Optimization of Lead In The MOLLER Experiment

A thesis submitted in partial fulfillment of the requirement
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Physics from the College of William and Mary in Virginia,

by

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Abstract

The MOLLER Experiment is planned to take place at Jefferson Lab within 10 years. The purpose of the experiment is to determine the weak charge of the electron, a measure of how strongly electrons interact with each other through the weak force. This will be accomplished by measuring the amount of parity violating asymmetry that results from electron-electron scattering (known as Mϕller scattering) from a liquid hydrogen target. Parity is a symmetry in nature that is only violated in weak interactions. In order to get an accurate measurement of the weak charge, the background of particles produced in the experiment needs to be accounted for. One particularly important background is due to π^- particles, which have the same charge as the electron and cannot be distinguished from electrons in the main Cherenkov detector as a result. To filter out the pions, a separate pion detector will be installed behind the main detector array, which will be shielded by lead and tungsten in order to prevent the high energy electrons from making it to the secondary detector while allowing the pions to continue through relatively unimpeded. Before the detector is built it is necessary to optimize the amount of lead needed to sufficiently suppress the rate of electrons detected in the pion detector.

Chapter 1

Introduction

1.1 Motivation

The Standard Model of Particle Physics is the theory of matter and interactions that describes our world at its most fundamental level. There is however ample reason to suspect that the Standard Model is not complete. For example, it does not contain gravity. Consequently, the purpose of many high energy experiments in nuclear physics is not to confirm the Standard Model, but rather to find physics beyond it. Current theory is able to predict the weak charge of the electron. If an experiment were able to measure a significantly different value, then the theory is at least partially wrong. The process of explaining the new physics by correcting current theories or creating new ones leads to a better, more complete understanding of our world. If the experiment finds that the theoretical prediction is correct, this can be used to constrain theories beyond the Standard Model.

1.2 The Goal of the Experiment

The goal of the MOLLER (Measurement of Lepton Lepton Elastic Reactions) Experiment is to measure the weak charge of the electron. Just as the electric charge quantifies how strongly a particle interacts through electromagnetic forces, the weak charge quantifies how strongly a particle interacts through the weak force. Three of the four fundamental forces in nature obey the symmetry called parity, while only the weak force violates this symmetry. Parity is the symmetry in which inversion of all the coordinate axes of a system does not change the correctness of theories applied to them. For example, Newton's Second Law (if correctly converted for the chosen coordinate system) will yield the correct result even if all coordinate axes are inverted.

The weak charge is difficult to directly measure. It can be determined by measuring the amount of parity-violating asymmetry that occurs in interactions between two particles of the same species as this asymmetry can only be caused by weak interactions. The predicted asymmetry is on the order of 35 parts per billion. Electron-electron scattering, or Mϕller scattering, is utilized in the experiment by shooting an 11 GeV beam of polarized electrons at a liquid hydrogen target. The electrons are then tracked to measure parity-violating asymmetry to a high degree of precision, estimated at 0.5 parts per billion. Electrons are not the only particles generated and detected, and they are not the only weakly interacting particles. This means that in order to get an accurate measurement for only the electrons, we must account for the measured background and correct for it.

One important background particle is the pi minus (π^-) meson. This particle will be produced in significant numbers during the experiment, and while it is much more massive than the electron(approximately 140 MeV compared to the electrons 0.5 MeV), it carries the same electrical charge. Since the experiment uses magnetic fields to focus electrons onto the detector, π^-'s will also be able to make it into the detector. This is problematic because the particles are essentially all hyperrelativistic ($v \approx c$), and consequently act the same in our detector. Since the weak charge of the pion is significantly larger than what is predicted for the electron, this could seriously affect the measured asymmetry.

The main detector apparatus will be an integrating Cherenkov detector, with quartz serving as the primary medium. Because the incoming particles will travel faster than the speed of light in the quartz, they will emit Cherenkov radiation in the form of photons. Light guides will focus these photons into photocathodes which will detect the signal produced. There will be six radial bins of detectors, located to measure the main Mϕller scattering as well as background processes. After the main barrel detector, there will be a "shower-max" detector made of sandwiched quartz and tungsten to provide a second, independent measurement.

While the main Cherenkov detector will detect both π^- particles and electrons, it is possible to isolate the signals produced by the pions through the use of a secondary pion detector. While the design for this detector has not yet been finalized, it will likely be a second Cherenkov detector with larger segmentation located behind the tungsten showermax detector and an additional layer of lead shielding. Electrons interact readily with most atoms and their energy is quickly absorbed while traveling through matter. π^- particles, in contrast, rarely interact with matter and can proceed through solid lead with relatively minor energy loss. Ideally, the amount of lead and tungsten will be enough to stop the electrons, while the pions will make it through to be detected in the secondary detector. Given the finite amount of space in the experimental hall, and the expense of purchasing lead or tungsten, we run simulations in Geant4 to determine how much lead is needed to reduce the electron rate in the pion detector.

Chapter 2

Theory

2.1 Cherenkov Radiation

Cherenkov radiation is emitted when a charged particle travels faster than the speed of light in a medium. While it is impossible for a particle to exceed the speed of light in a vacuum, in other mediums with indices of refraction greater than one this is possible. To make an analogy, while it would be extremely difficult to fire a bullet faster than the speed of sound in water (1498 m/s), it is quite easy for that same bullet to exceed the speed of sound in air (343 m/s). Similarly, while an electron is physically restricted by the speed of light in vacuum, it can travel faster than light is able to propagate through other materials. Cherenkov radiation is often compared to the sound waves produced by a supersonic object. The object itself is traveling faster than the sound waves it produces, forcing the waves to spread out conically behind it. The electron will produce a "light boom" radiating photons in an expanding cone behind it as it travels through the new medium.

As shown in the 2016 Review of Particle Physics by the Particle Data Group [1] the number of photons produced per unit path length per unit wavelength is:

$$\frac{d^2N}{dxd\lambda} = \frac{2\pi\alpha z^2}{\lambda^2}(1 - \frac{1}{\beta^2 n^2(\lambda)}) \tag{2.1}$$

α is the fine structure constant, z is the electric charge, λ is the wavelength of the emitted photons, β is defined as $\frac{v}{c}$ and $n(\lambda)$ is the index of refraction as a function of photon wavelength.

The only factors in this equation that are particle dependent are the charge z, and β. Consequently, if we show that β is approximately equal for two particles with the same charge, we can determine that they will emit the same amount of light as they travel through the Cherenkov detector (given the same path length).

