Development of Sub-Nanosecond, High Gain Structures For Time-Of-Flight Ring Imaging In Large Area Detectors

Matthew Wetstein, on behalf of the LAPPD collaboration

Abstract

Microchannel plate photomultiplier tubes (MCPs) are compact, imaging detectors, capable of micron-level spatial imaging and timing measurements with resolutions below 10 picoseconds. Conventional fabrication methods are too expensive for making MCPs in the quantities and sizes necessary for typical HEP applications, such as time-of-flight ring-imaging Cherenkov detectors (TOF-RICH) or water Cherenkov-based neutrino experiments. The Large Area Picosecond Photodetector Collaboration (LAPPD) is developing new, commercializable methods to fabricate 20 cm^2 thin planar MCPs at costs comparable to those of traditional photo-multiplier tubes. Transmission-line readout with waveform sampling on both ends of each line allows the efficient coverage of large areas while maintaining excellent time and space resolution. Rather than fabricating channel plates from active, high secondary electron emission materials, we produce plates from passive substrates, and coat them using atomic layer deposition (ALD), a well established industrial batch process. In addition to possible reductions in cost and conditioning time, this allows greater control to optimize the composition of active materials for performance. We present details of the MCP fabrication method, preliminary results from testing and characterization facilities, and possible HEP applications.

Keywords: microchannel, MCP, time-of-flight, water-Cherenkov, neutrinos
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1. Introduction

For decades, the High Energy physics community has relied on photomultiplier tubes to provide low cost, large-area coverage for a wide variety of detector systems. Increasingly, the demands of HEP experiments are pushing for capabilities beyond those of traditional phototubes, towards better spatial and temporal resolutions. Time-of-flight measurements, when combined with other particle identification techniques, can greatly improve the mass sensitivity in collider detectors. Figure 1 shows particle identification confidences based on time-of-flight information across 1.5 meters. At 10 GeV, three-sigma separation beween even kaons and protons requires timing resolutions better than 10 picoseconds. In long baseline, water Cherenkov-based neutrino experiments the largest reducible background is the $\pi^0 \to \gamma\gamma$ decay, where the two, typically forward gammas fake an electron. The simultaneous use of space and time information, at resolutions of order 100 picoseconds and a few millimeters, could enable full track and vertex reconstruction of water Cherenkov events. This improved sensitivity to track and vertex separation could enable experiments to better resolve the two forward gammas, thereby further supressing this background.

One possible candidate to replace the traditional PMT is the microchannel plate photomultiplier tube (MCP) [1], a compact imaging detector capable of micron-level spatial imaging and timing measurements with resolutions below 10 picoseconds [2]. Conventional fabrication methods are too expensive for making MCPs in the quantities and sizes necessary for typical HEP applications, such as time-of-flight ring-imaging Cherenkov detectors (TOF-RICH) or water Cherenkov-based neutrino experiments. The Large Area Picosecond Photodetector Collaboration (LAPPD) is developing new, commercializable methods to fabricate 20 cm^2 thin planar MCPs at costs comparable to those of traditional photo-multiplier tubes. The DOE funded collaboration includes 4 national laboratories, 3

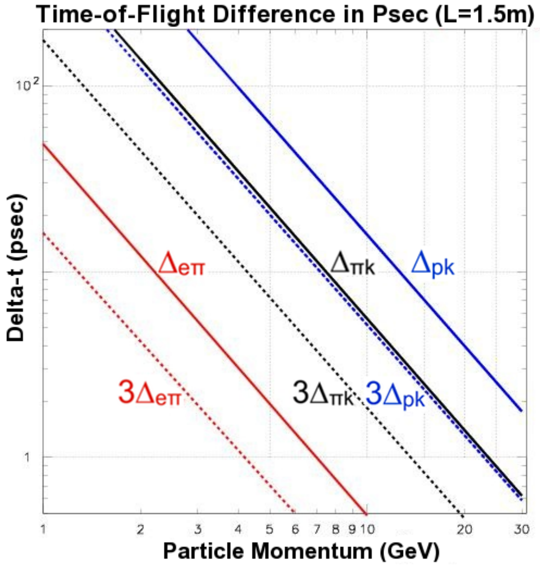

Figure 1: Differences in time-of-flight over 1.5 meters for particles of equal momentum and different mass, as a function of momentum scale. Overlaying contours indicate three-sigma confidences for separating between electrons and pions, pions and kaons, and kaons and protons.

