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# Search for GeV gamma ray bursts at Mount Chacaltaya

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**Abstract.** INCA is an air shower array working at Mount Chacaltaya, Bolivia, at 5200 m above sea level, searching for GRBs in the range of energies ~1 GeV - 1 TeV. The altitude of INCA and the use of the "single particle" technique allows to work with a detection threshold as low as few GeVs.

In this paper we present the results of a search for GRBs in coincidence with satellites events in the period 1996 December - 2001 March. No significant signals are observed during the occurrences of 135 GRBs, and the obtained upper limits on the energy fluence in the interval 1-$10^3$ (1-$10^2$) GeV, range from 1.7 (4.6) $10^{-5}$ to 9.6 $10^{-2}$ (2.6 $10^{-1}$) erg cm$^{-2}$ depending on the zenith angle of the events.

These limits, thanks to the extreme altitude of INCA, are the lowest ever obtained in the sub-TeV energy region by a ground based experiment.

## 1 High energy Gamma Ray Bursts

So far the radiation emitted by GRBs in the GeV-TeV energy band has been very poorly studied due to the extremely low fluxes. EGRET, the high energy detector aboard the satellite CGRO, during its life detected only few very intense events containing some GeV photons (Catelli et al., 1997). However many models predicts emissions in the GeV-TeV region and one cannot exclude the possibility that all GRBs contain a high energy component (Meszaros and Rees, 1994; Vietri, 1997; Baring, 1997; Totani, 1998; Dermer and Chiang, 1999; De Paolis et al., 2000).

The low flux is not the only problem to face when studing the high energy component of the GRB spectrum. A major obstacle is the absorption of gamma rays in the intergalactic space. GeV and TeV gamma rays interact with the infrared photons emitted by stars and dust and produce electrons and positrons pairs. The flux of photons of energy $E$ decreases as $dN/dE = (dN_0/dE)e^{-\tau(E,z)}$, where $z$ is the redshift of the source. The optical depth $\tau$ increases with $E$ and $z$; due to the difficulty of measuring the infrared field in the far universe it is not easy to evaluate. According to a model (Salamon and Stecker, 1998) the optical depth becomes equal to 1 for energies as low as $E$ ~ 40-70 (200-400) GeV when $z$=1(0.2).

Now we know that GRBs are huge explosions occurring in galaxies located at very large distances. So far about 15 redshifts of GRBs hosts have been measured: they range between 0.4 and 4.5, clustering around $z \sim 1$. Hence even if GRBs emit TeV-PeV gamma-rays we unlikely could detect them, unless we are so lucky to observe an event occuring very close to us. As a consequence, to study the high energy component of GRBs we must concentrate our efforts in the region of energy less than 1 TeV.

## 2 Detection of GRBs by ground based experiments

Air shower arrays can study high energy GRBs detecting the secondary particles of air showers generated by the interactions of gamma rays with the atmosphere nuclei.

They usually work with energy thresholds of ~ 10-100 TeV, but in searching for transient events as GRBs, they can lower the threshold to few GeVs using the "single particle technique" and operating at very high altitude.

The single particle technique (Vernetto, 2000; Aglietta et al., 1996) consists in counting all the particles giving a signal in the detector (not requiring any coincidence among detectors as it is usually done to detect air showers). In this way it is possible to detect the lonely survivals of small showers produced by primaries of relatively low energy. Obviously with only one particle per shower it is not possible to reconstruct the arrival direction nor the energy of the primary and a GRB is detectable only as a short duration excess over the single particle background, possibly in coincidence with a GRB satellite detection. The background is due to all secondary cosmic rays from all the sky above the horizon.

The signal from a GRB strongly increases with the altitude of the detector. Going from 2000 to 5000 m, a 10 (100) GeV

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signal at zenith angle $\theta$=30° increases by a factor $f_s$ ∼100 (50); since the background increases only by a factor $f_b \sim$ 4, the sensitivity will improve by a factor $f = f_s/\sqrt{f_b} \sim 50$ (25).

Following these considerations we decided to adopt the single particle technique to search for high energy GRBs, exploiting the highest Cosmic Ray Laboratory in the world, at Mount Chacaltaya, in Bolivia, at 5200 m of altitude.

## 3 The INCA experiment

The INCA experiment, taking data since December 1996 (Cabrera et al., 1999; Castellina et al., 2001), utilizes a subset of detectors of the air shower array BASJE, located at the Cosmic Ray Laboratory of Mount Chacaltaya. BASJE is operating since 1963, with several upgrades since then (Ogio et al., 2001).

