Results of the Prototype Camera for FACT

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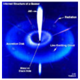
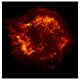
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Overview

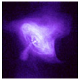
What is VHE γ-ray astronomy?

Some cosmic sources emit photons in the Very High Energy range:


AGN

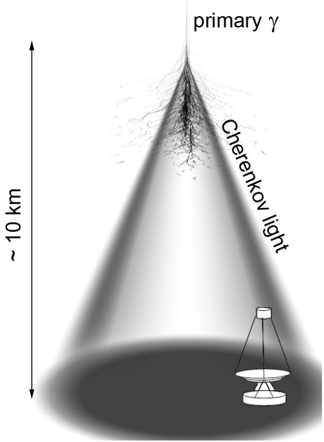

SNR


GRB


Pulsars

Indirect measurement of these photons:

- Primary γ induce air shower
- Secondary particles emit Cherenkov light...
- ...which is detected by Imaging Atmospheric Cherenkov Telescopes (IACT)
- See talks on MAGIC, H.E.S.S. and CTA



Camera requirements

Sensitivity: very few photons, eg. for $E_\gamma \approx 1\ TeV$: 100 photons/m^2 (300-600 nm, 2200 m a.s.l.).

Speed: very short flashes of a few nanoseconds.

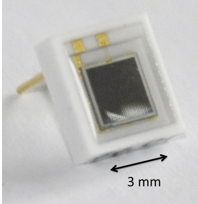
Ruggedness: operation under outdoor conditions with high night sky background ($> 2 \cdot 10^{12}$ (m^2 s sr)$^{-1}$) and temperature variations.

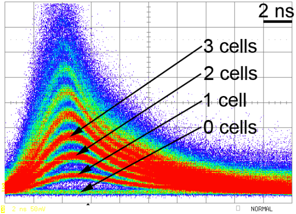
Ease of use: homogeneity, accidental triggers...

Today's IACTs (eg. MAGIC, H.E.S.S., VERITAS...) use cameras based on photomultiplier tubes.

General properties of G-APDs

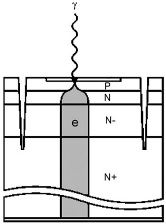
Geiger-mode Avalanche Photodetectors (G-APDs or SiPM, MPPC, PPD...)

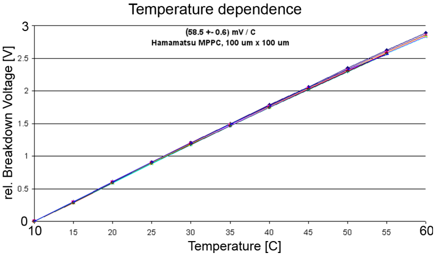




- are semiconductor photosensors
- are divided into a matrix of cells, 30-70% active area
- are very sensitive: photon detection efficiency 30 %-50 %
- have a gain of $10^5 - 10^7$
- operate at low bias voltages $< 100\ V$
- are tolerant to bright light
- show no ageing

Working principle and temperature dependence

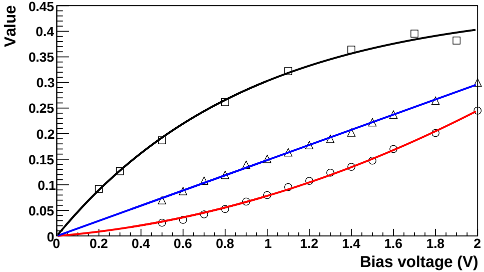




- Electron-hole pair production of the incoming photon
- Operation voltage V_{op} applied $\rightarrow$ avalanche amplification
- If V_{op} larger than the breakdown voltage V_{bd}: the avalanche is self-perpetuating
- Active or passive quenching to stop the avalanche
- Crosstalk: neighbouring cells get triggered by photons emitted during the avalanche process
- The breakdown voltage V_{bd} is temperature dependent ($\approx 58\ mV/K$)

Voltage (temperature) dependencies

Light pulses of constant height: the signal of the G-APD depends on several parameters varying with the so-called overvoltage $V = V_{op} - V_{bd}$:



