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The HESS project camera, tests, and status

M. Punch, for the HESS collaboration

Physique Corpusculaire et Cosmologie, Collège de France et Université Paris VII, France (IN2P3/CNRS)

Abstract. The cameras for the HESS atmospheric Cherenkov detector (described in a companion paper) use fast electronics and a sophisticated trigger situated just behind the focal plane comprised of 960 PMs ($0.16°$ pixel size, $5°$ field of view), from which the digitized information is sent via the on-board acquisition system to the central data collection farm. The ensemble of the camera characteristics (electronics, mechanics, Winston cones, local acquisition system) is described, and the tests performed are detailed. The installation of the first such camera takes place this autumn.

1 Introduction

The HESS atmospheric Cherenkov detector is a next-generation high-resolution stereoscopic imaging system which, for the phase I, will consist of four telescopes with $\sim 100\,\mathrm{m}^2$ mirror area and $\sim 15\ \mathrm{m}$ focal length. The focal plane detectors contain imaging cameras with 960 photo-multipliers ("PMs") of $0.16°$ pixel size, for a $5°$ camera field of view. The installation of the first telescope is proceeding at the site in Namibia. Further details are provided in a companion paper (Hofmann *et al.*, 2001).

In this paper, we describe in particular the cameras for phase I, which are currently under construction in Paris. One key innovation for these cameras is the localization of all the electronics (trigger, digitization, read-out, and local data-acquisition) within the camera, which communicates with the central acquisition system via ethernet. In consequence, we avoid the signal loss and broadening of the Cherenkov pulses from the images which would result from their travelling over tens of metres to a remote electronics. Thus, our trigger can take advantage of the short intrinsic time-spread of pulses to reject events due to night-sky background ("NSB"). Since the trigger response is rapid and also does not need to be sent from a remote point, we can digitize the images after a short storage time in analogue memory, thus obviating the need for expensive flash-ADCs. The mechanics for such a complex camera needs to be adapted for ease of access and replacement of defective components, especially since the telescopes will be operation at a rather remote site.

The status (on June 1$^{\mathrm{st}}$, 2001) of the mechanics, Winston cones, electronics, and local data-acquisition system is given.

2 Mechanics

The mechanics for the HESS camera (shown in Fig. 1) is designed for ease of access to the electronics. The PMs and their associated electronics are grouped into 60 "Drawers" (Sect. 4.1) which can be plugged-in interchangeably from the front of the camera after removal of the plate holding the Winston-cone light collectors (Sect. 3). The position of this plate defines focal plane, and is accurate to 0.1 mm relative to the PM photo-cathodes.

The rear of the camera contains a retractable rack on telescopic rails which can be slid out after manually opening the back lid, for access to the crate electronics and low-voltage supplies (Sect. 4.2). The side hatches permit access to the rear of the drawer pigeon-hole plate, which holds the ventilation fans for each drawer and the cables from the fixed connectors (into which the drawers are plugged) to the crate electronics and power supplies.

The camera lid can be operated remotely using a pneumatic system (including pneumatic logic) at $7\mathrm{bar}$ with a $100\mathrm{l}$ reservoir, which has the advantage of closing automatically in case of loss of power. The lid is required to be quite rigid, since it also contains a system of LEDs for each PM for on-site calibration purposes, and so requires pneumatic "hooks" to hold the lid closed.

The camera's size is such that it would fit within a $\sim 1.5\,\mathrm{m}$ cube. The total weight of the camera, including mechanics, electronics, and low voltage supplies, is estimated to be $820\ \mathrm{kg}$. The mechanics for the first camera has been completed, and final operating tests are underway.

