University of Zurich[UZH]

Physik-Institut

cta cherenkov telescope array

Flash Cam

FlashCam: A Novel Cherenkov Telescope Camera with Continuous Signal Digitization

A. Gadola[1], F. Canelli[1], D. Florin[1], S. Steiner[1], U. Straumann[1], A. Vollhardt[1], D. Wolf[1], in collaboration with MPIK Heidelberg[2], Universität Tübingen[3], Universität Erlangen-Nürnberg[4], Universität Innsbruck[5]

[1] Physik-Institut, Universität Zürich, Winterthurerstrasse 190, 8057 Zürich, Switzerland; [2] Max-Planck-Institut für Kernphysik, P.O. Box 103980, D 69029 Heidelberg, Germany; [3] Institut für Astronomie und Astrophysik, Abteilung Hochenergieastrophysik, Kepler Center for Astro and Particle Physics, Eberhard-Karls-Universität, Sand 1, D 72076 Tübingen, Germany; [4] Physikalisches Institut, Friedrich-Alexander Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, D 91058 Erlangen, Germany; [5] Institut für Astro- und Teilchenphysik, Leopold Franzens Universität Innsbruck, Technikerstraße 25/8, A 6020 Innsbruck, Austria

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.
- γ-rays point back to their source because they are not deflected by interstellar magnetic fields.

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 m^2).
- Structure of shower is mapped onto telescope camera.
- Shape, orientation, timing and amplitude of mapped structure used to determine energy and direction of γ-ray.

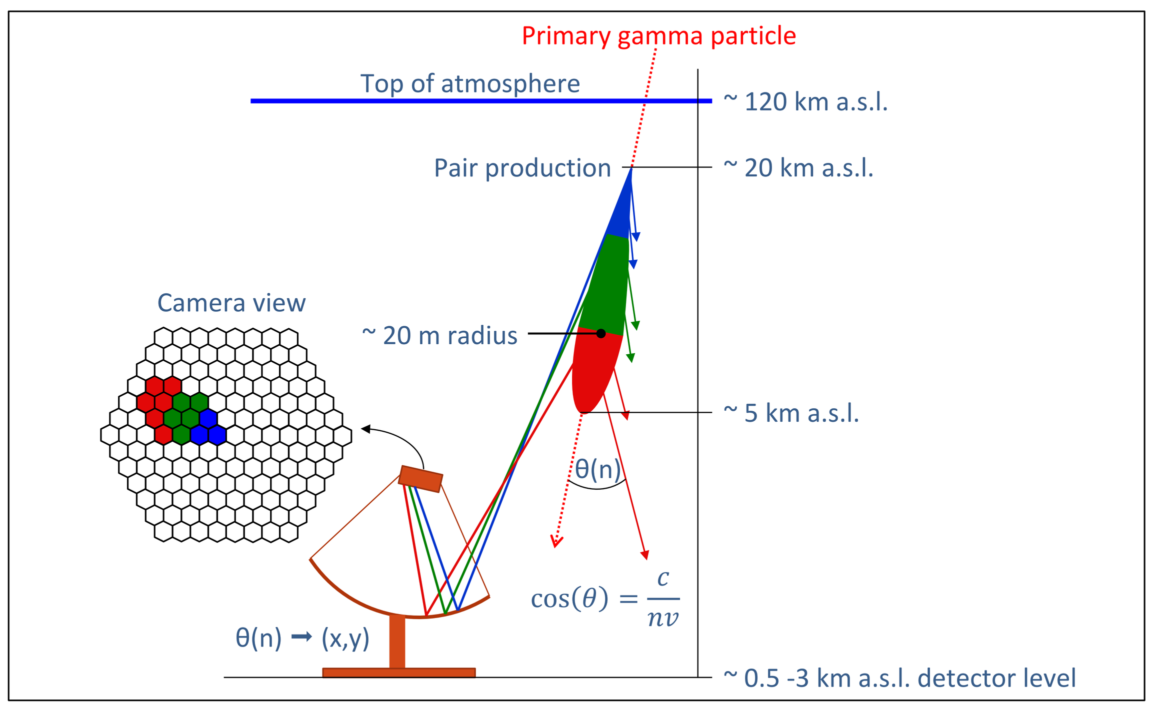


Fig.1: Working principle of detection of VHE γ-rays with a Cherenkov telescope. The tesselated mirror of the telescope maps the incoming Cherenkov light angle θ to an x-y position onto the camera's sensor plane.

