ATL-TILECAL-2001-006
29 / 11 / 2001

Performance and tests of the cooling system for the ATLAS Tile hadron calorimeter modules calibrations

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Abstract

The cooling system used for the ATLAS Tile calorimeter modules calibration in beam is presented. The cooling system unit and the monitoring system are described. The performance of the cooling system and its influence on the calorimeter response to electrons and pions are shown.

1 Introduction

A new cooling system has been installed and operating in the H8 beam zone for the summer 2001 beam calibrations. This cooling system is identical to the one that will be used in building 185 for the Cesium calibrations. It uses the so-called Leakless Cooling System [1], as expected in the ATLAS detector for the Tile and LAr calorimeters, e.g. use of water at sub-atmospheric pressure. It is described in the next section.

The power consumption of a super-drawer is approximately 200 W. The finger low voltage power supplies will dissipate of the order of 100 W. In ATLAS both the front-end electronics located in the super-drawers and the low voltage power supplies located in the fingers will be cooled by the same line. Therefore, each cooling channel will have to dissipate of the order of 300 W. During the summer 2001 calibrations, the final finger power supplies were not installed. External low voltages have been installed outside the fingers without the final cooling circuit. During the normal operating conditions, the cooling water temperature was 18 ^oC and the water flow was 60 l/h.

In section 2, the cooling unit is presented and its operation is explained. In section 3, the cooling monitoring system as well as the general Detector Control System used for the calibrations are described. In section 4, the stability of the cooling system is given. Finally, in section 5, the performance of the cooling system and its influence on the calorimeter response to electrons and pions are shown.

2 Description of the Cooling Unit

The cooling system is designed to evacuate 2 kW and able to supply up to six drawers with their corresponding low voltages at the same time. The required temperatures are 18 ^oC for the modules inlet water and up to 20 ^oC for the outlet water. The unit is a closed liquid circuit working according to the LCS v.2 principle [1] and connected to a primary circuit through a heat exchanger. The system is locally controlled by a Programmable Logical Controller. In the following, a description of the main elements of the cooling unit and its operation are given.

Fridge circuit:

The primary (fridge) circuit consists of a closed evaporative circuit with a hermetic compressor (see label 20 on figure 1), an air-cooled condenser, a refrigerating tank and a coaxial evaporator (11). The refrigerating liquid pressure is reduced through an expansion valve (17) at the input of the evaporator. The compressor is equipped with an oil sight glass, a crankcase heater and a three ways valve. It is protected against high and low pressures by an automatic reset switch. The designed power is 2000 W with an evaporative temperature of +10 ^oC and a condensing temperature of +40 ^oC. The refrigerating liquid is R134a (HFC). A filter dryer (19) (molecular sleeve 3A) and a sight glass control the humidity of the fluid.

Secondary circuit:

The secondary circuit is a closed liquid circuit connected to the pipes running into the drawers to be cooled. The liquid is held in a storage tank below atmospheric pressure which is controlled by a vaccum pump (7) via a pressure switch (4). A second switch sets a maximum pressure point which stops the circulator in case of a main leak. The whole system is stopped and needs to be resetted if the vaccum pump runs for more than 20 minutes. A check valve (15) discharges any excess of air in the event of a drainage and prevents the pressure in the storage tank from rising above the atmospheric pressure. A circulator pump (9) moves the fluid from the pressurized storage tank to the exchangers through a resistor heater (10) and the coaxial evaporator (11). The pressure at the various points of the circuit depends on the head losses and on the hydrostatic pressure between the pump outlet and the storage tank. A variable speed control (13) associated to the pump maintains a constant outlet pressure. At start-up, the vaccum pump is activated if the pressure in the storage tank is not low enough. While the vaccum pump is operating, the circulator cannot run in the event, for instance, on an air intake. The pressure throughout the circuit is still equal to the pressure in the storage tank. An auto tunning PID controller (23) adjusts the temperature of the outlet fluid by regulating the 3kW electrical resistor heater (10) from a temperature probe (Pt100 (21)). A discharge valve (24) between outlet and return manifolds controls the differential pressure and assumes a minimum flow in the system to prevent any ice in the evaporator. The storage tank has a capacity of 80 liters and features a visual liquid level (2) and a capacitive switch float level (3). The fluid is demineralized water. The distribution is provided by one outlet and one inlet manifolds, both having six channels. Therefore, the cooling unit is able to cool six drawers. Each channel is equiped with an ON / OFF valve (8) and a quick disconnect shut off valve (16). A small Programmable Logical Controller (22) controls the parameters of the Leakless v.2 cooling system.

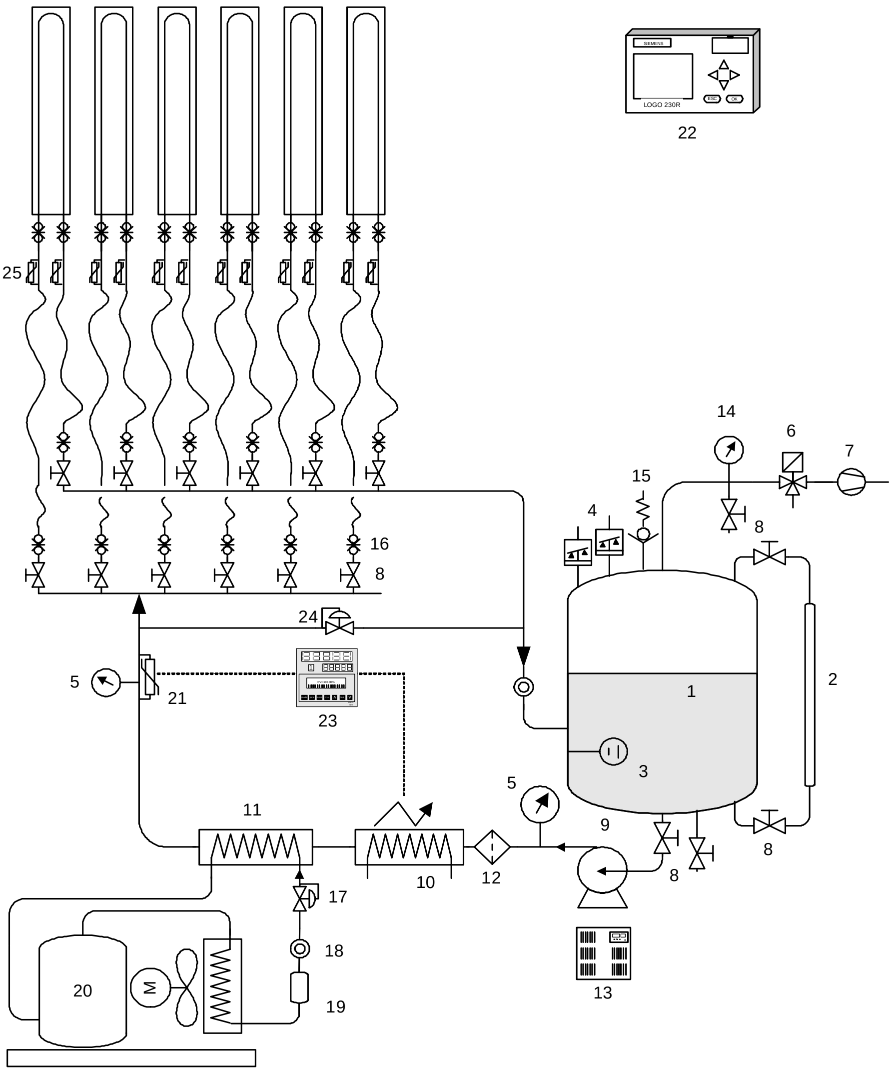


Figure 1 Schematic of the Coolig System used in the Tile calorimeter beam calibrations.

