Preliminary Testbeam Results from the CALICE Tile Hadron Calorimeter

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The CALICE collaboration has constructed a testbeam hadron calorimeter based on scintillator tiles, individually read out by novel multi-pixel Geiger mode photodiodes. The purpose is to establish the technology and to record hadron shower data with unprecedented granularity for the validation of simulation models and the development of clustering algorithms. First testbeam results of the partially instrumented calorimeter from electron and pion beams at CERN are presented, the latter taken together with an electromagnetic calorimeter in front and a tail-catcher and muon-tracker behind.

1 Introduction

The CALICE collaboration has constructed a physics prototype hadronic tile calorimeter (HCAL), a 38-layer plastic-scintillator/steel sandwich structure with a lateral dimension of about $1\,\mathrm{m}^2$ and a total depth of $4.5\,\lambda$. The scintillator is segmented in tiles between 3×3 and $12 \times 12\,\mathrm{cm}^2$ in size. The 216 tiles of one layer are mechanically mounted inside a cassette with side-lying readout electronics, which are inserted into the mechanically independent stack of absorber plates. For calibration and monitoring, each HCAL module is equipped with a versatile LED system allowing to inject controlled light signals to each individual tile. A wavelength-shifting fiber inside a groove collects and converts the UV scintillation light of one tile and guides it to one green sensitive Silicon Photo-Multiplier (SiPM) [2].

SiPM are multi-pixel Geiger mode photodiodes with 1156 pixels on $1 \times 1\,\mathrm{mm}^2$ sensitive area. Each pixel has a resistor of few $\mathrm{M}\Omega$ for passive quenching of the Geiger avalanche initiated by electron-hole-pairs in the depleted region of the silicon. The gain reached is of order 10^6 despite the relatively low operation voltage below 100 V. The resulting dead-time in conjunction with the readout gate lead to non-linear behavior at high signal amplitudes.

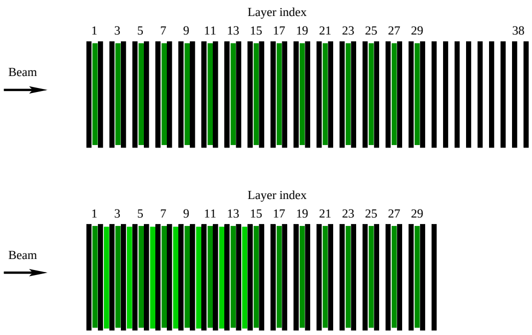

Figure 1: Configuration of active HCAL modules and absorber plates in August/September 2006 (top) and October 2006 (bottom), respectively.

The HCAL with an initial instrumentation of 15 (23) active modules distributed over 29 layers of the absorber stack as illustrated in Fig. 1 has been installed at the CERN SPS testbeam area and took data from electron, muon, and pion beams during two periods in summer 2006. Data has been taken stand-alone as well as together with an electromagnetic calorimeter (ECAL) upstream and a tail-catcher and muon-tracker (TCMT) downstream of the HCAL. The ECAL is a silicon-tungsten sampling calorimeter, and the TCMT is also a scintillator/steel sampling detector based on SiPM readout. All three calorimeters with more than 10,000 channels use the same data acquisition, which also includes scintillator triggers, a threshold Cerenkov counter and three multi-wire proportional chambers as further beam instrumentation.

In the following, the calibration and reconstruction strategies [3] of the HCAL are introduced. The response of the detector to electrons is analyzed from data recorded with 15 active HCAL modules and no ECAL in front in order to validate the reconstruction procedure by means of well understood electromagnetic showers. A preliminary analysis of pion data recorded with 23 active HCAL layers together with both ECAL and TCMT is also presented.

2 Calibration and reconstruction

By convention, equalization and energy calibration of all channels is achieved by the most probable energy deposition of a minimum ionizing particle crossing the tile at normal incidence, the so-called MIP scale. This scale is available in data as well as in simulations and has been measured using muons behind a closed beam dump during parasitic running to another upstream experiment. The muon beam was wide enough to cover the whole HCAL front face and has been triggered with two $1 \times 1\,\mathrm{m}^2$ scintillator plates firing in coincidence. Besides calibration, the MIP scale is also used for zero-suppression by rejecting amplitudes below 0.5 MIP.

