Background Estimates of Radiative Pion and Muon Capture for Mu2e Experiment

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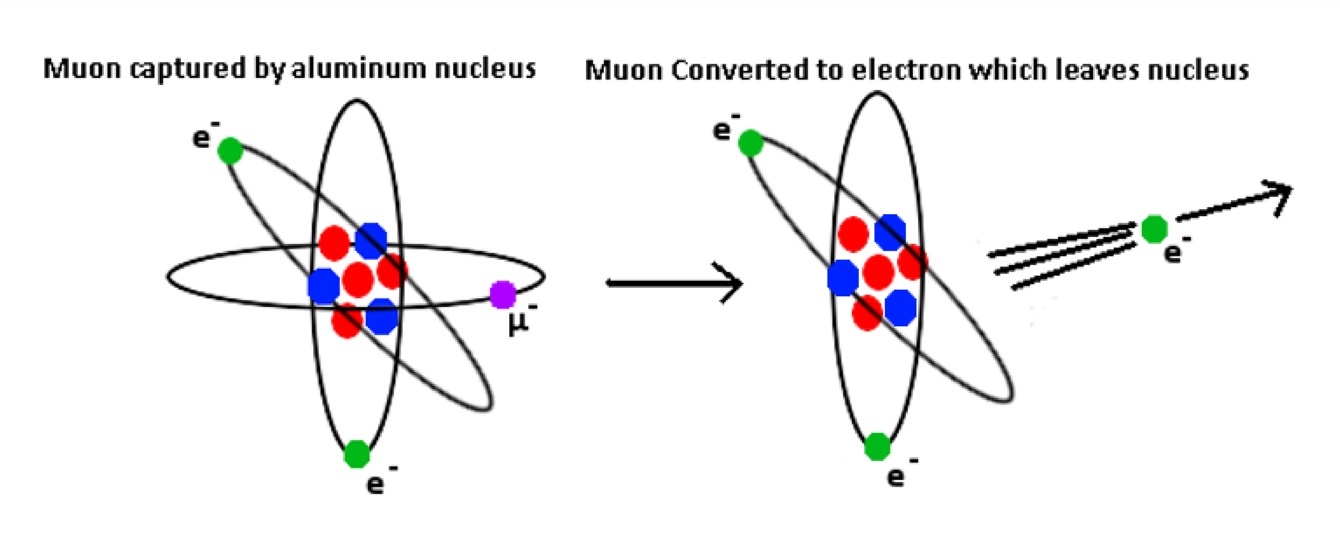
Big Picture

The Mu2e experiment seeks to observe muon-electron conversion.

$$\mu^- + {}^{27}\text{Al} \rightarrow e^- + {}^{27}\text{Al}$$

A muon interacts with an aluminum nucleus and is converted into an electron, which emerges with momentum and energy on the magnitude of the muon's mass (~106 MeV).

This conversion process is an example of lepton flavor violation which is when lepton family number is not conserved. This has never been observed experimentally, and according to the standard model of particle physics it has essentially a zero chance of happening. If the experiment succeeds, then it will serve as evidence that there is new physics beyond the standard model.



Experiment Setup

Production Solenoid

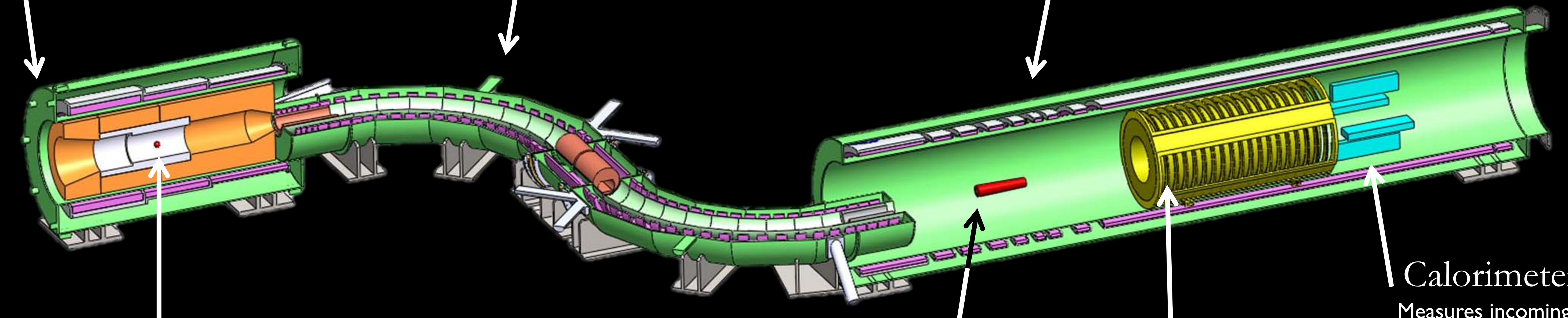
Here the production target is hit with an 8 GeV (10^9 eV) proton beam which produces many particles, the most important being pions.
Graded magnetic fields cause many particles to flow into the transport solenoid.

