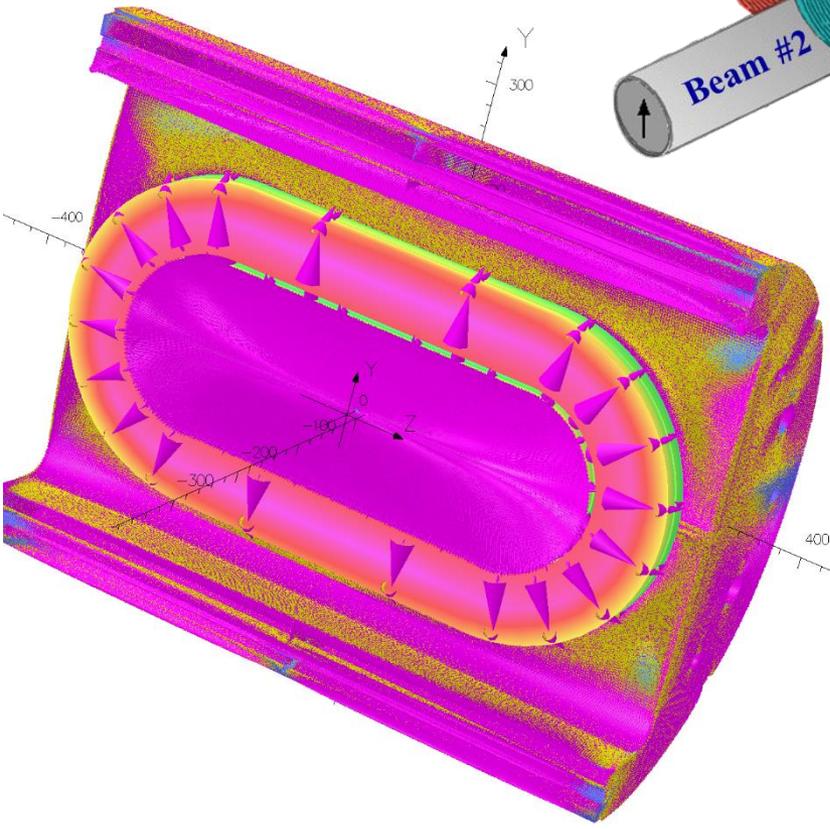
Direction of the Field between the Coils in the Open Space of DCC017

Surface contours: B

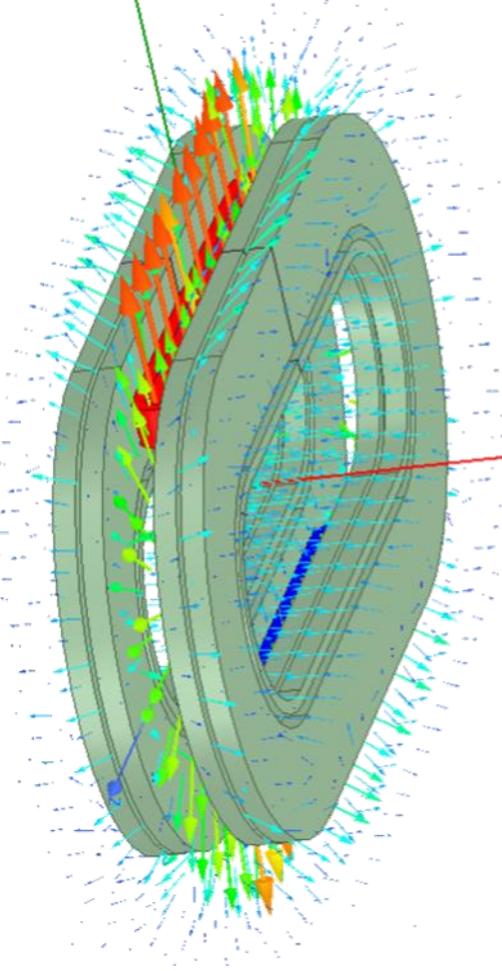


DCC017
(magnet only)

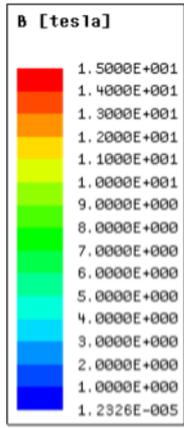
@ 10 kA



DCC017
(with an insert coil)

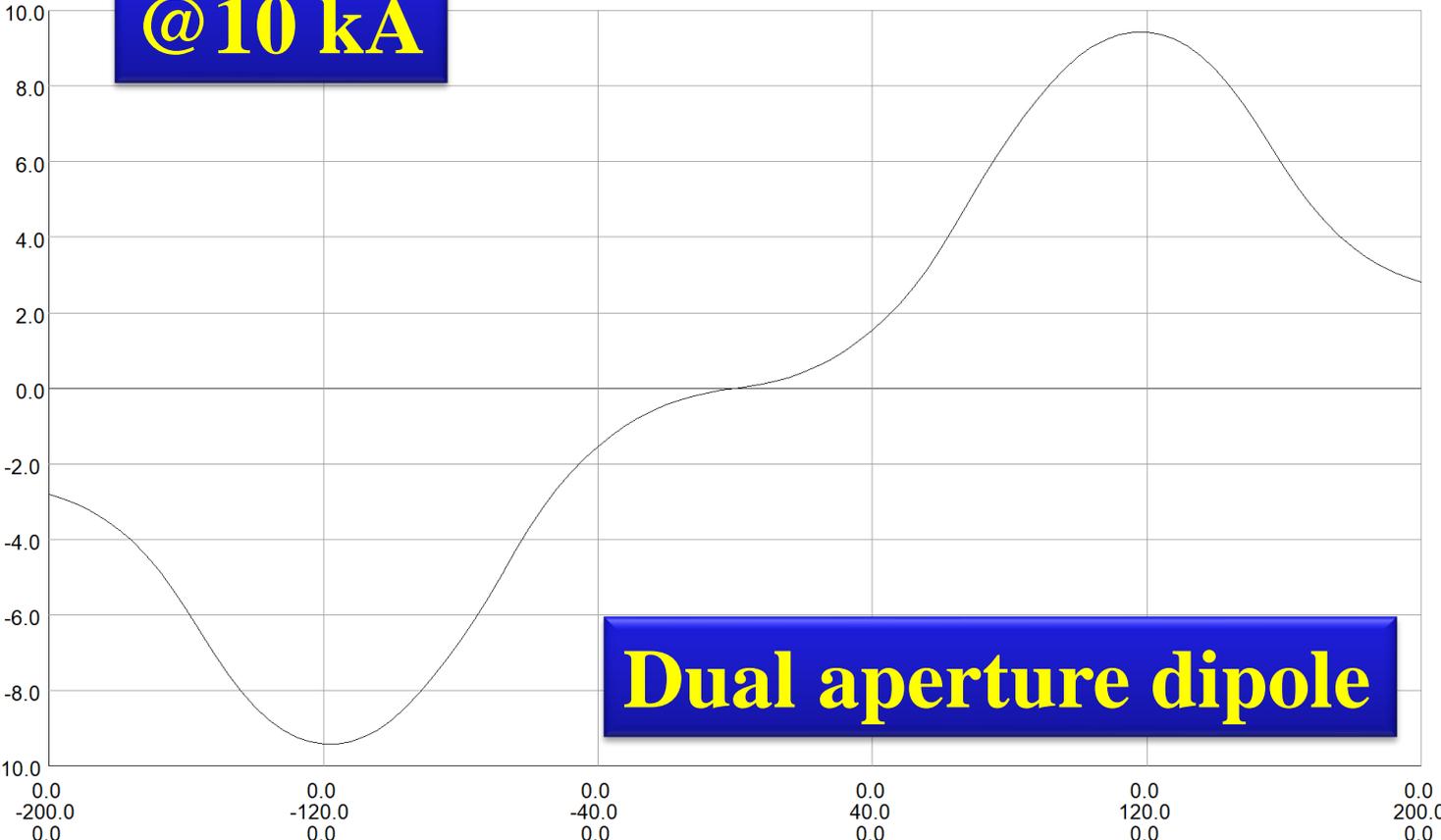


COMSOL



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

@ 10 kA



X coord 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord -200.0 -120.0 -40.0 0.0 40.0 120.0 200.0
 Z coord 0.0 0.0 0.0 0.0 0.0 0.0 0.0

Component: BY, from buffer: Line, Integral = 0.0208363806530265

UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
dcc017-no-ins-usmdp.ap3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
47698232 elements	
945431 nodes	
8 conductors	
Nodally interpolated fields	
Activated in global coordinates	
Reflection in XY plane (Z field=0)	
Reflection in YZ plane (X field=0)	

