Group C Report

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Outline:

Main:

1. PMT noise rate, rising and falling time.

1.1. Set up:

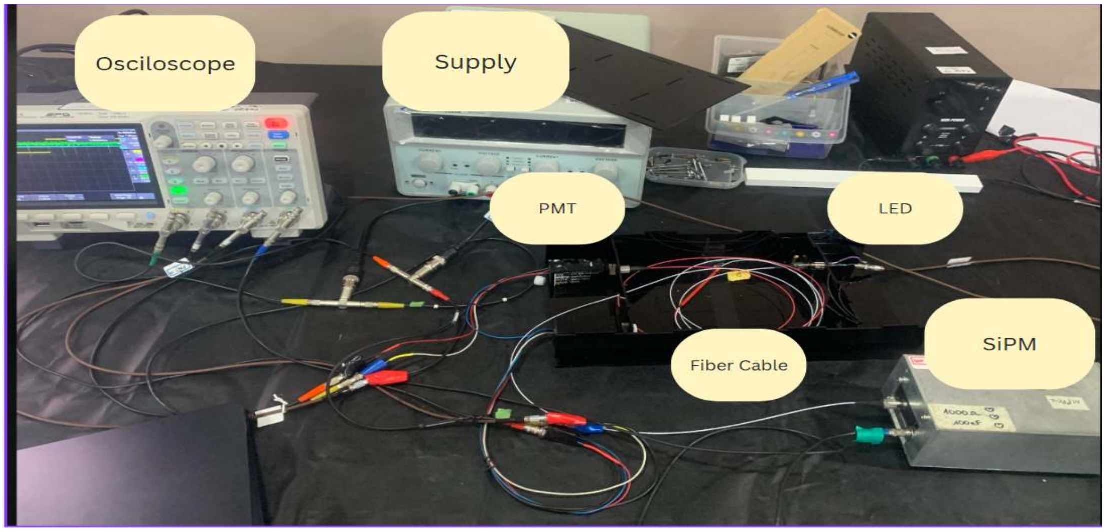


Fig 1: Setup for Rising falling time, sensitivity, and Dynamic Range

- We measure the PMT noise rate without LED at two levels of trigger: -0.9mV and -1mV with DC power supply. We measured the PMT noise rate two times.

1.2 Result

+ With DC power supply off, at -0.9mV trigger, we have the PMT noise rate:

+ Following the data in this capture, we have mean frequency: 717Hz with standard deviation 2493Hz, it means that the uncertainty of this measurement is high. So, the noise rate in this case is high.

COUNTER	Frequency
Value	320.746Hz
Mean	717.751Hz
Min	9.05277Hz
Max	17.5850kHz
Stdev	2.49300kHz
Count	49

Fig 2: PMT noise rate at -0.9mV with DC power supply off

+ With DC power supply on, at -0.9mV trigger, we have the PMT noise rate:

COUNTER	Frequency
Value	40.7023kHz
Mean	9.49996kHz
Min	112.437Hz
Max	51.3707kHz
Stdev	12.9156kHz
Count	32

Fig 3: PMT noise rate at -0.9mV with DC power supply on

+ Following the data in this capture, we have mean frequency: 9.5kHz with standard deviation 13kHz, it means that the uncertainty of this measurement is high. So, the noise rate in this case is still high.

+ With DC power supply on, at -1mV trigger, we have the result of the PMT noise rate:

COUNTER	Frequency
Value	87.6726Hz
Mean	75.0878Hz
Min	24.4631Hz
Max	255.443Hz
Stdev	46.0779Hz
Count	26

Fig 4: PMT noise rate at -1mV with DC power supply on

+ When we change the trigger to -1mV, the values of measurement look better than before with mean frequency: 75Hz and Standard deviation: 46Hz. So, in this case the rate noise is lower than before.

+ After that, we measured the noise rate with trigger level at -1.1mV with DC power supply on and off, and the results are same with the case at trigger level at -0.9mV.

- We measure the noise rate of MPPC at different threshold (0.5 PE, 1.5 PE, 2.5 PE) with different operation voltage (56V, 57V, 58V)

+ Step 1: We have value of Y1, Y2 and $\Delta Y = Y2 - Y1$. Gap value between Y1 and Y2 is a photoelectron (PE).

+ Step 2: We calculate the value of threshold that we need to measure the noise rate of MPPC:

$$0.5\,PE = Y1 + \frac{Y2}{2};\ 1.5\,PE = Y1 + \frac{3Y2}{2};\ 2.5\,PE = Y1 + \frac{5Y2}{2}$$

	V = 56.07 Voltage	V = 57.06 Voltage	V = 58.05 voltage
0.5 PE	23.9 ± 6 kHz	56 ± 4 kHz	71 ± 6 kHz
1.5 PE	537 ± 256 Hz	796 ± 232 kHz	1.1 ± 0.15 kHz
2.5 PE	No signal	30 ± 60 Hz	15 ± 6 Hz

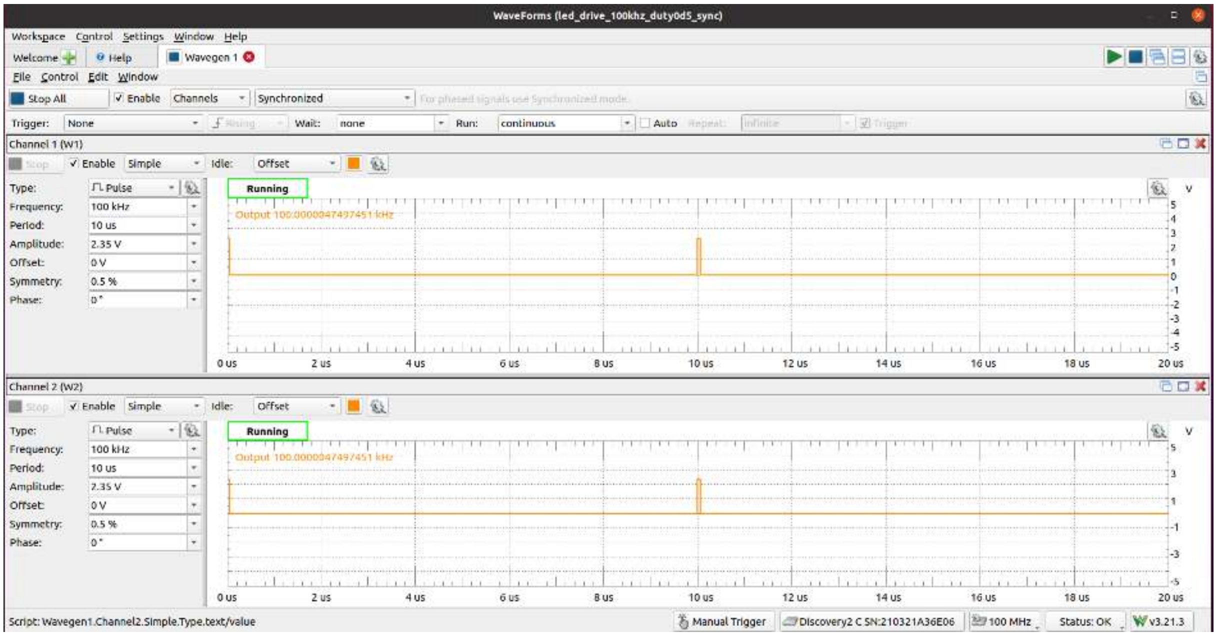
+ Following the data in table above, with threshold at 2.5 PE the signal is unstable, we can't get signal with V = 56.07 Voltage.

