First G-**A**PD **C**herenkov **T**elescope

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Würzburg

First G-**A**PD **C**herenkov **T**elescope
Major Goals

Proof of principle:

Silicon based photo sensors (G-APDs*) in Cherenkov Telescopes

✓ First successful use in regular operation

Longterm monitoring of bright TeV Blazars

→ Flare alerts to other instruments
→ Multi-wavelength studies
→ Flare studies of AGN

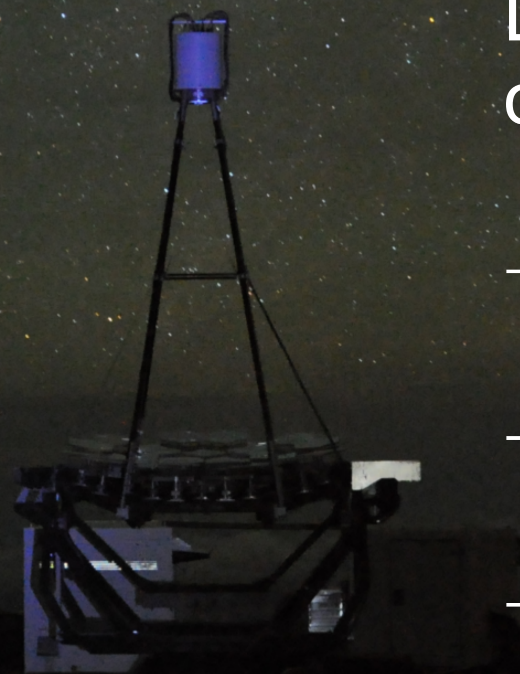
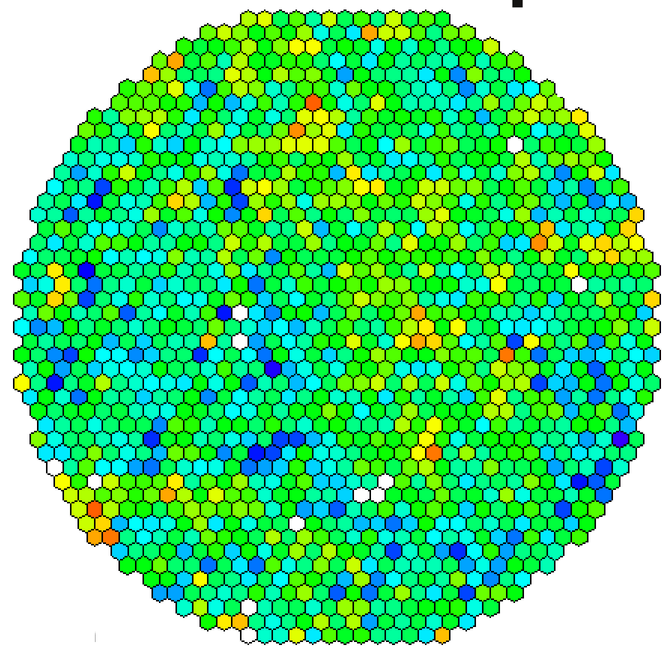


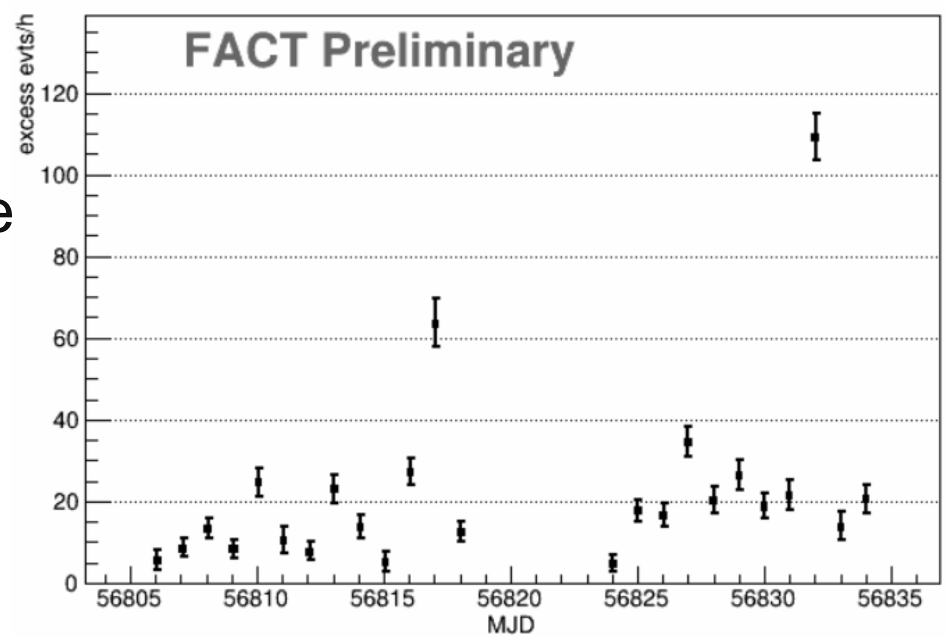
Photo: Thomas Bretz

* Geiger-mode Avalanche Photodiodes

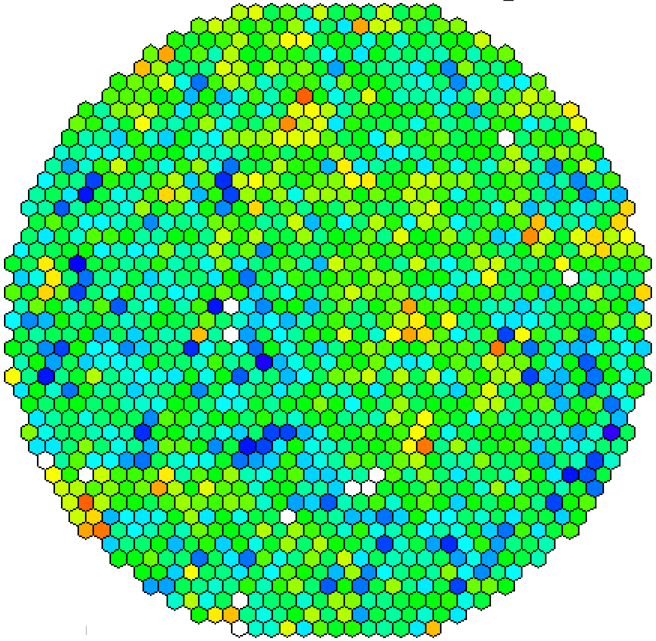
First G-APD Cherenkov Telescope



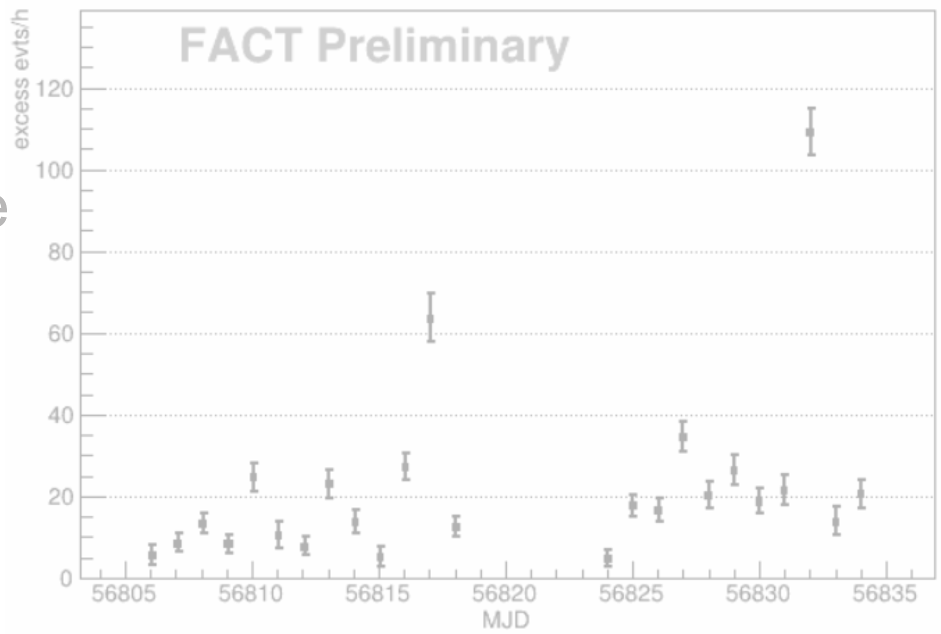
- G-APD camera
  - Telescope and camera
  - Photosensors
  - Detector performance
  - Gain stability and feedback system
- Longterm Monitoring
  - Blazar variability
  - Imaging Air Cherenkov Technique
  - Excess rate curves
  - Quick Look Analysis
  - Flare alerts

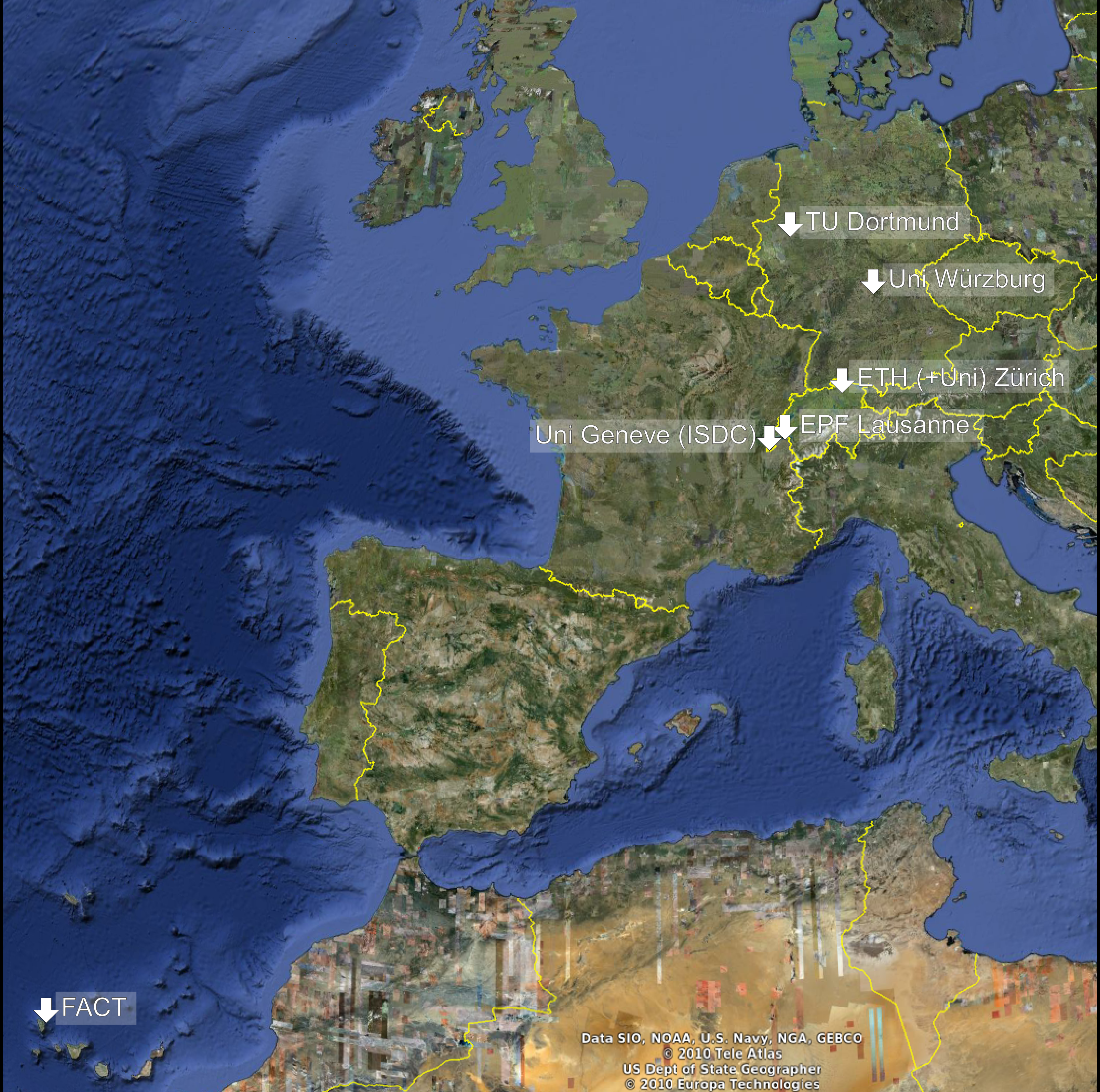


First G-APD Cherenkov Telescope



- G-APD camera
  - Telescope and camera
  - Photosensors
  - Detector performance
  - Gain stability and feedback system
- Longterm Monitoring
  - Blazar variability
  - Imaging Air Cherenkov Technique
  - Excess rate curves
  - Quick Look Analysis
  - Flare alerts



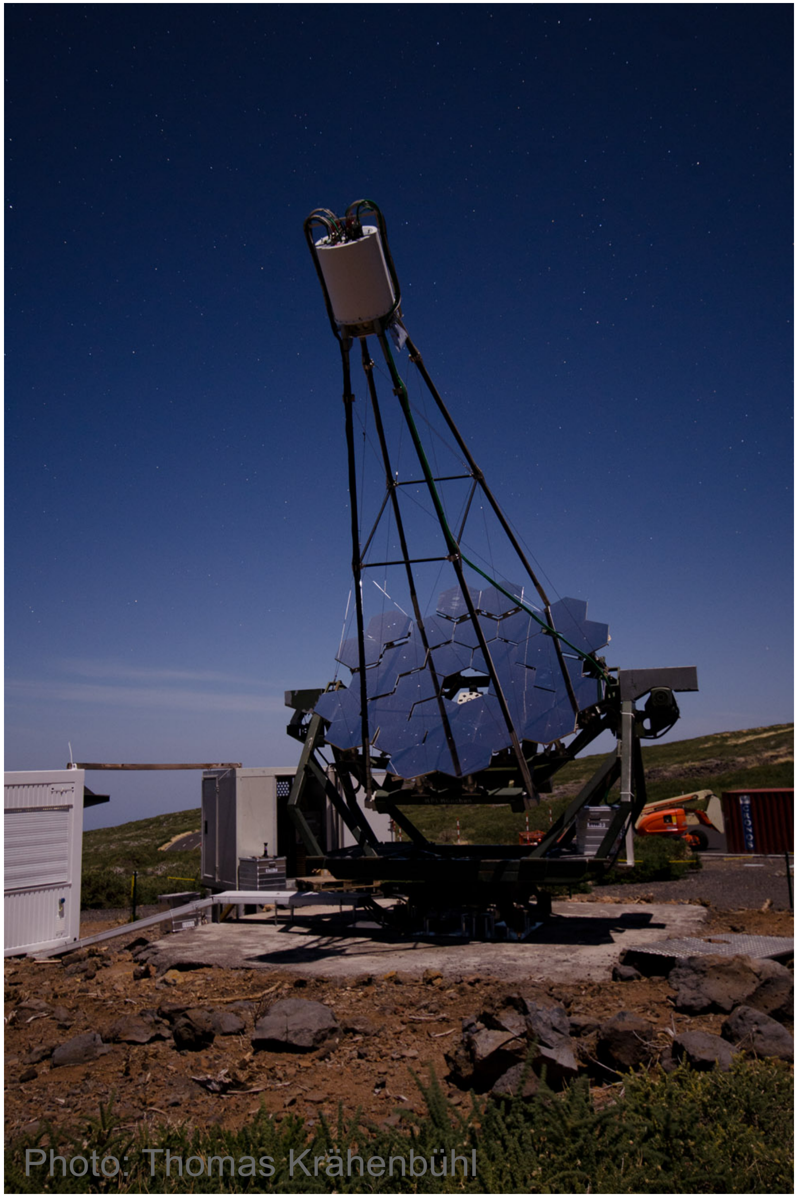


TU Dortmund
Uni Würzburg
ETH (+Uni) Zürich
EPF Lausanne
Uni Geneve (ISDC)
FACT
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2010 Tele Atlas
US Dept of State Geographer
© 2010 Europa Technologies

How the project was born:

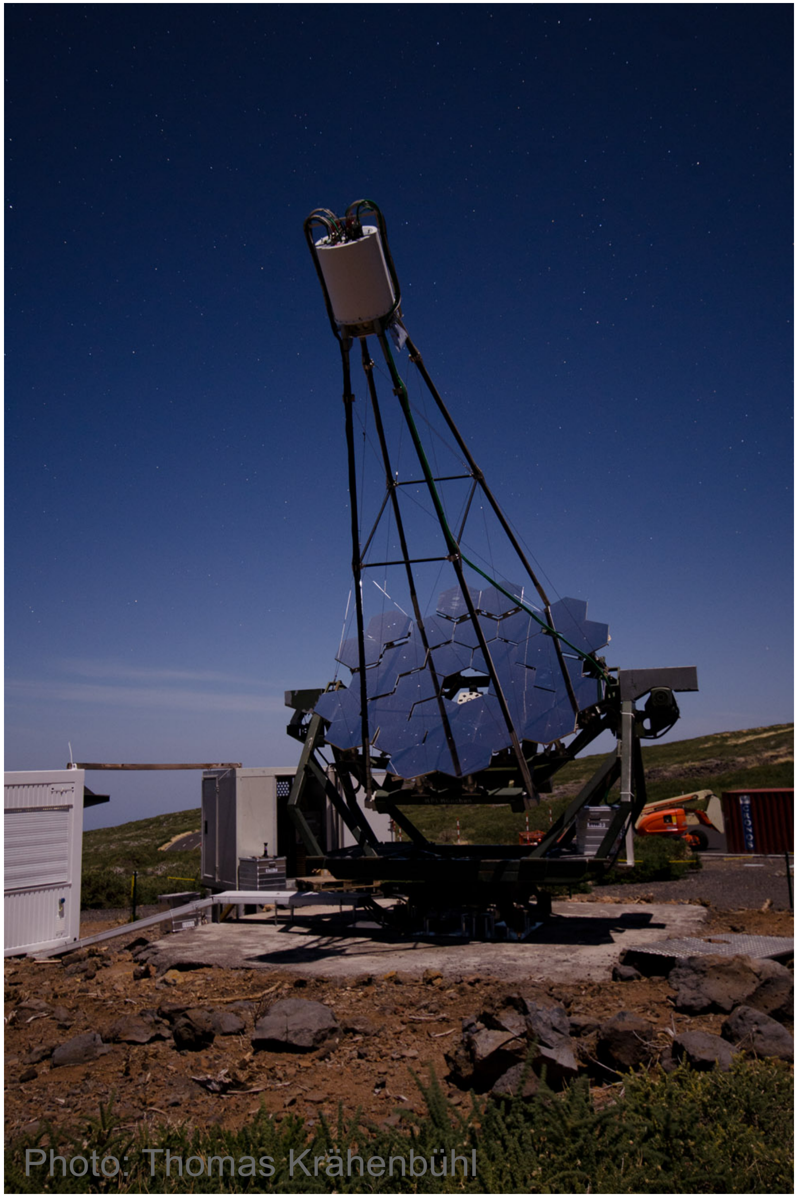
* Concept for monitoring telescope DWARF: Uni Würzburg, TU Dortmund
* G-APD camera in Cherenkov astronomy: ETH Zürich
* 2008: joint effort: FACT
* 2010 further institutes joined
* 2011 start of operation

Facts about FACT



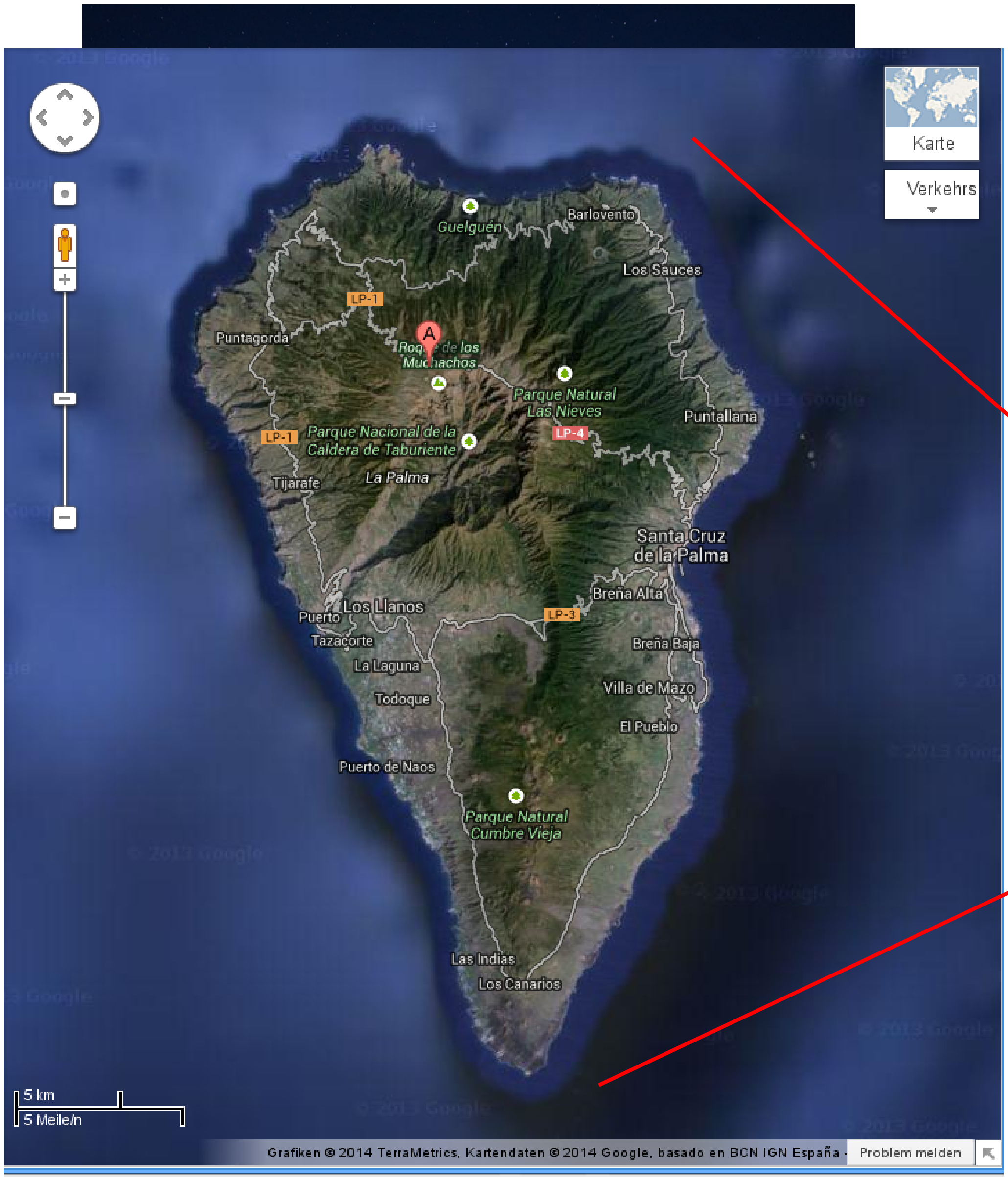
- 2200 m a.s.l.
  Observatorio del Roque de los Muchachos, La Palma

Facts about FACT



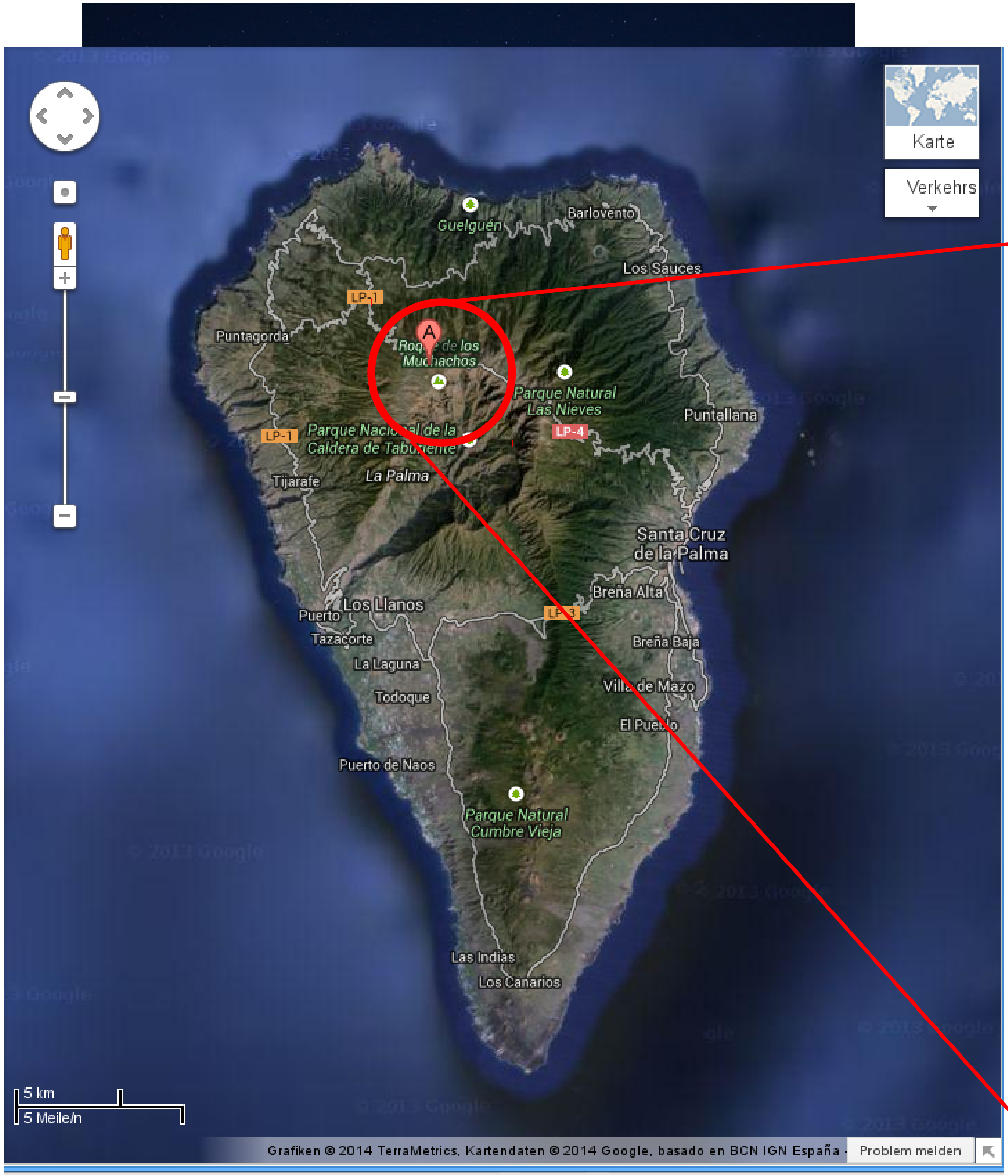
- 2200 m a.s.l.
  Observatorio del Roque de los Muchachos, La Palma

Facts about FACT



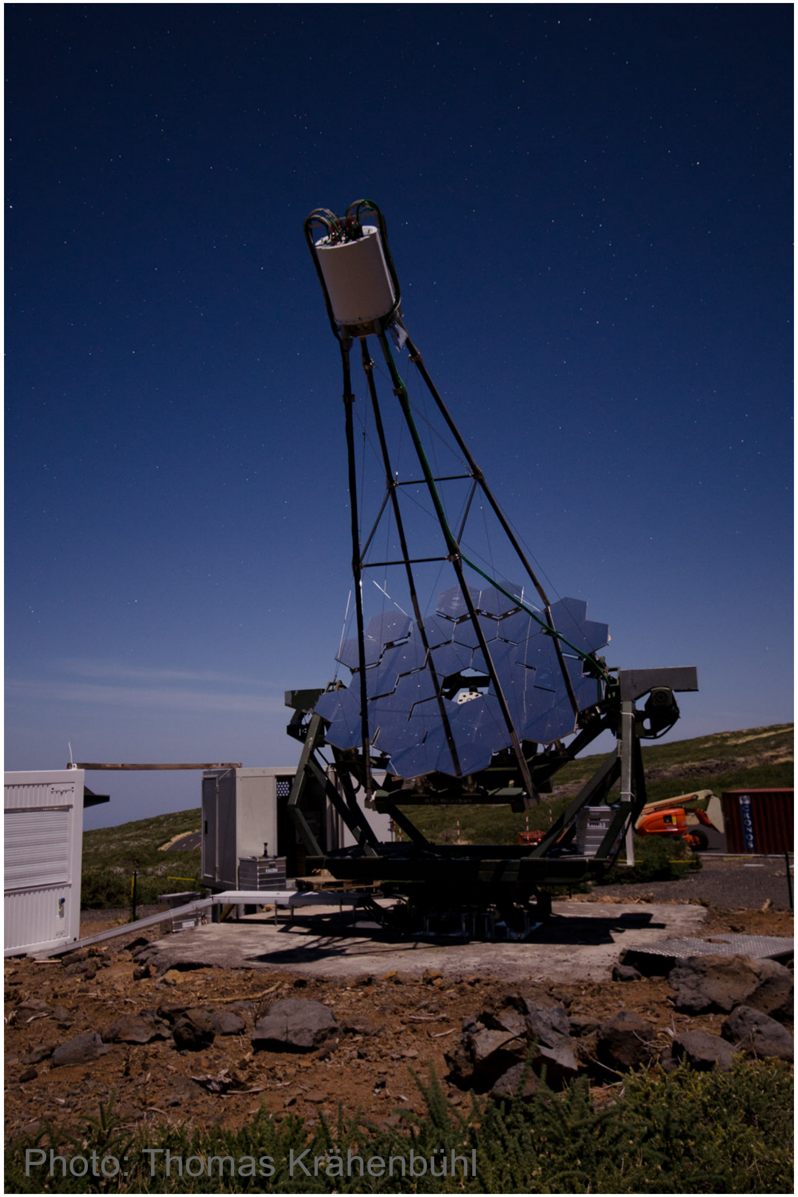
- 2200 m a.s.l.
  Observatorio del Roque de los Muchachos, La Palma

Facts about FACT



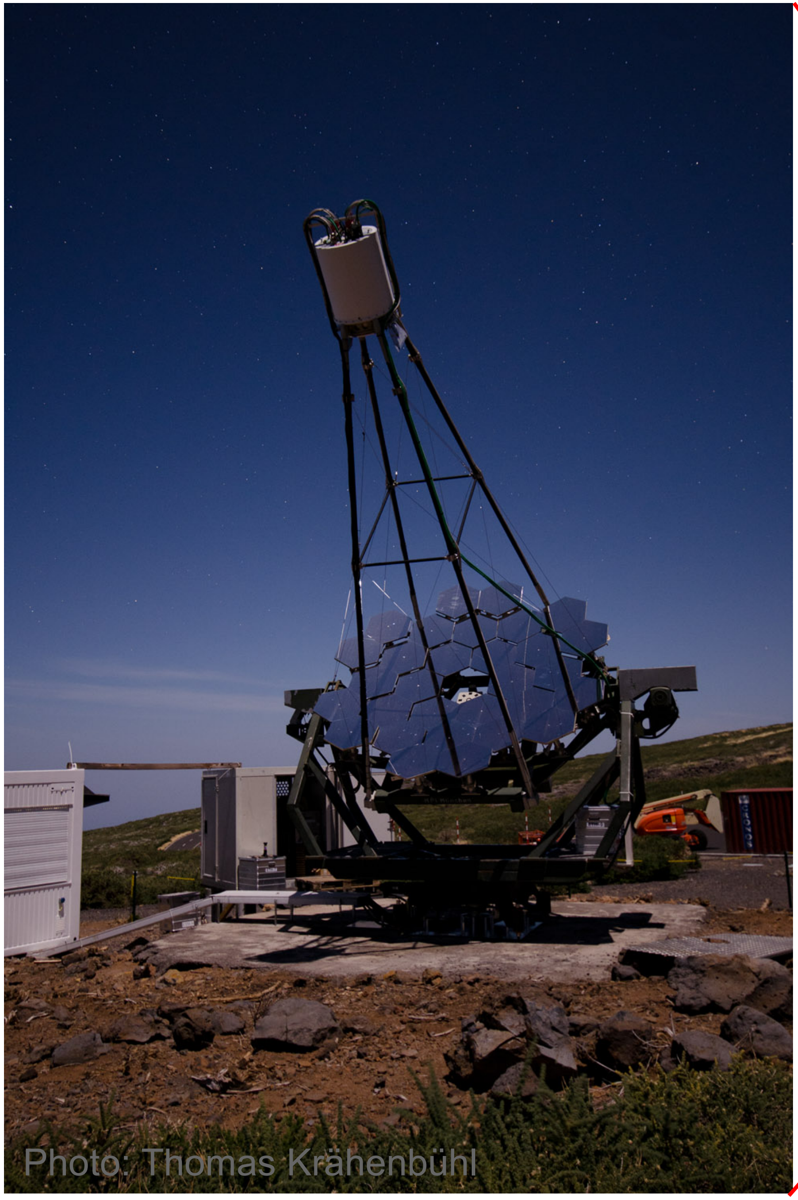
- 2200 m a.s.l.
  Observatorio del Roque de los Muchachos, La Palma

Facts about FACT

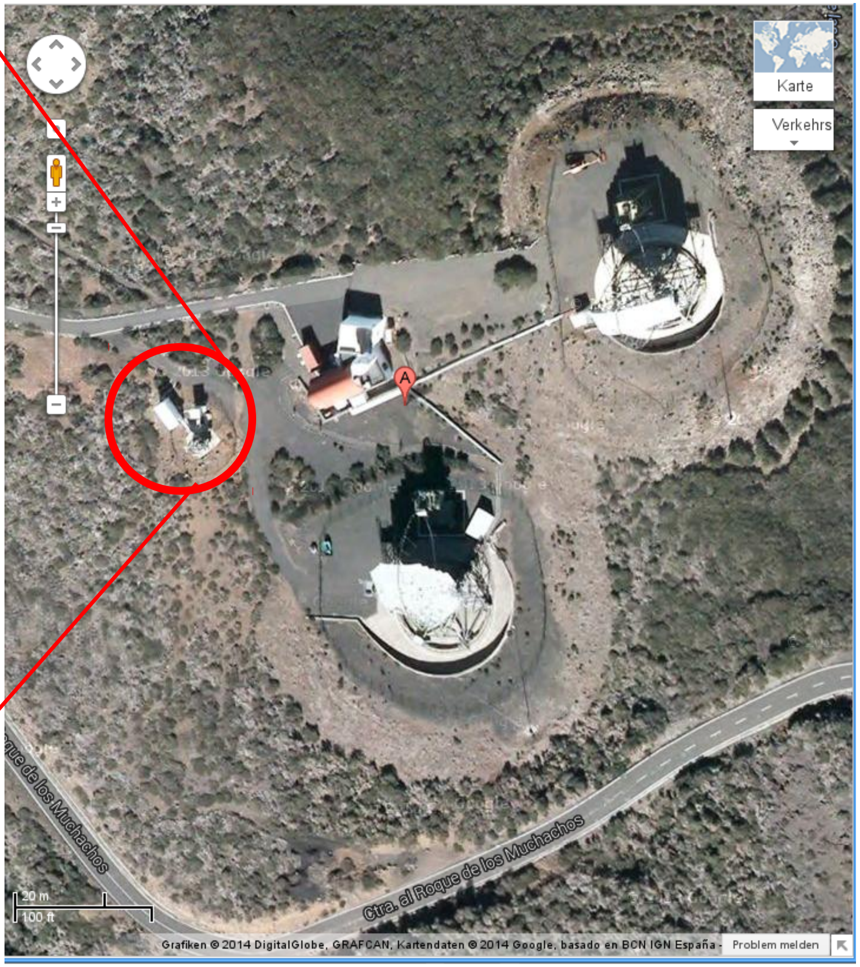


- 2200 m a.s.l.
  Observatorio del Roque de los Muchachos, La Palma

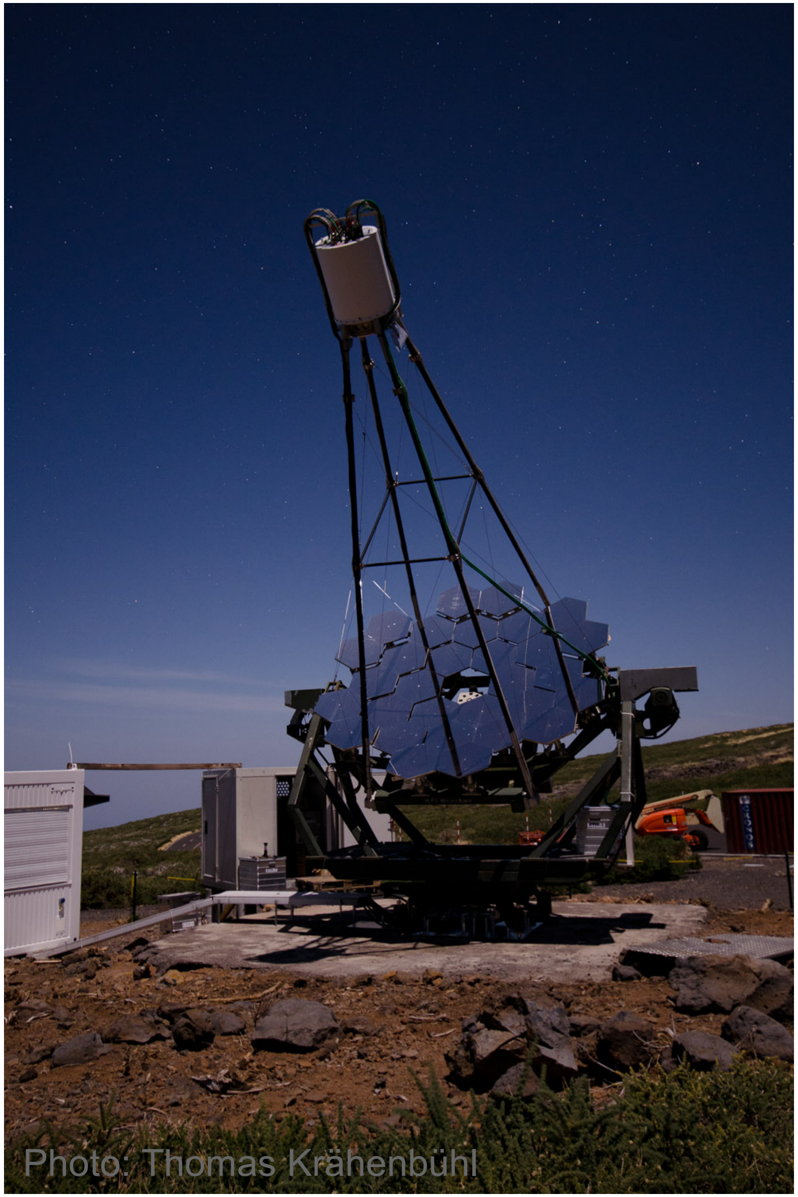
Facts about FACT



- 2200 m a.s.l.
  Observatorio del Roque de los Muchachos, La Palma



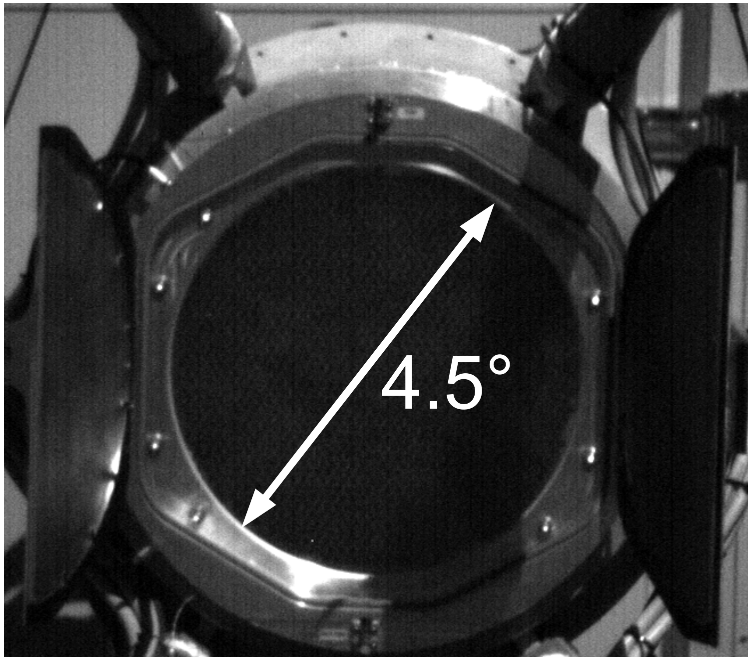
Facts about FACT



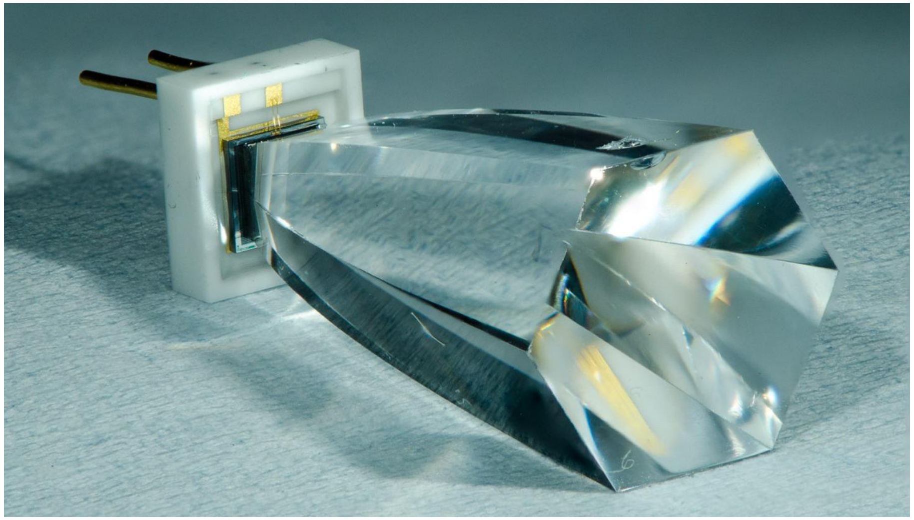
- 2200 m a.s.l.
  Observatorio del Roque de los Muchachos, La Palma
- Refurbished HEGRA CT3
  - New drive system
  - Recoated CT1 mirrors
- 9.5 m² mirror area
- G-APD camera
- More Details:

Design and operation of FACT – the first G-APD Cherenkov telescope
H Anderhub et al 2013 JINST 8 P06008

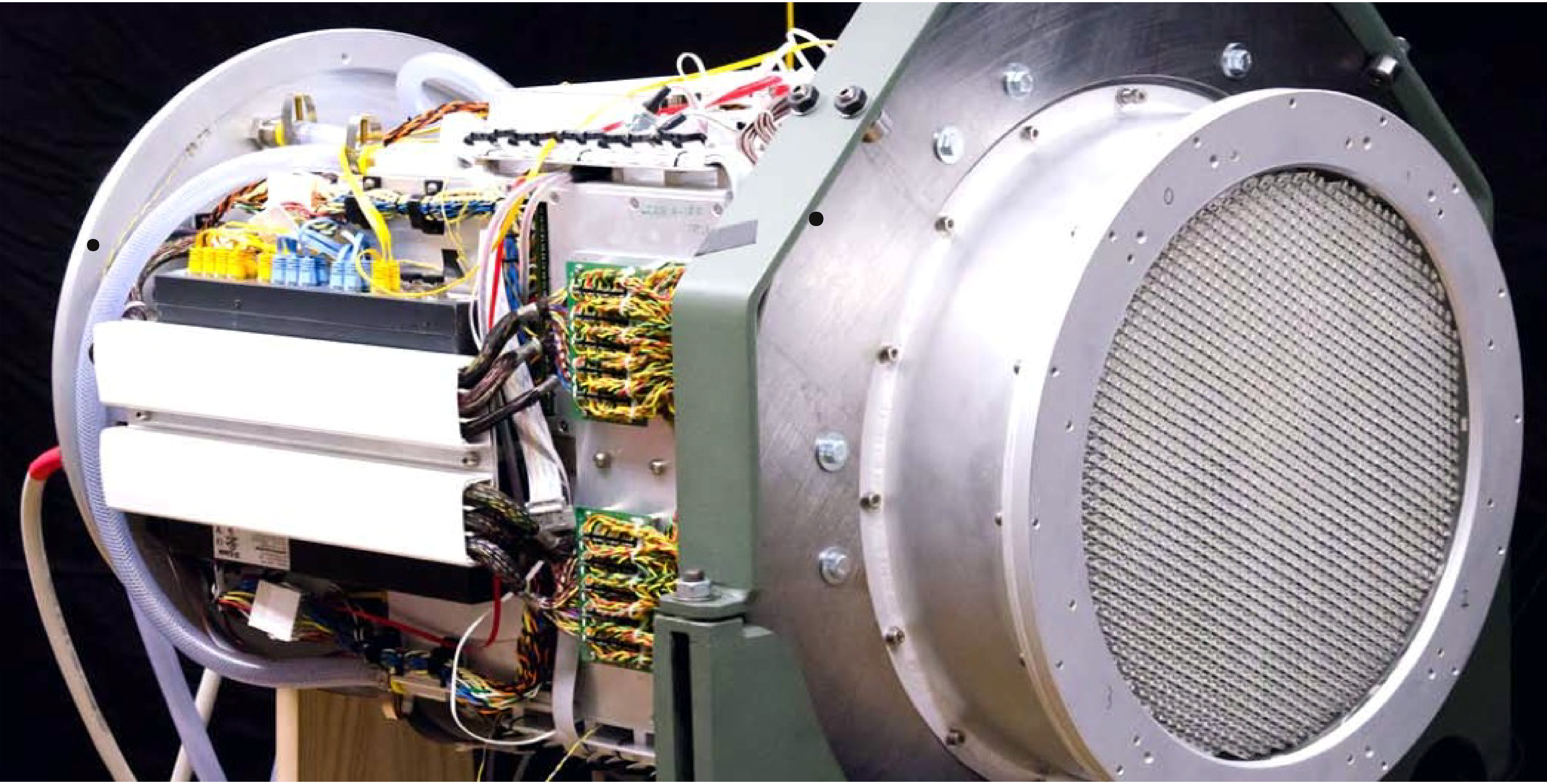
G-APD Camera



- 4.5° FoV
- 1440 Pixels
- Solid cones
- 160 trigger patches: sum of 9 pixels



Integrated Electronics



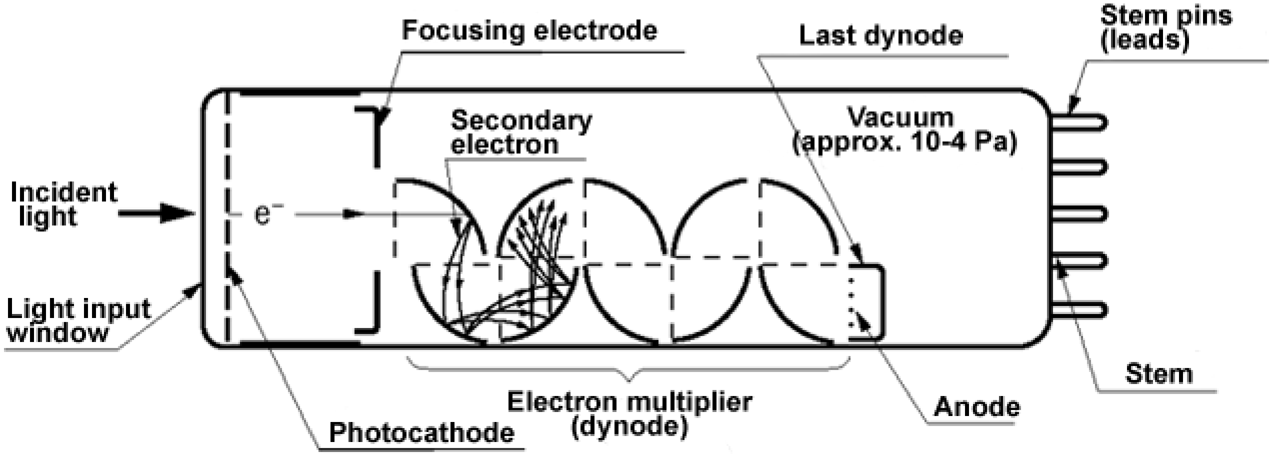
- Power consumption ≤ 500W
- Readout: DRS4 Chip
- Ethernet readout
- 320 bias voltage channels

More info: *A Biland et al.* **arXiv:1403.5747**
Calibration and performance of the photo sensor response of FACT

Photosensors

Previously used:
Photomultiplier tubes (PMTs)

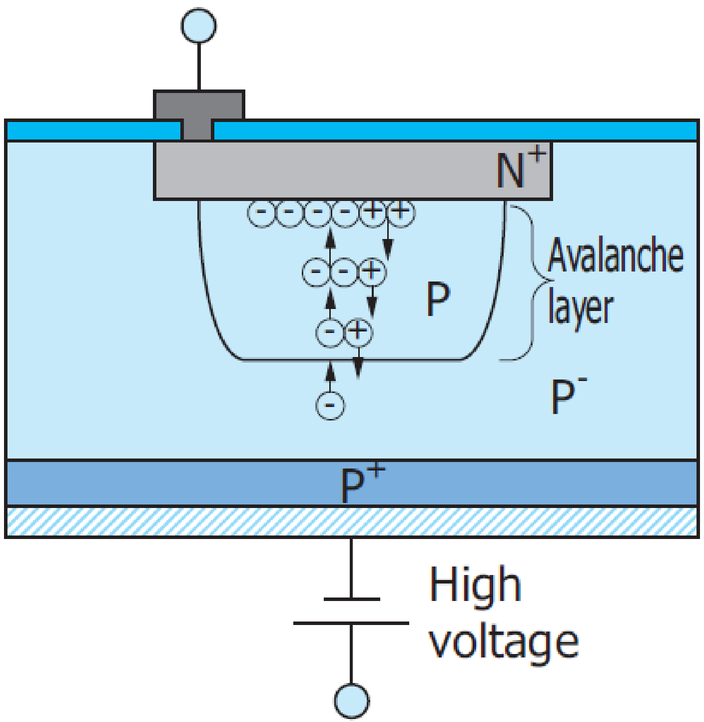
PMT Handbook, Hamamatsu



Photosensors

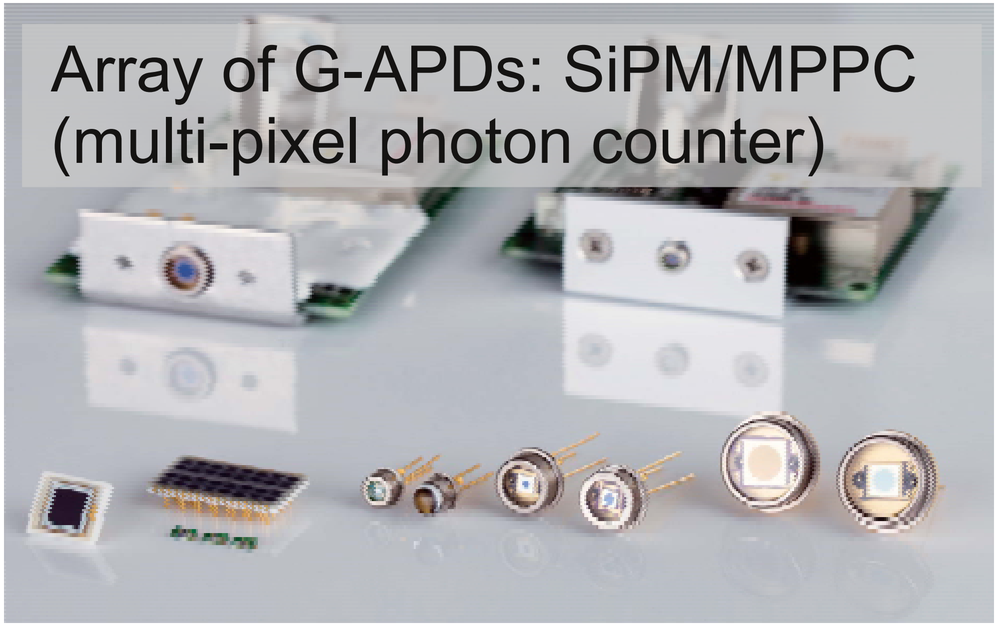
New in Cherenkov Astronomy: G-APDs
Geigermode **A**valanche **P**hoto**D**iodes

Avalanche Photodiode



APD Handbook, Hamamatsu

Geigermode:
operate APD above breakdown voltage → larger gain



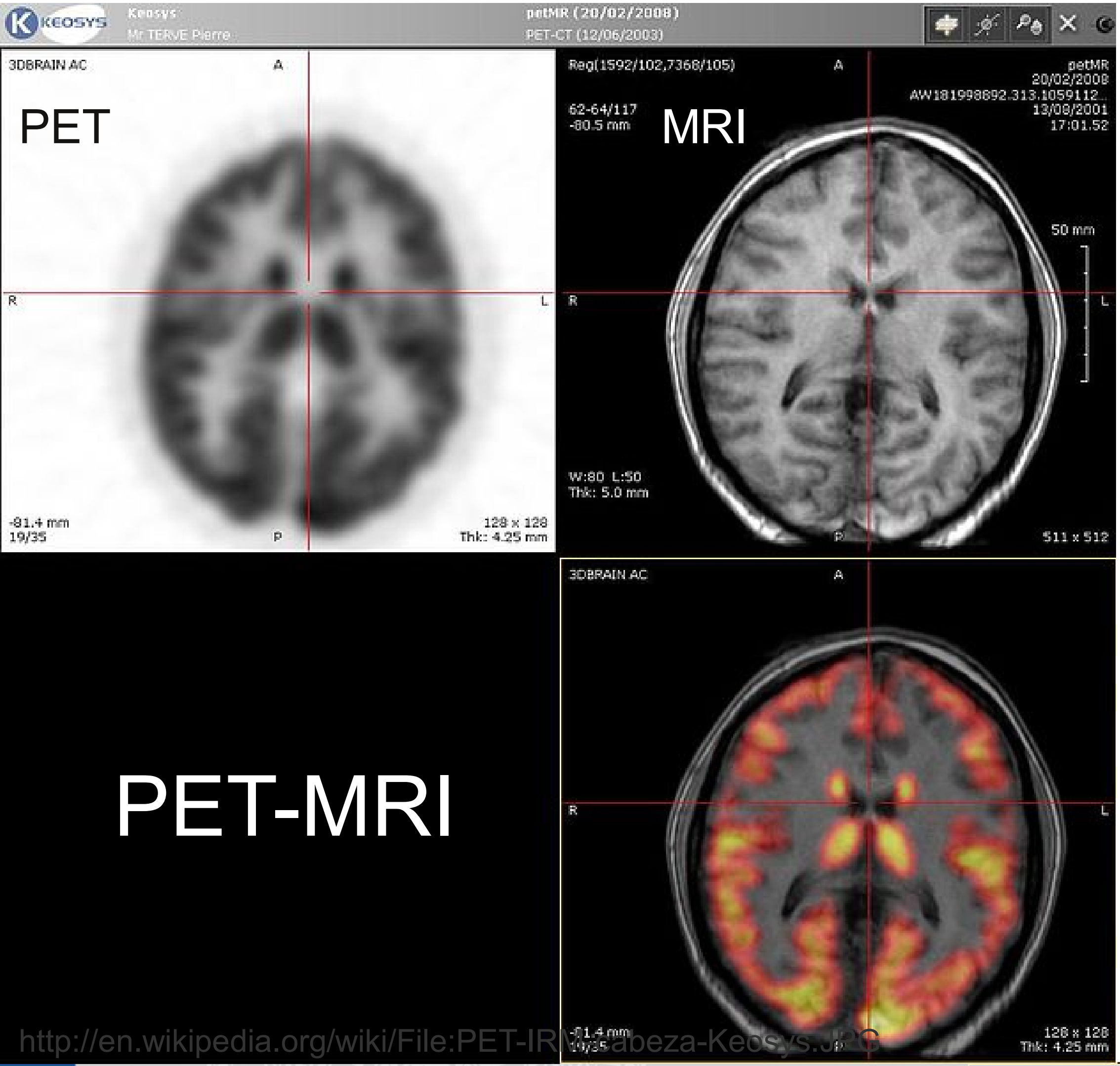
G-APDs

- Performance comparable to best available PMTs
- Future potential (PDE ~70%)
- Cheaper than PMTs
- Very good timing (jitter)
- Very easy to handle (U<100V)

G-APDs

- Insensitive to
  - Magnetic field
  - Mechanical impact
  - Strong light

G-APDs



http://en.wikipedia.org/wiki/File:PET-IRM-cabeza-Keosys.JPG

- Insensitive to
  - Magnetic field
  - Mechanical impact
  - Strong light

G-APDs

- Insensitive to
  - Magnetic field
  - Mechanical impact
  - Strong light
- Afterpulses, crosstalk and darkcounts are no problem for Cherenkov telescopes

Gain of G-APDs

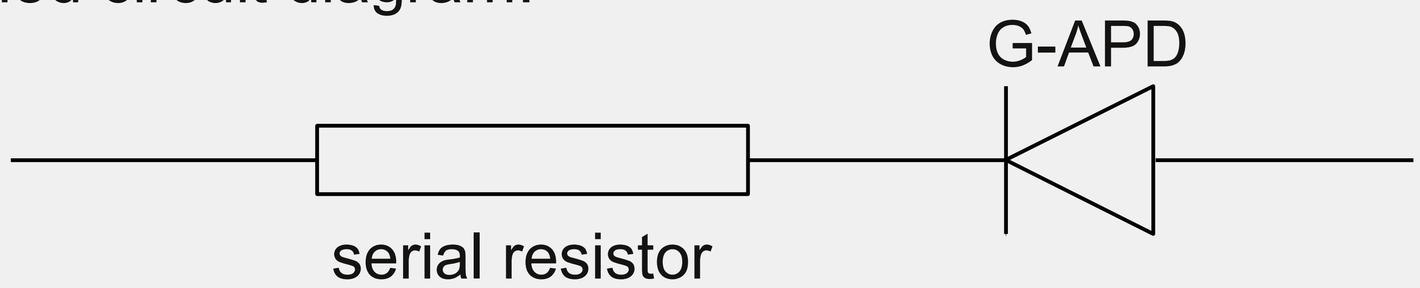
Gain depends on

- Temperature
- Applied voltage

- Correct for temperature dependence by adapting voltage (55 mV/K)
- Measure gain with light pulser (temperature stabilized)

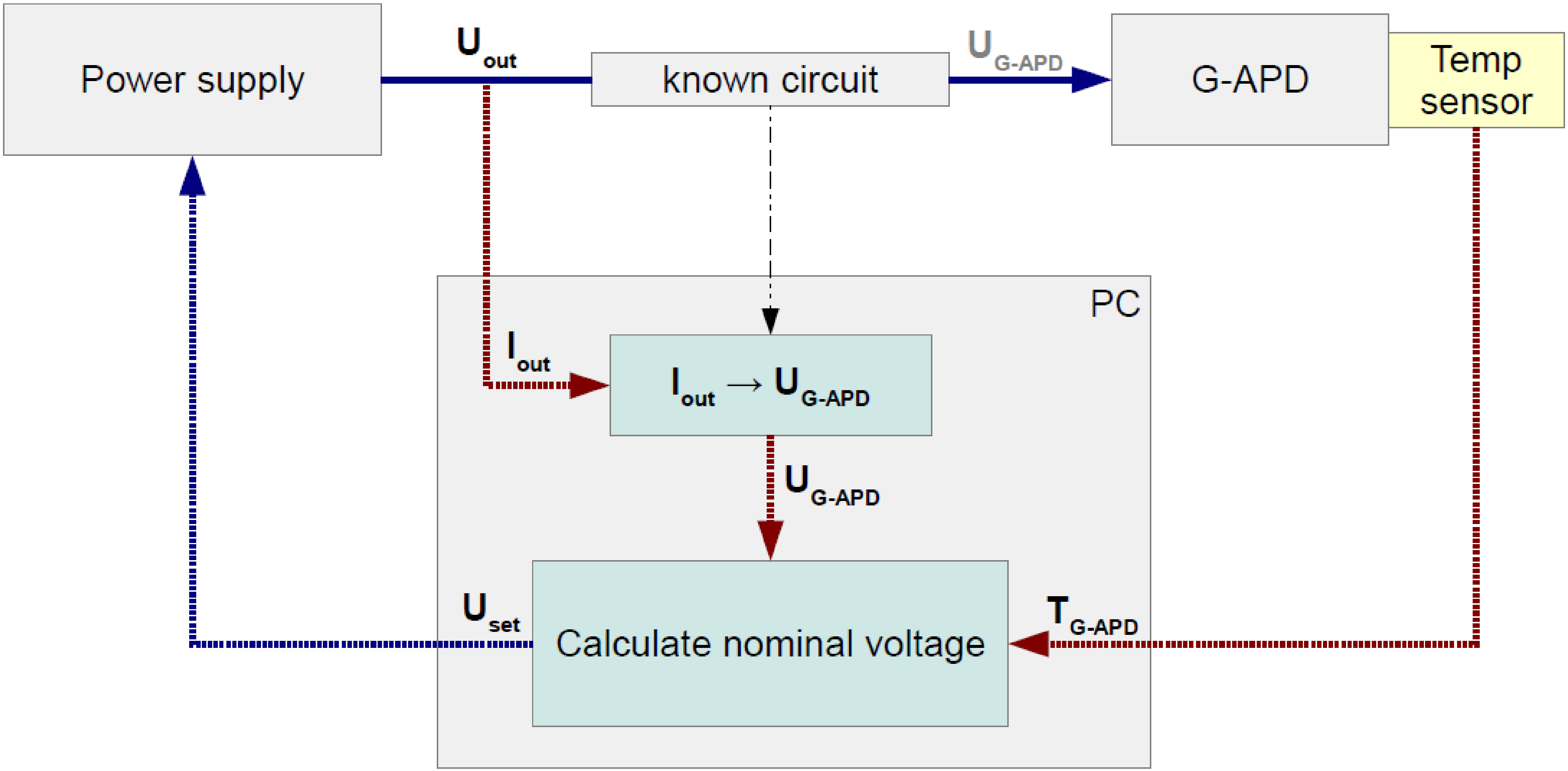
Goal: Stable Gain

Simplified circuit diagram:



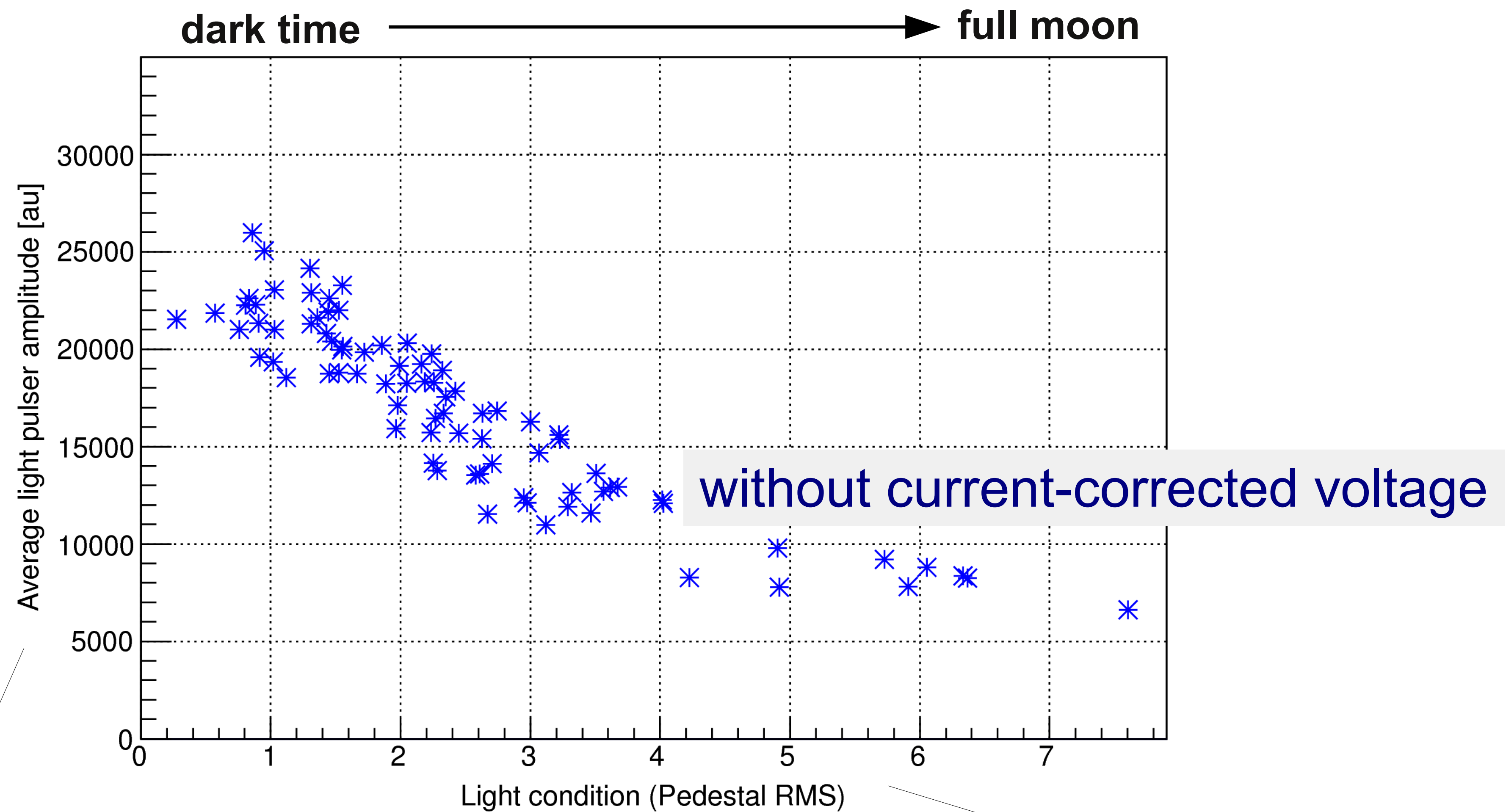
- Night sky background light
  → Continuous current
  → Voltage drop at resistor
- Correction method:
  Measure current
  → Adapt voltage accordingly

Feedback System



T. Bretz et al. IEEE/RT 2014

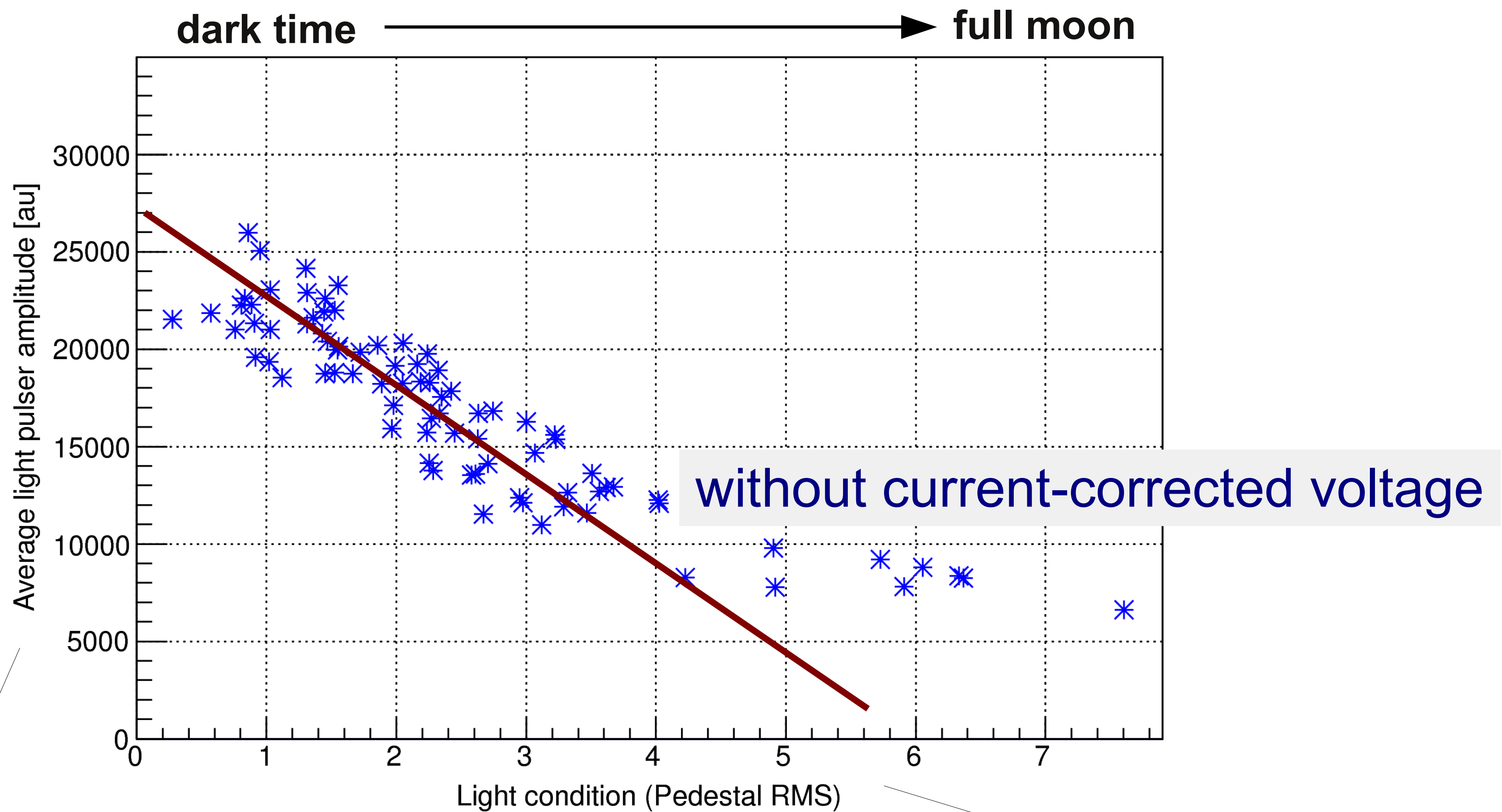
Light-pulser amplitude vs. light condition



Indirect measurement of the gain

The noise of the data is a measure for the brightness

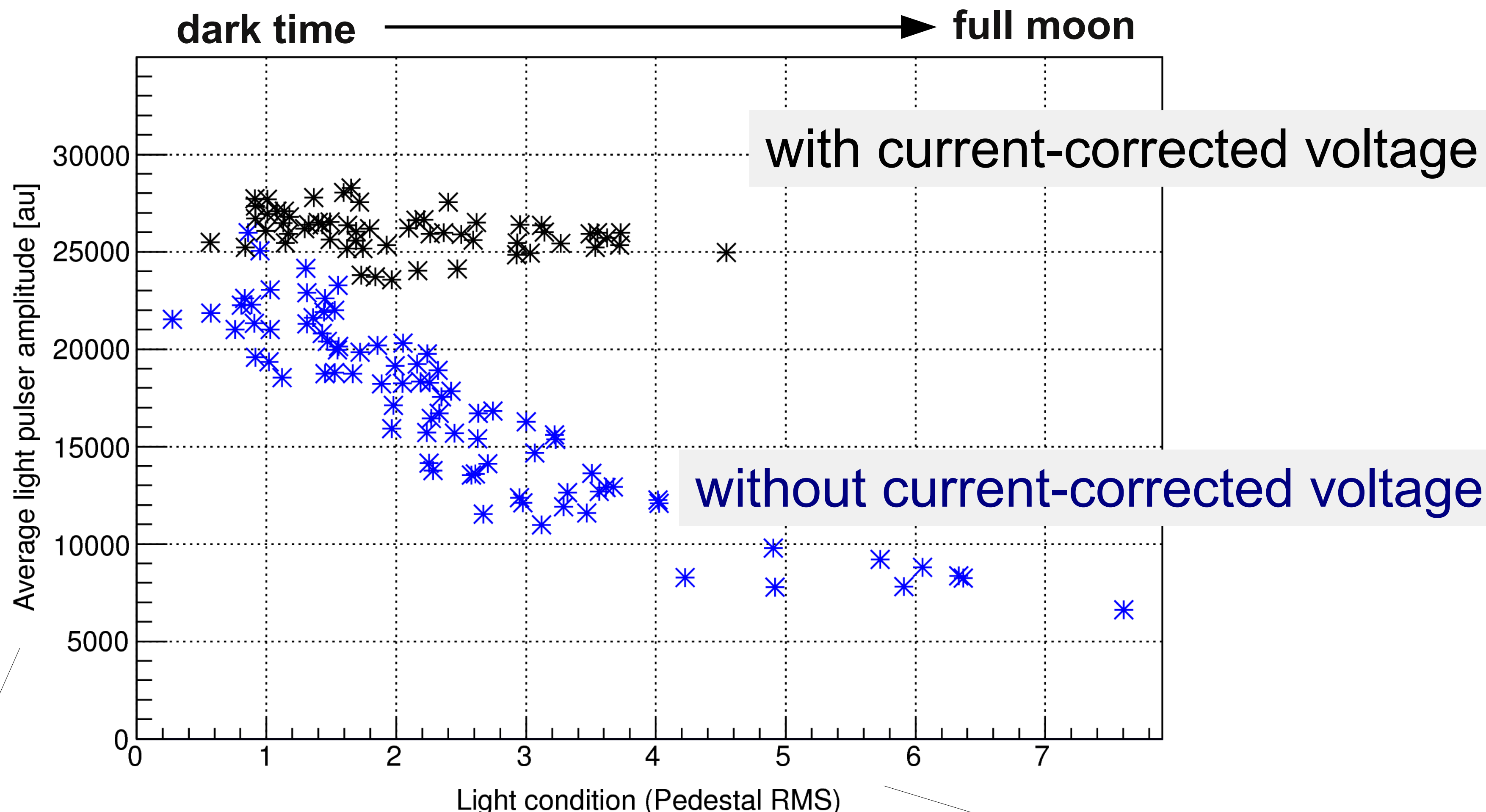
Light-pulser amplitude vs. light condition



Indirect measurement of the gain

The noise of the data is a measure for the brightness

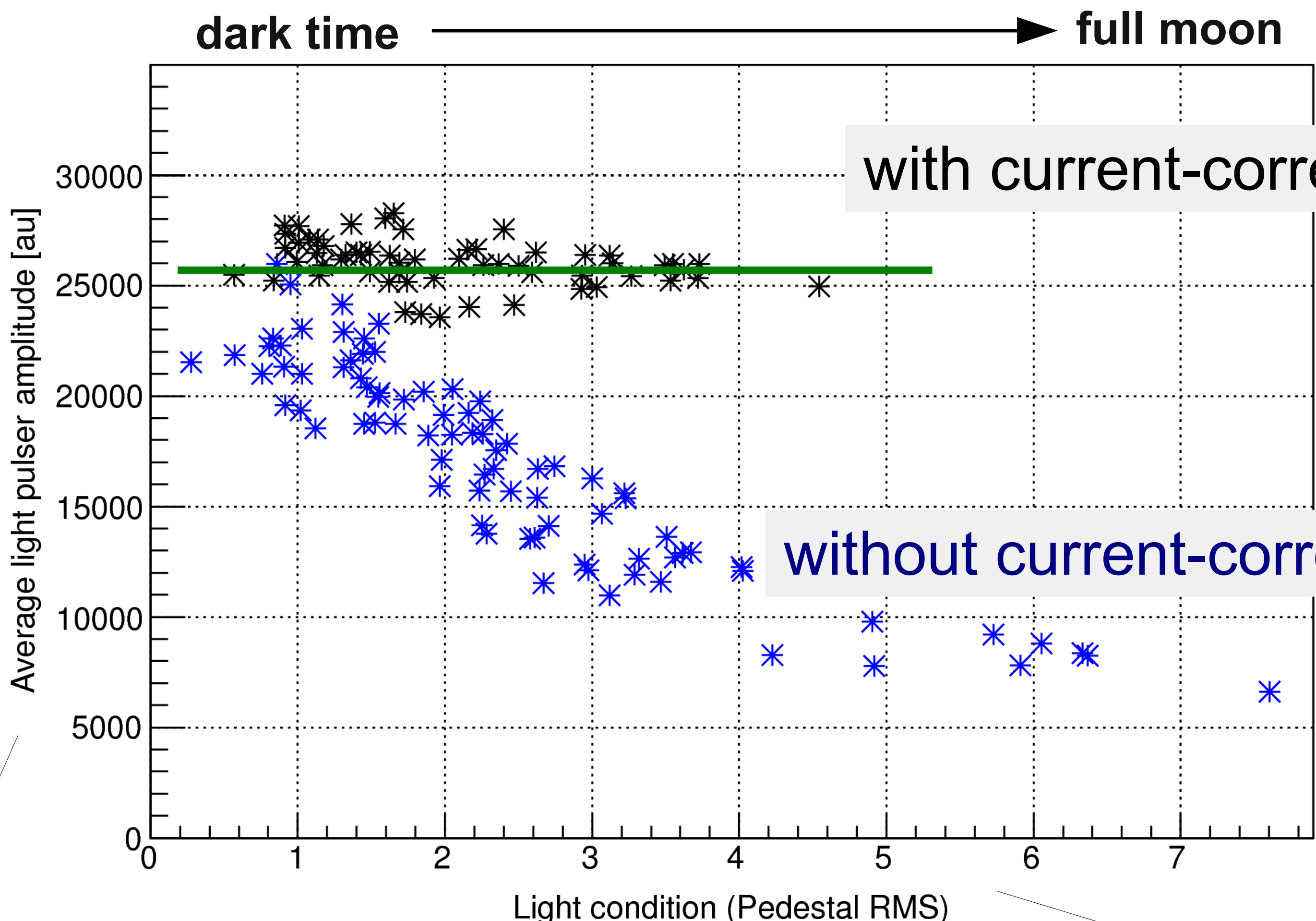
Light-pulser amplitude vs. light condition



Indirect measurement of the gain

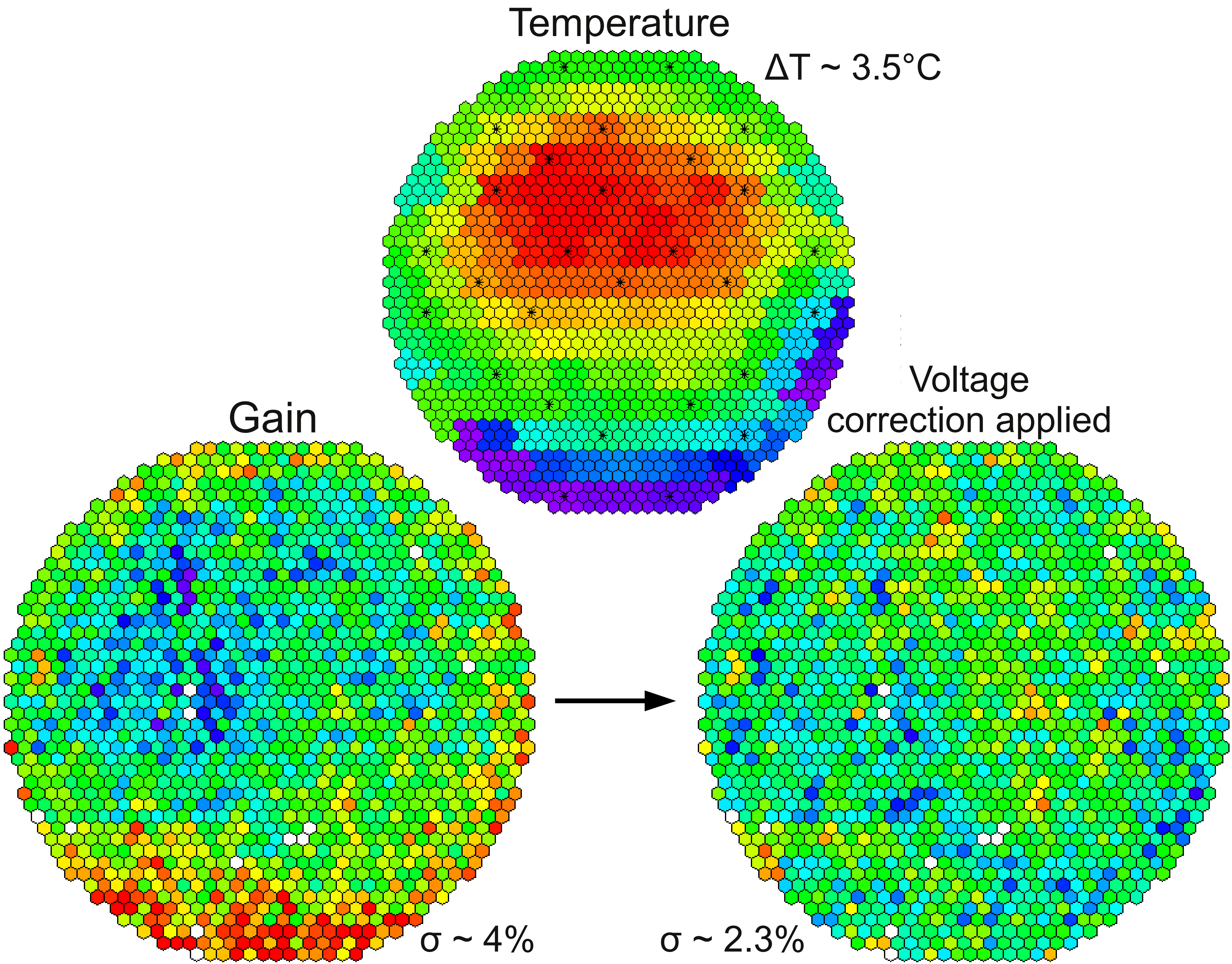
The noise of the data is a measure for the brightness