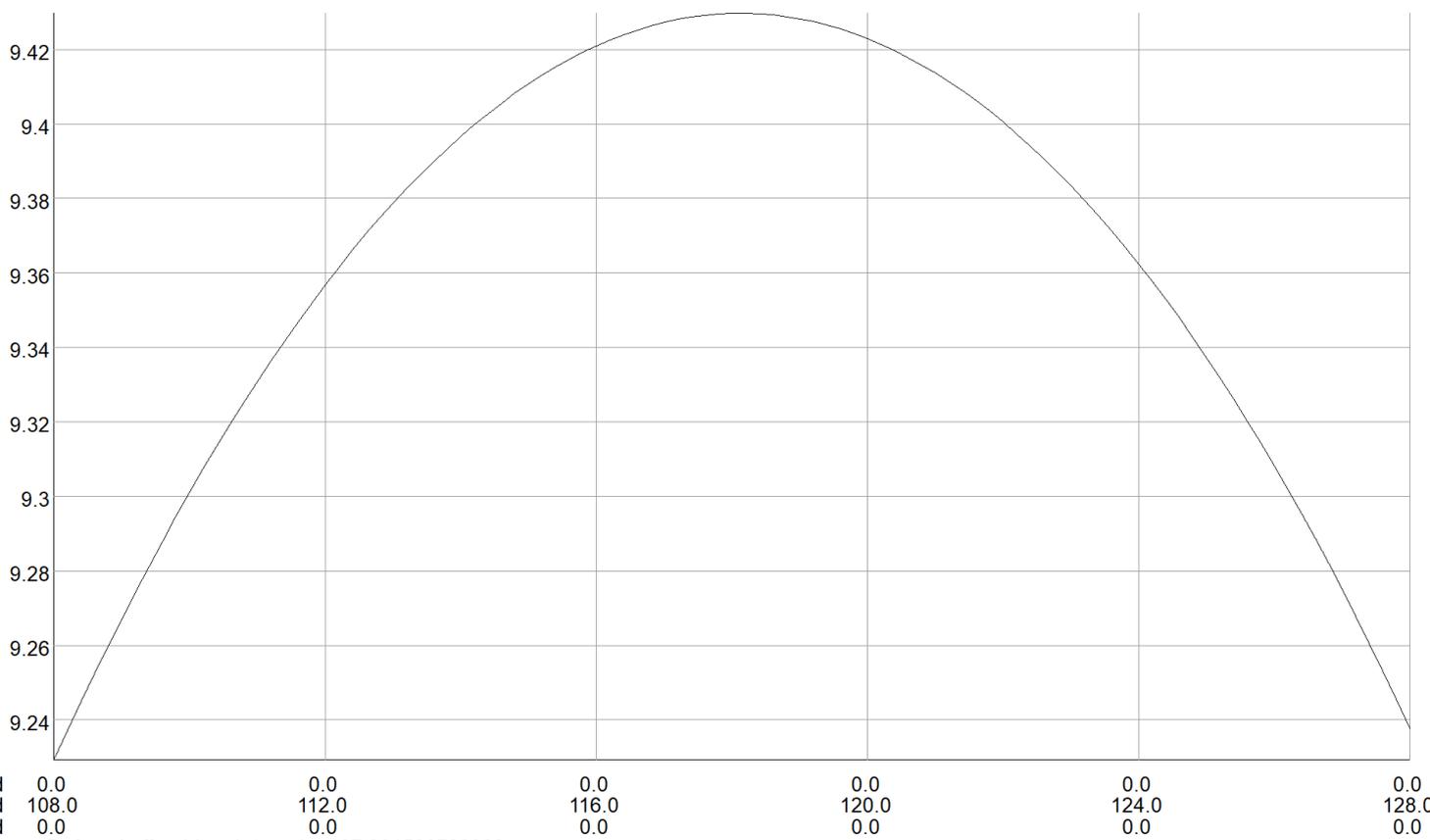
FIELD POINT Local Coordinates	
Local = Global	

FIELD EVALUATIONS		
Line LINE (nodal) 101	Cartesian	
x=0.0	y=-200.0 to 200.0	z=0.0

Opera

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

6/Aug/2019 10:23:23



UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Wb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 dcc017-no-ns-usmdp.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 47698232 elements
 9454251 nodes
 8 conductors
 Nodally interpolated fields
 with B and H by integration
 Activated in global coordinates
 Reflection in XY plane (Z field=0)
 Reflection in YZ plane (X field=0)

Field Point Local Coordinates
 Local = Global

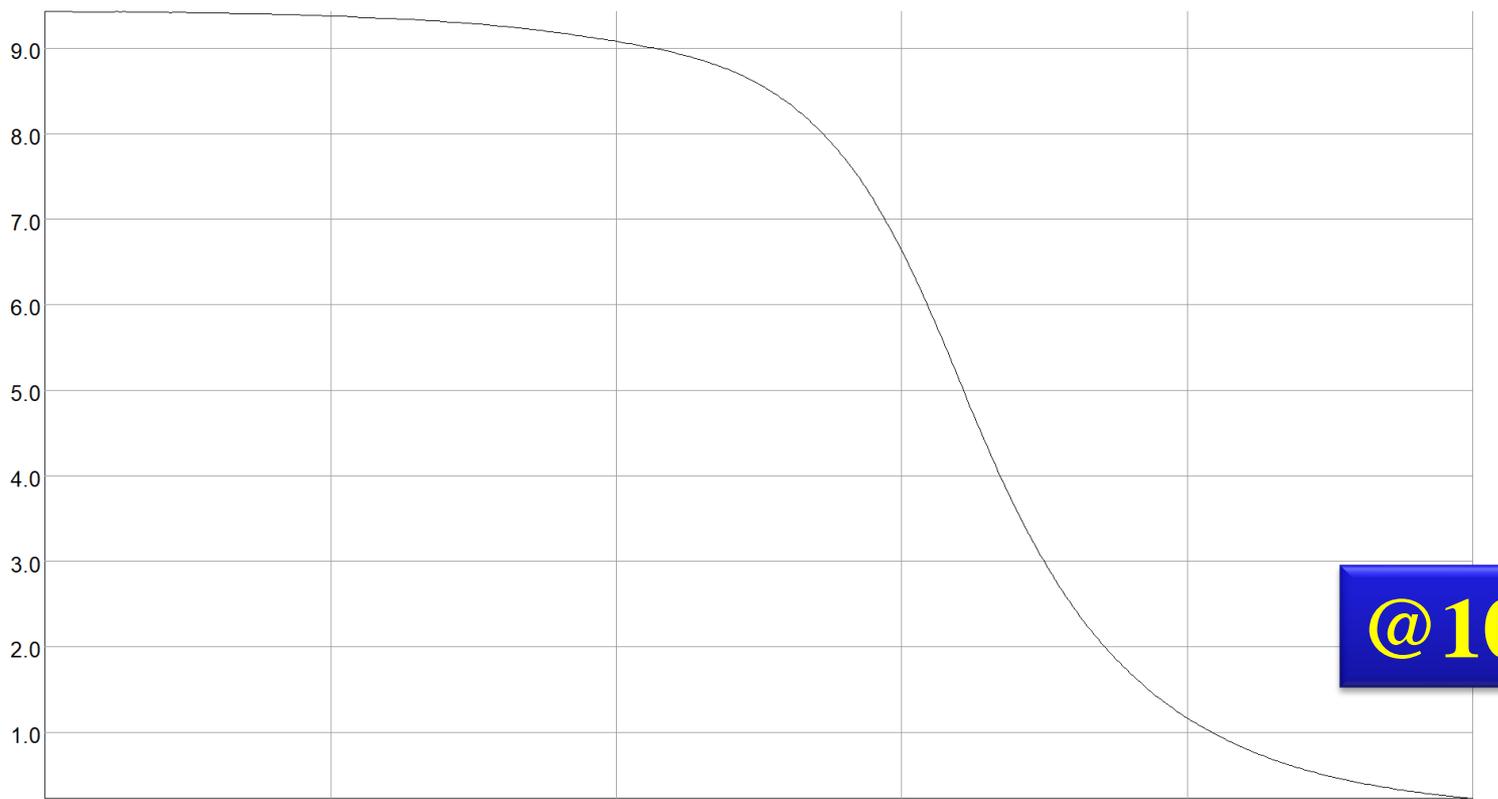
FIELD EVALUATIONS
 Line L:HE (nodal-ente) 101 Cartesian
 x=0.0 y=108.0 to 128.0 z=0.0

Component: B, from buffer: Line, Integral = 187.291536722363

@10 kA

Opera

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



X coord	0.0	0.0	0.0	0.0	0.0	0.0
Y coord	118.0	118.0	118.0	118.0	118.0	118.0
Z coord	0.0	80.0	160.0	240.0	320.0	400.0