Non-linearity of SiPMs is an effect scaling with the number of pixels firing. Any correction therefore depends on the possibility to translate a given amplitude to the pixel scale. Low light intensities from the LED system and a special high-amplification mode of the readout electronics allow the separation of single photon signals, the so-called gain calibration. Beam data is taken with lower amplification of the readout electronics for a larger dynamic range. A second measurement with the medium LED intensities therefore is needed to relate the response to identical signals with the two different electronics modes, the so-called electronics inter-calibration. Two different approaches for non-linearity correction are used: an analytic method assumes binomial saturation correction, while a more complex method involves the saturation curve measured with a calibrated light source before mounting each SiPM on its tile [4].

The number of pixels firing at an amplitude equivalent to one MIP is referred to as lightyield and is an important figure-of-merit for the HCAL. This value can directly be determined as ratio of the three calibration constants. Channels with a small lightyield are characterized by large statistical fluctuations of the amplitude (which is always an integer number of pixels) and yield larger noise contributions above 0.5 MIP, while channels with large lightyield exhibit a stronger non-linear behavior and are limited in their dynamic range. It is therefore desirable to operate the calorimeter at an average lightyield close to the design value of 15 pixels/MIP. This goal has not quite been matched for the first 2006 data taking period, but could be corrected for the second period by raising the bias voltage.

3 Response to electrons

High energetic electromagnetic showers are in contrast to hadron showers very well understood and are therefore best suited to assure full understanding of the detector response. In case of the tile HCAL, they in addition mark a special benchmark scenario, since they are much more compact than hadron showers, lead to higher hit amplitudes, and consecutively end up at higher levels of non-linearity to be corrected for. For 123 out of 3240 channels from 15 active modules, one or more calibration constants could not be extracted. Although some of these channels can be calibrated in principle, all of them are excluded for this analysis.

The amplitude measured in each channel is reconstructed to the MIP level, amplitudes below 0.5 MIP are removed from the event. For all others, non-linearity is corrected using the channel-dependent saturation measurements.

The reconstructed energy sum after this steps is shown in Fig. 2 (top) for various electron beam energies. The mean response is extracted from Gaussian fits to the core of the distributions and subtracted by the mean energy in random trigger events (noise) of the same run. The energy scale is fixed by the difference in response between the 10 GeV and 20 GeV beam, which minimizes the impact of noise contributions.

The comparison between beam and reconstructed energy is shown in Fig. 2 (bottom). The green band indicates the uncertainty region from the calibration measurements, and the blue line corresponds to digitized simulations including various experimental effects: realistic geometry and material budget of beam instrumentation and HCAL, sensitivity holes due to excluded cells, leakage of scintillation light to neighboring cells, SiPM saturation, pixel statistics, electronic noise, and SiPM dark current. Inhomogeneities due to varying SiPM properties (lightyield, saturation behavior, noise and dark current) are taken into account as well, based on the calibration measurements described above.

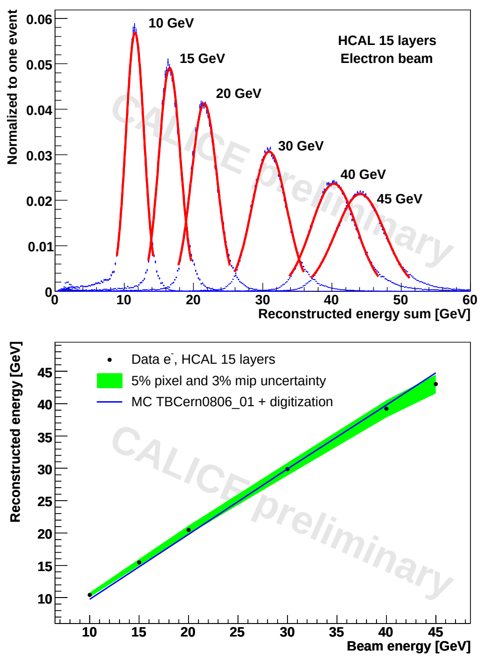

Figure 2: Reconstructed energy sum (top) and the correlation between reconstructed and beam energy (bottom) for electron beams between 10 and 45 GeV.

