Proposal to DOE/NSF for ILC Detector R&D

May 26, 2006

Proposal Name

Design and Prototyping of a Scintillator-based Tail-catcher/Muon Tracker.

Classification (accelerator/detector: subsystem)

Detector: Calorimeter/Muon.

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) [1] group is interested in detector R&D for the proposed International Linear Collider. Specifically, in this proposal, we address the design and construction of a cubic meter sized scintillator-steel prototype which will serve as both a tail-catcher and muon tracker (TCMT). We are scheduled to expose this device to a hadron and muon test beam during the period 2006-2007 [2].

There is a growing consensus that Particle Flow Algorithms (PFAs) [3] offer the most promising path to date of realizing the full physics program of an International Linear Collider

Detector (ILCD). It is in this context that the design of the calorimeter and muon systems for the Linear Collider will have to be optimized. This in turn implies that, any detector that sits behind the hadron calorimeter will have to address the following in a comprehensive manner:

Shower Validation: Current hadronic shower models differ significantly from each other. This puts conclusions on detector performances drawn from PFAs on rather shaky ground. Thus one of the most important goals of the LC test beam program is the validation of hadronic simulation packages. A TCMT which can provide a reasonably detailed picture of the very tail-end of showers will be very helpful in this task.

Energy Leakage: Hermeticity and resolution constraints require that the calorimeters be placed inside the superconducting coil to avoid serious degradation of calorimeter performance. On the other hand cost considerations associated with the size of the coil imply that the total calorimetric system will be relatively thin (4.5-5.5 λ). Thus, additional calorimetric sampling may be required behind the coil to estimate and correct for hadronic leakage.

Muon ID and Reconstruction: Many key physics channels expected to appear at the Linear Collider have muons in their final states. Given the smallness of the expected cross sections, high efficiency in tracking and identification of the muons will be paramount. Since the precise measurement of the muon momentum will be done with the central tracker, a high granularity muon system which can efficiently match hits in it with those in the tracker and calorimeter will be needed.

The TCMT prototype will have a fine and a coarse section distinguished by the thickness of the steel absorber plates. The fine section sitting directly behind the hadron calorimeter and having the same longitudinal segmentation as the HCAL, will provide a detailed measurement of the tail end of the hadron showers which is crucial to the validation of hadronic shower models, since the biggest deviations between models occurs in the tails. The following coarse section will serve as a prototype muon system for any design of a Linear Collider Detector and will facilitate studies of muon tracking and identification within the particle flow reconstruction framework. Additionally, the TCMT will provide valuable insights into hadronic leakage and punch-through from thin calorimeters and the impact of the coil in correcting for this leakage.

This project is a good fit for NIU/NICADD. Our group has participated in the construction and testing of calorimeter and muon systems for the DZero experiment. At present we are involved in research and development of a finely segmented scintillator hadron calorimeter for the Linear Collider Detector (LCD). Additionally NICADD bought and with Fermilab jointly operates an extruder facility where the scintillator for this project has been prototyped and will be produced.

Basic Design Parameters of the TCMT

GEANT4 based simulation studies [4] of muon reconstruction, background rejection and hadronic energy leakage were used to support the geometry and segmentation chosen for the TCMT.

(a) 16 layers, each of active area 1m x 1m,

(b) Extruded scintillator strips 5cm wide and 5mm thick,

(c) Steel absorber with thickness 2cm (8 layers) and 10cm (8layers),

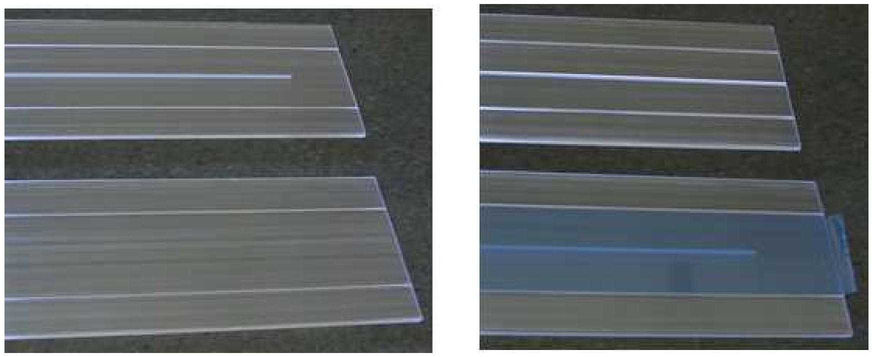

Figure 1: Strip processing stages.

