ICRC 2001

Development of Light Guides for the Camera of CANGAROO-III Telescope

F. Kajino[1], **A. Maeshiro**[1], **A. Asahara**[2], **G.V. Bicknell**[3], **R.W. Clay**[4], **P.G. Edwards**[5], **R. Enomoto**[6], **S. Gunji**[7], **S. Hara**[8], **T. Hara**[9], **S. Hayashi**[1], **C. Itoh**[10], **S. Kabuki**[6], **H. Katagiri**[6], **A. Kawachi**[6], **T. Kifune**[11], **H. Kubo**[2], **J. Kushida**[2], **S. Maeda**[1], **Y. Matsubara**[12], **Y. Mizumoto**[13], **M. Mori**[6], **H. Muraishi**[14], **Y. Muraki**[12], **T. Naito**[9], **T. Nakase**[15], **K. Nishijima**[15], **M. Ohishi**[6], **K. Okumura**[6], **J.R. Patterson**[4], **R.J. Protheroe**[4], **K. Sakurazawa**[8], **R. Suzuki**[6], **D.L. Swaby**[4], **T. Tanimori**[2], **F. Tokanai**[7], **K. Tsuchiya**[6], **H. Tsunoo**[6], **K. Uruma**[15], **A. Watanabe**[7], **S. Yanagita**[10], **T. Yoshida**[10], **and T. Yoshikoshi**[16]

[1]Department of Physics, Konan University, Kobe, Hyogo 658-8501, Japan
[2]Department of Physics, Kyoto University, Sakyo-ku, Kyoto 606-8502, Kyoto, Japan
[3]MSSSO, Australian National University, ACT 2611, Australia
[4]Department of Physics and Mathematical Physics, University of Adelaide, South Australia 5005, Australia
[5]Institute of Space and Astronautical Science, Sagamihara, Kanagawa 229-8510, Japan
[6]Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan
[7]Department of Physics, Yamagata, Yamagata University, Yamagata 990-8560, Japan
[8]Department of Physics, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan
[9]Faculty of Management Information, Yamanashi Gakuin University, Kofu, Yamanashi 400-8575, Japan
[10]Faculty of Science, Ibaraki Univeriesty, Mito, Ibaraki 310-8521, Japan
[11]Faculty of Engineering, Shinshu University, Nagano, Nagano 380-8553, Japan
[12]STE Laboratory, Nagoya University, Nagoya, Aichi 464-8602, Japan
[13]National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan
[14]Ibaraki Prefectural Univeriesty, Ami, Ibaraki 300-0394, Japan
[15]Department of Physics, Tokai University, Hiratsuka, Kanagawa 259-1292, Japan
[16]Department of Physics, Osaka City University, Osaka, Osaka 558-8585, Japan

Abstract. The camera of the CANGAROO-III Cherenkov telescope consists of many photomultiplier tubes (PMTs), with significant dead space between the PMTs. Light guides reflect photons directed at dead spaces, to the effective area of a PMT. We performed Monte Carlo simulations for various shapes of light guides to evaluate their performance, compared with experimental values, and determined the optimal shape of the light guide for the CANGAROO-III telescope.

We calculated the light collection efficiency as a function of incident angle for various types of light guides using the Monte Carlo simulation. The best efficiency of the light guide was obtained for the following conditions: The cross sectional shape cut along the central axis of the light guide should have the Winston cone shape, though the entrance finestra is hexagonal, and the gap between the light guide and the PMT should be as small as possible.

To decrease the energy threshold of CANGAROO-III telescope, good light collection efficiency is very important.

Correspondence to: F. Kajino (Email: `kajino@konan-u.ac.jp`)

1 Introduction

The camera of the first telescope of the CANGAROO-III array subtends about 3° and consists of 552 PMTs of half-inch diameter. The PMTs are arranged in square grid pattern. (Mori et al. , 2000).

On the other hand the camera of the second telescope of the CANGAROO-III array consists of 427 Hamamatu R3479UV photomultiplier tubes with diameters of 19 mm and sensitive diameters of at least 15 mm. The PMTs are arranged in hexagonal honeycomb pattern (Mori et al. , 2001). The field of view of the new camera is 4.2° which is wider by 1.2° than that of the first telescope. The dead space of the new camera is about 65% of the total surface area.

