# Very High Energy Gamma-rays from the Galactic Center

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## Abstract

The Galactic Center is one of the most interesting sources observed in multi-wavelength from radio to gamma-rays. In the high energy region, EGRET detected the strong gamma-ray signals near the Galactic Center (i.e., 3EG1746-2852). In the TeV gamma-ray region, Whipple group and HEGRA group reported null result (upper limits) at 2TeV and 4.5TeV, respectively. We have observed the Galactic Center with the CANGAROO-II telescope in the southern hemisphere for two years. We have advantage of higher elevation angles and we can observe with the lower threshold energy than other groups. We analyzed data taken in 2001 with a likelihood method. The energy threshold was estimated to be 400 GeV. Here we report a preliminary result.

## 1. Introduction

The Galactic Center is by far the nearest core of galaxies and has been extensively observed in various energies from radio to gamma-ray. In particular, fluxes at radio and GeV energies are large [7][9]. The radiation mechanism are not well understood. Some theories predict TeV gamma-ray radiation [2][10]. Whipple group and HEGRA group, however, reported the upper limit at 2 TeV [3] and 4.5 TeV [1]. We observed the Galactic Center with the CANGAROO-II 10m telescope in the southern hemisphere in 2001 and 2002. The observation from the southern hemisphere has an advantage with higher elevation angles than that from the northern hemisphere, i.e., a lower energy threshold is expected. Here we report a preliminary result for the observations in 2001.

## 2. Analysis

CANGAROO group operates an imaging telescope at Woomera, South Australia ($S31°06'$, $E136°47'$,160m asl). The imaging camera has 552 pixels which

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subtends an angle of 0.115° each and has a field-of-view of 3 degrees. Details of the telescope are described elsewhere [11][12].

Our imaging analysis is based on the method of likelihood analysis [4]. Noise reduction and selection of clustered images, which enhance shower images of Cherenkov light, were executed as pre-selection processes. Then we apply the likelihood analysis using image parameters.

### *2.1. Pre-selection*

First, we applied a cluster cut as follows. At least 5 adjacent PMT hits were required, where ADC (analog to digital converter) threshold for each pixel is 300 ADC counts (∼3.3 photo electrons). After this cluster cut, event rate was plotted. The data taken in good weather conditions shows a stable rate of about 2Hz, so that we can cut bad periods affected by clouds and dew. Then we cut the data with lower elevations of less than 60 degrees. After these cloud and elevation cuts, 60% of data survived in good condition (summarized in Table 1).

**Table 1.** Observation time for good condition.

| observation [date] | ON data [hours] | OFF data [hours] | remark |
|---|---|---|---|
| July 2001 | 20.8 | 22.1 | preliminary result |
| July 2002 | 32.0 | 17.9 | analyzing |
| August 2002 | 20.1 | 14.9 | analyzing |

In the next step, we generated gamma-rays with a power law spectrum of index -2.5 in the Monte-Calro simulation. The energy spectra of generated events and accepted events after the pre-selection similar to real events are shown by the solid and dashed histograms in Fig. 1. The energy threshold was thus estimated from the peak of the energy distribution of the accepted events, which was about 400 GeV.

### *2.2. Imaging analysis : Likelihood method*

In order to obtain a better S/N ratio, image shape parameters which Hillas introduced were used [6][8]. These parameters strongly depend on energy as shown in Fig. 2(a),(b). Here we used summation of ADC counts (SUMADC) in the cluster instead of energy of gamma-rays. Two-dimensional likelihood analysis [4][5] was used for correcting of this effect. First, we made Probability Density Functions (PDF) using these histograms. PDFs for gamma-rays and protons were made for “Length”, “Width” and “Asymmetry”. Second, we defined Likelihood

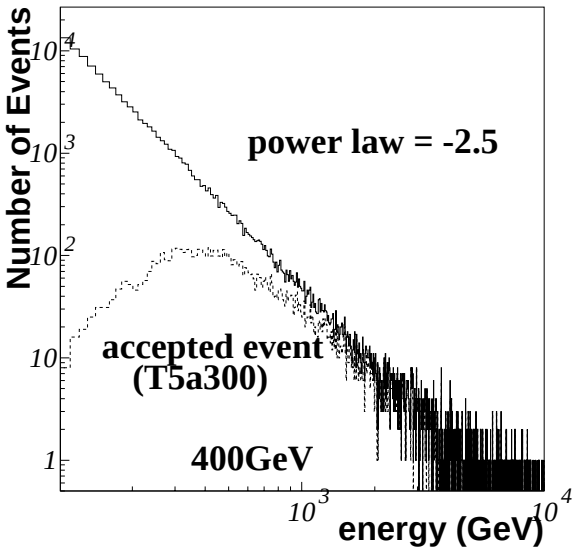


**Fig. 1.** The energy spectra of generated gamma-rays (the solid histogram) and accepted events after pre-selection (the dashed histogram). The power law spectrum with index of -2.5 was used in the Monte-Carlo simulation. The accepted events peaked at around 400 GeV.

