OPTIMIZING LIGHT COLLECTION FOR LOW INDEX AEROGELS USED IN CHERENKOV DETECTORS

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Abstract

The Aerogel Cherenkov Detector built at CUA is currently being used at JLab in the Super High Momentum Spectrometer (SHMS) in Hall C to differentiate Kaons from Protons. The detector features four refractive aerogel indices ranging from n = 1.03 to n = 1.01. The lowest index is expected to produce a very small signal and it is thus important to collect this signal with the highest possible efficiency. One possible way to amplify this signal is to cover the interior of the detector with the best possible reflective material. A prototype utilizing cosmic rays was built to investigate possible optimizations of light collection for low aerogel refractive indices. Different reflective materials were used on the inner walls of the prototype and the resulting average number of photoelectrons detected by a photomultiplier tube (PMT) compared. The reflective materials tested included Aluminized Mylar, Millipore, Teflon Tape, and Gore. The coincidence trigger for these tests was constructed from the prototype set up between two scintillator paddles. This configuration ensured that only cosmic ray passing perpendicularly through the entire setup were recorded by the data acquisition software. The PMTs used in this setup were calibrated using a blue LED, which is in the optimal wavelength range for the PMT. I will discuss the effect of the different reflectors on the average number of photoelectrons recorded. I will also discuss other possible optimizations of the light collection, which could include wavelength shifters to shift the wavelength of light produced by the Aerogel into the optimal range of the PMTs, and the effect of absorption and scattering on the detector’s performance.

Introduction

Physicists are still trying to deduce the origins of mass for every object in the universe. These studies have begun to focus on the quark gluon interactions and the underlying hypotheses that make up the theory of Quantum Chromodynamics (QCD). To understand these interactions, one must first be able to detect and observe these microscopic particles. The High Momentum Spectrometer (HMS) and the Super High Momentum Spectrometer (SHMS) located at JLab are used to identify the particles released from the high energy collisions from the particle accelerator. The Kaon Aerogel Cherenkov Detector is used specifically to differentiate the incoming Kaons from Protons so scientist can record data and observations specific to only the Kaon. To do so, the Kaon Aerogel Detector (KAD) uses low index materials to induce Cherenkov radiation. Since the detectors are placed in a constant setup with fixed strength magnets, the physicists can determine the speed of each particle which enters the detector, thereby calculating the amount of radiation each particle is expected to emit. This radiation is then used to distinguish which particle passed through the detector. From this data, one can begin to build a comprehensive observation about any of the particles created by the accelerator.

The premise of the Aerogel Cherenkov Detector is the idea that particles can travel faster than light in a certain material and emit Cherenkov radiation, which can be measured. As light travels slower in materials than in a vacuum, particles with high amounts of energy can travel faster than the light in a material. When a particle passes through the material, it slightly polarizes the molecules around it when it separates them. If it is going fast enough, then the particles cannot regroup quickly enough and release light to conserve momentum and energy. As the emitted light is approximately proportional to wavelength, mostly ultraviolet and blue light is emitted.

Photomultiplier Tubes (PMTs) are used to amplify the small amounts of Cherenkov radiation created by the kaon traveling through the aerogel. These PMTs receive the numbered photons produced by the aerogel and amplify the signal through the photoelectric effect. When the photons hit a certain material, they excite the electrons at the surface. These electron then "bounce" to the next dynode and repeat the process. These resulting electrons are called photoelectrons. The inside of the PMT is metal as the photoelectric effect affects the charge of the metal, which can be easily recorded. A high voltage current must be applied to readjust the charge difference otherwise the photoelectric effect will cease to occur.

To optimize this entire process of the Kaon Aerogel Detector, I altered the reflective material that coats the inside of the detector. I used a smaller prototype to facilitate the changing of the reflective material. I used Aluminized Mylar, Teflon Tape, Millipore, and Gore as the different reflectors on the inside of the prototype. These experiments each ran for two or three 24 hour increments. This experiment will help any scientists looking to build a light sensitive detectors in the future, as they will have a comparison of the different reflective materials available to them and a normalized comparison of their reflectivity and effectiveness with low light.

I also altered the number of aerogel tiles inside the prototype to observe the effects of absorption and scattering on the amount of photoelectrons produced. Since each aerogel tiles produces and absorbs photons, it is essential to know the optimal number of aerogel tiles to place in the full scale detector to maximize the number of photoelectrons recorded by the computer.

Methods

The objective of this experiment was to optimize the main Kaon Aerogel Detector at JLab. To do so, I tested the effect of the reflective material on the number of photoelectrons produced by an aerogel detector. First, a prototype was constructed of aluminum, and a five inch PMT was attached to the detector. This detector was built to detect cosmic rays, as they are abundant and free. Then, ten tiles of aerogel were placed in the prototype, and all junctions were sealed until they were light tight. Then, two scintillator PMTs were created. These PMTs had plastic scintillators attached and were sealed so that no external light entered the system. These scintillator PMTs were used to ensure that data was only recorded for cosmic rays which passed perpendicularly through the detector. Each PMT was supplied high voltage and the data was sent to a data acquisition software.

