

Measuring the Lifetime of Cosmic Ray Muons Using One NaI Scintillation Detector

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Abstract

Cosmic rays are energetic particles from outer space that penetrate and interact with the atmosphere, producing more particles. One of these particles that reaches the surface of the Earth is the muon. A muon is a "heavy" lepton (the same family as electrons) with a mean lifetime of 2.2 microseconds. Muons lose their energy continuously as they penetrate materials, like detectors, and some of them stop and decay inside the detector. I am measuring the mean lifetime using a sodium iodide (NaI) scintillation detector and nuclear instrumentation modules (NIMs).

Background

Cosmic rays are energetic particles coming from outer space; they are mostly protons, elements' nuclei, and electrons. When they collide with the upper atmosphere they create more particles, like the pions. Charged pions have a very short mean lifetime of 26.033 nanoseconds; they decay to muons and neutrinos. Muons (μ^+ and μ^-) are elementary charged particles of the leptons family, with a charge of 1 electron charge (e) and spin of half. Muons lose their energy continuously as they penetrate materials, and if they lose all their kinetic energy to a medium, they will stop in it. A muon's mean lifetime is 2.2 microseconds. Muons decay into electrons or positrons, neutrinos and antineutrinos. They are detected when they arrive at a scintillation crystal, and they are detected if they decay inside the crystal too. My goal is to use thallium-doped sodium iodide (NaI) scintillation detector (fig.1 and fig. 2) and nuclear instrumentation modules (NIMs) to measure the mean lifetime of the cosmic ray muons that reach the Earth's surface.

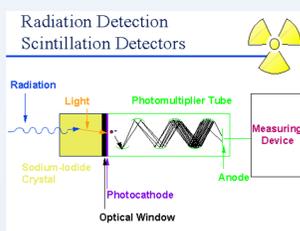


Fig. 1



Fig. 2

Setup

I am using a 9-inch NaI detector (fig. 2) and NIMs as outlined in the diagram in fig.3. The used NIMs (fig. 4) are TC 241 amplifier, TC 451 Single Channel Analyzer (SCA), TC 862 time-to-amplitude converter (TAC), and TC 412A delay. The final output goes to a UCS 30 multichannel analyzer (MCA).

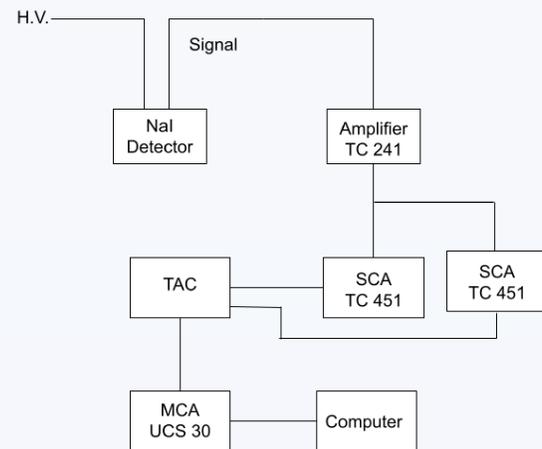


Fig. 3

The NaI detector produces a negative-going pulse (fig. 5) when a particle, such as a gamma photon or a muon, causes scintillation in it. Then the signal is being amplified by the amplifier, which has a positive-going output pulse. An input and output signal of the amplifier are shown simultaneously in fig. 6.



Fig. 4

The output goes to two SCAs, which "filter" the output by allowing only a certain window for the signal: if the signal is within this window the TAC sends a signal out (fig. 7), otherwise it does not send any output. By knowing the coming muons energy range, this window is adjusted to allow the detection of the muon arrival and muon decay signals. Then I introduced a range of delays using the delay NIM to calibrate the TAC and test the system.

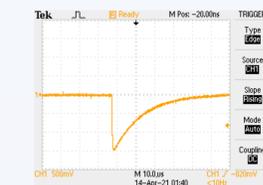


Fig. 5

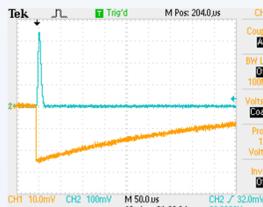


Fig. 6



Fig. 7



Fig. 8

Results and Discussion

I have tested and calibrated the NaI detector by taking gamma spectra of different radioactive isotopes including Na-22 (fig. 9).

By adjusting the detector's high voltage and the amplifier gain, I took a spectrum of cosmic ray muons depositing their energy into the detector (fig. 10 and fig 11).

