Stability Study of a Hadronic Calorimeter Prototype Response

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1 Introduction

High-energetic particles like protons, pions or electrons interact with matter through the strong or electromagnetic interaction. In these processes, the particles lose energy, e.g., through ionization of the passed medium. They may also create numerous secondary particles, through nuclear reactions or through radiative processes (bremsstrahlung). Also these secondaries lose energy on their way through the medium and they may create tertiaries, etc. This process, called shower development, eventually leads to (almost) complete absorption of the energy carried by the initial particle.

Detectors based on absorption of the particles are called calorimeters. They play a crucial role in modern, accelerator-based experiments at high energy and luminosity. Many hadron calorimeters used in high-energy physics experiments are of the sampling type. These detectors consists of a mixture of active and passive material, arranged in some regular pattern, referred to as "sandwich","spaghetti",or "accordion"structures. Typically, at least 90%, and frequently more than 99%, of the mass is contained in the passive absorber material. The active material produces light or charge signals which are considered representative for the shower development process and, when integrated over the volume in which the shower develops, are a measure of the particle's initial energy. Only a small fraction of the energy carried by the particles absorbed in a sampling calorimeter is deposited in the active layers and thus transformed into a signal. For sampling calorimeters to work properly, it is important that this fraction is constant, independent of the energy of the detected particles.

The absorption of particles subject to the strong interaction (hadrons) in a block of a matter proceeds in the following way, when a high energy hadron penetrates a block of matter, it will at some point interact with one of its nuclei. In this process, mesons are usually produced (π,K,etc.). Some fraction of the initial particle energy is transferred to the nucleus. The excited nucleus will release this energy by emitting a certain number of nucleons (and at a later stage, low energy γ's) and it will lose its kinetic (recoil) energy by ionization. The particles produced in this reaction may in turn lose their kinetic energy by ionization and/or induce new reactions, thus causing a shower to develop.

2 The ILC

The international linear collider, ILC, is the next large project in particle physics, following the LHC. This machine will allow the precision study of the top quark and the electroweak gauge bosons. It will explore the Higgs sector, and study possible extensions of the Standard Model like supersymmetry with great precision. The ILC is a e^+e^- collider. Two 12 Km long linacs, one for the electrons and one for positrons, will accelerate the particle bunches toward the collision point.

CALICE is an international collaboration of 39 institutes from 12 countries, whose main objective is the development of the next generation of calorimeters for future HEP detectors. Within CALICE prototypes of electromagnetic and hadronic calorimeters, as well as of a tailcatcher and muon tracker, are being pursued. During my summer student period my main activity was to check the stability of a first hadronic calorimeter option.

The Analogue Hadronic Calorimeter prototype (HCAL) is a calorimeter with a longitudinal segmentation of 38 active layers separated by 2 cm of steel. Each active scintillator layer is divided into 216 tiles. The highly granular core of 30×30 cm^2 is covered by a matrix of 100 3×3 cm^2 tiles; the outer most part of the active layer is divided in 12×12 cm^2 tiles. The scintillation light produce in the tail is collected via a wavelength shifting fiber and coupled to a newly develop silicon-based photo-detector (SiPM). The prototype consists of ∼8000 scintillator tiles with analogue readout performed via SiPM directly mounted on each tile. A dedicated ASIC chip has been developed to match the requirements of large dynamic range, low noise, high precision and large number of readout channels needed. The very front-end (VFE) electronics to steer the chip settings and readout has been designed at DESY and it is matched to the data acquisition developed within CALICE.

During summer 2006 and 2007 the HCAL has been installed and tested at the CERN SPS test-beam facility together with an electromagnetic (ECAL) and tail catcher (TCMT) prototype. The three detectors were successfully operated for several months and over 10000 channels were readout by the combined data acquisition system. Pions and electrons of various energies from 6 up to 120 GeV have been recorded for different positions of the detector system relative to the beam and for different angles.
In the following I will concentrate my comparison to a subsample of 10 GeV pion data, which have been recorded for different detector positions and different temperatures.

These data sample gives the possibility to observe differences in the reconstructed energy due to these changes. Therefore, the analysis consists of several parts. First, I have done studies on the temperature distribution in the HCAL prototype. Afterwards, I have studied differences in the HCAL detector response with selected muons and pion showers.

