The Next Generation Scintillator-based Electromagnetic Calorimeter Prototype and Beam Test

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Abstract

We are studying next generation scintillation detectors for future collider experiments. For precise energy measurement of energetic jets in future experiments, particle flow algorithm with fine granular scintillator strip calorimeter will play an important role. To establish the technology of the calorimeter, we are studying the properties of small plastic scintillator strips with size of (10-5) x 50 x 3 mm, which is a fundamental component of the calorimeter. As a part of this R&D study, small extruded plastic Scintillator of size 10 x 45 x 3 mm and a tungsten plate with 3.5 mm thick are sampled together to Fabricate a Scintillator base electromagnetic calorimeter prototype. Prototype has a stack of 30 layers, having dimension of 20 x 20 cm. Fine Scintillator strips in successive layers aligned in orthogonal to achieve effective 1 x 1 cm segmentation. The total number of channels is 2160 for readout. scintillation light produced in plastic Scintillator strips enters the wavelength shifting (WLS) fiber placed inside the plastic Scintillator are guided to the sensitive photo detector 1600 pixel MPPC (Multi Pixel Photon Counter) with a sensitive region of 1 x 1 mm². The electromagnetic calorimeter performance has been studied with test beam during summer 2008 and 2009 at Fermilab. We have injected 1-30 GeV electron and 60 GeV Pion beams and measured energy resolution and linearity of response toward input energy. In this presentation we will present obtained performance of the calorimeter prototype.

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Keywords: ILC; Electromagnetic calorimeter; Granularity; Scintillator; MPPC;

1. Introduction

The International Linear Collider (ILC) is a future e⁺e⁻ collider experiment that operates with a centre-of-mass energy 220-1000 GeV. The main goals of the ILC are the precise measurement of the Higgs boson and SUSY particles as well as precise tests of the Standard Model using W, Z bosons and the top
quark. Since these important physics processes will decay predominantly to multi-jet final states, the utmost target of the detector performance is the jet energy resolution. The goal of the jet energy resolution is set to $\Delta E/E \sim 30%/\sqrt{E}$ [1]. The Particle Flow Algorithm (PFA) is adapted to achieve this jet energy resolution [2]. In the PFA approach every particle in the final state is reconstructed.

Each individual particle in a jet is separated into charged or neutral particle, and measure the jet energy by combining momentum of charged particles measured by tracker and energy of neutral particles by the calorimeter. In order to realize the PFA, the main aim of the calorimeter at the ILC is to separate and identify each particle in a jet with fine segmentation. To achieve such fine granularity with a sandwich-type sampling calorimeter, the design of ScECAL consists of 3 mm thick tungsten layers as absorber and Scintillator strip layers as shown in Figure 1. Size of individual Scintillator strip is 1 x 4.5 cm with thickness of 2 mm. The Scintillator strips are orthogonal in successive layers to achieve effective 1x1 cm cell size. Signal from each individual strip is read by a novel type semiconductor photo-sensor, called Multi Pixel Photon Counter (MPPC) [3]. The MPPC is attached at the end of each Scintillator strip. In this Proceeding we report on development of the Scintillator strip electromagnetic calorimeter (ScECAL) prototype which is one of the on-going activities in the CALICE collaboration [4].

2. The Scintillator Strip Calorimeter Prototype

An electromagnetic calorimeter test module with an extruded Scintillator-strip structure has been constructed and tested. Figure 2 shows the structure and picture of the ECAL prototype fabricated.

The module consists of 30 pairs of Scintillator and Tungsten as absorber layers of thickness 3 and 3.5 mm respectively. The size of each extruded Scintillator strip is 10 mm x 45 mm x 3 mm. As shown in Figure 3, each Scintillator strip is totally wrapped by a reflector film produced by Kimoto Co. to optically isolate them from each other and to increase amount of light conducted by the MPPC. The scintillation light produced in plastic Scintillator strips enter the wavelength shifting (WLS) fiber placed into the center hole of plastic Scintillator which are guided to the sensitive photo detector 1600 pixel MPPC (Multi Pixel Photon Counter) with a sensitive region of 1 x 1 mm$^2$. In order to get the best performance, great care should be taken in exact matching of the position of WLS fiber to the surface of photon sensor. The flat cable is used as a bridge for directing the signal from MPPC to the readout electronic baseboard.
Each active layer is a matrix of 72 Scintillator strips. In successive alternate layers Scintillator strips are orthogonal to achieve 1 cm granularity both in two perpendicular (X and Y) directions. Overall size of the ScECAL is 18 cm × 18 cm × 20 cm with a total length equivalent to 21 radiation lengths (21X₀).

3. Beam test at Fermilab and Preliminary Results

The ScECAL beam tests were performed in September 2008 and May 2009 at the Fermilab meson test beam line (MT6 section B). These tests were carried out with a combined system of ScECAL, followed by a hadronic calorimeter (AHCAL) [5] and then a Tail catcher (TCMT) [6], the latter two both built from a Scintillator-iron sandwich structure as shown in Figure 4(right). One of the main goal of the beam test is to establish the Scintillator-based ECAL technology by evaluating the performance of the ScECAL prototype.

