# DEPLOYMENT OF TWO COMPACT, REFRACTIVE IACTs *HAWC's EYE* AT VERY HIGH ALTITUDES

## IMPLEMENTACIÓN DE DOS IACTs COMPACTOS REFRACTIVOS HAWC's EYE A MUY GRANDES ALTURAS

**JOSÉ SERNA**[†1]

R. Alfaro[1], J. Audehm[2], T. Bretz[2], G. Do[2], M.M. González[3], A. Iriarte[3], F. Maslowski[2], Y. Pérez[3], F. Rehbein[2], M. Schaufel[4], and I. Torres[5]

[1] Instituto de Física, Universidad Nacional Autónoma de México, Mexico
[2] Physics Institute III A, RWTH Aachen University, Germany
[3] Instituto de Astronomía, Universidad Nacional Autónoma de México, Mexico
[4] Physics Institute III B, RWTH Aachen University, Germany
[5] Instituto Nacional de Astrofísica, Óptica y Electrónica, Mexico

[†] Speaker

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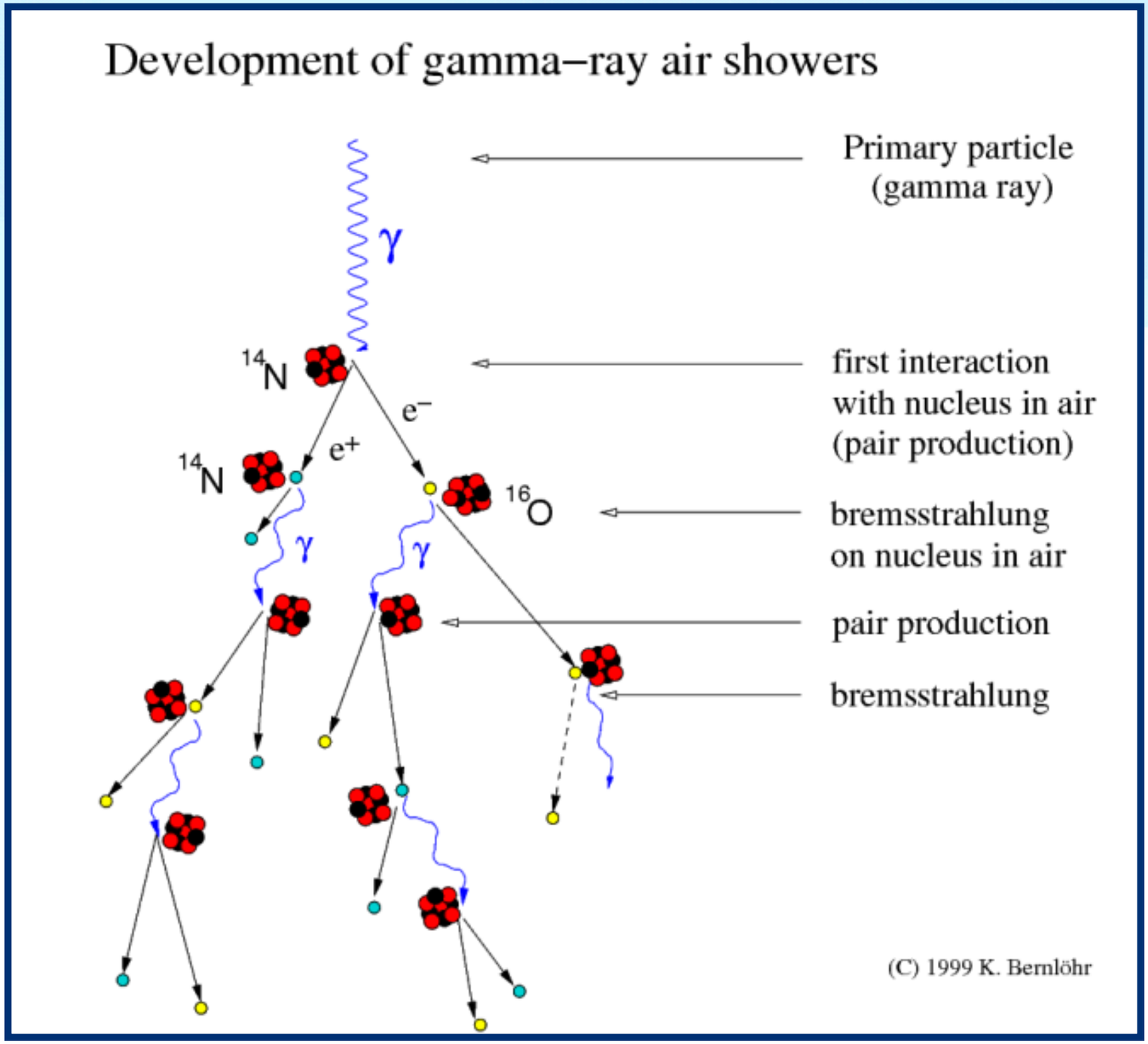
# EXTENSIVE AIR-SHOWERS (EAS) INDUCED BY GAMMA-RAYS

- Gamma-rays
- **Energy**
- **Arrival direction**




http://mpi-hd.mpg.de

# GAMMA-RAYS INDIRECT DETECTION TECHNIQUES

http://www.magic.lac.es

Imaging Air-Cherenkov Telescopes (IACTs):

**MAGIC**, HESS, VERITAS y CTA†

Wide Field-of-view Detectors (WFD):

**HAWC**, LHAASO y SWGO†

http://www.hawc-observatory.org

†In development

# GAMMA-RAYS INDIRECT DETECTION TECHNIQUES

## IACTs

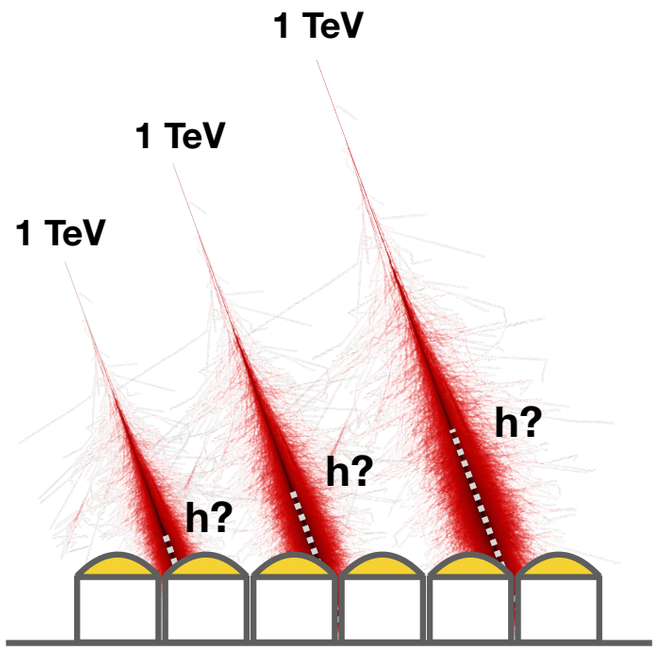
- Telescopes with ~5 m to ~25 m of diameter
- Collects the Cherenkov light produced in the atmosphere
- Duty cycle: 5% ~ 10%
- Particular environmental conditions
  - No sunlight, no moonlight, no albedo, no rain, no clouds, no artificial lights, no snow…
  - Just clear nights
- Angular resolution ~0.01°
- Energy range: from ~10 GeV to ~10 TeV
- Observation of point sources
- Can not do simultaneous observations
- High production cost

## WFDs

- Extended arrays of detectors (hundreds of $m^2$)
- Collects the Cherenkov light produced in an specific medium
- Duty cycle: >95%
- Do not need specific environmental conditions
- Angular resolution: ~0.1°
- Energy range: from ~100 GeV to >100 TeV
- Observation of extended sources
- Can perform simultaneous observations
- High cost of production

# HYBRID PERFORMANCE

## EXTENSIVE AIR-SHOWER DETECTOR




Identical air-showers at different heights (h)
- Different signals

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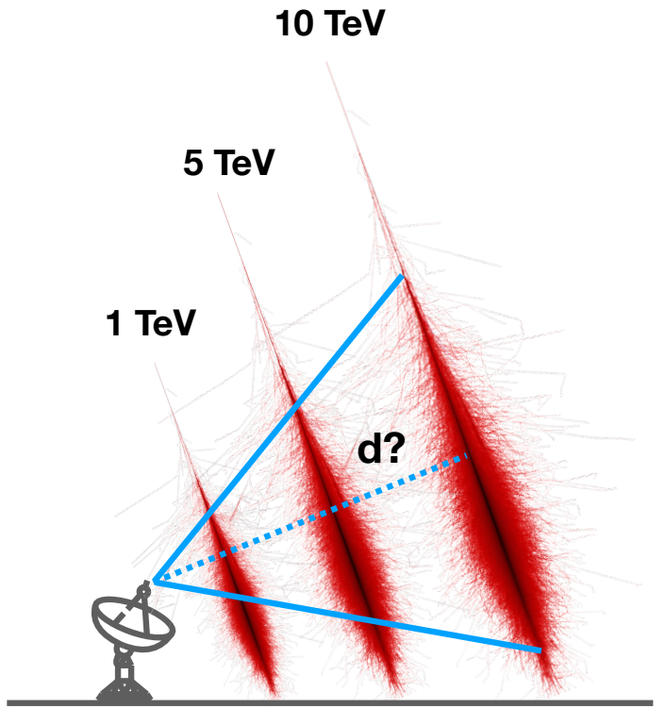
## IMAGING AIR-CHERENKOV TELESCOPE




