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Instrumentation of a Cherenkov tank for the project LIDRAE

V. P. LUZIO[1,*], M. A. LEIGUI DE OLIVEIRA[1], R. J. QUINTILIANO DA SILVA[1].

[1] *Universidade Federal do ABC (UFABC), 09210-170, Santo André, SP, Brazil*

[*] *vitor.luzio@ufabc.edu.br*

Abstract: The laboratory for instrumentation of high energy radiation detectors (LIDRAE) at UFABC aims to provide data for applied and academic research on high energy physics. The laboratory must rely on experiments that detect particles created in high-energy collisions produced by cosmic rays in the high atmosphere. We have installed computational and experimental apparatuses for the research and the development of radiation detectors. The initial system comprises three water Cherenkov tanks made of 1000 liters water reservoirs with an 8 inch photomultiplier tube at its top.

Keywords: Cosmic rays, Extensive air showers, Cherenkov detector.

1 Introduction

We call extensive air shower (EAS) [1] the cascade of particles generated by the interaction between a particle from a primary cosmic ray (CR) and the Earth's atmosphere. One of the techniques for the detection of EASs is based on array of detectors, which are distributed over a wide area with scintillation detectors or Cherenkov tanks. When the front of the EAS particles interact with the detectors, is possible to measure the energy deposited in each detector, as well its arrival direction, analysing the time differences in trigger between the detectors. With the data obtained from energy and arrival direction, it is possible to perform simulations of EASs using Monte Carlo techniques [2], then estimating the energy of the primary cosmic particle.

The Cherenkov effect [3] occurs when a charged particle moves in a dielectric medium with a speed exceeding the speed of light in the medium ($\upsilon > c/n$, where n is the index of refraction), polarizing the particles of the medium which rapidly return to its equilibrium state, emitting electromagnetic radiation in a cone of semi-angle:

$$\theta = c/(\upsilon \cdot n) \tag{1}$$

Several experiments of high energy cosmic rays use the Cherenkov effect in their detection techniques, including the telescopes: H.E.S.S. [4], MAGIC [5], VERITAS [6] and CTA [7] (under development) , detecting Cherenkov radiation in the air, the observatories: Pierre Auger [8] and HAWC [9], detecting Cherenkov radiation in water tanks, generated by the electromagnetic component of EAS and the large neutrino detectors SNO [10], Ice Cube [11] and Super-Kamiokande [12], detecting the radiation into water and ice.

The surface detectors are stable, inexpensive and operate continuously, independent of weather conditions or illumination, being very efficient for determinations of zenithal angle of EASs, however, the determination of the energy is imprecise and dependent on models and calibration. In order to optimize the acquired data, must take into account a careful job of instrumentation of the experiment, performing the characterization and calibration of acquisition and processing electronics, and also of the detector, usually a photomultiplier tube (PMT) developed to detect photons from Chereknov effect.

2 The LIDRAE project

The laboratory for instrumentation of high energy radiation detectors (LIDRAE[1])[13], is the result of research projects in cosmic rays of ultra-high energies developed in UFABC. In order to provide support for the development of academic and applied research in high energy physics, the laboratory aims at the development and study of radiation detectors, through the installation from a computational and experimental apparatus, as well the training and qualification of people to work in experiments in high energy physics.

2.1 Experiments in LIDRAE

The laboratory shall have the following experiments:

- Scintillation detectors;
- Cherenkov tank detectors;
- Fluorescence telescopes (MonRAt [14]).

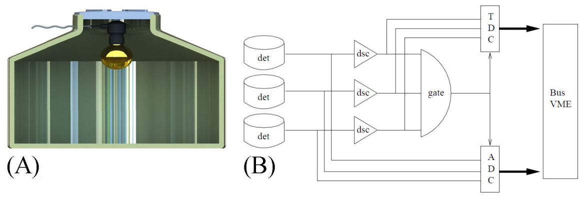

Figure 1: (A) Representation of a Cherenkov tank; (B) Diagram of electronic modules for the data acquisition.

