August 10, 2007

Report on the Review of "ILC Calorimetry R&D" Hamburg, May 31-st to June 4-th

The ILC Detector R&D panel organised a review of the current status and future plans of the world-wide R&D for calorimeters to be used in future ILC detectors. For the review a committee of 10 calorimetry experts from outside the ILC community was formed to critically examine the research work. All collaborations and groups registered by the R&D panel have been invited to prepare a written report on their results and plans prior to the review and give presentations in open sessions.

The Review Committee

The members of the committee are:

Marcella Diemoz, Univ. di Roma I "La Sapienza"
Andrey Golutvin, ITEP Moscow
Kazuhiko Hara, Tsukuba University
Robert Klanner, Hamburg University
Peter Loch, University of Arizona
Pierre Petroff, LAL Orsay
Jim Pilcher, University of Chicago
Daniel Pitzl, DESY
Peter Schacht, MPI Munich
Chris Tully, Princeton University

In addition, three regional representatives were invited:

For the Americas	Michael Rijssenbeek, Stony Brook University,
For Asia	Junji Haba, KEK
For Europe	Jan Timmermans, NIKHEF

The Machine R&D panel was represented by:

Bill Willis, Columbia Nevis Labs

The committee was assisted by the panel members

Jean-Claude Brient, Ecole Polytechnique Palaiseau
Chris Damerell, Rutherford Appleton Lab
Ray Frey, University of Oregon
Wolfgang Lohmann, DESY, Chair

Administrative support was given by the secretaries:

Martina Mende, DESY
Naomi Nagahashi, SLAC

Introduction

The calorimeters for the ILC detectors must have excellent performance to fully exploit the physics potential of the ILC. Many processes, unique for the physics program of the ILC, are characterised by final states containing multiple hadronic jets. The experiments seek to reconstruct these states with unprecedented precision using new calorimetry techniques.

One goal is to improve the jet energy resolution achieved in current experiments by a factor of two. Furthermore, the ability to resolve hadronic tau-lepton decays or the determination of the direction of an electromagnetic shower are essential for physics.

Hence we need to develop these novel technologies and show by direct measurement that they work and can be built.

Another stringent requirement for excellent performance in new particle searches is a hermetic detector. This means in practice that calorimeters should extend down to the smallest possible polar angles. At small polar angles we face a new phenomenon, e^+e^- pairs created by beamstrahlung hit the calorimeters and deposit several MGy dose per year. Hence radiation hard sensors are needed. Finally, the physics requires a measurement of the delivered luminosity to one part in a thousand or better. This requires special calorimeters in the very forward region with precisely controlled fiducial areas in polar angle.

There is already substantial ongoing R&D effort for ILC calorimeters. Since the schedule for the ILC machine is taking shape it is essential now to enhance the R&D to allow reliable planning of the ILC program and to ensure that ILC detectors of the necessary performance are ready in time for the machine start.

During the LCWS and ILC2007 workshops in Hamburg the Detector R&D Panel organised a global review on calorimetry R&D. The panel formed a dedicated committee of ten calorimetry experts from outside the ILC community and representatives from the major regions - Americas, Asia and Europe - to critically examine the ongoing R&D activities and to give guidance to the collaborations to sharpen the R&D goals.

The panel invited all collaborations and groups working on the field of calorimetry- six in total- to summarise their R&D status, goals and plans in a written report available for the committee members two weeks in advance.

The first-one-and-a-half days of the review were devoted to presentations of the research results in open sessions, held in the large FEL lecture hall at DESY.

After the open sessions the committee invited each research group to a closed session allowing the committee members to discuss research goals, technological priorities and the plans for the future in more detail. Finally the committee drafted preliminary conclusions, communicated to the research groups in a closeout session.

The Collaborations and Research Groups

The six entities invited to the review are four collaborations, CALICE, DREAM, FCAL and SiD-CAL, and two smaller groups from the University of Kansas and from Fermilab.

CALICE is a world-wide R&D collaboration, consisting of about 200 physicists from 41 institutes. DREAM has 12 members from 8 institutes in United States and Europe. Within FCAL about 80 physicists from 15 institutes from United States and Europe are working together. SiD-CAL consists of xx institutions, mostly from United States, collaborating within the SiD concept. Several of these groups are also members of CALICE.

CALICE and SiDCAL propose fine segmented electromagnetic and hadron calorimeters using particle-flow analysis (PFA) techniques for the determination of the jet energy and momentum. DREAM is based on the 'dual readout' concept, measuring scintillation and Cerenkov light induced in a shower separately. FCAL is devoted to the design of special forward calorimeters. The groups from University of Kansas and Fermilab made simulation studies to design calorimeters using PFA techniques or dual readout, respectively, for jet energy measurement.

