Background Material

For Detector R&D Activities at Argonne National Laboratory

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I. Summary of Major Achievements

1. Introduction

This set of seven sections describes the Detector R&D program in the HEP division at Argonne National Laboratory. It lists the achievement over the last three years and the ongoing activities describing the current status. It concentrates in the Research Plan on outlining the plans, directions and intentions for the future of this program. The program outlined is not only funded by DoE, but in many cases is also funded by Laboratory Directed R&D funds (LDRD) or other sources. The purpose of this documentation is to describe the overall program, how the activities interrelate and how resources are leveraged to strengthen the particle physics program. We do not limit ourselves to those programs that are solely DoE funded. This places the detector development in full context and provides the reader with a complete overview of the program and insight in its strategic direction. Our work in the area of optical readout, for example, illustrates this. The development work was initiated using LDRD funding and to date that has been its only support. The R&D has already been very successful and is now being carried forward directly from LDRD funding to being part of the ATLAS upgrade R&D within the energy frontier. The request made here is for continued R&D based on the success to date. The funding source for each effort is always indicated. We also try to indicate what the status of the funding is: either funded or future funding has been requested. All this information is in the text, but to make it somewhat more easily accessible an overview table listing all the R&D areas that are described in the document is given below indicating what the funding status and sources are. The amount of funding for each, either in hand or requested can be found in the accompanying budget tables. When there is no entry in the table it means that no funding is requested.

Detector R&D Area	**Initiation**	**FY10-12**	**FY13**	**FY14**	**FY15**
Digital RPC HCAL	*LDRD*	*DoE funded*	*DoE request*	*DoE request*	*DoE request*
Telescope Design	*LDRD +UofC Seed funds*	*LDRD + DESY*			
Topological Trigger	*LDRD*	*LDRD + DOE*			
CCD Testing	*LDRD*	*LDRD*			
Transition Edge Sensors	*LDRD*	*LDRD + DOE*	*DoE request*	*DoE request*	*DoE request*
Large Area Photo Detectors	*LDRD, UofC Seed funds + ARRA funding*	*DoE funded*	*DoE request*	*DoE request*	*DoE request*
Trigger	*Early Career*	*Early Career*	*DoE request*	*DoE request*	*DoE request*
Optical Readout	*LDRD*	*LDRD*	*DoE request*	*DoE request*	*DoE request*

Table 1: *Funding history and request for current Detector R&D projects.*

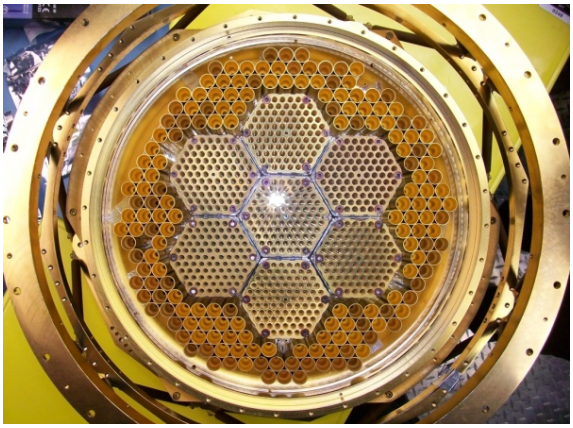
2. Sensors

2.1 Transition Edge Sensors

The major milestone accomplishment for the ANL superconducting detector group is the successful deployment of SPTpol, a CMB polarization experiment on the South Pole Telescope (SPT) focused on probing the physics of inflation and constraining the sum of the neutrino masses. For SPTpol, ANL fabricated and delivered 376 dual polarization 90 GHz Transition Edge Sensor (TES) bolometers (see Figure 1, left). Successful deployment involved:

1. Optimization of detector design and fabrication including fine-tuning of the detector thermal conductance and normal-superconducting transition. Throughout this process, ANL has pioneered the technique of using lithographed superconducting structures to engineer the superconducting-normal transition width of a TES (see Figure 2). The ANL developed transition engineering enables stable TES operation while using high quality, well-controlled thin films.
2. Fabrication of science-grade detectors, beginning in April 2011 and ending in December 2011.
3. Extensive testing and quality assurance after which the detectors were delivered and installed onto the SPT platform. The detectors comprise the 90 GHz channel of the SPTpol focal plane (Figure 1, left) and are operating successfully. All devices have the desired saturation power, noise, loop gain, time constant, co-polar coupling, and cross-polar isolation.

This work was initially funded through Laboratory Directed R&D (LDRD) and was carried out in the HEP division in collaboration with the Materials Science Division at ANL and the University of Chicago. The successful deployment and operation on the South Pole Telescope represents a major achievement for the ANL-TES program. An image of the galactic HII region taken with these detectors is shown in Figure 1 (right).



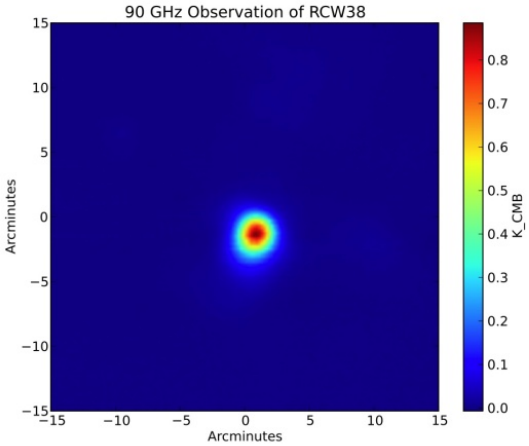


Figure 1: *The SPTpol focal plane. ANL developed detectors observing the CMB at 90 GHz constitute the outer ring of the focal plane. The detectors were successfully deployed in austral Summer 2011-12 and achieved first light on January 26, 2012 (left). SPTpol 90 GHz image of the galactic HII region, RCW38, taken during commissioning (right).*

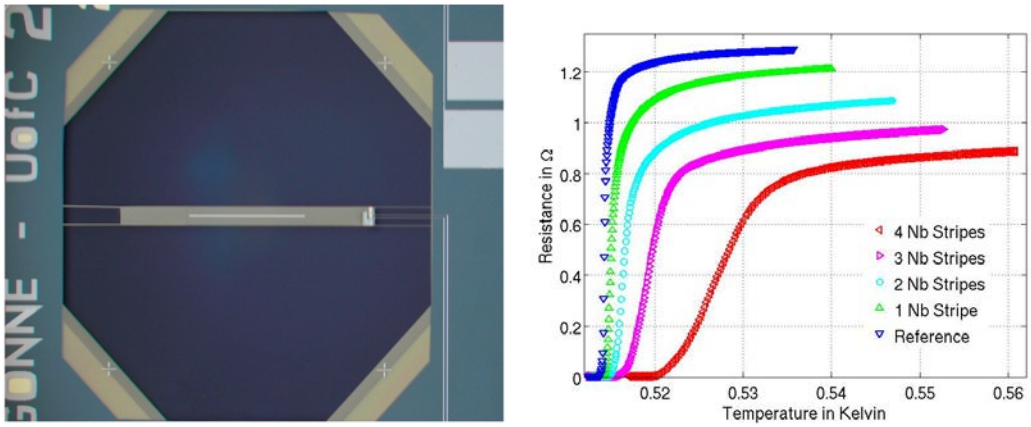


Figure 2: *Left: The ANL developed CMB polarimeter consists of a half wavelength dipole-like antenna, which couples to a single waveguide mode and a Mo/Au bi-layer TES on a thermally isolated silicon nitride rectangle. The TES measures temperature changes caused by the absorbed CMB photons. Right: Demonstration of tailoring the TES normal-superconducting transition width through lithographed structures. The reference curve is for a 40 µm wide and 70 µm long Mo(20nm)/Au(30nm) bi-layer TES with 2 Nb leads. The other curves represent the same TES but with one, two, three, or four 3 µm wide and 100 nm thick Nb stripes equally distributed on top. The transition widths of the TESs are 0.4 mK, 1.7mK, 2.5mk, 4.5mK, and 9.7 mK for the reference TES and the TESs with one, two, three or four Nb stripes respectively. The use of Nb lithographed structures on the TES permits tailoring of the superconducting-normal transition width for an optimized TES performance in CMB applications.*

2.2 Large-Area Picosecond Photo-Detector

The Large Area Picosecond Photo Detector (LAPPD) project is an R&D effort to develop 8” x 8” planar, cost-effective photodetectors, which can be assembled in 2 x 3 or 3 x 4 arrays (see Figure 3). The project started with LDRD funding followed by seed funding through a University of Chicago – Argonne collaborative grant and ARRA funding and then transitioned to full support from the DoE generic detector development program. During the past three years, we have fabricated 8 inch square photocathodes for these tiles with efficiencies of ~20% at 400 nm (see Figures 4 and 5); 8 inch square pairs of microchannel plates with gains of ~10^7, time resolutions of ~10 psec; and position resolutions of ~1 mm; and waveform sampling ASIC electronics which can readout microchannel plate signals while preserving signal resolution (see Figure 6).

The project is broken down into four technical areas: borosilicate glass capillary array Micro-Channel Plate (MCP) development, hermetic mechanical assembly, photocathode development and characterization, and electronics and system integration. Argonne manages the entire project, provides the technical expertise and capability for microchannel plate Atomic Layer Deposition (ALD) activation with Secondary Electron Emission (SEE) materials and characterization of these materials. We would like to note that the Large Area Microchannel Plate ALD Technology has recently received an R&D100 award[1]. The laboratory has acquired a Burle system for the development of large area photocathodes, and has been leading the development of an all-glass tile housing. It is expected that one or more 8” tiles will be successfully fabricated before the end of the 2012 fiscal year. Industry has licensed the ALD technology from Argonne for large area MCP fabrication and is showing interest in tile fabrication. The Advanced Photon Source at Argonne provides femto-second laser testing and measurement capability.

[1] The R&D100 Award is organized annually by R&D magazine since 1962 for the top technologies and is widely considered to be the “Oscars of Innovation." http://www.rdmag.com/News/2012/06/R-D-100-Awards-Top-Technology-Innovations-Names-For-50th-RD-100-Awards/

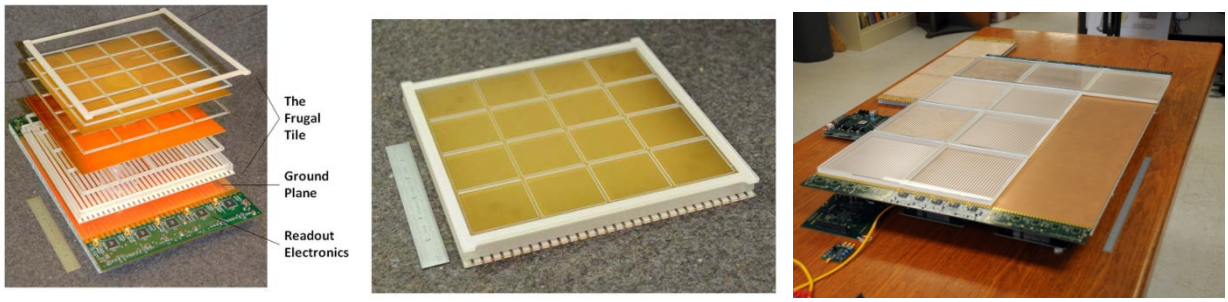


Figure 3: *An exploded view of an 8"x8" planar photodetector is shown on the left with a picture of the assembled package in the center. The picture on the right shows the 4x3 supermodule concept.*

High energy physics applications include use in water Cherenkov neutrino detectors for track reconstruction based on timing, time-of-flight measurement systems for both charged particles and photons, and precision spatial resolution detectors for charged particle beams. These photodetectors are also expected to have applications in nuclear physics, basic energy sciences, medical imaging, and homeland security. A few details of our accomplishments in the four areas are listed in the next four paragraphs.

Borosilicate Glass Capillary Array Microchannel Plates of high quality, hollow core, economical borosilicate substrates have been successfully produced at Incom, Inc. through a collaboration with the project. Their subsequent functionalization via atomic layer deposition (ALD) promises to have a transformational effect on fabrication of microchannel plates (MCPs), which has been recognized through an R&D100 award. Incom, Inc. has licensed the ALD technology from Argonne. The major accomplishments in this area are:

1. Developed a test facility at Argonne that includes a femto-second UV laser for position, time response, and gain measurements. At Space Sciences Lab/Berkeley (SSL) lifetest/aging and gain-mapping facilities have been developed.
2. Successful separation of the optimization of the three components of an MCP: the substrate, the resistive structure within the pores, and the secondary electron emitter. Systematic characterization measurements at Argonne of secondary emission materials versus incident electron energy were carried out to determine the choice and thickness of the ALD secondary-emitting layer.
3. Developed and licensed the process for functionalizing MCPs with a tunable resistivity ALD layer
4. Demonstrated gains of up 3×10^7 from pairs of ALD-functionalized 8"-square plates and a gain of 3×10^5 from a single 8" plate.
5. ALD-functionalized pairs of plates have been shown to have no degradation of gain up to a present test limit of 7 C/cm^2 extracted charge.
6. Completed full simulation of shower development within the MCP that models electric field structure, secondary emission, and shower development at the atomic level.

Packaging of MCP pairs into a hermetically sealed housing has proceeded through two alternative efforts at Argonne/University of Chicago and SSL. The SSL group is developing a ceramic-brazed housing with an indium alloy top window seal made under high temperature so that the indium melts; high voltage is applied to the MCPs and photocathode individually with pin penetrations and signals from the anode striplines are brought out via pins. At Argonne, an all-glass housing has been developed which accomplishes HV input and signal output without the use of pin penetrations. Our accomplishments with regard to the packaging alternatives are:

1. Design of an economical tile vacuum with no external pin penetrations and an internal ALD-based resistive HV divider integrated into the MCPs and glass spacers.
2. Fabricated a 50Ω stripline anode from silk-screened silver ink fired onto the B33 glass bottom plate and completed a detailed design of a $0.5m^2$ "Supermodule".

3. Demonstrated hermetic indium top window seals on 1” and 4” prototypes at Argonne and at the University of Chicago.
4. Completed the design, cost, and schedule for an 8” all-glass tile fabrication system using vacuum transfer at Argonne.
5. Developed a hermetic 8” ceramic housing using a top window seal made with molten indium.
6. Characterized the multi-strip anode for the ceramic package at SSL.

Figure 4: *The LAPPD laser test lab developed at the Argonne APS (left); The glass cathode forming well before installation in the Burle equipment; This glass well was created by a 4th generation glass blower at the Argonne glass shop (middle); The Burle PMT facility at Argonne (right).*

Bi-alkali photocathode development and characterization is ongoing at both SSL and Argonne. SSL is pursuing a NaKSb photocathode (see Figure 5) and Argonne is developing a K_2CsSb photocathode. The accomplishments for photocathode development are:

1. Studied the compatibility between plate glasses, underlying oxide layers, and the alkali photocathodes.
2. Growth of uniform 8” NaKSb photocathodes with quantum efficiency up to 25% at SSL.
3. Growth of uniform ~6” photocathodes with QE of ~17% and characterization at ANL for tile photocathode development. A UHV system for high QE development is being assembled.
4. Acquired a commercial PMT production system from Burle/Photonis for transfer of the Burle bialkali PMT photocathode recipe. Photocathodes with QE of 24% have been produced on 1” tubes supplied by Burle.
5. Established a measurement and theory-based multi-institutional program with BNL, Washington University at St. Louis and the University of Chicago to understand the scientific basis for growth and performance of alkali photocathodes.

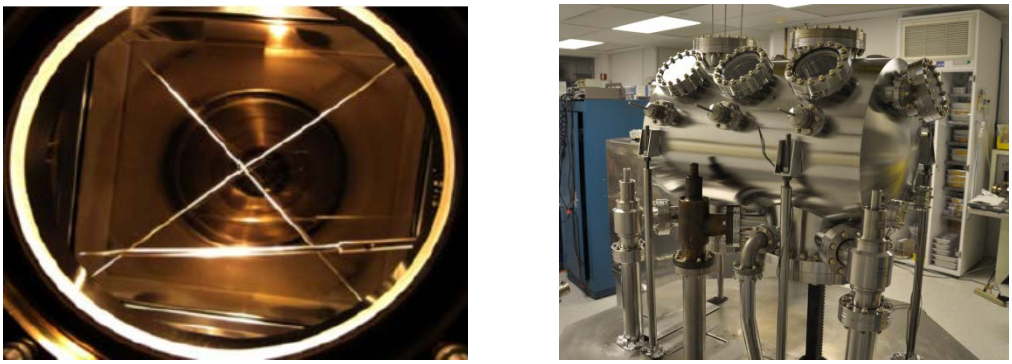


Figure 5: *LAPPD 8” alkali photocathode with QE of over 20% produced by the Berkeley group at SSL (left); the large process tank at SSL for the photocathode growth (right).*

In support of the work done at Argonne, described above, front-end electronics for the readout of both the SSL ceramic tube and the Argonne glass tile has been designed and fabricated by the Universities of Chicago and Hawaii. Their major accomplishments in the framework of the LAPPD project, though not necessarily Argonne accomplishments, are:

1. Developed scalable modular large-area Tile-Tray with precision space and time resolutions but low electronics channel count.
2. Developed a 6-channel waveform-sampling ASIC with 17GHz sampling rate, 10-bit resolution, 750µV noise, and 1.6GHz analog bandwidth (see Figure 6).
3. Developed a five ASIC front-end analog card interfaced to a 30-strip anode.
4. Developed a Digital Card to provide local computation of time, charge and shape of waveforms.
5. Developed a Central Card for collection of time and shape information from 4 Digital Cards to compute time and position of hits over the full "SuperModule" plane and transmits data to a DAQ computer
6. Developed a package for waveform analysis.

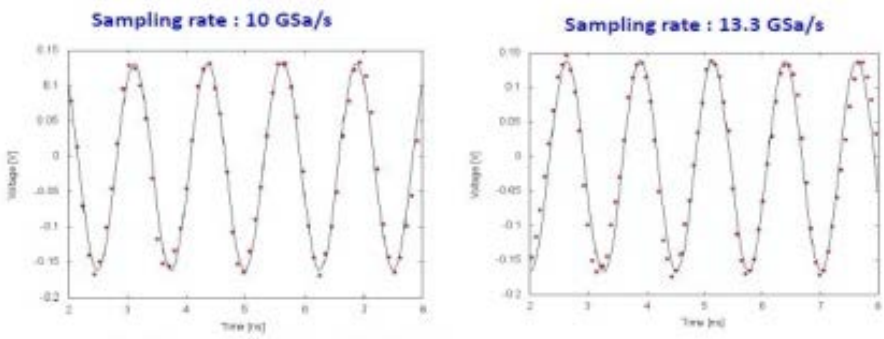


Figure 6: *Performance of the PSEC-4 ASIC (red points) to an 800 MHz, 300 mV peak-to-peak input sine wave sampled at 10 and 13.3 GHz. Only a simple pedestal correction has been applied (left). A simultaneous display of a fast pulse digitized on a Tektronix scope (price at time of purchase $142,000) and the PSEC-4 ASIC.*

Figure 7 shows the test results from a pair of 8" ALD-functionalized MCPs. The left figure shows the pulses as measured at both ends of an 8" glass tile anode strip. The signal is produced using the femto-second laser at the Argonne Advanced Photon Source illuminating an aluminum photocathode. The differential time resolution versus noise for an MCP pair compared to a simple simulation is shown in the right figure. A timing resolution of better than 5ps and a space resolution better than 0.5mm has been achieved to date.

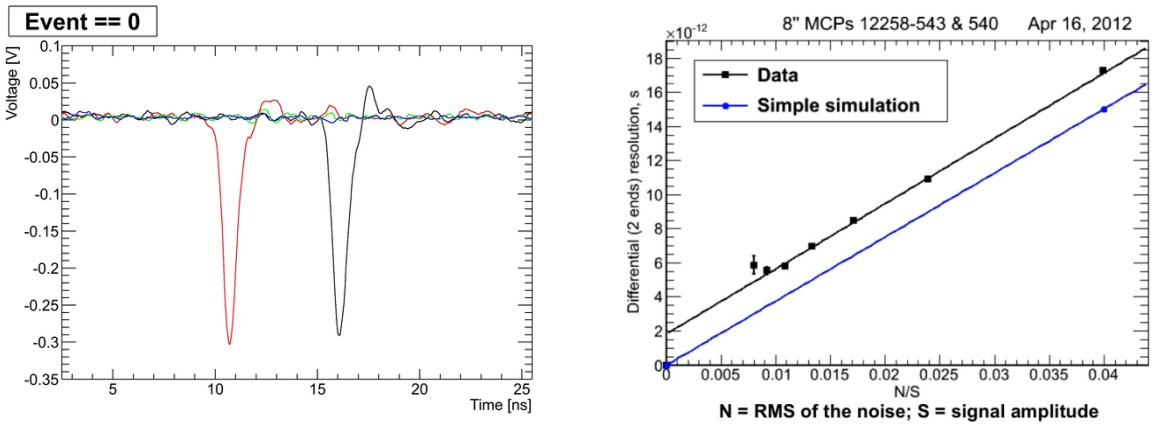


Figure 7: *Pulses from a pair of 8" ALD-functionalized MCPs measured at both ends of an 8" glass tile anode strip (left); Differential time resolution versus noise for an MCP pair compared to a simple simulation (right).*

3. Charge-Coupled Devices

ANL has developed a portable Charge Coupled Device (CCD) test stand to study various types of anomalies found in CCDs. This device has been used at the Argonne Advanced Photon Source X-ray laboratory to study backside illuminated (normal) and frontside illuminated CCD diffusion and edge effects [1]. Observed shifts in measured centroids for backside-illuminated CCDs are compatible with published engineering models of the CCD electric field line distortions. For two different frontside-illuminated CCDs, diffusion over several pixels perpendicular to the edge was observed (see Figure 8). This is not consistent with published models and is not understood. The back-illuminated data is being used as input to the reconstruction of galaxy weak-lensing in the Dark Energy Survey (DES) experiment and is an integral part of its science program. This work was solely supported by LDRD funds and has been completed during the review period.

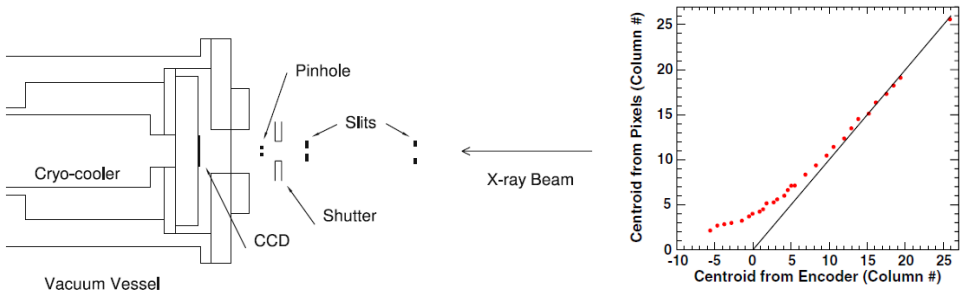


Figure 8: *A sketch of the setup at the Argonne Advanced Photon Source X-ray facility, showing the beam and defining slits, pinhole, shutter, CCD, and vacuum vessel (left). A comparison of centroids from the xyz stage encoder and as measured by the CCD for front-illuminated CCDs (right).*

4. Data Acquisition and Electronics

4.1 Level 2 and Topological Trigger

This R&D, initiated using LDRD funds and completed using detector R&D funds, has focused on applying particle-physics detection techniques to develop a fast pattern trigger for real time analysis of nanosecond timescale phenomena to particle astrophysics experiments. This work has been in collaboration with Iowa State University (ISU). The topological trigger architecture uses Cherenkov shower images from particle astrophysics experiments and the parallactic displacement of the reconstructed shower detected in multiple telescopes to provide gamma/hadron separation capabilities at the telescope array trigger level [2]. An intricate part of our trigger design relies upon a single telescope Level 2 (L2) trigger capable of alignment of pixels better than a nanosecond. Based upon our implementation of a L2 trigger demonstrator system installed on a single telescope at VERITAS, we successfully competed in a VERITAS NSF upgrade proposal and built and delivered a new L2 trigger with all the hooks in place to add a future array level topological trigger, also designed by Argonne. The new L2 trigger allows for a much narrower coincidence gate between adjacent pixels in the camera, down to 3-4 ns, compared to the previous L2 9-10ns coincidence. The new L2 trigger has been built, tested and installed by ANL & ISU on all four telescopes at VERITAS. Figure 9 shows the trigger rate in Hz as function of the Constant Fraction Discriminator (CFD) threshold of the photodetector in mV before (left) and after (right) implementation of the new L2 trigger. The colored curves are the response for the four different telescopes; the black curve is the response after the VERITAS multiple telescope requirement. It is clear that the response of the telescopes is much more uniform with the new trigger. Also the inflection point, which indicates the transition from the night sky background (steep curve) to the cosmic ray flux (power law curve), is lowered significantly.

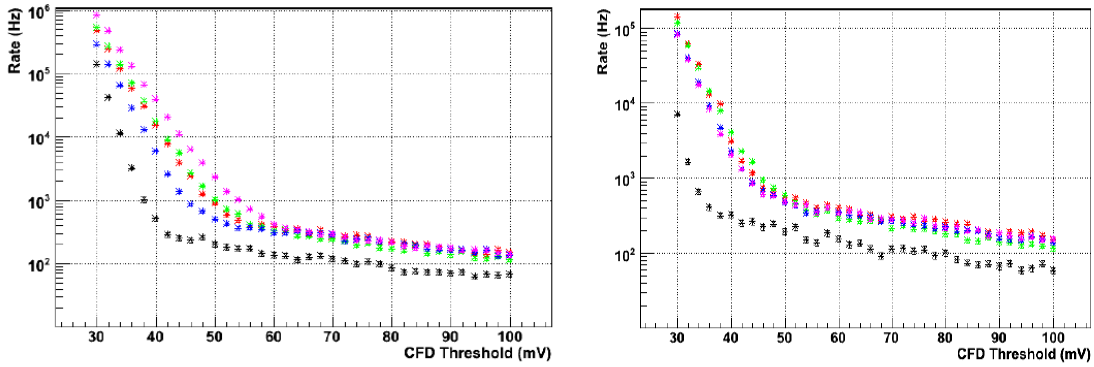


Figure 9: *Trigger rate in Hz of the four VERITAS telescopes as function of the discriminator threshold of the photodetector in mV, with the trigger response in black after the multiple telescope requirement before the Argonne built Level 2 implementation (left) and after (right).*

Commissioning continues in preparation for the final phase of the upgrade in the summer of 2012 when the focal plane PMTs will all be replaced with higher QE PMTs. Although this work has been completed, further R&D is possible within the framework of the Cherenkov Telescope Array (CTA) where the impact of a topological trigger would have a large effect on reducing and stabilizing the high trigger and data rates. ANL and ISU are pursuing R&D ideas for implementing an array level topological trigger.

4.2 Optical Data Transfer

Argonne has been developing experience with modulators over the past three years funded by the laboratory's LDRD program. One of the original motivations for this work was to develop a more robust, lower mass replacement system for the LHC detector optical fiber readout systems. The initial system that was constructed used a continuous wave (CW) laser with a Lithium-Niobate ($LiNbO_3$) light modulator to generate an optical data stream in air using Micro Electro Mechanical System (MEMS) mirrors to allow remote steering of the optical data stream to the detector. Two demonstrator systems were constructed which operated over ~1 meter at 1 Gb/s. The first used MEMS mirrors and optical feedback with sophisticated filters in order to steer the beam. The second one used a second laser beam for alignment to enhance the angular range over which steering could be done.

Another demonstrator was built and operated at 1 Gb/s over 80 meters using diffraction limited beams to eliminate most of the $1/r^2$ loss and technology was developed to enhance the steering over much larger distances. It was found that the very small beam sizes required for long distance transmission in air put very stringent constraints on the optical qualities of the MEMS mirrors. The MEMS mirror for this test was constructed at the Argonne Center for Nanoscale Materials (CNM) and was found to be both electrically and optically unacceptable. CNM is now pursuing a second iteration.

When it became clear that the LHC detector groups (the ATLAS calorimeter group in particular) were not concerned about eliminating the small detector mass of the optical fibers in the readout system but were much more interested in finding a higher bandwidth, radiation hard replacement for the VCSEL-based links currently in use, the primary focus of our R&D moved to optical modulators. An Electro Optical Modulator (EOM) is ideally suited to replace both copper and VCSEL-based links. They provide very large gains in bandwidth, footprint, power and reliability and can work with reliable, stable, continuous wave (CW) lasers either on or off detector.

EOMs use a material with an electro-optic effect to modulate a beam of light with an electrical signal. There are two basic kinds of EOMs of interest, Electro Absorption Modulators (EAM), and Mach-Zehnder Interferometer-based modulators (MZI). Recently many commercial EOMs have been developed based on semiconductors. These EOMs are extremely small in size, ultra-low in power consumption and can be integrated into CMOS. Luxtera has monolithically fabricated a 0.13µm CMOS Silicon On Insulator (SOI) integrated 40 Gb/s single chip MZI modulator-based transceiver [3]. This is a 4-channel transceiver with the drivers, modulators and PIN diodes all integrated into a single CMOS chip. A functional block diagram and a photo of the CMOS die are shown in Figure 10. The Commercial Off-The-Shelf (COTS) version of this chip has a CW laser integrated in the package. Given the enormous progress made by industry in this area, we believe that the development of radiation tolerant COTS devices for use in collider detectors is the most promising avenue to address the future needs of the particle physics experiments.

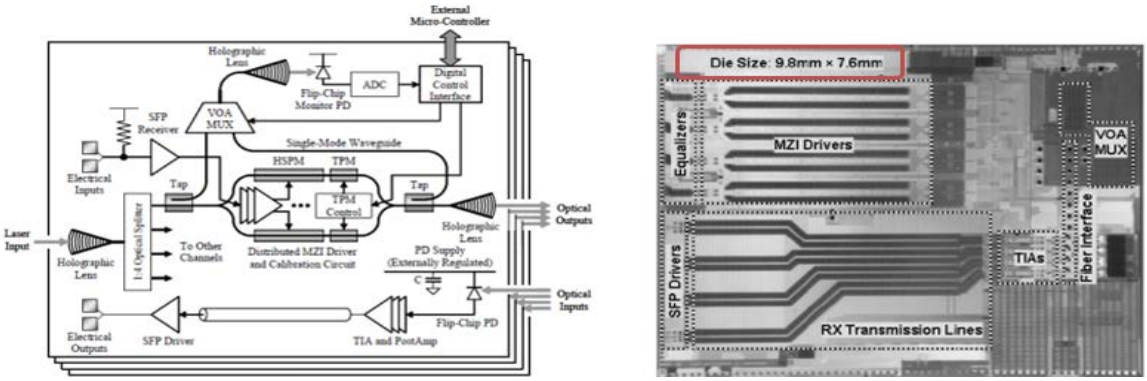


***Figure 10**: Luxtera 0.13 µm CMOS SOI integrated 40 Gb/s single chip MZI modulator-based transceiver: Block diagram (left) and photo of the CMOS layout (right).*

To this end we have started a collaboration with Luxtera and characterized the 4-channel, bi-directional, Quad Small Form-factor Pluggable (QSFP) module manufactured by Luxtera. It is a 40 Gb/s transceiver with 4 channels of 10 Gb/s bi-directional links (see Figure 10), which has great potential for the ATLAS calorimeter system data acquisition system. This link was characterized at 10 Gb/s in the lab with 200 m of fiber and the 'bathtub plot' of the bit-error-rate (BER) tests and the eye diagram for that system is shown in Figure 11. The predicted BER is less than 10^{-18} based on the bathtub plot (see Figure 11). This exceeds the current VCSEL BER by six orders of magnitude.

