PHOTOMULTIPLIER TUBE GAIN TESTING

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ABSTRACT

We evaluated two batches of 14-stage photomultiplier tubes (PMTs) to use in our muon detectors, the PMTs available had to be tested and sorted. The important characteristics to be measured were net output current light and the ratio of light current to dark current. Using a standard candle (pulsed green LED in acrylic block), a pulse generator, a pulse-amplifier, a picoammeter, and an oscilloscope, the sensitivities and ratios of light current to dark was measured. We started with 25 unused Thorn PMTs and 8 unused Hamamatsu tubes. The testing setup relied primarily on the linear nature of the output of an LED, as seen in the far right frame. By controlling the light output of the LED with the light generator and measuring resulting output current from the PMT, the sensitivities and ratios of light current to dark were determined as a function of high voltage.

Example Data Analysis

The measured values were plotted as gain curves showing the sensitivity of light to dark current across a range of voltages. Through these graphs, the 4 most sensitive tubes were determined.

METHODS

Mechanical check of PMT
• Check base. Remove black tape and two small screws that secure the base.
• Tighten the nuts on the BNC connector for the HT input and signal outputs if necessary.
• Slide the shield back onto the PMT (be sure to connect the ground from the PMT shield to the base) and replace the screws and black tape.
• Connect testing rig according to chart below.

Setup
• Connect the PMT to the output cables and HT input and mount on the stand, with the end of the tube 50 cm from the LED source.
• Setup a data table with 4 columns: Voltage, I-dark (0V), I-dark (testV), and I-light (Voltage in kV, I in nA).

Testing
• Set up data table with 4 columns: Voltage, I-dark (0V), I-dark (testV), and I-light (Voltage in kV, I in nA).
• Record the 0V current on the picoammeter (PAM). (The picoammeter’s baseline may shift over time.)
• Connect the PMT to the output cables and HT input and mount on the stand, with the end of the tube 50 cm from the LED source.

Testing Setup:
Pictured are, from left to right, the dark box, the picoammeter, the pulse generator, the High Voltage source, and the oscilloscope.

Conclusion

The Hamamatsu tubes are considerably more sensitive than the PARTICLE and Thorn tubes. Consequently, the PMTs used in the detector will be Hamamatsu tubes. At operating voltage (1.4 kV) the mean current was 60.4 nA and the mean light current/tube dark current ratio was 36.7. We decided to use an operating voltage of 1.400 volts because beyond this point, the mean current on the oscilloscope was only 60.4 nA.

Example Data Analysis

Individual Thorn PMT: current data and the net light current/dark current ratio. A higher ratio represents lower noise for the tube.

Thorn PMTs: acceptable sensitivity and SNR. The mean light current up to 1.5 kV is 7.0 nA.

Hamamatsu PMTs: highest sensitivity and best SNR of all tubes. The mean light current up to 1.5 kV was 37.2 nA.

Thorn vs. Hamamatsu: This demonstrates the superior sensitivity of the Hamamatsu PMTs.

Tested materials included:
Acrylic block with Embedded LED and Slit Window
Picoammeter Set to 200 nA range
Ch 1Ch 2
Ch 1Ch 2
Input 1 MΩ DC
Input 50 Ω DC
Timing 5 µs / div
1 µA current on picoammeter 1800 V high voltage
10 mV/div.
1 V/div.
Trigger Ch 2 +0.1 V + slope
Pulse Generator
Pulse Period 5 ms
Pulse Amplitude 2.5 V
Polarity +
Transition Time 5 µs
A2 to Sig 4
A1 to Sig 3
ABSTRACT

We tested three distinct models of tubes: 8 Hamamatsu R5686 tubes, 26 Thorn 9954B tubes, and 22 Quarknet tubes. The Hamamatsu tubes were the most sensitive and displayed the best light to dark current ratio. At or below 1.5 kV the Hamamatsu tubes were 4.7x more sensitive than the Thorn tubes. The Thorn and Quarknet tubes had similar net light currents. It was discovered that the Quarknet tubes had an unsatisfactory signal to noise ratio (SNR), with measured dark current being considerably higher than the light current at high voltages. Since the Hamamatsu tubes were superior in both sensitivity and SNR, they were selected for use in the 10 ft. detectors.
In order to find matching photomultiplier tubes (PMTs) to use in our muon detectors, the PMTs available had to be tested and sorted. The important characteristics to be measured were net output current light and the ratio of light current to dark current. Using a standard candle (pulsed green LED in acrylic block), a picoammeter, a pulse generator, a HV source, and an oscilloscope, the sensitivities and light to dark ratios of PMTs were measured. We started with 25 untested Thorn PMTs and 8 untested Hamamatsu tubes.

