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Čerenkov detectors for cosmic rays

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Summary. — Cosmic rays are generated by the most powerful existing particle accelerator: the Universe. Cosmic rays reaching the ground are mainly muons, that can be detected with the Čerenkov effect. This article describes two muon detectors built using simple materials: a thermos and an aquarium filled with water and read out by photomultiplier tubes. The readout electronics provides the pulse height of the generated Čerenkov light and the time of arrival of the particle. The detector is easy to transport and use with a laptop PC and represents an advanced and relatively low cost didactic tool, without requiring any complex setup or dedicated radiation sources.

1. – Introduction

Cosmic rays are particles coming from space originating from different sources; when they reach the Earth atmosphere, they interact with the atmosphere nuclei generating secondary cosmic rays; at sea level, they are mostly muons, as shown in [1]. To identify this secondary component, the Čerenkov effect can be used. When a charged particle crosses a medium with a speed larger than the one of light in that medium, it produces Čerenkov light typically in the blue or near-ultraviolet range.

Experiments such as Super-Kamiokande [2] exploit this effect to detect neutrinos.

This article presents the two Čerenkov detectors developed by the INSULAB group to detect the cosmic ray muon component.

Section **2** briefly describes how the two detectors have been built and the experimental setup to study their performance. Section **3** presents the efficiency measurement of both Čerenkov detectors.

2. – The Čerenkov detectors and the experimental setup

The Čerenkov detectors described in this paper (fig. 1) use water as a Čerenkov radiator [3]. The photons originated by the Čerenkov effect are mirrored by the reflective walls inside the detectors and reach the photomultipliers, located on top of the detectors,

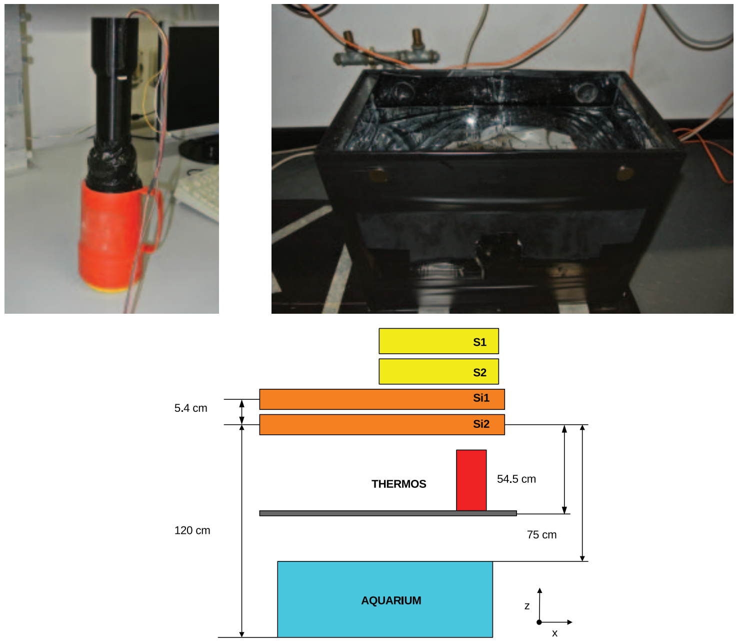

Fig. 1. – Left: the thermos detector. Right: the aquarium detector. Bottom: schematic of the setup for the efficiency measurement [6].

which transform light into an electrical signal. The signal is processed by an electronic readout chain [4, 5], that provides pulse height (PH), proportional to the light irradiated in water, and the time at which it was detected.

The two Čerenkov detectors are the thermos and the aquarium [6] shown in fig. 1.

The thermos detector consists of a Dewar made of silver-coloured reflective glass, with an inner diameter of 6 cm and a height of 20 cm filled with water, with a Sens-Tech P30CW5 photomultiplier [7] located on the top. In order to keep the detector as protected as possible from the external light, it was covered with black plastic. It is a portable and relatively low cost detector, inspired by the idea developed in other works already present in the literature such as [8]. It is also able to measure the muon incoming direction using the pulse height information and it will be implemented in a compact, self-triggering system to be taken to schools.