3 Temperature Measurement

First I have focussed on the study of the temperature of the active HCAL layers. Each layer of the HCAL is monitored by 5 temperature sensors, which are placed in a vertical line in the middle of each layer. It would be preferable to maintain a constant temperature, because the increase of temperature produces a decrease of the amplitude of the measured signal. Since the detector temperature depends on the outside temperature, the detector response has to be corrected for the observed temperature changes. The dependence of the detector readout system due to temperature changes is dominated by the temperature sensitivity of the used photodetector, the SiPM. The amplitude increase with temperature as measured in the HCAL is modeled by the equation:

$$\frac{dA}{dT} = -4.5\%/K. \tag{1}$$

One example of the temperature changes is reported in Figure 1. The temperature measured in the sensor at the bottom of the HCAL prototype in layer 6 is shown as a function of time. A total temperature change of 3° C has been determined for a running time of 2 days, which leads to a significant change in the response of around 12 %.

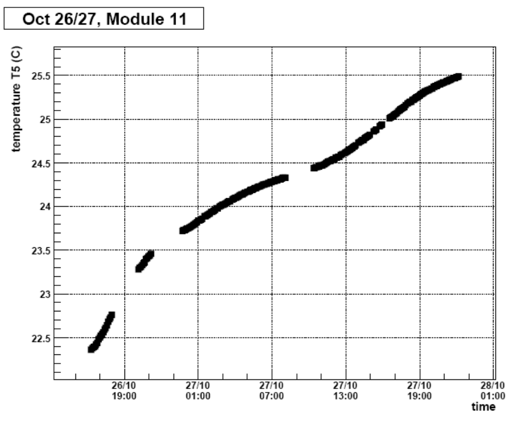

Figure 1: Temperature dependence of Layer 6 (bottom sensor).

(a) (b)

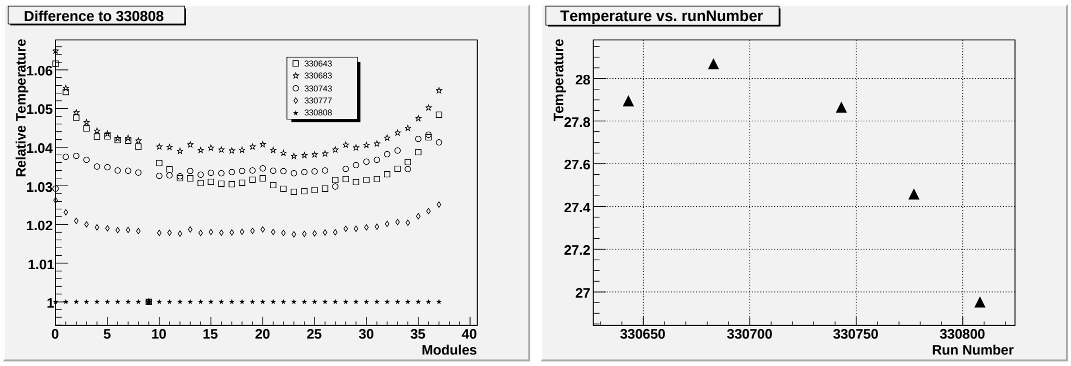

Figure 2: (a) Stability of the 38 layers and (b) average temperature per run

Another interesting question is how the temperature profile over all 38 layers in the HCAL looks like. This gives an indication if for the temperature correction one average value is sufficient or if the temperature profile has to be parameterized. In Figure 2 (a) it is visible that the outer modules have larger temperature fluctuations than the inner ones. This can be explained by the heat exchange with the surrounding air. In the plot the y-axis represents the relative temperature normalized to the measured temperature during run number 330808.
The temperature change for the 10 GeV pion subsample, which will be discussed in detail in the following, is shown in Figure 2 (b). A total difference of approximately 1° C has been determined.

4 Energy Measurement

In the next step I have determined differences in the HCAL detector response and I have tried to correlate these changes to observed temperature changes. In the following I will concentrate my comparison to a subsample of 10 GeV pion data, which have been recorded for different detector positions and different temperatures.

4.1 Event selection

For each run the pion sample is divided into three parts. First I have selected events which have left a track in the ECAL, which means that they might start to shower in the HCAL. An additional requirement takes into account only those particles which have only small leakage to the TCMT ($E_{TCMT} < 3$ GeV). A typical event is shown in Figure 3. The beam is coming from the right. In the first detector (ECAL) a clear track is visible, followed by a starting shower in the next detector (HCAL), which is fully contained inside this detector. No energy is observed behind the HCAL, which can be measured by the TCMT. Furthermore, each pion run consists of additional muon events. These events are determined by asking for a track in all three detectors ECAL, HCAL and TCMT. In average around 8 % of the total events are muons, which is summarized in Table 1.

