

The Context of Ground-based Gamma-ray Astronomy

Ulisses Barres de Almeida
CBPF

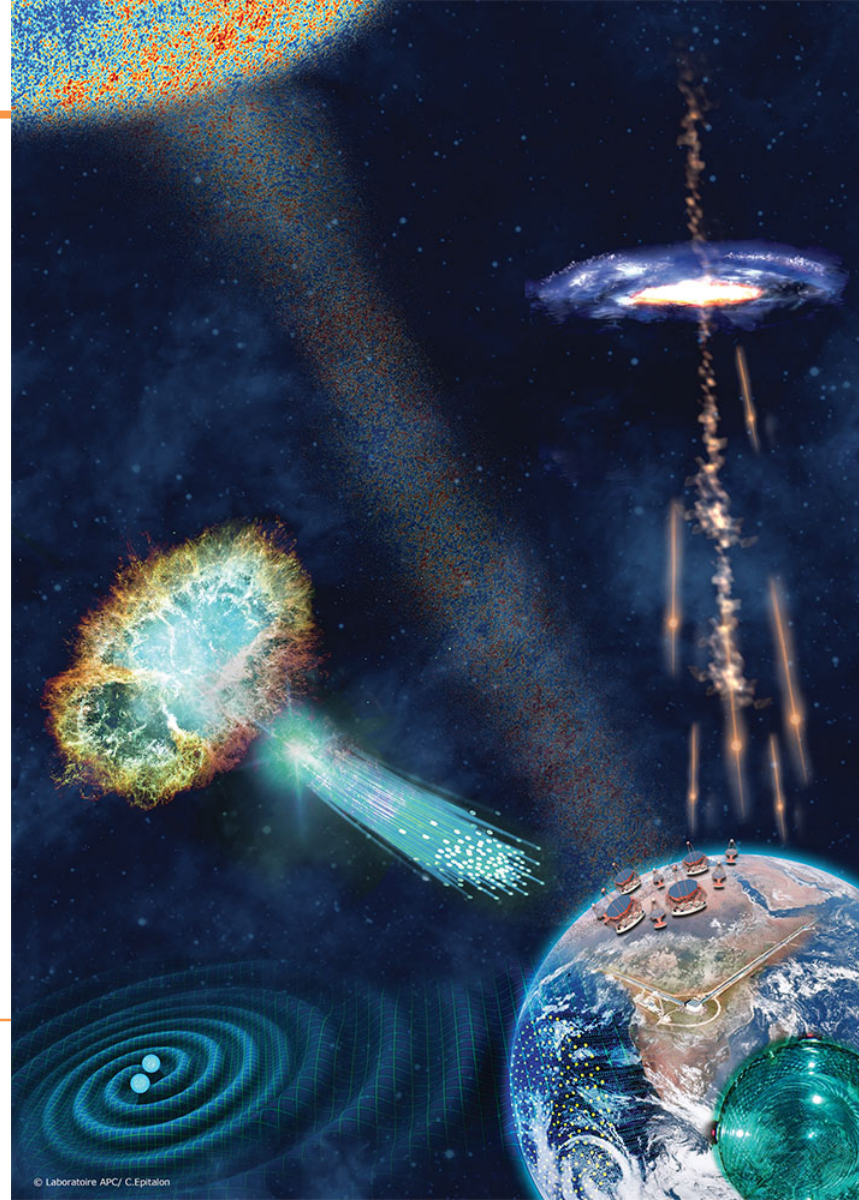


CBPF
Centro Brasileiro
de Pesquisas Físicas

— 9 to 40 SSTs | 20-24 July | Haus Sexten 2026 —

Content

1. Introduction
 2. Prelude to a new era
 3. CTAO is coming online
 4. EAS arrays in the south
 5. The future in South America
-



Ground-based Techniques

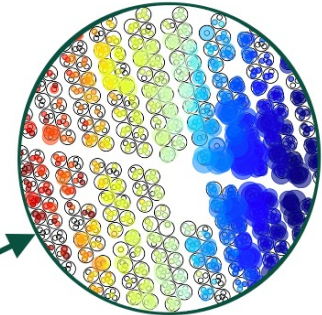


Air-shower particle arrays

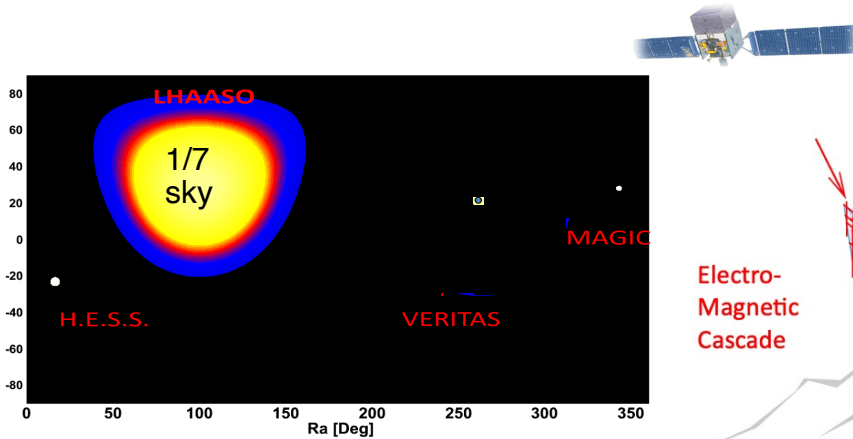
High Duty Cycle

Wide-Field of View

UHE Performance



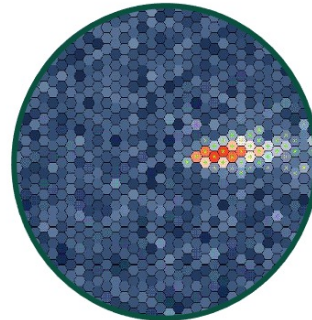
Few ns spread in particle arrival at each detector



Electro-Magnetic Cascade

Few ns light flash

Cherenkov Light



© Armelle Jardin-Blicq

CTAO

Air-Cherenkov Telescopes

Low Duty Cycle

Pointing instruments

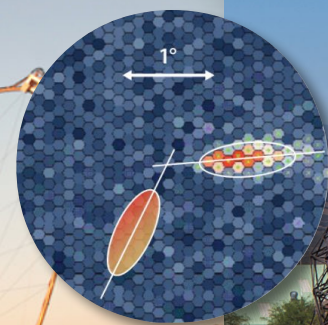
Precision Astronomy



Ground-based Gamma-ray Astronomy Network



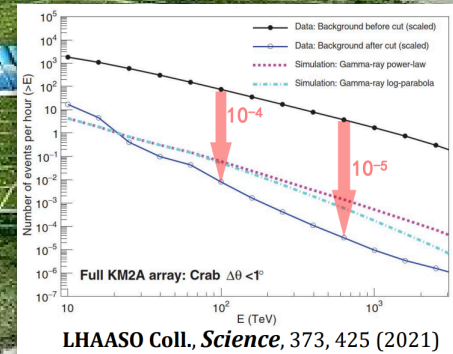
- Large reflectors + Fine-pixel camera
- Wide field of view for imaging and background
- Stereoscopy → excellent shower reconstruction



Precision Astronomy at VHEs



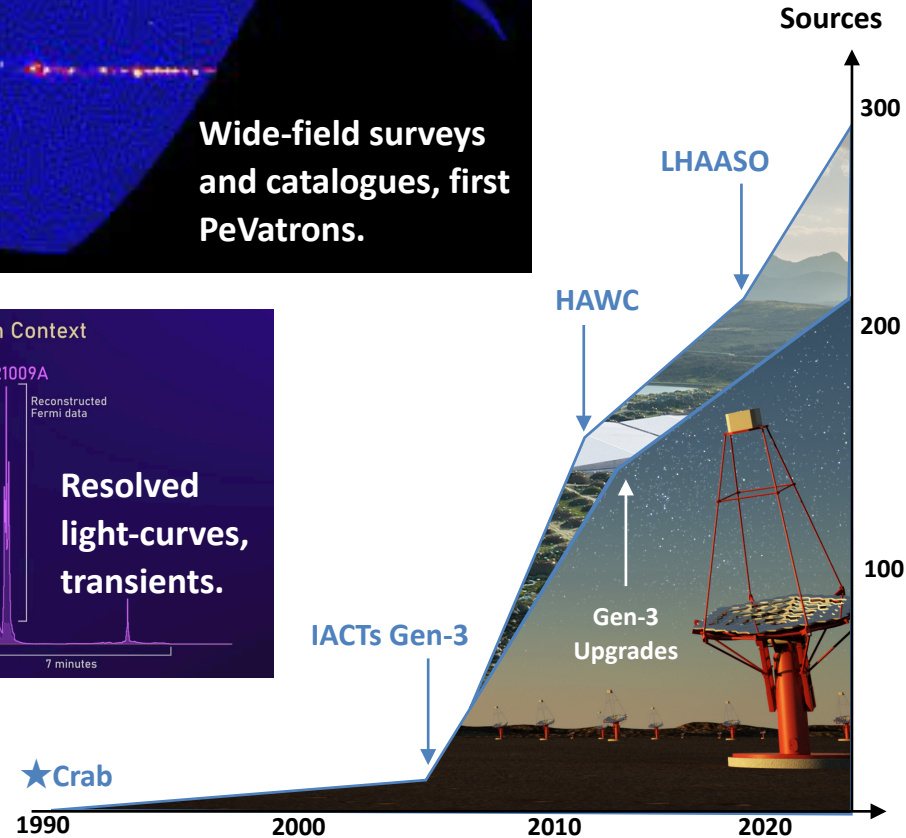
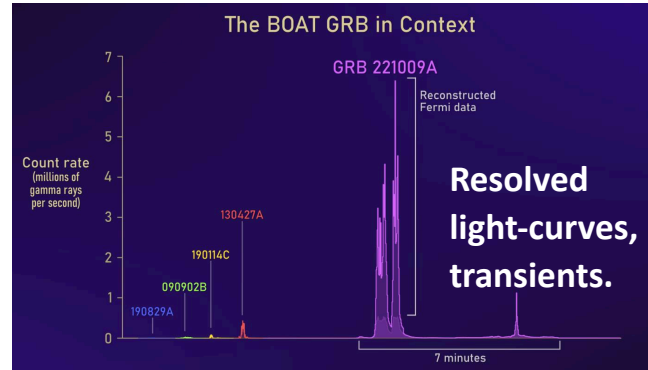
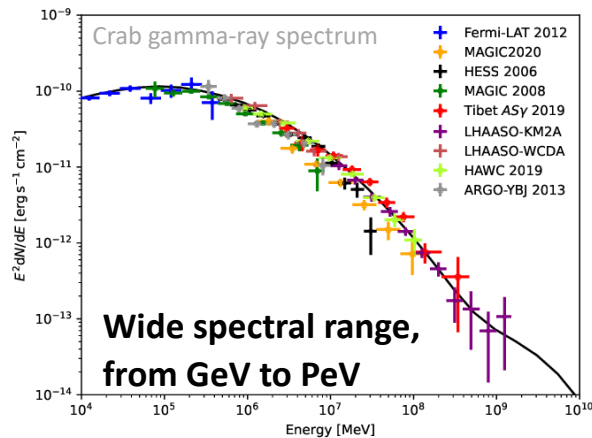
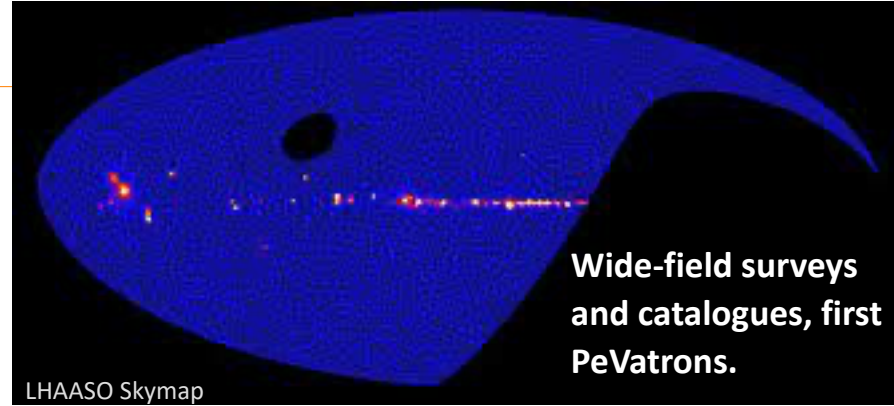
- High altitude & fill factor → dense shower front sampling
- Large array areas for efficient shower detection
- Large Muon Effective Areas



