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Time Resolution Measurements on SiPM for High Energy Physics Experiments

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ABSTRACT

Scintillator detector have been used in a wide range of experiments in different areas: Nuclear and High Energy Physics, Medicine, and Radiation Security among others. It is common to use scintillator counters coupled to Photomultiplier Tubes (PMT) as a read out detectors. Nowadays, there has been a great interest in using the Silicon Photomultipliers (PMSi) as a replacement for PMT's due to their high photon detection efficiency (PDE) and their high single photon time resolution (SPTR). The fast the signal is detected, the whole detection system will be useful to search for new physics. PMSi is also known to have a good compactness, magnetic field resistance and low cost. In our lab we are measuring the time resolution of two different models of PMS in order to build a fast radiation detector system.

1. Introduction

In High Energy Physics, scintillation detectors is used commonly to detect charged particles. These detectors basically consist of a scintillation material that can be liquid or solid; these last can be plastic or crystal scintillations, which generate a light when charged particles hit it or by high-energy electromagnetic waves interactions. Scintillators are coupled with light sensors that detect the light generated in the plastic. These sensors previously were the photomultiplier tubes. Nowadays, the use of solid-state photomultipliers (SiPM) is being generalized in addition to an associated electronics, which is very precise and accurate for data acquisition, processing and analysis.

2. Description

In the present paper, we describe the objective, the procedure and the results of the characterization of the low level light sensors called SiPM (Silicon photomultipliers), as well as the characterization, description and comparative analysis of 4 types of plastic scintillators. Finally, there was the choice of the elements to make the most efficient scintillation detector to detect charged high energy particles.

3. Plastic Scintillator Selection

Four different kind of plastic scintillators were tested. The plastic which collected more light was chosen coupled with the same SiPM. BC-404 was the most efficient detector in this case, see Figure 1.

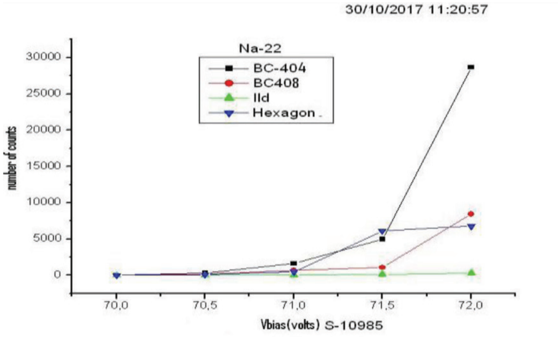

Figure 1: Comparison among four kind of plastic scintillators.

4. Characterization of SiPM

The SiPM are light sensors (in this case scintillator light) made of thousands of photodiodes (APD) connected in parallel in order to accumulate all the signals for a final magnified one.

Taking into account the electronic specifications, the Hamamatsu SiPM brand was selected over the SensL SiPM brand (see Table 1). Its characterization was done as follows.

Calculate and design the polarization circuit of the SiPM, Determine its Quantum Efficiency, Photon Detection Efficiency (PDE) of both SiPM, and measure its Dark Current.

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Specifications comparison sheet, Hamamatsu & SensL SiPM

Table 1: Comparison of the specifications for 2 different SiPM devices from different manufacturers: Hamamatsu Brand Type S10985 and Brand SensL Type C 60035 [1].

Parameter	Symbol	Hamamatsu	SensL	Units
Number of channels		4(2X2)	4(2X2)	ch
Effective area / channel		3 X 3	6 X 6	mm
Number of pixels / channel		3600	18980	p-ch
Pixel size		50 X 50	35	um
Factor fill		61.5	64	%
Spectral response range	λ	320 a 900	300 950	nm
Sensitive peak wavelength	λp	440	420	nm
Operating voltage range		70 +/-10	24.5 + 5	V
Dark counts / channel		6 000	1200	kcps
Maximum dark count / channel		10 000	3400	kcps
Terminal / channel capacitance	Ct	320	48	pF
Gain	M	7.5 x 10*5	3 x 10*6	-
PDE at λp		50	41	%

