CALICE-UK Report to the PPARC Oversight Committee

September 25, 2006

1 Introduction

The CALICE collaboration is a worldwide effort to study calorimetry for the International Linear Collider (ILC). The collaboration is described in more detail in Section 2 below.

UK involvement in CALICE started in 2002. The PPRP granted seedcorn funds for five groups in December of that year to join the collaboration. In February 2005, seven UK groups then returned to the PPRP for further funding to complete the ongoing programme of beam tests as well as start several longer-term R&D programmes, which were funded to March 2009. An overview of the UK work is given in Section 3.

The UK CALICE groups were also part of the successful EUDET infrastructure bid to the EU, which was approved in January 2006. This gives the UK funding to produce a DAQ system for reading out future calorimeter prototypes also being produced within the EUDET framework.

The individual workpackages are described in more detail in Sections 4 to 8. The GANNT charts, milestones, financial and risk tables are supplied separately and some related points are discussed in Section 9.

2 General status of CALICE

The CALICE collaboration is undertaking a major programme of R&D into calorimetry for the ILC. It now has 200 members from 32 institutes worldwide and is by far the largest group studying calorimetry for the ILC. New groups continue to join CALICE and since the last OsC meeting, these have included groups from India, Japan and Canada, which are the first from those countries.

It is the only collaboration within the ILC community studying both electromagnetic (ECAL) and hadronic (HCAL) calorimeters in an integrated way. The collaboration will test pre-prototypes of an ECAL along with at least two types of HCAL in electron and hadron beams over the next 18 months. The CALICE programme also covers simulation studies incorporating the results of these tests, all directed towards the design of an ILC calorimeter optimised for both performance and cost. In addition, the collaboration serves as an umbrella organisation for longer-term ILC calorimeter projects where developments can be tested together. CALICE is a cross-detector collaboration which has contributors in all three design groups, although it originated from the TESLA TDR design effort and hence has strongest ties to the LDC group.

2.1 Beam test program

The CALICE ECAL pre-prototype is a silicon-tungsten sampling calorimeter and consists of 30 layers of silicon wafers interspersed between tungsten sheets. Each wafer layer contains a 3×3 array of silicon wafers, each containing 36 $1 \times 1\,\mathrm{cm}^2$ diode pads. There are around 10,000 channels in total occupying a volume of approximately $(18\,\mathrm{cm})^3$. The ECAL is mainly a collaboration between the French and UK groups, with the former responsible for the mechanics and silicon detectors and the latter for the readout electronics. The ECAL assembly is currently paced by the silicon wafer production and there were problems with wafer production throughout 2005. Around 2/3 of the silicon wafers have been manufactured and installed, with the rest expected over the next six months so completion will be in May 2007.

The analogue HCAL (AHCAL) is a sampling calorimeter with 40 layers of steel absorber sheets instrumented with scintillator tiles. The total volume is approximately $(1\,\mathrm{m})^3$. The tiles are of varying sizes, with the highest granularity central region using $3 \times 3\,\mathrm{cm}^2$ tiles, increasing to $12 \times 12\,\mathrm{cm}^2$ for the outermost tiles. As the name implies, the readout is be analogue, with the off-detector UK electronics being common to the ECAL. The AHCAL has around 8,000 channels in total. It is a collaboration of many small European institutions but is lead by a large DESY group. The readout electronics is the same UK design as for the ECAL. The rate of production of tiles depends mainly on the manufacturing of the silicon photomultipliers used to read out the tiles. Approximately half of the layers have been produced so far. The AHCAL is complemented by a "tail-catcher" (TCMT) consisting of 96 cm of iron instrumented with 16 layers of 5 mm $\times$ 5 cm scintillator strips, which tag shower leakage and detect muons. Again, about half of these layers have been installed so far. Both these detectors will be complete by March 2007.

The digital HCAL (DHCAL) is a binary readout sampling calorimeter. The sensitive layers will be mainly resistive plate chambers (RPC) although for some of the tests, one or more layers may be replaced with gas electron multiplier (GEM) detectors. The RPC (or GEM) pads will be $1 \times 1\,\mathrm{cm}^2$, giving 380,000 channels, each reading one bit. Both the RPC and GEM developments are being done by US groups. As one of the main aims of the beam tests is to compare the performance of these HCAL options, the same absorber structure and tail catcher as for the AHCAL will be used, so as to eliminate any spurious differences which might otherwise arise. Hence, the DHCAL is also around $(1\,\mathrm{m})^3$ in volume. The DHCAL is being developed by US groups, who are currently applying for funds for the production of readout electronics (common to RPC and GEM). An announcement on the level of funding granted is expected by the end of 2006. Assuming funding is secured, the DHCAL should then be completed towards the end of 2007.

2.2 Other work

CALICE has many other smaller areas of calorimetry R&D which are ongoing. The biggest is the preparations for the EUDET "Module 0". This will be mechanically of the size of a final ILC detector ECAL module, specifically 1/40 of the total barrel calorimeter. It will be partially equipped with sensitive channels; one region will have full depth and one complete layer will be instrumented. This will be exposed to beams from late 2008 or early 2009 onwards. It will serve as a test bed for the various projects within CALICE; layers can be replaced by alternative designs (such as MAPS) allowing a controlled comparison between them in a very similar environment.

3 General UK Overview

For the UK, the overall objective of the CALICE-UK work is clearly to allow the UK to participate in the ILC detector collaborations and hence exploit the eventual ILC data. The shorter-term major steps towards this goal are to contribute strongly to the detector TDRs (which are likely to be completed in 2009/10), to get a reputation for ourselves as competent and reliable collaborators, and to establish a significant presence in the ILC community. We are aiming to achieve this both through our work within CALICE and also through more general work within the three ILC detector design groups.

Within CALICE, we have established our technical competency already through the very successful delivery and operation of the readout electronics and DAQ system for the beam tests at DESY and CERN this year; see section 4 below. This was a critical item as it was our first major contribution to the collaboration. We have also lead much of the analysis work. Outside CALICE, we have had many UK talks at ILC meetings, both within Europe and worldwide. In particular, CALICE-UK personnel gave three talks at the last LCWS meeting. These talks have not only been showing UK calorimetry work but also presenting results from CALICE as a whole; this is a sign of our visibility and standing within the collaboration.