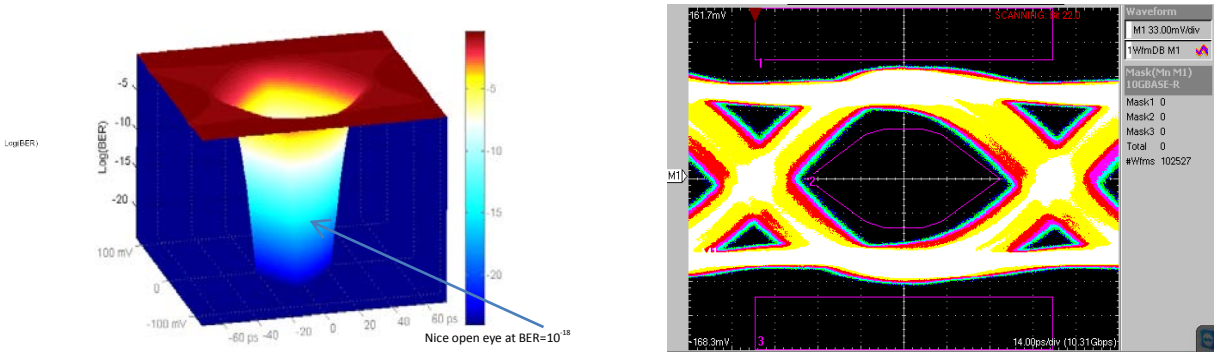


***Figure 11**: Bathtub plot of BER tests done at Argonne showing an extrapolated BER of 10^{-18} (left); measured eye diagram of the commercial Luxtera modulator at 10Gb/s with 200m of fiber (right).*

Radiation studies were carried out using both protons at Massachusetts General Hospital (MGH) to test for single event effects (SEE) and electrons at the Argonne Van der Graaff Accelerator for total ionizing dose (TID). Preliminary results show that the basic integrated optics chip is rad-tolerant up to the levels we tried, and that work is needed on external support chips. With protons, it is clear that no SEE happens with a fluence of ~10^{11} p/cm^2. However, with protons and electrons, we do observe a control problem at a TID of ~65 krad. This control problem may be due to the on-board microcontroller and we aim at developing external controls for the modulator using rad-tolerant FPGAs. All work to date has been supported by LDRD funds.

The success of this R&D has been communicated with the LHC community and the integration of the Luxtera chip into the readout is now being carried out as part of the ATLAS upgrade R&D within the energy frontier. This is one example where LDRD initiated detector development has found direct application into a running experiment, skipping any direct DOE detector support. Based on our success in this area we propose an extended research plan, beyond the ATLAS tile-cal application, described in detail in the research plan.

5. Detector Systems

5.1 Digital Hadron Calorimeter with Resistive Plate Chambers

This project aims at developing a viable hadron calorimeter for the application of Particle Flow Algorithms to reconstruct hadronic jet energies with excellent energy resolution. It was initiated using LDRD funds and subsequently supported from the DOE generic detector development program. Within the PFA paradigm the role of the hadron calorimeter is to measure the energy associated with neutral hadronic particles, such as neutrons and K_L's. In this approach the challenge is to unambiguously classify energy deposits in the calorimeter as belonging to charged particles (and therefore to be ignored) or to neutral particles (and therefore to be measured). As a consequence, the optimal application of PFAs requires calorimeters with the finest possible segmentation of the readout. In addition, PFAs impose further requirements on the active element. Since both the electromagnetic and the hadronic calorimeters are foreseen to be located inside the coil, the thickness of the active elements needs to be minimized. The noise rate needs to be reasonably small, to minimize confusion with the identification ad classification of energy deposits in the calorimeter. Finally, the active elements need to satisfy general performance criteria, such as reliability, stability, rate capability and affordability.

Resistive Plate Chambers (RPCs) fulfill all these requirements [4]. During the review period a full-scale prototype calorimeter was built. In preparation for the construction of this prototype, the study of various RPC designs, the construction and testing of a small scale calorimeter prototype, and a Vertical Slice Test (VST) was carried out. The results of the VST were published during the current review period [6-9]. The deliverable for the current review period was the construction and testing of a full-scale DHCAL physics prototype.

The DHCAL prototype contains 54 layers, each approximately 1 x 1 m^2 in size. The layers are subdivided into three RPCs each with the dimensions of 32 x 96 cm^2. A top view of a chamber is shown in Figure 12. The distance between the glass plates is maintained with the help of fishing lines and a sleeve surrounding the lines. The challenge of reading out large numbers of channels was met with the development of an ASIC, the DCAL chip. Each chip is connected to 64 pads. A common threshold is applied to all pads and the output is a hit pattern together with a time-stamp with a 100 ns resolution. The electronic readout consists of a Readout board, a Data Collector system and a Timing and Trigger module. Each Readout board covers half an RPC and consists of a Pad-board (containing the 1x1 cm^2 pads) and the Front-end board (containing the DCAL chips and a data concentrator). The Data Collector system is based on VME and receives the data from the data concentrators. The Timing and Trigger Modules provide the overall synchronization of the readout system. The RPCs and the

readout boards are combined into a detector layer. The layers contain a 2mm thick copper front-plate to cool the ASICs and a 2 mm thick steel back-plate. Figure 12 shows a photograph of such a layer. With 54 active layers the DHCAL counted 497,664 individual readout channels, a world record for both calorimetry and RPC-based systems.

The DHCAL was tested extensively in the Fermilab testbeam. The layers were inserted into CALICE Analog HCAL Steel absorber structure, which in turn rests on a movable stage. The DHCAL was tested in various configurations: with the scintillator Tail Catcher, with the Tail catcher equipped with RPCs, with or without the CALICE Silicon – Tungsten ECAL in front, and also with minimal absorber material between layers. Table 2 summarizes the five data taking periods at Fermilab.

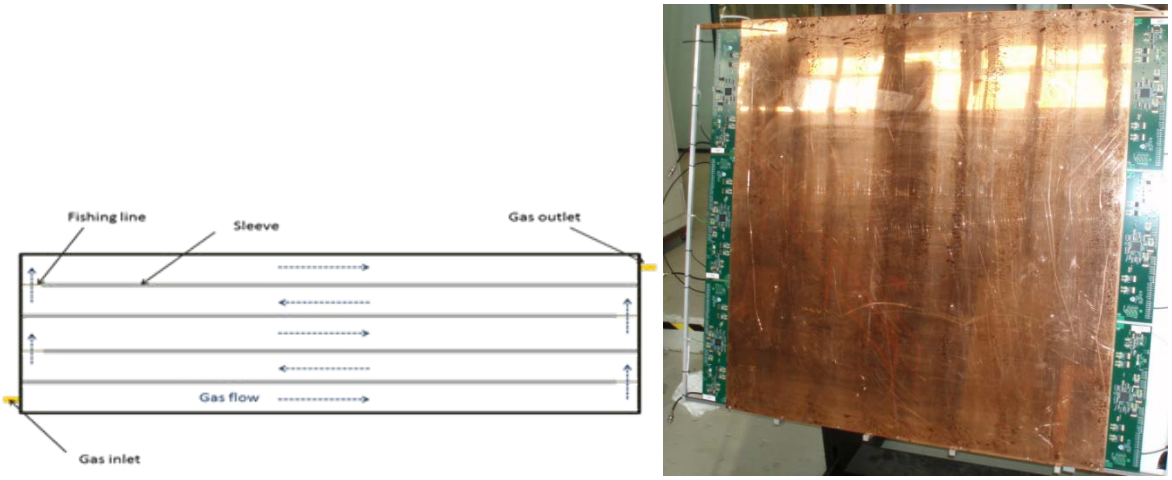


Figure 12: *A top view of an RPC showing the layout of the fishing lines and their sleeves (left). The gas flow is indicated with the dashed arrows (drawing is not to scale); A photograph of a detector layer (right).*

In 2012 the DHCAL layers were transported to CERN where they were inserted into the CERN Tungsten absorber structure. Measurements at the Proton Synchrotron with beams in the momentum range of 1 – 10 GeV/c have been completed. The tests at the Super-Proton-Synchrotron (SPS) are currently ongoing. The SPS offers tests beams with energies in the 10 – 350 GeV range. So far about 30 Million events have been collected in the CERN test beam.

Run period	**Configuration**	**Detector layers**	**Collected μ events**	**Collected secondary beam events**
October 2010	DHCAL	38	1.4 M	1.7 M
January 2011	DHCAL+ TCMT	38 + 13 = 51	1.6 M	3.6 M
April 2011	Si-Tungsten ECAL+ DHCAL+ TCMT	30 + 38 + 14 = 82	2.5 M	5.1 M
June 2011	DHCAL+ TCMT	38 + 14 = 52	3.3 M	2.7 M
November 2011	Minimal absorber	50	0.6 M	1.3 M
Total			**9.4 M**	**14.4 M**

Table 2: *Summary of the data taking periods at Fermilab.*

The DHCAL is a novel type of calorimeter. To first order the energy E of an incident particle is reconstructed as being proportional to the number N of pads hits. However, a non-vanishing noise rate and variations in the chamber efficiencies and average pad multiplicities need to be corrected for, such that the energy of an incident particle is reconstructed as

$$E \propto \sum_{i=0}^{n} N_i \cdot \frac{\varepsilon_0}{\varepsilon_i} \cdot \frac{\mu_0}{\mu_i} - N_{noise},$$

where the sum runs over all layers of the detector, ε_0 and μ_0 are the average MIP detection efficiency and the average pad multiplicity of the detector, respectively, and ε_i and μ_i are the MIP detection efficiency and average pad multiplicity of layer I, respectively. N_{noise} is the average contribution from noise. The accidental noise rate was measured both with random triggers and with trigger-less acquisitions. Confirming our measurement with the VST [5], the rate was found to be relatively low, but with dependence on the temperature and pressure of the stack. For a given event, the accidental noise rate adds on average 0.01 to 0.1 hits in the entire DHCAL, where 1 hit corresponds to about 60 MeV.

Muons traversing the DHCAL were collected using the 32 GeV/c secondary beam of the Fermilab MTBF facility, a 3 m long iron absorber and a trigger based on the coincidence of a pair of 1x1 m^2 scintillator paddles located upstream and downstream of the detector. Muon events were utilized to align the layers geometrically, to measure the response across a single pad, and to measure the local response of RPCs (efficiency and average pad multiplicity). As an example, Figure 13 (left) shows the MIP detection efficiency ε_i, the average pad multiplicity μ_i and the so-called calibration factors, $c_i=(\varepsilon_i\mu_i)/(\varepsilon_0\mu_0)$, as measured with two different techniques (long tracks and track segments) versus layer number. The average response, i.e. the distribution of the number of hits, in clean regions of the stack, i.e. away from borders and fishing lines, was measured and is being used to tune the Monte Carlo simulation of the RPC response. Figure 13 (middle) shows a comparison of the measured and simulated RPC response.

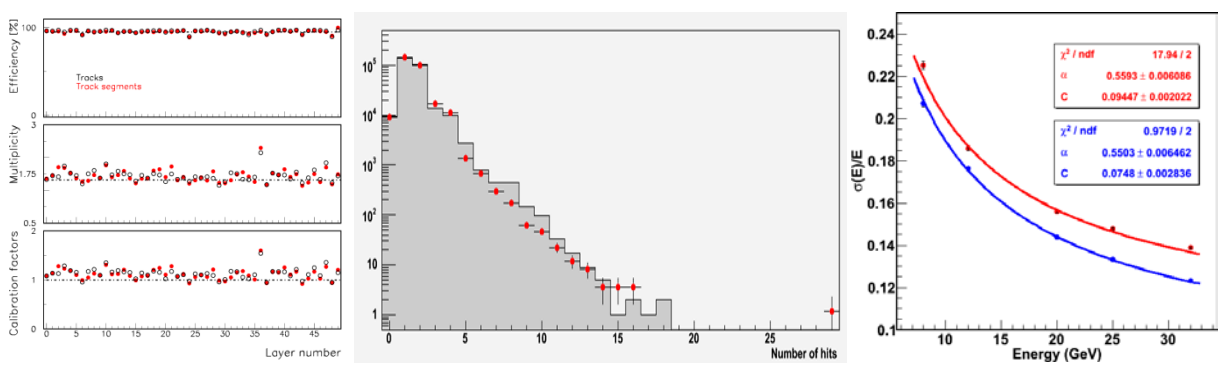


Figure 13: *MIP detection efficiency, average pad multiplicity and calibration factors as function of layer number, as measured with both tracks and track segments (left); Response of a detector layer to muons averaged over the entire DHCAL with the histogram (red data points) showing data (simulation) (middle); Measured energy resolution for pions. The red (blue) lines and points correspond to an event selection without (with) a longitudinal containment requirement (right).*

Secondary beam particles were collected at momenta between 1 and 60 GeV/c. In addition, large data samples with the primary 120 GeV proton beam were also collected. Due to the rate limitation of RPCs, the trigger (provided by the coincidence of two 19 x 19 cm2 scintillator paddles positioned upstream of the DHCAL) accepted positrons and hadrons indiscriminately. The particles were later identified offline based on the information from the Cerenkov counters. As an example, Figure 13 (right) shows the measured resolution for pions in the range of 8 to 32 GeV/c. The red (blue) points are without (with) a longitudinal containment requirement. These results are in good agreement with predictions based on GEANT4 and the simulation of the RPC response based on measurements with the VST [9].

In this review period we set out to build a full-scale prototype digital hadron calorimeter and expose it to test beams to study the PFA paradigm to complete our R&D program. All of our milestones have been met and the program is arguably the most successful program within the CALICE calorimeter project. With the data analysis still in a preliminary state, there are nevertheless a few conclusions to be drawn regarding an RPC-based digital hadron calorimeter:

- The RPC technology fulfills the requirements of the active media of a highly segmented calorimeter.
- The dark rate in the DHCAL is below 1 Hz/cm^2 and corresponds to a negligible amount of energy added to a single event [5].
- RPCs with glass plates as resistive plates are reliable and operate stably; Long-term tests showed no changes in performance [5].
- The rate capability of RPCs is well understood and is adequate for most of the solid angle of a hadron calorimeter in an e^+e^- colliding beam detector [6].
- Due to the large number of channels and the novel way of measuring energy, the calibration of the DHCAL is very challenging. Several different approaches are being studied, but a final procedure has not yet been established.
- The response of a given layer needs to be uniform all the way to the edges. This is achieved by maintaining a constant thickness of the gas gap. Due to a minor imperfection in the channels used to construct the rims of the chambers, in the DHCAL the gas gaps at the rim often increase slightly, leading to a reduced response. This problem and its cause have been studied and are understood. In general, tolerances in chamber construction need to be kept at a level well below 100 µm.
- The response to muons has been studied in great detail and resulted in a precise geometrical alignment of the layers, a scan of the response across the surface of a single pad, and the measurement of the response to single particles across the surface of a detector plane. The results are well understood and have been adequately reproduced using Monte Carlo methods.
- The response to positrons is as expected and consistent with predictions based on the VST [8]. As predicted the response to positrons is non-linear, due to saturation effects introduced by the finite size of the readout pads.
- The response to pions is as expected and consistent with predictions based on the VST [9]. The response appears to be linear up to about 30 GeV/c where again saturation effects diminish the response.
- The response in the Tungsten stack is lower compared to the steel stack. Showers appear to be more compact both longitudinally and laterally. To match the performance with steel absorbers, a higher granularity of the readout is required.

To date the results are still preliminary. The group will release its first physics papers shortly and then complete the sophisticated analyses, such as the exploration of software compensation. Because of its success, the CERN Lepton Collider group has requested the DHCAL to be tested with tungsten as passive medium. These tests will be completed by the end of the fiscal year.

5.2 Cherenkov Telescope Design

ANL has been carrying out R&D on the mechanical designs for future ground based imaging Čerenkov telescopes as part of the division's involvement in Very High Energy Gamma-ray Science. The telescope work was initiated using LDRD funds and is currently fully supported by DESY. The focus of this R&D is to develop a novel and

robust telescope design, which could be mass-produced for future astrophysics experiments (such as the European led Čerenkov Telescope Array (CTA) experiment), which need large arrays of ground based telescopes. At the time of the last review only a preliminary study of a Schwarzschild-Couder (SC) telescope design of an optical support structure that minimizes deflections had been completed. The R&D has been expanded to two parts. The first task is the design and structural analysis of a medium size telescope (MST) with a diameter of 12 meters and a focal length of 16 meters (see Figure 14). The second task continued the development of an optical support structure for a Schwarzschild-Couder (SC) dual mirror telescope.

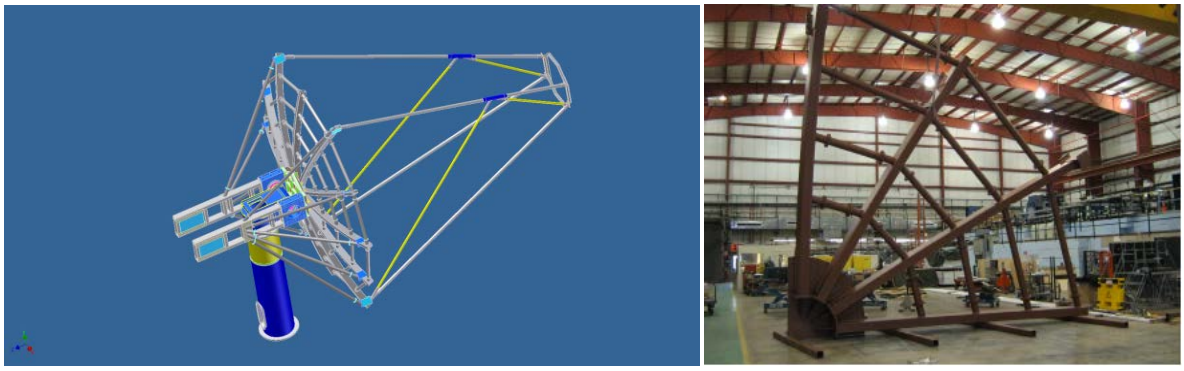


Figure 14: *ANSYS model of the assembled MST telescope mounted on a DESY designed pedestal (left); a prototype quarter dish built using beams fabricated at a Chicago based steel company and assembled in the ANL HEP high bay building (right).*

For the first part of the R&D detailed analyses of possible MST support structures were carried out to establish an overall design, to identify those parameters that constrain deformations to sufficiently small values to meet performance requirements, and to determine the stiffness needed to slew the telescope at a high rate. An important design goal was to allow component fabrication anywhere in the world where costs are minimal and then ship the fabricated components in standard shipping containers to the observation site where they would be assembled into the final telescope.

A quarter-dish prototype (Figure 14) was constructed to tests fabrication methods, costs, and the assembly concept, and to provide a test bed for mounting mirror sections. The dish sections were all fabricated at Chicago-based steel companies, shipped to ANL where they were assembled in December 2010 into the complete prototype in six hours, dismantled in three hours, and packaged in standard shipping containers. They were then sent to DESY where they were re-assembled in March 2011 and used for testing mirror mounting. This is a major step in the design of a precision device that can then be disassembled, shipped to the site on a truck, and then be reassembled to the original high precision with semi-skilled labor.

The second, smaller part of the R&D has been carried out in collaboration with UCLA, the University of Chicago, and DESY, Zeuthen and Krakow, Poland. During the past year, our ability to evaluate mirror deformations and SC telescope performance has been improved using an upgraded Monte Carlo developed at UCLA. Two mechanical designs are now being considered. The first is based on prior ANL work and uses a traditional counterweights approach to optical support structure design and is expected to be compatible with the DESY MST mount and drive system without any modifications. The second design, developed by the group at the Institute of Nuclear Physics in Krakow, has a number of novel ideas and significantly reduced counterweights.

Several iterations of the two designs were made and a finite element analysis for each design has been carried out. The current version of the traditional design already meets nearly all design specifications at certain angles but additional work is required for this design to meet all the design deformation specifications. The Krakow design has just begun and the initial results are still far from the design specifications. Further development of this design is ongoing.

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II. Detector R&D Core Program

Core Program

The Argonne detector R&D program is driven by the needs of the field for pursuing new technologies and new directions that enable the science goals. Our approach is to identify ways in which the laboratory can make a unique contribution to the overall program. A successful instrumentation program requires a base support of facilities and staff for engineering, fabrication and testing of new detector technologies. This part of the program is referred to as the detector R&D core program. Below, the roles of the core efforts in various projects within the R&D program are discussed. The projects themselves are discussed at length elsewhere.

A large detector R&D initiative is the Large Area Picosecond Photo Detector project (LAPPD), a joint University of Chicago, Argonne Laboratory project to develop single units and arrays of 20cm square tile photodetectors. These photodetectors, whose proof-of-concept is being finalized after a three year development project, have demonstrated photocathode efficiencies of > 20%, pulse timing capabilities in the range of 10 picoseconds, and spatial resolutions of a few millimeters. A second phase of the project, for which Argonne will be the lead institution, is to produce and distribute small numbers of tiles to members of the High Energy Physics Community as well as to study and improve photocathode efficiency, and to facilitate the transfer of this technology to industry. The core support is provided by two staff scientists whose responsibilities are, respectively, the construction and operation of the tile production facility and the development of photocathodes. The facility will be setup for use as a general user facility for the community. The core support will also be the interface with industry in transferring the technology.

Argonne R&D core scientists are also involved in superconducting Transition Edge Sensor (TES) development work which has led to detectors for use in the South Pole Telescope project. There is particular interest in improving the readout efficiency for these sensors, readout multiplexing, and in providing onboard frequency spectrum filtering. Superconducting sensors also play an increasingly important role in the study of dark matter. This development is fundamentally a materials science technology to enable construction of these devices out of superconducting materials that meet the physics requirements. There is unique expertise at Argonne built through the successful collaboration with the materials science division to build the detectors for the SPT experiment, which is part of our core program. The core provides 50% support of a staff scientist with strong materials background with the TES technology.

Leveraging Argonne's current R&D activities with optical links and our collaboration with the Argonne Center for Nanoscale Materials, research on the development of commercial optical modulators for particle physics experiments has been initiated to develop high speed, radiation hard readout systems for next generation experiments at low power using low mass, high speed optical modulator to provide up to 40 Gb/sec digital readout. With the anticipated increased data volumes and increased data throughput, R&D is also carried out to study the use and development of advanced 3D layered silicon detectors, which can be used in a variety of applications ranging from pixel detectors with integrated readout electronics to memory chips for pattern recognition. One post-doc constitutes the core of this effort.

A considerable amount of detector development at Argonne involves integrated circuit design and development. Commercial software for this purpose is very expensive. The most efficient way for Argonne to access this software without having to purchase its own licenses is through a Memorandum of Understanding (MOU) with

Fermilab, which licenses several seats of Cadence software. In support of its integrated circuit development needs, Argonne has a MoU with Fermilab at a cost of $175k per year as part of its core program.

In order for any detector R&D program to operate effectively, it is essential to have a small full time technical or engineering staff to maintain and oversee the utilization of laboratory space and the construction and maintenance of laboratory apparatus.

While the multi-disciplinary nature of Argonne provides unique opportunities, it also impacts the requirement for core support, though minimally. Use of the facilities in the Materials Science Division for the deposition of superconducting materials, the facilities at the Center for Nanoscale Materials and other facilities at the laboratory such as the Argonne Advanced Photon Source require extensive training. The training is time-consuming and highly specialized. Given the nature of the work, it is critical to maintain continuity in that expertise and that new staff and post-docs be trained in the use of the equipment.

In summary, the core program consists of essentially 2.5 FTEs of scientific effort, spread between all projects but with a major emphasis on the Large Area Photo Detector project and a smaller emphasis on cryogenic superconducting Transition Edge Sensors. A small engineering and technical staff supports the scientific effort and supports the maintenance of the equipment and infrastructure. There is also support for electrical engineering mainly through a cost-effective MoU with Fermilab. The combination of the scientific and engineering staff manages the program, provides guidance and looks for new opportunities for collaboration with other divisions in Argonne in trying to apply their expertise to HEP problems. Needless to say that it is not always the same people that are supported by the core program, because the effort is more related to a direction than to a particular person. It allows the division to start an R&D project on a small scale and develop it to a point where it can either be abandoned, because it turns out to be impractical, or developed to a point where one can apply for additional funding based on the initial studies. The core detector R&D group is also heavily involved in shaping and supporting the overall HEP instrumentation program in the country through its participation in the Coordinating Panel for Advanced Detectors and the 2013 Community Summer Study.

III. Research Plan

1. Introduction

This section describes the proposed Detector R&D program in the HEP division at Argonne National Laboratory for the next three years. Its target is to enable the science at the three frontiers of particle physics in a way that builds not only on our existing strengths but also builds on the breadth and depth of expertise available at a multi-disciplinary laboratory. In each area, unique ways of addressing scientific bottlenecks are explored, bringing together advances in other scientific disciplines. We believe that a multi-disciplinary approach is key to ensuring the vitality and viability of the field.

For our research program we have targeted key fundamental physics questions and focused on those technologies where Argonne has unique capabilities and expertise. Within the Sensor Thrust, we propose to develop next generation Transition Edge Sensors sensitive to multiple wavelengths with multiplexing capability. Materials science expertise and the fabrication of superconducting structures are at the core of this technology, which is provided by the materials science division at Argonne. This effort has been initiated by LDRD funds. Based on our recent success with the design, fabrication and deployment of the detectors for the South Pole Telescope, we propose to develop next generation detectors. This is the first time we request generic detector R&D funding for this R&D. The LAPPD project targets the development of inexpensive, large-area photodetectors. It is a very broad multi-disciplinary collaboration, bringing together the Energy Systems and Materials Science Divisions at Argonne where the Atomic Layer Deposition process was developed, the Advanced Photon Source for their expertise in femto-second laser programs and expertise in photocathodes, the Mathematics and Computing Science Division to understand the growth of photocathodes by design, and the Nuclear Engineering division for hermetic glass seals. Industry is a crucial partner of the collaboration. In the DAQ/Electronics thrust, we have focused on the development of optical modulator technology and trigger implementations for upgrades in the energy and cosmic frontiers. Our initial efforts, all LDRD funded, have been adopted early by particle physics projects. Building on our success, we plan on extending the optical modulator program and the development of associated memories to deal with the very high data rates expected for future experiments. Also here, industry is a critical collaborator. Within the Detector thrust, our focus is on finalizing the digital hadron calorimeter program and bringing it to a project stage.

2. Sensors

2.1 Transition Edge Sensors

The ANL Transition Edge Sensors (TES) group focuses on developing the critical technologies required for scientific applications of TES detectors. We propose to develop two new technologies, which will enable future TES based HEP projects. The two technologies are:

- Low-loss superconducting microstrips required for multi-chroic CMB detectors which are central to next generation CMB polarization measurements;
- A new Transition Edge Sensor (TES) multiplexer with large (~1 MHz) per channel bandwidth. This multiplexer allows the operation of many TES detectors on a single pair of coax cables which is important for a future ton-scale Dark Matter experiment using cryogenic detectors.

The work involved for both of these efforts is modest in scope and builds on the unique multi-disciplinary capabilities that we have cultivated at the laboratory along with our recently developed expertise with microfabricating and testing TES based devices. Success with these technologies will not only enable new and improved measurements of fundamental physics, but will also establish ANL as a leader in detector technology, positioning the lab to lead the next generation of superconductor-based instruments.

2.2 Low-loss Superconducting Microstrip for future CMB Detectors

Scientific Context

The accurate measurement of the CMB polarization is critical for extending our knowledge of both the early universe and fundamental physics at high energies. Recent results demonstrate that modern CMB experiments are on the verge of exploring new physics including probing new light relativistic degrees of freedom (eg: sterile neutrinos) [1,2], measuring the sum of neutrino masses [3], and constraining the Dark Energy equation of state [3]. The CMB polarization is also unique in its ability to determine the energy scale of inflation.

CMB measurement is a sensitivity-limited field of research. As such, CMB science is led by detector innovation. The frontier of CMB detector development is focused on improving TES bolometers with the most competitive detector efforts pursuing devices coupled through superconducting microstrip. Examples of these technologies are the lenslet-coupled antenna of the POLARBEAR experiment [4], the phased-array antenna of the BICEP2/KECK experiments [5,6], and the feedhorn coupled TES polarimeters utilized by SPTpol [7].

Current state-of-the-art CMB detectors observe in only a single optical pass band with approximately 40 GHz of optical bandwidth. Our goal is the development of a low-loss microstrip technology, which will enable a single CMB pixel to observe in multiple optical passbands simultaneously. Figure 1 outlines a schematic of how superconducting microstrip is typically implemented for multi-chroic detectors. Since multi-chroic architectures rely on resonant microstrip structures to achieve the needed filtering, the performance of any multi-chroic detector depends critically on the loss properties in the microstrip. Optimal performance can be achieved only if the microstrip is nearly lossless.

Technological Approach

Our proposed work will utilize our resources at HEP and MSD along with our TES microfabrication expertise to develop a nearly lossless superconducting microstrip technology. This technology will enable optimal multi-chroic CMB detector performance. Recent work has shown that the microstrip loss is dominated by a distribution of Two-Level Systems (TLSs) [8] associated with defects and contaminants in the amorphous dielectric and at the interfaces between the dielectric and the superconductor. Thus, the problem of loss is intrinsically a problem of material science and microfabrication technology. The objective of our program is understanding, controlling, and reducing the loss in superconducting microstrips.

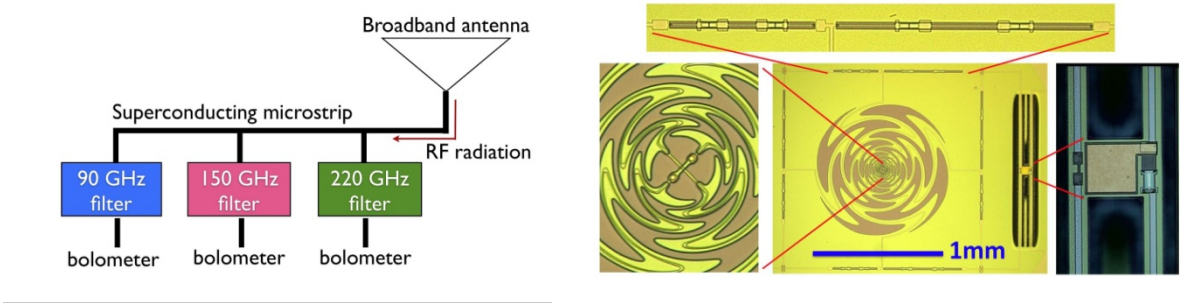

Figure 1: *Left: Schematic illustrating the concept of a microstrip-based multi-chroic CMB detector. A broadband antenna receives radiation from the sky and couples the signal onto a superconducting microstrip transmission line. Resonant filters along the line divide the radiation into three bands, which are then each coupled to a bolometer. Right: Photograph of a prototype dual-band multi-chroic detector developed at Berkeley [10]. Shown are the antenna structure with antenna to microstrip transition (lower left), lumped element resonant filters (top), and one of the TES bolometers (right).*

Our plan for the first year is the development of lithographic and thin film deposition techniques required for integrating ANL TES technology into microstrip-coupled bolometers. This work involves extending our current TES microfabrication capabilities to depositing and etching superconducting microstrips, and coupling radiation through the microstrip onto the detectors. Our detector architecture will utilize a design that has been explored by Berkeley (Figure 1, right) [10] as a template. In this layout, the detector couples to freespace radiation through a lenslet coupled log-periodic sinuous antenna. The antenna structure has good polarization properties and possesses two octaves of bandwidth. RF radiation picked-up by the antenna is coupled onto superconducting microstrip, which uses lumped element resonant filters to define the individual optical passbands. The microstrip terminates on suspended TES islands where the radiation is thermalized and measured. At the end of the first year we plan to deliver an array of microstrip-coupled detectors.