Special relativity gives us the formula:

$$E = \gamma mc^2 \tag{2.2}$$

E is the total energy of the particle, γ is defined as $\frac{1}{\sqrt{1-\beta^2}}$, m is the rest mass of the particle, and c is the speed of light in a vacuum.

Simple algebra allows us to solve for β:

$$\beta = \sqrt{1 - (\frac{mc^2}{E})^2} \tag{2.3}$$

Using $m = 0.511 \frac{MeV}{c^2}$ as the rest mass of an electron, and setting E = 1 GeV, we find that for a 1 GeV electron $\beta = 0.9999999$.

With $m = 139.57 \frac{MeV}{c^2}$ as the rest mass of a π^-, and also setting E = 1 GeV, we find that $\beta = 0.990$. The ratio of the β values of a 1 GeV π^- and a 1 GeV electron is 0.990000 which means the difference is negligible.

Given that electrons and π^-'s have the same charge, and a negligible difference in velocity on energies scales of GeV, Equation 2.1 tells us that the two particles will emit the same amount of Cherenkov light as they travel through a given material. This demonstrates the necessity of a separate detection system for pions, as there is no way to distinguish them from electrons in the main detector.

2.2 Parity Violation

Parity violation occurs when a system behaves differently depending on the signs of the coordinate axes. In electromagnetic, strong and gravitational systems parity is conserved. The weak force interacts differently with particles depending on their helicity, i.e. "handedness" or the direction of their spin. In general, this can be described as shown in the Review of Particle Physics (2014 Edition) by the Particle Data Group [2]

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \quad , \tag{2.4}$$

A is the asymmetry, and $\sigma_{R,L}$ is the cross-section for the scattering of a right or left-handed electron.

For polarized Mϕller scattering in a fixed target the parity violating asymmetry, A_{PV} can be expressed as: [2]

$$\frac{A_{PV}}{Q^2} = -2g_{AV}^{ee}\frac{G_F}{\sqrt{2}\pi\alpha}\frac{1-y}{1+y^4+(1-y)^4} \quad , \tag{2.5}$$

Q^2 is the momentum transfer, y is the fractional energy transfer between the electrons, $g_{AV}^{ee} = 0.0190 \pm 0.0027$, G_F is the Fermi constant and α is the fine structure constant.

Chapter 3

Experimental Technique

Before a large nuclear physics experiment is run, it is necessary to run simulations to inform the process of designing the detector. The MOLLER Collaboration primarily runs simulations using Geant4, a software framework designed by CERN to track the propagation of particles in matter. My research uses a customized code base, called remoll, that comes with added functionality and geometry for the MOLLER Experiment. The remoll code base allows a user to specify the detector geometry using a language called GDML (geometry detector markup language). Remoll has both a Mϕller electron generator and a pion generator (along with others). These generators can be thought of as essentially particle sources that shoot specific particles, simulating the outcome of reactions in the liquid hydrogen target. While the simulation runs through each "step" the particle takes, i.e. what it does as it travels some distance dx, data is only recorded when a particle passes through a "sensitive volume."

Geometry is specified in GDML using three steps. First, a shape is defined, the physical dimensions, such as length, width, radius and thickness are set here. Second, a shape is used to create a "logical volume." This is where the material the shape is to be made out of is set, along with auxiliary parameters. These additional parameters can be used to specify whether a volume will be "sensitive" and serve as a detector. They also allow the detector to be assigned a number, which can be used during analysis to select only the hits on that detector. Lastly, a logical volume is used to specify a "physical volume." This is where the physical position is specified in the simulation. At present, the detector apparatus has not been finalized, so the geometry in use is greatly simplified for my purposes. This means that rather than try to simulate optical photons traveling through a light guide, I have basic disc detectors that tell me what crosses a boundary. These discs have their material specified as vacuum, meaning they don't affect particles traveling through them. Below, Figure 3.1 depicts a rendering of the geometry I used in the simulation, while Figure 3.2 depicts a view in profile of the various detectors.