3.1 UK Political Strategy

With the work of the current grant, we need to cement this good start, continuing WP1 until the time of the TDRs and expanding our activities to position us with a lead in at least one major area of calorimetry. Given the nature of R&D, it is clearly difficult to predict which area of work will be successful and hence will provide the UK with a leading role. Therefore, we have taken a multi-pronged approach which gives us confidence that there will be UK leadership later.

The strategy is to have a very high profile (but high risk) project, the MAPS work of WP3, which would give the UK a central position if it proved viable. This is clearly not a definite outcome so there is a second major project, the DAQ work of WP2, which we know is essential, will be technically possible, can be applied to more than the ECAL, and where there is little (if not effectively zero) competing work elsewhere in the ILC community. To maintain a presence in the calorimeter itself, we also have a somewhat smaller project, the thermal and mechanical studies of WP4, where we have targetted a project which makes use of existing UK expertise in these areas and which will allow us to expand later if desired. In addition to these projects, the final major area of work is in the physics and simulation studies of WP5. This allows us to contribute in many areas, including the physics reach studies, detector design, calorimetry MC validation and optimisation and simulation support for the other UK work.

We view working on several projects as an insurance which will ensure we can take a leading role by the time of the TDR. If the MAPS approach to the ECAL proves not to be viable, then it is likely the UK groups will combine to provide a major part of the calorimeter (or even overall detector) DAQ system; as such, we would have the expertise and experience to dominate this area. However, if the MAPS approach turns out to be workable and is accepted, then the UK would be leading the calorimeter sensor design. In this favourable circumstance, how the UK effort is divided between the MAPS and DAQ work would need to be defined at the time and would clearly depend on many other factors which cannot be predicted now, including the status of the work of the LCFI and LC-ABD groups.

The scientific goals we have set ourselves contribute directly to achieving the above objectives. The status of the work towards these goals is detailed below in Sections 4 to 8.

4 WP1: Beam Test Program

This workpackage covers the ongoing beam test program, the UK effort to support it, and the analysis of the data collected. The work of WP1 will give a large dataset of interactions which can be used to tune and verify the realism of the various simulation models on the market. This is to ensure we have a reliable simulation for all the studies needed for WP5.

This workpackage has the highest degree of interaction with, and dependence on, non-UK groups. The past six months have been be dominated by preparations for, and participation in, the main test beam runs of the CALICE pre-prototypes at DESY and CERN. The UK groups have contributed strongly to this work, as experts in the DAQ system, monitoring and data analysis.

4.1 Task 1.1: Support for beam tests

The original PPRP seedcorn award funded the production of readout electronics for the full ECAL and an online computing system for the whole experiment. Nine custom-designed CALICE Readout Cards (CRC) were designed and fabricated by RAL/EID, each of which can read out 1728 channels. This work was carried out successfully during the first grant period. The UK-designed electronics was subsequently adopted by the AHCAL and TCMT for their readout systems. Hence a further seven CRCs were produced through RAL during 2005, funded by non-UK groups. Delivery of these boards was completed in May 2006.

Almost all the firmware for the readout electronics has now been completed, by Imperial, Manchester and UCL. The major improvement since the last OsC meeting was the ability to use fully the 8 MByte buffers on each CRC and so store 2000 events during a spill. This was completed in time for the CERN runs, where this facility was essential to get a reasonable event rate. Other minor improvements were made in trigger distribution reliability and flexibility of use. Further small changes of this type are to be expected but the main bulk of the work is now complete. Since the DHCAL has decided to use a different readout board, and hence the US groups will provide the firmware for this, some further upgrades by the UK may be needed in the future when this detector is incorporated into the DAQ but these will again be minor.

The online software, developed by Imperial, was also tuned up for the CERN run so as to perform to the required level. The complete DAQ system using multiple crate readout for the ECAL, AHCAL and TCMT, as well as TDCs for tracking, was assembled and integrated together, first at DESY and then at CERN. A rate of over 150Hz was achieved; this was with fewer calorimeter channels than the final system but implies the target readout rate of 100Hz with the completed calorimeters will be straightforward. Rates to disk of 5 MBytes/s were standardly achieved throughout the CERN run. The DAQ downtime was around the percent level throughout the beam period, which was negligible compared with the downtime due to other sources (mainly beam rate and availability). During periods of good beam with high intensity, a sustained average rate, including changing beam energies, starting and stopping runs, etc, of over 120Hz was achieved; indeed over 10M events were recorded on the best day; see Fig 1.

As the calorimeters are completed, then small changes will be needed to the online software but until the DHCAL is integrated late in 2007, the remaining work will be mainly maintanence rather than significant development.

One point to note; the DAQ system, i.e. the CRC electronics and other hardware, is the only component of CALICE which has currently been completed. This has significantly enhanced the reputation of the UK groups and also means we are well-positioned to lead the analysis of data.

4.2 Task 1.2: DESY test beam

In December 2004 the first 10 layers of the ECAL pre-prototype, in which an area of $12 \times 18\,\mathrm{cm}^2$ was instrumented, were calibrated using around 1M cosmic muon events taken in Paris. Then in January-February 2005 the prototype, by then extended to 14 instrumented layers ($\sim 7.2X_0$), was moved to DESY for tests in an electron beam. That run was highly successful, with around 20M events and some 250 GB of data being recorded. Electron beams of energies 1-6 GeV were fired at the detector at normal incidence and at angles of 10°, 20° and 30°. The detector was

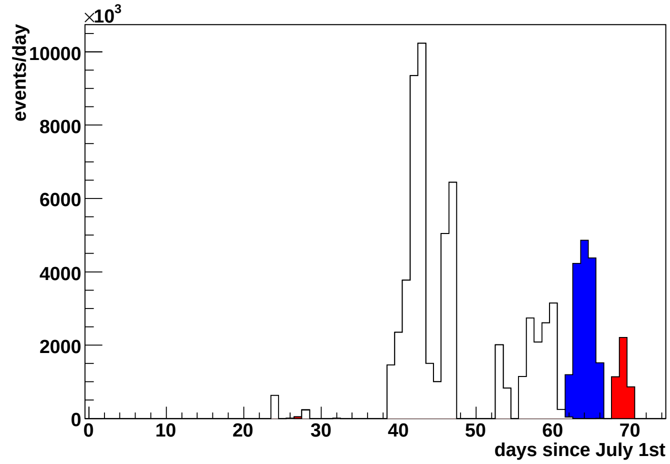

Figure 1: *Number of events recorded per day over the CERN beam test period. The data around day 25 were the first run period. The period from days 40-48 was parasitic running with the beam dump installed, where the intensity was highest. The period from day 52 onwards was the second run period, within which the red histogram shows the data in the AHCAL-only period and the blue in the ECAL-only period.*

moved so that the beam was fired into each silicon wafer, and at various points near to the inter-wafer gaps.