The initial system will be composed of three Cherenkov tank detectors, made up water tanks with a photomultiplier tube (PMT) on its top (Figure 1-A). The tanks are filled with distilled water, to maintain the optical quality and ensure a long operation without the need for maintenance. The inside of the tank shall be white, because as Cherenkov radiation is emitted in the forward direction in a cone of approximately 2 degrees, and when reflecting with a white surface will be diffused, reaching the PMT. The layout of the data acquisition system is shown in figure 1-B and will

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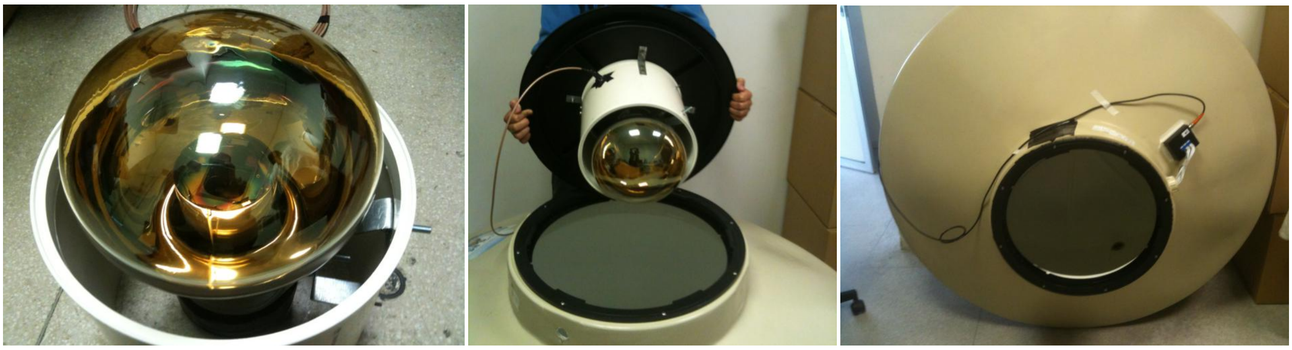

Figure 2: Left: PMT R5912; Center: PMT coupled to the lid of the water tank, Right: Cherenkov tank being tested.

have discriminator modules, analog-to-digital converters (ADC) and time-to-digital converters (TDC).

3 Cherenkov tank

The Cherenkov tanks (Figure 2) with a volume of 1000 liters have a PMT detector - R5912 Hamamatsu [15] - with 8-inch diameter, typical surface area of 380 cm^2 and typical gain of 1.0×10^7 supplied with voltage of 1500 V. NIM and VME modules are used for the acquisition and processing of the signals and feeding the PMTs voltage.

3.1 Eletronic acquisition and processing

The acquisition electronics used in Cherenkov tanks consists of NIM and VME modules manufactured by CAEN [16], namely N472, N843, N108a, V462, V965A, V1718, high voltage source, discriminator, delay, gate generator, charge-to-digital converter and USB bridge, respectively. To determine the charge value, converted by the module V965A, it is necessary to perform the calibration of each of its eight channels. Providing known signals of electric charge and analyzing the converted data provided by the module, we can determine its limits of operation and its transfer function (Figure 3), which are within the limits stipulated by the manufacturer, with low range 0-100 ρC and high range 0-900 ρC.

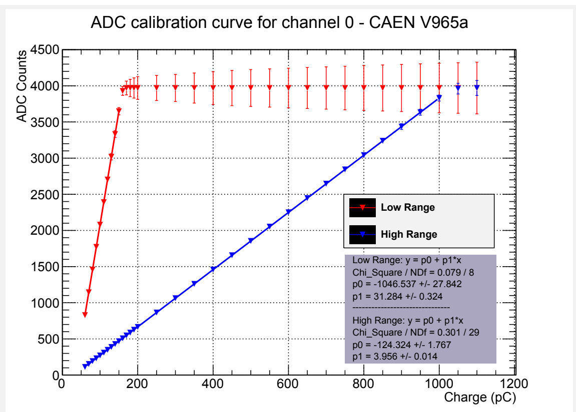

Figure 3: Calibration curve for channel 0 of the module CAEN – V965A.

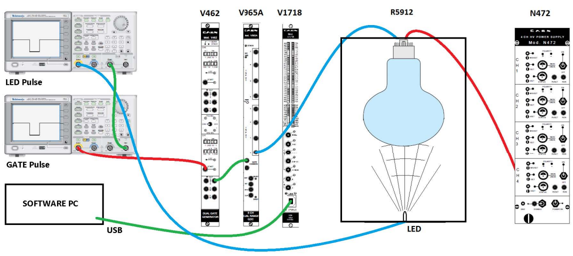

Figure 4: Schematic diagram of PMT characterization in darkroom.

3.2 PMT Characterization

The PMT characterization was conducted in a darkroom (Figure 4) in order to check the proper operation of the detector, using as light source a blue LED, operating at 1 kHz.

Initially, the mapping of operation limits for the PMT was performed by varying the LED intensity in order to provide different amounts of light to the detector and a hundred thousand acquisitions were performed for each light intensity. With the results obtained, it was possible to determine the response curve of the PMT (Figure 5), which typically behaves linearly into the operating limits of electronics.