The main goal of the second year will be the characterization and reduction of superconducting microstrip loss at mm-wavelengths. A broad spectrum of microstrip designs and materials will be explored, including various dielectrics (eg: SiOx, SiN, AlO) and superconductors (eg: Nb, NbTiN) deposited in different ways. One particularly interesting direction of investigation is studying films deposited by Atomic Layer Deposition (ALD) in collaboration with Dr. Thomas Proslier, who has a joint appointment with MSD and HEP, is applying ALD to the development of high-gradient superconducting cavities. To the extent of our knowledge, no other group has performed loss measurements on ALD deposited films at mm-wave frequencies. The deliverable will be the loss characterization and modeling for a wide variety of superconducting microstrips.

In the third year, our efforts will focus on integrating the best low-loss microstrip technology into our microstrip-coupled TES bolometer arrays and optimizing the detector properties for CMB applications. A prototype array with performance sufficient for deployment on future CMB instruments will be delivered.

The project milestones are:

1. Develop techniques for fabricating microstrip coupled TES bolometer arrays;
2. Loss characterization of various superconducting microstrip materials;
3. Delivery of a working prototype multi-chroic CMB detector utilizing low-loss microstrip technology and suitable for constructing large focal plane arrays

Broader Benefits

Though the scientific context of this development is CMB measurement for High Energy Physics, the benefits of this research will impact a broad spectrum of applications. One example is the implementation of microstrip coupled TES detectors as a thermal imager for national security applications [9]. Another direction of impact is superconducting resonators for quantum computing where dielectric loss limits the lifetime of qubit states.

2.3 SQUID-based Microwave TES Multiplexer for a future ton-scale Dark Matter search

Scientific Context

Our second proposed research direction is to implement and demonstrate a novel DC Superconducting Quantum Interference Device (SQUID) based TES multiplexing technique which provides high per-channel bandwidth (~1 MHz). The goal of this work is to demonstrate a TES multiplexer that enables a future ton-scale Dark Matter experiment based on cryogenic detectors (eg: SuperCDMS technology). This effort will be conducted in collaboration with the National Institutes of Standards and Technology (NIST) who will provide the SQUID multiplexing chips. ANL will utilize our TES detector development capabilities to design and microfabricate the test devices and perform the cryogenic measurements required for successful demonstration of the technology.

The challenge for future Dark Matter experiments is to increase sensitivity through increased target mass and improved control/rejection of backgrounds. Among the most competitive of Dark Matter searches are experiments utilizing TES based detectors (eg: CDMS-II [11] and CRESST [12]). For these experiments to scale up to required target masses (~1 ton), a technology must be developed to multiplex the TES readout while maintaining the excellent background rejection of the detectors. The readout technology we propose to develop and demonstrate will make such detector arrays possible.

The proposed detector research and development exploits a moment of technical opportunity. The current affordability of high-speed digital electronics and the recent implementation of microwave-based SQUID readouts by NIST, along with ANL's superconducting detector microfabrication and measurement expertise, provide us with the ingredients required for revolutionizing the readout of TES arrays. Developing this technology will enable a ton-scale cryogenic Dark Matter search experiment and strategically positions ANL to lead a future next generation Dark Matter search through the contribution of a critical technology.

Technological Approach

The fundamental basis for our proposed multiplexing scheme is to utilize microwave electronics and superconducting resonators to measure the inductance of a DC SQUID [13]. A similar low-bandwidth (<100 Hz) implementation of this readout has been recently demonstrated by NIST [14]. In our scheme (see Figure 3), we use a coil to couple changes in TES current to changes in the SQUID magnetic flux. The change in the magnetic flux produces a measureable change in the SQUID inductance (Figure 2, left), which can be measured by inductively coupling the SQUID to an on-chip microfabricated quarter wavelength coplanar waveguide (CPW) resonator. In this configuration, modulating the SQUID inductance changes the resonance frequency (Figure 2, right). The resonator is subsequently capacitively coupled to a microwave CPW transmission line (see Figure 3). The resonator has a very high quality factor, Q, and couples strongly only to frequencies near resonance with unity transmission to off resonant tones. By monitoring the amplitude and phase of a single microwave tone near resonance we can directly measure the resonator impedance and thus, the SQUID inductance.

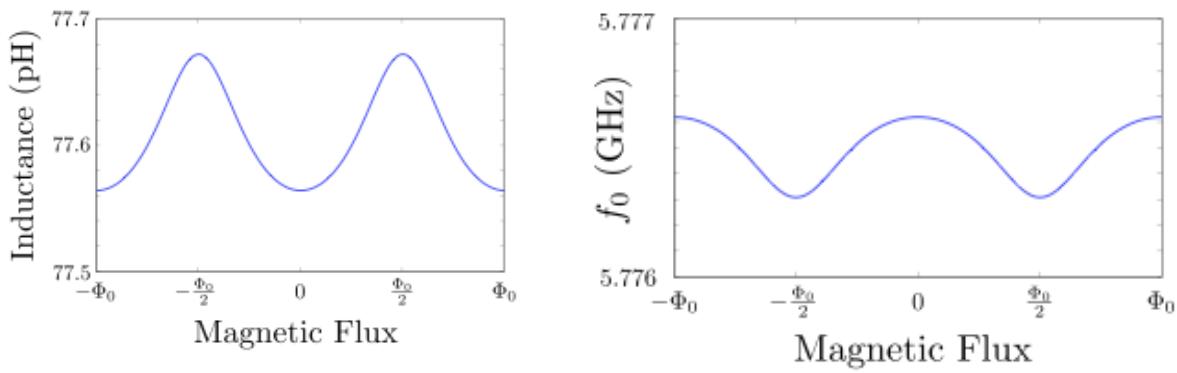

Figure 2: *Left: dependence of SQUID inductance on magnetic flux through the SQUID. The SQUID has an inductance, $L(\phi)=L_J \sec(\phi)$, where $\phi=2\pi\Phi/\Phi_0$ is the phase difference of the superconducting order parameter across the junction and depends on the magnetic flux Φ through the SQUID loop. Here $L_J=\Phi_0/2\pi I_C$, with $\Phi_0=2\times10^{-15}$ Weber, the quantum of magnetic flux, and I_C is the Josephson junction critical current. Right: SQUID magnetic flux versus resonant frequency of a coupled quarter-wave resonator. The change in the SQUID inductance produces a change in the resonant structure.*

As illustrated in Figure 3, by tuning multiple resonators to different resonant frequencies, it is possible to read out multiple detectors using a single probe line. The resonator frequencies will range from 4-10 GHz with each resonator having more than 1 MHz of bandwidth. As such, our proposed TES readout can multiplex ~1000 TES devices on just one pair of microwave coax cables with each channel having ~1 MHz of bandwidth. This is precisely what is required for multiplexing cryogenic Dark Matter detectors where 1 μs time resolution is needed for event reconstruction used for background rejection.

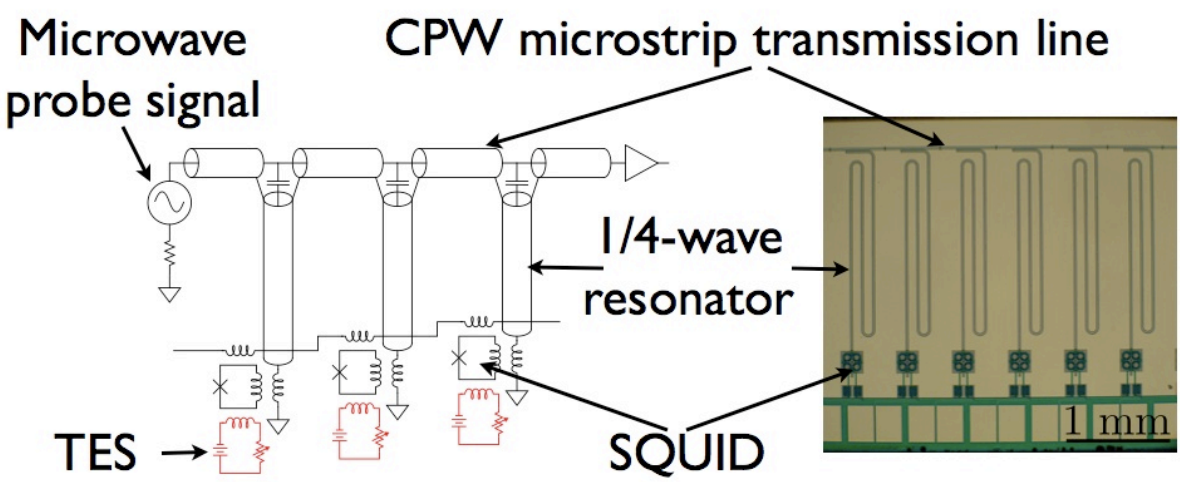

Figure 3: *Left: Illustration of a SQUID-based microwave multiplexer for TES readout. The current from individual TES detectors is coupled to the magnetic flux in a SQUID through coils. Each SQUID is inductively coupled to a quarter wavelength resonator, which is capacitively coupled to a single transmission line. Each resonator is tuned to its own unique resonant frequency. Changes in the individual TES currents modulate the individual resonator impedances, which in turn modulate the amplitude and phase of microwave tones near the corresponding resonances on the transmission line. Right: Image of a prototype multiplexer chip fabricated at NIST [14]. The CPW transmission line, quarter-wave resonators, SQUIDs and coupling inductors are all microfabricated on to a 3 mm chip.*

The first stage of this R&D involves the design, development, microfabrication and characterization of a suitable test TES detector. We propose to demonstrate the viability of the readout using TES-based x-ray detectors because they can be readily characterized with radioactive sources in a manner similar to the calibration of cryogenic Dark Matter detectors. We will use our developed techniques at the Argonne Material Science Division (MSD) and the Center for Nanoscale Materials (CNM) to fabricate from scratch a 300μm x 300μm x 1μm mushroom shape Bismuth X-ray absorber on top of a Mo/Au TES with a dielectric spacer. We expect to deliver suitable test detectors by the end of FY13.

The second stage of this project is the design and construction of the proposed cryogenic microwave readout system. This involves the acquisition and commissioning of a microwave test bed, which includes a sub-Kelvin cryogenic system, a 20 GHz Anritsu microwave signal generator, a 20 GHz vector network analyzer, a coax cable chain with programmable attenuators and amplifiers, and an IQ mixer. Contemporaneous with the development of the microwave test bed will be the design and microfabrication of SQUID resonator chips at NIST. We expect to finish the construction of the test bed and the microfabrication of SQUID resonator chips in parallel before the end of FY14.

The final stage of the project is the operation of the ANL manufactured and characterized x-ray detector using our proposed multiplexing scheme. From this measurement, we will demonstrate that we can couple a number of TES detectors to a single pair of microwave coax cables with each channel possessing ~1 MHz of bandwidth. We will also demonstrate that we can multiplex the TES detectors through simultaneous readout of multiple devices. By the end of FY15, we plan to demonstrate the viability of a new SQUID-based microwave multiplexer for TES detectors.

The project milestones are:

1. Design, microfabrication, and characterization of a TES x-ray microcalorimeter;
2. Construction and commissioning of a cryogenic microwave test bed along with design and fabrication of SQUID multiplexer chips;
3. Demonstration of SQUID based microwave multiplexer technology for TES detectors with broadband (~1MHz) operation.

Broader Benefits

Our proposed development also has impact across a large spectrum of other applications. Currently, the integration of TES devices into competitive scientific instruments has been limited by the small size of achievable TES arrays. Specifically, though it is possible to manufacture large arrays of TES based detectors, current TES readout technology is only capable of multiplexing ~50 detectors per channel with at most 10 kHz of bandwidth per detector. Our proposed SQUID-based microwave multiplexer will be capable of multiplexing ~1000 detectors per channel with nearly 1 MHz of bandwidth per detector. Modest development of the readout scheme has the potential to further increase this to multiplexing factors of ~10,000 while maintaining >100 kHz of bandwidth. As such, the development of our proposed technology will be a breakthrough for TES readouts and paves the way for Megapixel TES arrays. Application of these arrays outside of HEP include high resolution x-ray spectrometers (ΔE~5 eV) capable of supporting high count rates (~1 Mcps), high resolution and radiation hard calorimeters with large target areas (~10-20 cm^2) for studies of heavy ion physics [15], and high resolution and high throughput optical spectrophotometers to replace current Integrated Field Units employed by optical astronomy.

3. Large-Area Picosecond Photo-Detector

During the last three years, the Large Area Photo-detector project has advanced from a tabula rasa to the production of 8" ALD-functionalized MCPs, 8" photocathodes with QE ~25%, two alternative hermetic housing packages, and a complete waveform sampling DAQ system with several picosecond timing and millimeter position resolution. At the end of this fiscal year, the technical advances necessary for the fabrication of one or a small number of 8"x8" photodetector tiles will be in place. However, in order to turn the previous three years of R&D into a product that can be inexpensively produced in quantity by industry it will be necessary to optimize the hermetic housing package for mass production. We have learned enough to further improve the uniformity and reproducibility of the microchannel plate glass blanks and the ALD processing with industry. The process for assembling a photocathode in a photodetector tile can be optimized and the design and fabrication of the readout electronics needs to be finalized. In parallel, we will continue R&D work improving the efficiency and resolution of the tile photodetectors. This includes understanding and improving their quantum efficiency, optimizing microchannel plate pore geometry, and increasing the bandwidth of the analog readout electronics. This second phase of the LAPPD project will move the tile photodetectors beyond an R&D project to a commercial product. A significant component of the second phase of this project will be industrial involvement. Industry has already licensed the ALD technology from Argonne to develop and fabricate large area microchannel plates and it has recently expressed interest in carrying out the fabrication of the complete photodetector tile. Discussions are currently underway with industrial partners exploring the use of SBIR/STTR funding, complementary to the project support for unique Argonne resources such as the specialized ALD R&D, advanced materials characterization, the Argonne glass shop and specialized capabilities at collaborating institutions.

Our research plan consists of four main components: field deployment of large-area picosecond photodetector systems, the single tile production facility, photocathode development, and the development of picosecond and sub-picosecond timing. These areas are described in more detail below.

3.1 Field Deployment of Large Area Pico-second Photo-detector Systems

Thin, inexpensive, large-area planar detectors with high gain, high bandwidth, time resolution significantly better than 100 psec. and space resolutions of a few mm, have been recognized as a 'disruptive' technology[2]. This task is the further development, testing, and initial field deployment of small numbers of large-area, fast photo-detector systems suitable for new generations of large detectors in high-energy physics and other fields. The group has had discussions with companies, scientific collaborations, and individual researchers in obtaining the detectors for testing. We propose to produce an adequate number of panels with the full DAQ chain for these first adopters. A key issue is cost; vacuum transfer, the classic technique for assembling MCP-PMT's, is inherently expensive and fragile. Photomultipliers, however are made via 'tubulation', i.e. the vacuum vessel is the vacuum tube itself. Both vacuum transfer and tabulation will be pursued with industry. We have been in discussions with several interested vendors with relevant experience. Potential first adopters have also contacted us, such as water Cherenkov counters for neutrino detectors, cryogenic neutrino detectors, collider TOF applications, rare kaon decay experiments and medical imaging.

3.2 Single Tile Production Facility at Argonne

A Single Tile Processing Facility (STPF) will be built at Argonne to produce the ALD functionalized MCP photodetectors one unit at a time in a dedicated multi-chamber vacuum transfer system. While the 8" active

[2] The Large Area Microchannel Plate ALD Technology received an R&D100 in June 2012.

area detector is our baseline, the STPF is designed to be flexible enough to produce different form factors of photo-detectors. In parallel, sealed "standalone" Large Area photo-detectors will be produced by our collaboration at the Space Sciences Lab-Berkeley in a ceramic package. This effort has already produced an 8" photocathode and is using a well-tested design for the indium seal. The transfer of information and the sharing of resources and facilities has already proven to be very beneficial for all parties involved. Below we describe the program at Argonne to produce the more economical all-glass tile photodetector.

The Argonne STPF will produce the all-glass tiles in quantities sufficient for demonstration in the HEP detector community. The facility will also allow for production of prototype detectors incorporating improved or alternative ALD coatings, readout format, photocathodes, and detector size. One of the goals of the LAPPD project is to transfer the technology to American manufacturing to produce detectors in large quantities. Large-scale production does not readily admit to rapid testing of changes in the LAPPD format. This is where the STPF, shown in Figure 4, will be important for continued development of the photo-detectors.

A detailed initial design has been completed and subjected to review. The review found no "show-stoppers" and made several recommendations for improving the implementation of the facility. Establishment of an operating facility is estimated to take 1.5-2 years from initiation. The major tasks by year for the STPF for the next three years are the following:

In the first year the main tasks are the development and commissioning of: i) the Vacuum Transfer System, ii) the Photocathode subsystem including the modifications to the existing optical characterization system for use with STPF, iii) the Scrubbing and Baking subsystem to expose functionalized microchannel plates to an electron or ultraviolet beam at low gain in order to outgas residual trapped gas from the plates and, iv) the Top Seal subsystem to enable indium sealing in vacuum. In the second year the emphasis will be on the integration of all the systems as a process unit for the fabrication of single tiles. The goal for the third year is routine fabrication of production 8" tiles for field deployment.

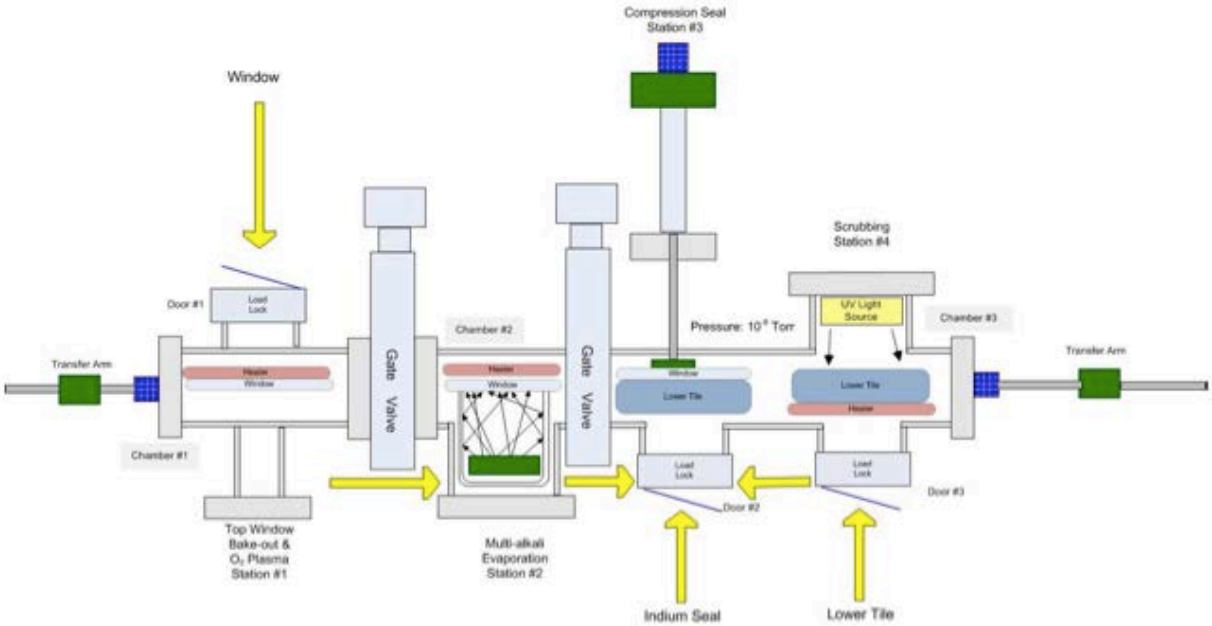

Figure 4: Schematic layout of the Single Tile Processing Facility (STPF) illustrating the multi-chamber vacuum transfer system. The top window on which a bialkali photocathode will be fabricated enters on the left through a load lock. Bake-out of the window, plasma cleaning, and photocathode evaporation are staged in the left two chambers while insertion of a tile base containing MCPs pairs and grid spacers/supports occurs on the right hand chamber. The design allows for bake-out and possible scrubbing of MCPs before the tile base is moved to the top window sealing station for final assembly.

The techniques developed to date as part of the three-year Large Area Picosecond Photodetector project will be transferred to the STPF components. This includes the development of the indium seal and fabrication of 8" photocathodes at Argonne. The photocathode growth will be described in more detail in the next section. As for the indium seal, industry routinely makes indium seals. The details, however, are proprietary and the collaboration is pursuing three parallel efforts on the seal: a brazing technique, pursued by SSL, an indium thermopressure seal and a hot seal.

When established, the STPF could function as a national MCP detector development facility serving the interests and needs of HEP scientists for such detectors as well as the needs of researchers in the wider scientific community.

3.3 Photocathode Development

An integral part of the STPF is the photocathode deposition chamber. We have already achieved the growth of 8" NaKSb photocathodes at SSL. Na based photocathodes, however, plateau at a QE in the low to mid 20%. K_2CsSb based photocathodes are expected to allow for a much higher QE. It is now widely believed that significant improvements in quantum efficiency can be made due to the advances in materials science, purities of materials and new technologies [16, 17, 18]. ANL and Chicago are members of a widespread informal strong collaboration using advanced light sources and other technologies to explore the basic science of photocathodes [19]. With the addition of a senior hire and in collaboration with BNL, the University of Chicago, UC-Berkeley, Washington University, and UIUC and our colleagues at the ANL Advanced Photon Source, R&D on cathodes will be done with the further development of a dedicated ultra-high vacuum system at ANL with specialized instrumentation for the theory-inspired development of high-yield, robust recipes for the growth of multi-alkali photocathodes with high quantum efficiencies. Fundamental understanding of the correlation between the device structure, functionality and fabrication processing will be sought through a system enabling in-situ measurements during cathode growth. This facility has already been built but has not been commissioned yet. It allows testing a wide range of known growth recipes on small samples, to develop new ones, and to probe the intermediate states in situ by using various optical and electrical measurements. The cathodes grown in the industrial facility can be replicated in the ultra-high-vacuum setup with the added capability of near continuous in situ characterization.

Studies of typical photocathode growth recipes have been initiated to reveal the growth mechanism and to understand how the growth parameters affect overall quantum efficiency. The first step in the growth of a photocathode is the deposition of an Sb layer. A series of photocathodes with different Sb thickness were made to study the relation of Sb thickness and the overall cathode quantum efficiency. The dependence of the quantum efficiency on the antimony film thickness, at a wavelength of 400nm, indicates that there is an optimal Sb film thickness (Figure 5, left). When the Sb thickness is thinner than the optimal thickness (penetration depth), only a fraction of the light is absorbed by the cathode; when the Sb film is thicker than the optimal thickness, fewer and fewer photoelectrons can escape to the vacuum. Indications are that the optimized Sb film thickness is about 9nm (78% transmission).

Using in-situ X-ray scattering measurements, in collaboration with Brookhaven National Laboratory, clearly show the growth process for bi-alkali photocathodes at the atomic level. Figure 5 (right) is the real-time X-ray reflectivity measurement during K deposition on top of an ex-situ grown Sb layer. Figure 5(a) is a measurement of the ex-situ grown Sb layer and shows that the thickness of the Sb layer prior to K deposition is about 20nm. As K is deposited on the Sb layer, the thickness increases constantly. The amplitude of the peak, however, decreases because the K is forming islands and the surface is getting rough (Figure 5(b)). During further deposition the peak completely disappears indicating that the surface has become very rough (Figure 5(c)). As the K islands get bigger during further deposition, they start to touch adjacent islands and produce a thin film. At that moment, a peak starts to appear again (Figure 5(d)) indicating a smoothening of the surface.

It is exactly these kinds of studies that will enable the microscopic understanding of the cathode growth process and the relation to its macroscopic properties. The crucial step in this process is to correctly correlate the microscopic and macroscopic measurements for the cathode development. Hence we propose to continue R&D on photocathodes, as the previous studies have demonstrated that we are able to identify the key parameters for high QE photocathode.

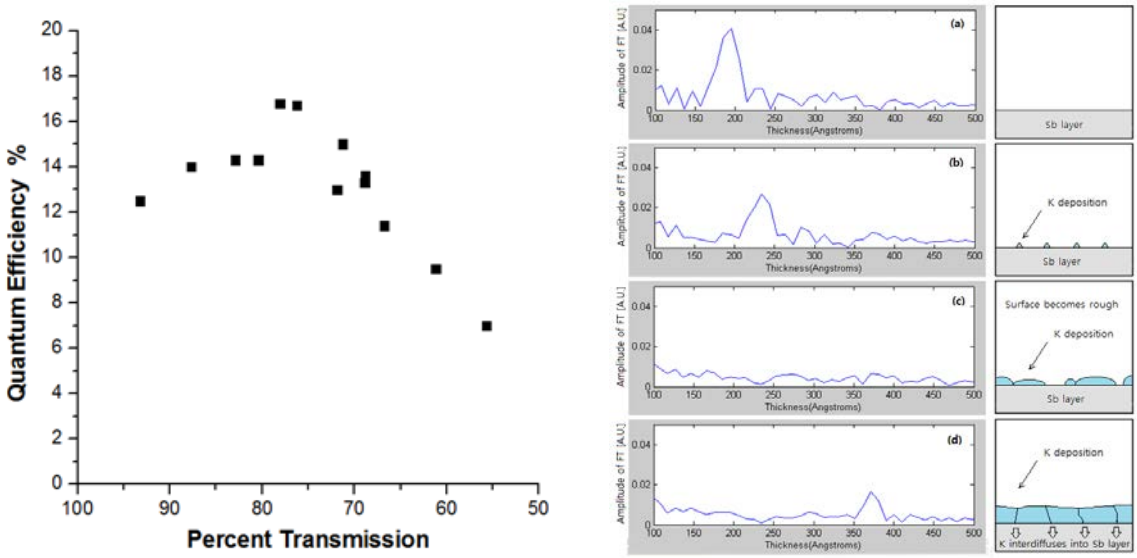

Figure 5: *The dependence of the overall QE as a function of the transmission of the base Sb film, indicating an optimal thickness of about 9nm (78% transmission) (left). The real-time X-ray reflectivity measurements during K_2CsSb photocathode growth on top of an ex-situ grown Sb layer (right). The panels on the far right show the physical interpretation of each reflectivity measurement. (a) smooth Sb layer grown ex-situ before K deposition; (b) Sb peak reduces as K is deposited and forms islands; (c) Peak disappears when surface becomes very rough by forming K cluster; (d) During further deposition, islands of deposited K grow bigger, meet adjacent islands, K starts to form a thin film and fringes start to appear again.*

Our proposed milestones and deliverables for the next three years can be summarized as follows. In the first year in-situ and ex-situ studies of alkali photocathodes will be carried out to correlate the microscopic measurements with the macroscopic performance parameters such as quantum efficiency and noise. A suite of experimental measurement tools will be developed to enable photocathode characterization under both conditions. In the second year the focus will be on understanding the details of the alkali diffusion process, and optimize the alkali growth process to generate a cathode growth recipe for cathodes with QE over 35%. The growth recipes will be transferred to the STPF. During the third year routine growth of high QE photocathodes in the STPF is the goal.

3.4 Development of Picosecond and Sub-Picosecond Timing

With the present technology, we have observed 2ps relative time resolutions using MCP-based photo-detectors and waveform sampled RF-anodes. Four parameters have been identified that determine the time resolution [20]. They are: i) the signal size; ii) the signal-to-noise ratio; iii) the waveform sampling frequency; and iv) the analog-bandwidth. A parameterization of the time resolution versus these parameters by Ritt [21] predicts that improving the analog bandwidth from 1.6 GHz to 3 GHz should give a resolution of 100 fsec using the present values of the other three parameters. These improvements are technologically feasible. Simulations of smaller pore sizes, a funnel pore geometry, and reflective cathode point to even faster rise-times. In addition, we have proposed further optimization of the cathode geometry, shape of the capillaries, ALD coatings, anodes, and

packaging for specific applications. We note that for the first time the limits in time and space resolution are fairly well understood as a function of the parameters of the MCP's, anodes, and electronics, and it should be possible to push down into the deep sub-psec regime.

For the next three years we propose to address two key areas: the readout system and the microchannel plates themselves. Even using highly optimized anodes and sampling electronics, certain fundamental timing limitations are imposed by the geometry, structure, and material properties of the microchannel plates in the gain stage of the detector. Optimization of these parameters can further improve time resolution. Increases in MCP gain would enhance the signal-to-noise ratio, and could be pursued by developing new Secondary Electron Yield (SEY) materials for the surface coating. The current LAPPD program has focused almost exclusively on aluminum oxide and magnesium oxide for the SEY layer of the MCPs. However, many new material compositions are possible through atomic layer deposition and will be explored.

The intrinsic single-photon time resolution of microchannel plates is ultimately limited by jitter in the formation of electron avalanches within the pore. Microchannel plate pores serve as a continuous dynode structure. Thus, the trajectories and striking points of electrons within the pores are variable. Statistical fluctuations early in the development of an avalanche, particularly the first strike, lead to fluctuations in signal arrival time. For an MCP with 20 micron pores and an 8 degree bias angle, simple back-of-the-envelope calculations show that the transit time of the cascade can vary by O(10) picoseconds, depending on where the initial photoelectron first strikes the pore. One simple way to address this problem is to reduce the pore diameter. MCPs used in time-of-flight detectors typically have pores smaller than the 20 micron diameter of the nominal LAPPD design, and approach single picosecond precision. Through continued work with Incom, it should be possible to achieve substrates with pores below 10 microns for use in LAPPD detectors.

More radical variations in MCP geometry could also reduce the intrinsic time jitter of MCPs. Narrow pores with funnel-shaped entrances could be developed with the photocathode deposited on the funnel surface. With appropriate aspect ratios, one could channel the photoelectrons into very narrow pores, thus reducing the fluctuations in cascade formation. It may also be possible to fabricate microchannel plates with a discrete dynode structure to produce repeatable, well-defined avalanches. This structure could be achieved either through novel deposition techniques developed by our ALD group or by slicing the MCP substrate into discrete, electrically isolated layers.

4. Data Acquisition and Electronics

4.1 Topological Array Trigger for Cosmic Gamma Rays

The topological array trigger relies on the fact that gamma ray and cosmic ray induced showers show different topologies on the camera focal plane of an Imaging Atmospheric Cherenkov Telescope (IACT). Gamma ray showers are electromagnetic in nature and produce compact Cherenkov light images whereas hadronic showers exhibit a large spread in both lateral and longitudinal shower profile due to multiple sub-showers. Simulations of a large array of telescopes (N>4) suggest that a topological trigger requiring image centroid positions from at least 3 telescopes provides a cosmic ray rejection by an order of magnitude while keeping more than 90% of gamma-ray showers [21,22]. A topological trigger may be implemented using a software-based solution. In fact, current generation experiments like VERITAS use offline analysis to take advantage of cosmic ray rejection using image topology cuts. However, the dramatic reduction in background rates makes a hardware topological array trigger a powerful tool for reducing and stabilizing the high trigger and data rates that will be associated with future IACTs like the Cherenkov Telescope Array (CTA) experiment.