The layout of the CALICE calorimeters in the test beam line is shown schematically in figure 4(left). Upstream of the calorimeters there are four layers of drift chambers for beam position measurement. Signal from 10×10 cm or 20×20 cm trigger Scintillators are used for data taking trigger. We have used electron, charged pion and muon beams with energy range of 1-32 GeV.

This fine granular structure allows for identification of tracks generated by Minimum Ionizing Particle (MIP) passing through the detector. This capability is an excellent tool for detector calibration. The data analysis has been started by the calibration of the strip response using MIP signal by muon beam. Therefore the measured energy is expressed in unit of MIP equivalent. After the calibration, energy measurement of the electron beam with various energies has been done. The energy spectra of electrons measured by the ScECAL are displayed in Figure 5.

Fig. 4. (left) Schematic view of beamline setup. (right) Detector side view showing ScECAL+AHCAL+TCMT

Fig. 5. Preliminary results of the energy resolution and linearity are shown in Figures 6(left) & 6(right) respectively. Detailed analyses to evaluate energy resolution and linearity response are currently underway.
The data points are fitted with a formula
\[ \frac{\sigma_E}{E} = \sqrt{\frac{\sigma_{\text{stat}}^2}{E^2} + \sigma_{\text{const}}^2} \]
where \( \sigma_{\text{stat}} \) and \( \sigma_{\text{const}} \) denote stochastic and constant terms of the energy resolution, respectively. As a result of the fit, we obtain \( \sigma_{\text{stochastic}} = 15.15 \pm 0.03\% \) and \( \sigma_{\text{constant}} = 1.44 \pm 0.02\% \) (errors are statistical only) which are reasonably good for a preliminary result [7].

4. First look into beam test 2009 data

One of the differences between the two beam tests in May 2009 and September 2008 is a temperature system. The beam test in September 2008, the temperature data could not recorded properly due to a problem in temperature sensor. An air conditioner were used to keep the temperature constant of the experimental hall as much as possible, however during the beam test a malfunction was observed in the air conditioning system which gives a temperature shift in the early few days of beam test as shown in the figure 1. After repairing the air conditioner the average calorimeter temperature decreases from 27°C to 22°C. This shows a clear change of temperature prior to May 6 as separated with a blue line in figure 1, the observed temperature variation is about 5°C over the full data acquisition period.

5. MIP Calibration and Energy Spectra

At first response calibration among individual strips is done using 32 GeV muon beam which passes through the detectors as MIPs with constant amount of energy deposition. A typical MIP event display on the ScECAL is shown in Figure 4 (left). To select the MIP events with a target strip on X (Y) layer, we require that the strips in the same strip position on the other X (Y) have more than 10 hits.
Fig. 7. An event display (left) and the ADC distribution (right) of a typical MIP events after the MIP event selection.

On each channel the MIP response is obtained as corresponding charge in ADC counts between the pedestal peak and the most probable value (MPV) of the distribution of MIP events. The MPV of MIP signal is measured as a fitting result with the Landau function convoluted with the Gaussian function. The distribution of MIP constants of 2160 channels is shown in Figure 4(right). The averaged MIP constant of 2160 channels is 176.0 ADC counts. The MIP calibration constant is used for the response calibration of the ScECAL.

Fig. 8. Energy spectra of electrons measured on the ScECAL

After calibrating all the channels, measured energy spectra with clear Gaussian shape are obtained. Those spectra are shown in Figure 8 for various beam momenta. Although electron events are taken with Čerenkov counters trigger, the electron data are still contaminated by Pion and muon events. The beam test shows feasibility of the ScECAL as the fine granular calorimeter. More detail and comprehensive analysis results following the CALICE note [7] will be presented in near future.

6. Summary

We have built the ScECAL second prototype and performed a beam test combined with the AHCAL + TCMT system using $e^-$, $\pi^-$ and $\mu^-$ beams. In energy range of 1-32 GeV & have observed a clean electron energy spectra measured with the ScECAL. Although the entire datasets are still extensively being analyzed, the preliminary results demonstrate a basic concept of a proposed ScECAL design. The beam test also provides us an invaluable experience in operation of the detector, electronics and various monitoring system.
Acknowledgements

The author would like to thank to Misung Chemical Co., Daegu, Korea, for producing Scintillator strips with a good quality. This work has been carried out with the support of the World Class University project (WCU) by Korea National Research Foundation. Many people contribute to this project. In particular, I’d like to express special thanks to Fermilab accelerator staffs to provide a good quality of beam. This work is also supported in part by the Creative Scientific Research Grants No.~18GS0202 of the Japan Society for Promotion of Science (JSPS).

References

[7] CALICE Analysis Note 016
“First Stage Analysis of the Energy Response and Resolution of the Scintillator ECAL in the Beam Test at FNAL, 2008”