Component: B, from buffer: Line, Integral = 2473.79306925243

@10 kA

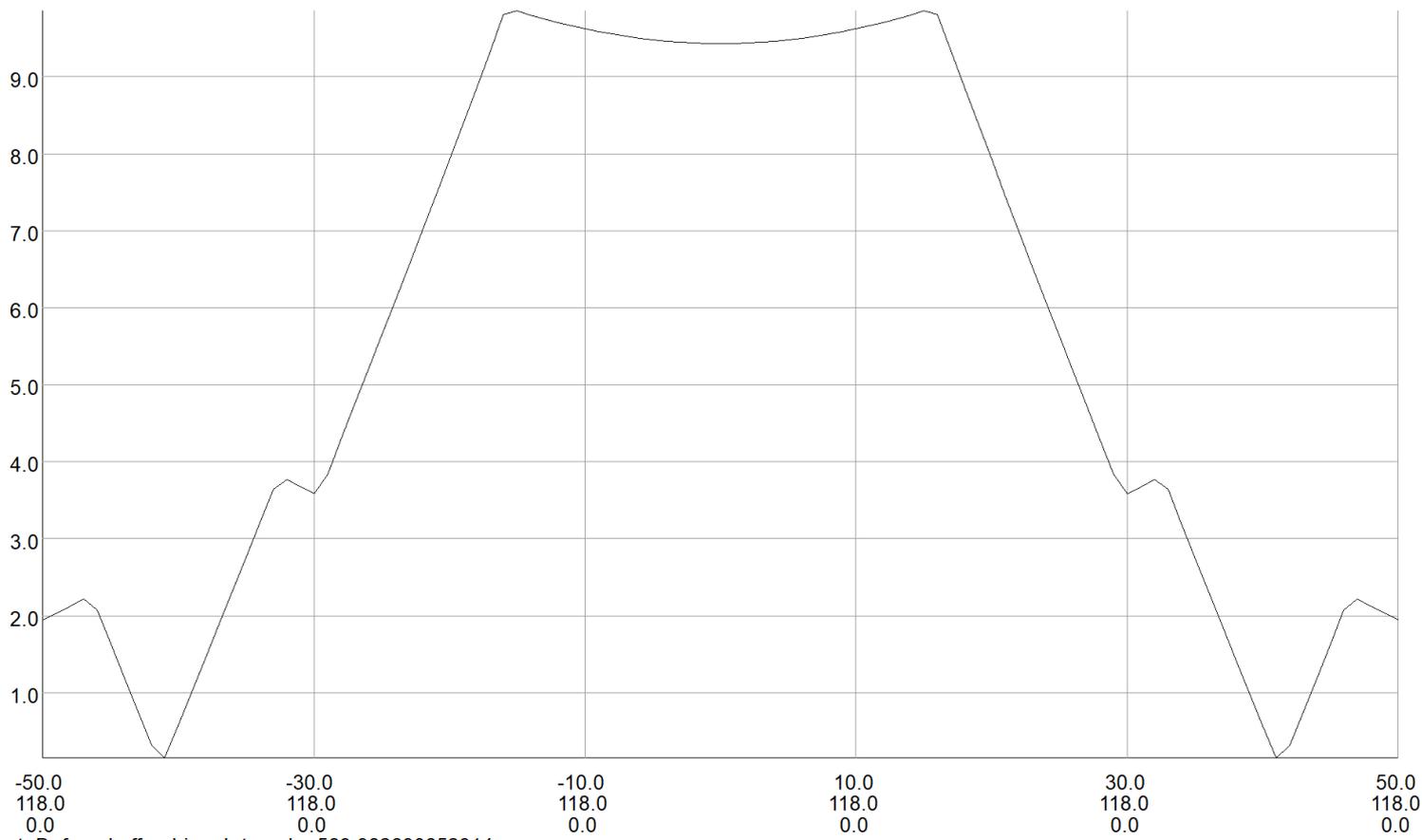
UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Wb m⁻¹
 Elec Flux Density Cm⁻¹
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 dc017-no-ns-usmdp.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No. 1 of 1
 47698232 elements
 9454251 nodes
 8 conductors
 Nodally interpolated fields
 Activated in global coordinates
 Reflection in X-Y plane (Z field=0)
 Reflection in Y-Z plane (X field=0)

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE (node) 401 Cartesian
 x=0.0 y=118.0 z=0.0 to 400.0

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



UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Wb m⁻¹
 Elec Flux Density Cm⁻¹
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 dc017-no-ris-usmdp.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No. 1 of 1
 47698232 elements
 9454251 nodes
 8 conductors
 Nodally interpolated fields
 with B and H by integration
 Activated in global coordinates
 Reflection in XY plane (z field=0)
 Reflection in YZ plane (x field=0)

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE (nodal) 101 Cartesian
 x=-50.0 to 50.0 y=118.0 z=0.0

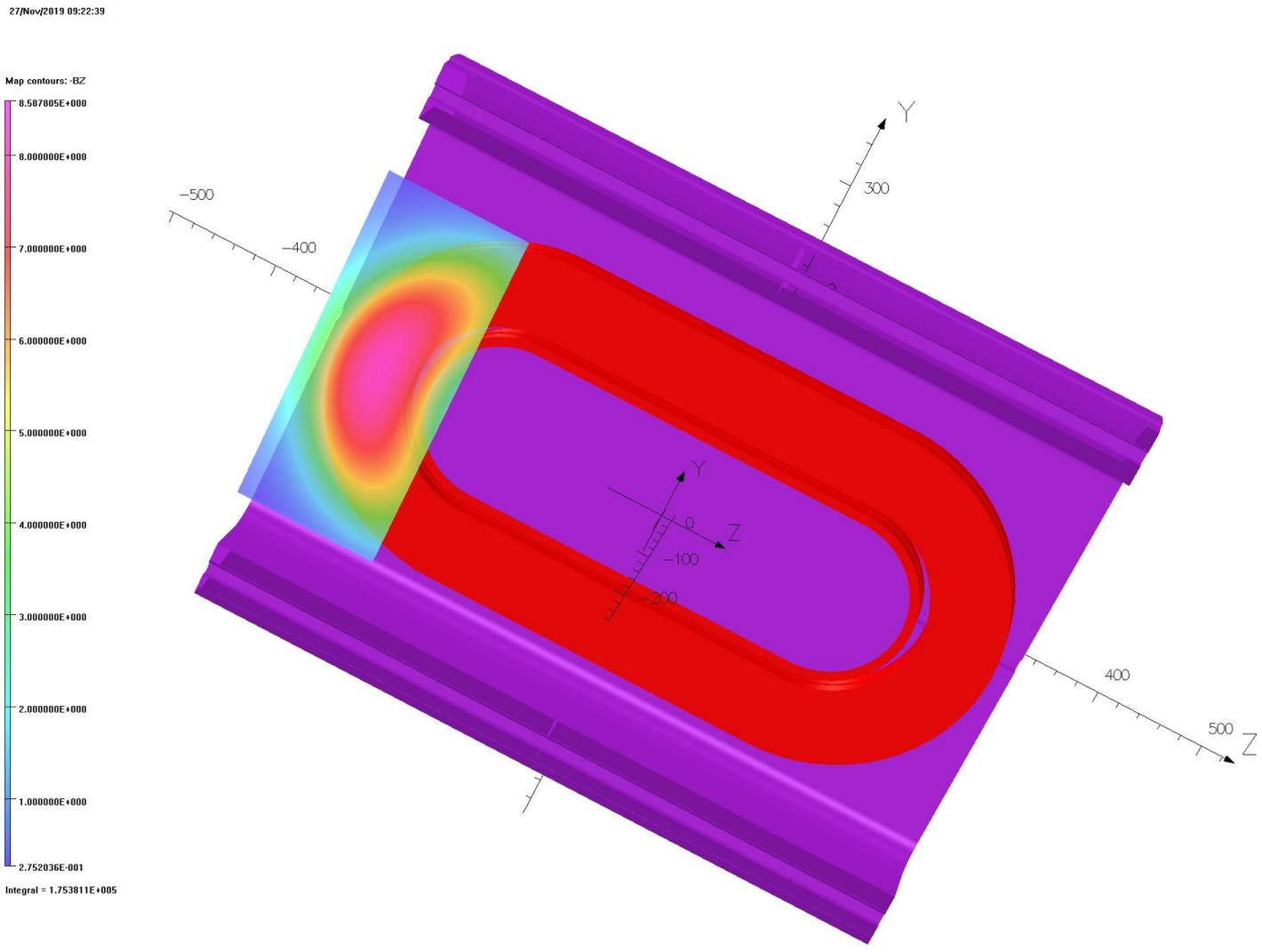
X coord -50.0 -30.0 -10.0 10.0 30.0 50.0
 Y coord 118.0 118.0 118.0 118.0 118.0 118.0
 Z coord 0.0 0.0 0.0 0.0 0.0 0.0

Component: B, from buffer: Line, Integral = 569.982690652314

@10 kA

Opera

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



UNITS

Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scaler Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA

dcc017-no-ins-usmb.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No. 1 of 1
 47598232 elements
 9454251 nodes
 8 conductors
 Nodally interpolated fields
 Activated in global coordinates
 Reflection in XY plane (Z field=0)
 Reflection in YZ plane (X field=0)

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS

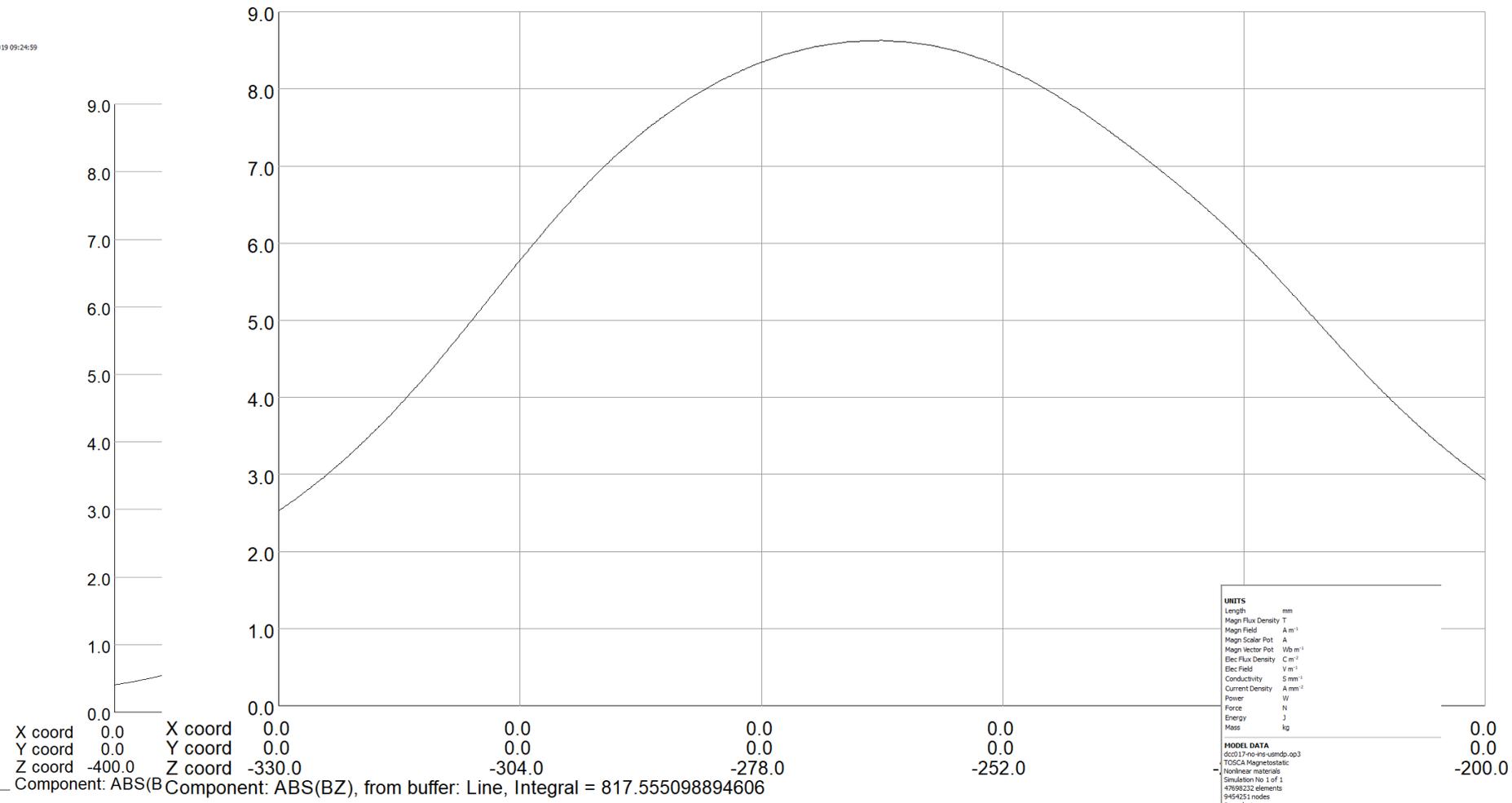
Cartesian	CARTESIAN (nodal)	20x20	Cartesian
x=0.0	y=-160.0 to 160.0	z=-330.0 to -200.0	