The PFA Technique for the Measurement of the Jet Energy

The PFA method is a novel approach in calorimetry. It assumes that the energy of charged particles will be accurately measured with the tracking detectors and the energy of photons will be accurately measured in the electromagnetic calorimeter. This leaves the primary role of the hadron calorimeter to measure the energy of long lived neutral hadrons. Fine granularity is essential to ensure that hits can be uniquely assigned to energy clusters and correspondingly assigned as charged or neutral electromagnetic objects, charged hadrons or neutral hadrons. The anticipated jet energy resolution is $30\%/\sqrt(E)$, about a factor of 2 better than that of calorimeters operating in collider experiments.

A number of effects degrade the PFA performance. These include the overlap of energy deposition of hadrons and photons in the electromagnetic calorimeters and of charged and neutral hadrons in the hadron calorimeter. Also, confusion in the charged particle tracker can lead to a degraded momentum measurements as well as miss-association of tracks with calorimeter energy depositions.

The first challenge for the PFA approach is to understand how the performance of the algorithm for well-defined benchmarks behaves as a function of cell granularity, radius of the tracking detectors, hit response, containment and external factors such as magnetic field and tracking material budget.

The second challenge is to determine how an ideal detector performance with perfect understanding of the particle response is modified by imperfect knowledge of the cell calibration and hadron shower simulations.

Presently all information is based on MC studies. Thus any approach to assess the impact of the 'confusion term' has large uncertainties. The hope to use test-beam data e.g. from the MIPP collaboration, to improve present GEANT4 versions might be too optimistic on the timescale required. In the past GEANT4 iterations took quite some time and the convergence of this process is by no means established. Therefore it is of interest to use wherever possible real data from detectors as close as possible with the ones planned for the ILC.

The PFA group is planning simulations of test-beams as already done within CALICE in order to test and tune the shower simulation programs which fit the best with the different detector's data. The CALICE collaboration started a test beam campaign in 2006 and plans to continue up to 2009. A test beam of neutral hadrons may be available at Fermilab if there is sufficient interest, although some members of CALICE are skeptical of its utility. One might also obtain information on neutron interactions from proton and pion test beams but obviously real data would be preferable. A comparison of these results with the related MC simulation might reveal shortcomings in the MC simulation. Also the use of test beam data - at least partially - in jet simulations might yield more realistic results.

As the impact of the PFA approach is crucial, the following studies need special attention:

- More detailed performance studies for a common set of physics benchmark processes to understand the combined performance of several detector subsystems are necessary. From these, a list or sample of low-level benchmarks (W/Z mass resolution, τ identification and measurement, particle identification) is to be derived for optimization of individual subsystems.

- Rather generic PFA studies with respect to the optimisation of the detector granularity (longitudinal and lateral) are required. The understanding of the performance on the granularity selected is essential for cost optimisation.

- PFA studies should include more realistic assumptions about detector uniformity, stability, calibration and expected cell losses, with the goal of exploring the robustness of the results.
- For each of the above studies the energy dependence of the performance needs to be understood up to the highest jet energies. As 'fall back' alternative all results should be compared with results based on software compensation methods .

CALICE

CALICE is the largest Collaboration in calorimetry R&D, uniting about 200 researchers from 41 institutes around the world. The committee appreciated the clear structure and responsibilities within the collaboration, the high level of cooperation between the different groups and the creation and successful use of common infrastructure. Many of the general issues pertaining to PFA calorimetry are already addressed by this common effort. These comments will therefore focus on steps needed to further improve this R&D effort and, in particular, in ways that are critical for converging on technology choices.

CALICE follows two main R&D directions, the "physics prototypes" and "technical prototypes". The "physics prototypes" studies are based on large electromagnetic and hadronic calorimeters built with technologies anticipated for the ILC. They undergo beam tests to acquire large data sets for several beam particles and energies. These tests first will allow to collect experience for the construction and operation of fine-grained and extremely dense calorimeters which will in the final version have three orders of magnitude more readout channels as e.g. LHC calorimeters. The data taken will then be used for comparisons with several models used in Monte Carlo shower simulations where the goal is to identify the shower model showing the best agreement with the data and tune it for further studies to optimise the detector. Beam tests are ongoing or planned for different calorimeter technologies both for the electromagnetic and hadron calorimeter allowing a systematic comparison of their performance.

The feedback on design parameters from PFA studies should be strengthened. The issue is addressed by the recently created PFA working group, and we encourage that CALICE continues to participate in this group and incorporate and test the suggestions of this group in their test beam program.

The technical prototype developments are devoted to built semi-realistic ILC detector like calorimeter modules. They are intended to give crucial information on integration issues and constraints for a full-scale calorimeter. Test in particle beams are planned in 2009-2010.