The main round of ECAL beam tests at DESY took place in May 2006. At that time, 24 layers of silicon detectors were installed (placed in layers 1-22 and 25-26 of the calorimeter), each covering an area of $12\times18\,\mathrm{cm}^2$. For the electron beam energies available at DESY, up to 6 GeV, this provided sufficient instrumented depth to contain the showers. Data were recorded covering the energy range 1-6 GeV, at several beam impact points on the calorimeter, and at angles 0°, 10°, 20°, 30° and 45°. In all around 10M beam triggers were recorded. Preliminary analysis of these data has taken place, but full analysis needed to wait for muon data recorded at CERN in August in order to obtain calibrations. The successful completion of this beam run (i.e. the recording of electron data from 1-6 GeV at a range of positions and angles with full containment in the ECAL) corresponds to the one milestone in WP1 (ID9 in the Gannt chart) which was scheduled to be completed since the previous OsC meeting.

The UK groups have been involved in several areas of data analysis. The RHUL group have been responsible for describing the beam line in the Monte Carlo simulation (important in order to take account of showering upstream of the calorimeter) and for track reconstruction in the drift chambers. The UCL group has been looking at detailed understanding of the DAQ and electronics. Imperial has been working on position and angular resolution, and on digitisation issues such as noise and cross-talk and their implementation in the simulation. Cambridge and Birmingham have been studying the data and making comparisons with simulation.

As well as providing essential data on low energy electrons, the DESY run was an important dry run for the major test beam campaign at CERN. Part of the analogue HCAL was operated along with the ECAL, and therefore much of the commissioning of hardware, of the DAQ and online software, of run procedures such as monitoring, and of the offline software, could be carried out at DESY.

4.3 Task 1.3: CERN test beam

Installation of the ECAL and the AHCAL at CERN took place successfully around the end of June 2006. Approximately two weeks of high energy electron running with the ECAL were scheduled for late July/early August, followed by stand-alone tests of the AHCAL later in August, with the main combined ECAL-AHCAL-TCMT data taking planned for October 2006.

The installation and commissioning of the detector went quite smoothly. The ECAL was fully equipped in depth with 30 layers of sensors, each covering an area of $12{\times}18\,\mathrm{cm}^2$. The ECAL has $\sim 99\%$ of its 6480 sensors working. At the time of the first runs, the AHCAL was equipped with 16 layers of scintillator tiles (giving a total of around 3500 channels), arranged in alternate slots of the iron structure so as to give reasonable containment of showers. Further layers, though not the full complement, will be installed before the October run.

Unfortunately the beam was not available for much of the first running period, owing to a PS magnet problem. Nevertheless, a significant volume of data were recorded during the final two days, consisting of electrons at 10, 20, 30, 40 and 50 GeV at normal incidence. Sizeable samples of π^-, mainly at 60 GeV, were also recorded. Roughly 2 million electron events and 300,000 pions were taken, with a broad beam, which effectively provides a scan across the calorimeter face. In addition, a substantial volume of muon data were recorded, mainly parasitically, which are crucial for calibrating both the ECAL and the AHCAL. This showed that the gains of the ECAL pads show only small pad-to-pad differences, with an r.m.s. variation of $< 5\%$.

The second period of test beam running at CERN, starting in late August, was originally intended to be devoted to the AHCAL. However, because much of the first data period was lost and the AHCAL is not in its complete form, the plan was modified and we collected a large sample of both hadron and electron data in this period. We now have samples of electrons from 10-50 GeV at angles 0-45° to the ECAL which, combined wuth the DESY data from 1-6 GeV, will be sufficient to evaluate the performance of this calorimeter. The electron tests of the ECAL can therefore be regarded as having been successfully completed. In addition, a sizable volume of pion data were recorded.

The UK groups provided a strong presence in the test beam running at DESY and CERN, with emphasis on the DAQ and short-term monitoring and data checking. Monitoring software written at Cambridge was used to provide near-online histograms and an event display (see Fig. 2). These were produced using an offline job running on the data files was they weere being written during the ongoing run, thereby providing very rapid feedback. This was of great value in providing feedback during the running period.

The major task of understanding the combined data and comparing with simulations has started. For example, in Fig. 3 we show a first study from the UK groups of the linearity and resolution of the ECAL for electrons, based on preliminary calibrations.

The UK groups, because of their knowledge of the DAQ system, and their track record in data analysis and simulation already, are in a prime position to take the lead in this effort. We intend that the UK should maintain its leading rôle in understanding the CALICE data and in validating the Monte Carlo tools.

The final 2006 running period at CERN in October will be largely devoted to hadron running and will be complete by the time of the next OsC meeting. There will be improvements to the detector geometry (closing gaps between the different calorimeters) and additional instrumented planes in the AHCAL and TCMT. The overall goal of all the beam tests is to accumulate a sample of around 10^8 beam events including both the AHCAL and DHCAL, i.e. around 50M events for each. We have recorded around 35M beam events with ECAL and/or AHCAL at DESY and CERN so far this year. In addition, we obtained 25M muon calibration events when running parasitically. With good beam, we are confident that we can get at least 20M more events in the October run.