Correspondence to: M. Punch (punch@in2p3.fr)

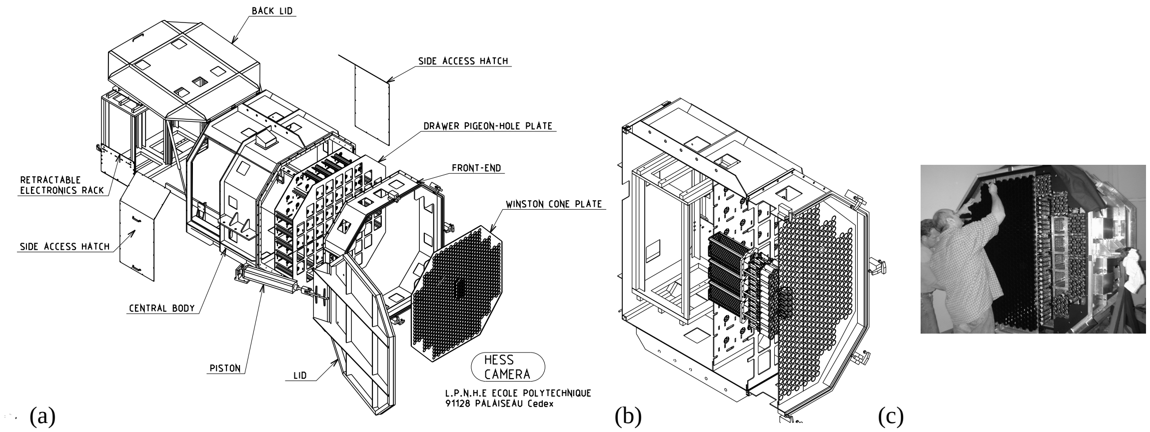

Fig. 1. Mechanics of the HESS camera: (a) exploded view, showing all elements (b) cut-through view of closed camera with three drawers in place (c) test mounting of drawers and cone plate with unaluminized cones.

3 Winston Cones

The Winston cone optical elements are designed so as to minimize the dead-space between the photo-cathodes of the PMs, while additionally cutting out albedo light from angles beyond the mirror as viewed by a PM. For the HESS telescopes, the cut-off is set to be at 30°, corresponding to the maximum input angle from the mirror for a PM at the edge of the camera. They are moulded from polycarbonate in two half-cones which are aluminized and protected with a quartz overcoating before assembly and mounting on the Winston-cone plate. Moulding also permits an hexagonal (rather than circular) cross-section to be used, further limiting the dead-space by allowing the cones to be packed as a honeycomb, while losing little of the ideal cut-off characteristics.

The form of the response in angle has been verified on a test-run of moulded samples using a test-bench consisting of light-source sent through a liquid fibre to the focal point of parabolic mirror to give parallel beam which is automatically scanned over a range of angles. Using a PM with a larger photo-cathode than the input hexagon of the cone, we measure that $\sim 82\%$ of the light at normal incidence which enters the cone arrives at the photo-cathode.

Each assembled cone will be tested to verify that it has acceptable characteristics, using a test-bench in which the PM/cone view a back-lit screen which covers the same range of solid angle as the mirrors. This test-bench allows an automatic test of 40 cones sequentially.

The half-cones for all of the phase I cameras have now been produced, and their aluminization is proceeding.

4 Electronics

The electronics for the camera is separated both mechanically and conceptually in two parts: the “Drawers”, each containing the electronics associated with a group of 16 PMs; and the “Rack”, containing the data-acquisition crate (with the CPU and camera trigger, and other general electronics) and the low voltage supplies. One common element of the custom-built cards in both parts is the use of Altera FPGAs to implement most of the complex logic functionality (bus communications, etc.). These are programmed using VHDL (Very High-speed Description Language) which permits all functions to be tested by simulation.

4.1 “Drawer” Electronics

Each of the 60 drawers contains 16 PMs with their active bases (which enable their high-voltage or “HT” to be individually controlled using a low-voltage input), connected to two cards (referred to as the “Analogue Memory” or “MA” cards) containing the read-out and trigger electronics (each card treats the signals from 8 PMs) which are mounted on a Slow Control (“SC”) card.