Electromagnetic Calorimetry

While the energy resolution requirement for the electromagnetic calorimeter, ECAL, is relatively modest, the granularity required for PFA is extreme leading to large numbers of readout channels. Technological choices under study are silicon-tungsten and scintillator-tungsten sandwich calorimeters. Because the required granularity is completely driven by the PFA approach, we again stress the need for proof of robustness of the PFA approach measured on the benchmarks under realistic operational conditions.

The thin sensor layers possible with silicon also limit the effective Moliere radius to about 1 cm and thus the transverse size of the electromagnetic showers, thereby improving PFA performance. It seems that the silicon-tungsten option for the ECAL is much further advanced and possibly superior to the scintillating strip readout option due to finer granularity and a lower effective

Moliere radius. However, significantly better energy resolution has been demonstrated with a scintillator-tungsten ECAL. The ECAL energy resolution might be important for several physics cases like b-jet measurements with several π^0 mesons, e.g. the possible reconstruction of π^0 mesons from the photon showers may have impact on the b-jet measurement.

Scintillators are readout by novel silicon photo sensors, called MMPC[1], operated in the Geiger mode. Concerns have been addressed to the sample-to-sample fluctuation in mass production, the long-term stability, the temperature dependence of the response, the linearity and the relatively large cross-talk probability.

Test beam data are just taken with "physics prototypes". Preliminary results demonstrate that the prototypes are operating within expectations. However, some issues of large-scale operational performance remain and need addressing: reliability, uniformity, calibration, stability, and robustness against loss of (groups of) cells. It seems that realistic studies of in-situ calibration schemes have barely began.

The silicon-tungsten ECAL "technical prototype" concept is nicely detailed (design studies, electronics, heat load) and seems quite robust. The FE readout chip, called SKIROC, is based on SiGe technology.

Hadron Calorimetry

Sampling calorimeters with iron as absorber are studied. For the sensors several options are considered:

- Scintillator tiles of 3x3 cm^2 size readout by novel photo sensors called Silicon Photo-Multipliers, SiPMs. This technique is hereafter referred to as analog HCAL
- Gaseous Electron Multipliers, GEMs, with a one or two bit readout
- Resistive Plate Chambers, RPCs, with a one or two bit readout
- Micromegas, with a one or two bit readout

Current simulations of hadron showers have significant differences, although no mention was made of similar comparisons for test beam studies of the LHC detectors.

An almost complete one m^3 prototype of the analog HCAL, supplemented by a tail catcher, is under test in electron, muon and hadron beams in the energy range from 5 - 40 GeV.

The use of SiPMs allows fine segmentation without external fibers. About 15 photons per mip are expected and a direct measurement of the gain is possible from the position of the few-photon response peaks. A LED pulser and PIN diodes will be used to monitor performance. Development of a configuration with direct coupled SiPMs is under study. The future test beam program will and needs to assess the impact on long term stability, failure rate, aging and monitoring (time-dependence, LED monitoring) issues. Also the mip and calibration procedures in major systems need to be understood. Further the energy dependence of the hadron response on the electromagnetic scale has to be studied. Therefore it is important to extend the lever arm in particle energy to lower and higher energies. The upcoming tests at Fermilab will yield this crucial information.

Preliminary results on the performance were presented. The analog HCAL was tested at CERN with an ECAL in front and a tail catching muon tracker (TCMT) behind. The response to 10 and 20 GeV hadrons is quite symmetric and agrees well with GEANT4 simulations. The analysis is continuing.

[1]MMPC are devices similar to the Silicon PMs mentioned below manufactured by Hamamatsu Corp.

Plans are presented to test a one m^3 HCAL configuration using shower sampling in a gaseous medium with fine-grained digital readout. The iron absorber structure will be equipped with RPCs, GEM, and MicroMegas detectors. The test-beam data obtained will allow to compare the different sensor and read-out technologies.

The technical prototype preparation, including the integrated FE electronics, is well on schedule.

Summary

CALICE has successfully brought in several detector technologies to work together on compiling a common set of data to compare the performance and pros and contras of different technologies. While keeping an open door to the testing of new detector technologies, the collaboration needs to define a procedure and goals for the test beam data in order to aid in the convergence on final detector choices. It is well known that small low-containment test beam modules provide limited input on full scale hadron calorimeter performance. The construction of a m^3 HCAL modules is essential for providing reliable data for PFA performance comparisons. The RPC, GEM and Micromegas technologies need to be studied urgently in a larger system. Again, issues like long term stability, calibration, aging, reliability, technical risks, rate capability need to be addressed in the near future. The consequence of the one bit digital read-out needs to be compared in detail with the analogue option. Also a comparison to a 2-bit digital read-out (more than one threshold) might be useful.

