Nuclear Instruments and Methods in Physics Research A 718 (2013) 569–572

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

SiPM time resolution: From single photon to saturation

S. Gundacker [a,*], E. Auffray [a], N. Di Vara [a], B. Frisch [a], H. Hillemanns [a], P. Jarron [a], B. Lang [b], T. Meyer [a], S. Mosquera-Vazquez [b], E. Vauthey [b], P. Lecoq [a]

[a] European Organization for Nuclear Research (CERN), 1211 Geneva 23, Switzerland
[b] Physical Chemistry Department - Sciences II - University of Geneva 30, Quai Ernest Ansermet, 1211 Geneva 4, Switzerland

ARTICLE INFO

Available online 8 February 2013

Keywords:
SiPM
TOF-PET
Single photon time resolution
Multi pixel photon counter (MPPC)
NINO
Femtosecond laser

ABSTRACT

The time resolution of photon detection systems is important for a wide range of applications in physics and chemistry. It impacts the quality of time-resolved spectroscopy of ultrafast processes and has a direct influence on the best achievable time resolution of time-of-flight detectors in high-energy and medical physics. For the characterization of photon detectors, it is important to measure their exact timing properties in dependence of the photon flux and the operational parameters of the photodetector and its accompanying electronics. We report on the timing of silicon photomultipliers (SiPM) as a function of their bias voltage, electronics threshold settings and the number of impinging photons. We used ultrashort laser pulses at 400 nm wavelength with pulse duration below 200 fs. We focus our studies on different types of SiPMs (Hamamatsu MPPC S10931-025P, S10931-050P and S10931-100P) with different SPAD sizes (25 μm, 50 μm and 100 μm) coupled to the ultrafast discriminator amplifier NINO. For the SiPMs, an optimum in the time resolution regarding bias and threshold settings can be reached. For the 50 μm type, we achieve a single photon time resolution of 80 ps sigma, and for saturating photon fluxes better than 10 ps sigma.

1. Setup

The tests comprised a series of systematic studies of SiPMs in terms of: SiPM fill factor or SPAD size, i.e. 25, 50 and 100 μm; SiPM bias voltage; Discriminator (NINO [1]) threshold; optical density (OD) of the light attenuators. We characterized the SiPMs regarding their break-down voltage and dark count. An overview of their properties can be seen in Table 1.

As can be seen in Fig. 1, the 50 μm type has the lowest dark count rate, even for high bias overvoltages.

In our investigations we always used SiPMs (MPPCs) with the same active area of 3×3 mm^2 produced by Hamamatsu Photonics. The setup can be seen in Fig. 2. The data was acquired with a fast LeCroy Oscilloscope DDA 735Zi 40 Gs/s that achieves 1 ps time resolution by interpolation. The femtosecond laser operated at 400 nm wavelength with a pulse width of 200 fs. For each attenuation factor, measured in optical density (OD) of the laser beam we scanned the SiPM bias and NINO threshold to find the optimum values.

2. Time reference

To establish a precise trigger we split the beam into two, each illuminating a 25 μm – SiPM with approx. 8000 photons. The performance of the trigger was then tested by measuring the time delay between the two 25 μm type SiPMs. The signal of the SiPMs was directly fed into the oscilloscope without using any further electronics. We obtained a coincidence time resolution of $\sigma = 4.1$ ps. Thus the trigger jitter is about $\sigma = \frac{4.1}{\sqrt{2}}$ ps $= 2.9$ ps.

3. Data analysis

NINO uses the time-over-threshold method and produces a square pulse. The leading edge gives the time information, and the pulse width is proportional to the input charge [3].

A small area around the peak of the pulse width histogram was selected and the corresponding delay time spectrum was plotted, Fig. 3. With this selection we reduce the influence of time walk and the Poissonian photon flux jitter on the time distribution.

Table 1
Properties of three different photodetectors from HAMAMATSU, with 3×3 mm^2 active area.

Type: S10931	SPAD size (μm^2)	Number of cells	Fill factor (%)	Break down (V)	Opt. bias for PET [2] (V)
–100P	100×100	900	78.5	69.3	70.3
–050P	50×50	3600	61.5	70.5	72.4
–025P	25×25	14,400	30.8	69.2	73

* Corresponding author. Tel.: +41 22 767 4623.
E-mail address: stefan.gundacker@cern.ch (S. Gundacker).

