Evaluation of Sample Silicon Photomultiplier Devices

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Abstract

This report serves as an update on the photon tagger microscope development undertaken by the nuclear physics group at the University of Connecticut. Testing of candidate silicon photomultipliers (SiPM) has begun and preliminary data on their operating parameters has been gathered.

Photons with energies up to 12 GeV will be produced in Hall D in Jefferson Lab via coherent bremsstrahlung (CB) of electrons in a diamond crystal. This technique produces a broad radiation spectrum: the energy of the photon is not known *a priori*. Its energy, however, can be measured (i.e. it can be "tagged") by measuring the energy of the post-bremsstrahlung electron that produced it, which has a known initial energy equal to the beam energy: 12 GeV.

This tagger will be implemented by dispersing the post-bremsstrahlung electrons in a magnetic spectrometer and detecting them on the focal plane. This spectrometer is equipped with a broad band detector array and a higher resolution detector "microscope" covering the narrow energy band of the primary CB peak. The latter detector is instrumented as a packed array of about 600 square 2mm scintillating fibers with SiPMs used for photon detection. The following are the principal advantages of SiPMs compared to the more commonly used photo-multiplier tubes (PMTs):

1. no high voltage required (bias voltages of order 50V are sufficient)
2. response times are about a factor two faster
3. geometric cross section comparable to that of the fiber

Thus, the Connecticut group is searching for SiPMs of comparable gain, response times of order one nanosecond, low dark rate and a 2×2 mm^2 active area. Tests have begun on commercially available SiPM devices in the test stand designed for this purpose [1]. In what follows, we report on the study of the 1×1 mm^2 Photonique device: SiPM SSPM-050701GR-TO18 shown in Fig. 1.

Figure 1: Photonique device SSPM-050701GR-TO18: 1×1 mm^2 sensitive area with 556 pixels. Note the millimeter markings for scale.

1 Test Setup

Final calibration of the test stand was performed with a pulsing yellow (∼590 nm) LED. These were found to have the shortest pulses compared to other LEDs available in the lab. The detection efficiency of the SiPM characterized in this report happens to peak in the yellow range with an efficiency about twice that obtained at 500 nm (green range).

The test stand was calibrated with a hybrid photo-diode (HPD). Using its efficiency and gain specifications, the photon flux on the HPD window has been determined. The total detection efficiencies of the HPD and SiPM weighted by the emission spectrum of the yellow LED have been determined to be 8.7% and 29% respectively. The low efficiency of the former is due to the fact that the HPD is designed for the UV range. The ratio of the efficiencies of the two devices is thus about 3.4. The efficiency distributions of both devices are shown in Fig. 2.

Since the photon flux at the location of the HPD window is now known, the SiPM has been mounted just over it as shown in Fig. 3. A bias of -40 V is the typical value used for this device, so the tests described below have been conducted at this voltage. This SiPM was characterized by collecting many snapshots of its reponse (as shown in Fig. 6) and plotting the distribution of the integral of the signal.

