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Cooling system for the TILECAL hadron calorimeter of the ATLAS detector

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Abstract

The Leakless Cooling System (LCS) for the TILECAL hadron calorimeter is described with the results obtained during the 1997 test beam period. The presentation shows that the LCS is the more adequate cooling system for the TILECAL calorimeter design. The results give a stability of the temperatures in the drawers and inside the PMT blocks better than 0.25^0C, involving a drift on the PMT gain less than 0.05%.

1 Introduction

All the electronics inside the drawers of the TILECAL modules is expected to dissipate a non negligible amount of heat. A study of the power consumption, see table 1, gives approximatively a maximum of 200 W per super-drawer. During the Module 0 test beam in 1996, two temperature probes (one in each drawer) had shown that the temperature was stabilised around 35^0C in the drawers, with no cooling. For this test, the power consumption was approximatively 50% of the full power (the pipeline was not in the drawers).
Furthermore, the simulations (made at Clermont-Fd) have shown that with a temperature of 18^0C in the drawer, the temperature on the chips is expected to be between 40 and 50^0C. For a good working of the electronics, a temperature less than 45^0C is recommended. Therefore, it seems necessary to cool the drawers. Experimental simulations (made at Chicago) in a mock-up have shown that by keeping the drawer at a temperature of 18^0C, the temperature inside the PMT block would reach a plateau at about 30^0C.

Sources of power	Central barrel (in $Watt$)	Extended barrel (in $Watt$)
3-in-1 cards	69	46.5
Mother boards (total)	1.75	1.75
Cesium board	2.65	2.65
Pipeline boards	80	60
Pipeline controller	5	5
Adder boards	1.8	1.6
HV cards (total)	17.5	17.5
Others (CANbus, ...)	5	5
TOTAL	182.7 W	140.0 W

Table 1: First estimation of the detailed power consumption inside a super-drawer.

On an other side, a temperature less than the dew point is dangerous because of the possible water condensation on the electronic boards which could create some short-circuits. It could also have an impact on the working of the PMTs and the light mixers. Figure 1 shows the dew point as a function of the relative humidity for a cavern temperature at 18^0C and 20^0C. From this figure, it is clear that the temperature should be stable. Indeed, for a relative humidity of 70%, the dew point varies between 12.4^0C and 14.4^0C following the temperature in the cavern between 18^0C and 20^0C [1]. Furthermore, the humidity should be controlled with a good accuracy. If we consider an ambient temperature of 20^0C, the dew point varies between 12.0^0C and 16.4^0C when the humidity ranges from 60% to 80%.

A requirement could be to have the drawers at a temperature greater than 14^0C,

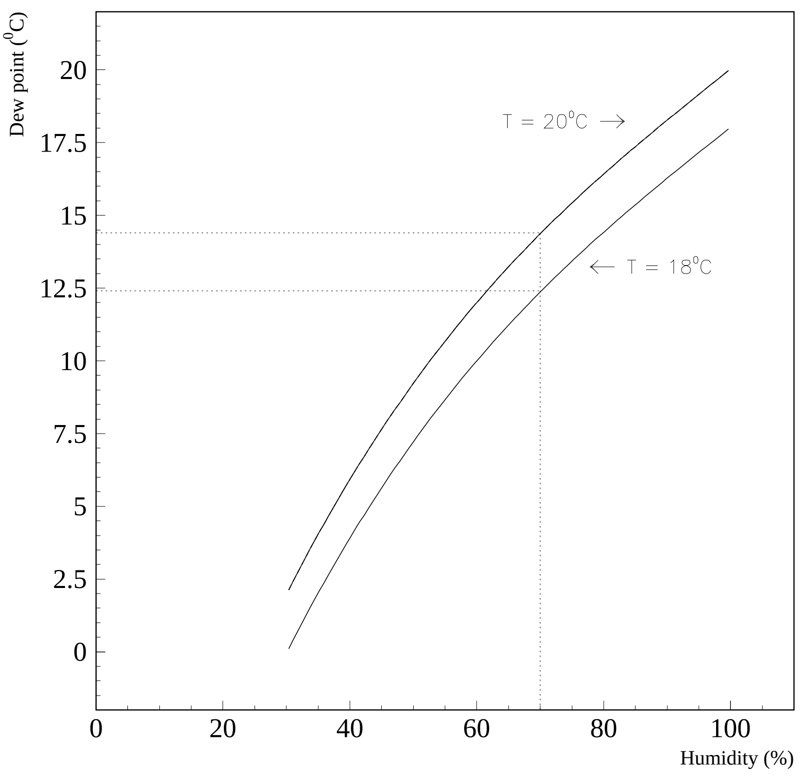

Figure 1: Dew point versus the relative humidity for an ambient temperature of 18^0C and 20^0C.

this value being based on an ambient temperature of 18^0C and a relative humidity around 70%.

2 Constraints on the cooling system

In addition to the above temperature considerations, the other requirements are the following.

2.1 General requirement

The cooling system must be connected to each super-drawer by taking into account the following points:

1. The temperature of the drawer material (casted aluminium) must be as close as possible to the girder temperature (the girder is made with an heavy iron mass which contributes also to the cooling: this mass is at the ambient cavern temperature (in the range $18-20^0C$), following an acceptable gradient of some degrees with respect to the height).

2. The temperatures must be as uniform as possible all along the super-drawer length.

3. The cooling system must be safe and efficient; it means:

   - <u>Safe:</u>
     - no risks of liquid leaks: the drawers are inside a closed box (the girder) containing a lot of electronics using Low Voltages and High Voltages, ...
     - no risk of water condensation: in any cases, the cooling temperature must be above the ambient dew point.
   - <u>Efficient:</u> the various temperatures (drawers, PMT blocks, electronics cards) must remain constant within 0.5^0C, over a very long time.

4. The system must be simple, easily and quickly disconnected at the super-drawer level (because of the access to the drawers) without leaks.

5. The global cost of the cooling system, including its impact on the cost of the design of the drawers, must be considered.

6. The chosen system must have been experimentally demonstrated in realistic conditions (inside a detector).

7. It must work at the same temperature in the test beam area as in the cavern, because of the transfer of the cesium calibration on 1/8 of the modules from one site to the other one.

2.2 Mechanical requirements

The system must fit the design of the drawers. It includes the mechanical and the electronical constraints:

1. The positioning of the Girder-Rings is very accurate, but the experience has shown that some flexibility in between the 2 Drawers is required (at least in the horizontal plan when the PMT blocks are set in an horizontal plan), when the drawers are inserted or extracted.
2. This requirement is strongly increased in the special cases where the access gives the obligation to have a train of 2 super-drawers (that means 4 drawers!).
3. According to the various designs of the patch panel, an other flexibility is needed either between the external drawer and the patch panel or between the patch panel and the external world.
4. In the mounting or dismounting operations, the patch panel must be disconnected. Once the super-drawer is taken out, the 2 drawers must be disconnected.
5. The free spaces for the connectors of the cooling system are very restricted; this room aspect is directly forced by the space allowed to the electronics and for the sliding of the drawers.

