

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

Classification:

Linear Collider Detector Muon System Readout

Institution and Personnel requesting funding:

Colorado State University

Robert J. Wilson, Professor

David W. Warner, Engineer

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

Collaborators:

Stefan Vasile; President, aPeak Inc.

Scintillator Based Muon Detector Collaboration (E. Fisk, P. Karchin et al.)

Tail Catcher / Muon Tracker Collaboration (V. Zutshi et al.)

Project Leader:

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Project Overview:

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

Geiger-mode Avalanche Photodiodes (GPDs) are an interesting candidate photodetector to replace PMT read-out of WLS fibers. We have been working together with aPeak¹, a small firm in the Boston area that develops novel photodetector devices, to direct their development of GPDs specifically for these applications. GPDs have several features that are important for these types of applications: relatively high detection efficiency at typical WLS light wavelengths (compared to typical PMTs); high gain; acceptably low dark count rates (for gated operation) with modest cooling; low sensitivity to magnetic fields; and greatly simplified readout electronics, supply voltage requirements, and cable plant. The GPD is intrinsically a digital device, but a certain degree of photon-counting capability could be achieved by multi-pixel readout of each fiber (as is the principal of the Si-PM) - such a configuration could be self-triggering by incorporating multiplicity logic in the readout.

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

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

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

Broader Impact:

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

¹ <http://www.apeakinc.com/>

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

Results of Prior Research:

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

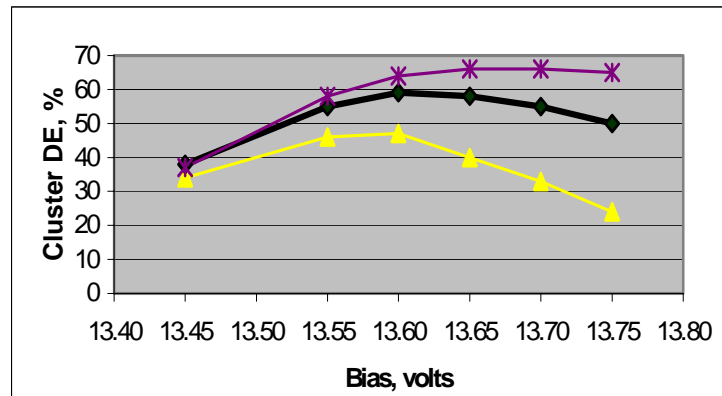


Figure 1: Detection Efficiency for GPD Cluster. Statistical uncertainty is 2% for bias 13.75 V, increasing to 8% for 13.45 V (From Phase I SBIR Report)

Thanks to the SBIR funding we received for this project, we have had pixel arrays available for testing at CSU for much of the past year. As our primary contribution to the SBIR phase 1 work, we have concentrated on measuring the detection efficiency for GPD readout of WLS fibers. Using a simple scintillator hodoscope, we have collected cosmic ray data from sample 8-pixel GPD arrays attached to a 30 cm sample of a scintillator bar with embedded wavelength-shifting fibers (similar to that in the MINOS experiment²). As shown in Figure 1, our results indicate that the array was approximately 60% efficient for detecting cosmic rays, depending on bias voltage setting and background subtraction method: the middle thick line is the best estimate; the top line is the expected value based on the efficiency of individual pixels in the absence of correlated backgrounds; the bottom line is a worst case scenario that greatly overestimates the effect of thermally generated noise.

² <http://www-numi.fnal.gov/>

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

Results from the testing work at CSU have been presented by Wilson at the Victoria Linear Collider Workshop, summer 2004³. Extensive additional results are also included in an internal report from CSU to aPeak at the conclusion of Phase I⁴. Results from the full Phase I effort were also presented by Vasile (aPeak) at the NSS 04 conference in Rome⁵.

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

Facilities, Equipment and Other Resources:

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

Year 1 Project Activities and Deliverables:

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

Year 2 Project Activities and Deliverables:

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

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

³ http://www.linearcollider.ca/lc/vic04/abstracts/detector/muonpid/bob_wilson_.pdf

⁴ http://hep45.hep.colostate.edu/~wilson/GPD/CSU_aPeakPhaseI_report.pdf

⁵ <http://www.apeakinc.com/images/N305.pps>

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

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

Budget Justification:

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

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

Budget:

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

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