IMPLEMENTATION OF AN HYBRID SYSTEM FOR THE DETECTION OF HIGH ENERGY GAMMA RAYS WITH THE COMPACT IACTS HAWC'S EYE AND THE HAWC OBSERVATORY FOR HIGH ENERGY GAMMA RAYS

JOSÉ SERNA[1]

RUBÉN ALFARO[1], JAN AUDEHM[2], THOMAS BRETZ[2], OSCAR CHAPARRO[3], GIANG DO[2], MAGDALENA GONZÁLEZ[4], ARTURO IRIARTE[4], ALBERTO MALDONADO[3], JESÚS MARTÍNEZ[3], MIGUEL MARTÍNEZ[3], YUNIOR PÉREZ[4], FLORIAN REHBEIN[2], MERLIN SCHAUFEL[5] AND IBRAHIM TORRES[6]

[1]INSTITUTO DE FÍSICA, UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO, MEXICO

[2]III. PHYSICS INSTITUTE A. RWTH AACHEN UNIVERSITY, GERMANY

[3]CENTRO DE INVESTIGACIÓN EN COMPUTACIÓN, INSTITUTO POLITÉCNICO NACIONAL, MEXICO

[4]INSTITUTO DE ASTRONOMÍA, UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO, MEXICO

[5]III. PHYSICS INSTITUTE B. RWTH AACHEN UNIVERSITY, GERMANY

[6]INSTITUTO NACIONAL DE ASTROFÍSICA, ÓPTICA Y ELECTRÓNICA, MEXICO