VHE Astronomy in the 2020s

Resolved skymaps,
arcmin-scale

Gamma ray image
of supernova
RX J1713.7-3946





CTAO will:

- Reach the limits of angular resolution
- Push the boundaries of survey capabilities
- Expand energy coverage towards the 100 TeV+

Next Frontiers?



Hybrid
Techniques



Towards
lower energies

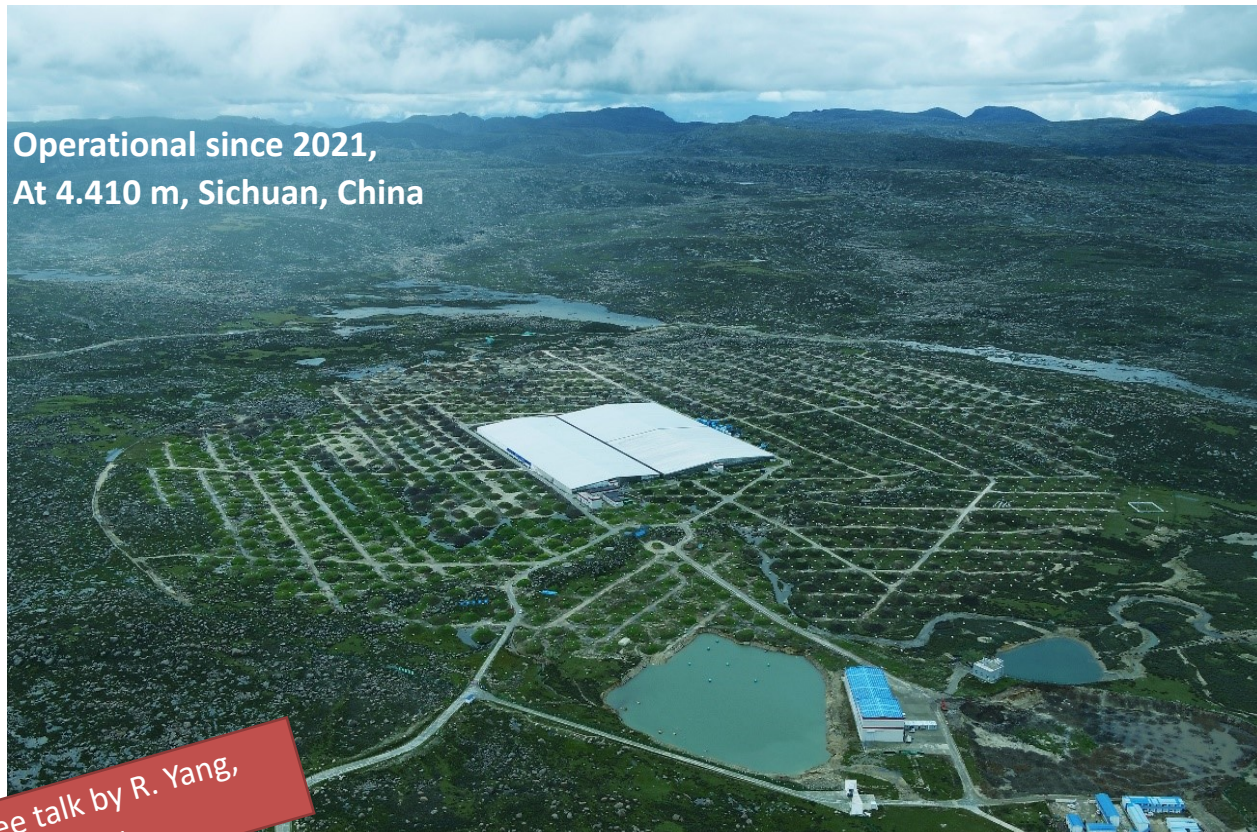
Cost-effective
CR suppression

Improved angular
resolution

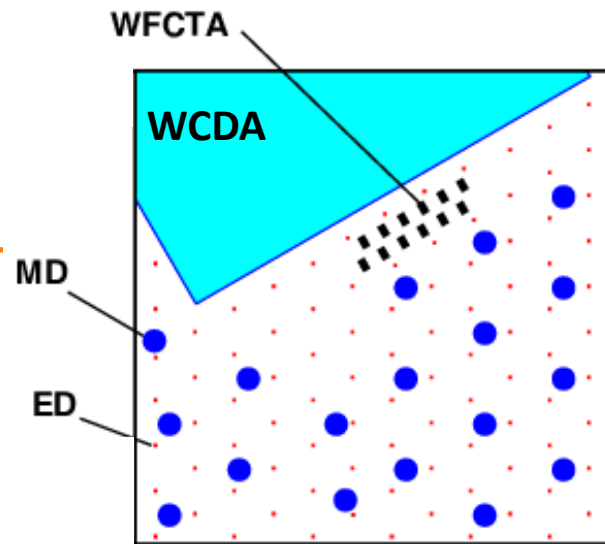


LHAASO

Operational since 2021,
At 4.410 m, Sichuan, China



See talk by R. Yang,
tomorrow

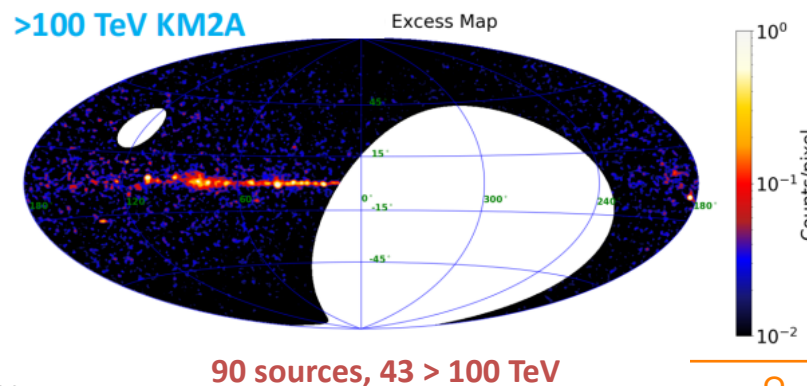
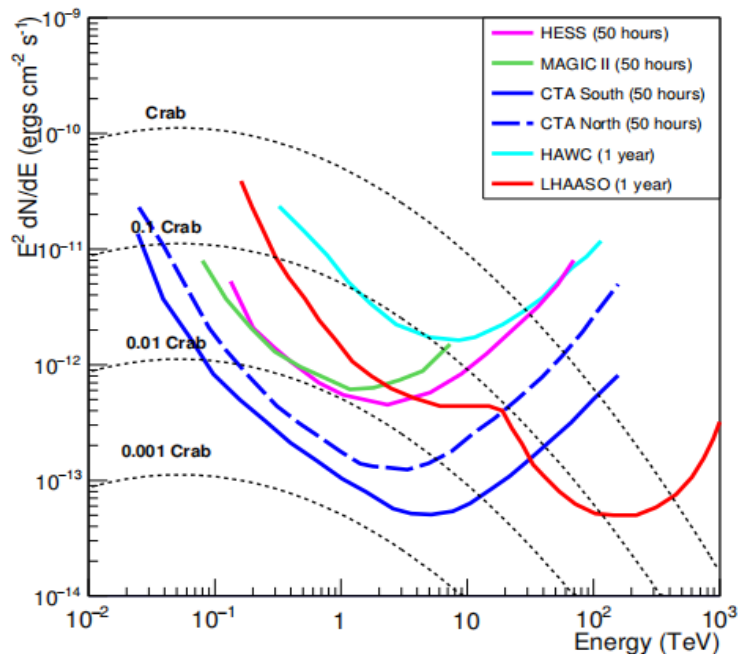


- ⊙ **WCDA**, 80,000 m², operating < 10 TeV
- ⊙ **ED** x 5,216 units, covering 1.3 km²
- ⊙ **MD** x 1,188 units, with 4% FF
- ⊙ **WFCTA**, Cherenkov imaging of air-showers