If the storage tank pressure is maintained between the operating setting and the upper point (switching difference) the circulator and the temperature regulation (controller and heater) run. The vaccum pump and the electro-valve are off. This is the running mode. If the pressure goes higher than the upper point of the vaccum switch the vaccum pumps starts, the 3 ways electro-valve is activated after two seconds and the pressure goes down to the lowest setting of the pressure point (the minimum admissible pressure). The circulator and the temperature regulation are still running. A manual vaccum pump switch lets the operator to active it to gas out the circuit or to fill the storage tank with fluid (3 positions switch on PPV). A picture of the cooling unit is shown on figure 2.

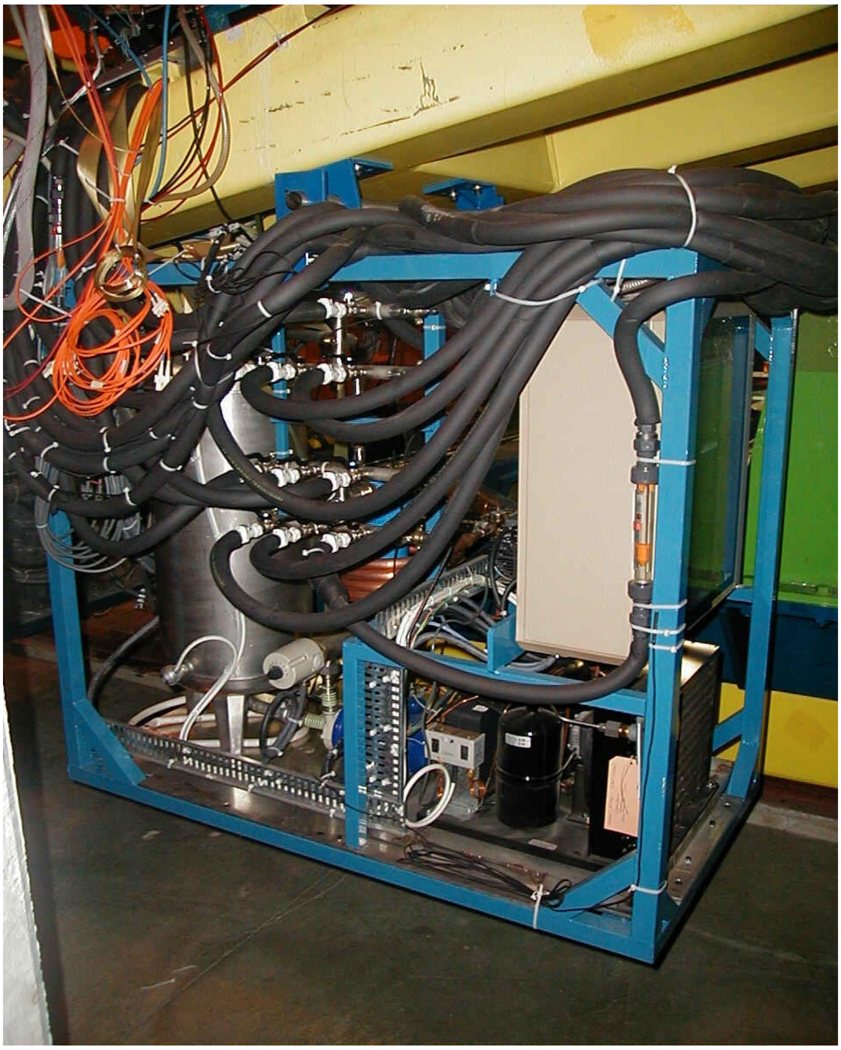


Figure 2 Picture of the cooling unit installed in the H8 zone. The cooling unit is fixed to the frame of the scanning table.

3 Tilecal Detector Control System

3.1 Introduction and scope

A flexible Detector Control System (DCS) was developed for the calibration periods of the Tilecal modules in summer 2001. The application uses the standard tools chosen to develop the final DCS [2, 3] of the ATLAS experiment. It aimed at the integration of the different DCS subsystems within Tilecal, namely the Low and High-Voltage (LV and HV) and the cooling systems and scanning table, shown in figure 3. It provided the needed tools to monitor and control the running parameters and operational conditions of the Tilecal modules. The DCS also enabled the communication with external systems like the SPS accelerator, to retrieve the information of the beam line H8, and to interact with the Data Acquisition system (DAQ) by means of the ATLAS DAQ-DCS Communication (DDC) package [4]. This software product allows a bi-directional communication between both systems so that all relevant DCS parameters were transferred to the DAQ for offline analysis.

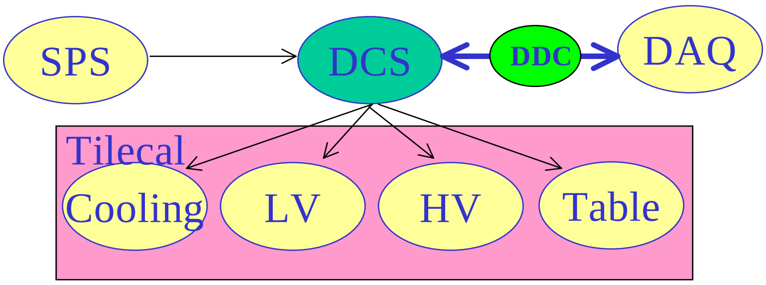


Figure 3 Testbeam system organization

The DCS consists of two main components: the distributed supervisor system running on PCs called “Back-End” (BE) and the different “Front-End” (FE) of the detector subsystems. For the former, the commercial Supervisory Control And Data Acquisition (SCADA) system PVSS-II [5] has been selected in the framework of the Joint COntrols Project (JCOP) [6] at CERN. PVSS-II gathers informations from the FE equipment and offers supervisory control functions such as data processing, execution of control procedures, alert handling, archiving, etc. It is a device-oriented product where devices are modelled by structures called “data-points”. Applications can be distributed over many stations on the network. These features of modelling and distribution facilitate the mapping of the control system onto the different subsystems within ATLAS.

