PROCEEDINGS OF SCIENCE

Analysis of Background Cosmic Ray Rate in the 2010-2012 Period from the LAGO-Chacaltaya Detectors

H. Asorey[1,2,3], P. Miranda[5], A. Núñez-Castiñeyra[4], L.A. Núñez[3,4], J. Salinas[5], C. Sarmiento-Cano[*3], R. Ticona[5], A. Velarde[5], for the LAGO Collaboration[6]

[1] *Laboratorio Detección de Partículas y Radiación, Instituto Balseiro y Centro Atómico Bariloche, S.C. de Bariloche, Argentina.*
[2] *Sede Andina, Universidad Nacional de Río Negro, S.C. de Bariloche, Argentina.*
[3] *Escuela de Física, Universidad Industrial de Santander, Bucaramanga, Colombia.*
[4] *Centro de Física Fundamental, Dept. de Física, Universidad de Los Andes, Mérida Venezuela*
[5] *Instituto de Investigaciones Físicas, Universidad Mayor de San Andrés, La Paz, Bolivia*
[6] *lagoproject.org, see the full list of members and institutions at lagoproject.org/collab.html*
e-mail: `lago-pi@lagoproject.org`

The Latin American Giant Observatory (LAGO) is an extended Cosmic Rays observatory composed by a network of Cherenkov Detectors (WCDs) spread over Latin America. This work will report the analysis of three years of data from three LAGO WCD located in Cerro Chacaltaya, Bolivia, at 5200 m a.s.l. Background cosmic ray rate from these detectors is checked for DAQ issues and inconsistencies, and corrected for atmospheric effects. An analysis for short transients up to the minute timescale is performed, in search for coincidence with transients observed by satellites. Sidereal and solar long term epoch data analysis are also presented.

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

*Speaker.

1. Introduction

Due to the atmospheric absorption, it is very difficult to directly detect low energy cosmic rays or photons in 10 GeV −10 TeV energy range from ground level. Very large detection areas or very high altitude sites are currently used around the world to complement direct measurements made on board of satellites. Since 2006, the LAGO (Latin American Giant Observatory, formerly Large Aperture Gamma Ray Burst Observatory) project [1] has been developing and operating sites at high altitude montain in Latin America [2].

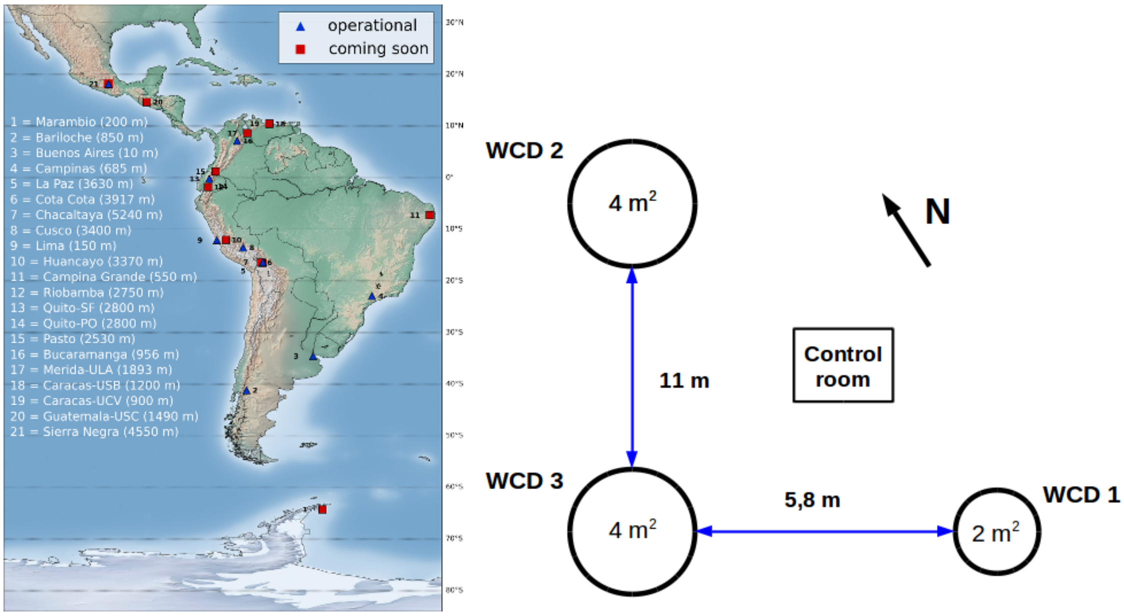
Nowadays, the LAGO Project is an extended Astroparticle Observatory at a continental scale [3], mainly oriented towards developing astroparticle physics at Latin America and doing basic research in three areas: search for the high energy component of GRBs at high altitude sites, Space Weather phenomena, and Background Radiation at ground level [4]. The LAGO detection network consists in particle detectors deployed at ground level, spanning over different sites located at significantly different latitudes (currently planned from Mexico down the Antarctic region) and different altitudes (from sea level up to more than 5000 meters over sea level), covering a large range of geomagnetic rigidity cut-offs and atmospheric absorption/reaction levels [5]. The current distribution and status of the LAGO detection network in the American continent is shown in figure 1. This network of detectors is operated by the LAGO Collaboration, a non-centralized and distributed collaborative network of more than 80 scientist from institutions of nine Latin American countries (currently Argentina, Bolivia, Brazil, Colombia, Ecuador, Guatemala, Mexico, Peru and Venezuela) and Spain. Due to its proved reliability, high detection efficiency to all components present in atmospheric extensive showers, and low cost, water Cherenkov detectors (WCD) are currently used at LAGO sites [3].