The aquarium detector consists of a $20 \times 40 \times 30\,\mathrm{cm}^3$ box, filled with water. The walls are covered with mirrors and two Philips XP 2020 photomultiplier tubes are located on the lid.

To test the detectors efficiency, the experimental setup shown in fig. 1 has been used [6]. The setup includes two $10 \times 10\,\mathrm{cm}^2$ plastic scintillators (S1, S2) [9], read by photomultipliers, to generate the trigger, and two large area high resolution XY silicon microstrip detectors([1]) (Si1, Si2) [10, 11] which allow reconstructing the track of the single cosmic ray and select those crossing the Čerenkov detectors with an accuracy of 30 μm.

([1]) The silicon detectors are spare ones of the tracker of the AGILE (Astro-Rivelatore Gamma a Immagini Leggero) satellite.

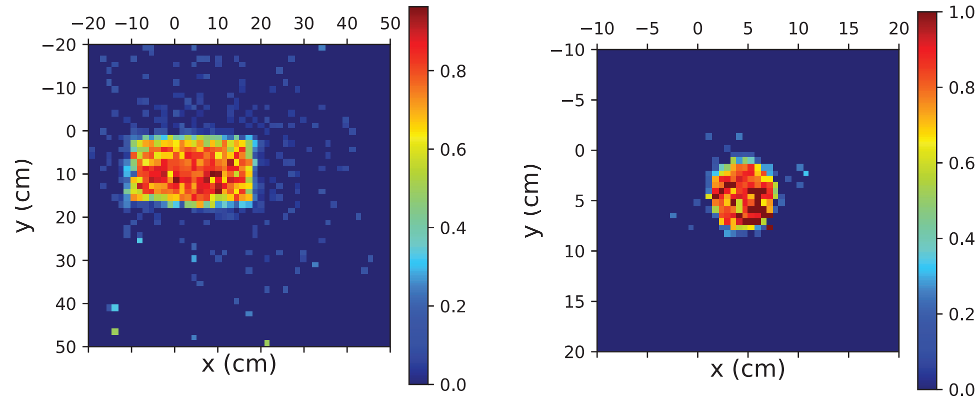

Fig. 2. – Left: aquarium detector efficiency of the right photomultiplier. Right: thermos detector efficiency [6].

3. – Efficiency measurement

The signals produced by the photomultipliers are sampled with a CAEN DT5730 [12] 14-bit 500 MS/s Digitizer module. The data acquisition software processes the digitized waveforms, computing their maximum value (pulse height-PH). In order to identify the events that were successfully detected, a threshold on the PH is set [6].

The efficiency is defined as the ratio of the number of detected particles over the total number of incident particles.

The trajectory of the cosmic ray is reconstructed by the silicon detectors and projected onto the x-y plane of the two Čerenkov detectors obtaining a two-dimensional histogram of the tracks distribution. The 2D histogram with the pulse height cut mentioned above divided by the one of all the events provides a 2D map of the efficiency as shown in fig. 2.

The average efficiency is obtained by computing and fitting the 1D efficiency profiles, shown in fig. 3. The efficiency profile for the aquarium is obtained by computing an average on the 2D profile along the y axis, limiting the y coordinate within the region occupied by the detector. The efficiency profile for the thermos was computed with

