

A G-APD based camera for Imaging Air Cherenkov Telescopes

Oliver Grimm, ETH Zürich

for the FACT collaboration

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Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Overview

- 1) Principles of Imaging Air Cherenkov Telescopes
- 2) Test module for a G-APD based camera
- 3) Design of final camera

First **G-APD** **C**herenkov **T**elescope

The FACT collaboration

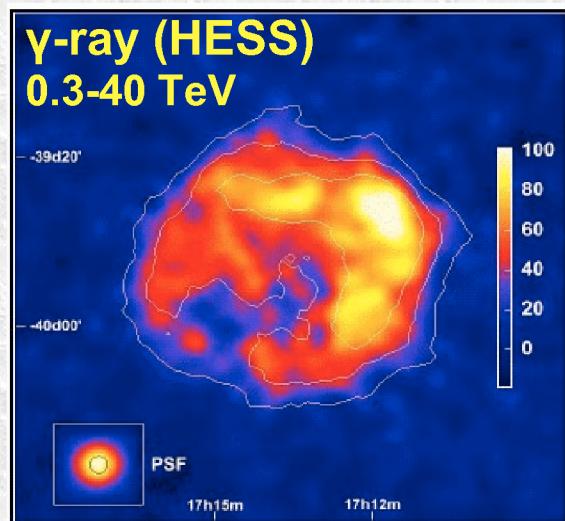
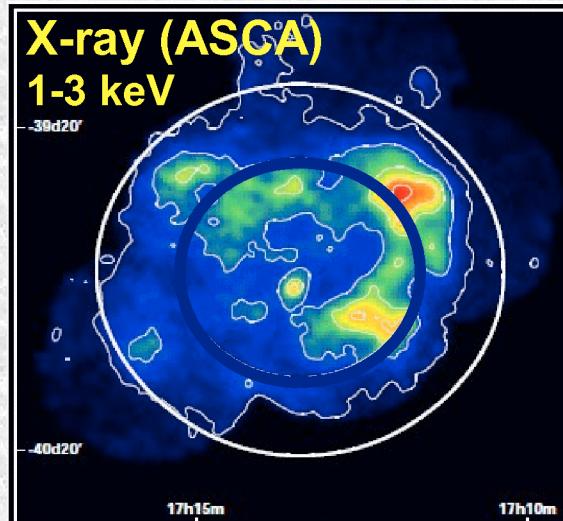
ETH Zürich

TU Dortmund

University of Würzburg

EPF Lausanne

Two results from γ -ray astronomy



Supernova remnant
RX J1713.7-3946
Constellation Scorpius
Distance \approx 3000 light years

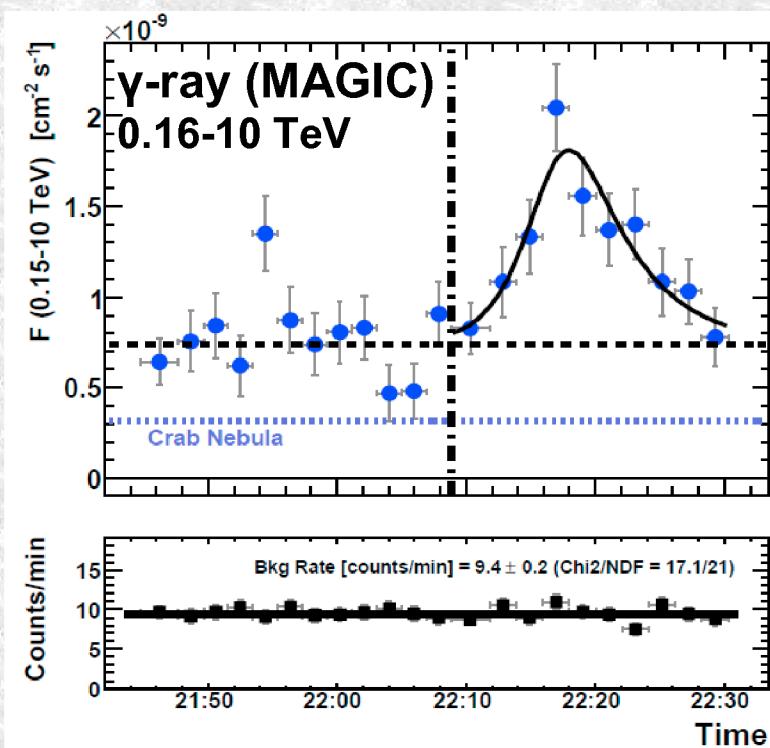
Support for synchrotron self-compton
model of γ -ray generation

Image angular size
→ pinhead viewed at 2 m distance

Active galactic nucleus
Markarian 501

Constellation Hercules
Distance 440×10^6 light years

Flux variability on minutes
→ high bulk Lorentz factors >50 in jets



Gamma-ray detection

No photons from space with wavelength shorter than UV reach ground

Direct detection only in space or on high-altitude balloons

Cost implies size and weight limit

Event rate very low above ≈ 50 GeV (Crab nebula > 30 GeV: ~ 0.2 photons/cm²/year)

Above ≈ 60 GeV: resulting air showers attain detectable size

Detection through particles or induced radiation (fluorescence, radio, Cherenkov light)

Atmosphere is 27 radiation length deep

Challenge is discrimination against hadronic showers (γ/p ratio $< 10^{-4}$)

1948 Suggestion of Cherenkov light emission in the atmosphere (Blackett)
 10^{-4} of night sky brightness is Cherenkov light

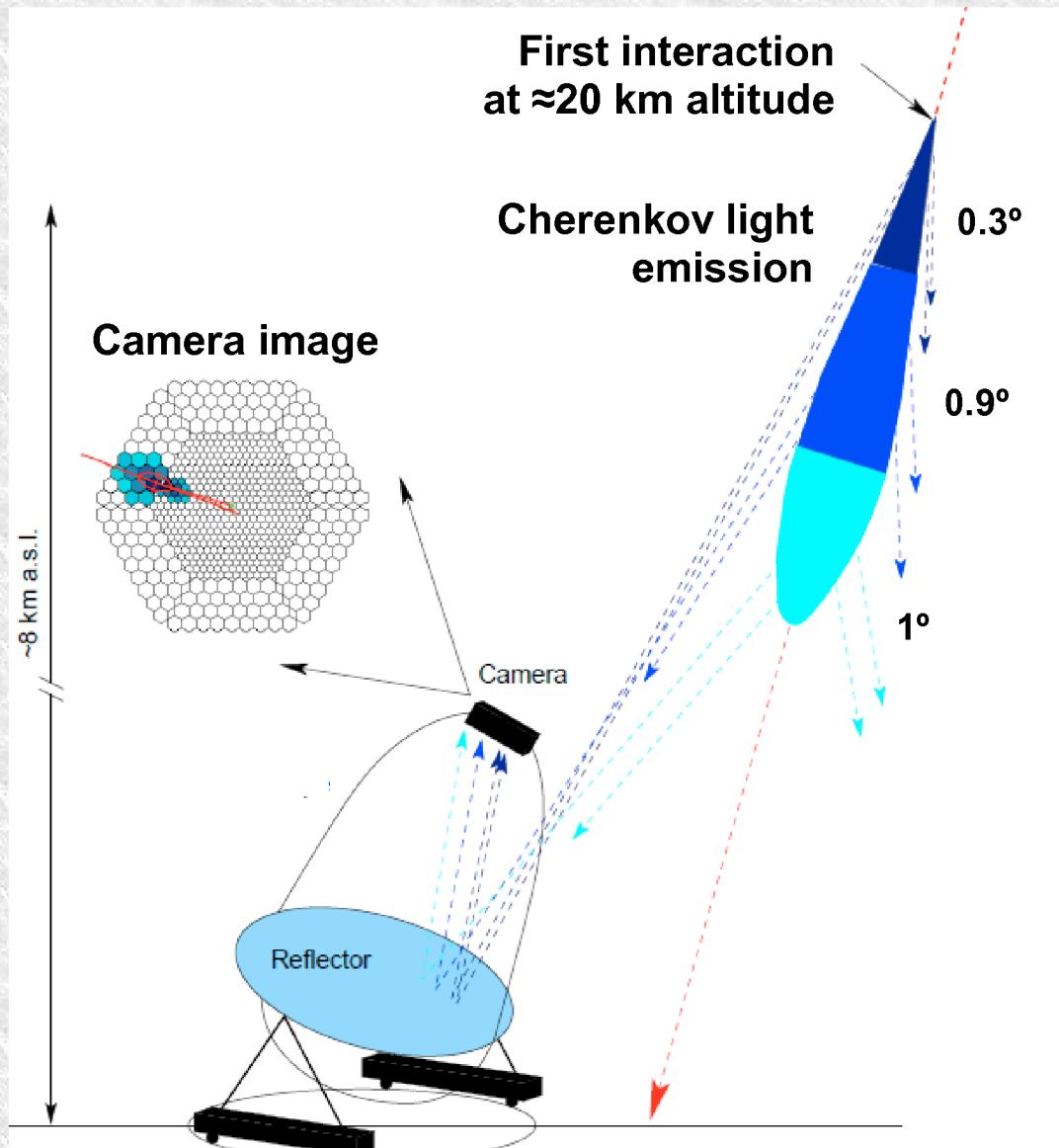
1952 First Cherenkov light pulses detected (Galbraith&Jelley)
Hadron showers, using search-light mirrors

