BATSE GRBs in Milagrito

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1 Introduction

We looked at 50 BATSE triggered bursts in Milagrito data. All bursts with zenith angles less than 45 degrees were included in the sample. These bursts have a relatively wide range of fluences at BATSE energies, and the duration in which BATSE observed 90% of the events ranges from 0.1 seconds through 200 seconds. Most of these bursts were only observed by BATSE and their location is poorly known. A small fraction of these bursts have IPN (interplanetary network) information, in which more than one satellite saw the burst. This allows the position of the burst to be narrowed down to a thin annulus. Two of the bursts had counterparts at lower energies and have very well defined positions. These two bursts are also among the brightest BATSE bursts and thus Milagrito may be able to set interesting upper limits for these bursts.

A detailed description of the results and upper limits obtained for this sample will be discussed in a later memo. Here we will mostly discuss just one burst, GRB 6188 which occurred on April 17 1997. One of the surprises of this analysis was the discovery of the possible detection of this gamma-ray burst at TeV energies with a probability of 2.9×10^{-8} before trials. After accounting for the size of the search region and the fact that we looked at 50 bursts, the probability becomes 1.5×10^{-3} post trials.

2 Analysis Method

EGRET detected several GRBs with irrefutable significance by considering the period in time in which BATSE detected 90% of the events during the burst. We therefore decided to initially search for TeV counterparts to BATSE grbs during the same time interval. This time duration is known as T90; the trigger time of the BATSE burst is designated T0. The BATSE web page provides several tables of information on each burst. The information provided in these tables includes T90, T0, the offset of the onset of T90 from T0, position uncertainty, RA, DEC etc. These tables are read directly by the analysis programs to define the position, time, duration and search radius for each burst.

For each burst, a circular search region was defined which consisted of the BATSE systematic [?] and statistical errors added in quadrature. The radius of this region ranged from 7 to 20 degrees for the bursts observed by Milagrito. Events that arrived during T90 were binned in a 0.1x0.1 degree grid. A similar grid for the background was also filled as described in section 2.1. These bins were then combined to form an array of bins 1.6 degrees in radius spaced 0.2 degrees apart covering the search region. We calculated the Poisson probability that each 1.6 degree signal bin was drawn from the background and the bin with smallest probability was used to calculate an upper limit or flux measurement for that burst.

2.1 Background calculation

The background was calculated using two hours of data around each burst, using the same method that Gus used for his burst search. The events during this period are binned in 0.1x0.1 degree bins of hour angle and dec. These coordinates are constant in time and the resulting map therefore characterises the angular distribution of background events on the sky. An example of one of these background maps is shown in figure **??**. This background map, along with the total number of events in the map, are saved to a file.

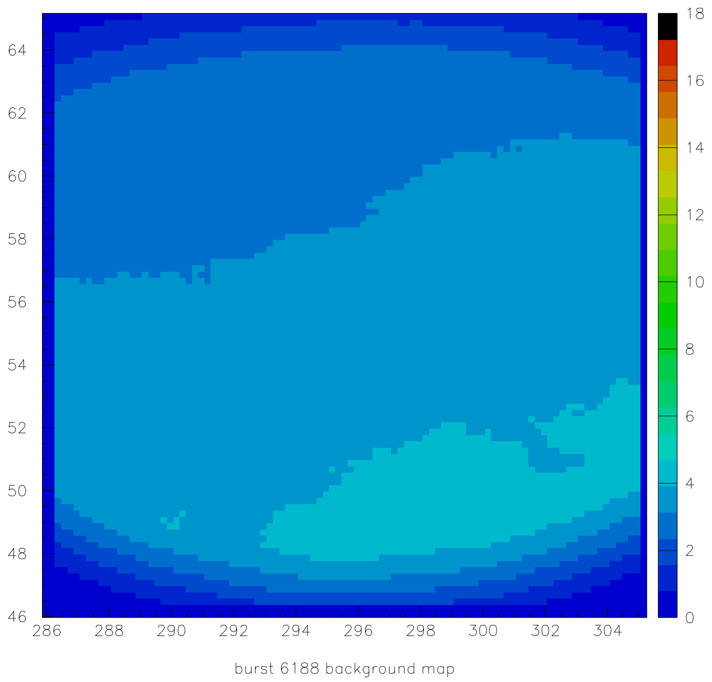

Figure 1: Background map of the search region during t90 for GRB 6188

To obtain the background level for a given grb, the background map is normalised to the number of events recorded by Milagrito during the time period of interest, and the coordinates are shifted to RA and DEC. As an example, consider the background map of the sky for grb 6188 during T90 (7.9 secs). During the 7.9 seconds of the BATSE T90 2195 events were recorded by milagrito. The total number of events in the two hour hour period used to obtain the un-normalised background map was 1950921. Right ascension and hour angle are related by:

$$RA = sidereal\ time - hour\ angle$$

The un-normalised background map is transformed to RA, DEC coordinate system and the background level (bkg) during T90 is given by:

$$bkg[ra][dec] = \underset{2}{backmap[ra][dec]} \times \frac{2195}{1950921}.$$

Clearly, since a map in RA and DEC is not constant in time, if one wishes to form a background map where the time period of interest is large then this procedure must be repeated by considering sufficiently small time periods such that the sky moves an insignificant amount relative to the binsize (0.1 degrees) being considered. The time interval used in this analysis was 10 seconds. For longer bursts, the background map in RA and DEC for each individual time interval are summed to obtain the final background map.

3 Results

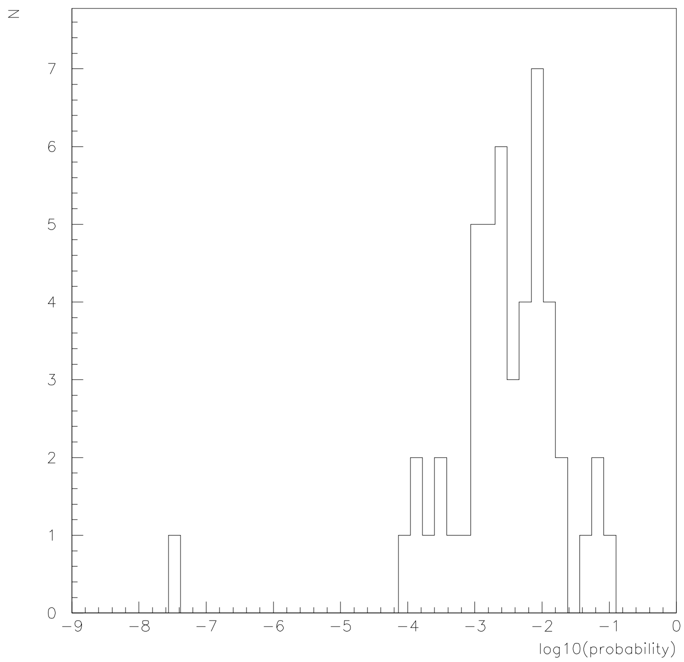

Figure 2: Distribution of probabilities for all bursts in the sample

The distribution of most significant probabilities for each of the Milagrito bursts are shown in figure 2. There is one entry in this histogram with a probability very much less than the rest of the bursts in the distribution. This corresponds to GRB 6188, a weak BATSE burst which occurred on 17 April 1997. This is the data on which the rest of this memo concentrates.

4 GRB 6188

This burst looks sufficiently interesting that we looked a little closer. The coordinates (J2000) of the most significant bin were: RA = 289.89, DEC = 54.0. 18 signal events were observed with an expected background level of 2.9×10^{-8}.

