The FACT Project
First G-APD Cherenkov Telescope
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The FACT Project

Key Question:

can newly developed Si-based photosensors [G-APD, SiPM, MPPC,...] be used in Cherenkov Telescopes?
- reduction of operation complexity (less fragile, no HV)
- stable remote operation
- eventually lower cost and higher efficiency by profiting from development for large market for Si-based technology

Main Problem:
PMTs and G-APD have rather different features
==> 'difficult' to compare datasheets

Solution:
Build a CT using new photosensors and try
==> First G-APD Cherenkov Telescope
The FACT Project

Main Components:
- Refurbished HEGRA CT3 telescope at LaPalma
  (9.2m² mirror area, f/d = 1.4, new drive system)

Camera:
- G-APDs (HAMAMATSU MPPC S10362-33-050C)
- Solid Light-Concentrators
- Electronics (DRS-4 based) in camera
- readout using standard ethernet
Refurbished HEGRA-CT3 Telescope at La Palma:
- new mirrors installed (refurbished from CT1)
- new drive system installed
- new container as 'counting house'
- awaiting camera ....

9.2m² mirror area (next to MAGIC with 2x 236m² mirror...
G-APD Basics

Geiger-mode Avalanche Photodiode:
(also called: SiPM, MPPC, PPD, …)

Pixelized Si-based photosensor: a (single) photon hitting a cell has some probability to create a 'breakdown' -> always same signal

Many small cells ==> total signal analogue sum of the isochronous single-cell signals

cell-sizes $O(100 \times 100 \, \mu m^2)$
G-APD Basics

Typical values:

Bias Voltage: 50-100 V (no HV needed!)
Gain: \(10^5 \ldots 10^7\)

Photo-detection efficiency: 30...40 % (?)
[wavelength dependent]

no ageing (even if accidentaly exposed to daylight)
[but limited long-time experience]

several manufacturers:
CPTA/Photonique, Perkin-Elmer, Hamamatsu, Zecotec, MPI Semiconductor Lab, …
**G-APD Features**

**Saturation** (if >>10% of cells occupied; NSB!!)  
larger cell size --> higher PDE (less dead area)  
but also worse saturation  
**FACT:** use 50x50um² to be able to run with high NSB

**Temperature dependent gain** (~5% / degree)  
==> temperature stabilization or  
*gain stabilization via feedback system*

**Sensitive also >>700nm**  
==> more NSB
G-APD Features

slower rise and decay time than best PMTs,

but very constant signals (if constant gain)

FACT:
final G-APDs
final pre-amps
oscilloscope

LED spectr., 2 ns horiz., 50 mV vert. spacing
G-APD Features

- **Dark counts**
  - Cells can be triggered by any free carrier, e.g., thermally generated or field assisted tunneling.
  - Rate: some 100 kHz up to MHz per mm$^2$ at room temperature.

- **Afterpulses**
  - The delayed release of carriers trapped during a breakdown in a cell can trigger the cell again.
  - Afterpulse probability 5 – 20% depending on the gain.

- **Crosstalk**
  - Defines the spectrum of the two phenomena above.
  - Crosstalk probability 5 – 20% depending on the gain.

![Typical dark count spectrum of a G-APD (crosstalk 13%). Peaks up to 6 triggered cells can be discerned. The spectrum also includes afterpulses of previous dark count events.](image-url)
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- **Crosstalk**
  - Important for single photon counting, but less for CTs: can be calibrated (e.g., measure on average 11 instead of 10 p.e. for 10% Crosstalk)

![Typical dark count spectrum of a G-APD](image)

Typical dark count spectrum of a G-APD (crosstalk 13%). Peaks up to 6 triggered cells can be discerned. The spectrum also includes afterpulses of previous dark count events.
G-APD Features

- Dark counts have a random time distribution.
- Afterpulses have an exponentially decreasing probability after an initial breakdown.

