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FlashCam: A Novel Cherenkov Telescope Camera with Continuous Signal Digitization

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1. VHE gamma-ray astrophysics

- Very High Energy (VHE) γ-rays: 10 GeV to > 100 TeV.
- Galactic and extragalactic sources: supernova remnants, pulsars, active galactic nuclei, maybe dark matter annihilation?, and others.
- Interstellar magnetic fields do not deflect γ-rays: they point back to source.

Detection with ground based telescopes **(Fig. 1)** possible:

- VHE γ-ray produces highly relativistic particle shower in atmosphere.
- Relativistic particles produce Cherenkov light pulses: duration O(few ns), covered area on ground O(50'000 m²).
- Structure of shower is mapped onto telescope camera.
- Shape, orientation, timing and amplitude of structure are used to determine energy and direction of primary γ-ray.

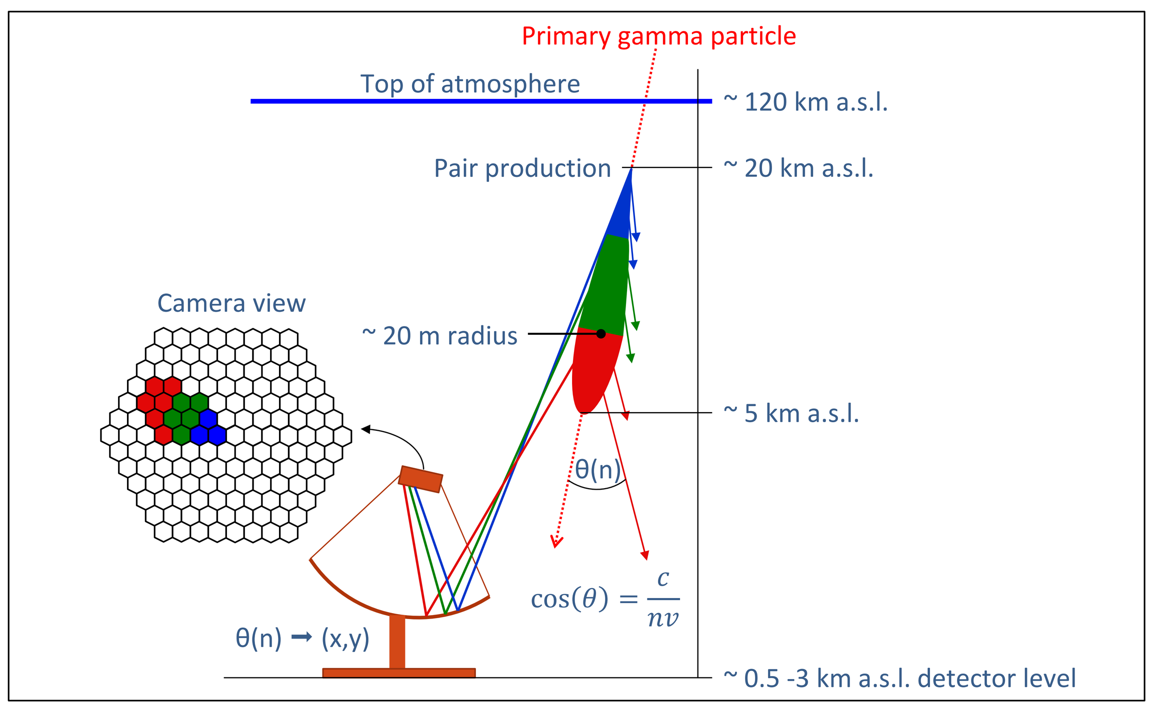

Fig.1: Working principle of detection of VHE γ-rays with a Cherenkov telescope. The tesselated mirror of the telescope maps the incoming light angle to an x-y position on the camera's sensor plane. Cameras for a 12 m diameter mirror telescope have in the order of 2000 individual pixels.

