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Status of the second phase of the MAGIC telescope

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Abstract: The MAGIC 17m diameter Cherenkov telescope will be upgraded with a second telescope with advanced photon detectors and ultra fast readout within the year 2007. The sensitivity of MAGIC-II, the two telescope system, will be improved by a factor of 2. In addition the energy threshold will be reduced and the energy and angular resolution will be improved. The design, status and expected performance of MAGIC-II is presented here.

Introduction

The 17m diameter MAGIC [1] telescope is currently the largest single dish Imaging Atmospheric Cherenkov telescope (IACT) for very high energy gamma ray astronomy with the lowest energy threshold among existing IACTs. It is installed at the Roque de los Muchachos on the Canary Island La Palma at 2200 m altitude and has been in scientific operation since summer 2004. Within the year 2007 MAGIC is being upgraded by the construction of a twin telescope with advanced photon detectors and readout electronics. MAGIC-II, the two telescope system, is designed to achieve an improved sensitivity in stereoscopic/coincidence operation mode and simultaneously lower the energy threshold.

All aspects of the wide physics program addressed by the MAGIC collaboration ranging from astrophysics to fundamental physics will greatly benefit from an increased sensitivity of the observatory. The expected lower energy threshold of MAGIC-II will have a strong impact on pulsar studies and extend the accessible redshift range, which is limited by the absorption of high energy γ-rays by the extragalactic background light. Simultaneous observations with the GLAST satellite, which will be launched by the end of 2007, will allow detailed studies of the high energy phenomena in the Universe in the wide energy range between 100 MeV and 10 TeV.

Detailed Monte Carlo studies have been performed to study the expected performance of MAGIC-II [2]. In stereo observation mode, i.e. simultaneously observing air showers with both telescopes, the shower reconstruction and background rejection power are significantly improved. This results in an better angular and energy resolution and a reduced analysis energy threshold. The overall sensitivity is expected to increase by a factor of 2 (see figure 1). Following the results of a dedicated MC study showing moderate dependence of the sensitivity on the distance of the two telescopes the second MAGIC telescope has been installed at a distance of 85 m from the first telescope.

In order to minimize the time and the resources required for design and production the second MAGIC telescope is in most fundamental parameters a clone of the first telescope. The lightweight carbon-fiber epoxy telescope frame, the drive system and the active mirror control (AMC) are only marginally improved copies of the first telescope. Both telescopes will be able to reposition within 30-60 min to any sky position for fast reaction to GRB alerts.

Newly developed components are employed whenever they allow cost reduction, improve reliability or most importantly increased physics potential of the new telescope with reasonable efforts. Larger 1 m^2 mirror elements have been developed for MAGIC-II reducing cost and installation efforts.
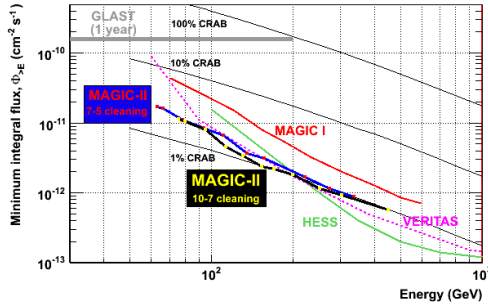
Figure 1: MAGIC-II system sensitivity compared with other existing experiments (MAGIC-I, HESS and VERITAS). The Crab flux is also shown for comparison.

The newly developed MAGIC-II readout system features ultra fast sampling rates and low power consumption. In the first phase the camera will be equipped with increased quantum efficiency (QE) photomultiplier tubes (PMTs), while a modular camera design allows upgrades with high QE hybrid photo detectors (HPDs). A uniform camera with 1039 identical 0.1^o field of view (FoV) pixels (see figure 2) allows an increased trigger area compared to MAGIC-I.

