Search for Sub-TeV Gamma Rays Coincident with BATSE Gamma Ray Bursts

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Abstract

Project GRAND is a 100m × 100m air shower array of proportional wire chambers (PWCs). There are 64 stations each with eight 1.29 m^2 PWC planes arranged in four orthogonal pairs placed vertically above one another to geometrically measure the angles of charged secondaries. A steel plate above the bottom pair of PWCs differentiates muons (which pass undeflected through the steel) from non-penetrating particles. FLUKA Monte Carlo studies show that a TeV gamma ray striking the atmosphere at normal incidence produces 0.23 muons which reach ground level where their angles and identities are measured. Thus, paradoxically, secondary muons are used as a *signature* for gamma ray primaries. The data are examined for possible angular and time coincidences with eight gamma ray bursts (GRBs) detected by BATSE. Seven of the GRBs were selected because of their good acceptance by GRAND and high BATSE fluence. The eighth GRB was added due to its possible coincident detection by Milagrito. For each of the eight candidate GRBs, the number of excess counts during the BATSE T90 time interval and within ±5° of BATSE's direction was obtained. The highest statistical significance reported in this paper (2.7σ) is for the event that was predicted to be the most likely to be observed (GRB 971110).

1. Introduction

The mystery of the astrophysical origin for gamma bursts (GRBs) has been present for some time. Although there is no one complete paradigm for their origin, it is likely that energetic ($\sim$ TeV) gamma rays might also be produced along with the low energy burst. Previous literature presents at least some evidence for a possible association of energetic gamma rays with low-energy GRBs. EGRET detected several GRBs which emitted high energy photons in the $\sim$ 100 MeV to 18 GeV range [2,3,12]. There have also been some results from the Tibet air shower array suggestive of gamma rays beyond the TeV range [1,8]. Possible evidence for TeV emission in coincidence with a BATSE GRB has been reported from the Milagrito detector [5,6,7].

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2. Project GRAND

GRAND is located at 86.2° W and 41.7° N. It detects cosmic ray secondaries at ground level by means of 64 tracking stations of proportional wire chambers (PWCs). Each station has eight 1.29 m^2 PWC planes. Each secondary muon is measured to 0.26° precision, on average, in each of two orthogonal planes. A 51 mm thick steel plate is located between the sixth and seventh PWC plane allowing muons to be distinguished from electrons. The data presented here are from single-track triggers with only the muon tracks selected. Secondary muons are primarily the result of interactions of primary cosmic rays with the atmosphere producing pions, which then decay into muons. The muons are produced at small angles relative to the pion and are then deflected in the earth's magnetic field and scattered in the atmosphere resulting in an effective net angular resolution of about ±5° (depending slightly on the primary spectral index; see Fig 6 in [10]). Thus the experimental angular resolution is much better than the effective angular resolution which is governed by the deflections suffered by the muons before they reach the detector.

GRAND utilizes the fact that gamma rays have a detectable signal of muons from gamma-hadro production in the atmosphere making it possible to study coincidences between GRBs and gamma ray showers in the 10 GeV $\leq E_\gamma \leq$ 1 TeV energy region (see Fig 6 of [10]).

In the gamma primary energy region above 10 GeV, the recorded muon rate is 2400 Hz. A FLUKA MC simulation shows that a 1 TeV gamma ray normally incident upon the earth's atmosphere produces an average of 0.23 muons which reach detection level. Paradoxically, muons are used as a *signal* for gamma ray primaries. Our response to primary gamma rays has a threshold of $\sim$ 10 GeV (optimum response). Our ability to correlate short bursts of muons with an identifiable source of primary radiation has been shown in a detection which was coincident with the solar flare of 15 April 2001 [9]. The statistical significance of this observation was 6.1σ for a ground level event of 0.6 hours duration.

3. Data Analysis

For each GRB, an acceptance factor, based on the elevation angle of the burst and the geometry of the array, was multiplied by BATSE's fluence in their highest energy bin to obtain a rudimentary likelihood, $LogLk$, that we could observe the GRB. The top seven GRBs for which we had data were selected for analyses. In addition the Milagrito event, GRB 970417a, was included.

