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Development of a web monitor for the water Cherenkov detectors array of the LAGO project

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ABSTRACT

The Latin American Giant Observatory (LAGO) consists of a network of water Cherenkov detectors installed in the Andean region at various latitudes, from Sierra Negra in México 18° 59′ N to the Antarctic Peninsula 64° 14′ S 56° 38′ W and altitudes from Lima, Peru at 20 m.a.s.l. to Chacaltaya, Bolivia at 5400 m.a.s.l. The detectors of the network are built on the basis of commercial water tanks, so they have several geometries (cylindrical in general) and different methods of water purification. The LAGO network of detectors also spans a wide range of geomagnetic rigidity cut offs and atmospheric absorption depths. All these features, along with their manufacturing differences, generates different structures in the atmospheric radiation spectra measured by our detectors. One of the main scientific goals of LAGO is to measure the temporal evolution of the flow of secondary particles at ground level. The atmospheric flux produced by the interaction of cosmic rays with the atmosphere at different sites is measured to study the solar modulation of galactic cosmic rays. In the present work we describe the features of a web monitor system developed to integrate, monitor and share the data of the LAGO detectors and discuss the criteria used to estimate the signals left by the secondary particles at the detector, which are based on a novel semi-analytical method that combines simulations of the total cosmic ray spectrum and the detector's response. We also show the detector calibration method applied on three detectors of the network, including the one operated in the Machu Picchu Base (62° 05′ S 58° 28′ W) during the last Peruvian scientific campaign in Antarctica (January 2018). Finally, we review observation of a Forbush decrease measured in the detectors using this calibration technique.

1. Introduction

The installation of large-scale experiments in astrophysics in Latin America, such as the Pierre Auger Observatory and the High-Altitude Water Cherenkov Observatory, both based on the use of Water Cherenkov Detectors (WCD's), has prompted the training of professionals with diverse expertises such as electronic instrumentation, intensive data analysis and detector simulations. Building upon these different kinds of expertise, the LAGO collaboration has installed a network of WCD's in universities and Research Centers throughout Latin America, to allow studies of the variations in the flux of secondary cosmic rays measured at ground level.

To achieve its scientific goals, the LAGO collaboration has developed its own data acquisition system [1] for the WCD's and a detailed simulation chain [2]. These real-time calibration and monitoring elements allow the cosmic ray flux at ground level to be estimated based on the detailed detector geometries and the properties of the muon flux reaching them.

The signal produced by high energy particles going through the WCDs is a negative pulse typically with a sharp rise time of ∼10 ns and a decay time of ∼70 ns dominated by the attenuation length of Cherenkov photons in the detector. The pulse shape depends on the geometry of the water tank, the water purity, the reflectivity in the inner coating of the detector and on the response of the photomultiplier transit time spread (typically around 3 ns FWHM for a 20 cm diameter hemispheric bialkali type.

The LAGO acquisition system allows to digitize the pulses in 10 bit resolution ADC (976 μV per bin) at 40 MHz. Upon a trigger, 12 time stamp bins are acquired: (including 2 after and 9 before the trigger). For these bins full pulse data is stored, with triggered data packed into one hour duration files. All pulses have time stamp with 25 ns resolution synchronized by PPS signal of a GPS receiver. The charge histogram of a WCD is obtained by time integration of the individual pulses measured in the WCD (in ADC units) [3].

As described in [4] and [5], the LAGO detector network array is non-centralized, which causes the detectors not to have standardized

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Fig. 1. The two peruvian WCDs of the LAGO project, one in Huancayo (left): 2,4 m diameter - 0,9 m height, and the other in Peru's Antarctica Camp (right): 1,2 m diameter - 1 m height, used in this work.