Our proposed R&D plan leverages our current VERITAS L2 trigger deliverable and our continued collaboration with the ISU group. We are in a position to develop a topological array trigger for cosmic gamma rays if funding is available. In the first phase, we propose to build a topological trigger demonstrator that could be tested within the VERITAS L2 framework. The L2 trigger upgrade that we built and installed at VERITAS has all the hooks in place to be able to parasitically test a hardware topological trigger. The remaining R&D to fully demonstrate in hardware the topological trigger concept includes development of additional firmware for the current VERITAS L2 trigger boards and the development of an additional trigger module board which would be located in a separate mini crate and be capable of receiving data from each of the different telescopes. This data would include moment calculations and timestamps (R, phi, nhit, timestamp). The transfer of the data could be done by optical fiber or by wireless transmission. The optical data transmission would leverage the work done for the ATLAS project. Both options would be considered. The FPGA trigger module board would adjust the data according to the proper time delays and perform the coincidence logic between N telescopes using a lookup table. Once the array trigger condition is met, a trigger signal with time stamp would be recorded. In the second phase, we plan to focus on a topological trigger design that is not restricted to a "VERITAS" camera. We would pursue a more ideal topological trigger architecture like the Advanced Telecommunications Computing Architecture (ATCA) framework, a framework that is being heavily used in particle physics experiments and in which area we are gaining experience with the ATLAS experiment. The goal is to implement a scalable topological trigger architecture in a decentralized fashion. In this case, each telescope would form its own local array trigger in real time, based on the timestamps and image centroid from its own camera trigger and those from neighboring telescopes. The decision would be made in a two-step process: if more than three time-stamps received from telescopes within the cell provide a local coincidence, stereoscopic image analysis is activated for a rapid trigger decision that, if passed, issues a readout command only to the local frontend electronics. This approach has the advantage of being scalable to any size telescope array.

4.2 3D Content-Addressable Memory for Real-Time Tracking

The ultimate physics reach of the LHC experiments will depend critically on the ability of the tracking trigger to discriminate between interesting rare events and background. For example, the CMS muon trigger will reach an unacceptably large trigger rate at high luminosity due to the number of hits in the muon detectors. The first-level trigger can be reduced to an acceptable level if tracks are found in the inner detector and matched to the muon candidates. In addition, a track trigger can facilitate the online identification of heavy fermions such as b quarks and tau leptons, which is important since many interesting channels of new phenomena produce heavier elementary particles.

Hardware-based pattern recognition for fast triggering on particle tracks was first developed for the CDF Silicon Vertex Trigger (SVT) at the Fermilab Tevatron in the 1990's. The method used there was based on algorithms that use a massively parallel associative memory architecture to identify patterns efficiently at high speed. However, there is an enormous challenge in implementing pattern recognition for a track trigger at the LHC due to much higher occupancy and event rates and the fact that the LHC detectors have a much larger number of channels in their tracking detectors. Approximately three orders of magnitude more associative memory patterns are required than what was used in the original CDF SVT. A figure of merit for an AM-based track reconstruction system is the number of predetermined track patterns or roads that can be stored in the Associative Memory bank. The original CDF SVT system had a total number of associative memory patterns of 384,000, while the proposed Atlas Fast Tracker (FTK) system for the Level 2 trigger would require ~ 1 billion patterns in order to handle higher luminosity above 3×1034 cm-2s-1. The Level 1 Track Trigger upgrade for both CMS and Atlas likely will require even more AM patterns running at higher speed. Significant improvement in the architecture of associative memory structures is needed to run fast pattern recognition algorithms of this

scale. Scaling of current technologies is unlikely to satisfy the scientific needs of future projects, so investment in transformational new technologies is needed.

The Argonne group is already deeply involved in the development of the Fast Track Trigger (FTK) for the Phase-I ATLAS upgrade. That work will proceed as planned in the framework of the energy frontier program. Building on that expertise we intend to develop hardware-based technology that advances the state-of-the-art for pattern recognition and track reconstruction for fast triggering. Specifically, we propose to develop a new Associative Memory custom chip using 3-dimensional (3D) fabrication technology. This is a critical component in achieving the needed performance because adding a "third" dimension opens up the possibility for new architectures that could dramatically enhance pattern recognition capability. The overall goal is to develop the critical technology to the point where we can propose it as a viable solution for track triggering at the LHC in Phase 2 operations.

The Fermilab ASIC Design Group is a leader in 3D ASIC design, and has expertise with the design of the memory cells. The preliminary VIPRAM design work already done by the group [23,24] would be a starting point for this project. The Fermilab Atlas Group already has a significant role in the development of the Atlas FTK for Phase 0 implementation (~2015), and is well poised to understand the requirements for Phase 1 and Phase 2 implementation. The Argonne Atlas Group currently has a leading role in the Atlas FTK project, with strong engineering and scientific connections to the Atlas Trigger-DAQ community and to the experiment. We believe that this is the critical mass of technical and scientific expertise to execute the design and construction of this crucial component in the system. The near term R&D goal is to have a functional device by ~ 2016. This would be a proof-of-principle device with the goal to demonstrate to funding agencies for possible implementation in Phase 2 of the LHC program.

While our focus here is on the Energy Frontier (e.g. the LHC with CMS and ATLAS), the approach may have applications in experiments in the Intensity Frontier and the Cosmic Frontier as well as other scientific and medical projects. In fact, the technique that we are proposing is very generic and could have wide applications far beyond track trigger, both within and outside HEP.

Our near term goal (over three years) is to design and perform the ASIC engineering necessary to realize a prototype Vertically Integrated Pattern Recognition Associative Memory (VIPRAM) device. The project aims to increase significantly the Associative Memory (AM) chip capability by using 3D technology. A block diagram of the final device is shown in Figure 6. The project has three stages. The first would be to develop a 2D prototype of the new CAM cells. The design would be done in such a way that they would be identical to what is needed for the 3D design. The second would be to design the control tier in 2D, which would mate with the 2D CAM cells. These two stages would ensure that all the relevant design blocks can be tested in 2D before 3D integration. Finally, the first 3D implementation would be a single Control Tier with a single CAM tier to test the vertical interconnections, followed by a single Control Tier with two or three CAM tiers. This prototype will test all the necessary processing steps involved in a complete VIPRAM.

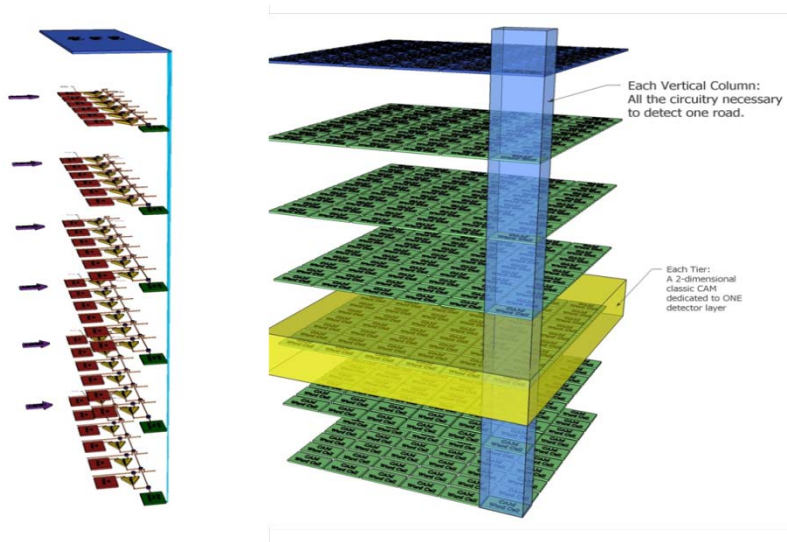

Figure 6: *3D VIPRAM Concept.*

We will begin the R&D using standard 130 nm technology. We expect up to 200K patterns per cm square with 130nm and 4 um Through Silicon Vias (TSV) spacing. This would allow for relatively inexpensive prototyping. As 3D technology evolves, TSV spacing and other structures unique to 3D integration will likely allow further increases in density as the feature size gets smaller. The overall design and coordination of the project would be a joint responsibility between Argonne and Fermilab. The ASIC design and the related 3D process engineering work would primarily be the responsibility of Fermilab. The testing of the prototypes, both at the bench and in the FTK system test stand would be the responsibility of Argonne. This leverages our current work with the FTK project, as well as our long experience in performance testing new prototype ASICs, as a precursor to building the new FTK system around these devices.

4.3 Optical Data Transfer

Current readout of large HEP detectors is already stressing the current optical data link technology. All the current links are based on modulating the actual lasers, and these are VCSELs (Vertical Cavity Surface Emitting Lasers). For the LHC upgrades, as well as other large detectors, it will be very difficult to use the VCSEL based technology. Our group has been working with optical modulators for about three years. We have come to the conclusion that the use of light modulators along with CW lasers is the by far the best direction for the future. This is also the direction that industry is going. These modulators are simple, reliable, low power, and some versions have a factor of 10^6 lower bit error rates and a factor of 2 to 8 more bandwidth per fiber. CW lasers are more reliable than VCSELS due to different internal structure. Furthermore, these lasers could be placed outside the detector and fibers can be used to get light off the modulators on the detector. We are also investigating other modulator materials for use in very high radiation environments.

Another part of our program addresses tracking detectors which currently convert analog signals to digital on-detector, leading to a large overhead in mass, electrical power, and latency time for tracking triggers. A combination of new technologies may make it possible to read out each pixel or strip in analog mode, and have it optically multiplexed onto a single fiber along with many other pixels in the row. This would displace the mass and power off-detector, and eliminate some parts of the latency. We will investigate the combination of integrated silicon optics- (optical light guides on silicon), along with new materials such as graphene for modulators to this end.

Based on our experience with modulators over the past three years we plan to extend our research in optical data transfer into two areas. The first is the radiation testing of commercial off-the-shelf (COTS) silicon based modulators and group III-V semiconductor modulators (such as InP) and design custom circuitry to make the devices radiation hard and adapt them to high-energy physics applications. The second is the development of graphene-based electro-optical modulators. The latter may eventually lead to a new generation of pixel detectors.

4.4 COTS Modulators

Data acquisition systems in particle physics experiments are facing serious problems and the challenges will only increase in the future. VCSEL devices, currently being used in large numbers in the LHC experiments, are failing at an alarming rate. Even if the mortality issue can be resolved, its bandwidth will still be limited and will not meet the demands for the upgraded experiments. High-speed optical modulators are a very attractive alternative because they are relatively low-cost, small, simple and reliable devices that can be made radiation hard. They have the potential to replace both existing copper cables and VCSEL-based optical readout systems with very large gains in bandwidth, footprint, power consumption, and reliability. They can work with reliable, stable, continuous wave (CW) lasers either on or off detector and even between trigger processing boards to provide higher bandwidth in a smaller space. With the incredible progress made by industry in the last decade and their road map to develop devices with stunning high data rate transfer capabilities, we believe the best approach is to work with industry to develop digital optical links using modified Commercial Off-The-Shelf silicon photonic transceivers and adapt them for use in high radiation environments for collider detectors.

We have started a collaboration with Luxtera to further develop one of their commercial optical modulators (see Figure 7). This modulator offers potentially significantly higher bandwidth per fiber, vastly lower bit error rate, low power consumption and greater reliability than the optical links presently proposed, which are based on VCSELs. The modulator uses single mode optical fibers, and that alone gives the potential for significant cost reduction over the alternative schemes being considered today. A key issue is radiation tolerance. Initial tests have indicated that the device is close to being acceptable for use in modest radiation environments, such as the calorimeters in the LHC experiments. More studies, however, are needed and in particular a problem has been identified in the controller used to configure the modulator. There is a similar concern associated with point of load regulators used in the circuit to power the chip. Argonne has recently signed a Non-Disclosure Agreement with Luxtera and will work with the company engineers to understand how isolate the controller from other components in the circuit in order to better understand the effect of radiation and thereby identify technical solutions to mitigate its effect, such as replacing it with a radhard FPGA. The research plan calls for developing modifications to the circuit and to test the modified device to doses up to those required for radiation qualification in the ATLAS tile calorimeter, which requires a Total Integrated Dose (TID) up to ~100 krad. We plan on testing ten modified devices using a gamma source. We will also test for Single Event Upsets (SEUs), initially using the 200 MeV proton beam available at the Massachusetts General Hospital and then other hadron beams, including reactor neutrons.

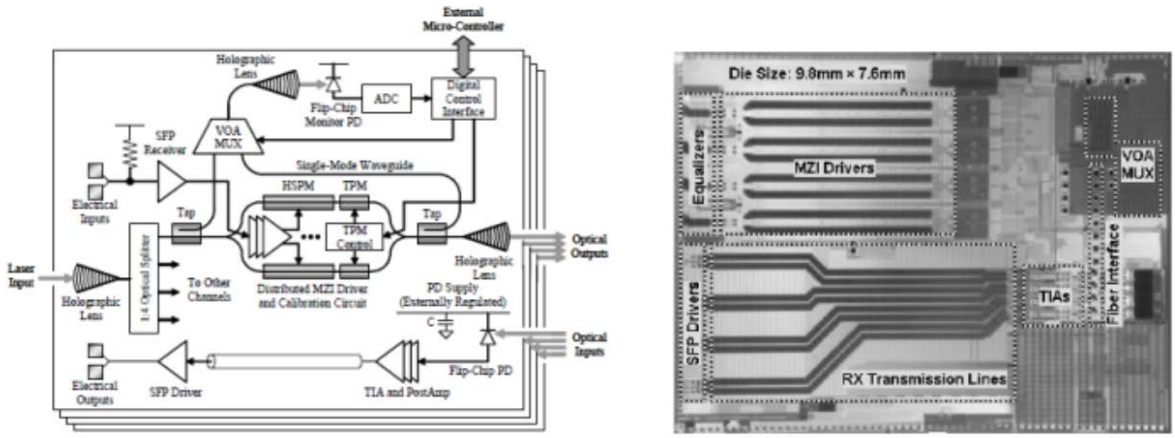

Figure 7: *A Luxtera CMOS Silicon-on-Insulator 4x10 Gb/s single chip optical Modulator. On the left a block diagram and on the right a photograph of the actual device.*

Concurrently with the development of a radiation tolerant version of the optical modulator, we will design an interface board to connect the modulator to the proposed upgrade electronics. As a test of a prototype, this would then allow the modulator to be used directly in the ATLAS detector following the 2012-14 shutdown.

The next step is to make the modulators radiation hard to be used in the innermost detector elements at the LHC, including the pixel detector and the silicon strip tracker. The deliverable for this research is a 40 Gb/s radiation hard, single mode, optical modulator that is radiation tolerant for conditions at the sLHC. Group III-V semiconductors have a larger band gap than silicon and optical modulators based on these semiconductors would be expected to be more radiation tolerant than silicon devices. Testing of commercial off-the-shelf versions of these modulators has also begun and will continue.

4.5 Graphene-based EOM

A second branch of research, in-line with Argonne's multi-disciplinary strengths, is the development of modulators based on new materials and new techniques. The Center for Nanoscale Materials (CNM) at Argonne is presently producing graphene for our group. A graphene-based modulator has at least four distinctive advantages: speed; a very broad absorption spectrum, not limited to one wavelength; room temperature operation; and compatibility with CMOS integration. The first is high-speed operation. With an ultra-high carrier mobility at room temperature (one of the highest observed), the optical absorption of graphene can be rapidly modulated through the band-filling effect. Also photo-carrier generation and relaxation processes operate on the timescale of picoseconds; hence the graphene-based electronics have potential to operate at very high speeds such as 500 GHz, depending on the quality of graphene. The second advantage is the strong interaction of graphene with light. A monolayer of graphene possesses a much stronger interband optical transition than other electro optical effects. Graphene also provides the possibility for broadband operation. The optical absorption of graphene is independent of wavelength since high frequency dynamic conductivity for Dirac fermions is constant. The absorption is constant over the entire telecommunication spectrum (mid- and far infrared). And, lastly, a clear advantage is the compatibility of graphene with CMOS integration processes.

A graphene-based waveguide-integrated electro-absorption modulator is described in reference [25]. In this device two graphene layers with an atomic layer deposited Al_2O_3 layer in the middle is used to modulate laser light as shown in Figure 8. This device uses silicon as a waveguide for the light.

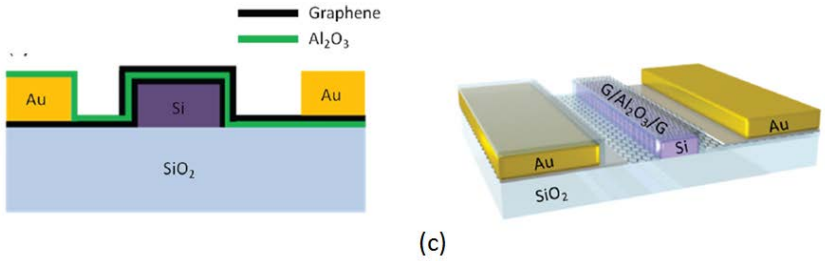

Figure 8: *Schematic of the construction of the graphene-based modulator [25].*

We propose to develop an EOM using a graphene double layer combined with a simple single mode fiber. The first step is to build a simple setup to demonstrate the interaction of graphene with an evanescent field of the light travelling inside a single mode fiber. This device is based on in-line optical modulators implemented on an optical fiber modified so as to allow interaction with the propagating electric field as shown in Figure 9.

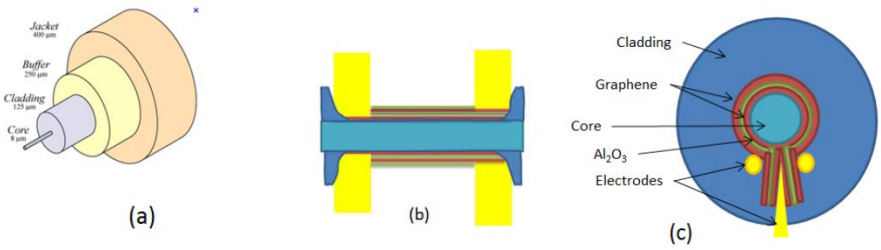

Figure 9: *(a) Cross section of the fiber (b) Cross section of side polished fiber modified to use for the modulator (c) Cross section of etched fiber modified to use for the modulator.*

Figure 9(a) shows an isometric view of a standard commercial fiber. Side-polished fibers, which are commercially available, provide access to the fiber core over a short distance (see Figure 9(b)). The field of a propagating wave contained within the central core of the fiber extends beyond the core cladding. This field is then accessible with a side-polished fiber. By placing a graphene layer around the cladding material close to the core interface, within the evanescent tail, the propagation of the wave changes. Therefore the optical wave in the fiber can be manipulated by electrically modifying the Fermi level of the graphene layer. Figure 9(c) shows the projection of the cross section of a side-polished fiber: where the fiber jacket and cladding have been removed, a double graphene layer is wrapped around the fiber core with an electrode attached to each layer. Using this configuration we will demonstrate the concept of the proposed modulator. We are working with the Argonne Center for Nanoscale Materials for the growth of the graphene and with the Energy Systems Division to attach the graphene-Al_2O_3-graphene sandwich to the fiber and attach very low resistance electrodes to minimize capacitance. Preliminary and rather rudimentary tests so far in our laboratory with graphene placed on an etched fiber show very promising prospects.

After having established realization in single-mode fibers of light modulation using graphene, as described above, we propose an EOM design based on the concept shown in Figure 8, but will use a graphene double layer combined with a micro ring resonator. Broadband light would enter though one straight waveguide and part of the light with its frequency close to the resonance frequency of the ring will propagate to the ring and circulate (evanescent-wave coupling). Similarly, part of this circulating light will propagate out to the other straight waveguide. Due to this behavior, the effective length of the waveguide will be much larger than the physical size

of the ring [26, 27, 28]. Since the modulation uses only the resonance frequency of the ring, it is possible to add many rings along the waveguides with slightly different resonance frequencies to modulate the light in frequency. Due to large effective interacting length of the ring resonator, it is possible to reduce the footprint to ~10 μ m while getting a 10dB modulation depth at 1.3V.

As discussed above, changing the Fermi level of the graphene layer above the ring will allow the circulating light to either be absorbed or not, thus creating a tiny modulator. Taking this concept one step further, we can change the Fermi level in the graphene by attaching a piece of silicon to the resonator, and with the passage of a charged particle or photon, the collected charge can change the Fermi level, thus turning on or off the light circulating in the ring.

We apologize that further details of this concept leading to next-generation pixel detectors cannot be discussed at this time, however. There is a patent application pending, and on advice from the IP experts at the Argonne legal department, we are not to disclose more than what is written here. The DOE program managers have been briefed about this development.

With increased operational speed, the pixel detectors could be used for ultra-fast X-Ray cameras for synchrotron light sources. It is most likely a layer of silicon or other solid material would not produce enough charge from a single x-ray to modulate the light. With a layer of gamma conversion material, a layer of micro-channel plate, and a layer of the ring modulators, one should be able to get data from a pixel array with picosecond timing.

The three-year work plan for the development of the optical data transfer is as follows:

<u>2013:</u>

- We will acquire COTS devices and investigate their radiation tolerance for TID, SEE and NIEL sources
- Components deemed susceptible will be identified and will be replaced if possible with more radiation tolerant parts to provide an acceptable optical link to use in collider detectors
- Testing will include the effects of environmental parameters, such as temperature and magnetic field
- Initiate development of electroded graphene attached to fibers for work on inline fiber modulators

<u>2014:</u>

- Complete a prototype 10 Gbps per link modulator device
- Complete a proof of principle demonstration of its operation in the TileCal demonstrator program at CERN
- Perform extensive environmental and radiation measurements
- Start our work on the ring resonators with graphene for next generation tracking detectors
- Parameterize inline fiber modulators.

<u>2015:</u>

- Continue with COTS modulators, but investigate the properties of the next generation COTS devices
- Investigation and radiation testing of an integrated pixel and ring resonator detector

5. Detector Systems

5.1 Digital Hadron Calorimeter

In 2012 the DHCAL is being tested together with the Tungsten absorber stack in the CERN test beams at the PS and the SPS at CERN. Four separate test beam campaigns have been scheduled, with two already completed. The measurements will be compared to similar measurements already performed with the scintillator-based Analog HCAL prototype and to the DHCAL with Steel plate absorbers.

The group is developing a novel 1-glass RPC design, which features distinct advantages, such as an average pad multiplicity close to unity, a thinner chamber, a higher rate capability and insensitivity to the surface resistivity of the resistive paint.

Together with COE college (Grand Rapids, Iowa) the group is developing semi-conductive glass, with the goal to increase the rate capability of glass RPCs by several orders of magnitude. Small glass samples with the desired resistivity have already been made available. In addition, in collaboration with the University of Michigan and several institutes in the People's Republic of China the group is evaluating possibilities to develop and use low-resistivity Bakelite to achieve higher rate capabilities. High rate capabilities are required in the forward direction of colliding beam detectors, with possible applications also at the LHC and in Heavy Ion experiments at GSI.

The group is initiating the development of the next generation readout system. Discussion on the design of a new front-end ASIC have focused on: a) lower power consumption, b) token ring passing, c) redundancy and reliability, and d) increased channel count. Wireless data transmissions schemes are being developed at Argonne and will be tested with the DHCAL prototype. Collaboration with other institutions interested in the development of the DHCAL is being considered.

A new high voltage distribution system is being developed to provide the high voltage to all layers in a given calorimeter module. A prototype of the system has recently been tested with RPCs. Currently, the system contains only a single channel, which can be turned on and off without tripping the power supply. The capability of monitoring the current and an expansion to a higher number of channels is being worked on. In tests with DHCAL RPCs it was shown that the distribution system does not affect the measured noise rate.

In the coming months the emphasis will shift from data taking to data analysis. There are concrete plans for several papers based on the data taken at Fermilab. Several of the topics will be the subject of Master's or PhD thesis:

- Instrumentation paper: This paper will describe the design, construction, commissioning and testing of the DHCAL. The paper already exists in draft form.
- Electronics paper: This paper will describe the electronic readout system in great detail. Measurements of the noise floor and the sensitivity as function of signal charge will be included.
- Muon calibration paper: This paper will report on the analysis of muon events in the DHCAL and compare the results to Monte Carlo simulations based on GEANT4. The analysis will include the geometrical alignment of the detector, the scan of the response across a single readout pad, the measurements of the efficiency and average pad multiplicity etc. The paper already exists as a CALICE technical note.
- Positron and Pion response: This paper will summarize the results obtained with positrons and pions in the Fermilab test beam. This analysis requires a complete understanding of the calibration of the DHCAL, currently a major thrust in our analysis effort.

- Noise rate: This paper will report on the detailed measurement of the noise rate in the DHCAL. Even though the noise rate is in general very small and negligible for most analyses, a deep understanding is required for the measurement of electromagnetic and hadronic shower shapes. This paper is expected to be completed later this year.
- Software compensation: Work has initiated on second level analyses of DHCAL data, which involve more than just the counting of pads above threshold. Effects of layer-to-layer weighting and/or of hit weighting (depending on the surrounding hit density) are being explored.

In addition, the analysis of data taken at CERN has already begun and will become a major effort as well. Here the analysis will be performed in collaboration with the CERN Linear Collider group.

The DHCAL went a long way to validate the concept of a digital hadron calorimeter. Based on the experience with the DHCAL, the group is pursuing the development of a realistic design of an HCAL module. In this design the active elements are parallel to the direction of incident particles (see Figure 10). A Monte Carlo model exists and is being used to tune the various design parameters. In particular, as a starting assumption, the design work is based on a concept utilized in the past by the ATLAS tile-calorimeter. In this design the active elements are oriented along the incident particle direction. The advantages of such a design are many: the number of RPCs with different sizes is reduced from say 40 to a manageable number like five, the number of readout boards with different sizes is equally reduced; the gas, low voltage and high voltage connections to the outer rim of the hadron calorimeter can be located on the side of the module, in addition to other minor advantages. Figure 10 shows a possible design of such a module. Extensive Monte Carlo simulations and event analyses are underway to optimize the parameters of this type of calorimeter. This work is being done in collaboration with University of Oregon.

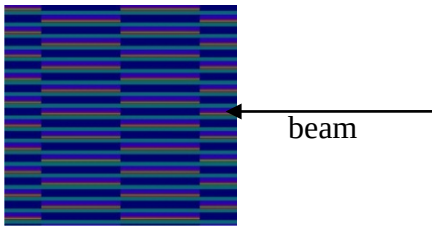

Figure 10: *Model of a digital hadron calorimeter with the active elements parallel to the incident beam direction.*

In the coming years the DHCAL group will complete the test beam activities with the publication of the results/measurements in refereed journals. In addition the group is and will be actively searching for applications for the technology developed with the DHCAL. Contributions to the ORKA calorimeter, ATLAS muon trigger upgrade, LBNE veto shield, and FAIR time-of-flight systems are being considered. The group is also pursuing R&D to expand the applicability of RPCs, by e.g. improving the rate capability or their basic design features.

To maintain the viability of the DHCAL option for possible applications at a future lepton collider, such as a low-energy ILC or the high-energy CLIC machine, the group plans to tackle technical issues which have not yet been addressed by the DHCAL. For instance, for use at the CLIC machine the electronic readout system needs to be completely revised. The new readout is required to provide nano-second timing, which is one of the new features to be implemented into the next version of the front-end ASIC. In addition, the use of the DHCAL

technology at a future lepton machine will require a gas recirculation system, high-voltage distribution systems (capable of handling 6 – 8 kV) and possibly high-rate RPCs.
The group is in the process of establishing a new collaboration with several Chinese institutions, which have shown strong interest in the DHCAL. If successful, the DHCAL will profit from a significant boost in both effort and resources.

2013:

- Completion of data taking in the CERN test beam. (In collaboration with CERN.)
- Publication of instrumentation, noise rate (in collaboration with IIT) and muon response papers.
- Assembly of large 1-glass RPCs and tests.
- Assembly of first RPCs using semi-conductive glass and beam tests. (In collaboration with COE college.)
- Assembly of prototype high-voltage distribution system and bench tests. (In collaboration with University of Iowa.)
- Development of gas recirculation system. (In collaboration with University of Iowa and CERN.)
- Development of a new front-end ASIC for the RPC readout. (In collaboration with FNAL.)

2014:

- Publication of the positron and pion response papers. (In collaboration with University of Iowa.)
- Publication of paper on software compensation (in collaboration with UTA).
- Publication of first W-DHCAL papers (in collaboration with CERN).
- Beam tests of several large prototype 1-glass RPCs.
- Beam tests of RPCs using semi-conductive glass (with even lower resistivity) to establish rate capability. (In collaboration with COE college.)
- Use of high-voltage distribution system in beam tests. (In collaboration with Iowa)
- Construction of gas recirculation system and tests with the DHCAL. (In collaboration with Iowa.)
- Prototyping of the new front-end ASIC for the RPC-readout and tests with new front-end readout board. (In collaboration with FNAL.)

2015:

- Completion of the Fe-DHCAL data analysis with publication of final papers.
- Completion of the W-DHCAL data analysis with publication of final papers.
- Design and test of new front-end readout system for RPCs.

5.2 Novel Robust Telescope Designs

The nature and fundamental properties of dark matter remains one of the biggest mysteries in all of physics. Solving this puzzle will require the full repertoire of experimental techniques developed over the years in particle physics. There are multiple complementary approaches for studying dark matter. Indirect detection using cosmic gamma rays employs the Cherenkov light generated in the earth's atmosphere when a cosmic gamma ray interacts to form a shower in the medium. Simulations have shown that the superior angular resolution and better background rejection of dual-mirror telescopes improves the angular resolution of a single telescope by at least a factor of two compared to the traditional single-mirror design.

Our proposed R&D program includes the development of a full mechanical design of a dual-mirror telescope with a primary mirror diameter of 9 meters. We will focus on mechanical designs, which meet the structural specifications required to improve the physics performance.. A dual-mirror telescope has more stringent structural performance requirements than a traditional single-mirror telescope design, the latter of which is used by all the current generation experiments. Deformations and deflections in a dual-mirror design require the optical surfaces be positioned with an accuracy of better than a few mm and to be aligned to better than

0.2mrad. The telescope optical support structure must not deviate from the perfect aspheric surface by much more than 0.1mm over a length of one meter. Our proposed R&D program includes developing detailed preliminary designs of a two-mirror telescope structure employing mechanical design methods such as finite element analyses. Our structural analysis will investigate different loading scenarios, different construction materials, and different motion systems. Especially important for a generic dual-mirror telescope will be those elements in the design that focus on long-term reliability and remote robotic operations.

