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Search for GeV GRBs with the INCA experiment

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Abstract. INCA is an air shower array located at Mount Chacaltaya in Bolivia, at 5200 m a.s.l., searching for Gamma Ray Bursts of energy $E > 1$ GeV. The results presented here concern a GRB search made in correlation with 70 events recorded by BATSE since December 1996 to August 1998. For every burst, the INCA counting rate has been studied both during the BATSE detection time and in 2 hours around. No significant excess has been found in any of the trials. Assuming for the burst a power low energy spectrum extending up to 1 TeV with a slope $\alpha = -2$ and a time duration of 10 s, the obtained 1 GeV $\div$ 1 TeV energy fluence upper limits range from 5.3 10^{-5} erg cm^{-2} to 2.9 10^{-2} erg cm^{-2} depending on the event zenith angle.

Key words: gamma-ray bursts

1. Introduction

Gamma-ray bursts in the GeV energy range can in principle be observed by ground based experiments as air shower arrays. Secondary $e^{\pm}$ generated in the atmosphere by gamma-rays with energy as low as $E \geq 1$ GeV can be detected at the ground level, provided the detector is located at very high mountain altitude. Although the number of secondaries is too small to reconstruct the primary gamma-ray direction, a GRBs can be seen as a short time increase in the single particle counting rate.

Figure 1 shows the number of secondary charged particles reaching the ground as a function of the altitude above the sea level, generated by a gamma-ray with a zenith angle $\theta = 30°$. The curves are given for 3 different gamma-ray energies.

The background consists of secondary particles ($e^{\pm}$ and $\mu^{\pm}$) generated by charged cosmic rays. Is it worth to note that the single particle cosmic ray background increases much more slowly with the altitude than the gamma-ray signal does. As an example, going from 2000 m to 5000 m the background rate increases by factor $f_{\rm b} \sim 2-3$ (depending on the latidude), while the "signal" of a 100 GeV gamma-ray increases by a factor $f_{\rm s} \sim 30$. As a consequence the detection sensitivity increases by a factor $f_{\rm s}/\sqrt{f_{\rm b}} \sim 20$.

2. Data analysis and results

The INCA experiment is running since December 1996 at Mount Chacaltaya in Bolivia, at 5200 m above the sea level. It consists of 12 scintillator modules of 2 × 2 m^2 area, distributed over a $\sim 20 \times 20$ m^2 area. Its geographic location is suitable for the observation of a large part of the southern sky.

The data analysis consists in the search for significant excesses in the scintillators counting rates during the GRBs observed by BATSE (Castellina 1997). In 20 months of data taking, 70 BATSE events have occurred in the INCA field of view (zenith angle $\theta < 60°$) (Brainerd 1998). For each BATSE event the INCA data recorded during 10000 s around the burst time were selected. In this time interval the counting rates of each detector were carefully studied in order to identify possible electronic noises or anomalous behaviours. Finally the detector counts were summed and the time

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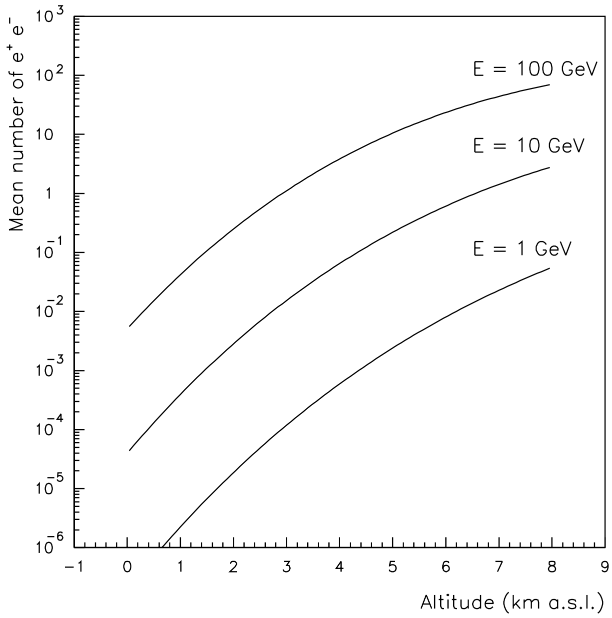

Fig. 1. Mean number of $e^{\pm}$ reaching the ground generated by a gamma-ray of different energy and zenith angle $\theta = 30°$, as a function of the altitude above the sea level

