SWGO: a Southern hemisphere wide field of view observatory

Andrea Chiavassa

Università degli Studi di Torino & INFN

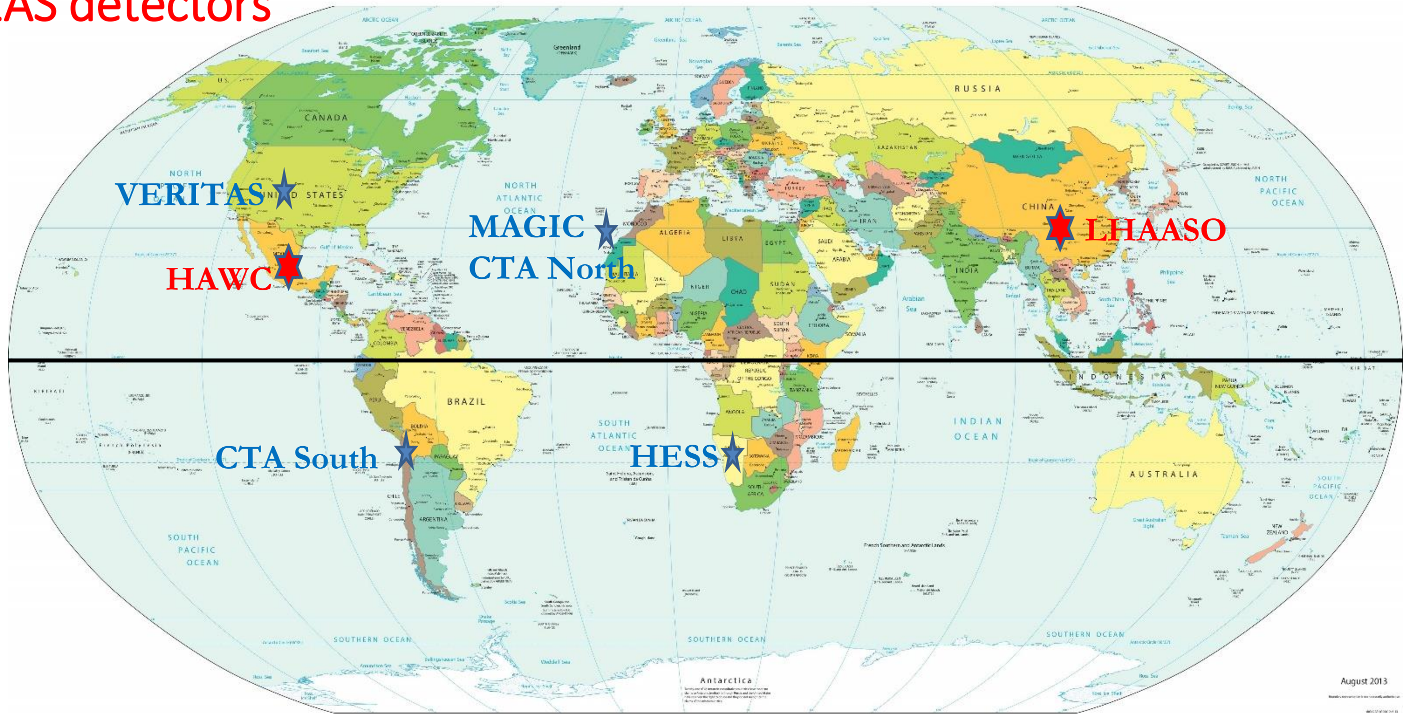
VHE and UHE γ-ray astronomy

- Ground based search for very and ultra high energy gamma ray sources is performed with two complementary techniques: IACT and EAS particle detection.
- IACTs reach better angular and energy resolution but are pointing instruments and have a limited duty cycle.
- EAS particle detectors have a wide field of view and high duty cycle but are limited in angular and energy resolution.
- At ultra high energy (E>100 TeV), working in background free mode EAS particle detectors have currently reached a better sensitivity.
- In the last years "wide field of view" observatories (LHAASO and HAWC) detected gamma ray sources at E>50 TeV
  - HAWC (ICRC 2023) 28 sources E>56 TeV; 17 E>100 TeV; 6 E>177 TeV
  - LHAASO (2305.17030v1) 43 sources E>100 TeV