The operation and test of the MA cards has been described in detail in Punch *et al.* (1999). As shown in the schematic of this card (Fig. 2), the signal from each PM is sent to a high-gain and low-gain channel (up to 100γe, and from 16–1600γe respectively, in order to have a sufficient dynamic range), as well as to the trigger electronics. The analogue signals are written at $1\mathrm{GHz}$ to a 128-cell deep analogue memory (implemented as a circular buffer) with 9-bit linearity and dynamic range of 1000. When a trigger signal arrives (70–$80\,\mathrm{ns}$ after the event), writing to memory stops and the samples from a pre-defined time range of the analogue memories (the “read-window”) is read out to a multiplexed 12-bit ADC for digitization. The digital sum (i.e., the integral of the signal over time) of the samples is calculated on the MA card and sent to the local acquisition system. For test purposes, the read-out may optionally be done in “sample” mode.

The trigger logic in implemented partly on each MA card and partly in the Rack. Signals from a PM can be individually enabled to take part in the trigger under slow-control. Each PM pulse goes to a comparator (the level of which is set in slow-control, for example to the equivalent of $\sim 4\gamma$e) and the ensuing logic signals of the eight PMs on the card are

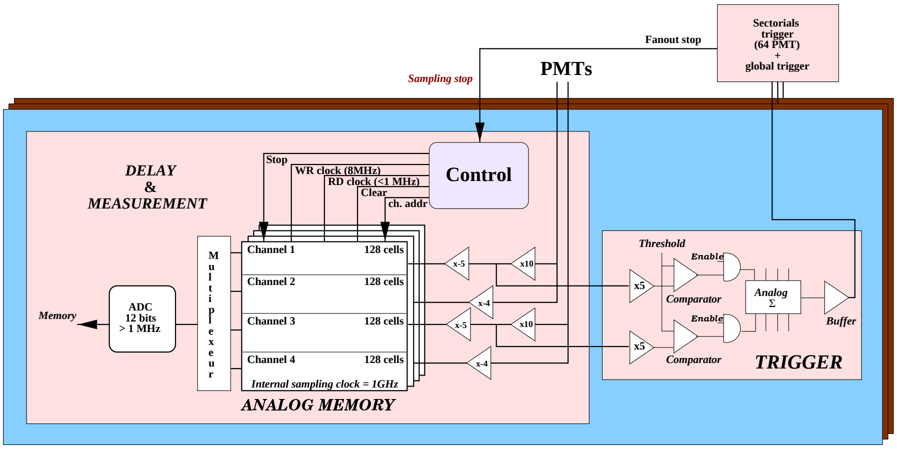

Fig. 2. Schematic of the Analogue Memory card. The signal from each PM divides into three branches with different amplifications, two of these are written to the analogue memory (high- and low-gain channels), the third goes to the trigger logic.

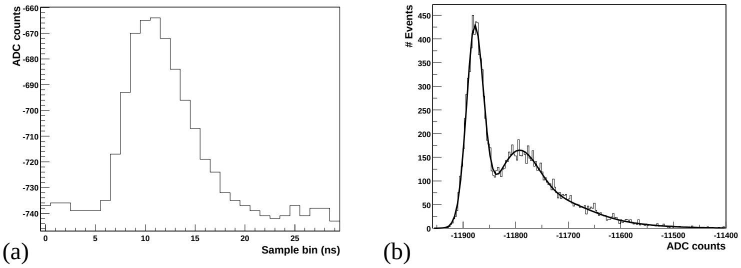

Fig. 3. Response of the Analogue Memory cards: (a) a sampled 10γe pulse from a PM as read by the card after storage in the memory and subsequent digitization (the read-window used in actuality runs from 5 to 21 ns on this plot), (b) histogram of the response to a 1γe signal, showing the pedestal, the single-γe peak, and a fit to these.

sent to an analogue adder. The result is buffered and sent to the camera trigger in the Rack.

The MA and SC cards for the first camera have been built and tested, with measurement of the amplification and linearity for the electronics channels, comparator switching, scaler operation, and tests of all DAC/ADC functions and the several tens of slow-control I/O data words, for currents, voltages, temperatures, etc.

