PROCEEDINGS OF SCIENCE

LAGO: the Latin American Giant Observatory

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The Latin American Giant Observatory (LAGO) is an extended cosmic ray observatory composed by a network of water-Cherenkov detectors spanning over different sites located at significantly different altitudes (from sea level up to more than 5000 m a.s.l.) and latitudes across Latin America, covering a huge range of geomagnetic rigidity cut-offs and atmospheric absorption/reaction levels. This detection network is designed to measure the temporal evolution of the radiation flux at ground level with extreme detail. The LAGO project is mainly oriented to perform basic research in three branches: high energy phenomena, space weather and atmospheric radiation at ground level. LAGO is built and operated by the LAGO Collaboration, a non-centralized collaborative union of more than 30 institutions from ten countries.

In this work, we will describe several scientific and academic programs that are conducted within the LAGO framework, its present status and future perspectives.

The 34th International Cosmic Ray Conference,
30 July-6 August, 2015
The Hague, The Netherlands

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PoS(ICRC2015)247

1. Introduction

Astroparticle physics is nowadays one of the scientific fields that evidence large interdisciplinary contributions. This is not only possible but even needed, given the large array of topics this discipline covers: from high energy astrophysics (e.g. acceleration mechanisms) to computational sciences (e.g., data lineage and provenance). Cosmology, radiation-matter interactions, magnetohydrodynmics, Earth sciences, atmospheric science, detector physics, chemistry, biology and medical physics, have to be turned up to correctly interpret our results and to asses the extent of our predictions.

A large, enthusiastic and very active community has been emerging around this discipline as it can be observed at this conference. Several space borne and ground based cosmic rays observatories have been built or are being designed, comprising hundreds or even thousands of scientists working in large international collaborations. In the particular case of Latin America, the successful installation and commissioning of the Pierre Auger Observatory [1] in Malargüe, Argentina, generated an outstanding opportunity to develop Astroparticle physics and High Energy Physics in this region. Nowadays this is one of the main academic objectives of the Latin American Giant Observatory (LAGO), formerly known as Large Aperture Gamma Ray Bursts Observatory, a project conceived in 2006 [2] to detect the high energy component of Gamma Ray Bursts (GRBs) using low cost water Cherenkov detectors (WCDs) at high altitude sites across the Andes.

From this initial milestone, LAGO project has been evolved toward an extended astroparticle observatory at regional scale, currently operating WCDs and other particle detectors at nine countries in LA. Currently, LAGO has three main scientific objectives: to study high energy gamma events at high altitude sites, to understand space weather phenomena and monitoring it at continental scale and decipher the impact (direct and indirect) of the cosmic radiation on atmospheric phenomena. These objectives are complemented by two main academic goals: to train students in astroparticle and high energy physics techniques, and foremost, to support the development of astroparticle physics in LA. This paper is organized as follows: in the next section, the project, its organization, detector concepts and main objectives are described. Then, in section 3, some of our programs are described. Finally, in section 4, the future perspectives are presented.

2. The Latin American Giant Observatory

The Latin American Giant Observatory was originally designed to search for the high energy component of GRBs (with typical energy of primaries $E_p \gtrsim 20\,\mathrm{GeV}$) by installing $10\,\mathrm{m}^2 - 20\,\mathrm{m}^2$ of sensitive area at very high altitude sites across the Andean ranges [3]. Later in 2013, a new data analysis procedure was developed, allowing the possibility to study, at the same time, Space Weather phenomena by observing the Solar modulation of Galactic Cosmic Rays (GCR), and taking the advantage of several WCDs installed at low altitude sites [4].

At present, the LAGO Project is being built as an extended Astroparticle Observatory at a regional scale, operated by a cooperative and non-centralized collaboration of 26 institutions from 9 Latin American countries (Argentina, Bolivia, Brazil, Colombia, Ecuador, Guatemala, Mexico, Peru and Venezuela) and the recent incorporation of institutions from Spain. The geographic distribution of our sites, involving different countries with different cultures, idiosyncrasies and procedures, requires a highly dynamic and extended organizational schema. The “Coordination Committee” is the decision making entity of the project and consists of a principal investigator and one democratically elected representative for each participating country. All the collaboration members are organized in four working groups: WG1-Physics, WG2-Detectors, WG3-Data and WG0-Management.