LHAASO

- LHAASO has expanded the catalogue of UHE sources into the PeV range
- **Plurality of source types**, dominated by PWN and Halos with UHE emission & SNRs
- Morphology : CR interaction with surrounding MCs
- YMSCs, including the Cygnus super-pegatron
- mQSOs as potential PeV accelerators
- **Diffuse emission up to PeV**, excess flux towards inner GP
- **Potential for study of GRBs and fast transients demonstrated with the BOAT**

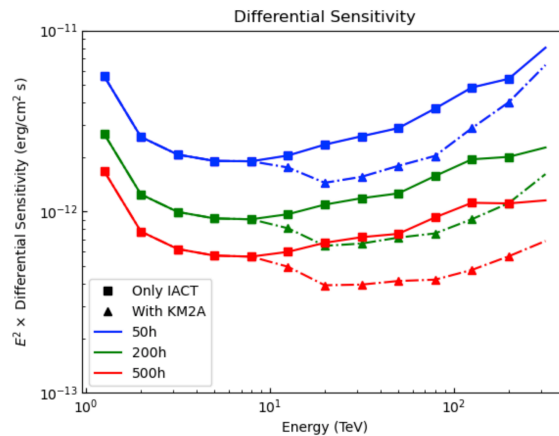
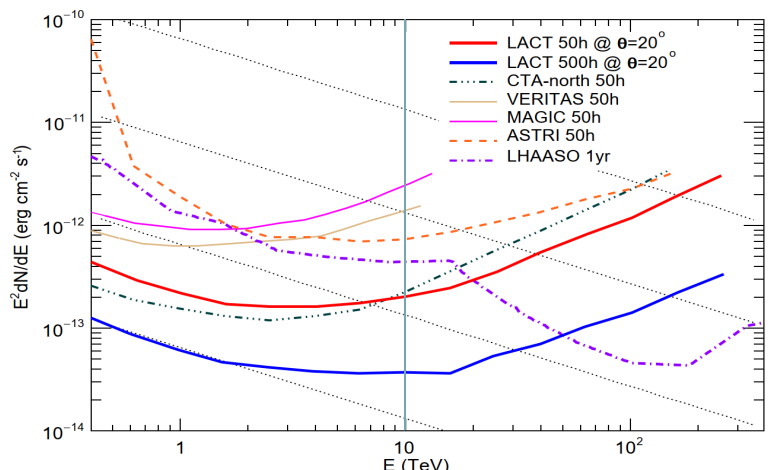
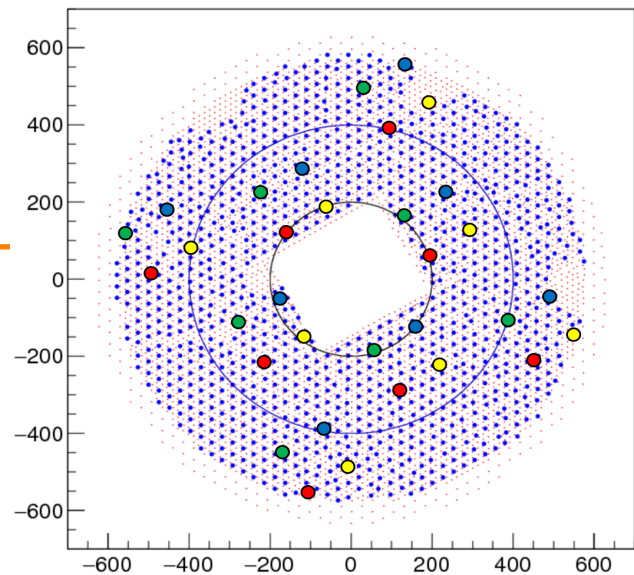
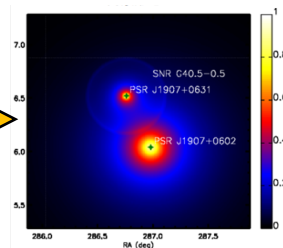
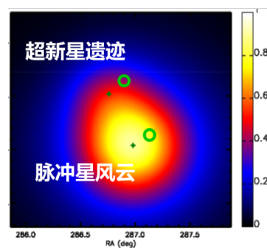


See talk by R. Yang,
tomorrow



LACT

- Installation of 32 6-m IACTs in LHAASO site
- Project status:
 - 2025 - first telescope
 - 8 telescopes exp. 2026
 - Full-array in 2028

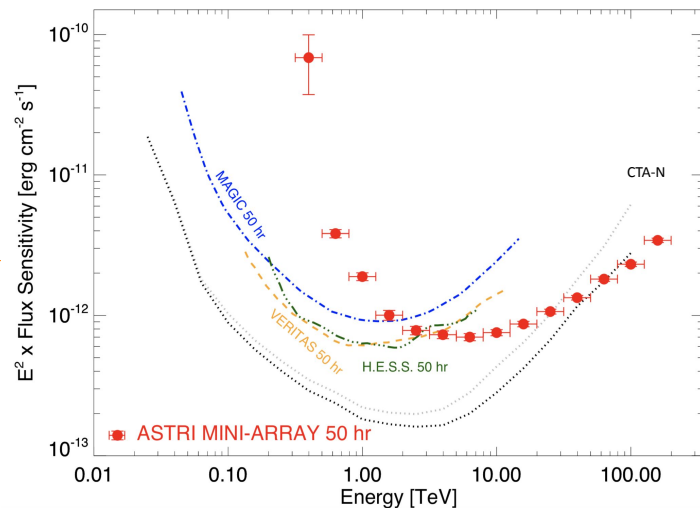


Improved sensitivity
when operating in conjunction
with LHAASO particle array

See talk by R. Yang,
tomorrow

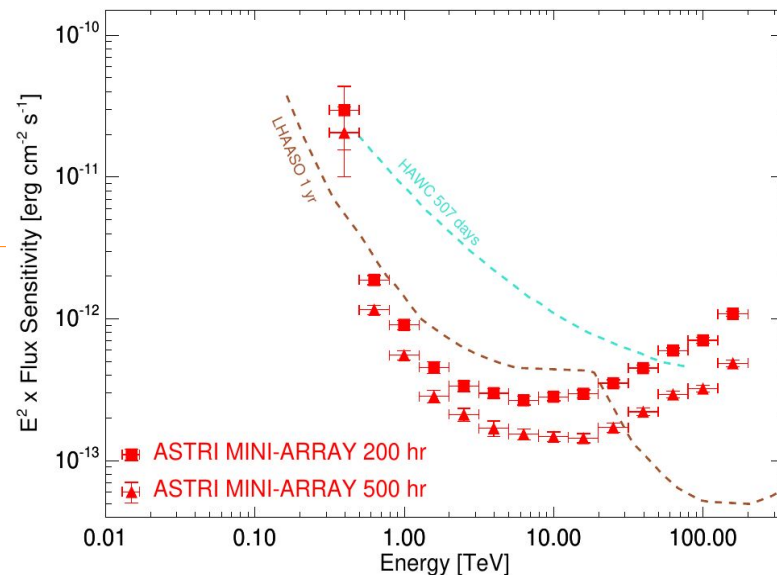
The 9...

- The array will be completed this year
- Successful Blazar Monitoring with ASTRI-1
- First Stereo Crab Observations performed in 2026

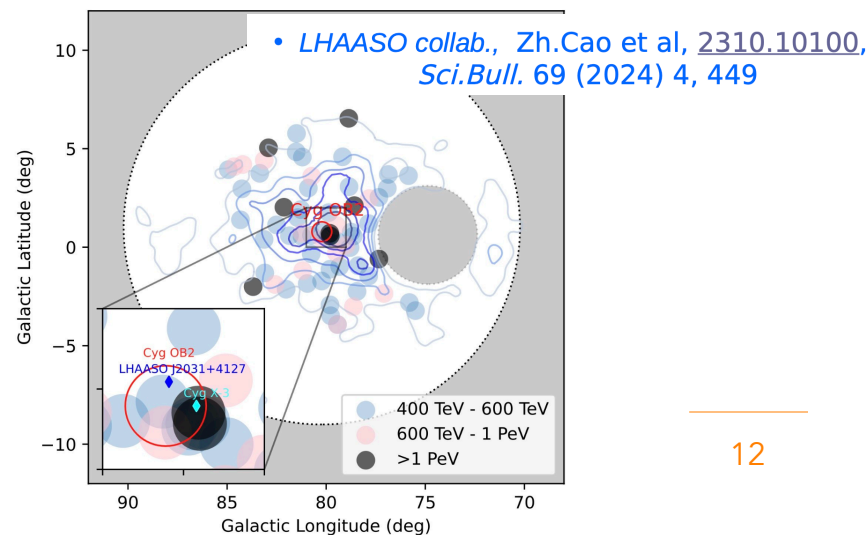
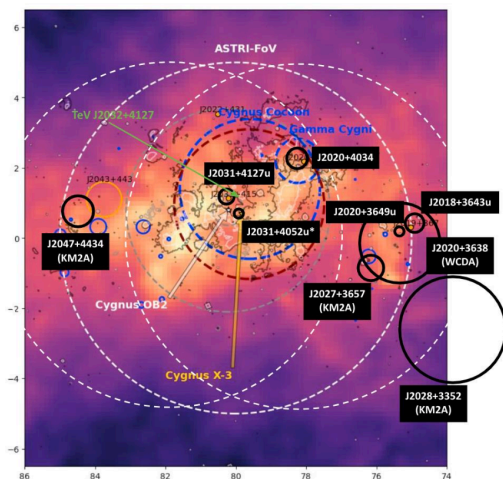


