FY2009
University ILC Detector R&D

Scintillator Based Muon System & Tail-Catcher R&D

January 23, 2009

Personnel and Institutions requesting funding

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Mitchell Wayne, Mike McKenna, , *University of Notre Dame, Notre Dame, Indiana*

Paul Karchin, Kranti Gunthoti, Alfredo Gutierrez, Caroline Milstene, *Wayne State University, Detroit, Michigan*

Collaborators

H. Eugene Fisk, Kurt Krempetz, Adam Para, Paul Rubinov, *Fermilab, Batavia, Illinois*

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Marcello Piccolo, *INFN, Laboratori Nazionali di Frascati, Frascati, Italy*

Giovanni Pauletta, Walter Bonvicini, Diego Cauz, Anna Driutti, Aldo Penzo, Lorenzo Santi, *Universita di Udine and INFN Trieste – GC Udine, Italy*.

Steven Manly, *University of Rochester, Rochester, New York*

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Project Leaders

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Project Overview

Our focus is on the design of an ILC muon detector and hadronic shower “tail-catcher” using scintillator strips readout by silicon photomultipliers (SiPM). Our group works primarily with the SiD collaboration, but some of us also collaborate with the CALICE and ILD collaborations. The SiD muon system is designed to identify muons from the interaction point with high efficiency and to reject almost all hadrons (primarily pions and kaons). The muon detectors will be installed in the gaps between steel layers of the solenoid flux return. The muon system will start outside of the highly segmented electromagnetic and hadronic calorimeters and the 5T solenoid cryostat at a radius of 3.40 m. The muon detectors will be inserted in the 4 cm gaps between steel plates. In the barrel, a detector layer is also inserted between the solenoid and the first steel plate. The total detector area needed in the barrel is 2050 m^2 and each endcap has a total detector area of 1220 m^2.

Muon systems characteristically cover large areas and are difficult to access or replace. Reliability and low cost are major requirements. Over 2.2 meters of steel thickness will be required for the solenoid flux return, providing 13.2 hadron interaction lengths to filter hadrons emerging from the hadron calorimeter and solenoid. Since the central tracker will measure the muon candidate momentum with high precision, the muon system only needs sufficient position resolution to unambiguously match calorimeter tracks with muon tracks. Present studies indicate that a resolution of 1-2 cm is adequate.

In 2000 it was noted that the ILC muon system requirements could be met with a MINOS type scintillator detector design [1] that would give both muon identification and be used to measure the tails of late developing or highly energetic hadron showers. This seems rather appropriate since the depth of the ILC calorimeters is limited because they are inside a superconducting solenoid. As an example, neutral hadrons that represent ~11% of the final-state energy in Higgs and W-W production, primarily neutrons and K-longs, prove to be difficult to identify and measure [2]. The physics case for tail catching of showers is based on improvement of jet energy resolution when the energy downstream of the SC solenoid is included in the definition of jet energy [3, 4].

The MINOS experiment has proven that a strip-scintillator detector works well for identifying muons and measuring hadronic energy in neutrino interactions. The ILC muon scintillator detector R&D effort [5-10] is directed at

- understanding how to deploy such detectors in the ILC environment,
- making possible improvements that could lead to reduced complexity and /or cost, with photon detection based on SiPMS, and
- establishing the potential performance of an hadronic tail-catcher based on analysis of TCMT test beam data.

To accomplish these goals, we propose to characterize the performance of various SiPMs from different manufacturers and to assemble prototype planes of scintillator strips with imbedded wavelength shifting fibers readout by SiPMs. This involves developing an effective optical coupling to the SiPM and a front-end electronics board for the SiPM that will provide enough amplification to transmit the SiPM signal to a data acquisition module, while maintaining low noise. We will consider the required accuracy for maintaining the temperature and bias voltage of the SiPMs to insure stable operation of a multi-channel detector system. Liquid nitrogen temperature operation of the SiPMs will be investigated as a possible trigger option. We will use radioactive sources, cosmic rays and a particle beam at the Fermilab Meson Test Beam Facility to establish the operational performance of the prototypes.

We plan continued analysis and operation of the CALICE-TCMT prototype calorimeter and hadronic tail catcher. (CALICE stands for CAlorimeter for a LInear Collider with Electrons and TCMT stands for tail-catcher/muon-tracker.) The data will be used to quantify the improvement in jet energy resolution that can be expected and to demonstrate operational performance of a large channel count (~300) scintillator strip system read out by SiPMs.

All of these efforts are towards establishing the performance and cost of a full-scale system for SiD and other potential ILC detectors.