2.3 Summary

As a first conclusion, the best system should be based on the use of:

- flexible connections (internal/external drawers, external drawer/patch panel, patch panel/outside world),
- small connectors.

The TILECAL chosen solution is using the so-called Leakless Cooling System (LCS) that fits the totality of the previous requirements.

Furthermore, this system has already been used in the L3 experiment during more than 10 years to cool the electronics in the racks and in the detector. Over all that period no water leak has been observed. It has been also used in many other places in the world.

3 Principle of the Leakless Cooling System

The LCS is studied to work with water but without leak, and is composed by two units separated by about 3 meters in height, see figure 2 for the prototype used in the TILECAL test beam.

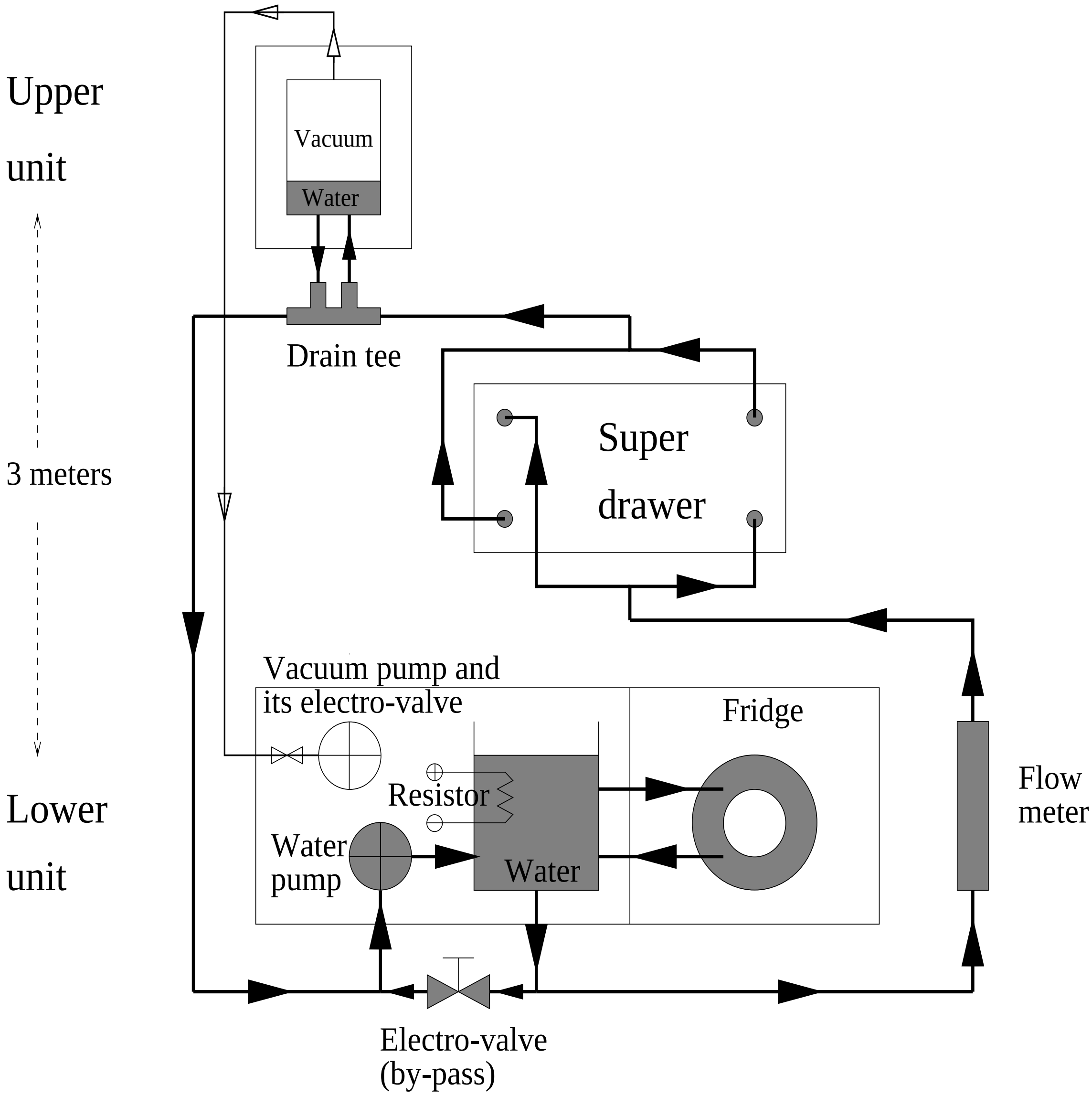

Figure 2: Diagram of the Leakless Cooling System.

The main components of the lower unit (with the dimensions $98 \times 81 \times 45$ cm^3) are the following:

- a tank of water with a volume of 10 litres,
- a fridge to cool the water in the tank,
- a heating resistor to stabilise the temperature of the water in the tank at a given temperature (18^0C for example),
- a water pump for the circulation of the water,
- a water flow meter to check the cooling condition,
- an electro-valve (called by-pass) for a fine tuning of the water flow,
- a vacuum pump with its electro-valve to maintain the vacuum in the upper unit.

The upper unit (with the dimensions $45 \times 15 \times 6$ cm^3) is only a glass jar under vacuum (at 0.3 bar) connected by two tubes, via a drain tee, to the main water circuit. Such a system allows to ensure the circulation of the water by depression (with the help of the water pump) and to avoid leaks in the case of a failure of a tube or a connector. For example, if a tube is broken in a drawer, all the water after the failure will be suck up by the upper unit, while all the water before the failure will fall down in the tank. So instead of having the water going out of the tube, the air goes in the water circuit, making impossible a water leak inside a drawer.
Let us note that during a test in July 1997, the cooling system has been put by error in a working mode with a tube not linked between the two drawers of a module, and no leaks were observed.

In the drawers, the uniformity of the temperature is obtained with two crossed circuits at the top and the bottom, see figure 3. The water circulates in stiff tubes (duralumin) glued inside grooves with aluminium loaded glue. The links between the two drawers of a super-drawer and the two tubes at the extremity of the internal drawer are ensured with flexible plastic tubes.

The inlet and outlet tubes for the water at the level of the patch panel can be seen on figure 4. Let us mention that a new Patch Panel design is under study.

In order to respect the constraint of a loss of head of about 0.3 bar (corresponding to 3 meters) and for the best working of the present LCS, the sizes (lengths and diameters) of the various tubes have been optimised. This constraint can be different in the ATLAS framework.

For a good working of the Leakless Cooling System, the difference in height between the lower and the upper units can not exceed 3 meters. If the difference is bigger, the depression would be too important for a good working.

Figure 3: View of the water circuits in a super-drawer.