In this work we show a new analysis of the scalers rates (an implementation of the single particle technique [6]) of the LAGO WCDs installed at Mount Chacaltaya (section 2). This analysis is conducted for the search of short transient events ($\Delta t \lesssim 1$ minute) as we show in section 3). Finally, in section 4 we show our epoch analysis in solar and sidereal time for the search of periodic signals.

2. LAGO at Mount Chacaltaya

The WCD of the LAGO project in Bolivia are located at Mount Chacaltaya (16°21′00″S, 68°07′53″W), at 5270 m above sea level. In one of the main buildings of the Chacaltaya Astrophysical Observatory, three LAGO WCD (two of them with a detection area of 4 m^2 and the third of 2 m^2) register the flux of secondary particles as a function of time. Each WCD is buit by using a commercial water tank filled with purified water, and a single photomultiplier tube located in the center of the detector roof is submersed in the water volume. An internal coating made from Tyvek assure the diffusion of the Cherenkov radiation produced by the passage of ultra-relativistic charged particles trough the detector volume. This setup improve the detection efficiency by diminishing the dependence with the direction of propagation of the secondary particles inside the detector.

The spatial configuration of the array can be seen in the right panel of figure 1. The instrumented area and the high altitude of this site provide enough sensitivity to detect the high energy component of Gamma Ray Bursts (GRBs) [2].



(a) (b)

Figure 1: (a): The Sites of the Latin American Giant Observatory, located at Latin America in eight countries. The first detectors are starting in operation (blue triangles), and some other detectors (red squares) are planned to start in operation in 2015-2016. (b): The spatial distribution of the LAGO WCD in the Chacaltaya Observatory. The WCD2 and WCD3 detectors have a detection area of $4\,\mathrm{m}^2$, while the effective area of the WCD1 is $2\,\mathrm{m}^2$.

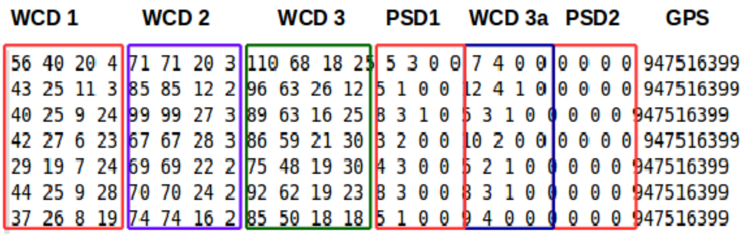
Two generations of the data acquisition system (DAQ) have been developed and used in the LAGO WCDs. The first acquisition system used [2] was based on an adaptation of the electronics of the first engineering-array phase of the Pierre Auger Observatory [7]. Since Jun 2012 a new LAGO specific electronic system was installed at the Chacaltaya site. Since then this new data acquisition system has been being installed at the different sites of the LAGO project [5].

By using the first electronic system, in the period 2010-2012 the Chacaltaya station has collected data during ~ 17000 hours of detection for WCD1 and WCD2, and ~ 15700 hours for WCD3. Recent studies [8], based on CORSIKA [9] simulations, show that the angular aperture of the Chacaltaya site can be extended up to a zenith angle of 25° in the energy range of interest for GRB and other Gamma originated signals at Chacaltaya. Combining these result with the uptime of each WCD at Chacaltaya in this period, the total exposure of this site accumulated during the 2010-2012 period was $2.7 \times 10^8\,\mathrm{m}^2\,\mathrm{s}\,\mathrm{sr}$.

