30th International Cosmic Ray Conference
ICRC'07 Mérida, México

Search for Gamma Ray Bursts using the single particle technique at the Pierre Auger Observatory

X. Bertou[1] for the Pierre Auger Collaboration[2]
[1] *Centro Atómico Bariloche (CNEA), (8400) San Carlos de Bariloche, Río Negro, Argentina*
[2] *Av. San Martin Norte 304 (5613) Malargüe, Prov. de Mendoza, Argentina*
bertou@cab.cnea.gov.ar

Abstract: The Pierre Auger Observatory, with an array of currently more than 1200 Cherenkov detectors filled with 12 m^3 of water, can detect the putative high energy emission of a GRB (photons down to a few hundreds of MeV) by the so-called "single particle technique", through a coherent increase in the average background particle rates over the whole array, due to secondary particles in the photon-induced showers. We present a search for bursts on data collected since September 2005, as well as a search for excesses in coincidence with bursts observed by satellites.

Introduction

Since their discovery at the end of the 60s[1], 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 total energy emission during this flare is typically between 10^{51} and 10^{55} ergs, should it be isotropic. Good source candidates for this bursts are coalescence of compact objects (for short bursts, less than 2 seconds) and gravitational supernovae (type Ib and II, for LONG BURSts). Mechanisms based on internal shocks of relativistic winds in compact sources give good agreement between theory and observations.

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

A classical method to use is called "single particle technique" [2]. When high energy photons from a GRB reach the atmosphere, they produce cosmic ray cascades that can be detected. The energies are not enough to produce a shower detectable at ground level (even at high altitudes). However, a lot of these high energy photons are expected to arrive during the burst, in a short period of time. 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[3] in Bolivia and ARGO[4] in Tibet. A general study of this technique can be found in [5]. Up to now, it has only been applied to arrays of scintillators or RPCs. We have already proposed using instead Water-Cherenkov Detectors [6, 7]. Their main advantage is their sensitivity to photons, which represent up to 90% of the secondary particles at ground level for high energy photon initiated showers.

The Pierre Auger Observatory[8] spans over $3000\,\mathrm{km}^2$ in Malargüe (Argentina), at 1400 m a.s.l., investigating the ultra high energy cosmic rays. Its surface detector (SD), when completed, will consist of 1600 Water-Cherenkov Detectors, making it the ideal test-bed for the above mentioned technique.

Scalers data of the Pierre Auger Observatory

The final version of the scalers was deployed over the whole array on 20 September 2005, after 6 months of tests and improvements. These 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, where they are stored. They record the counting rates of events above 3 ADC counts above baseline and below 20 ADC counts (approximately between 15 and 100 MeV deposited in the detector). This has been determined to be the cut optimising signal to noise ratio, given the expected signal extracted from simulations [9], and the background signal derived from real data histograms. With these cuts, the average scaler rate over the array is of about 2 kHz per detector.

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 detectors (noisy or unstable baselines, unstable PMTs, bad calibration, etc.). Detectors with less than 500 Hz of scaler counts are discarded (this discards a few badly calibrated detectors). For each individual second, only 95% of detectors are kept, removing the 5% with extreme rate counting (2.5% on each side). This removes 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.

One then needs to have the array operating properly. 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 a fixed number of stations to be operating, but given the growing array one needs to use the afore-mentioned parameter. Cutting at 97% (3% of stations not operating), one keeps 90% of the data. To recover the missing 10% a special analysis would be needed.

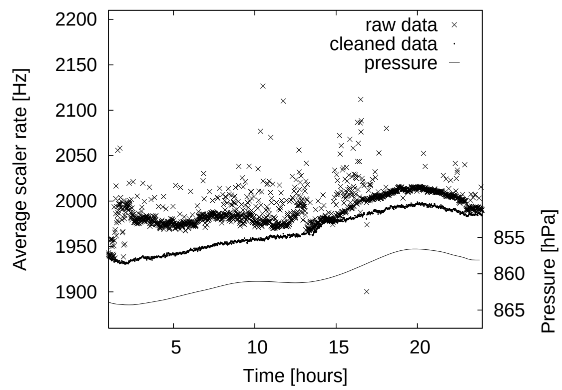

Figure 1: Average scaler rate for the first day of data, using all data (crosses), and after cleaning (dots). All the artefacts caused by misbehaving detectors have been removed. The global trend on the cleaned data is mainly correlated with pressure (thin line).

