The Large Aperture GRB Observatory (LAGO)

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Abstract: The Large Aperture GRB Observatory (LAGO) is aiming at the detection of the high energy (above 50GeV) component of Gamma Ray Bursts, using the single particle technique in arrays of Water Cherenkov Detectors (WCD) in high mountain sites (Chacaltaya, Bolivia, 5300m a.s.l., Pico Espejo, Venezuela, 4750m a.s.l., Sierra Negra, Mexico, 4650m a.s.l, Marcapomacocha,Peru,4450m a.s.l). WCD at high altitude offer a unique possibility of detecting low gamma fluxes in the 10GeV - 1TeV range. An update of the status of the Observatory and data collected from 2007 to date will be presented.

Keywords: Gamma Ray Burst, water Cherenkov detectors, LAGO Observatory.

1 Introduction

Gamma Ray Burst are the most powerful events in the universe characterized by a sudden emission of electromagnetic radiation at hard X-ray and soft Gamma-ray energies during a short period of time, typically between 0.1 and 100 seconds. Since their discovery at the end of the 60s by the VELA satellites [1], GRB have been of high interest to astrophysics.
They occur at an average rate of a few events per day, and their duration shows a bimodal distribution with two different populations, short duration GRBs (sGRB), characterized by durations of less than two seconds, usually thought to be generated by the gravitational coalescence of two compact objects (neutron stars or black holes) and long duration GRBs (lGRB), usually associated with the core collapse (collapsar) of a massive star, which tends to have a softer spectrum than sGRB. A first large data set of GRB was provided by the BATSE instrument on board the Compton Gamma Rays Observatory (1991-2000). BATSE GRBs incoming directions were isotropically distributed with no evidence of clustering. The fluences observed were furthermore incompatible with uniform distribution of sources, exhibiting a deficit at low fluences. GRBs origin was determined following afterglows identification by Beppo-SAX (1996-2002). Due to better angular resolution than BATSE, afterglows could be detected at other wavelengths. Spectroscopic measurements allowed the direct measurement of GRBs redshifts, confirming they were cosmological in origin. Currently, GRB are registered by HETE, INTEGRAL, Swift and GLAST (renamed Fermi Gamma-Ray Space Telescope). In the last 10 years, observation of the GRB phenomena. GRBs are now detected up to z = 8.26 [2],[3]. Differences, in their rest frame properties, which could be related either to distance or to observing conditions are under study [4]. Most observations have however been done below a few GeV of energy, and the high energy (above 10 GeV) component in the GRB spectrum is still poorly known. Fermi/GLAST sensitivity has already provided some hints on the high energy component of GRBs [5], and could allow to get individual GRB spectra up to 300 GeV should the flux of HE photon be above a few per m2 . As of early 2011, LAT at FERMI/GLAST had detected 21 GRBs. Amongst these, the long GRB 090902B [6] and the short GRB 090510 [7] are notable for being very bright and having non-Band hard power-law components. To date, the highest energy photon recorded from a GRB is 33 GeV from GRB 090902B (or 94 GeV corrected for redshift) [6]. Fermi probably did not detect higher energy photons because of its limited size.

In the meantime, and at the highest energies where the flux is low, the only way to detect a high energy emission of GRB is to work at ground level. Water Cherenkov detector arrays, such as LAGO, benefit from a very large field of view and near 100% duty cycle that will allow for observations in the prompt phase. They are also sensitive to energies beyond those covered by satellites. Water cherenkov observatories, are thus useful high-energy GRB detectors that complement the observations by satellites such as Fermi.