[1] Para, A. ``Solid Scintillator-based Muon Detector for Linear Collider Experiments'' Physics and Experiments with Future Linear e+e- Colliders, ed. A. Para and H. E. Fisk (2001) pg. 865-869, American Institute of Physics, Melville, New York (Vol. 578).

[2] Frey, R. ``Experimental Issues for the Workshop'', International Conference on Linear Colliders -- LCWS 2004, p 29 Eds. H. Videau & J-C. Brient, Editions de l'Ecole Polytechnique, Julliet 2005, 91128 Palaiseau Cedex.

[3] M. Charles, SiD Workshop, University of Colorado, Status of PFA in SiD, September 17, 2008 (unpublished).

[4] P. Salcido, (CALICE Collab.) LCSW08 Calorimeter & Muons Session: TCMT and combined analysis, Nov. 17,2008.

[5] P. Karchin, “A Scintillator Based Muon Detector for the Linear Collider,”
in proceedings of the meeting of the Division of Particles and Fields of the American Physical Society, University of California, Riverside, August, 2004, International Journal of Modern Physics A, World Scientific Publishing Company.

[6] R. Abrams et al., “LC scintillator-based muon detector tail-catcher R&D”. FERMILAB-CONF-07-589-E, LCWS-2007-CAL14, Nov 2007. 5pp. International Linear Collider Workshop (LCWS07 and ILC07), Hamburg, Germany, 30 May - 3 June 2007, SLAC eConf C0705302 Proceedings, S. Riemann (ed.).

[7] `”Investigation of a Solid-State Photodetector'', D. Beznosko et al, NIM A545:727-737, 2005; “Effects of a Strong Magnetic Field on LED, Extruded Scintillator and MRS Photodiode'', D. Beznosko et al, NIM A553:438-447, 2005; ``Modular Design for Narrow Scintillating Cells with MRS Photodiodes in Strong Magnetic Field for ILC Detector'', D. Beznosko et al, NIM A564:178-184, 2006.

[8] J. Hill, “Temperature dependence of MPPC parameters”, LCWS08 Calorimeter & Muon session, Nov. 19, 2008.

[9] P. Salcido, (CALICE Collab.), “TCMT and combined analysis”, LCWS08 Calorimeter & Muon Session: Nov. 17, 2008.

[10] Web page: www.physics.niu.edu/nicadd/research/lcd/tcmt for the TCMT (in preparation).

Status Report

Earlier strip-scintillator R&D [5] using 4.1 cm wide by 1 cm thick extruded MINOS style scintillator that was readout with multi-anode photomultiplier tubes (MAPMTs) demonstrated that > 9 photo-electrons were achieved with 1.8m long strips in which the wave-length shifted scintillation light was carried to MAPMTs through a thermally fused clear optical fiber to the MAPMT a few meters away [6]. The light transmission was required to be > 80% for each splice.

We have recently procured silicon based photon detectors (SiPMs) for tests with our scintillator. Sixty multi-pixel photon counters (MPPCs) have been purchased from Hamamatsu: 20 each of 100, 400 and 1600 pixels in a 1 mm square array. In addition INFN Udine-based collaborators have obtained about 100 IRST SIPMS that have approximately 688 pixels inside a 1.2mm dia. circular matrix for muon/tailcatcher R&D.

Recently strips with MPPCs and IRST devices have been assembled and tests with beam have begun. A real advantage of the SIPMS is the ability to see the summed output of several pixels and observe a number of photo-electron peaks. A disadvantage is that they put out spontaneous pulses with no defined input (noise). This disadvantage can be parlayed into an advantage in terms of calibration. On a good oscilloscope, as shown in Figure 1, we can see bands of 1, 2 and sometimes 3 photo-electrons that give a reasonable calibration. This calibration aspect needs study and engineering, which is part of our proposed R&D program. Figure 2 shows SiPMs mounted in transistor-style cases, a specially developed front-end board on which the SiPM is mounted, and the charge response of the SiPM to light pulses from an LED. The individual peaks for *n* photons are clearly visible.

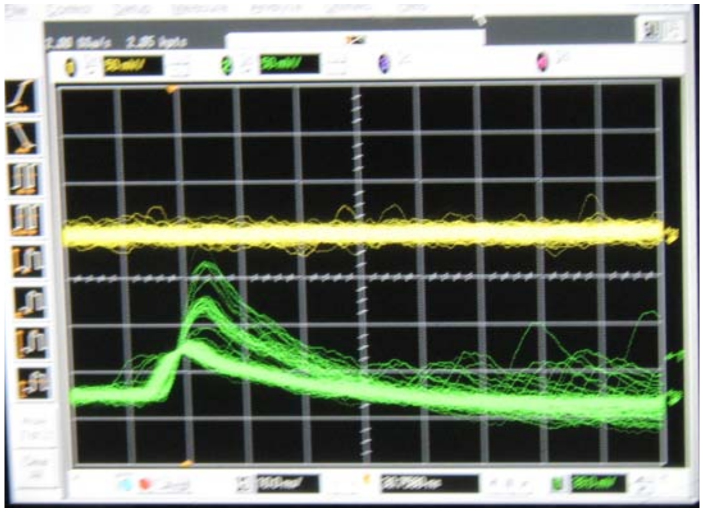

Figure 1. Oscilloscope display of pulses from SiPMs showing bands for 1, 2 and 3 photons.

