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Characterization of novel Hamamatsu Multi Pixel Photon Counter (MPPC) arrays for the GlueX experiment

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ABSTRACT

The novel Hamamatsu Multi Pixel Photon Counter Array S12045(X) is an array of 16 individual MPPCs (3×3 mm^2) (further in the paper MPPC array channel) each with 3600 G-APD (Geiger-mode Avalanche Photodiodes) pixels (50×50 [μm^2]). Each MPPC in the array works with its individual reverse bias voltage mode (around 70 V). The paper summarizes the characterization process of MPPC arrays used in GlueX experiment (Hall D, Jefferson Lab). We studied the main features of each MPPC array channel for 2800 MPPC arrays at different temperatures. Two measurement stations were built to extract gain, breakdown voltage, photo detection efficiency (PDE), optical crosstalk and dark rate for each MPPC array channel. The hardware and the data analysis are described, which includes new analytical expressions to obtain the mean number of photo-electrons and optical crosstalk. The dynamical behavior of characterization parameters is presented as well.

1. Introduction

The recent progress in technology of solid state photo-sensors [1] makes possible technological upgrades in experimental physics as well as in others disciplines [2]. In this context the Universidad Técnica Federico Santa María (UTFSM) is in the process of testing 2800 MPPC arrays at three different temperatures. All MPPC arrays are bought from HAMAMATSU and after testing are shipped to JLab. The test includes the measurements of gain, breakdown voltage, photon detection efficiency (PDE), optical crosstalk and dark rate for each single MPPC in every array. To perform the test, the UTFSM group has built three special measurement stations and performed all required data analysis.

2. Measurement procedure

To perform the characterization of the MPPC arrays three distinct equipment stations were built. In station 1 a visual inspection of the MPPC arrays was done using a wide-angle lens photo-camera (the description of this station is out of the scope of this paper).

Station 2 objective is to measure the PDE (photo detection efficiency) for MPPC arrays. For this purpose, 415 nm LED (light-emitting diode) light goes through an optical fiber that feeds a light mixer made of Plexyglas® (see Fig. 1). The light mixer is connected to each of 16 MPPC array channel through wavelength shifting (WLS) fibers (Kuraray, Y11(200)). As a result each MPPC array channel is provided with light with average wave length of 518 nm. Additionally one WLS fiber is connected to a PMT (Photomultiplier Tube) which was previously calibrated using a special PIN diode (Hamamatsu, S3590-03). The PMT provides the monitoring signal which is required for the reconstruction of the PDE of the MPPC array. The amplified signals from the MPPC array and the signal from the PMT are collected by a QDC (charge to digital converter) with 100 pC/channel resolution using a 120 ns gate. All devices are located in a special dark box, besides that a thermistor is placed near the PMT. The bias voltage is supplied by a Source-meter (Keithley, 2400) and the trigger is generated by a pulse generator (Keithley, 3402) (see Fig. 1).

Station 3 objective is to measure the gain, breakdown voltage, and the optical crosstalk of the MPPC arrays. The measurement system consists of a dark box ($1.5 \times 0.5 \times 0.45$ m^3) made of three layers in the body (see Fig. 3) and 2 layers at the 2 face ends designed to avoid light and air leakages, and to increase thermal insulation. Inside the box there is a LED source and a diffuser in one end and 32 MPPC arrays located in 4 rows with 8 MPPC arrays each in the other end (Fig. 4). All MPPC arrays are attached to a copper plate (front copper plate) through a thermal pad (Gap Pad®) for temperature stabilization purpose. The temperature control is done using a chiller connected through pipes to the copper plate. The chiller has a temperature controller included. The temperature is monitored using 21 thermistors distributed through all the dark box, 16 of them are located in the front copper plate with the MPPC arrays.

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Each MPPC array is connected to the QDC with 100 fC/channel resolution using a 120 ns gate, through current amplifiers (based on AD8001) and analog multiplexers (AD8184) (see Fig. 5). The MPPC arrays are biased by independent remotely controlled power supplies (Caen, A1519B) while the currents and voltages are monitored with a multimeter (Keithley, 2100) (see Fig. 2).