Different air-showers at different distances (d)
- Similar signals

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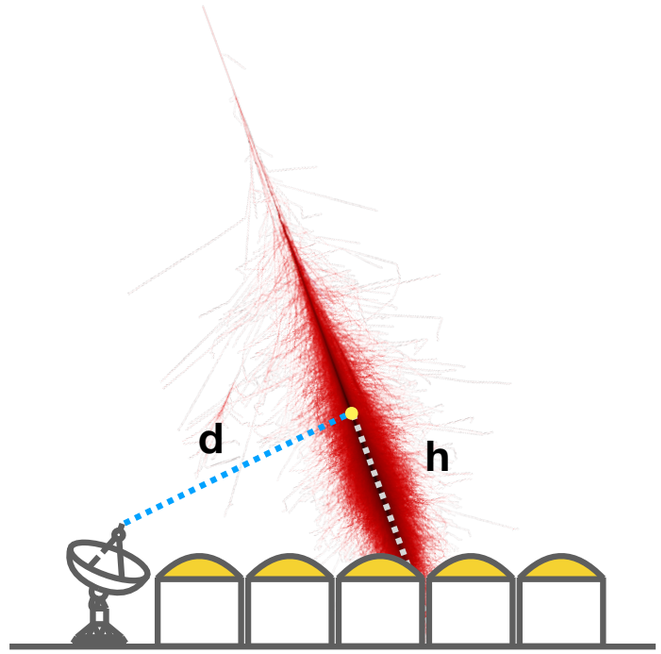
## HYBRID DETECTOR




Resolved ambiguities
- Better energy resolution
- Beter angular resolution
- Better particle identification

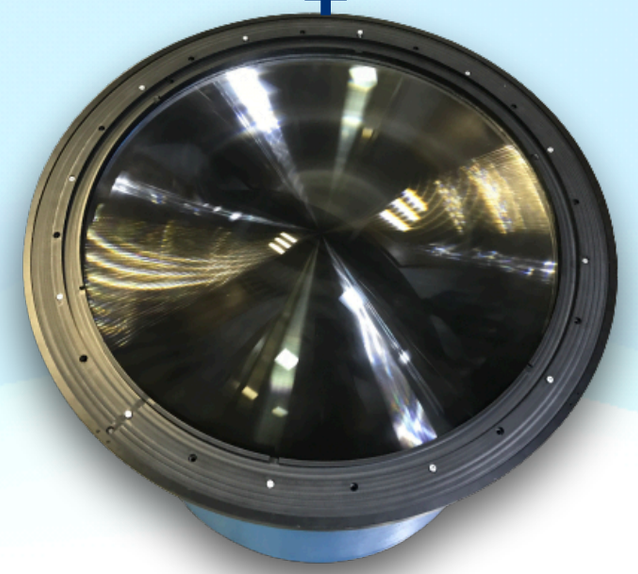
The **main problem** to develop an hybrid observatory is the **high cost of production**

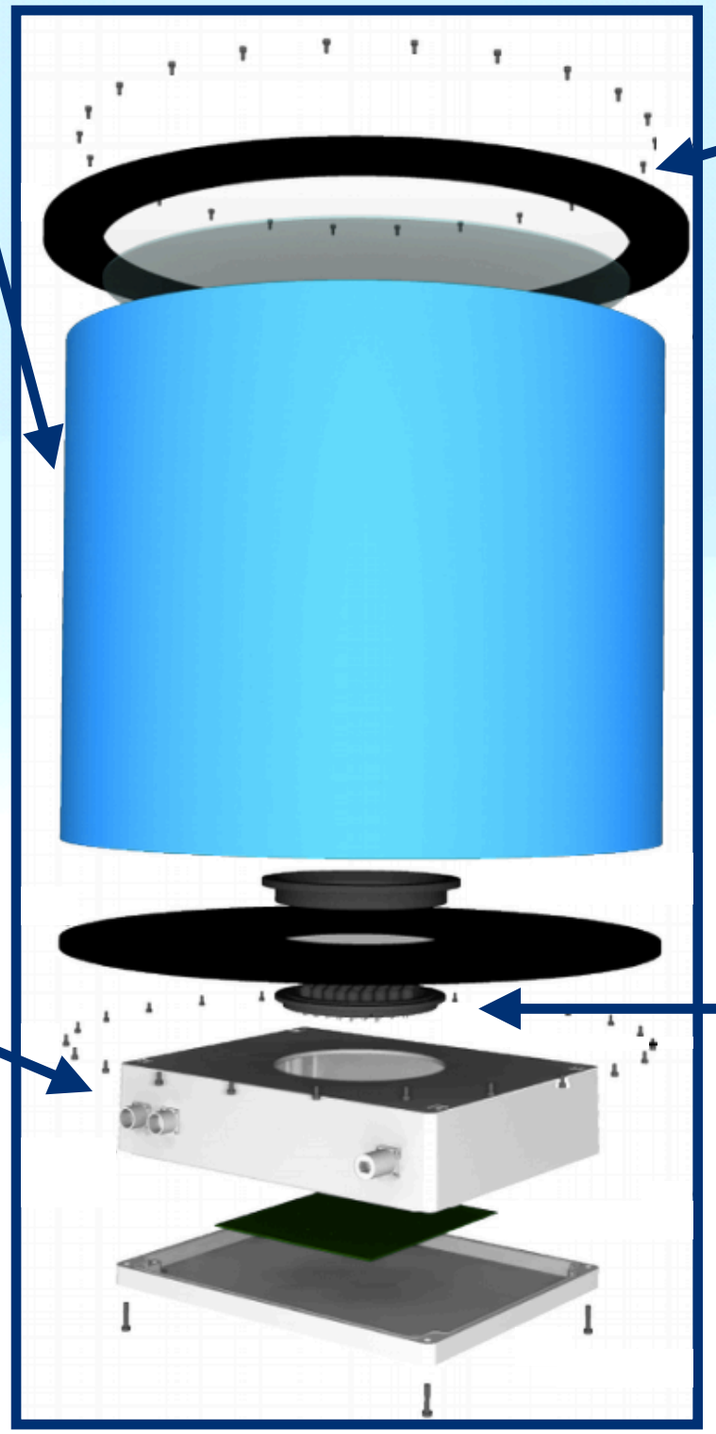
# HAWC's Eye

**Prototype of a refractive, compact, low-cost IACT**

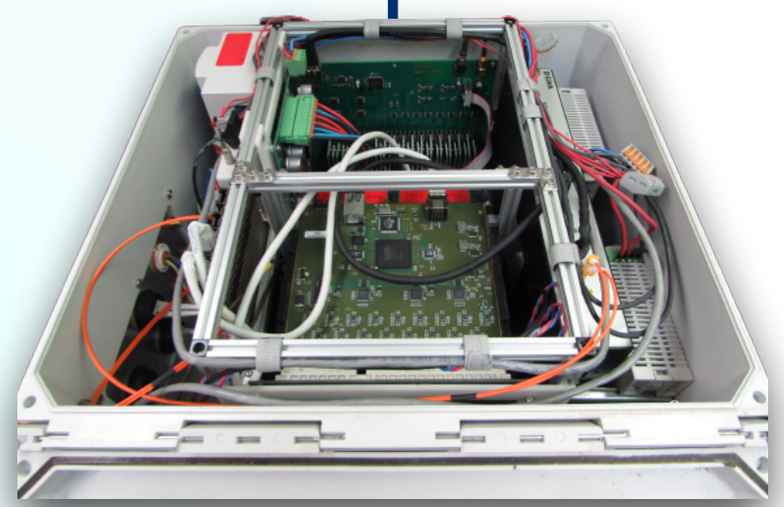
**Carbon-fiber barrel**

**Fresnel lens**

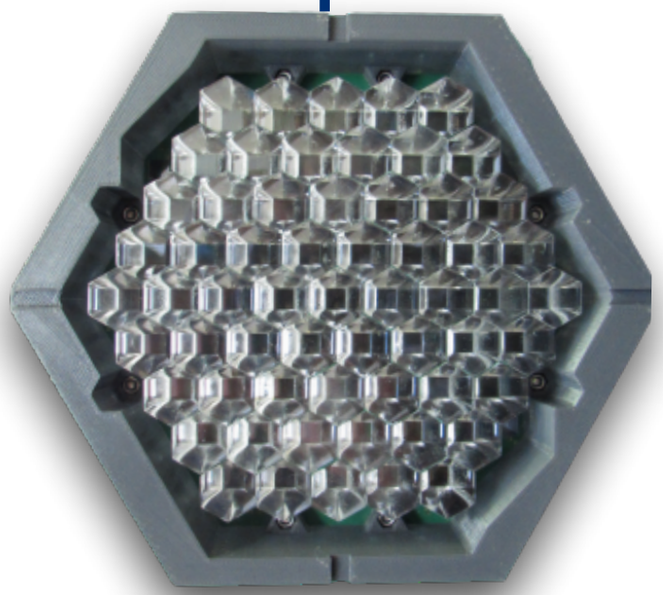




**FACT's DAQ**



**61(+3) SiPM based pixels camera**

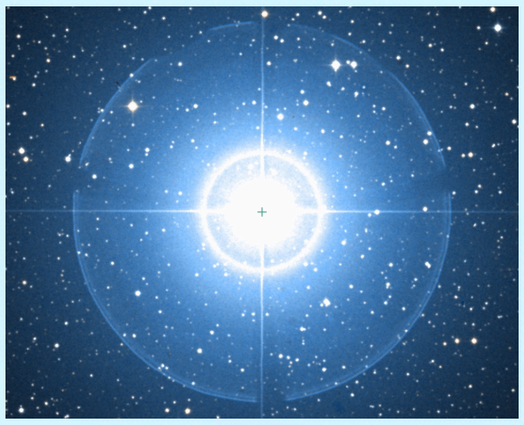


**¡~10,000 eur each telescope!**

# HAWC's Eye Status

- Two functional HAWC's Eye telescopes located at the HAWC's site
- Four successful observation campaigns
  - Hybrid observations