ASTRI-LHAASO Synergies

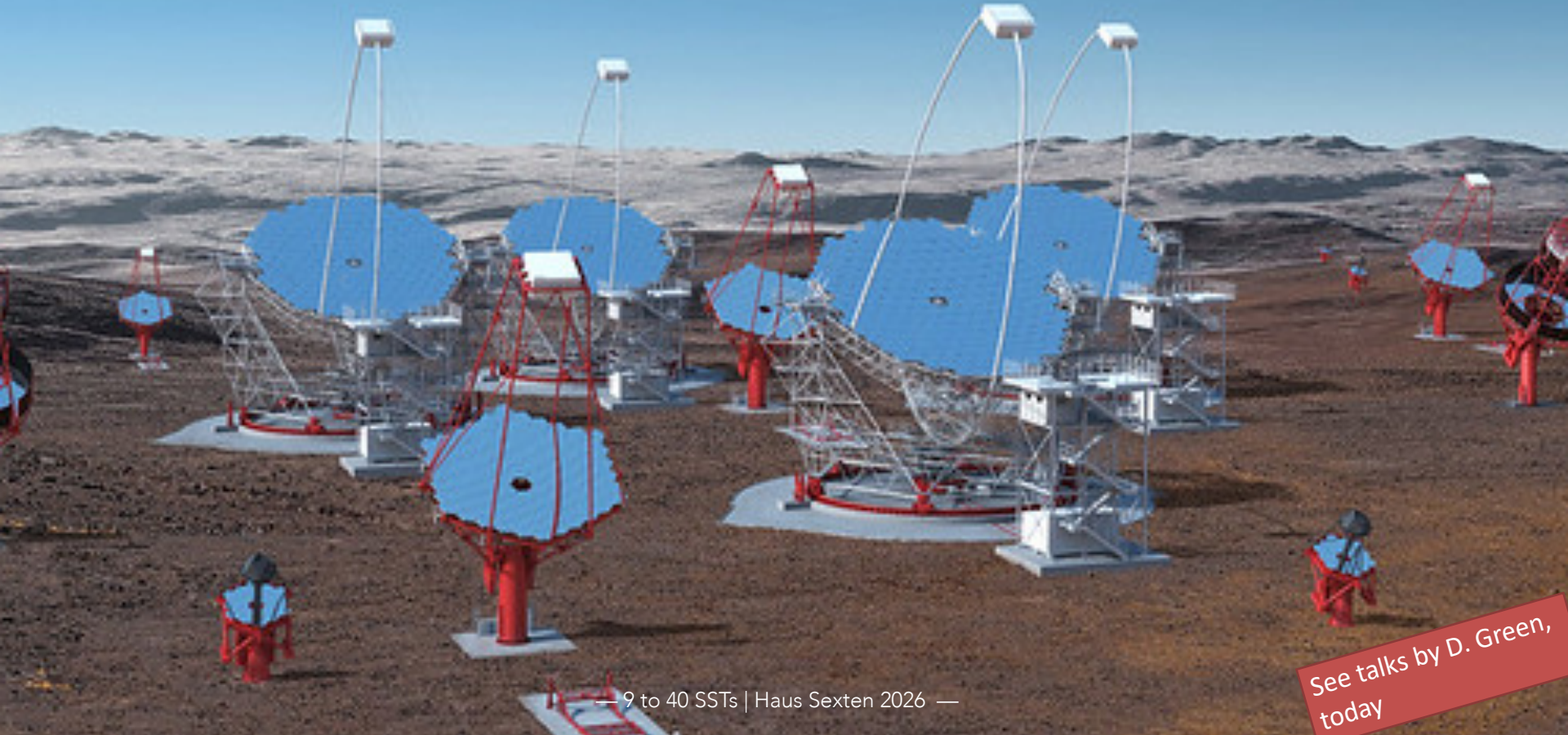
- ◉ The ASTRI-LHAASO synergies are a prelude to gamma-ray astronomy in the coming decade
 - Exploiting the complementarity of the two observational techniques
- ◉ ASTRI observing strategy will allow for a deep study of the most interesting LHAASO sources



The Cygnus region



The arrival of CTAO

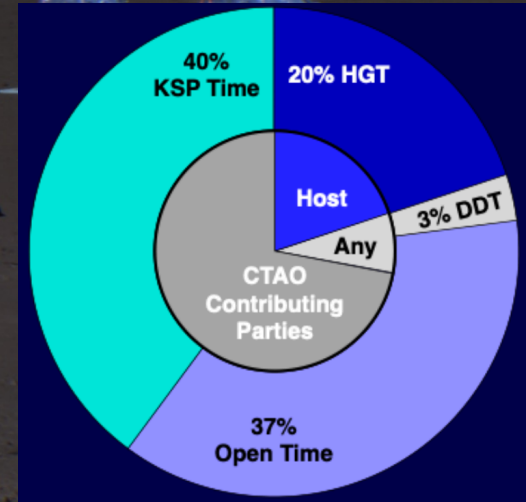
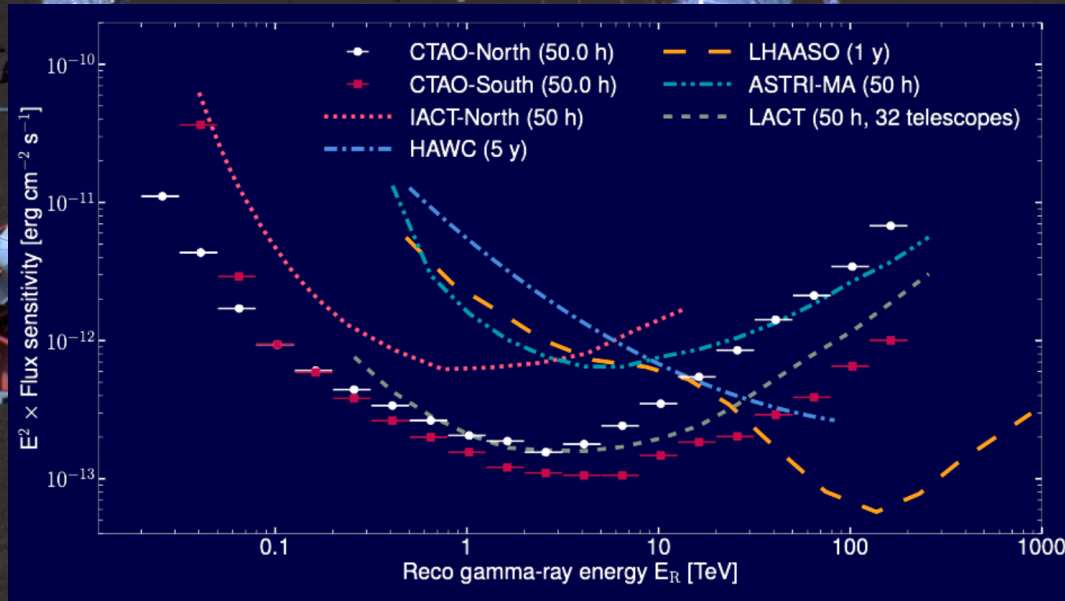
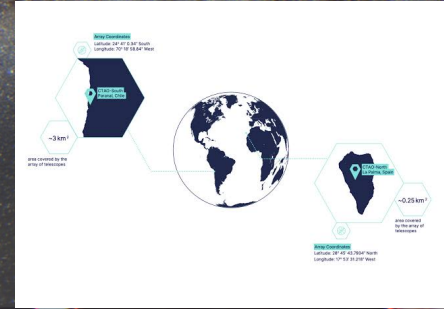


— 9 to 40 SSTs | Haus Sexten 2026 —

See talks by D. Green,
today

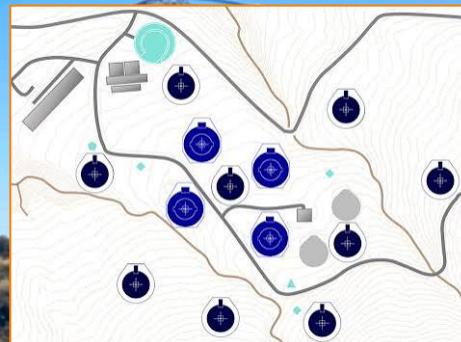
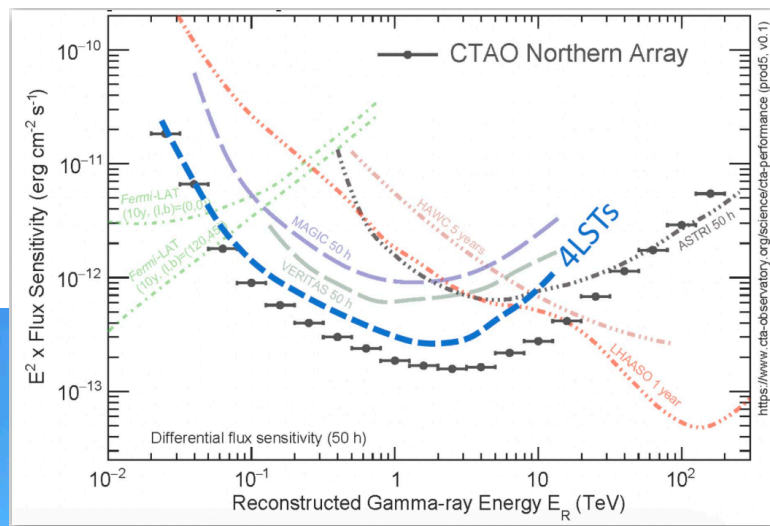
CTAO is the definitive IACT array

- Ultimate instrumental performance
- Alert and follow-up capabilities
- A proposal-driven observatory
- Multiple observing modes
- Full-sky coverage



The LST Array

- LST-1 operating since several years
- Inauguration and Commissioning in the next months
- Fast slewing and low-energy threshold of ~ 20 GeV
- Ideal instrument for soft, transient sources



See talks by A. Carosi,
today

Future Perspective

IKC Construction

- Telescopes
- Array Common Elements
- Commission of array elements
- CTAO software

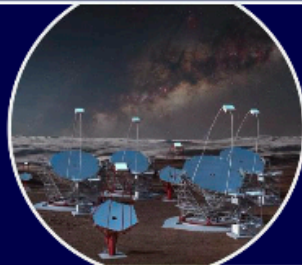
Array Commissioning

- Integration, verification, and validation of array elements and software
- Science verification of intermediate array configurations



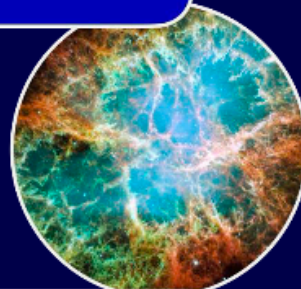
CTAO Construction

- Infrastructure



Early Science

- Call for proposals
- Guaranteed observing time for Contributors to construction project