1989 First Gamma ray source detected (Whipple telescope)
Crab nebula, imaging technique, Monte Carlo simulations
21 years after first operation

Now Decrease energy threshold
Overlap with test-beam calibrated space telescope (Fermi)



Imaging Air Cherenkov Telescope: Principle



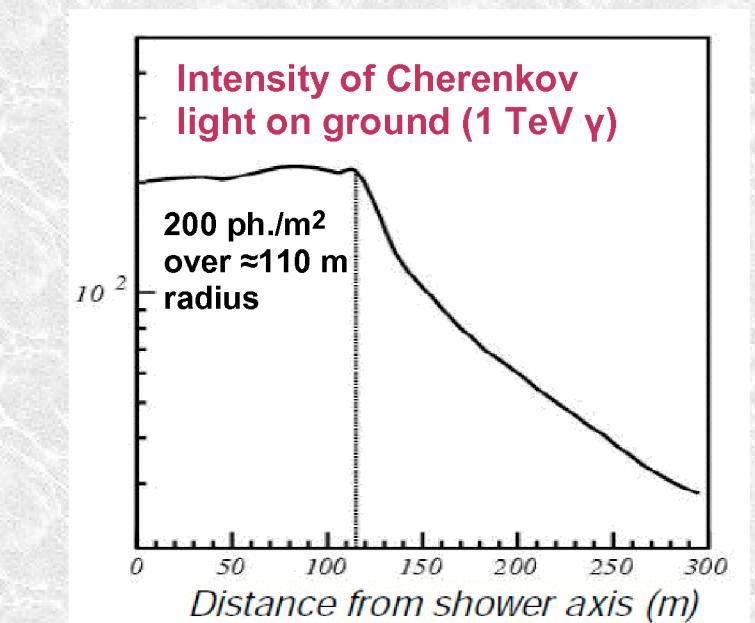
from: S. Commichau, PhD thesis, ETH Zürich (2007)

Statistical analysis of image parameters

Gamma/hadron separation
benefits from sub-ns time resolution

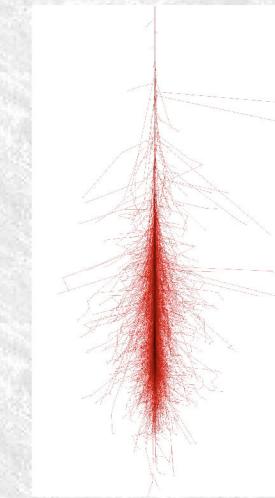
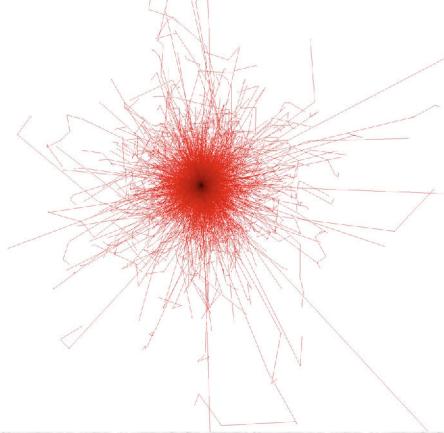
γ -ray energy
≈15% resolution for large telescope

Arrival direction (source location)
≈10 arcmin resolution
→ simple mirrors, large camera pixels

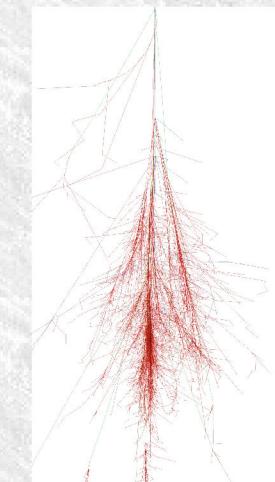
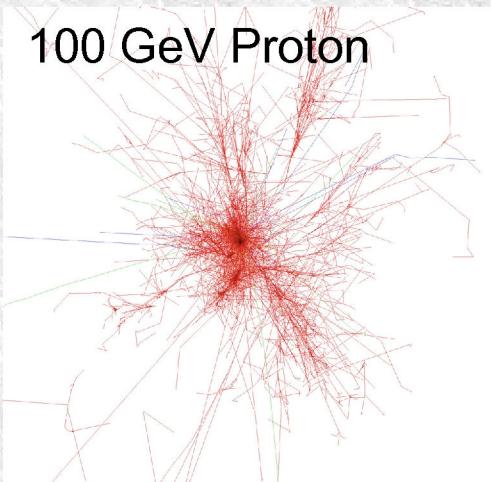


Monte-Carlo simulation of shower development

100 GeV Photon



100 GeV Proton

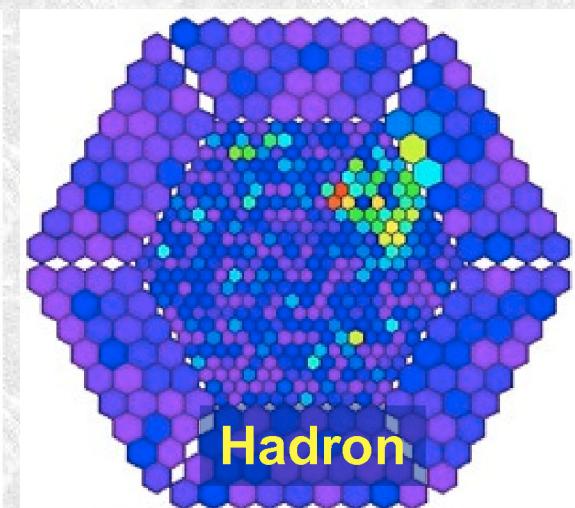
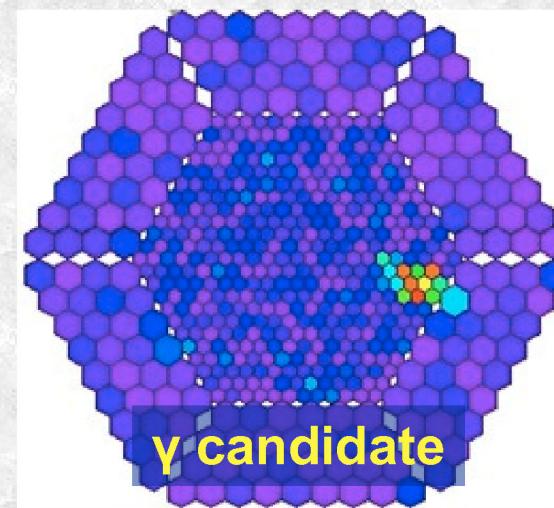