The second scintillator PMT was placed twenty two inches above the first scintillator, allowing room for the detector to be placed in between the two. The detector was placed in between the two scintillators. The prototype received 1800 volts while the scintillator PMTs received 1600 volts each. The signals were then processed through a series of logic boards[1] and the data was recorded by CODA, a data acquisition software. The constants for this setup included the height of the scintillators, the voltage to each of the PMTs, the number of aerogel tiles (10), and the logic board setup. The data was then analyzed and graphed through CERN's ROOT. From the data, the amount of photoelectrons was produced and then compared to determine the best reflector of the four materials.

The second alteration that I made to the prototype was the number of tiles of aerogel in the prototype. This would alter the number of photoelectrons produced because each tile of

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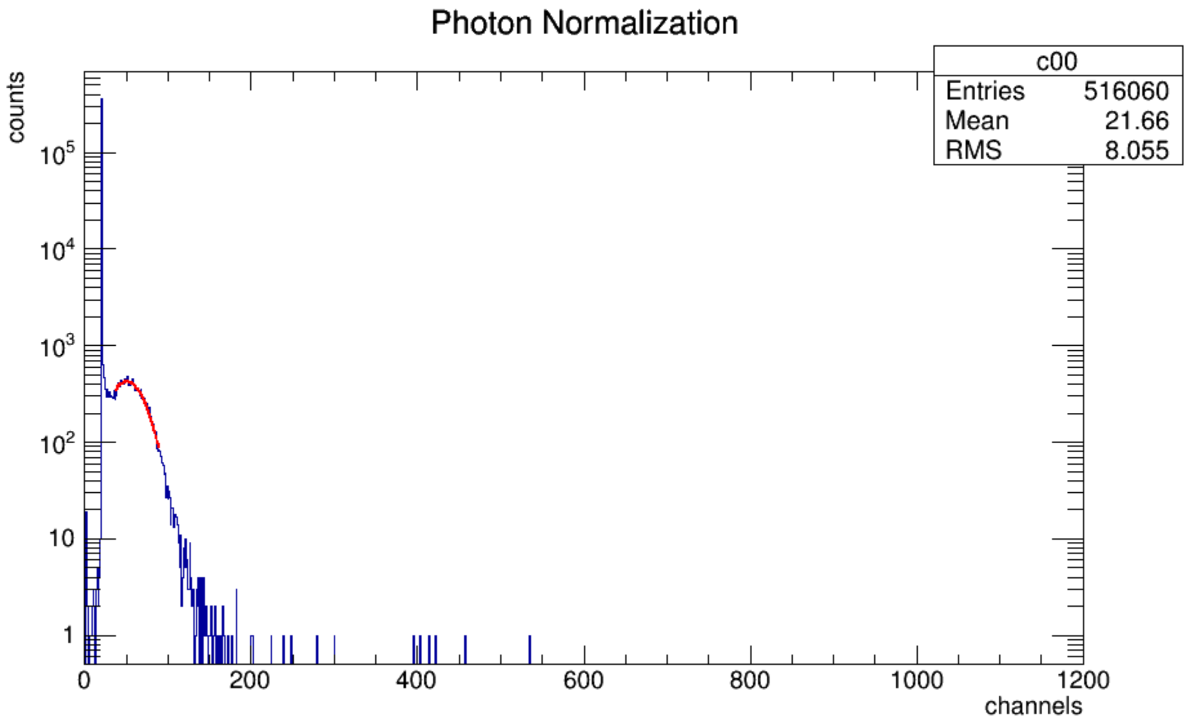
[1] Appendix A

aerogel produces light, but it also absorbs light. To find the optimum number of tiles, I started with ten tiles and took one away until I had six tiles. This provided me five levels of comparison to create a trend line to extrapolate the optimum number of aerogel tiles to produce the most amount of light for the detector. The constants in this setup included the height of the scintillators, the reflective material (Gore), the voltage to each PMT, and the logic board setup.

Data

Different Reflective Materials



The first set of data recorded was a form of calibration for the PMT, as its amplification of the signal varies with the amount of high voltage and model. To understand the gain provided by this specific PMT, and LED was set to emmit one photon at a time, and the resulting number of channels were recorded. This run was repeated twice to ensure that emissions of solely one photon was reached. From this data, one could calculate the output created by one photon, in the case of this PMT, ≈ 50 channels.[2] This allows for a normalization factor which can be applied to each reflector and the ability for future exeriments to duplicate this setup and compare their results.