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IV. Curriculum Vitae

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Selected Publications Related to Picosecond Instrumentation:

1. B.W. Adams, M.F. DeCamp, E.M. Dufresne, D.A. Reis, **Picosecond Laser-Pump, X-Ray Probe Spectroscopy of GaAs**, Rev. Sci. Instrum 73, 4150-4156 (2002)
2. B.W. Adams, **Femtosecond Synchronism of X-rays to Visible Light in an X-ray Free-Electron Laser**, Rev. Sci. Instrum. 76, 063304 (2005)
3. A. Grigoriev, D.-H. Do, D.M. Kim, C.-B. Eom, B. Adams, E. Dufresne, P.G. Evans, **Sub-nanosecond piezoelectric x-ray switch**, Appl. Phys. Lett. 89, 021109 (2006),
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6. A. Grigoriev, D.-H. Do, P.G. Evans, B. Adams, E. Landahl, E.M. **Dufresne Synchronizing fast electrically driven phenomena with synchrotron x-ray probes**, Rev. Sci. Instrum. 78, 023105 (2007)
7. B.W. Adams, **Femtosecond Synchronism of X-rays and Visible/Infrared Light in an XFEL**, Rev. Sci. Instrum. 78, 123302 (2007)

Other Selected Publications:

1. B.W. Adams (ed.), Nonlinear Optics, Quantum Optics, and **Ultrafast Phenomena with X-Rays**, subtitled Physics with X-Ray Free-Electron Lasers, Kluwer Acad. Publishers (2003), ISBN 1-4020- 7475-1.
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Teacher, Wisconsin School of Electronics (1982)
Engineer, Lunar Radiation Corporation (1981)

Awards, Memberships, and Professional Service:
Member of NIM committee, 1993-1994
Member, VME International Trade Association, 1992

Selected Research Accomplishments:
Lead Engineer, design of trigger and data acquisition systems, Digital Gammasphere, 2010-present
Project Engineer, Trigger Upgrade, VERITAS experiment : 2008-2011
Lead Engineer, design of trigger system for GRETINA experiment : 2006-2009
Chief Electrical Engineer, D-Zero experiment, 2001-2005
Project Engineer, design of analog front end for Central Fiber Tracker, D0, 1999-2002

Selected Publications:

1. **"Commissioning and Performance of a Fast Level-2 Trigger System at VERITAS"**, IEEE Real Time Conference, 2012
2. **"Implementation and performance of the electronics and computing system of the Gamma Ray Energy Tracking In-Beam Nuclear Array (GRETINA)".** Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2011 IEEE
3. "**A Topological Trigger System for Imaging Atmospheric-Cherenkov Telescopes".** Aug 2009. 4 pp. e-Print: arXiv:0908.0179 [astro-ph.IM]
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Education:
Ph.D. (2002 M.S.) Astronomy & Astrophysics, University of Michigan, 2008
NASA Graduate Student Researchers Program Fellow 2003 – 2006
Rackham Graduate School Regents' Fellow 2000 – 2003
M.S., Physics, University of Kentucky, 1998
U.S. Dept. of Education Areas of National Need Fellow 1996 – 1997
B.A., Physics, University of Chicago, 1996
General & Physics Department Honors 06/1996, Dean's List 1993 – 1996

Professional Employment:
Postdoctoral Appointee, Argonne National Laboratory, 2012 – Present
Computational Postdoctoral Fellow, Argonne National Laboratory, 2010-2012
Postdoctoral Appointee, Argonne National Laboratory, 2008 – 2010
Engineering Assistant, Argonne National Laboratory, 2007 – 2008
Adjunct Faculty, Bluegrass Com/Tech College, 1999 – 2000
Select Concurrent Appointments
Adjunct Faculty, American Public University, 2010 – 2012
Astronomy Mentor, Thomas Edison State College, 2009 – 2010
Adjunct Faculty, College of DuPage, 2009

Selected Awards, Memberships, and Professional Service:
Full Member, American Astronomical Soc., 2008 – Present
Board Member, Postdoc Society, Argonne National Laboratory, 2008 – 2011
Pacesetter Award, Argonne National Laboratory, 2009

Selected Publications:

1. **JPB**, R. Kessler, S. Kuhlmann et al., *Supernovae Simulations and Strategies for the Dark Energy Survey*, Astrop. J., accepted (2012)
2. J. Marriner, **JPB**, R. Kessler et al., *A More General Model for the Intrinsic Scatter in Type Ia Supernova Distance Moduli*, Astrop. J., **740**, 72 (2011).
3. S. Kuhlmann, H. Spinka, **JPB** et al., *Narrow-Beam X-Ray Tests of CCD Edge Response*, Exp. Astron., **29**, 135 (2010)
4. R. Kessler, **JPB**, D. Cinabro et al., *SNANA: a Public Software Package for Supernova Analysis*, Pub. Astron. Soc. Pac., **121**, 1028 (2009)
5. **JPB**, P. A. Hughes, *Refining a relativistic, hydrodynamic solver: admitting ultra-relativistic flows*, J. Comput. Phys., **228**, 6212 (2009)
6. **JPB**, S. P. Bhavsar, *Models for the Magnitude-Distribution of Brightest Cluster Galaxies*, Mon. Not. Royal Astron. Soc., **322**, 625 (2001)

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Education:

B.S., Bogazici University, Istanbul, Turkey, Mechanical Engineering, 2001
M.S., Bogazici University, Istanbul, Turkey, Physics, 2006
Ph.D., University Of Iowa, Iowa City, Physics, 2011

Professional Employment:

Postdoctoral Research Associate, University Of Iowa, Iowa City, IA and Argonne National Laboratory, Argonne, IL (2011-Present)

Awards, Memberships, and Professional Service:

Member of CMS and CALICE Collaborations.

Selected Publications:

1. U. Akgun et.al, "Boron and thermal neutron interactions on borosilica window photomultiplier tubes", JINST 5 P08005, 2010

2. CMS HCAL **C**ollaborati**o**n, **"**Study of various photomultiplier tubes with muon beams and Čerenkov light produced in electron showers", JINST 5 P06002, 2010

3. U. Akgun et.al., "CMS Hadronic Endcap Calorimeter Upgrade Studies for SLHC 'P-Terphenyl Deposited Quartz Plate Calorimeter Prototype'", IEEE Transactions on Nuclear Science, Vol. 57, No. 2, p. 754, 2010

4. Q. Zhang et.al., "Environmental dependence of the performance of resistive plate chambers", JINST 5 P02007, 2010

5. B. Bilki et.al., "Hadron showers in a digital hadron calorimeter", JINST 4 P10008, 2009

6. B. Bilki et.al., "Measurement of the rate capability of Resistive Plate Chambers", JINST 4 P06003, 2009

7. B. Bilki et.al., "Measurement of positron showers with a digital hadron calorimeter", JINST 4 P04006, 2009

8. B. Bilki et.al., "Calibration of a digital hadron calorimeter with muons", JINST 3 P05001, 2008.

Karen Byrum

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Education:
B.S., Old Dominion University 1983
Ph.D., University of Wisconsin, Madison 1991

Professional Employment:
Physicist, ANL (2000-present)
Assistant Physicist, ANL (1995-2000)
Postdoctoral Fellow, ANL (1992-1995)

Awards, Memberships, and Professional Service:
High Energy Physics Advisory Panel (HEPAP) member (2011-2013)
D.O.E./N.S.F Review panels (numerous)
Conference organization (15+)
Invited talks (7 at international conferences)
Publications including conference proceedings (630).
ANL service committee work (LDRD, Strategic Planning, Pacesetter)
ANL Strategic Initiative Leader for Astrophysics and Cosmology
Graduate of first cohort of Strategic Laboratory Leadership Program (2007-2008)
Elected Member of Fermilab Users Committee (1997-1999)
CDF Service work (convenerships, detector reviews, Shift Leader)
VERITAS Service work (Science Board, Speakers Committee, Shifts)

Selected Research Accomplishments:
VERITAS Level 2- Trigger Upgrade (2010/2012)
Leader of Laboratory Astrophysics Program (2007-2010).
White Paper on the Status and Future of Ground-based Gamma-ray Astronomy (2007)
TrICE Telescope (2005/06).
Construction and operation of CDF shower maximum frontend electronics (1995).
Shower max. e/γ level-2 trigger (1992).
Observations of first forward/backward muons at CDF (1988)

Selected Publications (Karen Byrum):

1. **"VERITAS Deep Observations of the Dwarf Spheroidal Galaxy"**, E.Aliu et al., Physical Review D85, 062001 (2012)
2. **"Detection of Pulsed Gamma Rays Above 100 GeV from the Crab Pulsar",** E.Aliu et al., Science 334 (2011), 69
3. **"The Track Imaging Cherenkov Experiment",** S.A.Wissel et al.,NIM in Physics Res, Sec A, Vol 659, Issue 1, 11, Dec 2011, pg 175-181
4. **"Development of Large Area Fast Microchannel Plate Photo-detectors",** K.Byrum for the LAPPD Collaboration , Proc. SPIE 8033, 80330U (2011); doi:10.1117/12.884032
5. **"VERITAS Search for VHE Gamma-ray Emission from Dwarf Spheroidal Galaxies",** Astrophysical Journal, Vol 720, 1174-1180 (2010)

Selected Publications (Karen Byrum-continued):

6. **"A Search for Dark Matter Annihilation with the Whipple 10m Telescope"**, M.Wood et al, Astrophysical Journal, Vol. 678, Issue 2, pp 594-605 (2008)
7. **"The TrICE Prototype MAMPT Imaging Camera"**, K. Byrum et. el., 30th International Cosmic Ray Conference.arXiv:0710.0659v1 (2007)
8. **"Shower Maximum Trigger for Electrons and Photons at CDF"**, K. Byrum, et. el Nucl. Instrum. Methods, A364 (1995)

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Education:

Ph.D., University of California, Berkeley, Physics 1988
A.B. cum laude ,Vassar College, Physics 1981

Professional Employment:
Scientist, Argonne National Laboratory, 2010
S. Chandrasekhar Distinguished Service Professor, U. Chicago, 2000
Professor Physics U. Chicago, 2000
Professor Astronomy & Astrophysics, Enrico Fermi Institute, U. Chicago, 1998

Awards, Memberships, and Professional Service:

Fellow of the APS (2010); Beatrice M. Tinsley Prize of the AAS (2006); Robertson Memorial Lecturer of the NAS (2005); Magellanic Premium Medal of the Am. Phil. Soc (2005); Elected to the NAS (2002); Fellow of the Am. Acad. Arts & Sci (2000); James S. McDonnell Centennial Fellowship (1999); John D. and Catherine T. MacArthur Fellowship (1998); NASA Medal for Exceptional Scientific Achievement (1997)

National Academy of Science; American Academy of Arts and Sciences; American Physical Society (Fellow); American Astronomical Society; International Union of Radio Scientists (URSI)

NASA Sen. Rev.; NSF Sen. Rev.; Astro2010 Decadal Survey; FNAL PAC

Selected Publications:

1. "DASI First Results: A Measurement of the Cosmic Microwave Background Angular Power Spectrum,'' N. W. Halverson, *et al*., 2002, ApJ,568, 11
2. "Detection of the Polarization in the Cosmic Microwave Background with DASI,'' J. Kovac, *et al.*, 2002, *Nature*, Dec 19, 2002, 420, 772-787
3. "Cosmology with the Sunyaev-Zel'dovich Effect,'' Carlstrom, J.E., Holder, G.P., Reese, E.D., *Annual Reviews of Astronomy and Astrophysics*, 2002, V40, 643
4. "Galaxy clusters discovered with a Sunyaev-Zel'dovich effect survey," Z. Staniszewski, *et al*., 2009, ApJ, 701, 32-41
5. "Measurements of Secondary Cosmic Microwave Background Anisotropies with the South Pole Telescope," M. Lueker *et al*., 2010, ApJ, 719, 1045
6. "Galaxy Clusters Selected with the Sunyaev-Zel'dovich Effect from 2008 South Pole Telescope Observations", Vanderlinde et al., 2010, ApJ in press, arXiv:1003.0003
7. "A Measurement of the Damping Tail of the Cosmic Microwave Background Power Spectrum with the South Pole Telescope," R. Keisler et al. 2011 *ApJ*, **743** 28
8. "Cosmological Constraints from Sunyaev-Zel'dovich-Selected Clusters with X-ray Observations in the First 178 Square Degrees of the South Pole Telescope Survey", B.A. Benson, *et al*., 2011 ApJ submitted, arXiv:1112.5435

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Education:

Ph.D., Stanford University, 2005
B.A., University of Chicago, 1997

Professional Employment:

Staff, ANL (2010-present)
Research Scientist, University of Chicago (2008-present)
KICP Fellow, University of Chicago (2005-2008)
Postdoctoral Scholar, Stanford University (2004-2005)

Awards, Memberships, and Professional Service:

KICP Fellow (2005)

Selected Publications:

1. "Cosmological Constraints from Sunyaev-Zel'dovich-Selected Clusters with X-ray Observations in the First 178 Square Degrees of the South Pole Telescope Survey", B.A. Benson, et al., arXiv:1112.5435
2. "A Measurement of the Damping Tail of the Cosmic Microwave Background Power Spectrum with the South Pole Telescope," R. Keisler et al. 2011 *ApJ* **743** 28
3. "Galaxy clusters discovered with a Sunyaev-Zel'dovich effect survey," Z. Staniszewski, et al., 2009, ApJ, 701, 32-41
4. "Development of Absorber Coupled TES Polarimeter at Millimeter Wavelengths," G. Wang et al., IEEE Transactions on Applied Superconductivity, 19(3), 544–547 (2009)
5. "Thermal Design and Characterization of Transition Edge Sensor (TES) Bolometers for Frequency-Domain Multiplexing," M. Lueker et al., IEEE Transactions on Applied Superconductivity, 19(3), 496–500 (2009)
6. "Limits on Spin-Independent Interactions of Weakly Interacting Massive Particles with Nucleons from the Two-Tower Run of the Cryogenic Dark Matter Search," D. S. Akerib et al., Physical Review Letters 96(1), 011302 (2006)
7. "Limits on spin-dependent WIMP-nucleon interactions from the Cryogenic Dark Matter Search," D. S. Akerib et al., Physical Review D (Particles and Fields) 73(1), 011102 (2006)
8. "First Results from the Cryogenic Dark Matter Search in the Soudan Underground Laboratory," D. S. Akerib et al., Phys. Rev. L93, 211301 (2004)

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Education:

Institute of Technology, Eindhoven, Undergraduate Studies, Physics, 1976-1982
University of Amsterdam, Graduate Studies, Physics, 1983-1986
State University of New York, Stony Brook, Postdoctoral Research, Physics, 1987-1992

Professional Employment:

Senior Scientist, Argonne National Laboratory, 2010 – present
Scientist II, Fermi National Accelerator Laboratory, 2001 – 2010
Scientist I, Fermi National Accelerator Laboratory, 1996 – 2001
Adjunct Professor of Physics ("Bijzonder Hoogleraar"), University of Amsterdam, 1999 – 2009
Wilson Fellow (Associate Scientist), Fermi National Accelerator Laboratory, 1992 – 1996

Awards, Memberships and Professional Services:

Member of the BNL Electron Ion Collider Detector Advisory Committee, 2011– present
Program chair for the TIPP 2011conference, 2011– present
Member of the KEK BELLE Program Advisory Committee, 2010 – present
Co-chair, w/ Prof. Ian Shipsey, of the DPF Task Force on Instrumentation in
High Energy Physics, 2010 – present
Convener of the Detector R&D common task group for the Physics and Experiment
Board of the ILC, 2008 – present
Co-PI, with Prof. Jim Brau, of the university Linear Collider Detector R&D program, 2008 – present

Selected Publications:

1. R. Adolphi *et al.* (CMS collaboration), *The CMS experiment at the CERN LHC,* Journal of Instr., JINST **3** S08004 (2008); [http://www.iop.org/EJ/abstract/1748-0221/3/08/S08004/]
   V.M Abazov *et al* (Dzero collaboration), *The upgraded Dzero detector*, Nucl. Instr. and Meth. **A565,** 463 (2006)
2. W. Cooper *et al.*, *Electrical properties of carbon fiber support systems,* Nucl. Instr. and Meth. **A550**, 127 (2005) M. Abolins *et al., Hadron and Electron Response of Uranium/Liquid Argon Calorimeter Modules for the Dzero Detector*, Nucl. Instr. and Meth. **A280**, 36 (1989)
3. S. Abachi *et al.* (Dzero collaboration)*, Measurement of the W-Boson Mass*, Phys. Rev. Lett. **77**, 3309 (1996) S. Abachi *et al.* (Dzero collaboration)*, Observation of the Top Quark*, Phys. Rev. Lett. **74**, 2632 (1995)
4. B. Adeva *et al.* (Mark-J collaboration), *The production and Decay of Tau Leptons*, Phys. Lett. **179B**, 177 (1986) G.P.A. Berg et al., *High resolution spectroscopy of* ^{102}*Ru(d,p)*^{103}*Ru and* ^{104}*Ru(p,d)*^{103}*Ru reactions*, Nucl. Phys. **A379,** 93 (1982)

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Education:
B.S.E.E., University of Wisconsin – Madison, 1982
M.S.E.E., University of Wisconsin – Madison, 1983

Professional Employment:
Senior Engineer, ANL (2008-)
Engineer, ANL (1997-2008)
Engineer, Fermilab (1983-1997)

Awards, Memberships, and Professional Service:
Member, IEEE (1994)
Argonne Pacesetter Award – June, 2007, June, 2011
Publications (20)
Additional published conference proceedings (29)
Unpublished technical reports (53)

Selected Research Accomplishments
Design Engineer, design and production of front-end electronics for the calorimeters of the CDF detector, Run I at Fermilab (1983-1989).
Design of custom integrated circuits (1994-1996).
Lead Project Engineer, design and production of front-end electronics for the Shower Maximum Detector for the CDF, Run II Upgrade at Fermilab (1995-1999).
Lead Project Engineer and Level 3 Manager, design and production of the readout instrumentation for the MINOS Near Detector at Fermilab (1999-2005).
Design of Cockroft-Walton photomultiplier base for the BCAL detector of the Zeus Experiment at DESY in Hamburg, Germany (1999-2000).
Design of a custom backplane for the Level 2 Trigger of the ATLAS Experiment at the LHC at CERN in Switzerland (2004-2005).
Development of beam monitoring electronics for the NuMI Beamline at Fermilab (2003-2005).
Telescope camera R&D for the TrICE Telescope at Argonne (2003-2006).
Lead System Engineer, design and production of readout instrumentation for Digital Hadron Detector R&D for CALICE (Detector R&D for the International Linear Collider) (2003-present).
Development of a 1-GHz Photon-Counting Custom Integrated Circuit for Ground-Based Air-Cherenkov Telescopes. (2005-2008).
Development of 1-Picosecond timing instrumentation for HEP applications (2005-present).
R&D on detector development using silicon photomultipliers (2006-2008).
Switching power supply support for the Barrel Calorimeter of the ATLAS Experiment at the LHC at CERN in Switzerland (2006-present).
Lead engineer, design of high-speed topological trigger for future telescope arrays for gamma-ray astronomy (2007-present).

Development of new switching power supplies for the upgrade of the Barrel Calorimeter of the ATLAS Experiment at the LHC at CERN in Switzerland (2008-present).
Development of new readout instrumentation for the upgrade of the Barrel Calorimeter of the ATLAS Experiment at the LHC at CERN in Switzerland (2008-present).

Selected Publications (Gary Drake):

1. "An Upgraded Front-End Switching Power Supply Design for the Atlas TileCal Detector of the LHC," *IEEE 2011 NSS Conf. Rec.,* 2011, 8 pages.

2. "Production and Commissioning of a Large Prototype Digital Hadron Calorimeter for Future Colliding Beam Experiments," *IEEE 2011 NSS Conf. Rec.,* 2011, 12 pages.

3. "A New High-Speed Pattern Recognition Trigger for Ground-Based Telescope Arrays Used in Gamma-Ray Astronomy," *IEEE 2008 NSS Conf. Rec.,* 2008, 8 pages.

4. "The MINOS Near Detector Front End Electronics *IEEE Trans. Nucl. Sci.,* vol. 53, 2006, pp. 1347-1355.

5. "DCAL: A Custom Integrated Circuit for Calorimetry at the International Linear Collider," *IEEE 2005 NSS Conf. Rec.,* 2005, 8 pages.

6. "The Shower Maximum Front-End Electronics for the CDF Upgrade," *IEEE Trans .Nucl. Sci.,* vol. 49, 2002, pp. 2567-2573.

7. "The Upgraded CDF Front End Electronics for Calorimetry," *IEEE Trans. Nucl. Sci.*, vol. 39, 1992, pp. 1281-1285.

8. "A Large Dynamic Range Charge Amplifier ADC for the Fermilab Collider Detector Facility," *IEEE Trans. Nucl. Sci.,* vol. 33, 1986, pp. 893-896.

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Education:

Ph.D., Physical Chemistry, The University of Chicago 1995
B.A. in Chemistry, *Summa cum Laude*, Cornell University 1988

Professional Employment:

Senior Research Associate, University of Colorado, 2000-2002
Visiting Scientist, Argonne National Laboratory, 2002-2005
Chemist, Argonne National Laboratory, 2005-2009

Selected Publications:

1. J. W. Elam, G. Xiong, C. Y. Han, H. Hau Wang, J. P. Birrell,U. Welp, J. N. Hryn, M. J. Pellin, T. F. Baumann, J. F. Poco, and J. H. Satcher, Jr, **"Atomic Layer Deposition for the Conformal Coating of Nanoporous Materials"**, Journal of Nanomaterials, **2006**, 1–5, (2006).
2. T. W. Hamann, A. B. F. Martinson, J. W. Elam, M. J. Pellin, and J. T. Hupp, **"Atomic Layer Deposition of TiO_2 on Aerogel Templates: New Photoanodes for Dye-Sensitized Solar Cells"**, J. Phys. Chem. C, **112** (27), 10303–10307, (2008).
3. T. W. Hamann, A. B. F. Martinson, J. W. Elam, M. J. Pellin, and J. T. Hupp, **"Aerogel Templated ZnO Dye-Sensitized Solar Cells"**, Advanced Materials, in Press, (2007).
4. A. B. F. Martinson, J. W. Elam, J. T. Hupp, and M. J. Pellin, **"ZnO Nanotube Based Dye-Sensitized Solar Cells"**, Nano Letters, **7** (8) 2183-2187, (2007).
5. J. W. Elam, D. A. Baker, A. B. F. Martinson, M. J. Pellin, and J. T. Hupp, **"Atomic Layer Deposition of Indium Tin Oxide Films Using Nonhalogenated Precursors"**, J. Phys. Chem. C, **112**, 1938-1945, (2007).
6. S. O. Kucheyeva, J. Biener, Y. M. Wang, T. F. Baumann, K. J. Wu, T. van Buuren, A. V. Hamza, and J. H. Satcher, Jr., J. W. Elam and M. J. Pellin, **"Atomic Layer Deposition of ZnO on Ultralow-Density Nanoporous Silica Aerogel Monoliths"**, Appl. Phys. Lett., **86**, 083108 (2005).
7. J. W. Elam, D. A. Baker, A. J. Hryn, A. B. F. Martinson, M. J. Pellin, and J. T. Hupp, **"Atomic Layer Deposition of Tin Oxide Films Using Tetrakis(dimethylamino) Tin"**, J. Vac. Sci. Tech. A., **26** (2) 244-252, (2008).
8. J. W. Elam, J. A. Libera, P. C. Stair, and M. J. Pellin, **"Spatially Controlled Atomic Layer Deposition in Porous Materials"**, Appl. Phys. Lett., **91** 243105-1 – 243105-3, (2007).

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Education:
B.Sc., University of Colombo, Sri Lanka, 2002
M.S., Ohio State University, Columbus, 2005
Ph.D., Ohio State University, Columbus, 2010

Professional Employment:
Post Doctoral Appointment, HEP, Argonne National Laboratory, 2010-present

Awards, Memberships, and Professional Service:
Member, IEEE, APS
Gold Medal for Physics Project (2001), University of Colombo, Sri Lanka
1st and 2nd prize National Awards For Inventions (1996), Sri Lanka Inventers Commission
2nd prize Industrial Awards For Inventions (1997), Sri Lanka Industrial Development Board
2nd prize Presidential Awards For Inventions (1997), Sri Lanka Inventers Commission

Selected Publications:

1. **Radiation-hard/high-speed data transmission using optical links,** *K.K. Gan, B. Abi, W. Fernando, H.P. Kagan, R.D. Kass, A. Law, M.R.M. Lebbai, F. Rizatdinova, P.L. Skubic, D.S. Smith***,** Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 607, Issue 1, 1 Aug 2009, Pages 240-243.
2. **Overview and status of ATLAS Pixel Detector,** *W. Fernando*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 596, Issue 1, 21 Oct 2008, Pages 58 – 62.
3. **Radiation-hard optical link for SLHC,** *K.K. Gan, W. Fernando, H. Kagan, R. Kass, A. Law, S. Smith, M.R.M. Lebbi, P.L. Skubic,* Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 596, Issue 1, 21 Oct 2008, Pages 88 - 92
4. **Optical link of the ATLAS pixel detector**, *K.K. Gan, W. Fernando, P.D. Jackson, M. Johnson, H. Kagan, A. Rahimi, R. Kass, S. Smith, P. Buchholz, M. Holder, A. Roggenbuck, P. Schade, M. Ziolkwoski,* Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 570, Issue 2, 11 Jan 2007, Pages 292 – 294.
5. **Bandwidth of Micro Twisted-Pair Cables and Fusion Spliced SIMM-GRIN Fibers and Radiation Hardness of PIN/VCSEL Arrays**, R.D. Kass, **W. Fernando**, K.K. Gan, H.P. Kagan, A Law, M.R.M. Lebbai, P.L. Skubic, D.S. Smith, Nuclear Science Symposium Conference Record, 2006. IEEE Volume 2, Oct 29 2006 - Nov 1 2006 Page(s) 717 – 720.
6. **Development of Low Mass Optical Readout for High Data Bandwidth Systems**, D. Underwood, P. DeLurgio, G. Drake, W. Fernando, D. Lopez, B. Salvachua-Ferrando, and R. Stanek, IEEE. Nuclear Science Symposium Conference Record (NSS/MIC), 624 - 629, 2010.
7. **Radiation Hard Optical Link for SLHC**, *K K Gan, B Abi,* ***W Fernando****, H P Kagan, R D Kass, A Law, M R M Lebbai, A Rau, F Rizardinova, P L Skubic and D S Smith,* Journal of Physics: Conference Series 110 (2008) 092011.
8. **The ATLAS Experiment at the CERN Large Hadron Collider**, *G Aad et al,* 2008 JINST 3 S08003.

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Education:

B.S., University of Illinois, Urbana-Champaign, Electrical Engineering, 1988
M.S., Northern Illinois University, DeKalb, Physics, 2004
Ph.D., Northern Illinois University, DeKalb, Physics, 2010

Professional Employment:

Postdoctoral Research Associate, Argonne National Laboratory, 2010-Present
Graduate Researcher, Northern Illinois Center for Collider and Detector Development, 2002-2010
Software Engineer, Panasonic/MIECOA, Elgin, IL 1995-2002
Video game developer, V-Real, Redwood City, CA/Brian A. Rice Inc. Hinsdale, IL, 1994-1995
Electrical Engineer, Panasonic Technologies, Franklin Park, IL, 1990-1994

Awards, Memberships, and Professional Service:

Member of CALICE Collaboration and IEEE.

Selected Publications:

1. K. Francis, for the CALICE Collaboration, "Construction of the DHCAL", Physics Procedia, PHPRO2387, 10.1016/j.phpro.2012.02.377, 2012

2. G.C. Blazey et.al., for the CALICE Collaboration, "Construction and Performance of a Silicon Photomultiplier/Extruded Scintillator Tail-Catcher and Muon Tracker", JINST 7 P04015, 2012

3. K. Francis, "Results of Beam Tests on the Prototype Calorimeter for a Linear Collider", PhD Dissertation, May 2010

4. A. Dyshkant, et.al "Small scintillating cells as the active elements in a digital hadron calorimeter for the e+e- linear collider detector", INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICSJ. Phys. G: Nucl. Part. Phys. 30 (2004) N1–N16 PII: S0954-3899(04)76470-1 RESEARCH NOTES FROM COLLABORATIONS

5. K. Francis, for the CALICE Collaboration, "TIPP 2011 Proceedings: Construction of the DHCAL", Physics Procedia, in preparation

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Education:
B.A. (Physics), 1966, Harvard University
Ph.D. (Physics), 1971, Univ. of California, Berkeley

Professional Employment:
Professor of Physics, University of Chicago, 1984-Present
Associate Professor of Physics, University of Chicago, 1977-1984
Assistant Professor of Physics, University of Chicago, 1973-1977
Instructor of Physics, University of Chicago, 1971-1973
Joint Appointment, High Energy Physics Division, Argonne, 2009-Present

Honors:
Harvard College Scholarship, 1962-1963 and 1965-1966
Leeds and Northrop Foundation, Predoctoral Fellow, 1966-1967
Fellow, American Physical Society, 1986
Quantrell Award for Excellent in Teaching, University of Chicago, 1992
University of Chicago Provost's Teaching Award 2006-2007

Synergistic Activities:
Chair, Nominating Committee, Division of Particles and Fields, APS, 1992
Fermilab Program Advisory Committee, 1990-94
Panofsky Prize Committee, American Physical Society, 1994-95
Divisional Councilor, Division of Particles and Fields, APS, 1/95-12/98
Committee on the International Freedom of Scientists, 1996-1998
Vice-Chair, Board of the Bulletin of the Atomic Scientists, 2003- 2005
Tanaka Prize Committee, American Physical Society, 2005
Board of the Bulletin of the Atomic Scientists, 2002- present
Spokesperson of the Committee of the Council of the University Senate (elected) 2004-2005
Organizing Committee: Aspen Winter Conference, ``New Physics at the Electroweak Scale and New Signals at Hadron Colliders'', Jan. 8-13, 2007
Organizing Committee: Pico-Sec Timing Hardware Workshop; Chicago, IL, USA; 18 Nov., 2005
Organizing Committee: Pico-Sec Simulation Workshop; Chicago, IL, USA; 12 December, 2006
Organizing Committee: Workshop on Timing Detectors, March 8-9, 2007, Saclay, France
Organizing Committee: XXXXIIIth Rencontres de Moriond --Electroweak Interactions and Unified Theories, March 1-8, 2008, La Thuile, Italy
Organizing Committee: Workshop on Psec Timing, Chicago, IL, USA; March 17-18, 2008

Selected Publications (Henry J. Frisch):

1. **A limit on the Branching Ratio of the Flavor-Changing Top Quark Decay t->Zc ,** with Alexander Paramonov and the CDF Run II Collaboration (A. Abulencia et al.). To be submitted to Phys. Rev. D., Spring 2009.
2. **Large area, pico-second resolution, time of flight detectors**, United States Patent 20070187596; (with Harold Sanders, Fukun Tang, and Timothy Credo).
3. **New Developments in Fast-Sampling Analog Readout of MCP-Based Large-Area Picosecond Time-of-Flight Detectors**, (with Fukun Tang et al.); Proceedings of IEEE 08, October 2008, Dresden Germany.
4. **Transmission-Line Readout with Good Time and Space Resolutions for a Planicon MCP-PMT**, with Fukun Tang et al.; Poster presented at the Topical Workshop on Electronics for Particle Physics (TWEPP), Prague, Czech Republic, Sept. 6, 2007.
5. **The Timing System for the CDF Electromagnetic Calorimeters**; with M. Goncharov, D. Toback, et al.; Nucl. Instrum. Meth. A **565:538-542**, 2006.
6. **MCP-PMT Anode Development of Psec-Resolution Time-of-flight Detectors**, with Timothy Credo et al.; IEEE 2006 Nuclear Science Symposium, San Diego, May 2006.
7. **A 96-channel FPGA-based Time-to-Digital Converter**, with M. Bogdan et al.; Nucl. Instrum. Meth. A **554**, 444 (2005).
8. **Virtual Prototype Method Used in Design of Electronic Circuitry for CDF**; with W. Ashmanskas et al.; Nucl. Instrum. Meth. A **518**, 491 (2004).