Although FE systems are under the responsability of the subdetector groups, a general-purpose I/O concentrator called “Embedded Local Monitor Board” (ELMB) [7] has been developed by the central DCS team. This module is called to provide standardization among the ATLAS subdetectors and hence, minimise development and maintenance efforts. It offers up to 64 ADC channels and digital I/O functions, is radiation tolerant for use outside of the calorimeters of the LHC detectors and operates in a strong magnetic field. CANopen is used as high-level communication protocol for the readout of the ELMB.

The interface PVSS-CANopen is based on the industrial standard OPC [8] (OLE for Proccess Control). OPC comprises a set of interfaces designed to facilitate the integration of control equipment into Windows applications. A CANopen OPC server [9] developed by the ATLAS DCS team is used.

These 3 building-blocks (PVSS-II - CANopen OPC Server - ELMB) formed the so-called “ATLAS DCS Vertical Slice” [10]. An integrated monitoring application for the LV and cooling system was developed using the elements described above. For the LV system the standard functionality of the ELMB was extended to drive analogue output channels by means of off-board DAC chips. For the monitoring and control of the HV system an existing Labview application was used. This application was developed by the Tilecal DCS group and interfaces a VME crate, which directly controls the FE equipment in the drawers via the CAN fieldbus.

In the following, a detailed description of the monitoring of the cooling system used in this test is given.

3.2 Monitoring of the cooling system

The monitoring of the cooling system of the Tilecal modules can be split into three main applications:

- Monitoring of the temperatures of the cooling liquid along the pipes (outside the drawers).
- Interface to the HV system to retrieve the temperatures of the seven probes that are placed inside the drawers.
- Monitoring of states and alarms of the different devices integrating the cooling unit.

Experimental Setup:

During the three beam periods in summer 2001, a total of 4 Tilecal extended barrels and 1 barrel modules were calibrated with particles beam. Figure 4 shows the setup in the beam line H8, where up to 6 modules were provided with HV, LV and cooling. As previously mentioned, the transfer lines of the cooling system and the modules were instrumented with probes to determine the temperature of the cooling liquid and different elements integrated in the drawers. The location of these sensors in the modules is shown in figure 5.

Outside the drawers, three temperature sensors (10 kΩ NTC) per module were employed. They were in contact with the cooling water and therefore measuring the temperature of the liquid at the entrance and exit of the drawers, as well as, the temperature of the liquid after the LV power supplies.

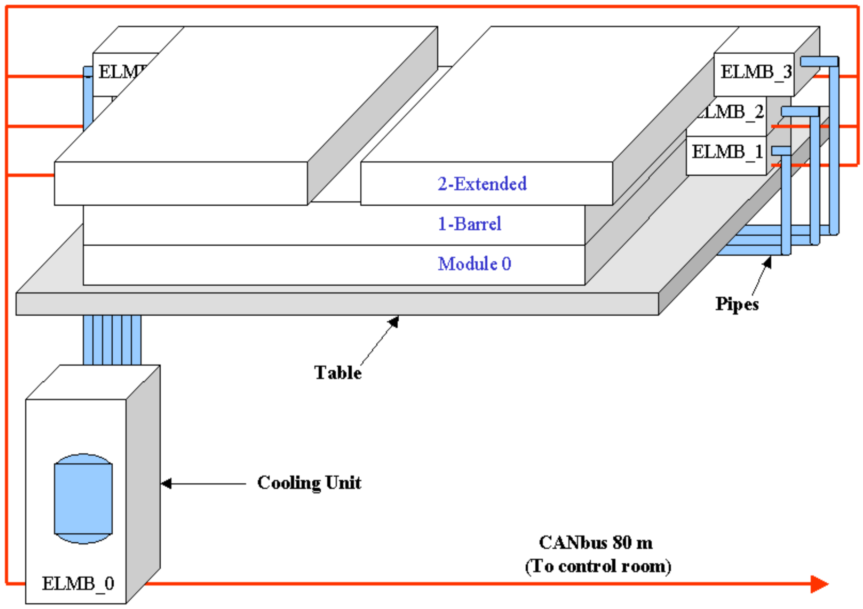


Figure 4 Setup for beam calibrations in the H8 beam zone. On the scanning table, from bottom to top, a barrel prototype (module 0) is installed, then a production barrel module and two production extended barrel modules. The cooling unit is fixed to the frame of the scannig table.

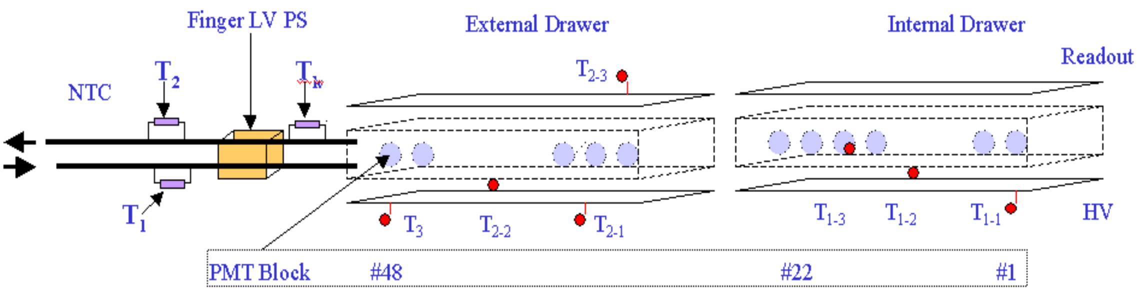


Figure 5 Location of the temperature probes in the drawers and cooling pipes. The readout electronics is located on top of the drawer whereas the HV system cards are located on the bottom of the drawer.

Additionally, the temperature of the cooling liquid leaving and returning to the unit and the ambient temperature were also monitored. The NTC probes were calibrated with a external reference temperature with a relative accuracy of about 0.1 ^{o}C. The formula used to determine the temperature as function of the resistance of the sensor is given in equation 1:

$$T = \frac{1}{a + b \cdot \ln((R_{NTC}) + c(\ln(R_{NTC}))^{3})} - T_{offset} \quad (1)$$

where a = $9.577x10^{-4}$, b $=2.404x10^{-4}$, c $=2.341x10^{-7}$ and T_{offset} is a calibration constant.

The status and alarms of the central cooling unit were also monitored. Their states were transmitted as relay contacts between the pins of two burndy connectors. As the outputs of the unit are isolated, these contacts were measured feeding a small current through the pins. The following parameters were read:

- Status ON / OFF of the vacuum pump and circulator
- Two levels of alarms from the temperature controller.
- General alarm of the cooling unit.