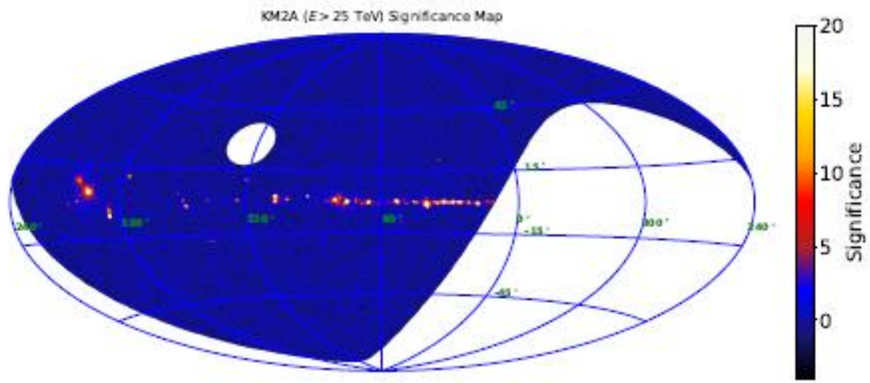
Operating ground based experiments

★ → IACT

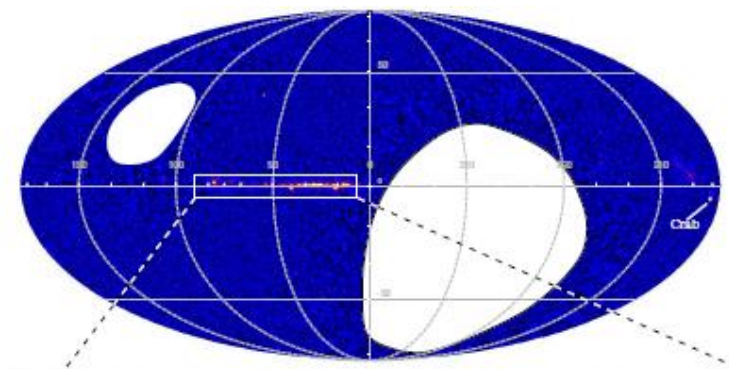
★ → EAS detectors



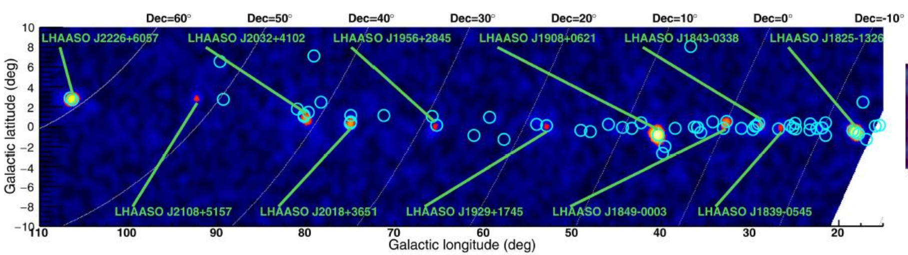
LHAASO Sky coverage



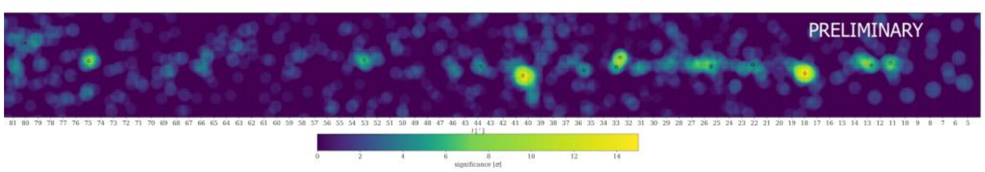
HAWC Sky coverage



and Galactic Plane map (E>100 TeV)



and Galactic Plane map (E>100 TeV)



