ILC Detector Research and Development
Status Report and Urgent Requirements for Funding

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EXECUTIVE SUMMARY

This report has been produced by the ILC Detector R&D Panel (members are listed on the title page as editors). In Section 2 we summarise the ILC detector R&D work currently under way world-wide. Work for each subdetector system is described in an introduction by a Panel member, followed by a research statement by the contact person for each project (these physicists are listed on the title page as contributors). Research statements that are missing were not received in time for our deadline. Further details for all the projects can be found from the web page maintained by the Panel, https://wiki.lepp.cornell.edu/wws/bin/view/Projects/WebHome. The web page has the advantage of being constantly updated, whereas this report provides only a snapshot at end of 2005. Next, our report summarises the funding information provided by all the contact persons, in response to a supplementary request made to the Panel by the ILCSC in September 2005.

This funding information relates to the R&D urgently needed in order to establish proof-of-principle for detector topics which if successful, will significantly increase the physics reach at the ILC, or significantly reduce the detector costs, or both. The degree of urgency depends on the subdetector type. For the most expensive subdetectors (tracking, calorimetry, solenoid magnet) we suggested the timescale to be the next 3 years 2006-2008, by which time collaborations may be forming and needing to write LOIs. For less expensive but high-tech subdetectors, such as vertex detectors and small angle calorimeters, we suggested that it will be in order for the collaborations to leave their decisions open till there has been time to demonstrate proof-of-principle by approximately 2010. We asked the contact persons firstly to classify their R&D topics into two categories, Priority 1 (urgent and important, as defined above), and Priority 2 (necessary in order to optimise performance, but results could wait till after LOIs, into the early years of the approved experiment collaborations at ILC). For their Priority 1 topics only, we asked them to tell us firstly their levels of 'established support' for the 3- or 5-year period, and secondly what additional support would be required to achieve their Priority 1 goals on that timescale.

The question of timescale is blurred by the fact that some of the funding is linked to EUDET* support which spans the 4-year period 2006-2009. For this reason, it is best to interpret our figures as establishing the integrated requirements for a period of 4 ± 1 years, with the funds for the larger systems being somewhat more urgent than for the smaller ones. Given the uncertainties in the ILC schedule, we suggest that it is more appropriate to consider the integrated requirements rather than the funding profiles at this stage.

Equipment budgets are quoted in US dollars. Regarding manpower, we asked our contact persons to quote these in man-years, in order not to be concerned about different salary levels and overhead charges round the world.

The results of our survey are summarised in tables and plots in Section 3 of our report, the most important being reproduced here as Fig 1. These results support the widely-held opinion that the current level of investment in ILC detector R&D is seriously inadequate in some regions. Those doing the work in all the critical subdetector areas believe that a factor of approximately two increase in support will be needed if they are to deliver proof-of-principle demonstrations for their detector technology on the required timescale. Globally, the established support is estimated to be $15M and 1160 m-y, while the total requirements amount to $32M and 1870 m-y. If we simplify the manpower to be predominantly postdocs at $100k p.a., and simplify the time period to be 4 years for all projects, this amounts to *established support world-wide of $33M p.a., a requested increment of $22M p.a., making a total request of $55M p.a. of which approximately 85% is manpower.* This overall growth seems appropriate as the world of particle physics moves towards one of its biggest ever projects.

However, we should issue a word of caution that increased funding alone would not solve the problems. New funding must be accompanied by robust peer review to ensure that the resources are well directed. At present, this aspect seems to be satisfactory - in all the projects of which we are aware, there is very little indication of lack of focus. The peer review systems round the world are working well, and with clear planning should continue to do so during the next 3-5 critical years.

Figure 1 shows that the perceived need for increased support has a strong regional bias. In Europe, R&D programmes were given a healthy start by the ECFA/DESY workshops and an energetic push towards TESLA. For example, support in the UK was minimal for several years from the time of LCWS 1991, because the ILC was 'not on the PPARC roadmap'. After arduous groundwork, the ILC was included on that roadmap in January 1998, and the UK support for detector R&D has expanded steadily ever since. In the USA, the fact that the ILC is even now not in the DOE 'base program' has held back support for detector R&D to a low level, and there exists a similar problem in Japan. Both in equipment and manpower budgets, only the Korean groups feel their current support levels to be approximately adequate. In Europe, the situation is patchy between countries, but this is difficult to disentangle due to complicating factors such as EUDET being of general benefit across and even beyond Europe.

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* EUDET: EU Sixth Framework programme: 'Detector R&D towards the International Linear Collider'

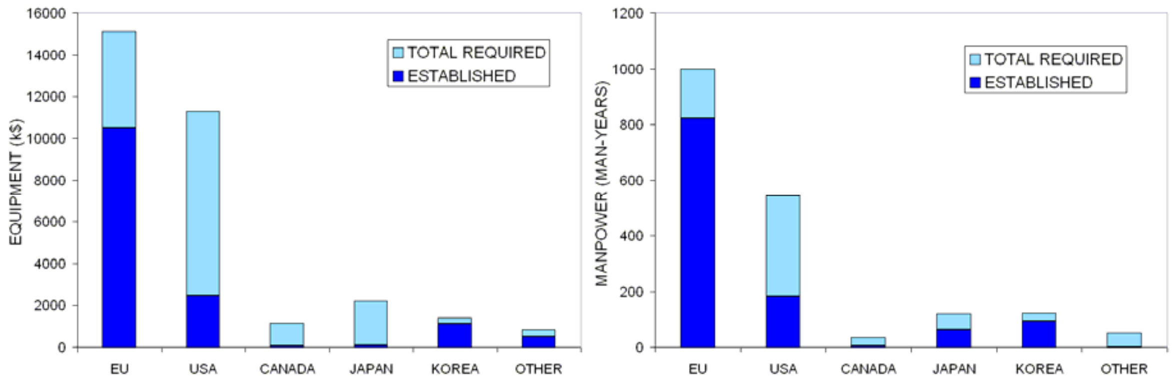

Fig 1. Urgent R&D support levels over the next 3-5 years, by funding country or region. 'Established' levels are what contact persons think they will be able to get under current conditions, and 'total required' are what they would need in order to establish proof-of-principle for their projects.

We were also asked to identify 'missing topics' in the world-wide detector R&D. We discuss two examples in Section 4. These are not missing in the sense that nobody has thought of them, but in the sense that entirely inadequate resources have been found for their study, that they could have an important impact of the design of the detectors, and that time is running out. If efforts are not ramped up soon, the detector designs may be frozen in ways which will unnecessarily restrict their physics potential. In our opinion, the neglect of these topics (and possibly others we have overlooked) is mainly a consequence of the thinly stretched band of ILC physicists working on detector R&D and the associated simulations. There is an urgent need, not only for increased funding, but for longer term jobs for the young people who could turn this funding into winning R&D results.

Given the difficulty of estimating the precise cost of R&D work, the financial figures in this report are of course approximate, and will need to be supported by detailed proposals from the projects listed as well as from the currently missing projects.

Since Snowmass 2005, a number of detector issues have been considered from the viewpoint of the associated 'luminosity factor', the factor by which the hard-won luminosity of this expensive machine would be effectively degraded by a detector with sub-optimal performance. The ILC community is at serious risk of having inadequate detectors thrust upon them, because time is running out for the R&D that could change the outcome. This would be an unfortunate example of inadequate resources now, resulting in a serious loss of cost-effectiveness later. One should compare the cost of building and operating the machine with the relatively modest level of support required to properly complete the detector R&D programme. By following the recommendations in this report, the ILC community has the potential to develop two superb complementary detectors, which will enable the most subtle physics results to be extracted from the collider, thereby making optimal use of the precious luminosity for many years into the future.

1. INTRODUCTION

The ILC Detector R&D Panel was formed at the initiative of the World-Wide Study Organising Committee (WWS-OC) just before the LCWS 2005 workshop at Stanford U in March 2005, where our first meeting was held. The initial charge included setting up and maintaining a register of relevant R&D activities. This was done by creating a Panel web page under the direction of Dan Peterson with help from colleagues at Cornell U. This can be found at https://wiki.lepp.cornell.edu/wws/bin/view/Projects/WebHome. We have attempted to persuade representatives of every ILC detector R&D project world-wide to register on this web page, and provide details of their work. The initial response was limited, but it improved dramatically once we were also given some funding-related responsibilities. We decided to make the links between our Panel and the community by asking each R&D project to nominate a single clearly-defined contact person, of which we now have 65. These contact persons are listed as the contributors to this report. In Section 2, we list the principal detector subsystems, provide a brief overview of activities in each, followed by the 'research statements' from our contact persons, which we have extracted from the Panel web page, where further details of each project can be found. Some of the contact persons have updated this information during the year, and it is part of our role to ensure that this continues in response to important developments for all the projects. Panel members have expertise covering all subdetector systems, and we have allocated areas of responsibility accordingly, so that Panel members remind contact persons in cases where progress in their work is believed to warrant updating their web entries.

As well as producing the register, we were asked to review the R&D needs of the detector concepts. We have done this by inviting the R&D coordinators for the concepts (Ties Behnke, Andy White and Yasuhiro Sugimoto for LDC, SiD and GLD respectively) to attend all our meetings, in person or by phone. They have become *de facto* members of our Panel and have provided valuable advice on issues related to their detector concepts. They also produced reports on detector R&D from the perspective of their concepts, at the time of the Snowmass ILC workshop in August 2005. These reports can be found from the Panel web page. The 'fourth' concept is represented in the calorimetry section of the Panel web page.

We were originally asked to review the status of detector R&D activities, but this was somewhat overtaken by events. On 27th September 2005, at the request of the chair of the ILCSC, we were given a new responsibility for identifying and prioritising topics and areas of detector R&D in urgent need of increased support. Details of this request, and how we responded to it, are described in Section 3. In essence, we asked our contact persons to help provide this information, since only they have detailed knowledge of the challenges in their projects. Based on their information, we produced summaries of the current funding levels and those which will be needed to achieve the urgent goals in a timely fashion. We were asked not to present results for individual projects, and our contact persons provided their estimates on this understanding. There would be obvious sensitivities in publishing information that might reflect on the status of specific projects. What we have done is to provide the information for the different types of subdetector, and for the different funding regions. This is the first comprehensive world-wide review of ILC detector R&D, and we hope the results presented in Section 3 will be useful in providing a broad perspective for future planning.

We were asked to identify 'missing topics' in the world-wide detector R&D. We discuss two examples in Section 4. These are not missing in the sense that nobody has thought of them, but in the sense that entirely inadequate resources have been found for their study, that they could have an important impact of the design of the detectors, and that time is running out. If efforts are not ramped up soon, the detector designs may be frozen in ways which will unnecessarily restrict their physics potential.

2. SUBDETECTOR SYSTEMS

2.1. Measurement of Luminosity, beam energy and polarisation (LEP) and Machine-Detector Interface (MDI)

A fundamental asset of an electron-positron collider is that the initial state is clearly defined. However, the benefits of this advantage are not fully realized in a linear collider unless the properties of the initial state -- luminosity, beam energy, and polarization (LEP) -- are measured. However, the unique collision dynamics at the ILC make these measurements particularly challenging, which requires some well-directed R&D. In particular, beamstrahlung gives rise to a collision energy spectrum which depends strongly on the beam parameters, and hence will vary with time. The luminosity-weighted energy spectrum, or luminosity spectrum, is then an important aspect of ILC experimentation.

One critical input to the luminosity spectrum is the measurement is the beam energy averaged over the beam populations, preferably both before and after the IP. An energy measurement of 200 ppm will suffice for most cases. However, a 100 ppm measurement would be required to ensure that this not limit a light Higgs mass measurement. If the program includes a very precise W mass measurement or a Giga-Z program with positron polarization, then a 50 ppm measurement would be required. This is an accuracy which challenges conventional techniques. The leading technique is the magnetic spectrometer, either using the accelerator lattice itself or a separate extraction line. In the former case, the position measurement might be carried out using BPMs, while in the latter case other position-sensitive detectors can be used. In either case, R&D is needed to ensure that viable solutions are available. One can hope to access the variable energy-loss spectrum by direct measurement of the beamstrahlung. At the SLC these measurements also provided important feedback on IP collision parameters. At the ILC, one might hope to avoid the high power in the forward hard photon beamstrahlung, opting to access the lower-energy parts of the spectrum. Other aspects of the luminosity spectrum determination will be carried out within the detectors themselves. These include the measurement of the acollinearity distribution of Bhabha pairs, the measurement of radiative return events, the Bhabha scattering rate at large and small angles, and the direct measurement in very forward calorimeters of low-energy pairs produced at the IP. The forward calorimeters which provide some of these measurements are included in the calorimetry section of our report.

The measurement of beam polarization would need to be determined to about 0.25% in the most demanding elements of the experimental program, as currently envisioned. The use of Compton scattering of the beam electrons with a polarized laser beam was carried out successfully at the SLC to an accuracy of 0.5%. However, the ILC presents greater challenges. Because there is significant depolarization at the IP, one hopes to make a Compton measurement both before and after the IP. Any R&D needed to ensure that these measurements can be carried out is important.

The machine-detector interface (MDI) is a catch-all term which includes not only the LEP measurements, but all aspects of interplay between the accelerator and the experiment, including the configuration of the beamline magnets and masking in the detector halls. An especially important issue is that of backgrounds – their production mechanisms and transport to the detectors. Some of this work has been carried out as part of the accelerator design efforts. However, it is crucial that studies which simulate the appearance of backgrounds in the detectors be supported. As the detector concepts move closer to technical designs, the need for detailed background studies will increase. The coupling between accelerator and MDI also means that the requirements for MDI R&D will evolve with the accelerator design, especially with respect to IP beam crossing angle configurations, beam parameters, or beam time structure.

Project: Integrated Luminosity Performance Studies

CERN

Contact: Daniel Schulte (CERN)

Project: Polarimetry at LC (Compton Polarimeter (at IPBI))

University of Iowa, Iowa State University, Fairfield University, Karlsruhe-Germany, Trieste-Italy, Turkish Universities

Contact: Yasar Onel (U. Iowa, USA)

Project: Luminosity monitor (at IPBI)

University of Iowa, Fairfield University, Turkish Universities

Contact: Yasar Onel (U. Iowa, USA)

Project: Fast, Radiation Hard Gas Cerenkov Beam and Luminosity Monitor

Iowa State University, Texas Tech University, SLAC, Purdue University, NITP

Contact: John Hauptman (Iowa State University, USA)

Project: A Demonstration of the Electronic and Mechanical Stability of a BPM-Based Energy Spectrometer for the ILC

University of Notre Dame, LBNL, Univ. California at Berkeley, SLAC, University College London, Cambridge University

Contact: Michael Hildreth (University of Notre Dame, USA)

Project: Extraction Line Energy Spectrometer

University of Oregon, SLAC, FNAL

Contact: Eric Torrence (University of Oregon , USA)

The physics program of the ILC demands a precise knowledge of the center-of-mass collision scale. One ingredient to achieve this is a real-time absolute measurement of the colliding beam energies at the 100 ppm level of precision and accuracy. This project is intended to design and demonstrate the feasibility of an energy spectrometer in the ILC extraction line which can achieve this goal. This work is equally applicable to all detector concepts, and is actively working on designs for all foreseen IR designs.

This work is primarily being done at the University of Oregon by Eric Torrence, although close collaboration has also been ongoing with SLAC related to detector tests in End Station A.

This work has been proceeding on two fronts. First, simulation work at Oregon has been ongoing to understand the operational parameters and environment in the extraction line. A realistic beamline simulation based on BDSIM is currently under development. Second, work on detector development has been ongoing for several years using Cherenkov radiation in Quartz fibers to detect secondary electrons from the hard synchrotron radiation produced in the spectrometer magnets. A first prototype has already been built at SLAC and will see its first beam time at SLAC in Fall 2005.

Over the coming year, we intend to finish first studies of the extraction line environment with a complete Geant4 simulation of the beamline and XLS detectors. We also will take first data with the prototype device and validate the Geant4 prediction of the expected signal rate.

On a longer term timescale, we expect to build a full-blown prototype spectrometer in coordination with the upstream BPM-style device in SLAC ESA. The timing of this project depends upon funds available and the results of the first round of beam tests. A second prototype detector which would be suitable for this test is currently in the design phase.

Project: Polarimetry Design at ILC

SLAC, DESY, Orsay, Tufts U. U. of Oregon

Contact: Ken Moffeit (SLAC , USA)

What are the goals of this R&D project. How does this R&D project address the needs of one or more of the detector concepts?

The primary goal of this R&D project is the design of the polarimeters which is coupled with the optics design for the Beam Delivery System, both upstream and downstream of the IP.

Precise polarimetry with 0.25% accuracy is needed. Compton polarimeters are being designed to achieve this and have been included in the baseline beam delivery design. Preliminary designs for polarimeter diagnostic chicanes are included upstream and downstream of the IP for both the 2mrad and 20mrad IR designs. Detailed studies are underway to refine these designs and evaluate their performance capabilities. To achieve the best accuracy for polarimetry and to aid in the alignment of the spin vector, it is desirable to implement polarimeters both upstream and downstream of the IR. The beam optics need to be designed such that the polarization vector can be fully longitudinal simultaneously at the collider IP and the two polarimeter IPs.

The upstream polarimeter measures the undisturbed beam during collisions. The relatively clean environment allows a laser system that measures every single bunch in the train and a large lever arm in analyzing power for a multi-channel polarimeter, which facilitates internal systematic checks.

The downstream polarimeter measures a priory the polarization of the outgoing beam after collision. The average depolarization for colliding beams is 0.3%, and for the outgoing beam 1%. Due to a clever choice of the extraction line optics the beam can, however, be focused such that its polarization is very similar to the luminosity-weighted polarization. The polarization of the undisturbed beam can be measured as well with non-colliding beams. The much higher background requires a high power laser that can only probe one or a few bunches per train and the lever arm in analyzing power is smaller.

The upstream polarimeters are located ~1400 meters before the e+e- IP. The design has evolved from an earlier study for the TESLA machine. Most major aspects of this work, except for the spectrometer configuration, remain valid for the ILC. In particular it is foreseen to use a similar laser as will be used for the electron source. A prototype for such a laser was developed by Max-Born Institute, for the TTF injector, and is well adapted to the ILC pulse structure.

Dedicated 4-magnet chicane spectrometers will be employed, similar to those at the extraction line polarimeters. This will eliminate some of the operational shortcomings inherent in the original TESLA design that relied on beamline magnets in the existing BDS lattice. The horizontal width of the good field region of the individual dipoles is chosen to accommodate a maximum dispersion of 11 cm for the lowest expected beam energy of 45.6 GeV for the Giga-Z option. The laser beam enters and exits between the inner two dipoles, which must be separated by some 8 meters for a vertical beam crossing of 10 mrad. A possible optical arrangement was given at LCWS-05.

Compton electrons generated at the laser IP at mid-chicane will propagate essentially along the electron beam direction . The third dipole D3 will fan out the Compton electron spectrum, while the fourth dipole can be used to restore the angular direction, if it has sufficient width. The Compton electrons are detected behind the last dipole in a gas Cerenkov hodoscope with 20 identical channels. It is planned to build a prototype for the electron Cerenkov hodoscope detector to show that the precision of 0.25%, which is required by physics analysis can be achieved.

The layout for the 20 mrad crossing angle interaction region has the Compton interaction point approximately 142 meters downstream from the e+e- Interaction Point. All bends are in the vertical plane. The extraction line apertures are designed to accommodate the ±0.75mrad cone of beamsstrahlung photons produced in the e+e- interaction and the low energy disrupted electrons. The 2 mrad crossing angle extraction line first moves the extracted beam away from the incoming beam line and then bends the beam back to the direction it had at the e+e- interaction point . This is done in the horizontal plane. The Compton polarimeter is located 226 meters downstream from the 2 mrad crossing angle e+e- interaction point and the polarimeter chicane bends in the vertical plane.

The Compton interaction point is located at a secondary focus in the middle of a chicane with 20 mm dispersion, but with no net bend angle with respect to the primary IP. At the middle of the chicane the Compton scattering occurs and the scattered electron is confined to a cone having a half-angle of 2μrad and is effectively collinear with the initial electron direction.

A 532-nm (2.33eV) circularly polarized laser beam collides with the electron beam in the middle of the Polarimeter Chicane . Compton-scattered electrons near the kinematic edge at 25.1 GeV are detected in segmented detectors near the last chicane magnet.

The beam-beam depolarization effects are measured in the extraction line polarimeter directly by comparing beams in and out of collision. Also, spin precession effects due to the final focus optics and beam-beam deflections can be studied by correlating the polarization and Interaction Point beam position monitor measurements.

The SLAC, University of Oregon and Tufts University work is primarily focused on the downstream polarimeters. The DESY work is primarily focused on the upstream polarimeters. Orsay work is toward both areas.

Are there significant recent results?

Preliminary designs for the upstream and downstream polarimeters.

What are the plans for the near future(about 1 year)? What are the plans on a time scale of 2 to 3 years?

R&D Required for Baseline Design :

Comparison of extraction line polarimeters for 2mrad and 20mrad IRs • backgrounds (synchrotron radiation, disrupted electron beam, beamsstrahlung, radiative Bhabhas) • sensitivity to misalignments of spin orientation, collision offsets • compatibility with energy spectrometer • requirements and feasibility for chicane magnets

Develop spin alignment procedures and uncertainties. Study sensitivity to crossing angle and DID.

Develop detailed Compton laser, IP and detector designs The R&D on the electron Cherenkov hodoscope detector will be performed by a new group at DESY Hamburg funded by an Emmy-Noether grant of the German Science Foundation, which will start in January 2006. In the first years, several options for the electron detector will be tested and compared. After that it is foreseen to build a full prototype. For this part the funding is still open.

R&D Required for Alternative LASER Configuration for upstream polarimeter: Evaluate use of a Fabry-Perot cavity for the laser at the Compton IP at the upstream polarimeter; this technology may have better applications for the laser systems for a Compton-based polarized positron source or a gamma-gamma collider.

If there are multiple institutions participating in this project, please describe the distribution of responsibilities.

The SLAC, University of Oregon and Tufts University work is primarily focused on the downstream polarimeters. The DESY work is primarily focused on the upstream polarimeters. Orsay work is toward both areas.

Is the support for this project sufficient? Are there significant improvements that could be made with additional support?

Present support for this project is sufficient.

Project: Visible and microwave beamstrahlung at the ILC

Wayne State University

Contact: Giovanni Bonvicini (Wayne State University, USA)

Project: Integrated Design of the Central Beam Pipe and Support of Vertex Detector Elements

FNAL, SLAC, University of Washington

Contact: Bill Cooper (FNAL, USA)

The beam pipe for SiD is expected to consist of a short, central portion of radius approximately 12 mm, conical portions which grow in radius and extend symmetrically in each direction from the central portion, and guided bellows which accommodate thermal contraction and misalignment of the detector with respect to accelerator beam line elements. The central portion is expected to be thin-walled (0.4 mm or less) beryllium. Regions of the conical portions are also expected to be beryllium, but to have a greater wall thickness (approximately 1 mm). Liners (presently suggested to be titanium 0.025 to 0.075 mm thick) are required. Shield masks made of tungsten or similar material are expected near the outer ends of the conical portions. The specifications for shielding materials will be developed under a separate R&D proposal submitted by T. Markiewicz. Participants in the two proposals will interact closely to ensure an integrated beam pipe design.

One model for servicing of the vertex detector assumes that the vertex detector is fully supported from the beam pipe. Providing such support places constraints on the beam pipe wall profile and thickness. Minimizing the consequences of beam pipe material on physics capabilities of the detector requires careful selection of beam pipe materials and thicknesses.

During the first year of R&D, analytic and finite element calculations of beam pipe deflections and stresses will be made as an aid in specifying the desired beam pipe radial profile, wall thickness, and materials. Initial estimates of required shielding materials will be taken into account. A proposal will be developed which specifies the profile, wall thickness, and materials of the beam pipe taking into account shielding requirements. That proposal will be discussed with industry to aid in understanding its feasibility and the extent to which specialized fabrication procedures would need to be developed. Contracts will be issued to begin fabrication of representative portions of the beam pipe to develop those fabrication procedures. Deliverables at the end of the first year will consist of the following:

1. beam pipe deflections and stresses as a function of longitudinal position
2. a proposal for beam pipe radial profile, wall thickness, and materials which takes into account initial estimates of shielding requirements
3. an iteration of beam pipe deflections and stresses as a function of longitudinal position for that proposal
4. an evaluation, based upon contacts with industry, on the feasibility of the proposed design
5. initiation of fabrication of prototypes of critical regions of the beam pipe.

During the second year of R&D, prototypes representing each portion of the beam pipe will be completed and tested, designs will be iterated, and a prototype beam pipe made of stainless steel will be obtained and tested. Designs for tungsten masks (or equivalent) and guided bellows will be developed. Deliverables at the end of the second year will consist of the following:

6. prototypes representing each critical region of the beam pipe
7. test results of those prototypes
8. an evaluation of fabrication techniques and procedures for each region of the beam pipe
9. iteration of the design to take into account a more complete knowledge of required shielding materials
10. a mechanical prototype of the beam pipe based upon stainless steel
11. measurements of deflections and stresses of the stainless steel beam pipe
12. designs for guided bellows.

During the third year of R&D, guided bellows will be obtained and tested, then added to the stainless steel beam pipe. Deflections of the full assembly of stainless steel beam pipe, bellows, and simulated masks will be measured. Designs and fabrication drawings for the final beam pipe will be completed. Procedures will be developed for acceptance testing, including a bake-out and leak check. Budgetary quotes will be obtained based upon those drawings and associated specifications. Deliverables at the end of the third year consist of:

13. a full stainless steel beam pipe, including guided bellows and simulated tungsten masks
14. measurements of deflections under load of that beam pipe
15. full fabrication drawings of a final beryllium beam pipe
16. procedures for beam pipe acceptance testing, including a bake-out and leak check
17. a budgetary cost estimate for that beam pipe.