3. Methodology

For each MPPC in the array we measure the response (charge) under different conditions-LED switch on/off, three temperatures, 13 different bias voltages with 0.1 V step above breakdown voltage. An example plot from station 3 is shown in Fig. 6(a) and (b). From these we extract gain, optical crosstalk, mean number of photo electrons and dark rate as a function of voltage, and the breakdown voltage.

4. Voltage dependence of observables

In order to get information about operational voltage, each MPPC in the array is characterized as a function of the bias voltage. Fig. 7 shows this dependence for one particular MPPC array.

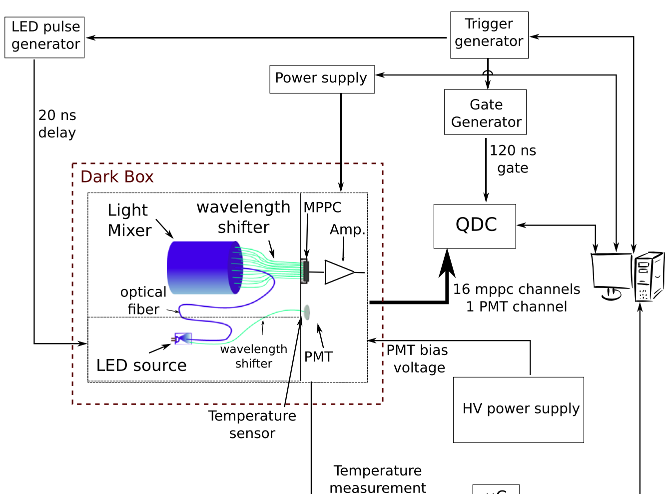

Fig. 1. Station 2 for PDE measurement. Acquisition is done by a QDC with 100 fC resolution and a 120 ns gate. One MPPC array capacity. Room temperature measurement.

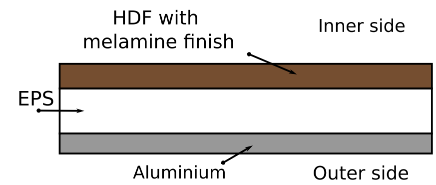

Fig. 3. Dark box walls transversal section.

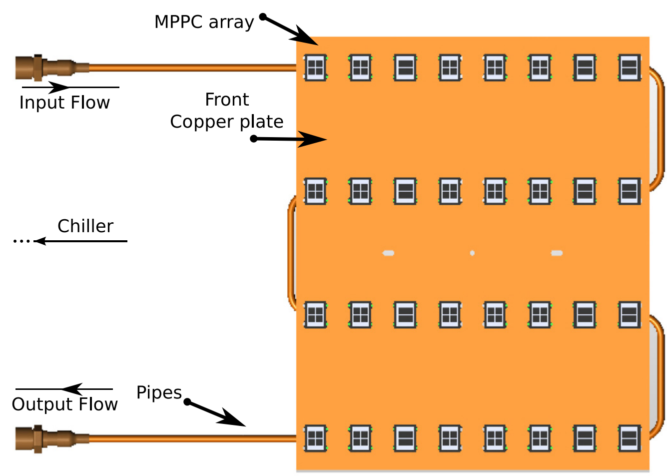

Fig. 4. MPPC arrays on copper plate, 4 rows of 8 MPPC arrays each.

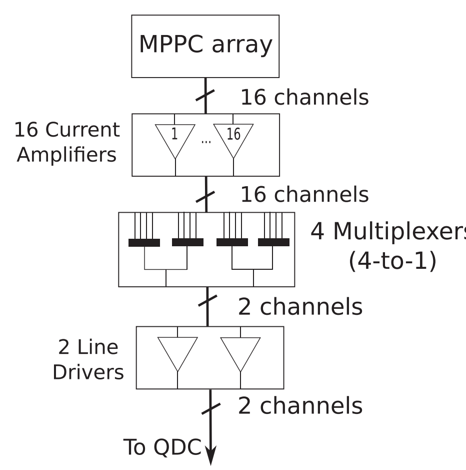

Fig. 5. Schematic diagram of the Readout for one MPPC array.