Light-pulser amplitude vs. light condition



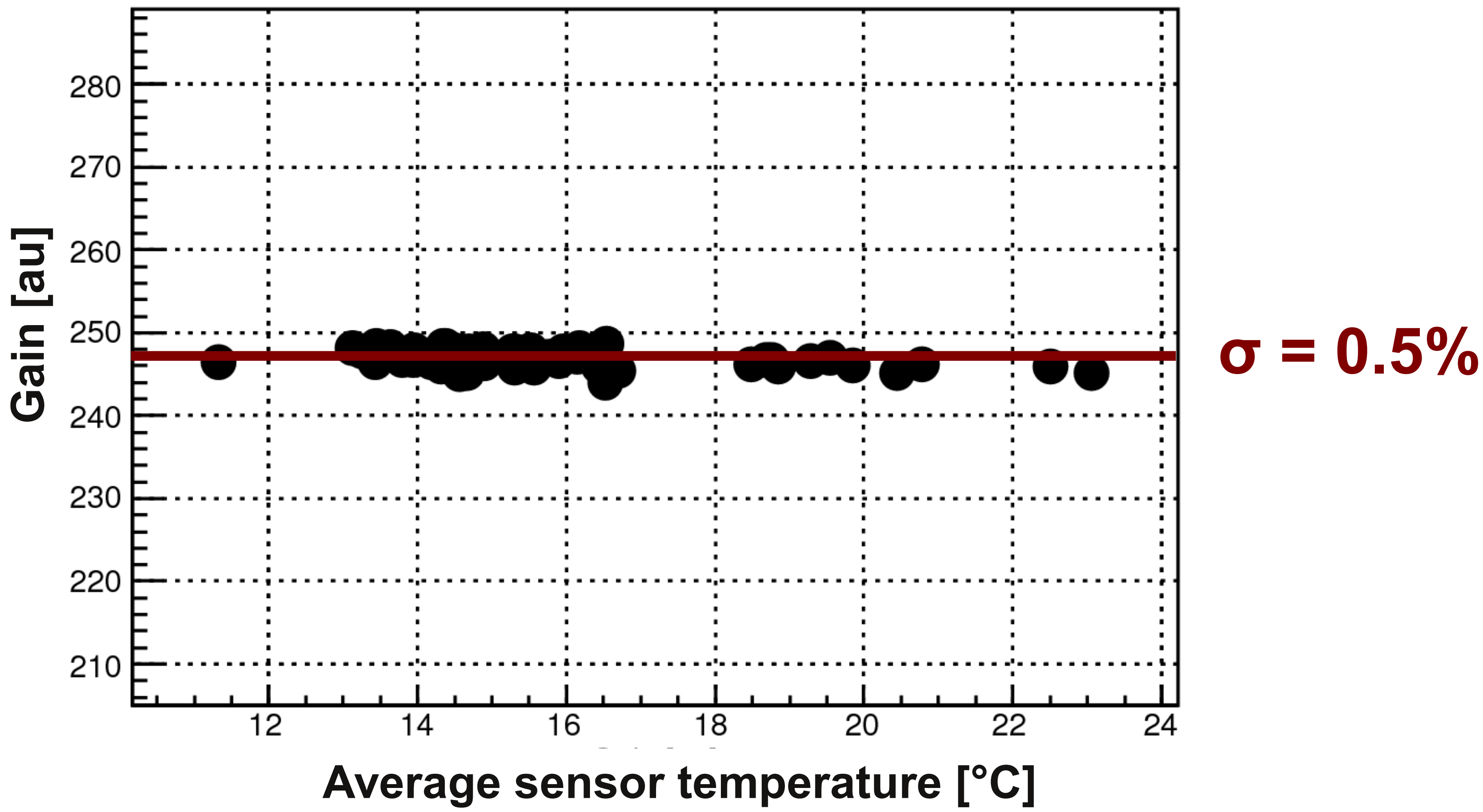
Indirect measurement of the gain

The noise of the data is a measure for the brightness


Temperature
ΔT ~ 3.5°C
Gain
Voltage
correction applied
σ ~ 4%
σ ~ 2.3%

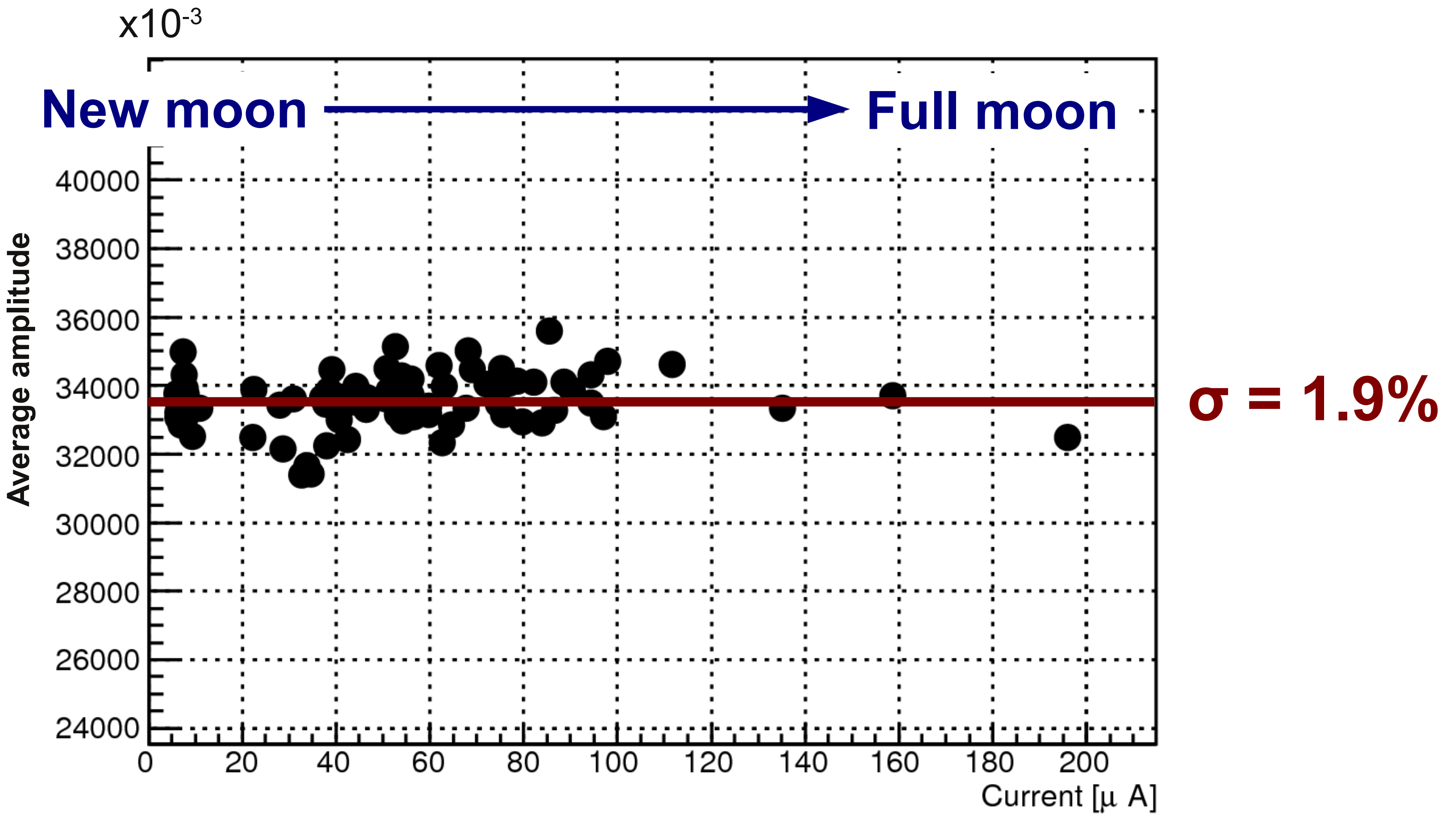
Gain: Temperature Dependency

Average gain of all pixels vs average sensor temperature

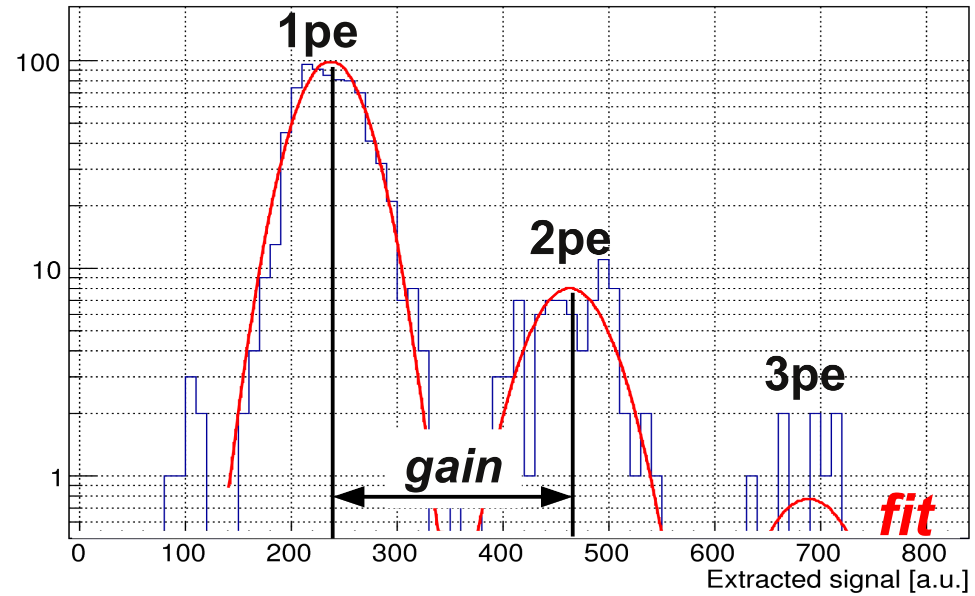


Gain: Current Dependency

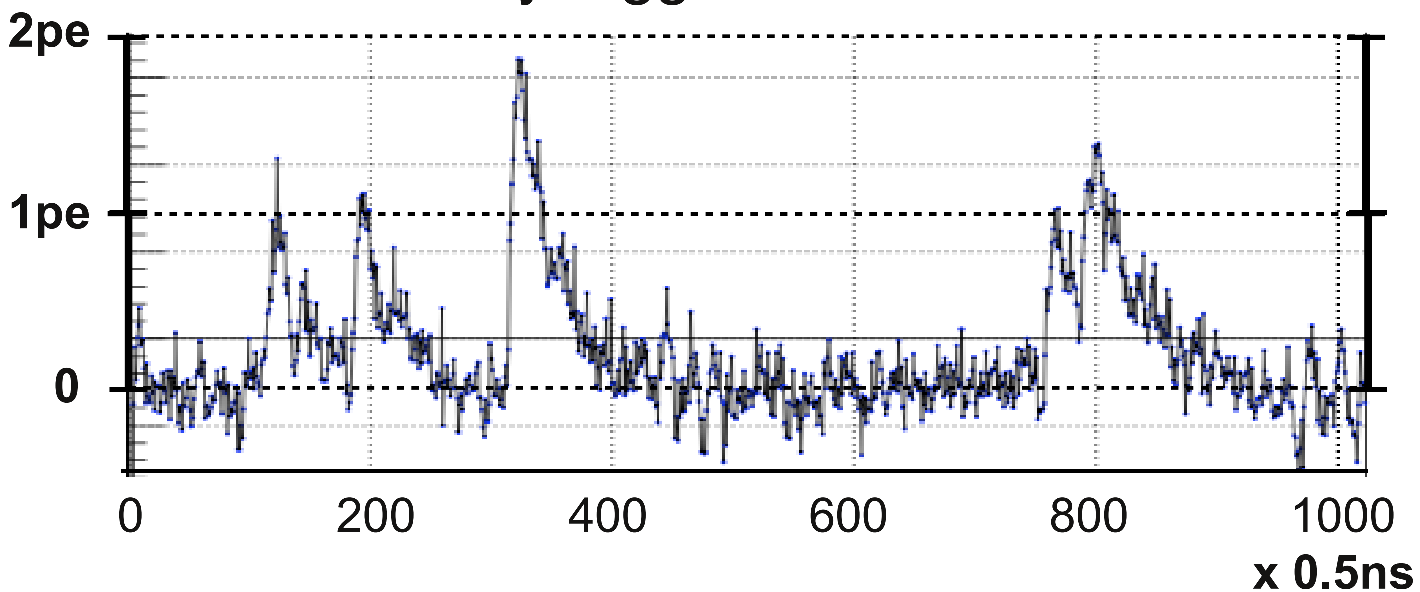
Average light-pulser amplitude vs average current



Spectrum



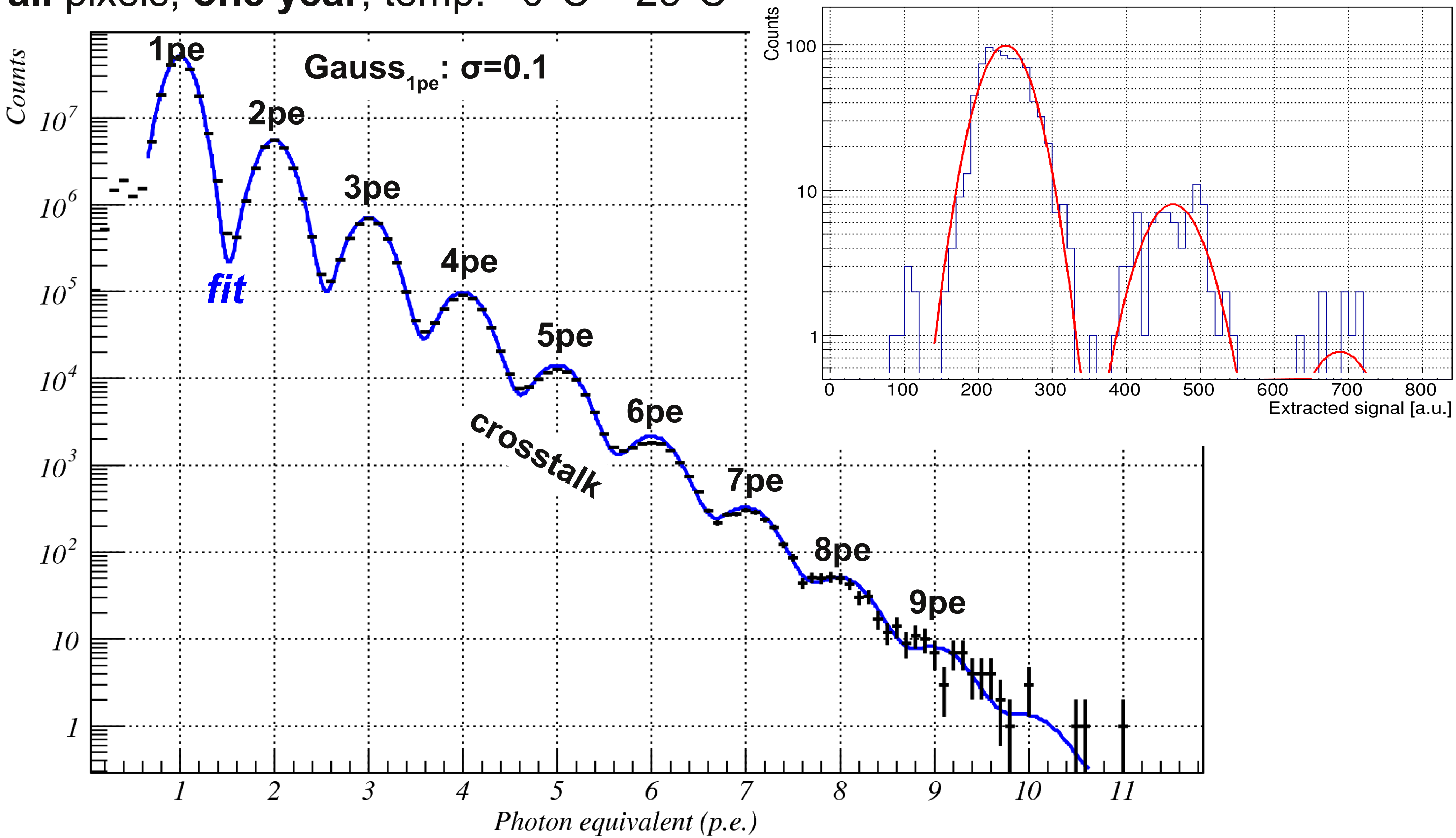
Randomly triggered dark counts



only possible
with closed lid

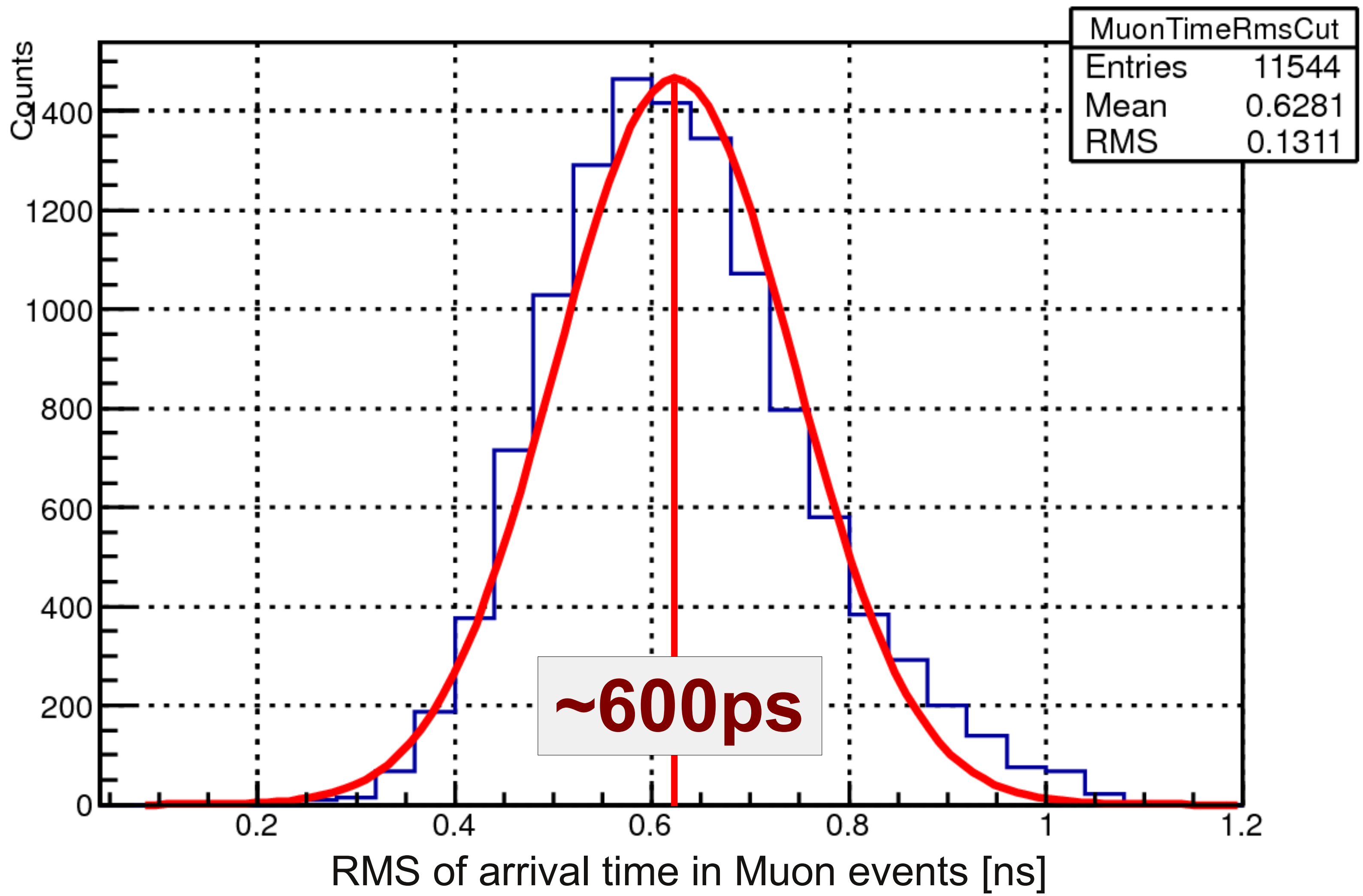
Dark Count Spectrum

all pixels; **one year**; temp: ~0°C – 25°C

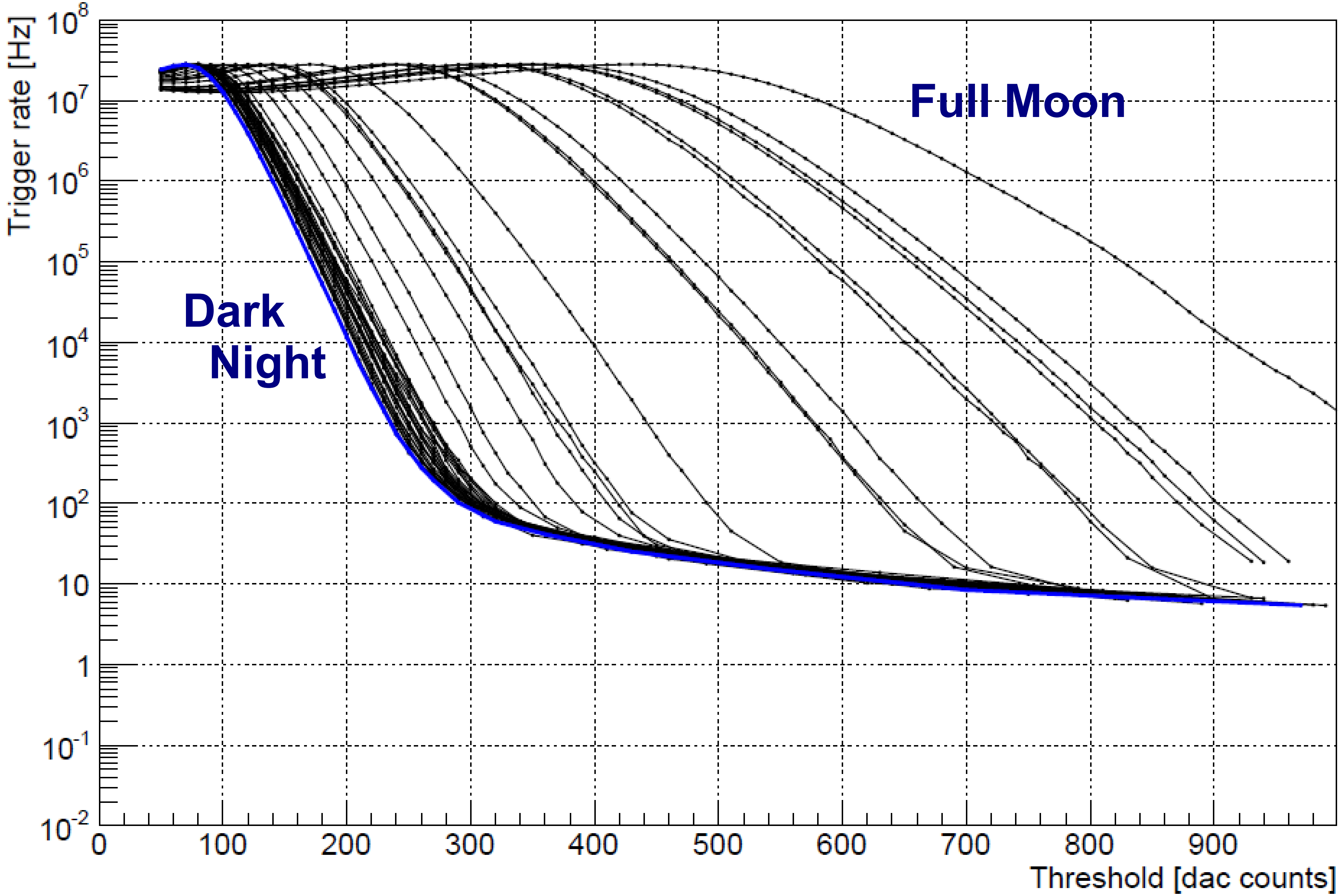


Time Resolution

→ Time resolution of the **whole system better than 600ps**
(typical signal per pixel in muon rings in FACT: **<10pe**)

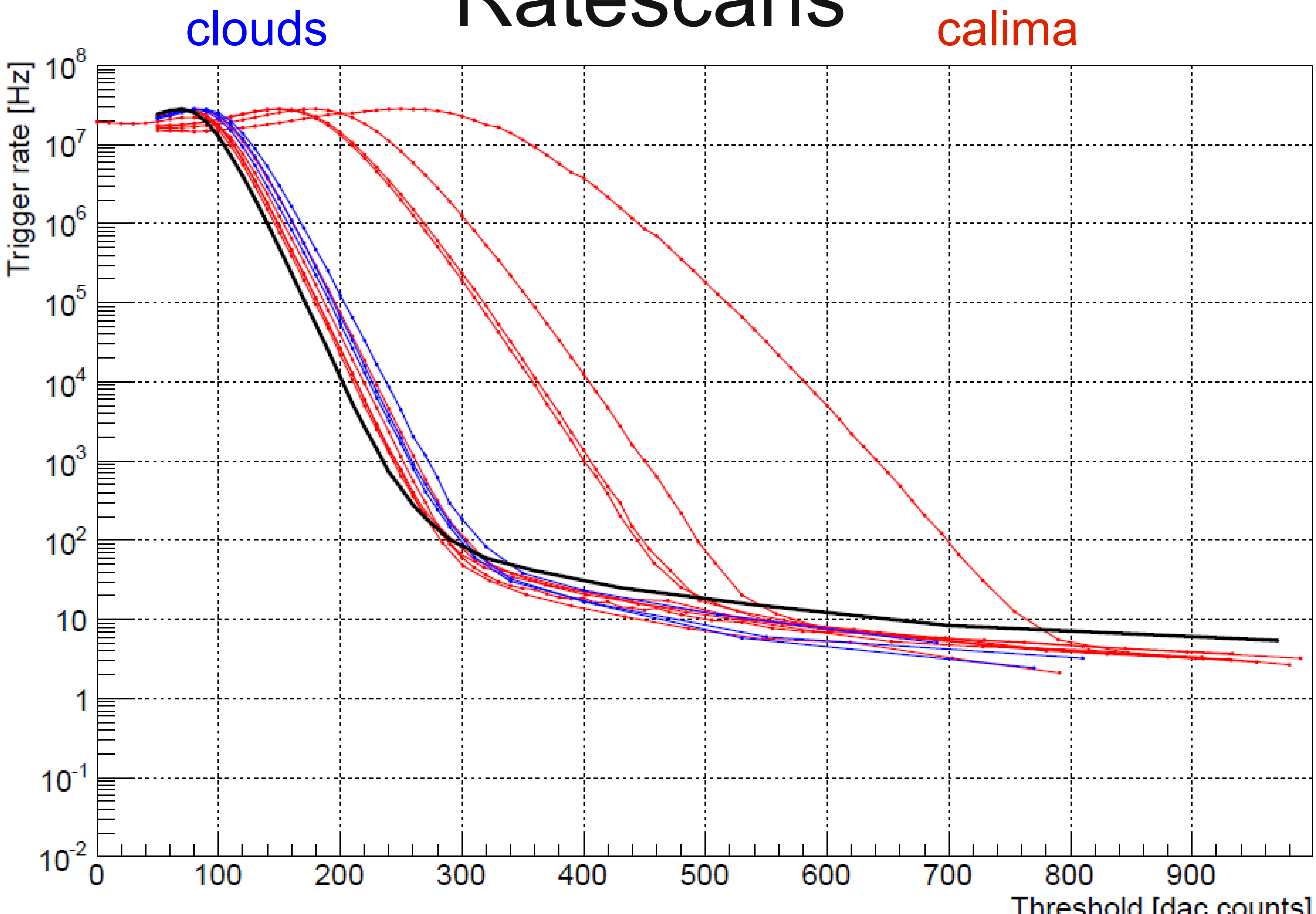


Ratescans

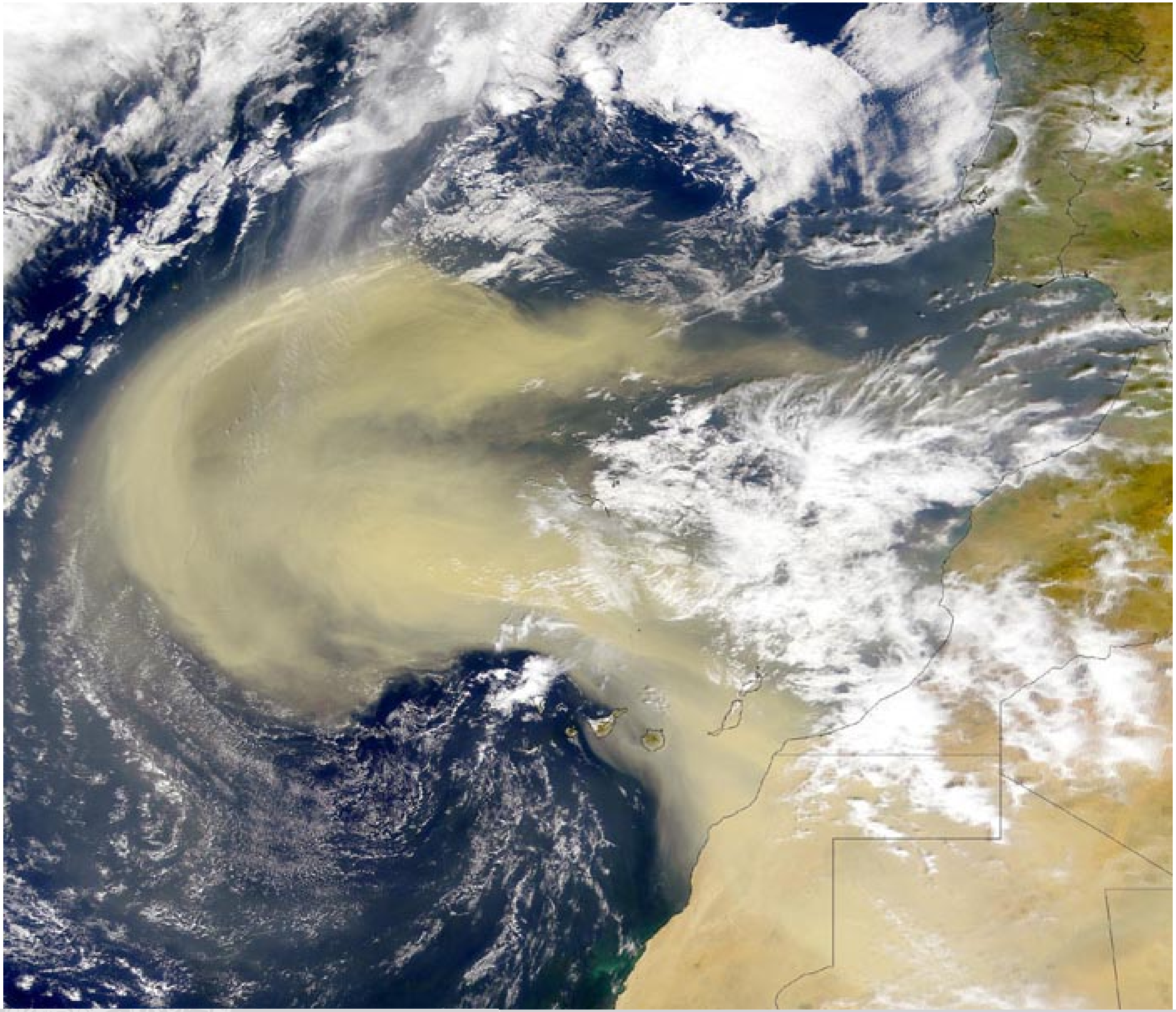


Trigger rate [Hz]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
100
200
300
400
500
600
700
800
900
Threshold [dac counts]
Full Moon
Dark Night

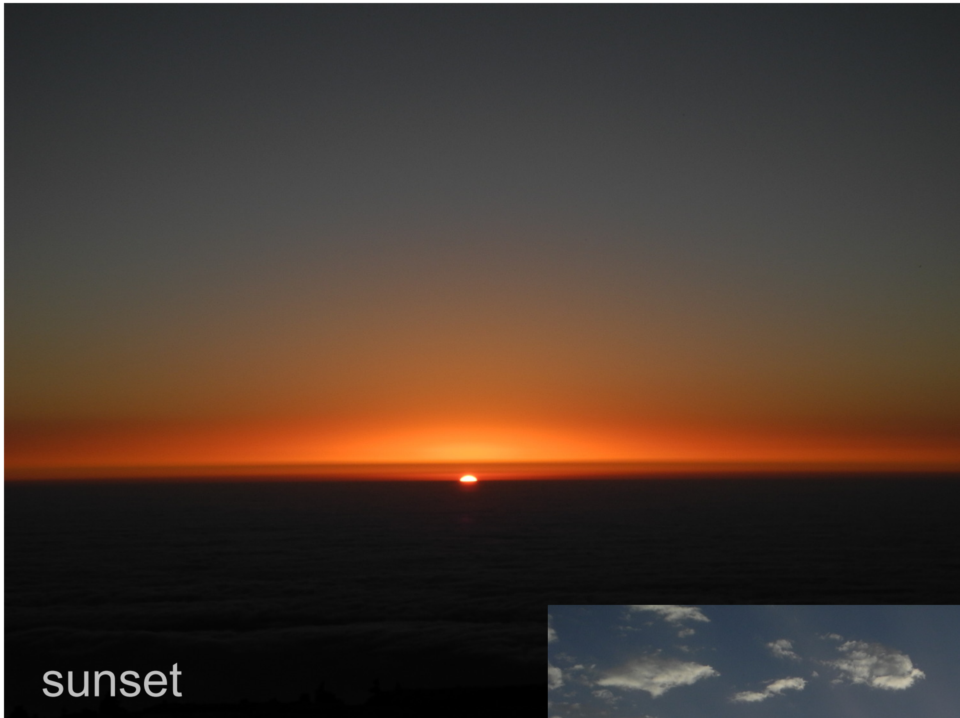
Ratescans


clouds
calima
Trigger rate [Hz]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
100
200
300
400
500
600
700
800
900
Threshold [dac counts]