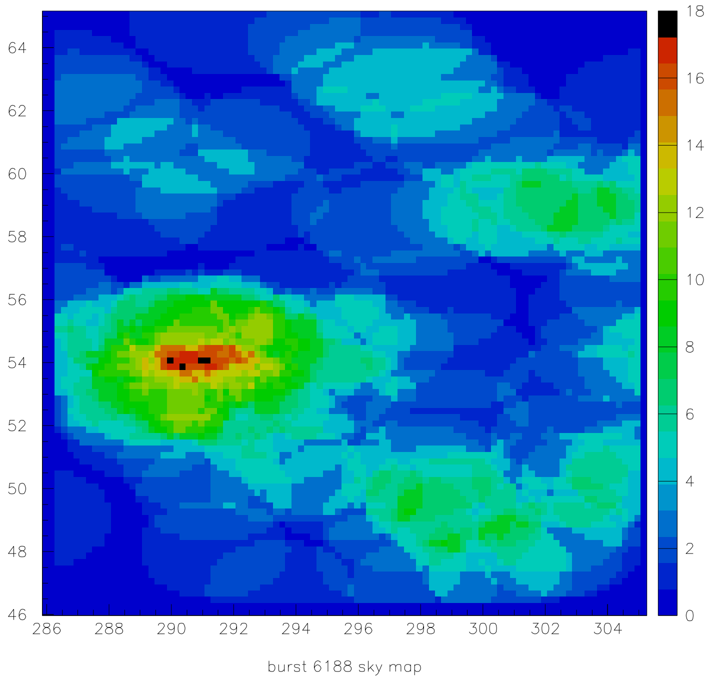

Figure 3: The region around GRB 6188 during t90, 7.9 sec integration

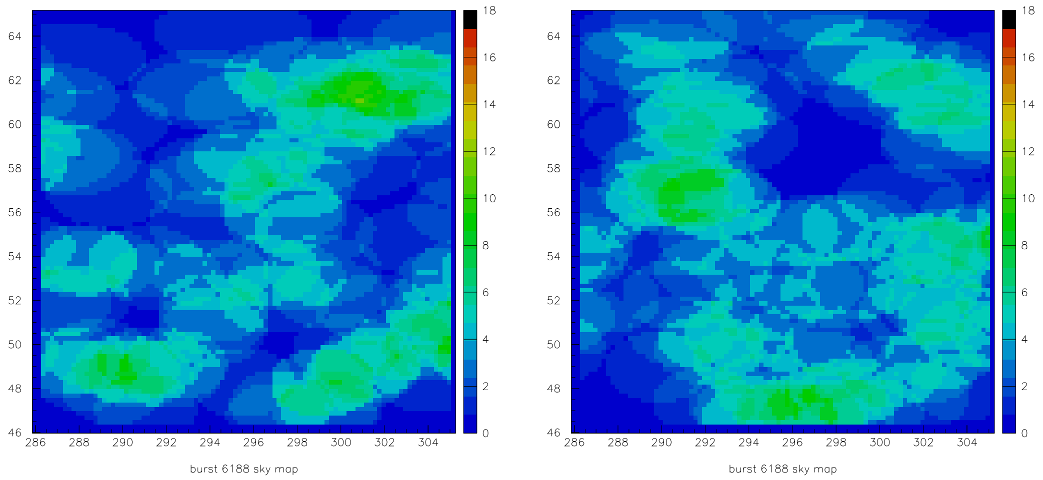

Figure 4: The region around GRB 6188 immediately before T90 (top) and after t90, 7.9 sec integration

4.1 Before, during and after t90

Figure 3 shows the region around the BATSE position during T90. Plotted here are the number of events in the 1.6 degree overlapping bins. What is interesting to note is that there are several bins that contain 18 events each, the most significant bin is just the bin with least background rather than the bin in which the events are best centered. This possibly means that the coordinates of the most significant bin need not correspond exactly to the correct location for this burst.

For comparison figure 4 show the same region of sky for 7.9 seconds immediately before and 7.9 seconds immediately after the burst. There is no evidence for an excess in either of these time periods.

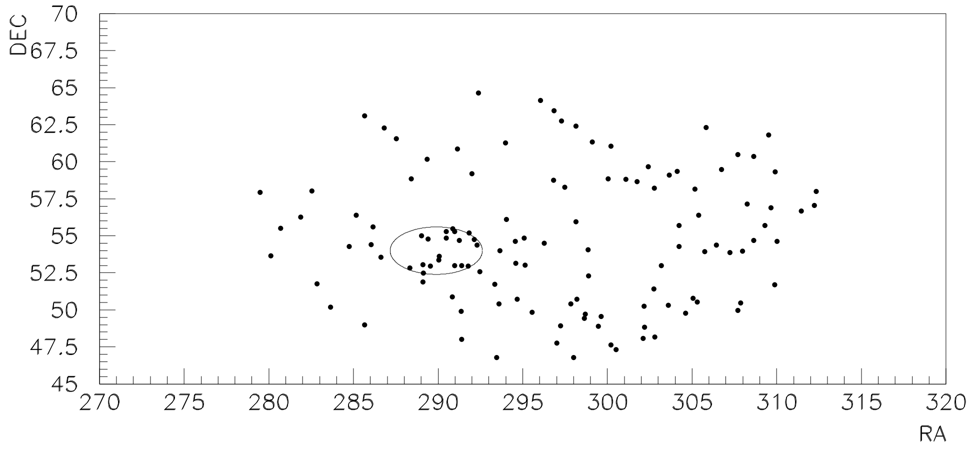

Figure 5: Events in the BATSE error box for grb 6188 during T90. The ellipse shows 1.6 degree bin which contained the signal

Figure 5 shows a map of all of the events collected by milagrito in the BATSE error box during T90. The ellipse is the 1.6 degree radius bin which contained the strongest signal from Milagrito during T90. At a glance it looks like our bin might have been carefully chosen to just include all the events. This is not the case, 2 of the events on the line of the ellipse are not included in the signal bin.

