Proposal to the
University Consortium for a Linear Collider

September 6, 2002

Proposal Name

Development of energy-flow algorithms, simulation, and other software for the LC detector.

Classification (accelerator/detector: subsystem)

Calorimeter (+ tracker): simulation, software, and algorithm development.

Personnel and Institution(s) requesting funding

M. Arov, G. Blazey, D. Chakraborty, A. Maciel, M. Martin, R. McIntosh, V. Zutshi.
Northern Illinois Center for Accelerator and Detector Development/ Northern Illinois University

Collaborators

S. Magill et al., *Argonne National Laboratory*,
J. Yu et al., *University of Texas at Arlington*,
N. Graf et al., *Stanford Linear Accelerator Center*,
M. Oreglia et al., *University of Chicago*,
R. Frey et al., *University of Oregon*,
U. Nauenberg et al., *University of Colorado, Boulder*,
G. Wilson et al., *University of Kansas*,
N. Varelas et al., *University of Illinois at Chicago*,
J. Butler et al., *Boston University.*

Contact Person

D. Chakraborty
`dhiman@fnal.gov`
(630)840-8569

Project Overview

The Northern Illinois University(NIU)/Northern Illinois Center for Accelerator and Detector Development (NICADD, http://nicadd.niu.edu) group is interested in calorimeter R&D for the proposed LC. Our group proposes to develop, in simulation and in prototype, designs for a hadron calorimeter (HCal) optimized for jet reconstruction using energy-flow algorithms (EFA, see below). Simulations/algorithm development and hardware prototyping are envisaged as the two main components of our efforts. This proposal addresses the first component while the second is the subject of a separate proposal.

An e^+e^- linear collider is a precision instrument that can elucidate Standard Model (SM) physics near the electroweak energy scale as well as discover new physics processes in that regime, should they exist. In order to get the most out of the potential anticipated from a machine of this type, the collection of standard high energy physics detector components comprising an experiment must be optimized, sometimes in ways not yet realized at current experiments. One such example is the hadron calorimeter which will play a key role in measuring jets from decays of vector bosons and other heavy particles such as the top quark, the Higgs boson(s), etc. In particular, it will be important to be able to distinguish, in the final state of an e^+e^- interaction, the presence of a Z or a W boson by its hadronic decay into 2 jets. This means that the dijet mass must be measured to a precision of ~ 3 GeV, or, in terms of jet energy resolution, $\sigma(E) \approx 0.3\sqrt{E}$ (E in GeV), something yet to be achieved in any existing calorimeter. Similar precision in measurements of jet and missing energy will be crucial for discovery and characterization of several other new physics processes as well as for precision tests of the Standard Model. Such ambitious objectives place stringent demands on the performance of the caloriemters working in tandem with the tracking system at the LC which will necessarily require the development of new algorithms and technology in this sphere.

The most promising means to achieving such unprecedented resolutions at the next linear collider is through energy flow algorithms(EFA) which seek to separate and measure in a jet clusters of energy initiated by neutral hadrons, carrying, on average, only $\sim 11\%$ of a jet's total energy. The tracker is used to measure with much better precision the charged components ($\sim 60\%$ of jet energy) and the electromagnetic calorimeter (ECal) to measure the photons with a resolution $\sigma(E) < 0.15\sqrt{E}$ ($\sim 25\%$ of jet energy). A net jet energy resolution of $\sigma(E) \approx 0.3\sqrt{E}$ is thus achievable by using the HCal only to measure the charged hadrons with a resolution $\sigma(E) \approx 0.6\sqrt{E}$.

A calorimeter designed for EFAs must be finely segmented both transversely and longitudinally for 3-D shower reconstruction, so hits initiated by charged particles can be separated from those initiatied by neutral particles by associating the former to corresponding tracks found in the inner tracking volume. This requires a realistic simulation of both the physics processes and the shower development that occurs in materials. The design optimization requires the simulation, graphics, and analysis packages to be highly flexible, which can only be achieved through careful design and implementation of the software itself. Very large numbers of events will have to be simulated to evaluate the impact of competing designs on physics capabilities. Much of the physics in question is beyond the SM, requiring simultaneous coverage of broad ranges of undetermined parameters. Parametrized fast simulation programs will thus have to be developed once the algorithms have been stabilized. Parametrization of EFAs will require much work, and is one of our key objectives.

In January 2002, members of NIU, UTA (the University of Texas at Arlington), and ANL (the Argonne National Laboratory) began collaborating on EFAs, simulations, and software development efforts. Many of the results that emerged through discussions at our regularly scheduled meetings have been presented at the CALOR 2002 conference, the ECFA/DESY meeting at St. Malo, the American LC workshop in Santa Cruz, and at the International LC Physics and Detector Workshop in Korea.

Towards the optimization of the HCal design, the NIU+ANL team have started investigating both analog (cell energy measurements) and digital (hit counting) readout methods as functions of the cell size. Our preliminary findings indicate that for small enough cell sizes, the digital method yields a more precise measurement of the hadron energy, suggesting that hit density fluctuations are smaller than energy fluctuations in a hadronic shower. Three independent approaches to the implementation of an EFA are taking shape. These will help us determine the optimal cell sizes and geometry for best charged/neutral hadron shower separation in jets within the context of some specific overall detector parameters. Our HCal optimization efforts can be summarized as follows:

HCal absorber/active media properties: The detector simulation and analysis of physics events within the Java Analysis Studio (JAS)-based software environment developed at SLAC, is flexible in the choice of absorber and active media type and thickness within the limits of the HCal volume. NIU has recently put together a GEANT4-based detector simulation package to work within this environment, and produced many data sets spanning a range of cell dimensions and particle types. The ANL team has used a standalone GEANT3 program for limited tests of geometries that have yet to be supported in the above environment. We will optimize the HCal by comparing dense materials (W, Pb) to less dense ones (Cu, Stainless Steel, Brass) as absorbers using as performance measures the containment of hadronic showers, the density of hits, and single particle energy resolution.