The LAGO detection network, shown in figure 1 on the left, consist of single or small arrays of astroparticle detectors installed in different sites across the Andean region [5]. Currently, ten WCDs are in operation and we expect to have another eleven detectors starting their operation and calibration in the 2016-2017 biennium. As it is clearly visible in the map, our detection network spans from the south of Mexico, with a small array installed at Sierra Negra (4550 m a.s.l.), to the Patagonia, with three WCDs installed at Bariloche (865 m a.s.l.). Moreover, it was recently funded the installation of two WCDs at the Marambio Base (Arg., 200 m a.s.l.) located in the Antarctic Peninsula [6], mainly oriented for Space Weather studies and monitoring [7]. In the same figure, on the right, the geomagnetic rigidity cut-off (in GV) of each site as a function of its geographic latitude (connected with the map on the left) is shown. In this sense, the distribution of the network, comprises quite similar geographical longitudes but large differences in geographical latitudes and altitudes. Then, by combining simultaneous measurements at different rigidity cutoffs and atmospheric absorption reactions places we are able to produce near-real-time information at different energy ranges of, for example, disturbances induced by interplanetary transients and long term space weather phenomena.

Each LAGO water Cherenkov detector consist of a plastic tank containing 1 m^3 to 40 m^3 of purified water, where one [8] to four [9] on-top large photomultiplier tubes (PMT) collect the Cherenkov light produced by ultra-relativistic particles moving through the water volume. An internal coating of an ultra-violet light highly reflective and diffusive fabric is used. The WCD signals are shaped and digitized by a custom made 40 MHz electronic board controlled by a Digilent Nexys2 FPGA [10, 9].

The need to measure very different physical magnitudes in remote places with almost no infrastructure requires autonomous and reliable detectors and components. Moreover, we based our design in commercial off-the-shelf devices, which have to be available in all the countries where LAGO operates. For this, a different approach was introduced by changing our station concept and to consider the WCD just as an additional sensor that accounts for cosmic radiation. In the same way, the main component is the electronic system that operates the complete station. Other sensors are integrated in an Arduino controlled common sensor module to measure atmospheric pressure, air temperature, solar radiance, cloudiness, and even CO_2 and other greenhouse and smog gasses concentrations such as CO, NO_x, CH_4 and H_2O. A commercial global navigation satellite system module is included for timing synchronization and to allow the calculation of ionospheric total electron content (TEC) calculations in some sites [11]. All these devices, including the WCD electronics boards, are powered by solar panels and are controlled by a single board computer that includes a GPRS module to transfer telemetry and on board pre-analyzed data by using mobile phone networking data services. This new concept produces data that extends the typical objectives of a cosmic ray observatory, allowing several scientific, academic and even citizen science communities to take advantage of our regional scale detection network [13, 14, 15].

