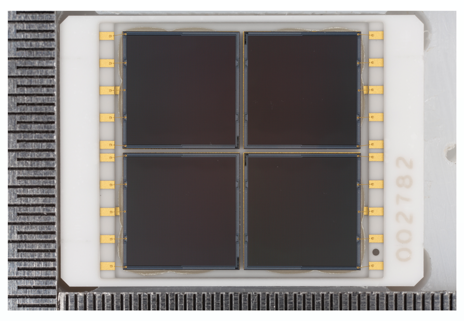

Characterization of Novel Hamamatsu Multi Pixel Photon Counter Array for GlueX Experiment at Jefferson Lab, Hall D

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Introduction

The novel Hamamatsu Multi Pixel Photon Counter Array S12045(X) is an array of 16 individual MPPCs (3x3 [mm^2]) each with 3600 G-APD (Geiger-mode Avalanche Photodiodes) pixels (50x50 [μ m^2]). Each MPPC in the array works with its individual reverse bias voltage around 70[V].

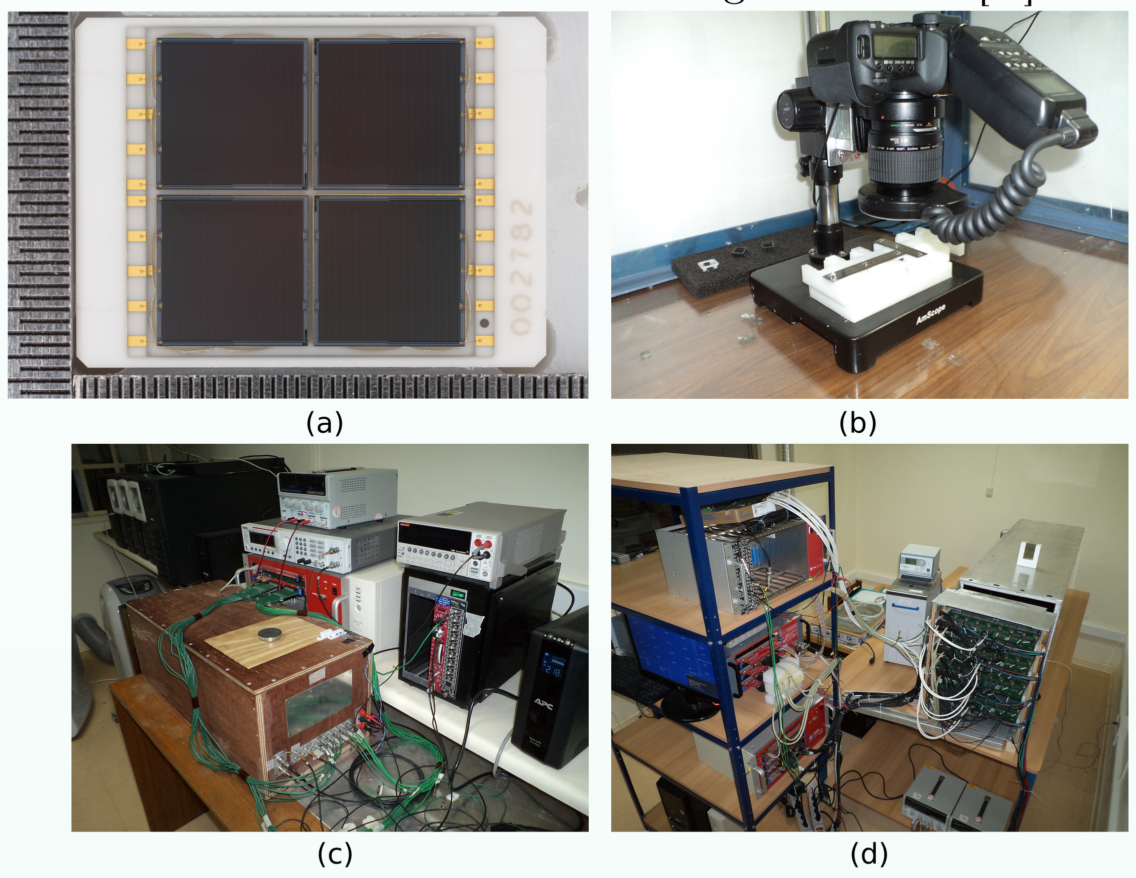
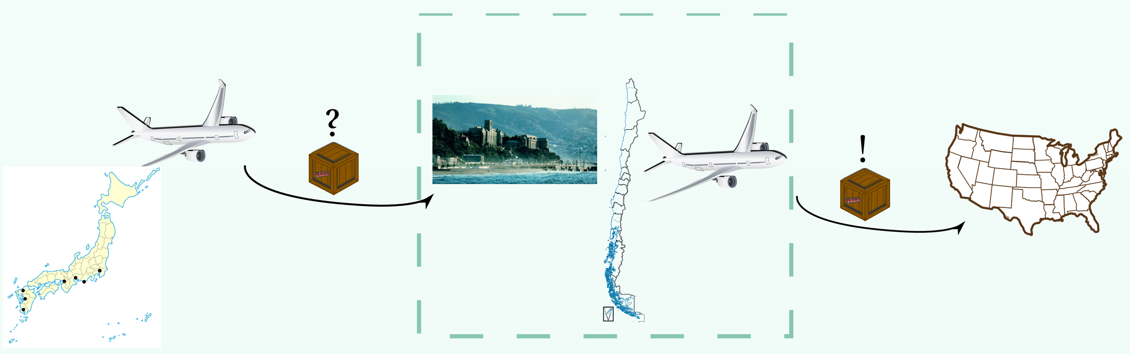