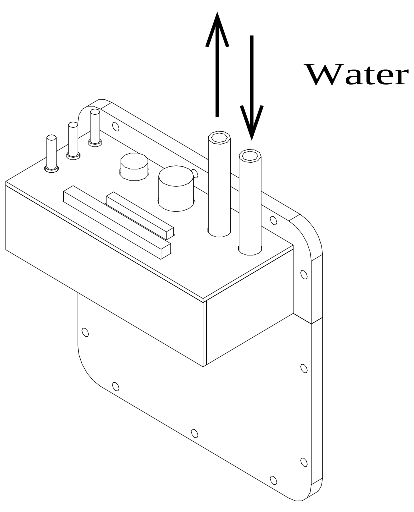

Figure 4: View of the patch panel with the tubes of the water circuits.

A photo of the test beam experiment is shown on figure 5 where we can see the table supporting the two extended barrel modules 0 and the five old prototypes. Below the table there is the lower unit of the cooling system and above the table (higher than the two modules 0) there is the upper unit. Because of the various movements of the table versus the fixed position of the particle beam, the lower and upper units are hanging in such a way that they are kept, respectively, in horizontal and vertical positions in any circumstances.

Figure 5: Photo of the test beam experiment with the lower unit of the cooling system just under the table and the upper unit above.

4 Monitoring of the cooling

The two diagrams of the monitoring system which will be used in 1998 for the test beam period are presented on the figures 6 and 7. The monitoring used in 1997 was similar but less sophisticated.

When the cooling system is turned ON, if in the upper unit the water level is below the high threshold in the glass jar, this means that the depression is not significant enough. Then, the circulator (water pump), the vacuum pump and its electro-valve are activated; the water goes up in the glass jar (see the upper scheme of figure 8). Now, if the water level is below the low threshold 5 seconds after the activation, the circulator does not work as long as the level has not reached the low threshold. Next, when the high threshold is reached, the vacuum pump and its electro-valve are turned OFF.
If the water level is at the high threshold when the system is put ON, only the circulator will be activated.
All the air bubbles are trapped in the glass jar, the water level will decrease. When the level reaches the low threshold, the vacuum pump and its electro-valve are activated until the high threshold is reached.
During the operation, if the high threshold is not reached in the next 90 seconds, the alarm “Air intake” is triggered and after 200 seconds the vacuum pump and its electro-valve are stopped. It can simply mean that a pipe is disconnected.
During the 1997 test beam period, this operation took approximatively 10 seconds and its frequency was every 90 minutes.

The water flow is tuned with the help of the electro-valve called by-pass. The electro-valve is activated only 10 seconds after the stop of the vacuum pump. If the flow is below the minimum allowed, the electro-valve closes by itself step by step (0.5 second of closing and 2 seconds of pause) and the flow increases (see the middle scheme of figure 8). Whereas, if the flow is above the maximum, the electro-valve opens by itself step by step and the flow decreases.
During the regulation, if the water level stays more than 75 seconds below the minimum authorised flow, an alarm “Insufficient flow” is triggered. This means that either the minimum flow required is too high or that a pipe is pinched.

The fridge unit works always at its maximum, and the water temperature is tuned at 18^0C with the help of the heating resistor in the tank. In the next design, for the 1998 test beam, two other alarms will be installed in the water tank: one to control the temperature and one for the water level, see the lower scheme of the figure 8. An alarm will be triggered, if the water temperature decreases down to 16^0C or if the water level decreases down to the minimum allowed value.

All the alarms are displayed on a NIM box, see figure 9 showing the front panel, and a buzzer sounds each time one of the alarms is triggered. A button on the NIM box allows to stop the buzzer. NIM output signals are delivered (in the rear part) as flags for a pattern unit implemented in the DAQ system.

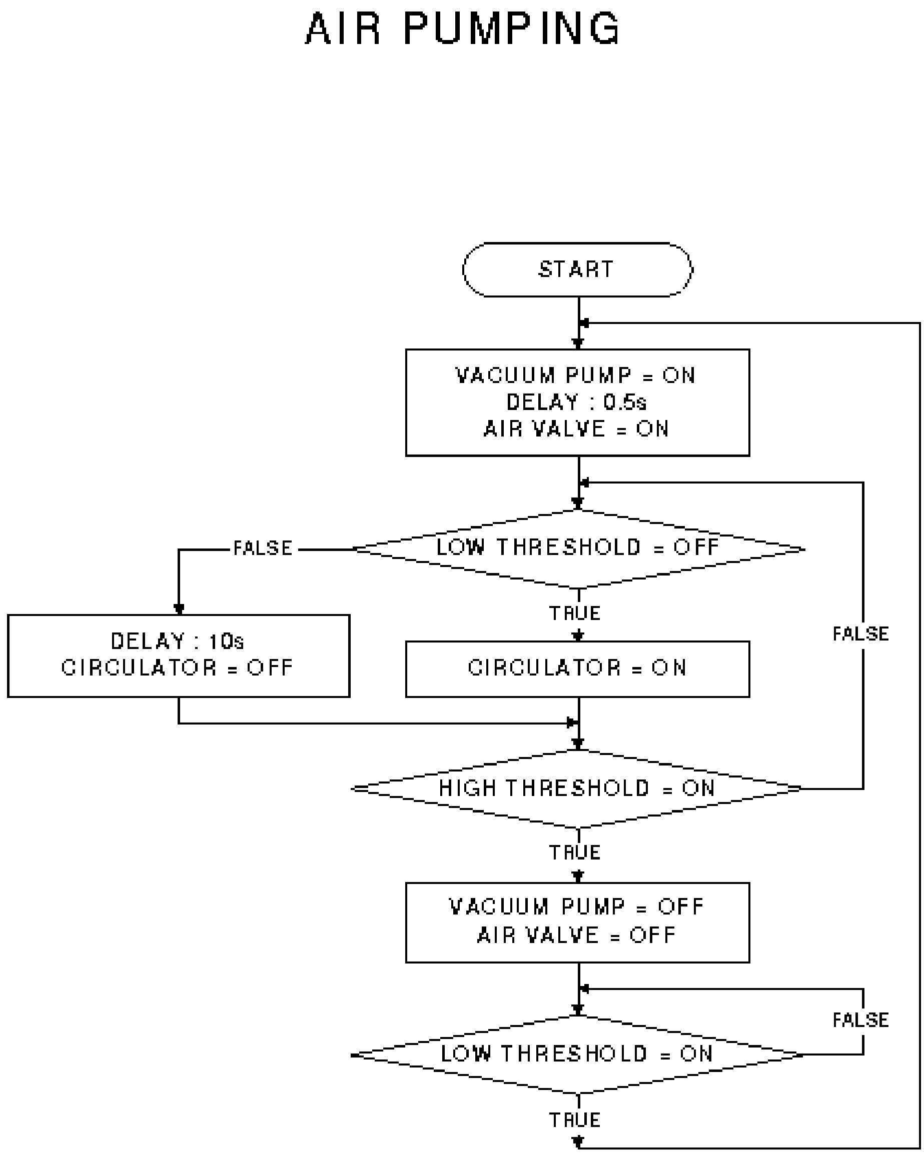

Figure 6: Monitoring diagram of the vacuum circuit which will be used in 1998.

