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Search for point sources of gamma rays using GRAPES-3 experiment

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Abstract: The GRAPES-3 experiment observes extensive air showers using a high-density array of scintillation detectors and a large area tracking muon detector. The showers due to charged cosmic rays can be identified by measuring their muon content using tracking muon detector. We have been able to determine the angular resolution of the array using the shadow of Sun and Moon. Here we report on the status and some results of the search for gamma rays from the 'standard candle' CRAB nebula using the GRAPES-3 data.

Introduction

GRAPES-3 experiment is located at Ooty (E76.7°, N11.4°, 2200m asl), India. The GRAPES-3 air shower array with a large field of view and long duty cycle can observe the northern sky by measuring the secondery particle distribution of extensive air showers originated from the primary cosmic rays. The array consists of about 300 scintillation detectors each having an area of $1m^2$ with 8 m separation from each other and 16 large area muon detectors having a total area of $560m^2$. Triggar rate of the array during the period of this analysis is about 13Hz. To identify the showers to be charged particle induced or gamma induced, we check the track of the muons accompanying the showers recorded at muon detectors with the reconstructed air shower direction. Detail of the muon detectors is mentioned in the next section.

The search for gamma ray point sources is one of the most important goal of GRAPES-3 experiment. Because primary gamma rays produce extensive air showers in the atmosphere which should have very few number of muons, we can classify showers according to their muon content and suppress the huge background level of hadron-induced showers by using large area tracking muon detectors. The most famous gamma ray point source is the Crab Nebula which has a steady emission of TeV gamma rays. We have carried out a search for gamma ray point sources especially for Crab Nebula using the data recorded during 2000-2003. The results of the observation on the Crab Nebula and the effect of hadron cut by using the muon detector will be presented here.

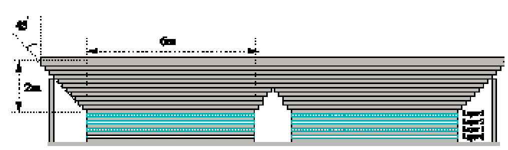

Figure 1: A muon station has four muon detector modules each consisting of 232 proportional counters. There are four muon stations inside the air shower array with a clustering arrangement (Figure2).

Muon detector

GRAPES-3 large area ($560m^2$) tracking muon detector which allows us to distinguish showers initiated by primary gamma rays from that of charged cosmic rays through a cut on the hadron content. It is very important feature of our array for gamma ray point source search. A muon detector module with a sensitive area of $35m^2$ consists of 232 proportional counters arranged in 4 layers, each having 58 counters (Figure1). Each counter has a cross sectional area of $10cm \times 10cm$ and $6m$ long. Two successive layers of proportional counters are separated by $15cm$ thick concrete. Because alternate layers are placed in orthogonal directions, track of muons can be measured with an accuracy of about $6°$.

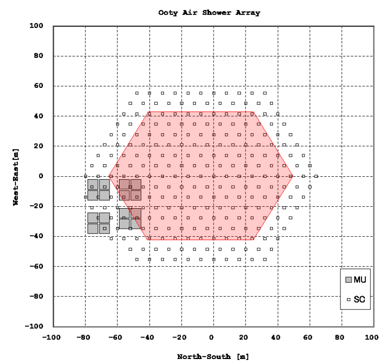

Figure 2: GRAPES-3 air shower array in the period of 2000-2003. Each small box indicates a scintillation detector and each gray box indicates a muon detector module.

Event selection

To select properly reconstructed showers we applied some quality cuts. Ratio of number of particles detected in the outer 2 rings of scintillation detecter array to a total number of particles should be less than 0.35 for the purpose that the shower core could be estimated properly. The estimated shower core must be inside the hexagonal area masked with red color in the Figure2. The zenith angle of reconstructed air shower direction is required to be less than 40°. The data which seems to have noisy counters was removed from analysis. And the data set with an amplitude of azimuthal angle distribution of more than 1.5% was not used in this analysis, because the angular resolution is not good in that period. The data set in this analysis was recorded between 2000 March and 2003 May. Total number of events after the above quality cuts becomes 8.9×10^5. This data set was used for the Crab analysis.

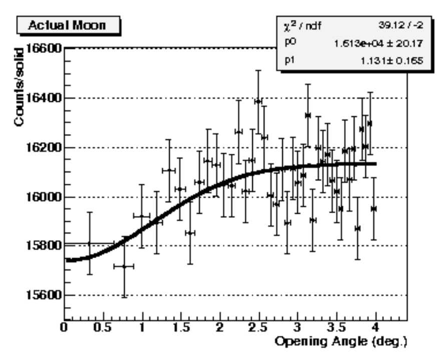

Figure 3: Variation of shower rate with opening angle centered on the Moon. Each bin has same solid angle. Angular resolution was calculated to be 1.13° with the shower size of log10(Size) $\geq$ 3.2.

Analysis and results

We already have information about the angular resolution of GRAPES-3 air shower array from the Moon shadow analysis using equal solid angle method in which the search area centered on the Moon position was divided into several bins of an annuli each having same solid angle[1]. Because all bins have the same solid angle, same number of showers will come into each bin if there is no astrophysical object shadowing cosmic rays. The angular resolution of array used during this analysis is 1.13° with the shower size of log10(Size) $\geq$ 3.2. We show the deficit of shower rate due to shadowing by the Moon as a sample in Figure3.

