SWGO science and the status of the project



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Outline

- Why gamma rays matter for cosmic-ray physics
- SWGO: design, status and Mexican contributions
- Science with a cosmic-ray focus
  - → Spectrum and composition, anisotropy, muon puzzle, the Sun
- Summary and questions



Credit: J. Hinton

Gamma rays probe cosmic rays

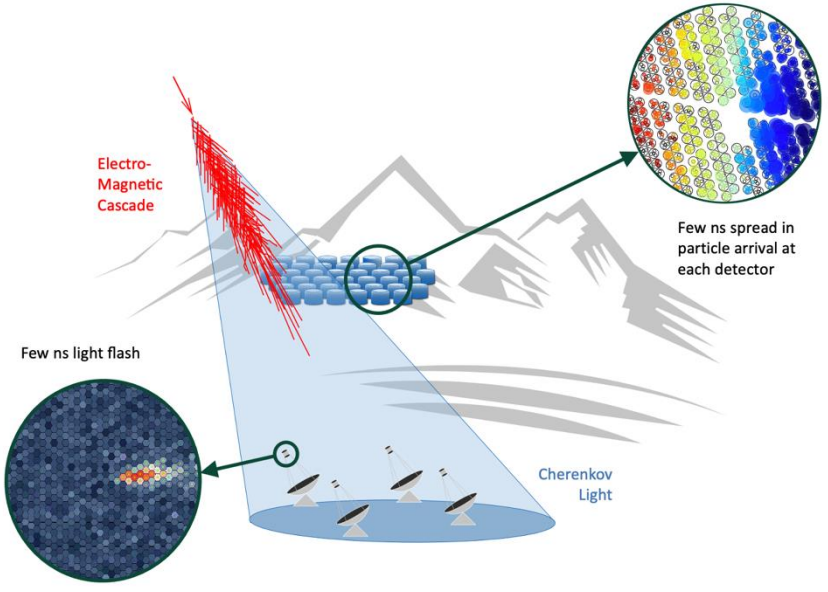
- Cosmic rays are charged: magnetic fields scramble their directions
- Gamma rays and neutrinos are neutral and point back to their sources
- Hadronic sources: π^0 decay. Leptonic sources: inverse Compton
- At PeV energies, neutral messengers are needed

Charged cosmic rays
Deflected by Galactic magnetic fields: the direction to the source is lost

Gamma rays and neutrinos
Travel in straight lines: they point back to the accelerator

Ground-based techniques

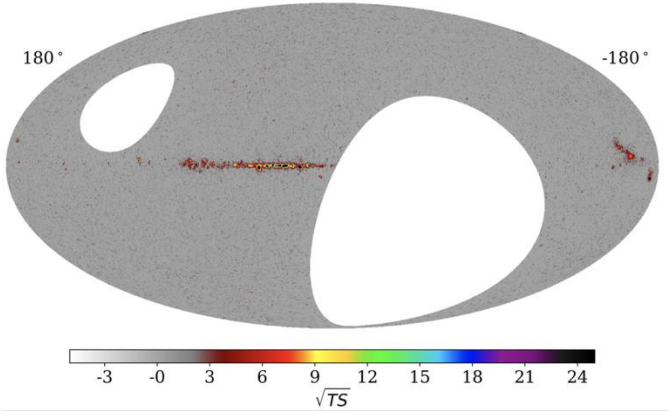
- IACTs: ~15% duty cycle, ~4° field of view, high precision, large collection area
- Particle arrays: ~100% duty cycle, steradian field of view, modest precision, large exposure
- That **continuous operation** and that huge **field of view** are exactly what extended structures and cosmic rays need.



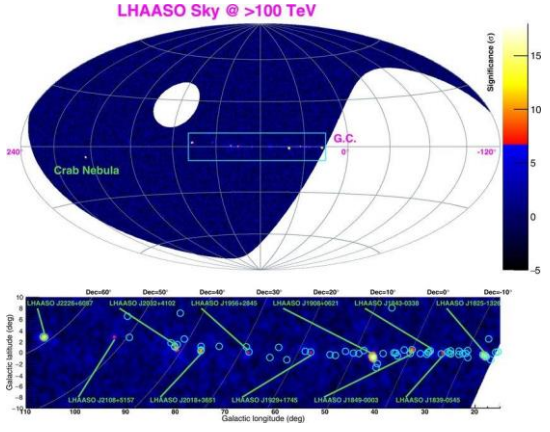
Credit: A. Jardin-Blicq, via J. Hinton

HAWC and LHAASO

- LHAASO: > 40 sources above 100 TeV; photons above 1 PeV from the Crab and Cygnus Cocoon
- No Galactic hadronic PeVatron confirmed yet
- HAWC and LHAASO: softening and hardenings in the cosmic-ray spectrum
- TeV- PeV, that is where we want to contribute.



