Comparison of the muon flux measured with the AMD5 detector during 2018 and 2019

Abstract

We studied the fluctuation of the muon flow relative to the seasons. The experiment lasted two years. These measurements were performed using the AMD5 detector of the high school "Lycée Ermesinde, in 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 AMD5 detector is only designed for the detection of muons. It consists of two 10.8 cm long Geiger-Müller tubes (GMTs) of the SBM 20 model with a diameter of 1 cm, stacked one above the other at distance of 6 cm.

Our conclusion for this experiment is that we measured a higher flux of the muon flow in the cold seasons.

(Received 28 January 2020; revised 29 April 2020 ; accepted 6 May 2020; published 11 May 2020)

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Keywords:

- Muon flux
- Blackett effect
- AMD5
- Sun activity

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]. However, 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 trigger nuclear radioactive processes. Nevertheless, the muons interact with the electrons of the surrounding atoms and lose a minimal energy, which is, however, by far sufficient 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 effect of the temperature on muons is conclusively caused by their interaction with the atomic nuclei present in the atmosphere. The temperature thus influences both the creation and disintegration process of muons in the atmosphere. Generally, the temperature effect is described in two parts: positive and negative. The positive effect is related to the temperature influence on pion decay, which is the major source of muons in the cosmic ray cascade process. The higher the temperature, the lower the atmospheric pion absorption, which implies a higher generation rate of muons [5]. In its turn, the negative effect is associated with changes of the muon average path along the atmosphere. It is expected that most muons are generated at higher altitude in summer due to the atmosphere expansion occurring during this period. Thus, they have a longer path to cross before reaching the ground, which allows more of them to decay, causing a decrease in their intensity at surface [6]. Considering that low energy muons have a higher probability to decay, a small change in their path related to the temperature effect can be easily noticed when we are monitoring their intensity at ground. On the other hand, small modifications in the path of high-energy muons are not simple to observe due their lower decay probability. Patrick Blackett, a British experimental physicist known for his work on cloud chambers and cosmic rays, understood that dependence on atmospheric pressure (hence, as already mentioned, also on temperature) is crucial [11]. He found that muons are actually formed when the atmospheric pressure has a value of around 100 mbar, which can be defined as an atmospheric layer whose altitude is determined by temperature. All this leads to the conclusion that the muon flow on the earth’s surface decreases significantly in the summer months, because the 100 mbar layer is at a higher altitude, which extends the travel distance for the arriving muons. With this we will try to prove this effect by measurements that are carried out continuously during the summer months.

We will also use the 2018 and 2019 muon flow data for comparison to confirm or deny our hypothesis about the influence of direct solar radiation and the corresponding atmospheric heating on the muon flow measured on Earth. We further estimate that higher solar activity should increase the amount of muons that reach the earth's surface.

2. Project and instrumentation

Figure 1 - ADA project detector network in Europe.

The AMD5 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 the national territory and beyond to schools, associations and private astronomical observatories [7]. 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, but also for independent committed scientists [8].

The AMD5 detector is a particle detector that counts muons. Basically, it consists of two 10.8 cm long and 1 cm wide cylindrical Geiger-Müller counter tubes (for short also GMT, Geiger-Müller tube) of the SBM 20 model, one above the other, at a distance of 6 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 [9]. Today they continue to be produced in all ex-Soviet countries. The SMB 20 model is one of the few to have published electronic features. Therefore, the same technology is still being used in today's GMTs. The AMD5 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. Thus, they are the only particles that can pass through the two Geiger-Müller tubes almost simultaneously (Fig. 2).

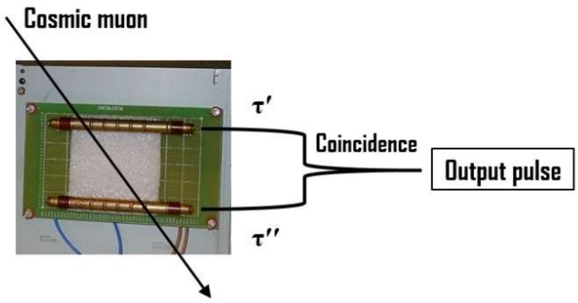


Figure 2 - A cosmic muon passes through the two Geiger-Müller detector tubes during the time window Δτ. The coincidence is confirmed and the detector electronics will count it as a signal.

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) [10]. With the AMD5, the time in which both GMTs must have sent a signal to produce a "coincidence" match is fixed at 66 ms and is sufficient to exclude the majority of the particles that are not cosmic rays. Since the muons have to cross through both GMT's that are superimposed on the same vertical at a distance of 6 cm, we have a field plane angle of incidence β of about 18° for effective measurement.