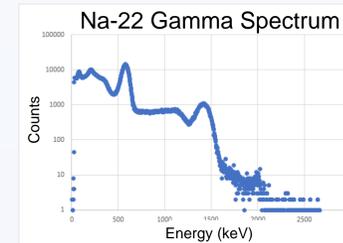


Fig. 9

Fig. 10 uses a logarithmic scale, while fig. 11 is a close-up of the muon peak with a linear scale. The spectrum was taken over 4 days.

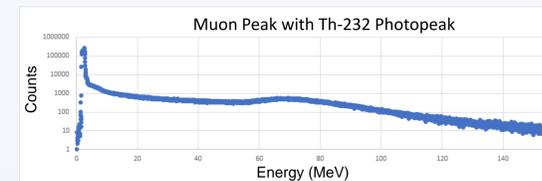


Fig. 10

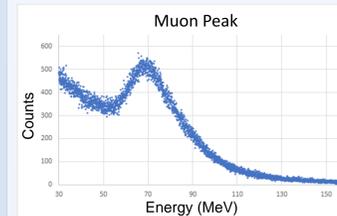


Fig. 11

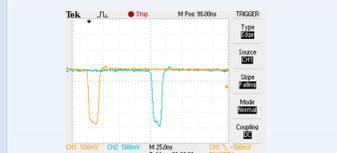


Fig. 12

The TAC output is triggered by a start and a stop pulse (fig. 12), and its output is proportional to the delay between them (fig. 8).

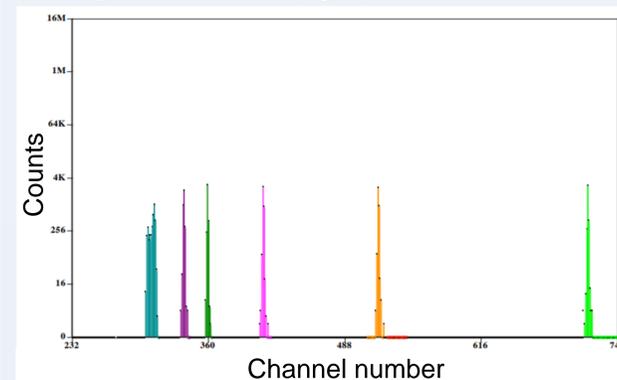


Fig. 13

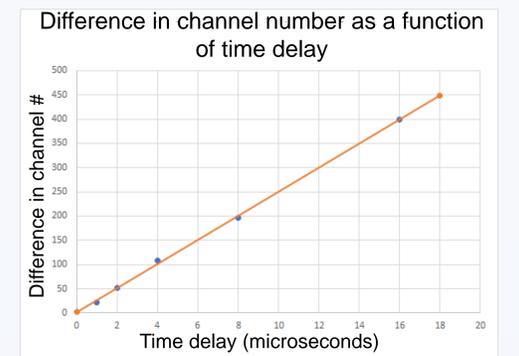


Fig. 14

I did not get any coincidences using this setup, and we think this is due to the detector's inability to resolve the difference between the consecutive signals of the muon arriving and the muon decaying. A plastic scintillator has a shorter output signal width and could solve this issue, but we do not have one available. While we are waiting for a plastic scintillator, I built a variation of the system with two NaI detectors shielded by lead and iron blocks as shown in fig. 15. The goal is to detect a muon coming into the upper detector as the start pulse and its decay in the lower detector as the stop pulse. The data I collected in 20 hours is shown in fig. 16, but I still need about 8-10 more days of data before I can analyze and interpret it.



Fig. 15

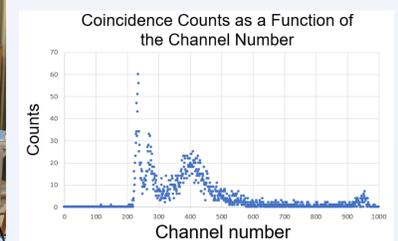


Fig. 16

References

- Melissinos, A. C., & Napolitano, J. (2011). *Experiments in modern physics*. Academic Press.
- Ho, C. Y. E., *Cosmic Ray Muon Detection using NaI Detectors and Plastic Scintillators*: <https://home.fnal.gov/~group/WORK/muonDetection.pdf>
- https://www.ntanet.net/wp-content/uploads/2015/09/radiation_Detection_scintillation_detectors.gif