EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANISATION EUROPÉENE POUR LA RECHERCHE NUCLÉAIRE

CERN - ST Division

CERN-ST-2000-025
February, 2000

STUDIES AND DESIGN OF THE ECAL (CMS) COOLING SYSTEM

D. Gasser

Abstract

The Electromagnetic CALorimeter (ECAL) sub-detector for the CMS experiment has to achieve very tight requirements in terms of temperature stability. The CV group is now involved in the design of a cooling system for ECAL. The status and the content of the work which has been done will be explained. The theoretical studies which helped to understand the ECAL thermal behaviour and the efficiency of the hydraulic network in charge of the cooling will first be briefly presented. Moreover, it will be shown how these studies helped to improve the cooling design inside ECAL. A proposal for an external cooling system of ECAL will be presented as well. Finally, experimental thermal tests, which are planned for April 2000 on a prototype corresponding to a part of ECAL, will be described. These tests aim to check the technical solutions which can be applied in the context of the real ECAL detector.

Presented at the 3rd ST Workshop
Chamonix, France, January 25 - 28, 2000

1 INTRODUCTION

This paper provides a summary of the contributions made by the CV group in the design of a cooling system for the ECAL sub-detector of CMS.

Thermal and hydraulic simulations of ECAL are presented first. Then, a solution principle for the external cooling system of ECAL is proposed. Finally, experimental thermal tests, which are planned for April 2000 on a prototype corresponding to a part of ECAL, are described.

2 PRESENTATION OF ECAL

The Electromagnetic CALorimeter (ECAL) is a sub-detector of CMS. It is mainly in charge of studying the physics of electroweak symmetry breaking. Lead tungstate ($PbWO_4$) crystals are the core of ECAL. The information of the particle collisions captured by the crystals is processed in photodetectors and then in some electronics close to the crystals.

ECAL comprises a cylindrical barrel and two end-caps (see Fig. 1). The present article deals with the cylindrical barrel only, which will be referred to as the 'ECAL barrel'.

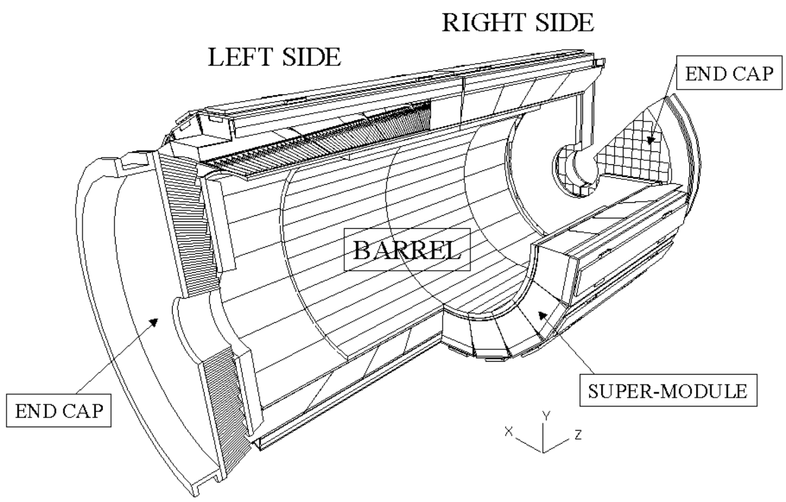

Figure 1: 3D view of ECAL.

The ECAL barrel is divided into two identical parts (left and right side), each of them containing 18 super-modules. All super-modules are identical, and correspond to the basic entity of the ECAL barrel.

Each super-module is designed so it is thermally independent. A super-module consists of an assembly of 1700 crystals on top of which are located the electronic boxes. Figure 2 shows a 3D view of a super-module; it can be seen that the structure of a super-module is itself divided into four modules (three modules contain 400 crystals and one module contains 500 crystals).

The requirement in terms of temperature stability is that the crystals must remain, during operation, at $18^{o}C \pm 0.05$ K. Besides, the heat dissipated by the ECAL barrel mostly arises from the electronics. Therefore, a super-module is cooled down by two independent hydraulic circuits embedded along the electronic boxes and the crystals (see Fig. 2): the power circuit in charge of removing the heat dissipated by the electronic boxes; and the regulating circuit in charge of keeping the crystals at a stable temperature.