(a) (b)

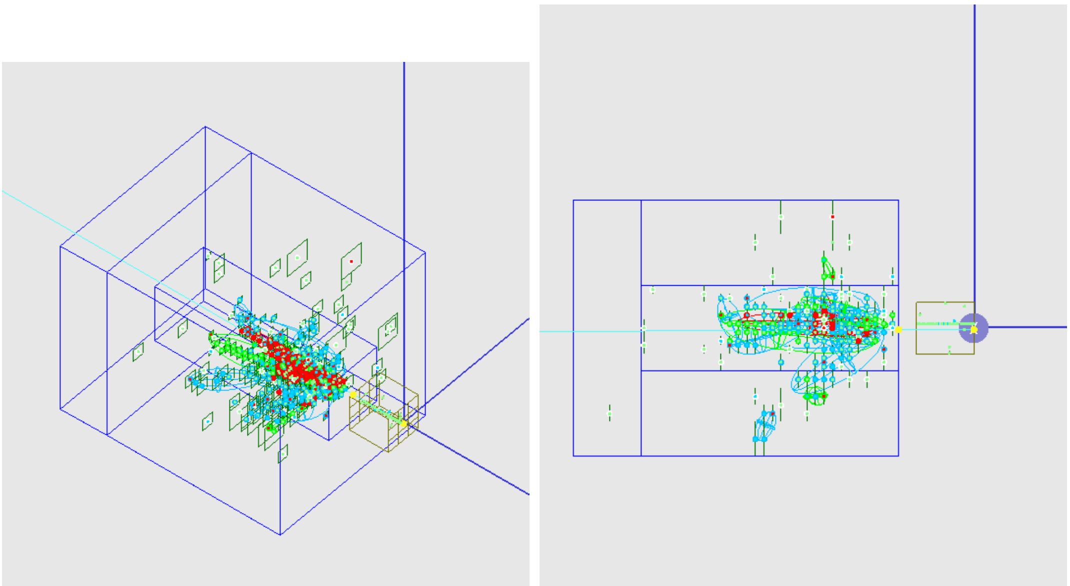

Figure 3: (a) Example of a hadronic shower in the HCAL and (b) from the side.

4.2 Muon Analysis

In case a muon is going through the detectors, the observed signal corresponds to a mip peak, which can be described by a Landau distribution (see Figure 4). I have studied the temperature dependence of the energy of the detected muons. The muon spectrum in each of the five runs was fit to obtain the most probable value of the deposited energy. The used fit function is a Landau distribution which describes the energy loss by charged particles due to ionization.

The values obtained for the 5 runs considered are shown in Figure 6 (a). Figure 6 (b) shows a maximum variation of 6 % between the runs. The value obtained for run 330808 suffers from the wrong fit value presented in Figure 5 (b). The relative change of the mean energy respect to the first run is shown in Figure 6 (b), in which we observe that our fit is not suitable for the last run. If we restrict our analysis only to the other four runs the changes in the muon response is in the order of ≈ 3 %.

Run Number	Muon Events	ratio[%]
330643	2874	8
330683	3686	10
330743	2688	7
330777	2658	7
330808	5025	14

Table 1: Muon events found in five runs.

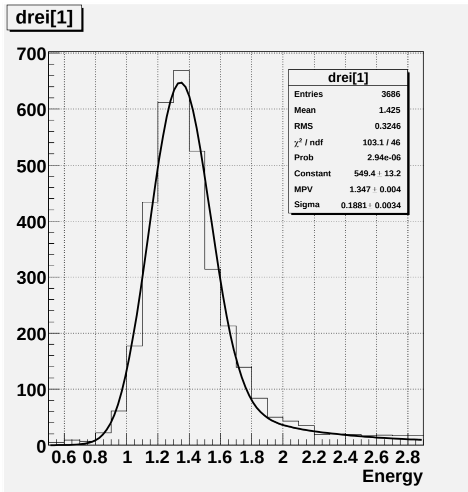

Figure 4: Energy spectrum deposited by a muon in the HCAL.

