PROCEEDINGS OF SCIENCE

Educational outreach activities on cosmic rays: investigate the correlation between muon counts and atmospheric parameters

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Cosmic rays are energetic, subatomic particles constantly reaching the Earth atmosphere from all directions. Several technological tools currently available can be used to introduce the students to research activities in the particle physics field. The Legnaro National Laboratories (LNL) of the Italian Istituto Nazionale di Fisica Nucleare (INFN) host a muon telescope. This telescope is formed by plastic scintillators and silicon photomultipliers, mostly used for outreach purposes during the International Cosmic Day (ICD). It is well known that local atmospheric parameters affect the rate of muons reaching the Earth's surface. In this contribution, we, along with high school and bachelor students in Physics at the University of Padova, investigate the anticorrelation between muon counts and atmospheric pressure. This correlation was measured with the muon telescope in LNL using the data collected in 2022 and 2023. The results from our analysis confirm the presence of a significant anticorrelation. Further analyses with a larger datasample allow us to improve the precision of the result, as well as possibly investigate other atmospheric-related correlations, such as with temperature and humidity and the variation in time of these correlations. In addition, we bought a new educational tool: a Cosmic Hunter detector developed by the CAEN group. We are currently testing the instrument performances and we plan to use this instrument to confirm our results and explore new possible educational activities for students.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08-01.09.2023
University of Vienna

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PoS(TAUP2023)323

1. Introduction

Outreach Cosmic Ray Activities (OCRA) [*] is a national outreach project born in 2018 of the Istituto Nazionale di Fisica Nucleare (INFN). The goal is to build a national framework which includes 24 INFN divisions and laboratories all over Italy for the INFN public engagement activities in the field of cosmic ray physics. The activities span from international projects as the International Cosmic Day (ICD), a worldwide yearly outreach event organized by DESY [†], to local activities as the OCRA summer camp, local workshop and tutorships, online laboratories, European Researchers' Night and Pathways for Transversal Competences and Orientation (PCTO) activities for high school students [1].

These activities are focused on educational and outreach tasks performed on cosmic-ray physics including presentations, hands-on measurements and data analysis with INFN or University instrumentations. During the ICD groups of scientists, teachers, and students meet for one day to learn about cosmic rays and perform an experiment on the dependence of the distribution of atmospheric muons with the zenith angle. Activities are performed using the data collected by a muon telescope hosted in the Laboratori Nazionali di Legnaro (LNL). This instrument is formed by a two plastic scintillators slabs with silicon photo-multipliers (SiPM) at a distance of 1 m each other, with a Pb shield between the scintillators to filter lower energy particles. A counter of coincidences is linked to the scintillators with a counter circuit mounted on a programmable custom board. Then, a recorder is programmed to reset every minute, and transmit the data through a USB serial link. Data are then collected every day and always available online.

The department of Physics and Astronomy at the University of Padova offers a PCTO project for students from high-school in collaboration with INFN Padova focused on cosmic rays analysis, including a detailed study of the effect that atmospheric parameters can have on the moun counts.

2. The atmospheric effects on cosmic rays

Muon flux at the Earth surface is influenced by the weather and climate conditions. In particular the dependence with pressure (barometic effect) was discovered in the 1920s and interpreted in following studies as an absorption, decay and generation effect [2]. Also the temperature dependence was interpreted in the 1930s in terms of decay of muons and pions [2, 3]. Other effects involving humidity or gravitational effects were also mentioned in [2]. In the last years a few contributions on the topic [4–8] were presented exploiting different instrumentations to explore the correlation between muon counts and atmospheric parameters.

3. Results

We investigate the relationship between moun counts and atmospheric parameters using the data from the LNL muon telescope. Three high-school students were involved in the PCTO activities in 2022 and 2023: V. Di Toro, C. Degasperi, E. Premrù. The activities have been supervised by M.Doro, D.Miceli and E.Prandini.

[*] https://web.infn.it/OCRA/
[†] https://icd.desy.de/

We build a collaborative repository making use of the open-source web platform *GitLab*. In this environment, the students in collaboration with the supervisors wrote the *Python* scripts to perform the analysis of the data of the LNL muon telescope. In particular, the online data were downloaded and stored into a `pandas DataFrame` saving all the most valuable information, i.e. time, number of coincidences and pressure values. Then, the data were selected for the data analysis depending on the position of the telescope. We analyze the data online considering two setup for datataking: (i) telescope in fixed position with slabs inclined of 45° (28 January 2022 - 08 February 2022); (ii) telescope in vertical position (July 2022 - April 2023). Finally, the average muon counts with their uncertainties at different pressures were computed and plotted and the correlation between these quantities was derived making use of the Pearson linear correlation index. The results from the dataset (i) were published in the LNL annual report [9] showing a strong anticorrelation between average muon counts and pressure values (Pearson index = -0.885). In Figure 1 the results from the enlarged dataset (ii) are presented. A strong anticorrelation is still present (the estimated Pearson index is -0.916) although some other effects, e.g. temperature or humidity, may affect the results, especially at high pressures.

