Detection of GRB with Water Cherenkov Detectors

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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. This technique has already been used with plastic scintillators. Use of water Cherenkov detectors provides a main advantage with respect to scintillators by being sensitive to photons converting in the water. This should increase significantly the detection efficiency as the ratio photons to electrons in GRB photon showers is about 9 to 1 in the shower tail. The Pierre Auger observatory, with 1600 water Cherenkov detectors, could be a good candidate to check the efficiency of the technique. Similar detectors at higher altitude (Puebla 4500 m, Chacaltaya 5200 m) could bring better sensitivity to the high energy part of the GRB with much less surface to be covered.

Key words: GRB, Cherenkov, Auger
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1 Introduction

Since their discovery at the end of the 60's[1], the Gamma Ray Bursts (GRB) have been of high interest to the astrophysicists. A GRB is characterized by a sudden emission of gamma rays during a very short period of time (between 0.1 and 100 second). The luminosity reached during this flare is typically between 10^{51} and 10^{55} ergs if the emission is 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 a relativistic wind in a compact source give good agreement between the theory and the 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 where then detected by BEPPO-SAX (1997-2002). Current 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 in the GRB spectrum is still a mystery.

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

A classic technique to use is called “single particle technique”. When high energy photons from a GRB reach the atmosphere, they produce a cosmic ray cascade that one can detect. 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 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. 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 will present here a study using Water Cherenkov Detectors (WCD).

Currently under construction in Argentina, the Pierre Auger Observatory (PAO) will consist of 1600 WCD of 10 square meters, over a total surface of 3000 km^2. It is aimed at the understanding of the highest energy cosmic rays detected up to now, above 10^{20} eV. It has started to take data in January 2004 with 150 detectors, and after one year, in January 2005, it can count with 600 WCD in operation, making it more than 10 times larger than the previous largest cosmic ray experiment (AGASA, in Japan). Even if it is located at relatively low altitude (1400 m a.s.l), its large size would make it a good GRB detector.

A complete simulation of an Auger WCD response to a GRB shower will be presented, and expected performance of the Auger array will be discussed. Simulations at different altitude level will stress the interest of having a few WCD at high altitude (around 5000 m a.s.l).

2 General properties of GeV photon showers

The first step is the simulation of showers of high energy photon primary. 250 millions showers with primary energies of 50 MeV to 100 GeV were generated, for zenith angles from 0 to 30 degrees. Ground was set at 1400 m, the altitude of the southern site of Auger. No thinning was applied (meaning all the particles for each shower were followed until absorbed in the atmosphere or on the ground). Simulation was performed using the Corsika[5] shower generator.

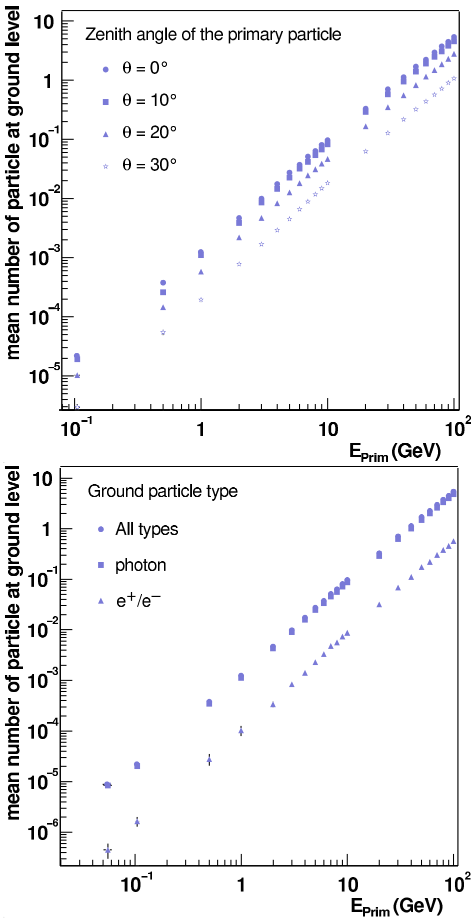

Fig. 1. Average number of particle at ground level. Top: for different primary energy and zenith angle. Bottom: composition of secondaries.

Figure 1 shows the average number of particle at ground level as a function of energy and zenith angle (top), as well as their nature (bottom). As expected, the amount of particles increases with energy, and decreases with zenith angle (higher atmosphere to cross). The right plot clearly indicates the predominance of photons secondaries. A detector blind to such photons (this is mostly the case for scintillators) would miss an important part of the shower. WCD on the other end are dense enough to force high energy photons to convert into the detector volume.

