October 25, 2007

To whom it may concern:

The report of the ILC Calorimetry R&D Review Committee is attached. The review was held during the International Linear Collider Workshop at DESY in June, 2007.

The World Wide Study R&D Panel, chaired by Chris Damerell of Rutherford Appleton Laboratory, UK, organized the review. The review was endorsed by the GDE, the ILCSC, ICFA, and the FALC. The Review Committee of experts on calorimetry was chaired by Wolfgang Lohmann of DESY, and included several consultants from outside the ILC community. The main goal for the review was to examine the efforts of the calorimeter R&D teams within the global context, to enhance communication, and to advance the R&D program toward timely completion on a time scale consistent with the ILC accelerator R&D program.

The review was a success. Each of the R&D groups was responsive to the request for materials, which resulted in valuable interactions between the committee and the researchers during the meeting in Hamburg. The committee recommendations have been given serious and thoughtful consideration by the R&D teams, and are certain to help achieve the goals for the review, namely advancing the R&D program.

The World Wide Study is grateful to the Review Committee for their conscientious efforts and thoughtful comments and recommendations. The recommendations will now be considered carefully by the World Wide Study Organizing Committee, in consultation with the R&D teams.

Sincerely,

WWS co-chairs
Jim Brau, Francois Richard, and Hitoshi Yamamoto

October 4, 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 were 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"
Kazuhiko Hara, University of Tsukuba
Peter Loch, University of Arizona
Jim Pilcher, University of Chicago
Peter Schacht, MPI Munich
Andrey Golutvin, ITEP Moscow
Robert Klanner, Hamburg University
Pierre Petroff, LAL Orsay
Daniel Pitzl, DESY
Chris Tully, Princeton University

In addition, three regional representatives were invited:

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| 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
Ray Frey, University of Oregon
Chris Damerell, Rutherford Appleton Lab
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 beyond what was achieved in previous 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, available resources 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 SiDCAL, 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. SiDCAL consists of 17 institutions, mostly from United States, collaborating within the SiD concept. Several of these groups are also members of CALICE.

CALICE and SiDCAL propose finely 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 goal for jet energy resolution motivated by physics 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, electrons 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 mis-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 e.g. of the cell calibration or hadron shower simulations.

Presently, all information is based on MC studies with showers simulated by GEANT4. There are large uncertainties in the simulation of charged and neutral showers, leading to large uncertainties in the 'confusion term' between charged and neutral energy depositions. Since this confusion term dominates the uncertainty in the jet energy deduced by the PFA algorithm, it is most important to obtain experimental verification of the shower simulations.

Relevant studies are under way by the CALICE collaboration, taking data on showers induced by identified electrons and charged hadrons ($\pi^{\pm}$, p, $\bar{\text{p}}$) incident on realistic 'physics prototypes' of large scale ECAL/HCAL assemblies. While it would not be possible to undertake ILC physics studies on the basis of shower libraries of all the particles in each jet, these data will be extremely important in selecting the shower simulation model(s) which best fit the data, and possibly tuning the model parameters to refine the fits.

Since the goal of the PFA is to optimally disentangle the neutral energy deposited in the calorimeter assembly, it seems desirable to consider the need of tagged neutral beam (neutrons, $\text{K}^0_\text{L}$ and anti-neutrons) data. In particular at relatively low energies (below 20 GeV) there seem to be in principle uncertainties in the shower simulation of e.g. neutrons and neutral kaons. Data taken with protons or charged kaons cannot simply be related by isospin-invariance to neutron or neutral kaon shower shapes. It might be a task for the PFA working group to evaluate the impact of this effect. In parallel, the calorimeter R&D groups are encouraged to evaluate the possibilities to take neutral beam data at the relevant energies at the accelerator centers[1]. Unless a way can be found

[1] In the past the CALICE collaboration estimated the feasibility to get such data using the MIPP facilities at Fermilab after the planned upgrade. Since the expected rates and backgrounds were not appropriate using the current DAQ the effort was stopped. However, it might be worthwhile to reconsider this possibility

to obtain neutral beam data with realistic physics prototypes, there may remain a considerable uncertainty in the achievable PFA performance. It would be unfortunate to wait for ILC start-up to uncover limitations which could have been understood and possibly avoided at the stage of prototype evaluation.