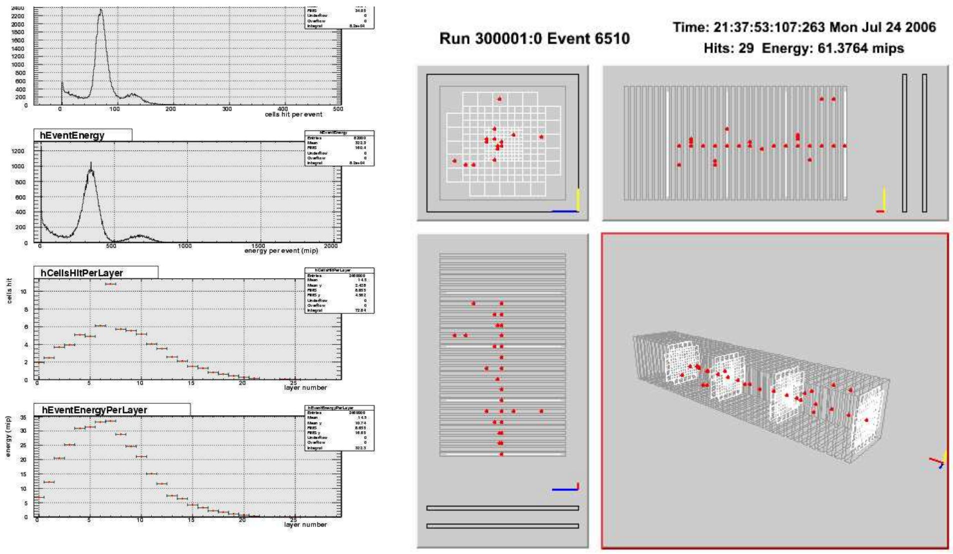

Figure 2: *Near-online monitoring – typical histograms (left) and AHCAL event display for a throughgoing muon (right).*

For 2007, the ECAL and AHCAL will both be complete by the time the CERN test beam period starts in May 2007. Due to the ongoing upgrades at FNAL not being completed until July (see below), then we will bid for further run time at CERN between May and July 2007 to take data with the completed detectors before moving to FNAL. In addition, the AHCAL wil by that time be mounted on a movable stage, allowing non-normal incidence for the beam in the AHCAL also. Successful completion of the CERN beam tests will require the measurement of samples of at least 10^5 fully-contained hadronic showers with energies from roughly 6-100 GeV at angles from 0 to 45°.

4.4 Task 1.4: FNAL test beam

The TCMT has already taken some test data at the FNAL MTBF beam with one of its 16 layers during February 2006 in a hadron beam at FNAL, using 120 GeV protons and 16 GeV pions. This was a technical commissioning run and around 1M events were collected. However, it provided us with first experience of the beam line which has helped in planning.

Significant improvements are currently being made to the test beam at FNAL, especially in regard to low energy hadrons (of special importance for Monte Carlo validation). These improvements will continue in 2007 with a second downtime in June and July.

The exact timing of the runs in 2007 is not fixed although it is most likely that the ECAL, AHCAL and TCMT will move to FNAL in September 2007 and take data there for the rest of the year. This will provide lower energy hadrons than available at CERN and will cross check the FNAL and CERN beam results. Running the AHCAL at FNAL will also assist in the comparison between the AHCAL data and the DHCAL data. When it is complete, late in 2007 or early 2008, the DHCAL will be moved in to replace the AHCAL and so running throughout early 2008 is expected.

5 WP2: DAQ

The aim of WP2 is *not* to design a DAQ system; given the speed to technology developments over the period before the ILC will be built, then any design based on current technology would

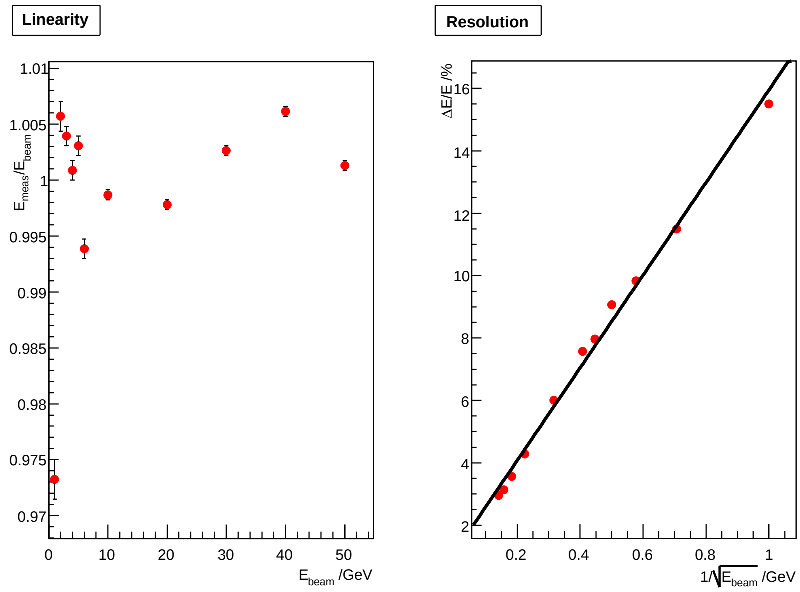

Figure 3: *ECAL energy response and energy resolution plotted as a function of electron energy, combining data from the DESY and CERN runs. These results are preliminary.*

be obsolete before it was built. The aim is to understand the issues and throughputs of the required DAQ system. We have identified what we believe to be the bottlenecks and critical points of the system and have targetted the R&D onto these areas. By studing these, and keeping on top of technical developments, this will allow us to propose a feasible DAQ system for the TDR. In addition, by working in generic areas of the DAQ, then most of the work would be equally applicable to the HCAL or even the rest of the detector to a large extent.

As well as meeting the goals of the grant awarded by PPARC, this workpackage needs to achieve the work programme set out in the EUDET project. This will put the UK at the forefront of DAQ activities for the calorimeter (if not wider) and place us in a position to build the DAQ for the final detector when it is constructed. The effort in EUDET concentrates on providing a technical prototype by the beginning of 2009 at which point we should have a working DAQ system to readout this detector. Although not directly under the remit of PPARC, relation to the EUDET activities is stated where applicable.

5.1 Task 2.1: Readout of prototype VFE ASICs

The current version of the Very Front End (VFE) ASIC chip is being used to read out the existing CALICE ECAL prototype. This chip does not meet the requirements for the ILC ECAL and the development of the design is an ongoing project in LAL/Orsay. The LAL group expect to have a new version of the ASIC developed for each of the next few years. We will provide valuable tests of these ASICs and feedback into the next rounds of design. Close collaboration with the French groups is ongoing, also in connection with the EUDET project.