A better light guide for the camera of CANGAROO-III telescope is required to lead photons directed at the dead space of the camera surface to the sensitive area of a PMT.

Various types of light guides have been simulated to obtain the best solution for the new camera. Their results and performance are reported in this paper.

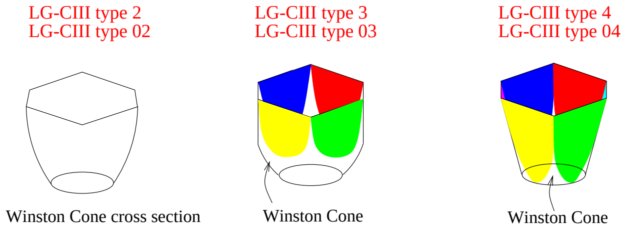

Fig. 1. Light guides simulated using the Winston cone shape. Colored surfaces named as type 3, type 4, type 03 and type 04 are flat planes.

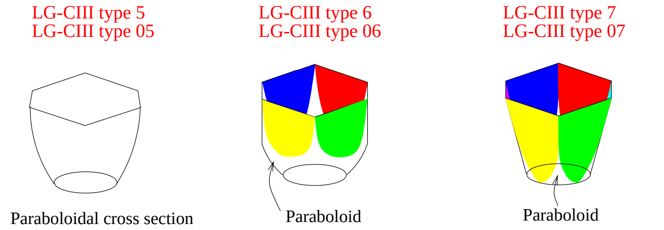

Fig. 2. Light guides simulated using paraboloidal shape. Colored surfaces named as type 6, type 7, type 06 and type 07 are flat planes.

2 Shapes of light guides

We have tried to test two types for curved surfaces, the Winston cone and a paraboloid.

2.1 Using the Winston cone shape

The Winston cone is a non-imaging optical shape to concentrate all photons whose incident angle is less than a certain angle. (Winston , 1983) (Winston , 1991)

Three types of light guides shown in Fig. 1 are simulated using the Winston cone for the curved surface.

The maximum incident angle to the light guide is determined by the light from outer edge of the 10 m mirror dish, which ranges from 32.2° to 35.2° depending on position of a camera surface.

Though the entrance shape of the original Winston cone is round, as the PMT's are arranged in a hexagonal shape with a spacing of 24 mm, the present shape of the entrance is determined to be hexagonal.

Every inner surface of cross section cut through the central axis of the light guide of type 2 in Fig. 1 is determined to be the Winston cone shape.

Flat planes for type 3 are all determined to be vertical. Flat planes for type 4 are tangential to the edge of the bottom circle.

The gaps between the light guides for the above types are assumed to be 0 mm. The gap of 1 mm is also assumed for very similar types as type 02, type 03 and type 04.

The ratio of the entrance area and the exit area of the light guides is 2.68 for the case of the gap of 0 mm and 2.46 for 1 mm.

2.2 Using a paraboloidal shape

A paraboloidal shape is used for the curved surface for three types shown in Fig. 2. Every inner surface of cross section cut through the central axis of the light guides of type 5 in Fig. 2 is determined to be the paraboloidal shape. Flat planes for type 6 are all determined to be vertical. Flat planes for type 7 are tangential to the edge of the bottom circle.

Gaps between the light guides for the above three types are assumed to be 0 mm. The gap of 1 mm is also assumed for very similar types as type 05, type 06 and type 07.

3 Light collection efficiencies

Simulations to obtain the light collection efficiency was performed based on the following assumptions.
1) Sensitive area of the PMT is 15 mm.
2) Distance between the center of neighboring PMTs is 24 mm.
3) Reflectance of the surface of the light guide is assumed to be 100% and 80%.
4) Reflectance at the surface of the PMT is assumed to be 0%.
5) Gaps between the neighboring PMTs are assumed to be 0 mm and 1 mm.
6) Gaps between the light guide and the PMT are assumed to be 0 mm and 2 mm.
7) Photons are incident on a paraboloidal mirror with 10 m diameter and photons reflected at the mirror surface are incident on a light guide centered at the camera position.
8) The camera position is assumed to be in the focal plane 8 m from the main reflector.

An example of resultant light collection efficiency of the simulations as a function of mirror radius is shown in Fig. 3. Collected photons are integrated from the center of the 10 m diameter mirror. The gap between the light guides is 0 mm, reflectance of the light guide is 80% and gap between the light guide and the PMT is 0 mm for this example.