2020 MEETING OF THE COSMIC RAY DIVISION OF THE MEXICAN PHYSICAL SOCIETY

MONDAY 23, 2020

CONTENT

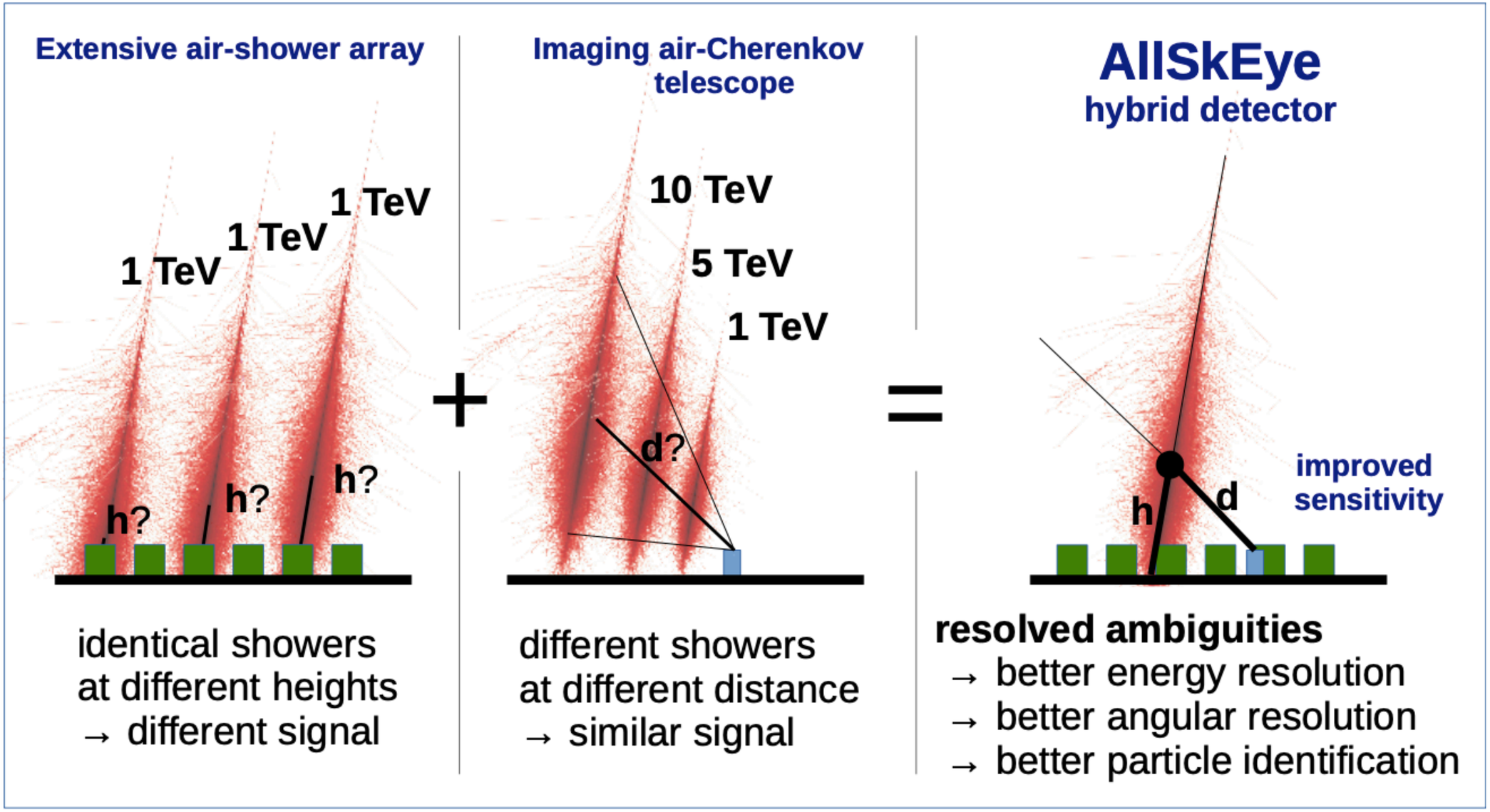
GAMMA-RAYS GROUND-BASED EXPERIMENTS

- Extensive air-shower array
  - Energy range: ~300 GeV to ~100 TeV
  - Its operation do not depends on the weather
  - Duty cycle $> 95\,\%$
  - Angular resolution $\geq 0.1^{\circ}$
    - Extended sources
  - Complete scan of the sky

- Hybrid experiment
  - Energy range: ~10 GeV to ~100 TeV
  - Its operation partially depends on the weather
  - Total duty cycle $> 95\,\%$
  - Angular resolution $\geq 0.01^{\circ}$
    - Point and extended sources

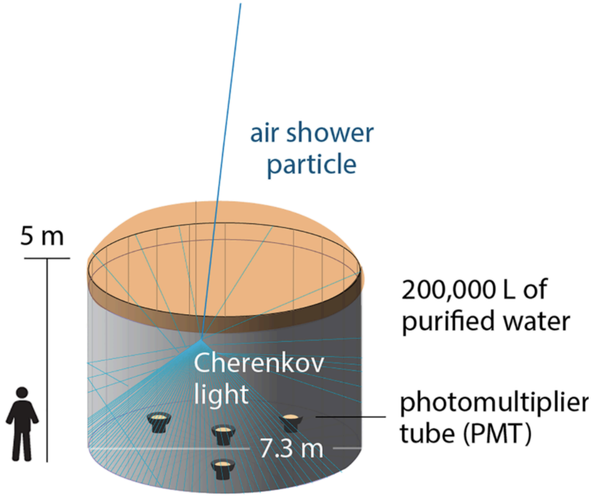
- Imaging Air Cherenkov Telescope
  - Energy range: ~10 GeV to ~10 TeV
  - Its operation depends of the weather
    - Functional just at clear dark nights
  - Duty cycle: $5\% - 10\,\%$
  - Angular resolution $\geq 0.01^{\circ}$
    - Point sources
  - Partially scan of the sky