All the cooling parameters were read out by means of one single ELMB (ELMB_0 in figure 4) placed onto the cooling unit as shown in figure 6. Table 1 shows the ADC settings of this node:

Table 1 ADC settings of the ELMB used for the monitoring of the cooling system

Mode	Unipolar
Conversion rate	32.5 Hz
Full Scale	5 V

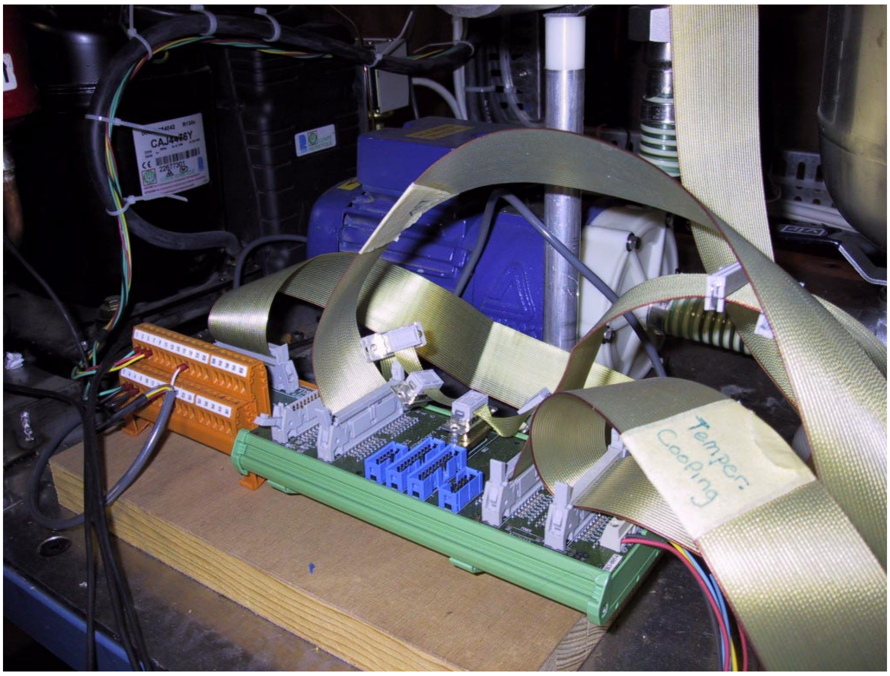


Figure 6 Elmb located onto the cooling unit

As these signals were of different types and ranges, it was neccessary to adapt them to the ELMB ADC range. Conditioning was done by means of signals adapters plugged onto the ELMB motherboard as described in reference [11].

This ELMB was connected to a NI-CAN II interface card, housed in a PC (Windows NT) situated in the control room, by means of a 80 m long CAN bus as shown in figure 7. The bus speed was set to 125 kbaud. This bus was shared with 7 ELMB modules (ELMB_1 to ELMB_7 in figure 4 and ELMB_8 in figure 7) used for the monitoring and control of the LV power supplies. The ELMBs were powered remotely from the control room via the bus with a 9 V DC power supply.

The temperatures inside the Tilecal drawers were measured through the HV system. The seven probes are located on both sides of the drawer, that are the readout electronic side and the HV system side (see their location on figure 5).

- T1_1 and T2_1: Internal and external HV opto board temperatures respectively.
- T1_2 and T2_2: Internal and external drawer temperatures.
- T1_3: Temperature of the PMT block 22.
- T2_3: Interface card temperature.
- T3: Temperature of the HV micro card.

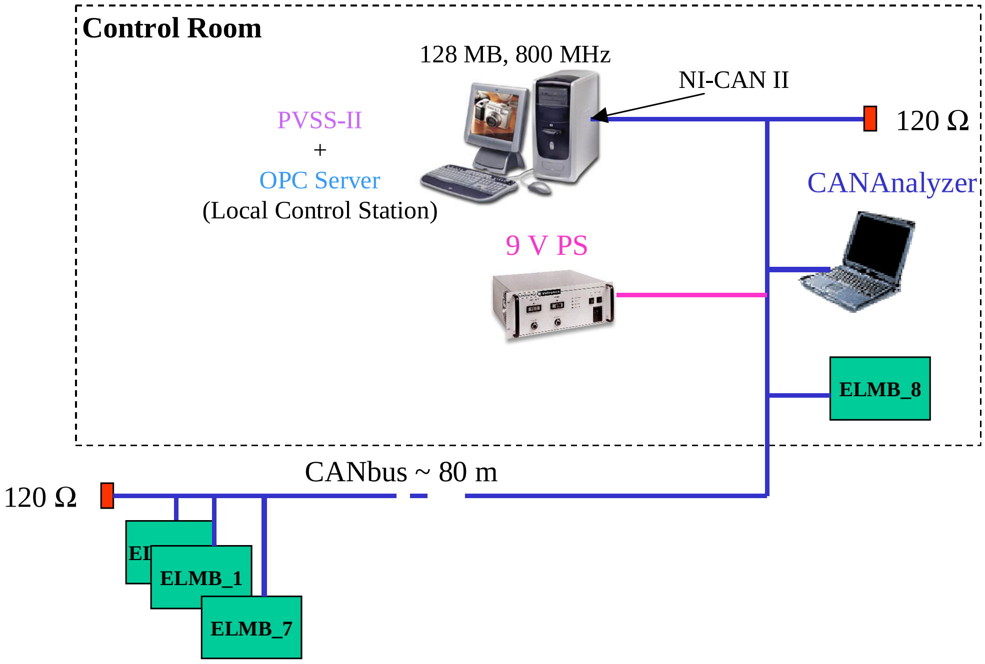


Figure 7 Experimental setup in the control room

The HV system is described in [12]. The temperature sensors and the voltage applied to the photomultipliers (PMTs) are read into a VME crate and then transferred, via TCP/IP, to a Labview control application running on a PC. The interface of this Tilecal subsystem within the PVSS-II framework was done via the DLL[1] written in C++.

SCADA Application:

All the data coming from these two sources, from the ELMB for the temperatures outside the drawers and the cooling unit, and via the DLL interface to the HV system for the temperatures inside the drawers, are stored in the PVSS-II historical database and then

1. DLL stands for Dynamic Link Library

transferred to the DAQ for offline analysis. The readout rate for both subsystems can be set independently, three seconds being the shortest possible interval.

The device-oriented nature of PVSS-II permits to model each Tilecal module as a structure or data-point, in the database as shown in figure 8. Similar data-ponits were created to model other devices in the setup like the cooling unit or ELMBs. This structure holds a hierarchical and logical representation of the different DCS subsystems of each module. The bottom-most leafs in these structures are called dp-elements and represent the actual variables of the systems, which can be addressed to hardware channels.

