CALICE Proposal 317

Calorimetry for a Future Linear Collider

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1 Introduction

The CALICE collaboration is studying calorimetry for a future e^+e^- linear collider (LC) in the 500-1000 GeV centre-of-mass energy range. The physics of a LC demands calorimetry capable of delivering high resolution for hadronic jet energies. CALICE is the only collaboration within the LC community studying both electromagnetic (ECAL) and hadronic (HCAL) calorimeters in an integrated way and believes this overall calorimetry approach is the only way to obtain a calorimeter system which will be capable of meeting the demanding physics requirements of a high energy LC detector. It aims to be at the forefront of LC calorimetry development by the time any detector collaboration is formed. The CALICE program covers beam tests of several technologies and simulation studies based on the results of these tests, so as to design a LC calorimeter optimised for both performance and cost.

2 The CALICE collaboration

The CALICE collaboration [1] now has around 150 members from 25 institutes in 8 countries, including membership from all three regions (Europe, US and Asia) involved in the LC program. It is the largest LC calorimetry group by around an order of magnitude [2] and will clearly have a large influence on calorimetry design in a future LC detector collaboration. This size allows a broad programme of tests for calorimeter technologies. Various potential calorimeter technologies are under study and several prototypes will be built and tested in beams. Besides gaining experience with the new technologies, these tests will allow a detailed comparison with simulation. Tuning of the Monte Carlo generators to these data, particularly for hadronic interactions, will give confidence when designing the actual LC calorimeters.

The ECAL work is focused on a tungsten-silicon sampling calorimeter design. The silicon wafers will have diode pads of 1×1 cm^2, with an array of 18×18 pads per layer and 30 layers, resulting in almost 10,000 channels for the CALICE prototype. There are conceptual designs for an HCAL with analogue or digital readout. The former uses scintillating tiles of around 5×5 cm^2 read out using silicon photomultipliers [3] and will have around 7,000 readout channels. For the latter, there are three options being actively considered; RPCs, GEMs and small scintillating tiles, all with cell sizes of around 1×1 cm^2. The resulting 400,000 channels are discriminated and so are read out as a single bit per channel.

Beam tests are the major focus of the collaboration work. The aim is for the ECAL to be tested with several HCAL options so that a meaningful comparison of their performances can be made. The HCALs will be housed within a common mechanical structure containing iron plates, between which the various active layers can be inserted. The ECAL is scheduled to be completed in mid 2004. The different HCAL options are in different stages of maturity;

the analogue tile and digital RPC HCALs are likely to be ready by early 2005, while the other options may be available by the end of 2005. The first beam test will be with the ECAL only and is scheduled to take place in October 2004 at DESY, using the 6 GeV electron beam. When the HCALs become available in 2005, then an 80 GeV pion beam at FNAL is foreseen. With the subsequent analysis of these data, the project will therefore continue into 2006.

The CALICE-UK collaboration was approved by the PPRP in December 2002. The agreed programme is for the UK groups to design and build the readout electronics for the ECAL, the data acquisition for CALICE as a whole, and to prepare for data analysis by undertaking detailed studies and comparisons of the various simulation programs available. In the year since approval, the UK has produced prototypes for the ECAL electronics readout and has become one of the leading regions within CALICE in the simulation studies.

3 Electronics development

The ECAL consists of 30 layers of silicon wafers interspersed between tungsten sheets. The silicon wafers in each layer are mounted on two "very front end" (VFE) PCBs, which provide mechanical support as well as control logic and front end electronics.

The UK readout electronics will drive and read out these VFE PCBs. This functionality has been implemented as 9U VME boards called CALICE ECAL Readout Cards (CERCs). These are closely based on the CMS tracker Front End Driver (FED) boards [4] and major sections of their design were reused for CALICE. Each CERC controls approximately five layers of silicon wafers and provides the trigger, front end control logic, digitisation, and storage of the data for these channels. The total readout system will require six CERCs for the ECAL, although extra boards might be used to read out the HCAL options (see below).