HAWC

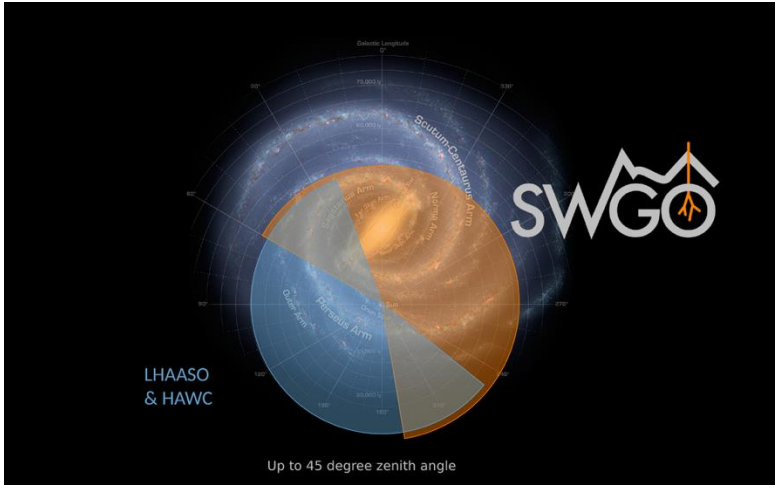


LHAASO sky above 100 TeV

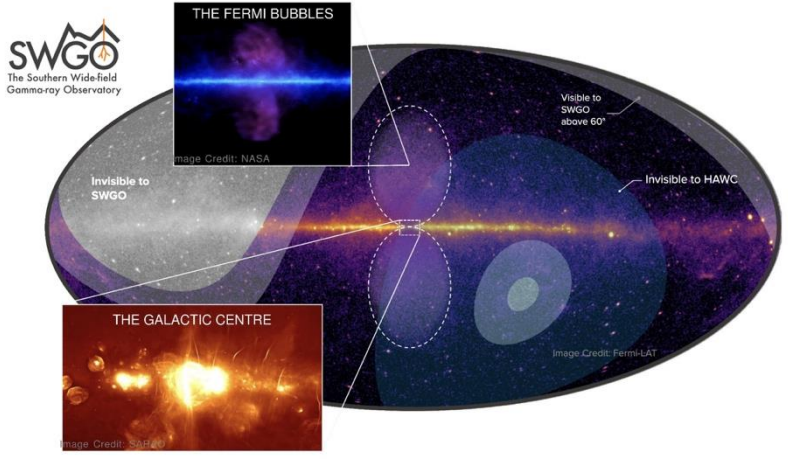
Credit: J. Goodman (Gamma 2022), via J. Hinton

The southern gap

- HAWC and LHAASO see up to 45° zenith: the inner Galaxy is poorly covered
- SWGO looks at the inner Galaxy: the Galactic Centre culminates at zenith
- Combining HAWC with IceCube is difficult because they overlap by only about few degrees, right where the reconstruction of both is worst, but SWGO, with a technique similar to HAWC's, would give a larger overlap.



Credit: J. Hinton LHAASO and HAWC: up to 45° zenith



SWGO: zenith < 45° (colour), < 60° (shaded); Fermi-LAT > 3 GeV

The collaboration

- Founded in 2019, now 16 countries
- Strong presence in South America, where the array will be built



SWGO members and guests at the site of the project, Pampa La Bola
(12th Collaboration Meeting, San Pedro de Atacama, 5-9 May, 2025)

Development timeline

- 2019: R&D phase starts
- May 2020: science benchmarks defined
- Feb 2022: candidate configurations defined
- May 2024: inner array baseline
- Jul 2024: site selection
- Jun 2025: science white paper
- Aug 2026: outer array baseline
- Early 2027: design report and on-site prototypes, entering a new phase

SWGO R&D Phase Milestones	
M1	R&D Phase Plan Established
M2	Science Benchmarks Defined
M3	Reference Configuration & Options Defined
M4	Site Shortlist Complete
M5	Candidate Configurations Defined
M6	Performance of Candidate Configurations Evaluated
M7	Preferred Site Identified
M8	Design Finalised
M9	Construction & Operation Proposal Complete

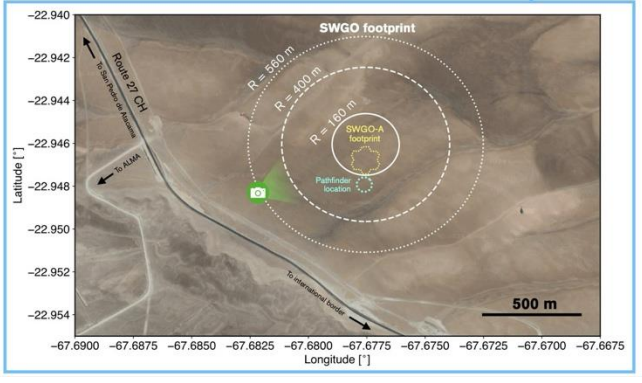
The site: Pampa La Bola

- Atacama Astronomical Park, northern Chile
- 4770 m a.s.l. (HAWC: 4100 m)
- Selected among 10 candidate sites in 4 countries
- About 45 minutes from San Pedro de Atacama, near ALMA



