European Calorimeter Activities and Plans

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The Calice collaboration is assembling a prototype calorimeter composed of an electromagnetic calorimeter, a hadronic calorimeter and a tail catcher. The calorimeter will be tested in particular in a hadron test beam in 2006-07. The goals of the project are to demonstrate the feasibility of a highly granular calorimeter optimised for the use at the International Linear Collider (ILC), and to deliver data to tune the hadronic models of the simulation GEANT4.
One third of the silicon-tungsten electromagnetic calorimeter has been assembled and tested with cosmic muons and with electrons of 1 to 6 GeV in the test-beam at DESY. Some preliminary results are shown.

1. INTRODUCTION

In order to fulfil the physics goals of the International Linear Collider (ILC), a highly granular and dense calorimeter is needed [1]. Concepts for the electromagnetic and hadronic calorimeter have been studied intensively with the GEANT4 simulation. It turned out that the various hadronic models predict results which may differ by as much as 60% [2].

The Calice collaboration is constructing a prototype calorimeter to demonstrate the feasibility of a highly granular calorimeter and to deliver data to tune the hadronic models of the GEANT4 simulation. The prototype will be composed of an electromagnetic calorimeter, a hadronic calorimeter and a tail catcher. The electromagnetic calorimeter will be a silicon-tungsten calorimeter with 30 sensitive layers with a granularity of $1 \times 1\,\mathrm{cm}^2$ [3] with a total radiation length will be $24\mathrm{X}_0$. There are two options planned for the hadronic calorimeter [4]. One will have an analog read-out and the other one will have a digital read-out but will feature much finer granularity. Both options will use stainless steel plates as absorber. The analog calorimeter will use scintillating fibres contained in tiles of $3 \times 3\,\mathrm{cm}^2$ to $9 \times 9\,\mathrm{cm}^2$. The digital calorimeter will use RPCs with a pad size of $1 \times 1\,\mathrm{cm}^2$. The tail catcher will be made of stainless steel plates interleaved with scintillators [5].

Ten layers of the electromagnetic calorimeter were assembled by December 2004 and were tested first for 15 days with cosmic muons, then with electrons between 1 and 6 GeV in the DESY test beam. The preliminary results are discussed in the following section.

2. FIRST RESULTS WITH 10 LAYERS OF THE CALICE ECAL PROTOTYPE

2.1. Test with Cosmic Muons

Ten layers of the detector were assembled by December 2004, with a total radiation length of $\sim 4\mathrm{X}_0$. Each layer was equipped with the central PCB which hosts 3×2 silicon wafers of $6.2 \times 6.2\,\mathrm{cm}^2$ with 6×6 pads. The lower PCB which will host 3 additional wafers was still missing. A first test was performed with cosmic muons. The detector and the data acquisition were running without interruption for 15 days. Roughly 1 million events were collected.

The data acquisition was triggered with scintillator strips of 5 cm width. The scintillators were arranged above and below the detector, parallel to the x and to the y directions (the z-axis is oriented perpendicular to the detector layers), covering a region slightly larger than the detector. For triggered events, the amplified signals from all pads of the silicon wafers were digitised with 16bit resolution and stored [6].

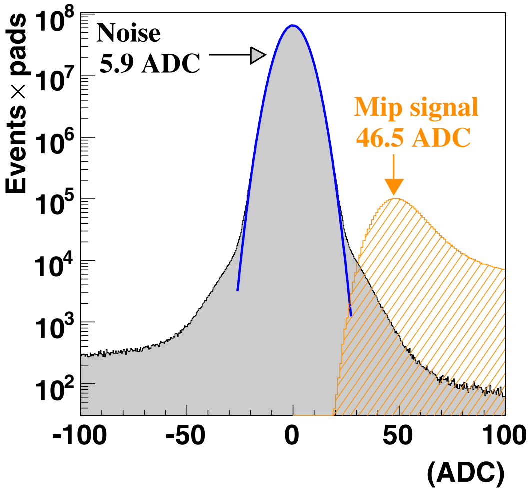

Figure 1: The distribution of the noise and the signal of all pads of the ten layer Calice ECAL prototype. The Distributions are obtained from ~ 1 million events with cosmic muons.