10 km transverse

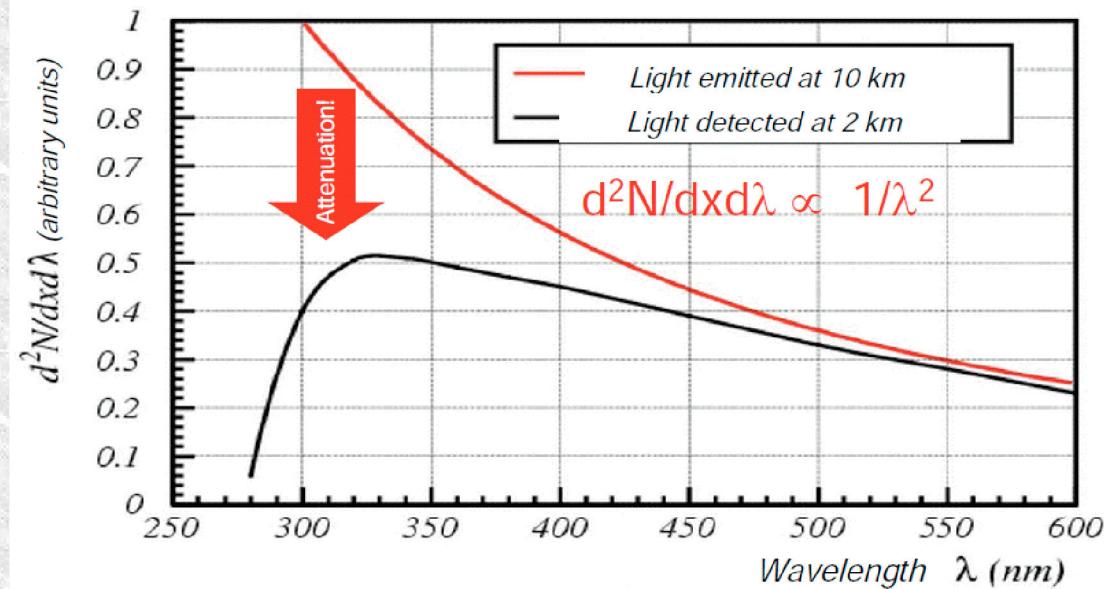
from:
www-ik.fzk.de/corsika/

30 km longitudinal

Typical camera images (MAGIC)

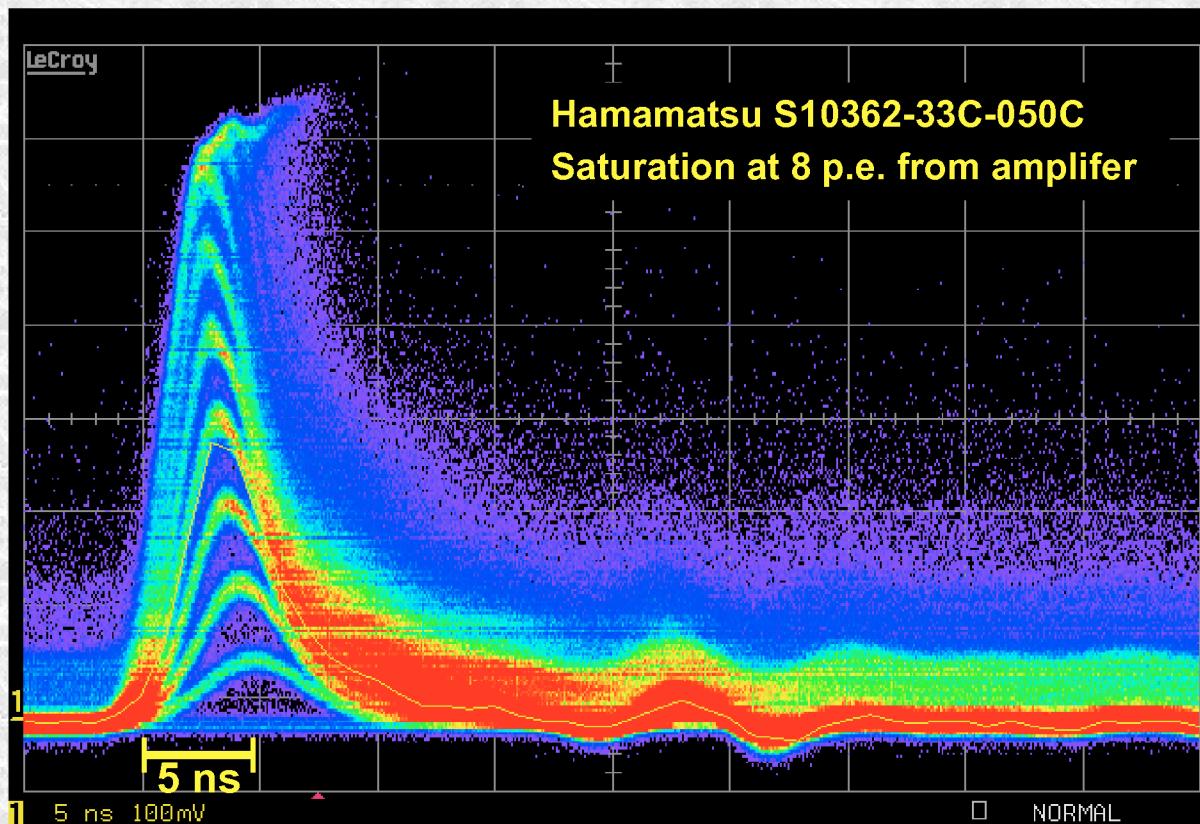


Required spectral coverage



Geiger-mode APD

- High photon detection efficiency
52% peak, 30% spectral average in our case
- Uniform angular acceptance to large angles
allows high concentration factor with light guide
- Resistant to background light, rugged
- Low bias voltage
 ≈ 70 V