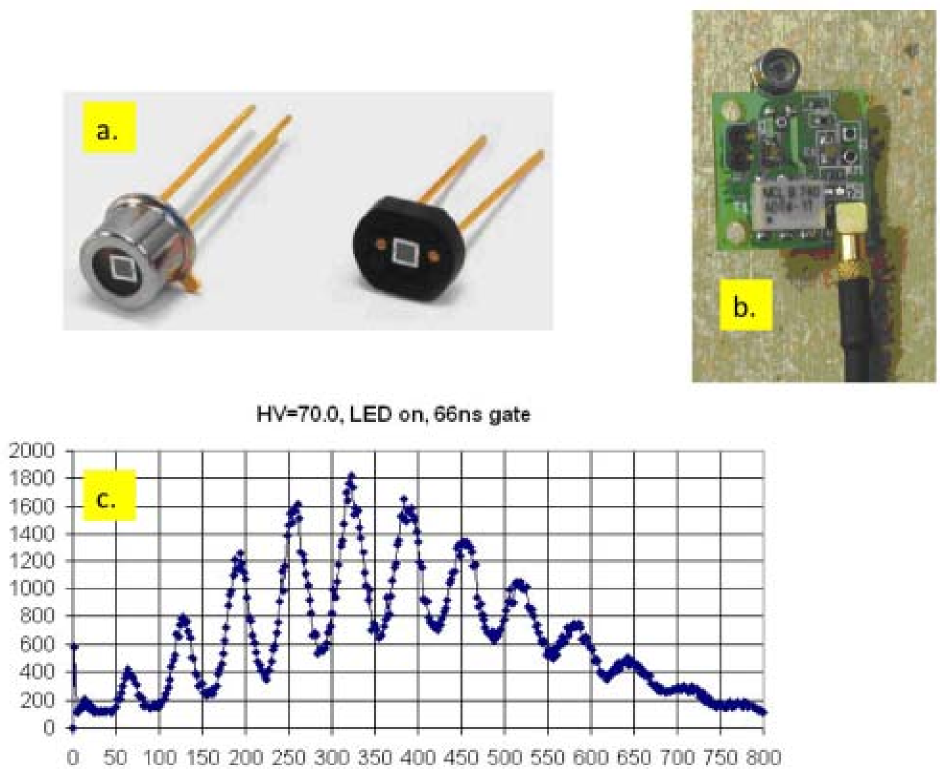

Figure 2. (a) Hamamatsu MPPC devices in transistor-style packages; (b) front-end electronics board with SiPM mounted on the top edge; (c) charge distribution from LED pulsing.

In November of 2008, we tested a MINOS 1.8 m long scintillator bar with embedded WLS fiber readout with Hamamatsu and IRST SiPMs as part of Fermilab test experiment T956. The front-end board shown in Figure 2 was mounted close to the end of the scintillator bar so that the WLS fiber could abut the SiPM. The response of the IRST SiPM to a 120 GeV pion beam through the scintillator is shown in Figure 3. The gain is calibrated using the single photon "tail" of the pedestal. The signal for through-going protons is very clear and corresponds to approximately 25 detected photons.

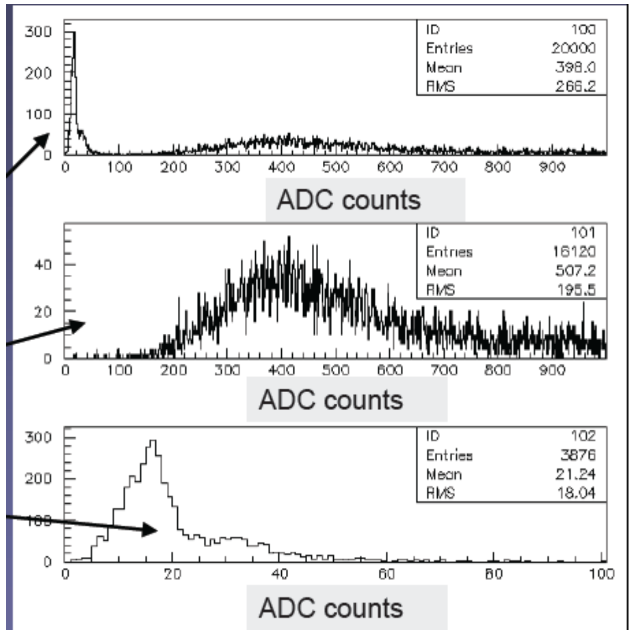

Figure 3. Charge distributions in response to 120 GeV proton beam through MINOS scintillator bar with WLS fiber readout with an IRST SiPM. top: "loose" trigger allowing large pedestal contribution; middle: "tight" trigger using other counters to select a good track; bottom: "loose" trigger with region of small ADC counts showing pedestal "tail" from single photons.