3. Custom Support Software

To gain access to the measured data, the AMD5 detector is supplied with the software

AstroRad [10]. The main purpose of this software is to survey live data from the detector. However, a long-term analysis is not possible with AstroRad

Furthermore, each participant in ADA should normally open remote access to the computer that registers the data for the ADA team. In the beginning, this was a great problem for our astrophysics Lab. For almost a year, we weren't connected to the global AMD Data-Archive and we had to get the data with Flash Drives or even with external Hard Drives. By a long, time-wasting and stressful procedure, we had to prepare the data for the final analysis in Microsoft Excel.

The first step to making data analysis easier was to shorten the time we needed to process a small sample of useful daily data. Since it is not allowed to install and run custom programs on our school's computers, we decided to create a website that could do weeks of work in just a few minutes. Usually a website is a bad choice for the software that is supposed to process a lot of data. With our website, however, everyone in the Lab can instantly access the data over the Internet, and small updates can also be easily made. The raw data-files can be uploaded with this website and three different options are now possible:

1. Table of daily data - In the first option, a table is created that shows the daily average and daily sum of each uploaded recording day.

2. Data preparation for MS-Excel - In the second option, an intermediate file is created to prepare the data of the uploaded files for in-depth-analysis in Microsoft Excel. We use a prepared Excel workbook (a template) to receive the intermediate data file from this option and to process the data automatically. At the same time, a diagram is also created. The complete data for a selected day can be displayed on the last sheet of the template. For the standard work, some VBA code is also included in the template.

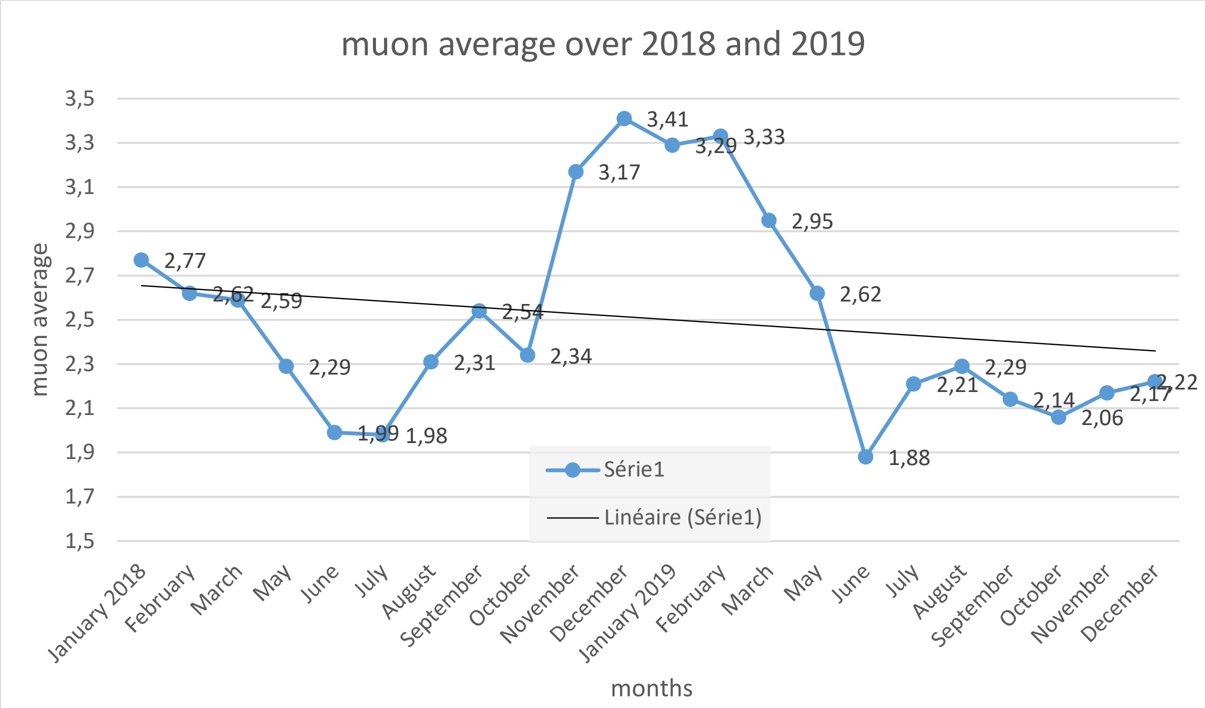
3. Individual days, all details - The third and last option creates a table with the individual data records, the median, the average, the sum and further details for a day. At the top you can select different dates.

All problems of data analysis were solved with this website and the corresponding Excel template. However, we still had to copy the data to flash drives to access it.