0168-9002/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nima.2013.01.047

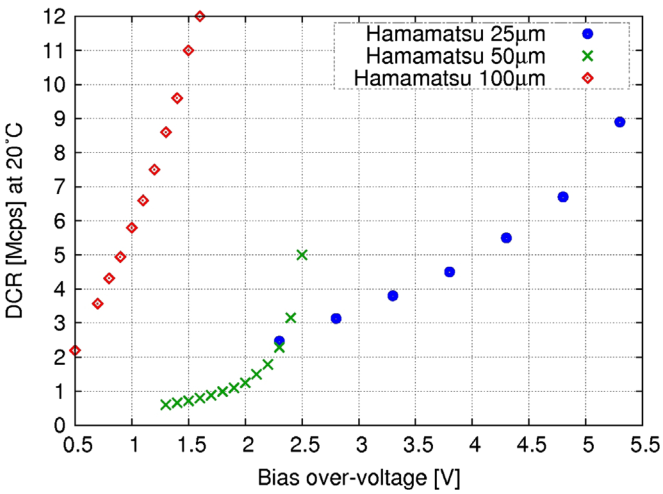

Fig. 1. Dark count rate vs. bias voltage. The 50µm type shows the lowest dark count rate even for high overvoltages.

4. Single photon time resolution

Single photon time resolution was measured at very low light intensities to ensure single photon hits on the detector, Fig. 4. The chosen NINO threshold was 40 mV. Making dark count scans, this value was found to be low enough to detect the firing of a single photon avalanche diode (SPAD).

5. Time resolution vs. light intensity (OD), threshold and overvoltage

In Fig. 5 we show the time resolution versus the photon intensity, i.e. the number of photoelectrons. We observe that the time resolution follows a $1/\sqrt{N_{p.e.}}$ behaviour. At high photon intensities the time resolution saturates at around 20 ps for low threshold values. This is related to the intrinsic limit of the electronics and because of the very low threshold deteriorated by the SiPMs dark count. For higher threshold values we measure time resolutions of around 8 ps sigma, see Fig. 6. For the

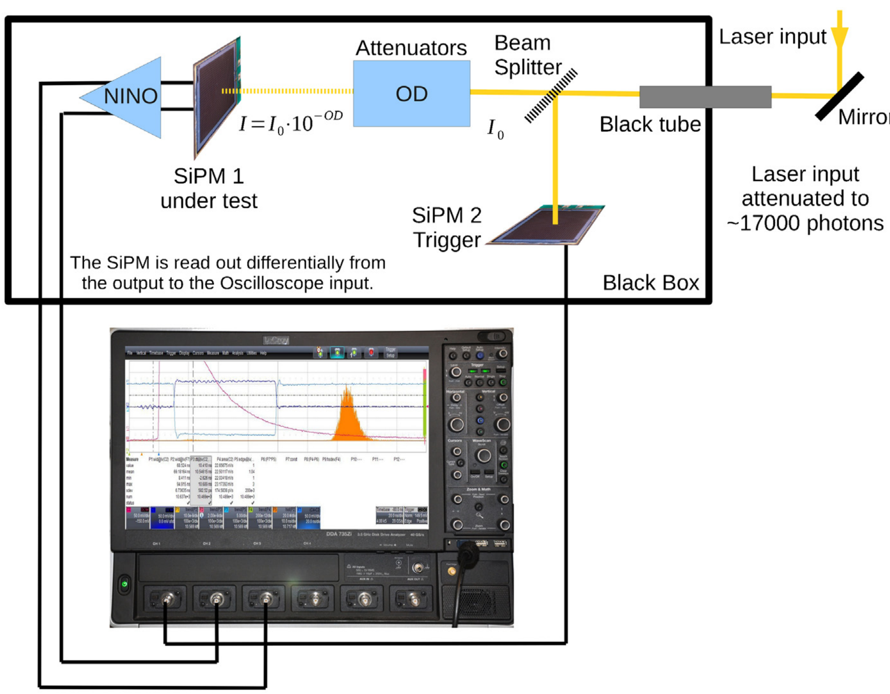

Fig. 2. Setup as used for the tests. We used laser pulses at 400nm wavelength with pulse duration below 200fs. The trigger jitter was determined to 2.9ps sigma.