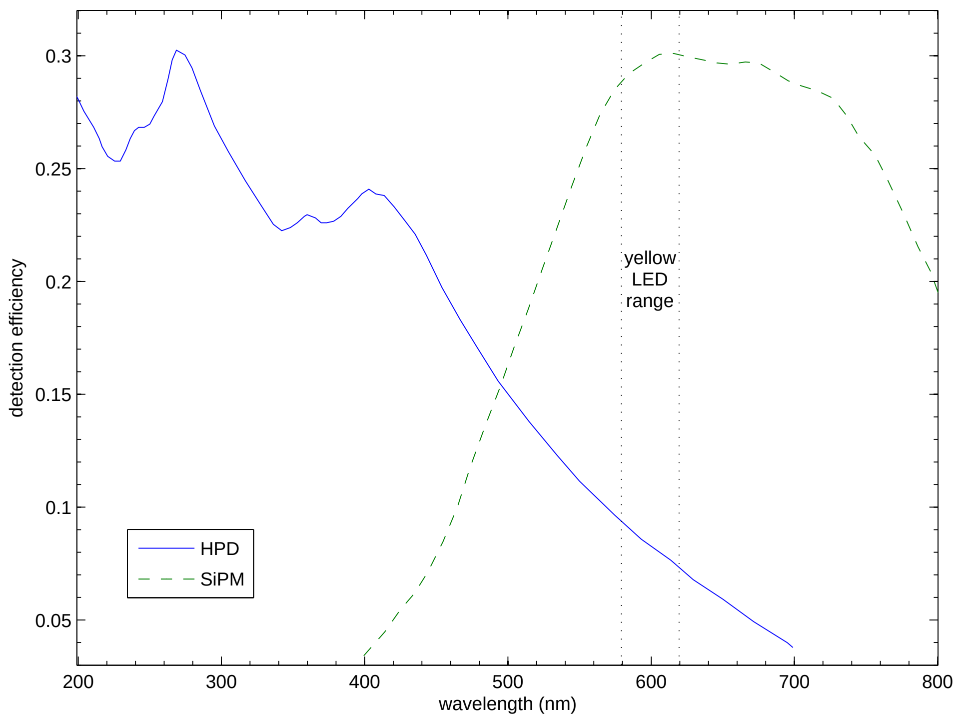

Figure 2: Detection efficiency distributions of the HPD and the SiPM.

Figure 3: The 1×1 mm^2 active area SiPM and amplifier from Photonique are shown mounted over a covered HPD window (outlined with the dashed circle). The SiPM is thereby exposed to the same photon flux as that measured by the HPD.

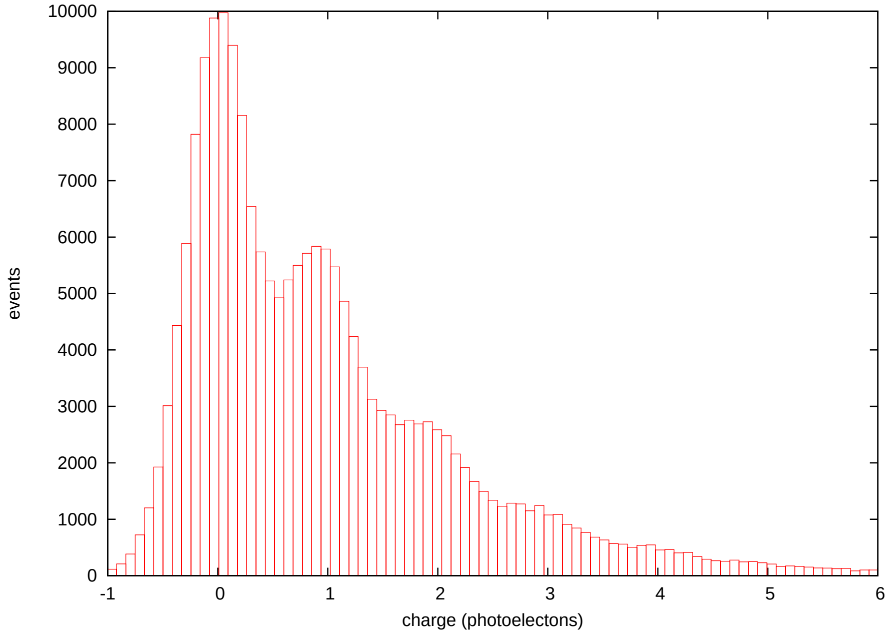

Figure 4: Histogram of the SiPM charge integrated over a random 100 ns window under dark conditions. The pulse integral has been normalized to give one unit per pixel firing during the gate.

2 Results

Avalanche of discrete pixels was observed and can be seen in the form of discrete peaks shown in Fig. 4 and Fig. 5. These discrete peaks enable normalization of the gain of the SiPM amplifier so that the output is measured in pixels. Furthermore, the discrete response of the SiPM allows a straight-forward calibration of the device in terms of quantum detection efficiency.

The mean dark rate can be deduced from Fig. 4. A typical sample of this distribution is shown in a screen shot of our data acquisition software (Fig. 6). Preliminary measurements show an approximate dark rate of 9.8 MHz at 22° C and -40 V bias.

The SiPM was tested with a small light input which, according to the HPD calibration and efficiency data, should be about 5.6 photons per 1 mm^2 (the SiPM active area). Note that the distribution (shown in Fig. 5) has a mean of several photons. The SiPM efficiency-compensated and dark rate-subtracted average photon count is 1.6 per 1 mm^2, leading to a measured ratio of efficiencies of the two devices of 3.2, very close to the expected figure of 3.4.