Figure 1: (a) MPPC array; (b) Station 1; (c) Station 2; (d) Station 3.

Hall-D/UTFSM Working Plan



UTFSM has committed to test 2800 MPPC arrays at 3 different temperatures. All MPPC arrays are bought from HAMAMATSU and after test shipped to JLab. The test includes the measurements of Gain, Breakdown Voltage, Photon Detection Efficiency (PDE), Optical Cross-talk and Dark rate for each single MPPC in array. To perform the test UTFSM group has built 3 special measurement stations and performed all required data analysis.

Measurement systems

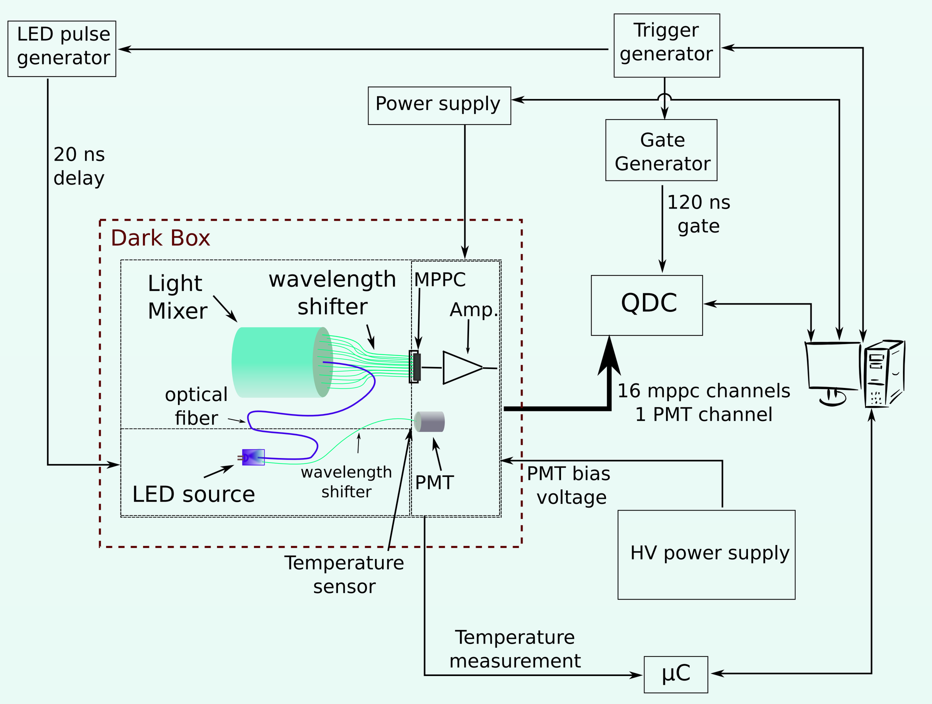


Figure 2: Station 2 for PDE measurement. Acquisition is done by a QDC with 100[fC] resolution and gate 120 [ns]. 1 MPPC array capacity. Room temperature measurement.

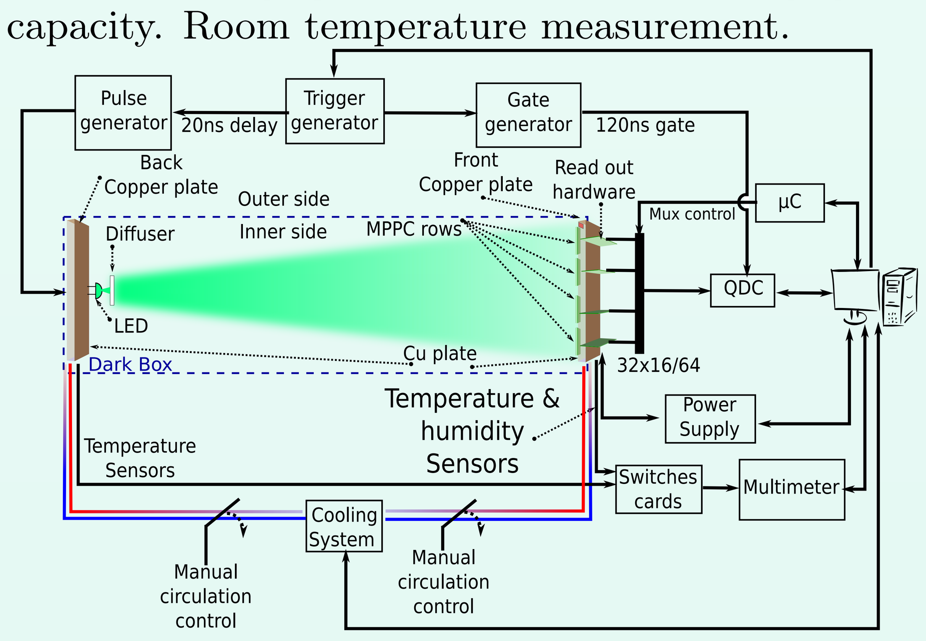


Figure 3: Station 3 for gain, breakdown voltage, optical cross-talk and dark rate measurements. Acquisition is done by a QDC with 100[fC] resolution and gate 120 [ns]. 32 MPPC arrays capacity. Temperature-controlled measurement.

References

[1] G. B. et al., "Limited geiger-mode microcell silicon photodiode: new results," *NIM A*, vol. 442, no. 1-3, pp. 187 – 192, 2000.

[2] D. Renker and E. Lorenz, "Advances in solid state photon detectors," *J. of Instrumentation*, vol. 4, no. 04, p. P04004, 2009.

[3] K. Y. et al., "Development of multi-pixel photon counter (mppc)," in *Nuclear Science Symposium Conference Record, 2006. IEEE*, vol. 2, 29 2006-Nov. 1 2006, pp. 1094 –1097.

[4] V. Golovin and V. Saveliev, "Novel type of avalanche photodetector with geiger mode operation," *NIM A*, vol. 518, pp. 560–564, 2004.

Methodology

For each MPPC in the array we measure the response (charge) under different conditions - LED switch on/off, 3 temperatures, 13 different bias voltages with 0.1 [V] step over breakdown voltage. An example plot from station 3 is shown below.