+ And with each voltage level, at threshold level = 0.5 PE we have the signal with low standard deviation (minimum is about 7.1% and maximum is about 25%).

+ So, we can conclude that the case with 57.06 voltage and 0.5 PE threshold level give us a good MPPC noise rate.

2. Rising falling time:

2.1. Set up



WaveForms (led_drive_100khz_duty0d5_sync)

Stop All ☑ Enable Channels Synchronized

Trigger: None Wait: none Run: continuous

Channel 1 (W1)

☑ Enable Simple Idle: Offset

Type: Pulse
Frequency: 100 kHz
Period: 10 us
Amplitude: 2.35 V
Offset: 0 V
Symmetry: 0.5 %
Phase: 0 °

Running

Output 100.0000047497451 kHz

Channel 2 (W2)

☑ Enable Simple Idle: Offset

Type: Pulse
Frequency: 100 kHz
Period: 10 us
Amplitude: 2.35 V
Offset: 0 V
Symmetry: 0.5 %
Phase: 0 °

Running

Output 100.0000047497451 kHz

Script: Wavegen1.Channel2.Simple.Type.text/value

Fig 5: Input signal set up

+ For 2 channels of device system, we synchronize the set up with Pulse signal type. The signal was created with 100 kHz frequency, 10 micro-second period, 2.35 Voltage and 0.5% symmetry.

2.2. Result

+ The first experiment for measuring the rising and falling time, we performed two separate experiments to measure the rising time and the falling time for two channels and compare them together. And we get the results:

COUNTER	Frequency
Value	***
Mean	7.53477MHz
Min	2.00000Hz
Max	61.8062MHz
Stdev	19.6607MHz
Count	89

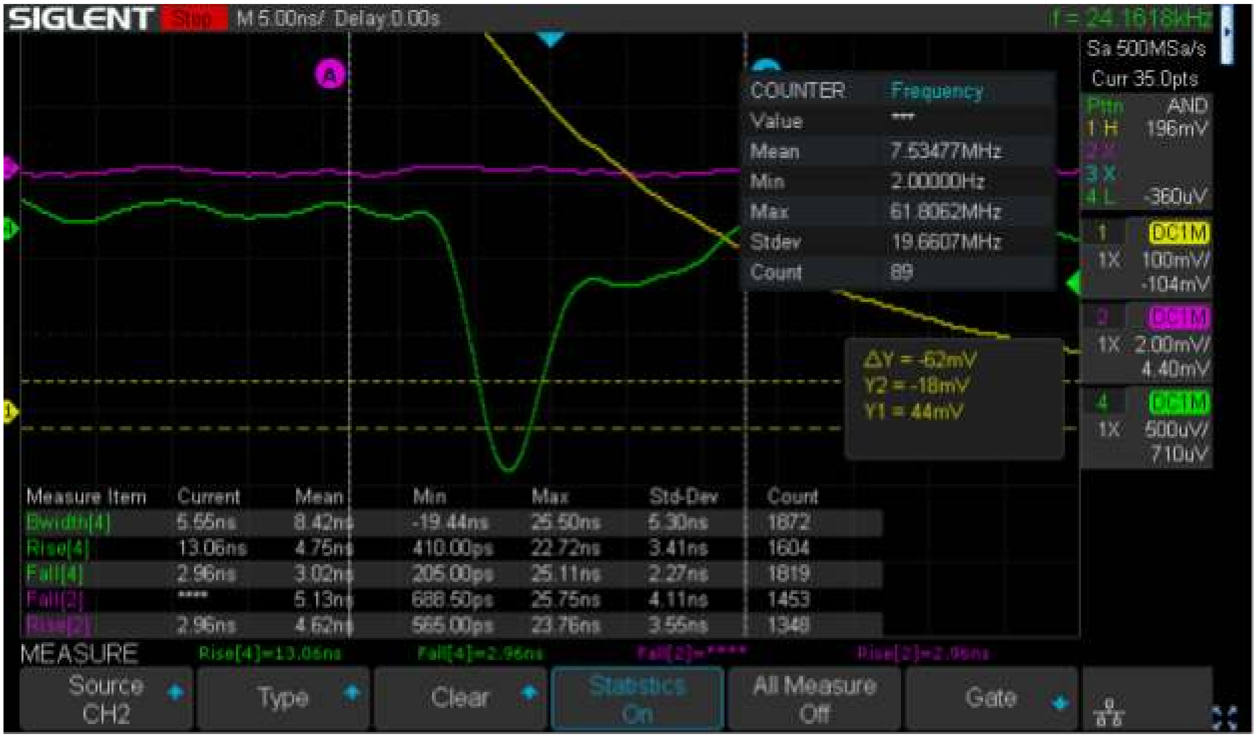
ΔY = 42mV
Y2 = -22mV
Y1 = 40mV

Measure Item	Current	Mean	Min	Max	Std-Dev	Count
Bwidth[4]	****	****	****	****	0.00ys	0
Rise[4]	****	****	****	****	0.00ys	0
Fall[4]	****	****	****	****	0.00ys	0
Fall[2]	2.35ns	2.66ns	995.00ps	6.91ns	531.98ps	725
Rise[2]	2.98ns	2.82ns	960.00ps	11.30ns	813.21ps	725

Fig SEQ fig * ARABIC 5: rising and falling time in two separate channels. The upper for channel 2 and the lower for channel 4

+ Then, we measure the falling and rising time of both channels simultaneously. And we get the result below:

+ Channel 2 exhibits a lower error rate in rising and falling times compared to channel 4. Measurement via channel 2 will yield superior results with reduced error levels in rising and falling times.



COUNTER	Frequency
Value	***
Mean	7.53477MHz
Min	2.00000Hz
Max	61.8062MHz
Stdev	19.6607MHz
Count	89

Measure Item	Current	Mean	Min	Max	Std-Dev	Count
Bwidth[4]	5.66ns	8.42ns	-19.44ns	25.50ns	5.30ns	1872
Rise[4]	13.06ns	4.75ns	410.00ps	22.72ns	3.41ns	1604
Fall[4]	2.96ns	3.02ns	205.00ps	25.11ns	2.27ns	1819
Fall[2]	****	5.13ns	688.50ps	25.75ns	4.11ns	1453
Rise[2]	2.96ns	4.62ns	565.00ps	23.76ns	3.55ns	1349

Fig SEQ fig * ARABIC 6: Rising and falling time of both channels

+ And, when measuring simultaneously with both channels, the rising and falling times of the two channels are approximately equal. Furthermore, they exhibit comparable error rates. Therefore, we can consider that when performing measurements using both methods concurrently for comparison purposes, the errors associated with the rising and falling times of the two methods can be disregarded.