For a SiPM system deployed in full-scale ILC detector, variations in noise rate and gain among channels and as a function of time will have to be kept to acceptable levels. The temperature dependence for a 100-micron pixel-size Hamamatsu SiPM is shown Figure 4. Such measurements are needed for a good sample of devices and are proposed for our future R&D program.

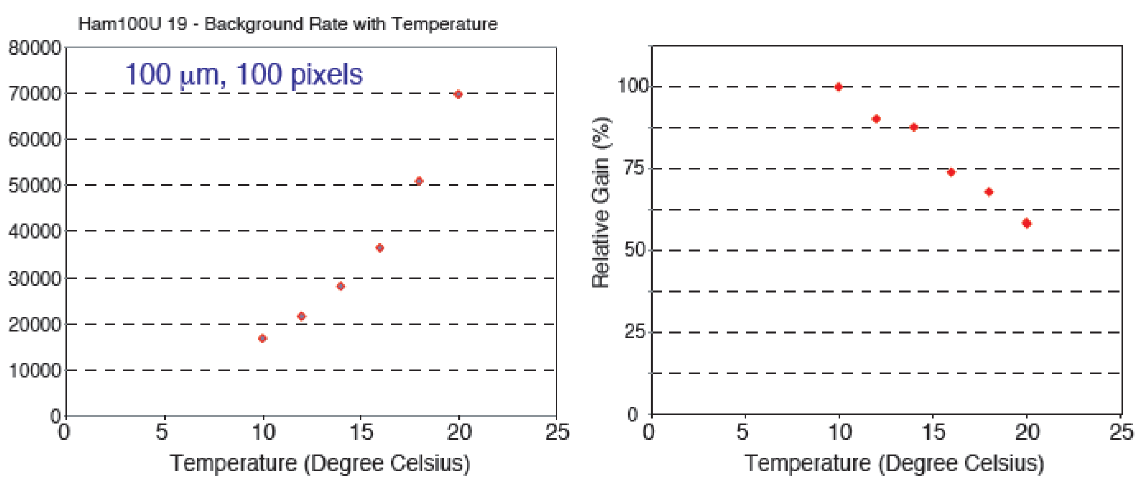

Figure 4. Hamamatsu 100 micron SiPM – effect of temperature on (left) background rate; (right) gain.

NIU's effort has been in two areas. The first is continued studies of silicon photomultipliers from a number of manufacturers including some studies of their matching to scintillator elements. These included the constitution, shape, size, and surface treatment of scintillating elements, light collection and routing of wave-length shifting fiber, response uniformity, efficiency, cross-talk, ageing, and radiation hardness. Detailed measurement of the characteristics of the photon detectors included operating bias voltage, dark rate, linearity of response, temperature dependence, stability, radiation hardness and immunity to magnetic fields were made [7]. Recently NIU has been doing additional studies (with A. Para) on the temperature dependence of characteristics such as breakdown voltage, gain, dark rates, IV curves, carrier density, crosstalk, and after-pulsing of the latest detector generation [8]. Devices studied include Hamamatsu 025u, 050u, 100u MPPCs and IRST SiPMs. Additional studies (with P. Rubinov) have begun to look at the performance of a number of devices (IRST SiPM and CPTA MRS) at liquid nitrogen temperatures. For the IRST, a reduction of about 100 in dark current and a lowering of the breakdown voltage were observed during the initial study.

