Design options for DUNE Near Detector Magnet

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Outline

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- DUNE ND Magnet Location & Hall layout
- Detector magnet requirements
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  - Option 2: Three Coil Helmholtz Design
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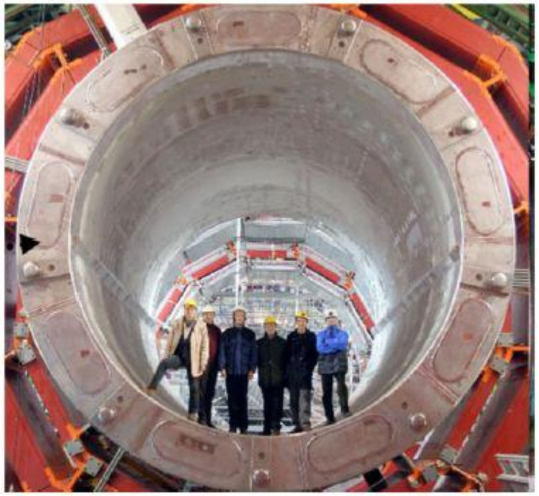
  - Option 4: Two Coil Helmholtz Design
- Summary

Superconducting Solenoid detectors presently in operation

Magnet	Central B (T)	Bore ID (m)	Magnet L (m)	Matrix Material	Coil Location	Thickness (Rad. Len.)	Magnet E (MJ)	S/C J (A mm^{-1})	Cooling Type
CLEO-1	1.5	2.0	3.7	Cu	Outside	0.7	10.0	~350	Forced
PEP-4	1.5	2.04	3.84	Cu	Outside	0.85	10.9	645	Forced
CELLO	1.3	1.5	4.02	Al	Outside	0.6	5.0	?	Forced
CDF	1.5	2.85	5.4	Al	Inside	0.84	30	64	Forced
TOPAZ	1.2	2.72	5.4	Al	Inside	0.7	20	56	Forced
VENUS	0.75	3.4	5.6	Al	Inside	0.52	12.0	?	Forced
ALEPH	1.5	4.96	7.0	Al	Inside	1.6	136	30.8	Natural
AMY	3.0	2.39	2.11	Al	Outside	> 2	40	50	Pool
ZEUS	1.8	1.72	2.9	Al	Inside	> 2	16	?	Forced
DELPI	1.2	5.2	7.4	Al	Inside	1.7	108	46.3	Forced
H-1	1.2	5.2	6.0	Al	Inside	1.8	130	46	Forced
CLEO-2	1.5	2.9	3.8	Al	Inside	2.2	25	41.3	Natural
BaBar	1.5	2.76	3.85	Al	Inside	< 1.4	23	37 & 67	Natural
BEPCH	1.0	3.89	3.4	Al	Inside	~0.8	9.5	44.8?	Forced
ATLAS	2.0	2.4	5.3	Al	Inside	0.66	39	59.6	Forced
CMS	4.0	6.0	12.5	Al	Inside	4.3	2700	14.1	Forced

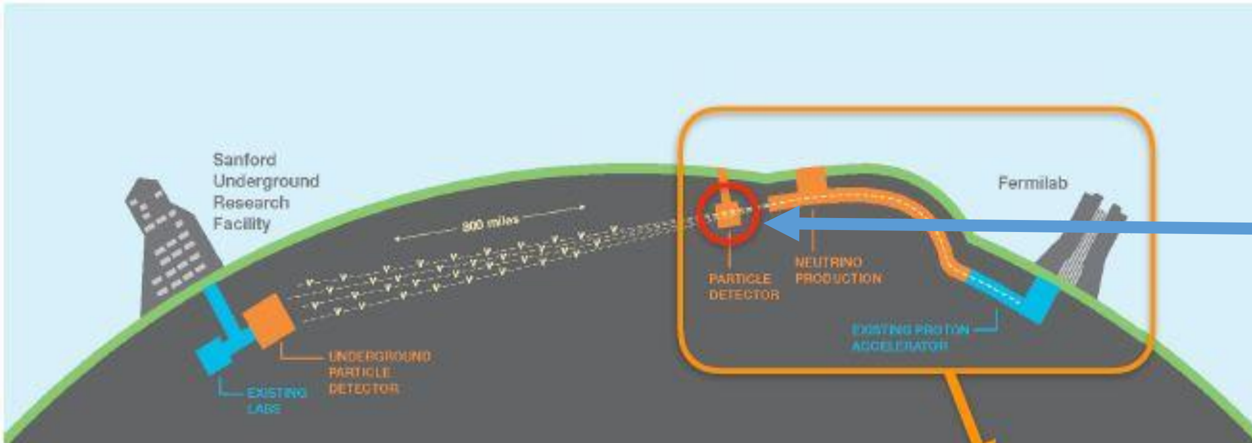
DELPHI Solenoid Magnet



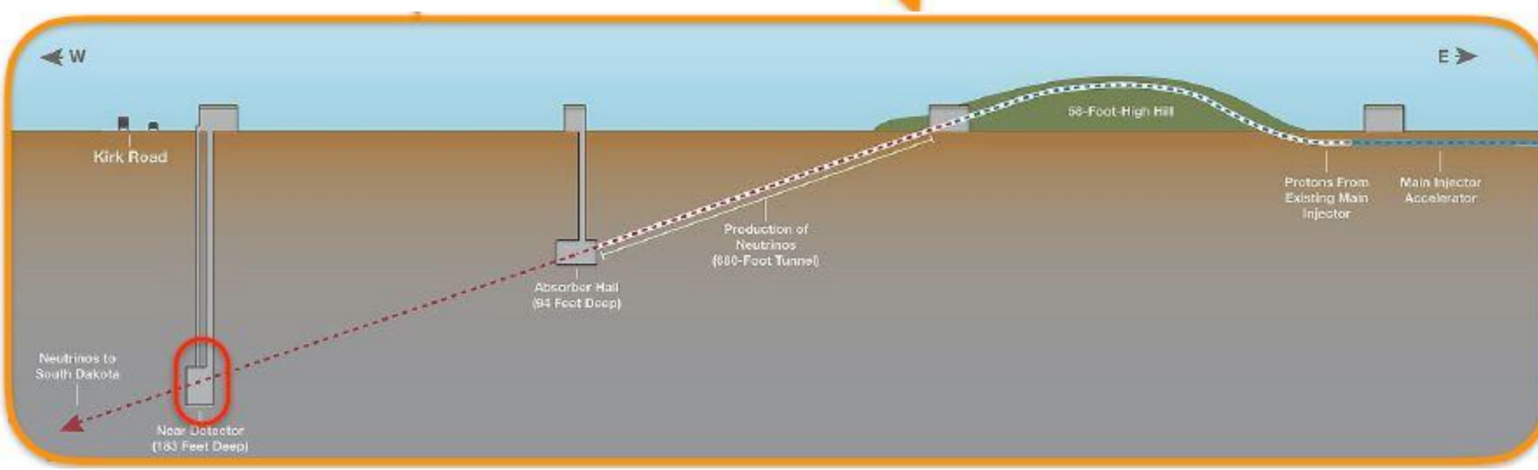
CMS Solenoid Magnet Detector

- Due to limited radiation lengths, most of the detector magnets are thin solenoid magnets.
- CLEO-1 and PEP-4 uses Cu-NbTi cable in a copper channel whereas all other detector uses Cu-NbTi cable in an Aluminum channel
- Ultrapure Aluminum matrix (RRR> 1000) increases quench velocity at higher currents and minimum propagation zone is also longer.

DUNE Near Detector Magnet Location



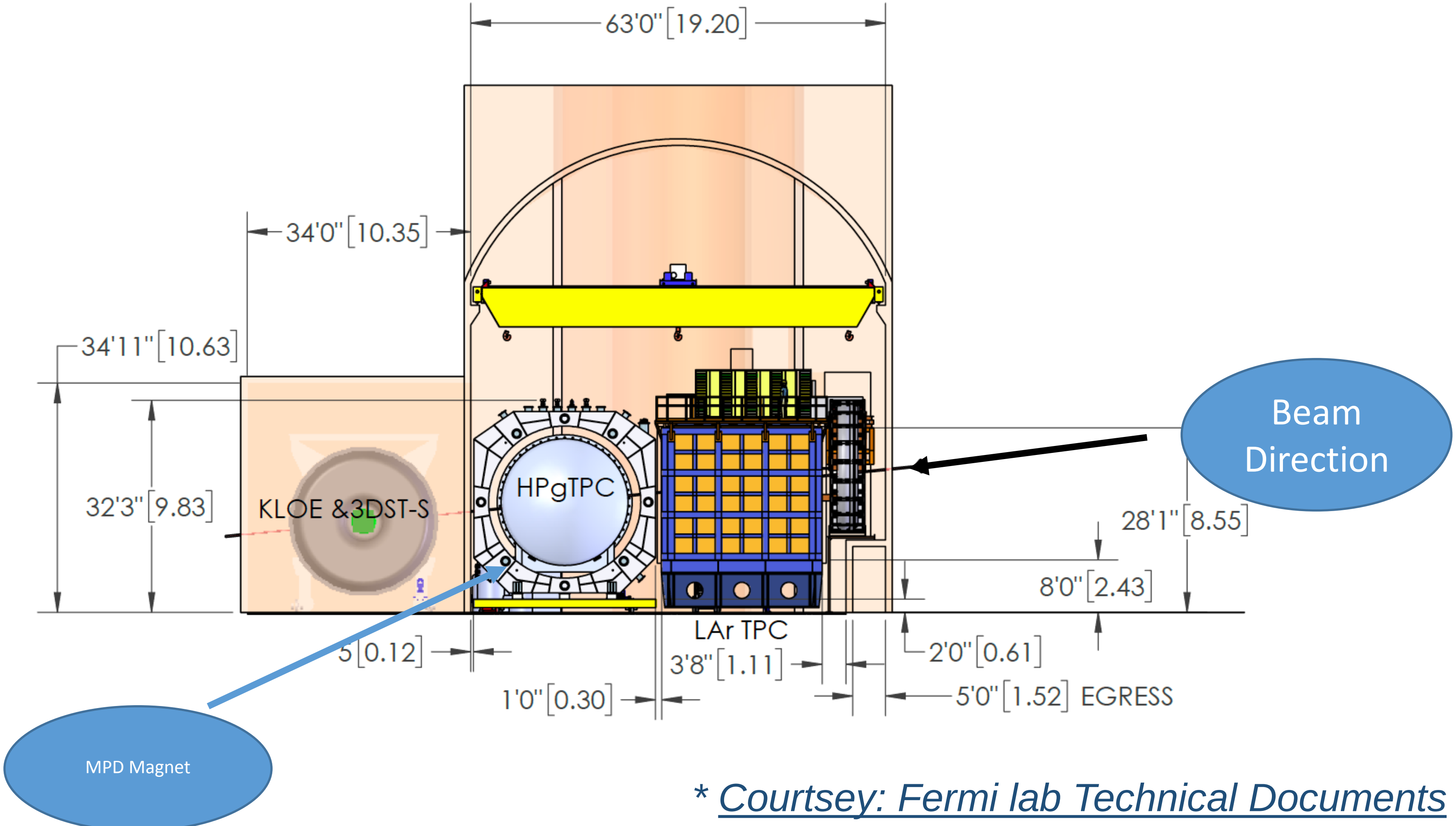
DUNE ND Magnet



LBNF sends broadband intense beam of neutrinos 1280 Km from FNAL to the DUNE Far Detector at SURF in South Dakota

