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TEMPERATURE DISTRIBUTION IN AN ECAL ELECTRONIC BOX

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Abstract

In the design of the ECAL Cooling System a particular interest is represented by the temperature distribution in an electronic box.

ECAL is one of the sub-detectors of CMS, it will house 82.728 crystals of lead tungstate, which have to work within a very tight temperature spread of ± 0.05 K.

To ensure adequate operating conditions it is of the uppermost importance that the heat dissipated in the electronic boxes is transferred to the power cooling circuit, preventing it to reach the regulating cooling circuit and thus provoking unacceptable temperatures on the crystals. For this reason a simulation of the boxes was performed and analysed.

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1 INTRODUCTION

The Compact Muon Solenoid (CMS) is a cylindrical detector that will make use of the Large Hadron Collider (LHC) accelerator currently under design at CERN.

The CMS is composed of different concentric sub-detectors placed in layers. ECAL (Electromagnetic Calorimeter) is one of the CMS sub-detectors and it will play an essential role in the study of the physics of electroweak symmetry breaking, particularly through the exploration of the Higgs sector (see Fig. 1). ECAL is a scintillating crystal calorimeter that offers excellent performance for energy resolution since most of the energy from the electrons or photons is deposited within the homogeneous crystal volume of the calorimeter. The scintillating crystals of the ECAL emit light with certain intensity when particles pass through. Photodetectors on the top of each crystal will measure the intensity and duration of these beams; the resulting electrical impulses will be transferred to electronic components situated in an electronic box. Each of these boxes can process signals coming from ten crystals **[2]**.

To ensure adequate operation conditions, it is of the uppermost importance that the heat dissipated in the electronic box is conducted to the power cooling system, preventing it from reaching the regulating circuit. If a value of more than 10% of the total heat goes to the regulating cooling circuit unacceptable temperatures would be provoked on the crystals, which have to work within a tight temperature spread in time and space of ± 0.05K at a temperature of about 18°C **[3]**.

This report presents the geometry, boundary conditions, results and conclusions of a thermal study performed with the CFD code Star-CD. A 2-Dimensional finite volume model of an ECAL electronic box, with its corresponding grill, thermal shield and crystal served as a basis for the thermal analysis. It updates a previous technical report concerning the cooling of the ECAL electronic box **[1]**. Since then, the development of the project produced major change mainly on the geometry of the structure.