SWGO

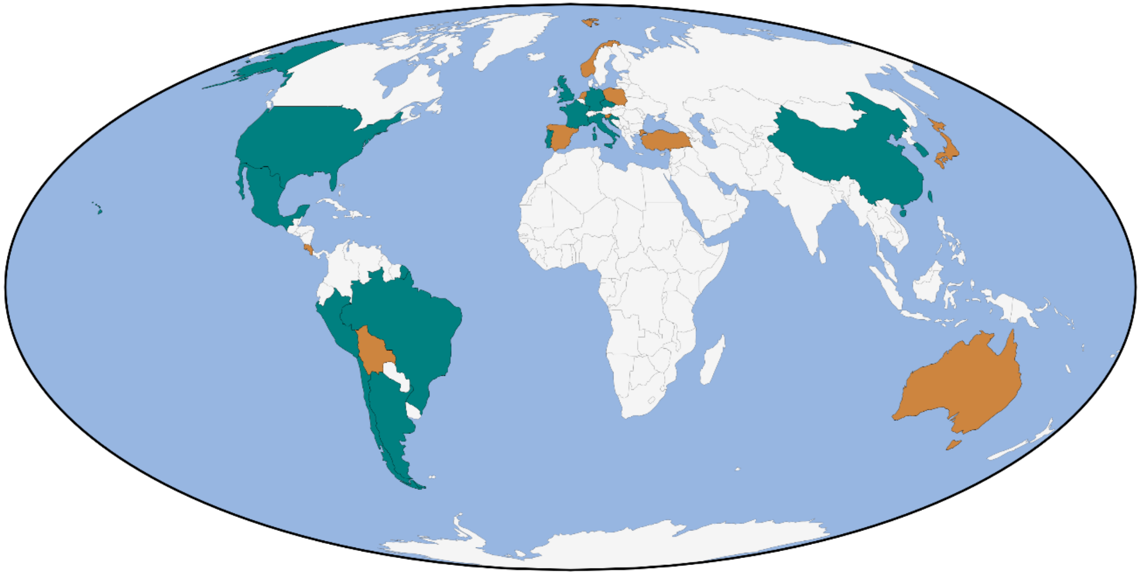
- SWGO: The Southern Wide-field Gamma-ray Observatory is a gamma-ray observatory based on ground-level particle detection, with close to 100% duty cycle and order steradian field of view.
- SWGO is currently in the R&D phase.
- Willing to cover the 100 GeV-1 PeV energy range the array must be located at an altitude of 4.4 km or higher (low energies) and extend over a km^2 area (high energies).
- Located in South America at a latitude between 10° and 30° south.
- Based primarily on water Cherenkov detector units.
- With a high fill-factor core detector with area considerably larger than HAWC and significantly better sensitivity, and a low-density outer array.
- Improved angular (<0.2°) and energy resolutions (<30%) above 10 TeV.

SWGO Science Benchmarks

Core Science Case	Design Drivers	Benchmark Description
Transient Sources: Gamma-ray Bursts	Low-energy Site altitude	Min. time for 5σ detection F(100 GeV)= 10^{-8} erg cm^{-2} s^{-1}
Galactic Accelerators: PeVatron Sources	High-energy sensitivity Energy resolution	Maximum exp-cutoff energy detectable 95% CL in 5 years for: F(1 TeV)= 5 mCrab, index= −2.3
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity Angular resolution	Max. angular extension detected at 5σ in 5-yr integration for: F(>1 TeV)= 5×10^{-13} TeV cm^{-2} s^{-1}
Diffuse Emission: Fermi Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-4} level at 1 TeV.
Fundamental Physics: Dark Matter from GC Halo	Mid-range energy sensitivity Site latitude	Max. energy for $b\bar{b}$ thermal relic cross-section at 95% CL in 5-yr, for Einasto profile.
Cosmic-rays: Mass-resolved dipole Multipole anisotropy	Muon counting capability	Max. dipole energy at 10^{-3} level. Log-mass resolution at 1 PeV – goal is A = 1, 4, 14, 56; Maximum multipole scale > 0.1 PeV.