2.1 Data provenance of Chacaltaya LAGO data

The first data acquisition board can control up to three independent WCD and six independent signal channels. Usually, the last dynode and the anode of the PMT of each WCD are measured. Four different signals thresholds are set for each channel, three of them are for fixed values above the baseline and correspond to different limits in the deposited energy (E_d) inside the detector by the registered secondary particles. The first one of these sub-channels records particles with $E_d \lesssim 5\,\mathrm{MeV}$, the second sub-channel counts particles that deposited between 5 MeV and 10 MeV within the water volume, while the third one is for signals with $E_d \gtrsim 50\,\mathrm{MeV}$ [10]. The fourth sub-channel is intended to register the occurrence of undershoot pulses at the PMT, which are associated with signal saturation, high frequency noise due to lightnings at the site and other possible noise electronic sources. The trigger condition is that the signal amplitude should be above (or below for sub-channel 4) the corresponding threshold.

The sampling frequency in the first LAGO DAQ is of 200 Hz, corresponding to time bins of 5 ms. The data is recorded in plain ascii compressed files containing one hour of data, with a single row per temporal bin with 25 columns: the first 24 columns account for the counting rates of each threshold for each channel, and an extra column is used to provide timing information from the GPS module on board the station. A sample of one of the 1-hour data files is shown in Figure 2. A very simple check of the quality of the acquisition procedure is to verify that every GPS should contain 200 lines, and so every 1-hour file must contain 720,000 lines and 3,600 different GPS labels.



WCD 1	WCD 2	WCD 3	PSD1	WCD 3a	PSD2	GPS
56 40 20 4	71 71 20 3	110 68 18 25	5 3 0 0	7 4 0 0	0 0 0 0	947516399
43 25 11 3	85 85 12 2	96 63 26 12	5 1 0 0	12 4 1 0	0 0 0 0	947516399
40 25 9 24	99 99 27 3	89 63 16 25	8 3 1 0	5 3 1 0	0 0 0 0	947516399
42 27 6 23	67 67 28 3	86 59 21 30	3 2 0 0	10 2 0 0	0 0 0 0	947516399
29 19 7 24	69 69 22 2	75 48 19 30	4 3 0 0	5 2 1 0	0 0 0 0	947516399
44 25 9 28	70 70 24 2	92 62 19 23	8 3 0 0	8 3 1 0	0 0 0 0	947516399
37 26 8 19	74 74 16 2	85 50 18 18	5 1 0 0	9 4 0 0	0 0 0 0	947516399

Figure 2: A 35 ms sample of a data file collected in the Chacaltaya station, where all six channels are operative. Each signal channel is represented by a four columns block, corresponding to the four sub-channels described in the text. Each line correspond to the count of signals that satisfied the trigger condition for each sub-channel within a 5 ms interval. Channels 1, 2, and 3 are connected to WCD1, WCD2 and WCD3 respectively. The remaining channels were used at that time to acquire data from detectors of the INCA project operating also at the Chacaltaya Astrophysical Observatory.

After introduced those simple quality cuts in the acquired data it was found that data collected in 2008 and part of 2009 have a sampling frequency that shifts between 128, 200 and 256 samples per second, this problem was identified and solved in 2010.

Another way to verify that data is being collected correctly is to examine the background behaviour, which variations have known sources, such as the atmospheric conditions at the site and can be corrected. Large deviations from the expected background are carefully analyzed to check for possible signals or inconsistencies. A possible source of this deviations could be the electronics system overload due to multiply programmed parallel tasks on the station board. To check for these issues, we stacked the data from several 1-hour files and found that 5 minutes after the beginning of each hour a sudden decrease in the counting rates occurs. This happens during the transfer of the previous data file from the station to the computer that controls the DAQ system. As the data acquired during this short period of time can't be used, then are labelled as bad data and are not used to perform physics analysis.

These validations and data quality cuts were introduced over all of the data collected in the Chacaltaya station [11] and after that, the surviving data was stored in the LAGO data repositories of the collaboration [12].

3. Search for Short Transient Events

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 [13]. 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 pontential transient candidate.