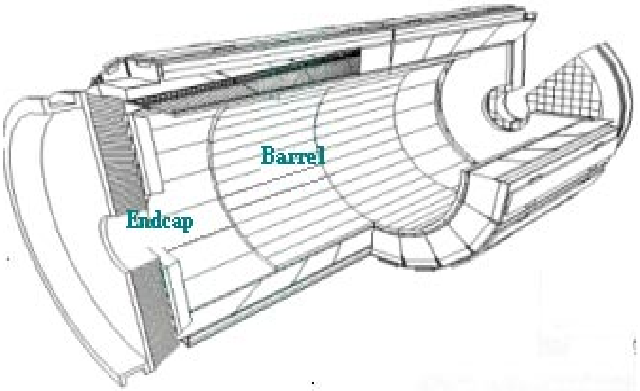

Figure 1 - Sub-detectors in CMS

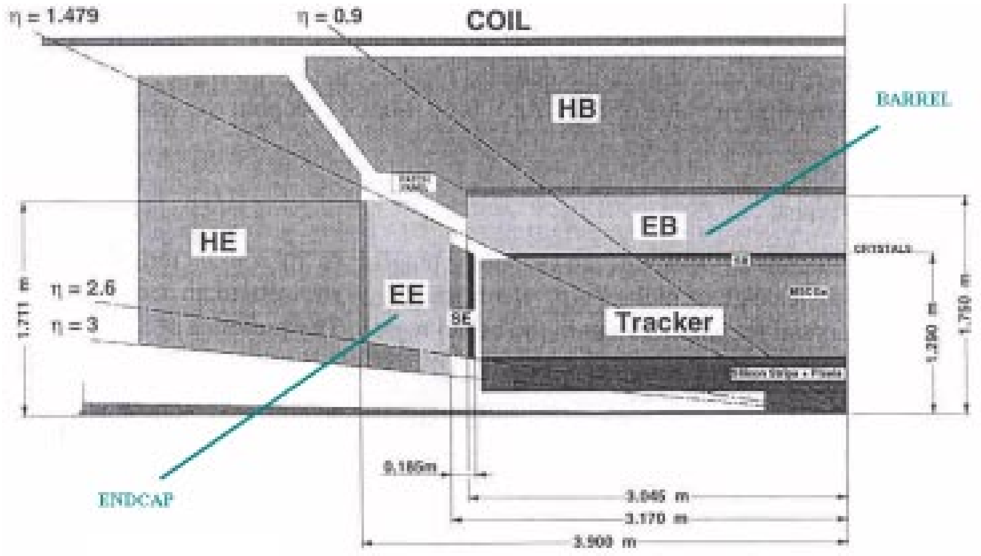

Figure 2 - Schematic view of ECAL sub-detector, barrel and endcaps

2 THE ELECTRONIC BOX

The ECAL consists of 82.728 crystals of lead tungstate positioned in a barrel divided in two halves, and two endcaps. Each half barrel consists of 18 supermodules. Each supermodule is divided in four modules: three of them house 40 crystals and the fourth 50 (see Fig. 2). Thermal bridges are carefully avoided as they may connect different thermal domains and impair the thermal stability of the supermodule.

The pipes are lagged to maintain accurately the required temperature up to the volumes to be cooled. This avoids accidental condensation and the thermal perturbation of the subdetectors traversed. For further information concerning the mechanical design see **[2]**.

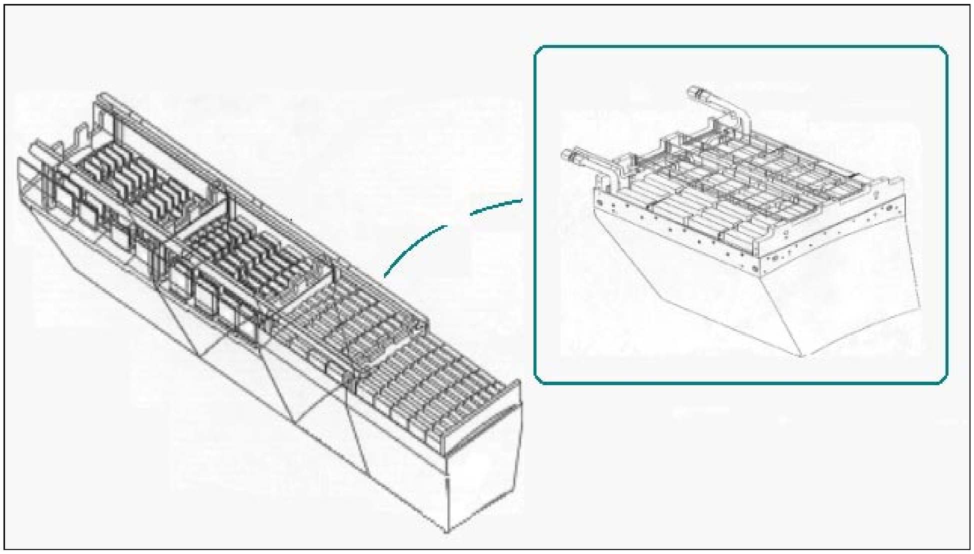

Figure 3 - View of a whole supermodule and highlight of a module

The cooling pipes of the power circuit and the box are thermally linked by means of copper braids. The boxes are mounted on a grid cooled by embedded pipes of the regulating circuit that absorbs the residual heat flux not transmitted to the power circuit. Each electronic box accommodates one pair of PCB's on each side. Each PCB has 5 columns of chips and each column processing the signal of one crystal, dissipates 1.005 W in total. This makes a total of 10 crystals being processed by an electronic box.

The chips in the different rows dissipate different power, from top to bottom, the values are 130 mW, 100 mW, 600 mW and 175 mW.

