Simulated performance of a 55 compact IACTs array at high altitude

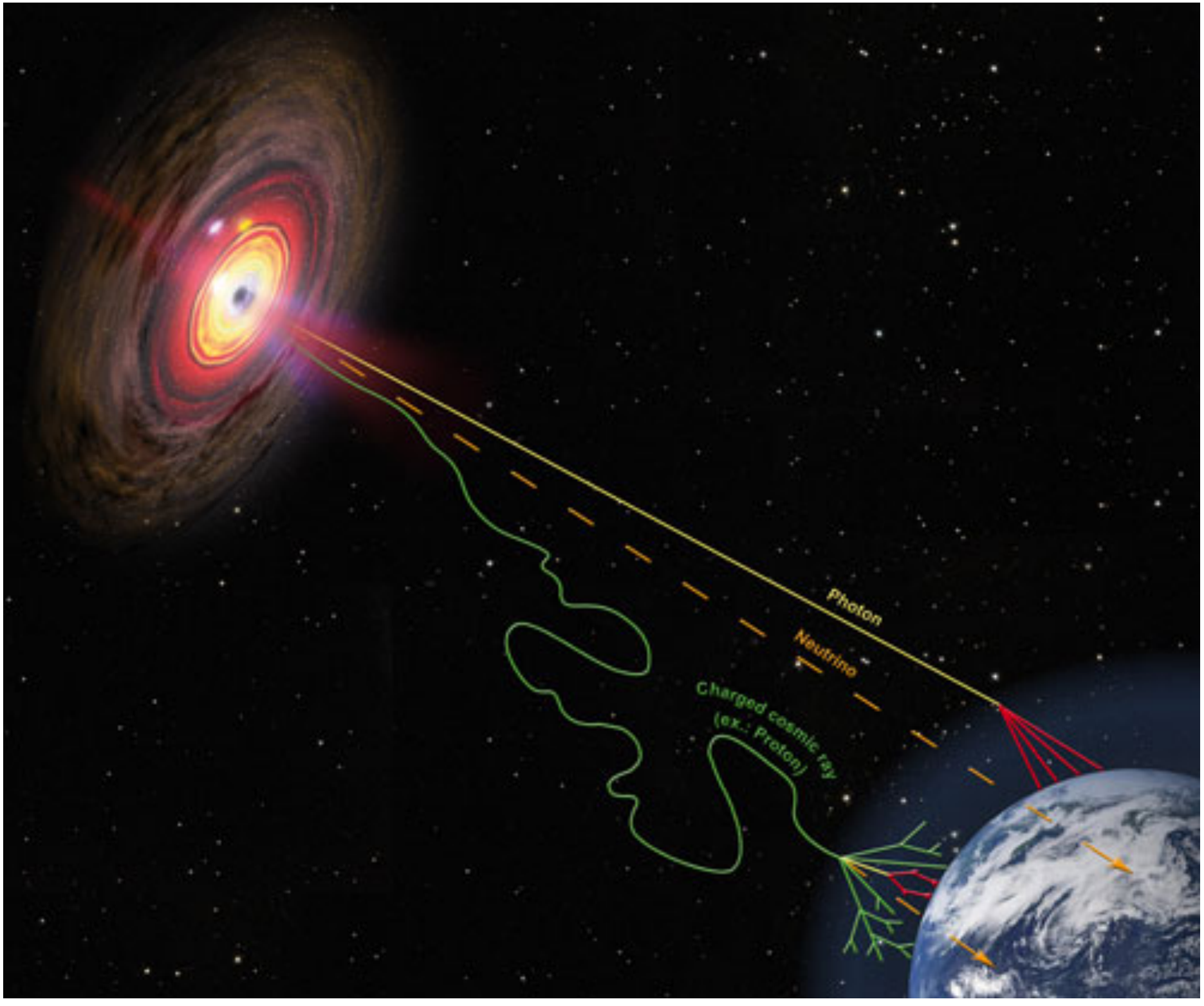
JOSÉ SERNA[1†], Rubén Alfaro[1], Jan Audehm[2], Thomas Bretz[2], G. Do[2], M.M. González[3], Francisco González[3], Arturo Iriarte[3], Frank Maslowski[2], Yunior Pérez[3], Florian Rehbein[2], Merlin Schaufel[4], and Ibrahim Torres[5]

[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 Astronomía, Óptica y Electrónica, Mexico*

[†] *Speaker*

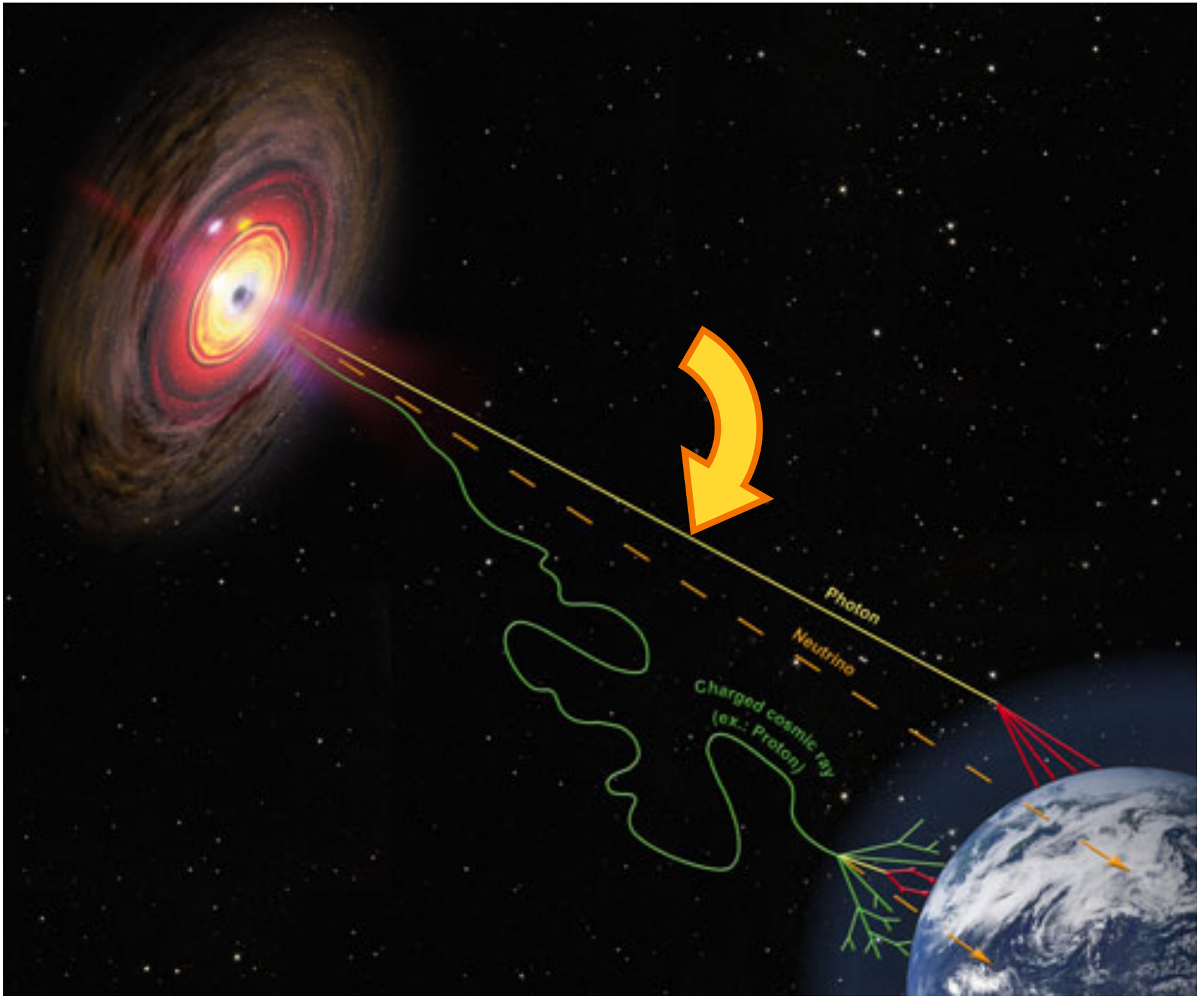
10th IWARA 2022 - Antigua, Guatemala

HIGH ENERGY GAMMA-RAY DETECTION



- Charged particles
- Neutrinos
- Photons
  - Direction
  - Energy

HIGH ENERGY GAMMA-RAY DETECTION

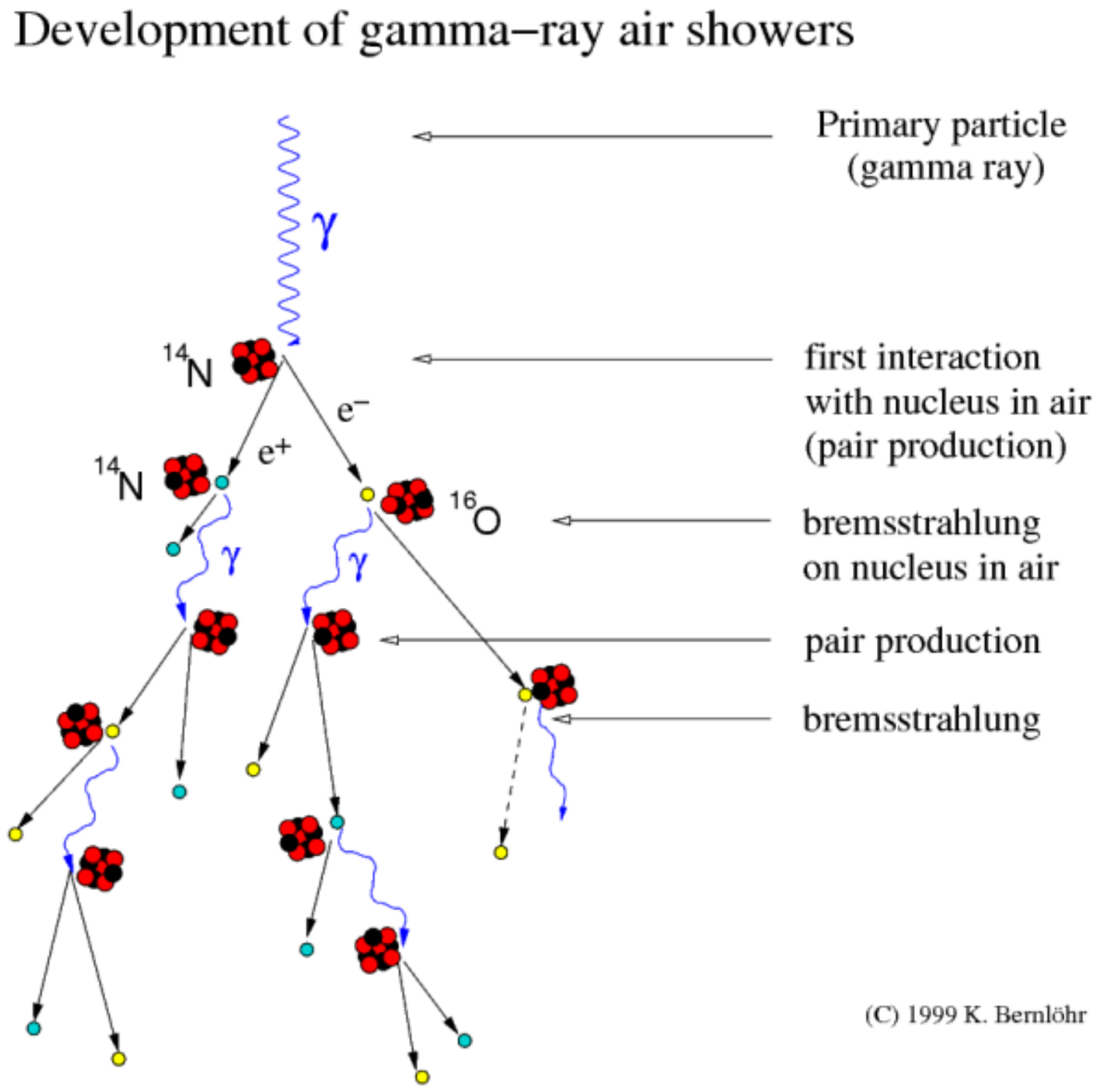


- Charged particles
- Neutrinos

- Photons
  - Direction
  - Energy

10^{-4} OF COSMIC PARTICLES!

