FACT – the First G-APD Čerenkov Telescope

Status and Experience from Seven+ Years Operation of the First SiPM Camera

Dominik Neise for the FACT Collaboration
Cherenkov telescopes measure faint flashes of Cherenkov light emitted when a cosmic-ray particle or gamma ray interacts with the atmosphere.

Typically one measures showers with 50 Cherenkov photons within few ns over a 50 GHz night sky background for dark night conditions.

Number of Cherenkov Photons is ~proportional to energy of primary particle.
Very harsh environment intrinsic to IACT

Sensors

Electronics
Detailed List of Problems due to G-APD (SiPM)
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thank you for your attention
FACT – History
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2007: First Cherenkov flashes seen with few G-APDs attached to MAGIC camera [NIM A 581]

2008: Collaboration of ETH Zurich and Universities Dortmund, Geneva, Würzburg (+EPF Lausanne) to build a G-APD based camera for HEGRA CT3

2009: Module0 (36 pix, 4 G-APD/pix) records self-triggered Cherenkov images from the roof of ETH Zurich [JINST4 P10010] → go for complete camera
Focal Plane

1: glue G-APD to cone
2: glue cones to front window
3: solder connector cables to G-APDs
4: install baffle plate

1440 pixels

completed sensor plane
Integrated electronics
DRS4 readout

320 bias voltage channels
(1 per 4\5 G-APDs)

Power consumption ≤500W
Readout via Ethernet

160 trigger patches
(sum of 9 channels)
FACT – the First G-APD Cherenkov Telescope

Oct. 2011: mounted in refurbished HEGRA CT3 (9.5m² mirror) at La Palma

some faces changed; large fraction of the active collaboration; many tasks manpower limited ...
FACT – Selected events of the first nights of data-taking (October 2011)
Uniformity & Stability of Camera – 1 Year of data

(our) G-APD gain has strong temperature dependency (~4%/degree) → Feedback system → adjust applied voltage to Temp. (and DC)

Nowadays you can even buy power supplies doing this for you.
Uniformity & Stability of Camera – 1 Year of data

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Monitor gain with 1pe spectra:
(dark noise + crosstalk are your friends)

→ dark noise + crosstalk allow calibration without any external device
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Overlay of all pixels and ΔT~25°C
⇒ excellent uniformity & stability
FACT – Stability of System

The graph shows the relationship between trigger rate [Hz] and threshold [dac counts]. The x-axis represents the threshold in dac counts, ranging from 0 to 1000, while the y-axis represents the trigger rate, ranging from $10^{-2}$ to $10^8$ Hz. The data points are plotted on a log-log scale, indicating a power-law relationship between the threshold and trigger rate.
FACT – Stability of System

For a given pointing, trigger should always see the same rate of cosmic rays.

Ratescans show cosmic ray trigger-rate independent of moon, sensor temperature and age of sensors.
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Ratescans show cosmic ray trigger-rate independent of moon, sensor temperature and age of sensors.

Bad atmospheric conditions give us a handle on 2\textsuperscript{nd} order effects.
Trigger Rate uncorrelated with Temperature

D. Hildebrand et al., Higher Order Temperature Dependence of SiPM used in FACT, PoS(ICRC2017) 778

Preliminary
FACT – Stability of 2nd order temperature effects

Preliminary

Width (3.4%) almost completely explained by statistics (2.8%); the remaining ~2% is dominated by the precision of the power supply.

D. Hildebrand et al., Higher Order Temperature Dependence of SiPM used in FACT, PoS(ICRC2017) 778
FACT – Longevity
sensitivity curve of the first G-APDs not well adjusted to Cherenkov spect.

collect much more NSB (and moon) than optimized PMTs

Nevertheless, FACT can operate with lot of moonlight without aging
Today exist G-APDs, that are much better adapted to the needs of IACTs.
June 23rd 2013
brightest
fullmoon
of the year
FACT – Collected Charge

integrating over time, divide by dark-night DC (5μA) for each sensor:

collected same charge as in ~1.6k dark night observations
dark noise: ~0.5μA (laboratory)

⇒ collected same charge as in ~43 years continuous op. in laboratory
FACT – Automation
FACT – Automation

onsite data-taking (2011)

remote data-taking from anywhere (since mid 2012)

follow us at http://fact-project.org/smartfact
FACT – Automation

Calls shifter if human interaction is needed
FACT – Science
FACT – Science

long-term monitoring of bright variable TeV sources and sending alerts:

- Mrk 421
- Mrk 501
- 1ES 1959+650

Modified Julian Date

Flux $[10^{-11} \text{ph/cm}^2/\text{s}]$

ATEL
XMM-Newton
INTEGRAL
SWIFT-XRT
MWL Partners manual

SiPM Bari 2019

D. Neise: FACT – Status and Experience from Seven Years Operation
FACT – Science

1ES 1959+650 – X-ray (keV) / TeV Correlation

One-zone SSC fit

XRT (keV) → FACT (TeV)

Good description, but fails to describe short bright flares

PoS (ICRC2017) 608
Conclusion

- G-APDs are excellent sensors for IACTs

- temperature dependence can easily be corrected for

- (moderate) dark noise and crosstalk deliver an excellent calibration device for free (no need for lightpulsers etc.)

- stability allows to predict trigger rates; allows to measure quality of the atmosphere; ideal for long-term monitoring

- long term stability in IACTs much better than PMTs
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We all know: G-APD are not a 1-to-1 replacement of PMT
thank you for your attention