Magnetic Field Analysis of the Mu2e Solenoid System

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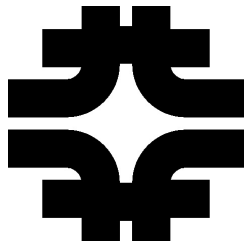
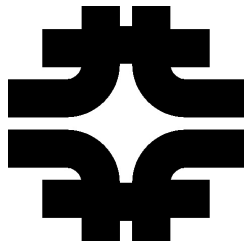
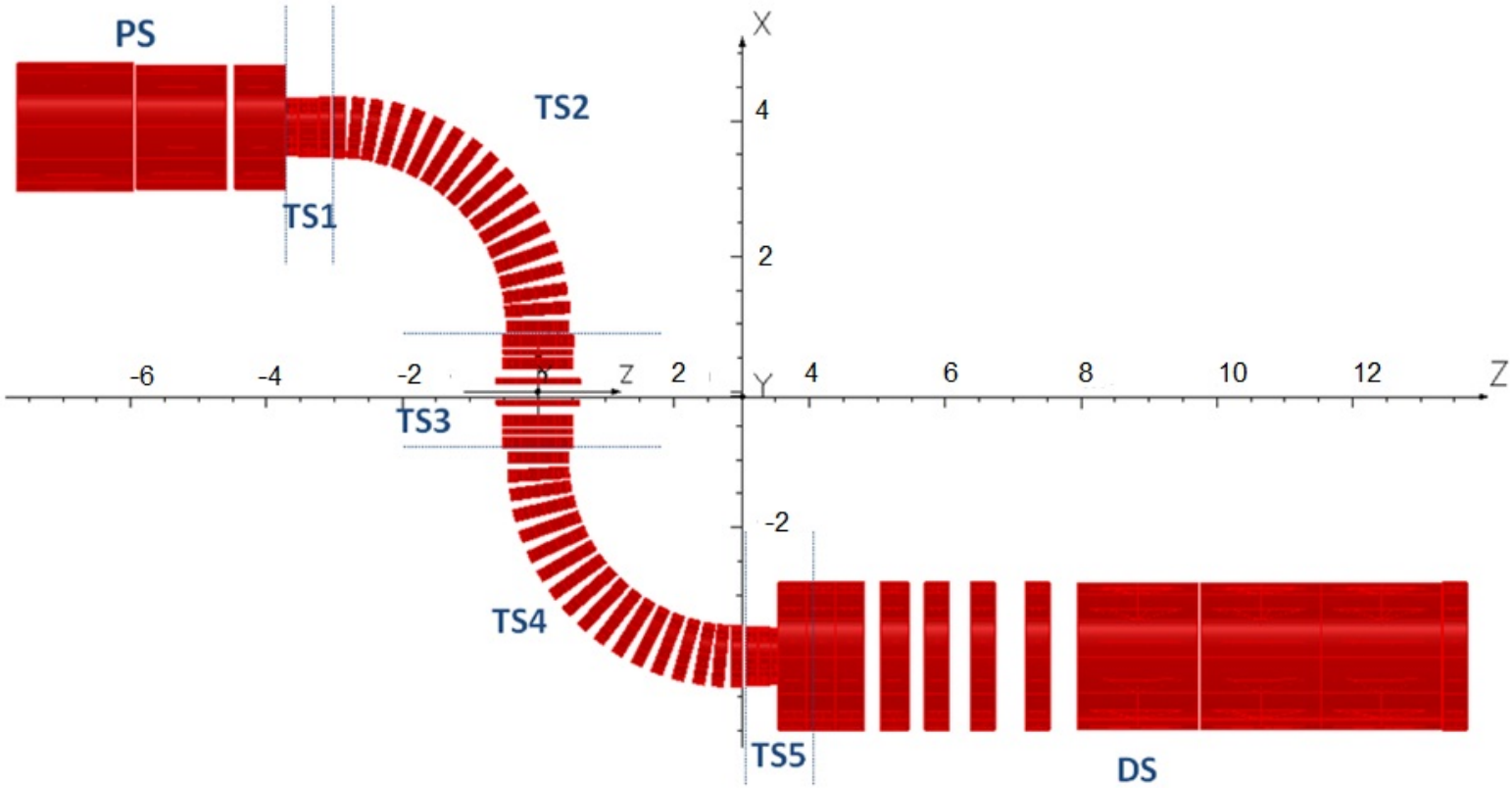
August-September 2013





The Mu2e Solenoid System



Main issues

Field distortion caused by ferromagnetic material

The environment surrounding Mu2e solenoids is populated by ferromagnetic materials that influence the magnetic field.
A high field could also damage equipment.

Effects of coils misplacing and updates

The field may not fulfill the requirements due to misalignments occurred when mounting or updates of the geometry.

Forces on shielding blocks

Shielding blocks have a small percentage of iron so a magnetic force acts on them.

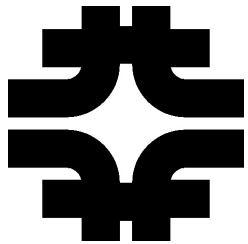
Uniform magnetic field and iron blocks

Objective of the study

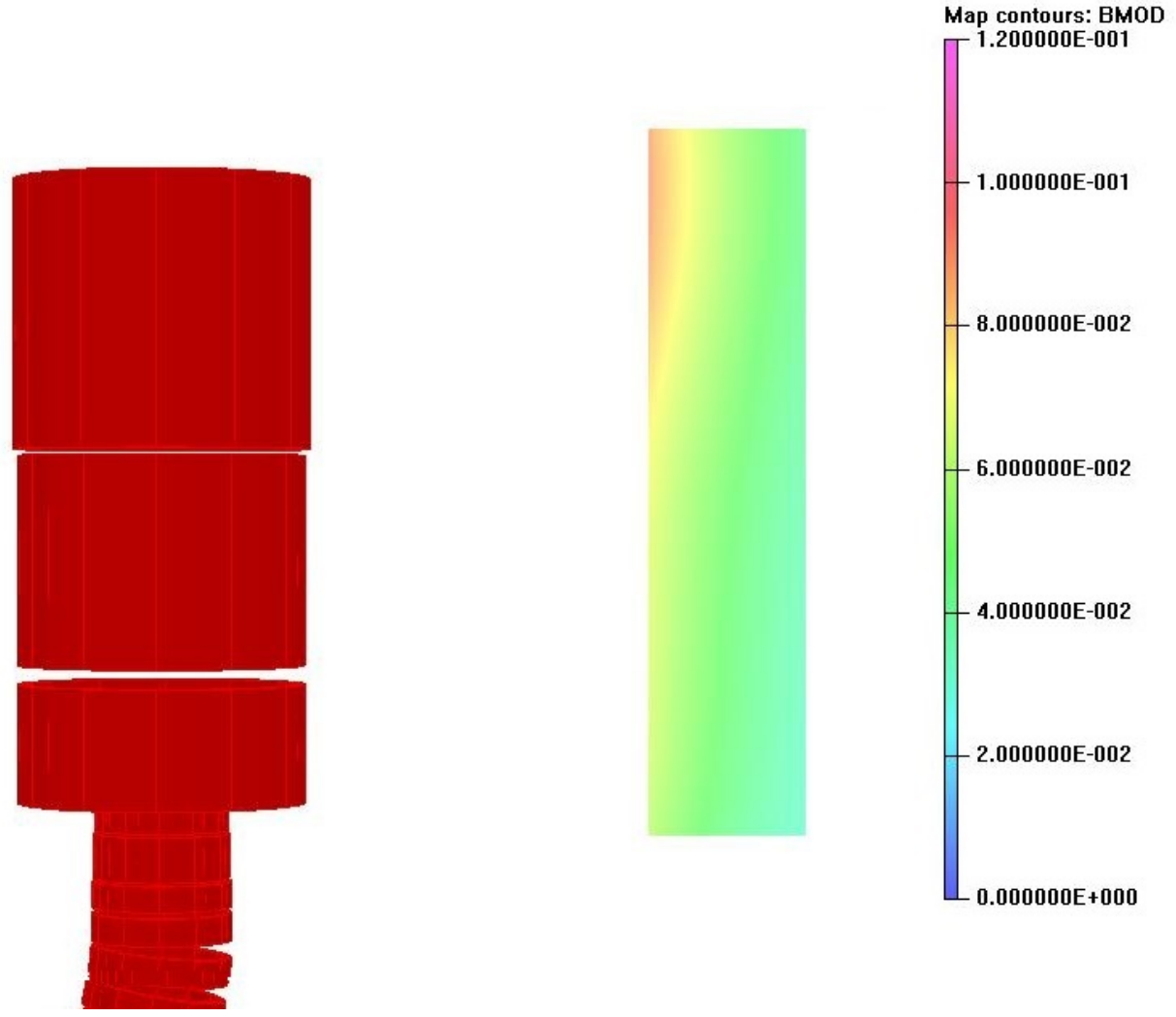
Estimate the distortion of a magnetic field due to the presence of ferromagnetic materials and the field inside them.