As members of the CAlorimeter for a LInear Collider with Electrons (CALICE) collaboration, NIU designed and built, using extruded scintillator strips read out with MPPCs, the tail-catcher/muon-tracker (TCMT) section (Fig. 5) of a full-depth prototype calorimeter, which has been undergoing beam tests at CERN and Fermilab since 2006. A silicon-tungsten electromagnetic calorimeter and a steel-scintillator hadron shower imager were exposed to test beams in the H6B area at CERN for a month each in 2006 and 2007 and the MTBF at Fermilab in 2008. The hadron shower imager physically consists of two parts: a hadron calorimeter (HCAL) and the TCMT. Both devices use SiPMs to read out scintillator elements with embedded WLS fibers. The active layers of the TCMT consist of 1m long, 5 cm wide and 5 mm thick extruded scintillator strips. The strips were manufactured using the NIU/NICADD extruder at Fermilab's Scintillator Detector Development Laboratory (SDDL). A 1.2 mm outer diameter Kuraray WLS fiber is inserted into the co-extruded holes that run along the length of the strips. The strips and their associated SiPMs in each layer are enclosed in a light tight sheath or cassette which also provides the skeletal rigidity. The 16 cassettes (in total 320 channels) are inserted, alternately in the X and Y orientation, in a steel absorber stack which has a fine and coarse section. The upstream fine section consists of eight 2 cm thick steel plates while the coarse section is comprised of 10 cm thick steel absorber for a total of approximately six interaction lengths. The fine section sitting directly behind the hadron calorimeter and having the same longitudinal segmentation as the HCAL provides detailed measurements of the tail-end of a hadronic shower while the following coarse section serves as a prototype muon system. Both the HCAL and TCMT use common electronics and DAQ boards developed by CALICE.

A large sample of electron, pion, proton and muon events along with pedestals and LED calibration data were collected. Analysis of the CERN data, which includes studies of the calibration, attenuation, cross-talk, efficiency, and noise, clearly indicates that the TCMT performed to specifications. The rightmost panels in Fig. 6 demonstrate that hadrons punching through the HCAL section of the CALICE module deposit significant energy in the TCMT. Energy resolution can be improved by correlating the shower shape in the HCAL with the leakage estimated with the TCMT. Results from these analyses have been shown at various conferences including LCWS08 [9].

Figure 5. The 1m cube, 5 ton TCMT.

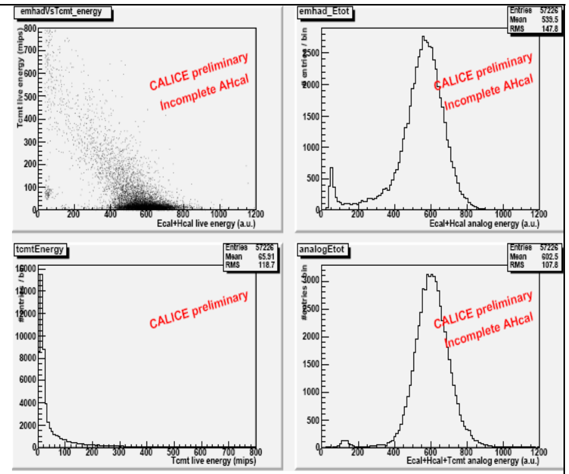

Figure 6. Response of CALICE calorimeter with and without the TCMT.

Recent analysis of TCMT data measures how the energy uncertainty for hadronic showers decreases with calorimeter depth for pions in the energy range 10 to 80 GeV, as shown in Figure 7. These measurements illustrate the importance prototype systems for accurate design of large scale detectors.

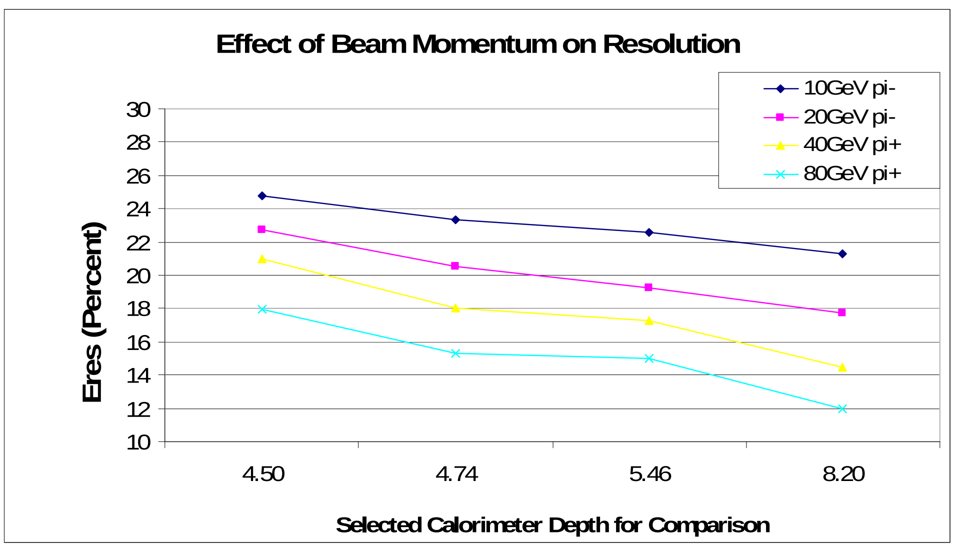

Figure 7. Analysis of data from Tail-Catcher/Muon Tracker operation showing how energy resolution improves with absorber thickness. The TCMT is the first large scale system using scintillator bars with SiPM readout.

