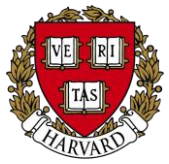


PANORAMIC SETI

Calibration of SiPM-based Cherenkov Telescopes for High-Energy Gamma Ray Detection

Yuriy Popovych









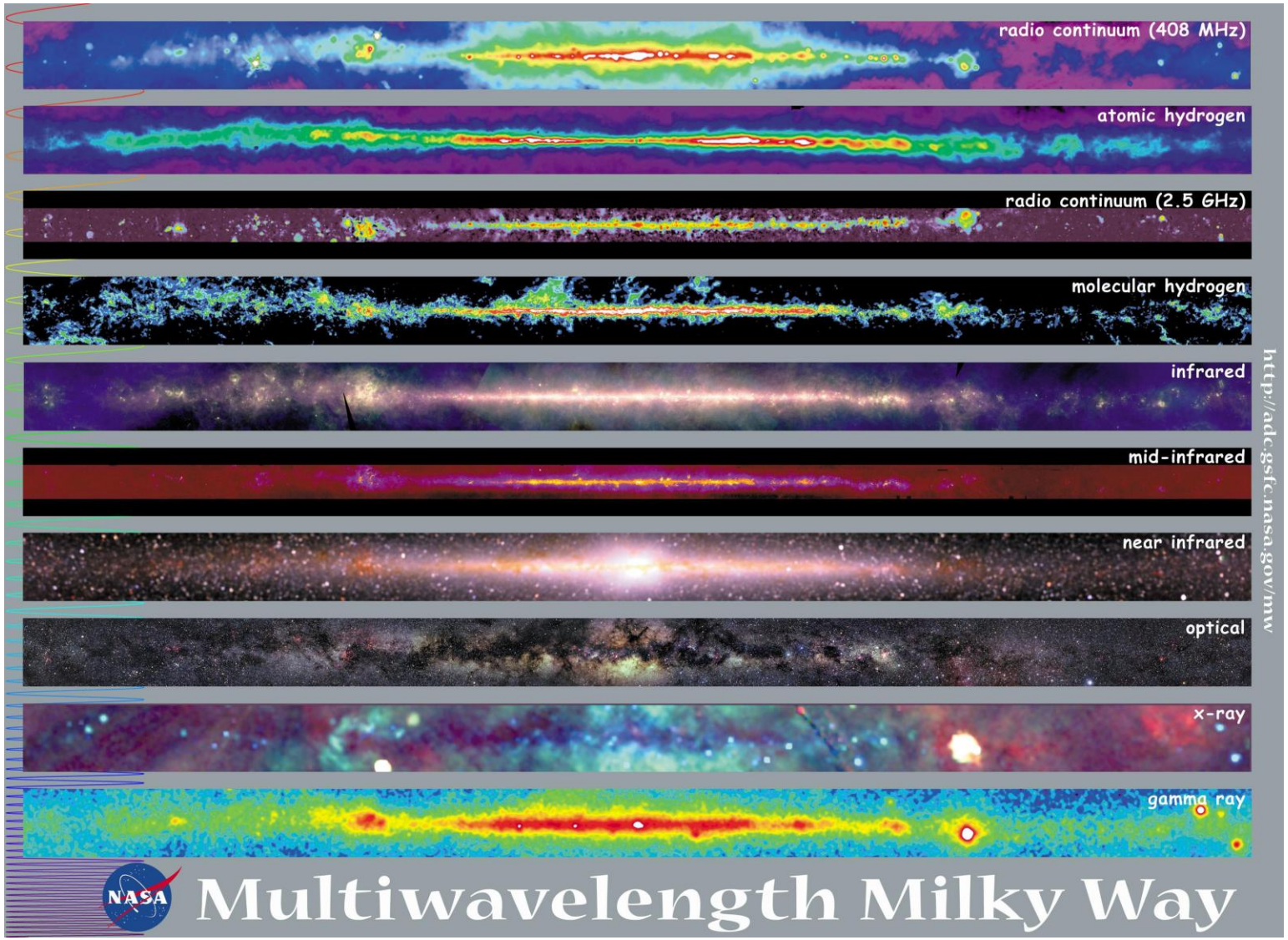






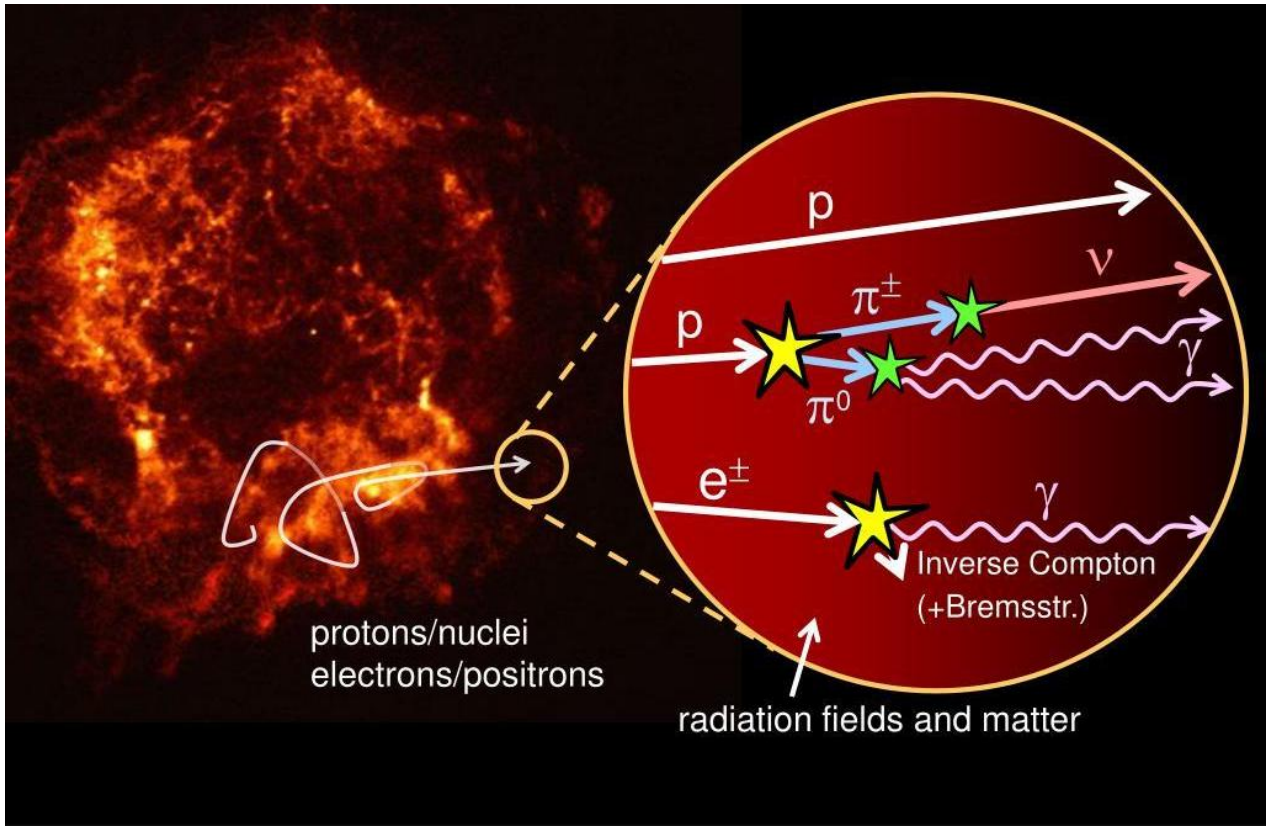
BERKELEY SETI
RESEARCH CENTER

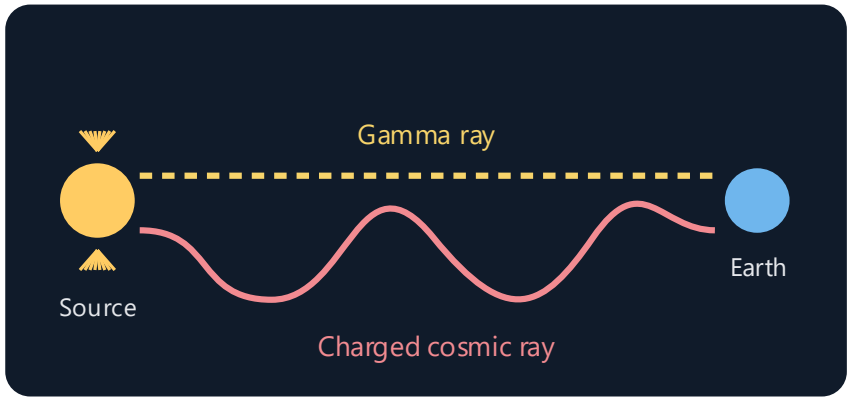
Multiwavelength Observations



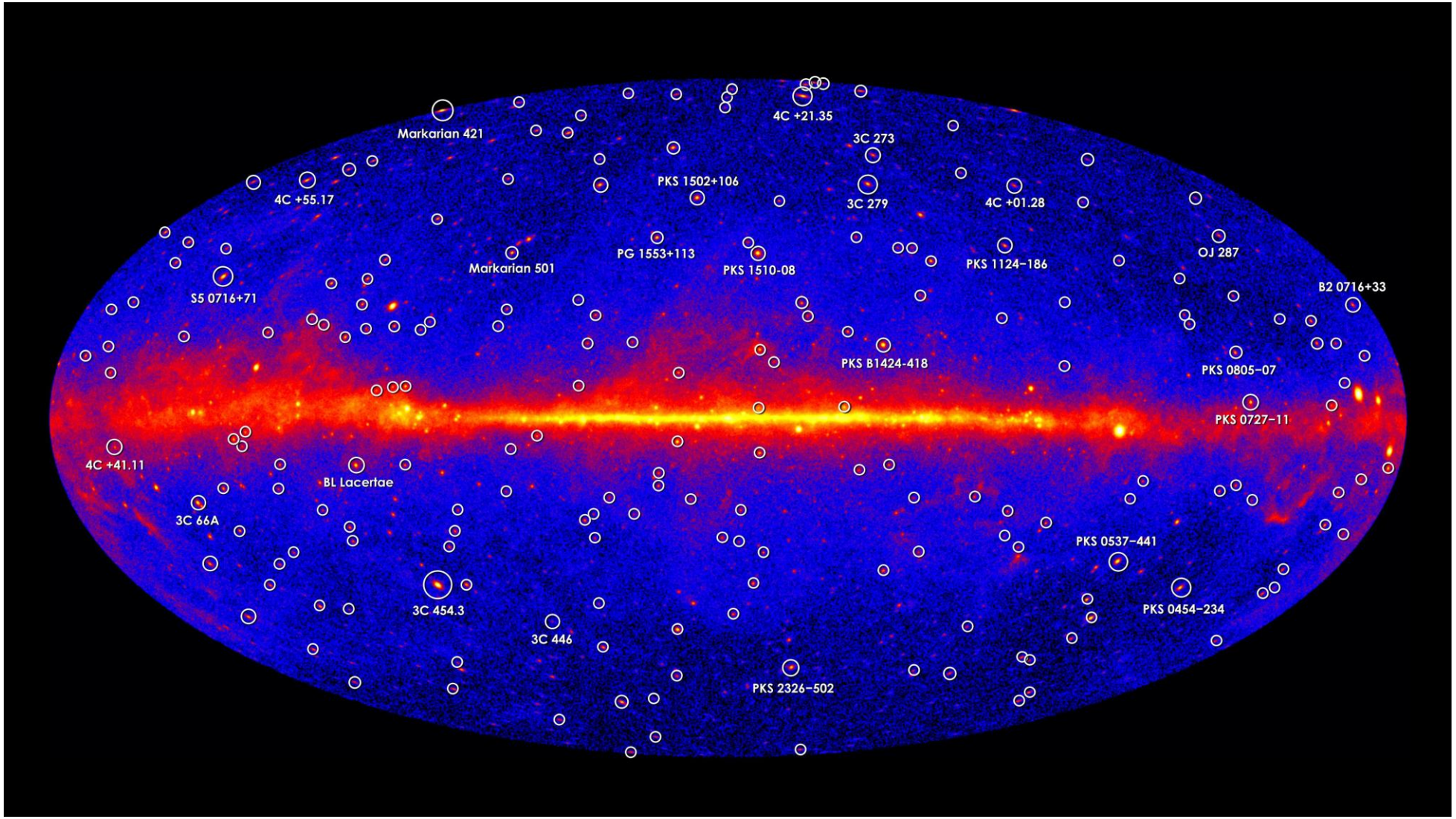
Gamma Rays

- Photons at very high energies (**GeV-PeV**)
- Production in Cosmic Accelerators through **hadronic** and **leptonic** processes
- Tracing detected particles back to their source