For drawer assembly, PMs are sorted according to their HT and response to blue light (as provided by the manufacturer) prior to insertion, in order to have an homogenous response and especially to have equivalent transit times to $< 1.5\,\mathrm{ns}$ so that the trigger pulses overlap comfortably.

The full drawers are tested with their complement 16 PMs as in the final camera, using a laser pulse (at $337\,\mathrm{nm}$, FWHM $\sim 3\,\mathrm{ns}$). For these tests, firstly the optimal start of read-window relative to the trigger pulse is set, see Fig. 3(a) (since the time for a drawer will depend on the PM transit time and also the ARS response time which has been measured in a preceding test). Then the HT of each PM is set to give a gain of 2×10^5 using the single photo-electron (γe) response, where the single γe falls at 80 d.c. above the pedestal in the high-gain channel (see Fig. 3(b)). The pedestals, HT currents and base currents are measured with and without a continuous light to imitate NSB; the shift in pedestal with increased illumination can be noted for these a.c.-coupled PMs. The response to a 10γe signal is also measured, with and without the simulated NSB. Finally, measurements of the scaler response as a function of threshold with simulated NSB illumination is taken in order to determine the after-pulse probability for each PM. The testing for approximately half the drawers of the first camera has been completed at this time.

4.2 Rack Electronics

The principal element in the retractable rack is the mixed Crate, shown schematically in Fig. 4. One half of the crate uses the new CompactPCI bus (or cPCI) norm, to house commercial cards such as the central processor and GPS, as well as some custom-built cards which require the transfer of much data. The other half uses a “custom bus” which was necessary for many of the custom-built cards (Trigger Management, Camera trigger, Trigger fan-out, LED control) for the following reasons. These cards require voltages and especially currents which cannot be furnished by any standard bus; the cPCI bus is limited to 8 slots in its simplest implementation; and these cards don’t need to send or receive large quantities of information from the CPU, so the bus interface can be made simpler, slower, and cheaper.

The trigger logic in the rack implements a sectorial trigger over all the camera. The 8-PM trigger sums provided by the MA cards are summed into 64-PM overlapping sectors, implemented on 6 trigger cards on the Custom Bus. If a sufficient number of PMs in one of these sectors are above the threshold simultaneously, the camera is triggered and the trigger signal is fanned-out (using two CustomBus cards) to all drawers so the the read-out may begin. Counters are provided for all Sector triggers, and also for the camera trigger rate, in order that dead-time can be correctly taken into account. As can be seen, the camera can trigger over all of its sensitive area, which is well-adapted for extended or off-centre sources.

Read-out of data from the drawers is performed using a specially designed 16-bit parallel bus dubbed the “BoxBus”. For speed purposes, there are four BoxBuses in the camera

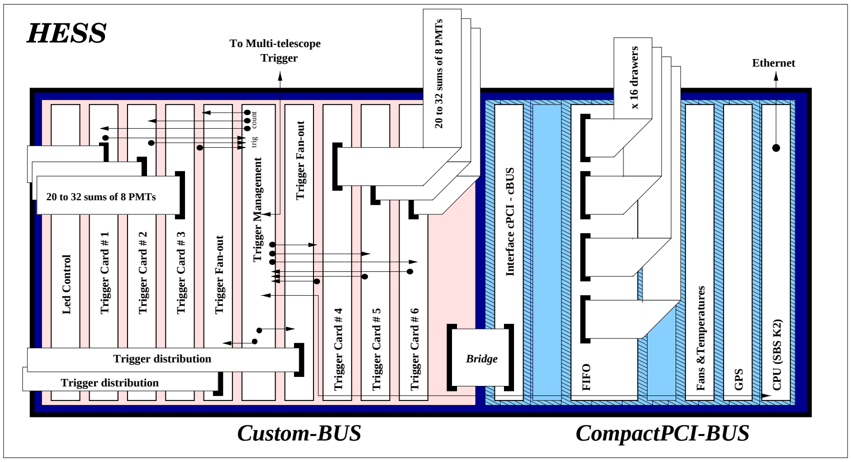

Fig. 4. Schematic view of the Mixed CustomBus/CompactPCI crate. Custom bus half holds essentially the electronics pertaining to the trigger logic, while the CompactPCI half holds the processor card (crate controller), the GPS, the FIFO card which reads/writes to the drawers over the BoxBus, and some control/readout for ventilation fans and temperatures.