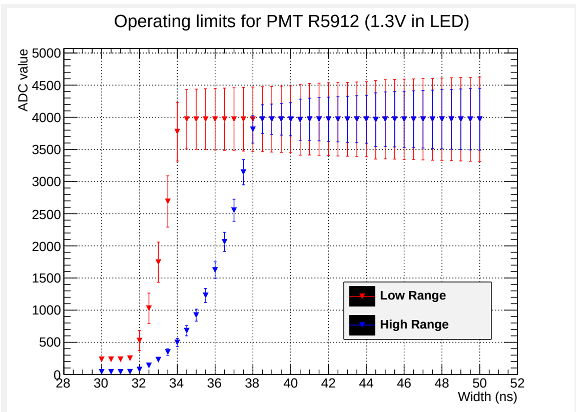

Figure 5: Graph of the response curve of the R5912 PMT according to the intensity of light acquired.

Also with the same results, including acquisitions with lower light intensities, it was possible to determine the single photon spectrum for the PMT, presented at figure

6. As an alternative way to get the gain of the PMT, it is possible to use a statistical method that takes into account the physical behavior of the PMT, together with the electronics data acquisition [17].

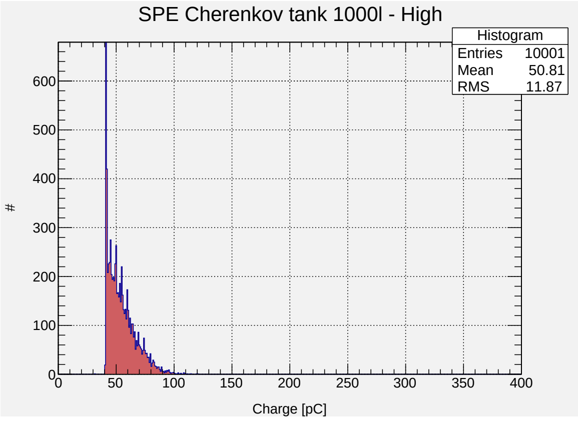

Figure 6: Single photon spectrum for PMT R5912.

In this method several acquisitions are performed in a large range of light intensities incident on PMT. For each data set, it must be considered the average (μ) and the square of the variance (σ^2) of the results, and then organized into a graph. With the graph obtained by the statistical method, it is possible to obtain the value of the PMT gain (Figure 7). For statistical method, we estimate a gain of 4.31×10^5, that conforms with specifications of the manufacturer [15].

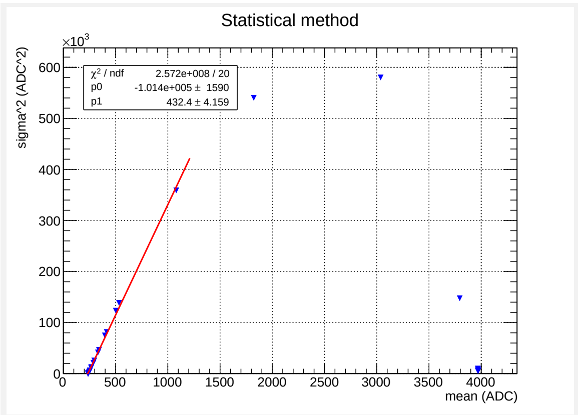

Figure 7: Graphic of statistical method for determining gain of the R5912 PMT.

3.3 First measurements and data acquisition

With the conclusion of the characterization and calibrationsteps for the first Cherenkov tank (Figure 8), the tank was filled with water and light isolated to initiate the acquisition of real data. The PMT was connected with 1000 V and the signal was then adjusted to the setting of auto-trigger[2], amplified and split into two, one of them going through a discriminator module and formatted for the gate signal and the another pulse just going through a delay module in order to synchronize and positioning pulses within the same time window. The signal from the tank in operation is shown in figure 9.

The next steps consists of keep the tank in direct operation and monitor the flow of data acquisition, verifying the

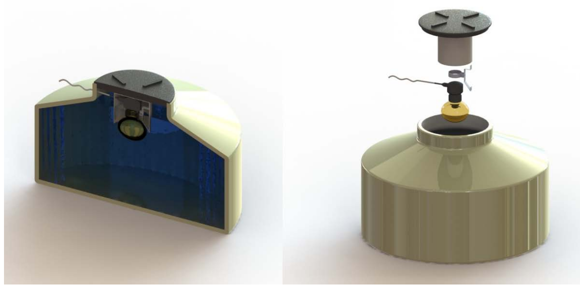

Figure 8: Drawing of sectional and exploded view of the Cherenkov tank developed for the LIDRAE.