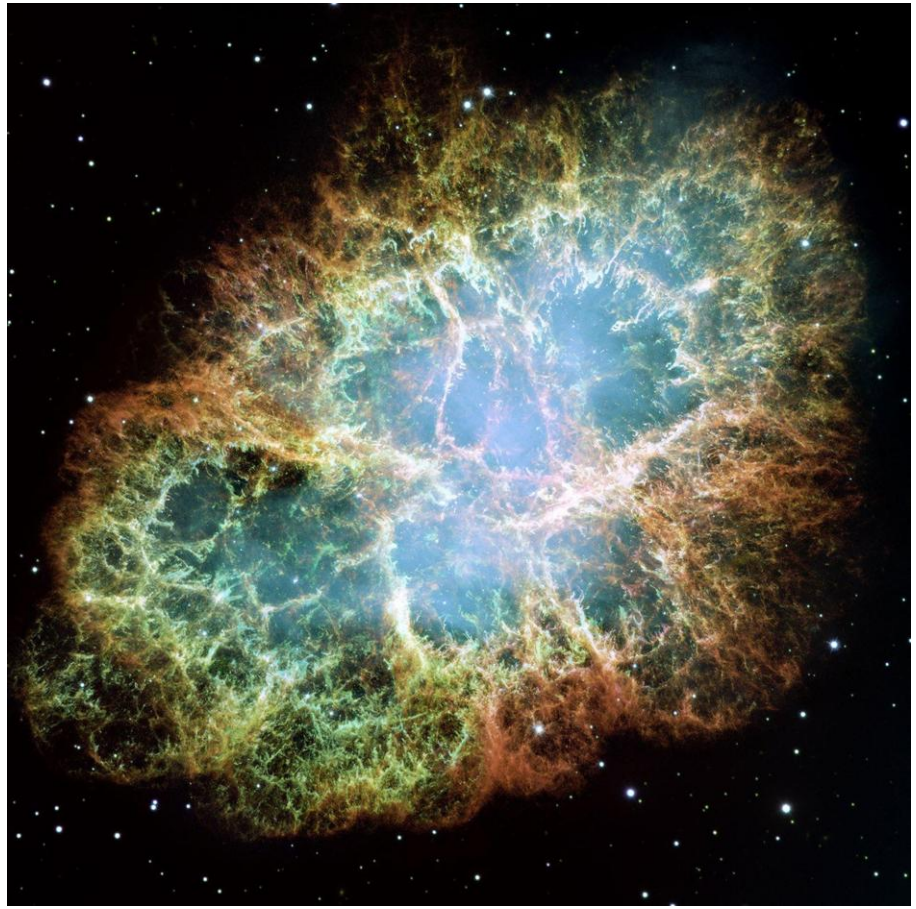
The Gamma Ray Sky



Famous Gamma Ray Sources

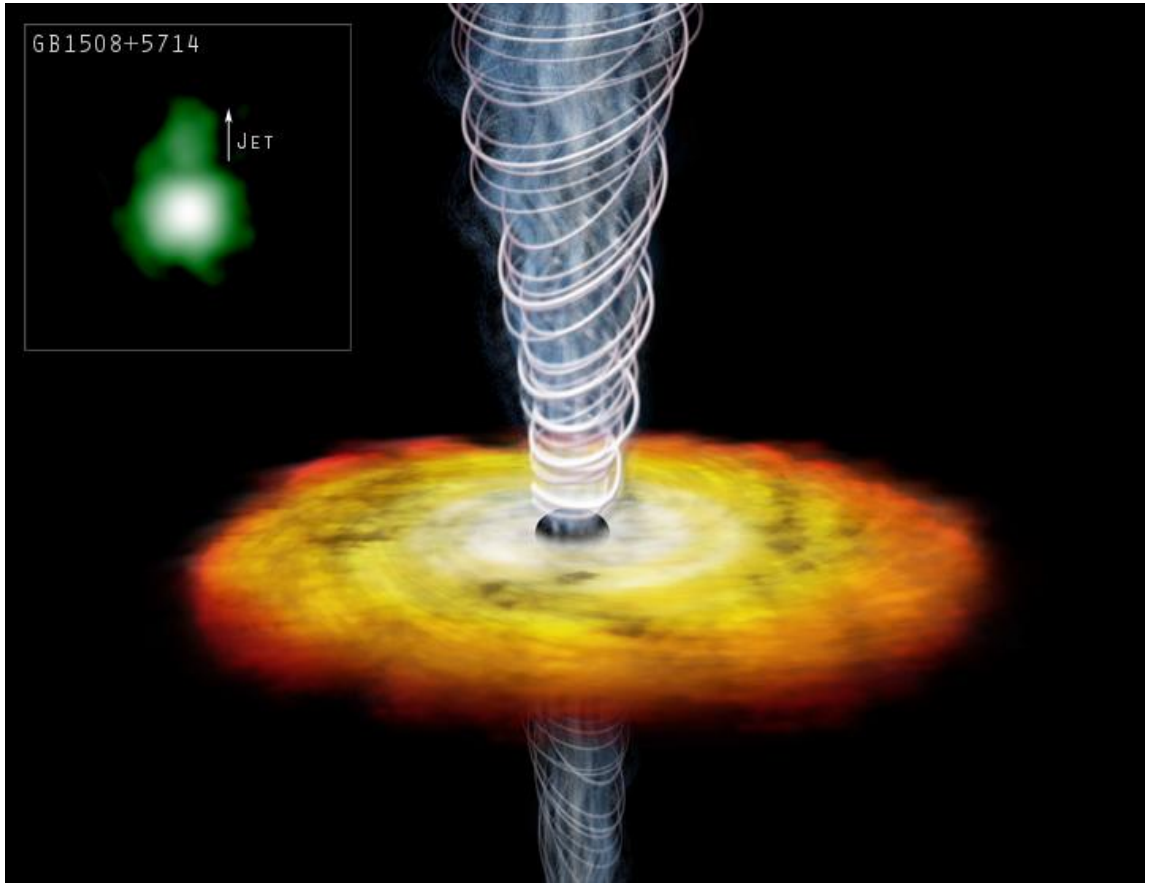
Crab Nebula

(Distance: ~ 6500 ly)



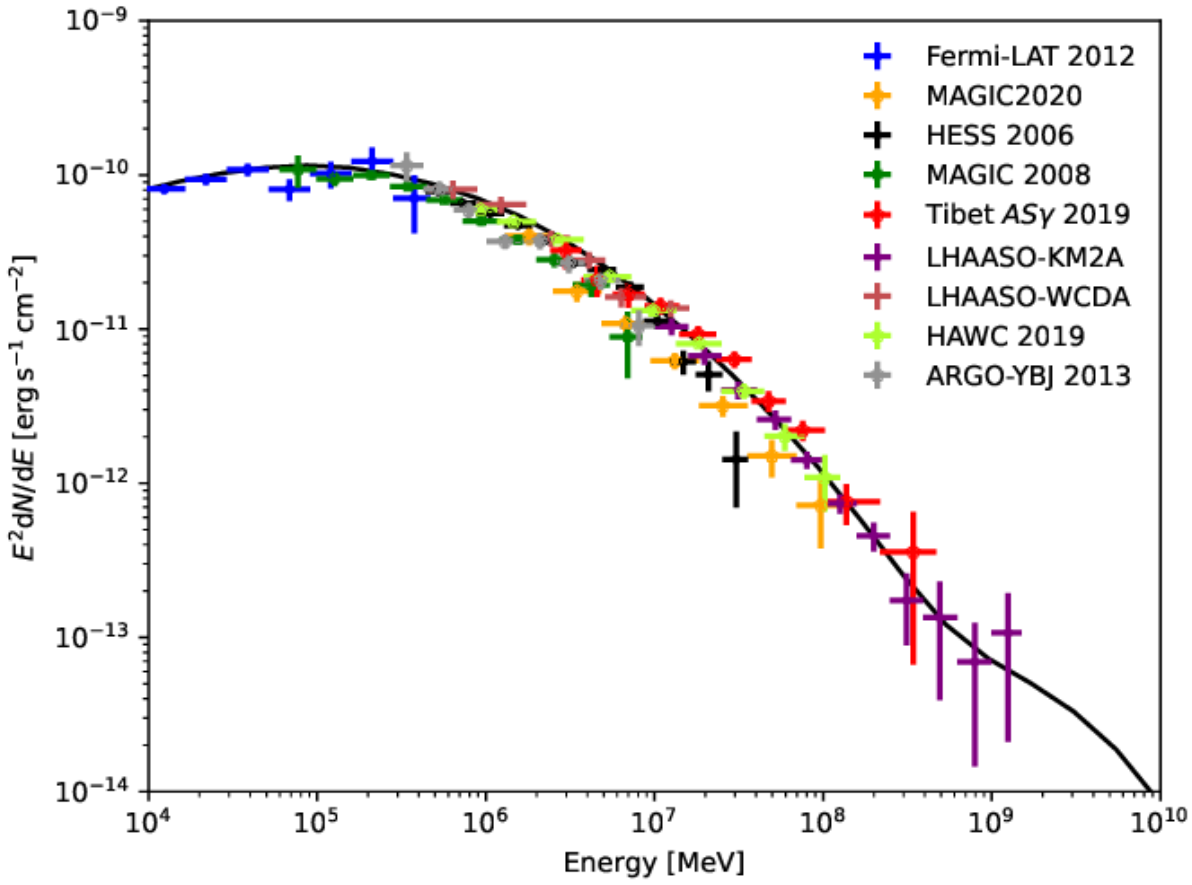
Mrk 421

(Distance: ~ $402 \cdot 10^6$ ly)

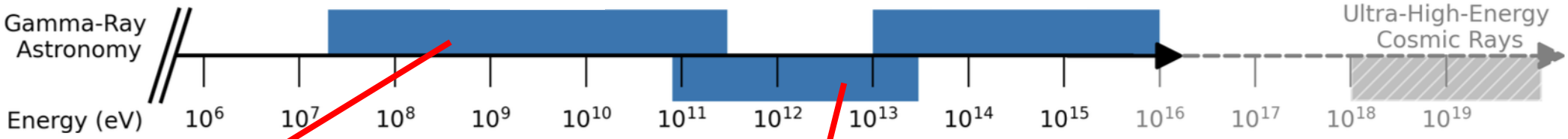


Gamma Ray Spectrum (Crab)

- Energy spectrum of Crab Nebula taken by different experiments
- Gamma rays up to **PeV** energies
- Follows power-law $\boldsymbol{\phi \sim E^{-\gamma}, \gamma \approx -2.6}$
- Extremely low flux at very high energies



Gamma-Rays



High Energy (100 MeV – 100 GeV)

- Space for high-altitude ballons (e.g. Fermi-LAT)



Very High Energy (30 GeV – 100 TeV)

- Ground based Experiments
  - IACTs (VERITAS, MAGIC, HESS)
  - Close-packed particle detector arrays (HAWC, Tibet Asγ)

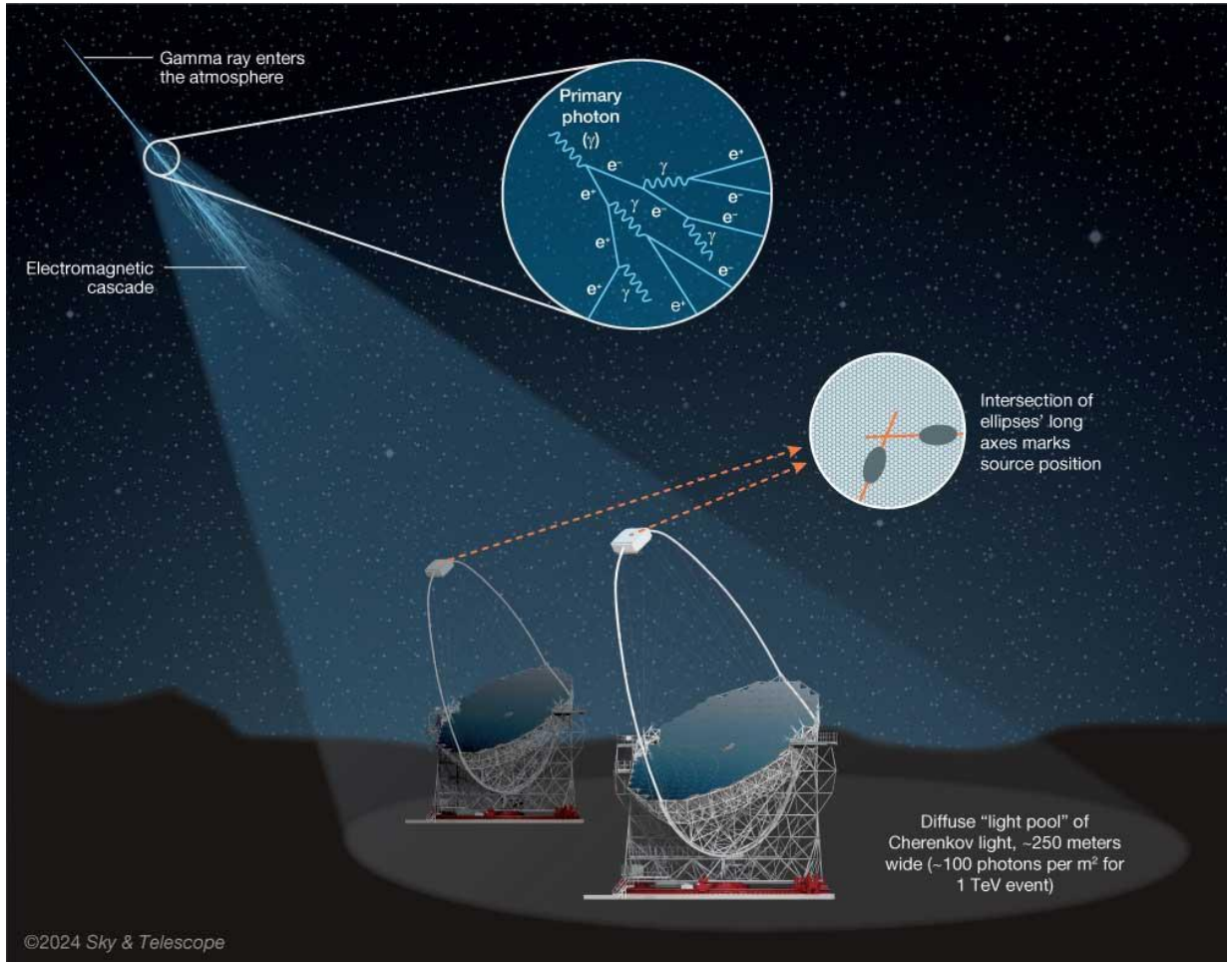




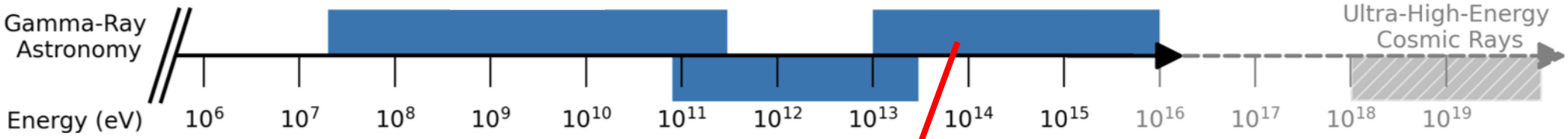


Imaging Air Cherenkov Telescopes (IACTs)

- Extensive air shower produced by primary particle
- Air-Cherenkov cone from charged secondary particle
- IACTs within cone see shower from different sides
- Triangulation to localize source