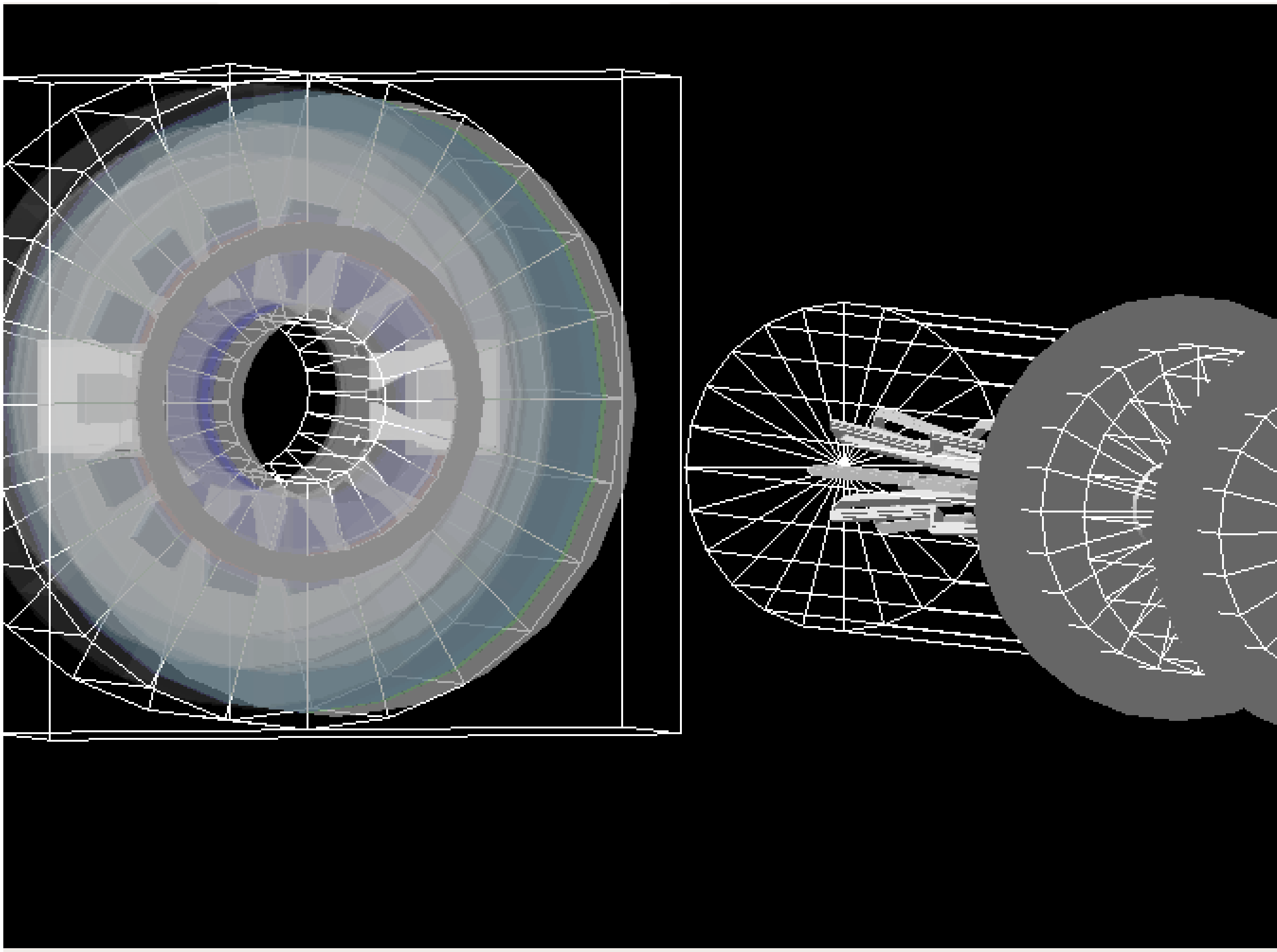

Figure 3.1: Pictured above is the rendered geometry used in the simulation. The discs to the right are sensitive volumes at the positions of the two collimators (not visible). In the center is a portion of the toroidal magnet, and left is a series of disc detectors as well as the tungsten showermax and lead doughnut.

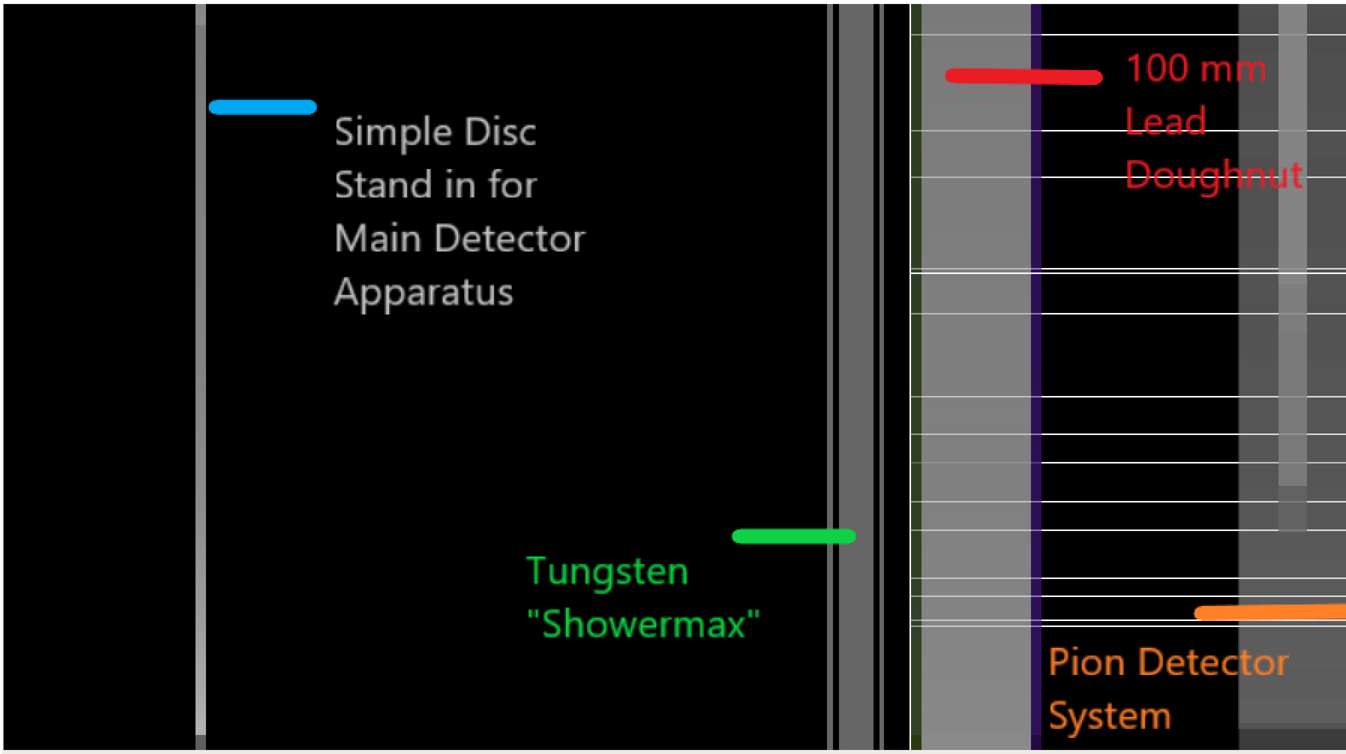

Figure 3.2: Pictured here is a cross sectional view of the detector geometry in place for my simulations. The total distance depicted is around one meter.

Data from the simulations is stored and analyzed using ROOT, a C++ based plotting and analysis software used extensively in high energy physics. Root allows data to be stored in a hierarchy of trees, branches and leaves, meaning that many different parameters can be organized and accessed with ease. Whenever a particle crosses the boundary of a sensitive volume (there are measures in place to prevent double counting the same particle), a large amount of data about the particle is stored in a root file. The data stored includes the energy and momentum (both the magnitude and x, y, z components), the position of the hit in x,y,z, the type of particle (given by a particle ID number), the event cross section and a rate weighting factor among others. This is more information than we would actually have access to in the experiment as there is, after all, no Laplacian demon to neatly label each particle as a discrete and distinguishable entity. However the information is useful for understanding what goes on in the simulation (e.g. identifying whether an unexpected behavior is a bug in the code or something that wasn't accounted for in the physics).

In general, high statistics are preferable for these simulations, meaning that it is much faster to split a ten million event simulation into 100 smaller ones, which can be run separately and then recombined later. This is done using Jefferson Lab's computing cluster. Once the root files are written, they can be pulled into an analysis script together and every individual hit recorded by a sensitive volume in the simulation can be iterated through. Cuts for particle ID, detector number, energy and other parameters can then be placed so that histograms can be filled with relevant data and plotted. A large part of my research involved creating and interpreting histograms.