The inclusion of calibration data methods, i.e. mips and test pulses, is also important in understanding what data is needed to maintain the performance of these high granularity calorimeters in an experiment. The comparison of the performance of the various technologies needs to be done on the basis of real data rather than MC studies. Therefore attention should be paid to have the set-up of the various modes as similar as possible both for ECAL and HCAL technology options.

The committee is impressed by the exceptional quality and the enormous collaborative effort of the CALICE collaboration. The collaboration should be further supported and commended for its achievements. In particular, the funding agencies are strongly requested to support the one m^3 engineering and test beam effort. Groups that are unable to test e.g. their HCAL technologies on this scale will have a little chance only of being selected as a technology for the final ILC detectors.

The development and test of the technical prototypes will allow to answer many concerns addressed above. Hence the committee fully supports also this program.

SiDCAL

The SiD group presented a number of concept-dependent issues on the calorimeter design. The group has an active PFA analysis that is able to give them specific feedback on design parameters and external factors such as magnetic field and tracker material budget.

PFA studies are reported to optimise the hadron calorimeter in the SiD detector. It was found that an absorber of steel or copper gives better resolution than one of tungsten or lead and that a hadron calorimeter thickness greater than 5λ is desirable. This specific feedback is important and will likely be a leading effort in the horizontal working group on PFA jet energy measurement.

The SiD group pursues for the ECAL a silicon-tungsten calorimeter very similar to CALICE. The major difference is the readout chip. SiD develops a CMOS chip, called KPiX, for the readout of 1024 channels with bunch tagging capability. The KPiX chip will be integrated in the sensor planes allowing a minimal gap size important for a small Moliere radius. Prototypes of the KPiX chip exist and the tests so far are promising to reach the goal for linearity and dynamic range. Larger scale tests on sensors planes to quantify e.g. effects of stray-capacitance, cross-talk and stability are regarded to be mandatory.

All the comments made for the silicon-tungsten ECAL of CALICE hold also for the SiD ECAL. The HCAL activities of SiD are part of CALICE.

Conclusions for PFA based Calorimetry R&D

The combined effort of the CALICE groups to move from a first phase R&D to a more close collaboration and carrying out test-beam programs is fully acknowledged. CALICE will acquire expertise in operating extremely dense and fine grained calorimeters under real conditions mandatory for the construction of the ILC detector.

The data taken now by CALICE with the physics prototypes will be essential to better understand the potential of PFA for jet energy measurements using different sub-detector technologies. To set up a common infrastructure with respect to hardware (absorber structures, read-out, DAQ, beam instrumentation) and also software (PFA, MC simulation, analysis code) is the right way to go. We would encourage the groups to go even further and try to get a standard set of tools and evaluation criteria to compare the performance of the various alternative detector options.

For an outsider, it is clear that the silicon-tungsten R&D effort should be performed with tight consultation between CALICE and the SiD ECAL groups. We encourage the SiD ECAL group to collaborate more closely and more formally with the CALICE collaboration This will also avoid painful "shoot-outs" in the future. A shoot-out will have politically damaging consequences. Clearly, there are a number of parallel R&D efforts (e.g. CMOS KPiX vs its European equivalent SiGe SKIROC); overlapping efforts must be limited in scope and time, and a mechanism for selection must be implemented. In view of the growing importance of larger-scale test beam efforts, the limited number of sites offering test beams, and limited manpower and financial resources, it seems that a much tighter collaboration between the ECAL concept proponents will be necessary to take data for a reasonable comparison of the specific technological choices.

The following items are regarded as important:

1. It would be desirable to include in the PFA studies more realistic detector models.
2. It would be useful to compare the performance for physics benchmark channels of the PFA approach with that of a jet energy algorithm based on an energy-weighting as used by H1 at HERA. This would help justify the cost and complexity of the fine spatial granularity being proposed.
3. Test beam program with "physics prototypes" must be completed to provide data for all configurations close to those of the proposed detectors. This will allow tuning of the Monte Carlo simulations and should provide a reliable basis for full simulations of the concept detectors.
4. Technical prototypes, which from size and complexity are close to the final modules, will yield valuable information on large scale calibration and monitoring issues, reliability, homogeneity and aging effects.
5. Next to performance issues also large scale production issues as quality control questions, tolerances and cost relevant production options are important.
6. Given the large number of channels, common systematic effects in calibration (coherent effects) or changes in internal properties of the detector need more attention and can be studied easier in full size systems. In addition the robustness of the performance to failures should be studied.

7. The US R&D funding is considered to be inadequate. There is the risk that ideas from the US groups may not be sufficiently developed to influence final designs.

With the rather tight timescale for the EDR in mind - 2010 - a clear definition of milestones and a detailed road-map are required to be able to come to decisions on the timescale given. Even if a final decision on this time scale is difficult, a baseline option with potential alternatives or fallback options should be specified.

