Study of the magnetic field for the T600 and of the related mechanical forces

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Purposes

The next phase of the ICARUS programme foresees the possibility to introduce a magnetic field in the active volume, to achieve recognition and momentum measurement of charged particles.

A dedicated simulation was performed to study possible configurations of the field surrounding ICARUS T600, aiming to have a field inside the active volume of the order of 1 T.

The purpose is to evaluate:

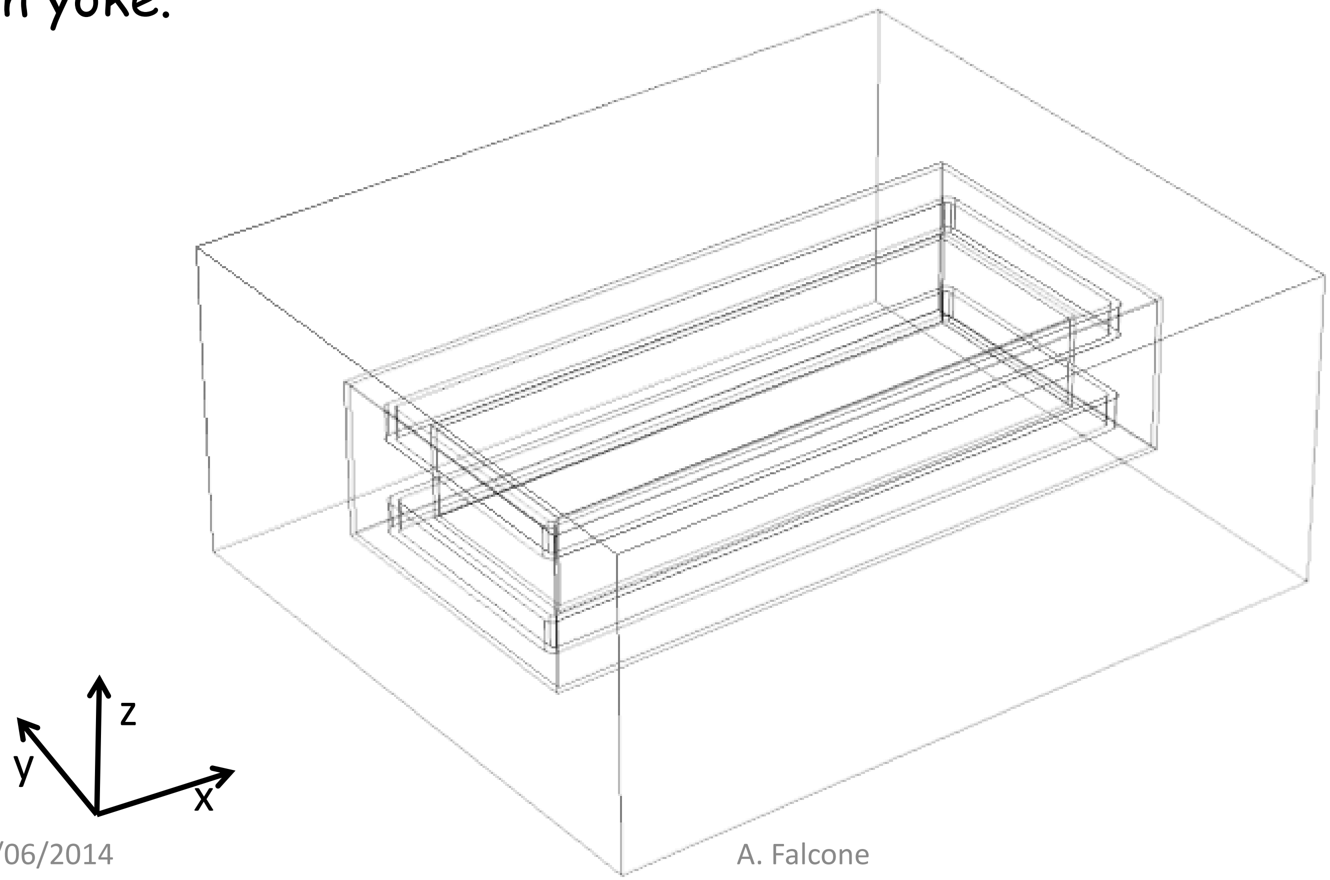
- field intensity and uniformity in the active argon volume
- forces on the structures

Simulation model (1)

A complete 3D simulation is performed with the COMSOL Multiphysics® software.

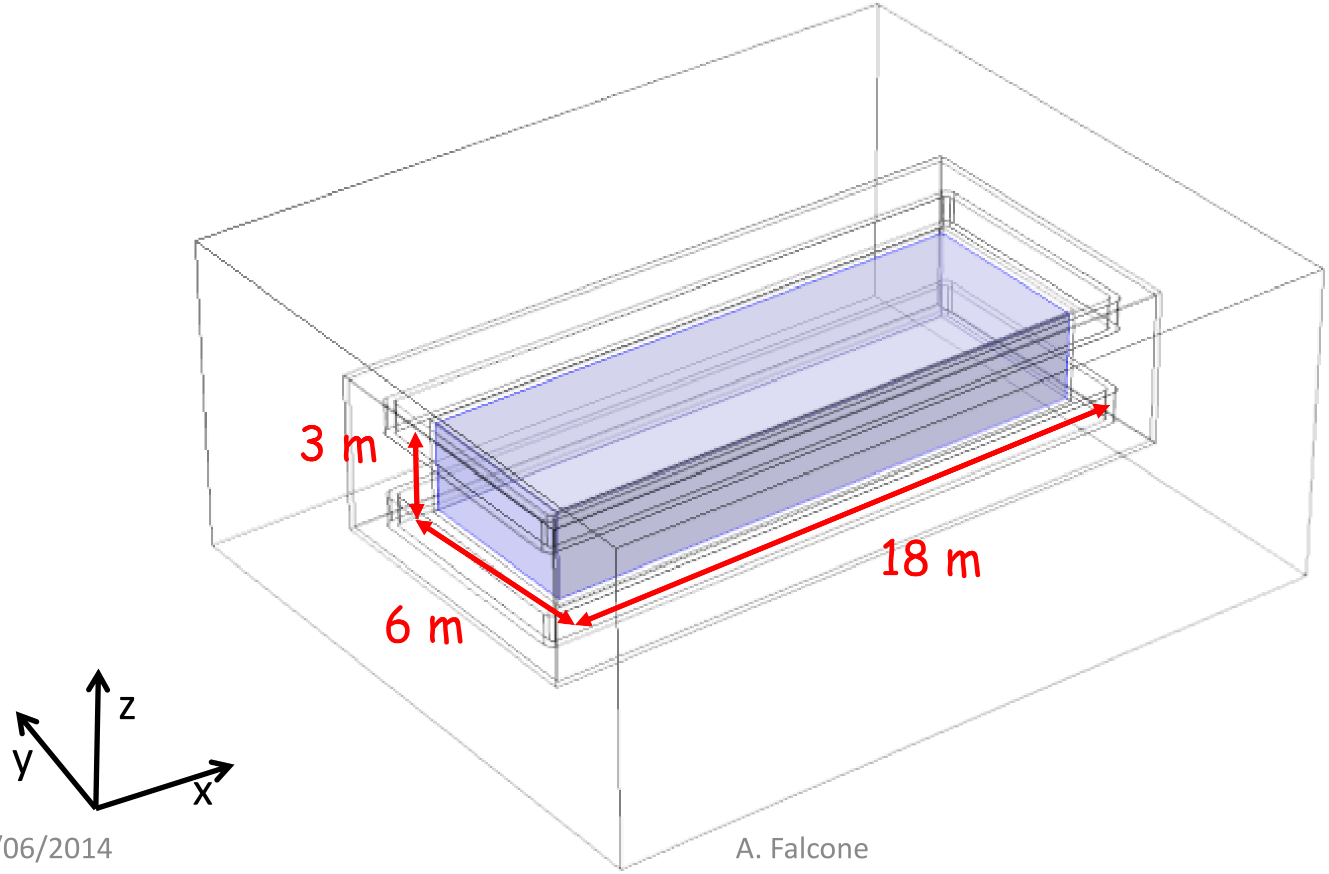
The geometrical model is composed by the following elements:

- inner detector;
- conductive Helmholtz coils;
- iron yoke.