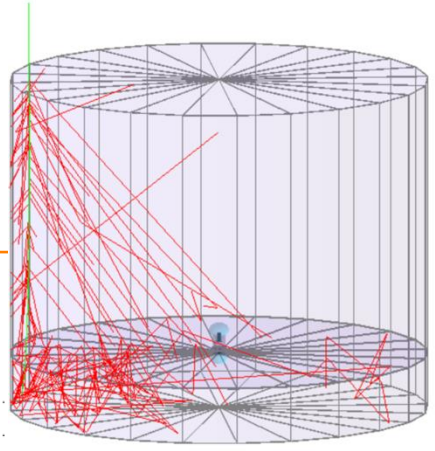


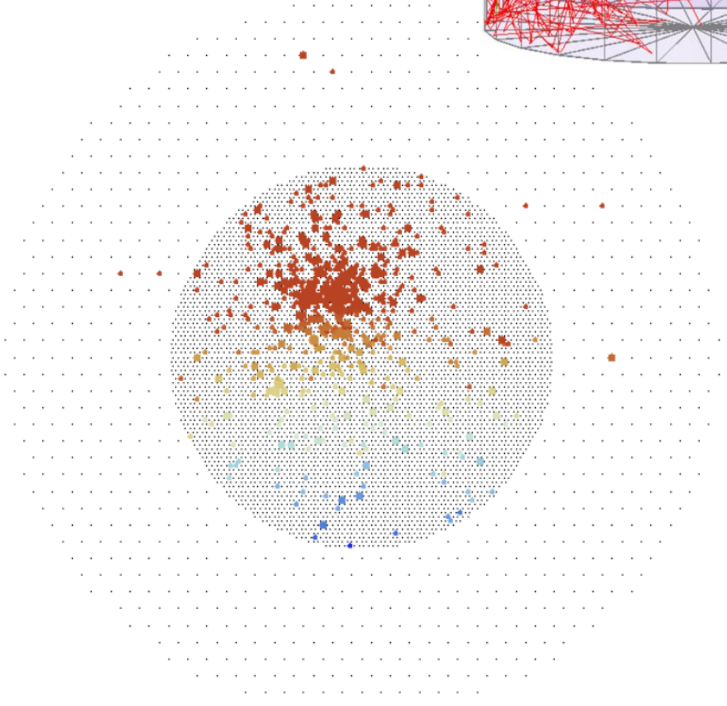




Simulations

- CORSIKA air-shower simulations
- Geant4 detector simulation (HAWC heritage)
- FastSim: parametrized simulation for UHE (Chiavassa and Negro 2026)
- Large-scale effort at many computing centres

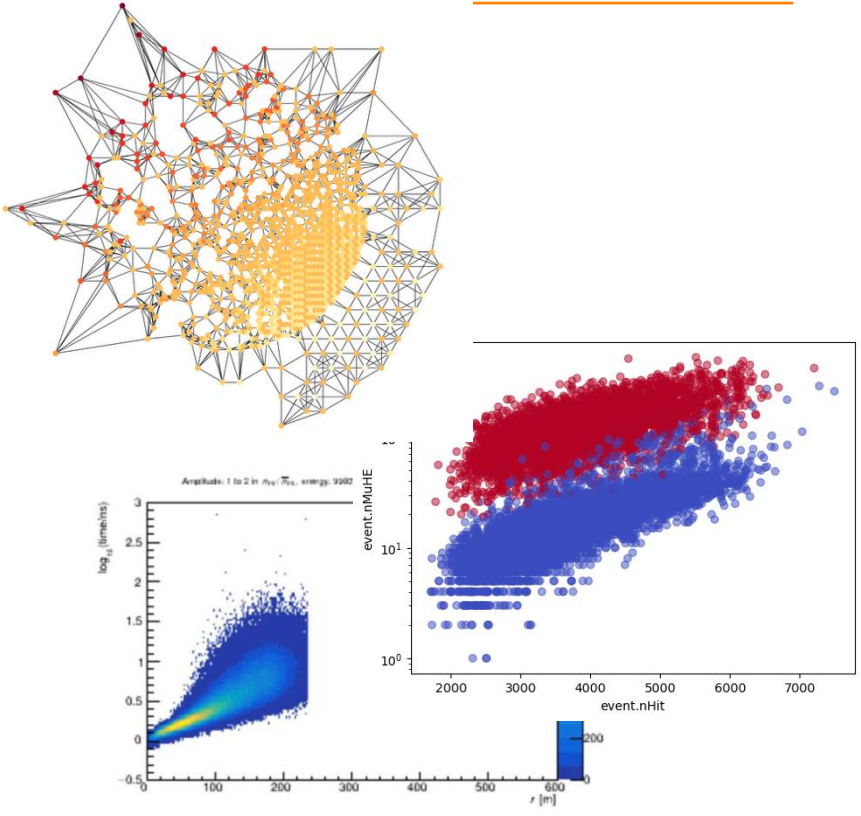




Simulated gamma shower: 600 GeV, 35° zenith

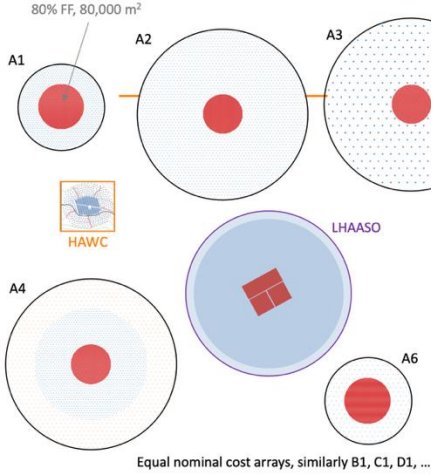
Data analysis

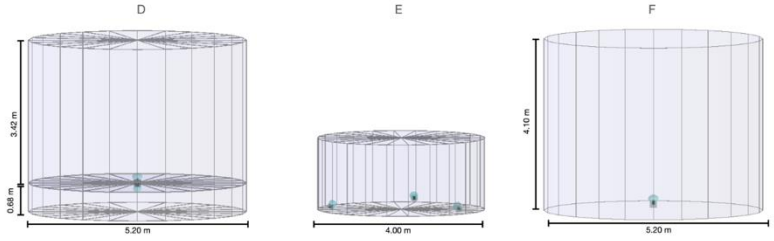
- Per tank and layer: arrival time and photoelectrons
- Direction, core and energy reconstruction
- Background rejection: machine learning and muon tagging
- Deep learning: GNN (Glombitza et al. 2024),