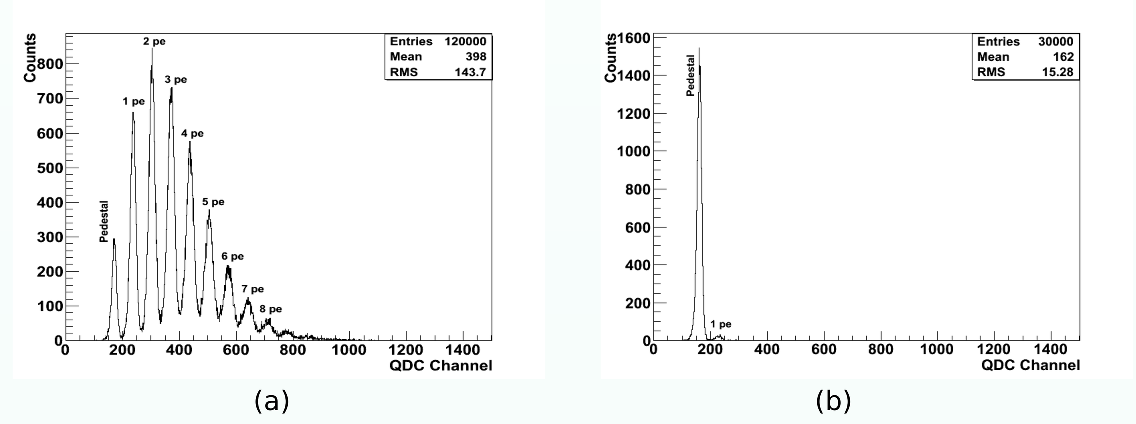


Figure 4: Measurement Sample: (a) LED ON; (b) LED OFF.

From these we extract gain, optical cross-talk, mean number of photo electrons and dark rate as a function of voltage, and the breakdown voltage.

