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Validation of Calibration and Digitization Procedures for an Analog HCal Prototype Based on Scintillator Tiles with SiPM Readout using Electron Beam Data

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Abstract

This note updates the analysis of electromagnetic showers recorded with the CALICE tile Hcal prototype at the CERN test-beam facilities, as presented in CAN-010. It is intended for LCWS 2008 and describes the intermediate status of calibration corrections for temperature effects. The preliminary corrections described here are sufficient to eliminate the aparent data-simulation descrepancy in the energy scale, while the disagreement in linearity and resolution remains.

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1 Introduction

The calibration and correction scheme for the analogue tile HCal prototype has been described already in previous notes, together with the benchmarking using muon and electron/positron data [1, 2]. This note describes a similar study with an additional correction for temperature fluctuations applied during the calibration of data. Monte Carlo simulation and digitization as well as the following analysis has been unchanged w.r.t. [2].

Both gain and MIP calibration constants depend on temperature conditions. Both values are measured at a given temperature and applied to data, which in principle could have been recorded at different conditions. Since the temperature dependency on the coefficients is known [3], this effect can be compensated by extrapolating the measured coefficient to the conditions of those data, where they are applied to during calibration.

In the following, we describe how the determination of the temperature difference for gain and MIP coefficients and quantify the impact on the analysis of electromagnetic showers.

2 Temperature Measurements

Temperature measurements inside the AHcal stack are available via five temperature sensors on each module. For 36 out of 38 modules, the sensors are arranged in a vertical line in the horizontal middle of the active area, while two modules have one sensor in the geometrical center and one sensor each close to the four corners.

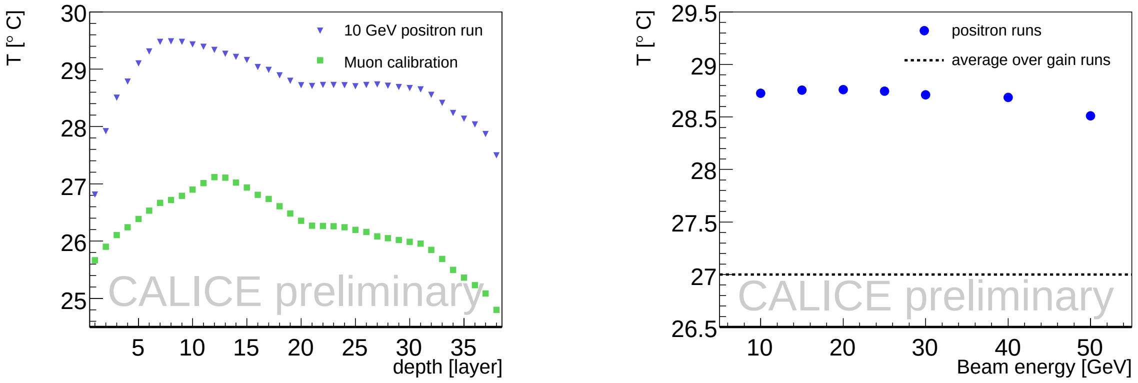

Figure 1: *The temperature averaged over each module of the 10 GeV positron run and all muon calibration runs averaged module wise for temperature reference (left). The temperature difference per module is used to correct the MIP constants for reconstruction. Temperature of positron runs averaged over all modules. The dashed line is the average temperature of all calibration runs used to extract the gain constants for CERN 2007 (right).*

In order to correct for temperature fluctuations between calibration and beam data measurements, it needs to be explained how the calibrations constants used for data reconstruction are determined.

The MIP constants are measured from a set of muon runs being recorded within a relatively short period of time (order one day). For these runs, the temperature measurements are averaged module-wise, resulting in the temperature profile shown in Fig. 1 (left) together with the corresponding profile from the 10 GeV positron run of the EM shower analysis of [2]. A substantial difference in the temperature level as well as the shape of the profile is clearly visible.

The situation for the gain constants is more diverse. They have been determined as channel by channel average over all successful measurements during the whole 2007 test-beam campaign at CERN plus additional calibration data taken at DESY after shipping back the equipment. The set of gain runs considered can vary from channel to channel depending e.g. on the availability of the LED system. The reference temperature therefore is used to be the average temperature over all gain runs used for determining the calibrations, and over the whole calorimeter. The resulting 27 °C are compared in Fig. 1 (right) to the detector-wide average temperature of the seven positron runs of the EM shower analysis of [2]. The difference is obvious, but smaller than for the MIP calibrations.