As for what cooling needs are concerned, the temperature and heat flux distribution in each electronic box is very important because, ideally, the power circuit would absorb the total heat flow generated by the electronics, however, in reality, part of it passes to the air and through the insulators and may affect the thermal stability of the crystals.

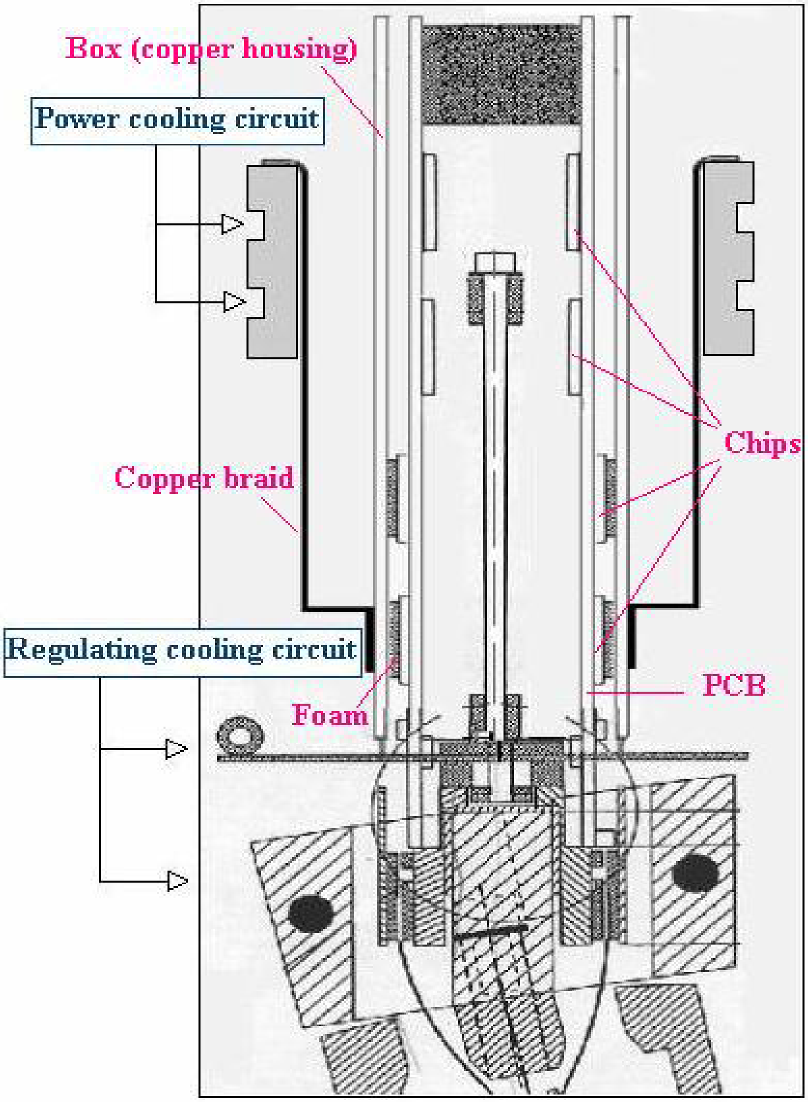

Figure 4 - The electronic box of the ECAL sub-detector: Z-Cross section

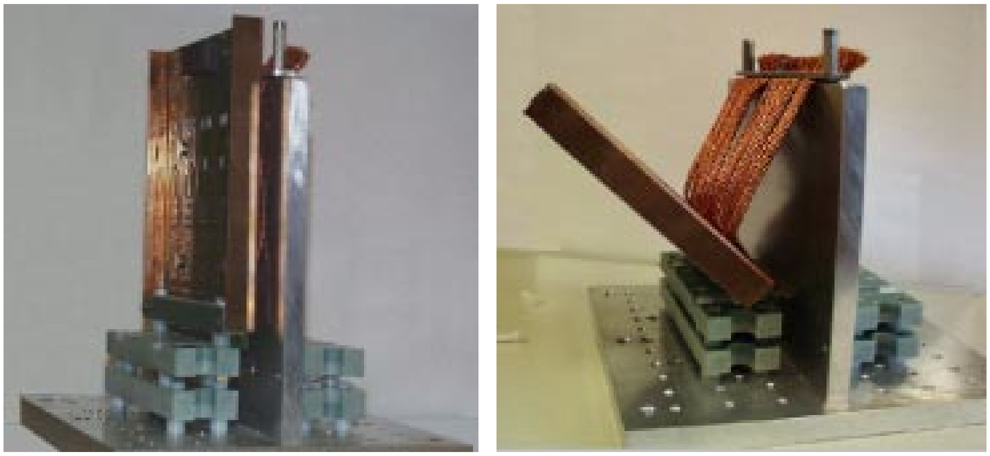

Figure 5 - The electronic box of the ECAL sub-detector: pictures of a prototype

3 THE FINITE VOLUME MODEL

3.1 The Code

The model of the electronic box has been performed using the preprocessing software PROSTAR and has been solved by StarCD code **[4]**.

StarCD, written in FORTRAN 77 and C, operates by solving the governing differential equations of the flow physics by numerical means on a computational mesh. PROSTAR is an interactive, command-and menu driven, combined pre-processing and post-processor with on-line facilities, including geometry modeling and mesh generation, specification of control parameters, material's properties, boundary conditions, etc.

3.2 Introduction to the Mesh

The expected predominant heat flux and air velocity directions are x and y, therefore it can be assumed the problem and the model to be 2D. The box and the connecting region between boxes can be assumed to be symmetric in the y plane therefore, by applying symmetry conditions only half of the box needed to be modeled. In the mesh, each colour represents a different material or element (see Fig. 4 and Table. 1). The study of a 2D model of an electronic box was made in parallel with the work of the team involved in the construction of the prototype. Basically, the models for the different cases studied were always based on the results of either one of the parts involved in the process. From the analysis of the results other potential solutions have been taken in to consideration.