HYBRID DETECTION: EXTENDED ARRAY + IACT



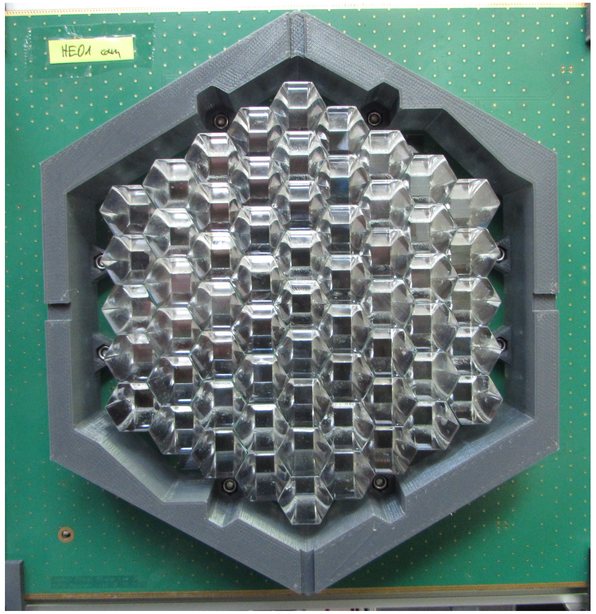
HAWC GAMMA-RAY OBSERVATORY

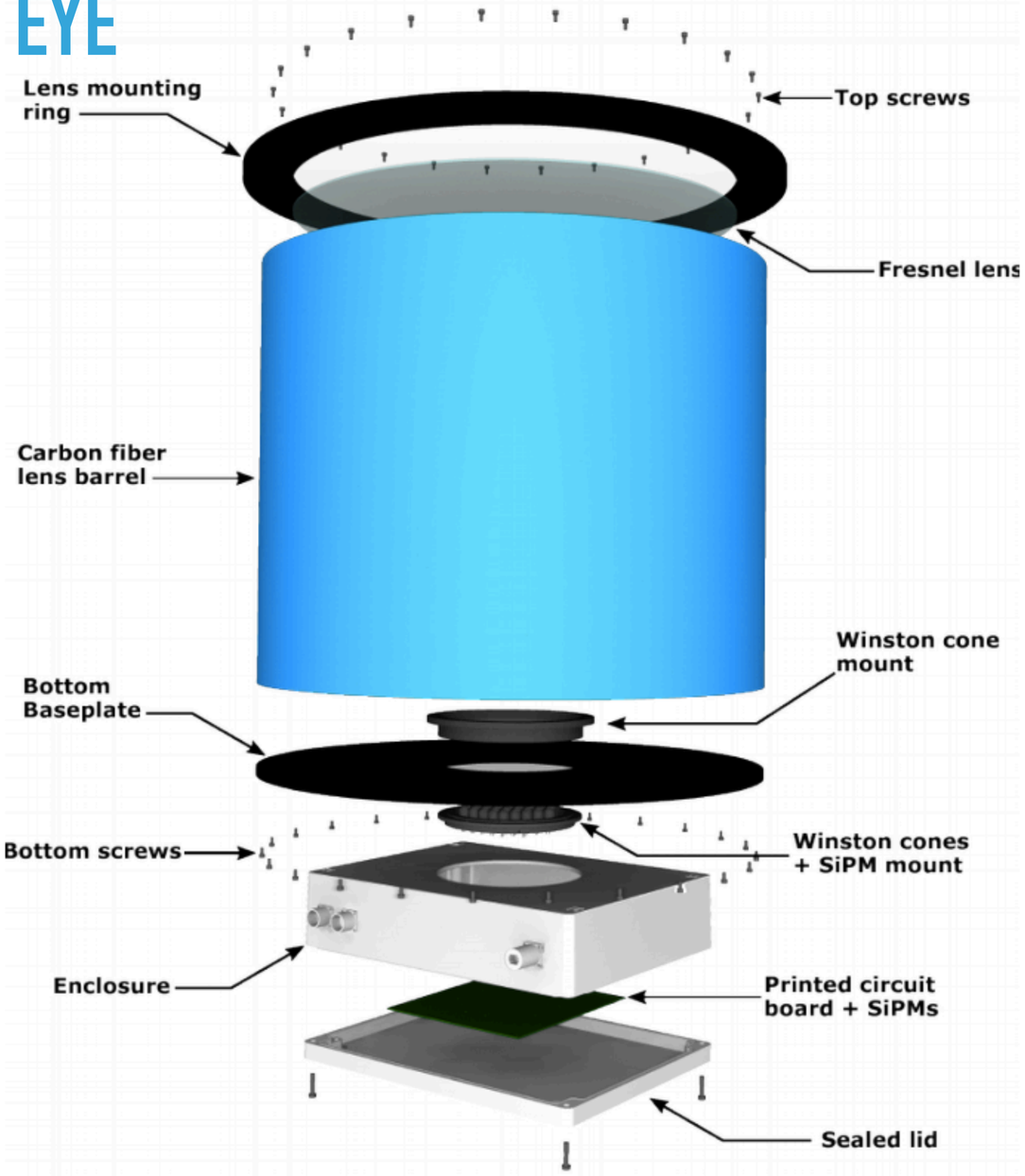
- Extensive air-shower array
- Located in Sierra Negra, Mexico
- 300 Water Cherenkov Detectors (WCD)
  - 7.3 m diameter × 5 m depth
  - 200,000 L per WCD
- Energy range: 300 GeV to 100 TeV
- Altitude: 4,100 m asl
- Instantaneous FoV: 2 sr
- Duty cycle $> 95\,\%$
- Angular resolution $\geq 0.1^{\circ}$
- Footprint of HAWC $\sim 22{,}000\ \mathrm{m}^2$



IMAGING AIR CHERENKOV TELESCOPE: HAWC'S EYE

- Compact IACT
- Fresnel lens $f \approx D \approx 0.5$ m
- 61(+3) SenseL MicroFJ SiPMs based pixels
- Hexagonals PMMA light concentrators
  - Covers 100% surface area
- $1.5°$/Px $\sim 12°$ total FoV
- 72 ch, DRS4 DAQ 2 GS/s
- Recent improvements
  - Remote control
  - Bias power supply
  - Trigger master
- $\sim 10{,}000$ €





