Eur Phys J C **33**, s01, s938–s940 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2004-03-1630-2

EPJ C direct
electronic only

Status of the 17 m diameter MAGIC telescope

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Received: 4 November 2003 / Accepted: 22 January 2004 /

Abstract. The 17m diameter MAGIC telescope is in commissioning phase now. MAGIC is the worldwide largest air Cherenkov imaging telescope and is located on the Canary island of La Palma on the mountain altitude of 2200m a.s.l.. For the first time MAGIC will allow to perform measurements of very high energy cosmic gamma ray sources below 100 GeV energy regime. The current status of the telescope is reported below.

1 Introduction

With the firm detection of the first gamma ray signal from the Crab Nebula the Whipple collaboration has opened a new window in astronomy in 1989 [1]. In the following years several new gamma emitting sources have been discovered in the energy range above 300 GeV. Some of the new sources have been measured with high significance and were independently confirmed while some other sources were just marginally discovered and still need to be re-measured and confirmed by other collaborations [2]. Today, in 2003, in total about a dozen of sources are discovered. The newest generation telescopes CANGAROO, HESS, MAGIC and VERITAS are in the construction or completion phase. They promise to provide a rich harvest of new gamma sources in the coming few years. Since 1995 we have planned MAGIC to be a very large telescope with aperture of 17 m [3]. We have designed MAGIC to provide about an order of magnitude lower energy threshold setting compared to a Whipple-class telescope and thus for the first time to provide measurements in the $sub - 100GeV$ energy region. To make it real we needed to critically consider the function of all different parts of the telescope. As a result we have developed several new techniques and technologies for the telescope as well as optimized the design of each component. Given the price-performance constraints our idea was at the beginning to construct just one single telescope operating in the not yet explored energy domain $\geq 30GeV$ [4]. After understanding of the performance of the first MAGIC we were (and still are) planning to upgrade our project by constructing a few more telescopes of the same or similar type. These could provide even lower threshold setting and somewhat higher precision and sensitivity. In the recent years a big and strong international collaboration, mostly from European countries, has been formed around MAGIC [6]. Now the first MAGIC telescope is starting its operation [5]. Below I will present a short report on the current status of the MAGIC telescope.

2 The current status

2.1 The technological novelties

One can not build a very large telescope just as an upscaled version of a small one. One needs to develop new techniques and technologies in order to make the construction of a very large telescope realistic and to meet the price-performance requirements. Below are listed the technological novelties which we have developed, extensively tested over the past years and finally used for the construction of MAGIC.

- The square shape mirrors of a side length of 49.5 cm of MAGIC are entirely made from Al and include internal heating. The mirror front surface is polished by using a diamond cutter providing a beam divergence of $\sim 2'$. A single mirror tile weighs $\sim 4.2Kg$. A quartz layer deposited on the front surface is protecting the mirrors from weathering.
- Every four mirror tiles are fixed on a carrying panel of $\sim 1m^2$ size and are optically adjusted to perform as (or strictly speaking better than) a single piece $1m^2$ mirror. The reflector of MAGIC includes 245 panels of the above mentioned type. The panels are attached to stepping motor based electro-mechanical actuators (under the control of micro-controllers) in order to adjust their orientation when varying the elevation angle of the telescope and the gravitational loads are changing.
- In the current design of MAGIC we are using semiconductor laser pointers working at wavelength of $\sim 650nm$ in the active mirror control (AMC) system. These lasers are fixed at the mirror panel center's and their light spots in the focal plane are adjusted to show

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the location of the reflected light spots of corresponding mirrors. A CCD camera is fixed on the reflector and measures the differences in the orientation of different panels from their must be positions and sends correction signals to the corresponding panel steering micro-controllers.

- In order to provide low weight and inertia the reflector frame is made from reinforced carbon-fibre tubes.
- 6-dynode ultrafast hemispherical PMTs with enhanced quantum efficiency (*produced by Electron Tubes, England*) are especially designed for the needs of MAGIC.
- Light guides of a special form, well matching the hemispherical shape of the PMT input window, are designed to maximize the double hit chance of the photocathode by incident photons. This provides an increase in the quantum efficiency.
- A special "milky" wavelength shifting coating of PMT windows provided a substantial increase in quantum efficiency.
- Ultrafast analog signal transmission by using VCSEL diodes and optical fibres helps, in spite of 162 m fibre length from the camera to the counting house, to preserve the original shape of the ultrafast pulse for further processing.
- A 10 layer printed circuit mother-board in the camera is used to distribute the control and supply voltages and also as a mechanical support for installing the pixels.
- The heat released inside the camera by the electronics ($\sim 600W$) is transported away by by circulating water through its case. A closed loop regulated thermostat located on one of the bogeys of the telescope, allows to control the temperature inside the camera.
- The 3 level trigger provides tight time coincidence (equivalent to 5 ns gate) and strong rejection of different backgrounds on hardware level. While the 1st level does simple discrimination, the 2nd level provides a next neighbour trigger logic (selectable 2,3,4,5 neighbours) and the 3rd level can trigger on given pixel patterns.