2.2. Vertex detector systems

The performance requirements for the vertex detector to satisfy its physics goals have become clear only over the past year. Previously used benchmarks (related to *b* and charm tagging) were relatively insensitive. However, the SLD experiment pioneered the use of 'vertex charge' as a superior method of quark charge sign-selection (b vs $\bar{b}$, c vs $\bar{c}$). This capability has been shown to be of great value for physics at the Z^0 (see for example [1]) and will be even more important at ILC, where essential benchmark reactions which depend on it have now been recognised. Since the vertex charge is defined to be the total charge of all tracks in the decay chain, excluding all tracks from the IP, its measurement depends on the quality with which the lowest momentum tracks in the jet can be measured. It has been demonstrated [2] that there is a major advantage in 'luminosity factor' (the factor by which the integrated luminosity would have to be increased, to compensate for an inferior detector) if the detector can be built to satisfy the following requirements:

beampipe radius at most 12-15 mm
pixel-based sensors
point measurement precision at worst ~ 3 μm
2-track resolution at worst ~ 40 μm
barrel layer thickness at most 0.1% X_0
micron-level mechanical stability
power dissipation at most tens of watts (in order to avoid the material budget associated with liquid cooling)
adequate radiation resistance
adequate tolerance to electromagnetic interference
etc

While these requirements have now become well-established, at the first LCWS (Finland, 1991) the conventional wisdom was that a lower-performance LEP-style detector based on silicon microstrips could do the job [3]. By the time of LCWS 1993, the SLD vertex detector based on monolithic silicon pixels in the form of CCDs had demonstrated its superiority, and the simulated backgrounds at the ILC ruled out microstrips [4]. Since that time, the world-wide R&D for the ILC vertex detector has focused exclusively on monolithic silicon pixels, but the variety of different pixel architectures has blossomed to the point that there are now about 10 different candidates under development. While this situation might suggest a need for consolidation, this is far from obvious. The 'warm' ILC option would have provided a relatively comfortable environment for vertex detectors, so that a modest upgrade to the SLD detector design could have done the job. Readout spanning a number of bunch trains (as at SLC) would have sufficed. However, the time structure of the cold machine (about 3000 bunches in a 1 ms train) is far more challenging. At first sight, in order to limit backgrounds to an acceptable level, it is necessary to read the detector ~20 times per train, hence with 50 μs readout time. Achieving this with low power dissipation for a detector of ~1 Gpixels is pretty challenging. Some options (CPCCD, CMOS MAPS, DEPFET) intend to follow this approach. Others (FPCCD) integrate the background through the entire bunch train, but compensate by having very fine-grained pixels. Still others (FAPS, CAP, ISIS) store the signals in approximately 20 storage locations within each pixel, which are filled sequentially during the train, and are read out at leisure between trains. Of this class, the FAPS/CAP involves charge-to-voltage conversion and storage on tiny capacitors, while the ISIS involves shifting the signal charges accumulated during each time window to a string of tiny potential wells (CCD pixels) within the buried channel of the silicon. One option known as the macro-pixel design is a monolithic variant of the LHC vertex detector concept; it provides time-stamping at the single bunch level, and hence superb background suppression. However, whether their pixels can be made small enough to satisfy the precision and 2-track resolution requirements, remains an open question for the present. In short, there is not a single existing architecture which has established capability to satisfy the physics requirements listed above, and for this reason ongoing R&D on all options is not only justified but also essential.

A serious concern, given the problems encountered at SLD, relates to electromagnetic interference in the accelerator environment. A linear collider (in contrast to storage rings), needs a large quantity of invasive diagnostics in the IR (beam position monitors, beam-size monitors, kicker magnets etc). Despite considerable precautions, it is quite possible for brief but intense pulses of RF power associated with the electromagnetic 'pancake' that accompanies the beam traveling down the beampipe, to escape into the experimental environment. It is also easy, counter-intuitively, for this short RF pulse to penetrate the detector Faraday cage, then to penetrate the screening of the sensor chips, and to excite ringing of parasitic LC circuits within the chip. Recurring at 300 ns intervals, these interference pulses could play havoc with the delicate sensor circuitry throughout the bunch train. As at SLD, this could disrupt the operation of the sensor/readout chip, degrading or even disabling the DAQ. Concerns about this problem stimulated interest in the ISIS architecture, in which the activity during the train is restricted to the robust procedure of charge transfer within the buried *n*-channel of the device, and the sensitive readout takes place entirely during the quiescent 200 ms periods between trains. The FPCCD option will be equally robust as regards pickup. Furthermore, a general strategy has been proposed [5] for minimising the risks of EMI related to the beams and beam delivery system (kicker magnets etc) for all types of pixel architecture. Part of the strategy is to qualify every candidate ladder design regarding its resistance to EMI, just as will be done regarding resistance to ionising radiation.

There have been numerous estimates of the radiation environment of the ILC vertex detector. The principal source of ionising radiation is the background of e^+e^- pairs generated by the beam-beam interaction. Dose rates are modest, and the most rad-soft of the options (CCDs) will be able to cope with them. The dominant effect is generation of p-V defects (the Si-A centre) from dislocation of single atoms in the *n*-type material of the CCD buried channel. If the degradation of charge-transfer inefficiency (CTI) is too severe, this problem can be solved (as was done at SLD) by cooling. In fact, the higher background occupancy and faster readout at ILC implies that it is easier to keep the traps saturated, so the cooling requirements may be much less extreme; instead of operating at around 180 K, something like -10 C may suffice. As well as ionising radiation, the neutron background also needs to be considered carefully. This is produced from the beam dump and beamstrahlung dumps, so is dependent on the details of the transport system for the spent beams. Neutron bulk damage in silicon produces damage clusters, hence many defect levels, which makes it less responsive to cooling. Radiation effects are a concern for all the candidate architectures. It is a frequently stated but dangerous oversimplification, to claim that submicron CMOS devices are 'intrinsically rad hard'. Particle sensors in every technology are very different from typical analogue and/or digital electronic devices, and careful design and testing is needed to establish the radiation resistance of each individual structure.

The choice of sensor architecture is also coupled to the choice of overall detector layout. The LDC concept, following from the SLD detector and the TESLA TDR, has retained the long-barrel approach as its baseline. The SiD and GLD concepts think more in terms of short barrels plus forward disks. The long-barrel layout has the advantage that one can be somewhat relaxed about additional material at the ends of the ladders (eg storage capacitors, connectors and cables) and one can certainly design the mechanical support system to achieve the required micron-level stability. The short-barrel layout has the possible advantage of somewhat better angular coverage, but it creates severe constraints on the end-of-ladder material as well as on the support structure for the barrel system. If one is not careful, the slightly improved angular coverage might be won at the expense of seriously degraded barrel performance. To choose between these options requires a significant R&D programme, which is of course strongly related to the choice of sensor technology.

It will take years before full-sized ladders incorporating all performance requirements become available, hence for all these tests to be carried out meaningfully. For this reason, it will be impossible for some time to 'pick winners' among the architectures described in this Section, as has sometimes been the fashion with funding agencies. What should certainly be agreed are standard procedures against which all candidate ladders should be evaluated by 2010. From the funding information sent to us, it will require a miracle for some of the options to reach the stage of full-sized, full-performance ladders on that timescale. However, one may be agreeably surprised in some cases, even if funds remain grossly inadequate for development via any conventional route. Some groups have formed fruitful relationships with device manufacturers who value their participation in common R&D activities. We have very little idea at present which if any architecture will satisfy the stringent requirements for ILC, and which will fall by the wayside. If none reaches the requirements, it will be necessary to equip the experiments with stop-gap detectors while the development work continues. This indeed is what happened at SLC. The CCD architecture, while preferred because of its higher potential performance, could not be developed in time for the start of physics, so the Mark II detector ran with a microstrip-based vertex detector. When SLD was installed a couple of years later, it was just possible to have a CCD-based vertex detector ready in time. However, even that was marginal in some respects, and it was replaced after a few years by an upgraded detector built with much larger and thinner CCDs. It is worth recalling this evolution, since something similar could easily happen at ILC. For this reason, the vertex detector community has emphasised the need for a design of the overall detector that allows easy access for repairing or replacing the vertex detector, as well as the other high-tech equipment in the small-radius region within the volume of the central tracking detector.

[1] SLD Collaboration, PRL 94, 7 March 2005, 091801

[2] Physics potential of vertex detector as function of beampipe radius, S Hillert and CJS Damerell, Proc Snowmass ILC workshop 2005 (to be published)

[3] Experimental challenges at linear colliders, DL Burke, Proc LCWS 1991, World Scientific, 51

[4] Progress report on a CCD-based vertex detector design, and some observations on the microstrip detector option, CK Bowdery and CJS Damerell, Proc LCWS 1993, World Scientific, 773

[5] 'Vertex detectors - how to overcome electromagnetic interference', CJS Damerell, Proc Snowmass ILC Workshop 2005 (to be published)

Project: DEPFET pixel based vertex detector

RWTH Aachen, Bonn University, Mannheim University, and MPI Munich, Halbleiterlabor

Contact: Ladislav Andricek (MPI Munich, Halbleiterlabor)

DEPFET pixels offer the unique possibility for a high resolution pixel vertex detector as the innermost component of the tracking system in an ILC detector. The key idea of DEPFET sensors is the integration of amplifying transistors into a fully depleted bulk in such a way that all signal charges are collected in the 'internal gates' of the transistors. The excellent noise performance obtained through the low input capacitance in combination with the full primary signal leads to a large S/N ratio. The sensor itself can therefore be made very thin (50 µm) without loss of efficiency. Readout is performed by cyclic enabling of transistor rows in a large matrix. The total system, including readout and sequencing chips, is expected to dissipate about 4W for a 5 layer geometry assuming a 1:200 power duty cycle. Like all of the technologies proposed for the vertex detector at the ILC, the DEPFET apporach is applicable to all three of the overall detector concepts (SID, LDC, and GLD).

Presently, there are three German institutes participating in this project. The MPI Semiconductor Laboratory is developing the DEPFET sensor and its technology, and is responsible for the production of the matrices, which takes place in the clean room of the MPI Semiconductor Laboratory. The Universities of Bonn and Mannheim are responsible for the readout chip CURO and the steering chip for the row wise read out of the matrix. System design and evaluation is also part of the responsibilties of these two Unversities. A group form Aachen University has recently joined the project.

The most important achievements are the realization of several prototype sensor matrices using double metal technology, the design, fabrication and characterization of fast steering and readout chips, the realization of an ILC suited prototype system, the preliminary measurement of its performance in the lab as well as in the test beam, progress in and validation of the thinning technology and studies on the radiation tolerance of DEPFET sensors. In particular, DEPFET pixel sensors have proven to be radiation tolerant in excess of 1Mrad ionizing dose. In 2005 a 64 x 128 DEPFET pixel matrix system with close to ILC specs has been tested and evaluated in test beams with excellent results regarding noise and hit reconstruction performance.

After the successful evaluation of the first prototype system, the project will move 2006 in the next phase with the production of optimized larger matrices and new submissions of the readout and steering chips. An important step towards a full size demonstrator with thinned DEPFET matrices, planned for 2009, is also the elaboration of an engineering model for the vertex detector at the ILC.

The project is currently sufficiently supported by the German Ministry for Research (BMBF), the European Union through the EUDET program, and the Max-Planck-Society (MPG and MPI fuer Physik in Munich).

Project: SOI-based vertex detector

AGH, University degli Studi dell'Isubia, Institute of Electron Tecnology

Contact: Halina Niemiec (AGH-University of Science and Technology, Poland)

Growing demands of the high energy physics experiments require novel solutions of semiconductor detectors characterised by improved parameters in terms of granularity, readout speed, radiation hardness and sensor thickness. Nowadays a common trend in the field of highly segmented ionising radiation detectors is the development of monolithic active pixel detectors, which allow integration of a pixel detector and readout electronics in one entity. It is expected that the monolithic approach will enable reducing material budget in future experiments and will allow lowering sensor costs due to the elimination of complicated bump-bonding flip-chip processing.

One of the methods that allow developing monolithic active pixel sensors is exploitation of the Silicon-on-Insulator (SOI) technology. A common SOI wafer consists of a thin layer of single-crystal silicon, separated from a bulk silicon substrate by an electrically insulating layer - typically silicon dioxide. In standard integrated circuits the top silicon film, called device layer, is used for manufacturing of electronic devices while the bottom silicon substrate, called support layer or handle wafer, acts only as a mechanical support. The multilayer structure of the SOI wafer may be advantageous for the design of monolithic active pixel sensors. The main idea is utilization of the silicon support layer as the radiation sensitive substrate of a monolithic detector and fabrication of the readout electronics in a conventional way in the device layer. Relying on this basic concept, a new monolithic pixel sensor has been developed. This device exploits commercially available wafer-bonded SOI substrates consisting of a high resistivity handle wafer and a low resistivity device layer. The proposed solution allows detector operation at the full depletion region and the integration of a fully complementary MOS readout circuitry in a sensor cell.

Development of a monolithic active pixel detector basing on SOI technology required a non-standard technology, integrating pixel manufacturing technique with typical CMOS process. The major challenges of such technology were processing from both sides of the buried oxide and preserving high quality detector diodes despite manufacturing steps of the CMOS devices in upper silicon layer. In order to match those demands, special technology, consisting of more than 120 processing steps, was developed at the Institute of Electron Technology. Using this technology, simple sensor test structures as well as first real-size prototypes (with active area of 1-4 square centimetres) were produced. The configuration of these sensors was imposed by requirements of medical applications of "Silicon Ultra-fast Cameras for Electron and Gamma Sources in Medical Applications" project (European Union GROWTH Project G1RD-CT-2001-000561), which was carried on from 2001 to 2004. The tests of the manufactured sensors proved their sensitivity to ionising radiation and opened the way for further development.

At present, the major research effort is focused on improvement of the production yield and noise performance of the SOI sensors. In order to reduce sensor dark currents, a joint research effort with a SOI substrate manufacturer is planed within a 1-year time-scale. From the point of view of the vertex detector application, one of the key issues of further SOI sensor development is moving sensor production into deep-submicron CMOS process. Technology redefinition will require 2-3 years. It will be followed by radiation hardness tests, detector back-thinning and development of fast readout architecture and signal pre-processing on-chip.

The SOI detector workgroup consists of AGH-University of Science and Technology in Krakow (Poland), Institute of Electron Technology in Warsaw (Poland) and Universita' degli Studi dell'Insubria in Como (Italy). AGH is responsible for device-level simulations, technology verification, sensor design and tests, IET – for technology development and Universita' dell'Insubria – for system-level integration.

The SOI detector R&D is currently supported by Polish funding agency, but the allocated resources are insufficient. Purchasing of SOI substrates and sensor prototyping require additional support.

Project: LCFI Collaboration

Univ. of Bristol, Univ. of Glasgow, Univ. of Liverpool, Univ. of Nijmegen, Univ. of Oxford, Rutherford Appleton Laboratory

Contact: J Goldstein (RAL)

The LCFI Collaboration is developing the sensors, electronic systems and mechanical support structures necessary for the construction of a high performance vertex detector at the ILC, and investigating the contribution such a vertex detector can make to the physics programme of any of the detector concepts currently being considered. The goal of LCFI is to produce and test full-scale sensors with the accompanying electronics, support and cooling systems necessary. The design must allow polar angle coverage in the range $\cos \theta < 0.96$, readout or signal storage within 50 µs, and have a material budget of at most 0.1% X0 for normally incident particles, providing an impact parameter resolution of ≤ 5 µm for tracks with momentum as low as 1 GeV/c.

LCFI has demonstrated the operation of column parallel (CP) CCDs at high clock speeds (up to 25 MHz) and low clock clock voltages (1.9 V), and using both charge and voltage sensitive amplifiers on ASICs bump-bonded to the sensors with a 20 micron interconnect pitch. The near future will see the delivery and testing of a new generation of CPCCDs, including full-scale and high speed "busline-free" devices. Corresponding new ASICs with on-chip cluster finding and data reduction are already being tested.

Different sensor technologies are now being actively considered with the first test structures for Imaging Sensors with In-situ Storage (ISIS) soon to be tested. Within the next 2-3 years, far more advanced ISIS prototypes will be made, along with active pixel storage sensors and a further generation of CPCCDs.

Mechanical studies have already shown the limitations of ladders using unsupported silicon or thinned silicon on a beryllium substrate. Detailed study of designs using carbon fibre or ceramic foams are underway, with a decision on a preferred technology foreseen by Summer 2007. LCFI is also beginning to study the integration of individual ladders into a complete detector design.

The Collaboration has an active physics programme, developing and using flavour tagging and heavy flavour charge identification tools. These investigations are being extended both to optimise the vertex detector design and to maximise the physics potential of the ILC. There is also work to make these tools available to the wider community.

The electronics design work is centred at Oxford and RAL, with Glasgow, Liverpool and Nijmegen being primarily involved with device testing. Mechanical and physics studies are carried out by the Bristol, Oxford and RAL groups.

The prototyping of different sensor technologies is limited by the funds available, the relatively slow start to storage sensor prototyping being designed to fit within financial constraints.

Project: SOI and 3D Detector Geometries

Fermilab, Purdue University

Contact: Ronald Lipton (Fermilab, USA)

- *What are the goals of this R&D project. How does this R&D project address the needs of one or more of the detector concepts?*

The object of this work is to develop and demonstrate a pixel detector based on three-dimensional integration of sensor and readout electronics. Development of this technology will allow production of pixel sensors which are thin (<50 microns), have excellent and well controlled charge collection using fully depleted devices, and can use full CMOS readout without parasitic charge collection. These detectors will also be radiation hard. Such a device can be used as part of the vertex or forward detector for any of the detector concepts. Two approaches are being examined, Silicon on Insulator (SOI) technology and three-dimensional integration.

SOI is based on a thin “device wafer” with CMOS circuitry processed on a thicker “handle wafer”, which is normally passive. In this work we will explore using a high resitivity handle wafer as a detector with vias between the device and detector layers. The detector diode is formed in the handle wafer as part of the topside processing.

A second approach which we will study is “three dimensional” integration of CMOS readout and detector wafers. This approach is similar to SOI, but the CMOS and detector wafers are processed independently, thinned, and then bonded. Bonding can be done using known good readout die bonded to a sensor wafer. Vias are then etched and filled to connect the CMOS and detector layers.

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- *If there are multiple institutions participating in this project, please describe the distribution of responsibilities.*

Fermilab will provide support for CMOS design and testing, radiation testing, and test beam and laser test work. For the SOI work American Semiconductor will provide device design and modeling, define process flow, and manage device fabrication. Purdue will provide support for device testing and detector layer design.

- *Are there significant recent results?*

No, this project is just beginning.

- *What are the plans for the near future(about 1 year)? What are the plans on a time scale of 2 to 3 years?*

The initial phase (~1 year) of the SOI work will concentrate on the type (float zone, epitaxial, or Cz material) and model the processing, of the handle wafer, including wafer thinning and backside contact fabrication. We will also irradiate samples of FLEXFET SOI transistors. CMOS processing will be in 0.18 or 0.13 micron technology. If successful this will be followed in phase II (2-3 years) by a ~9 mm square pixel device with test structures and prototype pixel readout. This phase will require full custom processing of a batch of 200 mm SOI wafers. This will allow radiation tests, device thinning, and charge collection studies. We are submitting a DOE STTR grant for this work with American Semiconductor Inc. Our collaboration with American Semiconductor gives us access to a state-of-the-art IC line with the ability to specify the details of the process flow.

The initial phase (~1 year) of the 3D work will use BTeV readout and detector wafers to explore bonding and interconnect technology. We will choose an interconnect technology, measure yields, and test the quality of the detector wafer after processing. If the first phase is successful, the second phase (2-3 years) would use an ILC-specific sensors and readout using standard 0.25 or 0.13 micron CMOS designed specifically for the ILC. This will require design and fabrication of both the detector and readout wafers. The readout wafers could be part of a multi-project submission

- *Are there critical items that must be addressed before significant results can be obtained from this project?*

The effects of charges in the oxide or adhesive which separate the readout and detector layers in the SOI and 3D devices need to be understood. A choice of substrate which is compatible with the SOI process and which can be thinned with a backside contact provided will be a focus of the phase I SOI work and should also address similar issues for the 3D device.

- *Is the support for this project sufficient? Are there significant improvements that could be made with additional support?*

The support for the SOI part of this project will be sufficient if the American Semiconductor STTR proposal is approved. Additional support as listed in the ("prioritization") form will be needed to implement phase II of the 3D work.

Project: Pixel-level sampling CMOS Vertex Detectors for ILC

U. of Hawaii, U. of Tokyo, H. Niewoniczanski Inst. of Nucl. Phys., KEK, U. of Pittsburg, Nova Gorica Polytechnic, FNAL

Contact: Gary Varner (University of Hawaii , USA)

Our Pixel Vertex Detector R&D Effort for ILC is an outgrowth of a pixel upgrade effort for the Belle detector at the KEK B Factory. For this further development we are joined by Fermilab, and consist of groups from Europe, Japan and the US. Any readout architecture capable of surviving the much harsher and lower track momentum requirement of a Super KEKB environment, should be a viable alternative for an ILC Pixel Vertex Detector. Given the near-term nature of this development, it provides the possibility to evolve and test a full detector system under actual running conditions at the world's highest luminosity collider.

Deep submicron CMOS shows great promise for ILC vertexing through the implementation of complex algorithms to reduce occupancy. We intend to explore these possibilities, with the current 3 generations of experience in such technologies to guide our effort.

To date we have made good progress in addressing some of the key issues needed before a CMOS (MAPS) type of detector may be used in the ILC environment:

- Signal processing/SNR
- Radiation hardness
- Mechanical support/cooling of thin devices
- Readout speed/functionality

Much work remains to be done:

- Thinning/active edges
- EMI impact on pixel storage and readout

Project: CMOS Pixel Vertex Detectors

IReS, DAPNIA

Contact: Marc Winter (IReS, Strasbourg, France)

Project: CCD Vertex Detector

KEK, Tohoku University, Tohoku-Gakuin University

Contact: Yasuhiro Sugimoto (KEK, Japan)

As a candidate of the vertex detector for ILC, we propose a vertex detector based on fine pixel CCDs (FPCCD). In this idea, the hit signal is accumulated during a train and readout in 200ms interval between trains. We would carry out the R&D program including development of the new sensors, readout ASICs for them, and fabrication of prototype ladders.

Why FPCCD?

At ILC, 2820 bunches of electron and positron beam make collisions successively with 337ns bunch intervals. This succession of 2820 bunches is called "train", and trains are repeated at a rate of 5Hz. Due to low energy electron/positron beam background, the hit rate of the innermost layer of the vertex detector is estimated to be ≈1.5 hit/cm^2 at R=2.0 cm and B=3T for one bunch crossing (BX). If the hits are accumulated for one train, the hit density becomes very high, and the pixel occupancy for a pixel detector with 25μm pixel size exceeds 10%, which is not acceptable.

One method to keep the pixel occupancy acceptable level (≈0.5%) is to read out the sensors more than 20 times in one train. There are R&D activities by several groups based on this method. This method requires very fast readout speed, and the feasibility has not been demonstrated yet.

In the FPCCD vertex detector, we use very fine (≈5μm) pixel CCDs. The pixel occupancy will be less than 0.5% even if the hit signal is accumulated during a total train of 2820 bunches. In order to suppress the number of hit pixels due to diffusion in the epitaxial layer, the sensitive layer of the FPCCD should be fully depleted.

Recently, CCDs with the pixel size less than 5μm are used for digital cameras. So, we believe the FPCCD is technically the most feasible option for the vertex detector.

R&D goals

Our major R&D goals are:

- Development of the new type of sensors (FPCCD)
- Thinning of the wafers and their support structure

We also have to work on the following items:

- Development of the readout ASIC
- Minimization of the power consumption
- Data compression and the backend electronics
- Cooling system with minimum material
- Thin beam pipe

Present activities

At present, detector simulation studies of the FPCCD vertex detector is being carried out at Tohoku University. A basic study of fully depleted CCDs (not fine pixel) using LASER light is done at KEK. In order to attack our major R&D goal, the funding support is absolutely insufficient.

Project: Si Pixel R&D for the ILC

LBNL, University of California at Berkeley

Contact: Marco Battaglia (Lawrence Berkeley Nat. Lab., USA)

Project: Vertex detector R&D for Future High Energy Linear e+e- Colliders

University of Oregon, Yale University

Contact: Jim Brau (University of Oregon, USA)

The Pixel Vertex Detector R&D project of the Oregon-Yale group is aimed at developing a vertex detector sensor for the ILC that satisfies the physics and machine requirements for vertexing. The time structure of the ILC necessitates an extremely fast sensor for the vertex detector elements. This effort, therefore, has started on the development of monolithic CMOS pixel detectors that allow extremely fast, non-sequential readout of only pixels containing hits. This feature significantly decreases the readout time required from a device that reads out all pixels, such as a CCD.

Another important possibility for these CMOS detectors is the time stamping of hits with single bunch crossing precision. This significantly reduces the effective backgrounds.

During 2004-5, in collaboration with SARNOFF, Inc. (RCA’s silicon fabrication house) with whom we had an R&D contract, we developed a draft conceptual design for a device. Each chip consists of two particle detection layers, one consisting of an array of 50μ x 50μ pixels (Macro Pixel Array) and one consisting of an array of 5μ x 5μ pixels (Micro Pixel Array) Each pixel of the Macro Pixel Array detects up to four hits in an ILC bunchtrain (~ 1 msec) and records the time of the hits to a precision better than the inter-bunch spacing. The Micro Pixel Array records hits in the x-y array with 3 bit pulse height resolution within each pixel.

The project is now ready to move on to detailed design, which will start in 2005-6.

Issues to be addressed during the detailed design phase include:

- Achieving all the design features simultaneously on one chip
- Thinning of the devices
- Radiation hardness
- Power consumption
- Impact of electromagnetic interference on the functioning of the device at the pixel level

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Project: Hybrid pixel detector R&D

FNAL

Contact: David Christian (FNAL , USA)

Over the last ten years, a number of groups worldwide have invested a large amount of effort in a successful program to develop hybrid silicon pixel detectors. The current generation of detectors combines radiation tolerant n-in-n silicon pixel sensors with high speed, radiation tolerant, CMOS readout electronics. These devices provide extraordinary pattern recognition power and near 100% efficiency. The spatial resolution that can be achieved depends on the area required for readout electronics, which in turn depends primarily on the readout speed that is required. BTeV beam tests demonstrated that spatial resolution (in the narrow pixel dimension) better than 10 microns is possible for all incident track angles given 50 micron x 400 micron pixels and a sensor thickness of 300 microns.

In a hybrid pixel detector, the sensor and readout chip are bump bonded to one another using a process that does not change any of the electrical properties of either the sensor or the readout chip. This means that the sensor and the readout chip can be developed separately and can be optimized separately. The current generation of detectors has been optimized for use at high luminosity hadron collider experiments. These detectors are not attractive candidates for use at the ILC because the total amount of material is typically ~2% of a radiation length per measurement.

The object of this effort is to explore the possibility of greatly reducing the amount of material in a hybrid silicon pixel detector while still retaining near 100% efficiency, excellent time resolution, and high-speed, zero-suppressed readout. To this end, two questions will be addressed:

1. How far can the readout chips be thinned without making flip-chip assembly problematic?
2. Can the cooling requirements of the readout chip be reduced to the point that gas cooling of the hybrids is sufficient?

In FY06, existing prototype BTeV pixel readout chips will be thinned and bump-bonded to prototype BTeV pixel sensors. The ALICE pixel detector uses readout chips that are thinned to 150 microns. Our initial goal is to demonstrate proper detector operation with BTeV readout chips thinned to 80 microns thickness. If additional funds are available in FY06, we will purchase additional BTeV-style pixel sensors fabricated using silicon wafers thinner than our existing 270 micron thick prototypes.

