Search for TeV Counterparts of 1994 and 1995 BATSE Gamma-Ray Bursts

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Abstract

Gamma ray bursts recorded in 1994 and 1995 by the BATSE instrument on board of the Compton Gamma-Ray Observatory in the field of view of the HEGRA detector are searched for emission in the energy range above $13\,TeV$. The method uses the data of the scintillator array and the wide angle Cherenkov counter array AIROBICC of the HEGRA experiment and exploits the gamma-hadron shower separation capability of the two arrays. A signal is searched for in the $2\,\sigma$ region around the BATSE's most probable location coordinates or if available in the smaller error window provided by the Compton/Ulysses Interplanetary Network of Satellites. The search is made with several time windows. First results are presented.

1 Introduction

The BATSE experiment [1] has been in operation since April 1991. It registers γ-rays in the energy range between $20\,keV$ and $2\,MeV$. On average it records one gamma-ray burst each day with a flux threshold of $\approx\ 10^{-7}\,erg\,cm^{-2}\,s^{-1}$.

The extensive air shower experiment HEGRA investigates neutral and charged cosmic rays in the energy range between $500\,GeV$ and $10\,PeV$. The experiment began operation August 1988 on the Canary Island La Palma (2200 m a.s.l., $lat\ =\ 28.8^0\,N$,$long\ =\ 17.9^0\,W$) and has steadily been extended since that time [2].

In a former analysis [3] radiation with energies above $35\,TeV$ coincident with gamma-ray bursts of the second BATSE catalog was searched for with the scintillator array of the HEGRA detector. The analysis did not show any significant excess and yielded flux upper limits (90% confidence level) of typically between $10^{-8}cm^{-2}\,s^{-1}$ and $10^{-10}cm^{-2}\,s^{-1}$.

In this analysis the BATSE bursts recorded from 1994 until the start of this conference will be searched for TeV emission not only with the HEGRA scintillator array, but also with the HEGRA wide angle Cherenkov counter array. The AIROBICC energy threshold for primary photons is as low as $13\,TeV$ for showers with zenith angles less than $30°$. The two arrays have a high trigger rate of $\approx\ 24\,Hz$. As will be shown in section 3, combining the data of both arrays allows us to estimate the photonic character of an excess and thus increases the sensitivity of the search for

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photon signals. Since the detection of a delayed 18 GeV photon 75 minutes after the end of the low energy emission of a gamma-ray burst [4], it is not clear whether the TeV photons should be expected in coincidence with the keV and MeV emission. Therefore the search presented here is made for time windows of several hours preceding and following the burst. In section 2 the method for searching an excess is discussed and in section 4 the results of the method applied to the BATSE burst GRB 950403 (23:33:46 UT) are presented.

2 Method of search

Bursts recorded by BATSE have durations from some milliseconds to some hundreds of seconds. We search with three classes of time intervals for a possible TeV excess. The first search is made for the time interval in which BATSE recorded 90% of the burst flux. Then a search for short and long time emission is performed for the time interval in which the search region is in the field of view of the HEGRA detector (zenith angle for BATSE's most probable location $< 30°$). The short time search is performed with one minute time windows, two successive time windows overlapping half a minute. For the long time search n time windows with a length of 2^i minutes, $i \in [0, ..n]$ centered at the burst time as determined by BATSE are analyzed. The number of time intervals n is chosen such that all the time windows fit into the time interval when the search region is in the field of view of the HEGRA experiment.

The BATSE $1\,\sigma$ error for the location of a burst ranges from 4^0 to 13^0 depending on the number of burst photons registered. The Interplanetary Network of Satellites Compton/Ulysses (IPN) reduces the error window for a subclass of bursts to a small segment of a ring in the sky with a width of $\approx 0.1^0$ and with a length given by the intersection of the BATSE and the ULYSSES error windows. For a burst without IPN information all points within the $2\,\sigma$ region around BATSE's most probable location are searched for an excess. In order to exploit the much better angular resolutions of the HEGRA arrays in comparison to the BATSE error, the search is made with searching grids [5]. The search region is covered by a grid of adjacent rectangular bins of width $const \times \sigma_{63\%}$ in declination δ and of width $const \times \sigma_{63\%}/\cos(\delta)$ in right ascension α. Here $\sigma_{63\%}$ denotes the angular resolution of the HEGRA arrays and the constant is chosen to be 2.6, taking thereby into account the low number of expected background events within a search bin [6]. When only the scintillation matrix operates, $\sigma_{63\%}$ is 0.7° with $E_\gamma > 35\,TeV$. When in moonless and clear nights also the AIROBICC array takes data, $\sigma_{63\%}$ is also 0.7° but with $E_\gamma > 13\,TeV$. In order to assure that the true burst position lies well inside one of the search bins, the search is done with four grids. The second grid is shifted 1/2 of a bin width in δ, the third 1/2 of a bin width in α and the fourth 1/2 of a bin width in both. For a burst with IPN information a band of adjacent optimal search bins is spanned over the ring segment that contains the true burst position. The search is repeated two times. The second time the search band is shifted by 1/2 of a bin size along the ring segment.

Following the ideas of ref. [6], the background expectation for each search bin is calculated, using the absolute times of the recorded triggers and the experimentally determined detector acceptance in horizontal coordinates. Using the same method a sample of Monte Carlo data sets equivalent to the measured data set is created.

