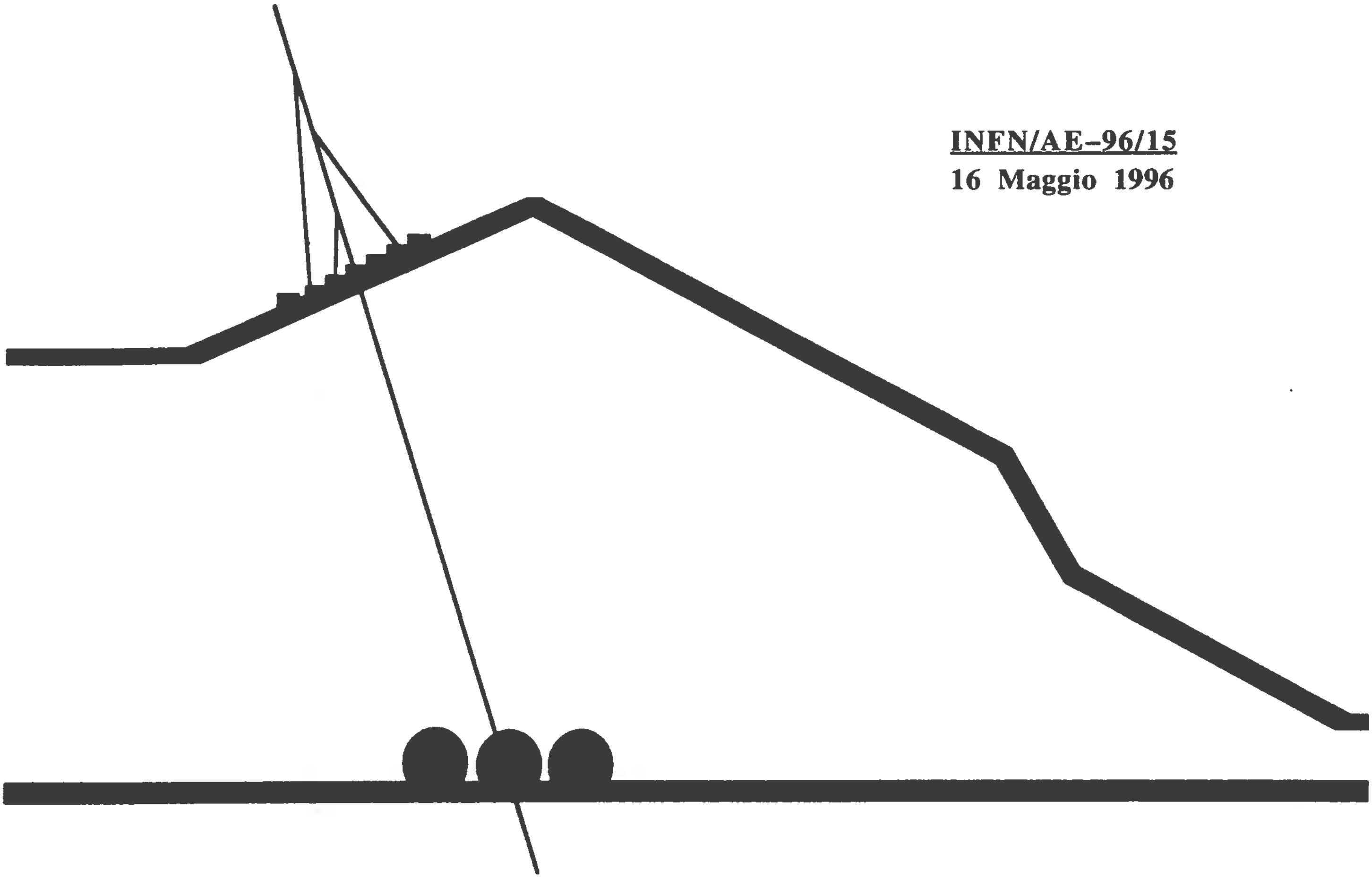

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Search for Gamma Ray Bursts at photon energies E $\geq$ 10 GeV and E $\geq$ 80 TeV

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Abstract

The EAS-TOP Extensive Air Shower array is operating since 1992 in the search for Gamma Ray Bursts at primary energies $E_1 \geq 10$ GeV and $E_2 \geq 80$ TeV. The study is performed by searching for short transients in the cosmic ray intensity in the single particle (E_1) and Extensive Air Shower (E_2) counting rates at mountain altitude (2005 m a.s.l.). We discuss the method and the results obtained both in a sky survey and in correlation with BATSE events.