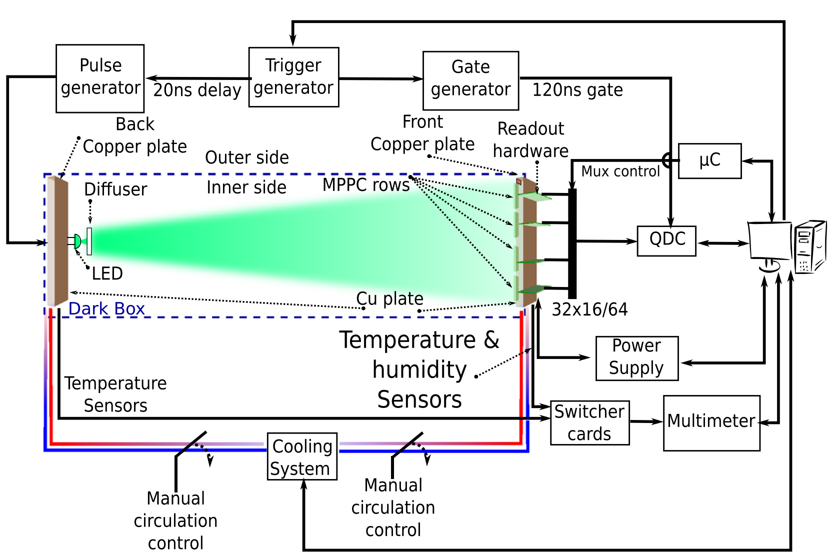

Fig. 2. Station 3 for gain, breakdown voltage, optical crosstalk and dark rate measurements. Acquisition is done by a QDC with 100 fC resolution and a 120 ns gate. 32 MPPC arrays capacity. Temperature-controlled measurement.

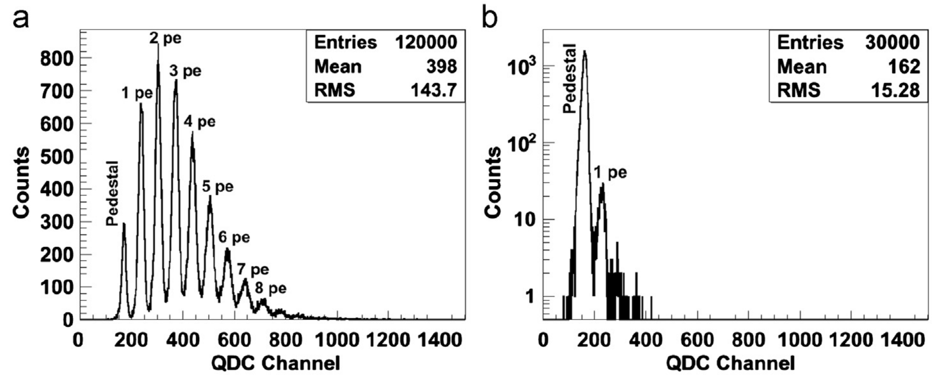

Fig. 6. Measurement histograms: (a) LED ON; (b) LED OFF.