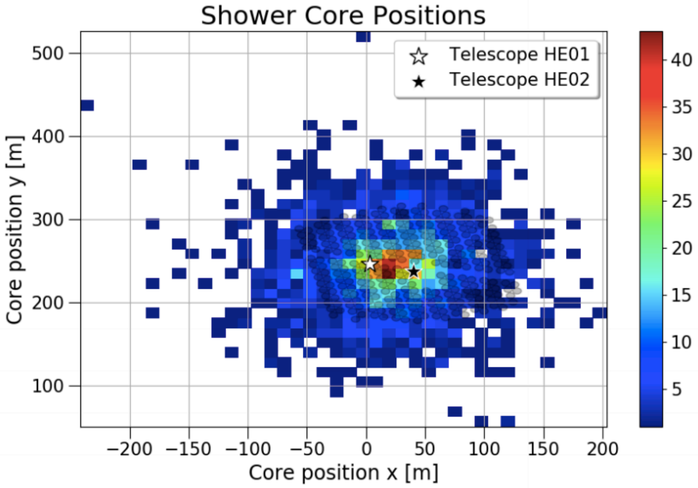
HYBRID OBSERVATION CAMPAIGNS

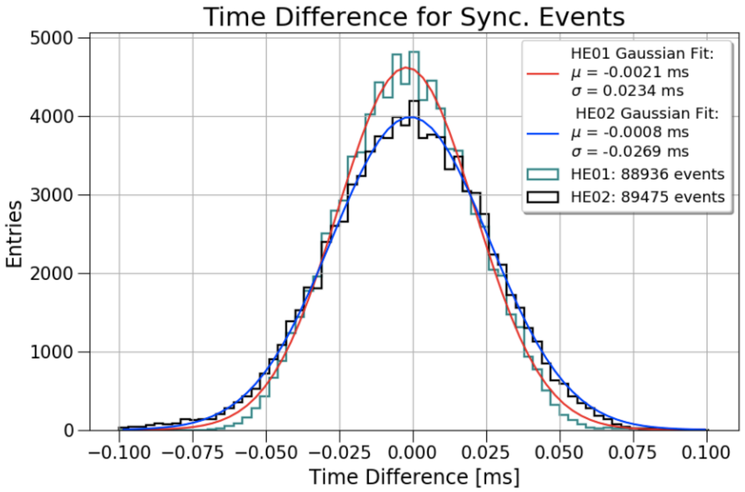
- 1st campaign (First light)
  - July 2017
  - One single telescope
  - Telescope v1
  - Excelente environment conditions
- 2nd campaign
  - September 2019
  - Two telescopes
  - First stereo data
  - Telescopes v2
  - 1.5 hr data
  - Frozen lens
- 3rd campaign
  - December 2019
  - Two telescopes
  - Telescopes v2
  - >5 hr data
  - Excellent environment conditions
- 4th campaign
  - November 2020
  - Two telescopes
  - Telescopes v2
  - >13 hr data
  - Excellent environment conditions
- Next campaigns
  - ~14/Dec/2020 (authorized)
  - ~12/Jan/2020 (in plans)
  - ~11/Feb/2020 (in plans)

DATA ANALYSIS

- Data from the 2017 observation campaign (single telescope)
  - Helped to improve the telescope performance and characterized it
- Data from the 2019 observation campaign (stereoscopic data)
  - Estimation of the shower's for position
  - Successful time synchronization
    - HAWC's and HAWC's Eye data synchronized
    - Using HAWC's Eye FAD time counter and HAWC's GPS time
    - Time synchronization: time window $< 100\ \mu s$

