Influence of the TileCal Parameter Modifications on the B-field

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1 Formulation of problem

Due to various reasons the TileCal parameters are undergoing some modifications. And these changes are sometimes rather large. Naturally, one wants to know what would be the by-product consequences of such modifications for various aspects of the system functionality. A distortion of the TileCal magnetic field is one of those aspects. Here we shall try to answer on some of the questions arising in connection with the desire to get the TileCal parameters modified [1], [2]. Another purpose of this calculation is to get more detailed information in some specific areas of the system.

Below we summarized the above mentioned questions:

- What will be the field situation in the PMTs and scintillator if the end plates be changed?
  - End plates will be in Aluminum and no more in iron.
  - End plates will be in Aluminum only in the middle part and in iron at the both sides radially with 20 cm extension.
  - They will be of 1 cm thick instead of 2 cm presently.
  - They will be much thinner along the beam axis and manufactured with high permeability material.
  - From the mechanical structure point of view the end plates are not needed any more according to the new design. The only justification for them is to conduct the solenoidal return flux. Is there possibility to construct more simple and small set up to fulfil this destination and to protect the tiles from the solenoidal return flux?
- Could be the front plates withdrawn at all as far as the B-field concerned?
- What will be an effect of the changes in girder?
  - There some details have been changed in the girder and have substituted a plate with continuous iron for a laminated one.
  - A decrease by 20% the amount of iron in the girder.
  - According to a new drawing for the girder, the iron distribution is the same in cross section, but different in geometry.
  - At the interface between the Barrel part of the girder and the extension of the Extended Barrel girder part iron distribution is the same in cross section as in the previous structure, but very different in the geometry presently.
  - Is there concern about the holes in the drawer to insert the fibers? There is a plan to have every 106 mm an hole of 45 mm diameter. What will append with the field in the presence of the holes?

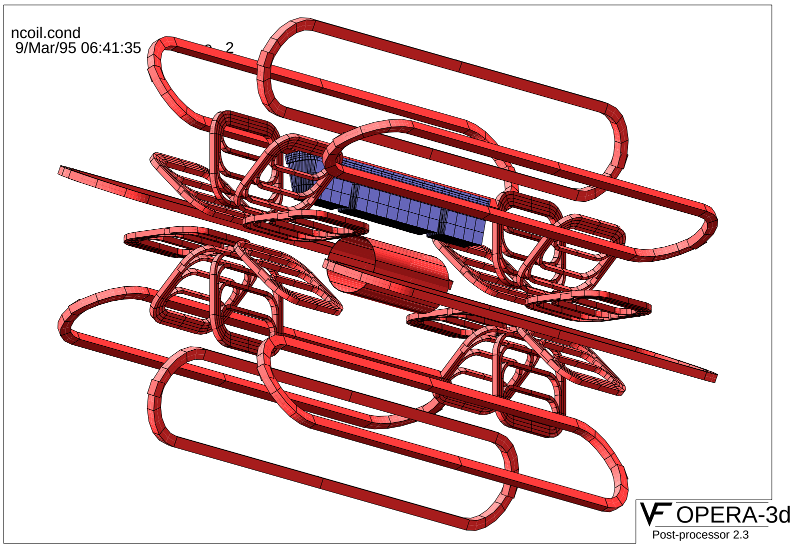

Figure 2.1: Computer model of the ATLAS magnetic system

- What will be an effect of the changes of some dimensions by 3 cm in radius and the length of the detector?
- What will be an effect of the changes according to the latest drawings of the cross section of a module?
- What is the field map near the TileCal crack region between the TileCal and Barrel Toroid?

2 Results of Calculations

2.1 Models

The best answers for the questions put would be obtained with an application of the 3D computer model of the magnet. Various aspects of the ATLAS magnetic system are shown in Fig 2.1. There one can see the Barrel Toroid (BT), two End-Cap Toroids (ECTs) with the distributed windings, the Solenoid and the part of TileCal iron. Only several TileCal sectors are shown for the clarity of the image and according to the symmetry conditions used to construct a 3D computer model [3].