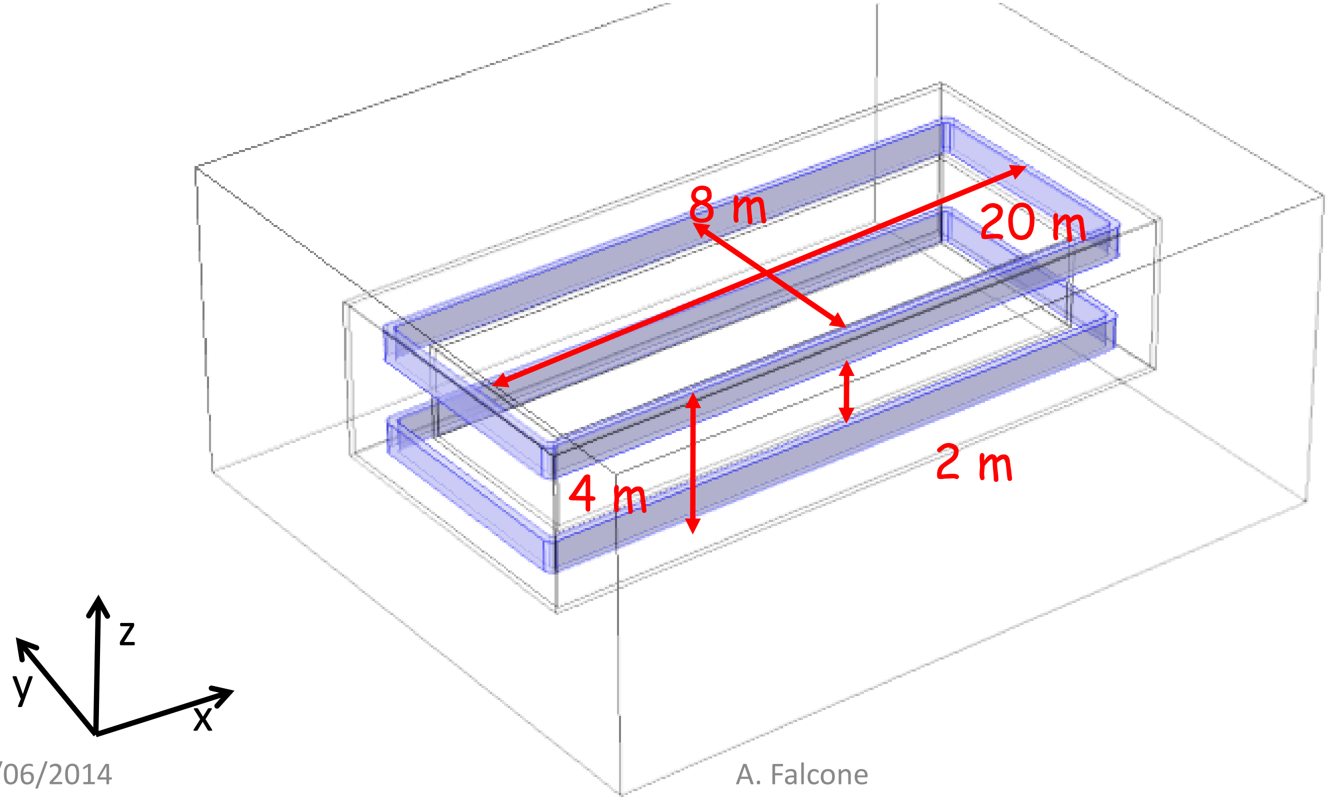
Simulation model (2)

- The inner detector is represented as a single volume filled with liquid Argon.
- Its dimensions are 3 x 6 x 18 m^3, as shown in figure below.



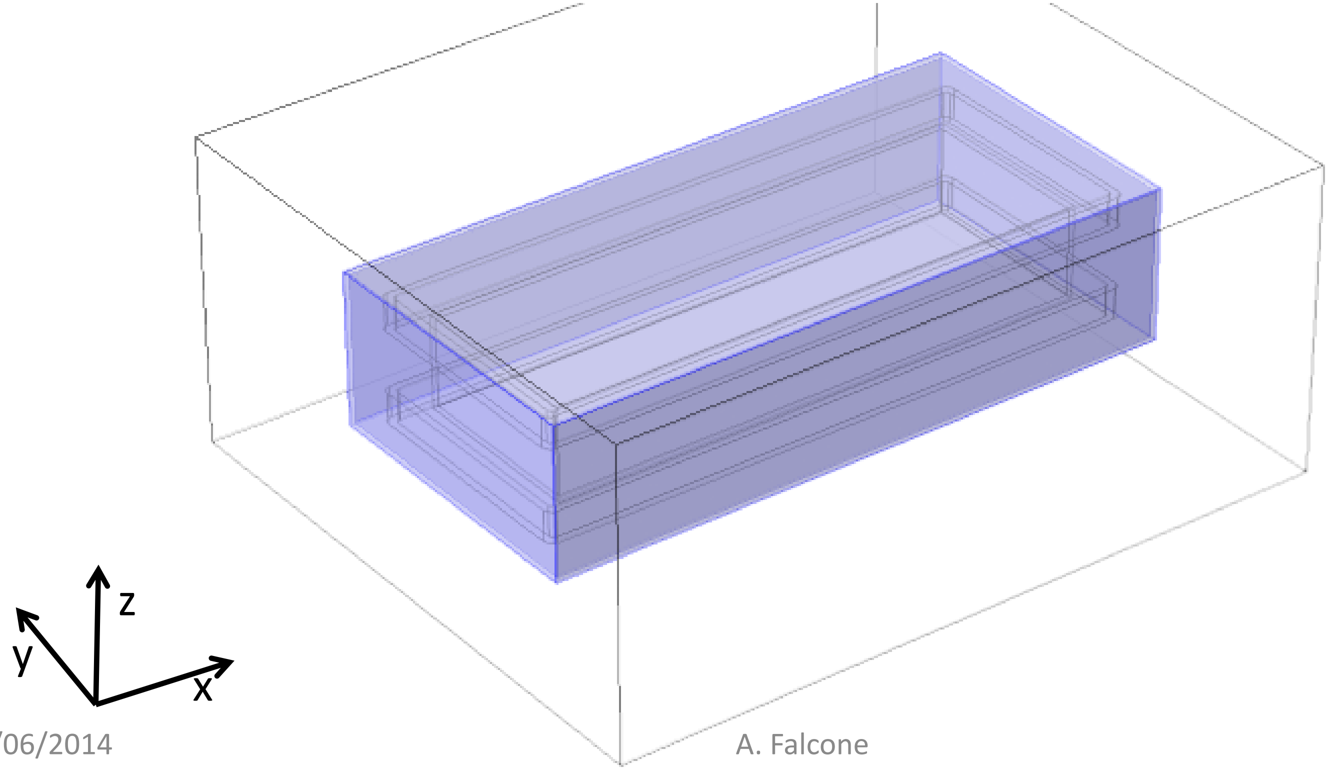
Simulation model (3)

- The coils are represented by a perfect superconductive material.
- 400 turns per coil are assumed, but they are considered only for the intensity of the current; no force is simulated between the different turns.
- The coils have rectangular section (1x0.25 m^2). The shape seems not to affect significantly the result of the simulation.
- To obtain a field of around 1 T, the current is set as i = 20 kA.



Simulation model (4)

• An iron yoke is used to have a contained return path and to significantly lower the magnetic field in the region around the detector. A reinforcement of the field inside the active Argon volume is found, as expected.
• The yoke is simulated as a 20 cm thick shell surrounding both the inner detector and the coils. The thickness was chosen considering both the material characteristics and field intensity.



Field intensity and uniformity

- In the next four slides the results of the simulation are reported. In particular the maps of the field, in the symmetry planes, parallel and perpendicular to the ones of the coils, are shown. In each slide the intensity colour map and the contour levels are drawn.