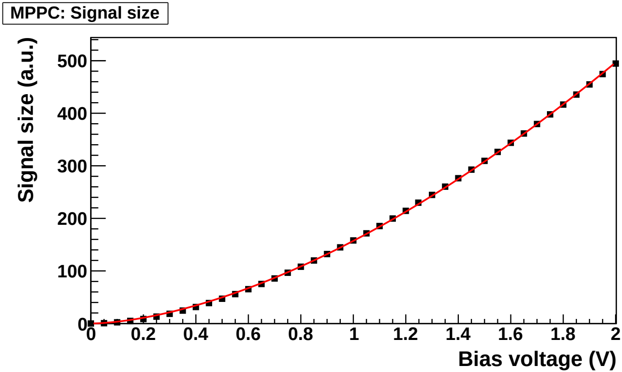
Photon detection eff.	Gain (scaled)	Crosstalk probability
Probability of a photon to trigger a G-APD cell	Charge released per triggered cell [in elementary charges]	Probability of a triggered cell to trigger another cell

Parametrization

$p_1 \cdot (1 - e^{-V/p_2})$	$p_3 \cdot V$	$p_4 \cdot V^2 + p_5 \cdot V$

Total dependence on the overvoltage (temperature)

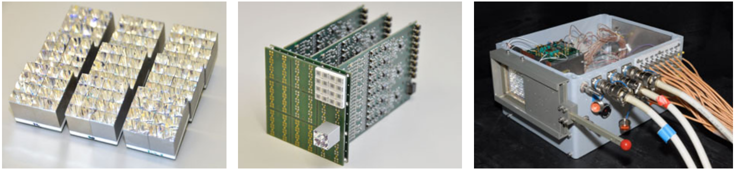
⇒ The total dependence on $V = V_{op} - V_{bd}$ is non-linear.
Hamamatsu S10362-33-050C: approximately proportional to $V^{1.66}$.



V_{bd} is temperature dependent.
⇒ The response of G-APDs is temperature dependent.

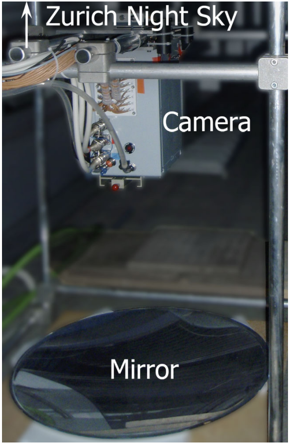
Prototype: design

The First G-APD Cherenkov Telescope (FACT) Project: build an IACT camera based on G-APDs.
Prototype camera module: gain first practical experience.



- Simple light collectors: concentrate the incoming light onto the sensitive area
- 144 G-APDs (Hamamatsu S10362-33-050C): 4 G-APDs per pixel (total 36 pixel)
- Preamplifier boards: distribute also the bias voltage
- Weatherproof camera box including a cooling system

Prototype: Setup at ETH Zurich



Goal: record the first air shower pictures with a G-APD camera

Mirror: $f = 80$cm, 1° field of view per pixel

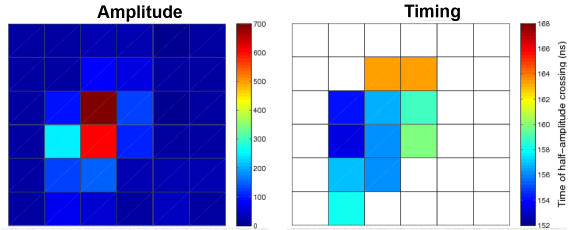
Trigger: N out of 16 majority, N=3 or 4, 20 ns coincidence window

Trigger thresholds: $\sim 4 - 7$ photons

Ambient temperature: $20^\circ\mathrm{C}$

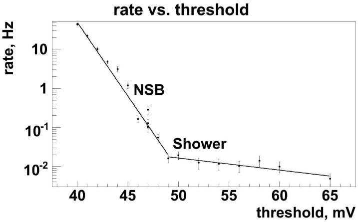
Night Sky Background: 1 GHz per pixel

First air shower measurements



Goal achieved: the first air showers measured with a G-APD camera are recorded during summer 2009 in Zurich.