(a) (b)

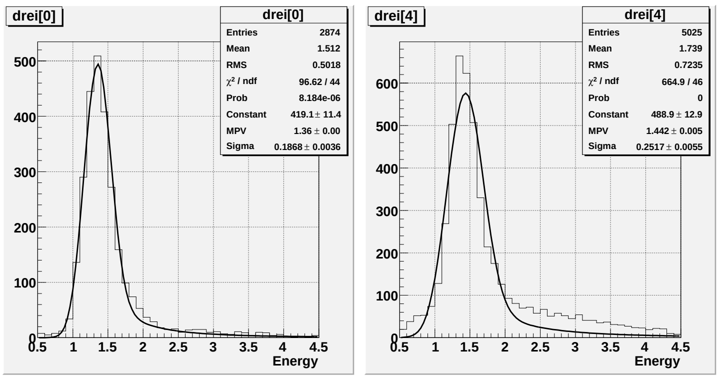

Figure 5: Energy spectrum deposited by a muon in the HCAL including Landau fit for two runs. (a) for a successful fit and (b) for a problematic one.

Figure 7 shows the dependence of the energy deposited by the muon to the detector temperature. The measured amplitude variation is 0.08 GeV / K and has to be nor-

(a) (b)

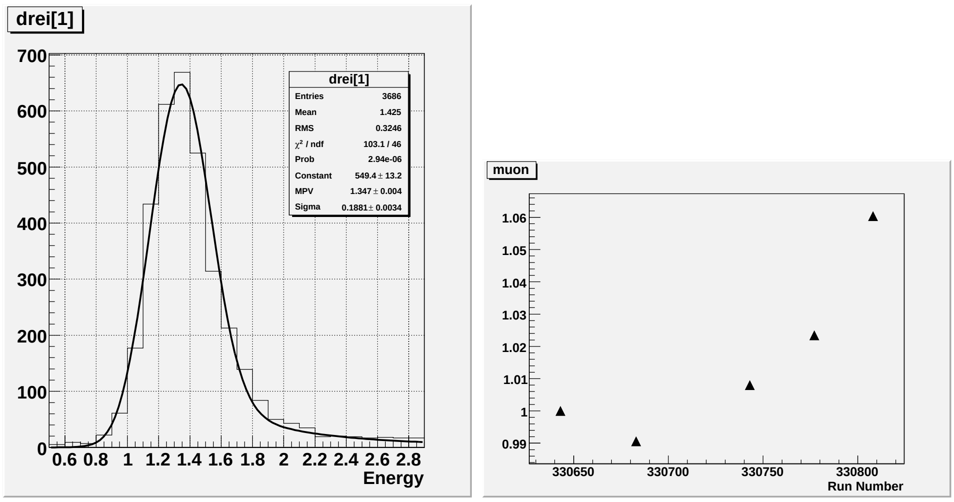

Figure 6: (a) Muon energy and (b) variation of muon mean energy deposited over the 5 analyzed runs.

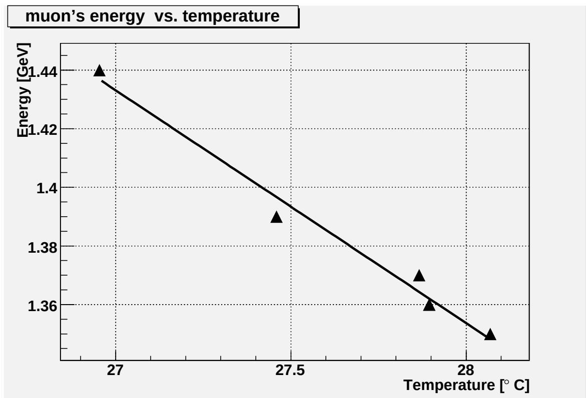

Figure 7: Temperature dependence of the muon energy.

malized to the average muon deposited energy of 1.4 GeV. This gives a HCAL response change due to temperature of $dA/dT \sim 5.7\%$ / K, which is in rough agreement with the expectations of previous measurements.

4.3 Pion analysis

Figure 8 is an example of the detector response to the pion beam. The left plot (a) shows the histogram with all the detected signals including those which shower in

ECAL. On the right side (b) the same histogram with the requirements of a shower in the HCAL is shown. A nice Gaussian distribution is visible. These events are called contained pion showers in the HCAL.