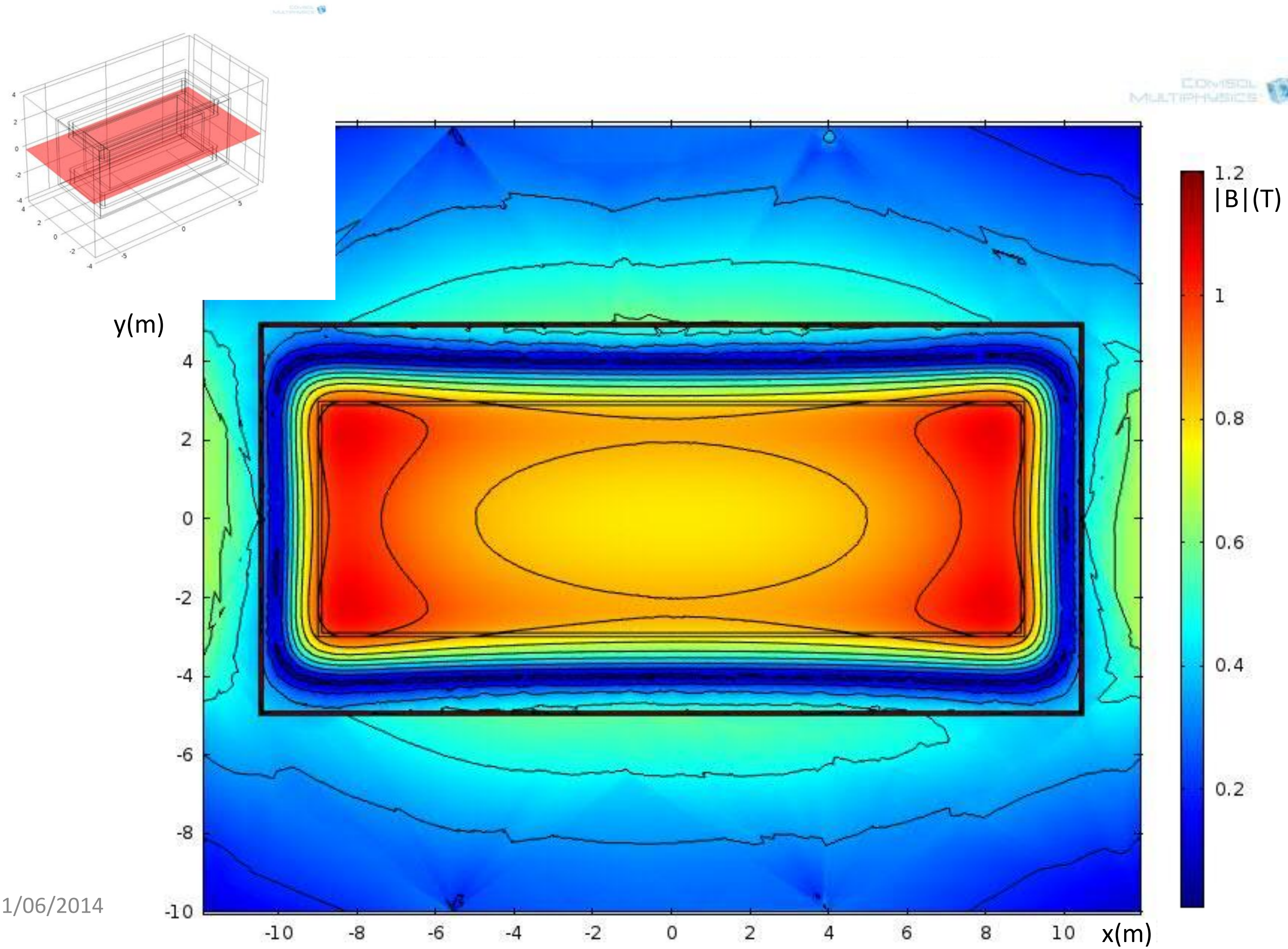
- Mean intensities of the absolute value |B| and of the vertical component B_z in the active Argon volume are

$$|B| = 0.92 \pm 0.12\ \mathrm{T} \qquad B_z = 0.92 \pm 0.12\ \mathrm{T}$$

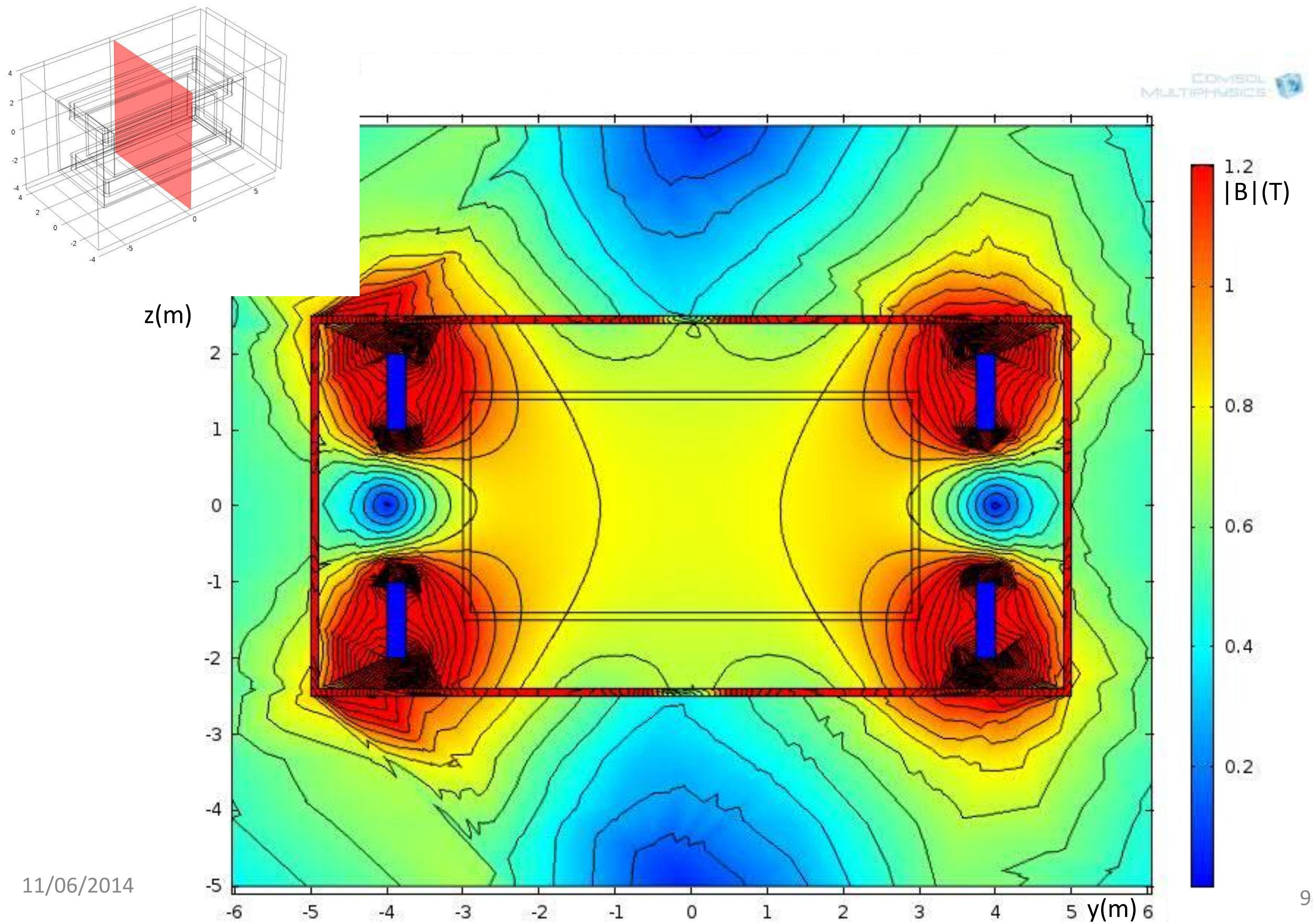
with a dispersion of 13%.

- Black sectors represents out-of-scale magnetic field.