Design optimisation

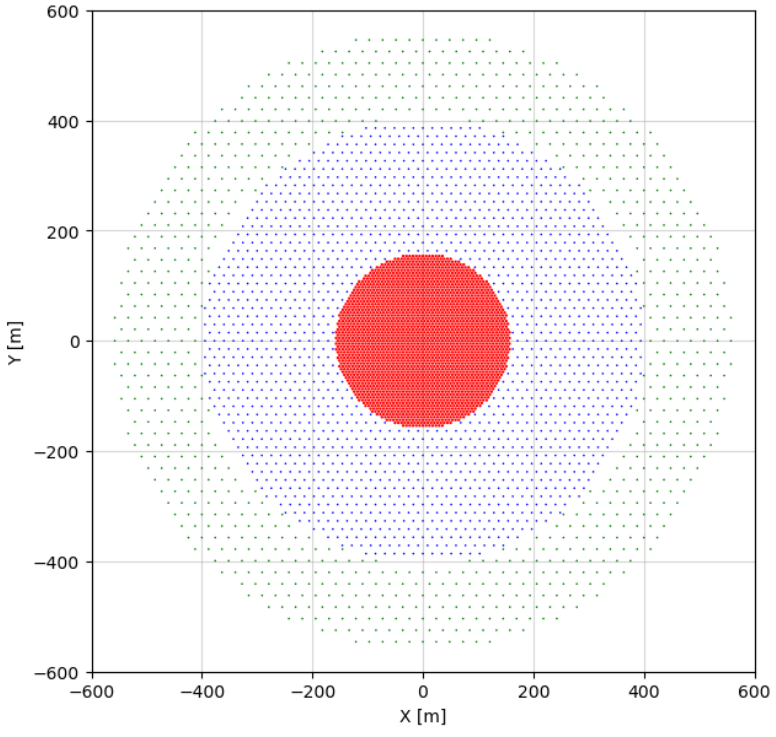
- Step 1: 6 detector-unit options and 7 layouts, inner and outer arrays
- Inner array converged in 2024: > 50% fill factor, 5.2 m dual-layer tanks
- Step 2: outer-array tanks at 1 to 4% fill factor
- Best performance and cost compromise





Baseline array layout

- Inner array: FF 65%, R = 156 m, 2587 tanks of 5.2 m
- Outer array: FF 4%, R = 400 m, 1656 tanks of 3.6 m
- Outer array: FF 1.7%, R = 560 m, 804 tanks of 3.6 m
- Modest mixed zone outside the inner array
- Total more than five thousand tanks spread over close to one square kilometre.



Inner array tank design

- Steel tanks assembled on site: 5.2 m diameter, 4.0 m water depth
- Double-PMT unit in each detector: 10-inch PMTs, 900 available
- Field Nodes serve 55 tanks each, 250 MS/s digitisation



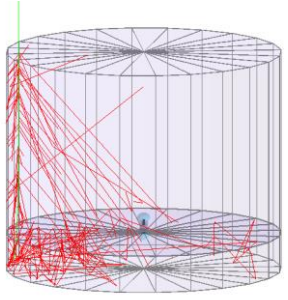




Inner array: LDPE bladder

- Custom LDPE bladder inside each steel tank
- Two layers separated by a membrane
- Lower chamber: background rejection and muon tagging
- Reflective Tyvek lining; inflated with air to check light leaks



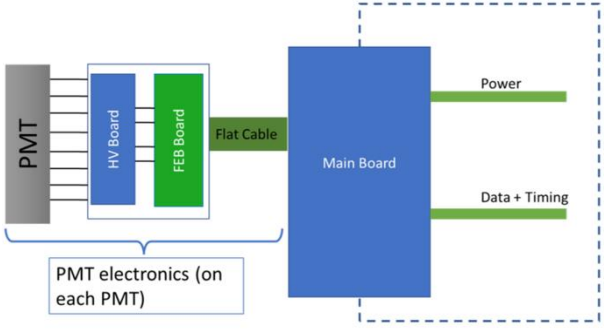


Outer array tank design

- 3.6 m diameter, 2.9 m water depth; rotomolded tank (Auger heritage)
- Single layer with a multi-PMT sensor: 7 × 3-inch PMTs (Napoli/INFN)
- Depth improves gamma/hadron separation enough to offset the cost