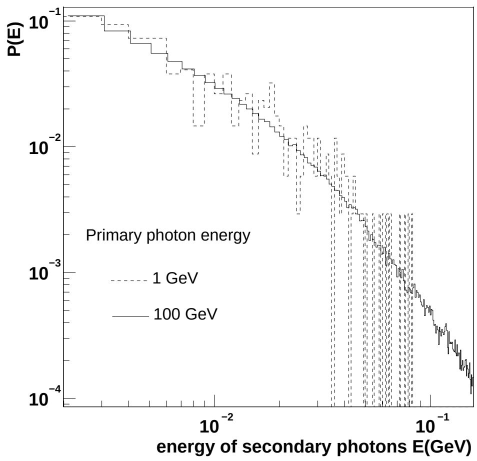

Fig. 2. Differential spectrum of photons at ground level for primary photons of 1 and 100 GeV.

An increase of signal of one order of magnitude is therefore expected with respect to the signal given only by charged particles.

Figure 2 shows the differential spectrum of photons at ground for a primary photon of 1 and 100 GeV. They are both remarkably similar. A similar feature is found for the secondary electron spectrum. This property of the electromagnetic cascade will help us in the simulation of the response of the Auger detector: one only needs to know now the response of a WCD to this spectrum. Response to a GRB will be obtained by scaling this response by the appropriate factor. On the other hand, it is a bad news as there will be no way to derive for example the GRB spectrum index from the data: a burst of 10 GeV photons will look like a burst of 1 GeV photons 10 times more luminous.

3 Response of an Auger WCD to GRB secondaries spectra

The distribution of particles at ground shows that only the highest energy showers reach ground with more than one particle, and the typical distance between them is of the order of 50 meters. One therefore can safely consider a single WCD of Auger won't usually detect more than one particle for a given shower, and limit the simulation to know what is the probability of a single WCD to detect a shower generated with a given primary energy and zenith angle.

An Auger WCD is a 10 m^2 tank, filled with 12 tons of ultra pure water, in a highly diffusive and reflective bag. Three photomultiplier tubes (PMT) overlook the water volume and are controlled by a local electronics. The simulation of the Auger WCD was done with a simple simulator called EASYSIM which allows reasonably fast tank simulation. Further studies will be made with GEANT4, but time of simulation was too important for our preliminary study. 200 000 electrons and photons were simulated, from 1 to 100 MeV and 0 to 60 degrees of zenith angle (typical range of values found in our shower library). For each simulated particle, a simple trigger of 2 ADC channels above baseline in all 3 PMT in coincidence has been asked. This corresponds to 4% of a vertical and central muon, the unit used for calibrating the tanks. An equivalent detected energy would be 5 MeV (even if the response will depend a lot on where the particle impacted the tank).

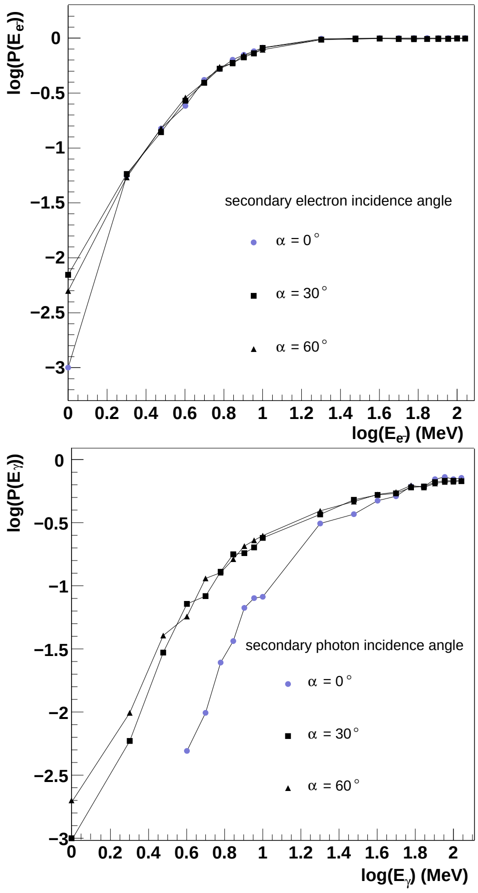

Fig. 3. Probability of detection of secondary photon or electron for different energies and incoming angle

Result of the simulation can be seen in figure 3. The probability of detecting secondaries is mostly independent on the incident angle (except for vertical photons) and slightly higher for electrons than for photons. It is important to note that this simple trigger is a very conservative one in the sense it asks for the coincidence of the 3 PMT. This makes difficult detection of low energy particles which mainly illuminate the closest PMT. However, when going to lower level of coincidences, the noise increases quickly at low threshold, and further studies of real rate of events in an

