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ScienceDirect
Nuclear Instruments and Methods in Physics Research A 567 (2006) 353–355
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Timing by silicon photomultiplier: A possible application for TOF measurements

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Available online 15 June 2006

Abstract

The Silicon Photomultiplier (SiPM) is intrinsically a very fast device, its single photoelectron timing resolution is about 100 ps FWHM. Therefore real timing properties of the system scintillator + SiPM is determined mostly by timing properties of the scintillator + light collection system. We present the experimental results for timing properies of SiPM + scintillator (or Cherenkov radiator) for two cases: (1) timing resolution in a few GeV electron beam with fast plastic scintillator or Cherenkov radiator + SiPMs with a size of $1 \times 1\,\text{mm}^2$ and $3 \times 3\,\text{mm}^2$ and (2)time-of-flight resolution for detection of 511 KeV photons by two LSO crystals + SiPM ($3 \times 3\,\text{mm}^2$), as a possible application for PET.

PACS: 29.40.Mc; 85.60.Gz; 87.58.Fg

Keywords: Silicon Photomultiplier; Time-of-flight measurements; PET gamma detection

1. Introduction

A novel silicon-based photodetector, known as Silicon Photomultiplier (SiPM), is currently under development by the Pulsar enterprise (Moscow) in collaboration with MEPHI and DESY.

The SiPM [1–3] is a pixellated avalanche photodiode operated in limited Geiger mode. The detector surface of $1 \times 1\,\text{mm}^2$ is divided into 1024 pixels. The analog output is obtained by adding the response of all pixels fired as independent digital counters. The SiPM are operated at about 50–70 V, and are capable of gains of the order of 10^6. This device offers a very fast response with a typical rise time of less than 1 ns and very fast recovery time. The time resolution for a single pixel fired, attainable with low flashes of light is approximately 30–40 ps σ. These latest characteristics makes it possible to study the applicability of SiPM for time measurement detectors. The SiPM has already been established as an excellent photodetector for recording green light from a wavelength shifting fiber (WLS) used to collect the light produced by individual scintillating tiles for calorimetric applications [4]. For the purpose of time resolution measurements, some improvements on the developed SiPM are necessary. The dark noise should be reduced, which degrades the time resolution and a larger active area should be provided, which makes the light collection easier and faster.

2. Timing resolution measurements

The time resolution for various combinations of plastic scintillators and WLS fiber systems was tested (Fig. 1). For these measurements the DESY electron test beam (3 GeV) was used. The set-up scheme is shown in Fig. 2. A trigger

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2006.05.142

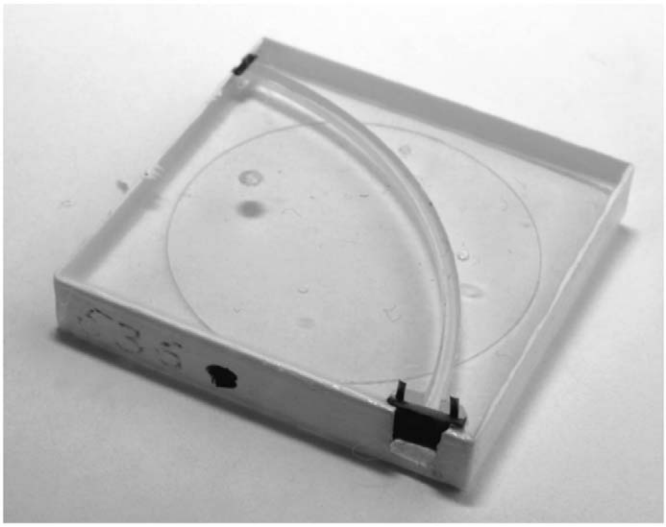


Fig. 1. WLS fiber is placed in the system.

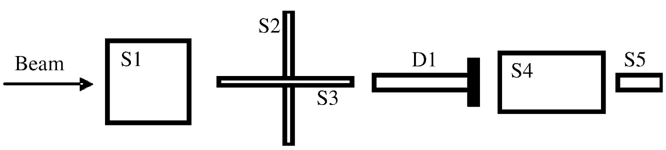


Fig. 2. Experimental setup.