Stereo Hybrid Data: 2 Telescopes + HAWC



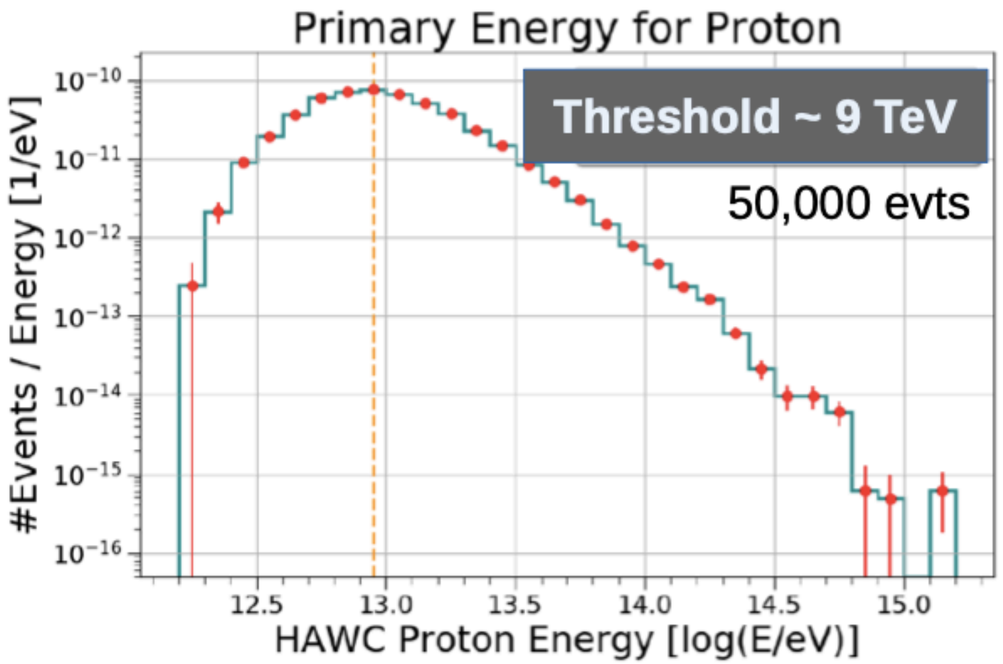


Successful synchronisation with time window $< 100\mu s$

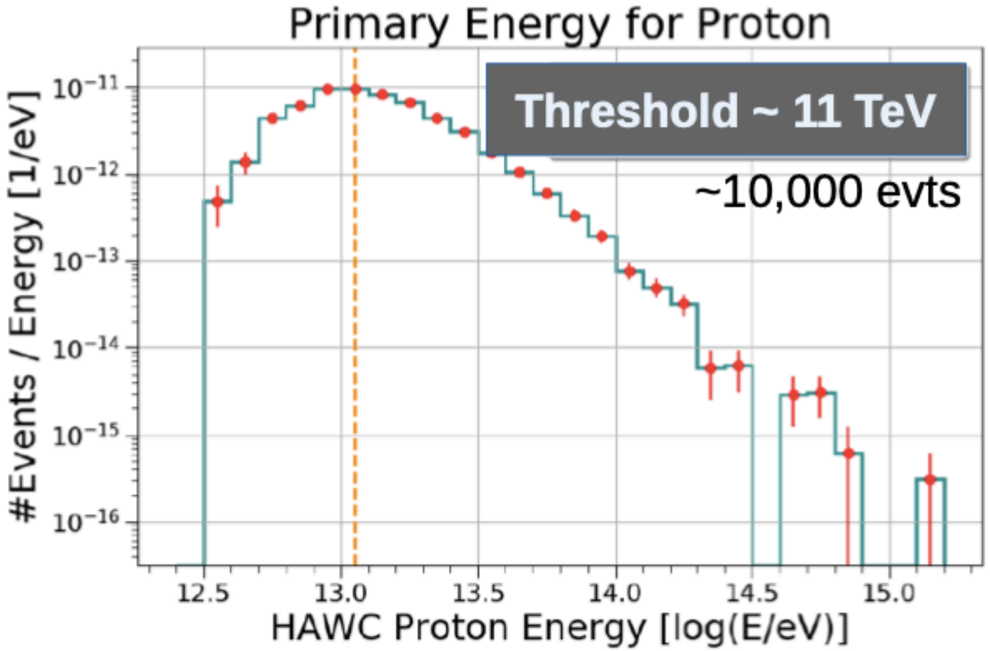
DATA ANALYSIS

- Energy threshold (protons)
  - Based on the HAWC's energy measurement

For Hybrid Events
(HAWC + 1 telescope):