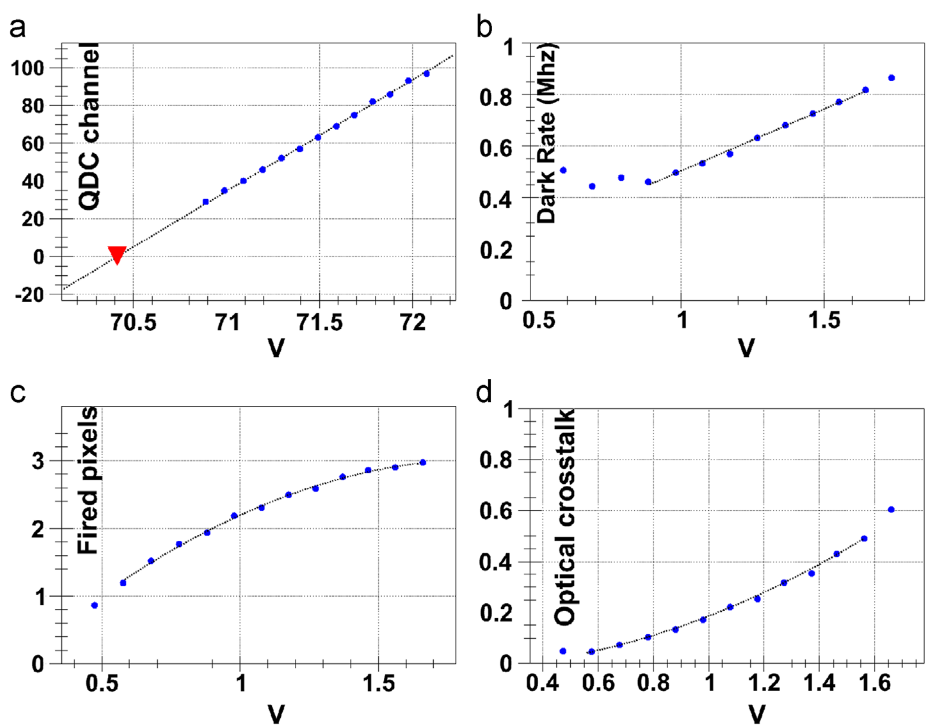

Fig. 7. Behavior as a function of bias voltage, in (b), (c) and (d) the *x*-axis represents voltage above breakdown. (a) Gain (triangle indicates breakdown voltage); (b) dark rate; (c) mean number of fired pixels; (d) optical crosstalk.

5. Analytical expressions

First, consider the optical crosstalk probability (the probability of firing a neighbor pixel given a fired pixel).

$$P(k)=\binom{N_n}{k}p_{xt}^k(1-p_{xt})^{N_n-k} \tag{1}$$

where N_n is the number of neighbor pixels for a given pixel, p_{xt} is optical crosstalk probability and $P(k)$ is the probability of having k neighbor pixels fired due to crosstalk. Considering neighbor pixels N_n and i, the number of pixels fired, this Binomial distribution can be approximated by a Poisson distribution.

$$P(k)=\frac{\lambda_{xt}^k e^{\lambda_{xt}}}{k!} \tag{2}$$

where $\lambda_{xt}=N_n i p_{xt}$.

Finally defining OC≔$N_n p_{xt}$, that is the mean number of fired pixels due to crosstalk given a fired pixel, and convolving Eq. (2) with the Poisson distribution from the probability of having fired pixels due to incident photons [3]; the following model which describes the probability of having N fired pixels is obtained.

$$P(N)=\sum_{k=0}^{n}\frac{\langle N\rangle^k e^{-\langle N\rangle}}{k!}\cdot\frac{(k\cdot OC)^{n-k}e^{-k\cdot OC}}{(n-k)!}. \tag{3}$$

From this model we extract the mean and the variance using the Probability Generating Function.

$$\mu=\langle N\rangle(1+OC) \tag{4}$$

$$\sigma^2=\langle N\rangle(1+3OC+OC^2). \tag{5}$$

Finally we extract OC and $\langle N\rangle$.

The gain and breakdown voltage is done using a the formula in Ref. [4]; in combination with Ref. [5]; and the dark rate is measured using the procedure described in Ref. [6];