3. Sensitivity

3.1. Theory

+ In the context of sensitivity, our assigned task involves determining the quantum or detection efficiency. Quantum efficiency refers to the fraction of photon flux that contributes to the photocurrent in a photodetector or pixel. Essentially, we aim to measure the proportion of photons at the plane of sensor contact. However, this measurement presents challenges because while we can count the number of electrons read from the sensors, quantifying the exact number of photons that will interact with the sensors remains elusive.

+ To address this, we assess the efficiency of the entire system. By controlling the amplitude of the input signal, we effectively regulate the number of photons reaching the diode. Our approach involves counting how many times the signal is read within a one-second interval, based on the known frequency of applied input photons.

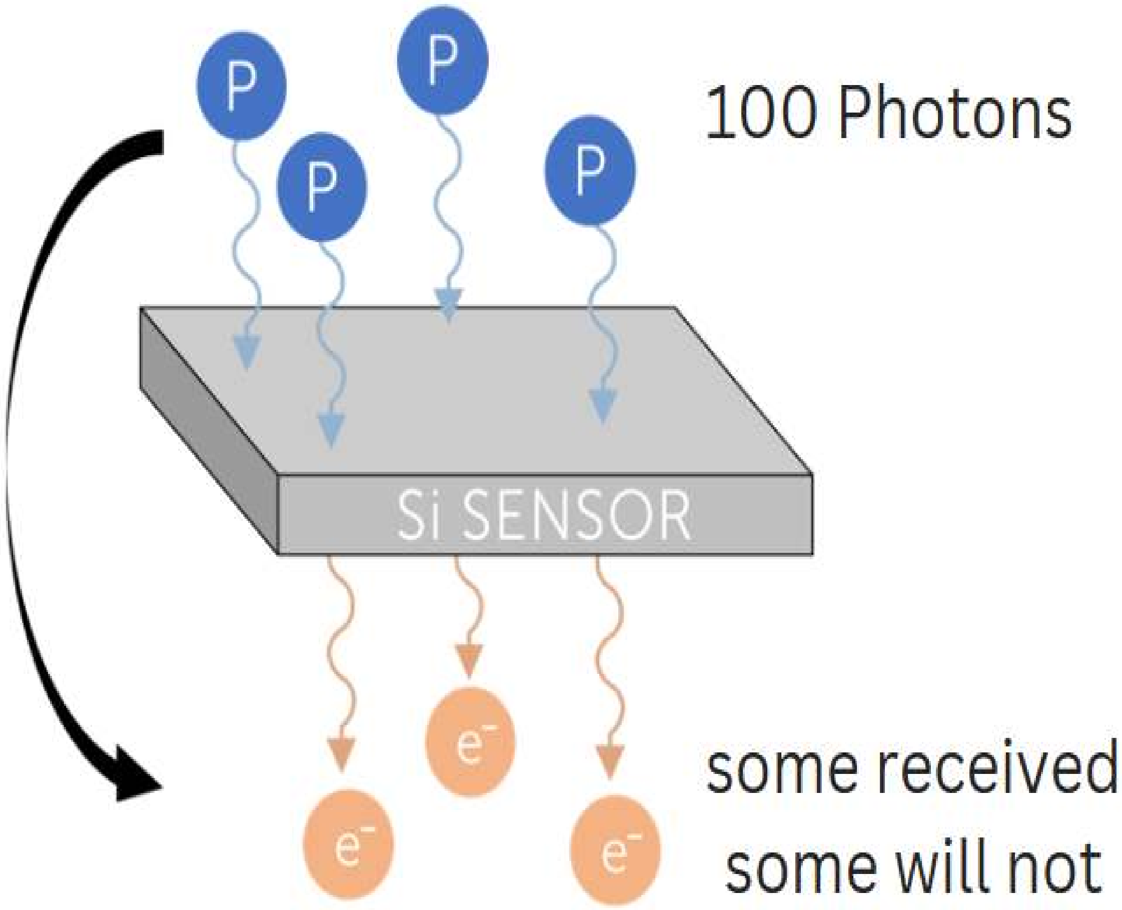


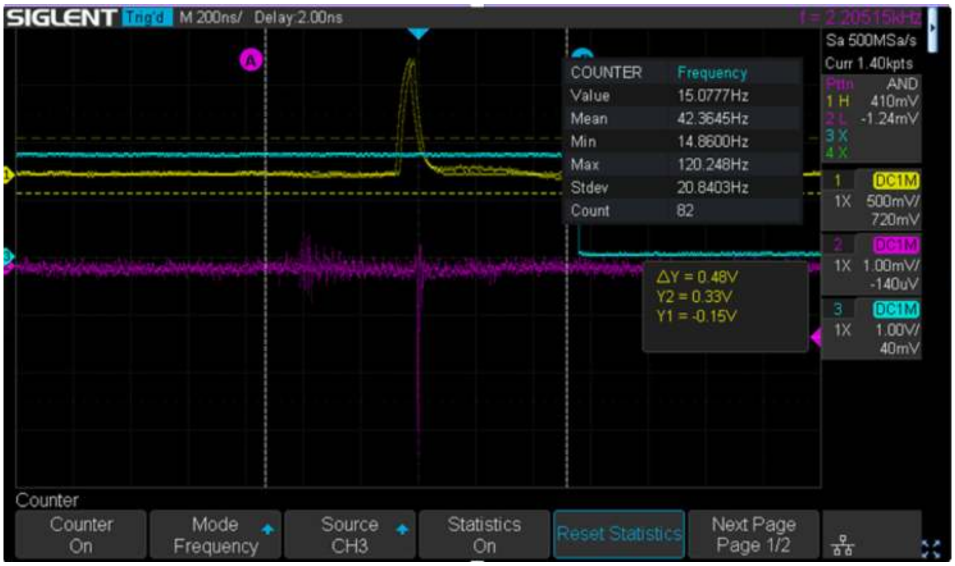
Fig 7: Visualization of sensitivity

As we know at the setup, we will fix the input frequency. We will only change the diode supply voltage.

As part of our setup, we will keep the input frequency fixed while varying the diode supply voltage. During our measurements, we encountered an issue with the oscilloscope algorithm inaccurately counting events without a reference signal. To address this, we connected the reference signal from the oscilloscope source to CH3, establishing it as the baseline for our counting measurements. Subsequently, we captured the frequency response of CH3, which serves as our result.

