Analysis of the detected cosmic muon flux with the AMD13 detector based on the altitude

Abstract

We investigated the variation of the cosmic-ray muon count rate depending on the altitude of the detector. The experiment was carried out on the mountain "Charmant Som" near Grenobel in the south of France (16thJuly 2019). It was divided into four 30-minute series and each series of measurements was carried out at a different altitude, which varied from 511m up to 1867 m above sea level. These measurements were performed using the AMD13 detector of the high school "Lycée Ermesinde", in Mersch (Luxembourg), which was developed as part of the ADA (Astroparticle Detector Array) project.

ADA is an Italian educational project for the detection of high-energy cosmic rays and was developed with the intention of promoting astroparticle physics and making it available to schools, observatories and scientific associations. The AMD13 detector is able to detect cosmic muons with a coincidence of 2 and 0.2 ms. It consists of two 22 cm long Geiger-Müller tubes (GMTs) of the model SI 22 G with a diameter of 2 cm, stacked one above the other at a distance of 7 cm. Our conclusion for this experiment is that the altitude effect has a significant impact on the muon flux, as it is greatly reduced with decreasing altitude.

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Authors: G. Stevens[1], A. Pinjic[1], N. Stevens[1], C. Luis[1]

Supervisors: A. Grana[2], J. Majerus[2, 3]

[1] *Students of the high school "Lycée Ermesinde Mersch (LEM)" 45, rue de la Gare, L-7590 Mersch, Luxembourg. (Science Section)*

[2] *Astrophysics Teacher of the high school "Lycée Ermesinde Mersch (LEM)" 45, rue de la Gare, L-7590 Mersch, Luxembourg. (Science Section)*

[3] *Science Teacher of the high school "École Privée Fieldgen" 21, rue d'Anvers, L-1130 Luxembourg*

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1. Introduction

Cosmic radiation is the flow of elementary particles and atomic nuclei that circulate in space at speeds close to that of light. Depending on the case, their origin is to be found in the Sun and in stellar processes inside or outside our galaxy. Galactic and extra-galactic cosmic rays represent the highest energy particles (they can reach energy values up to 10^{20} eV). When primary cosmic rays, mainly protons, collide with molecules in the upper atmosphere, depending on their initial energy, they create a cascade of up to 10 billion secondary particles, called an atmospheric shower, which can extend over 40 km^2 when it reaches the ground [1]. Among these secondary subatomic particles are protons, neutrons, pions, kaons, photons, electrons and positrons. Through the disintegration of pions and kaons, muons occur, which represent most of the cosmic radiation measurable at sea level [2] since they interact very little with matter. They belong to the lepton family and have the same physical properties as the electron, except for its mass, 207 times greater (105 MeV/c^2), and for its very short lifetime (2.2 µs) at rest [3].

Since the incoming muons have a high energy, the temporal dilation effect described by the special relativity allows them to reach the Earth's surface. If interactions with molecules in the atmosphere are not taken into account, a muon with energy of 4 GeV (mean energy of cosmic muons) could theoretically travel about 25 km. However, due to the ionization and excitation of the medium, the muons continuously lose energy when they pass through the atmosphere [4]. Thus, by making another example, a muon with energy of 2.4 GeV travels only a maximum of 9 km instead of 15 km. Ionization occurs when the kinetic energy of a muon is not high enough to initiate some nuclear radioactive processes. Nevertheless, the muons interact with the electrons of the surrounding atoms, losing a minimal energy, although enough to release an electron from its nucleus. Due to this process, the matter along the muon's trajectory gets ionized and the muon gradually loses energy.

The 'Altitude Effect' is the study of the variation of cosmic ray intensity with altitude. The effect of altitude on muons is conclusively caused by their interaction with existing atomic nuclei in the atmosphere. The results differ depending on the altitude at which the detector is located. If the altitude is lower, the muons passing through the detector have already covered a longer distance. Thus, they have to cross a longer path before they reach the detector, which can cause more of them to decay, which leads to a decrease in their intensity as they approach the surface of the earth. Considering that low-energy muons are more likely to decay, a longer journey that takes more time, increases the likelihood of decay and therefore not to be measured by the detector.

The altitude effect is therefore directly related to the amount of muons detected [5]. In summary, our hypothesis is that the altitude directly affects the cosmic muon flow. We predict that if the detector is at a higher altitude, due to the shorter travel of the muons, more muons will be detected, so that lower energy muons can reach the detector before they decay. If the detector is placed at a lower altitude, the low energy muons will be more likely to have decayed before reaching the detector. Higher energy muons tend to reach the earth's surface regardless of a small path variation. With this, we will try to prove this effect with measurements performed at four different altitudes.