# HAWC's Eye Performance

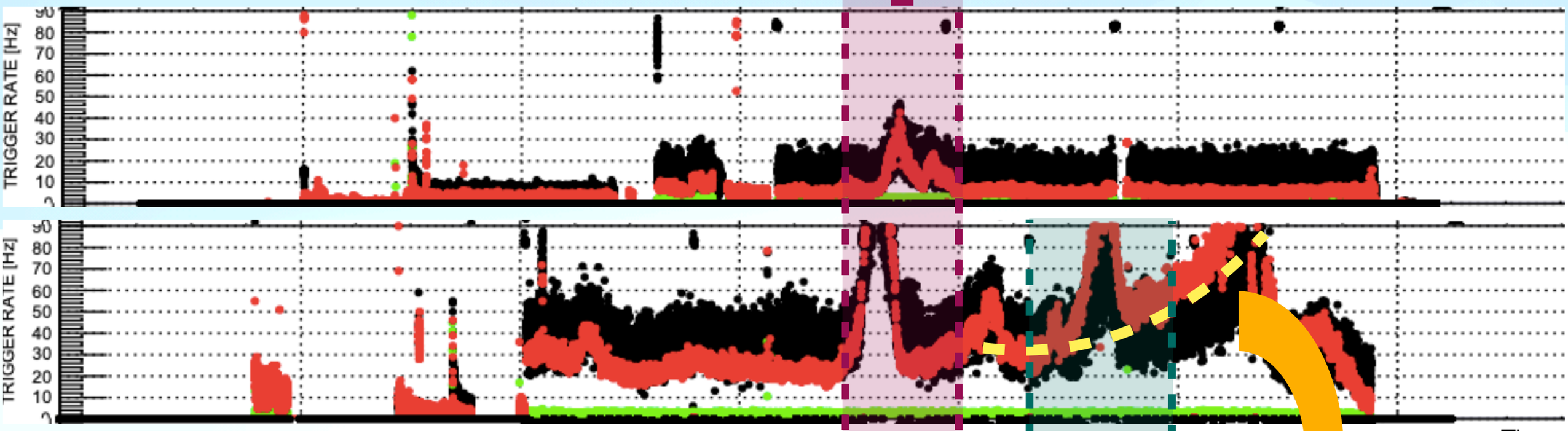


https://simbad.unistra.fr/simbad/

Optical noise due to Zeta Tauri

Optical noise for each telescopes depends of their positions

**HE01**




**HE02**

Excellent single performance (1 telescope), stereo (2 telescopes), and hybrid (+HAWC) (Do, 2021; Serna-Franco, 2022)

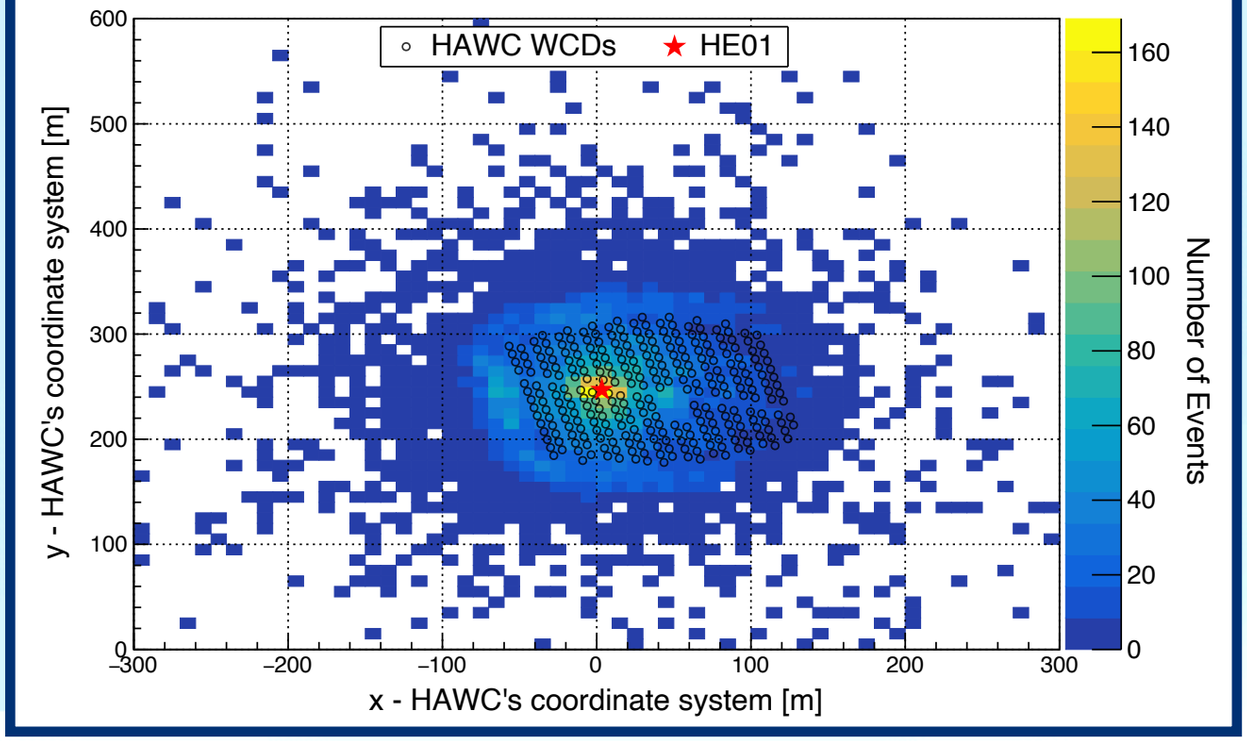
!

