THE HESS ARRAY
A NEW SYSTEM OF 100 GEV IACTs
FOR STEREOSCOPIC OBSERVATIONS

GERMAN HERMANN
Max–Planck–Institut für Kernphysik Heidelberg
Postfach 103980, 69029 Heidelberg, Germany

We are planning to build a system of imaging atmospheric Cherenkov telescopes for stereoscopic observations. The system will consist of 16 telescopes with a mirror area of about 82 m^2 each. Detailed simulations on the performance of the system predict a flux sensitivity F_{min}(E>100 GeV) of better than 10^{-12} photons/cm^2s and an energy threshold below 100 GeV.

1 Introduction

In the past various techniques have been applied to detect very high energetic γ–rays with ground based instruments. Up to now the imaging atmospheric Cherenkov technique, pioneered by the Whipple observatory, has proven to be the most sensitive. Detections of γ–rays from two galactic sources, the Crab Nebula and PSR B1706-44, and from the two AGNs Mrk 421 and Mrk 501 have demonstrated the potential of the IACT technique.
Further developments of this technique will most probably tend into two directions:

- Pushing down the energy threshold of the telescopes to several 10 GeV, to finally fill the gap between ground based and satellite borne detectors. This objective requires Cherenkov telescopes with large mirrors of more than 100 m^2 area and/or new types of high quantum efficiency photon detectors. Currently several experiments and projects, like 'Super CANGAROO' or 'MAGIC' follow this approach.

- The emphasis of the second approach is on a significant increase of the sensitivity of the telescopes in the energy range above about 100 GeV. This goal can be reached by improving the background rejection efficiency and by an increase of the detection rate, using a system of multiple medium size telescopes in stereoscopic mode, with detection areas up to ~ 1 km^2. Projects like 'VERITAS' and the proposed 'HESS' telescope array follow this direction.

The principle of the stereoscopic technique is based on the simultaneous observation of air showers with several telescopes under widely different angles. This allows a full 3–dimensional reconstruction of the showers with an unambiguous determination of the shower direction, core location and primary energy on an event by event basis. Furthermore, by triggering the telescopes in coincidence background triggers generated by the light of the night sky or by local muons will be strongly suppressed. Therefore it is possible to lower the energy threshold of the system in comparision to independent single telescopes. Ultimately the sensitivity of a stereoscopic system is significantly better than that of independent operating telescopes in the given energy range.
The power of the stereoscopic approach has been for the first time successfully demonstrated by the HEGRA–experiment (*Hermann et al.* [2] and *Daum et al.*[1]). The very encouraging results have lead us to propose the **H***igh* **E***nergy* **S***tereoscopic* **S***ystem* which will be described in the following.

2 The HESS Telescope Array

The HESS IACT array aims for an improvement in sensitivity by an order of magnitude with respect to existing IACT installations. Taking advantage of the stereoscopic approach the HESS array will serve as an instrument for spectroscopic and morphological investigations of sources with an extension of up to 1^o and as an effective sky survey instrument. It will consist of 16 IACTs with reflectors of about 10 m diameter, equipped with high resolution cameras with a large field of view ($\geq 4^o$), to be able to observe moderately extended sources. The concept of HESS is based on quadrangular cells consisting of 4 telescopes, which build logical units concerning the trigger (fig. 1). Initially we plan to build a single 4 telescope cell. In a second step the array will be enlarged to a 3×3 and finally 4×4 array. The effective area and thus the minimal detectable flux of pointlike sources in a survey mode then simply scales by the number of cells. It is also foreseen to be able to operate the sytem in a mode, where it is subdivided into 4 independent cells, for monitoring of different sources simultaneously.
The expected performance of HESS has been studied in large detail with Monte Carlo simulations (Aharonian et al.[3]). These simulations have been performed for a very conservative choice of the hardware parameters, namely an effective mirror area times photon conversion efficiency of 10 m^2, a pixel size of 0.25^o and a pixel threshold of 25 photoelectrons. Therefore the following numbers serve as a lower limit of the expected performance:

- The Energy Threshold will be below 100 GeV. About 50 % of 100 GeV γ–showers incident on the area of the array will be detected. At 200 GeV the detection efficiency is nearly 100 %.
- The angular resolution is expected to be better than 0.1^o on an event by event basis. This allows high sensitivity for pointlike sources and also the possibility to resolve the emission region of moderately extended sources. In addition the absolut location of a source can be determined with a precision of an arc minute or better.
- An energy resolution of better than 20 % for individual γ–rays will allow spectroscopic investigations especially the search for cutoffs in the energy spectra.
- Improved background suppression. Compared to single telescopes an IACT system provides already on the trigger level improved background supression. Noise triggers due to the light of the night sky or triggers caused by local isolated muons are strongly suppressed