Three different situations were simulated in a first approach, each having a slightly different geometrical structure of the box:

- Case 1: A lower connection of the copper braid to the electronic box.
- Case 2: A lower connection with the introduction of an upper portion of foam.
- Case 3: An upper connection with the upper portion of foam.

3.3 The Materials

The following table lists the different materials and their colour in the model, as well as their thermal conductivities.

Material or element	Colour	Thermal conductivity (W/mK)
Air	Light gray	1
Copper	Red	384
Epoxy –PCB	Light green	1.4
Chip1 (silicon)	Light blue	100
Chip2 (silicon)	Pink	100
Chip3 (silicon)	Yellow	100
Chip4 (silicon)	Dark blue	100
Capsule	Orange	2
Crystal	Dark brown	1
Foam	Green	0,5
Isolant	Light green	0,23
Kapton	Purple	127
Aluminium	Light brown	134

Table 1 Materials and respective thermal conductivities

3.4 The Boundary Conditions

The geometry of the model, as above explained, allows the setting of symmetry conditions in the Z plane and at the left and right vertical planes of the model. The upper part of the mesh is set to a fixed temperature of 18 ^{o}C to simulate the thermal conditions in the surroundings of the box. The white holes represent the cooling pipes. The wall temperatures of these holes are also at 18 ^{o}C. The rest of the external surfaces are considered to be adiabatic.

The thermal contact resistance between solid surfaces depends mainly on the materials in contact, the surface quality and roughness, contact pressure and on the interfacial fluid. The following overage values have been taken from literature: 2.75 10^{-4} m^2K/W for all contact surfaces except for the copper-copper, 17 10^{-4} m^2K/W and the copper-aluminium interface 8 10^{-4} m^2K/W.

3.5 Geometry Arrangements

The first geometry configuration constitutes the starting point for the design, the other two are possible variations conceived for the search of a better thermalisation.