Noise associated with optical stars

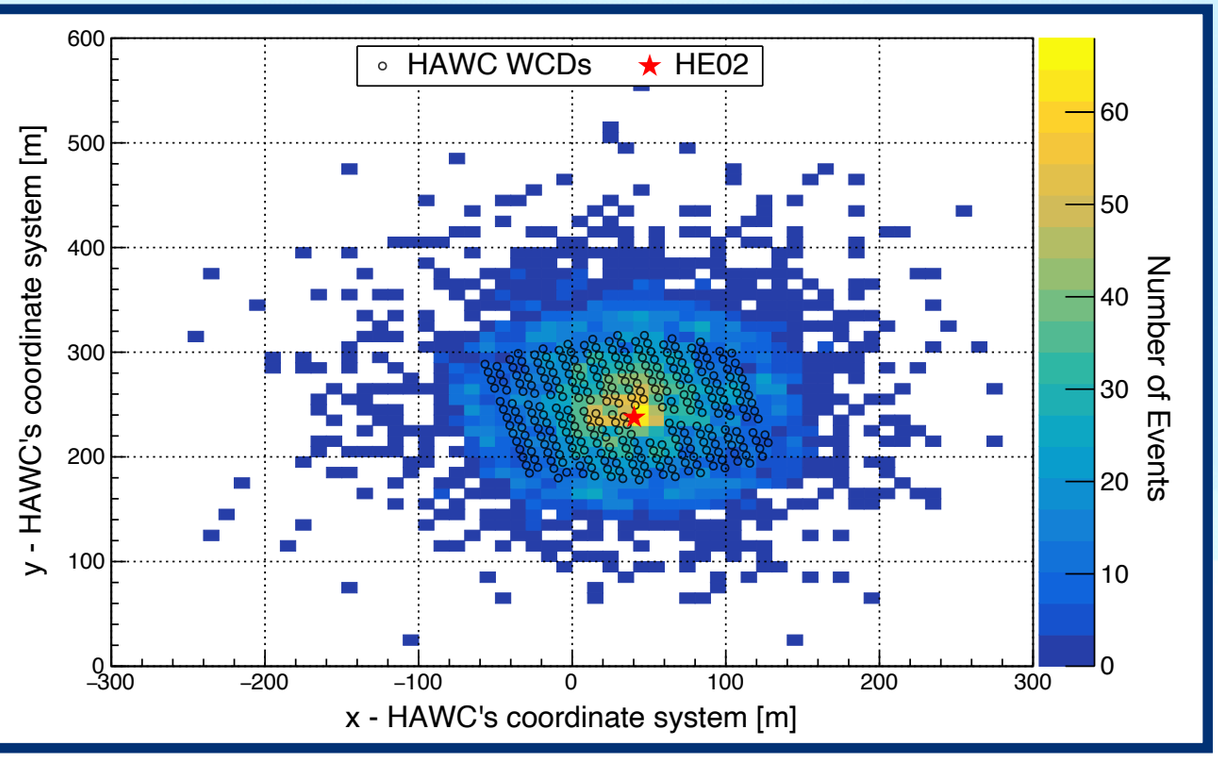
Increasing baseline due to the moonrise

# HAWC's Eye Performance

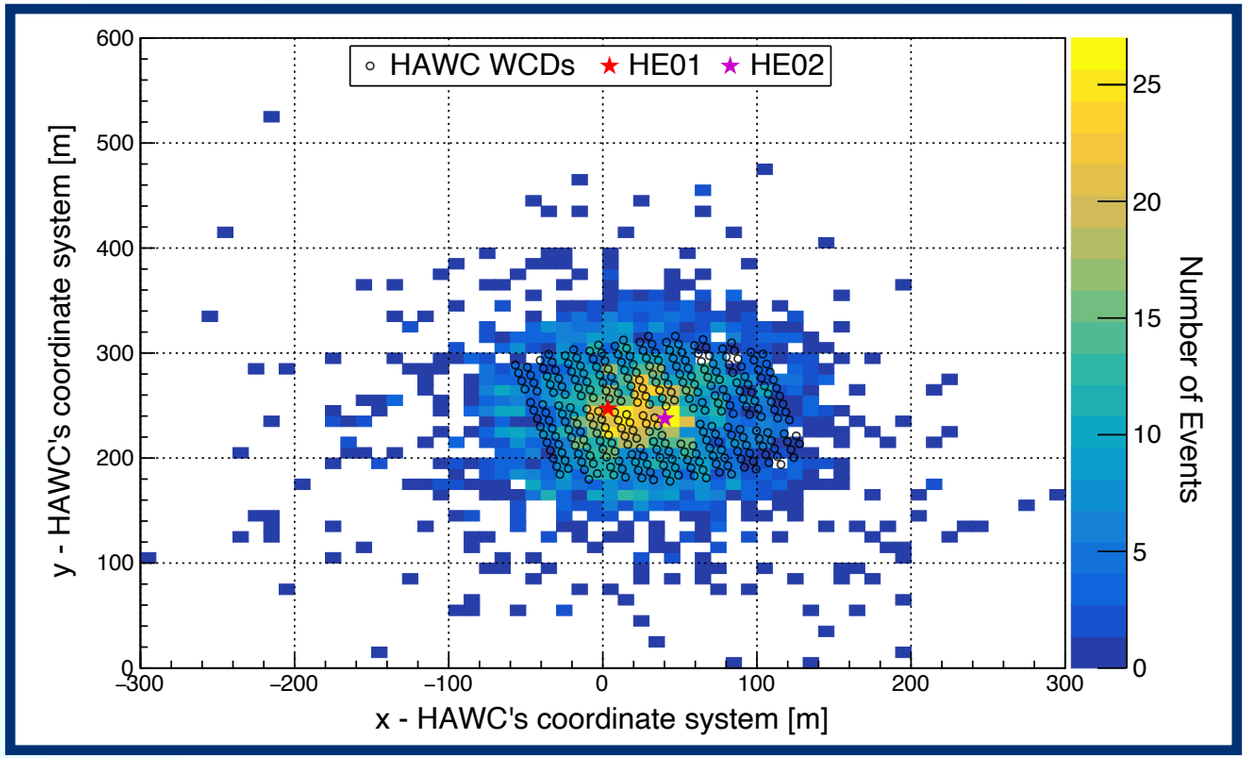
## HE01+HAWC




## HE02+HAWC



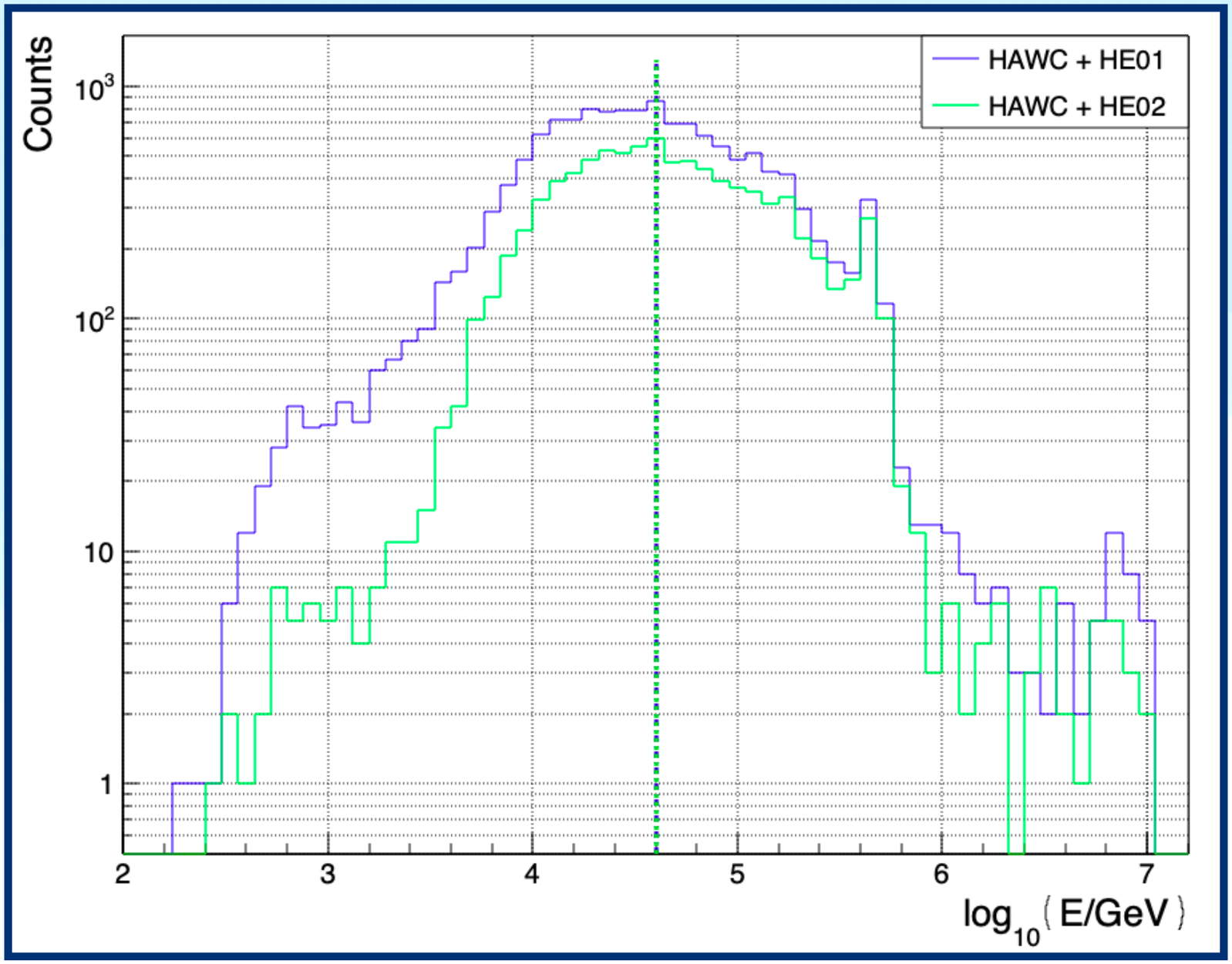

## HE01+HE02+HAWC




- Events detected by hybrid observations
- HAWC's Eyes positions reconstructed with the event distributions

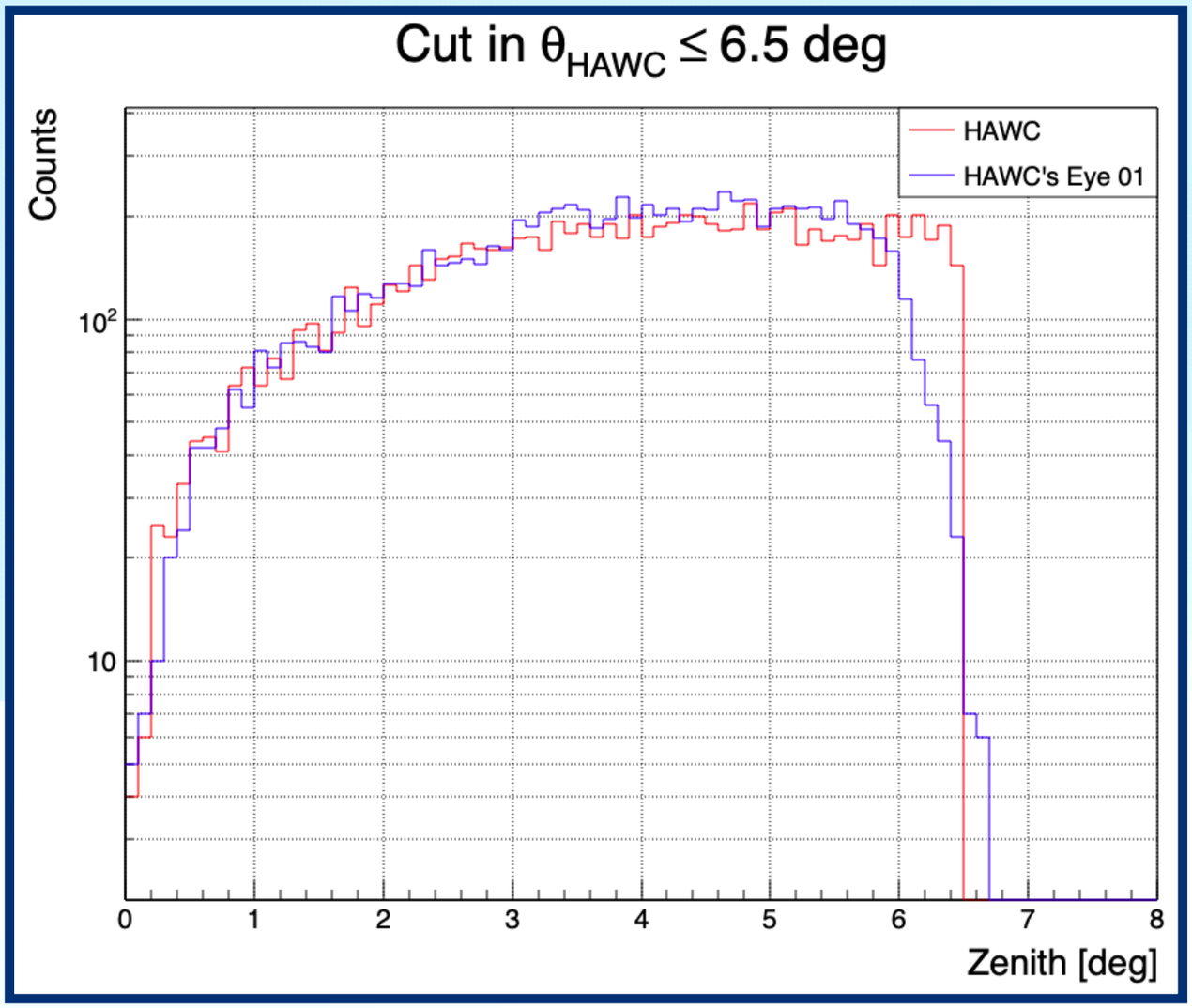
(Serna, 2022) (Serna, 2022) (Serna, 2022)