small companies, and 5 Universities. The project has just entered its second year, with the goal of developing a commercializable prototype, ready for mass production in three years. The potential for these low-cost, large-area MCPs goes well beyond bottom-line cost reductions or merely meeting the minimal requirements of the HEP community. They are likely to enable entirely new analysis techniques.

2. Fabrication of the Microchannel Plate Detectors

Figure 2 shows the structure of a generic MCP-based detector. Light is incident on a photocathode, producing electrons by the photoelectric effect. These electrons accelerate accross a potential gap toward a pair of high gain structures consisting of thin plates with high secondary electron emmission (SEE) enhanced, micro-engineered pores. Voltages of roughly 1 kV are applied across each plate. Each electron entering a pore, accelerates and strikes the pore walls, producing an avalanche of secondary electrons. The avalanche builds until the amplified pulse exits the bottom of the second MCP. This electrical signal is collected on an anode structure and passed through the vacuum assembly to front-end electronics, which digitize the signal.

Conventional fabrication of microchannel plates is expensive and requires a long conditioning process to achieve the right combination of resistance and SEE properties. Moreover, the same material is used for all functions of the plate: pore structure, resistivity, and secondary electron emissivity. This project relies on advances in material science and nanotechnology that enable the separation of the structural, resistive, and SEE characteristics of microchannel plates for independent optimization. Use of batch processes such as Atomic Layer Deposition (ALD) allow materials to be to be applied uniformly and conformally to large surface areas in bulk and with potential for significant cost reduction [3, 4]. This project is examining two candidate substrates, chosen for their ability to provide the necessary pore structure and their potential for low-cost batch production: glass capillary structures and anodic aluminum oxide (AAO), which can be grown with an intrinsic pore structure [5, 6]. The substrates are coated using ALD, first with a layer of resistive material and then with a high SEE layer. Different chemistries are being pursued for both layers. Finally, thermal evaporation or sputtering techniques are used to deposit a metal electrode layer on both sides of each plate.

The LAPPD collaboration is pursuing two directions for fabricating large-area photocathodes. One approach is simply to scale conventional multi-alkali films up to 8” by 8”, flat-panel geometries. This work is primarily happening at Berkeley Space Science Lab (SSL). A parallel effort at Argonne National Laboratories seeks to leverage their expertise and infrastructure to create an advanced photocathode laboratory. This facility is charged with fundamentally understanding conventional photocathode chemistries, as well as pursuing novel materials and processing.

The complete detector assembly must be mechanically robust and vacuum-tight, with both high bandwidth readouts and high-voltage connections through the vacuum seal. This technology must also permit scaling to mass production lines and meet low-cost design goals. Efforts at Berkeley SSL are adapting conventional brazed-ceramic designs to the larger dimensions of the 8” channel plates. A parallel effort at ANL is developing glass, flat panel technology to build the sealed tubes at further cost reduction.

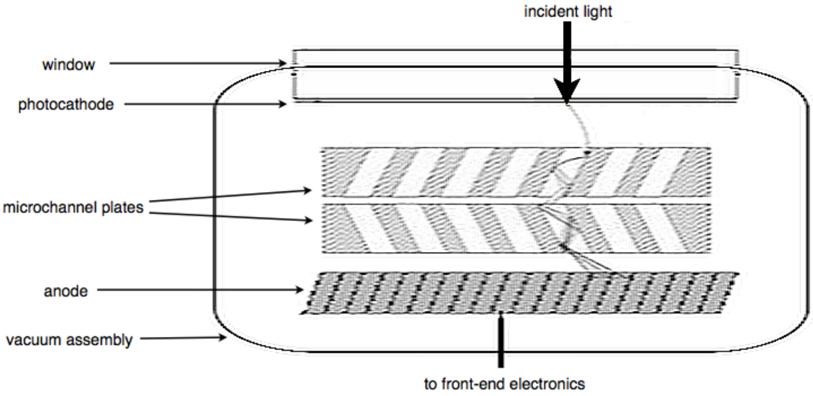

Figure 2: The structure of a generic MCP photomultiplier tube.