3.2 Result

- PMT result



COUNTER Frequency
Value 15.0777Hz
Mean 42.3645Hz
Min 14.8600Hz
Max 120.248Hz
Stdev 20.8403Hz
Count 82

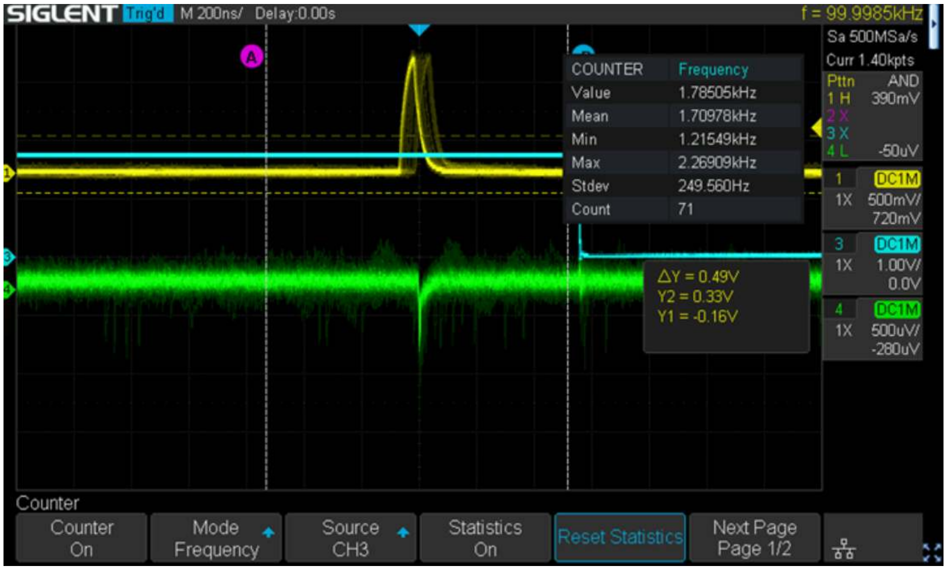
ΔY = 0.48V
Y2 = 0.33V
Y1 = -0.15V

Fig 8: PMT signal (purple) and reference signal (cyan)

- The Figure 8: above shows the response frequency read from the oscilloscope. We use a counter method to count the value of frequency of CH3.

Supply voltage (V)	Receiving frequency (Hz)
2.3	40 ± 20
2.31	60 ± 17
2.32	100 ± 21

- SiPM result



COUNTER Frequency
Value 1.78505kHz
Mean 1.70978kHz
Min 1.21549kHz
Max 2.26909kHz
Stdev 249.560Hz
Count 71

ΔY = 0.49V
Y2 = 0.33V
Y1 = -0.16V

Figure 9: SiPM signal (green) and reference signal (cyan)

- With the above technique we also apply the same supplied for SiPM. Below is the result of SiPM

Supply Voltage (V)	Receiving frequency (Hz)
2.3	1200 ± 213
2.31	1450 ± 183
2.32	1700 ± 250

3.3 Comparing result

- The result show that SiPM has much higher response frequency.

- Discussion: Although the measure result show that SiPM is better, SiPM are designed to catch more wavelength than PMT, as a result it has more chance to catch photon

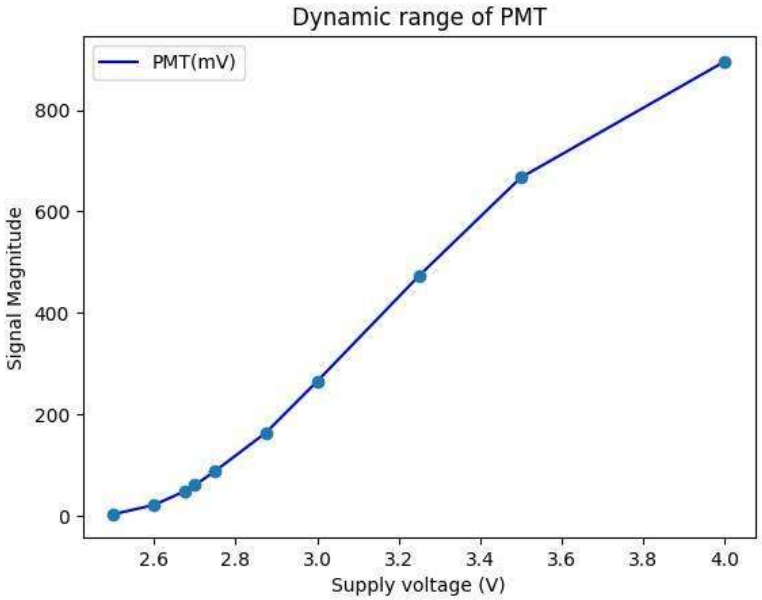
4. Dynamic range

4.1 Theory:

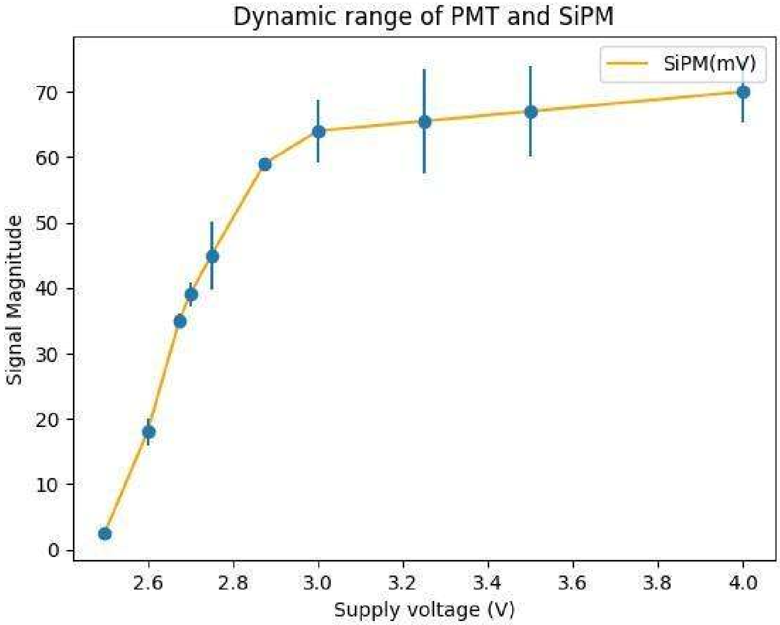
- In any sensors, the is a upper limitation where if the signal is higher than that limitation, the response signal amplitude will be saturated.

- On this measurement, we will try to increase the number of photons until the signal is saturated. Moreover, we want to check the linearity of PMT and SiPM to compare to what is written in the specification.

4.2 Result:



A: PMT curve



B: SiPM curve

Figure 11: Dynamic Range of PMT (A) and SiPM (B)

- PMT gives a stronger response signal magnitude.

- Both SiPM and PMT show linearity at some ranges.