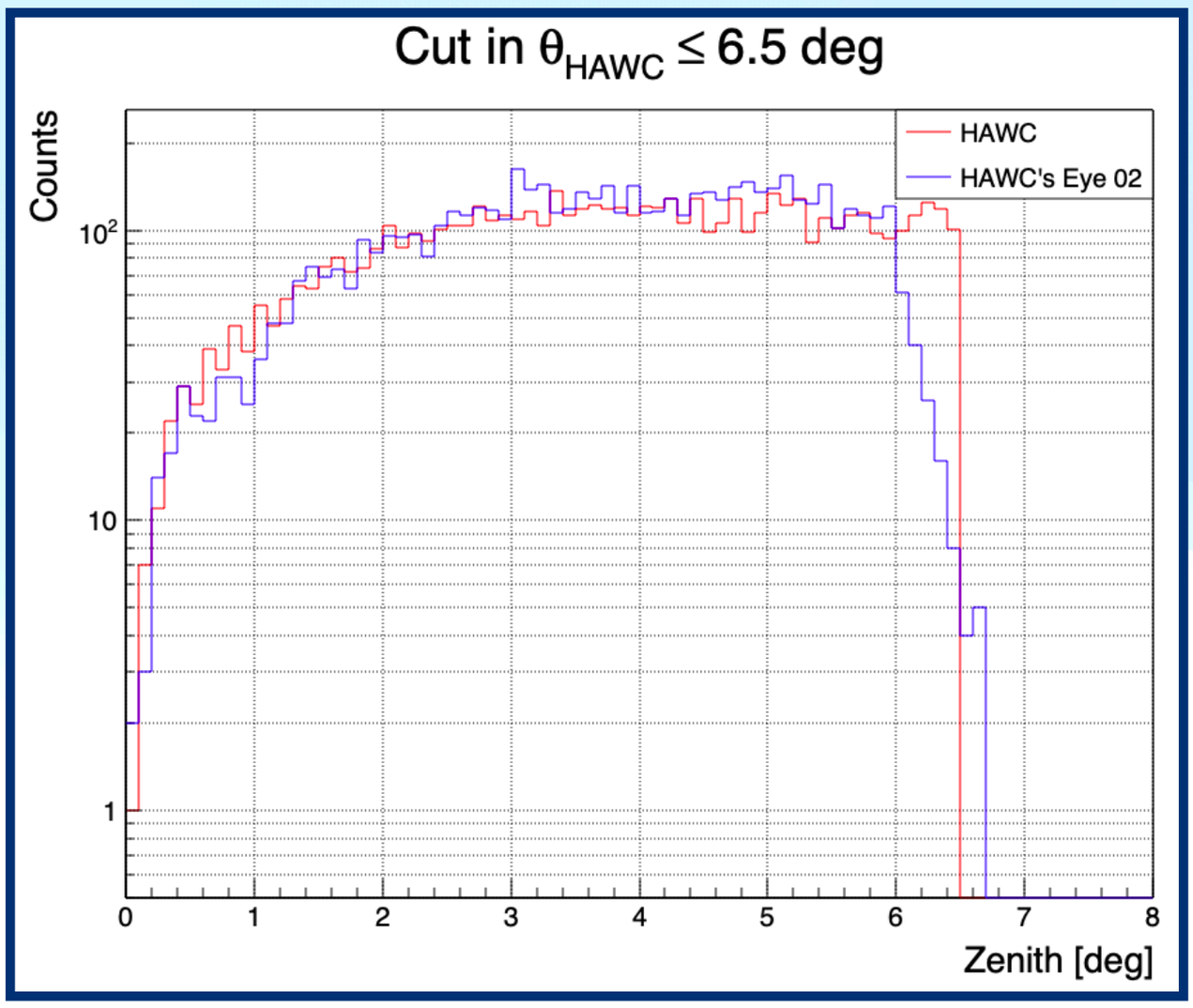
# HAWC's Eye Performance




- Both energy thresholds at $E_T \approx 39.8$ TeV
- Detected events with energies $E > 100$ TeV

# HAWC's Eye Performance




- Zenith angle geometrically reconstructed
- Quality cut: $\theta_{\mathrm{HAWC}} < 6.5^{\circ}$
- Very good zenith reconstruction with the HAWC's Eye telescopes

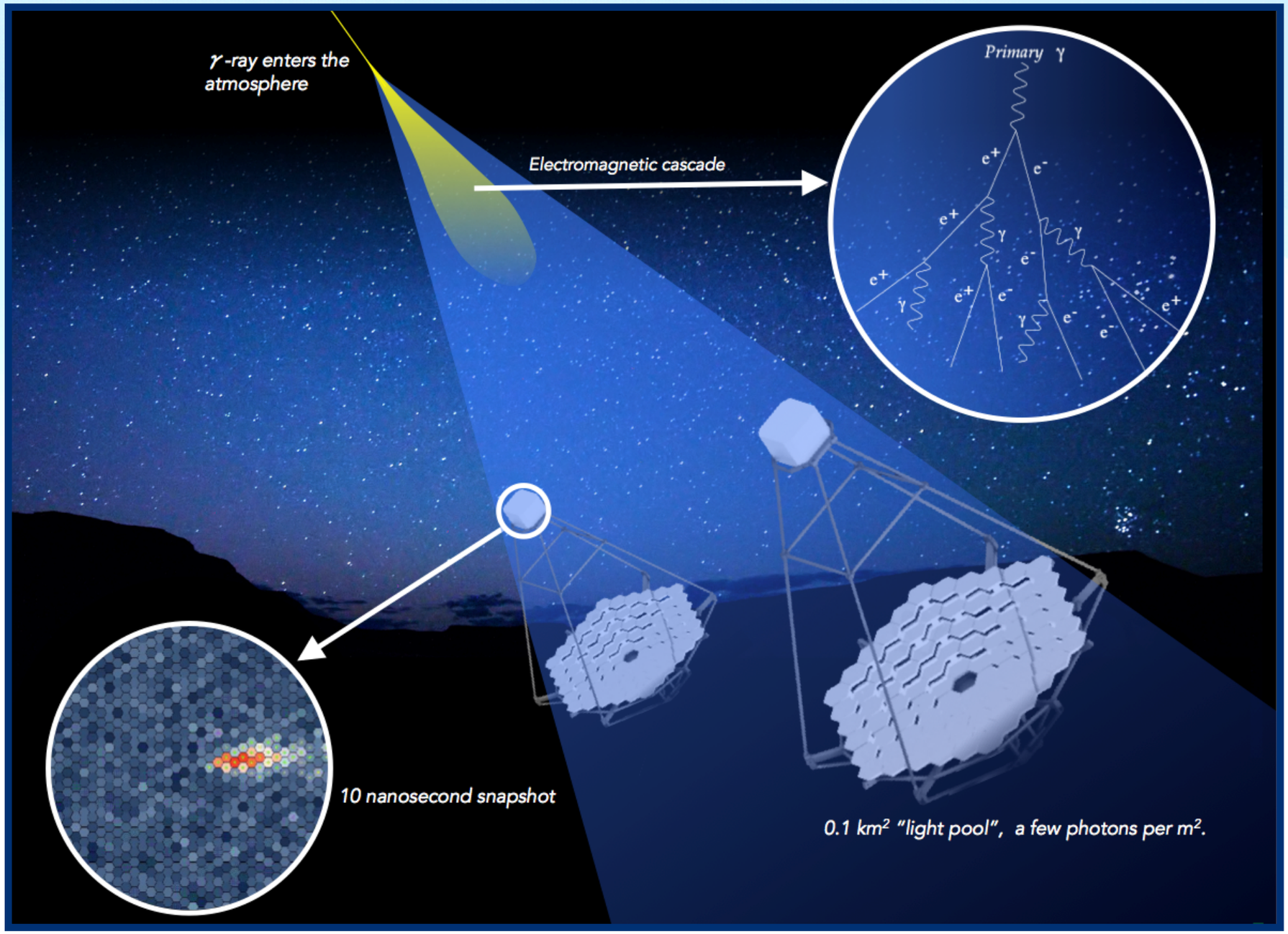
# SUMMARY AND CONCLUSIONS

- **Totally functional** compact IACT prototype
- **Excellent performance** during the stereo and hybrid observations
- **Low cost of production**
  - More telescopes can be build
- **New techniques** of reconstruction and estimation of data parameters
  - Random Forest, machine learning techniques, etc.
  - Estimation of **energy** and **arrival direction**
- **Ideal candidate** as a complement for current and future WFD
  - Gamma-ray observatories: **HAWC and SWGO**
  - Neutrino observatories: **IceCube**


# Backup Slides

# IMAGING AIR-CHERENKOV TELESCOPES (IACTs)

- Collects the Cherenkov radiation produced in the atmosphere
- Telescopes with big reflective area