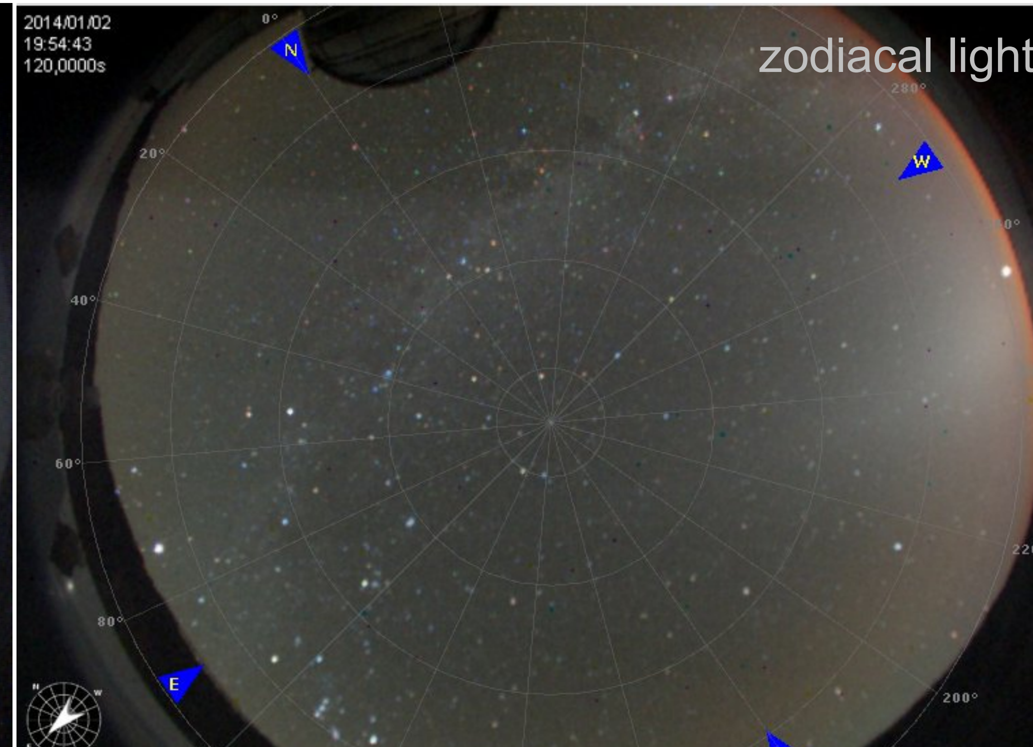
Calima aka Saharan Air Layer

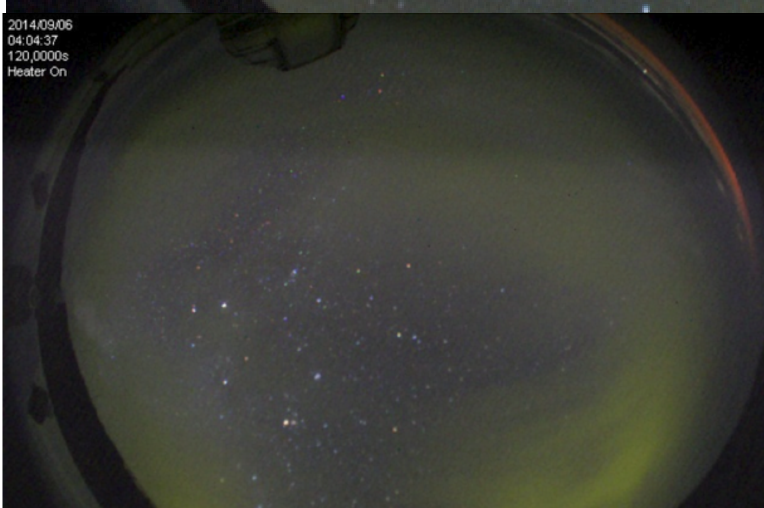


Calima aka Saharan Air Layer

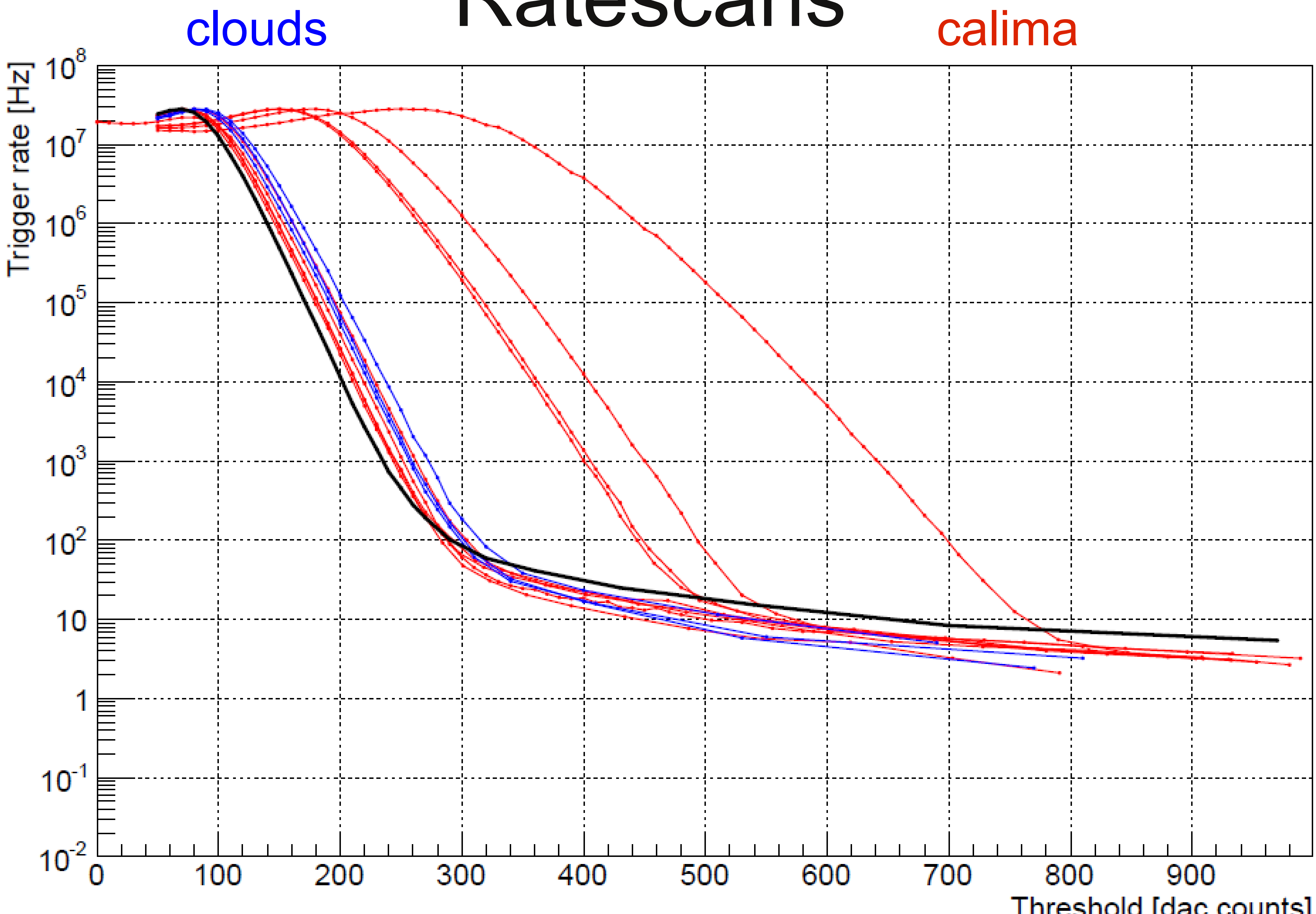


Calima and other influences



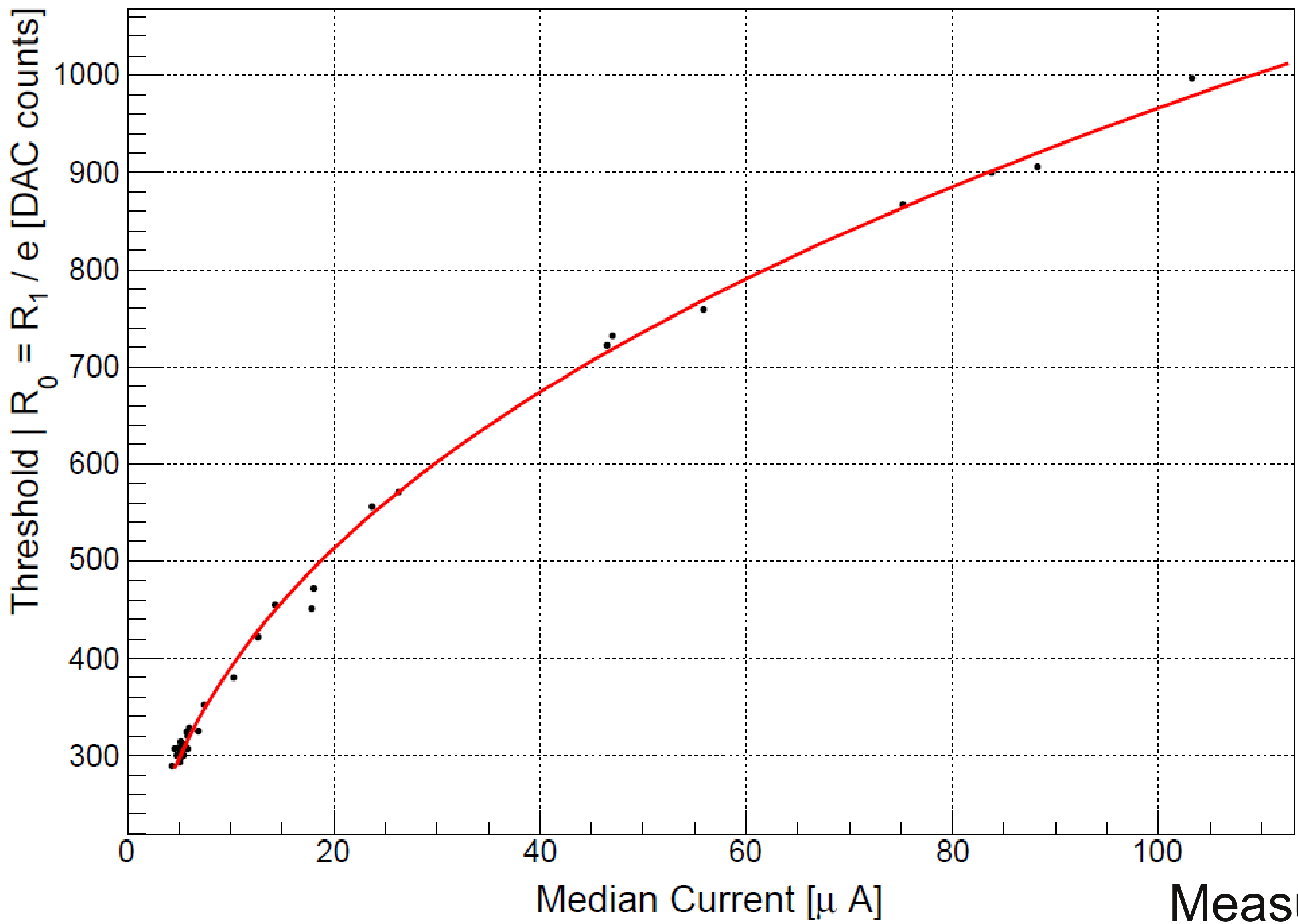


Ratescans



clouds
calima
Trigger rate [Hz]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
100
200
300
400
500
600
700
800
900
Threshold [dac counts]

Threshold vs Currents



Measure current

→ Set threshold

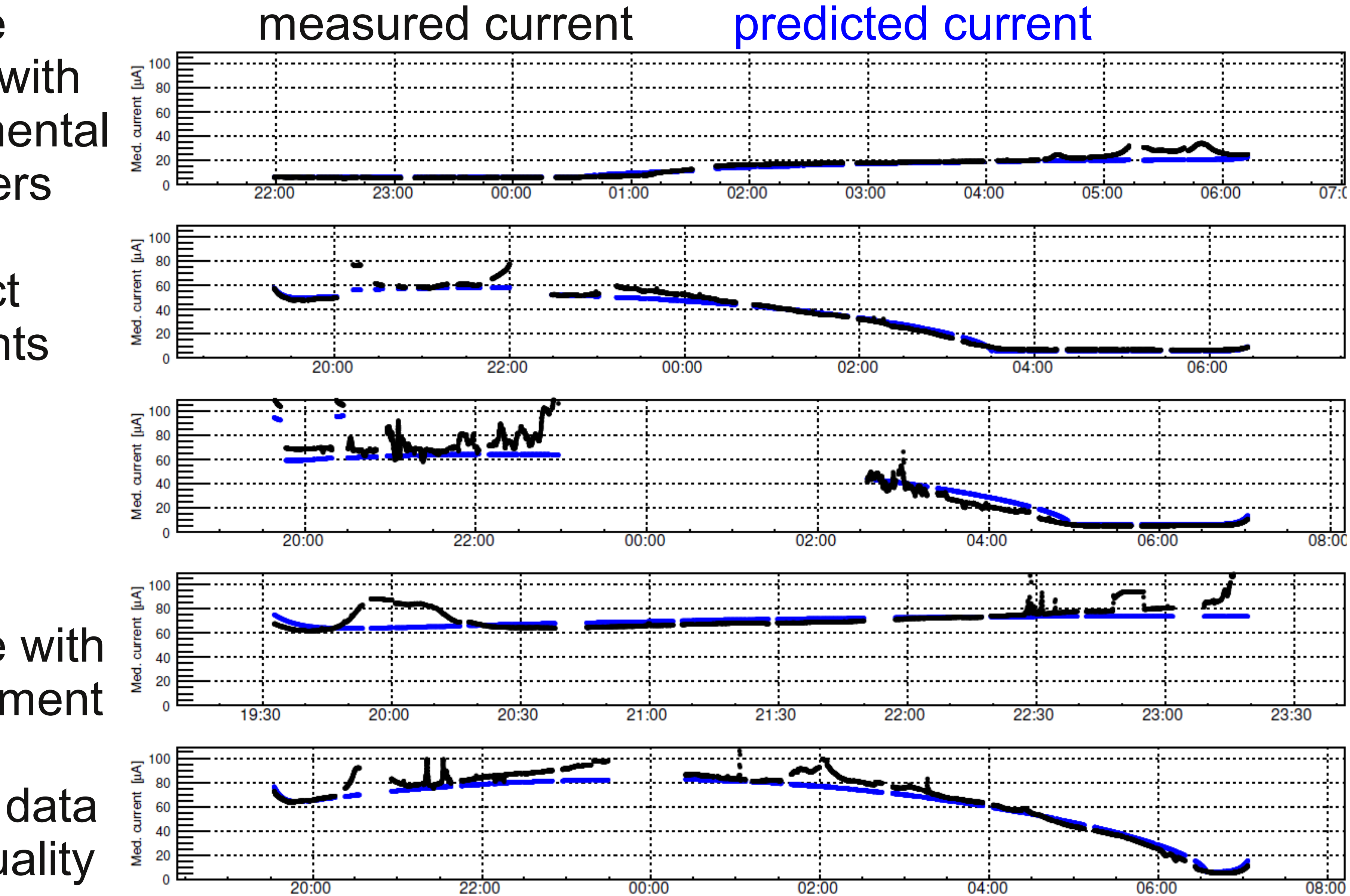
Current Prediction

Correlate currents with environmental parameters

→ Predict currents

Compare with measurement

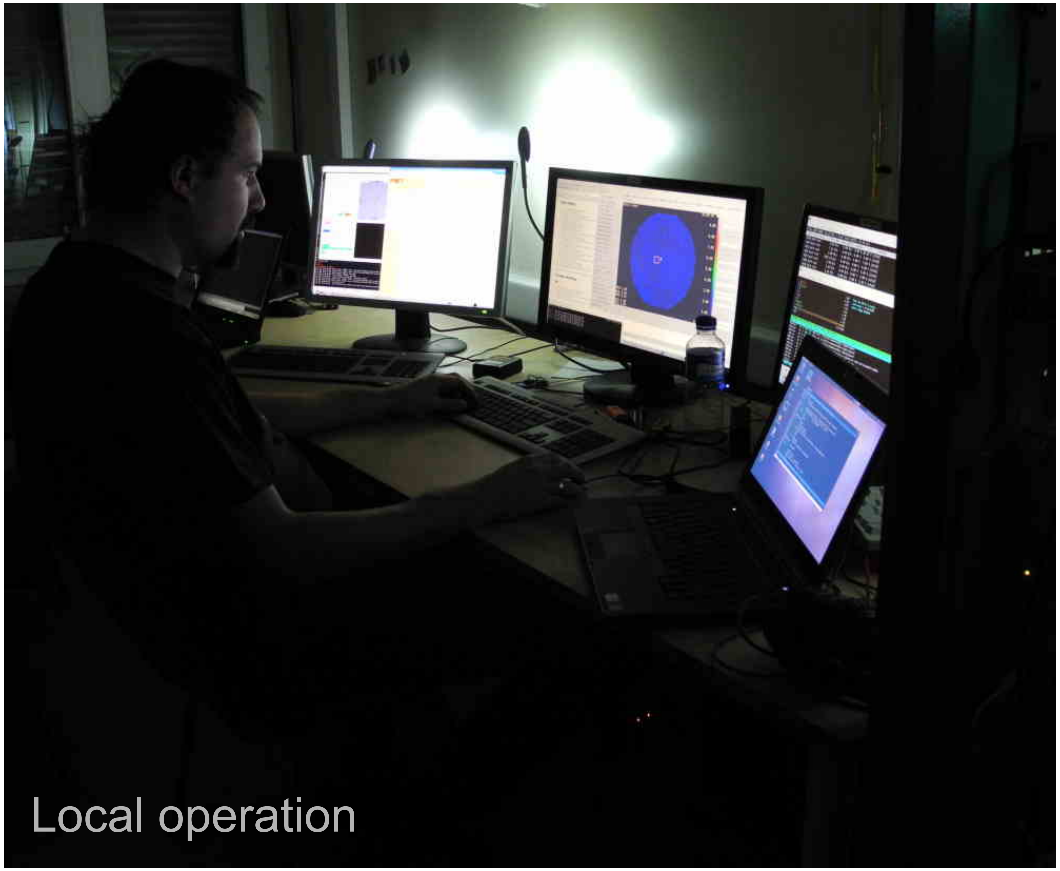
→ data quality

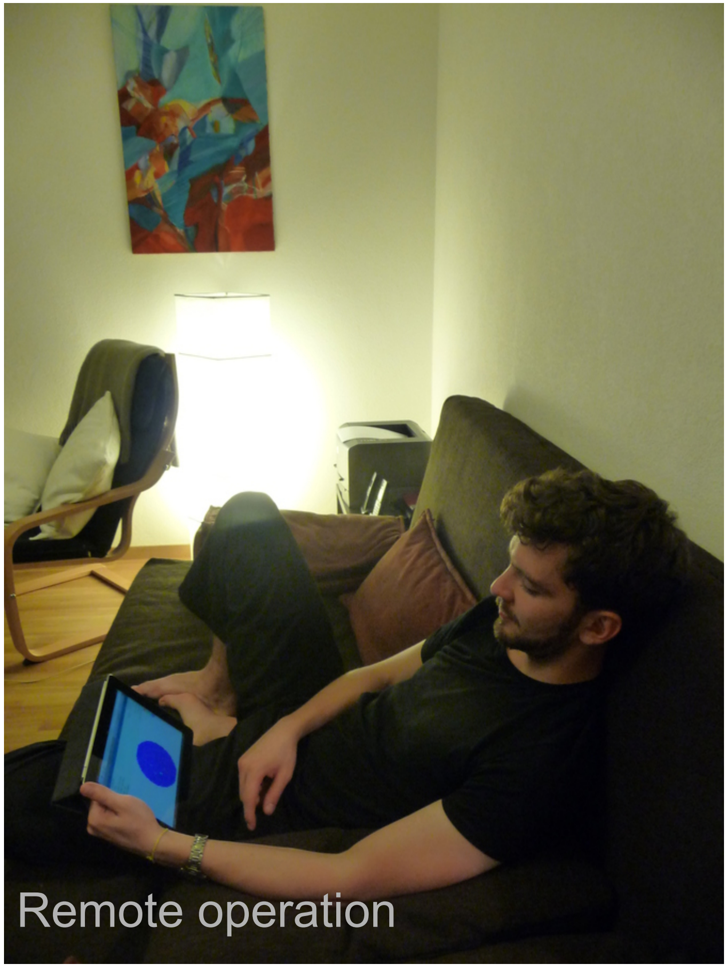


G-APDs – the Revolution in Cherenkov Astronomy

- Robust and stable
  → Stable telescope performance

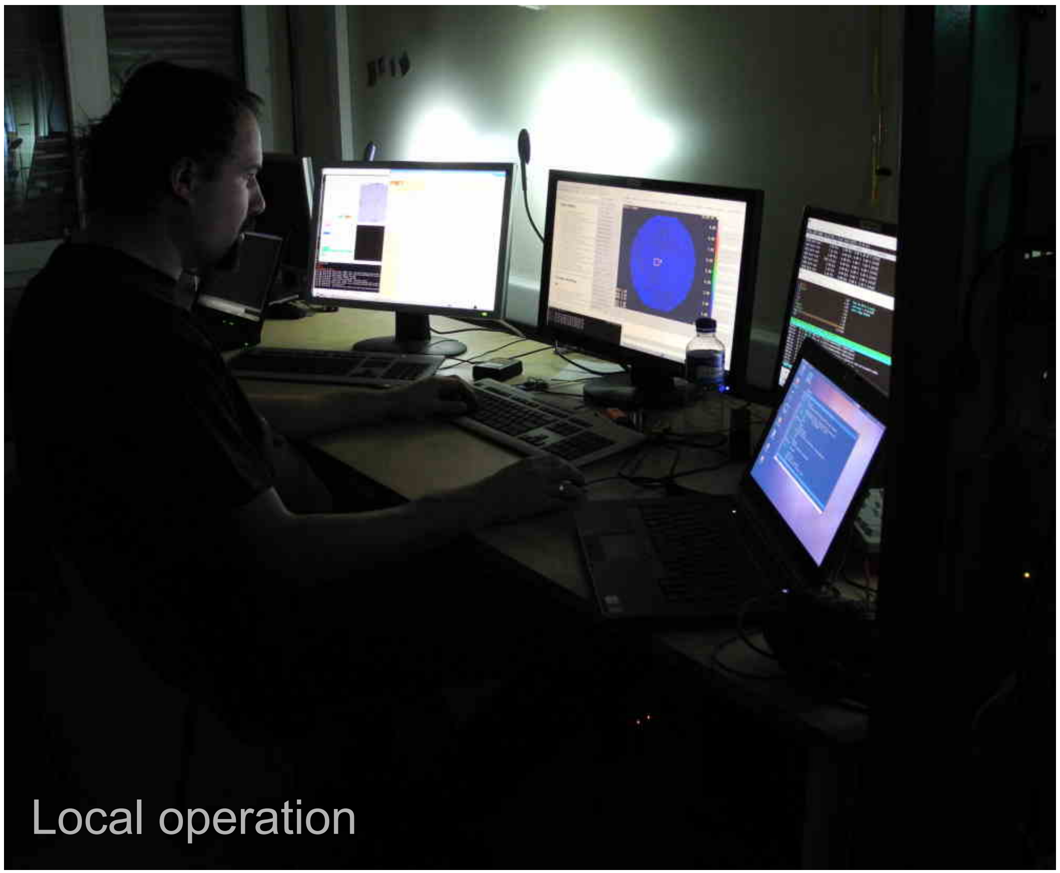
Towards Robotic Operation

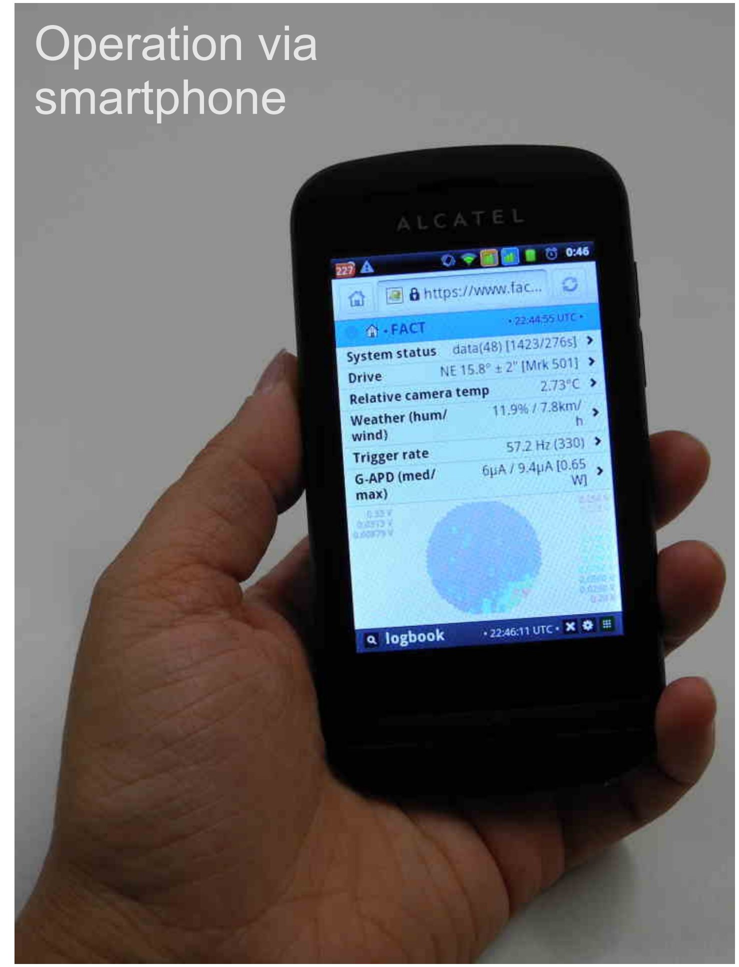




http://www.fact-project.org/smartfact

Towards Robotic Operation





Automatic Operation

http://www.fact-project.org/smartfact

G-APDs – the Revolution in Cherenkov Astronomy

- Robust and stable
  → Stable telescope performance

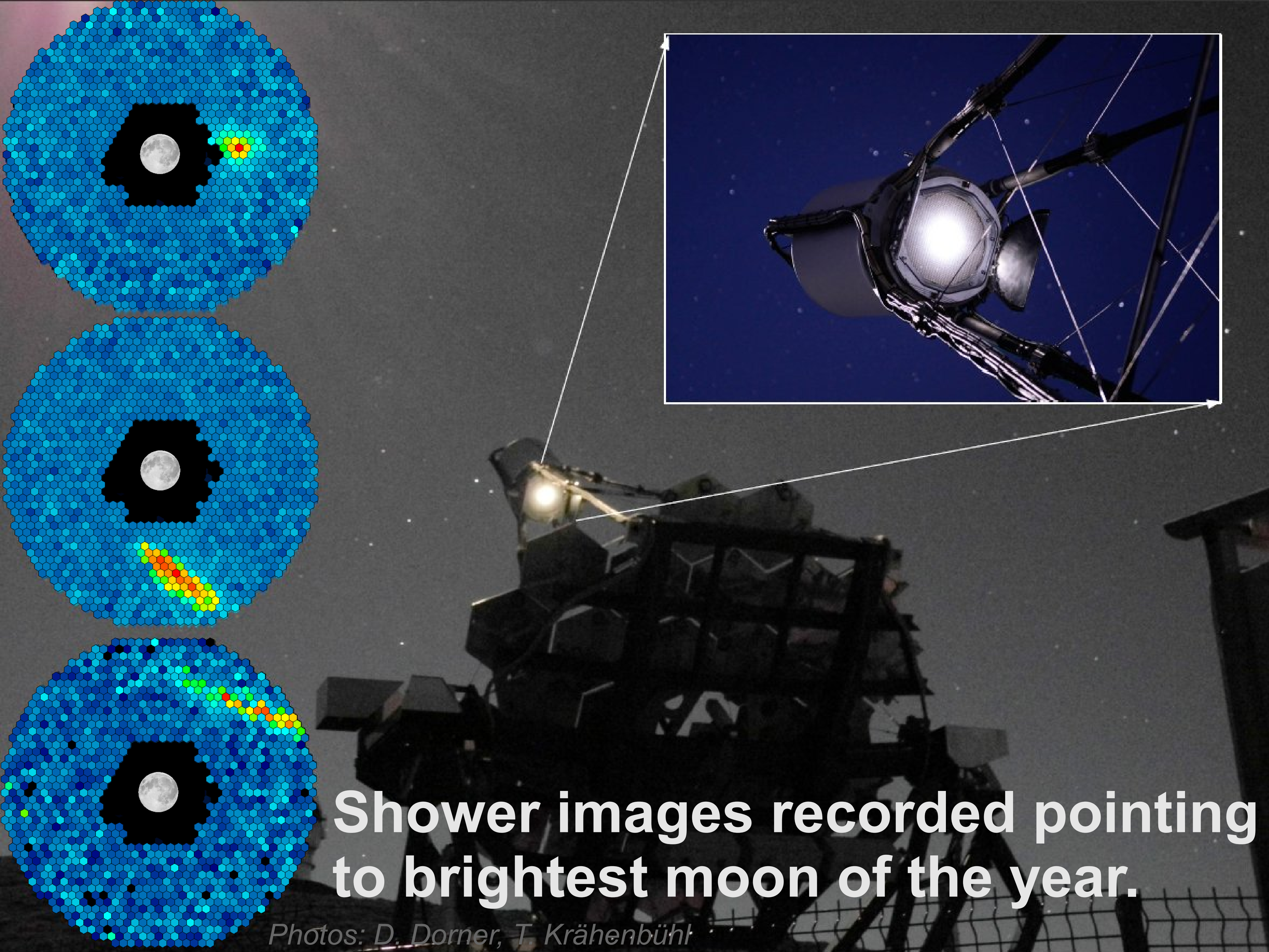
  → High data taking efficiency

G-APDs – the Revolution in Cherenkov Astronomy


Photo: Daniela Dorner

- Robust and stable
  → Stable telescope performance

  → High data taking efficiency
- Observations during strong moon light

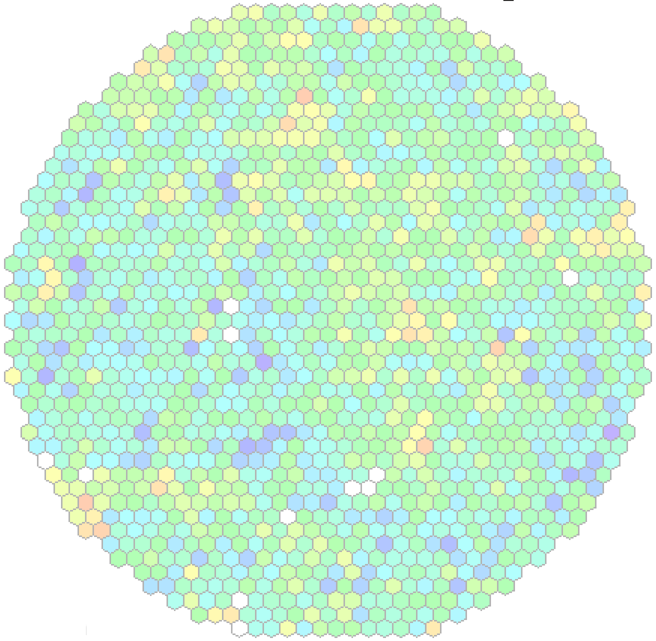

Shower images recorded pointing to brightest moon of the year.
Photos: D. Dorner, T. Krähenbühl

G-APDs – the Revolution in Cherenkov Astronomy

- Robust and stable
  → Stable telescope performance
  → High data taking efficiency
- Observations during strong moon light
  → Larger duty cycle
  → More complete data sample

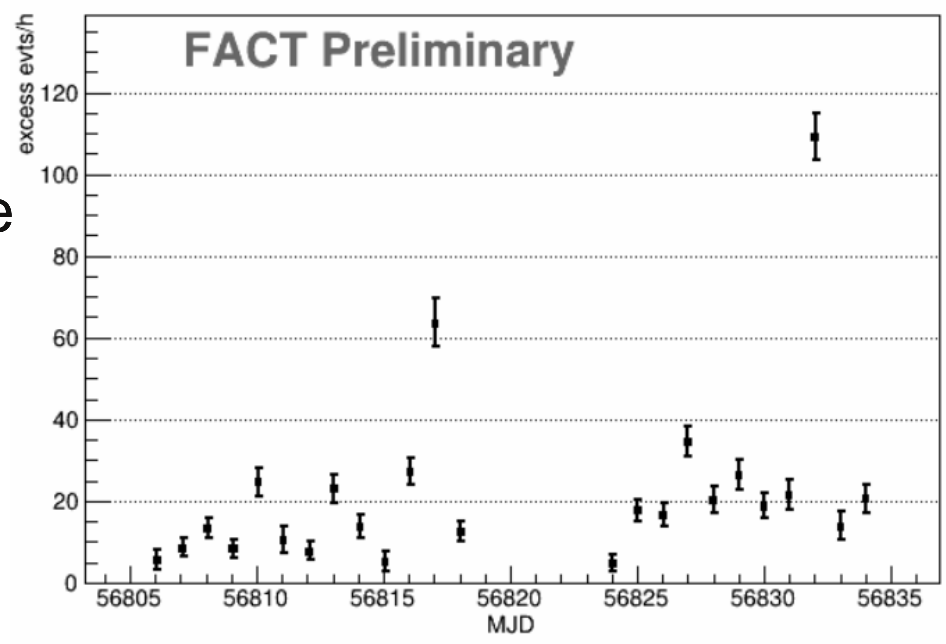
Ideal for Monitoring

First G-APD Cherenkov Telescope

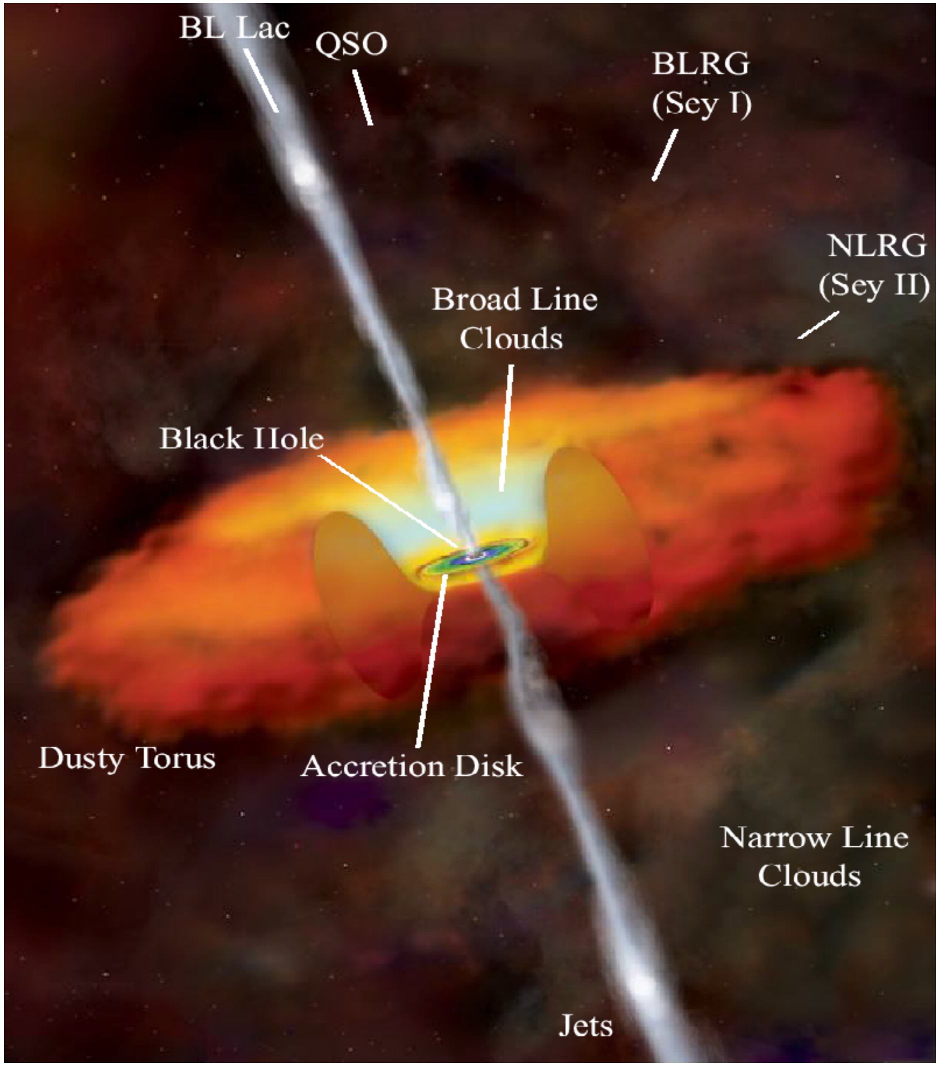


- G-APD camera
  - Telescope and camera
  - Photosensors
  - Detector performance
  - Gain stability and feedback system

- Longterm Monitoring
  - Blazar variability
  - Imaging Air Cherenkov Technique
  - Excess rate curves
  - Quick Look Analysis
  - Flare alerts



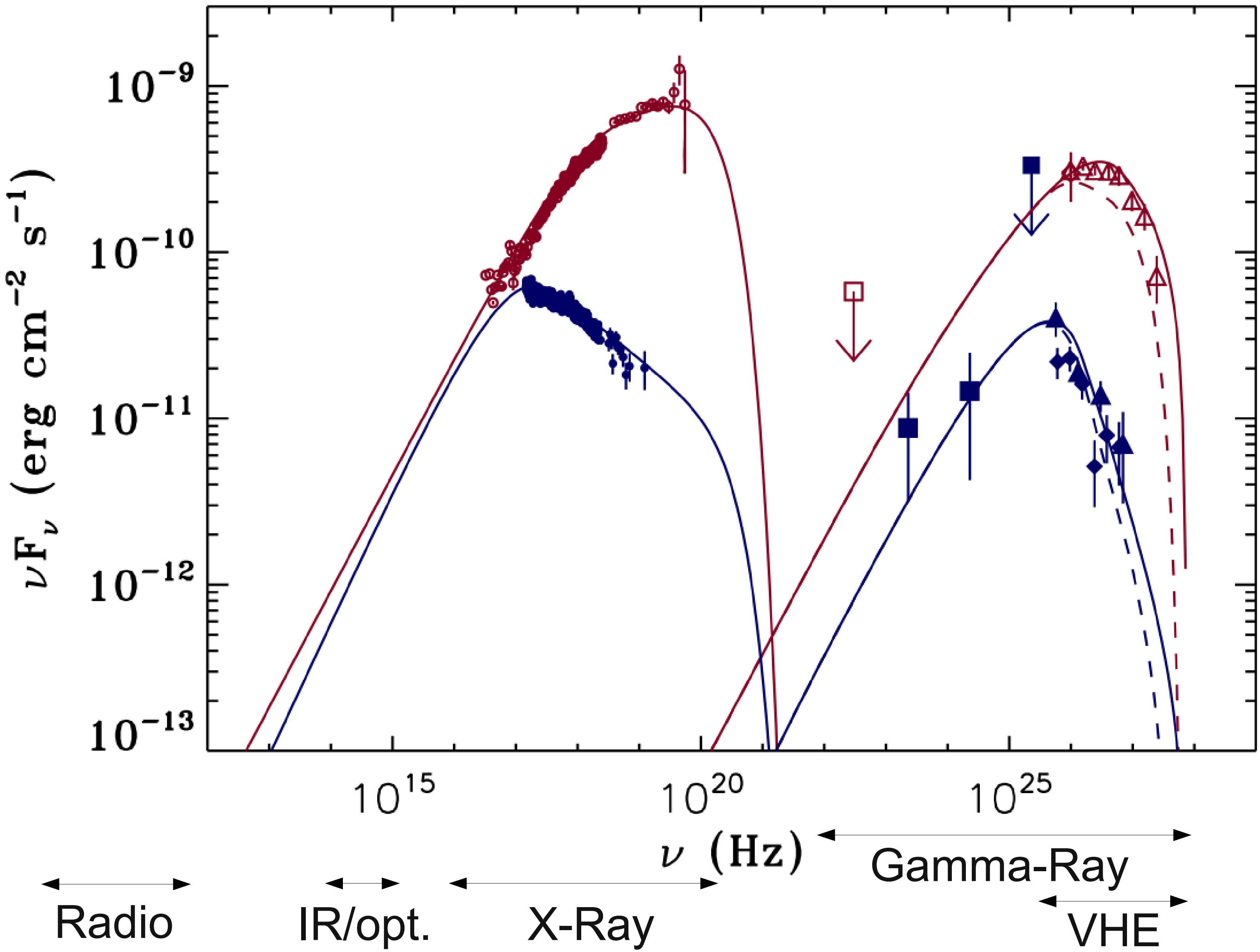
Active Galactic Nuclei



http://chandra.harvard.edu/resources/illustrations/quasar.html

- Central black hole
- Jet: Acceleration to extreme energies
- Classification depending on viewing angle
- Extreme variability on different time scales
- Spectral energy distribution: Two-peak structure