4.2 Does everything look normal in the data/detector during GRB 6188 ?

The quick answer is yes, everything looked fine. The water on the cover had been pumped off about 3 weeks earlier. Some light leaks may have been present, but these had been covered by tarps about 1 week before. The runstatus log, which provides information on the number on online errors (bad events, gps errors etc), showed nothing unusual.

The trigger rates were constant during this period. Figure 6 shows the trigger rates for 2 hours, 30 min and 1 min around the burst.

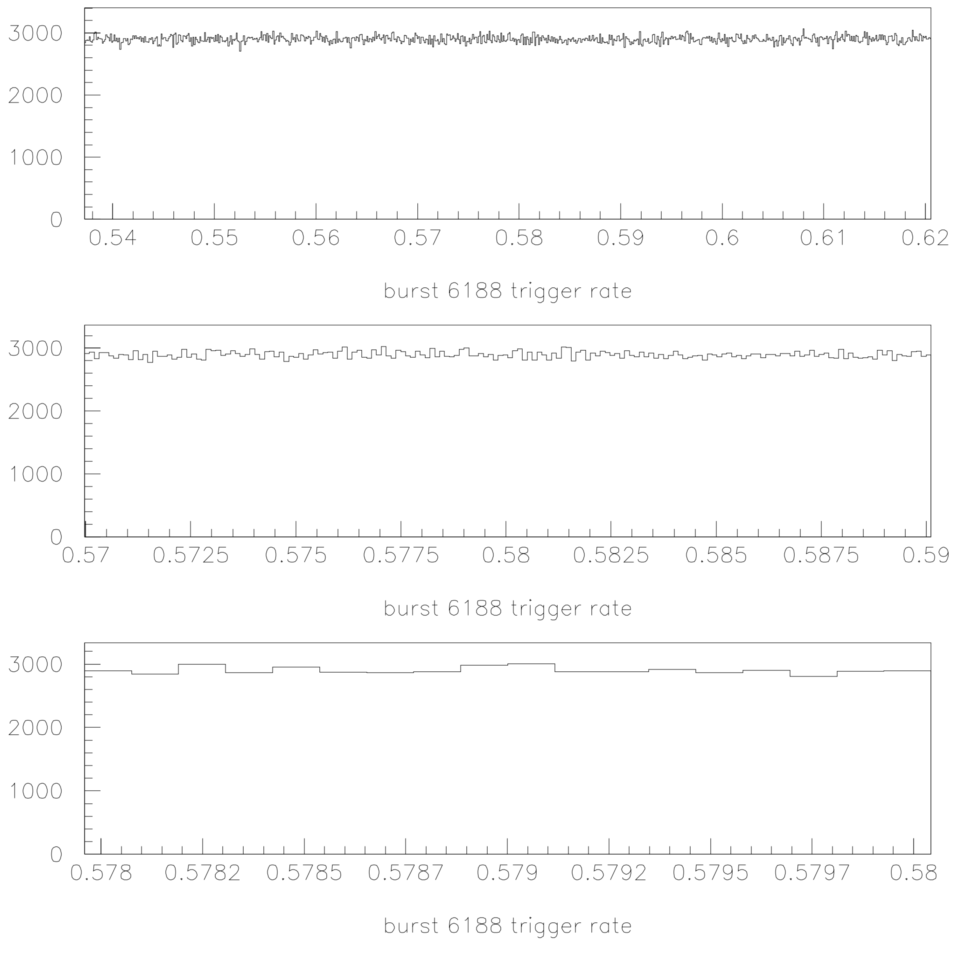

Figure 6: Raw trigger rates for the period surrounding GRB 6188

All the events had different RA, DEC and times. Each event was inspected using the event display and they all looked reasonable. The Nfit and Ncal (number of tubes calibrated) distributions for the 18 events are shown in figure 7. The average value for Nfit and Ncal for run 139 subrun 58 (the subrun containing the burst) were 55 and 126 respectively. The distributions of Nfit and Nhit for the burst are consistent with this.