Expectations from simulations show perfect linearity, which is expected since identical functions have been used for simulation and correction of SiPM saturation. Non-linearity of order 5 % is observed in data for the highest shower energies, but remains smaller than the calibration uncertainties up to 30 GeV beam energy. The excess of reconstructed energy in data w.r.t. simulations have been found to be due to coherent noise, which has not been simulated. For the second data taking period, coherent noise could be reduced to uncritical level by modifications of the readout electronics.

4 Response to pions

Pion showers from beam energies between 6 and 20 GeV are studied using combined data taken with the ECAL, the HCAL (with 23 layers, see bottom of Fig. 1) , and the TCMT.

The ECAL is used as a pre-shower veto in order to discard showers which started before the HCAL, and the TCMT is used to identify those showers fully contained in the HCAL.

Calibration and reconstruction is done similar to the analysis of electron showers described before, only that the energy scale is fixed from the 10 GeV beam alone and that the analytic ansatz for saturation correction is used. An obvious effect of leakage into the TCMT is observed as shown in Fig. 3 (top). The bottom part of the same figure illustrates that linearity between beam and reconstructed energy is observed. For illustrative purposes, equivalent curves for two shower simulations based on GEANT3 without digitization are shown as well. Good level of agreement with data is only achieved if the energy scaling factor from the MIP to the GeV scale is determined independently for each of the three curves.

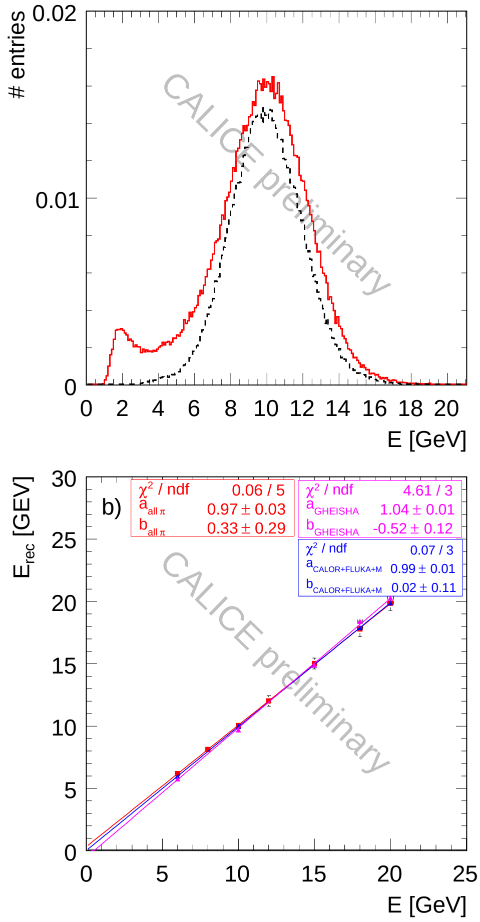

Figure 3: Top: Reconstructed energy for all showers starting after the ECAL (solid) and those which in addition are contained in the HCAL (dashed) from 10 GeV π^-. Bottom: Correlation between reconstructed and beam energy for π^- beams between 6 and 20 GeV for data and two different shower simulations.

5 Outlook

The CALICE testbeam program successfully continued in summer 2007 with the same subsystems as presented. The HCAL was fully equipped with 38 active modules and was positioned together with the ECAL on a movable stage allowing for horizontal, vertical, and angular scans. The analysis of this data set is ongoing and will give a much more comprehensive picture of the capabilities of the CALICE tile calorimeter than this initial analysis of data taken with the partially instrumented detector.

References

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