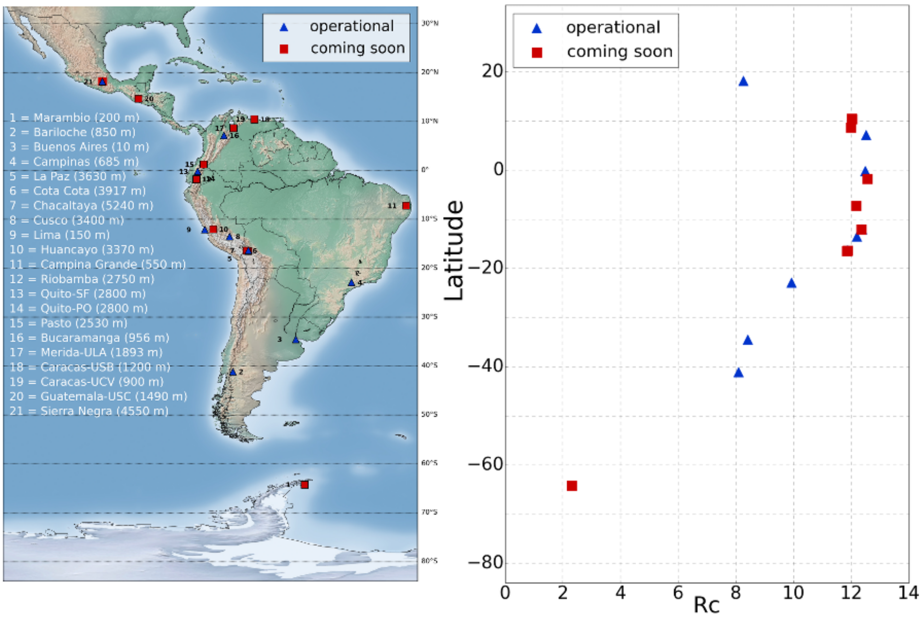

Figure 1: Geographical distribution and altitudes of the operational LAGO water Cherenkov detectors (blue triangles), and those that are being deployed and will start its operation during the 2016-2017 biennium (red squares). At the right panel, the vertical rigidity cut-off of each LAGO site is shown.

3. The LAGO Programs

Scientific and academic objectives are organized in different programs and are carried out by the corresponding working groups. LAGO programs cover several aspects of the project, from the installation [6, 8], calibration and operation [16, 9] of the detectors to the search for pathways to transfer data from remote sites [13]. Complete simulation chains involving all the related aspects (from CR propagation to detector response) [16, 7], data analysis techniques specially designed for the very different energy and temporal scales of the studying phenomena [7, 17, 9], data preservation [13], and the design of new experiments to be conducted in graduate and undergraduate lectures in the participating Universities [15, 14], are just some examples of the range of the objectives of the LAGO project. In this section some of these programs will be described and some of the scientific results presented at this conference will be highlighted.

High altitude sites ($h > 4500$ m) are designed and operated mainly for the search of high energy components of GRB. The main purpose to climb to this high altitudes mountains is to diminish the atmospheric absorption of extensive air showers (EAS) initiated by low energy cosmic rays. As at this altitudes the muonic component of EAS are not fully developed (see e.g. [4] for the background muon content at the LAGO site of Chacaltaya), it is not possible to use the vertical equivalent muon (VEM) technique to calibrate WCD (see e.g. [1, 7]). In this case, instead of looking for the characteristic muon hump in the histogram of time-integrated pulse signals (charge histograms), the VEM is obtained by looking for a slight change in the charge histogram slope. However, to increase electromagnetic-muon separation at single pulse level, a method based on the total charge and pulse rise-time analysis is also implemented, as can be observed in the left panel of figure 2. The increase in separation performance can be used to improve the search for possible GRB candidates, as gamma initiated showers evidence lower muon fractions at detector level when compared with hadronic primaries.

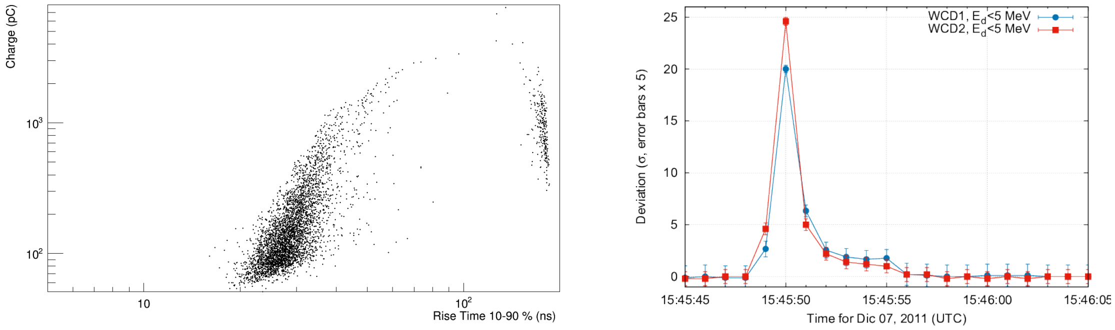

Figure 2: Left: component separation by using pulse shape analysis of individual signals: here, the total integrated charge as a function of the 10% → 90% rise-time shows a clear separation of low and short signals (mainly electromagnetic) from typical muon signals (from [9]). Right: Signal alert for a potential event candidate registered on Wed Dec 07 15:47:02.378 UTC 2011 detected by LAGO at Chacaltaya, Bolivia, 5250 m a.s.l. (from [17]).