After that, we also required that such deviation must be observed simultaneously in at least two operating detectors in the site, and must be present in at least the low and the intermediate deposited energy sub-channels. Finally, an additional criterium is imposed: during the observed excesses in sub-channels 1 and 2 of the triggered detectors, no significant excess must be observed in the noise counting sub-channel. All these criteria are required to discard, for example, signals produced during lightning discharges that could be misinterpreted as potential candidates during the standard $\sigma - \delta$ analysis [2]. If all those criteria are fulfilled, the data is labeled as candidate and is separated for a detailed analysis.

After applying this method and imposed the quality cuts described, over 2 terabytes of data collected in the period 2010-2012 at Chacaltaya, we found a potential candidate, started on Wed Dic 07 15:45:49.675±0.005 UTC 2011 (unix time $(1323272749.675 \pm 0.005)$ s). At this time, the equatorial coordinates of the Chacaltaya zenith were RA/Dec (J2000) $16^{\mathrm{h}}17^{\mathrm{m}}31.3^{\mathrm{s}}/-16^{\circ}21'00"$, with an acceptance aperture of $\theta \lesssim 25^{\circ}$.

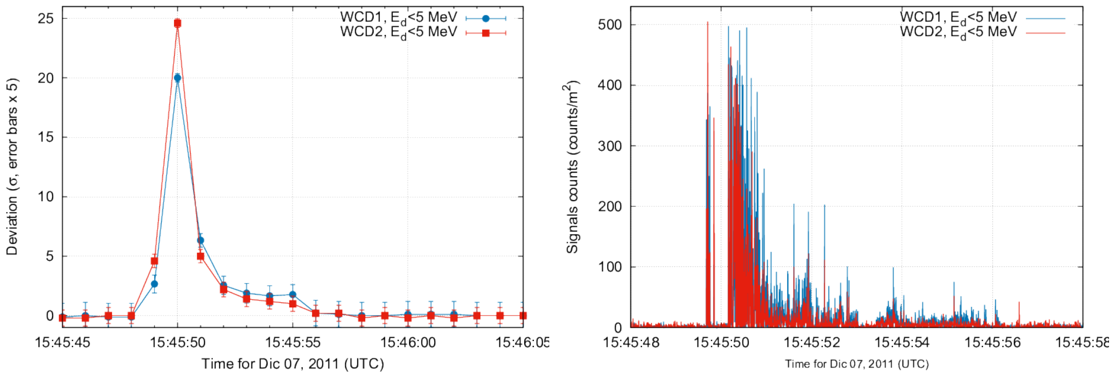
By integrating the signal shape, we determine a duration of 5.5 s (T_{95}, i.e, the time needed to reach 95% of the integrated signal), with a rise time ($T_{50} - T_{10}$) of 0.55 s and a fall time ($T_{90} - T_{50}$) of 3.5 s. This signal was observed on both WCD1 and WCD2 simultaneously in the sub-channels 1 ($E_d \leq 5$ MeV) and 2 ($5 \leq E_d \leq 10$ MeV) and a less significant excess on the sub-channel 3 of both detectors. After a careful examination of the signals shapes, calibration data and operation metadata of our detectors and the atmospheric database of this site, we discarded the possibility that this event was produced by detectors malfunctions, HF noises, electric lightnings or other phenomena of atmospheric origin.

After this blind analysis, we look for coincidences with events registered on both the SWIFT [14] and Fermi [15] satellites and also at the Gamma-ray Coordinates Network (GCN) database[1]. However, at this time the field of view of Fermi was outside of our acceptance cone in Chacaltaya.

4. Long Term Epoch Analysis

On the search for periodic signals we performed a series of analyses over large periods of time on the data collected at the Chacaltaya station. 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. If any not random, periodic, signal were to exist, and if sufficient data were to be summed in a scale in which this signal happened at the same time every day or month or week. No matter how small this signal could be it will build an observable rise on the line that represent the summed data, as the random fluctuations will mutually cancel and the signal will grow [8].