Disadvantages

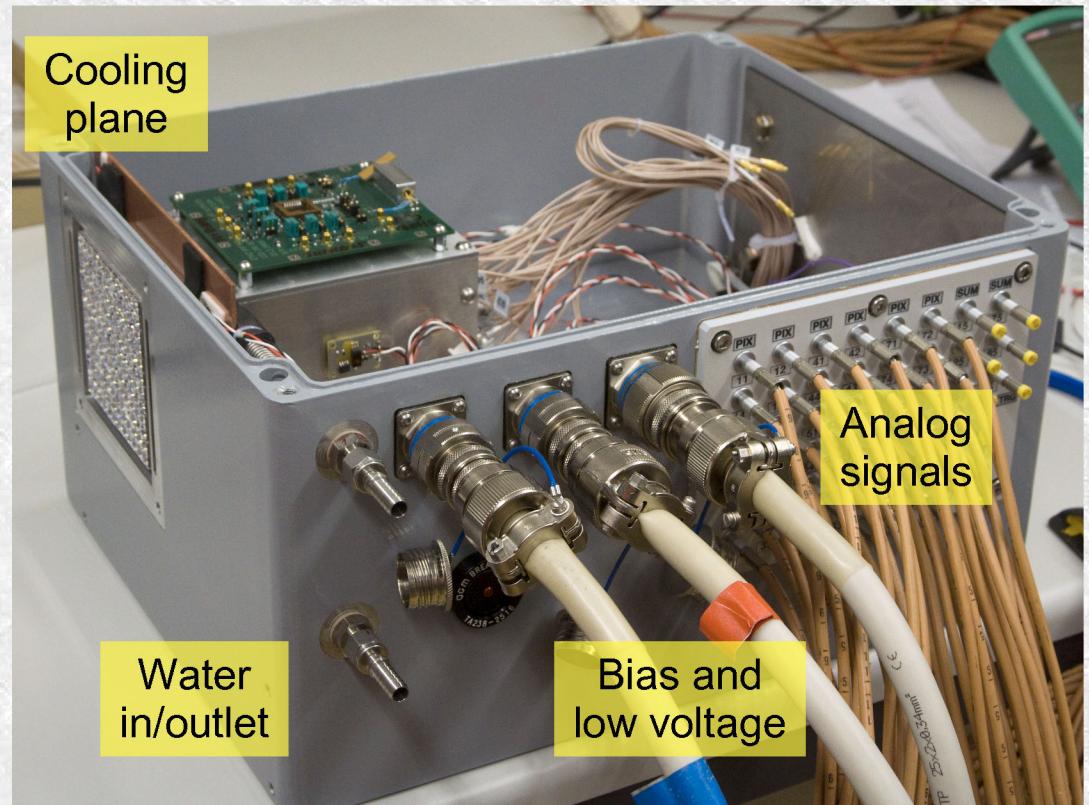
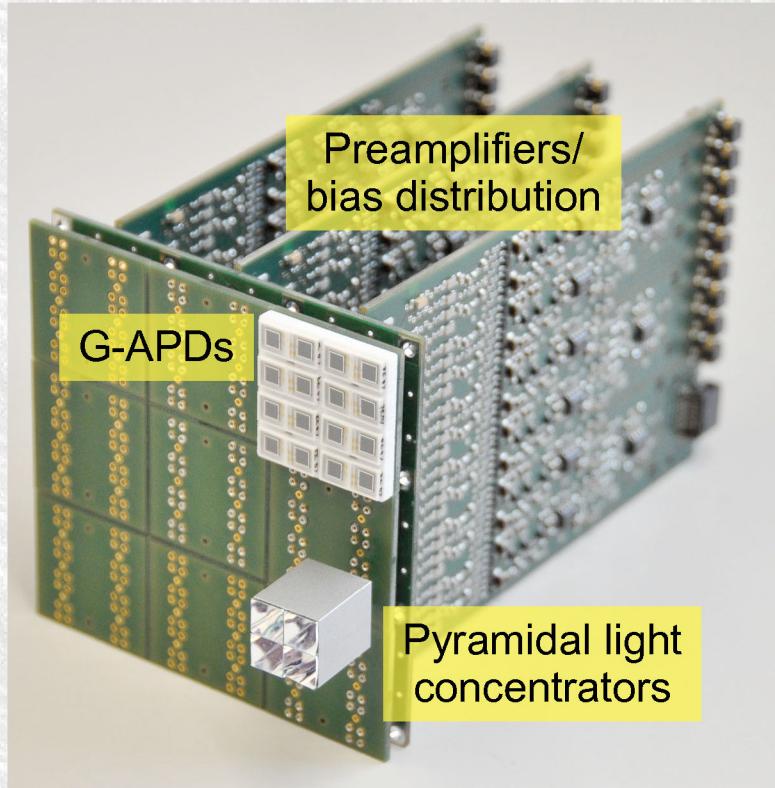
- 1% gain variation for
 - 0.2 K temperature change
 - 13 mV voltage change (3×10^{-4})
- Long decay time constant
- Optical cross-talk
- No long term experience under IACT conditions

Non-linear response no significant disadvantage for IACT application

Test module M0

Gain first practical experience with G-APD camera

Design and results published in JINST 4, P10010 (2009)



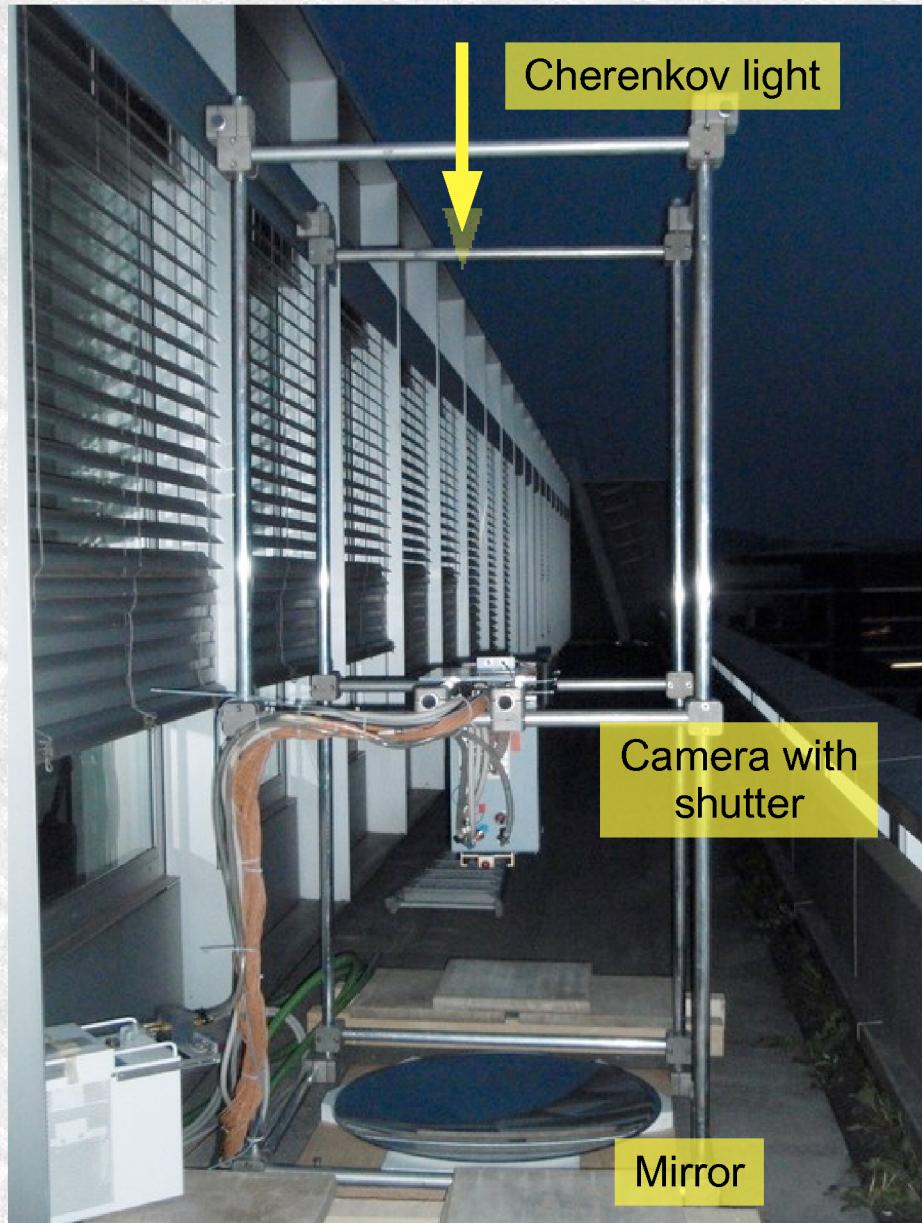
144 Hamamatsu S10362-33C-050C G-APDs, 4 sensors per pixel (total 36 pixel)