Methodology

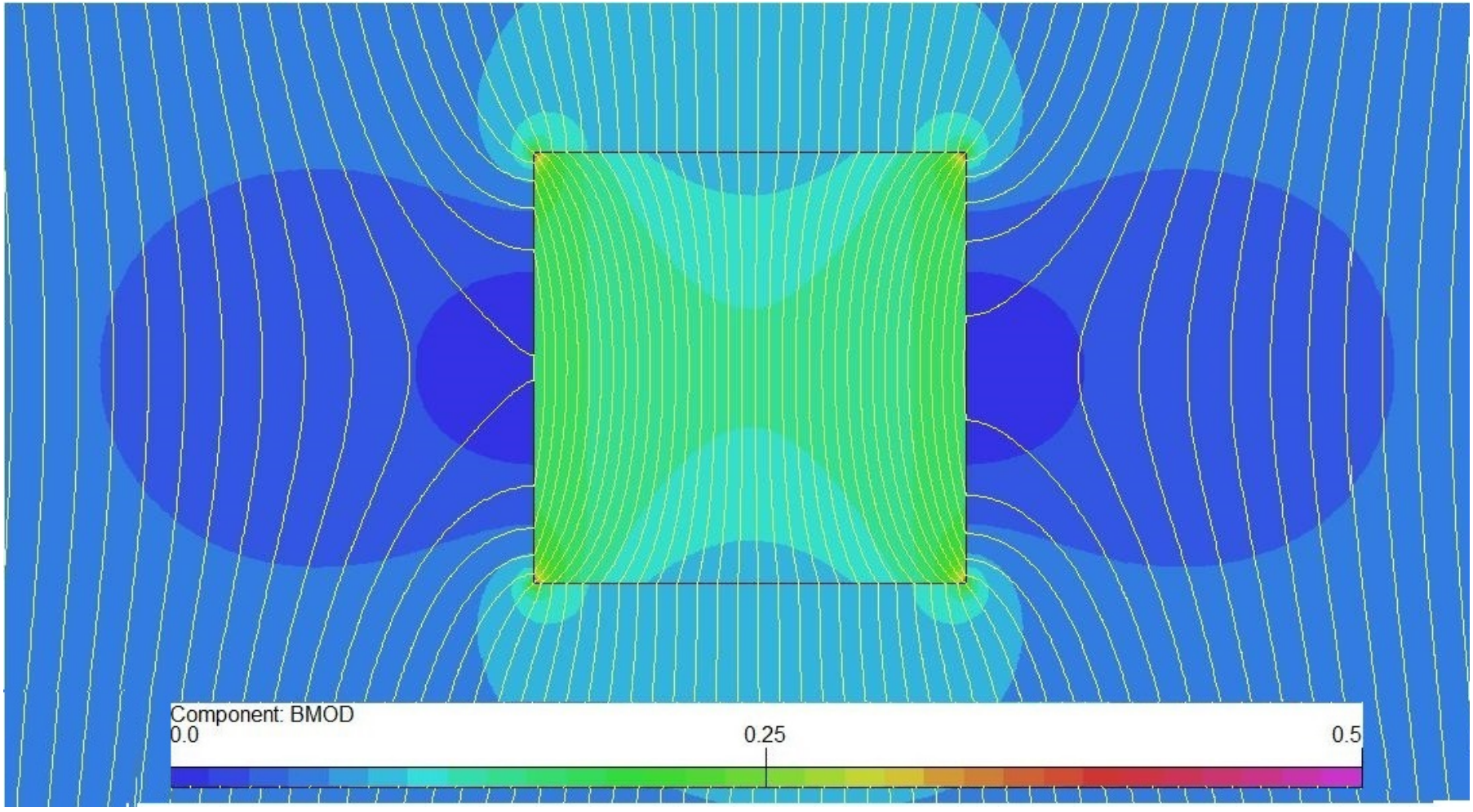
Computation of the field using a FEM 2D model of a block and simulating an uniform magnetic field.



Why uniform?


Map contours: BMOD
1.200000E-001
1.000000E-001
8.000000E-002
6.000000E-002
4.000000E-002
2.000000E-002
0.000000E+000

Example



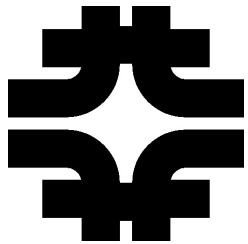
Outcomes

Field at the centre of the block

It has been used to estimate the amplification of the field inside the ferromagnetic material.

The radius of distortion

It is a parameter used to quantify the range of the distortion.
Def: "the maximum distance from the surface of the block to a point where the field is varying more than 5%".



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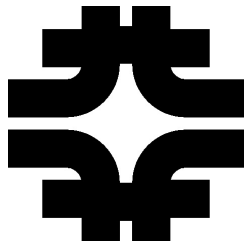
The behaviour of both of these parameters was investigated when changing

- the size of the block,



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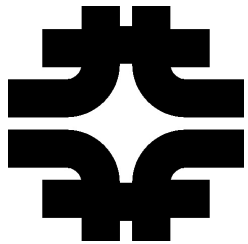
- the shape of the block,



Outcomes

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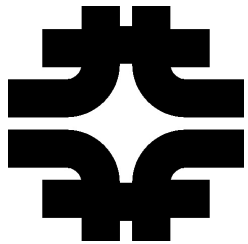
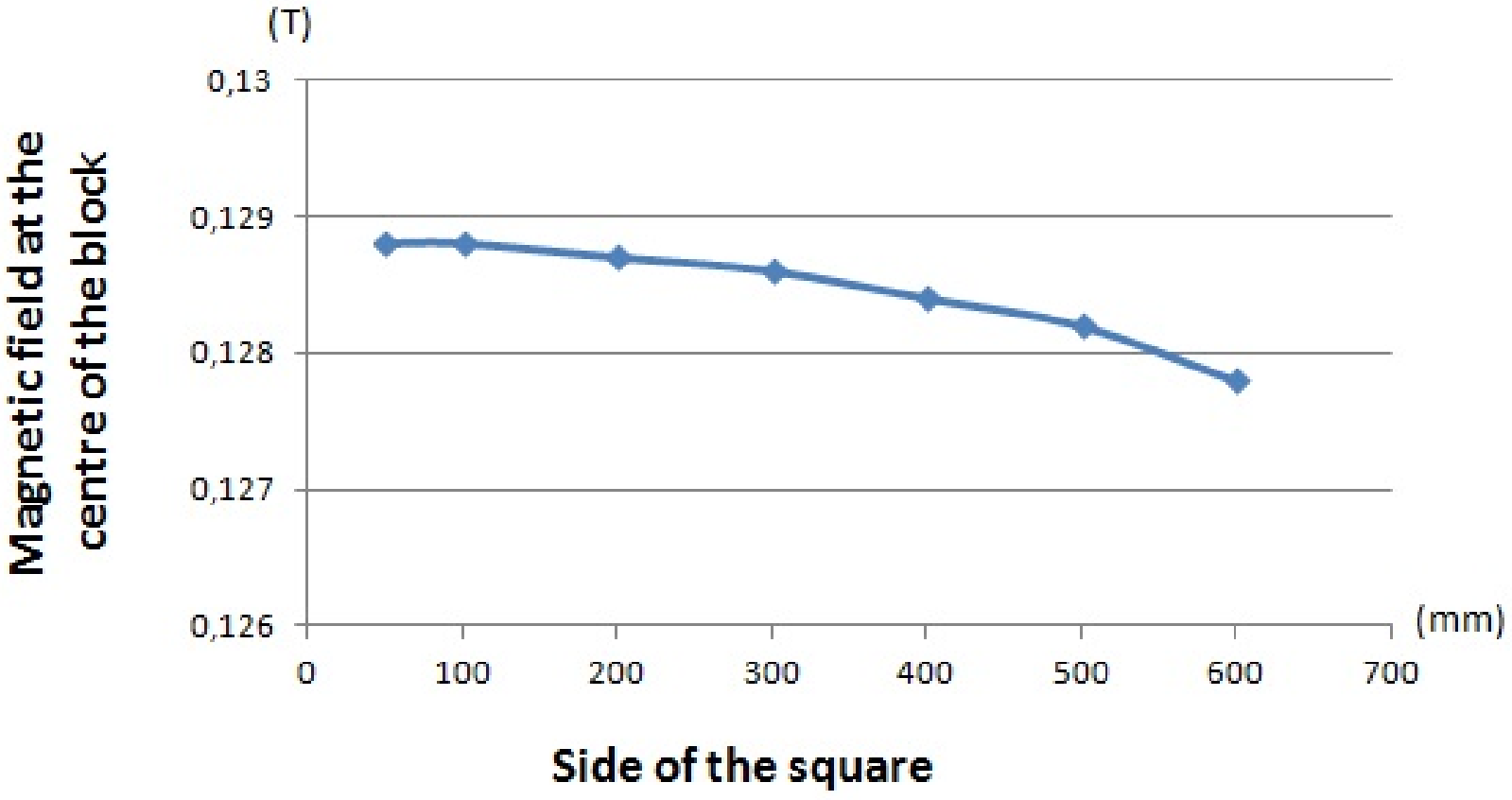
The behaviour of both of these parameters was investigated when changing