Steady State Operations

- Full Alpha configuration
- Normal Operations begin
- KSP begins

Now

2027 - 2028

2028 - 2030

2030+

Future Perspective



4x LST
1x MST

Observatory
Release 2

Verified in 2028
AO Call in 2029

2x MST
5x SST

Early Science
OP 1

2028

2029

4x LST
5x MST

Observatory
Release 3

Verified in 2029
AO Call in 2030

TBD

+ 2 LST
(CTA+ project)

Early Science
OP 2

2030

4x LST
9x MST

Observatory
Release 4

Verified in 2030
AO Call in 2031

14x MST
37x SST

Early Science
OP 3

2031

4x LST
9x MST

Official Start
of Operations

AO Call in 2032

14x MST
37x SST

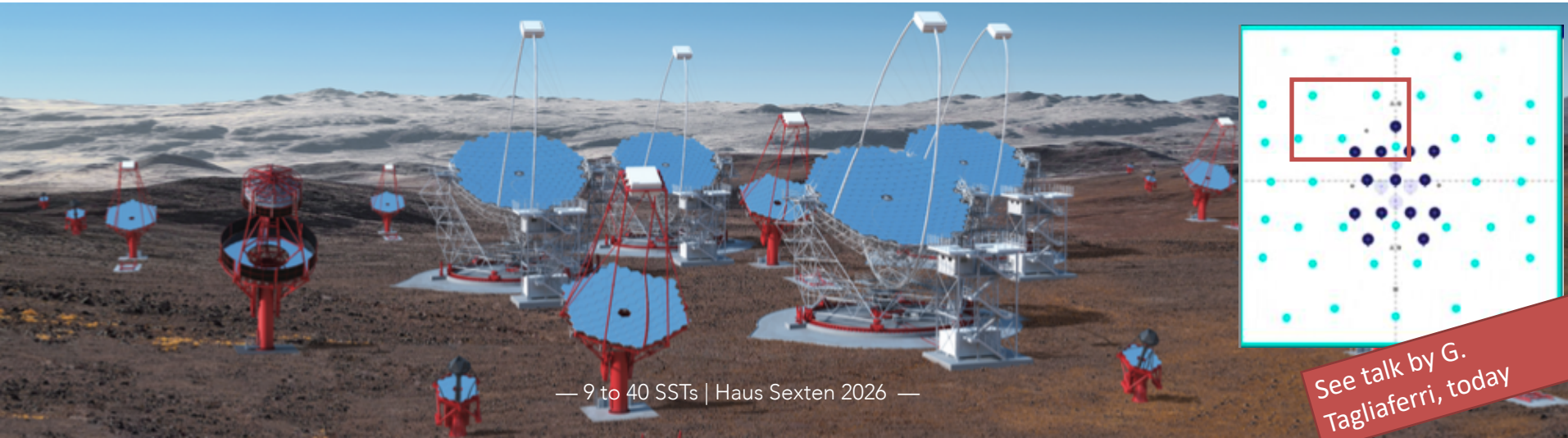
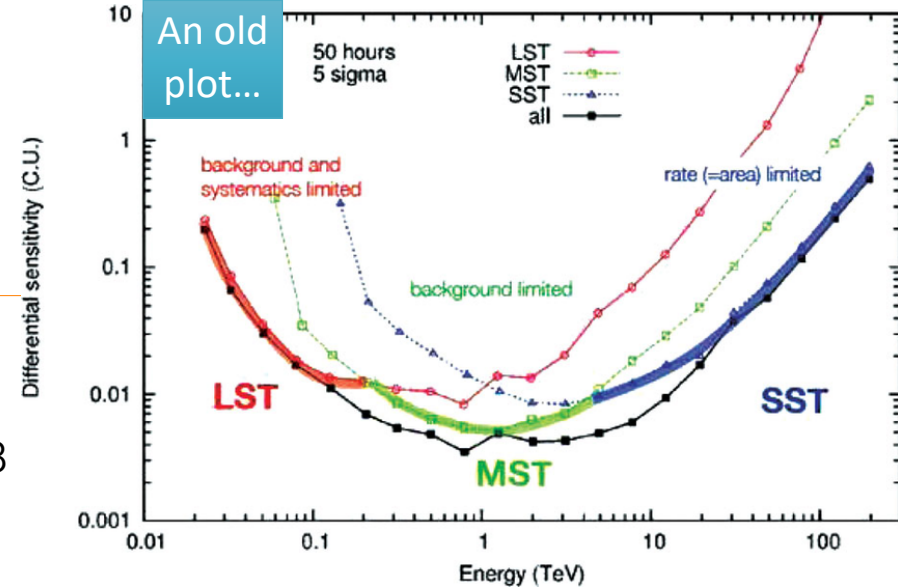
OP1

2032



The 40...

- SST sub-array expected for 2031 (37 tels)
- Intermediate configuration operations from 2028
- SSTs will bridge CTA with wide-field arrays, such as SWGO, in the Southern Hemisphere



Motivation for Southern Wide-field Arrays

- H.E.S.S. Galactic Plane survey
- H.E.S.S. Extended GP survey

+ transient synergies with CTA

Galactic Center

Westerlund 1

RX J1713.7-3946

Sun

LHAASO +
HAWC

Crab Nebula

HESS A&A 621 (2018)

*Based on figure 16

19

EAS Arrays in the South

A 3D topographic map of South America, specifically focusing on the Andean region. A green dot on the northern slopes of the Andes is connected by a green line to the ALPACA text. An orange dot further south, in the Atacama Desert region, is connected by an orange line to the SWGO text. The map shows the coastline of Chile and Peru, with the Pacific Ocean to the west.

ALPACA

**Andes Large Area Particle Array
for Cosmic rays and Astronomy**

Chacaltaya

SWGO

**Southern Wide-Field
Gamma-ray Observatory**

Atacama

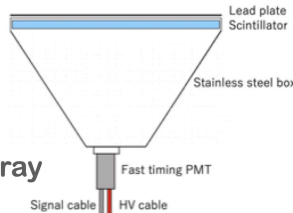
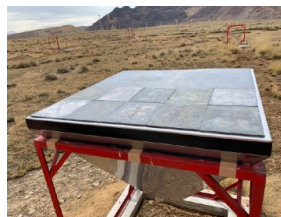


ALPACA (2028+)

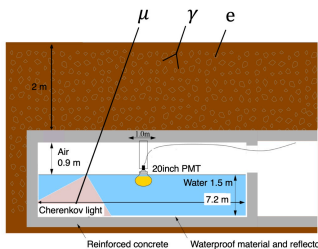
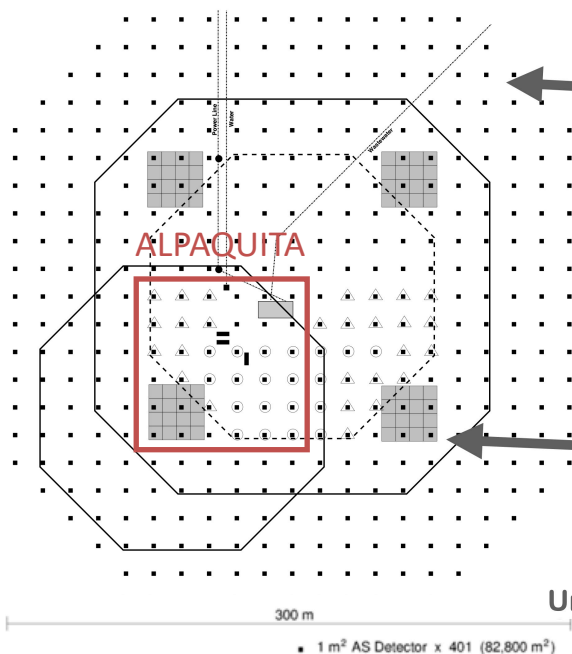