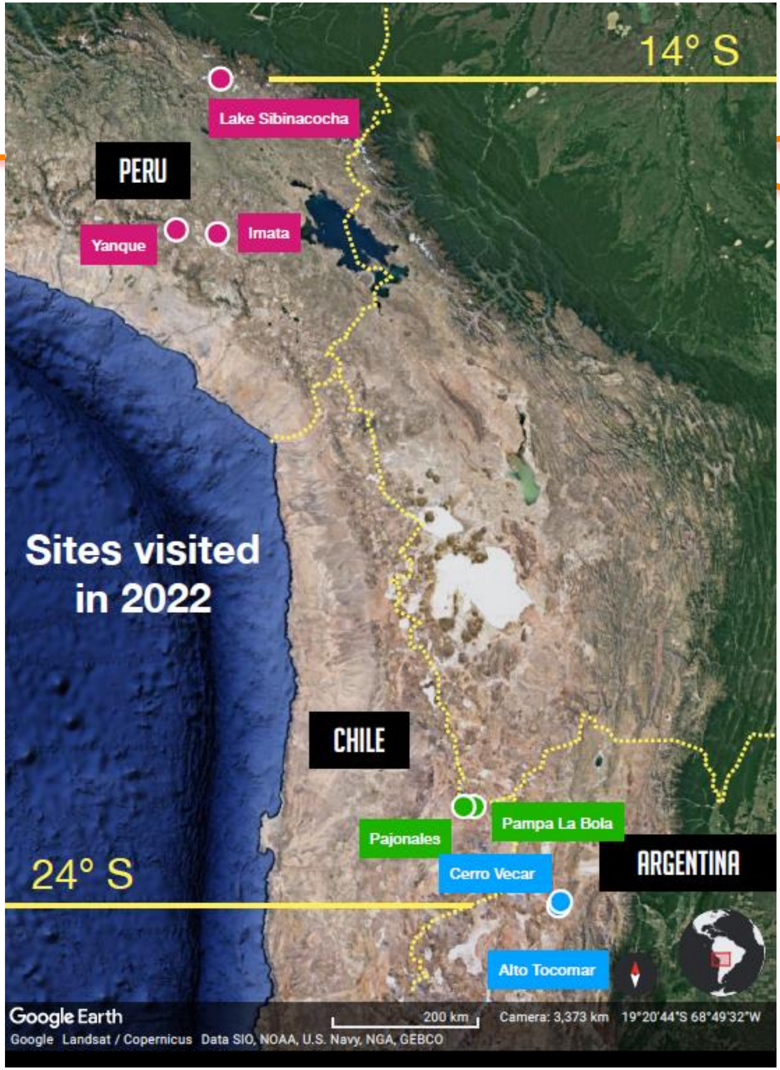
SWGO Collaboration

- SWGO Collaboration:
  - 15 Nations, +90 Institutions
  - Argentina, Brazil, Chile, China, Croatia, Czech Republic, France, Germany, Italy, Mexico, Perù, Portugal, South Corea, United Kingdom, United States.



Site Search

- Candidate Sites identified in Argentina, Chile and Perù.
- Latitude between 14°S and 24°S
- Altitude between 4400m and 4850m a.s.l.
- All sites can host a 1 km^2 array.
- The SWGO collaboration is aiming to mantain a close engagment with the local communities during the site selection process.