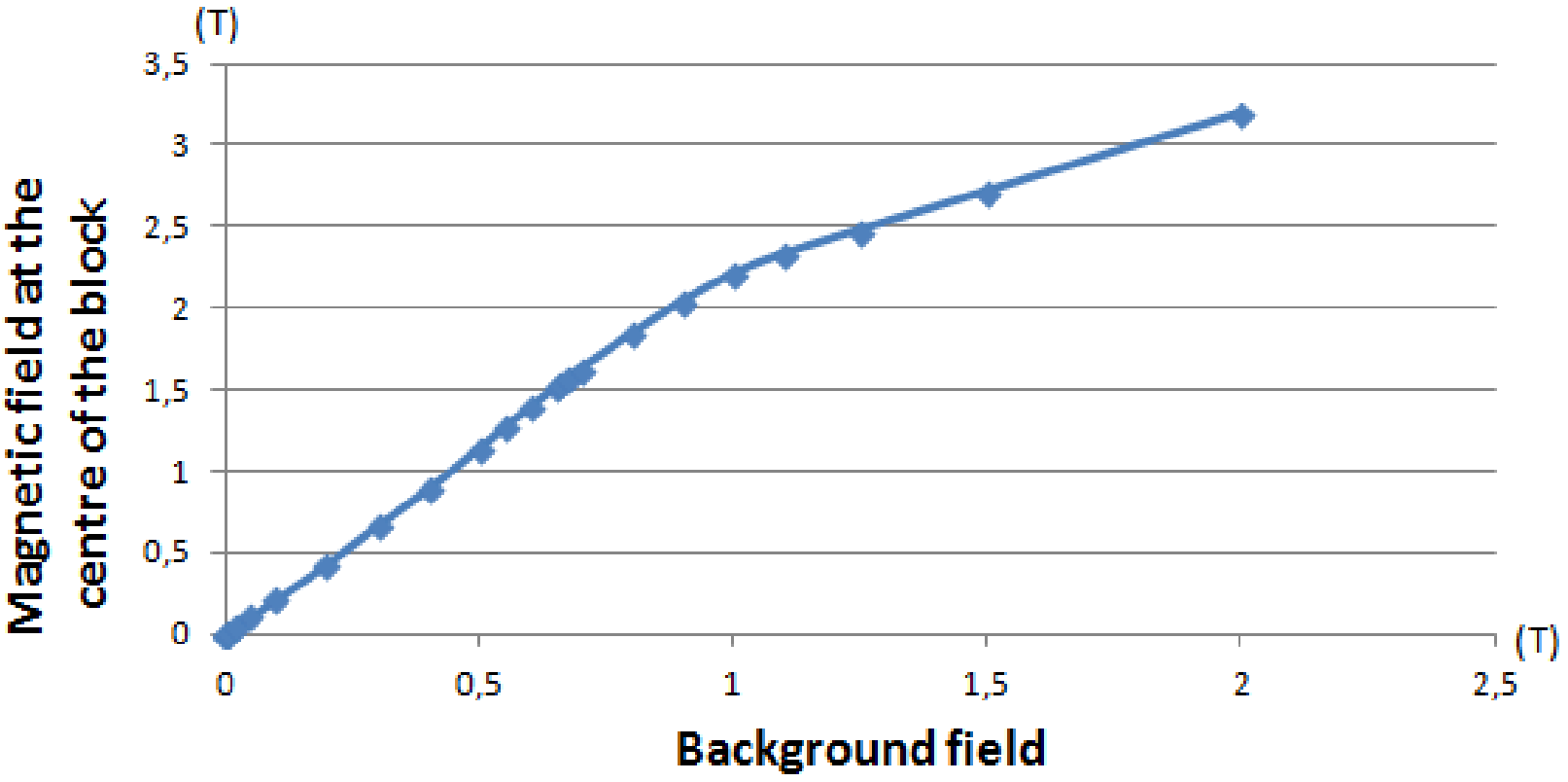
- the size of the block,
- the shape of the block,
- the background field.



