Magnetic field maps of the OPERA spectrometer

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Abstract

A detailed description of the magnetic field map foreseen in the OPERA spectrometers is presented. Fringe field maps in air and parasitic magnetization of the support structure are also computed.

1 Introduction

The studies performed in Frascati on the prototype of the OPERA dipolar magnet [1] allowed a detailed check of the magnetic properties of the apparatus and have been used as a basis to carry out the simulation of the full spectrometer. In this note we compute the field maps foreseen for the final design of the magnet and discuss the possible sources of error. In sec.3 we analyse the field expected in the bulk of the spectrometer, relevant to assess the performance on momentum and charge reconstruction. Sec.4 deals with the fringe field expected in the air gap housing the RPC and in the surrounding areas up to the Target Tracker (TT). Finally, in sec.5 the parasitic magnetization of the support structure is analysed.

2 Simulation

The magnetic behavior of the apparatus has been simulated using the TOSCA code [2]. TOSCA is a finite-element based solver of the magnetostatic Maxwell equations in presence of steady driving currents. The magnet is modeled by defining its geometry in a base plane and then extruding that geometry into the third dimension. The materials considered for the spectrometer are a non-linear steel making up the bulk of the magnet, ideal conductors (the drive coils) and air. TOSCA is not able to deal with hysteresis phenomena and requires a uniquely defined BH-curve. The BH-curve has been drawn from the measurements of small sample toroids produced from the same heat as the steel of the Frascati prototype. A description of these curves can be found in [1]. The geometry of the iron dipole does not differ from the one of the OPERA Proposal [3]. The coil, however, has been redesigned [4]. At present, the geometry of the driving coils has been fixed but the working current is still under discussion. The new design foresees the construction of two driving coils made up of 20 copper bars with a section of 20×100 mm^2. In this condition it is possible to run with a working current of 1600 A ("setup 1"). In principle, however, a smaller value of 1380 A ("setup 2") is enough to reach the nominal magnetic field. This value corresponds to an overall magnetomotive force of $20 \times 2 \times 1380 = 55200$ A·turns, i.e. the one quoted in the Proposal. In the following both the configurations will be considered. A scheme of the geometry is depicted in fig.1. The z axis is along the height of the experimental hall. The x axis runs through the slabs as in fig.1-left. Units are in mm and, in the reference frame adopted, the ground of the hall is located at $z = 2000$ mm. Magnetic fields are given in Tesla. In the following, the numbering of the slab is from the outermost (1) to the innermost (12).

3 Field in the bulk of the iron

The field ($|\vec{B}|$) along the height of the spectrometer versus the height is shown in fig.2 (setup 1) and 3 (setup 2). The three lines correspond to the slab 12 (black), 6 (red) and 1 (green). The field is computed at the center of each slab. Inner slabs suffer from the strongest non-uniformities since in the central area flux is lost in air while in the upper and lower region a field excess is present due to the smaller distance from the driving coils. The uniformity among the various slabs can be inferred from figg.4,5. Here the three lines represent the field along the horizontal direction through the twelve slabs of

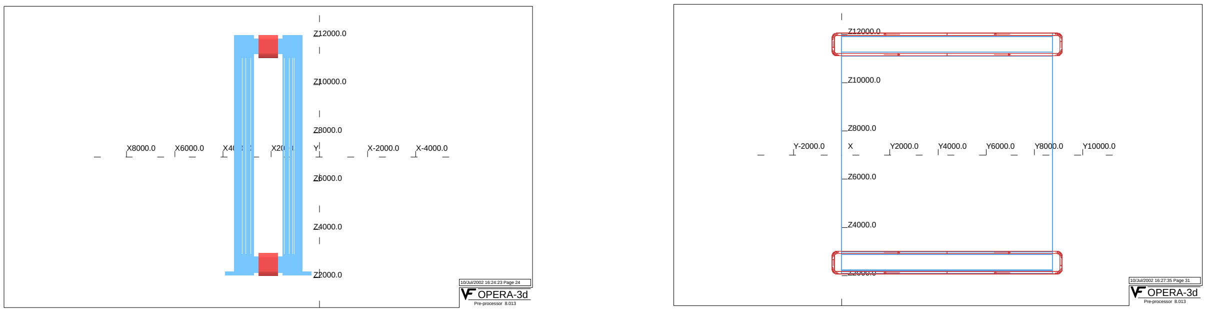

Figure 1: Section of the spectrometer: $x - z$ (left) and $y - z$ (right) plane. Units are in mm.