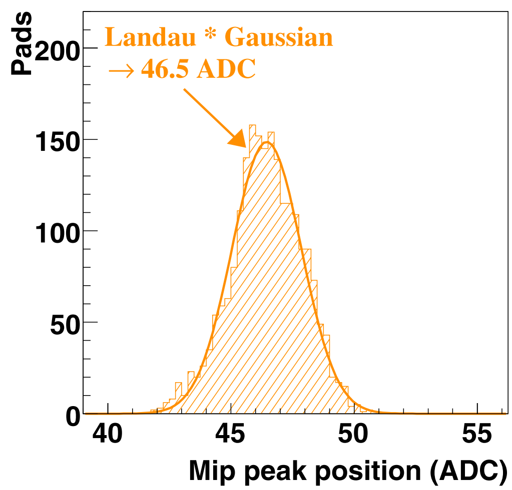

Figure 2: The most probable value of the Landau distribution determined for each pad. A Landau folded with a Gaussian is fitted to the signal distribution of cosmic muons for each separately.

All pads with a signal-over-noise ratio ≥ 5 are considered to be hits, where the signal is the measured value minus the pedestal. The pedestals and the noise are calculated per pad from the same data set. To determine initial pedestal and noise values for all the pads, all signals are considered to be noise for the first 20 events. The mean and rms values are considered to be the pedestals and the noise. Since, the events contain a small hit fraction the noise and the pedestals are biased to slightly larger values. From then on, the noise and the pedestals are slowly adjusted, where the knowledge of the pedestals and noise is used to reject hits. The original pedestal and noise values get a weight of 20 the new values a weight of 1. The hit rejection may reject a small fraction of high noise values, as a consequence the noise and the pedestals are biased to slightly lower values. The bias is of the order of percent.

Events were considered to be signal events if at least two hits were found in two different layers within a distance ≤ 1 cm (distance between the centres of adjacent pads) in x and y. Figure 1 shows signal and noise distributions resulting from all the pads. The average noise is ~ 6 ADC. The signal generated by muons i.e. minimum ionising particles (mip), is Landau distributed. The most probable value (MPV) of the distribution is used to calibrate the gain of the individual pads. To take the noise into account, not just a Landau distribution is fitted to the signal histogram, but the convolution of a Landau and a Gaussian distribution. The width of the Gaussian is initialised with the estimated noise value of the corresponding pad but it is left a free fit parameter. The MPVs resulting from the fit are displayed in Figure 2. The dispersion between the pads is $\sim 3\%$. The fit errors are smaller than 1% where the corresponding χ^2 are distributed as expected. This yields an average signal-to-noise ratio of ~ 8.

The coherent or common mode noise was estimated by investigating the signal correlation of two pads and the average signals measured on a whole PCB or half a wafer (each wafer is connected to two independent amplifiers). No significant correlation between two pads was seen. Exemplary, Figure 3 shows the correlation between adjacent pads. In a few events, there are correlated positive signals between pads (entries in upper right quadrant). The events roughly cluster around the MPV of mips, thus they are most likely caused by a pair resulting from the electromagnetic interactions. Sometimes the pedestals change in-between two events. Generally, the pedestal changes are recognised and handled. However, it may take several events until the pedestals are adjusted to the correct values. The incorrect pedestals cause the entries in the lower quadrant. The average signal measured by a whole PCB is shown in Figure 4. The distribution has a Gaussian core with a width ~ 0.8 ADC but slightly wider tails. Assuming Gaussian noise and the average noise values determined for each pad which are about 4 to 8 ADC, a width of 0.3 ADC would be expected. The larger width could be caused by coherent noise of ~ 0.7 ADC if it equally effects a whole PCB. In

