

Proposal to DOE/NSF for ILC Detector R&D

February 22, 2005

Proposal Name

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

Classification (accelerator/detector: subsystem)

Detector: 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 muon system R&D for the proposed International Linear Collider. Specifically we propose to design and build 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 muon and hadron test beam during the period 2005-2007 [2]. The end goal of this research project will be the development of a robust design with reliable cost and performance estimates for a scintillator-based muon system suited for an e^+e^- collider.

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 muon system for the Linear Collider will have to be optimized. This in turn implies that, any prototype of the muon system will have to address the following in a comprehensive manner:

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.

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.

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.

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 a scintillator-based muon system 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,

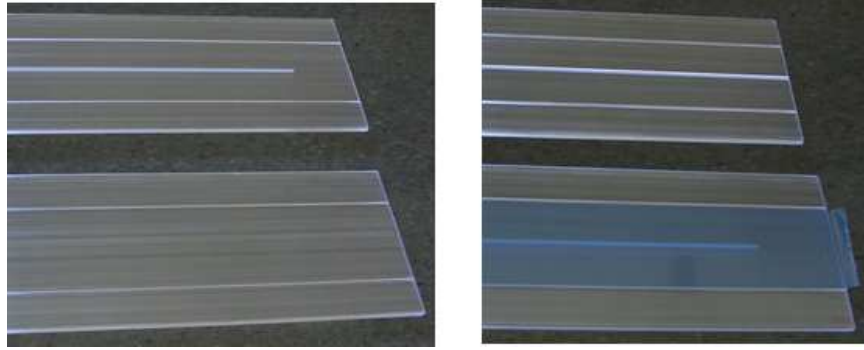


Figure 1: Strip processing stages.

- (c) Steel absorber with thickness 2cm (8 layers) and 10cm (8layers),
- (d) X or Y orientation of strips in alternate layers,
- (e) Silicon Photomultiplier (SiPM) photodetection.

Scintillator

The extruded scintillator strips will be 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 will be 1m long, 10cm wide, 5mm thick and will have two co-extruded holes running along the full length of the strip. A 1.2mm outer diameter Kuraray wavelength shifting fiber will be 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 will be ten centimeters wide. To have the required five centimeter wide readout segmentation each of the strips will have a 0.9mm 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 semiconductor) 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 (≈ 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

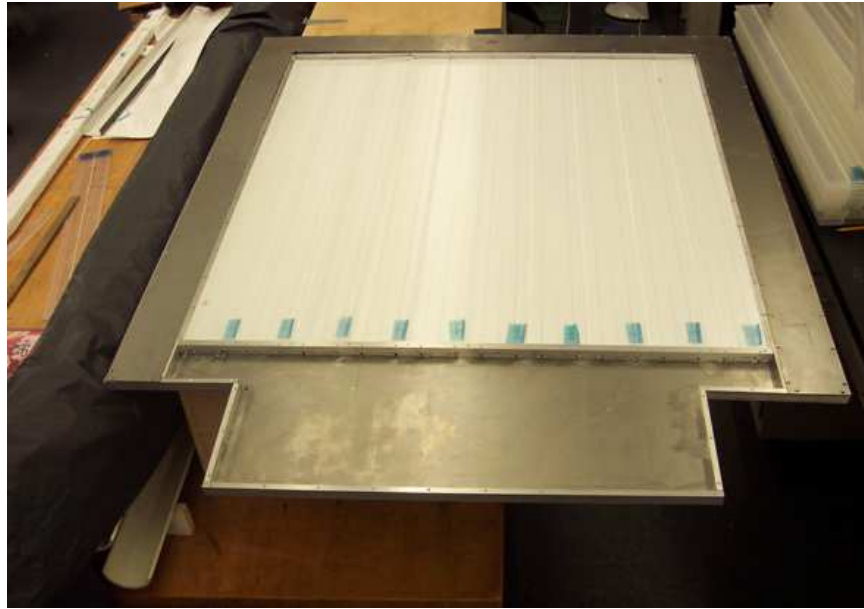


Figure 2: Mechanical prototype of cassette.

scintillator surface eliminates the problems associated with handling and routing of a large 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 will be 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 some 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 preamplifier 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 will necessitate the custom development of TCMT baseboards which will carry the preamplifier boards and communicate with the DAQ ones (see Fig. 3). We will carry out the design and fabrication of these boards in collaboration with DESY and Fermilab electrical engineering departments. The photodetectors inside the cassette will be connected to this baseboard with 50 ohm multi-coax cables with connectors at both the detector and board ends.

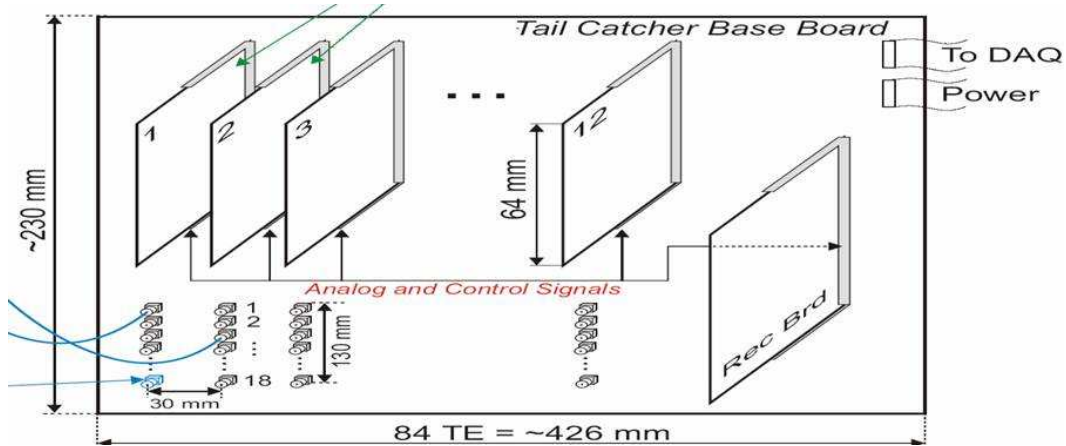


Figure 3: Electronics architecture for the TCMT.