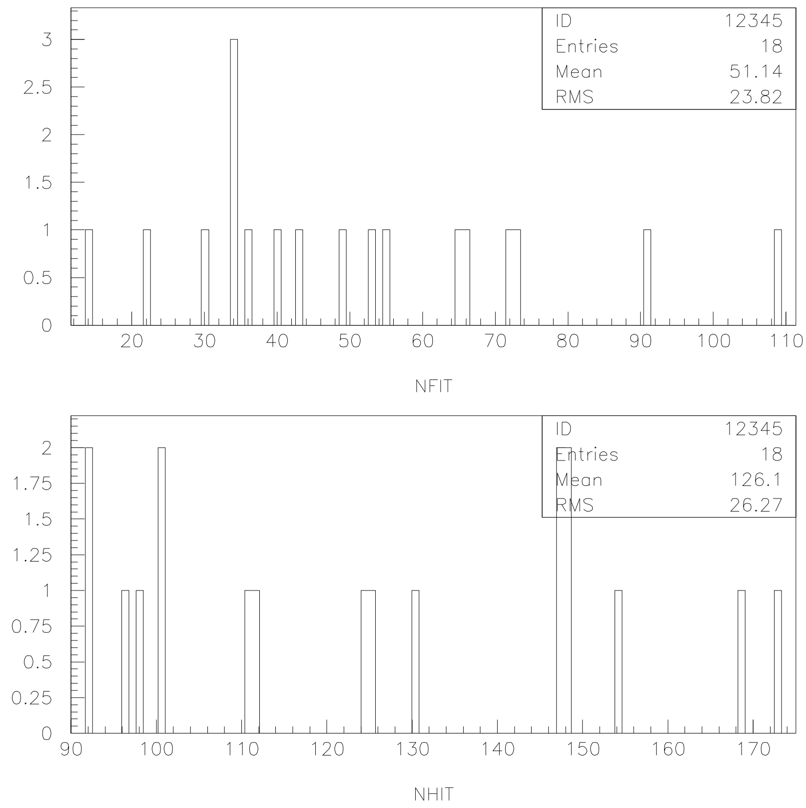

Figure 7: Nfit (top) and Ncal (bottom) distributions for grb 6188

4.3 Does the TeV emission extend over a longer time period

To check for extended emission (in time), the same analysis was applied as before, except that the integration time was 1 hour rather than t90. In the same bin as we saw the peak emission during t90 there were 1441 signal events and 1380.6 background. This corresponds to a 1.6 sigma excess - which is not significant. A background subtracted map of the burst region for these data is shown in figure 8.

4.4 Determining the true probability of this burst

To find out the true probability of seeing this burst, a dataset containing the same number of events as were seen during T90 was randomly drawn from the background distribution. The same analysis method was applied to this 'fake' dataset. This was repeated over a million times. The true probability is taken to be the number of times we see probabilities less than 2.89×10^{-8} divided by the total number of 'fake' datasets. we have analysed 1029064 fake datasets; probabilities of less than 2.89×10^{-8} were found on 25 occasions. Therefore, the true probability for seeing GRB 6188 given the oversampling in the search over the BATSE error region was $25/481000 = 2.4 \times 10^{-5}$. By taking the number of bursts

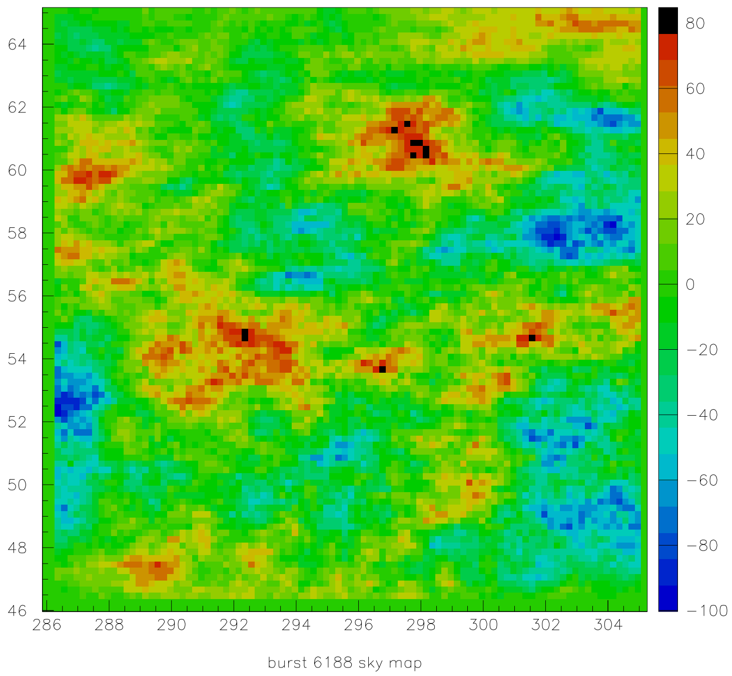

Figure 8: Excess events in the region around GRB 6188 integrated for an hour after the BATSE trigger

we looked at (50) the final probability that we have seen a TeV counterpart to a BATSE burst is 1.2×10^{-3}. The distribution of these probabilities is shown in figure 9.