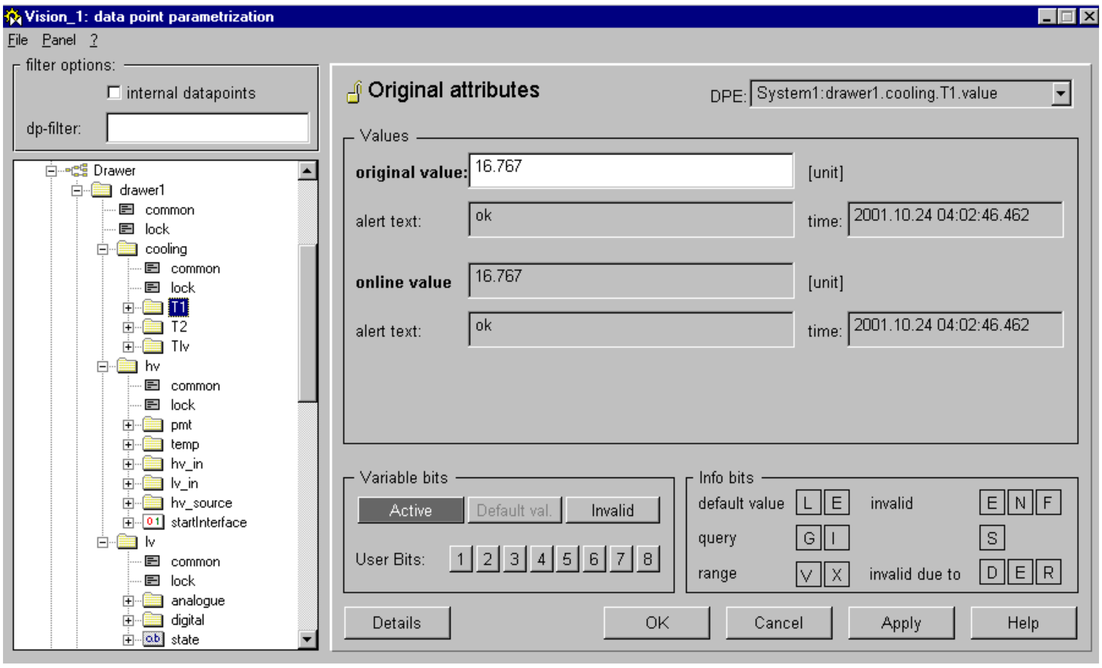


Figure 8 Drawer data-point.

Figure 9 shows the main panel of the PVSS-II application. The general states of the different data sources are color-coded and the current readings of the operational parameters are also shown in the panel. Dedicated panels for each subsystem and a graphical interface to the historical database for trending and exporting of data, as well as, alert handling are also provided. Figure 10 shows the trends of the cooling parameters for drawer 1 over several days. In this plot, the LV system was switched off and with no cooling. Ambient, output and return temperatures are also shown in the panel.

Due to the need of accessing the DCS data remotely, a dedicated web interface[1] to the application was developed. This interface allows for SQL queries to the PVSS-II database from any web browser. Figure 11 shows the online values of the cooling parameters accessed with a web browser. Historical data can also be exported to a downloadable ASCII file. In this case, the SQL query can be performed for a particular run number or a defined time interval.