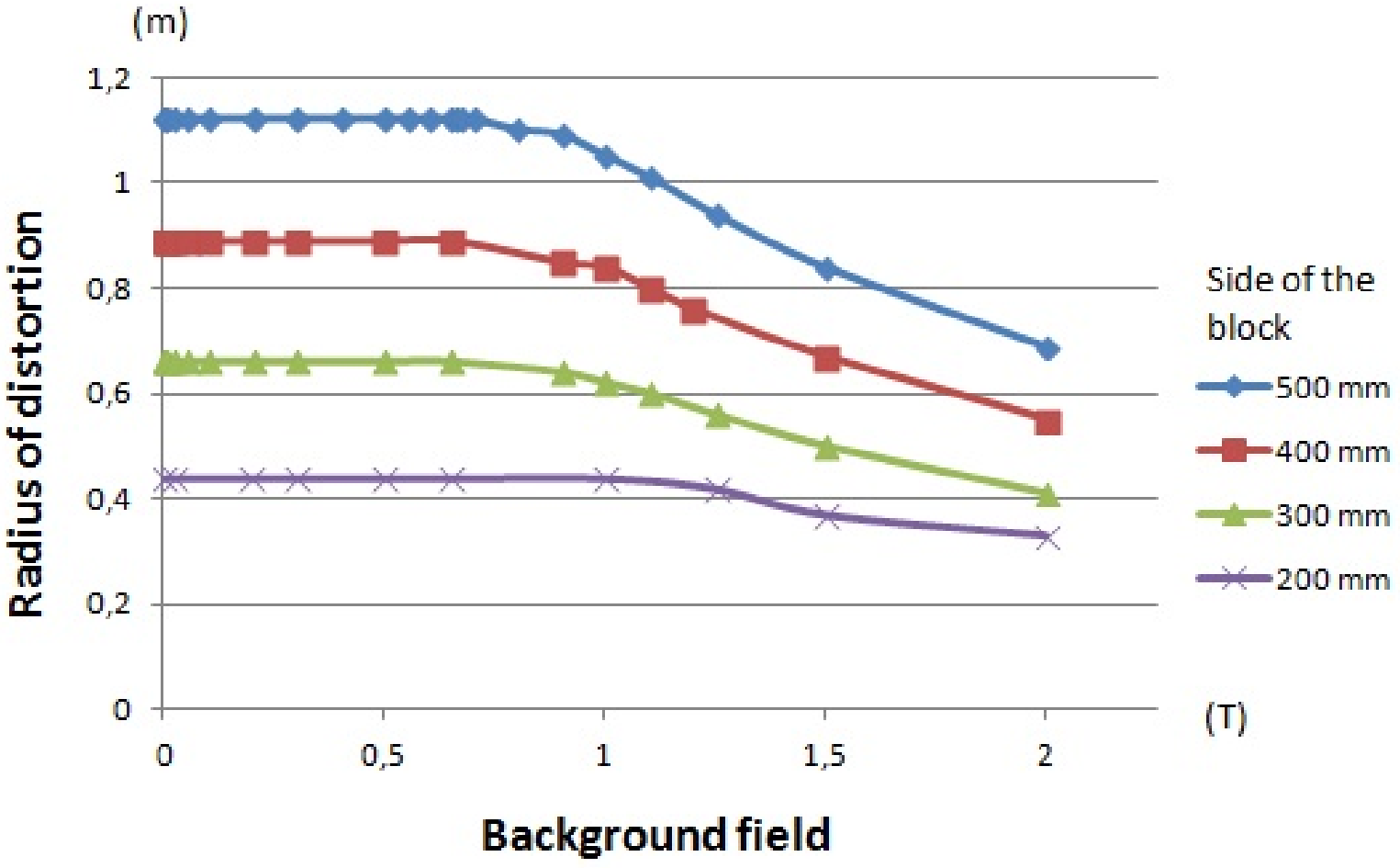
Field inside the block



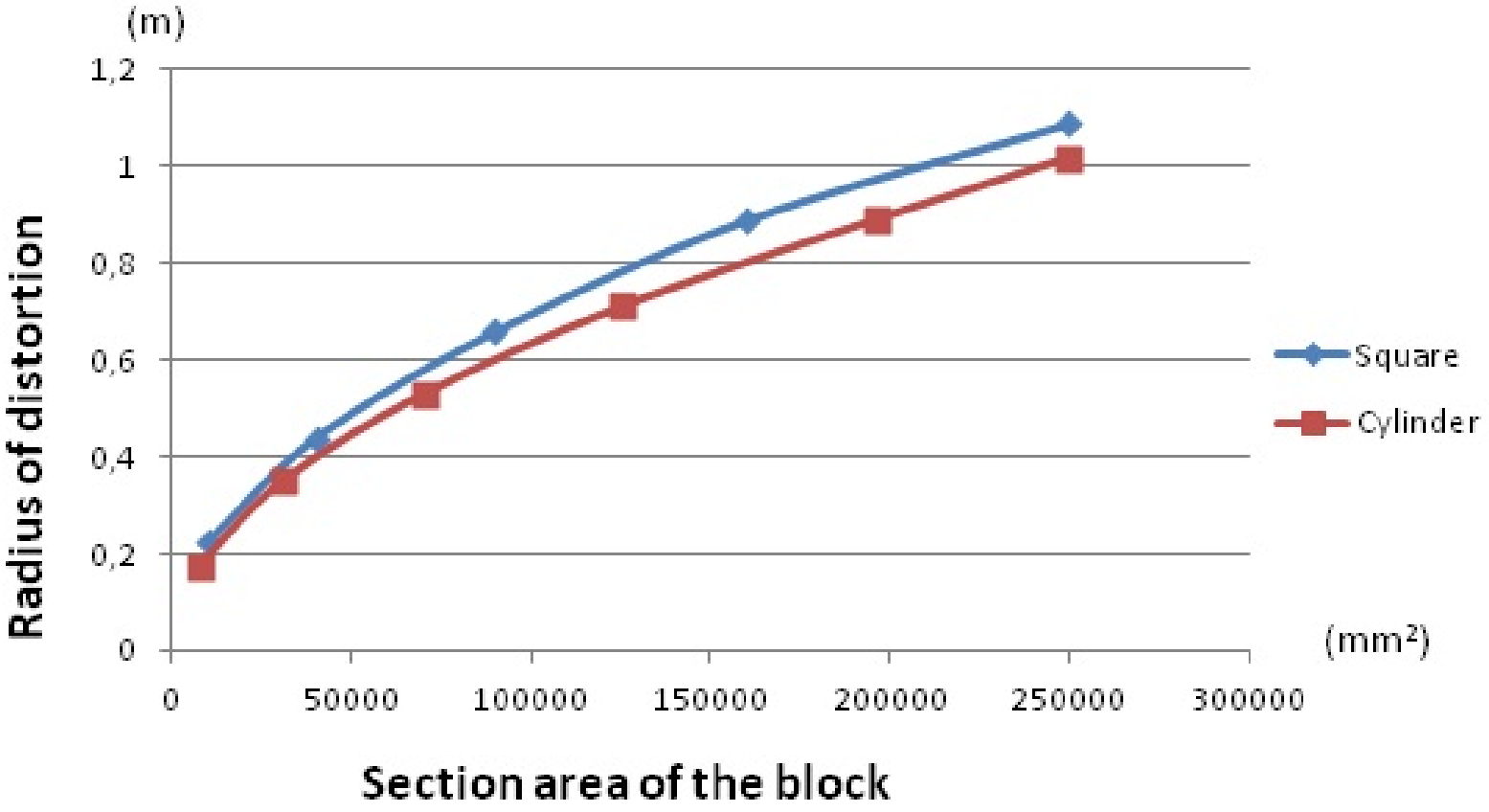
Field inside the block



Radius of distortion



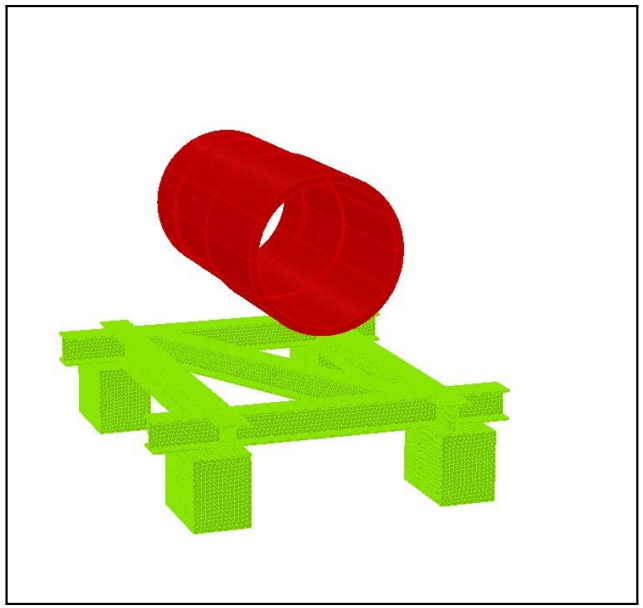
Radius of distortion



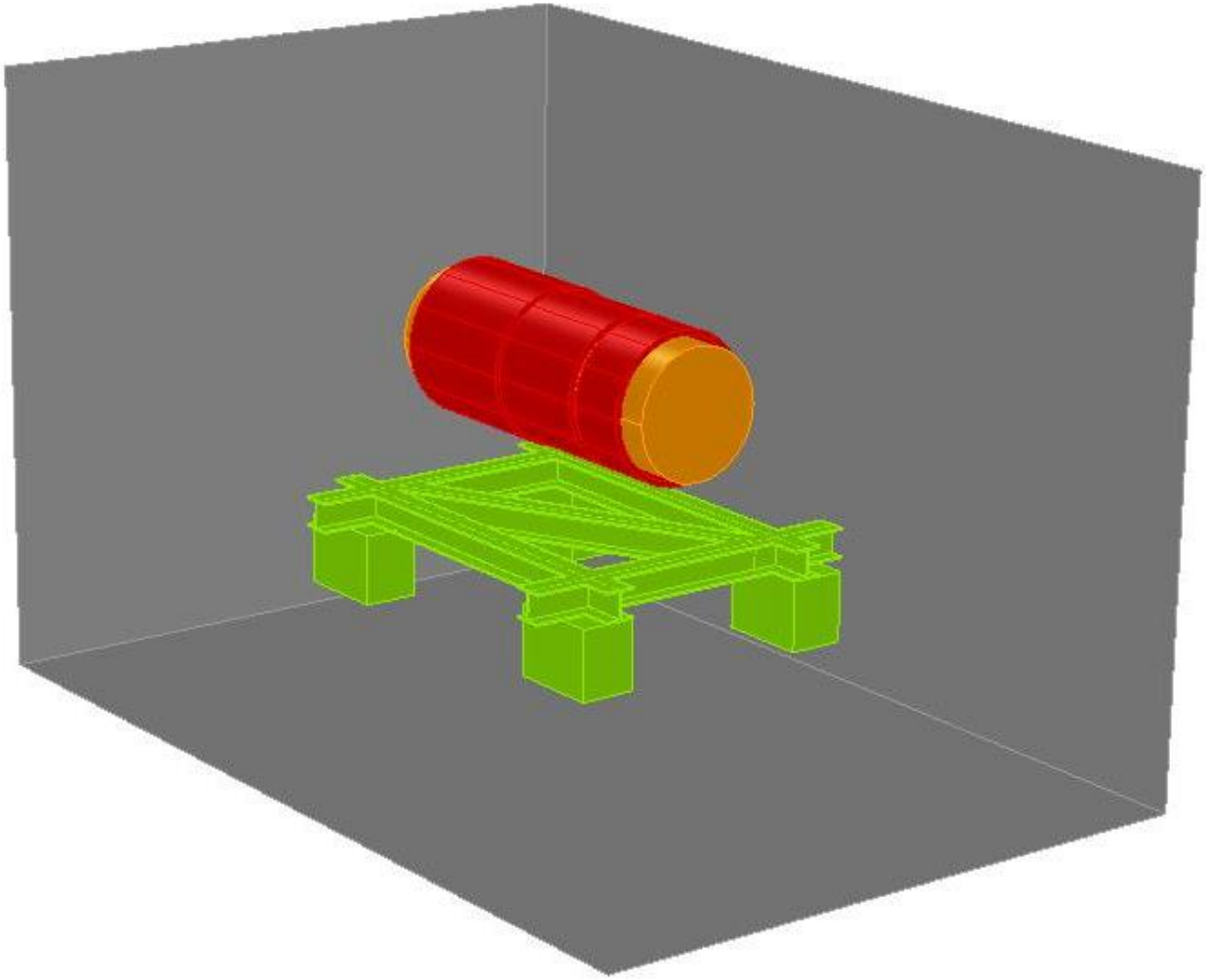
PS Support

Description

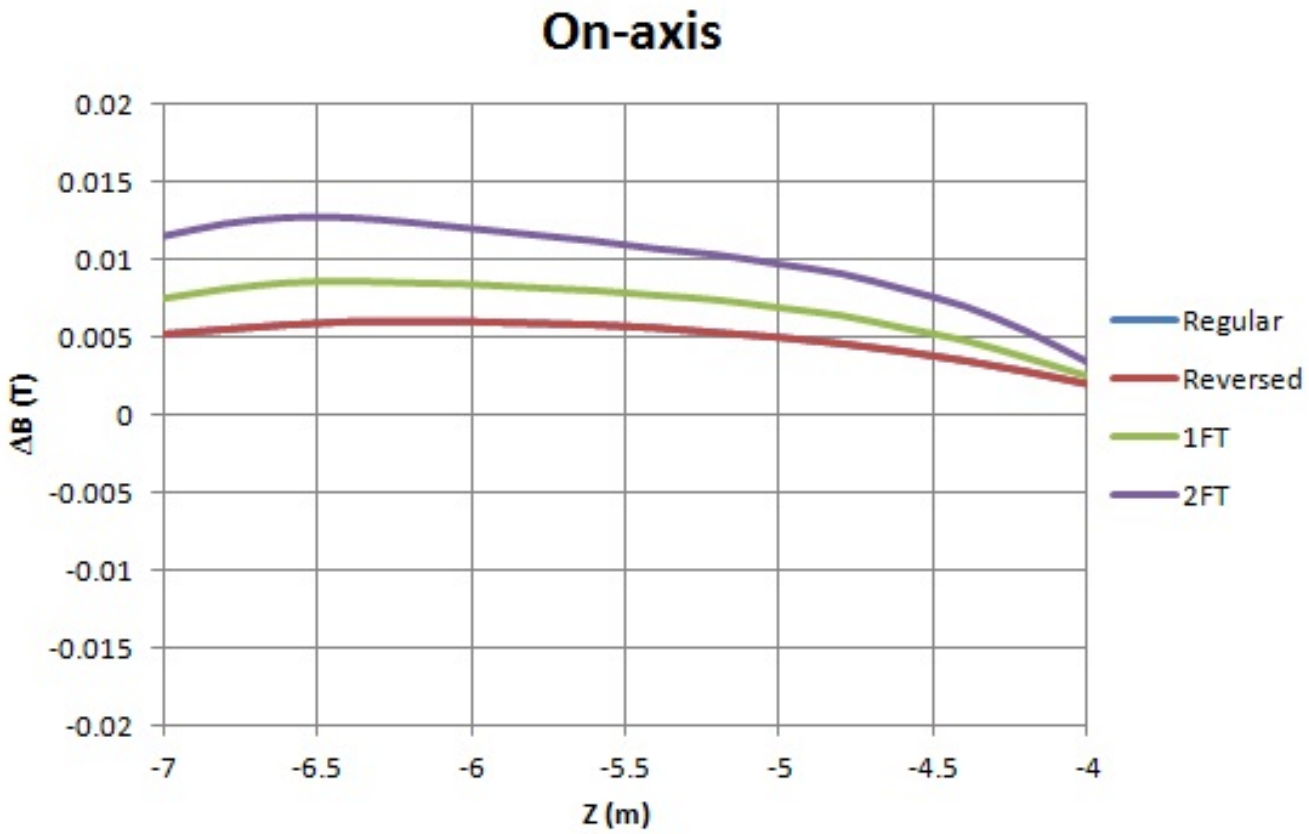
Ps is supported by an iron beam frame, so the field is altered.
Data from a previous analysis were not enough precise.