Chapter 4

Results and Conclusions

4.1 Results

We want the lead to be thick enough that the electron rate is suppressed below that of the π^- particles. This would mean that even though pions are relatively scarce numerically, after going through the tungsten showermax and lead barrier, there will be more pions per unit time than electrons (and positrons since there isn't any distinction in the Cherenkov detector).

In addition to the rate, the energy of the particles is also important to understand. Energy not only affects the velocity of a particle as shown in Equation 2.3, but also how much material it can be expected to travel through. Particle energies tend to decrease much more noticeably than their rates, which allows them to provide information on the suppression of the particles that may not be evident from only their rate.

There are three detectors of particular interest to this research, the detector in front of the showermax, the detector behind the showermax, and the detector behind the lead.

We want to answer two questions about the showermax. First, what portion of primary electrons go on to produce "offspring" that leave the showermax. Second, what is the multiplicity on generated electrons.

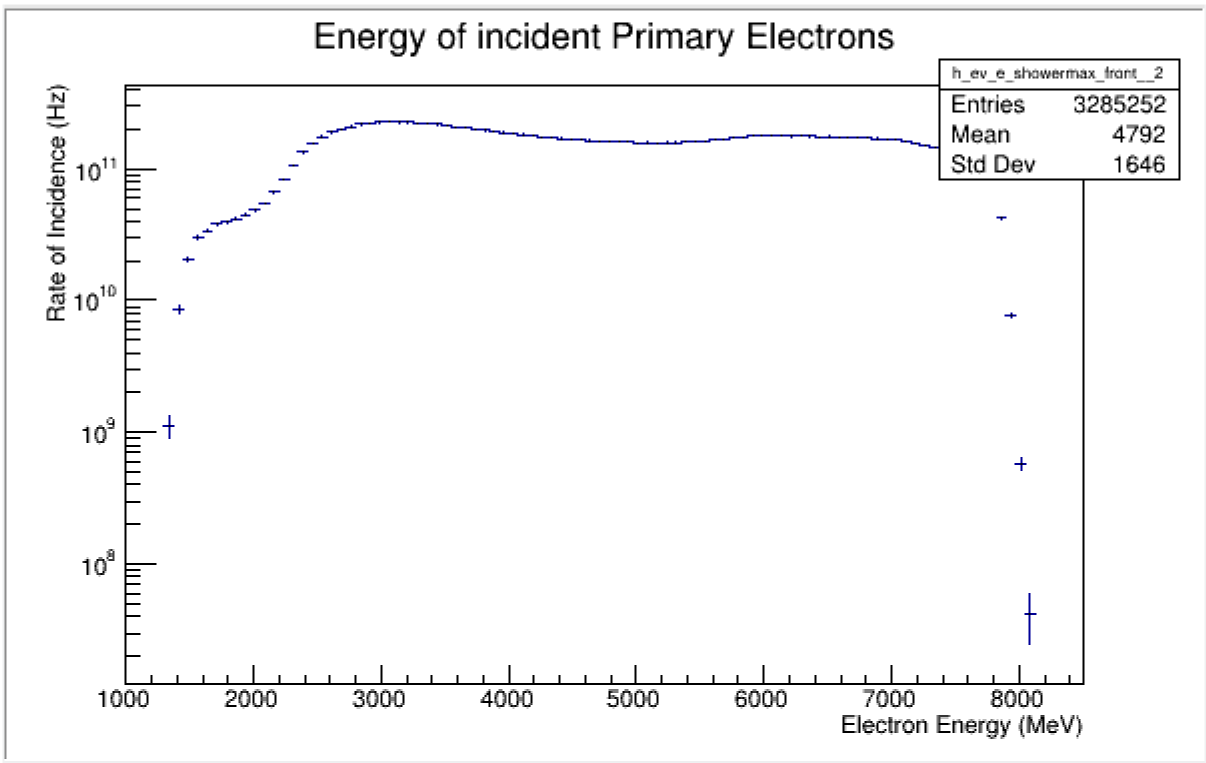

Figure 4.1: The energy spectrum of primary electrons incident on the showermax is shown. Note that the Y-axis is set to a log scale

The designation "primary" simply means that the electron was a Mϕller scattered electron produced at the start of the simulation, rather than an electron produced through secondary means such as pair production. As seen in Fig 4.1, out of 8.2 million events thrown, 3.28 million primary electrons hit the showermax, with a mean energy of 4.79 GeV and a rate typically on the order of 100 GHz (10^{11} Hz).

Also note that there are few electrons below 2 GeV, and almost none above 8 GeV, with a featureless distribution betweeen these limits. This plot is effectively the "input" of unsuppressed electrons.

The showermax is designed to catch the showers of electrons coming off the main detector. Tungsten is a very dense material, and has more stopping power than lead. This means that there is a high probability that the electrons hitting it will interact and shower off the tungsten itself (The actual detector will not be a solid block of tungsten but this provides a reasonable analog to the affect it will have on electrons passing through).

Prior to the showermax, with the current simplified geometry, the generated electrons either have their tracks killed on contact with the collimators, or pass through ≈ 28 meters of vacuum to get to the showermax. The electrons can lose energy, but the loss is relatively small, and almost all the incident electrons were generated in the target rather than through secondary processes. In contrast, virtually all the electrons coming out of the showermax were produced somewhere in the bulk of the showermax.