3 Outlook

We plan to test this SiPM further: measure the dark rate as a function of bias voltage and temperature. Then we intend to characterize in the same fashion a $2{\times}2$ mm^2 SiPM received

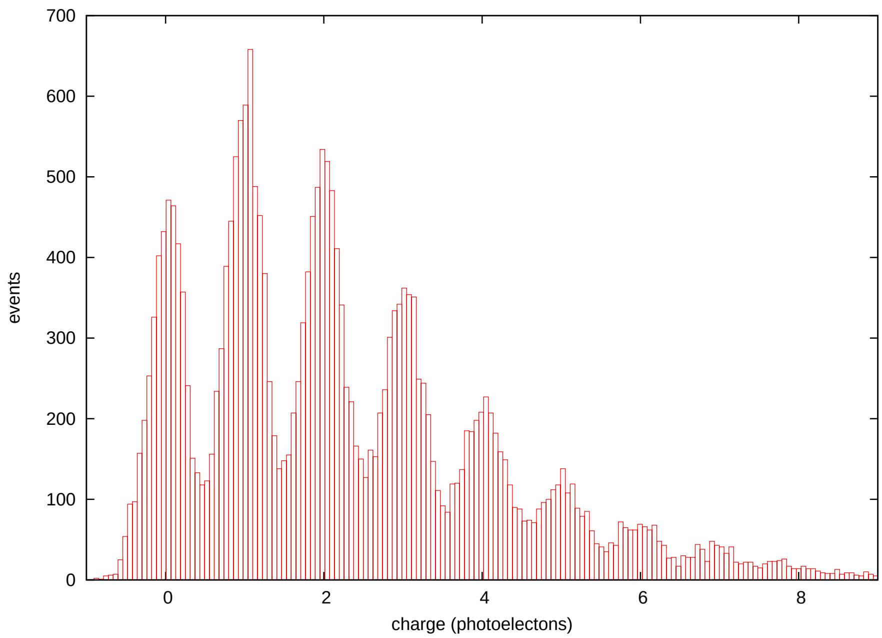

Figure 5: Histogram of the SiPM charge under a flux of about 5.6 photons per mm^2 integrated over 100 ns window timed to coincide with a pulse from the LED pulser. The SiPM pulse integral has been normalized to give one unit per pixel firing during the gate.

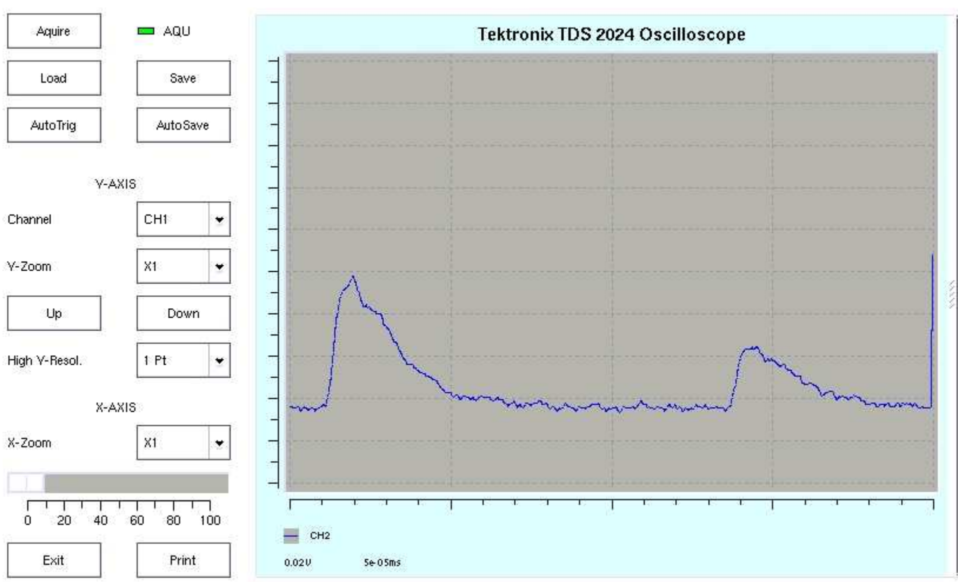

Figure 6: A screenshot of the data acquisition software. The display shows typical pulses under dark conditions. The first pulse contains two pixels, presumably firing together due to cross-talk.

from Photonique. Such preliminary evaluations in our test stand will be followed by tests with scintillating fibers illuminated by a radioactive beta source.

References

[1] I. Senderovich, R.T. Jones, "Construction of a Test Stand for Evaluation of Silicon Photomultiplier Devices" GlueX-doc-677-v1 (2006).