Different mesh



New result


On-axis
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
ΔB (T)
-7
-6.5
-6
-5.5
-5
-4.5
-4
Z (m)
Regular
Reversed
1FT
2FT

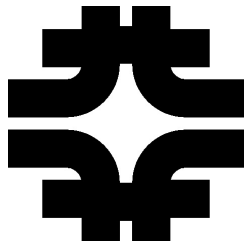
DS tolerences

Requirement

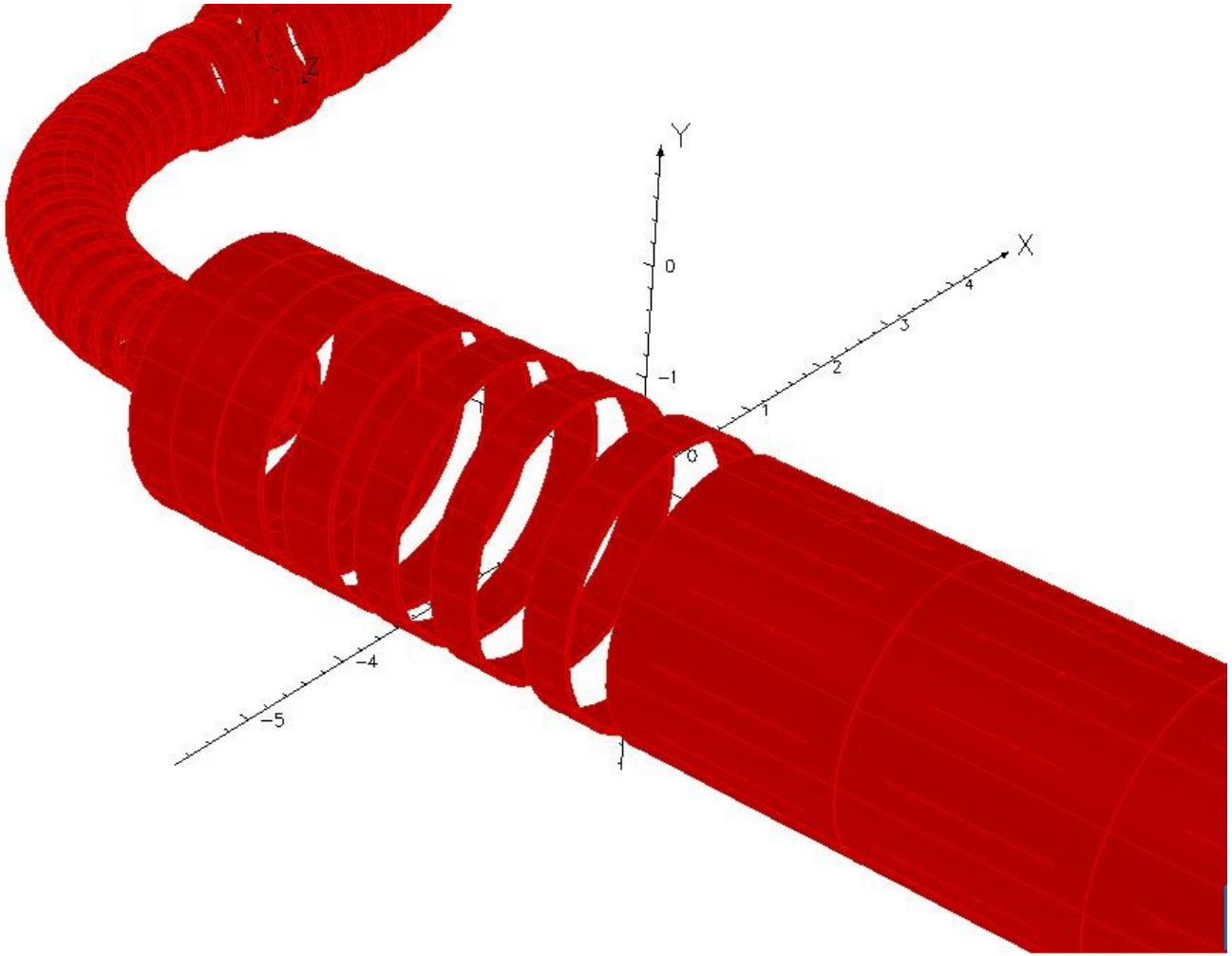
The field gradient inside the DS must be negative to perform the experiment. Coils misplacing can make it positive.

Previous analysis

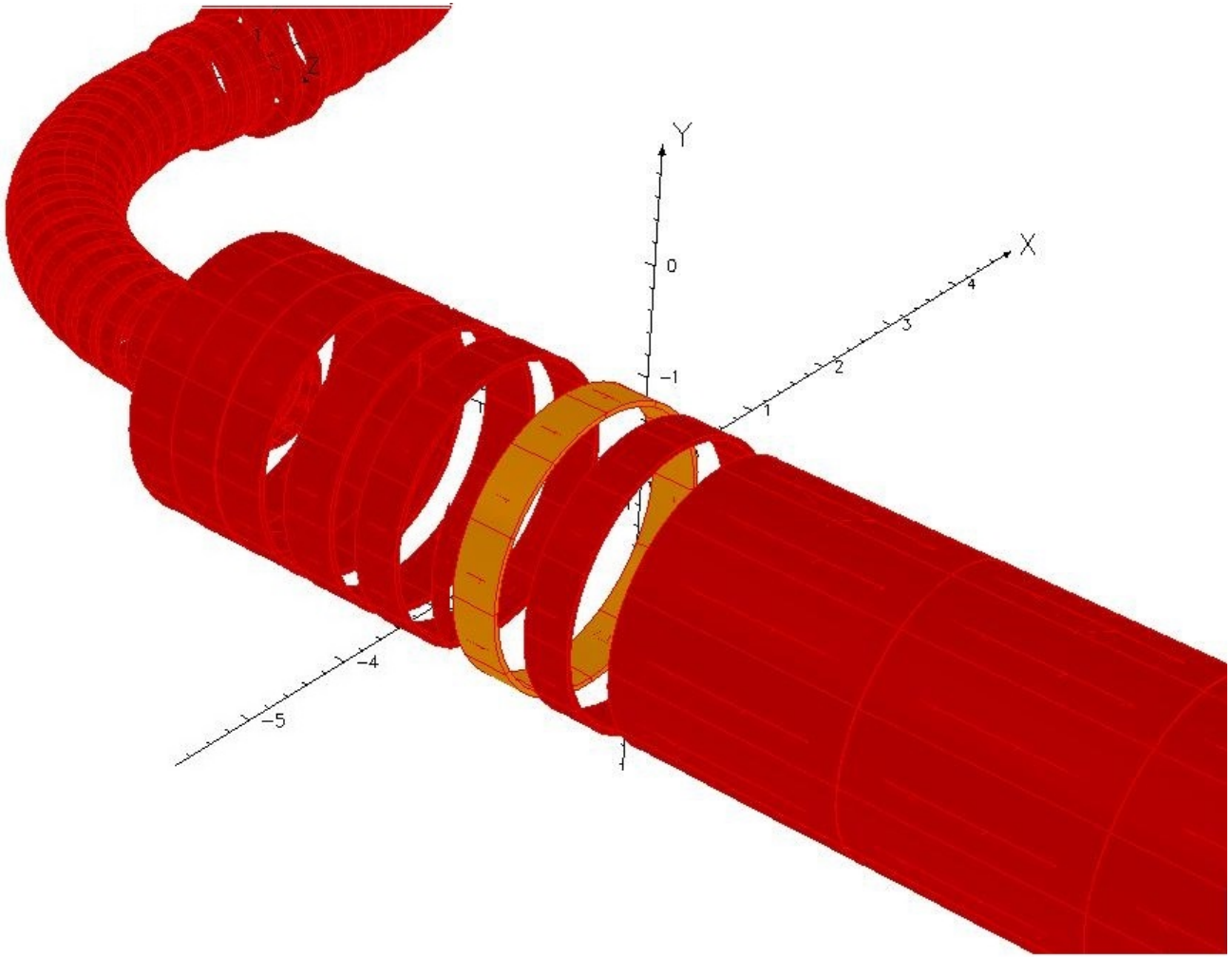
In a previous study a MatLab script was written to introduce positioning errors and calculate the field gradient in the last part of DS.