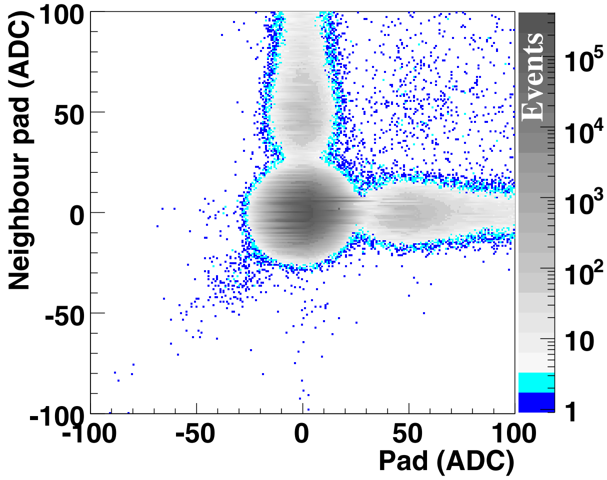

Figure 3: The signal of two adjacent pads on the same wafer which are connected to the same readout chip. The noise peak is clearly visible at the centre with an extension $\ll$ 25 ADC and the mip signal (MPV $\simeq$ 47 ADC) for the two pads. The isolated signals in the upper right quadrant are most likely caused by pairs, since they cluster around the MPV of mips. The few events in the lower left quadrant are due to pedestal changes which are only recognised with a delay of several events.

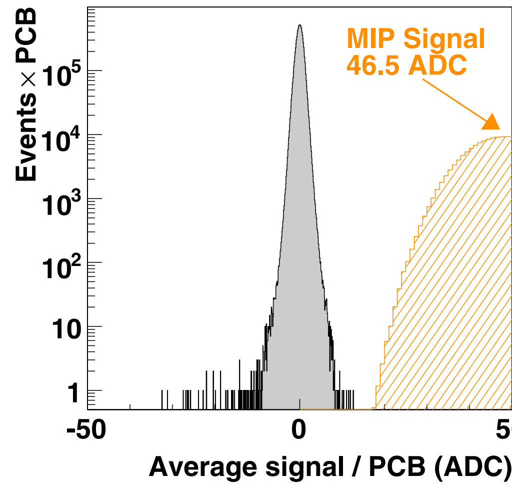

Figure 4: The average signal measured by one PCB (216 pads). The pedestals are subtracted and hits (i.e. signals with a signal-to-noise ratio > 5) are rejected. The distribution has a Gaussian core with a width between 0.7 and 0.8 ADC and slightly wider tails.

the worst case that all pads of the PCB are just above the hit threshold this would cause an error of 3%. In case the coherent noise extends over half a wafer, it would be of the order of 2 ADC to account for the observed width. In the worst case (all pads are just above threshold), this would case an error of 7%. In the general case in which large signals are generated only on a few pads the error is much smaller. In summary, this 15 days test does not give indications for a significant coherent or common mode noise.

2.2. Tests with Electrons up to $6\,\mathrm{GeV}$

In January/February 2005, the ECAL prototype was tested with electrons in the DESY test beam at energies between 1 GeV and 6 GeV. The detector was extended by 4 layers leading to a total radiation length $\gtrsim 7\mathrm{X}_0$. Figure 5 shows an event in which two electrons enter the detector in a distance $\lesssim 4\,\mathrm{cm}$ at an angle of 30°.

The detector was mounted on a table movable in the x and y-directions (perpendicular to the beam axis) and was placed at 4 angles w.r.t. to beam axis. In front of the detector, drift chambers were installed. They provide a $200\,\mu$m resolution on the impact point position of the electrons at the detector front. This allows to investigate the signal as a function of the impact position where the zone between wafers and the guard ring are of particular interest (see [7] for a preliminary result). More detailed results will follow. The analysis of the test beam data is still on going. A preliminary result is shown in Figure 6. The Figure shows the average signal generated in each layer as a function of the radiation length. The angle between the detector and the beam axis was 20°. With the currently installed detector layers only the showers of 1 GeV electrons are mostly contained. More detailed results concerning the energy resolution etc. will follow when more detector layers are installed.