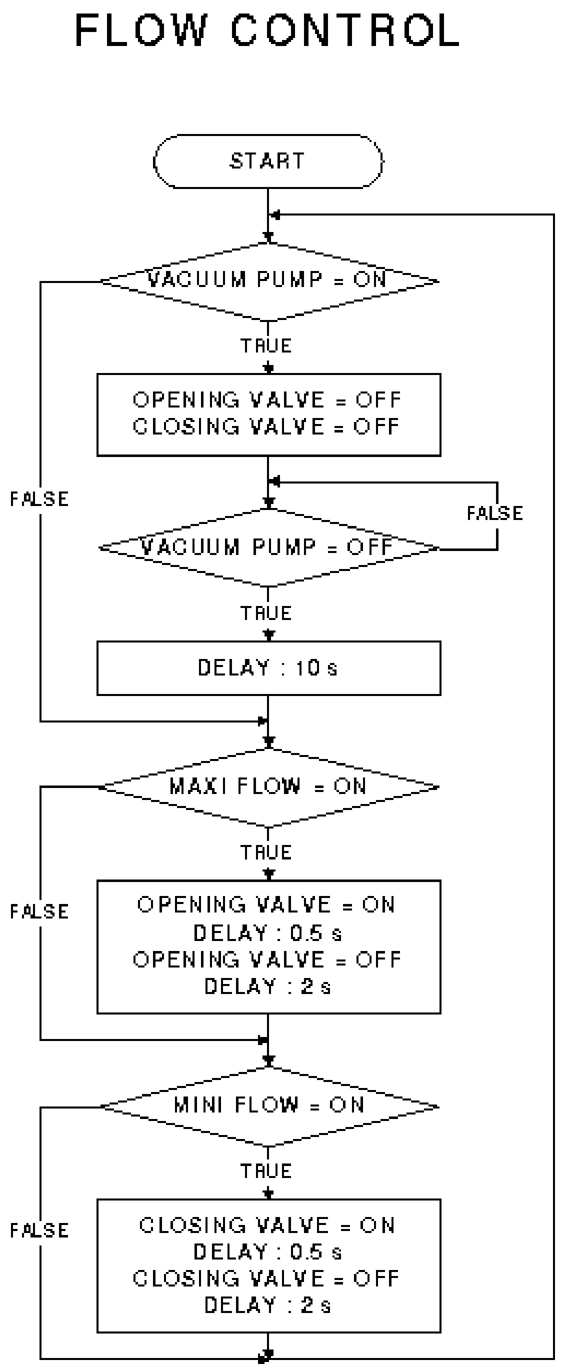

Figure 7: Monitoring diagram of the water flow which will be used in 1998.

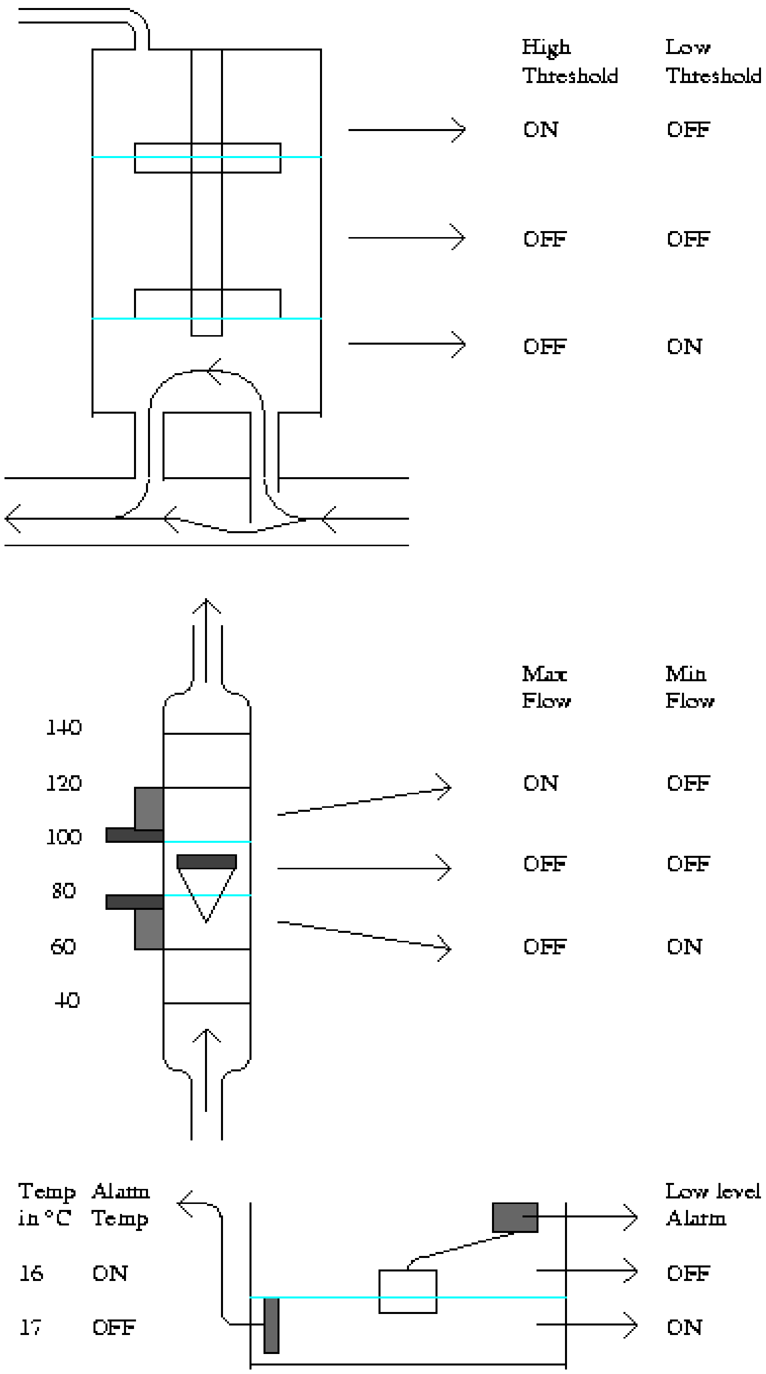

Figure 8: Principle of the monitoring for the glass jar (upper scheme), the flow meter (middle scheme) and the water in the tank (lower scheme).