@10 kA

Opera

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

27Nov/2019 09:24:59



UNITS	
Length	mm
Magn Flux Density T	A m ⁻¹
Magn Field	A
Magn Scalar Pot	Wb m ⁻¹
Magn Vector Pot	C m ⁻¹
Elec Flux Density	V m ⁻¹
Elec Field	A mm ⁻¹
Conductivity	N
Current Density	J
Power	kg
Force	0.0
Energy	0.0
Mass	0.0

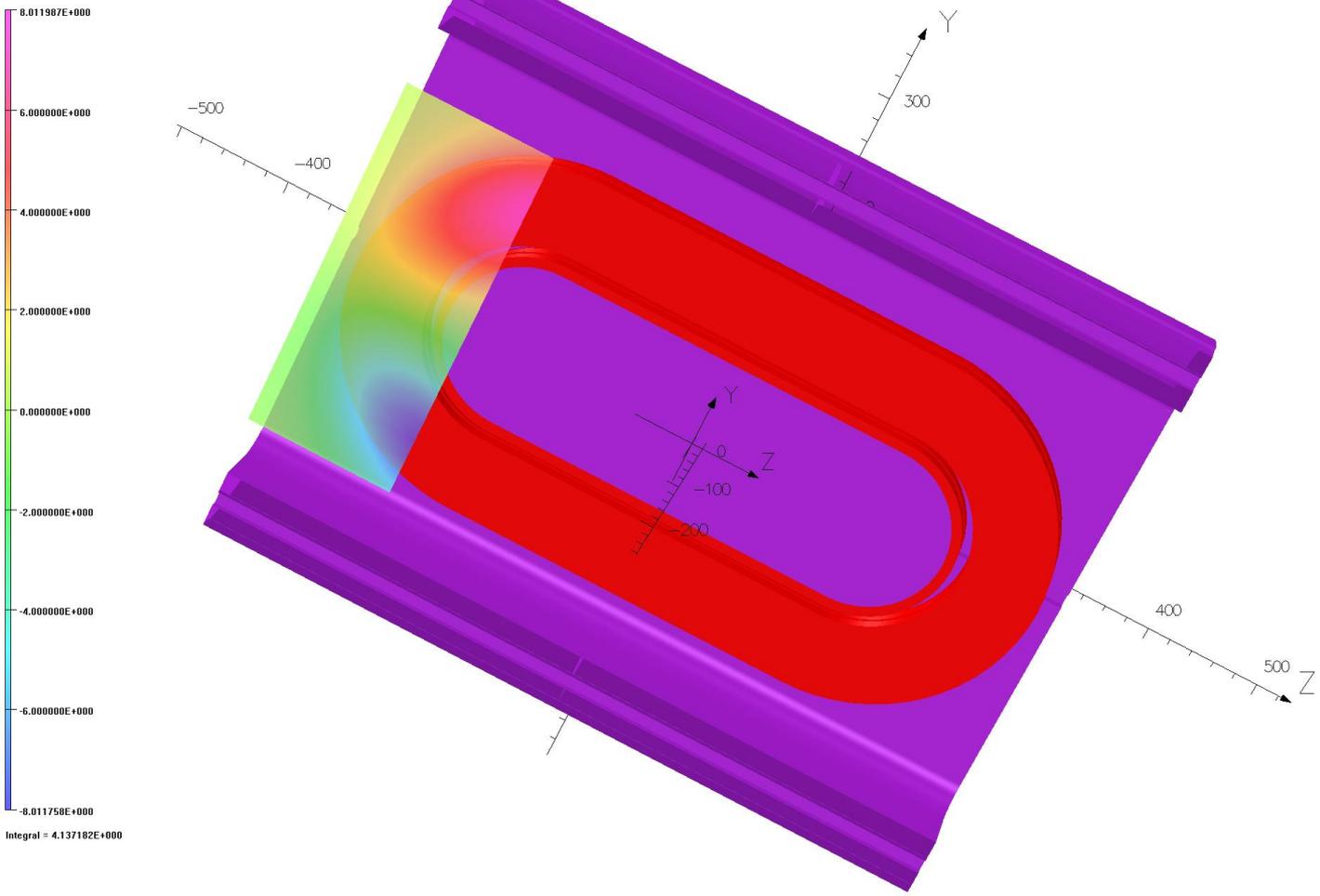
MODEL DATA	
DCC017/m0-m6-s4mids-op3	-200.0
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No. 1 of 1	
47598232 elements	
9454251 nodes	
8 conductors	
Nodally interpolated fields	
Activated in global coordinates	
Reflection in XY plane (Z field=0)	
Reflection in YZ plane (X field=0)	



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

27/Nov/2019 09:21:05

Map contours: BY



UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scaler Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻¹
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
dco17-no-ins-umdb.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No. 1 of 1	
47696232 elements	
9454251 nodes	
0 conductors	
Nodally interpolated fields	
Activated in global coordinates	
Reflection in XY plane (Z field=0)	
Reflection in YZ plane (X field=0)	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Cartesian CARTESIAN (nodal) 20x20	Cartesian
x=0.0	y=-160.0 to 160.0 z=-330.0 to -200.0

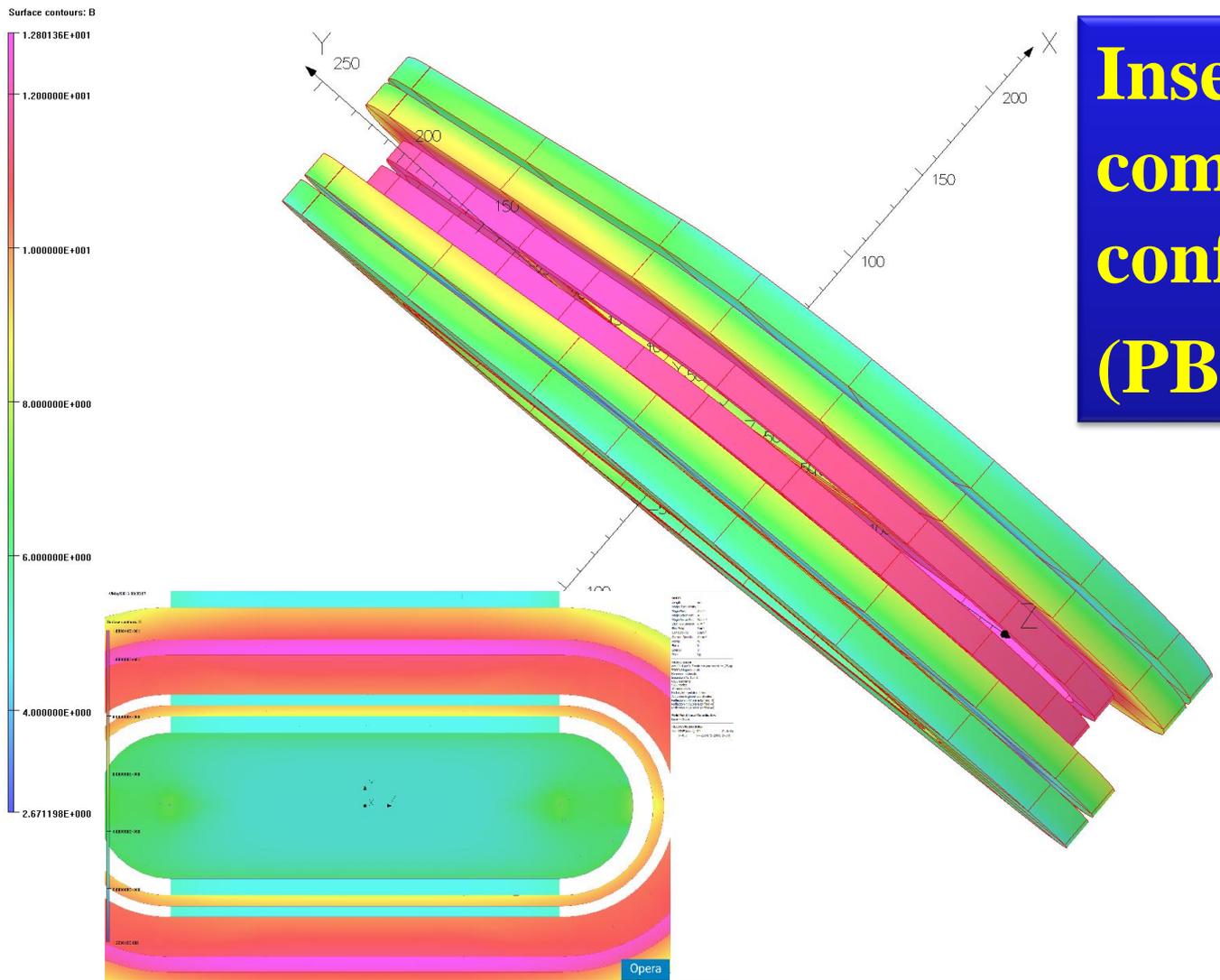
@10 kA

Opera

Models of Insert Coil Testing in DCC017

Insert Coil Test Configuration #1 (common coil insert)