(d) X or Y orientation of strips in alternate layers,

(e) Silicon Photomultiplier (SiPM) photodetection.

Scintillator

The extruded scintillator strips have been produced at the Scintillator Detector Development Lab (SDDL) extruder facility operated jointly by Fermilab and NICADD [5]. The extruder uses polystyrene pellets and PPO and POPOP dopants to produce scintillator with good mechanical tolerances and an average light yield that is 70% that of cast scintillator. The strips produced are 1m long, 10cm wide, 5mm thick and have two co-extruded holes running along the full length of the strip. A 1.2mm outer diameter Kuraray wavelength shifting fiber is inserted in each of the holes. Detailed studies of the strip-fiber system were carried out to converge on this solution [6]. Not only was the performance of this novel fiber-coextruded-hole configuration better than anything that could be obtained for a fiber-machined-groove geometry it is also significantly less labor intensive since no machining, polishing or gluing is involved. Due to the size of the die currently available the strips rolling off the extruder were ten centimeters wide. To have the required five centimeter wide readout segmentation each of the strips has a 0.9 mm wide epoxy filled separation groove in the middle (see Fig. 1). Further R&D on the strip-fiber system optimization will continue in co-ordination with groups pursuing conventional photomultiplier readout [7].

Photodetectors

We propose to use novel solid-state devices like SiPMs [8] or MRS (metal resistive semi-conductor) for photodetection. For the purposes of this discussion we will refer to these devices collectively as SiPMs. SiPMs are room temperature photo-diodes operating in the limited Geiger-mode with performances very similar to conventional photo-multiplier tubes i.e. they have high gain ($\approx 10^6$) but relatively modest detection efficiency (quantum x geometric efficiency $\approx$ 15%). Not only is the signal obtained for minimum ionizing particles with these devices large ($>$ 10 photo-electrons for our 5mm thick extruded scintillator strips), their small size (1mm x 1mm) and low bias voltage ($\approx$ 50 V) implies that they can be mounted in or very close to the scintillator strips. Consequently little light is lost since it does not travel large distances in the fiber to the photodetector, the need for interfacing to a clear fiber (connectors, splicing etc.) is obliterated and the quantity of fiber required is significantly reduced. Even more importantly, the generation of electrical signals, inside the detector, at or close to the scintillator surface eliminates the problems associated with handling and routing of a large

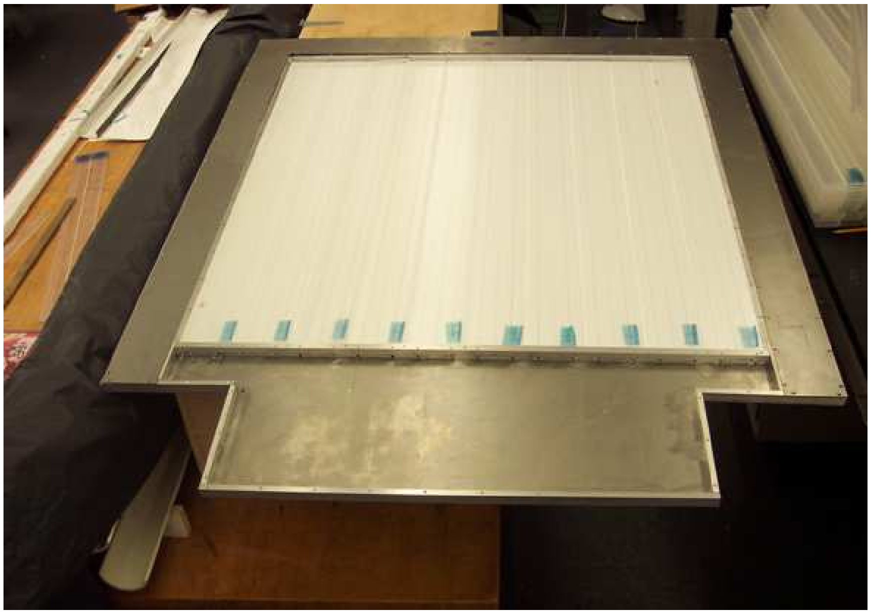

Figure 2: Mechanical prototype of cassette.

number of fragile fibers. Our detailed investigations [9][10] into the characteristics of these photodetectors confirms their suitability for a dual purpose muon detector. While SiPMs are our preferred solution for the TCMT prototype we will remain active in evaluating the potential of new photodetector developments (for example [11]) as and when they become available.

