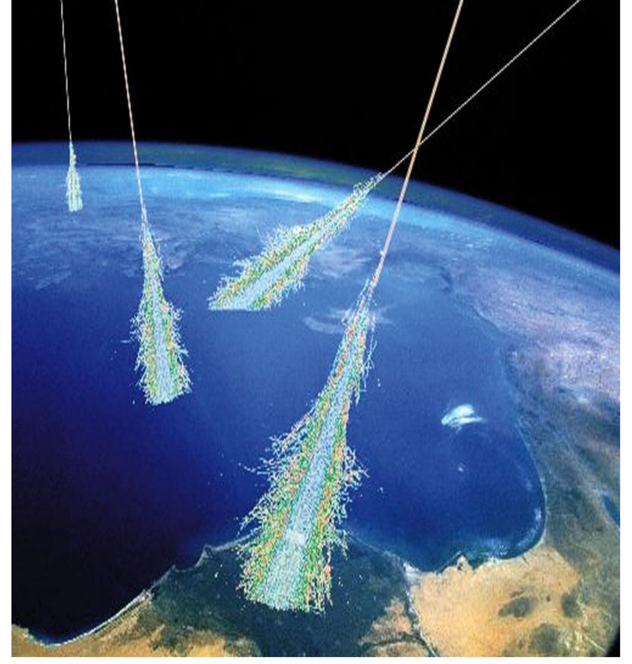

Measurement of Muon Flux and Muon Lifetime Using the Bellarmine Cosmic Ray Muon Detector

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ABSTRACT

In order to measure the muon flux and the muon lifetime, several experimentsal runs were conducted at Bellarmine University using a high resolution Cosmic Ray Muon Detector. The muon detector consisted of a cylindrical column containing scintillator pads, a photomultiplier tube, and a high voltage power source. These were connected to an external data acquisition module via a BNC cable. The detector's data was fed to a laptop PC via a USB cable which ran the muon data acquisition software. This software was able to display the muon hits, the number of muon decay events and the muon decay rate. Several experimental runs were conducted to determine the mean muon flux rate and the average muon decay rate for the Louisville area. In our final experimental run, the muon lifetime was also measured.

INTRODUCTION & BACKGROUND

Cosmic rays are all around us. As shown in Figure 1, one type of cosmic ray that strikes the earth is a muon (μ). On average, one muon strikes the fingertip every single minute (i.e. a mean muon flux of one muon/min/cm²). In order to measure the muon flux count (number of muons hitting the earth's surface per minute in a given area) for the Louisville area, and determine the muon lifetime, a high resolution electronics-based muon detector was used.

Most muons come from what are known as cosmic rays. A muon is roughly 200 times heavier than an electron. The history of cosmic rays started in the beginning of the 20th century. In 1912, Victor Hess (Figure 2) was in his hot air balloon soaring at an altitude of about 5,000 meters, when he noticed "penetrating radiation" coming from outer space. Following the ideas of Hess was Robert Millikan in 1925 who introduced the name "cosmic rays." In 1929 Dimitry Skobelzyn built the first cloud chamber to test the theory of cosmic rays. In 1935, the *Explorer II* balloon mission ascended to 22,066 meters in space while collecting data about cosmic rays. In 1937, Seth Neddermeyer and Carl Anderson discovered the muon using a cloud chamber. In a major discovery in 1938, Pierre Auger discovered "extensive air showers" in the outer atmosphere. These showers were made up of secondary subatomic particles caused by the collision of high-energy cosmic rays with air molecules, which is now defined as a cosmic ray shower.

There are two categories of cosmic rays: primary and secondary cosmic rays. Primary cosmic rays can generally be defined as all particles that come to earth from outer space. When these primary cosmic rays hit Earth's atmosphere, they ionize the atmosphere forming a shower of matter and anti-matter particles. This is where the muons come from - they are the results of an interaction between a proton (which are abundant in the universe) and the atmosphere that produces a pion (a subatomic particle). Primary cosmic rays are particles such as a single proton (nuclei of hydrogen; about 90% of all cosmic rays) traveling through the interstellar medium. Most of these originate outside of the solar system (i.e. from supernovae and distant galaxies), but some of the cosmic rays come from the sun as wel. When a high-energy proton hits the earth's atmosphere at around 30000m above the surface, it will collide with a nuclei of the atmospheric gas molecules. As a result of this collision, many secondary particles are produced, including lots of particles called pions. A (charged) pion decays to a muon and two muon-neutrinos at an altitude of about 10000m (10 km). Some of these muons can make it through the Earth's atmosphere which can be detected using a muon detector. A muon eventually decays into an electron, a electron neutrino and an anti-electron neutrino as shown in Figure 3.