In both energy ranges the observed fluctuations in the event rate obtained in the sky survey during $\sim$ 800 days of live time are compatible with the statistical fluctuations of the cosmic ray background. A single candidate of time duration $\Delta t \sim 2$ s and energy fluence $F(10 < E < 100 \text{ GeV}) = 1.7 \times 10^{-4} / (\cos\theta)^{10.5}$ erg cm^{-2} (where θ is its unknown zenith angle) has been observed on 1992 July 15 at 13:22:26 UT in the energy range $E_1 \geq 10$ GeV with significance 10.6 and 20.1 s.d. in two measurement channels.

In the analysis made in correlation with $\sim$ 50 events detected by BATSE no burst candidate was found in time coincidence nor in the 2 hour interval around the BATSE detection time. The following ranges of upper limits F_{max} to the energy fluence in the time interval Δt_{90} in which BATSE detected 90% of the counts are obtained:

$F_{max} = 2.3 \times 10^{-5} \div 7.4 \times 10^{-3}$ erg cm^{-2} $(10 < E < 100 \text{ GeV})$
$F_{max} = 1.6 \times 10^{-6} \div 3.3 \times 10^{-5}$ erg cm^{-2} $(100 < E < 1000 \text{ TeV})$.

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1. Introduction

The nature of Gamma Ray Bursts, discovered more than 20 years ago (Klebesadel et al. 1973), is still an unsolved problem in spite of the large amount of data collected up to now. The search for counterparts at wavelengths other than the KeV-MeV region is of great importance for the understanding of the emission processes and the identification of the sources. In the GeV energy range positive observations have been reported by EGRET, aboard the Gamma Ray Observatory; in particular the detection of a 18 GeV gamma ray delayed of 1.5 hours after the onset of the intense burst of 1994 February 17 shows that the phenomena can even be more complex with increasing energy (Hurley et. al 1994).

Observations beyond few tens of GeV can be performed by means of large area ground based detectors operating at mountain altitude, recording the secondary particles of Extensive Air Showers (EAS) generated in the atmosphere by primary gamma rays. While from the physical point of view the measurements have to deal with the large cosmic ray background, from the technical point of view the detectors have to fulfil severe requirements of stability and reliability, often conflicting with their locations and running conditions. Searches made by ground based detectors began as soon as GRBs were discovered and upper limits in different energy ranges were reported (see e.g. O'Brian & Porter (1976) at $E \geq 100$ GeV, Morello, Navarra & Periale (1984) at $E > 5$ GeV, Aglietta et al. (1992) at $E > 5$ GeV, Alexandreas et al. (1994) at $E \geq 100$ TeV).

In this paper we present the result of a search made with the EAS-TOP Extensive Air Shower array in the energy ranges $E \geq 10$ GeV and $E \geq 80$ TeV since January 1992 to March 1995 (preliminary data have been presented in Aglietta et al. 1992, 1993a). This work includes *a)* a sky survey and *b)* a search in correlation with BATSE, onboard the Compton Gamma Ray Observatory (Fishman et al. 1994). For the correlated search, the following BATSE datasets have been used: 1) the 2^{nd} BATSE catalogue including 585 events detected since 1991 March up to 1993 March, 2) a list of the most intense BATSE bursts occurred since 1993 March to 1994 December (Kouveliotou 1994).

2. The EAS-TOP detector

EAS-TOP is an array planned to detect the various components (electromagnetic, hadron, low energy muon, atmospheric Cerenkov light and radio emission) of the Extensive Air Showers (EAS) produced in the atmosphere by cosmic rays (Aglietta et al. 1986). The array is located at Campo Imperatore (lat 42°27'N, long 13°34'E) at the altitude of 2005 m a.s.l. (INFN National Gran Sasso Laboratories).

The search for Gamma Ray Bursts is performed using the data of the electromagnetic detector, made up of 35 scintillator modules enclosing an area of $\sim 10^5$ m^2; each module consists of 16 scintillators, 4 cm thick, for a total area of 10 m^2 viewed by 16 photomultipliers, and operates at an energy loss threshold $\Delta E_{th} \sim 3$ MeV (corresponding to ~ 0.3 m.i.p.). The data used in this analysis include:

1) in the energy range $E \geq 10$ GeV: the counting rates of the individual modules operating at the single particle level. In particular: *C1*) sum of the numbers of counts/s of 15 modules (subarray E1, modules no.1÷15), *C2*) sum of the numbers of counts/s of 15 modules (subarray E2, modules no.16÷30), *C3*) number of counts/100 s of every module. The total counting rate is ~ 60 kHz /subarray.