Hollow light concentrators covered with Vikuiti foil, cross-section reduction by 6.6

LED system to control G-APD gain integrated into window

VME-based read-out with DRS2 analog pipeline chip (2 GHz sampling)

Test setup at ETH Zürich



Spherical mirror $f=80$ cm

1° field-of view per pixel

Night sky background

1.2 GHz per pixel (4 G-APDs)

Temperature close to ambient

$\approx 20^\circ\text{C}$

3 or 4-fold majority trigger

20 ns coincidence window

Trigger threshold > few TeV

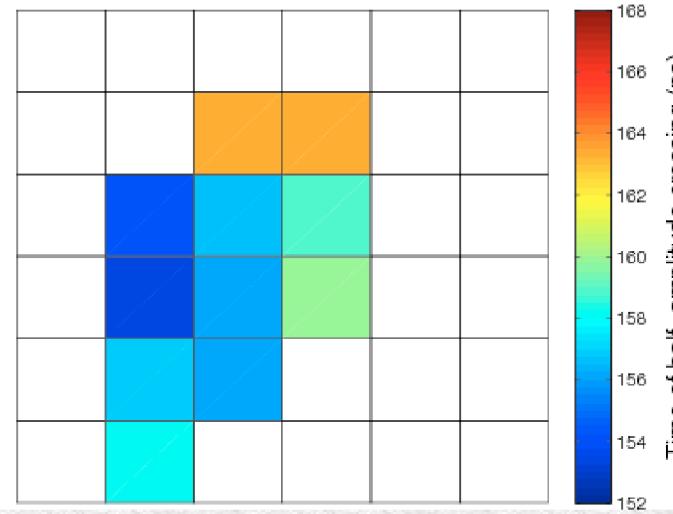
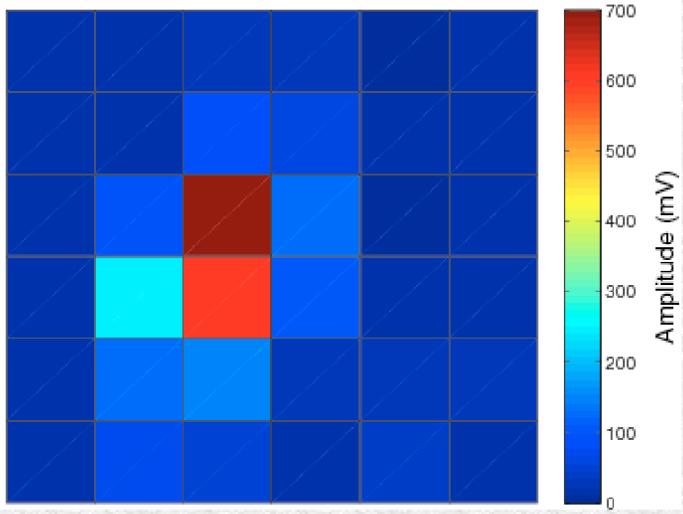
Rate 0.02 Hz (@ 1-3 kHz single rate)

VME based

Impossible to discriminate proton- and gamma-induced showers

M0 – Events

Run 206, Event 14

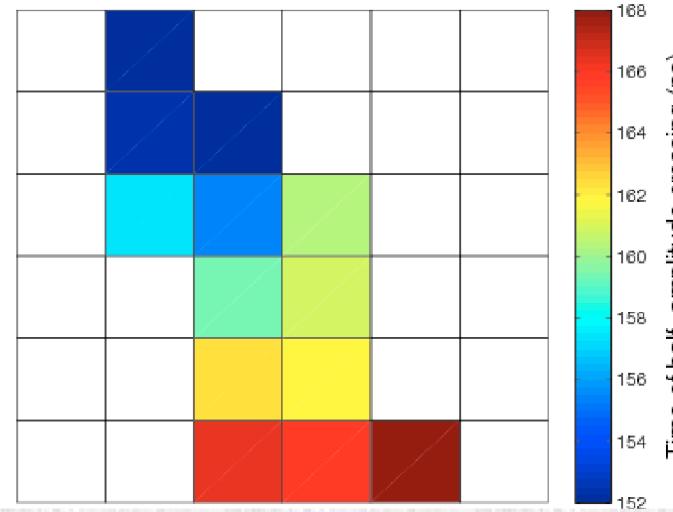
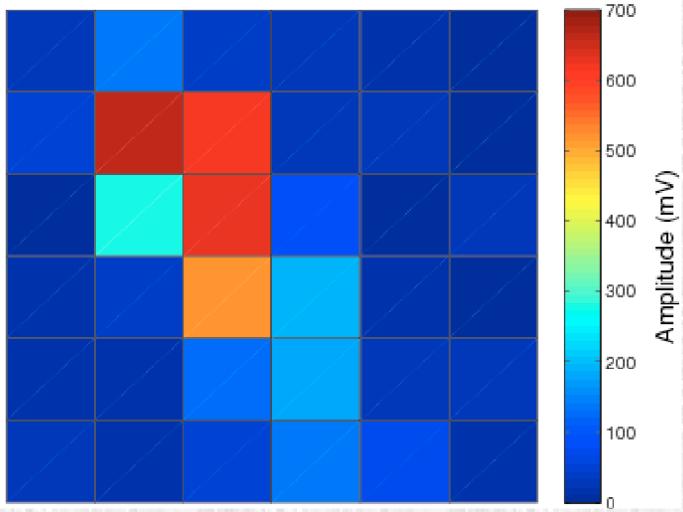