- SiPM is saturated earlier than PMT, the cutting point is around supply voltage. 2.8-3.2 V. PMT on the other hand, remains stable although the voltage of diode reachs its limitation, as we still cannot Figure (number): out the cutoff magnitude of PMT.

5. FILTERED SIGNAL MEASUREMENT

- Using: light source **White LED,** filter

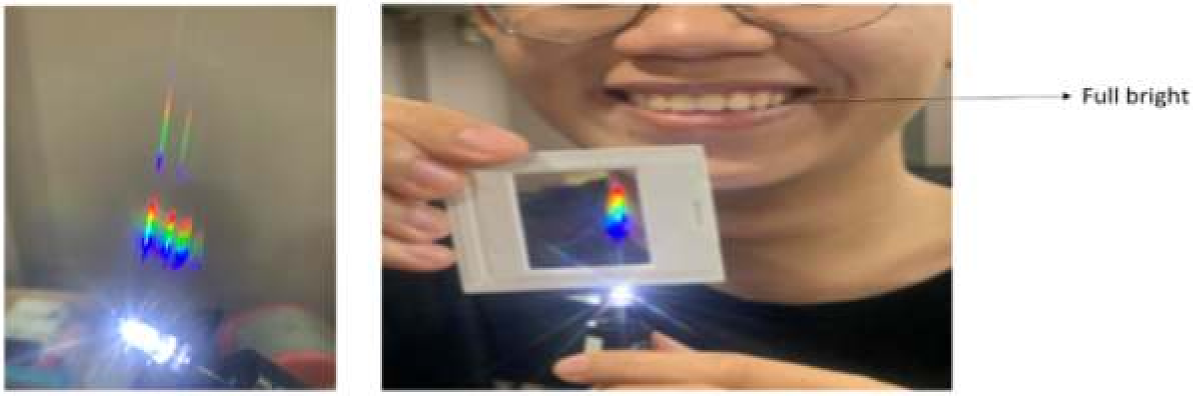


Fig 12: Spectrum of white light observed through a diffraction grating

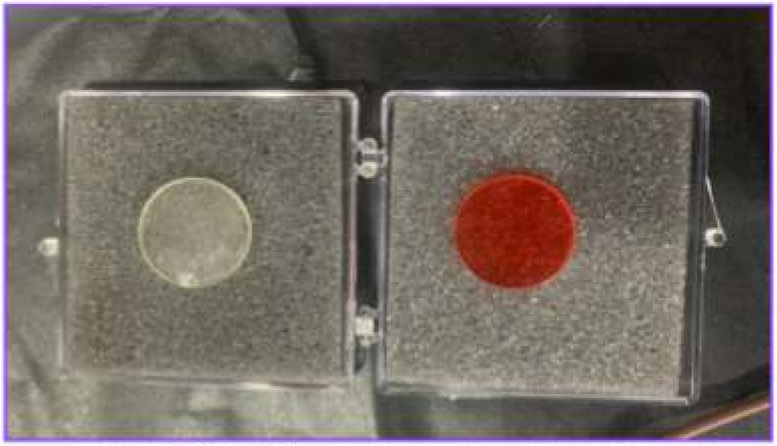
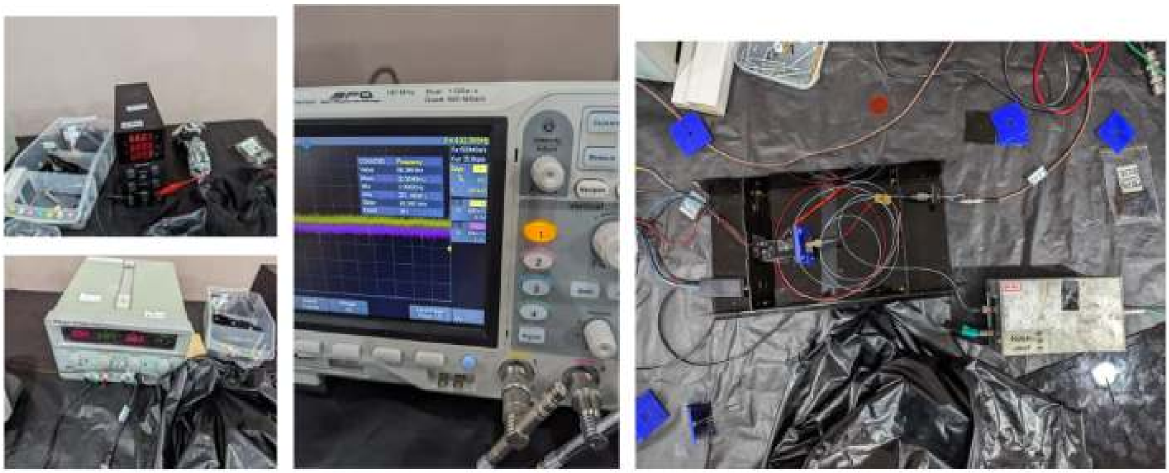


Fig 13: 400nm filter (left) & 550nm filter (right)

5.1 Set up:



5.2 Result:

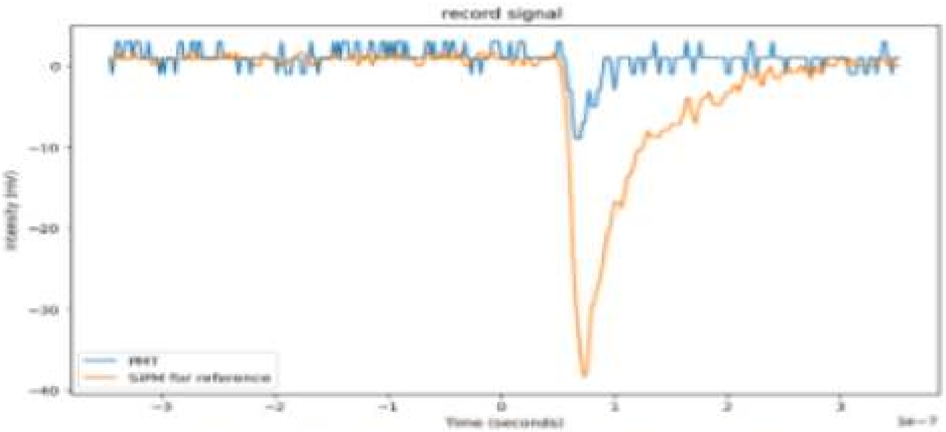


Fig 13: Intensity of light through PMT and SiPM -

- Measurement method: in this experiment, we performed light filtering using optical filters and measured the signal response for a PMT. We then compared it with the signal obtained from an unfiltered SiPM. Subsequently, we utilized the PMT measurements to estimate the energy intensity of the light signal.

- The graph illustrates that the peak of signal intensity detected by the SiPM is higher compared to the signal intensity by the PMT. Additionally, it is evident that the SiPM peak exhibits a significant broader base region than the PMT peak, indicating a wider signal acceptance range for the SiPM. The discrepancy contributes to the observed difference in signal intensity between the SiPM and PMT measurements.

