7. Muon System

Introduction to Muon System R&D

The identification and precise measurement of muons is critical to the physics program of the linear collider. The muons produced from decays of W and Z bosons and from B-hadrons are key parts of the signatures for the Higgs and hypothesized new particles. Muons may also be produced directly from decays of new particles such as supersymmetric scalar muons.

The linear collider detector design includes a sub-system that will identify muons, as distinct from hadrons, primarily by their penetration through the iron flux return. This muon system should operate over the widest possible momentum range with high efficiency for muons and low contamination from pions. In addition, it may be used to measure the leakage of hadronic showers from the calorimeter and hence improve the energy resolution of hadronic jets.

Because the muon system is the largest one in the LC detector, it is important that a realizable design, verified by prototyping, is established early, so that an optimal detector is delivered on time and within budget. The muon system must maintain stable operation with high reliability since the detectors are largely inaccessible. These are challenging requirements for operation over a span of perhaps 20 years.

The proposals here advocate a muon detector technology based on alternating layers of solid scintillator and steel. Solid scintillator is a robust and well-established detector medium that can be read out with wavelength shifting (WLS) optical fibers. However, the performance of such a system in terms of efficiency and mis-identification probability can only be established in beam tests of prototype detectors. Furthermore, the improvement in hadronic jet resolution by measuring the shower leakage into the muon detector can only be established by such beam tests.

These proposals also address the optimization of the detailed design of the scintillator geometry and fiber readout. Issues considered are the reflective coating of the scintillator, mechanical scheme for embedding the WLS fiber and the fusion of WLS to clear fiber. Three different technologies for light detection are explored in these proposals. The baseline light detector is the well established multi-anode photomultiplier tube. Emerging alternative technologies are the silicon photomultiplier and the Geiger-mode avalanche photodiode. A coordinated approach is proposed for front-end electronics and data acquisition systems.   Readout is appropriate for each light detector technology, but with, as much as possible, a common architecture that takes advantage of designs for existing experiments as well as other linear collider R&D projects.

The physics performance of the muon system will ultimately rest on the foundation laid by the careful studies of prototypes, as proposed here.

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(renewal)

Muon System

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Institution(s)
UC Davis
Fermilab
Northern Illinois
Notre Dame
Rice
Wayne State
UT Austin

Funds awarded (DOE)
FY04 award: 11,000

New funds requested
FY05 request: 162,067
FY06 request: 165,547
FY07 request: 160,937

Scintillator Based Muon System R&D: 3-Year Proposal

Subsystem: Muon and Particle ID

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Project Overview

We propose a three year research program to design and test a prototype muon detector for the linear collider detector. The identification and precise measurement of muons is critical to the physics program of the linear collider. 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.

The linear collider detector design includes a muon system that will identify muons, as distinct from hadrons, primarily by their penetration through the iron flux return. The muon system should operate over the widest possible momentum range with high efficiency for muons and low contamination from pions. Because the proposed calorimeters are thin in terms of interaction lengths, hadronic showers will leak into the muon steel. With an adequately designed and proven muon system, it may be possible to measure the leakage and hence improve the energy resolution of hadronic jets. The muon system must maintain stable operation with high reliability since the detectors are largely inaccessible. These are challenging requirements for operation over a span of perhaps 20 years.

A promising design for the muon system is suggested by the successful operation of scintillator and iron calorimeters used in neutrino experiments, such as CDHS, to measure the energy of jets. For example, with 10 cm of Fe between counters, hadronic resolutions of ~0.8/sqrt(E) are typically achieved. A scintillator strip calorimeter based on MINOS style detectors may provide the resolution required for a useful measurement of shower leakage.

For the muon system we propose for the linear collider, the general layout of the barrel muon detectors consists of planes of scintillator strips inserted in gaps between 10 cm thick Fe plates that make up octagonal barrels concentric with the e^+e^- beamline. The scintillator strips, ~5 cm wide and 1 cm thick, contain one or more ~1 mm diameter wavelength shifting (WLS) fibers. Light produced by a charged particle is transported via clear fibers to multi-anode photomultipliers located outside the Fe yoke where it is converted to an electronic signal. There are 15 planes of scintillator with alternating strips oriented at $\pm 45^o$ with respect to a projection of the beam line onto the planes.

We propose to optimize the design of a scintillator-based muon system with a coordinated program of simulation studies and performance measurements of prototype detectors. The simulation studies will include development of software that is integrated into the ILC framework. The software will support different geometry descriptions, parametric variation of geometries and will have a user friendly interface. We will develop techniques to produce the components of a prototype system: iron absorber plates and mechanical support, extruded scintillator strips embedded with wavelength shifting optical fibers, splicing and routing of fibers and their interface to multi-anode photomultiplier tubes and readout electronics. In the first year, several prototype planes and readout will be produced. In the second year, the prototype system (including absorber) will be tested with cosmic rays. In the final year, a system of 7 or more planes and absorber will be operated in a test beam. Because the muon system is the largest one in the ILC detector, it is very important that a realizable design, verified by prototyping, is established early, so that a well-working detector is delivered on time and within budget.

The close collaboration between the institutions requesting funding and Fermilab is described in detail in this proposal. Other collaborating institutions are also involved.

Northern Illinois University will continue to work with us on source testing of scintillator, simulation software and software infrastructure. We will closely follow NIU's independent work on scintillator extrusion and coating and the application of silicon photomultipliers for fiber readout. The UCD group will work with Fermilab to develop a common solution for front-end electronics and data acquisition.

Indiana University will help us test the 1m X 0.5m prototype module at Fermilab. The University of Texas at Austin will continue to provide us consultation about MAPMT's based on their experience with MINOS.

Colorado State University is developing geiger mode avalanche photodiodes and will test their devices with our prototype modules. In addition, the CSU group will participate in the overall muon system development.

Rice University is not currently active, but intends to work on this project in the future.

We also keep abreast of the work led by of Marcello Piccolo of Frascati on resistive plate chambers and muon simulation which is complementary to this work.

Broader Impact

The work outlined in this proposal, if supported, will have an educational impact at several levels. Many of the projects described will be carried out at the universities, and thus are good matches for undergraduate and graduate student participation. Over the past year, both a sophomore physics major and a first year graduate student have helped with the fiber R&D at the University of Notre Dame. So far, one undergraduate and one graduate student each at WSU and two graduate students and three undergraduates at UCD have participated in this effort at various times. Research and development projects like this muon detector proposal are particularly beneficial for student training, since most of the U.S. particle physics program is currently focused on either data analysis of existing experiments, or the construction and commissioning of the LHC experiments at CERN.

In terms of even broader educational outreach, each of the lead institutions on this proposal supports a QuarkNet center, and Prof. Wayne is currently one of four co-principal investigators of the national QuarkNet program. These centers are firmly established as communities of scientists and educators that engage in a wide range of activities. The QuarkNet centers offer direct research involvement to high school students and teachers, and often provide a "hands-on" experience for people from traditionally underrepresented groups. A high school teacher has been very active in this research at WSU under the QuarkNet program. Several of the projects making up this proposal are ideally suited for student/teacher participation. The high school teachers and students affiliated with Notre Dame and WSU will certainly be involved in the fabrication of muon detector planes during the upcoming summer.

Some of the university groups also participate in NSF-sponsored REU programs, and we expect that at least a few undergraduates will work on the muon system for their research projects this summer. The REU program at UCD is in its second year. We expect to recruit students to work on the muon test-stand during the summer.

While the focus of this effort is towards research in experimental particle physics, the results of this type of R&D often find application in other areas. Scintillator based detectors are used in a wide range of areas. The detection and timing of very small light levels is of interest to many fields, both in basic research and in the private sector. There has been a great deal of interest recently in the potential use of particle physics detection techniques to enhance our national security. Of particular interest is whether very large detector arrays, like our muon system, can be used as efficient, cost-effective tools to monitor the safety of large items transported into the country (e.g. containers brought in by ship)

Results of Prior Research

During the past year, a collaboration of Fermilab, UC Davis, NIU, Notre Dame and Wayne State has worked to understand the scintillator-based ILC Muon detector hardware issues and to pursue those issues with the priority and manpower that is possible with the limited funding for the universities presently involved. Fermilab, which requests no funds from this proposal, has separate funding for ILC detector work: $45K in material costs during FY04 and approximately an equivalent amount in technician and engineering manpower support. We expect continued support from Fermilab.

The University of Notre Dame group, led by Mitch Wayne, has focused on the mechanical design and construction of the muon detector planes. As described above, the muon detector is comprised of large planes of scintillator strips, each with a green waveshifting fiber embedded along the length of the strip. The waveshifting fibers are in turn connected to identical clear fibers that pipe the light to the photodetectors, in our case multi-anode photomultiplier tubes (MAPMTs). A key element of our design is that each waveshifter-clear fiber connection is done individually with a thermal splice. This simplifies the mechanical design of the detector planes and the routing of the clear fibers to the PMTs. Thermal splicing also eliminates the need for complicated connectors.

The WSU group consists of P. Karchin (faculty), A. Gutierrez (research engineer) and R. Brockhaus (high school teacher). A. Gutierrez has 9 years experience with electronics and computers in HEP, including work on CDF, ILC R&D, HERA-B, CLEO and B-TeV. R. Brockhaus is a science teacher at Mumford High School in Detroit and works with WSU as part of the QuarkNet program. In previous years, a graduate student and an undergraduate student have worked on the ILC muon project. The WSU group has concentrated on the overall coordination of the scintillator-based muon collaboration (P. Karchin is co-coordinator with H. E. Fisk) and the application of MAPMTs as the optical detectors.

The relatively low per-channel cost of the Hamamatsu MAPMT provides a cost-effective readout that allows for reasonable granularity of the scintillator elements. Furthermore, MAPMTs are reliably produced by a commercial manufacturer and are well established in running HEP experiments, such as MINOS (near and far detectors) and CDF (end-plug calorimeters and central pre-shower detectors). Thus, the MAPMT is an excellent candidate for a full-scale ILC muon detector and also serves as a well-understood detector to measure the response of prototype scintillator/fiber detector elements.

The UCD group, led by Mani Tripathi, has focused on the readout electronics aspect of the project. The electronics shop at UCD has been developing readout electronics for HEP for the last

3 decades. Juan Lizarazo, a graduate student in both physics and electrical engineering, has worked on several HEP projects including CACTUS and D0, where he was a visiting engineer for two years. During FY03, the UCD group developed large bandwidth amplifiers for 16-channel MAPMTs. During FY04, a custom readout system using commercial TDCs and FPGAs was built by borrowing some components from PREP at Fermilab. Several undergraduate students have worked on this project over the last two years. Below we describe, in greater detail, the progress made by these groups.

Fermilab Most of Fermilab's development support has been in the area of scintillator and fiber procurement and tests, fiber splicing via thermal fusion, a PMT test setup at Fermilab in parallel with a similar setup at WSU to measure MAPMT properties, and the beginning of an involvement of Fermilab engineering in the evaluation of a scintillator readout scheme based on electronics originally designed for D0 scintillator fiber readout that has been prototyped for a possible future neutrino experiment.