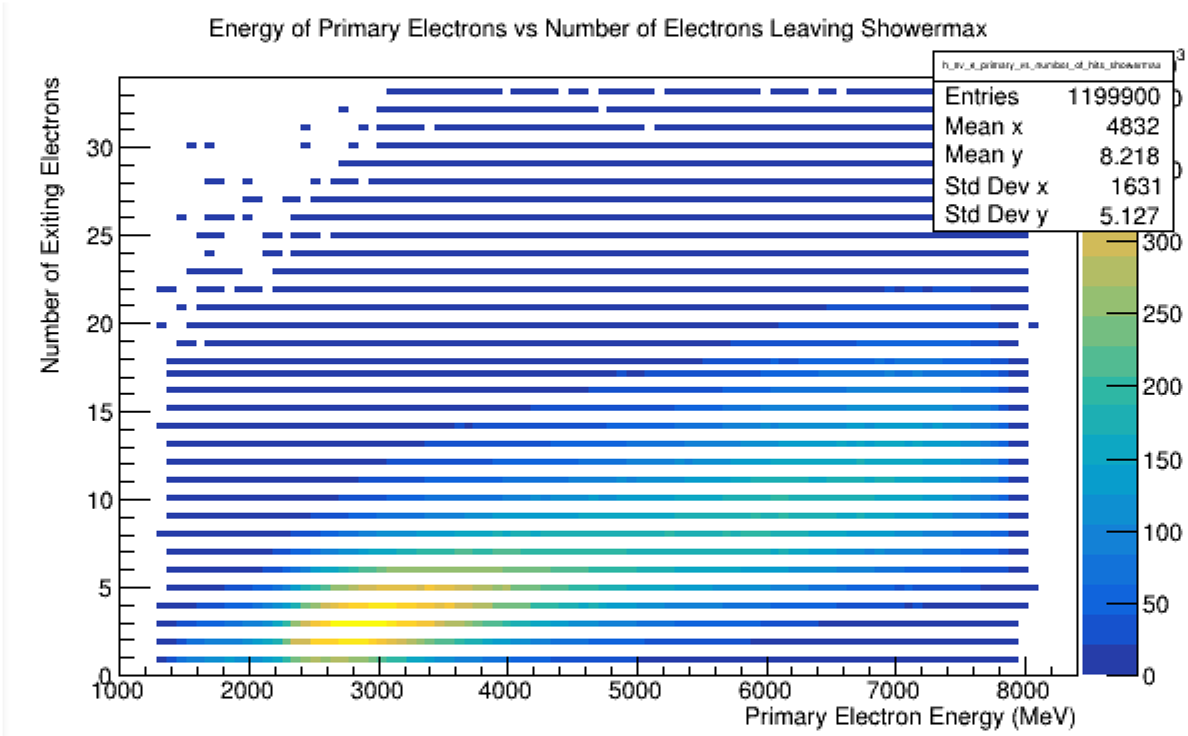

Figure 4.2: The correlation between the energy of incident primary electrons and the net number of exiting electrons is shown. The plot has coloration to indicate the density of data. Due to the fact that there can only be integer numbers of electrons, the plot takes the form of horizontal lines.

Due to the way the collimators are designed only one Mϕller electron can make it into the detector per event thrown. Only those primary electrons that had offspring are shown in Fig 4.2. Out of the 3.28 million incident electrons, only 1.2 million produced electrons that left the showermax. This may sound like the net number has decreased however the mean number of exiting electrons was 8.2. This means that about 63 % of the incoming electrons interacted with the tungsten in such a way that no electrons came out the back of the showermax. The other third of the primaries produced 8.2 exiting electrons on average. In total the net number of electrons has increased after the showermax.

The color scaling of this plot shows that while a single incoming electron could produce up to 33 exiting electrons, the majority of the time there were between 3 and 15 exiting electrons. There is a linear trend with higher energy primary electrons tending to produce more exiting electrons.

One consideration is that most of these electrons are relatively low energy. In fact more electrons are produced than shown, however a 1 MeV minimum energy is required for an electron to be counted, the reason being that even if an electron below that energy reaches the detector it is unlikely to produce much light due to the short path length expected. That said, the raw number of electrons incident on the lead (which is to say exiting the showermax), is not necessarily a useful metric as most of them will not make it very far in the lead (being low energy). Instead we can look at the net energy of all the electrons produced by a single primary. This will indicate how much energy was actually deposited in the lead from that primary.

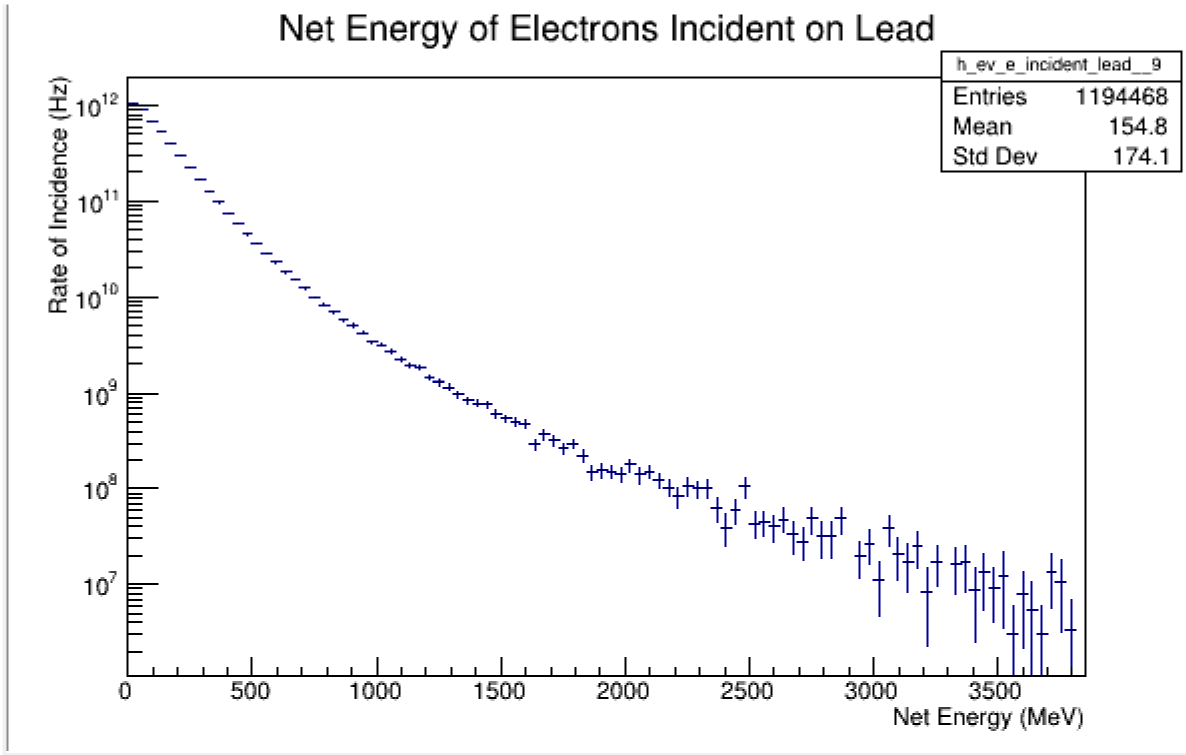

Figure 4.3: The net energy of electrons incident on the lead per event. First note that the Y axis uses a log scale, and in fact this plot indicates an extreme bias towards lower energies (< 500 meV). This is reflected in the fact that the mean energy has dropped from 4832 MeV to 154.2 MeV. This indicates that the showermax absorbs the vast majority of incoming energy.

While the mean energy has decreased drastically the peak rate we observe has actually increased (from about 100 GHz up to 1 THz) in Fig 4.3. This is due to the high multiplicity of electrons leaving the showermax. However, while the overall rate has increased the rate of higher energy electrons has decreased markedly.