* *Courtesy: Fermi lab Technical Documents*

DUNE Near Detector Hall Layout



[Courtsey: Fermi lab Technical Documents]

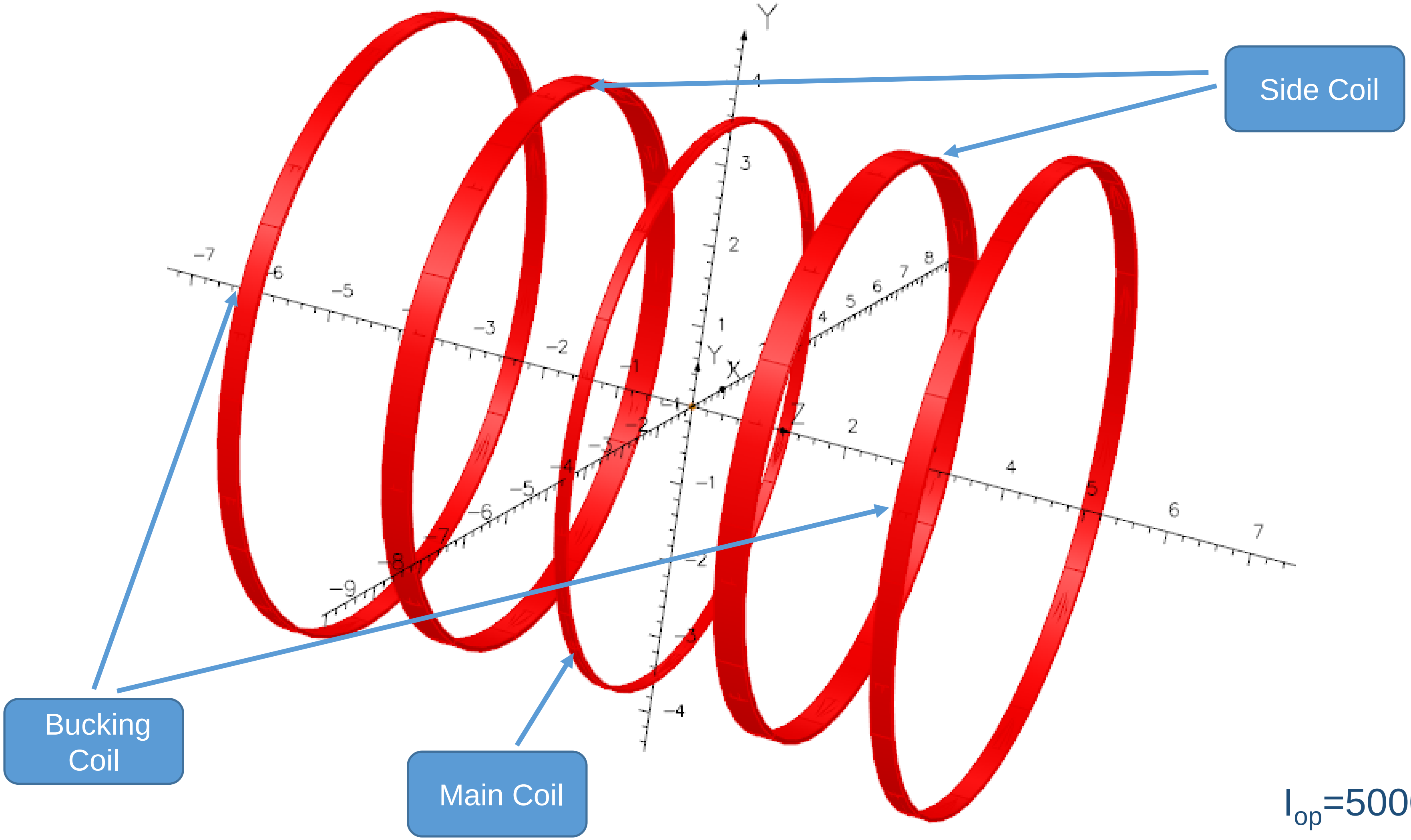
DUNE Near Detector Magnet Design

Requirements:*

- Multi coil design due to finite radiation length (Copper: 3.5 mm, Aluminum: 88.9 mm, NbTi: 20.4 mm) and ease of assembly
- Central Magnetic Field : B(0,0,0) ~ 0.5T
- Magnet Inner Diameter: > 6 m
- Magnet Outer Diameter: < 8.8 m
- Magnet Length: less than 12 m
- Fringe Field :B(6,0,0) < 200 Gauss (20mT)
- Uniformity :< 50% in DSV of 5.2 m

