Detection and analysis of astroparticles using WCD at 2800 m a.s.l. in Quito

You may also be interested in:

Astrophysics and elementary particles
Alberto Carramiñana

Simulation of Fano factor at HAWC-30 array
M A Castillo, H Salazar, A Tepe et al.

Search for SQM in cosmic rays at high altitude laboratories
S Balestra, S Cecchini, F Fabbri et al.

From The Pierre Auger Observatory to AugerPrime
Alejandra Parra, Oscar Martínez Bravo and Pierre Auger Collaboration

Dome C Site Characterization in 2006 with Single-Star SCIDAR
Christophe Giordano, Jean Vernin, Merieme Chadid et al.

Characterization of a outer detector (outriggers) for HAWC
T Capistrán, I Torres and E Moreno

New low threshold detectors for measuring electron and gamma ray fluxes from thunderclouds
Karen Arakelyan, Karen Avakyan, Ashot Chilingarian et al.

Instrumentation development for an array of water Cherenkov detectors
F Sheidaei, M Bahmanabadi, A Keivani et al.

Space Environmental Viewing and Analysis Network (SEVAN) – characteristics and first operation results
Ashot Chilingarian, Karen Arakelyan, Karen Avakyan et al.

Detection and analysis of astroparticles using WCD at 2800 m a.s.l. in Quito

A Correa[1] S Vargas[1] N Vásquez[1] and A Delgado[1], for the LAGO Collaboration[2]

[1] Escuela Politécnica Nacional, Department of Physics, Ladrón de Guevara E11253, Quito-Ecuador
[2] http://lagoproject.org, see the full list of members and institutions at lagoproject.org/collab.html (lago-pi@lagoproject.org)

E-mail: `melida.correa@epn.edu.ec`

Abstract.   At the Escuela Politécnica Nacional we have assembled a WCD (Water Cherenkov Detector) prototype for the LAGO (Latin American Giant Observatory) project in Ecuador. This article presents the data as well as the analysis corresponding to October, 2015. We present the obtained Charge Distribution Histogram (CDH). We shaped the conditions in which the equipment is operating given the environmental parameters and the value for the first VEM (Vertical Equivalent Muon) for the "Politanque".

1. Introduction

The Latin American Giant Observatory (LAGO) project is a collaboration created in 2005 which consists of 10 countries, with more than 80 scientists and students of different disciplines [1]. The detection of the high energy component in Cosmic Rays (CR) takes advantage of places located above 4000 meters above the sea level. The main objectives of this project are: study the high energy component of CR, transitory events, long term events, climate and space weather. We can also study solar modulation, monitor CR and do other analysis.

Fig. 1 presents three detectors in Ecuador that are located in: ESPOCH at 2750 m a.s.l. - Chimborazo province, USFQ and EPN at 2800 m a.s.l. - Pichincha province.
Astroparticle Laboratory of Escuela Politécnica Nacional (EPN) is where the third detector- "Politanque" is located, it works with undergraduate and master students, and scientists to encourage the study of astroparticles in different fields, from construction of a detector to the study of the theory that this implies.

1.1. Cosmic Rays

The energy spectra for individual elements of cosmic rays are obtained directly with satellite and balloon experiments at the top of the atmosphere; these experiments can detect CR with energies up to 10^{15} eV. Due to the fast decreasing flux, measurements at higher energies require large detection areas or long exposure times, which can only be obtained in groundbased detector systems. These detectors measure extensive air showers generated by interactions of the
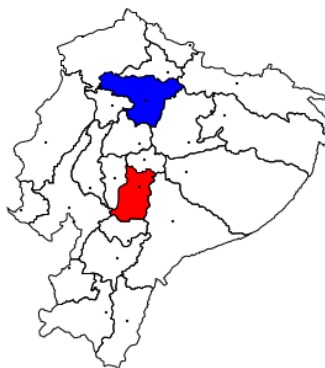
Figure 1. Political map of Ecuador showing LAGO locations. The Chimborazo province where the "Chimbito" detector is located is printed in red, and the Pichincha Province where the "Panchito" and "Politanque" detectors are located, in blue. [3]

high energetic cosmic rays with nuclei in the atmosphere [2].