Thanks to Takashi Sako & Kato Sei

- 400 x 1 m² plastic scintillator SD
 - 15-m spacing; 82,800 m²



Air Shower Array



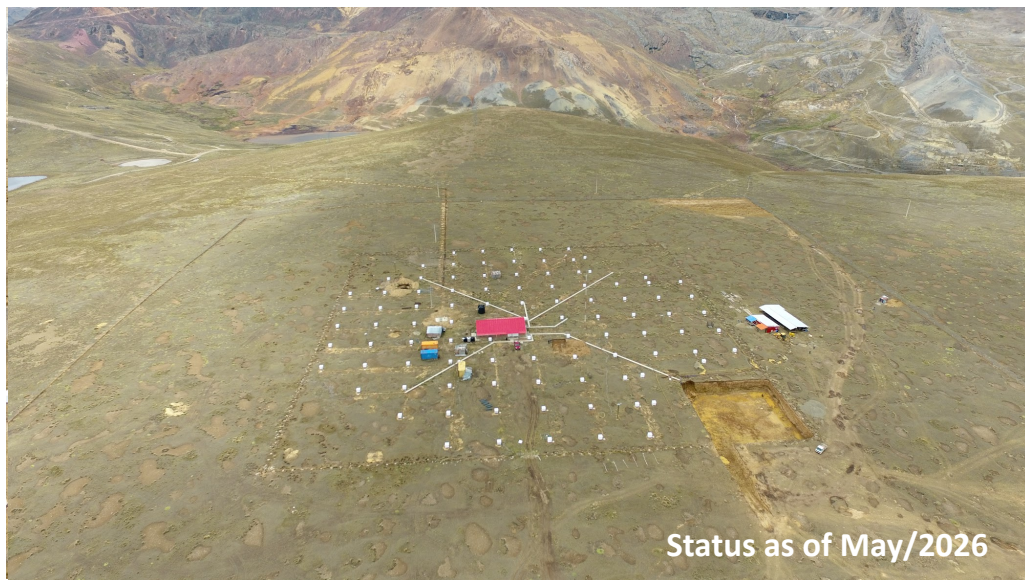
Underground Muon Detector Array



- 64 x 56 m² WCD muon array
 - 4 x 16 cell clusters; 4% FF

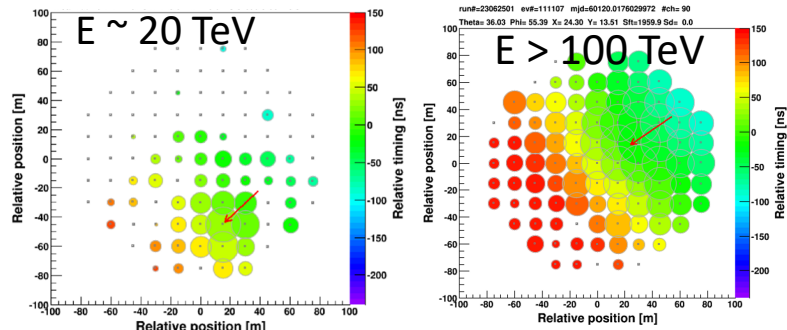


ALPAQUITA

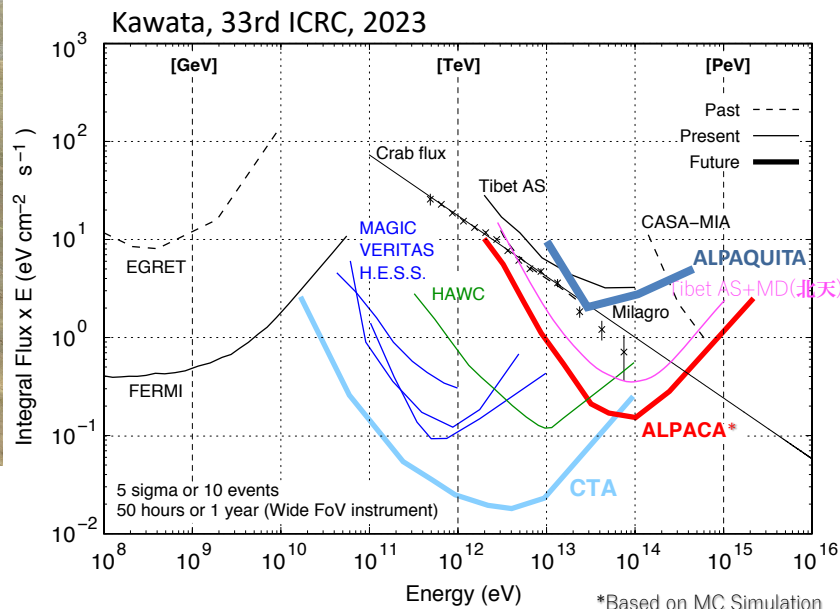


1/4 ALPACA array

- 97 SD units; 18,450 m²
- muon array under construction, exp. 2027



Subieta-Vasquez, 33rd ICRC, 2023

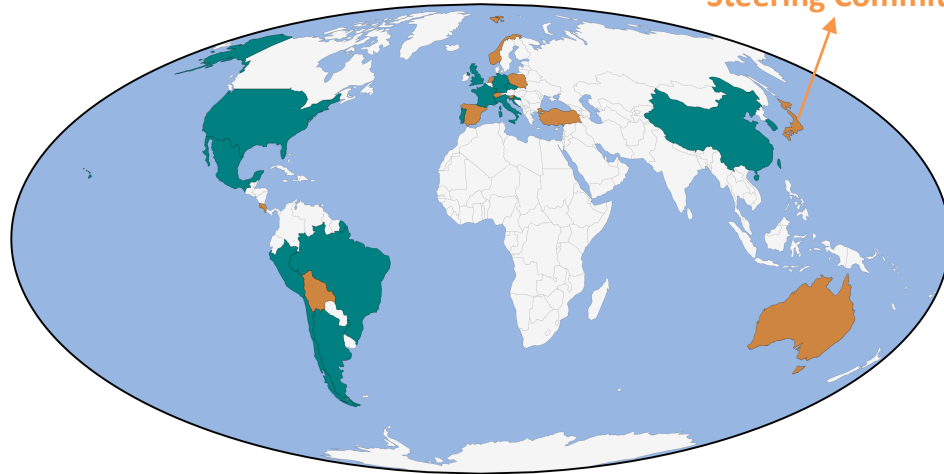


- Angular resolution $\sim 0.2^\circ$ @100TeV
- Energy resolution $\sim 20\%$ @100TeV

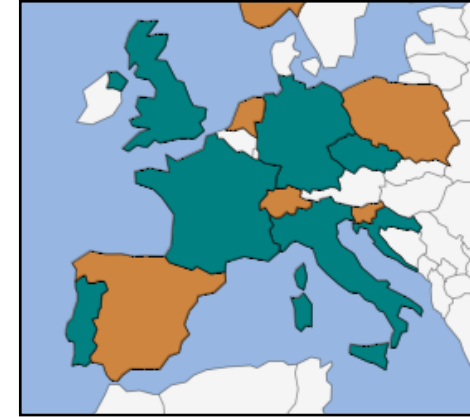
SWGO Collaboration

Member Institutes

Supporting Scientists



ICRR-Tokyo now an
invited member of the
Steering Committee



Argentina

Brazil

Chile

China

Croatia

Czech Republic

France

Germany

Italy

Mexico

Netherlands

Peru

Portugal

South Korea

United Kingdom

United States

SWGO partners

→ 16 countries, circa 100 institutes

→ + supporting scientists

Project Status

Science Prospects for the Southern Wide-field Gamma-ray Observatory: SWGO

P. Abreu^{1,2}, R. Alfaro³, A. Alfonso⁴, M. Andrade⁵, E. O. Angüner⁶, E. A. Anita-Rangel⁷, O. Aquines-Gutiérrez⁸, C. Arco⁹, R. Arceo¹⁰, J. C. Arteaga-Velázquez¹¹, P. Assis^{1,2}, H. A. Ayala Solares¹², A. Bakalova¹³, E. M. Bandeira¹⁴, P. Bangale¹², U. Barres de Almeida^{14,15}, P. Batista¹⁶, I. Batković^{9,17}, J. Bazo¹⁸, E. Belmont³, J. Bennemann¹⁹, S. Y. BenZvi²⁰, A. Bernal⁷, W. Bian²¹, C. Bigongiari²², E. Bottacini^{9,17}, R. Branada²³, P. Broneira^{1,2}, A. M. Brown⁶⁴, T. Rutik²⁴, K. S. Caballero-Mora¹⁰, P. Camarri^{25,26}, W. Cao²⁷, Z. Cao²⁷, Z. Cao²⁸

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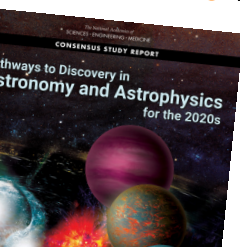
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<https://arxiv.org/abs/2506.01786>

SWGO R&D Phase Milestones		
2019	✓	M1 R&D Phase Plan Established
	✓	M2 Science Benchmarks Defined
2020	✓	M3 Reference Configuration & Options Defined
	✓	M4 Site Shortlist Complete
2022	✓	M5 Candidate Configurations Defined
	✓	M6 Performance of Candidate Configurations Evaluated
2024	✓	M7 Preferred Site Identified
	→	M8 Design Finalised
	→	M9 Construction & Operation Proposal Complete

⦿ Roadmaps

- US Decadal Review
- SNOWMASS, APPEC, Astronet
- LASF4RI, in Latin-America



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<https://arxiv.org/abs/2506.01786>

Funding?

