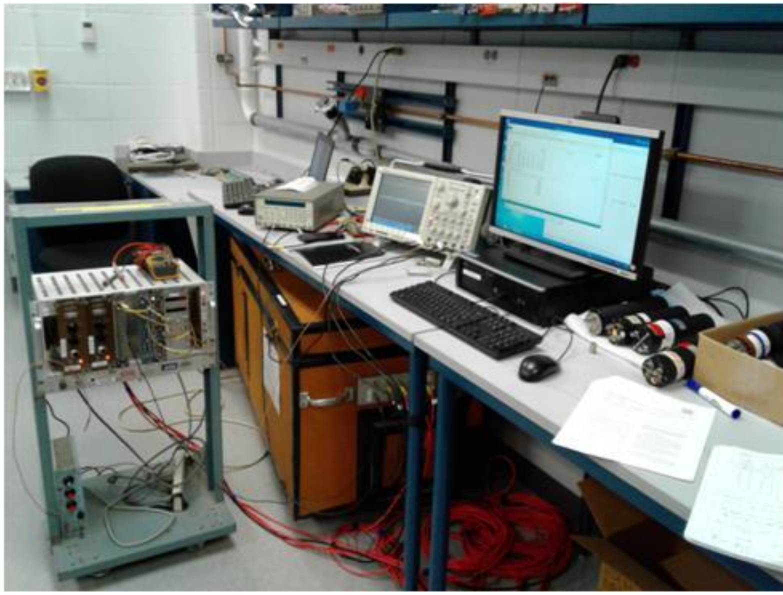
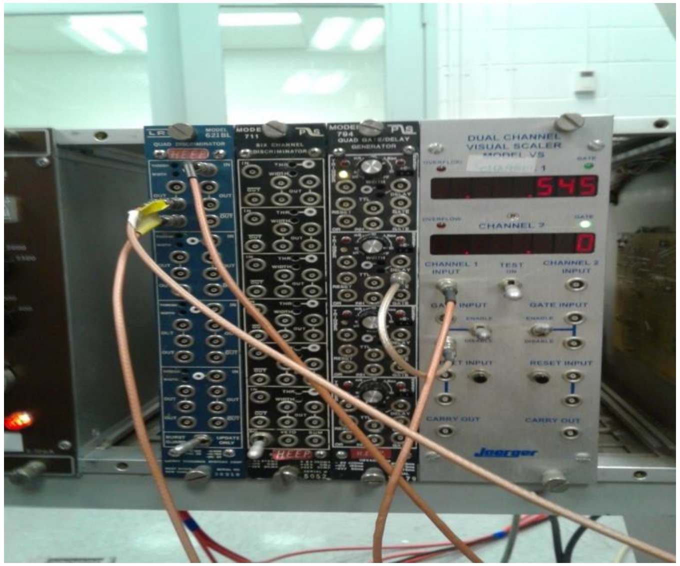
Building a photomultiplier tube testing lab and measuring dark rate

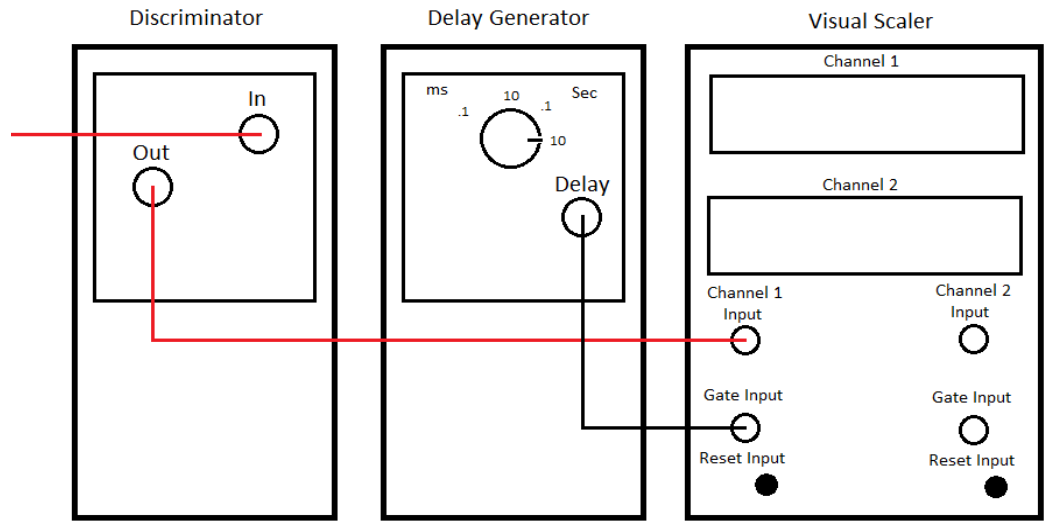
Suffolk County Community College
and Brookhaven National Lab