2. Cherenkov Telescope Array

- The CTA project [1] will consist of O(100) telescopes of 4m, 12m, 24m single mirror and dual mirror classes **(Fig. 2)**.
- CTA aims at a factor 10 better sensitivity than current instruments and energy coverage from some 10 GeV to some 100 TeV.
- Telescope cameras have to be very sensitive: few ns exposure time, faint light pulse (1 – 3000 photoelectrons per pixel with steep falling spectrum towards large pulses).

⇒ CTA needs a low cost high performance camera concept

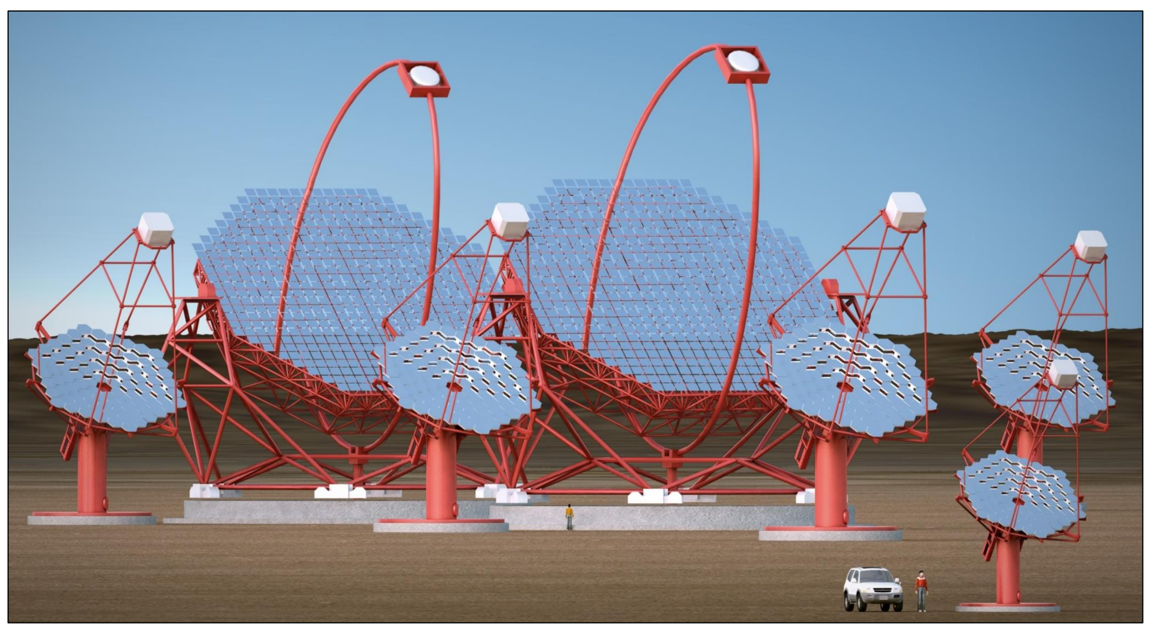

Fig.2: An artist's impression of the Cherenkov Telescope Array with three different single mirror telescope sizes.

Main FlashCam items	Power consumption
Photon detector plane (147 modules)	400 W
Readout electronics	2'600 W
Slow control, cooling, miscellaneous	≤ 1'500 W
Total	**≤ 4'500 W**

Tab.1: Power consumption of a fully equipped FlashCam with 1764 pixels.

3. FlashCam concept

The FlashCam [2] camera is based on 3 main parts **(Fig. 3)**:

- the detector plane, including the light sensors with electronics divided into modules each of 12 sensors **(Fig. 4)**,
- the readout electronics **(Fig. 4)**, where the analogue sensor signals are digitized and trigger algorithms run in FPGAs,
- the DAQ, which receives the data stream of all pixels (up to 3.8 GByte/s transmission tested), trigger information and slow control data after a trigger condition occurs.