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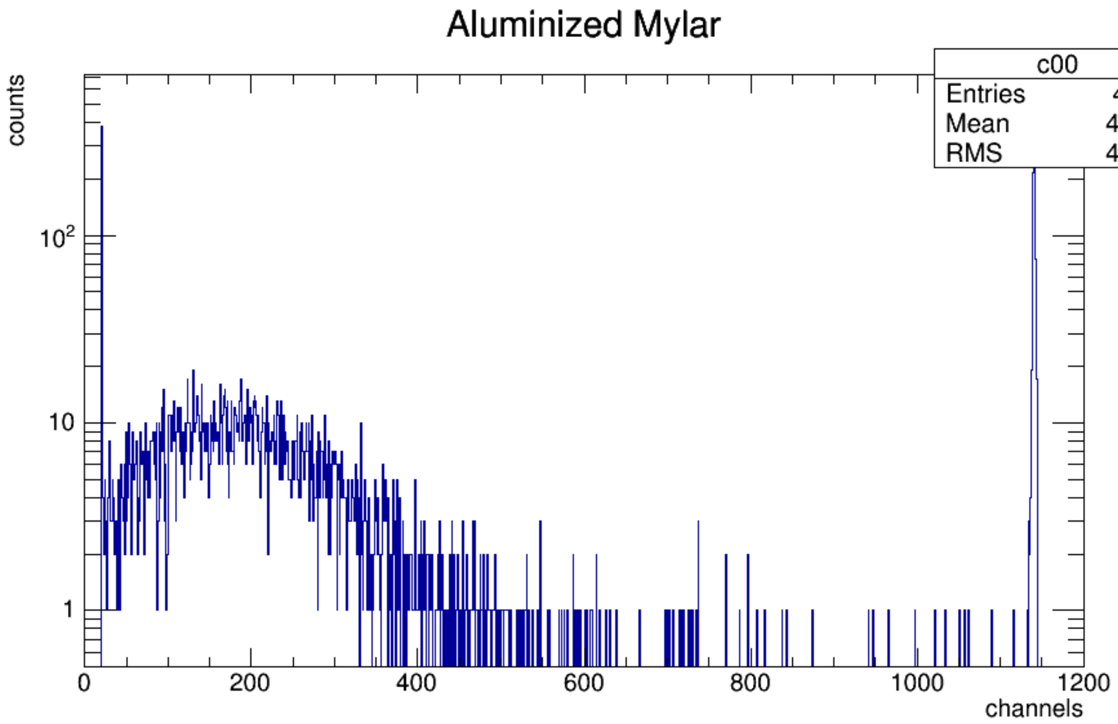
[2] Appendix B



The first reflective material tested was Aluminized Mylar. The prototype was left to run for three periods of twenty four hours, and the data was then processed into this histogram. From this data, one can also find the average number of photoelectrons detected by the PMT with this reflective material.[3] With Aluminized Mylar in the prototype, an average of 5.4 ± 0.1[4] photoelectrons were produced.

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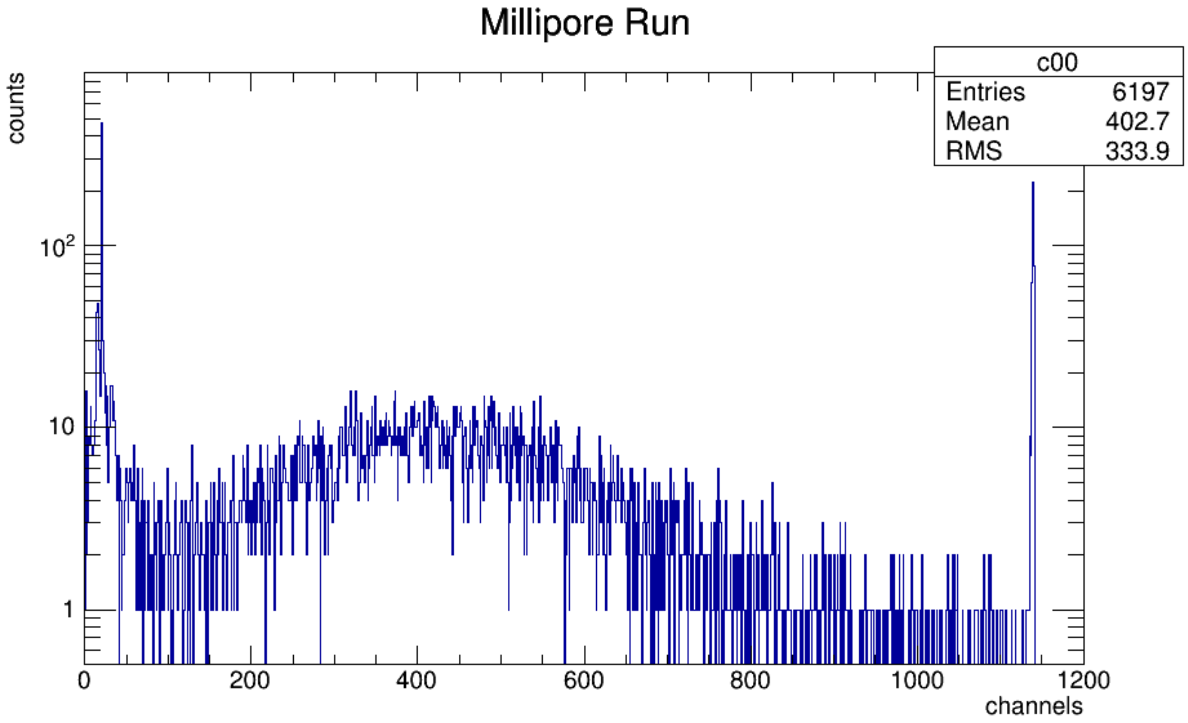
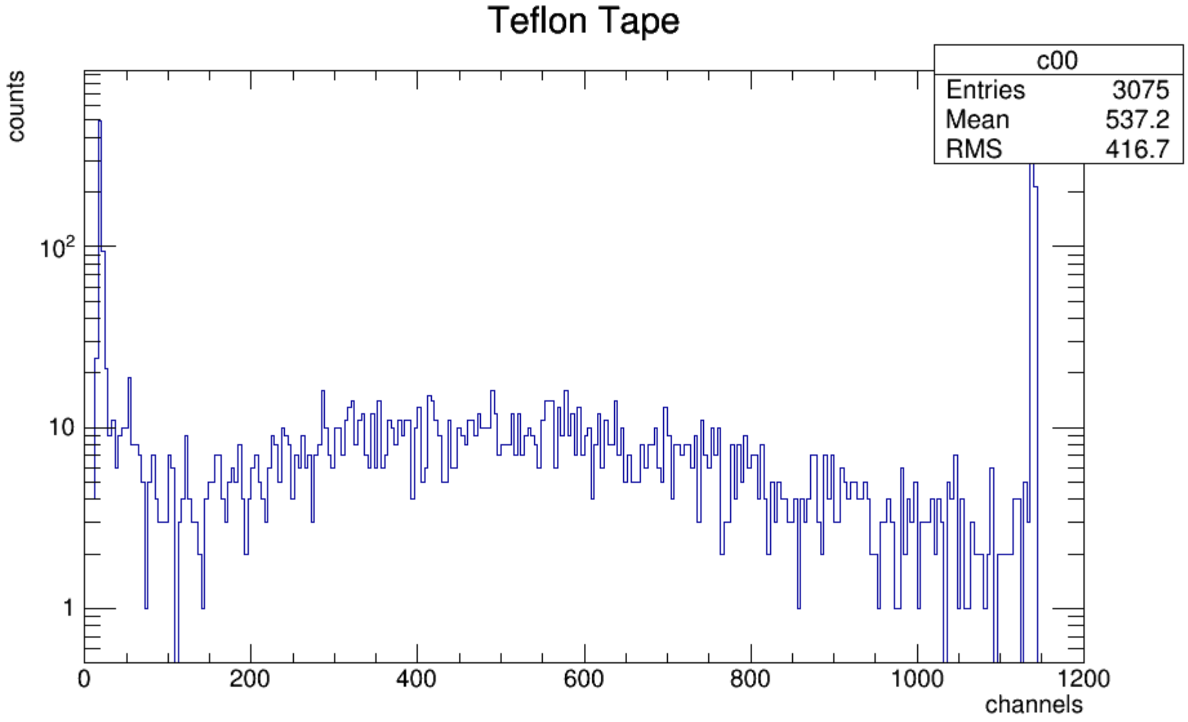
[3] Appendix C