For the experimentally recorded events the probability of background yielding at least the number of observed events is calculated for all search bins of all search grids of all time intervals under consideration. Comparing the smallest chance probability found by this procedure with the equivalent probabilities calculated for the generated Monte Carlo data sets yields the "burst probability", i.e. the probability that the most significant excess found in the data is *not* a background fluctuation.

For each search bin an upper limit (90% confidence level) of the observed particle flux is calculated according to

$$\mathrm{F_{ul}}(>\mathrm{E}) = \frac{\mathrm{N_{ul}} \times \mathrm{f_{cr}} \times \Omega}{\mathrm{N_{bg}} \times \beta} \tag{1}$$

where $\mathrm{N_{ul}}$ is the upper limit on the number of burst events in the search bin, $\mathrm{f_{cr}} =$ is the integral flux of the recorded cosmic ray spectrum as known from experimental measurements, Ω is the solid angle of a search bin, $\mathrm{N_{bg}}$ is the expected number of background events in the search bin and β(with IPN) $= 0.84$ and β(without IPN) $= 0.81$ is the expected fraction of source photons falling inside the bin. The search bin that yields the highest flux limit gives the flux upper limit. The flux upper limit is calculated for each class of time windows and for the time windows with increasing length separately.

3 Gamma-hadron separation

For photon induced showers the ratio of the Cherenkov light intensity to the number of shower particles is higher and the lateral spread of the shower particles is smaller than for hadron induced showers at the detection level. A method based upon the measurement of the Cherenkov light intensity and the number and the lateral spread of the charged particles allows a gamma-hadron separation also at a detection threshold of $13\,TeV$. The method, described in another contribution to this conference [7], provides the separation parameter *pearl* [7] that shows smaller values for photon induced showers than for hadron induced showers.

For the small number of background events expected in each search bin (≈ 0.3) there is no cut value of the separation parameter *pearl* that increases significantly the sensitivity of the search method. In a first approach we use the comparison of the *pearl* distribution of the excess events with the distributions expected for hadrons respectively photons as an additional handle on the evaluation of the significance of an excess.

4 Results

The method is applied to the BATSE burst GRB 950403 (23:33:46 UT). The burst lasted 55 seconds and showed a multi-peaked low energy emission. Photons with energies above $300\,keV$ were registered. The burst was in the field of view of the HEGRA detector (zenith angle $= 29^0$) and was recorded with both arrays. In figure 1 the events recorded by HEGRA in coincidence with the low energy emission are shown. The most significant excess, three events recorded where 0.47 are expected, leads to a burst probability of $P_{burst} = 90\%$. The excess matches exactly the most probable direction given by the IPN, but the *pearl* values of the three events lead to very low photon probabilities. The same applies to the most significant excess of the search for long time emission which was found in the 16 minutes interval. The excess is also located at the most probable IPN location but the *pearl* values are

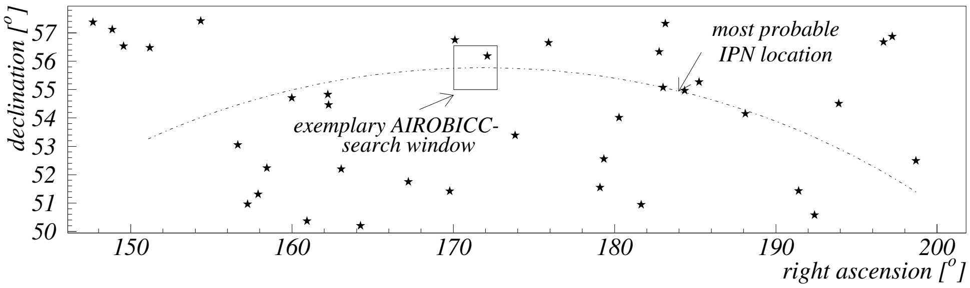

Figure 1: HEGRA events coincident with the emission recorded by BATSE (55 sec.). The arc shows the burst location as determined by IPN.

distributed as expected for hadron induced showers. The flux upper limits and the burst probabilities P_{burst} for all classes of time windows are summarized in table 1.

TABLE 1

Results for GRB 950403 (23:33:46 UT)

Class of Time Windows[a]	${N_{sig}}^{b}$	${N_{exp}}^{c}$	${P_{burst}}^{a}$	$F_{ul}(E_\gamma > 13\,TeV)^d$ $[cm^{-2}s^{-1}]$
BATSE 55 sec. interval	3	0.47	90%	7.94×10^{-10}
Short time emission	5	0.60	30%	6.26×10^{-9}
Long time emission[e]	17	7.30	94%	$1.2 \cdot 10^{-10} < F_{UL} < 8.0 \cdot 10^{-10}$

[a] See section 2
[b] Number of events in most significant search bin
[c] Expected number of background events in most significant search bin
[d] 90% confidence level upper limit on the integral flux
[e] The flux upper limits were calculated for each of the time windows separately, the longest time interval being 16 minutes

5 Conclusion

With the scintillator array and the wide angle Cherenkov counter array AIROBICC a sensitive search for emission of photons with energies above $13\,TeV$ from gamma-ray bursts can be performed. A searching method was described and was applied to GRB 950403 (23:33:46 UT). Although no very significant excess was found, the results look promising. At this conference the application of the method to all known bursts from 1994 and 1995 will be presented.

References

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