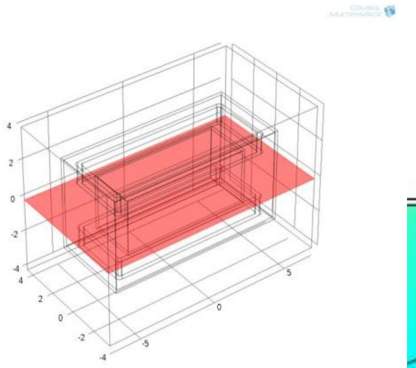
Field maps - |B| in the xy plane

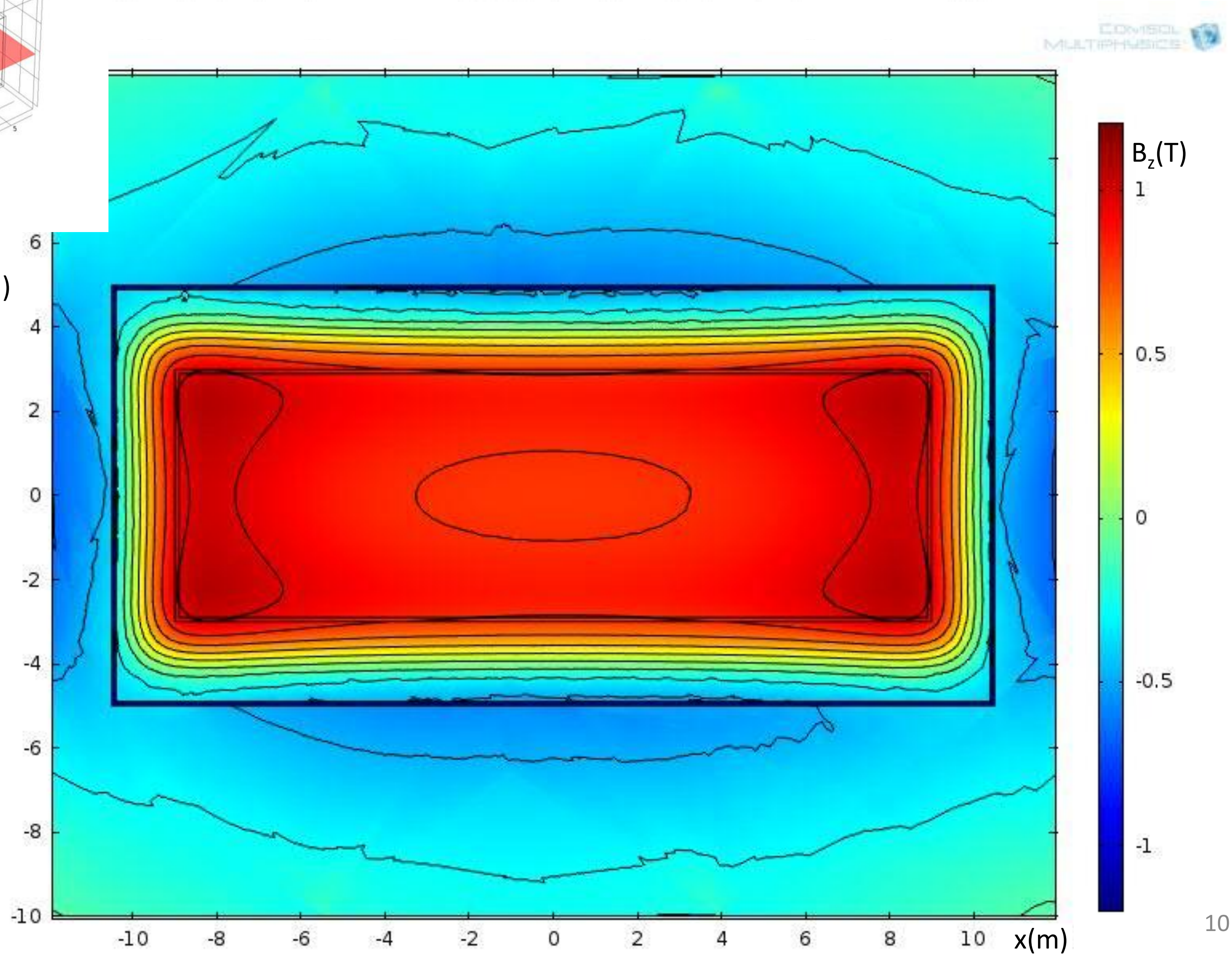


Field maps - |B| in the yz plane

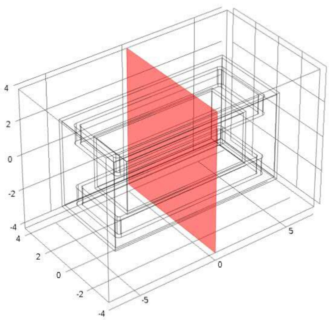


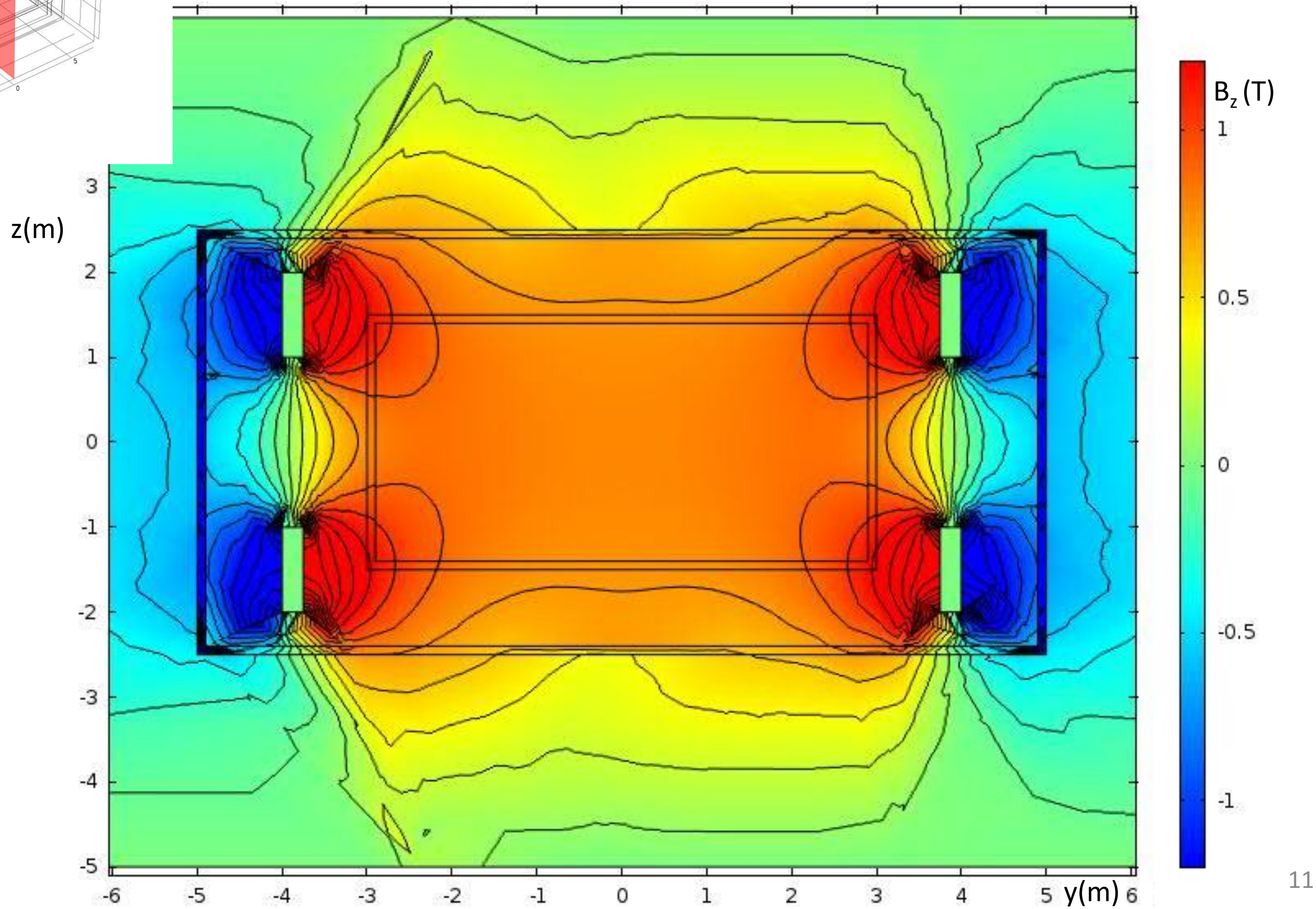
Field maps – B_z in the xy plane





Field maps – B_z in the yz plane





Forces on the coils (1)

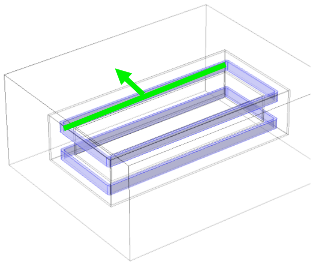
- The calculation of the forces is made considering the coils as single conductor and the presence of the iron yoke which can modify the force field. On the other end, the interactions between different turns of the coils are not considered.