The entire signal chain from the PMTs to the FADCs is designed to have a total bandwidth as high as 500 MHz. The Cherenkov pulses from γ-ray showers are very short (1-2 ns). The parabolic shape of the reflector of the MAGIC telescope preserves the time structure of the light pulses. A fast signal chain therefore allows one to minimize the integration time and thus to reduce the influence of the background from the light of the night sky (LONS). In addition a precise measurement of the time structure of the γ-ray signal can help to reduce the background due to hadronic background events[3].

The fully installed structure of the second MAGIC telescope can be seen in figure 2. In the following the main new developments are discussed.

Figure 2: In the foreground the second MAGIC telescope. The structure is already fully installed. In the background the first MAGIC telescope which has been in scientific operation since summer 2004.

Mirrors

Like in MAGIC-I the parabolic tessellated reflector consists of 249 individually movable 1 m^2 mirror units, which are adjusted by the AMC depending on the orientation of the telescope. While in MAGIC-I each mirror unit consists of 4 individual spherical mirror tiles mounted on a panel, MAGIC-II will be equipped with 1 m^2 spherical mirrors consisting of one piece.

Two different technologies will be used for the production of the 1 m^2 mirrors [4]. Half of the mirror tiles will be all aluminum mirrors consisting of a sandwich of two 3 mm thick Al plates and a 65 mm thick Al honeycomb layer in the center. During production the sandwich is already bent into a spherical shape, roughly with the final radius of curvature. The polishing of the mirror surface by diamond milling is done by the LT Ultra company. Finally, a protecting quartz coating is applied. The reflectivity $refl$ and the radius R_{90} of the circle containing 90% of the spot light have been measured to be around $refl = 87\%$ and R_{90} = 3 mm.

The other half of the mirrors will be produced as a 26 mm tick sandwich of 2 mm glass plates around a Al honeycomb layer using a cold slumping technique. The frontal glass surface is coated with a
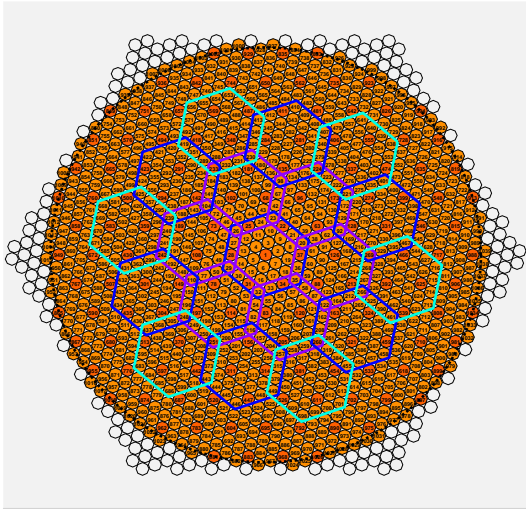
Figure 3: Schematics of the MAGIC-II camera. Only colored pixels in a round configuration will be equipped. The hexagonal shapes indicate the trigger region.

reflecting Al layer and a protecting quartz coating. The glass-Al mirrors show a similar performance as the all Al mirrors.

Camera

A modular design has been chosen for the camera of the MAGIC-II telescope [5]. Seven pixels in a hexagonal configuration are grouped to form one cluster, which can easily be removed and replaced. This allows easy exchange of faulty clusters. More importantly, it allows full or partial upgrade with improved photo detectors. The 3.5^o diameter FoV will be similar to that of the MAGIC-I camera. The MAGIC-II camera will be uniformly equipped with 1039 identical 0.1^o FoV pixels in a round configuration (see figure 2).

In the first phase increased QE PMTs will be used. The Hamamatsu R10408 6 stage PMTs with hemispherical photocathode typically reach a peak QE of 34% [6]. The PMTs have been tested for low afterpulsing rates (typically 0.4%), fast signal response ($\sim$1 ns FWHM) and acceptable aging properties.