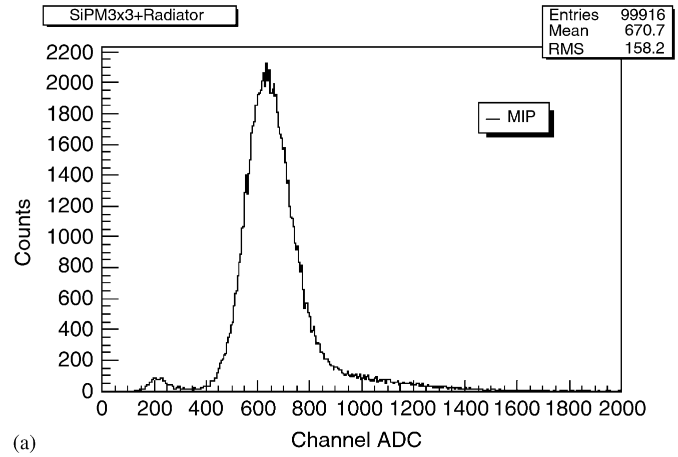
Table 1
Experimental results for different scintillator tile + WLS fiber systems

WLS fiber systems	Amplitude (pixel)	Time resolution σ (ns)
Vladimir + Y11(300)	14.5	1.26
Vladimir + BCF92	15.3	1.17
NE102 + BCF92	9.5	0.88

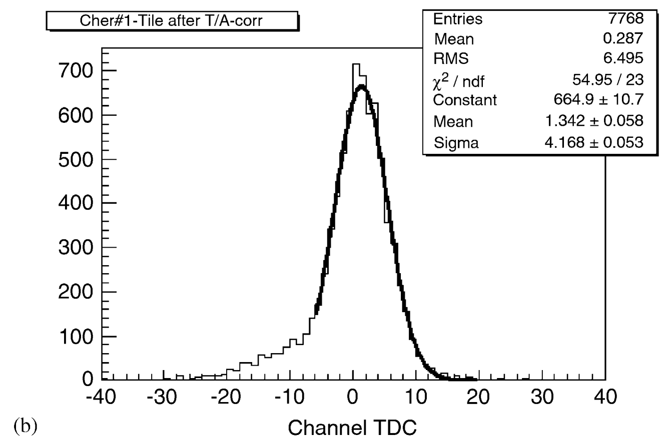
signal is created by the coincidence of the 4 scintillator counters (S1, S2, S3, S5) and one Cherenkov counter (S4). In the position D1 is placed the detector under investigation. For the timing measurement a TDC (CAEN V488) was used, with 25 ps bin width. For amplitude measurements, an ADC LeCroy 1182 was used. At first, the tile–fiber system optimized for calorimetry applications has been tested, which consists of a $1 \times 1\,\text{mm}^2$ SiPM mounted on a $3 \times 3 \times 0.5\,\text{cm}^3$ plastic scintillator with a curved WLS fiber of approximately 5 cm. The time resolution obtained is better than 0.9 ns σ for 1 MIP signal amplitude. In addition, scintillator strip systems have been measured, which can be exploited in ToF detectors for heavy nuclei for astrophysics applications. All results for various tile–fiber and strip–fiber systems are reported in Table 1.

3. Measurements on SiPM with larger active area

Using SiPM with larger active area ($3 \times 3\,\text{mm}^2$) it is possible to collect light directly from the scintillator



(a)



(b)

Fig. 3. Amplitude and time spectrum for Cherenkov detector.