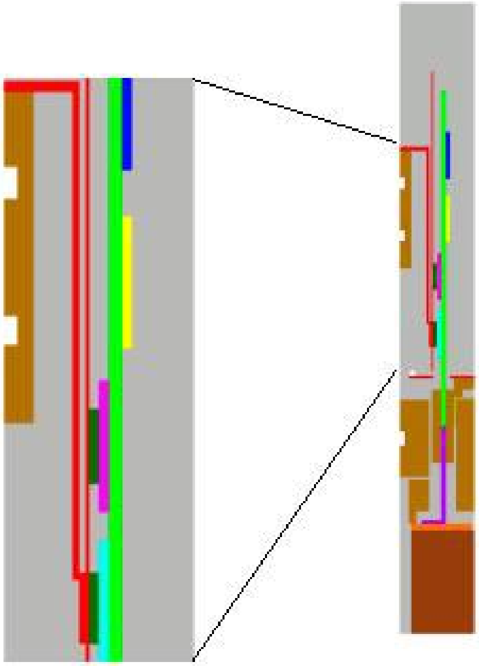

Figure 6 - Case 1: Low connection and no foam at upper chips.

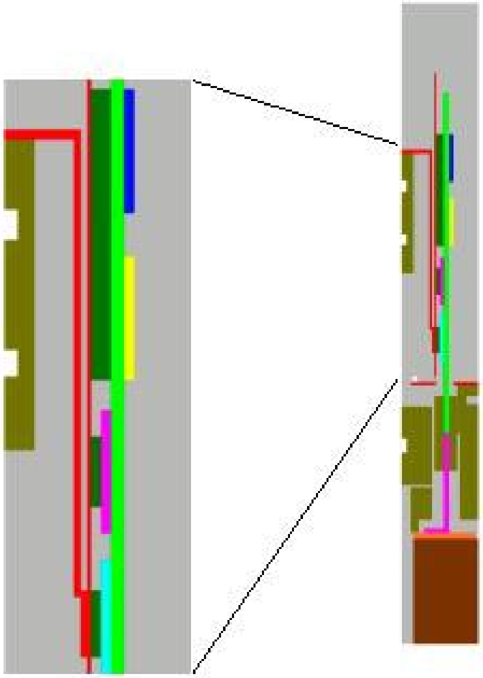

Figure 7 - Case 2: Low connection and foam at upper chips.

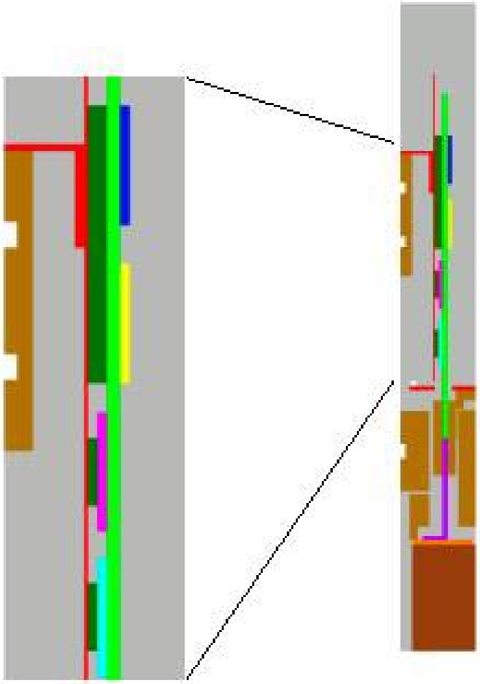

Figure 8 - Case 3: Upper connection and foam at upper chips.