A next ASIC version for testing will be fabricated by the end of February 2007 which should incorporate all features expected of the ILC ASIC. Initial tests of this chip will be done on a small scale at Imperial and will require us to build a simple PCB to read out multiple chips. This will give us valuable experience with these chips and enable us to feedback any design problems for the next version expected a year after that. The results will allow modifications to be made before the final ASIC design is produced for the technical prototype which will be fully finished at the beginning of 2009. Due to this schedule, this task is yet to start; preparatory work will start at the end of 2006.

5.2 Task 2.2: Study of data paths over 1.5 m slab

The design of a model 1.5 m PCB is now almost complete. This consists of five shorter PCBs stitched together as shown in Fig. 4. Each of these PCBs contains a number of FPGAs which act as pseudo ASICs to allow tests of the data transfer along such a board. The general structure has been decided upon by Cambridge in collaboration with the French groups who will build the technical prototype using the results of this task.

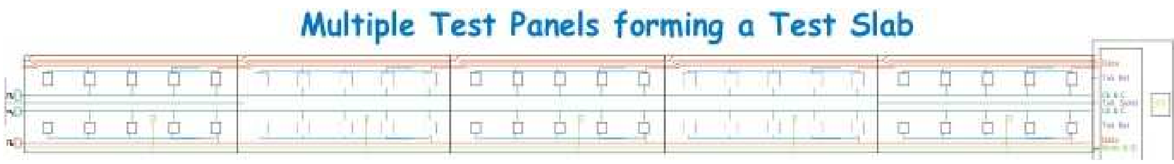

Figure 4: *Design of a test PCB using five short panels.*

The board schematics are finished as shown in Fig. 5 and the layout almost completed. The functionality of the ASIC chips has been coded into FPGAs and suggestions on improving this fed back to the French groups designing the ASICs. The front-end board design work is about to start with the test system commissioned and ready for the data transfer tests in January 2007. It should be noted that the design of the front-end board for EUDET has been an open project with none of the CALICE/EUDET groups committed to it. Our work here should allow us to take on this role for the EUDET technical module; an additional activity which gains us more influence within the project.

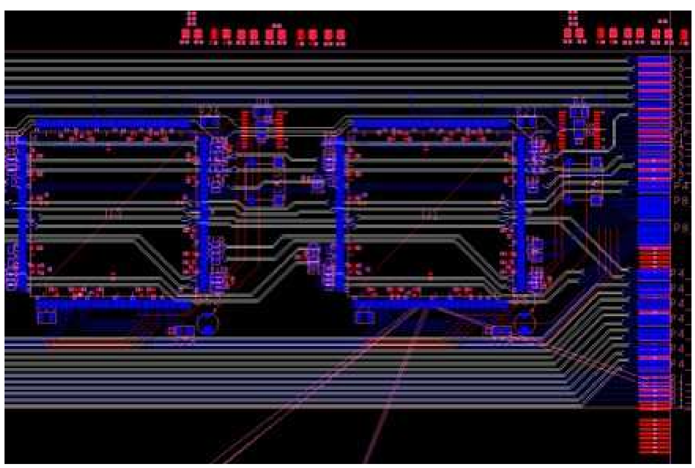

Figure 5: *Schematics of slab PCB.*

5.3 Task 2.3: Connection from on- to the off-detector receiver

The main activities at Manchester within this task have been firmware development for the connection of the FPGA to Gigabit ethernet and setting up a lab for 10 Gbit tests. Using a PCI card similar to that shown in Fig. 6, the first part is now complete (and will also be useful for

Task 2.5) and data transfer tests have started. The first of these corresponds to milestone ID37 in the WP2 Gannt chart.

These tests will continue during the coming months culminating in a report on the FPGA and ethernet data transfer tests at the beginning of 2007. The lab completion has been delayed due to the contractors not having physically finished the refurbishment. Once this is complete, the lab should be set-up quickly.

5.4 Task 2.4: Transport of configuration, clock and control data

The two major initial activities in this task are to simulate the radiation environment at the front-end electronics and a literature search of expected problems and other tests performed on FPGAs, both being undertaken at UCL. The latter is progressing and will be finished by the end of the year. The former was making good progress with over half of it done and most importantly the general concept and structure in place for simulating the radiation dose impinging on the electronics. Unfortunately, the UCL Research Associate working in this area has decided to leave and has left this project hanging. We hope to re-hire quickly and will have this task as top priority for the new RA. Having initially planned to have results for this report, we have now put this back by three months assuming we can hire someone immediately.

5.5 Task 2.5: Prototype off-detector receiver

Three PCI cards (one for each of the institutes involved in the task, specifically RHUL, Manchester and UCL) have been bought from a company, PLD Applications. These cards meet all the specified requirements, which means there will be no time-consuming rounds of fabrication. Acquisition of these cards completes milestone ID86.

A picture of the card is shown in Fig. 6, which contains a large FPGA, Gbit ethernet and a $\times 8$ lane PCI Express; they are now hosted in PCs in the respective University labs.

Figure 6: *PLD Applications PCI card.*

A block diagram of the system design has been made, where the first task, “Stage 1”, is shown in Fig. 7 which will allow data to be read in and out of the host memory and throughput measured. Each box is a modular task assigned to a person and the code collected in a common repository. The darkly shaded boxes in the interface card are complete. Work on the others is ongoing with the Gigabit ethernet tasks close to completion by using the work already done in Task 2.3. This is the most important task for the EUDET project which will require a working DAQ system by 2009.

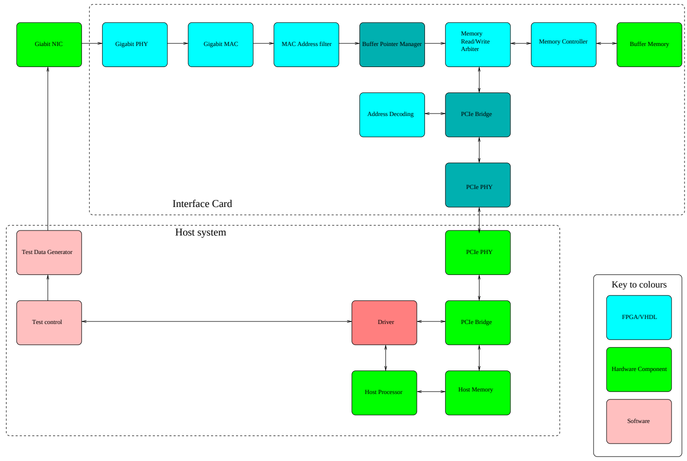

Figure 7: *Block diagram of Stage 1 of the system.*

6 WP3: MAPS Development

The MAPS project has continued effectively on schedule since the last OsC meeting. The project has had regular meetings throughout this period[1]. The study is currently in the sensor circuit design phase with fabrication of the first sensor due in April 2007.

