A new camera for the HESS phase II experiment


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Abstract. The HESS experiment is now fully operational with the four telescopes installed by the end of December, 2003. Many galactic and extragalactic objects have been observed since operation began and the detection of various sources has proven the performance of the detector and validated the technical options chosen. The collaboration is currently studying the next phase of the HESS project. The detector system currently in operation has a threshold around 100 GeV. Many sources such as pulsars, micro-quasars, or neutralino annihilation are expected to emit gamma radiation at lower energy. The second phase of the HESS experiment consists of an additional larger telescope positioned in the centre of the existing four-telescope array. The new system may reach a threshold as low as 10–20 GeV in single telescope mode and about 50 GeV in coincidence with the four other telescopes. It will also improve the sensitivity of the existing system above 100 GeV. The construction should start next year and the installation is expected to take place in 2008, less than one year after the launch of the GLAST satellite. After a brief overview of the HESS phase I experiment, we will describe the upgraded parameters of the HESS camera. Then the set-up and expected performance are presented.

INTRODUCTION

The HESS experiment[1] is a new generation of Imaging Array of Cherenkov Telescope (IACT). It takes advantage of the three main evolutions of the previous generation of experiment: telescopes are equipped with large mirrors, increasing the collection efficiency; the online acquisition system is based on the stereoscopy of four units to reject efficiently the background and to improve the image reconstruction; and lastly the cameras have large fields of view (for the observation of extended sources but also searches for new objects in the vicinity of the pointed target) with fine granularity (for a better image reconstruction) and fast electronics (to minimize the dead-time). These characteristics makes HESS the most efficient apparatus available at the current time for the study of high energy gamma rays above 100 GeV, and the recent results presented this summer at various conferences prove its excellent performance. The detection of galactic sources such as the Crab Nebula[2] at a sensitivity of $29 \sigma/\sqrt{N}$ at high
zenith angle, the scan of the galactic center region[3] and extragalactic objects such as PKS 2155-304 with a significance of 45σ or Mrk 421[4] detected in less than 12 hours at 96σ, or more impressive the sky-map of the SNR RXJ1713.7-3946[5] where for the first time in gamma rays we can see an image of an extended source with a resolution of the order of that obtained at other wavelengths. In the current context and to advance our understanding of the VHE gamma-ray sky, two solutions for the future can be considered. The extension of the current array to more telescopes may allow simultaneous observation of different object but also, with enough telescopes, one can envisage the possibility of performing a full scan of the sky with a subset of telescopes while at the same time performing detailed examination of TeV candidates with others. Another possibility is to enlarge the energy range of detection by decreasing the threshold of the experimental system. This second solution has two advantages: it offers the possibility to see more objects emitting at lower energy such as pulsars or micro-quasars; and it permits a better overlap with the future GLAST satellite.

THE HESS II CAMERA

To decrease the energy threshold it is necessary to increase the light collection efficiency. This parameter depends mainly on the size of the reflector of the telescope, the Winston cone geometry and reflectivity for concentrating the light onto the active part of the photocathode, and the efficiency of the phototubes. The new HESS telescope consists of a large steel alt-azimuthal structure 50 metres high with a weight of 230 tonnes located in the middle of the HESS I telescope square array. The dish holds 824 mirror tiles assembled on a parabolic structure. Such structure introduce a lower time dispersion than the Davis-Cotton mirror geometry used for the first four telescopes, which allows the integration window to be decreased but increases the point spread function. Each tile has an hexagonal shape and is supported by a system which performs individual alignment. The total reflector size is about 647 m² (compared to 107 m² for HESS phase I). The Winston cones have an hexagonal geometry so as to minimize the dead zone between phototubes. They are moulded in polycarbonate and with an aluminium coating for a reflectivity of about 75% for incident angles lower than 30°, which corresponds to the angular size of the dish. New processes of aluminization are under study to increase the quality of the inner face reflectivity. The phototubes used by HESS I were provided by the Photonis Company. The XP2960 exhibits good performance in quantum efficiency (peak at 35%), after-pulse rate, and peak-to-valley ratio (~ 1.4) for reasonable cost. New solutions are under study in collaboration with this company to improve their performance. Different processes of fabrication are under test, with flat and hemispherical entry windows.