Lab Setup

- Dark box set up to hold four Photomultiplier tubes simultaneously and output signals
- Three step data collection
  1. Discriminator
  2. Delay Generator
  3. Visual Scalar
- Labview collects and files data and Oscilloscope shows signal outputs from PMTs



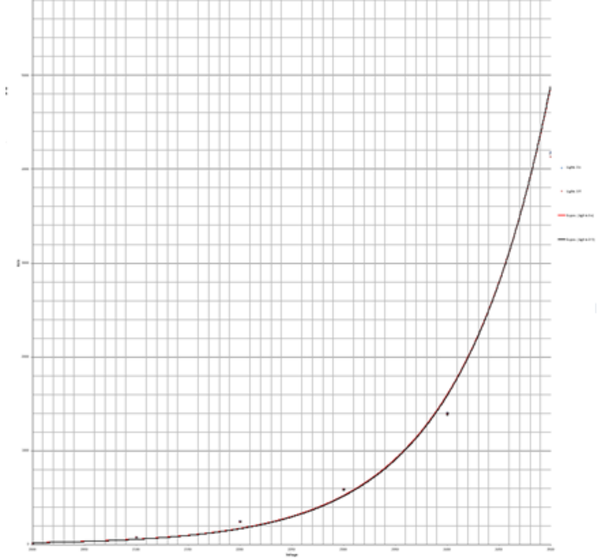


Wiring

Discriminator: The PMTs constantly output a signal (Dark current) regardless of whether or not it detected a photon. The discriminator sets a voltage that has to be exceeded for the signal to pass through.

Delay Generator: The delay generator receives the input from the discriminator and outputs to the visual scalar. When active, the delay generator allows the signal to pass through, but only for a set period of time.

Visual Scalar: The visual scalar receives the output from the delay generator and outputs the number of signals it receives.



	Lights On Channel 3											
Voltage	2000.00		2100.00		2200.00		2300.00		2400.00		2500.00	
Trial	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate
1	155.00	12.92	852.00	71.00	2968.00	247.33	7140.00	595.00	16352.00	1362.67	49998.00	4166.50
2	134.00	11.17	872.00	72.67	2893.00	241.08	7048.00	587.33	16666.00	1388.83	50143.00	4178.58
3	146.00	12.17	918.00	76.50	2902.00	241.83	6894.00	574.50	16440.00	1370.00	50757.00	4229.75
4	113.00	9.42	922.00	76.83	2857.00	238.08	7015.00	584.58	17048.00	1420.67	49908.00	4159.00
5	134.00	11.17	884.00	73.67	2910.00	242.50	6996.00	583.00	16743.00	1395.25	49817.00	4151.42
6	140.00	11.67	917.00	76.42	2871.00	239.25	7092.00	591.00	17128.00	1427.33	49708.00	4142.33
Average	137.00	11.42	894.17	74.51	2900.17	241.68	7030.83	585.90	16729.00	1394.13	50055.17	4171.26
Errorr	8.57	0.71	14.29	1.19	22.66	1.89	50.21	4.18	158.40	13.20	214.13	17.84

	Lights Off Channel 3											
Voltage	2000.00		2100.00		2200.00		2300.00		2400.00		2500.00	
Trial	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate
1	126.00	10.50	913.00	76.08	2813.00	234.42	6834.00	569.50	16655.00	1387.92	49666.00	4138.83
2	126.00	10.50	921.00	76.75	3013.00	251.08	6923.00	576.92	16944.00	1412.00	49944.00	4162.00
3	152.00	12.67	870.00	72.50	2854.00	237.83	6982.00	581.83	16369.00	1364.08	49260.00	4105.00
4	126.00	10.50	859.00	71.58	2773.00	231.08	7038.00	586.50	16638.00	1386.50	49585.00	4132.08
5	144.00	12.00	877.00	73.08	2848.00	237.33	7035.00	586.25	16612.00	1384.33	49510.00	4125.83
6	106.00	8.83	840.00	70.00	2872.00	239.33	7160.00	596.67	16914.00	1409.50	49468.00	4122.33
Average	130.00	10.83	880.00	73.33	2862.17	238.51	6995.33	582.94	16688.67	1390.72	49572.17	4131.01
Error	9.39	0.78	16.53	1.38	48.99	4.08	66.54	5.55	117.37	9.78	139.62	11.64