Observables voltage dependence

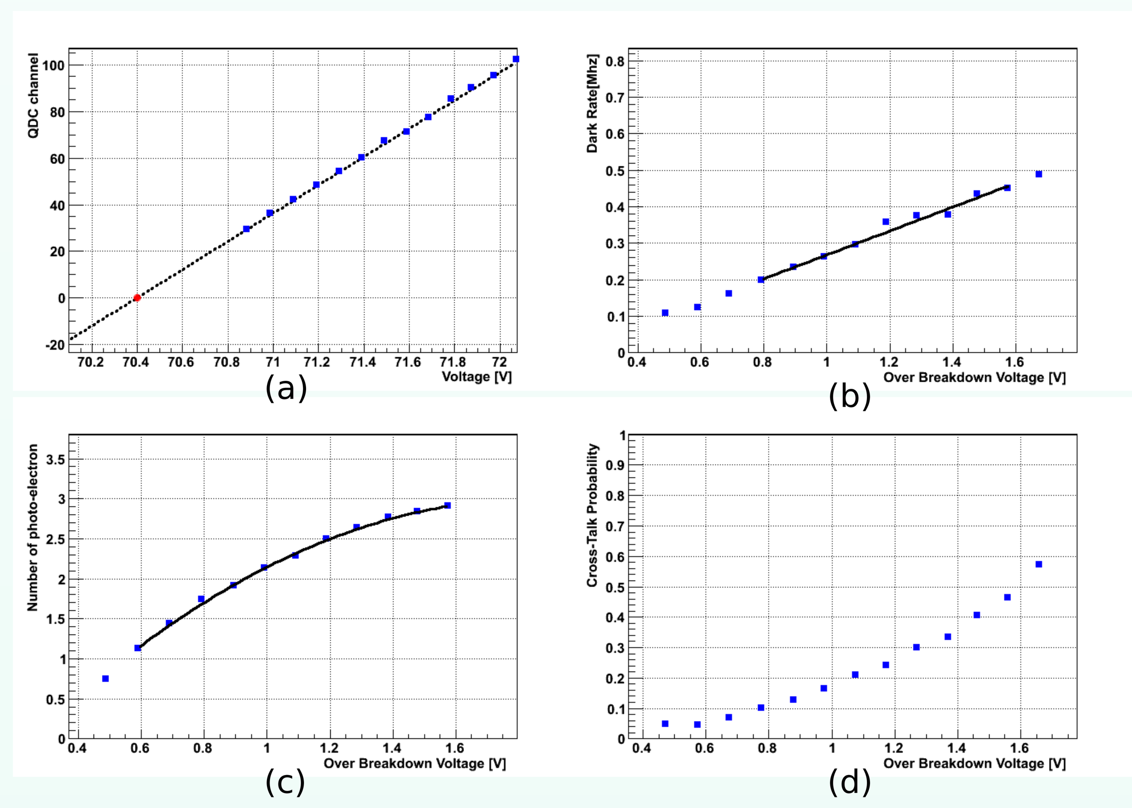


Figure 5: Behavior as a function of bias voltage: (a) gain, red dot indicates breakdown voltage; (b) dark rate; (c) mean number of fired pixels; (d) optical cross-talk probability.

Analytical expressions

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

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

Then, if we consider neighbor pixels N_n and i number of pixel fired we can approximate this Binomial distribution by a Poisson distribution

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

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

Finally if we define $OC := N_n p_{xt}$, that is the mean number of fired pixels due to cross talk given a fired pixel, and convolve (2) with the Poisson distribution from the probability of having fired pixels due to incident photons, we get the following model which describes the probability of having N fired pixels .