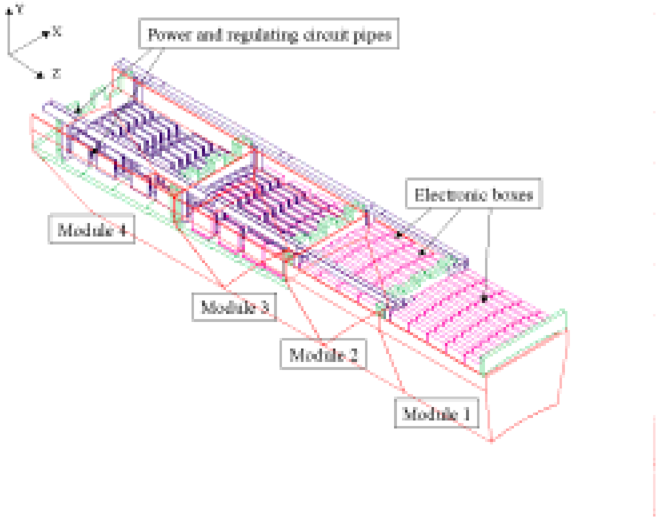

Figure 2: 3D view of a super-module.

In order to evaluate the flow rate to be provided in the two cooling circuits, the following dimensioning figures are chosen.

- Total heat dissipated in a super-module: Ptot = 3400 W.
- Heat dissipated in the electronic boxes (to be removed by the power circuit): 85% to 95% of Ptot.
- Remaining heat dissipated to be removed by the regulating circuit: 5% to 15% of Ptot.

Concerning the regulating circuit, the tight requirements to be achieved for the temperature stability of the crystals do not allow a ΔT above 0.1 K between inlet and outlet. This leads to a flow rate of about 1.38 l/s in a super-module and 50 l/s in the whole ECAL.

Concerning the power circuit, there are no particular requirements for the temperature stability of the electronic boxes, the only constraint is that the electronic temperature should not exceed 50°C. Thus, if a reasonable ΔT of about 5 K is considered between inlet and outlet of the circuit this leads to a flow rate of 0.138 l/s in a super-module and 5 l/s in the whole ECAL.

3 THERMAL AND HYDRAULIC STUDIES OF A SUPER-MODULE

3.1 Hydraulic analysis of the piping network inside a super-module

The principle of the study is to simulate the hydraulic behaviour of the power and regulating piping network inside ECAL. In particular, the flow sharing in the different lines and the head losses in the circuits are calculated. To do so, an analogy between a hydraulic and an electric network is done using the Spice[1] software.

The structures of the two cooling networks inside a super-module are similar.

- Each circuit feeds in parallel the four modules.
- In each module, 10 lines in parallel are embedded between the rows of electronic boxes for the power circuit, and between the crystals and the electronic boxes for the regulating circuit (see Fig. 3).

[1] Spice is a scientific software enabling a formal simulation of any electric circuit.

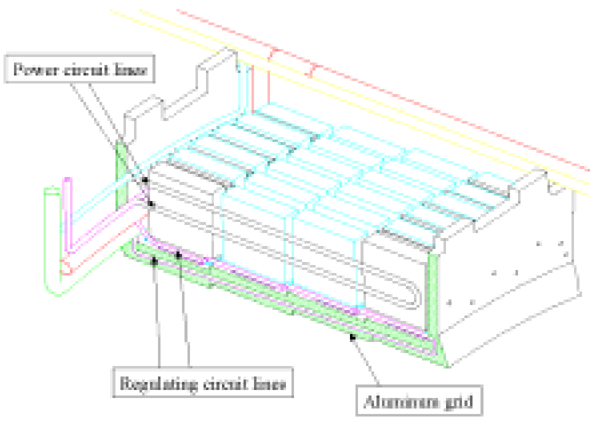

Figure 3: Detail of the cooling circuits in a module.

The same electrical model was used for both cooling circuits. In this model, all the singularities (tee junction, elbows) responsible for head losses are represented by resistances depending on the friction coefficient and the geometry of the singularity. The head loss arising from the fluid viscosity is simulated by a single resistance depending, for each line, on the tube length and the friction coefficient.

First of all it was checked that, for both circuits, the flow rate is equally shared in the different lines thanks to similar resistances.

Concerning the total head loss inside a super-module, it was calculated to be about 0.2 bar for both circuits, which is an acceptable value.

