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Development of a 10 ps level time of flight system in the Fermilab Test Beam Facility

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ABSTRACT

We describe here the development of a time of flight (TOF) system with 10–20 ps resolution for particle identification in a beam line. The detector resolution also was measured with the start and stop counters close together in the 120 GeV proton beam of the Fermilab Test Beam Facility. We tested both microchannel plate photomultipliers (MCP PMT) and silicon photomultipliers (SiPMs), in both cases using Cherenkov light produced in fused silica (quartz) radiators.

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1. Introduction

For a beam of particles of known momentum, measuring the time-of-flight (TOF) between a start and stop counter separated by several meters gives the mass of the particle. The mass resolution depends on the timing resolution of the detector and its electronics, with contributions from beam momentum spread and its spatial properties. Typical TOF resolutions have been of the order of $\sigma = 100$ ps due to slow detection media (such as scintillators), and to the poor single photoelectron time resolution (SPTR, also known as transit time spread or TTS) of dynode structured photomultipliers (PMT). The latter is caused by the large feature size of the dynodes and their separation.

A new generation of photodetectors with small feature size can give significantly better timing performance. One such photodetector is the micro-channel plate PMT (MCP-PMT), with a parallel array of thin microtubules containing an emissive layer for electron amplification [1]. The pore size is typically on the order of 10 μm and the distance from photocathode to the first amplification stage is only a few mm. One advantage of these devices is their large area, which is similar to standard PMTs. We obtained several MCP-PMT devices from Photek for our timing study.

The other new photodetector is the solid state silicon photomultiplier (SiPM), which is a device with an array of tiny Geiger mode avalanche pixels, whose count above background is equal to the number of photons hitting the device [2,3]. Among the unique properties of SiPMs are perfect single photoelectron pulse height spectra, as each photoelectron causes an independent discharge, a quantum efficiency up to 65%, insensitivity to magnetic fields, low mass, low applied bias voltage ($\sim$30–70 V) and relatively good radiation hardness. Several companies are already involved in SiPM production [4]. The dependence of SiPM parameters on temperature and bias voltage can be overcome with standard techniques [5]. The Hamamatsu SiPM (multi-pixel photon counter or MPPC) is an interesting option for TOF systems. SiPMs produced by STMicroelectronics, Catania, Italy [6], are also good candidates. We tested timing characteristics of both of these types of SiPM.

Both of these detectors allow for a much better SPTR because of their fast avalanche spread (<100 ps). We describe in this paper several studies of timing properties on the devices described earlier, including a design for a very fast TOF system for beamline measurements.

2. Photek PMT240 and PMT210 study

The setup at the Silicon Detector Facility at Fermilab to study photodetector timing at the picosecond level has been already described [2–5]. For this study it was used first to test timing