2.2 Main parameters of the telescope

A short summary of the main parameters of the telescope is shown below:

- mount type: alt-azimuth
- total weight: $\sim 65tons$
- re-positioning time to any arbitrary direction in the sky: $\leq 20s$
- reflector ø, area, shape: 17 m, 239 m^2, parabolic
- reflector optics: $F/D = 1$
- reflector frame structure: 3-layer reinforced carbon-fibre space frame
- number of mirror tiles and their mean reflectivity: 940, 85 %
- camera field of view: $\sim 4°$
- pixel sizes: 397 central pixels of 0.10° ø, 180 outer pixels of 0.20° ø
- PMTs: 6 dynode enhanced bialkali hemispherical ET 9116 (25 mm ø) and ET 9117 (38 mm ø)
- DAQ: 300 MSample/s FADC readout
- DAQ dynamic range: effective 10 bits
- DAQ event rate capability: $\sim 1kHz$ sustained rate

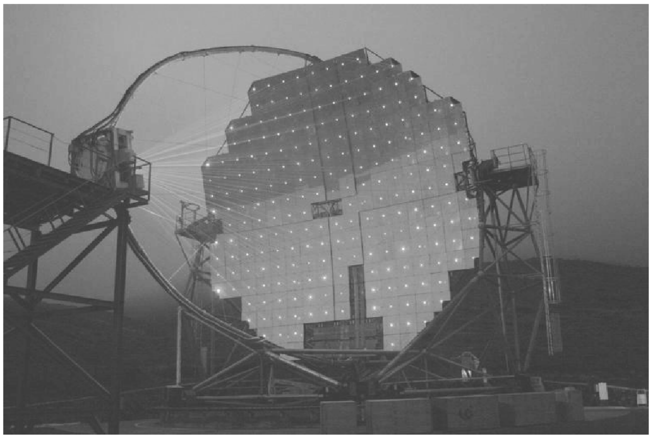

Fig. 1. MAGIC with the AMC lasers on. Due to the occasional dense fog one could see the scattered light from individual laser beams. Photo: courtesy R. Wagner

2.3 Discussion on the novelties

The carbon-fibre structure allowed us to make the telescope body reasonably stiff while keeping the weight at very low level. Low weight is essential for rapid repositioning of the telescope in the case of a fast gamma ray burst alert from satellite detectors. Also, the low temperature expansion coefficient of carbon fibre makes it preferred material for construction of large-scale instruments like MAGIC. An *all-Al* mirror has very similar optical performance compared to a usual glass mirror. On top of that it has several important advantages compared to glass mirrors:

- the "sandwich" type *Al* mirrors used for MAGIC weigh ~2 times less compared to the glass mirrors of the same size
- an *all-Al* mirror is somewhat cheaper compared to a glass one
- because of the production method by using a digitally controlled milling machine, one can easily produce mirrors with any given radius of curvature.

The last point above was quite important when producing the mirrors for MAGIC: because of the varying radius of curvature along the parabolic shape reflector radius we had to produce in total 11 groups of mirrors with different radii of curvature. The very high resolution camera of MAGIC of the pixel size of 0.10° in its central part together with the fine granularity $F/1$ tessellated optics (providing a spot size of $\leq 0.10°$) will allow to measure the tiny differences in the shapes of gammas from other imitating backgrounds like hadrons and muons. These shall provide strong background suppression and high sensitivity. The total increase of the quantum efficiency of the PMTs of $\sim 25\%$ because of the

- shape of the light guides and
- the "milky" layer of the wavelength shifter deposited on the PMT window

allows to convert substantially more light into electrical charge [7]. This can be seen as a strong increase in the mirror area of the telescope which in its turn translates into a correspondingly lower threshold setting. Note that it is much more expensive to construct a telescope with larger mirror area compared to an equivalent option of using light sensors with higher (or boosted up) quantum efficiency.

3 Performance of the telescope at very low energy threshold setting

One may assume that when entering a new energy domain with a pioneering instrument one can encounter unexpected surprises. Although the Monte Carlo simulations show that in fact the telescope can successfully operate above the energy threshold of $30 GeV$ one shall keep in mind that some backgrounds like, for example, light from numerous bright stars in the field of view could, at least in the initial phase of operation, pose serious constraints in lowering the threshold. The preliminary studies show that after "classical" image analyses of Monte Carlo data the main remaining background is due to the electromagnetic showers initiated by hadrons (by π°s). Note that images of the latter type, except for whenever applicable angular and orientation parameters, should be very similar to electromagnetic shower images induced by gamma rays. This can play a role of ultimate limiting the sensitivity factor. The other components due to the electron showers and due to the so-called isolated muons are few times less intense compared to the above mentioned one. Even under the above mentioned sensitivity limiting factors the telescope shall still have very high sensitivity allowing to measure a statistically significant gamma ray signal from strong sources like the Crab Nebula just in a few minutes time. Also, one has to mention that because of the changing character of air shower images at very low energies when they are becoming "patchy" often with few "islands" of concentrated charge because of *a)* lower number of produced secondary particles in the shower and *b)* increased fluctuations in height (read along the image long axes) because of the more extended geometry (the low energy showers develop higher in the atmosphere where the air density is low) the "classical Hillas" type analysis is becoming not very efficient. We are developing new analyses methods for higher sensitivity.

3.1 Better sensitivity and precision with more telescopes

As it is now established in the TeV energy regime adding up of more telescopes (the so-called *stereo* regime) is increasing the sensitivity of the installation roughly proportional to $\sqrt{N}$ where N is the number of telescopes. In the *sub-100 GeV* energy regime probably we expect that some other aspect of the multi-telescope approach, namely *the coincidence character* will play a more dominant role allowing one to lower the threshold setting in spite of strong backgrounds. Along with on-going activities within the feasibility study of even larger and lower threshold and/or advanced camera telescopes for enhanced sensitivity as a next step the MAGIC collaboration is going to construct the second MAGIC telescope, probably on some 80m distance from the first MAGIC telescope. The construction will start already in 2004 and the second telescope will be completed at the end of 2005.

4 Conclusions

The MAGIC telescope is starting its operation. The first gamma ray signals from strong sources will be measured very soon. After a few months of debugging and understanding of the telescope's performance the gamma source hunting can start in full power. The construction of the second MAGIC telescope for enhanced sensitivity will start soon.

Acknowledgements. I thank many of my colleagues from the MAGIC collaboration for useful discussions on the topic of this report.

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