

Status of the CALICE analog calorimeter technological prototypes

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Abstract. The CALICE collaboration is currently developing engineering prototypes of electromagnetic and hadronic calorimeters for a future linear collider detector. This detector is designed to be used in particle-flow based event reconstruction. In particular, the calorimeters are optimized for the individual reconstruction and separation of electromagnetic and hadronic showers. They are conceived as sampling calorimeters with tungsten and steel absorbers, respectively. Two electromagnetic calorimeters are being developed, one with silicon-based active layers and one based on scintillator strips that are read out by MPPCs, allowing highly granular readout. The analog hadron calorimeter is based on scintillating tiles that are also read out individually by silicon photomultipliers. The multi-channel, auto-triggered front-end chips are integrated into the active layers of the calorimeters and are designed for minimal power consumption (power pulsing). The goal of the construction of these prototypes is to demonstrate the feasibility of building and operating detectors with fully integrated front-end electronics. The concept and engineering status of these prototypes are reported here.

1. Introduction

One of the physics goals at a future linear collider (LC) is the separation of hadronic W- and Z-boson decays. To achieve this goal a relative jet energy resolution of $\sim 3\%$ is necessary, while typical jet energies are of the order of 100 GeV and typical single particle energies are about 10 GeV. One of the strategies to achieve such a jet energy resolution is to measure the details of the shower development in order to separate the showers of individual jet particles. This information is then combined with the information obtained from the tracking detectors, such that only the energies of neutral particles are determined with the calorimeter system. The approach is known as *particle flow*. This implies a number of challenges for the design and the construction of the calorimeters:

- High granularity: ECAL (HCAL) cell size $< (\sim)$ Molière radius, longitudinally $< (\sim) 1 X_0$,
- Explosion of channel count: ECAL $\sim 10^8$, HCAL $\sim 10^7$,
- Compactness: the calorimeters are placed inside the magnet coil,
- Heat development: power pulsing the integrated front-end electronics becomes necessary,
- 4th dimension: information about the time of each hit with respect to the bunch clock is needed.

The CALICE collaboration [1] is developing and testing new technologies for calorimeters for a future LC experiment. Technological prototypes are meant to provide answers and solutions

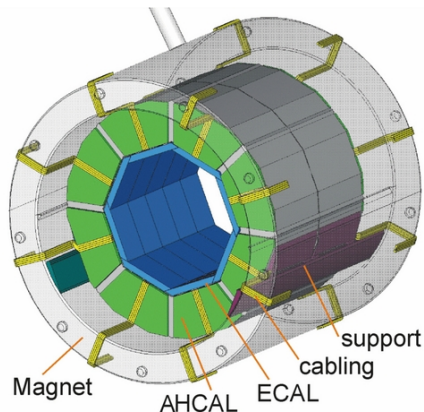


Figure 1. Layout of the barrel calorimeter system of a LC detector. The ECAL is shown in blue and the AHCAL in green, while the structure is surrounded by the magnet.

to the challenges listed above. These technological prototypes are developed in a phase where physics prototypes already provided valuable information about the physics of hadron showers from extensive beam test programs [2]. Therefore the main goal is to demonstrate that the construction of a realistic detector with fully integrated front-end electronics is feasible. Figure 1 shows a layout of the calorimeter system of a LC detector. The ECAL is shown in blue, the analog HCAL option is shown in green, while the structure is surrounded by the magnet.

Common developments in the collaboration, like a data acquisition system for all CALICE detectors or readout chips and electronics boards that are similar for different detectors, allow for a parallel and cost effective development of different technology options. In the following, three detectors will be described in more detail. These are the analog scintillator tile hadron calorimeter (AHCAL) and the SiW ECAL, as well as the scintillator strip ECAL. For a review of the physics prototypes of these detectors see [3, 4, 5]. For a review of the latest status of (semi-) digital hadron calorimeters see [6].