From this figure the best shape for the light guide was proved to be type 2, with a collection efficiency of 77.3 %.

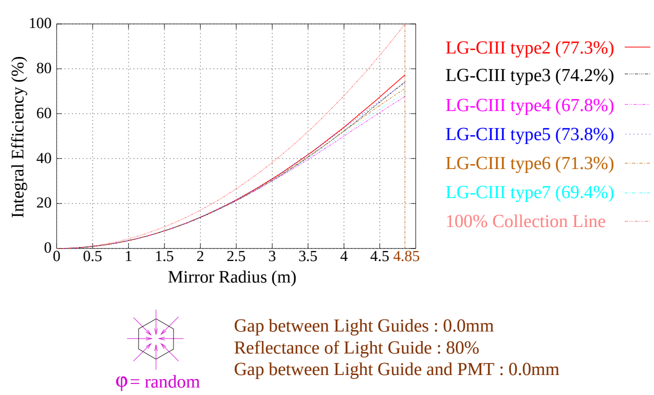

Fig. 3. Comparison of integrated light collection efficiencies for various types of light guides.

Table 1. Simulated light collection efficiencies for various cases.

	type 2	type 02
Gap between LGs	0 mm	1 mm
Reflectance of LG : 100 % Gap between LG and PMT : 0 mm	94.3 %	87.0 %
Reflectance of LG : 80 % Gap between LG and PMT : 0 mm	77.3 %	72.2 %
Reflectance of LG : 80 % Gap between LG and PMT : 2 mm	69.0 %	66.4 %

Results of the simulation is listed in Table 1 with various parameters of conditions: gap between light guides, reflectance of light guide and gap between the light guide and the PMT.

It is shown that even the small gap of 2 mm between the light guide and the PMT reduces the efficiency by about 8%. Therefore it is suggested not to leave any gap between the PMT and light guide.

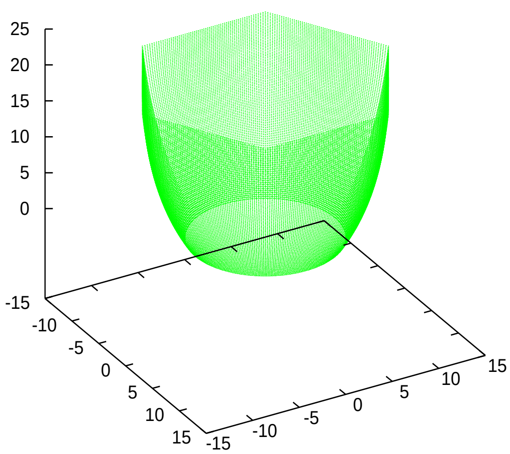

Fig. 4. Data points of the inner shape of the new light guide.

Based on these simulated results we chose type 2 for which the cross section cut through the central axis was the Winston cone shape, entrance shape was hexagonal, and exit shape was round. Having a 0.5 mm gap between the light guides was chosen to take into account manufacturing accuracy.

A mold was tuned with a computer controlled machine in which simulated data shown in Fig. 4 was input. The mold was finally polished by hand.

Polycarbonate plastic is used for the base material. A picture of the finished product is shown in Fig. 5. The manufacturing error of the size was measured and proved to be less than 0.1 mm.

Aluminum vapor was deposited on the inner surface of the light guide and the surface was then coated by silicon oxide.

Fig. 5. Left : Light guide for CANGAROO-II telescope. Right : New light guide for CANGAROO-III telescope.

The light collection efficiency was measured for the manufactured light guide as a function of incident angle using a blue LED with a wavelength of 470 nm. Fig. 6 shows that the measured efficiency agrees very well with the simulation when the reflectance of the inner surface is assumed to be 89%.

4 Reflectance vs. wavelength

Flat glass samples were put in the same vessel of the vapor deposition with the light guides. Reflectance of the samples were measured by a spectrophotometer. One of the result is shown in Fig. 7 as a function of a wavelength. Incident angles for this measurement were 5° and 60°. The reflectance value ranges from 80% to 90% above the wavelengh of 300 nm for both of the incident angles.

5 Discussion and conclusions

The expected Cherenkov photon spectrum generated by air showers at sea level is obtained by a Monte Carlo simulation and is shown in Fig. 8.