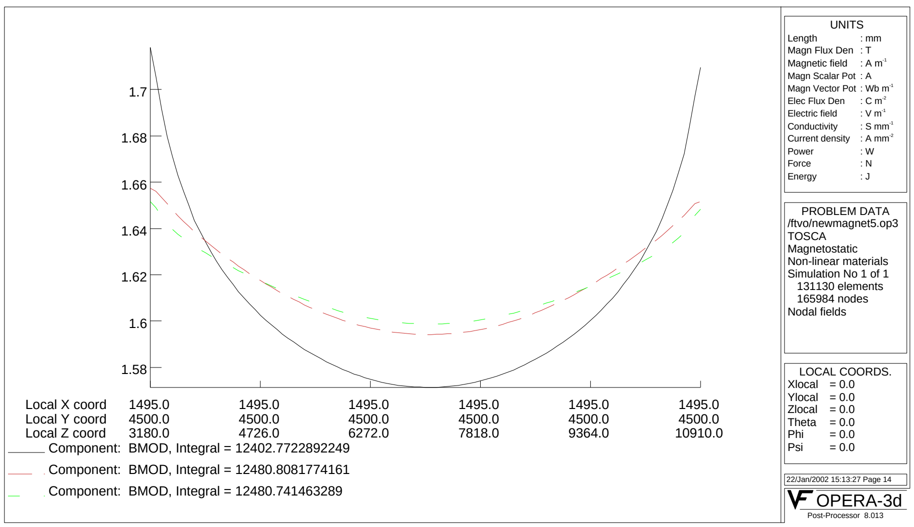

Figure 2: Magnetic field along the height for setup n.1 (see text for details).

the spectrometer wall. The field is taken at three different heights: $z = 3200$ mm (i.e. 1.2 m from the floor; black) $z = 7000$ mm (red) and $z = 10800$ mm (green). Finally the field map in the y-z plane section (slab 6) is shown in figg.6,7. It is worth stressing that measurements done on the prototype have shown a field deficit w.r.t. simulation of about 4%. Hence, this value should be considered as a systematic uncertainty on the present maps and added quadratically to the numerical error on the bulk magnetic field (0.5%).

4 Fringe field in air

The determination of the fringe field in the surrounding air is much more complicated due to the strong dependence of the actual field on the mechanical contact among the slabs. Studies done with the prototype show that variations up to a factor two are possible. On the other hand, far from the junctions among slabs the fringe field is more reliable.

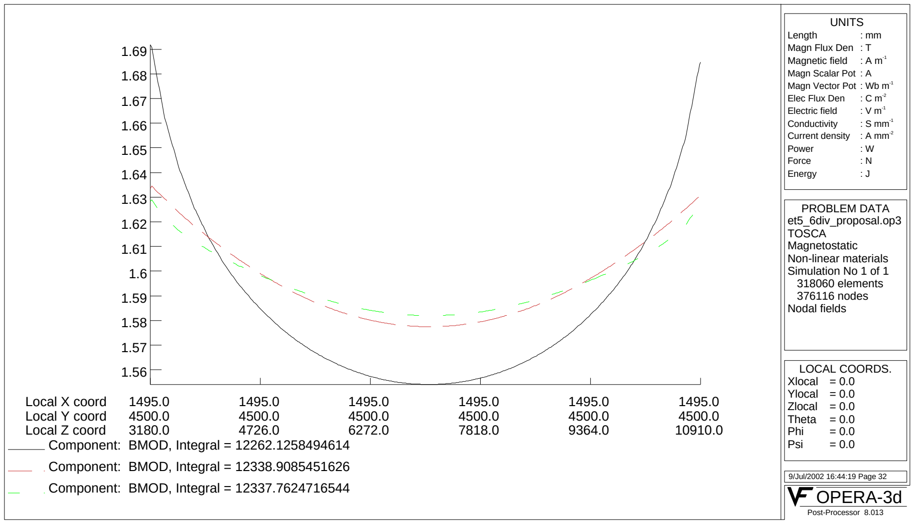

Figure 3: Magnetic field along the height for setup n.2 (see text for details).