Of course, this suppression is an unintended side effect of the showermax. It is designed to provide a second, independent measurement of the particles detected in the main detector. The fact that the tungsten it uses serves as additional shielding for the pion system is not intended, however we need to account for this to accurately determine the amount of lead needed.

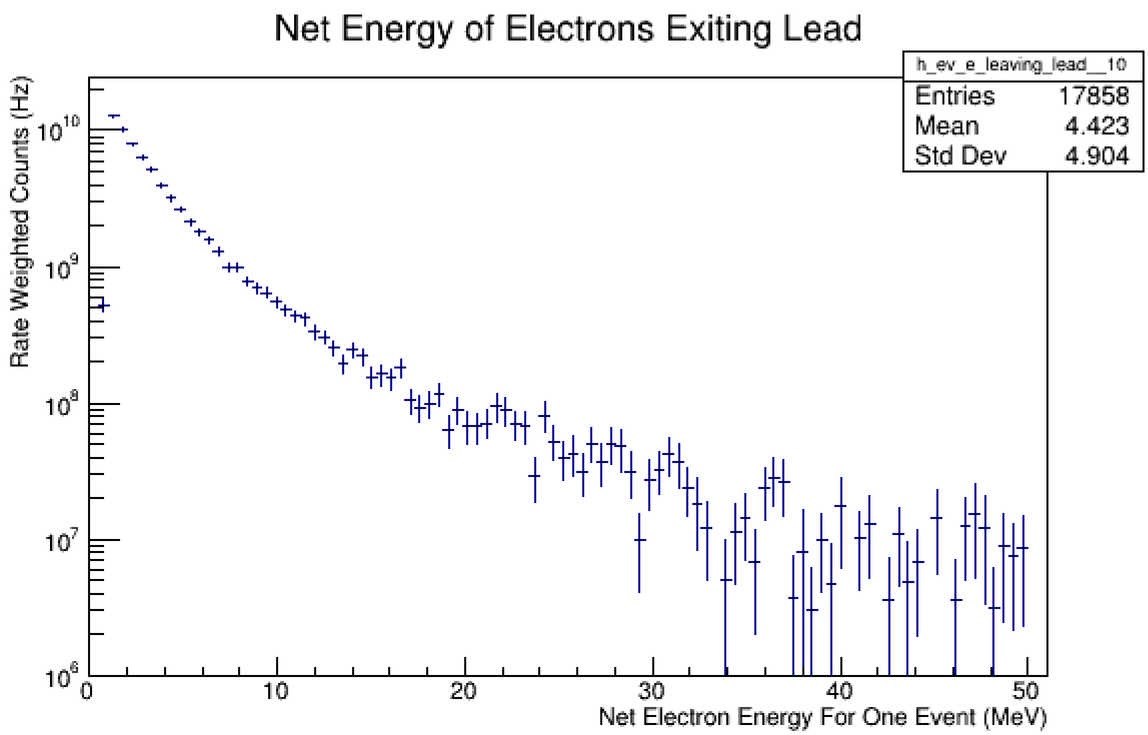

Figure 4.4: After the 100 mm of lead, there are very few electrons remaining, and those that do have lost almost all their energy. While this plot depicts the net energy of electrons, the multiplicity of exiting electrons was 1.05 per event, meaning that essentially, regardless of how many electrons it generated, a primary will not go on to have multiple electrons exit the lead.

Compared to the 3.28 million incident primary electrons, Fig 4.4 shows that only 17,858 electrons made it through the lead. The mean energy has decreased in total from 4832 MeV to 4.42 MeV. This is a reduction in mean energy by over 1000 times, however the peak rate has only fallen by an order of magnitude. Even if we were extremely generous and took the average rate to be 100 MHz, this is not the degree of reduction that we initially expected. Furthermore, if we were to account for positrons produced we would expect the rate to roughly double (since most of these electrons would be generated via pair production). With that said, what matters is how the pion rate compares, not the absolute magnitude of the rate we see.

As we talk about pions it's important to make note of several things, firstly the pions produced in the experiment will be at a ratio of 100 or 1000 to 1 with electrons. This is important because the pion simulations effectively shot a beam of ten million π^- particles which makes the data for the pion simulations disproportionate to the electron simulations. Rate weighting will account for this, however the raw number of events will not. Secondly, while the data set used for the electron plots above only pulled in 8.2 million events (10 million were submitted, however only 8.2 million were ultimately written to tape), the data set used for the pions had 10 million events, meaning that it has approximately 22% more data. The statistics are sufficiently high that this will not cause any discrepancies in the actual distribution, but will require a factor to be applied to compare the numbers of particles. Thirdly, pions have a rest mass of $\approx 140\frac{MeV}{c^2}$. This is notable because a low energy pion will have at least that much "energy," despite the fact that it may have less momentum than that. Consequently the energy distributions depicted are actually momentum distributions to avoid having this offset. Lastly, the term "pion" technically refers to three different mesons π^-, π^+ and π^0, which refer to the negative pion, positive pion, and neutral pion respectively. However I will use the term to only refer to negative pions, as the other types can largely be ignored for the purposes of this experiment.