- The evaluation is made with the Ampere formula

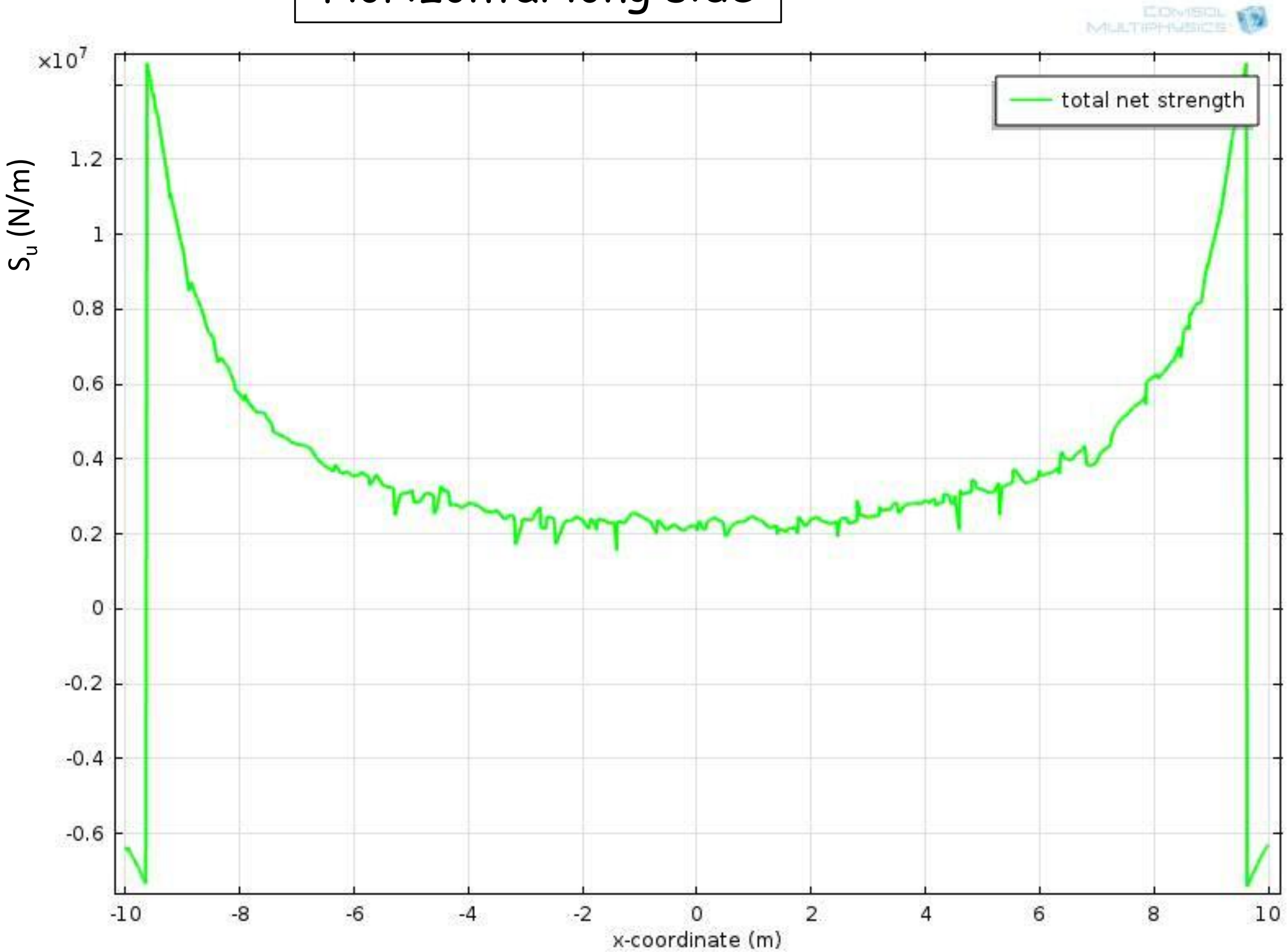
$$\mathbf{F} = (\mathbf{i} \times \mathbf{B})\, L$$

- Both for the long and for the short side of the coil, the horizontal and vertical components of the strength per unit length (S_u) are shown.

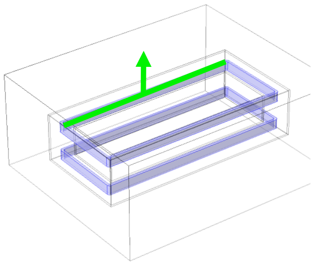
Forces on the coils (2)



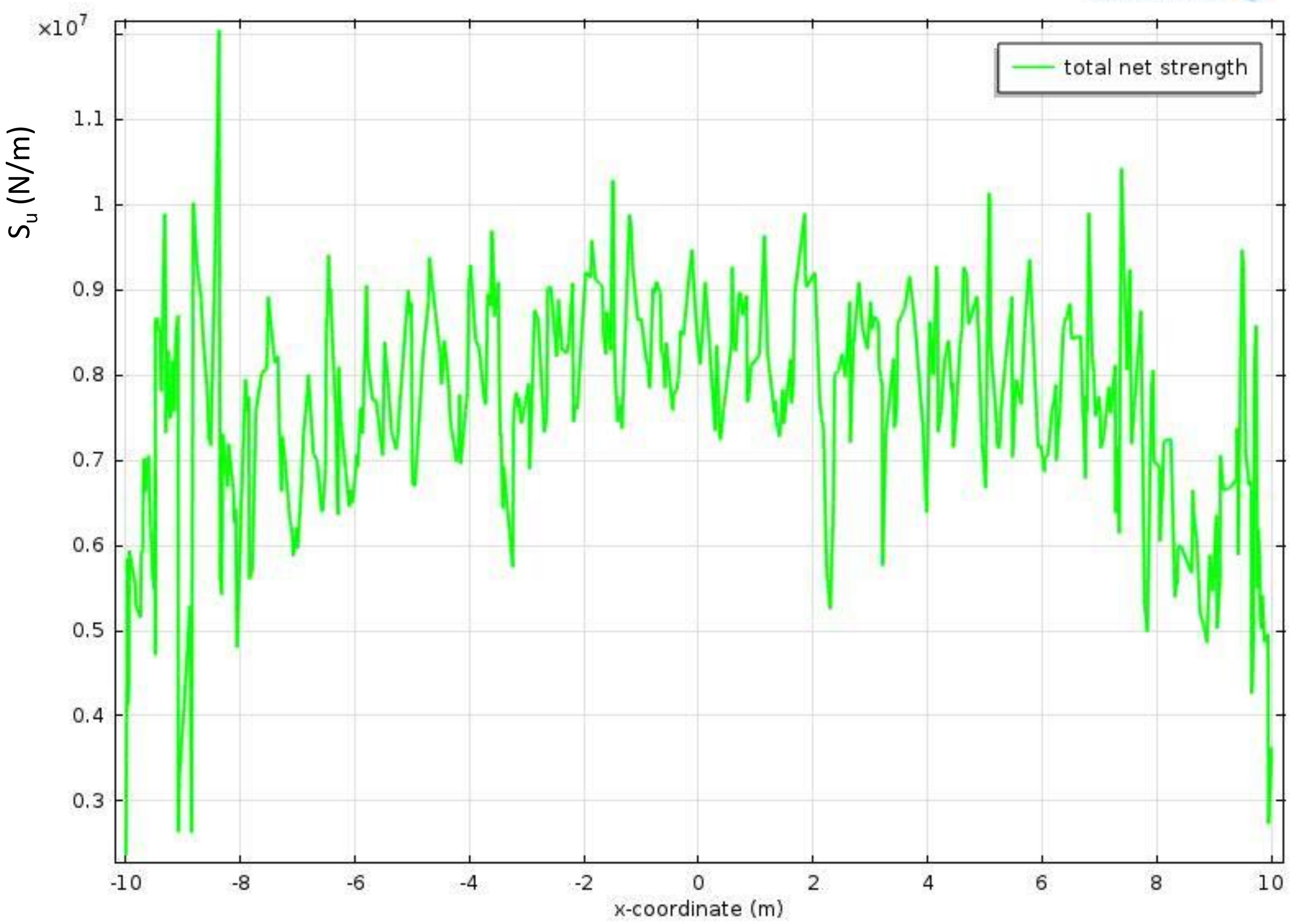
Horizontal long side



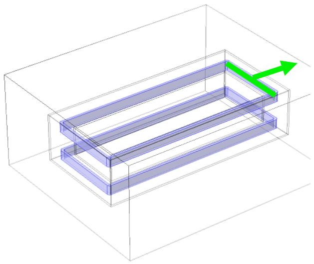
Forces on the coils (3)



