Test Beam Performance of CALICE Electromagnetic Calorimeter Physics Prototypes

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The CALICE collaboration develops calorimeter technology for future linear collider detectors, in particular for the Particle Flow approach to jet energy measurement. Two Electromagnetic calorimeter prototypes have been constructed and tested in test beams. Both are sampling calorimeters with Tungsten absorbers, and differ in their choice of active materiel. One is based on Silicon detectors with readout pads of size $1 \times 1cm^2$, while the other is based on $1 \times 4.5cm^2$ scintillator strips individually read out by MPPC devices. This paper reports on their performance in test beams, presenting the linearity and resolution of their energy response.

1 Introduction

A Linear Collider is widely proposed as the next accelerator to study the high energy frontier of particle physics at the TeV scale. The final state of many interesting physics processes will consist of one or more massive bosons. A particular challenge is the identification of hadronic W and Z boson decays, which requires an improvement of jet energy resolution by at least a factor of two with respect to current detectors.

A promising technique to achieve this is the so-called “Particle Flow” approach [1], which relies on the fact that around 65% of a jet’s energy is in charged particles, around 25% in photons, and the remaining 10% in neutral hadrons. Particle Flow requires the topological separation of individual particles’ calorimeter energy deposits, which allows the tracking system to be used to measure the charged energy, and the calorimeters to measure the neutral components. This topological separation requires a very highly granular calorimeter.

These considerations have led to the design, construction and testing of two EM calorimeter prototypes, both studied within the CALICE collaboration. Both are sampling calorimeters using Tungsten absorber due to its small Moliere radius, short radiation length, and relatively long hadronic interaction length. The two designs differ in the choice of technology for the active layers. One is based on Silicon sensors segmented into $10 \times 10\text{mm}^2$ readout pads (SiECAL), while the other uses $10 \times 45\text{mm}^2$ strips of plastic scintillator, individually read out by MPPC devices (ScECAL).

The ECAL prototypes were tested in various particle beams at DESY, CERN and FNAL. The detectors were exposed to beams of muons (largely for calibration purposes), electrons and positrons, and charged pions and protons, in the momentum range 1–180 GeV/c.

2 Silicon-Tungsten EM calorimeter

The Silicon-Tungsten prototype [2] has active sensors made of 525 micron thick high resistivity Si, segmented into $10 \times 10\text{mm}^2$ PIN diodes, fully depleted by a 200V bias voltage. 6 sensors are glued onto a PCB which channels signals to the very front end electronics. Two such PCBs are mounted on either side of a carbon-fibre composite structure, which also incorporates a layer of Tungsten. These slabs are then slid into an alveolar structure, constructed of carbon-fibre composite and additional Tungsten absorber layers. The first ten absorber layers are 1.4 mm thick (corresponding to 0.4 X_0), the next ten are at 2.8 mm, and the last ten have a thickness of 4.2 mm. In total, the calorimeter has a thickness of 20 cm/24 X_0, an active area of $18 \times 18\text{cm}^2$, and a total of around 10k readout channels.

The detector was calibrated using muon beams. These calibrations were very stable over the three year data taking period. The linearity and resolution of the detector's energy response to electrons and positrons was measured. Any non-linearity was shown to be at a level smaller than 1% in the energy range 1–45 GeV, and the energy resolution can be parameterised as $\sigma_E/E = 16.5/\sqrt{E} \oplus 1.1\%$, as shown in fig 2. A Geant4-based MOKKA [3] simulation of this ECAL prototype has been developed, and accurately describes the performance measured in the testbeam.

3 Scintillator-Tungsten EM calorimeter

This detector is based on 3.5 mm Tungsten absorber layers with active layers consisting of $45 \times$ 10 $times$3mm^3 plastic scintillator strips [4]. The strips' orientation is alternated in successive layers. A Multi Pixel Photon Counting device (MPPC) [5] is placed at the end of each strip to measures the scintillation light. This device is very compact, insensitive to magnetic fields, inexpensive, and has excellent gain and quantum efficiency characteristics. The MPPC is coupled to the scintillator either directly or by means of a wavelength-shifting fibre (WLSF) running along the centre of the scintillator strip.