- 1-3 kHz single pixel trigger rate
- $\sim$ 0.02 Hz data taking
- rate scan confirms the expected behaviour

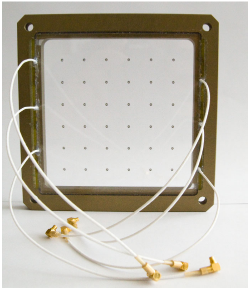


Controlling temperature variations: the feedback system

Outdoor conditions: temperature variations change the camera properties.

Temperature $\rightarrow$ breakdown voltage $\rightarrow$ overvoltage

$\Rightarrow$ Changing photon detection efficiency, crosstalk probability, gain



Feedback system:

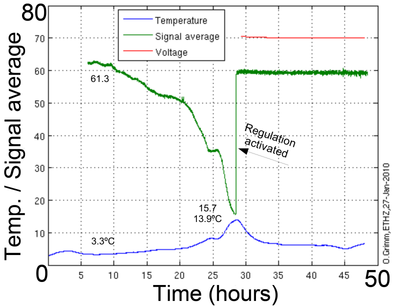
- Temperature stabilized LEDs in the entry window
- Short pulses
- Pulse reconstruction
- Voltage adjustment towards a target value

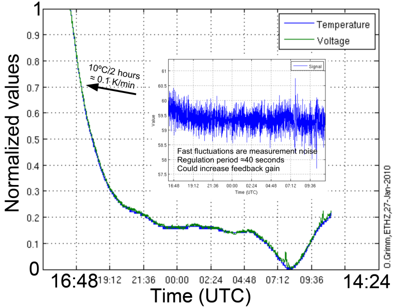
Feedback system test

Long-time measurement: January 20-22 2010.

First phase: feedback system deactivated, temperature change 10.6 K

Second phase: feedback system running, temperature change 7.6 K

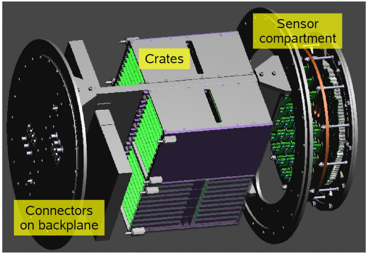




⇒ Signal size stable within ≈ 0.5%.

Without feedback system: variations by more than a factor of 2.

The FACT Camera



- Goal: build and operate the first Cherenkov telescope based on G-APDs
- 1440 G-APDs, fully integrated DAQ based on the Domino Ring Sampling DRS4 chip
- Trigger using analog sums of 9 pixels
- Telescope mount
  - situated at La Palma, Canary Islands
  - a refurbished telescope from the HEGRA experiment
  - 9.5 m^2 mirror area
- Starting point for the Dedicated Multi-Wavelength AGN Research Facility (DWARF)

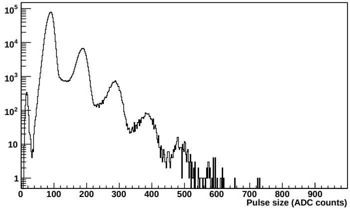
Summary

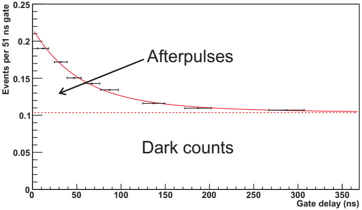
- A prototype module consisting of 144 G-APDs successfully tested and in operation since summer 2009
- First air shower pictures with a camera based on G-APDs
- Feedback system to correct for changes in the ambient temperature: gain stability $\approx 0.5\%$.
- Full-sized camera under construction

Backup slides

Afterpulses

The delayed release of carriers trapped during a breakdown in a cell can trigger the cell again.





Spectrum:

Measured spectrum of dark counts and afterpulses (crosstalk 13%).

Timing:

Number of pulses per gate for variable delays after an initial pulse. The number of pulses decreases exponentially to the level of dark counts.

⇒ Afterpulses are not a problem for the trigger.