PMT plot

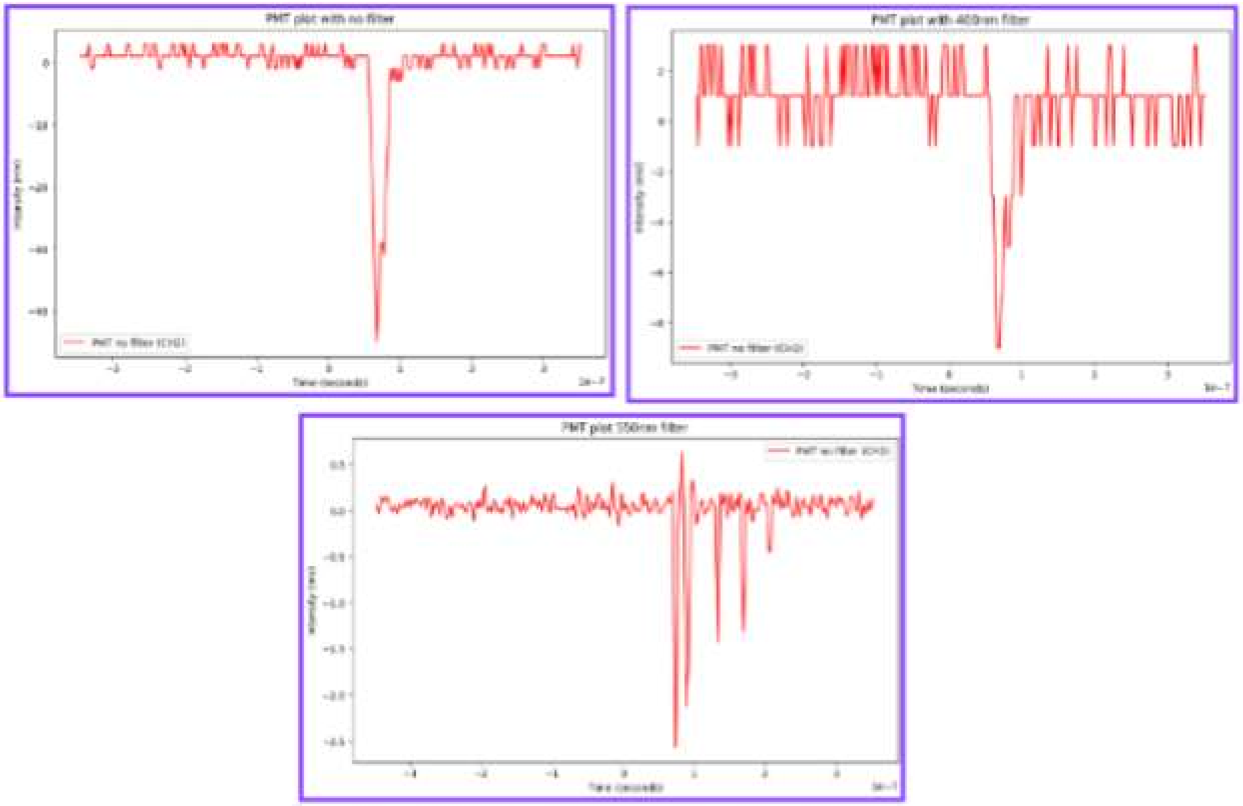
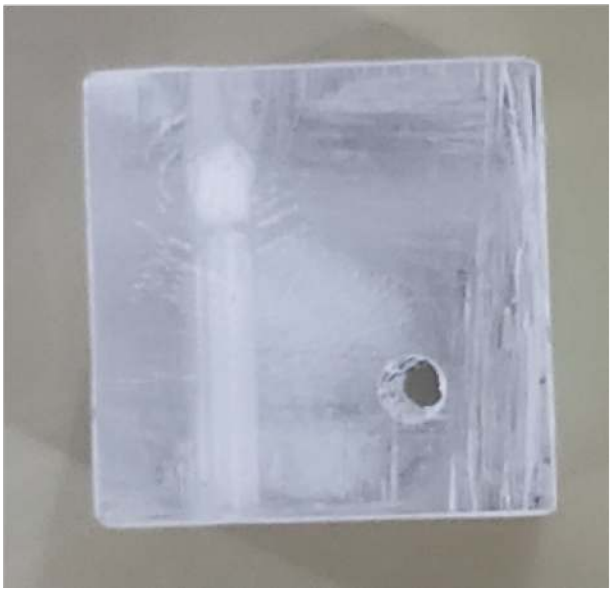


Fig 14: intensity of light signal with no filter and with filter of PMT

- When comparing the three graphs corresponding to the cases of no filter, and filters at 400nm and 440nm wavelengths, the graphs for the filtered cases exhibit lower light intensity compared to the unfiltered case. Consequently, the noise signal ratio of the light beam becomes higher for the filter cases. This observation suggests that the filters, while blocking wavelengths shorter than their respective passbands, also attenuate the energy of the incident light beam. This attenuation enhances the ability to detect and discriminate monochromatic light signals.

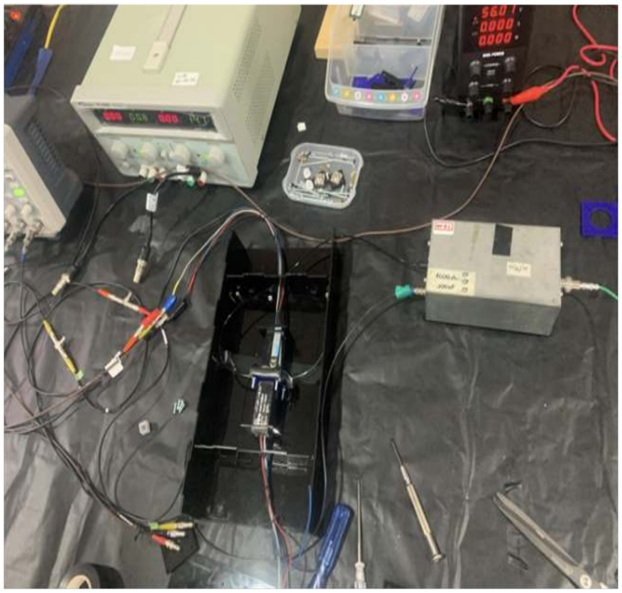
6. Measuring Cosmic Muon Rate

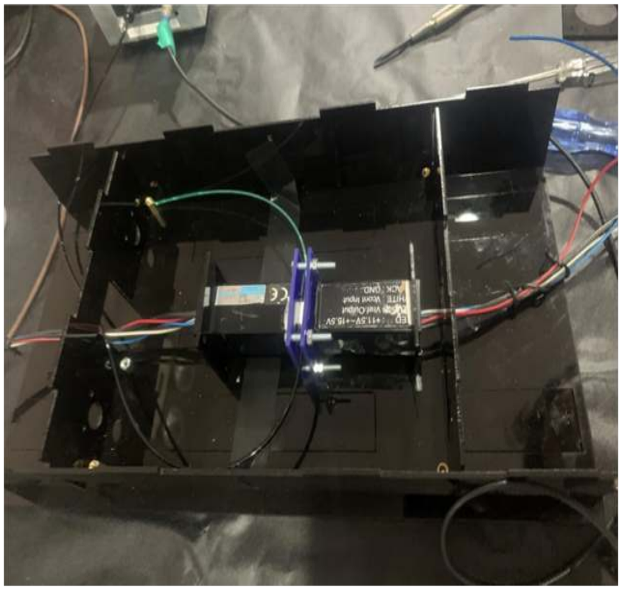
6.1 Set up:



