Measuring Muon Count Compared to Ionizing Radiation Rates at Varied Altitudes

High Altitude Balloon

Section 1:

- What is the scientific question or inquiry you want to answer or what invention you are proposing to build and test to see if it works?

How does the count of muons at different altitudes of the atmosphere compare to the amount of gamma ionizing radiation? How does it compare to the amount of beta radiation? How capable are small handheld muon detectors and electronic pocket geiger sensors at measuring these values at altitude?

- What do you plan to measure, monitor, or evaluate during the flight?

We plan to measure muon count & ionizing radiation at different altitudes on the high altitude balloon and evaluate the performance of small muon detectors that use scintillating plastic/silicon photomultipliers as well as the performance of the pocket geiger counters. We can compare our data to other's experimental values of muon flux at altitude, such as from the University of Northern Colorado.

- What background research have you done?

Muons are fundamental unstable subatomic particles of the lepton class. They can penetrate any material, even miles deep into the earth's surface. Muons are created by interactions between cosmic rays (p^+) and gasses (mainly N_2 and O_2) in the atmosphere. These secondary cosmic rays have an extremely short lifespan of only ~2.2 microseconds (College Physics 8th Edition); despite this, they still make it through earth's atmosphere due to their near light speed & time dilation as formulated by special relativity. Most muons are created in the stratosphere near 15 km altitude (Georgia State University). If not for time dilation, a muon traveling at 99% light speed relative to any observer on earth would travel only 660 meters, on average, before decaying. Because of time dilation the observed lifetime is longer, such as a muon travels a distance of $4.8x10^3$ meters, on average, as measured by an observer on earth (College Physics 8th Edition). Though muons themselves are not radioactive, they can be used to detect radiation through muon radiography (Department of Energy) and muon tomography. Muon flux at sea level is ~ $1\mu^-/cm^2/sec$.

Ionizing radiation is energy waves or energetic particles that have enough energy to steal electrons from atoms; this kind of radiation is of higher frequency than non-ionizing radiation. Alpha particles, beta particles, and gamma-rays are three of the different kinds of ionizing radiation (US Environmental Protection Agency). Our experiment will focus on the latter two, beta and gamma, because alpha particles are heavy and non-penetrating so they cannot pass through materials.

- What is your hypothesis?

Our hypothesis is that muon count will increase up to 15 km of altitude and then decrease as the payload approaches higher altitudes while ionizing radiation continues to increase with altitude due to less atmosphere to absorb radiation. We hypothesize that, when properly insulated and installed, our sensors will function nominally at high altitude.

Section 2:

- How would you design your experiment to operate during flight and achieve your goals?

The reason we will build two muon detectors is to increase the accuracy of our measurements. Orienting the detectors one on top of the other will allow us to program them to have something called coincidence, where it will count only when both the detectors sense a muon at the same time (recall that muons are known to be able to pass through any material). This method will select only muons and separate from non-muon energized particles, increasing accuracy. In order to measure differences in gamma and beta, one electronic geiger counter will measure ionizing radiation indiscriminately, and one will be encased in copper shielding to filter out beta particles: the resulting difference can tell us about the amounts of each radiation (shielded reading = amount of gamma; unshielded reading - shielded reading = amount of beta). We may insulate the components as well.

-How would you capture and analyze the results of your experiment to understand whether it worked and determine what you were able to learn?

The data collected via the detectors and sensors will be tabulated via word processing software, providing a visual display of the information. We can then determine how closely our results match our hypothesis, and how it may be improved upon to be more accurate. Measurements will show how well the detectors perform; if there are large gaps in data, or definite anomalous measurements, we will know to refine techniques to attain consistent data, leading to improved experimental design.