Two prototypes of such an ECAL have been constructed. The first small prototype had 26 layers with an active area of $9 \times 9\text{cm}^2$, and was used to test various types of scintillator and

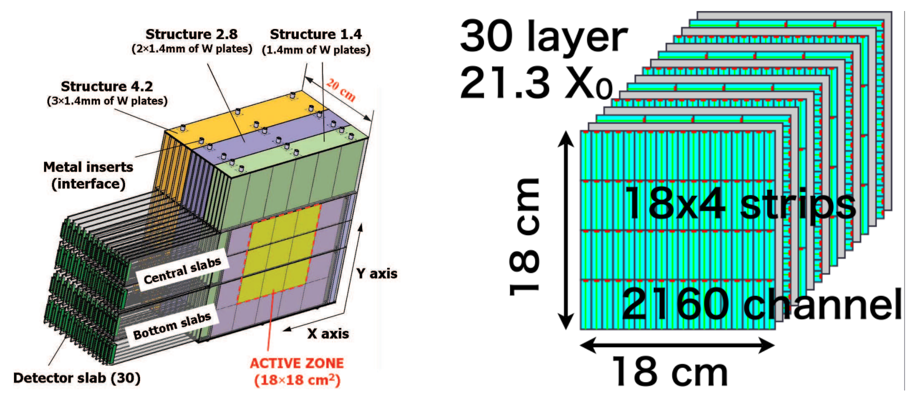

Figure 1: Structure of Silicon (left) and Scintillator-based (right) ECAL prototypes.

WLSF configurations, as well as gaining experience operating a large number of MPPCs. The second, larger, prototype consisted of 30 layers with active area $18 \times 18\text{cm}^2$, allowing the full containment of electromagnetic showers. Extruded scintillator strips with WLSF readout were used. This prototype was exposed to beams with a wider energy range and of different particle types. The collected data are being analysed. Figure 2 shows the energy response to electrons of different energies. By placing an iron target a few metres upstream of the calorimeter, tests of neutral pion reconstruction were also performed.

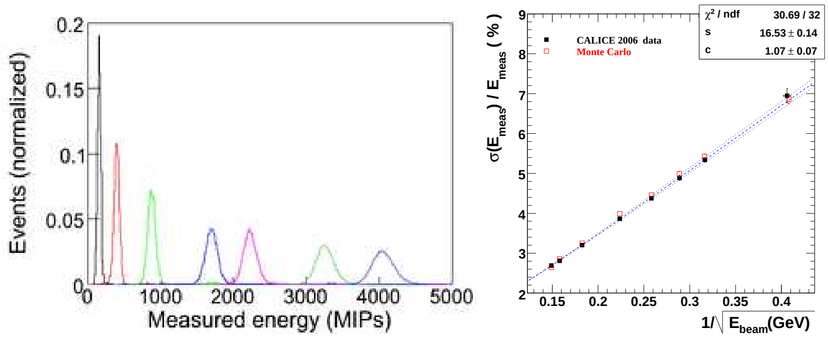

Figure 2: Response to electrons of ScECAL (left), and energy resolution of SiECAL (right)

4 Conclusions

The CALICE collaboration develops calorimetry for ILC detectors, based on the Particle Flow paradigm. This requires an ECAL with high granularity and excellent separation of hadronic and EM showers. Several different technological approaches have been proposed. Here we report on one based on Silicon active layers and a second based on scintillator strips read out by MPPCs. Prototype detectors of both types have been made, and exposed to a wide variety of particle beams in an intense test beam program. These data show that both technologies have sufficiently good energy resolution and linearity to meet the requirements for a LC ECAL. The results found are in good agreement with the results of detailed simulations.

References

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