2. Project and instrumentation

Figure 1 - ADA project detector network in Europe.

The AMD13 detector was designed as part of the ADA project (Astroparticle Detector Array). ADA is an Italian educational project designed to detect high-energy cosmic rays, or UHE (Ultra High Energy) radiation for short. The structure of the network (Fig. 1) is comparable to that of the professional cosmic ray observatories. Individual detectors are distributed throughout Italian territory and beyond, to schools, associations and private astronomical observatories [6]. ADA was developed with the intention of promoting astroparticle physics and making it accessible to everyone. Furthermore, ADA is an interesting field of research not only for teachers and students, but also for independent committed scientists [7].

The AMD13 detector is a radiation and particle detector that may also counts muons. Basically, it consists of two 22 cm long and 2 cm wide cylindrical Geiger-Müller counter tubes (for short also GMT, Geiger-Müller tube) of the SI 22 G model, one above the other, at a distance of 7 cm. This model, which works with a mixture of the noble gases neon, argon and bromine, was originally produced in the 80s and 90s in the Soviet Union in large quantities. Today they continue to be produced in all ex-Soviet countries. The SI 22 G model is one of the few to have published electronic features. Therefore, the same technology is still being used in today's GMTs.

The AMD13 detector measures muons, which arise during high energetic events in the upper atmosphere and therefore have very high energies, which far exceed the energies of radioactive radiation. They are the only particles that can pass almost simultaneously through the two Geiger-Müller tubes (Fig.2).

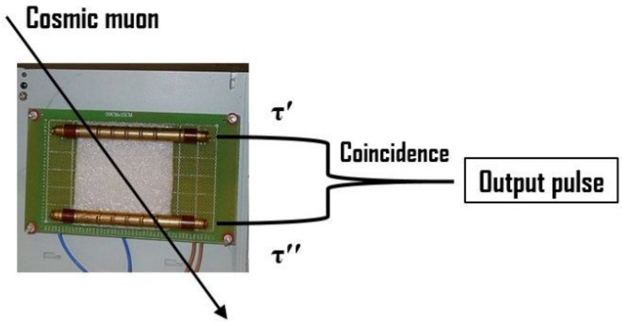

Figure 2 - A cosmic muon passes through the two Geiger-Müller detector tubes during the time window Δτ. The coincidence is confirmed and the detector electronics will count it as a signal.

Further along the GMT detectors, the counter electronics only counts the events in which there is a "coincidence". In other words: The counter needs a signal from both GMTs almost simultaneously (within a very short time, given by a fixed time window Δτ) [8]. With the AMD13, the time in which both GMTs must have sent a signal to produce a "coincidence" match may be fixed between 2 and 0.2 ms. This is largely sufficient to exclude the majority of the particles that are not cosmic rays.

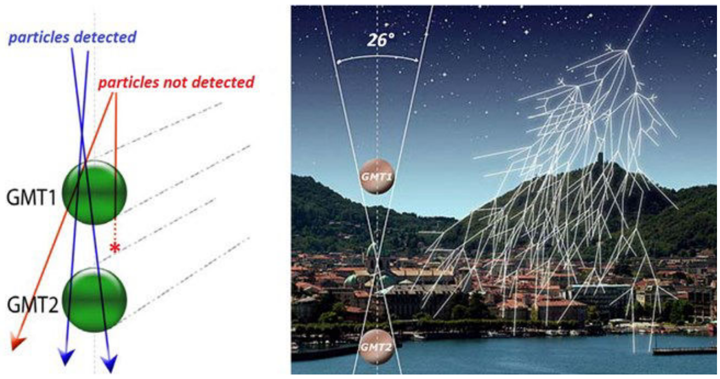

Figure 3 - To the left the coincidence method, on the right the AMD13 geometry

Since the muons have to cross through both GMT's that are superimposed on the same vertical at a distance of 7 cm, we have a field plane angle of incidence β of about 26° for effective measurement (Fig.3).

3. Custom Support Software

To gain access to the measured data, the AMD13 detector is supplied with the software AstroRad [9]. The main purpose of this software is to survey live data from the detector. However, a long-term analysis is not possible with AstroRad

For the analysis of the data, development of the results and the creation of the charts we used Microsoft Excel. Due to the lack of data, we used a statistical method called bootstrapping which calculates alternate data using the same probability of occurrence as the already existing data. After completion we were in possession of a considerable amount of reliable data.

4. Results and conclusion

The AMD13 detector was configured so that the number of measured muons is recorded every minute with a coincidence time set to 2 ms. The entire measurements took only two hours. At four different altitudes of 511 m, 1007 m, 1564 m and 1867 m, a series of measurements was carried out over 30 minutes.