For this decision process the construction of 'module 0' type calorimeters and the evaluation of their performance in test beams is essential.

In view of the extreme requirements, full-scale module prototypes and realistic engineering studies (supports, services, signal and power cabling, reliability, repair schemes, cost estimates) have become increasingly important and should be vigorously pursued by the sub-detector groups. This requires new funding for the engineering manpower.

DREAM

DREAM follows a completely different concept to achieve the optimum jet energy measurement precision for an ILC detector. DREAM is a sampling calorimeter in which the Cerenkov light produced in clear fibres and light produced scintillation fibers is read-out separately. In this way an electron/pion response ratio of one can be achieved, resulting in an optimum energy resolution for hadrons, a linear response and a Gaussian response function.

The committee members agree that the novel idea of the DREAM calorimeter is extremely interesting and appreciate the promising results from simulations studies presented. We fully support the continuation of the ongoing test beam activities. The transition from the current test beam module to larger scale module, however, needs a number of concerns to be clarified:

1. The influence of inert upstream material on the performance of the calorimeter needs to be studied. We suggest that the group performs Monte Carlo simulation as well as test beam measurements where material is distributed upstream to mimic the foreseen tracking devices and beam-pipe.

2. The performance for bench mark physics processes needs to be further studied. The processes should include τ identification through its $\tau \to \pi\pi^0$ decay, hence two photons from the π^0 decay should be resolved. We encourage the group to study the performance in close contact with the physics and other calorimeter groups to exchange the knowledge such as on shower simulations and jet reconstruction.

3. The baseline calorimeter module, consisting of crystals of 2x2cm face section and copper block where scintillation and quartz fibers are embedded, needs to be optimized further in view of items listed above.

4. Key parameters which must be controlled for the large scale calorimeter system should be identified. Gain calibration and monitoring are the essential parameters. Clear identification of the methods to control the parameters is required.

In the following we describe our concerns related to the items listed above in detail.

1. Energy scale calibration:
   The test beam module DREAM1 demonstrated the effectiveness of separate measurement of scintillation and Cerenkov lights to achieve compensated shower energy measurement. The

calorimeter performance was excellent for electrons, muons and pions with various energies once their energy scales were calibrated with 40 GeV electrons only. The same method will not be applicable to the proposed baseline hadron calorimeter because of the EM calorimeter section in front. A method to calibrate in-situ both EM and hadron calorimeter sections needs to be evaluated. Combining isolated electron events and isolated hadron events with their momenta measured by the tracking system may make it possible to calibrate both sections. The statistics and achievable precision, however, need to be evaluated in view of possible non-uniform response over the calorimeter face and available number of events.

The energy scale calibration employed at the test beam relied on the response uniformity in longitudinal and lateral directions. The monitoring and calibration of the response uniformity in the both directions are indispensable to the large system to be operated for a long period.

2. Longitudinal uniformity:
   Since no longitudinal segmentation is planned, and hence no internal calibration is possible in the long hadron calorimeter fibers, it is essential to monitor and maintain the long term stability of both fiber types: scintillation and quartz/clear fibers. Some radiation damage is possible - radiation leads to the creation of absorption centers especially in ultra violet region, and Cerenkov signals may encounter substantial absorption if clear fibers are used. Scintillation fibers may also be affected. Estimation of the radiation level along the calorimeter depth is required to evaluate these effects. There are some data[1] concerning the plastic fiber durability under radiation, which may be useful for a preliminary evaluation. In-situ monitoring of longitudinal uniformity using tools such as muons or LEDs needs to be investigated. If the radiation turns out as the single source of long-term instability, namely the fibers turn out to be stable in non-radiation environment, LEDs could be placed on a sampling basis. The magnitude of the energy resolution degradation originating from the residual, or un-corrected, non-uniform response should be evaluated, as for Item 1.

3. Photo-sensors:
   Compact photo-sensors working in magnetic fields, such as SiPMs, are required for the proposed calorimeter. The sensitive area and dynamic range of SiPMs are so far limited: they are not applicable for, e.g., EM crystals. It will also limit the hadron segmentation.

4. Monitoring of photo-sensor gains and other uniformity:
   For reliable energy scale calibration in long term operation, monitoring system needs to be investigated for the photo-sensors, scintillators, and other critical components. This includes the temperature monitor and control both for the EM and hadron components.

5. Fibers:
   Development of square fibers is interesting to eliminate the space not filled with fibers and for better matching to the photo-sensors. Long- term stability of such fibers needs to be established. Concerning the effort to increase the Cerenkov light yield, similar caution is required if double-clad square fibers are to be investigated.