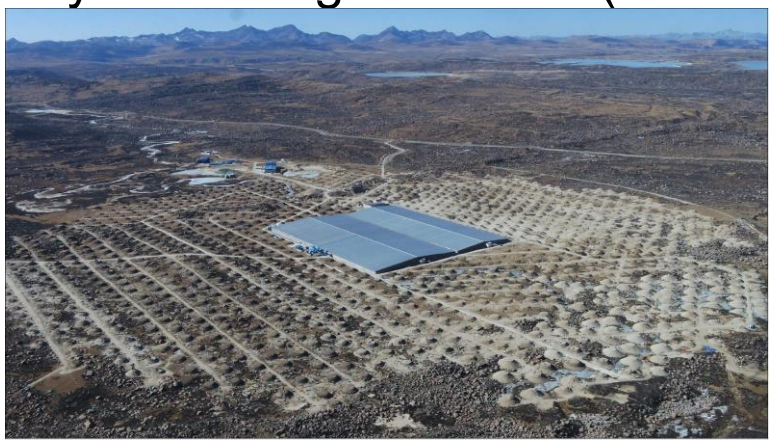


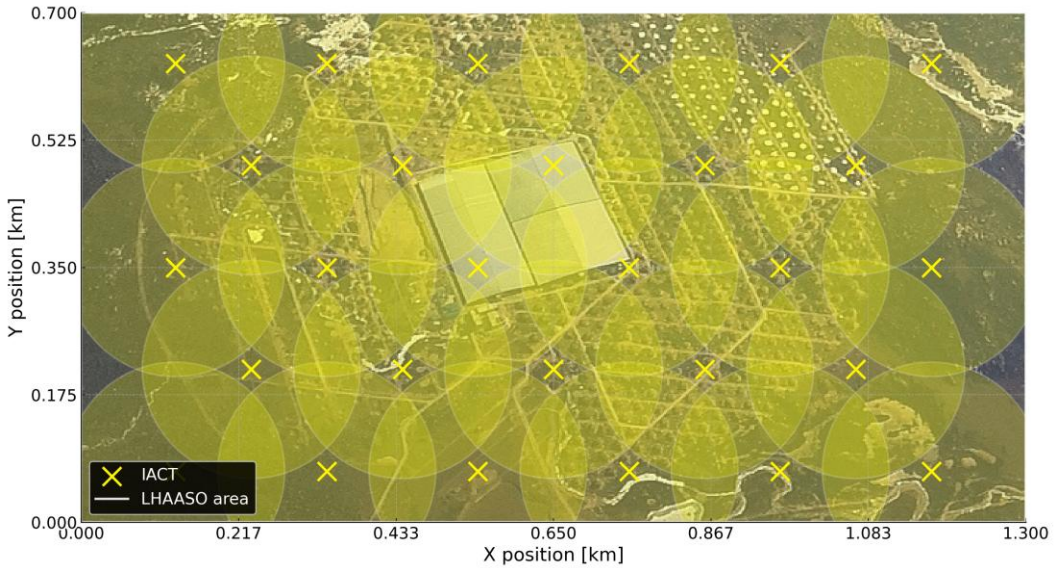
Gamma-Rays



Ultra High Energy (10 TeV – PeV)

- Very low flux and large extended air showers
- Ground based experiments
  - Wide-spaced particle detectors (LHAASO)
  - IACT arrays with long baselines (**PANOSETI**)





PANOSETI - Outline

1. Instrumental Design and Operations

2. Calibrations and Lab Measurements

3. Data Processing and Analysis



PANO SETI

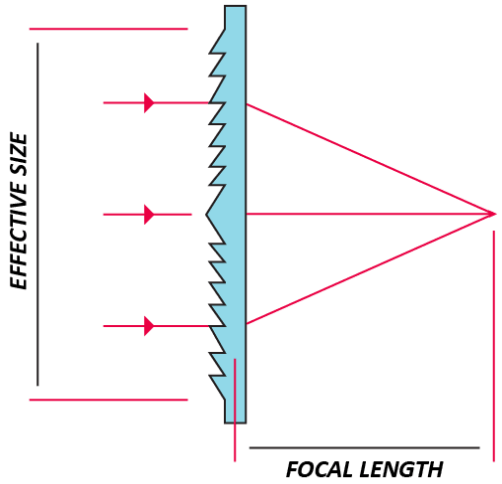
Instrumental Design and Operations

PANOSETI Telescope

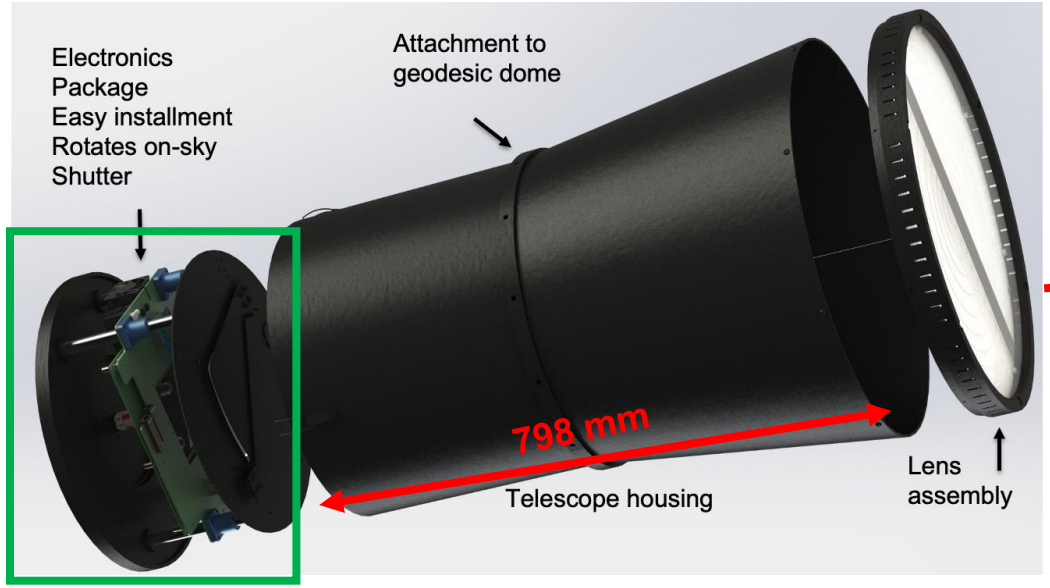




- **Fresnel lens:**
  - 0.42 m diameter
  - 1.8 mm thickness
  - Focusing light on camera based on incident angle
  - Covered by plexiglass

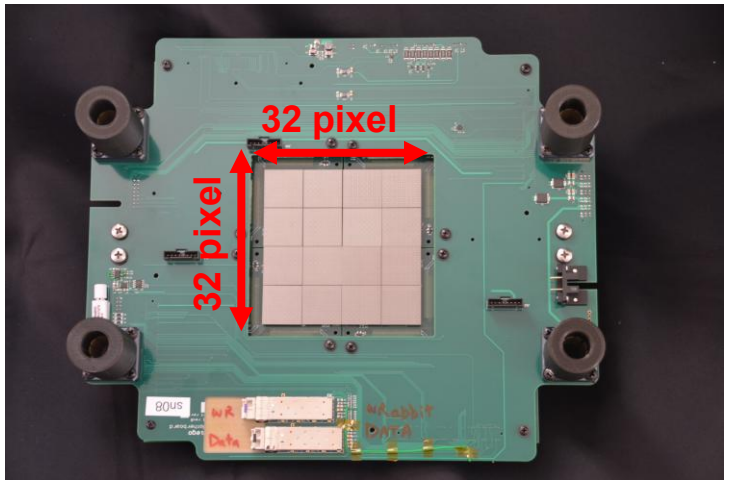


PANOSETI Telescope

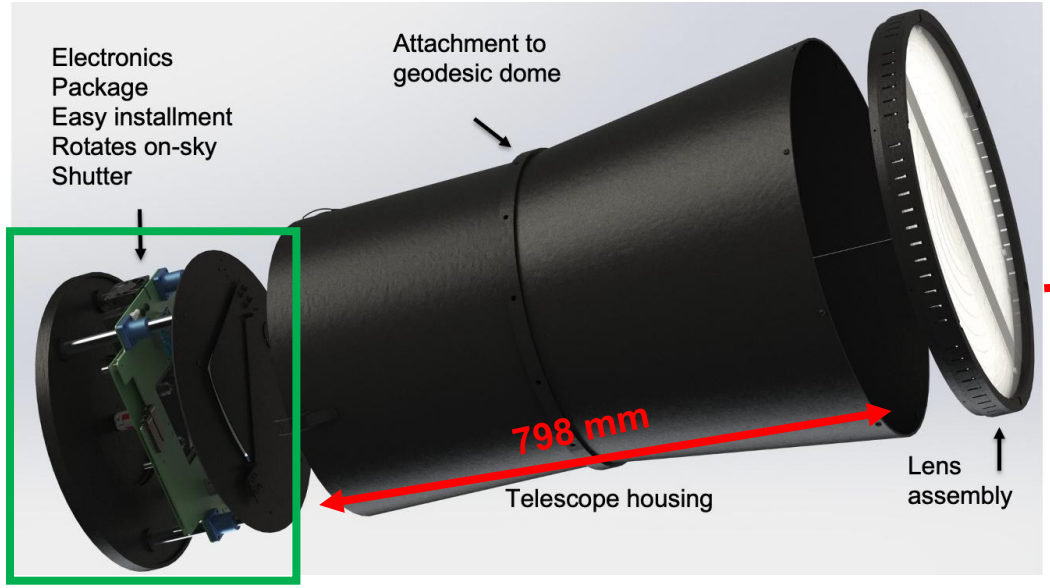




- **Camera:**
  - 4 x 4 SiPM arrays with 8 x 8 pixels each
  - 32 x 32 pixel in total
  - Field of view: 10° x 10°
  - Angular size: 0.31° per pixel

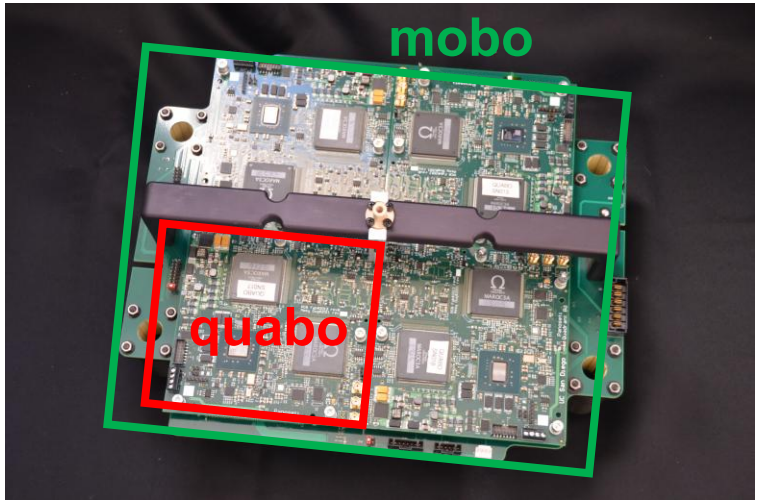


PANOSETI Telescope



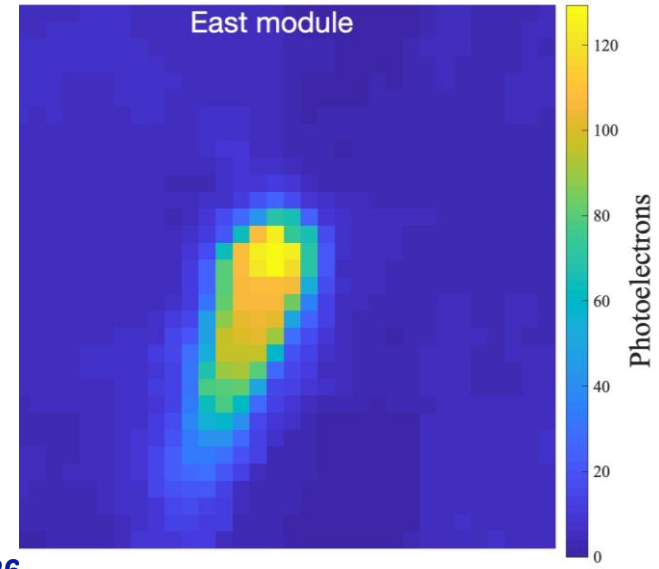


- **Readout:**
  - Group into 4 quadrant boards (**quabos**)
  - Readout and digitization via Maroc3A chips
  - Quabos mounted on Mother Board (**mobo**)