In the first chart (Fig. 4) we notice that an increase in altitude also means an increase in the number of muons counted per minute. We can therefore conclude that the altitude is an important detection parameter.

The altitude becomes an influential factor, as the muon flux starts at an altitude of 10 to 15 km above sea-level. As you get closer to where the muons were created, you can count more muons. But this also means that the muons "die" on the way down to sea level. The mean lifetime of a muon at rest is 2.2 µs (microseconds), but since they travel at almost the speed of light, they can travel long distances due to the relativistic time dilation.

That means, at a higher altitude, the distance from the muon's creation place to the surface is shorter. Therefore, they have less time to "die" and as a consequence, we can measure more muons. This result confirms our hypothesis, stated in the introduction.

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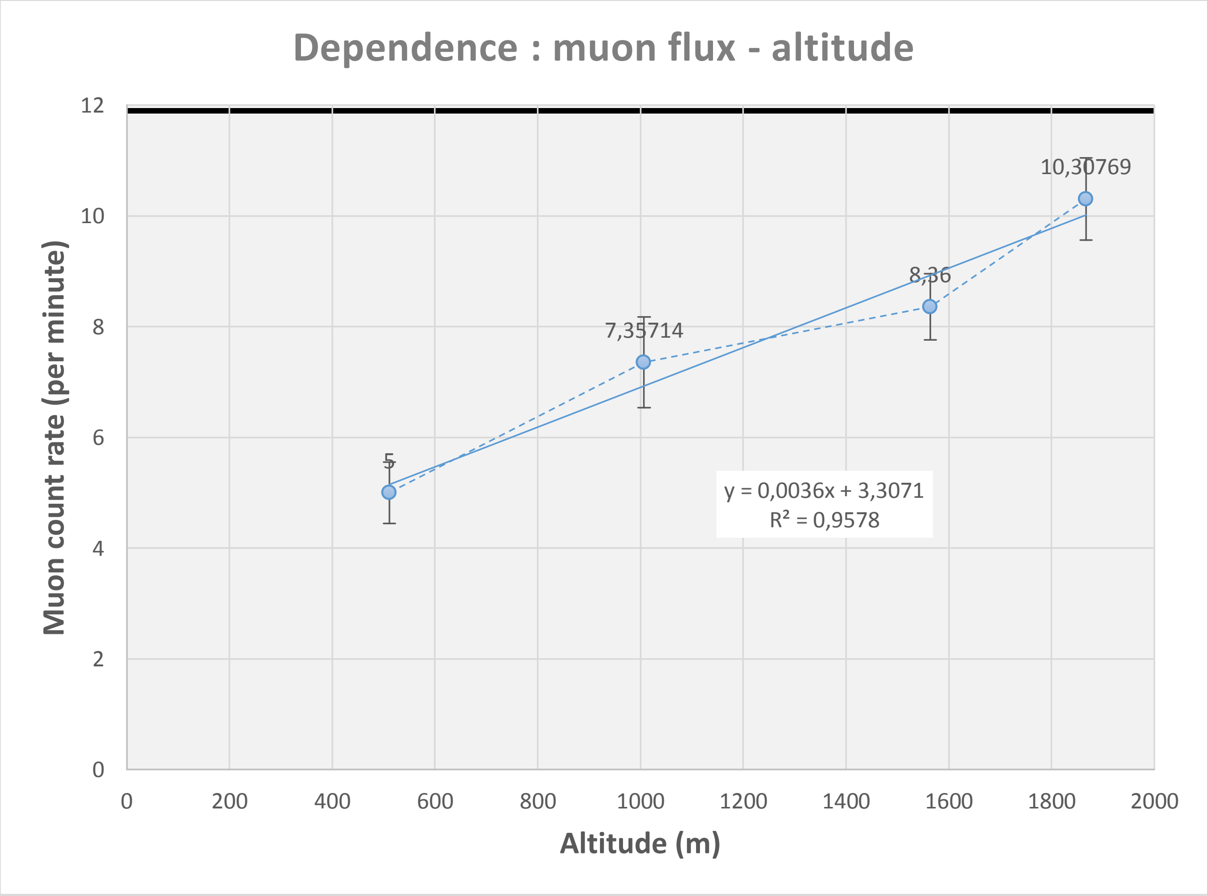
6. Charts and statistics



Figur 4 - *With increasing altitude, a visible increase in the muon count rate can be observed. When the height increases by one meter, an average of 0.0036 additional cpm are detected. The linear trend line is the leased square fit of the data, and represents an increase of 43% per measurement, concluding that the muon count per minute (cpm) rises with the altitude.*