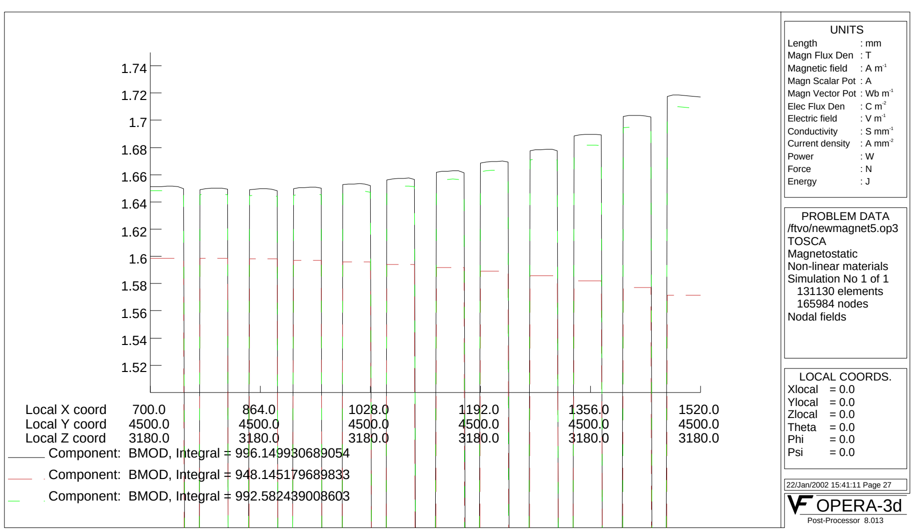

Figure 4: Magnetic field in the slabs along the horizontal direction for setup n.1 (see text for details).

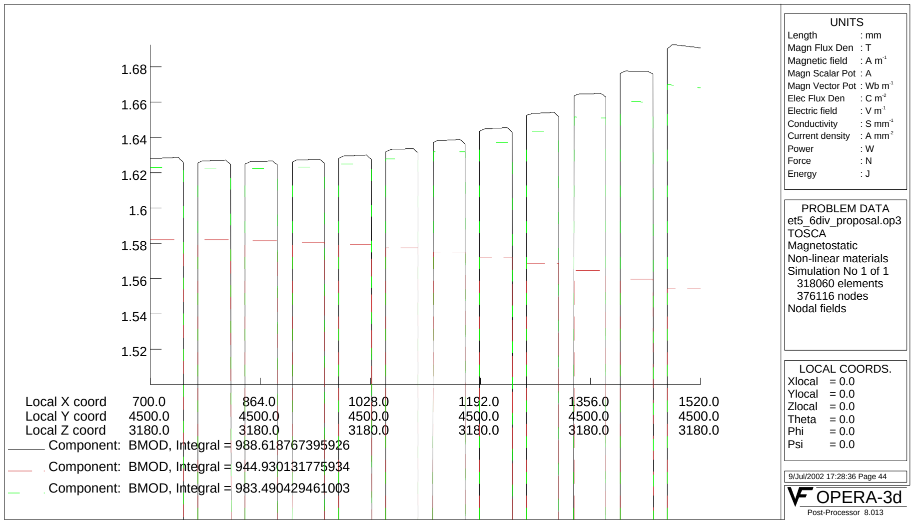

Figure 5: Magnetic field in the slabs along the horizontal direction for setup n.2 (see text for details).