4 RESULTS FROM THE CFD CALCULATIONS: TEMPERATURE MAPS

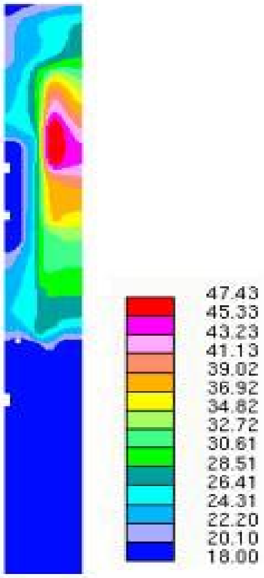

Figure 9 - Temperature map for case 1

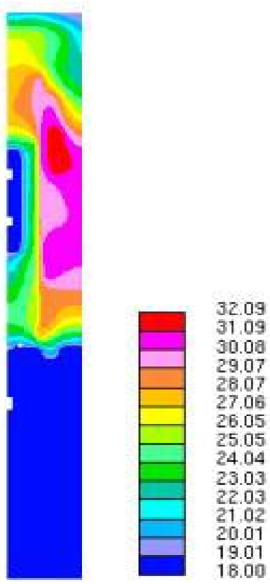

Figure 10 - Temperature map for case 2

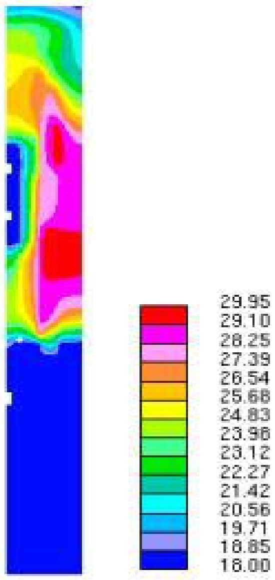

Figure 11 - Temperature map for case 3

The results obtained in each of the three cases show that the maximum temperatures in case 1, 2 and 3 are, respectively 47 ^{o}C, 32 ^{o}C and 30 ^{o}C concentrated around the upper chips. As to the lower region, close to the crystals, it can be observed that the temperature is stabilized at around 18 ^{o}C.

5 FIRST CONCLUSIONS

It can be concluded that the best thermalisation to the power cooling circuits is that shown in case 3 provoking less temperature rise in the air because of a higher heat flux transferred to the power cooling circuit.

It is important to remark that, following the advancements of the work of the team responsible for the prototype, the solution presented in case 3, being the best from a thermal point of view, had to be abandoned due to mechanical reasons related to the mounting of the box on the grid.

Therefore, in view of the temperature difference between case 2 and 3, which was found to be small (~ 2K), case 2 was set to be the best possible solution.

6 VARIATIONS FROM CASE 2

From the solution presented in case 2, two other different studies where derived.

In the first one (case 4), the thickness of the electronic box (copper wall) was reduced, in the second one, as the boxes will be mounted in different spatial orientation, a study of a box rotated 180 ^{o} in the Z axis has also been performed (case 5). The geometries and resulting temperature maps for cases 4 and 5 are presented in the next figures.

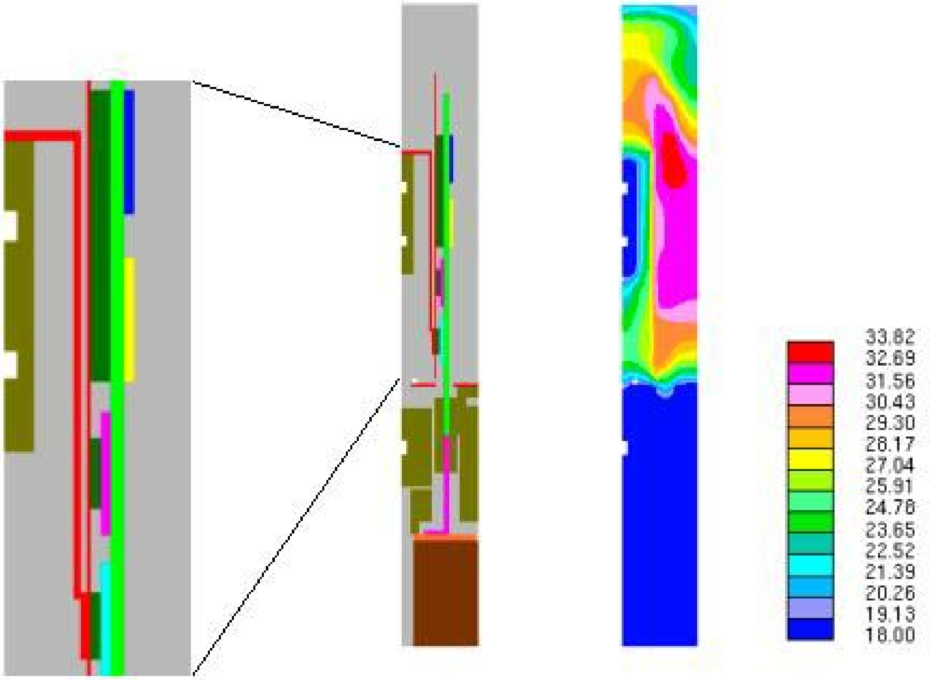

Figure 12 - Case 4: Lower connection and foam at upper chips, thinner copper housing.