The microchannel plates couple to a microstripline anode structure, optimized for high-bandwidth, fast electronics and designed to maintain 50 Ω impedance. This delay-line design greatly reduces the necessary channel count. Hit positions are determined by the signal centroid in the direction perpendicular to the striplines, and by the difference in time-of-arrival at the two ends of the striplines, in the direction parallel to the strips. The electronic readout is designed to use low-cost, low power CMOS technology. Arrival times and gains of the pulse trains are measured by waveform sampling, which offers the best timing resolution.

3. Testing,Characterization, and Simulation

The LAPPD collaboration has gathered a wide variety of resources and expertise for testing and characterization at many levels, ranging from basic material science to prototype systems. Facilities at the Material Science Division of ANL characterize the SEE properties, structure, and composition of relevant materials. Resources at Berkeley SSL test a variety of components, from the MCPs themselves to multialkali photocathode samples. The test stand at the Advanced Photon Source (APS) at ANL is designed to test near-device-level configurations of microchannel plates and anodes, using pulsed lasers and >10 GHz electronics. Complete sealed-tube detectors can be tested at the HEP laser lab at ANL.

In addition to the testing and characterization efforts, the LAPPD collaboration has an active group developing MCP simulations. We expect that these simulations, based on first principles and measured material properties, will guide the final design and optimization of the photodetectors.

4. Year 1 Milestones

By the end of year 1, the LAPPD collaboration has succeeded in fabricating 33 mm sample MCPs by ALD on glass capillaries. These MCPs achieved gains above 10^3 in line with the project milestones. Figure 3 shows the average signal shape of a single photoelectron-generated pulse, measured from a pair of MCPs at the APS test stand. Additional achievements include demonstration of a vacuum seal on an 8” module, the attainment of sub-ns, sub-mm resolutions from a microstripline readout, and the development of a 2-channel ASIC with 20 GHz sampling rate and >1.5 GHz analog bandwidth. Tests of the electronics demonstrated differential time resolutions between the two ends of a stripline of better than 10 picoseconds.

5. Conclusion

At the end of year one, the LAPPD project has achieved its major milestones. The second-year goals include the fabrication and testing of the first 8” prototypes, demonstration of gains and aging performance of pairs of microchannel plates comparable to or better than commercial plates, design

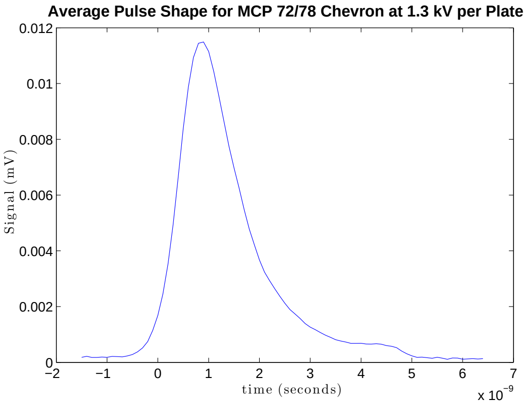

Figure 3: Average response of an ALD-functionalized MCP chevron pair to single photoelectrons. Pulses were generated by direct photoexcitation of the electrode plating on the surface of the MCP stack, using UV laser light. Pulses were captured using a 3 GHz oscilloscope.

and costing of a photocathode fabrication and testing facility, and the design and costing of an 8" glass tile assembly facility.

This project represents an exciting opportunity to direct detector development towards the unique needs of the HEP community. The vast improvement of spatial and temporal resolutions provided by this technology will permit enhanced particle identification in collider experiments, and a variety of tracking and vertexing capabilities in water Cherenkov-based neutrino detectors. These new capabilities will in turn drive the development of new data analysis algorithms.

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