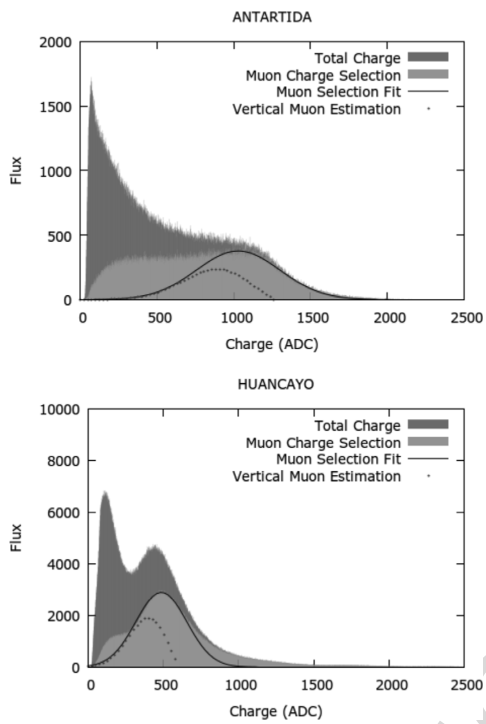

Fig. 2. Measured secondary cosmic ray charge spectrum and Vertical muon charge distribution estimation on Peru's WCDs.

geometries or the same water purification treatments; they may even have different types of PMTs. As an example the two Peruvian WCDs, one located in Huancayo, and the other installed in the Antarctic peninsula are shown on Fig. 1. Furthermore, the LAGO network covers a large range of geomagnetic rigidity cutoffs and atmospheric absorption/depth, resulting in different structures for the detector's charge histograms. In order to calibrate the detectors, we must estimate the expected charge distributions produced in the detector by Vertical Equivalent Muons (VEMs) [3].

2. Calibration method

The current LAGO calibration method looks for the second maximum in a charge histogram collected in one month and performs a Gaussian fit in the vicinity of this maximum, identifying this fitting function as the VEM distribution, where a central muonic band is defined. The limits in the band are given by the expected charge of muons that travel the maximum possible path in the detector (upper limit) and the transition point (local minimum) between the electromagnetic and the muonic regions of the spectrum. Based on [6] assuming a Gaussian distribution for the charge (q) spectrum generated by vertical muons ($V(q)$) that cross a cylindrical WCD, an analytical transformation of the charge spectrum ($F(q)$) generated by atmospheric muons is performed finding that:

$$F(q) + \frac{q}{\alpha} F'(q) \propto V(q) \qquad (1)$$

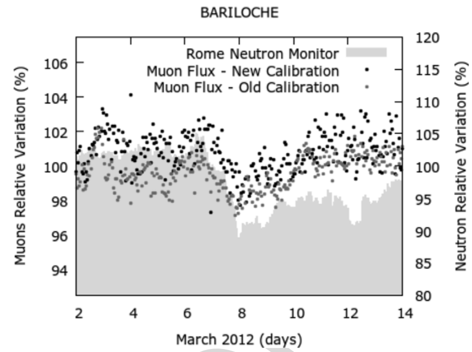

Fig. 3. Muon band analysis of the Forbush Decrease of March 8th, 2012, measured in a single 1.8 m^2 WCD in Bariloche, Argentina under the LAGO old calibration (dark gray dots) and the new (black dots), compared with neutron flux measured by the Rome neutron monitor (light gray histogram).

where α is a constant that depends on the track length distribution of muons in the detector. Eq. (1) is used to perform the calibration in three steps:

1. The LAGO-CORSIKA tools simulation chain [2] is used to estimate the path distribution of the muons inside the detector. Since the deflections are negligible, the path distribution only depends on the muon entry point and its direction. This distribution has a maximum in the vertical direction and α is given by the inverse exponential shape of the distribution. For instance, in Huancayo (Peru) $\alpha = 5$ and in Antarctica $\alpha = 8$.
2. By following the criteria used in [7], a muon selection (light gray) in the total charge spectrum (dark gray) is performed (both can be seen in the top and bottom histograms of Fig. 2). Between two consecutive pulses, the one with the highest charge generated in the detector by secondary cosmic rays is chosen.
3. Finally, a Gaussian function is fitted to this secondary distribution (solid line) using Eq. (1) in order to estimate $V(q)$ (dots). As the energy deposited by muons in water is well known, having $V(q)$ allows WCD energy calibration [3].