Dark Box "light tight" testing

- The first problem we encountered with the dark box was there was there was a measureable difference in counts when testing with the lights on vs. the lights off. This meant that the box wasn't completely sealed
- We taped any visible weaknesses in the box and added a layer of foam tape between the box and the lid
- We tested the modified box at several different voltages with the lights both on and off and the differences were negligible
- The data is plotted above, the red line represents the data collected with the lights on and the **black** line represents the data with the lights off

	Lights On											
	Channel 3											
Voltage	2000.00		2100.00		2200.00		2300.00		2400.00		2500.00	
Trial	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate
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	Lights Off											
	Channel 3											
Voltage	2000.00		2100.00		2200.00		2300.00		2400.00		2500.00	
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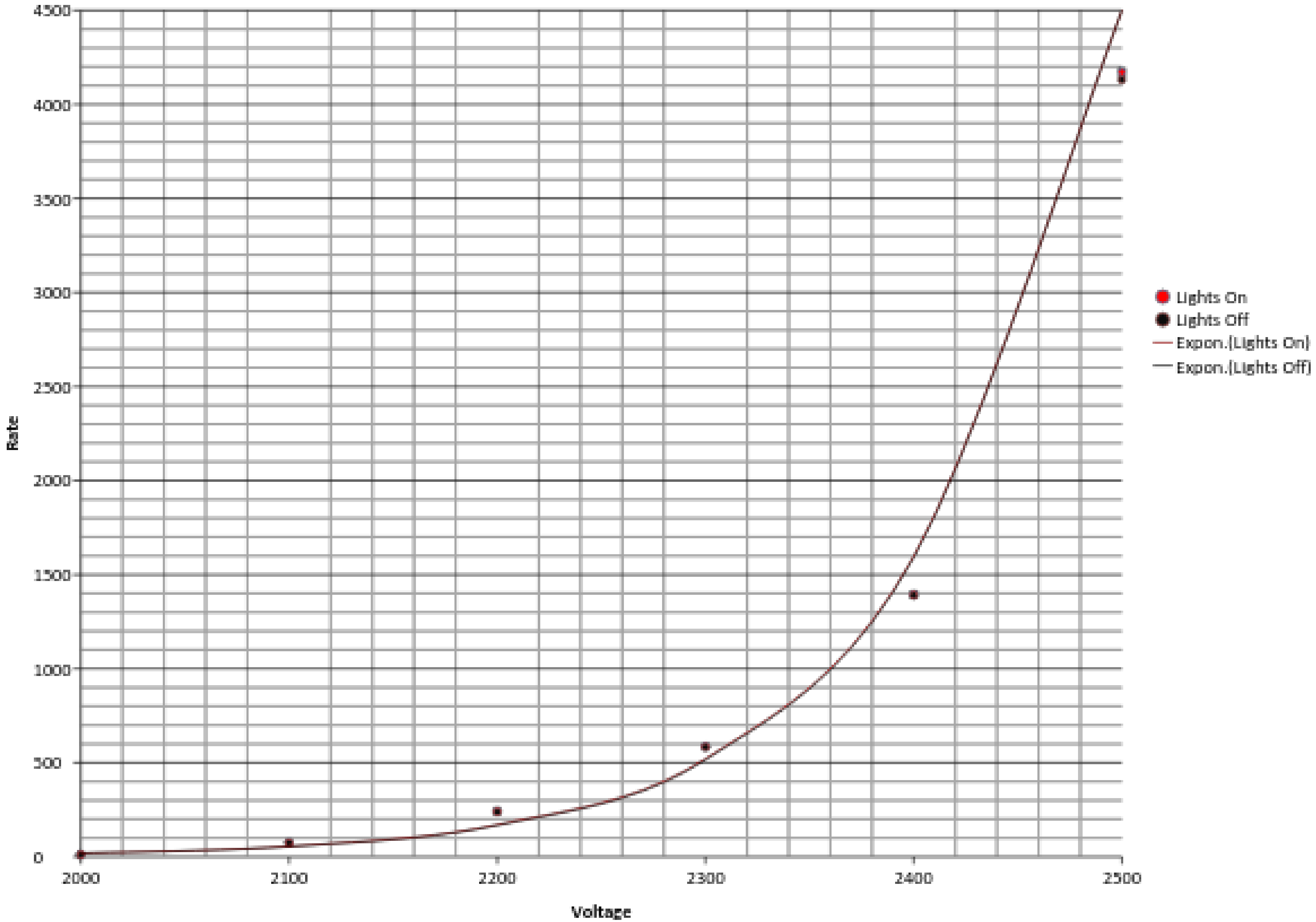


