Operating Water Cherenkov Detectors in high altitude sites for the Large Aperture GRB Observatory

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***Abstract*. Water Cherenkov Detectors (WCD) are efficient detectors for detecting GRBs in the 10 GeV - 1 TeV energy range using the single particle technique, given their sensitivity to low energy secondary photons produced by high energy photons when cascading in the atmosphere. The Large Aperture GRB Observatory (LAGO) operates arrays of WCD in high altitude sites (above 4500 m a.s.l.) in Bolivia, Mexico and Venezuela, with planned extension to Peru. Details on the operation and stability of these WCD in remote sites with high background rates of particles will be detailed, and compared to simulations. Specific issues due to operation at high altitude, atmospheric effects and solar activity, as well as possible hardware enhancements will also be presented.**

***Keywords*: New experiments, water Cherenkov detectors and high energy photons**

I. INTRODUCTION

Since photons coming from GRBs can not penetrate easily the atmosphere, it is necessary to use satellites to detect them. However, as the photon energies increase, the photon flux decreases as a power law. Therefore, in order to detect small fluxes of gamma radiation or high energy photons in the range of GeV to TeV is necessary to construct more sensitive detectors with larger areas. Satellites with large collecting areas become impractical due to their cost. However, with inexpensive ground-based experiments of large area, it is possible to detect the relativistic secondary particles induced by the interaction of GeV or TeV gamma-ray photons with the molecules of the upper atmosphere. Water Cherenkov Detectors (WCD) are efficient detectors for detecting GRBs in the 10 GeV - 1 TeV energy range using the single particle technique, given their sensitivity to low energy secondary photons produced by high energy photons when cascading in the atmosphere.

Currently or in the recent past, a handful of ground-based experiments around the world are searching GRBs: Chacaltaya at 5200 m a.s.l. in Bolivia (INCA); Argo at 4300 m a.s.l. in Tibet; Milagro at 2650 m a.s.l. in New Mexico; the Pierre Auger Observatory at 1400 m a.s.l. in Malargüe, Argentina and LAGO (with several sites). Of all these experiments only the prototype of Milagro called Milagrito has reported the

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possible detection of signals associated to a GRB, GRB 970417. Milagro is the largest area (60 m×80 m) water Cherenkov detector capable of continuously monitoring the sky at energies between 250 GeV and 50 TeV. Although designed to study ultra high energy cosmic rays, the Pierre Auger Observatory is also a competitive high energy GRB ground-based detector due to its large area and the good sensitivity to photons of its water Cherenkov detectors . The Large Aperture GRB Observatory (LAGO) operates arrays of WCD in high altitude sites (above 4500 m a.s.l.) in Mexico, Bolivia and Venezuela (see figs. 1, 2, 3), with planned extension to Colombia, Guatemala, the Himalaya and Peru.

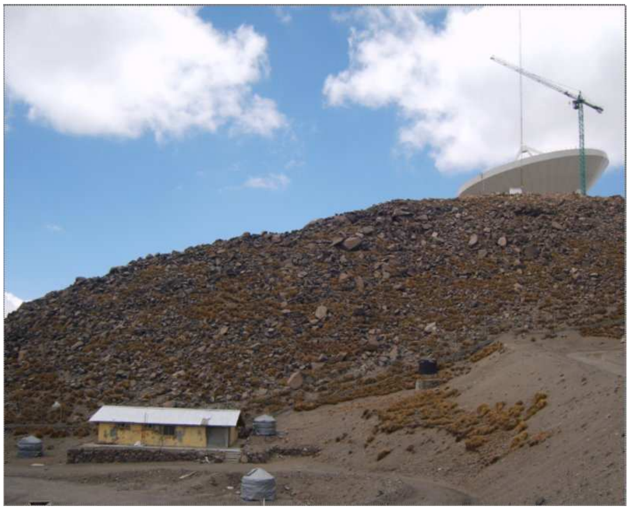

Fig. 1: LAGO-Sierra Negra site Mexico at 4550 m a.s.l.

Fig. 2: LAGO Chacaltaya site at 5280 m a.s.l.

Details on the operation and stability of these WCD in remote sites with high background rates of particles will be detailed. Specific issues due to operation at high altitude, atmospheric effects, as well as possible hardware enhancements will also be presented.

Fig. 3: LAGO Merida site at 4780 m a.s.l.

Two basic conditions are needed to achieve a more sensitive water Cerenkov detector: a higher site and a larger area detector. LAGO is looking for the first option increasing the altitude of the detectors and spreading their detectors in several latitudes.

Further improvements can be made in the design of the detector in order to reach full autonomy, low energy consumption, easiness in deployment and remote monitoring system.