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.

Many artificial bursts are found in the cleaned data set, due to lightning. Lightning strikes produce high frequency pick-up noise on the Auger phototube cables, and this noise is misinterpreted as a succession of numerous particles. This signal also triggers the Auger central trigger, producing so-called lightning-events in the SD main data stream. We can therefore use the SD data to flag lightning periods, independently of the scaler data.

The whole SD data set was scanned, and the time stamp of the lightning events was kept. To remove lightning periods, one has to define a time around each lightning event which is considered as stormy and should not be used. The characteristic time scale of these lightning storms is found to be of a few thousands of seconds, and a cut at 7200 seconds (2 hours) was chosen, producing a 2.3 % dead time.

Search for bursts

$\sigma - \delta$ method

To search for bursts, the average rate for each second as well as a longer term average rate have to be computed. As a burst would produce a similar increase in all stations, a good estimator of the average rate for each second, r, is the median of the rates of all the stations. It is much less sensitive to misbehaving detectors than the arithmetic average. Then, to estimate a long term average R, a $\sigma - \delta$ method is used with $\sigma = 0$ and $\delta = 0.1\,\mathrm{Hz}$, meaning that every second the average 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 variation Δ of the rate r of a specific second using:

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

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

The $\sigma - \delta$ parameters chosen above ensure that the R parameter follows any variations 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 for bursts, and its histogram can be seen on figure 2, both before and after applying the lightning veto. The underlying Gaussian has a width of 1.4 (it would have a width of 1 if the arriving flux of particle was poissonian, the fluctuations of each detector were independent, the baselines of the detectors were not fluctuating, and the $\sigma - \delta$ method gave the true average at each moment). One sigma of deviation corresponds roughly to 1.5 particles per detector, i.e. a flux at ground level of $0.15\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}$.

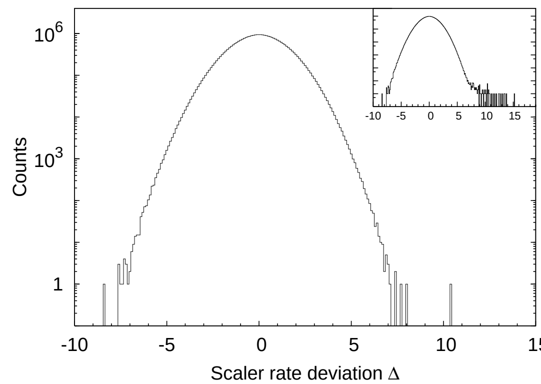

Figure 2: Histogram of the deviations Δ of the scaler counting rates. Inset is the version before lightning rejection, where a large number of spurious bursts can be seen. The final Δ histogram after all cleaning only presents one significant excess.

Search for self-triggered bursts

Once all the cuts defined above have been applied, a total of 79% of the data period (21 September 2005 - 30 April 2007) is available for a search for bursts. The resulting Δ histogram is shown on figure 2.

Only one significant burst is observed. In order to be related to 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 observed burst does not present such a feature, as only a fraction of the array sees a significant excess (about 40 stations in a compact configuration with a large increase of the rate, above 3 kHz out of 1000). The burst is therefore artificial and cannot be attributed to a GRB.

Search for satellite-triggered bursts

In the period studied, 36 bursts detected by satellites occured in the field of view of Auger (zenith of less than 90 degrees). For all these bursts, the scaler data were checked within 100 seconds of the burst for a one second excess. The period corresponding to the $T90$ reported by the BAT instrument of SWIFT[10] was also integrated. No excesses were found and the resulting 5 σ fluence limits were computed assuming a GRB spectra $dN/dE \propto E^{-2}$ in the 1 GeV - 1 TeV energy range (as in [3]). The limits are reported on figure 3.