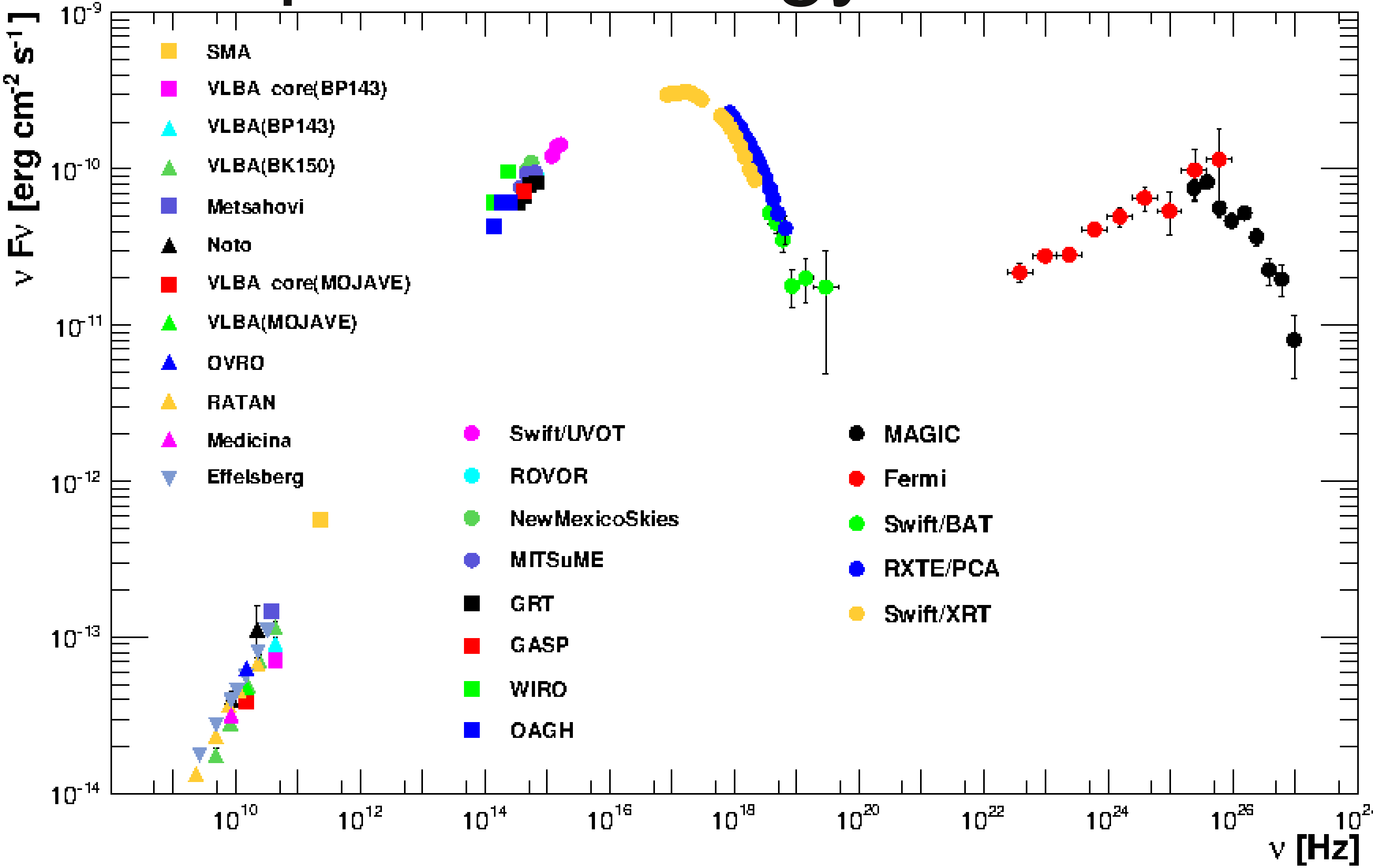
Spectral Energy Distribution



V. A. Acciari et al. (VERITAS), ApJ 729: 2, 2011

Mrk 501

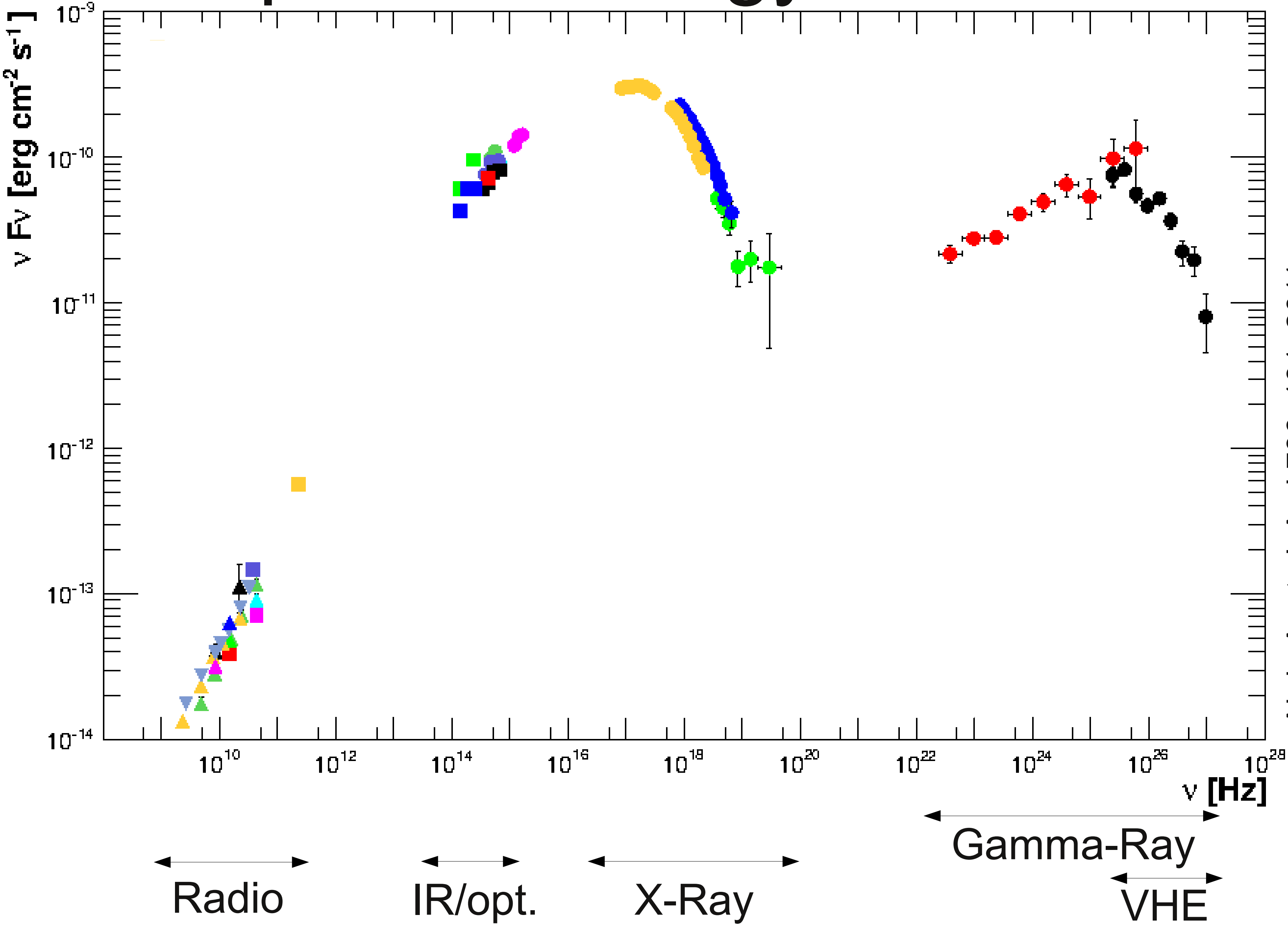
Spectral Energy Distribution



Mrk 421

Abdo A. et al. ApJ 736, 131, 2011

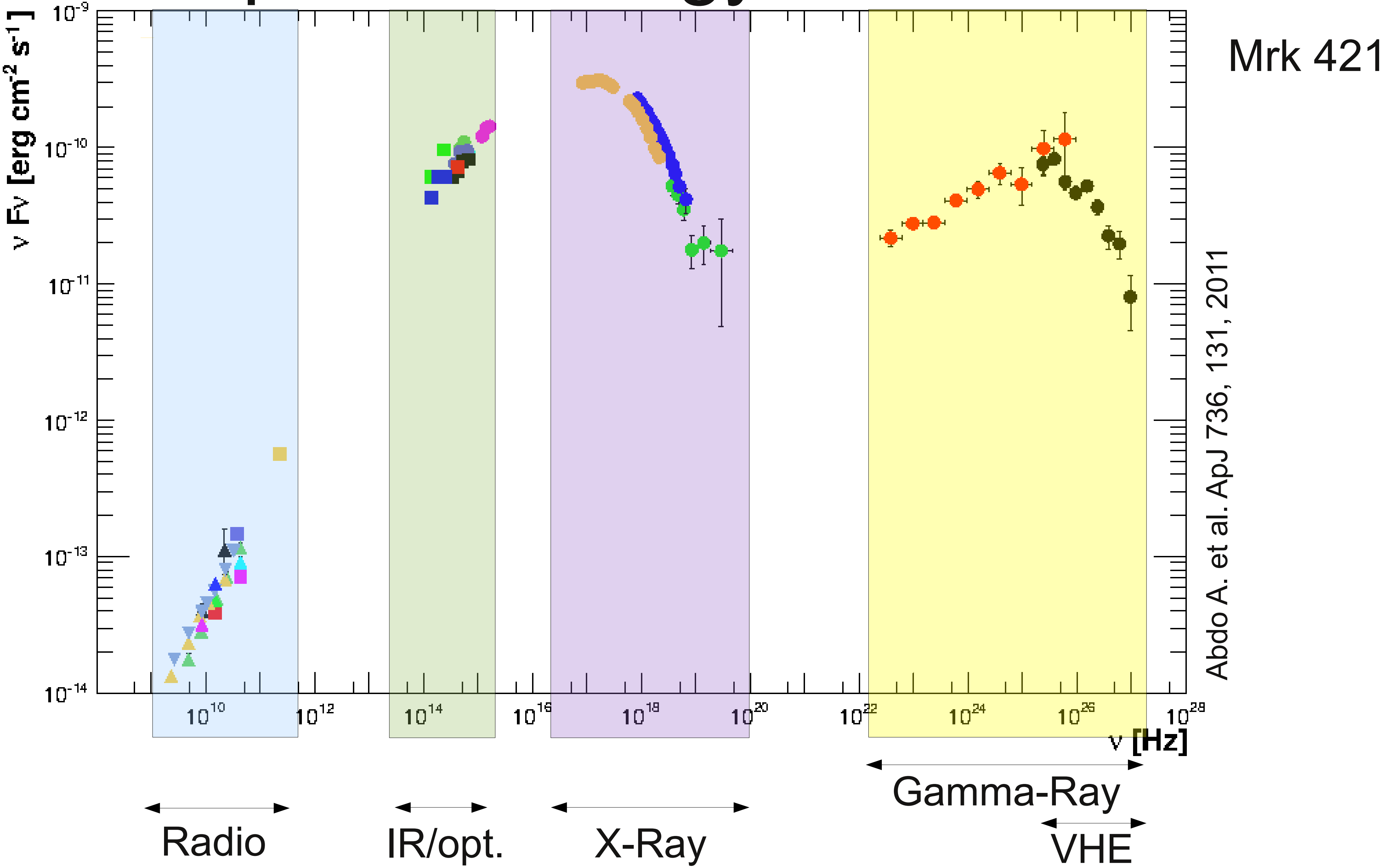
Spectral Energy Distribution



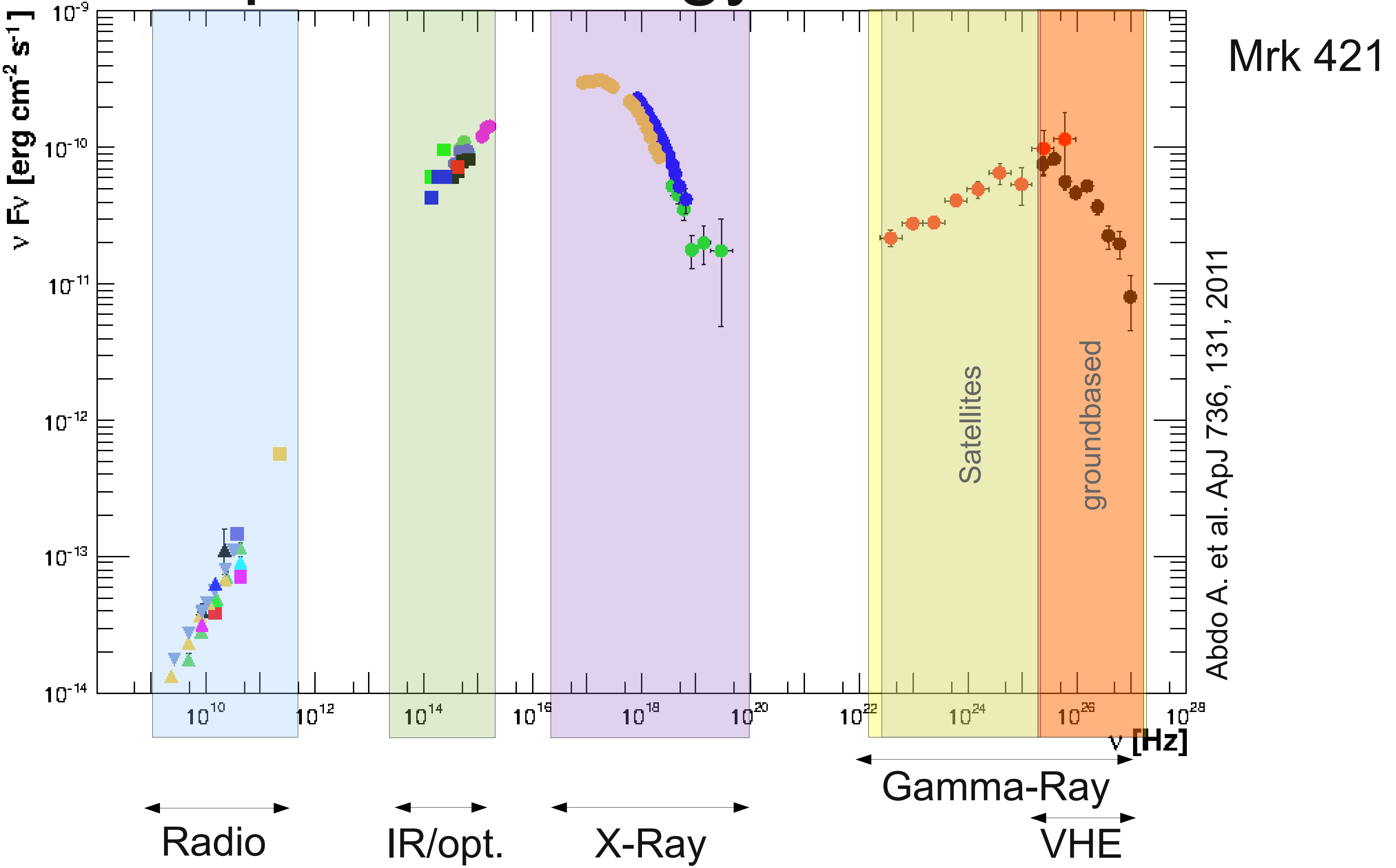
Mrk 421

Abdo A. et al. ApJ 736, 131, 2011

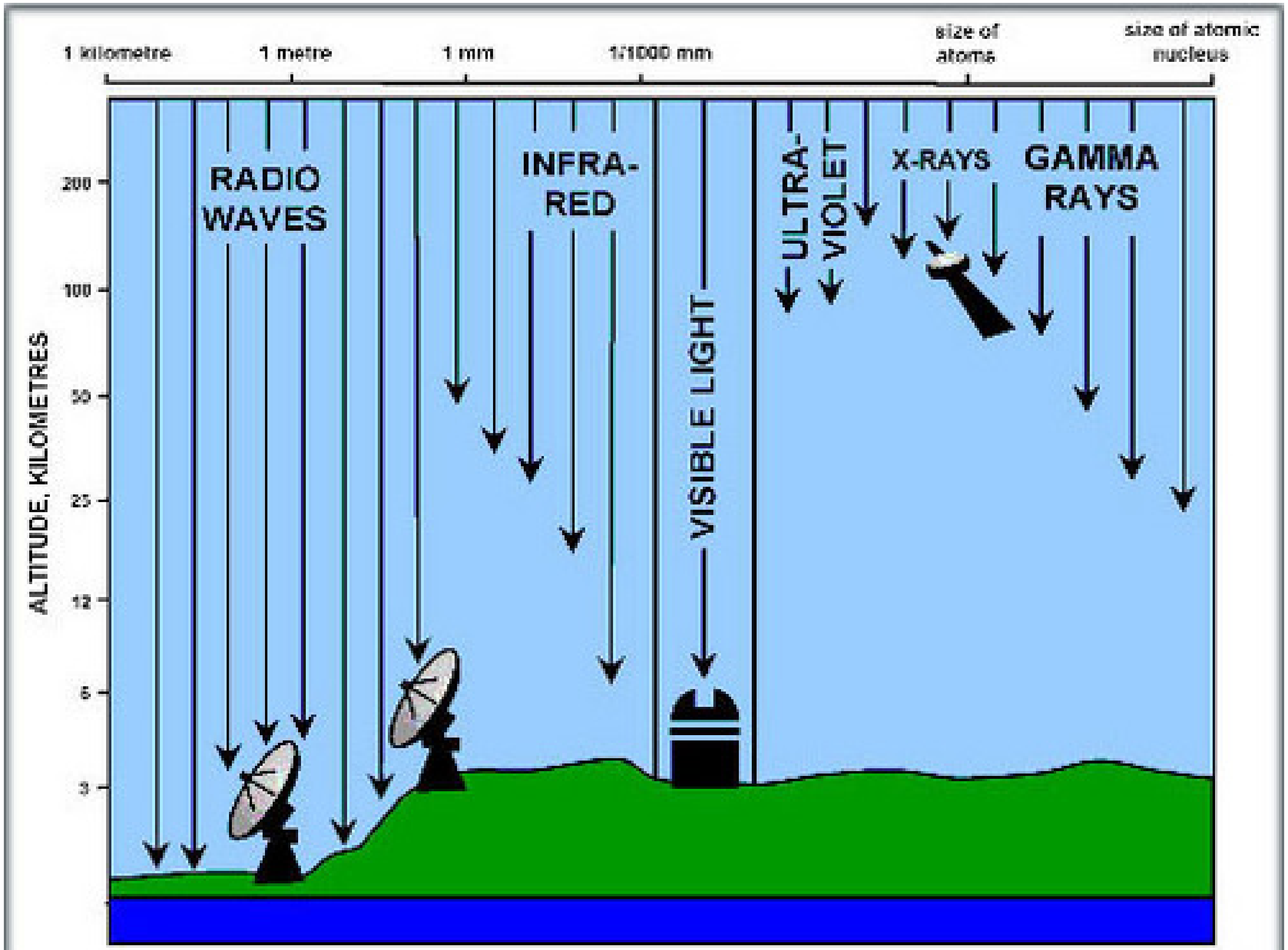
Spectral Energy Distribution



Spectral Energy Distribution



Gamma-Ray Astronomy

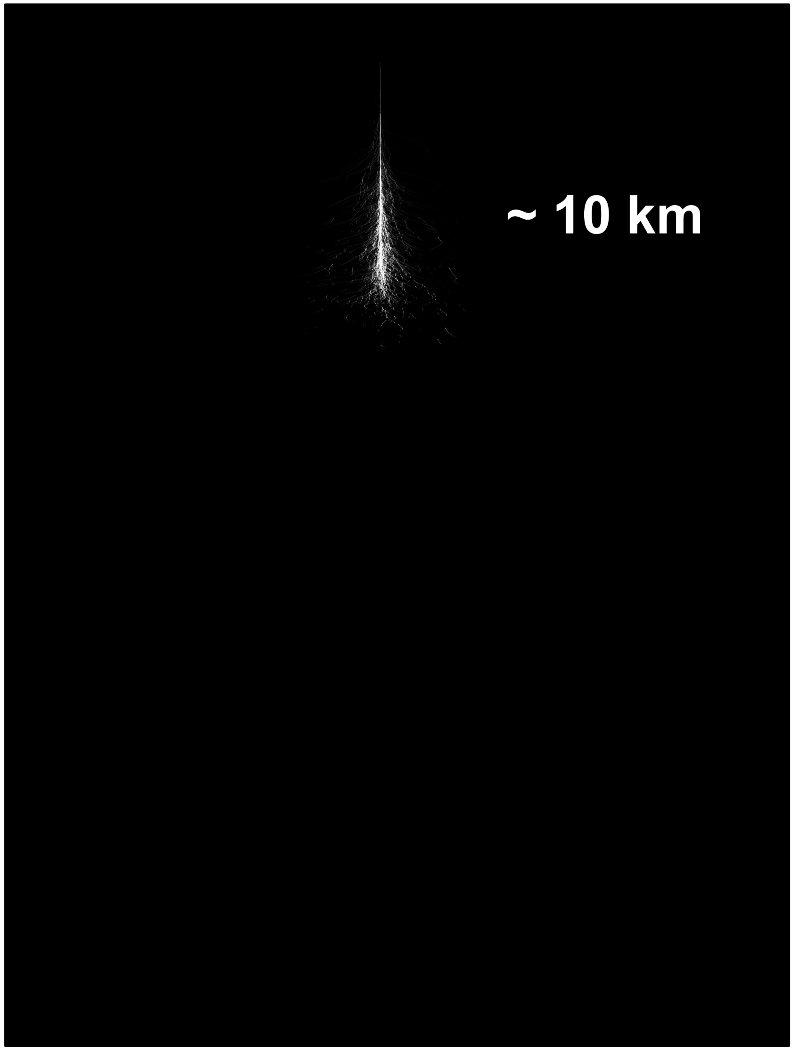


http://astrobob.areavoices.com/astrobob/images/thumbnail/Radio_spectrum_window21.jpg

Atmosphere is not transparent to gamma rays
→ indirect detection method from ground

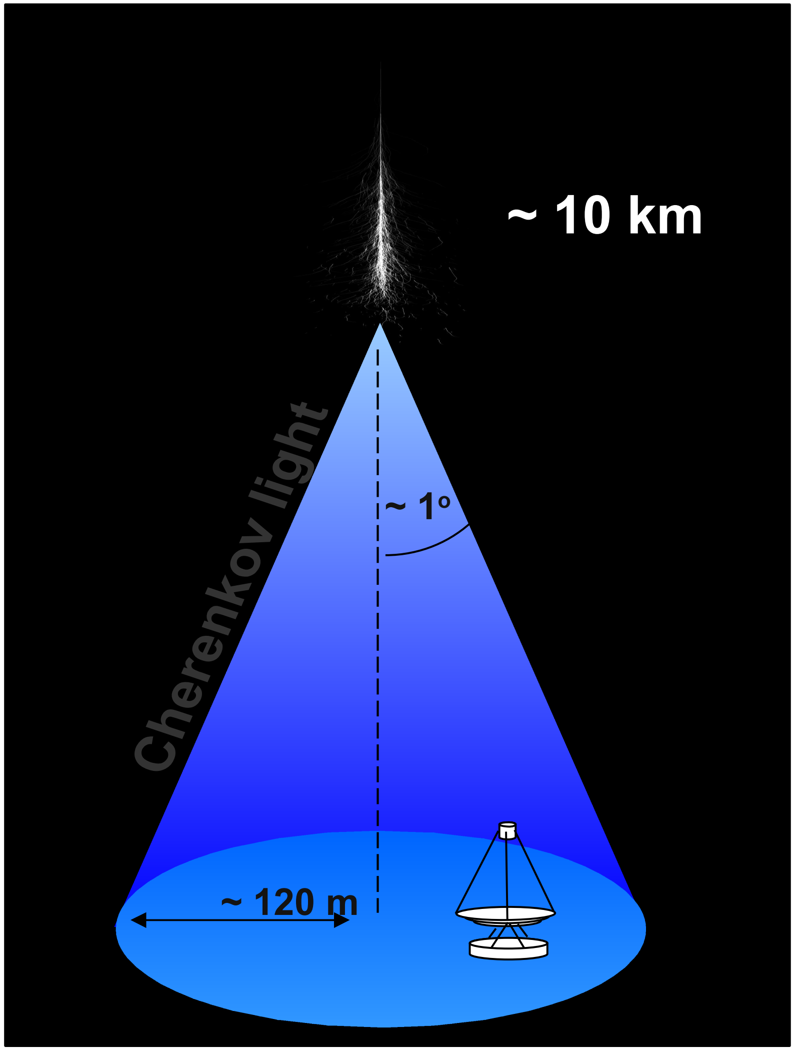
Imaging Air Cherenkov Technique

Gamma



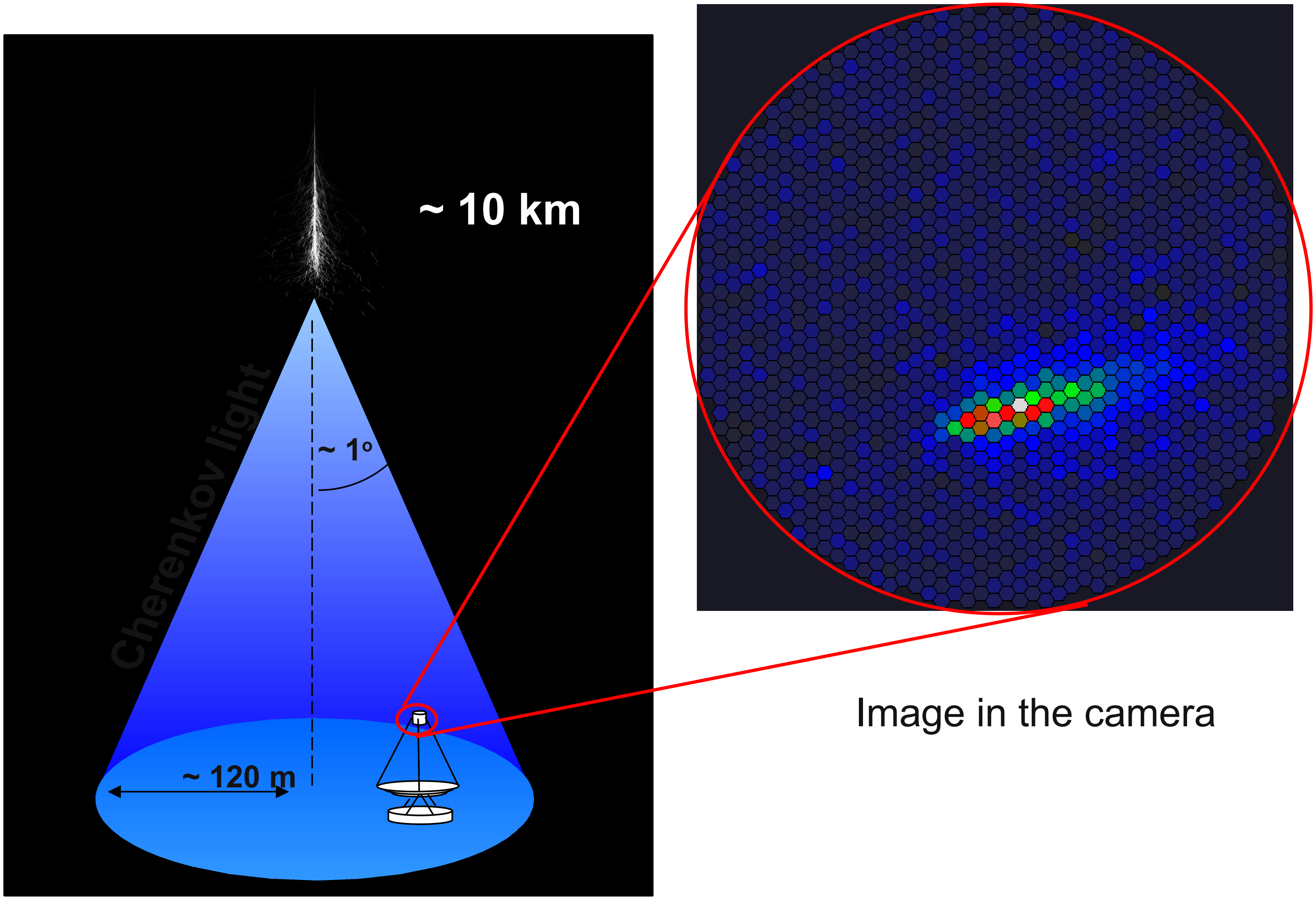
Particle shower

Imaging Air Cherenkov Technique



Emission of
Cherenkov light

Imaging Air Cherenkov Technique



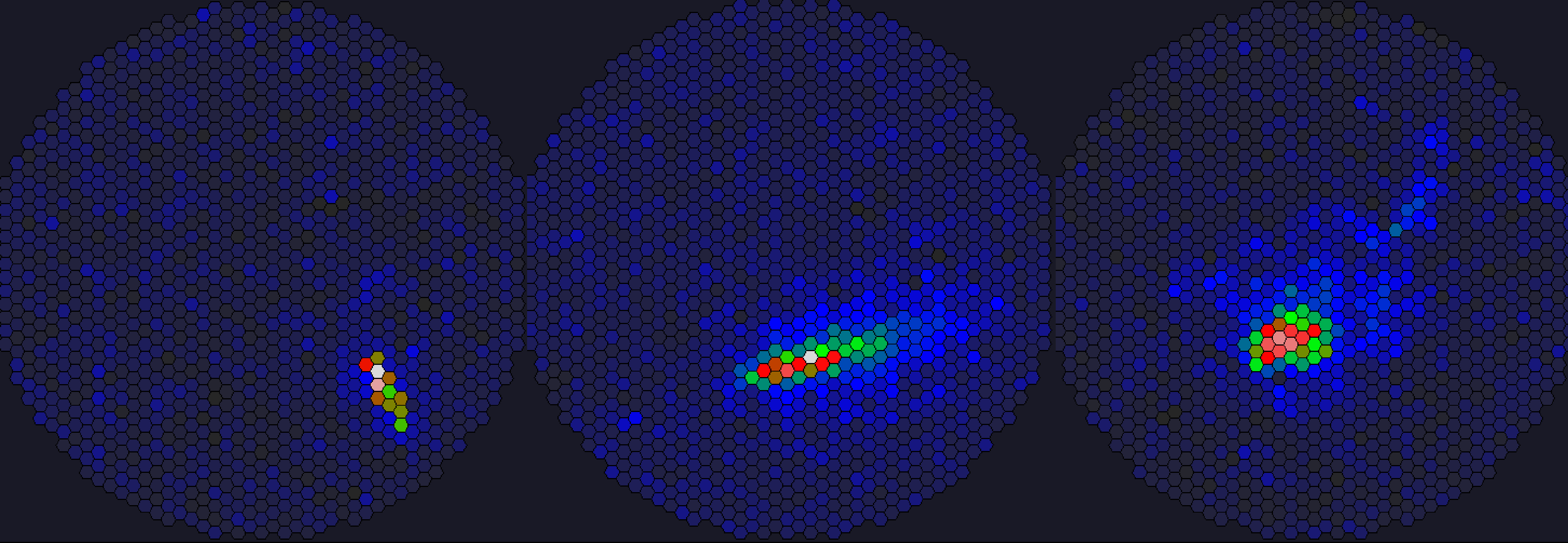
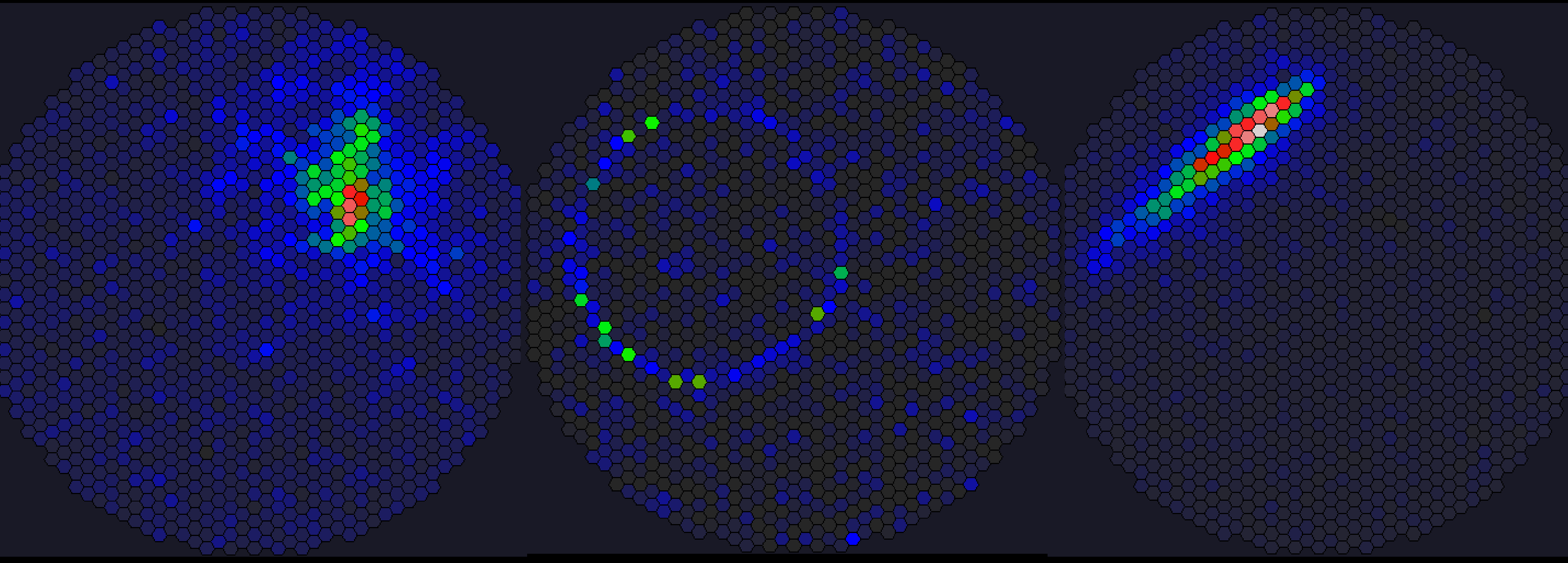
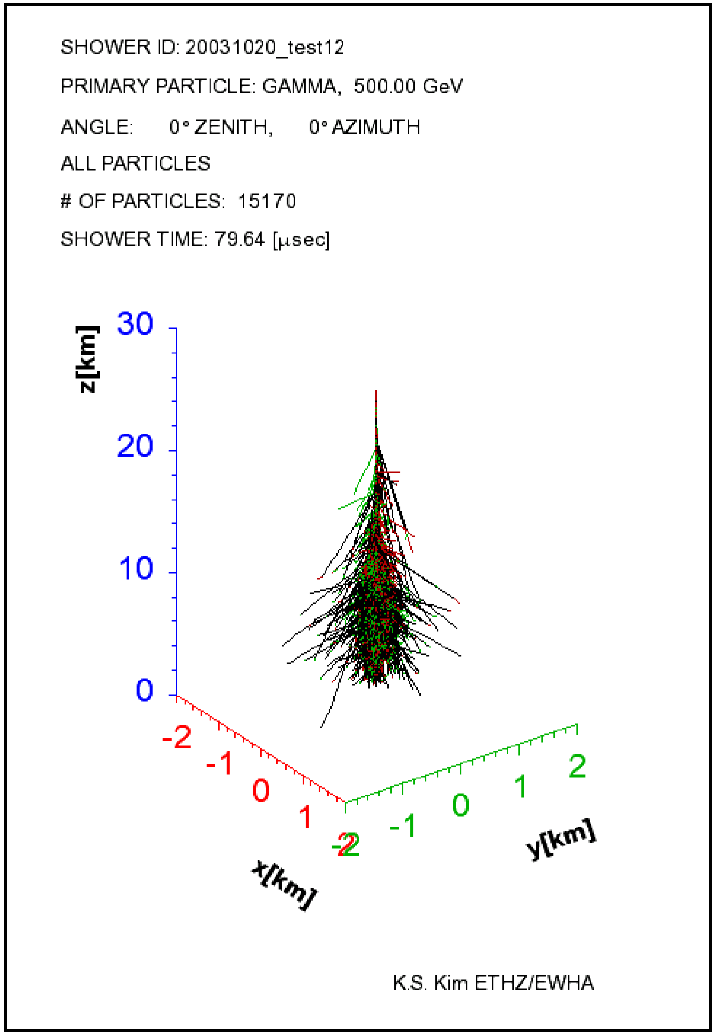


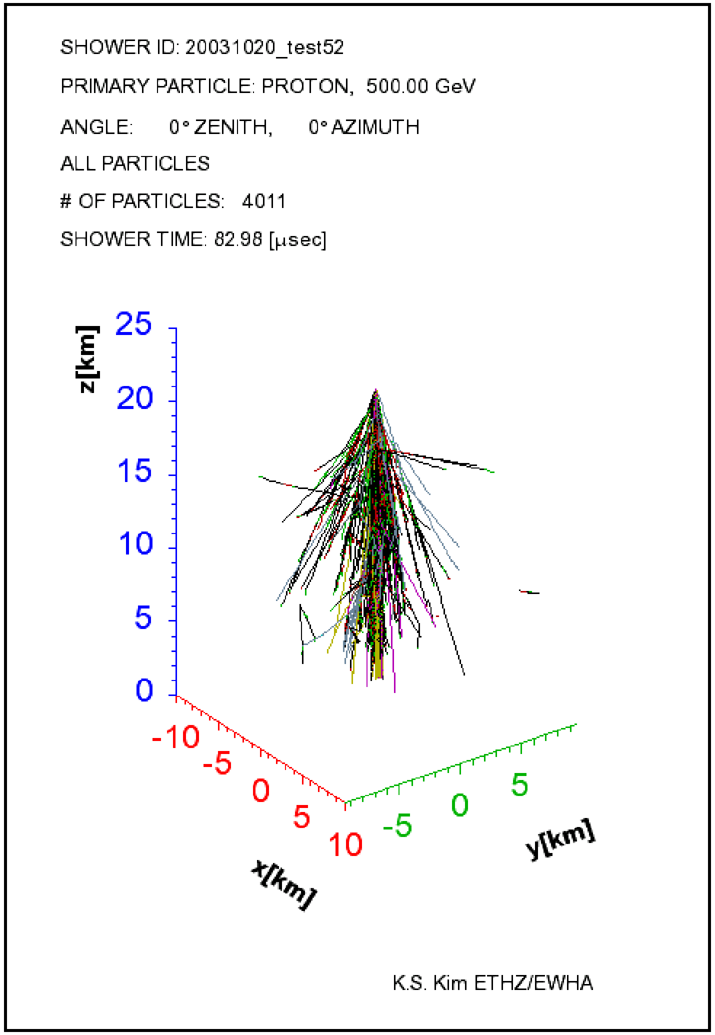
Image analysis: Reconstruction of particle type, shower origin, energy