Cosmic Rays (about 90 % protons, 9 % alpha particles and other heavy nuclei) hit the Earth's atmosphere where they ionize the atoms. Most relativistic cosmic rays have energies comparable to or greater than its rest energy. Few of them have ultra-relativistic energies exceeding 10^{20}eV, eleven orders of magnitud larger than the rest energy of the proton [4].

The particles that come from the Sun are relatively few and are characterized by temporal association with violent events in the sun and thus by a rapid viariability [4]. In contrast, cosmic rays are anticorrelated with solar activity, therefore during the increased periods of solar activity the CR flux on the Earth is lower. Cosmic rays with very high energy have typical Larmor radii which are larger than the size of the galaxy which points to their extragalactic origin.

The primary cosmic rays hitting the outer layers of the atmosphere undergo collisions with atmospheric nuclei. These collisions result in showers of new elementary particles of all kinds (such as electrons, positrons, pi mesons, muons, etc.). These showers eventually reach the surface. The secondary cosmic ray showers may reach an area of several square kilometers.

To estimate the number of possible interactions of the particles (generated in the showers) traversing the atmosphere, we need to first determine the mean free path, [2, 4]

$$\lambda_i = \frac{N_A}{A_i}\sigma_i\Big[\frac{gr}{cm}\Big]. \tag{1}$$

Where N_A is Avogadro number, A atomic number, σ_i cross section of interaction - Atmospheric depth. The indirect detection of cosmic rays depends on the energy of the primary particle which arrives the top of Earth's atmosphere, the angle of incidence, the magnetic rigidity and height of the first interaction.

Considering the proton as the primary particle that arrives perpendicularly to the location of Ecuador, the number of muons generated in the showers increases with the depth of the atmosphere because the interaction cross-section for the incident proton increases with atmosphere depth. The increasing interaction cross-section is illustrated by the number of
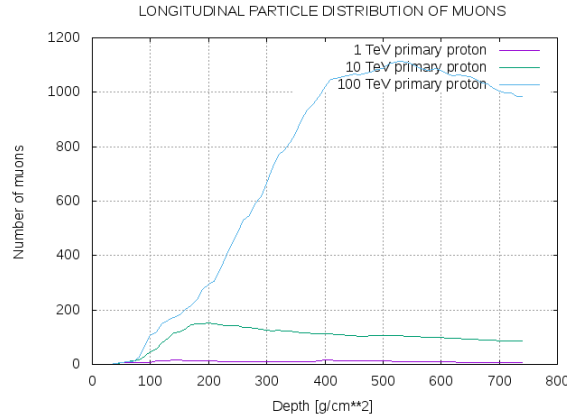
generated muons with atmospheric depth in Figure 2.

Figure 2. Longitudinal Distribution of Muons from a primary proton with different energies 1 TeV, 10 TeV and 100 TeV.

Muons and neutrinos are the most penetrating components of the secondaries cosmic rays, they are the result from the interaction mechanisms that produce pions and kaons through the decay chains. Pions(π^+, π^-) decay into muons (μ^+, μ^-) and neutrinos ($\nu_\mu, \bar{\nu}_\mu$). Since muon is a lepton, it decays to an electron or a positron plus neutrinos.

$$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu \ ,$$
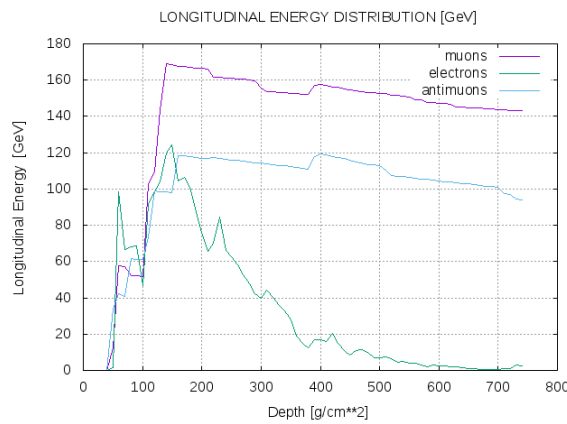$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu \ .$$

Figure 3. Longitudinal Energy Distribution of muons, antimuons and electrons from a primary 1 TeV proton.