Number of pulses per gate for variable delays after an initial pulse. The number of pulses decreases exponentially to the level of dark counts.
Prototype Camera (2009)

- Mirror with 80 cm focal length ⇒ 1° f.o.v / pixel
- NSB from buildings and moonlight: \( \sim 300 \text{ MHz} / \text{G-APD} \) (= 1.2 GHz / pixel)
- Meas. at 22° night temp., G-APD plane cooled to 18°, no voltage feedback
Prototype Results (2009)

FACT run 396 event 26

Prototype Results (2009)

FACT run 396 event 30

two additional PMT in +/-7m distance

drs-2 with known cross-talk problems
HV Feedback System

Not sufficient to correct for gain-variation in offline analysis: Does also affect the trigger !!!

Instead of rather complicated Temp. stabilization, use 'feedback':

- stabilized calibration signal
- measure signal
- adapt voltage to keep signal const.
G-APD Features

angular acceptance:

constant PDE over large angles

==> allow for larger concentration

factor with winston-cones

==> 'lower cost' per area

package shadow
Why Solid Light Concentrators

Liouville theorem: can not shrink phase-space

Area <----- Angular Distribution

==> Solid cones allow higher area-concentration!
(important for photosensors with high cost/mm²)

FACT:
~80mm²
9.0mm² (7.8mm²)
Why Solid Light Concentrators

In case of sealed camera: less Frensel reflection

but: absorption

==> do not want too large G-APD area

Can use inexpensive casting (UV transparent PMMA)

Complicated shapes possible (FACT: square -> hexagon)
Too high pressure during casting reduces overall transmission (also micro-bubbles)

Tedious and time consuming glueing

minor PMMA impurities destroy UV transmission
FACT Camera (2011)

1440 G-APDS
=1440 Pixels
(0.1deg/Pixel
4.4deg FoV Camera)

320 HV Groups
for feedback system

160 Trigger cells

40 Elec. Boards
in 4 Crates

Weight: ~200kg
Power: ~1kW
IP67
Sensor Plate

G-APDs with Winston cones

Front baffle plate

Cable adapters / bias feed

GAPD bias

1440x

Co-axial signal cables, 50 ohm, ~35 cm
Sensor Plate

Analogue Data and Bias-V cables

2 Boards holding 9 G-APDs each

Solid light concentrators

Plexiglas Window
Sensor Plate (elec. side): Ready
Sensor Plate (window side): Progress

All ~1500 G-APDs glued to solid cones and tested

June 9th: >1000 cones with G-APDs glued to front window (expect all done by end of this conference...)

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Camera Electronics: Ready

- Preamp.
- Trigger Mezzanin
- DAQ (DRS-4 & ADC)
- 40 units X 4 crates
- Trigger Distrib.
- DAQ Ethernet
Camera Electronics:

Linearity test of electronics cables & preamp & DRS & ADC

Very linear
perfect fit with 2nd polynomial
(can't see the error bars ;)

36 channels

no gain adjustment
Data Acquisition 1: Ready

40 Boards a 36 Pixels

each board:
- 4x DRS-4 analog pipeline (0.7 - 5 GHz) with 9 Channels
- 4x serial ADC 33MHz
- FPGA, Ethernet

global Clock and Trigger signals
Data Acquisition 2: Ready

Standard Ethernet readout Counting-'House'

>5 times higher throughput possible when using parallel ADCs and 1GB/10GB ethernet components [but more power => more cooling]
'HV' Power Supply: Ready

HV crate: 320 channels
- 1 crate controller with USB interface
- 10 HV mother boards ==> 320 Channels
- power conversion /distribution and control bus wired in the back of the crate

Single channel board
- HV operational amplifier OPA454
- controlled by a 12 bit serial DAC (DA8034U)
- output voltage adjustable (0 – 90) V
- calibration using trim potentiometer
- voltage set precision 22 mV
- High side current monitor (HV7800)
- Over current protection, limit (1-5)mA

32 channel HV mother boards

In counting house
FACT Status

- Telescope ready for comissioning

Camera:
- 'HV' built and tested
- Electronics: built, final tests going on
- solid cones: all tested
- G-APDs: all tested and glued to solid cones; glueing to front window almost finished
- final cabling of full camera going on

==> Delivery to La Palma: July 2011(?)
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First light: Summer 2011 (?)