IACT: Background

1 Gamma	1000 Background

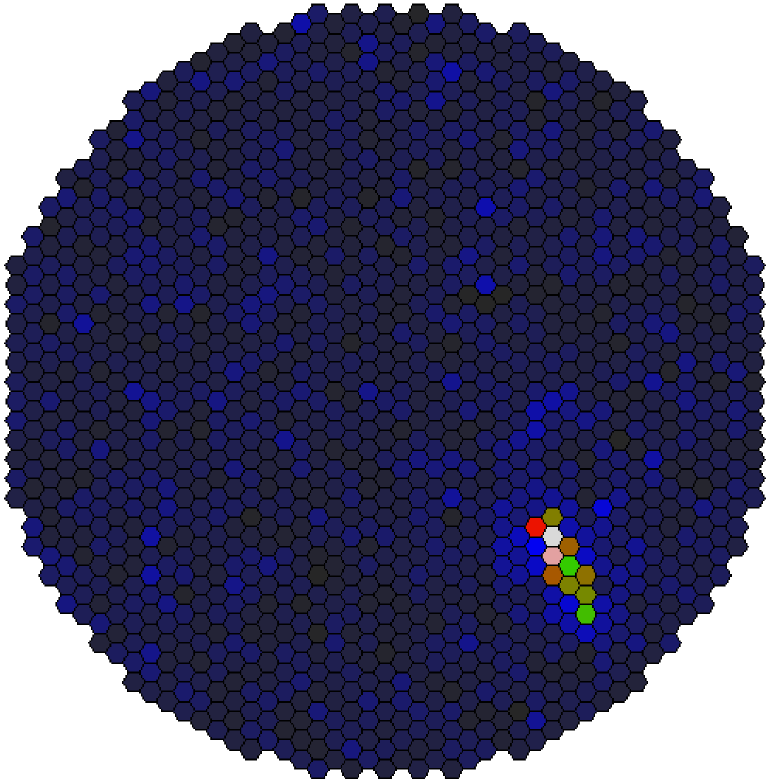


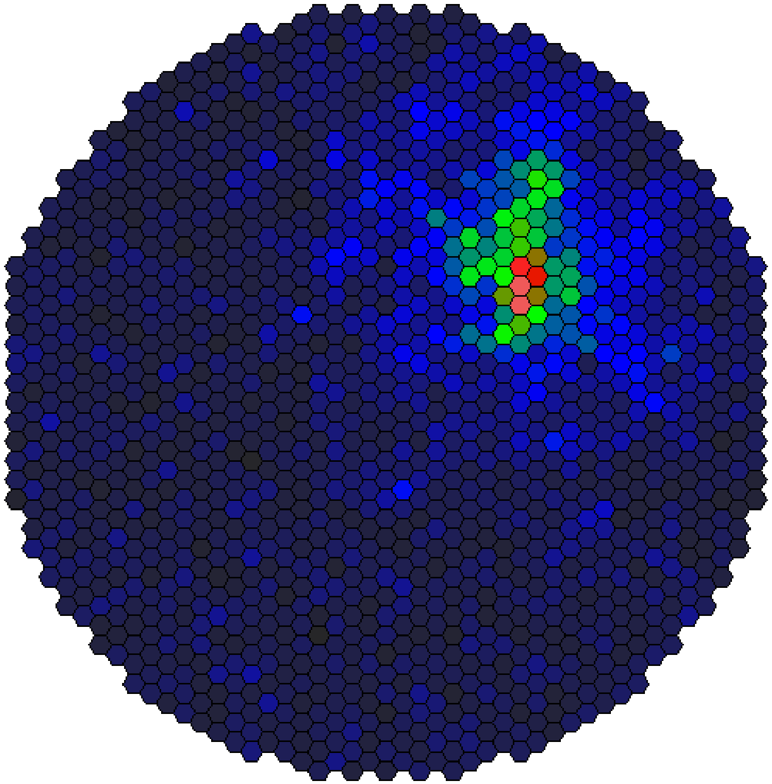


IACT: Background Suppression

1 Gamma

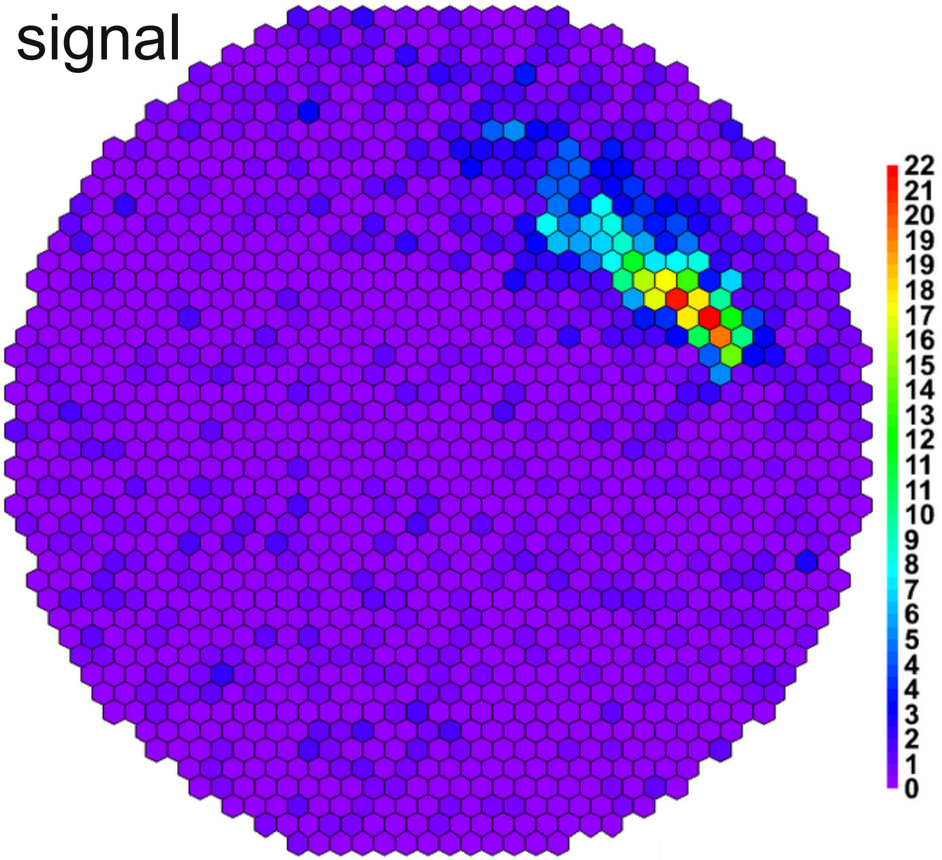
1000 Background

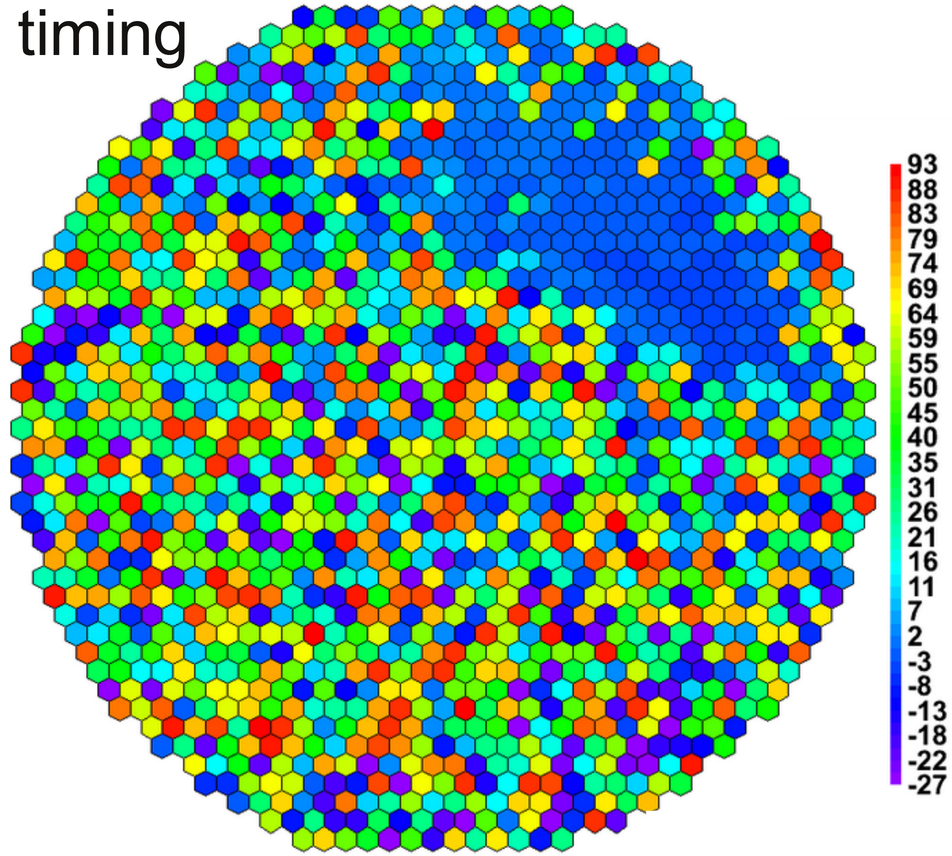




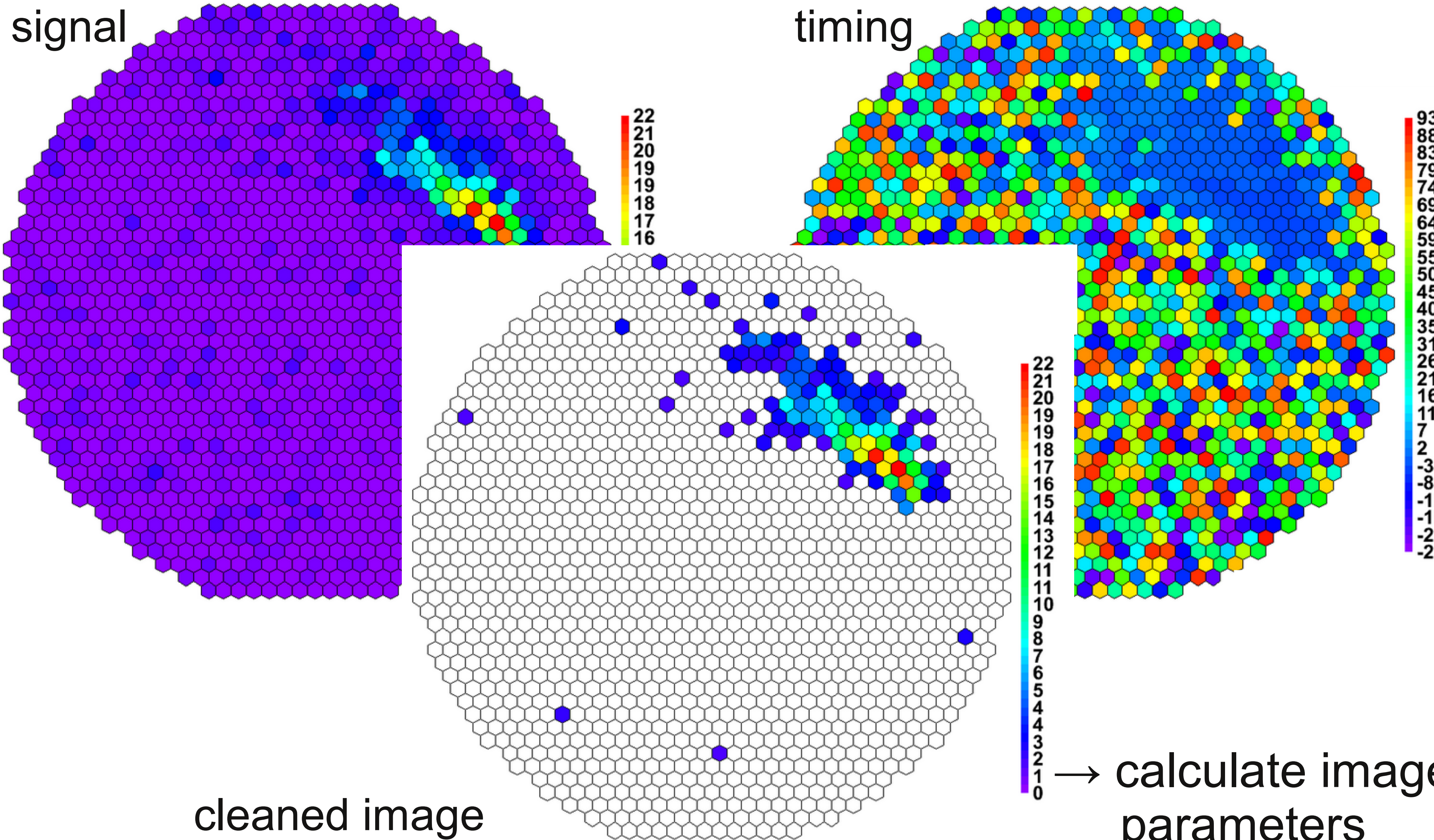
Shower morphology → Reconstruction of particle type

IACT: Image Cleaning





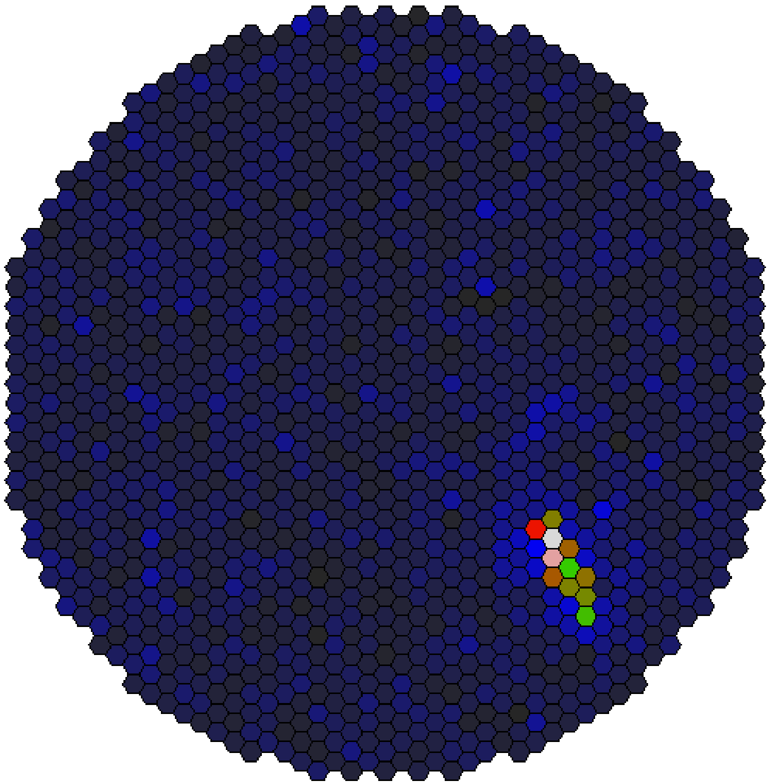
IACT: Image Cleaning



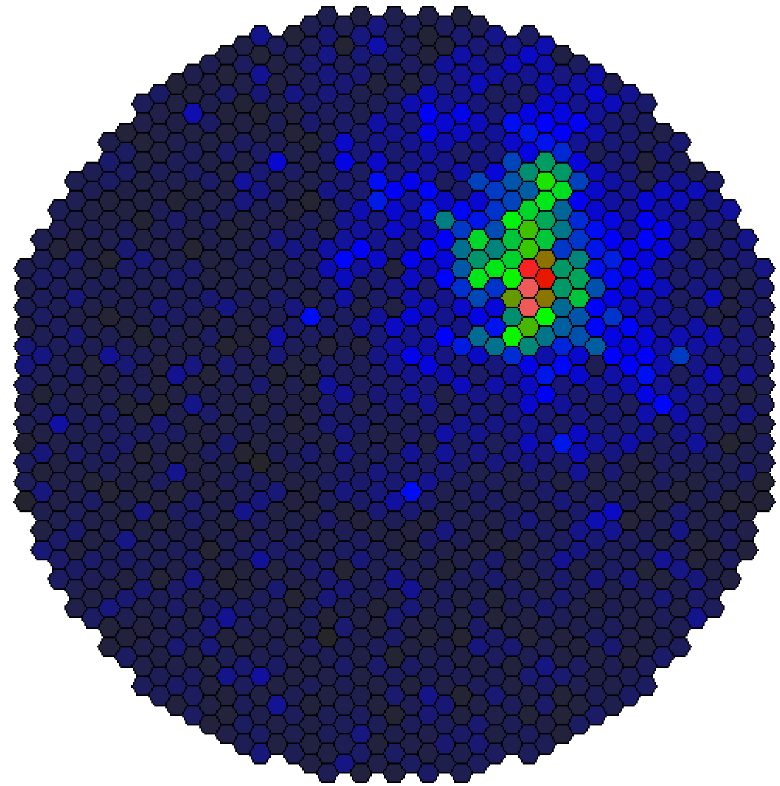
→ calculate image parameters

IACT: Background Suppression

1 Gamma



1000 Background

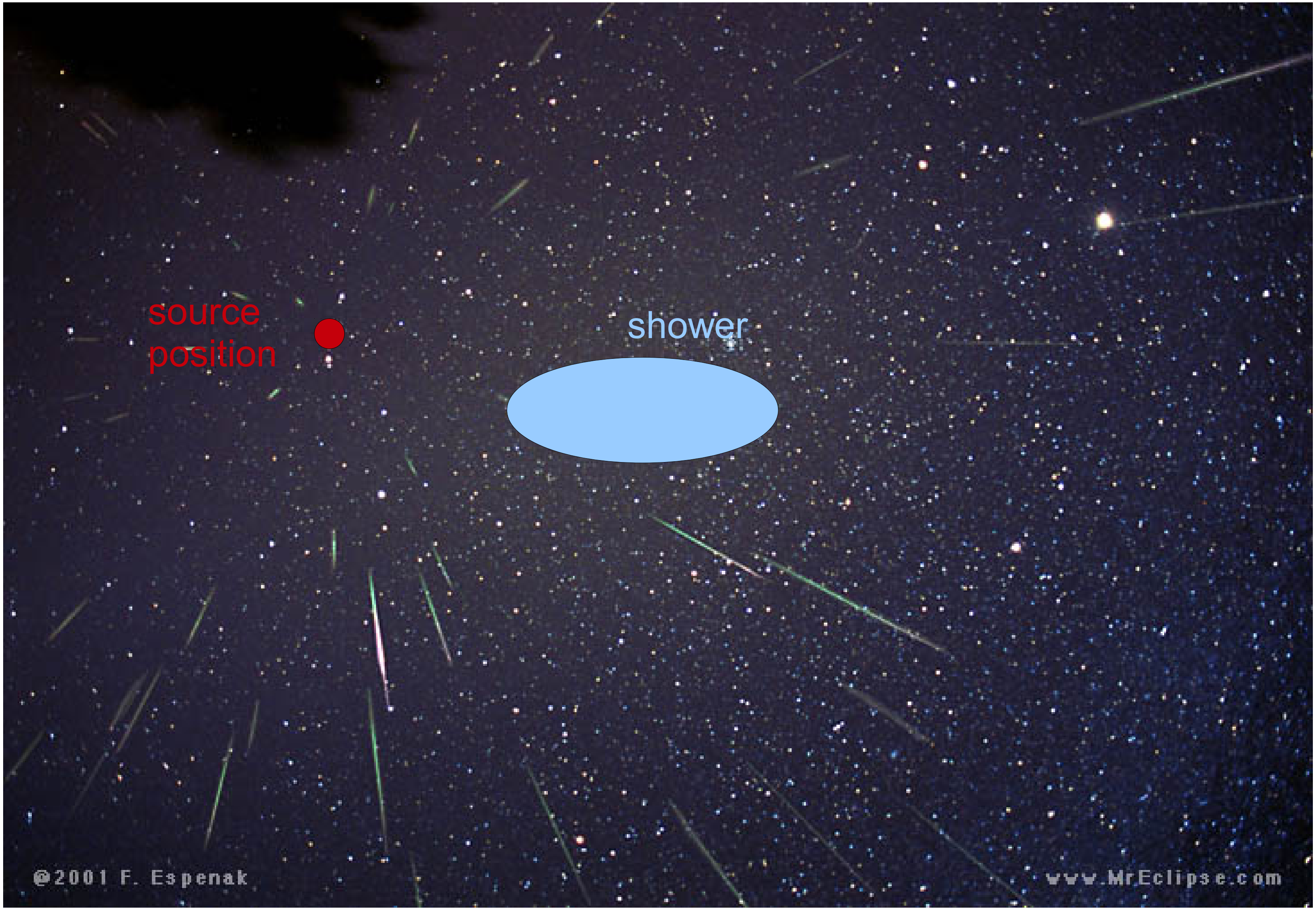


Shower morphology → Reconstruction of particle type
(Cuts in Image Parameter distributions)

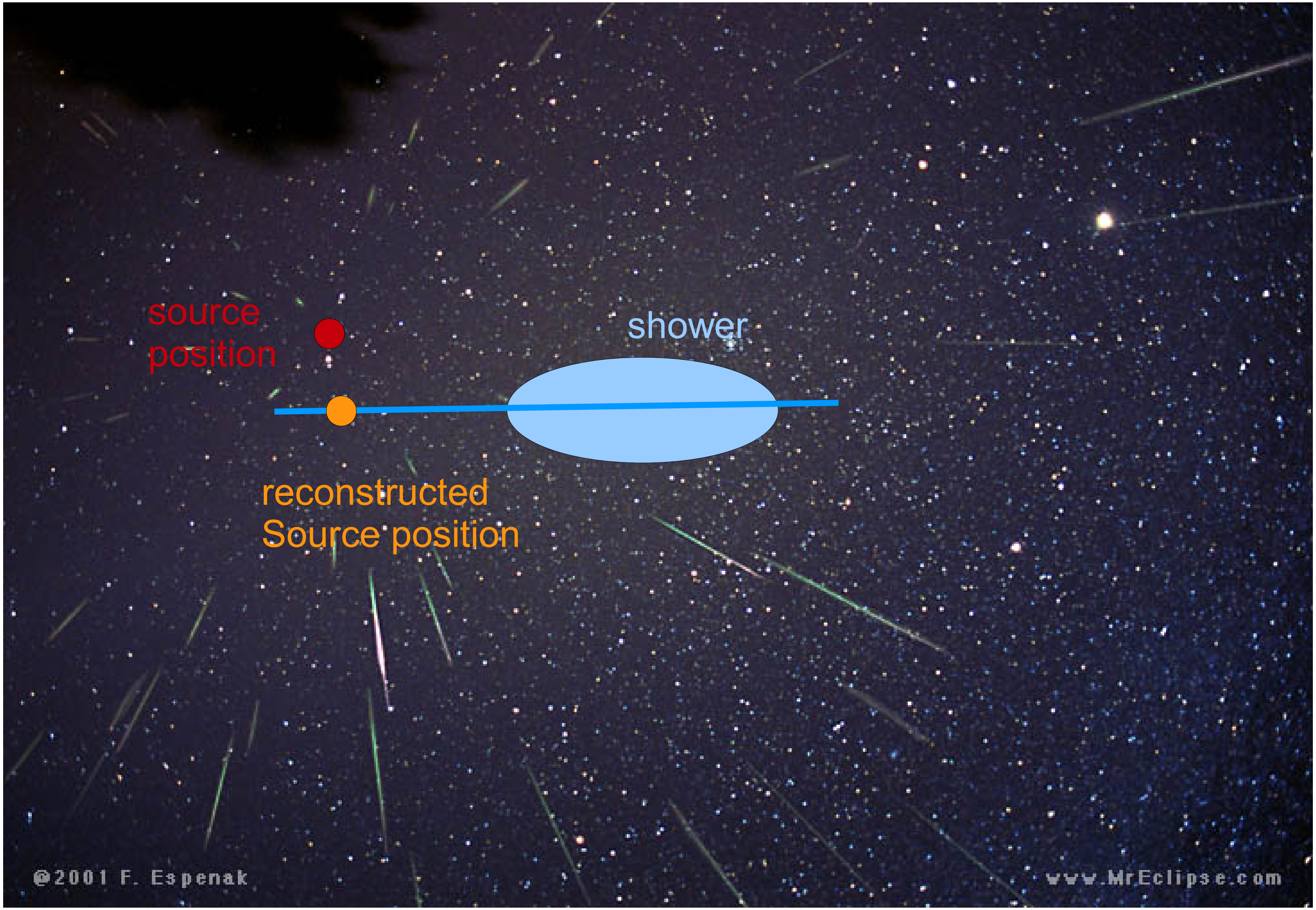
IACT: Shower Origin

IACT: Shower Origin

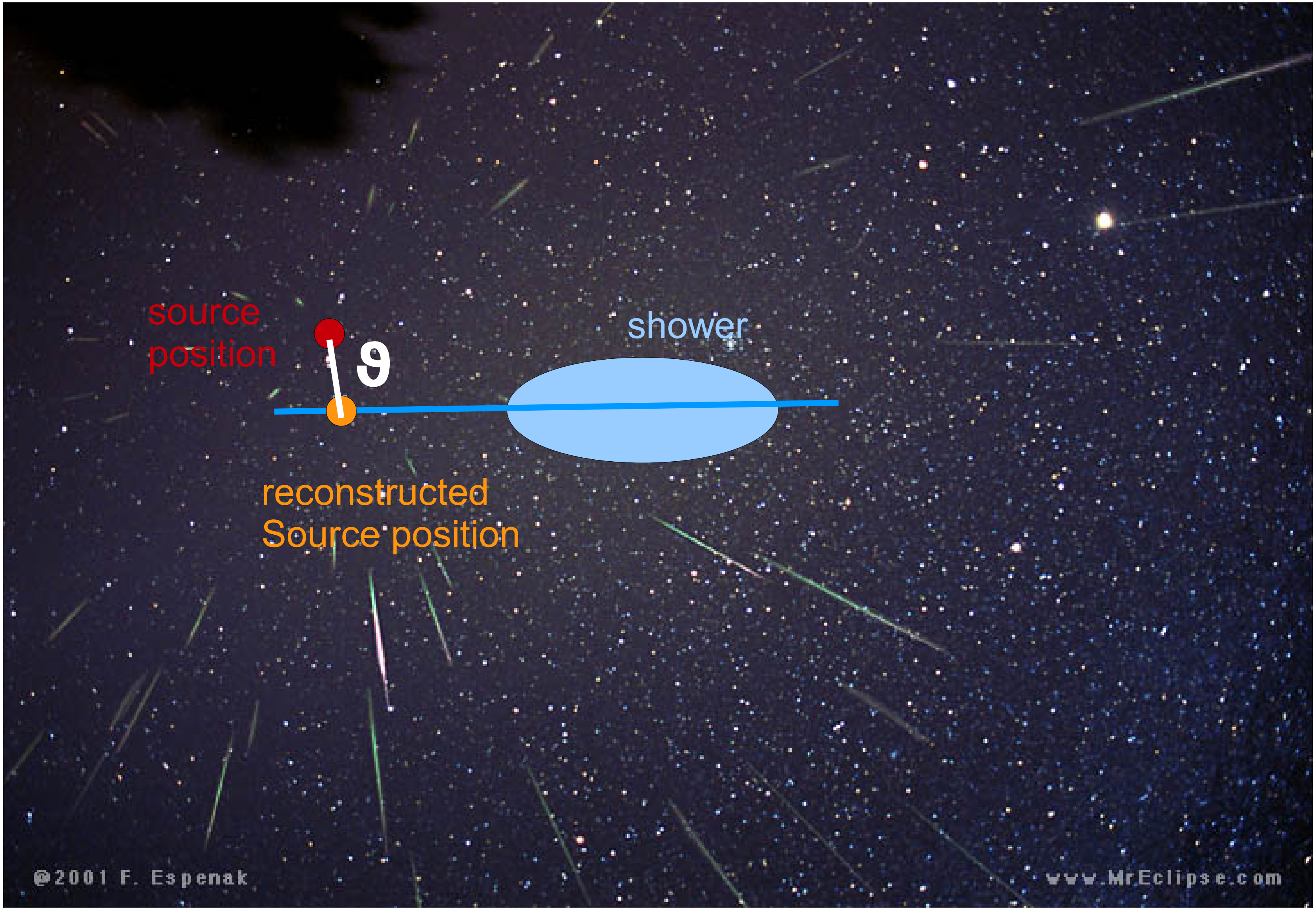
IACT: Shower Origin



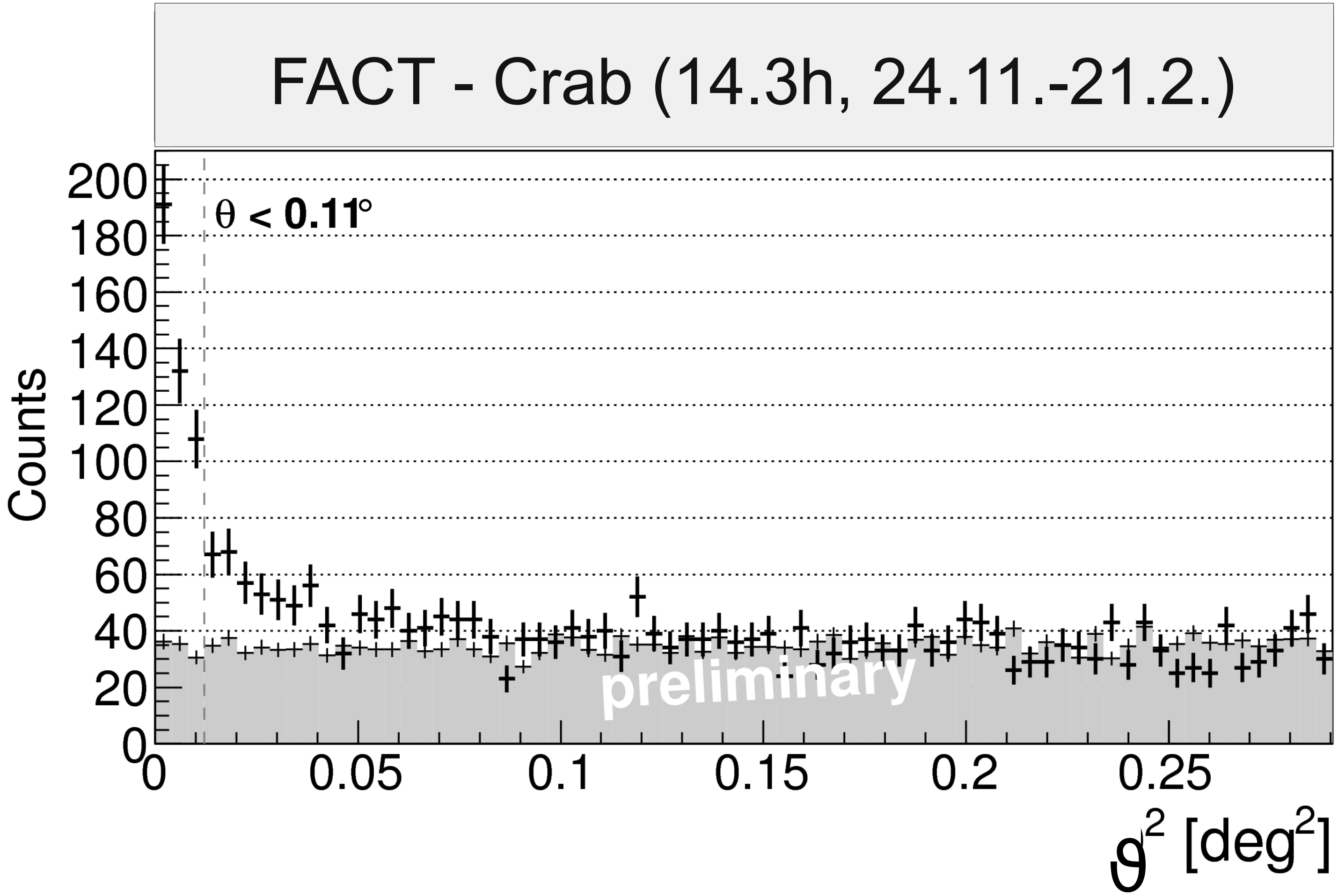
IACT: Shower Origin



IACT: Shower Origin

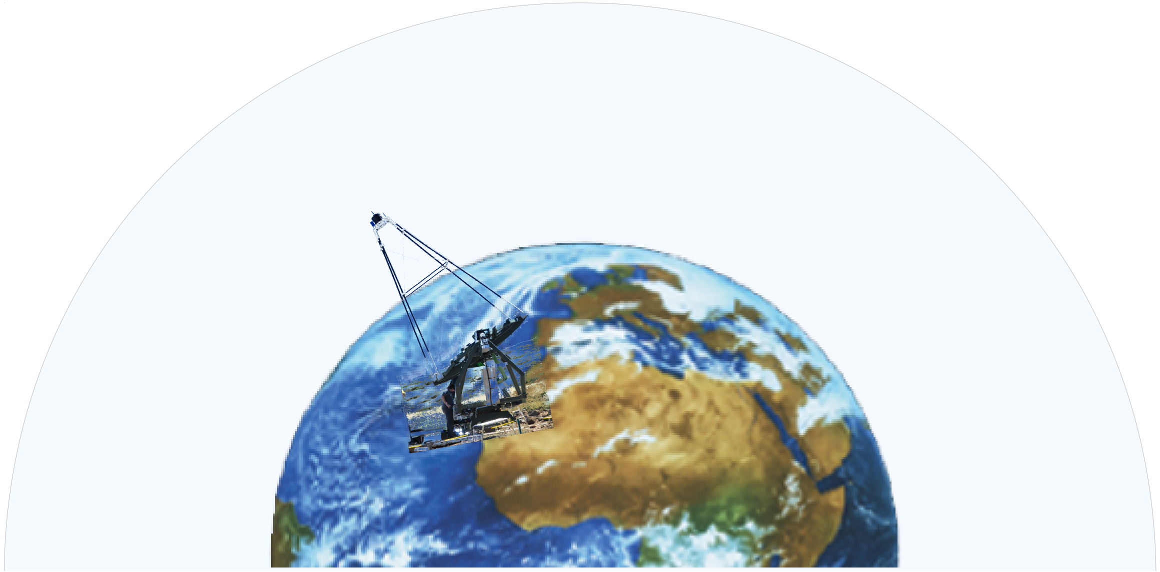


IACT: Signal Detection



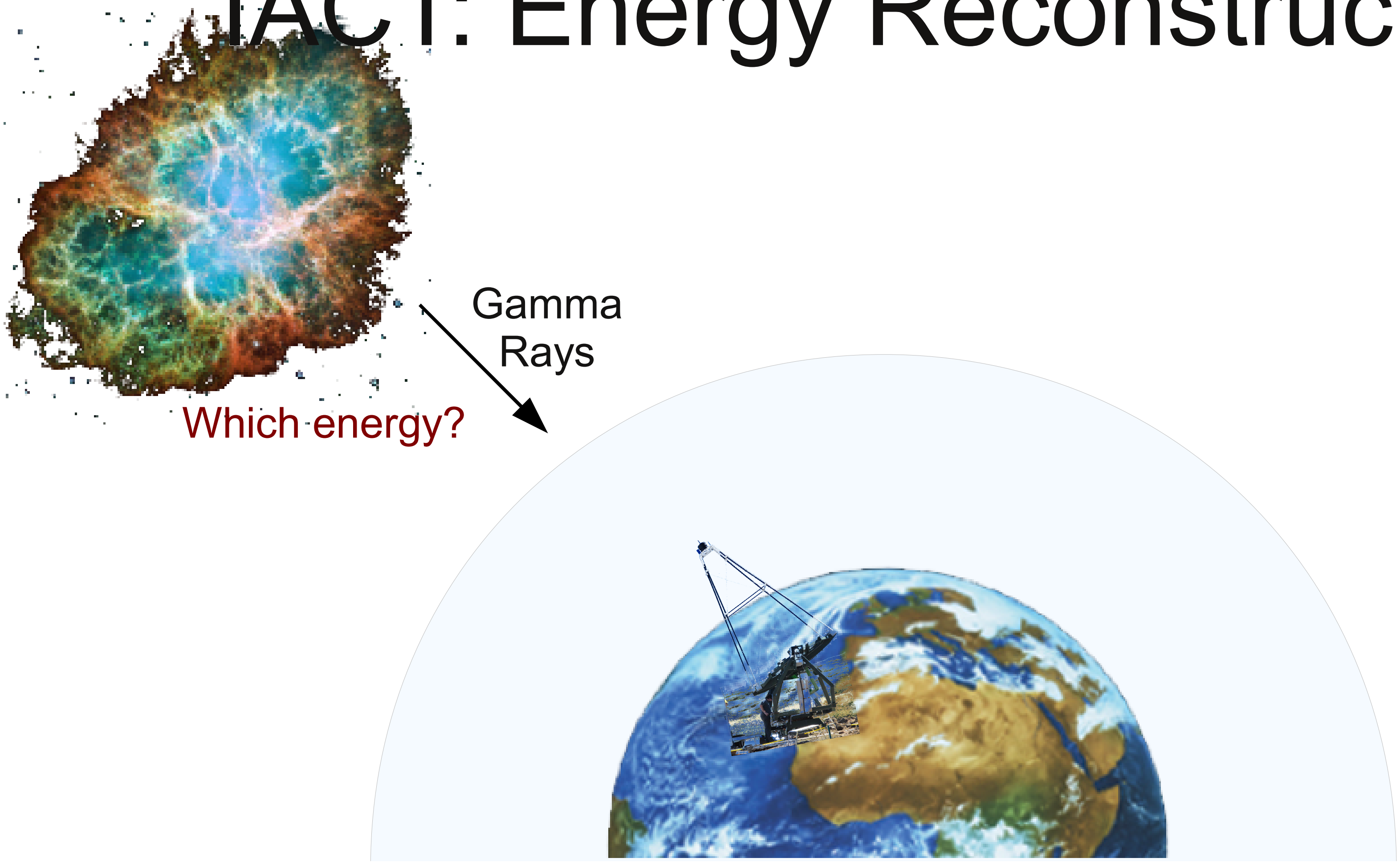
Angle between reconstructed shower origin and target position

IACT: Energy Reconstruction



Problem: How to calibrate the detector in energy?
Atmosphere is part of the detector

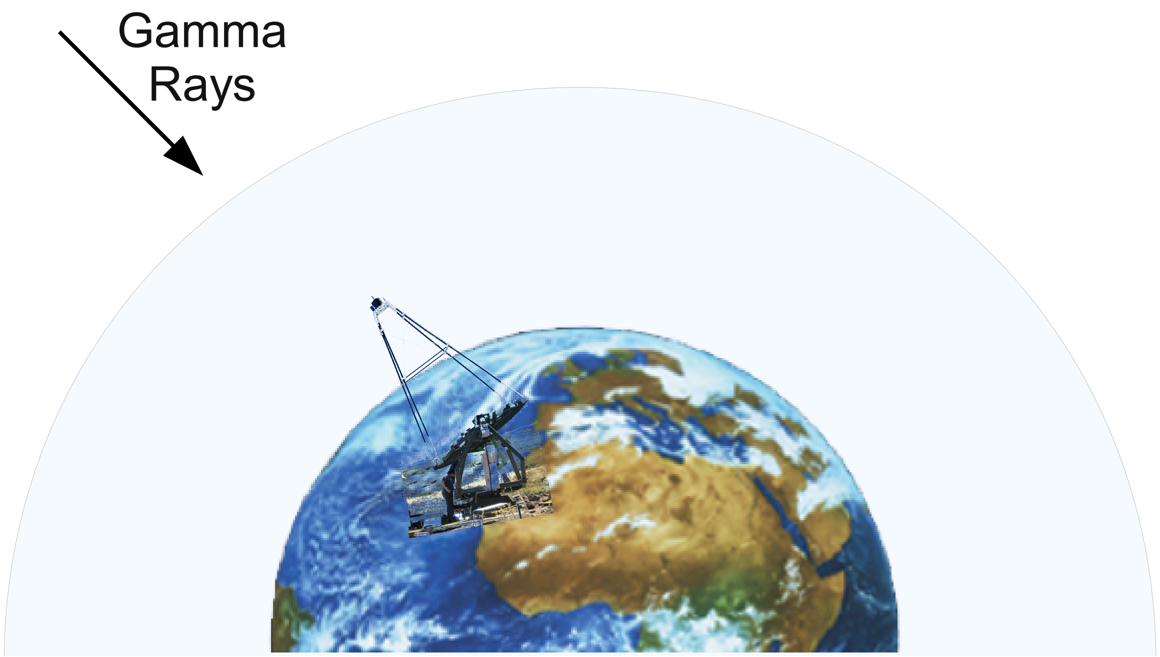
IACT: Energy Reconstruction



Problem: How to calibrate the detector in energy?

Atmosphere is part of the detector

IACT: Energy Reconstruction



Problem: How to calibrate the detector in energy?

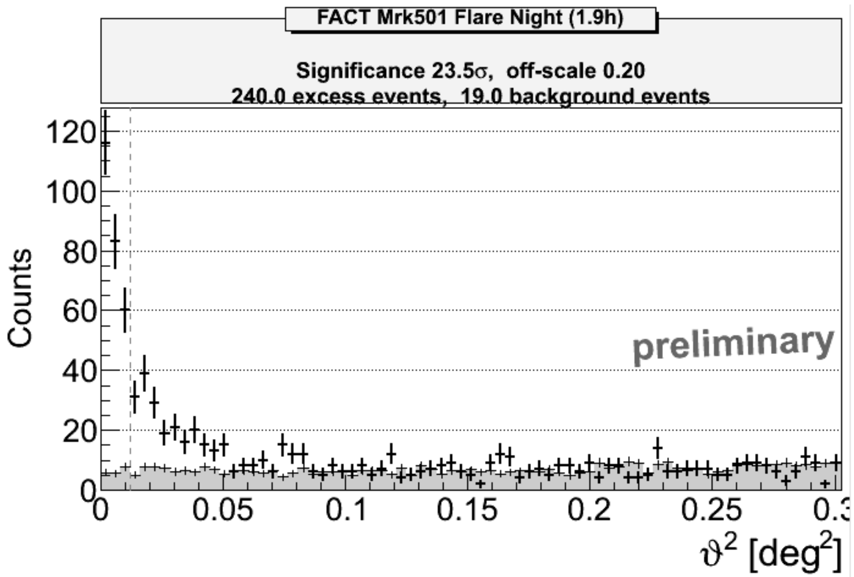
Atmosphere is part of the detector

We cannot bring CERN to space...

→ Simulations are needed for energy reconstruction

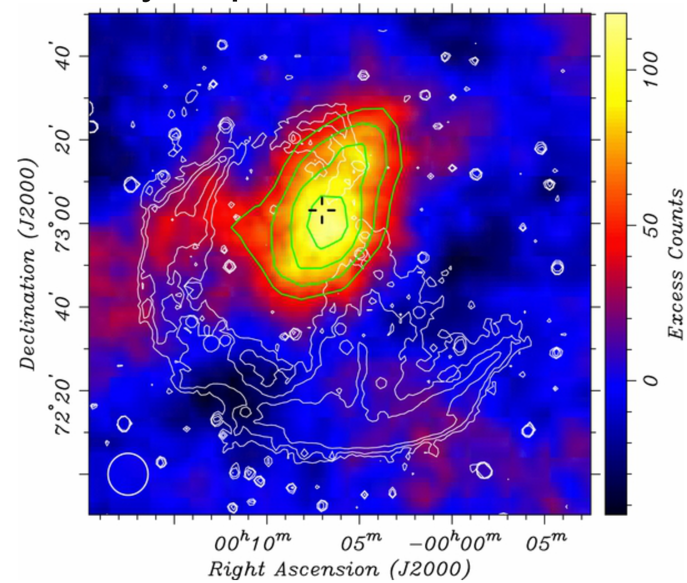
IACT: Type of Results

Signal → detection



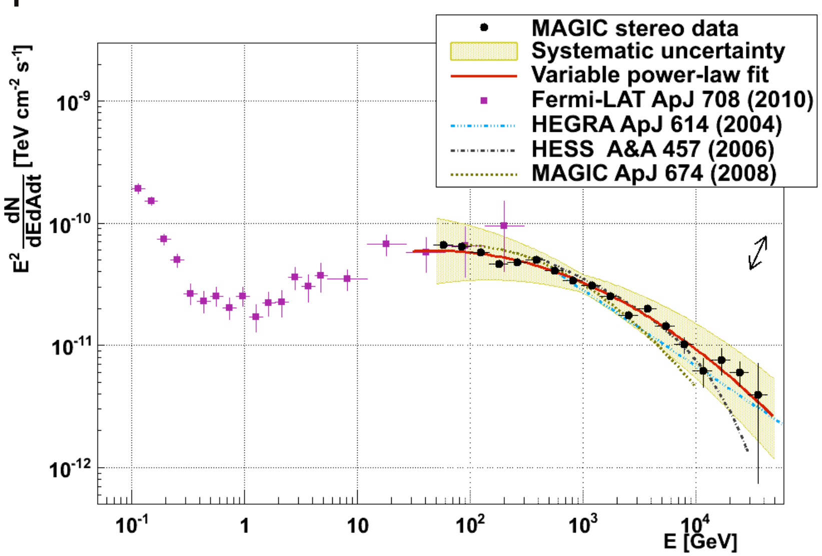
2D →

Skymap → extended sources



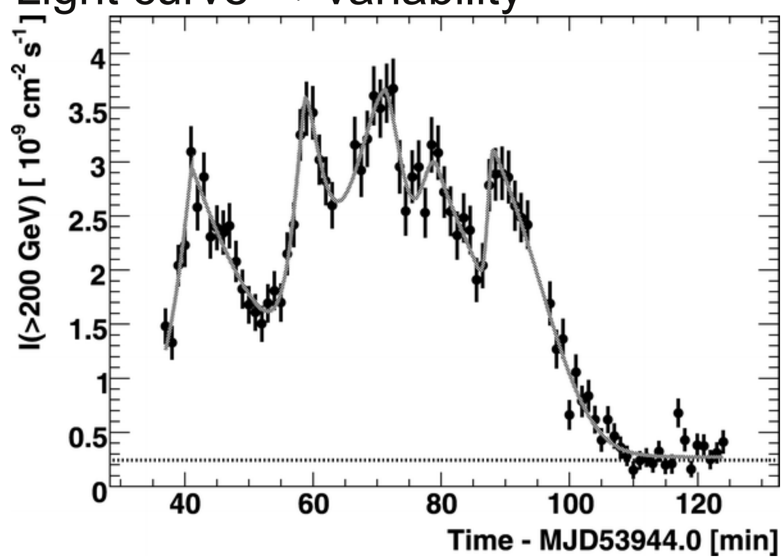
Aliu et al.2013 ApJ 764 38

Spectrum → SED



integrated flux over time →

Light curve → variability



F. Aharonian et al. 2007 ApJ 664 L71

Current Instruments

VERITAS

MAGIC
Telescopes

H.E.S.S.