Therefore the manufactured light guide was proved to have a good spectral efficiency for detecting Cherenkov photons from air showers.

Light collection efficiency of the light guide for the camera of the second telescope of CANGAROO-III was very much improved by about 60% compared with that of the first telescope. Negative high voltages are applied to the first telescope camera, which causes discharge problems if the light

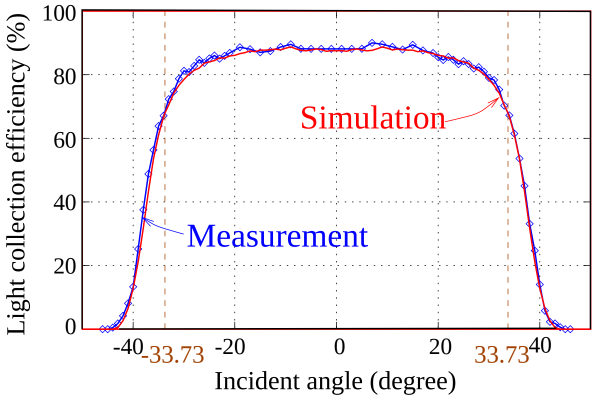

Fig. 6. Comparison of light collection efficiency between a simulation and a measurement of the light guide.

guides are attached directly to the PMTs. Avoiding this requires keeping gaps of about 2 mm between the light guides and PMTs, which reduces the light collection efficiency. The second telescope camera will use positive high voltage to prevent the discharge, and so the light guides can be attached directly to the surface of the PMTs.

Owing to the usage of the Winston cone shape, the light collection efficiency of the new light guide changes rapidly at around 35° which corresponds to nearly the edge of the 10 m mirror, whereas that for the first telescope changes much more slowly. Therefore light collection efficiency has been improved very much. Background photons coming from outside the mirror will be also suppressed very much by this property, which will be useful to limit the trigger rate.

In conclusion, we have performed simulations for various types of light guides for the camera of the CANGAROO-III telescope and it is found that the best collection efficiency for them is obtained when the the cross sectional shape cut along the central axis has the Winston cone shape and the gap between the light guide and the PMT is 0 mm.

Reflectance of the light guide was measured and it was found to be good enough to observe Cherenkov photons from

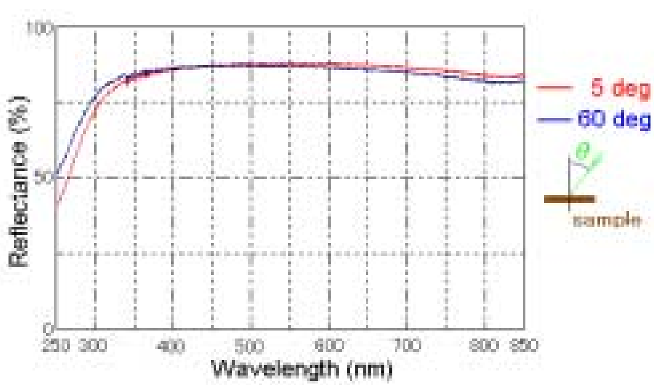

Fig. 7. Measured reflectance of the new light guide.

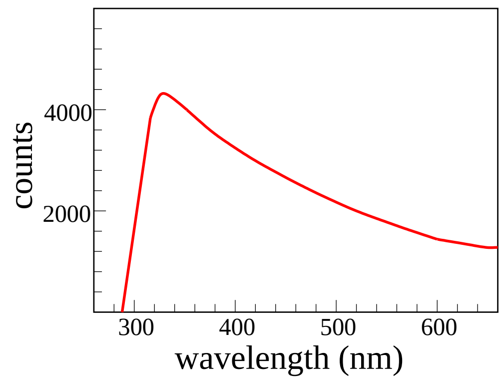

Fig. 8. Expected spectrum of Cherenkov photons from air showers at sea level.

air showers.

Acknowledgements. This project is supported by a Grant-in-Aid for Scientific Research of Ministry of Education, Culture, Science, Sports and Technology of Japan, and the Australian Research Council.

References

Winston, R. and O'Gallagher J., Int. Journal of Ambient Energy, Vol. 4, 171, 1983.

Winston, R., Scientific American, March 1991.

Mori, M. et al., Int. Symp. High Energy Gamma-ray Astro., Heidelberg, 578, 2000.

Mori, M. et al., in these proceedings.