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SHOWER ARRAY**

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Gamma Ray Bursts as seen by a Giant Air Shower Array

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Abstract

The potentiality of a Giant Shower Array to low energy gamma rays from gamma ray bursts is discussed. Effective areas are calculated for different scenarios and the results are encouraging. If gamma ray bursts have a spectrum which continues in the high energy gamma ray region, the Pierre Auger Observatory will be able to detect it.

I. INTRODUCTION

Gamma Ray Bursts (GRB) are one of the most intriguing mysteries in the Universe and models abound trying to explain them. A recent review of models is given in ref. [1]. In ref.

[2] a compilation of more than 100 models is given. A complete phenomenological review with many references is given in ref [3].

Recently, thanks to the accurate measurement of the position of a GRB by the BeppoSAX satellite [4] it was possible to measure a source counterpart in other frequencies (X rays, optical and radio bands) and a measurement of the redshift [5] was given for the GRB970228 ($0.86 \leq z \leq 2.3$) implying a truly cosmological distance.

In this respect it will be most interesting to measure the flux of high energy photons from gamma rays burst. We should remember that one does not expect high energy photons if GRB are cosmological. Even a 100 GeV photon flux would suffer a considerable attenuation for cosmological distances (\sim Gpc). Therefore, looking for high energy photons would be an invaluable tool in discriminating cosmological scenarios from extended halo or mixed models.

In this letter we discuss the potential of a giant surface array, specifically the Pierre Auger Project [6] to measure bursts fluxes of low energy (GeV – TeV) photons. Studies of this type have been done for a variety of detectors and limits have been put by different collaborations, see for instance [7,8]. All present results are negative and only upper limits could be put on fluxes on high energy. An interesting result is, however, the 10σ candidate event detected by EAS-TOP [7]. Although the event could not be associated to any GRB's this could be an indication of the "delayed phenomena" [9]. In this work, the acceleration of the highest energy cosmic rays is related to GRB. Delayed high energy photons appear naturally as a consequence of the propagation and cascading of the cosmic rays through the photon (CMBR and IR) fog. The delay time depends on the intergalactic magnetic structure and could be of the order of hours to days (or even years).

Recently, a work similar to ours was written by DuVernois and Beatty [10] where calculation of the effective area for the Auger detector was done. However, our results indicate that their effective area is overestimated by a factor of 15 with respect to us. We have been unable to trace back the cause of discrepancy.

II. SIMULATION

We have run several thousands photon initiated showers for different energies using the program Aires [11]. Threshold energies for both muons and e.m. particles have been set above the respective threshold for Cerenkov light production in water. The ground depth was set to 850 gr/cm² [6]. In table I we can see some parameters of the run. The thinning level is always chosen so as to guarantee that all particles in the shower are kept until they reach the threshold value.

For every shower we have done the following simulation. At ground level an infinite grid is built. Each cell in the grid has an area of $a = 10 \text{ m}^2$ equal to the area of the detectors in the Auger Project. For each shower we compute the number of particles that reach each cell at the ground. If the number of particles is above a given number, k , we will count it as a trigger. Results of the simulation are given in the table I. Let $N_k(E)$ be the number of triggers for showers of energy E . Then a convenient parametrization is given by:

$$N_k(E) = N_0(k) E^{1.68}, \quad (1)$$

where $N_0(k)$ depends on k but it is independent of the energy. In fig.1 we can see the result of our calculation of N_k for different values of k as a function of energy. Also plot is the above parametrization. We can see that for medium energies ($10 < E < 100 \text{ GeV}$) the parametrization is good. At high energies it overestimates the values of N_k .

Given the value of N_k we can calculate the effective area for detecting low energy showers as follows. A shower of some given energy will have an "effective area" given by:

$$A_S(E) = a N_k(E), \quad (2)$$

where a is the area of each detector. This expression for the effective area reflects the low energy character of the photon initiated shower which has shower maximum position much higher than the ground level, giving a surface distribution of particles bearing no relation to the initial shower axis direction.