II. THE LAGO SITES

The LAGO project aims at observing GRBs by the single particle technique using water Cherenkov detectors (WCD). It would consist of various sites of large efficiency to GRB detection for their altitude. Suitable sites above 4500 metres with support infrastructure, namely an access road, electricity and Internet are hard to find. However LAGO requires a very small flat area and should not need human operators in the site.

The Sierra Negra volcano is the site of the Large Millimetre Telescope/Gran Telescopio Milimetrico (LMT/GTM). The development of the LMT/GTM site started in 1997 with the construction of the access road, followed with the installation of a power line and an optical fibre link to the Internet, both currently functional.

Sierra Negra is inside the Parque Nacional Pico de Orizaba, named after Pico de Orizaba, the highest mountain in Mexico with 5610 m a.s.l. The National Park comprises both volcanoes, whose summits are separated by 7 km. Pico de Orizaba is a potential site for a second stage of LAGO project.Sierra Negra at 4550 m a.s.l. is first LAGO site with water Cherenkov detectors working (since early 2007). Currently $3\times4\,\mathrm{m}^2$ area Cherenkov detectors in a 30 m triangular array are taking data at this site.

Monte Chacaltaya at 5270 m a.s.l. is the highest and older observatory in the world having the Pion discovery has one of the most important results. Currently 3 cherenkov detectors are taking data at this site: two of them of $4\,\mathrm{m}^2$ area and the third one of $2\,\mathrm{m}^2$ area. They are positioned in an $15\,\mathrm{m} \times 10\,\mathrm{m}$ rectangular array. Measurement of the atmospheric pressure and temperature, as well as two neutron monitors are included in the site see fig. 4.

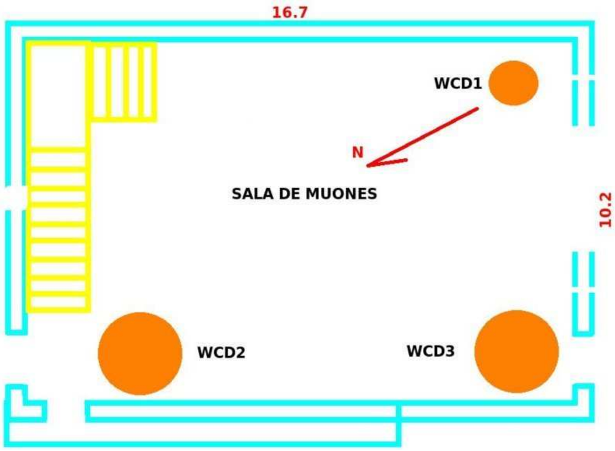

Fig. 4: LAGO Chacaltaya Layout.

The LAGO Pico Espejo station is situated at the last station of the Merida Cable Car (Teleferico de Merida), at 4765 metres, overlooking the city of Merida. The data acquiring system will be situated in the Humboldt Research Station, a facility provided by Universidad de Los Andes. As a part of the international LAGO collaboration, three water Cherenkov detector are being installed at Pico Espejo, in the Sierra Nevada National Park, Merida, Venezuela. The project is a collaboration between Universidad de Los Andes at Merida, Universidad Simon Bolivar, at Caracas, and the LAGO project.

Recently Peru joined the LAGO collaboration and its first prototype is under construction. High altitude site near Lima and in the Cuzco region are under consideration for the Peruvian LAGO site.

III. Operation and monitoring

The operation of the running detectors at Chacaltaya and Sierra Negra LAGO sites consists mainly on the measurement of the rate of signals with amplitude higher than three different thresholds (scaler mode). The number of pulses above threshold is measured every 5 ms in order to look for transient events with more than 5 sigma deviations. The average is evaluated with 60 thousand entries (5 minutes). However, in order to match the efficiency of operation of the detectors and to have a calibration point, we run also the detectors in calibration mode so that we can get pulse height and integrated charge histograms. Traces and muon decay mode are also allowed by the acquisition system. We are using the electronics of the first engineering-array phase of the Pierre Auger Observatory to readout data of the water Cherenkov detectors[1].

We made simulations of the WCD using Geant4 and the comparison can be seen in fig. 5, where a real charge histogram is compared with the simulated data, including a simulation corresponding to vertical muons only, used as a calibration reference. The simulations exhibit a more pronounced muon peak, probably due to an underestimation of the flux of electromagnetic secondaries at these altitudes.