2. Cherenkov Telescope Array

- Collaboration of over 1'350 scientists from 32 countries.
- The CTA project [1] will consist of O(100) telescopes of 4m, 12m, 24m mirror classes **(Fig. 2, top)** distributed on a northern and southern hemisphere site **(Fig. 3, bottom)**.
- 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 low cost, high performance concepts

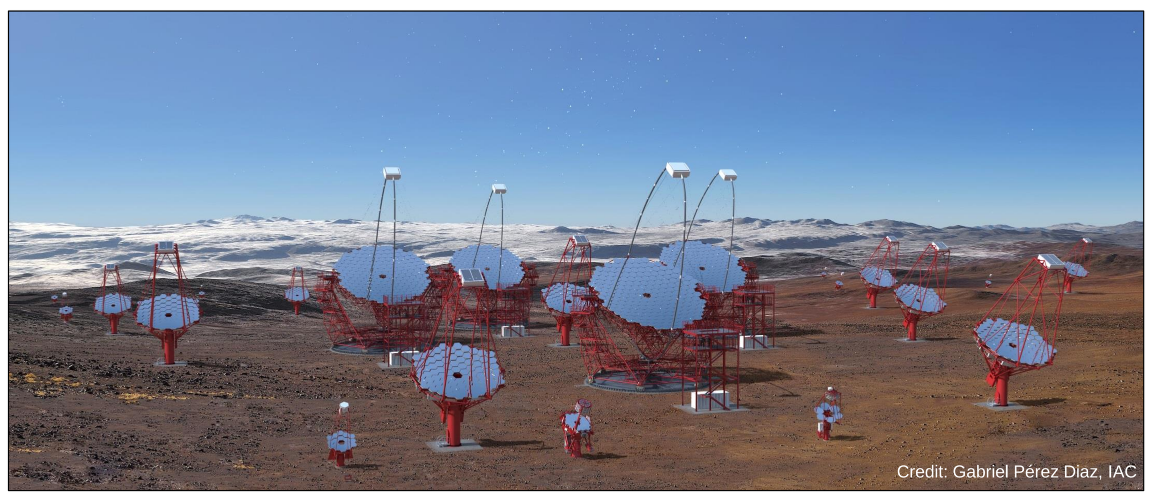


Fig.2: Top: Artist's impression of the southern telescope array. **Bottom:** Locations of the two arrays, HQ and data centre.

3. FlashCam concept

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

- the detector plane, including the light sensors with electronics, subdivided into modules with 12 sensors **(Fig. 4)**,
- the readout electronics **(Fig. 4)**, where the analogue sensor signals are digitized and trigger algorithms run on 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 which allows a continuous data handling in the FPGAs (Xilinx Spartan-6). The digitized data is sent to the DAQ using a raw Ethernet protocol.