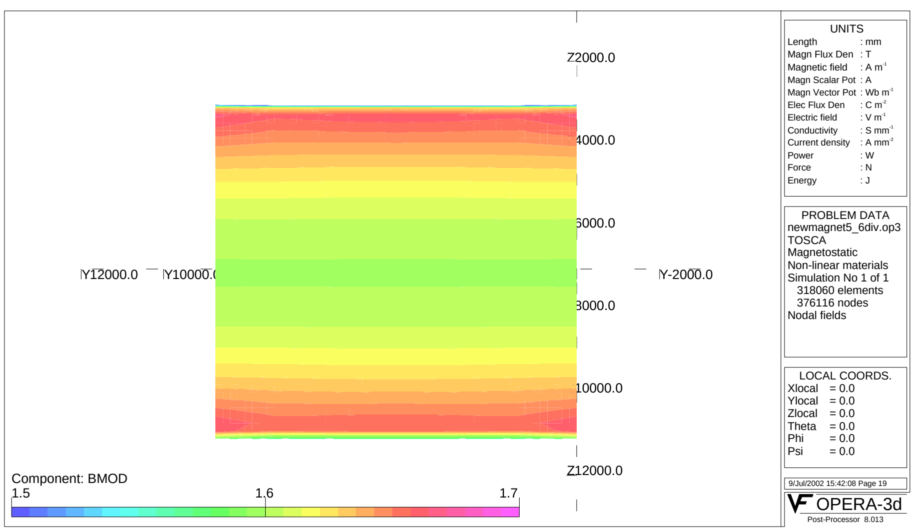

Figure 6: Magnetic field in the y-z plane at slab 6 (setup n.1 - see text for details).

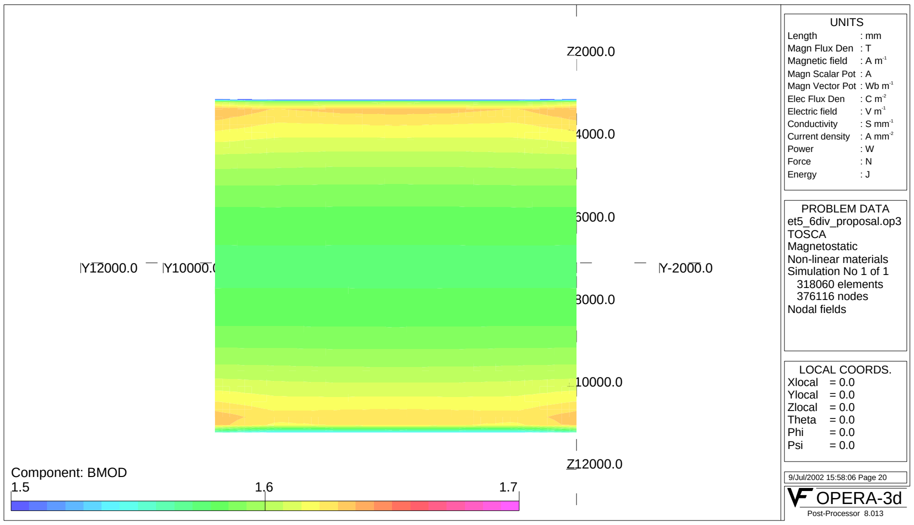

Figure 7: Magnetic field in the y-z plane at slab 6 (setup n.2 - see text for details).

Here the numerical error is below 40%. Fig.8 (setup 1) show the fringe field up to three meters from the magnet wall (i.e. up to the TT) [1]. The field is drawn in the $x-z$ plane at $y = 4.5$ m: at about the center of the magnet in the lateral (y) direction. Also the direction of the field is shown by means of arrows. Only fields below 50 G are plotted. In fact, in the junction regions the field is supposed to be higher. This area (a zoom of fig.8) is shown in fig.9. Moreover, the region near the driving coil is interesting for the design of the manipulator. Fig.10 shows the fringe field in this area at a height of 10 cm from the floor ($z = 2.1$ m). The arrows follow the direction of the field. It is assumed that no ferromagnetic material is installed around the magnet and all the other materials (drift tubes, brick support, bricks and scintillators) are considered as air. The support structure is ignored and discussed separately in sec.5. The fringe field in the gaps housing the RPC is shown in figg.11,12. The black line represents the field versus height at the gap between slab 11 and 12 (innermost) and, as expected, shows the highest non-uniformity. The red and green lines correspond to the gaps between slab 6 and 7 (central) and 1 and 2 (outermost), respectively. Finally, the field between the two walls of the magnet is shown in fig.13. Again, the field is shown in the $x-z$ plane at $y = 4.5$ m and the arrows show the direction of the field.