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

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

$$\mu = \langle N \rangle (1 + OC) \qquad (4)$$

$$\sigma^2 = \langle N \rangle (1 + 3OC + OC^2) \qquad (5)$$

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

Conclusions

- We have tested about 1700 MPPC arrays. Gain, breakdown voltage, PDE, optical cross talk, dark rate were measured for each MPPC in each array at 13 different voltages in the range of [0.5V - 1.7V] over breakdown voltage for three temperatures 5°C, 7°C, 20°C.
- A model was developed and applied for calculations of optical cross talk and mean number of fired pixels where a realistic photo statistic with optical cross talk was taken into account.
- Optimal operational voltage was found to be in the range of [0.9V - 1.2V] over breakdown voltage.

Measured Observables

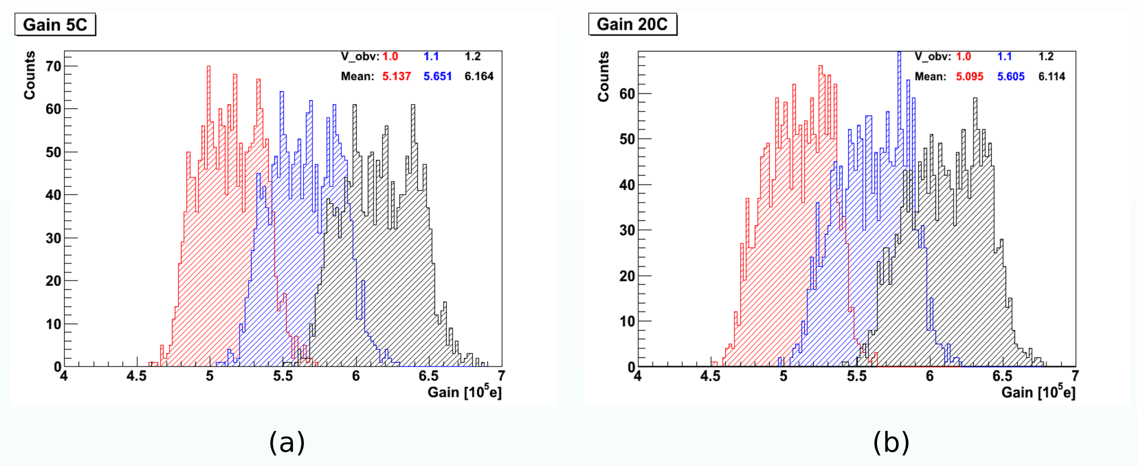


Figure 6: Gain for ∼ 1700 MPPC for three different over voltages: (a) 5°C; (b) 20°C.