Some rough estimations of specific effects could be done with the help of the 2D computer models described in Refs. [4] and [5]. The structure of one of these models and the corresponding field map are shown in Fig. 2.2.

2.2 End Plates Modifications

To study this issue the 2D model in Fig. 2.2 was used. The concern was a possible increase of the magnetic flux penetration to tiles. In Figs. 2.3 and 2.4 the region with the maximum field level (the corner of the Barrel close to solenoid) is shown.

It can be seen that in the case of the Al end plates the flux lines became normal to the interface plane between the edge tile row and the end plate and not tangential any more as it was with the Fe end plates. Due to boundary conditions at the interface iron - air (tiles) the magnetic induction value in the edge tiles will increase by a factor approximately equal to the iron permeability value in the vicinity of the interface. In the following Table the results of field calculation in the edge tile rows are presented.

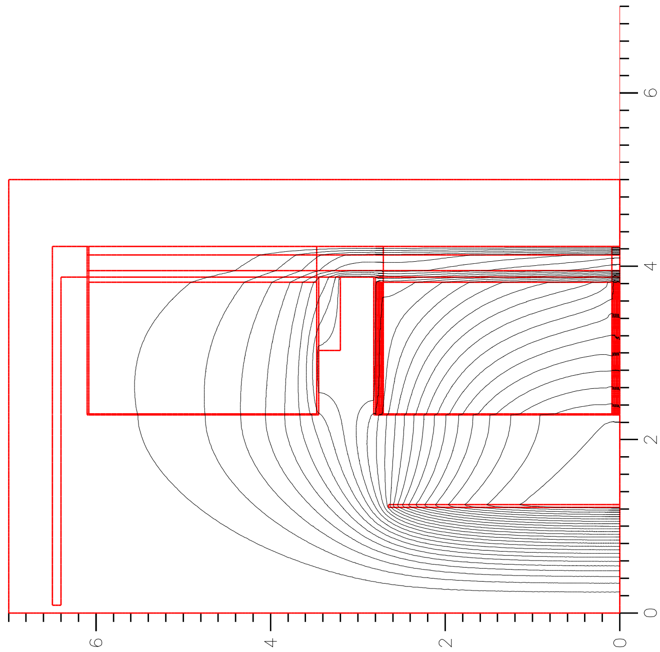

Figure 2.2: 2D field map for μ_z=500

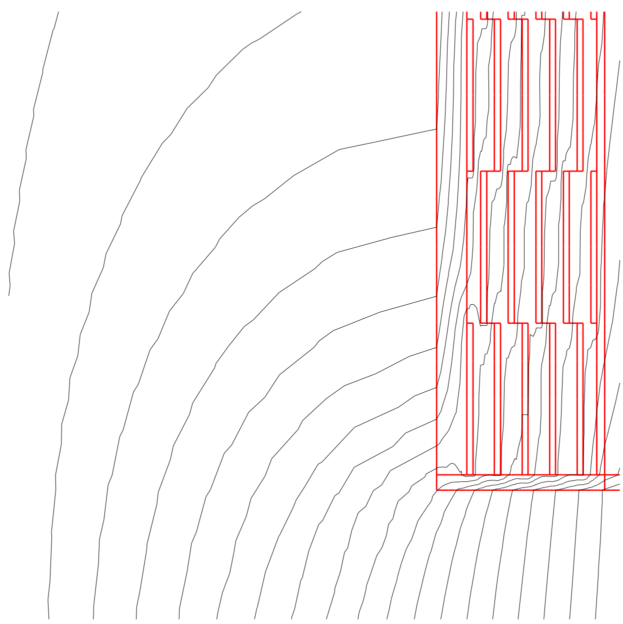

Figure 2.3: Field map near the Barrel corner with iron end plate

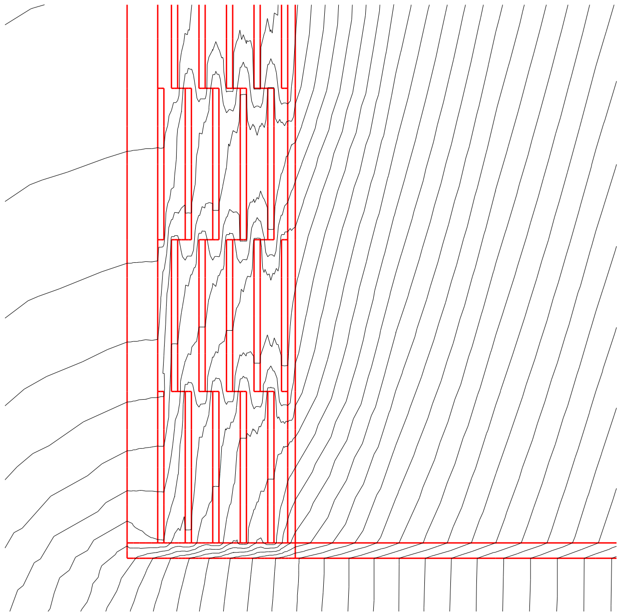

Figure 2.4: Field map near the Barrel corner with Aluminum end plate

Barrel (μ_z=500)		
	Fe - end plates	Al - end plates
Radius (m)	B_{tot} (mT)	B_{tot} (mT)
2.3	4.7	146
2.5	4.0	55
2.8	1.6	15
3.0	0.6	4
3.3	0.4	0.8