Mechanical design of the Camera

The camera is made up of 2048 pixels distributed in 128 drawers. The pixel size is smaller than 0.1° which provides a total FoV of 3.5°. The mechanical structure is
approximately a cylinder of 2.5 metres diameter, 1.9 metres long. With a focal length of
35 metres, the mechanical stress implies that the total weight should not exceed 2 tonnes.
The mechanics can be roughly divided into three parts. In the centre of the camera a
pigeon-hole plate receives the 128 removable drawers. All drawers are identical and,
as they are fixed by only two screws, they can be easily replaced. A drawer contains 16
phototubes, with their active bases, two analogue cards for the front-end data acquisition
storage and the first-level trigger. In front of these drawers a large plate holds the 2048
Winston cones that concentrate the light on the active part of the photo-multipliers. At
the back, there is room for the electronic crates of the DAQ and part of the trigger,
the power supply, and the network devices. On the front and back side, lids close the
full system. Due to the size of the new camera, the front lid is divided in two parts,
and is controlled remotely by pneumatics. As for the HESS phase I camera, only three
connections to the ground will be present, one for the power, a second for the network
and probably a final one for the stereoscopic system event tagging. In HESS phase II, this
new camera will also be a fully-integrated system. The cooling system should dissipate
about 10 kWatt of power. The temperature will be controlled by 8 vortex-cooling systems
which inject pressurized air. The vortex principle provides two airflows, a hot flow
ejected from the camera and a cooled flow injected inside. Fans are distributed inside the
body of the camera to improve the mixing of air inside the whole volume. Temperatures
will be checked by sensors distributed over all the camera.

![Figure 1. Mechanics of the HESS II camera](image)

**Camera Electronics**

The main characteristics of the HESS phase I cameras[6] are fast electronics, pro-
viding a trigger decision in less than 70 ns, signal digitization at 1 GHz, and a system
fully-integrated in the camera. Based on the experience gained with HESS I, a new cam-
era will be built to improve the dead-time of the data acquisition and the sensitivity of
the detector.

The HESS phase I readout channel was based on the usage of analogue ring memories
(ARS0) initially developed for the ANTARES[7] experiment by the CEA/DAPNIA-SEI,
which sample the incoming signal at 1 GHz. New memories named SAM (“Swift
Analogue Memory”) are currently being developed for HESS phase II to improve the performance compared to the previous version. A new chip prototype will be built during the summer containing 2 channels of 256 cells each, input bandwidth of 300 MHz, with cross-talk estimated to be less than 0.1%. The sampling rate is controlled by an external clock and can be changed from 500 MHz up to 2 GHz. The readout speed has been improved to reach 10 MSamples/s and, including the synchronization after an event, the total dead-time should not exceed 2.3 µs. A second version of this chip is already under development and will include (in addition to the memories) forty 12-bit ADCs, which correspond to one ADC for each of the 20 cells to be read out per channel. A memory is composed of a matrix of 16x16 elements and the incoming analogue signal is distributed to each of the 256 cells individually and buffered inside an amplifier. The depth of these memories is sufficient to store the signal until the trigger decision arrives. When a trigger arrives, taking into account the trigger delay due to the propagation of the signal inside the trigger channel, a pointer is set at the position of the beginning of the signal and the event is read.

The signals coming from phototubes is split in two channels with different gains, sampled and stored inside the buffers. Then a window of each memory around the signal region is read out, and digitized by a 12-bit ADC at 80 MSamples/s for storage inside a 1k × 18bits FIFO. 50 events can be stored in the FIFO. A second-level trigger is under study to reject some of these events with more sophisticated criteria (see [8]). Accepted events are read out by an FPGA which reads information from the 8 phototubes per analogue card. The information is formatted and sent over 16 custom-designed busses to the central DAQ system installed in the rear of the camera. The data transfer from drawers to FIFO cards involve master/slave transactions. The masters are the drawers that handle the busses when a transfer window is available. There is only one slave for each bus of 8 drawers, that is the FIFO card. This card satisfies requests from drawers. A system of data counters is used to signal when the transfer has been completed. This information is scanned by the processor, interrupted few micro-seconds previously by the trigger system. The CPU accesses the FIFO card though a cPCI bus and performs data transfer of 64-bits words at 33 MHz. Extrapolating from the HESS phase I experiment, an event can be read in 120 µs, in which case data acquisition cannot exceed 8 MHz without adding more CPU cards per cPCI bus.