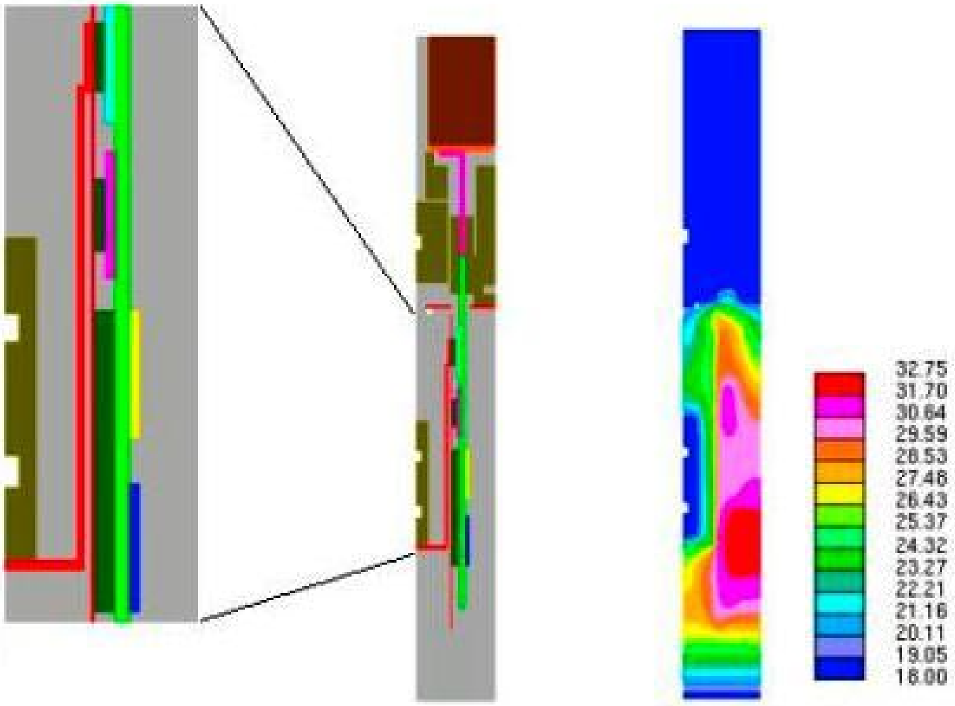

Figure 13 - Case 5: Low connection and foam at upper chips. Box rotated by 180 degrees.

7 ANALYSIS OF CASE 4 AND CASE 5

It can be observed for case 4, that the temperature is slightly higher (~1.7 K) than in case 2. Concerning case 5, the maximum temperature obtained is just slightly higher (~0.5 K) than in case 2, which means that the thermalisation is not much conditioned by its spatial orientation.

8 FINAL CONCLUSIONS

A 2D study of the electronic box in ECAL subdetector has been performed to evaluate some proposed cooling strategies to thermally insulate the crystals from the boxes. It can be deduced that the best results for the thermalisation were those found for case 3 (connection between the copper braid and the copper housing at the upper part and an insulating foam element near the upper chips), however the structure proposed for this case presents difficulties concerning the welding between the copper housing and the copper braids. Case 2 also showed good thermal performance, suggesting that the foam should be in fact used. The additional cases, derived from Case 2, confirmed the good choice of the case2-based geometry. It showed that there would be no major improvements by reducing the wall thickness of the copper housing. It also confirms that the box could be placed in different spatial orientations without any visible thermal change.

9 REFERENCES

[1] G.Peon & G. Nuβle “Temperature distribution in an electronic box of the ECAL sub-detector”, Technical report – ST-99-01
[2] The CMS ECAL Group “The Electromagnetic Calorimeter Project” -Technical Design Report, CERN LHCC/97-33,1997
[3] P.Baillon “Description of the cooling scheme of ECAL”, January 29 -1999
[4] StarCD, Version 3.10 - Computational Dynamics Ld.