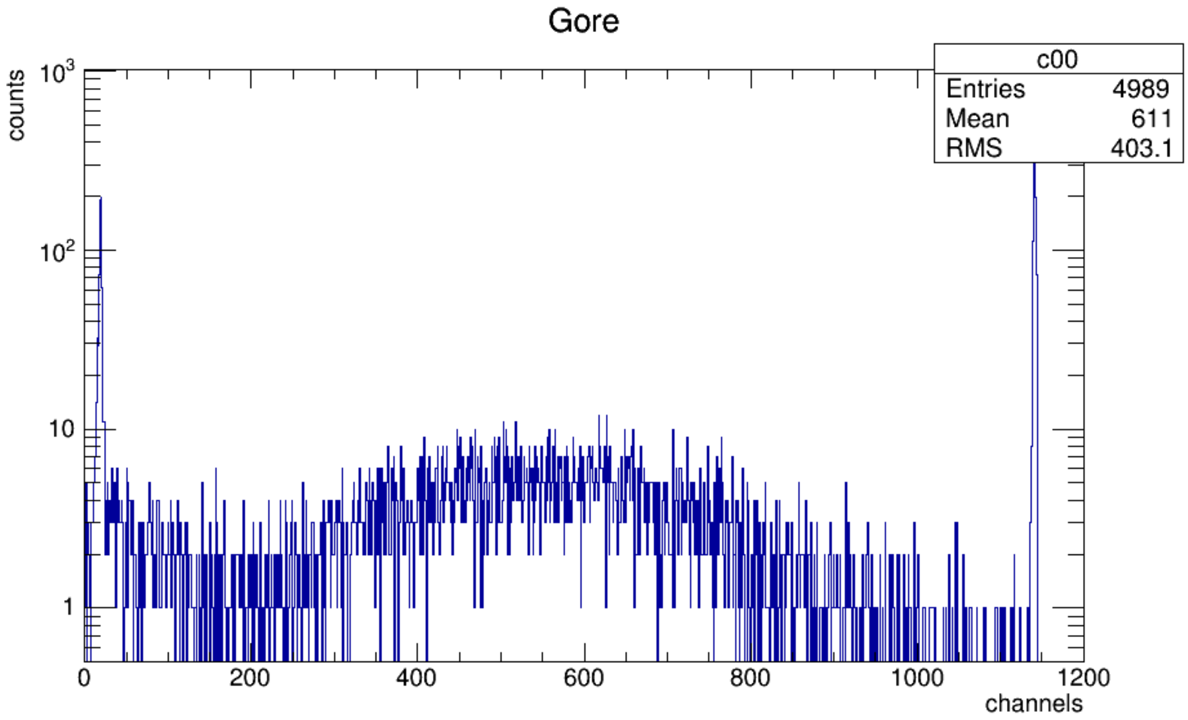
[4] Appendix D



The second reflective material tested was Millipore. The same procedure was repeated, with Millipore running for three days. Millipore averaged 13.0 ± 0.1 photoelectrons.