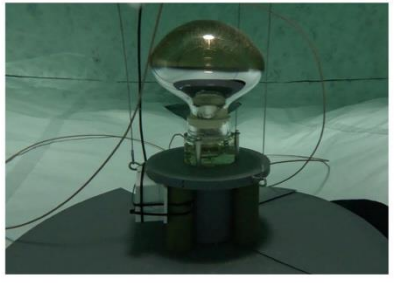






Prototyping work

- Low-altitude test sites: Rio, Heidelberg, Milano, Temple University
- Plus HAWC (Mexico) and Atacama
- Several prototypes installed and tested at the HAWC site



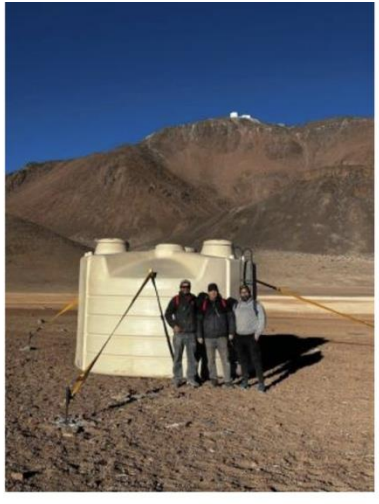


Test installation at altitude

- Test installation above the SWGO site, at about 5000 m a.s.l.
- Goal: test the impact of freezing

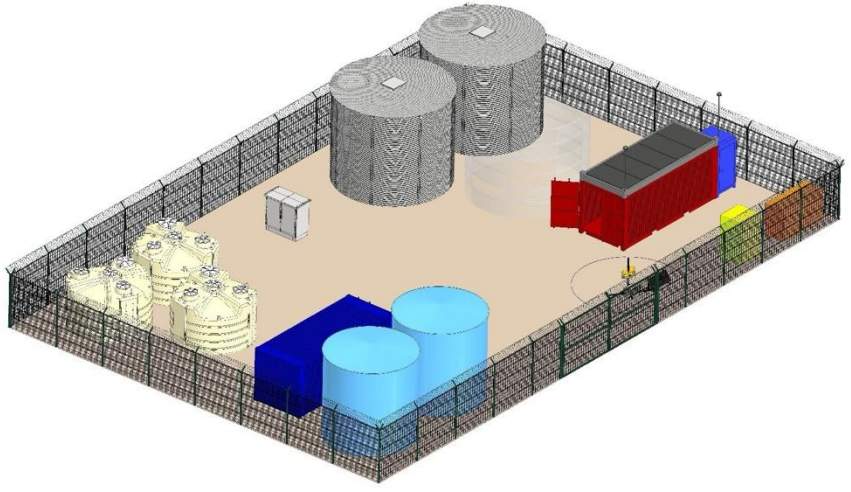






The Pathfinder

- Validates technologies and procedures for the full-scale array
- 30 × 30 m fenced area at Pampa La Bola
- Inner and outer array detector units
- Field node, water purification and storage

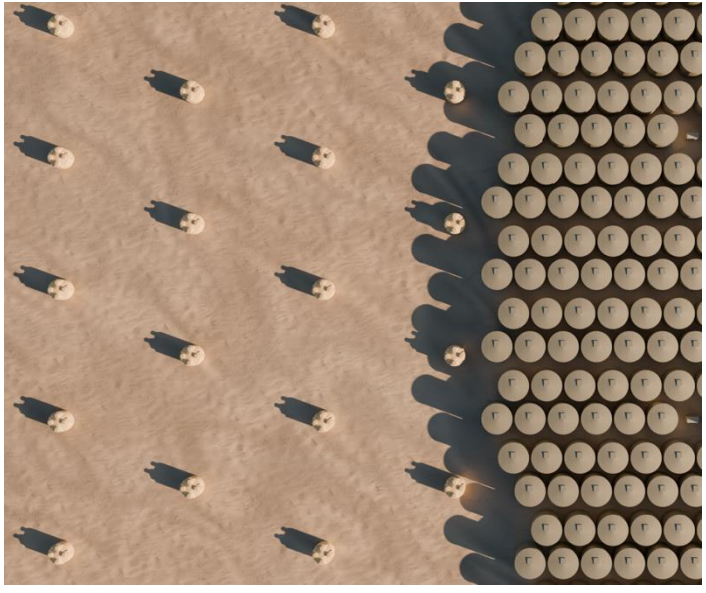


Mexican contributions

- Co-authors of the SWGO science white paper from UNAM, UNACH, UMSNH, UDEM and INAOE, across several topics
- IPN-INAOE: simulation studies with deep learning to improve air-shower reconstruction
  - → Master's students Hubert Misonia and Erick Mpangi Musungu
- Prototype installation and tests at the HAWC site