4.5 Lightcurves

Brenda compared the arrival time of our events to the BATSE lightcurve. The 18 events in the signal bin are plotted on the top line of figure 10. The average position of the 18 events was found and events within a 2.7 degree radius of this averaged position (to get approx. 90% of the events given our expected angular resolution) were also considered. These extra points are plotted on the second line. The BATSE lightcurve is also shown.

Figure 11 shows the data from the 1.6 degree bin binned in time bins of T90 for 800 seconds before and after the burst. This is almost certainly not the optimal way to do this analysis. Since we can clearly see from figure 5 that the center of this bin is not in fact the center of the events which arrived during T90, it would probably be better to optimise bin position, binsize, analysis method etc on the first burst and then apply the new improve analysis to see what else we can say about delayed bursts. Obviously the detection probability for seeing a GRB during T90 will still come from the original analysis. There appears, from this plot, to be evidence for a second burst of lesser intensity occuring 24 seconds later. Figure 12 shows the distribution of probabilities that the number of events recorded per time bin could be drawn from background.

A plot of the binned data for the BATSE error box is shown in figure 13. Figure 14

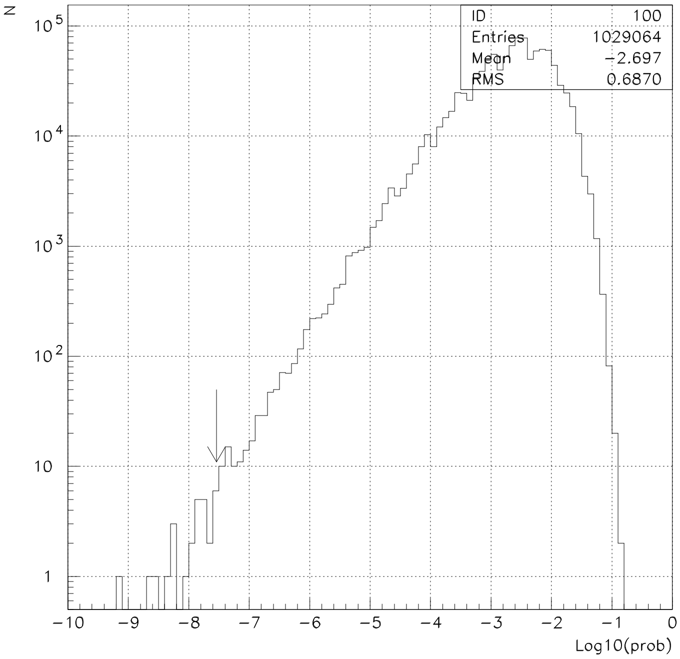

Figure 9: Distribution of probabilities for 1.03^6 fake datasets.

shows the distribution of events in the BATSE error box during this period.

5 Conclusion

This represents a progress report rather than the final, shiny full analysis. There are lots of things that still need to be done.