In December 2003 Fermilab took delivery of 756 strips of 3.5m X 4cm X 1cm extruded (MINOS type) scintillator and 4.5/3 km of clear/WLS 1.2mm diameter fiber. During the manufacture of the extruded scintillator at Itasca Plastics in St. Charles, IL we had them provide a 1m long strip hourly so we could monitor the quality of the scintillator. We used 15 of these strips to do WLS fiber-gluing tests using various adhesives. Clear RTV-615C, Epon 815 and BC600 were each tested. Measurements by NIU personnel with a Cs^{137} source show that all three performed approximately equally well.[1]

The delivered scintillator and fiber is sufficient to build 8 single-layer planes of muon detectors 5m X 2.5m. The purpose of the R&D with planes was to establish a knowledge basis to insure that all technical, cost and physics implications were well enough understood to build an ILC muon system that would not only detect, track and identify muons, but that it could also be used to measure hadronic energy from late showering hadrons, i.e. as a backup calorimeter. While a size of 5m X 2.5m is sufficient to provide full coverage in the outer gaps of an octagonal Fe return-yoke 10m in length, by using 4 such planes per gap, test beam considerations, especially space limitations, have convinced us to begin with planes that are 2.5m X 1.25m. We call these planes the ¼ (sized) planes. In preparation for building the first four ¼ planes, a pre-prototype module 1m X ½ m was built at Notre Dame. It is presently under test at Fermilab. The focus of the pre-prototype was scintillator layout, gluing, fiber splicing, fiber routing, fiber bending, etc.

Instead of using fiber connectors to make the WLS-Clear connection we have chosen to thermally fuse clear-to-WLS fiber as discussed below in the Notre Dame section of this document. The splicing was done in Lab 7 at Fermilab where the method was first established for the CDF end-plug calorimeter.

In collaboration with WSU, a testing area was set up in Lab 6 at Fermilab for testing MAPMTs, scintillator and electronics. The setup is essentially identical with the one at WSU that is described below for measuring the gain of MAPMTs.

[1] see www.linearcollider.ca:8080/lc/vic04/abstracts/detector/muonpid/gene_fisk_new.ppt

In November ‘04 during discussions about readout electronics we learned that the Fermilab ASIC's project group has developed a 16 channel board, for a possible future neutrino experiment, based on a chip developed for D0 and the SVX chip, as discussed in the UC Davis section of this document that may be well suited to our application. Collaborative engineering on this board, with contributions from UCD and Fermilab, is now underway.

University of Notre Dame The UND group has worked in conjunction with Lab 7 at Fermilab to test the effectiveness of thermally splicing fibers together. In our first test, a total of 64 eight-meter long pieces of clear fiber were measured for light throughput before and after splicing. In our system, green LED light is injected into the near end of the fiber while the light exiting the far end is measured with a photodiode. The photodiode response is digitized and read into a computer. Our system utilizes a bank of 8 LEDs and 8 photodiodes, all intercalibrated to normalize their response. Most of the 64 fibers were then cut in half, polished and spliced back together at Fermilab. A small number were left whole to monitor any changes in our measurement system. When the spliced fibers were remeasured, the results were not satisfactory – there was a large spread in the light transmission from piece to piece. However, several splices did show good transmission of 90% or above. After some minor adjustments to the procedure, a second, smaller test was performed with acceptable results.[1] We are now confident that large numbers of fiber splices can be made with repeatable results.

One complication in fiber splicing is that both the waveshifting and clear fibers are stored on large, circular spools. This creates a residual curvature in the fiber, making it more difficult to precisely align the two faces of the fibers being spliced. Our group has developed a technique to straighten out the ends of the fibers using gentle heating. Concerned about potential damage to the fibers from the heating, we tested the light throughput of several pieces of both clear and waveshifting fiber before and after heating. To our surprise, the light throughput increased by about 10% for each fiber end that was straightened. This is an interesting and encouraging result that needs further study.

To help demonstrate the mechanical design and work through many of the fabrication steps, the Notre Dame group recently constructed a “pre-prototype” detector plane with scrap materials. Figure 1 is a photograph of the readout end of the module showing the routing of the clear fibers to the cookie mounted on the support frame. Also visible at lower right is the flat optical panel used for calibration. The cookies and calibration scheme are discussed below.

Figure 1: A photograph of the pre-prototype module.

Wayne State University The WSU group has developed a scheme to calibrate the single photo-electron response of a MAPMT using fast pulses from a light-emitting diode (LED). We used a 16-channel Hamamatsu H8711 MAPMT.[2] A clear fiber transmits light from an LED and is aligned to the photo-cathode face by an aluminum guide with an array of holes corresponding to the cathode pixel grid. A mass termination connector provides a transition from the anode pins to a miniature (RG174) coaxial cable. The single-shot digital oscilloscope trace in Figure 2 shows the voltage pulse driving the LED and the response from a single anode channel, for a high voltage bias of 850 volts. The anode response for this single primary photo-electron is seen to be narrow (width at half max is about 4 ns) with a peak amplitude of about 30 mV. Electronic noise is visible with peak-to-peak amplitude of about 8 mV. Tests with a high quality Faraday cage show that the noise can be reduced with improved electromagnetic shielding.

Charge spectra from anode pulses, initiated by the LED, were recorded with a LeCroy QVT. Spectra for three different high voltage bias values are shown in Figure 3. The spectra were analyzed under the assumption of Poisson statistics for the number of primary photoelectrons produced during a timing gate centered on the LED pulse. For 825 volts bias, the charges corresponding to 1 and 2 photoelectrons are indicated in the figure. The gain is measured to be about 23 x 10^6, consistent with data provided by Hamamatsu.

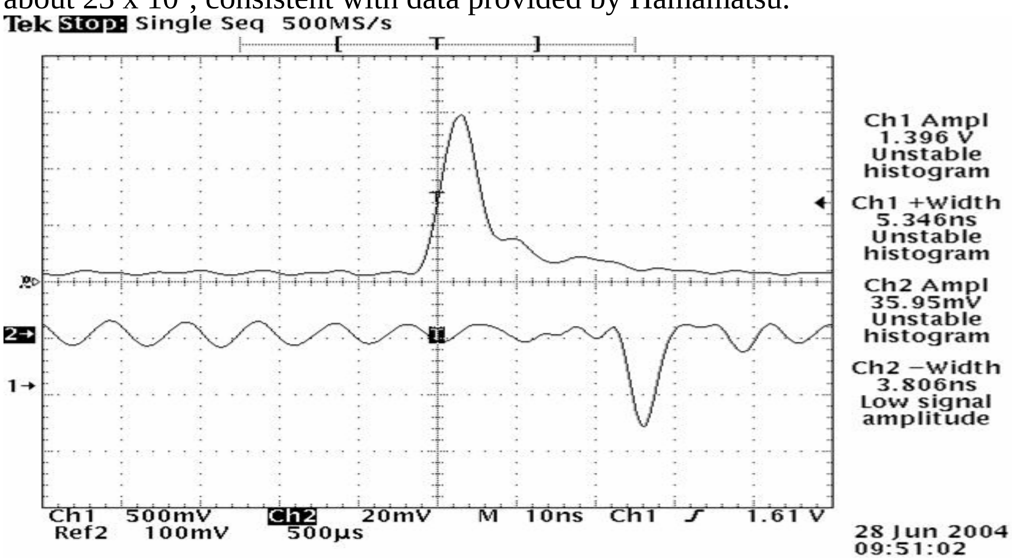

Figure 2: Single-shot digital oscilloscope trace for LED voltage pulse (top) and single anode response (bottom).

The technique presented here, using LED pulsing, can be used to calibrate the single photoelectron response. We plan to extend this technique for an in-situ calibration scheme, injecting LED light into the scintillator strips.

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[2] For further details and a photograph of the MAPMT and associated components see the DPF 2004 paper by P. Karchin at http://physics.ucr.edu/~billdbrk/papers/paper214.ps and the talk by P. Karchin at the 2004 Victoria LC conference at http://www.linearcollider.ca:8080/lc/vic04/abstracts/detector/muonpid/paul_karchin_v2.ppt

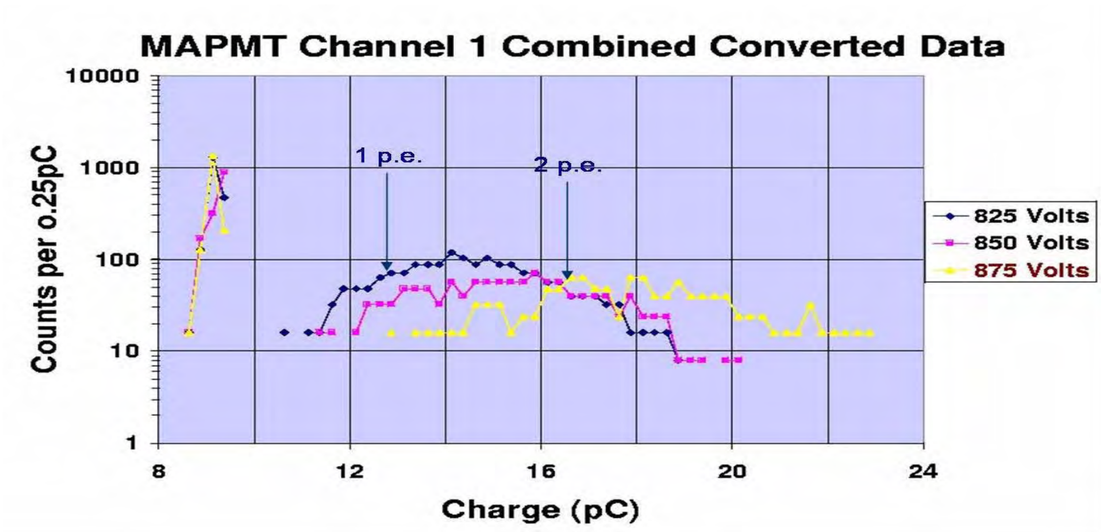

Figure 3: Charge spectra from anode pulses for three different cathode bias values. For 825 volts bias, the mean charges corresponding to 1 and 2 photoelectrons are indicated in the figure.

University of California, Davis During FY2004, the UCD group completed the development of a readout system for the prototype muon test-stand. This system, shown in Figure 4 in a schematic form, utilizes CAMAC modules that are on loan from PREP at Fermilab. Fast discriminators that are used to convert the analog signals to digital pulses preserve the time-over-threshold (TOT) information to better than 1 ns, while the TDCs record both the rise-time and the fall-time with a 0.5 ns resolution. This ability to provide dual-edge recording allows us to get a crude measurement of the pulse-height via TOT with an effective resolution of 20 mV/ns.[3] The wide bandwidth (~1.5 GHz) amplifiers that we had developed in FY2003 preserve the pulse from the MAPMTs to a high accuracy, thus giving us confidence in our ability to measure pulse-heights in a 1V dynamic range with an effective 5-bit resolution. The TDCs are read out from the front-panel ECL bus and fed into an FPGA which also provides trigger and control features. This Xilinx XCV1000 FPGA board, along with auxiliary boards for level-translation (ECL-LVDS and TTL-LVDS), was also developed at UCD. The data from the FPGA are read out into a Linux computer via the parallel port operating in the EPP mode, capable of providing 8 Mbps data transfer. The readout system was tested successfully on the bench with trigger rates exceeding 1 KHz.