The analogue sensor signals are transmitted differentially with ordinary CAT6 cables to the readout. The digitization of the signals is done with 250 MS/s 12 bit ADCs and allows a continuous data handling in the FPGA (Xilinx Spartan-6). The digitized data is sent to the DAQ using a raw Ethernet protocol after a trigger condition occurs.

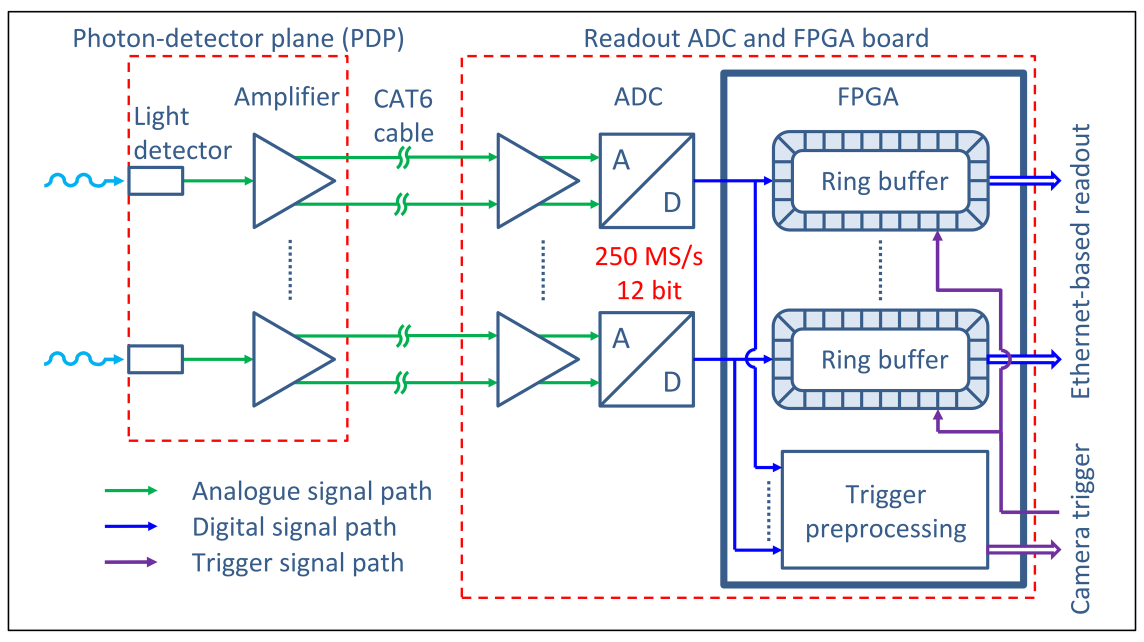

Fig.3: Schematic structure of the FlashCam camera. The detector plane is physically separated from the readout electronics. The DAQ is located in a counting house outside the camera.