2) in the energy range $E \geq 80$ TeV: showers detected by the coincidence of at least four contiguous modules. The arrival directions of the primary particles are reconstructed from the measurements of the times of flight among the modules. Core location, lateral distribution of EAS electrons and shower size are obtained from the measurements of the energy losses in the scintillators (Aglietta et al. 1993b). The events are divided into two trigger classes: *S1*) showers hitting at least 7 modules and whose cores are contained inside the edges of the array (angular resolution $\sigma_{EAS} = 0.8°$, trigger rate = 1.9 Hz, energy threshold ~ 100 TeV), *S2*) showers hitting at least 4 modules and not included in class S1 (angular resolution $\sigma_{EAS} = 2.5°$, trigger rate = 25 Hz, energy threshold ~ 80 TeV). The Universal Time of each event is measured with an accuracy of 100 μs.

3. Search for GRBs at $E \geq 10$ GeV

Most of the shower particles generated in the atmosphere by primary gamma rays of ~ 10-100 GeV are absorbed before reaching the detector level. Given a gamma ray of energy $10 \leq E \leq 1000$ GeV and zenith angle $\theta \leq 50°$, the average number of signals due to energy losses $\Delta E \geq \Delta E_{th}$ in a hypothetical EAS-TOP scintillator of infinite area is $N_s(E,\theta) \simeq 1.2 \times (E[GeV]/100)^{1.68} \times (\cos\theta)^{9.5}$. This expression is the result of a simulation of electromagnetic cascades in the atmosphere and in the detectors performed using the EGS4 code. Being $N_s(E,\theta) < 1$ for E < 100 GeV, GRBs in this energy range have to be searched for by operating with the scintillator modules in "single particle" mode, i.e. measuring the single particle counting rate of the individual modules. With this technique the primary arrival directions cannot be measured and GRBs can be detected only as short time increases of the cosmic ray counting rate. Cosmic rays of energy as low as a few GeV are modulated by the atmospheric pressure, the solar activity, and the 24 hour solar anisotropy. However, since the time scale of such phenomenon (at least a few hours) is much larger then the typical GRBs duration, it does not interfere with the burst search.

Assuming a power law differential spectrum of photons in the burst $S(E) \propto E^{-\gamma}$ in the energy range effective for the detection $E_{min} \le E \le E_{max}$, given an excess of N events above the cosmic ray background, the corresponding energy fluence F in the energy range $E_1 \le E \le E_2$ is given by:

$$F = \frac{N \times \int_{E_1}^{E_2} E^{-\gamma+1}\, dE}{\int_{E_{min}}^{E_{max}} E^{-\gamma} \times A_{eff}(E,\theta)\, dE} \qquad (1)$$

where $A_{eff}(E,\theta)$ is the effective area of the detector for a primary gamma ray of energy E and zenith angle θ. In the 10 GeV ÷ 1 TeV energy range the probability for more then one shower particle to hit the same module is negligible, hence the effective area can be written as $A_{eff}(E,\theta) \simeq N_s(E,\theta) \times A_d \times \cos\theta$, being A_d the sensitive area of the detector.

All fluences are calculated by using expression (1) with $\gamma = 2$, $E_{min} = 10$ GeV, $E_{max} = 1$ TeV, $E_1 = 10$ GeV, $E_2 = 100$ GeV, $A_d = 150$ m^2; i.e. $F = 3.1 \times 10^{-8} \times N \,/\, (\cos\theta)^{10.5}$ erg cm^{-2}.

The C1, C2 and C3 data, as defined in the previous section, are used in the analysis. C1 data, i.e. the number of counts per second of subarray E1 (of sensitive area $A_d = 150$ m^2), are analyzed to search for burst candidates , while C2 data are used for possible confirmations. C3 data allow a check of the stability of each individual module. In fact, the operation in single particle mode requires a continuous check of the detector stability. A severe data 'cleaning' is performed before the analysis, by requiring the consistency of the counting rates of all the modules (for a detailed description of the method see Aglietta et al. 1992). The procedure leads on average to the rejection of 12% of the observation time.

a) Sky survey

The aim of the analysis is singling out possible excesses in the counting rate with time durations $\Delta t \le 1$ s. The number of counts C_i of subarray E1 in the i^{th} second of a 15 minutes interval is compared with the rate $\overline{C}$ averaged over the interval. In 15 minutes the variations of the cosmic ray intensity are negligible, hence the distribution of the quantity $F_i = (C_i - \overline{C})/\sqrt{\overline{C}}$ is expected to be Gaussian with mean value V = 0 and r.m.s. $\sigma = 1$. Fig. 1 shows the F_i distribution for a total live time of 757.3 days (since 1992 January to 1995 March). We observe:

a) the distribution is well fitted up to ~ 7 standard deviations by a Gaussian curve with mean value V = 0.0023 ± 0.0001 and r.m.s. $\sigma = 1.14$ and shows the good stability of the detector over long operation times, at the level of a single measurement over 6.5 × 10^7 trials.