Focus on detection of new sources
Observation time too expensive for longterm monitoring

FACT: Observed Sources

- Sources bright at TeV energies
- Crab Nebula
  → study detector performance
- Bright AGN

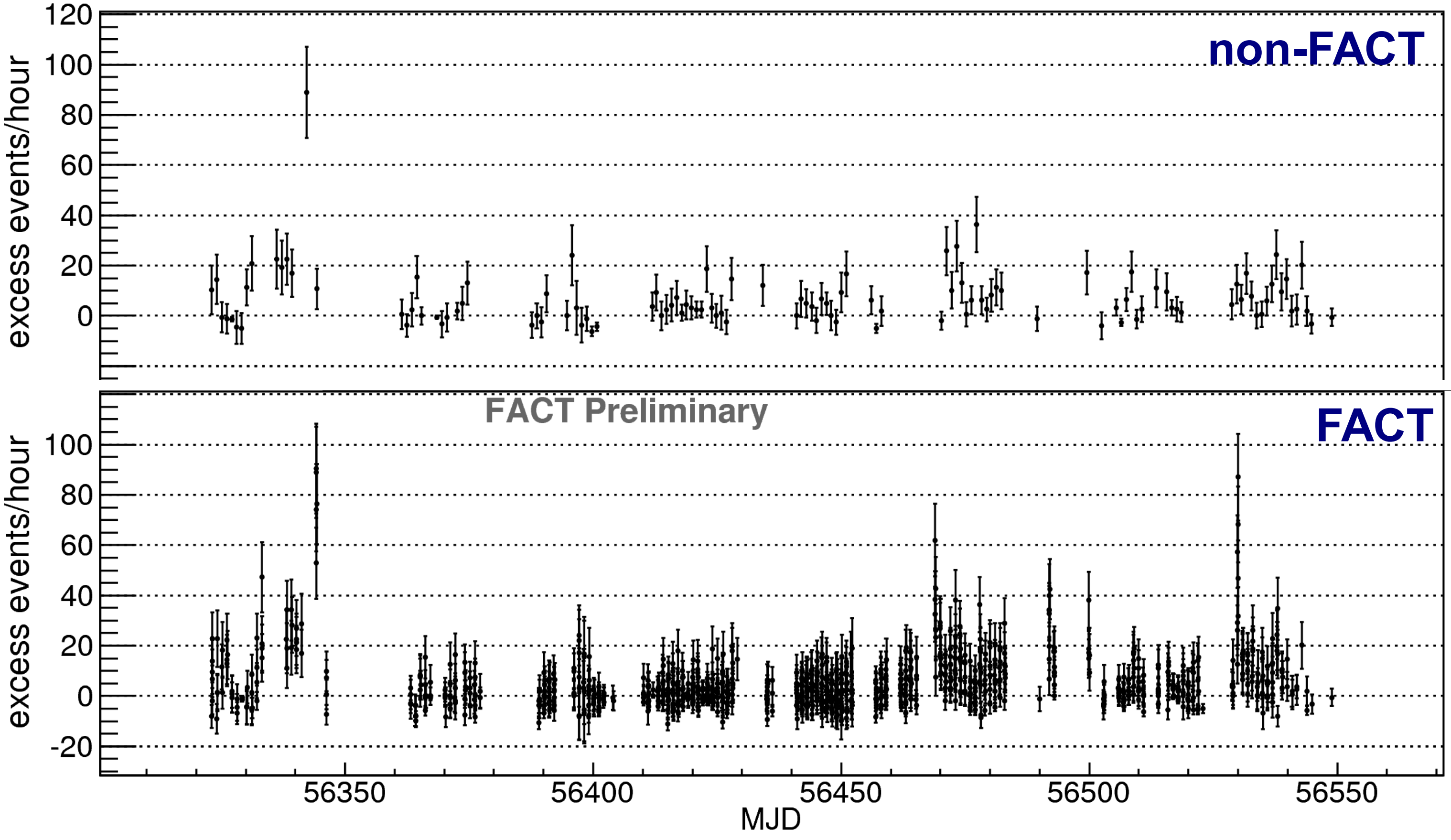
  → Flare studies

  → MWL observations

- Current source list
  - Crab Nebula
  - Mrk 421
  - Mrk 501
  - 1ES 1959+650
  - 1ES 2344+51.4
  - 1ES 1218+304
  - IC 310

Longterm Monitoring

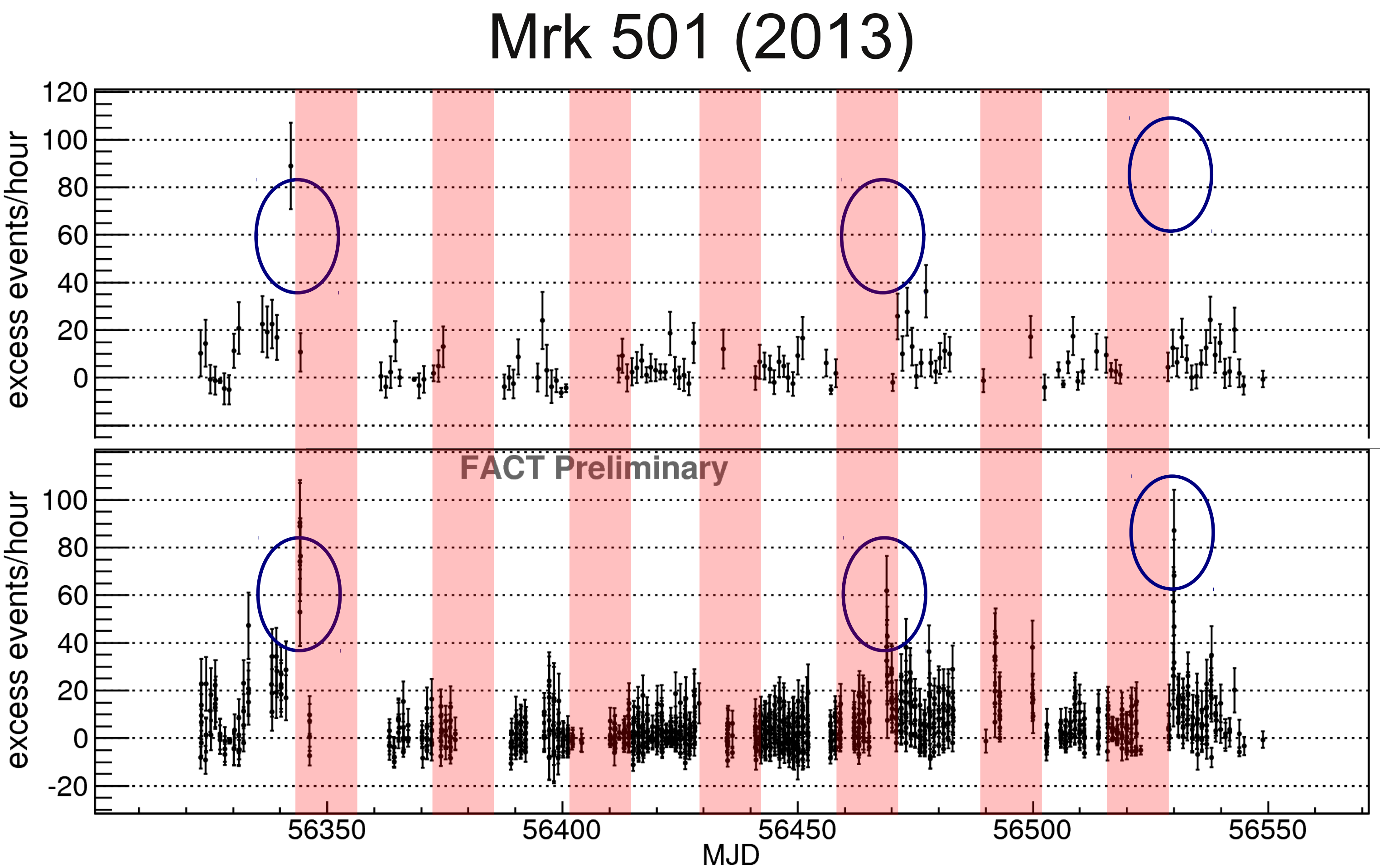
Mrk 501 (2013)



Limited to:
- moon disk < 65% ~320h
- 1 · 20min / night ~43h

All data ~430h

Longterm Monitoring



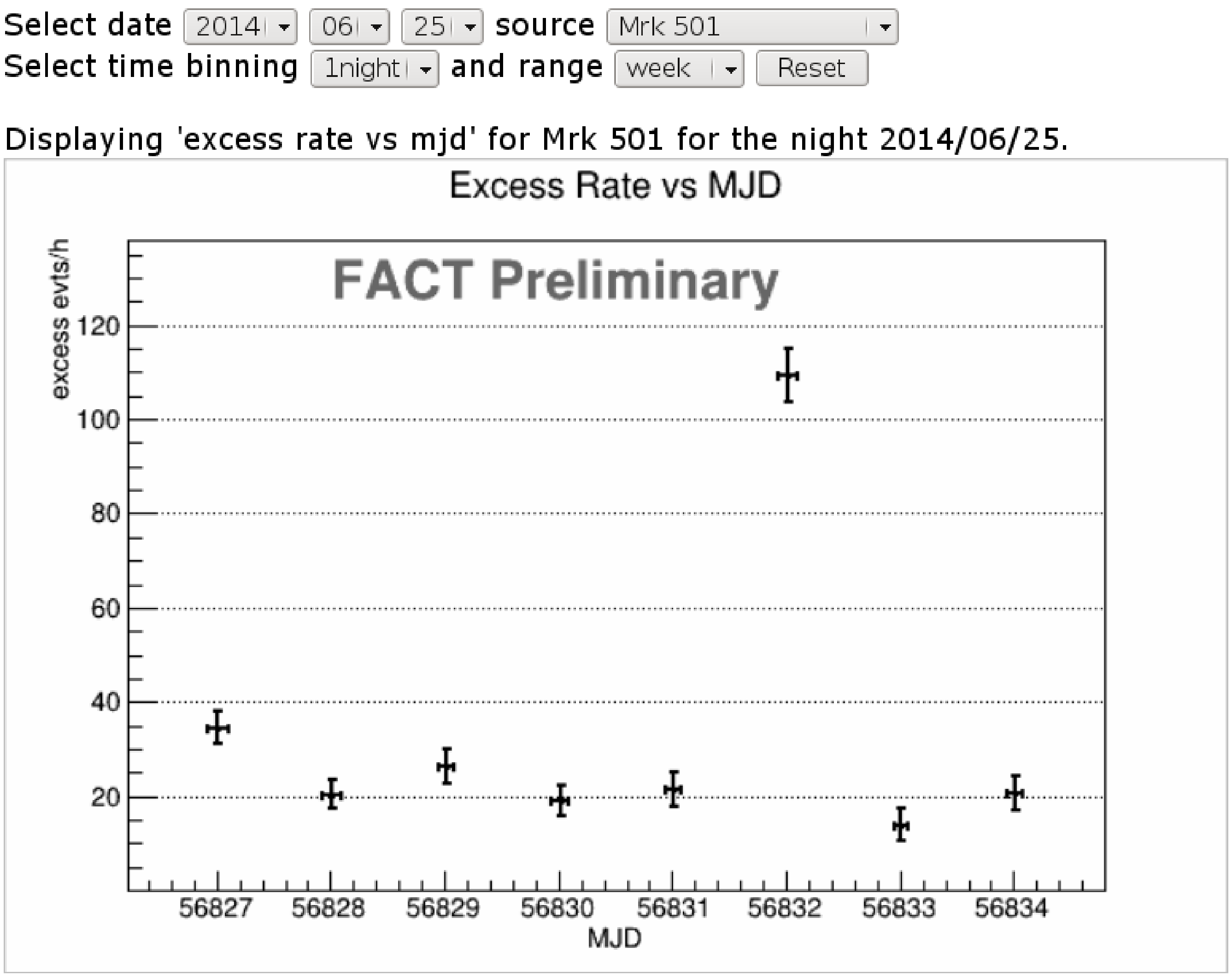
Limited to:

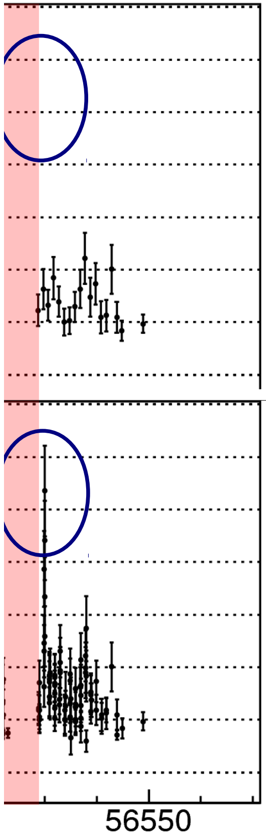
- moon disk < 65% ~320h
- 1 · 20min / night ~43h

All data ~430h

Longterm Monitoring

FACT Quick Look Analysis





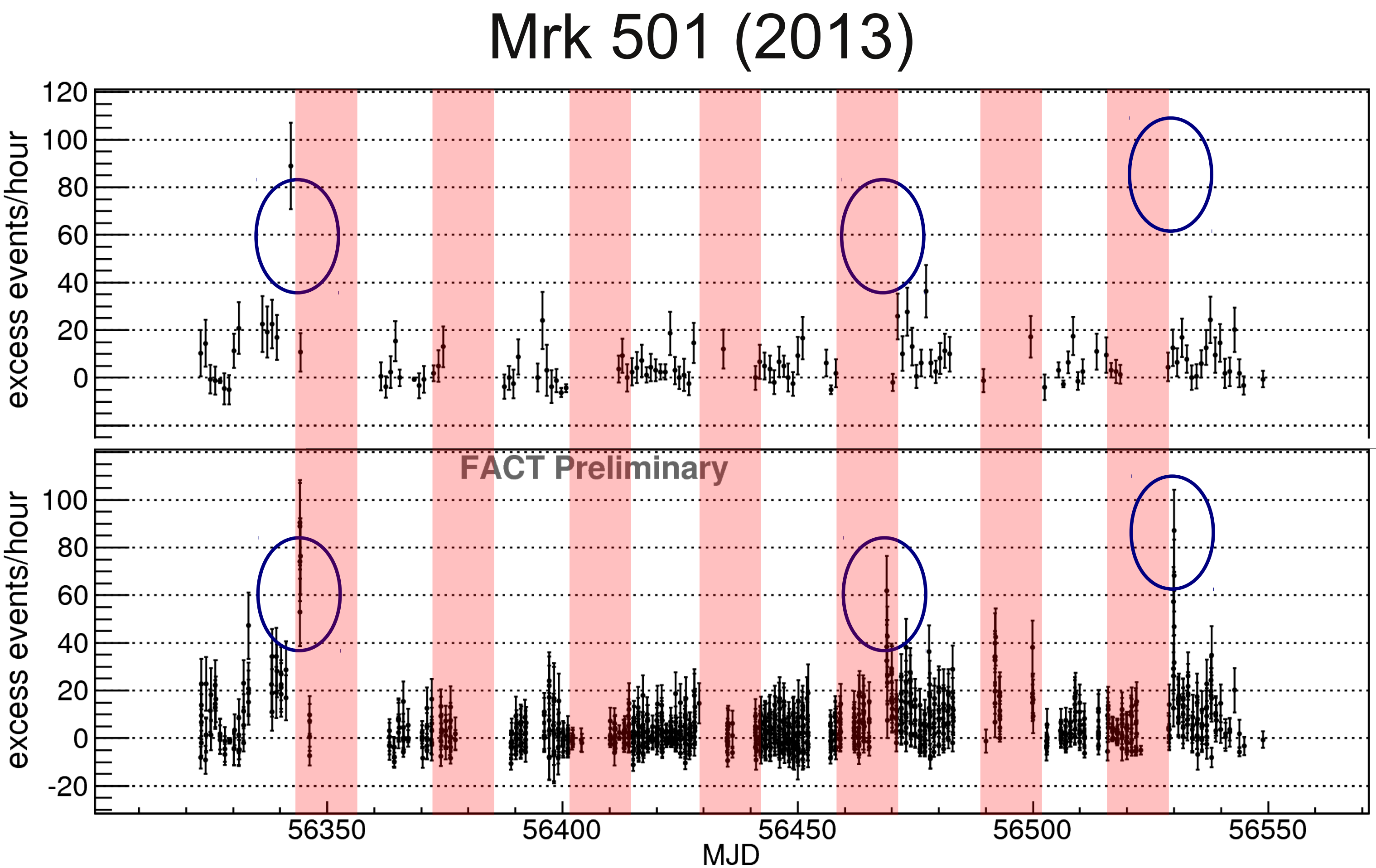
Limited to:

- moon disk < 65% ~320h
- 1 · 20min / night ~43h

All data ~430h

short flares might remain undiscovered

Longterm Monitoring



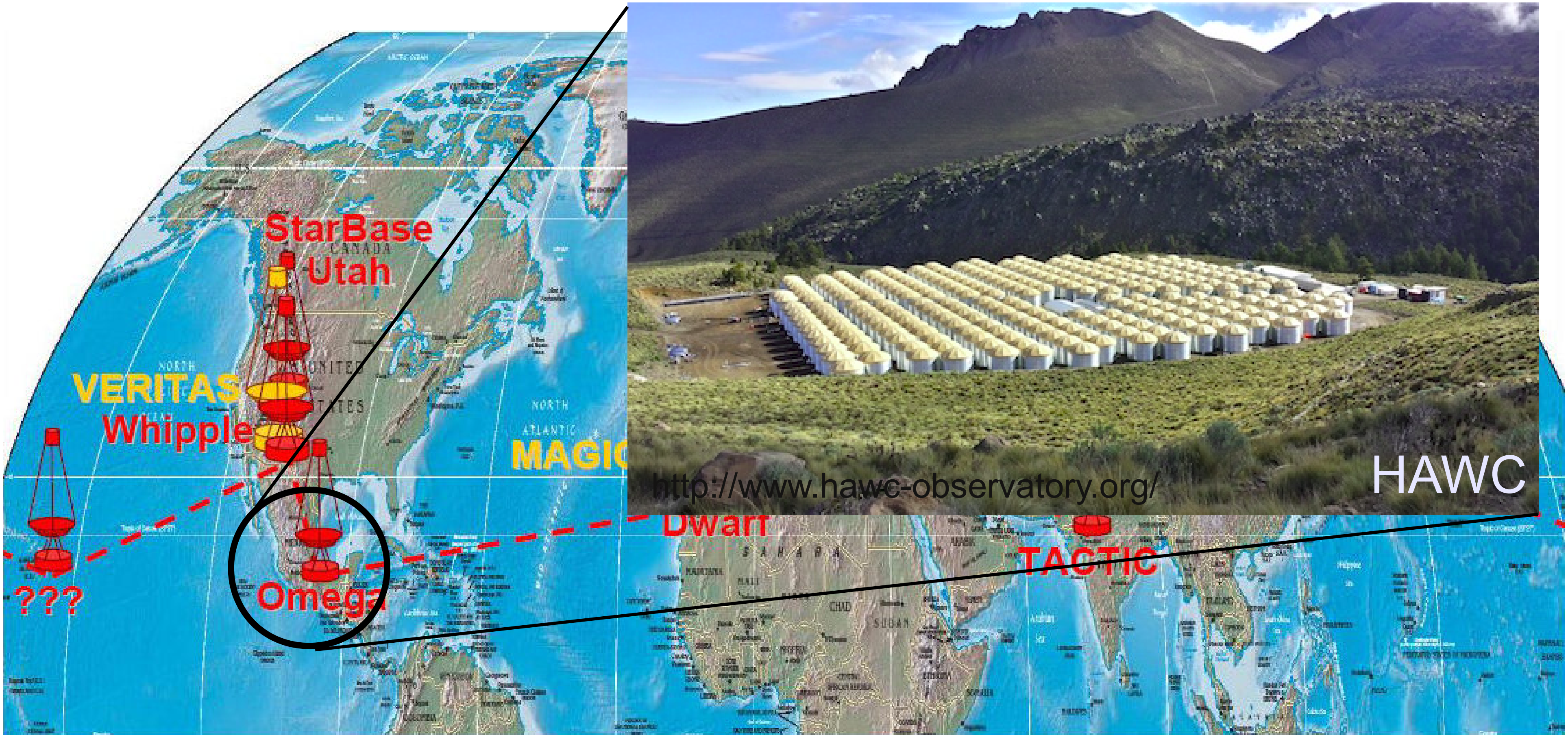
Limited to:
- moon disk < 65% ~320h
- 1 · 20min / night ~43h

All data ~430h

→ Collect enough statistics to study flare probabilities and flare properties

Ideal Case: 24/7 Monitoring

High Altitude Water Cherenkov Gamma-Ray Observatory



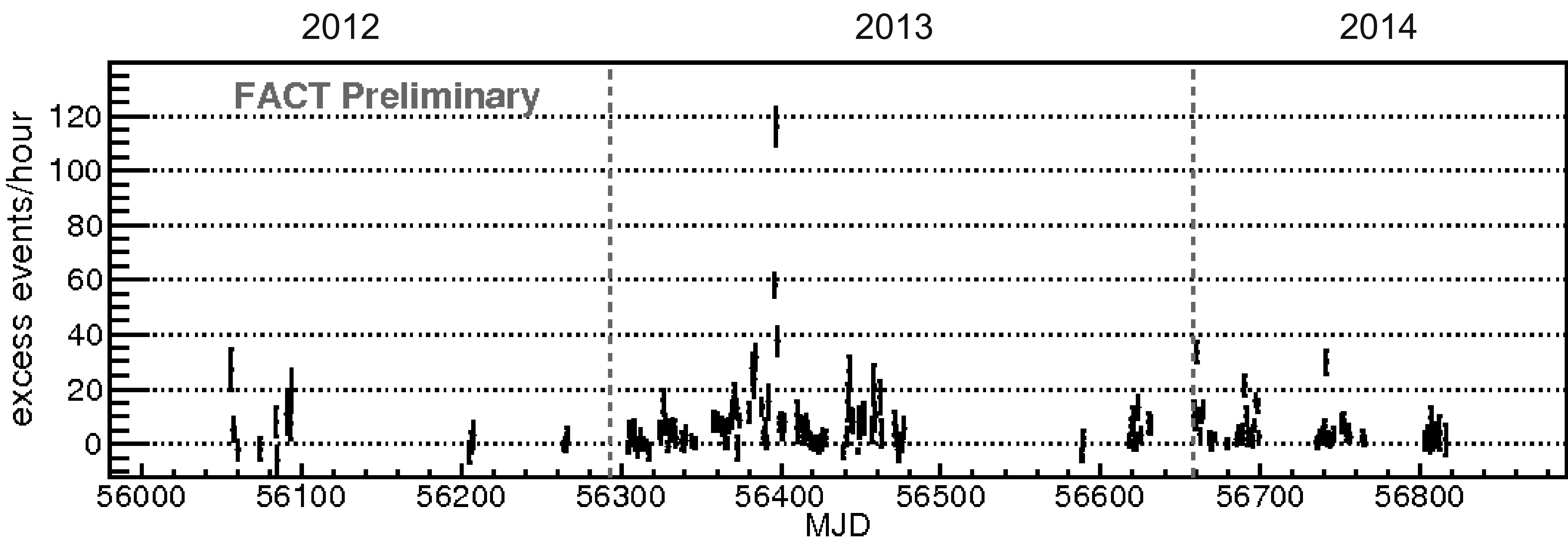
Observations at TeV Energies

Multi-Wavelength Observations

- Correlations with other VHE instruments
  - Cherenkov Telescopes
  - HAWC
- MWL campaigns for Mrk421 Mrk501
  - Cherenkov Telescopes
  - Optical Telescopes
  - Radio Telescopes
  - Swift, NuStar
- ToO proposals: XMM, Swift, Integral
- Flare Alerts → MWL observations

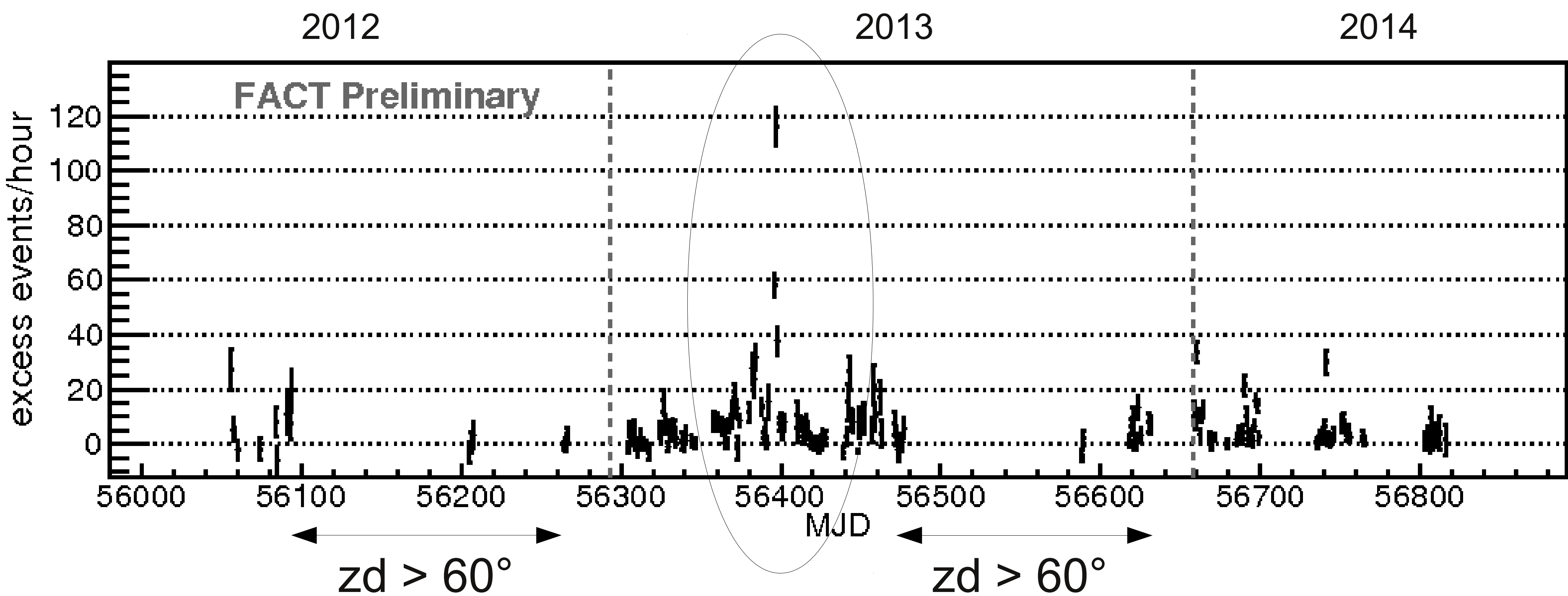
Excess Rate Curve Mrk421

May 2012 – Now



Excess Rate Curve Mrk421

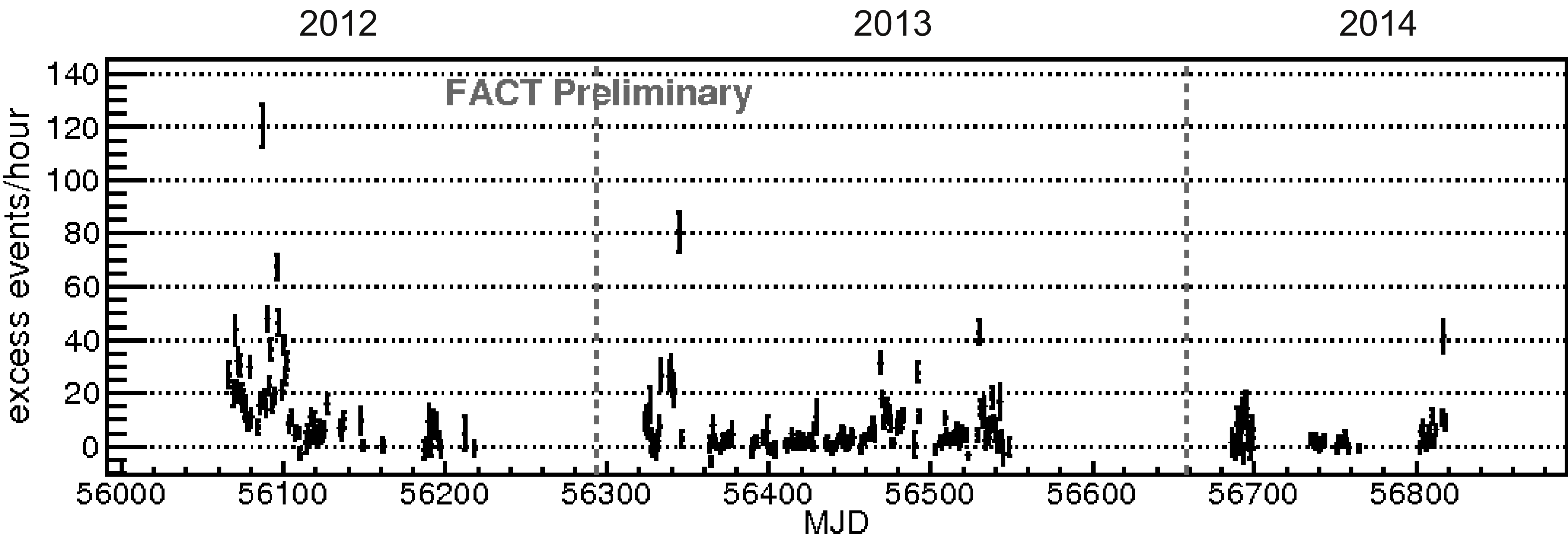
May 2012 – Now



Flare in April 2013

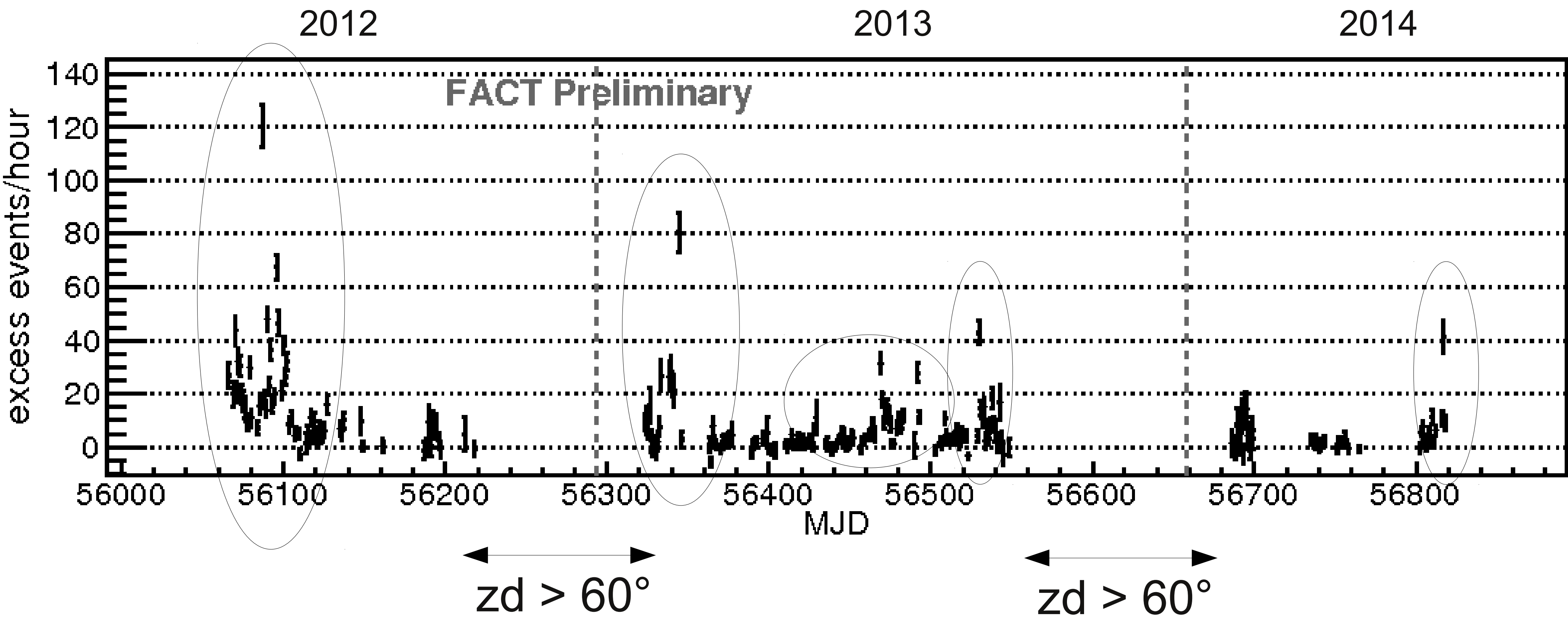
Excess Rate Curve Mrk501

May 2012 – Now



Excess Rate Curve Mrk501

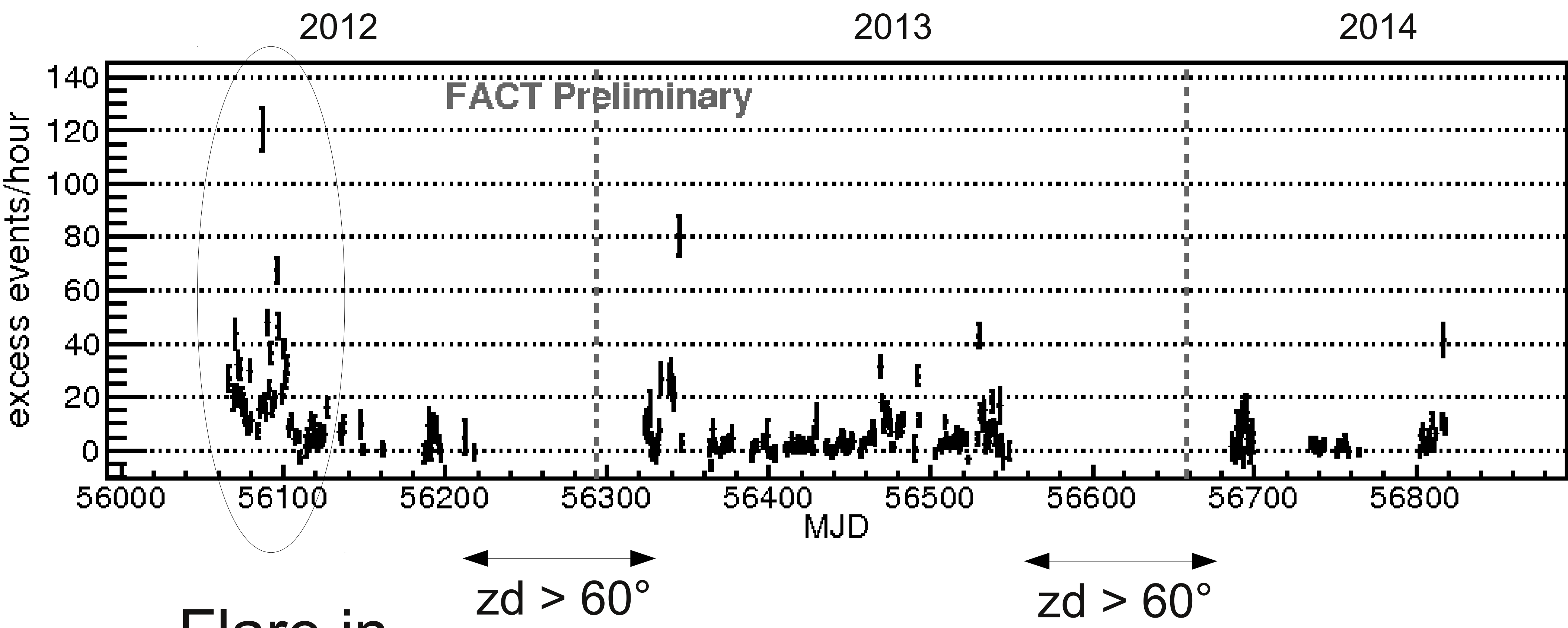
May 2012 – Now



Several flaring activities within 3 years

Excess Rate Curve Mrk501

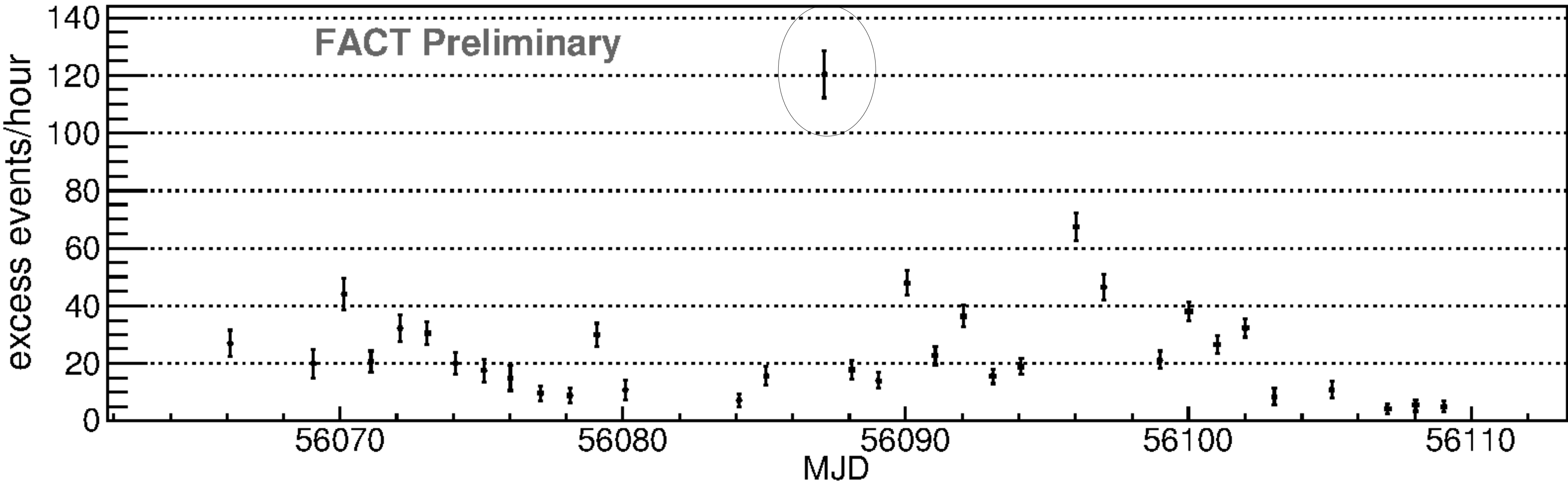
May 2012 – Now



Flare in
June 2012

Excess Rate Curve Mrk501

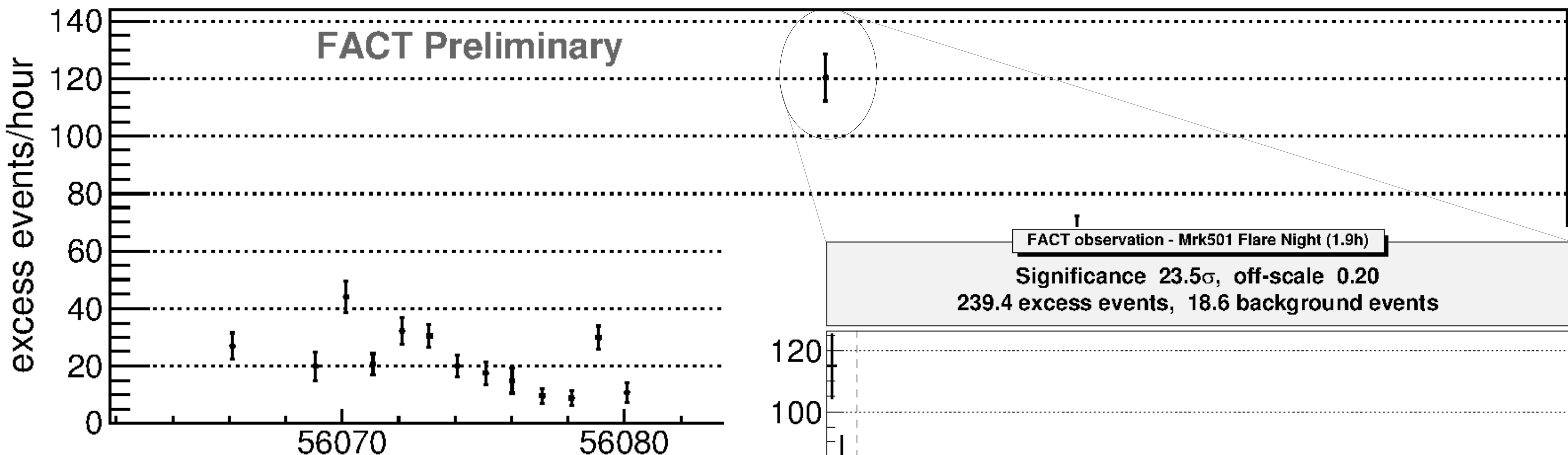
18.5.-30.6.2012

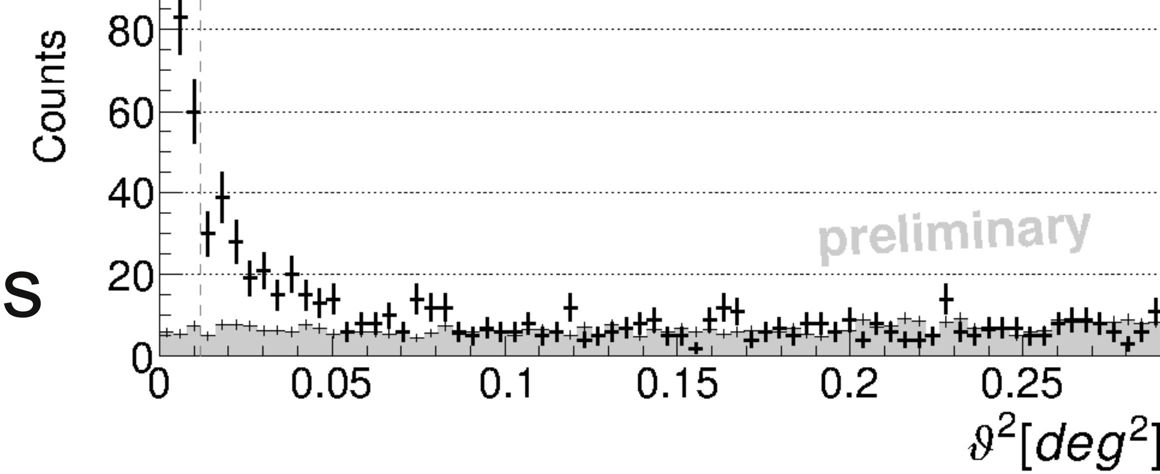


Increase in excess rate by factor 6
> 5 sigma in 5 minutes

Excess Rate Curve Mrk501

18.5.-30.6.2012





> 5 sigma in 5 minutes
  → Flare alerts

Quick Look Analysis: Flare Alerts

- Fast processing on site: Excess rate curves
- Results in almost real time

  → Flare alerts to other telescopes
- Not including:
  - Correction for dependence of threshold on zenith distance and ambient light
  - Detailed data check

http://www.fact-project.org/monitoring

QLA

fact-project.org/monitoring/index.php?y=2014&m=02&d=01&source=1&timebin=3&plot=night

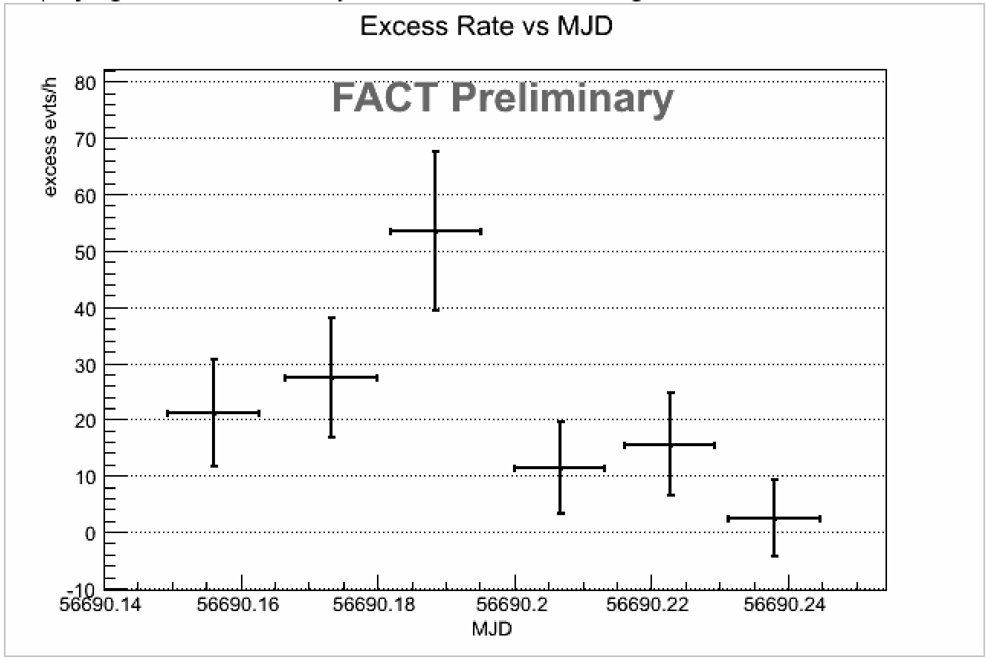
http://www.fact-project.org/monitoring

FACT Quick Look Analysis

Select date 2014 ▾ 02 ▾ 01 ▾ source Mrk 421 ▾

Select time binning 20min ▾ and range night ▾ Reset

Displaying 'excess rate vs mjd' for Mrk 421 for the night 2014/02/01.