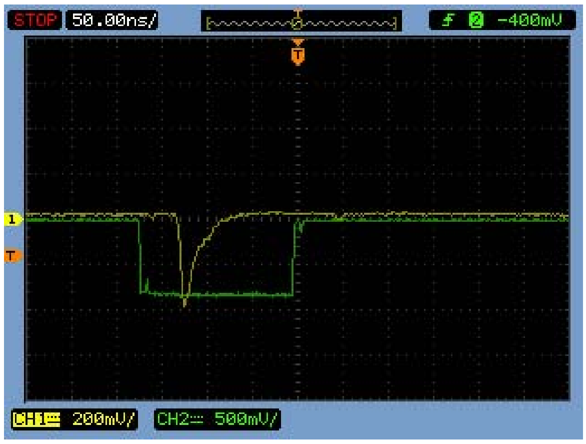

Figure 9: Signal obtained by the operation of the Cherenkov tank.

compliance with the average flow of cosmic rays of a given energy. Simulation steps of the particles that pass through the tank will be necessary, since we only have, until the moment, the information about the number of photons detected by PMT in each event. We need to know the amount of energy deposited in the detector by each particle, determining the ratio of conversion of photons to energy of incident muons, for example.

Verified the full operation of the tank, the trigger threshold of the experiment will be adjusted according to the desired energy, thus completing the steps of tank calibration.

4 Conclusions

We present the steps of instrumentation, characterization and tests from one Cherenkov tank to be used into LIDRAE experiments. Work with modules for data acquisition and data processing were performed as well as the whole process of characterization of PMT R5912, where we present two techniques for obtaining the PMT gain, via single photon spectrum and for statistical method. With the conclusion of the 3 tanks, we can determine the energy and arrival direction of the primary cosmic ray, thus allowing us to contribute with data to the research community of cosmic rays in the world.

2. Configuration where the trigger of the experiment is generated with the signal obtained

5 Aknowledgements

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References

[1] P. Auger, P. Ehrenfest, R. Maze, J. Daudin, Robley, and A. Freón, 1939, Rev. Mod. Phys. 11, 288.
[2] D. Heck, J. Knapp, J. N. Capdevielle, G. Schatz, and T. Thouw, *Report FZKA 6019*, 1998, Forschungzentrum Karlsruhe; http://www.ik.fzk.de/heck/publications/fzka6019.pdf
[3] P. A. Čerenkov, Dokl. Akad. Nauk SSSR, 2 (1934) 451.
[4] J.A. Hinton, New Astron. Rev. 48, 331 (2004).
[5] J. Albert *et al.*, Astrophys. J. 674, 1037 (2008).
[6] J. Holder *et al.*, Proc. 4th International Meeting on High Energy Gamma-Ray Astron., eds. F.A. Aharonian, W. Hofmann, and F. Rieger, AIP Conf. Proc. 1085, 657 (2008).
[7] E. Lindfors, S. Wagner and A. Sillanpää for the CTA Consortium, *The CTA Observatory*, Proc. of the 31st ICRC, Łódź (2009), Sesion OG 2.7, ID= 1341.
[8] J. Abraham *et al.*, Nucl. Instr. and Meth. in Phys., 2004, A523: 50.
[9] J. Goodman for the HAWC Collaboration, *HAWC in the Fermi Era*, Proc. of the 31st ICRC, Łódź (2009), Sesion OG 2.7, ID= 0649.
[10] J. Boger *et al.*, Nucl. Instrum. Methods A449, 172 (2000).
[11] T. Kowarik, T. Griesel, A. Piegs for the IceCube Collaboration, *Supernova Search with the AMANDA/IceCube detectors*, Proc. of the 31st ICRC, Łódź (2009), Sesion OG 2.5, ID=1251.
[12] M. B. Smy for the SK Collaboration, *Solar Neutrino Physics with Super-Kamiokande*, Proc. of the 31st ICRC, Łódź (2009), Sesion HE 2.2, ID= 0773.
[13] M. A. Leigui de Oliveira, *Instrumentação de um Laboratório de Altas Energias e Análise de Dados do Observatório Pierre Auger*, Auxílio à Pesquisa Jovem Pesquisador, Processo FAPESP:2008/00879-4.
[14] M. A. Leigui de Oliveira *et al.*, *The MonRAt telescope for atmospheric radiation*, Proc. of the 32nd ICRC, Beijing (2011), Sesion HE 1.4, ID= 1041.
[15] Hamamatsu Photonics K.K., http://www.hamamatsu.com
[16] CAEN Eletronic Instrumenation, http://www.caentechnologies.com/
[17] VILAR, A. B. *Instrumentação para observação de fluorescência de raios cósmicos com fotomultiplicadora multianódica*. Dissertação (Mestrado em Instrumentação Científica) — CBPF - Centro Brasileiro de Pesquisas Físicas, 2009.