- Under negotiation in BR
- Production of WCD units for PeVatron array

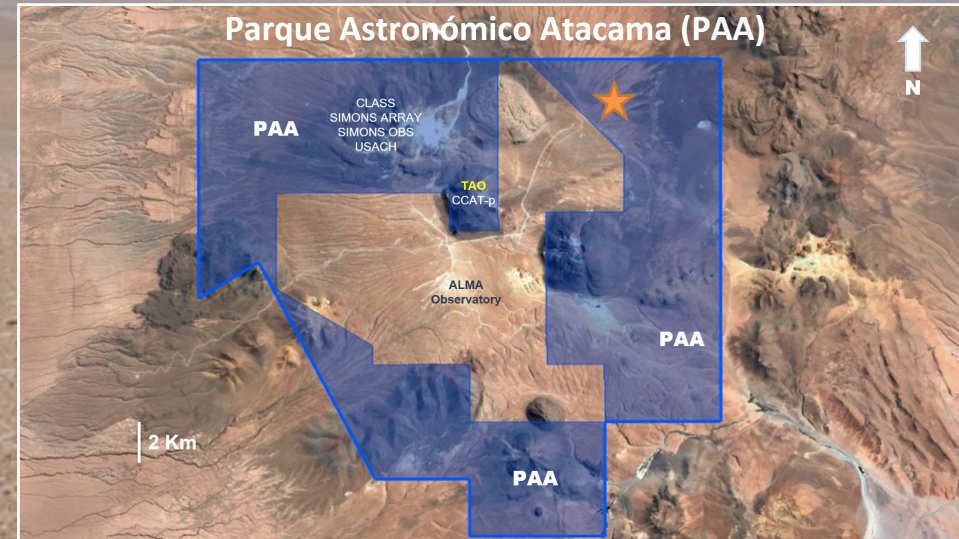


Site Selection

Preferred and back-up site announced on 12th August 2024

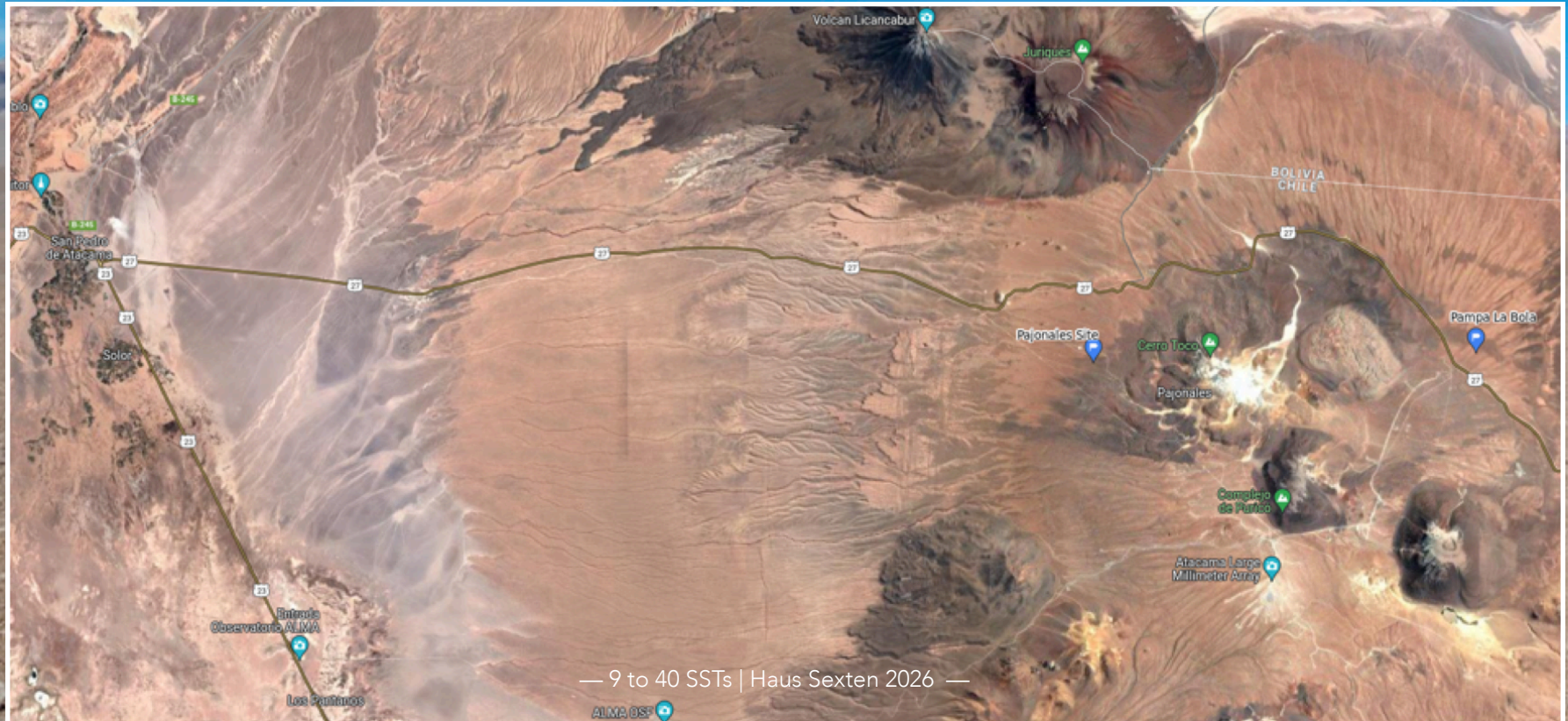
Pampa La Bola, Atacama Astronomical Park (Chile)

- Vast plateau at 4,770 m a.s.l.
- 23° South, 68° West
- Available area superior to 1 km²
- At the international road Chile-Argentina
 - ✓ Few km from ALMA
 - ✓ 40 min from San Pedro de Atacama
 - ✓ 2 hours from Calama (airport)



Site Selection

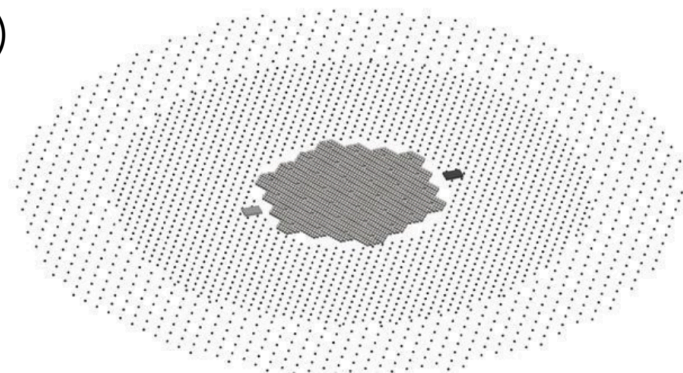
- Pampa La Bola, Atacama Astronomical Park (Chile)



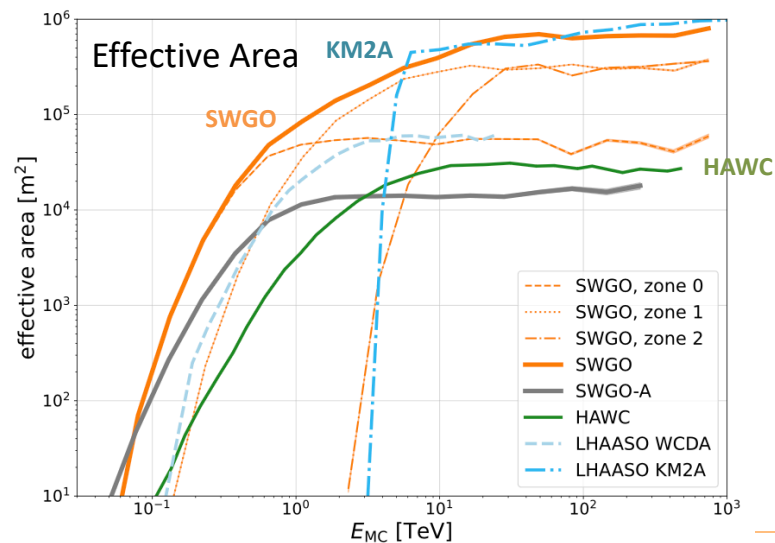
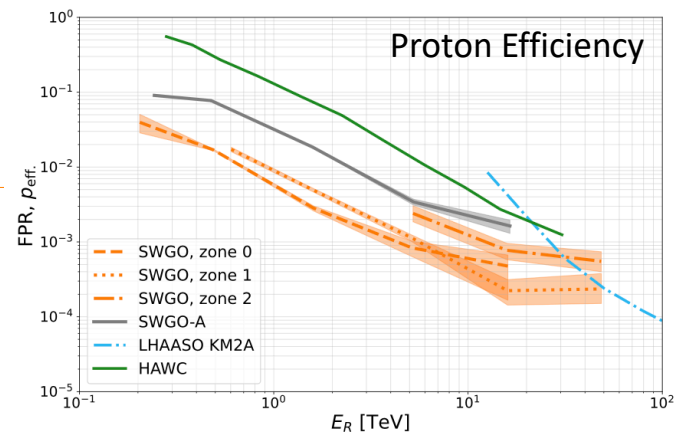
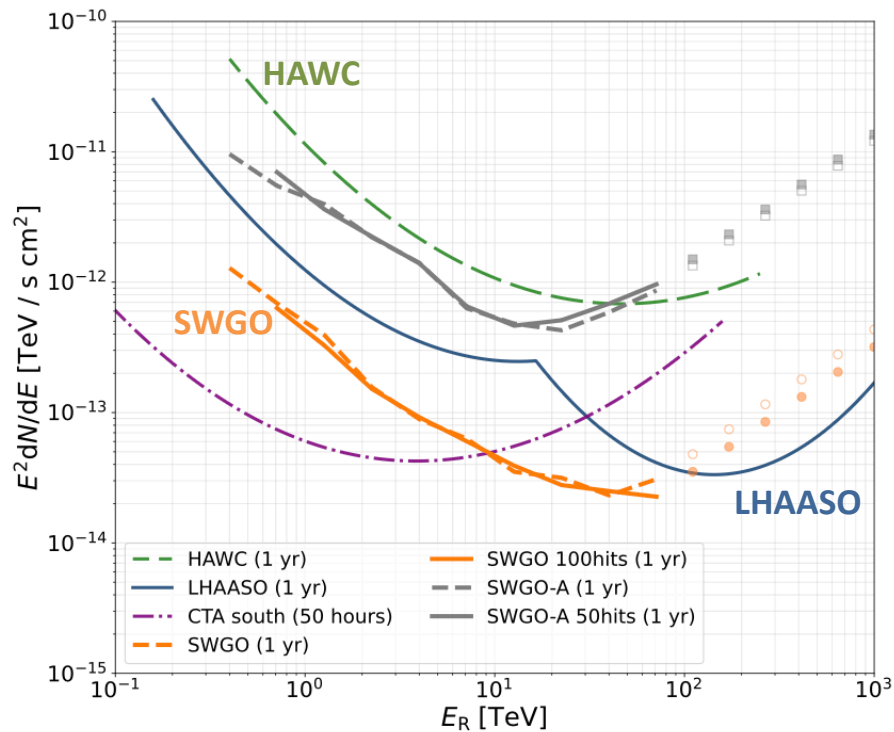
The baseline array layout



- ◉ Graded fill-factor from core to outer-array
- ◉ Inner array: FF=65%, 80,000 m², 2,450 tanks (90 m³)
- ◉ Outer array:
 - Zone 1: FF=4%, R=400 m, 1,660 tanks (15 m³)
 - Zone 2: FF=1.6%, R=560 m, 760 tanks (15 m³)



