Tile HCAL Test Beam Analysis: Positron and Hadron Studies

Riccardo Fabbri
on behalf of the CALICE Collaboration
FLC, DESY, Notkestrasse 85, 22607 Hamburg, Germany
E-mail: Riccardo.Fabbri@desy.de

The CALICE collaboration has constructed a hadronic sandwich calorimeter prototype with 7608 scintillating plates, individually read out by multi-pixel silicon photomultipliers (SiPMs). For the first time ever the read out is performed using SiPMs on a large scale. Results of test beam operations with muon, positron and hadron beams at CERN are presented here, validating the feasibility of the novel SiPM technology. Results of the application of the particle flow approach in shower energy reconstruction are presented for the first time ever using real data.

1 Introduction

The CALICE collaboration is performing calorimeter development aiming to fulfill the hardware and physics demands of the International Linear Collider physics program [1]. The ambitious required jet energy precision ($\approx \frac{0.3}{\sqrt{E(\text{GeV})}}$) could be achieved with extremely segmented calorimeters using the particle flow approach (PFLOW) [1].

The CALICE tile hadron calorimeter prototype (HCAL) is a 38 layer sampling calorimeter with 1 m$^2$ lateral dimension, and total thickness of 5 nuclear interaction lengths. Each layer consists of 2 cm thick steel absorber and a plane of 0.5 cm thick plastic scintillator tiles. The tile sizes vary from 3x3 cm$^2$ in the center of the layer, to 6x6 cm$^2$ and 12x12 cm$^2$ in the outer regions. Each tile is coupled to a SiPM via a wavelength shifting fiber.

Together with the CALICE silicon-tungsten electromagnetic calorimeter (ECAL) and the CALICE tail-catcher and muon tracker (TCMT), the HCAL was exposed to muon, positron and hadron beams at the H6 test beam line at CERN in 2006 (partially instrumented with 23 layers) and 2007 (fully instrumented with 38 layers, 7608 scintillating plates). The results of the CERN data analysis are presented here.

2 Calorimeter calibration

The SiPM is a multi-pixel avalanche photodiode which provides a signal gain factor of $\approx 10^6$. The gain of each SiPM is monitored via dedicated measurements during test beam data taking, illuminating the device with low intensity LED light [2]. During the extensive test beam operations at CERN a gain calibration efficiency of $\approx 97\%$ was observed, confirming the stable and high performance of SiPMs in a large scale calorimeter.

The energy deposited by a particle in the scintillating plate is read by the SiPM, and converted into ADC units. The energy calibration was performed measuring the response to the passage of minimum ionising particles (mip), using muons as mips [2]. The muon signal deposited in a tile was fitted with a Gaussian convoluted with a Landau distribution, and the most probable value of the distribution was assumed to be one MIP unit, corresponding to 0.861 MeV, as obtained by Monte Carlo simulations [2]. The systematical uncertainty on the energy calibration due to the intrinsic short-term operational variations of the detector

LCWS/ILC 2008
properties was found to be $\approx 3\%$. In the analysis, the rejection of hits with energy below 0.5 MIP results in a mip hit detection efficiency of about 93% [2].

Due to the limited number of pixels and to the finite pixel recovery time ($> 100$ ns), SiPMs are non-linear devices. The reconstructed energy is corrected for non-linearity effects using response curves, measured individually for every SiPM [2]. SiPMs are temperature dependent devices. Therefore, a temperature monitoring system was implemented to measure and correct for the single pixel gain, Fig. 1, and for the mip amplitude temperature dependence. The slope of the temperature dependence of the gain $G$ and of the mip amplitude $A$, averaged over all channels, was found to be $\frac{1}{T} \frac{dG}{dT} = -1.75 \%$ and $\frac{1}{A} \frac{dA}{dT} = -3.75 \%$ [2], respectively.

3 Analysis of positron data

Being the description of underlying physics reasonably understood, Monte Carlo (MC) simulation of electromagnetic showers in the detector can be compared to the data to validate the calibration procedure, and to validate the detector effects introduced in the Monte Carlo simulation (digitisation). The data shown here have been collected during 2007.