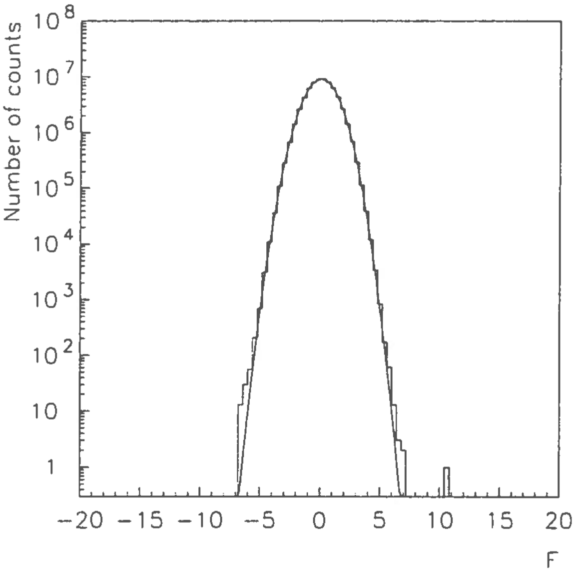

Fig. 1.— Distribution of $F_i = (C_i - \overline{C})/(\overline{C})^{1/2}$ in 757.3 days of run (see text). The excess observed on 1992 July 15 is visible at 10.6 standard deviations.

b) a statistically significant excess of 10.6 standard deviations has been observed on 1992 July 15 at 13:22:26 UT; this is confirmed by a 20.1 s.d. excess in the E2 dataset (the two significances, although different, are not in contradiction in view of the different energy thresholds of the individual detectors). This event, already proposed to be searched in other experiments datasets [1], is discussed in detail in Aglietta et al. (1993a). An excess in the number of counts is also observed in the next 1 s interval (5.2 s.d. in E1 and 11.7 s.d. in E2). The total excess observed in subarrays E1 + E2 ($A_d = 300$ m^2) in 2 s consists of 10680 counts against a mean value of 2.05 10^5. Assuming this event to be due to gamma rays the corresponding energy fluence in the range $10 < E < 100$ GeV is:

$F = 1.7 \times 10^{-4} / (\cos\theta)^{10.5}$ erg cm^{-2}.

b) Search in correlation with BATSE events

From BATSE data, 45 Gamma Ray Bursts occurring in the EAS-TOP field of view (i.e with zenith angle $\theta \leq 50°$) since 1992 February up to 1994 July have been selected.

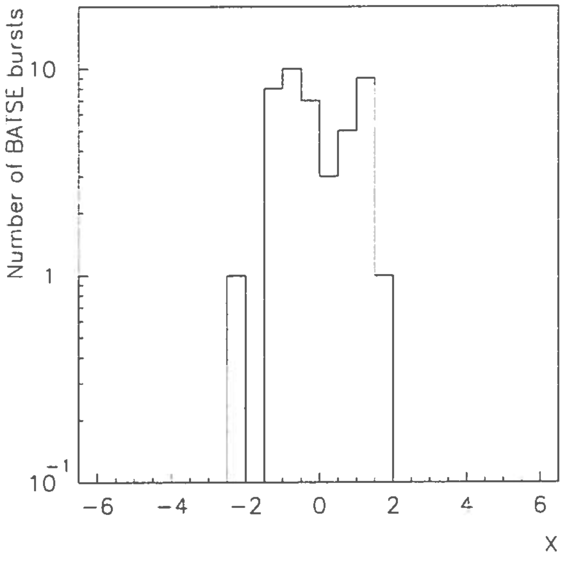

Fig. 2.— Distribution of $X = (N_{E1} - N_{B1})/(N_{B1} + (N_{B1}\ \Delta t_{90}/600))^{1/2}$ during the Δt_{90} BATSE time interval for 45 GRBs (see text).