REMARKS:

- These are the results of a **fast quick look analysis** on site, i.e. they are **preliminary**.
- The quick look analysis includes all data, i.e. no data selection done.
- The shown curves are not fluxes but **excess rates** (number of excess events per effective ontime), i.e. there is a dependence on trigger threshold and zenith distance of the observation (with the current analysis for zenith distance > 40 degree and trigger threshold > 500 DAC counts).
- The curves are provided with 20 min binning and nightly binning.
- In case, you need further details about the data or a different binning, please do not hesitate to contact us.
- Time range 'all' refers to all data since 12.12.2012. For older data, please contact us.

If you intend to use the data or information from this website, please let us know for reference.

Please cite this webpage and the FACT design paper when using information from this webpage or any FACT data.

Reference FACT Design Paper: H. Anderhub et al. JINST 8 P6008 ADS open access

Contact: Daniela Dorner *dorner<at>astro.uni-wuerzburg.de*.

QLA

fact-project.org/monitoring/index.php?y=2014&m=02&d=01&source=1&timebin=3&plot=night

http://www.fact-project.org/monitoring

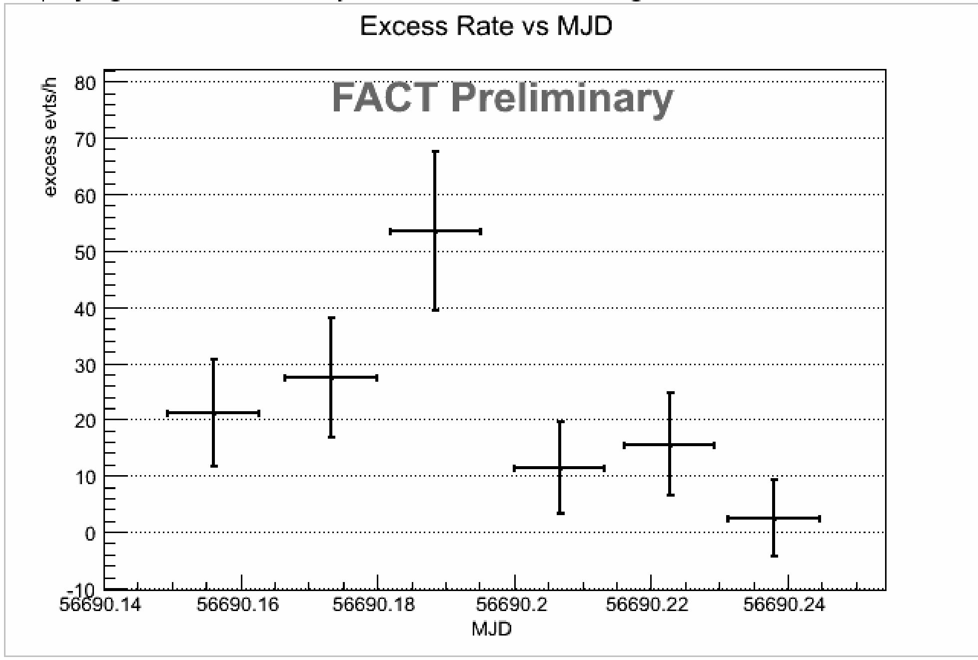
FACT Quick Look Analysis

Select date 2014 02 01 source Mrk 421

Select time binning 20min and range night Reset

Select
→ date
→ time range
→ source
→ binning

Displaying 'excess rate vs mjd' for Mrk 421 for the night 2014/02/01.



REMARKS:

- These are the results of a **fast quick look analysis** on site, i.e. they are **preliminary**.
- The quick look analysis includes all data, i.e. no data selection done.
- The shown curves are not fluxes but **excess rates** (number of excess events per effective ontime), i.e. there is a dependence on trigger threshold and zenith distance of the observation (with the current analysis for zenith distance > 40 degree and trigger threshold > 500 DAC counts).
- The curves are provided with 20 min binning and nightly binning.
- In case, you need further details about the data or a different binning, please do not hesitate to contact us.
- Time range 'all' refers to all data since 12.12.2012. For older data, please contact us.

If you intend to use the data or information from this website, please let us know for reference.

Please cite this webpage and the FACT design paper when using information from this webpage or any FACT data.

Reference FACT Design Paper: H. Anderhub et al. JINST 8 P6008 ADS open access

Contact: Daniela Dorner *dorner<at>astro.uni-wuerzburg.de*.

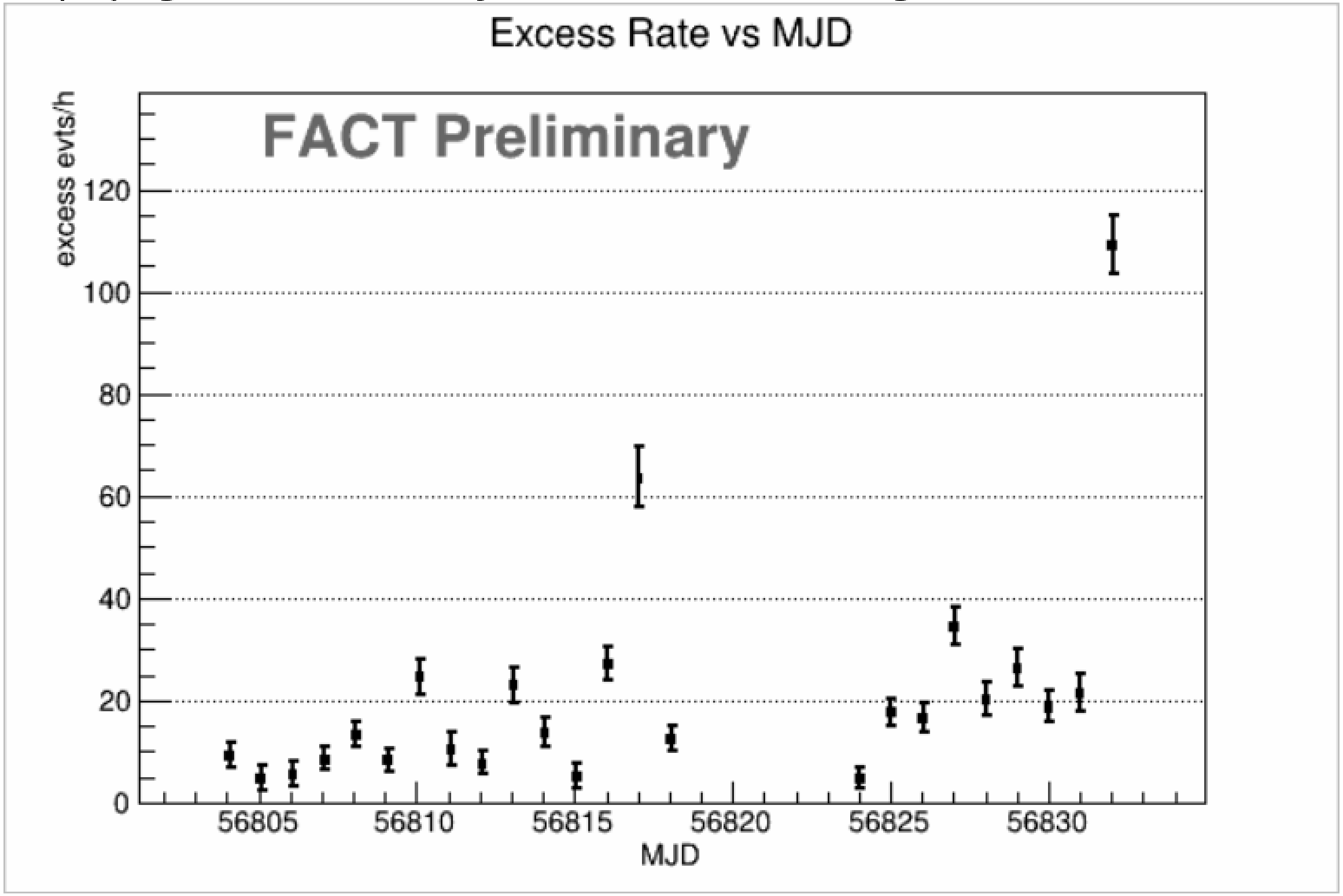
Mrk501 – Flare Alerts in Summer 2014

FACT Quick Look Analysis

Select date 2014 06 23 source Mrk 501

Select time binning 1night and range 28 days Reset

Displaying 'excess rate vs mjd' for Mrk 501 for the night 2014/06/23.

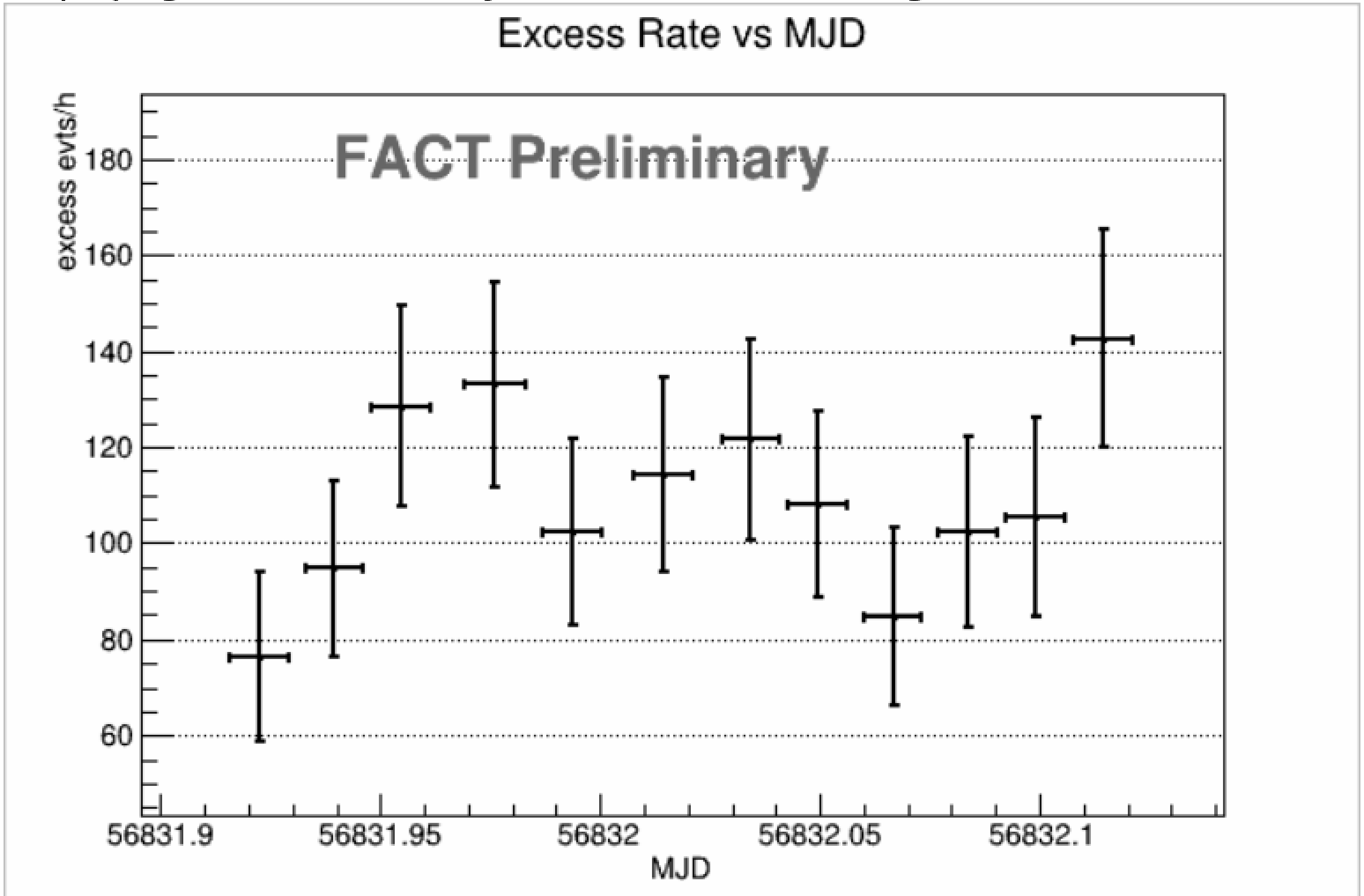


Mrk501 – Flare Alerts in Summer 2014

FACT Quick Look Analysis

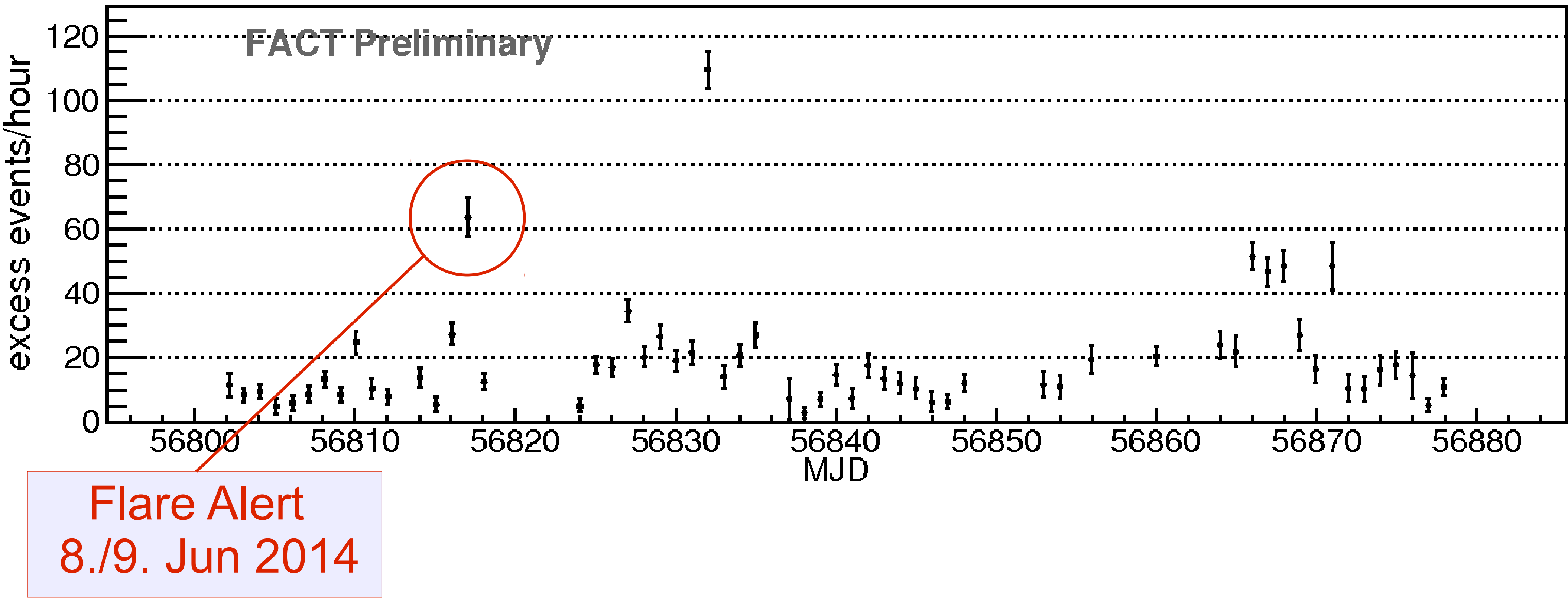
Select date 2014 06 23 source Mrk 501
Select time binning 20min and range night Reset

Displaying 'excess rate vs mjd' for Mrk 501 for the night 2014/06/23.



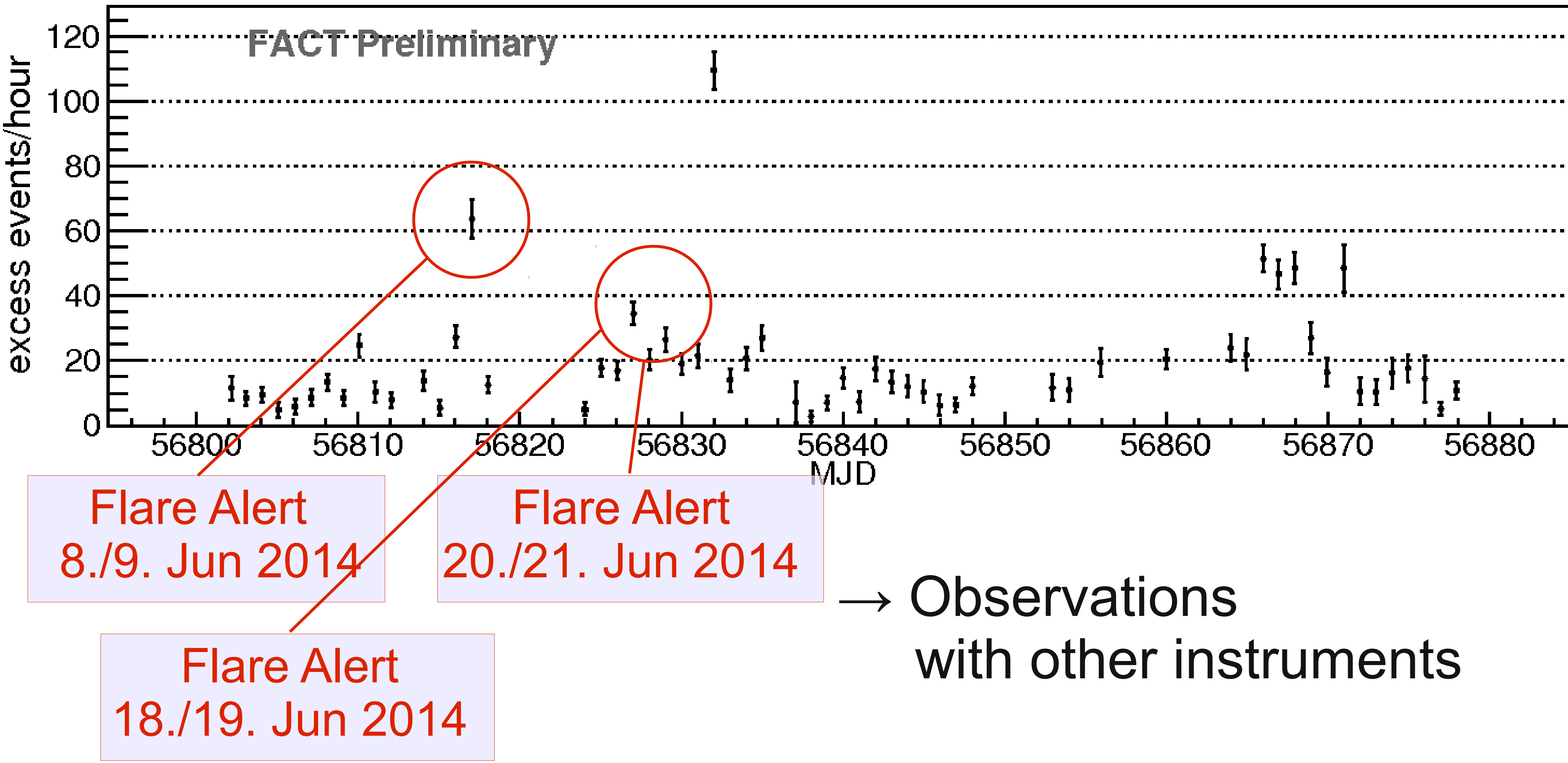
Mrk501 – Flare Alerts

Excess rate curve from QLA: 1.6.-10.8.2014



Mrk501 – Flare Alerts

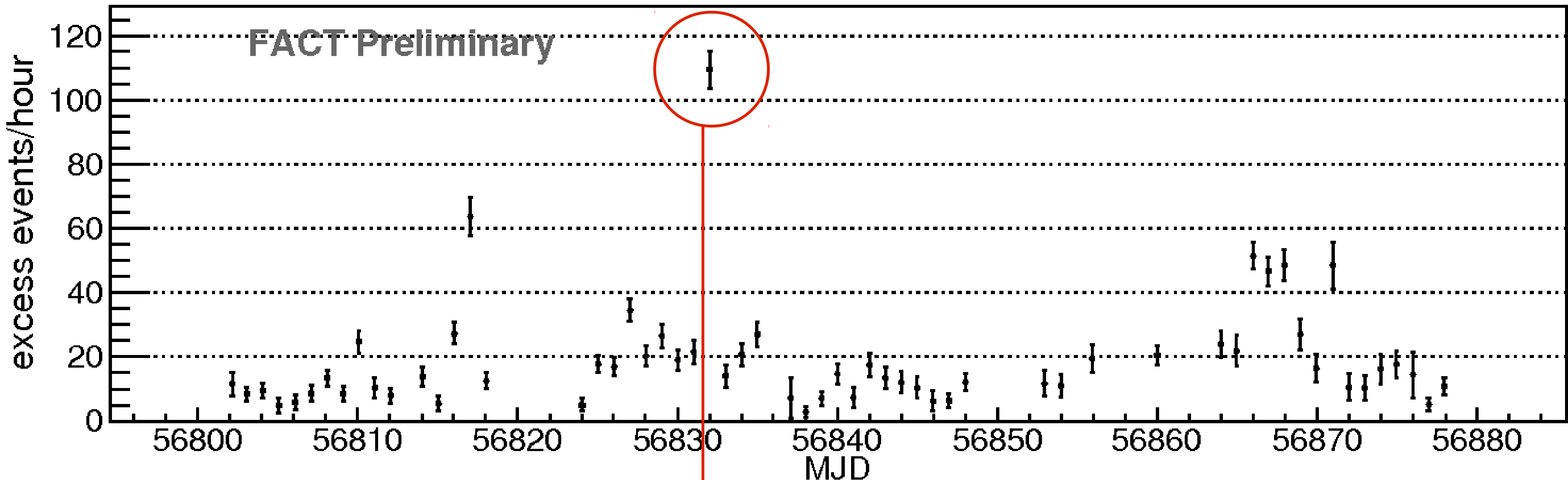
Excess rate curve from QLA: 1.6.-10.8.2014



→ Observations
with other instruments

Mrk501 – Flare Alerts

Excess rate curve from QLA: 1.6.-10.8.2014

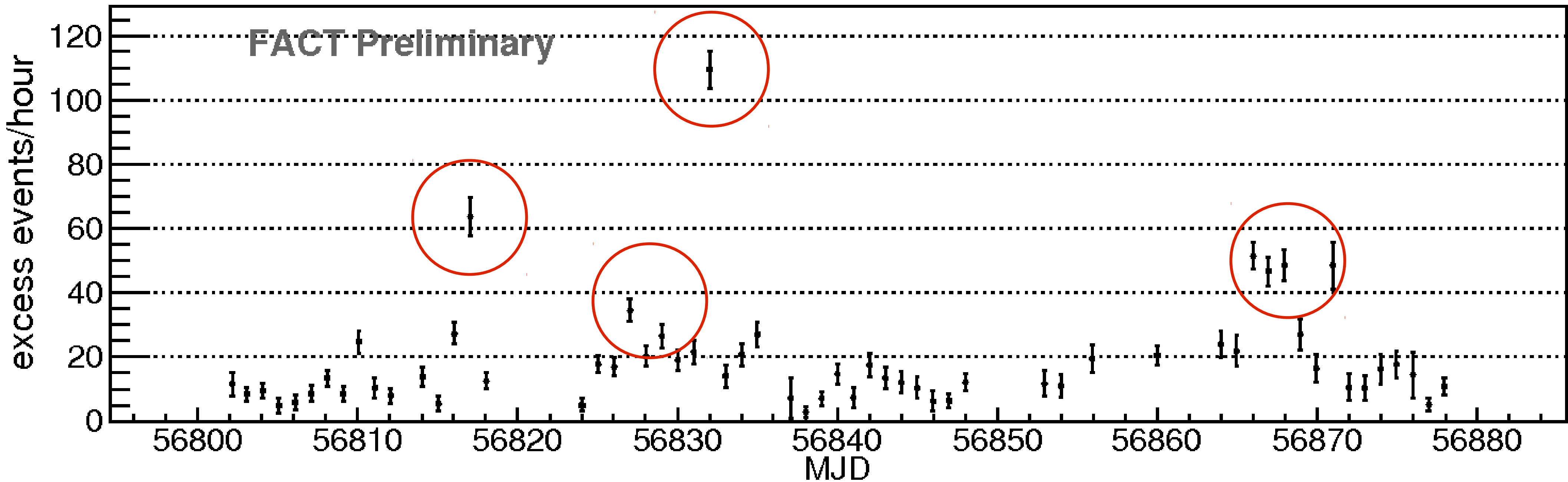


Flare Alert
23./24. Jun 2014

→ Atel #6268

Mrk501 – Flare Alerts

Excess rate curve from QLA: 1.6.-10.8.2014



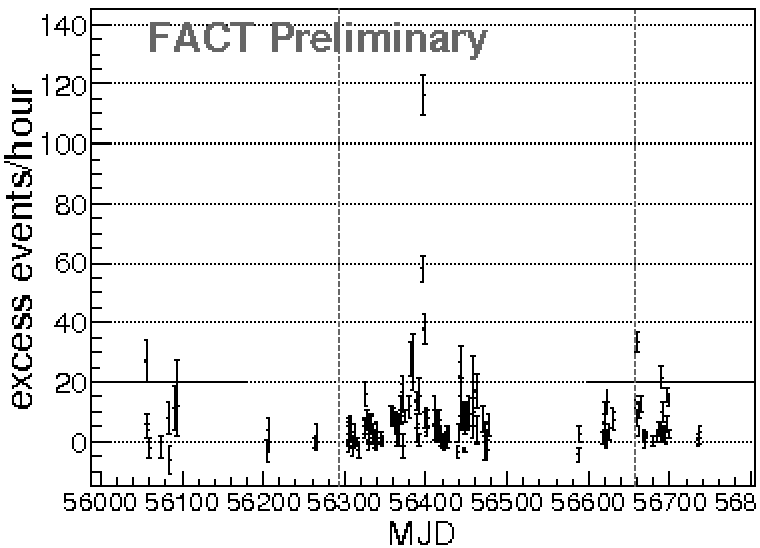
Several Flare Alerts
in Summer 2014

Summary and Outlook

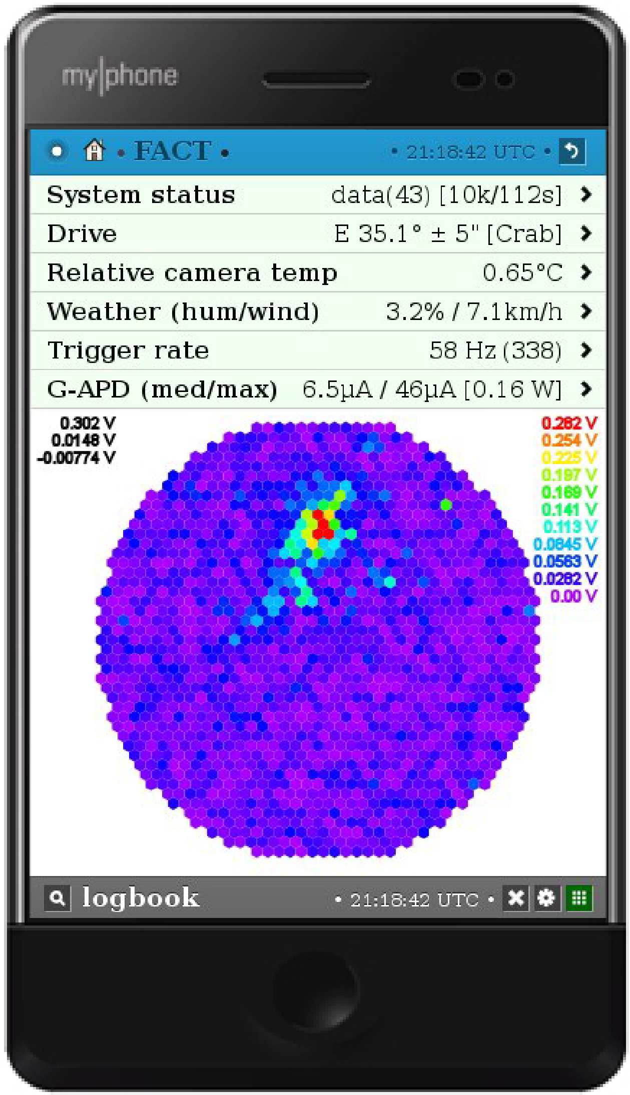
- First G-APD Cherenkov Telescope
  - Stable Performance → Remote and automatic operation
  - No aging → Observations during strong moon light
- Longterm monitoring of bright TeV blazars
  - Quick Look Analysis
    → Several flare alerts for Mrk501
    in summer 2014
  - Several flaring activities
    → MWL studies
  - Total observation time: > 3400 h (> 1600 h in 2013)
  - Complete data sample for variability studies
    e.g. > 1000h for Mrk501

Check out our monitoring results!

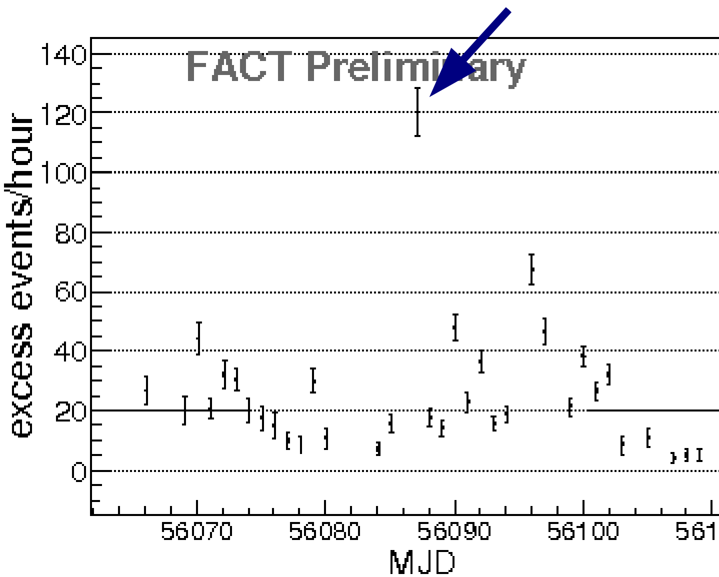
http://www.fact-project.org/monitoring



3 years monitoring



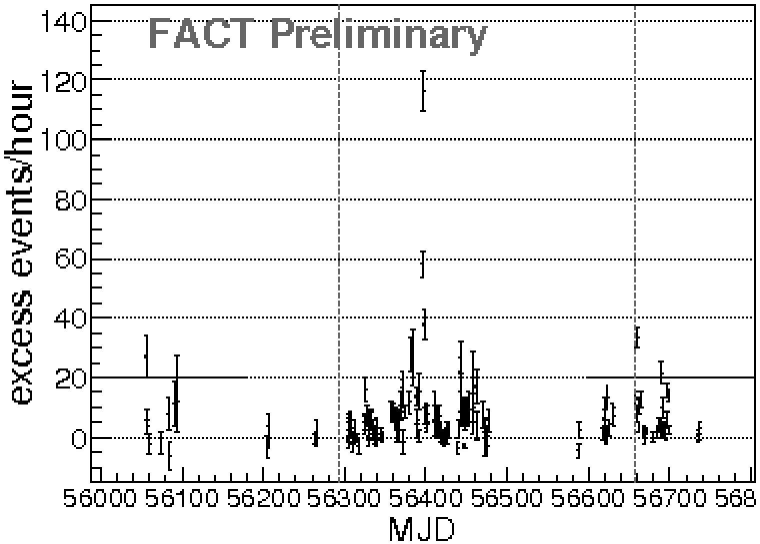
~5σ in 5min



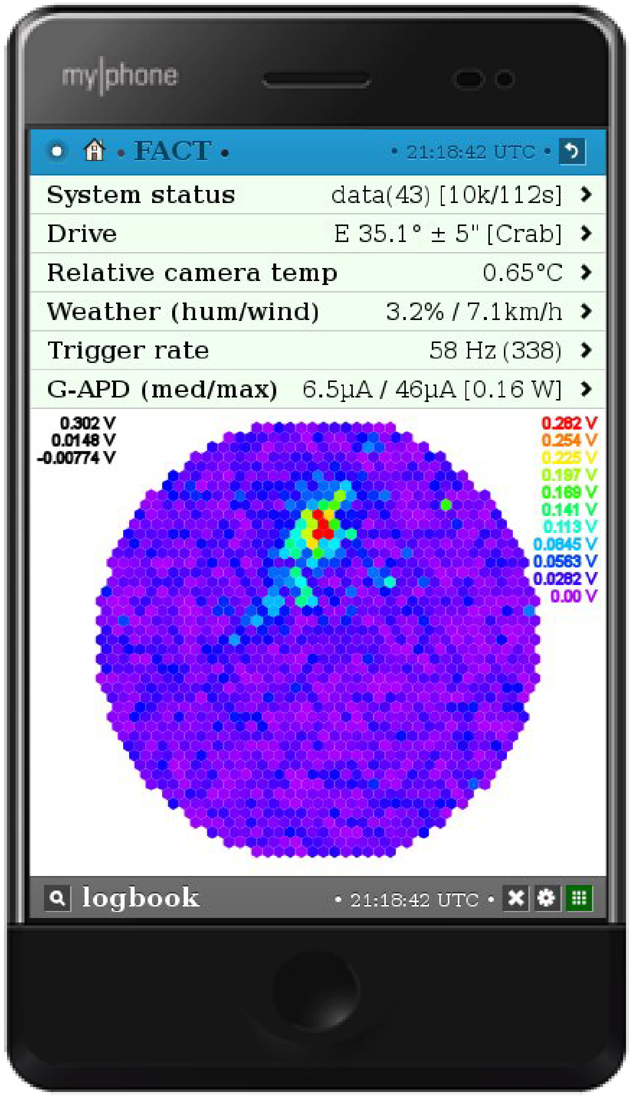
[JINST **8**(2013) P06008]
arXiv:1403.5747

Observing Night – **TONIGHT** from 21h

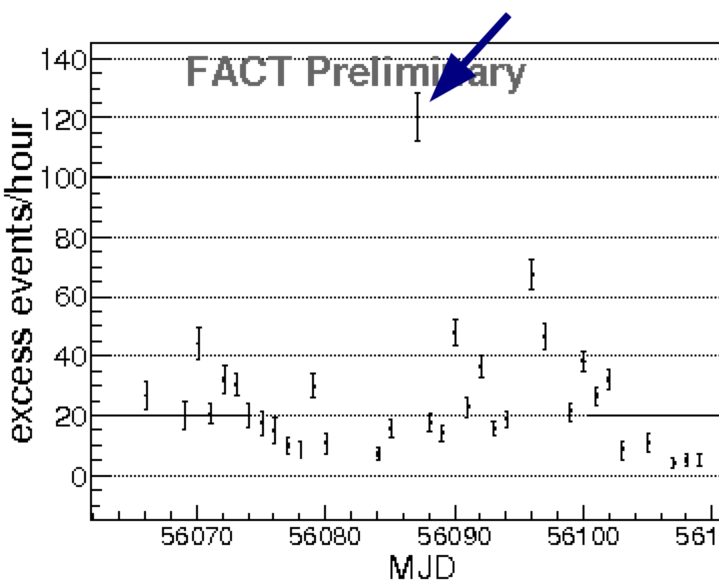
http://www.fact-project.org/smartfact



3 years monitoring



~5σ in 5min



[JINST **8**(2013) P06008]
arXiv:1403.5747