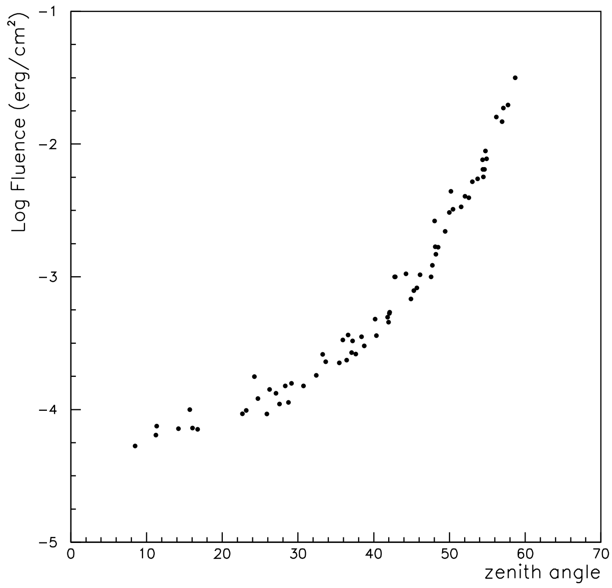

Fig. 2. Upper limits on the energy fluence in the energy range 1 GeV ÷ 1 TeV for the 70 GRBs analyzed, in a time window of 10 s starting from the BATSE trigger time, as a function of the zenith angle of the events

distribution of the total counting rate was studied to single out statistically significant fluctuations.

We looked for excesses of different durations $\Delta t = 1$, 2, 6, 10, 20, 50, 100, 200 s, setting the excess start time in time coincidence with the BATSE trigger time. The counts C recorded in Δt were compared with the expected background B calculated using the counts measured in 30 minutes around Δt. The distribution of the C-B difference in unit of standard deviations obtained in the 560 trials (70 events × 8 time durations), is well fitted by a Gauss distribution with rms = 1.17. We found no statistically significant excess for any burst and time duration. Looking for possible delayed or anticipated excesses with respect to the BATSE burst, the same search was performed in a 2 hours time interval centered around the BATSE time. Also in this case non excess was found.

Figure 2 shows the obtained upper limits on the energy fluence in the photon energy range 1 GeV ÷ 1 TeV for the 70 bursts analyzed, in a time window of 10 s starting from the BATSE trigger time, as a function of the zenith angles of the events. The fluences have been calculated at 5 standard deviations level, assuming a GRB spectrum $dN/dE \propto E^{\alpha}$ with $\alpha = -2$, extending up to 1 TeV.

Among the GRBs whose afterglow was observed by Beppo-Sax only GRB 980326 was in the INCA field of view, but with the very unfavorable zenith angle $\theta = 55°$. The obtained upper limit on the fluence in the 1 GeV ÷ 1 TeV energy range during the time duration of the gamma event (5 s) is 4.9 10^{-3} erg cm^{-2}.

If GRBs sources are located at cosmological distances, the high energy gamma-ray flux is absorbed in the intergalactic space through the interaction $\gamma + \gamma \rightarrow e^+e^-$ on low energy starlight photons. Assuming the GRB sources located at the distance $z = 0.5(1.0)$, according to the opacity calculated by Salomon & Stecker (1998), the fluence upper limits have to be increased by a factor $\sim 7(10)$.

3. Conclusions

The obtained upper limits show that INCA could observe GRBs with fluence $F \sim 10^{-5} \div 10^{-4}$ erg cm^{-2} in the 1 GeV ÷ 1 TeV energy range, occurring at small zenith angles. About 1/10 of the bursts observed by BATSE have a fluence larger than 10^{-5} erg cm^{-2} in the 20 ÷ 300 KeV region. Moreover fluences of few 10^{-5} erg cm^{-2} have been measured by EGRET in the 30 MeV÷5 GeV energy range during GRB 940217 and in the 1 MeV ÷ 1 GeV energy range during GRB 930131. In both cases the spectrum slope was $\alpha \sim -2$ and no energy cutoff was visible up to some GeV, suggesting that a considerable fraction of GRBs could have a high energy tail. A slope $\alpha \sim -2$ implies equal amount of power per decade of energy, hence a fluence $F > 10^{-5}$ erg cm^{-2} is expected in the INCA energy region from the most intense bursts, provided the spectrum does not change its slope up to 1 TeV and the distance of the burst is $z \leq 0.1$ to avoid gamma ray absorption.

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