Stack

The design of the absorber stack and table is being developed in collaboration with Fermilab mechanical engineering (see Fig. 4). The design foresees the welding of the steel absorber plates 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 stack will have the capability of being rotated by 90° 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 drawings for the absorber stack and table are available and construction can commence soon. We have already located (Fermilab scrapyards) and reserved most of the absorber plates required for the TCMT. Some processing in the shape of flame cutting, welding etc. will however be required. Only a couple of plates will have to be bought outright.

FY2005 activities and deliverables

- (a) Production and quality control of all strips required for the TCMT,
- (b) Initiate assembly of the first eight TCMT cassettes,
- (c) Fabrication and testing of TCMT baseboards,
- (d) Construction of absorber stack and movable table.

The first year deliverable is a partially commissioned TCMT.

FY2006 activities and deliverables

- (a) Production and installation of LED calibration system for all the channels,
- (b) Assembly and commissioning of the remaining cassettes of the TCMT,
- (c) Integration of TCMT electronics with the DAQ system,
- (d) Exposure of fully functional TCMT to a hadron test beam.

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

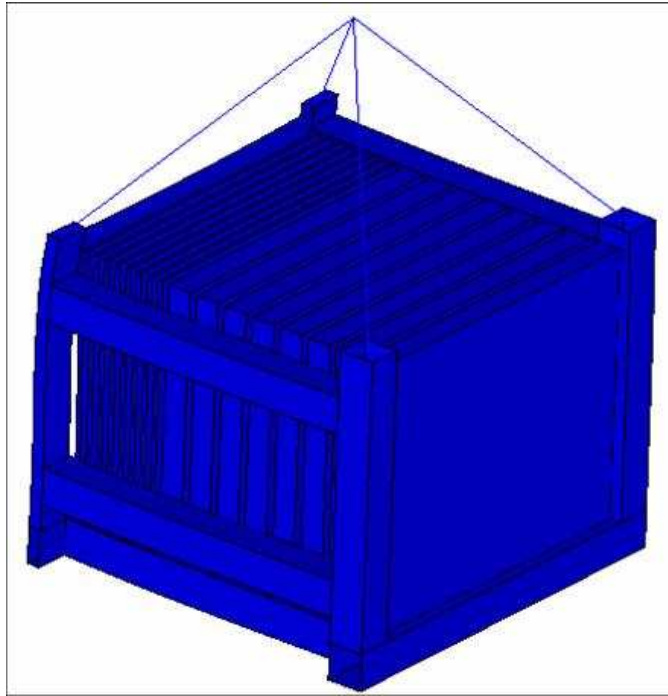


Figure 4: TCMT absorber stack structure.

FY2007 activities and deliverables

- (a) Finish analysis of the collected data,
- (b) Enhancements/modifications as dictated by the test beam experience,
- (c) Conceptual and mechanical design of the full muon system for the LCD.

The third year deliverable will be a Technical Design Report based on our test-beam experience.

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

FY2005: Production and quality control of strips, testing of the multi-channel electronics and assembly of the first 8 cassettes will involve NICADD staff members (not included in the NIU budget presented here) and a graduate student (1.0 FTE). Undergraduate students will participate in the research during the summer months. The equipment costs relate to electronics (TCMT base-board fabrication, photodetectors) and absorber stack assembly

(flame cutting, riveting, welding). Fiber, glue, paint, absorber plates and machined parts for the cassette make up the materials and supplies.

FY2006: Continued assembly and commissioning of the TCMT modules, operation of the test beam, calibration and analysis of data will be done with the additional support of a post-doctoral associate (0.5 FTE). Support for 1.0 FTE graduate students will be maintained. Summer support for undergraduates will be continued. The equipment costs relate to the fabrication of the LED driver boards. The costs incurred in maintenance of the detector are reflected in the materials and supplies.

FY2007: Full conceptual and mechanical design of the muon system for the LCD will require the additional support of a mechanical engineer (0.3 FTE). Continued operation in the test beam, analysis of data and construction of one or two new cassettes to further optimize the design with lessons learnt from operation in the beam will require continued support of a post-doctoral associate (0.5 FTE) and a graduate student (1.0 FTE).

The travel funds (2005-2007) will cover costs of travel by group members to collaborating institutions and for attending conferences/meetings for the purposes of this project only.

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	0	21.0	50.0	71.0
Graduate Students	21.0	21.5	22.0	64.5
Undergraduate Students	4.0	4.5	5.0	13.5
Total Salaries and Wages	25.0	47.0	77.0	149.0
Fringe Benefits	0.3	11.5	26.9	38.7
Total Salaries, Wages and Fringe Benefits	25.3	58.5	103.9	187.7
Equipment	25.0	10.0	5.0	40.0
Travel	3.0	3.5	4.0	10.5
Materials and Supplies	15.0	5.0	3.0	23.0
Total direct costs	68.3	77.0	115.9	261.2
Indirect costs	19.5	30.1	49.9	99.5
Total direct and indirect costs	87.8	107.1	165.8	360.7

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>
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