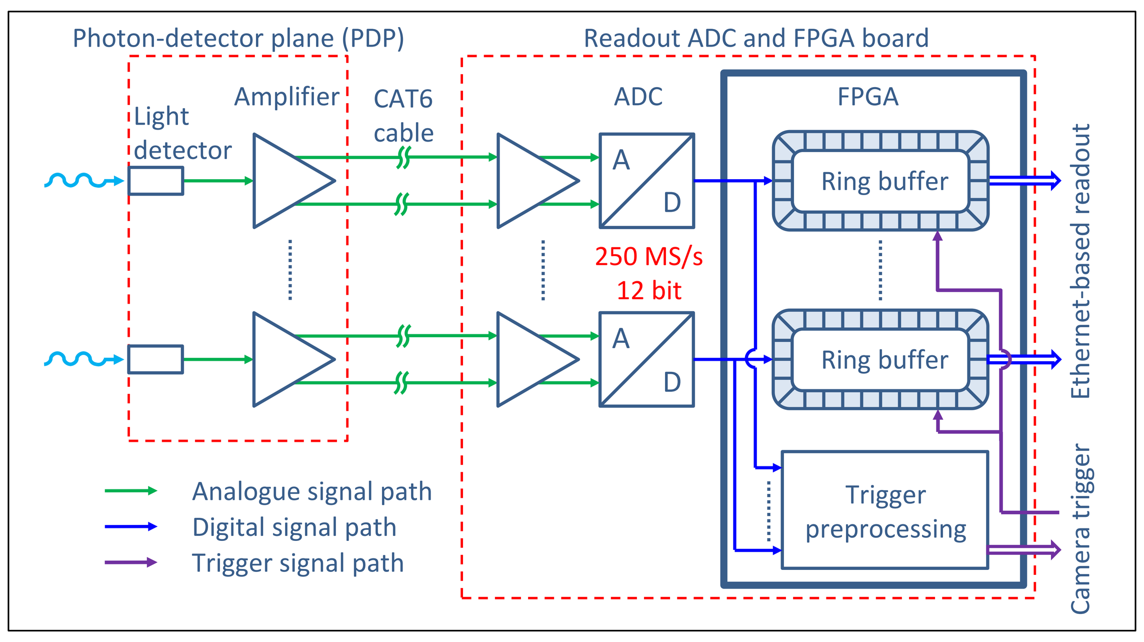
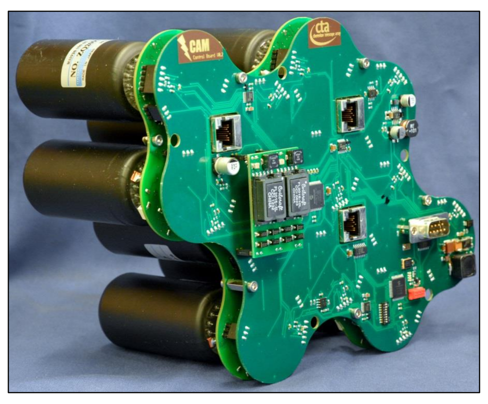


Fig.3: Schematic structure of the FlashCam camera. The detector plane is physically separated from the readout electronics. The DAQ is located in a counting house outside the camera.



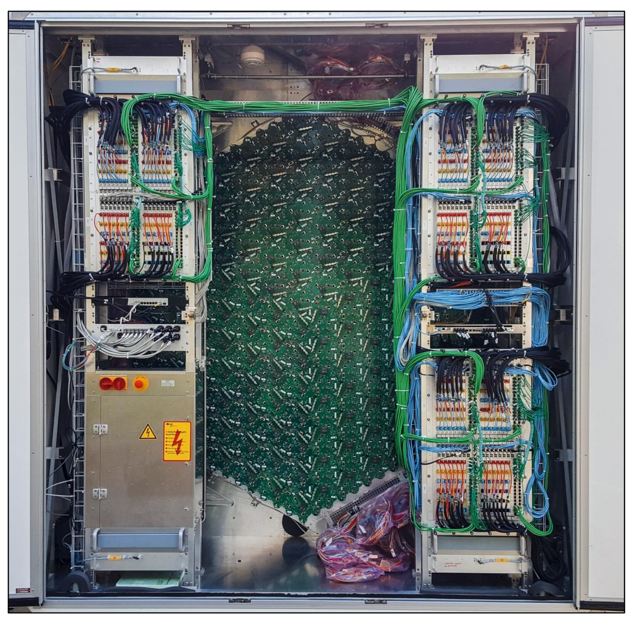


Fig.4: Left: Detector module with 12 PMTs and local high-voltage generation (-1.5kV). Analogue signals are transmitted via CAT6 cables to the readout. **Right:** Rear view of the complete camera before wiring of the detector modules. The readout electronics (digitization and triggering) and the safety and power cabinet are installed in the two racks. The digitized data is transmitted via commercial switches to the DAQ. The expected throughput for a fully equipped camera is >2 GByte/s.