In cosmic ray showers, both muons (matter) and anti-muons (anti-matter) are produced in the upper atmosphere . Although the muon at rest has a lifetime of only 2.2 μs, it should have decayed after traveling a distance of only 660m. Thus one would conclude that muons produced at this high altitude of 10000m from earth should not reach the ground. But muons can travel all the way down from a height of 10000m (10 km) above the surface of the earth while traveling at 99.8% the speed of light. The reason is that according to Einstein's Special Theory of Relativity, the muons age more slowly (in fact, about 16 times) since they are traveling very fast at about 99.8% the speed of light. This effect is called "time-dilation." From the point of view of an observer on Earth, the muon's new lifetime can be determined from Einstein's Special Theory of Relativity. Thus this relativistic time dilation allows the muon to travel about 16 times farther (10000m instead of 660m) than would have been expected otherwise. At higher altitudes more muons can be detected. Fewer muons are counted from the horizontal direction than from the vertical as shown in the Figure 4. In the horizontal direction, the muons must travel further to reach the Earth's surface, so more of them decay. By studying the cosmic rays, it is possible to find out the detection level of muons due to the the variation in weather patterns, and extra-terrestrial events, such as solar flares. Also of interest are the long term effect of cosmic ray muon radiation on humans, such as the cause of certain types of cancer, DNA mutations, and premature aging.