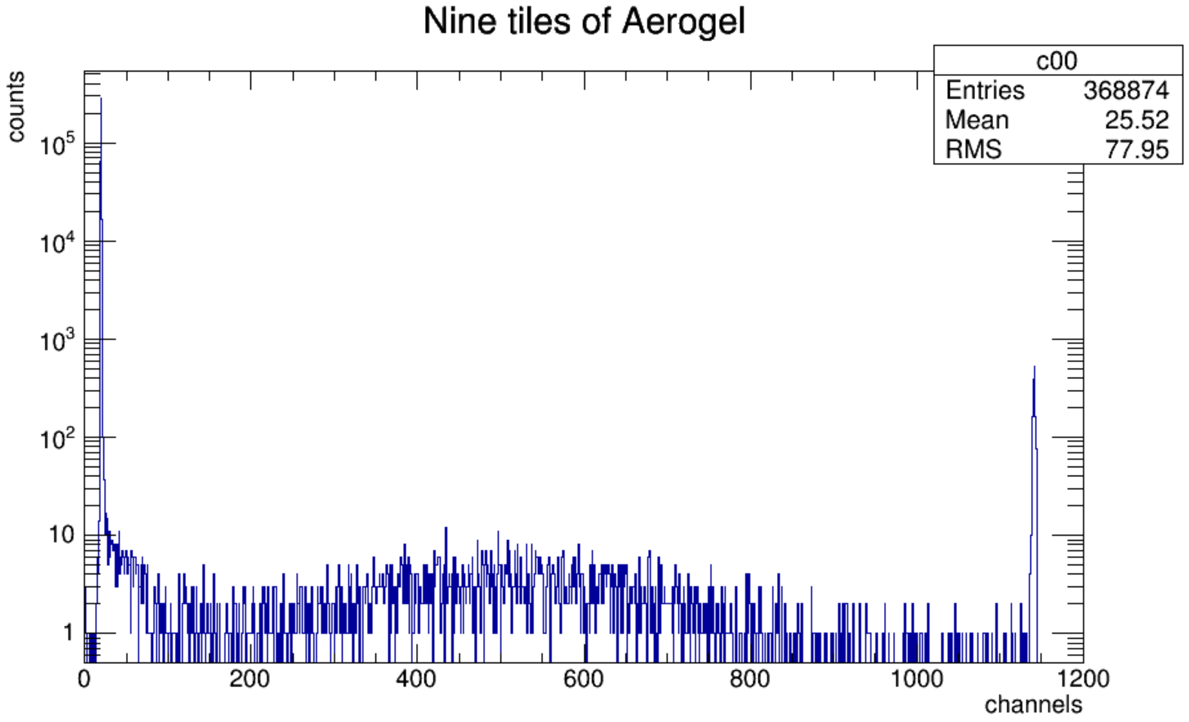
Teflon Tape was the third material tested in the prototype. It ran for two days and produced on average 14.9 ± 0.3 photoelectrons.



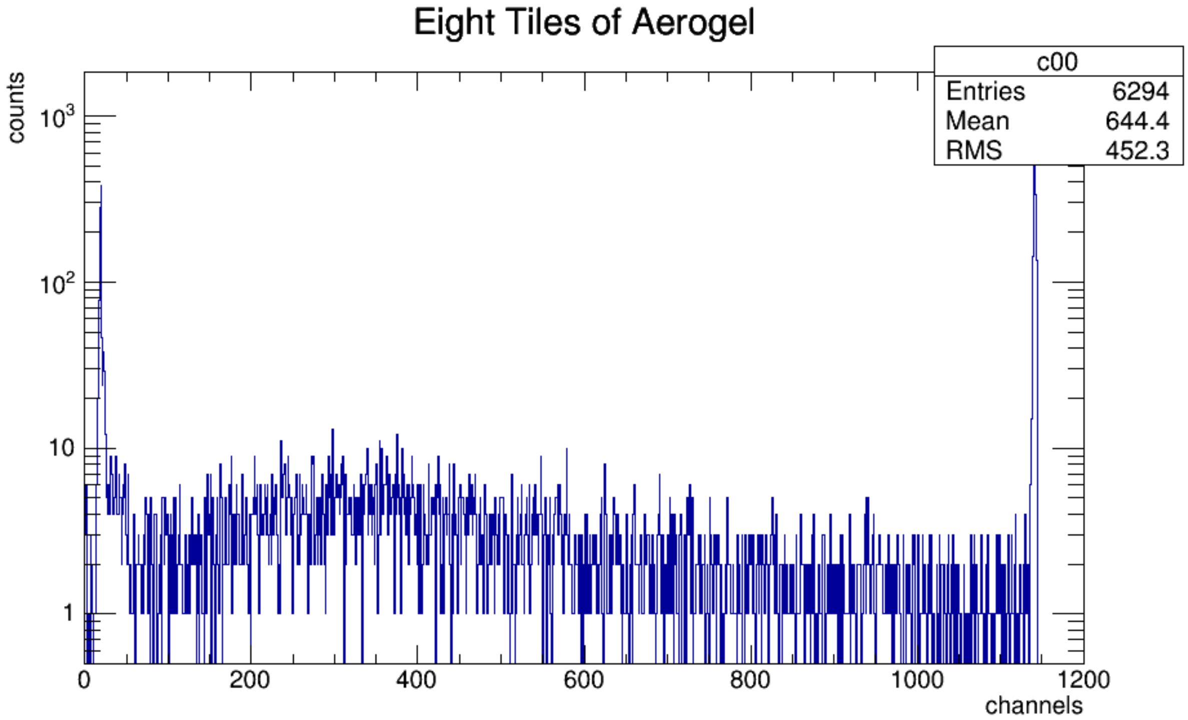
Gore was the final material tested. It tested for three days and produced on average 16.4 ± 0.2 photoelectrons.

