Analysis of the Auger scaler data in search for GRBs

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Abstract

The detection of a high energy tail of photons from GRB should be possible with the single particle counting technique. A group of detectors would detect a higher rate of events on a short time scale, of the order of the second. Scalers were implemented on the whole array on 30th March 2005, and an improved version was installed on 20th September 2005. This note reports the analysis of the new data set, up to 13th October 2006.

1 Introduction

Since their discovery at the end of the 60's[1], the Gamma Ray Bursts (GRB) have been of high interest to astrophysics. A GRB is characterised by a sudden emission of gamma rays during a very short period of time (between 0.1 and 100 seconds). The luminosity reached during this flare is typically between 10^{51} and 10^{55} ergs, should the emission be isotropic. The astrophysical source of these bursts is still not clear but candidates could be coalescence of compact objects (neutron stars), and mechanisms based on internal shocks of relativistic winds in compact sources give good agreement between theory and observations.

A first large data set of GRB was provided by the BATSE instrument on board the Compton Gamma Rays Observatory (1991-2000). More GRB were then detected by BEPPO-SAX (1997-2002). Current GRBs are registered by HETE, INTEGRAL and Swift. In the last 5 years, afterglows were observed allowing a much better understanding of the GRB phenomena. Most observations have however been done below a few GeV of energy, and the presence of a high energy (above 10 GeV) component in the GRB spectrum is still a mystery.

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GLAST will be the next generation of GRB satellite experiment and should be launched in fall 2007. Its sensibility should allow to get individual GRB spectra up to 300 GeV. In the meantime, the only way to get to the high energy emission of GRB is to work at ground level.

A classical method to use is called "single particle technique". When high energy photons from a GRB reach the atmosphere, they produce a cosmic ray cascade that can be detected. The energies are still quite low to produce a shower detectable at ground level (even at high altitudes). However, we expect a lot of these photons to arrive during the burst, in a short period of time (typically, one second). Some of them could produce a shower which would give a few hits in a ground based detector, on a time scale of one second. One would therefore see an increase of the background rate on all the detectors on this time scale. This technique has already been applied in INCA[2] in Bolivia and ARGO[3] in Tibet. A general study of this technique can be found in [4]. Up to now, it has only been applied to arrays of scintillators. We have already presented the advantages of using a Water Cherenkov Detector [5]. Its main advantage is its sensitivity to photons, which represent 90% of the particles at ground level for high energy photon initiated showers.

2 The Scalers

On 30th March 2005, a first version of the "scalers" were implemented in the local station (LS) code. The "scalers" are simple counters that can be set like any other trigger. They are read every second and sent to the Central Data Acquisition System (CDAS). At CDAS, they are stored in specific files and, once per day, a scaler file is built. This file is available as:
`/Raid/monit/Sd/YYYY/MM/scaler_YYYY_MM_DD_00h00.dat.bz2`
with `YYYY`, `MM` and `DD` the year, month and day of the data. It is a `bzipped` file, which can be uncompressed with `bunzip2`. The resulting file is in `ASCII` format, with one line per second. The first field is the GPS second, the second one the total number of counts for that second, the third field is the total number of tanks sending data, and the field number i is the number of counts of tank Id i.

Several limitations were reported in a previous GAP note (see [6]). In order to address them, a new software version of the scalers has been deployed over the whole array on 20th September 2005. Together with solving the timing issues, this version also limited the counting rates to events above 3 ADC counts above baseline and below 20 ADC counts. This has been determined to be the cut optimising signal to noise ratio, given the expected signal extracted from simulations [7], and the background signal derived from muon histograms. With these cuts, the average scaler rate over the array is of about 2 kHz per detector.

3 Data cleaning

3.1 Misbehaving detectors

The first necessary step is to do some data cleaning. Some individual detectors quite often get abrupt increase in their counting rates, and the average counting rate over the array can be influenced by only a few misbehaving detector. In order to clean up the scaler data, the following algorithm has been applied:

- seconds with less than 300 tanks in operation are removed
- tanks with less than 500 Hz of scaler are removed
- for each individual seconds, only 95% of tanks are kept, removing the 5% with extreme rate counting (2.5% on each side)

This methods clearly gets rid of outliers which could impact on the average rate of a specific second, without affecting the GRB detection capability, as GRB would appear as an increase of counting rates in all the detectors. An example of the effect of such cleaning is given in figure 1.