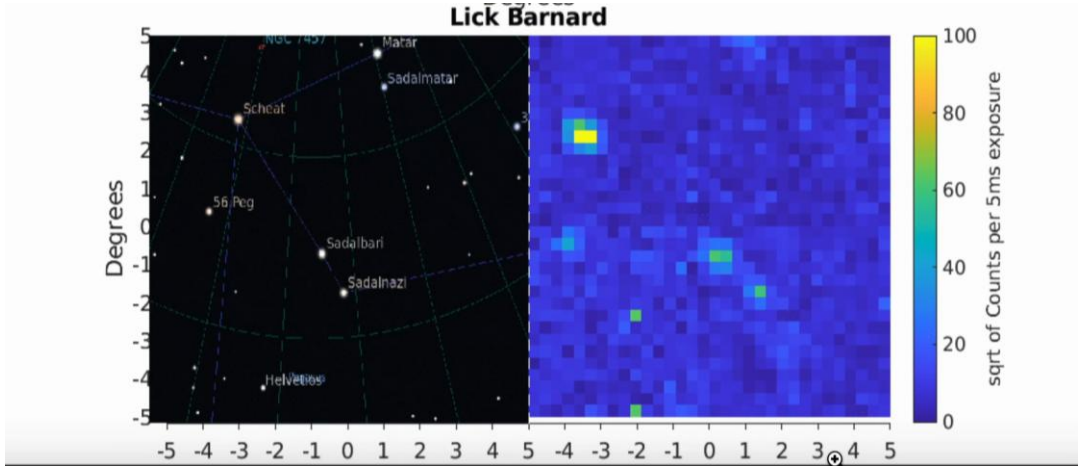


Operation Modes

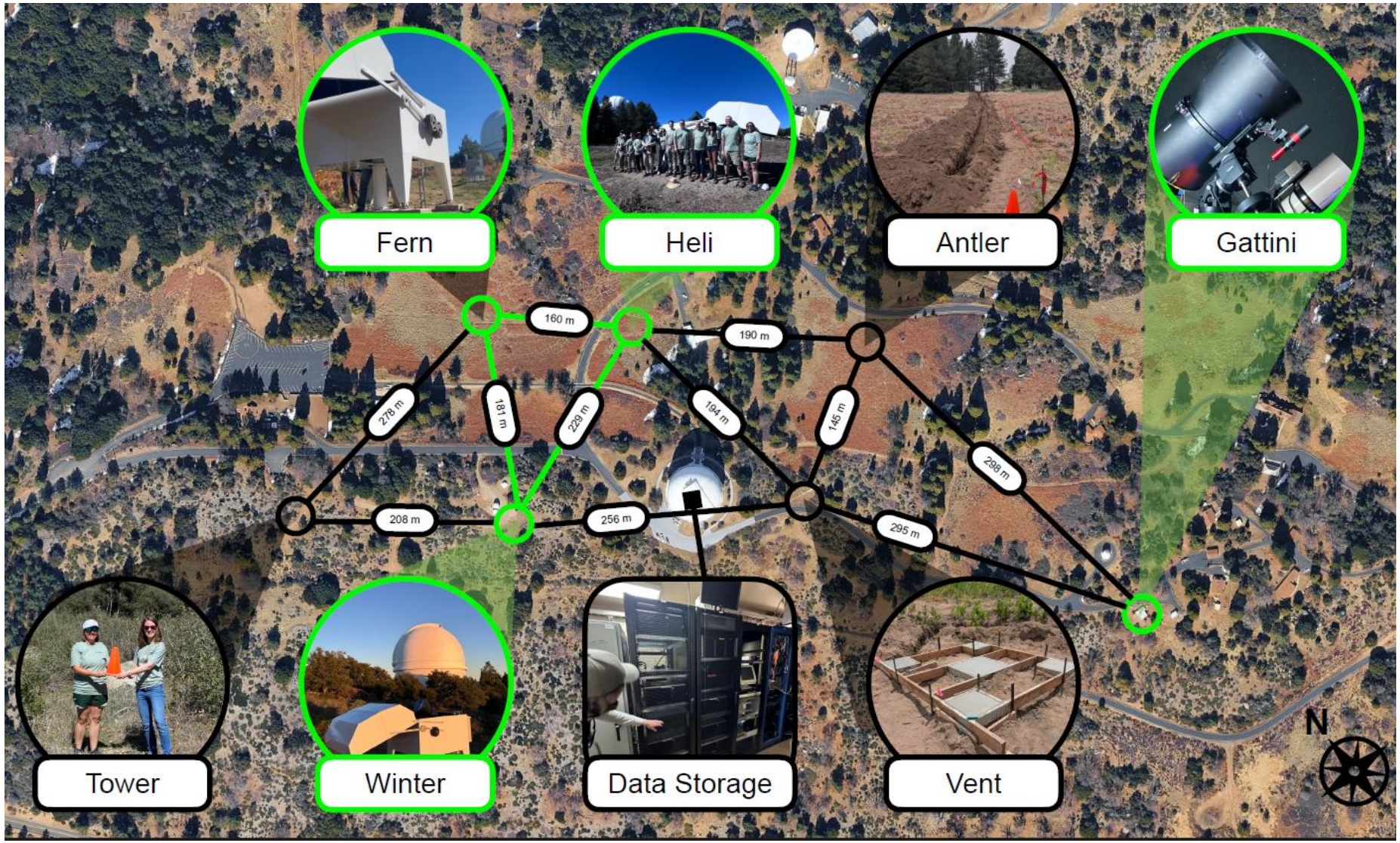
- **PH-Mode**
  - Read out frame of full camera if trigger condition is met (2 pixel on same quabo above set Photo-Electron (PE) threshold)
  - Record single triggered events
  - ns timescale



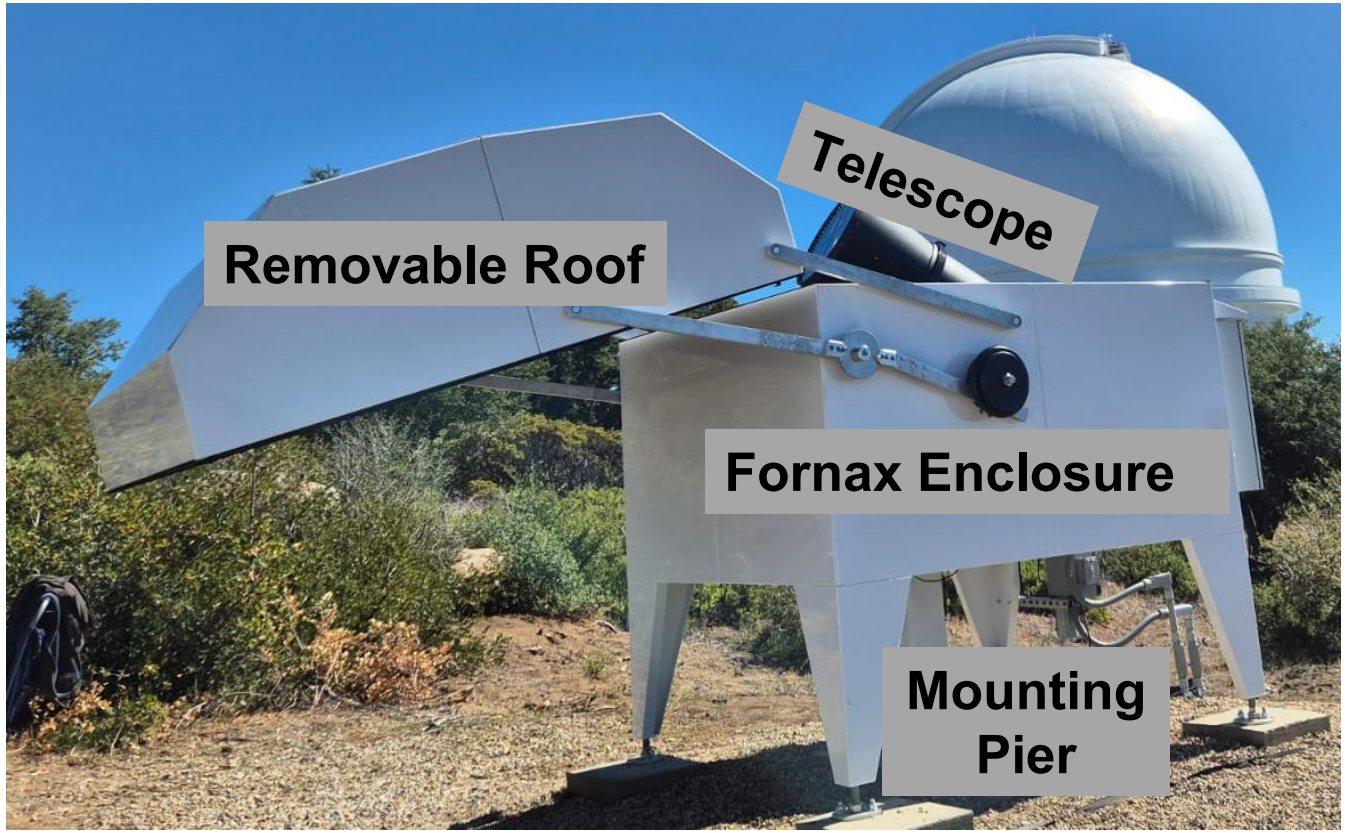
- **Imaging-Mode**
  - Count number of triggers per pixel over set exposure time
  - Record video of sky with set frame rate (given by set exposure time)
  - µs – s timescale

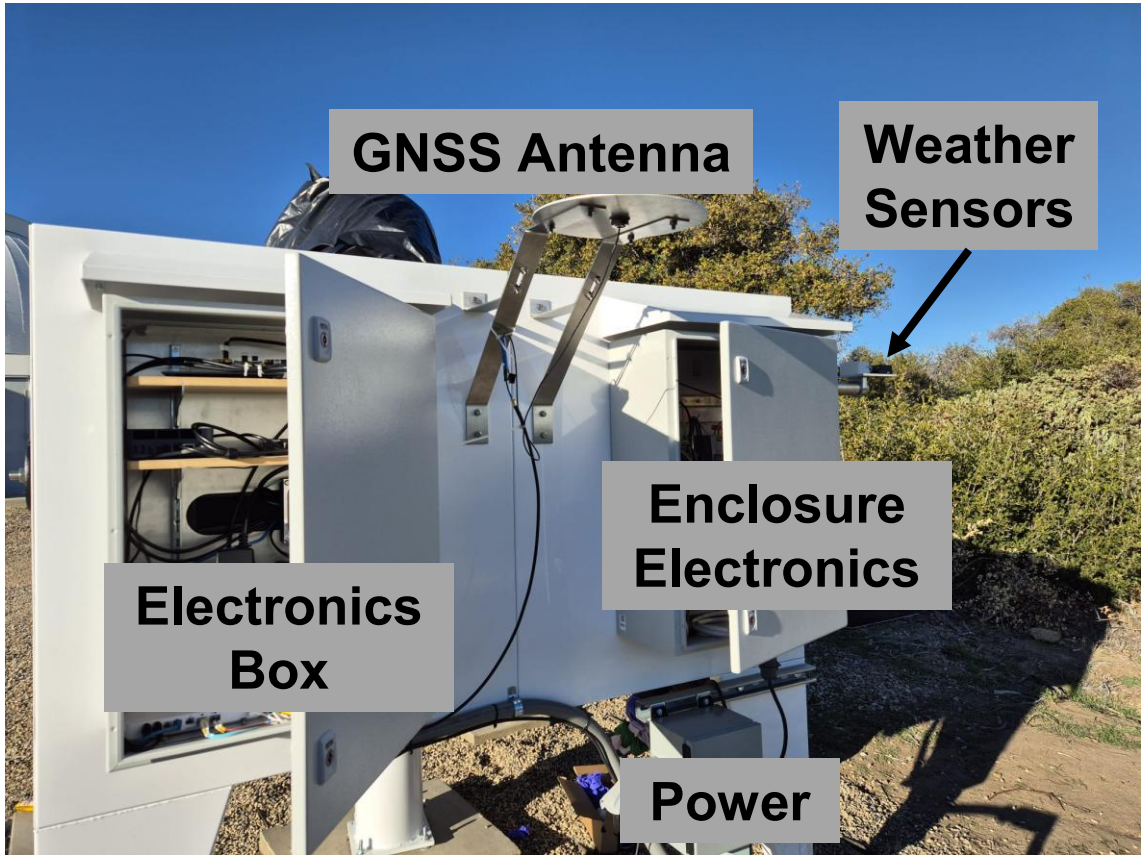


Palomar Observatory



PANOSETI Site



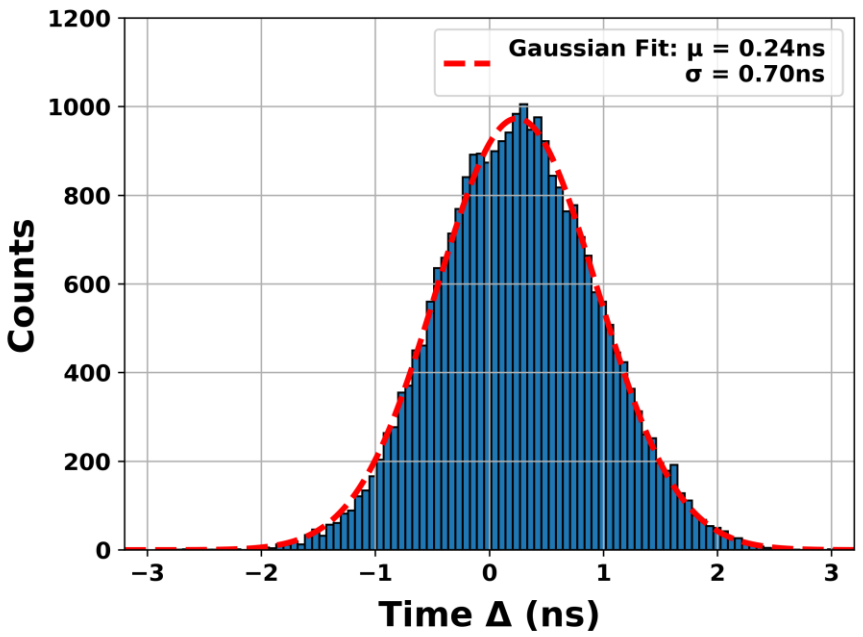


Timing with GNSS



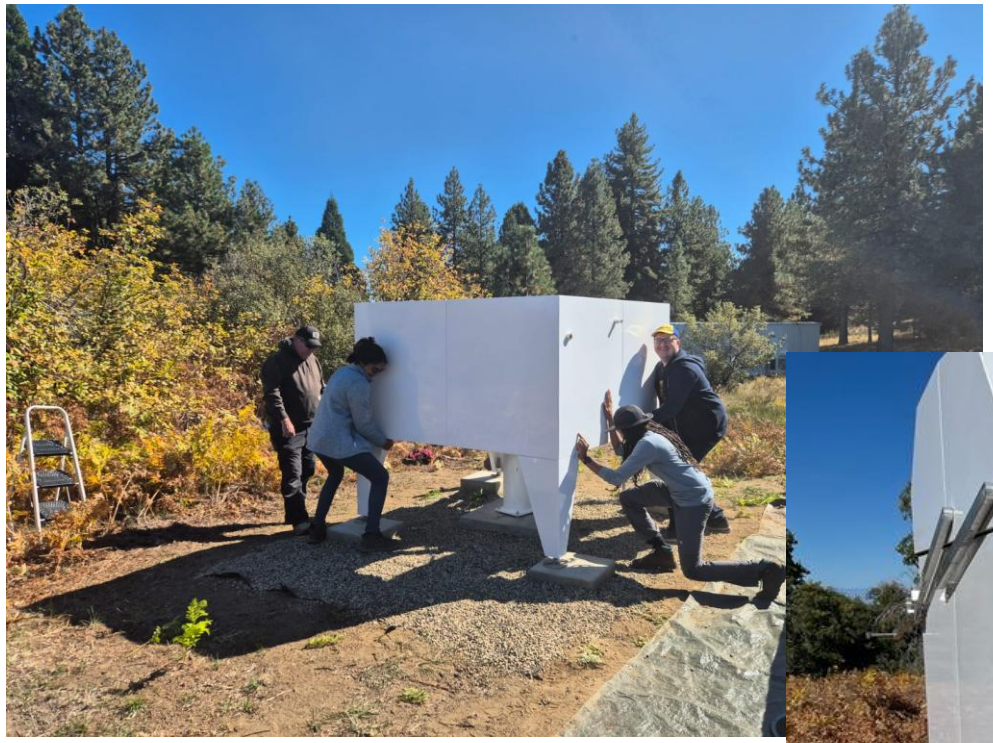
- Localization of GNSS antennas
- Receive high precision timing signals from GNSS satellites (1 Hz and 10 MHz)
- Runtime differences between sites calibrate absolute clock for all telescopes
- Absolute timing for coincident Cherenkov events