The project moved from the preliminary to actual design phase following the Preliminary Design Review (PDR) in May 2006 the only scheduled milestone in WP3 so far, corresponding to ID3 on the Gannt chart. This review is part of the ISO9001 process used in RAL/EID. The review included two external reviewers and documented the effort, risks and of the project. The documentation for the review is publically available[2]. The PDR also required the sensor tests to be documented in some detail so as to define the criteria for judging whether the sensors are working to a sufficient level. This included an estimate of the time needed for the sensor tests. As expected with small sensors, the time to accumulate enough cosmics determines the time needed once the sensors can be made to function reliably. The cosmics data run is expected to take around two to three months.

One outcome of the PDR was the decision to use $0.18\,\mu$m technology. This will allow a higher density of connectivity between the MAPS pixels and the common clock/readout sections, resulting in a smaller dead area. Other active areas of study are the optimisation of the charge collection in the signal diodes compared with charge loss in the n-well areas due to the on-pixel circuitry and the reduction of noise through various reset schemes.

All future reviews will be covered by the ISO9001 system and will require sign-off by the WP leader. We also plan to use external reviewers in all cases. The next will be the Interim Design Review (IDR), which is milestone ID5. This is scheduled for Oct 4, before the OsC meeting in November, This review will include three external reviewers and will allow the project to move from design to layout phase. The layout is heavily dependent on the foundry design rules used for the fabrication and so a decision on the foundry will need to be made at this time. A call for tenders for the fabrication was issued in July and three bids were received by the September deadline; these are currently being evaluated and a decision will be taken by the time of the IDR.

Longer term, it is of course not yet clear exactly how the actual technology eventually used in the ECAL will be chosen. Assuming any design under serious consideration is capable of

[1] `http::/www.hep.ph.imperial.ac.uk/calice/mapsMeetings/meetings.html`

[2] `http::/www.hep.ph.imperial.ac.uk/calice/maps/pdr/pdr.html`

fulfilling the physics requirements, then the most critical issues are cost and power. However, it is almost inevitable that the decision will not be purely technology-driven and that political issues will play a part. This means we have to broaden the support for a MAPS ECAL beyond the UK by the time of the TDR and this in turn requires proof of the concept. The technical goals of WP3, which are to produce a real sensor, are aimed directly towards achieving this proof of concept.

7 WP4: Thermal and Mechanical Studies

WP4 is a smaller project which is using existing expertise in the Manchester group, arising from their work in ATLAS, to study thermal and mechanical aspects for the ECAL mechanical structure. While the UK is not leading the ECAL mechanical design, this work gives us a foothold in this area which we may choose to exploit at a later date. There are currently two main avenues of investigation – studies of conducting glues and thermal simulation of the calorimeter slabs and associated electronics with the third due to start next year.

7.1 Task 4.1: Bonding and glue studies

Milestone ID4, the literature search and subsequent documentation on various conducting glues, has been completed[3] and sample procurement is underway for the long-term tests that are scheduled to begin in October – details of the glues can be found in the report appendix[4]. These tests require construction of PCBs to host the glue samples and interconnects in various configurations. The PCB has been sent out for manufacture and we expect the completed boards before the end of September.

In order that the tests are as realistic as possible, samples of the test structures from the silicon wafers used to produce the actual CALICE diode pads have been obtained from our collaborators in the Czech Republic, shown in Fig. 8. Also in hand in Manchester are full-sized wafers that have failed quality control for use in the ECAL prototype but that can be used for the glue tests and surface interface studies, also in Fig. 8.

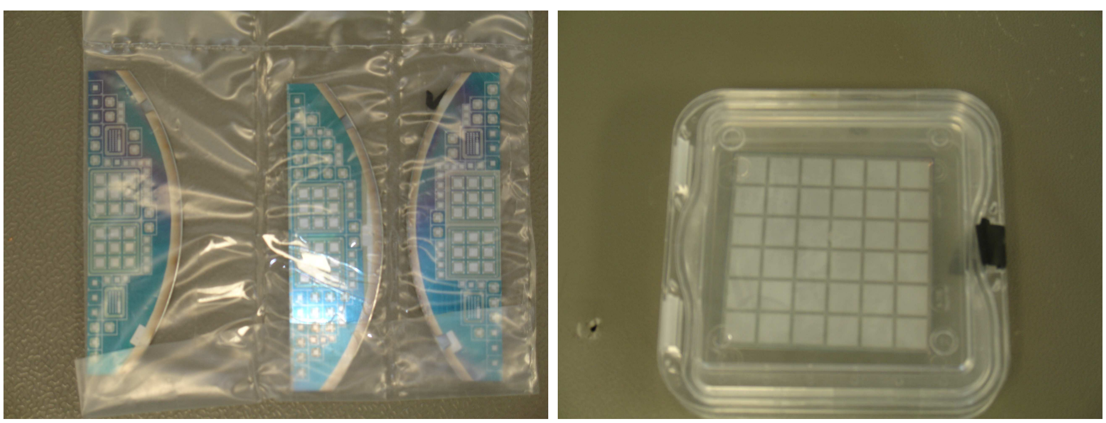

Figure 8: *Left: Test structures from the edge of the CALICE wafers. Right: One of the full-sized CALICE wafers for use in glue tests.*

Long-term tests will begin in October and run through March 2007, after which an assessment of the suitability of conductive glue for use in the ILC detectors will be made. If the glue proves

[3]http://www.hep.man.ac.uk/calice/GlueReport.pdf
[4]http://www.hep.man.ac.uk/calice/GlueReportAppendix.pdf

unsuitable, a study will be undertaken to investigate wire-bonding the front end ASICs directly to the diode pads. It is now possible to carry out wire-bonding tests in house at Manchester, but some design work will be necessary beforehand to modify the wafer layout.