5 Magnetization of the support structure

A simulation of the support structure has been performed. The geometry is described in fig.14 where just the ferromagnetic parts of the layout are shown. Here three spectrometers were simulated and the current in the driving coils was the same in each magnet. The magnetic properties of the support rails were assumed to be the same as for the spectrometer iron. The inox steel supports are assumed to be non-ferromagnetic (air).

[1] The corresponding plots for setup n.2 do not differ by more than a few G.

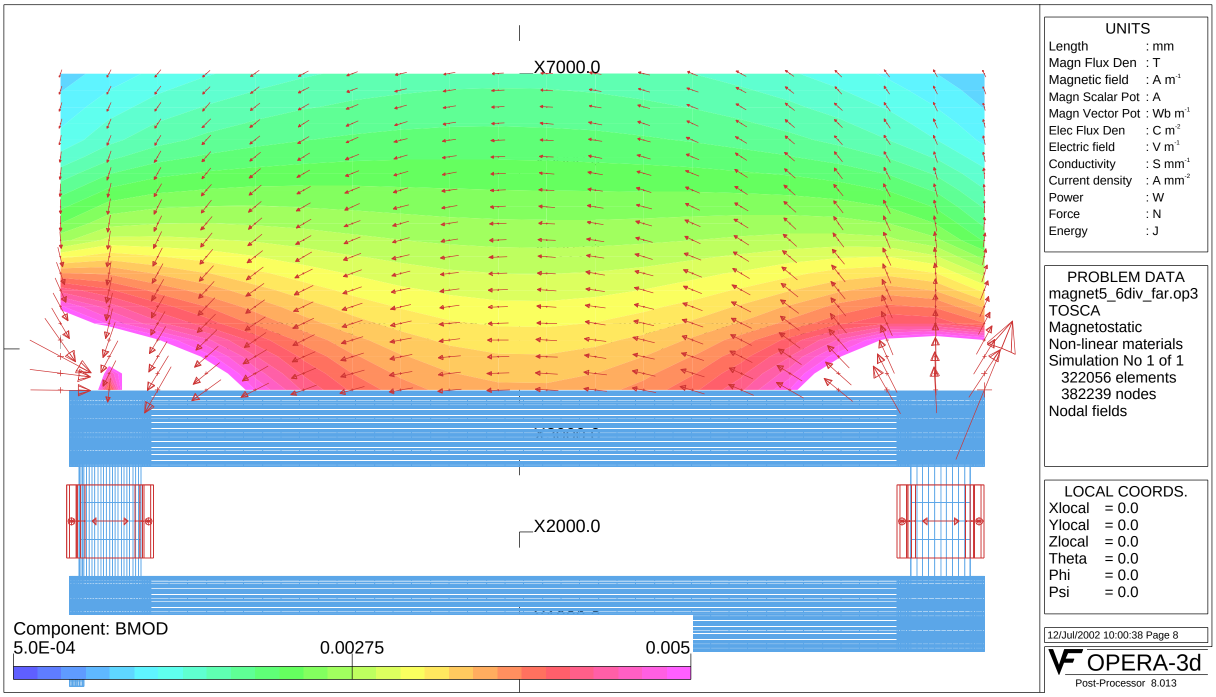

Figure 8: Magnetic field in the x-z plane near the TT at the center of the magnet in the lateral (y) direction (setup n.1 - see text for details).