Then, the flow regime was calculated in the different lines. For the regulating circuit, the Reynolds number remains above 4500, which is enough to provide a turbulent regime in the pipes and thus a good heat-transfer coefficient. For the power circuit, it appeared that in the 10 lines located between the electronic boxes, the Reynolds number was about 1000, which is too small to reach a turbulent regime. To increase the Reynolds number in these lines, it was impossible to reduce the inner diameter, which was already 4 mm. So, it was decided to change the structure of the power circuit network: The 10 lines in parallel were transformed into 2 parallel lines by grouping 5 lines in series on one side and the other 5 in series on the other side; this led to a flow rate and Reynolds number five times higher and then to a good turbulent regime. The drawback of this new solution is that the total head loss, for the power circuit inside a super-module, rises to about 0.8 bar, although this is still an acceptable value.

3.2 Thermal analysis of an electronic box

This study aims at simulating the thermal behaviour of an electronic box and the crystals located underneath [1].

Figure 4 shows a Z–view of an electronic box and the crystals located underneath. It can be seen that an aluminium grid is supporting the electronic box above and the crystals below. The heat is almost entirely dissipated inside the electronic box; a thermal shield allows the crystal to be insulated from the electronic box. The Kapton cable allows the transmission of the crystal signal to the electronic board.

The lines of the regulating circuit consist of holes drilled along the grid (for inlet) and pipes welded on top of the thermal shields (for outlet). Concerning the power circuit, the inlet and outlet pipes are thermally connected to the electronic boxes by aluminium fins. The heat flux arising from the electronic boxes that the power circuit does not remove is 'caught' by the thermal shield (made of copper) and then removed by the outlet lines of the regulating circuit.

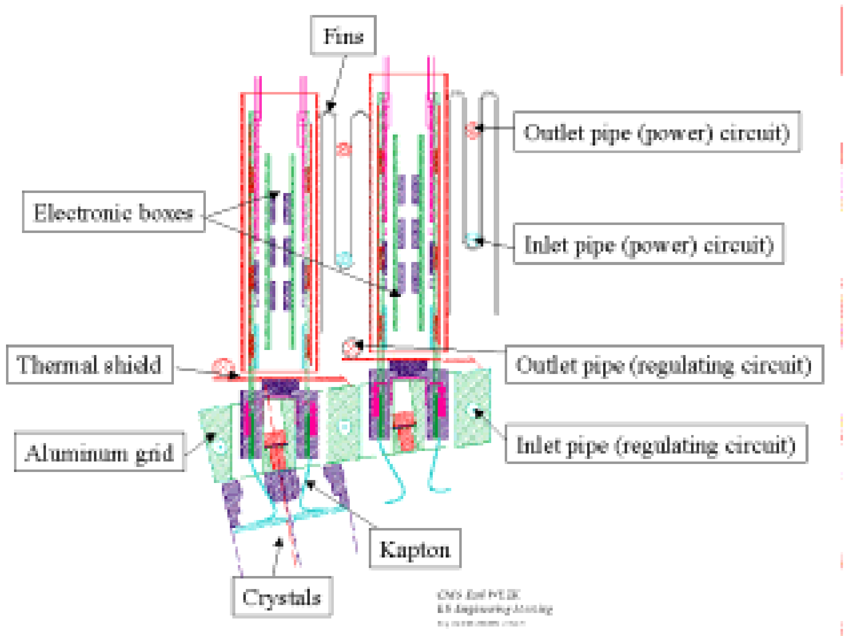

Figure 4: Z-view of an electronic box.

A 2D model, including all the elements of the set shown in Fig. 6, was constructed using the CFD code StarCD. The equations of heat convection and conduction were then solved in this model. The main parameter studied in the simulation was the thermal resistance (Rth) between the aluminium fins and the electronic boxes. According to the value of Rth, the fraction of heat removed by the power and regulating circuits is quite different (see table below).

Rth (m^2.K/W)	% of heat flux to power circuit	% of heat flux to regulating circuit	% of heat flux to the air
2.75×10^{-4}	94	5.5	0.5
2.75×10^{-2}	75	20	5

Depending on the value of Rth, the fraction of heat removed by the two cooling circuits may or may not remain within the dimensioning figure given in Section 2. Actually, only a very good fin-box thermal contact (Rth = 2.75×10^{-4}) allows to comply with the dimensioning figure.