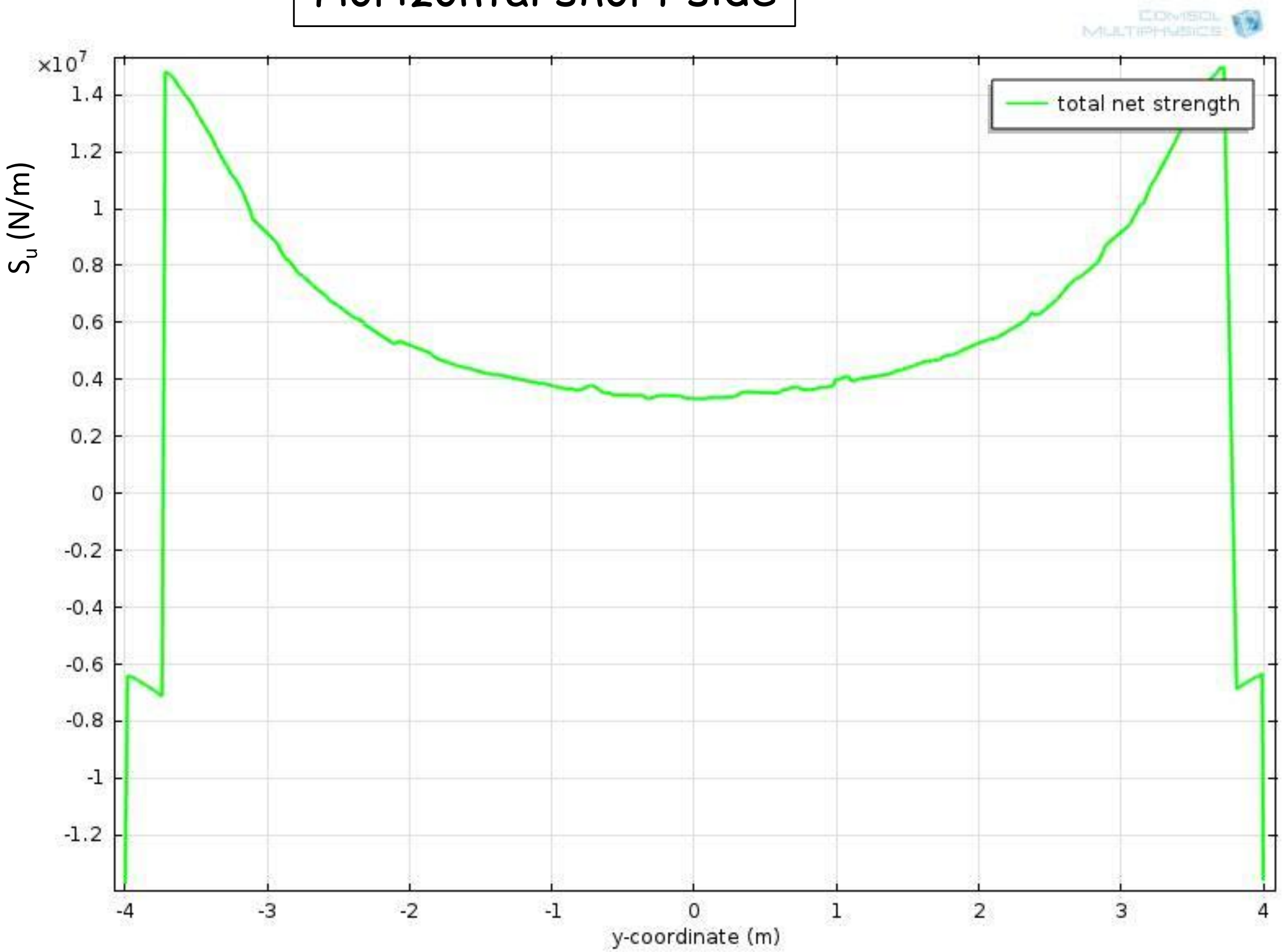
Vertical long side



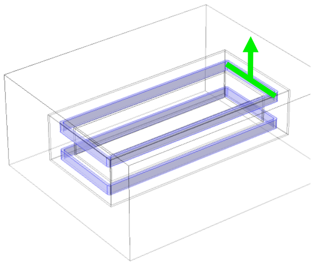
Forces on the coils (4)



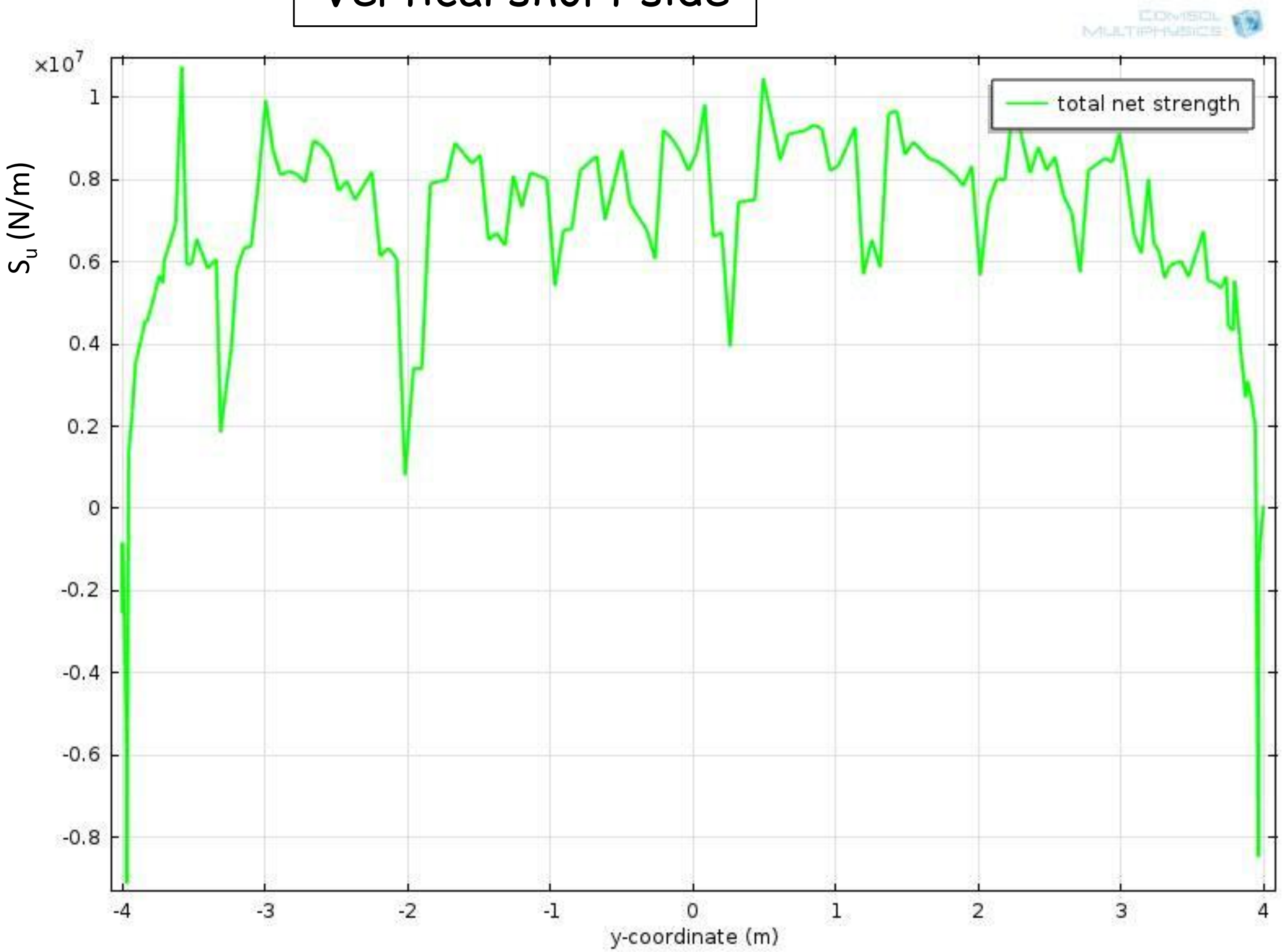
Horizontal short side



Forces on the coils (5)