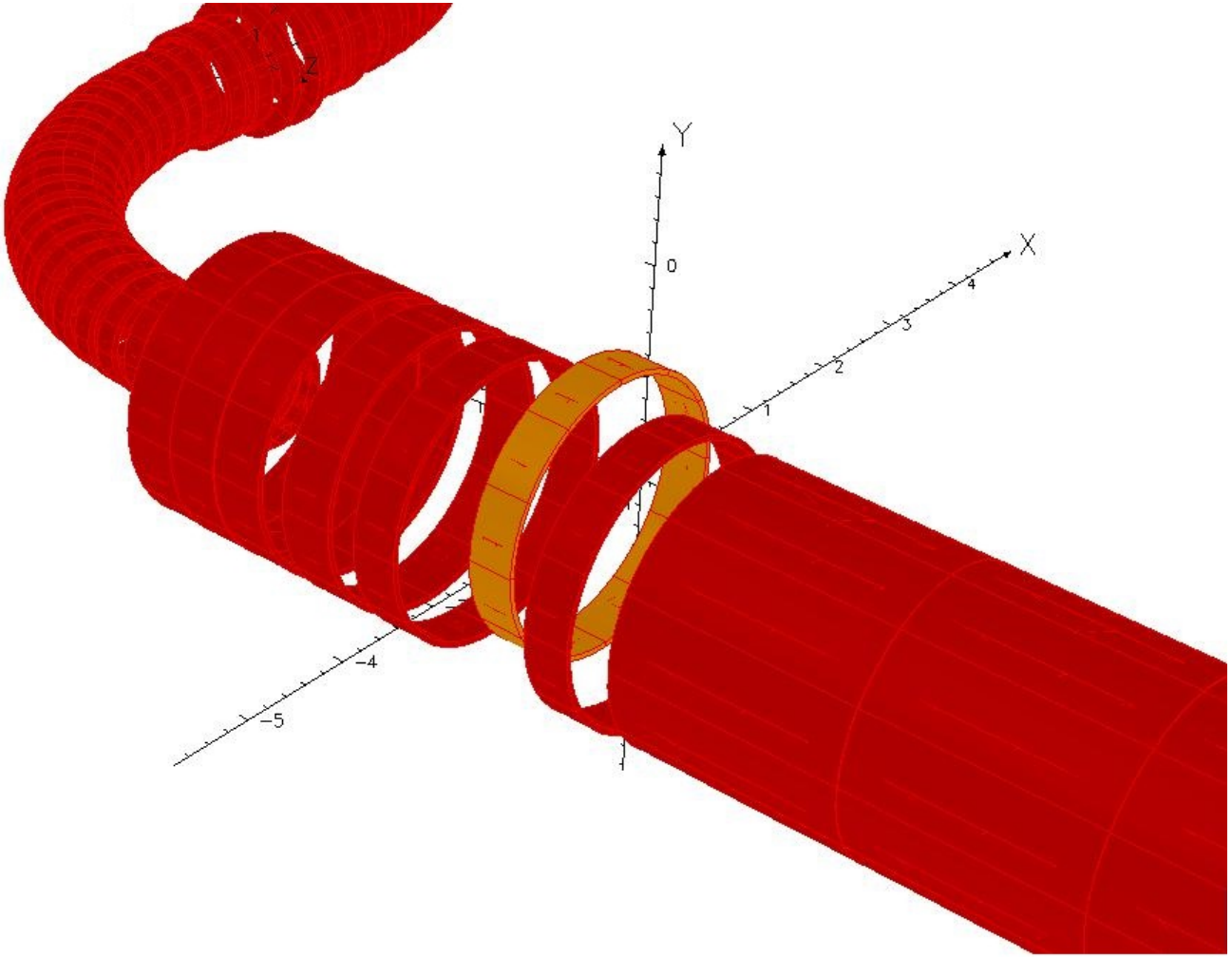
Ideal configuration



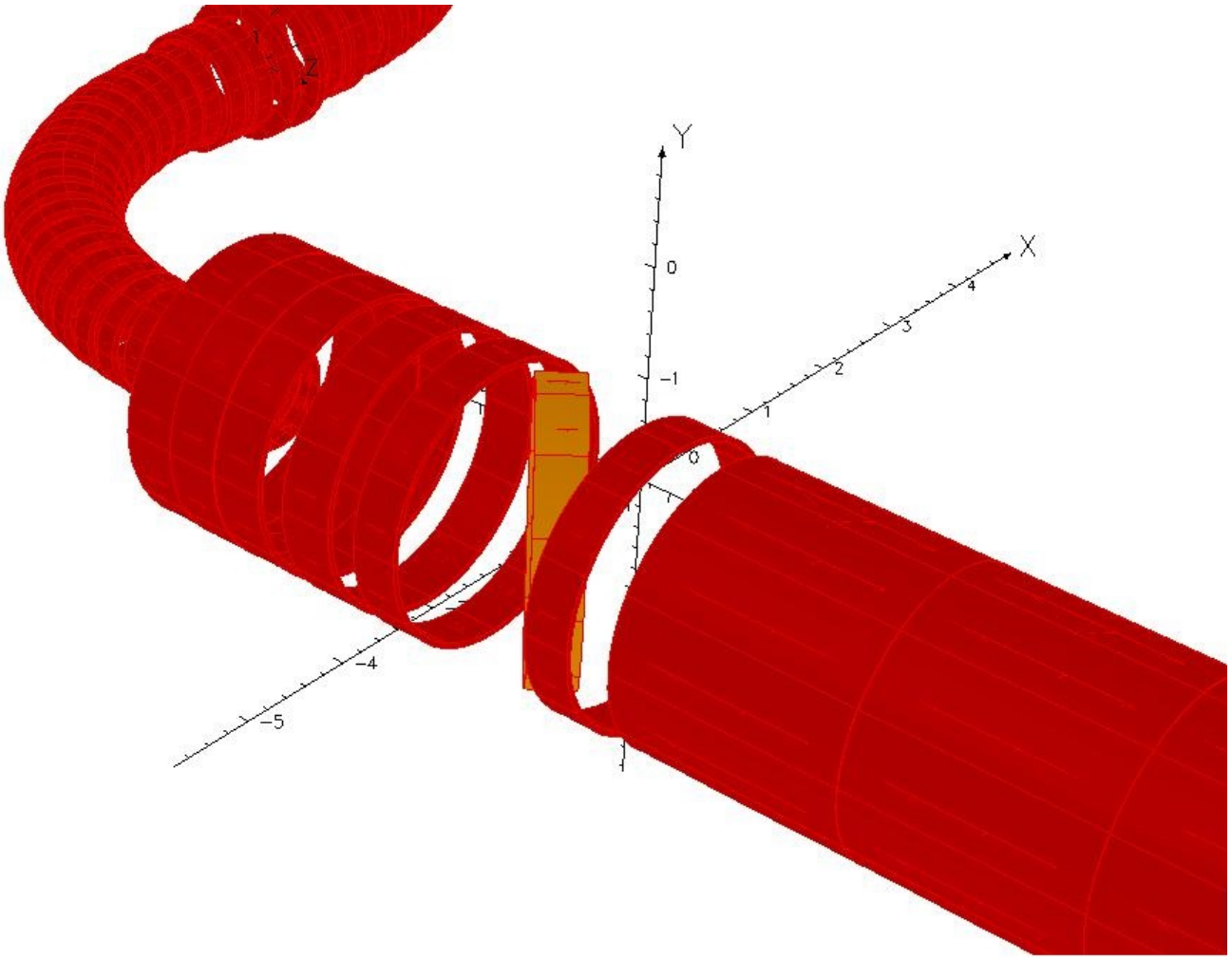
Errors - axial



Errors - radial



Errors - yaw angle



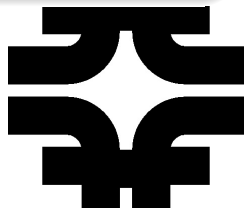
Worst case analysis

Definition of worst cases

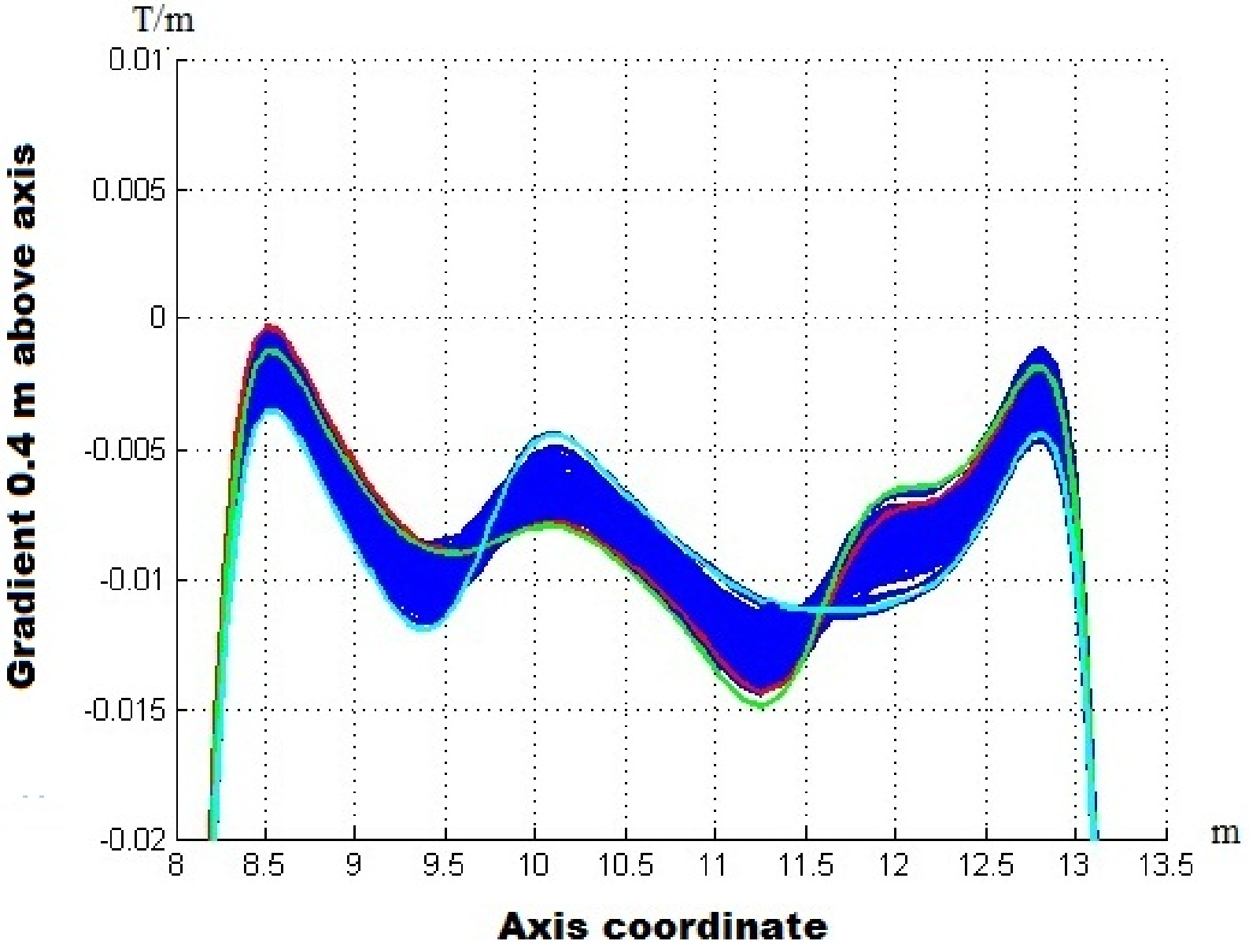
The field gradient was evaluated in three positions: on the axis of the coils, 0.4 m and 0.7 m far from the axis in the vertical direction.
Maximum and minimum gradient have been calculated for the second case (0.4 m).

Methodology

A routine to find configurations which provide maximum and minimum was implemented. These configurations have been imported in Opera to calculate field maps.