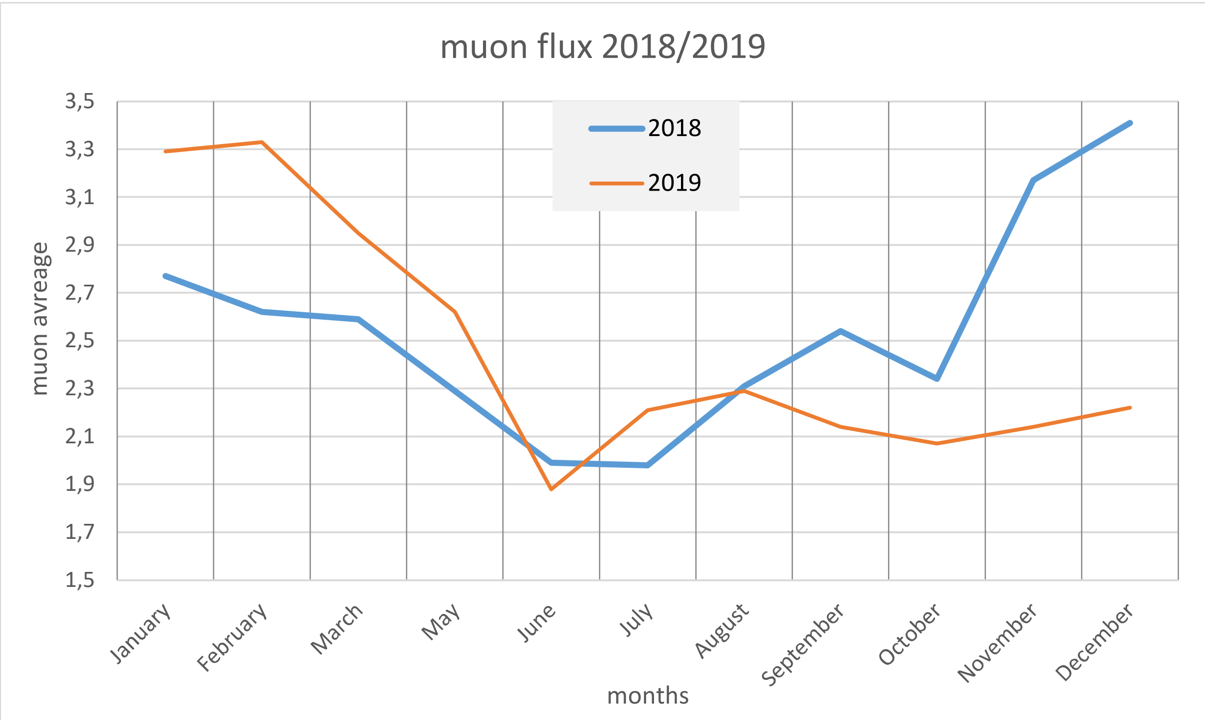
In October we noticed that FTP was activated in our school network. It didn't take long for the following protocol to run: Every day at 1:00 AM, a simple Windows Batch script runs on the computer and uploads the entire data archive after it has been compressed via FTP on a school server. The batch file also opens the website and its "PHPScript" unpacks the data just uploaded to the server and then deletes the old data. On the computer, a second script is executed every five minutes, which uploads the file "daily-data.txt", in which all data of the current date is saved. The file itself is updated by the detector every minute.

We have created another website to list the entire archive. It is a simple list in which you can access the individual files and then download a selection of these files. We created a standalone PHP script to create ZIPs and stream them to clients to download the selected files. When we were finally fully online, we were able to send the archive's directory link and ADA can now access it and added it to their AMD archive on their official website.

4. Results



(1) This graphic shows the average muon count per month in 2018 and 2019, with a trend line, to clarify the tendency of the two years.



(2) This graphic shows the muon flux average in 2018 (blue) and 2019 (orange).

5. Analysis

As shown in the first graphic (1), the average muon flux was higher in 2018 than 2019 and the trend line clearly indicates that it will continue on decreasing. At first glance, this disputes our hypothesis that the trend line should rise.

The results of the second graphic (2) confirm our assumptions about the Blackett effect that the muon flow on the earth's surface decreases in summer. The lower muon flux in the summer months is clearly visible in both 2018 and 2019.

This second graph also shows an unexpected flat behavior since summer 2019, where the annual increase can no longer be observed during winter time. This could indicate a special event, which needs further investigation. The linear weakening of the muon signal over the years 2018 to 2019 could also be due to this phenomenon.

6. Conclusion

In this study, we monitored muon flow to determine if the Blackett effect is real and to confirm or deny the increase in muon flow in 2019.

In our hypothesis, we speculated that the flow would increase in 2019, but our results clearly show a decrease. Our hypothesis is therefore denied.

After comparing our results with data from other participants in the ADA project, we concluded that the decrease in muons may have been caused by the 25th solar cycle.

However, the well-known Blackett effect was proven and confirmed by this study. It can be seen in both the 2018 and 2019 data.

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