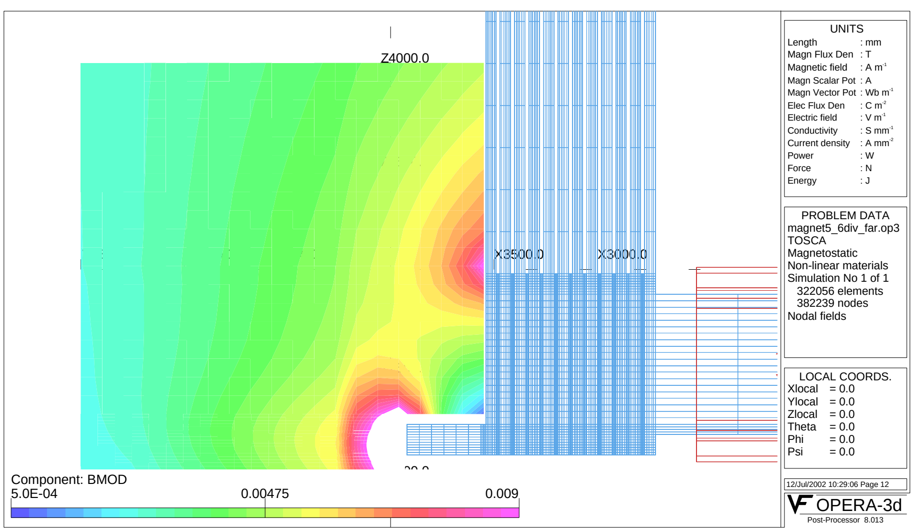

Figure 9: Zoom of fig.8 in the junction region.

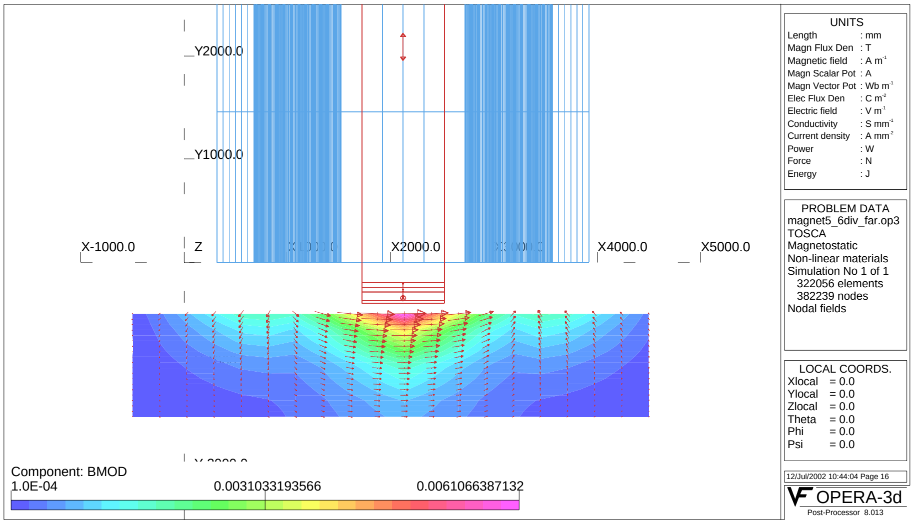

Figure 10: Magnetic field in the region near the manipulator rails at 10 cm from the floor (setup n.1).

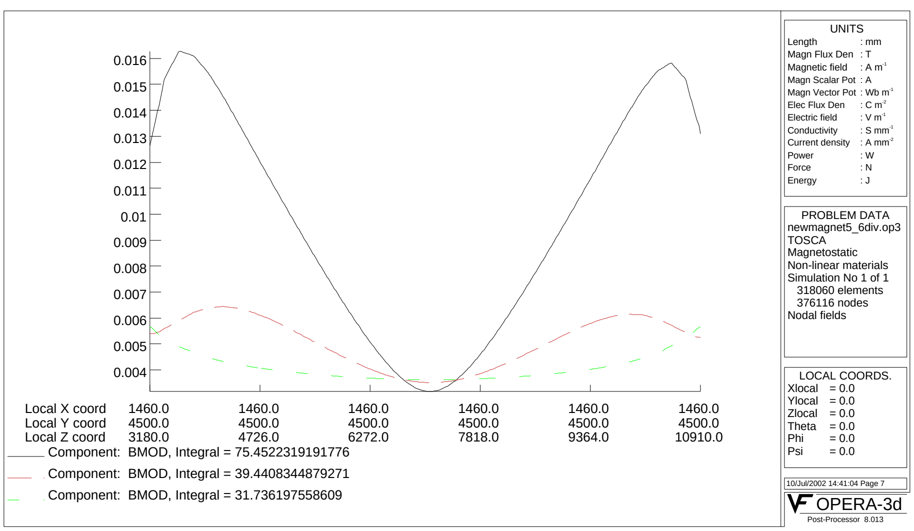

Figure 11: Magnetic field in the air gap housing the RPC (setup n.1 - see text for details).