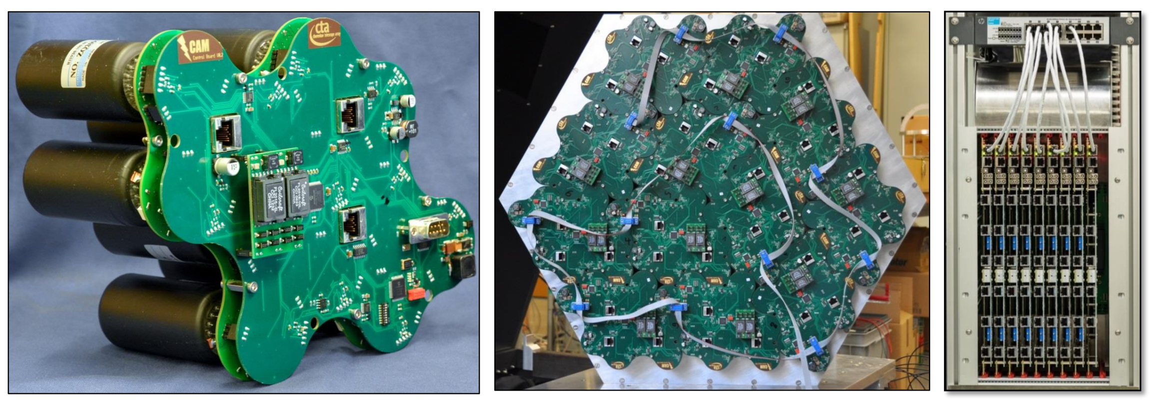

Fig.4: Left: Detector module with 12 PMTs. Analogue signals are transmitted via the three CAT6 connectors. 24 V and CAN-bus are wired to the D-Sub 9 connector. The HV Royer generators (0.5 and 1.5 kV) are implemented on the small piggyback. The two PCBs separate the control and the analogue part. **Centre:** Rear view of the 144 pixel camera with daisy-chained CAN bus. **Right:** Crate assembled with 8 ADC/FPGA boards for 192 pixels and a trigger card (on the right side). The pixel data is transmitted via a commercial switch to the DAQ. The expected throughput for a fully equipped camera is about 2 GByte/s.

4. Trigger

- Traces are preprocessed for trigger in FPGA: sum of unique *M* pixels and reduction of bandwidth to ≤ 8 bit. *M* pixel patch (P*M*) information is sent each clock cycle (4 ns) to 12 trigger cards to form patches of *N* P*M* patches around each P*M* patch. Simulations **(Fig. 5)** show best overall performance for a sum of *N*=7 clipped *M*=3 pixel patches (P3-7).
- The system is **not** limited to the sum trigger class only.
- The system runs deadtime free for trigger rates ≤ 30 kHz.

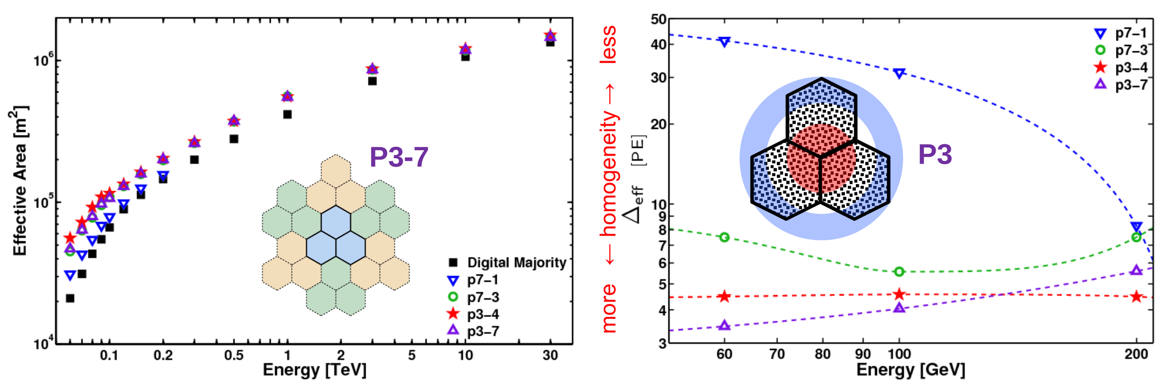

Fig.5: Left: Influence of trigger configuration on effective telescope detection area. An example of a P3-7 pixel patch is also shown. **Right:** Spatial trigger homogeneity for different clipped sum trigger configurations. Δ_{eff} describes the area between the two trigger efficiency curves of the trigger roll-off between equal inner (red) and outer (blue) areas of the basis shape (e.g P3) for each patch.

5. Performance

Many parameters of the camera have already been verified with prototype electronics. The single-pixel charge resolution, being one of the most important ones, is shown in **(Fig. 6)**. The measurements show that the requirement and the goal of CTA are both fulfilled. The single-pixel time resolution (not shown here) is better than ≤1.3 ns for signals ≥ 5 pe and likewise fulfills the CTA goal (<2 ns @ ≥5 pe).