7.2 Task 4.2: Thermal studies

Thermal simulations of the current CALICE prototype have been carried out and results reported within CALICE[5]. The new simulations were improvements on previous iterations using the most recent materials and designs supplied by our French collaborators. Fig. 9 shows the latest design as implemented in the FlexPDE package. The result of the simulation for three adjacent cells with a heatsink at the top of the figure is shown in Fig. 10. This detailed model shows good agreement with the simple calculations carried out previously, showing that the expected temperature rise along a slab cooled at one end is of the order of 10°C. One of the major uncertainties in the simulation is the thermal conductivity of carbon fibre transverse to the fibre plane. Measurements will be carried out to compare thermal conductivities in and out of plane and the simulations updated accordingly.

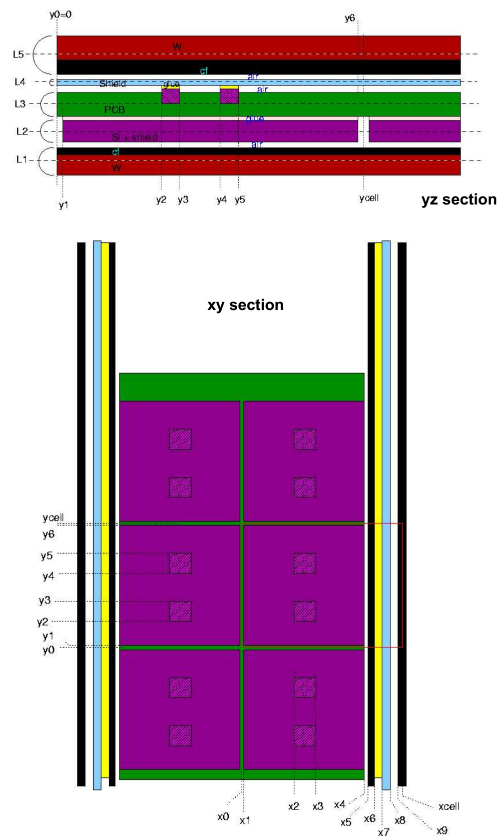

Figure 9: *Slab layout used for improved thermal simulation. In particular the ASICs are now discrete heat sources.*

If the current slab design requires modification in the light of results from the long-term glue tests, these simulations will have to be repeated. Design of the cooling system for the slabs will thus be postponed, pending the outcome of these tests.

[5] http://www.hep.physics.mcgill.ca/XHEP/ILC/calice/meeting/talks/2_ECAL/2_07_bailey.pdf

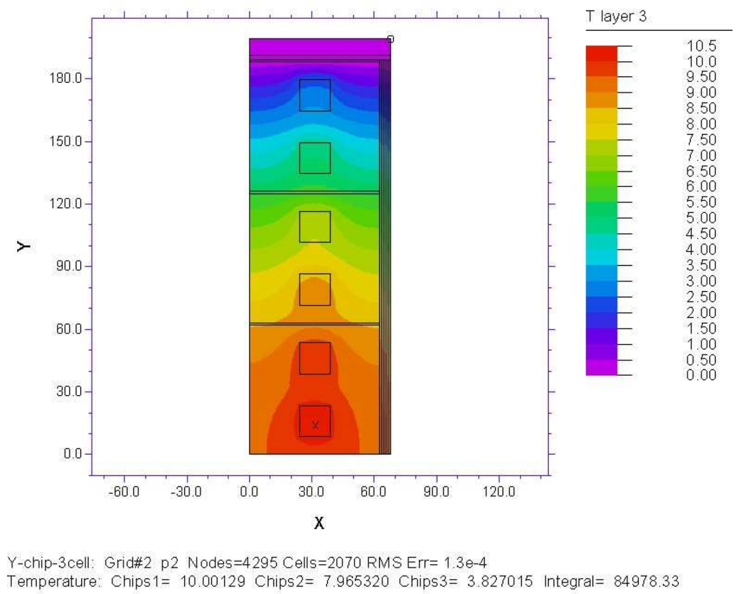

Figure 10: *Thermal simulation results carried out using the latest slab layout. Cooling is applied at the top of the figure. Three cells (wafers + ASICs) are simulated.*

7.3 Task 4.3: ECAL assembly

Work on design and prototyping of the ECAL slab assembly machines will start in 2007 after the glue assessment has been completed as the latter has a direct impact on any automated assembly system.

8 WP5: Physics and simulation studies

The simulation and physics work package has made steady progress during six months since the previous report. Regular UK group meetings have continued with details on the project web pages[6]. A European ILC software workshop[7] was hosted by the Cambridge group in April 2006, and this has been followed up by a new series of meetings discussing (largely European) reconstruction software, jointly organised by Cambridge. During this period, the expected milestones were achieved as outlined below, some of which were critical to the project schedule. The progress already made in all four tasks of the project outlined in the CALICE proposal, both within the UK and in the wider international context, is summarised below.

8.1 Task 5.1: Energy Flow algorithms

In the previous report, it was noted that the MarlinReco package had been released by the DESY group in Aug. 2005, providing a de facto standard on which studies could be based, and that a new particle flow algorithm was being developed within the UK. A major milestone, ID8 in the Gannt chart, was the first public release of a version of PandoraPFA in Aug. 2006[8]. The codehas been used within the Cambridge group for studies of WW/ZZ separation[9], within

[6] `http://www.ep.ph.bham.ac.uk/exp/CALICE/sim/`

[7] `http://www.hep.phy.cam.ac.uk/~thomson/meetings/ilcsoft/`

[8] M.A.Thomson talk at ECFA Software meeting, Aug. 2006, `http://ilcagenda.cern.ch/getFile.py/access?contribId=5&resId=0&materialId=slides&confId=1040`

[9] `http://ilcagenda.cern.ch/getFile.py/access?contribId=7&resId=0&materialId=slides&confId=1040`

RHUL for ZHH and WW/ZZ[10] separation, and at Birmingham in studying MAPS cluster finding efficiency[11].