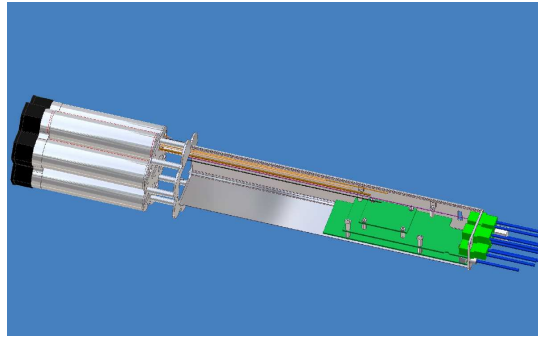Hamamatsu delivers PMT modules which include a socket with a Cockcroft-Walton type HV gener-

Figure 4: Technical drawing of a MAGIC-II camera cluster with 7 pixels.

ator. The PMT socket and all the front-end analog electronics is assembled to form a compact pixel module. The broadband opto-electronic front-end electronics amplifies the PMT signal and converts it into an optical pulse, which is transmitted over optical fibers to the counting house.

A cluster consists of 7 pixel modules and a cluster body which includes common control electronics, power distribution and a test-pulse generator (see figure 4). On the front side the PMTs are equipped with Winston cone type light guides to minimize the dead area between the PMTs. The slow control electronics sets the pixel HV and reads the anode currents, the HV values and the temperature of each pixels. It is in turn controlled by a PC in the counting house over a custom made RS485 and VME optical link.

Special care has been taken to minimize the weight and the power consumption of the camera. A water cooling system ensures very good temperature stabilization.

In a second phase it is planned to replace the inner camera region with HPDs [7]. These advanced photo detectors feature peak QE values of 50% and will thus significantly increase the sensitivity for low energy showers. The flexible cluster design allows field tests of this new technology within the MAGIC-II camera without major interference with the rest of the camera. Upon successful test the whole central region of the camera will be equipped with HPDs.
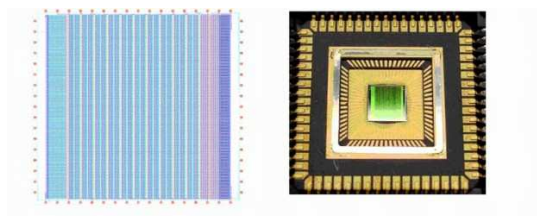
Figure 5: Microphotograph of the Domino chip (left) and inside the package (right).

Readout

The optical signals from the camera are converted back to electrical signals inside the counting house. The electrical signals are split in two branches. One branch is further amplified and transmitted to the digitizers while the other branch goes to a discriminator with a software adjustable threshold. The generated digital signal has a software controllable width and is sent to the trigger system of the second telescope. Scalers measure the trigger rates of the individual pixels.

The new 2 GSamples/s digitization and acquisition system is based upon a low power analog sampler called Domino Ring Sampler (see figure: 5). The analog signals are stored in a multi capacitor bank (1024 cell in DRS2) that is organized as a ring buffer, in which the single capacitors are sequentially enabled by a shift register driven by an internally generated 2 GHz clock locked by a PLL to a common synchronization signal. Once an external trigger has been received, the sampled signals in the ring buffer are read out at a lower frequency of 40 MHz and digitized with a 12 bits resolution ADC. The analog sampler, originally designed for the MEG experiment, has been successfully tested on site and showed a very good linearity and single photon discrimination capability.

Data management is performed by 9U VME digital boards which handle the data compression and reformatting as well. Every board hosts 80 analog channels plus auxiliary digital signals for trigger and monitor purposes. For a 1 kHz trigger rate and a 2 GHz frequency sampling, the data throughput can be as high as 100 MBytes/s thus being a challenge for modern data transmission and storage solutions. The data are transferred to PCI memory via Gbit optical links using the CERN S-link protocol and to the mass storage system.

Trigger

The trigger system of the second telescope like the trigger of the first telescope is based on a compact next neighbor logic. However, the uniform camera design allows an increased trigger area of 2.5^o diameter FoV. This increases the potential to study extended sources and to perform sky scans.

When the two telescopes are operated in stereo mode a coincidence trigger between the two telescopes will reject events which only triggered one telescope. This reduces the overall trigger rate to a rate which is manageable by the data acquisition system.

Acknowledgments

References

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