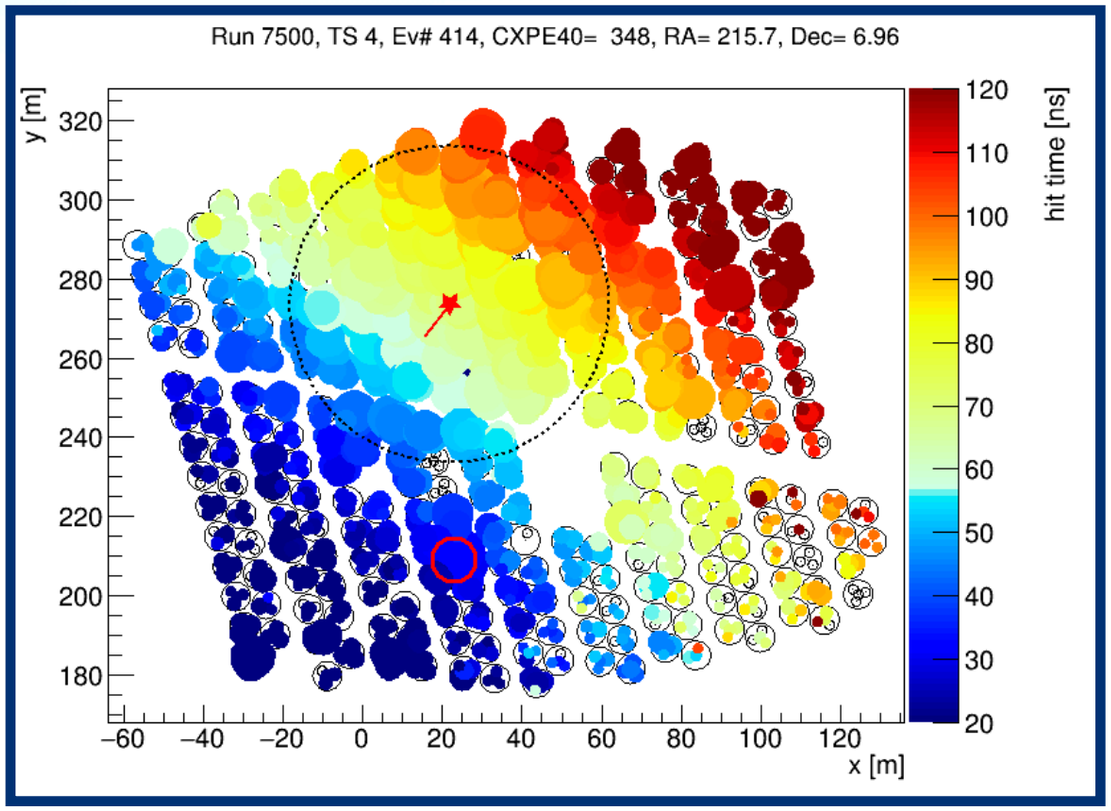



http://www.cta-observatory.org

# WIDE FIELD-OF-VIEW DETECTORS (WFDs)

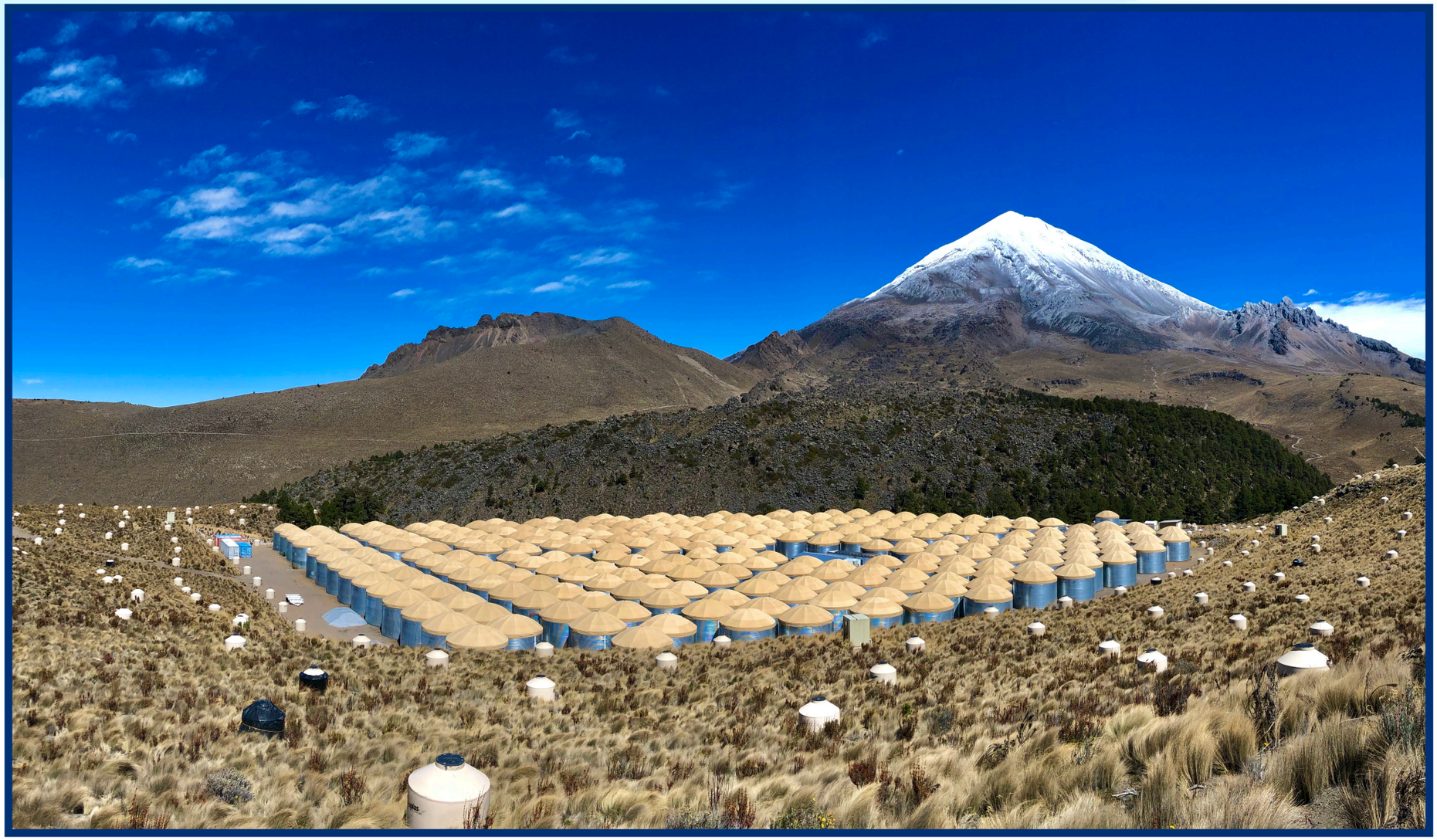
http://www.hawc-observatory.org

- Collects the Cherenkov light produced in a specific medium inside the detectors
  - The medium can be water, ice, etc.
- Extended arrays of several detectors



# THE HAWC OBSERVATORY

- Located at **Volcán Sierra Negra, Mexico**
- **Altitude**: 4,100 m a.s.l.
- **Duty cycle** > 95%
- 300 **Water Cherenkov Detectors** (WCDs) and 350 outriggers
- **WCD - size**: 7.3 m of diameter and 5 m tall
- **WCD - capacity**: 200,000 L each one
- 1,200 **Photo-Multiplier Tubes (PMTs)**
  - 4 PMTs in each WCD
- **Energy range**: from 300 GeV to 250 TeV
- **Angular resolution**: ~0.1˚
- **Instantaneous FoV** of 2 sr
  - 2/3 of the visible sky
- **HAWC's footprint**: ~200,000 $m^2$
  - ~100,000 $m^2$ with the outriggers