For every BATSE event the number of counts N_{E1} recorded by E1 during the Δt_{90} time interval in which BATSE recorded 90% of the total observed counts is compared with the number N_{B1} expected from the background (obtained from the average counting rate in 600 seconds around the burst). The durations Δt_{90} range from 0.2 s to 154 s for the 45 bursts (for a few bursts Δt_{90} is not given in the catalogue, in this case $\Delta t_{90} = 100$ s is assumed). The distribution of the 45 differences $N_{E1} - N_{B1}$ in unit of standard deviations, i.e. $(N_{E1} - N_{B1})/\sqrt{N_{B1} + (N_{B1}\ \Delta t_{90}/600)}$ is shown in Fig. 2. The distribution, with a mean value $V = -0.091 \pm 0.15$ and r.m.s $\sigma = 0.99$, is compatible with the statistical fluctuations of the cosmic ray background.

In a second step of the analysis, looking for possible gamma rays delayed or anticipated with respect to the KeV-MeV emission, or with a different time duration, we searched for excesses in time windows $\Delta t = 1, 2, 5, 10, 20, 50, 100$ s shifted by steps of Δt inside a 2 hour interval around the BATSE recording time. In all these trials the distributions of the numbers of counts are compatible with the statistical fluctuations. Fig. 3 shows the distribution of the excesses in unit of standard deviation fitted by a Gaussian curve with mean value V = -0.0003 ± 0.0014 and r.m.s. $\sigma = 1.095$.

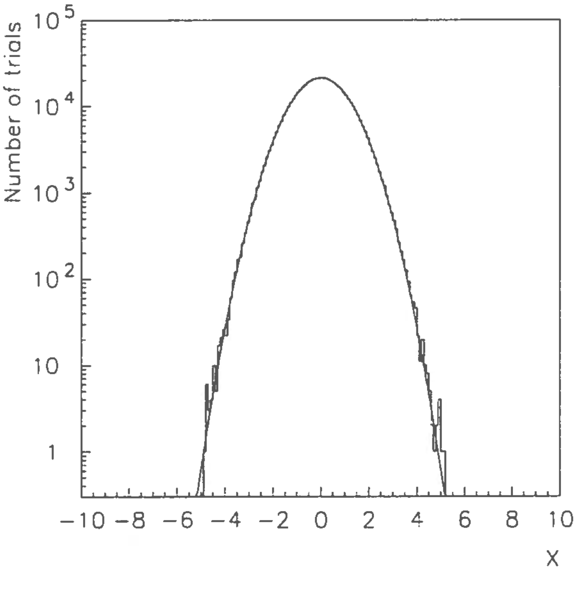

Fig. 3.— Distribution of $X = (N_{E1} - N_{B1})/(N_{B1} + (N_{B1}\ \Delta t_{90}/600))^{1/2}$ in 2 hour intervals around 45 BATSE bursts using different time windows Δt (see text).

The upper limits to the energy fluences are calcu-

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[1] The contemporary BATSE data are not available

lated for every burst by using expression (1) with the proper zenith angle θ and with N_{max} corresponding to a 3 standard deviations excess. Region *a* of Fig. 4 represents the range of such upper limits in the energy range 10-100 GeV, during the time interval Δt_{90} for the 45 bursts:

$$F_{max} = 2.3 \times 10^{-5} \div 7.4 \times 10^{-3} \text{ erg cm}^{-2}.$$

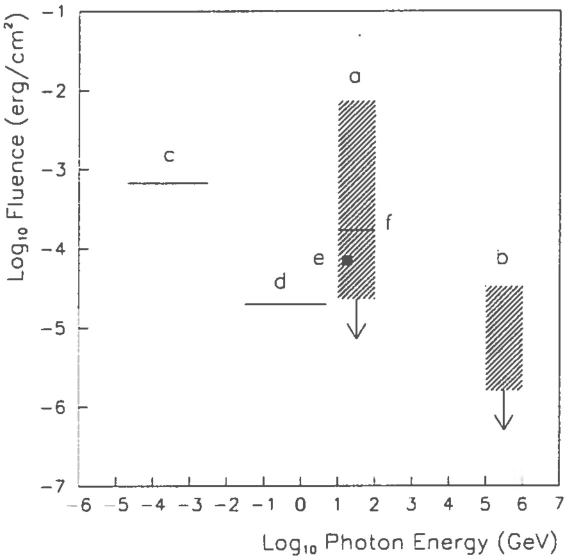

Fig. 4.— *a)* Range of upper limits to the energy fluence obtained by EAS-TOP in the energy range 10-100 GeV during 45 BATSE bursts, *b)* range of upper limits to the fluence in the energy range 100-1000 TeV during 56 BATSE bursts, *c)* and *d)* fluences respectively measured by BATSE and EGRET during GRB940217, *e)* fluence associated to the 18 GeV photon observed by EGRET 1.5 hours after GRB940217, *f)* fluence associated to the EAS-TOP candidate of July 15, 1992, assuming $\theta = 0$.