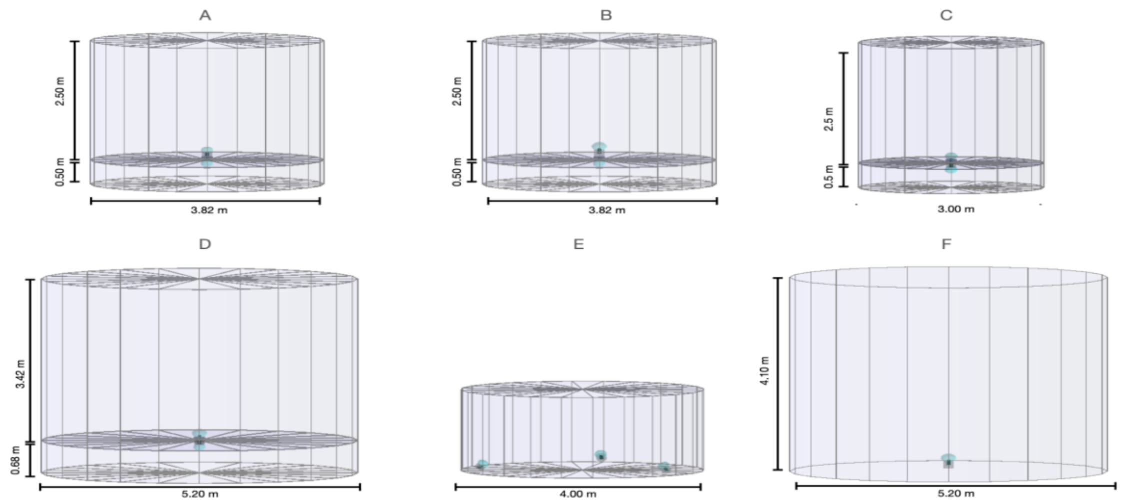


Site Search

- Three sites under evaluation as primary candidate sites for a tank array.
- Lake option currently considered as part of the SWGO programme for a future extension towards higher energies.
- Pond option is feasible only at the Imata site.

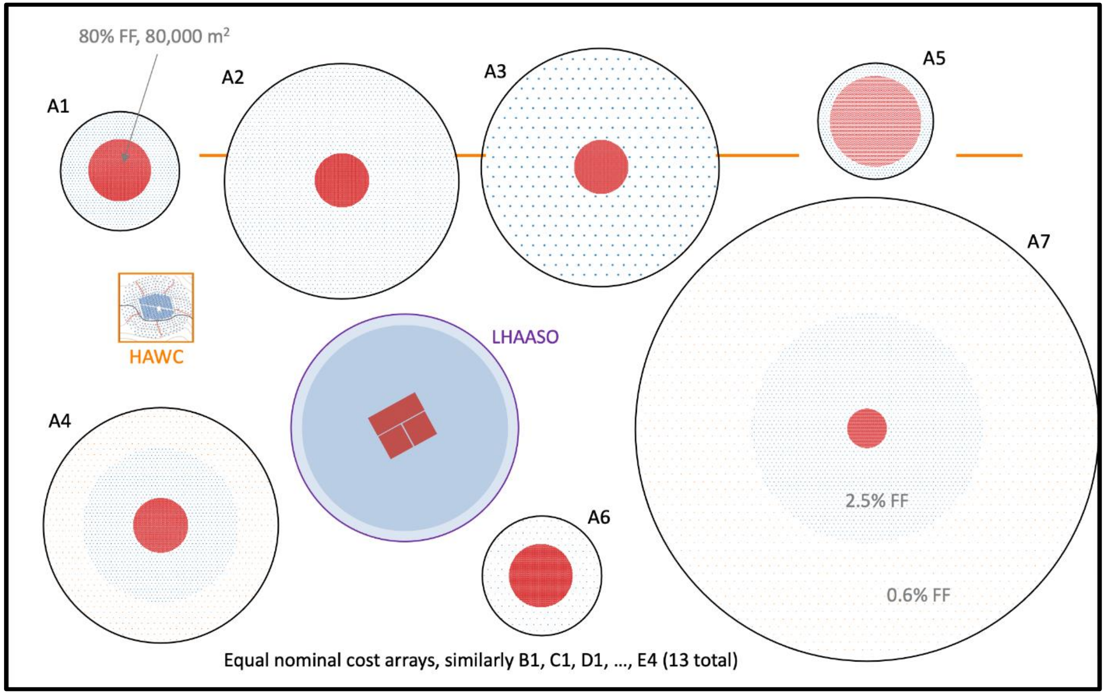
Array Optimization Studies

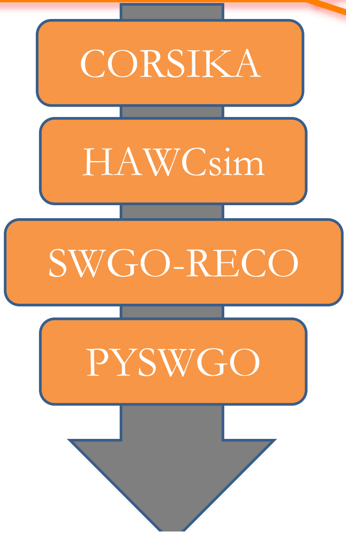
- Simulation of the performance of different WCD tank concepts and array configurations to select most promising candidates.
- Results at E>50 TeV are strongly limited by the available simulation statistics.