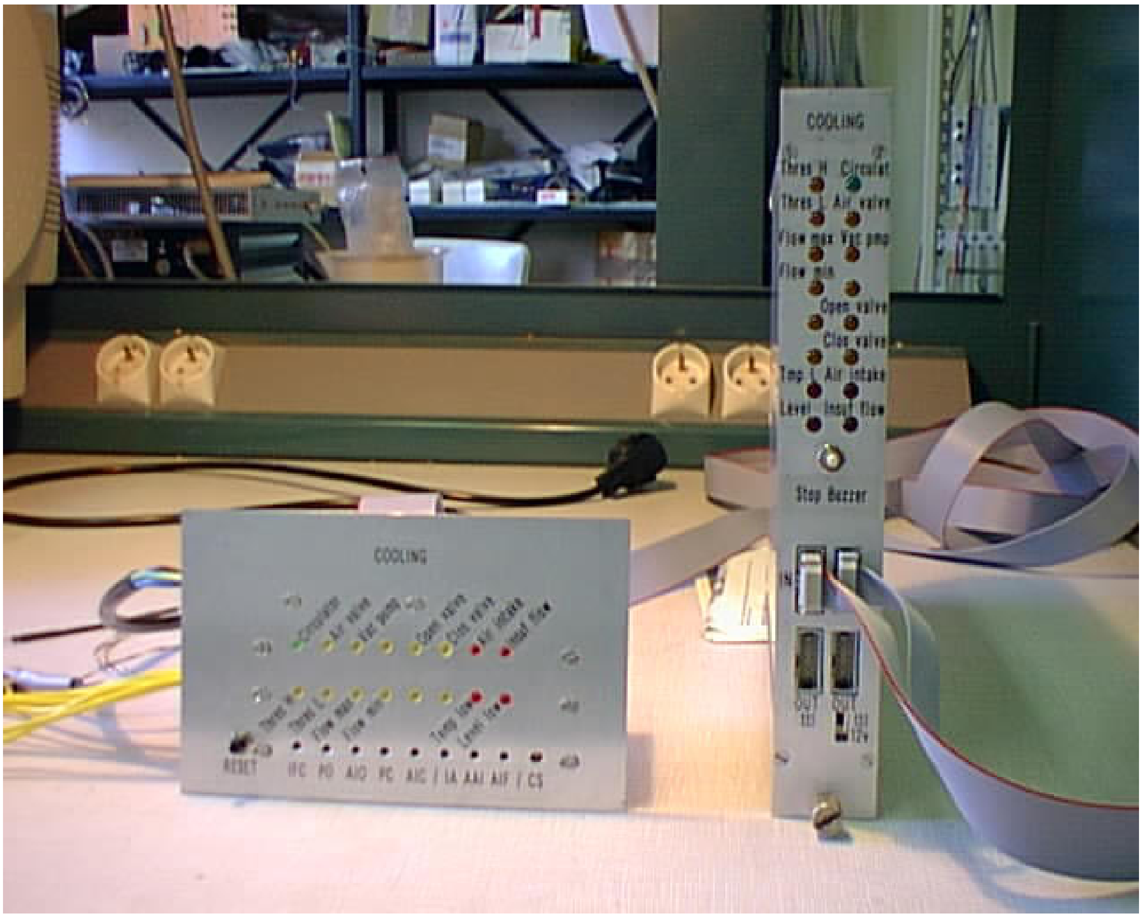

Figure 9: Photo of the front panel of the new modules for the cooling system.

During the test beam period, the cooling system was working in a standalone mode, but it could be easily implemented in the slow control.

5 Stability of the temperatures during the 1997 test beam period

5.1 Setup

To study the temperature in the drawers of the two extended barrel modules 0, six probes have been installed in each module (see figure 10):

- one in the middle of the internal drawer on the High Voltage side,
- two in the PMT blocks 22 and 24 of the internal drawer,
- one in the middle of the external drawer on the High Voltage side,
- two in the PMT blocks 34 and 38 of the external drawer.

Let us note that the electronics in the PMT blocks of the Argonne module (called ANL in the following) used the compressor technique, while the Barcelona module (called BCN in the following) used the bigain technique (for the channels equipped with temperature probes).

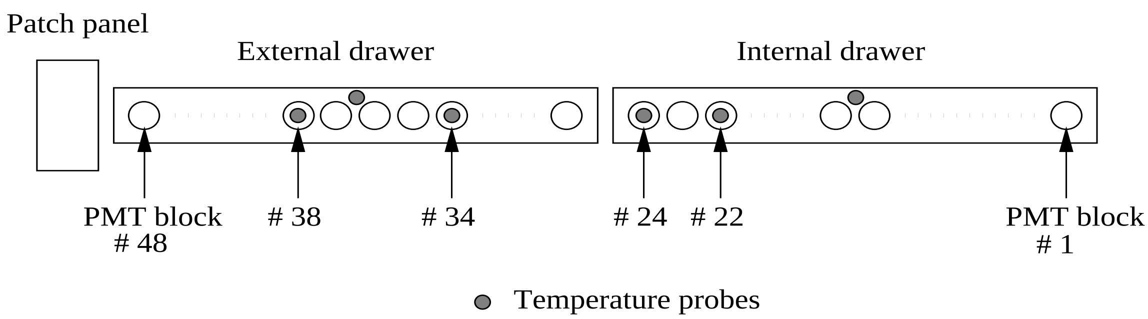

Figure 10: Location of the temperature probes in a super-drawer.

All the probes have been calibrated in a water-ice mixture (namely at 0^0C) with an absolute accuracy of about 0.5^0C. The relative accuracy given by the less significant bit of the ADC used for the readout is around 0.1^0C.

During all the test beam period the LCS has been used with a water flow of 90 $l/hour$ at 18^0C.

5.2 Stabilisation time

Without cooling, the temperature in the drawers is around 30^0C and in the PMT blocks approximatively 37^0C. When the cooling is switched ON the temperature in the drawers starts to decrease immediately while 10 minutes are necessary before something happens inside the PMT blocks, see figure 11. This latency is due to the iron material of the PMT blocks (protecting the electronics inside). Thus a permanent change of the temperature in a drawer will be seen only 10 minutes later inside the PMT blocks.

The plots on figure 11 show that less than 1 hour is necessary to stabilise all the temperatures. After stabilisation, the temperature in the drawers is around 19^0C and around 29^0C inside the PMT blocks.

Let us note that at the beginning, the water in the tank was not at 18^0C but at 20^0C. Before its stabilisation, the temperature of the water starts to increase because of the higher temperature in the drawers, the effect of the fridge being seen only 20 minutes later. And in the same way as for the drawer, less than 1 hour is required to stabilise the temperature in the tank at 18^0C.

Finally, the cooling system decreases the temperature in the drawers by more than 10^0C and by approximatively 8^0C in the PMT blocks.

The water flow can vary between 0 and 180 $l/hour$. With a decrease of the water flow from 90 $l/hour$ to 45 $l/hour$, an increase of the temperature inside the PMT blocks by less than 1^0C has been observed. So the sensitivity of the temperature to the water flow can be considered as being small.

5.3 Long term stability

The stability of the temperature has been studied over several months. The temperatures were recorded every two minutes. The average temperatures in the drawers and inside the PMT blocks of the two modules are shown on figure 12. For each individual temperature the stability versus the time is completely similar as we can see for the three temperatures presented on figure 13.