3.7	0.8	0.4

According to Ref. [6] an effect of the magnetic field on the light yield of the tile become especially noticeable above induction values 50 mT ÷ 100 mT. Due to this above mentioned end plate material replacement is not recommended here.

Some intermediate solutions to get less material in the end plates could be considered as a next step. In Fig. 2.5 there are shown the edge tile rows field dependencies for various stack factor (f_s) in end plate iron.

The f_s=1 corresponds to the present situation with the overall iron in the end plates. It can be seen that the end plate might be on 20 % thinner, still keeping the maximum tile field below 10 mT. Further decrease in its thickness would produce a big magnetic field penetration to tiles. This analysis method with the stack factor modification was confirmed by the actual calculation with the half in thickness end plates which is more difficult to perform due to some technical reasons. There was a sufficient agreement between those two approaches.

2.3 Front Plates Modifications

To answer the question, concerning the front plates removal effect on the tile field, the region in the very corner of the Barrel was looked at for different stack factors of front plate iron. In Fig. 2.6 the field map is shown for the case with the front plate almost withdrawn at all (f_s=0.2).

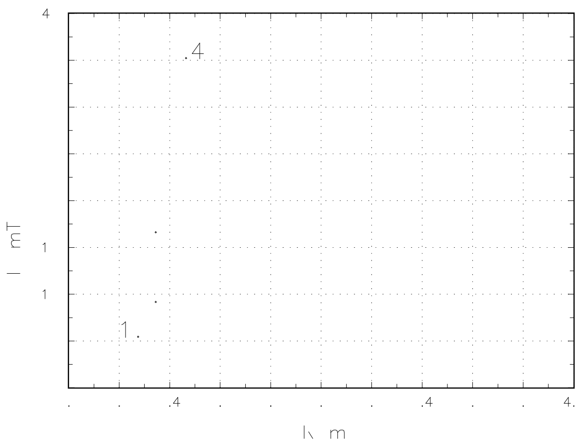

Figure 2.5: Barrel corner tile rows field for various relative end plate thicknesses