4500
4000
3500
3000
2500
2000
1500
1000
500
0
Rate
2000
2100
2200
2300
2400
2500
Voltage
Lights On
Lights Off
Expon.(Lights On)
Expon.(Lights Off)

Dark Current

- PMTs constantly output a very low signal whether or not the have detected a photon. This is called the Dark current.
- When analyzing data collected by the tubes, the dark rate has to be accounted for.

N_γ	Number of photons incident on photocathode
N_{pe}	Number of photoelectrons emitted by photocathode
$QE = N_{pe}/N_\gamma$	Quantum efficiency of PMT
N_e	Number of electrons emitted by anode
$g = N_e/N_{pe}$	Gain of PMT
$e = 1.6x10^{-19}$C electron charge	
$Q =$	Charge emitted by anode
$I =$	Photocurrent emitted by anode
I_D	Dark Current emitted by anode

Signal over noise: minimum light detection and PMT dark current

The minimum amount of light detectable by a PMT is determined by its dark current, gain, and quantum efficiency; in order for the PMT anode output to be above its dark current :

$$I = \frac{\Delta Q}{\Delta t} = \frac{N_e e}{\Delta t} = \frac{N_{pe} g e}{\Delta t} = \frac{N_\gamma QE g e}{\Delta t} > I_D,$$

thus:

$$\frac{N_\gamma}{\Delta t} > \frac{I_D}{QEge} \;;$$

for energy per photon at a given wavelength, the incident light power on the photocathode should be:

$$P = \frac{N_\gamma}{\Delta t}\frac{hc}{\lambda} > \frac{I_D}{QEge}\frac{hc}{\lambda};$$

for violet light at $\lambda = 420$ nm, and a PMT with $I_D = 100$ nA, $QE = 0.2$, $g = 2.5x10^6$, the incident light power required for detection is:

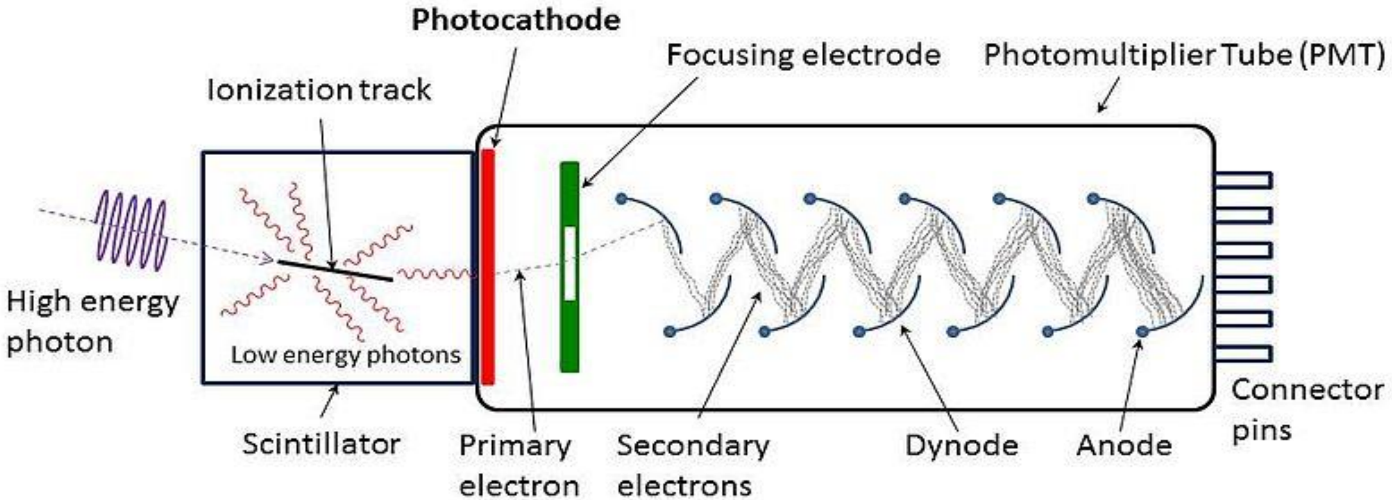
$$P_{\text{required}} > \frac{100\text{x}10^{-9}\text{A}}{0.2\,(2.5x10^6)(1.6x10^{-19}\text{C})}\frac{(6.6x10^{-34}\ \text{m}^2\text{kg/s})2.99x10^8\ \text{m/s}}{420\ \text{x}10^{-9}\text{m}}$$