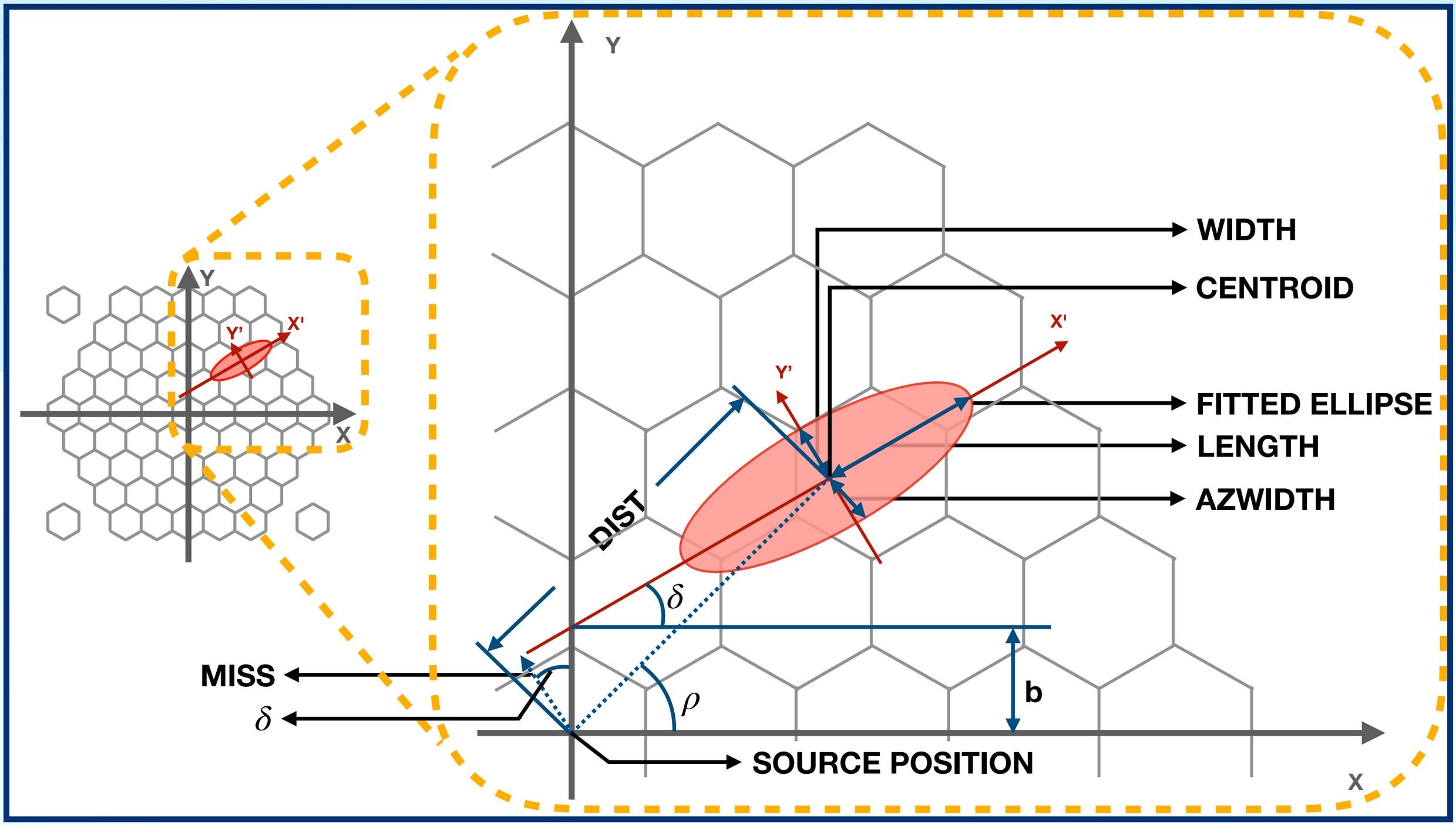


hawc-observatory.org

# HAWC's Eye


- **Compact IACT** (Bretz, 2018)
- **Fresnel lens** $f \approx D \approx 0.5$ m
- **Camera**: 61(+3) SiPMs SenseL MicroFJ based pixels
- **Solid hex-to-square guidelines** of PMMA (Winston cones)
- **FoV**: 1.5˚/Px ~12˚ total
- **FACT's DAQ** (Anderhum, 2013)
- **72 channels** of DRS4 DAQ
- **Low cost:** ~10,000 eur per telescope

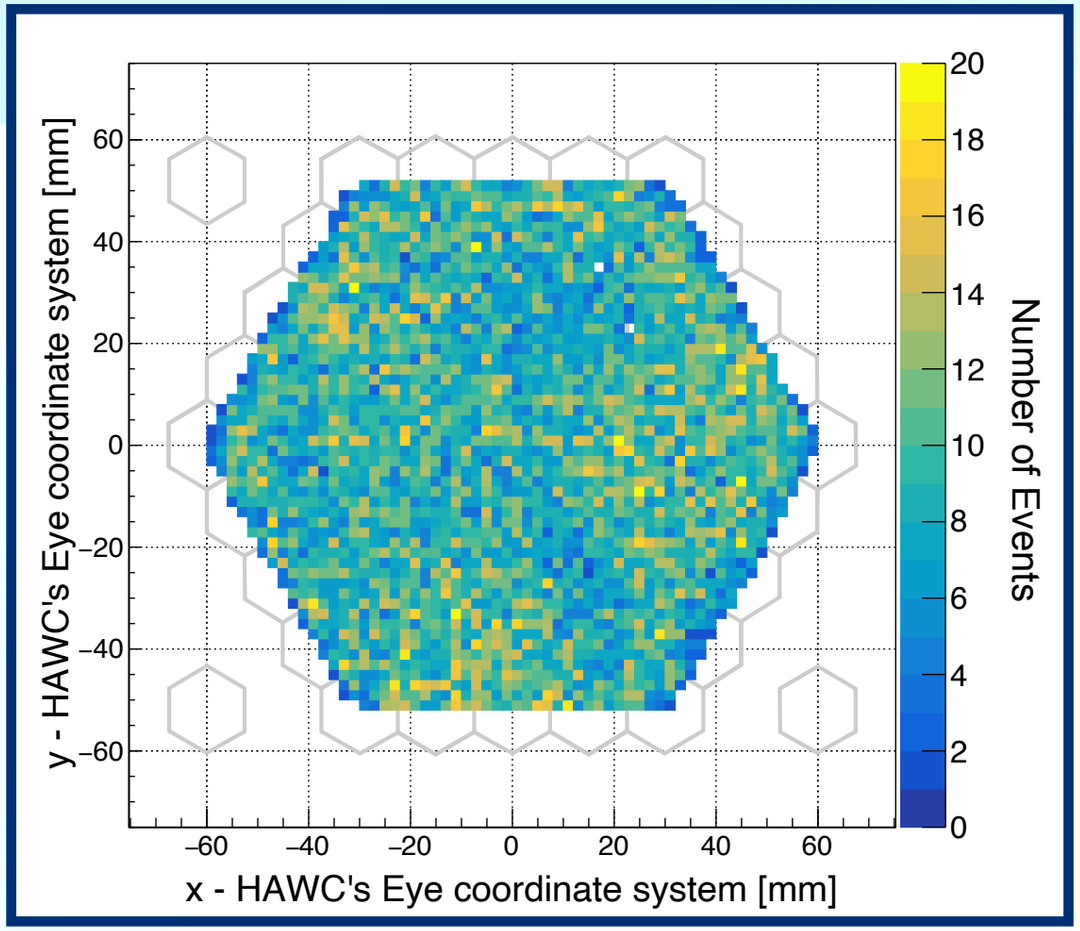
# HILLAS PARAMETERS



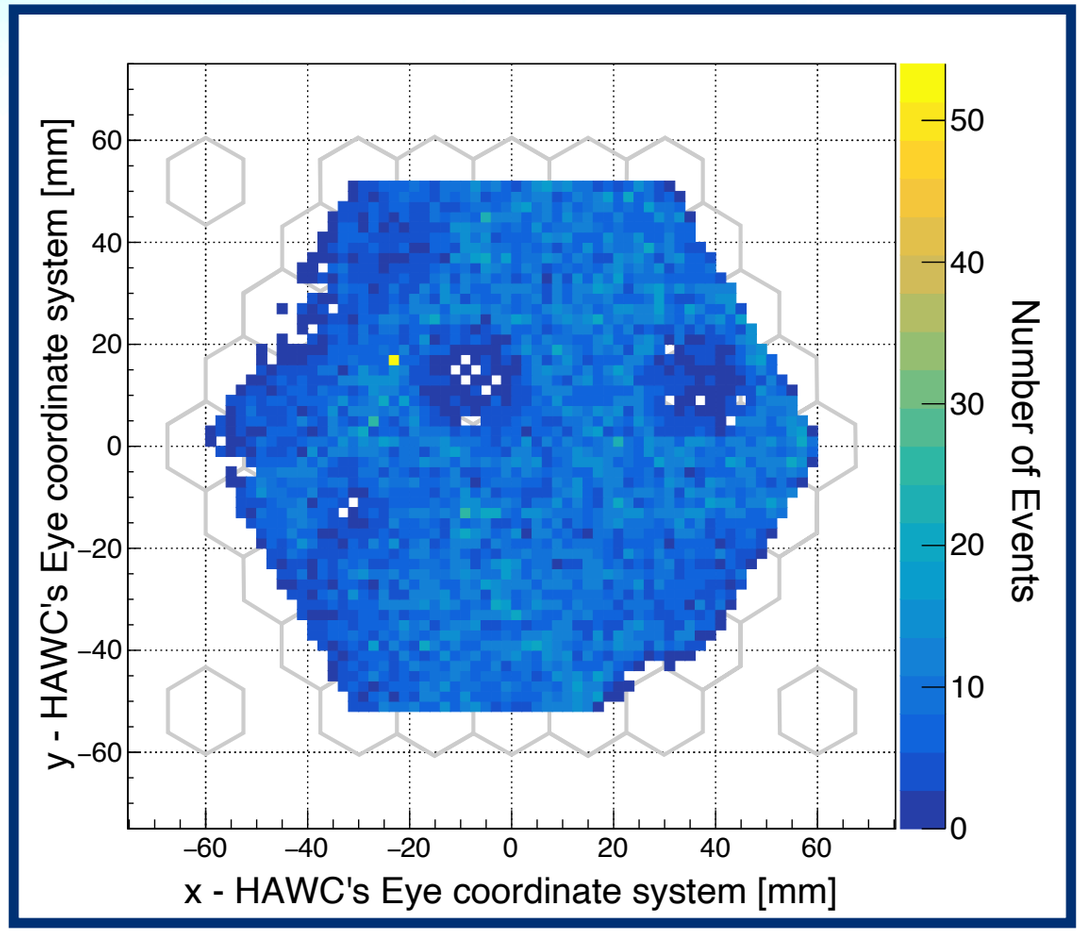
# EVENT's CORES DISTRUBUTION IN THE CAMERAS

- Isotropic distribution of the cores in the camera
- Low-signal spots consistent with hardware damage (HE02)

