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New Developments in Fast-Sampling Analog Readout of MCP-Based Large-Area Picosecond Time -of-Flight Detectors

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Time-of-flight techniques with resolutions between one to several picoseconds will allow the measurement of the quark content of relativistic particles in high energy colliders, and could also allow the direct association of photons with collision vertices. Precision timing could have applications in accelerator physics, nuclear physics, geophysics, astrophysics, and within our own field, allow the construction of spectrometers for muon cooling experiments without the need for expensive magnets. The availability of photo-detectors with intrinsic single single-photo-electron resolutions of tens of picoseconds may make it possible to build large-area time-of-flight systems. The challenge is to solve the problem of collecting signals over transverse distances large compared to the time resolution while preserving the fast timing properties inherent to the small feature size of the detectors themselves. The solution also has to have a manageable number of electronics channels with sufficient time-resolution and low total power.

Micro-Channel Plate photomultiplier tubes (MCP-PMTs) have the required intrinsic time resolution. Cherenkov light in a thin radiator plate plus the front window provides a fast signal source. To solve the problem of retaining the intrinsic resolution over an area large compared to 300um (one pSec at the speed of light), and keeping the number of channels manageable, we have constructed an anode readout consisting of transmission lines coupled to the 32-by-32 array MCP-PMT anode pads of a Planicon tube from Photonis, reducing the number of fast timing channels from 1024 to 64. Simulations and tests showed that analog sampling between 10 and 40 GSPS and 8-bit digital-to-analog conversion can achieve timing resolution of a few picoseconds and position resolutions below one millimeter, as well as a 8-bit pulse-height resolution. The results of simulations and tests are presented.

Summary

The results presented here use Planicon micro-channel plate photomultiplier tubes (MCP-PMT) from Photonis. The MCP-PMT is characterized by single pulse rise times of the order of 200 pSec and transit time spreads (TTS) of the order of 30 pSec, and an anode array of 32 by 32 pads (1024 in total). We have studied several different approaches, and present here the design of a new anode configuration that makes use of transmission-line readout. The anode board is implemented on a Rogers 4350B printed circuit board with 32 parallel 50-ohm transmission lines on 1.6 mm centers, each traversing one row of pads. The board is soldered to the 32 by 32 array, with dual read-out of each transmission line to determine the position, the time, and the pulse-height. We have simulated the electrical properties of the transmission-line readout board with Hyperlynx and Spice. The simulation results predict that the readout transmission-lines can achieve a signal bandwidth of 3.5 GHz, which should not significantly degrade the time and spatial resolutions intrinsic to the MCP-PMT signals.

This paper is a continuation of work presented earlier on the development of instrumentation for achieving picosecond resolution for a time-of-flight detector. Previously we reported on an equal-time anode structure developed for MCP-PMTs. In this paper we have studied alternative techniques to reduce power consumption and channel count. We have developed a simulation program to predict and compare the performance of several techniques for measuring the time-of-arrival of fast pulses in a photo-detector. Leading edge threshold, multiple thresholds, constant fraction, and pulse sampling are compared, using as inputs simulated and measured fast signals from MCP-PMT. For the simulated pulses, both shot and thermal noise are added to the input signals. The number of photoelectrons is input as a parameter of the simulation since it determines the width of the pulse height distribution and, with the single-photon transit-time-spread (TTS), the intrinsic jitter on the leading edge.

The performance of the four methods is evaluated as a function of the signal-to-noise ratio, the number of photoelectrons, and parameters specific to the timing technique used, such as the values of thresholds, the constant fraction value and associated delay, the sampling rate, the sampling jitter, and the number of bits in the analog-to-digital conversion.

Based on results from these studies, we have pursued a new approach for the anode interface and front-end instrumentation. The anode is an array of 32 by 32 pads (1024 in total). We have designed an anode board that has 32 parallel 50-ohm transmission lines on 1.6 mm centers, each traversing one row of pads on the anode. The board is soldered to the 32 by 32 array, with dual read-out of each transmission line to determine the position, the time and the pulse-height.

We use a fast-sampling technique to continuously digitize the signals that are received at the ends of each transmission line, and use digital-signal-processing techniques to extract timing and position information. We have simulated the electrical properties of the transmission-line readout board with Hyperlynx and Spice. These simulations predict that MCP-PMT signals sampled at rates between 10 and 100 GHz should lead to timing resolutions in the order of one picosecond or less for signal-to-noise ratios above 50, even in presence of quantization noise due to an 8-bit analog-to-digital conversion, and sampling jitters up to 10 picoseconds (sigma).

To test our results, we have designed the anode board, fabricated it using a Rogers 4350B printed circuit board, and have measured performance. As a first step, we test the transmission-line architecture using a 40-GSPS digital oscilloscope as well as Ortec constant-fraction discriminators and time-to-digital converters having 3.1 pSec resolution. We present some of the performance results from the Argonne laser test stand and from beam tests at Fermilab. Ultimately, we intend to develop a 40 GHz waveform-sampling custom integrated circuit. The design of a custom ASIC that incorporates fast sampling of the MCP pulses is in progress.