2 GRB DETECTION AT GROUND LEVEL

A classical method to use is called the single particle technique [8] where the detectors are used to count individual particles. When high energy photons from a GRB reach the atmosphere, they produce a cosmic ray cascade with secondaries at ground level that can be detected. One is looking for an increase of the background rate on all the detectors of a ground array on this time scale. This technique has already been applied in EAS-TOP (9) in Italy, INCA (10) in Bolivia and ARGO (11) in Tibet. A general study of this technique can be found in (12). It has not been applied in the past to arrays of Water Cherenkov Detector (WCD). The main advantage of using the water Cherenkov technique over the usual scintillator/RPC detectors is the WCD sensitivity to photons, which represent up to 90% of the particles at ground level for high energy photon initiated showers. This significantly increases the efficiency of detection, as reported in (13). This method has been implemented since March 2005 in the Pierre Auger Observatory (14). The Pierre Auger Observatory is the largest cosmic ray observatory in operation. It is composed among other detectors by 1600 WCD located in Malargue, in Argentina. Despite its low altitude (1440 m.a.s.l.), its large collecting surface (16000 m2) and sensitivity to secondary photons makes it a possible competitor to higher altitude experiments. The LAGO project compensates a much smaller area of detection by going for high altitude sites, and uses a dedicated acquisition, optimized for the SPT with rates being monitored on a short time scale.

It started in 2005 as collaboration between groups from Argentina, Bolivia and Mexico and has in 2010 extended to Venezuela, Peru and Colombia. Brazil, Chile and Guatemala are likely to join the LAGO collaboration in 2011. Furthermore, this year we started the upgrade of the LAGO project at Sierra Negra, Mexico, increasing the collection area up 16 times the initial one (160m2@2011, 10m2@2007).

3 LAGO EXPERIMENTAL SETUP AND SITES

1)Sierra Negra, Mexico, 4550 m.a.s.l. This is the first LAGO site, in operation since 2007. It is nearby the Large Millimetric Telescope (LMT) and above the HAWC site. Three 4 m2 and two 1 m2 WCD have been in operation at the site in a 30 m triangular array. Currently, 4 new detectors of 40 m2 are being under instrumentation, one of them is fully operational.

2)Monte Chacaltaya at 5270ma.s.l. is the highest and older observatory in the world. Currently 3 cherenkov detectors are taking data at this site, two of them of 4m2 area and the third one of 2m2 area. They are positioned in an 15m 10m rectangular array. They have been taking data since 2008. Measurement of the atmospheric pressure and temperature is included at the site.

3)Marcapomacocha, Peru, 4450 m.a.s.l.: this is the last LAGO site to be in operation, with one 2 m2 WCD taking data since 2010. It is expectedto take data with a new 4m2 WCD during 2011. Higher sites in Peru are under investigation.

The operation of the running detectors at Chacaltaya, Sierra Negra and Marcapomacocha LAGO sites consists mainly on the measurement of the rate of signals with amplitude higher than three different thresholds (scaler mode), produced in a WCD by the secondary cosmic rays. The WCD consists in a 4 m2 container filled with high quality purified water up to a level of 1.2 to 1.5 m.
The water is contained in a reflective and diffusive bag, made either of Tyvek or Banner, to achieve optimal uniformity of the detector response, independently on the direction and entry point of the particle in the detector. The water volume is overlooked by a single photomultiplier (PMT) tube, usually of 8". The PMT is connected to an acquisition board from the prototype phase of the Pierre Auger Observatory [14]. The number of pulses above threshold is measured every 5ms 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.

Monitoring and calibrating a WCD at high altitude is a more complex task than at sea level. The characteristic hump left by muons in aWCD (such as the one used for calibrating the Pierre Auger Observatory WCDs, see (9) is smeared by the large background of electrons, positrons and photons. While the muon hump is almost indistinguishable on a pulse amplitude histogram, a characteristic shoulder can be seen on a charge histogram. One can therefore use this break point to intercalibrate detectors. Traces and muon decay mode are also allowed by the acquisition system.

4 LAGO EXPERIMENTAL SETUP AND SITES

Currently at Sierra Negra site, and upgrade of the detection system is under construction. 4 new WCD detectors of 40 m2 are being under instrumentation. One of them is fully operational. The new detectors are cylindrically, with 7.3 m of diameter and 1.15 m height. The body and the bottom of the detector are covered with a high diffusive and reflective Banner bag. The bag is filled with high quality purified water up to a level of 1.1 m. The water volume is overlooked by 5 PMTs, all of them of 5".