GAMMA-RAY EXTENSIVE AIR SHOWERS (EAS)



GAMMA-RAY INDIRECT DETECTION TECHNIQUES

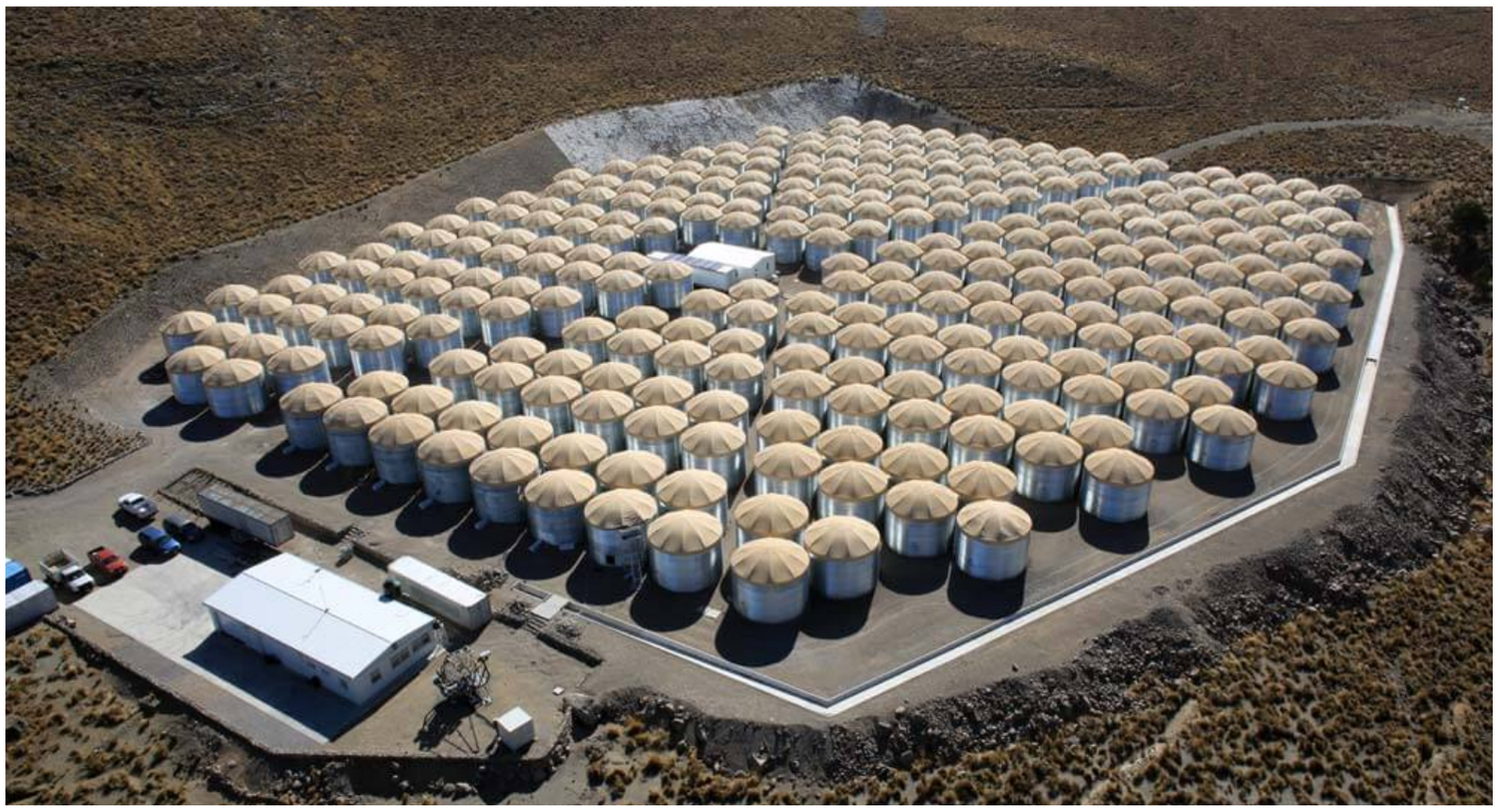
www.magic.lac.es

Imaging Air-Cherenkov Telescopes (IACTs):

MAGIC, HESS, VERITAS and CTA

Wide-Field of view Detectors (WFD):

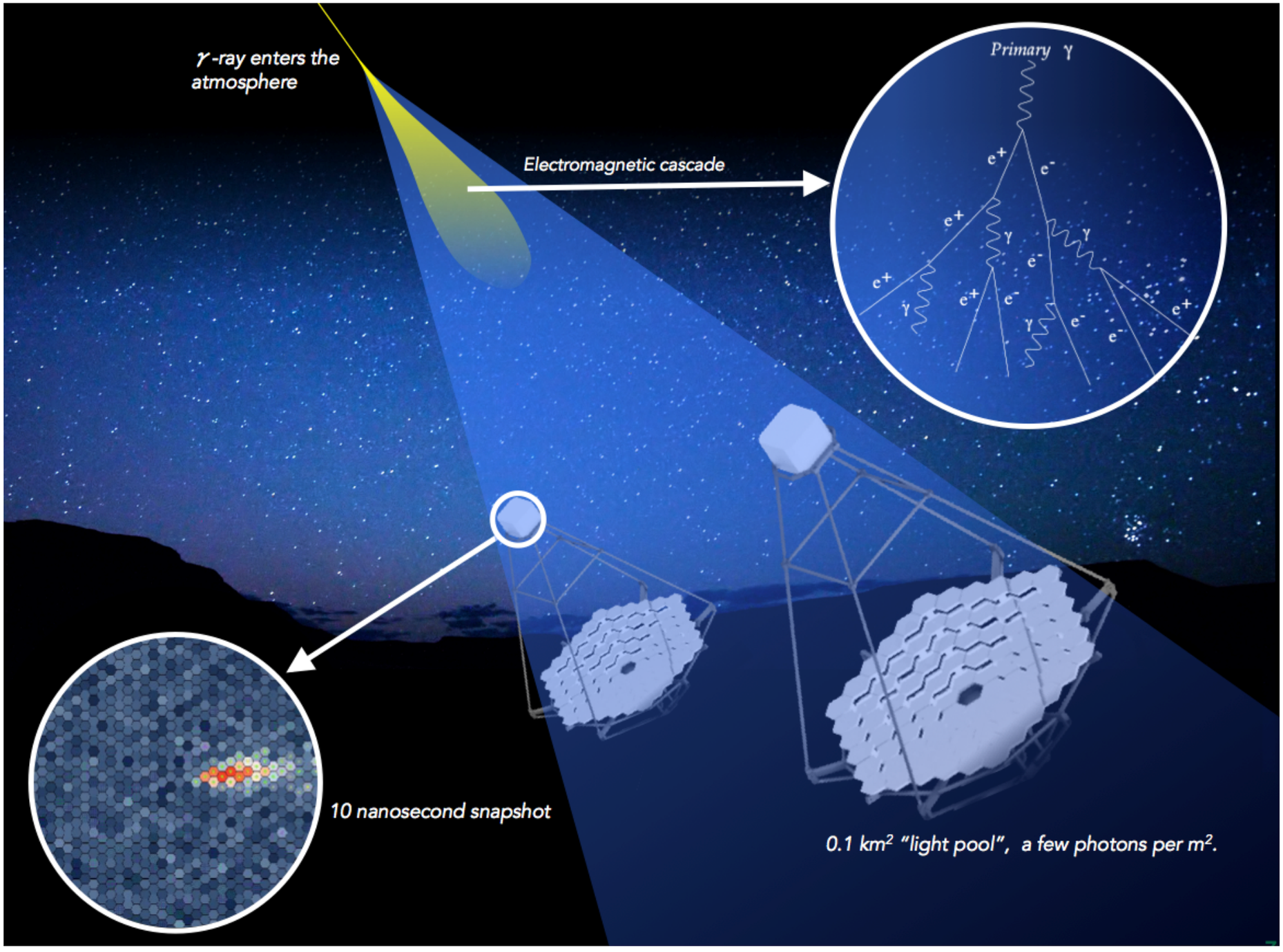
HAWC



www.hawc-observatory.org

Imaging Air-Cherenkov Telescopes (IACTs)

- Collects the Cherenkov light in the atmosphere
- Individual telescopes

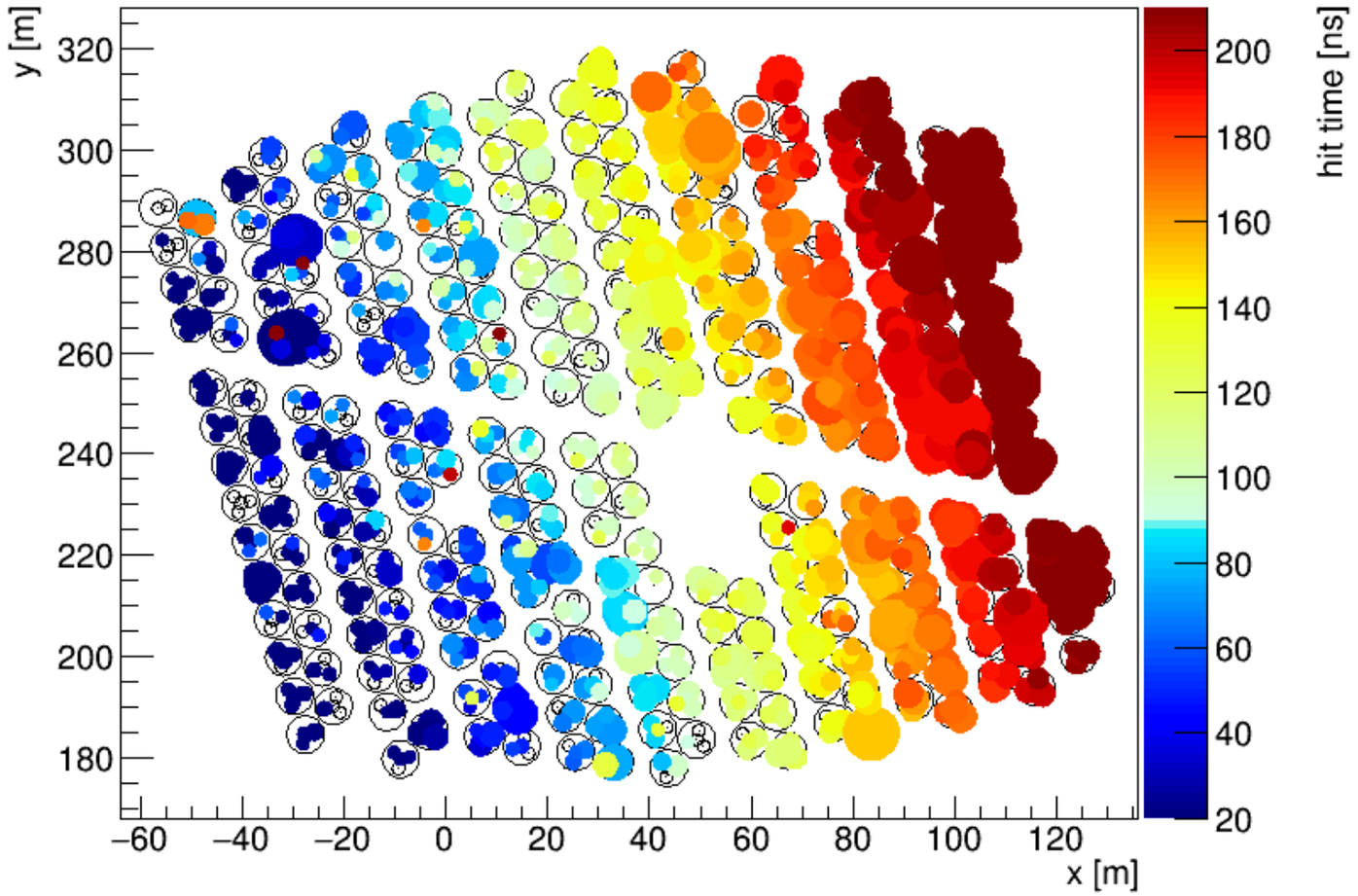


Wide-Field of view Detectors (WFD)

- Collects the Cherenkov light in the contained water (or a specific medium)

- Extended array of several detectors

www.hawc-observatory.org



Comparison between Techniques

Imaging Air-Cherenkov Telescopes (IACTs)