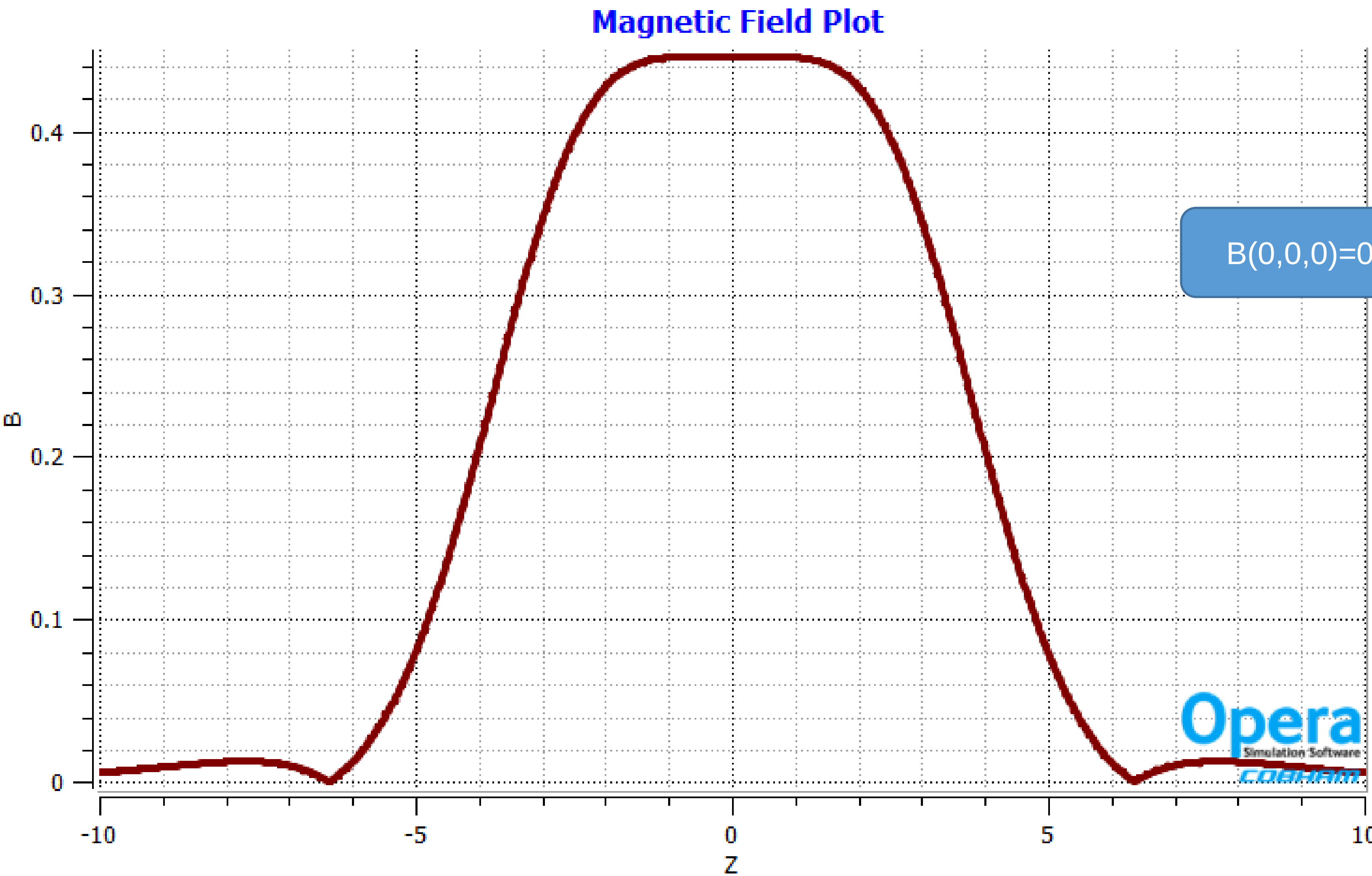
* *DUNE-ND magnet meetings*

Design Option-1: Three coil Helmholtz Configuration with shield coils



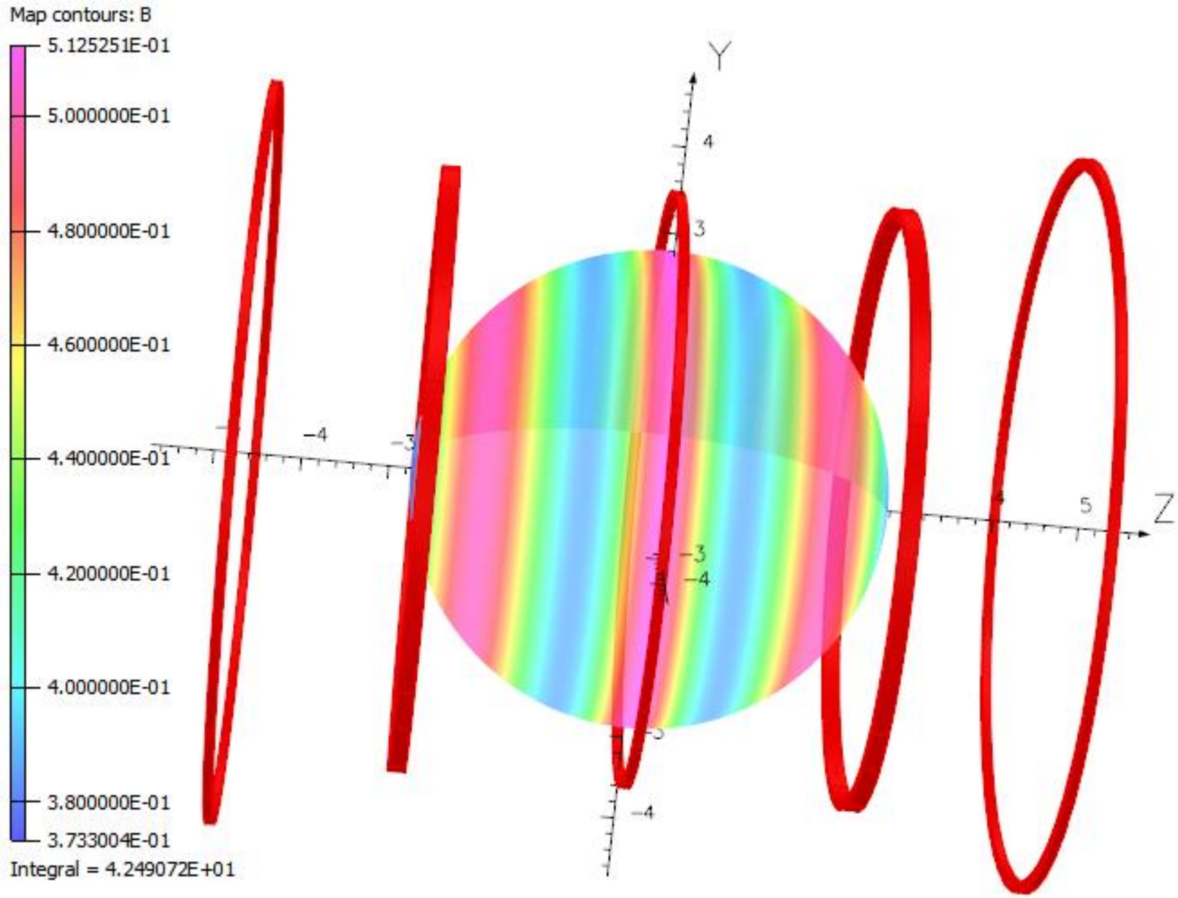
I_{op}=5000A

Design Option-1: Three coil Helmholtz Configuration with shield coils



B(0,0,0)=0.45 T

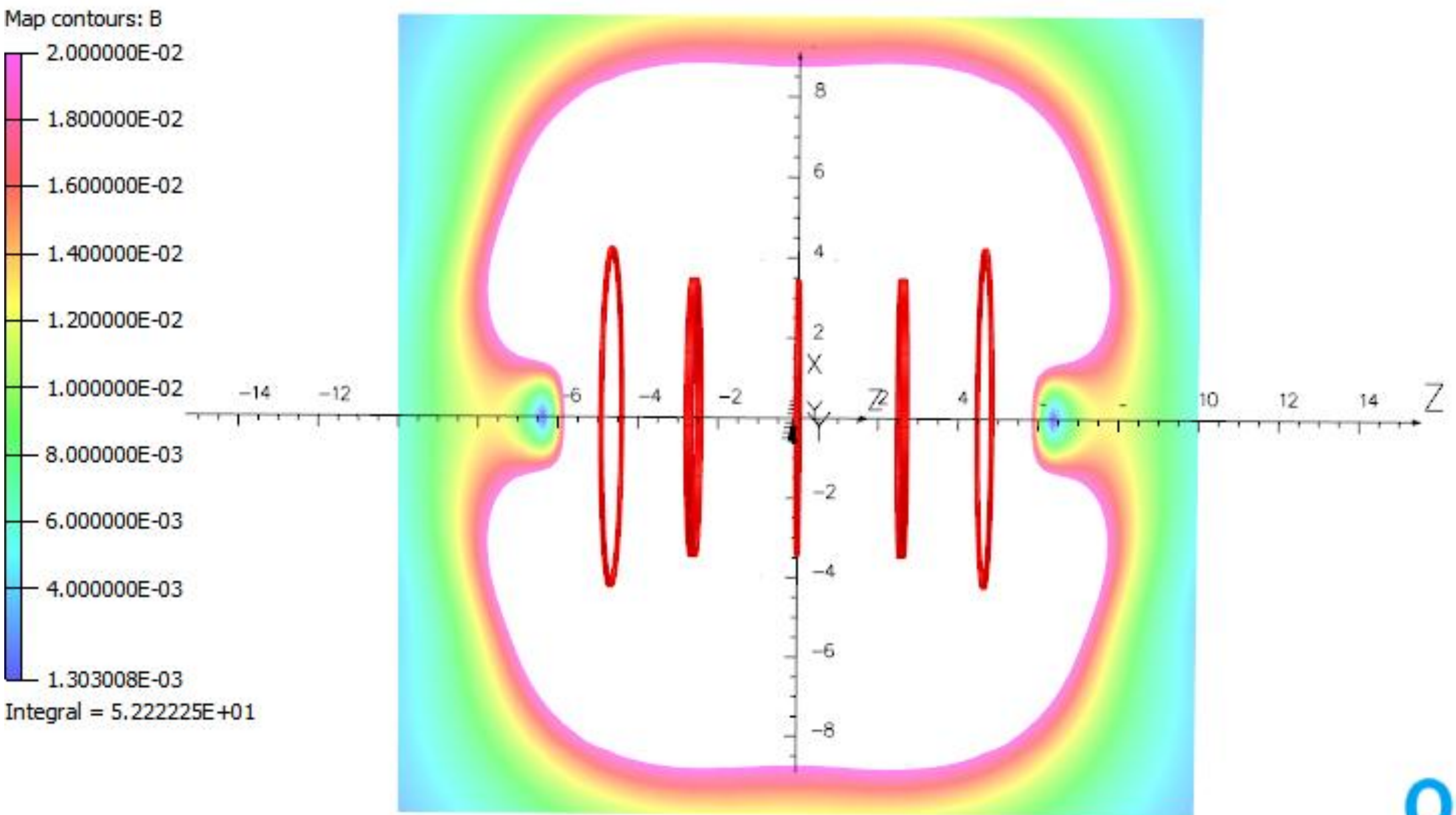
Design Option-01 Field Uniformity



B(0,0,0)=0.45 T

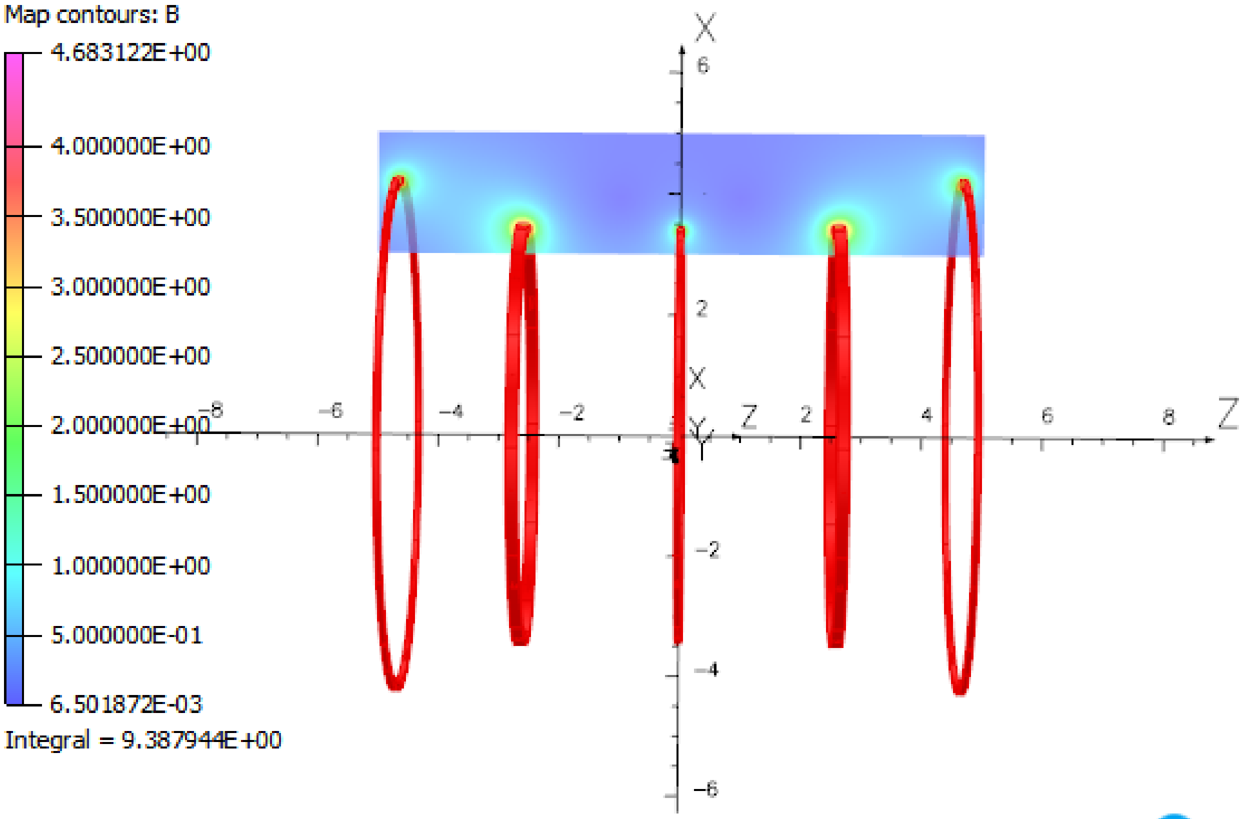
$B_{uniformity}$= 17%

Design Option-01: Stray Magnetic Field