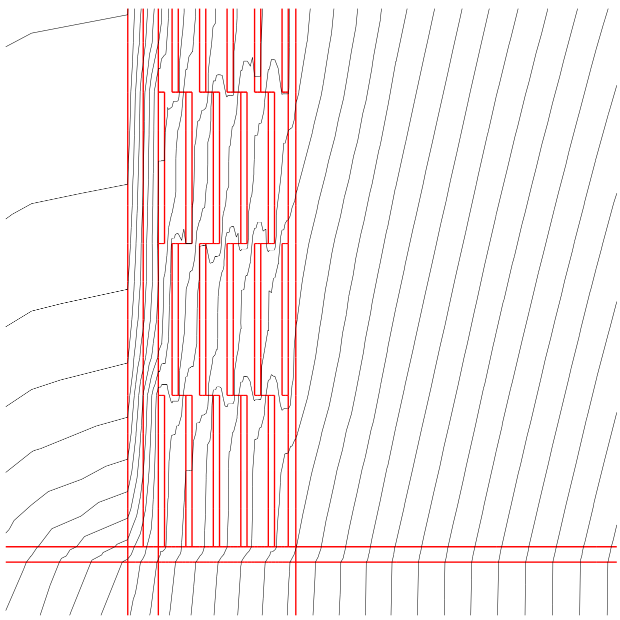

Figure 2.6: Field map near the Barrel corner for the front plate stack factor=0.2

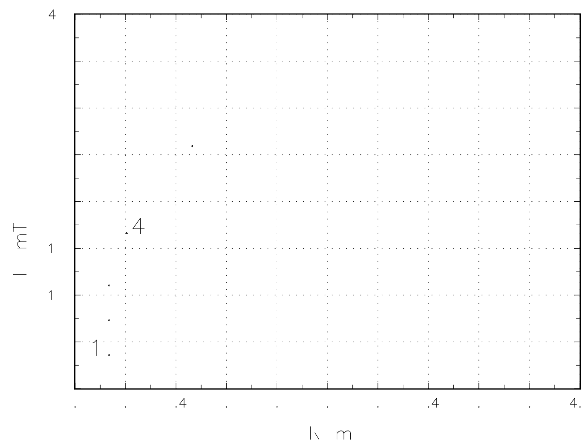

Figure 2.7: Barrel corner tile rows field for various relative front plate thicknesses

One can see that without the front plate the larger fraction of the magnetic flux concentrated there thus increasing the tile field as a result. A variation of the effective front plate thickness shows that one could decrease it of no more than on 30 % still keeping the maximum tile field below 10 mT (Fig. 2.7).

From the above written it became clear that mainly the Barrel corner region close to solenoid should be good protected magnetically from the solenoidal return flux. The end and front plate modification have no noticeable effect on the PMT location field. The girder plays the major role in the protecting PMTs from the outside field sources.

2.4 Girder Cross Section Modifications

To study the girder cross section modifications effect on the field at the PMT location we also used one of the 2D models described in Ref. [5]. In this model the magnetic system projection to the coordinate plane XOY, normal to the beam axis, is considered. Only BT stray field is taken into consideration. Solenoidal field could not be included in the model due to intrinsic limitations of this 2D model. So the model can be used just for the first glance on the effects and more deep investigation still needed later on. In the following Table the results of field calculation are summarized.

PMT location field (mT)		
B-reference	0.4	1.8
Cylinder $f_s = 0.8$	0.5	3.2
Holes in the "pillars"	0.5	4.3
Cylinder $f_s = 0.8$ and holes in the "pillars"	0.6	10.9

Firstly, the girder outer cylinder thickness was decreased by 20% thus making weaker its ability to protect the TileCal from the Barrel Toroid stray field. To this end the stack factor for the cylinder iron was assumed to be 0.8 instead of the normal value = 1.0. It appears that the PMT location field became on 20 % larger at the initial 0.4 mT. When we used on purpose the BT current increase to get the upper estimation of the initial PMT location field 1.8 mT, published in Ref. [7], the field after iron modification became on 75 % larger. This obtained result could not be of any surprise and is just the manifestation of the nonlinear