HCal transverse granularity/Longitudinal segmentation: This can also be changed in JAS (within certain limits that we are working to remove). We plan to optimize the 3-D granularity of cells for the most promising EFAs and then determine an optimal active medium for the desired cell size. The methods developed here are generalizable to different total detector geometries, i.e., SD, LD, TESLA, ... The basic performance measure here is the ability to separate showers from charged and neutral hadrons - the key to any EFA.

Analog vs. digital readout: Once the optimal 3-D granularity has been determined, the choice of the readout method can be evaluated by comparing jet resolutions with both analog and digital readout. It may be prudent to consider both the best analog and the best digital version of the HCal for eventual evaluation with test beams provided both prove petentially capable of meeting the energy resolution requirement. Testing both options will allow for future advances in readout technology which might favor one option over another.

Energy-flow algorithms: For the first time in calorimeter development, it is necessary to include the reconstruction program in the optimization of the detector. It is anticipated that the choice of EFA will play a key role in the ultimate achievement of thte best jet energy resolution. As a first step, we plan to implement an EFA that does not require calorimeter cell clustering. Rather, it relies on associating calorimeter cells to extrapolated tracks, substituting the track momentum for the calorimeter energy measurement, finding photons in the ECal based on analytical shower shapes, applying an appropriate jet algorithm with the tracks and photons as input, and finally, associating the remaining calorimeter cells within the jet cone to the jet (these are predominantly due to neutral hadrons).

The NIU group has been working on simulation software since early 2002 and has made significant progress. All of the current American LCD simulation software, both event generation and a detector simulation based on the "GISMO" package, has been ported to the Linux platform. Since April, 2002, we have been processing simulation requests from several groups engaged in LC R&D on a 40-node Linux farm allocated to this project by Fermilab. We have recently developed, in close collaboration with the ALCPG simulation group, a GEANT4-based simulation package based on standard C++ that is completely independent of any specific analysis platform. The package derives much from the LCDRoot package, but not its dependence on ROOT. The new package, yet to be named, fully complies with the model specifications put forth by the simulation group. Most importantly, the detector description is specified at run-time through an XML interface, and the output is available in both the standard `sio` format as well as `root` files. Upon completion of tests currently underway, this package is expected to become the standard for ALCPG. Subsequently, it should be integrated into the U. of Chicago/ANL GRID facility currently under development.

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 who have similar interests. Active links have been established with SLAC, U. of Chicago, and several other institutions. A workshop is being planned at NIU/NICADD in October, 2002, to bring the groups together to get up to speed, identify an agenda, and set out in an organized manner.

Activities outlined in this proposal are synergistic to the proposals for hardware prototyping of different technology choices. We will maintain close communication with the groups involved in hardware development for the ECal and the HCal.

FY2003 activities and deliverables

During the first year we will concentrate on the development of EFAs for the electromagnetic and hadronic calorimeters. Both analog and digital versions of the algorithms will be investigated for the hadronic section. The first year deliverable will be a class of full-fledged energy flow algorithm based on full simulation and reconstruction of the calorimeter and the tracking system. In addition, the standard GEANT4-based simulation facility (farm+server) will be available for to the entire LC community through a web-based request form.

FY2004 activities and deliverables

Apart from further tuning of the algorithms, extensive studies of critical physics processes will be carried out to understand the impact of the calorimeter performance on the physics program of the

Linear Collider. These studies will employ analog and digital versions of our EFAs. The second year deliverables will be a quantified assessment of physics reach vs calorimeter performance for the Linear Collider including comparisons between digital and analog options for the hadronic calorimeter.

FY2005 activities and deliverables
In the third year we will embark on the development of parameterized simulations of the energy flow algorithms. The technology and geometry are expected to have been narrowed down by that time setting the stage for such parametrized fast simulation for extensive physics studies. The third year deliverable will be a fast simulation program based on EFAs.

Three-year budget, in then-year K$

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	21.0	44.0	65.0
Graduate Students	27.5	29.5	30.5	87.5
Undergraduate Students	0	0	0	0
Total Salaries and Wages	27.5	50.5	74.5	152.5
Fringe Benefits	0	8.5	18.0	26.5
Total Salaries, Wages and Fringe Benefits	27.5	59.0	92.5	179.0
Equipment	0	0	0	0
Travel	4.0	8.0	8.0	20.0
Other direct costs	0	0	0	0
Total direct costs	31.5	67.0	100.5	198.0
Indirect costs (44% of non-equipment)	13.9	29.5	44.2	87.6
Total direct and indirect costs	45.4	96.5	144.7	285.6

Budget justification
The first year's activities revolve around the development of energy flow algorithms. This will involve NICADD and ANL physicists (not included in the budget shown here) and 1.5 FTE graduate students. Optimization and detailed performance studies of the algorithm will be carried out in the second year by 1.5 FTE graduate students and 1/2 post-doc with additional support from NICADD and ANL. During the third year, the development of parameterized simulations will be supported by a post-doc, together with 1.5 FTE graduate students.

Existing Infrastructure and available resources

The above requested resources will be augmented by the following support, totaling approximately $500K, from other sources:

(a) NIU/NICADD personnel,

(b) ANL personnel,

(c) Computing hardware and support provided by NICADD,

(d) 40-node Fermilab Linux farm (run by NIU personnel), open to expansion as the need arises.