UNITS
Length: mm
Magn Flux Density: T
Magn Field: A m⁻¹
Magn Scalar Pot: A
Magn Vector Pot: Wb m⁻¹



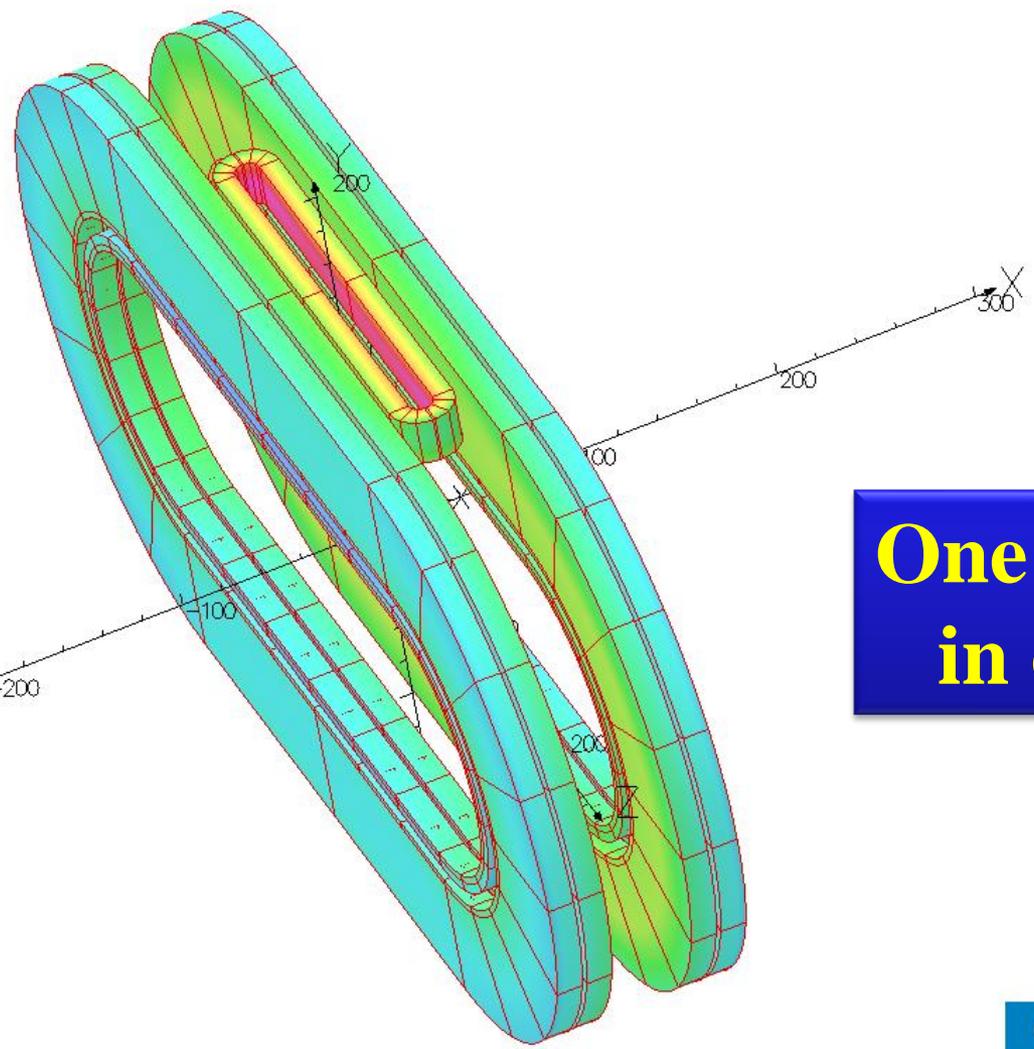
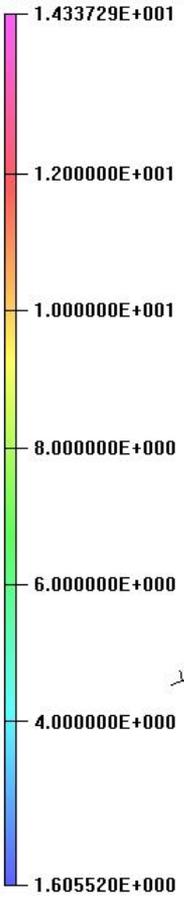
**Insert coils in
common coil
configuration
(PBL/MT25)**

Opera

Insert Coil Test Configuration #2 (one coil insert in one bore)

1/Nov/2014 16:42:51

Surface contours: BMOD*.8



UNITS

Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S m ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

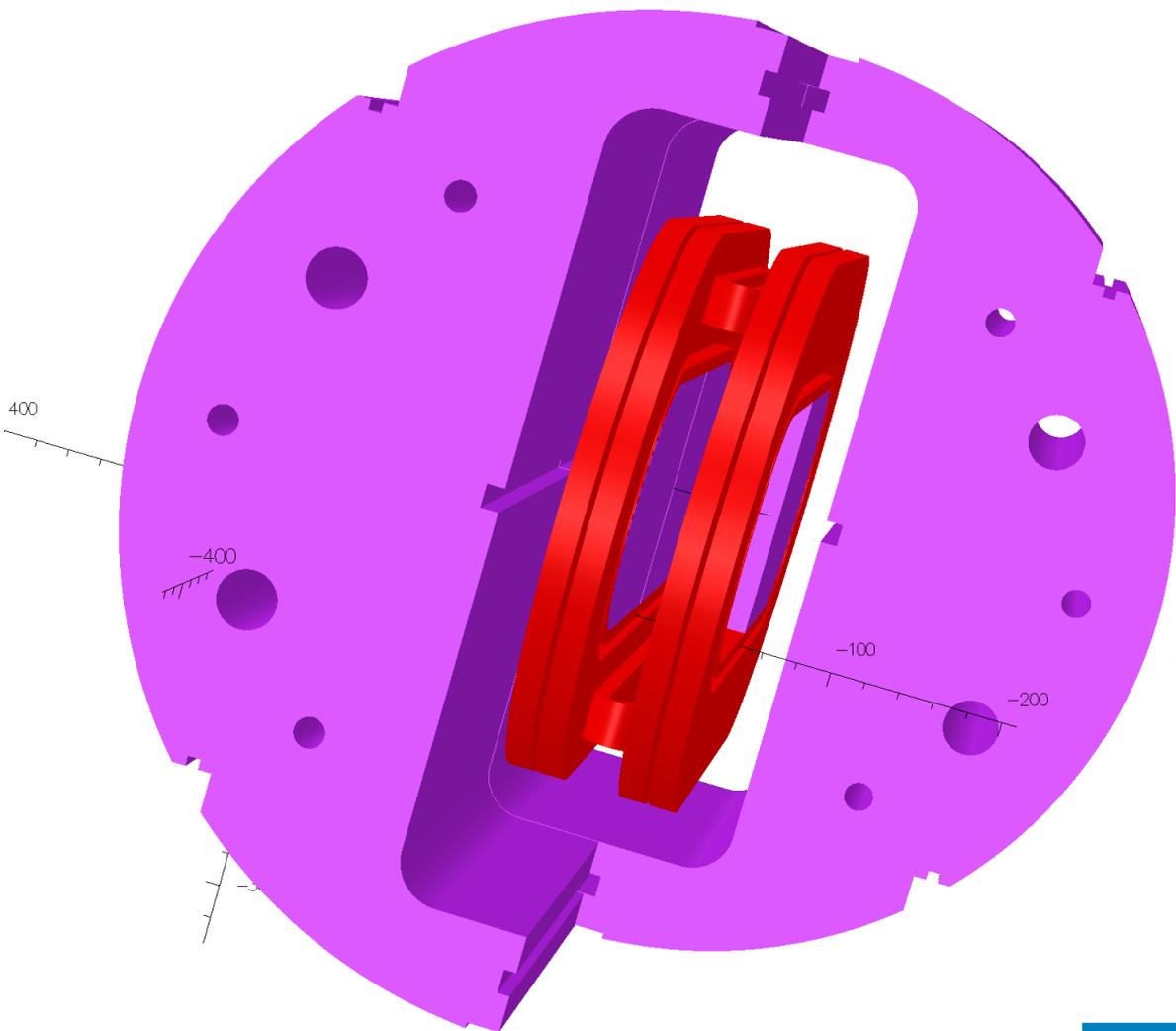
MODEL DATA
17 conductors

Field Point Local Coordinates
Local = Global

**One insert coil
in one bore**

Opera

Insert Coils Test Configuration #3 (two coils in two bores, parallel)



