FACT – the First G-APD Cherenkov Telescope

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

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From Tubes to Silicon Devices
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Are novel Geiger-mode Avalanche Photo Diodes (G-APD aka SiPM) a valid alternative for IACT cameras?

Build a camera and test it ➔ FACT (First G-APD Cherenkov Telescope)
Detailed List of Problems due to G-APD (SiPM)
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
**FACT – History**

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
6 weeks, 3 FTE

completed sensor plane
Integrated electronics
DRS4 readout

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

Power consumption $\leq 500W$
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)
FACT – Operation

Since late 2012:
remote controlled automatic operation
→
very high data taking efficiency

data taking efficiency:
100% = time between astronomical twilights, including repositioning and non-data tests.

follow us at http://fact-project.org/smartfact
FACT – Experience
**FACT – Sum-Trigger**

Readout: nine channels per DRS-4 chip

- trigger patch of nine channels

- simple sum-trigger (analog sum of 9 pixels)

No need for ‘clamping’:
confirmed by analyzing data
setting 50% clamping limit would reduce trigger rate by few %.

While clamping usually needed for PMTs due to afterpulsing, no need when using G-APD in sum-trigger.

[863 / 1GA(68)]
FACT – Night Sky Background

G-APD: Hamam. S10362-33-50C
PMT: Hamamatsu R10408

sensitivity curve of the first G-APDs not well adjusted to Cherenkov spect. ➔
collect much more NSB (and moon) than optimized PMTs (+new G-APD)

Nevertheless, FACT can operate with lot of moonlight without aging
Today’s G-APD are much better adapted to the needs of IACTs
June 23rd 2013
brightest
full moon
of the year
FACT – Collected Charges

integrating over time, divide by dark-night DC

collected same charge as in
>15’000 hours dark night obs.

dark noise: ~0.5\(\mu\text{A}\) (laboratory)

collected same charge as in
>150’000 hours in laboratory

(for 1440 sensors in parallel)
winter 2014/15 ➔ humidity problem in camera

1 pixel stopped working (connector ?)

at worst: 1 sensor died in 3.5 years ➔ < 0.02% failures per year
FACT – Uniformity, Stability, Calibration

(our) G-APD gain has strong Temperature dependency

- feedback system
- adjust applied voltage to Temp. (and DC)

check quality with 1pe spectra:

- (dark noise + crosstalk are your friends)

⇒ dark noise + crosstalk allow calibration without any external device
For a given pointing, trigger should always see the same rate of cosmic rays.

Rate scans show cosmic ray trigger-rate independent of moon, temperature and age of sensors.
FACT – Uniformity, Stability, Calibration

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Rate scans show cosmic ray trigger-rate independent of moon, temperature and age of sensors.

Due to this stability, it is possible to identify bad atmospheric conditions (without external device) [33rd ICRC, 709]
FACT – Uniformity, Stability, Calibration

Muon rings allow to measure
the PSF of the optics and
the time resolution of the system.

Novel mirror-alignment method

~320ps for >7pe; including:
- physics
- G-APD resolution
- electronics
- signal extraction
FACT – Science


- Crab: 14.3h
- Mrk501: 35.1h
- Mrk421: 23.4h

e.g. public QLA [http://fact-project.org/monitoring](http://fact-project.org/monitoring)

- Mrk 501
- Mrk 501 [707 / 1GA(56)]
- Crab [704 / GA 18]
- Mrk 501 [806 / GA 07]
- [865 /3GA(65)]

- Crab spectrum [707 / 1GA(56)]
Outlook

pre-FACT: all CTA designs based on (multianode) PMTs [Exp.Astr. 32.3(2011)]
plus projects for future MST and LST cameras

post-FACT: many SiPM-based CTA projects.

Actual SiPM much better than those used in FACT
⟹ expect significantly better performances

& CTs outside CTA

Gaps due to daytime
→ Continuous monitoring around the globe needed
FACT – Conclusion
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- 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
- G-APDs limited in size; Module0 and Sum-Trigger show that several sensors can easily be added to form large pixel
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Be open minded:

G-APD are not a 1-to-1 replacement of PMT

(that’s why I prefer the name G-APD over SiPM)
thank you for your attention