2. The AHCAL technological prototype

The CALICE collaboration is currently developing a technological prototype for an AHCAL [7]. It is based on scintillating plastic tiles read out by silicon photomultipliers (SiPMs), while steel or tungsten can be used as absorber material with a thickness of 16 mm and 10 mm, respectively. Figure 1 shows how the AHCAL is placed inside the magnet and outside the ECAL system. It is divided into four sections along the beam direction, the two endcaps and two half-barrels. Each half-barrel is further divided into 16 sectors in ϕ -direction. Each sector consists of 48 layers. The total thickness is 110 cm, while the total length of the barrel is 220 cm. A single active layer is made of three parallel slabs of HBUs (HCAL base units). Each HBU has a size of $36 \times 36 \text{ cm}^2$ and has 144 detector channels. The latest HBU version is shown in Fig. 2(a). It is equipped with four SPIROC2b ASICs [8] each to read out the photo detectors. On the backside of the module the scintillating tiles are attached to the PCB via alignment pins with a nominal distance of $100 \mu\text{m}$, as shown in Fig. 2(b). Synergies between different CALICE detector technologies are achieved by deriving the PCBs for an alternative AHCAL option (by mounting the SiPMs on top of the PCB), as well as for the scintillator strip ECAL, from the HBU design.

The tiles have a size of $30 \times 30 \times 3 \text{ mm}^3$ and are equipped with a wavelength shifting fiber to guide the light to a SiPM with a size of 1.26 mm^2 and 796 pixels. The latest batch of SiPMs from CPTA that are used in the current HBUs have a gain in the range of 1 to 3 million with a noise frequency around 50 Hz at a 0.5 MIP threshold. An alternative option for the tile design is currently under investigation, where the tiles are read out directly by SiPMs, e.g. without a wavelength shifting fiber. This reduces the mechanical complexity, since otherwise the SiPM has to be aligned precisely to the fiber. First tests already showed that the tiles are very uniform.

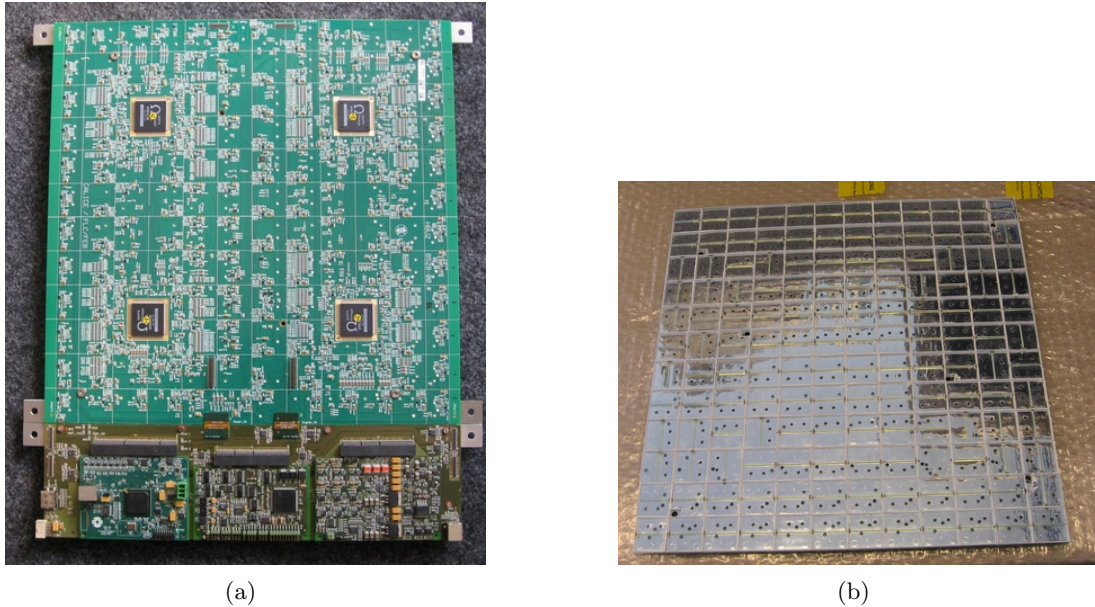
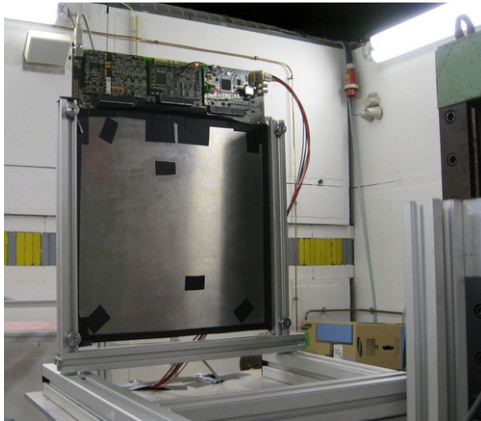


Figure 2. (a) Photo of the latest basic AHCAL module, equipped with four SPIROC2b ASICs. The DAQ interface modules are also shown. (b) Photo of tiles that are assembled below an HBU. The orientation of the wavelength shifting fibers depends on the position of the holes for the pins. This is determined by the details of the PCB design.