6. EM calorimeter readout:
   The proposed methods of discriminating scintillation and Cerenkov lights in the EM section require further investigation to provide numerical evaluations on the electron/hadron separation and energy measurement ability.

7. Consideration of different calorimeter configuration: The baseline calorimeter configuration, consisting of a crystal EM section and a fiber hadronic section, with proposed lateral segmentation, is required to be re-visited in view of physics performance. The primary concern

is that the lateral segmentation is not fine enough for the events where interaction occurred in the tracking volume. Without fine segmentation, such events may have to be excluded from the data sample, thus the available luminosity will be effectively reduced. A calorimeter consisting of one fiber calorimeter section with finer lateral segmentation would be interesting if it can measure the EM energy precisely enough and can have sufficient electron-hadron discrimination ability. The latter may not be impossible from precise measurement of the lateral shower spread and inherent novel idea of the DREAM calorimeter. Such a calorimeter would make the energy scale calibration easier as has been demonstrated from the test beam. Also, grouping to smaller number of fibers would make easier the application of SiPMs for signal readout. Alternatively, addition of a fine segmented layer in front of the EM crystal may help distinguish interaction events that occurred at outer structure of the tracking device in front and to separate two photons from π^0. This, however, diminishes to some extent the novel feature of the DREAM concept. Finer EM crystal segmentation may be required for the same reason.

The best configuration, among the above configurations and possible others, should be selected from the performance to the benchmark physics processes, and scalability to the large system, especially robustness of calibration.

The committee is concerned about the relatively limited resources of the DREAM collaboration. It strongly supports a significant strengthening. Since most of the critical topics should be clarified by more detailed simulation studies before a new hardware construction program can be recommended the committee recommends funding for several postdoc positions both in United States and Europe. A group of software-experienced postdocs would be able, under the guidance of the experienced physicists in DREAM, in a relatively short time to perform the simulation studies allowing to answer the questions listed above.

———————— [1] K. Hara et al., Nucl. Instrum. and Methods A 411 (1998) 31.

FCAL

The FCAL Collaboration consists of 15 groups from 12 countries in Europe and United States, which comprises almost the entire body of physicists working on ILC forward calorimetry. The fact that they have come together to form a well- coordinated collaboration is extremely positive. Given the considerable magnitude of the technical challenges, it is appropriate that this large number of physicists (approximately 80) has joined forces to drive this essential R&D forward. The high quality of the coordination enables them to cover all urgent issues, and (as far as the committee was able to tell) avoid unnecessary duplication of R&D. However, there are severe shortages in manpower support in some areas which need to be addressed by the funding agencies, in order that they can hope for timely completion of their work. These issues are discussed separately for each of the three detector systems involved.

The committee was particularly impressed by the written report of their activities, where both the physics requirements and the technical implications were clearly presented. The presentations in the review were of an equally high standard, so that the committee learned what it needed to know - the full outline road-map for this R&D to the point of readiness for detector construction. Of course, there are numerous uncertainties in such a challenging program, but we have confidence that all reasonable avenues are being explored, and that timely solutions will be found.

1. LumiCal
   In order that the luminosity measurement should not limit the physics reach of the high energy ILC running, precision of better than 10^{-3} is needed; for the GigaZ mode, this needs

to be improved to 10^{-4}. This can be achieved by measurement of the Bhabha scattering cross-section between about 40 and 150 mrad. By designing a detector with an angular resolution of 0.03 mrad, the rejection of background can be made highly efficient. Virtually 100% reconstruction efficiency is of course essential to minimise normalisation uncertainties, and their chosen technology, already proven in precision luminosity measurements at LEP and SLD, can be engineered to achieve this. The situation is more complex than at lower energies due to several complicating factors, particularly beam- beam effects. Beamstrahlung radiation causes deflection of the incoming beams, and electromagnetic deflection of the Bhabha electrons can be significant. Effects of the longitudinal polarisation of one or both beams induce further effects requiring small corrections. All these effects have been carefully evaluated by this collaboration.

Regarding the design of the LumiCal, this follows from previous experience and detailed simulations. The plan is for a 30-40 layer silicon-tungsten sandwich, 1 X0 per layer, with the deeper detector being required for full 1 TeV operation. Using silicon wafers patterned with the appropriate pad layout, it is easy to achieve the fine granularity in θ and relatively coarse granularity in ϕ needed to reconstruct the Bhabha events with excellent background rejection. 8-bit ADCs are shown to suffice for the measurement of the signal charges on the pads.

Precision alignment of the sensors is essential. Within each module, this can be provided by a laser system following proven practices, but how to establish the alignment between the two modules, and separately their alignment to the physical beams? The committee wondered about a line-of- sight laser system linking these modules. In any case, the alignment and stability of the FF quads is obligatory in order to maintain luminosity, and it is not excluded that there could be a mechanical or optical linkage between their cryostats and the LumiCal modules nearby.