The testing setup relied primarily on the linear nature of the light output of an LED, as seen in the far right frame. By controlling the lighting of the LED with the pulse generator and measuring resulting output current from the PMT, the sensitivities and ratios of light current to dark current of the tubes were determined.

The measured values were plotted as gain curves showing the sensitivity to light of the PMTs across a range of voltages. Through these graphs, the 4 most sensitive tubes were determined.
Mechanical check of PMT

- Check base: Remove black tape and two small screws that secure the base.
- Tighten the nuts on the BNC connector for the HT input and signal outputs if necessary.
- Reseat the PMT and tape the PMT to the base.
- Slide the shield back onto the PMT (be sure to connect the ground from the PMT shield to the base) and replace the screws and black tape.

Setup

- Connect testing rig according to chart below.
- Check the LED source by moving the pulse width to maximum on the generator. A faint glow should be seen through the window in the LED block. Return the pulse width to 10 μs.
- Connect the PMT to the output cables and HT input and mount on the stand, with the end of the tube 50 cm from the LED source.

Testing

- Set up a data table with 4 columns: Voltage, I-dark (0V), (I-dark (testV), and I-light (Voltage in kV, I in nA).
- Record the 0V current on the picoammeter (PAM). (The picoammeter’s baseline may shift over time.)
- Turn on the HV and raise the voltage to 1 kV. Record the test voltage dark current (Take approx. 10 sec to try and determine the mean value, the PAM reading will fluctuate considerably.)
- Turn on the LED by switching the polarity back to +. If PAM read OL switch back to - and seek problem.
- Record I-light. Switch off the LED and repeat measurements (I-dark (0V), I-dark (tV), I-light) up to 1.8 kV). I-dark (0V) can be recorded by disconnecting the BNC connector from the power supply to the PMT.
- If necessary, adjust the PAM range to 2 μa, but never allow the current to go above 1 μa.
- Replace PMT and repeat.
Setup for PMT Tests

Note: Never exceed:
1 μA current on picoammeter
1800 V high voltage

Ch 1
Input 1 MΩ DC
10 mV/div.

Ch 2
Input 50 Ω DC
1 V/div.

Timing 5 μs/div
Trigger Ch 2 +0.1 V + slope

Keep V < 1800 V

Pulse Period 5 ms
(set CRO to 5 ms/div to check)
Pulse Width 10 μs
Pulse Amplitude 2.5 V
Polarity +
Transition Time 5 ns
(at minimum setting)
Conclusion

The Hamamatsu tubes are considerably more sensitive than the Quarknet and Thorn tubes. Consequently, the PMTs used in the detector will be Hamamatsu tubes. At operating voltage (1.4 kV) the mean current was 60.4 nA and the mean light current/dark current ratio was 36.7. We decided to use an operating voltage of 1400 volts because beyond that there is no major increase of SNR, so there is no significant gain in sensitivity. Excepting a few bad tubes, most of the Thorn tubes seemed to be of similar sensitivity with an acceptable SNR. At 1.5 kV the mean current was 26.2 nA and a 17.4 light current/dark current ratio.

The Quarknet tubes were found to be noisy overall. They seemed to have the highest sensitivity and SNR at around 1.4kV, but often the dark current exceeded the light current. The mean dark current is 100.5 nA higher than the mean light current. As result of the overall higher SNR they would not be the first choice for testing with the large scintillators.
Testing Setup:

Pictured are, from left to right, the dark box, the picoammeter, the pulse generator, the High Voltage source, and the oscilloscope.
PMT Mount in the dark box (50 cm from LED block)

Acrylic Block with Embedded LED and Slit Window

Pulse width graph demonstrating the linear relationship between the LED pulse width and the output current.
Individual Thorn PMT: current data and the net light current/net dark current ratio. A higher ratio represents low noise for the tube.
Thorn PMTs: acceptable sensitivity and SNR. The mean light current up to 1.5 kV is 7.9 nA.
Quarknet PMTs: signal to noise ratio was exceptionally poor when tested with green LED. The mean up to 1.5 kV was 8.1 nA.
Hamamatsu PMTs: highest sensitivity and best SNR of all tubes. The mean light current up to 1.5 kV was 37.2 nA.