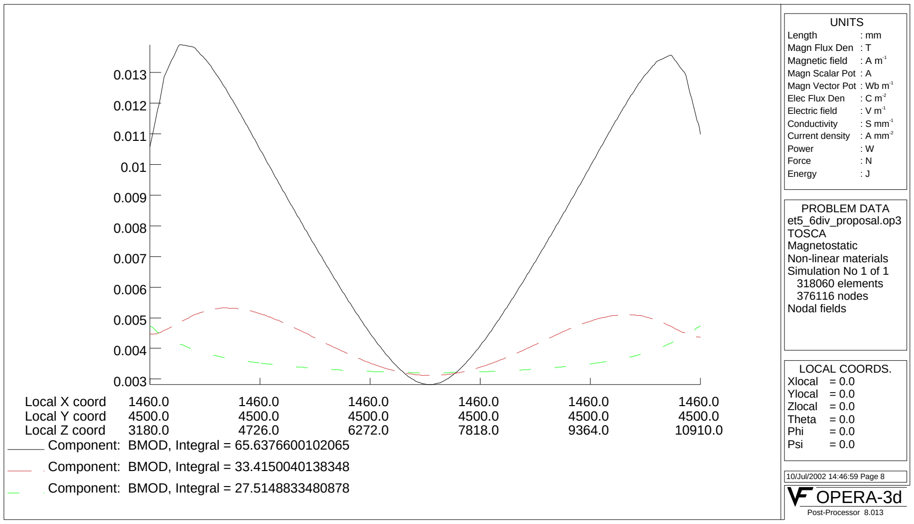

Figure 12: Magnetic field in the air gap housing the RPC (setup n.2 - see text for details).

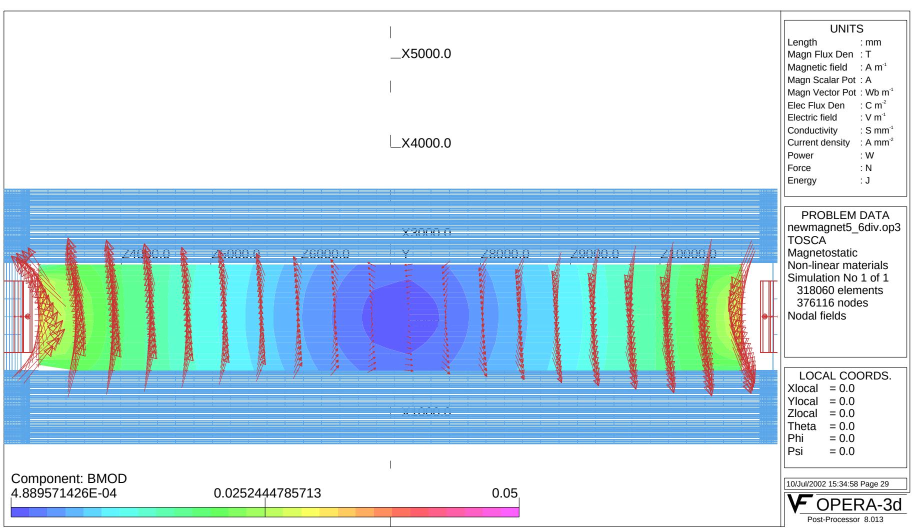

Figure 13: Magnetic field in the air between the spectrometer walls. (setup n.1 - see text for details).