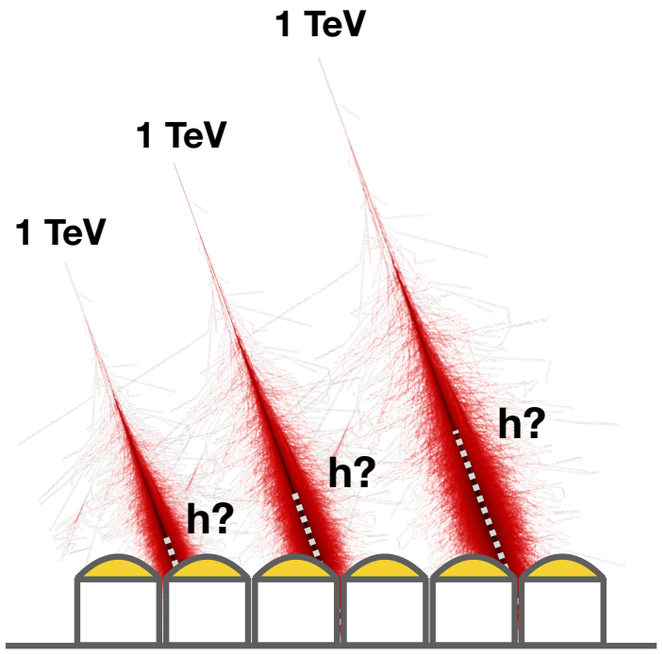
- Telescopes of ~ 5 m up to ~ 25 m diameter
- Collects the Cherenkov light produced in the atmosphere
- Duty cycle: $5\,\% \sim 10\,\%$
- Specific environmental conditions
  - No sunlight, no moonlight, no rain, no snow, no clouds, no near artificial lights, no albedo; just clear nights
- Angular resolution: $\sim 0.01^{\circ}$
- Energy range: from 20 GeV up to 30 TeV
- Point-like sources
- No simultaneously observation
- High cost of production

Wide-Field of view Detectors (WFD)

- Extended arrays of detectors (hundreds of m^2)
- Collects the Cherenkov light produced in the water (or another medium)
- Duty cycle: $> 95\,\%$
- No specific environmental conditions
- Angular resolution: $\sim 0.1^{\circ}$
- Energy range: from 100 GeV up to 100 TeV
- Extended sources
- Simultaneously observation
- High cost of production

HYBRID DETECTION

Extensive Air-Shower Detector

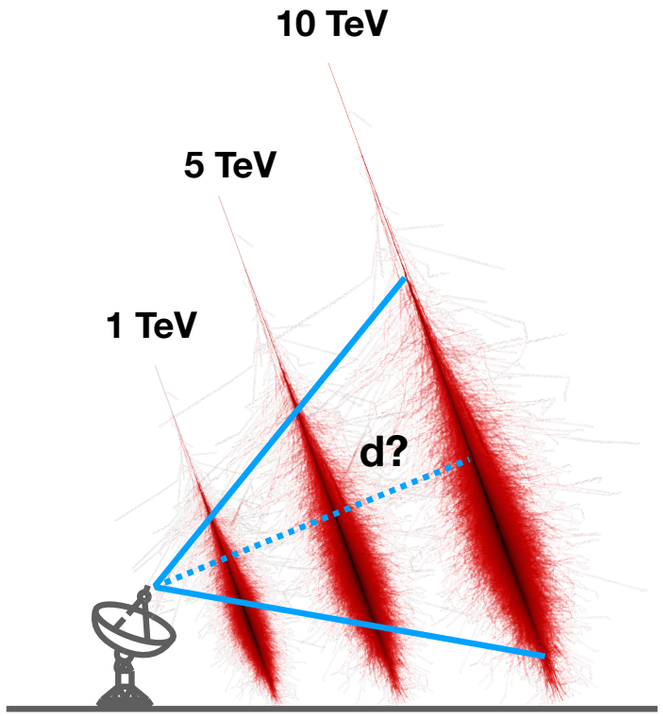


Identical air-showers at different heights (h)

- Different signals

+

Imaging Air-Cherenkov Telescope

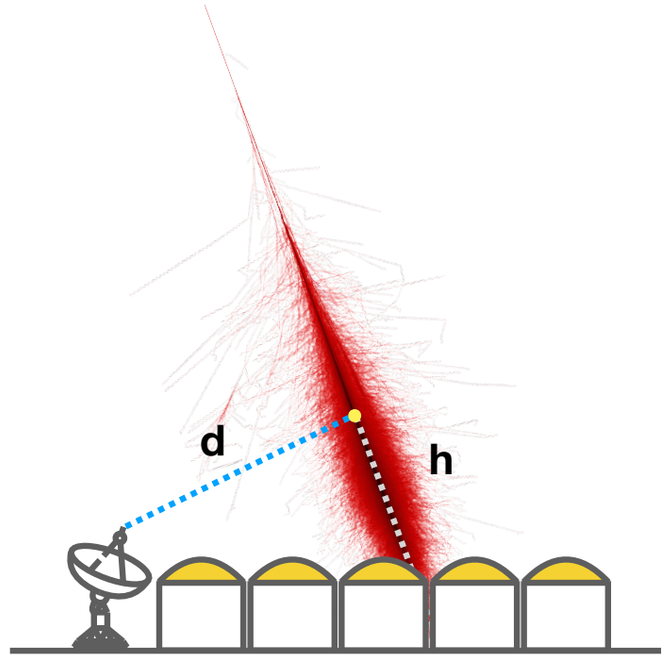


Different air-showers at different distances (d)

- Similar signals

=

Hybrid Detector



Resolved ambiguities

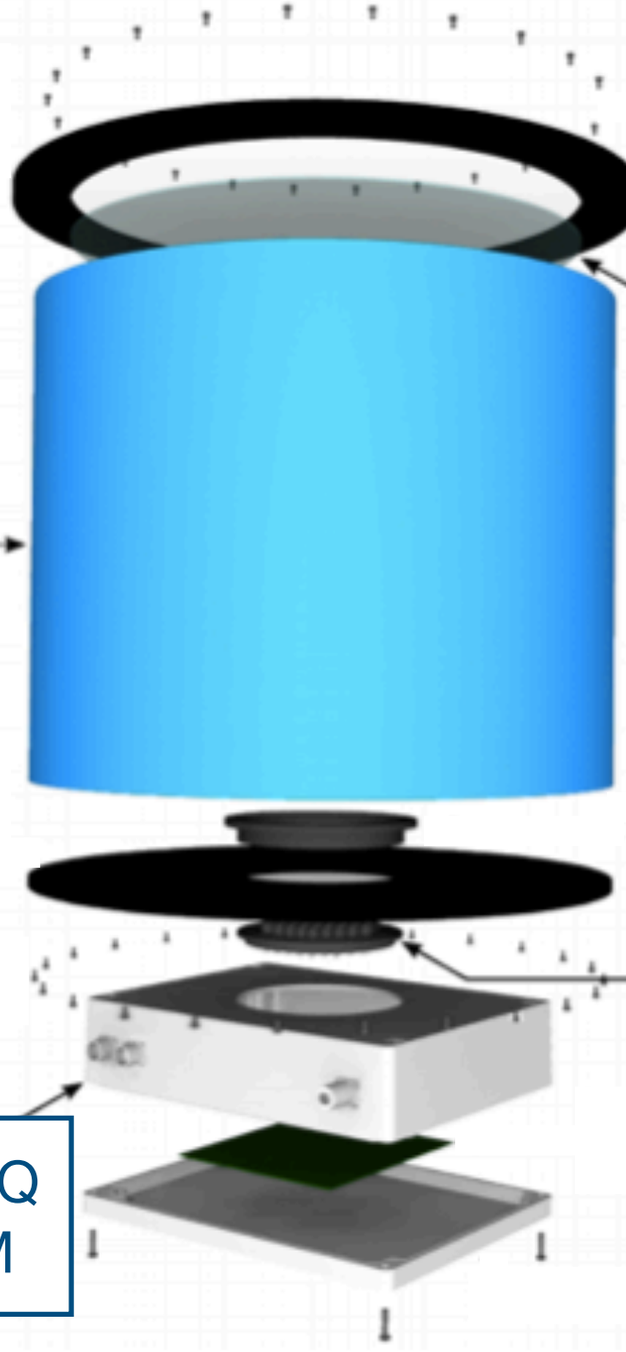
- Better energy resolution
- Beter angular resolution
- Better particle identification

The main problem to develop this hybrid technique is the high cost of production

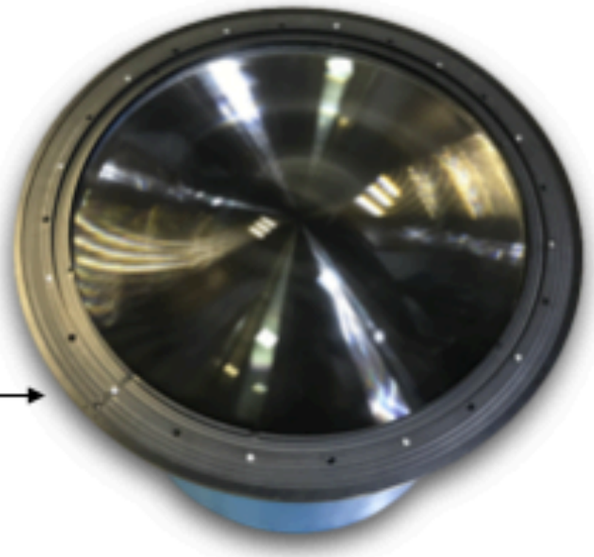
HAWC'S EYE

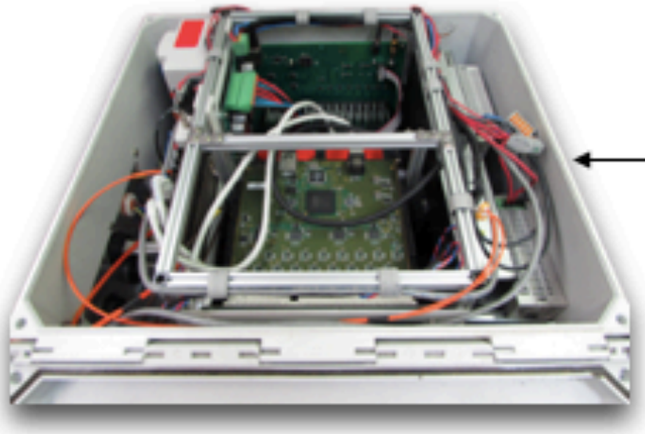
Proposal of a **LOW-COST COMPACT REFRACTIVE** IACT

CARBON FIBER LENS BARREL



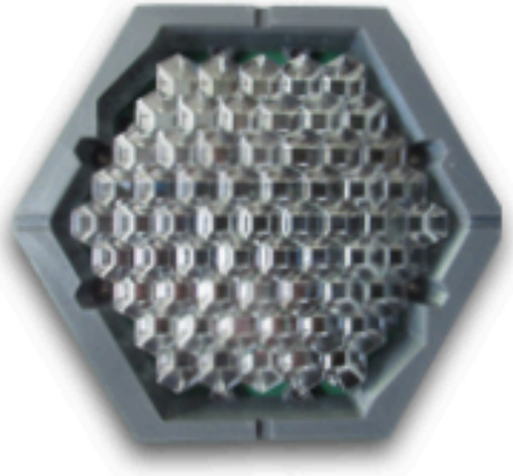
FRESNEL LENS





FACT DAQ SYSTEM

61(+3) SiPM-BASED PIXELS



~ 10,000 **eur each telescope!**

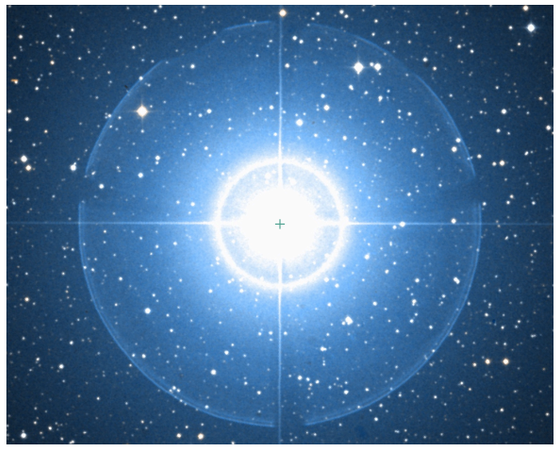
HAWC'S EYE

- 2 functional HAWC's Eye telescopes located at the HAWC observatory (4,100 m a.s.l.)
- 4 successful observation campaigns done