[3] see: http://www.linearcollider.ca:8080/lc/vic04/abstracts/detector/muonpid/mani_tripathi.PPT

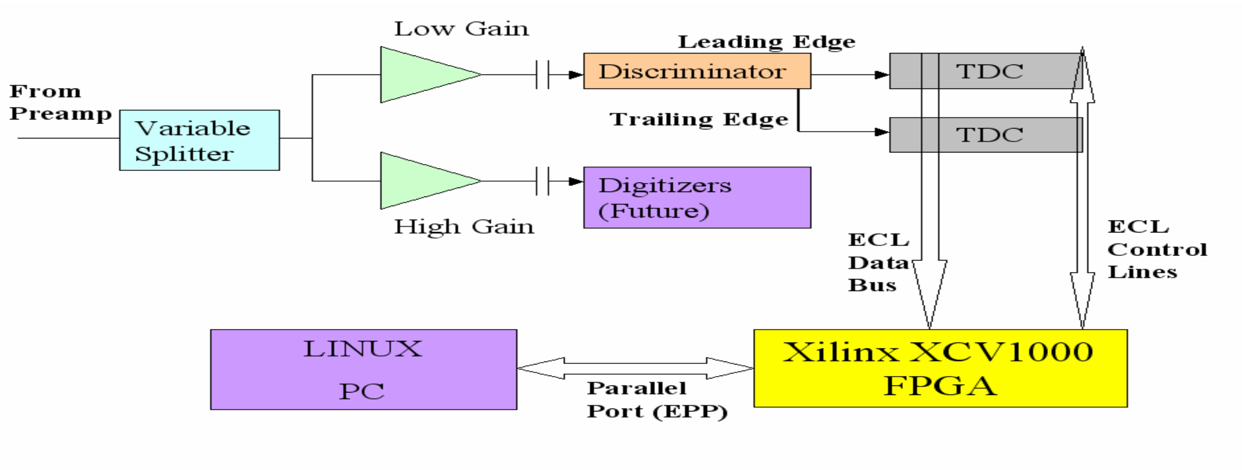

Figure 4: A box-diagram of the readout system that was developed at UCD for use at the prototype muon detector test-stand at Fermilab.

Muon Detector Software Development Caroline Milstene at Fermilab has developed muon tracking and identification software packages in the framework of the JAVA based JAS. This encompasses four areas: (1) rework of the tracking code that simultaneously takes into account both energy-loss and charged particle acceleration in the solenoid and Fe return yoke magnetic fields, (2) improved efficiency for matching low momentum muon candidates with upstream charged particles, (3) studies to predict fake rates partly due to punch-through of nearby charged hadrons in the barrel detector that satisfy the criterion for muon identification, and (4) initial study to implement Kalman filtering to provide greater analytical power in matching upstream tracks with muon candidates and thereby further reduce mis-identified punch-through.

Stepper Software/Low Momentum Tracking Efficiency Improvements The original projection of Monte Carlo charged particles through the tracking detectors and calorimetry into the muon system did not take into account dE/dx. This caused inefficiency in the matching of muon detector candidates that were generated via GEANT, which included the full detector geometry and materials (dE/dx, etc.), especially for muons below 10 GeV/c. The Stepper software (Fermilab TM-2274E) uses a matrix approach to simultaneously include dE/dx and q***v** x **B** effects in projecting central detector tracks into the calorimeters and muon detector. Excellent agreement is obtained between the projected and identified muon track candidates (14 hits in 14 layers for the SiD geometry) with the Stepper.

A "before" and "now" plot of projected and actual phi vs. layer number (radial depth) hits for a 3 GeV/c muon are shown in Figure 5, where "now" is with the Stepper software. The improvements in efficiency are shown in Table 1. The Ad-Hoc line in the table refers to a momentum-dependent enlargement of the (theta, phi) road that allowed improvement of the efficiency; the Stepper can be seen to further improve tracking efficiency.

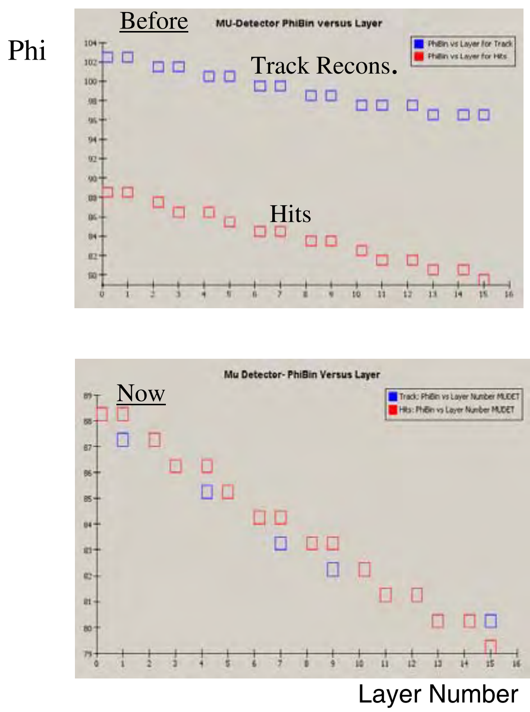

Figure 5: Improvements achieved with the Stepper software as described in the text.

E (GeV/c) / Technique	3	4	5	10
No dE/dx	0.06%	70%	97%	99%
Ad-Hoc dE/dx	23%	95%	97%	99%
V x B + dE/dx	33%	96%	99%	100%

Table 1: Muon Tracking Efficiency

Muon Mis-identification and Hadronic Punch-through In jets, the presence of many nearby particles provides a challenge that was studied with 10,000 b-quark pair produced events (20,000 b's). From the b-jets there were 18,666 (34% of the produced) π's, 4,473(54%) K's and 1,622 (58%) protons that had momenta (> 3 GeV/c) sufficient to penetrate the first 14 plates of the muon detector, assuming they ranged out before interacting. From these hadrons, 70 π's, 41 K's and 2 protons met the muon ID criteria. These numbers include12 π's and 3 K's that decayed to muons. Thus, the fake rate probabilities for π's, K's and protons, including punch-through, are 0.0037, 0.0092 and 0.0012, respectively, using the present Stepper algorithm. Because many of these 113 muon candidates have hits in the first four layers of the muon detector, but then meet the 14 layer hit-criterion using hits that belong to nearby muons or late interactions, a more sophisticated algorithm may make it possible to further reduce fakes due to punch-through.

Kalman Filter Work has started on the development of a Kalman filtering algorithm that will include track fitting as a way to eliminate extraneous hits from neighboring tracks

Facilities, Equipment and Other Resources

At the University of Notre Dame, several laboratory spaces are available for the work described in this proposal. These include rooms in the main physics building as well as a 5000 square foot off-campus laboratory. These spaces have been used for general fiber R&D and for the construction of clear fiber waveguides for the D0 central tracker. The Department of Physics also houses a full-service machine shop with a numerically controlled mill and lathe, a wire EDM, along with several more conventional machines. A LINUX cluster, SGI cluster and IBM RS6000 clusters are all available in the high energy physics area. Various PC's, Macs, SUN workstations and other terminals are also in use in offices.

At the University of California, Davis the electronics shop has capabilities for designing, simulating and laying out circuits using state of the art software tools. The fabrication is usually done by vendors in Silicon Valley but all of the testing is done in-house. The test lab contains a full suite of instrumentation for high bandwith analog signal analysis and debugging of multi-channel digital logic. The labs are also equipped with hardware and software for FPGA firmware development, VLSI chip design and probing of bare ASICs. A clean room and an electromagnetically shielded room provide space for testing sensitive components. A 32 node Linux cluster is available for large scale data analysis along with 3 TB of data storage space.

Wayne State University has both an electronics instrumentation laboratory and a machine shop which are used for the MAPMT work. There are also computing facilities which currently support the group's work on the CDF experiment at Fermilab and are available for use on the muon project.

The scintillator-based ILC muon detector R&D effort is supported by several Fermilab facilities and personnel. We are using the fiber splicing facilities and personnel, Eileen Hahn, in Lab 7. We have a PMT test area in the high bay of Lab 6 largely setup by Paul Karchin and Alfredo Gutierrez (Wayne State) and are presently testing our pre-prototype module in Lab 6. We sometimes make use of the PMT test area, set up by Hogan Ngyuen in Lab 6 and we have previously used a radioactive source and light-tight scintillator strip test box in Lab 5 that has now been moved to Lab 6. An engineer from UC Davis has worked with the ASICs Project Group/Paul Rubinov on the Minerva board in the High Rise and we expect this to continue over the next year or so. We infrequently make use of the Physics Research Equipment Pool and expect to continue to do so. We plan a more involved test area in Lab 6 and use of the MTest beam starting in about a year. We will make more use of Fermilab office space, computing and other facilities in the future.

FY2005 Project Activities and Deliverables

University of Notre Dame During the upcoming year, the Notre Dame group will lead the fabrication of 4, quarter-size muon detector planes, with dimensions 2.5 m by 1.25 m. These will be fully functional detectors based on our current design, with thermal splicing between the waveshifting and clear fibers. Each of the four planes is comprised of 64 scintillator strips. Two planes will be read out at one end, while the other two will have clear fiber readout from each end of the strips. The planes will have strips oriented with alternating 45^0 stereo angle. For both the single-ended planes and double-ended planes, each clear fiber will be read out by a separate pixel of a 64-channel Hamamatsu PMT. The final product will be a complete detector array of 4 planes which can be studied thoroughly in a test beam or cosmic ray telescope.

At Notre Dame we will cut the scintillator strips to appropriate lengths and at the correct angle. The strips are then glued onto a supporting structure to create the detector plane. Clear and waveshifting fiber will be cut to length and measured with our LED-photodiode system. Fibers with throughput below a pretermined value will be rejected. Once the requisite number of fibers are ready, their ends will be thermally straightened. The fiber ends will be finished at Fermilab with an ice polishing technique and then the clear and waveshifting fibers will be spliced together. The spliced fiber lengths will be transported back to Notre Dame, tested for light transmission, and glued into the scintillating strips. Notre Dame will design and fabricate "cookies" in which the clear fibers are terminated. These cookies must precisely align the clear fiber ends with the PMT pixels in a safe and light-tight manner. Our group will design the mounting scheme to mate the cookie to the PMT.

One important design feature is the calibration system. For these prototype detectors we propose a system using flat optical panels, a technique our group developed for the D0 fiber tracking detector. An LED injects light into the panel, creating a uniform ribbon of light approximately 20 inches long and 2 inches wide. By laying the panel across the strips, several channels can be illuminated simultaneously with a relatively well-controlled amount of light. This system will also be useful for debugging the detector readout and for monitoring performance over time. The panels are commercially available from Lumitex.

Wayne State University The WSU group will procure, test and calibrate enough MAPMTs to read out the 4 quarter-size prototype planes. This requires six 64-channel tubes or two 64-channel tubes in combination with two 16-channel tubes. The 16-channel tubes read out 8 fibers per pixel whereas the 64-channel tubes read out 1 fiber per pixel.

