Testing a Silicon Photomultiplier Time-of-Flight (TOF) System in Fermilab Test Beam Facility

A. Ronzhin[1], E. Ramberg[1], M. Albrow[1], J. Vavra[2], H. Frisch[3], T. Natoli[3], C. Ertley[3], H. Kim[3], A. Kobach[3], F. Tang[3], S. Wilbur[3], J.-F. Genat[3], E. May[4], K. Byrum[4], J. Anderson[4], G. Drake[4]

[1]*Particle Physics Div, Fermi National Accelerator Laboratory, Batavia, Il, USA*

[2]*SLAC, CA, USA*

[3]*University of Chicago, Chicago, IL, USA*

[4]*Argonne National Laboratory, Il, USA*

Abstract. **The first results from a time-of-flight beam test of silicon photomultipliers (SiPm) with quartz Cherenkov radiators obtained in the Fermilab Test Beam Facility are discussed. The timing measurement was performed with commercial electronics that were commissioned in the Fermilab SiPm timing facility. The plan for a new time-of-flight system for the test beam facility, with the goal of obtaining a few tens picosecond time resolution is presented.**

I. Introduction

Because time-of-flight (TOF) measurements are very useful in identifying particle species, it is crucial to understand the time resolution limitations of various photon detectors. As part of a systematic study of photodetector timing resolution, we studied silicon photomultiplier (SiPM) devices. We found that these devices have sufficient timing resolution, in conjunction with Cherenkov radiators, such that they could be used as part of an upgrade to the capabilities of Fermilab's Meson Test Beam Facility (MTBF).

II. Bench setup to study SiPM timing

The setup for our tests (Fig.1) contains a dark box where we placed the SiPMs. The SiPM output was connected to an Ortec 9327 module (preamplifier and constant fraction discriminator-CFD-combined in a single unit). An Ortec VT120 amplifier or an attenuator (depending on the amount of light delivered to the SiPM) was used between the SiPM output and 9327 input. The SiPMs were initially illuminated by a PiLas laser (635 nm head with light pulse duration of 40 psec). The PiLas allows changing the light intensity in the dynamic range 0-100%. We monitored the laser light by a PIN diode and a small size photomultiplier. A Peltier element was used to stabilize the SiPM's temperature, but was then replaced by a "Ranque-Hilsch vortex tube" to increase the temperature dynamic range and improve the temperature's stability. The range is +25C to -20C inside the dark box. Four thermocouples were installed in different places inside and outside the box to get better temperature control. The temperature could be changed, stabilized and monitored with about 0.1C accuracy by hardware managed by a PC using the LabView framework.

The Pilas trigger signal is the start and the 9327 NIM out signal is the stop signal applied to an Ortec 567 Time to Analog Convertor (TAC) 567 which was connected to an Ortec AD114 14 bit ADC. The PC read out this ADC through a CAMAC crate controller. A Keithley power supply was used for biasing the SiPMs. The unit allows keeping the supplied voltage with 10mV accuracy.

We tested Hamamatsu samples of 1x1mm^2 active area with 100x100 um2 (100 pixels), 50x50 μm^2 (400 pixels) and 25x25 μm^2 (1600 pixels) pixel size. The IRST devices were 2.8 mm diameter with 50x50 μm^2 pixel sizes, 2500 pixels and 1x1 mm^2 with 40x40 μm^2 pixel sizes, 625 pixels total. The CPTA devices were 2.1x2.1 mm^2 of the sensitive area with pixel size 50x50 μm^2. A single photoelectron's time resolution (SPTR) spectra were taken as a first step. To take the SPTR the PiLas light intensity was set such that an efficiency of a single photons registration was less than 10%. The deposit of events with doubled photoelectron amplitude in the timing distribution could be neglected. An SPTR level of 180 psec was obtained for most of the SiPMs when illuminated by a 40 psec light pulse of the 635 nm of the PiLas with 1 Volt of the over voltage. An SPTR of about 120 psec was obtained with higher over voltage. The time spread due to the Pilas could be neglected. An inverse square root dependence of the SiPMs time resolution was observed when we increased the number of photoelectron's detected (fig.2). The number of photoelectrons was estimated on the basis of the single

Manuscript received November 14, 2008. Anatoly Ronzhin is with Fermi National Accelerator Laboratory, Batavia, IL 60510 USA (telephone: 630-840-8630, e-mail: ronzhin@fnal.gov).

photoelectron's signal which is perfectly defined for the SiPMs. The tails or bumps for some of the single photoelectron's time distribution was observed. This effect could be referenced to an optical crosstalk into the SiPMs according to some control measurements.