For the two modules, there are large deviations of the temperatures for the 6^{th} of October. These deviations are due to four openings of the BCN module between noon and midnight for some hardware operations. During this time the cooling and the High Voltages were switched OFF.
If we exclude this period to study in more details the stability of each temperature, one gets the results given in the table 2 with the following parameters:

- the average of each temperature over the time $< T >$;
- the root mean square of each temperature σ_T calculated with the classical for-

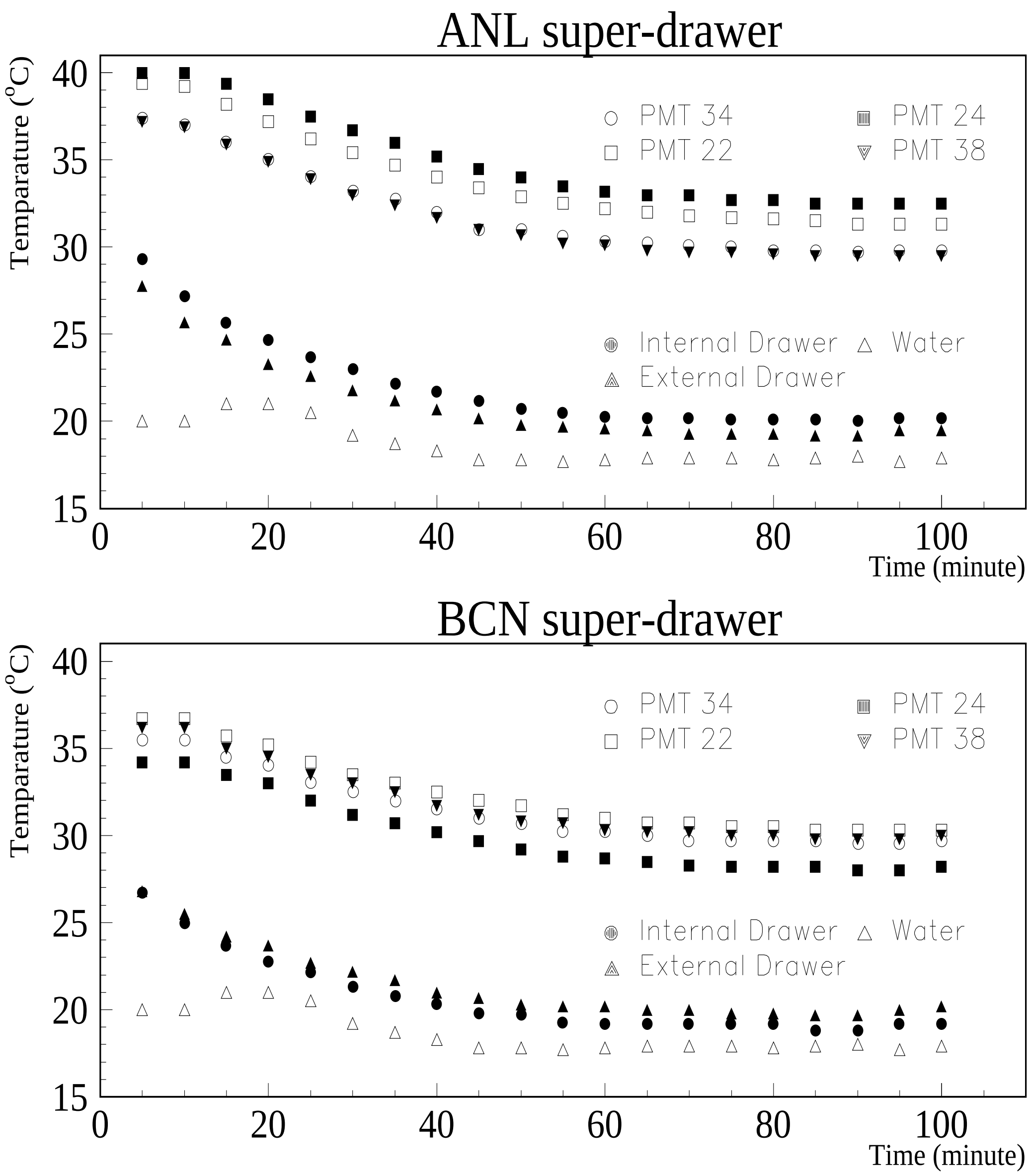

Figure 11: Temperature in the drawers and inside the PMT blocks as a function of the time in minute during the stabilisation period: for the ANL module (upper plot) and the BCN module (lower plot).