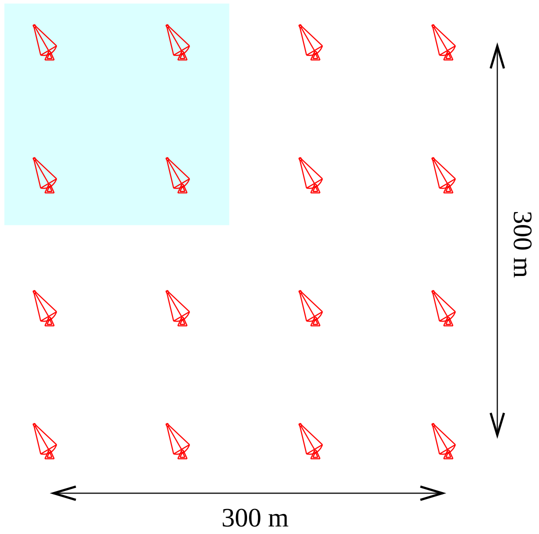

Figure 1: Principle layout of the HESS IACT array.

for a system of IACTs. Also the hadronic background is already suppressed on the trigger level, due to the inhomogeneous lateral light distribution of hadronics showers. With the knowledge of the shower energy and the core distance, provided by an IACT system, improved differential γ–selection criteria can be applied on the analysis level. The combined rejection of hadronic events amounts to 10^3. For pointlike sources the directional information allows an additional suppression of the order of 10^2.

- The flux sensitivity, pushed by the improved background supression, will be in the 'milli–Crab' range, about 1 order of magnitude below the sensitivity of present IACT intrumentations.

3 Technical Concept

The design concept for the HESS IACT system is based on experience gained in the construction, installation, commissioning and with the operation of the HEGRA IACT system. The MPI für Kernphysik in Heidelberg has developped the high resolution cameras with their readout electronics and most of the trigger and DAQ system, as well as the complete control software. Due to the large number of telescopes of the new system, an efficient production and commissioning and a high reliability will be crucial aspects of the design. Therefore, and to reduce the technical risk, profit should be taken from standard technologies, like for example the construction of large communications antennas. In the following paragraphs some basic conceptual ideas on the construction of the HESS IACT–array are presented.

3.1 Mirror Structure and Telescope Mount

The energy threshold of the system is governed by the size of the mirror of the telescopes. With a typical effective photon to photoelectron conversion factor of about 0.15, the images of 100 GeV γ–showers will consist of more than 100 photoelectrons given a mirror area of about 70 m^2. This is ample not only to trigger the camera, but also to perform reasonable imaging. To provide a small extra margin we aim for a mirror area of about 80 m^2.
The reflector will consist out of 420 single mirrors with a diameter of 50 cm, arranged following the Davis Cotton design. The focal length of the reflector will amount to 12 m to 15 m. Given this design the mirror structure fulfills the basic requirements: the resulting point spread function of the reflector should be of the order of 0.05^o rms width or below, determined by the minimal

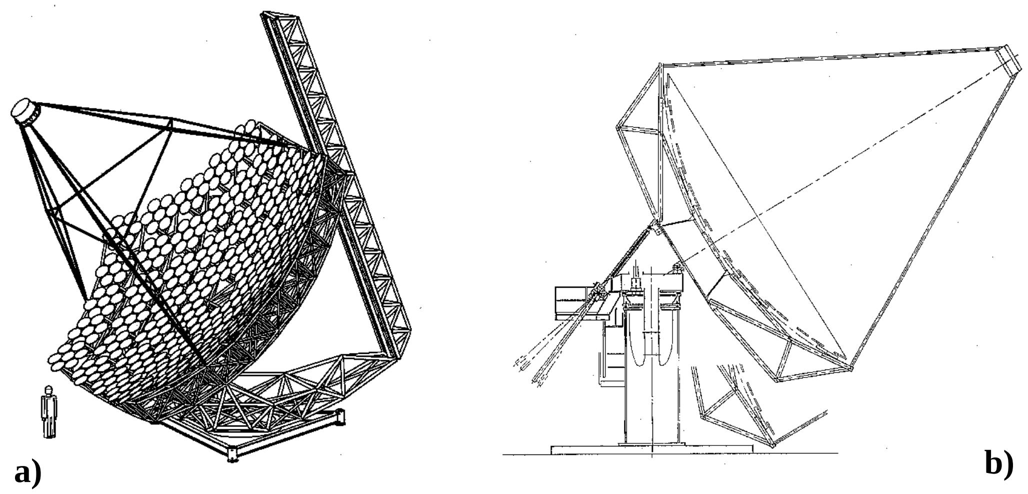

Figure 2: Design studies on telescope mounts with a modified alt–azimuthal mount a) and with a 'standard' mount derived from communications antennas b).