Transport Solenoid

The shape of this solenoid combined with the magnetic fields force many of the unwanted particles to exit the system and the experiment. Positive, neutral, heavy, and light particles will be filtered out. Ideally, only negatively charged pions and muons will make it to the detection solenoid.

Detection Solenoid

This is where the aluminum stopping target is placed and where the muons will interact and convert into electrons. The tracker is designed to detect electrons with a transverse momentum larger than 100 - 105 MeV.



Production Target

Aluminum Stopping Target

Tracker
Measures incoming particle momentum

Calorimeter
Measures incoming particle energy

Radiative Pion Capture (RPC)

Because the decay of particles is a probabilistic process, there will be a number of pions that don't decay. Therefore, if any surviving pions make it to the muon stopping target they can interact in the following way:

$$\pi^- + {}^{27}\text{Al} \rightarrow \gamma + X$$

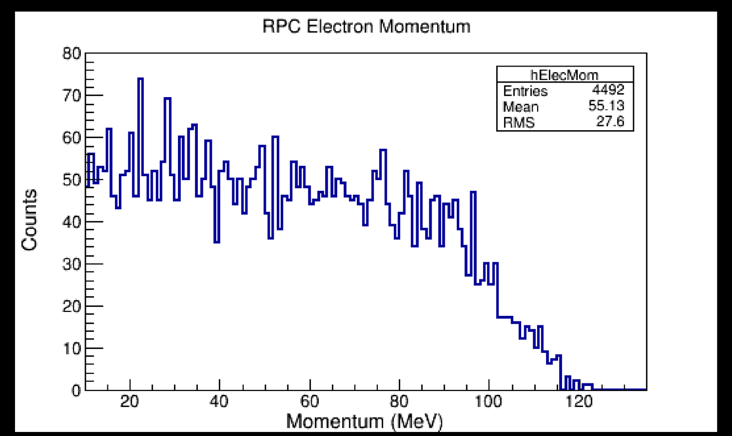
The X represents that there will be more than one nuclear state which suggests the energy of the photon will not be monochromatic but rather follow a spectrum structure. This makes the background harder to estimate.

Radiative Muon Capture (RMC)

RMC is similar to RPC. In this process, a muon converts into a photon and a neutrino, described by the following equation:

$$\mu^- + {}^{27}\text{Al} \rightarrow \gamma + \nu_\mu + \text{Mg}$$

In both RPC and RMC, the pion or muon gives some of its energy to the photon which can produce an electron-positron pair. If the photon is energetic enough, there is a chance that the electron produced has a similar momentum and energy to an electron produced from muon-electron conversion (~105 MeV). **This means that this electron could be confused with a Mu2e electron which poses a problem.**



C.

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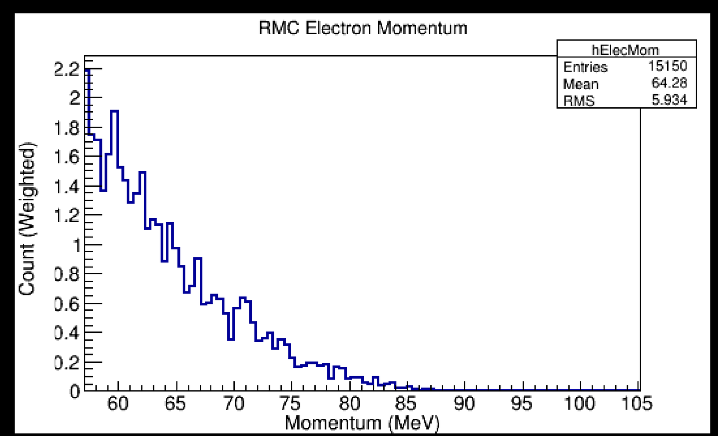
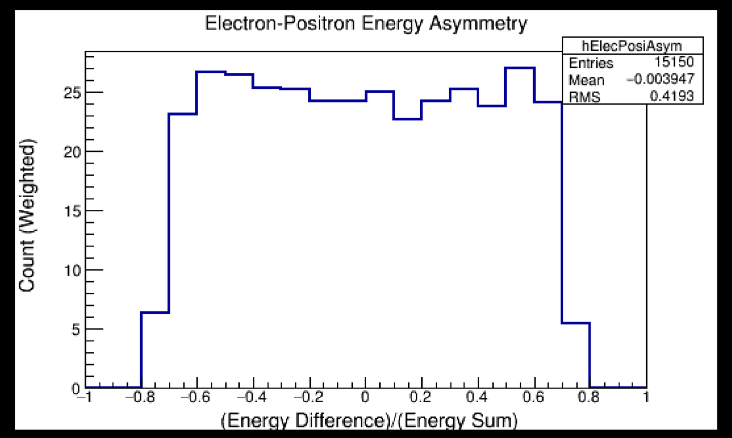
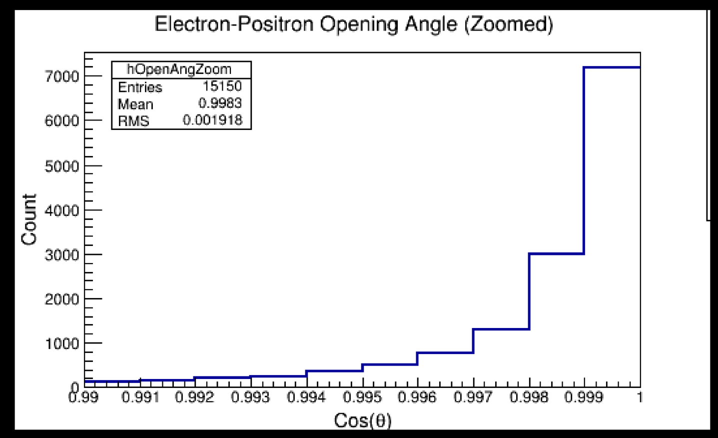




