Module-to-module uniformity at 180 GeV in 2002-2003 TileCal calibration testbeams

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Abstract

The response of several Tile Calorimeter production modules to a 180 GeV hadron testbeam was studied. The uniformity in the mean response was calculated for several η values. Averaged over η, the uniformity of the mean response was found to be $1.37 \pm 0.15\%$.

1 Introduction

Several Tile Calorimeter production modules were exposed to hadron testbeams in the years 2002 and 2003. The typical TileCal configuration in the testbeam is shown in Figure 1. Module 0, one barrel production module, and two extended barrel production modules were placed on a movable table. In 2002 and 2003 there were six different run periods, during which six different sets of production modules were tested. In August 2003 a slightly different configuration was used, with a second barrel production model replacing the two extended barrel modules. All of the runs studied in this note were taken in a projective geometry, with the beam impinging on the production barrel module. The η range studied in the testbeam was $-0.85 < \eta < 0.45$.

The modules were exposed to several different beam particles at several different energies. During five of the six run periods mentioned above, the central barrel module was exposed to a 180 GeV beam of positive polarity composed primarily of hadrons and electrons with some muon contamination. The hadrons in the beam were pions and protons.

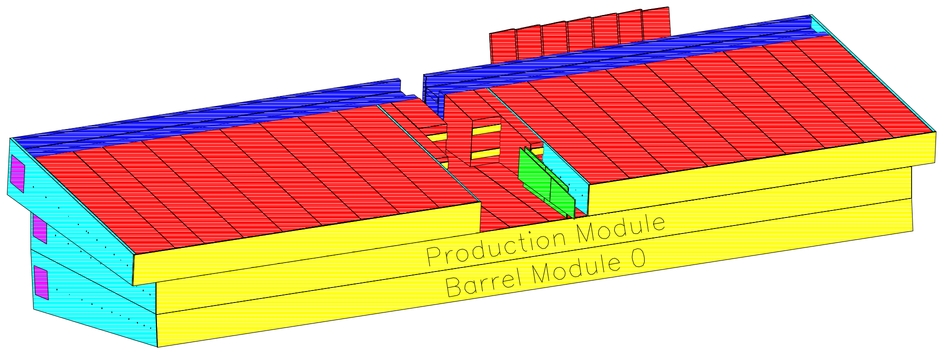

Figure 1: Configuration of the Tile Calorimeter modules in the testbeam.

2 Energy reconstruction

The beam was cleaned of multi-particle and off-axis events using scintillators and beam chambers upstream of the calorimeter. Upper thresholds were placed on energy deposited in each of three upstream scintillators. Particles were required to be within a certain rectangle in both of the beam chambers, as well as to be traveling within a certain angle relative to the beam axis. The exact cuts changed from testbeam period to testbeam period because the properties of the beam and the beam detectors changed.

Muon contamination was removed from the beam by requiring the energy deposited in the calorimeter to be greater than 5.0 GeV. To remove electrons the variables C_{long} and C_{tot}, which characterize the size of the shower in the calorimeter, are used. They are described in detail in Reference [1]. A correlation plot for these two variables is shown in Figure 2. The points above the line are electrons and those below the line are hadrons. There was no cut made to separate pions from protons. At 180 GeV, about 76% of the hadrons in the beam were protons [1].

The energy deposited in the calorimeter was determined by adding the energy in cells in a 0.3×0.3 region in $\Delta\eta \times \Delta\phi$ around the beam axis. The 0.3 region in η in the extended barrel modules was approximated, since the towers of the extended barrel do not match the towers of the barrel.

In each testbeam period there were some bad components: dead or misbehaving channels or drawers. Bad components were determined using calibration runs. A summary of bad components is given in Table 1. If there were bad channels, the response in the other readout channel of the same cell was doubled. If a whole module was bad, all runs using this module were left out of the analysis.