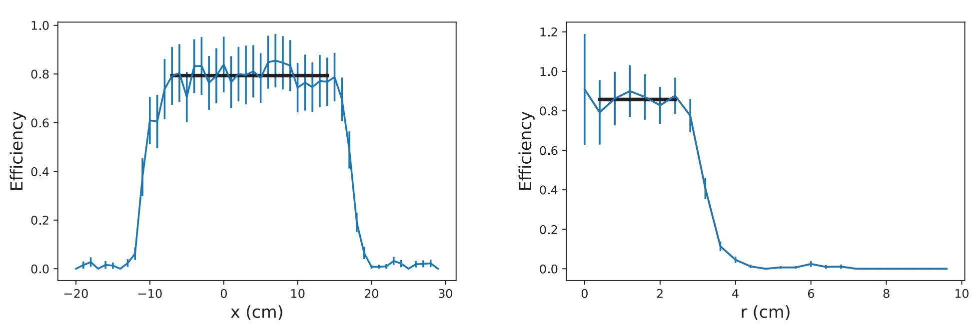

Fig. 3. – Left: aquarium detector efficiency in the x profile of the right photomultiplier. Right: thermos detector efficiency profile in polar coordinates, due to its cylindrical shape, as a function of the radius. The black line corresponds to the fit of the data [6].

reference to the radial coordinate. Both profiles are fitted with a constant function and yield an efficiency of 80% ± 2% for the aquarium and 85% ± 5% for the thermos [6].

4. – Conclusions

The detector described in this paper, together with its characterization with a dedicated test setup (which will not be used in the work with schools), demonstrates how it is possible to create a relatively simple system to detect the secondary muon component of cosmic rays reaching the ground, presenting two simple Čerenkov detectors and their efficiency measurement.

The thermos detector, thanks to its cylindrical shape, can be used to perform incoming direction measurements to reconstruct the muon incoming directions with respect to the detector axis using the pulse height information, as done in [13].

The next step will be designing a stand-alone system in which the trigger is the thermos detector itself and the Čerenkov radiation is detected replacing photomultiplier tubes with silicon photomultipliers, semiconductor devices which are more compact, faster, cheaper and require a low supply voltage.

It will then be possible to implement the thermos in a dedicated system similar to the one described in [14] and in [9] with a discriminator, an FPGA to measure the rate and evaluate the time over threshold and a laptop to control data acquisition, in order to perform flux measurements outside the laboratory.

Detectors of this type can be an advanced didactic tool in the field of modern physics, in particular particle physics [13]. Indeed, they allow students not to limit to a purely theoretical approach, but to develop a real experimental setup able to perform several physics measurements.

REFERENCES

[1] Particle Data Group (Tanabashi M. *et al.*), *Phys. Rev. D*, **98** (2018) and 2019 review.
[2] Kamioka Observatory: `http://www-sk.icrr.u-tokyo.ac.jp/index-e.html`.
[3] Jelley J. V., *Br. J. Appl. Phys.*, **6** (2018) 227.
[4] Bonfanti S., Master Thesis, Università degli Studi dell'Insubria (2012) `http://cds.cern.ch/record/1523716`.
[5] Lietti D., PhD Thesis, Università degli Studi dell'Insubria (2015) `http://cds.cern.ch/record/2626151`.
[6] Fanzini C., Bachelor Thesis, Università degli Studi dell'Insubria (2020) `http://dx.doi.org/10.13140/RG.2.2.17689.34404`.
[7] Sens-Tech P30CW5 photomultiplier: `https://www.sens-tech.com/pdf/P30CW5_iss01.pdf`.
[8] Kamiokanne: `http://kamiokanne.uni-goettingen.de/kamiokanne.htm`.
[9] Selmi A., Bachelor Thesis, Università degli Studi dell'Insubria (2019) `http://dx.doi.org/10.13140/RG.2.2.23546.62404`.
[10] Bolognini D., Bachelor Thesis, Università degli Studi dell'Insubria (2008) `https://cds.cern.ch/record/1143063/files/CERN-THESIS-2008-097.pdf`.
[11] Prest M. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **501** (2003) 280.
[12] CAEN DT5730: `https://www.caen.it/products/dt5730/`.
[13] Lezzani G., Bachelor Thesis, Università degli Studi dell'Insubria (2021) `http://dx.doi.org/10.13140/RG.2.2.27234.25281`.
[14] Bomben L. *et al.*, *JINST*, **16** (2021) P12008.