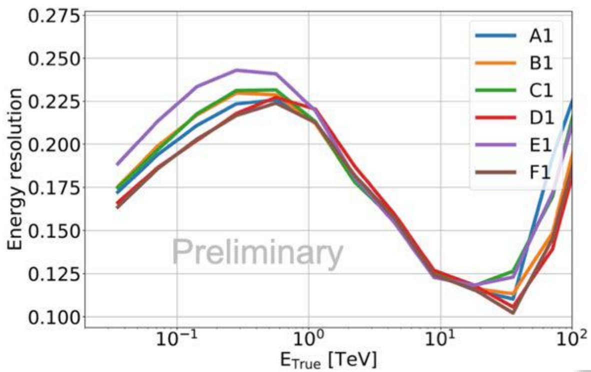


Array Optimization Studies

Different layouts are defined at equal nominal cost.

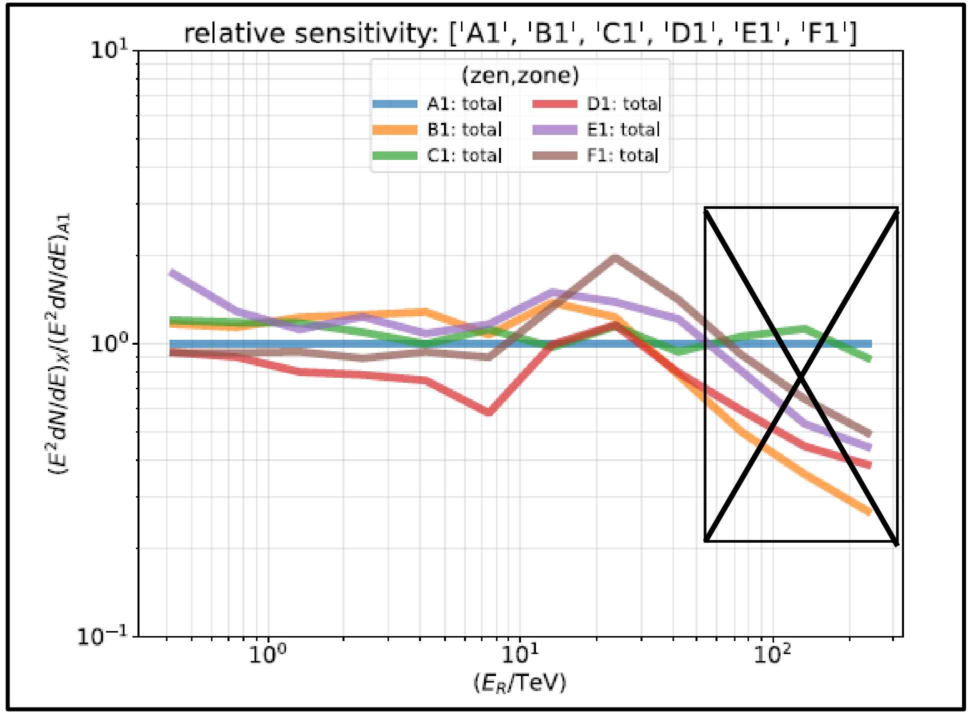






WCD Unit Design

- Different tank designs have been compared:
  - double layer (with a single central PMT per layer)
  - deep single layer with a single central PMT
  - shallow single layer with 3 PMTs.
- All models reach a performance allowing to obtain the SWGO scientific objectives.



WCD Unit Design

- For the inner array double layer tanks give the most promising performance.
- Large WCD unit results in significant improvements in background rejection.
- The results of the simulation studies suggest that inner array tanks should be:
  - A double layer tank with a single centrally deployed photo-sensor unit
  - Diameter between 3.8m and 5.5m
  - Overall depth between 3.0m and 4.5m
  - White wall lower chamber and either partially or fully black upper
- The current statistics at UHE do not allow us to reach strong conclusions on the outer array WCD.