Cassette

The scintillator strips and their associated photodetectors in each layer are enclosed in a light tight sheath which we refer to here as a cassette (see Fig. 2). The top and bottom skins of the cassette are formed by 1mm thick steel with aluminum bars providing the skeletal rigidity. The aluminum bars also divide the cassette into distinct regions for scintillator, connectors, cable routing and LED drivers such that they can be independently accessed for installation, maintenance or repairs.

Electronics

One of the practical advantages of using the SiPMs is that we can use a significant fraction of the electronics being developed for the scintillator-based hadron calorimeter, another project with which we are actively involved. Thus we will be using the front-end and DAQ boards already developed for the HCal. However the different structure and channel count of the device will necessarily lead to a different architecture of the electronics. This has necessitated the development of an adaptor board which connects to the HCal baseboard. The baseboard in turn carries the preamplifier cards and communicates with the data acquisition system. The design and fabrication of these boards has been carried out in collaboration with DESY and Fermilab electrical engineering departments. The photodetectors inside the cassette are connected to the adaptor board with 50 ohm multi-coax cables with connectors at both the detector and board ends. A schematic of the full readout chain can be seen in Fig. 3.

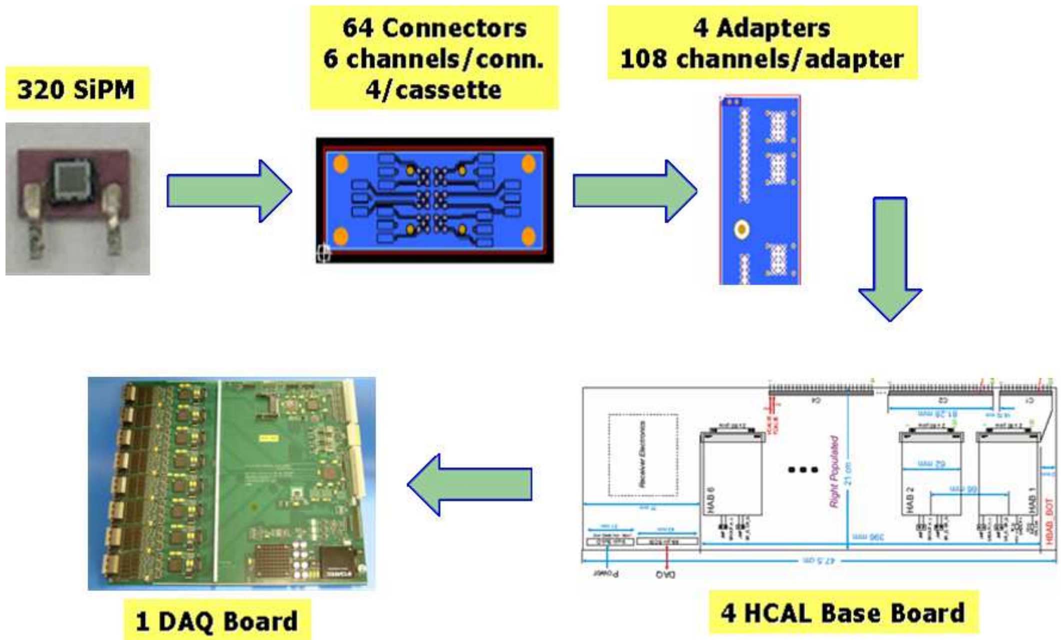

Figure 3: Electronics architecture for the TCMT.