III. Test Beam Results

The Fermilab Meson Test Beam Facility is a versatile beamline open to all users, once they have agreed to a Memorandum of Understanding with the laboratory. We established such an MOU and were designated experiment T979. The test beam facility exists in the Meson Detector Building. The beamline can be tuned for 120 GeV/c protons from Fermilab's Main Injector, or the beam can be brought onto a target and then lower momentum secondary beam delivered to the user areas.

When we first setup in the test beam at Fermilab in June, 2008, we had in hand only a few 3x3 mm^2 Hamamatsu blue sensitive SiPM. Each of the two SiPMs were coupled with 6x6x12 mm^3 Cherenkov radiators, made of quartz. Two Keithley power supplies with a standard circuit board schematic applied the bias voltage. The ORTEC fast preamps, VT120C, were used in series with the SiPMs output signals. Just as in the bench tests, the SiPM signals were delivered to the 9327 CFD, followed by the time measurement of the TAC567/AD114 combination. The single ADC count corresponded to 3.1 psec. The full dynamic range was 50 nsec.

The SiPMs with the Cherenkov radiators were aligned along the beam at normal incidence. The distance between the two SiPMs was 50 mm. The trigger counter was based on two small size PMT looking at a single scintillator with 2x2 mm^2 transverse size, and 16 mm along the beam. The counter was located on a movable stage allowing alignment of the scintillator with 30 μm accuracy. Both SiPMs and trigger counter were placed in a light-tight dark box with coppered G10 inside (Fig.3) acting as an RF shield. The data were taken with a 120 GeV/c proton beam. The overvoltage for each SiPM was about 1 Volt. The gain of the SiPMs with this overvoltage is in the range 10^5-10^6. The gain of the ORTEC preamps is x20. We estimated the amount of photoelectrons as about 10 for the SiPMs. The obtained time resolution was about 70 psec per SiPM.

Another attempt to improve the TOF resolution on a beam was performed during August, 2008. The same Hamamatsu SiPms with 3x3 mm^2 of the sensitive area with optically attached Cherenkov radiators made of plexiglass were tested on 120 GeV/c beam. This time, with improved systematics, a time resolution of 48 psec per SiPM device was obtained, as shown in Figure 4. The number of photoelectrons was calculated to be 15, as shown in Figure 5. The temperature was under control during the measurements with 1 degree F of accuracy. We feel that the obtained time resolution could be improved with another design of the Cherenkov radiators. It is possible to make two TOF counters based on SiPMs arranged as plain matrix with Cherenkov radiators for the normal particle's incidence. The transverse size of the counters would then cover the beam. The thickness of each TOF counter will be of an order of a few mm including the Cherenkov radiator and the SiPm itself.

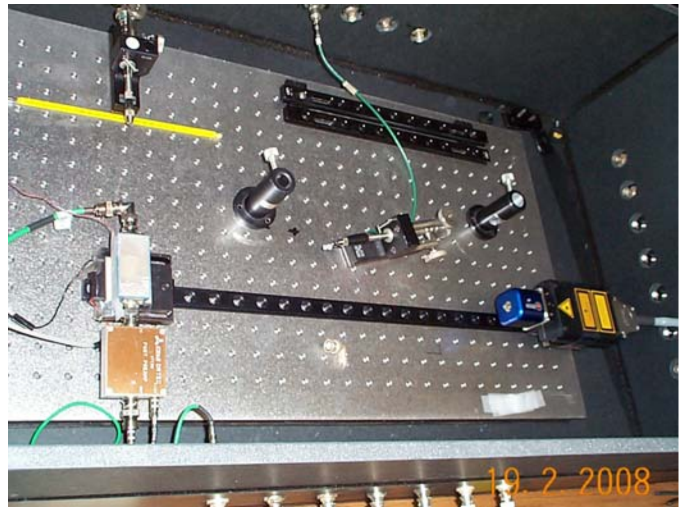
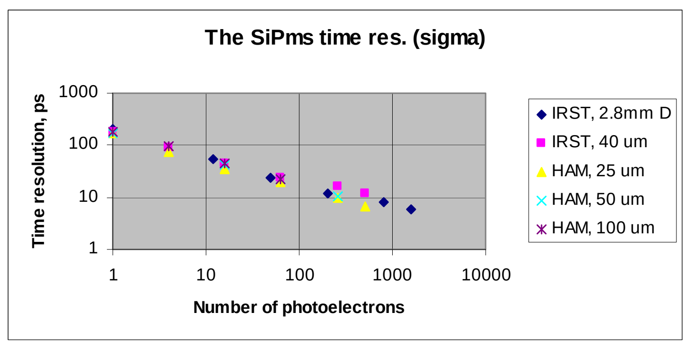


Fig. 1. Setup for the SiPm timing study. Optical table located in a dark box. Picosecond Laser (PiLas) head attached to rail on the right side, and SiPm box with Ortec preamplifier is on the left side.