We will calibrate every MAPMT channel using the method developed in our previous work. In addition, we will establish procedures for in-situ gain monitoring using light injected into the scintillator bars. We will install and debug the tubes at Fermilab and participate in data taking and analysis using radioactive sources and cosmic rays. We will prepare written reports of our work and present it at conferences and/or publish it in journal form.

University of California, Davis While the readout system described above is good for debugging/calibrating MAPMTs and for reading out prototype planes, it cannot be scaled up for reading out a 512 or 1024 channel muon test-stand. For this purpose, we are proposing to work with a readout system that has been developed at Fermilab for the Minerva experiment. It utilizes a TriP chip, developed for D0, which combines the functionality of the SIFT and SVX chips. It is being developed for use in several Fermilab experiments. This board will not only provide 16 channels of amplification and discrimination but it will also be capable of storing the charge in an analog pipeline and subsequently digitizing the data with an 8-bit accuracy after receiving an external trigger. An FPGA is used to latch the time-of-arrival of the discriminated pulses with a resolution of about 2 ns. This is worse than the 0.5 ns provided by the CAMAC system, but it is expected that the accuracy will improve as FPGAs with higher clock frequencies become available. Moreover, the 8-bit digitization is vastly superior to the 5-bit information gained from the TOT technique. A prototype of this board exists but it needs several corrections before it can enter a production stage.

A UCD graduate student, Juan Lizarazo, has worked with Fermilab physicists and engineers to learn the circuit schematic and board layout. Copies of all of the electronic design documents now exist at UCD. During FY05, we will be developing a modified version of this board for our purposes, including the ability to mate 4 16-channel boards to a 64-channel MAPMT and providing some improvement to the time synchronization circuitry. The TriP chip has some problems in maintaining the thickness of the finished die which makes it difficult for automated wire-bonding. The UCD group will work with vendors to custom wire-bond 40 chips into plastic chip carrier packages. During FY05, we will provide 16 boards for the prototype muon test-stand.

The group at NIU is working on a tail-catcher for the ILC. We will work with them to ensure that there is commonality in the readout system and that the data from the beam test will have a common format.

FY2006 Project Activities and Deliverables

University of Notre Dame In the second year the emphasis will move towards the fabrication of full-size detector planes. Based on our experience in building and operating the 4 prototype detector planes, we will make any necessary design changes, and also concentrate on developing "assembly-line" production methods for the final detector. A large, clean work area and the infrastructure necessary to handle and transport large detector components must be developed.

The group also plans to help in the analysis of data collected with the 4 detector array. These results will be key in several final design decisions, including which PMTs to use and the multiplicity of fibers presented to each PMT pixel.

Wayne State University We will procure, test, calibrate and install additional MAPMTs to read out full-size prototype planes. Tubes from the quarter-size modules will be re-mounted on the full-size planes. The choice of additional 16 or 64 channel tubes will be made based on the results of the Year 1 tests.

We will participate in data taking at Fermilab with a test beam and contribute to the data analysis. We will prepare written reports of our work and present it at conferences and/or publish it in journal form.

University of California, Davis The long term plan is to develop 40 boards at a cost of $18K, or about $30/channel. The first year will be spent in developing the design and making a batch of 16 boards. During the second year, we plan to build a second batch of 16 boards. It is expected that there will be minor improvements made with this design. We will also implement a version of the data acquisition software that already exists for the Minerva experiment. We will send a graduate student to reside at Fermilab and help with the data taking and calibration of the prototype muon detector. The student will also help with analysis of the calibration data.

FY2007 Project Activities and Deliverables

University of Notre Dame By the third year we will be fabricating full-size detector planes. Cosmic ray and beam test measurements with these planes will provide important tests of the design choices. Assembly techniques will be optimized. Work will continue on integration of the muon detector with the rest of the detector systems.

Wayne State University We will complete the work for the full size planes described in Year 2. In all years, we will coordinate our work with the world-wide effort on specific detector designs. We will help evaluate the potential of novel light detectors such as geiger-mode photodiodes and silicon PMTs for use with a scintillator based muon detector. We will help provide cost estimates for readout of a full-scale ILC muon detector and help coordinate muon detector design and integration with the rest of the ILC detector.

University of California, Davis In the third year of the program, we expect to have fully analyzed the data. We will work on designing a full-scale readout system for a muon detector consisting of large scintillator planes. The lessons learned from the prototype system will be implemented in terms of design improvement, most notably in the time-synchronization area, and a version of the readout board with a large number of TriP chips will be developed. We expect that this work will be done by a graduate student at UCD. A cost estimate based on this new design will emerge and will be applicable to a realistic ILC muon detector.

Budget Justification: University of Notre Dame

Support is requested for 50% of the salary of one technician, Mr. Mike McKenna. Mr. McKenna is a skilled technician with more than 25 years of experience working in particle physics. He has worked the majority of his career (more than 20 years) at Fermilab and is now a member of the Notre Dame HEP group. We also request support for 25% of a single graduate student to work summers on detector construction, and later, data analysis. Equipment funds are needed to constuct the various tables, jigs, transports and other apparatus needed for detector assembly. Finally, a small amount of travel funds are budgeted to cover the cost of transportation of materials between Notre Dame and Fermilab.

Three Year Budget – University of Notre Dame

ITEM	2005	2006	2007	Total
Other Professional	$30,000	$30,000	$30,000	$ 90,000
Graduate Student	$ 5,000	$ 5,000	$ 5,000	$ 15,000
Undergraduate Student				
Total Salaries and Wages	**$35,000**	**$35,000**	**$35,000**	**$105,000**
Fringe Benefits (20% of other prof.)	$ 6,000	$ 6,000	$ 6,000	$ 18,000
Total Salaries, Wages and Benefits	**$41,000**	**$41,000**	**$41,000**	**$123,000**
Equipment	$ 2,000	$ 6,000	$ 4,000	$ 12,000
Total Travel	$ 2,000	$ 2,000	$ 2,000	$ 6,000

Materials and Supplies				
Other Direct Costs				
Total Direct Costs	**$45,000**	**$49,000**	**$47,000**	**$141,000**
Indirect Costs (26% of MTDC)	$11,180	$11,180	$11,180	$ 33,540
Total Direct and Indirect Costs	**$56,180**	**$60,180**	**$58,180**	**$174,540**

Budget Justification: Wayne State University

Salary support is requested for 2 months per year for Research Engineer Alfredo Gutierrez in support of MAPMT instrumentation and testing. He has 9 years experience with computers and electronics for high energy physics experiments and has 2 years experience with MAPMT work for this project.

Support is requested for a graduate student for 1 academic term and during the summer, each year, to peform calibration measurements, take data using the prototype modules at Fermilab and to analyze the data.

Travel support is requested for 2 1-week trips to Fermilab for the student, 4 trips of 2 days each to Fermilab for the P.I. and for travel to a domestic and international conference for the P.I.

Funds are requested to purchase 4 MAPMTs and associated electronics components per year to instrument the prototype modules. Minor costs are also included for shipping of materials and for publications.

Three Year Budget – Wayne State University

ITEM	**2005**	**2006**	**2007**	**Total**
Other Professional	$ 8,670	$ 8,843	$ 9,020	$ 26,533
Graduate Student	$11,999	$12,239	$12,484	$ 36,722
Undergraduate Student				
Total Salaries and Wages	**$20,669**	**$21,082**	**$21,504**	**$ 63,255**
Fringe Benefits (26.4%)	$ 5,457	$ 5,566	$ 5,677	$ 16,700
Graduate Student Fee Remission	$ 3,871	$ 3,948	$ 4,027	$ 11,846
Total Salaries, Wages and Benefits	**$29,997**	**$30,596**	**$31,208**	**$ 91,801**
Equipment				
Total Travel	$ 6,500	$ 6,500	$ 6,500	$ 19,500
Materials and Supplies	$ 8,300	$ 8,300	$ 8,300	$ 24,900
Other Direct Costs				
Total Direct Costs	**$44,797**	**$45,396**	**$46,008**	**$136,201**
Indirect Costs (26% of MTDC)	$10,641	$10,776	$10,915	$ 32,332
Total Direct and Indirect Costs	**$55,438**	**$56,172**	**$56,923**	**$168,533**

Budget Justification: University of California, Davis.

Salary support is requested for a graduate student for two academic quarters and during the summer quarter, each year. During the first year, the student will work on the layout of the modified Minerva board and help with testing the prototypes. A total of 400 hours of undergraduate student support (@ $7.25/hour) is requested for each year.

Travel support is requested for three 1-week trips to Fermilab. In the first year this will be for installing the readout electronics at the muon test-stand. Additional support for travel to one domestic and one international Linear Collider workshops is requested for the P.I.

Equipment funds are requested to fabricate the modified Minerva boards. During the first year, we anticipate NRE costs of $3K and an additional $7.8K for producing 16 boards. In the second year, we will produce another 16 boards at a cost of $ 8K followed by 8 boards in the third year. The supplies budget of $2K/year is for miscellaneous electronics parts, software licenses, telephone and printing charges.

Three Year Budget – University of California, Davis.

ITEM	**2005**	**2006**	**2007**	**Total**
Other Professional				
Graduate Student	$16,785	$17,289	$17,808	$ 51,882
Undergraduate Student	$ 2,900	$ 2,900	$ 2,900	$ 8,700
Total Salaries and Wages	**$19,685**	**$20,189**	**$20,708**	**$ 60,582**
Fringe Benefits	$ 389	$ 397	$ 405	$ 1,191
Graduate Student Fee Remission	$ 6,166	$ 6,783	$ 7,461	$ 20,410
Total Salaries, Wages and Benefits	**$26,240**	**$27,369**	**$28,574**	**$ 82,183**
Equipment	$10,800	$ 8,000	$ 3,000	$ 21,800
Total Travel	$ 4,500	$ 4,725	$ 4,961	$ 14,186
Materials and Supplies	$ 2,000	$ 2,000	$ 2,000	$ 6,000
Other Direct Costs				
Total Direct Costs	**$43,540**	**$42,094**	**$38,535**	**$124,169**
Indirect Costs (26% of MTDC)	$ 6,909	$ 7,101	$ 7,299	$ 21,309
Total Direct and Indirect Costs	**$50,449**	**$49,195**	**$45,834**	**$145,478**

7.5: Continuing Studies of Geiger-Mode Avalanche Photodiodes for Linear Collider Detector Muon System Readout

(renewal)

Muon System

Contact person
Robert J. Wilson
wilson@lamar.colostate.edu
(970) 491-5033

Institution(s)
Colorado State

Funds awarded (DOE)
FY04 award: 15,000

New funds requested
FY05 request: 36,560
FY06 request: 91,572
FY07 request: 0

Continuing Studies of Geiger-ModeAvalanche Photodiodes for Linear Collider Detector Muon System Readout

Classification:

Linear Collider Detector Muon System Readout

Institution and Personnel requesting funding:

Colorado State University
Robert J. Wilson, Professor
David W. Warner, Engineer

Wilson and Warner have worked with photodetectors for many years at various levels including for: the SLD experiment Cerenkov Ring Imaging Device (CRID); BaBar Detector of Internally Reflected Cherenkov light (DIRC); Pierre Auger Observatory; GPD applications for detection of Cerenkov and scintillation light.