Test Beam

The TCMT will be exposed to a test beam first at CERN (August-October 2006) and then at Fermilab in 2007. This will be done as part of the CALICE test beam program which is an ambitious multi-year program focussed on testing the various calorimeter technologies and collecting data with unprecedented granularity to test and validate hadronic shower Monte Carlo's. To achieve these goals, electron, hadron and muon beam over a wide range of energies and incident angles will be taken. In preparation for these tests we have, in the meantime, tested a fully instrumented TCMT cassette in an electron beam at DESY and a hadron test beam at Fermilab (see Figs. 4 and 5). These runs have been instrumental in testing the full the electronics and data acquisition chain and in verifying the performances (light yield, uniformity, cross talk etc.) expected of the TCMT detector.

Stack

The TCMT cassettes will sit in an absorber stack composed of steel absorber plates welded to a frame which also doubles as a lifting fixture. This structure will be then placed on top of a table capable of forward-backward and left-right motion with the help of Hillman rollers. The design of the absorber stack and table has been developed in collaboration with Fermilab mechanical engineering. The stack will have the capability of being rotated by 90^o for taking normally incident cosmics during beam downtime. The electronics crates will be attached to the stack to keep the cable lengths to a minimum. The construction of the stack has already been completed (see Fig. 6) and the that of the motion frame has begun. For the purposes of the stack flame cut and welded steel absorber plates from the Fermilab scrapyard were used.