envisaged pixel diameter of 0.15^o. The image quality should be homogeneous througout the field of view of the camera with a diameter of about 4^o. Finally the arrival time dispersion of the Cherenkov photons generated by by the reflector should be below the intrisic width of the light pulse of γ–showers of about 3 nsec.
To simplify the installation and the adjustment of the mirrors, 7 mirrors are arranged on a rigid, pre–adjusted cluster. The clusters will be remotely adjustable by actuators, to be able to compensate for possible deformations of the mirror dish. The mirrors will most probably be built on aluminum in bulk form. As surface protective either anodization or a quarz coating is envisaged.

For the construction of the mirror dish and the mount different options are under consideration. Finally the most cost effective solution which fulfills the specifications will be adopted. Basically the telescope mount has to make possible precise tracking, on the order of 0.01^o, to allow to fully exploit the advantages of the high angular resolution of stereoscopic measurements. Any direction above 10^o elevation should be accessible. The mount and the dish have to be stiff enough that deflections of the camera under its own weigth and the weight of the masts remain below 1/2 of the minimal pixel size of 0.15^o. Finally the mount has to withstand wind speeds of up to 200 km/h and should allow operation at wind speeds up to 50 km/h.
Two design options have been studied so far: a modified alt–azimuthal mount with a space frame dish and a standard mount, derived from the construction of communications antennas.
In the first option the mirror dish is build of a space frame with triangular cells, on which the mirror clusters are mounted (Fig. 2 a). The dish is supported by three, symmetrically distributed points, conntected to a modified alt–azimuthal mount. Two of the support points define the altitude axis, while the third point is moved by a linear drive for the elevation adjustment. For the azimuthal positioning the whole structure rotates around a vertical axis. The principle advantage of this design is a strong reduction of deformations, since the dish is supported on three points, from which also the camera masts emerge. Moments generated by the camera weight and by the weight of the structure are taken by the support points. The second option is based on the construction of communications antennas in the 10 m to 20 m range. In this construction the mechanisms for the rotation of the telescope are relatively compact (Fig. 2 b). The dish is supported by a central hub, from which radial trusses emerge. The altitude adjustment is driven by a spindle. The design proposed by the manufacturer makes use of off–the–shelf components, which allows rather moderate costs per unit. Studies on the static and

dynamic properties under gravitational– and wind load of these two and other options are in progress.

3.2 The Camera and Readout Electronics

The cameras for the telescope system will have a field of view with a diameter of 4^o or more in order to be able to observe moderately extended sources ($\leq 1^o$), one of the main aims of the experiment. For the same reason the pixel size will be uniform within the camera to attain a flat acceptance for γ–showers over the field of view. The size of the pixels is a compromise between costs and performance. We consider two options for the camera, depending on the costs per channel of the readout electronics (see below): in the case of a standard readout electronics a pixel size of 0.25^o would be chosen, resulting in a 271 pixel camera. If a cheap, highly integrated custom designed electronics could be installed, the camera will consist of 768 pixels with a favourable diameter of 0.15^o. As photon detectors photomultipliers (PMTs) with standard Bialkali photocathodes will be used. At present and in near future no other, more sensitive detectors are available, which fit the requirements for an IACT camera. However the mechanics of the camera and the front–end electronics will be built in way, that the photon detectors can be exchanged easily without major changes as soon as suitable detectors with higher quantum efficiency are available.
The readout electronics of the HESS telecopes will be based on the VME–standard. A number of modules initially developed for the HEGRA–array can be adopted without major changes. Each telescopes will be equipped with the same electronics. Up to several CPUs at each telescope will be used for to read out the event data and to control the telescope parameters. For the digitization of the camera signals wave form recorders will be installed to fulfill the following requirements:

- Integration time: the signal from air showers is concentrated within 3 to 5 nsec. To minimize the fluctuations in the signal induced by the background light of the night sky, the charge integration time should not be much longer. We aim for an effective integration time of about 10 nsec.
- Time and pulse shape information: from the shape of the digitized pulses a reduction of night sky induced background light can be achieved. Furthermore from the arrival time of the camera signals, the relative arrival time of the shower front at the telescopes can be measured, allowing an independent determination of the shower direction. A time resolution of about 1 nsec is mandatory.
- Signal history: the telescopes will only be read out, when at least two telescopes of a cell have fired. Mainly due to propagation delays of the cables, the trigger signal will be delayed by up to 2 μsec. The digitization system has to provide an appropriate signal buffer.