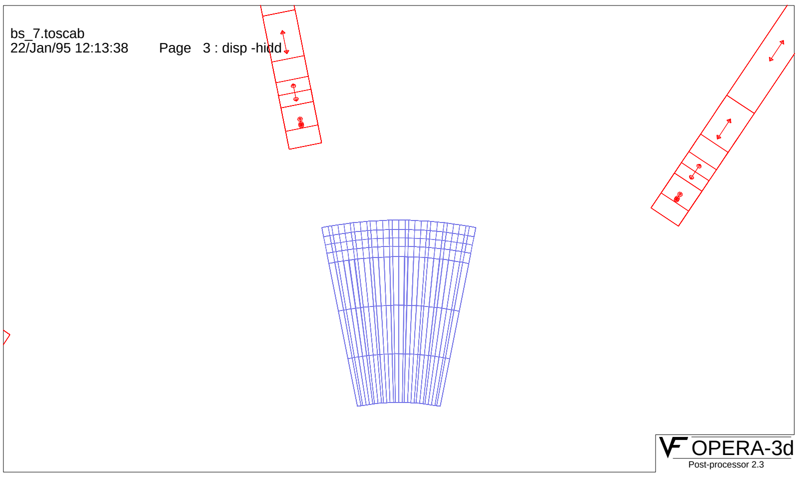

Figure 2.8: Computer model cross section near the interface region between the TileCal and BT

nature of the magnetic field effects in ferromagnetic media. With the solenoidal field included the situation could be even worse due to extra magnetization of the girder outer cylinder.

Secondly, the previously mentioned holes in the so-called "pillars", iron pieces separating the compartments for the PMTs in azimuthal direction, were introduced in the 2D model. These holes were presented in the model with the help of the suitable stack factor (0.57) for the "pillar" material at the locations of the holes. Calculations showed that the PMT location field became only on 25 % larger at the initial 0.4 mT there. So it looks as no harm would be introduced with these holes but once again: it was just a rough estimation and more sophisticated investigations needed. Par example in the case of the initial 1.8 mT field value a rather large PMT location field increase occurred there (see the Table).

A combined action of these two girder cross section modifications causes rather small effect at the initial 0.4 mT. But in the case of the initial 1.8 mT the effect is again nonlinear and the final field increases by a factor of 6, though the absolute field value is not very high still and can be diminish to the acceptable level with the planned PMT shielding system.

Having in mind the above said we do not recommend a decreasing of thickness of the outer girder cylinder.

2.5 Others Parameter Evolution

Some of the parameter modifications were just gradually included into the computer models and no special investigation of their impact on the B-field distribution have been conducted up to now. But still it is possible to indicate the tendency of the B-field variation due to these changes.

Thus the shift of the whole TileCal system radially on 3 cm outward will produce relatively small effect on the field distribution because it is rather small (several %) in comparison with the distances between the field sources (solenoid and Barrel Toroid) and the TileCal iron.

There is also no noticeable effect expected due to the replacement of the solid plate on a laminated one at minor radii of girder until the lamination air gaps are kept small enough.

2.6 Barrel Toroid Stray Field

Preliminary estimations showed that field map near the TileCal crack region between the TileCal and Barrel Toroid would be of order 0.1 ÷ 0.2 T according to Ref. [3], Ref. [5] and Ref. [7]. More detailed direct stray field calculation using 3D model gave $B_{max} \approx 0.4$ T there.

The region geometrical structure and the stray field maps are shown in Figs. 2.8, 2.9, 2.10, 2.11.