The experimental setup used by INCA to record the single particle counting rate consists of:

A) 12 scintillator detectors of area 2x2 $m^2$ (with one photomultiplier of 15 cm diameter each) spread over an area of ∼20x20 $m^2$, detecting the surface component of air showers.

B) 16 scintillator detectors of area 2x2 $m^2$ operating under a depth of 320 g $cm^{-2}$, detecting the muon component of air showers.

The former group of scintillators is used to detect the possible GRB signal, as a short duration excess in the electron and positron counting rate, while the latter one is used as an "anticoincidence" detector, since in a gamma ray signal of energy less than $\sim$ 1 TeV, the contents of muons is expected to be negligible. In case of detection of a GRB candidate, the muon counting rate is studied in order to exclude the possibility that the observed excess is a fluctuation of the secondary cosmic ray flux. The muon counting rate acquisition has been implemented in July 2000.

Every second INCA records:

a) the number of counts of each detector;

b) the atmospheric pressure;

c) the Universal Time, with an accuracy better than 1 $\mu s$.

The average counting rates measured by INCA are:

$R_1 \sim$ 900 countings $m^{-2}$ $s^{-1}$, for surface detectors

$R_2 \sim$ 200 countings $m^{-2}$ $s^{-1}$, for muon detectors

Counting rate modulations due to atmospheric pressure changes, solar activity and 24 hours anisotropy do not hamper the GRBs search, since the time scale of these phenomena are much larger than the typical GRB duration.

## 4 INCA sensitivity

Since the average INCA total background rate (summed over the 12 surface detectors) is $C_b \sim 4.5\ 10^4$ $s^{-1}$, a GRB of time duration $\Delta t$ = 1 s is detectable with a significance of 4 standard deviations if the number of detected particles is larger than the threshold value $C_{th}$ = 4 $\sqrt{C_b} \sim 840$. For a generic duration $\Delta t = t$ s, $C_{th}$ increases by a factor $\sqrt{t}$. To compare $C_{th}$ with the expected signal from a GRB, we considered 14

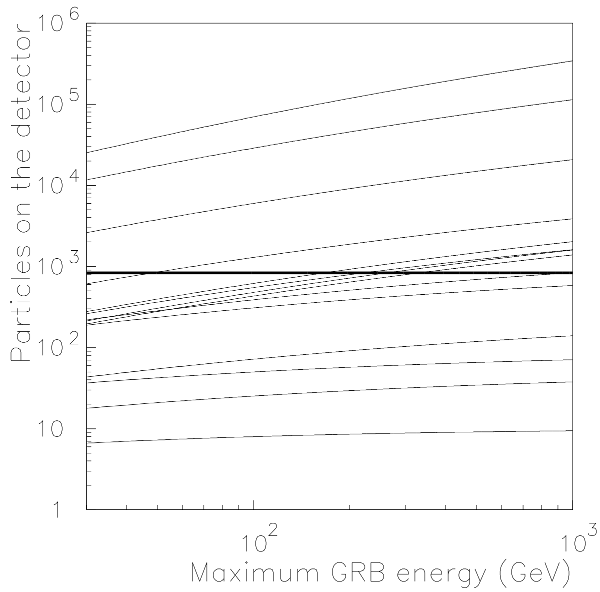


**Fig. 1.** Number of particles hitting the INCA detectors from 14 EGRET GRBs, as a function of the maximum GRB energy. The thick orizontal line represents the minimum number of particles necessary to give a signal with standard deviations $\sigma > 4$, for a GRB duration of 1 s.

GRBs detected by EGRET whose spectrum has been published (Catelli et al., 1997). All EGRET spectra have a power law behaviour without breaks up to the maximum energy that the EGRET sensitivity could observe, with an average slope $\alpha \sim$ -2.2. For simplicity we have assumed that each spectra could be extrapolate with a slope equal to the measured one up to a cutoff energy $E_{max}$ and than zeroes (due to an intrinsic cutoff at the source or to the intergalactic absorption). Fig.1 shows the number of particles hitting the detector produced by the EGRET bursts as a function of $E_{max}$, assuming a burst zenith angle $\theta$=0°, compared with the minimum number $C_{th}$ necessary to give a signal. For $E_{max}$ = 1 TeV, 8 (4) bursts out of 14 are detectable if $\Delta t$ = 1 (10) s, while for $E_{max}$ = 100 GeV the number of detectable bursts is reduced to 4 (3). These calculations show that INCA could detect GRBs of intensity comparable to the most intense observed so far by EGRET, if they occure at small zenith angles and the energy spectrum extends at energy E $\geq$ 100 GeV.