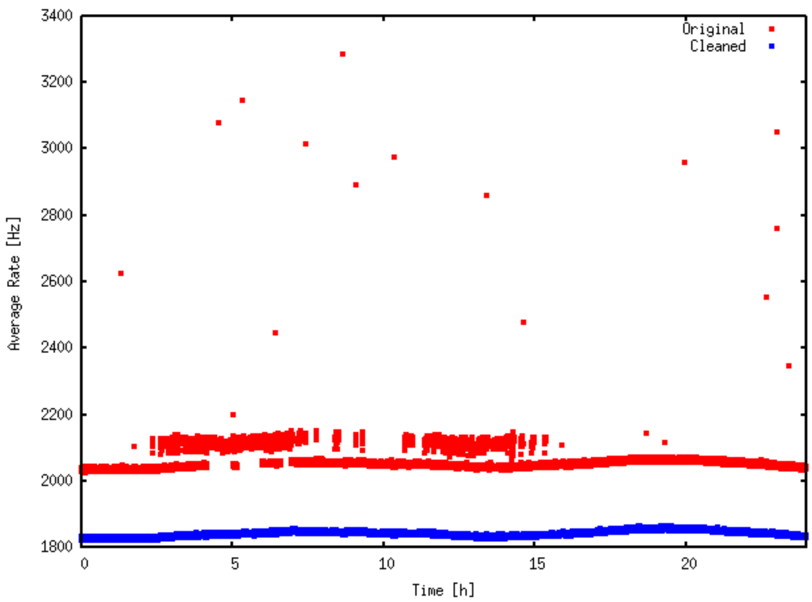

Figure 1: Average scaler rate for one day (10$^{\text{th}}$ September 2006) using all data (red), and after cleaning (blue). To enhance visibility, the blue data points have been shifted down by 200 Hz. All the artefact caused by misbehaving tanks have been removed.

3.2 Array issues

One then needs to have the array properly operating. Losing suddenly a significant fraction of the array will cause jumps in the scaler rate, as this rate is not uniform over the whole observatory.

A relevant parameter is the total number of active stations at each moment, compared with the maximum number of stations that had been active at any time before. Ideally one would just cut asking for more than maybe 95% of the array to be operating, but given the growing array one needs to use the afore-mentioned parameter. Figure 2 shows than cutting at 97% (3% of stations not operating), one keeps 90% of the data. To recover the missing 10% one would need a special analysis.

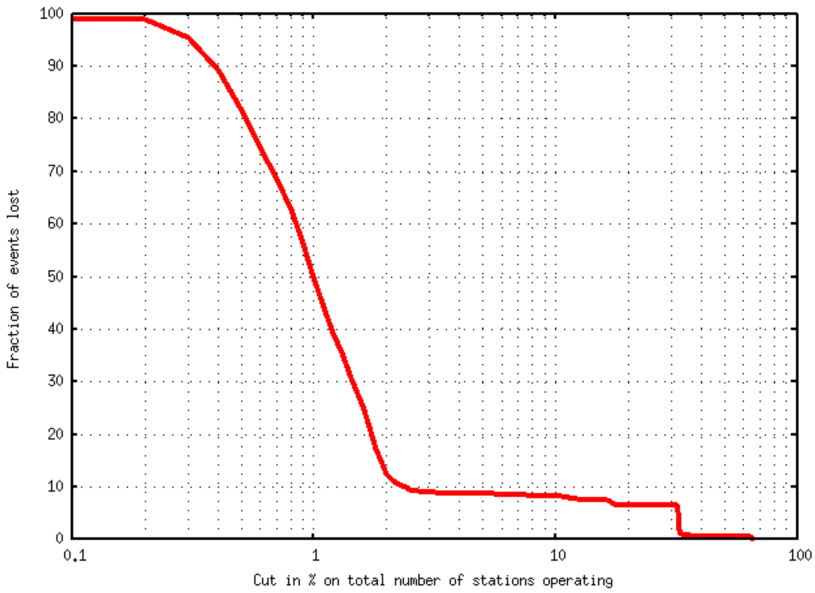

Figure 2: Fraction of events lost as a function on a cut on the fraction of the number of active detectors with respect of the maximum number that had been active at that date. A cut at 3% allows a loss of less than 10% of the data.

Figure 3 shows the final data set over one year, compared to the one without the array cut. Finally, one asks for at least 5 continuous minutes with data, in order to be able to compute reasonable averages and see eventual bursts. This removes less than 1.5% of the remaining data set.