- **Precision of ~0.7 ns**



2 antennas at 800 m distance

Deployment and Observations



Setting up Enclosure



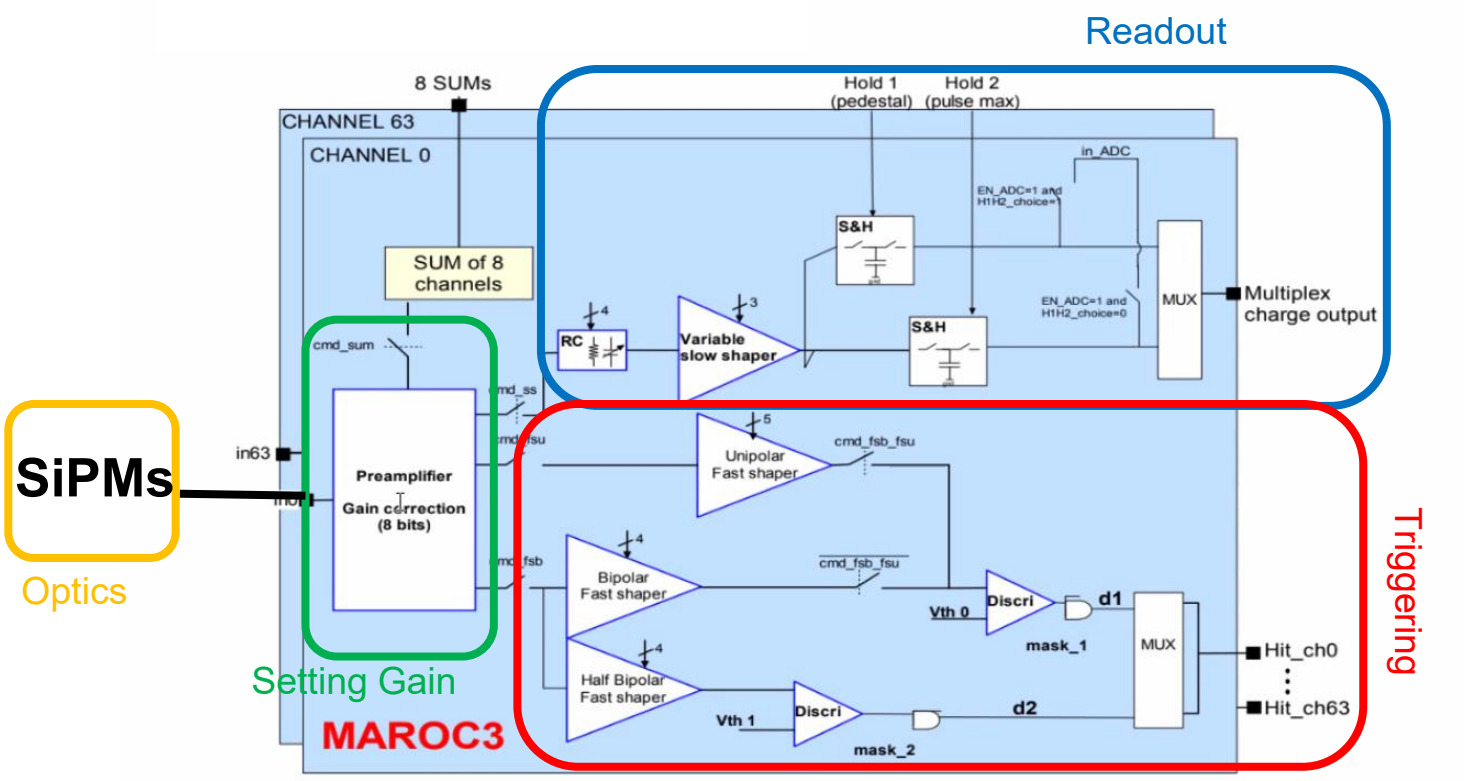
Installing Power

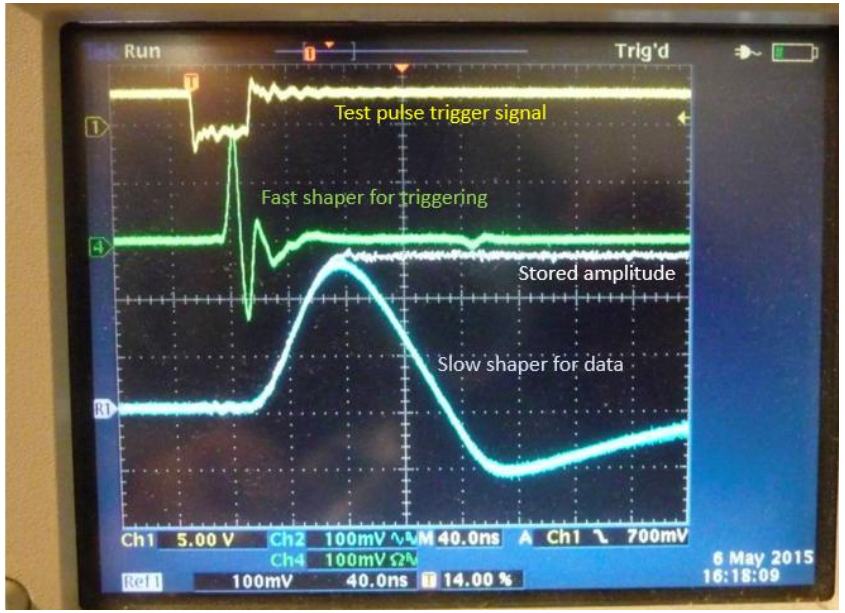


PANO SETI

Calibrations and Lab Measurements

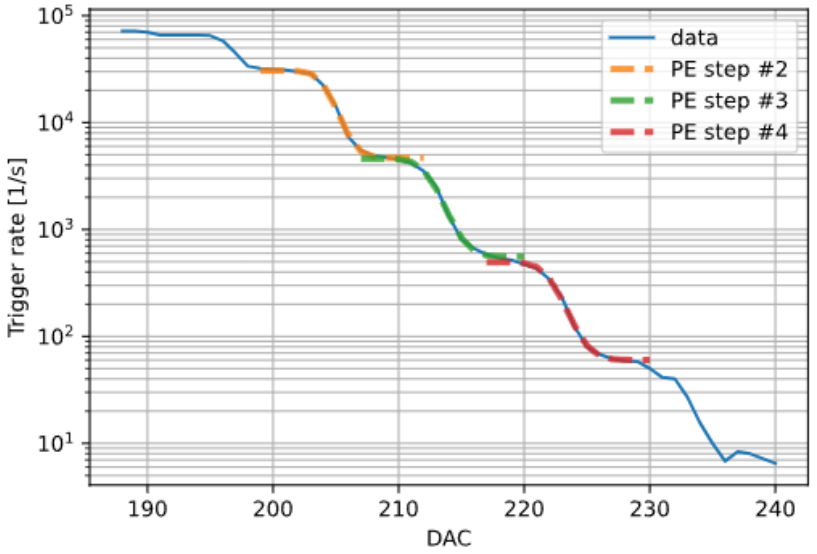
Signal Processing

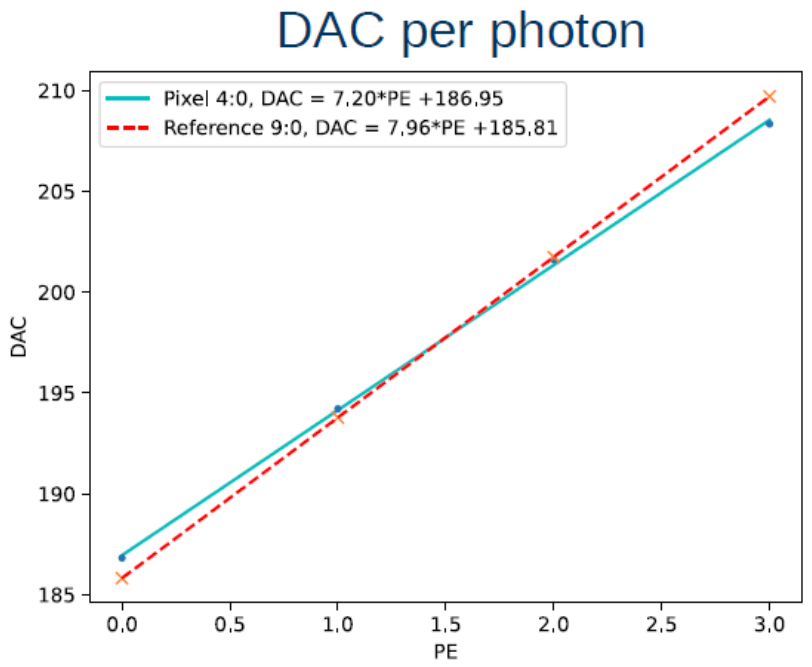




Trigger Calibration

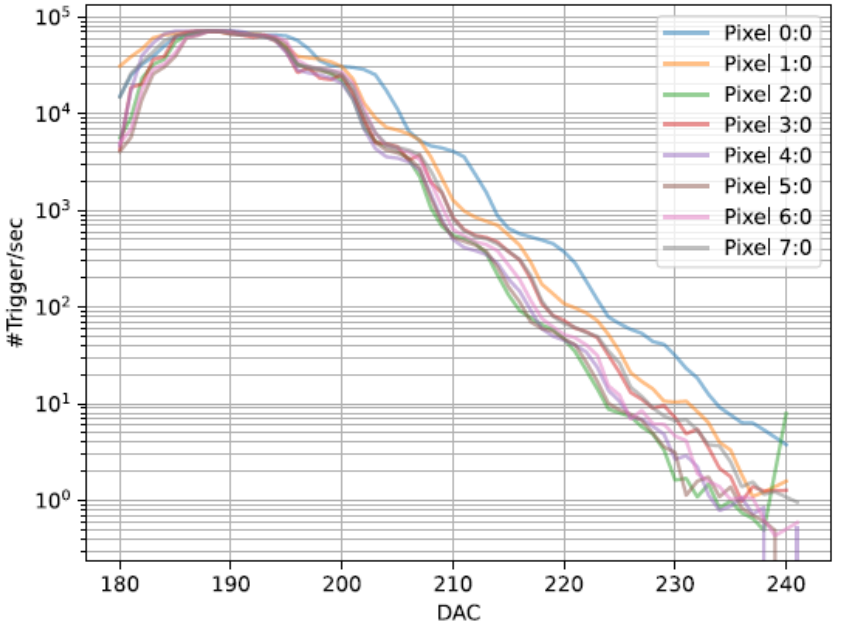
- Threshold set in DAC counts
- DAC scan measuring Dark Rate trigger frequency
- Localizing steps
- Linear fit for DAC to PE calibration