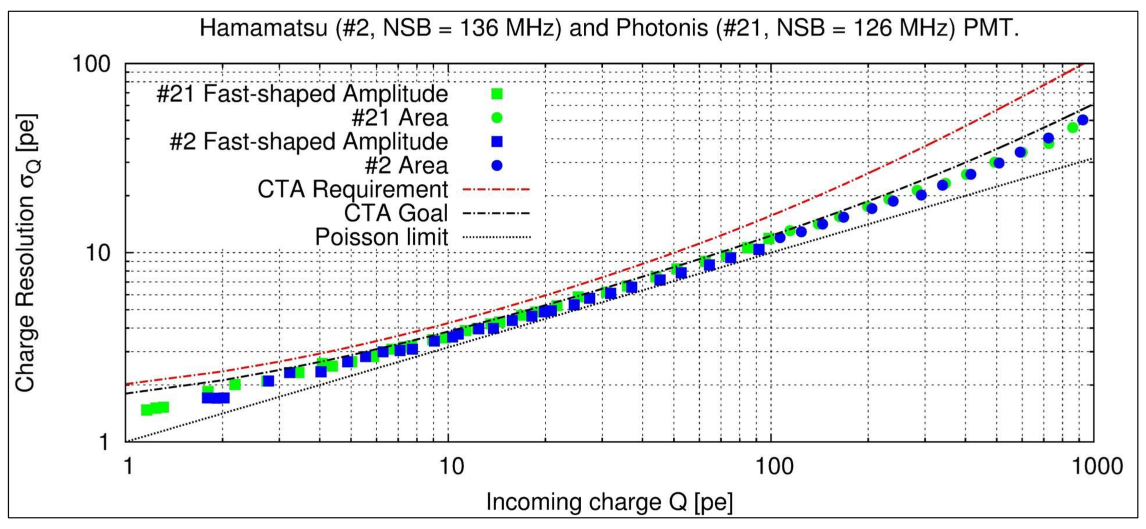

Fig.6: Measured charge resolution of two representative pixels. The red dashed-dotted line represents the CTA requirement, the black dashed-dotted line the CTA goal and the black dotted line the statistical limit of the resolution. The PMTs have been illuminated with a pulsed laser to simulate a γ-ray event and a steady light source to simulate the night sky background light (NSB). All measured values lie well below the requirements and the goal.

6. Body

The 3 x 3 x 1.1 m³ camera body **(Fig. 7)** is light and water tight and allows easy access to all components for maintenance. The total weight of the final camera is expected to be ≤1.7 t.

Fig.7: First full-size camera body with lid half closed (left), back doors closed (centre) and open with racks for the 12 readout crates and the slow/safety control (right).

Key message

- FlashCam is an excellent option for CTA cameras:
  - Commercial components used exclusively.
  - Easy maintenance due to modular construction and simple camera access (doors).
  - Easy adaption of detector plane for new sensors / pitch.
  - Dead-time-free and continuous digitization.
  - Very flexible trigger implementation using digitized traces.
- Performance validation of all components of 144 pixel test setup nearly finished:
  - All CTA requirements are fulfilled.
  - 4x10 Gbit readout successfully tested.
- Construction of a full-size camera prototype with 1764 pixels for a 12 m telescope is ongoing:
  - Camera body nearly completed.
  - Readout electronics, sensor electronics, cooling and slow control procurement in preparation.

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References

[1] M. Actis et al., The CTA Consortium, Exp. Astron. 32, 193 (2011), doi:10.1007/s10686-011-9247-0

[2] G. Pühlhofer et al., for the CTA consortium, FlashCam: A fully digital camera for the Cherenkov Telescope Array, Proc. of the 33th ICRC Rio de Janeiro (2013), astro-ph/1307.3677

Acknowledgments

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