1. URL: http://pcatlas206.cern.ch:2001

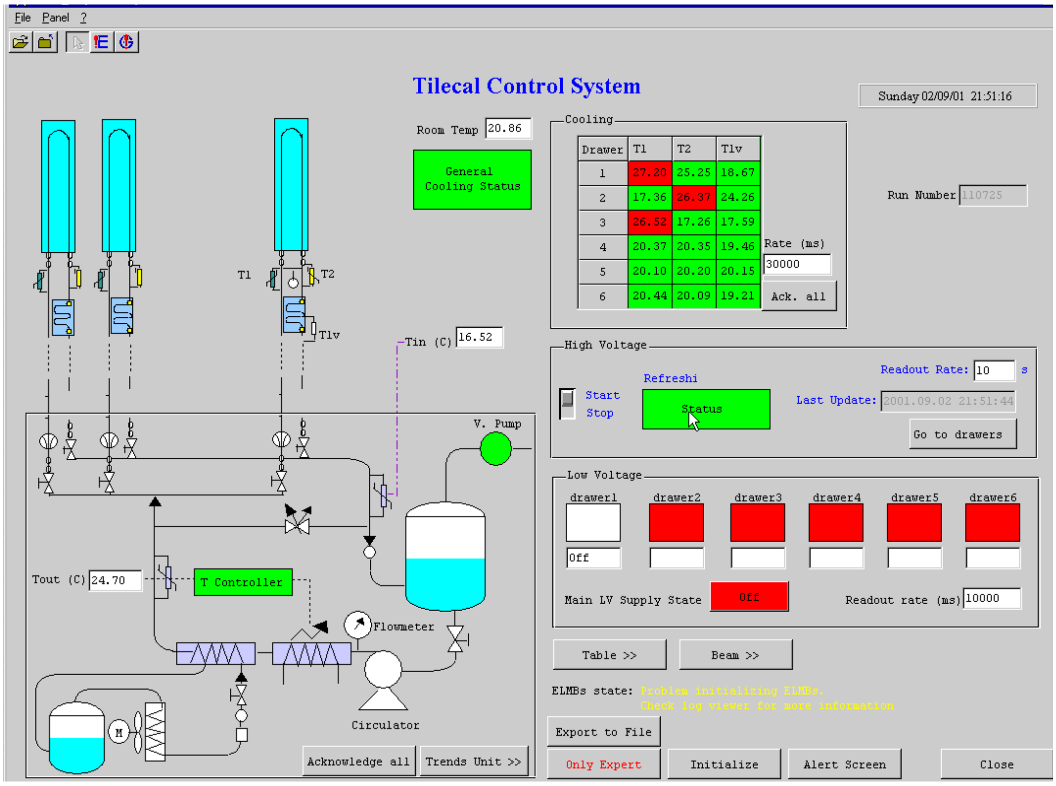


Figure 9 PVSS-II operator main panel

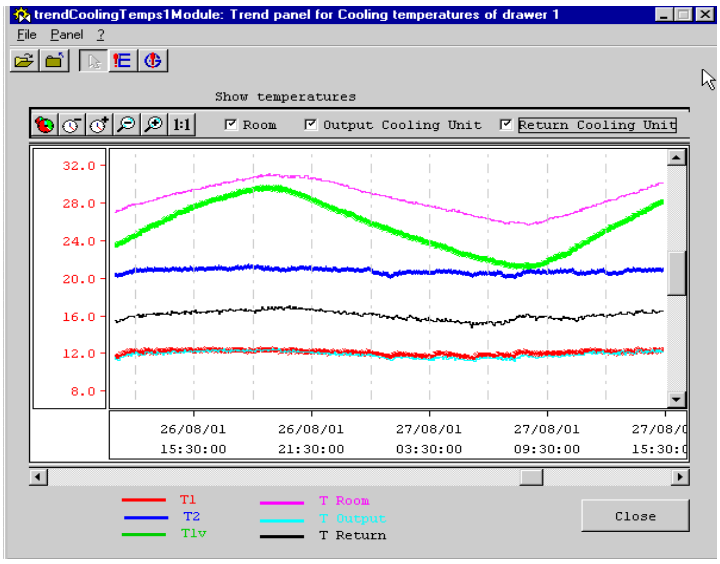
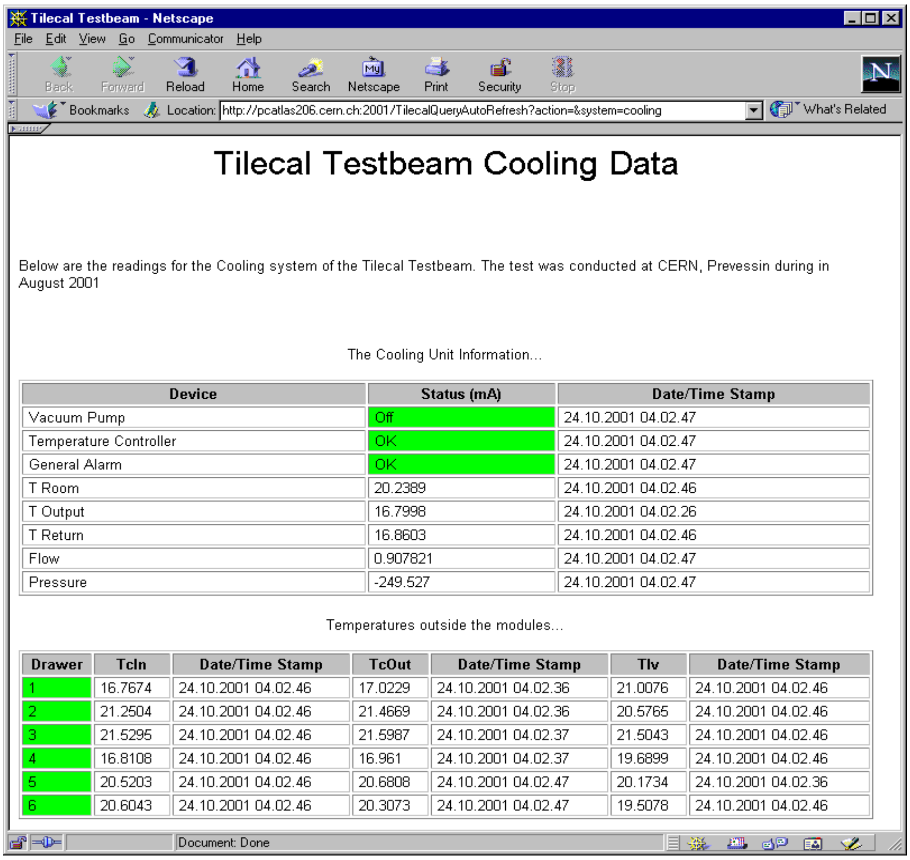


Figure 10 Trend panel of the cooling system, that are the inlet and outlet drawer 2 temperatures, the return water temperature and the ambiant temperature.


Tilecal Testbeam - Netscape

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Back Forward Reload Home Search Netscape Print Security Stop

Bookmarks Location: http://pcatlas206.cern.ch:2001/TilecalQueryAutoRefresh?action=&system=cooling What's Related

Tilecal Testbeam Cooling Data

Below are the readings for the Cooling system of the Tilecal Testbeam. The test was conducted at CERN, Prevessin during in August 2001

The Cooling Unit Information...

Device	Status (mA)	Date/Time Stamp
Vacuum Pump	Off	24.10.2001 04.02.47
Temperature Controller	OK	24.10.2001 04.02.47
General Alarm	OK	24.10.2001 04.02.47
T Room	20.2389	24.10.2001 04.02.46
T Output	16.7998	24.10.2001 04.02.26
T Return	16.8603	24.10.2001 04.02.46
Flow	0.907821	24.10.2001 04.02.47
Pressure	-249.527	24.10.2001 04.02.47

Temperatures outside the modules...

Drawer	TcIn	Date/Time Stamp	TcOut	Date/Time Stamp	TIv	Date/Time Stamp
1	16.7674	24.10.2001 04.02.46	17.0229	24.10.2001 04.02.36	21.0076	24.10.2001 04.02.46
2	21.2504	24.10.2001 04.02.46	21.4669	24.10.2001 04.02.36	20.5765	24.10.2001 04.02.46
3	21.5295	24.10.2001 04.02.46	21.5987	24.10.2001 04.02.37	21.5043	24.10.2001 04.02.46
4	16.8108	24.10.2001 04.02.46	16.961	24.10.2001 04.02.37	19.6899	24.10.2001 04.02.46
5	20.5203	24.10.2001 04.02.46	20.6808	24.10.2001 04.02.47	20.1734	24.10.2001 04.02.36
6	20.6043	24.10.2001 04.02.46	20.3073	24.10.2001 04.02.47	19.5078	24.10.2001 04.02.46

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Figure 11 PVSS-II Web Interface showing the online values of the cooling system.

4 Stability of the cooling system

One of the main requirements of the Tilecal readout electronics is the stability of the output signals. In particular the gain of the photomulplier has to remain stable within 0.5% during normal operating conditions. Previous measurements in lab [13] showed that the gain of the photomultipliers vary as 0.2% / ^{o}C. Since the other components of the readout chain are little affected by temperature variations (within a few degrees), the temperature nearby the photomultipliers has to remain stable within 2.5 ^{o}C.

The stability of the cooling system has been monitored during the September 2001 calibration period, using temperatures probes located inside and outside the drawers. During the September period, only two super-drawers were installed (in the extended barrel modules EBC-15 and EBC-24). In the following, drawer 2 refers to the super-drawer installed in module EB-C-15 and drawer 5 to module EBC-24.

Figure 12, represents, as a function of time and for a period of 5 days, the value of the inlet and outlet water temperature of the two super-drawers and of the water temperature at the output of the cooling unit. The values of the inlet temperatures and at the level of the cooling unit are very similar since isolated pipes of 10 meters long were used between the cooling unit and the super-drawers. One can see that the behavior of the five temperature probes as a function of time is the same. The small unstabilities are due to the regulation cycles of the cooling system.

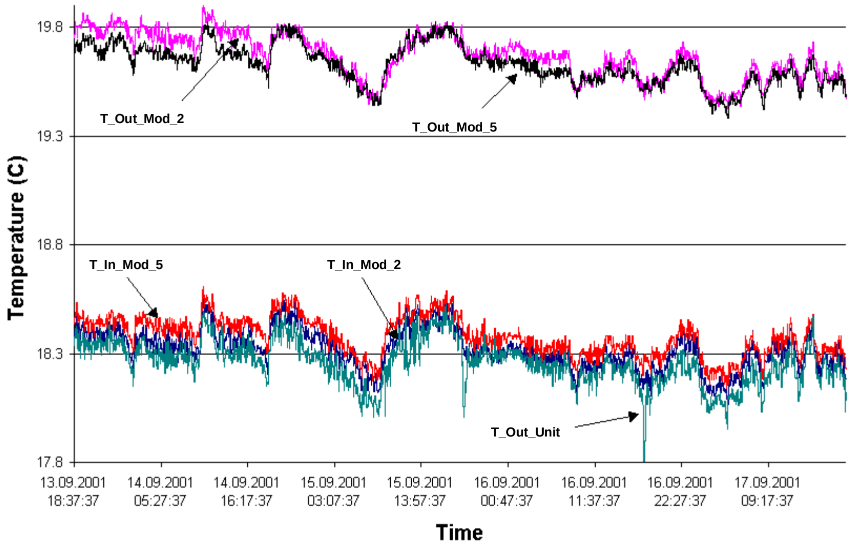

Figure 12 Variation of the temperature of the water at the input and output of the two drawers and at the output of the cooling unit, as a function of time during the September calibration period.