The experimental setup is as follows:

1. Plastic Scintillator (1 cm x 1cm x 1cm)
2. Two Photo-Multiplier Tubes
3. Wavelength Shifting Fiber
4. DC High Voltage Source
5. Oscilloscope
6. SIPM





6.2 Principle:

Scintillator cube which emits blue light when a radiating particle loses energy while passing through the cube. We collect these photons by coupling a two PMT's (Photo-Multiplier Tube) with the two opposite sides of the cube.

By ensuring that only the coincident signals are collected we intend to reduce false signals (wrongly accepting dark noise) as much as possible.

consists of Scintillator cube which emits blue light when a radiating particle loses energy while passing through the cube. We collect these photons by coupling a two PMT's (Photo-Multiplier Tube) with the two opposite sides of the cube.

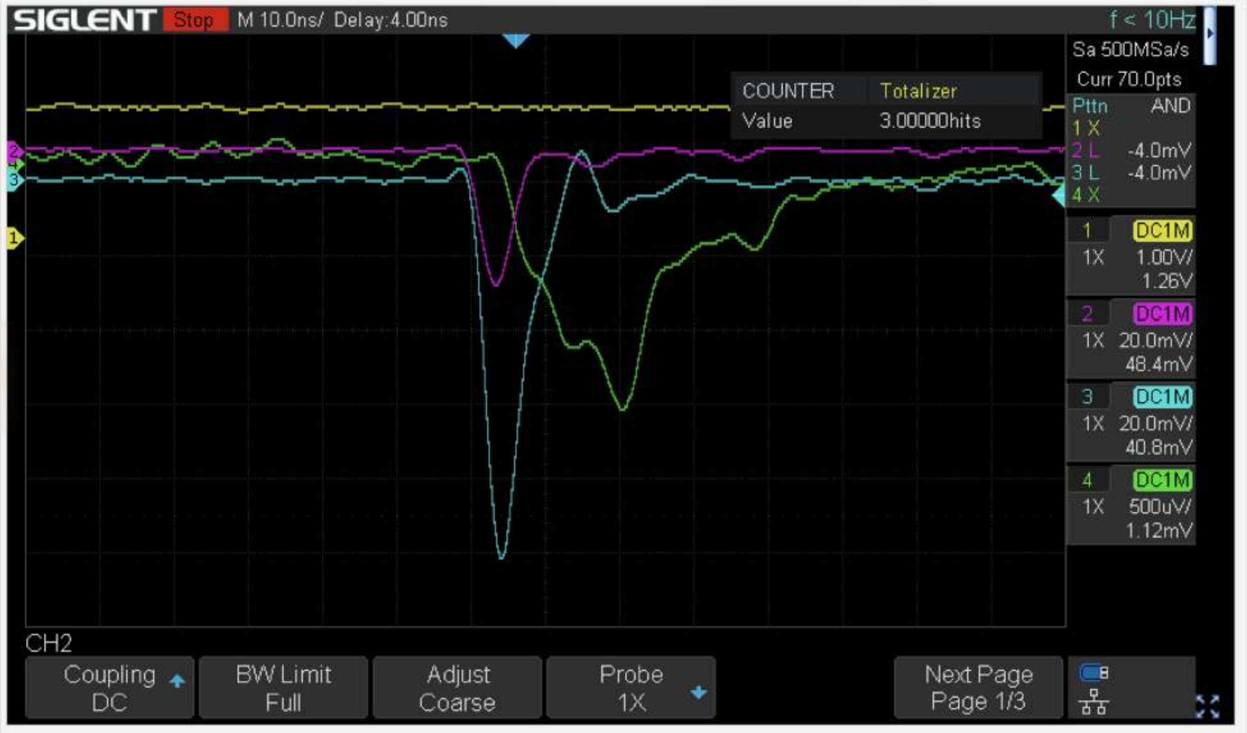
By ensuring that only the coincident signals (between the PMTs) are collected we intend to reduce false signals (wrongly accepting dark noise) as much as possible.

We measured the rate of (Muons + Noise) as function of Discriminator Threshold of Single PMT by triggering at the falling edge as one method to reduce the acceptance of dark noise.

The second method is to measure the rate of (Muons + Noise) as a function of Discriminator Thresholds of both PMTs by triggering at the coincidence of both the PMTs.

During the entire process we monitor the signal from SIPM by collecting blue photons of scintillator using wavelength shifting fibre (absorbs blue photons and emits green photons) and coupling it to SIPM.

