A Compact High Energy Camera for the Cherenkov Telescope Array

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Abstract: The Compact High Energy Camera (CHEC) is a camera-development project involving UK, US, Japanese and Dutch institutes for the dual-mirror Small-Sized Telescopes (SST-2M) of the Cherenkov Telescope Array (CTA). Two CHEC prototypes, based on different photosensors are funded and will be assembled and tested in the UK over the next ≈18 months. CHEC is designed to record flashes of Cherenkov light lasting from a few to a hundred nanoseconds, with typical RMS image width and length of ≈0.2° × 1.0°, and has a 9° field of view. The physical camera geometry is dictated by the telescope optics: a curved focal surface with radius of curvature 1 m and diameter ∼35 cm is required. CHEC is designed to work with both the ASTRI and GATE SST-2M telescope structures and will include an internal LED flasher system for calibration. The first CHEC prototype will be based on multi-anode photomultipliers (MAPMs) and the second on silicon photomultipliers (SiPMs or MPPCs). The first prototype will soon be installed on the ASTRI SST-2M prototype structure on Mt. Etna.

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1 Introduction
The highest energy photons are large, bright, but rare events so for CTA to achieve sensitivity a sparse array of Small Size Telescopes (SSTs) with large fields of view is required. A dual-mirror SST solution allows less expensive small plate scale focal plane detectors to be used, the resulting camera savings means a greater number of SST-2Ms can be built allowing a greater coverage on the ground. The Compact High Energy Camera (CHEC) is a camera-development project specifically with both the ASTRI[1] and GATE[2] prototype SST-2M structures. Two CHEC prototypes, one based on multi-anode photomultipliers (MAPMs) and the second on silicon photomultipliers (SiPMs), are funded to allow competing technologies to be compared. The results of this prototyping phase will then be merged into the production telescopes for CTA.

2 CHEC
The design concept for CHEC is given in Figure[1]

- Photosensors - MAPMs and SiPMs will be used for CHEC-M and CHEC-S respectively.
- Preamplifiers - Signal amplification and shaping to optimise camera triggering and readout.
- TARGET Modules - 64-channel signal capture modules based on the TARGET ASIC for data digitisation, read out, pixel-level triggering and slow control.
- Backplane Board - All 32 TARGET Modules plug directly into a large backplane PCB that provides: camera-level triggering, clock distribution, communication with the TARGET Modules and routing to the DACQ board.
- DACQ Board - High-speed serial data from the TARGET Modules are routed to the outside world. Also provides control for camera ‘peripherals’ such as the lid and calibration systems.
- Peripherals Board - An interface to the various slow control peripherals, eg calibration units, lid/shutter motor controller, ambient light sensors, etc.
- Mechanics - The internal support structure, cooling system, enclosure and lid/shutter.

The physical camera geometry is dictated by the telescope optics: a curved focal surface with radius of curvature 1 m and diameter ∼35 cm is required. Figure[2] shows the camera structure and one of the photodetector modules. In addition to the elements listed CHEC will contain a calibration
system based on LED flashers, reflecting light from the secondary mirror back on to the focal plane.

2.1 Simulations
Simulations of CHEC performance have been made using CORSIKA output, assuming perfect optics, and a custom electronics model. The following specifications are needed for CHEC-M to meet the CTA requirements for triggering:

- **Pulse Shape** (after pre-amplifier/at TARGET input): 10-90% rise-time 3.5-6.0 ns, and FWHM 5.5-10.5 ns. **Trigger logic:** analogue sum of 4 pixels, discriminated and sent to the camera trigger where a neighbour requirement and a minimum multiplicity of 2 is applied within a coincidence window. **Camera Trigger Coincidence Window:** 6-10 ns. **Time jitter on digital inputs to camera trigger:** < 2 ns for a 10 ns coincidence window, < 1 ns for a 6 ns window. **Electronic Noise:** < 0.5 mV rms per pixel on the trigger path. **Pixel to pixel gain variations:** < 25% rms (4-pixel sum).