The average value as well as its error, for the five temperatures, is given in table 2.

Table 2 Mean value of the temperature of the water at the input and output of the two drawers and at the output of the cooling unit. These values area averaged over the five days of the September calibration period.

Temperature	Average value (^{o}C)
Inlet drawer 2	18.3 ± 0.1
Inlet drawer 5	18.4 ± 0.1
Cooling output	18.3 ± 0.1
Outlet drawer 2	19.7 ± 0.1
Outlet drawer 5	19.6 ± 0.1

Therefore, we see that the cooling unit shows a very good stability, as well as the temperatures at the output of the unit, they are stable within 0.1 ^{o}C. Over the same period, the temperature difference between the inlet and outlet water is ΔT= 1.35 ^{o}C ± 0.05 ^{o}C for drawer 2 and ΔT=1.25 ^{o}C ± 0.05 ^{o}C for drawer 5. If the final finger low voltage power supplies would be installed, the expected ΔT would be approximately 2 ^{o}C. This will be confirmed during next year calibrations.

The stability of the temperature inside the drawers has also been measured by the use of the temperature probes readout by the HV system (see section 2). Figure 13 represents the variation of the seven temperature probes inside drawer 2 during the September period. One can see that all the seven temperatures are very stable. The probe located near the photomultiplier PMT22 gives an average value of 24.5 ^{o}C, with a stability of 0.1 ^{o}C. Therefore, one can conclude that with this cooling system, the variation of the gain of the photomultipliers due to temperature variations is totally negligible.

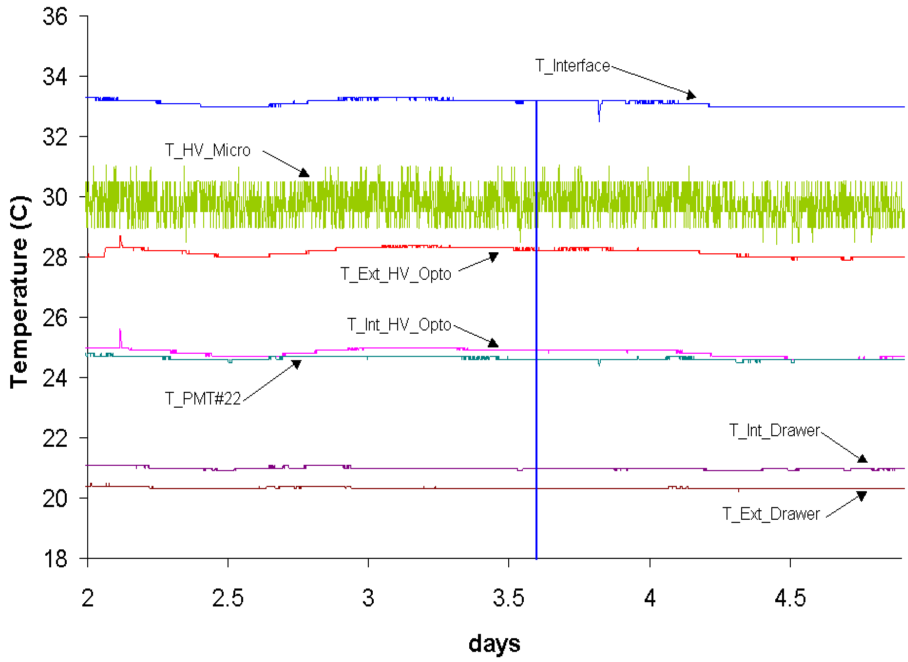

Figure 13 Variation of the temperature of the seven probes located in drawer 2 as a function of time during the September calibration period. One observes the same behaviour for drawer 5.

5 Effect of cooling parameters on calorimeter performance

The final values of the operating cooling parameters (temperature and flow) depend on the stability requirements of the Tile calorimeter and power dissipation with all the components installed, including the finger low voltage power supplies. At the end of the September period, some dedicated cooling tests were done in order to check and to measure the performance of the cooling system and the response of the calorimeter as function of the cooling settings. One of the tests consisted in varying the water flow and looking at the evolution of the temperatures in the system. Another test consisted in varying the water cooling temperature and in measuring the effect on the temperatures inside the drawers and on the gain of photomultipliers.

Water flow variations:

This measurement was made at a constant cooling water temperature of 18 ^{o}C. The water flow was varied between 10 l/h and 60 l/h. At each setting of the flow (10, 20, 40 and 60 l/h) and after stabilization, the temperatures inside drawer 5 were measured. Figure 14 shows the variations of the seven temperatures as a function of the flow. In the region 40-60 l/h, the temperatures tend to be almost independent from the flow. One has to keep in mnd that this test was done without the finger LV power supplies. The flow will have to be optimized with the finger power supplies installed.

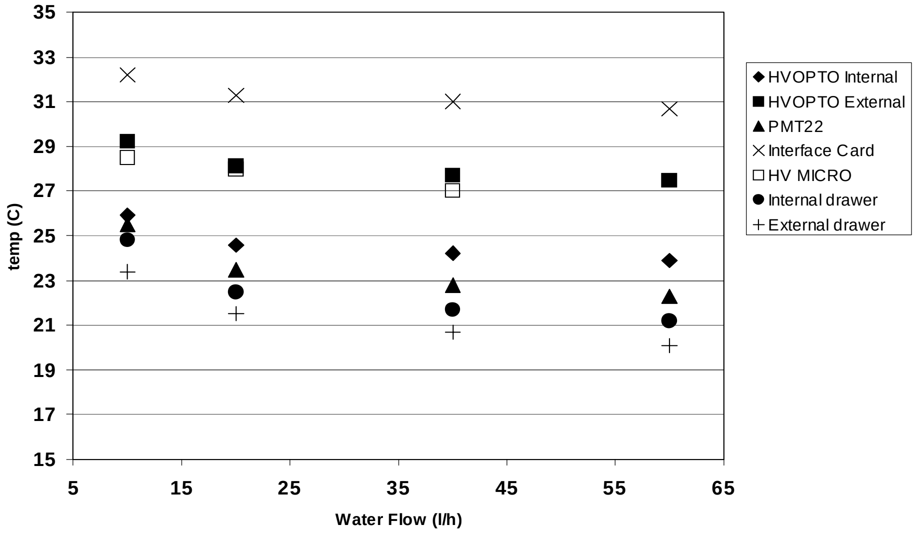

Figure 14 Variation of the temperature of the seven probes located in drawer 5 as a function of the cooling water flow.