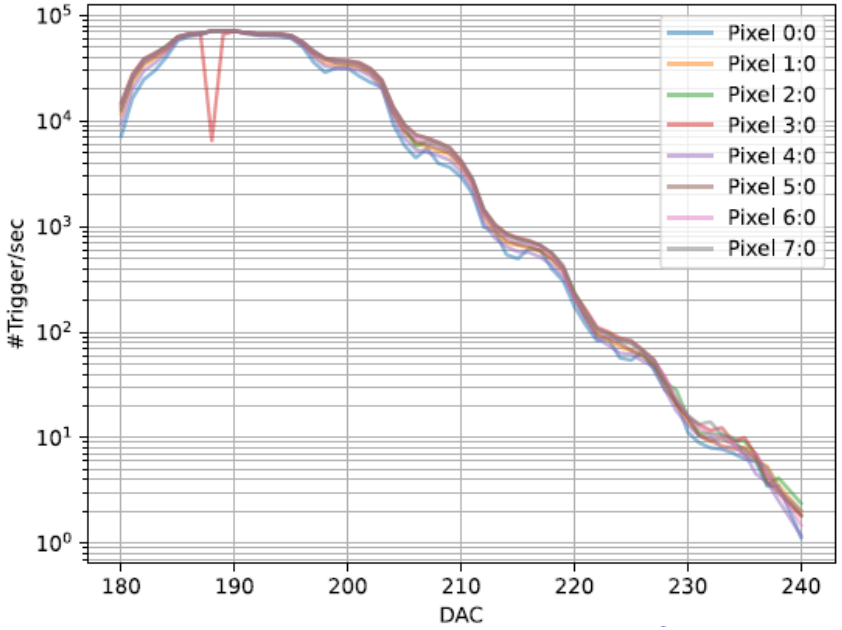




Trigger Calibration

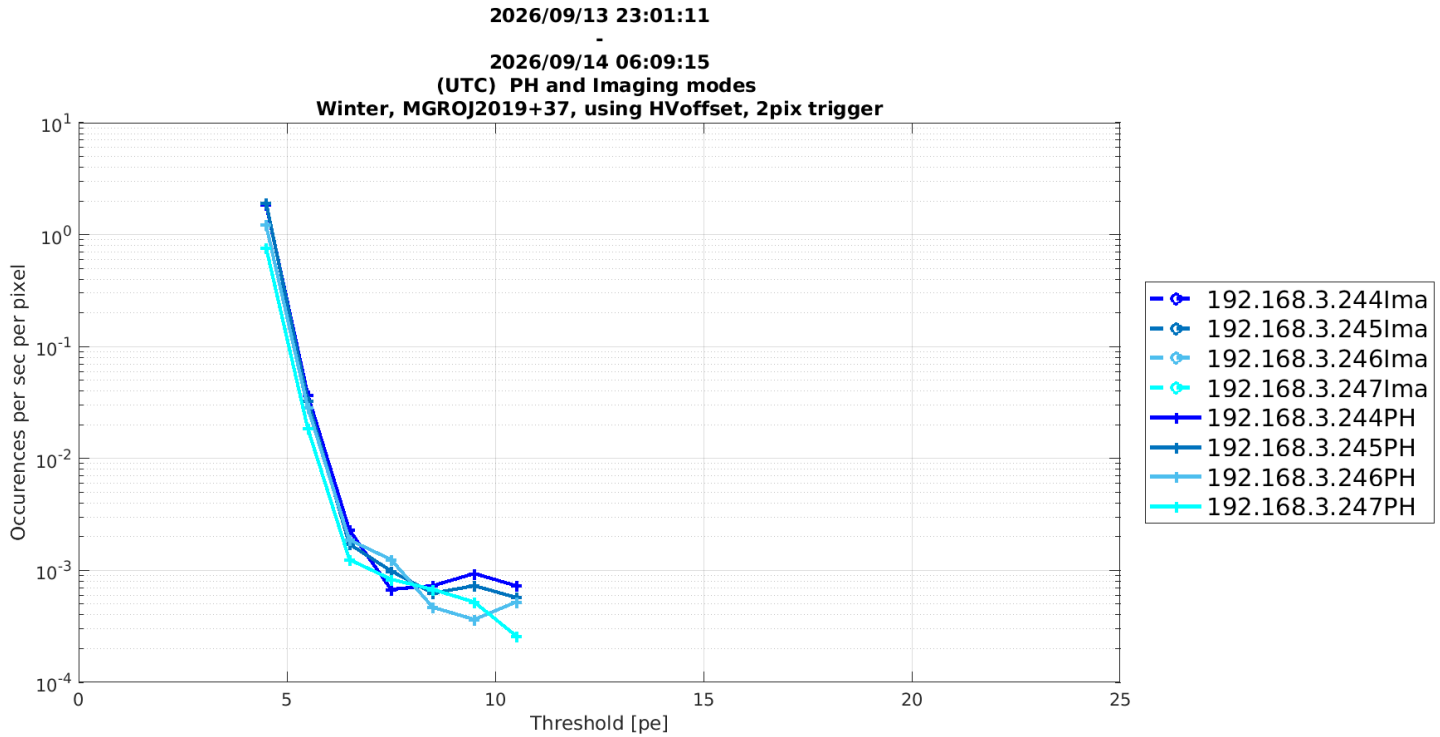
- Adjustable (pre-amp-)Gain for each pixel
- Set gain for the trigger scan curves to overlap
- Same trigger sensitivity for every pixel





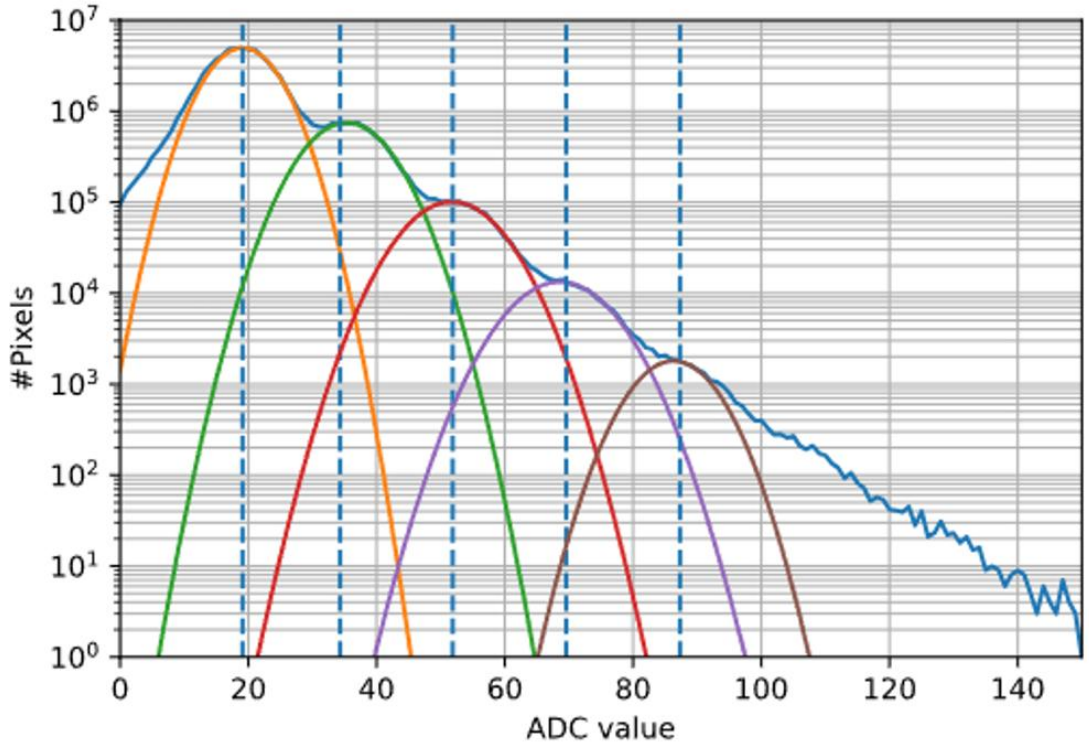
Bias Curves

- Determine optimal trigger threshold for observations
- 2-pixel trigger: 2 pixel on same quabo above threshold
- Set trigger just above NSB noise level



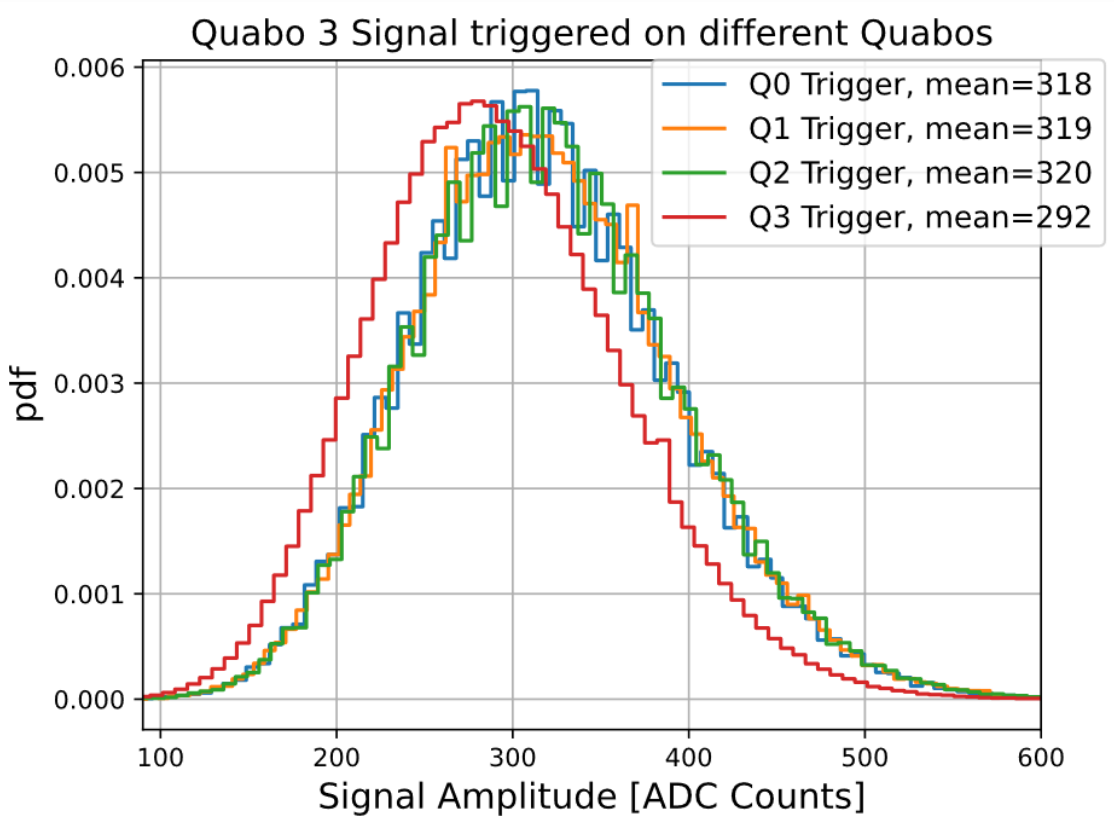
ADC to PE calibration

- SPE spectrum from Dark Rate
- Gaussian fits
- Linear fit for ADC calibration
- Plan for flatfielding with flashers



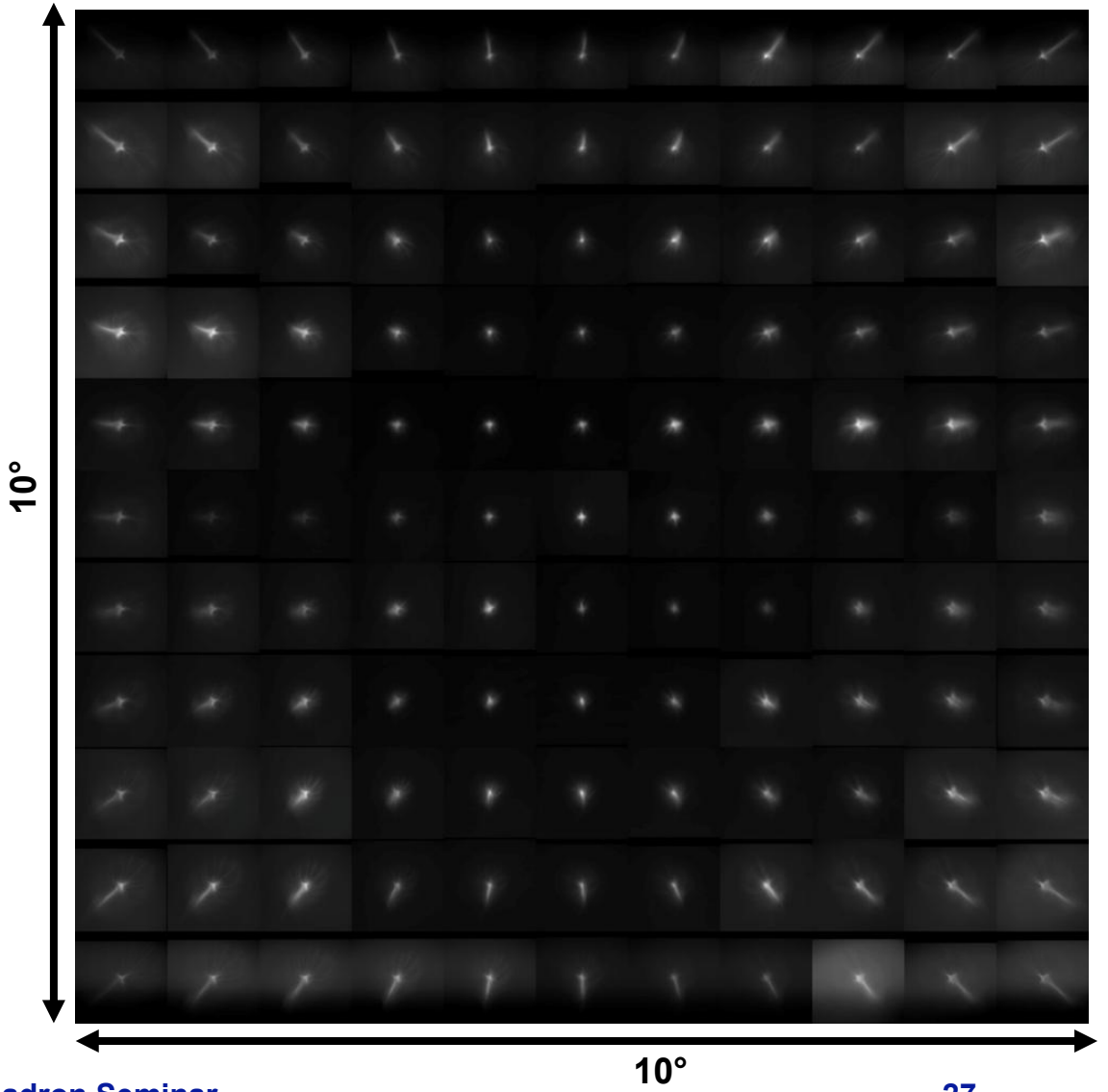
Flatfielding Camera

- Isotropic light source shining on telescope
- Comparing height if triggered and untriggered quabo
- Shift in time of ~10 ns results in ~10% amplitude change



Point Spread Function (PSF)

- Measuring PSF of lens along 10° x 10° FoV
- Want to have source at center of camera
- Additional uncertainty on source position