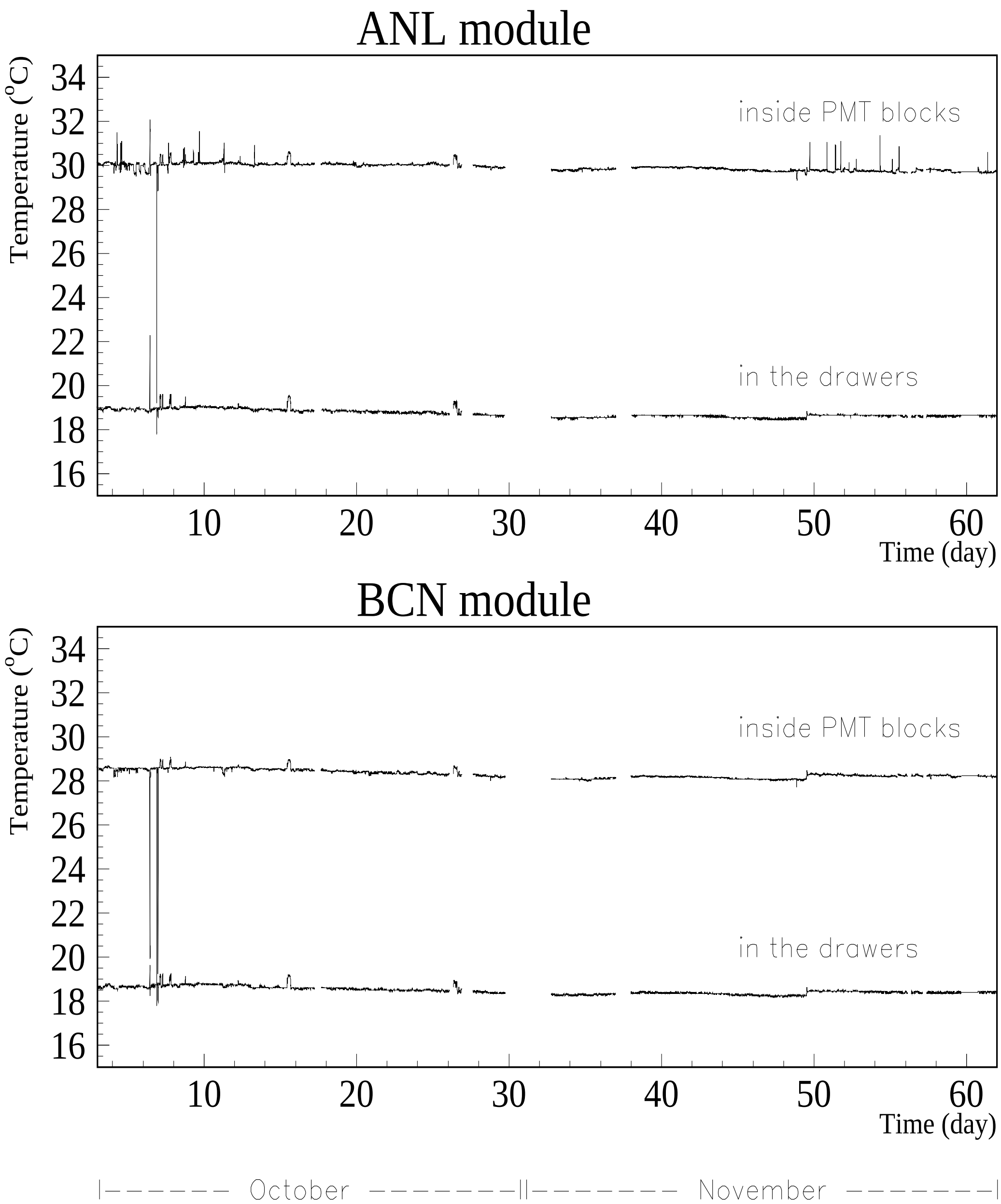

Figure 12: Temperature as a function of the time in day from the 3^{rd} of October up to the 30^{th} of November: for the ANL module (upper plot) and the BCN module (lower plot).

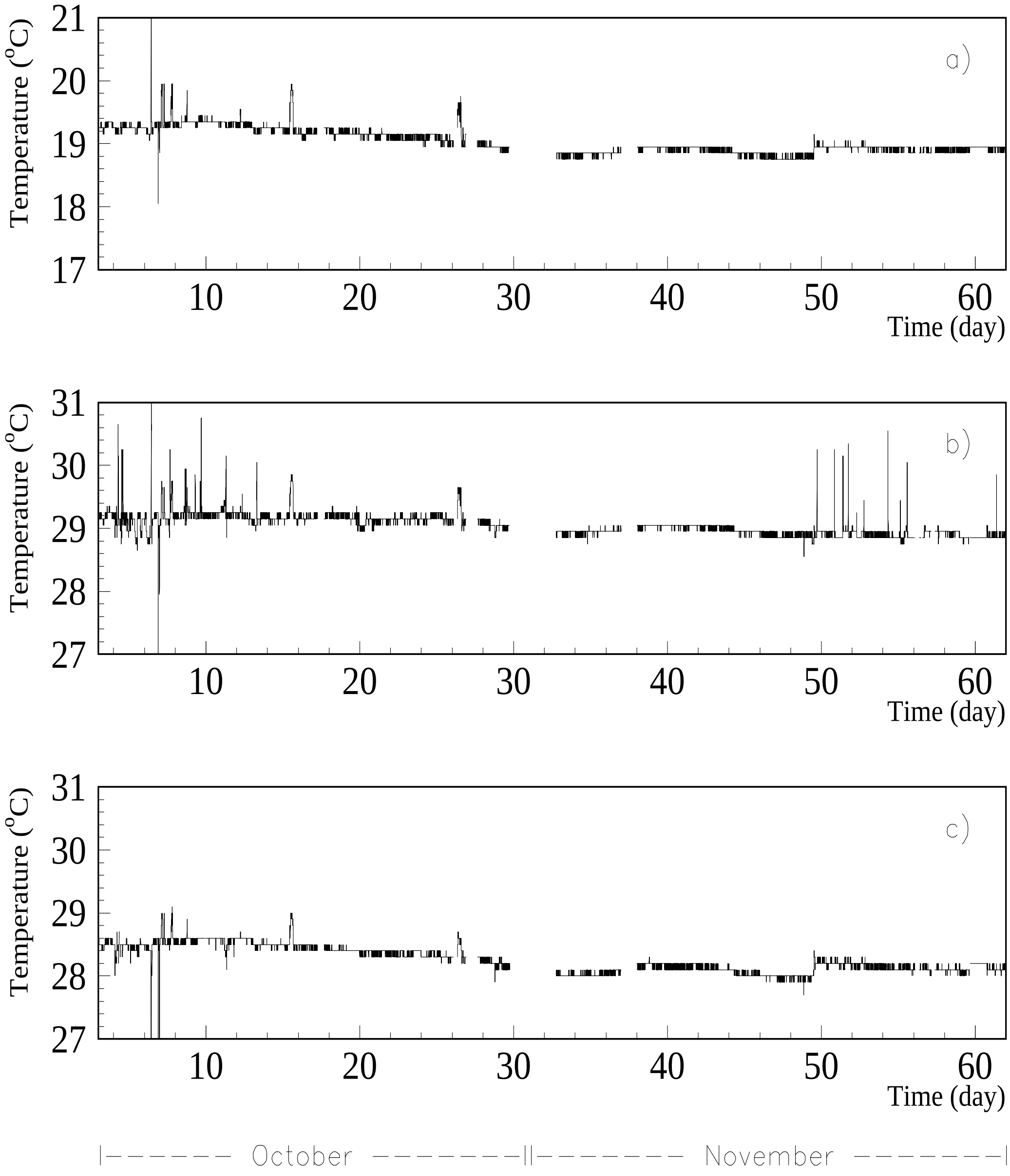

Figure 13: Temperature as a function of the time in day from the 3^{rd} of October up to the 30^{th} of November: a) for the internal drawer of the ANL module, b) for the PMT block 34 of the ANL module and c) for the PMT block 34 of the BCN module.

mula: $\sigma_T^2 = \frac{\sum_{i=1}^{N}(T_i - <T>)^2}{N-1}$, where the number of recording N is greater than 10000;

- and the difference between the average temperature obtained in autumn with respect to the average temperature obtained during the summer: $\Delta T = <T>_{autumn} - <T>_{summer}$.

Let us note that the temperatures recorded during the summer are not shown on the plots, because it represents only 12 days with only 2 or 3 recordings per day.

Module	Probes	$<T>$ in ^0C	σ_T in ^0C	ΔT in ^0C
	inter	19.02	0.19	-0.65
A	exter	18.39	0.16	-0.46
N	pmt22	30.39	0.17	-0.45
L	pmt24	31.47	0.21	-0.51
	pmt34	29.05	0.16	-0.19
	pmt38	28.71	0.14	-0.17
	inter	18.00	0.17	-0.64
B	exter	18.93	0.15	-0.58
C	pmt22	29.41	0.16	-0.60
N	pmt24	26.97	0.18	-0.64
	pmt34	28.25	0.20	-0.96
	pmt38	28.59	0.20	-1.01

Table 2: Results on the stability of the temperatures in the drawers and inside the PMT blocks of the modules 0. $<T>$ is the average temperature obtained over the time, σ_T the root mean square of the temperature, and ΔT the temperature difference between the autumn and the summer.