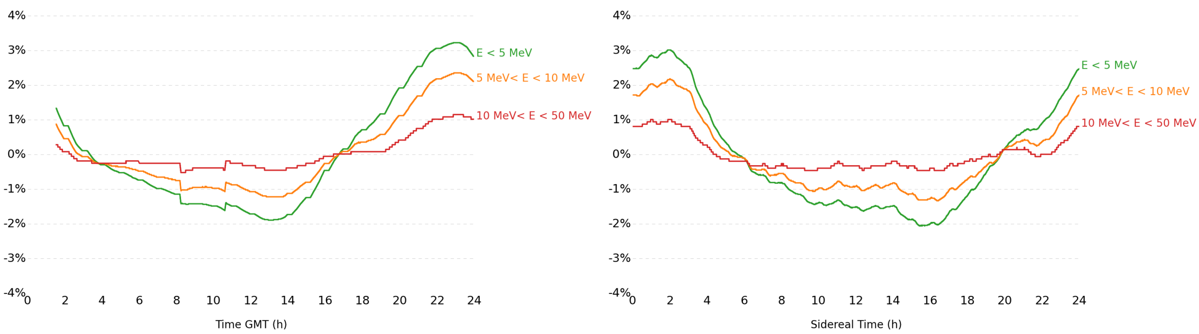
[1]http://gcn.gsfc.nasa.gov/



(a) (b)

Figure 3: Potential candidate signals for the event registered on Wed Dic 07 15:47:02.378 UTC 2011. In panel (a) we show our alert as described in the text, while in the panel (b) the registered signals in 5 ms temporal bins are shown

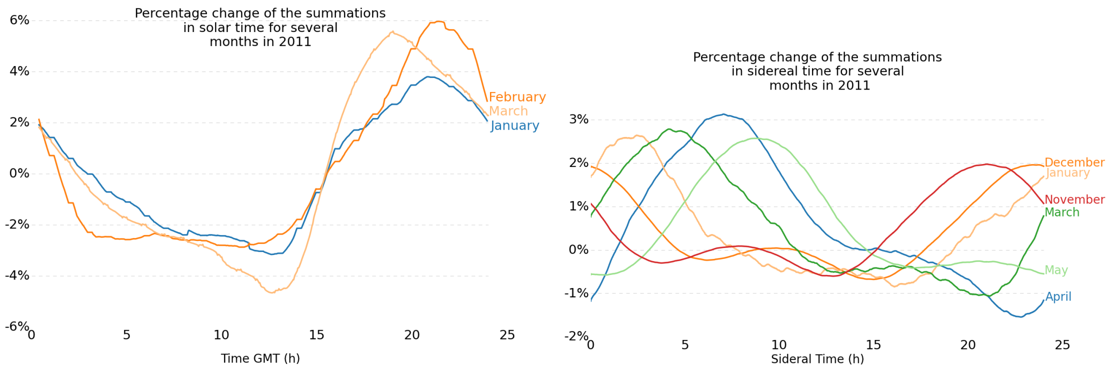
This summation of data were made on two different systems: sidereal time, for signals coming from outside of our Solar System and in solar time, for signals modulated by Solar activity. A minute average signals were summed with the average of the corresponding minute of the next day, solar or sidereal. The sudden drop in the counting rate described in the previous section produced a huge peak at every summed hour when it is not corrected. In figure 4 the results of the summation of the data of April 2011 are shown for the three signal related sub-channels of WCD1. A WMA analysis was performed over the stacked data on both time systems, looking for excesses on the summed data that could be associated with the passage of known point sources by the sky at Chacaltaya. In this way, as the single particle technique lacks of directional reconstruction, we are exploiting atmospheric absorption as a source selection tool. Additionally, a method based on CORSIKA simulations was developed to account for the sensitivity of the LAGO detectors at high altitude sites for different gamma sources in the tens of GeV-TeV energy range [8, 16].



(a) (b)

Figure 4: Solar (a) and sidereal (b) summation over the data gathered in the month of April of 2011 for the WCD1 detector at Chacaltaya. The green lines represents the observed modulation in the low energy sub-channel. The orange lines represent the energy threshold corresponding to particles with energies between 5 MeV and 10 MeV and the red lines particles with energy higher than 10 MeV. The vertical axis represent the percentage of change form the middle value of each sub-channel in the solar or sidereal time analysis.

The results of the complete summation on the data collected in the Chacaltaya station in 2011 is show in figure 6 where both solar time and sidereal time are shown here, and have consistent results. In solar time it appears a rise on the counts that holds in the same stage of the solar day while in sidereal time the rise moves about two hour every month. These facts are clear indicators of the solar nature of this phenomenon. The amplitude and phase observed on the solar time variations are consistent with the well known daily modulation of solar origin in the flux of low energy cosmic rays.



(a) (b)

Figure 5: Solar daily modulation in the flux of cosmic rays observed at the LAGO site in Chacaltaya. This phenomena was observed by stacking and summing the measured and corrected fluxes in solar (a) and sidereal (b) times.