Facilities, Equipment and Other Resources

The key resources at Fermilab are the Meson Test Beam Facility, SciDet and the CALICE-TCMT apparatus. The universities seeking funding under this proposal have electronics instrumentation for making SiPM measurements (all) and mechanical facilities for scintillator and fiber preparation (NIU and ND).

FY2009 Project Activities and Deliverables

We plan to fabricate and test a modest number (of order 10) of scintillator strips readout with various SiPM devices, including ones from Hamamatsu, IRST and possibly SensL and Zapotec. We will employ a general purpose readout with 12 bit precision and 4 ns sampling. Radioactive sources, cosmic rays and particle test beams at Fermilab will be employed.

An extensive bench test program is planned to characterize the SiPMs with measurements of I-V characteristics, gain, and noise rate, their dependence on temperature, and the distribution of parameters for a sample of several tens of devices of a single type. The data will be used to design a control system to minimize the gain and noise rate variations to acceptable levels for a large system.

We plan to continue analysis of the existing Tail Catcher Muon Tracker (TCMT) data and continue operation of CALICE-TCMT in the Fermilab test beam.

For the universities requesting funding here, the proposed activites are as follows:

- Northern Illinois University – procurement of new SiPM devices, comparison of LN2 and room temperature operation of SiPMs, CALICE-TCMT operation and analysis
- University of Notre Dame – gain and noise of SiPMs versus temperature at room temperatures, comparison of commercial and specialized front-end amplifiers, strip and fiber mechanical R&D
- Indiana University – design of bias voltage and temperature control system, test-beam support
- Wayne State University – comparison of SiPMs from different manufacturers, test beam support

Following are detailed goals for each university and laboratory group, including related activities of collaborators not funded under this proposal.

<u>Northern Illinois University</u>

NIU, in collaboration with Fermilab, has coordinated procurement of SiPM devices from Hamamatsu and SensL using previous ILC funding. New vendors are emerging, including Zapotec. NIU will continue to coordinate procurement.

NIU will continue characterization of silicon photodetectors at room and liquid nitrogen temperatures and development of their associated electronics including calibration and DAQ. This will be done in collaboration with Fermilab using test setups at Fermilab and NIU.

Analysis of existing CALICE-TCMT test beam data is ongoing plus NIU will participate in future runs at the Fermilab test beam. Among the questions which can be addressed are the impacts of the coil, return yoke, and support structures on hadronic energy resolutions for different configurations of the fine calorimeter and tail catcher.

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<u>University of Notre Dame</u>

Item 1. Test of SiPM devices as a function of temperature, gain and other parameters. We have put together a test bench that will allow us to vary from room temperature down to about -30 C. We will also compare our own amplifiers vs. the Hamamatsu amp.

Item 2 - Strip and Fiber Mechanical R&D. Mike McKenna has already done some nice work here. We will continue to work on coupling fibers to the SiPM, mirroring, and fiber polishing in-situ.

<u>Indiana University</u>

The Indiana (IU) group will perform continued measurements of temperature variations of noise, bias voltage, and gain as a function of temperature for SiPMs from different vendors as supplied by Fermilab. They will work with the WSU group on the temperature measurement, temperature control, and bias voltage requirements suitable for a selected SiPM, leading to the design and fabrication of a prototype monitoring, LED flasher, and control system. This system will be implemented in the testing of prototype muon detectors run in a testbeam or in a cosmic ray setup.

The IU elecrical engineer Paul Smith (supported by the Department) will also work with Fermilab as needed, contributing to the modification/interfacing of Fermilab data aquisition electronics reading out all channels of the prototype muon detectors.

Wayne State University

The WSU group will measure the variances of SiPM gains and noise rates for sufficiently large quantities of devices from the same vendor. This will determine the requirements on the detector control system for the precision of bias voltage control and monitoring of temperature and bias voltage. WSU will coordinate the design of the detector control system with Indiana University. WSU will assist in procurement of SiPMs, and operation of prototype detector systems with cosmic rays and/or a particle beam.

COLLABORATING INSTITUTIONS:

Fermilab

The Fermilab group continues to work on the issues that confront calibration of scintillator-derived signals using SiPMs. We measure a mean of ~25 photo-electrons (1m long strips) when all aspects of the muon prototype system are working properly. To adopt the strip-scintillator/SiPM our calibration and monitoring scheme must be proven. A simple and particularly convenient calibration would be to make use of noise pulses that result in one, two and three photo-electrons. We note that typically the bias-voltage for each SiPM is slightly different. We further note that both the SiPM noise rates and SiPM gain depend on the temperature of the SiPM. A possible solution to the latter problem may be to provide an appropriate vernier voltage to add to the nominal ground to equalize gains among different SiPMs as does T2K.