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

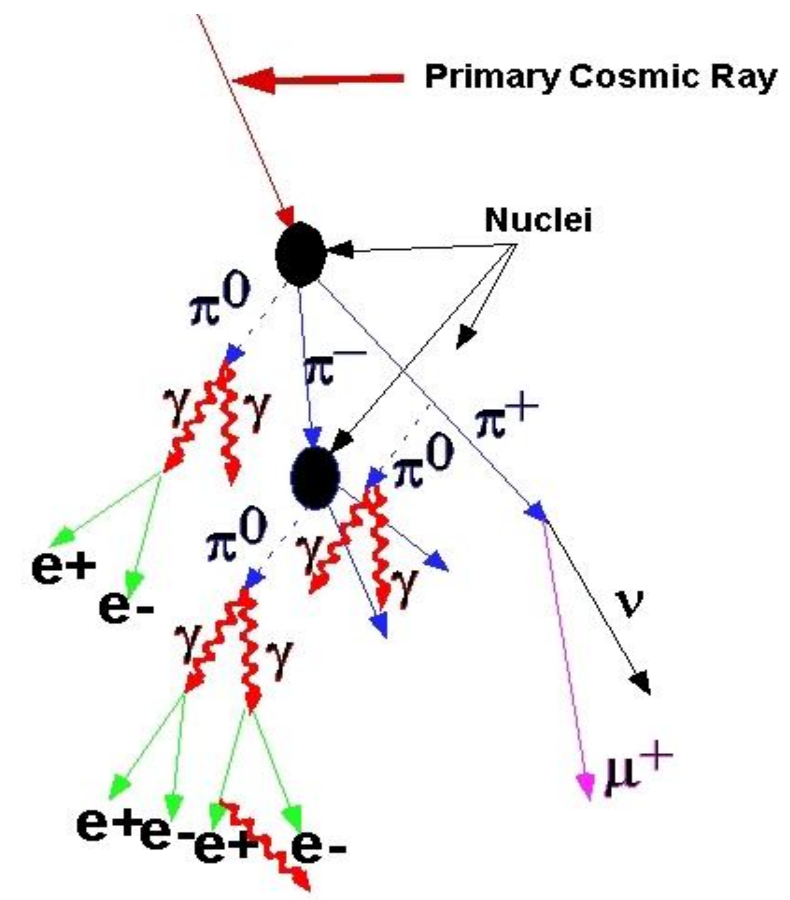


Figure 1: Cosmic Ray Muon Shower

Figure 2: Victor Hess in his hot air balloon

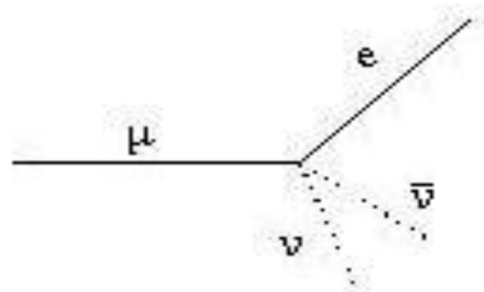


Figure 3: Muon decay into an electron, an electron-neutrino and an anti-electron neutrino .

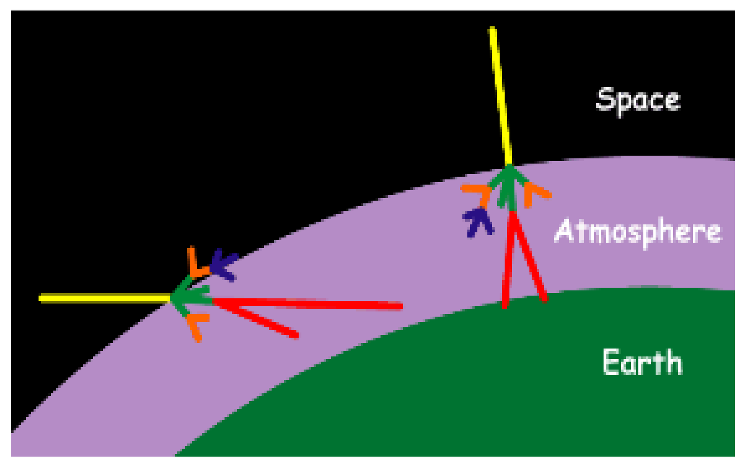


Figure 4: Muons entering the Earth's surface.