Typical event

Core pixels within ≈ 6 ns
Possible sub-shower

Energy >10 TeV

Run 207, Event 16



Time spread 16 ns

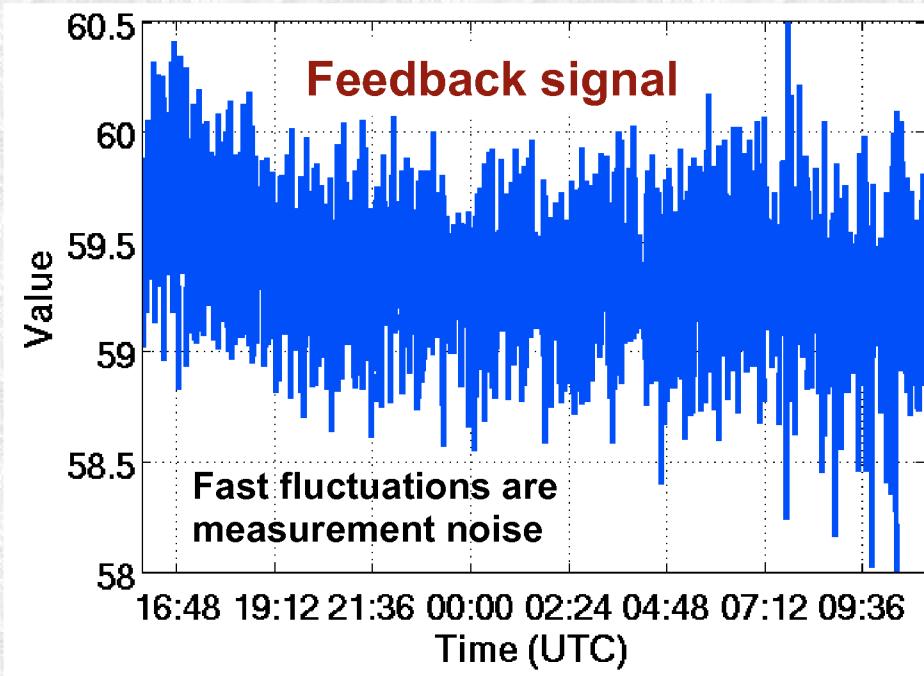
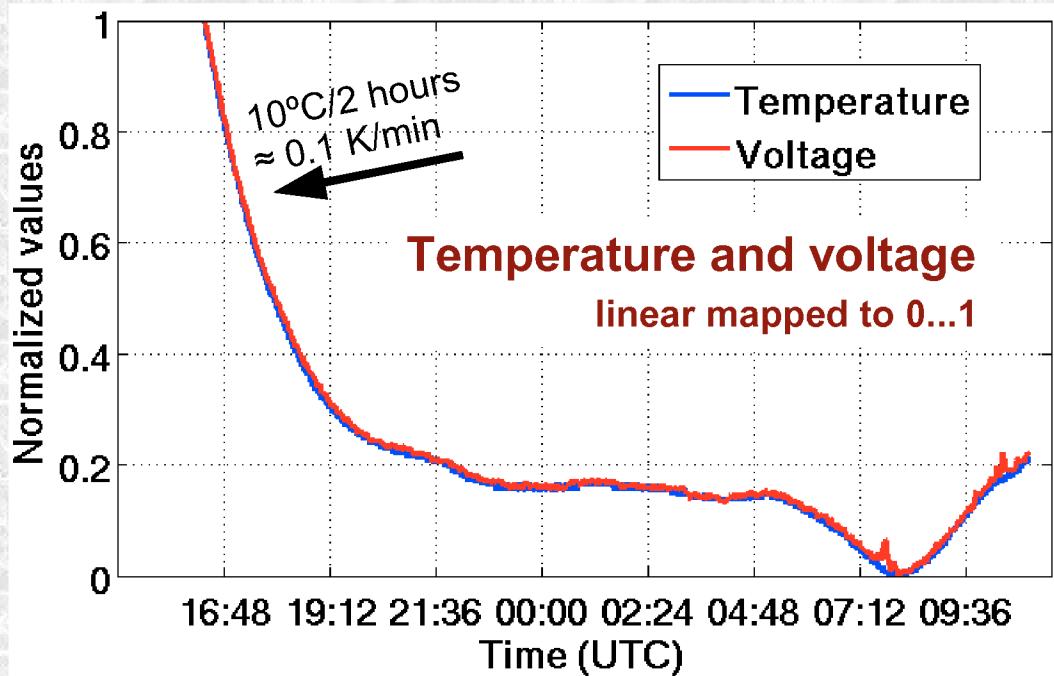
Possible large
inclination shower

Similar events seen
by MAGIC

M0 - Bias voltage feedback

Feedback regulates on signal from stabilized LED pulse

→ compensates G-APD gain variations



Run 20 hours, no active temperature control, shutter closed (following ambient)

Temperature **12.6°C → 5.0°C**

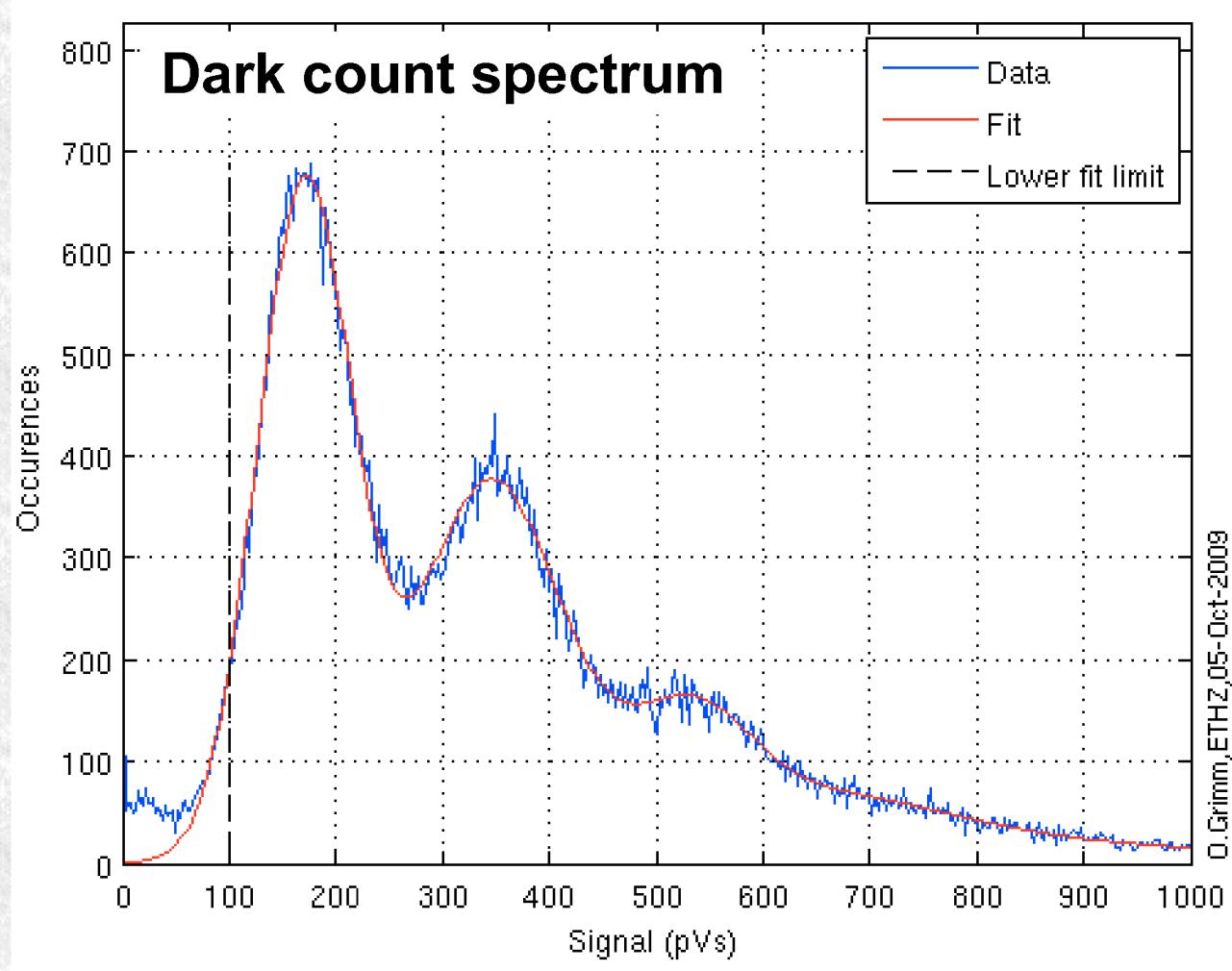
Voltage **70.55 V → 70.05 V**

Signal **stable to 1%**

(gain change would be ≈50% without feedback)

Extracting gain from dark spectrum

Peak-finding algorithm applied to dark count signals sampled with DRS2



Temperature 20°C
Dark count rate \approx 5 MHz
Extra analog gain x9
Fit with 5 Gaussians

*Impossible at 500 MHz
night sky background*

Peak separation limited by DRS2 resolution and front-end electronics noise

FACT – Overview

Full-scale camera for long-term monitoring of variable Gamma-ray sources

4.5° field-of-view (0.11° per pixel)

1440 pixels (same G-APD type as for M0)

Operation also under twilight/moon (background rate up to 5 GHz)

Power consumption ≈ 1 kW

Gain stabilization to $\approx 5\%$ with feedback

Winston-cone solid light concentrators

Digitization and triggering integrated in camera

DRS4 analog pipeline chip (PSI development)

