Demonstration of Geiger Mode Avalanche Photodiodes for Linear Collider Muon System Readout

- LCRD Proposal

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Proposal Abstract

We propose to demonstrate the use of a new solid-state photodetector as the readout of a scintillator-based LCD muon system. Such a device could reduce the subsystem cost considerably. Prototype devices have been produced and characterized by aPeak[1], a small company funded by a DoE Small Business Innovative Research award. This proposal will enable a high energy physics group to verify the key performance characteristics and to demonstrate the suitability of the device for use with the LCD muon system.

[1] aPeak: 63 Albert Road, Newton, MA 02466.
General Manager: Dr. Stefan Vasile.

Motivation

- WLS readout of scintillator strips is current ALCPG muon system option for LCD
- Standard photodetector – photomultiplier tubes, great devices but…
  - “Expensive” including electronics etc.,
  - Bulky, magnetic field sensitive (implies long fibers, large cable plant)…
  - Multi-anode PMTs a great step forward.
- Geiger-mode Avalanche photodiodes (GPDs)
  - high quantum efficiency
  - large pulse (~volt); relatively fast
  - low voltage operation (~10s volts); modest physical plant
  - compact; low mass; magnetic field insensitive
  - compatible with CMOS -> cheap?
- GPD system cost estimate from aPeak
  - 8000-fiber readout system for MINOS-style scintillator/WLS fiber
  - $40 per channel, including the GPD pixel, active quenching circuit and a fiber mount system

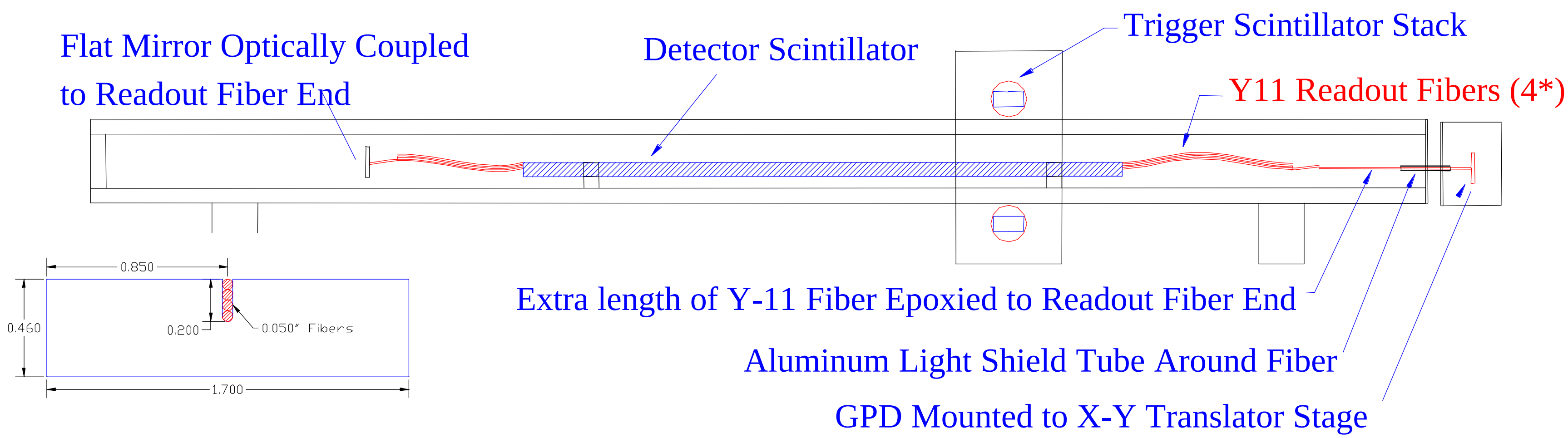
GPD – fiber tracker readout

- The GPD is intrinsically a digital (hit/no-hit) device
- Limited photon-counting capability by multi-pixel readout of each fiber
  - To a modest degree with our current layout
  - To a much larger degree by B. Dolgoshein *et al.*

    "The Advanced Study of Silicon Photomultiplier":

    http://www.slac.stanford.edu/pubs/icfa/fall01/paper3/paper3a.html
- Such a configuration could be self-triggering by incorporating multiplicity logic in the readout.
- "Digital calorimetry" application?
- High dark count rate/area is the biggest challenge.