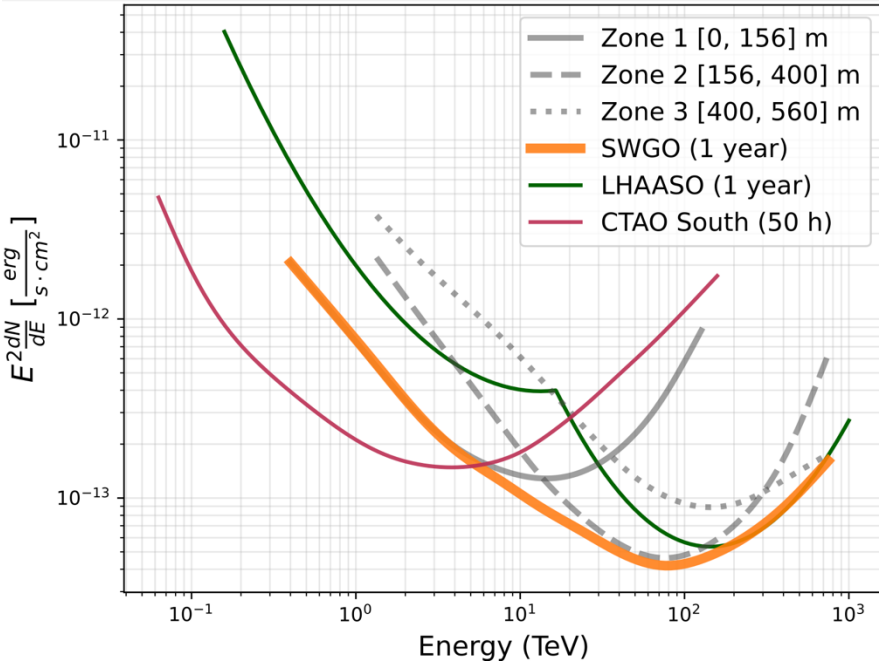
Into a new phase

- Engineering array of ~30 tanks, operating by early 2029
- 800-antenna radio array (SWGO-TURBO)
- Brazil: $10M allocated for rotomolded tank production
- Large fraction of outer-array tanks built in 2029 to 2030
- 3-inch and 10-inch PMTs already available
- APPEC supports construction on a sustainable path



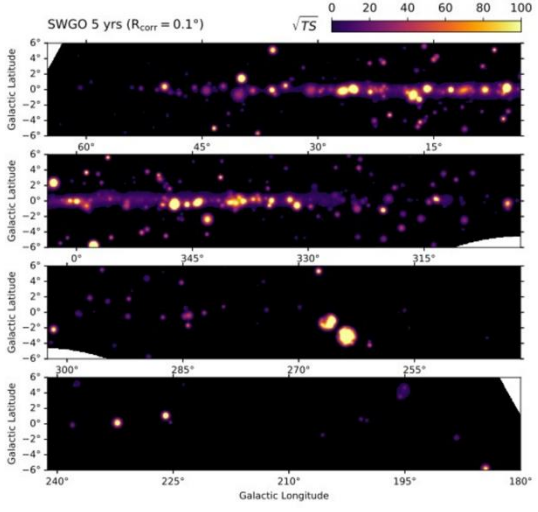
Sensitivity vs LHAASO and CTAO

- Point-source sensitivity of the baseline array (1 year)
- Complementary to CTAO-South; improves on LHAASO at low and medium energies
- Key aspect: background rejection power

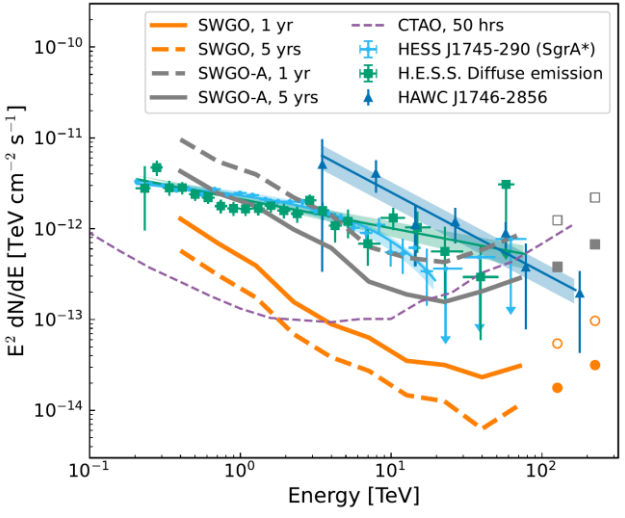


Galactic plane and PeVatrons

- SWGO 5 years: 487 detections vs 461 for CTA-GPS in the same region
- SWGO 10 years + CTA-GPS: 603
- No Galactic hadronic PeVatron confirmed
- We could measure these spectra well beyond the energies where current instruments run out of photons