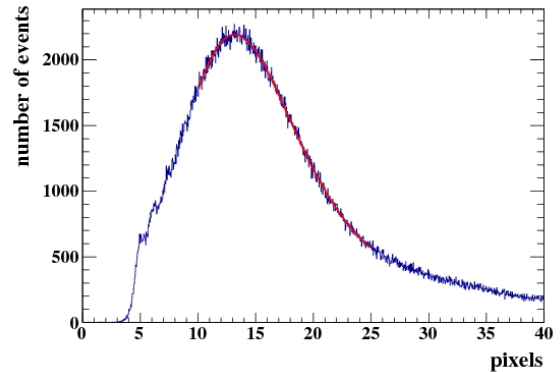
The 36-channel SPIROC2b ASIC is specifically designed for LC operation. It comprises an input DAC for channel-wise bias voltage adjustment for the SiPMs, it can be power pulsed in order to reach a power consumption of not more than $25 \mu\text{W}$ per channel (for details see e.g. [9]) and it can be operated in a self-triggering mode. Besides setting a global threshold per chip, a channel-wise tuning of the threshold is possible with a dynamic range of about 0.25 MIP. A dual-ramp TDC allows for precise time measurements of individual hits with a resolution of less than 1 ns [7]. Strong synergies between the different CALICE calorimeter technologies are also achieved here, since the SPIROC2b is also used in the scintillator strip ECAL and a similar chip, called SKIROC, is used in the SiW ECAL. Detailed laboratory and test beam measurements have lead to a detailed understanding that allows further developments. For example, the next generation chip SPIROC2c is currently investigated in the HBU environment.

Four fully equipped new HBUs are currently available and are extensively tested in the DESY laboratory and test beam facility. Figure 3(a) shows the setup of a light-tight aluminum HBU cassette as it is mounted on a movable stage in order to scan all channels with a 2 GeV electron beam. The MIP signals are measured in self-triggering mode and a typical spectrum is shown in Fig. 3(b).

There are several important steps to be done in the near future. Since there are enough PCBs available to built a full slab, it is possible now to test the power pulsing mode in a more realistic environment. The mechanical prototype structure is also in place and therefore realistic temperature measurements can be performed as well. On the other hand it is possible now to built a 2×2 HBU layer that can be used in a hadron beam test. Besides important technical aspects that can be tested with such a device, it offers the possibility to measure the radial time distribution of hadron showers when used as an additional layer behind another CALICE calorimeter.



(a)



(b)

Figure 3. (a) Setup of the light-tight HBU cassette as it is mounted on a movable stage at the DESY test beam facility. (b) Typical MIP spectrum obtained from a 2 GeV electron beam.

3. The ECAL technological prototypes

The basic requirements for an electromagnetic calorimeter at a particle flow experiment are similar to the requirements for the hadron calorimeter. It has to have an extremely high granularity, while being compact and hermetic. In order to achieve this, tungsten has been chosen as the absorber material for narrow showers ($X_0 = 3.5$ mm, $R_M = 9$ mm). Two different options for the active layers are currently under development.

3.1. SiW ECAL

One of the options for the ECAL active layers is to use silicon as active material. The key parameters of the technological prototype that is currently developed by the CALICE collaboration are [10]:

- Individual cell size of 5.5×5.5 mm²,
- Depth of $24 X_0$,
- Thickness of an individual layer of 3.4 mm and 4.4 mm according to the position within the calorimeter.

Figure 4(a) shows the geometry of the mechanical construction that is realized as a tungsten carbon composite to serve simultaneously as the absorber structure, where individual detector slabs are inserted. Figure 4(b) shows a detailed view of the structure.