B (0,0,6) = 200 Gauss

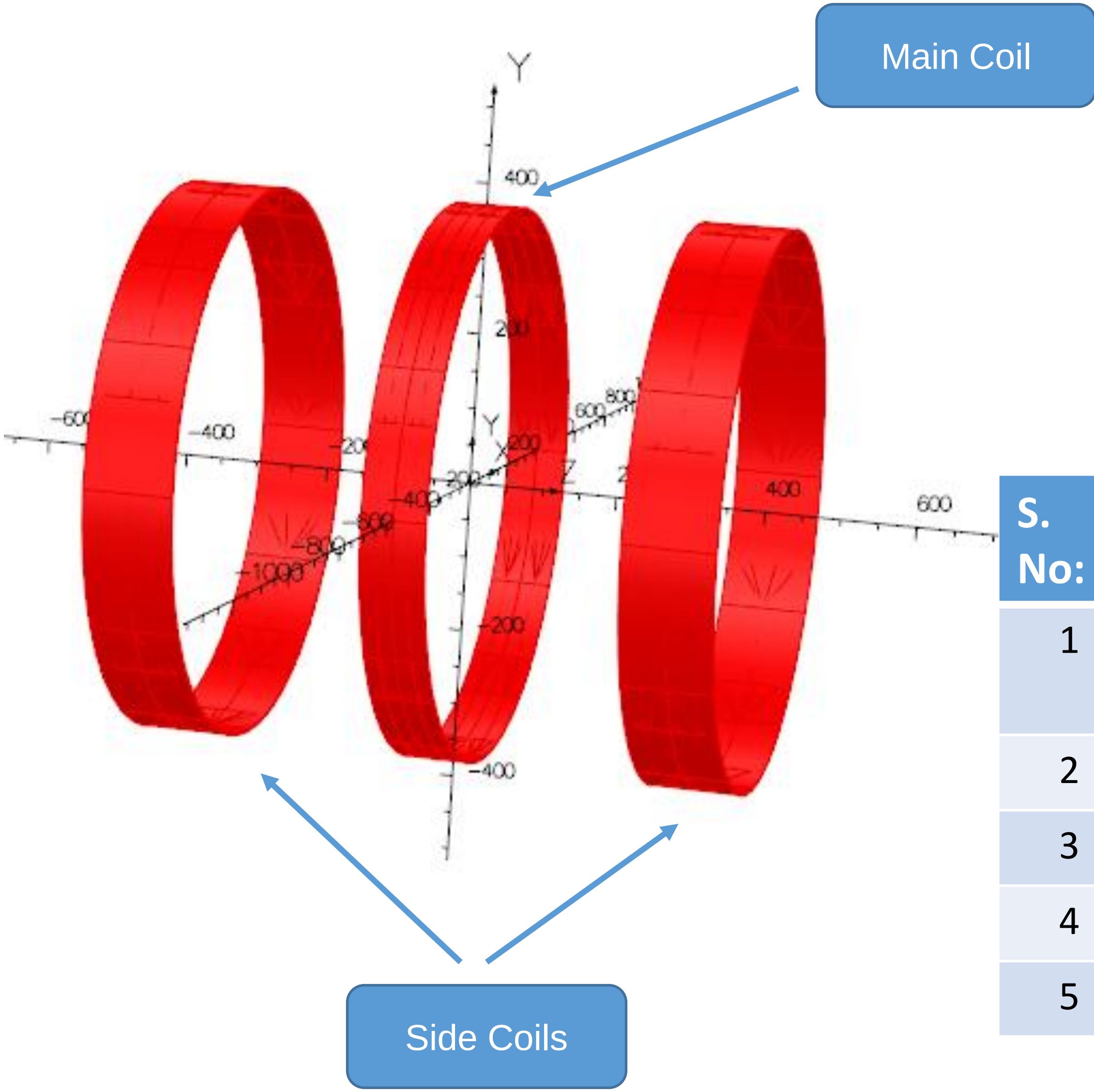
Design Option-01: Peak Magnetic Field



B_{peak}=4.7 T

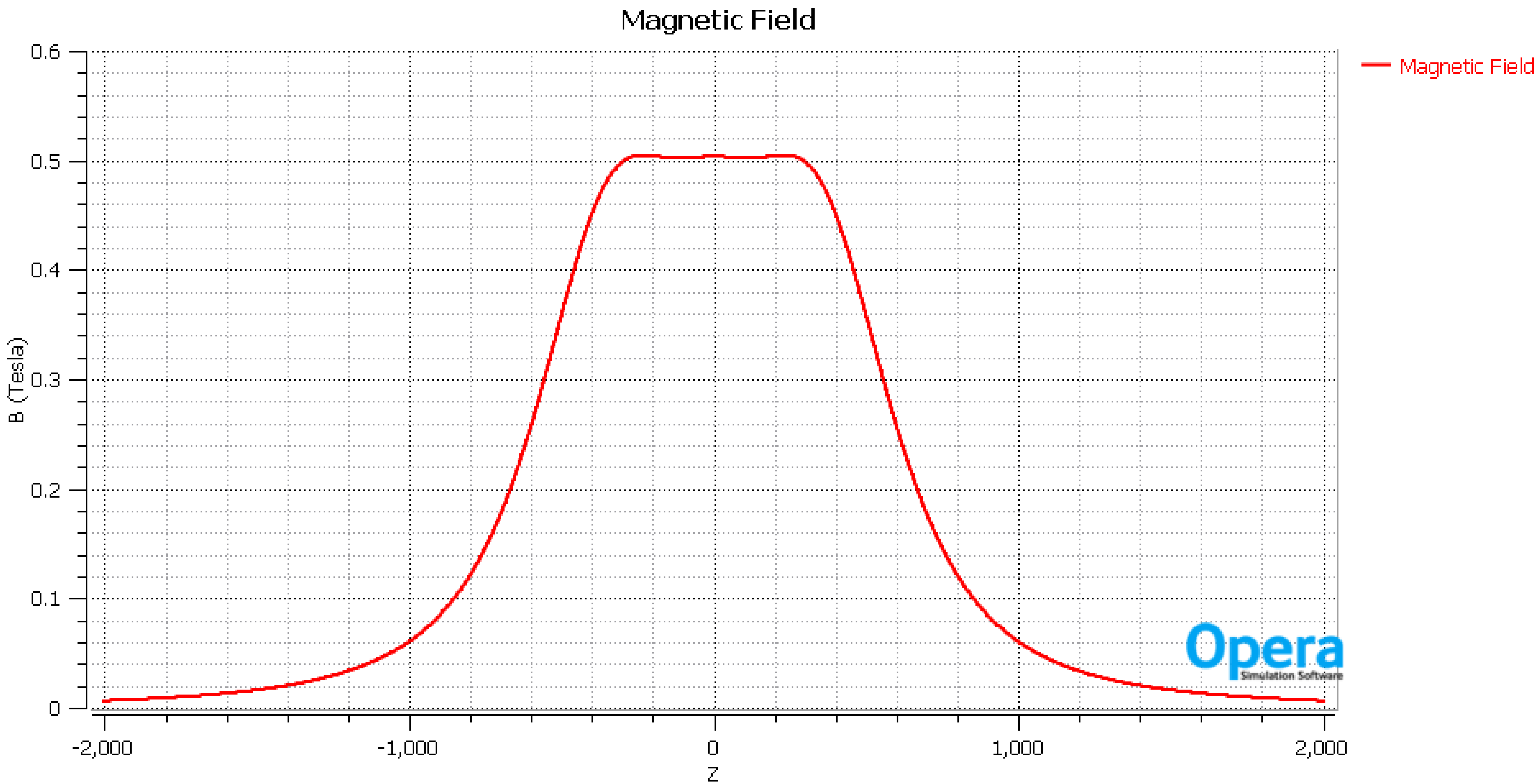
Stored Energy = 112 MJ

Design Option-2: Three coil Helmholtz Configuration



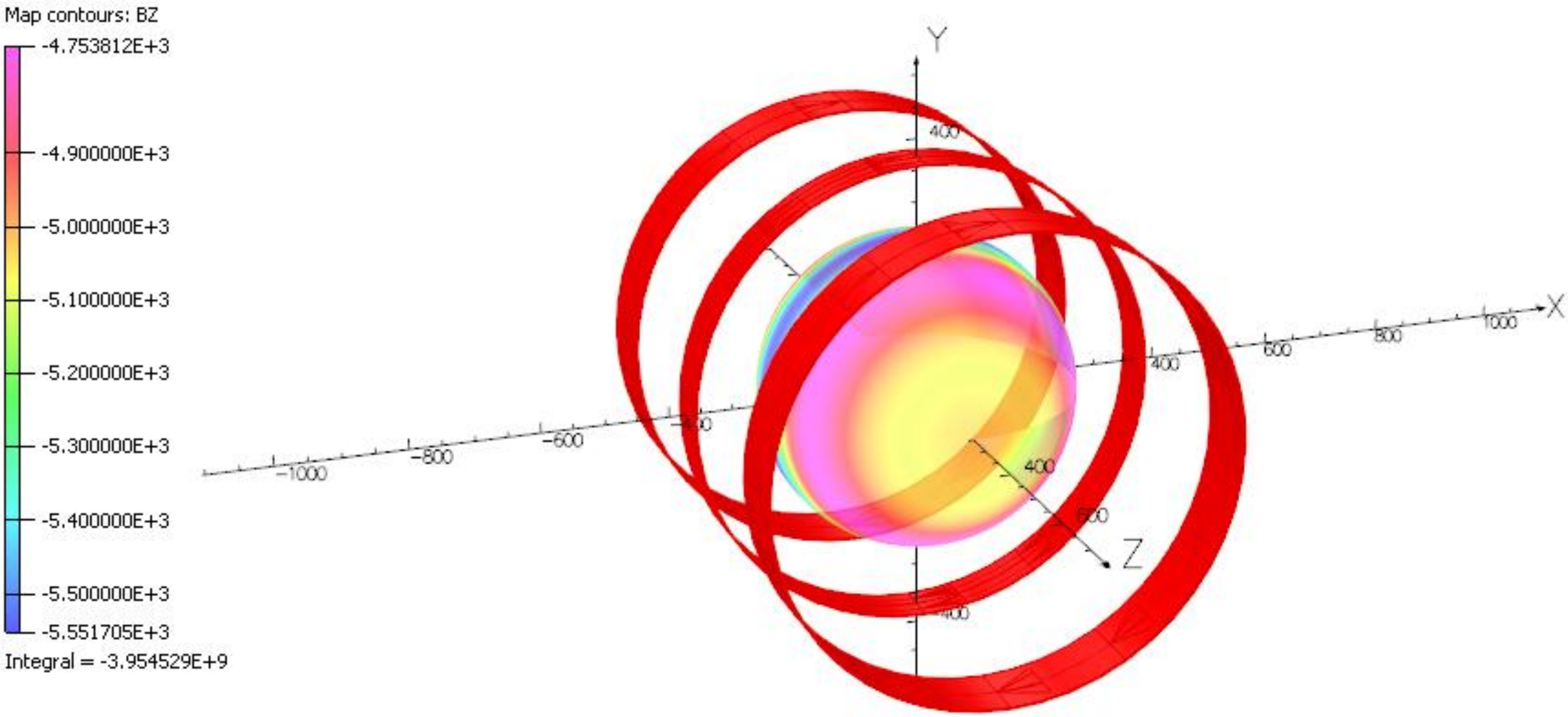
S. No:	Parameters	Description
1	Distance between Centre coil & side coil	2.9 m
2	Coil Inner diameter	7.4 m
3	No of turns (main coil)	240
4	No of turns (side coil)	776
5	Current	3000 Amp