4. Camera body

The 3 x 3 x 1.1 m^3 camera body **(Fig. 5)** is light and water tight and allows easy access to all components for maintenance. The white lid protects the sensitive light detectors during daytime and is used as a projection plane for mirror alignment.

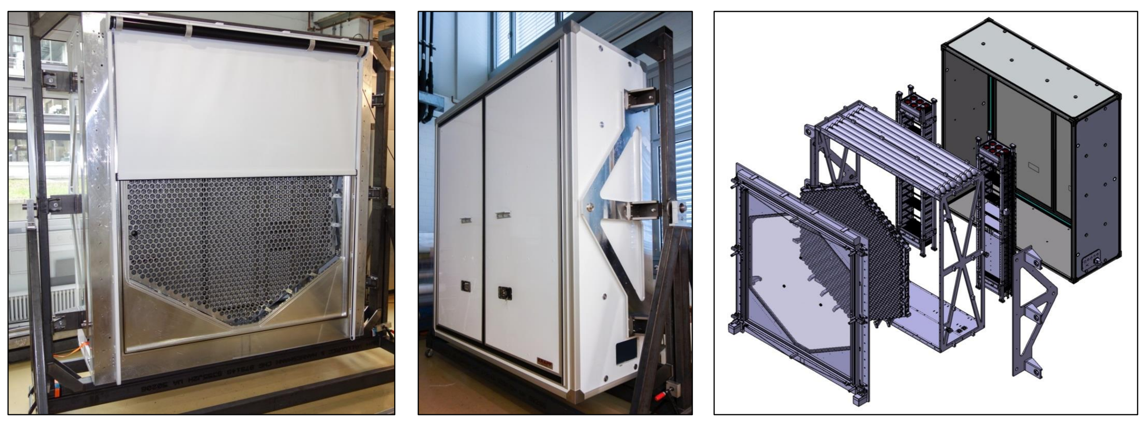


Fig.5: Left: Camera body with lid half closed. **Centre:** Back doors closed. **Right:** Exploded view of the FlashCam prototype.

FlashCam specifications	
Number of pixels / readout channels	1758
Deadtime free trigger rate	30 kHz
Readout window per event	≤ 32 μs
Digitization	250 MS/s, 12 bits
Max. power consumption	≤ 4'500 W
Size, weight	3x3x1.1 m^3, 2 t
Cost (estimated)	**<0.9 MEuro**

5. Performance

All parameters of the camera have already been verified with prototype electronics and a fully equipped prototype camera. The single-pixel charge resolution, being one of the most important parameters, 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).