Collaborators:

Stefan Vasile; President, aPeak Inc.
Scintillator Based Muon Detector Collaboration (E. Fisk, P. Karchin et al.)
Tail Catcher / Muon Tracker Collaboration (V. Zutshi et al.)

Project Leader:

Robert J. Wilson
wilson@lamar.colostate.edu
(970) 491-5033

Project Overview:

Wavelength Shifting (WLS) fiber readout of scintillator strips remains the primary candidate for the US Linear Collider Detector (LCD) systems in central or intermediate tracking or large area muon systems. Indeed, two proposals to continue developing this technology for LCD applications are being submitted in response to this solicitation. These proposals envision using multi-anode PMTs and SiPM/MRS photodetectors for fiber readout. Multi-anode PMTs are an improvement over traditional single-anode PMTs for this application, but they are still expensive, in large part due to the need for relatively sophisticated electronic readout with amplification, as well as high-voltage supply requirements. We believe this is sufficient motivation for further investigation of alternative photodetectors.

Geiger-mode Avalanche Photodiodes (GPDs) are an interesting candidate photodetector to replace PMT read-out of WLS fibers. We have been working together with aPeak[1], a small firm in the Boston area that develops novel photodetector devices, to direct their development of GPDs specifically for these applications. GPDs have several features that are important for these types of applications: relatively high detection efficiency at typical WLS light wavelengths (compared to typical PMTs); high gain; acceptably low dark count rates (for gated operation) with modest cooling; low sensitivity to magnetic fields; and greatly simplified readout electronics, supply voltage requirements, and cable plant. The GPD is intrinsically a digital device, but a certain degree of photon-counting capability could be achieved by multi-pixel readout of each fiber (as is the principal of the Si-PM) - such a configuration could be self-triggering by incorporating multiplicity logic in the readout.

A combination of the GPD features could reduce the system cost considerably. Geiger-mode devices produce volt-size signals that do not need a preamplifier and the simple active quench circuit required could be done on-chip, providing a digital output. The low voltage power supply and cabling cost should be somewhat lower than for a PMT HV system. Insensitivity to magnetic fields and small size would allow the photodetector to be close to the active detector region, which could reduce the optical fiber plant considerably, resulting in a robust, compact, and relatively inexpensive readout system.

This proposal is a continuation of our proposal for research into Geiger-mode Avalanche Photodiodes submitted and partially funded as part of the LCRD program last year. A small (but valuable) component of that proposal was funded late last year - a temperature control system, which is in progress. In addition to the LCRD funding, in 2004 we completed a successful separate R&D program funded by a Phase I SBIR (Small Business Innovative Research) R&D award to aPeak. The results from this research were sufficiently interesting that aPeak has been granted a Phase II award of $735,000 to continue this research, with a subcontract to CSU of approximately $170,000 over two years. Many of the goals set out in the last year's LCDRD "Year 1" request are supported by this SBIR funding, but to be most useful for the prototype scintillator systems proposed for LCD there are two critical efforts that are not. Here we request follow-on funding through the LCDRD program to allow us to continue development specifically targeted at the LCD muon system; in particular to:

- participate in the design and planning of the muon system test beds to insure compatibility with the GPDs (Year 1) ;
- design a fiber readout system optimized for GPDs using the experience from the SBIR-funded research and in the LCD muon system test bed (Year 2).

Broader Impact:

Low light level high detection efficiency photodetectors are a critical part of many fields of physics research and commercial applications. It is difficult to overstate the potential value of a low cost, high gain, high reliability alternative to the photomultiplier tube for these applications. In addition to high energy physics applications described here, GPDs

[1] http://www.apeakinc.com/

may be useful in many other traditional PMT applications, such as atmospheric monitoring, astronomy, nuclear medicine and medical imaging, chemistry, illicit radiation source detection, and many other fields.

Results of Prior Research:

During the previous LCRD funding cycle, CSU was awarded $15,000 to investigate the impact of cooling the GPD junction on the level of thermally generated false signals. This funding has allowed us to develop a computer controlled Peltier junction-based cooling system for measuring the noise performance of prototype devices as a function of temperature over the range from approximately +20 to -40 degrees Celsius. These important measurements would not have been possible with aPeak funds alone and are a good example of how a modest amount of LCRD funding has allowed us to add flexibility to a substantial SBIR-funded research program, and even to increase our influence over the aPeak GPD development project.

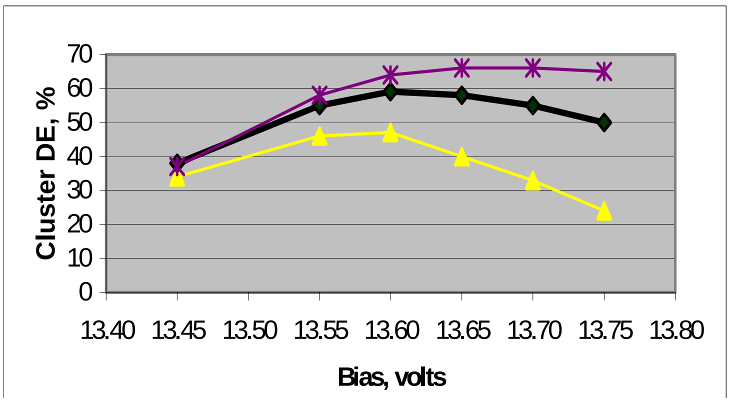

Figure 1: Detection Efficiency for GPD Cluster. Statistical uncertainty is 2% for bias 13.75 V, increasing to 8% for 13.45 V (From Phase I SBIR Report)

Thanks to the SBIR funding we received for this project, we have had pixel arrays available for testing at CSU for much of the past year. As our primary contribution to the SBIR phase 1 work, we have concentrated on measuring the detection efficiency for GPD readout of WLS fibers. Using a simple scintillator hodoscope, we have collected cosmic ray data from sample 8-pixel GPD arrays attached to a 30 cm sample of a scintillator bar with embedded wavelength-shifting fibers (similar to that in the MINOS experiment[2]). As shown in Figure 1, our results indicate that the array was approximately 60% efficient for detecting cosmic rays, depending on bias voltage setting and background subtraction method: the middle thick line is the best estimate; the top line is the expected value based on the efficiency of individual pixels in the absence of correlated backgrounds; the bottom line is a worst case scenario that greatly overestimates the effect of thermally generated noise.

[2] http://www-numi.fnal.gov/

We anticipate being able to increase the system detection efficiency to nearly 100% by increasing the photosensitive surface area, improvements to the active quenching circuitry, and improved optical coupling to the fiber.

Results from the testing work at CSU have been presented by Wilson at the Victoria Linear Collider Workshop, summer 2004[3]. Extensive additional results are also included in an internal report from CSU to aPeak at the conclusion of Phase I[4]. Results from the full Phase I effort were also presented by Vasile (aPeak) at the NSS 04 conference in Rome[5].

The final report of Phase I progress was submitted to DoE as part of our request for Phase II support. Unfortunately, this report contains proprietary information from aPeak, and has not yet been released as a public document.

Facilities, Equipment and Other Resources:

Our proposal is greatly enhanced by our ability to purchase test equipment, readout electronics, and materials and supplies necessary for operating the GPD arrays in the LCD prototype from funds provided through the SBIR program – these include a new PC-based data acquisition system with LabView, readout electronics, cables, funds for mechanical design and fabrication of detector interface. Sufficient laboratory space with power, internet access etc. and low cost access to a machine shop with precision lathes, mills, drills etc is provided by the university.

Year 1 Project Activities and Deliverables:

The CSU work plan for our involvement in the aPeak SBIR explicitly specifies that we are responsible for "Development of the packaging, interface, and physical plant for use in a realistic detector, culminating in testing the arrays in a prototype test bed of the LCD muon system if possible. The LCD test bed and possible beam tests will be coordinated with the LCD Muon Group that includes Fermi National Accelerator Laboratory, Northern Illinois University, University of Notre Dame, and Wayne State University." Our deliverable under this LCRD proposal would be the engineering and interaction necessary to insure satisfactory testing in the LC muon system test bed(s).

Year 2 Project Activities and Deliverables:

Year 2 activities would move the design from prototype status towards manufacturability, both in terms of the production of the GPDs and the physical plant required to operate them. This would involve:

- Design of optical interfaces (possibly light concentrators) to connect WLS or scintillating fibers to GPD pixel arrays;

[3] http://www.linearcollider.ca/lc/vic04/abstracts/detector/muonpid/bob_wilson_.pdf
[4] http://hep45.hep.colostate.edu/~wilson/GPD/CSU_aPeakPhaseI_report.pdf
[5] http://www.apeakinc.com/images/N305.pps

- Development of cooling systems (such as piezoelectric coolers) to reduce the temperature and provide the required temperature stability for reliable operation;
- Optimization of pixel array layouts to minimize cost and maximize performance;
- Investigation of on-chip active quenching and signal processing to further reduce costs;
- Design of a system to fit within the constraints of a straw-man muon tracking system developed by the muon tracker task.

At the completion of this phase, we would expect to be ready to produce significant numbers of GPD pixel arrays to read out a large-scale muon system prototype.

Budget Justification:

We request support from the LCRD program in Year 1 for 2 months engineering support and travel (3 trips to FNAL/Illinois: 2 for Warner, 1 for Wilson) and 1 semester (summer) of graduate student support. The travel is an integral part of tying the SBIR funded project with the LCRD program. The graduate student will work on for data analysis and testing during the summer and part time during the academic semester. Warner is the central person for the technical aspects of the program. There is no HEP base program grant support for Warner – all costs, including travel, associated with this proposal must be provided by the project he is working on.

In Year 2, we include 3.5 months of engineering support for system design and integration studies; 1 semester of grad student support for data analysis and testing; 3 trips to Fermilab for systems integration with our collaborators, and a custom run of GPDs specifically matched to the muon system prototype requirements ($30,000).

Budget:

Item	FY2005	FY2006	Total
Other Professionals (Warner*)	$17,000	$29,750	$46,750
Graduate Students	$4,500	$4,500	$9,000
Undergraduate Students	$0	$0	$0
Total salaries & Wages	$21,500	$34,250	$55,750
Fringe Benefits*	$162	$162	$324
Total Salaries, Wages and Fringe Benefits	$21,662	$34,412	$56,074
Equipment	$0	$30,000	$30,000
Travel	$3,000	$3,000	$6,000
Materials and Supplies	$0	$4,500	$4,500
Other Direct Costs (tuition)	$800	$800	$1,600
Total Direct Costs	$25,462	$72,712	$98,174
Indirect Costs	$11,098	$18,860	$29,958
Total Direct and Indirect Costs	$36,560	$91,572	$128,132

*Warner's salary is charged through the CSU Technical Design Facility at a flat rate of $50/hour, with no explicit fringe associated.

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

(new proposal)

Muon System

Contact person
Vishnu Zutshi
zutshi@fnal.gov
(815) 753-3080

Institution(s)
Colorado State
DESY
Fermilab
NIU
Pavia
Wayne State

New funds requested
FY05 request: 87,800
FY06 request: 107,100
FY07 request: 165,800

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

G. Blazey, D. Chakraborty, A. Dyshkant, D. Hedin, A. Maciel, V. Rykalin, V. Zutshi.
Northern Illinois Center for Accelerator and Detector Development/ Northern Illinois University.