We can define a muon band as in the actual LAGO calibration method, but using the new VEM estimation. Then we integrate this band to obtain the total flux. In Fig. 3 we compare the total flux time evolution obtained using the two methods for the Bariloche detector and for the Rome Neutron monitor (which has similar magnetic rigidity cut-off to the Bariloche site) during the Forbush decrease of March 8th, 2012 (during the peak year in the most recent 22 year solar activity cycle). The method corrects the previous VEM estimation for the effects of the detector geometry, but uses the previous estimation of the muon flux from simulations. Both methods show similar behavior during the Forbush event, but this has to be studied in more detail.

3. The web monitor

As a tool to monitor the flux of secondary cosmic rays, a dedicated web monitor has been developed. The monitor uses the calibration described previously to show the charge flux, corrected by atmospheric pressure, deposited by muons in the detectors every hour.

The web monitor works on a Ubuntu 14.04 server installed in a cloud computer service. As input, the web monitor consumes the charge histograms generated every hour by the acquisition system of each detector. The data processing is performed using GNU Octave and the results are organized and stored in a SQLite data base. The front-end and data visualization is done using scripts written in HTML and CSS for stiles and Javascript for functionality, and executed on a HTTP Apache server.

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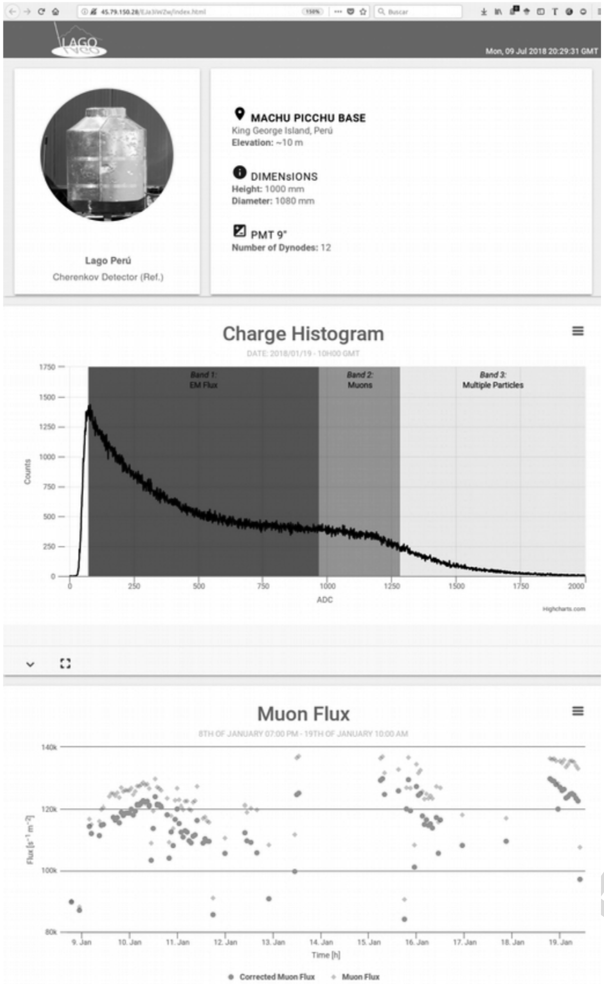

Fig. 4. Capture of the web monitor developed for the detectors in the LAGO Observatory, top-down: detector characteristics, particle flow divided into bands and total flow in the muon band hourly with (dark gray dots) and without pressure correction (light gray dots). Data obtained during the last Peruvian scientific campaign at Antarctica (January 2018).

The web monitor shows public information about some detector features: the current charge histogram divided in bands (as described earlier), and the last 720 h (one month) of muon flux. There is also private information (password protected) available only for the LAGO collaborators that shows atmospheric pressure, pressure correlation index and VEM time evolution.

In Fig. 4 we show the web monitor, with data obtained at the Machu Picchu Base (62° 05′ S 58° 28′ W) during the last Peruvian scientific campaign at Antarctica (January 2018).

4. Conclusion

A web based monitoring tool has been implemented for the LAGO detector network, based on a new calibration method. This method relies on previous knowledge of the muon flux that traverses the detector and the geometry of the particular detector. The method has been applied to two "opposite" (size and site) detectors of the network. From the results, we conclude that this method could be applied to most of the detectors on the LAGO grid.

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