UNITS

Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot.	A
Magn Vector Pot.	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA

d3c0117-nl-nomex-hts-ins-both-usmdp.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation hp: 1 of 1
47698232 elements
9454251 nodes
10 conductors
Nodally interpolated fields
Activated in global coordinates
Reflection in XZ plane (Z field=0)
Reflection in YZ plane (X field=0)

Field Point Local Coordinates

Local = Global

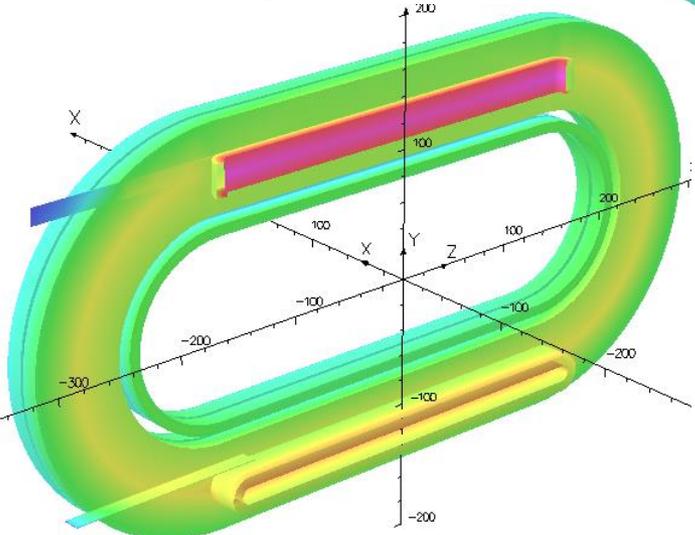
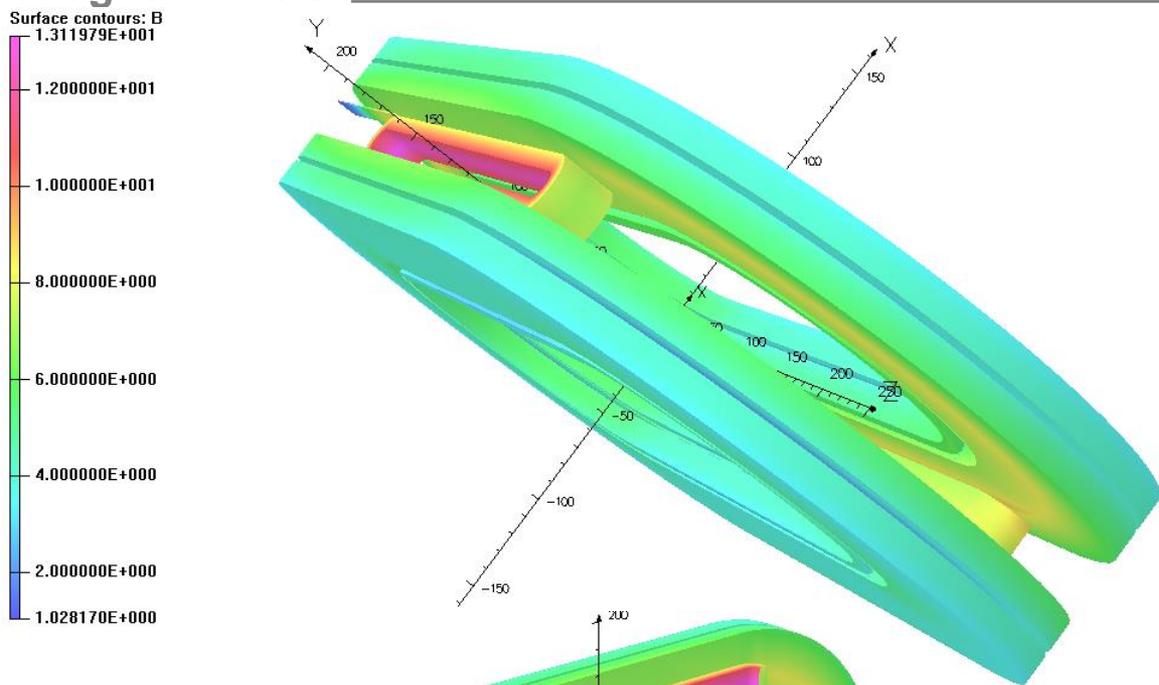
FIELD EVALUATIONS

Line LINE (nodal) 101 Cartesian
x=0.0 y=-300.0 to 300.0 z=0.0

**Two insert coils
in two bores
(Feb 2020 test)**

Opera

Insert Coils Test Configuration#4 (two insert coils, parallel & perpendicular)



Cut away view

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

Insert Coil Test Configuration #5 (one coil insert, one side in bore)

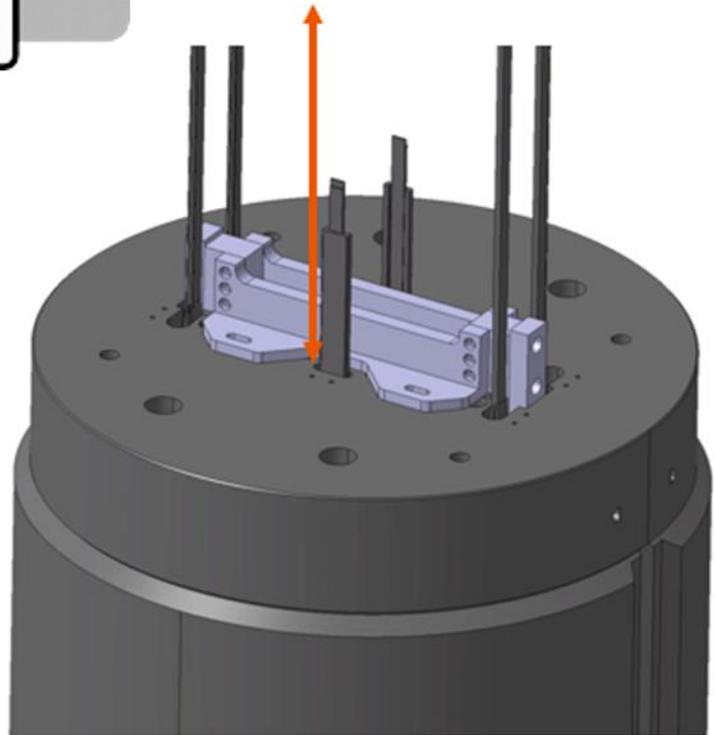
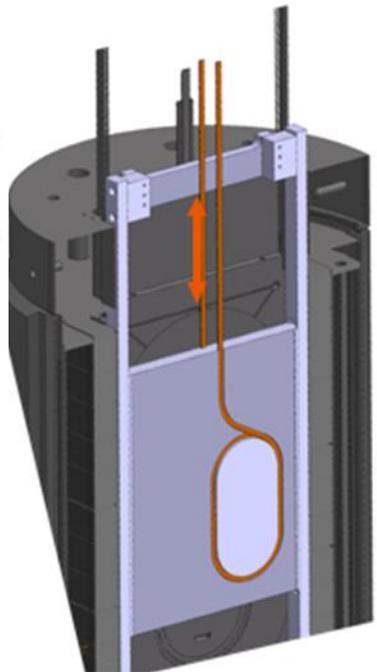
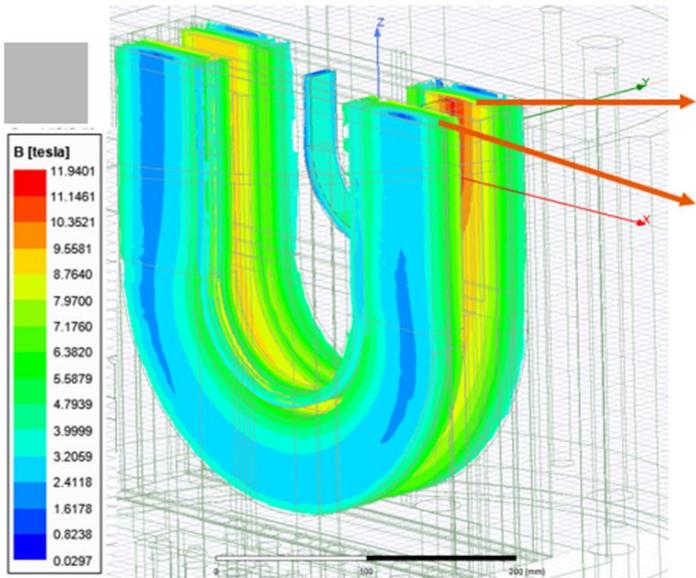


Coil partially in field (one side of the coil in one bore)

D. Martins Araujo :: on behalf of MagDev team :: Paul Scherrer Institute
BigBOX
modelling and engineering design progress
PSI / BNL-MDP Collaboration meeting, February 2022