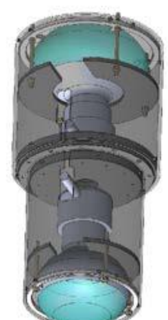
Array Layouts

- At the low energies a smaller inner array with an extreme fill factor doesn't allow to reach better sensitivity and resolution if compared to a larger inner array with a smaller fill factor.
- Inner array will have a radius between **140m and 220m** and a fill factor between **40% and 80%.**
- At the high energies the currently simulated statistics is not allowing strong conclusions above 50 TeV.
  - Too large arrays (FF<1%) have a poor low-mid energy performance.
  - A two zones (with degrading FF) approach looks promising.
  - We don't see a negative impact on the performance clustering the outer array stations.
- Outer array radius between **600m and 800m**. Details will be studied by a dedicated simulation.

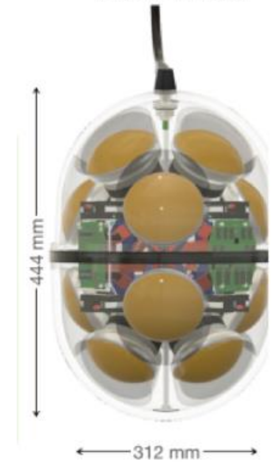
SWGO
The Southern Wide-field Gamma-ray Observatory

- **Photodetectors**
  - Detector
    - Large-area PMT
    - SiPM array
    - Multi-sensor
    - Distributed sensor
  - Light guide
    - None
    - Winston cone
    - WLS plate or fibres

- **Electronics chain**
  - Photodetector supply
    - Active base
    - Multi-channel HV
  - Digitiser
    - High-rate sampling
    - Medium-rate sampling + TDC
    - Time-over-threshold (ToT)
  - Clock distribution
    - White Rabbit
    - RapCal



16 PMT model

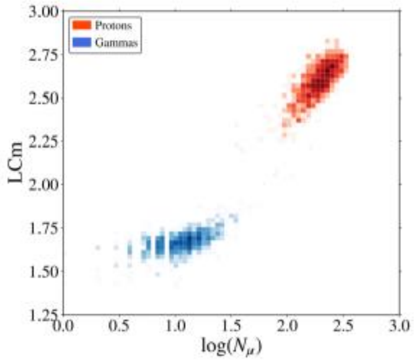


New strategies

◎ The use of double layer tanks is a new solution for WCD arrays, engineering solutions to realize them are under test.

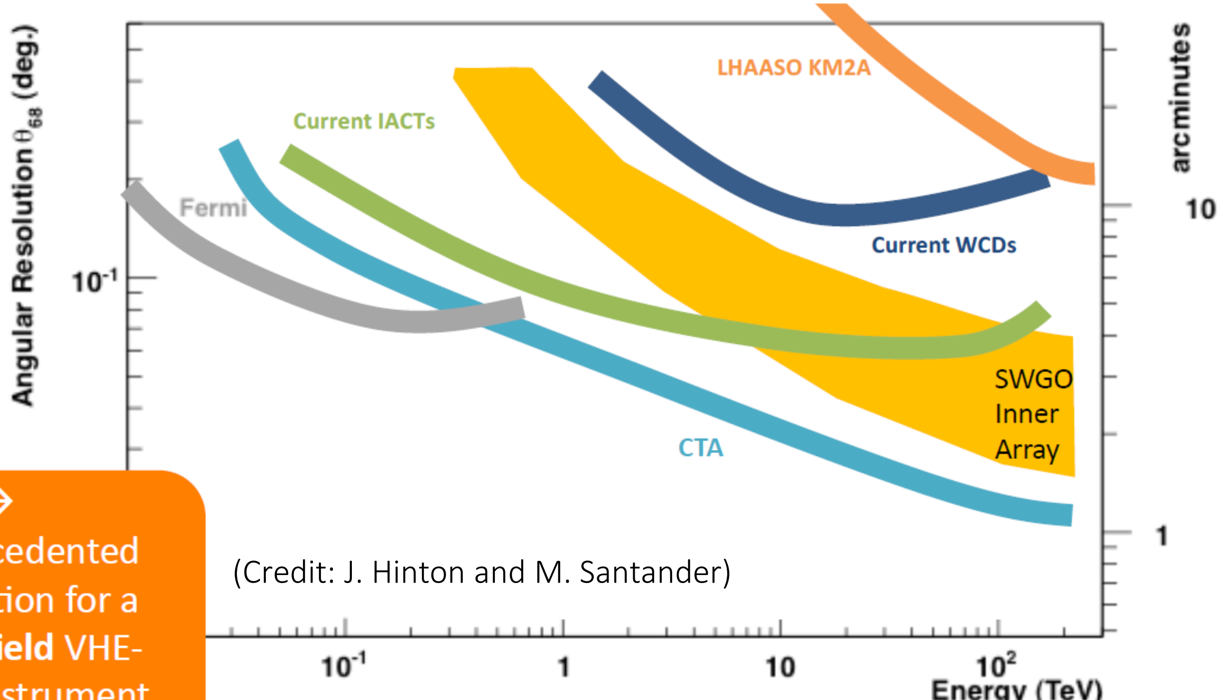
◎ We are studying new variables to perform the gamma/hadron discrimination