All the LAGO programs exploit the single particle technique (SPT) [18] by looking for significant excesses in the counting of background signals at different sites. In particular, the LAGO facilities at Chacaltaya mountain consist of three LAGO WCDs with a total detection area of $10\,\mathrm{m}^2$. In the period 2010-2012 the Chacaltaya station has collected data during $\sim$ 17000 hours of detection for WCD1 and WCD2, and $\sim$ 15700 hours for WCD3. Recent studies, based on CORSIKA simulations, show that the angular aperture of the Chacaltaya site can be extended up to a zenith angle of 25^{o} in the energy range of interest for GRB and other Gamma originated signals at Chacaltaya. Combining these results with the uptime of each WCD at Chacaltaya in this period, the total exposure of this site accumulated during this period was $2.7\times10^8\,\mathrm{m}^2\,\mathrm{s\,sr}$. Considering the typical variations on the flux at the time scales of interest, we base the first steps of our analysis in the moving window average (MWA) method. Using this method, we look for $\geq|3\sigma|$ instantaneous deviations in the central 5 ms bin on a moving average window of 2 minutes (24,000 time bins) of duration. If such a deviation is observed, the data is tagged as a potential transient candidate. Then, a strict criterion based on searching for simultaneous deviations in different energy subchannels and detectors is imposed (see [17]). Following this procedure, a new potential candidate was found, started on Wed Dec 07 15:45:49.675±0.005 UTC 2011 and a duration of 5.5 s, as can be seen in the right panel of figure 2. At this time, the equatorial coordinates of Chacaltaya zenith were RA/Dec (J2000) $16^{\mathrm{h}}17^{\mathrm{m}}31.3^{\mathrm{s}}/-16^\circ21'00''$, with an acceptance aperture of $\theta\lesssim25^\circ$. At this time, Fermi satellite was outside of our acceptance cone in Chacaltaya.

While this technique has the lack of directional reconstruction, it is however possible to use atmospheric absorption as a selection tool for periodic signals like gamma point sources. Data stacking or summation in two different time systems, solar and sidereal, were made over the data. The idea behind this process is based on the random, poissonian, nature of the majority of the radiation measured by our detectors. When a non random and periodic signal exists, sufficient data can be summed in a scale in which this signal happened at the same time every day or month or week, thus increasing the signal-to-noise ratio. In particular, sidereal and solar time epoch stacking were performed, observing clear indications, both in phase and in amplitude, of solar modulation of the flux of galactic cosmic rays. These observations support the fact that, by using an adapted analysis technique to the characteristics of our small detectors, it is possible to observe space weather phenomena at different time scales from ground level in the LAGO network of WCD.

Simultaneous measurements of galactic cosmic rays flux modulation at different locations on Earth using the same type of detectors, can provide important information, e.g., about certain properties of the global structure of the magnetic clouds reaching the terrestrial environment during interplanetary Coronal Mass Ejection (iCME) pointing towards Earth (e.g. [12]). By using WCDs, we are able to determine the flux of secondary particles at different bands of deposited energy within the detector volume. These bands are dominated by different components of the CR reaching the Earth atmosphere (primaries). This is what we called the multi-spectral analysis technique (MSAT), and constitutes the basis of our Space Weather oriented data analysis [7]. Then, by combining all the data measured at different locations of our detection network, the LAGO project will provide very detailed and simultaneous information of the temporal evolution and of the small and large scales characteristics of the disturbances produced by different transient and long term space weather phenomena.

A complex and complete chain of simulations support this program [7, 16, 8]. For every LAGO site, the directional rigidity cutoff R_c is determined for secular and altered geomagnetic field conditions, such as those produced during intense geomagnetic storms. After that, we determine the expected number of primaries by integrating the measured flux of all the hadronic cosmic rays with $1\,\mathrm{GeV} < E_p < 1\,\mathrm{PeV}$. A set of CORSIKA simulations is then used to determine the expected number of secondary particles at ground level. Only those secondaries originated on primaries with rigidities above local cut-offs are included. As an example, the effect of geomagnetic field corrections for the LAGO site of Bucaramanga, Colombia, is shown in the left panel of figure 3. The expected flux of secondaries without corrections is compared with the corresponding flux after considering geomagnetic effects, as a function of the secondary momentum. The peak observed at $\simeq 0.5\,\mathrm{GeV/c}$ corresponds to the neutron-dominated region. For this particular component, the decrease at ground level in geomagnetic secular conditions represents a diminution of -36.6%. This could be an indication of the sensitivity of secondary neutron flux as a proxy of the changing conditions in the near-earth space environment. Finally, expected secondary particles are injected into a Geant4 based model of the LAGO WCD to obtain the signal flux at detector level [16].