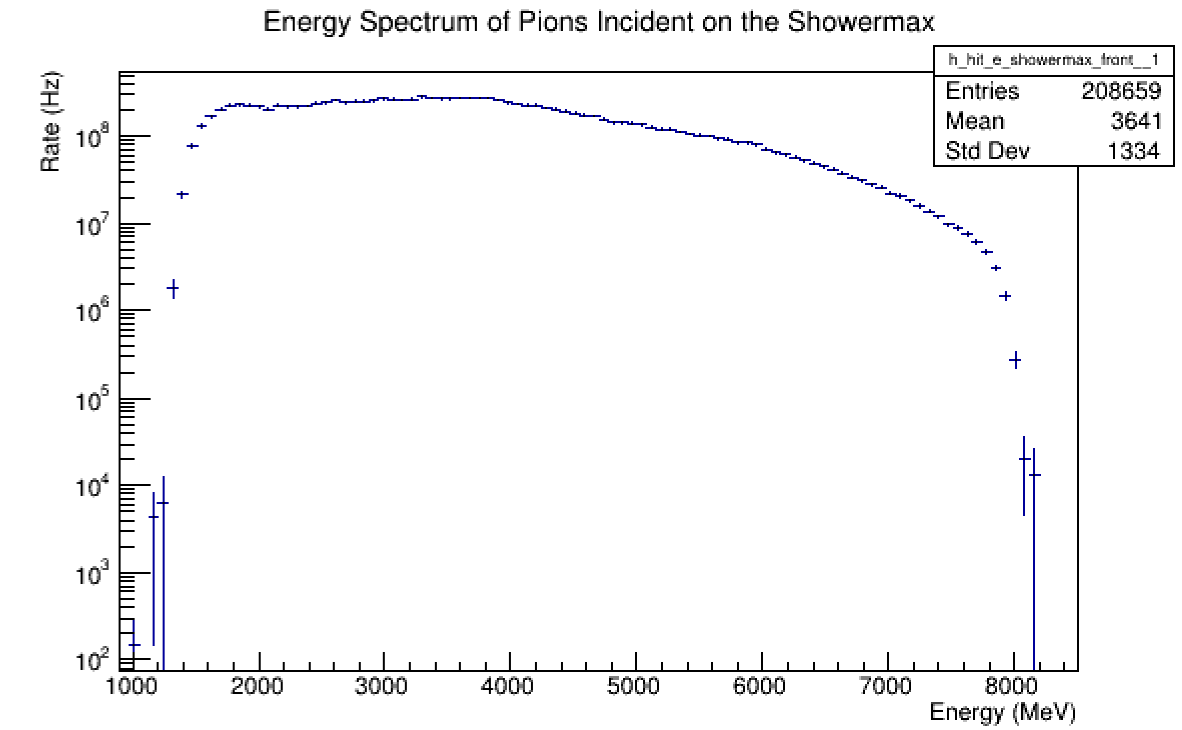

Figure 4.5: The energy spectrum of pions incident on the showermax. The spectrum appears to only cover the range between 1 and 8 GeV and has a mean energy of 3.64 GeV. The pions seem to almost all have a rate on the order of 10^8 Hz, or 100 MHz

Of the 10 million pions thrown, only 208,000 make it to the showermax as seen in Fig 4.5. Part of the reason for this is that the simulation throws pions in a full 360 degrees with respect to phi, meaning that about half of the 10 million are actually thrown backwards in the lab frame. There is no physical reason for this behavior, it's simply how the parameter was entered in the source code. While throwing over the full angular range does not affect the physics, it is inefficient and should be changed in the future.

Another reason that so few pions make it to the showermax is because the pions occupy a larger radial range than the electrons. The relatively narrow showermax only accepts a fraction of the total pions on its plane of incidence.

Despite the fact that the number of incident pions is small compared to the amount thrown, there are enough events for good statistics. As mentioned previously, the actual number of pions doesn't matter so much as the relative decrease due to suppression.

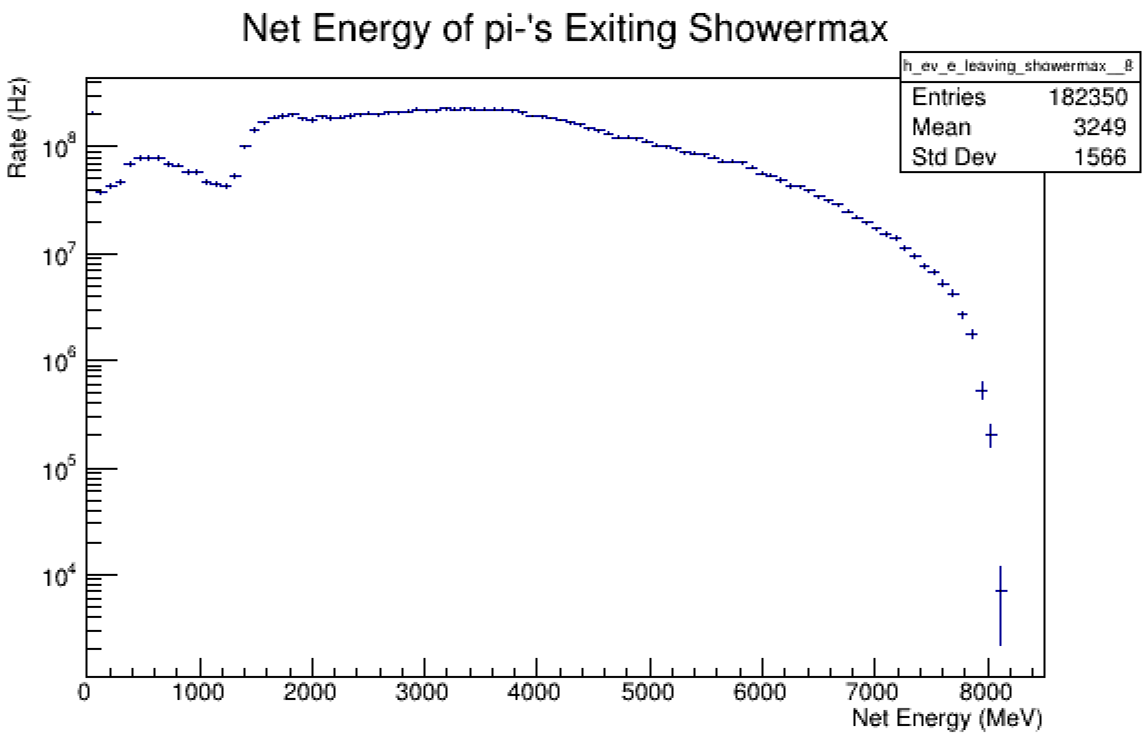

Figure 4.6: Depicted is the energy spectrum of pions exiting the showermax. This is a "net" spectrum meaning that it includes cases where multiple pions left the showermax from a single event, however such cases are extremely rare so there is a negligible difference between the net energy and the energy per event.

Unlike the incident spectrum, Fig 4.6 shows that pions exiting the showermax (which is functionally the same as being incident on the lead) cover the entire range from 0 to 8 GeV, whereas previously there were little to no pions below 1 GeV. There is a feature at low energies where there appears to be a wedge shaped depression in an otherwise smooth curve. This is most likely due to geometry, with some pions exiting the showermax at a larger angle and missing the detector. Regardless it occupies less than an order of magnitude so it doesn't appear to be indicative of any major trends.

Compared to the 208,000 incident pions, 182,000 made it through the showermax. This attrition rate is actually lower as most of the pions were "lost" from radial spread rather than from interaction with the tungsten. However for the purposes of what the detector "sees" it looks like a roughly 10 % decrease in number. The mean energy has gone down from 3640 MeV to 3249 MeV, which is relatively small, especially considering the electron mean energy dropped by more than a factor of 30 passing through the same material. Also of note is that the rate appears largely unaffected still appearing to average on the order of 100 MHz.

