Electronics for the camera of the First G-APD Cherenkov Telescope (FACT) for ground based gamma-ray astronomy

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First Geiger-mode Avalanche Photodiode Cherenkov Telescope

The FACT collaboration:

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Basics of Cherenkov Astronomy

- Some cosmic sources emit $\gamma$-rays in the very high energy range (50 GeV – 100 TeV)
  $\rightarrow \gamma$-radiation as a part of cosmic rays

- Indirect detection: using the earth's atmosphere as a calorimeter

- Cosmic ray induced airshower emit Cherenkov light in the visible and near UV range

- Cherenkov light cone
Basics of Cherenkov Astronomy II

- Weak and fast light flashes: few ns
  \[
  \approx 100 \text{ photons} / \text{m}^2 \ @ 1 \text{ TeV primary } \gamma\text{-energy}
  \]
- Detection by Imaging Atmospheric Cherenkov Telescopes (IACTs)
- IACT cameras based on photomultiplier tubes (PMTs)

FACT
Why G-APDs?

- All currently operational IACTs use PMTs
- G-APDs offer several advantages:
  - Single photon resolution
  - High photon detection efficiency
  - Insensitive to bright light
    i.e. nightsky background / moonlight
    → higher duty cycle
  - Much lower bias voltage (~70 V instead of kVs)
  - Mechanically more robust
  - Insensitive to magnetic fields
  - No known ageing
The FACT Camera: Overview

G-APD & Winston Cones
Sensor compartment
Sensitive to few photons

Integrated digitisation based on the DRS4 chip
Readout electronics
Fast enough for flashes of few nanoseconds

1440 Pixels

Pixel size:
9.5 mm hexagon
Corresponding to 0.11° / pixel

Front window diameter:
40 cm
The FACT Camera Schematic

DAQ

FACT Camera Housing

36 (x40)

Preamplifier

36 (x40)

Trigger Unit

40 Trigger Primitives

Slow Control

Trigger ID

Reset DRS Clock Time Marker Trigger

Fast Control Signal Distribution

Bias

Cooling Unit

Light Pulser

1440 G-APD

x 160

x 40

x 40

x 40

x 2

Ethernet Switch

x 4

Ether-Net fibre

48 V Power

Trigger
Trigger System Concept

- analogue sum over the 9 pixels of one trigger patch
- Non-overlapping trigger patches
- central trigger master
- two fast signal distribution boards
- electronics fully integrated into the FACT-Camera
- trigger rates in the order of 50 Hz; up to 1 kHz possible in combination with a software trigger
• set a threshold to every patch of nine pixels
• trigger unit generates trigger primitives from 4 patches
• counting the rates in every patch
• each pixel can individually be excluded from the trigger patch, e.g. to exclude stars or noisy pixels
• RS-485 bus to the trigger master
• FPGA based (Xilinx Spartan®)
Preamplifier and Trigger Unit

- A trigger unit sitting on the pre-amplifier board
- Minimum threshold $\approx 20$ photoelectrons per patch (average of about 2 photoelectrons per pixel)
Trigger Master

- collects the 40 trigger primitives
- generates:
  - Trigger signal
  - trigger-ID
  - calibration pulses (to lightpulsers)
  - DRS clock for the DAQ (clock conditioner)
- controlled via Ethernet
- performs trigger unit slow control (via RS-485)
- FPGA based (Xilinx Spartan®)
Trigger master
Data Acquisition

- 40 Boards with 36 channels each
- DRS-4 analogue pipeline
- Sampling rate: 2 GSPS default
- 100 Mbps fast Ethernet interface on each board

First events taken with our light pulser
DRS – 4
Domino Ring Sampler

- Switched capacitor array
- External analogue-digital converter
- Developed at Paul Scherrer Institute
- Sampling rate: 700 MSPS – 5 GSPS
- 9 channels with 1024 storage cells each
- Dynamic range: 11.5 bits
- Region of interest (ROI) adjustable for each channel
Data Acquisition

Linearity measurement, not calibrated
Data Acquisition

- 40 Hz “physics” plus 10 Hz interleaved calibration events reached in the lab with full ROI
- Interleaved calibration: keep G-APD gain constant i.e. compensate for temperature and NSB variations
- 2 mV electronic noise ↔ 10 mV photoelectrons
- Data rate: up to 300 MB/s
Single photon spectrum of all working pixels "out of the box" i.e. without calibration
DAQ: Ethernet Readout

Counting–’House’

- ANA-PC
  - Compression
  - Data Storage
  - Calibration
  - Online Analysis
- Switch 2x1000, 2x1000F
- DAQ-PC
  - Event-Builder
  - Consistency check
  - L3-Trigger
  - Monitoring
- Switch 2x1000, 2x1000F

Camera

- Switch 2x1000, 2x1000F
- Switch 2x1000, 2x1000F
- Switch 2x1000, 2x1000F

Connection:
- 4x1000Mb Copper
- 4x1000Mb Fibre
- 40x100Mb Copper

FTM

Crates:
- Crate 0
- Crate 1
- Crate 2
- Crate 3
Trigger and Clock Distribution

Channel to channel:
- Jitter < 20 ps
- Skew < 250 ps
FACT in the Lab II

Images taken using FACT's external and Internal lightpulsers
Summary and Outlook

- All boards developed in-house
- Trigger and DAQ:
  - Hardware fully commissioned and installed in the camera
  - Firmware and control software ready and tested
  - Various laboratory tests of the full system done
    data analysis still ongoing
- The FACT camera is on the way to La Palma
Summary and Outlook
Backup
Cherenkov Astronomy II

- First IACT: Whipple (Arizona, 1961)
- Current IACTs: MAGIC, HESS, VERITAS
- Future: CTA, Cherenkov Telescope Array
- Hadronic background: $\gamma / \text{had} \approx 10^4 - 10^5$