Data transfer via Ethernet

Majority-trigger logic of non-overlapping patches

Former HEGRA CT3 telescope
La Palma, Canary Islands



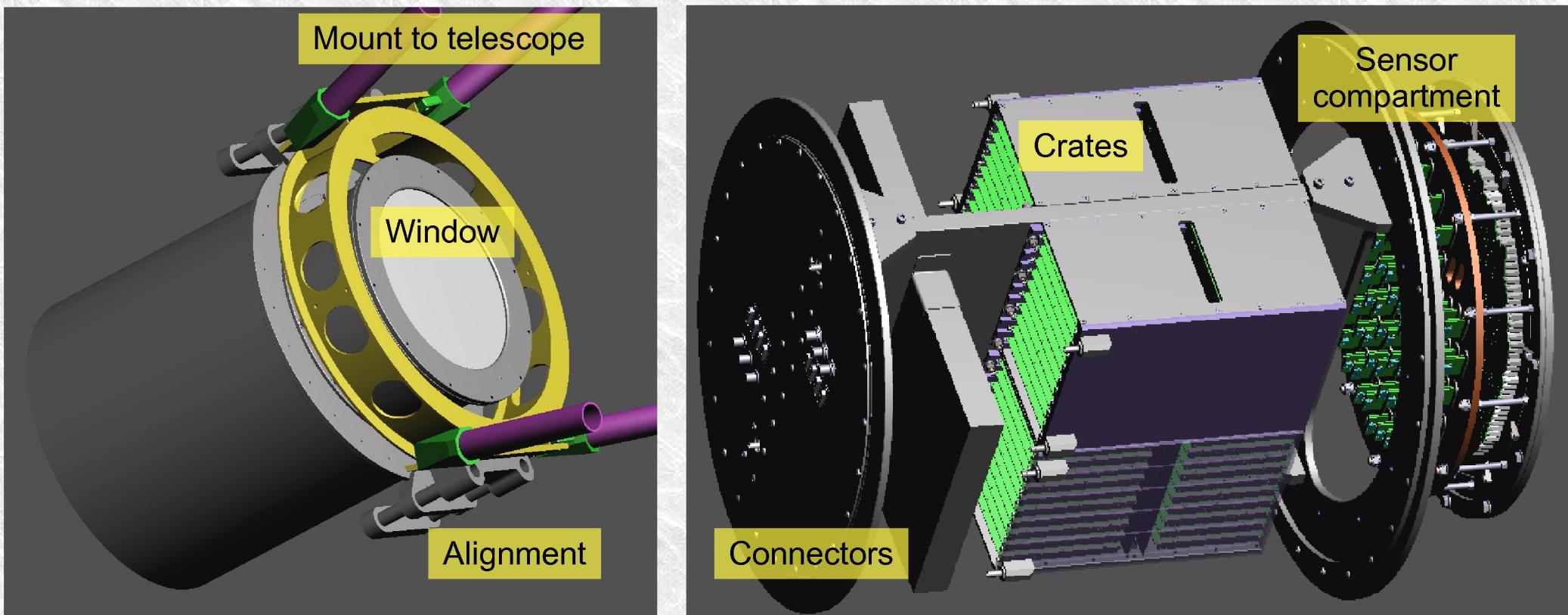
FACT – Mechanical design

Length 812 mm, diameter 532 mm, weight approx. 80 kg

4 cooled electronic crates

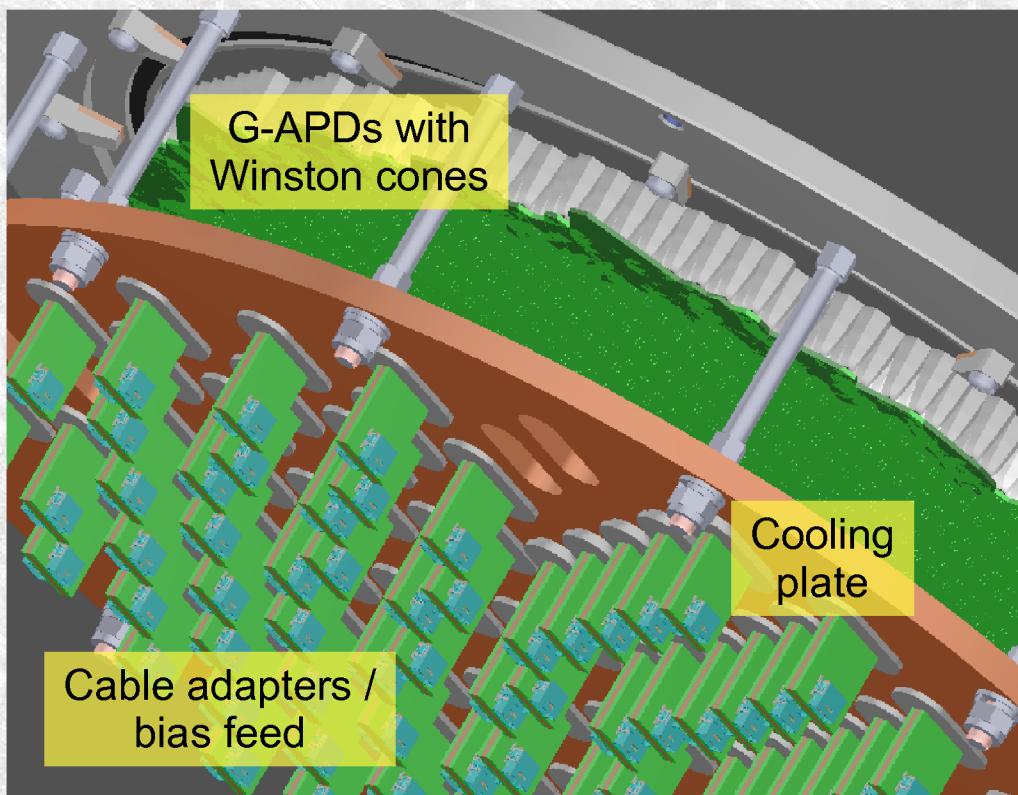
Sensor compartment thermally separated

Longitudinal movement to adjust for optimum mirror focus



FACT – Sensor compartment

G-APDs glued to Winston cones
Cones glued to front window
Cables fed through cooling plate