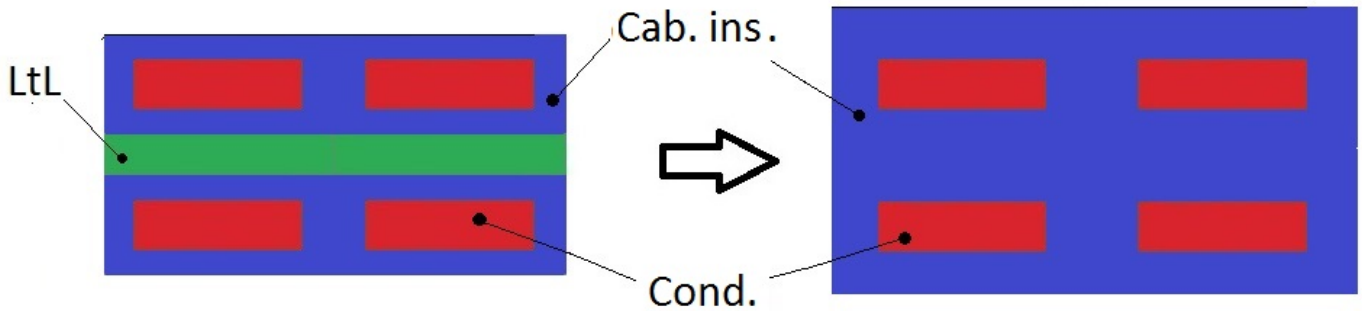
Gradient


T/m
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
Gradient 0.4 m above axis
8
8.5
9
9.5
10
10.5
11
11.5
12
12.5
13
13.5
m
Axis coordinate

Gradient inside TS - change of geometry

Modification of insulating system

Conductors (in red in the figure below) are currently insulated with a cable insulation (Pr. ins.: white with black outline) and layer to layer insulation (LtL: green).



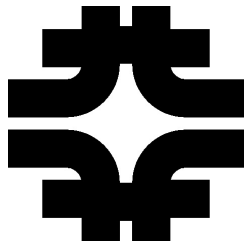
Verifying this possibility

Requirement

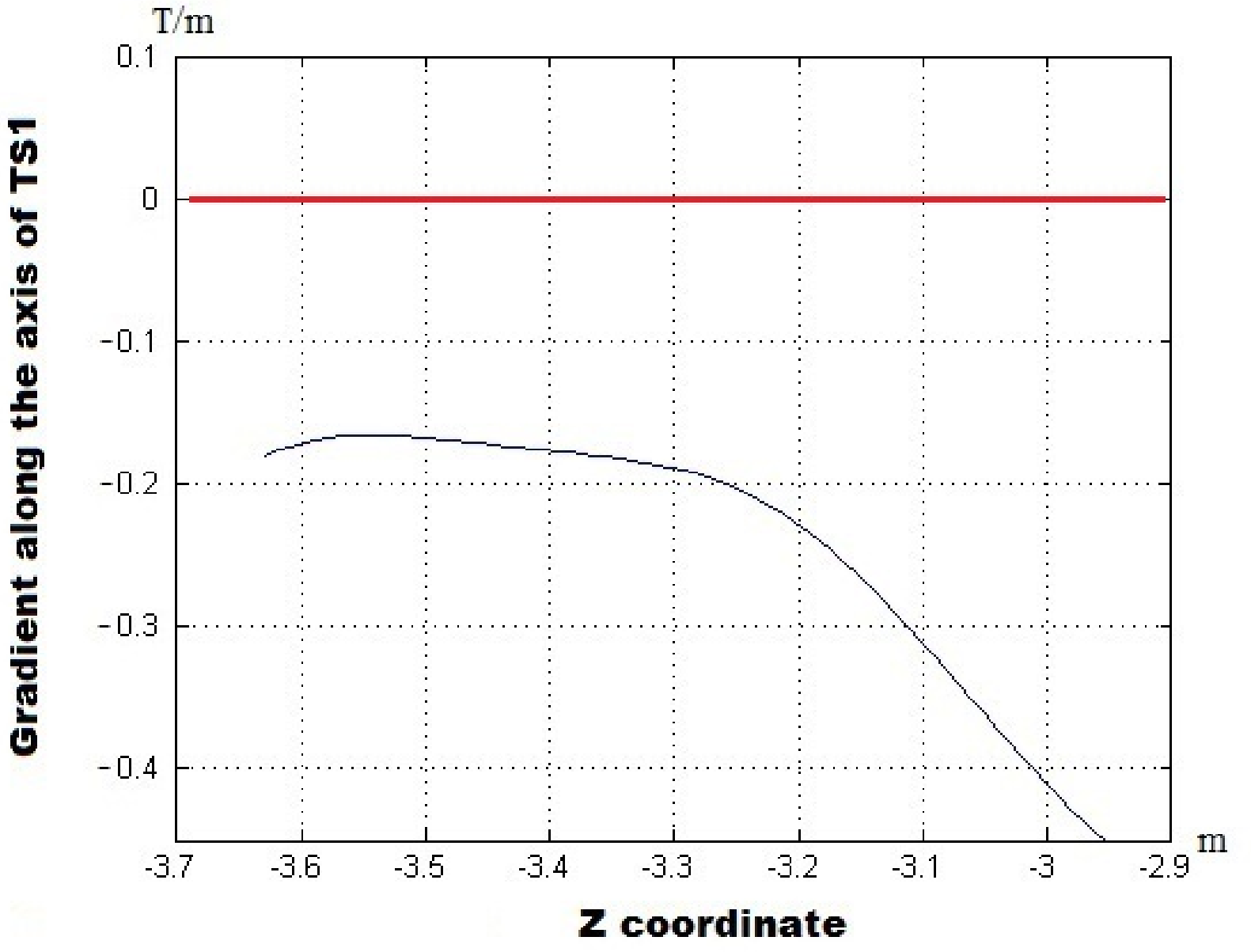
The gradient of the magnetic field must be negative in TS1, TS3 and TS5 within a certain volume surrounding the axis.

Technique of analysis

The geometry of Mu2e has been updated then imported in MatLab where the field gradient has been comuputed on the axis of the whole TS, 0.45 m above the axis, 0.45 m and -0.45 m in the horizontal direction.



