

Developing a Quantum Efficiency Measurement System for LAPPD's

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Abstract

Large area picosecond detectors can be developed and applied to detect photons in fields like science and medicine, allowing improvement in the speed and quality of photon detection. The development of the detectors includes the building a vacuum environment for assembly of the detector, use of the most optimal material in each part of the detector, and the ability to very precisely test the detector. This report describes quantum efficiency (QE) setup adjustments for testing the effectiveness of the photocathode in the detector, manifold maintenance, and the implementation of Node-Red onto the PSEC2 server in order enhance plotting and live data.

1 Introduction

Large-Area Picosecond Photodetectors (LAPPD's) are detectors developed to measure particles at picosecond timing resolution. Applications of the LAPPD include accelerator instrumentation, neutrino detection, and PET scans. Currently the PSEC group at UChicago works on developing LAPPDs. Some of the main tasks are developing a vacuum system for creating the photocathode and testing the quantum efficiency of the LAPPDs. Another task is determining the best materials and process for the development of the detectors.

2 Quantum Efficiency

One of the main purposes for having a solid quantum efficiency set-up for the LAPPD project is to be able to properly test (Quantum Efficiency) Q.E. once they're properly developed. Consequently, the need arises to have a system in place maximizes conditions for the best QE tests possible. QE is tested within a darkbox and surround with foam, in order to prevent external sources of light that could interfere with an acute measurement of light going through either a PMT LAPPD. Light completely debilitates the PMT at less than 600 or so photons per second. Quantum Efficiency itself is defined as a measure of the effectiveness of a photo-cathode, as a ratio.

$$\text{Quantum Efficiency} = \frac{\# \text{ of Electrons}}{\# \text{ of Photons}}$$

Photon energy is energy carried within a single photon, and is directly proportional to the photon's electromagnetic frequency, and inversely proportional to the wavelength. Photons at shorter wavelengths carry higher energy compared to those at longer lengths, and contribute to an increase in photoemission probability.

$$E = \frac{h * c}{\lambda}$$

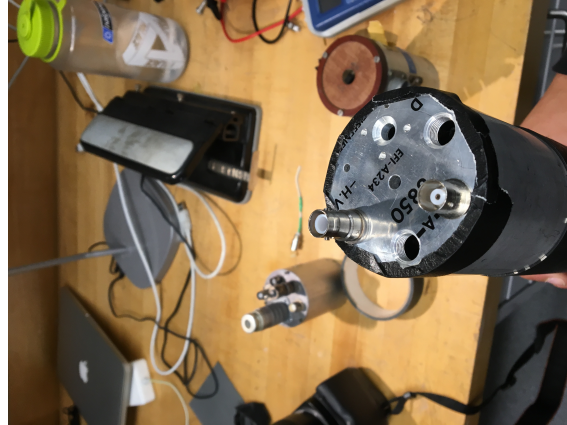
In the equation above, h = Planck's constant, c = speed of light, and λ = photon's wavelength

3 Photo Multiplier Tube

Within the PMT there exists a photocathode, which has negatively charged electrodes (electrical conductor used to make contact with nonmetallic part of a circuit) in a vacuum sealed tube. This

the primary emission, and those electrons from it get sent into secondary emission to gain acceleration. Additionally, there are dynode's which are additional electrode's (electrical conductor's) that serve as electron multiplier's through secondary emission. Each dynode is at a more positive potential, in a range of 50-100 Volts, than the preceding one. Finally, there's an anode that has negatively charged electrodes (electrical conductor used to make contact with nonmetallic part of a circuit) in a light detection device, and outputs electron current to outer device. Adjustments

Figure 1: PMT



needed to made on the PMT given, in order to complete the task list of

1. Get PMT operating with pulse on a scope
2. Tie all dynodes together and hook up current monitoring circuit
3. Calibrate a diode source
4. Take Q.E. measurements such as position dependence, voltage dependence, light flux dependence, and wavelength dependence

There are 20 connector pins on the PMT, each labeled. Pins 18 and 20 had to be shorted together and separate from the others, in order to connect to the anode piece to get readings from the picoammeter. Consequently, this process required some soldering and a reconstructed shield piece for both getting current readings to the picoammeter as well as sending voltage from the High Voltage machine to the PMT.

4 QE Tests

4.1 Light Intensity Test

The purpose of the dial intensity test was to measure the number of photons in as a function of the dial's intensity on the diode box.

1. Begin first by using the 405nm setting on the Picomatrix device, and setting up the HV machine to a level of 200V. Be sure to start with readings from the PMT.
2. Set the dial to 0, and record the the current coming out.
3. Record such values up until 800DI.
4. Properly turn off HV machine, and switch out the PMT in the darkbox with the intensity detector connected to the Thorlab Power Meter device.
5. Once again, record all values, until until around 800DI.

The purpose of this test is to evaluate the range intensities in order to see just how strong the intensity can be at a varying distance from the PMT.