It then appeared that the present mechanical solution with a long aluminium fin pushed by its elasticity on the electronic box could hardly achieve a good thermal contact. Besides, the welding of the fin on the box to improve the contact is not easy. So, another solution was proposed where the power circuit is made with two longitudinal holes drilled in an aluminium bar; the thermal contact between the bar and the electronic box is provided by a kind of cornered metallic plate welded on the box and screwed on the bar (see Fig. 5).

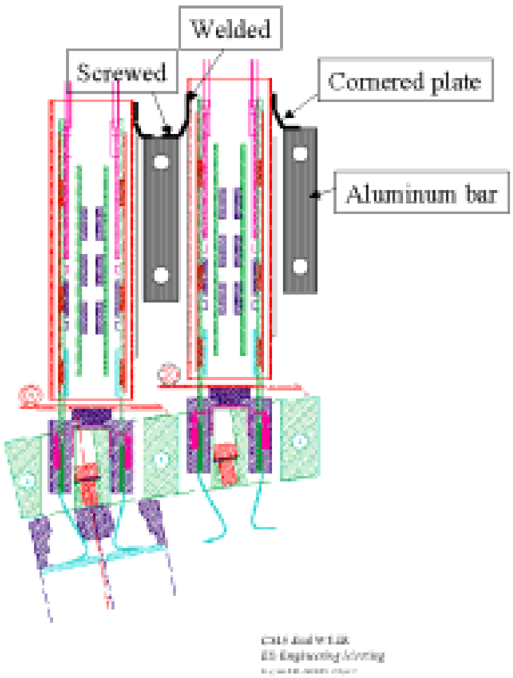

Figure 5: New design for the thermal connection between electronic boxes and the power circuit.

4 COOLING SYSTEM OUTSIDE ECAL

In the context of the real ECAL sub-detector, the outside cooling system consists of two independent ones which will provide demineralized water at the right temperature for both regulating and power circuits.

4.1 Cooling system for regulating circuit

The main requirement to be achieved by the system is to provide a constant water temperature of 18°C ± 0.05 K at the ECAL inlet. To do so, the following principle is proposed (see Fig. 6).

At the ECAL outlet, the circuit is divided in two lines; one goes straight to a mixing tank, while the other passes through the evaporator of a cooling group and then connects to the mixing tank. The flow sharing between the two lines is controlled by the regulating valve. In the tank, the flows coming from the two lines are mixed at the temperature of Ti = 18°C and then sent to the ECAL regulating circuit.

At the ECAL outlet, a heating unit warms up the water to a constant temperature To, whatever the heat dissipation fluctuations inside ECAL. This allows the cooling group to work at a constant $\Delta T = To - Tc$.

If k is the fraction (from 0 to 1) of the total flow-rate Q in ECAL passing through the cooling group, the relation between Ti, To and Tc is, in a permanent regime,

$$Ti = To - k\,(To - Tc) = To\,(1 - k) + kTc.$$

This relation shows two advantages of the system. The fluctuations of the temperature Tc provided by the cooling group can be corrected by acting on the regulating valve (that is to say the k coefficient) in order to keep a constant Ti. The precision on the temperature Tc given by the cooling group might be worse than that required for Ti; indeed, if k = 0.25 a precision of ± 0.05 on Ti can be achieved, with a precision of ±0.2 on Tc.

Moreover, the mixing tank acts as a buffer tank too. Indeed, in case of a breakdown of the cooling group, for a while it can provide water at the right temperature.