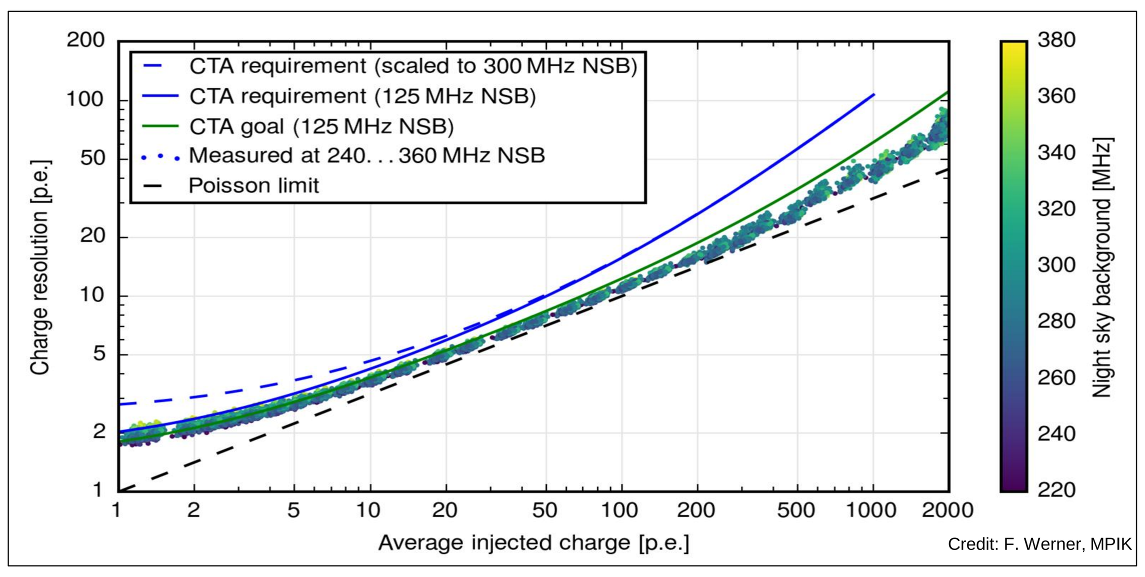


Fig.6: Measured charge resolution of 450 pixels at different night sky background (NSB) levels. The blue dashed and full line represent the CTA requirements, the green line the CTA goal and the black dashed line the statistical limit of the resolution. The PMTs have been illuminated with a pulsed laser and a continuous light source to simulate a γ-ray event and the NSB.

6. Prototype

A fully functional prototype camera has been built and its functions thoroughly tested. The tests include two layovers at the mid-size telescope (MST) protoype site in Adlershof Berlin. During the total three months periode mechanical and electrical functionality as well as real data recording have been performed. First light **(Fig. 7)** was recorded in Oct. 2017.

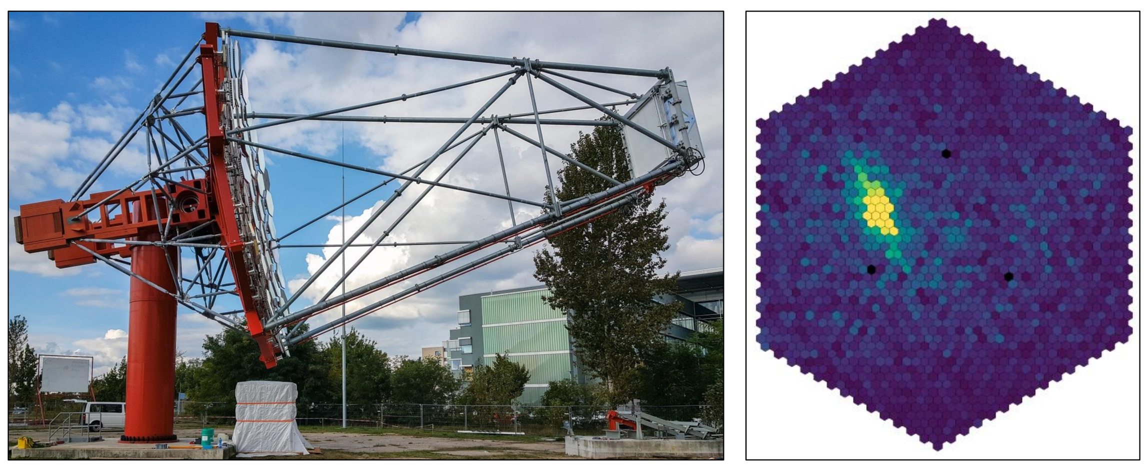


Fig.7: Left: Matching FlashCam with the MST prototype structure. **Right:** First real light seen by FlashCam. The entrance window of the camera is covered with a special foil to reduce ambient light. Data shown before image cleaning.

Key message

- FlashCam is an excellent option for CTA cameras:
  - Commercial components used exclusively.
  - Easy maintenance due to modular construction and easy camera access (back doors).
  - Easy adaption of detector plane to future sensor types possible.
  - Dead-time-free and continuous digitization.
  - Very flexible trigger implementation using digitized traces.
- Performance validation of all components with camera:
  - All components tested individually and as system.
  - All CTA requirements are fulfilled.
  - >12 weeks outdoor test with prototype telescope .

Contact

Group Prof. U. Straumann

Arno Gadola agadola@physik.uzh.ch www.physik.uzh.ch

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