Two options for the digitization system are envisaged: the first option is a FADC system similar to that used in the HEGRA telescopes. Taking advantage of further developments, sampling frequencies from currently 120 MHz up to 200 MHz could be achieved. The FADC modules incorporate ring buffers for the digitized signals with a depth of 4k, ample to wait for the system trigger. In principle this FADC system could be used as it is. However, due to the overall costs per channel, this system would dominate the camera cost and would only be implemented in a 271 pixel camera. The second option is based on switched capacitor pipeline ASICs for the storage of the analog signals (Fig. 3). Using a clocked shift register the capacitors are connected to a read/write line with frequencies of up to 300 MHz and the signal voltage is sampled with with this frequency. For the read out the clock is stopped and selected cells of the pipeline

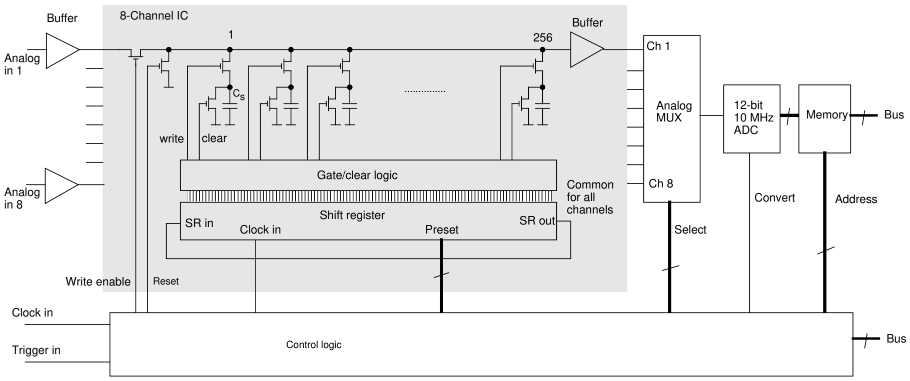

Figure 3: Switched capacitor pipeline for sampling and storage of the input signal at frequencies between 250 and 300 MHz.

are connected to an external ADC at lower frequencies of 5 to 10 MHz. Several channels can be multiplexed to a 10 to 12 Bit ADC. This rather inexpensive solution would allow to build high granularity cameras with up to 800 pixels. However this option pushes technological limits, involving a certain risk.

3.3 The Trigger and Data Acquisition System

The trigger of the HESS array will be organized on three levels. On the first level a telescope trigger is released if the signals of a minimum number pixels exceed a preset threshold. Depending on the pixel size between 2 and 4 pixels will be required. The information on the triggered pixels is then latched to the second level topological trigger, which requires a minimum number of triggered pixels to form a compact cluster. Such a condition reduces dramatically the rate of night sky induced noise triggers, while maintainig most of the γ–ray triggers. The signal of the second level trigger is routed to the third level, global trigger, which fires if a minimal number of telescopes within a cell have triggered. To compensate arrival time differences of the shower front at the telescopes, depending on the inclination, the incoming trigger signals are delayed by programmable delay lines. The global trigger signal together with an event number is then sent to the telescopes of the cell and to the neighboring telescopes, where the read out of the event is started. Depending on the kind of camera and the exact trigger condition, typical trigger rates of the system will be of the order fo 50–100 Hz.
The event data read out by the CPUs of the telescopes will be transmitted to a data server via a local Fast Ethernet network. For the event building, quality control and quasi online analysis a small farm of central computers (Pentium Pro or PowerPC based PCs) will be installed.

4 Status and Outlook

Detailed simulations on the properties of the telescopes system have been finished. At present we are investigating different options on the design of the mirrors, the telescope mount and of the readout electronics. Also investigations for the site of the HESS telescope system are under way. A detailed *Letter of Intent*[4] has been published in early 1997 and collaborators are invited to participate. The first cell of the stereoscopic system could start operation in the year 2000.

1. A. Daum et al., in preparation
2. G. Hermann et al., these proceedings
3. F. Aharonian et al., *Astroparticle Phys.*, in press
4. F. Aharonian, W. Hofmann, H. Völk et al., Max–Planck–Institut für Kernphysik Heidelberg; see also: http://eu6.mpi-hd.mpg.de/~wh/hess.html