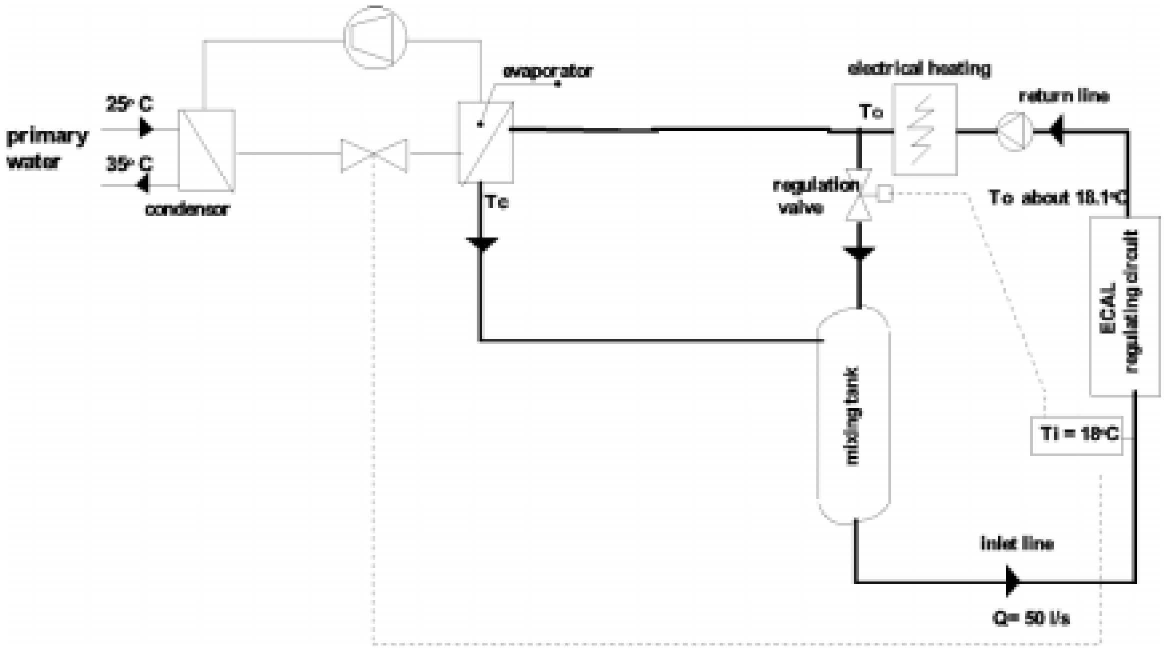

Figure 6: Principle schematic of the cooling system for the regulating circuit.

4.2 Cooling system for power circuit

Here, the requirements to comply with in terms of temperature precision are quite standard: The system shall provide a water temperature between 15 and 18°C with a precision of ± 0.5 K. Therefore the proposed principle for the cooling system is rather simple (see Fig. 7).

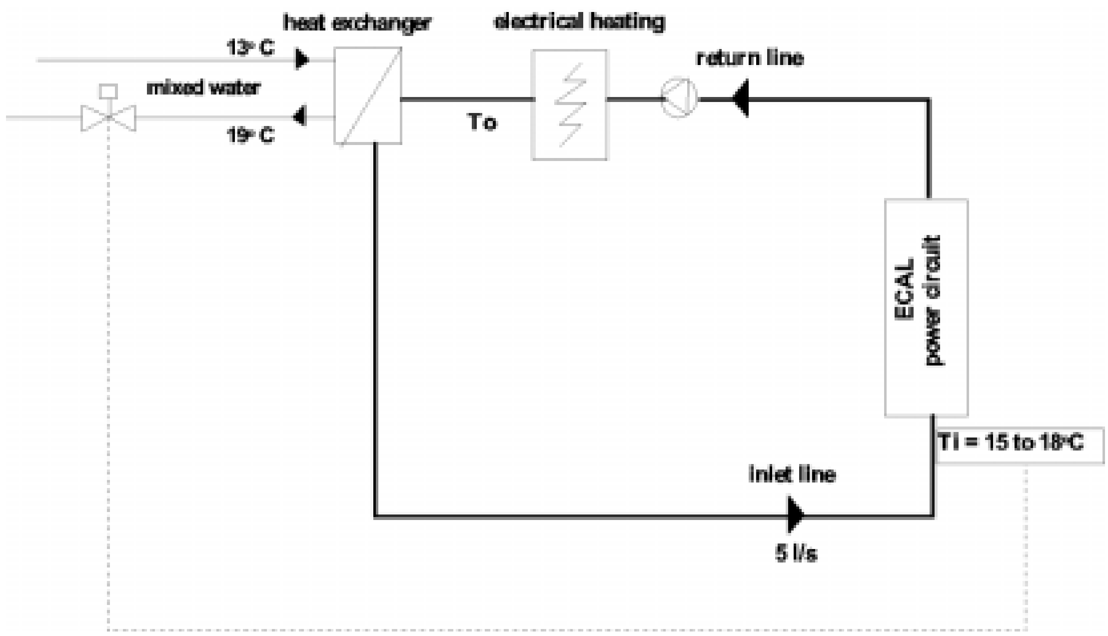

Figure 7: Principle schematic of the cooling system for the power circuit.