In Fig. 3 we plot the energy of selected interaction products (generated by a 1 TeV proton) as they traverse the atmosphere. Muons typically lose 2 GeV while transiting the atmosphere due to ionization, consequently, muons dominate the charged-particle spectrum at the earth's surface (they also lose energy by bremsstrahlung and production of e^- e^+ pairs, photonuclear reactions like Compton production, etc.)

1.2. Cherenkov Effect

A charged particle that moves through a medium where the atoms forming the material are arranged and connected to each other, in a moment of time, in the region closer the path of the charged particle, the electric field of the particle distorts atoms, moving their charge causing polarization around that point. If the particle moves faster than the speed of light in the azimuthal plane, the symmetry is preserved, but along the axis there is a resultant of the dipole field and the bias field is not symmetrical, this field is momently created to the particle by a short electromagnetic pulse. [8]

Taking the principle of Huygens, the waves radiated that are in phase with each other resulting in a field at a distance from the observation point. This radiation is observed at an angle θ with respect to the trajectory of the particle, these waves are coherent and are combined in a plane wave. [9] As the particle travels faster than the speed of light in the medium, it produces Cherenkov radiation and it is given by:

$$cos\theta = \frac{1}{n\beta}. \tag{2}$$

Where θ is the emission angle, n is the refractive index of the medium and $\beta = \frac{v}{c}$ is the relativistic velocity coefficient.

In general:

$$\frac{d^2W}{dw.dx} = \frac{e^2w}{c^2}\left[1 - \frac{c}{n\nu}\right]w. \tag{3}$$

The fundamental features depend only on the charge and not of the mass of the moving particles, as well as the spectral dependency on the frequency is linear for the homogeneous medium.[8, 9]

This effect is used to determine muons which are the most energetic particles when they arrive at the earth's surface, and they are part of the secondary particle showers where the number of particles generated is directly proportional to the energy of the primary particle.[8]

Single particle technique is to take a count of these particles to estimate the energy of the generating particle. This count depends on the height above sea level where the detector is located and the mean-life time of the secondary particles [5].

2. Experimental setup

The "Politanque" detector is installed at the Escuela Politécnica Nacional (EPN). It's a small-sized detector accessible to students and teachers from within the university as well as other collaborating scientists. Its aim is to serve as a developing detector set up. "Politanque" has been fully operational for a small period of time. [3]

2.1. WCD "Politanque" and Data acquisition

The detector consists of a black polyethylene tank (volume $0.11\,\mathrm{m}^3$, height $0.23\,\mathrm{m}$ and radius $0.23\,\mathrm{m}$); a 5" EMI 9530A photomultiplier, a high-voltage source and a data acquisition system. The hardware and software used for data acquisition are from the EAS-BUAP project [3].

This system works with a voltage input $\sim 1450[V]$ for the PMT where the output signal is collected in a digitizer board–DAQmx (based on Dual ADC AD9216-100MS/s, 10bit resolution, 4-channel input), the information is then processed by a Nexys2 Board programed using VHDL, for being stored and processed in a PC with Ubuntu 12.04 (See Fig. 5).
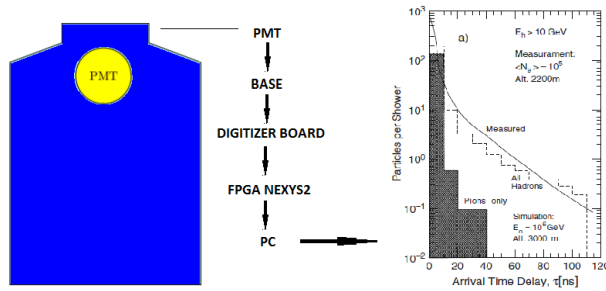
Figure 4. Experimental setup scheme.