The architecture of the CERC closely follows that of the FED. It has several Front End (FE) FPGAs, each handling up to two input cables, and these are controlled and read out using a Back End (BE) FPGA interfaced to a VME FPGA. Each FE controls 12 ADC channels which digitise more than 200 multiplexed silicon pad signals. Each FE also has a DAC and calibration circuitry to inject pulses to the VFE PCBs. All the CERC I/O, configuration, control and event readout is done via the BE FPGA. The trigger control and distribution is also done within a single BE FPGA for the whole system. The firmware for the FEs and BE is under development; versions of the CMS code for the BE and VME FPGAs have been used as a starting point and so have saved significant design effort.

The CERCs have been designed to allow for the option of reading out the HCAL prototypes also. The analogue HCAL could be very similar to the ECAL with regard to readout and minimal modifications would be needed to the FE firmware in this case. The digital HCAL would clearly be quite different. However, a large array of jumpers has been mounted immediately behind the input cable connectors. This allows the analogue signals to and from the FE to be bypassed, making the whole set of cable signals digital and driven directly from the FE. Together with modified FE firmware, this will allow the digital HCAL to be controlled and read out. Hence, the UK would then be responsible for all CALICE readout.

Two prototype CERCs were manufactured in November 2003, see Fig. 1. These are currently under test. The full ECAL electronics readout chain will be assembled and tested for the first time in February 2004, after which the production of the required final CERCs will be done. Details of the current status can be found at [5].

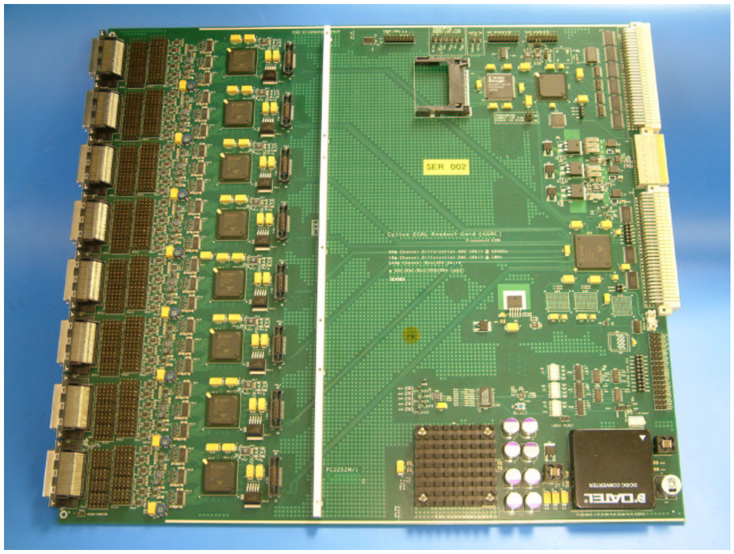

Figure 1: *One of the two prototype* CALICE *ECAL Readout Cards (CERCs). The eight input connectors are visible on the left hand edge of the board. Immediately behind these are the eight jumper arrays followed by the eight front end FPGAs and their associated ADCs and DACs. On the right hand side, just behind the J2 connector, the back end FPGA can be seen.*

4 Simulation studies

The UK CALICE groups are complementing their electronics and DAQ work for the CALICE prototype test with a broad program of simulation work. One of the main aims of the CALICE beam test is to perform a comparison between data and Monte Carlo simulation for various projectiles and energies. A necessary prerequisite for the optimization of a full-scale calorimeter design for a LC is the development of a Monte Carlo simulation, including hadronic showers, whose veracity has been carefully tested.

The most detailed Monte Carlo program for LC calorimetry is `Mokka`, based on `Geant4`. Many studies have also been performed using `Brahms`, based on `Geant3`. Our aim in the UK is to conduct a critical comparison of the physics content of various Monte Carlo programs, particularly the response to hadrons, and to assess the impact of any differences seen on the design and expected performance of LC calorimeters. In this way we expect to identify key areas in which results from the CALICE test beam will be essential to test the expected performance of the calorimetry for a future LC experiment.