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Education:
University of Wisconsin, Milwaukee - Undergraduate coursework in Chemistry, Zoology, Mathematics, English, Computer Science, Economics and Accounting

College of DuPage, Glen Ellyn, IL - Tungsten Inert Gas (TIG) welding course, 2002
Metal Inert Gas (MIG) welding course, 1995

Professional Employment:

Principal Scientific Glass Blower Specialist, Argonne National Laboratory, 1980-Present
Plant Superintendent and Head Scientific Glassblower, Pope Scientific, Inc., Menomonee Falls, WI., 1974-1980
Head Scientific Glassblower, Aldrich Chemical Company, Milwaukee, WI, 1973-1974
Scientific Glassblower, Pope Scientific, Inc., Menomonee Falls, WI, 1969-1973

Awards, Memberships, and Professional Service:
Director's Award, Argonne National Laboratory, November 2011
Outstanding Service Award, University of Chicago, Board of Governors for Argonne National Laboratory July, 2011
Argonne National Laboratory 2011 Director's Team Award for Outstanding Safety Performance, July 2011
Argonne National Laboratory "Pacesetter Award", December 2009
ASGS "President's Achievement Award", June 2008
Argonne National Laboratory "Pacesetter Award", April, 2004
ASGS Southeast Section's *Dana Sampson Award* for the best "Lampshop Hint"
Published in *Fusion* during 2003
William A. Wilt Award for Outstanding Technical Workshop at the ASGS National Symposium, Cleveland, OH, 2003

Patents

United States Patent #413,678 for the "Gregar Extractor" invention September 9, 1999
United States Patent # 7,271592 for the "Toroid Cavity/Coil NMR Multi-Detector" September 18, 2007

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Education:

B.S., Illinois Institute of Technology 1987
M.S., Illinois Institute of Technology 1988
Ph.D., University of Illinois at Chicago 1999

Professional Employment:

Engineer, ANL (1993-Present)
Assistant Engineer, ANL (1989-1993)

Awards, Memberships, and Professional Service:
Licensed Illinois Professional Engineer
U.S. ATLAS Tilecalorimeter Project Engineer – responsible for all US structural design, fabrication, and assembly on the ATLAS Tilecalorimeter at the LHC
NOvA Project Engineer – responsible for the analysis of the NOvA structure and the design and fabrication of all construction equipment for the detector
MINOS Project Engineer – responsible for the design and fabrication of machinery for constructing MINOS modules.

Selected Publications:

1. **"Stability of the EB When Cryostat Load is Applied"** Argonne National Laboratory Technical Report ANL-HEP-TR-04-65; June 23, 2004

2. **"Analysis of the Connections Between Modules in the EB"** Argonne National Laboratory Technical Report ANL-HEP-TR-02-056; May 16, 2002

3. **"Stress Analysis Of The Welds In The Girder"** Argonne National Laboratory Technical Report ANL-HEP-TR-98-06; December 1, 1997

4. **"Extended Barrel Support Saddle Design and Analysis"** presented at the Atlas engineering meeting at The European Center for Nuclear Research (CERN), Geneva, Switzerland; August, 2001

5. **"Proposal for the Completion of the Outstanding Work, Scheduling and Alignment of the SDC Central Calorimeter"** Argonne National Laboratory Technical Report ANL-HEP-TR-93-101; November 1993

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Education:

Bachelor of Science in Computer Engineering
University of Illinois, Champaign-Urbana, IL

Professional Employment:

Argonne National Laboratory, Argonne, IL 60439
High Energy Physics Division - Engineering Specialist (2004 - Present)
Electronics & Computing Technologies Division - Engineering Specialist (2000 - 2004)

Selected Publications:

1. **A topological array trigger for AGIS, the Advanced Gamma-ray Imaging System.**
   F. Krennrich *et al.* 2009. 4pp.
   Published in AIP Conf.Proc.1085:894-897, 2009.
2. **A new high-speed pattern recognition trigger for ground-based telescope arrays used in gamma ray astronomy**
   Anderson, John; Byrum, Karen; Dawson, John; Drake, Gary; Haberichter, Bill; Horan, Deirdre; Krennrich, Frank; Kreps, Andrew; Madhavan, A.; Schroedter, Martin; Smith, Andy;
   Nuclear Science Symposium Conference Record, 2008. NSS '08. IEEE
   19-25 Oct. 2008 Page(s):2773 - 2780
3. **Calibration of a digital hadron calorimeter with muons.**
   Burak Bilki *et al.* FERMILAB-PUB-08-066-E, Feb 2008. 17pp.
   Published in JINST 3:P05001, 2008.
4. **A new readout system for "Digital Hadron Calorimetry" for the International Linear Collider**
   Butler, J.; Cundiff, T.; Drake, G.; Haberichter, W.N.; Hazen, E.; Hoff, J.; Holm, S.; Kreps, A.; May, E.; Repond, J.; Underwood, D.; White, A.P.; Shouxiang Wu; Lei Xia; Jaehoon Yu;
   Nuclear Science Symposium Conference Record, 2007. NSS '07. IEEE
   Volume 3, Oct. 26 2007-Nov. 3 2007 Page(s):2145 - 2153
5. **2-D scintillation position-sensitive neutron detector**
   De Lurgio, P.M.; Farrar, K.A.; Kreps, A.S.; Madden, T.J.; Naday, I.; Weizeorick, J.T.; Hammonds, J.P.; Miller, M.E.; Schultz, A.J.;
   Nuclear Science Symposium Conference Record, 2005 IEEE
   Volume 2, 23-29 Oct. 2005 Page(s):648 - 653
6. **A new detector for time-resolved small angle X-ray scattering studies**
   De Lurgio, P.M.; Hessler, J.P.; Weizeorick, J.T.; Kreps, A.S.; Molitsky, M.J.; Naday, I.; Drake, G.R.; Jennings, G.;
   Nuclear Science Symposium Conference Record, 2005 IEEE
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Ph.D. Physics, Purdue University, 1988
B.S. Physics, Wichita State University, 1984

Professional Employment:

Argonne National Laboratory, Physicist 1997-Present
Argonne National Laboratory, Assistant Physicist 1992-1997
Enrico Fermi Fellow, Argonne National Laboratory, 1990-1992
Postdoctoral Appointee, Argonne National Laboratory, 1988-1990

Awards, Memberships, and Professional Service:
Dark Energy Survey ANL group leader
Member SDSS Supernova group
Member LSST Supernova group
Member American Astronomical Society
Airfly/Auger Collaboration member (April 2004 – December 2007)
Former DOE Level 2 Manager CDF Calorimeter Upgrade
Former Project Leader CDF Preshower Detector Upgrade
Former CTEQ Co-Spokesperson
Former Physics Coordinator CDF QCD Group
SSC Fellowship

Selected Publications:

1. **"SNANA: a Public Software Package for Supernova Analysis"**, R. Kessler *et al.,* submitted to Publications of the Astronomical Society of the Pacific

2. **"Dark Energy Survey Supernovae Simulations and Survey Strategy"**, J. P. Bernstein, R. Kessler, S. Kuhlmann, H. Spinka, Dark Energy Survey Collaboration, in "Cosmology.

3. Proceedings of the 43rd Rencontres de Moriond", Eds. J. Dumarchez, Y. Giraud Heraud, and J. Tran Thanh Van, World Publishing Company, Hanoi, Vietnam, 2009

4. **"Global QCD Analysis Of Parton Structure Of The Nucleon: CTEQ5 Parton Distributions"**, H.L. Lai *et al.,* Eur.Phys.J.C12:375-392,2000

5. **"Observation of Top Quark Production in Anti-P P Collisions"**, CDF Collaboration (F. Abe *et al*.), Phys.Rev.Lett.74:2626-2631,1

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Ph.D Physics, University of Rochester, Rochester, NY 1976
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Professional Employment:

Physicist, Argonne National Laboratory, 1985-Present
Assistant Physicist, Argonne National Laboratory, 1980-1985
Postdoctoral Appointee, Argonne National Laboratory, 1977-1980
Postdoctoral Appointee, Physics Department, University of Rochester, Rochester, NY, 1976-1977

Selected Publications:

1. **"Beam test- of a Tiime-of-Flight detector prototype"**, J. Va'vra, D.W.G.S. Leith, B. Ratcliff, E. Ramberg, M. Albrow, A. Ronzhin, C. Ertley, T. Natoli, E. May, K. Byrum, Nuclear Inst. and Methods in Physics Research, A 606 (2009) pp. 404-410
2. **"Testing a silicon photomultiplier time-of-flight (TOF) system in Fermilab Test Beam Facility"**, Ronzhin, A.; Ramberg, E.; Albrow, M.; Vavra, J.;Frisch, H.; Natoli, T.; Ertley, C.; Kim, H.; Kobach, A.; Tang, F.; Wilbur, S.; Genat, J.-F.; May, E.; Byrum, K.; Anderson, J.; Drake, G.; Nuclear Science Symposium Conference Record, 2008. NSS '08. IEEE 19-25 Oct. 2008 Page(s):2392 – 2394.
3. **"New developments in fast-sampling readout of Micro-Channel Plate based large area pico-second time-of-flight detectors",** Anderson, John T.; Byrum, Karen; Drake, Gary; Ertley, Camden; Frisch, Henry J.; Genat, Jean-Francois; May, Edward; Salek, David; Tang, Fukun; Nuclear Science Symposium Conference Record, 2008. NSS '08. IEEE 19-25 Oct. 2008 Page(s):2478 – 2481.
4. **"Calibration of a digital hadron calorimeter with muons"**, Burak Bilki et al. FERMILAB-PUB-08-066-E, Feb 2008. 17pp. Published in JINST 3:P05001,2008.
5. **"A data skimming service for locally resident analysis data"**, J. Cranshaw (Argonne) , R.W. Gardner (Chicago U., EFI) , G. Gieraltowski, D. Malon (Argonne) , M. Mambelli (Chicago U., EFI) , E. May (Argonne) . 2008. 9pp. Published in J.Phys.Conf.Ser.119:072011, 2008.
6. **"GSIMF: A web service based software and database management system for the next generation grids"**, Nanbor Wang, Balamurali Ananthan (Tech-X, Boulder) , Gerald Gieraltowski, Edward May, Alexandre Vaniachine (Argonne) . 2008. 7pp. Published in J.Phys.Conf.Ser.119:062049,2008.

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Education:

Postdoctoral Fellow, Materials Science Department, Tohoku University, Japan (1998-2001).
Ph.D. Physics, Verkin Institute for Low Temperature Physics and Engineering, National Academy of Sciences, Kharkov / Ukraine (1998)
State Diploma in Mechanical Engineering (with Honors), Zhukovsky National Aerospace University of Ukraine (1993).

Employment:

Materials Scientist, Argonne National Laboratory, 2005-Present
Assistant Scientist, Argonne National Laboratory, 2001-2004

Awards, Memberships, and Professional Service:

Post-doctoral Fellowship of Japanese Ministry of Education, 1998.
Best PhD Student Award, International Science Soros Foundation (USA-Ukraine), 1996.
Referee, Journal for Chemistry and Physics of Solids, Journal of Magnetism and Magnetic Materials, Journal of Applied Physics, Applied Physics Letters, Physical Review B, Physical Review Letters, Journal of Nanotechnology and Nanoletters.
Reviewer for U. S. Department of Energy's SBIRR/ STTR programs (2007-2008).

Selected Publications:

1. V. Yefremenko, G. Wang, V. Novosad, A. Datesman, J. Pearson, R. Divan, C. Chang, T. Downes, J. McMahon, L. Bleem, A. Crites, S.S. Meyer, and J.E. Carlstrom, **"Low Temperature Thermal Transport in Partially Perforated Silicon Nitride Membranes"**, Appl. Phys. Letter, **94**, 183504 (2009).
2. V. Yefremenko, A. Datesman, G. Wang, J. Pearson, V. Novosad, R. Divan, C. Chang, T. Downes, L. Bleem, A. Crites, S.S. Meyer, and J.E. Carlstrom, **"Control of Membrane Thermal Transport Supporting Superconducting Detector Development",** IEEE Trans. of Applied Superconductivity, accepted.
3. V. Yefremenko , E. Gordiyenko , G. Shustakova , Yu. Fomenko , A. Datesman , G. Wang, J. Pearson, E.E. W. Cohen, and V. Novosad, **"A broadband imaging system for research applications",** Review of Scientific Instruments, **80**, 056104 ,2009.
4. G. Wang, V. Yefremenko, A. Datesman, J. Pearson, V. Novosad, R. Divan, C. Cheng, T. Downes, J. McMahon, L. Bleem, A. T. Crites, S. S. Meyer, and J. E. Carlstrom , **"Absorber Type TES Bolometer for Polarimetry at Millimeter and Sub-millimeter Wavelength",** IEEE Trans. of Applied Superconductivity, accepted.
5. A. Belkin, V. Novosad, M. Iavarone, J. Fedor, J. Pearson, A. Petrean-Troncalli, and G. Karapetrov, **"Tunable transport in magnetically coupled MoGe/Permalloy hybrids"**, Appl. Phys. Lett., **93**, 072510 (2008).
6. A. Datesman, J. Pearson, G. Wang, V. Yefremenko, R. Divan, T. Downes, C. Chang, J. McMahon, S. Meyer, J. Carlstrom, D. Logan, T. Perera, G. Wilson, and V. Novosad, **"Frequency selective bolometer development at Argonne National Laboratory",** *Millimeter and Submillimeter Detectors and Instrumentation for Astronomy IV*, Book Series: Proc. of SPIE, Vol. **7020**, pp 2029-2029, 2008.
7. A.Datesman, T. Downes, C. Chang, T. Perera, D. Logan, S. Meyer, G. Wilson, G. Wang, V. Yefremenko, V. Novosad, J.Pearson, R.Divan, L. Bleem, A. Crites, J. McMahon, and J. Carlstrom, **"TES Development for a Frequency Selective Bolometer"**, IEEE Trans. of Applied Superconductivity, accepted.
8. V. Yefremenko, E. Gordiyenko, V. Pishko, and V. Novosad, **"METHOD FOR DETECTION AND IMAGING OVER A BROAD SPECTRAL RANGE"**, US Patent # 7,274,019 B2, Sept. 25, 2007.

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Education:

The University of Chicago, Ph.D. Physics, 2009. Advisor: Henry J. Frisch
M.S. Physics and Applied Math with Honors, Moscow Institute of Physics and Technology (Russia) 2005
B. Sc. Physics and Applied Math with Honors, Moscow Institute of Physics and Technology (Russia) 2003

Employment:

Argonne National Laboratory, Maria Goeppert Mayer Postdoctoral Fellow, 2009-2012

Honors and Awards:

Best Poster Award for "Search for the Neutral Current Top Quark Decay t→Zc", Hadron Collider Physics Symposium 16-20 November 2009, Evian (France)
Maria Goeppert Mayer (Argonne Named) Postdoctoral Fellowship 2009 (accepted)
CERN Postdoctoral Fellowship for 2009 (declined)
Sugarman award for Excellence in Graduate Student Research, 2006-2007
Diploma at all-Russian Olympiad in physics, 1999

Presentations and Posters:

1. "Background Rejection Techniques in Measurements with Jets", Chicago 2012 workshop on LHC Physics, May 2012
2. "Study of jets produced in association with a vector boson", HEP Seminar, Iowa State University, April 2012
3. "W/Z + jets and W/Z + heavy flavor production at the LHC", 47th Rencontres de Moriond on QCD and High Energy Interactions, La Thuile, Italy, March 2012
4. "ATLAS: Physics Highlights", US LHC Users Organization Annual Meeting, Argonne National Laboratory, November 2011
5. "Measurement of the production cross sections for *W*- and *Z*- bosons in association with jets at ATLAS", US ATLAS Physics Workshop, Boston University, August 2011
6. "Invariant mass distribution of jet pairs produced in association with one lepton and missing transverse energy at the ATLAS experiment", Implications at the LHC of BSM interpretations of CDF's ttbar forward-backward asymmetry and Wjj anomaly, LHC Physics Center at CERN, May 2011
7. "Measurement of the production cross section for W- and Z-bosons in association with jets with the ATLAS detector", Particle Physics Seminar, University of Notre Dame, February 8, 2011
8. "Measurement of W/Z-boson production in association with jets at ATLAS", Plenary talk at the Conference on LHC First Data, Ann Arbor (MI, USA), December 2010

José Repond

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Education:

Diploma, Basel University, Basel, Switzerland, Physics, 1980
Ph.D., Basel University, Basel, Switzerland, Physics (High Energy Physics), 1985

Employment:

Group Leader of Digital Hadron Calorimeter, Argonne National Laboratory, 2001-Present
ZEUS Group Leader, Argonne National Laboratory, 1997 – Present
Physicist, Argonne National Laboratory, 1993 – Present
Assistant Physicist, Argonne National Laboratory, 1988 – 1993
Postdoctoral Research Associate, Argonne National Laboratory, 1985–1988

Awards, Memberships, and Professional Service:

International Advisory Committee for the Deep Inelastic Scattering Workshop series.

Selected Publications:

1. J.Repond, **"The International Linear Collider and its Detectors"**, BPL **16**(1), 296 (2009).
2. B.Bilki et al., **"Measurement of Positron Showers with a Digital Hadron Calorimeter"**, ArXiV 0902.1699. JINST **4** P04006 (2009).
3. B.Bilki et al., **"Measurement of the Rate Capability of Resistive Plate Chambers"**, ArXiV 0901.4371. JINST **4** P06003 (2009)
4. J.Repond et al., **"Design and Electronics Commissioning of the Physics Prototype of a Si-W Electromagnetic Calorimeter"**, JINST **3** P08001 (2008).
5. B.Bilki et al., **"Calibration of a Digital Hadron Calorimeter with Muons"**, JINST **3** P05001 (2008).
6. G.Drake et al., **"Resistive Plate Chambers for Hadron Calorimetry: Tests with Analog Readout"**, Nucl. Inst. and Meth. **A578**, 88 (2007).
7. G.Drake et al., **"A Digital Hadron Calorimeter with Resistive Plate Chambers for the Linear Collider"**, Int. J. Mod. Phys, **A20** 3830 (2005).
8. S.Chekanov et al., **"Dijet Production in Neutral Current Deep Inelastic Scattering at HERA"**, Eur. Phys **C23**, 13 (2002).

Harold Spinka

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Education:

B.A., Physics, Northwestern University, 1966
Ph.D., Physics, (minor astronomy), California Institute of Technology, 1970

Professional Employment:

Senior Physicist, Argonne National Laboratory, 1987 – present
Physicist, Argonne National Laboratory, 1976 – Aug. 1987
Adjunct Assistant Professor, University of California at Los Angeles 1973-1976
Postdoctoral Fellow, Argonne National Laboratory 1970 – 1973

Awards, Memberships, and Professional Service:

Fellow, American Physical Society
Member, Sigma Xi and Phi Beta Kappa

Selected Publications:

1. "Experimental Determination of the Total Reaction Cross Section of the Stellar Nuclear Reaction $^{16}O + ^{16}O$," H. Spinka and H. Winkler, Nucl. Phys. **A233**, 456 (1974).

2. "Observation of Structures in the pp Total Cross-Section Difference of Pure Helicity States in the Mass Range of 2100 to 2500 MeV," I.P. Auer et al., Phys. Rev. Lett. **41**, 1436 (1978).

3. "Measurements of Triple- and Double-Spin Parameters in Elastic p-p Scattering at 6 GeV/c," I.P. Auer et al., Phys. Rev. **D32**, 1609 (1985).

4. "Measurement of C_{LL} and C_{SL} in np Elastic Scattering at 484 and 634 MeV," G.R. Burleson et al., Phys. Rev. Lett. **59**, 1645 (1987).

5. "Analyzing Power in Inclusive π^+ and π^- Production at High x_F with a 200 GeV/c Polarized Proton Beam," D.L. Adams et al., Phys. Lett. **264B**, 462 (1991).

6. "Measurement of the Differences in the Total Cross Section for Antiparallel and Parallel Longitudinal Spins and a Measurement of Parity Nonconservation with Incident Protons and Antiprotons at 200 GeV/c," D.P. Grosnick et al., Phys. Rev. **D55**, 1159 (1997).

7. "Evidence From d + Au Measurements for Final State Suppression of High p_T Hadrons in Au + Au Collisions at RHIC," STAR Collaboration (J. Adams et al.), Phys. Rev. Lett. **91**, 072304 (2003).

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Education:
B.S., University of San Francisco 1971
MS., The University of Chicago 1973
Ph.D.,The University of Chicago 1977

Professional Employment:
Physicist, ANL (1989- present)
Assistant Professor, University of Maryland (1982-1988)
Postdoctoral Staff, LANL (1979-1981)
Postdoctoral Staff, LBNL (1978-1979)
Postdoctoral Staff, UCLA (1977-1978)

Awards, Memberships, and Professional Service:
Co-spokesperson for Parity Violation experiment at LAMPF (1980-81)
ZEUS Service work (Run Coordinator, 1992)
University of Maryland Summer Grant (1983)
ANL service committee work (LMS R&D Process, Pacesetter Awards, Astrophysics Initiative)
MINOS Service Work (WBS Level 3 manager)
NOvA Service work (WBS Level 2 manager, EVMS certification, Exec. Board)

Selected Research Accomplishments:
Built low noise ion chambers & electronics to detect parity violation with proton beams (1973-80)
Designed and built highly efficient veto wall and electronics for LAMPF neutrino experiment (1979-81)
Detected electron-neutrino scattering interaction with electrons LAMPF (1986)
Detected electron-neutrino transmutation of carbon nucleus to nitrogen at LAMPF (1987)
Designed CYGNUS cosmic ray experiment muon detection electronics at LAMPF (1985-6)
Designed & built ZEUS First Level Calorimeter Trigger (1989-1992)
Designed and built ZEUS small rear tracking detector Trigger (1993-1995)
Led ANL prototype beam tests for MINOS detector (1996-7)
Developed extruded scintillator for MINOS (1998-2001)
Led MINOS Near Detector Scintillator Assembly Factory (2000-2001)
Led OMNIS and ADONIS supernova neutrino detector design group (2002-2005)
Developed highly reflective PVC extrusions for NOvA (2006-2007)

Selected Publications:

1. **"Measurement of Neutrino Oscillations with the MINOS Detectors in the NuMI Beam"**, Phys. Rev. Lett. 101, 131802 (2008).
2. **"The magnetized steel and scintillator calorimeters of the MINOS experiment"**, NIMA 596, 190 (2008).
3. **"OMNIS, The Observatory of Multiflavor Neutrinos from Supernovae"**, Nucl. Phys. A718,222 (2003)
4. **"Search for Lepton Flavor Violation in e-p collisions at 300 GeV cm energy"**, Z. Phys C73, 613 (1997)

<u>Selected Publications (Richard Talaga-continued)</u>:

5. **"Measurement of the Exclusive Cross Section $^{12}C(\nu_e, e^-)\ ^{12}N(g.s.)$"**, Phys. Rev. Lett. 64, (1990).
6. **"First Observation and Cross Section Measurement of $\nu_e + e^- \rightarrow \nu_e + e^-$"** Phys. Rev. Lett. 55, 2401 (1985).
7. **"Central Collisions with a Projectile of 1.8 GeV/Nucleon ^{40}Ar"**, Phys. Lett. 79B, 325 (1978).
8. **"Limit on Parity Violation in p-Nucleus Scattering at 6 Gev/c"**, Phys. Rev. Lett. 34, 1184 (1975).

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Ph.D., Physics, University of Chicago, 1973
M.S., Physics, University of Chicago, 1968
B.S., Massachusetts Institute of Technology, 1967

Professional Employment:

Staff Physicist, Argonne National Laboratory, 1980-Present
Assistant Physicist, Argonne National Laboratory, 1976-1980
Research Associate, University of Rochester, NY, 1972-1976

Awards, Memberships, and Professional Service:
Member of APS, Member of IEEE
Occasional reviewer for Physics proposals and Rev. Sci. Inst.
Served on various reviews within STAR experiment
One Patent

Selected Publications:

1. **"Longitudinal double-spin asymmetry for inclusive jet production in p+p collisions at s**(1/2) = 200-GeV"**, By STAR Collaboration (B.I. Abelev et al.). Phys.Rev.Lett.100:232003,2008.
2. **"The optical instrumentation of the ATLAS tile calorimeter"**,ATLAS TileCal Collaboration (J. Abdallah et al.). ATL-TILECAL-PUB-2008-005, ATL-COM-TILECAL-2007-025, 2009.
3. **"Beam Performance of Tracking Detectors with Industrially Produced GEM Foils"**, F. Simon, et al, arXiv:0808.3477, 2008
4. **"RPC R&D for DHCAL at ANL"**, D. Underwood, et al, Paris LCWS2004
5. **"Comparison of spin asymmetries and cross-sections in pi0 production by 200-GeV polarized anti-protons and protons"**, E704 Collaboration (D.L. Adams et al.). Phys.Lett.B261:201-206,1991
6. **"Measurement of the isolated prompt photon cross-sections in anti-p p collisions at s**(1/2) = 1.8-TeV"**, CDF Collaboration (F. Abe et al.). Phys.Rev.Lett.68:2734-2738,1992.
7. **"The Design And Performance Of The Fnal High-Energy Polarized Beam Facility"**, FNAL-E581/704 Collaboration (D.P. Grosnick et al.). Nucl.Instrum.Meth.A290:269,1990.
8. **"Large Doppler shift in RADAR Detection of Ultra High Energy Cosmic Rays"**, D. Underwood, Proceedings IEEE Radarcon2008

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Ph.D. in Physics and Mathematics, Academy of Sciences of Uzbekistan, 1993
Diploma Thesis in Physical Engineering (physical electronics), summa cum laude degree,Tashkent Polytechnic Institute, 1985

Professional Employment:

Staff Scientist, Materials Science Division, Argonne National Laboratory, 1998-present
Visiting Scientist, Department of Chemistry, University of Antwerp (UIA), B-2610 Antwerp, Belgium, 1997-1998
Staff Scientist, Arifov Institute of Electronics, Academy of Sciences of Uzbek Soviet Socialist Republic / Republic of Uzbekistan, Tashkent 700143, USSR / Uzbekistan, 1990-1995
Engineer, Special Bureau for Design and Technology at Arifov Institute of Electronics, Academy of Sciences of Uzbek Soviet Socialist Republic, Tashkent 700143, USSR, 1985-1990

Awards, Memberships, and Professional Services:

International Science Foundation (ISF) subsistence grant (1993)
STA Fellowship (Science and Technology Agency, Japan, 1996)
DWTC/OSTC Scholarship (Office for Scientific, Technical and Cultural Affairs, Belgium, 1997)
American Geophysical Union and American Society for Mass Spectrometry
Refereeing manuscripts for Analytical Chemistry, Nuclear Instruments & Methods in Physics Research Sections A and B, Review of Scientific Instruments; Reviewing proposals for DOE and NASA

Selected Publications:

1. **"Efficient multiple beam ion optics for quantitative surface analysis: from simulations to a fully operational instrument", Veryovkin I. V.**, Tripa C. E., Pellin M. J., *Physics Procedia*, 1 (2008) 379-389 (*invited*)
2. **"Laser-Driven Acoustic Desorption of Organic Molecules from Back-Irradiated Solid Foils"**, Zinovev, A.V., **Veryovkin, I.V.**, Moore, J.F., and Pellin, M. J., *Analytical Chemistry*, Vol. 79, (21), (2007), 8232-8241
3. **"Detection of In-Situ Derivatized Peptides in Microbial Biofilms by Laser Desorption 7.87 eV Postionizaton Mass Spectrometry"**, P. D. Edirisinghe, J. F. Moore, K. A. Skinner-Nemec, C. Lindberg, C. S. Giometti, **I. V. Veryovkin**, J. E. Hunt, M. J. Pellin, L. Hanley, *Analytical Chemistry*, Vol. 79 (2) (2007), 508-514
4. **"Development of a cesium sputter ion source compatible with commercial SIMS instruments"**, Belykh, S. F.; Palitsin, V. V.; **Veryovkin, I. V.**; Kovarsky, A. P.; Chang, R. J. H.; Adriaens, A., Dowsett M., Adams, F.; *Review of Scientific Instruments*, 78, 085101 (2007) 9 pages
5. **"Vacuum Ultraviolet Postionization of Aromatic Groups Covalently Bound to Peptides"**, Edirisinghe, P. D.; Moore, J. F.; Calaway, W. F.; **Veryovkin, I. V.**; Pellin, M. J.; and Hanley, L.; *Analytical Chemistry* Vol. 78 (16) (2006) 5876-5883

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Education:

B.S., Physics, University of Illinois-Urbana, 1972
M.S., Physics, University of Illinois-Urbana, 1973
Ph.D., Physics, University of Illinois-Urbana, 1978
Postdoctoral, Particle Physics, Argonne National Laboratory, 1977-80

Professional Employment:

Argonne National Laboratory, Physicist, (1984–present)
Argonne National Laboratory, Assistant Physicist, (1981-1984)

Awards, Memberships, and Professional Service:
Member, American Physical Society
R&D100 Award, Large Area Microchannel Plates (June, 2012)

Selected Publications:

1. **The Track Imaging Cherenkov Experiment**, S.A. Wissel *et al.*, Nucl. Instr. And Meth., **A659**, 175-181 (2011).

2. **VERITAS Search for VHE Gamma-ray Emission from Dwarf Spheroidal Galaxies**, V.A. Acciari *et al.* (VERITAS Collaboration), ApJ **720**, 1174-1180 (2010).

3. **A Search for Dark Matter Annihilation with the Whipple 10 m Telescope**, M. Wood *et al*. (VERITAS Collaboration), ApJ **678**, 594-605 (2008).

4. **The TrICE Prototype MaPMT Imaging Camera,** K.Byrum, J.Cunningham, G.Drake, E.Hays, D.Kieda, E.Kovacs, S.Magill, L.Nodulmann, R.Northrop, S.Swordy, R.Wagner, S.Wakely, S.Wissel, Proc. 30th Int. Cosmic Ray Conf. (Merida), Vol. 2 (OG part 1), 469-472 (2008)

5. **The Timing System for the CDF Electromagnetic Calorimeters**, M Goncharov *et al.*, Nucl. Instr. And Meth., **A565**, 543 (2006).

6. **Observation of Top Quark Production in pbar-p Collisions with the Collider Detector at Fermilab**, F. Abe *et al.* (CDF Collaboration), Phys. Rev. Lett. **74**, 2626 (1995)

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Education:

San Jose State University (1984, M.S. Mechanical Engineering)
University of California, Berkeley (1979, B.S. Manufacturing Engineering)

Professional Employment:

Principal Engineer, Argonne National Laboratory, (2010 until Present)
Engineer, Argonne National Laboratory (2007 – 2010)
Engineer, Argonne National Laboratory, Experimental Facilities Division, (2003 – 2007)
Manager of Mechanical and Product Engineering, Veeco Instruments – Ion Tech Division (2001-2002)
Engineer, Argonne National Laboratory – Accelerator Systems Division (1991-2001)

Awards, Memberships, and Professional Service:
Large Area Picosecond Photo-detector Project Engineer
Sincrotrone Trieste Optical Beamline Diagnostics Principle Investigator
Linac Coherent Light Source Diagnostics Technical and CA Manager
LCLS Vacuum System Technical Lead and CA Manager
Member of Board of Directors, Vacuum Technology Division, American Vacuum Society (1996-1998)

Patents
Dan Meisburger, et al., "Electron Beam Inspection System and Method," Patent No. United States Patent 5,502,306, Issued March 20, 1996
D. Walters, G. Este, "Thin Film Application Method for Small Aperture Vacuum Vessels," Argonne National Laboratory application ANL-IN-06-062, published 3 March 2009.

