Application of SiPM for Modern Nuclear Physics Practical Workshop

A S Chepurnov¹, O I Gavrilenko², Massimo Caccia³, Cristina Mattone⁴, A N Oleinik⁵ and V V Radchenko¹

¹ Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
² Physics department, Lomonosov Moscow State University, Moscow, Russia
³ Department of Science and High Technology, University of Insubria, Como, Italy
⁴ CAEN S.p.A., Viareggio, Italy
⁵ Laboratory of Radiation Physics, Belgorod National Research University, Belgorod, Russia

Email: gawrilenko.olga@gmail.com

Abstract. Silicon PhotoMultipliers (SiPM) are state of the art light detectors with very high single photon sensitivity and photon number resolving capability, representing a breakthrough in several fundamental and applied Science domains. So, introduction of SiPM in to the education is important process increasing the number of specialists involved in the SiPM development and application. As a result of collaborative efforts between industry and academic institutions modular set of instruments based on SiPM light sensors has been developed by CAEN s.p.a. It is developed for educational purposes mainly and allows performing a series of experiments including photon detection, gamma spectrometry, cosmic ray observation and beta and gamma ray absorption. In addition, an educational experiments based on a SiPM set-up guides students towards a comprehensive knowledge of SiPM technology while experiencing the quantum nature of light and exploring the statistical properties of the light pulses emitted by a LED. The toolbox is actually an open platform in continuous evolution thanks to the contribution of the research community and cooperation with high schools.

1. Introduction

Instruments and methods for nuclear radiation detection and imaging have undergone a tremendous development over the past decade. This was driven by the latest generation of nuclear and particle physics experiments together with medical imaging, nuclear power generation and industrial applications. Advances were so rapid that education lagged somehow behind, both because of the natural inertia and of the unavailability of state-of-the-art educational systems. A renewed nuclear physics workshop is suggested to eliminate this gap.

One of the recent scientific advances - silicon photomultipliers (SiPMs) are widely used in a range of scientific applications, especially where detection of single photons is required. SiPM application areas include biotechnology (single molecule spectroscopy), astrophysics (neutrino detection), medical physics (PET tomography) and a number of other fields.
In order to correspond to the latest achievements in nuclear technology, nuclear workshops of leading Russian Universities should be equipped with spectrometers based on Silicon Photomultipliers and modern scintillators (LYSO, BGO) and up-to-date signal processing electronics (flash ADCs).

2. A Joint project: New Spectrometer based on SiPM

2.1 CAEN Educational

CAEN s.p.a. is known to many experimenters as a developer and manufacturer of novel electronics for nuclear and particle physics research. Several years ago CAEN announced Educational Kits specially designed for teaching purposes.

The toolbox developed by CAEN s.p.a. is based on high-end equipment designed and optimized for modern nuclear and astroparticle physics. It was customized for University students, being offered the possibility to design and perform a set of experiments starting by basic building blocks and up-to-date detectors. CAEN educational kits include front-end electronics for standard detectors, Flash ADC for getting students acquainted with the basic of digital signal processing for spectral signals including Pulse-Shape Discrimination, and a Silicon photomultiplier educational kit allowing to perform a series of experiments on photon detection, gamma spectrometry, cosmic ray observation and beta and gamma ray absorption.

The toolbox is an open platform in continuous evolution thanks to contributions of the research community and cooperation with high schools.

2.2 Joint educational Project

It is known that SiPMs were originally invented and described by Boris Dolgoshein (MEPhI, Russia) [1]. Now the SiPM laboratory continues to study its properties and developing SiPM-based detectors for different applications [2-4], thus remaining Russia’s leading SiPM manufacturer and developer. There are several workshop exercises in the laboratory designed for MEPhI students who study detectors based on Silicon Photomultipliers.

The suggested idea is to create a spectrometer using SiPMs manufactured at MEPhI that together with CAEN modular educational products and well tested methodological approaches of leading Russian Universities can become a basis for renewed nuclear physics workshop. The existing classic workshop exercises like α-, β- and γ- spectroscopy or interaction of radiation with matter can be updated by replacement of the classical spectrometric tract with flash ADCs and installation of the new, SiPM-based spectrometers. In addition to that, the whole range of new exercises focused on the study of SiPM properties is suggested.

3. Exercises to Study SiPM Properties

Exercises on SiPM properties require a well-isolated SiPM with a holder, a LED driver and signal processing electronics. Exemplary exercises are listed below.

3.1 Dependence of SiPM properties on bias voltage

The main features of the SiPM are expected to depend on the bias voltage. In this exercise students are to study resolution - bias, gain - bias and dark count rate - bias dependences (figure 1 a-c). The exercise focuses on fundamental principles of SiPM operation, understanding the nature of dark counts and explanation of the Resolution-Bias curve.
Figure 1. The study of SiPM properties: Dependences of Resolution, Gain and Dark Count Rate (DCR) on Bias Voltage [5].

3.2 SiPM After-Pulses

Charge carriers from an initial avalanche may be trapped by impurities and released at later stage resulting in delayed avalanches named After-Pulses [6]. The experimental procedure of this exercise starts by defining two gates (figure 2 a), synchronized to the light pulse. The minor gate G1 corresponds to the initial pulse created by the light pulse while G2 is used to calculate charge generated by re-avalanches. Exemplary After-pulse spectrum is shown in figure 2 b.

Figure 2. After-pulse signal procession using G1 and G2 parameters (a) and exemplary spectra (b) [6]

3.3 Advanced photon Counting Statistics

It was shown that photon counting statistics can be described with Poissonian distribution [7]. However, dark counts, optical cross-talk (OCT) and after-pulses that occur stochastically can affect the probability density leading to deviations. In order to estimate deviations caused by OCT, a compound Poissonian distribution (P×G) was suggested [5].

In this exercise students are to study the statistical contribution of the OCT effect into experimentally observed distribution. The key point in the analysis technique is the estimation of the area underneath every peak, allowing the reconstruction of the probability density functions. For this purpose, a Multi-Gaussian Fit (MGF) procedure was implemented in MATLAB to analyze the full spectrum (figure 3 a). After procession the data is compared to Gaussian and P×G distributions (figure 3 b).
Conclusion

A SiPM – based spectrometer for the practical workshop aimed at students of different branches of nuclear physics has been proposed. A number of exercises based on SiPM study is suggested.

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