Six of the latest modules (FEV8, front-end version) have been tested recently in the DESY test beam facility. Each FEV8 has been equipped with four 64-channel SKIROC ASICs, that are specifically designed for the readout of the ECAL silicon cells. The wafers have a size of 9×9 cm² and comprise 324 pixels. Figure 5(a) shows a photo of the current setup, including the DAQ interface cards. The main goals for the beam test are the determination of the signal-to-noise ratio, the establishment of a calibration procedure for a large number of cells and the measurement of the homogeneity of the response. During the beam test it was possible to insert tungsten absorber plates between the active layers and measure electron showers between 1 and 6 GeV. Additionally, this beam test has also successfully demonstrated the functionality of the common CALICE DAQ concept and hardware that ran smoothly over the complete data taking period. Further beam tests will follow in the near future, where power pulsing tests and tests with magnetic field will be performed.

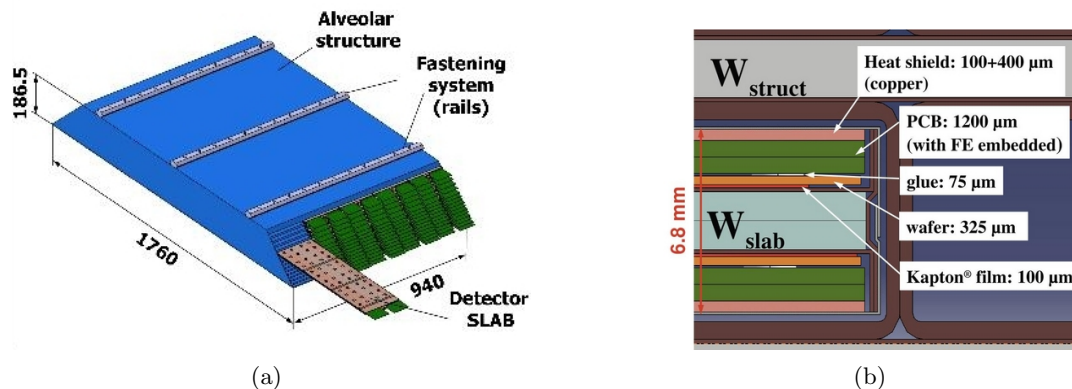


Figure 4. (a) Schematic of the ECAL alveolar structure, which shows how the slabs are inserted into the mechanical housing. (b) Cross section of two ECAL layers. The sensitive material and the front-end electronics are mounted on both sides of a tungsten carbon composite plate.

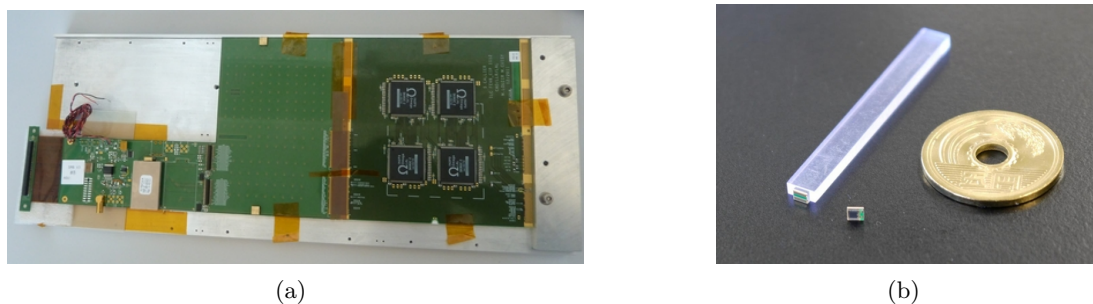


Figure 5. (a) Photo of the FEV8 together with the DAQ interface. (b) Scintillator strip coupled to an MPPC as it is used in the active layers of the scintillator strip ECAL.

Besides the testing of the existing modules, there are further current and future challenges. Among these are the optimization of the guard ring (to suppress cross talk between the modules), the low cost production of silicon wafers (3000 m^2 for LC detector), the glueing of the wafers to the PCB, the optimization of the PCB thickness and the interconnection of individual units (in order to reduce mechanical stress to the wafers).