ratio ($L$) as

$$L \equiv \frac{Prob(\gamma)}{Prob(\gamma) + Prob(proton)}$$

, where Prob($\gamma$,proton) means the product of each PDF (Length, Width and Asymmetry), for gamma-rays and cosmic-ray protons, respectively. Fig. 2(c) shows the distribution of $L$s for gamma-ray Monte-Calro and OFF source runs. Here, PDF for cosmic-ray proton was made using OFF source data. The $L$ for cosmic-ray protons peaked at zero and that for gamma-rays peaked at 1. In this analysis, we set the cut of the $L > 0.23$ for the data after distance cut ($0.4 < Distance < 1.2$).

## 3. Results

The alpha (image orientation angle) distributions obtained after the above selection are shown in Fig. 3. The histogram was normalized by OFF source events with entries at $\alpha > 30°$. These distributions indicates a marginal excess around $\alpha = 0°$. This result is preliminary and we need further analysis about noise reduction of individual pixels.

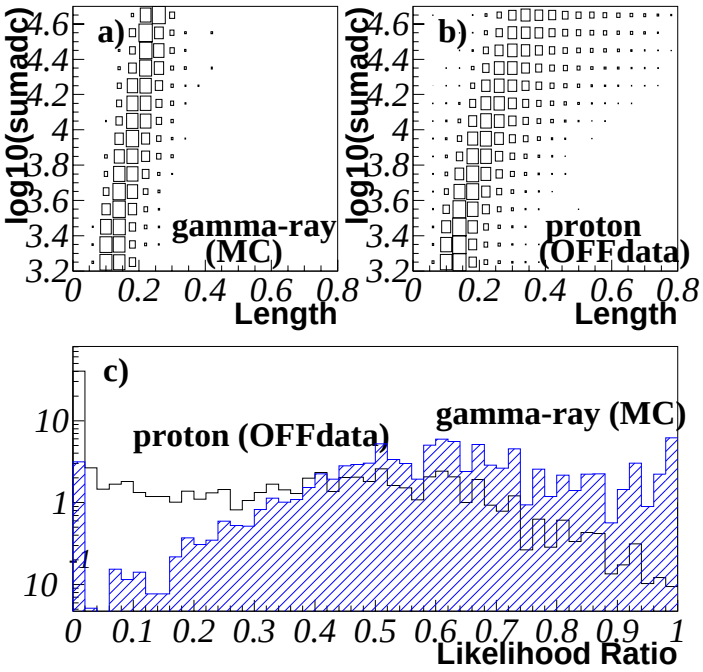


**Fig. 2.** Likelihood analysis; a) The energy dependence between the total energy and "Length". The total energy was approximated by summation of ADC values in the cluster. b) That for the OFF source run. c) The likelihood ratios (described in the text) were calculated using 2D histograms shown in a) and b). The hatched histogram is for the gamma-ray simulation and the blank histogram is for the OFF-source events. The cut was set at 0.23.

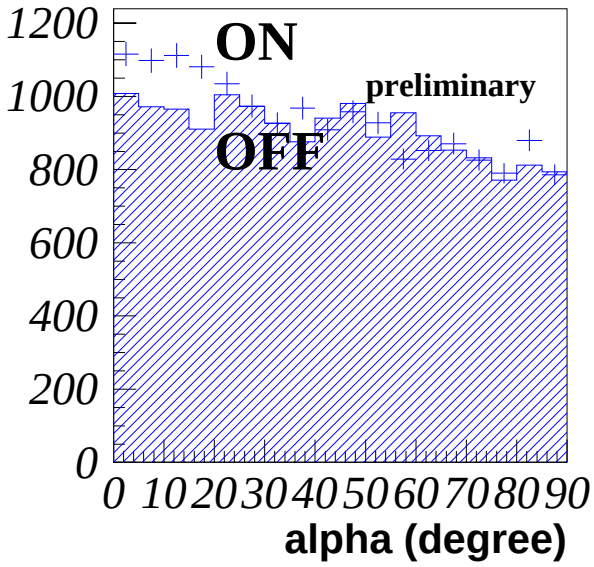


**Fig. 3.** Image orientation angle ($\alpha$) distributions. The points with statistical error bars are those for the ON source run and the hatched histogram are for the OFF source run. The normalization was carried out using the events with $\alpha > 30°$. Note that this result is preliminary.

## 4. Summary

We observed the Galactic Center with the CANGAROO-II telescope for two years. The total observation time was $\sim$ 73 hours for the ON source data and $\sim$ 55 hours for the OFF source data. We analyzed the data taken in 2001 with 2D-Likelihood method. The energy threshold was about 400 GeV and we obtained a preliminary alpha distribution. We plan to analyze the data taken in 2002 as soon as possible to confirm the preliminary result for the 2001 data.

## 5. Acknowledgements

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