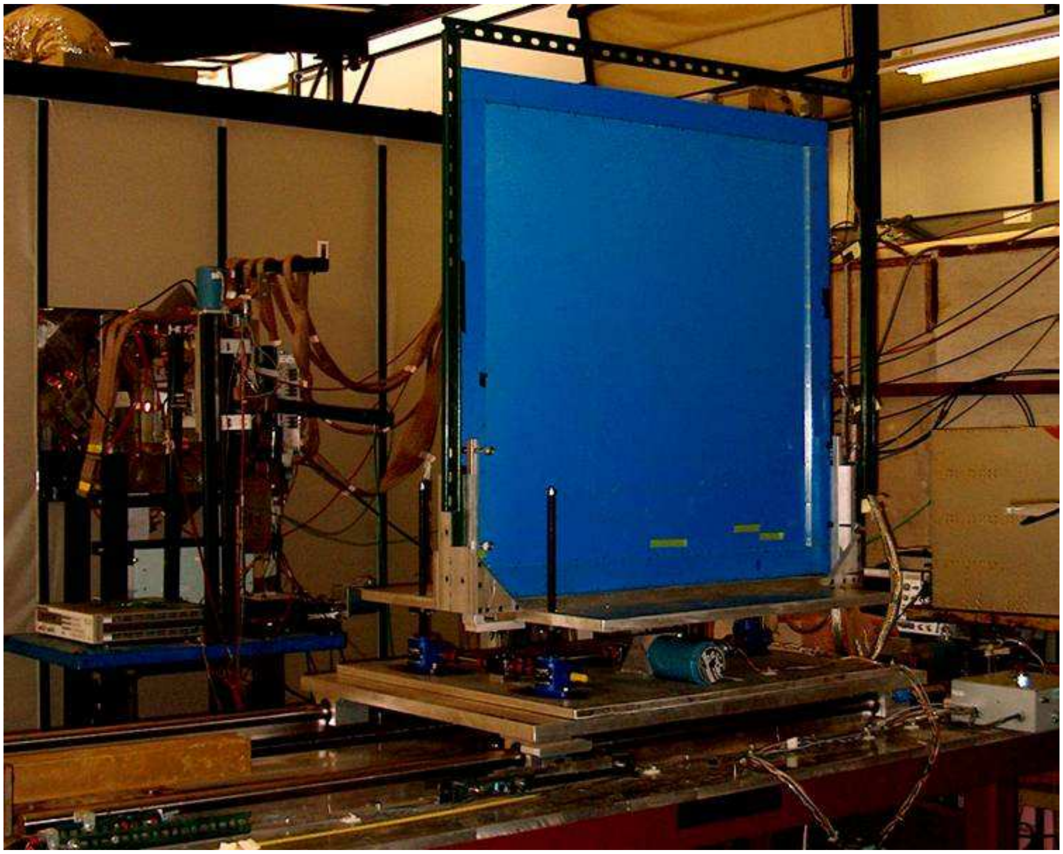

Figure 4: TCMT cassette in the Fermi test beam area

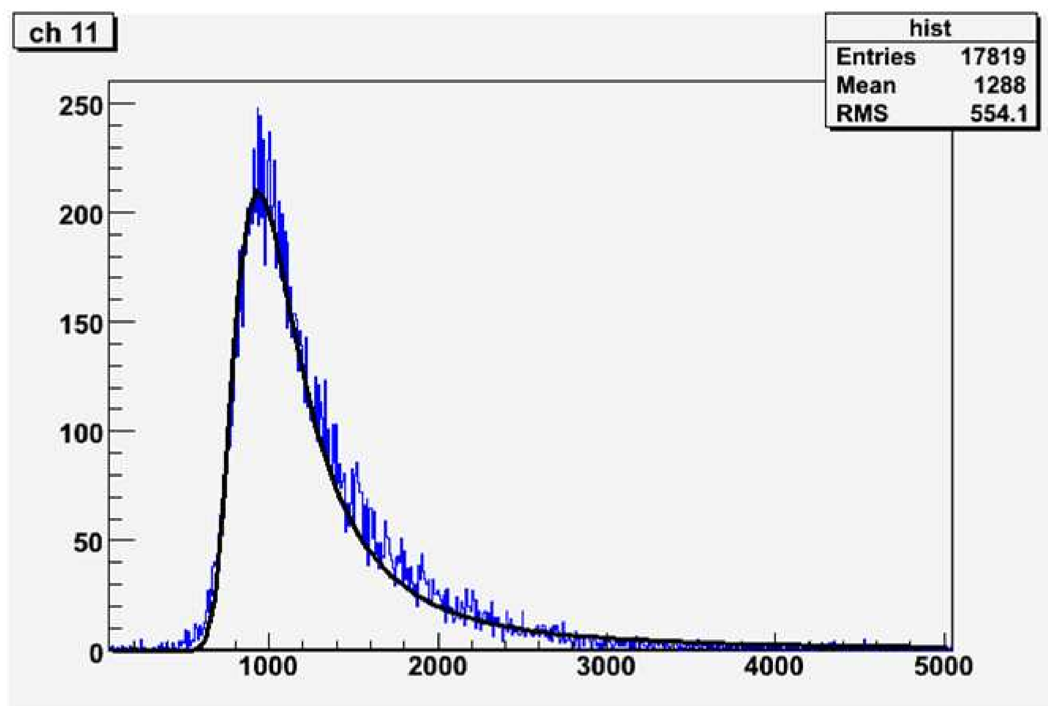

Figure 5: Pulse height distribution from a 120 GeV proton beam

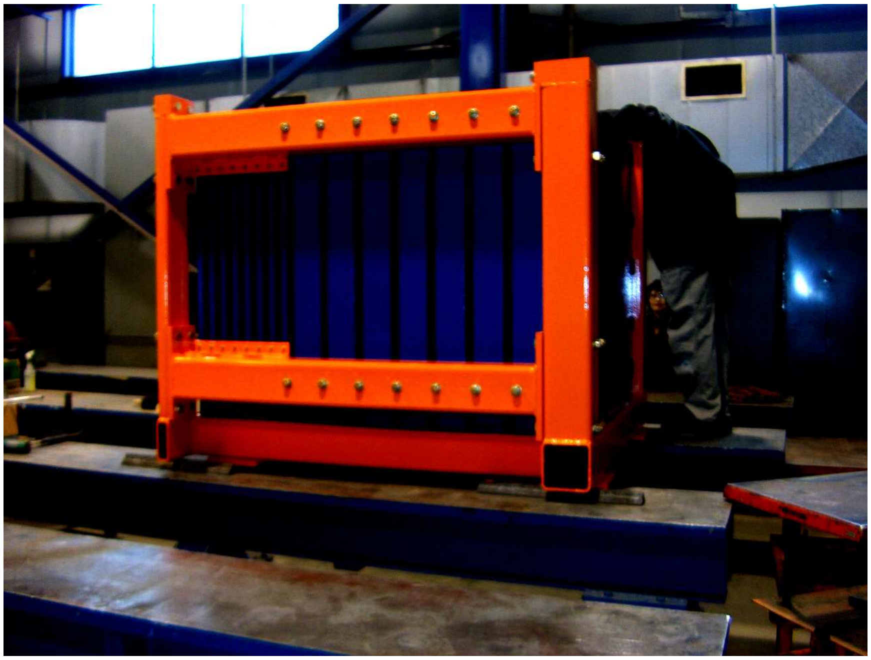

Figure 6: TCMT absorber stack structure.