**HE01**



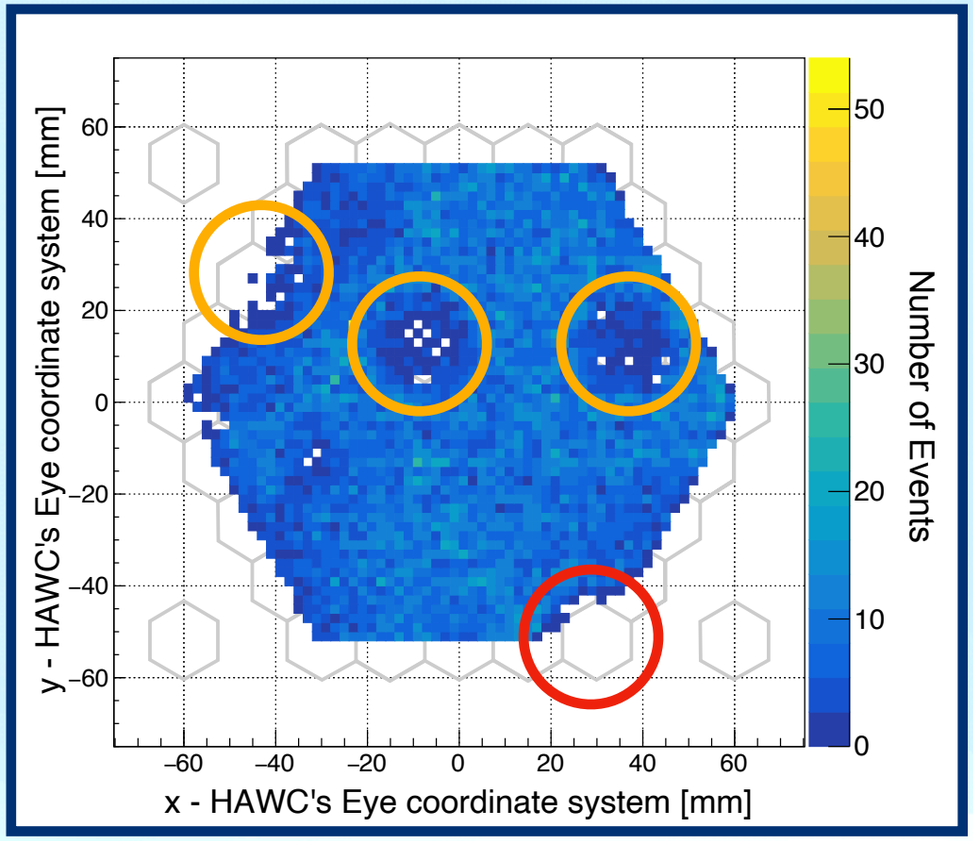

**HE02**

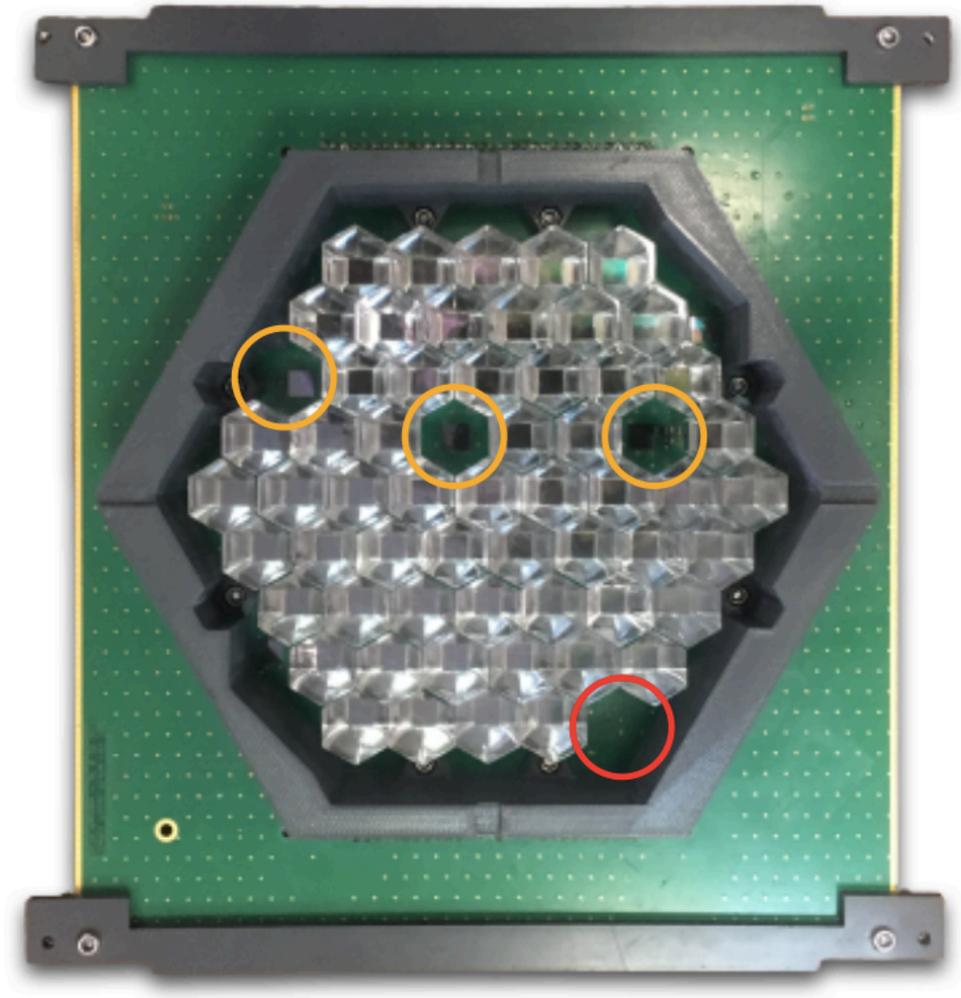


# HE02 CAMERA DAMAGES

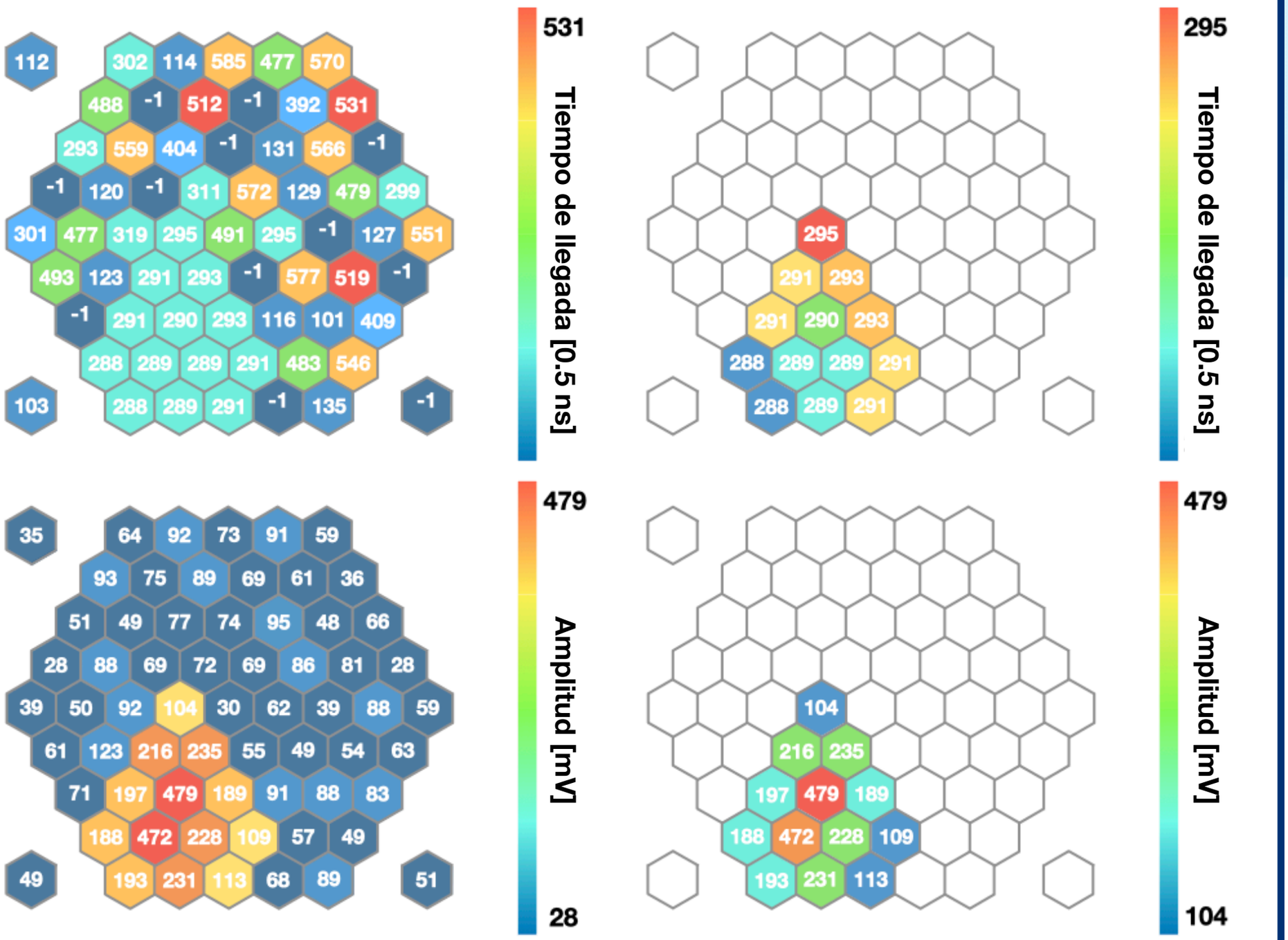
- Pixels with functional SiPM but without Winston cone
- Pixels without SiPM neither Winston cone

- Distributions **consistent with the hardware damages** in the camera
  - **Correct performance** of the software
  - **Correct performance** of the DAQ system
- Indirect confirmation of the **good performance of the telescopes**



# HAWC's Eye Performance




- Image cleaning
- Image characterization (Hillas parameters)
- Gamma/Hadron discrimination