Photo: Jesús Martínez

Photo: José Serna

HAWC'S EYE PERFORMANCE

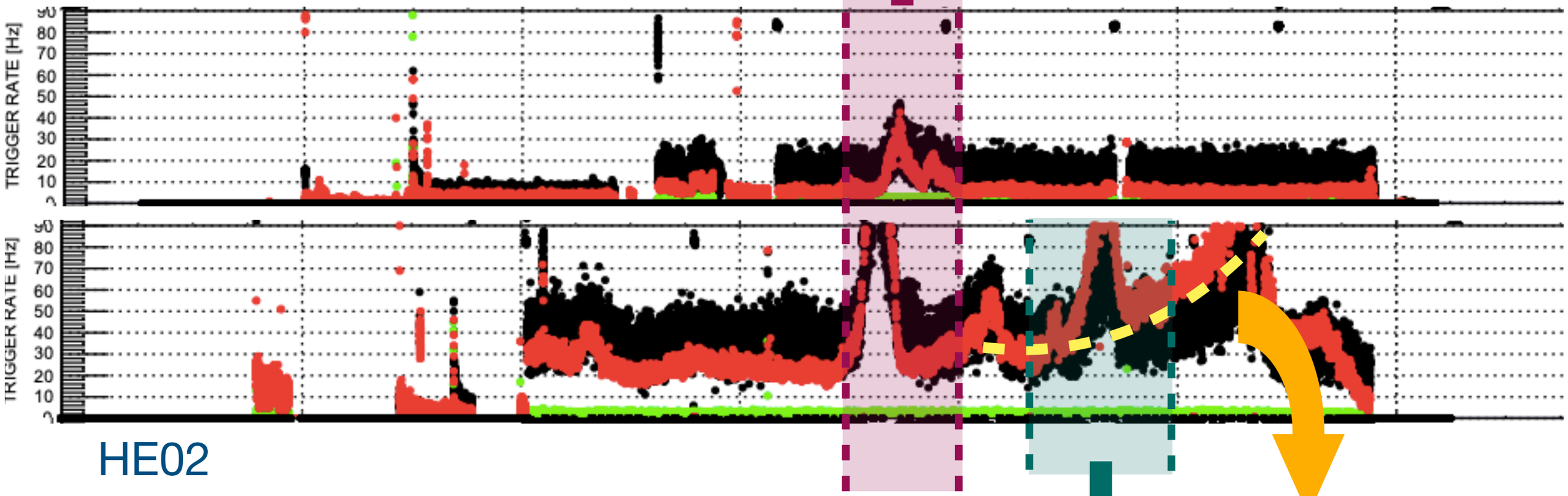


https://simbad.unistra.fr/simbad/

Optical noise due to Zeta Tauri

Different optical noise for each telescope due to their positions in the site

HE01



HE02

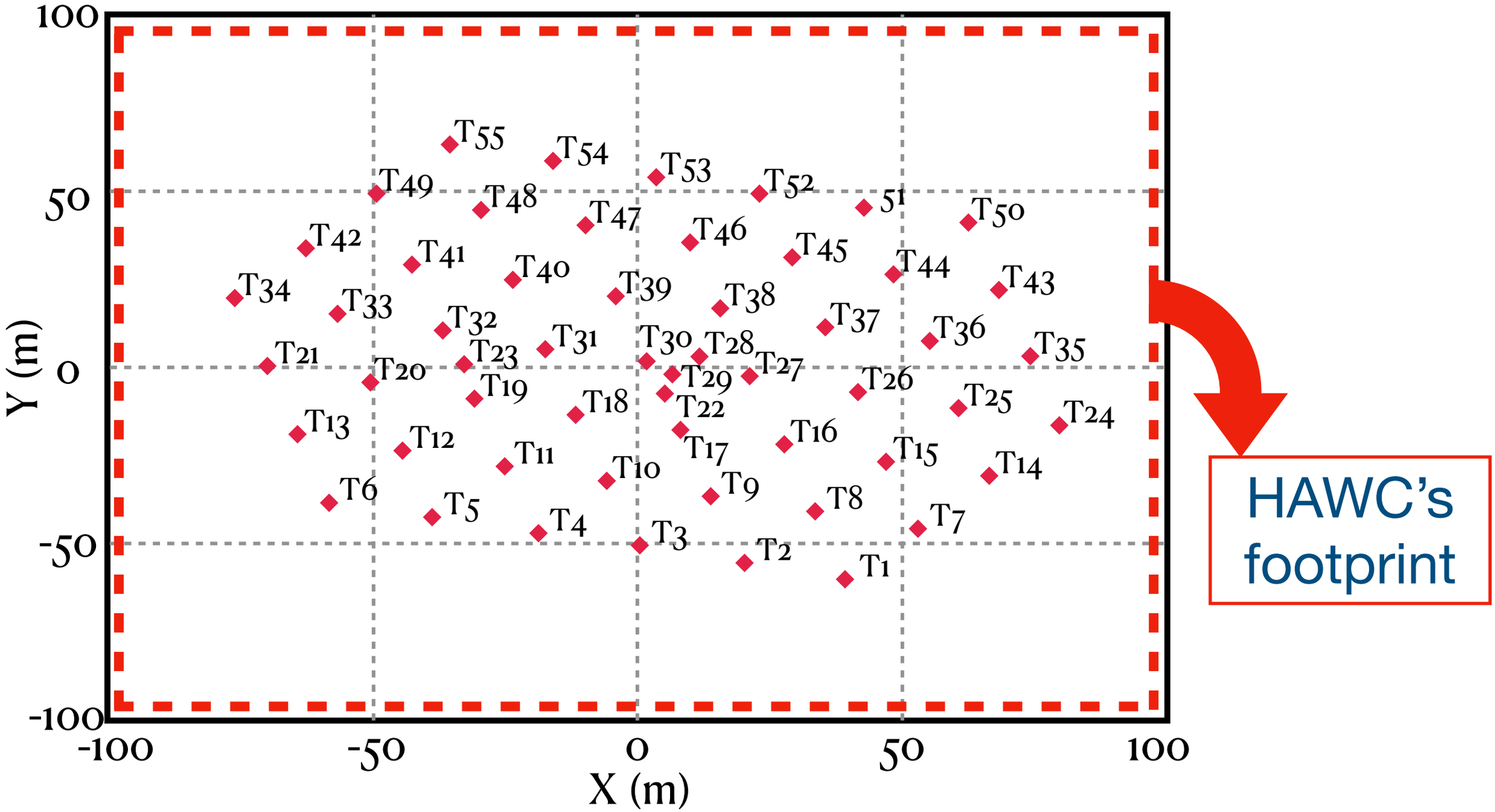
Noise due to more optical stars

Increasing baseline due to moonrise

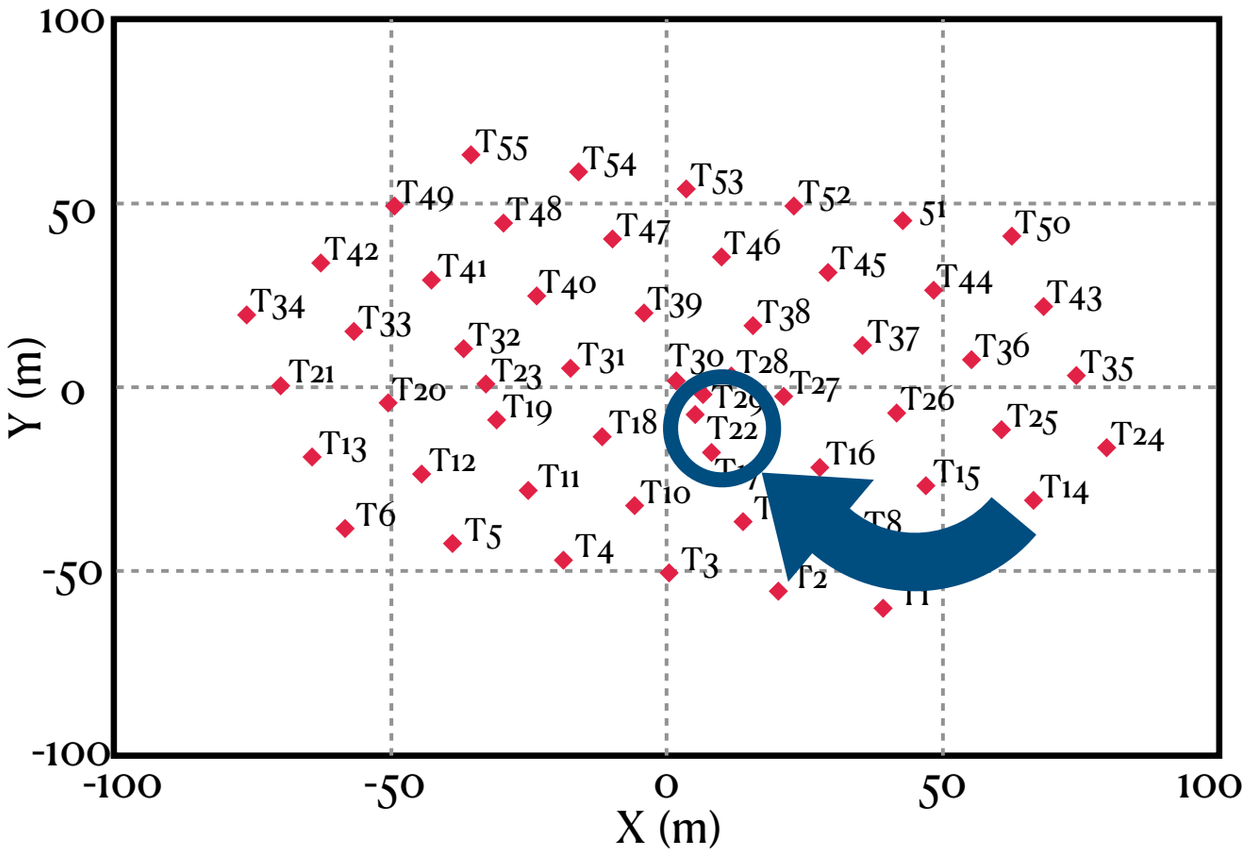
Excellent performance in single (1 telescope), stereo (2 telescopes) and hybrid (+ HAWC) performance (Do, 2021; Serna-Franco, 2022)

HAWC'S EYE ARRAY

Due to the good results during the observation campaigns, we simulate a 55 HAWC's Eye telescopes array at high altitude (4,100 m a.s.l. as HAWC)