Testbeam period	Bad component (Channel, Module)	Location in (η, ϕ)	Action
August 2003	39, N0 24, P2	(-0.85, -0.1) (0.35, 0.1)	Double channel 38 Double channel 25
July 2003	39, N0 9, P1	(-0.85, -0.1) (0.15, 0.0)	Double channel 38 Double channel 6
June 2003	16, N1 23, N2 1, P1 39, N0	(-0.35, 0.0) (-0.45, 0.1) (0.0, 0.0) (-0.85, -0.1)	Double channel 19 Double channel 24 Double channel 1, N1 Double channel 38
August 2002	23, P2 27, P1 22, N1 26, N1 35, N1	(0.45, 0.1) (0.45, 0.0) (-0.45, 0.0) (-0.45, 0.0) (-0.65, 0.0)	Double channel 24 Double channel 26 Double channel 23 Double channel 27 Double channel 36
July 2002	All of Module P0	(-0.85 to 0.05, -0.1)	Don't consider runs in this η region

Table 1: List of bad components for testbeam periods considered. In the notation used for the modules, the N or P signifies the negative or positive side of the module, while the 0, 1, and 2 refer to Module 0, the barrel module, and the extended barrel modules respectively. For example, N1 is the $\eta < 0$ side of the barrel module. Channel refers to PMT number, counting from 1.

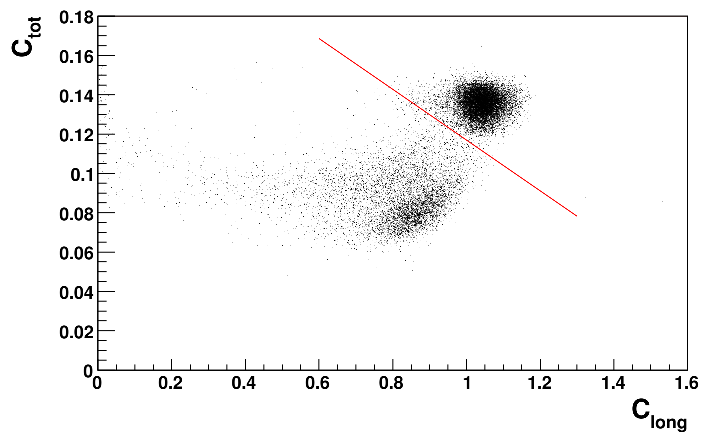

Figure 2: Correlation of C_{long} and C_{tot}. These variables characterize the shape of the shower in TileCal, so they can be used to separate hadrons from electrons. In this run, points above the line are considered electrons, points below the line hadrons.

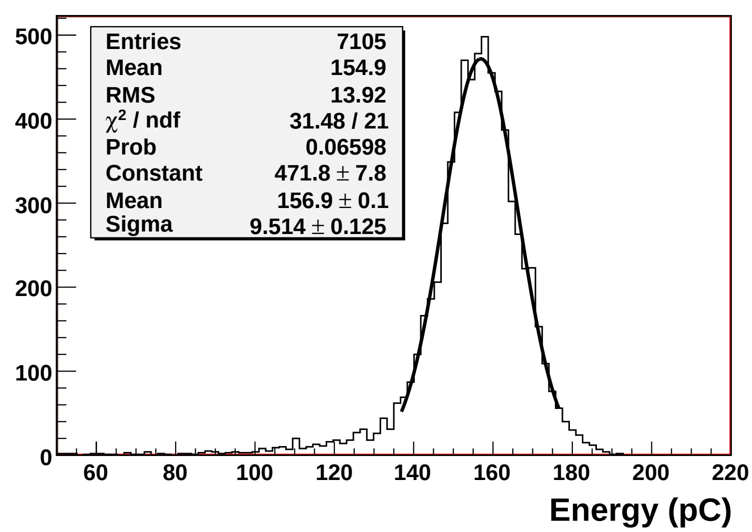

Figure 3: Gaussian fit to reconstructed energy for a run at $\eta = -0.45$ from August 2003.

The reconstructed energy in TileCal is shown in Figure 3 for a run at $\eta = -0.45$ taken in August 2003. The shape was fit with a Gaussian in a range of $\mu \pm 2\sigma$.

The TileCal channels were intercalibrated using the Cesium and charge injection calibration systems. An absolute calibration to the electromagnetic scale was determined by measuring the calorimeter's response to electrons. A separate calibration factor (usually referred to as the pC/GeV factor) was derived for each module. Since only a limited number of modules were exposed to the electron testbeam, it is desirable to use an average of all of the calibration factors rather than separate factors for each module. For the uniformity study in section 3, one overall factor was applied to all modules. For comparison, in section 4 the same study is performed with each module calibrated to the electromagnetic scale separately.