The calibration constants are scaled to match the conditions of a given beam data runs, with the temperature being averaged layer-wise for the MIP and detector-wide for the gain constants, respectively. The temperature slope averages over all channels [3] of

$$\frac{1}{A_{\mathrm{MIP}}}\frac{dA_{\mathrm{MIP}}}{dT} = -3.7\frac{\%}{\mathrm{K}} \quad \text{and} \quad \frac{1}{G}\frac{dG}{dT} = -1.7\frac{\%}{\mathrm{K}}$$

are used for MIP and gain constants, respectively.

3 Impact of Temperature Correction on Electromagnetic Shower Analysis

Fig. 2 shows the reconstructed energy of the seven positron runs of the EM shower analysis of [2] with (top) and without (bottom) temperature correction. The response distributions shown are used to analyze the energy scale, detector linearity, and intrinsic electromagnetic resolution in a similar way as described in [2].

Energy Scale

The energy scale, fitted to the three data points with 10, 15, and 20 GeV beam energy, is found to be $(42.7 \pm 2.5_{\mathrm{syst.}} \pm 0.03_{\mathrm{stat.}})$ MIP/GeV with an offset of $(2.1 \pm 7.25_{\mathrm{syst.}} \pm 0.4_{\mathrm{stat.}})$ MIP. Unlike the previous results without temperature correction [2], these values agree within errors with the Monte Carlo expectations of $(44.1 \pm 0.06_{\mathrm{stat.}})$ MIP/GeV and an offset of $(-5.8 \pm 1_{\mathrm{stat.}})$ MIP. The main effect on the energy scale originates from the correction to the MIP calibration constants.

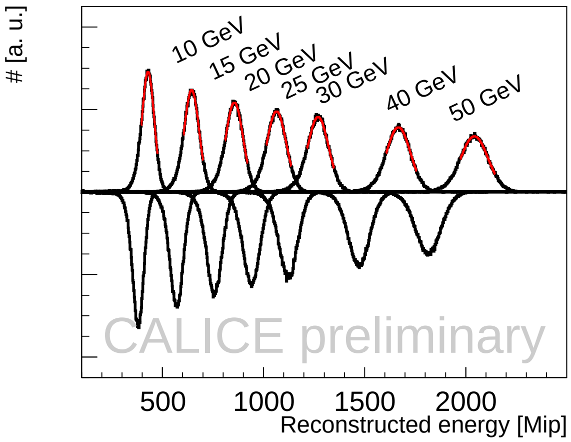

Figure 2: *Energy sum spectra of all seven energies. The upper half shows the reconstruction with additional corrections, the lower half the reconstruction without. The improvement is large since the 50 GeV reconstructed energy sum is without additional corrections lower than the 40 GeV energy sum with corrections for temperature and saturation level.*

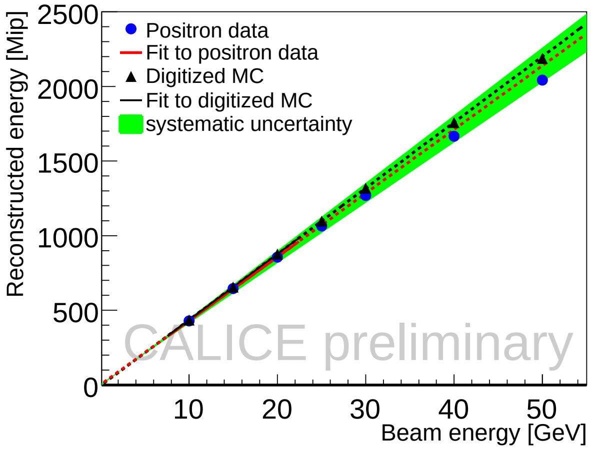

Figure 3: *Mean reconstructed energy extracted from the distributions in Fig. 2 as a function on the beam energy. The lines are results of a straight line fit, with the solid part indicating the fit range. The green band indicates variations of the fit result due to calibration uncertainties on both the MIP and saturation scales. From the straight-line fit, the energy scale is extracted as decsribed in the text.*