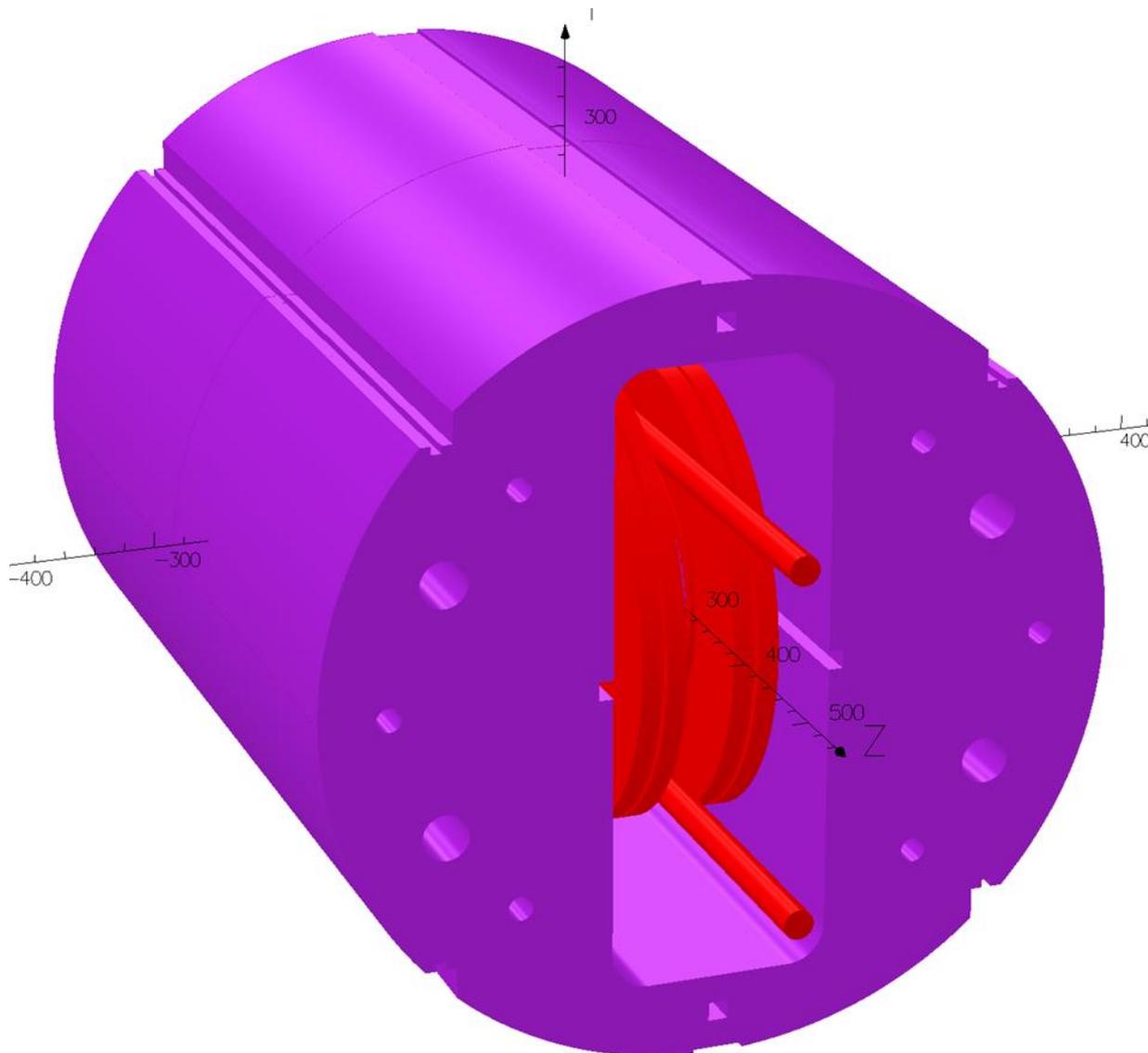


Test planned in 2022



Models of Cable Testing in DCC017

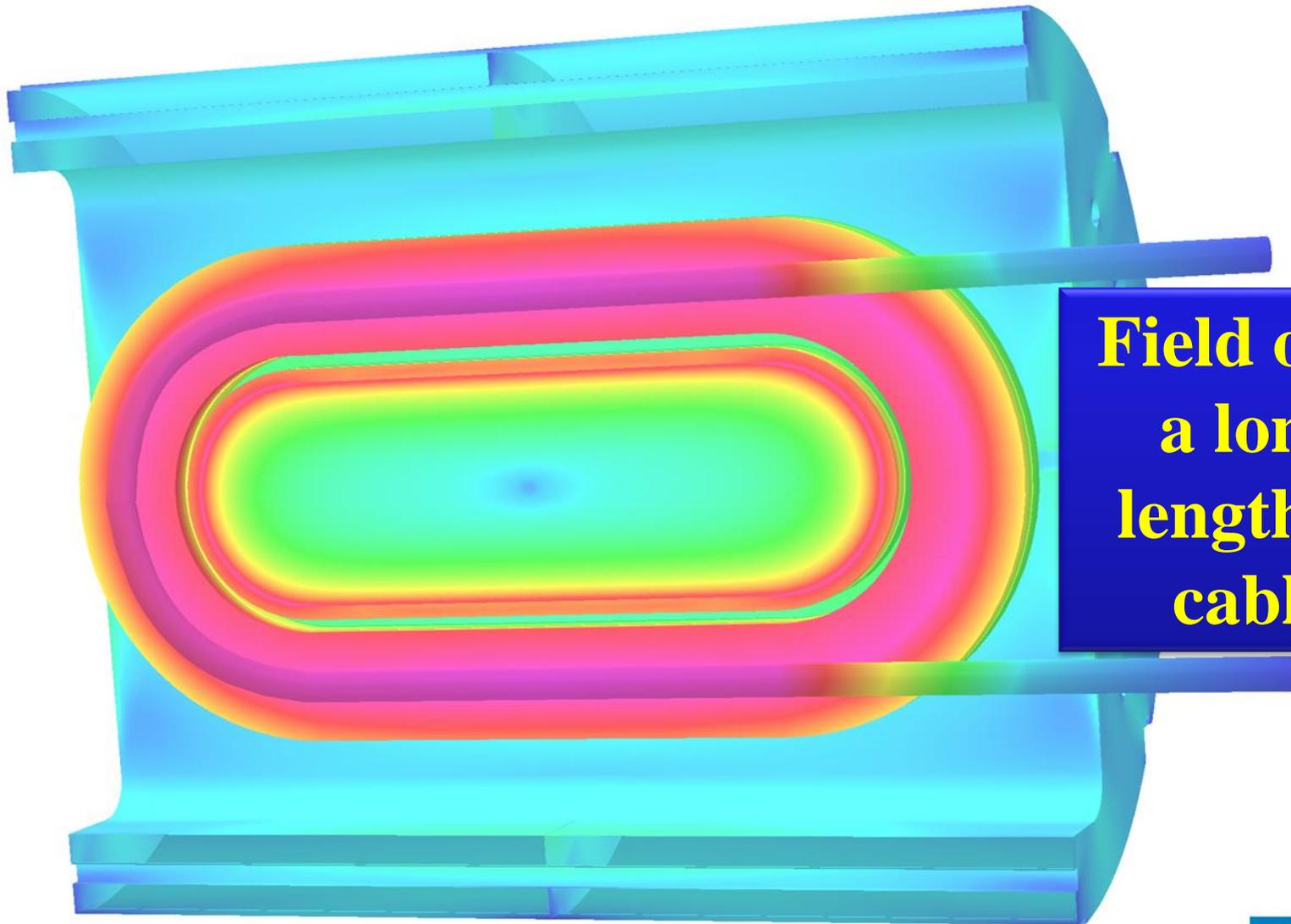
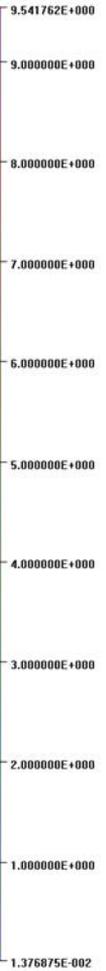
Cable Testing Model - View 1