Here, as also for the BeamCal, experience suggests that it might be useful to include precise timing information ($\tilde{1}$ ns) in the signal processing, since this could be used to veto spurious signals emerging from sources other than the IR.

2. BeamCal

   Two-photon events form one of the most serious backgrounds for several physics studies, notably channels characterised by missing energy and missing momentum. These background events can in principle be vetoed by tagging the electron and/or positron that emerges at small angles to the beam line. The goal is to cover the region 5-45 mrad, but with the 14 mrad crossing angle, holes need to be left for the outgoing beam, which will slightly reduce the coverage.

   The BeamCal can be made with a similar design to the Lumical, but now using very fine segmentation in θ as well as in ϕ in order to most efficiently suppress the background of beamstrahlung pairs that populate this very small angle region. Detailed studies by this collaboration have established the limits in angle and in secondary electron energy to which this veto can work, and hence (for example) the limits in reach for SUSY particle masses and mass differences, before becoming flooded by background.

   The use of an anti-DID or a DID magnetic field, associated with the 14 mrad crossing angle, complicates the situation wrt the case of small crossing angles. The use of an anti-DID field causes no problems, but a DID field throws more pair electrons into the active region of the BeamCal, considerably reducing the sensitive region for detecting staus in the cosmologically-motivated co-annihilation region (low stau-neutralino mass difference).

While the pair background is unwelcome for SUSY searches, it can provide a valuable monitor of conditions at the IR. The BeamCal can thus be used to provide feedback on conditions, including effective luminosity, while running.

The most challenging issues for the BeamCal relate to different options for the ILC final focus optics, as well as the auxiliary magnets (DID, anti- DID, etc). This collaboration is providing vigilant monitoring, with feedback as required, to the designers of the final focus system.

3. GamCal

   This is a novel component of the FCAL system. It monitors the beamstrahlung photons (intercepting just 10^{-4} of them in a thin target). It is found that the flux and energy of these photons can be used, in conjunction with information from the BeamCal, to measure beam parameters at the IP (vertical offsets, overall luminosity, etc). The procedure is to sweep aside and detect positrons from the pairs produced in the foil, the whole system being named the IBS (Integrated Beamstrahlung Spectrometer). Simulations are ongoing to establish the full potential of combining the information from the BeamCal and GamCal in a feedback system to optimise ILC luminosity, in conjunction with the faster feedback provided by the FONT system which uses real-time signals from precision BPMs very close to the IP.

   The flux and energy spectrum of the electrons is measured by the IBS calorimeter, a row of tungsten and quartz plate modules. As well, a 2-D image of the beamstrahlung transverse to the beam is measured by bending aside and determining the image of low energy positrons by means of an array of quartz rods and photodetectors.

   This novel detector system is in the hands of experienced physicists whose main current problem is to obtain well-deserved support for this new project.

4. Sensor Development

   Both the BeamCal and LumiCal need to operate stably in a high radiation environment. This collaboration has people with the relevant expertise, and is working closely with groups investigating new sensor materials for future experiments at hadron machines. Doses of low energy electrons and positrons (in contrast to the situation at hadron machines) will amount to several MGy per year in the most populated parts of the BeamCal, for the worst configuration of DID field. The group is investigating CVD diamond (which suffer from performance instabilities), single crystal diamond (which may be unaffordable), gallium arsenide (which suffers from numerous complications) and 'rad-hard silicon'. Currently, the silicon option may fall short by a factor of 10, but developments continue and further work is needed to characterise the material for the ILC conditions. The effects of non-uniform irradiation, which may cause time-dependent systematics shifts in the position measurement should be addressed.

5. Readout Electronics

   The electronics chip designs are now beginning, with many lessons learned from other parts of the ILC calorimetry systems. One major difference is the high radiation conditions, particularly for the BeamCal. However, in contrast to the sensors, it is not necessary to subject the electronics to these high doses. It is estimated that short cables (acceptable as regards performance) can route the signals to front-end amplifiers in a relatively benign environment of 0.01 MGy per year, for which CMOS chips following standard design rules are adequate.

   One question raised by the committee was whether precise timing information might be obligatory, given the high rate and possibly high background environment in which the FCAL sensors will be working. It may be that the true signal rates are so high that nothing can be gained by trying to reject background in this way, but we feel it to be worth exploring.

6. Recommendations regarding resources

   Technically, the work of this collaboration is extremely well-organised. They are making excellent progress with limited resources. The most urgent requirement is enhanced funding for the US university participants, where the work is suffering badly, to the point that one or two institutes are on the verge of giving up. It is most important that this crisis is averted. Beyond that, the work so far has received little engineering support, and this will soon be needed to establish proof-of-principle at the system level.