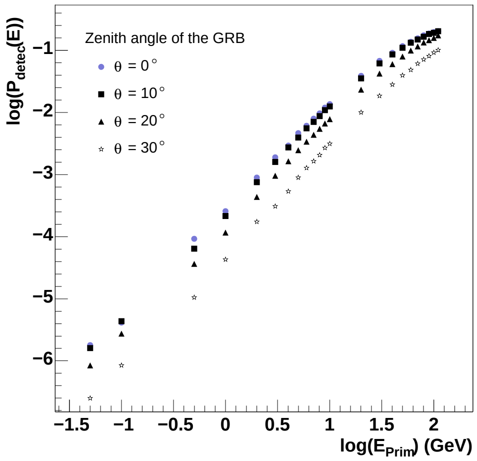

Fig. 4. Probability of detecting a photon primary in a WCD as a function of its energy

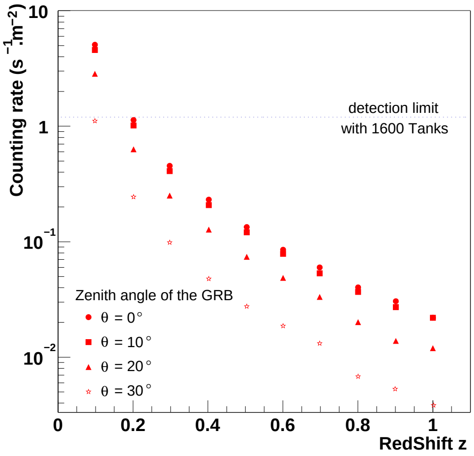

Fig. 5. Probability of detecting a GRB in Auger as a function of its distance and zenith angle

Auger WCD are needed before considering other triggers. This study can be considered in any case as a lower bound to what Auger could do.

Convolving the single particle response to the secondaries spectra, one can get the probability of detecting a high energy photon primary by an Auger WCD. The given probability can be seen in figure 4. In 85% of the case, the detected secondary is a photon. This confirms the impression given above that WCD are very powerful detectors for GRB. A scintillator would miss all these events.

4 Response of the PAO to a GRB

Once the probability of detecting a primary photon has been computed, one needs the primary spectrum at the level of the atmosphere for a given GRB to check if it can be detected. There is no definite high energy spectrum for the GRB, but some reasonable assumptions and extrapolations can be made. It is not the purpose of this paper to study individual GRB or different models (one can refer to [6] for a more detailed study). Figure 5 shows the probability of detection of a GRB using the internal shock model[7] as a function of its distance z, using standard values of $\Gamma = 600$ and $L = 10^{52}$ erg.s^{-1}, as a function of its zenith angle.

In order to implement this GRB detection scheme, one needs to add this new trigger for all the Auger detectors and collect the data centrally for each second. The Auger Central Data Acquisition System is perfectly able to do such a task, as second level triggers of the tanks are already collected on a second time scale. Adding a single word indicating the number of background hits at low threshold will not perturb in any sense the experiment. This extra data stream will be added to the system in March 2005. Note that it will also allow to monitor the behavior of the detectors at low threshold and might be useful to identify faulty detectors.

5 Conclusions and Perspectives

WCD have been shown to be very good GRB detectors due to their sensibility to photons secondaries. A complete simulation of the photons showers and detector response of Auger WCD has been presented, indicating Auger might see a few GRB over its operating time (20 years). This result is quite conservative, and there are many ways one could improve the detection efficiency to get maybe to a detection rate of a few GRB per year.

We've shown above that the best way is to improve the trigger. It is the only free parameter we have, since we must keep in mind the PAO is built for something else, but going from a 3 PMT coincidence to a lower level would probably boost the detection efficiency.

Another possibility would be to have a dedicated detector. Simulations will be done on how to optimize the detector to GRB detection. It needs to be deep enough to convert photons, but shallow enough to reduce the absorption in water. There is no need to have 3 PMT like in Auger (this was done to get a good detector uniformity, what we don't need here), or a specific tank shape ($10\,\mathrm{m}^2$ in Auger), allowing to reduce costs.

Then, the main point is to go higher in altitude. Some simulations were done at 5200 m of altitude, with mount Chacaltaya (Bolivia) in mind. At such altitudes, the properties seen above were conserved (same spectra of secondaries, independent of primary energy), but scaled of course as the atmosphere absorption is much less. The amount of particles at ground level is 2 orders of magnitude higher than at 1400 m. Given an increase of 8 in noise level[4], this gives an increase of $100/\sqrt{8} = 35$ in signal to noise. One Auger WCD at 5200 m would therefore be equivalent to 1250 WCD at 1400 m. With an improved detector design, and a specific trigger, one could get a fairly effective detector at a very reasonable cost.

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