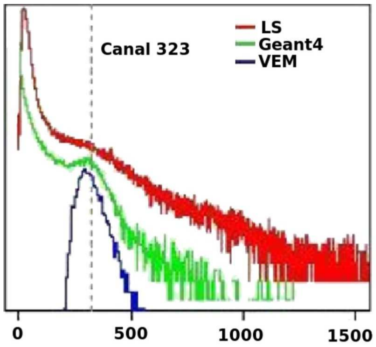

Fig. 5: Real and simulated histograms of charge integrated in ADC channels for one of the Chacaltaya detectors. The top curve is real data taken by the Local Station (LS). The intermediate has been produced by Geant4 simulations. The lower Gaussian distribution corresponds to vertical simulated muons.

Calibration points are extracted from real data histograms by finding the change of slope corresponding to the muons in the charge histogram. We use them to fix the position of the three thresholds and then we run all the detectors in scaler mode. We show the stability of the Sierra Negra and Chacaltaya detectors, including rate averages for different periods of time and standard deviations in figs. (6, 7, 8, 9).

Finally we compare the second threshold scaler rate at Chacaltaya with the atmospheric conditions in fig. 10. The flux of secondary particles at ground level is expected to be anti-correlated with the atmospheric pressure, as more pressure means more absorption of the low energy cosmic ray cascades. The bimodal daily variation of the pressure is present in the scaler data, but stronger effect is seen during day than at night. This effect could be caused either by the effect of temperature on the electronics or some slight light leak. The effect is under investigation.

Searches for GRBs in coincidence with satellites are reported separately in these proceedings[2].

IV. New Data acquisition system

Field programmable gate arrays (FPGAs) are playing an increasing role in DAQ systems in cosmic ray experiments due to their high speed and integration and

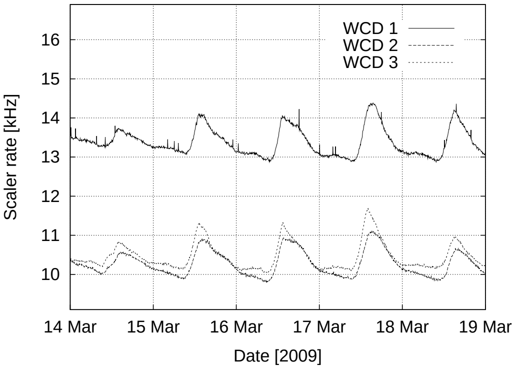

Fig. 6: Five minutes average rate corresponding to the lower threshold in Sierra Negra detectors. WCD 1 has some apparent light leak, explaining its higher rate and the spikes.

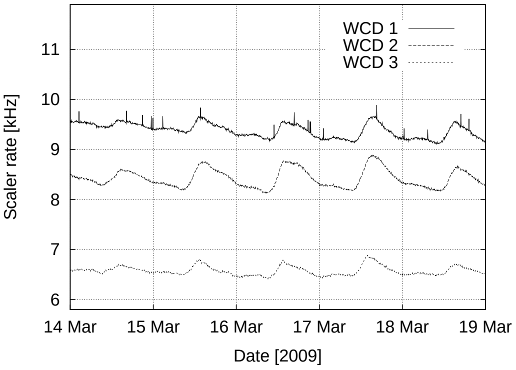

Fig. 7: Five minutes average rate corresponding to the second threshold in Sierra Negra detectors. The different rates indicate calibration issues.

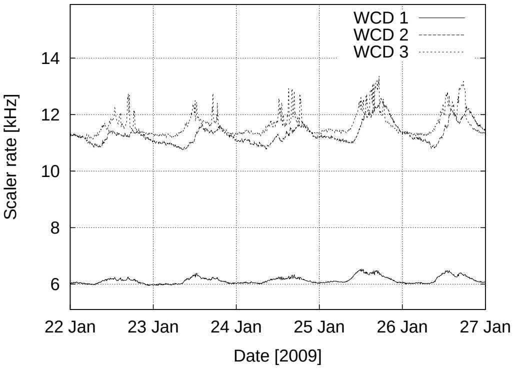

Fig. 8: Five minutes average rate for the detectors at Chacaltaya corresponding to lower threshold. All three detectors are at about 3 kHz/m^2 since WCD 1 is only 2 m^2 while WCD 2 and 3 are 4 m^2. WCD 3 exhibits some peaks in daytime indicating light leaks.

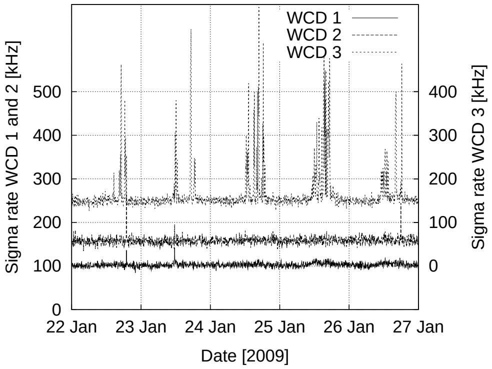

Fig. 9: Stability of WCD at Chacaltaya. We plot the standard deviation of the scaler rate every 5 minutes for the lower threshold. WCD3 clearly exhibits a noisy behaviour during the day, proof of a light leak. Te ease the readability, WCD 3 sigmas have been moved up 100 Hz and the relevant scale is indicated on the right.