2.2 Photosensors
The CHEC-M detector plane will contain 32 H10966B MAPMs with Super-Bialkali photocathode, rotated and tiled to approximate the 1 m radius of curvature optical focal plane. Each MAPM contain 64 pixels of size ≈ 6 x 6 mm². This corresponds to an average angular size of 0.19° when installed on ASTRI, and 0.17° installed on GATE with the PSF (θ50) smaller than 6 mm over the full CHEC field of view on both.

- **Dynamic Range** - By 1000 pe the response is 20% non-linear. As CHEC will provide full waveform data, useful information can still be extracted from saturated channels via pulse fitting (to within 5% at 1000 pe).

- **Angular Response** - The SST-2M optics result in off-axis angles of up to 70° onto the focal plane. The angular response of a MAPM channel means at 70° ~ 30% of the light is lost, but the incidence-angle averaged photon detection efficiency will be comfortably above that required over the whole camera field of view.

- **Uniformity** - As there is a single HV supply for the 64 MAPM pixels photon detection efficiency variations can not be removed and thus affect the achievable dynamic range. The effect on charge resolution is not expected to be significant, provided the gain of each channel is measured to within ~5%. Such variations also affect the trigger threshold of the camera. One solution may be to include a variable input amplifier stage in the TARGET ASIC.

- **Ageing** - The gain of the MAPM pixels is expected to decline over time in relation to the integrated anode current in the device. Tests show that for expected operating voltage and NSB level this effect is at an acceptable < 20% level over a decade of operation.

It is foreseen the MAPMs will be operated at a gain of 8 x 10⁴. The choice of SiPMs for CHEC-S will be made in Autumn 2013.

2.3 Signal Amplification and Shaping
The MAPMs must be operated at relatively low gain due to the high illumination levels from stars and the NSB. Pream- plifiers are required in close proximity to the photosensors to minimise electronic noise and to shape the output signals for digitisation.

CHEC-S will require a different preamplifier circuit to shape and amplify SiPM signals to the required range. This
development will begin in full once the SiPM for CHEC-S has been selected, but still allow the same interface to the digitisation electronics as CHEC-M.

2.4 Digitisation

Digitisation of the amplified and shaped analogue signals will be performed by the TARGET Modules developed at SLAC. Each TARGET Module will supply a single MAPM with high voltage, digitise the signals from all 64 channels, and provide these digitised signals together with trigger information to the Backplane. These modules are based on the TARGET ASIC [3]. The shaped signal from the preamps will be digitised at 500-1000 MSa/s over ~100 ns. The digitisation rate over this time results in an acceptable dead time for an expected camera trigger rate of ~200 Hz. Above saturation the pulse area can be recovered by fitting the digitised waveform, to an accuracy of ~5% at 1000 pe.

2.5 Trigger

The TARGET ASIC provides the first level of triggering for the camera. The trigger consists of the analogue sum of 4 neighbouring pixels, which is then discriminated. A camera trigger requires any 2 neighbouring trigger patches be present within a programmable coincidence time. External inputs to the FPGA from the DACQ board will also allow the camera to be artificially triggered. Due to the relatively low event rate per telescope, no inter-telescope hardware array trigger is envisaged. When a telescope triggers, all data is read out to the central location over ethernet. Triggers are compared at the central location for several telescopes to decide whether to write the data to disk. To make this possible an accurate array-time distribution / event tagging scheme is required. Within the CHEC prototype we plan to include an internal clock distribution and event-time-stamping system via a High Speed Deterministic Time Data Link (HSDTDL). The clock/array interface will be implemented on a daughter board and connected directly to the Backplane. This provides flexibility for changing the interface to match the final solution and/or try other options; for example, we are also considering the inclusion of a White Rabbit interface board [4].