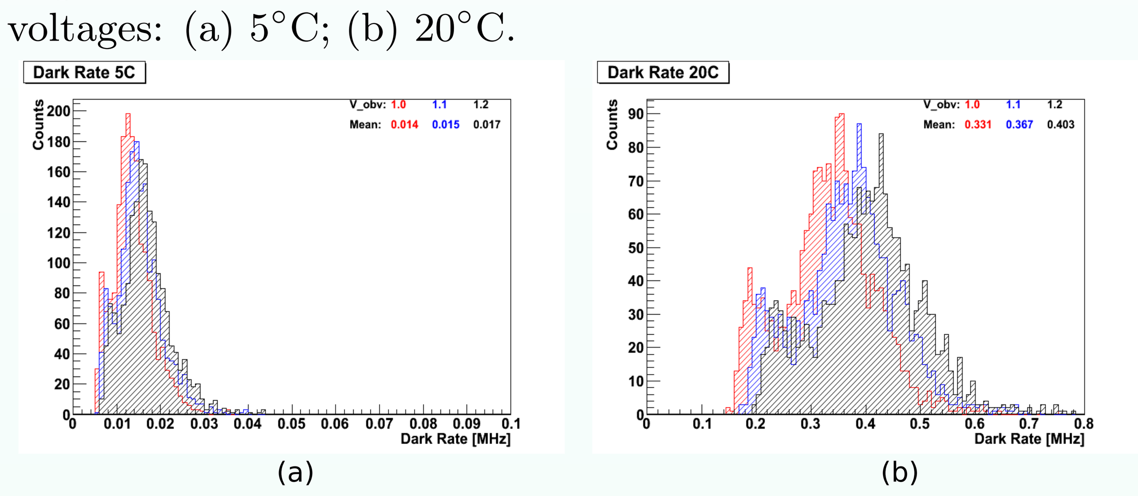


Figure 7: Dark rate for ∼ 1700 MPPC for three different over voltages: (a) 5°C; (b) 20°C.

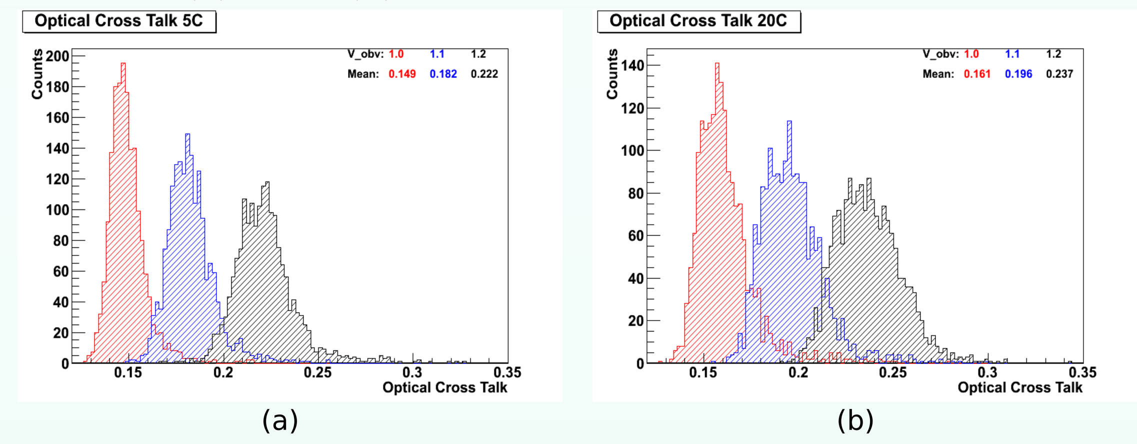


Figure 8: Optical cross talk for ∼ 1700 MPPC for three different over voltages: (a) 5°C; (b) 20°C.