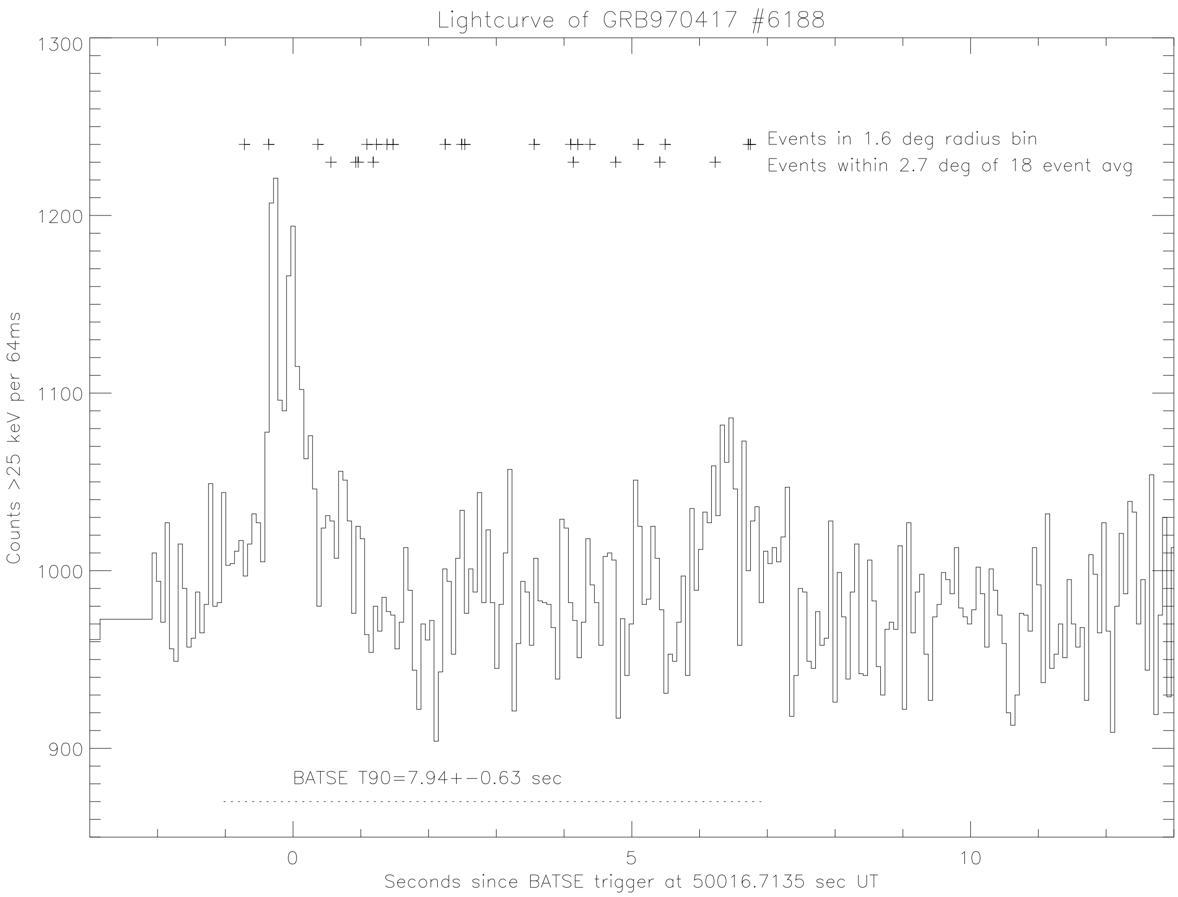

Figure 10: Arrival times of TeV events (top) and BATSE lightcurve (bottom)

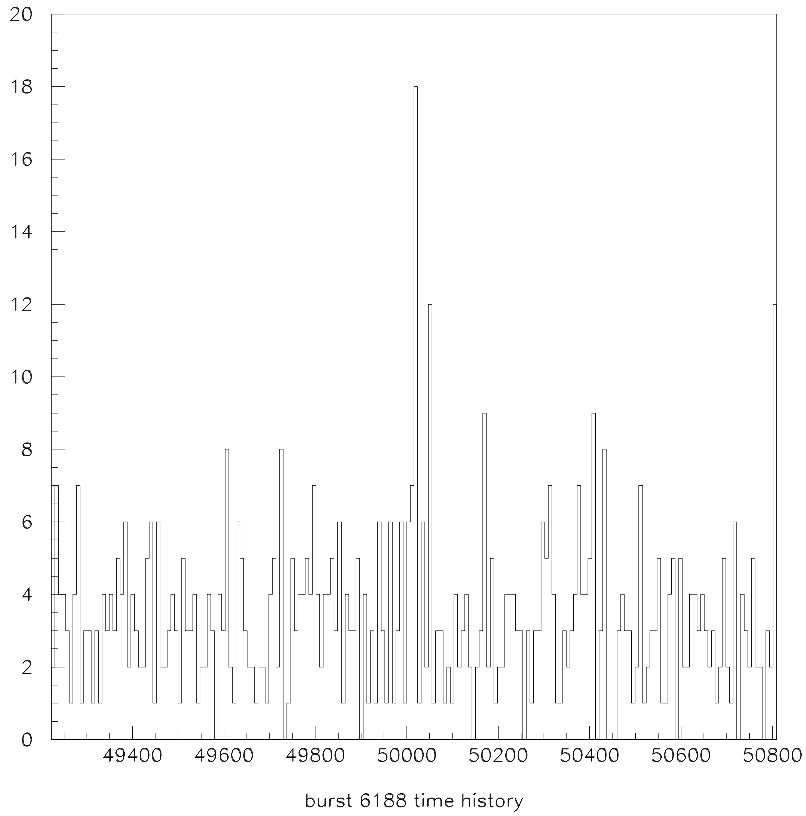

Figure 11: Lightcurve of the TeV burst counterpart from T0 - 800 secs to T0 + 800secs, binned in intervals of T90