3.2. Scintillator strip ECAL

A second option for the active ECAL layers is to use scintillator strips with MPPC readout [5]. The idea is to use alternating layers with fine segmentation in x- or z-direction, which leads to an effective channel size of $5 \times 5 \text{ mm}^2$. After the successful validation of the concept with a physics prototype, the CALICE collaboration is currently constructing a technological prototype with fully integrated front-end electronics. The EBU (ECAL base unit) is therefore adapted from the AHCAL design and also the SPIROC2b ASIC is used to read out the MPPCs that are coupled to the strips. Strips are developed that do not incorporate a wavelength shifting fiber, but are read out directly with the MPPC, see Fig. 5(b). The next important step is to integrate all components and start testing the complete system in the laboratory and in the DESY test beam environment.

4. Summary

The CALICE collaboration has extensively and successfully tested physics prototypes for particle flow calorimeters in the past. Therefore the phase of the validation of particle flow concepts has finished and lead to the construction and development of technological prototypes. These prototypes are used to prove the feasibility of the technological concepts to built realistic linear collider detectors with fully integrated front-end electronics. Prototypes for electromagnetic as well as hadronic calorimeters have already taken data and although the development is still ongoing, basic concepts could already be addressed and verified:

- Operation of fully integrated electronics,
- Power pulsing,
- Mechanical engineering and
- Costs and mass production issues.

In this report the current status of two electromagnetic and an analog hadron calorimeter were presented. The tests that have been performed so far, have lead to an increased understanding of the details of the systems that allow further developments and larger beam test campaigns in the near future.

Acknowledgments

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References

- [1] CALICE home page: <https://twiki.cern.ch/twiki/bin/view/CALICE/CaliceCollaboration>
- [2] M. Ramilli, *Hadron showers from CALICE test beam data*, these proceedings.
- [3] C. Adloff et al., *Construction and commissioning of the CALICE analog hadron calorimeter prototype*, JINST 5 (2010) P05004, arXiv:1003.2662.
- [4] J. Repond et al., *Design and Electronics Commissioning of the Physics Prototype of a Si-W Electromagnetic Calorimeter for the International Linear Collider*, JINST 3 (2008) P08001, arXiv:0805.4833.
- [5] K. Kotera, *Study of the granular electromagnetic calorimeter with PPDs and scintillator strips for ILC*, Proc. 2010 12th Vienna Conference on Instrumentation, NIM, A628, 347 (2011).
- [6] B. Bilki, *Tests of a Digital Hadron Calorimeter*, J.Phys.Conf.Ser. 293 (2011) 012075, arXiv:1005.0409; M.C. Fouz, *The 1m³ Semidigital Hadronic Prototype*, Proc. 2011 LCWS, arXiv:1202.5567; J. Yu, *Application of Large Scale GEM for Digital Hadron Calorimetry*, arXiv:1110.4326.
- [7] O. Hartbrich et al., *Recent Advances of the Engineering Prototype of the CALICE Analog Hadron Calorimeter*, Proc. 2011 LCWS, arXiv:1201.5264; M. Reinecke, *Towards a full scale prototype of the CALICE tile hadron calorimeter*, Proc. 2011 IEEE Nuclear Science Symposium (NSS11); M. Terwort, *Concept and status of the CALICE analog hadron calorimeter engineering prototype*, Proc. 2011 Technology and Instrumentation in Particle Physics (TIPP), arXiv:1109.0927.
- [8] L. Raux et al., *SPIROC Measurement: Silicon Photomultiplier Integrated Readout Chips for ILC*, Proc. 2008 IEEE Nuclear Science Symposium (NSS08), NSSMIC.2009.5401891; M. Bouchel et al., *SPIROC (SiPM Integrated Read-Out Chip): dedicated very front-end electronics for an ILC prototype hadronic calorimeter with SiPM read-out*, Proc. 2010 TWEPP, JINST 6 (2011) C01098.
- [9] P. Göttlicher, *A concept for power cycling the electronics of CALICE-AHCAL with the train structure of ILC*, Proc. 2011 Technology and Instrumentation in Particle Physics (TIPP).
- [10] R. Pöschl, *A large scale prototype for a SiW electromagnetic calorimeter for a future linear collider*, Proc. 2011 LCWS, arXiv:1203.0249.