The ILC is expected to operate with “trains” of beam bunches approximately 1 millisecond long, separated by 199 milliseconds. If the pixel readout chips do not require power for most of the 199 milliseconds between bunch crossings, then the heat generated by the readout chips will be greatly reduced. During FY06, we will use existing prototype BTeV readout chips to explore the extent to which cooling requirements can be reduced by power management. Alternative readout chip designs may also be considered and simulated.

If the results obtained in FY06 are promising, then in FY07 a new readout chip will be designed. This chip will be a modification of the BTeV design optimized for low power consumption. Depending on the availability of funds we will either fabricate a full sized version of the new chip, or we will fabricate a smaller readout chip as part of a multi-project wafer submission. An engineering run of a full sized chip will provide many wafers that can be thinned and bump bonded to sensors. If a smaller device is fabricated as part of a multi-project wafer submission, we will measure the performance and power consumption of bare chips (not bump bonded to sensors).

Depending on the progress made in earlier years, hybrids will be constructed and tested in FY08 using thin sensors and low power readout chips.

Either in FY07 or FY08, the status of this R&D effort will be assessed. If the results are sufficiently promising, further plans will be made to develop ultra-thin hybrid pixel detectors. If not, the experience gained in thinning readout chips and bump-bonding ultra-thin chips to sensors will be invaluable experience for the various monolithic pixel projects and for the mechanical design of future vertex detectors.

Project: Vertex Detector Mechanical Support

FNAL, SLAC

Contact: Bill Cooper (FNAL , USA)

INTRODUCTION

The silicon-based vertex detector is expected to be assembled at room temperature. Depending upon the sensor technology chosen, its operating temperature is expected to fall within one of two ranges: 0degC to room temperature or -80degC to 0degC. For either range, structures which support and position silicon sensors should ensure that sensor geometry, both within a sensor and among the full array of sensors, is reproducible to a precision of better than 5 µm from one cool-down to the next. When the vertex detector is at operating temperature, variations in sensor geometry should be negligible during any period of less than a month.

GOALS

Vertex detector sensors are expected to be arrayed in ladders within barrel sub-assemblies and wedges within disk sub-assemblies. For any ladder or wedge, the number of radiation lengths represented by material other than silicon and its readout should be less than 0.015% at normal incidence to the silicon surface. Over the range of possible incidence angles, additional support material to combine ladders into a barrel or wedges into a disk should add not more than 0.2% of a radiation length. Structures to support the combined assembly of one five-layer barrel and seven single-layer disks (per barrel end) should total not more than 0.1% of a radiation length at normal incidence and not more than 0.15% of a radiation length at the worst angle of incidence.

The material required for cables, cooling, and thermal insulation are expected to be dependent upon the sensor and readout technologies chosen and will be evaluated as part of the R&D.

During the first year of R&D, designs, materials, and procedures for fabricating ladders and wedges will be evaluated and tested, as will be those for fabricating, assembling, and supporting a barrel and a disk. Deliverables at the end of the first year will consist of the following:

- at least one prototype ladder
- at least one prototype wedge
- a design for the support structure of a barrel
- a design for the support structure of at least one disk
- analysis of deflections under gravity of an assembled barrel
- analysis of deflections under gravity of an assembled disk
- analysis of expected thermal distortions between room temperature and operating temperature for a ladder, a wedge, a barrel, and a disk
- proposed paths for cables and services for the vertex detector
- an analysis of weights and numbers of radiation lengths represented by those objects.

During the second year of R&D, designs will be iterated and measurements of design performance will be made. Deliverables at the end of the second year will consist of the following:

- measurements of ladder deformations between room temperature and operating temperature
- measurements of wedge deformations between room temperature and operating temperature
- a prototype support structure for a barrel
- a prototype support structure for a disk
- measurements of deformations between room temperature and operating temperature of the prototype barrel and disk.
- a design for the structure to support a barrel and all disks.

During the third year of R&D, designs will be completed and prototypes will be built of the remaining disks, thermal and cooling analyses will be completed for the two ranges of operating temperature, and a full prototype of the mechanical support structure for the vertex detector will be built. Deliverables for the third year will consist of:

- prototypes of all disks
- thermal and cooling analyses for each range of operating temperature
- at least one full mechanical prototype of the vertex detector
- an analysis of the weight and number of radiation lengths represented by the completed structure.

SUPPORT

The current level of support is inadequate for carrying out the proposed research. The level of shortfall is listed on the prioritization form.

Project: Pixel Vertex Detector Simulation and Design Optimization

SLAC, LCFI Collaboration (U Bristol, U Glasgow, U Liverpool, U Nijmegen, U Oxford, RAL), U Oregon, FNAL

Contact: Dong Su (SLAC , USA)

The main goal of this project is to evaluate the vertex detector design performance through simulations and physics benchmark analyses, in order to assist the key design decisions.

Some of the main branches of the project:

1) Vertex detector simulation in GEANT and performance studies

- Improving the track ionization and digitization model. This includes the incorporation of proper ionization fluctuation model from Hans Bichsel and improvements on charge diffusion/collection models. They are essential for allowing detailed sensor design optimization studies on e.g. pixel size, active silicon thickness and depletion depth and reconstruction clustering algorithms. This improvement for GEANT simulation will hopefully have generic applications also for many other silicon detector simulations.

- Updating the SiD vertex detector description with progressively more details of mechanical and other realistic system components. This will allow an integrated design optimization to evaluate geometry designs and sensor technologies with corresponding engineering reality taken into account for the overall system performance.

2) Vertexing analysis tools: For detector performance studies, improvements on analysis tools are essential. Some currently identified major areas:

- Track reconstruction quality classification and diagnostics.
- Track fitting utilities to decouple different effects.
- Topological vertexing utility
- Advanced vertexing utilities for b-tag and vertex charge.

3) Vertexing physics benchmark analyses: These analyses relating the physics performance to the detector design options, will ultimately help to judge the relevance of the various detector performance parameters to assist establishing priority of design effort and evaluating the trade-off of performance and design risks.

These projects are expected to be a continuous effort in the next 3 years with most of the components at least establishing the basic utilities in 2006 to serve the need of the SiD detector concept layout description document. The resource needs are primarily the travel support for staff physicists, postdocs and students.

Project: Development of Position and Time Sensing APSs for Tracking and Vertexing at the ILC

Brookhaven Natl Lab, Politecnico di Milano, INFN Milano, State University of New York at Stony Brook, INstitut de Recherces Subatomiques, Strasbourg

Contact: Pavel Rehak (Brookhaven National Laboratory , USA)

- *What are the goals of this R&D project. How does this R&D project address the needs of one or more of the detector concepts?*

The goal of this R&D is to develop a new type of Active Pixel Sensors (APSs) to track charged particles produced at the intersection region of International Linear Collider (ILC). The electric field of the desirable shape is created inside the active volume of the pixel, introducing the drift component in movement of the signal electrons toward charge collecting electrodes. Sharing of the signal electrons between adjacent pixels by diffusion is strongly reduced with respect to classical APS devices. The proposed sensor is fabricated using a standard industrially available Complementary Metal Oxide Silicon (CMOS) process. It represents a large improvement of the state of the art of sensors for detection of position and of the time of occurrence of charged particles crossing the sensors. There are two main advantages of the proposed detectors as compared to the present (2005) state of the art. The first advantage is the reduction of the charge collection time thanks to the added transport mechanism (drift). The second advantage is the freedom to use of both kinds of MOS transistors within each pixel of the sensor. Thus, the full functional power of CMOS architecture can be embedded in situ. The reduced collection time combined with the state of the art electronics within each pixel provides the most complete information about the position and the timing of incident charged particles. Position resolution of a few microns is the retained from standard APSs. Timing precision should be about 100ns. Moreover, the active depth of the sensor and the associate electronics is less than about 20 microns and a thinned down sensor together with its beryllium backing can have the total thickness of less than 0.1% of one radiation length. The reduction of the thickness of the detector reduces the amount of multiple scattering within the detector. The determination of the momenta and of the origins of particles can be improved. The proposed APSs should be radiation resistant.

- *If there are multiple institutions participating in this project, please describe the distribution of responsibilities*

BNL – 1) Design of epitaxial layer with optimized drift field, 2) Partial design of front end electronics, 3) Testing
Milan – 1) Partial design of front end electronics, 2) Partial design of timing logic
Stony Brook – 1) Partial design of timing logic, 2) Testing
Strasbourg – 1) Thinning, 2) Testing

- *Are there significant recent results?*

No hardware has yet been produced. Only results are of simulations which confirm the idea behind the project.

- *What are the plans for the near future(about 1 year)? What are the plans on a time scale of 2 to 3 years*

Within about 1 year from obtaining funding we shall have a working prototype with arrays of lower number of pixels. Within about 2 years we shall have prototypes of full size arrays without any attempt of thinning. Within about 3 years we shall have prototypes of thinned down Active Pixel Sensors.

- *Are there critical items that must be addressed before significant results can be obtained from this project?*

No. The most critical question, that is, the independence of the hole current generating the field and signal current of electrons was already proven by a test of the pre-prototype of Strasbourg collaborators.

- *Is the support for this project sufficient? Are there significant improvements that could be made with additional support?*
-

No. The project is not yet supported. No progress can be made without (additional) support.

2.3. Tracking systems (gaseous)

Unprecedented tracking performance, combining precision measurement, reconstruction efficiency in a multi-track environment, and immunity to radiation-related noise, is required to meet the demands of the ILC physics program. In addition, tracking must be integrated into detector concepts that have aggressive goals for calorimetry. Thus, tracking detectors must present minimal material at all polar angles to reduce interactions of particles and photons before entering the calorimeters. Gaseous detector technologies are being pursued as options for both central and forward tracking at the ILC. For both cases the technology is advanced; gas-amplification is not based on the traditional wire technology. Rather, all groups are pursuing designs that employ the relatively new micro-pattern-gas-detector technologies: GEM and Micromegas.

Forward direction planar detectors are being studied by the Louisiana Tech group. Chambers employ GEM gas-amplification technology offering good point resolution and fast readout time suitable for the angular region of $0.90 < \cos(\theta) < 0.99$. Detectors are potentially less expensive, and add less material when compared to silicon detectors. Current studies involve the development of a radiation hard system with using the larger, 30cm, GEMs from the 3M corporation. Optimization studies involve simulations of the forward tracking detectors between the central tracking device and the forward calorimeters. There is only one group investigating this option. Increased funding would allow an expansion of the group and an earlier completion of the studies. With sufficient funding, test beam studies can be carried out at Jefferson Lab.

A time projection (TPC) has been selected as the central tracking device for two of the currently established concepts, LDC and GLD. Continuous tracking in the TPC has the potential to provide excellent reconstruction efficiency for both primary and secondary tracks. A system including a TPC, an inner vertex detector, and an intermediate silicon tracker has the potential to provide the required measurement precision. These goals can be met with a high granularity TPC providing a point resolution of about 100 μm.

Several groups in Asia, Europe, and North America are working on the development of a TPC using either GEM or Micromegas gas-amplification technology. Most of these groups work cooperatively within the LC-TPC organization. Over the past two years, point resolutions of about 100 μm has been demonstrated in magnetic fields using small chambers with 10 to 20 mm^2 pads and readout areas of about 100 cm^2 . In the next phase of development, the groups will collaborate on a large prototype with diameter of about 80 cm and length about 90 cm.

The small chamber program will continue for the purpose of making detailed comparisons of the resolution and operating characteristics of the gas-amplification options, including measurements of ion-feedback. Ion-feedback measurements are a high priority because results influence the decision to implement a gating grid in front on the readout.

The large prototype will be used for the development of a thin field cage. The large prototype will accommodate interchangeable endplates to allow groups to test both GEM and Micromegas gas-amplification readouts and to study optimization of tiling the endplate with readout modules. The large prototype will also be used to engineer and evaluate thin, precision, endplates. Low material is required for calorimetry. However, to meet the momentum resolution goal, the endplates must also be precise, to about 50 μm, to provide an alignment knowledge that is independent of the drift trajectory and the magnetic field map. Finally, the large prototype will be used to tests options for low power electronics.

Simulations are being used to determine and optimize the reconstruction efficiency of the system with respect to momentum, direction and jet density. Studies also include quantifying the acceptable levels of noise coming from overlapping events and beam background.

Testing of the large prototype will be carried out at DESY in a facility funded by EUDET. EUDET funds will also cover the costs of constructing the field cage. A successful program, however, will depend on additional funding to construct the interchangeable endplates, readout modules, and readout electronics. Current funding is insufficient at this time. World-wide, over the next 3 years, the additional equipment support needed for the TPC development program, including the large prototype program, the continuation of the small prototype programs, and the electronics development is about $1.6M.

Project: TPC Resolution studies using the concept of charge dispersion in MPGDs with a resistive anode

Carleton University, TRIUMF, University of Montreal, Dapnia, CEA, Saclay, CNRS/IN2P3, LAL, Orsay (affiliated with LC-TPC)

Contact: Alain Bellerive (Carleton University, Canada)

A TPC read out with a system of Micro Pattern Gas Detectors (MPGD) such as the Micromegas or the Gas Electron Multiplier (GEM) will not have the systematic problems of existing wire/pad TPCs. The MPGD-TPC could, in principle, reach the diffusion limit. However, charge position determination methods that work for the wire/pad TPC are less effective and make the MPGD TPC resolution significantly worse than the diffusion limit. Narrower pads indeed lead to a better spatial resolution, but also lead to an increase in the number of readout channels and in complexity, which ultimately affect the overall cost of the detector.

Recent R&D at Carleton has focused on developing new techniques to improve the MPGD-TPC resolution over that achievable with normal techniques. A new concept based on the phenomenon of charge dispersion in MPGDs with a resistive anode has been developed which could enable one to approach the statistical limit of resolution from transverse diffusion. The resistive anode allow a controlled dispersal of track avalanche charge over a larger area to improve the determination of position centroids with wide pads. Our recent studies with the GEM and the Micromegas detectors instrumented with a resistive anode are quite promising as a possible readout option for the LC TPC. Using 2 mm wide pads, we have demonstrated better GEM/Micromegas-TPC resolution with a resistive anode readout than has been achieved with conventional MPGD TPC readout systems. The resolution is near the diffusion limit of resolution for a gaseous TPC. In cosmic tests with no magnetic field, the measured resolution follows the expectations from transverse diffusion and electron statistics. Beam tests in a magnet is next to demonstrate good resolution for a MPGD instrumented TPC in a magnetic field. A resolution of ~100 microns for all tracks (2.5 m drift) using ~2 mm wide pads appears feasible with a resistive anode for the ILC TPC readout. The next step is an active participation in the construction of a large TPC prototype to investigate many readout schemes, including the readout concept of charge dispersion in MPGDs with a resistive anode.

Project: Linear Collider Gaseous Tracker R&D in Asia

CDC Collaboration (KEK, Tsukuba, TUAT, Kogakuin, Kinki, Hiroshima, Saga, Minadanao) (affiliated with LC-TPC)

Contact: Akira Sugiyama (Saga Univiversity, Japan)

After completed the R&D program on Jet chamber for JLC in 2003, the CDC group decided to move up to TPC R&D for ILC. This group has started a performance study of TPC since 2004, and simulation study byimplementing TPC into the full GEANT4 simulation frame work (JUPITOR) is also on going.

The TPC performance study has been carried out using the MPI TPC prototype, a Persistent-Current superconductive solenoid (PCMAG), and the Pi2 test beam from the KEK Proton Synchrotron (PS). Goals of this performance study are (A) to compare and understand the performance of different types of TPC such as MWPC, GEM and Micromegas, and (2) to demonstrate stable operations of these TPC in beam. This work has been carried out as an international collaboration with LC TPC R&D groups at MPI/Munich, DESY, Orsay and Saclay, and Carleton University.

The MPITPC is a small TPC prototype made at MPI/Munich. It has a detachable end-flange on which we mount a TPC end-detector of 10 cm x 10cm. The maximum drift distance is about 26cm. To readout out the TPC end-detector, we use the preamplifier and digitizer for ALEPH TPC. We can readout as much as 256 channels.

In the beam test, we make the best use of thin wall (20%rl) of the PCMAG. The inner diameter of the PCMAG is 850mm, the effective length 1m, and the maximum field 1.2T. The filed at the center is uniform enough for MPITPC although the magnet is an open magnet. For cosmic test, another PCMAG with yoke, and thus a better filed uniformity, is available at the KEK cryogenic center.

We have so far performed four beam tests at the pi2 test beam from KEK PS.:

(1) Test of a MWPC TPC in June 2004,

(2) Test of a TPC with three layers of GEM in April 2005,

(3) Test of a Micromegas TPC in June 2005, and

(4) Test of Micromegas (and GEM) with resistive anode readout in Oct 2005.

The MWPC TPC operated in the TDR gas in the test (2) was so called an ﾒultimateﾓ MWPC having the anode wire spacing of 2mm and a 1mm gap between the anode wires and the cathode readout pads. The size of pads was 6mm x 2.mm (6.3 mm x 2.3mm in pitch). Although the ultimate MWPC TPC provides an improved space resolution, it certainly suffers from the poor two-track separation and the large E x B effect. Although the group has been testing Japanese-made GEMs, in the test (2) we used the GEM foils from CERN. Here we employed a pad plane with 6mm x 1.17mm (6.3mm x 1.27mm) matching to a narrow signal of GEM. In the test (3) and test (4), we tested Micromegas TPC without and with the resistive anode. In both cases the pad size was same to one for MWPC. The test (4) was the first test of the resistive anode readout of Micromegas (and GEM) in the magnetic filed. In the test (4), the Carleton TPC prototype was also used.

We are getting understood our measured position resolutions and the pad responses, by a numerical calculation and a simulation, in term of pad pitch, diffusion, pad response function, and the effective number of primary electrons resulted from the fluctuation of gas amplification.

We are also working on newly produced GEM foils which are employing different methods (plasma etching and laser etching) for polyimido trimming by Japanese company.

Plans for the next year;

1) Complete small prototype test

2) Simulation study of TPC performance under realistic ILC condition

3) Optimization of MPGD-readout system (including digital TPC)

Plan for the next 2-3 years End-detector for a large prototype TPC under LC-TPC

We had submitted a budget request for large prototype TPC production for two years without any success. Our support is not sufficient to continue R&D program.

Project: TPC signal digitization simulation and reconstruction studies

Cornell University (affiliated with LC-TPC)

Contact: Dan Peterson (Cornell University , USA)

Full efficiency for charged particle reconstruction is required for precision particle flow analysis. A TPC for the linear collider must be designed to provide this efficiency over a large solid angle in an environment of high density jets and high noise occupancy. Reconstruction efficiency can be improved with higher readout pad segmentation to the limit of the signal charge width, about 1mm. While it is not even proven that this maximum segmentation would be sufficient to provide full efficiency, there are other limitations to such a high pad density: cost, material, heat, and complexity, that may force a larger pad size. Thus, it is necessary to optimize the readout geometry for reconstruction efficiency.

Simple models of the TPC response are not sensitive to the issues of noise. In the simple models, TPC hits are simulated as 3-dimension space points in the detector as shown in figure 1 on the project page. Charge depositions are treated independently providing no straight-forward way simulate the effects of overlapping hits.

The goal of the this study is to model the charge spreading and signal overlap to provide sensitivity to the effects of overlapping tracks and noise. In the Cornell simulation, charge is spread over neighboring pads (figures 2 and 3), and then accumulated in a simulation of the pulse train (figure 4) observed by the readout electronics, usually a FADC. The pulse train is analyzed to find the unambiguous threshold crossings in the same way that real data is analyzed. Thus, signal overlap is fully simulated. Reconstruction of tracks from the resulting charge/time signals is far more complicated, requiring pattern recognition of time clusters (figure 4) and space clusters (figure 5.

This study uses a modification of the CLEO track reconstruction algorithm to recognize track in this complex environment. Preliminary results were shown at LCWS04, Paris (April 2004). Results indicating the pad segmentation sufficient for full pattern recognition were shown at ALCPG, Victoria (July 2004). Most recently, at ECFA, Vienna (November 2005), results were shown for the noise tolerance (figure 6) for the specific case of random noise hits and a particular pad size.

This study currently uses the older sio data format. Further developments will require adopting the LCIO data format and access routines which will allow more complicated events and the addition of noise hit distributions derived from beam halo calculations.

In the near future, the simulation program will be modified to interface to the LCIO format directly. The next step, later in the next year, the simulation will be fully integrated into Mocha. This will make the simulation accessible to researchers and allow expanded studies of the efficiency dependency on the readout geometry and the various possible noise conditions. The interface to LCIO and integration into Mocha will also provide opportunities to further optimize the pattern recognition.

Support is not sufficient. Up to this point, all development has been done by D. Peterson. Further development will require support for a student to perform the LCIO and Mocha work as described above.

Project: Direct comparison of Micro Pattern Gas Detector Readouts

Cornell University, Purdue University (affiliated with LC-TPC)

Contact: Daniel Peterson (Cornell University, USA)

Several groups are currently studying gas-amplification devices in prototype TPCs. Results are encouraging; spatial resolutions of less that 100 micrometers have been measured with micro-pattern gas detector (MPGD) devices. However, measurements of different gas-amplification devices are difficult to compare because they are taken by different groups under various conditions. The goal of this project is to compare multiple examples of various gas-amplification devices, including GEMs, Micromegas and wires, under the same environmental conditions. This comparison will provide input into the TPC endplate design for both the LDC and GLD concepts.

In the past year, the Cornell group has constructed and commissioned a TPC, shown in Figure 1 on the main page, with a 64 cm drift field and 10 cm square readout aperture. To commission and operate the TPC, Cornell has purchased high voltage and data acquisition (DAQ) systems. The high voltage system provides 20kV for the drift potential as well as biasing voltages for the gas-amplification devices. The VME based DAQ has low noise power supplies to improve the signal sensitivity for prototype detectors. TPC signals are digitized with commercial Flash-ADCs. Cornell has purchased four 8-channels Flash-ADC units with 105 MHz sampling rate, +/- 200mV input range, and 14 bit resolution. The Purdue group is supplying the MPGD gas amplification devices mounted on Cornell supplied read-out pad boards. Results from a single-GEM were shown at Snowmass. An early cosmic ray event is shown in Figure 2 on the main page. The Purdue group has mounted a double-GEM in Sept. 2005. There are plans to provide a 3M-produced Micromegas, soon.

Preliminary studies have been done with 5mm pitch pads. In the next year we will increase the number of channels in the DAQ system to allow spatial resolution measurements using 2 mm pad pitch with several gas-amplification devices and several gas mixtures. An aggressive near-term goal is to measure the positive ion feedback for the various devices by directly collecting the ions for single tracks on the field cage termination grid.

Beginning in 2006, we anticipate that the world TPC group will collaborate to build large prototype to be tested at DESY. We expect to contribute by taking responsibility for the design and construction of a major component such as a tiled endplate.

The most critical requirement for future progress is funding for the expanded DAQ syetm and other equipment.

Our support is not sufficient. While we received 2005 LCRD funding, the total was about 30% of the request. Additional funding, would improve the resolution measurements and provide for measurements in an off-site test magnet.

Project: Cosmic-ray tests of a large Micromegas TPC in a 2T magnetic field

LBNL, Orsay, Saclay (affiliated with LC-TPC)

Contact: Paul Colas (CEA/DAPNIA Saclay, France)

Project: VLSI Readout for the TPC

LBNL, University of California at Berkeley, University of California at Davis

Contact: Marco Battaglia (Lawrence Berkeley Nat. Lab., USA)

Project: LC-TPC: Large Collaborative Projects

LC-TPC Collaboration

Contact: Ron Settles (Max-Plank-Institut fuer Physik, Munich, Germany)

Executive Summary

A Time Projection Chamber (TPC) has been chosen as the central tracking device for two of the current detector concepts at the International Linear Collider. The LC-TPC group is carrying out a comprehensive R&D program to develop the technology and prove the feasibility of a high-performance TPC required for this application. The new Micro-Pattern Gas Detector (MPGD) technologies, Gas Electron Multiplier(GEM) or Micromegas(MM), are attractive candidates for the gas-amplification because better precision and granularity may be achieved than in past TPCs. Extensive testing using GEM and MM is being pursued with the results being compared with each other and with the multi-wire proportional chamber (MWPC) technology used in TPCs up to the present. In addition, the proof-of-principle of CMOS readout techniques is being studied with both GEM and MM; if successful this will be a candidate for a final TPC. In addition to optimization of the gas-amplification, other issues including minimizing endplate material alignment and calibration most be understood before a TPC can meet the goals of the ILC. The R&D work is proceeding in three phases: 1) demonstration phase using small prototypes; 2) consolidation phase consisting of the building of a Large Prototype TPC with GEM and MM using both standard and CMOS readout techniques; 3) design phase which will profit from the experience gained in the first two phases. Presently (2005) phase 1) is under way and phase 2) is starting.

This project involves groups from institutions in all regions as listed below. To meet these goals the institutes listed on this research statement are working together, sharing information and experience in the process of developing a TPC for the linear collider, and of providing common infrastructure and tools to facilitate these studies. The distribution of efforts among these institutions is given in the text.

America *Canada:* Carleton, Montreal, Victoria. *USA:* Cornell, Indiana, LBNL, MIT, Purdue, Yale.

Asia *China:* Tsinghua. *Japan:* Chiba, Hiroshima, KEK, Kinki U Osaka, Saga, Kogakuin U Tokyo, Tokyo UAT, Tokyo ICEPP, NRICP Tokyo, Tsukuba. *Philippines:* Minadamo SU-IIT.

Europe *France:* LAL Orsay, IPN Orsay, CEA Saclay. *Germany:* RWTH Aachen, DESY Hamburg, Freiburg, Hamburg, Karlsruhe, MPI-Munich, Rostock. *Netherlands:* NIKHEF. *Poland:* UMM Krakow. *Russia:* BINP Novosibirsk, PNPI St.Petersburg. *Sweden:* Lund. *Switzerland:* CERN.