Different Number of Aerogel Tiles

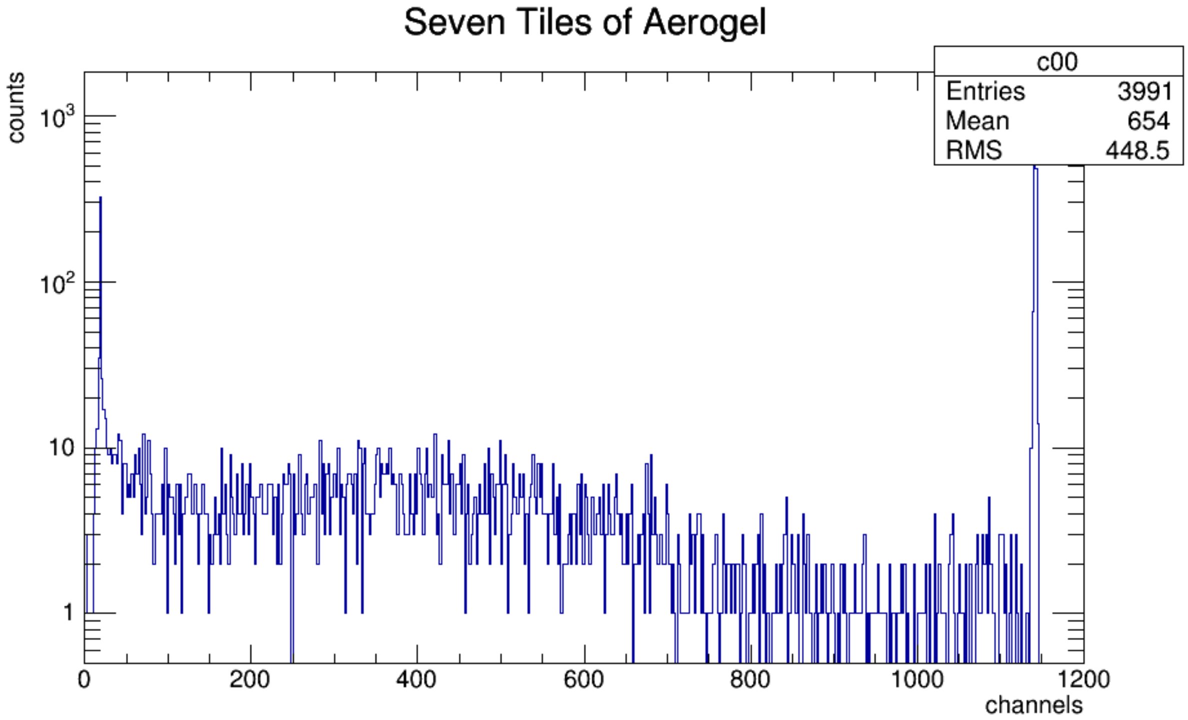
To test the different number of tiles of aerogel, I decided to keep Gore as the reflector because it was the most reflective material as well as the reflector that is sixty percent of the covering used in the actual detector at JLab. The data for ten tiles of aerogel is identical to the run which tested Gore as the reflective material.