6.2 Reults:



M 10.0ns/ Delay:4.00ns

f < 10Hz

Sa 500MSa/s

Curr 70.0pts

COUNTER: Totalizer

Value: 3.00000hits

Pttn: AND

1 X

2 L -4.0mV

3 L -4.0mV

4 X

1: DC1M, 1X, 1.00V/, 1.26V

2: DC1M, 1X, 20.0mV/, 48.4mV

3: DC1M, 1X, 20.0mV/, 40.8mV

4: DC1M, 1X, 500uV/, 1.12mV

CH2

Coupling: DC

BW Limit: Full

Adjust: Coarse

Probe: 1X

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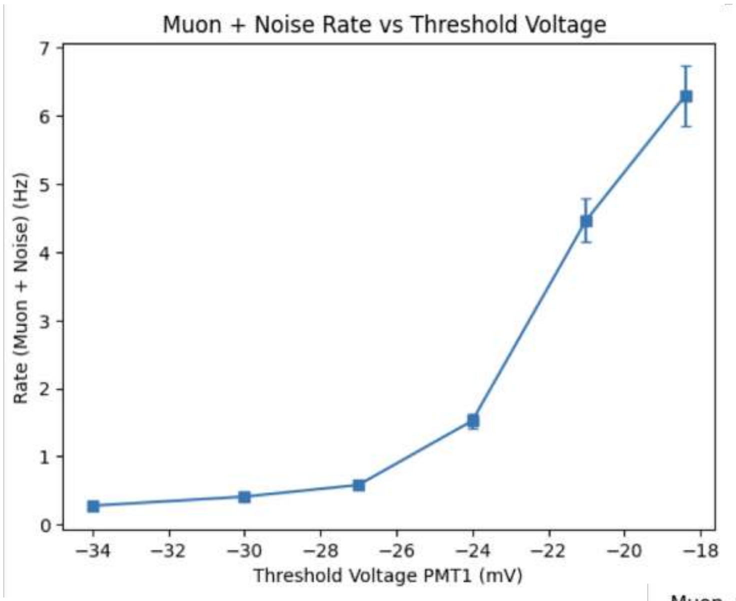
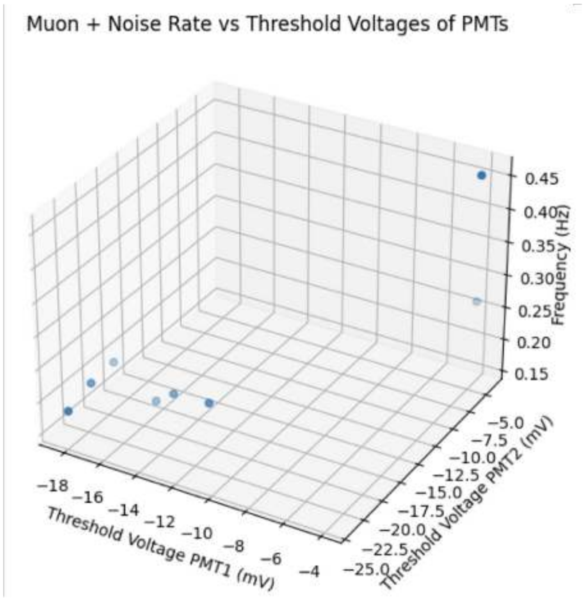
This is a typical muon and we can see the signall both the the PMTs (pink and blue) as well as the SIPM (green). The delayed response of green signal is due to the delayed arrival photons travelling through wavelength shifting fibers. The multiple peaks are due to photons arriving at multiple times.



The image in left is the (muon + noise rate) as function of discriminator threshold voltage. We can see that as we decrease the threshold voltage (increasing in magnitude) we keep eliminating most of the dark noise and accept as much of the signal.

There exists a Threshold voltage at which the signal to noise ratio is maximum.



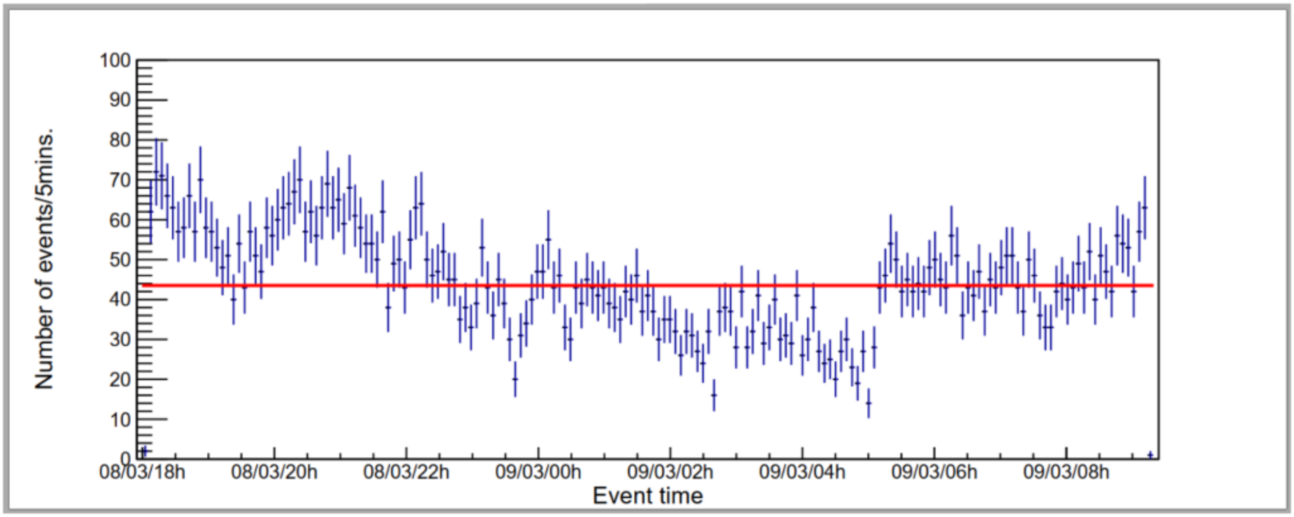
The second since it very less probable for 2 dark noises to coincide or occur in a small interval, the rate should be nearly independent of threshold voltages of PMTs.

Apart from unexplanatory or spurious two data points at the right end of the image on the right, we can say that the rate at different threshold voltages are within the statistical uncertainities.

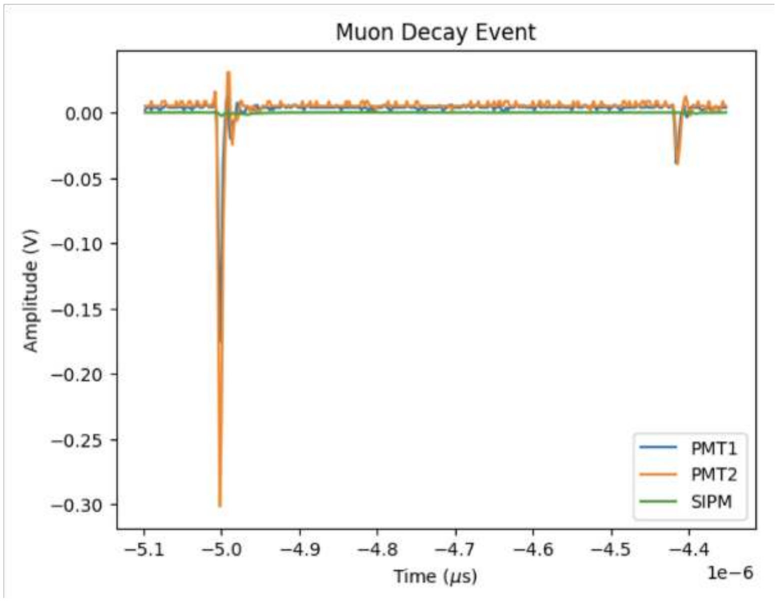
So we decided to collect the data by putting the two discriminator thresholds at -18mV. The image below shows the muon rate variation across the entire night.

Assuming that the average muon flux at sea level is 1 muon/ cm^2/ min. The lower bound for the rate is then 5*1/(60) = .084 Hz. Assuming that the cube is covered by a half sphere above of radius $\sqrt{.5^2 + .5^2 + 1^2} = 1.22$ cm. The rate through this half sphere is $2\pi R^2/(60) = 0.15$ Hz is the upper bound.

So the measured average rate .146 Hz is consistent with theoretical upper bound and lower bound under the assumptions.



Upon looking through all the muon events of the entire night we found one event which is most likely to be a muon decay event. The image on the left is the muon decay event where the first peak corresponds to muon and the second one most likely corresponds to electron.



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