Goals and addressing the needs of the detector concepts

The goal of the LC-TPC group is to develop a TPC to serve as the tracking device of a detector meeting the demands of the ILC physics program. A detector at the International Linear Collider (ILC) will combine a tracking system of high precision with a calorimeter system of very high granularity. This detector will measure charged tracks with excellent accuracy, typically surpassing the precision of previously built detectors at LEP, the Tevatron, HERA or the LHC by a factor of 10. At the same time this detector must be optimized for the reconstruction of multi-jet final states stressing the jet energy resolution and the reconstruction of individual particles in jets. For the latter, the efficiency and reliability in reconstructing charged tracks are more important than precision. A TPC has been chosen as the central tracking device for two of the current detector concepts: the Global LC Detector concept (GLD) and the Large Detector Concept (LDC). These concepts each have a tracking system consisting of a large TPC combined with silicon detectors for vertexing, intermediate and external tracking. The GLD and LDC concepts differ mainly in their calorimetry. Arguments for a TPC as main tracker are:

- The tracks can be measured with a large number of (r/phi,z) space points, so that the tracking is continuous and the efficiency remains close to 100% for high multiplicity jets and in presence of large backgrounds.
- It presents a minimum of material to particles crossing it. This is important for getting the best possible performance from the electromagnetic calorimeter, and to minimize the effects from the ~10^3 beamstrahlung photons per bunch crossing which traverse the detector.
- The comparatively moderate point and double-hit resolution are compensated by the continuous tracking and the large volume which can be filled with fine granularity.
- The timing is precise to about 1-2 ns (corresponding to 50 micrometer/ns drift speed of tracks hooked up to the Si detector with 25 micrometer strip-pitch), so that tracks from different bunch crossings can readily be distinguished via time stamping.
- It is well suited for a large magnetic field since the electrons drift parallel to the B-field, which in turn improves the two-hit resolution by compressing the transverse diffusion of the drifting electrons.
- Non-pointing tracks, e.g. from the decays of neutral particles, are an important addition to the particle-flow measurement and help in the reconstruction of physics signatures in many scenarios beyond the standard model.
- The TPC gives good particle identification via the specific energy loss, dE/dx, which is important for many physics analyses, electron-identification and particle-flow applications.

- A TPC is easy to maintain because, when designed appropriately, an endplate readout chamber can readily be accessed or exchanged if it is having problems.

Several issues must be addressed in developing a TPC to meet the requirements of the ILC physics program. TPCs have been used in a number of large collider experiments in the past and have performed well. However, these TPCs were read out using multi-wire proportional chambers (MWPCs). The thrust of our present R&D is to develop a TPC based on novel micro-pattern gas detectors (MPGDs), which promise better point and two-track resolution than possible with the MWPC readout and to be more robust in high backgrounds.

To obtain good momentum resolution and to surpress backgrounds near the vertex, the TPC must operate in a strong magnetic field. This magnetic field must be mapped and understood to O(10^-5) to minimize corrections for the distortion of drifting electrons.

There are two features of a TPC which must be compensated by proper design work as part of our R&D program. First, the readout endplanes and electronics present a significant amount of material to the interaction products in the forward direction. The goal is to keep this below 30% X_0. Second, the 50 microsecond memory time of the the readout (due to the TPC drift length) integrates over background and signal events from 160 ILC bunch crossings at 500 GeV. The latter is being compensated by designing for the finest possible granularity: the sensitive volume is envisaged to consist of at least 1.5 x 10^6 pads and 10^3 time buckets per pad, giving more 1.5 x 10^9 3D-electronic readout voxels (two orders of magnitude better than at LEP). In the case that CMOS techniques are ripe, the granularity could be one to four orders of magnitude larger, depending on the design. The occupancy of the TPC predicted by present simulations is about 0.3% due to backgrounds from beam-beam effects and gamma-gamma interactions based. The TPC will be designed to cope with a factor ~50 higher backgrounds

Results to date

Systems under study at the moment are Micromegas meshes (MM) and Gas Electron Multiplier (GEM) foils. Both operate in a gaseous atmosphere and are based on the avalanche amplification of the primary produced electrons. The gas amplification occurs in the large electric fields in the MPGD microscopic structures with sizes of the order of 50 micrometers. MPGDs lend themselves naturally to the intra-train un-gated operation at the ILC, because, with proper voltage settings, they display a significant suppression of the number of back-drifting ions.

Small test TPC have been operated using GEM and MM gas-amplification with results presented at the international and regional ILC workshops.

- The Aachen group has studied GEM gas-amplification and suppression of back-drifting ions. In addition, the Aachen group is studying techniques for reducing the material in the field cage.
- The LBNL, Orsay amd Sacly groups have studied MM gas-amplification in a magnetic field.
- The Carleton, Orsay and Saclay groups have studied GEM and MM gas-amplification with a resistive coating on the pad structure to disperse the signal to the optimum size.
- The Cornell and Purdue groups have studied MWPC and GEM gas-amplification, with plans to include MM, in zero magnetic field. There are plans to make comparative measurements of ion back-drift.
- The DESY group…
- The NIKHEF group is studying CMOS readout techniques using GEM and MM gas-amplification.
- The MPI and Asian groups are carrying out a systematic comparison of MPWC, GEM and MM gas-amplification in a ?T magnetic field.
- The Victoria group has studied GEM gas-amplification is a ?T magnetic field.
- others
- others
- and others
- including every institution listed

Plans

The TPC R&D work is taking place in three phases:

(1) Small prototying

Subgroups have been performing studies using small TPC prototypes, with sensitive pad sizes ~ 10-20 mm^2 and pad planes ~ 100 cm^2, in magnetic fields up to 5T, for a few years. These studies will continue for another year or so. During these studies much experience has been gained in the GEM and MM technologies. Most of the work has been done with cosmic rays using Star or Aleph electronics. At this time, serious test-beam studies have started. There are several plans for this phase listed below.

- Operate MWPC and MPGDs in small test TPCs in magnetic fields and compare to prove that MPGDs can be used reliably in the final LC TPC.
- Investigate the charge transfer properties in MPGD structures and understand the resulting ion backflow.
- Study the behaviour of GEM and MM with and without magnetic fields.
- Study the achievable resolution of a MPGD-TPC for different gas mixtures and carry out ageing tests.

(2) Large prototype

The large prototype study, currently in the design stage, will continue for another four years. During this phase, the subgroups will consolidate to build a TPC prototype with a diameter of 80 cm to be operated in a B-field of 1T. We will use the large prototype will test the manufacture of large chambers with GEM and MM technologies and the feasibility of CMOS readout techniques. Envisaged is also the manufacture of prototype electronics better matched to these new technologies. This phase will gain experience for building a final TPC and will allow the final choice as to which technology is appropriate for the LC. Studies of using the large prototype will take advantage of a detector R&D facility to be built in Desy, which will be used by vertex, TPC and calorimeter groups. Other plans during this phase are listed below.

- Study ways to reduce the area occupied per channel of the readout electronics by a factor of at least 5 compared to the Alice experiment.
- Study alternatives for minimizing the endplate mechanical thickness, such as the use of power switching of the electronics to minimize power and cooling.
- Investigate the possibility of using Si-readout techniques (CMOS) or other new ideas for handling the large number of channels.
- Investigate ways of building a thin field cage which will meet the requirements at the ILC.
- Devise strategies for robust performance.
- Pursue software and simulation developments needed for understanding prototype performance.

Distribution of responsibilities for the components of the large prototype is being organized at present (2005).

(3) Design and construction phase.

Based on the experience gained, the the TPC for an ILC experiment will be designed, built and commissioned. This will take another four years, so that altogether the final TPC will be ready for installation in the ILC detector by 2015.

For more details of the R&D program see LC Note LC-TPC-2001 at http ://www-flc.desy.de/lcnotes/ .

Critical Items and funding

Timely construction of the EUDET test facility at DESY is a critical item for the large prototype phase of this project. Beyond that, all groups are in need of increased funding for all phases. This is particularly true of the large prototype phase. It is planned that EUDET will provide the field cage as well as the magnet and other infrastructure. However, other critical, costly components, such as the endplates and and read-out modules must be provided by the contributing institutions.

Project: Studies with the MPI prototype

Max-Plank-Institut fuer Physik, Munich (affiliated with LC-TPC)

Contact: Ron Settles (Max-Plank-Institut fuer Physik, Munich, Germany)

The use of a Time Projection Chamber is being considered as central tracker for the detector at the Internation Linear Collider, and an R&D programme is underway to develop the technology and prove the feasibility of a high-performance TPC required for this application.

At MPI-Munich, a small prototype TPC was built towards gaining understanding as to how to build a TPC for the ILC detector. For the gas-amplification technology, the new Micropattern Gas Detectors (MPGD) technologies, Gas-Electron Multiplier (GEM) or Micromegas (MM), are attractive possibilities, since better precison may be achieved than in earlier TPCs. Extensive testing using GEM and MM is being pursued, and results are being compared with the well proven multi-wire proportional chamber (MWPC) technology which was used in past TPCs. All three technologies are to be tested in the MPI chamber to be able to compare on an equal footing. This work is being carried out together with the CDC groups in Asia, Desy/Hamburg and Orsay/Saclay in Europe and Carlton in America.

Beam tests at KEK began in summer 2004 with MWPC technology, followed using GEMs in April 2005 and continued using MM in June 2005. One more beam run is foreseen for October/November 2005. Results comparing all three technologies should be ready at the end of 2005.

In general, the funding situation must improve in future but is adequate for the moment.

Project: Performance studies in magnetic fields

University of Victoria (affiliated with LC-TPC)

Contact: Dean Karlen (University of Victoria and TRIUMF, Canada)

A TPC prototype was constructed specifically for tests in solenoidal magnets at TRIUMF and DESY, to evaluate the capabilities of a GEM-TPC in strong fields. A laser delivery system was added for further tests of the two track separation power of the device. For modest drift distances (up to 30 cm), at 4 Tesla the TPC surpasses the required spatial resolution to achieve the momentum resolution at the LC. The two track resolution is approximately the pad width. The expected dE/dx resolution is achieved.

A novel track fitting algorithm (using maximum likelihood) has been developed in order to meet these resolution goals. Other groups are incorporating this method for their prototype studies.

In mid 2005, we are presently analyzing the data collected in 2003 and 2004, for publication. We plan to get involved in the development of a large scale prototype in collaboration with other LC-TPC groups.

We have received adequate support from NSERC/Canada, along with local infrastructure support.

Project: Development of GEM-based Forward Tracking Prototypes for the ILC

Louisiana Tech

Contact: Lee Sawyer (Louisiana Tech University , USA)

The Center for Applied Physics Studies at Louisiana Tech University is developing prototype tracking chambers based on Gas Electron Multiplier (GEM) technology. This work is an outgrowth of our center's interdisciplinary GEM development work, which includes faculty with expertise in simulations, fast analog and digital electronics, and nuclear and high-energy physics experimentation. In addition to the chambers under development for the ILC, the center is also constructing a GEM-based tracking detector for the QWEAK experiment at Jefferson Lab, and applying GEM-based imaging technology to biomedical applications.

- What are the goals of this R&D project. How does this R&D project address the needs of one or more of the detector concepts?

The goals of this project include both detector development and testing, and simulation studies. On the hardware front, we seek to develop a triple-GEM tracking chamber with good point resolution, fast readout time, radiation hardness, and low material profile. We will evaluate the applicability of these chambers to the ILC detector environment, concentrating on the intermediate to forward angular regions of cos(theta) roughly between 0.9 and 0.99. Our particular interest in using these chambers as the FCH (Forward Chamber) in the TESLA and initial LDC detector designs.

On the simulations front, we will study the intermediate to forward angular region on the LDC baseline designs, and understand the impact of the TPC endplate on tracking resolution, the necessity of adding an FCH to improve tracking in this region, and the physics requirements for such a device.

Our studies are primarily aimed at the FCH in the LDC detector concept, but could be applicable for similar tracking chamber in other designs.

- If there are multiple institutions participating in this project, please describe the distribution of responsibilities.

Currently, Louisiana Tech is the sole institution on this project. We have collaborated in the past with Oklahoma University on general forward tracking studies, and are currently collaborating with Indiana University and members of the SiLC collaboration on tracking studies for LDC.

- Are there significant recent results?

Among recent work at Louisiana Tech are the construction of a second 10cm X 10cm prototype chamber with improved high voltage routing, gain measurements and studies of QE dependence on $ArCO_2$ gas pressure (the basis for Jena Kraft's thesis), and simulations of multiple scattering effects in GEM foils (the basis of Narayanan's thesis). We have also performed simulation studies of the effect of the FCH in the LDC tracking system using the SGV fast simulation program, which were presented at the Snowmass workshop.

- What are the plans for the near future(about 1 year)? What are the plans on a time scale of 2 to 3 years?

In year one of our renewal request, we will build a prototype GEM-based tracking detector using the new 30cm x 30cm GEM foils from3M, Inc. We will carefully test this chamber's performance compared to the 10cm x 10cm prototypes currently being tested, which are constructed with foils manufactured at CERN. We will use our new X-ray test facility, as well as source and cosmic ray testing. The X-ray lab is a new addition to the center, is based on carbon nanotube technology to facilitate pulsing and is capable of delivery 1 kHz of 8 and 20 keV photons. The goal of these tests will be to establish the operational limits of the proto-type device.

We will continue our simulation studies of forward tracking at the ILC. We will use the Mokka front-end to GEANT4 to perform detailed studies of the improvement to tracking with a Forward Chamber (FCH) between the TPC endplate and the EM calorimeter. We will begin studies of different detector readout configurations and begin the process of optimizing the detector design for the GEM tracker FCH. In year two, we will perform beam tests of a prototype tracker module. We plan to install the device at Jefferson Lab's Hall C which is capable of delivering up to 100 microamps of 6 GeV electrons to a target. This would be preferably in conjunction with a running experimental setup but we could conceivably setup a standalone beam test. The goal of these tests will be to evaluate the operational rate limits of the detector readout system and determine the impact of radiation damage.

In year two, we will finalize a design for the FCH, based on our simulation studies. This should coincide with the timetable for detector conceptual design to be formulated. We will contribute to the conceptual Design of a Large Gaseous Detector for the International Linear Collider, with emphasis on the FCH and tracking in the intermediate to forward regions.

In year three, we will analyze the results of the beam studies. In conjunction with the results of simulation studies, we will then be able to propose a full forward tracking detector for the ILC Large Gaseous Detector, which will hopefully be in the Technical Design stage by this point (year 2006-2007). We will use the pulsed X-ray facility at Louisiana Tech to investigate the effect of ionization chamber and GEM preamplifier wall thicknesses and spacing on pulse rise-time in the GEM.

- Are there critical items that must be addressed before significant results can be obtained from this project?

While we have been successful in testing prototype chambers, a major continuing problem is having sufficient readout electronics. A dedicated readout chip would be a significant help in our chamber studies. We are exploring the development of such a chip with other groups working on GEM-based detectors.

- Is the support for this project sufficient? Are there significant improvements that could be made with additional support?

The current level of support, including baseline support for the high energy group and university funds, is barely sufficient to fund the planned activities detailed above. Much time is being lost in training new graduate students, since most of our students are pursuing Masters' degrees and there is a high rate of turnover. The project could be brought to completion much faster with support for a postdoc, who would be in charge of supervising chamber construction and would also take a lead in simulation studies. As mentioned in the last item, we could also use additional funds for readout electronics.

2.4. Tracking systems (silicon)

All detector concept studies for the ILC require some tracking based on silicon strip detectors. The spectrum varies from an all silicon based tracker in the SiD concept to the use of silicon detectors to augment the gaseous tracking either in particular regions or to improve the momentum resolution. Typically these devices are silicon strip detectors although there may be some need for large pixel detectors in the forward region.

Emphasis in the ongoing R&D is in the central detector region. It needs to be emphasized that the forward region needs more attention, because at the ILC especially at higher energies the same performance is needed in the forward region as in the central region and that performance is currently not established.

The ongoing R&D broadly focuses on the following areas:

- Development of actual strip detectors: what is their length that is actually read out. The physical length of a strip detector before ganging into readouts is limited by the manufacturers capabilities.
- Development of the associated electronics, which depends on the length of the strip, the desire to have identical modules throughout the tracker, the need to bump bond the readout chips directly to the silicon, avoiding intermediate hybrid electronics and other considerations.
- Alignment of the detectors and monitoring it
- Mechanical and Electrical support structures with an emphasis on reducing materials. For example: avoiding liquid cooling, which impacts the electronics
- Thinning of sensors
- Development of the corresponding tracking software, which is dependent on the particular design concept being considered.

This R&D is pursued by several groups around the globe. The SILC collaboration has presented parts of this program to the DESY PRC and its members participate in nearly all design concepts studies with varying degrees of involvement. There are additional efforts, with connections to SILC and which pursue some of the issues listed above. Activities at SLAC and Fermilab currently focus on SiD issues, especially in the area of optimizing the all silicon tracker for SiD.

Silicon tracking detectors are and have been widely used in particle physics. The participants in this R&D all have experience with such detectors, are aware of the issues that need to be addressed and are aware of what others are pursuing and investigating. The R&D is not aimed at developing a new technology, but to refine the current state of the art in such a way that the desired performance for the ILC can be obtained. The desired performance is mainly driven by the momentum resolution requirements at the ILC.

Project: Simulation Studies for a Silicon Tracker

Brown University

Contact: Richard Partridge (Brown University, USA)

The goals of this project are to help develop track reconstruction software in the org.lcsim framework and to use this software to study the tracking performance of design variants for the SiD silicon strip tracker. These studies will play a crucial role in optimizing the tracker design to meet the physics requirements of the ILC.

This project is just beginning, with no significant results to date.

For the near future, our goal is to develop a detailed and realistic track reconstruction program in the org.lcsim framework. In the longer term, we plan to work with other groups in the SiD Tracking and Vertexing groups to use simulations as a tool in optimizing the tracker design and to demonstrate that the SiD concept is able to achieve the physics goals for the ILC.

The critical item at this point is the development of the detailed hit digitization, track finding, and track fitting software in the org.lcsim framework. Currently, we are working on the track finding aspect, with other groups focusing on the hit digitization and track fitting aspects.

This effort is currently manpower limited. Additional funding would directly increase the postdoc FTE that can be devoted to this project and would significantly advance this project.

Project: R&D Towards a Long Shaping-Time Silicon Strip Central Tracker

University of California at Santa Cruz (affiliated with SiLC)

Contact: Bruce Schumm (University of California, Santa Cruz)

The goal of the long shaping-time silicon sensor readout project is to develop readout and data-handling architecture optimized for an ILC detector. Although motivated by an interest in reading out long silicon sensor ladders (to minimize the complexity and material burden of the readout electronics), this R&D is also applicable to the readout of short modules. All current detector concepts include a substantial area of silicon strip detectors; thus, this R&D is globally applicable to Linear Collider detector R&D. Although our group's nominal affiliation is with the SiD concept study, we also consider ourselves contributors to the GLD and LDC efforts, and are lead participants in the SiLC group.

The Santa Cruz Institute for Particle Physics (SCIPP) hardware effort on silicon microstrip readout began with the creation of a detailed simulation of the development, amplification, and digitization of signal pulses induced by incident charged particles. This simulation guided the choice of several aspects of the readout chip design. In particular, the simulation indicated that efficient readout with low occupancy for a 167 cm ladder (one-half the length of the outermost layer of the baseline SiD tracker) could be achieved with a 3 microsecond shaping time. Chosen for the prototype ASIC, this shaping time would also permit timing to within a few crossings of the LC beams, more than adequate for the expected occupancy levels.

The simulation also suggests that, given the extent of fluctuations in the deposited energy, no information would be lost by using the essentially logarithmic time-over-comparator-threshold response to estimate analog pulse heights. However, in order to avoid losing neighboring channel information, a second, lower-threshold comparator needs to be applied to channels neighboring a channel whose pulse-height excites the nominal comparator, whose higher threshold it set to limit noise occupancy. This dual-comparator strategy allows for better than 7 micron resolution for 167 cm ladders (see Figure). It is important to note that, should the SiD design incorporate short, tile-like ladders, this resolution would improve substantially.

The dual-comparator "LSTFE2" front-end ASIC is currently undergoing testing at SCIPP. The amplifier output in mV in response to a calibration step in shown in a second figure (1 MIP is corresponds to about a 3.5 mV step). As designed, the response quickly saturates into its time-over-threshold response; such a high gain is chosen to avoid the effect of process variations on the application of the threshold to sub-MIP signals, which can degrade the effective noise performance of the chip for a multi-channel system.

The SCIPP group has also developed a back-end strategy for buffering and reading out the comparator output. Leading and trailing edges are stored for all high-comparator transitions, as well as low-comparator transitions that are sufficiently close in time and space to high-comparator transitions. The simulation has suggested that a 400 nsec readout clock (roughly 10% of the shaping time) is adequate to preserve time-over threshold information. We have tested this strategy in a simulation of the innermost layer, for a conservative (high) rate of noise and background-hit occupancy, as a function of the low-comparator threshold. The result of this study is shown in the third figure. The predicted data rate of less than 10 kbit per LC machine spill per 128 channel chip scales up to an overall data rate of less than 0.5 GHz to be transmitted off the detector through optical fiber (this would increase by roughly a factor of 10 for short strips), which is a very modest data rate.

SCIPP continues to test the prototype LSTFE2 chip, and is working towards a additional submissions of refined LSTFE designs that will further optimize noise performance as well as expand the channel multiplicity from eight to 128 channels. Within the next year, we hope to have this refined and expanded ASIC under testing at SCIPP, to have verified our digital architecture scheme, and to have explored the properties of the existing LSTFE2 chip on a 1-2 meter long silicon sensor assembly, confirming signal-to-noise projections and timing resolution.

We hope to use the LSTFE chip in a testbeam run in late 2007 or early 2008. In this testbeam run, we will need to demonstrate the power-cycling capabilities of the ASIC, measure efficiency and space-point resolution as a function of incidence angle, and verify the back-end architecture in a realistic environment. While we plan at this point to still have the back-end architecture implemented on an FPGA, incorporation of this digital logic onto the amplifier/comparator ASIC should be relatively straightforward.

Although supported with approximately $50,000 per year of DOE LCRD funding, and some support from the SCIPP base DOE grant, we believe that we will need an augmentation of funds to carry this work out. Design and fabrication of one or two additional prototype ASIC's, and the preparation for and execution of a testbeam run, is only partially covered by existing funding levels. We will need some additional staff, student, equipment, and travel support to be assured of success.

Project: R&D for the alignment of the Silicon LC tracker

Instituto de Física de Cantabria (CSIC-UNICAN) (affiliated with SiLC)

Contact: Iván Vila (Instituto de Física de Cantabria (CSIC-UNICAN) , Spain)

Hybrid approach for the alignment of the Silicon LC tracker: Integrated co-linearity monitors and offline track alignment.

The usual limiting factors in the accuracy of a position monitoring system based on optomechanical devices are: mechanical transfers, between the monitored imaging sensors and the active particle tracking elements; and non-strait propagation of the reference laser lines; quite often, extremely precise position monitoring systems suffer from poor accuracy due to the previous two factors. The approach we propose here will solve the first issue and reduce the effect of the second one.

Concept for the alignment of the silicon system.

This conceptual design is built on its successfully application to the AMS-1 tracking system [1], and on the current developments for the CMS silicon tracker alignment. The main features of the proposed concept are the following:

- Collimated laser beam (IR spectrum) going through silicon detector modules. The laser beam would be detected directly in the Si-modules. The alignment readout is fully integrated in the silicon readout; tracks and laser beam share the same sensors removing the need of any mechanical transfer.
- No external reference structures. All the elements of the alignment system (laser beam collimators, steering optics, etc.) are mounted directly on the tracker elements.
- No precise positioning of the aiming of the collimators. The number of measurements has to be redundant enough to reconstruct the detector without any knowledge of the laser beam initial parameters.
- Optical and tracking data will be combined to optimise the alignment procedure.
- A minimal impact of the alignment system on the layout of the tracker and its production technology.
- Based on previous AMS-1 experience we can project that few microns resolutions would be achieved.

Gaussian laser beams and Si-sensor treatment

From the point of view of the instrumentation, the two key stones of this hybrid approach to the tracker alignment are: non-magnetic hard-rad fiber collimators, delivering a extremely pure gaussian beam; and the anti-reflecting coating of the Si-modules for increasing sensor transparency. The first issue has been already solved in the context of the CMS global alignment for visible light, custom-made titanium collimators with a fused silica optical system deliver almost pure gaussian beams; here, we need to modify the optics design for the IR range. Concerning the Si-modules, a dedicated test stand will be built for the optical characterization of the Si-modules, testing the sensor coatings and treatments. The sensor coating will reduce its reflectivity, increase the transmittance and suppress the deflection of the beam after traversing the Si-module; the testing procedure is very well understood since we have carried out it extensively on semitransparent amorphous silicon sensor developed for the CMS alignment [2].

References:
1. Nuclear Instruments and Methods in Physics Research A 511 (2003) 76-81
2. Nuclear Instruments and Methods in Physics Research A 440 (2000) 372-387

Project: Silicon tracking for the ILC

Charles University in Prague, Institute of Particle and Nuclear Physics (affiliated with SiLC)

Contact: Zdenek Dolezal (Charles University in Prague, Institute of Particle and Nuclear Physics , Czech Republic)

Project: Continuation of Reconstruction Studies for the SiD Barrel Outer Tracker

University of Colorado

Contact: Steve Wagner (University of Colorado , USA)

Project: Calorimetry-assisted tracking and reconstruction of long-lived particles

Kansas State University, Bonn University

Contact: Eckhard von Toerne (Kansas State University, USA)

Dima Onoprienko (Kansas State), Eckhard von Toerne (Kansas State U. and Bonn U.)

The high energy physics group at Kansas State University participates in the Silicon Detector (SiD) design study. The SiD[2] has excellent prospects for the application of particle flow algorithms, resulting in improved energy and momentum measurements. One of the main challenges with respect to the SiD concept has been the reconstruction of long-lived particles, because the standard tracking approach relies on Vertex detector hits as seeds for tracks, assuming that the Tracker with only five layers is not capable of providing pattern recognition. Tracks from the decay of long-lived particles usually lack the vertex detector hits necessary to generate a track seed and these tracks are therefore lost.

The Garfield Trackfinder Package reconstructs tracks by extrapolating ECAL cluster (MIP-stubs) into the tracker volume. This calorimeter-assisted tracking is crucial in reconstructing long-lived particles with the SiD, such as K0-shorts and Lambdas, or more exotic, long-lived particles like the decay of a supersymmetric particle shown in the picture gallery. Long-lifetime supersymmetric particles occur in gauge mediated supersymmetry breaking scenarios and also within the MSSM assuming certain parameter tunings.

This work is funded by the University-based ILC Detector R&D program. Most recently we have ported the reconstructed algorithm into the org.lcsim (see http ://www.lcsim.org) framework. Our code is thus compliant with the LCIO standard.

We are working on reconstruction algorithms that will improve the ECAL to track matching and the identification of long-lived particles. A first release is planned for early next year with improved releases coming out on a regular basis.

Project: Development of the silicon microstrip sensors for a tracking detector

Kyungpook National Univ., Korea Univ., Chonnam National Univ., Seoul National Univ. (affiliated with SiLC)

Contact: Hwanbae Park (Kyungpook National University, Korea)

Project: Linear Collider Tracker Alignment System R&D

University of Michigan (affiliated with SiLC)

Contact: Keith Riles (University of Michigan)

- Our ultimate goal is to design and build a real-time alignment system for a silicon tracker (barrel for an silicon detector concept and forward disks for any of the detector concepts). A system based on frequency scanned interferometry, developed by the Oxford group for ATLAS, promises to give the required resolution. Our immediate goal is to verify in the laboratory that we can obtain better than 1 micron absoluate accuracy on distances as large as 1 meter, under unfavorable environmental conditions (e.g., temperature fluctuations, air flow). We have achieved much better accuracy (< 100 nm) under controlled conditions. Once the required accuracy is demonstrated, our next goal will be miniaturization of the components for a prototype.