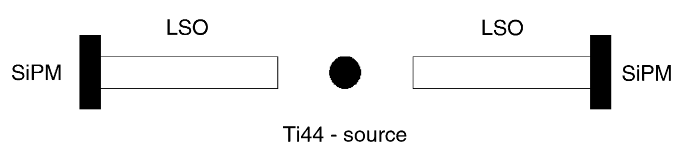


Fig. 4. PET experimental setup.

without the use of WLS fiber, which deteriorates the time resolution. Two systems have been measured with a prototype $3 \times 3\,\text{mm}^2$ SiPM: a scintillator strip of $3 \times 3 \times 40\,\text{mm}^3$ (BICRON—418) and a Cherenkov detector of the same dimension. In both the cases, the detectors have been positioned with the longest side along the beam direction. For the scintillator detector, we observe ~2700 pixel fired with a time resolution of approximately 33 ps σ. In the Cherenkov radiator the light emission is faster than in normal scintillator, therefore, the number of fired pixels is smaller (~10–14) and the time resolution is degraded by the worse signal-to-noise ratio (~83 ps σ). This result can be improved reducing the SiPM dark noise and the inter-pixel cross talk. In Fig. 3 the SiPM dark rate noise can be observed as an asymmetric tail in the TDC distribution.

In addition, we have measured time resolution for a detector with possible applications in positron-emission

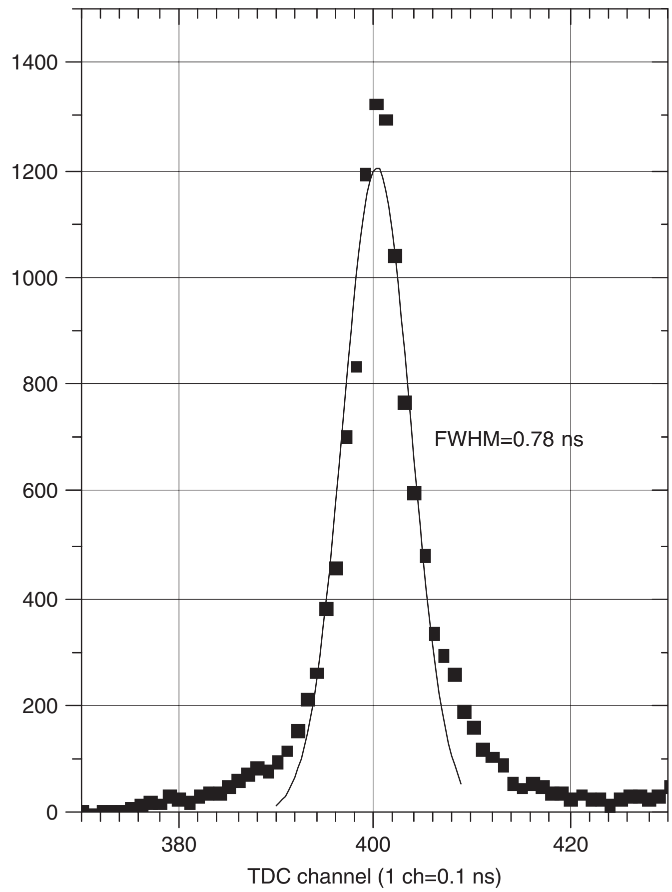


Fig. 5. Time spectrum for two PET detectors.

tomography (PET). For this measurement, we have used two systems with $3 \times 3\,mm^2$ SiPM mounted on LSO inorganic scintillators with dimensions $3 \times 3 \times 20\,mm^3$ and $4 \times 4 \times 10\,mm^3$, respectively. In the middle of the two detectors pointing face to face we have placed a Ti source. The schematic of the setup for this measurement is shown in Fig. 4. The obtained time resolution is presented in Fig. 5, and it is shown to be approximately 780 ps (FWHM).

4. Summary

Silicon Photomultiplier (SiPM) is a new generation of photodetector which gives high-quality analog readout for various types of detectors. Due to its very fast time response the SiPM can be utilized for measurements of time resolution. The time resolution of tile–fiber systems was measured and can be optimized for time-stamp information in calorimeters. SiPM with large active area ($3 \times 3\,mm^2$) can be used in combination with scintillator or radiator strips for fast time response measurement, i.e. in ToF systems. Studies of application of SiPM in medical detectors (PET) are underway.

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