Analysis of muon events recorded with the MAGIC telescope

M. Meyer and K. Mase
for the MAGIC collaboration

Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 München, Germany

Abstract. Measuring muon rings and arcs allows for the calibration of an Imaging Air Čerenkov Telescope, since the geometry of the muon track can be reconstructed by the image in the camera. We extracted ~0.5% muon events from the data obtained during commissioning of the MAGIC telescope in the summer of 2004, corresponding to a rate of 1 Hz. The distributions of the observed muon parameters agree well with the simulated ones.

INTRODUCTION

With Imaging Air Čerenkov Telescopes (IACT), the Čerenkov light from a single muon, generated in a hadronic shower, can be detected. MAGIC has the largest mirror area among the current IACTs (234 m²), a focal length to diameter ratio of $f/D = 1.0$, and a PMT camera consisting of 577 pixels. To understand the image of the muon in the camera, muon impact inside or outside the mirror dish have to be distinguished. When the muon hits the mirror, the light cone generates a characteristic ring in the focal plane, with radius equal to the Čerenkov angle. If the muon track does not pass through the mirror, only a fraction of the ring can be seen[1]. If the incidence of the muon is not parallel to the optical axis, the ring is shifted out of the center of the camera. Due to this characteristic shape (and intensity) of the ring, muons can be used as an independent check for the performance of the telescope.

METHOD

After flat fielding of the PMT response of the camera, the pixels with signal must be separated from those which are dominated by the fluctuation of the night sky-background light. For this image cleaning the content of each pixel is compared to its fluctuation. In the following analysis 3.0 sigma above noise level are used for the core and 2.0 sigma for the outer boundaries. Boundaries means, that such a pixel must have a neighbour pixel, which is classified as core.

After the image cleaning, the remaining image is fitted by a ring. Radius and position of the center are calculated (Fig.1,right). With this information, the intensity distribution
FIGURE 1. A muon event before image cleaning (left panel) and the same event after image cleaning with a fitted ring (right panel).

along the ring is calculated from the uncleaned image by adding the light content of all the pixels inside a certain margin around the radius (Fig.1, left).

FIGURE 2. Left: Intensity vs. azimuth angle along the ring, fitted by eqn.6 from [1]. Right: Radial intensity with a gaussian fit.

From this intensity distribution, we can define the length of the muon arc. The opening angle of the arc (ARCPHI), multiplied by RADIUS, gives the total ARCLENGTH. The width of the muon arc (ARCWIDTH) is defined as the sigma of a gaussian fit to the radial intensity distribution (Fig.2, right). It is dominated by aberration of the mirror. The distribution of ARCWIDTH can be used to measure the point-spread-function (PSF) of the optical system by comparing with simulated muon events.

DATA

A data sample from 8/14/2004 was used, when 3EG1727+04 was observed. The sample covers a total time of 42 min and contains 610042 events (245 Hz). We omitted all events,
in which less than half a ring could be measured. This selection criterion corresponds to the condition that the muon impact is inside the dish with an angle of incidence less than 1.5° relative to the optical axis. Further cuts are necessary to be sure that only muon events are selected. From this data sample, 2538 muon events survived the following cuts:

- $\text{RADIUS} > 0.60^\circ$
- $\text{RADIUS} < 1.35^\circ$
- $\text{ARCWIDTH} < 0.135^\circ$
- $\text{ARCPHI} \geq 180^\circ$

The ratio of muon ring events to all events is 0.42%, corresponding to a rate of 1.02 Hz. 69300 muon events with energies between 6 GeV and 200 GeV were simulated\(^1\), divided in four energy bins with different slopes from -1.9 to -3.0 for the differential flux\(^3\), assuming a power law. After analysing with the same algorithms and using the same cuts as to the observational data, 5811 muon events were selected. Fig.3 shows the distribution of RADIUS compared to that in the Monte Carlo sample. As the radius is equal to the Čerenkov angle, it depends on the refractive index in air. Thus the distribution of radius is sensitive to the atmospheric conditions. Differences in the assumed model atmosphere and the actual atmosphere during the observations may be the reason for the remaining small systematical differences in the RADIUS distribution between Monte Carlo and observed data.

\(^1\) Monte Carlo simulation of Čerenkov emission was carried out by means of the CORSIKA program\(^2\)
Fig. 4 shows the distribution of ARCWIDTH compared to the Monte Carlo sample. The simulation was made with an 0.5 cm point-spread-function.

**CONCLUSION AND OUTLOOK**

Muon rings and arcs, which show a ring segment with more than 180°, can be extracted from the data with a rate of ~1 Hz. The comparison between Monte Carlo and observational data shows acceptable agreement. The ARCWIDTH parameter can be used to continuously check the PSF of the optical system. To get a Monte Carlo independent method for measuring the PSF, unfolding of aberration effects and intrinsic PSF would be necessary. A distribution of SIZE vs. ARCLENGTH leads to absolute calibration of the camera response by muons, comparing observed with Monte Carlo data.

**ACKNOWLEDGMENTS**

We want to acknowledge the support of the german BMBF (05 CMOMG1/3).

**REFERENCES**