FY2006 activities and deliverables

(a) Production and installation of LED calibration system for all the channels,
(b) Characterization of all SiPM's used in the TCMT,
(c) Assembly and commissioning of all the cassettes of the TCMT,
(d) Exposure of fully functional TCMT to a hadron test beam,
(e) Development of reconstruction and analysis software.

The 2006 year deliverable is a fully assembled and functional TCMT taking data in a muon and hadron test beam.

Existing Infrastructure/Resources
The funds requested in this proposal will be augmented by the following support, totaling more than $1M, from other sources:

(a) NICADD personnel,
(b) Fermi-NICADD scintillator extruder line,
(c) NIU machine shops,

Budget Justification

FY2006: Characterization and calibration of the photodetectors, assembly and commissioning of the TCMT modules, operation in the test beam and development of the reconstruction/analysis software will be done with the support of three post-doctoral associates (3.0 FTE).

The budget takes into account the NIU mandated fringe (52%) and indirect cost (45%) rates.

Three-year budget, in then-year K$

Item	FY2005	FY2006	FY2007	Total
Other Professionals	-	165.0	-	165.0
Graduate Students	-	0.0	-	0.0
Undergraduate Students	-	0.0	-	0.0
Total Salaries and Wages	-	165.0	-	165.0
Fringe Benefits	-	86.0	-	86.0
Total Salaries, Wages and Fringe Benefits	-	251.0	-	251.0
Equipment	-	0.0	-	0.0
Travel	-	0.0	-	0.0
Materials and Supplies	-	0.0	-	0.0
Total direct costs	-	251.0	-	251.0
Indirect costs	-	113.0	-	113.0
Total direct and indirect costs	-	364.0	-	364.0

Broader Impact

Student involvement in research is a critical aspect of the proposed research program. Students can make significant contributions in detector R&D, construction, testing, software development, data collection and analysis. They are, in the process, exposed to cutting-edge research techniques and technology which they can utilize in industry or related fields.

The scintillator R&D involves collaborative work with chemists and mechanical engineers. As an example, faculty and students from NIU engineering department have been involved in extruder die design and operation. Improvements in this technology are applicable to many fields which need to detect particles including other sciences and medicine.

NICADD/NIU runs a vigorous outreach program which visits schools and civic organizations in the northern Illinois region with the purpose of increasing enthusiasm and public awareness for science. The presentations emphasize energy and light but also address how scientists make and interpret observations. Over 10,000 students per year attend these presentations. NIU/NICADD faculty and staff volunteer for the Fermilab 'Ask-a-Scientist' program.

References

[1] http://nicadd.niu.edu

[2] "Memorandum of Understanding for the 2005-2008 Meson Test Beam Program", T946, Fermilab

[3] D. Buskulic et. al, NIM A360:481-506, 1995 and P. Gay, "Energy flow with high-granularity calorimeters", Linear Collider Workshop, Fermilab, Oct. 2000.

[4] V. Zutshi et. al, Talks presented in 2004 at the ALCPG (January 7-10,SLAC and July 28-31, Victoria), LCWS (19-23 April, Paris), ECFA (September 1-4, Durham) and CALICE (June 28-29, CERN and December 7-8, DESY) meetings.

[5] A. Dyshkant et. al,"FNAL-NICADD Extruded Scintillator", FERMILAB-CONF-04-216-E.

[6] A. Dyshkant et. al,"About NICADD Extruded Scintillating Strips", FERMILAB-PUB-05-010-E.

[7] H. Fisk et. al, "Scintillator Based Muon System R&D 3-Year Proposal".

[8] B. Dolgoshein et. al, NIM A504:48-52, 2003.

[9] "Investigation of a Solid-State Photodetector", A. Dyshkant et. al, submitted to NIM A.

[10] "The MRS Photodiode in a Strong Magnetic Field", A. Dyshkant et. al, FERMILAB-TM-2284

[11] R. Wilson et. al, "Development of Geiger-mode Avalanche Photodiodes".