◎ New event reconstruction algorithms based on template fitting or on NN.



LCm, fluctuations of the azimuthal shower footprint

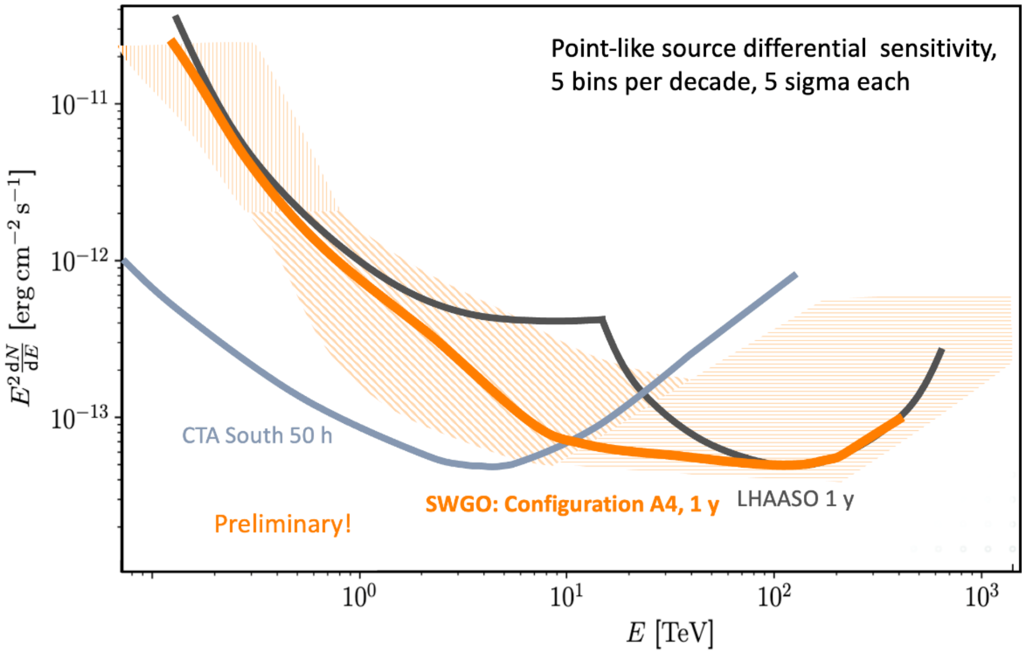
Angular resolution goal



Goal → unprecedented resolution for a **wide field** VHE-UHE instrument

(Credit: J. Hinton and M. Santander)

Expected Sensitivity



◎ Preliminary expected sensitivity calculated for one of the test configuration studied.

Conclusions

- SWGO is in an advanced phase of the R&D process
- Strong motivation for a wide field of view, high duty cycle observatory in the Southern hemisphere
  - → MMA studies
  - → Follow up of transients
  - → Gamma ray observations in the 100 GeV-1 PeV energy range
  - → DM searches
  - → CR anisotropy and spectra for different mass groups
- Synergies with current and future instruments
- 2026 engineering array
- 2027-2030 construction phase