The large dispersion of such values is due to the different zenith angles and time durations of the bursts.

4. Search for GRBs at E ≥ 80 TeV

The database used in this energy range includes the arrival direction and observation time of each recorded Extensive Air Shower. Hence GRBs are searched for not only as fluctuations in the events time distribution but also as spatial concentrations of events inside a sky window of size related to the angular resolution of the detector. The search is performed independently for the trigger classes S1 and S2, described in section 2.

In general, given an observed excess of N events inside an angular window in which a photon from a point source is detected with efficiency ϵ, assuming a power law differential spectrum of photons in the burst $S(E) \propto E^{-\gamma}$ in the energy range $E_{min} \leq E \leq E_{max}$, the corresponding energy fluence in the energy range $E_1 \leq E \leq E_2$ is given by:

$$F = \frac{N \times \int_{E_1}^{E_2} E^{-\gamma+1}\, dE}{\epsilon \times \int_{E_{min}}^{E_{max}} E^{-\gamma} \times A_{eff}(E,\theta)\, dE} \tag{2}$$

$A_{eff}(E,\theta)$, the effective area of the detector for a primary gamma ray of energy E and zenith angle θ, has been obtained through a simulation using the EGS4 code; $A_{eff}(E,\theta)$ increases with energy E up to a 'plateau' value $A_{max} \sim 5 \times 10^4$ m^2. For a typical zenith angle $\theta = 30°$, $A_{eff} = 0.004 \times A_{max}$ at E = 30 TeV and $A_{eff} = 0.80 \times A_{max}$ at E = 300 TeV.

All fluences are calculated using expression (2) with $\gamma = 2$, $E_{min} = 10$ TeV, $E_{max} = \infty$, $E_1 = 100$ TeV, $E_2 = 1000$ TeV.

a) Sky survey

The aim of the analysis is singling out statistically significant temporal and spatial concentrations of events in the sky region with zenith angle $\theta \leq 50°$. For every event i occurring at time t_i and zenith angle θ_i, we consider all clusters made by events $i, i+1, i+2, ...i+N-1$ whose arrival directions are inside a circular window w centered on it, with radius $\alpha = 2.2 \times \sigma_{EAS}$ and area $A_w = 2\pi(1-\cos\alpha)$, being σ_{EAS} the detector angular resolution, and satisfying the condition $\Delta t \equiv t_{i+N-1} - t_i \leq 10$ s (the adopted value of the radius α optimizes the signal to noise ratio). Every cluster is characterized by: 1) the number of events N, 2) the time duration Δt, 3) the zenith angle of observation $\theta \equiv \theta_i$. To estimate its statistical significance we calculate the mean rate $F_b(N, \Delta t, \theta, \phi)$ of clusters with $N_B \geq N$ events , generated by background fluctuations in an angular window of area A_w centered in the solid angle $\sin\theta d\theta d\phi$, inside a time interval between Δt and $\Delta t + dt$. If $f(\theta)$ is the background rate per steradian corresponding to zenith angle θ, and f_w is the rate of events in the angular window w (calculated considering the variation of the background rate inside the window because of the different zenith angles included) then: $F_b(N, \Delta t, \theta, \phi) = f(\theta) \times P_{last} \times P_{N-2} \times sin\theta d\theta d\phi$, where $P_{last} = f_w \; dt$ is the probability for the last event to occur in the time interval dt and $P_{N-2} = \sum_{n=N-2}^{\infty} \frac{e^{-f_w \Delta t}(f_w \Delta t)^n}{n!}$ is the Poisson probability for $\geq$ N-2 events to occur inside the time interval Δt.

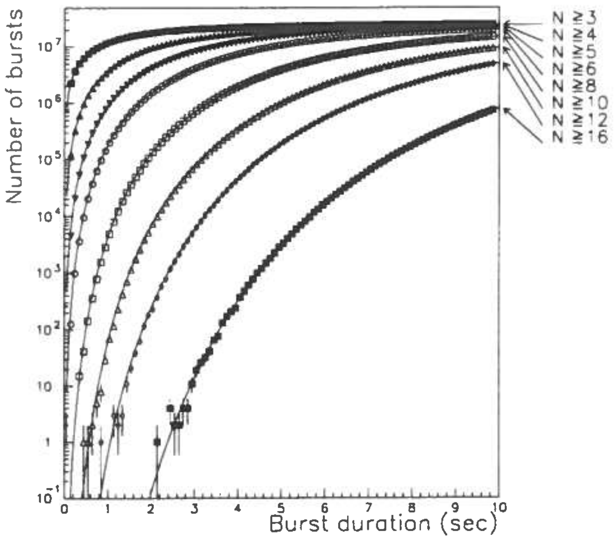

Fig. 5.— Distribution of the number of clusters of events S2 during 208.4 days as a function of the cluster time duration Δt, for different cluster multiplicities N.