   It is also desirable for one or more of the major participating labs or funding agencies to provide support for exchange of personnel, particularly in view of the breadth of the collaboration among 11 countries, some of which are not provided with high levels of support for HEP.

Report from the Kansas University Group

A group of four master students lead by G. Wilson investigates the performance of PFA for different designs of an ECAL. Such studies are primarily important to optimize the structure of an ECAL. Applying a mass constrained fit for π^0 reconstruction they found a significant improvement of the ECAL energy resolution. Furthermore, they investigated calibration strategies for sampling calorimeters using radioactive sources and the benefit of the use of timing information for particle information.

The studies presented are of excellent quality, and joining one of the collaborations exploiting to PFA technology would result in benefit both for the collaboration and for the Kansas University Group.

Report from the Fermilab Group

Physicists from Fermilab and University of Washington, organised by A. Para, studied the contributions to energy resolution in high precision dual readout calorimeters using GEANT4 simulations. Defining correction factors to account for the nuclear energy losses from the ratio of the Cerenkov and the scintillation light they reached a jet energy resolution of about of $25\%/\sqrt{(E)}$ both for homogeneous and sampling calorimeters.

The contribution presents several very interesting ideas for a dual readout calorimeter, and a natural way to go would be to join the effort with the DREAM collaboration.

Conclusions

With limited funding and manpower, a very impressive body of R&D work was done towards calorimeter concepts that require subsystems with heretofore-unmatched resolutions.

The test-beam program initiated by CALICE with larger scale prototypes of ECAL and HCAL using different sensors technologies is of highest relevance for the design and construction of an ILC detector with a performance to fully exploit the physics potential of the ILC machine. We fully support the completion of this program with the sensor technologies sufficiently mature to allow data taking up to 2010, the planned date for the EDR. In addition, we also support the development and test of technical prototypes to prepare the engineering of a full scale detector. There is a strong need for the participating groups from US to get an enhanced funding.

The construction of a prototype of the ECAL proposed by SiD is fully supported, however the beam tests should be prepared and performed in close collaboration with CALICE on the basis of common standards for the performance allowing a fair comparison. Therefor, the communication between the SiD ECAL group and CALICE should be developed on a more formal and regular basis.

The DREAM collaboration is encouraged to continue their running test-beam program. However, DREAM should enhance the effort in design studies with more realistic assumptions on a detector built with their technology, to convince the community first that such a calorimeter will match the physics requirements. In addition the impact of the overall detector on the DREAM calorimeter performance has to be evaluated. More support is needed from funding agencies to improve the person-power situation of DREAM.

FCAL has worked out a relatively advanced design for the BeamCal and LumiCal. GamCal is just in the phase of optimisation. FCAL should focus the activities in the in the coming years on the development of sensors and prototyping. Just now the most urgend requirement is an improved funding for the US institutions. For the engineering and hardware towards prototype test an enhanced funding for a relatively short time period will be necessary.

For all subsystems and technology choices, realistic initial engineering studies of subdetector concepts should commence in earnest. These studies should address issues of large-scale subsystem effects like alignment and surveying, dead material, uniformity of response, calibration procedures, reliability and failure rates/modes, and electronic noise and cross talk. Adequate funding for experienced engineering resources becomes now crucial as the LoI ”deadline” approaches. Engineering prototypes, on scales sufficient to make valid extrapolations to full-scale sub-detectors, should be funded in time for the EDR submissions.

Testing of ILC sub-detectors seems to come together around 2008-2009, when CERN will be fully occupied with the LHC start-up and tuning. It seems that significant manpower and funds need to be invested in testing at Fermilab. Fermilab beam physicist’s help is required.

Together with the GEANT group, a plan must be formulated on how best to proceed to feed back ILC test beam results into the GEANT shower simulations in a timely manner. In addition, an effort should be made to bring GEANT4 to a level similar to e.g. FLUKA in describing hadron showers.

Most of the work was done in collaborations of a global reach, thereby satisfying the ILC goal that the next large experimental HEP project be a world-wide effort by the HEP community. However, at this stage it seems that there is a growing imbalance in funding between the three regions; in particular the funding in the Americas and Asia is falling behind the European support, which is itself tight and just adequate. This funding situation does not adequately reflect the physicist talents and interests involved in preparation for the ILC, and should be improved and balanced. Politically, it is crucial to maintain a regionally balanced representation in the ILC Detector R&D effort. A relative decrease of America’s impact on the ILC detector R&D program will have negative repercussions on support for the ILC project both in the US, as well as globally. A twofold increase will enable the US-ILC R&D community to contribute to the worldwide effort in line with its talents and expertise and to keep leadership positions in areas of current strength.