Selected Publications:

1. Synchrotron Radiation Sources- A Primer, Chapter 8: Vacuum Systems, (Herman Winick editor), World Scientific Publishing Co., (1994) John Noonan and Dean Walters.
2. Qing Ma, **D. R. Walters**, and R. A. Rosenberg, "Electron-induced surface chemistry on TiN in ultra high vacuum," Applied Surface Science 185(3-4), 217-225(2002).
3. Stephen V. Milton, Efim Gluskin, Ned D. Arnold, Steven Berg, Willam Berg, Yong-Chul Chae, Edwin Crosbie, Roger Dejus, Patrc Den Hartog, Horst Friedsam, John Galayda, Arhur Grelick, James R. Maines, Issac Vasserman, N. A. Vinokurov, **Dean R. Walters**, et al., "Status of the Advanced Photon Source low-energy test line," Nuclear Instruments and Methods in Physics Research A 407, pp. 210-214 (1998).
4. **D. R. Walters**, J. Bailey, W. Berg, P. Den Hartog, M. Erdman, R. Lill, S. H. Lee, J. Morgan, G. Pile, E. Trakhtenberg, W. Toter, G. Wiemerslage, B. X. Yang, "Vacuum and Beam Diagnostics for the Linac Coherent Light Source (LCLS) Undulator System," Proceeding of the 30th International Free Electron Laser Conference (2008) TU

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Education:

Ph.D., Experimental Particle Physics, Case Western Reserve University, Cleveland, Ohio, 1999 – 2004
MSc, Lanzhou University, China, 1986 – 1989
BSc, Condensed Matter Physics, Lanzhou University, China, 1982 – 1986

Professional Employment:

Assistant Physicist, Argonne National Laboratory, 2011-Present
Postdoctoral Researcher, Argonne National Laboratory, 2007-2011
Postdoctoral Scholar, California Institute of Technology, Pasadena, California 2004-2007
Teaching Assistant, Case Western Reserve University, Cleveland, Ohio 1999-2000
Visiting Scholar, Cavendish Laboratory, Cambridge University, England 1998-1999
R&D Engineer, Low Temperature Department, Lanzhou Institute of Physics 1989-1998

Awards, Memberships, and Professional Service:

Director's Recognition Award for research excellence during postdoctoral appointee, Argonne National Laboratory, 2011.
ICMC Best Structural Materials Paper Award (2011) for "Thermal Properties of Silicon Nitride Beams Below 1 Kelvin" in "Advances in Cryogenic Engineering (Materials), Volume 56".
American Physical Society, 2001- present.
The American Association for the Advancement of Science, 2006-present.
The American Astronomical Society, 2006-present.

Selected Publications:

1. **Thermal properties of silicon nitride beams below one Kelvin**, G. Wang *et al*., IEEE Trans. on Applied Superconductivity, Vol. 21, pp. 233 (2011)
2. **Phonon Emission in Germanium and Silicon by Electrons and Holes in Applied Electric Field at Low Temperature**, G. Wang, Journal of Applied Physics 107, 094504 (2010)
3. **Development of Absorber Coupled TES Polarimeter at Millimeter Wavelengths,** G. Wang *et al*., IEEE Trans. on Applied Superconductivity, Vol. 19, pp. 544 (2009)
4. **Search for Weakly Interacting Massive Particles with the First Five-Tower Data from the Cryogenic Dark Matter Search at the Soudan Underground Laboratory**, Z. Ahmed *et al.*, Physical Review Letters 102, 011301 (2009)
5. **Surface Event Rejection Using Phonon Information in CDMS,** G. Wang (corresponding author), Nuclear Physics B - Proceedings Supplements, Volume 173, 2007

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Education:

B.S., Rutgers University 2001
Ph.D., University of Maryland 2009

Professional Employment:

Post-doctoral fellow, ANL and University of Chicago, 2009-present

Awards, Memberships, and Professional Service:

Calorimeter expert at D0
W boson Mass and Width Analysis at D0
Speaker at EPS 2007
Henry Rutgers Scholar, 2001
Mary Wheeler Wigner Scholar, 2001
Phi Beta Kappa Society
Rutgers Honors Program

Selected Publications:

1. *A Novel Method for Modeling the Recoil in W Events in Hadron Colliders*, D0 Collaboration (NIM draft in preparation)

2. *A Precision Measurement of the W Boson Width in 1 fb^{-1} at the Run II D0 Detector*, D0 Collaboration (PRL draft in preparation)

3. *A Precision Measurement of the W Boson Mass in 1 fb^{-1} at the Run II D0 Detector*, D0 Collaboration (PRL draft in preparation)

4. *Microstrip Sensors Based on CVD Diamond*, W. Adams et al. Nucl. Instrum. Meth. A **476**, 706 (2000)

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Education:
B.S., Peking University 1996
Ph.D., California Institute of Technology, 2002

Professional Employment:
Physicist, ANL (2012-present)
Assistant Physicist, ANL (2007-2012)
Term Assistant Physicist, ANL (2006-2007)
Postdoctoral Fellow, ANL (2002-2006)

Memberships, and Professional Service:
Co-editor, SiD Detailed Baseline Design document, hadron calorimeter section
Convener at international conferences (4)
Conference organization (3)
Invited seminars and talks (8)
Member of CALICE collaboration
Publications (136).
ANL HEP service committee work (division seminar, space)

Selected Research Accomplishments:
Digital Hadron Calorimeter (DHCal) physics prototype test beam running, data analysis
DHCal physics prototype design, construction, testing and commissioning
DHCal Slice-Test module test beam, simulation and data analysis
DHCal Slice-Test module design, construction and commissioning
Development of Particle Flow Algorithm
R&D of RPC and readout for a DHCal

Selected Publications:

1. B. Bilki, et al., "Environmental Dependence of the Performance of Resistive Plate Chambers" JINST 5 (2010) P02007
2. B. Bilki, et al., "Hadron Showers in a Digital Hadron Calorimeter" JINST 4 (2009) P10008
3. B. Bilki, et al., "Measurement of the Rate Capability of Resistive Plate Chambers" JINST 4 (2009) P06003
4. B. Bilki, et al., "Measurement of Positron Showers with a Digital Hadron Calorimeter" JINST 4 (2009) P04006
5. B. Bilki, et al., "Calibration of a Digital Hadron Calorimeter with Muons", JINST 3 (2009) P05001
6. G. Drake, et al., "Resistive Plate Chambers for Hadron Calorimetry: Tests with analog Readout", Nucl. Instr. And Meth. A (2007), doi: 10.1016/j.nima.2007.04.160
7. L. Xia, "Development of a Particle Flow Algorithm at Argonne", proceeding of CALOR'
8. P. Achard et al., L3 Collaboration "Search for Scalar Leptons and Scalar Quarks at LEP", Phys. Lett. **B580**, 37-49(2003)
9. P. Achard et al., L3 Collaboration "Search for Scalar Leptons in e^+e^- collisions at sqrt(s)=189 GeV", Phys. Lett. **B466**, 71-78(1999)

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Education:

B.S., Peking University 2005
Ph.D., Arizona State University 2010

Professional Employment:

Post-doctoral fellow, Argonne National Laboratory, 2010-present

Selected Publications:

1. J. Xie et.al on behalf of LAPPD collaboration, **Instrumentation for Theory-Inspired Photocathode Development within the Large Area Picosecond Photodetector (LAPPD) Project**, TIPP 2011, Chicago, IL, June 9-14,2010.
2. J. Xie et.al on behalf of LAPPD collaboration, **Development of Bialkali Transfer Photocathodes for Large Area Micro-Channel Plate Photomultipliers**, SORMA West 2012, Oakland, CA, May 14-17 2012.
3. J. Xie et.al on behalf of LAPPD collaboration, **Development of Bialkali Transfer Photocathodes for Large Area Psec Photo Detectors (LAPPD)**, PXPS12, Batavia, IL, June 14-23, 2012.

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Education:

M.S., Kharkov Aviation Institute, Ukraine/ Mechanical Engineering, 1975
Ph.D., Kharkov Aviation Institute, Ukraine/ Electronic Engineering, 1987

Professional Employment:

Physicist, HEP, Argonne National Laboratory, (2011-present)
Engineer, Material Science Division (MSD), Argonne National Laboratory,(2007 - 2011)
Visiting Scientist, MSD, Argonne National Laboratory (2003-2007)
Group Leader, Infrared (IR) Devices Group, B. Verkin Institute for Low Temperature Physics and Engineering, National Academy of Sciences of Ukraine (ILTPE), Kharkov, Ukraine (1997-2003)
Senior researcher, Department of Superconducting Electronics, ILTPE, Ukraine (1989-1997)
Engineer Department of Infrared Devices, Special Research and Development Bureau for Cryogenic Technologies, ILTPE, Ukraine (1975-1989)

Selected Publications:

1. A. T. Crites, B. A. Benson, **L. Bleem**, J. E. Carlstrom, C. L. Chang, A. Datesman, R. Divan, E. M. George, W. L. Holzapfel, A. Lee, M. Lueker, J. J. McMahon, J. Mehl, S. S. Meyer, T. Montroy, T. Natoli, V. Novosad, J. Pearson, J. Ruhl, J. Sayre, E. Shirokoff, K. Story, G. Wang, V. Yefremenko, E. Y. Young, "**Progress on ANL/KICP Bolometers for SPTpol"**, IEEE Transactions on Applied Superconductivity, vol. 21, issue 3, pp. 184-187 (Jun 2011).
2. V. Yefremenko, G. Wang, V. Novosad, A. Datesman, J. Pearson, R. Divan, C. Chang, T. Downes, J. McMahon, L. Bleem, A. Crites, S.S. Meyer, and J.E. Carlstrom, **"Low Temperature Thermal Transport in Partially Perforated Silicon Nitride Membranes"**, Appl. Phys. Letter, **94**, 183504 (2009).
3. V. Yefremenko , E. Gordiyenko , G. Shustakova , Yu. Fomenko , A. Datesman , G. Wang, J. Pearson, E.E. W. Cohen, and V. Novosad, **"A broadband imaging system for research applications",** Review of Scientific Instruments, **80**, 056104, 2009.
4. A. Datesman, J. Pearson, G. Wang, V. Yefremenko, R. Divan, T. Downes, C. Chang, J. McMahon, S. Meyer, J. Carlstrom, D. Logan, T. Perera, G. Wilson, and V. Novosad, **"Frequency selective bolometer development at Argonne National Laboratory",** *Millimeter and Submillimeter Detectors and Instrumentation for Astronomy IV*, Book Series: Proc. of SPIE, Vol. **7020**, pp 2029-2029, 2008.
5. V. Yefremenko, E. Gordiyenko, V. Pishko, and V. Novosad, **"METHOD FOR DETECTION AND IMAGING OVER A BROAD SPECTRAL RANGE"**, US Patent # 7,274,019 B2, Sept. 25, 2007.
6. V Yefremenko, E. Gordiyenko, G Shustakova, S D Bader, G Karapetrov and V Novosad, **Optically activated high Tc superconducting microbolometer"**, Journal of Physics: Conference Series vol.**43**, no.1 : 1342-5, 2006.
7. V. Yefremenko, E. Gordiyenko, J. Pearson, S. Bader and V. Novosad, **"Superconducting microbolometer with controllable coordinate sensitivity: an alternative approach to FPA design"**, Infrared Technology and Applications XXXI, 28 March 2005, Orlando, FL, USA. Proceedings of the SPIE - The International Society for Optical Engineering vol.**5783**, no.1 : 967-73, 2005.

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Ph.D. Physics, Illinois Institute of Technology, 1999
B.Sc. Physics, University of Wisconsin-Madison, 1985

Professional Employment:
Assistant Physicist, Argonne National Laboratory (2005-Present)
Postdoctoral Fellow, Argonne National Laboratory (2002-2005)
Postdoctoral Fellow, University of Connecticut (1999-2002)

Selected Publications:

1. S. Antipov, L. Spentzouris, W. Gai, M. Conde, F. Franchini, R. Konecny, W. Liu, J.G. Power, Z. Yusof, and C. Jing, **"Observation of wakefield generation in left-handed of metamaterial-loaded waveguide",** J. Appl. Phys. 104, 14901 (2008).
2. Z. Yusof, B.O. Wells, T. Valla, P.D. Johnson, A.V. Fedorov, Q. Li, S.M. Loureiro, and R.J. Cava, **"Angle-resolved photoemission study of the metal-insulator transition in bismuth cobaltates"**, Phys. Rev. B 76, 165115 (2007).
3. C. Jing, A. Kanareykin, J.G. Power, M. Conde, Z. Yusof, P. Schoessow, and Wei Gai, **"Observation of Enhanced Transformer Ratio in Collinear Wakefield Acceleration"**, Phys. Rev. Lett. 98, 144801 92007).
4. Zikri M. Yusof, Manoel E. Conde, and Wei Gai, **"Schottky-Enabled Photoemission in a rf Accelerator Photoinjector – Possible Generation of Ultralow Transverse Thermal-Emittance Electron Beam"**, Phys. Rev. Lett. 93, 114801 (2004).
5. J.G. Power, W. Gai, S.H. Gold, A.K. Kinkead, R. Konecny, C. Jing, W. Liu, and Z. Yusof, **"Observation of Multipactor in an Alumina-Based Dielectric-Loaded Accelerating Structure"**, Phys. Rev. Lett. 92, 164801 (2004).
6. J.F. Zasadzinski, L.Coffey, P. Romano, and Z. Yusof, **"Tunneling Spectroscopy of $Bi_2Sr_2CaCu_2O_{8+\delta}$: Eliashberg Analysis of Spectral Dip Feature"**, Phys. Rev. B 68, 180504 (2003).
7. T. Valla, P.D. Johnson, Z. Yusof, B.O. Wells, et al., **"Coherence-Incoherence and Dimensional Crossover in Layered Strongly Correlated Metals"**, Nature 417, 627 (2002).
8. Z. Yusof, B.O. Wells, T. Valla, A.V. Fedorov, P.D. Johnson, Q. Li, C. Kendziora, S. Jian, and D.G. Hinks, **"Quasiparticle Liquid in Highly Overdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$,"** Phys. Rev. Lett. 88, 167006 (2002).

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Education:

Ph.D., Mechanical Engineering, Northwestern University, 2008
M.S. Mechanical Engineering, University of Maine, 2002
B.S., Huazhong University of Sci Tech, China, 1996

Professional Employment:

Mechanical Engineer, Argonne National Laboratory (2007 – present)
Adjunct Professor, Mechanical Engineering Department, Northwestern University (2009 – present)

Awards, Memberships, and Professional Service:

Level 3 Manager, International Collaboration of NuMI Off-Axis ve Appearance Experiment, 2007-present
Level 3 Manager, International Collaboration of Dark Energy Survey (DES), 2007-present

Selected Publications:

1. D. L. DePoy, T. Abbott, S. Kuhlmann, H. Zhao, et al, **"The Dark Energy Camera (DECam),"** SPIE 2008, Marseille, France, June 23-28, 2008.
2. H. Cease, S. Kuhlmann, H. Zhao, et al, **"The dark energy survey CCD imager design,"** SPIE 2008, Marseille, France, June 23-28, 2008.
3. PH. Hu, H. Zhao, KF. Ehmann, "**Third-octave-mode chatter in rolling, Part 1, chatter model,"** Proc. IMechE, Part B: J. Engineering Manufacturing, Vol. 220, No. 8, 2006, p 1267-1277.
4. PH. Hu, H. Zhao, KF. Ehmann, **"Third-octave-mode chatter in rolling, Part 2, stability of a single-stand mill,"** Proc. IMechE, Part B: J. Engineering Manufacturing, Vol. 220, No. 8, 2006, p 1279-1292.
5. PH. Hu, H. Zhao, KF. Ehmann, **"Third-octave-mode chatter in rolling, Part 3, stability of a multi-stand mill,"** Proc. IMechE, Part B: J. Engineering Manufacturing, Vol. 220, No. 8, 2006, p 1293-1303.
6. S. Vel, V. Caccese, H. Zhao, **"Elastic coupling effects in tapered sandwich panels with laminated anisotropic composite facings,"** Journal of Composite Materials, Vol. 39, No. 24, 2005, p 2161-2183.

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Education:
Ph.D., Colorado Sate University 2002
M.S. in physics, Institute of High Energy Physics, China, 1997
B.S. in physics, Shanxi University, China, 1994

Professional Employment:
Assistant Physicist, ANL (2006- present)
Research Associate, University of Colorado (2004-2006)
Research Associate, MIT (2002-2004)

Awards, Memberships, and Professional Service:
ATLAS run manager
ATLAS MinBias trigger signature deputy convener
ATLAS DAQ/HLT coordination
ILC FCAL institution board
BABAR run coordination

Selected Research Accomplishments
ATLAS FTK project (2008- present)
ATLAS physics analysis (QCD, Higgs search) (2009- present)
ATLAS trigger and detector performance study (2008- present)
ATLAS TDAQ commissioning and operation (2006- present)
ILC very forward region calorimeter R&D (2004- present)
BABAR DCH electronics upgrade (2004-2006)
BABAR muon detector upgrade (2004-2006)
CP angle gamma measurement with Dalitz analysis at BABAR (2004-2007)
PHOBOS data analysis tools (2002-2004)
Initiated hybrid/glueball search at BABAR (1998-2006)

Selected Publications:

1. A. Andreani et al., "The FastTracker Real Time Processor and Its Impact on Muon Isolation, Tau and b-Jet Online Selections at ATLAS", IEEE Trans. Nucl. Sci. 59, 348 (2012).
2. ATLAS Collaboration, "Combined search for the Standard Model Higgs boson using up to 4.9 fb^{-1} of pp collision data at $\sqrt{s}$ = 7 TeV with the ATLAS detector at the LHC", Phys. Lett. B710 (2012) 49-66.
3. ATLAS Collaboration, "Measurements of underlying event properties using neutral and charged particles in p-p collisions at 900 GeV and 7 TeV with the ATLAS detector at the LHC", EPJC 71, 1636 (2011).
4. ATLAS Collaboration, "Charged-particle multiplicities in pp interactions at $\sqrt{s}$ = 900 GeV measured with the ATLAS detector at the LHC", Phys. Lett. B688, 21 (2010).
5. H. Abramowicz et al., "Forward Instrumentation for ILC Detectors", JINST 5, P12002 (2010).

Selected Publications (Jinlong Zhang-continued):

6. BABAR Collaboration, "Measurement of CP Violation Parameters with a Dalitz Plot Analysis of $B^{\pm} \rightarrow D_{\pi^+\pi^-\pi^0} K^{\pm}$", Phys. Rev. Lett. 99, 251801 (2007).
7. PHOBOS Collaboration, "The PHOBOS perspective on discoveries at RHIC", Nucl. Phys. A 757, 28 (2005).
8. BABAR Collaboration, "Rare B Decays into States Containing a J/psi Meson and a Meson with ssbar Quark Content", Phys. Rev. Lett. 91, 071801 (2003).

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Education:

B.S., Physics, Purdue University, West Lafayette IN, 2004
Ph.D., Physics, Purdue University, West Lafayette IN, 2010

Professional Employment:

Postdoctoral Research Associate, Argonne National Laboratory (2010 – Present)

Awards, Memberships, and Professional Service:

Member of the VERITAS Collaboration (2005 – Present)
VERITAS Service work (Paper committees, Observer, Shift Czar, etc.)
Organizing committee for Dark Matter mini-workshop at Fermilab (April 2012)

Selected Publications:

1. Zitzer, B. for the VERITAS Collaboration "Upgrade Plans for VERITAS" in prep.
2. Aliu, E at al (The VERITAS collaboration) "VERITAS Deep Observations of the Dwarf Spheroidal Galaxy Segue 1" Physical Review D, vol. 85, Issue 6, id. 062001
3. Aliu, E et al (The VERITAS collaboration) "Detection of Pulsed Gamma Rays above 100 GeV from the Crab Pulsar" Science, Volume 334, Issue 6052, pp. 69- (2011)
4. V.A. Acciari et al. (The VERITAS collaboration) "A connection between star formation activity and cosmic rays in the starburst galaxy M82" Nature, Volume 462, Issue 7274, pp. 770-772 (2009)
5. V.A. Acciari et al. (The VERITAS collaboration) "Detection of Extended VHE Gamma Ray Emission from G106.3+2.7 with Veritas" The Astrophysical Journal Letters, Volume 703, Issue 1, pp. L6-L9 (2009).
6. D. Hanna et al. (The VERITAS collaboration) "First results from VERITAS" Nuclear Instruments and Methods in Physics Research Section A, Volume 588, Issue 1-2 p. 26-32.
7. A. Konopelko et al. "Observations of the Unidentified TeV gamma-ray Source TeV J2032+4130 with the Whipple Observatory 10m Telescope" The Astrophysical Journal, Volume 658, Issue 2, pp. 1062-1068 (2007).

V. Major Facilities

In all experiments the Division has participated in or is participating in, members of the Division have played major roles in the design and construction of the hardware and detector sensors. These span the range of design and construction of large mechanical structures, to the development and construction of superconducting sensors, to the exploration of radiation hard optical readout systems. We provide electronics, installation and commissioning of integrated detector systems and maintenance during the life of the experiment. Due to the unique multi-disciplinary nature of the laboratory, we have access to the materials science expertise and micro and nano fabrication facilities within our materials science and energy systems divisions and our center for nano-scale materials division, which are used in the development of new detector sensors. A brief description of the major facilities is given below.

- Industrial building 366, a 23,000 sq ft high bay, 35 ton crane equipped, unique assembly area for large construction projects. CDF, ZEUS, MINOS and ATLAS modules as well as moving systems for ATLAS were built here. Recently the full prototype of a 56x56ft NOvA module was assembled here. The Argonne laboratory provides and maintains this space.
- There is a mechanical design group within the Division, with two mechanical engineers, typically supported by project funds. We also have access to a lab wide engineering group in case more effort is needed.
- The Division is the home of the electronics group with a total staff of ~ 9 engineers, designers and technicians who support all Argonne divisions. This group designs, builds and maintains electronics associated with detectors provided by the Division for experiments. Typically at least 3-4 members of that group work on HEP activities.
- Machine shop including 2D CNC machining capability (plus machinist) in the large assembly building, plus two smaller machine shops. We also have access to the large Central Shop maintained by the laboratory where a full range of machining capabilities is available including multi-axis CNC, EDM, welding, and precision inspection instrumentation.
- Cosmic ray test stand and optical research lab in HEP Building 362.
- Three Atomic Layer Deposition systems in the Energy Systems Division: a Beneq reactor, a Large Substrate Reactor (LSR), and a tube reactor. The latter is only for 33mm disks. The Beneq and LSR systems are for 8" plates.
- Plasma Atomic Layer Deposition Reactor in Energy System Division used for superconducting cavity development.
- Access to the Argonne Electron Microscopy Center, and a variety of surface analysis tools such as Low Energy Electron Diffraction, X-ray Photoelectron Spectroscopy, and Ultra-Violet Photoelectron Spectroscopy.
- Access to the Argonne Glass Shop run by a 4th generation scientific glass blower with 45 years of experience.
- Access to the IBM Blue Gene Q supercomputing capabilities within the Argonne Leadership Computing Facility
- High bandwidth electo-optical test stands with capabilities to test up to 11 Gb/s links. Bit Error Rate (BER) measurement facilities, motorized 2D stage for optical alignment, CW laser sources (650nm, 850 nm, 960nm, 1490nm, 1550nm), high speed receivers (10 Gb/s), optical power meters, Lens systems and alignment facilities.

- Femto-second UV laser test facility at the Argonne Advanced Photon Source
- Thin film synthesis tools, including two 5-targets sputtering systems (AJA, direct and con-focal gun configurations) to synthesize superconducting and thin films and heterostructures. The con-focal deposition system is dedicated for synthesis of superconducting films only, and provides film thickness uniformity of ~2% across the 6" wafer.
- Clean Rooms (Class 1000) equipped with microfabrication tools, including 100-kV electron-beam lithography (JEOL 9300 FS), 30-kV electron-beam lithography (Raith 150), focused ion beam/scanning electron microscopy (FEI Nova 600 NanoLab Dual Beam, Step-and-repeat nanoimprint (Nanonex NX-3000), and Optical mask aligner (Karl Suss MA6), Reactive-ion etch (RIE) station for high resolution anisotropic etching of silicon, silicon dioxide, silicon nitride with a high degree of selectivity, anisotropic etching of refractory metals and removal of organic residue (uses CHF_3, SF_6, CF_4 gas chemistry), Inductive coupled plasma reactive ion etching chlorine chamber (Cl_2, SF_6, BCl_3, HBr, CHF_3, CO, O_2, Ar) (Oxford Instruments Plasmalab 100); Reactive ion etching fluorine chamber (SF_6, CF_4, CH_4, CHF_3, HCFC-124, H_2, O_2, Ar) (Oxford Instruments Plasmalab 100); Table-top reactive ion etching chlorine chamber (Cl_2, CH_4, H_2, O_2, Ar) (March Plasma); Table-top reactive ion etching fluorine chamber (SF_6, CF_4, H_2, O_2, Ar) (March Plasma); Table-top reactive ion etcher (CF, SF_6, Ar, O_2) (Plasma Sciences 600); Barrel asher system (Ar, N_2, O_2) (PlasmaTherm), Wet Wafer Processing tools, including, Wafer rinse dryer tool (2-, 4-, and 6-inch), Electroforming (Au, Cu, Ni, Pt), Silicon anisotropic etching, membrane fabrication and wet etching.
- Metrological tools, including Optical microscopes (Olympus MX-61), Three-dimensional surface profilometer (Veeco Dektak 8), Profilometer (Tencor Alpha Step 500), and Reflectometer (Filmetrics); X-ray diffractometers and Atomic Force Microscopes for structure of the films and devices. The AFM system is equipped with Q-control module for enhanced sensitivity and has a vibration isolation enclosure, which helps to ensure that the system has a vertical noise resolution of less than 0.5 Angstrom.
- Conventional transport and magnetic characterization tools, including Physical Properties Measurements System (PPMS, Quantum Design) for measurements of magnetization, magnetic anisotropy, susceptibility and I-V four-probe transport measurements in temperatures 1.7K-400K, and magnetic fields up to 7 T, and Superconducting Quantum Interference Device (SQUID, Quantum Design) for high-sensitivity magnetization measurements at temperature range 1.7K - 350K, and magnetic fields up to 6 T.
- Sub-Kelvin transport characterization tools:
    i. An insert-type liquid helium cryostat (CIA) with an open-cycled He3 refrigerator (280mK base temperature);
    ii. Liquid helium cryostat (Chase cryogenics) with a closed-cycled He3 refrigerator (230mK base temperature);
    iii. Four series SQUIDs arrays with home-built readout electronics;
    iv. NIST time domain SQUIDs multiplexing read-out system, current one column first stage SQUIDs for 32 sensors readout, expandable to 32 x 8;
    v. Lakeshore temperature controllers and temperature monitors;
    vi. Lock-in amplifiers (Stanford Research, SR830) and one AC resistance bridges (Stanford Research, SIM921).
- Burle/Photonis photocathode growth facility for large area photocathodes, currently as large as 7''X7''. The facility consists of a PMT envelope tube, a turbo-pumped high vacuum system capable of 10^{-8} torr base pressure, oven and a control table.

Ultra-High Vacuum Growth and Characterization Facility, designed for the study of the cathode growth process. The chamber consists of a growth chamber, an optical and electrical characterization chamber and a surface science chamber.

- Photocathode electrical and optical characterization station for reflection, transmission and quantum efficiency measurement of various thin film materials, equipped with Newport 70511 Apex Monochromater Illuminator, Newport 74125 Oriel Cornerstone 260 1/4m monochromator, enclosed beam path, Si photodiode light detector, Femto DLPCA-200 Current amplifier, Keithley 2701 Ethernet Multimeter/Data Acquisition System and 6517B Electrometer/High Resistance Meter.
- VAC HE-43-6 DRI LAB glove box which provides a working area of inert atmosphere nearly free of moisture and oxygen, which permits handling of materials sensitive to moisture and oxygen contamination. The system consists of a gas delivery system, a hermetically sealed glove box, a side-mounted load-lock chamber and a full-view window.
- In addition we have access to the user facilities at the Center for Nanoscale Materials (CNM). These include: complex oxide film synthesis via molecular beam epitaxy (DCA R450 Custom), physical vapor deposition (Lesker CMS 18 and PVD 250), spin coating (Laurell WS-400), electron beam lithography system (JEOL 9300 Raith 150), focused ion beam (FEI Nova 600 NanoLab), laser pattern generator (Microtech LW405), nanoimprint nanonex (NX3000), wafer priming oven (YES-TA series), deposition facilities with AJA oxide sputtering 3-inch targets, atomic layer deposition (Sundew D200), lambda microwave plasma CVD System (nanocrystalline diamond deposition), oxford plasmalab 100 Inductively coupled plasma enhanced chemical vapor deposition, sputter deposition system (Emitech K675X), thermal/PECVD System for CNT and graphene synthesis; Wet Chemistry with Electroplating (Au, Cu, Fe, Ni, Pt), Selective wet chemical etching, Wafer Spin Rinse Dryer: VERTEQ; Inspection and Metrology with Atomic Force Microscope (Park Scientific XE-HDD), Potentiostat, Scanning Vibrating Electrode (SVET M370), Three-Dimensional Contact Profilometer (Dektak 8), UVISEL Spectroscopic Ellipsometer (Horiba Jobin Yvon); Post-Processing facilities with Chemical Mechanical Polishing (Logitech Orbis), Critical Point Dryer (Leica CPD030), Thermocarbon Dicing Saw (TCAR 864-1); Synthesis facilities with Complex oxide film synthesis via molecular beam epitaxy (DCA R450 Custom), Physical vapor deposition (Lesker CMS 18 and PVD 250), Spin coating (Laurell WS-400); Nanophotonics facilities such as Near-field scanning optical microscopy (NSOM), Confocal Raman microscopy, Ultrafast transient-absorption spectroscopy, Ultrafast microscopy, Nanophotonics nanoparticle synthesis laboratory, Near-Infrared microscope and spectrometer, NIR microscope (800-1700 nm) for electroluminescence and photoluminescence (650-nm excitation), Varian Cary-50 UV/VIS spectrophotometer.

VI. Collaborative Efforts

A famous quote of George Bernard Shaw is: "If you have an apple and I have an apple and we exchange these apples then you and I will still each have one apple. But if you have an idea and I have an idea and we exchange these ideas, then each of us will have two ideas." The Argonne HEP group fully embraces this philosophy for its detector development program and tries to live by it. In each project in which we are involved, we actively seek collaboration with scientists inside and outside of the laboratory. The multi-disciplinary structure of Argonne has been a key factor in many HEP detector projects.

The development of Transition Edge Sensors (TES) for the South Pole Telescope (SPT) owes its success to the collaboration and idea exchange between the Materials Science Division (MSD) at Argonne, the High Energy Physics (HEP) Division, the Center for Nanoscale Materials (CNM) and the University of Chicago. Understanding of the fundamental science for superconducting materials lies with Drs. Val Novosad from the MSD division, and Volodymyr Yefremenko, a joint HEP/MSD engineer, who both work with Dr. Gensheng Wang from HEP on the design, fabrication and testing of the devices using dedicated thin film deposition equipment in MSD. CNM provides support, tooling and resources for the bulk of detector microfabrication including photolithography and etching. At the University of Chicago there is a parallel TES testing and quality assurance setup, led by Dr. Clarence Chang and Prof. John Carlstrom, both with a joint UofC-Argonne position. The deployment of the ANL detectors to the SPT was a collaborative effort with the larger SPT team. SPT partners include the University of California-Berkeley, University of Colorado-Boulder, University of Michigan-Ann Arbor, Case Western Reserve University, the National Institutes of Standards and Technology (NIST) and McGill University. Development of the new high-bandwidth (~1 MHz) TES multiplexing technique using DC Superconducting Quantum Interference Devices (SQUIDs) is in collaboration with NIST, who have committed to providing the SQUID multiplexing chips.

For the development of the optical readout, we joined and initiated several collaborative efforts with other institutions and companies for different tasks. As a member of the US optical development collaboration, a consortium of Argonne, Fermilab, Southern Methodist University, Ohio State University, University of Minnesota and VegaWave, a small local company,we are testing commercial modulators for radiation hardness and signal integrity. At the same time we are collaborating with CERN and SMU on the testing of silicon photonic chips. Our proposed research program is geared towards the adaptation of commercial, off-the-shelf modulators for particle physics experiments and the development of graphene based optical modulators. We are are collaborating with Drs. Daniel Lopez and Nathan Guisinger from the Argonne Center for Nano-Scale Materials (CNM) to develop graphene for optical modulation. Drs. Anil Mane and Jeffrey Elam from the Energy Systems (ES) division at Argonne are collaborating with us on the development of Atomic Layer Deposition Techniques to electrode graphene. We also have an NDA with Luxtera for silicon photonics and another NDA with Purdue University to further develop graphene based direct optical readout for particle physics detectors.