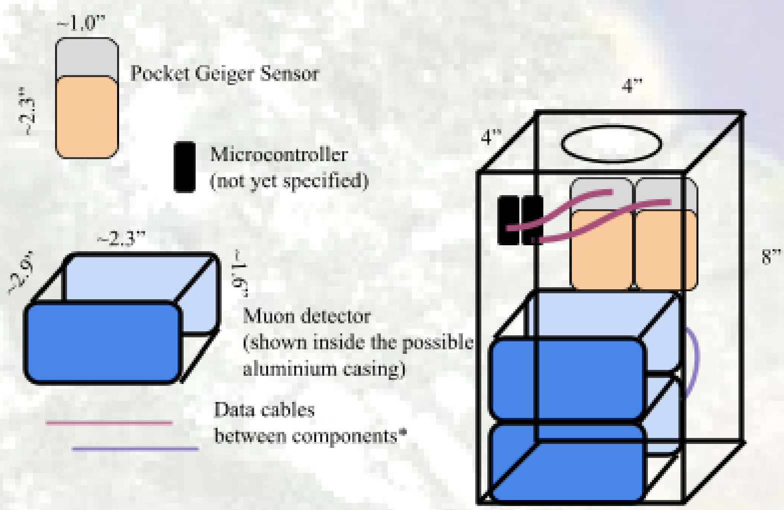
-What components could you use to build your experiment?

The method of detection will be scintillating plastic and a silicon photomultiplier (SiPM). An Arduino Nano is the intended microcontroller. Two printed circuit boards (PCBs), one main PCB and one PCB for the SiPM, will allow communication between these sensors and the microcontroller. An organic light-emitting diode display (OLED) and simple LED may also be included to display visual data for muon count. We may or may not choose to encase the detectors in aluminum to protect and contain all the components. A pocket geiger radiation sensor will make measurements of ionizing radiation, and a microcontroller (likely an Arduino), will record data; an SD/microSD card may be needed to store data. An aluminum structure may be used to position the components. The detectors/ sensors will be connected to onboard direct current power supply and data.

The concepts for our muon detectors are based on the Cosmic Watch, a desktop muon detector designed by physicists at Massachusetts Institute of Technology. Cosmic Watch is an outreach project encouraging highschool and undergraduate students to get involved with particle physics – only possible due to the relative simplicity and accessibility of the design. Each detector is made with common electronic circuit parts that cost only ~$100 for all the materials, and takes only about four hours each for students to assemble (MIT).

- How will your components fit into your flight box?

The two constructed muon detectors are estimated to be approximately 2.6” width, 2.9” depth, and 1.6” height each. They will sit at the bottom of the box, one on top of the other so that they can be programmed to have coincidence. The pocket geiger sensors will be secured adjacent to each other on the same wall for increased precision of measurements.



*Components will be connected to onboard power/data too, however it is too visually confusing to show all these connections and we will need more information before being able to accurately display them.

Section 3:

- Why send this experiment?

Our team became curious about the potential for investigating cosmic rays and ionizing radiation in the upper atmosphere. This experiment will provide many unique opportunities to prepare us with technical, engineering, and scientific skills for our careers. Already, we have gained skills in learning how to propose an idea and working effectively as a team. Just in researching our topic, we learned so much about the tiny particles produced in our atmosphere by primary cosmic rays—knowledge that could be expanded upon should our experiment fly. We will undoubtedly have opportunities to share our knowledge with our peers at school as well as the staff and people at the Jack C. Davis observatory. Testing our instruments that are smaller, cheaper, and more accessible than traditional muon detectors and geiger counters in extreme conditions, such as low pressure and temperature will be a challenge. However pushing these limits will expose areas of these technologies that could use improvement which will lead to even better designs. A reason to investigate muons and is for real life applications such as muon radiography and muon tomography. Muon radiography utilizes the natural shower of cosmic muons and special instruments to measure the levels of muons and inspect cross-border shipping for illicit materials. Muon tomography uses similar techniques to image the insides of volcanoes and pyramids. Knowing the expected count of cosmic muons, versus what they are actually measured to be, is crucial for these methods of detection.

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