The Fermilab group will continue to develop its DAQ system for LC hardware tests with cosmic rays and test beam based on its experiences with a prototype amplifier system that we have used to take data with a high frequency digital oscilloscope. A higher performance DAQ prototype board has been designed that for the most part uses pieces from other Fermilab experiments that the experiment support electronics group has previously developed and used in MICE, Minerva and MIPP (Troiseme DAQ module). The 8" X 4.5" 4 channel PCB module will report 12-bit digitizations at 4 ns intervals using four high-speed digitizers. It will include a high band-width differential amplifier and an FPGA (XC3S1200E) for data storage that can also be used for digital filtering, triggering, and zero-suppression. The board will also feature a USB interface and an on-board bias-voltage generation with individual channel adjustment, bias current measurement and support for measurement of SiPM temperature via a thermocouple.

This board is not a readout system for the ILC muon system or any other LC system. It is an R&D development tool that is not very expensive, but it can be added to via daughter cards to provide data storage and/or other functionality. The parts cost per board is about $650. The board has 12 layers and the layout follows good practices as requested by the parts manufacturers. The FPGA allows a programmable approach to prototyping future hardware development or data handling algorithms such as filtering, signal shaping, signal integration, etc. We consider this to be a very handy test station or test beam DAQ module for ILC development.

Colorado State University

Tests of A-Peak devices, coordination with T2K experiment.

INFN, Laboratori Nazionali di Frascati

Coordination with simulation and RPC R&D

INFN (Section of Trieste) and University of Udine

Our research interests/expertise include scintillator-based calorimetry and large-area scintillator based muon counters. In this context, we are interested in the development of light sensors and collaborate with FBK IRST (Trento) in the development and testing of SiPMs (Project FACTOR financed by INFN) We are also interested in the development of scintillator extrusion techniques.

Resources and infrastructure: INFN Trieste has extensive experience in detector development, including, in particular silicon detectors for both accelerator (e.g. ALICE) and space-based experiments (e.g. PAMELA) and extensive infrastructures (electronics shop, equipment and clean rooms for handling silicon and mechanical shop). Udine has particular experience in muon detectors and scintillator - based calorimetry (CDF) and has collaborated in the construction of the ATLAS silicon vertex detector.

Past activity in SiD muon R&D: We began collaborating on test beam experiment T956 with the introduction IRST SiPMs prototypes in 2006. These tests are continuing. IRST has furnished 100 customized 1.2 mm diameter SiPMs for the purpose. Recent (Nov. 2008) tests at MT show much improved collection efficiency compared to the prototype SiPMs. About 25 photoelectrons / mip were observed with T956 extruded strips in a 120 GeV beam.

Future Plans: We intend to continue collaborating on the development of muon counter/tail catcher for SiD. In addition to developing SiPMs for the project, we are also interested in collaborating on FE electronics and scintillator extrusion.

University of Rochester

Simulation, coordination with MINERVA and T2K

University of Wisconsin

Coordination with SiD, RPC R&D

Budget and Budget Justification

Northern Illinois University

Funds for a month for Alexandre Dyshkant are requested to support improvements to the SiPM test setup at NIU and for additional testing at liquid nitrogen temperatures. Funds to support a graduate student during the summer are also requested with this student working on further characterization of SiPMs and their associated electronics. The equipment funds will be used to purchase additional silicon photo-detectors for use by all collaborating institutions. Funds to support future TCMT activities including Fermilab test beam operations are in a separate proposal.

Northern Illinois University Budget FY2009

ITEM	**Amount**
Other Professional (research scientist), 1 month	$5,600
Graduate Student (3 months)	$5,400
Total Salaries and Wages	**$11,000**
Fringe Benefits (43% scientist)	$2,400
Graduate Student Tuition	
Total Salaries, Wages and Benefits	**$13,400**
Equipment	$10,000
Total Travel	$1,200
Materials and Supplies	$1,300
Other Direct Costs	
Total Direct Costs	**$25,900**
Indirect Costs (26% of MTDC)	$4,100
Total Direct and Indirect Costs	**$30,000**

Indiana University

Travel is for Electrical Engineer Paul Smith (supported by the Department) and student (TBD) to travel to Fermilab and Wayne State for design and installation work.