Dial intensity	I (μ W) PM100A	I(Current)
0	.033	.999
50	.232	6.19
100	.417	14.931
150	.575	20.446
200	.726	23.721
250	.877	31.037
300	1.023	35.731
350	1.164	38.5
400	1.302	38.45
450	1.436	38.799
500	1.567	40.84
550	1.696	41.109
600	1.817	41.379
650	1.938	41.570
700	2.050	41.817
750	2.16	42.017
800	2.36	42.23

Figure 2: Dial Intensity Impact on PM100A Intensity
Dial Intensity Impact on PM100A Intensity

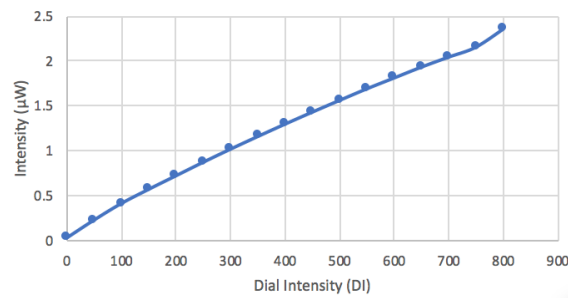
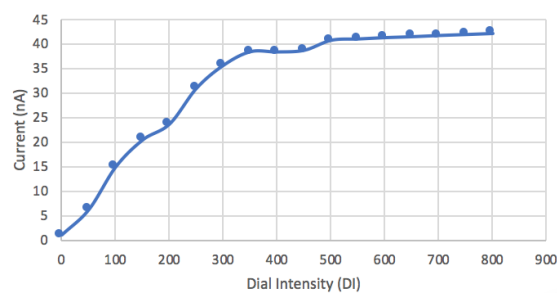


Figure 3: Dial Intensity Impact on Picoammeter Current
I (Current) V. Dial Intensity



4.2 Voltage Test

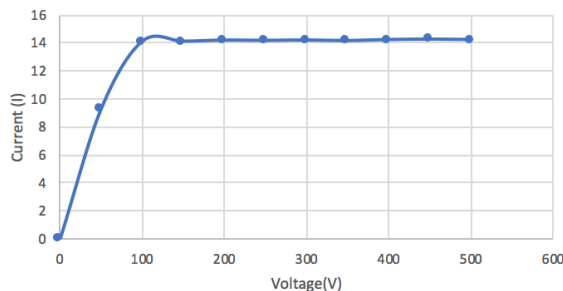
The purpose of the Voltage test was to see at what voltage does current become constant for a constant light flux

1. To begin, turn on HV machine properly by first switching on, then waiting for the standby to clear to begin to start up.
2. On the 405nm, set the DI to 100.
3. Start by having the switch for the Picomatrix off and record that value, then flip it on, wait ten seconds, and record that value.
4. Increase the voltage value by 50 and repeating this process, up until 500 volts.

Voltage	Current-off	Current-on	Current-final
0	.012	.079	.067
50	.110	9.430	9.32
100	.230	14.336	14.106
150	.320	14.420	14.1
200	.412	14.590	14.178
250	.497	14.661	14.164
300	.560	14.745	14.185
350	.651	14.803	14.152
400	.705	14.923	14.218
450	.803	15.050	14.247
500	.888	15.107	14.219

- After recording each value up to 100, subtract I-off from I-on values, in order to determine the current without the noise.

Figure 4: Voltage impact on Current
Voltage Impact on Current (I)



The graph above indicates that there is a necessary increase in voltage up to a certain point on all wavelengths, in order to achieve a consistent current output in proportion to voltage.

4.3 Wavelength Test

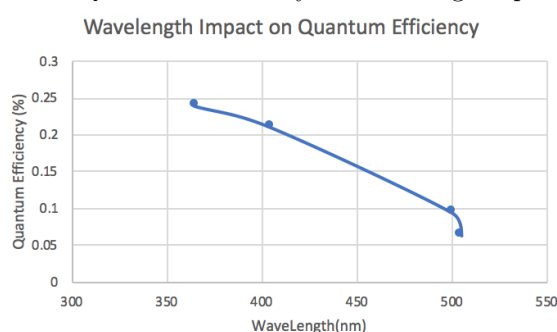
The purpose of the wavelength Test on the PMT is to get the QE measurement for the PMT which also requires the use of a intensity detector.