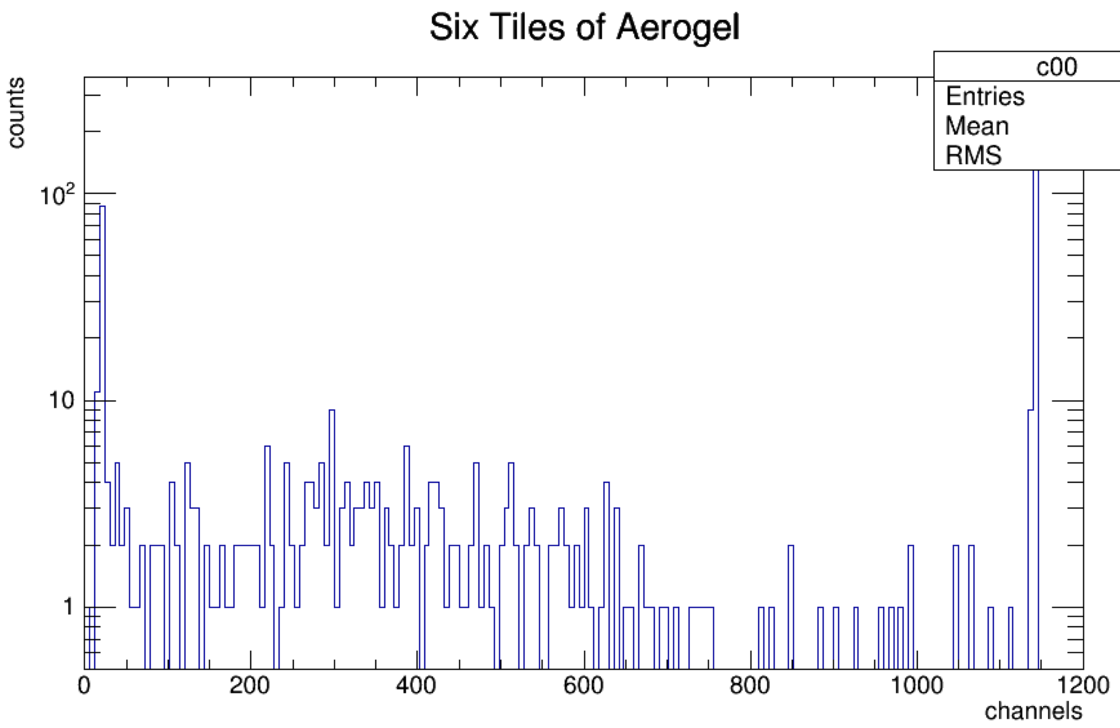
The prototype with nine tiles of aerogel performed well, but produced less photoelectrons than ten tiles of aerogel. Nine tiles produced 15.7 ± 0.2 photoelectrons. This run lasted for three days.



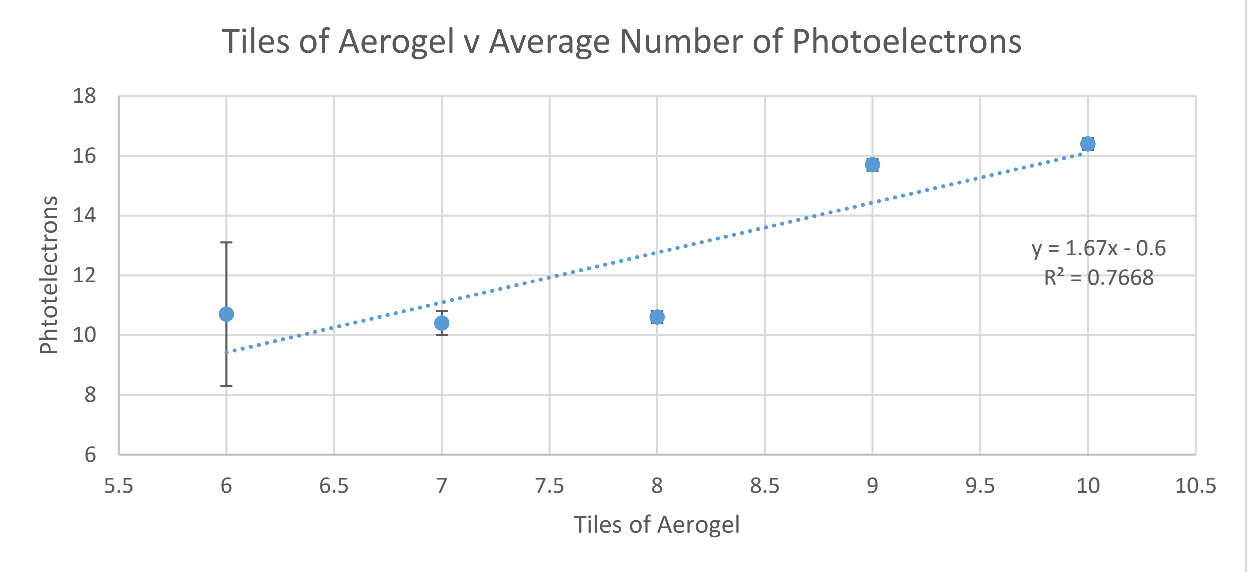
This run also lasted for three days. Eight tiles of aerogel produces around 10.6 ± 0.2 photoelectrons.



Seven tiles of aerogel ran for two days and produced approximately 10.2 ± .4 photoelectrons.



Six tiles of aerogel ran for two days and produced 10.7 ± 2.4 photoelectrons



Overall, the relationship between the number of aerogel tiles and the number of photoelectrons produced seems to be linearly related. However, as more tiles are added, the number should start to decrease again as the tiles of aerogel will start to re-absorb the light that they created, lowering the amount of photons that reach the PMT. Therefore, with more data points, one should begin to see a parabolic or logarithmic function emerge.

Conclusion and Evaluation

The objective for this experiment was to determine the best optimizations for the Kaon Aerogel Detector at JLab. To do so, I identified the best reflective material to coat the inside of the detector with and the optimal number of aerogel tiles. The four reflective materials tested were Aluminized Mylar, Millipore, Teflon Tape, and Gore. To test these materials, a prototype was constructed, and covered on the inside with each of these materials. To gather data, cosmic rays would pass through the detector, producing light, and therefore providing a benchmark to the material’s reflectivity. Once that data was collected, the average number of photoelectrons which hit the PMT were calculated. This determined the most reflective material of the four tested. To test the optimal number of aerogel tiles, the prototype was run with ten, nine, eight, seven, and six aerogel tiles. To determine the optimal number, the number of photoelectrons produces was calculated in the same manner as the reflective materials.