## 5 Data analysis

The data analysis consists of searching for significant excesses in the counting rates of surface detectors in coincidence with GRBs observed by satellites.

The large majority of GRBs used in this analysis has been observed by BATSE, aboard the CGRO satellite. Since 2000 May 27, when BATSE has been turned off, we are using the data taken by other instruments located on various satellites (as the members of the Interplanetary Network (IPN),

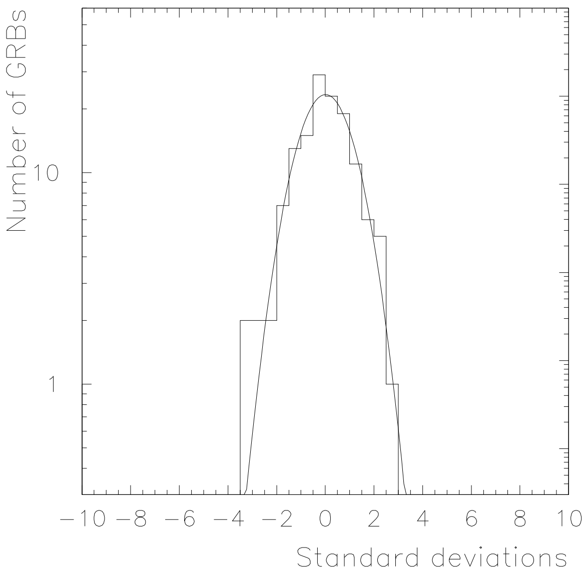


**Fig. 2.** Distribution of the fluctuations of INCA counting rates (in unit of standard deviations) during the time window $\Delta t_s$ in which the GRB has been observed by satellites , for 135 bursts. The curve is well fitted by a Gauss distribution with r.m.s.=1.1.

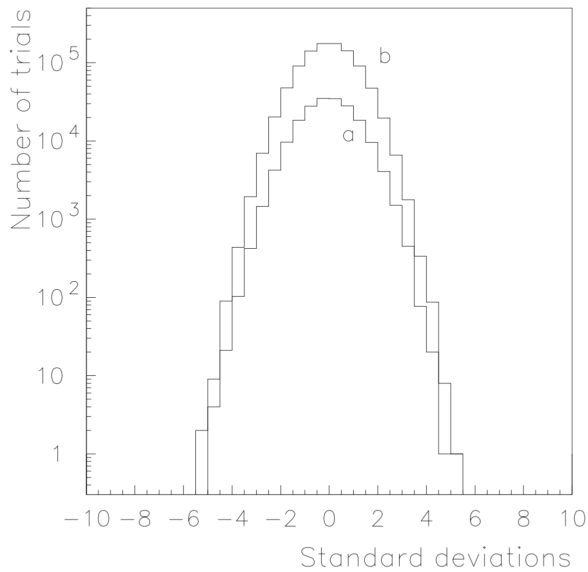


**Fig. 3.** Distributions of the fluctuations of INCA counting rates (in unit of standard deviations) in a time window $\Delta t$ = 1 s (curve *a*) and $\Delta t$ = 10 s (curve *b*), obtained shifting the window inside a 2 hours interval around the burst, for 135 GRBs.

Beppo-Sax, RXTE, Konus/Wind and HETE-2) all these data being distributed by the GRBs Coordinate Network (GCN) (GCN web site, @).

In the period 16 December 1996 - 27 March 2001, 135 bursts have occurred in the INCA field of view (i.e. zenith angle $\theta < 60°$), during the INCA running time, 127 out of them detected by BASTE, 8 by other instruments.

For each GRB we performed the following analisys:

*a) Selection of data*.

The counting rates of each detector recorded during $10^4$ s around the burst time are selected and carefully analysed to reject possible spurious event due to a noisy behaviour of some detectors. The counts of every surface detector are summed, to obtain the total counting rate distribution versus time, where we search for the GRB signal.

*b) Search for a signal in coincidence with the GRB.*

The excess is searched in a time window $\Delta t_s$ correspondent to the observed GRB duration. For BATSE data we used the "T90" duration, defined as the interval in wich the 90% of the total BATSE counts have been recorded. The GRBs durations have been rounded off to the next integer value. When the GRB duration is not known (in $\sim$25% of events) we set $\Delta t$ = 10 s.