E.

F.

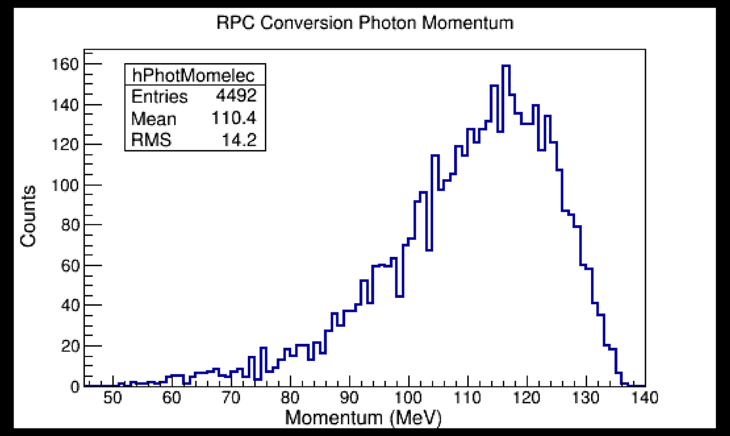


Approach to the Problems of RMC and RPC

One way to estimate the amount of background from RPC and RMC is to directly measure it. To do this, the number of conversion photons which produce electron-positron pairs must be known. Simulation software provides an estimate of the number and energies of conversion photons and electron-positron pairs. The following histograms were made using one million photons and describe some of the physics of RPC and RMC.

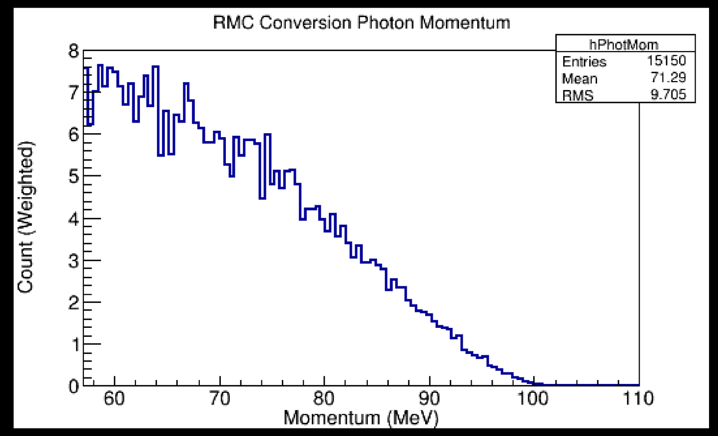
(RMC histograms took into account a larger geometry and therefore have a larger conversion rate and amount of entries).

RPC and RMC Histograms



A.

B.



A & B) These photon momentum distributions of RPC and RMC show that around to 0.4-1.5 % of total photons ended up being converted into electron-positron pairs. The spectrum shape of these processes can also be seen.
C) The majority of RPC electrons have between 20 and 80 MeV of momentum, however many still have momentum in the signal range (100-105 MeV) which is the quintessential problem that RPC poses.
D) The photon momentum was weighted where 57 MeV is the lowest known momentum where the weighting applies.
E) Asymmetry calculations show that neither the electron or positron is preferred when energy is distributed from the photon.
F) Opening angle refers to the initial angle between electron and positron momenta. They roughly head in the same direction.

Conclusion

The results of simulation show that 0.4% - 1.5% of RPC and RMC photons convert into an electron-positron pair. Taking into consideration experimental conditions the Mu2e experiment can expect to see around 150 billion pairs produced in the experiment. If Mu2e chooses to take the approach of direct measurement of RMC and RPC, it will not only account for the background, but also provide valuable data on those processes for potential other use.

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