GPD Scintillator/Fiber Test Bed



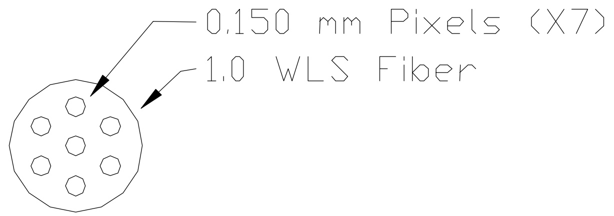
* For these measurements only a single fiber was instrumented with GPD readout.

- *Estimate* average 4 photons/event at the end of spliced 1 mm diameter Y11 cores fiber and 0.15 mm GPDs.
- Use *QE*A=0.069* estimated for <u>single</u> 150 micron GPD at 20^{o}C using LED - predict DE~0.24 neglecting additional losses, such as Fresnel reflection at the Y11-GPD interface.

- Preliminary measured detection efficiency in test bed: 21±5(stat.)±??(sys.)%

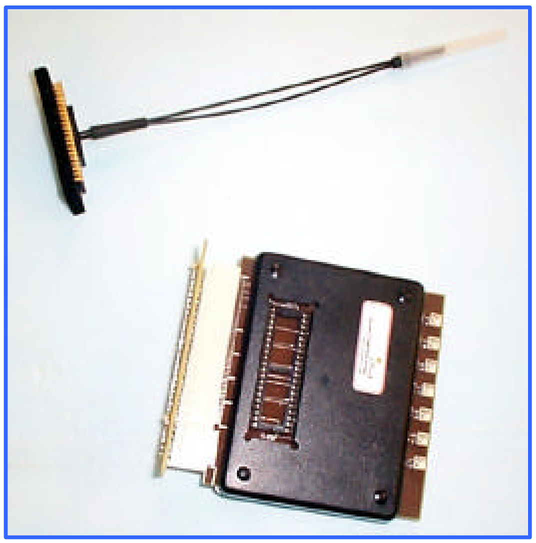
SBIR phase I project plan

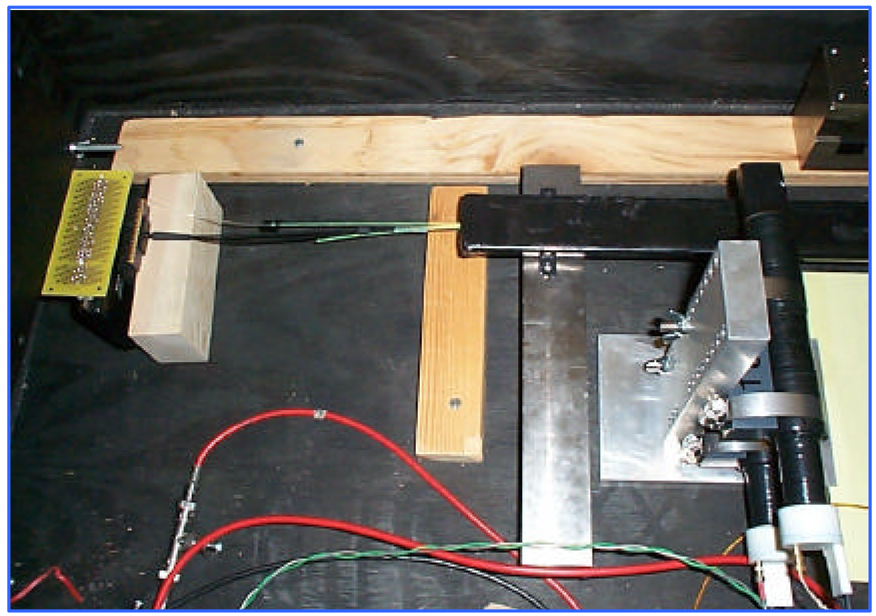
- 12/18/03 - received first 7 x 0.150 mm pixels with bonded 1mm fiber