(a) (b)

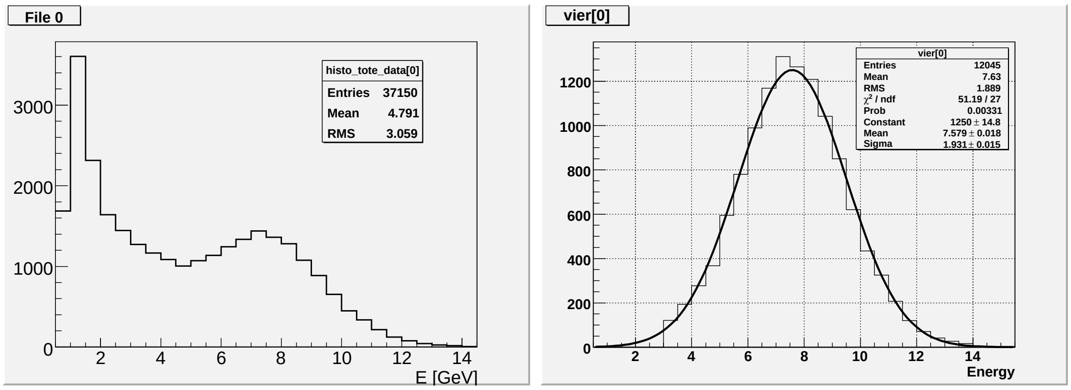

Figure 8: Comparison between unselected (a) and selected (b) data

Run 330643	%
No cut	100
Track in ECAL	33
Track in ECAL & $E_{TCMT} < 3$GeV	32

Table 2: Amount of events after each requirement in percent.

It is rather important to observe how many events are being selected after each requirement. This procedure helps to realize how much data are filtered and to avoid to request too strong requirements, which leads to a too small event sample in the very end. As an example the amount of events after each cut in percentage are shown in Table 2. To validate the analysis it is important that the cuts in each run give as a final result the same amount of data in terms of percentage. This is summarized in Table 3. The amount of events which have a contained shower in the HCAL is between 30 and 40%.

Run Number	Total Events	Analyzed Events	ratio[%]
330643	37150	12045	32
330683	36269	14956	41
330743	37351	11530	31
330777	37429	11643	31
330808	36248	14439	40

Table 3: Event statistics for the pion analysis.

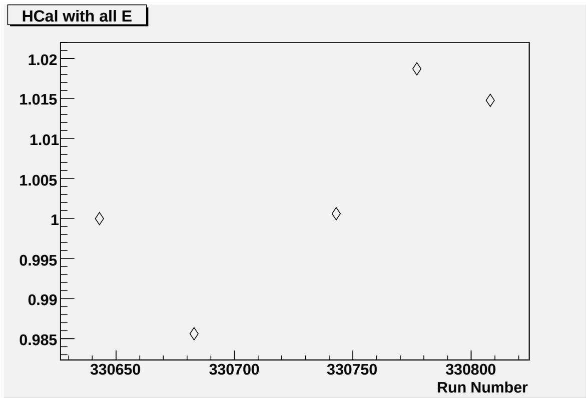

Figure 9: Change of the mean energy deposited by a pion shower in the 5 runs.

Figure 9 shows the relative difference normalized to the first run in the HCAL response to contained pion showers for the 5 analyzed runs. The total variation is around 4% between the runs. This is in agreement with the 3 % observed in the muon analysis.

Run Number	Temperature	E_π [GeV]
330643	27.9	7.58
330683	28.1	7.48
330743	27.9	7.59
330777	27.5	7.72
330808	27.0	7.70

Table 4: Reconstructed energy for the 5 considered runs with their average temperature.

In table 4 the reconstructed energy and the average run temperature are summarized. The total temperature variation is in the order of 1° C, which is in agreement with the observed change in the HCAL response of 4 %.
In addition, it is visible that the reconstructed energy does not reach the initial 10 GeV pion energy. This effect can be explained by processes inside of the hadronic showers, which does not deposit measurable energy in the detector. Therefore, an additional scaling factor has to be applied to scale back to the real energy.

5 Summary and Conclusion

A temperature analysis of the 38 HCAL layers was made over five runs. The average temperature and temperature profiles have been determined.
A first attempt to study the HCAL response stability for several runs to a 10 GeV pion

beam has been performed. For this purpose the calorimeter response to a minimum ionizing particle can be used as a calibration factor. Due to the large amount of muons in each pion run the mip amplitude can be used to correct temperature fluctuations of the calorimeter response in each run. This procedure tested on a small sample of data yields good results in agreement with previous studies based on the LED monitoring system of the calorimeter. Furthermore the response to pion showers has been investigated and compared to different runs. For the muon and the pion response an overall change of 3-4 % has been determined which is in agreement with the observed temperature changes.

These information are important for the correction of the data collected with the HCAL prototype during the test-beam periods and also give valuable information for the construction of an suitable ILC's calorimeter. Especially in the later case it will be important to have an established response, which is stable despite temperature fluctuations or easy to correct for.