29th International Cosmic Ray Conference Pune (2005) **00**, 101–104

Stereoscopic observations with the CANGAROO-III telescopes at the large zenith angles

T. Nakamori[a], Y. Adachi[b], A. Asahara[a], G.V. Bicknell[c], R.W. Clay[d], Y. Doi[e], P.G. Edwards[f], R. Enomoto[b], S. Gunji[e], S. Hara[b], T. Hara[g], T. Hattori[h], Sei. Hayashi[i], Y. Higashi[a], R. Inoue[h], C. Itoh[j], S. Kabuki[b], F. Kajino[i], H. Katagiri[a], A. Kawachi[h], S. Kawasaki[b], T. Kifune[k], R. Kiuchi[b], K. Konno[e], L.T. Ksenofontov[b], H. Kubo[a], J. Kushida[h], Y. Matsubara[l], Y. Mizumoto[o] M. Mori[b], H. Muraishi[p] Y. Muraki[l] T. Naito[g], D. Nishida[a], K. Nishijima[h], M. Ohishi[b], J.R. Patterson[d], R.J. Protheroe[d], Y. Sakamoto[h], M. Sato[e], S. Suzuki[q], T. Suzuki[q], D.L. Swaby[d], T. Tanimori[a], H. Tanimura[a], G. Thornton[d], K. Tsuchiya[b], S. Watanabe[a], T. Yamaoka[i], M. Yamazaki[i], S. Yanagita[q], T. Yoshida[q], T. Yoshikoshi[b], M. Yuasa[b], Y. Yukawa[b]

(a) Department of Physics, Graduate School of Science, Kyoto University, Sakyo-ku, Kyoto 606-8502, Japan
(b) Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 237-8582, Japan
(c) Research School of Astronomy and Astrophysics, Australian National University, ACT 2611, Australia
(d) Department of Physics and Mathematical Physics, University of Adelaide, SA 5005, Australia
(e) Department of Physics, Yamagata University, Yamagata, Yamagata 990-8560, Japan
(f) Institute of Space and Astronautical Science, Sagamihara, Kanagawa 229-8510, Japan
(g) Faculty of Management Information, Yamanashi Gakuin University, Kofu, Yamanashi 400-8575, Japan
(h) Department of Physics, Tokai University, Hiratsuka, Kanagawa 259-1292, Japan
(k) Department of Physics, Konan University, Kobe, Hyogo 658-8501, Japan
(l) Ibaraki Prefectural University of Health Sciences, Ami, Ibaraki 300-0394, Japan
(m) Faculty of Engineering, Shinshu University, Nagano, Nagano 480-8553, Japan
(n) Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Aichi 464-8602, Japan
(o) National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan
(p) School of Allied Health Sciences, Kitasato University, Sagamihara, Kanagawa 228-8555, Japan
(q)Faculty of Science, Ibaraki University, Mito, Ibaraki 310-8512, Japan
Presenter: T.Nakamori (nakamori@cr.scphys.kyoto-u.ac.jp), jap-nakamori-T-abs1-og22-oral

CANGAROO-III is a stereoscopic observation system with four telescopes, which started full operation in March 2004. We have observed the Crab nebula in 2003 and 2004 at zenith angles > 55 degrees because our telescopes are located in the southern hemisphere. The observations were made using with both an independent trigger mode and a global trigger mode using two (2003) or three (2004) telescopes. In the case of larger distances between showers and telescopes, events have a lower accuracy on the determination of intersection points, which degrades the theta-squared distributions. We are, therefore, trying to improve analysis methods. We report the current results of these observations and the performance of our system compared with Monte Carlo simulations.

1. Introduction

The Crab nebula(RA=5h24m32s, Declination=22°00'52") is known as one of the brightest and stable TeV gamma-ray point sources. So it is a very important target for calibration of the instruments and efficiency for gamma-ray detection. Emission of very high energy gamma-ray was confirmed by imaging air Cherenkov telescopes, Whipple[1], HEGRA[2] and CANGAROO-I[3], and the flux of the Crab nebula in the wide band for sub- to multi- TeV region has been reported. CANGAROO-II also measured the flux and the result was consistent under the systematic errors of Whipple and HEGRA[4]. Then we observed the Crab nebula to confirm the performance of the CANGAROO-III stereoscopic system.

2. Observation

The stereoscopic observation of the Crab nebula had been carried out in 2003 December with two telescopes, T2 and T3, and from 2004 November to 2005 January with the three telescopes, from T2 to T4. These observations were made by so called wobble mode, changing the pointing directions +/- 0.5 degree in declination apart from the target every 20 minutes. Then we could not only obtain "OFF-source" background events at the same time under the same environmental situation as those of "ON-source", but be free from the ambiguity in the normalization between ON and OFF. Before 2004 December each telescope was triggered independently under the condition of more than 4 pixels hits where each pixel included at least 7.6 photoelectrons. There is a 3rd magnitude bright star in the field of view, in order to avoid the effect from the star, high voltage for PMTs of the camera was turn off automatically around the star in 0.2 degree radius. GPS time stamp was recorded with each event at the same time and its accuracy is under 1 μsec. We selected coincident events if the difference of triggered time is less than 200 μsec. Trigger rate of each telescope is at most < 80Hz, and after the stereo event selection the event rate is about 8 Hz. Analysis was done for only the data taken at the elevation angle greater than 30 degree, rejecting the data taken in cloudy condition. The total used observation time are shown in Table 1.