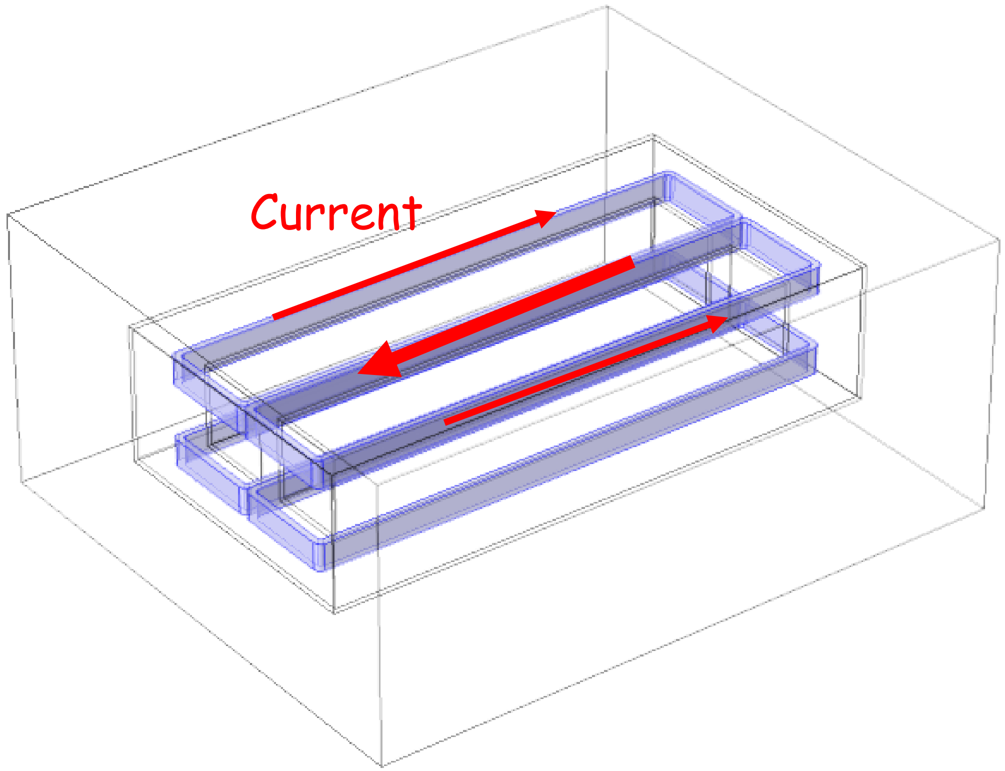
Vertical short side



Alternative configuration

- The confinement of the magnetic field can be further improved using two separate sets of coils, one for each chamber.

- In this configuration the magnetic field has opposite orientation for the two chambers, so about half of the force lines closes inside the detector.



Alternative configuration

- In the next two slides the results of the simulation are reported. The maps of the field for the B_z component are shown, in the symmetry planes parallel and perpendicular to the ones of the coils. In each slide the intensity colour map and the contour levels are drawn.

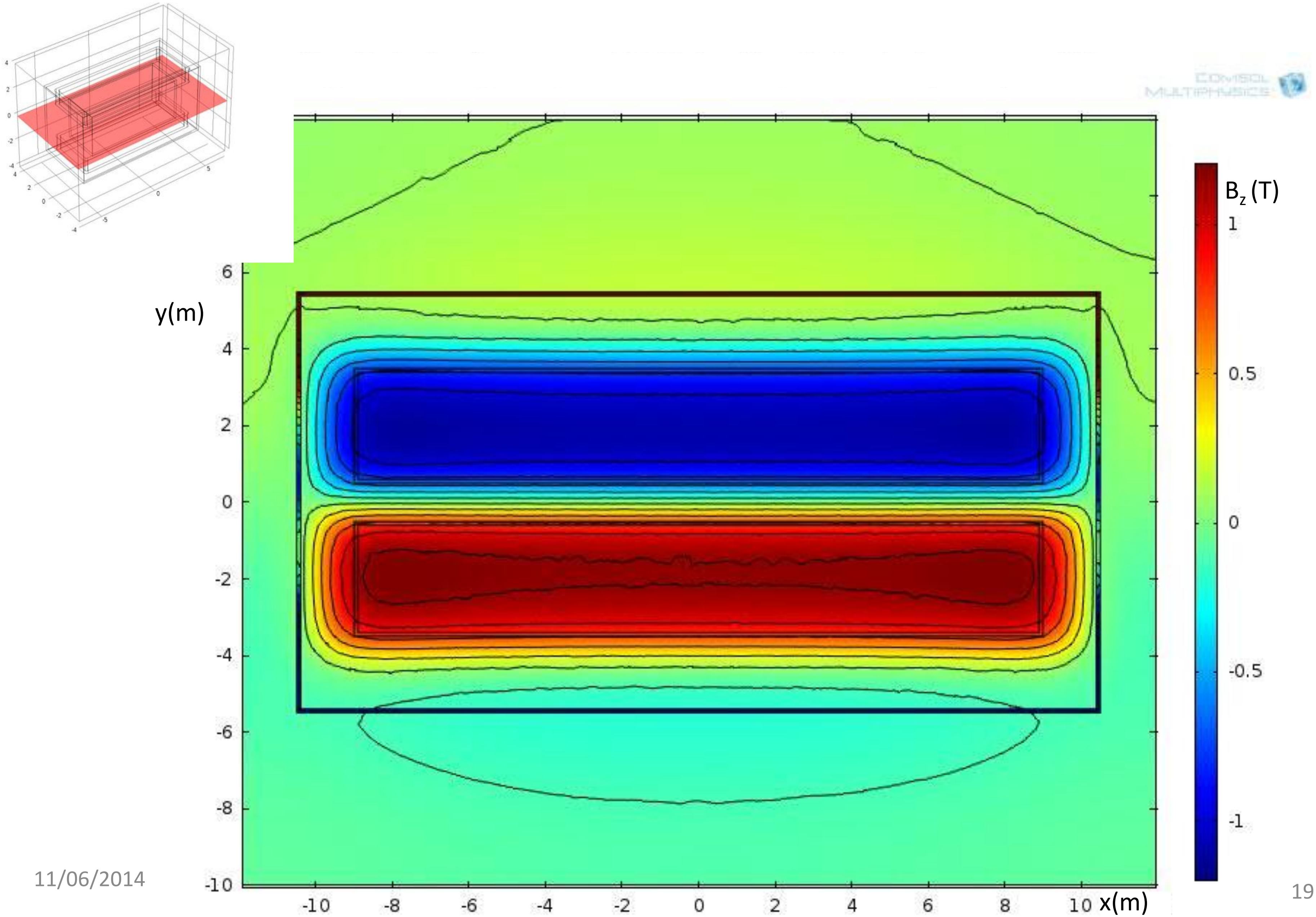
- Mean intensities of the absolute value $|B|$ and of the vertical component B_z in the active Argon volume are

$|B| = 1.22 \pm 0.16$ T $\qquad$ $B_z = 1.23 \pm 0.15$ T

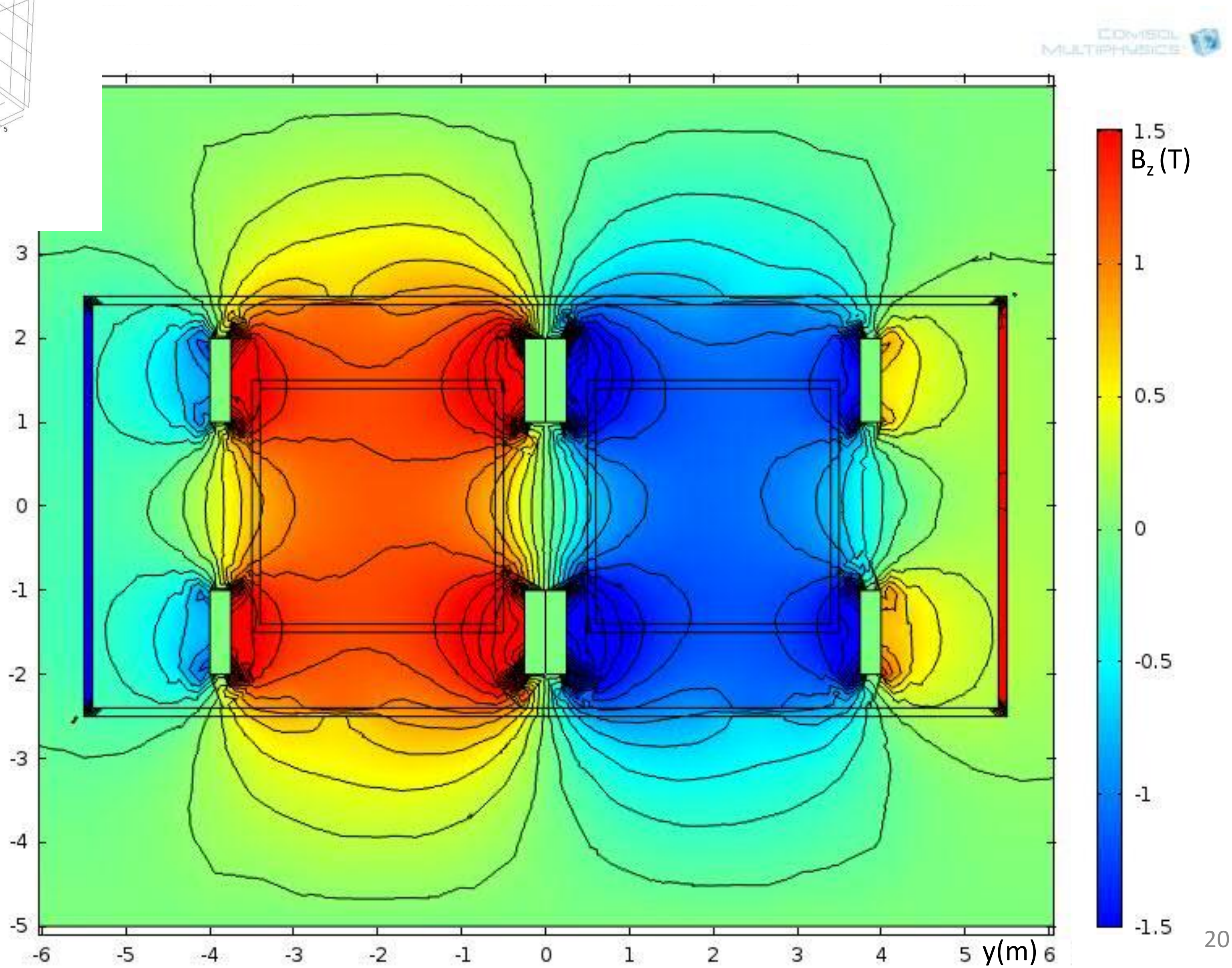
with a dispersion remaining at the level of 13%.