At the ECAL outlet, the flow goes straight to a heat exchanger working on mixed water and then comes back to the ECAL inlet. In the same way as described in the previous subsection, the heating unit, located at the ECAL outlet, warms up the water to a constant temperature To, whatever the heat dissipation fluctuations inside ECAL; this allows the heat exchanger to work at a constant $\Delta T = To – Ti$.

The critical point for the cooling system is that it is in charge of removing more than 80% of the heat dissipated by ECAL. So it must have the ability to detect any overheating of the electronics inside ECAL and then to generate the appropriate alarm. This alarm can be generated if the temperature at the ECAL outlet reaches a certain value.

5 EXPERIMENTAL TESTS ON MODULE-0 PROTOTYPE

5.1 Description of the prototype and purposes of the tests

Module-0 is a super-module prototype where only one module, the one in position 2 (see Fig. 2), is filled with the crystals and electronic boxes, the three other modules remaining empty. In this prototype the power and regulating circuit will be built with the final design described in subsections 3.1 and 3.2. The outside cooling systems for power and regulating circuits will be built according to the principle described in subsections 4.1 and 4.2.

The purposes of these tests are as follows.

- To evaluate the thermal efficiency of the regulating and power circuits to achieve the role which is expected from them. In particular, the percentage of heat removed by the two circuits will be measured.
- To evaluate the ability of the two outside cooling systems to achieve the right temperature requirements at the ECAL inlet.

5.2 Description of the experimental measurements

The experimental measurements will be the following:

- water temperature difference between module inlet and outlet (for regulating and power circuits),
- head losses between module inlet and outlet (for regulating and power circuits),
- flow rates in regulating and power circuits,
- temperature in different points around the electronic boxes and the crystals.

5.3 Instrumentation around the electronic boxes

The module-0 prototype contains 40 electronic boxes. Sets of six temperature probes will be placed around three of these electronic boxes.

Figure 8 shows how a set of six temperature probes (Pt100 kind) will be located around a box (the three sets are identical).

- Two probes (1 and 2) are fixed on the box’s wall and on the aluminium bar of the power circuit.
- Two probes (3 and 4) are fixed on the thermal shield and on the regulating pipe welded on it.
- One probe (5) is fixed on the grid; this temperature measurement will allow to check if the grid remains at a stable temperature (closest as possible to 18^{o}C) and is hence well insulated from the electronic box by the thermal shield.
- One probe (6) is fixed close to the Kapton and the crystal; this measurement will allow to check if the temperature remains stable in this area (close to 18^{o}C) and if the crystal is well insulated from the electronic box.

It is not planned to fix probes on the crystals because the crystals will be delivered with a temperature sensor already fixed.

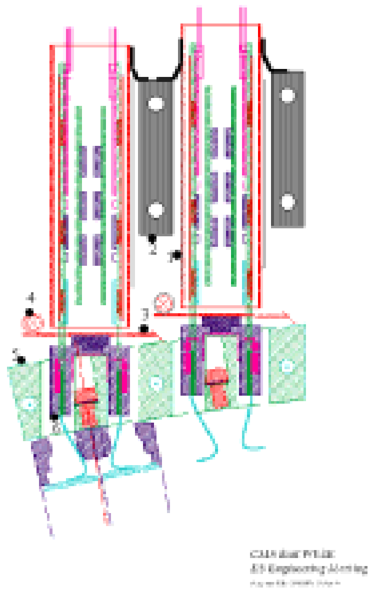

Figure 8: Temperature-probe positions around an electronic box.

6 CONCLUSIONS

The different studies and simulation performed, enabled a better understanding of the thermal and hydraulic behavior of ECAL. The modifications made to the design are expected to improve the efficiency of the cooling.

The proposition of a principle for the external cooling system of ECAL is a starting basis for future developments.

The tests on module-0 planned for April 2000 are an important step because they should validate the chosen solution for the design.

ACKNOWLEDGEMENTS

I first thank Guillermo Peón who performed the thermal and hydraulic studies.

I thank as well Bernard Pirollet for his help in the design of the outside cooling system principle.

REFERENCES

[1] G. Peón & G. Nüßle, ‘Temperature distribution in an electronic box of the ECAL sub-detector’, CERN–ST–99–001 (1999).