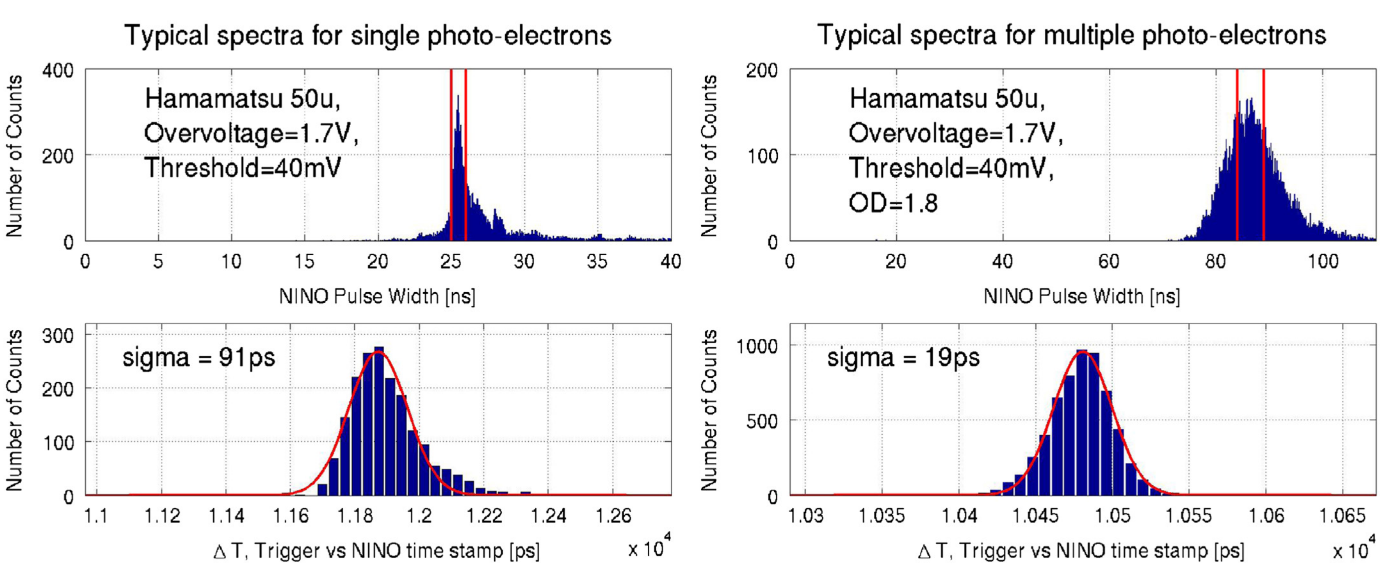

Fig. 3. Data analysis for low and high light fluxes.

100 μm and 25 μm type we observe a minimum time jitter at 1 V and 3.8 V overvoltage, respectively. These overvoltages are in agreement with the values achieved in a TOF-PET system, using the same SiPMs [2].

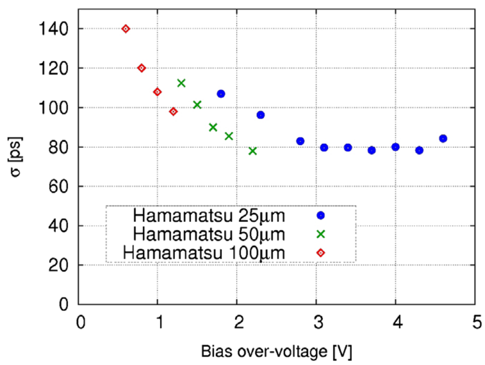

Fig. 4. Single photon time resolution of the three different SiPM types. The 100μm type could not be operated at higher overvoltages, because of the rapid increase in dark count.

6. Summary

Using NINO, we achieved good single photon time resolutions, down to 80 ps sigma. Light level scans show $1/\sqrt{N_{p.e.}}$ agreement. At saturating photon fluxes and high threshold values we even

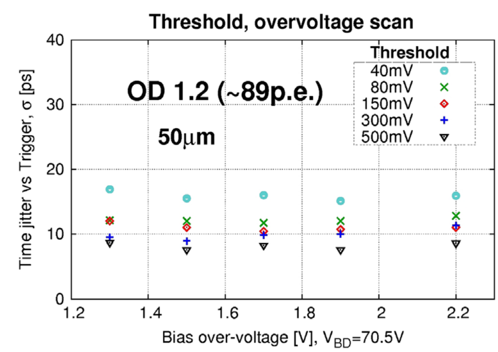

Fig. 6. Time resolution vs. overvoltage and threshold for the 50 μm type at high photon intensities.