Trigger

Analog sum of 9 sensors
→ discrimination
→ majority-logic

Bias

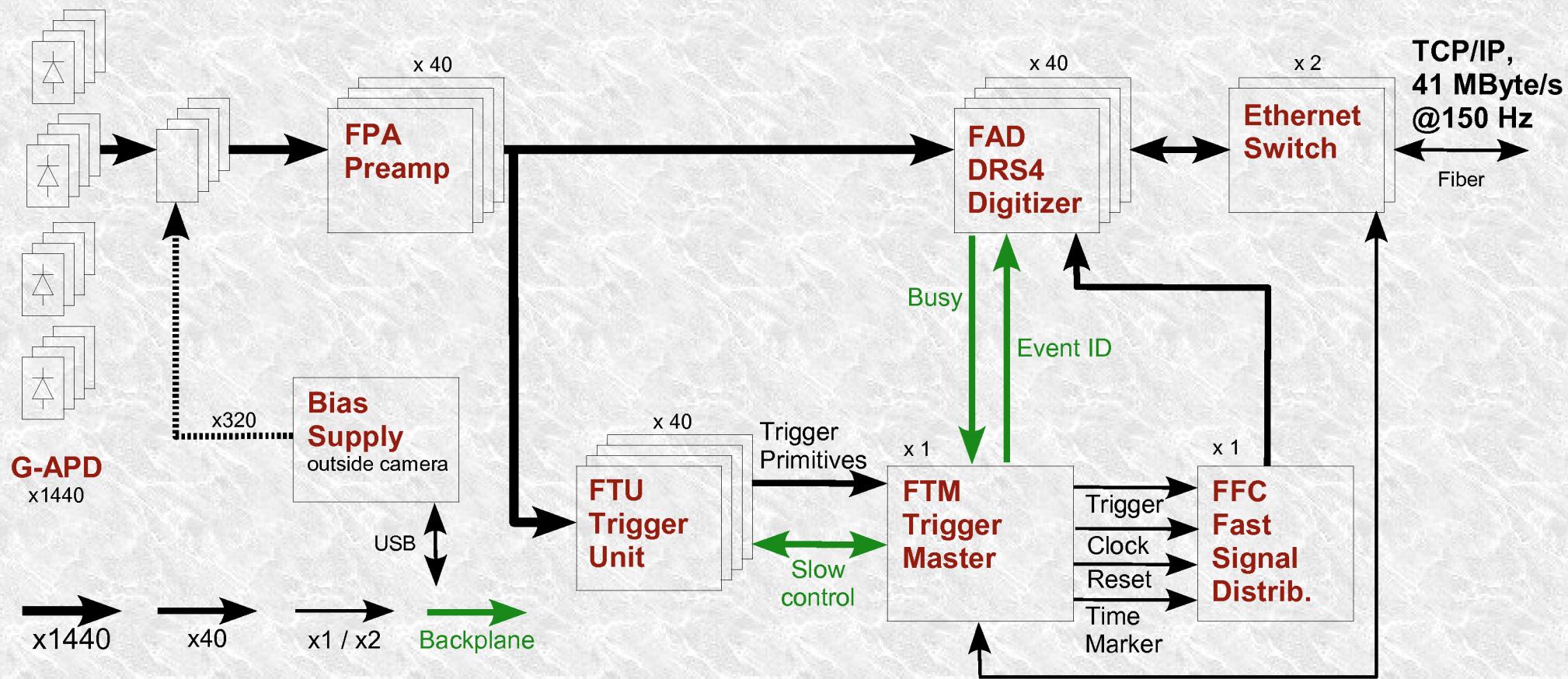
4 or 5 sensors on one channel



Cones and window from
UV transparent PMMA

Cones fabricated
by [injection moulding](#)

FACT – Electronics block diagram



Central event builder on PC, synchronization with event ID

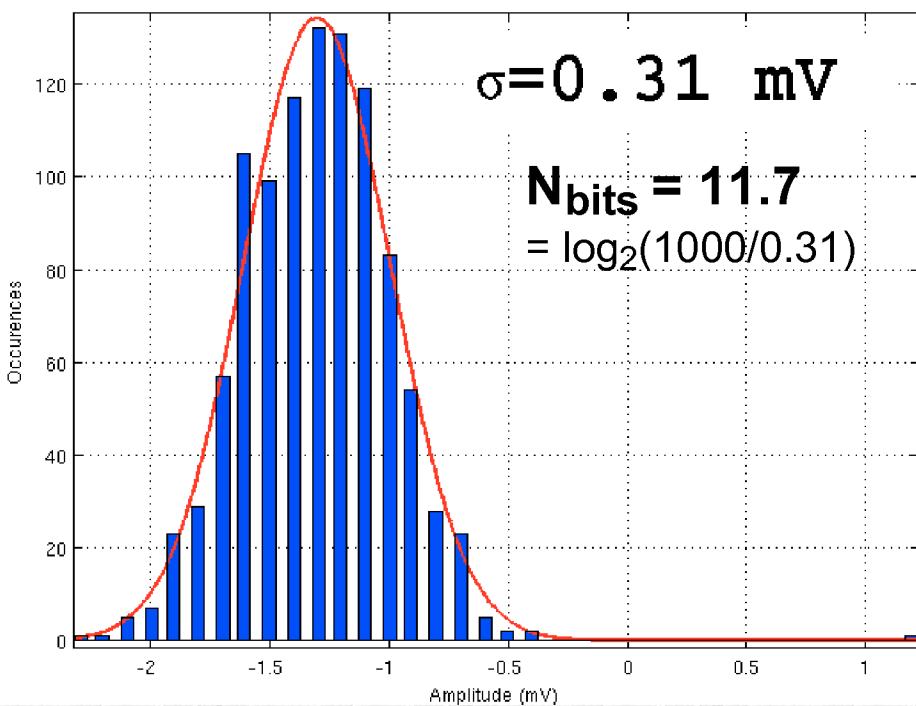
Raw data stored locally, daily transmitted to permanent storage

Control system based on DIM (CERN) and Qt-based GUI

Data analysis with standard tools used for MAGIC

DRS4 – Measurement results

Amplitude: Baseline noise



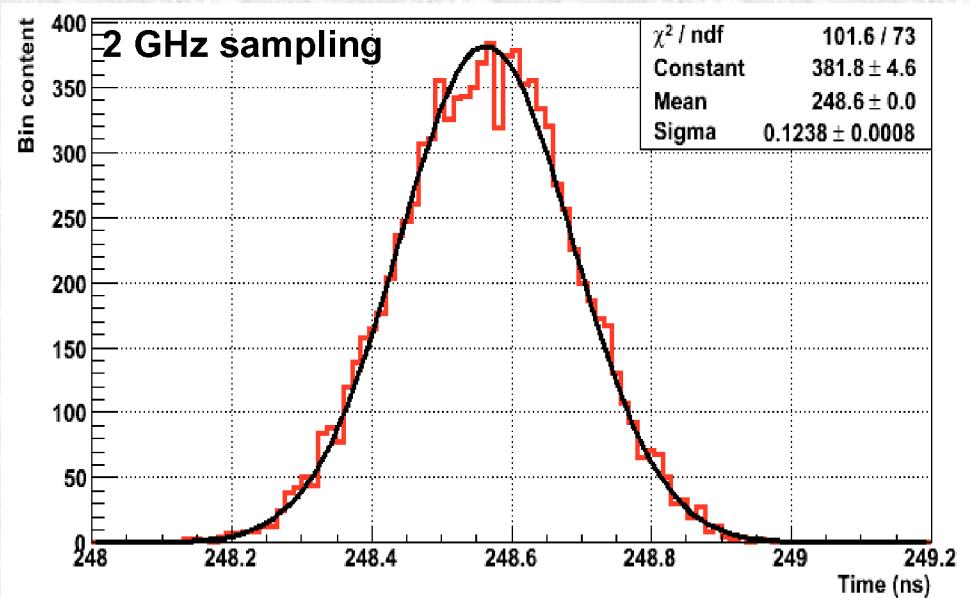
Without gain and offset calibration
 $\sigma \approx 7 \text{ mV}$

10°C temperature increase
→ $\approx 100 \mu\text{V}$ noise increase

Timing: Fixed-pattern aperture jitter

Variation of bin widths from manufacturing
Intrinsic time resolution only 4 ns at 2 GHz

Calibration with $\approx 200 \text{ MHz}$ low-jitter source



$f \text{ (GHz)}$	$\sigma_{\text{DRS}} \text{ (ps)}$	Measured on one chip
1	340	Corrected for 60 ps generator jitter
2	110	
4	50	PLL jitter $\approx 30 \text{ ps}$ @ 4 GHz

Conclusion

Feasibility of G-APD camera proven

Light from Cherenkov showers observed with test module M0

FACT camera ready by fall 2010 (Crab nebula visible on La Palma)

Mount of refurbished ex-Hegra CT3 telescope

Realistic performance evaluation for IACT only with full set-up

Expected energy threshold \approx 400 GeV

Monitoring selected, strong sources

FACT is an important step to establish G-APDs as option for next generation of large Cherenkov telescopes (AGIS/CTA)