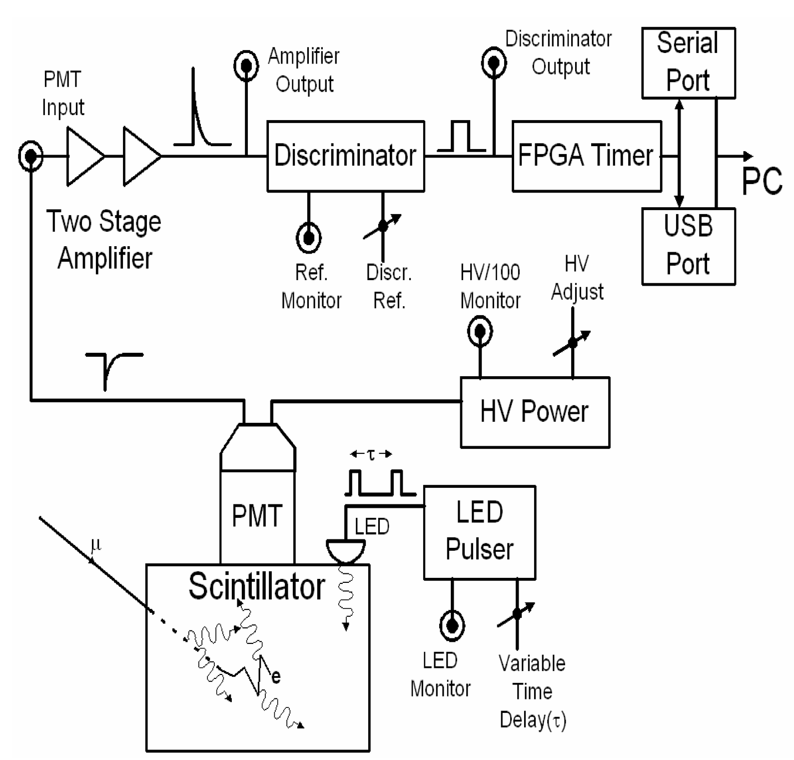


Figure 5: Schematics of the Muon Detector Readout Electronics

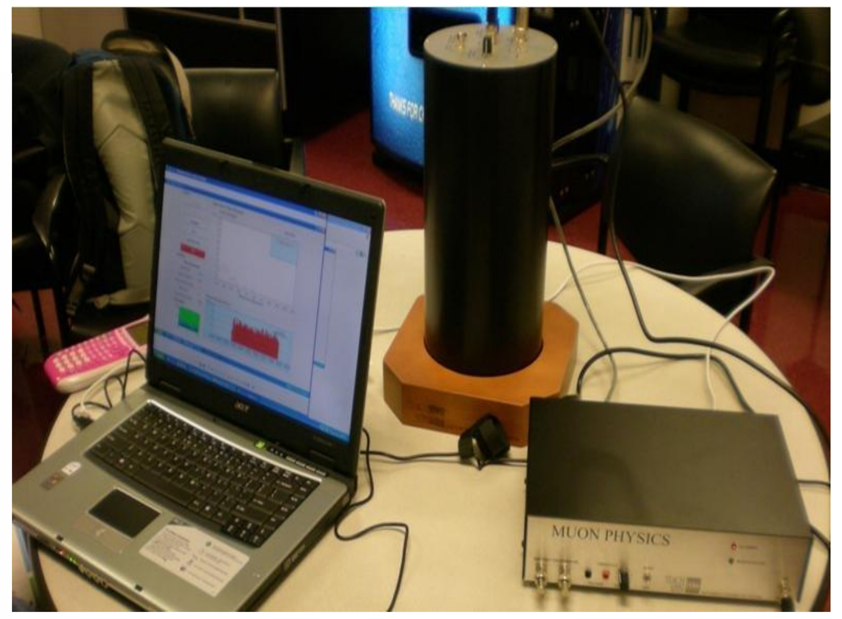


Figure 6: Picture of the experimental setup

Figure 7: Picture of the muon detector

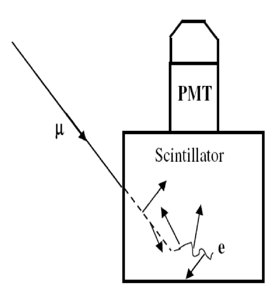


Figure 8: Schematic of the Scintillator and PMT

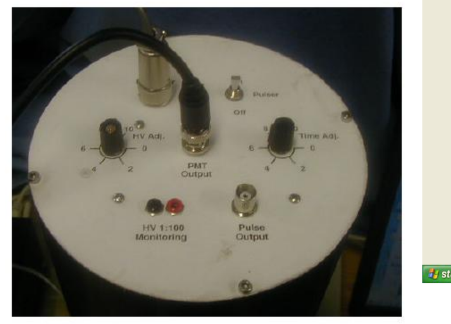


Figure 9: To view of Muon detector

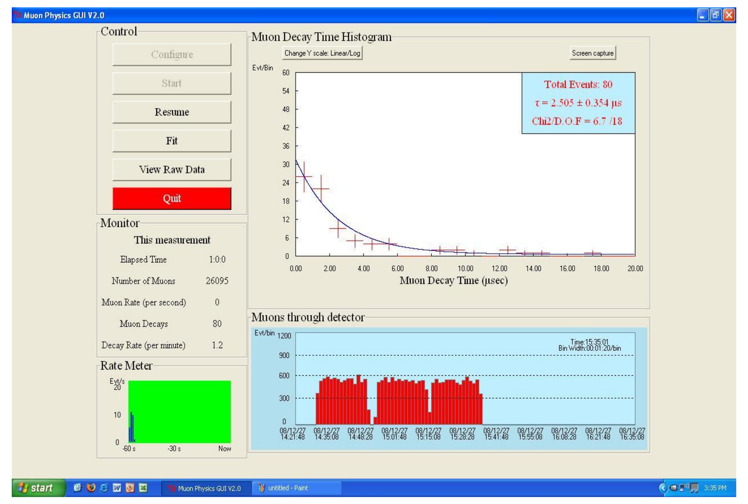


Figure 10: Screenshot from the first experimental run

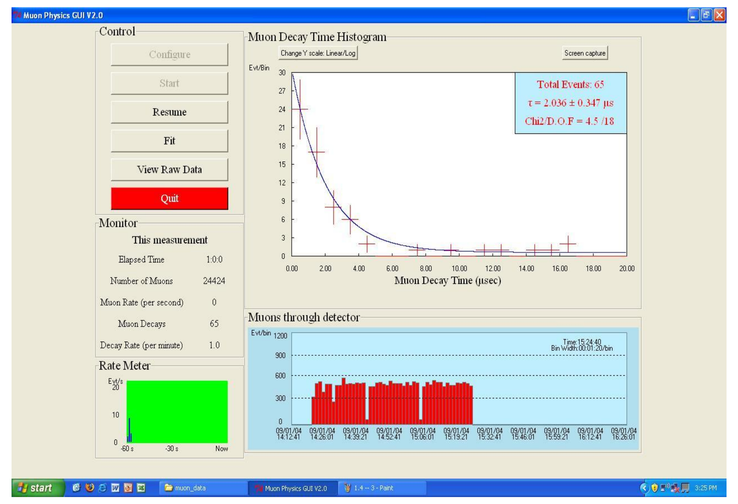


Figure 11: Screenshot from the final experimental run

PROCEDURE AND DESCRIPTION OF THE EXPERIMENTAL SETUP

The schematics of the muon detector readout electronics is shown in Figure 5 and a picture of the experimental setup is shown in Figure 6. As muons enter the detector, they are slowed, and eventually decay inside the plastic scintillator. The scintillator excitedly emits light that is detected by the photomultiplier tube, which produces a logic signal that triggers a timing clock. Once a muon has been stopped for a short while, it decays into an electron, an electron neutrino and an anti-electron neutrino. The muon detector cylinder contains a photomultiplier tube (PMT), a high voltage power supply, and the scintillator pads. The scintillator pads inside the muon detector are cylindrical in shape with the following parameters: a radius of 7.5 cm and height of 12.5 cm (shown in Figure 7). Figure 8 shows a schematic of the Scintillator and the photomultiplier tube and Figure 9 above shows the top of the muon detector cylindrical tower. DC power to the electronics inside the detector tube is supplied from the data acquisition device through the DC Power connector. The