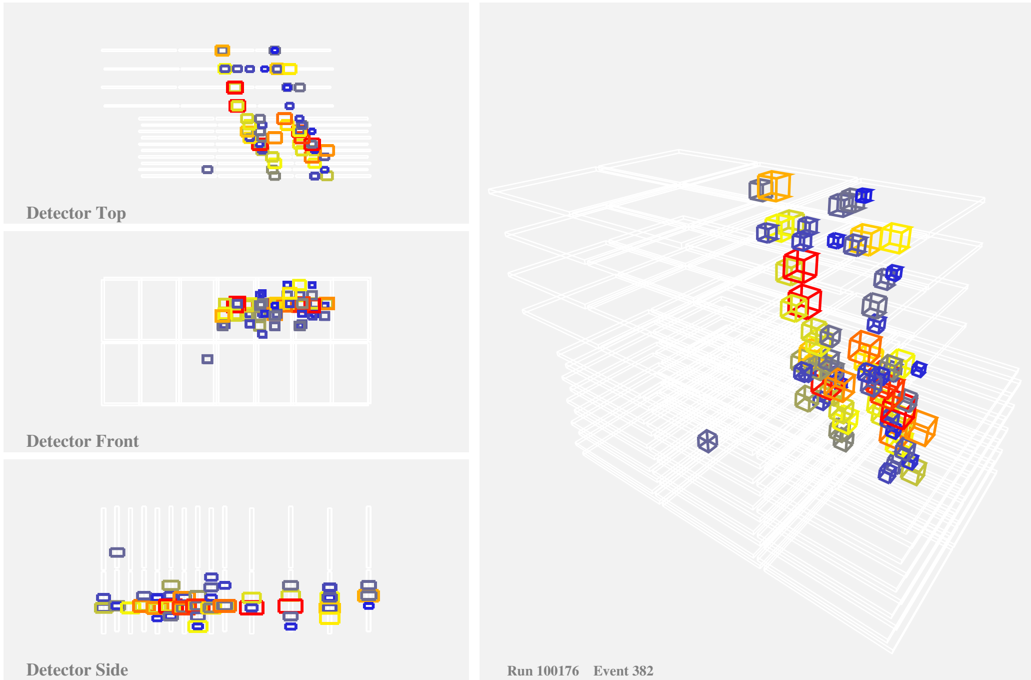

Figure 5: Two electrons of $\sim 2\,\mathrm{GeV}$ entering the detector at an angle of 30° in a distance $\lesssim 4\,\mathrm{cm}$.

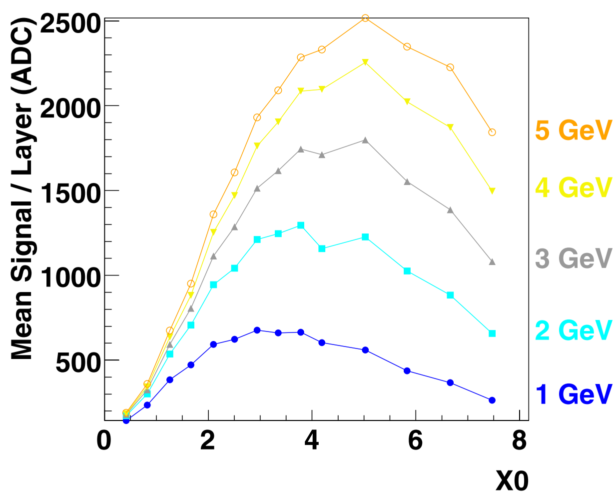

Figure 6: The average signal generated by electrons in the detector layers as a function of the radiation length. The electrons entered the detector at an angle of 20°

3. FUTURE PLANS

The ECAL prototype will be completed soon. Currently the construction is stalled due to a delivery problem of the silicon wafers [8]. When the detector is completed, an additional test will be done in the DESY electron test beam (beginning of 2006).

In summer 2006, a test in a hadron test beam is planned together with analog HCAL. Assuming that both detectors are completed by then. The tail catcher will take part if it is ready at that time. The test is planned to be performed in the meson test beam facility (MTBF) at the Fermi National Accelerator Laboratory (FNAL). For the test pion beams will be used in particular at energies between ~ 3 and 120 GeV. In 2007, the tests will be repeated with the digital HCAL in place of the analog one.

4. SUMMARY

The Calice ECAL prototype has been partially completed (upper half of 14 of the planned 30 layers). The prototype has been tested with cosmic muons and in an electron test beam at energies up to 6 GeV. It shows a signal-to-noise ratio of 8, where the signal is considered to be the most probable value of the Landau distribution resulting from minimum ionising particles. An improved readout electronic which is under development should improve this ratio by a factor of ~ 5 [9]. The precision of the gain calibration of the individual pads is better than 1% with $\sim 1200/\,\mathrm{cm}^2$ cosmic muons. Nevertheless, the dispersion between the pads is small ($\sim 3\%$). The correlated noise is at an acceptable level.

In the coming years the completed Calice ECAL and the two HCAL options will be tested in a hadron test beam, with the ultimate goal to deliver enough data to tune the hadronic models of the GEANT4 simulation. Moreover, the program should answer the question which hadron calorimeter type is better suited for the ILC.

Acknowledgments

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