Design Option2- Magnetic Field



B(0,0,0)=0.5 T

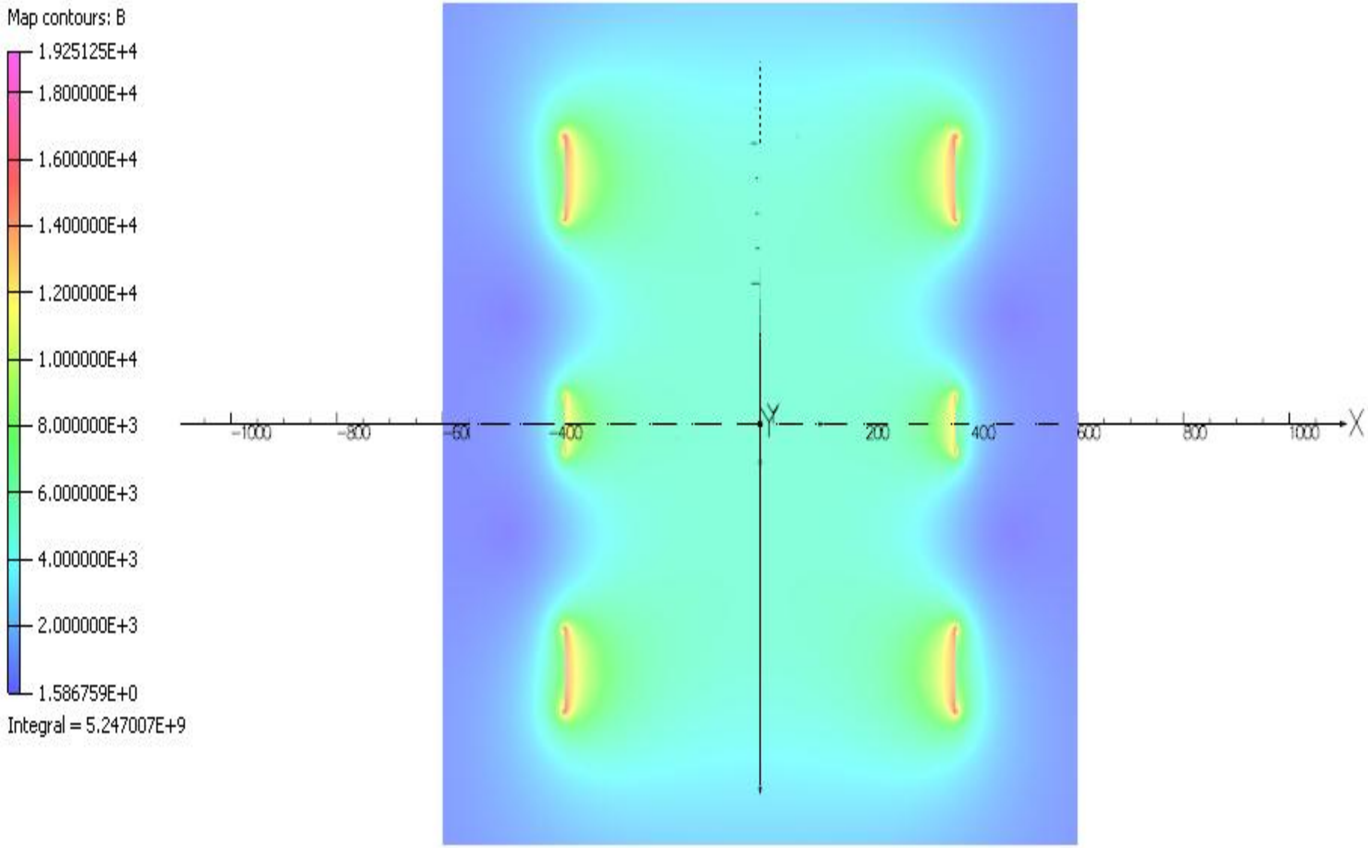
Design Option 2- Magnetic Field Uniformity