3 Module-to-module uniformity of response

The mean response of the calorimeter was compared for several different testbeam periods (i.e. for several different production modules). The response was compared for runs taken at the same η value, and positive and negative sides of the same barrel module were considered separate since they are instrumented separately.

The distribution of mean responses at $|\eta| = 0.35$ for nine different modules is shown in Figure 4. The RMS/mean for this distribution is $1.48 \pm 0.36\%$, and no modules fall outside the limits of the plot. The error of the RMS/mean was calculated using a toy Monte Carlo, which found the error associated with taking the RMS of the measured number of points generated from a Gaussian distribution. Due to the low number of measured points, the error on the RMS/mean is large.

The mean and RMS of the mean response were similarly calculated at each $|\eta|$ value. The number of different modules compared varied between four and nine. At $|\eta| = 0.05$, the response on the positive and negative sides of the setup are correlated, since the 0.3×0.3 regions overlap, so only the $\eta < 0$ side was used. At $|\eta| < 0.2$, data from August 2003 were excluded because of the slightly different setup used in that testbeam period[1].

Figure 5 shows the mean and RMS/mean as a function of $|\eta|$. The mean response is lower at low $|\eta|$ because of leakage out of the top of the barrel module (there is a gap between the two extended barrel modules as shown in Figure 1) and out of the

[1]As mentioned in Section 1, a barrel module replaced the two extended barrel modules, resulting in less leakage at low $|\eta|$.

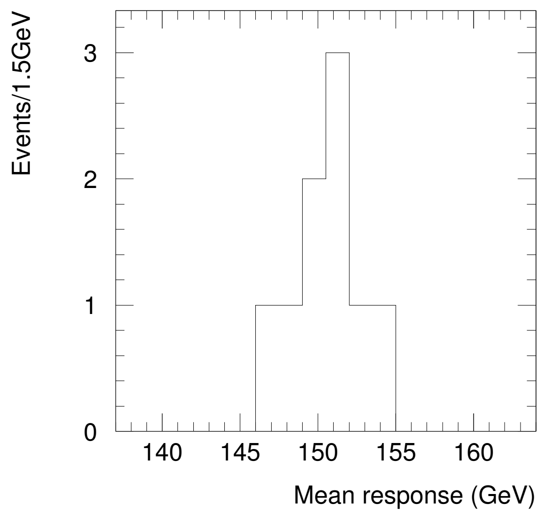

Figure 4: Distribution of the mean response to 180 GeV pions at $|\eta| = 0.35$ for several testbeam periods. The mean of the histogram is 150.6 ± 0.8 GeV, and the RMS/mean is $1.48 \pm 0.36\%$.

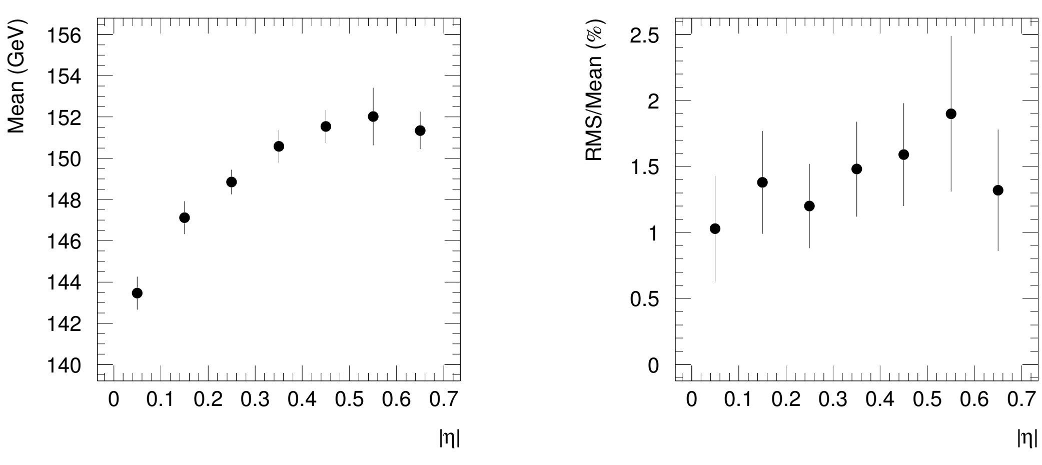

Figure 5: Mean and RMS of the mean response to 180 GeV pions as a function of $|\eta|$.