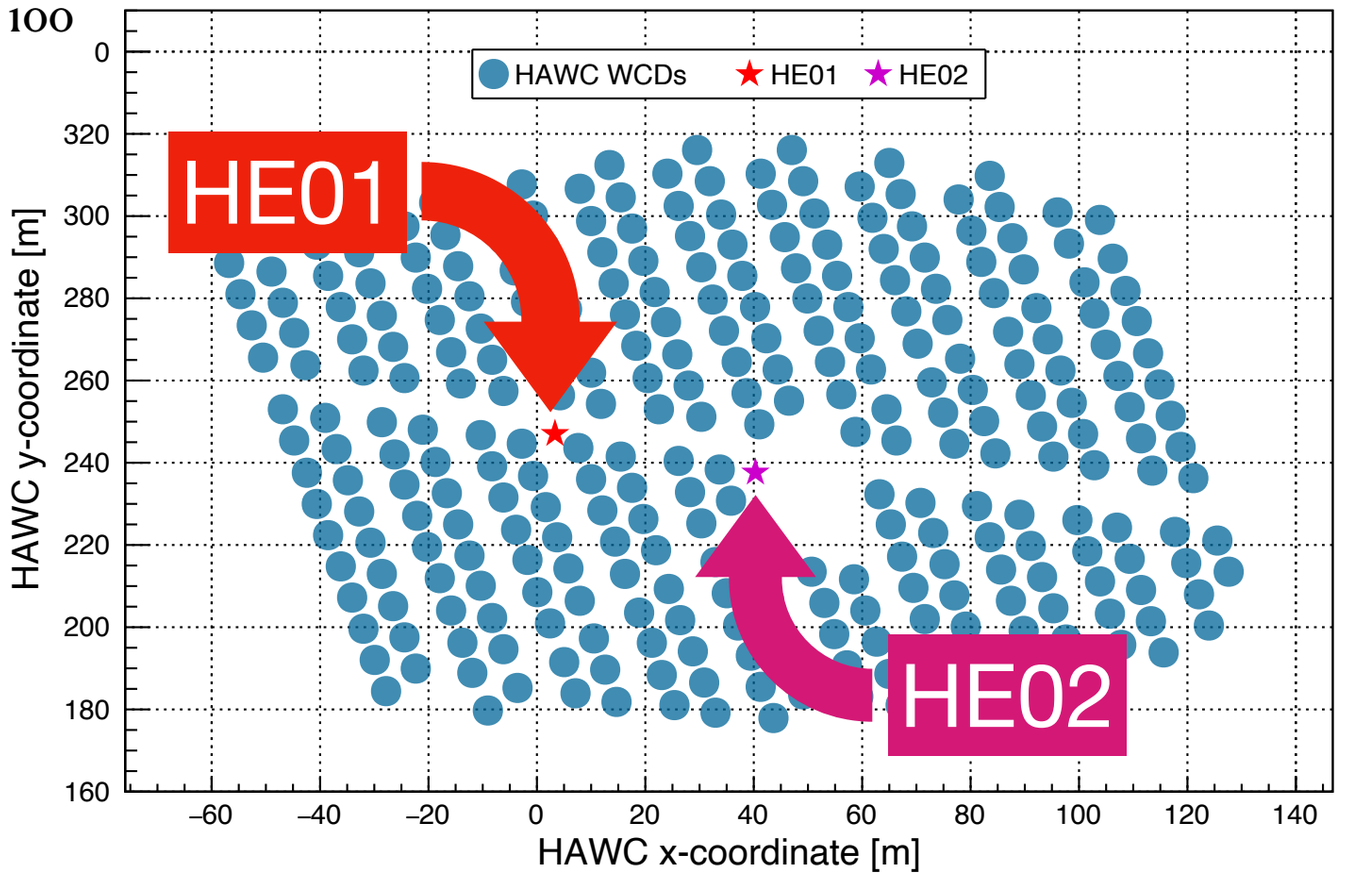


COMPARISON CHARACTERISTICS



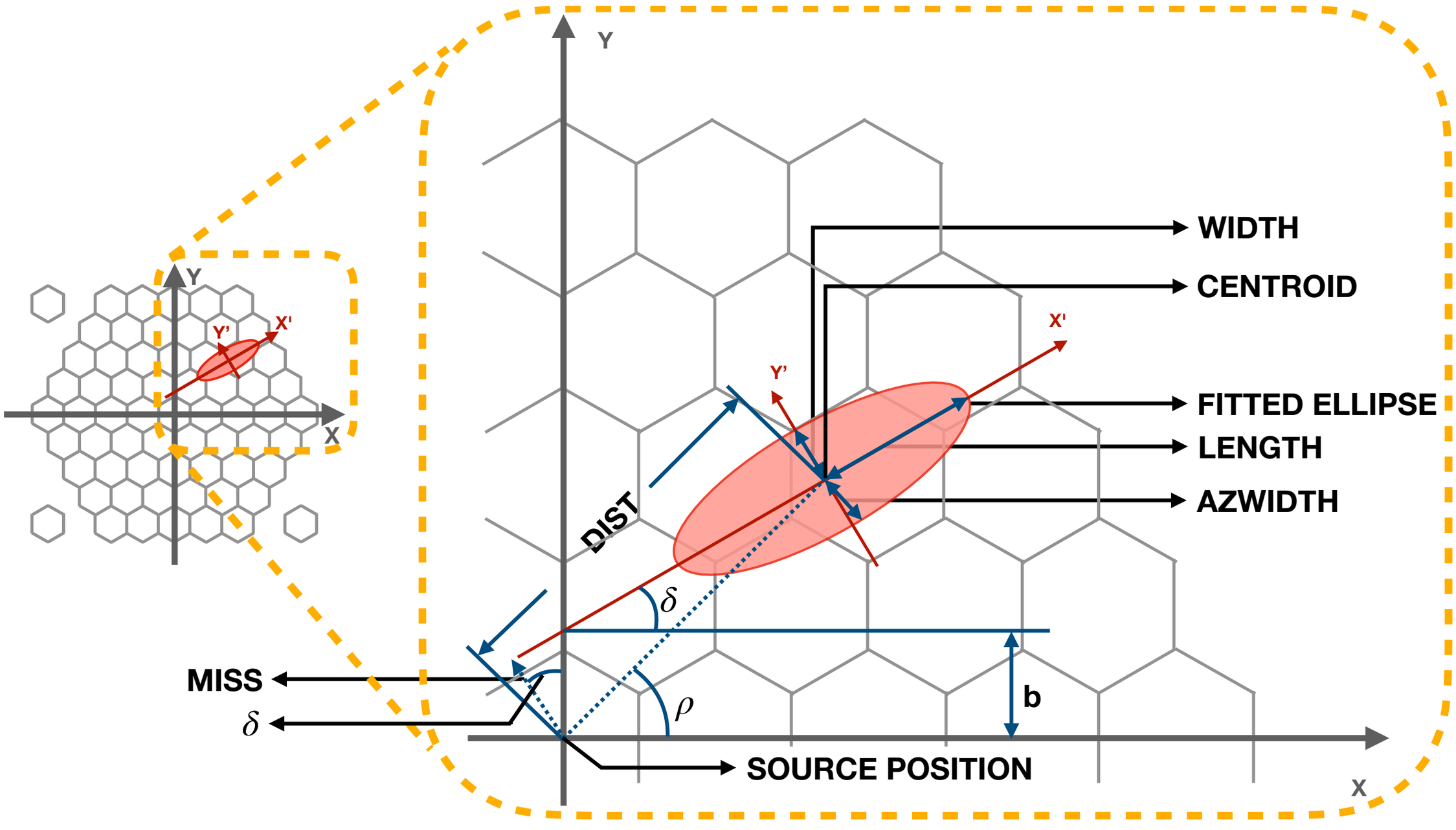
The performance of the telescopes are independent of the position in the array

- The T22 has the same position that HE02 in the HAWC's coordinates
- The telescope T22 was selected to make the comparison between data and simulations



DATA VS. SIMULATIONS

The **Hillas parameters** were used to compare the simulated performance of the telescopes with the real data