Indiana University Budget FY2009	
ITEM	**Amount**
Student (TBD), 3 months	$8,100
Electrical Engineer (Paul Smith), 6 weeks	$0
Total Salaries and Wages	**$8,100**
Fringe Benefits, Health insurance	$1,224
Student Fee remission	$1,449
Total Salaries, Wages and Benefits	**$10,773**
Equipment	$1,000
Total Travel	$1,131
Materials and Supplies	$3,000
Other Direct Costs	
Total Direct Costs	**$15,904**
Indirect Costs	
(Off-campus, 26% of ...	$294
(On-campus, 51.5% of	$4,802
salaries, fringe, travel, supplies and other)	
Total Direct and Indirect Costs	**$21,000**

University of Notre Dame

Salary support is requested for an undergraduate student for 10 hours/week over 15 weeks, three months for technician Mike McKenna, and ½ month for engineer Barry Baumbaugh.

Materials are for work on coupling fibers to SiPM readout, and to develop in situ methods for fiber polishing and end treatment.

University of Notre Dame Budget 2009

ITEM	**Amount**
Other Professional (research engineer), 0.5 month	$3,500
Other Professional (technician), 3 months	$9,900
Undergraduate Student, 15 weeks	$1,200
Total Salaries and Wages	**$14,600**
Fringe Benefits (30.4% eng., 15.2% tech.)	$2,565
Total Salaries, Wages and Benefits	**$17,165**
Materials and Supplies	**$1,000**
Total Direct Costs	**$18,165**
Indirect Costs (26% of MTDC)	$4,723
Total Direct and Indirect Costs	**$22,888**

Wayne State University

Travel is for Research Engineer Alfredo Gutierrez and graduate student Kranti Gunthoti to come to Fermilab for planning, installation and operation activities. Materials are for SiPM testing at WSU.

Wayne State University Budget 2009

ITEM	Amount
A. Gutierrez (research engineer), 1 month	$4,829
K. Gunthoti, graduate student (2 months - summer)	$4,723
Total Salaries and Wages	**$9,552**
Fringe Benefits (25.8% eng., 8.7% grad.)	$1,657
Graduate Student Tuition	$1,217
Total Salaries, Wages and Benefits	**$12,426**
Equipment	
Total Travel	$2,355
Materials and Supplies	$1,343
Other Direct Costs	
Total Direct Costs	**$16,124**
Indirect Costs (26% of MTDC)	$3,876
Total Direct and Indirect Costs	**$20,000**

Total Project Budget

Total Project Budget 2009

ITEM	Amount
Other Professionals	$23,829
Students	$19,423
Total Salaries and Wages	**$43,252**
Fringe Benefits (various)	$7,846
Graduate Student Tuition	$2,666
Total Salaries, Wages and Benefits	**$53,764**
Equipment	$11,000
Total Travel	$4,686
Materials and Supplies	$6,643
Other Direct Costs	
Total Direct Costs	**$76,093**
Indirect Costs (26% of MTDC)	$17,795
Total Direct and Indirect Costs	**$93,888**

Project Activities and Deliverables Beyond FY2009

While in FY2009 we will use a general purpose data acquisition system, beyond that we want to develop an ASIC and/or characterize an existing ASIC that is compatible with an SiPM and fits into a specific global architecture, such as SiD. For example the SiD KPIX chip may be modifiable for use with SiPMs.

Providing that a scintillator-based muon system remains a strong candidate for SiD or another detector design, we envisage construction of a larger-scale prototype – beyond that established in FY2009.

We would like to begin simulation studies of overall detector performance for muons, with a reasonably detailed model of the muon system, based on properties measured from real prototypes.

Broader Impact

The activities of the institutions on this proposal have had a number of broader impacts on education, both in physics and in related fields, and on the general public through outreach activities. Student involvement in research is a critical aspect of the program. Tasks included testing MPPCs and other silicon photodetectors, assembling and testing prototype counters, construction of the TCMT, and test beam efforts at CERN and Fermilab including data analysis. During the 2004-2008 period, 20 students from Indiana, NIU, Notre Dame and Wayne State worked on ILC muon detector R&D. This includes ten undergraduates and high school students, some supported by REU and QuarkNet funds. Some of these students end up as researchers in HEP and others are able to apply what they learn in diverse fields such as the oil industry, oceanography, and materials science. Two M.S. degrees were completed and it is anticipated that two additional M.S. degrees and a Ph.D. will be completed in 2009.

Members of this proposal are also involved in curricular innovations meant to expand the teaching of the concepts and technologies of particle physics to a broader audience. NIU has been working with mechanical engineering faculty and students who are designing and constructing apparatus as part of their required design class which we will be used in our detector R&D effort. In 2008 they designed and built a large temperature-controlled box which will be used for future MPPC studies. Outreach to the community and to K-12 schools is an important priority for our group. Notre Dame administers the Quarknet program and NIU, Notre Dame, and Wayne State held Quarknet summer institutions during the previous four year period, with students participating in scintillator-based detector R&D.