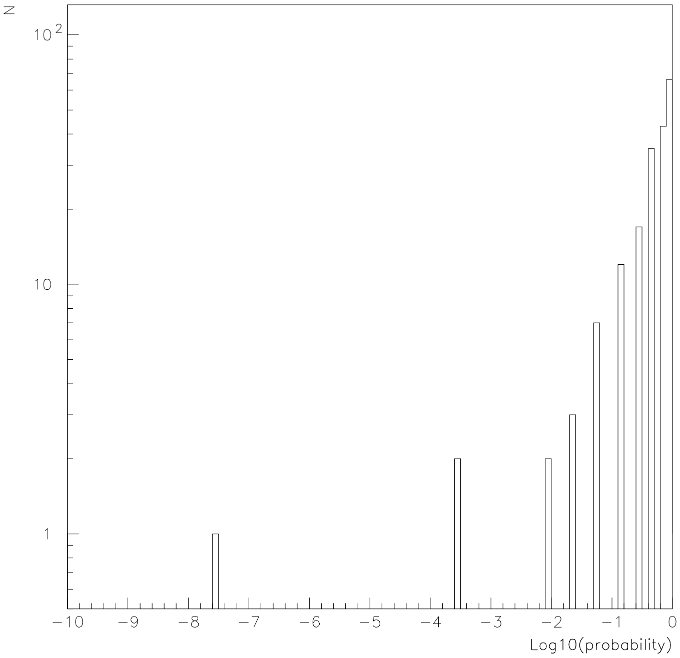

Figure 12: Distribution of probabilities for T90 bin from T0-800 to T0+800 secs

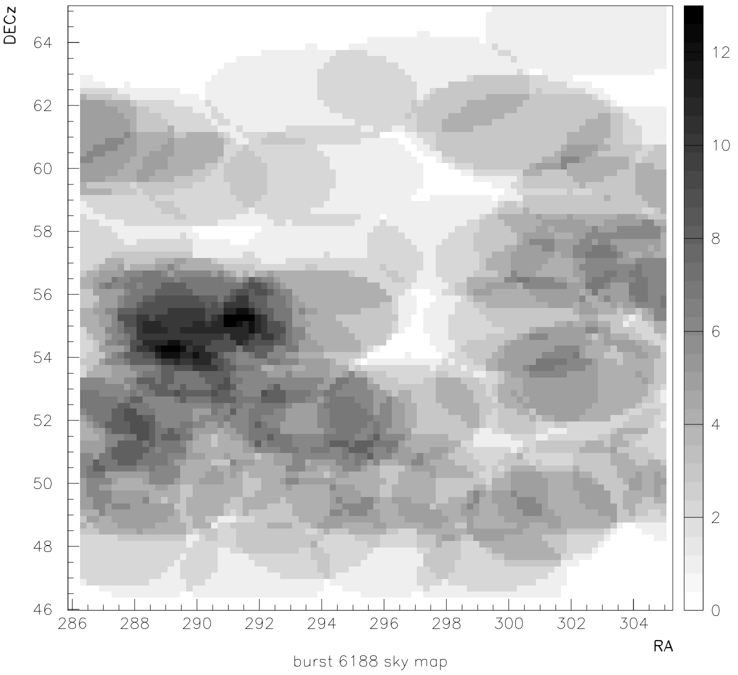

Figure 13: Binned map for GRB 6188 24 seconds after T0, 7.9 sec integration

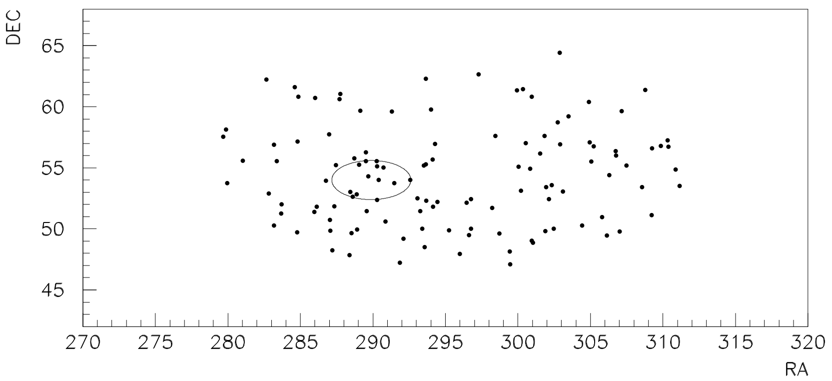

Figure 14: Map of the region of GRB 6188 24 seconds after T0, 7.9 sec integration