Linearity

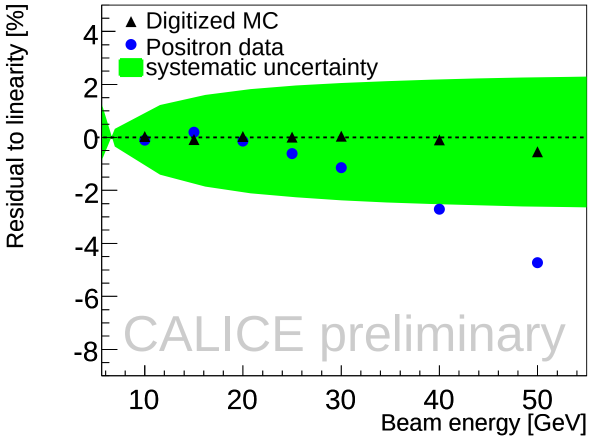

Figure 4: *Residual of data reconstructed with scaled response curves to the straight-line fit of Fig. 3. The green band indicates the influence of the calibration uncertainties on the saturation scale on the linearity hypothesis. In the residual, the effects due to MIP scale uncertainties cancel approximately and are therefore not included. The reconstructed response is linear within errors up to 30 GeV beam energy.*

The linearity of detector response to positrons however is not altered by aplying the temperature correction, as shown in Fig. 4. For particle energies larger than 30 GeV, the residual to linearity is beyond what could be explained by systematic uncertainties in data. The scale of roughly 3 (5) % at 40 (50) GeV non-linearity remains almost unchanged with respect to the reconstruction without temperature correction.
The residual to linearity is only affected by the gain calibration constants, where the temperature corrections, which are measured and temperature corrected in a much more average fashion than the MIP constants. Future investigations will have to show whether this is the reason for the absence of a similar improvement in the linearity as observed for the energy scale.

Resolution

Data is fitted with a stochastic term of $(22.5 \pm 0.4_{\mathrm{syst.}} \pm 0.1_{\mathrm{stat.}})\%/\sqrt{E}$ and a constant term of $(0 \pm 0.1_{\mathrm{syst.}} \pm 0.1_{\mathrm{stat.}})\,\%$. The stochastic term for digitized MC is $(20.4 \pm 0.2_{\mathrm{stat.}})\,\%/\sqrt{E}$ and a constant term of $(0 \pm 0.6_{\mathrm{stat.}})\,\%$.
The stochastic term of digitized MC (20.4%) lies between the one of true MC (18%) and the one of data (22.5%). The smearing effects included in the digitization improve the agreement, but are still not sufficient to explain the resolution observed in data. The digitization algorithm depends on the same input values as the reconstruction step

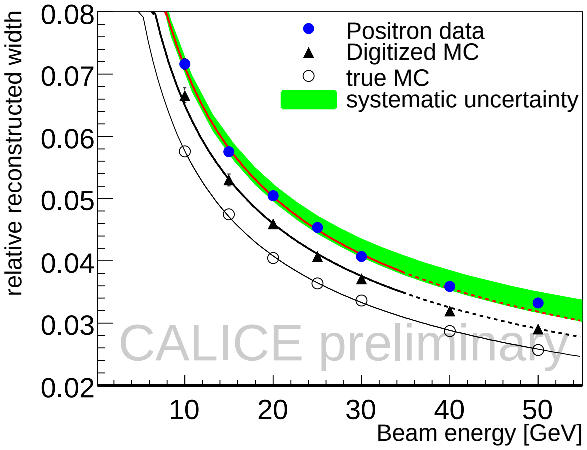

Figure 5: Resolution

(calibration constants, response curves). For the moment, identical values are used for MC digitization and reconstruction, respectively. This mimics a level of perfection, which is unreached in data.

4 Summary and Conclusions

As a next step of sophistication to the reconstruction of the AHcal prototype, constants for MIP and gain calibrations have been corrected for the difference in temperature between the runs where these constants have been measured and those data runs, where they get applied. This has positive influence on the data-simulation agreement in the electromagnetic energy scale, which for the first time could be established within errors. Linear response to positrons, clearly expected from simulations, however still could not be confirmed for beam energies above 30 GeV. Further studies are needed to find out whether a more detailed temperature determination and correction, especially in for the gain constants, can be more successful.

Acknowledgement

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References

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[3] Nils Feege, *"Silicon Photo-Multipliers: Properties and Application in a Highly Granular Calorimeter"*, Diploma thesis, 2008.