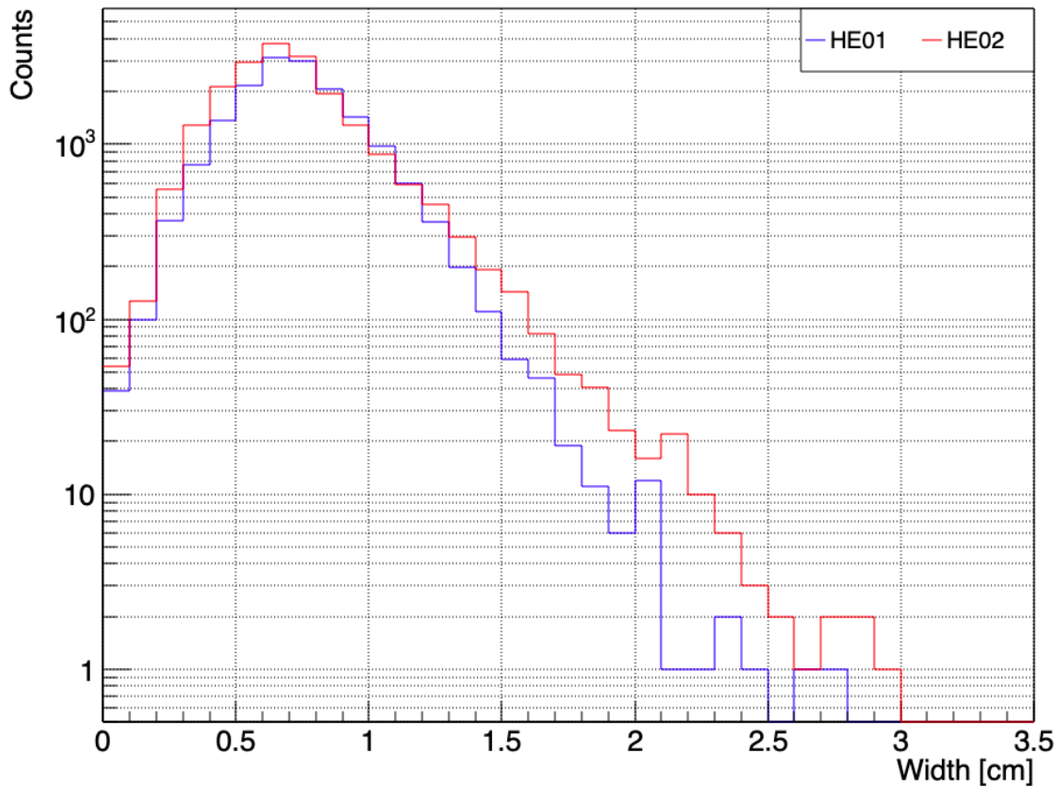


WIDTH COMPARISON

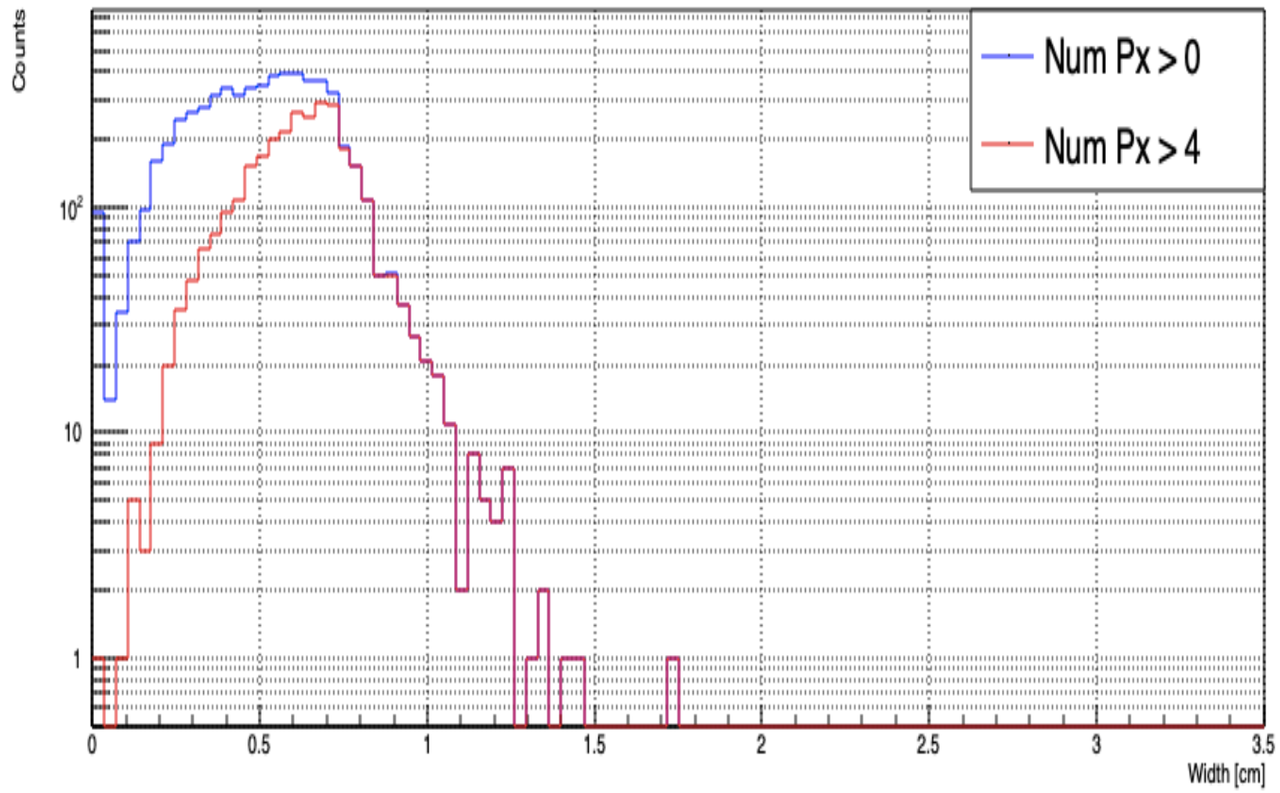
Width parameter distribution

Quality cut: event's images with > 4 pixels

Data



Simulations



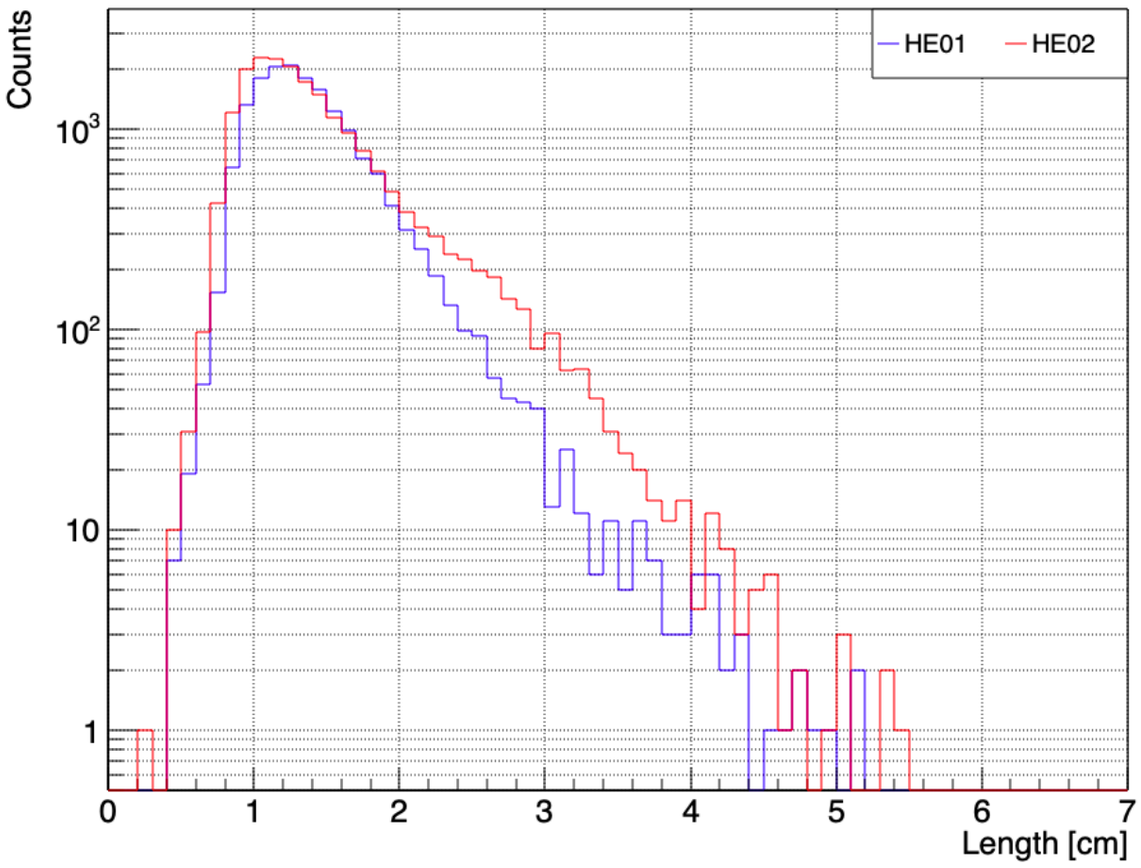
Reconstruction of simulated parameters **consistent** with the reconstruction of observational data

LENGTH COMPARISON

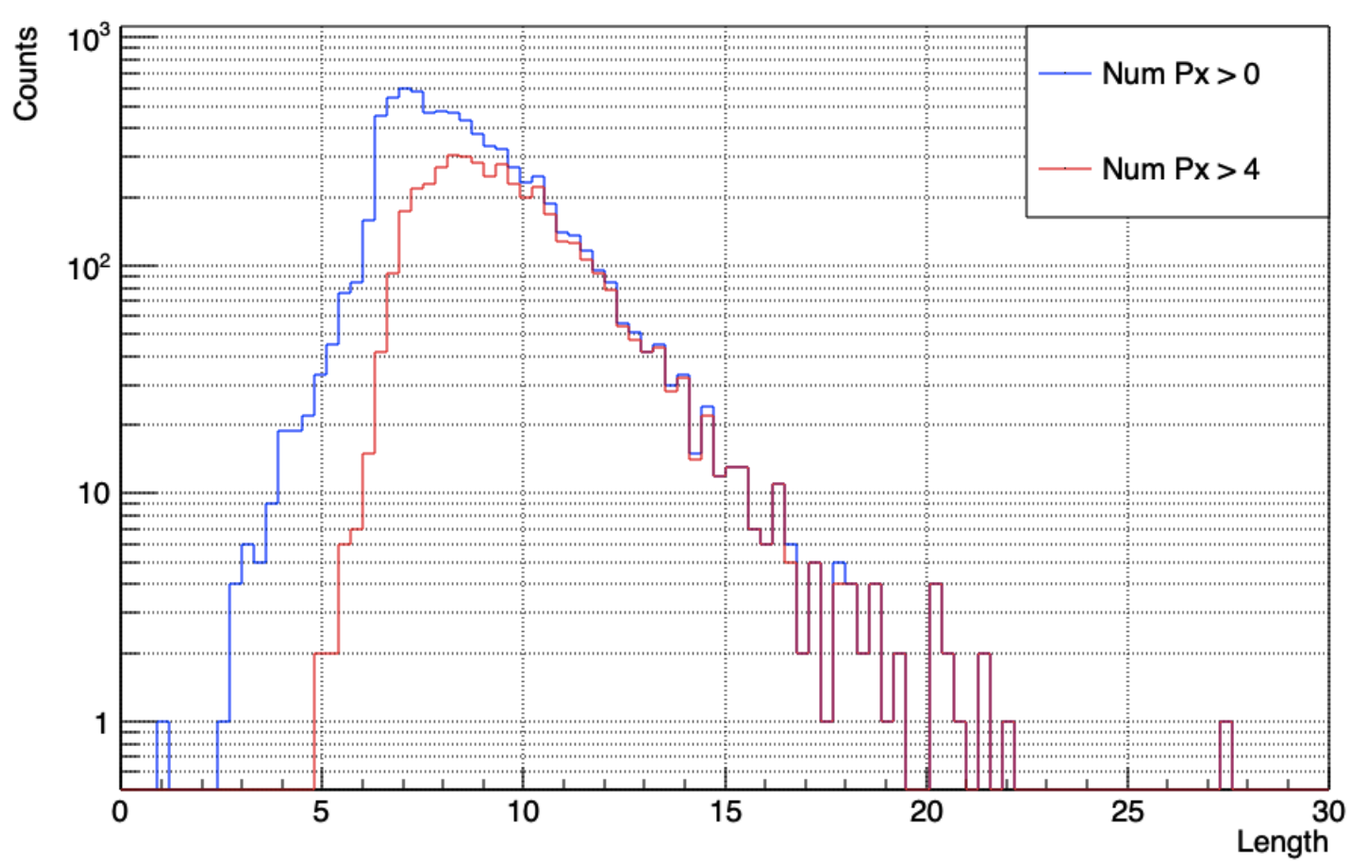
Length parameter distribution

Quality cut: event's images with > 4 pixels

Data



Simulations



Reconstruction of simulated parameters **consistent** with the reconstruction of observational data

CONCLUSIONS

- **Low-cost, compact IACT** functional prototype ***HAWC's Eye*** with a new observation technique: **refractive telescope**
- **Two functional telescopes** already deployed at the HAWC observatory (4,100 m a.s.l.)
- An **array of 55 HAWC's Eye** was simulated at high altitude
- The simulated performance is **consistent** with the observational data
- Promising candidate as an **extension for WFD**
  - **Gamma-rays**: HAWC & SWGO (*HAWC's Eye*)
  - **Neutrinos**: IceCube (*IceAct*)
  - **Cosmic-rays**: TAIGA (*TAIGA's Eye*)

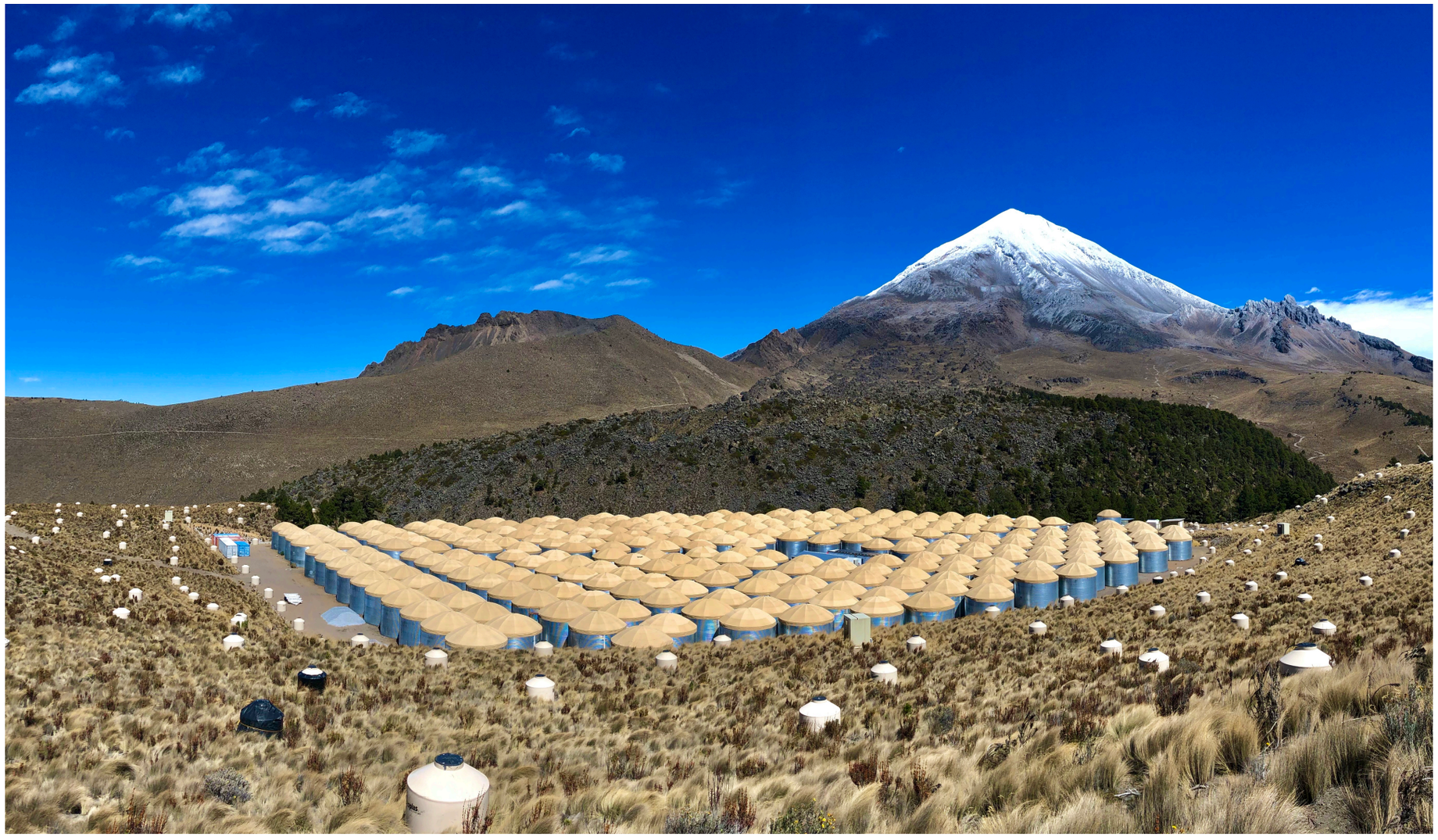
Backup Slides

The HAWC Observatory

- Located at Volcán Sierra Negra, Mexico
- Altitude: 4,100 m a.s.l.
- Duty cycle > 95%
- 300 Water-Cherenkov Detectors (WCD) and 350 outriggers

- WCD size: 7.3 m diameter and 5 m high
- WCD capacity: 200,00 L each
- 1,200 PhotoMultiplier Tubes (PMTs)
  - 4 PMTs inside each WCD
- Energy range: from 300 GeV to 250 TeV