- We have verified with both air- and fiber-transport single-laser interferometers that we can obtain much better than required spatial resolution on absolute distance measurements under controlled laboratory conditions. But as expected, systematic errors interfere with single-laser measurement under realistic detector conditions. These recent results have been presented at linear collider workshops. Somewhat older results are published in Applied Optics.

- We are now investigating a dual-laser system with different frequency scan ranges that allows extraction of systematic biases of distance measurements. Preliminary results indicate degradation of precision from single-laser measurements under controlled conditions, but that the requirement of 1 micron resolution is likely achievable. Analysis methods to cope with occasional laser mode hopping and with optically chopped data are being optimized.
- The critical item for this year is verifying we can meet requirements on the bench with a dual-laser system. Following that in the coming years will be the R&D needed to miniaturize the system for detector prototyping. More funding will be necessary before prototyping can begin.
- Present funding is at a level that supports essential manpower and modest travel to give reports at workshops. A higher level of funding will be needed to go beyond the present bench-top testing with commercial components.

Project: Large area Silicon microstrip trackers: Mechanical aspects and DSM Front-End Readout Electronics

Laboratoire de Physique Nucleaire et des Hautes Energies, Universite de Paris 6/IN2P3-CNRS (affiliated with SiLC)

Contact: Aurore Savoy-Navarro (LPNHE Universite de Paris 6/IN2P3-CNRS, France)

Project: Development of thin silicon sensors for tracking

Purdue University

Contact: Daniela Bortoletto (Purdue University, USA)

This project aims at establishing the feasibility of using thin silicon sensors for tracking at the ILC. Our R&D wil answer the following questions: Can thin detectors be manufactured with a reasonable yield? What signal to noise ratio and resolution can be obtained with thin sensors? Can mechanical handling and mechanical support challenges be met?

We have already manufactured in silicon strip sensors in the following thicknesses: 150, 200, and 300 microns in 4 inch technology. The sensors were manufactured using the masks developed for the silicon layer mounted on the CDF beam pipe. We have measured the DC characteristics of the sensors such as leakage current, interstrip resitastance and interstrip capacitance. We are currently evaluating the S/N with the SVX 4 readout chip. In the next few years we expect to start studies of the mechanical mounting and the stability of thin silicon strips. There are several ladder designs that are under discussion with the SiD community.

We are receiving minimal support for this project and we struggling to achieve the critical mass necessary to carry out these studies.

Project: SiLC: Collaborative Projects

SiLC Collaboration

Contact: Aurore Savoy-Navarro (LPNHE Universite de Paris 6/IN2P3-CNRS, France)

The LPNHE group has played a proponent role in launching an international R&D activity towards developing the next generation of large Silicon tracking detectors for the ILC, SiLC (Silicon tracking for the Linear Collider). This team was also instrumental in leading the submission of the SiLC proposal to the PRC-DESY by gathering 20 Institutions from Asia, Europe and USA and strengthening the collaboration spirit. LPNHE is actively participating to both the LDC and the SiD detector concepts and also follows the GLD concept developments through its connections with the Korean team that belongs also to the SiLC collaboration. Indeed SiLC is a generic R&D that applies to all the three proposed concepts (and now also the fourth one). The idea of a Silicon Envelope for the LDC case was proposed by the LPNHE; it includes Silicon detectors in the central barrel both in the internal part and the external part of the tracking and in the same way in the large angle and forward region. SiLC maintains also close contacts with the SiD concept and detailed studies are ongoing also including alternative proposal as the long ladders proposed by UCSC-SCIPP. LPNHE studies the medium size ladders that include tiles or longer strips. The Korean team is more closely related to the GLD design and ensures the link with this proposed detector concept and the SiLC collaboration.

The LPNHE was instrumental in allowing several teams to join the EUDET EU project as full partners (Helsinki, Prague and Santander) and also several other teams as associates (CNM-Barcelona, IFIC-Valencia, Obninsk State University and Moscow State University). The LPNHE is now developing ahead the SiLC collaboration and strengthening the collaboration by regular collaboration meetings and exchanged visits between partners of the SiLC collaboration. Although only a sub sample of teams from SiLC are part of the EUDET this project will play an essential role for this R&D and most of the other teams from SiLC will take part in particular to the test beams that are scheduled in the course of this project. Besides the LPNHE has developed close collaboration contacts with SLAC, FNAL, co-authoring DOE proposals with these two US Labs and UCSC-SCIPP respectively in 2003 and 2005.These two proposals were funded. LPNHE is developing collaborative contacts with CERN especially with people involved in the construction of the Silicon trackers for the LHC experiments, ATLAS and CMS and extending this way the SiLC collaboration.

The main R&D objectives of SiLC with the sharing of tasks between the SiLC Institutions are given here below:

- SENSORS: the baseline Silicon technology is the Silicon microstrips. However the SiLC collaboration is also considering possible alternative sensor technology that will be chosen accordingly to the precision and occupancy requirements for the various Si tracking components in the detector concepts.

  The following R&D issues are pursued for these different Si sensor technologies:
  - Strips: larger wafer + thinning of the substrat
  - Large pixel technology (derived from the ones proposed for the microvertex) for some parts of the detector
  - Construction of Fab lines and Quality Control Tests.

The participating institutions are IEKP-Karlsruhe, IMB-CNM, Helsinki, The Korean Institutions, SiLab,Torino and Vienna.

- ELECTRONICS: The main goal is to develop a complete Front End Readout electronic chain that includes the preamplifier, the shaper, the analog pipeline, a buffer and digitization of the signal on board. The design and construction of this chip is based on:
  - Very Deep sub micron technology
  - High Multiplexing, Processing of information on detector
  - New technologies for connecting electronics/pitch adaptation onto the sensor/cabling (minimized)

The participating Institutions are: LPNHE, UCSC-SCIPP, IMB-CNM, Obninsk State University and LPNHE is developing R&D collaborative efforts with CERN. The LPNHE is playing a proponent role in this R&D aspect. One of the R&D highlights of this year was the successful design, foundry and test of the first FE chip prototype in 180 nm UMC CMOS technology (see LCWS05, Snowmass and Vienna presentations). The goal is now to develop the next series of prototypes, with the first chips in 130nm CMOS technology already in 2006, in order to equip the detector prototypes submitted to the test beams in the EUDET project.

- MECHANICS: The main R&D objectives on this topic are to develop:
  - Large, light and robust support structure (new material, new support architecture)
  - Optimisation of the elementary module design (merging sensor + electronics on detector + mechanical support)
  - Cooling
  - Position monitoring and alignment system

The participating Institutions are: IFIC-Valencia, IFCA-Cantabria, LPNHE, Torino, Obninsk, University of Michigan. LPNHE is actively participating to the 3 first listed issues and has already delivered detailed CAD designs for the various Silicon tracking components. LPNHE also maintains fruitful regular exchanges including visits with FNAL mechanical experts.

LPNHE mechanical team has developed the concept of medium size ladders and is developing expertise to built them in the most economic way from the material budget point of view. This is done in close collaboration with the electronic staff. This group has developed these last two years realistic prototypes to test the needed cooling system. Progress in this area have been achieved towards the understanding of what would be really needed. Expertise from other teams involved up to now in the construction of the LHC trackers will be joining soon also on this item.

TEST BEAMS: The test beam activity is scheduled within the EUDET project:

- Prototype construction for both the FE electronics and the detectors
- Participation to the test beam set up and data taking

The participating Institutions are: Charles University, LPNHE, Torino, Moscow, Obninsk, Helsinki, Santander for the setting up and construction of the different devices needed. For the data taking and analysis they will be joined by most teams of the SiLC collaboration and also most probably people from FNAL and CERN. LPNHE will play an active role in the construction of detector prototypes and of the cooling system, the design, construction of the FE chips and will take part to the test beams. Helsinki will help in the DAQ part, Santander will develop the alignment prototype system, Charles University and Obninsk will actively contribute to the setting up of the test beam, the data taking and analysis. Most of the other SiLC teams will participate as well, even if not EUDET partners.

SiLC is also developing collaborative contacts with other sub detector collaborations for performing combined test beams.

SIMULATIONS: This activity includes several aspects:

- Silicon detector simulation packages that allows to study sensor performances and to give interesting inputs to the FE electronics designers. Several teams in SiLC are equipped with those packages and using them: IEKP Karlsruhe, CNM-Barcelona, Helsinki, LPNHE.
- Fast simulation packages: LPNHE has developed SGV fast simulation very useful for performing the first performance and detector design studies as well as Physics studies.
- Detailed GEANT 4 based full reconstruction for the Silicon tracking: this is a topic that is still really lacking. A preliminary work was performed this past year by Obninsk thanks also to the detailed CAD design of the Silicon tracking performed by the LPNHE team: the definition of the Silicon trackers in the GEANT 4 geometry database. But the full reconstruction has to be done; several interested teams: Obninsk, Santander, Vienna and LPNHE; But all are lacking manpower! They maintain close contacts with DESY and SLAC GEANT 4 developers.

The most crucial topics are:

- Minimizing the material budget
- Developing new Fab lines and transfer to Industry: Hamamatsu monopoly !
- Reconstruction in a detailed simulation Geant4 framework for study of performances and determination of the best designs/set up very much needed!
- Availability in time and price of new Silicon sensors prototypes and new FE electronics to equip the forthcoming prototypes for test beams (EUDET program).
- Difficulty to extrapolate the financing support and the FTE that will be needed, both for SiLC in the forthcoming years, because:
    - More teams are going to join in the next 2 or 3 years (after LHC is really launched), it includes also firms. What additional funds and expertise are they going to bring?
    - Depends also from the results in the first 3 years particularly on sensors and electronics.
    - Financing is allocated on annual basis for most institutions. And we hope to benefit of a continuous support from our local financial agency for the next coming years, i.e. these next 4 years. Not yet guaranteed!
    - Also a crucial need for new people (PhD students and post docs).

It is clear that with more manpower and particularly new young people, more funds several of the listed items could have been more advanced. This is particularly the case for the full simulations and also in different ways for all the other items. ILC is still not considered as a high priority.

Project: Development of Silicon Microstrip Sensor Modules

SLAC, Fermilab

Contact: Tim Nelson (SLAC, USA)

The baseline tracker design for the SiD detector concept takes advantage of the machine characteristics of the ILC to achieve a major reduction in material compared to previous large tracking systems based upon silicon microstrips. This requirement, considered essential for silicon tracking by all of the detector concepts, is realized in this design by the elimination of many components that have been essential in previous similar detectors. The other critical requirements for any large-scale silicon tracker; modularity and ease of mass production; arise naturally in this design by the use of very short (single sensor), monolithically-constructed, universal modules built from components mass produced by outside vendors. Progress to date consists of development of the detector module design (primarily at SLAC), and development of the overall tracker design that accommodates them (primarily at Fermilab). However, establishing the viability of this novel concept will demand significant new research and development efforts in order to establish a proof of principle in the form of a complete prototype detector module by 2007.

The key element in mass reduction is the complete elimination of hybrid electronic circuit boards that have been required in the past to service the front-end readout chips. This is achieved by bump-bonding the readout chips directly to the face of the silicon sensor, which leads to the need for several new developments in order to produce a working prototype:

- The development of bump-bondable silicon microstrip sensors that use a double-metal layer to connect a high-density bump-bonding array to the readout strips. Issues of capacitance, crosstalk and robustness to bump-bonding will have to be addressed. SLAC has begun the process of discussing the design with vendors and funds will be required in order to produce first prototypes for testing in 2006.
- The development of readout chips that bump-bond directly to the sensors. A first, small-scale prototype of this chip; a variant of the KPiX chip designed at SLAC for the SiD silicon-tungsten calorimeter; has been submitted and will be received for testing before the end of calendar year 2005. This chip uses analog storage cells and a pulsed power scheme to provide a beam-crossing stamp for each hit together with the quiet conditions during acquisition and low heat generation required by the direct mounting of the chip on the face of the silicon sensors. Future versions of this chip to be developed at SLAC during 2006 will need to be further differentiated from their calorimeter counterparts and will thus require significant funding and effort. It is expected that UC Davis will play an important role in the development of bump-bonding techniques required for the monolithic assembly of the modules.
- The development of flexible power and readout cables along with techniques for mechanical and electrical connection of the cables directly to the face of the silicon. While these cables are relatively simple, a safe and reliable scheme for low impedance connection of these cables directly to the silicon is required, since a double-metal layer on the silicon itself completes the connection of power and readout traces on the cable to the KPiX chip. In order to develop suitable techniques, a prototype cable must be designed alongside the silicon sensors during 2006, presumably at SLAC.

Finally, the routing of power and control signals between the cables and the readout chips via the double-metal layer of the silicon sensors creates new design issues for the sensors, as well unique issues for the grounding and filtering scheme for the modules. Although the digital portion of the chips are largely quiet during passage of the bunch train, it must be demonstrated that separate hybrid electronic circuit boards can be eliminated without incurring significant noise and crosstalk. It is this key point that must be proven with a complete and working prototype in order to prove the viability of the SiD tracker design.

The key elements in ensuring that the tracker modules are simple, inexpensive and easy to mass produce are the simplicity of the assembly process and the mass-producibility of individual components. The former arises naturally from the monolithic composition of a single detector module: a single silicon sensor with its own surface-mounted chip and cable attached to a simple support frame. The final challenge then is the design of a support frame that will be both light and stiff and can be mass produced by standard industrial processes. An initial design for this frame has been developed at SLAC, and must be developed further in cooperation with the overall mechanical design of the tracker at Fermilab so that prototypes can be obtained for assembly of a complete working sensor module. This will require a significant design effort and funding for tooling to produce prototypes in 2006 or 2007.

To date, support for this project has been minimal and has consisted primarily of manpower, sufficient only for producing initial designs. Real progress towards a working prototype has been made in 2005 by participation in the development of the tracking variant of the KPiX chip for the calorimeter at SLAC. However, a major increase in funding for this effort will be required in order to establish the viability of the baseline SiD tracker design with the production of working prototypes in the next two to three years.

2.5. Calorimetry

Calorimeters of the ILC detector are needed for precise jet energy and direction measurement, for the precise and fast measurement of the luminosity and to ensure hermeticity down to small polar angles.

From studies of physics benchmark processes a resolution of the jet energy measurement of 30%/√E is set as the goal for the ILC detector [1]. This resolution must be maintained over a large polar angle; hence particular attention has to be paid also to the instrumentation of the forward regions. An almost 4π solid angle coverage of the detector at least for electron detection, required to ensure the potential for new particle searches, is feasible with calorimeters in the very forward region

To approach the required jet energy resolution, research is done for two different calorimeter concepts. The first, followed by the majority of projects, is the development of fine-grained calorimeters to perform jet energy and direction measurement using the particle flow concept [2]. The latter needs the matching of tracks to depositions inside the calorimeters, allowing separating depositions from charged and neutral particles inside a jet. The jet energy is then determined from the charged track momenta and the neutral energy depositions. The particle flow technique benefits from the clear events of e^+e^- annihilations. Monte Carlo simulations have shown that a significant improvement of the jet energy resolution is feasible [3], but substantially more effort is needed to optimise both the calorimeter design and the particle flow algorithms. The second, followed by one group, exploits the dual readout of scintillation and Cerenkov light to separate the electromagnetic and hadronic component inside a shower (DREAM) [4].

To fully exploit the potential of the particle flow approach, fine grained electromagnetic (ECAL) and hadron (HCAL) calorimeters with shower imaging capability are needed. For the ECAL silicon-tungsten or scintillator-tungsten sampling calorimeters or a hybrid of both are under study. The sensor segmentation will be below the Moliere radius of about 1 cm. Two HCAL technologies are investigated. The analog HCAL uses scintillator tiles of a few cm^2 as active devices, recording the amount of deposition in each cell with photo detectors. The digital HCAL uses finer segmented scintillators, resistive plate or GEM chambers. The energy of a deposition is determined from the number of cells showing a signal above the threshold.

The ‘priority one’ goal of all techniques is to verify the potential of the particle flow concept. Prototypes of calorimeters based on each technology must be built and studied in appropriate test beams. Based on data obtained in these measurements shower simulations will be tested and jet reconstruction algorithms based on the particle flow concept will be developed.

The DREAM technology uses bundles of fibres as active devices, read out by photo sensors. Clear fibres detect only Cerenkov light, measuring mainly the electromagnetic component of a shower, whereas scintillating fibres measure electromagnetic and hadronic particles. The ‘priority one’ topic is to test the feasibility of the technique.

The size and complexity of the R&D projects is very different. CALICE includes a world-wide community to study the silicon-tungsten ECAL technology and analog and digital HCAL technologies. The ECAL and analog HCAL branches are relatively advanced. For the ECAL first beam tests with a small, partly equipped, prototype are done and will be continued. The readout of an analog HCAL using novel photo sensors (SiPMs) was tested for a small prototype calorimeter [5]. The use of SiPMs has shown the same resolution as obtained using classical photomultipliers. A $1m^3$ module for studies in a hadron beam is under construction. The joint effort of the institutes involved in ECAL and the analog HCAL made these first steps possible. The beam test ventures will lead to more activity and intense work. The digital HCAL branch, to a large extend covered by institutions from US, needs urgently significantly expanded support commensurate with the effort required. It is important here to mention that test beam studies with a digital HCAL are absolutely essential to prove the performance of the particle flow concept for this promising technology.

A Silicon-tungsten ECAL is also studied by several US institutions. Their design features a readout chip which is fully integrated with the silicon detectors. This allows the design to naturally achieve a high transverse segmentation (currently 3.5 mm) while maintaining a small readout gap (1 mm) so as not to degrade the small Moliere radius of tungsten. Here substantially more support is needed to establish a prototype test in the beam. Scintillator sampling calorimeters are under development in Japan and in a smaller US group. The group in Japan has collected valuable experience with beam tests of a small scintillator sampling calorimeter prototype with fiber readout. They now concentrate their effort on novel photo sensors (MPPC) and new prototypes with sufficiently fine segmentation. These projects must be pursued with significantly more effort in future. One European group follows the hybrid concept, based on scintillator strips with some silicon layers as sensors. Promising test beam data are published. An ECAL design based on this technology needs continuation of the project.

Several smaller groups in Europe and in the US joined the community proposing additional simulations to optimize the calorimeter structures for the best jet reconstruction performance using the particle flow concept. These studies are very important now, but would be on a much higher level of confidence when the shower simulation codes are verified by test beam data. Hence, in future a close connection to groups doing test beam measurements would be reasonable.

The DREAM technology was investigated in a test beam showing an improvement of the energy resolution for hadrons. Simulations to evaluate the performance of the technology to measure physics benchmark processes are not done. Therefore we think it is too early to make a judgment on the potential of this concept to match the requirements of the physics program of the linear collider.

Special calorimeters are needed for the measurement of the luminosity and the instrumentation of the region near the beam pipe [6]. One project, dominated by European institutes, is devoted to these calorimeters. An accuracy of better than 10^{-3} for the luminosity measurement is required to match the statistical accuracy of many cross section measurements. The luminosity will be measured using Bhabha scattering. To ensure the accuracy a very compact calorimeter with extreme mechanical precision is needed. So far mainly design studies are done to optimize the shape and structure of the calorimeter. Sensor studies, to be done in future, need additional effort. The calorimeter nearest to the beam pipe needs radiation hard sensors and special readout electronics to ensure a fast luminosity measurement for intra bunch-train luminosity optimization. In addition, the calorimeter must be extremely compact to allow the detection of high energy electrons on a large background from beamstrahlung. More sensor studies and beam tests of sensors, and in later phase also calorimeter prototypes, are necessary. Additional effort from groups in North America and Asia is of vital interest.

[1] see e.g. T. Barklow, "Physics Impact of Detector Performance", LCWS, Stanford 2005, to appear in the proceedings.
[2] J. E. Brau et al., Calorimetry for the NLC Detector, New Directions for High-energy Physics: Proc., Stanford 1997, pp. 437-441, eConf C960625:DET077, 1996; J.-C. Brient and H. Videau, Proc. of APS / DPF / DPB Summer Study on the Future of Particle Physics, Snowmass, Colorado, 2001, eConf C010630:E3047,2001, hep-ex/0202004.
[3] A. Raspereza, "Particle Flow Algorithm Summary", to appear in the Proceedings of the Snowmass Linear Collider Physics and Detector Workshop, 2005.
[4] J. Hauptman, to appear in the Proceedings of the Snowmass Linear Collider Physics and Detector Workshop, 2005.
[5] V. Andreev et al. "A high granularity scintillator hadronic-calorimeter with SiPM readout for a linear collider detector", Nucl. In strum. Meth. A **540**, 368 (2005).
[6] H. Abramowicz et al., "Instrumentation of the Very Forward Region of a Linear Collider Detector", IEEE Transactions on Nuclear Science, **51,** 2983 (2004).

Project: Conceptual Design for a Si/W Elecromagnetic calorimeter

Annecy le Vieux (LAPP), U of Oregon, SLAC

Contact: Yannis Karyotakis (Lab. de Physique de Particules d'Annecy le Vieux (LAPP), France)

The overall design of a future ILC detector is mainly driven by the performance of the electromagnetic calorimeter. An unprecedented resolution on jet energies of 30%/sqrt(E) is required to accomplish sufficient separation of W and Z jets. This can only be achieved with a dense and highly segmented calorimeters. We have chosen a Silicon Tungsten sampling electromagnetic calorimeter of 30 longitudinal layers. The transverse granularity is given by silicon pads of 12 mm^2, readout by a chip for 1k pads directly bump bonded to the detector. The goal of this project is to work out the conceptual design of such a detector. Preserving the tungsten Moliere radius (RM=9.5mm) requires a challenging and aggressive integration of the mechanics, the sensors and the electronics. We aim for 1mm gap between the absorber plates. Within these constraints we need to answer many fundamental questions. How the sensors are fixed, how do we get the signals out, how the heat is transferred, and how the tungsten plates are assembled to form modules and then a barrel or an end cap. This is the main purpose of the project. Three institutes will participate, Annecy le Vieux (LAPP), University of Oregon and SLAC. A realistic design for the barrel, leading to the construction of small prototypes, has to be developed in 2006, followed by an end cap design. By the end of 2007, we should be able to proceed with a technical design. The present support in personnel and funding has to be increased to achieve our goals.

Project: Digital Hadron Calorimeter with RPCs

Argonne National Laboratory, Boston University, University of Chicago, Fermilab, University of Iowa (affiliated with CALICE)

Contact: José Repond (Argonne National Laboratory, USA

We develop a Hadron Calorimeter for the Linear Collider, which will be optimized for the application of Particle Flow Algorithms (PFAs). The latter request a calorimeter with extremely fine segmentation of the readout, of the order of 1 cm^2 latteraly and layer-by-layer longitudinally. We propose to achieve this fine segmentation using Resistive Plate Chambers as active medium. Due to the fine segmentation of the readout a simple digital (one-bit resolution) readout is sufficient to provide the necessary energy resolution for single hadrons. Both the SiD and the LDC concepts feature a digital hadron calorimeter with RPC readout as default option for the hadron calorimeter.

We plan to build a prototype hadron calorimeter section with 400,000 readout channels. We completed the R&D on the chambers and will complete the prototyping of the electronic readout system in calendar year 2005. In calendar year 2006 we will construct the prototype section (120 RPCs), provided our funding requests will be approved (see below).

In 2007 we will move to the FNAL MT6 test beam. The purpose of exposing the prototype section to a test beam is

a) to measure hadronic showers with unprecedented spatial resolution,

b) to validate the simulation of hadronic showers in great detail (a prerequisit for optimizing the Linear Collider detectors with respect to the application of PFAs),

c) to validate the concept of a digital hadron calorimeter,

d) to validate our technical approach to a fine granularity hadron calorimeter using RPCs, and finally

e) to compare the performance with a more traditional approach based on scintillator and analog (multi-bit) readout being developed in Europe.

Of course, our plans can only be realized with significant support from the funding agencies. The cost of the prototype section is estimated to be of the order of $1M. Funding proposals have been submitted to both the DOE and the NSF. So far the results have been totally inadequate.

Project: Highly segmented electromagnetic calorimeter

Birmingham U, Cambridge U, LPC-Clermont, LPSC-Grenoble, Kangnung National U, Imperial College London, University College London, Royal Holloway, U of London, Manchester U, Orsay LAL, Palaiseau LLR, Palaiseau PICM, IP-Prague, Moscow State U, Rutherford Appleton Lab, Seoul EWHA U, Seoul Yonsei U, Suwon Sungkyunkwan U (affiliated with CALICE)

Contact: Paul Dauncey (Imperial College London, UK)

The goal of the project, within the framework of the CALICE collaboration, is to design an electromagnetic calorimeter (ECAL) capable of performing efficient particle flow (PFLOW) reconstruction.

Any design will be based on test beam results obtained from a prototype silicon-tungsten sampling calorimeter. The prototype will have a very small pad size, 1x1cm^2, which is essential for excellent PFLOW performance. As of late 2005, the prototype is nearing completion and will be tested in an electron test beam early in 2006 at DESY and in hadron beams later in 2006 at CERN. We foresee a wide programme of electron and hadron test beams at the Fermilab-MTBF facility in 2007 and beyond.

In parallel, longer-term technical R&D is being performed, aiming at a final ILC detector design. This includes new concept studies, such as even smaller pads or the use of MAPS CMOS sensors as an alterative to silicon diodes. In all cases, the aim is to design a very fine-grained ECAL device.

Project: Offset Tile Calorimetry R&D

University of Colorado at Boulder

Contact: Uriel Nauenberg (U. of Colorado at Boulder, USA)

We are proposing to develop a scintillator based electromagnetic/hadronic calorimeter with tiles offset in alternate layers. In this manner we develop a given granularity with an effective reduction of a factor of 4 in the number of readout channels. This reduces the costs substantially.

The goals is, first, to prove, via simulation, that the design has the resolution needed to separate two photon from single photon signals and, second, that we have the energy resolution to separate W and Z hadronic jets via the effective mass reconstruction. This simulation effort is being done with undergraduates. We want to show that this design is cheaper than others for any detector. Clearly this design is more effective the larger the radius of the detector; hence we are more appropriate for the LDC and GLD detector concepts but we will also test our design with the SiD detector concept.

We are presently the only institution working on this project.

We have significant results that were presented at Snowmass. One was the observation that there are a number of low energy tracks that loop in the calorimeter part of the detector. The removal of those hits near the end of the loop is important for a good energy flow algorithm. Our student, Jason Gray, has developed an algorithm that traces these using the tracker as the initial trace. He finds that if the track re-enters the tracking medium, he needs to use the tracking hits to find the last hits in the calorimeter. This work is continuing. We also found that if we bend a scintillating green fiber into a 2 cm. radius there is a time dependent deterioration in the light transmission of the fiber (about 6% loss/year). Both these studies are continuing.