So over 54 days, we see that all the temperatures are stable with an error between 0.14^0C and 0.21^0C. Furthermore, a decrease in the temperature of only -0.57^0C in average between summer and autumn is observed in the drawers and the PMT blocks. These results give a good confidence on the stability from a season to an other one, even though the temperature inside the North Hall is not constant (it is the same for the iron of the calorimeter surrounding the drawers).
Besides, no variation of the temperatures between day and night has been observed, as it is shown on figure 14.

We have mentioned above that the vacuum pump is activated about every 90 minutes during about 10 seconds. This effect is small but direct in the drawer temperature ($+0.3^0C$), but without any sizeable change inside the PMT blocks, because of the 10 minutes latency as shown previously.

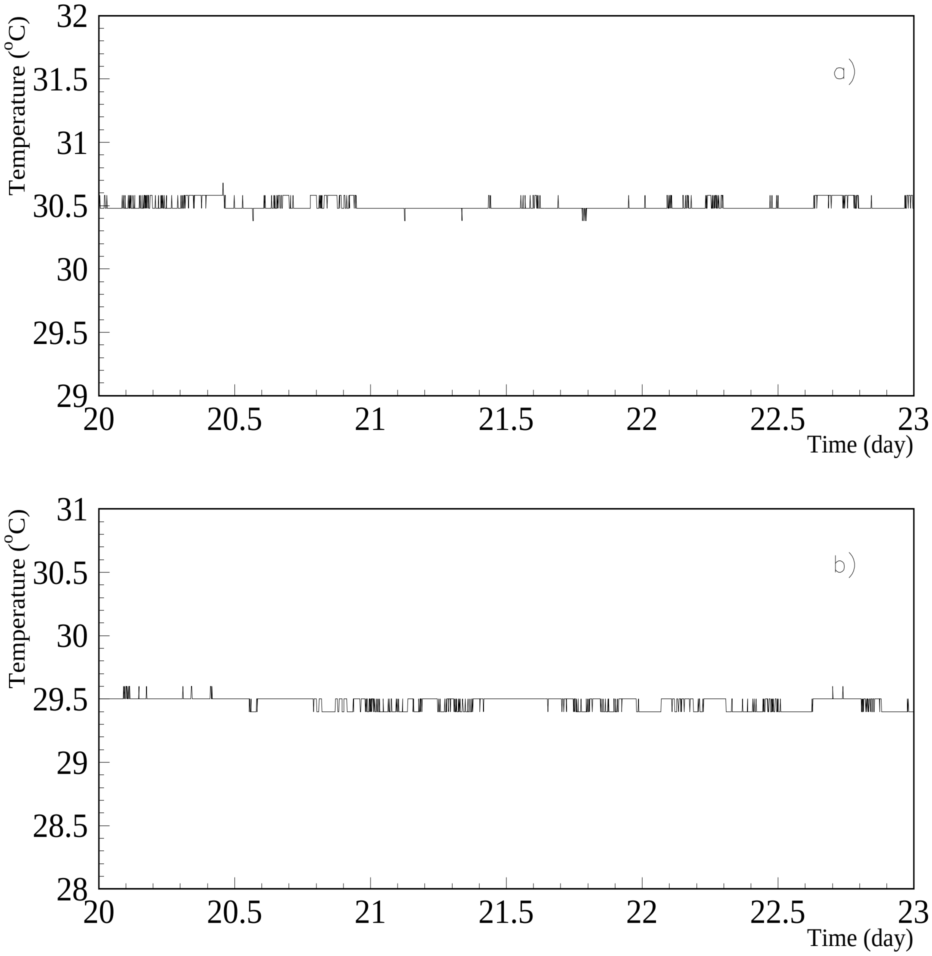

Figure 14: Temperature as a function of the time in day from the 20^{th} up to the 23^{th} of October: a) for the PMT block 22 of the ANL module and b) for the PMT block 22 of the BCN module.

Finally, no differences are observed for the PMT block temperatures between the ANL module and the BCN module, except for the PMT block 24 where the difference is around 4.5^0C (probably due to a bad offset in the absolute calibration). For the other probes, the difference between the two modules is less than 1^0C corresponding at 2 times the absolute accuracy of the probes.h Then, we can conclude that the power dissipated by the compressor technique is similar to the one dissipated by the bigain technique.

5.4 Implication on the PMT gain

It has been shown [3] that a variation of the temperature of 5^0C gives a variation of the PMT gain G of 1%. From the present results, $\sigma_T < 0.25^0C$, the expected variation of the PMT gain will be: $\frac{\Delta G}{G} < 0.05\%$.
Therefore the goal of an accuracy better than 0.5% for the PMT gain stability is not a problem at the level of the temperature stability considerations.

6 Conclusions and perspectives for ATLAS

6.1 LCS results

To conclude, the test beam results of the 1997 period have shown that the Leakless Cooling System is very suitable for the modules of the TILECAL calorimeter. The stability of the temperatures in the drawer and inside the PMT blocks where all the electronics is located is very good. The temperature is stabilised around 19^0C in the drawers and around 29^0C inside the PMT blocks with an average dispersion less than 0.25^0C. No periodic variations between night and day were observed; only a small drift (around 0.6^0C) between summer and autumn was seen, simply because of the variation of the temperature in the North Hall.
Thus, the implication on the PMT gain stability can be summarised as:

$$\sigma_T < 0.25^0C \quad \Rightarrow \quad \frac{\Delta G}{G} < 0.05\% \; .$$

6.2 ATLAS perspectives

6.2.1 Leakless Cooling System

Using the LCS, the perspectives are the following:

- never a water leak!
- the temperatures are stabilised within 0.25^0C,

- all the connections are very simple; they are done by flexible plastic tubes, without using any connectors,
- the working water temperature ($18^0 C$) can fit both the test beam Hall and the ATLAS cavern,
- the system is fully integrated in the design of the Drawers (mechanics and electronics).

6.2.2 Fluorocarbon pressurised solution

The solution as proposed by the ATLAS Review of Cooling System [4] should be the use of a fluorocarbon liquid, working at a lower temperature. It is a pressurised method that requires special connections and connectors, in contradiction with the wished flexibility and the room requirements for the electronics.

More generally, this method (not yet proved) will require a full re-design of the drawer system. We are supposed to provide for March 98 a design of the fingers, that implies a whole design of the drawer system, including the patch panel, the tools for the handling and the access, and so on.

In every case, there is no possibility to act on the degree of humidity in the North Hall; this means that we have to work above the dew point (which moves according to the seasons ... and the meteo), in full contradiction with the pressurised solution. The other possibility would be to have two different systems for the test beam and ATLAS, which is, once again, in full contradiction with the TILECAL calibration procedure.

References

[1] Handbook of Chemistry and Physics, 56^{th} Edition, 1975/1976.

[2] This reference has been provided by P. Bonneau and M. Bosteels:
Leakless cooling system, Proceedings of WECDEC Conference, October 1994, Lausannes.

[3] ATLAS note, TILECAL-No-108, 28 April 1997.

[4] Conclusions of the Review of Cooling System in ATLAS,
available on the Web.