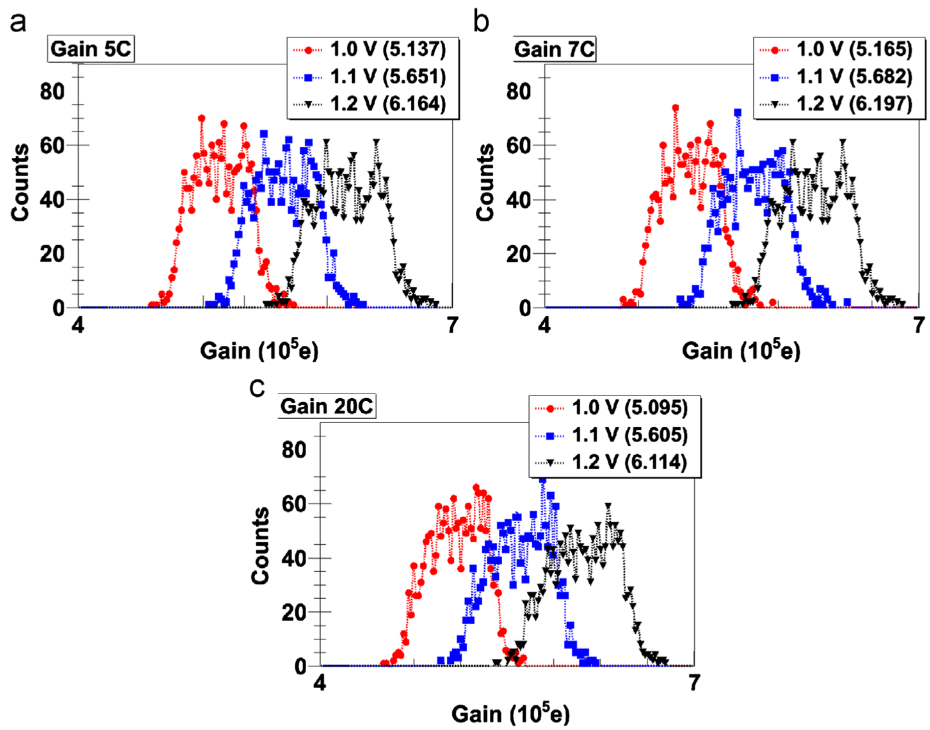

Fig. 8. Gain for 1700 MPPCs for three different voltages above breakdown, the mean of the histograms in parentheses. (a) 5 °C; (b) 7 °C; (c) 20 °C.

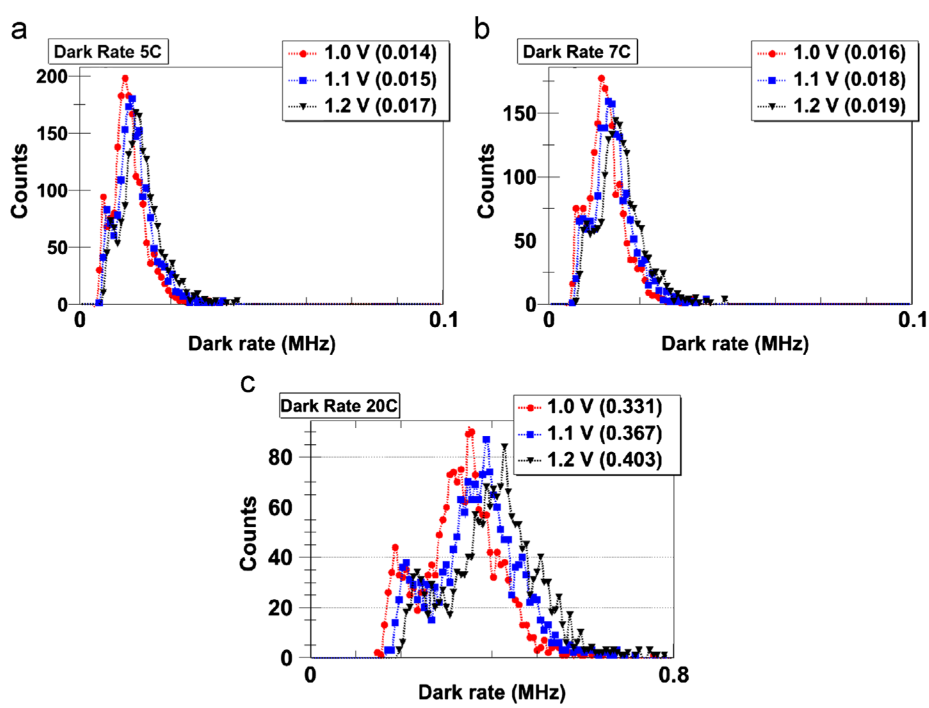

Fig. 9. Dark rate for 1700 MPPCs for three different voltages above breakdown, the mean of the histograms in parentheses. (a) 5 °C; (b) 7 °C; (c) 20 °C.

6. Measured observables

Figs. 8–10 show the results for each of the 16 MPPCs in each array for more than 1700 arrays at different temperatures and for three different voltages above breakdown. From these pictures the exponential behavior of dark rate and the uncorrelated behavior of gain and optical crosstalk can be extracted as a function of temperature.

Figs. 11–13 show a different MPPC array observable dependence on voltage above breakdown. From these pictures the linearity in gain and dark rate is demonstrated and the convergence of the optical crosstalk expression is exposed, from Eq. (2) the Poisson distribution approximation has bigger errors in the extremes (see Fig. 13). Worse gain measurement precision for voltages 1.5 above breakdown and higher result on bigger deviation in optical cross-talk estimations for some MPPC arrays (see Fig. 13(b)).