At present we are working on developing the simulation and on learning how to operate the silicon photosensors. The software structure we are using is the one developed by SLAC. We have imported it to Colorado and using the Colorado computing farm. We serve as testors of the software and report bugs as we find them. We also generate our calorimeter geometry files and the software needed to unravel the energy hit distributions produced by GEANT. In the scale of the next year we would like to develop our simulation to the point that we can demonstrate the resolution of our design. We also would like to understand the capabilities of the silicon photo-detectors. The present silicon photo-detectors need to be developed further if they are to be useful. We would like to continue to test these further.

In the scale of 2-3 years we would like to develop the readout electronics and build a prototype to carry out beam tests.

The critical needs for us is the support of a research associate, part time support for an electronics engineer and the purchase of electronics. Our initial first year funding for ILCR&D provided funding for 50% of a research associate and some funding for an electronics engineer. . We lost both in the second year. This has caused a dislocation in our simulation effort and in our ability to study the silicon photo-detectors. All our simulation effort and our study of silicon photo-detectors is being done with undergraduates using University funds. We need a more senior person to help with the more complicated software issues and an electronics engineer to help with the electronics. We also requested funds to work with a faculty member in the mechanical engineering department to carry out a "finite element analysis" of the structural integrity of a calorimeter module to determine how best to hold up the various elements so that they remain flat. This funding request was not supported.

In addition to this effort we are collaborating with Wolfgang Lohmann on the design of the Beam-Cal Detector that will be used to catch the two-photon background. We are simulating the Beam-Cal efficiency for the 20 mrad crossing angle case.

Project: R&D for the TESLA-Detector: Instrumentation of the very forward region

VINCA Belgrade, University of Colorado Boulder, AGH Univ. Cracow, INP Cracow, DESY, JINR Dubna, NCPHEP Minsk, IPASCR Prague, IHEP Protvino, TAU Tel Aviv

Contact: Wolfgang Lohmann (DESY, Germany)

The goal of the R&D project is the development of calorimeter technologies to instrument the very forward region of the ILC detector. In the current design two calorimeters are planned, BeamCal adjacent to the beam pipe, covers polar angles between 5 and 28 mrad, and LumiCal covers the polar angle range from 28 to about 90 mrad. These calorimeters will have several functions. Both of them improve the hermeticity of the detector, a feature important for new particle searches, and they shield the central detectors from backscattered particles [1].

LumiCal is the luminometer of the detector. From the physics program an accuracy of the luminosity measurement of better that 10^{-3} is required. Small angle Bhabha scattering will be used for this measurement. Design studies are ongoing to optimise the structure of a silicon-tungsten calorimeter to reach the accuracy. For a small beam crossing angle the design is advanced [2]. We started to develop a design for 20 mrad beam crossing angle. Sensor tests, the mechanics design and the design of the readout electronics will be the next steps.

BeamCal is hit by a large number of low energy electrons and positrons originating from beamstrahlung, adding up to several 10 TeV per bunch crossing and about 10 MGy per year of operation. Hence radiation hard sensors are needed. Simulations of a highly compact and fine segmented diamond-tungsten calorimeter have shown that single high energy electrons can be detected even in areas with high depositions from beamstrahlung remnants with high efficiency.

The distribution of beamstrahlung depositions depends strongly on the beam parameters. We have shown that the analysis of these depositions allows determining beam parameters with very good accuracy. Beam diagnostics can be supported by the measurement of the tails of the beamstrahlung photons using a third downstream calorimeter at very low angles, called PhotoCal. PhotoCal is a multilayer heavy gas ionisation chamber. Test beam studies with single electron showers are promising. A more detailed design is under work. A concept for a fast luminosity optimisation feedback system will be the next step.

Large area diamond sensors from several manufacturers are investigated. Measurements are done on the dependence of the response to ionising particles from several operation parameters. The linearity of the response is tested using bunches containing between 10^3 and 10^6 particles within 10 ns. These studies are ongoing. The study of the performance as a function of the absorbed dose is done for low doses and will be continued to doses expected at the ILC.

These calorimeters are necessary for each detector concept. The R&D is independent on the concept.

The collaboration, FCAL, is formed to unify and structure the efforts in the participating laboratories. The results from design studies and possible technologies are published in IEEE transactions of nuclear science. More recent results concern the requirements on the mechanical accuracy of LumiCal, the impact of the BeamCal performance on searches for supersymmetric particles, and testbeam measurements with diamond sensors. In a timescale of 2-3 years we will test sensor layer and readout electronics prototypes. In case the results are promising we will go to calorimeter prototype construction and test. Critical items are:

- the stability, homogeneity, linearity and dose dependence of the response of diamond sensors
- integrated readout electronics (dynamic range >1000, 12 bit, data capture within 150 ns, fast buffer, sparsification, low material budget)
- thin sensor planes with integrated bias supply and signal transmission
- the control of the mechanical frame of the LumiCal
- homogeneity and stability of silicon sensors used in the LumiCal, and their radiation hardness if used in the BeamCal

The support of the project in all laboratories was not sufficient so far, however, it is growing. We hope that the EUDET framework will give a boost to our effort to improve the support by the laboratories.

[1] W. Lohmann, Instrumentation of the Very Forward Region of a Linear Collider Detector, Proc. Snowmass Workshop, 2005.

[2] H. Abramowicz, Luminosity Detector for the ILC, Proc. of the Snowmass Workshop, 2005.

Project: Optimization of the ILC calorimeter for jet-jet mass resolution

Fermilab

Contact: Adam Para (Fermilab , USA) mail

INTRODUCTION

Exploitation of the full physics potential of the ILC requires the detection and identification of W and Z bosons in their hadronic decay modes. Relatively close proximity of the masses of W and Z bosons makes it very challenging and requires that unprecedented jet energy resolution is attained. Such a level of energy resolution can be, perhaps, achieved with the help of t Particle Flow Algorithm by combining the measuring power of tracking systems, electromagnetic calorimetry and hadron calorimetry. Its application requires a method of separation of energy depositions of neutral hadrons (other than pi-zeros) from those of charged particles and photons. To date, it has not been demonstrated that the jet energy resolution required to unearth the physics from an ILC can be obtained. This R&D proposal aims at understanding of limits of the possible attainable energy resolution and their dependence on the detector design.

GOALS

We plan to investigate factors related to jet-jet mass resolution and their interplay with the detector design. Besides the jet energy resolution they include jet clustering effects, calibration and linearity of the detector response.

The jet energy resolution is optimized with the help of Particle Flow Algorithm. We plan to investigate various methods of cluster analysis to find the most robust method of separation of energy deposits in the calorimeter related to charged and neutral jet components. In addition to the traditional agglomerative clustering methods we plan to investigate a possible use of divisive clustering algorithms.

We plan systematic studies of the performance of the PFA algorithm as a function of the detector design to identify the trade-offs between the detector granularity, sampling frequency, absorber material and the jet energy resolution.

Optimization and performance of the PFA algorithm depends on the simulation of the hadronic showers. We plan to compare and evaluate the available shower simulation models and establish a level of confidence for the performance of the PFA algorithms achievable with the Monte Carlo tools. We expect to develop a plan for the experimental verification of the performance of the PFA algorithm.

COLLABORATION

The studies will be carried out in close collaboration with the similar on-going efforts at NIU, Argonne and Iowa State U. We plan to investigate complementary clustering strategies of the divisive, rather than agglomerative type and to extend the studies of the jet energy resolution beyond the PFA algorithm.

Project: Establishing a Particle Flow Algorithm with the SiD Calorimeter for the ILC

The University of Iowa

Contact: Usha Mallik (The University of Iowa, USA)

The goal of the R&D project is to develop a successful Particle Flow Algorithm with the SiD detector in mind. This is critical to (1) establish that the energy resolution of 30%/sqrt(E) can be achieved, and (2) determine the detector configuration which gives optimum performance.

Preliminary results on electromagnetic shower reconstruction and hadronic shower reconstruction were shown at Snowmass 2005. It was demonstrated that electromagnetic showers could be reconstructed with high efficiency at separations down to 3cm. A novel method of reconstructing hadronic showers by taking advantage of the patterns in their internal structure, categorized as (a) dense clumps, (b) track segments, (c) a halo of less dense hits, and (d) secondary neutral fragments, was presented.

The immediate goal is to bring the shower reconstruction algorithms to an acceptable level for use in a full PFA. This can then be used to optimize the detector design for landmark physics processes at the ILC. Further improvements will continue as the detailed understanding of the detector grows (especially the calorimeter response).

As far as resources are concerned, we are very short-handed and cannot maintain the necessary effort with our present level of support.

Presentations:

- Dissecting the Structure of Hadronic Clusters, Mat Charles, SiD CAL session, Aug 17, 2005
- Electromagnetic Showers with the MST Algorithm, SiD CAL session, Niels Meyer, Aug 17, 2005
- Dissecting the Structure of Hadronic Clusters, Mat Charles, PFA session, Aug 22, 2005
- Electromagnetic Showers with the MST Algorithm, PFA session, Niels Meyer, Aug 22, 2005
- Status of Particle Flow Studies, Mat Charles, SiD CAL meeting, Sep 21, 2005

Project: Investigation of ECAL Concepts Designed for Particle Flow

University of Kansas

Contact: Graham W. Wilson (University of Kansas, USA)

The goal of this R&D project is to investigate electromagnetic calorimeter design concepts matched to the linear collider physics program with principal design criteria of i) hermeticity, ii) precise measurement of jet energies using particle flow and iii) suited to a general purpose experiment. These criteria are closely tied to the overall detector design concept and the work undertaken is very relevant to assessing the relative merits of the LDC, GLD and SiD approaches.

Recent results include:

i) ECAL clustering studies with nearest-neighbor and fixed-cone algorithms.

ii) Photon identification studies using the H-matrix approach.

iii) Investigating pi0 kinematic fits to improve pi0 energy resolution in jets. This work points towards ultra-fine granularity in the first layers of the ECAL and/or large radius.

Current work has contributed in part to development of particle-flow algorithms. Once these algorithms are more mature and robust, one can envisage estimating the specific impact of different ECAL designs on the overall particle flow performance. In the near future, we will concentrate on a quantitative understanding of the relative importance of the different sources of confusion (eg. photon/hadron separation) in particle flow performance. This should aid in understanding how much detector R&D should be aimed at ECAL or HCAL technologies.

The project lacks sufficient resources to make adequate timely progress on these issues while fulfilling critical commitments to a running experiment.

Project: GLD-CAL

KEK, Kobe, Konan, Niigata, Shinshu, Tsukuba, Kyungpook, Seoul, Sunkyunkwan, Mindano, JINR

Contact: Kiyotomo Kawagoe (Kobe University, Japan)

Scintillator based EM and Hadron calorimter for ILC

Scintillator strip will be a stable active material for the sandwich calorimeter, and depending on the strip length we can control the number of read out channels. Thus we can construct the calorimeter of high granurality in reliable way. We have to determine several parameters such as length , thickness and width of the scintillator strips. We will also use a sophisticated photon sensor of semiconductor which will be small enough compared to the strip itself.

R/D items

1) simulation to determine the detector parameters and to achieve PFA. (2005-2007)
2) development of photon sensor. (2005)
3) development of compact read out scheme (2005-06)
4) prototype of EM-cal production (2006)
5) prodcution of read out system (2006)
6) beam test of the EM-CAL prototype (2007)

Project: Scintillator-based Hadron Calorimetry

Northern Illinois U, DESY, JINR Dubna, Fermilab (not CALICE member), Hamburg U, Imperial College London, McGill U, ITEP Moscow, MEPHI Moscow, LPI Moscow, Obninsk State U (not CALICE member), LAL Orsay, INFN Pavia (not CALICE member), IPASCR Prague, U Regina (affiliated with CALICE)

Contact: Felix Sefkow (DESY, Germany)

1. Overview

The CALICE collaboration pursues an integrated approach to the development of electromagnetic and hadronic calorimetry within the particle flow (PFLOW) concept. In this concept, the jet energy resolution required to identify heavy bosons by their hadronic final state di-jet mass is achieved by reconstructing each particle in the jet individually. This imposes high demands on the imaging quality of the calorimeters and thus requires high longitudinal and transverse granularity.

The goal of this project is to develop the hadron calorimeter (HCAL) on the basis of scintillator as active material. With the advent of novel high gain silicon photo-sensors – so-called SiPMs - the high segmentation required for PFLOW reconstruction can be realized with scintillators at reasonable cost. The energy response of scintillators allows to trade amplitude resolution versus granularity and thus to optimize the cost of the readout electronics, too. In addition to the classical analogue readout, semi-digital concepts with few threshold bit information or a purely digital approach are also followed. A scintillator HCAL is a promising candidate for all PFLOW based detector concepts (SiD, LDC and GLD).

In a collaborative effort, the group is presently building a cubic-meter size scintillator steel calorimeter read out by 8000 SiPMs, for a combined testbeam program with the CALICE silicon tungsten electromagnetic calorimeter (ECAL), to be carried out at CERN and FNAL in 2006 – 2008. The setup includes a tail catcher module with scintillator strips, using the same readout components as the HCAL. The goal of the testbeam effort is the proof-of-principle of the PFLOW approach to calorimetry with a scintillator-based HCAL, and to collect hadron shower data with unprecedented granularity, needed to validate the simulations and develop the reconstruction algorithms.

The implementation of the technology for a full-size ILC detector is not yet addressed with the testbeam prototype. For example, the overall-cost relevant thickness of the active readout layer has not yet been optimized. These issues will be the focus of the R&D program for the forthcoming years, with the goal to propose a scintillator HCAL, and to demonstrate its feasibility with a realistic, scalable prototype, by the time of the GDE technical design report. To meet this goal, a significant increase of funding will be required.

2. Previous results

Multi-pixel Geiger mode avalanche photo diodes (SiPMs) have only recently become available in larger quantities from Russian industry. These millimeter-size devices can be mounted directly on scintillator tiles and can operate with moderate bias voltage in high magnetic field. With typically 1000 independently quenched pixels on a common load they provide a signal proportional to the number of pixels fired by registered photons and a gain comparable to that of vacuum photo-tubes. Nowadays, the technology is followed by several suppliers around the world and is also driven by non-HEP applications, e.g. astrophysics or medical imaging.

A subgroup of this project (Czech, German and Russian institutes) has built a first small scintillator steel prototype (the "minical") read out with 100 SiPMs, and successfully tested it in the DESY electron beam. An important conclusion from the published results was that the inherent non-linearity of the individual SiPMs, due to the finite number of pixels, can be controlled such that linearity and resolution of the calorimetric response is as good as with conventional APD or PMT readout, which were tested with the same setup. The results and the positive operational experience have established the SiPM as baseline for the future developments in this project.

3. Testbeam prototype and test program

The development and construction of a cubic-meter size calorimeter with 8000 readout channels with the given resources was only possible with a high degree of task-sharing and common use of resources not only within the scintillator HCAL project, but also with the other CALICE activities. The granularity has been optimized such that the analogue and the semi-digital approach (proposed by NIU) can be tested simultaneously. The readout chain will use the DAQ developed by the UK groups for the SiW ECAL from the ADC onwards, and the absorber stack and mechanics is designed to be also used with gaseous active detector layers.

The SiPMs are developed, produced and mounted at MEPHI in collaboration with PUSLAR, Moscow. Characterization and quality control of the SiPMs is performed at ITEP, where they are assembled and tested with the scintillator tiles provided by ITEP. Construction of the full active modules takes place at DESY where also the on-detector electronics boards were developed and produced. The central front end electronics component is an 18-channel ASIC developed at LAL on the basis of the ECAL chip. Electronics for LED monitoring and slow control is provided by the Prague group. The mechanical structure (stack and movable table) is a DESY project. The first HCAL modules have been assembled and successfully tested in the DESY electron beam in summer 2005.

The tail catcher and muon tracker with scintillator strip and SiPM readout has been developed and constructed at NIU. It was recently integrated into the HCAL front end and DAQ system at DESY and will be further commissioned and beam-tested in 2006 at FNAL.

The HCAL detector shall be completed and further commissioned at DESY, with support from MEPHI, NIU and Hamburg University, to be ready for first testbeam data taking in 2006 at CERN. Running with electrons and hadrons is foreseen, in the widest available energy range, with the HCAL alone and in conjunction with the ECAL. The testbeam program shall be continued in 2007 at FNAL, to allow direct comparison with other HCAL options.

Altogether, it will be necessary to collect a data volume of order of 108 events. This data set will provide novel in sight into the details of hadronic shower development and serve to validate the simulation programs. Presently these simulations hampered by model uncertainties which are far too large for a reliable detector optimization.

For calibration, analysis, simulation and reconstruction the collaboration is heavily relying on a structured software environment developed by CALICE in close interaction with the ILC software and simulations group. This should facilitate the feedback from the testbeam effort into the overall detector optimization with respect to ILC physics benchmark analyses.

The operational experience being collected during this construction and commissioning phase and to be expected from the first testbeam data taking is most valuable for the further development of the scintillator HCAL. All contributing institutes intend to further pursue R&D in their field of expertise.

4. Future R&D

The next phase of R&D must address the implementation of the novel SiPM technology into a large scale detector concept. This cannot be deduced from previous experience and must be developed before a realistic scintillator based HCAL is proposed for the ILC detector.

A key issue is to further consolidate the SiPM technology. This requires studies of long-term stability and radiation hardness, for example, and a further industrialization of production and quality control, to cope with the large total number of several million sensors ultimately needed.

There is a considerable potential for optimizing the performance of the sensors, e.g. their efficiency or spectral sensitivity, which would result in important simplifications of the coupling between sensor and scintillator and – or alternatively - allow to reduce the scintillator thickness.

Front-end electronics which optimally exploits the fast SiPM response still needs to be developed. Highly integrated state-of-the art ASICs should be placed inside the detector volume and deliver already digitized data on a small number of readout lines. Power dissipation issues raised in such an advanced concept need to be addressed.

The calibration concept will receive important input from the testbeam experience. A robust and redundant, but cost-effective system based on light injection, radioactive sources and / or ionizing particle events must be included in the detector design.

Altogether, an electro-mechanical concept, with a thin integrated readout layer (scintillator, photodetectors and electronics) needs to be developed and validated with a scalable, realistic prototype, corresponding to a section of a possible ILC HCAL. This project is followed by the European and Russian groups and receives support from the EU, which, however, will only cover part of the needs for the R&D outlined here.

In order to evaluate the benefits, in terms of electronics cost, of the semi-digital approach, a separate readout design effort should be undertaken, as part of the integration concept study. This is being proposed by US groups, but not yet sufficiently funded.

R&D for the purely digital variant has just started in Canada with the construction of a small single-layer prototype, with the aim of proceeding towards multi-layer prototyping later-on. The project has many issues in common with the already mentioned R&D, but the smallest cell size requires special solutions, e.g. for the photo-sensor coupling, and of course for the electronics, therefore extra resources will be required to study this option, too.

Project: Particle-Flow Algorithms and Related Simulation Software

Northern Illinois University, SLAC, Argonne National Laboratory

Contact: Dhiman Chakraborty (Northern Illinois University, USA)

The most promising means to achieving the unprecedented jet energy resolutions desired for the ILC is through particle-flow algorithms (PFA). A PFA attempts to separately identify in a jet its charged, electromagnetic, and neutral hadron components, in order to use the best means to measure each. On average, neutral hadrons carry only ~11% of a jet's total energy, which can only be measured with the relatively poor resolution of the HCal. The tracker is used to measure with much better precision the charged components (~64% of jet energy), and the electromagnetic calorimeter (ECal) to measure the photons with about $\sigma(E)=0.15\sqrt{E}$ (~24% of jet energy). A net jet energy resolution of $\sigma(E)=0.3\sqrt{E}$ is thus deemed achievable by using the HCal only to measure the neutral hadrons with $\sigma(E)=0.6\sqrt{E}$. However, this will certainly require extensive and simultaneous optimization of detector design and tuning of algorithm parameters.

A calorimeter designed for PFAs must be finely segmented both transversely and longitudinally for 3-d shower reconstruction, separation of neutral and charged clusters, and association of the charged clusters to corresponding tracks. This requires realistic simulation of parton shower evolution and of the detector's response to the particles passing through it. Accurate simulation relies heavily on analysis of data from beam test of prototype modules.

Very large numbers of events will have to be simulated to evaluate competing detector designs, in terms of both technology and geometry, vis-a-vis ILC physics goals. Characterization of signatures arising from processes predicted by some extensions of the SM will require simultaneous coverage of broad ranges of undetermined parameters. Parametrized fast simulation programs will thus have to be developed once the algorithms have stablized. Parametrization of PFAs will require much work, and is one of our key objectives.

Members of NIU became involved in developments of PFAs and simulation software development efforts in January, 2002. Toward the optimization of the HCal design, the NIU team has been investigating both analog (cell energy measurements) and digital (hit density measurements) methods as functions of the cell size. Indeed, the first fully digital PFA was developed by our team.

Our preliminary findings suggest that with sufficiently small cells, the digital method yields a more precise measurement of the hadron energy, i.e., fluctuations in hit density are smaller than those in the sampled energy of a hadronic shower. Use of local hit density in lieu of the deposited energy to weigh the calorimeter hits results in superior energy resolution and lateral profiling of single hadron showers. It should be noted, however, that use of local energy densities and gradients, instead of just individual cell energies, can also lead to similar improvements.

We have used our PFA (several variants) to perform full jet reconstruction and achieved similar results (in terms of Z->jj mass resolutions) as other groups, e.g. those at ANL and DESY. Presently, our primary focus is twofold: 1. to reduce the uncertainty arising from incorrect assignment of calorimeter hits to the parent particle (the so-called ``confusion term'' which limits a PFA-based jet energy resolution), and 2. to improve the understanding of the differences in energy deposition patterns between different types of particles (e.g. neutrons vs. K^0_L vs. anti-neutrons).

The NIU group has also made significant contributions to ILC detector simulation software since 2002. We have developed, in close collaboration with our colleagues at SLAC, a stand-alone GEANT4-based simulation package called ``LCDG4'', which was the first to fully comply with the model put forth by the ALCPG simulation group, and added several useful functionalities to it. Virtually all PFA development studies in North America from mid-2003 to mid-2005 relied on LCDG4.

Further, as members of the CALICE collaboration (CAlorimeter for the LInear Collider with Electrons, we contributed to the production of a GEANT4-based simulator, ``TBMokka'' for the detector prototype module that is expected to be exposed to test beams at Fermilab or CERN over a period of 3-4 years starting in mid-2006.

In another endeavor, we have developed a package called ``DigiSim'', which parametrically simulates the conversion of energy deposits produced by GEANT4 to electronic read-outs. This package offers the user a simple, flexible, and standard way to simulate the effects of thresholds, noise, cross-talk, inefficiencies, attenuation, and timing, that are involved in signal collection, propagation, and conversion (digitization). In essence, it allows the user to model an arbitrary transfer function from the energy deposited at the cell to the corresponding ``raw data''. DigiSim can be used either in a stand-alone mode to produce a persistent output, or as an on-the-fly preprocessor to the reconstruction program. In stand-alone mode, it produces output in the same format as that envisaged from the real detector (except, of course, the simulation output also contains the ``Monte Carlo truth'', which the real data does not). No high claim on the performance of an algorithm can be substantiated without a realistic accounting of the above-mentioned detector effects. Thus, DigiSim</nop plays a vital role, and has been warmly welcomed by the user community worldwide. We expect it to be used for the simulation of both the various test-beam prototypes and full-detector designs.

Among the members of our group we have adequate experience in calorimeter hardware, electronics, reconstruction software, and algorithm development. We anticipate close collaboration with other groups with similar interests. Active links have been established with ANL, SLAC, FNAL, DESY, and several university groups including the CALICE member institutions.

Our plans for the next 3 years:

During the first year we will concentrate on perfecting the usage of the DigiSim</nop package so the algorithms can be tuned on inputs that closely resemble real data. Beam tests will provide an opportunity to understand not only the detector hardware, but the simulation and reconstruction software as well. The first year deliverable will be a complete DigiSim</nop package that converts the energy deposits simulated by GEANT4 into raw data format, allowing for such detector effects as non-linearities, inefficiencies, noise, cross-talk etc. The latter are not easily simulated by GEANT4, but may well prove crucial to design decisions and algorithmic choices.

We also expect to have by the end of the first year a first version of a class of particle-flow algorithms based on full simulation and reconstruction of the central (barrel) region. Both analog and digital versions (for the hadronic section) of the algorithms, which give encouraging preliminary results, will be further investigated and optimized. In addition, the standard GEANT4-based simulation facility (farm+server) will be available for to the entire ILC community through a web-based request form.

In the second year, we will address the design issues that must be taken into account in order to extend PFAs to the forward regions. We also plan to design and implement the PFAs in such a way that they can be easily ported across detector design details. Algorithms will continue to be tuned, as simulations become more detailed and refined (the latter from analysis of test beam data).

Comprehensive studies of critical physics processes will have to be carried out in order to understand the impact of the calorimeter performance on the physics program of the Linear Collider. These studies will employ both the analog and digital versions of our PFAs. The second year deliverables will be further development of PFA-based jet-reconstruction and a partial assessment of physics reach vs calorimeter performance for the ILC.

In the third year we will complete the physics assessment with a clear statement on the desirability of a digital or analog option for the hadronic calorimeter. This will, of course, depend to a large extent on the test beam experience as well. If all goes well, we will also start the development of parameterized simulations of the particle-flow algorithms. The technology and geometry are expected to have been narrowed down by that time, thus setting the stage for such parametrized fast simulation for extensive physics studies. By the end of the third year we expect to produce, in collaboration with other groups, a fast simulation program based on PFAs. In addition, extensive benchmarking of critical physics processes, as well as evolution of pattern-recognition and reconstruction algorithms will continue.

The steady progress that we have achieved so far has been made possible by funding received received for this purpose during the past 3 fiscal years from DOE and NSF, in addition to generous, but less specific, funding from the Department of Education. However, the pace of progress has been limited by the level of support. The course of action is well laid out. A boost in available personpower will help ensure timely completion of the challenging task in our hands.

Project: Development of a silicon-tungsten test module for an electromagnetic calorimeter

University of Oregon, SLAC, Brookhaven National Lab, U California Davis

Contact: Raymond Frey (University of Oregon, USA)

We are interested in designing, contructing, and testing the fundamental building blocks for a sampling ECal with tungsten radiator and highly segmented silicon readout which could be practical for a real detector. Our design features a readout chip which is fully integrated with the silicon detectors. This allows the design to naturally achieve a high transverse segmentation (currently 3.5 mm) while maintaining a small readout gap (1 mm) so as not to degrade the small Moliere radius of tungsten. These two properties (segmentation and Moliere radius) are the two most important properties for an electromagnetic calorimeter of a detector concept which employs particle flow algorithms, such as SiD or LDC. The integration of the electronics makes our project unique and provides improved particle flow capabilities relative to more conventional designs. Our R&D also points to the favorable scalability of the integrated approach in terms of cost and thermal management (we only require passive cooling).