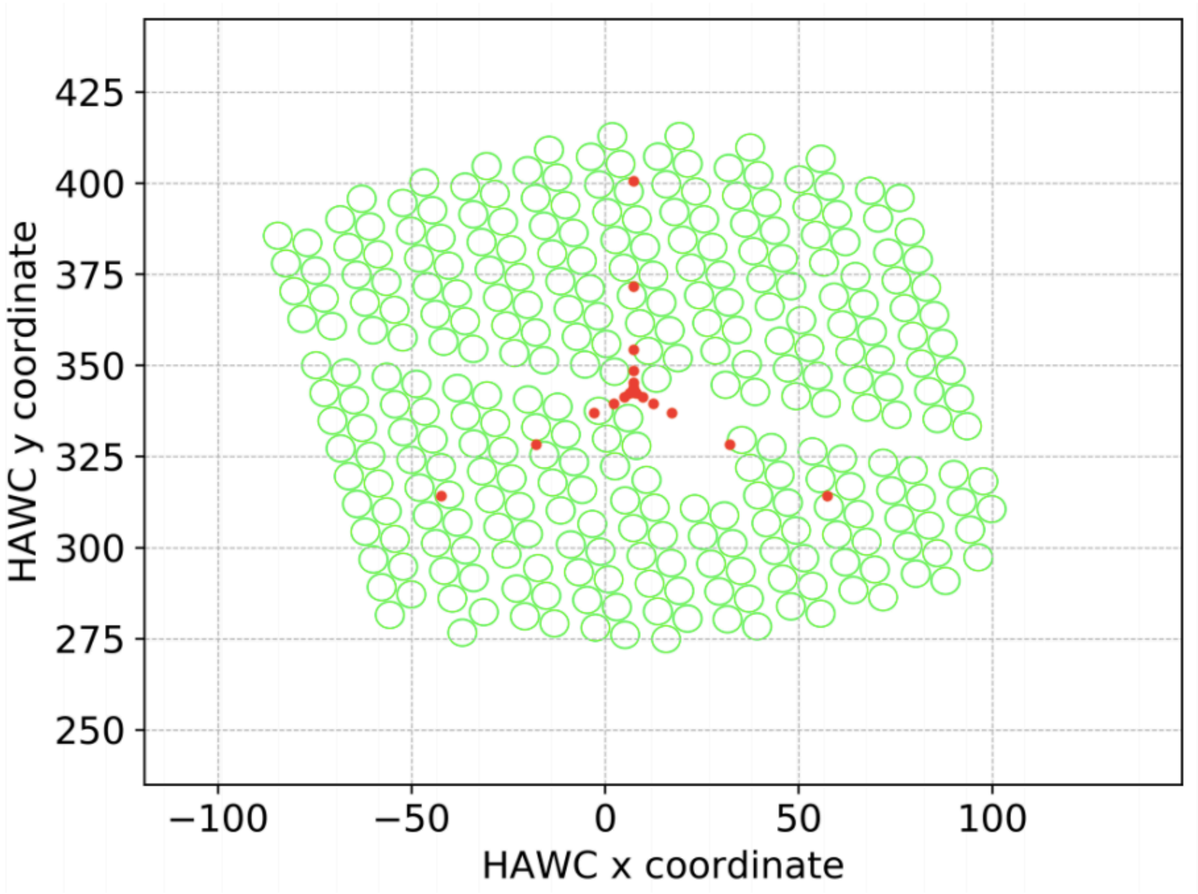


For Stereo Hybrid Events
(HAWC + 2 telescopes):



SIMULATION SET-UP

- Air shower simulations
  - CORSIKA v7.69
  - Energy range: 1 TeV to 100 TeV with energy $N(E) \sim E^{-1.5}$
  - Zenith range $< 8^{\circ}$
- Different detectors set-ups
  - 7 arrays of 3 detectors each ones