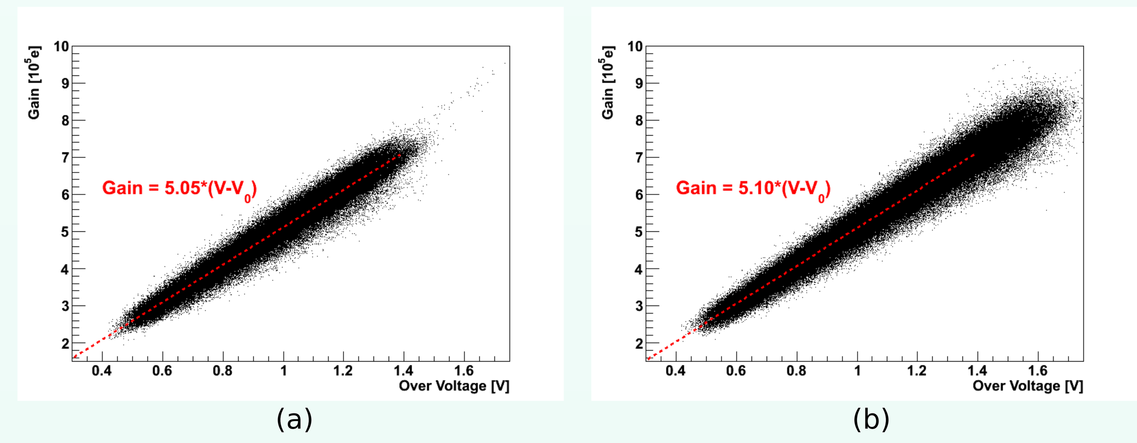


Figure 9: Gain vs. voltage for ∼ 1700 MPPC: (a) 5°C; (b) 20°C.

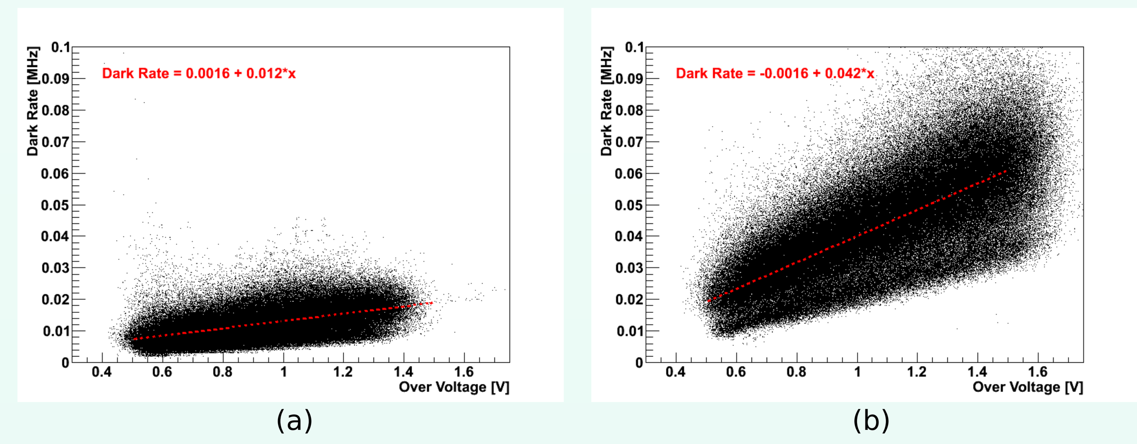


Figure 10: Dark rate vs. voltage for ∼ 1700 MPPC: (a) 5°C; (b) 20°C.