Period	Module	Calibration constant
August 2003	Barrel +	1.048
August 2003	Barrel -	1.023
July 2003	Barrel +	1.028
July 2003	Barrel -	1.033
June 2003	Barrel +	1.028
June 2003	Barrel -	1.019
August 2002	Barrel +	1.055
August 2002	Barrel -	1.056
July 2002	Barrel +	1.043
July 2002	Barrel -	1.051
All	Extended barrel and Module 0	1.040

Table 2: pC/GeV constants for each module studied [3] [4] [5] [6] [7]. The constants listed here are an average over all energies and all cells in a module for which the calibration constants were derived.

back. The average RMS/mean is $1.37 \pm 0.15\%$ and shows no significant evidence of variation with $|\eta|$. The confidence level for the hypothesis of a flat distribution is 90%.

4 Calibration to the electromagnetic scale

The uniformity study of the previous section was repeated, this time applying separate calibration factors to each module. A summary of the calibration factors used is given in Table 2. The barrel module calibration factors were derived from electron testbeams. For the extended barrel modules and Module 0, a constant calibration factor was applied.

The results of the uniformity study are shown in Figure 6. The RMS/mean as a function of $|\eta|$ is shown using both methods: one overall calibration factor or separate factors for each module. The average RMS/mean using a single calibration factor is $1.37 \pm 0.15\%$. When using several calibration factors, the RMS/mean is $1.15 \pm 0.12\%$. The difference between the two methods is $0.22 \pm 0.19\%$.

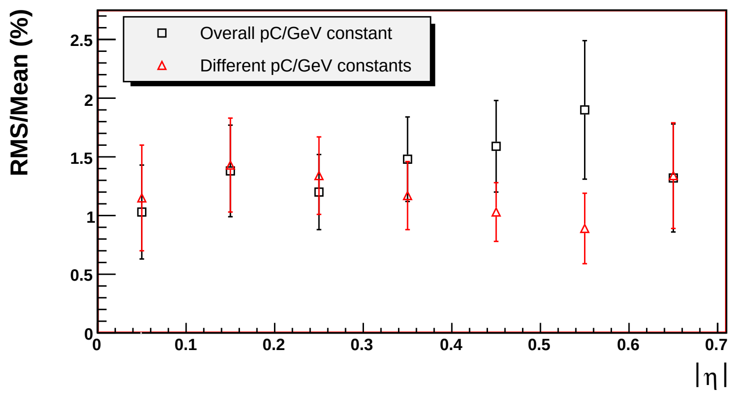

Figure 6: Comparison between uniformities derived using one overall calibration factor and using several factors.

5 Conclusions

The response of several barrel modules to 180 GeV hadrons was compared. The response was found to be uniform across different modules at constant η at the $1.37 \pm 0.15\%$ level. There was no evidence for variation in uniformity of the response with η. Use of different calibration constants for each module was found not to affect the uniformity of the response in a significant way.

References

[1] Tile Calorimeter testbeam summary paper, 2006.

[2] Y. A. Kulchitsky, Presentation in TileCal week, February 2003. `http://indico.cern.ch/materialDisplay.py?contribId=s1t2&sessionId=s1&materialId=0&confId=a03138`.

[3] Y.A. Kulchitsky, P.V. Tsiareshka and V.B. Vinogradov, ATL-TILECAL-2005-005.

[4] Y.A. Kulchitsky, Presentation in TileCal week, June 2003. `http://indico.cern.ch/materialDisplay.py?contribId=s1t3&sessionId=s1&materialId=0&confId=a031558`.

[5] Y.A. Kulchitsky, P.V. Tereshko, Presentation in TileCal week, June 2004. http://indico.cern.ch/materialDisplay.py?contribId=s1t3&materialId=0&confId=a042239

[6] J.A. Budagov, J.I. Khubua, Y.A. Kulchitsky and V.B. Vinogradov, Presentation in TileCal week, February 2004. http://indico.cern.ch/materialDisplay.py?contribId=s1t7&materialId=0&confId=a04565

[7] F. Sarri, Presentation in TileCal week, February 2004. http://indico.cern.ch/materialDisplay.py?contribId=s1t1&materialId=1&confId=a04565