- Angular resolution $\sim 0.1°$
- Instantaneously FoV of 2 sr
  - 2/3 of the visible sky
- HAWC's footprint:
  $\sim 22{,}000$ m^2
  ($\sim 100{,}000$ m^2 with the outriggers)



hawc-observatory.org

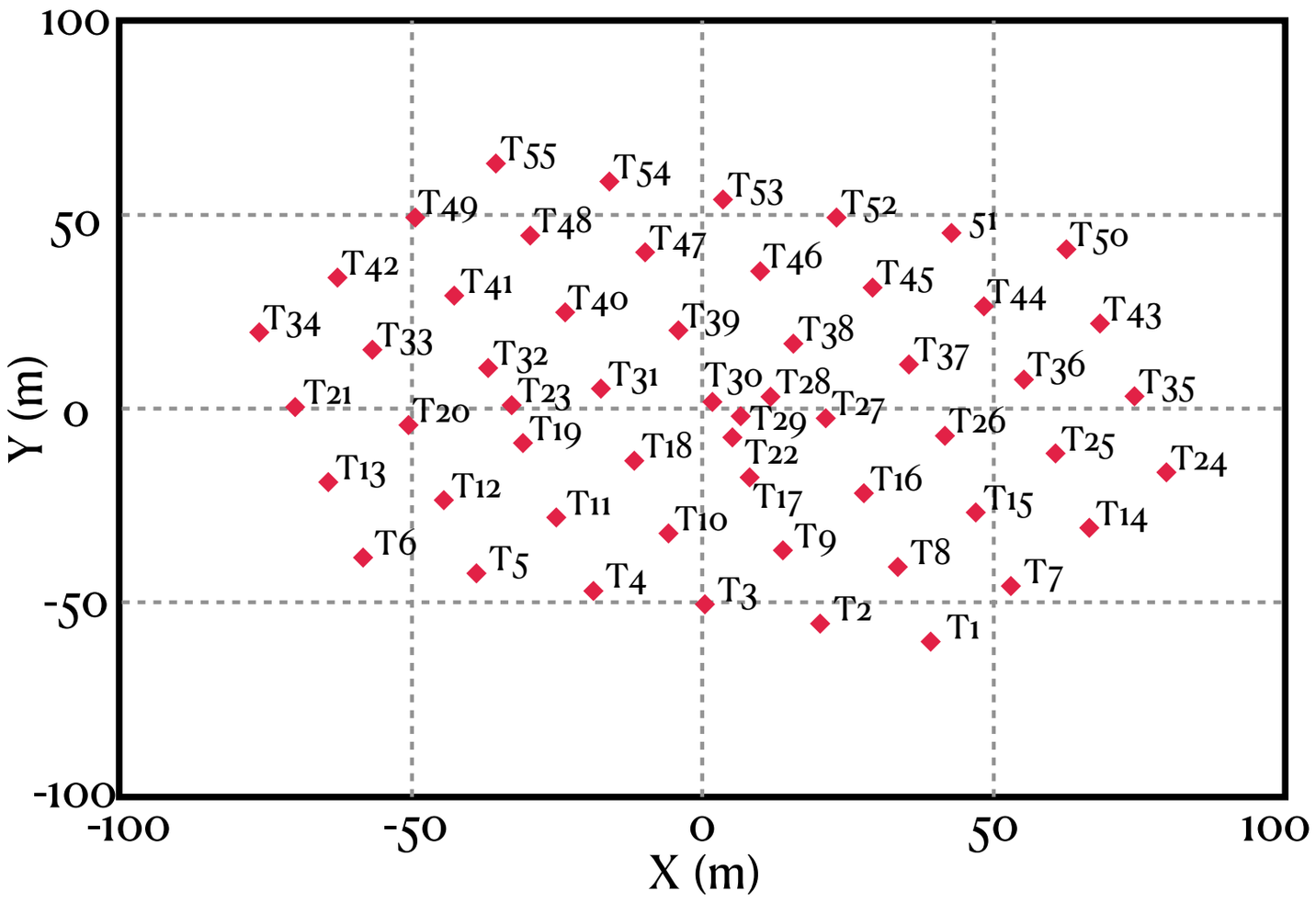
HAWC's Eye

Photo: Jesús Martínez

- Compact IACT (Bretz, 2018)
- Fresnel lens $f \approx D \approx 0.5$ m
- Camera: 61(+3) SiPMs SenseL MicroFJ based pixels
- Solid PMMA hex-to-square light-guides (Winston cones)
  - 100% collection area covered
- FoV: 1.5°/Px $\sim 12^\circ$ total
- FACT DAQ system (Anderhub, 2013)
- 72 DRS4 DAQ channels
- Remote control
- Cost: $\sim 10{,}000$ eur per telescope

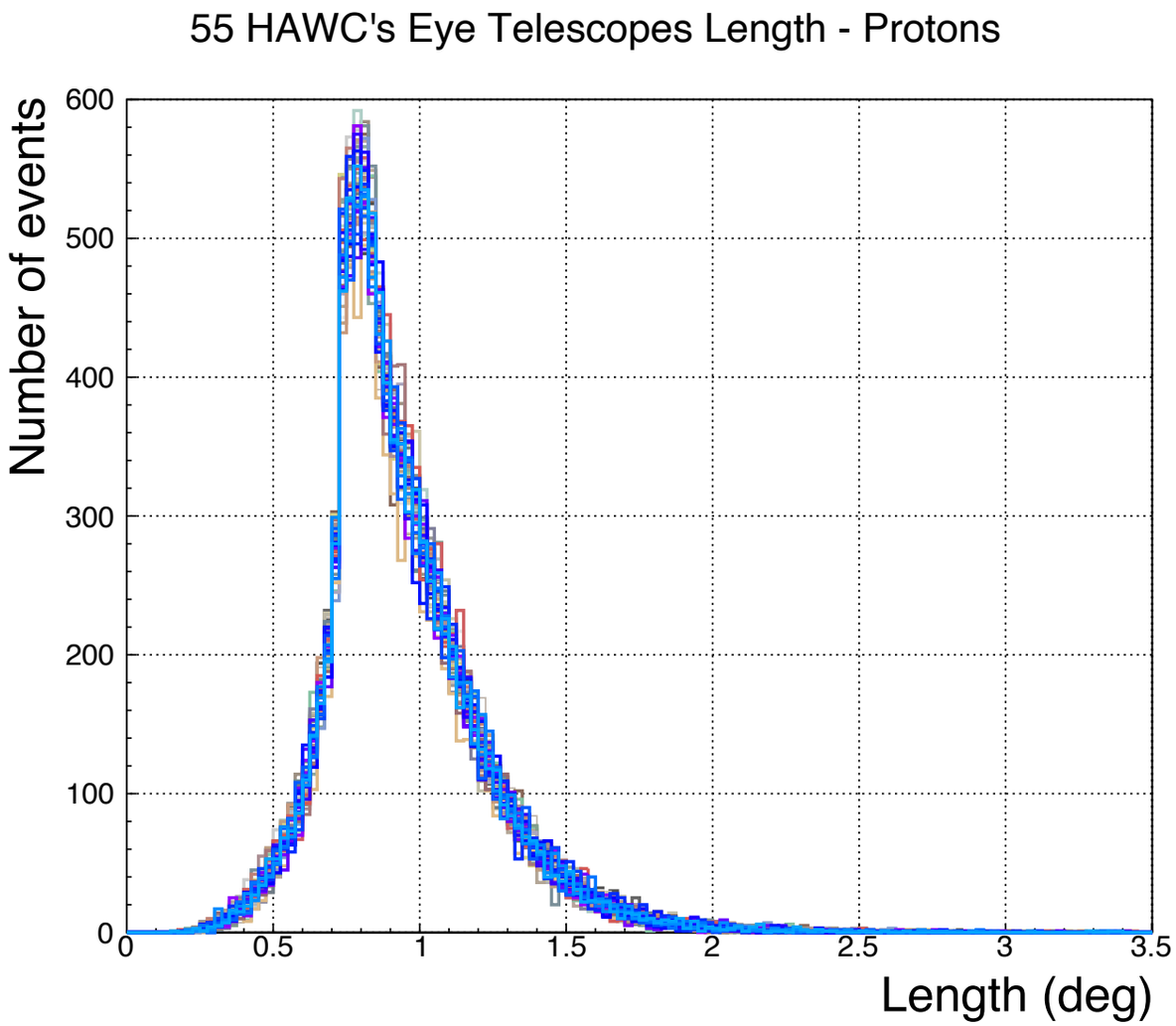
HAWC's Eye Array Simulation Setup

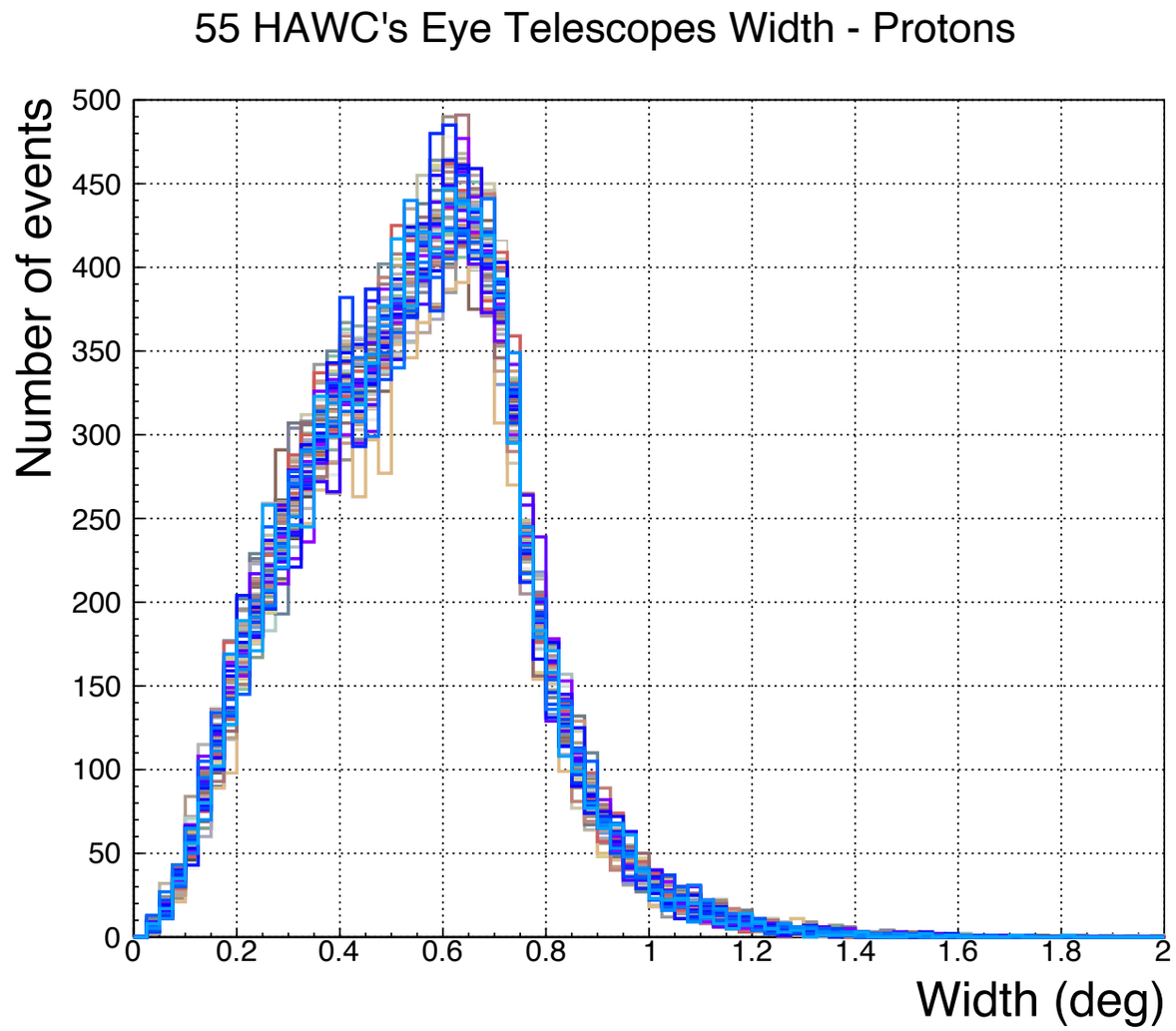
- Simulated performance of the 55 telescopes in the array
- Extensive air-showers simulated with CORSIKA v7.69
  - Showers induced by protons
- > 3 millions of events simulated
- Energy range: 1 TeV to 100 TeV
- Altitude 4,100 m a.s.l (as HAWC)
- Atmosphere model: *US standard atmosphere (7)*



- Vision cone: $8°$
- Dispersion area of the simulated showers: 500×500 m^2
- Data analysis made with *MARS*