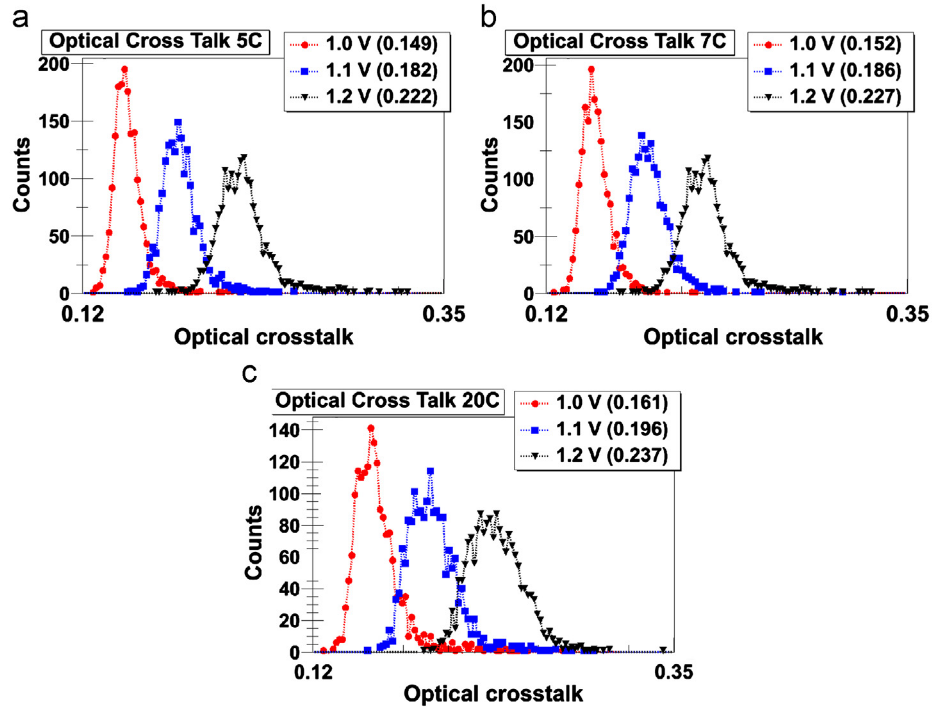

Fig. 10. Optical crosstalk for 1700 MPPCs for three different voltages above breakdown, the mean of the histograms in parentheses. (a) 5 °C; (b) 7 °C; (c) 20 °C.

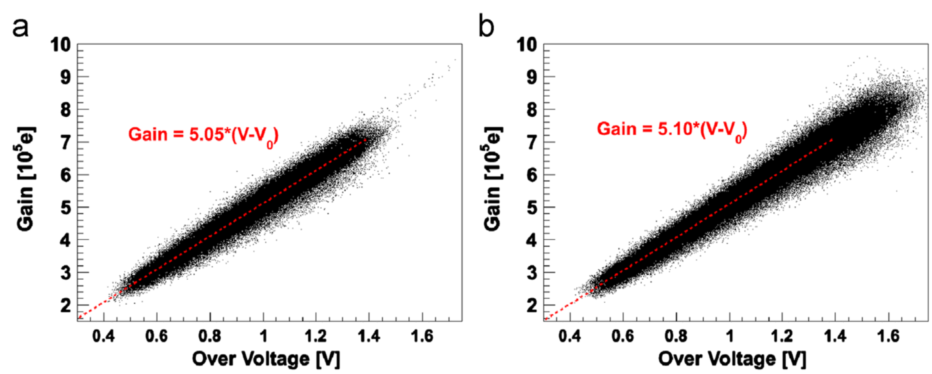

Fig. 11. Gain vs. voltage for 1700 MPPCs: (a) 5 °C; (b) 20,°C.