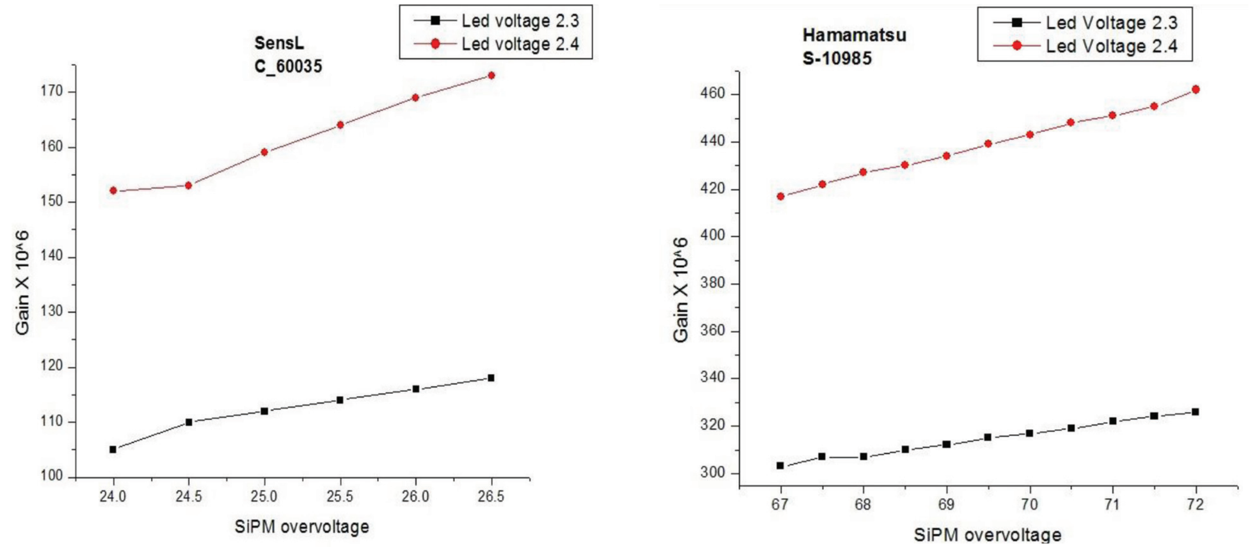


Figure 2: Gain comparison between SiPM's.

Note: All tests were performed at room temperature.

a) SiPM Polarization Circuit

In order to increase the temporal resolution, the decay and recovery time was reduced, modifying the polarization circuit of the SiPM.

b) Calculate your Quantum Efficiency

To obtain the first photon detection efficiency (PDE); quantum efficiency of the SiPM was calculated, for which the following procedure was performed:

(i) The level of illumination (Illuminance) generated by the blue LED (460ns) was measured by means of a calibrated Luxometer.

(ii) The amount of light (Luxes) in power (Watts) was converted, using the formula

$$P(W) = Ev(lx) \times A(m^2) / \eta(lm/W) \qquad (1)$$

$$P(W) = 0.4Lx \times 0.0000785m^2 / 60 = 5.23e^{-7W}$$

Where P = Power in Watts (W), is equal to the illuminance Ev in lux (lx) multiplied by the surface area A in square meters (m^2), divided by the luminous efficiency η in lumens per watt (lm / W):

(iii) The current of the SiPM was measured in picoAmpers and the following formula was applied

$$QE = \frac{Photocurrent\ Multiplicated}{Phocurrent\ Before\ Multiplication} \quad \textbf{(2)}$$

$$QE = \frac{1mA}{4.65uA} = 215\ EQ(S10985)$$
$$= 215\%\ EQ(C60035) = 162\%$$

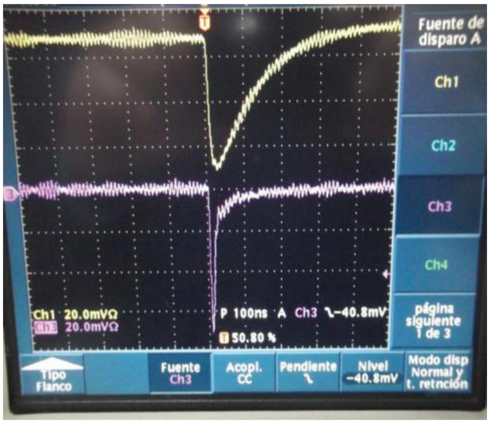


Figure 3: Polarization circuit before (up) and after (down) electronic improvement.

c) Determine the Photon Detection Efficiency (PDE)

Fourth, the PDE was determined by the following formula.

