Proposal to the
University Consortium for a Linear Collider

October 7, 2002

Proposal Name

Design and Prototyping of a Scintillator-based Digital Hadron Calorimeter.

Classification (accelerator/detector: subsystem)

Calorimeter: Hadron Calorimeter.

Personnel and Institution(s) requesting funding

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Project Overview

The Northern Illinois University(NIU)/Northern Illinois Center for Accelerator and Detector Development (NICADD, http://nicadd.niu.edu) and the University of Illinois at Chicago (UIC) groups are interested in calorimeter R&D for the proposed Linear Collider. We propose to develop, in simulation and in prototype, designs for a hadron calorimeter (HCal) optimized for jet energy measurement using energy-flow algorithms (EFA, see below). Software simulations/algorithm development and hardware prototyping are envisaged as the two main components of our efforts. This proposal addresses the second component while the first is the subject of a separate proposal. The end goal of this research project will be the development of reliable performance and cost estimates for scintillator-based digital hadron calorimeter options suited for, but not limited to, an e^+e^- linear collider.

It is clear that for the Linear Collider to fulfill its physics charter multi-jet final states will have to be exceptionally well measured. In particular, superior resolutions in jet ($30\%/\sqrt{E}$ or better) and missing energy measurements will be critical for discovery and characterization of the new physics as well as for precision tests of the Standard Model (SM). The most promising means to achieving such unprecedented resolutions at the next linear collider is through energy flow algorithms (EFA) which require fine lateral and longitudinal segmentation of the calorimeter (see below). We propose to conduct a comprehensive feasibility study of a finely segmented hadron calorimeter with transverse cell cross section of ≈6-16 cm^2 and 30-40 layers of active medium. The very large number (≈ 3-5 million) of readout channels pose a significant challenge in the form of complexity and cost of signal processing and data acquisition. Reducing the dynamic range of readout is a potential solution. At the extreme, it may be a "digital" calorimeter with a single-bit readout for each cell, with the threshold set to detect the passage of a minimum ionizing particle. Preliminary studies have indicated that with sufficiently small cells, a 1-bit digital readout may be adequate, but we propose to find the optimal balance between cost and performance in deciding on the cell size and dynamic range. For example, a 2 or 4-bit readout may improve performance without significantly adding to the cost.

Between the NIU and UIC groups, we have extensive experience in calorimeter hardware, electronics, software, and algorithm development, gained at the DØ experiment and elsewhere. The NIU/NICADD team has already started investigating a sampling digital hadron calorimeter with scintillator as the active medium. This capitalizes on proven detection techniques and well known readout devices. Absence of fluids, high-voltage, and electronics inside the detector aids longevity and operational stability. The main challenge to a scintillator-based digital hadron calorimeter is the cost of transforming light, from such a large number of channels, to electrical signals. We plan to seek the optimal solution by evaluating different options through simulation and prototyping studies.

A GEANT4-based simulation package has been installed and tested on several NIU machines and is now being used to model our preliminary prototype designs. We expect the synergy between these simulations and the hardware prototyping to contribute significantly to our understanding of the scintillator based design. NIU's simulation and algorithm development efforts, detailed in the other proposal, will provide valuable input in deciding the optimum transverse and longitudinal segmentation, absorber material and detector layout.

Already, on the hardware side, hexagon-shaped prototype cells of various sizes, thicknesses and fiber routings have been machined and are being evaluated together with fibers of different shapes, dimensions and optical treatments. Sufficient strength and excellent uniformity of response has been obtained using extrudable groove shapes. Apart from the relative light yield measurements for these various configurations, absolute measurements are also being carried out with the help of Visible Light Photon Counters (VLPC) as photo-detectors which have a quantum efficiency of ∼70% but require an operational temperature of liquid helium. Metal resistive structures, an emerging technology which offers quantum efficiencies ∼30% at room temperature, are also being considered. In addition, various choices for absorber material, investigation of tooling and mechanical assembly options and the use of extruded scintillator are slated for study.

FY2003 activities and deliverables

During the first year we will finish implementing our prototype design in a GEANT4 simulation, carry out relative and absolute light yield measurements for various scintillator cell sizes and material (for e.g. Kuraray/Bicron vs extruded). Optimum grooving, reflector treatment, and fiber size and shape will be studied. We will also characterize photo-detectors (VLPC's, MRS etc.) in terms of performance, reliability, stability of operation and cost. The first year deliverables are a GEANT4 prototype simulation and a decision on the optimum cell-fiber-grooving-treatment configuration.