Four of the PMTs are distributed at 2.4m from the center, with a regular separation. The fifth PMT is at the center of the cylinder (See Fig1). All the volume is covered with tyvek and protected externally with a black, light tight bag. We show in Fig2 the distribution of the new detectors and the first instrumented tank.

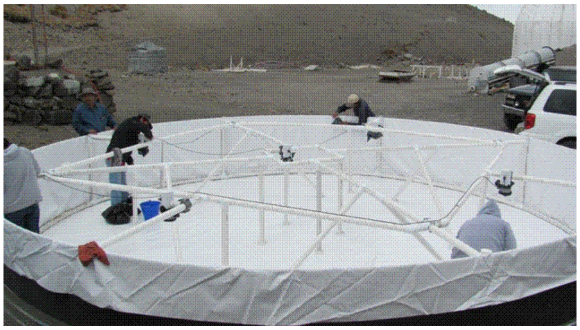

Figure 1: Photodetectors set up. PMTs are distributed at 2.4 m from the center of the tank, with a regular separation. One more is at the center of the detector.

Figure 2: New detectors distribution and the first instrumented tank.

The position of the photodetectors has been optimized by means of the measurement of the response of the detector (rate of signals above a fixed threshold) as a function of the distance to the center. We have measured the response of the detector for distances of 1.2m; 1.8m and 2.4 m to the center. The experimental result is in agreement with the simulation of the response of the new detectors to showers of low energies. In order to characterize the response of the PMTs, and then to set different levels of threshold for the scalers system, we have evaluated the amplitude distribution for one photoelectron as a function of the High Voltage. As an example we show the histograms in Fig 3 for one of the PMTs.

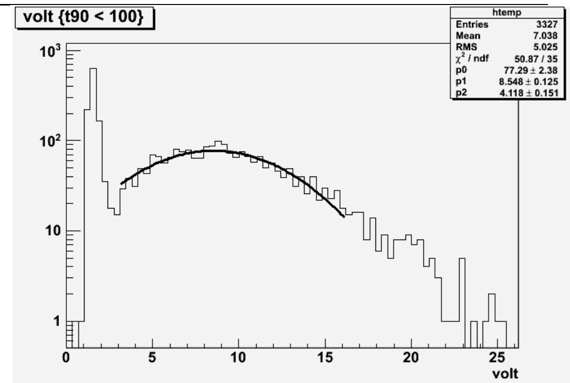

Figure 3: Amplitude distribution in mV. One photoelectron corresponds to 8mV amplitude.

New electronics has been developed for the new LAGO detectors and the complete replacement of the currently used electronics is foreseen for 2011. 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 100MSPS. Each event is tagged with precise GPS time using a GPS embedded receiver with 1 PPS (one pulse per second) synchronized 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 (Nexys 2 board with a Spartan 3E-500 FPGA from Digilent Inc).

5 CONCLUSIONS AND REMARKS

The LAGO project is an international effort of many groups in different countries to operate a network of WCD in high altitude sites in Latin America. Data taking has started in 2007, and no GRB has been observed to date. Limits on 40 GRBs were set, with the most stringent one being for GRB 080904 in the 0:5GeV - 100GeV energy range. LAGO data can also be used to monitor the solar activity through its modulation effect on galactic cosmic rays. A monitoring program has started in order to provide a network of observation during the current solar cycle, in particular during next maximum of activity in 2013.

When located in high altitude mountain sites, they can be a very important complementary method of observation of GRB, as their efficiency starts at high energies, where the flux of primaries is too low for satellite to perform observation. The upgrade of the LAGO experiment up to 16 times in Sierra Negra foreseen for 2011 and the incorporation of other high altitude sites in Latin America makes the LAGO Observatory very competitive.

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