- Measure detection efficiency for minions in scintillator bar (expect ~ 100%)
- Investigate timing characteristics of GPDs, and techniques for minimizing the impact of dark counts using pixel coincidences
- Light concentration techniques (tapered fibers) for focusing fiber output onto pixels

7-pixel GPD+fiber assembly





LCRD Proposal

- As part of the SBIR program, aPeak will continue its investigations of the device properties of GPD pixels and integrated r/o including active quenching circuits and possibly on-chip logic
- aPeak is a one-man operation – measurements need replication by HEP group
- Develop operating experience – *cf* MAPMT R&D plan
- We retain some SBIR GPDs – needs tech. support salary
- The full investigation at CSU can be divided into three (year-long?) main phases:
  - Verification of basic GPD properties and readout of small number of channels;
  - Demonstration of larger-scale HEP detector prototype readout (including the possibility of self-triggered operation and possible photon signal amplitude measurement);
  - Development of the packaging, interface, and physical plant for use in a realistic detector. At each stage a cost comparison with competing technologies will be performed.

Phase I-Year 1 : Device Characterization and Multi-pixel Fiber Readout Demonstration

- *Device uniformity*: Earlier GPDs, produced by another manufacturer (RMD, Inc., Watertown, MA) showed very significant variation in dark count rate and detection efficiency from pixel to pixel; even for pixels on the same die. The manufacturing techniques used to produce the aPeak pixels are based on robust and well-understood CMOS technology, and aPeak expects to improve the process further, however it will be important to confirm this improvement. CSU will retain 28 individual pixels for tests after the SBIR program, and thus can perform an independent evaluation.

- *Environmental testing*: The dark count rate and detection efficiency of GPDs vary strongly with temperature. Measurements of this effect at aPeak have been conducted by cooling the device to low temperatures (-40°C) and monitoring the variables as the device warms to room temperature. We propose to build an environmental chamber capable of maintaining a fixed temperature between -20°C and 20°C for long periods.

- *Cross talk*: Cross talk from dark count signals in one pixel may trigger neighboring pixels so minimizing cross talk reduces dark count rate from the array. However, minimizing cross talk may involve larger separation between pixels, reducing the packing fraction of pixels under a fiber. We will investigate cross talk of dark count signals between pixels in an array by measuring the change in count rate as power to masked adjacent pixels is turned on and off.

Phase I-Year 1 : Device Characterization and Multi-pixel Fiber Readout Demonstration

- *Long Term Stability*: Linear Collider applications will require long-term stability and high reliability from photodetectors. New devices, such as GPDs, with no "track record" will require extensive reliability testing to confirm that they will function reliably. We will conduct multi-month tests at known illumination levels with GPDs to look for changes in detection efficiency, noise rate, or timing characteristics. This will be done at various temperatures and illumination levels.

- *Basic "Portable" DAQ system*
  - For testing GPDs at the aPeak facility and in conjunction with muon system candidates at FNAL or other locations (SLAC?)
  - Develop a dedicated PC-based DAQ system, containing 64 channels of NIM/TTL gated hit register channels, 4 ADC channels, and 2 TDC channels.
  - Read out up to 64 GPD arrays in gated operation, with rudimentary timing and pulse height information

Summary

- Solid state devices have potential advantages over pmts
- Geiger-mode Avalanche Photodiodes (GPD) have some attractive properties
  - high QE, low voltage operation, simple r/o electronics, compact, low system cost
- … and some intrinsic disadvantages
  - limited to small pixels, high dark count rate, optical cross talk
- … and some correctable disadvantages
  - small vendor, limited production, limited hands-on experience
- At CSU we hope to correct the correctable and mitigate the intrinsic