(one per 15 drawers) which are read in parallel into a single card containing four sets of FIFOs. A separate set of four FIFOs is used in the same manner to send slow-control data to the drawers (which can be addressed individually or in broadcast mode). The data is “pushed” into the FIFOs (i.e., it is sent by a drawer as soon it has received data and the BoxBus is ready) using a token passing system, and according to a strict message passing protocol which aids in verifying the integrity of the data. Both the event data and the slow control data are sent on the same bus, but using separate token lines for each. The trigger signal is sent to the CPU through a programmable I/O register card which allows interrupts. This I/O card is situated on one of the CPU’s PMC slots (PC Mezzanine Card) and also serves as an interface to receive Stereo event numbers and associated data from the central telescope trigger system. The total time for a read cycle for a Cherenkov event (from trigger, to FIFO filling, to FIFO readout by the CPU) is estimated at $\sim 500\,\mu\mathrm{s}$.

Low Voltages are provided from four modules (for 2×30 drawers, and for the cPCI and CustomBus halves of the crate) designed to our specifications by Wiener, housed in the retractable rack, which can be controlled and monitored or over a CAN-Bus interfaced to the CPU on another PMC card. The camera is supplied with $350\,\mathrm{V}$ d.c. at $6\,\mathrm{kW}$.

Of the cards in the crate, the commercially-supplied cards (CPU, GPS, I/O register) have been purchased, the FIFO card, cPCI/CustomBus bridge, and the Trigger Fan-out cards have been built and tested, the sector Trigger cards and Fan/-Temperature cards are ready for testing, the Trigger Management card have been designed, with the LED control card design (already partially tested) being finalized.

5 Local telescope Data-Acquisition System

The data-acquisition is based on the Linux operating system and the cPCI bus norm. The “Hard-Hat” Linux distribution permits the system to be developed and maintained from a remote machine, which is necessary since we use a disk-less processor. The processor card, which controls the mixed cPCI/CustomBus crate, is a K2 from SBS, equipped with a PowerPC 750 CPU running at $400\,\mathrm{MHz}$ with $128\,\mathrm{MB}$ of SDRAM. The system kernel, acquisition programs, and configuration are stored in $8\,\mathrm{MB}$ of on-board flash memory, which allows the acquisition to be launched rapidly. The system is remotely controllable with a terminal server through which the CPU console can be accessed and which additionally allows the processor card to be reset remotely.

The cPCI is accessible over a 32-bit address range, and allows transfers of 64-bit data-words at $33\,\mathrm{MHz}$, so the four 16-bit FIFOs on the FIFO card can be read-out simultaneously. A Dual Bridge and Memory controller (using DMA, Direct Memory Access) can transfer up to $4\,\mathrm{kB}$ at a time, so two transfers will be needed for the readout of a full event (of size $4.8\,\mathrm{kB}$). The acquisition program, written in “c”, communicates with the central system using TCP/IP sockets; on one hand with the CORBA server of the central processor farm for the data transfer, and on the other with the client server (written currently in perlTK, to be modified to CORBA/Python in the future) for control of the camera. The system should be able to handle the expected $\sim 600\,\mathrm{Hz}$ local trigger rate, where the stereoscopic System rate is expected to be $\sim 300\,\mathrm{Hz}$ for a 2-telescope coincidence, so $100\,\mathrm{MBit}$ ethernet is needed for the data transfer.

6 Conclusions

The construction and tests of the mechanics, Winston cones, and electronics for the first camera of the HESS atmospheric Cherenkov detectors is nearing completion. The design and programming of the local data acquisition system is proceeding. The on-site installation of this camera is expected for early autumn, 2001, with the three subsequent cameras in 2002–2003.

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