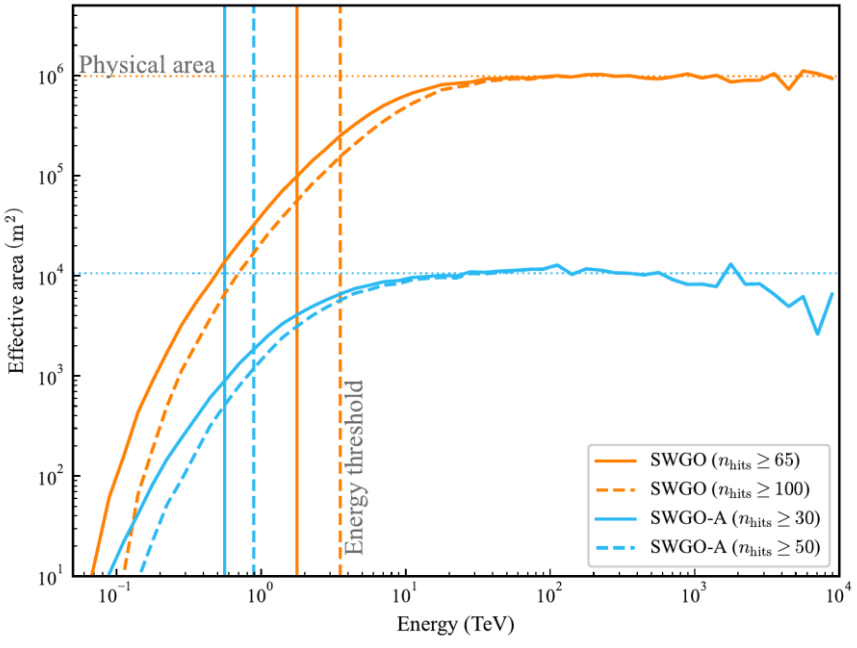
Simulated 5-year survey



Galactic Centre source: SWGO sensitivity vs H.E.S.S. and HAWC measurements

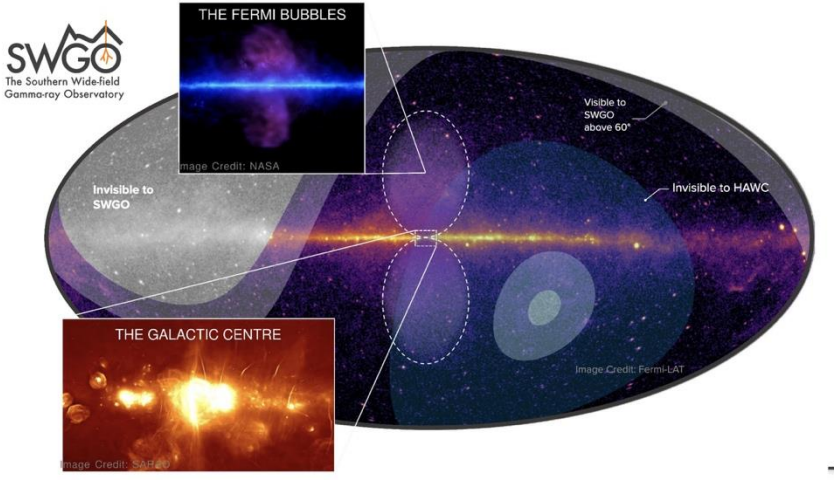
CR spectrum and composition

- Effective area approaches the ~1 km² physical area at tens of TeV
- Dual layer: top = electromagnetic calorimeter, bottom = muon counter
- Four mass groups (H, He, N, Fe) from E_EM vs N_μ
- Optimistic purity: ~90% protons, ≥ 95% heavier (preliminary)
- Point to measuring spectra by mass group and to clarifying the tensions between experiments



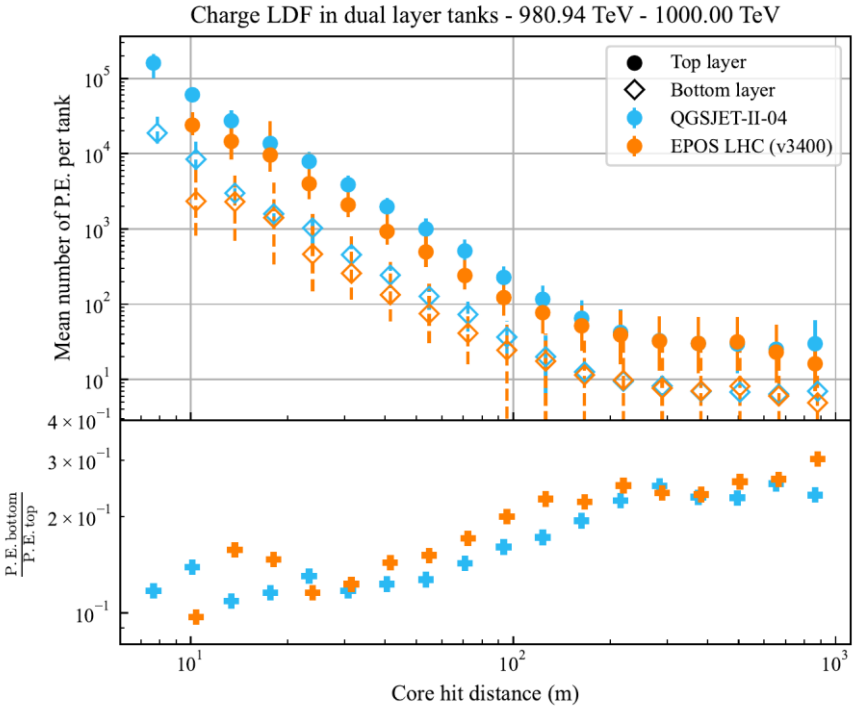
Cosmic-ray anisotropy

- Full-sky dipole needs overlap between hemispheres (HAWC + IceCube)
- IceCube: dipole phase and amplitude change with energy
- Composition-dependent anisotropy as a test of propagation, it should appear at different energies for different nuclei
- That is why we need to classify by species, and there SWGO's muon counting would allow a composition-dependent anisotropy measurement, something pioneering
- Angular resolution < 0.5° even with a simple plane fit
- **Prospects, not yet a quantitative sensitivity**