The total rate of clusters with higher or equal statistical significance is then given by:

$$F_{tot} = \sum_{N'=2}^{\infty} \int_0^{\pi/2} sin\theta' d\theta' \times \quad (3)$$

$$\times \int_0^{2\pi} d\phi' \int_0^{10} F_b(N', \Delta t', \theta', \phi')' d\Delta t' \quad (4)$$

with the condition:

$F_b(N', \Delta t', \theta', \phi') \leq F_b(N, \Delta t, \theta, \phi)$.

The cluster is considered a burst candidate if $F_{tot} \leq 0.001 \; y^{-1}$. As an example, for a burst with zenith angle $\theta = 30°$ and time duration $\Delta t = 1$ s (10 s), this condition is verified for N $\geq$ 6 (7), corresponding to an energy fluence $F_{min} = 8.4(9.8) \times 10^{-6}$ erg cm^{-2} in the range $100 < E < 1000$ TeV.

Every ~ 10 hours of measurement an on-line program calculates F_{tot} for every observed cluster; if a statistically significant cluster is found a message is printed out. In a total live time of 872.8 days no deviation from the poissonian fluctuations of the cosmic ray background has been observed. The least probable cluster consists of 5 S1 showers with zenith angle $\theta \sim 31°$ occurring within $\Delta t = 4.8 \; s$, against a mean value of 0.014; the probability to detect one or more clusters with an equal or higher statistical significance in the total run time is 0.28.

The good agreement between the experimental data and the theoretical estimates is shown in Fig. 5, where the distribution of the number of clusters of events S2 as a function of Δt (obtained by integrating over θ and ϕ and setting $dt = 0.1$ s) is compared with the expected one for a subset of data recorded during 208.4 days of live time.

Finally, no significant excess in S1 and S2 events has been observed during the occurrence of the 1992 July 15 candidate in the energy range E $\geq$ 10 GeV.

b) Search in correlation with BATSE events

We selected 56 BATSE bursts with zenith angle $\theta \leq 50°$. BATSE error boxes (defined as the 68 % C.L. location errors) are given for most of the events. For bursts lacking such information, we assume the radius of the error box equal to 10°.

Since the EAS-TOP angular resolution σ_{EAS} is better than the BATSE one, a burst should appear as a concentration of events inside an angular window smaller than the BATSE error box. Hence our search is performed by moving a circular window of radius $\alpha = 1.78 \times \sigma_{EAS}$ inside the BATSE error box and comparing the number of showers N_{EAS} detected in any window position during the time interval Δt_{90} with the expected number of background events N_B (calculated using the showers detected at the same zenith angle in a 2 hour time interval). The position of the center of the window is moved following a net of equidistant points covering the whole BATSE error box; each point is surrounded by 6 points, representing the vertex of an hexagon of side $p = 2 \times \sigma_{EAS}$. The number of windows obviously depends on the radius of the BATSE error box that ranges from 4° to 17° for the 56 bursts considered. For any window i we calculate the probability P_i to observe a number of events $N \geq N_{EAS}$ from the poissonian fluctuations of N_B.

We consider an observed excess of events as a burst

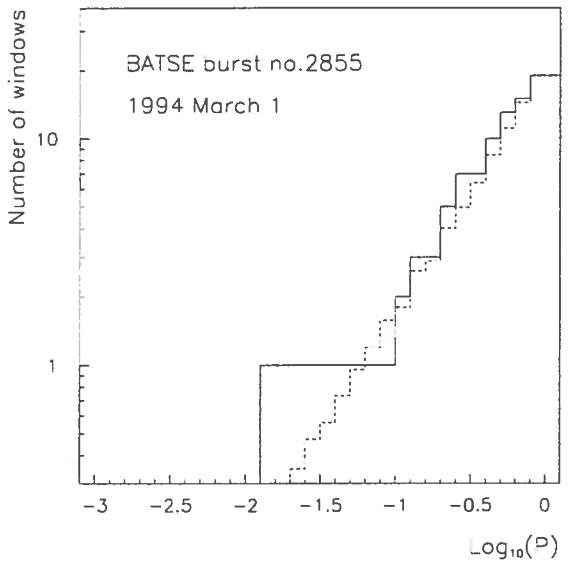

Fig. 6.— Integral distribution of P_i during GRB940301 (see text), compared with the expected distribution (dashed line).

candidate, if its probability P_{tot} to be generated by background fluctuations (calculated taking also into account the number of windows used) is less than $P_{max} = 0.001$. The values of α and p have been chosen in order to minimize the number of events necessary to form a burst with $P_{tot} < P_{max}$. With these values, the detection efficiency for a photon from a point source inside the BATSE error box is $\epsilon = 70\%$.