For an array of detectors, we have that the probability of a shower to trigger a detector is given by the ratio of the shower area by the inter detector area *i.e.*:

$$P(E) = \frac{A_S(E)}{l^2}, \quad (3)$$

where l is the separation distance between detectors. So the total effective area will be:

$$A_{\text{eff}}(E) = A_T P(E), \quad (4)$$

where $A_T \sim N_D l^2 \sim 3000 \text{ km}^2$ is the total area covered by the detector and N_D is the number of detectors. Finally we get:

$$A_{\text{eff}}(E) = a N_D N_k(E). \quad (5)$$

From fig. 1 we can estimate the effective area for the Auger Project. At $E \sim 100 \text{ GeV}$ we have $A_{\text{eff}} \sim a N_D \sim 1.6 \cdot 10^4 \text{ m}^2$. Even at so low energies as $E \sim 10 \text{ GeV}$ we have an effective area of $A_{\text{eff}} \sim 16 \text{ m}^2$, *i.e.* bigger than the effective area of EGRET [12]. This result is in contradiction with the result in ref. [10]. In fig. 1 we show their result as a continuous line. We can see that their result is ~ 15 times higher than ours even in the most optimistic scenario of $k = 1$. In comparison we also show the EAS-TOP result [7] which agrees with ours. This should be expected since the altitude for EAS-TOP is similar to the projected Pierre Auger (850 gr/cm^2) altitude and the area of each detector is equal (10 m^2). We conclude that our results are correct.

Due to the large distance between detectors for the Auger Project ($l \sim 1.5 \text{ km}$) the array always have to operate in single counting mode. Even at the highest energies ($\sim 100 \text{ TeV}$) the shower will certainly trigger on at most one detector and no correlation on neighbour detectors should be expected. This is in contrast to smaller arrays where the small distance between detector allows to measure correlation between neighbour detectors see for instance [7].

For the angular dependence we have simulated 1000 showers at fixed energies and at different angles. In table II we show the result of the simulation. We can parametrize the results in the form:

$$N_k(\theta) = N_0 \cos(\theta)^\alpha, \quad (6)$$

with $\alpha \sim 9$ which agrees with previous results [10,7]. We assume that this dependence is valid for other energies. With the result of our calculation we are able to calculate the effective area for GRB with arbitrary spectrum and for arbitrary arrival direction.

TABLES

Energy (GeV)	N_{sh}	$N_{k=1}$	$N_{k=5}$
1	10^4	3	1
5	10^4	40	8
10	10^4	250	62
20	10^4	767	216
25	10^4	$1.12 \cdot 10^3$	297
50	10^4	$4.45 \cdot 10^3$	$1.13 \cdot 10^3$
100	10^4	$1.52 \cdot 10^4$	$3.72 \cdot 10^3$
150	10^4	$2.89 \cdot 10^4$	$6.88 \cdot 10^3$
200	10^4	$4.79 \cdot 10^4$	$1.16 \cdot 10^4$
250	10^4	$6.91 \cdot 10^4$	$1.64 \cdot 10^4$
300	10^4	$9.36 \cdot 10^4$	$2.23 \cdot 10^4$
500	10^4	$2.02 \cdot 10^5$	$4.80 \cdot 10^4$
Energy (TeV)	N_{sh}	$N_{k=1}$	$N_{k=5}$
1	10^4	$5.75 \cdot 10^5$	$1.39 \cdot 10^5$
10	$5 \cdot 10^3$	$6.27 \cdot 10^6$	$1.98 \cdot 10^6$
20	10^3	$2.61 \cdot 10^6$	$9.53 \cdot 10^5$
50	10^2	$6.09 \cdot 10^5$	$2.67 \cdot 10^5$
100	10^2	$1.09 \cdot 10^6$	$5.35 \cdot 10^5$
500	70	$2.29 \cdot 10^6$	$1.37 \cdot 10^6$

TABLE I. Shower simulation parameters.

Energy = 100 GeV				
θ	$\cos(\theta)$	N_{sh}	$N_{k=1}$	$N_{k=5}$
0	1	10^4	15234	3718
10	0.985	10^3	1295	362
20	0.949	10^3	786	196
30	0.866	10^3	334	90
40	0.766	10^3	75	19

TABLE II. Angular dependence on trigger number.

Let's assume a burst with a spectrum $dN/dE = \Phi_0(E/E_0)^{-\gamma}$ between E_{\max} and E_{\min} occurs during a time T . Then the number of triggers in excess observed will be

$$S = T \int_{E_{\min}}^{E_{\max}} dE \Phi_0 \frac{E^{-\gamma}}{E_0} A_{\text{eff}}(E, \theta). \quad (7)$$

In the same time the number of background triggers will be $N = \nu T$, where ν is the background trigger rate. And the statistical significance is given by:

$$n_\sigma = \frac{S}{\sqrt{N}} = \frac{a \Phi_0 T N_D \zeta(\gamma, \theta)}{\sqrt{T \nu N_D}} \quad (8)$$

where $\zeta(\gamma, \theta)$ is given by

$$\zeta(\gamma, \theta) = \int_{E_{\min}}^{E_{\max}} dE E^{-\gamma} N_k(E, \theta). \quad (9)$$