8.2 Task 5.2: Global detector design

Using PandoraPFA, a study[12] of jet energy resolution has been carried out using the LDC model, investigating performance as a function of HCAL transverse segmentation and depth, and of TPC radius and magnetic field. This follows on from the single particle performance studies reported in March 2006 for LDC.

8.3 Task 5.3: Workpackage support

The work on DAQ local clustering has been rescheduled to start in January 2007, the estimated start time of the replacement RA at UCL; it is not on the critical path.

The implementation of the MAPS sensor geometry (passive substrate with active epitaxial layer of 15μm) has been made in Mokka-06-01 by Birmingham as planned, corresponding to milestone ID26. Previously it was noted that technical difficulties in implementing the $\sim 10^{12}$ sensors in the simulation (specifically in the I/O package, LCIO) had been identified. After discussion with the authors of LCIO, this has been resolved and is no longer an issue.

Pixel pitch is a critical design parameter for MAPS and so this has been varied in Mokka within the range 5–200μm. The resulting effect on key figures of merit such as pixel occupancy and multiplicity has been studied for a wide range of energies[13]. Although this work has begun[14], it is necessary to make improve the sophistication by inclusion of digitisation (with sensor-level simulation of efficiency) and subsequent use of a physics-based metric such as mass resolution.

8.4 Task 5.4: Physics studies

Physics studies using the ZHH process at RHUL have progressed well, achieving milestone ID33 to present initial results of this at a regional workshop in April 2006[15]. To make most efficient use of the effort available, the analysis code has itself been made publically available for others to use[16], although main development will naturally continue within RHUL. The analysis is not truly generic for technical reasons relating to the packages employed, for example the track reconstruction is intrinsically different for a TPC (LDC) and a silicon based tracker with a very small number of precisely measured space points (SiD). However, explicit dependence on a specific detector can be reduced, e.g. by using XML files (largely generated by the Geant4 detector simulation applications) to describe those aspects of the detector parameters required by the reconstruction code. With this baseline analysis based on a complete physics analysis in place for the LDC detector concept, it is planned to extend to SiD. This activity complements studies of jet resolution described above which are already well underway.

Alternative physics studies have also been initiated for $t\bar{t}$ at Cambridge, and WW/ZZ separation at Cambridge and RHUL, with updates presented to UK group meetings[17], LDC meetings

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[10] http://www.pp.rhul.ac.uk/~calice/giannell/Michele%20Faucci%20Giannelli,%20Cern%20coll.%20meeting,%2020-9-06.ppt

[11] http://www.hep.ph.ic.ac.uk/~calice/mapsMeetings/060906ral/hopkinson.pdf

[12] M.A.Thomson, talk at LDC phone meeting, Sep. 2006, http://ilcagenda.cern.ch/conferenceDisplay.py?confId=1097

[13] http://www.hep.ph.ic.ac.uk/~calice/mapsMeetings/060906ral/mikami.pdf

[14] See: http://www.hep.ph.ic.ac.uk/~calice/mapsMeetings/060906ral/hopkinson.pdf

[15] http://www.hep.phy.cam.ac.uk/~thomson/meetings/ilcsoft/

[16] See http://www.pp.rhul.ac.uk/~calice/giannell/

[17] http://www.ep.ph.bham.ac.uk/exp/CALICE/sim/meetings/index.html

and ECFA reconstruction meetings. Most recently, RHUL results were presented at a CALICE collaboration meeting[18].

9 Financial and managerial status

The Gannt charts, financial tables and risk tables are supplied separately.

9.1 Presentation of financial tables

The tables are presented in the requested format with the following interpretation of the columns.

Column 2 gives the actual spend to date and column 3 the spend as projected to date in the original approval. The penultimate column is the difference between these two columns and thus gives the underspend or overspend to date.

Column 5, being the sum of columns 2 and 4, gives the latest estimate of spend to the end of the project. Column 6, being the sum of the amount originally projected to be spent to date and the future intended spend profile, is not meaningful.

The final column is our current estimate of the variance in spend at the end of the project. The working allowance is not included in the total.

9.2 Comments on expenditure

Delayed appointments of PDRAs at Birmingham and Imperial transfer spend towards the end of the project, leading to small actual underspends and projected overspends. The variations in the RHUL and UCL effort reflect the transfer recently approved to allow an earlier start and later finish of a PDRA at RHUL from PPARC funds, with the UCL PDRA transferred to the EUDET grant. The final nine months of effort at RHUL from April 2009 (approximately £38k) has been included in FY08/9.

RAL has not been able to provide staff expenditure numbers in time for this paper. Thus the PPD and ED lines are our estimates. The ED line shows an underspend since one of the individuals involved has been working about 85% on the project rather than 100% as planned.

The equipment, consumables and travel expenditure has been obtained from the RAL FRS system. Since processing of expenditure in Universities takes a considerable time to reach the RAL system the actual underspend shown in these lines is significantly smaller.

9.3 Comments on Gannt charts

Since the last OsC meeting we have converted the Gantt charts to Microsoft Project format as requested. In parallel we have reviewed the tasks in each workpackage, and added more milestones. We have now frozen this version until the end of the project. Most of the changes to the schedule arising from this review are minor.

More significant changes to which we draw the OsC's attention are as follows:

- WP1: FNAL test beam running will now take place much later than originally scheduled (details discussed in Section 4 above).
- WP2: We have now defined the tasks in this workpackage in much more detail and comparison with the original version is difficult. For Task 2.5 we will now use a commercial PCI card rather than designing and building our own card.

[18] `http://polywww.in2p3.fr/services/cdsagenda/userLog.php?nextpage=%2Fservices%2Fcdsagenda%2FfullAgenda.php&nextquery=ida%3Da0627`

- WP4: The start of the thermal measurements and design of the cooling have been delayed but will be completed earlier than originally foreseen.
- WP5: The DAQ local clustering task has been delayed but has no impact on the final schedule.

10 Summary

During the time since the last OsC meeting, CALICE has made a lot of progress, with a very successful start to its combined data runs. These will continue at CERN in October but will be complete for 2006 by the time of the OsC meeting in November. Further runs at CERN and FNAL are expected in 2007 and 2008.

The workpackages other than WP1 have continued to make progress since the last meeting. They are all on, or close to, schedule and financially within the budget. No milestones have been missed and no significant problems have been identified yet.