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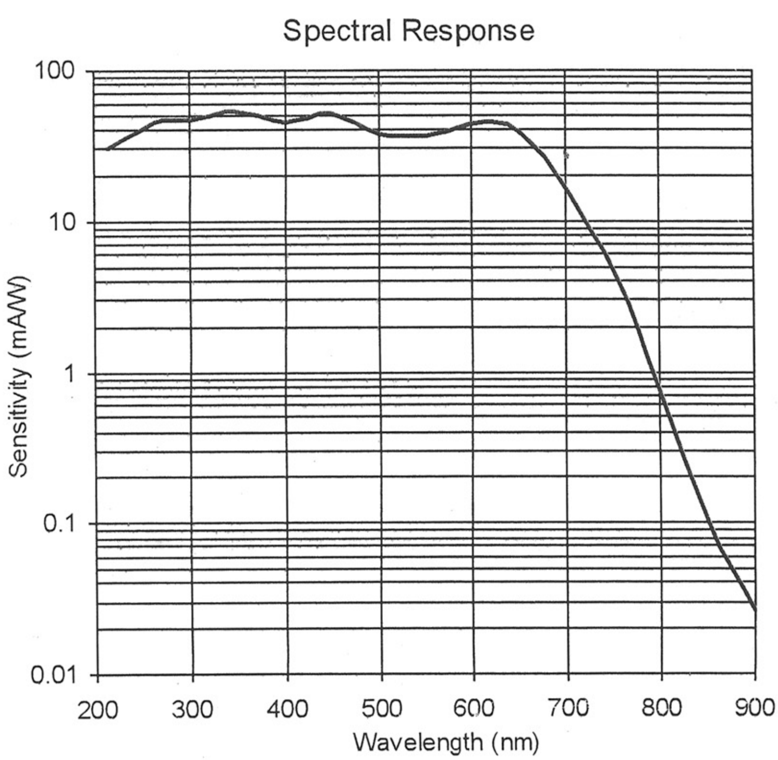
properties of the Photek PMT240 [7] and Photek PMT210 MCP-PMT's on the bench. Each device contains two microchannel plates, in a chevron pattern. The PMT240 has a 40 mm circular aperture, while the PMT210 has a 10 mm aperture. The PMT240 has a given SPTR specification of 100 ps, a parameter that we investigated more precisely. The input window material is quartz with extended UV quantum efficiency (Fig. 1). The window thickness is 9 mm for the PMT240 and 5.6 mm for the PMT210. The MCP pore size diameter is 10 μm for the PMT240 and 3 μm for the PMT210. The PMT240 was mounted inside a dark box and illuminated by 405 nm PiLas laser light. The light intensity was changed both by optical filters and by the TUNE setting of the laser. The high voltage (HV) unit was a Bertan model 380 N with 10 kV maximum HV. The PiLas laser trigger signal was used as a start signal. The anode signal, passed through an Ortec preamplifier and constant fraction discriminator (CFD 9327), was used as the stop signal. A time-to-amplitude converter TAC 567 followed by an AD114 pulse height digitizer was used to measure the time interval between the start and stop signals with an intrinsic electronics time resolution of 2 ps. The AD114 is a 14 bit ADC with 16,000 channels and 3.1 ps per channel. The LeCroy 2249 ADC was used to measure the PMT240 pulse height distribution. This is a 10 bit ADC with 250 fC per count sensitivity. We used an Ortec 120C preamplifier (noninverting, with a gain of 20) in series at the input of the ADC for the single photoelectron pulse height measurements. All timing resolution results reported here are for the standard deviation (σ) of a fitted Gaussian distribution to the time distribution.

We measured the SPTR as a function of the high voltage (HV) and on the position of illumination on the photocathode. We also measured the dependence of the time resolution on the number of photoelectrons, N_{pe}. Optical filters were used to attenuate the laser light over a few decades of dynamic range. To be dominated by single photoelectron events we required more than 90% of the events to have a pulse height in the zero signal region of the 2249 ADC. Typical oscilloscope traces of the PMT240 pulses in the single photoelectron mode, and a single photoelectron pulse height distribution are shown in Figs. 2 and 3. The traces were recorded on a Tektronix TDS 3054B oscilloscope with 500 MHz bandwidth.

In Fig. 3 distribution (a) corresponds to the full 40 mm diameter photocathode (PC) being illuminated, while distribution (b) has the light restricted to a 5 mm spot in the center of the photocathode. The SPTR dependence on HV is shown in Fig. 4. The two sets of points correspond to a 1 mm diameter spot in the center of the photocathode, and at a radius of 18 mm, close to the edge. Based on this data we used a HV in the range 4.4–4.9 kV. The SPTR measurement of the PMT240 worsens below 4.5 kV due to the front end electronics; the signal is then outside the optimum timing range of the Ortec 9327 CFD. Red and blue squares correspond to the PC's center illumination and 18 mm

DeviceType	Input Window	Cathode	Anode
PMT240	FS	BI	

SerialNo: 92090320 Customer: Sydor/University of Rochester
PhotekRef: 08-145 Specification No: SPMT240UR02 iss 1



Sensitivity: 145 μA/lm

	mA/W	%QE
214nm	30.39	17.61
254nm	42.29	20.64
270nm	47.07	21.62
280nm	45.61	20.20
290nm	46.81	20.02
300nm	46.32	19.14
350nm	52.54	18.61
400nm	44.57	13.82
450nm	51.725	14.253
500nm	37.821	9.380
532nm	38.532	8.981
550nm	36.482	8.225
650nm	38.265	7.300
750nm	4.828	0.80
800nm	0.78	0.12
850nm	0.10	0.01
900nm	0.03	0.00

Fig. 1. Photek 240 quantum efficiency vs. photon wavelength.