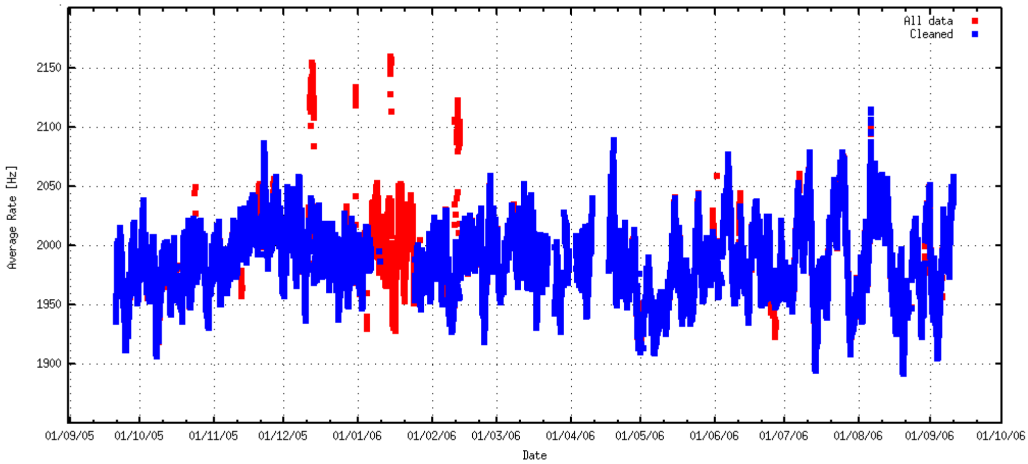

Figure 3: Average rate (one point per 15 minutes) for the whole data set, before (red) and after (blue) cutting on the fraction of active stations. Artificial jumps (like in December 2005 for example) are suppressed.

4 Search for bursts

4.1 $\sigma - \delta$ method

In order to search for bursts, an expected rate R for each second is determined by a $\sigma - \delta$ method using $\sigma = 0$ and $\delta = 0.1$ Hz, meaning every second the expected rate R is moved by 0.1 Hz towards the current rate r. After 30 seconds of data, this average converges to the expected average value, and one can compute the fluctuations Δ of the rate r of a specific second using:

$$\Delta = \frac{r - R}{\sqrt{r/N}}$$

where N is the number of active tanks at that second.

The $\sigma - \delta$ parameters chosen above ensure that the R parameter follows any fluctuation on a time scale larger than a few tens of seconds. This R parameter can therefore be used for long term monitoring, and to detect events on large time scales such as solar flares. A precise modelling of the evolution of R with weather parameters is however needed.

The Δ parameter can be used directly to search bursts, and its histogram can be seen on figure 4. As seen in previous studies[6], a lot of bursts are detected. A systematic method to get rid of lightning bursts needs to be implemented. The underlying Gaussian has a width of 1.5 (it would have a width of 1 if the fluctuations of each detector were independent and if the $\sigma - \delta$ method gave the true average at each moment).

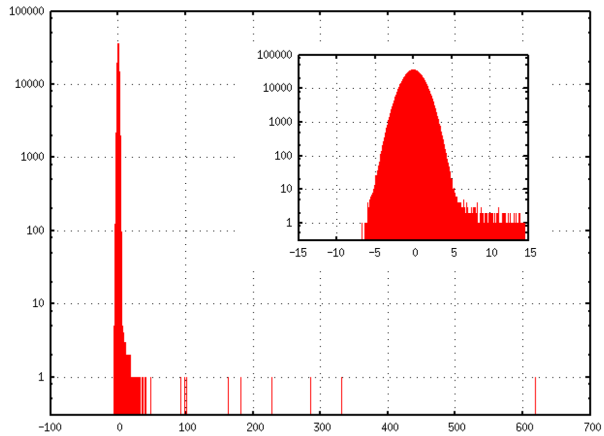

Figure 4: Histogram of the fluctuations Δ of the scaler counting rates. Inset is a zoom of the [-15:15] part. A large number of bursts can be seen, some with huge values of Δ.

4.2 Lightning removal

The artificial bursts were found in [6] to be due to lightning, in coincidence with so-called lightning-events of the SD main data stream. We will therefore use the SD data to flag periods as lightning ones, independently of the scaler data.

The whole SD data set was scanned for tanks flagged as lightning, and the time stamp of these events was kept. In order to remove the lightning period, one has to define a time around each lightning event which is considered as stormy and should not be used. Figure 5 shows the time distribution between 2 lightning events, as well as the dead time caused by a lightning cut. The characteristic time scale of these lightning storms is of a few thousands of seconds, and a cut at 7200 seconds (2 hours) was chosen, producing a 2.3 % dead time.

4.3 Results

Once all the cuts defined above have been applied, a total of 79% of the total running time of the experiment is available for a search for bursts. The resulting Δ histogram is shown on figure 6.