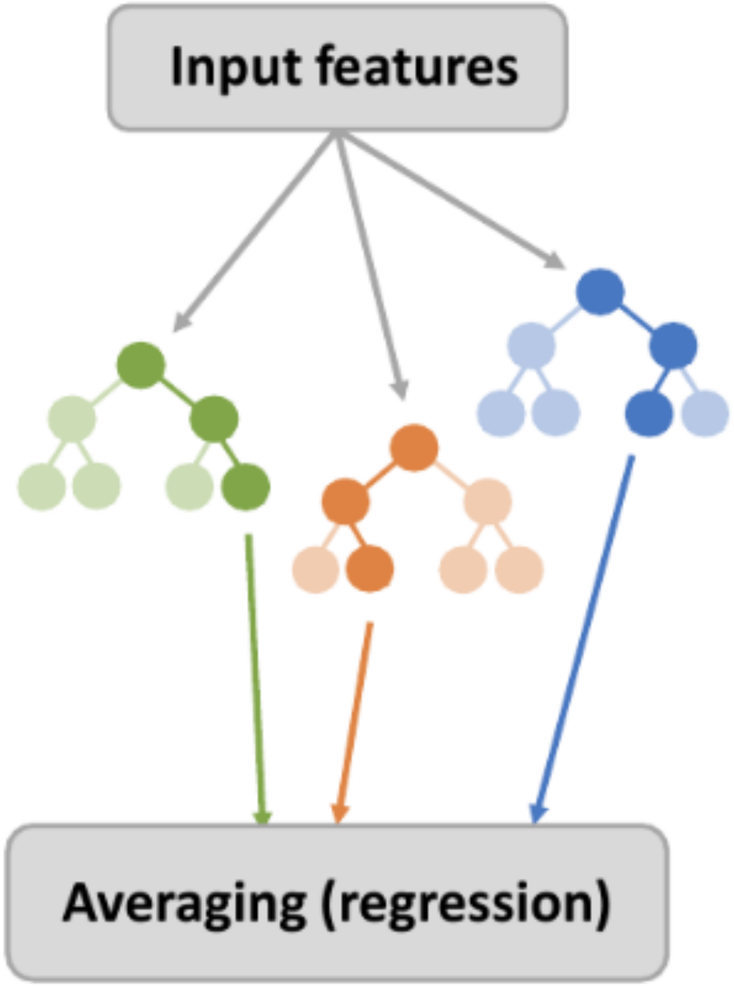
HAWC's WCD - HAWC's Eye Telescopes

Simulated area ~ HAWC's area

Equilateral triangles arrays with 1 m, 2 m, 5 m, 10 m, 20 m, 50 m and 100 m side lengths

SHOWER RECONSTRUCTION

- Shower reconstruction
  - Random Forest
    - Machine learning algorithm
    - Random decision trees
  - Prediction of energy properties
    - Predicting energy and arrival direction of γ
    - Hillas parameters from shower images
    - 80% training sample and 20% test sample



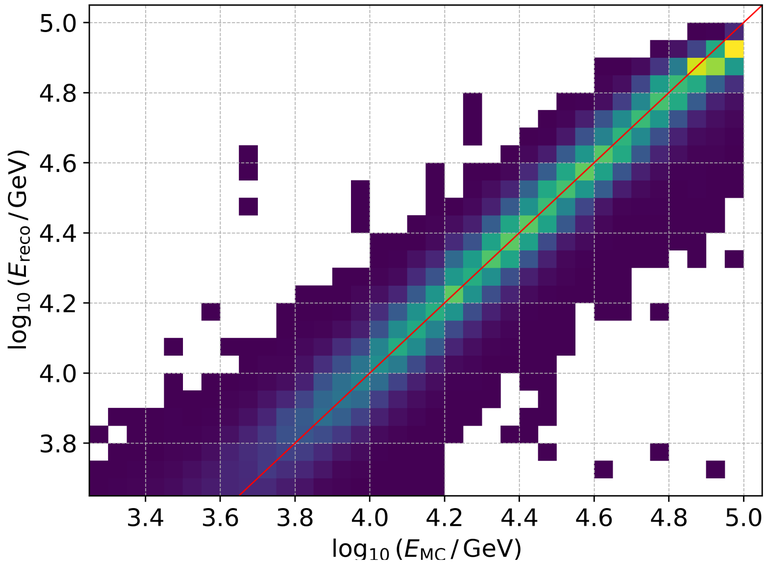
SIMULATION STATUS

- Set-up
  - 21 telescopes
- Altitude
  - 4,100 m asl
- Primary particles
  - Protons and gammas
- Area
  - 250 m × 250 m ~ HAWC's area
- Field of view
  - 8°
- Energy range
  - 1 TeV to 100 TeV

- Protons
  - Simulated
    - 986,000 events
  - Through HAWC's Eye software
    - 986,000 events
  - Through HAWC's software
    - 825,000 events
- Gammas
  - Simulated
    - 941,000 events
  - Through HAWC's Eye software
    - 941,000 events
  - Through HAWC's software
    - 853,000 events

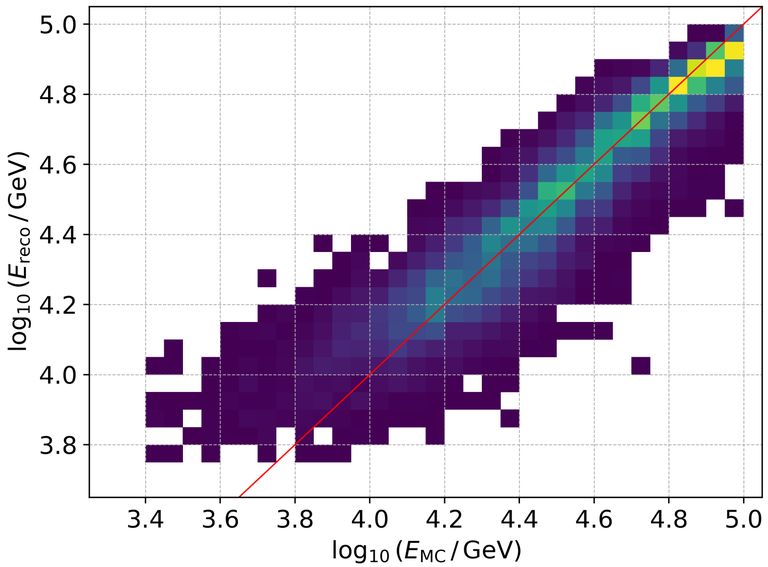
- Hybrid simulations available (partially)
- MC events synchronized