After applying all the calibrations described above, the detector response to electromagnetic showers is measured at different beam energy values. The residuals to the linear fit to the data is shown in the left panel of Fig. 2. Within both statistical and systematical uncertainties, the reconstructed response is linear up to 30 GeV beam energy. Superimposed to the data, is also shown the MC prediction. The energy resolution is shown in the right panel of Fig. 2 and compared with simulations with and without the inclusion of detector effects. The smearing effects included in the simulation improve the agreement, although the data have still systematically larger values than what predicted by the simulations. This can be possibly understood considering that not all the calibration uncertainties have been included in the MC yet. Their inclusion should result in larger values of the simulated resolution.

4 Analysis of hadron data

The understanding of electromagnetic showers in the HCAL was shown to be reasonably enough for a preliminary analysis of hadronic showers. The high granularity of the HCAL calorimeter allows the investigation of the longitudinal and lateral shower profiles with unprecedented precision. Different Monte Carlo physics model lists are available [3], and provide
Figure 2: Residuals to the linear fit performed to the detector response to electromagnetic showers (left panel), and energy resolution to electromagnetic showers (right panel) are shown for both the data and MC. The largest contribution to the systematical uncertainty is given by the calibration uncertainties on both the MIP energy determination and the non-linearity effects correction.

different predictions for the hadronic shower development, which can be constrained, in principle, by the precise results of the HCAL. As a first comparison, simulations are presented considering only the physics model lists which show the largest discrepancy among the investigated models, i.e., QGSP_BERT and LHEP. The results shown here were obtained using the above mentioned calibration procedures, and the latest MC digitisation.

The energy resolution of the response to pion beams is shown in the left panel of Fig. 3.

Figure 3: Left panel: The energy resolution to hadron-induced showers is shown for both the data and MC using the physics model lists QGSP_BERT and LHEP, open squares and triangles, respectively. The combined HCAL and TCMT 2006 CERN data were used here. Right panel: The exponential depth distribution of the first nuclear interaction in showers is measured versus the nuclear interaction length for 8 GeV $\pi^-$ mesons, and compared with MC simulations using the physics model list LHEP. The data shown here were collected in 2007, combining the information from both the HCAL and TCMT devices rotated at 30° with respect to the beam. The ECAL was displaced from the beam line.

LCWS/ILC 2008
and compared to MC simulations, with the Birks’ law included [3]. Being the positron data analysis not fully understood yet, models cannot be constrained at this stage of the analysis.

The fluctuations in hadronic showers development are larger than what is observed in electromagnetic showers. The high longitudinal granularity of the HCAL allows the investigation of shower profiles with respect to the shower starting point. An exponential fit to the depth distribution of the first interaction in showers as a function of the distance $z$ (in nuclear interaction length $\lambda_I$ units) from the start of the calorimeter was performed, and the interaction length for $\pi^-$ mesons was extracted [2], right panel of Fig. 3. Comparing the reconstructed shower energy with the corresponding known impinging beam energy, the leakage effects in the HCAL could be measured with respect to the shower start location in the calorimeter, and corrected for [2], left panel of Fig. 4.

The full investigation of the PFLOW approach requires also neutral test-beam data, at the moment not present in the accumulated data sets. Nevertheless, the proof-of-principle of the method can be investigated merging data for hadron showers induced by pions at two different beam energies, thus simulating events with multiple showers. Showers were then reconstructed, and, for the first time using real data [2], the energy sum of the respective obtained two clusters was compared with the reconstructed energy sum obtained fixing, in a PFLOW like approach, one shower energy to the corresponding known beam energy (in a real experiment provided by the tracking system), right panel of Fig. 4. Using data with larger shower separation is expected to improve the energy resolution obtained using the PFLOW approach.

References

[1] J. Brau et al., International Linear Collider Reference Design Report, ILC-REPORT-2007-001 (2007).
[2] N. Wattimena, DESY-THESIS-2006-039; N. Feege, DESY-THESIS-2008-050; CALICE Collaboration, CAN-009 (2007); CALICE Collaboration, CAN-010 (2007); CALICE Collaboration, CAN-011 (2007).
[3] J. Apostolakis et al., CERN-LCGAPP-2007-02; J. B. Birks, Proc. Phys. Soc. A64, 874 (1951).