Only 5 bursts survived the cuts, with 2 very close to the $5\,\sigma$ threshold. In order to be a GRB, the increase of the rate should be uniformly distributed over all the detectors. One can therefore check that each individual detector has on average an increase at the moment of the burst with respect of the previous seconds. The results are given on table 1 and none of the scaler bursts have a behaviour compatible with a GRB.

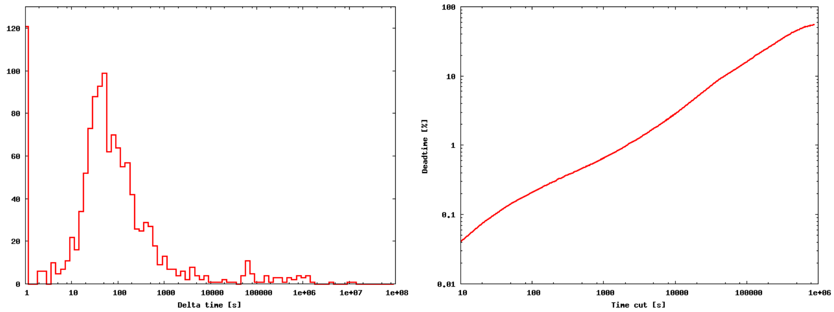

Figure 5: Left: time difference between 2 lightning SD events. The typical time interval is of less than an hour. A small peak is seen at about 1 day since in summer storms often occur every day at night fall. Right: dead time caused by the lightning cut. A cut at 2 hours produces a 2.3 % dead time.

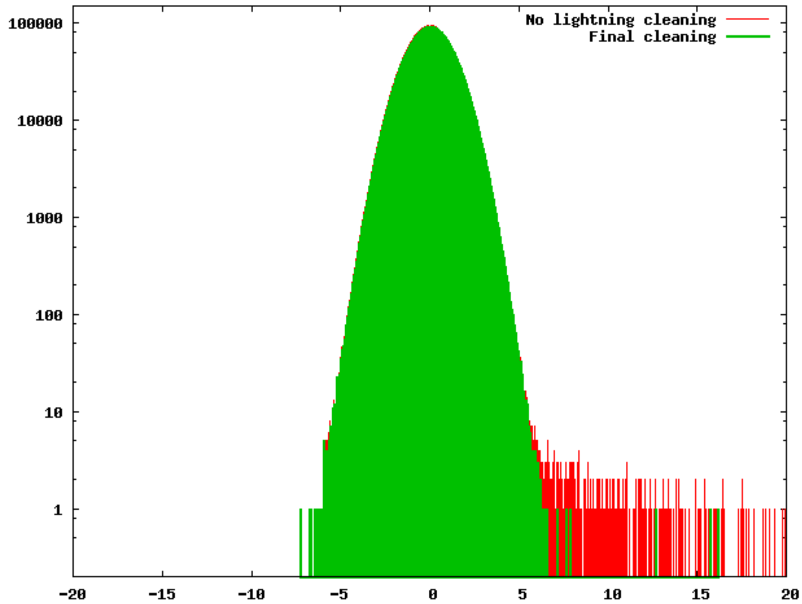

Figure 6: Final Δ histogram after all cleaning compared with the one before lightning period cleaning. 5 bursts survived the cuts.

5 Conclusion

A method to clean the scaler data in search for GRBs has been implemented, with a resulting uptime of 79% on a period over one year of data taking. Given the size of the array in the period studied, a signal would be expected for a detectable flux of secondary particles of about $1\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}$ at Auger ground level.

GPS Second	Expected Excess	Fit
817441877	19.85	1.5 ± 1.6
823302757	12.26	0 ± 1.9
825365311	25.07	0 ± 1.8
825367801	24.33	-4.2 ± 1.6
842667456	11.6	-3 ± 1.5

Table 1: The 5 remaining bursts and the expected average excess of counting rate per tank, compared with a Gaussian fit of the excess observed for each tank with respect of its individual average 5 seconds before the burst. No burst exhibit the characteristic expected for a GRB, and are due to a small group of tanks with high counting rates for the burst second.

No burst with characteristics similar to those expected for a GRB was observed in the one year period analysed. This study, together with one looking at the scaler signal when specific GRBs seen by satellites are in the Auger field of view, will allow to set upper limits on the high energy fluences of GRBs.

References

[1] Kleidesabel et. al, 1973, ApJ 182, 85

[2] Cabrera et. al, 1999, A&AS 138, 599

[3] Bacci et. al, 1999, A&AS 138, 597

[4] Verneto, 2000, APh 13, 75

[5] Allard et. al, ICRC 2005

[6] GAP 2005-053

[7] D. Allard, private communication