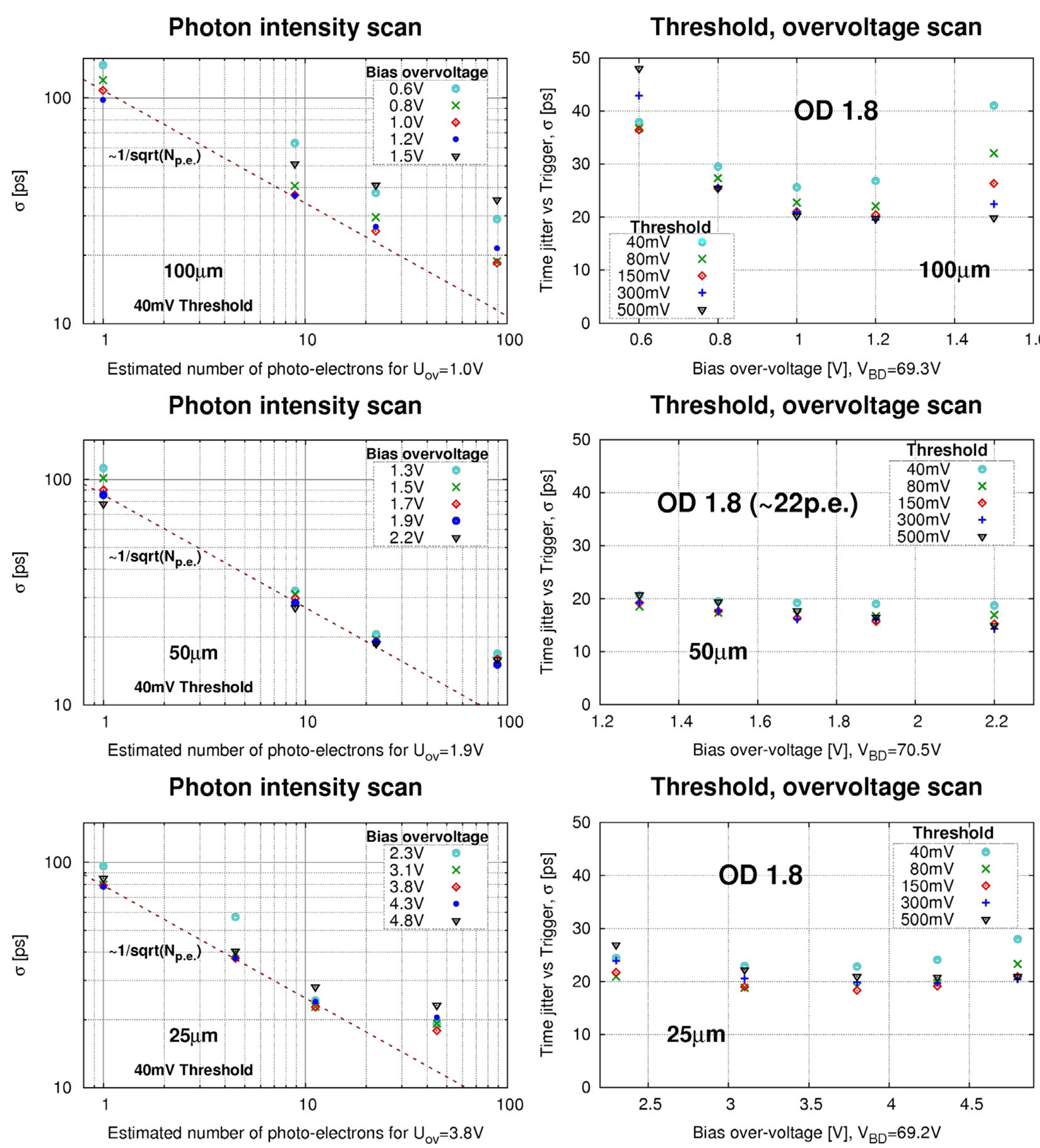

Fig. 5. Left column: photon intensity and overvoltage scan with fixed threshold at 40mV; right column: bias and threshold scan with fixed photon flux, for 100 μm top, 50 μm middle and 25 μm bottom.

measured a time resolution of less than 10 ps sigma. This approaches the timing limitations of the electronics (NINO) and the acquisition system. At lower NINO thresholds this value is strongly deteriorated by the SiPM's dark count.

In future tests the noise contribution to the single photon time resolution will be studied in more detail. This would include a full characterization of NINO with SiPM-like input pulses.

Acknowledgement

This work was carried out in the frame of the Crystal Clear Collaboration.

References

[1] F. Anghinolfi, et al., IEEE Transactions on Nuclear Science NS-51 (October (5)) (2004) 1974.
[2] S. Gundacker, et al., A systematic study to optimize SiPM photodetectors for highest time resolution in PET, IEEE Transactions on Nuclear Science 59 (2012) 1798–1804.
[3] P. Jarron, et al., in: Nuclear Science Symposium Conference Record (NSS/MIC), 2009 IEE, 2009, January 2010, pp. 1212–1219.