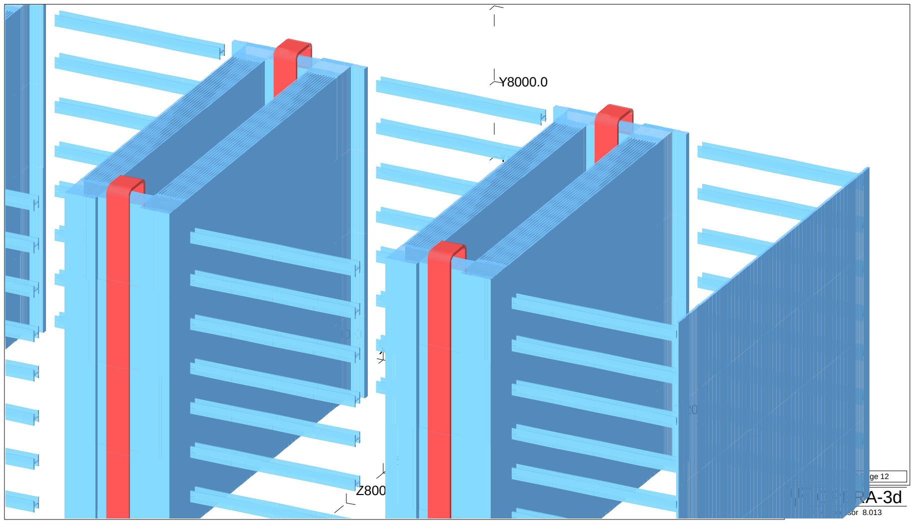

Figure 14: Geometry of the general layout of OPERA seen from the roof of the experimental hall. Only ferromagnetic materials are shown.

The presence of these supports connecting the rails with the spectrometer decouples the magnet from the rest of the structure. Parasitic magnetization of the rails is non negligible only for the most external ones (closest to the border of the spectrometer and the driving coils) where it reaches a maximum value of 0.4 T. All the other rails will be magnetized by less than 500 G (see fig.15). No significant difference is observed between the upper and lower set of rails.

6 Conclusions

In this note we computed the expected magnetic fields in the OPERA spectroments for two different configurations of the driving coils. In particular, we studied the field in the fiducial region of the magnet and the fringe field in the surrounding area where other subdetectors will be located. Computations were carried out using TOSCA and profiting of the results obtained from the Frascati prototype.

References

[1] G. Di Iorio et al., "Measurements of the Magnetic Field in the Prototype of the OPERA Spectrometer", OPERA note, LNF-01/028.

[2] OPERA-3d OPERA-2d and TOSCA are products by Vector Field Ltd., Oxford, UK (www.vectorfields.co.uk)

[3] The OPERA collaboration, M. Guler et al., CERN/SPSC 2000-028, SPSC/P318, LNGS P25/2000.

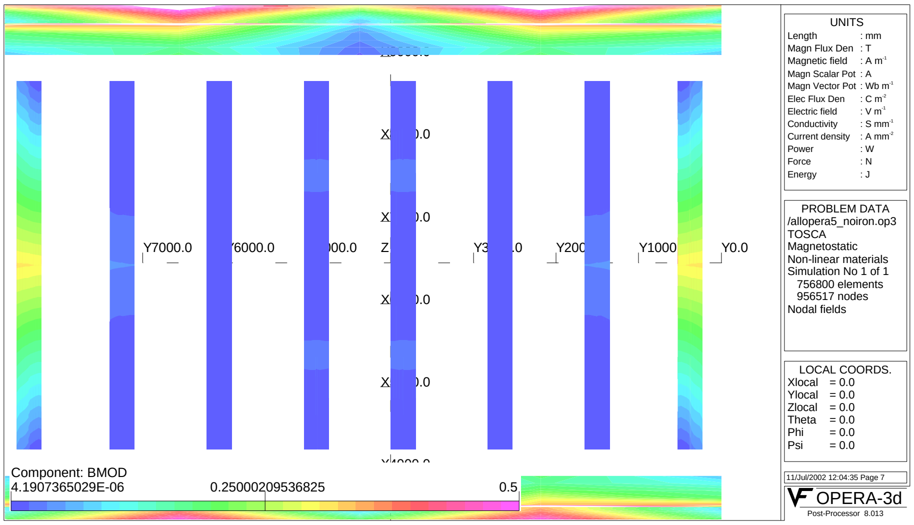

Figure 15: Parasitic field in the support rails.

[4] F. Terranova, talk at the OPERA General Meeting (Nagoya, 2002)