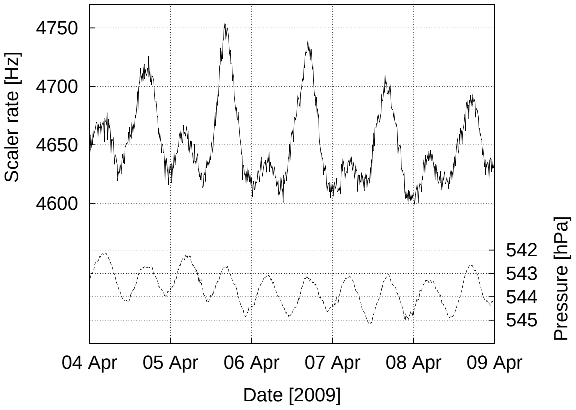

Fig. 10: Second threshold scaler rate for WCD 3 at Chacaltaya and atmospheric pressure measurements, with one data point per 10 minutes, for 5 days of April 2009. A clear anti-correlation is found (note the scale for pressure is reversed). The rates exhibit a stronger peak during the day (peaked at 18h local time) than at night, indicating a likely light leak or electronic temperature-related effect.

their low cost and low power consumption. Modern electronics based on on-chip fast analog to digital converters (ADCs) and powerful digital signal processors (DSPs) are ideal to be the basis of custom-made DAQ systems which are much more flexible, faster and much cheaper than the traditional DAQ systems based on modular electronics[3]. We took advantage of these recent developments, in particular in the area of very high integrated circuits in the form of ADCs and FPGAs for the design of the new system which consists of an ADC daughter board running at 200 MSPS. Each event is tagged with precise GPS time using a GPS embedded receiver with 1 PPS (one pulse per second) synchronised with the atomic clock on the GPS satellites within a corrected uncertainty of 50 ns (Motorola Oncore UT+ module). A pressure and Temperature sensor (HP03D) is adapted to the FPGA board (2FT Xilinx). A picture of the final setup in its RF box is visible in fig. 11.

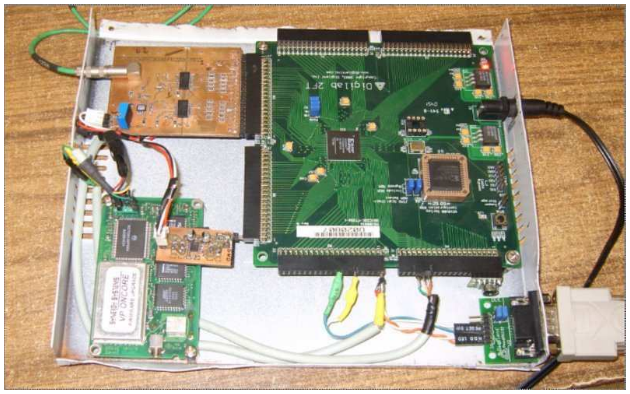

Fig. 11: New electronics for LAGO. The prototype can be operated at 100 or 200 MSPS. See text and [3] for more details.

This new system provides data in the same format as the previous one. Calibration histograms can also be extracted and are shown in figure 12 for a WCD at Sierra Negra.

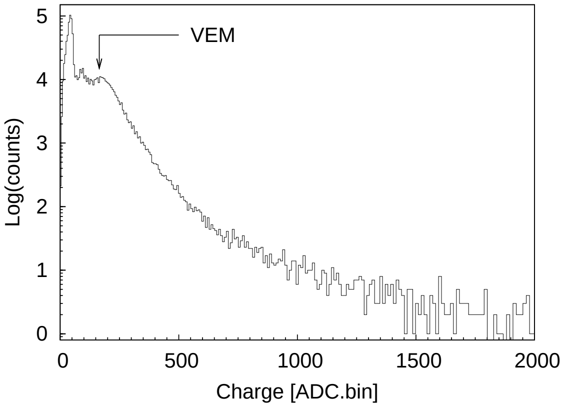

Fig. 12: Calibration histogram for Sierra Negra detectors with the new DAQ, the arrow shows the point for the VEM.

As a final note, it is worth mentioning that the prototype of the HAWC experiment, Proto-HAWC, is also located at Sierra Negra. Comparison and complementarity of LAGO and proto-HAWC could increase the sensitivity to transient events emitting high energy photons.

V. ACKNOWLEDGEMENTS

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