high voltage (HV) to the PMT can be adjusted by turning the potentiometer located at the top of the detector tube. To set up the equipment, a USB cable was connected to a laptop computer from the data acquisition module. Also, a BNC cable was connected between the muon detector cylinder and the data acquisition module. A crucial part of the experiment was to adjust and set the high and low voltages to an appropriate level. A multimeter was used to achieve this setup. The muon detector high voltage source was set and maintained at -1138 volts and the low voltage was set and maintained at 197.2 milli volts. The high voltage source is located inside the cylindrical tower of the muon detector. The low voltage source is located inside the data acquisition module.

Altogether four separate experimental runs were conducted to determine the muon flux and the muon lifetime. For each experimental run, the same high and low voltage settings were maintained. Each run was divided into three twenty-minute sessions. The muon detector measured the number of muon hits, the number of muons that decayed, the muon decay rate per minute, and the muon hit rate per second. After each twenty-minute period had passed, the data acquisition software module was paused, a screen shot was taken (both original and the post-fit version). Then the start button was pushed and data collection continued for the next session for twenty minutes. Three twenty minute sessions were conducted for each experimental run. The screenshots of the data acquisition window from the first and the fourth experimental run are shown in Figures 11 and 12, respectively. These post-fit version of the screen shots also shows the measured muon lifetime.