In parallel with the test-beam studies, it will be valuable to extend the simulation work, bearing in mind that revisions will be needed later, in the light of the experimental results. 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, $\tau$ 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 not negligible 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 'fallback' 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 was impressed by the excellent report prepared by CALICE and 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 will firstly 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 than 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.

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provided boundary conditions have changed.

The technical prototype developments are devoted to building 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. Relatively advanced technologies 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 allow the effective Moliere radius to be reduced to about 1 cm, limiting the transverse size of the electromagnetic showers, thereby improving PFA performance.

The silicon-tungsten option for the ECAL is further advanced and might be potentially superior to the scintillating strip readout option due to finer granularity achievable and a lower effective Moliere radius. However, 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 $\pi^0$ mesons, e.g. the possible reconstruction of $\pi^0$ mesons from the photon showers would improve the b-jet measurement.

Scintillators are read out by novel silicon photo sensors, called MPPC[2], 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" with a Moliere radius of around 2 cm. Preliminary results demonstrate that the prototypes are operating within expectations. However, issues of large-scale operational performance remain and need addressing: reliability, uniformity, calibration, stability, and robustness against loss of (groups of) cells. Realistic studies of in-situ calibration schemes are also required.

As a novel technological option the use of MAPS (Monolithic Active Pixel Sensor) instead of silicon pad sensors is investigated. The small pixel size allows to operate the calorimeter in the digital mode with a one-bit readout per pixel. This development, interesting for itself, is in a very early stage. Results of the first prototypes produced in the INMAPS process will demonstrate the performance of small area sensors. More effort is needed to understand the full potential of this technological option. One concern is that a large fraction of the energy deposited in an electromagnetic shower is in soft photons, so the binary readout approach could fail. However, the thin layers of active silicon in the MAPS sensors will reduce this problem. What is needed is a larger-scale prototype system that can be compared with the alternatives.

The silicon-tungsten ECAL "technical prototype" concept is nicely detailed (design studies, electronics, heat load). The FE readout chip, called SKIROC, is based on SiGe technology. The construction and operation of this larger scale system, aiming also to a smaller Moliere radius than the "physics prototype", is mandatory to study the effects of noise, pickup and cross talk.

[2]MPPC are devices manufactured by Hamamatsu Corp., similar to the Silicon PMs mentioned below.

### Hadron Calorimetry

Sampling calorimeters with non-magnetic steel 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

The last three options are referred to as digital HCAL. 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. The measurement of the signal size in photoelectrons is possible using the position of the few- photoelectron response peaks. The latter also are used to control the gain of the device. About 15 photoelectrons per minimum ionising particle, mip, are found. A LED pulser and PIN diodes will be used to monitor performance. Development of a configuration with direct coupled SiPMs (i.e. without wavelength shifting fibres) 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 calibration procedures in major systems, using e.g. also mips, need to be understood. Furthermore 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.

Plans are presented to test a one $m^3$ digital 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 one $m^3$ HCAL assembly 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 little chance 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 this program.

## SiDCAL

SiDCAL denotes a group of institutions, mainly from US, working together on calorimetry R&D within the SiD detector concept. The group is well structured with clear responsibilities and provided an excellent report for the committee. Several institutions performing R&D in hadron calorimetry are also part of CALICE.

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

Simulation 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 considerably greater than $5\lambda$ is desirable. This specific feedback is important and will contribute to detector design optimisation. The committee supports strengthening the PFA simulation efforts and their integration in the PFA working group.

The SiD group also pursues for the ECAL a silicon-tungsten sampling calorimeter. To ensure the best performance for resolving showers the design work focuses on a finely segmented calorimeter with the smallest possible Moliere radius. So far first sensor prototypes have been produced by Hamamatsu and detailed studies on the electric features were presented, demonstrating that the sensor features are in the required parameter range.

A second batch of sensors with 1024 pads will be obtained soon with a new layout of the signal traces to reduce stray capacitances.

A key issue is a CMOS FE chip, called KPiX, for the readout of finally 1024 channels with bunch tagging capability. This chip, bump-bonded to the sensor and contained between the tungsten planes, allows to keep the thickness of the sensor layer to be kept to about one mm. Operating it with pulsed power, no active cooling would be necessary. In addition, due to amplification range switching, the chip promises excellent performance for the detection of mips and the necessary linearity over the dynamic range required.

Prototypes of the KPiX chip are under development and the tests of 32 channel prototypes so far are promising.