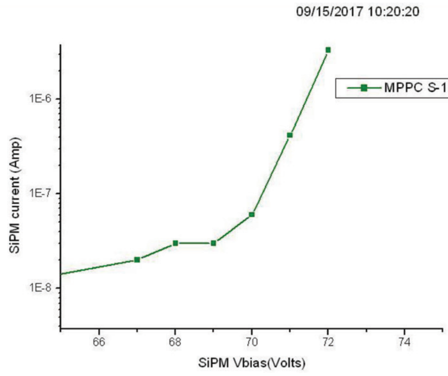
PDE=Fg x QE x Pa (3)

Where: Fg = Fill factor, QE = quantum efficiency,

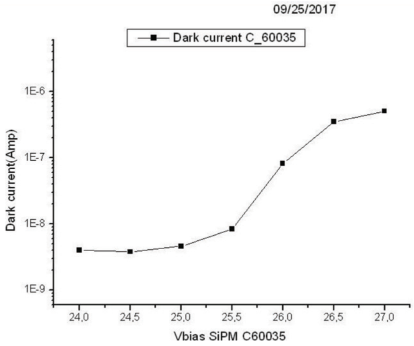
Pa = avalanche probability

PDE=0.65 x 215 x 0.1= 26.23%

d) Dark Current



(a)



(b)

Figure 4: Comparison of dark currents of both SiPM.

5. TDC Calibration

To measure the temporal resolution of the SiPM scintillation detector and BC 404 plastic, first a system calibration was done (Figure 5) and TDC module of type VME, V792N was used. The data was acquired on the computer through a CAEN V1718 interface module and through a Labview program. See Figure 6.

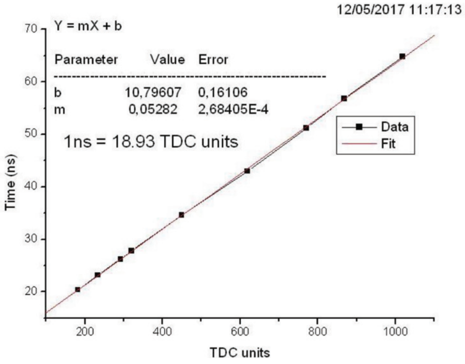


Figure 5: TDC calibration.

6. Obtain an Approximation of the Temporal Resolution

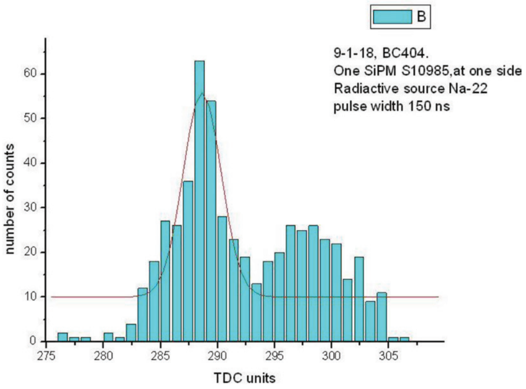


Figure 6: TDC temporal resolution.

Results

Among the main results are the reduction of the pulse width of the SiPM from 300ns to less than 100ns and the decay time from 20 to 5ns; it was possible to find the quantum efficiency of the two SiPM and a comparative analysis of the four types of scintillator plastic and the best elements were chosen to elaborate the Detector and characterize it; also the TDC system was calibrated and its temporal resolution was measured.

Pending work or next steps, find the correlation between the time and the load of the signals to be able to calculate the temporal resolution based on the energy. For this, it is necessary to be able to work with the TDC and the QDC simultaneously.

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