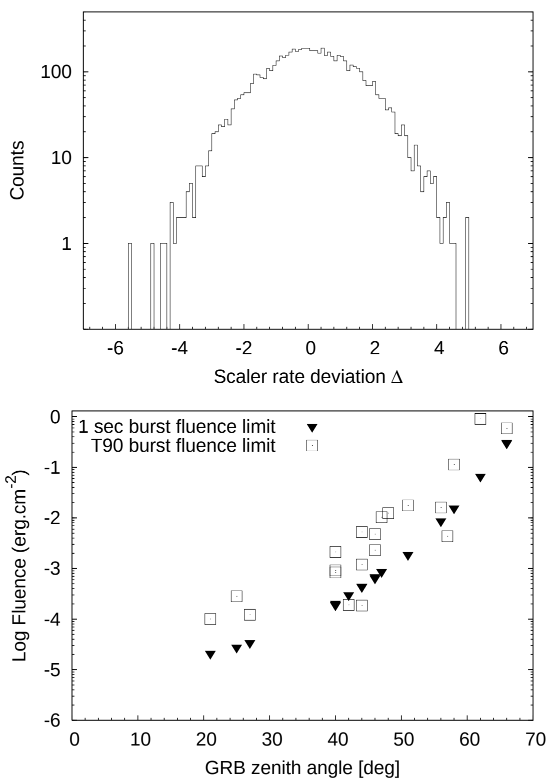

Figure 3: Top: histogram of the deviations Δ of the scaler counting rates within 100 seconds of the bursts reported by satellites. No significant excess is observed. Bottom: 5-σ fluence limits in the 1 GeV - 1 TeV energy range from Auger for these bursts, for a single second burst or for a burst of duration $T90$, assuming a spectral index of -2.

Conclusion

A method to clean the Auger scaler data in search for GRBs has been implemented, with a resulting uptime of 79% on a period of one year and a half 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.

No burst with characteristics similar to those expected for GRBs was observed in the period analysed. Fluence limits of up to $1.3 \times 10^{-5}\,\mathrm{erg\,cm}^{-2}$ (depending on the burst zenith and duration), were deduced for the 1 GeV - 1 TeV energy range. Note that models do not generally favor fluences above $10^{-6}\,\mathrm{erg\,cm}^{-2}$ in the energy range considered[11, 12]. To reach such a sensitivity, it is mandatory to cover a significant surface at higher altitude[13].

References

[1] R. W. Klebesadel, I. B. Strong, and R. A. Olson. *Astrophys. J.*, 182:L85, 1973.

[2] M. Aglietta et al. *Astrophys. J.*, 469:305–310, 1996.

[3] R Cabrera et al. *Astron. Astrophys. Suppl. Ser.*, 138:599–600, 1999.

[4] A. Surdo et al. 28th ICRC 2003, Tsukuba, Japan.

[5] Silvia Vernetto. *Astropart. Phys.*, 13:75–86, 2000.

[6] D. Allard [Pierre Auger Collaboration], 2005. 29th ICRC 2005, Pune, India.

[7] X. Bertou and D. Allard. *Nucl. Instrum. Meth.*, A553:299–303, 2005.

[8] J. Abraham [Pierre Auger Collaboration]. *Nucl. Instrum. Meth.*, A523:50–95, 2004.

[9] D. Allard [Pierre Auger Collaboration]. *Nucl. Phys. Proc. Suppl.*, 165:110, 2007.

[10] S. Barthelmy et al. astro-ph:0507410.

[11] N. Gupta and B. Zhang. arXiv.org:0704.1329 [astro-ph].

[12] Y. Fan et al. arXiv:0704.2063 [astro-ph].

[13] D. Allard et al. *paper #175, this conference.*