Table 1. Observation in this analysis

Observation term	Available time	Triggermode	Telescopes
2003 Dec	18.5h	Local	T2,T3
2004 Nov	10.0h	Local	T2,T3,T4

3. Analysis

According to Monte-Carlo simulations, there is some difficulty in stereoscopic observation at the large zenith angles, such as the Crab nebula for CANGAROO-III. Orientation angles of gamma-rays are reconstructed by the intersection point of the two (or more) axes of the shower images. If the opening angle between two axes is small, such an event is not to be used because of worse accuracy of intersection point. In the case of large zenith angles, the interval between telescopes looks smaller from the view of shower axes, which means more events have core distance far from telescopes than in the case of small zenith angles. That is, our observation of the Crab results in worse angular resolution (Fig.1) and small number of events. So we have to develop more effective analysis methods.

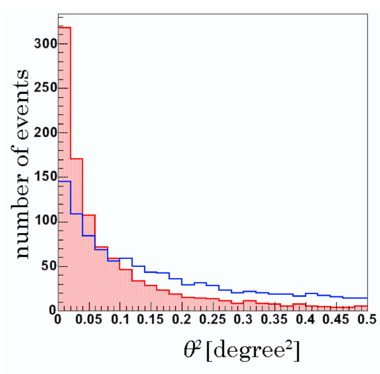

Figure 1. θ^2 distributions. The hatched line and the blank line show θ^2 of Monte-Carlo simulations in the case of the small (0 degree) and large (60degree) zenith angle, respectively. Angular resolutions are 0.16 degree and 0.21degree as the half width at half maximum.

To avoid the increased uncertainty of the intersection points, we paid attention to the distance between the intersection point and centroid of images, "IP distance", or $D_{\rm IP}$. If the determination of the intersection point is accurate, $D_{\rm IP}$ distribution should be the same as that of Hillas parameter DISTANCE. Then we search the best intersection point with the χ^2 defined as

$$\chi^2 = \sum_{\rm telescopes} \left[W^2 + \frac{(D_{\rm IP} - \langle D \rangle)^2}{\sigma_{\rm D}^2} \right],$$

where W is the width seen from the intersection point, $\langle D \rangle$ is the mean distance obtained by Monte-Carlo simulations for gamma-rays, and σ_D is its standard deviation. This search resulted in improvement of θ^2 distribution. After that we first used the conventional square cuts method taking into account of the difference of the spot size between each telescopes. After this standard analysis, we applied two different analyses. One is the Likelihood method[5] and the other is Fisher Discriminant[6][7]. Finally we obtained integrated flux from 2003 data sets consistent within the statistical and systematic errors. In the analysis of 2004 data sets, we're also trying to develop simpler analysis method for the objects at the large zenith angles. Fig.2 shows the distributions of θ^2 and IP distance. Monte-Carlo simulation says those events which have smaller IP distance contributes to worse angular resolution, and many of hadronic events have also small IP distance. The cut of $D_{\rm IP} < 0.3$ is effective both on the angular resolution and on the S/N ratio. In addition, we are studying the effects due to the bright stars in the field of view for the wobble mode. The result will be presented in the conference.

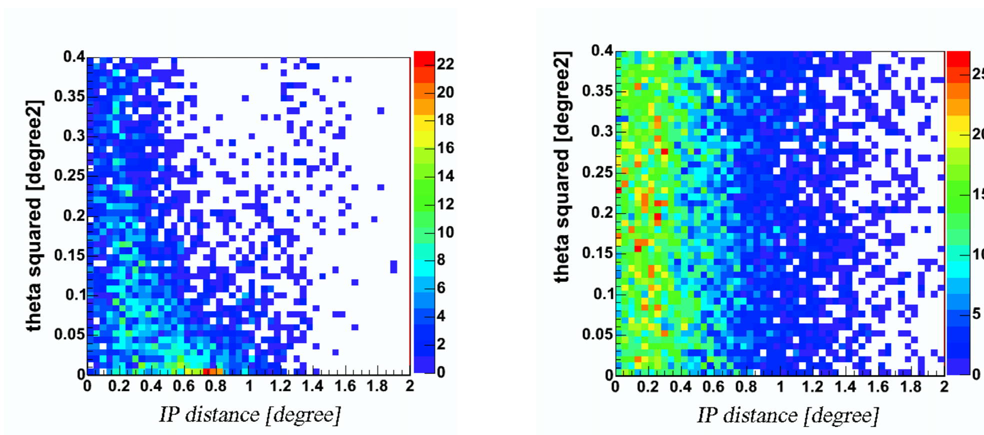

Figure 2. Distributions of θ^2 and $D_{\rm IP}$. The left figure shows the result of Monte-Carlo simulation for gamma-rays at the zenith angle 55 degrees. The right one is from observations of the Crab nebula.

4. Conclusions

CANGAROO-III has done stereoscopic observation on the Crab nebula and the obtained flux is consistent with other groups' results. We're developing the new analysis method for the object at the large zenith angles. We checked the performance of our system and we found that it was in line with our expectations.

References

[1] Hillas, A.M. et al., ApJ, 503, 744 (1998)
[2] Aharonian, F. et al., ApJ, 539, 317 (2000)
[3] Tanimori, T. et al., ApJ, 492L, 33T (1998)
[4] Itoh, C .et al., astro-ph/0304295 (2002)
[5] Enomoto, R. et al., Astropart. Phys., 16, 235 (2002)
[6] Enomoto, R. et al., ApJ, submitted (2005).
[7] Fisher, R. A., Annals of Eugenics, 7, 179 (1936)