Collaborators

F. Sefkow et. al, *DESY, Hamburg*,
H. Fisk et. al, *Fermi National Accelerator Laboratory, Batavia*,
R. Wilson et. al, *Colorado State University, Fort Hill*,
P. Karchin et. al, *Wayne State University, Detroit*,
G. Introzzi et. al, *University of Pavia, Pavia*,
The CALICE Collaboration.

Project Leader

V. Zutshi
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(815)753-3080

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,

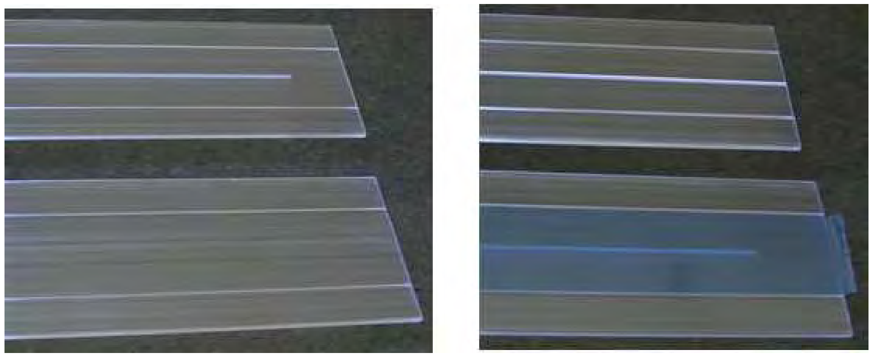

Figure 1: Strip processing stages.

(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 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 (≈ 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

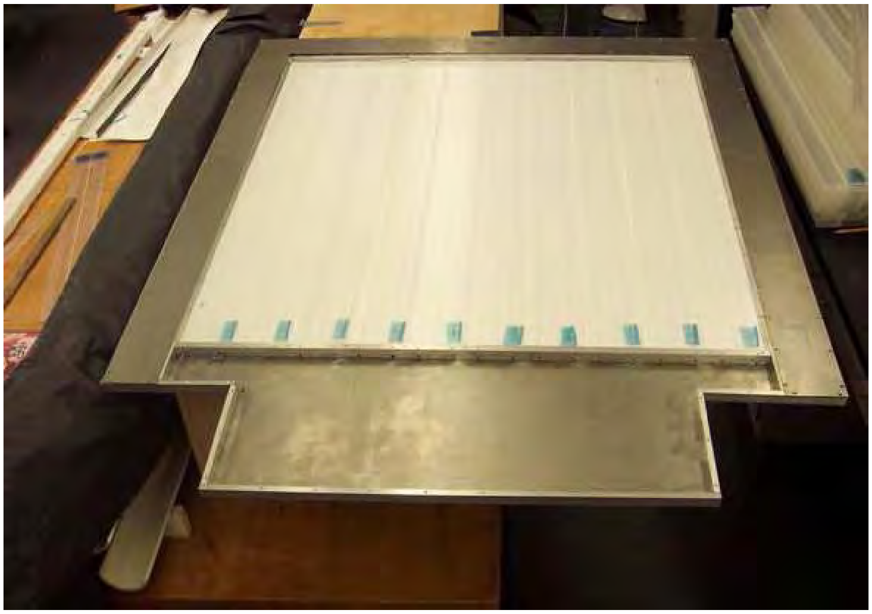

Figure 2: Mechanical prototype of cassette.

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.

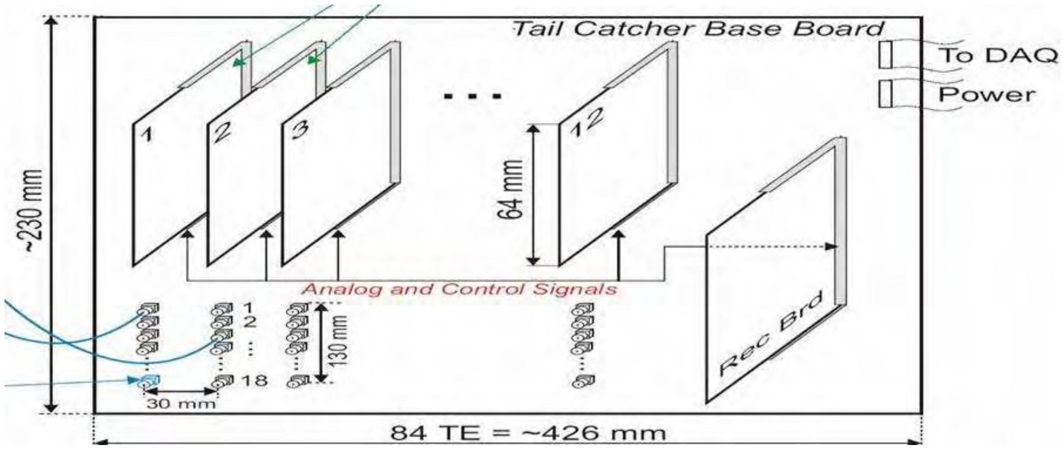

Figure 3: Electronics architecture for the TCMT.

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^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 drawings for the absorber stack and table are available and construction can commence soon. We have already located (Fermilab scrapyard) 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.

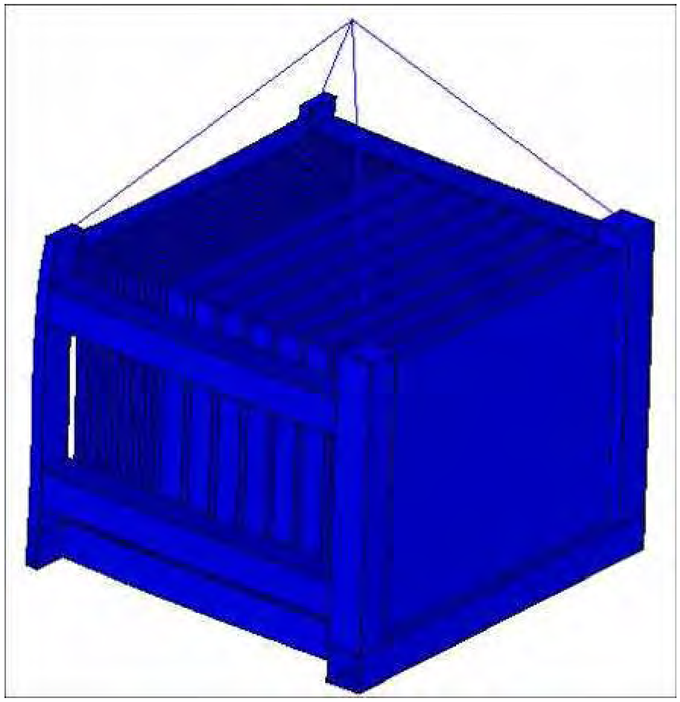

Figure 4: TCMT absorber stack structure.

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

[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".

Appendix and Reference

Appendix: Participation Data and Table of Project Summaries

Participation Data

Funds already awarded, DOE + NSF	FY04	FY05	FY06	proposals
Accelerator Physics total	$515,938	$601,780	$547,780	17
Luminosity, Energy, Polarization total	$75,000	$0	$0	4
Vertex Detector total	$72,000	$0	$0	1
Tracking total	$207,000	$0	$0	5
Calorimetry total	$320,000	$0	$0	6
Muon system and Particle ID total	$26,000	$0	$0	2
Total	$1,215,938	$601,780	$547,780	35

New funding requested by proposals	FY05	FY06	FY07	proposals
Accelerator Physics total	$1,133,885	$1,117,045	$959,950	18
Luminosity, Energy, Polarization total	$315,555	$362,855	$329,158	9
Vertex Detector total	$75,000	$150,000	$150,000	1
Tracking total	$737,595	$759,184	$733,030	11
Calorimetry total	$843,446	$1,153,644	$773,238	10
Muon system and Particle ID total	$286,427	$364,219	$326,737	3
Total	$3,391,908	$3,906,947	$3,272,113	52

Submitted (or continuing) projects	year 1	year 2	this year
Accelerator Physics total	33	29	30
Luminosity, Energy, Polarization total	9	9	9
Vertex Detector total	3	3	1
Tracking total	11	11	12
Calorimetry total	12	13	10
Muon system and Particle ID total	3	3	3
Total	71	68	65

Participation by institutions	year 1	year 2	this year
U.S. Universities	47	48	49
National and industrial laboratories	7	5	7
Foreign institutions	11	11	23
Total	65	64	79

Authors	year 1	year 2	this year
U.S. Universities	209	220	204
National and industrial laboratories	70	58	71
Foreign institutions	18	25	55
Total	297	303	330

Table of Project Summaries

progress report	2.2. Beam Test Proposal of an Optical Diffraction Radiation Beam Size Monitor at the SLAC FFTB (p. 34)		
Accelerator Physics	Yasuo Fukui	fukui@slac.stanford.edu	(650) 926-2146
Collaborating institutions: UCLA KEK SLAC Tokyo Metropolitan Tomsk Polytechnic			
Previously awarded support: FY04: 40,000 FY05: 45,000 FY06: 50,000 DOE			
Request for new support: FY05: FY06: FY07:			
progress report	2.3. Design and Fabrication of a Radiation-Hard 500-MHz Digitizer Using Deep Submicron Technology (p. 47)		
Accelerator Physics	K.K. Gan	gan@mps.ohio-state.edu	(614) 292-4124
Collaborating institutions: Ohio State SLAC			
Previously awarded support: FY04: 60,000 FY05: 135,000 FY06: 135,000 DOE			
Request for new support: FY05: FY06: FY07:			
progress report	2.4. RF Beam Position Monitors for Measuring Beam Position and Tilt (p. 55)		
Accelerator Physics	Yury Kolomensky	yury@physics.berkeley.edu	(510)642-9619
Collaborating institutions: UC Berkeley Notre Dame SLAC			
Previously awarded support: FY04: 40,000 FY05: 34,600 FY06: 34,600 DOE			
Request for new support: FY05: FY06: FY07:			
renewal	2.5. Non-intercepting electron beam diagnosis using diffraction radiation (p. 62)		
Accelerator Physics	Bibo Feng	bibo.feng@vanderbilt.edu	(615) 343-6446
Collaborating institutions: Vanderbilt			
Previously awarded support: FY04: 9,040 FY05: FY06: NSF			
Request for new support: FY05: 60,600 FY06: 62,700 FY07: 0			
renewal	2.6. Electro-optic measurement of picosecond bunches in a bunch train (p. 70)		
Accelerator Physics	Bill Gabella	b.gabella@vanderbilt.edu	(615) 343-2713
Collaborating institutions: Vanderbilt			
Previously awarded support: FY04: 18,083 FY05: FY06: NSF			
Request for new support: FY05: 46,400 FY06: 50,300 FY07: 0			
renewal	2.7. Design for a Fast Synchrotron Radiation Imaging System for Beam Size Monitoring (p. 76)		
Accelerator Physics	Jim Alexander	jima@lns.cornell.edu	(607) 255-5259
Collaborating institutions: Albany Cornell			
Previously awarded support: FY04: 21,082 FY05: FY06: NSF			
Request for new support: FY05: 23,503 FY06: 0 FY07: 0			