Results were positive



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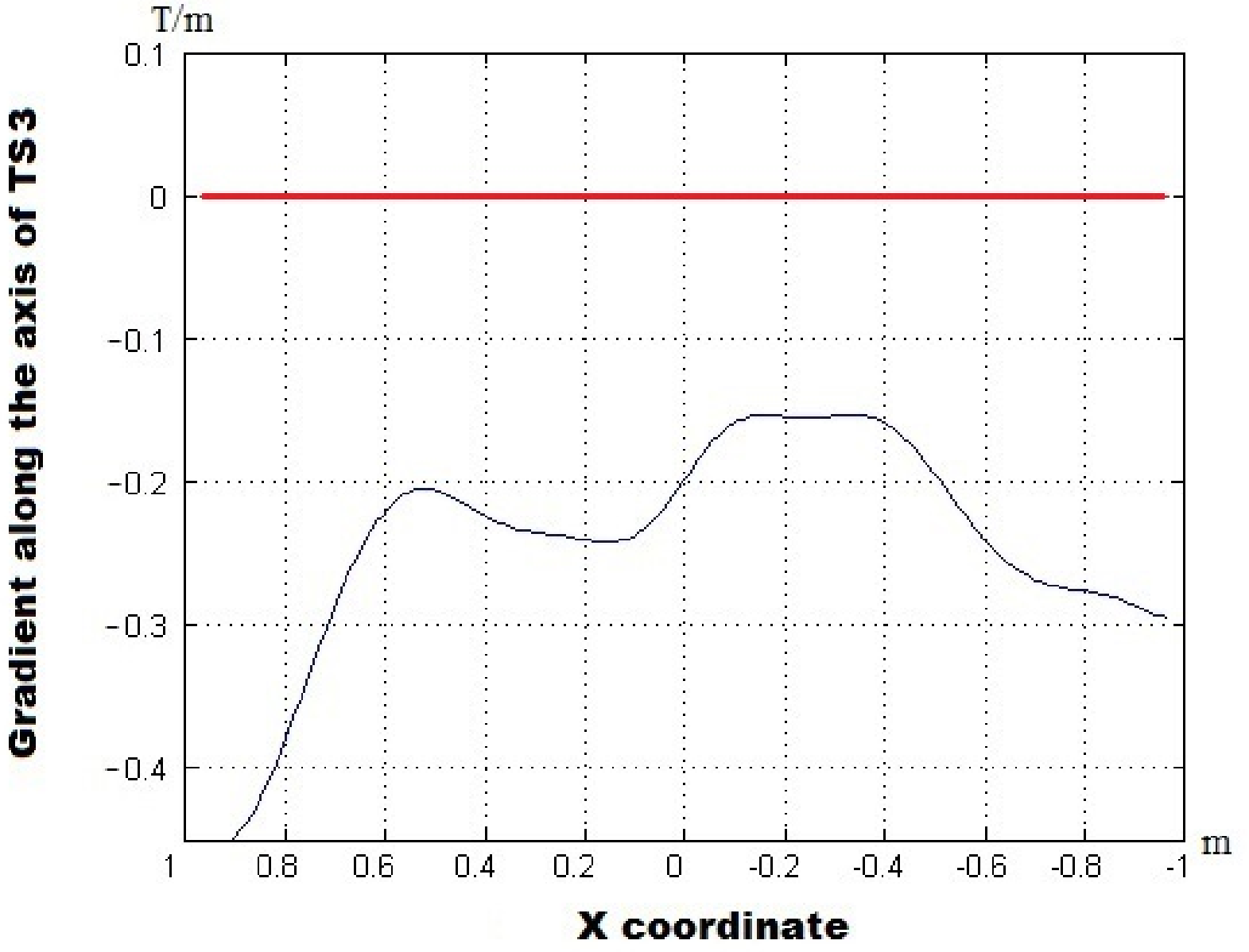
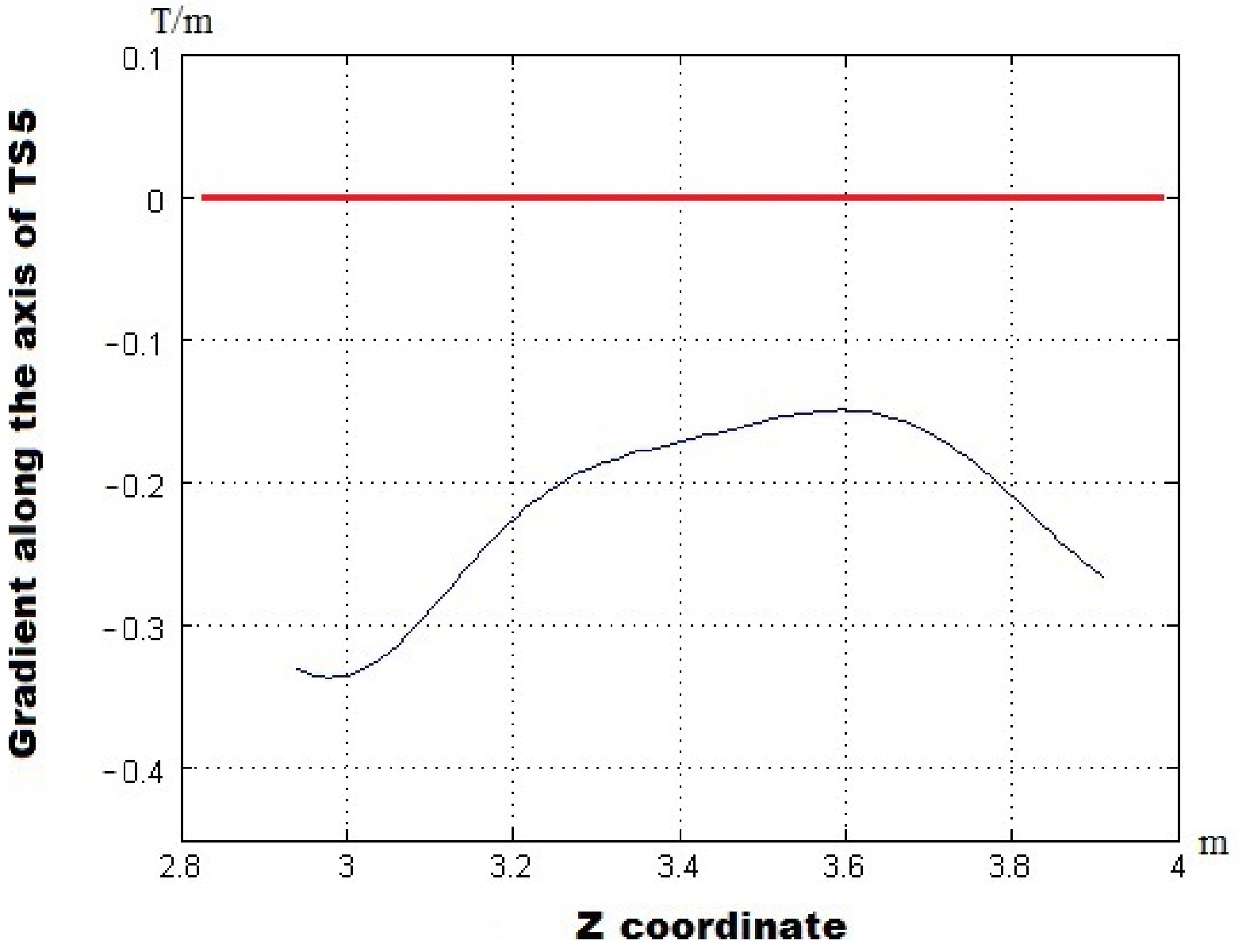


Results were positive



Forces on shielding blocks

Purpose of the study

Shielding blocks are partially made of iron so a magnetic force acts on them. Structural analysis need an estimation about its order of magnitude.

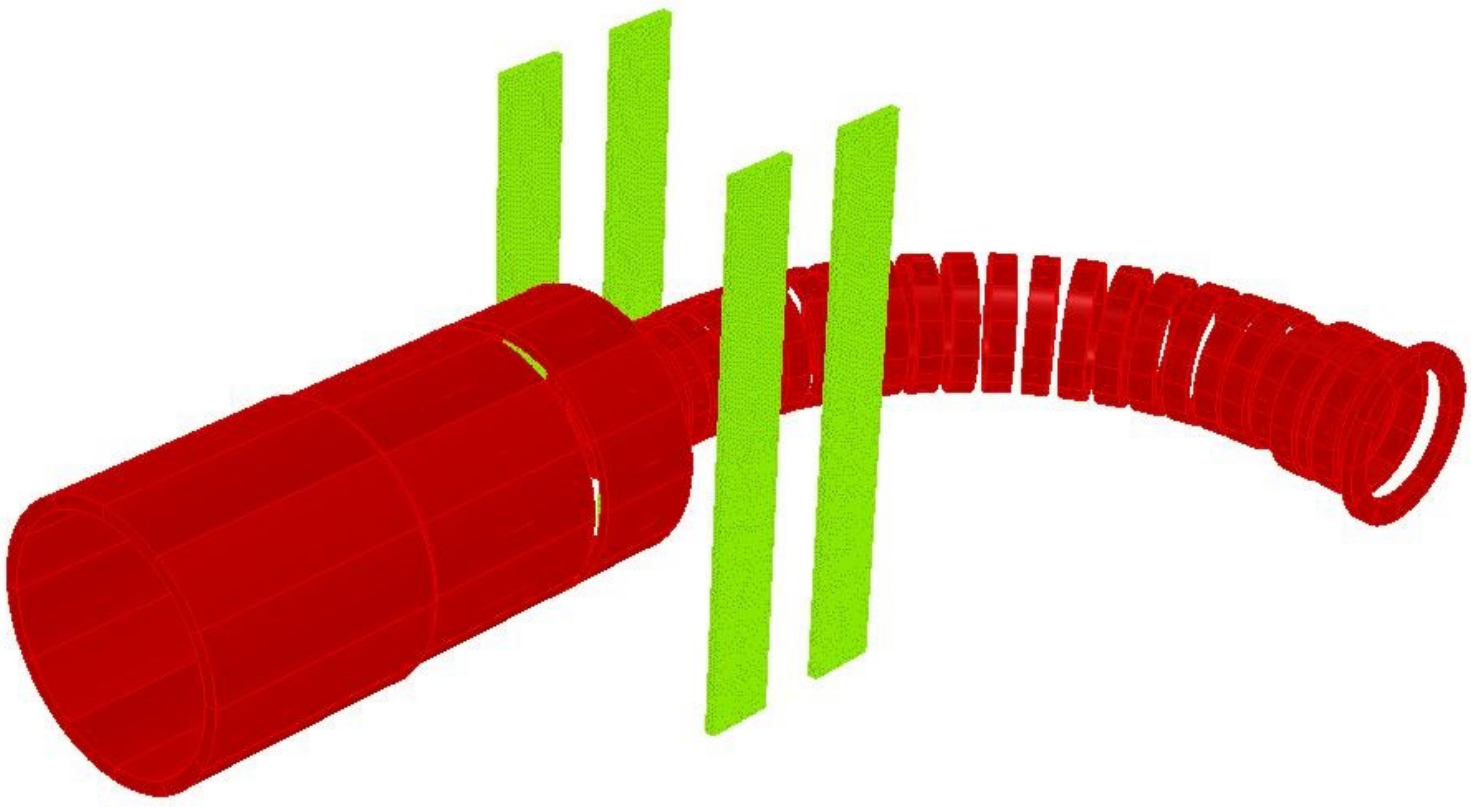
Methodology

Several 3D FEM simulation were performed: the model included PS, half TS and from 0 to 6 blocks.

About the blocks

Simulating the real geometry of a shielding block (with a wire frame) would be very time consuming; it has been substituted with a full iron block with the same mass.

Example - four blocks

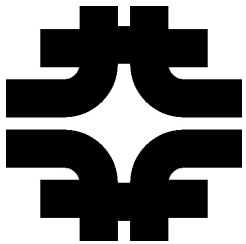


Results

Block #	6 blocks		5 blocks		4 blocks	
	Fx (N)	Fz (N)	Fx (N)	Fz (N)	Fx (N)	Fz (N)
1	3.7E+04	-4.7E+03	3.7E+04	-4.7E+03	3.9E+04	-7.1E+03
2	7.2E+03	-6.3E+03	7.3E+03	-6.3E+03	7.0E+03	-7.0E+03
3	4.0E+02	-9.4E+03	4.3E+02	-9.5E+03	-2.5E+01	-9.8E+03
4	-3.3E+04	-3.4E+03	-3.3E+04	-1.0E+04	-2.7E+04	-1.1E+04
5	-8.2E+03	-6.4E+03	-4.6E+03	-8.5E+03	-	-
6	-5.8E+02	-6.4E+03	-	-	-	-
Total	**2.7E+03**	**-4.3E+04**	**7.3E+03**	**-3.9E+04**	**2.0E+04**	**-3.5E+04**

Conclusions

- Results from the field distortion analysis could be helpful to evaluate if equipment which has to be placed near to the solenoid system can interfere with the experiment or be damaged.
- The DS Tolerance study has been deepened since it is possible to examine worst cases more in detail.
- The change of insulating system in TS does not compromise the field gradient.
- The order of magnitude of magnetic forces acting on shielding blocks may be useful for the structural analysis.



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