The HESS camera trigger is based on a sectorization of the pixels. A minimal number of pixels in coincidence above a programmed threshold is identified inside a sector of 64 pixels. There were 38 sectors in HESS I and only one of these sectors is sufficient to start an acquisition of the camera. In HESS II the same principle is used to trigger the camera but the number of sectors increases to 96 to cover all the new camera. In the new telescope the pixel size will be smaller but the same number of pixels per sector will be used. The effect will be to limit the combinations and therefore limit the number of random triggers due mainly to night sky background. The dead-time of the camera depends on the speed of the different components of the electronics. The first limit comes from the analogue memories used for data storage. The new readout speed is fast enough to introduce less than 0.5% dead-time at 3 kHz acquisition rate if no additional dead-time occurs. To limit the rate of background event readout and sending to the farm processor, an additional second-level trigger will be developed based on event topology already mentioned.
PERFORMANCES

In addition to the low threshold, a advantage of the future HESS II system is to provide an additional information on the image of the showers detected by the four smaller telescopes. Above the HESS I threshold the better image-definition in the new camera will improve the energy and angular resolution in the reconstruction. Simulations were done with both CORSIKA and KASCADE event generators and two different simulations of the HESS I detector adapted to HESS II. Evolution of the energy resolution as a function of the gamma energy and angular resolution of the direction of the incoming gamma ray are still under investigation. Also, different sizes of PM and readout window size are under study. With a mirror of 647 m$^2$, the new telescope is expected to reach a threshold of 10–20 GeV. Preliminary simulations have been made with different configurations.

![Graphs showing energy and angular resolution](image-url)

**FIGURE 2.** Predicted sensitivity of the new large telescope compare to the performance of HESS I system. The left plot show the improvement of the collection area, an order of magnitude is reached at 100 GeV. The right distributions show the threshold of the new telescope, the hybrid system and the HESS I telescope in single and stereoscopic operating mode.

When operating in mono-telescope mode the simulations predict a threshold of about 10–20 GeV (defined as the maximum of the flux for a $E^{-2}$ spectrum (blue down triangle distribution in the figure above). In coincidence with at least one of the four HESS I telescopes and with an adapted trigger criteria, the energy threshold is estimated at about 50 GeV (green up triangle). In comparison, the HESS-I threshold in stereoscopic (red square) and single telescope operation mode (black circle) are shown. The figure below is the estimated sensitivity of the HESS II system for a Crab-like source. In grey, the sensitivity of the big telescope in single-telescope mode show a comfortable overlap with the predicted sensitivity of the GLAST satellite. We can also notice an improvement of the current system at higher energy. The HESS phase II experiment combined with the GLAST experiment will provide the opportunity in 2008 to cover the Austral sky from 100 MeV up to 100 TeV. The effective area predicted by simulation for the big telescope (black circle in the left-hand picture) exhibits an improvement of one order of magnitude at the threshold of the HESS I system (red square curve). The threshold for the single big telescope is estimated at 15 GeV. The trigger configuration used in this estimation is the same as that currently in operation for the HESS I system.
FIGURE 3. HESS phase II sensibility as a function of the energy (grey curve). Compared to HESS phase I performance (black curve) and the future GLAST satellite (upper left curve).

CONCLUSIONS

The HESS experiment has proven the efficiency of the apparatus developed for high energy gamma detection and opened a new area of research. The new array equipped with an additional large telescope will lower the threshold of detection down to 10–20 GeV and improve the sensitivity of the full system by a factor of two. The construction of the HESS II telescope should start next year and the installation is expected to take place in 2008, less than one year after the launch of the GLAST observatory. These two detectors will be able to enlarge the window of gamma-ray investigation by six orders of magnitude, from 100 MeV up to 100 TeV in the Austral sky.

REFERENCES