First, the BATSE RA and Dec were transformed to a local horizon coordinate system and projected onto the xz-plane (θ_x) and the yz-plane (θ_y). A window of $\pm 5^o$ in $\Delta\theta_x$ and $\Delta\theta_y$ was centered on the location of the GRB. To correct for the experimental dead time, the total event rate over the whole sky was employed

Table 1. Summary of the Eight Events Analyzed

GRB	Trig	T90	RA	Dec	$\delta\theta$	Elev	$LogLk$	$N_\mu \pm \sigma_{Tot}$
971110	6472	195.2	242	50	0.6	81	5.18	466 ± 171
990123	7343	62.5	229	42	0.4	56	5.13	3 ± 36
940526	2994	48.6	132	34	1.7	66	4.68	20 ± 28
980420	6694	39.9	293	27	0.6	68	4.02	39 ± 47
960428	5450	172.2	304	35	1.0	70	3.83	57 ± 78
980105	6560	36.8	37	52	1.4	79	3.46	-15 ± 61
980301	6619	36.0	148	35	1.3	76	3.17	38 ± 56
970417a	6188	7.9	290	54	1.6	62	2.08	20 ± 17

as a high-statistics measure of the live time of each time bin; each bin's data were corrected for its corresponding live time. The background was determined during a time interval of 20×T90 before the start of the BATSE trigger (except for GRB 971110 which was 10×T90 in order to stay within the data tape for this event).

Table 1 lists BATSE data on eight gamma ray bursts: the date of the trigger, the trigger number, the time duration for 90% of the burst's counts to occur (in seconds); the right ascension, declination, and the BATSE angular error in degrees. Next is the angular elevation (degrees) above our horizon and our selection criterion ($LogLk$), described below. The last column of Table 1 summarize the muon secondaries observed by us within a $\pm 5^\circ$ square angular window centered on the burst location during the BATSE T90 time interval. The error is the total error (statistical plus systematic) which is discussed below. Further details on these observations can be found in [11].

4. Significance and Errors

The signal (Sig) calculated for a GRB is the difference between the total counts inside the T90 interval (corrected for dead time) and the background counts normalized to the live time of the T90 time interval and corrected for dead time. The statistical significance (number of standard deviations above background) of each event was determined according to the likelihood ratio method of Li and Ma, [4] which makes a good accounting of the true significance for events with differing background and event times.

It is possible that the background fluctuates in excess of the expected $\sqrt{N}$ statistics. As a check on systematic errors in the signal for GRB 971110, similar angular sections of the sky (which have the same absolute values of θ_x and θ_y and thus the same average counting rates) and the same time interval (T90) but at different, neighboring times were analyzed. These time intervals span ± 26 hours relative to the BATSE trigger for GRB 971110 and were analyzed in the same way as described in the preceding paragraphs. The standard deviation width of the distribution of these 1587 background cases is 171, whereas the expected statistical deviation based upon the square root of the background count rate is only 141. Adopting this total error as the quadrature sum of the statistical and systematic errors, then 97 counts are ascribed as the additional systematic error in our analysis for GRB 971110. With this additional systematic error, the ratio of signal-to-noise becomes $Sig/\delta Sig = 2.72$. The fractional additional systematic error for GRB 971110 was then used for the other GRB candidates in order to estimate their total errors. The final results with total errors (statistical plus systematic) are in the last column of the Table 1.

The probability of a $+2.7\sigma$ fluctuation in an assumed Gaussian white-noise distribution is 3.5×10^{-3}. The probability without assuming a Gaussian shape was measured with the 1587 background cases: There were ten random fluctuations $\geq |466|$ yielding a probability of 3.2×10^{-3} for a background fluctuation to produce a fluctuation of $\geq +466$. For one event out of the eight analyzed to exhibit this much deviation would correspond to a random probability of 0.025. Thus, the statistics of this event are interesting but not compelling.

No convincing evidence is found, though there is a possible 2.7σ detection associated with the most probable candidate.

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