Cooling water variations:

The cooling water temperature was varied by steps in the range 16 ^{o}C to 22 ^{o}C, at a constant flow of 60 l/h. After stabilization at four values (16, 17, 18, and 22 ^{o}C), the temperatures inside the drawers were measured. The stabilization time was of the order of 1-2 hours. Figure 15 represents the variation of the seven temperatures inside drawer 2 as a function of the cooling temperature. A similar temperature increase rate was found for all the temperature probes, e.g., the temperature close to PMT22 vary by half (3 ^{o}C) the variation of the cooling water (6 ^{o}C). This gives:

$$\Delta T(PMT) = 1/2\ \Delta T(cooling)$$

During this test, the variation of the gain of the photomultipliers as a function of the temperature was measured with the beam. A 180 GeV electron beam was hitting the module EBC-24 (corresponding to drawer 2) at projective η, in cell A14. The electron beam was highly contaminated with pions and muons. Electrons and pions were separated using a cut on the ratio of the energy deposited in the first sampling over the total energy deposited in the calorimeter. For electrons, the total energy is mainly contained in one cell (making the ratio close to unity) whereas for pions the energy is spread over a few cells. The cell A14 (the cell hit by the beam) is readout by the PMTs 21 and 22, the latter containing one of the temperature probes.

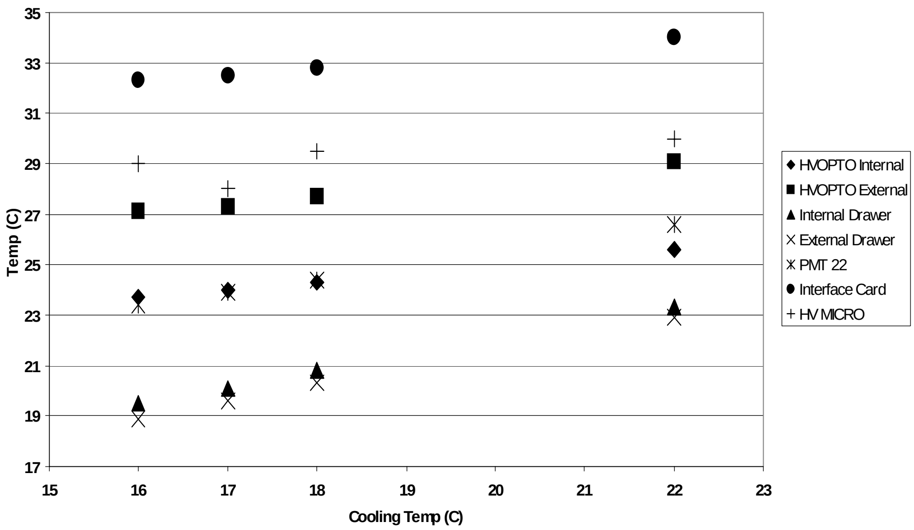

Figure 15 Variation of the temperature of the seven probes located in drawer 2 as a function of the cooling water temperature. One would see the same behaviour for drawer 5.

At each value of the cooling water temperature, the total energy in the module, for both electrons and pions, was reconstructed. Then, the total energy measured as a function of the temperature in the PMT block 22 was measured. At some point in the test, the cooling unit was switched off in order to further increase the temperature in the drawer. Figure 16 shows the variation of the total energy measured as function of the temperature in the PMT block 22, for both electrons and pions. The dashed lines represent a linear fit to the data points. The variation of the total energy and consequently of the gain of the photomultipliers as a function of the temperature in the PMT block is very similar for electrons and pions ($\Delta E / E = 0.21\% / ^{o}C$ for electrons and $\Delta E / E = 0.23\% / ^{o}C$ for pions). Since in the case of pions, many cells are hitten , this shows that the PMT gain variation as a function of the temperature is the same for all the photomultipliers. We can then confirm that:

$$\Delta E / E = 0.2\% / ^{o}C$$

This result confirms previous lab measurements for individual photomultipliers measured in a test bench [13].

Taking into account that the variation of the temperature inside the PMT block is only half of the temperature variation of the cooling water, the variation of the gain of the photomultipliers as a function of the cooling water temperature is then:

$$\Delta G / G = 0.1 \% / ^{o}C$$

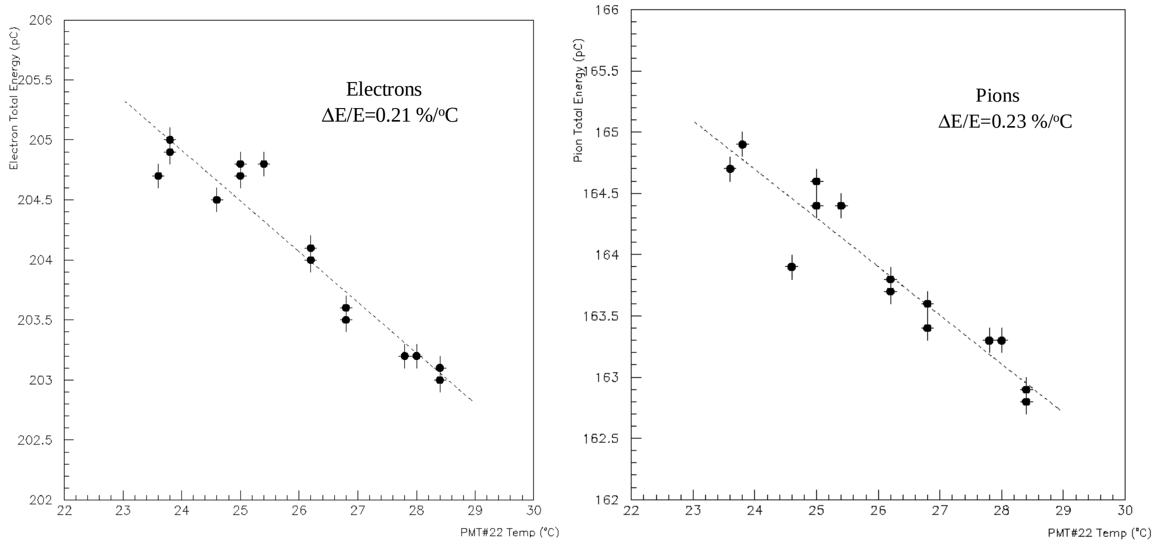

Figure 16 Variation of the total energy measured in the tile calorimeter for 180 GeV electron beam as a function of the temperature in PMT block 22, for electrons (left handed plot) and pions (right handed plot).

6 Conclusions

The cooling system used for beam and Cesium calibrations has been described. The monitoring system based on the PVSS-II SCADA product has been developed and operating very efficiently during the summer 2001 calibration periods. The stability of the cooling unit was very good, at the level of 0.1 ^{o}C, allowing a very good stability of the electronics located in the drawers. The variation of the gain of the photomultipliers as a function of the water cooling temperature is 0.1% / ^{o}C.

From these studies, we conclude that if the water stability would be the only factor responsible for the PMT gain stability, then in order to ensure a PMT stability of 0.5%, the temperature variations in the PMT block have to be smaller than 2.5 ^{o}C. This corresponds to a temperature variation in the cooling station of 5 ^{o}C. In the calibration setup, all the pipes were isolated. This will most likely not be the case in ATLAS due to space constraints. What remains to be done is the measurement of the stability of the inlet drawer water temperature using the non-isolated tubes that are expected to be used in ATLAS.

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