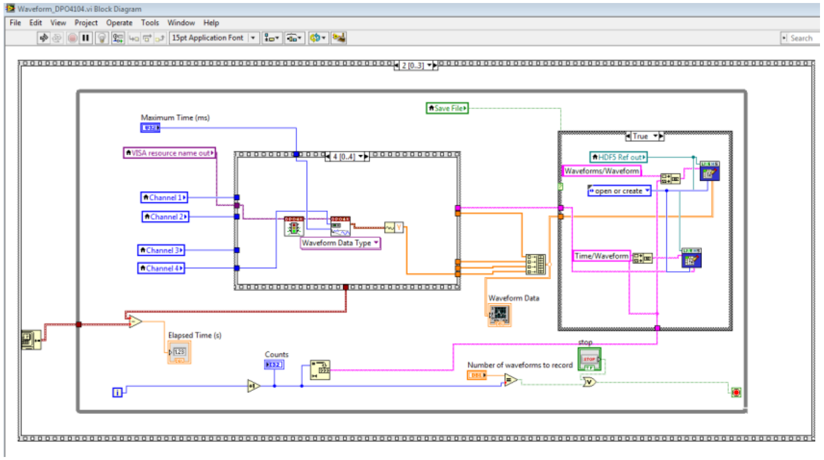
Generating the Signal and measuring gain

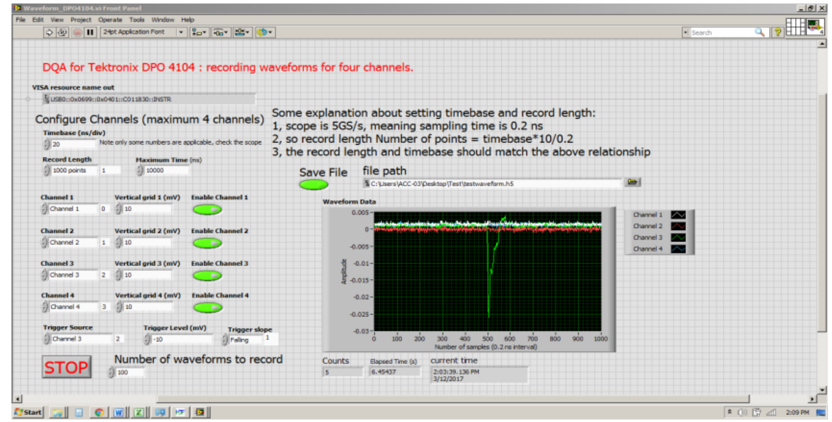
- The PMTs are to be tested by flashing a very dim LED light in the dark box with them.
- The LED is activated using the lowest possible voltage to emit the smallest number of photons possible.
- The light flashes very quickly (at roughly 10 Hz) and remains lit for only 11ns at a time.
- Using LabVIEW, we will measure data over the course of 20,000 pulses and use this data to calculate the gain of the PMTs.
- The gain of each PMT is the number of electrons that are emitted for the detection of a single photon.

Quantum Efficiency

- The Quantum Efficiency is the likelihood of a photon having enough energy to trigger a signal output
- PMT sensitivity is measured in Amps per Watt (A/W), which is the measure of current output per Watt of light that impacts the photocathode







Lab view block diagram

- This labview program controls the oscilloscope and records data
- The output from the PMTs is split between the Discriminator and an oscilloscope. The oscilloscope displays the output signal from the PMTs making it easy to distinguish (visually) between the dark current output and a photon detection. A spike on the oscilloscope means that a photon has been detected and the height of the spike is directly proportional to the energy of the photon.