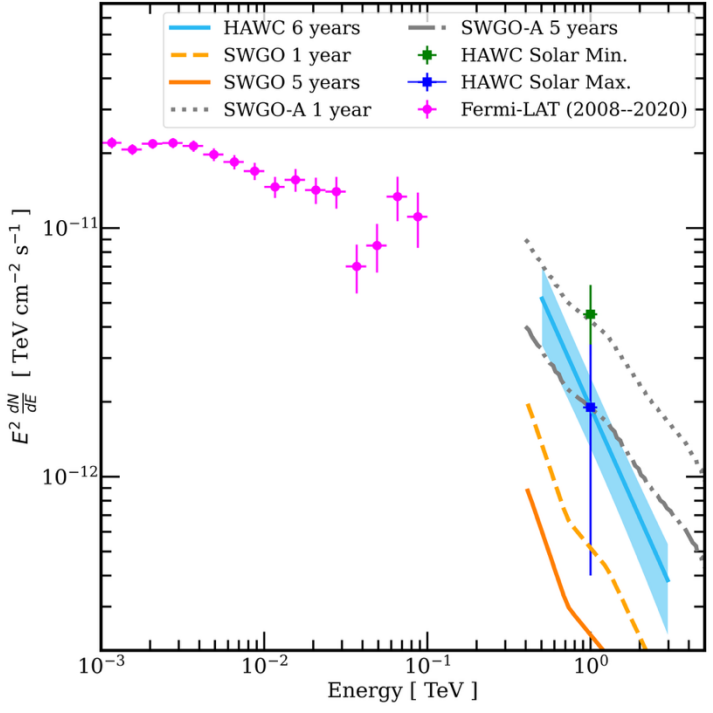
The muon puzzle

- Models tuned at the LHC underpredict muons in air showers
- SWGO identifies muons from a few hundred GeV to tens of PeV
- Bottom/top charge ratio: first-order, model-independent muon estimate
- Impact of energy reconstruction still to be evaluated



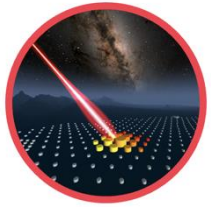
The Sun and the heliosphere

- Puzzling hard spectrum and morphology (Fermi-LAT, HAWC)
- Needs an all-sky instrument that works in daytime
- SWGO: precise spectrum over future solar cycles
- With SWGO we could measure the spectrum precisely over the coming solar cycles and look for time variations, which tells us about the local transport of cosmic rays in the Sun's magnetic field.



Multi-messenger, new physics

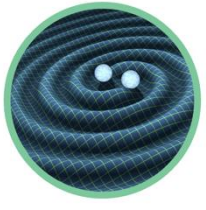
- Neutrinos: follow-up of IceCube southern tracks and KM3NeT events
- UHECRs: gamma-ray follow-up of the Cen A excess
- GRBs: ~0.7 per year; with CTAO, the full light curve
- Dark matter: WIMPs towards the Galactic Centre region



Cosmic rays



Neutrinos

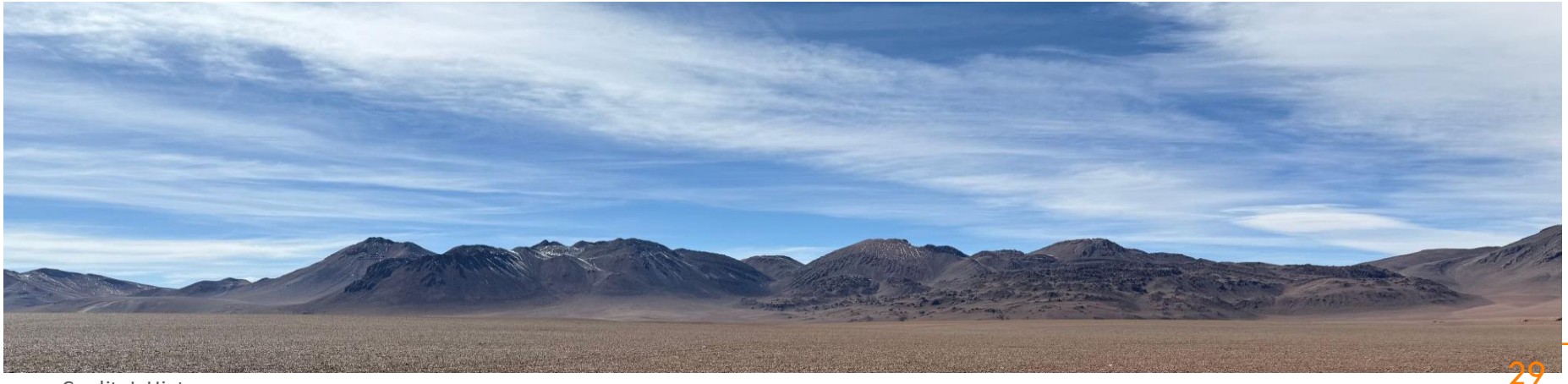


Gravitational waves and GRBs

Credit: J. Hinton

Summary

- SWGO brings the wide-field gamma-ray approach to the Southern Hemisphere
- Strongly complementary to CTAO-South
- Cosmic rays: spectrum and composition, anisotropy, muon puzzle, the Sun
- Approaching construction: Pathfinder at Pampa La Bola, outer array from 2029
- Science white paper: arXiv:2506.01786



Credit: J. Hinton