Larger scale tests on sensors to quantify e.g. effects of stray-capacitances, control signals on top of the sensors and cross-talk and stability are considered to be mandatory.

The SiDCAL group plans to prepare fully equipped sensor planes for a full depth prototype to be used for beam tests in 2008. Several technological steps towards this goal must be validated before then, e.g. to demonstrate the functioning of the full KPiX chip, of a full sensor equipped with a KPiX chip and a full sensor plane with bump-bonded FE chips with a performance matching the design parameters.

On a longer timescale the issues of large-scale operational performance: reliability, uniformity, calibration, stability, and robustness against loss of (groups of) cells must be addressed. Also more realistic studies of in-situ calibration schemes are required.

## 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. 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 in order to take the data needed for a reasonable comparison of the specific technological choices.

We encourage the SiD ECAL group to work with CALICE to agree on a procedure for combined testing of their ECAL with the CALICE HCAL prototypes. This will also avoid painful "shoot-outs" in the future. A shoot-out will have politically damaging consequences.

There are some parallel R&D efforts, e.g. the SiD CMOS KPiX vs its European equivalent SiGe SKIROC. These developments are regarded as being reasonable for the time being since they reduce the risk inherent in the development of novel FE electronics technologies. After tests with fully instrumented detector prototypes detector collaborations will have the basis for the selection of one of the technologies.

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. The 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. 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 large scale prototypes. In addition the robustness of the performance to failures should be studied.

6. Besides performance issues, large scale production issues are also important, for example quality control questions, tolerances and cost relevant production options.

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 allow decisions on the timescale given. Even if a final decision on this time scale might be difficult, the R&D must reach a level of maturity to define baseline options with potential alternatives or fall-back options. 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 in 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 both test-beam measurements and 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 benchmark physics processes needs to be further studied. The processes should include $\tau$ identification through its $\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu$ decay, hence two photons from the $\pi^0$ 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 on such topics as 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 light to achieve compensated shower energy measurement. The calorimeter performance was excellent for electrons, muons and pions with various energies once their energy scales had been 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 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 is found to be 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, a 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 between scintillation and Cerenkov light 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, should be re-visited in view of physics performance. The primary concern is that the lateral segmentation is not fine enough for the events where secondary interactions 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 only of a 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 in view of the inherently 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 finely segmented layer in front of the EM crystal may help distinguish interaction events that occurred in the outer structure of the tracking device in front, and to separate two photons from $\pi^0$. 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.

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 $\theta$ and relatively coarse granularity in $\phi$ 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 ($\approx$ 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 $\theta$ as well as in $\phi$ 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 photo-detectors.

   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 suffers 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 of the required radiation hardness 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 systematic 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 12 countries, some of which are not provided with high levels of support for HEP.

## Report from the Kansas University Group

A group of Master's and undergraduate students led 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 $\pi^0$ reconstruction they found a significant improvement of the energy resolution of the prompt electromagnetic component of hadronic jets. 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 has been 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 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 be awarded considerably increased 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 comprehensive comparison. Therefore, the communication between the SiD ECAL group and CALICE should be developed so as to allow this collaborative work.

The DREAM collaboration is encouraged to continue their current 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 design studies. FCAL should focus the activities in the coming years on the development of sensors, FE ASICs and prototyping. Just now the most urgent requirement is an improved funding for the US institutions. For the engineering and hardware towards prototype construction and tests an enhanced funding for this 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 is clear that significant manpower and funds need to be invested in testing at Fermilab. Substantial input from Fermilab physicists to these challenging programs will be crucial for their success.

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 the past, also comparisons of measurements with other shower simulation programs, e.g. FLUKA, were important for a better understanding of the hadron shower development.

Also data taken with the proposed MIPP upgrade facility, gathered from 30 different nuclear targets, will be of crucial importance to improve the hadron shower simulation. In case these data and their implementation into GEANT would be available in a reasonable timescale, refined shower simulation models could be developed giving a chance to resolve the currently large variability in predictions.

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 continuing 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 will need an enhancement in future to face the engineering challenges. This funding situation does not adequately reflect the physicist talents and interests involved in preparation for the ILC, and should be improved and balanced. Continuing insufficient resources for the ILC detector R&D program e.g. in the Americas will have negative repercussions on support for the ILC project in the US, as well as globally. An increase by approximately a factor of two would enable e. g. 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.

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