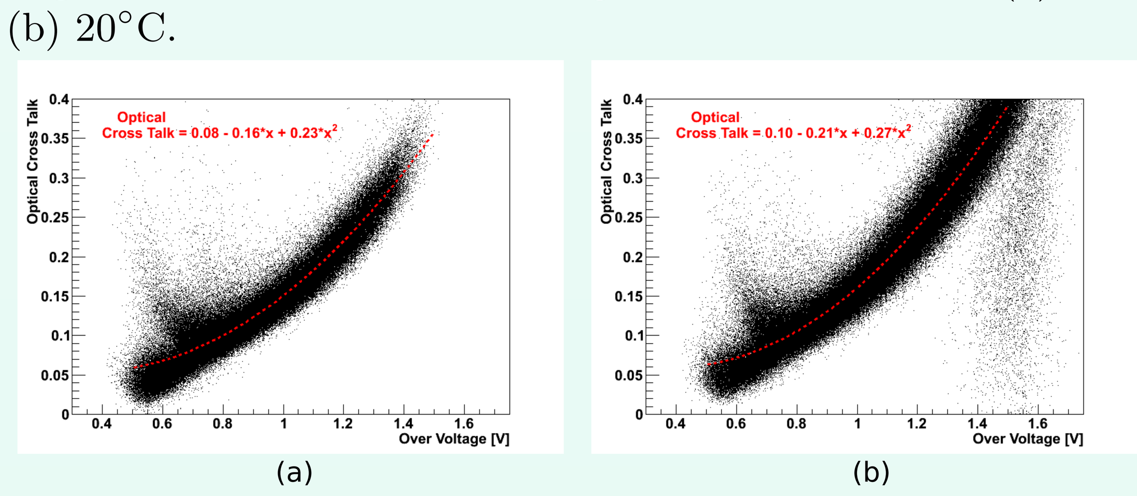


Figure 11: Optical cross talk vs. voltage for ∼ 1700 MPPC: (a) 5°C; (b) 20°C.

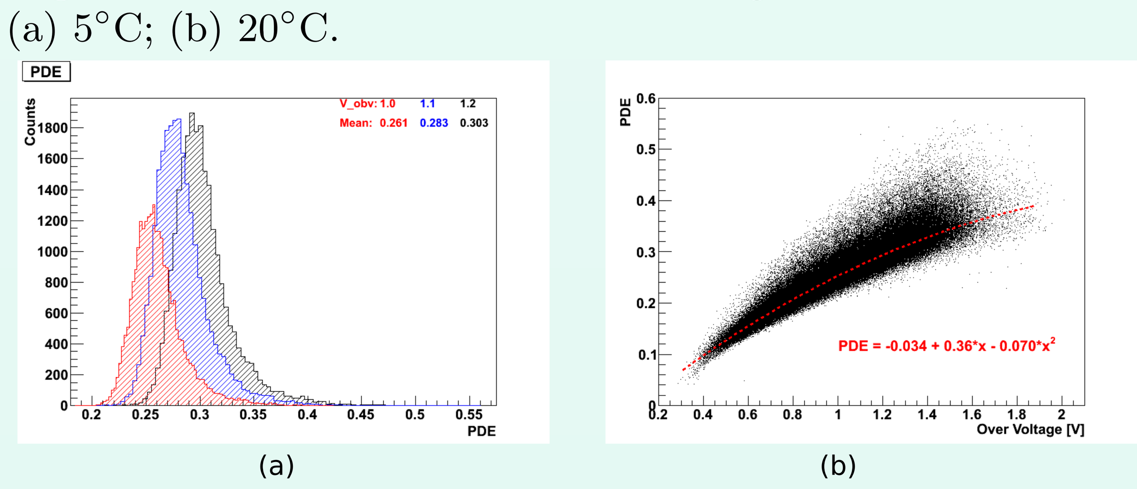


Figure 12: PDE for ∼ 1700 MPPC: (a) for three different over voltages; (b) vs. voltage.

The pictures above show the results for each of the 16 MPPC of the MPPC array for more than 1700 MPPC arrays.

Acknowledgment

We would like to thank the Jefferson Lab Hall-D team and especially Elton Smith and Yi Qiang.
This work was supported by the Chilean BASAL grant FB0821.