Hillas Parameters Reconstruction

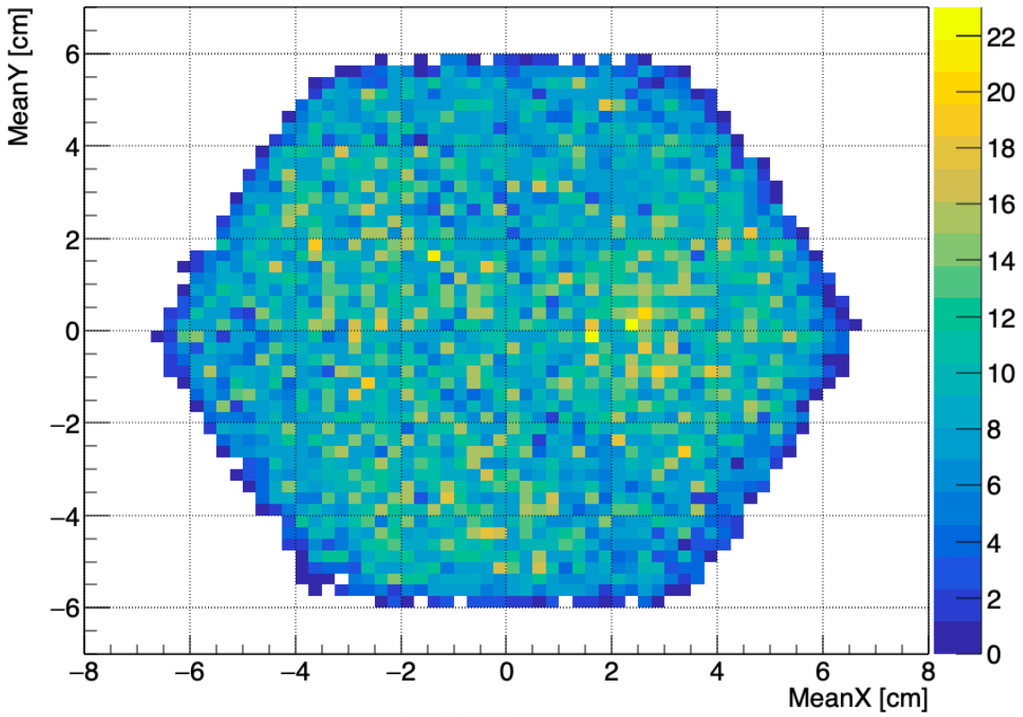




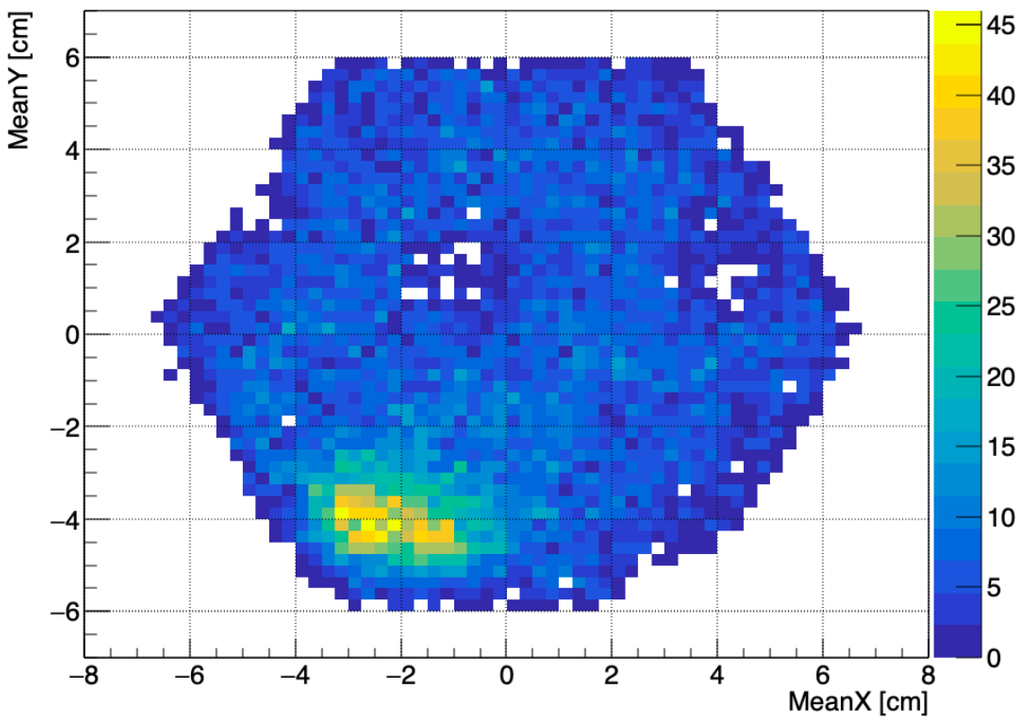
No significant deviations of the Hillas parameters between telescopes are no visible as expected (Serna-Franco, 2021)

Event Cores' Distribution in the Cameras

HE01



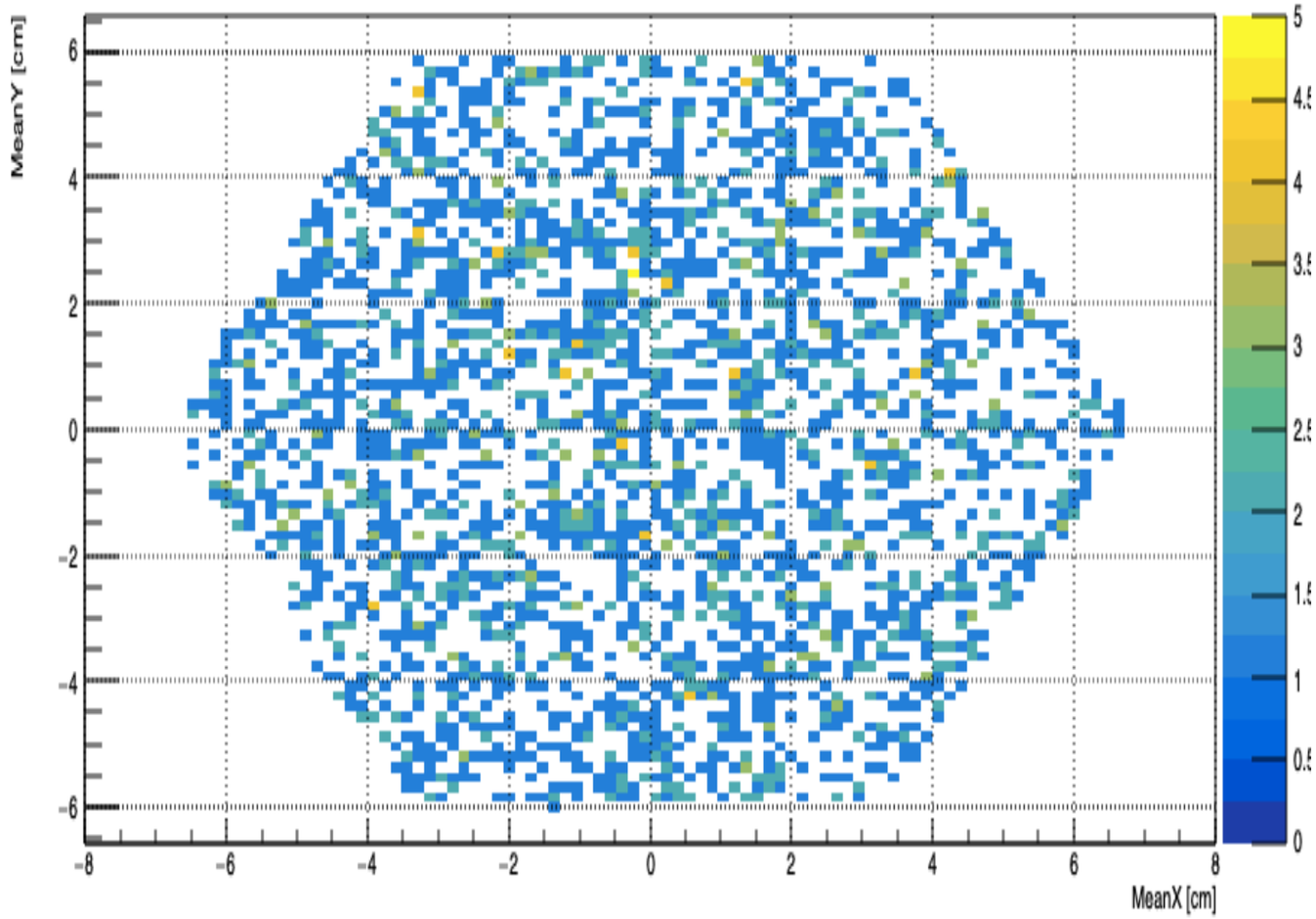
HE02



Distribution of the event's cores in the camera

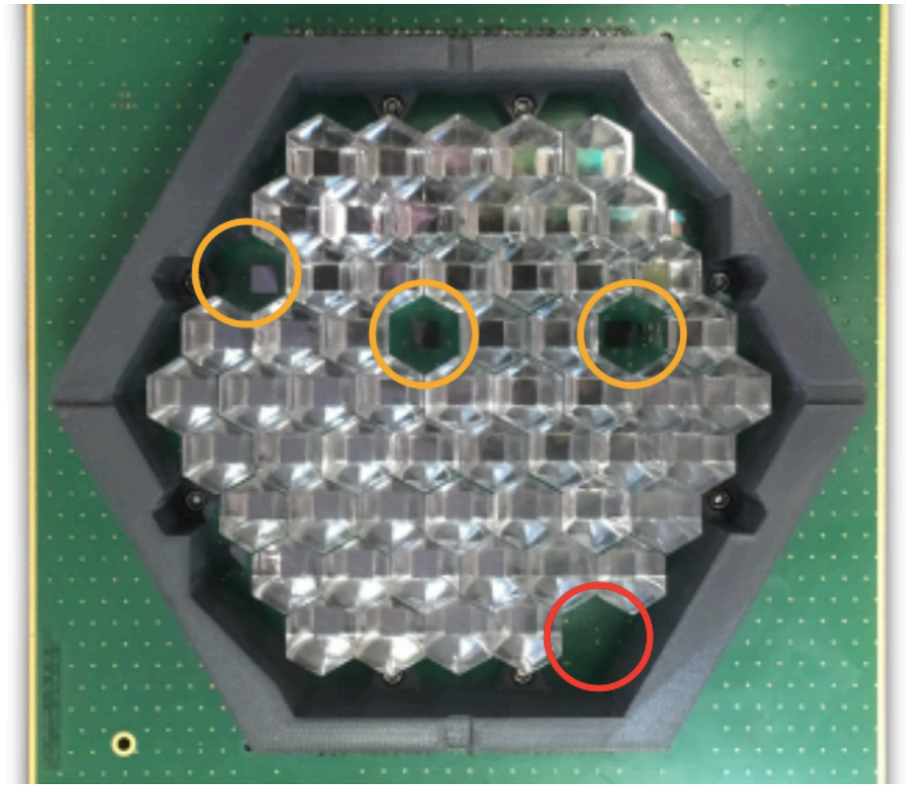
Quality cut: event's images with > 4 pixels

Simulations

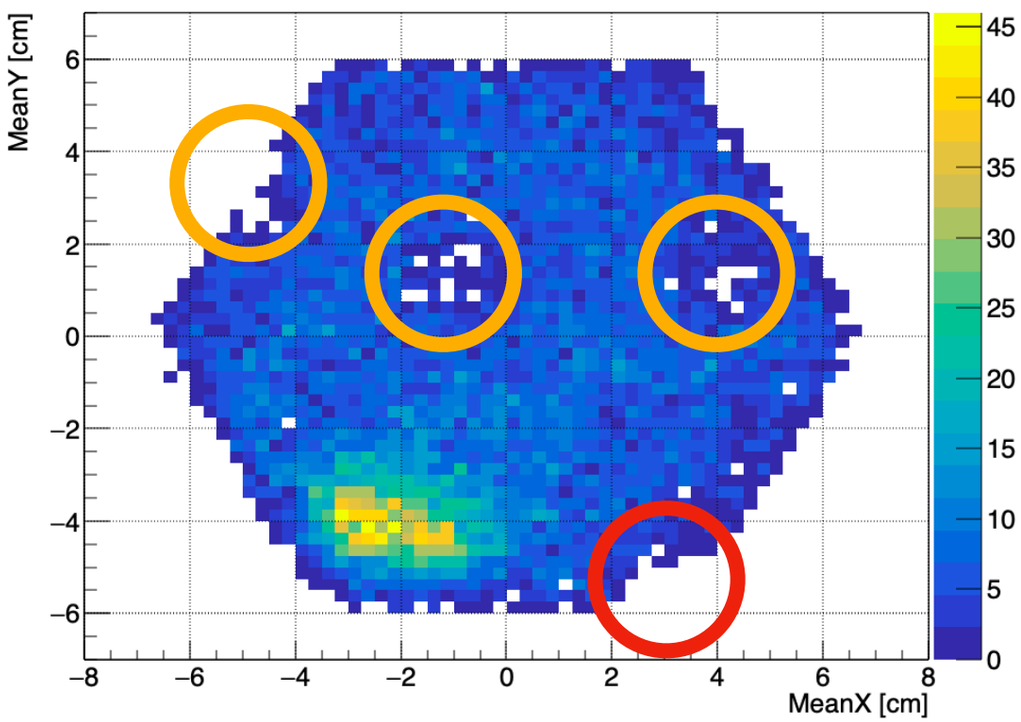


Similar results between data and simulations, but more simulated events needed

Comparison of Variables



HE02



HE02 discrepancies

Low-signal spots consistent with hardware issues (as expected)

A high-signal spot appeared and it is due to a calibration problem in a pixel (or neighborhood pixels)

All the differences can be explained by calibration or hardware issues