The development of the 3D Content-Addressable Memory (CAM) for real-time tracking will be a collaborative effort between Fermilab, Argonne, the University of Chicago and Tezzaron, a local company who is a leader in the development of the 3D integrated chip technology.

The development of the DHCAL is a long-standing collaboration between many universities and labs. Boston University was responsible for the design, construction and commissioning of the data collector system; Fermilab provided the DHCAL ASIC and the test beams; the University of Iowa designed and delivered the gas and high voltage systems; the University of Texas at Arlington, McGill University, Northwestern University and IHEP, Beijing were all involved in the construction. The work is being carried out within the framework and with

the support of the CALICE collaboration, which provided the steel absorber structure and the transporter, and supports the data taking campaigns. CERN has provided the tungsten absorber and also supports the data taking. Almost all groups, including Illinois Institute of Technology, participate in the data analysis. The University of Michigan, USCT and Tsinghua University are involved in discussions regarding future plans for the DHCAL.

The development of the topological trigger for VERITAS is a collaboration with Frank Krennrich and Amanda Weinstein at Iowa State University. This R&D initially started with LDRD funds at Argonne and an Advanced Detector R&D award at ISU Boston University.

The development of new telescope designs is an international collaboration between DESY, Zeuthen, CEA, France, Crakow, Poland, the University of Zurich, Switzerland and within the US a collaboration with the UC at UCLA and the University of Chicago.

Our most extensive collaborative efforts are within the LAPPD project for which most of the achievements that have been realized have been a combination of ideas and expertise across several Argonne divisions, a number of U.S. universities and several small U.S. companies. The involvement of US industry has been a signature of the LAPPD development from the very start. Three small US companies, Arradiance, Muons, Inc, and Synkera, were among the original set of collaborators. In the first year of the project another small US company, MinoTech, contributed to the development of the silk-screen method of anode deposition and identification of viable frits for anode/sidewall bonding. The ultimate success of the silver screening and the tile base bonding was achieved through the careful study of the process by Joe Gregar, the Argonne fourth-generation master scientific glassblower. Mr. Gregar was also responsible for the fabrication of the glass vacuum containment vessel used for photocathode development at Argonne and for the tile base used for the successful Demountable Tile. The latter has demonstrated a complete working detector system including micro-channel plates, voltage distribution grid spacers, anode readout and the complete PSEC4 readout chain.

As described in more detail in the accompanying documentation, the project has four main technical areas: development of the borosilicate glass capillary array Micro-Channel Plates; hermetic mechanical assembly; photocathode development and characterization; and electronics and system integration. We have worked closely over the last three years with the supplier of the glass microchannel substrates, Incom, Inc., on the development of the large plates, and the cleaning and transport methods. The project needed their expertise in the development of large area, uniform, glass capillaries while the company was very interested in our development of the Atomic Layer Deposition. This most successful collaboration has very recently led to an R&D100 award for the development of Microchannel Plates to Argonne as the lead developer and Incom, Inc. and Berkeley Space Sciences Laboratory as co-developers. The Atomic Layer Deposition process to functionalize the MCPs was developed in the Argonne Energy Systems Division in collaboration with the MSD and HEP divisions. The process has been patented and has been licensed to Incom, Inc. The project is also collaborating with NOVA Scientific, Inc on other applications of MCPs. Identification and characterization of secondary emission materials was performed by our collaborators in the Argonne Material Science Division. Using data obtained from this work, a simulation of the electron multiplication development in the MCP pore structure was carried out in collaboration with Dr. Matt Wetstein, Argonne/UChicago, Dr. Valentin Ivanov at Muons, Inc. and Dr. Zeke Insepov of the Argonne Mathematics and Computing Science Division.

Two approaches are being pursued for the hermetic assembly: a ceramic body with a hot indium brazed top seal and an all-glass compressed indium seal. The development of the former is carried out in collaboration with Prof. Ozzy Siegmund and Dr. Jason McPhate at Space Science Laboratory at Berkeley. They are working with United Supertek in California and Omley Industries in Oregon on developing the brazing techniques. The top window seal for the all-glass option is being developed at Argonne as a collaboration between the HEP and Nuclear

Engineering (NE) division with graduate student help from the Joining Science and Advanced Materials Research Laboratory at the University of Illinois at Chicago. As mentioned already, the Argonne scientific glass blower played a key role in the success of this effort.

To grow photocathodes at Argonne, the cathode deposition equipment was purchased from Burle Industries/Photonis which also provided the training and the initial photocathode fabrication "recipe". The development of photocathodes and understanding the correlation between the microscopic materials structure and the macroscopic cathode performance is being carried out in collaboration with the Brookhaven National Laboratory (Dr. Klaus Attenkofer, formerly at ANL, and Dr. John Smedley), the University of Chicago (Prof. Henry Frisch), Washington University at St. Louis (Prof. Jim Buckley and Dan Leopold), Xiuling Li and Ryan Dowdy at the University of Illinois-Urbana/Champaign, and recently with IHEP, Beijing (Dr. Qian Sen).

The development of the electronics and system integration is carried out through a collaboration between the University of Hawaii (Prof. Gary Varner, Dr. Kurtis Nishimura) and the University of Chicago (Eric Oberla, Hervé Grabas and Dr. Jean-François Genat).

We would like to note that the LAPPD project has an internal 'godparent' review program with reviewers selected from industry as well as from academia and national labs. Examples of godparents outside the collaboration itself include Dr. Paul Hink from Photonis, Dr. Scott Moulzolf, formerly with Photonis but now with the University of Maine and Michael Minot of Incom, Inc. who have served as reviewers for the hermetic packaging review; Dr. Ted Liu from Fermilab who has worked on the electronics review; and Kathy Harkay an accelerator physicist at Argonne's Advanced Light Source who works on the photocathode review. Drs. Hink and Moulzoff along with John Smedley from Brookhaven National Lab and Alexei Lyashenko from Yale University served on the review of the Single Tile Factory design. The collaboration is engaged in a constant dialogue with industry leaders, such as Incom, Perkin-Elmer, Photonis, Excelitas, ET Enterprises, and ADIT to discuss the transfer of the technology.

The Large Area Picosecond Photodetector project is arguably the most extensive cross-divisional collaboration that has occurred at Argonne. The project has benefitted greatly from the collaboration with a wide range of industrial partners and the unique expertise of a number of university groups. We foresee this collaboration continuing and expanding in the future not just for this project. Cross-divisional detector development, we believe, will be critical for the success of the field.

VII. Funding Tables

DOE Support FY 2012 (Actual)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD					**0**	**0.00**
Temporary PhD					**0**	**0.00**
Graduate Students					**0**	**0.00**
Engineer					**0**	**0.00**
Computing Professional					**0**	**0.00**
Technician					**0**	**0.00**
Administrative					**0**	**0.00**
TOTAL	**0.0**	**0.00**			**0**	**0.00**
DOE/HEP Funding (per activity):	-					
SWF (in $, include overhead)						**$0**
M&S (in $, include overhead)						**$0**
Travel (in $, include overhead)						**$0**
TOTAL		**$0**				**$0**

DOE Support FY 2013 (Proposed)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00			**2**	**2.00**
Temporary PhD	0	0.00			**0**	**0.00**
Graduate Students	0	0.00			**0**	**0.00**
Engineer	3	2.90			**3**	**2.90**
Computing Professional	1	0.10			**1**	**0.10**
Technician	1	1.00			**1**	**1.00**
Administrative	1	0.20			**1**	**0.20**
TOTAL	8	6.20			**8**	**6.20**
DOE/HEP Funding (per activity):	-					
SWF (in $, include overhead)		$1,700				**$1,700**
M&S (in $, include overhead)		$392				**$392**
Travel (in $, include overhead)		$121				**$121**
TOTAL		**$2,213**				**$2,213**

DOE Support FY 2014 (Proposed)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00			**2**	**2.00**
Temporary PhD	0	0.00			**0**	**0.00**
Graduate Students	0	0.00			**0**	**0.00**
Engineer	3	2.90			**3**	**2.90**
Computing Professional	1	0.10			**1**	**0.10**
Technician	1	1.00			**1**	**1.00**
Administrative	1	0.20			**1**	**0.20**
TOTAL	8	6.20			**8**	**6.20**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)		$1,772				**$1,772**
M&S (in $, include overhead)		$392				**$392**
Travel (in $, include overhead)		$121				**$121**
TOTAL		**$2,285**				**$2,285**

DOE Support FY 2015 (Proposed)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00			**2**	**2.00**
Temporary PhD	0	0.00			**0**	**0.00**
Graduate Students	0	0.00			**0**	**0.00**
Engineer	3	2.90			**3**	**2.90**
Computing Professional	1	0.10			**1**	**0.10**
Technician	1	1.00			**1**	**1.00**
Administrative	1	0.20			**1**	**0.20**
TOTAL	8	6.20			**8**	**6.20**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)		$1,847				**$1,847**
M&S (in $, include overhead)		$407				**$407**
Travel (in $, include overhead)		$121				**$121**
TOTAL		**$2,375**				**$2,375**

DOE Support FY 2012 (Actual)																
Personnel Support from DOE:	**LAPPD**		**TES**												**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	9	3.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**9**	**3.00**
Temporary PhD	3	2.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**3**	**2.50**
Graduate Students	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Engineer	4	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**4**	**1.50**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	3	0.60	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**3**	**0.60**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	21	8.80	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**21**	**8.80**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$1,769		$0		$0		$0		$0		$0		$0		**$1,769**	
M&S (in $, include overhead)	$1,189		$0		$0		$0		$0		$0		$0		**$1,189**	
Travel (in $, include overhead)	$42		$0		$0		$0		$0		$0		$0		**$42**	
TOTAL	**$3,000**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$3,000**	

DOE Support FY 2013 (Proposed)																
Personnel Support from DOE:	**LAPPD**		**TES**												**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	9	3.00	2	1.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**11**	**4.20**
Temporary PhD	2	2.50	3	3.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**5**	**5.50**
Graduate Students	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Engineer	4	1.50	1	0.30	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**5**	**1.80**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	3	0.70	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**3**	**0.70**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	20	8.90	6	4.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**26**	**13.40**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$1,888		$820		$0		$0		$0		$0		$0		**$2,708**	
M&S (in $, include overhead)	$1,689		$12		$0		$0		$0		$0		$0		**$1,701**	
Travel (in $, include overhead)	$73		$5		$0		$0		$0		$0		$0		**$78**	
TOTAL	**$3,650**		**$837**		**$0**		**$0**		**$0**		**$0**		**$0**		**$4,487**	

DOE Support FY 2014 (Proposed)																
Personnel Support from DOE:	**LAPPD**		**TES**												**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	9	3.00	2	1.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**11**	**4.20**
Temporary PhD	2	2.50	3	3.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**5**	**5.50**
Graduate Students	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Engineer	4	1.50	1	0.30	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**5**	**1.80**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	3	0.80	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**3**	**0.80**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	20	9.00	6	4.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**26**	**13.50**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$2,305		$858		$0		$0		$0		$0		$0		**$3,163**	
M&S (in $, include overhead)	$1,037		$12		$0		$0		$0		$0		$0		**$1,049**	
Travel (in $, include overhead)	$118		$5		$0		$0		$0		$0		$0		**$123**	
TOTAL	**$3,460**		**$875**		**$0**		**$0**		**$0**		**$0**		**$0**		**$4,335**	

DOE Support FY 2015 (Proposed)																
Personnel Support from DOE:	**LAPPD**		**TES**												**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	10	3.00	2	1.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**12**	**4.20**
Temporary PhD	3	2.50	3	3.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**6**	**5.50**
Graduate Students	2	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.00**
Engineer	4	1.50	1	0.30	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**5**	**1.80**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	3	0.80	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**3**	**0.80**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	23	9.00	6	4.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**29**	**13.50**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$2,216		$895		$0		$0		$0		$0		$0		**$3,111**	
M&S (in $, include overhead)	$1,165		$12		$0		$0		$0		$0		$0		**$1,177**	
Travel (in $, include overhead)	$119		$5		$0		$0		$0		$0		$0		**$124**	
TOTAL	**$3,500**		**$912**		**$0**		**$0**		**$0**		**$0**		**$0**		**$4,412**	

DOE Support FY 2012 (Actual)																
Personnel Support from DOE:	**DHCAL**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	3	2.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**3**	**2.50**
Temporary PhD	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Graduate Students	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Engineer	1.0	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0.0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	2.0	0.30	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**0.30**
Administrative	1.0	0.1	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	**10.0**	**6.10**	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**10**	**6.10**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$1,043		$0		$0		$0		$0		$0		$0		**$1,043**	
M&S (in $, include overhead)	$291		$0		$0		$0		$0		$0		$0		**$291**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$1,379**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$1,379**	

DOE Support FY 2013 (Proposed)																
Personnel Support from DOE:	**DHCAL**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Temporary PhD	2	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.50**
Graduate Students	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Engineer	1	0.25	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.25**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	9	5.95	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**9**	**5.95**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$804		$0		$0		$0		$0		$0		$0		**$804**	
M&S (in $, include overhead)	$112		$0		$0		$0		$0		$0		$0		**$112**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$961**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$961**	

DOE Support FY 2014 (Proposed)																
Personnel Support from DOE:	**DHCAL**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Temporary PhD	2	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.50**
Graduate Students	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Engineer	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	9	5.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**9**	**5.90**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$840		$0		$0		$0		$0		$0		$0		**$840**	
M&S (in $, include overhead)	$112		$0		$0		$0		$0		$0		$0		**$112**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$996**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$996**	

DOE Support FY 2015 (Proposed)																
Personnel Support from DOE:	**DHCAL**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Temporary PhD	2	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.50**
Graduate Students	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Engineer	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	9	5.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**9**	**5.90**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$876		$0		$0		$0		$0		$0		$0		**$876**	
M&S (in $, include overhead)	$112		$0		$0		$0		$0		$0		$0		**$112**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$1,032**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$1,032**	

DOE Support FY 2012 (Actual)												
Personnel Support from DOE:	**DAQ /FTK**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Temporary PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Administrative	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
TOTAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
M&S (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$0**		**$0**		**$0**		**$0**		**$0**		**$0**	

DOE Support FY 2013 (Proposed)												
Personnel Support from DOE:	**DAQ /FTK**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	0.60	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**0.60**
Temporary PhD	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	6	2.90	0	0.00	0	0.00	0	0.00	0	0.00	**6**	**2.90**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$420		$0		$0		$0		$0		**$420**	
M&S (in $, include overhead)	$678		$0		$0		$0		$0		**$678**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$1,098**		**$0**		**$0**		**$0**		**$0**		**$1,098**	

DOE Support FY 2014 (Proposed)												
Personnel Support from DOE:	**DAQ /FTK**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	0.60	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**0.60**
Temporary PhD	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	6	2.90	0	0.00	0	0.00	0	0.00	0	0.00	**6**	**2.90**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$439		$0		$0		$0		$0		**$439**	
M&S (in $, include overhead)	$554		$0		$0		$0		$0		**$554**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$993**		**$0**		**$0**		**$0**		**$0**		**$993**	

DOE Support FY 2015 (Proposed)												
Personnel Support from DOE:	**DAQ /FTK**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	0.60	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**0.60**
Temporary PhD	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**1.00**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	6	2.90	0	0.00	0	0.00	0	0.00	0	0.00	**6**	**2.90**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$458		$0		$0		$0		$0		**$458**	
M&S (in $, include overhead)	$609		$0		$0		$0		$0		**$609**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$1,067**		**$0**		**$0**		**$0**		**$0**		**$1,067**	

DOE Support FY 2012 (Actual)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00	9	3.00	3	2.50	0	0.00	**12**	**5.50**
Temporary PhD	0	0.00	3	2.50	1	1.00	0	0.00	**4**	**3.50**
Graduate Students	0	0.00	1	1.00	2	2.00	0	0.00	**3**	**3.00**
Engineer	0	0.00	4	1.50	1	0.20	0	0.00	**5**	**1.70**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	0	0.00	3	0.60	2	0.30	0	0.00	**5**	**0.90**
Administrative	0	0.00	1	0.20	1	0.10	0	0.00	**2**	**0.30**
TOTAL	0	0.00	21	8.80	10	6.10	0	0.00	**31**	**14.90**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$0		$1,769		$1,043		$0		**$2,812**
M&S (in $, include overhead)		$0		$1,189		$291		$0		**$1,480**
Travel (in $, include overhead)		$0		$42		$45		$0		**$87**
TOTAL		**$0**		**$3,000**		**$1,379**		**$0**		**$4,379**

DOE Support FY 2013 (Proposed)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	11	4.20	2	2.00	2	0.60	**17**	**8.80**
Temporary PhD	0	0.00	5	5.50	2	1.50	1	1.00	**8**	**8.00**
Graduate Students	0	0.00	1	1.00	2	2.00	0	0.00	**3**	**3.00**
Engineer	3	2.90	5	1.80	1	0.25	1	0.20	**10**	**5.15**
Computing Professional	1	0.10	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Technician	1	1.00	3	0.70	1	0.10	1	1.00	**6**	**2.80**
Administrative	1	0.20	1	0.20	1	0.10	1	0.10	**4**	**0.60**
TOTAL	8	6.20	26	13.40	9	5.95	6	2.90	**49**	**28.45**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$1,700		$2,708		$804		$420		**$5,632**
M&S (in $, include overhead)		$392		$1,701		$112		$678		**$2,883**
Travel (in $, include overhead)		$121		$78		$45		$0		**$243**
TOTAL		**$2,213**		**$4,487**		**$961**		**$1,098**		**$8,759**

DOE Support FY 2014 (Proposed)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	11	4.20	2	2.00	2	0.60	**17**	**8.80**
Temporary PhD	0	0.00	5	5.50	2	1.50	1	1.00	**8**	**8.00**
Graduate Students	0	0.00	1	1.00	2	2.00	0	0.00	**3**	**3.00**
Engineer	3	2.90	5	1.80	1	0.20	1	0.20	**10**	**5.10**
Computing Professional	1	0.10	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Technician	1	1.00	3	0.80	1	0.10	1	1.00	**6**	**2.90**
Administrative	1	0.20	1	0.20	1	0.10	1	0.10	**4**	**0.60**
TOTAL	8	6.20	26	13.50	9	5.90	6	2.90	**49**	**28.50**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$1,772		$3,163		$840		$439		**$6,213**
M&S (in $, include overhead)		$392		$1,049		$112		$554		**$2,108**
Travel (in $, include overhead)		$121		$123		$45		$0		**$288**
TOTAL		**$2,285**		**$4,335**		**$996**		**$993**		**$8,609**

DOE Support FY 2015 (Proposed)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	12	4.20	2	2.00	2	0.60	**18**	**8.80**
Temporary PhD	0	0.00	6	5.50	2	1.50	1	1.00	**9**	**8.00**
Graduate Students	0	0.00	2	1.00	2	2.00	0	0.00	**4**	**3.00**
Engineer	3	2.90	5	1.80	1	0.20	1	0.20	**10**	**5.10**
Computing Professional	1	0.10	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Technician	1	1.00	3	0.80	1	0.10	1	1.00	**6**	**2.90**
Administrative	1	0.20	1	0.20	1	0.10	1	0.10	**4**	**0.60**
TOTAL	8	6.20	29	13.50	9	5.90	6	2.90	**52**	**28.50**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$1,847		$3,111		$876		$458		**$6,292**
M&S (in $, include overhead)		$407		$1,177		$112		$609		**$2,306**
Travel (in $, include overhead)		$121		$124		$45		$0		**$289**
TOTAL		**$2,375**		**$4,412**		**$1,032**		**$1,067**		**$8,886**

The following tables are based on the FY12 budget minus 3%.

DOE Support FY 2012 (Actual)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00			**0**	**0.00**
Temporary PhD	0	0.00			**0**	**0.00**
Graduate Students	0	0.00			**0**	**0.00**
Engineer	0	0.00			**0**	**0.00**
Computing Professional	0	0.00			**0**	**0.00**
Technician	0	0.00			**0**	**0.00**
Administrative	0	0.00			**0**	**0.00**
TOTAL	0	0.00			**0**	**0.00**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)	$0				**$0**	
M&S (in $, include overhead)	$0				**$0**	
Travel (in $, include overhead)	$0				**$0**	
TOTAL	**$0**				**$0**	

DOE Support FY 2013 (Proposed)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	3	2.20			**3**	**2.20**
Temporary PhD	1	1.00			**1**	**1.00**
Graduate Students	1	1.00			**1**	**1.00**
Engineer	1	0.10			**1**	**0.10**
Computing Professional	0	0.00			**0**	**0.00**
Technician	1	0.10			**1**	**0.10**
Administrative	0	0.00			**0**	**0.00**
TOTAL	7	4.40			**7**	**4.40**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)	$901				**$901**	
M&S (in $, include overhead)	$200				**$200**	
Travel (in $, include overhead)	$69				**$69**	
TOTAL	**$1,170**				**$1,170**	

DOE Support FY 2014 (Proposed)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00			**2**	**2.00**
Temporary PhD	1	1.00			**1**	**1.00**
Graduate Students	0	0.00			**0**	**0.00**
Engineer	3	0.20			**3**	**0.20**
Computing Professional	0	0.00			**0**	**0.00**
Technician	1	0.20			**1**	**0.20**
Administrative	1	0.10			**1**	**0.10**
TOTAL	8	3.50			**8**	**3.50**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)	$888				**$888**	
M&S (in $, include overhead)	$200				**$200**	
Travel (in $, include overhead)	$82				**$82**	
TOTAL	**$1,170**				**$1,170**	

DOE Support FY 2015 (Proposed)						
Personnel Support from DOE:	**Core Program**				**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00			**2**	**2.00**
Temporary PhD	1	1.00			**1**	**1.00**
Graduate Students	0	0.00			**0**	**0.00**
Engineer	1	0.20			**1**	**0.20**
Computing Professional	0	0.00			**0**	**0.00**
Technician	1	0.10			**1**	**0.10**
Administrative	1	0.10			**1**	**0.10**
TOTAL	6	3.40			**6**	**3.40**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)	$886				**$886**	
M&S (in $, include overhead)	$200				**$200**	
Travel (in $, include overhead)	$84				**$84**	
TOTAL	**$1,170**				**$1,170**	

DOE Support FY 2012 (Actual)																
Personnel Support from DOE:	**LAPPD**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	4	2.40	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**4**	**2.40**
Temporary PhD	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Graduate Students	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Engineer	2	1.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.90**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	10	5.70	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**10**	**5.70**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$1,256		$0		$0		$0		$0		$0		$0		**$1,256**	
M&S (in $, include overhead)	$1,215		$0		$0		$0		$0		$0		$0		**$1,215**	
Travel (in $, include overhead)	$56		$0		$0		$0		$0		$0		$0		**$56**	
TOTAL	**$2,528**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$2,528**	

DOE Support FY 2013 (Proposed)																
Personnel Support from DOE:	**LAPPD**		**0**												**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	4	2.40	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**4**	**2.40**
Temporary PhD	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Graduate Students	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Engineer	2	1.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.90**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	10	5.70	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**10**	**5.70**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$1,309		$0		$0		$0		$0		$0		$0		**$1,309**	
M&S (in $, include overhead)	$1,100		$0		$0		$0		$0		$0		$0		**$1,100**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$2,454**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$2,454**	

DOE Support FY 2014 (Proposed)																
Personnel Support from DOE:	**LAPPD**		**0**												**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	4	2.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**4**	**2.20**
Temporary PhD	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Graduate Students	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Engineer	2	1.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.90**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	10	5.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**10**	**5.50**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$1,298		$0		$0		$0		$0		$0		$0		**$1,298**	
M&S (in $, include overhead)	$1,100		$0		$0		$0		$0		$0		$0		**$1,100**	
Travel (in $, include overhead)	$56		$0		$0		$0		$0		$0		$0		**$56**	
TOTAL	**$2,454**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$2,454**	

DOE Support FY 2015 (Proposed)																
Personnel Support from DOE:	**LAPPD**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	4	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**4**	**2.00**
Temporary PhD	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Graduate Students	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.50**
Engineer	2	1.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.90**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Administrative	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
TOTAL	10	5.30	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**10**	**5.30**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$1,283		$0		$0		$0		$0		$0		$0		**$1,283**	
M&S (in $, include overhead)	$1,100		$0		$0		$0		$0		$0		$0		**$1,100**	
Travel (in $, include overhead)	$71		$0		$0		$0		$0		$0		$0		**$71**	
TOTAL	**$2,454**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$2,454**	

DOE Support FY 2013 (Proposed)																
Personnel Support from DOE:	**DHCAL**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Temporary PhD	2	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.50**
Graduate Students	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Engineer	1	0.25	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.25**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	9	5.95	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**9**	**5.95**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$804		$0		$0		$0		$0		$0		$0		**$804**	
M&S (in $, include overhead)	$112		$0		$0		$0		$0		$0		$0		**$112**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$961**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$961**	

DOE Support FY 2014 (Proposed)																
Personnel Support from DOE:	**DHCAL**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Temporary PhD	2	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.50**
Graduate Students	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Engineer	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	9	5.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**9**	**5.90**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$840		$0		$0		$0		$0		$0		$0		**$840**	
M&S (in $, include overhead)	$112		$0		$0		$0		$0		$0		$0		**$112**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$996**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$996**	

DOE Support FY 2015 (Proposed)																
Personnel Support from DOE:	**DHCAL**														**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Temporary PhD	2	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**1.50**
Graduate Students	2	2.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**2**	**2.00**
Engineer	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.20**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
Administrative	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**1**	**0.10**
TOTAL	9	5.90	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**9**	**5.90**
DOE/HEP Funding (per activity):																
SWF (in $, include overhead)	$876		$0		$0		$0		$0		$0		$0		**$876**	
M&S (in $, include overhead)	$112		$0		$0		$0		$0		$0		$0		**$112**	
Travel (in $, include overhead)	$45		$0		$0		$0		$0		$0		$0		**$45**	
TOTAL	**$1,032**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$1,032**	

DOE Support FY 2012 (Actual)												
Personnel Support from DOE:	**DAQ**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Temporary PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Administrative	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
TOTAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
M&S (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$0**		**$0**		**$0**		**$0**		**$0**		**$0**	

DOE Support FY 2013 (Proposed)												
Personnel Support from DOE:	**DAQ**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Temporary PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Administrative	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
TOTAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
M&S (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$0**		**$0**		**$0**		**$0**		**$0**		**$0**	

DOE Support FY 2014 (Proposed)												
Personnel Support from DOE:	**DAQ**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Temporary PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Administrative	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
TOTAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
M&S (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$0**		**$0**		**$0**		**$0**		**$0**		**$0**	

DOE Support FY 2015 (Proposed)												
Personnel Support from DOE:	**DAQ**										**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Temporary PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Graduate Students	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Engineer	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Administrative	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
TOTAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
DOE/HEP Funding (per activity):												
SWF (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
M&S (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
Travel (in $, include overhead)	$0		$0		$0		$0		$0		**$0**	
TOTAL	**$0**		**$0**		**$0**		**$0**		**$0**		**$0**	

DOE Support FY 2012 (Actual)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	0	0.00	4	2.40	3	2.50	0	0.00	**7**	**4.90**
Temporary PhD	0	0.00	1	0.50	1	1.00	0	0.00	**2**	**1.50**
Graduate Students	0	0.00	1	0.50	2	2.00	0	0.00	**3**	**2.50**
Engineer	0	0.00	2	1.90	1	0.20	0	0.00	**3**	**2.10**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	0	0.00	1	0.20	2	0.30	0	0.00	**3**	**0.50**
Administrative	0	0.00	1	0.20	1	0.10	0	0.00	**2**	**0.30**
TOTAL	0	0.00	10	5.70	10	6.10	0	0.00	**20**	**11.80**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$0		$1,256		$1,043		$0		**$2,299**
M&S (in $, include overhead)		$0		$1,215		$291		$0		**$1,507**
Travel (in $, include overhead)		$0		$56		$45		$0		**$101**
TOTAL		**$0**		**$2,528**		**$1,379**		**$0**		**$3,907**

DOE Support FY 2013 (Proposed)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	3	2.20	4	2.40	2	2.00	0	0.00	**9**	**6.60**
Temporary PhD	1	1.00	1	0.50	2	1.50	0	0.00	**4**	**3.00**
Graduate Students	1	1.00	1	0.50	2	2.00	0	0.00	**4**	**3.50**
Engineer	1	0.10	2	1.90	1	0.25	0	0.00	**4**	**2.25**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	1	0.20	1	0.10	0	0.00	**3**	**0.40**
Administrative	0	0.00	1	0.20	1	0.10	0	0.00	**2**	**0.30**
TOTAL	7	4.40	10	5.70	9	5.95	0	0.00	**26**	**16.05**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$901		$1,309		$804		$0		**$3,014**
M&S (in $, include overhead)		$200		$1,100		$112		$0		**$1,412**
Travel (in $, include overhead)		$69		$45		$45		$0		**$159**
TOTAL		**$1,170**		**$2,454**		**$961**		**$0**		**$4,585**

DOE Support FY 2014 (Proposed)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	4	2.20	2	2.00	0	0.00	**8**	**6.20**
Temporary PhD	1	1.00	1	0.50	2	1.50	0	0.00	**4**	**3.00**
Graduate Students	0	0.00	1	0.50	2	2.00	0	0.00	**3**	**2.50**
Engineer	3	0.20	2	1.90	1	0.20	0	0.00	**6**	**2.30**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.20	1	0.20	1	0.10	0	0.00	**3**	**0.50**
Administrative	1	0.10	1	0.20	1	0.10	0	0.00	**3**	**0.40**
TOTAL	8	3.50	10	5.50	9	5.90	0	0.00	**27**	**14.90**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$888		$1,298		$840		$0		**$3,025**
M&S (in $, include overhead)		$200		$1,100		$112		$0		**$1,412**
Travel (in $, include overhead)		$82		$56		$45		$0		**$183**
TOTAL		**$1,170**		**$2,454**		**$996**		**$0**		**$4,620**

DOE Support FY 2015 (Proposed)										
Personnel Support from DOE:	**Core & Infrastructure**		**Sensors**		**Detector Systems**		**DAQ & Computing**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	2	2.00	4	2.00	2	2.00	0	0.00	**8**	**6.00**
Temporary PhD	1	1.00	1	0.50	2	1.50	0	0.00	**4**	**3.00**
Graduate Students	0	0.00	1	0.50	2	2.00	0	0.00	**3**	**2.50**
Engineer	1	0.20	2	1.90	1	0.20	0	0.00	**4**	**2.30**
Computing Professional	0	0.00	0	0.00	0	0.00	0	0.00	**0**	**0.00**
Technician	1	0.10	1	0.20	1	0.10	0	0.00	**3**	**0.40**
Administrative	1	0.10	1	0.20	1	0.10	0	0.00	**3**	**0.40**
TOTAL	6	3.40	10	5.30	9	5.90	0	0.00	**25**	**14.60**
DOE/HEP Funding (per activity):										
SWF (in $, include overhead)		$886		$1,283		$876		$0		**$3,044**
M&S (in $, include overhead)		$200		$1,100		$112		$0		**$1,412**
Travel (in $, include overhead)		$84		$71		$45		$0		**$200**
TOTAL		**$1,170**		**$2,454**		**$1,032**		**$0**		**$4,656**