The basic elements of the design consist of 15 cm silicon detectors with 1024 detector pixels and 1024-channel ASIC readout chips (called KPiX -- see attached talk by Breidenbach). The chips are bump bonded to the detectors. The KPiX chip performs the analog conditioning and full 15-bit digitization for all channels, taking into account the timing characteristics of the (superconductor-based) LC. The data are serialized for relatively simple transport to the readout using light cables within the 1 mm readout gaps. It is worth noting that KPiX could also be readily adapted for use with silicon trackers or hadronic calorimeter detectors at the LC.

The goal of our R&D is to fabricate a full-depth electromagnetic calorimeter prototype module. This nominally consists of 30 longitudinal layers, each consisting of a 15 cm detector outfitted with a KPiX chip sandwiched between 2.5 mm thick tungsten radiator layers. The full prototypes are necessary to study and understand hadron showers in finely segmented calorimetry in order to validate the simulations employed in particle flow, which in turn are used to optimize the overall detector design. Our ECal module would first be fully characterized for electromagnetic response and resolution in an electron beam, probably at SLAC in 2007.

We have purchased a first round of 10 15-cm detectors, which include the full metallizations necessary for the KPiX chip. These have been fully characterized in the lab (Oregon) -- see the attached talk by Strom. The KPiX chip has been fully designed (SLAC) and the first prototypes have been fabricated and will be evaluated in the first months of 2006. Meanwhile, the light cable is being designed and preparations for bump bonding are underway (Davis). The purchase of silicon detectors for the full module will require funding beyond that which can be expected from the LCDRD process.

Project: LCcal (Electromagnetic calorimeter with hybrid technique: scintillator-si pads.)

INFN Frascati, INFN Padova, INFN Trieste, U dell'Insubria, Institute of Electron Technology

Contact: Paolo Checchia (INFN Padova, Italy)

Q. What are the goals of this R&D project. How does this R&D project address the needs of one or more of the detector concepts?

A. The goal is to propose an Electromagnetic calorimeter having a sufficient high granularity at a reasonable number of channels and at a reasonable cost. The shower granularity should be defined by a restricted number of Si-pad planes while the energy can be measured by larger size scintillator tiles. This is addressed to the LDC concept were alternative detectors made only by silicon pads as active material imply an huge number of channels and an extremely high cost, and , consequently, to the GLD concept.

Q. If there are multiple institutions participating in this project, please describe the distribution of responsibilities.

A. The unique paying institution was INFN. The ITE Warsaw contribution was the Si pad production committed by INFN

Q. Are there significant recent results?

A. Yes ! As it is described in the notes and proceedings of conferences where the results were presented, the prototype was tested in different beam lines giving good results. In particular: the energy resolution is in the range 11-11.5%/sqrt(E) with a negligible constant term, the energy uniformity is at the level of few percents, the position reconstruction is about 2 mm at 30 GeV and the electron hadron separation is better than permille level.

Q. What are the plans for the near future(about 1 year)? What are the plans on a time scale of 2 to 3 years?

A. The lack of human resources due to additional engagements of the involved people imposes, at least on a short time basis, a delay on the expected progress of this project which could be recovered just by fresh injection of new actors in this game.

Q. Are there critical items that must be addressed before significant results can be obtained from this project?

A. It would be fruitful to exploit to the best level the particle to particle separation obtainable with this detector

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Q. Is the support for this project sufficient? Are there significant improvements that could be made with additional support?

A. NO ! the financial support was reasonable in the past but it is missing for the future.

Project: Digital Hadron Calorimetry using Gas Electron Multiplier Technology

U. Texas at Arlington, U.Washington, Tsinghua University, Changwon National U. (affiliated with CALICE)

Contact: Andy White (University of Texas at Arlington, USA)

We have been developing the implementation of digital hadron calorimetry for a future Linear Collider detector using Gas Electron Multiplier technology. This is a critical and essential development for future experiments that will rely on the Particle Flow Algorithm approach to achieve unprecedentedly precise jet energy and jet-jet mass resolutions. This level of performance is required to separate w and Z bosons and Higgs particles in their hadronic decay modes on an event-by-event basis. The digital approach relies on a fine transverse and longitudinal segmentation of the calorimeter and a linear relation between digital "hits" and energy. The energies of charged particle clusters are taken from the momentum measurement in the tracking system once the track/cluster associations have been made. The residual neutral hadron energy is measured using the digital information.

In the GEM approach, the ionization electrons released in the drift region of an active layer of the sampling calorimeter are amplified by using two successive GEM foils (double-GEM). The amplified charge is collected at the anode, or readout pad, layer which is at ground potential. This layer is subdivided into 1cm x 1cm pads needed to implement the digital approach.

We have built several 10cm x 10cm double-GEM prototypes using foils from CERN. We have measured the gain, efficiency, hit multiplicity, using sources and cosmic rays, for a variety of Argon-CO2 gas mixtures. We have demonstrated the viability of our approach with these results. We have also been developing large (1m x 30cm) mechanical modules to test production procedures. Working with 3M Corporation in Texas we have produced larger (30cm x 30cm) GEM foils. We shall use these to build the next, medium scale, prototype system, which will have five double-GEM chambers. In the longer term, we are developing plans to construct a full scale meter-cubed, 40-layer prototype for exposure in a test beam at Fermilab in 1-2 years timeframe.

We have been supported by the US DOE ADR and LCRD programs. While this has enabled us to develop and test initial prototypes, the current level of funding is significantly below that required to build and test a full scale hadron calorimeter module. It is critical that sufficient support is forthcoming to allow this module to be built and tested to verify the performance of this combination of technology and its accurate, detailed simulation using GEANT4. This is an essential precursor to the inclusion of this approach in any viable ILC detector proposal.

Project: DREAM

Texas Tech Univ., Univ. of California at San Diego, Iowa State University, INFN Trieste, Univ. of Pavia

Contact: Richard Wigmans (Texas Tech University, USA)

2.6. Muon tracking

The muon system in any of the ILC concept studies consist of instrumenting the return iron of the solenoid and is used to identify muons only. Given that the calorimeters of an ILC detector are very finely segmented, transversely and longitudinally, they in themselves already play an important role in muon ID, because MIP's can be tracked through them. However they are typically limited to about 4-5 interaction lengths, because of cost constraints. Preliminary studies show that additional muon ID outside the solenoid is required to get reasonable efficiency coupled with high background rejection. These studies have been done with limited samples and should be expanded to other channels. The open questions in this area are: what should be and is the most cost effective way of instrumenting the gaps in the muon steel? What segmentation (transverse and longitudinal) is needed ? Is it necessary to measure the tails of showers behind the solenoid to improve jet energy resolution ?

Currently there are two programs that are addressing these issues, one in the US and one in Europe. The main difference between the two is what they use for detectors. In the US it is scintillators and in Europe it is glass RPC's. The US effort is funded at a very low level and could use more funding . The funding of the European effort is unclear at this time.

Project: Scintillator-Based Muon System R&D

Colorado State U., Fermilab, Indiana U., Northern Ilinois. U., Rice U., UC Davis, U. Notre Dame U. Texas Austin, Wayne State U.

Contact: Paul Karchin (Wayne State University , USA)

Goals

The identification and precise measurement of muons is critical to the physics program of the ILC. The muons produced from decays of W and Z bosons provide key signatures for the Higgs and possible new particles. Muons may also be produced directly from decays of new particles. Our R&D project addresses three critical areas that have emerged from discussions inside the ILC detector community.

1. What is the additional capability for muon identification that an instrumented iron magnetic flux return can provide beyond that from a finely segmented particle flow capable hadron calorimeter?

2. What performance for muon identification (efficiency and purity) can be provided by a strip scintillator detector with barrel and endcap pieces combined with the hadron calorimeter?

3. What is the best candidate for photon detection for scintillator readout among the established and newly developed devices: multi-anode photomultiplier, Geiger-mode avalanche photo-diode, silicon photomultiplier and silicon avalanche photodiodes?

Question 1 above is relevant to all of the detector concepts which include an instrumented flux return muon detector. Scintillator technology is considered as a candidate technology in some of the concepts, and in all cases provides a benchmark for comparison.

Institutional Responsibilities

The Fermilab group has developed software for muon tracking, integrating the calorimeter and muon systems. The tracking employs a Kalman filter which takes into account multiple scattering, energy loss and magnetic field. Results have been presented on the efficiency and purity of muon identification for the barrel detector. See the talk by Caroline Milstene at Snowmass, 22 August, 2005. Since then, preliminary results show that the instrumented flux return muon detector significantly enhances the efficiency and purity.

The Fermilab group coordinates the fabrication and operation of the prototype detector. Fermilab purchased the scintillator and optical fiber and provides laboratory space, mechanical infrastructure and electronics instrumentation. The splicing of WLS and clear fiber is performed at Fermilab. See the talk by Eugene Fisk at Fermilab, June 3, 2005.

The Fermilab group coordinates the muon detector design with the Si-D detector collaboration.

The Indiana University group tests the prototype detector modules at Fermilab using radioactive sources and cosmic rays. See the talk by Robert Abrams at Snowmass, August 23, 2005.

The Northern Illinois University group is developing a tail-catcher, muon tracker (TCMT) detector using silicon photomultiplier readout. This effort is now integrated into the scintillator muon project. The NIU group fabricates scintillator bars using an extrusion facility operated jointly by Fermilab and the Northern Illinois Center for Accelerator and Detector Development. The bars are loaded with WLS fibers and assembled into complete detector planes with Si-PM readout and electronics. See talks by Gerry Blazey at SLAC, 18 March, 2005 and Snowmass, 14 August, 2005.

The Notre Dame University group fabricates the prototype scintillator planes, including cutting of the scintillator and assembly into modules, which are shipped to Fermilab. The spliced fibers are tested at Notre Dame. The optical interface between the clear fibers and the multi-anode PMT is fabricated at Notre Dame. See the talk by Mitchell Wayne at Snowmass, 22 August, 2005.

The University of California at Davis group built the readout interface between the Lecroy TDC system and the data acquisition PC and established its operation at Fermilab. See the talk by Mani Tripathi at SLAC, March 21, 2005.

The Wayne State University group develops test and calibration methods for the multi-anode photo-tubes and helps coordinate the work of the collaboration. See the talk by Paul Karchin at Victoria, July 29, 2004 and the article by Paul Karchin in proceedings of the DPF meeting at UC Riverside, August 28, 2004.

Associate collaborators from Colorado State University develop a geiger mode avalanche photodiode detector in a package that will be compatible with the optical interface of our prototype system.

Associate collaborators from Rice University have expressed interest in working with us in the future.

Associate collaborators from the University of Texas have loaned us spare PMT assemblies from MINOS which were used in earlier tests. They also provided advice on the initial specification of the prototype detectors.

Recent Results

A recent (Fall 2005) result of the collaboration is the operation of two 1/4 size prototype planes and the response to a radioactive source (Cs-137) and to cosmic rays.

Figure 1 of the publicity graphics shows two prototype muon scintillator detector planes under test at Fermilab. Each plane has 64 strips of cross section 1 by 5 cm with each strip readout by a wavelength shifting fiber fused to a clear fiber. All fibers in the top plane are routed to a single anode photomultiplier tube. Each fiber in the bottom plane is routed to one element of a 64-channel Hamamatsu multi-anode photomultiplier tube. A cosmic ray trigger is defined by scintillator paddles and absorbers above and below the planes.

Figure 2 shows typical phototube anode signals from the prototype planes of Figure 1. CH1 corresponds to the plane where all fibers are routed to a single anode phototube. CH2 corresponds to one fiber readout by one channel of the multi-anode phototube. The multiple peak structure is due, in part, to the approximately 7 ns decay time of the wavelength shifting fluor. Reflections inside the scintillator may also contribute to the multiple peak structure.

A plane of the tail-catcher muon tracker was recently operated (in October 2005) in an electron beam at DESY. A silicon photomultiplier assembly is shown in Figure 3. Scintillator bars extruded at the NICADD facility and assembled arrays are shown in Figure 4. Data from electron beam scans and LED pulsing is under analysis.

One Year Plans

In the next year, we plan to continue fabrication of prototype planes and tests with radioactive sources and cosmic rays. We want to obtain a detailed understanding of the relative contribution to the multiple peak signal structure from the fluorescence decay time in the WLS fiber and reflections inside the scintillator. We want to collect charge integral data from all the strips with sufficient statistics to measure the distribution of the mean number of photoelectrons. Furthermore, we want to study the dependence of the mean number of p.e.'s on strip position and strip length for single and doubled-ended readout. We plan to test whether it is possible to route two 1.2 mm diameter fibers to a single 2 mm X 2 mm photocathode cell. If detection efficiency is not degraded by this scheme, we could halve the number of photo-detector channels needed for strips with double-ended readout.

We hope to operate the prototypes in a test beam at Fermilab, before the March 1, 2006 accelerator shutdown. We want to measure position and timing resolution using upstream tracking as a position reference and upstream beam counters as a time reference.

Simulation studies will continue towards establishing the efficiency and purity for a barrel detector with and without an instrumented flux return detector. We would like to begin simulation of the endcap detectors.

2-3 Year Plans

On the time scale of 2-3 years, we hope to have well-established performance data from beam tests as well as realistic estimates from simulation studies of efficiency and purity for both barrel and endcap detectors.

Also, on the time scale of 2-3 years, we want to compare the performance of multi-anode photo-tube readout with the emerging solid state technologies employing avalanche photo-diodes and silicon photomultipliers. Of particular interest are the photo-electron yield, noise rate, and time accuracy. Unique requirements on the WLS fiber may be required for each type of optical detector.

We want to develop (or adapt) a dedicated readout chip (application specific integrated circuit) that measures both time of arrival and integrated charge. The Fermilab schedule calls for test beam operation in 2007 with a full EM and hadronic calorimeter with tail-catcher. We will explore the possibility for a common readout architecture between the Si-PMT's used for the tail-catcher and the muon system.

We expect to establish techniques for mechanical support systems, optical fiber splicing, routing of fibers and the interface between the scintillator and the various types of photodetectors.

We plan to establish realistic cost estimates for construction, testing and installation of an ILC muon detector system.

Funding Limitations

Currently our progress is limited by lack of personnel. The university groups have no external funding for students, support staff (engineers and technicians) or physicists (postdocs and research scientists). The universities have provided personnel through their own, limited institutional funding. We cannot answer questions 1-3 without enough personnel to operate the equipment, analyze the data and perform computer simulations.

Project: CAPIRE (glass RPC)

INFN-Frascati, INFN-Milano, INFN-Torino

Contact: Marcello Piccolo (INFN-Frascati)

2.7. Particle ID

Studies of particle ID (notably K/π separation) were carried out until relatively recently in the USA (see following research statement). Unfortunately, the severely restricted funding situation has brought this work to a temporary halt. In the mean time, there have been two important developments. Recent studies [1] have established the importance of heavy quark sign selection as a tool for physics at ILC, just as this was important at SLD. Vertex charge measurements provide one clean approach, but another is the association of charged kaons with either the secondary or tertiary vertices (from *B* or *D* decay respectively) in the decay chain. For this reason, the basis for a physics case has been strengthened.

The second major development is in ideas for very compact focusing DIRC devices, possibly equipped with the silicon PMT photodetectors under active development [2]. This presents for the first time the prospect that an appropriate system could consist of quartz bars only a few cm thick, immediately inside the ECAL, with extremely compact photon detection systems at the ends. Such a detector system might impose only a marginal reduction in the primary technical requirement of superb particle flow. While this is at present an open question, we believe it certainly warrants an inexpensive simulation study. The Panel register includes a project which if funded will re-awaken these important studies, and if successful evolve into a full R&D programme. There is at present no agreed home for such a detector within any of the concepts, however one can imagine that space would certainly be made available, once the physics case is established, provided (as seems likely) that this could be done with little if any degradation to the PFA performance.

[1] Physics potential of vertex detector as function of beampipe radius, S Hillert and CJS Damerell, Proc Snowmass ILC workshop 2005 (to be published)

[2] Development of photon detectors for a fast focusing DIRC, C Field et al, SLAC-PUB-11107 (2005)

Project: Investigation of hadron ID for ILC physics

Colorado State U

Contact: Bob Wilson (Colorado State U)

A primary goal of the next linear collider is to provide detailed investigations of fundamental physics in the 500-1000 GeV energy regime that are not possible with a hadron collider. While Particle Identification (PID) in the broad sense will certainly play a central role [1], the extent to which identification of stable hadrons (pi, K, p) is required remains an open question. The issue has particular relevance for detectors without gas-based tracking systems, such as the SiD detector concept, which lack even rudimentary hadron ID [2]. The primary purpose of this proposed research is to support the core of activity of a Linear Collider Detector Particle ID group.

A similar research plan proposed several years ago received strong support from the review panel at the time but, as with many other priority requests, the available level of support allowed for only slight progress. However, as a more concrete timeline for detector Conceptual Design Reports is now being developed, the issue has reach a level of urgency that warrants a renewed attempt to provide more concrete information on which to base detector design decisions.

We propose to build on previous work in three areas: (1) Investigation of the need for particle identification in linear collider physics analyses, with particular emphasis on hadron identification – in particular, this will include conversion and expansion of a an existing [3] fast Particle ID package and its integration into the Java Analysis Studio-based Linear Collider Detector (LCD) simulation package; (2) Investigation of the performance parameters required of a specialized hadron ID subsystem (if one is justified) and its impact on the overall experiment performance; (3) Liaison with groups investigating PID systems – this will include re-establishing and maintaining an ILC PID web site [4].

Investigation of the physics requirements for hadron will be done in collaboration with members of the various detector concepts groups and we will develop further contact with the Linear Collider Flavour Identification collaboration in the UK [5]. For hadron ID hardware subsystem issues we will communicate closely with Stanford Linear Accelerator Center (SLAC) scientist Blair Ratcliff and members of his group. The software infrastructure tasks will be done in close collaboration with Anthony Johnson and Norman Graf (SLAC).

[1] Wilson, R.J., “Report from the Particle ID/Muon”, Santa Cruz Workshop 2002.
[2] Wilson, R.J., “Hadron ID in the S2 Detector”, “PID – Santa Cruz Workshop 2002.

[3] Rolnick, S., Wilson, R.J., "PID Software for Linear Collider Detector Studies", Linear Collider Workshop, Victoria, July 2004.
[4] http://hep45.hep.colostate.edu/~wilson/flc/pid/pidmain.html
[5] http://hepwww.rl.ac.uk/lcfi/

2.8. DAQ and detector control system

Project: DAQ system development for ILC

DESY, Saclay Laboratory

Contact: Guenter Eckerlin (DESY)

The data acquisition (DAQ) for a future detector at the linear collider is proposed to run without a hardware trigger interrupt. The full data of a complete train of roughly 3 thousand bunch crossings will be stored at the detector front end in pipelines of about 1ms depth. After the pulse train has passed the pipeline will be read out and the data will be combined and processed by the software event selection.

Except for the readout electronics at the detector and the interface to the central DAQ system the components used will most likely be commercially available standard components, like VME, network switches, PCs , etc. The rapid development especially in the area of networking and processing suggests to wait for the final decision on the hardware used as long as possible.

But for the front end readout electronics and the interface to the DAQ, decisions have to be made during the prototyping phase of the large detector components. In addition the development of new standards, like Advanced Telecom Computing Architecture (ATCA), should be followed and experience with new techniques is needed to prepare the decision process.

This pilot project is meant to build a frame for the various DAQ aspects to be addressed in the next years and will spawn sub projects on special issues as need arises. The issues that are foreseen to be addressed are :

- sub detector readout interfaces
- accelerator/detector interconnection
- detector and slow control issues
- calibration and event selection strategies
- multi gigabit links
- explore industry(telecommunication) standards
- global detector network capability

A recent overview of the data acquisition conceptual work has been give at the ECFA ILC Workshop at Vienna [1].

For 2006 the pilot project issues should be defined in more detail and a preselection on topics to be addressed until 2008 should be made. Until 2008 a guideline document and selection criteria for the final decision on the DAQ concept, based on the experience gained, will be provided. This document should include interface definitions and basic conceptual designs of the main building blocks of the DAQ system.

The funding provided so far was adequate for the current phase but needs to improve as more person power is needed for the next phases.

[1] P. Le Du, https://ilcsupport.desy.de/cdsagenda/fullAgenda.php?ida=a0556

2.9. Electromagnetic interference (EMI)

Different detectors at collider experiments have had different experience regarding electromagnetic interference associated with the passage of the beams. In general, if problems were encountered, they were generally overcome by various screening procedures, at some cost in material budget. However, it is more or less certain that a continuous metal beampipe provides complete protection against such effects. Such a beampipe, free of penetrations, while easily provided at storage rings, will not be available at ILC, any more than it was at SLC. Beam position monitors, beam size monitors, kicker magnets and other instrumentation are essential in order to maintain luminosity during each bunch train. These penetrations provide apertures through which RF radiation associated with the massive electromagnetic 'pancake' that accompanies each bunch, can escape. The use of appropriate connectors and screened cable can and should contain the escaping radiation. The use of truly hermetic boxes at the remote end should do likewise. However, very high frequency RF can escape through narrow cracks. If it does, it has a surprising potency for penetrating the typical detector Faraday cage (which in the words of one experienced experimentalist comprises 'little more than a dust cover') and also for penetrating the conventional screening of integrated circuits. The most vulnerable by far will be the vertex detector sensors and associated readout chips. This is because of the tiny signals (~1000 e^-) associated with these monolithic pixel devices, and because of the high bandwidth readout required if ~10^9 channels are to be read out many times during each bunch train. As discussed in Section 2.2, some vertex detector architectures are more vulnerable to these effects than others.

These concerns are not purely theoretical. The SLD vertex detector was subject to beam-related pickup which would have been fatal, had the machine produced fast bunch trains as opposed to single bunches, and had it been necessary to read the detector during the train. The source of the RF leakage was never discovered, but the machine people claimed to have followed all reasonable precautions. A strategy has been suggested for avoiding the possibly severe consequences of a repetition at ILC [1]. In short, this consists of:

- qualifying the prototype detector systems as regards robustness against EMI, this information to be used as one criterion for selecting detector technologies
- careful measurement at the ILC interaction regions during the commissioning phase, when free access is available before the detectors are installed
- a standby Faraday cage which can provide a stopgap solution if required. This structure would impose an undesirable amount of material around the IP, and would only be retained until a replacement vertex detector, sufficiently robust regarding EMI, could be constructed.

Incidentally, the suggested beam tests will not only search for beam-related pickup. Other machine systems such as fast-pulsing kicker magnet supplies may also generate major pickup during the bunch train. The suggested EMI measurements during the ILC commissioning phase will also reveal screening deficiencies in any of these ancillary systems.

There is currently no funded activity covering this topic, but there is interest. Physicists at SLAC, KEK and DESY are discussing how best to get this moving. It is hoped that a project proposal may be developed early in 2006, for beam tests later in the year. The immediate work could be to investigate further the SLD assembly, which still exists, by passing a test beam through it and measuring where the RF leakage occurs. The next step could be to set up test procedures to be used to quantify the sensitivity of different detector technologies. Definitive results will have to wait till full-scale devices are in production a few years from now, but in the mean time tests with small prototypes may be very revealing, and provide important feedback for the detector designers.

[1] 'Vertex detectors - how to overcome electromagnetic interference', CJS Damerell, Proc Snowmass ILC Workshop 2005 (to be published)

2.10. Detector solenoid magnet

The solenoids needed to generate the required field in any of the current concept studies are all challenging, simply dictated by the fact that they contain the tracking volume, as well as the electromagnetic and hadronic calorimeters. This is driven by the required resolution and the PFA algorithm, as described in the calorimeter section. Figure 1shows an overview of existing and planned solenoids in a graph of Stored Energy/Cold mass (a measure of the capability to handle a quench) vs. the stored energy.

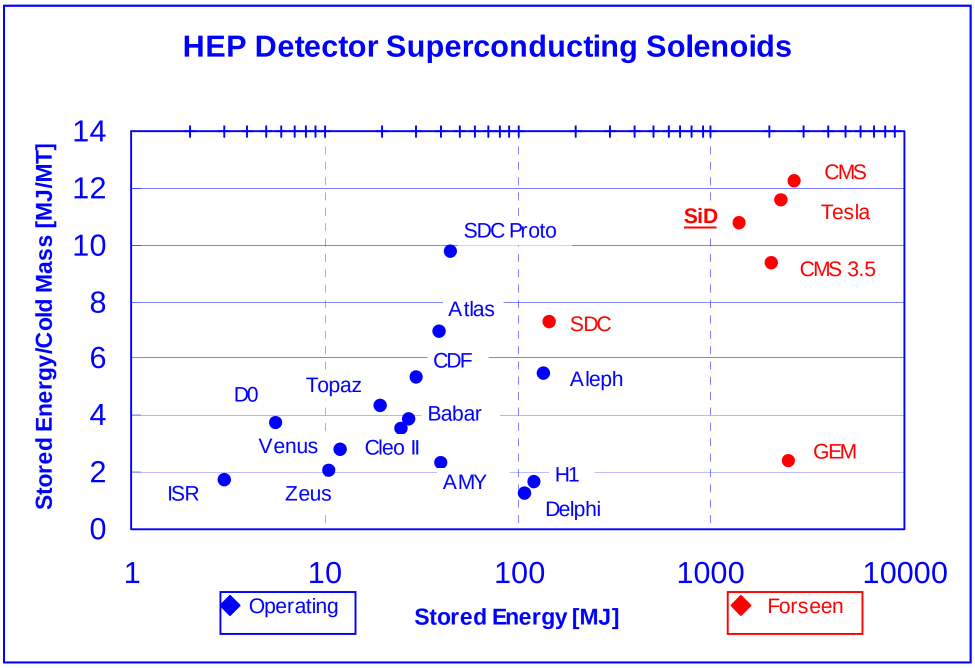

Fig 1. Stored energy/cold mass as a function of the stored energy in solenoids that are operating and solenoids that are/were planned

The CMS solenoid sets a new standard here and commissioning it, will be a milestone for further solenoid development. The challenge in the ILC solenoids is that they roughly store the same energy, but are shorter than CMS. For the SiD concept a feasibility study has been performed, based on the CMS design and conductor. Since the solenoid is one of the cost drives in ILC detectors, it is important to get a reliable cost estimate. To first order the CMS cost can be used for this and this has already been done. R&D is needed to see whether performance can be improved, resulting in reduced cost.

In addition to this detector specific designs are needed to satisfy field uniformity questions, get a better cost estimate and interact with the MDI group to address beam related issues. No explicit funding exists to do these studies and effort spent on this so far has been through use of internal national laboratory funds.