Fig. 2 shows typical results from a comparison between `Geant3` and `Geant4` for samples of 10^4 showers induced by 5 GeV π^+. Differences between the models are clearly seen in both the longitudinal and transverse development of the showers, which will require test beam data for their elucidation. Similar distributions are being studied for several different interaction models available in `Geant3` and `Geant4`. This will allow us to be well prepared to exploit the results from the beam tests and to ensure that the most relevant data are recorded to allow us to discriminate between models.

The `Fluka` Monte Carlo system is reputed to have the most detailed microscopic model of hadronic interactions on nuclei, and is regarded favourably by some LHC experiments. An old version of `Fluka` was interfaced to `Geant3`, but this version is now deprecated by the `Fluka` authors. We are therefore implementing a direct interface between `Fluka` and the geometry of the detector as described by `Geant4`. This package, called `FLUGG`, has been developed in a collaboration between the `Fluka` authors and ATLAS [6], and used e.g. by the ATLAS barrel

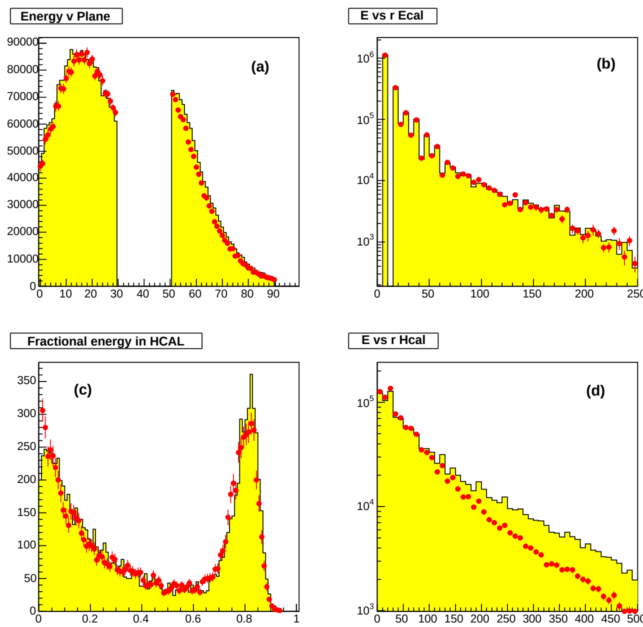

Figure 2: *Simulated showers induced by 5 GeV π^+ in the* CALICE *prototype. In all cases the points are* `Geant4` *and the solid histogram* `Geant3`*. (a) Longitudinal shower profile (plane number), weighted by energy. The plane number for the HCAL is incremented by 50 for the purposes of presentation. (b) Transverse shower profile (radius in mm) in the ECAL, weighted by energy. (c) Fraction of energy deposited in the HCAL. (d) Transverse shower profile (radius in mm) in the HCAL, weighted by energy.*

calorimeter group.

Work is also under way to study energy flow algorithms for jet energy reconstruction. In particular we aim to discover which features of the shower simulations are of the greatest importance in assessing correctly the energy flow performance. Our aim is to write these algorithms in such a way that the effect of alternative detector geometries can readily be investigated.

In optimising the calorimeter design, it is also important to maintain sufficiently good performance for high energy electrons and photons. A further strand of CALICE work in the UK is the study of radiative Bhabha events. The determination of the acollinearity angle in such events is a crucial part of determining the luminosity spectrum at a LC, which is essential for the measurement of the top mass. This determination therefore relies on excellent angular measurement of electrons, especially in the end-caps.

References

[1] Main web site `http://polywww.in2p3.fr/flc/calice.html`.

[2] For an overview of LC R&D worldwide, see `http://blueox.uoregon.edu/~lc/randd.ps`.

[3] P. Buzhan *et al.*, Nucl. Inst. Methods **A** 504 (2003) 48.

[4] See `http://www.te.rl.ac.uk/esdg/cms-fed/`

[5] See `http://www.hep.ph.ic.ac.uk/calice/electronics/electronics.html`

[6] M. Campanella, A. Ferrari, P.R. Sala and S. Vanini, "First calorimeter simulation with the FLUGG prototype", ATL-SOFT-99-004.