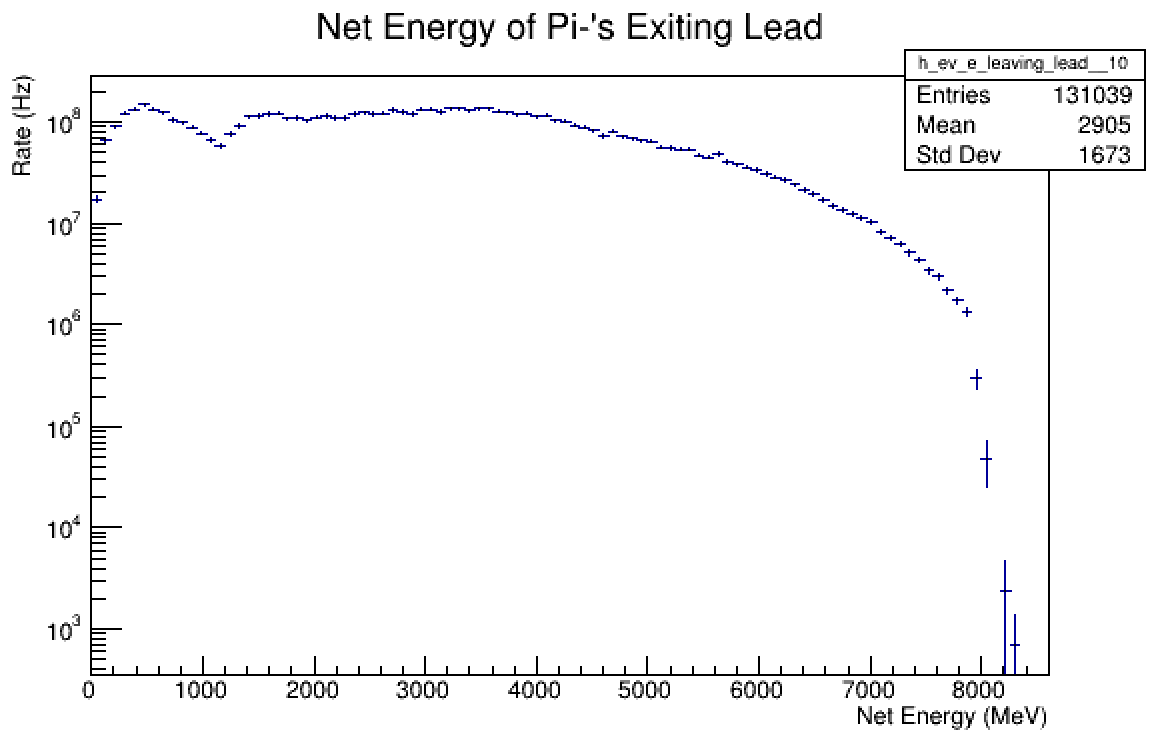

Figure 4.7: the energy distribution of pions exiting the lead. The spectrum appears very similar to the one shown in Figure 4.6, however while still present, the depression below 1 GeV has been lifted up more in line with the curve. The bump at the far left was also present in 4.6, however here it is completely insignificant with less than a $10^{0.1}$ height.

In Fig 4.7, we see that there were 131,000 pions that left the lead, compared to the 182,000 that were incident on it and the 208,000 that were incident on the showermax. This gives approximately a 35 % decrease in net number after the showermax + lead combination.

In total the mean energy decreased from 3641 MeV to 2905 MeV, which amounts to a difference of roughly 750 MeV. In contrast the rate still seems largely unaffected, hovering around the order of 100 MHz even after passing through both the showermax and lead.

4.2 Conclusions and Future Plans

At this point the groundwork has been laid to optimize a more accurate amount of lead for the experiment. The showermax contributes an effective 51.25 mm of lead (tungsten having ≈ 62 % the radiation length of lead), giving a total effective amount of 151.25 mm for the data analyzed. This amount is enough to suppress most electrons down to the order of a single MeV. However the peak electron rate is barely suppressed and the average rate is still higher than the pion rate after all the material. The pions in contrast lose relatively little energy, remaining for the most part above 1 GeV. The pion rate is largely unaffected by the presence of lead, which indicates that this technique should allow us to ultimately get the results we want, namely suppressing the electron rate to at least 1-1 with the pion rate.

The electron rate may approximately double with the inclusion of positrons in the analysis, however I do not anticipate this being an issue. Were we to only look at the rate suppression, it seems as if the increase in rate from the multiplicity of electrons exiting the showermax largely cancels out the decrease in rate from traveling through the lead. This would indicate that significantly more lead would be needed.

However, taking into account the final energy spectrum of the electrons, and the fact that in order for them to be detected they must travel through lucite to emit Cherenkov radiation, the actual amount of lead required may be close to 100 mm.

The reason for this is that the current analysis uses what could be considered an overly optimistic 1 MeV threshold for particle energy. While this may be enough for electrons to produce light within the lucite (a 1 MeV electron travels at $\approx 0.86c$), we would not expect them to travel far through the lucite at this energy. The amount of Cherenkov light produced is dependent not only on the speed of the particle, but also on the amount of distance it travels through the medium. Figure 4.4 shows that the difference in rate between 2 MeV and 4 MeV is most of an order of magnitude. Considering the logarithmic scale, raising the minimum energy to 3 MeV would lower the peak rate a significant amount.

Another consideration is the fact that even a 50 MeV electron is unlikely to travel far through lead. I would expect a precipitous drop in electron rate as lead is increased from 100 mm, simply due to the fact that the electrons have very little energy to give up at this point. After a few more radiation lengths (the amount of distance an electron needs to travel on average through a material to lose half its energy), its highly probable that most of the remaining electrons will be absorbed by the lead. Given that the radiation length of lead is 5.6 mm, I would estimate that 125 mm of lead should be sufficient to bring down the electron rate to a comparable, or even lower level than the pion rate.

In the future, I would recommend that a simulation be run with 125 mm of lead. After which true optimization can begin by moving the thickness of the lead up or down in small increments until the rate has dropped to a sufficient level. Afterwards, it will be necessary to implement a more realistic geometry, simulating optical photons traveling through the detector apparatus rather than using the simple counting detectors currently implemented. From there corrections can be made to the original estimate as needed.

Bibliography

[1] C. Patrignani et al. (Particle Data Group), Chinese Physics C, 40, 100001 (2016) Section 33.7

[2] K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014) pages 139-144.