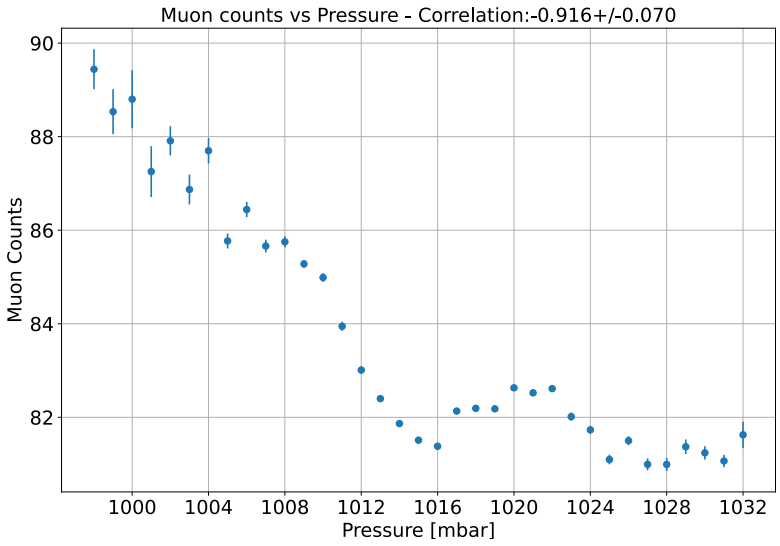

Figure 1: The anticorrelation between muon counts and atmospheric pressure with data from the LNL International Cosmic Day Detector as measured from Jul 2022 to Apr 2023.

To study these variations and the effect of winter-summer conditons on the muon counts and on the anticorrelation, the average muon counts at different pressures dividing the data for each month from July 2022 up to April 2023 were estimated. The results for the different months are shown in Figure 2. The anticorrelation can be seen stable over the different months although there is a variation of the muon counts all over the months, with lower counts for summer months and higher values for winter/spring months.

Another complementary study performed was to verify data on atmospheric pressure, by comparing them with those publicly available by ARPAV (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto) which provides long-term data on close-by stations from LNL. ARPAV pressure values were found to linearly correlate with pressure estimated by INFN

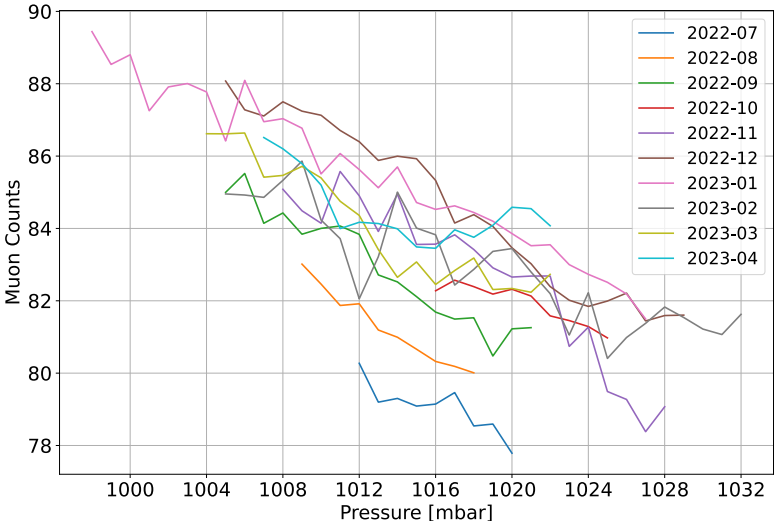

Figure 2: The monthly anticorrelation between average muon counts and pressure. The different months are reported in the legenda.

data. Assuming the ARPAV pressure to be more accurate, we found a formula to correct the INFN pressure values ($P_{\text{INFN,true}} = 350 + 0.657 P_{\text{INFN}}$). The reason for this correction is very likely due to the more calibrated and validated instrumentation to measure atmospheric pressure that ARPAV possesses. All in all, such correction does not affect the correlation studies presented but were useful to validate and test the quality of our instrumentation.

4. Conclusions

OCRA activities are growing every year, showing a high level of satisfaction among the participants [1]. In the PCTO activities presented here high-school students were able to work in close contact with INFN and University researchers, learn the activities involved in the life of a researcher and actively participate to a project including data analysis and interpretation of scientific results in the cosmic ray field. These activities gave the students the possibility to learn the basics of code-programming in *Python*, data analysis, graphical outputting of a research and science report writing. The approach was *problem-solving* with development of *Pyhton*-based scripts done by the students in collaboration with us. In these outreach activities the correlation between muon counts and atmospheric parameters was investigated. A strong anticorrelation between muon counts and pressure was found covering a long-term monthly monitoring. Additional studies performed reveal the presence of a variation of the counts depending on the season, with a variation from winter to summer that may indicate a dependence with other climate effects. In addition, the quality of our data was tested with other publicly available instrumentations. We will investigate the effects of other atmospheric variables suc as temperature and humidity or the East-West effect to further corroborate our findings. In order to perform these further studies a new muon telescope (Cosmic Hunter developed by CAEN group [‡]) have been bought and will be used for ICD 2023 and possible

[‡] https://www.caen.it/products/sp5620ch/

future PCTO activities.

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