ENERGY AND ARRIVAL DIRECTION RECONSTRUCTION

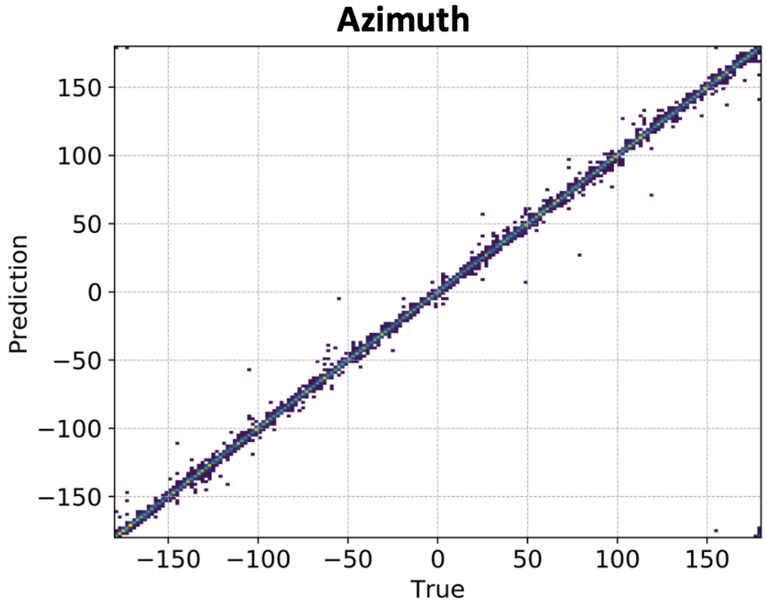


Gammas

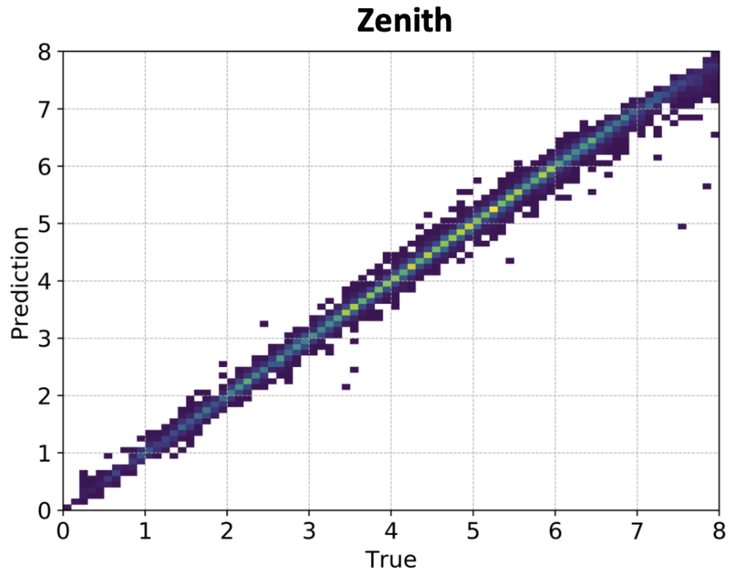
- Energy estimation
  - MC vs reconstruction
- "E_{MC}"
  - MC variable
- "E_{Reco}"
  - Reconstructed variable



Protons



- Arrival direction estimation
  - MC vs reconstruction
- "True"
  - MC variable
- "Predicted"
  - Reconstructed variable



FUTURE WORK AND PLANS

- Hybrid detection
  - Observation at the Crab
  - More data needed
    - Three more observation campaigns on plans
  - Hybrid analysis with HAWC and HAWC's Eye
    - Energy reconstruction
    - Arrival direction reconstruction (zenith and azimuth angles)
  - Comparison between measurements and simulations

- Hybrid simulations
  - Simulation sample: iron
  - Consider the atmosphere for HAWC's Eye (same as in the HAWC's simulations)
  - Larger energy range
    - 800 GeV to 500 TeV
  - Energy and angular direction estimation
  - Check difference of NSB to La Palma
  - Hybrid analysis: HAWC + HAWC's Eye (arrays)
  - Comparison between simulations and real data

- Definite implementation at the HAWC's site
- Construction of more telescopes
- Considered as an extension for The Southern Wild-field Gamma-ray Observatory (SWGO)

THANK YOU