Of the four reflective materials, Gore was the most reflective, being 11% more effective then Teflon Tape. The third reflective material was Millipore, and finally, Aluminized Mylar. These results confirm the decision that was made to cover the Kaon Aerogel Detector with 60% Gore and 40% Millipore. These results also provide a cost effective alternative for future detectors and Gore and Millipore are expensive and Teflon Tape performs well inside the prototype. A strength of this procedure was its similarity to the actual Aerogel Detector at JLab, and its ability to simulate the conditions of the fore coming experiments that the detector will be used in. One of the limitations of this experiment, however, was that we did not have access to Kaons to test the aerogel in the prototype. Another limitation was the time constraints for the experiment. The rate at which the data comes in dictates that the experiment need to be run for three days, however, this limited the amount of alterations I could run within the time frame of my internship. A possible extension to this project would be to run each reflective material for more time. Another extension to this project would be to test the radiation hardness of the reflective materials to observe the effects of radiation from the JLab experiments. This would aid in making the decision of which materials should cover the inside of the detector as radiation is prominent in experiments similar to the ones held at JLab.

The second optimization that I explored was the different number of aerogel tiles in the prototype. From the five levels that I tested, ten tiles performed the best, outperforming nine by four and a half percent. When the data was plotted, an approximately linear relationship was observed between the number of aerogel tiles and the number of photoelectrons produced by the prototype. These findings also reaffirm the amount of aerogel tiles used in the Kaon Aerogel Detector at JLab as it uses around 9 tiles of aerogel, which means that it is receiving a large amount of photoelectrons to measure for each particle that passes through the detector. The strength of this experiment was the setup which easily allowed a different number of aerogel tiles. Since the actual detector is very large, it is difficult to alter the number of aerogel tiles after the tiles are placed in the detector. This also ensures that only the necessary number of aerogel tiles are purchased, as the price of aerogel is expensive. A limitation of this experiment is the prototype could not hold more than ten tiles of aerogel, enforcing a boundary on the experiment. Secondly, the time restriction on this experiment limited the number of trials that I could do, as well as the number of data points per trial. An extension would be to run this project over a longer period of time to record more data point and create a more precise fit to the data.

Appendix

Appendix A

To be able to read the data coming from the prototype, the signals from both the scintillator PMTs and the prototype PMT had to be routed through a series of logic boards. The scintillator PMT signal go through a separate set of boards that the prototype PMT signal.

The first module for the scintillator PMTs was a discriminator. The discriminator alters the small signal received by the scintillator PMTs into constant pulses to be better recorded by the logic board. The logic board received the two signals from the discriminator and creates a signal if and only if the two signals coincide. The gate generator receives the coincidence signal, and creates a gate to tell the computer when to record the signal of the prototype's PMT. The fan in/out module then copies the input it receives and outputs four identical copies. This allows the user to run multiple setups at a time as either gate that creates a signal is copied and sent to the computer.

The first module for the prototype's PMT is the delay module. This module ensures that the signal from the prototype falls within the gate where the computer measures the signal. After that, the signal passes through and Analogue to Digital Converter (ADC) which transfers the analogue signal of the PMT into binary so the computer can record the data. This signal is then transferred to the computer for storage and analysis.

Appendix B

From the PMT’s signal when one photon is released, the amplification by the PMT can be calculated. The setup included an LED which pulsed, emitting one photon at a time. The ADC which translates the PMT’s data has a certain limit of precision which causes a peak at a non-zero number. This peak represents the zero for the ADC, and any readings below this threshold are placed here to let the user know that an event took place, but was not measurable by the ADC. This peak then becomes the zero point for the PMT’s data as well. The only peak other than the pedestal is then the peak produced by a single photon. When you subtract the number of channels of the pedestal from the peak created by the single electron peak (SEP), you then obtain the number of channels that corresponds to one photon. This data can then supply a normalization factor that can be used to compare different materials and different setups. For this specific ADC and PMT with 1800 volts, the pedestal was ≈ 20 and the SEP was ≈ 50, leaving approximately 30 channels per photon.

Appendix C

From the previous page, we know the number of photoelectrons per one photon. Therefore, if we can identify the number of photoelectrons on average that are created with a specific material, we can then divide the two numbers to acquire the average number of photons that were recorded by the PMT during the experiment. For Aluminized Mylar, the average number of channels was ≈ 180 channels. When a pedestal of approximately 20 is subtracted, a value of 160 channels. This value is then divided by the number of channels per photon (≈ 30), and a value of approximately 5.4 photons produced by the prototype with Aluminized Mylar.

Appendix D

The uncertainty for the number of photoelectrons was derived from the uncertainty of the Gaussian fit for the main peak of the data. The uncertainty from the fit was taken as a percentage of the main peak, and then multiplied by the average number of photoelectrons produced to ascertain the uncertainty associated with the final number.