Figure 5. Experimental setup; the electronics used for the experiment are from the EAS-BUAP project.

The USB-Serial Port connection from the preconfigured Nexys2 Board to the computer allows us to manipulate, via VHDL programing, the thresholds of the sampled data. The acquired data is in ADC in the range of nanoseconds. Each pulse has 16 samples of 10 nanoseconds each one [7].

3. Data analysis

The main characteristic of the detection of cosmic rays is the amount of energy deposited by each particle from 10 GeV to 100 GeV.

The script file adds a column of charge (x-axis), generating the *nuevos.dat* file; *picos_discriminados* counts the peaks based on a reasonable minimum height level (counts) and the deviation (to be defined). Fig. 6 shows 7 of such peaks obtained from a measurement.
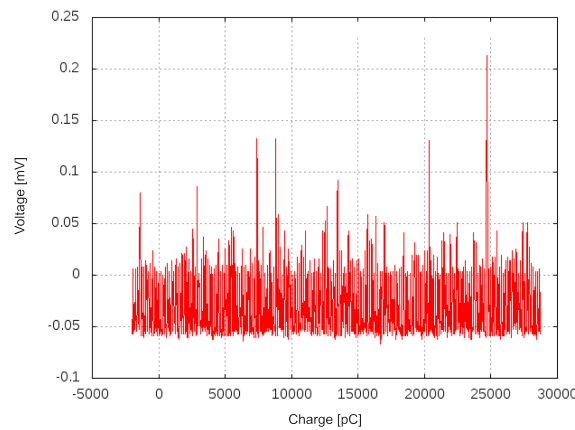

Figure 6. Diagram for counting peaks that work to VEM

Distribution of integrated charge of particles is depicted in the histogram in Fig. 7. Muons entering through the top and exiting through the side, muons entering and exiting through the side, and small showers that produce the first peak, as well as γ and e^- .

The main analysis is done with the Vertical Equivalent Muon (VEM) calibration that describes the average charge of the tank when it is crossed by a single incident vertical muon on the center of the top cover [6, 10].
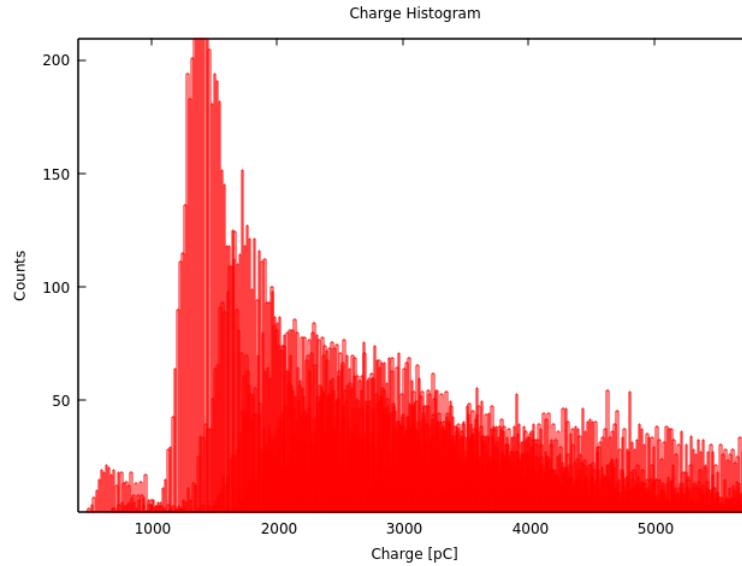