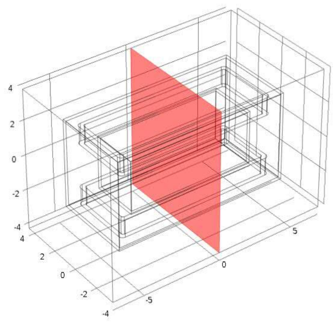
- Black sectors represents out-of-scale magnetic field.

Field maps – B_z in the xy plane



Field maps – B_z in the yz plane





Conclusions

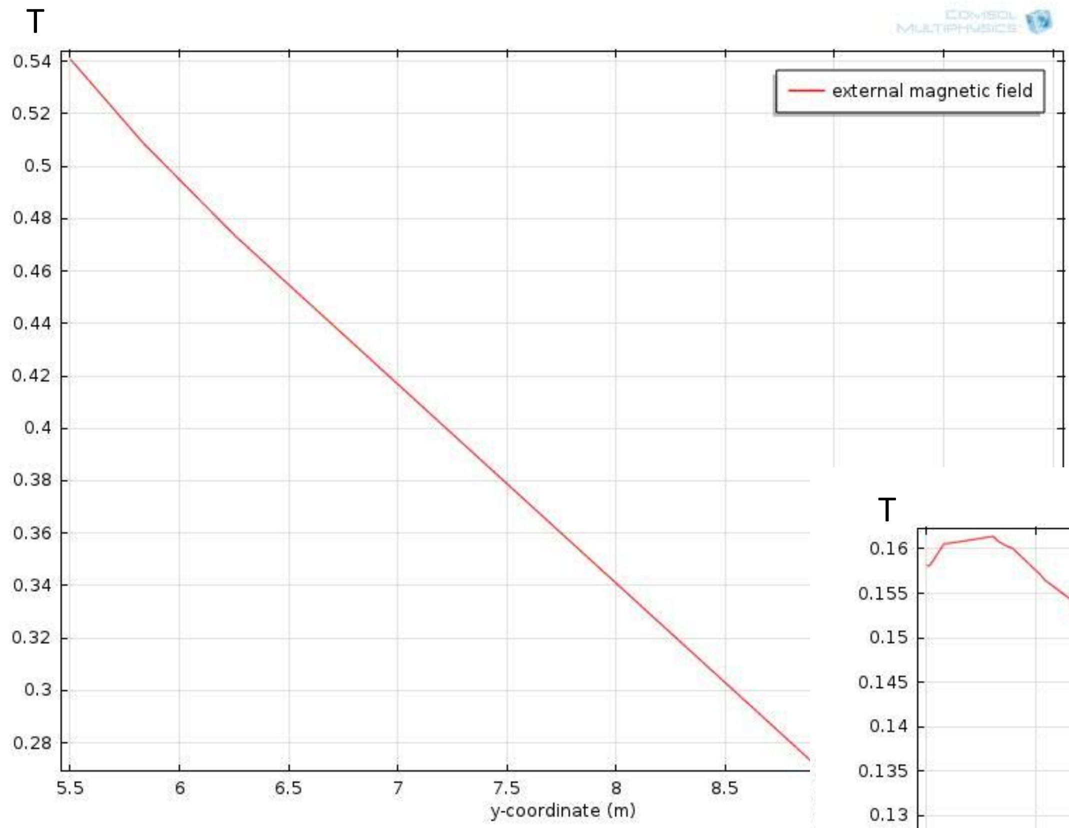
Following the requirements to improve the ICARUS T600 detector tracing capability, a study of the magnetic field achievable with a single Helmholtz coil configuration was performed:

- a reasonable uniformity can be obtained, with a average dispersion of 13%;
- forces on the coils are of the order of 10^7 N/m, manageable with standard support structure.

An alternative configuration, with two sets of coils, was tested and is still under investigation.

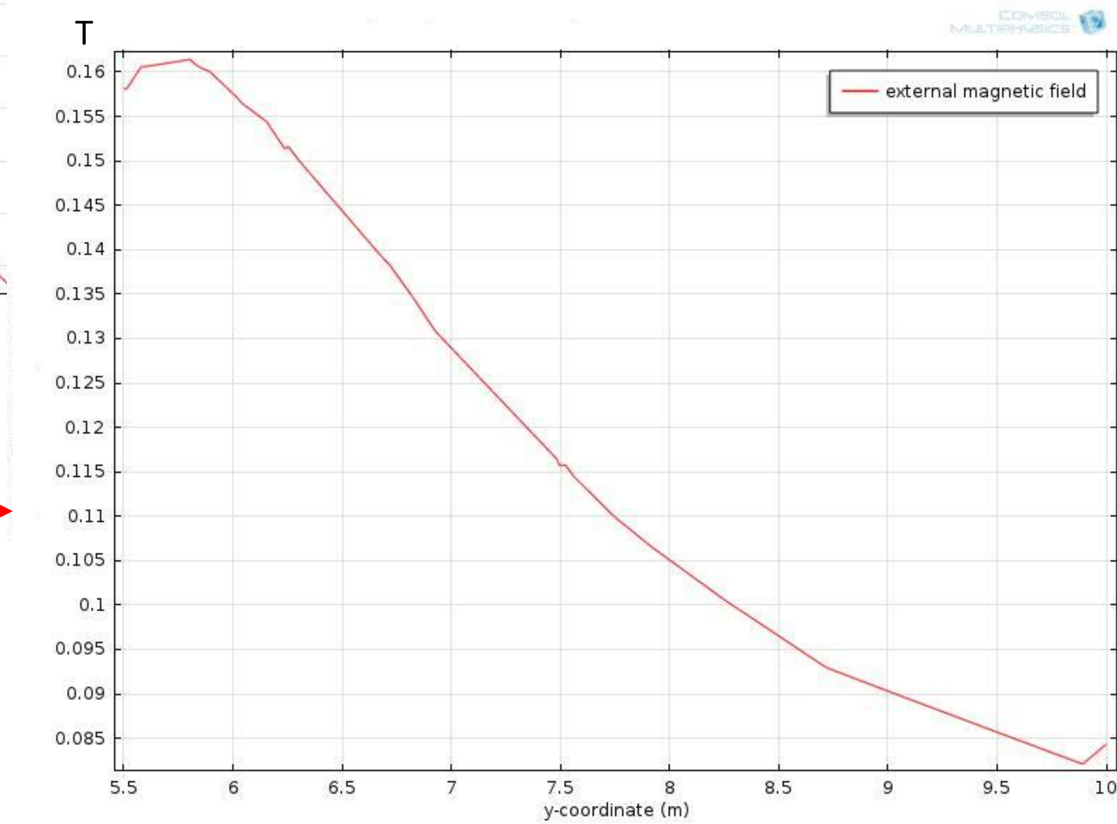
Thank you!

External field



One set of coils

Two set of coils



Simulation characteristics

- Simulation is performed with the COMSOL Multiphysic® software.

- It is a finite elements simulation tool: surfaces are divided in a number of sector (meshes) where the physical equations are solved. This can lead to discontinuities in the results at the borders of the meshes.