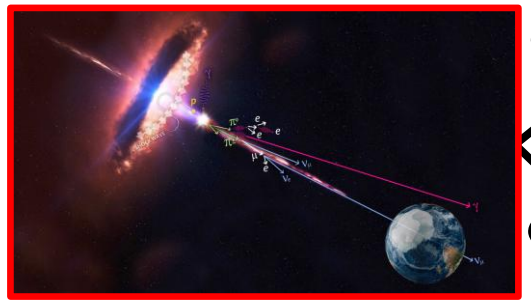


PANO SETI

Data Processing and Analysis

Gamma-Ray Analysis

Astrophysical Source

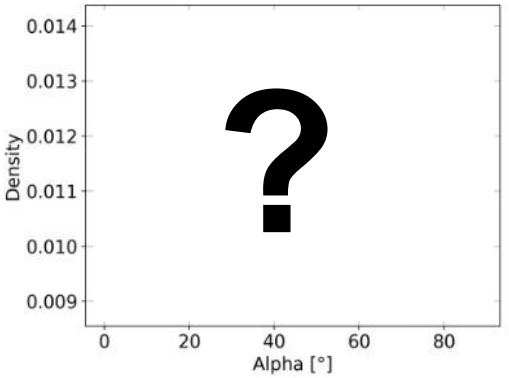


Observation



Processing and Analysis

Quality Cuts, Image Cleaning, Gamma-Hadron Separation, …



Simulation

Simulating Air-Showers

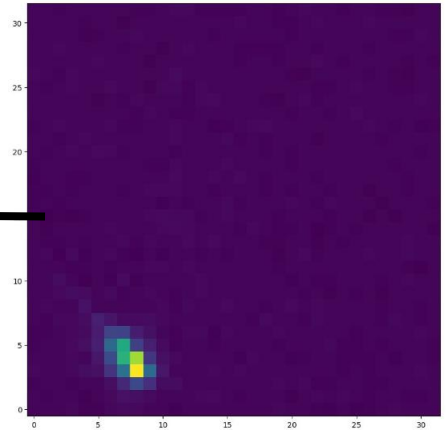
CORSIKA

Atmosphere + NSB

Array

Telescope Simulation

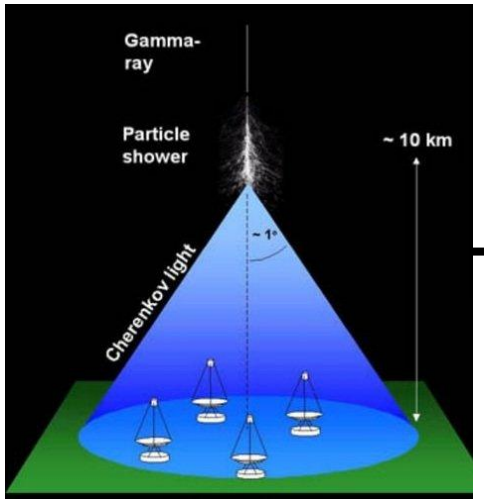
Simulated Telescope Data



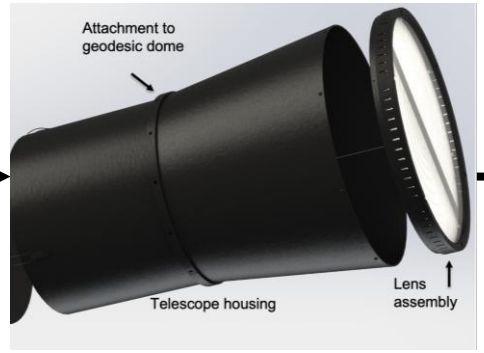
Telescope Simulation

for each telescope

Telescopes in Cherenkov Cone

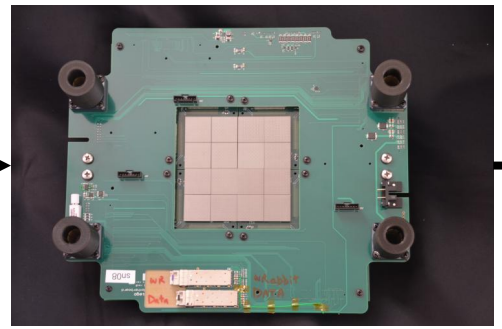


Telescope Aperture (Lens, Housing, ect.)



PSF/focusing of lens/housing

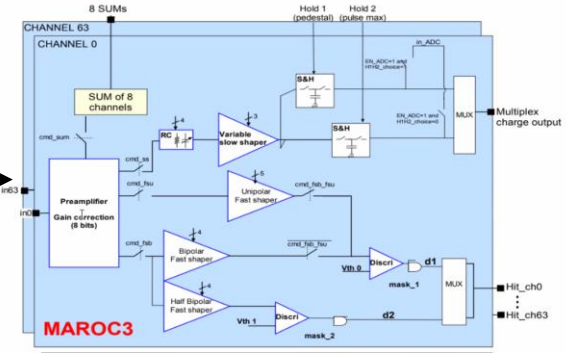
Event in camera



Calibration of Trigger and Readout

for each pixel

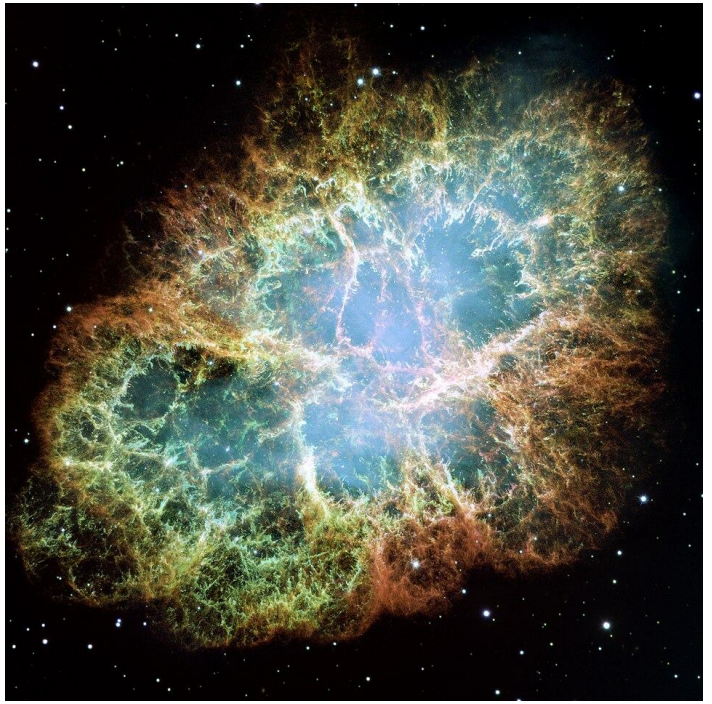
Electronic Readout

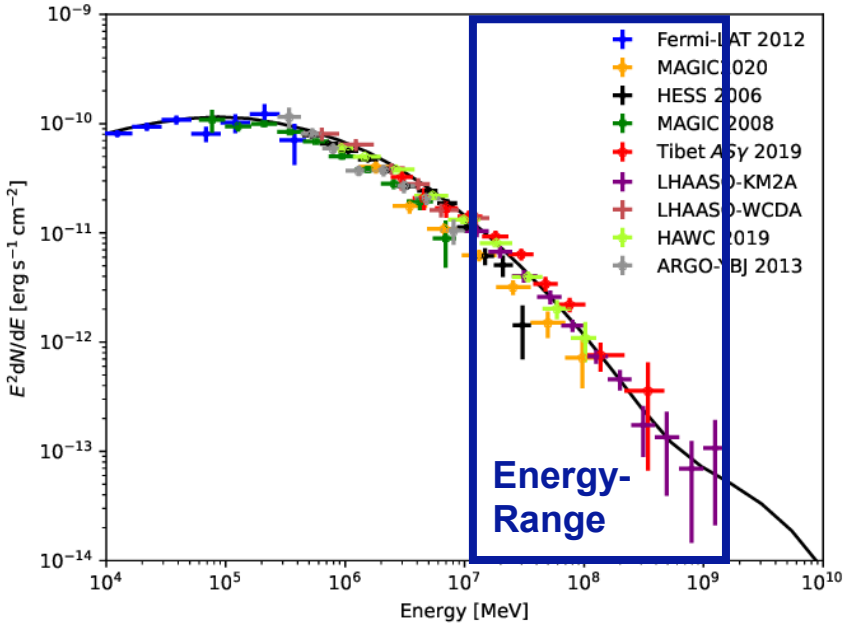


Signal processing through electronics

Crab Observations

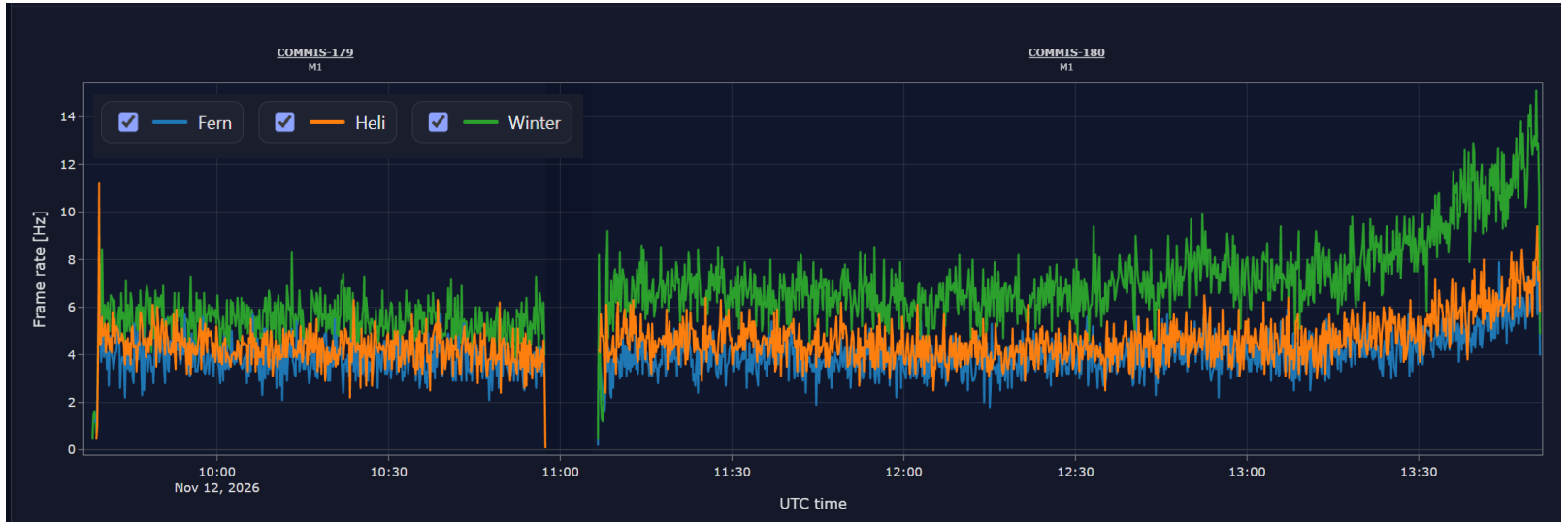
- **Crab Nebula:** Brightest γ-ray source on northern sky and standard candle
- Proof of concept for PANOSETI as an γ-ray instrument
- High energy threshold (~10 TeV) -> low flux -> high background
- **2 x 40 h** of data with **3 telescopes**