FY2004 activities and deliverables

Investigations into photo-detectors will continue. Assuming reasonable light yield from extruded samples, the NICADD extrusion line will be operated to deliver scintillator cells of the optimum shapes, sizes and groovings. Construction of a 7-cell wide and 12-layer deep test module will begin. The second year deliverable will be a full Linear Collider detector simulation incorporating our HCAL design based on a user-friendly geometry definition language, a decision on the type of photodetector we want to use for the scintillator-based HCAL and the construction of a module for cosmic-ray tests.

FY2005 activities and deliverables

During the third year we will complete the construction of prototype module(s) for cosmic ray and beam tests, collect and analyze data with them. A full specification of the support structure and fiber routing scheme of the HCAL module design will follow. This will have to be done keeping in view the evolving designs of the other subsystems of the detector so that interfacing will be a smooth operation. In addition, tooling for automated mechanical assembly will be done. The third year deliverable will be a Technical Design Report.

Existing Infrastructure/Resources

The funds requested in this proposal will be augmented the following support, totaling more than $1M, from other sources.

NIU

(a) NICADD personnel,
(b) NICADD scintillator extruder line,
(c) Interdisciplinary collaboration with NIU Mech. Engineering Dept. for extruder operation,
(d) NIU machine shops,
(e) Collaboration with Fermilab chemists on extruder dyes,
(f) $45K Advanced Detector Research DOE grant (FY2002-03).

UIC

(a) Labs for studying optical fibers and electronics including board design,
(b) Well-equipped departmental machine and electronics shops,
(c) Computing hardware.

Budget justification

FY2003: Prototype geometry implementation inside GEANT4 and light yield measurements for different scintillator cell configurations and various photo-detectors will involve NICADD staff members (not included in the NIU budget presented here) and 1.5 FTE graduate students (1.0 NIU + 0.5 UIC). The equipment requested are a test stand for the detector elements, photodetectors, and readout electronics. Relatively small volumes of scintillators, absorbers, optical fibers, optical paints, glue, and couplers make up the materials and supplies.

FY2004: Operation of the extrusion line and construction of the test module for will be done with the additional support of an engineering physicist (0.5 FTE, NIU) and a post-doc (0.25 FTE, UIC). Some additional equipment will be required to prepare for cosmic ray tests. The need for new materials and supplies is expected to remain roughly the same as in FY2003.

FY2005: Cosmic ray and beam tests and a full specification of the mechanical design of the HCAL and tooling for automated tower assembly will require an engineering physicist (0.5 FTE, NIU) a post-doc (0.5 FTE, UIC) in FY2005. Support will be needed for an additional 0.5 FTE graduate student (NIU). Much larger amounts of materials and supplies will be needed to build the final test modules. Photodetectors, readout electronics, and a data acquisition system for the tests account for the equipment request.

The travel funds will cover costs of travel by group members to between collaborating institutions for the purpose of this project only.

Three-year budget: see next page

Three-year budget, in then-year K$ (NIU)

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	41.0	42.5	83.5
Graduate Students	18.5	19.5	30.5	68.5
Undergraduate Students	0	0	0	0
Total Salaries and Wages	18.5	60.5	73.0	152.0
Fringe Benefits	0	8.5	9.0	17.5
Total Salaries, Wages and Fringe Benefits	18.5	69.0	82.0	169.5
Equipment	15.0	8.0	50.0	73.0
Travel	1.5	3.0	6.0	10.5
Materials and Supplies	5.0	5.0	35.0	45.0
Other direct costs	0	0	0	0
Total direct costs	40.0	85.0	173.0	298.0
Indirect costs (44% of non-equipment)	11.0	33.9	54.1	99.0
Total direct and indirect costs	51.0	118.9	227.1	397.0

Three-year budget, in then-year K$ (UIC)

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	11.00 (3 months)	22.00 (6 months)	33.00
Graduate Students (6 months)	8.85	8.850	8.85	26.55
Undergraduate Students	0	0	0	0
Total Salaries and Wages	8.85	19.85	30.85	59.55
Fringe Benefits	0	3.15	6.30	9.45
Total Salaries, Wages and Fringe Benefits	8.85	23.00	37.15	69.00
Equipment	0	0	0	0
Travel	0	0	0	0
Materials and Supplies	5.00	6.00	8.00	19.00
Other direct costs	3.05	3.05	3.05	9.16
Total direct costs	16.90	32.05	48.20	97.16
Indirect costs	3.60	7.54	11.74	22.88
Total direct and indirect costs	20.51	39.59	59.94	120.04