B(0,0,0)=0.5 T

$B_{uniformity}$= 16%
In a DSV of 5.2 m

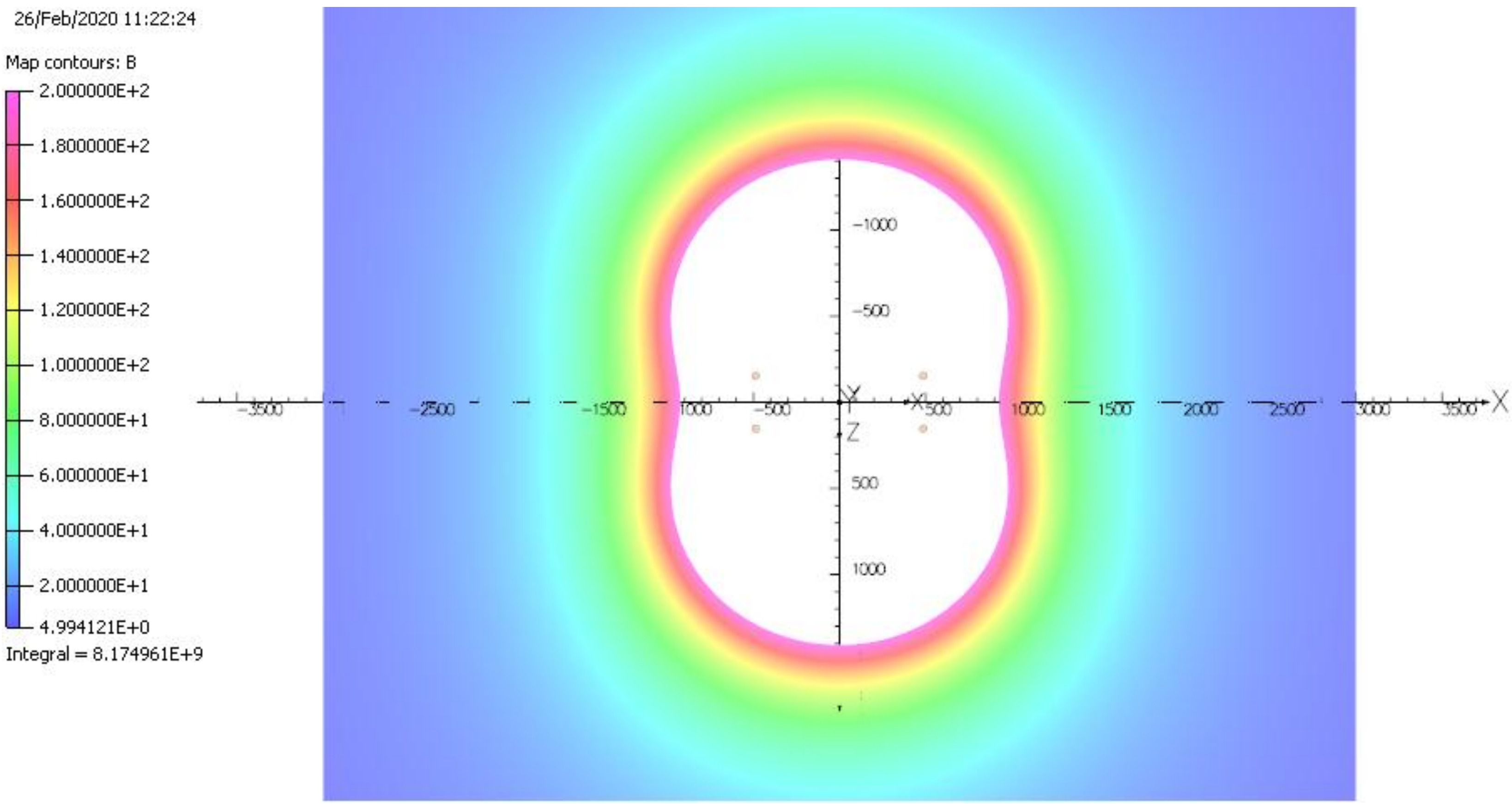
Design Option 2- Peak Magnetic Field



B_{peak}=1.92 T

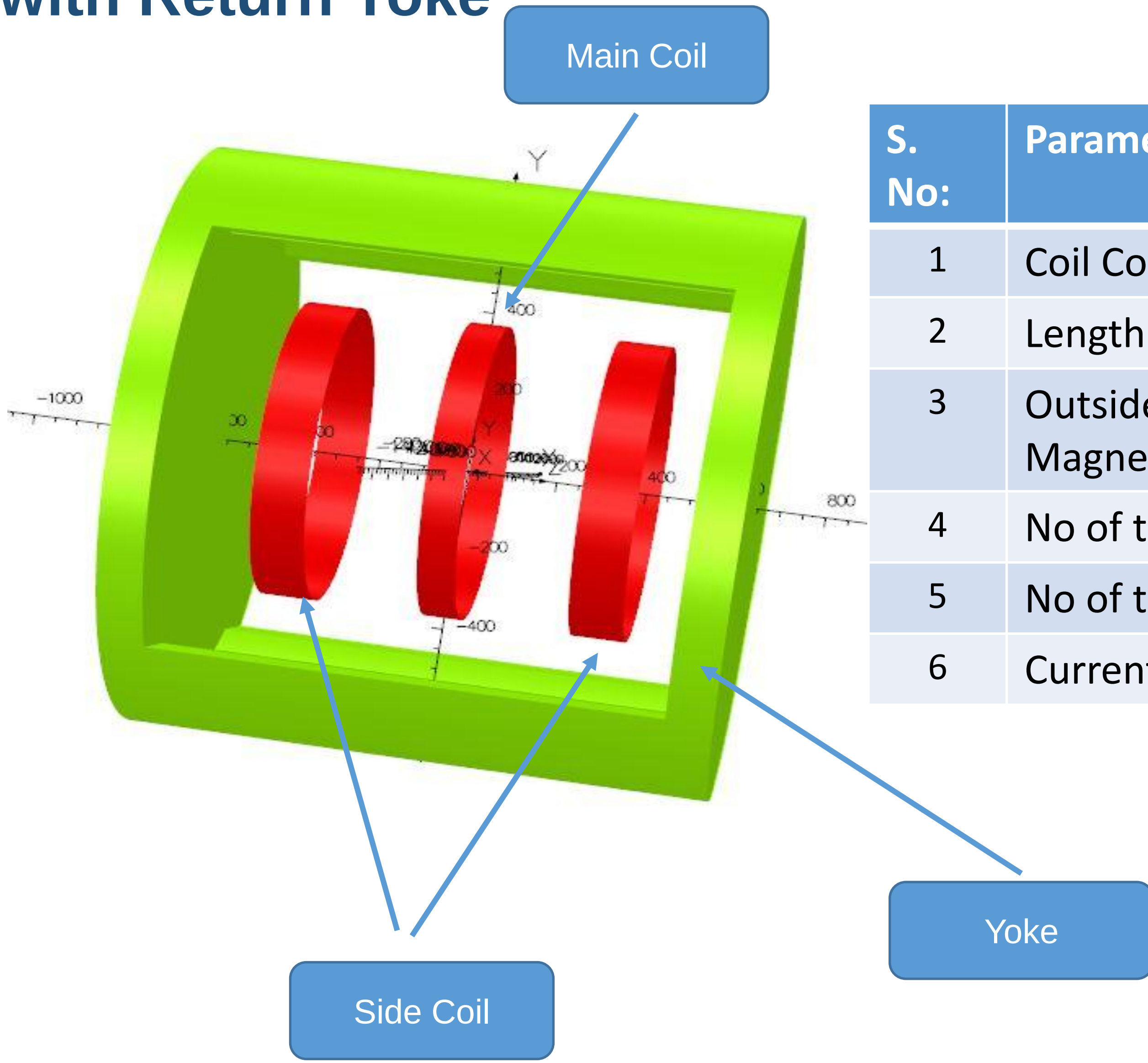
Stored Energy = 8 MJ

Design Option 2- Stray Magnetic Field



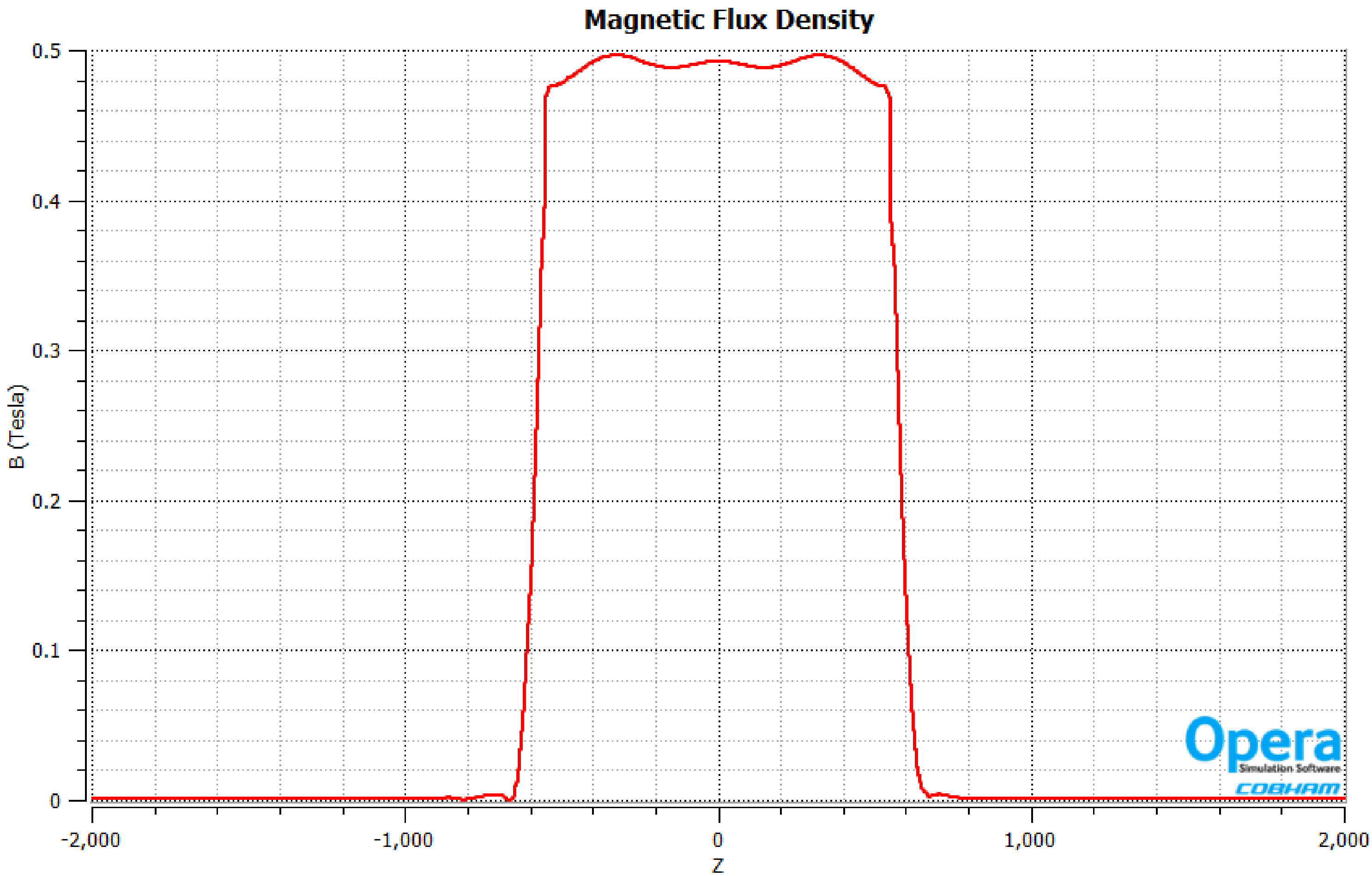
B(0,0,12)=200 Gauss

Design Option-3: Three coil Helmholtz Configuration with Return Yoke



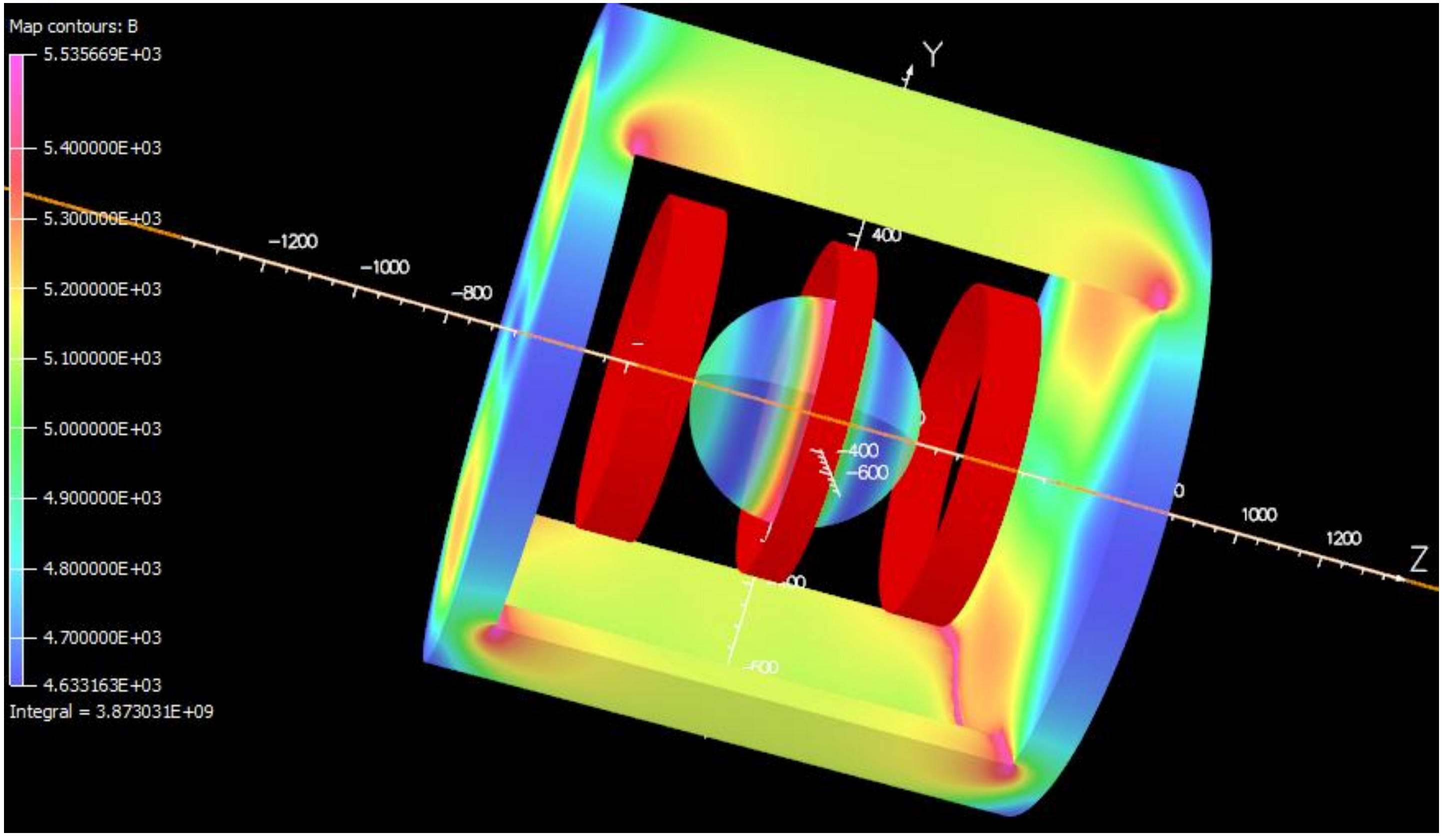
S. No:	Parameters	Description
1	Coil Configuration	3 coil
2	Length of Magnet	14 m
3	Outside Diameter of Magnet	12 m
4	No of turns (main coil)	240
5	No of turns (side coil)	776
6	Current	2500 Amp

Design Option 3- Magnetic Field



B(0,0,0)=0.5 T

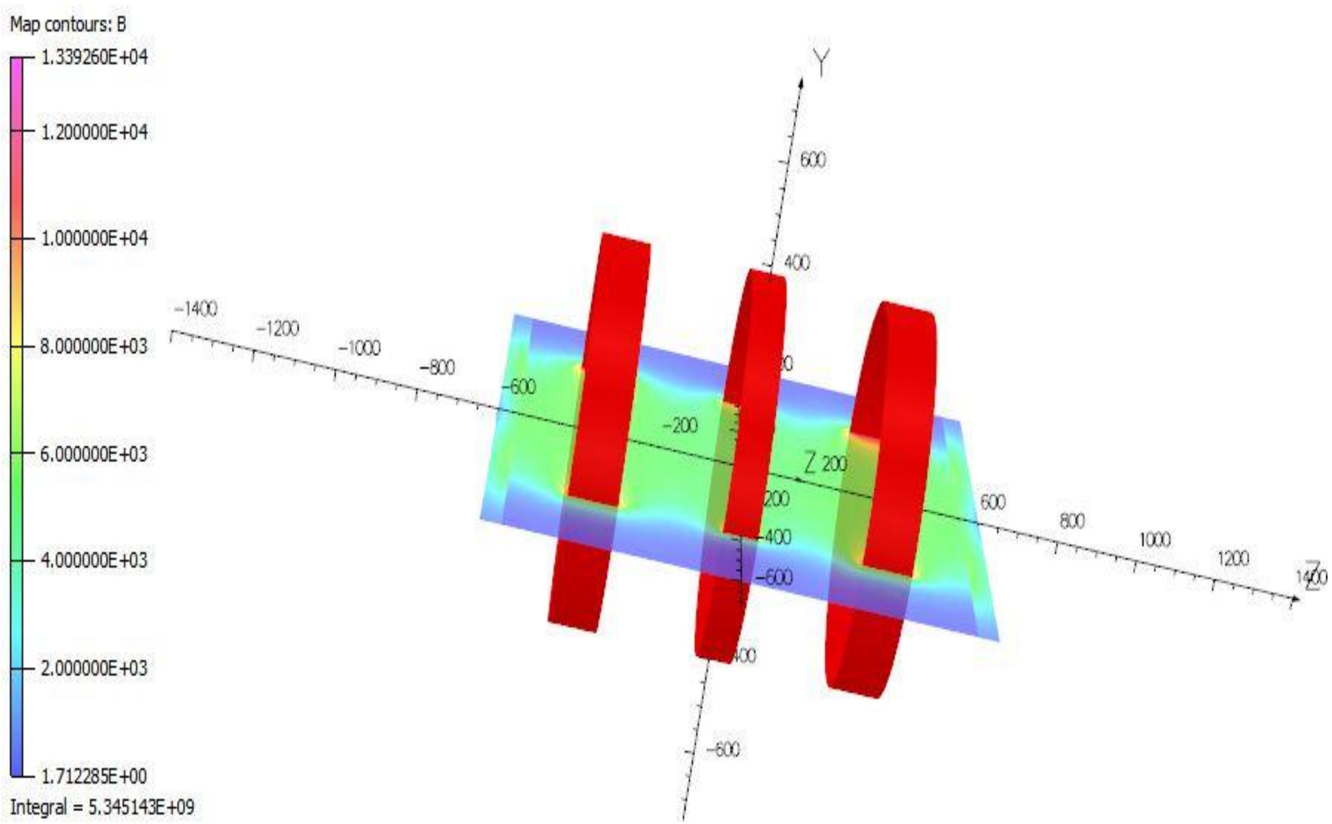
Design Option 3- Magnetic Field Uniformity