- position PMT in a manner such that it sits aligned with the laser
- SSH onto PI189 on PSEC2, then cd onto PicoAmmeter code, then finally run the continuous node red python code. This will start up the PicoAmmeter and have it adjusted to the proper settings, allowing for data readings of currents.
- Turn on powerbox for PicoMatrix Laser Box and connect specialized plastic fiber-optic cable, which then connects to a series of three $\text{\O}50 \mu\text{m}$, 0.22 NA, SMA-SMA Fiber Patch Cable, Low OH, 1 Meter cords that emit the frequency from the box onto the PMT.
- Turn on HV (High Voltage) machine properly and then adjust gradually by increments of 100 to 200V.
- Begin with the laser coming from the 365nm port, and set dial to 50DI. All ports dial settings should be 50DI.
- On the port stations there is a switch on the machine to turn the light on and off. Start with the light off, turn it on, wait ten seconds, then turn it off again and record the value at that moment. The reason for this is to allow for the fluctuation within the current reading to dissipate.
- Continue this procedure for the light frequencies of 405nm, 500nm, and 535nm.

Wavelength	Voltage	Power
305nm	5.0826nA	.072 μ W
405nm	9.4376nA	.137 μ W
500nm	5.4565nA	.143 μ W
535nm	1.291nA	.047 μ W

8. After recording all values, turn off HV machine gradually, and then switch out PMT with sensor connected to Thor Labs intensity reading device, PM100A
9. Measure all wavelength values again at 50DI, recording data from all four values
10. Once all values are recorded, calculate the Q.E. for each wavelength.

Figure 5: Quantum Efficiency V. Wavelength Spectrum



The reason why the Q.E. goes down for higher wavelengths is because those wavelengths have less power, which corresponds to less Q.E. This occurs because electrons lose the ability to travel through the photocathode medium, due to less energy. Consequentially, they lose their direction and fall off into the material.

4.4 Current Map Test

Finally, I designed a process of test Q.E. at different points on the PMT, in order to map out its characteristics. The purpose of this is to have a better understanding of the Q.E. spread on the PMT, and to refine the system in which Q.E. is measured for LAPPD testing.

1. Begin by measure the surface of the PMT's window, which turned out to have a radius of 2.4cm².
2. Using a connection piece directly attached to the wavelength transmitter, position the specialized plastic fiber-optic cable directly in the middle of the PMT, and touching against it so that the light is concentrated directly at the center.
3. Properly run picoammeter code, turn on HV machine, and turn on Picomatrix device.
4. Set the HV to 200V, the dial intensity to 100, and the wavelength to 405nm.
5. Flip switch on for 405 wavelength, and wait ten seconds before logging in order to get rid of potential noise affects.
6. Move fiber-optic cable around the screen of PMT, recording the position and current for all values.
7. Attempt to collect at least 15 values from all around the PMT surface.
8. Calculate the QE for each position by finding the current specific to each light intensity.

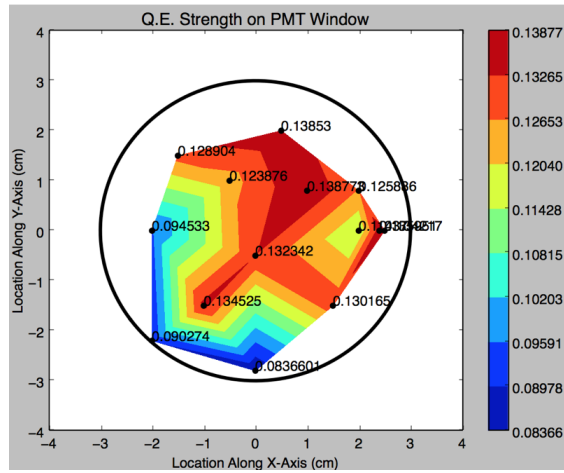
$$nE = \frac{\text{Current}}{e^-}$$

$$nP = \frac{P * \lambda}{h * c}$$

$$Q.E. = \frac{nE}{nP}$$

- Once points have corresponding Q.E. values, create a "heatmap" indicating the strength of the Q.E. based off of the location of selected point on the window.

Figure 6: PMT HeatMap



5 Q.E. Improvement Techniques

Margherita 2 is a vacuum chamber and system for cesiation and testing of the quantum efficiency of the LAPPD. The current QE setup in the Margherita involves a fiber optics cable that moves around and flashes light at desired wavelengths and at specific points of the LAPPD. Implementing differential connections using Ethernet cables is one technique used to elimination of noise. A differential signal is obtained from the difference in voltage between two wires, as opposed to the voltage of a wire relative to fixed ground. One wire has a positive current I , the other wire will have the negative current $-I$, so that the net current between the two is always 0, even if a changing signal is being emitted. An advantage of differential signaling is that noise affecting both wires equally does not change the relative voltage, and so the signal is unaffected (Gazda, 2017). Additional ways of improvement are

- Using linear power supplies instead of switch mode powers supplies
- Measuring the power output of the LED at the end of the fiber with a diode to consistently calibrate the photon output during measurement.
- Using stationary micro-fiber cables

5.1 Purpose of Q.E. System Development

The purpose of getting precise readings and having a quality Q.E. system is so that once an LAPPD is built, there's a proper system in place to check that the detector is operating as it should. By developing the "heatmap" code, there's a system in place to check all pieces of the detector and hopefully be a useful tool.

6 Acknowledgements

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