*c) Search for a signal in 2 hours around the GRB.*

Since we cannot exclude the possibility that the high energy emission is delayed or anticipated with respect to the KeV-MeV burst, or could have a different duration, we looked for a signal in different time windows $\Delta t$ = 1, 2, 6, 10, 20, 50, 100, 200 s, shifting the window position in step of $\Delta t$/2 (except the case $\Delta t$= 1s, where the step is $\Delta t$) inside a time interval of 2 hours around the burst time.

In both point *b)* and *c)* the number of counts $C$ recorded in $\Delta t$ is compared with the expected background $B$, calculated using the background rate during 30 minutes around $\Delta t$ (in 30 minutes the background modulations are negligible).

## 6 Results and discussion

In the analysis performed over 135 GRBs we observed no significant excess for any GRB in the time window $\Delta t_s$ in coincidence with the satellite detection. The obtained distribution of the fluctuations $f = C - B$ follows the expectations of a uniform background. Fig.2 shows the distribution of $f$ (in unit of standard deviations) in the time window $\Delta t_s$ for 135 bursts. The curve is well fitted by a Gauss distribution with r.m.s.=1.1.

The same result has been obtained considering time windows of different durations inside an interval of 2 hours around the GRB. No excess has been observed in any window for any GRB. Fig.3 shows the distributions of $f$ for $\Delta t$ = 1 s and $\Delta t$ = 10 s, obtained shifting the window in 2 hours around the burst for 135 GRBs. They can be fitted by Gauss distributions respectively with r.m.s. = 1.07 ($\Delta t$=1 s) and r.m.s.= 1.09 ($\Delta t$= 10 s).

Fig.4 shows the energy fluence upper limits in the energy range 1 GeV-1 TeV for the 135 bursts considered in this analysis, as a function of the zenith angle of the event. The fluences have been calculated at 5 standard deviations level assuming the GRBs spectra as $dN/dE \propto E^{\alpha}$ with $\alpha$ = -2 extending up to 1 TeV and a time duration equal to $\Delta t_s$. The

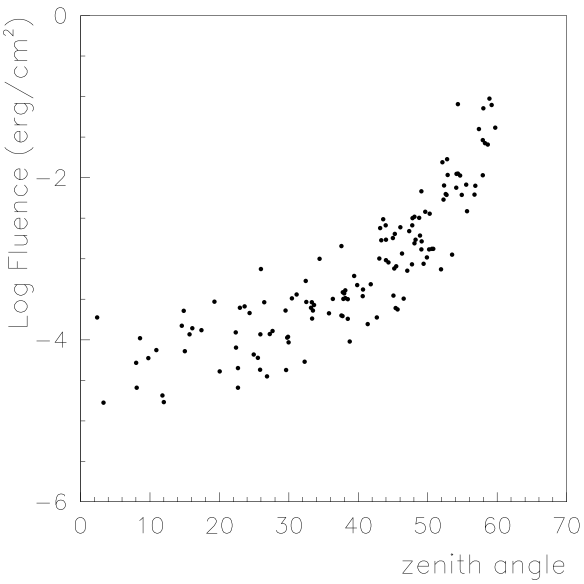


**Fig. 4.** Energy fluence upper limits in the energy range 1 GeV-1 TeV for 135 GRBs, as a function of the zenith angle of the event.

limits range from 1.7 $10^{-5}$ to 9.6 $10^{-2}$ erg $cm^{-2}$ depending on the zenith angle and on the time duration of the event.

If the spectrum extends only up to 100 GeV (a more realistical assumption due to the intergalactic absorption) the upper limits in the 1-100 GeV energy region become a factor 2.7 higher than the previously given values.

This analysis is an extension of previous papers (Cabrera et al., 1999; Castellina et al., 2001) where we presented the results of correlations with BATSE bursts. In this paper for the first time we use the actual duration of GRBs, while in the previous ones we set the duration at 10 s (since the BATSE durations of bursts occurred after 1996 were not yet published). Due to the spread of time durations, the distrubution of the fluence upper limits is broader than before. Since a part of GRBs have a duration less than 10 s, some of the obtained limits are a little more stringent, reaching 1.7 $10^{-5}$ erg $cm^{-2}$.

These values represents the lowest upper limits on the GRBs flux ever obtained in the $\sim$ 1 GeV - 1 TeV energy region by a ground based experiment.

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