progress report	2.9. Radiation damage studies of materials and electronic devices using hadrons (p. 82)		
Accelerator Physics	David Pellett	pellett@physics.ucdavis.edu	(530) 752-1783
Collaborating institutions: UC Davis Fermilab SLAC			
Previously awarded support: FY04: 33,059 FY05: 38,000 FY06: 38,000 DOE			
Request for new support: FY05: FY06: FY07:			
new proposal	2.10. BACKGAMMMON: A Scheme for Compton Backscattered Photoproduction at the International Linear Collider (p. 89)		
Accelerator Physics	S. Mtingwa	mtingwa@ncat.edu	(336) 334-7423
Collaborating institutions: NCA&T			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 160,200 FY06: 193,700 FY07: 207,000			
new proposal	2.11. Ground Motion studies at NuMI (p. 97)		
Accelerator Physics	Mayda Velasco	mvelasco@lotus.phys.nwu.edu	(847) 467-7099
Collaborating institutions: Northwestern			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 28,489 FY06: 0 FY07: 0			
progress report	2.15. Investigation of acoustic localization of rf cavity breakdown (p. 103)		
Accelerator Physics	George Gollin	g-gollin@uiuc.edu	(217) 333-4451
Collaborating institutions: Illinois SLAC			
Previously awarded support: FY04: 23,785 FY05: 35,000 FY06: 35,000 DOE			
Request for new support: FY05: FY06: FY07:			
progress report	2.18. Control of Beam Loss in High-Repetition Rate High-Power PPM Klystrons (p. 115)		
Accelerator Physics	Chiping Chen	chenc@psfc.mit.edu	(617) 253-8506
Collaborating institutions: Mission Research Corp MIT			
Previously awarded support: FY04: 20,000 FY05: 30,000 FY06: 0 DOE			
Request for new support: FY05: FY06: FY07:			
progress report	2.22. Investigation of Novel Schemes for Injection/Extraction Kickers (p. 123)		
Accelerator Physics	George Gollin	g-gollin@uiuc.edu	(217) 333-4451
Collaborating institutions: Cornell Fermilab Illinois			
Previously awarded support: FY04: 22,822 FY05: 16,822 FY06: 16,822 DOE			
Request for new support: FY05: FY06: FY07:			

progress report	2.25. Investigation and prototyping of fast kicker options for the TESLA damping rings (p. 165)		
Accelerator Physics	Gerry Dugan	gfd1@cornell.edu	(607) 255-5744
Collaborating institutions: Cornell			
Previously awarded support: FY04: 7,900 FY05: 135,000 FY06: 135,000 DOE			
Request for new support: FY05: FY06: FY07:			
new proposal	2.26. Continuing Research and Development of Linac and Final Doublet Girder Movers (p. 177)		
Accelerator Physics	David Warner	Warner@lamar.colostate.edu	(970) 491-1035
Collaborating institutions: Colorado State SLAC			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 57,000 FY06: 66,400 FY07: 58,400			
progress report	2.27. Effects of CSR in Linear Collider Systems: A Progress Report (p. 186)		
Accelerator Physics	James Ellison	ellison@math.unm.edu	(505) 277-4613
Collaborating institutions: New Mexico			
Previously awarded support: FY04: 36,758 FY05: 36,758 FY06: 36,758 DOE			
Request for new support: FY05: FY06: FY07:			
progress report	2.30. Beam simulation: main beam transport in the linacs and beam delivery systems, beam halo modeling and transport, and implementation as a diagnostic tool for commissioning and operation (p. 194)		
Accelerator Physics	Dave Rubin	dlr@cesr10.lns.cornell.edu	(607) 255-3765
Collaborating institutions: Cornell			
Previously awarded support: FY04: 16,060 FY05: 21,000 FY06: 32,000 DOE			
Request for new support: FY05: FY06: FY07:			
renewal	2.32. Supplementary Damping Systems for the International Linear Collider (p. 200)		
Accelerator Physics	S. Mtingwa	mtingwa@ncat.edu	(336) 334-7423
Collaborating institutions: NCA&T			
Previously awarded support: FY04: 22,600 FY05: FY06: NSF			
Request for new support: FY05: 160,200 FY06: 193,700 FY07: 207,000			
renewal	2.34. Experimental, simulation, and design studies for linear collider damping rings (p. 207)		
Accelerator Physics	Gerry Dugan	gfd1@cornell.edu	(607) 255-5744
Collaborating institutions: Cornell Minnesota			
Previously awarded support: FY04: 45,133 FY05: FY06: NSF			
Request for new support: FY05: 46,839 FY06: 72,006 FY07: 0			

progress report	2.37. Demonstration of Undulator-Based Production of Polarized Positrons at FFTB at SLAC (p. 216)		
Accelerator Physics	William Bugg	bugg@slac.stanford.edu	(865) 974-7799
Collaborating institutions: Princeton South Carolina Tennessee			
Previously awarded support: FY04: 65,000 FY05: 40,000 FY06: 0 DOE			
Request for new support: FY05: FY06: FY07:			
progress report	2.40. Development of Polarized Photocathodes for the Linear Collider (p. 226)		
Accelerator Physics	Richard Prepost	prepost@hep.wisc.edu	(608) 262-4905
Collaborating institutions: SLAC Wisconsin			
Previously awarded support: FY04: 34,616 FY05: 34,600 FY06: 34,600 DOE			
Request for new support: FY05: FY06: FY07:			
new proposal	2.43. Investigation of acoustic localization of rf coupler breakdown (p. 235)		
Accelerator Physics	Jeremy Williams	jbw@mail.lns.cornell.edu	(217) 649-8481
Collaborating institutions: University of Illinois SLAC			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 14,600 FY06: 24,300 FY07: 24,700			
new proposal	2.44. 20-MW Magnicon for ILC (p. 246)		
Accelerator Physics	J.L. Hirshfield	jay.hirshfield@yale.edu	(203) 432-5428
Collaborating institutions: Budker Institute Omega-P Inc. Yale			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 60,507 FY06: 64,875 FY07: 65,850			
new proposal	2.45. SCRF Low-Level RF (LLRF) Development for ILC-SMTF (p. 262)		
Accelerator Physics	Nigel Lockyer	lockyer@physics.upenn.edu	(215) 898-5806
Collaborating institutions: University of Pennsylvania			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 21,794 FY06: 95,232 FY07: 98,089			
new proposal	2.46. Polarized Positron Sources (p. 268)		
Accelerator Physics	Mayda Velasco	mvelasco@lotus.phys.nwu.edu	(847) 467-7099
Collaborating institutions: Livermore Northwestern			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 36,209 FY06: 0 FY07: 0			

new proposal	2.47. Magnetic Investigation of High Purity Niobium for Superconducting RF Cavities (p. 275)		
Accelerator Physics	P. Lee	lee@engr.wisc.edu	(608)263-1760
Collaborating institutions: Fermilab University of Wisconsin			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 66,702 FY06: 69,262 FY07: 71,941			
new proposal	2.48. 3D Atom-Probe Microscopy on Niobium for SRF Cavities (p. 283)		
Accelerator Physics	D.N. Seidman	d-seidman@northwestern.edu	(847) 491-4391
Collaborating institutions: Argonne Fermilab Northwestern			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 43,500 FY06: 44,300 FY07: 45,100			
new proposal	2.49. Experimental Study of High Field Limits of RF Cavities (p. 293)		
Accelerator Physics	D.N. Seidman	d-seidman@northwestern.edu	(847) 491-4391
Collaborating institutions: Argonne Northwestern			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 64,800 FY06: 66,300 FY07: 67,900			
new proposal	2.50. Evaluation of MgB2 for Future Accelerator Cavities (p. 305)		
Accelerator Physics	V. Nesterenko	vnesterenko@ucsd.edu	(858) 822-0289
Collaborating institutions: U.C. San Diego LANL			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 59,300 FY06: 59,300 FY07: 59,300			
new proposal	2.51. Investigation of Secondary Electron Emission from Nb Surfaces with Different Surface Treatments (p. 314)		
Accelerator Physics	Robert Schill	schill@ee.unlv.edu	(702) 895-1526
Collaborating institutions: U.N. Las Vegas			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 81,248 FY06: 0 FY07: 0			
new proposal	2.52. Investigation of Plasma Etching for Superconducting RF Cavities surface Preparation (p. 325)		
Accelerator Physics	Leposava Vuskovic	vuskovic@physics.odu.edu	(757) 683-4611
Collaborating institutions: Old Dominion University TJNAF			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 101,994 FY06: 54,670 FY07: 54,670			

renewal	3.1. A Fast Gas Cerenkov Calorimeter for Luminosity Measurement and Machine Monitoring (p. 337)		
Luminosity, Energy, Polarization	John Hauptman	hauptman@iastate.edu	(515) 294-8572
Collaborating institutions: Iowa State NIPT (Ukraine) Oregon Purdue SLAC Texas Tech			
Previously awarded support: FY04: 35,000 FY05: FY06: DOE			
Request for new support: FY05: 42,500 FY06: 45,500 FY07: 69,500			
new proposal	3.2. R&D for luminosity monitor (p. 345)		
Luminosity, Energy, Polarization	Yasar Onel	yasar-onel@uiowa.edu	(319) 335-1853
Collaborating institutions: META (Turkey) INFN (Italy) Fairfield Iowa Bogazici (Turkey) Cukurova (Turkey)			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 27,610 FY06: 30,120 FY07: 25,100			
renewal	3.4. Extraction Line Energy Spectrometer (p. 352)		
Luminosity, Energy, Polarization	Eric Torrence	torrence@physics.uoregon.edu	(541) 346-4618
Collaborating institutions: Oregon			
Previously awarded support: FY04: 24,000 FY05: FY06: DOE			
Request for new support: FY05: 38,467 FY06: 42,077 FY07: 0			
new proposal	3.5. A Demonstration of the Electronic and Mechanical Stability of a BPM-Based Energy Spectrometer for the International Linear Collider (p. 360)		
Luminosity, Energy, Polarization	Mike Hildreth	mikeh@undhep.hep.nd.edu	(574) 631-6458
Collaborating institutions: Notre Dame			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 28,000 FY06: 133,500 FY07: 141,100			
new proposal	3.6. Polarimetry at LC (p. 370)		
Luminosity, Energy, Polarization	Yasar Onel	yasar-onel@uiowa.edu	(319) 335-1853
Collaborating institutions: Bogazici (Turkey) Cukurova (Turkey) Fairfield Iowa Iowa State Karlsruhe (Germany) META (Turkey)			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 20,100 FY06: 35,800 FY07: 22,600			