2.6 DACQ and Control

The TARGET Module serialises event data for output to the Backplane via a high speed data link (HSDL) comprised of differential RX and TX pairs. Serialisation and readout of 64 channels in this way minimises the connections to modules and when combined with the conversion time translates to a dead time well below the required 5%. Both event data and control commands will be sent via this HSDL. The 32 RX and TX HSDLs from the TARGET Modules are routed to the DACQ board via the Backplane. In the current model, the interface from the DACQ board to the ‘world’ would be
A schematic of the camera structure is shown in Figure 2.

whilst the telescope is at the park position. During normal observations calibration will be performed continuously for any ambient effects.

2.7 Calibration
CHEC includes an internal multiple LED calibration system with light pulse of 3-4 ns (FWHM) at 400nm to flat-field the camera and cover a large dynamic range of illuminations, from 0.1 pe for absolute single-pe calibration measurements, up to 1000pe to characterise the camera up to and at saturation. The flasher units will be placed in the corners of the focal plane with diffusers to illuminate all pixels via reflection from the secondary mirror in a predictable way (see figure 3). The flasher system has been integrated into the camera mechanical design.

At the beginning of each evening, the camera will be illuminated by the internal LED flashers at the single pe level whilst the telescope is at the park position. During normal observations calibration will be performed continuously for flat-field and dynamic range/linearity monitoring, accounting for any ambient effects.

2.8 Mechanical structure and cooling
A schematic of the camera structure is shown in Figure 2.

The focal-plane positioning plate located at the front of the camera is responsible for the accurate positioning of the sensors. The TARGET Modules with preamplifier modules attached, are slotted through this plate and into the rack with the preamplifier module PCB flush to the surface and secured using screws. The MAPMs are then attached. The retention of the MAPMs will be provided by connectors reinforced with removable glue. A removable sealant will be used between each MAPM once they are attached to increase the retention and provide a seal against the elements.

For CHEC-S an ‘MAPM-like’ module will be constructed, to minimise changes to the mechanics. The pitch of the camera can be easily changed to accommodate different physical sized sensor blocks of 64 pixels due to the flexible ribbon cables used to remove the radius of curvature between the preamplifier and TARGET Modules.

Total power dissipation within the CHEC camera is expected to be ≤ 400 W. The resulting thermal control system consists of 4 fans coupled to a large water cooled heat sink. The fans, together with a system of baffles provide a recirculating airflow within the sealed camera enclosure.

To operate, CHEC requires power (12 V) and a chilled water supply. Both of these will be house in a ‘cabinet’ located on the telescope structure. A single multi-core fibre will carry data, control and clock signals. The software process controlling the camera is envisaged to run via a rack in the array control building.

2.9 Operational Concept
Due to the large number of SSTs and the anticipated long lifetime of CTA the reliability and maintainability requirements for CHEC will need to be superior to that of current IACT cameras, for which we are pursuing the following design routes:

- **Removable Camera** as maintenance concept. A light camera designed to be easily removable from the telescopes. The use of spare cameras and the ability to inspect all elements of a camera for maintenance in an electronics workshop environment will allow repair of multiple issues simultaneously (and additional preventative maintenance) once a threshold in the number of inoperable pixels is reached.

- **Sealed system.** The cooling solution for CHEC does not involve circulation of air drawn from the external environment thus preventing the ingress of dust into the system and makes it much easier to prevent the entrance of water/moisture into the system.

- **Extensive testing** at the prototyping stage. The test plan for CHEC is being designed to ensure that flaws in the design become apparent pre-mass-production. The accelerated ageing of electronics and vibration and environmental testing of the camera as a whole (including water-spray, salt-fog, hailstone impact tests, and thermal cycling) will identify weaknesses in the design.

3 Summary
In summary, two CHEC prototypes will be constructed using almost identical electronics and different photosensors. CHEC-M will be installed on the ASTRI prototype structure in late 2014. CHEC-S will be ready ~6 months later. CHEC will include an internal LED flasher system for calibration of the camera. The development of CHEC includes simulations of the trigger and readout performance to establish the specifications for hardware such that the CTA requirements are met.

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