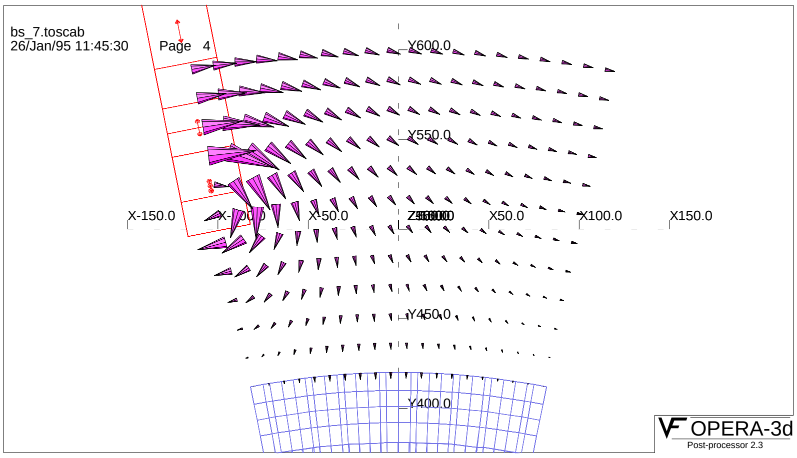

Figure 2.9: Field map in the interface region between the TileCal and BT

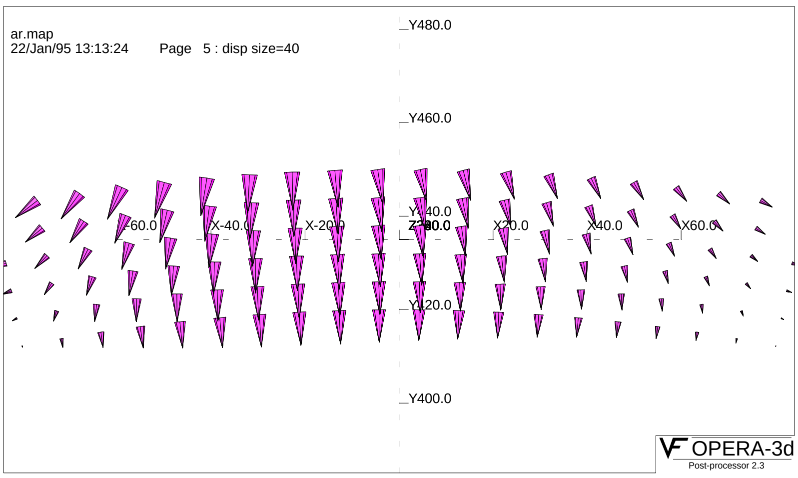

Figure 2.10: Zooming of the field map in the interface region between the TileCal and BT

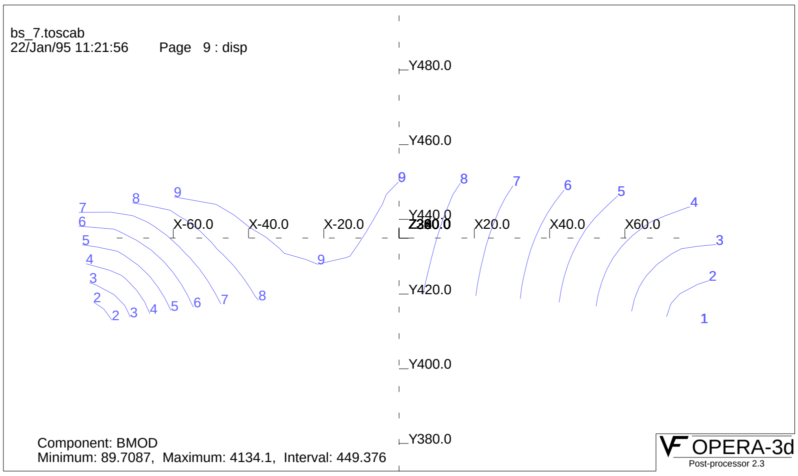

Figure 2.11: Field value map in the interface region between the TileCal and BT

In Fig. 2.9 and 2.10 the length of arrows represents in relative units an induction value at observation points. Fig. 2.10 shows a detailed distribution of the stray field in the region just in the outer radial range near the TileCal iron. In Fig. 2.11 one can see the azimuthal location of the maximum and minimum field value in this area.

3 CONCLUSION

- The end plate can be made on 20 % thinner but further decrease in its thickness would produce rather big magnetic flux penetration to tiles.
- The front plate can also be made thinner on 30 %.
- Calculations show that it is not recommended to decrease on 20% the amount of iron in the girder.
- An unavoidable introduction of the holes in the "pillars" will cause the PMT location field to increase. The absolute value of the resulting field is still tolerable and could be diminished to the acceptable level with the PMT shielding system.
- There are still questions to be answered on. Some of them require a genuine 3D approach and can not be considered in the 2 dimensional space. Effects of the Barrel and Extended Barrel girder interface modification is an example.

References

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