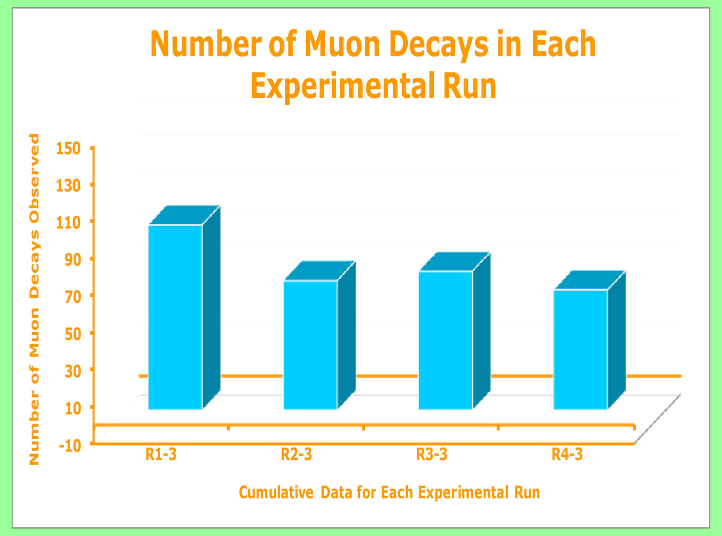
ACKNOWLEDGEMENT

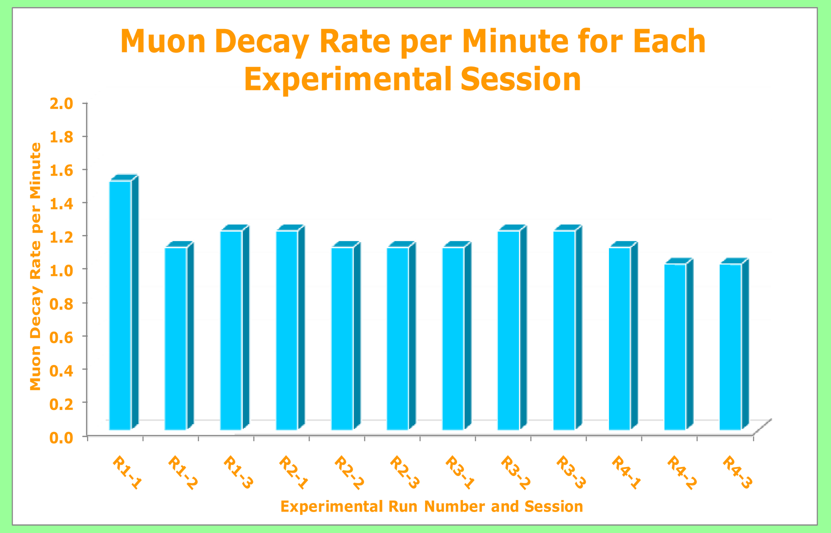
We would like to thank Lori and Leah Wilson from duPont Manual High School for taking part in this project and assisting us with data acquisition.

RESULTS

RUN NUMBER	Experimental Sessions	Time	Number of Muons Detected	Total Number of Muon Decay Events	Number of Muons Detected/Sec.	Muon Decay Rate/Minute
RUN ONE	First 20 Mins.	20	8,877	31	7.4	1.5
	Second 20 Mins.	40	17,529	40	9.0	1.1
	Third 20 Mins.	60	26,095	100	9.0	1.2
RUN TWO	First 20 Mins.	20	6,457	26	5.3	1.2
	Second 20 Mins.	40	12,577	46	5.2	1.1
	Third 20 Mins.	60	18,522	70	5.2	1.1
RUN THREE	First 20 Mins.	20	6,023	22	5.4	1.1
	Second 20 Mins.	40	12,408	50	5.1	1.2
	Third 20 Mins.	60	18,222	75	5.1	1.2
RUN FOUR	First 20 Mins.	20	8,189	24	6.8	1.1
	Second 20 Mins.	40	16,303	43	6.8	1.0
	Third 20 Mins.	60	24,424	65	6.8	1.0

Total Muon Events Detected in Four Hours	87,263
Average Number of Muon Events/Hour	21,816
Average Number of Muon Events/Min	363.6
Muon Flux (Number of Muon Events/Min/cm²)	2.6
Average number of Muon Decays/Hour	77
Average Muon Decay Rate/Min	1.1





Using the Bellarmine Muon Detector, the mean muon flux was measured to be 2.6 muons/min/cm². Altogether about 21,816 muons were detected per hour and approximately 77 muons decayed per hour. Therefore, the average muon decay rate is about 1 muon/minute. In our final experimental run, the muon lifetime was measured to be 2.036 ± 0.347 s.

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