Project: Design of a 5T Solenoid

Fermilab

Contact: Marcel Demarteau (Fermilab , USA)

INTRODUCTION

A large 5 Tesla superconducting solenoid unquestionably transcends present experience in magnet design. It has been suggested that mechanical considerations lead to an upper limit of about 60 T^2m for the figure-of-merit B^2R for superconducting solenoids. For the SiD solenoid this quantity is 62.5 T^2m, suggesting that the feasibility of such a magnet is best determined by appeal to experience and careful engineering extrapolation where required. The CMS solenoid, nearing completion at the CERN Large Hadron Collider, will provide a 4 T field in a bore 5.9 m in diameter and 13 m long. This magnet provides a substantial proof-of-concept for the SiD solenoid. The CMS conductor consists of a 32-strand NbTi cable, stabilized by a co-extrusion of high-purity aluminum, which is welded to two bars of strong aluminum alloy. CMS achieves its design field with four winding layers; SiD will require six layers using the same conductor. The smaller aspect ratio (magnet length divided by diameter) of SiD vs. CMS -- approximately one for SiD but more than two for CMS -- means that more linear current density than simple proportionality of the higher field is required. CMS operates at 19.5 kilo-Amperes (kA) and its windings provide a linear current density of approximately 3500 A/mm; SiD requires 4800 A/mm, a factor of almost 1.4 more than CMS for a field only 25% more intense.

GOALS

The SiD detector calls for a five Tesla solenoid. This proposal will carry out the necessary research and development to establish the feasibility of a design, prepare a realistic cost estimate and establish the contacts with industry for construction of the magnet by industry. The R&D proposed consists of the testing of optimized finished stabilized high purity aluminum alloy conductor at the 20kA, 4-6 Tesla scale to establish the conductor design concepts. Under study in this optimization effort are the hardening of the high purity aluminum with specific alloys to improve is behavior in high stress conditions, and the use of better optimized hard aluminum alloy reinforcement for the conductor. These studies would be complemented with 3-d FEA modeling of 5T solenoid using CMS parameters and 3-d FEA modeling of 5T solenoid with results from new conductor tests to establish the proof of principle for a 5T solenoid by the year 2007.

Beam particles entering the detector at a finite horizontal crossing angle will deviate in the vertical plane. This deviation can be corrected by a special dipole field at the intersection region. For maximum efficiency this special field can be provided by saddle coils mounted on the outer support cylinder of the solenoid. This Detector-Integrated-Dipole (DID) corrector can also be used to compensate for rotation of the beam polarization or beam size growth due to synchrotron radiation. Locating the DID coils on the solenoid outer support cylinder offers an ideal environment for them. There is minimal solenoidal field in that region, a slight increase in the size of the solenoid cryostat readily provides for the dipole coils, and the large winding radius of the dipole coils ensures a high quality dipole field on the beam axis with modest attention to the dipole winding geometry. Approximately 550 kA-turns are needed for the required ~ 600 G dipole field from each of the coils. This proposal calls for a continuation of the R&D on the DID and evaluation of its effects on the physics.

COLLABORATION

The conductor R&D would be carried out in collaboration with CERN. CERN is responsible for obtaining samples of new conductors. CERN is in the process of having the extrusion vendor, used for the CMS conductor, perform another extrusion of stabilizer onto some existing leftover CMS superconducting cable. Instead of ordinary high purity aluminum, they will use a leftover billet of Akira Yamamoto's special stabilizer alloy prepared for the ATLAS solenoid, and perhaps another similar alloy under development at CERN. Then leftover reinforcing bars from CMS will be welded onto the extrusion. The yield would be samples of finished conductor at the CMS scale (20 KA, 4-6 Tesla) for further study and measurement which would be shared by CERN and us.

SCHEDULE

The goals for this project to be accomplished within the next two years are to:

1) Fabricate “CMS” conductor samples with improved aluminum stabilizer
2) Fabricate “CMS” conductor samples with improved aluminum reinforcement
3) Test finished stabilized alloy conductor at the 20kA, 4-6 Tesla scale
4) Perform 3-d FEA modeling of 5T solenoid using CMS parameters, including DID
5) Perform 3-d FEA modeling of 5T solenoid with results from new conductor tests, including optimum conductor design, to establish the proof of principle for a 5T solenoid by the year 2007.

Based on the results of the first phase, a complete conceptual design of cold mass support system and cryogenic cooling technique for a 4-6 T solenoid will be developed in the years following, i.e. 2008 and following years.

SUPPORT

The current level of support is inadequate for carrying out the proposed research. The level of shortfall is listed on the prioritization form.

3. URGENT FUNDING REQUIREMENTS

On 27th September 2005, the ILCSC gave the ILC Detector R&D Panel a new responsibility, as follows:

Produce a written report by the end of 2005 which identifies and prioritises the topics and areas of detector R&D which need immediate support. Inputs to this should be collected both from the detector concept teams and from all the detector R&D collaborations and groups interested, via their contact persons with the Detector R&D Panel. Individual proposals should not be identified. This report will initially be submitted to the WWS-OC, and then passed to the ILCSC.

After discussing a few options, our Panel decided that the best way to deal with this request would be to rely on the expertise of our 65 contact persons. However, there was some debate initially as to whether this would produce results beneficial to the detector concepts. As previously noted, our links to the detector concepts are provided by representatives (Ties Behnke, Yasuhiro Sugimoto and Andy White for the LDC, GLD and SiD respectively), who participate as full members of our Panel. Their guidance has been important throughout the process, and has (we hope) ensured that our procedures remained entirely in tune with the needs of the concept groups.

We sent each of our contact persons a form to complete, asking them to identify those topics within their projects which were particularly important, either in order to extend significantly the ILC physics reach, or to reduce the detector cost, or both. Furthermore, we wished to know which of these topics were urgent, in that answers would be needed for the experiment collaborations to prepare their LOIs. For the larger subsystems (tracking, calorimetry etc) we suggested a timescale to reach their goals of three years, ie to end of 2008. For the smaller, high-tech systems such as the vertex detector or BEAMCAL, we suggested an extended timescale of 5 years, to end of 2010, on the grounds that the experiment collaborations would be able to keep their options open on these subdetectors for about two years beyond the LOI timescales, in order to give time for the R&D groups to complete their critical work. *We classify these important and urgent topics as Priority 1.*

We classify all other topics as Priority 2, for example those which are important, but for which the results can extend beyond 2008 or 2010, since they seek to refine parameters of detectors for which the proof-of-principle will have been established.

We next asked our contact persons about their levels of support for Priority 1 topics, separately for manpower (in FTEs for each year of the work) and equipment budgets. We asked about manpower in FTE units so as not to have to take account of different salary and overhead levels around the world. Under 'equipment', we asked them to include everything other than staff costs (therefore comprising hardware, commercial services and contracts, travel costs, etc). For both manpower and equipment, we asked them to tell us their 'established' levels of support. Many people don't know what these will be 3-5 years from now, so we suggested in that case to assume level funding at their 2005 level. In some cases this will be optimistic, in others pessimistic, but is probably a reasonable assumption on average. We then asked them, separately for manpower and equipment, to estimate the level of *additional support* that would be needed to achieve their Priority 1 goals by the end of the R&D period. As an example, for the vertex detector, it is generally accepted that the Priority 1 goal for all projects will be to have full-size detector elements ('ladders'), operating in test beams by 2010. On the basis of these tests, it will be possible for the experiment collaborations to choose one or two options to be used for the first years of operation at ILC. There are similarly well-defined Priority 1 goals for most of the other subdetectors.

Our contact persons took this job seriously. Nearly all of them provided the information requested, and the results make interesting reading. One or two told us frankly that none of their work rated Priority 1, though they argued convincingly that it should continue to be supported at current levels, since the long-term payoff for the ILC would be valuable. For most projects, their work consists of a mixture of Priority 1 and Priority 2 topics, and there are clear arguments why the Priority 2 work should continue. However, in view of the serious shortfall in support for Priority 1 activities, we recommend that there should be no expansion in Priority 2 work in the immediate future. Given the sensitivity of information (some people were understandably reticent about publicising what they thought they could get from their funding agencies over the next 3-5 years) we agreed to restrict their information to the Panel members, or in a few cases to the Panel chair alone.

In a few cases, it is difficult for our Panel to judge whether the figures provided by the contact persons are realistic. Some projects are based on intimate collaborative arrangements with semi-academic companies, and such 'special relationships' may enable the groups to achieve challenging goals with modest equipment budgets. Projects in our register have been subject to national peer review involving open session presentations, refereeing etc, and in many cases also international review (for example, via the DESY PRC), or are a recognised part of a laboratory programme. The detailed judgments about these projects have been made by committees with a lot more information than has been available to our Panel. We are confident that our contact persons have provided by far the best estimate of what is currently available regarding world-wide support for ILC detector R&D, as well as quantifying the mismatch between what is available and what is needed to finish the work.

It could be argued that we have not completely satisfied our brief (above) in that we have let the contact people select the Priority 1 topics, rather than doing this within our Panel. However, the latter option would have been entirely unrealistic. For example, where there are different technology options being investigated for a particular subdetector, one could in principle economise on the R&D by 'picking winners'. However, this is the job of the funding agencies via their peer review systems, and some options have indeed disappeared following rigorous reviews. Those which survive today have convinced the community that they have a chance to be winners. Some of these options will possibly be dropped in the future, reducing the overall R&D support needed. However, in most cases, the choices will be made on the basis of the measured performance of prototypes which will be built, and for which our contact persons have made their budgetary estimates.

This is the first time that a comprehensive global picture of ILC detector R&D has been compiled, and we feel that the figures, while approximate, are extremely informative. Even within individual countries, some information is new. For example, we believe that this is the first time that one sees in a single report full coverage of the R&D work going on in the USA, summed over all funding sources (DOE via the universities, DOE via the national labs, NSF, as well as various sources of internal university funds). Also for the first time we have a picture of the scale of the R&D between different subdetector systems. Our compilation of about two thousand numerical estimates from 65 contact persons is presented in the form of two tables with accompanying figures.

Subdetector	**Equipment (k$)**		**Manpower (man-years)**	
	Established	**Total Required**	**Established**	**Total Required**
LEP	1129	2573	69	142
Vertex	6076	12959	321	543
Tracking (gas)	1343	3389	93	194
Tracking (Si)	2017	2868	285	361
Calorimetry	4036	9142	388	570
Muon tracking	117	482	6	23
Particle ID	7	365	0	29
DAQ	0	150	0	10
Solenoid	35	70	1	1
TOTALS	14760	31998	1163	1873

Table 1. Equipment and manpower budgets for Priority 1 topics, by subdetector. LEP means the measurement of luminosity, energy and polarisation.

Table 1 and Fig 1 show the breakdown between subdetectors. The figures are integrated over the time estimated to achieve the urgent goals, typically 3 years for tracking and calorimetry, 5 years for vertex detectors, BEAMCAL and other less expensive but high-tech subsystems which are currently far from their design goals. However, there are other factors which influence timescales, for example the EUDET funding which runs for 4 years from 2006. While the integrated figures in the Table are believed to be reasonably accurate, the associated timescale should be regarded as uncertain at the level of 4 ± 1 years. Ongoing uncertainty about available funding and the ILC schedule could further influence the estimated timescales, but the integrated figures should be reasonably stable.

Figure 1 shows firstly that, as could be expected, there is roughly equal manpower support (established and required) between the three main R&D areas of vertexing, tracking and calorimetry. In equipment budgets, vertexing is more expensive, reflecting the high cost of the customised integrated circuits which comprise their sensors. Figure 1 next shows that, for these systems, there is an across-the-board need for about a factor two increase in support (equipment and manpower) if their urgent R&D goals are to be achieved. Of the smaller systems, particle ID has shrunk almost out of existence, and will need an urgent injection of funding if it is to receive the attention it deserves.

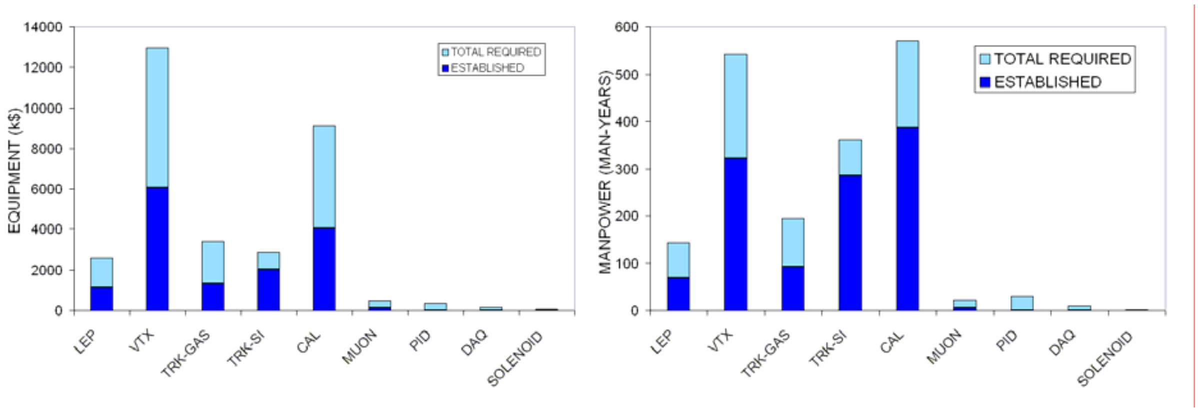

Fig 1. Urgent R&D support levels over the next 3-5 years, by subdetector type. 'Established' levels are what contact persons think they will be able to get under current conditions, and 'total required' are what they would need in order to establish proof-of-principle for their projects.

Table 2 and Fig 2 show the breakdown between the major countries. We summed the contributions from Europe because many European projects receive support from several countries, and the EUDET funds are explicitly pan-European. The figures show that the Europeans and Koreans are providing the firmest base for ILC detector R&D. Their projects have urgent needs for increased resources (manpower and equipment) of about 50%, which is reasonable to hope for as the ILC ramps up to becoming a real project. However, the USA, Japan and Canada are in an extremely difficult position. They are currently at a very low level, and need a large injection of new money by a factor of 4-5 in order to realise their urgent goals. We hope that this information, arrived at from about two thousand numerical estimates sent to us by virtually all the R&D groups round the world, will provide a clear message to the funding agencies.

Funding Country	**Equipment (k$)**		**Manpower (man-years)**	
	Established	**Total Required**	**Established**	**Total Required**
Europe	10513	15113	822	1000
USA	2467	11313	181	544
Canada	60	1139	4	35
Japan	90	2218	62	119
Korea	1130	1390	94	123
Other	500	825	0	52
TOTALS	14760	31998	1163	1873

Table 2. Equipment and manpower budgets for Priority 1 topics, by region. One should be careful not to misinterpret these numbers. Some American Panel members initially thought that the 'established' US equipment budget (column 1) must be under-estimated. They were overlooking the fact that most of the US funds so far have gone into supporting postdocs, not equipment. These are included in the established manpower estimates (column 3). Overall support is the sum of equipment plus manpower. 'Other' refers to smaller national contributors and cases where the support is undefined between two or more countries.

Overall, the established equipment funds world-wide for the next 3-5 years are estimated to amount to approximately $15M, and the established manpower to 1160 man-years. The R&D groups estimate that they will need approximately $32M and 1870 man-years if they are to achieve their urgent goals. If we simplify the manpower to be predominantly postdocs at $100k p.a., and simplify the time period to be 4 years for all projects, this amounts to *established support*

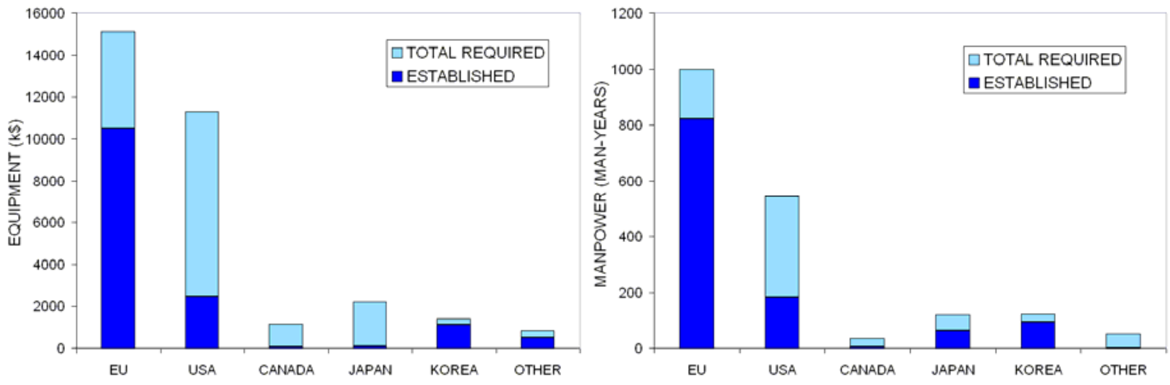

Fig 2. Urgent R&D support levels over the next 3-5 years, by funding country or region. 'Established' levels are what contact persons think they will be able to get under current conditions, and 'total required' are what they would need in order to achieve proof-of-principle for their projects.

world-wide of $33M p.a., a requested increment of $22M p.a., making a total request of $55M p.a. of which 85% is manpower. This overall growth seems appropriate as the world of particle physics moves towards one of its biggest ever projects.

If funds become available, will it be feasible to increase manpower to the levels suggested? Our contact persons indicated the type of additional support they need, subdivided between academics, students and support staff. The bulk of the increase would of course be in new postdocs. If the entire 710 additional man-years were allocated to 4-year postdoc positions, this would amount to 180 people, half of them in the USA. We are confident that there would be no problem in filling these posts quickly. As an example, a single startup ILC accelerator R&D project in the UK (the LC-ABD collaboration) was awarded 25 new postdoc positions about two years ago, and was able to fill all of them without difficulty. Finding 180 talented young people from around the world to participate in established ILC detector R&D projects would be easy, and could transform the activities in this field.

In Section 4, we mention two examples of topics which are 'missing', in the sense of receiving so little support as to be in danger of failure. In our opinion, the neglect of these (and possibly other topics we have overlooked) is mainly a consequence of the thinly stretched band of ILC physicists working on detector R&D and the associated simulations. There is an urgent need, not only for increased funding, but for longer term jobs for the young people who could turn this funding into winning R&D results.

While the investment urgently needed in detector R&D for the ILC represents a significant and challenging programme, this is small compared to the overall cost of the collider. Having detectors which fail to satisfy the extremely challenging physics needs, would be an unfortunate example of inadequate resources now, resulting in a serious loss of cost-effectiveness later. There is still time to rectify this situation, and the levels of support over the next few years will be critical in determining whether the detectors will be up to the job, or whether much of the hard-won luminosity will be wasted because the events cannot be analysed with sufficient precision. The benefit in effective luminosity of high-performance subdetectors has become widely appreciated by the ILC community, following on a study reported at Snowmass 2005 [1]. 'Luminosity factors', the factors by which the machine luminosity would be effectively degraded by a detector with sub-optimal performance, are now quoted for various subdetector options. The benefits of finding the resources to do this work properly, and the disadvantages of failing to do so, are considerable in terms of scientific output and financial cost effectiveness. There are important lessons from the past. It is possible that LEP might have discovered the Standard Model Higgs, and that SLD would have measured the B_s mixing parameter, a result for which we are still waiting 5 years later, had these colliders been able to provide a beampipe radius of approximately 10 mm. The corresponding situation at ILC creates pressure both on the machine groups to deliver the required background conditions at the IR, and on the detector R&D groups, which need to develop the detectors able to take advantage of this great opportunity. Unless both these efforts are successful, the loss in ILC physics may be considerable. Similar arguments can be made for tracking and calorimeter systems. Appropriate investment in the R&D urgently needed for the ILC detectors, will pay for itself many times over, once the machine turns on and each event delivered by the hard-won luminosity will be analysed with the precision needed to unravel the new physics.

[1] Physics potential of vertex detector as function of beampipe radius, S Hillert and CJS Damerell, Proc Snowmass ILC workshop 2005 (to be published)

4. MISSING TOPICS

As well as surveying the current R&D activities, the Panel was asked to identify missing topics, and here we would like to draw attention to two of them. The first (and less serious, in that it is more easily corrected) is the study of particle ID, notably K/π separation. This was an active topic for several years, but support has recently evaporated because the physics case was considered insufficient, in an atmosphere where severely inadequate funding led to tough decisions. Meanwhile, the physics case has been strengthened by the combined use of kaon identification with topological vertexing in SLD. Such a tool for *b*- and *c*-quark sign selection could be extremely useful, along with vertex charge, in the multi-jet environment at ILC. Furthermore, the technical possibility of an extremely compact PID system has emerged, based on the focusing DIRC technology, so the resulting degradation in PFA performance may be negligible. Our Panel would like to see this activity revived, initially to complete the feasibility study, progressing to detector development only if results look promising.

Our more serious 'missing topic' is forward tracking, down to the limit of around 7° set by the beampipe/mask assembly. This falls well below the limit achievable with the vertex detector (for which the small-angle coverage is restricted by the $e^\pm$ pair background inside the beampipe) so the argument that the vertex detector and outer tracker can perform track reconstruction independently of one another does not apply in this region; everything depends on the forward tracking system. The importance of this angular region has been apparent ever since LCWS 1991 [1]. Figure 1 shows the confusion of tracks from a 6-jet event ($e^+e^- \to t\overline{t} \to WbWb$ at 500 GeV), as well as the clarity with which the underlying Feynman diagram is revealed by a PFA algorithm. Notice that two of the jets are in the forward tracking region, a situation which will be quite typical for multi-jet processes at ILC, so the tracking performance in this angular region will be of critical importance for physics. Poor tracking performance in this region could represent the Achilles heel of the ILC detectors, if serious work is not started urgently. It is not only the forward jets which are affected. Low-p_T particles from intermediate angle jets will be deflected into this region, and their efficient reconstruction will be equally important if the PFA for those jets is to achieve the required performance. Our concerns regarding forward tracking stem partly from the fact that this has never yet been made to work properly in a collider environment. In a recent attempt (the H1 upgraded forward tracker), the performance is reasonable for individual particles, but degrades badly for particles in jets. The detector Monte Carlo needed to be tweaked drastically in order to match the poor performance. Other experiences (LEP and SLD) have been similarly disappointing. Mechanical support structures, endplates of central tracking detectors, electronics and cabling from other systems such as vertex detectors, tend to populate this region, creating unwanted material which causes photon conversions, secondary interactions of charged and neutral hadrons, as well as producing δ-electrons which are carried along the magnetic field lines, producing spurious signals in adjacent detectors. Despite the passage of time (15 years) since LCWS 1991, there has been no serious simulation/reconstruction study of ILC forward tracking. These studies are long overdue, if one is to arrive at a reasonable detector layout, then initiate the appropriate detector R&D.

An early attempt to address this problem was undertaken for the TESLA TDR [2]. The suggested layout was 3 disks of silicon pixels followed by 4 disks of silicon strip detectors, either side of the IP. It may be that the 3 pixel planes will, for the first time, provide the required high level of track reconstruction efficiency in jets, but this has still to be established by simulation. It may be that the 4 disks of strip detectors will provide adequate momentum resolution despite the unfavourable direction of magnetic field, but this has also to be demonstrated. The suggestion in the TDR of planes of hybrid pixel detectors as used in the ATLAS vertex detector, seems dubious. Such devices would provide massive overkill in timing resolution, but at the expense of an extremely unfavourable material budget.

We are concerned that the PFA performance may be more sensitive to the material budget than has been assumed. Photon conversions are probably a tractable headache. Potentially more serious are secondary interactions, in which elastic scattering, charge exchange scattering, and inelastic processes tend to degrade the particle flow in different ways, all of which will need to be treated separately. If secondary interactions were seen clearly as such, the interaction products would simply comprise some additional charged and neutral particles for the calorimetry to deal with. The charged particles would still have their momenta measured (with reduced precision) so the 'standard PFA procedure' would still apply. Therefore, the problem should not be associated with the calorimetry, which can be made as fine-grained as required, but with the ability of the tracking system to observe all the primary and secondary charged particles which impinge on the face of the calorimeter. While products of secondary interactions constitute a general problem for PFA, the additional material makes this a particularly sensitive issue in the forward region.

One point of view is that forward tracking is the business of the concept groups, and that one should wait for them to develop the tools to study this question. However, after all this time, it may be that a combined initiative would be more appropriate. Many detector studies are carried out for the common good, beyond the boundaries of the separate concepts, and this may be another example which would benefit from a broader approach. The first requirement would be to make full Geant-4 based Monte Carlo simulations for a few detector options, and investigate how well one could

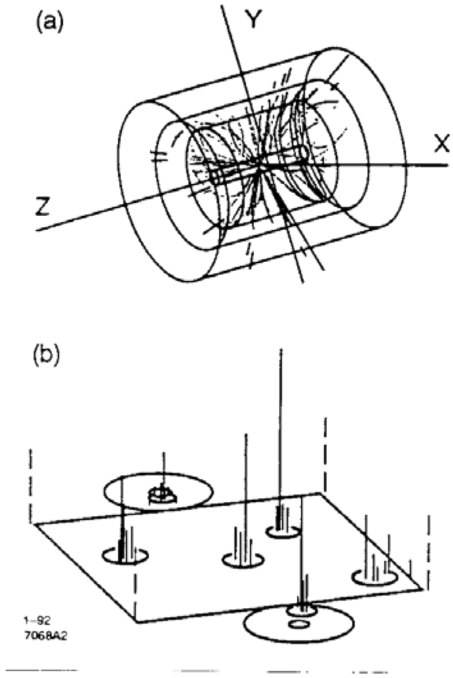

Fig 1. A 6-jet event at ILC, (a) showing the charged tracks and photon showers, and (b) an unfolded Lego plot of the observed energy flow in the event.

achieve reconstruction of all the particles in jets. Having selected some suitable combination of (presumably) silicon pixels and strips, one would then need to subject this to reality checks by the detector groups best placed to construct such systems. The strip detectors would find a natural home in the groups currently working on the tracking detector for the SiD concept, and it may be that one or more of the vertex detector R&D groups could investigate the design of the inner pixel disks, assuming that this is shown to be the desirable approach. We are faced with large systems here, which will carry their own weight of services etc. The layout suggested in the TESLA TDR implies double the area of pixel detectors as that required for the 5-barrel vertex detector system. The fact that no group has signed up to this major R&D topic is in stark contrast to the high level of activity on pixel devices focused on the vertex detector system.

As already established for the other subdetectors, there should eventually be plans for beam tests of the forward tracking system, once a design becomes established. Ideally, this prototype should be tested in conditions which replicate those in which it will need to operate. One possibility would be to embed the system in a suitable magnetic field, and measure the reconstruction efficiency of particles in 'jets' in the form of products of highly inelastic reactions induced by (for example) 100 GeV pions on a thin metal target. One could introduce dead material to simulate the mechanical supports and cables that will be found in the forward region. When discussed recently with one of the concept groups, such tests were considered overly ambitious. But if this is not done, will we end up with another generation of dysfunctional forward tracking systems? This time, the consequences for physics would be far more serious than in previous experiments where jet multiplicities were lower.

[1] Experimental challenges at linear colliders, DL Burke, Proc LCWS 1991, World Scientific, 51
[2] TESALA TDR Part IV (DESY 2001-011), 28

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