Measurement of the cosmic ray flux by an ArduSiPM-based muon telescope in the framework of the Lab2Go project

V. Agostini([1]), B. Arcese([1]), N. Ascani([1]), P. Astone([3]), V. Bocci([3]),
S. Caperna([1]), F. Casaburo([2])([3])(*), A. Cerica([1]), C. Dauria([1]),
G. De Bonis([3]), D. Deda([1]), F. Di Mauro([1]), A. Di Vico([1]), R. Faccini([2])([3]),
L. Frasca([1]), G. Galuppi([1]), G. Giovannetti([1]), F. Iacoangeli([3]),
G. Ludovici([1]), L. Martone([1]), B. Marucci([1]), L. Mizzoni([1]), A. Moriconi([1]),
G. Organtini([2])([3]), F. Piacentini([2])([3]), A. Pietrobono([1]), F. Pongelli([1]),
F. Severa([1]) and D. Vona([1])

([1]) Liceo Scientifico "L. Pietrobono" - Alatri, Italy
([2]) Dipartimento di Fisica, Università di Roma - Roma, Italy
([3]) INFN, Sezione di Roma - Roma, Italy

Summary. — Within Istituto Nazionale di Fisica Nucleare (INFN) outreach activities, the Lab2Go project is of great significance. Its goal is involving high school teachers and students in several laboratory activities, aiming at increasing the weight of experimental contents in teaching and learning. In this article, we present the measurement, carried out in the framework of the Lab2Go project, of the cosmic muon flux made by an ArduSiPM-based muon telescope.

1. – Introduction

At the end of the XVIII century, a spontaneous discharge of electroscopes was observed [1]. After Röntgen's X-rays discovery [2], it was proposed that the leakage of electric charge was due to ionization caused by radioactivity coming from the underground. This hypothesis was dismissed by Pacini, who showed that radiation under the sea was significantly lower than at the surface [3]. In 1912, during a balloon flight up to an altitude of 5200 m, Hess observed an increasing of radiation with altitude [4], proving that it comes from the space. Later, Millikan named this radiation Cosmic Rays (CRs) [5].

(*) Corresponding author. Currently at Dipartimento di Fisica, Università di Genova and INFN, Sezione di Genova - Genova, Italy.

When CRs enter the atmosphere, they interact producing particle showers called Extensive Air Showers (EAS), that can be divided into three components: the hadronic, electromagnetic, and muonic component [6]. The latter, due to the low interaction between muons and the atmosphere, can be detected at sea level. Here, the muon flux is approximately $1\,\mu^{\pm}/\text{min}/\text{cm}^2$ [7], but it depends on Zenith angle θ and, for $\theta < 75°$, it is

$$F\left(\theta\right) = F_0 \cos^2 \theta \,\, \text{counts}/s/\text{m}^2,\tag{1}$$

being F_0 the flux at $\theta = 0$ [8]. Experimentally, we can measure it by rotating the detector, and thus verifying the expected formal relation between measured flux and angle. In this article, we present the measurement of the cosmic muon flux made by an ArduSiPM-based muon telescope in the framework of the Lab2Go project [9] at Liceo "L. Pietrobono" in Alatri (Italy). Despite our experimental setup does not allow estimating electron contamination, due to the higher interaction of electrons in the atmosphere, it is negligible for our educational purpose.

2. – Experimental setup and procedure

The experimental setup (fig. 1(a)) consists of a muon telescope made of two ArduSiPMs. ArduSiPM is a transportable particle detector [10] created and developed by INFN Roma, constituted by an electronic shield connected to an Arduino DUE [11], a $5\,\text{cm} \times 5\,\text{cm} \times 5\,\text{mm}$ scintillator and a Silicon PhotoMultiplier (SiPM). To build up the muon telescope, the two ArduSiPMs are placed on a mechanical structure that hosts the scintillators as well, and is free to rotate. The distance between scintillators is $7.8\,\text{cm}$, corresponding to an acceptance of 0.16 [12]. To automatize the angle measurement, the inclination is derived by $\vec{g}$ components measured by an accelerometer at rest connected to the rotating mechanical structure.

The number of events measured by each one of the ArduSiPMs and by both of them (time width = $10\,\mu$s), the acquisition time, and the angle are read by an M5Stack (fig. 1(b)) [13].