Therefore a limit with a n_σ confidence level can be obtained from no observation for fluxes bigger than

$$\Phi_0 = \frac{n_\sigma}{a} \sqrt{\frac{\nu}{T N_D}} \frac{1}{\zeta(\gamma, \theta)}. \quad (10)$$

For the Auger detector the single counting ratio will be about 2.5 kHz and the integration time can be of order 1 s, although given the uncertainty in the time profile for high energy photons, specially if the delayed phenomena is general, this time should be refined. Thus we get, assuming a spectrum index of 1.5 in the region of 1 GeV to 1 TeV:

$$\Phi_0 = 5.1 \times 10^{-6} n_\sigma \frac{\text{ph.}}{\text{cm}^2 \text{s GeV}}. \quad (11)$$

We should use $n_\sigma \geq 10$ in order to avoid accidental triggers. With this values we would get upper limit fluxes which are competitive with actual Cerenkov detectors, see for instance ref. [13].

The present technique will not be able to give any indication of the arrival direction of these photons, contrary to Cerenkov detectors, therefore the actual detection will be possible only on the basis of timing considerations and correlations with other experiments. An advantage, however, is that it is sensitive to a much larger range of energies than Cerenkov

detectors: from lower energy photons to photons of hundreds of TeV and more (limited only by the source), allowing, in principle, to fill the gap between EGRET and Cerenkov detectors.

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FIGURES

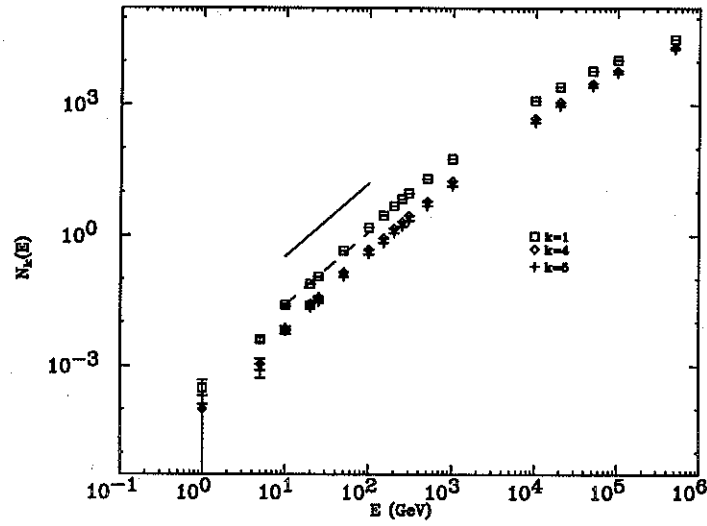


FIG. 1. Number of triggers as a function of photon energy and k (see text) for photons arriving vertically. Also shown is the parametrization of DuVernois and Beatty (continuous line) and the parametrization of EASTOP (dashed line).

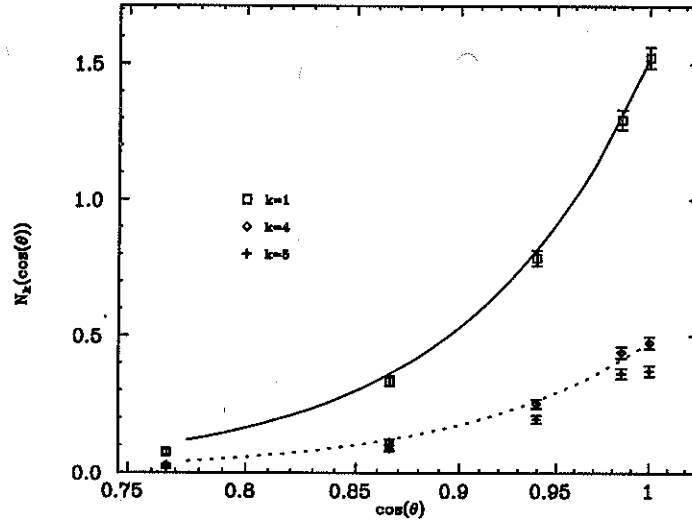


FIG. 2. Number of triggers as a function of arrival angle and k for photons of 100 GeV. Also shown are the $\cos(\theta)^\alpha$ fit.