renewal	3.7. Compton polarimeter backgrounds (p. 377)		
Luminosity, Energy, Polarization	William Oliver	william.oliver@tufts.edu	(617) 627-5364
Collaborating institutions: SLAC Tufts			
Previously awarded support: FY04: 10,000 FY05: FY06: DOE			
Request for new support: FY05: 14,000 FY06: 14,000 FY07: 14,000			
renewal	3.8. Incoherent and coherent beamstrahlung at the LC (p. 383)		
Luminosity, Energy, Polarization	Giovanni Bonvicini	giovanni@physics.wayne.edu	(313) 577-1444
Collaborating institutions: Wayne State			
Previously awarded support: FY04: 6,000 FY05: FY06: DOE			
Request for new support: FY05: 41,000 FY06: 0 FY07: 0			
new proposal	3.9. Development of radiation hard, 3d-electrode array, silicon radiation sensors (p. 396)		
Luminosity, Energy, Polarization	Sherwood Parker	sher@slac.stanford.edu	(510) 841 2012
Collaborating institutions: Hawaii			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 53,878 FY06: 51,858 FY07: 51,858			
new proposal	3.10. Beam-Diagnostic TPC (BDTPC) (p. 405)		
Luminosity, Energy, Polarization	Mike Ronan	ronan@lbl.gov	(510) 486-4396
Collaborating institutions: Indiana LBNL Notre Dame			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 50,000 FY06: 10,000 FY07: 5,000			
renewal	4.1. Pixel Vertex Detector R&D for Future High Energy Linear e+ e- Colliders (p. 413)		
Vertex Detector	Charlie Baltay	baltay@yalph2.physics.yale.edu	(203) 432-3386
Collaborating institutions: Fermilab KEK Oklahoma Oregon Rutherford Lab SLAC Yale			
Previously awarded support: FY04: 72,000 FY05: FY06: DOE			
Request for new support: FY05: 75,000 FY06: 150,000 FY07: 150,000			
new proposal	5.1. Development and Evaluation of Forward Tracking in the Linear Collider (p. 430)		
Tracking	Michael Strauss	mgstrauss@ou.edu	(405) 325-3961
Collaborating institutions: Oklahoma			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 40,552 FY06: 42,580 FY07: 44,709			

renewal	5.2. Development of a GEM based Forward Tracking Prototype for the ILC (p. 436)		
Tracking	Lee Sawyer	sawyer@phys.latech.edu	(318) 251-2407
Collaborating institutions: Louisiana Tech			
Previously awarded support: FY04: 35,000 FY05: FY06: DOE			
Request for new support: FY05: 32,220 FY06: 30,420 FY07: 29,120			
renewal	5.4. Studies of Gas Electron Multipliers for a Time Projection Chamber for the International Linear Collider (p. 447)		
Tracking	Peter Fisher	fisherp@mit.edu	(617) 253-8561
Collaborating institutions: Harvard MIT			
Previously awarded support: FY04: 45,000 FY05: FY06: DOE			
Request for new support: FY05: 61,500 FY06: 61,150 FY07: 61,150			
progress report	5.5. Studies of the Use of Scintillating Fibers for an Intermediate Tracker which Provides Precise Timing and Bunch Identification: Progress Report and Request For Funds (p. 456)		
Tracking	Rick VanKooten	rvankoot@indiana.edu	(812) 855-2650
Collaborating institutions: Fermilab Indiana Notre Dame			
Previously awarded support: FY04: 10,000 FY05: FY06: DOE			
Request for new support: FY05: 0 FY06: 0 FY07: 0			
new proposal	5.7. Development of a Micro Pattern Gas Detector Readout for a TPC (p. 465)		
Tracking	Dan Peterson	dpp@lns.cornell.edu	(607) 255-8784
Collaborating institutions: Cornell Purdue			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 92,476 FY06: 82,407 FY07: 74,416			
renewal	5.8. Linear Collider Tracker Simulation Studies and Alignment System R&D (p. 478)		
Tracking	Keith Riles	kriles@umich.edu	(734) 764-4652
Collaborating institutions: Michigan			
Previously awarded support: FY04: 45,000 FY05: FY06: DOE			
Request for new support: FY05: 142,000 FY06: 127,000 FY07: 164,000			
renewal	5.10. R& D Towards a Long Shaping-Time Silicon Strip Central Tracker (p. 488)		
Tracking	Bruce Schumm	schumm@scipp.ucsc.edu	(831)-459-3034
Collaborating institutions: UC Santa Cruz Fermilab LPNHE Paris			
Previously awarded support: FY04: 72,000 FY05: FY06: DOE			
Request for new support: FY05: 75,000 FY06: 75,000 FY07: 0			
new proposal	5.13. Continuation of Reconstruction Studies for the SiD Barrel Outer Tracker (p. 499)		
Tracking	Stephen Wagner	stevew@pizero.colorado.edu	(303) 735-6072
Collaborating institutions: University of Colorado			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 66,000 FY06: 63,600 FY07: 65,900			

new proposal	5.14. Simulation Studies for a Silicon Tracker (p. 503)		
Tracking	Richard Partridge	partridge@hep.brown.edu	(401) 863-2634
Collaborating institutions: Brown			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 39,997 FY06: 41,497 FY07: 43,055			
new proposal	5.15. Calorimeter-based Tracking for Particle Flow and Reconstruction of Long-lived Particles with SiD Detector (p. 509)		
Tracking	Eckhard von Toerne	evt@phys.ksu.edu	(785) 532-1644
Collaborating institutions: Kansas State			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 26,500 FY06: 23,900 FY07: 24,500			
new proposal	5.16. TPC VLSI Readout R&D (p. 518)		
Tracking	Marco Battaglia	MBattaglia@lbl.gov	(510) 486-7029
Collaborating institutions: U.C. Berkeley U.C. Davis LBNL			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 87,000 FY06: 139,000 FY07: 146,000			
new proposal	5.17. Development of thin silicon sensors for tracking (p. 524)		
Tracking	Daniela Bortoletto	daniela@physics.purdue.edu	(765) 494-5197
Collaborating institutions: Purdue			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 74,350 FY06: 72,630 FY07: 80,180			
renewal	6.1. Design and Prototyping of a Scintillator-based Semi-Digital Hadron Calorimeter (p. 538)		
Calorimetry	Vishnu Zutshi	zutshi@fnal.gov	(815) 753-3080
Collaborating institutions: University of Colorado DESY Fermilab ITEP NIU Pavia			
Previously awarded support: FY04: 50,000 FY05: FY06: DOE			
Request for new support: FY05: 88,400 FY06: 176,700 FY07: 175,400			
renewal	6.2. Calorimetry R&D at Colorado: Progress Report of Work in 2004 and Proposed Work for 2005, 2006, 2007 (p. 549)		
Calorimetry	Uriel Nauenberg	uriel@pizero.colorado.edu	(303) 492-7715
Collaborating institutions: Colorado Fermilab			
Previously awarded support: FY04: 60,000 FY05: FY06: DOE			
Request for new support: FY05: 191,766 FY06: 315,177 FY07: 163,581			
renewal	6.4. Particle Flow Studies with the Silicon Detector (SiD) at the International Linear Collider (ILC) (p. 566)		
Calorimetry	Usha Mallik	usha-mallik@uiowa.edu	(319) 335-0499
Collaborating institutions: Iowa			
Previously awarded support: FY04: 50,000 FY05: FY06: DOE			
Request for new support: FY05: 83,910 FY06: 98,849 FY07: 0			

renewal	6.5. Development of a silicon-tungsten test module for an electromagnetic calorimeter (p. 581)		
Calorimetry	Raymond Frey	rayfrey@cosmic.uoregon.edu	(541) 346-5873
Collaborating institutions: Oregon SLAC			
Previously awarded support: FY04: 55,000 FY05: FY06: DOE			
Request for new support: FY05: 45,000 FY06: 0 FY07: 0			
renewal	6.6. Digital Hadron Calorimetry for the Linear Collider using GEM based Technology (p. 591)		
Calorimetry	Andy White	awhite@uta.edu	(817) 272-2812
Collaborating institutions: UT Arlington University of Washington			
Previously awarded support: FY04: 70,000 FY05: FY06: DOE			
Request for new support: FY05: 105,170 FY06: 108,018 FY07: 112,457			
renewal	6.9. Development of Particle-Flow Algorithms and Simulation Software for the ILC Detector(s) (p. 602)		
Calorimetry	Dhiman Chakraborty	dhiman@fnal.gov	(630) 840-8569
Collaborating institutions: Argonne Fermilab Iowa NIU Oregon SLAC U.T. Arlington			
Previously awarded support: FY04: 35,000 FY05: FY06: DOE			
Request for new support: FY05: 94,200 FY06: 154,900 FY07: 156,800			
new proposal	6.10. Investigation of ECAL Concepts Designed for Particle Flow (p. 613)		
Calorimetry	Graham Wilson	gwwilson@ku.edu	(785) 864-5231
Collaborating institutions: Kansas			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 30,000 FY06: 0 FY07: 0			
new proposal	6.14. Construction of a Prototype Hadronic Calorimeter with Digital Readout (p. 624)		
Calorimetry	José Repond	repond@hep.anl.gov	(630) 252-7554
Collaborating institutions: ANL Boston University Chicago Fermilab Iowa			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 105,000 FY06: 130,000 FY07: 55,000			
new proposal	6.16. Dual-Readout Calorimetry for the ILC (p. 634)		
Calorimetry	Richard Wigmans	Richard.Wigmans@ttu.edu	(806) 742-3779
Collaborating institutions: U.C. San Diego Iowa State Texas Tech			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 50,000 FY06: 120,000 FY07: 80,000			
new proposal	6.17. Ultimate Hadron Calorimetry (p. 644)		
Calorimetry	Richard Wigmans	Richard.Wigmans@ttu.edu	(806) 742-3779
Collaborating institutions: U.C. San Diego Iowa State Texas Tech			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 50,000 FY06: 50,000 FY07: 30,000			

renewal	7.2. Scintillator Based Muon System R&D: 3-Year Proposal (p. 655)		
Muon System	Paul Karchin	karchin@physics.wayne.edu	(313) 577-5424
Collaborating institutions: UC Davis Fermilab Northern Illinois Notre Dame Rice Wayne State UT Austin			
Previously awarded support: FY04: 11,000 FY05: FY06: DOE			
Request for new support: FY05: 162,067 FY06: 165,547 FY07: 160,937			
renewal	7.5. Continuing Studies of Geiger-Mode Avalanche Photodiodes for Linear Collider Detector Muon System Readout (p. 673)		
Muon System	Robert J. Wilson	wilson@lamar.colostate.edu	(970) 491-5033
Collaborating institutions: Colorado State			
Previously awarded support: FY04: 15,000 FY05: FY06: DOE			
Request for new support: FY05: 36,560 FY06: 91,572 FY07: 0			
new proposal	7.6. Design and Prototyping of a Scintillator-based Tail-catcher/Muon Tracker (p. 679)		
Muon System	Vishnu Zutshi	zutshi@fnal.gov	(815) 753-3080
Collaborating institutions: Colorado State DESY Fermilab NIU Pavia Wayne State			
Previously awarded support: FY04: FY05: FY06:			
Request for new support: FY05: 87,800 FY06: 107,100 FY07: 165,800			

Reference

Technical documentation evolves, design reports are supplanted, but the marvelous carrot cake recipe endures: http://www.hep.uiuc.edu/home/g-gollin/carrot_cake.html.