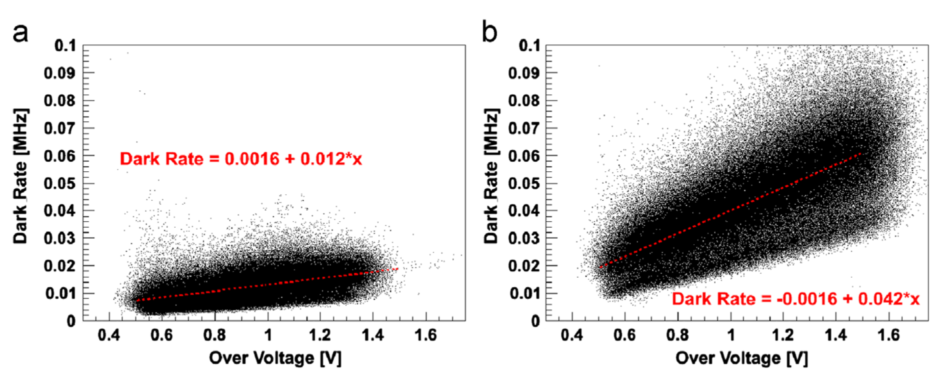

Fig. 12. Dark rate vs. voltage for 1700 MPPCs: (a) 5 °C; (b) 20 °C.

7. Conclusions

We have already tested about 1700 MPPC arrays. gain, breakdown voltage, PDE (Fig. 14), optical crosstalk and dark rate were measured for each MPPC in each array at 13 different voltages in the range of (0.5 V–1.7 V) over breakdown voltage for three temperatures 5 °C, 7 °C, 20 °C.

A model was developed and applied for calculations of optical crosstalk and mean number of fired pixels where a realistic photon statistic with optical crosstalk was taken into account.

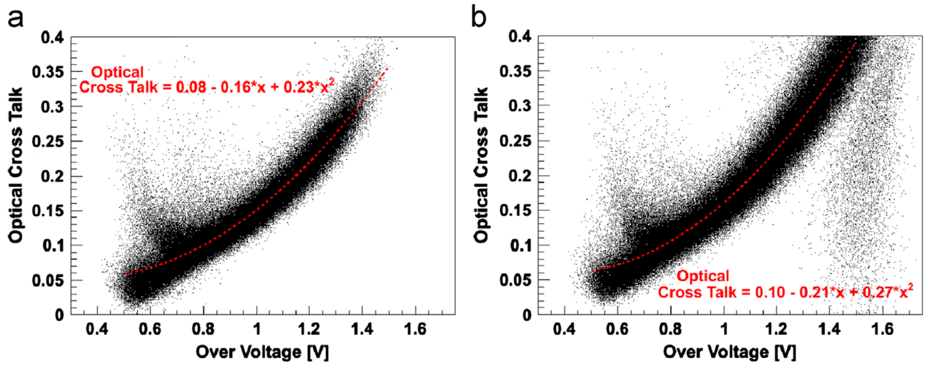

Fig. 13. Optical crosstalk vs. voltage for 1700 MPPCs: (a) 5 °C; (b) 20 °C.

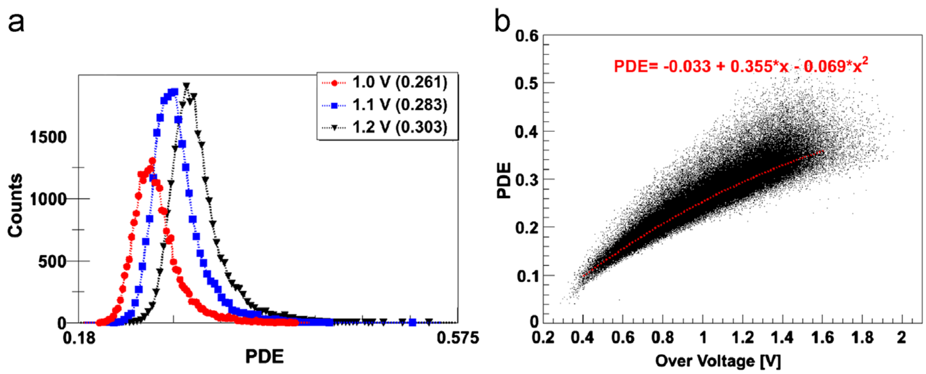

Fig. 14. PDE for 1700 MPPCs: (a) for three different over voltages; (b) vs. voltage.

Optimal operational voltage was found to be in the range of (0.9 V–1.2 V) above breakdown voltage.

Acknowledgments

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