**Single
turn
cable test**

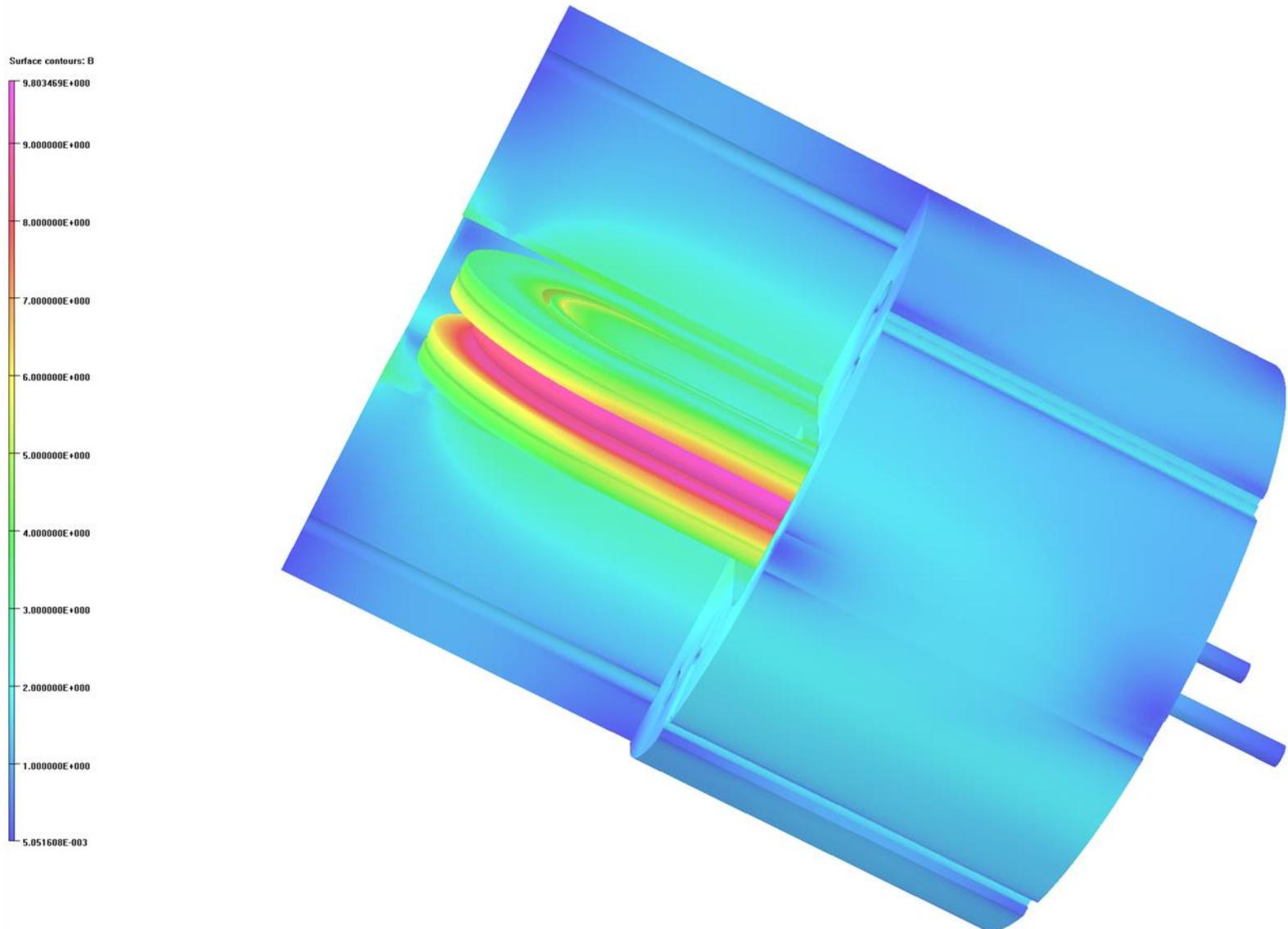
Cable Testing Model - View 2

Surface contours: B

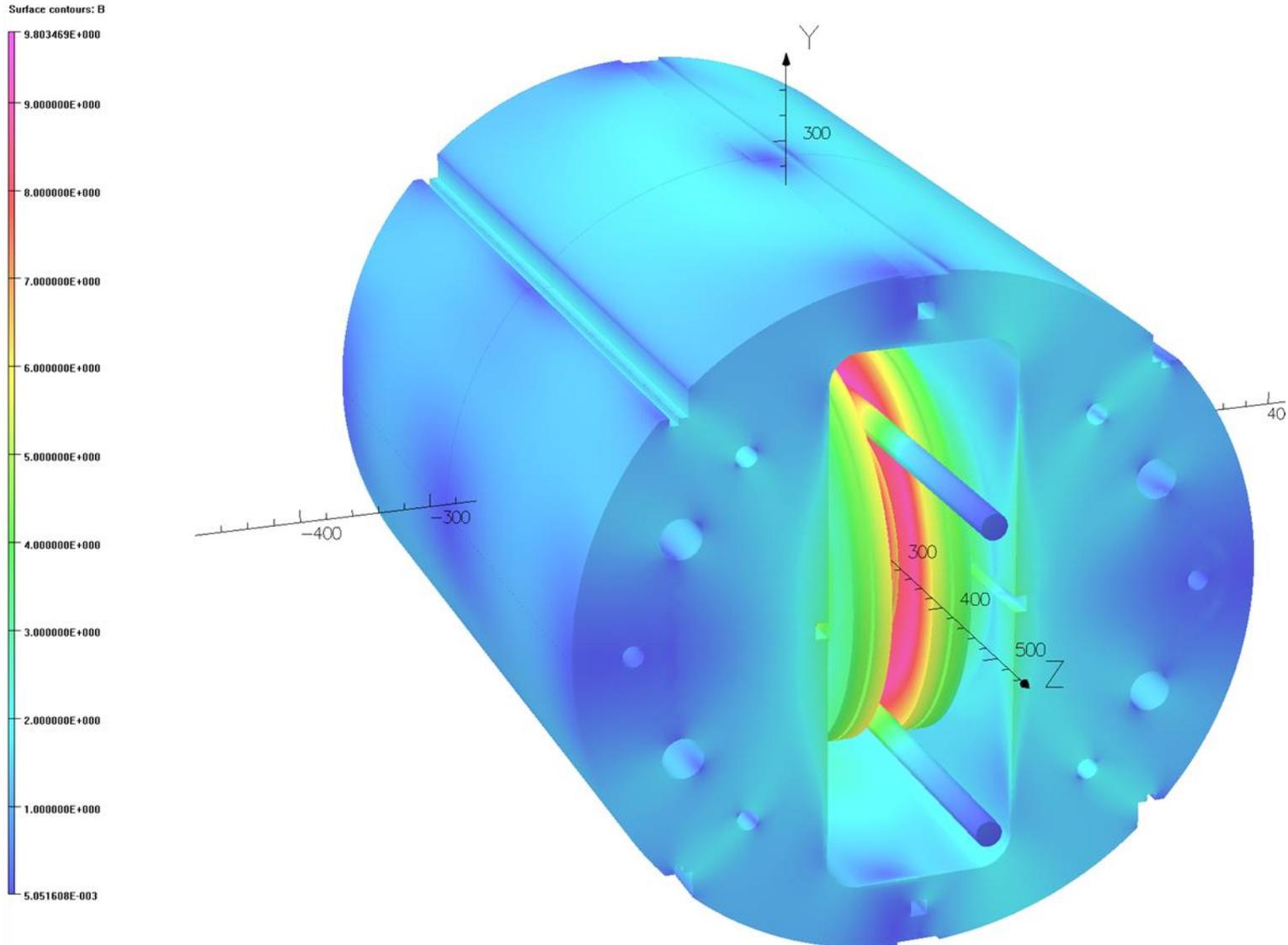


**Field over
a long
length of
cable**

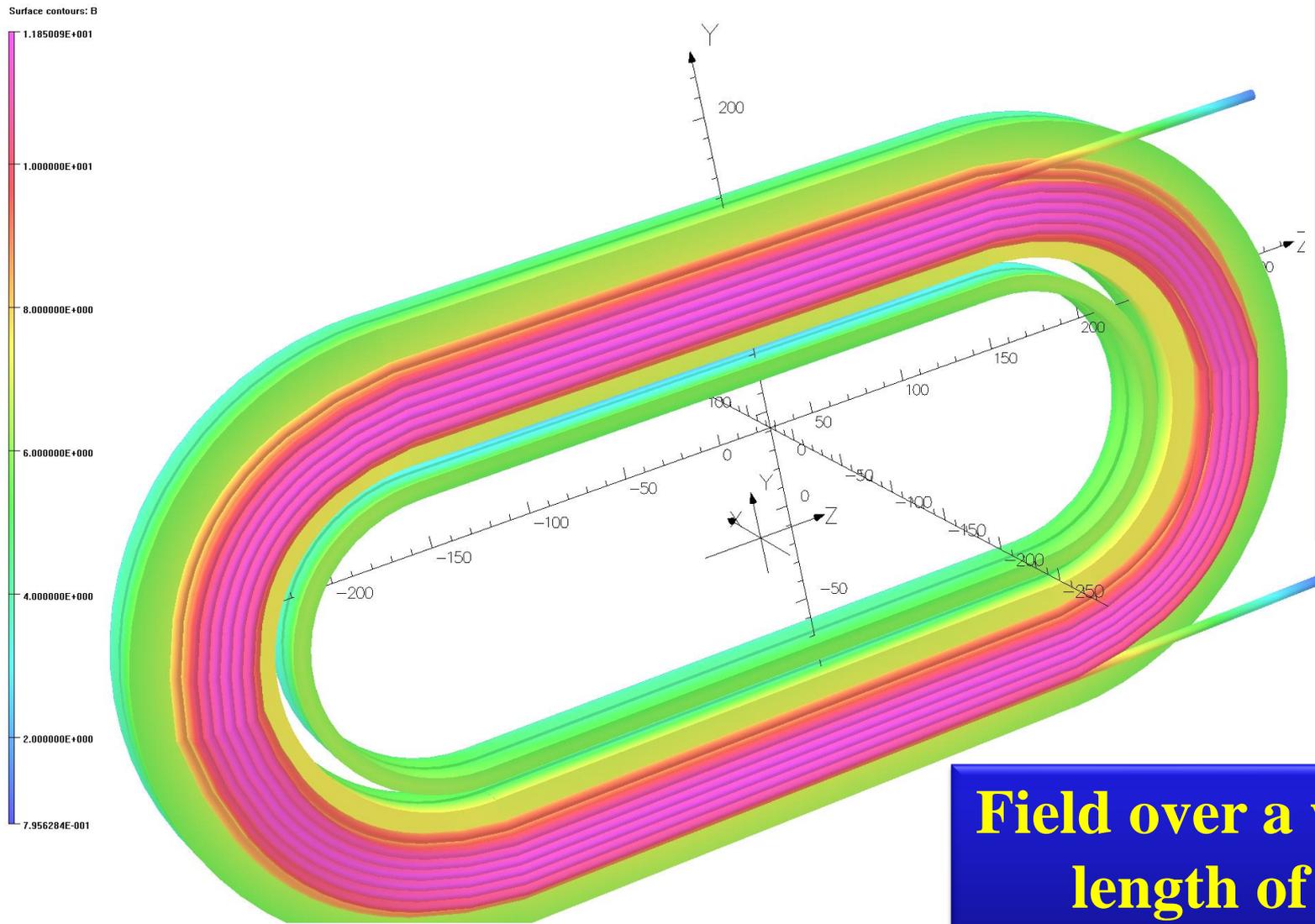
Cable Testing Model - View 3



Cable Testing Model - View 4



Multi-turn Cable Test



UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S m ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
66 conductors	

Field Point Local Coordinate	
Local = Global	

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