The LAGO implementation of MSAT take advantage of the WCDs capability to measure deposited energy of secondary particles entering the detector. Charge pulse histogram has different features that can be correlated with electromagnetic secondaries flux, muon dominated flux and multiple-particles flux. Thus, with the LAGO MSAT we are able to determine the evolution of the flux observed at those three bands. As the transition points between these different regimes are characterized by changes in the histogram slopes, a fully automated algorithm searches for all these

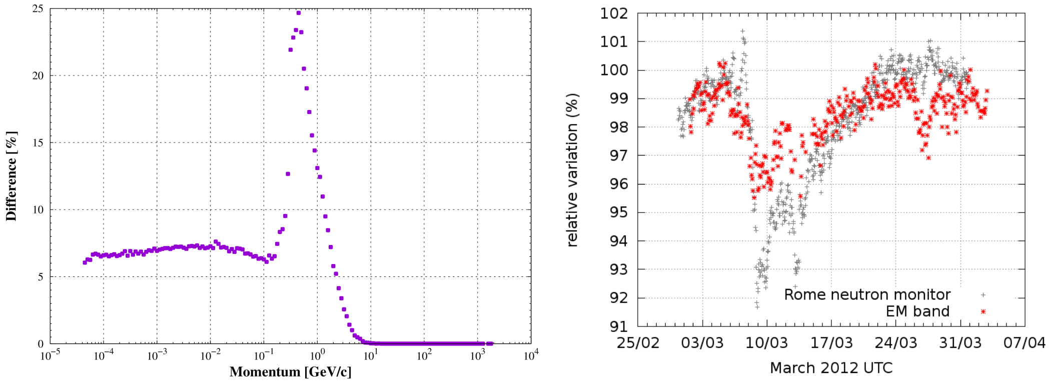

Figure 3: Left: The effect of geomagnetic corrections in the flux of secondary particles is shown as a function of their momentum, for the simulations performed to characterize the LAGO site of Bucaramanga, Colombia. Right: Multi-spectral analysis of the Forbush Decrease of March 8th, 2012, measured in a single 1.8 m^2 WCD in Bariloche, Argentina (red stars), compared with neutron flux measured by the Rome neutron monitor (gray pluses).

features in 1-hour calibration histograms. From this, we determine the integrated total flux at each band, with typical integration windows between 1 minute and 15 minutes. As an example, in the right panel of figure 3 the measurement of the Forbush decrease occurred on March 8th, 2012, is shown for the electromagnetic dominated band. These measurements evidence WCDs capabilities to extend present studies of space weather phenomena using low cost detectors from ground level.

4. Conclusions

In this paper we give a basic sketch of the Latin American Giant Observatory, its main scientific capabilities and implications for the development of astroparticle physics at Latin America. We also described the key programs of LAGO, oriented to search for GRBs, high energy phenomena, and space weather, using low cost and reliable detectors at ground level. A complete chain of simulations and different data analysis techniques have been developed and presented, exploiting the WCDs capabilities to measure at different energy regimes. Several examples summarize here the LAGO capabilities to study these very different astrophysical phenomena, and, as new detectors are starting to operate (such as the new LAGO site in Antarctica) a large and unprecedented detection network emerges at regional scale.

Besides its scientific importance, the LAGO project is also a seeder for astroparticle physics development in the Andean region. A proof of this is the fact that most of the results presented at this conference have been obtained by several undergraduate and master students working in coordinated collaboration at several Latin American countries.

In summary, LAGO is a promising observatory that is helping to support the development of several interdisciplinary branches associated with Astroparticles in Latin America.

Acknowledgments The LAGO Collaboration is very thankful to all the participating institutions and to the Pierre Auger Collaboration for their continuous support.

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