In this analysis, we looked at the direction of Crab Nebula using the equal solid angle method in the same way as for the Moon shadow analysis. We set the center of circular search window with a radius of 4° on the position of Crab Nebula. Because we want to know the effect of hadron cut using muon detector also, the analysis was carried out in two steps, first the data set was analyzed without applying muon cut, next the data was analyzed with the muon cut. We also looked at another region to see the background area at the same time. Background area was selected by shifting the position of actual Crab in the right accension by $\pm 8°$ with the same search window.

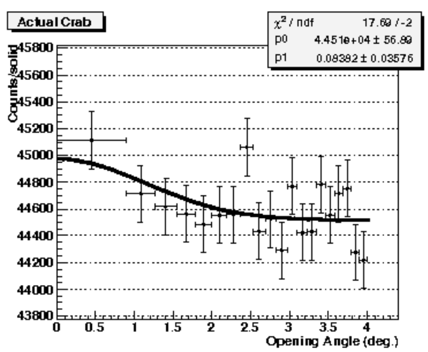

Figure 4: Excess number of events from Crab direction without hadron cut applied. Significance of the excess is about 1.0σ. The value of "p1" is 0.084.

The data was fitted by assuming the shape of the excess part on the center of a search window to be 2D gausian like. There are two fitting parameters in each graph, "p0" represents the level of background and "p1" represents a ratio of the excess amount to a "p0". The parameter "p1" is a kind of indicator of an excess. We used the value of "p0" of the off-source data as the background, because fluctuation of the off-source region is large. Therefore the significance derived in this analysis was

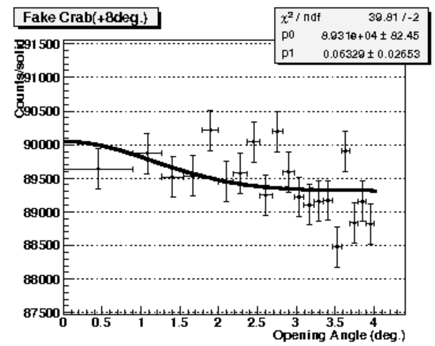

Figure 5: Two background regions were added together. Background regions were set at the place distant from the Crab position by $\pm 8°$ in the right accension. The value of "p1" is 0.063.

slightly over estimated. Figure4 and Figure5 show the on-source region and the off-source region of the data set without hadron cut respectively. The value of parameters "p1" in the both the data are very small and almost same together. We can't see an enough excess in the Figure4.

We applied the hadron cut which selects only the showers having no muon recorded in the muon detectors. But this hadron cut used in this analysis is a very simple, because gamma induced showers also have some hadronic content even thogh the primary particle is a low energy gamma ray and have a lateral distribution of muons which depends on the shower size. For higher energy, the provability of gamma induced showers containing hadronic content becomes large.

After applying hadron cut to all data, the total number of events reduced from 8.9×10^5 to 2.3×10^5. Figure6 and Figure7 show the on-source region and the off-source region for the data set with hadron cut applied respectively. The parameter "p1" of the on-source data is 0.274 and of the off-source data is 0.065. The latter is almost same as that of off-source data without hadron cut applied. The "p1" of the on source data with hadron cut is 3.3 times larger than without hadron cut. This suggests that we were able to suppress the background due to charged primary particles effectively.

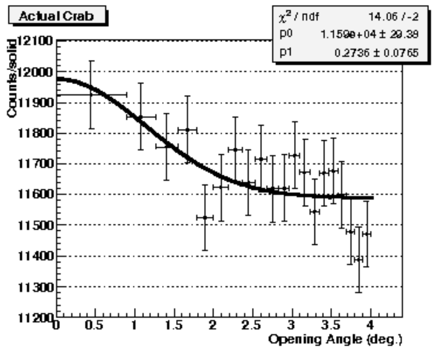

Figure 6: Excess number of events from Crab with hadron cut applied. Assuming the background level to be a half of Figure7, significance becomes to be about 3.2σ. The value of "p1" is 0.274.

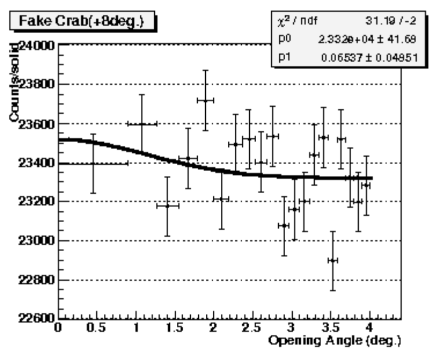

Figure 7: Two background regions were added together. The value of "p1" is 0.065.

Summery

We analyzed the data from 2000 March to 2003 May to see Crab Nebula which is well known as 'Standard Candle' in the gamma ray astronomy. We got an excess number of events from the Crab Nebula by using tracking muon detectors to reject the showers containing muons. Using muon detectors we can increase the sensitivity of GRAPES-3 air shower array to gamma induced showers. In this analysis we selected only muon zero showers as representing gamma ray induced showers.

Acknowledgements

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