N phes	IRST 2.8 diam 50mk, 2500 pixs	IRST1mm2 40mk, 625 pixs	HAM-025U-10 25mk, 1600 pixs	HAM-050U-9 50mk, 400 pixs	HAM-100U-10 100mk, 100 pixs
1	210	178	164.6	171.4	182.2
3					
4		89	72.3		93.3
12	53.7				
16		44.6	35.1	42.5	45.8
50	24.2				
64		23.6	19.5	22	22.7
200	12				
256		16.1	9.9	10.2	
512		11.9	6.8		
800	7.9				
1600	5.9				

Fig. 2. The SiPms time resolution dependence (in picoseconds) on the number of photoelectrons.

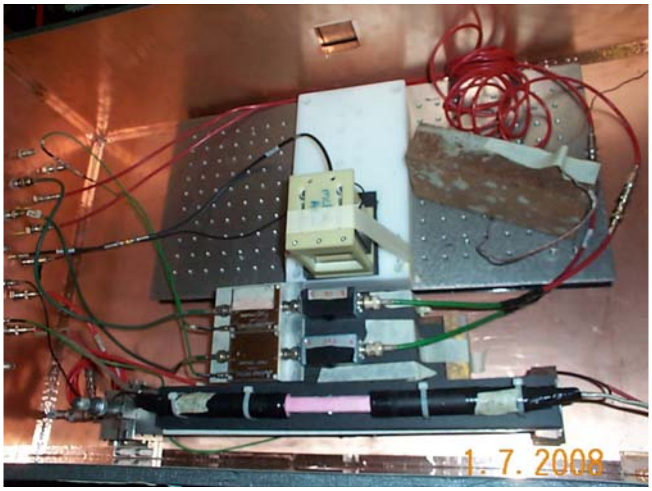


Fig. 3. The setup at the beam, 120 GeV protons. 2 SiPms boxes with the Ortec preamplifiers located inside of the light-tight dark box with coppered G10, acting as RF shielding. Trigger counter with 2 PMTs placed upstream, and PMT with micro channel plate (MCP) is downstream.

7

Test beam SiPM time resolution, 48 ps per device

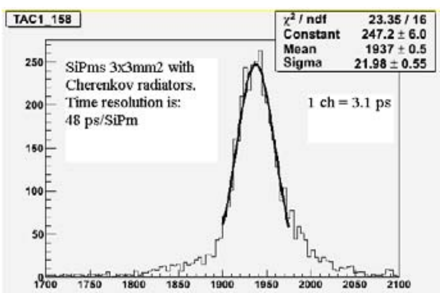


Fig. 4. Timing spectrum, obtained on the beam. SiPms are MPPCs, Hamamatsu, 3mmx3mm of sensitive area with Cherenkov radiators. Time resolution (sigma) is 48 picoseconds per MPPC.

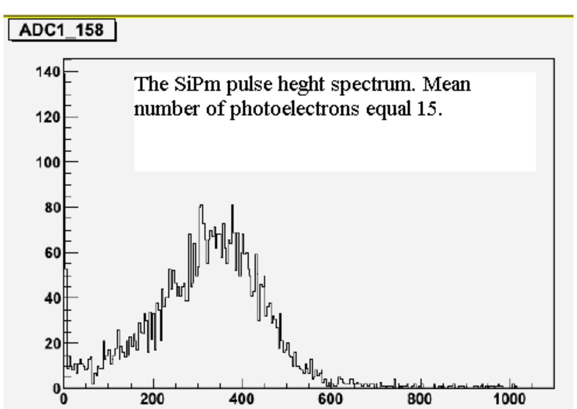


Fig. 5. The MPPC pulse height spectrum, obtained with 120 GeV protons.

Acknowledgment

We thank Sergey Los, Adam Para and Hogan Nguyen for technical support and useful discussions.