As an example of the method, Fig. 6 shows the integral distribution of P_i during GRB940301, where 19 windows have been used for class S2 events, compared with the expected distribution (dashed line). A similar good agreement between experimental and expected distributions is observed for every BATSE burst. The most significant excess consists of 11 S2 events, against 3.5 expected from the background, during GRB920420; the probability P_{tot} for such a cluster to be generated by a background fluctuation is $P_{tot} = 0.004$. Considering the number of GRBs analyzed, the probability becomes $\sim 20\%$.

Region *b* of Fig. 4 represents the range of 90% C.L. upper limits to the energy fluence F in the energy range $100 < E < 1000$ TeV during the time Δt_{90} for the 56 bursts, calculated using the number of events S1 recorded in the window containing the most significant excess, according to expression (2):

$F_{max} = 1.6 \times 10^{-6} \div 3.3 \times 10^{-5}$ erg cm^{-2}.

Repeating the same analysis in the 2 hour interval centered at the BATSE time and using the time windows $\Delta t_{EAS} = 1, 2, 5, 10, 20, 50, 100$ s shifted by steps of $\Delta t_{EAS}/2$, we found probability distributions compatible with background fluctuations. The most significant excess was found 1940 s before the occurrence of GRB930201: it consists of 7 events of class S2 detected in $\Delta t_{EAS} = 20$ s, against a mean background of 0.43 events; taking into account the number of time windows used the probability for this cluster to be a background fluctuation is 0.014. Considering the number of GRBs analyzed, the probability becomes $\sim 54\%$.

5. Conclusions

The method and the results of a search for Gamma Ray Bursts performed by the electromagnetic detector of the EAS-TOP array in the energy ranges E $\geq$ 10 GeV and E $\geq$ 80 TeV are presented.

In the search in correlation with BATSE events, no evidence for gamma ray emission is observed in both energy ranges, either in coincidence with $\sim$ 50 BATSE bursts, nor in the 2 hour intervals around the BATSE recording times. The ranges of upper limits to the energy fluence during the time intervals in which BATSE detected 90% of the flux are drawn in Fig. 4, for the energy intervals 10-100 GeV and 100-1000 TeV. The fluence limits span over large ranges due to the different time durations and zenith angles of observation of the events. As a comparison, in the same figure the fluences measured by BATSE (line *c*) and EGRET (line *d*) (Hurley et. al 1994) at lower energies during the powerful GRB940217 are reported, together with the fluence associated to the 18 GeV photon detected by EGRET 1.5 hours after the onset of the burst (this burst is not included in our analysis being below the EAS-TOP horizon).

In the sky survey, during $\sim$ 800 days of live time, the distributions of the numbers of events recorded in different time intervals follow the expectations from the background fluctuations in both energy ranges, showing the stability of the experiment at a poissonian level over long running times.

In the energy range E $\geq$ 10 GeV a single statistically significant excess (10.6 and 20.1 standard deviations in 2 different measurement channels) was observed during a time interval of 2 s on 1992 July 15 at 13:22:26 UT. Assuming this candidate to be due to gamma rays, the corresponding energy fluence is $F = 1.7 \times 10^{-4} / (\cos\theta)^{10.5}$ erg cm^{-2} for $10 < E < 100$ GeV. This value, together with the upper limits given in Fig.4 and compared to the fluence $F = 7 \times 10^{-5}$ erg cm^{-2} associated to the 18 GeV photon detected by EGRET following GRB940217, shows that EAS-TOP, in the 10-100 GeV energy range, has a sensitivity comparable to the EGRET one and (at least concerning the temporal structures, not having a specific energy resolution) could integrate the satellite measurements.

In the energy range E $\geq$ 100 TeV, the 90% C.L. upper limit to the rate of GRBs of time duration Δt = 1 s (10 s) and energy fluence F > $8.4(9.8) \times 10^{-6}$ erg cm^{-2} ($100 < E < 1000$ TeV), is R < 1.14 y^{-1} sr^{-1}.

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