3. – Data analysis and results

The number of coincidences per unit time was measured at different angles as $\frac{N(\theta)}{T}$, being $N\left(\theta\right)$ the number of events detected by both ArduSiPMs and T the acquisition time. Due to the low rate of detected muons (it depends on the acceptance), long acquisition time was needed for each angle, from approximately 1 h at $\theta = 0$ up to
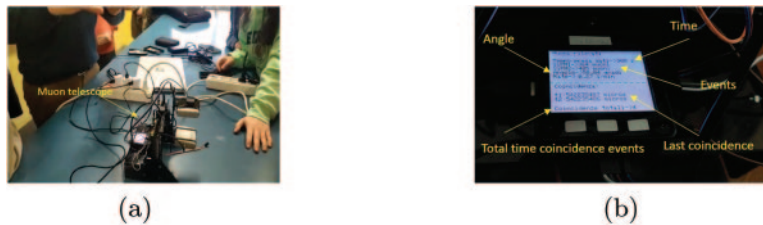

Fig. 1. – (a) Muon telescope during measurement at Liceo "L. Pietrobono". (b) Data read by the M5Stack.
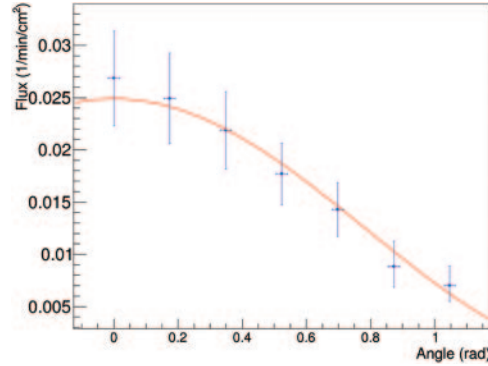
Fig. 2. – Flux interpolation.

approximately 2 h at $\theta = 60°$. The uncertainty on $N(\theta)$ has been evaluated assuming a Gaussian uncertainty when counts were >30, and a Poisson uncertainty otherwise.

Being A the area of the scintillator, values of $F(\theta) = \frac{N(\theta)}{TA}$ for several angles have been interpolated (fig. 2) with the function eq. (1), resulting in $F_{0_{esti}} = (2.49 \pm 0.18) \cdot 10^{-2}$ counts$/$min$/$cm² as derived from the fit. Despite the large uncertainties due to poor statistics (few tens of detected muons), the relation in eq. (1) is qualitatively verified as shown in fig. 2.

In addition, to further stress out the need for a quantitative validation and to allow students to acquire the concept of agreement between measurements, we evaluated a test function. In particular, we started assuming no-correlation between the estimated $F_{0_{esti}}$ and measured $F_{0_{meas}} = (2.68 \pm 0.45) \cdot 10^{-2}$ counts$/$min$/$cm² flux parameters (zero-hypothesis) and we considered $t = \frac{|F_{0_{esti}} - F_{0_{meas}}|}{\sqrt{\sigma_{F_{0_{esti}}}^2 + \sigma_{F_{0_{meas}}}^2}}$, whose result ($t = 0.4$) has been used to estimate a one-sided Gaussian p-value. We got p-value $= 0.7$ (>0.05, then verified at 95%C.L.) and an agreement within 1σ.

4. – Students' satisfaction

At the end of the Lab2Go course, an anonymous satisfaction questionnaire was proposed to each one of 17 students (10 boys and 7 girls) attending Lab2go, in order to
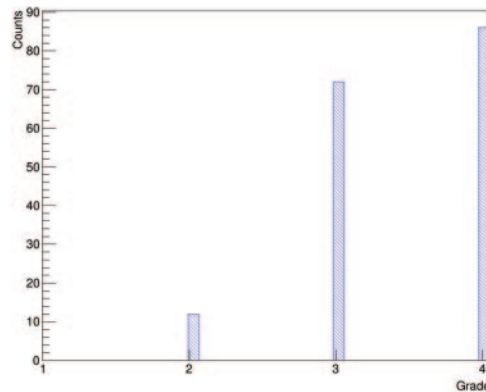

Fig. 3. – Results of satisfaction questionnaires.

evaluate their level of satisfaction concerning the lecture topics, their engagement, the quality of teaching and the overall project. For each of the 10 questions, students (attending the last three years of Liceo Scientifico) could express their impression, from a minimum of 1 (unsatisfactory) to a maximum of 4 (very satisfactory). The results of the total 170 answers (17 students $\times$ 10 questions) have been summarised in a histogram (fig. 3) resulting in a mean grade $\mu = 3.435 \pm 0.048$.

5. – Conclusions

In the framework of Lab2Go, the measurement of the cosmic muon flux by an ArduSiPM-based muon telescope has been proposed to students of Liceo "L. Pietrobono" in Alatri. Thanks to this experiment, we were given the possibility to introduce many topics, as CRs, particle physics, muons, antimatter, special relativity, particle detectors and time coincidence, going far beyond the topics commonly taught in physics lectures at high schools. Moreover, students learned how to process, interpolate and show data, taking into account uncertainties and estimating the agreement between measurements. A satisfaction questionnaire proposed to students at the end of the course reported a positive evaluation of the proposed activity and, in general, of Lab2Go overall.

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