Figure 7. Charge Distribution Histogram (CDH) for "Politanque" detector
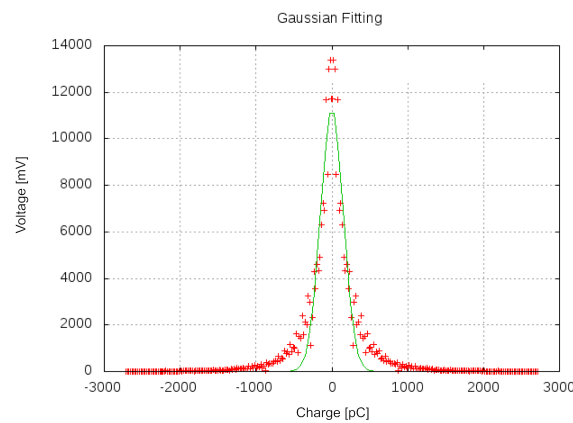

Figure 8. Vertical Equivalent Muon(VEM) calibration adjusted by a Gaussian fit. We found a value of 499.000 pC with a statistical error of 106.

The results obtained from the analysis of Charge Distribution Histogram (CHD) for a sample of 770000 events are presented in the Fig. 7. The peak value of 499.000 ± 101 pC for the VEM was determined by a Gaussian fit presented in Fig. 8.

With this we can also see the quality of water, because, if the water is pure enough, muons will produce Cherenkov effect and photons will be able to lose a minimum of absorption energy, reaching the PMT after several bounces and achieving detection.

4. Conclusions

The Data obtained with "Politanque" show that for a better fit of the VEM, the acquisition periods should last longer. Additionally, following the special behavior of the CR energy spectrum, a high energy threshold demands a higher energetic event, which was found in the relation between the number of events and the thresholds at the same exposure time. We took into account that higher energetic events have the property of decrease its frequency.

Cosmic Rays particles that reach the Earth atmosphere produce new particles. In their propagation through the atmosphere they can interact with the molecules in the air or they can decay. In the performed simulations with proton as primary particle, a shower of new particles is obtained by the proton interaction with the atmosphere. As the shower increases its atmospheric depth, muons predominate as the most energetic particles, which can be seen in the longitudinal energy distribution of the particles.

5. Acknowledgements:

6. References

[1] The Latin American Giant Observatory (LAGO), (2014). Retrieved Sep. 23, 2016, from http://lagoproject.org/
[2] GRIEDER, P. K. (2010). *Extensive Air Showers (p. 303).* Heidelberg: Springer.
[3] VARGAS, S., MANTILLA, C., MARTINEZ, O., & VÁSQUEZ, N. FOR THE LAGO COLLABORATION. (2015) *Implementing a set of WCD detectors for Space Weather research: first results and further developments.,* Proceedings, 34rd International Cosmic Ray Conference (ICRC2015).
[4] GAISSER, T., PROTHEROE, R., TURVER, K., & MCCOMB, T. (1978). *Cosmic ray showers and particle physics at energies 10 15-10 18 eV.* Reviews of Modern Physics, 50(4), 859.
[5] ASOREY, H., DASSO, S., NEZ, L., PREZ, Y., SARMIENTO-CANO, C., & SUREZ-DURN, M. (2015). *The LAGO space weather program: Directional geomagnetic effects, background fluence calculations and multi-spectral data analysis.* The 34th International Cosmic Ray Conference, Vol. PoS (ICRC2015).
[6] COTZOMI, J., MARTÍNEZ, O., MORENO, E., SALAZAR, H., VILLASEOR, L. (2005). *Air shower array at the university of Puebla for the study of cosmic rays,* Revista Mexicana de Física, 51(1), 38-46.
[7] SÁNCHEZ, C., RUBÉN, J. (2015). *Instrumentación para el Arreglo de Detectores de Superficie LAGO-México,* Benemérita Universidad Autónoma De Puebla, PHD Thesis, México.
[8] GRIEDER, P. K. (2010). *Primary Cosmic Radiation and Astrophysical Aspects.* Extensive Air Showers, 479-588.
[9] *Gaisser, T. K., Engel, R., & Resconi, E. (2016, June 2). Cosmic rays and particle physics.* Cambridge University Press.
[10] ASOREY H. FOR THE LAGO COLLABORATION. (2015). The LAGO Solar Project, Proceedings, 34th International Cosmic Ray Conference (ICRC2013), Rio de Janeiro, Brazil.