This observations confirm that, by using an adapted analysis technique to the characteristics of our small detectors, it is possible to observe different type of signals of solar nature at different time scales from the ground level in the LAGO network of WCDs across Latin America.

Acknowledgements:

The LAGO Collaboration is very thankful to the Pierre Auger Collaboration for its continuous support. The authors of this paper gratefully acknowledge the financial support from CDCHT-ULA project C-1598-08-05-A and Vicerrectoría Investigación y Extensión Universidad Industrial de Santander.

References

[1] D. Allard et al., *Use of water-cherenkov detectors to detect gamma ray bursts at the large aperture grb observatory (lago)*, *Nuclear Inst. and Methods in Physics Research, A* **595** (2008), no. 1 70–72.

[2] D. Allard et al., *The Large Aperture GRB Observatory*, *ArXiv e-prints* (June, 2009) [arXiv:0906.0816].

[3] H. Asorey, S. Dasso, and the LAGO Collaboration, *Lago: the latin american giant observatory*, in *The 34th International Cosmic Ray Conference*, vol. PoS(ICRC2015), p. 247, 2015.

[4] H. Asorey, S. Dasso, L. Núñez, Y. Pérez, C. Sarmiento-Cano, M. Suárez-Durán, and for the LAGO Collaboration, *The LAGO space weather program: Directional geomagnetic effects, background fluence calculations and multi-spectral data analysis*, in *The 34th International Cosmic Ray Conference*, vol. PoS(ICRC2015), p. 142, 2015.

[5] I. Sidelnik and the LAGO Collaboration, *The sites of the latin american giant observatory*, in *The 34th International Cosmic Ray Conference*, vol. PoS(ICRC2015), p. 665, 2015.

[6] S. Vernetto, *Detection of gamma-ray bursts in the 1 GeV-1 TeV energy range by ground-based experiments*, *Astroparticle Physics* **13** (Mar., 2000) 75–86, [astro-ph/].

[7] **Pierre Auger** Collaboration, The Pierre Auger Collaboration, *The Pierre Auger Cosmic Ray Observatory*, *Accepted in Nucl. Inst. Meth. A. arXiv:1502.01323.* (2015) [arXiv:1502.0132].

[8] A. Nuñez-Castiñeyra, *Sensibilidad del proyecto lago a señales gamma proveniente del centro de la galaxia*, Master's thesis, 2015.

[9] D. Heck et al., *CORSIKA : A Monte Carlo Code to Simulate Extensive Air Showers*, *FZKA* **6019** (1998) 1–98.

[10] A. Velarde, R. Ticona, and P. Miranda, *Proyecto lago bolivia*, *Revista Boliviana de Física* **15** (2009), no. 15 32–38.

[11] L. Núñez, F. Quiñonez, and C. Sarmiento-Cano, *Validación del linaje de los datos de la colaboración LAGO. Instalaciones Sierra Negra y Chacaltaya*, *ITECKNE* **10** (Jul, 2013) 104.

[12] H. Asorey, D. Cazar-Ramírez, R. Mayo-García, L. Núñez, M. Rodríguez-Pascual, L. Torres-Niño, and the LAGO Collaboration, *Data accessibility, reproducibility and trustworthiness with lago data repository*, in *The 34th International Cosmic Ray Conference*, vol. PoS(ICRC2015), p. 672, 2015.

[13] C. Sarmiento-Cano, *Identificación de destellos gamma en los repositorios de datos de la colaboración lago*, Master's thesis, 2012.

[14] S. D. Barthelmy, L. M. Barbier, J. R. Cummings, E. E. Fenimore, N. Gehrels, D. Hullinger, H. A. Krimm, C. B. Markwardt, D. M. Palmer, A. Parsons, G. Sato, M. Suzuki, T. Takahashi, M. Tashiro, and J. Tueller, *The burst alert telescope (bat) on the swift midex mission*, *Space Science Reviews* **120** (Oct., 2005) 143–164, [astro-ph/0507410].

[15] F. Acero, M. Ackermann, Ajello, et al., *Fermi Large Area Telescope Third Source Catalog*, *Astrophysical Journal* **218** (June, 2015) 23, [arXiv:1501.0200].

[16] A. Núñez-Castiñeyra, H. Asorey, and L. A. Núñez, *Sensitivity of ground based single water cherenkov detectors to search of gamma point sources*, *in preparation* (2015).

PoS(ICRC2015)414