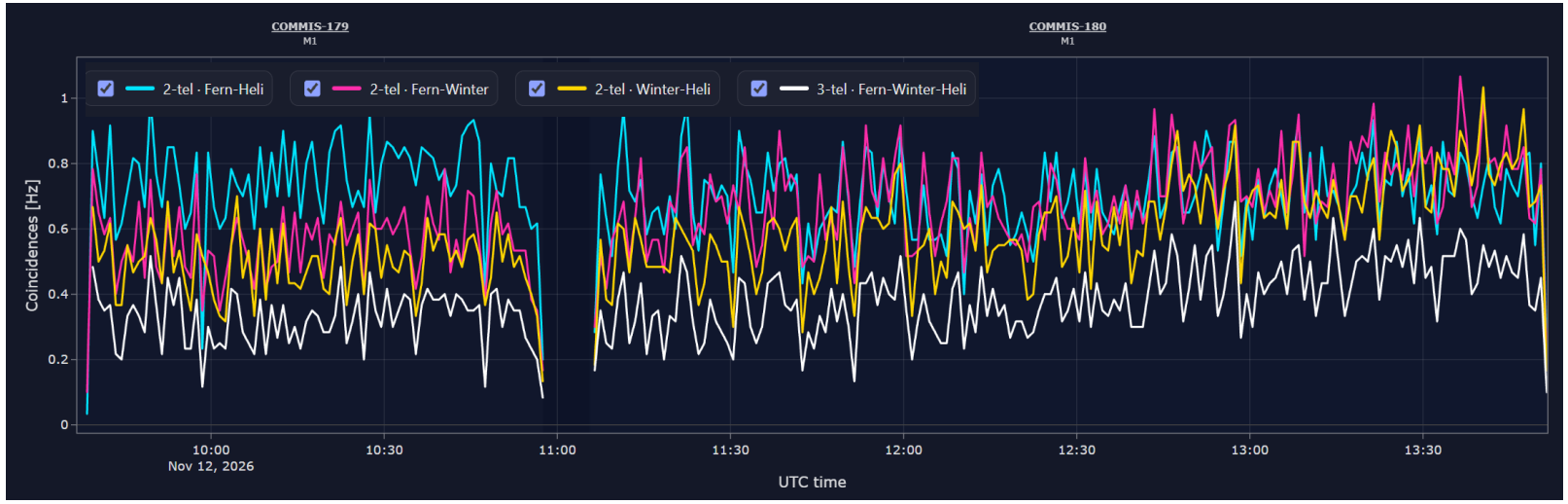


1. Identifying coincident events

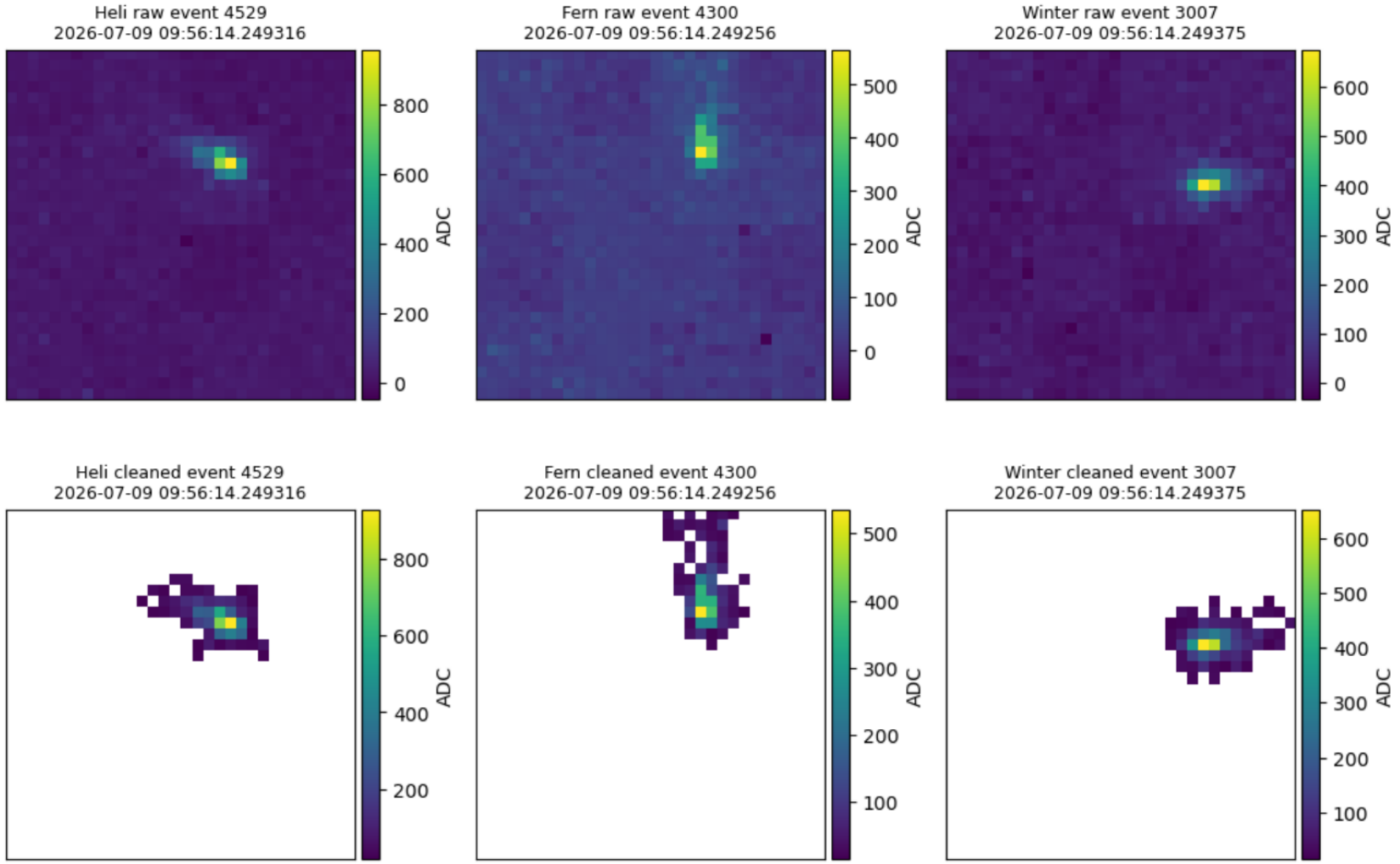
Single Telescope Events



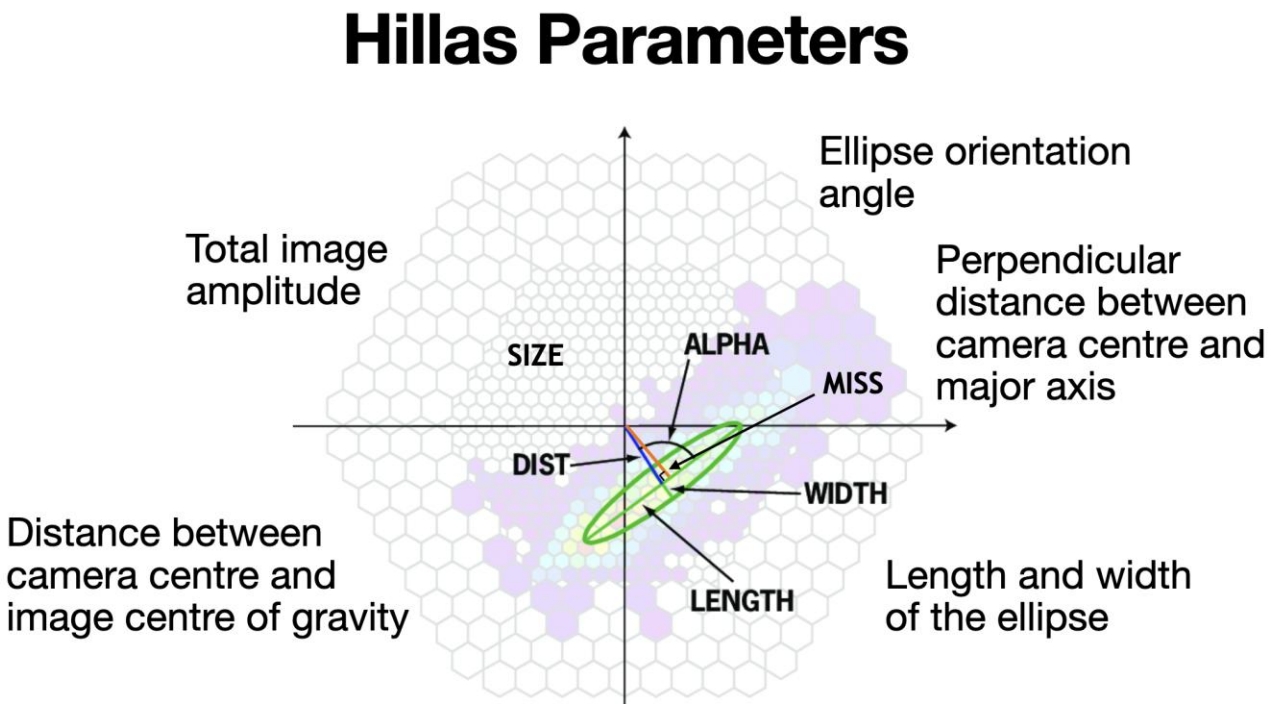
Coincident Events

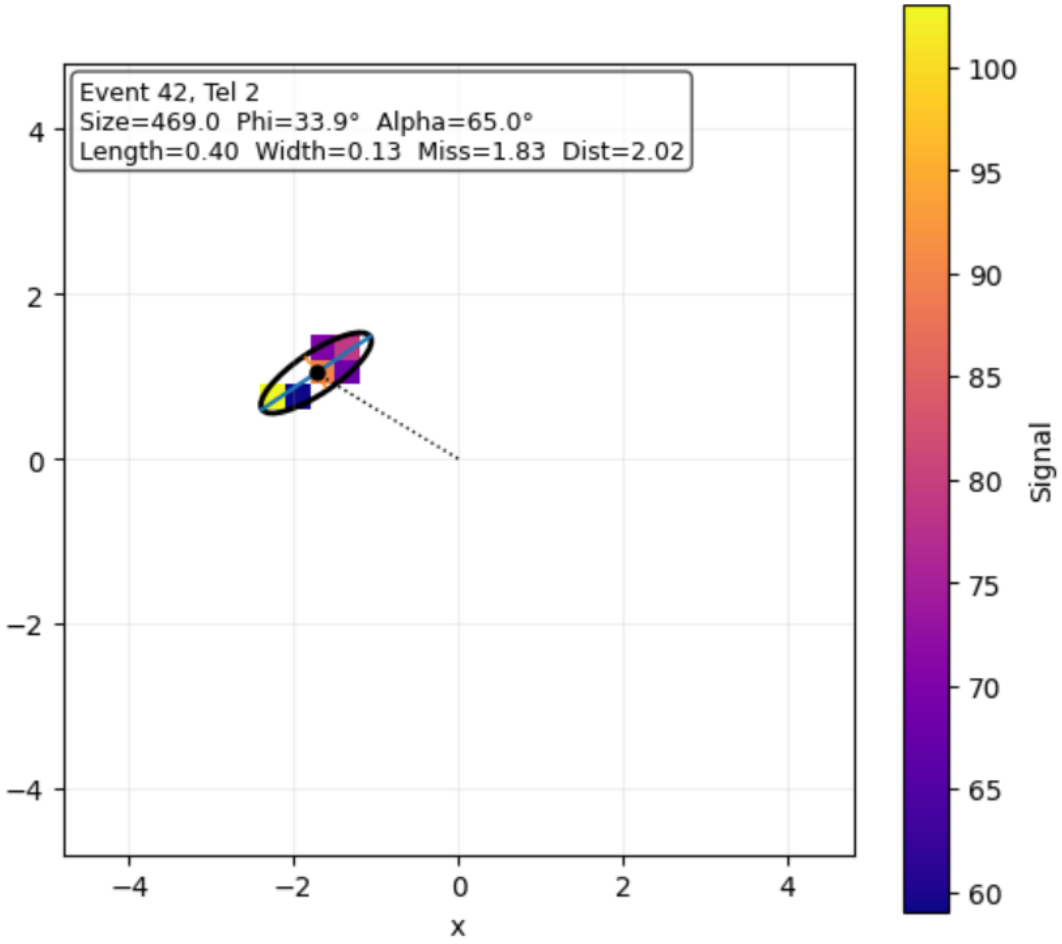


2. Image Cleaning



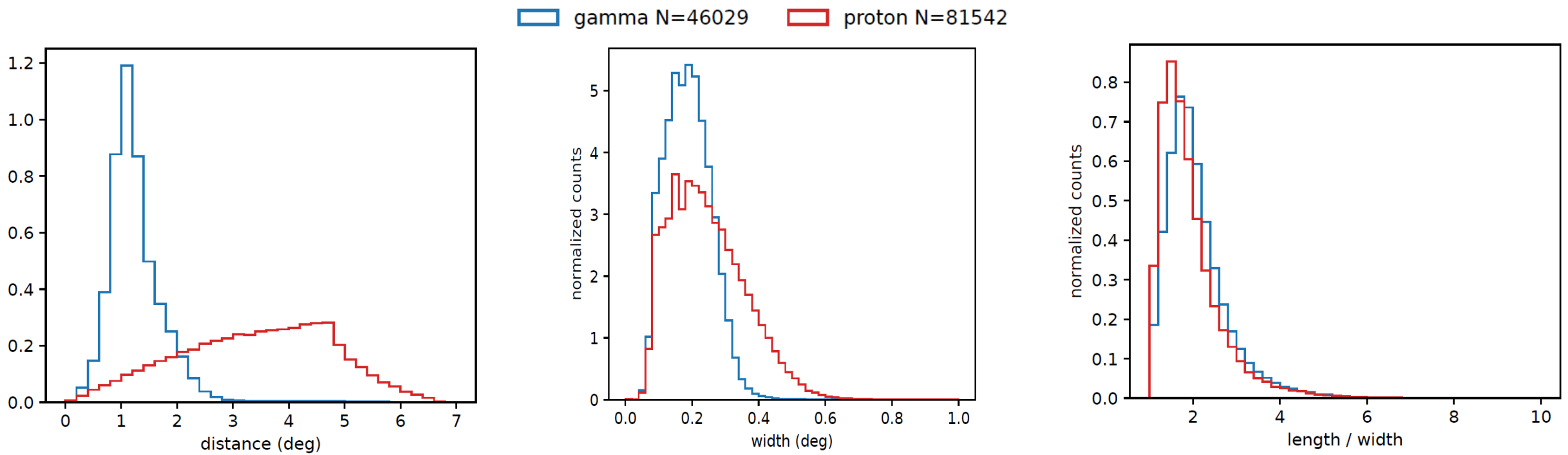
3. Hillas-Parametrization





4. Gamma-Hadron-Separation

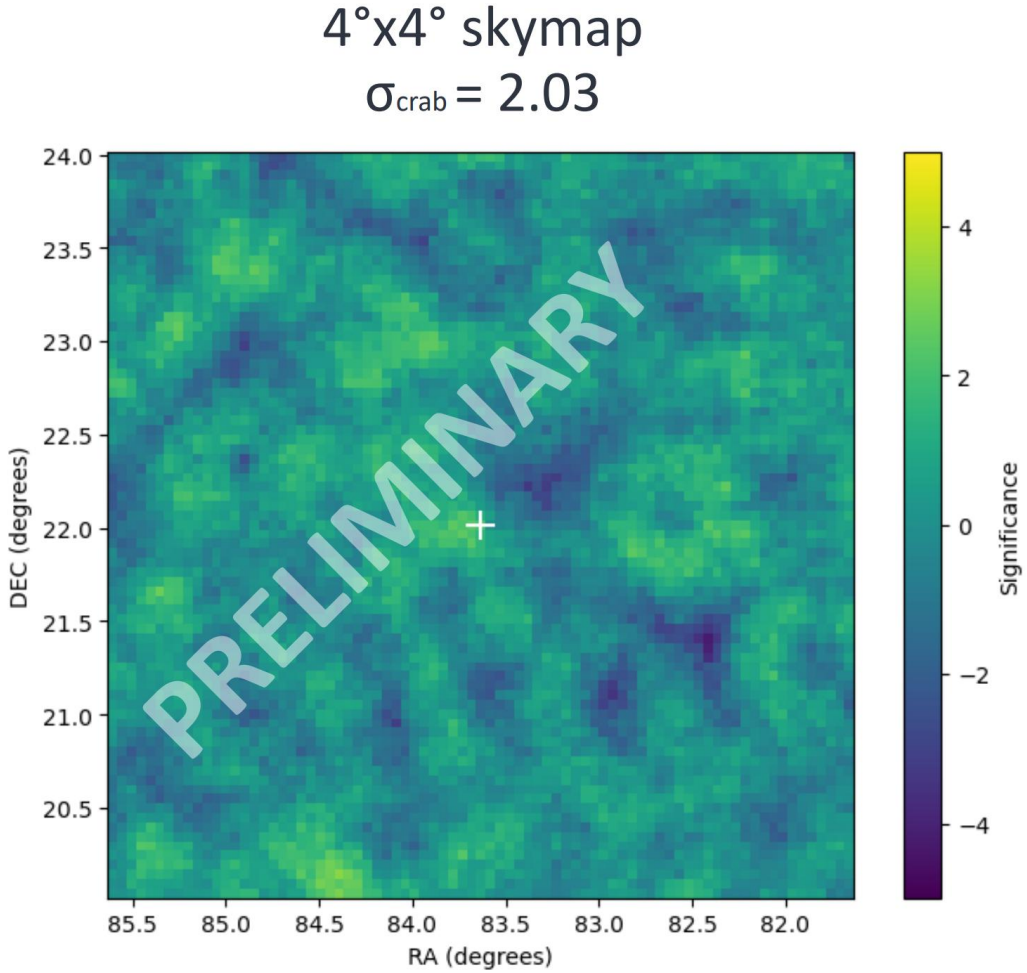
- Most of the signal is proton background
- Reject most background while keeping all gammas
- Training of BDTs for enhanced separation



5. Significance Sky Map

- Expecting >5σ excess at Crab‘s position

- Improved systematics for new dataset:
  - Pointing
  - Focusing
  - Gamma-Hadron Separation



Conclusion and Outlook





- 4 PANOSETI telescopes deployed taking data
- Improving different systematics for cleaner data
- Lab measurement to implement full simulation chain

- Repeating crab analysis with new, clean dataset
- Deplyment of 3 new telescopes soon
- Studies of Ultraheavy Dark Matter in the future

Sensitivity curves for 5σ signal excess