B(0,0,0)=0.5 T

$B_{uniformity}$= 22%
In a DSV of 5.2 m

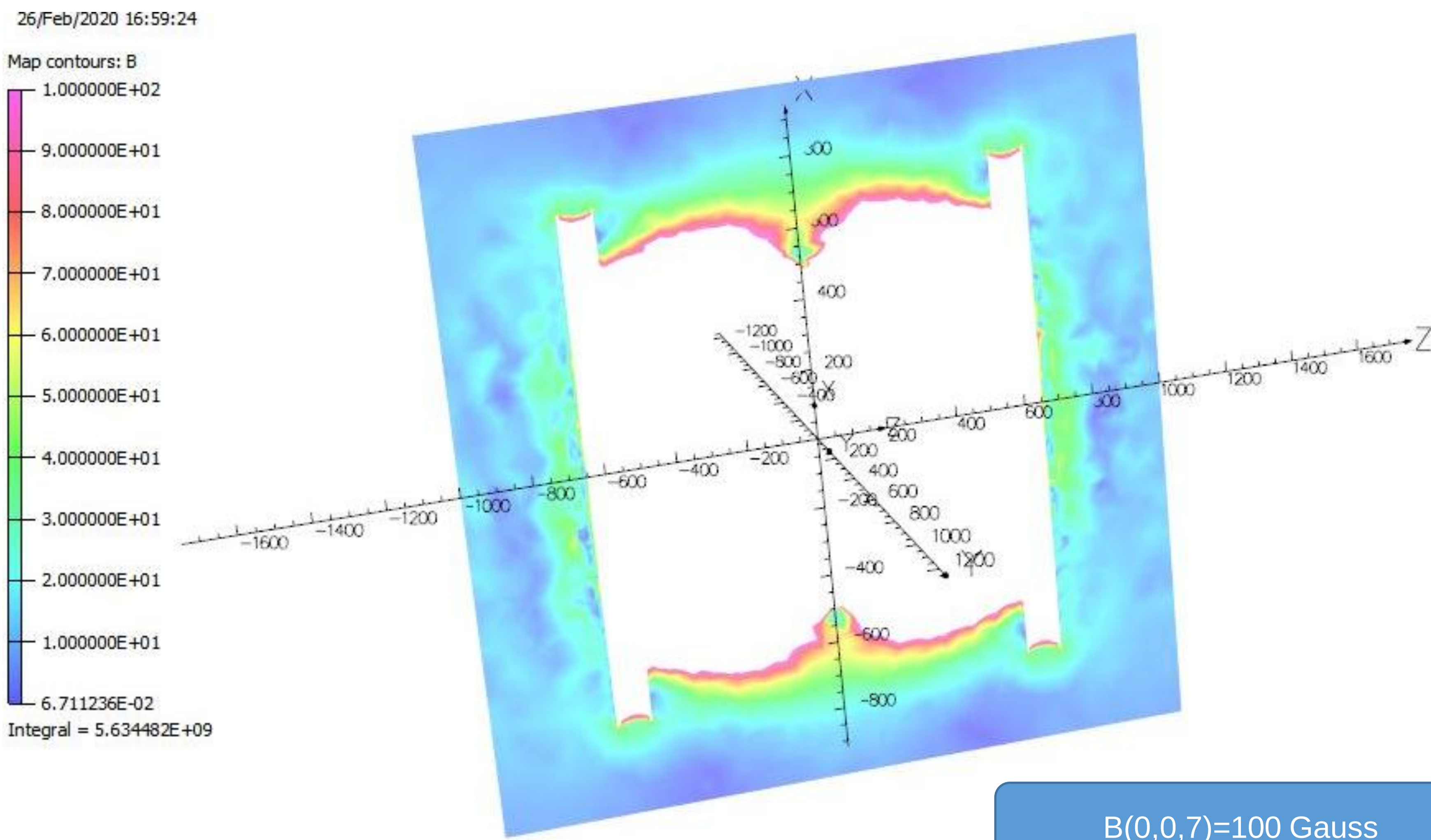
Design Option 3- Peak Magnetic Field



B_{peak}=1.34 T

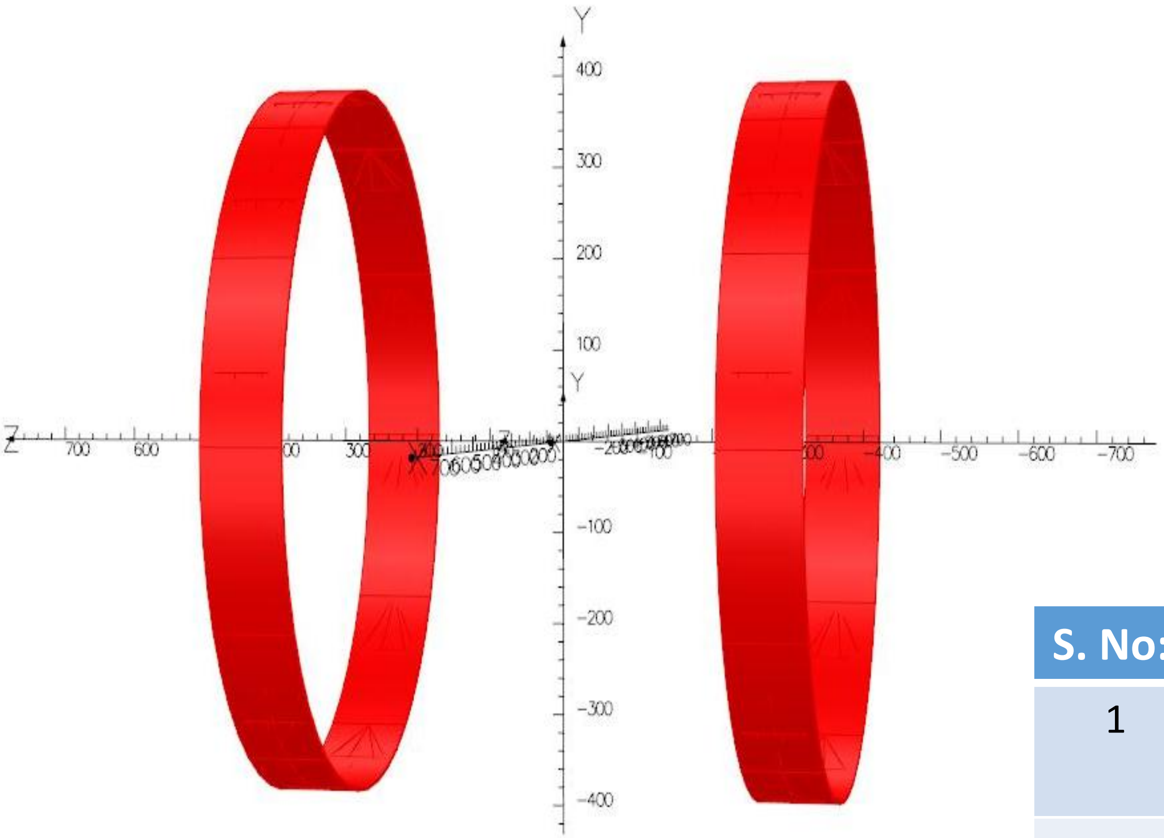
Stored Energry= 50 MJ

Design Option 3- Stray Magnetic Field



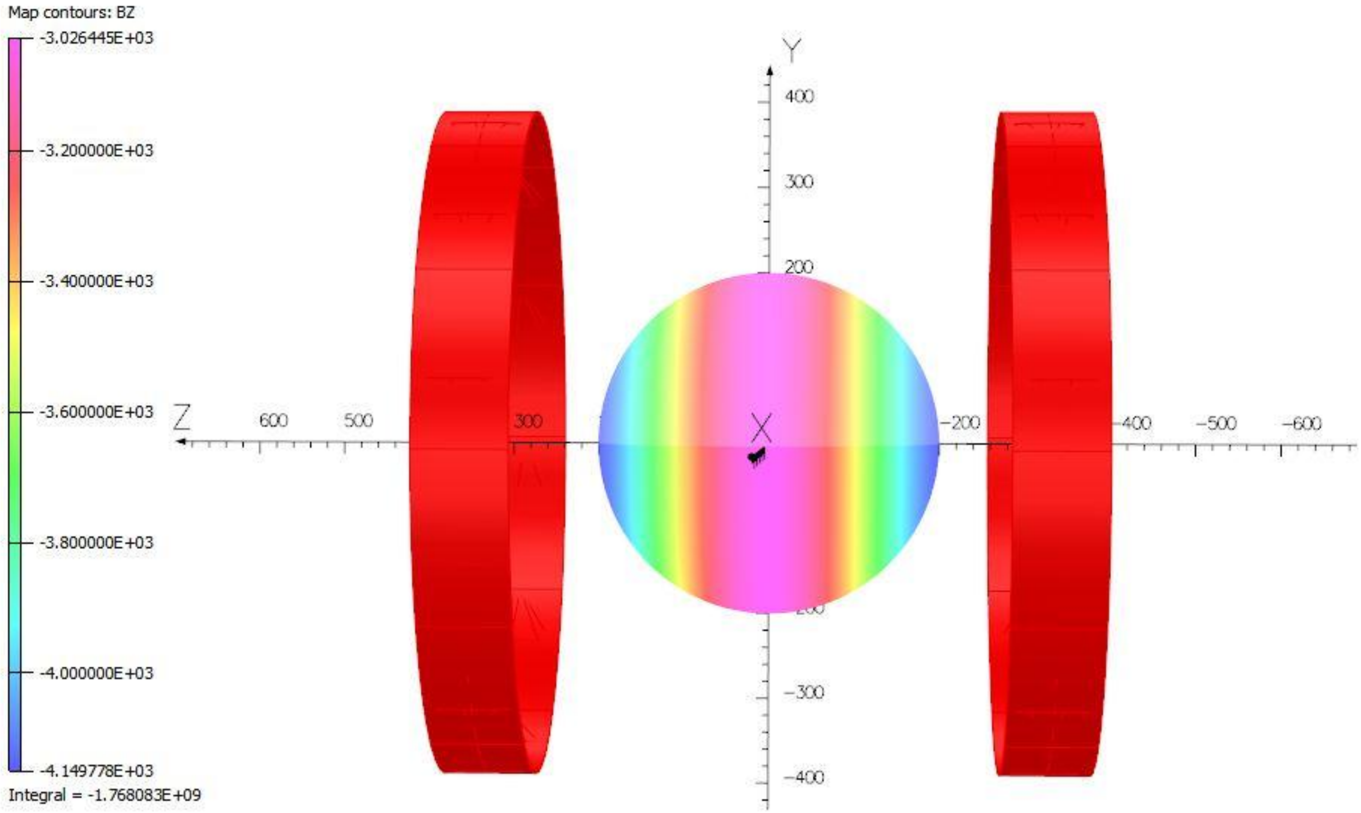
B(0,0,7)=100 Gauss

Design Option-4: Two coil Helmholtz Configuration



S. No:	Parameters	Description
1	Distance between Two coils	5.4 m
2	Coil Inner radius	7.7 m
3	No of turns	720
4	Current	3600 Amp

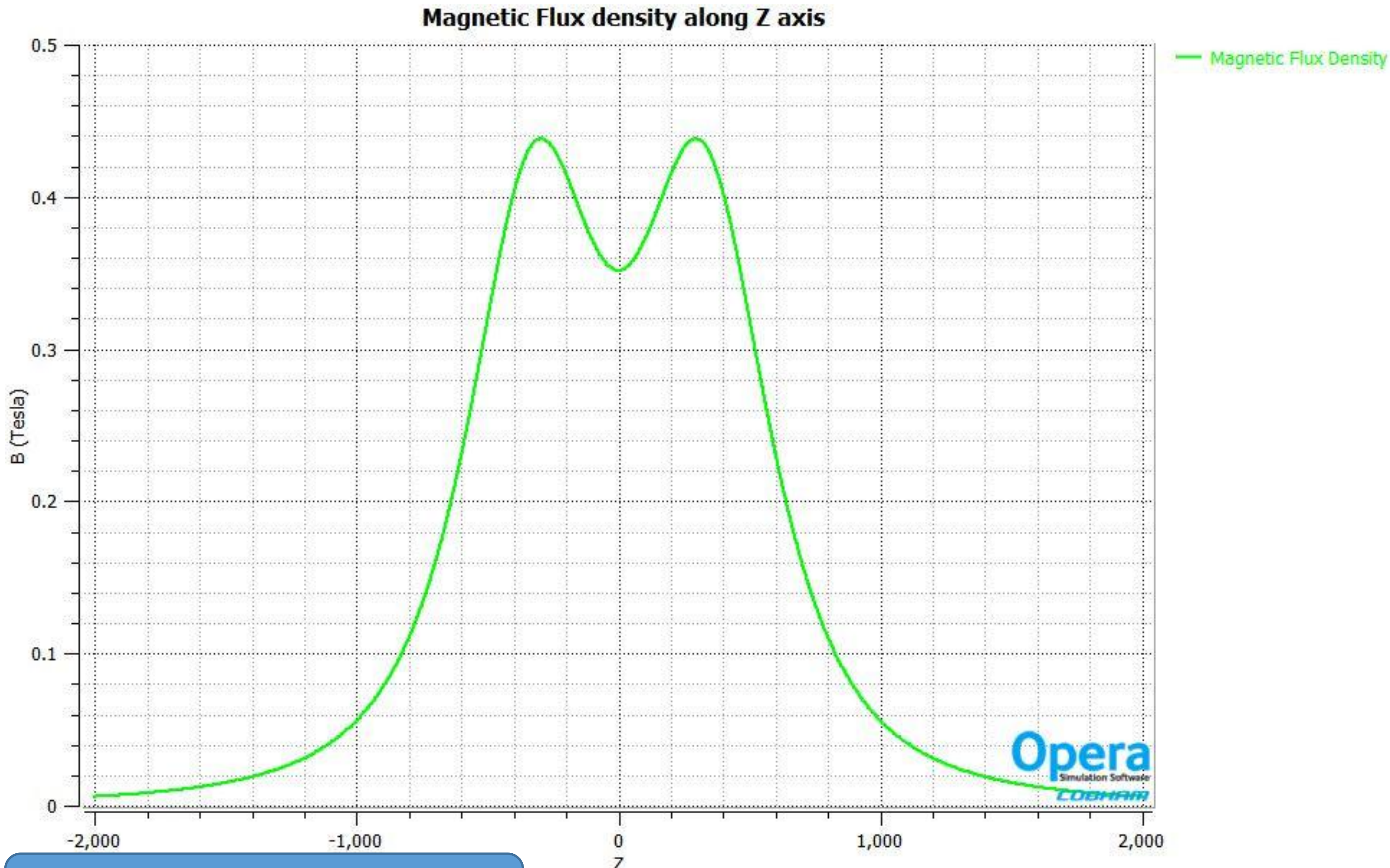
Field Uniformity Configuration-04



B(0,0,0)=0.45 T

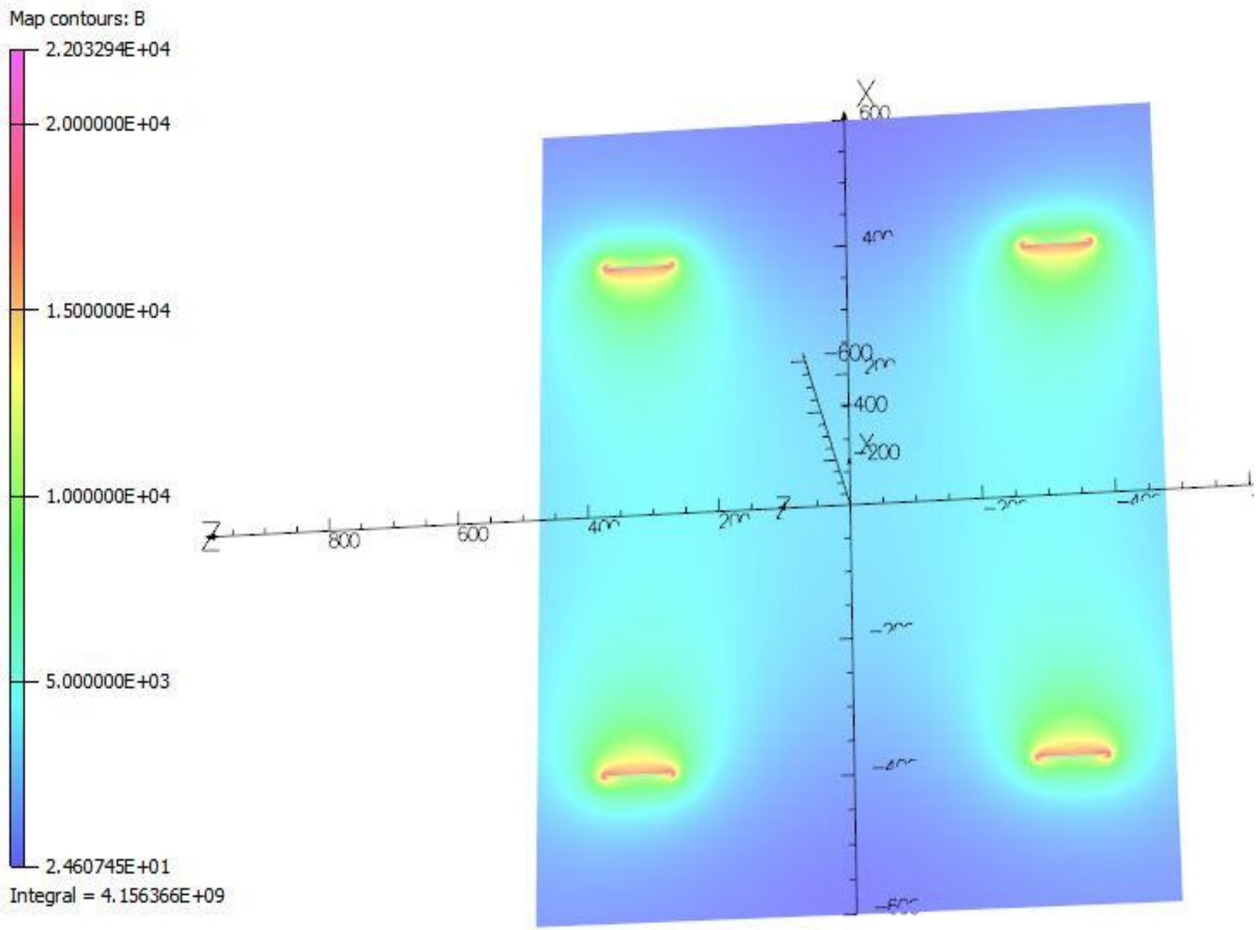
$B_{uniformity}$= 37%
In a DSV of 4.5 m

Design Option 4- Magnetic Field



B(0,0,0)=0.45 T

Design Option 4- Peak Magnetic Field



B_{peak}=2.2 T

Stored Energy = 4 MJ

Magnet Design Options comparison

Magnet Parameters	Five Coil Design			Three Coil Design		Three coil design with Return Yoke		Two coil Design
Magnet ID (m)	7	7	8.2	7.2	7.2	7.2	7.2	7.7
Length(m)	0.085	0.2	0.1	0.4	1	0.4	1	0.9
Number of turns	112	481	250	240	776	240	776	720
Number of layers	7	13	14	3	4	3	4	4
Length of cable (km)	38			23		23		20
Operating current(A)	5000			3000		2500		3600
B_{peak} (T)	4.7			1.92		1.34		2.2
Overall Magnet Length(m)	10			7.8		13		5.4
B_{stray}	200 Gauss			2100 Gauss		100 Gauss		1800 Gauss
Uniformity	17 %			16 %		22 %		37%

What is next ?

- Optimization of three coil design with backing iron to reduce the magnet size.
- Mechanical Design & cryogenic heat load estimation of the magnet has to be carried out

Thank you