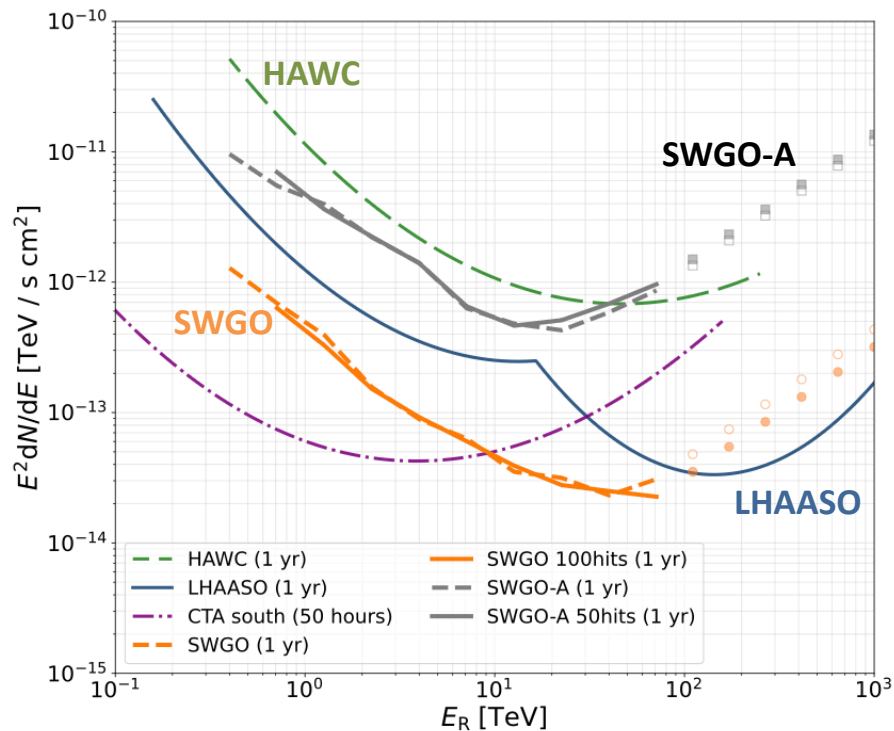
Expected Sensitivity



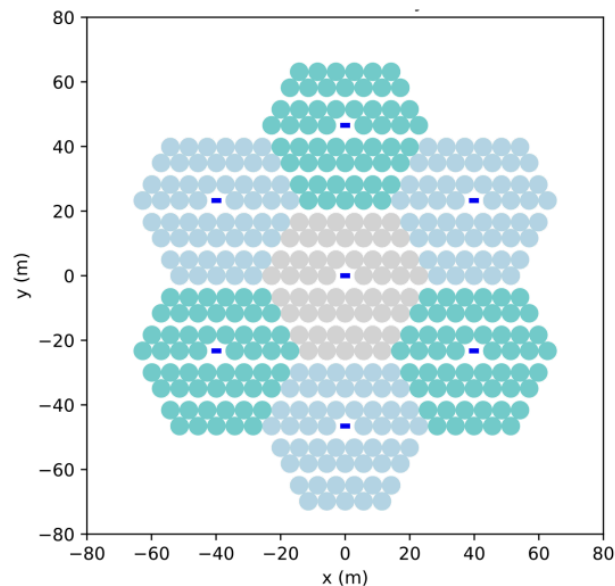
At 4,770 m a.s.l.

[arxiv:2506.01786](https://arxiv.org/abs/2506.01786)

Expected Sensitivity - SWGO-A



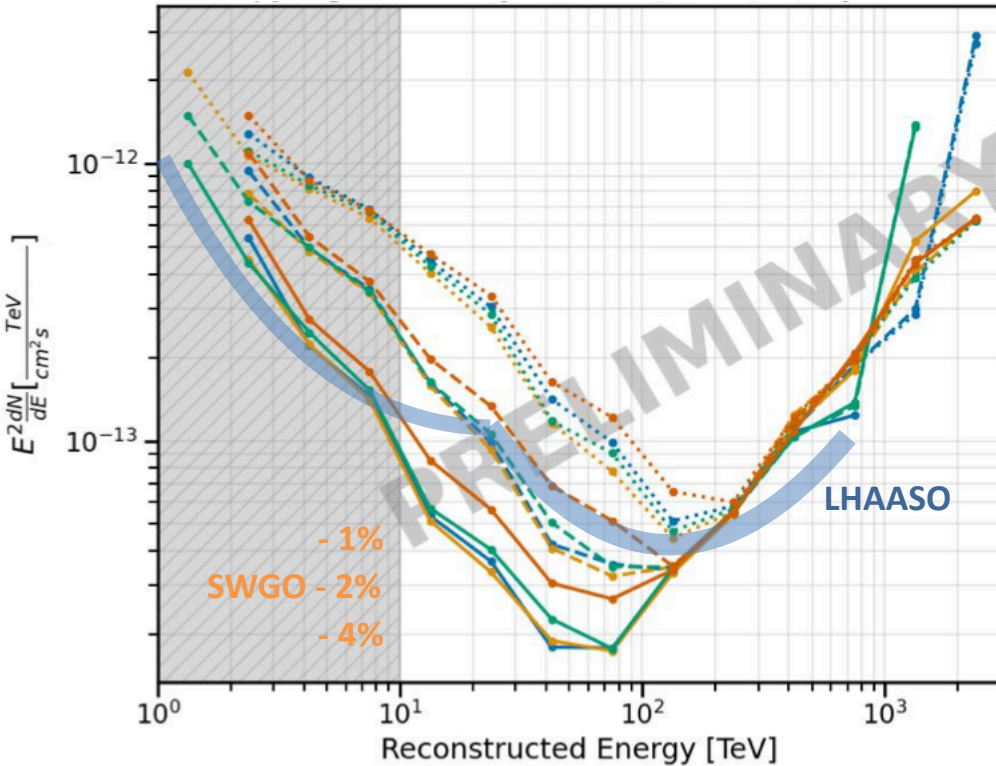
SWGO-A 12,000 m²
385 tanks



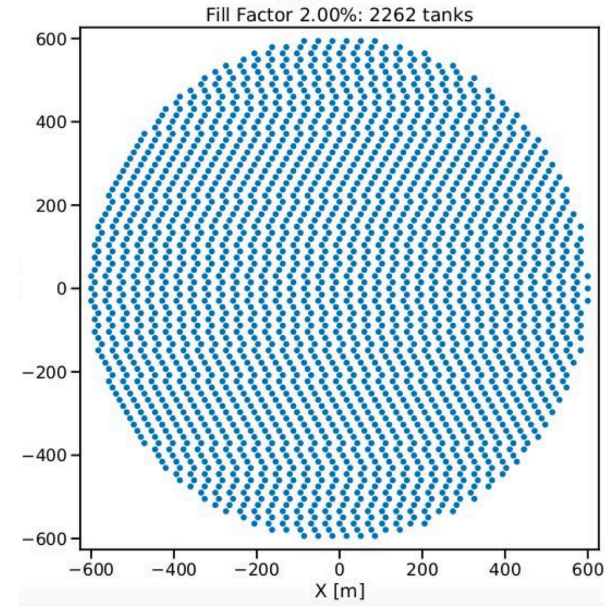
At 4,770 m a.s.l.

[arxiv:2506.01786](https://arxiv.org/abs/2506.01786)

Expected Sensitivity - PeV Array

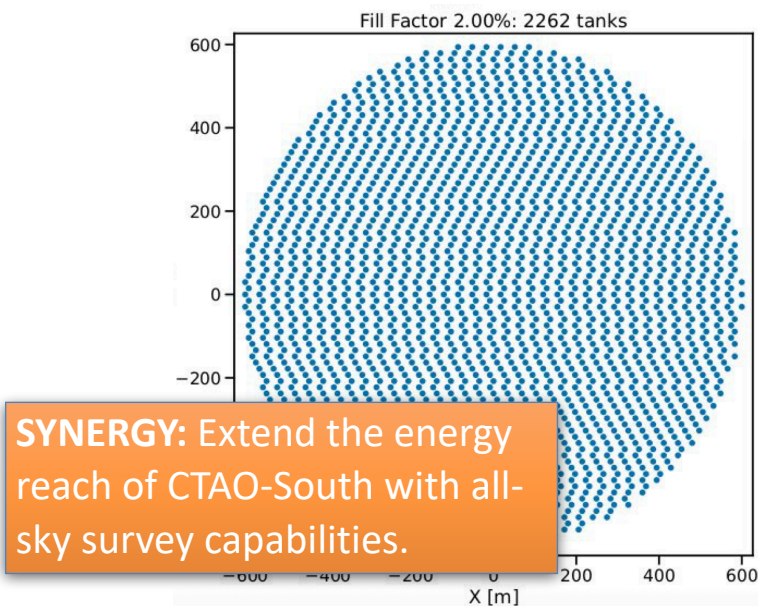
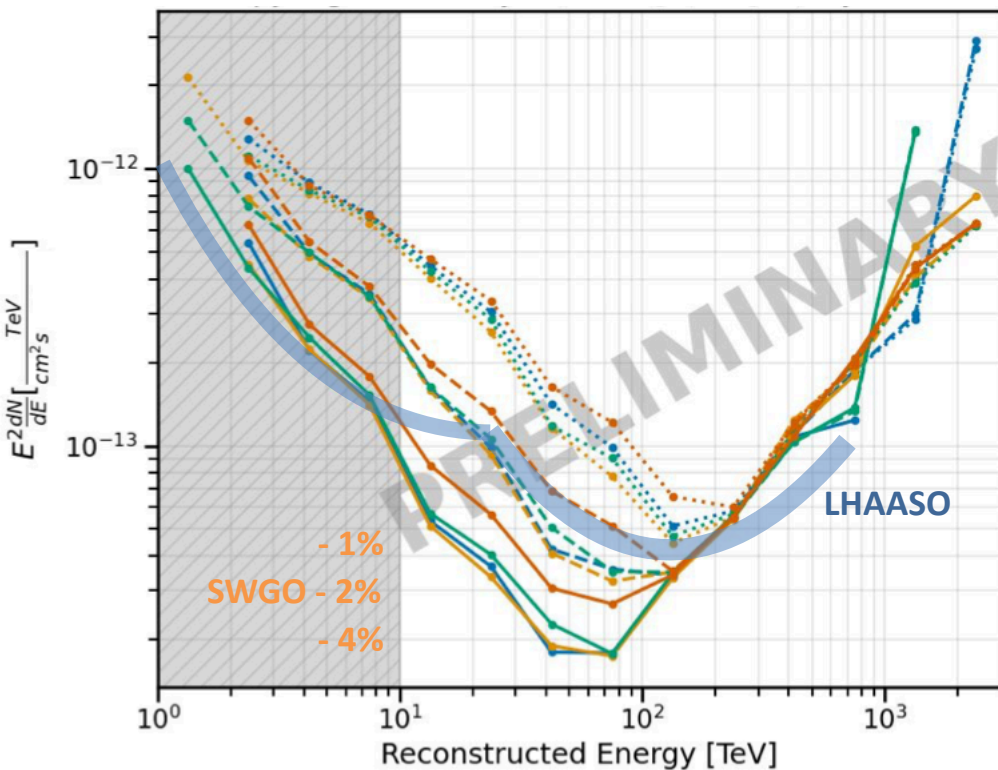


SWGO-PeV
(Preliminary) 1.0 km²
2,100 tanks
FF 2%



Preliminary Results

Expected Sensitivity - PeV Array



Preliminary Results

Target Angular Resolution

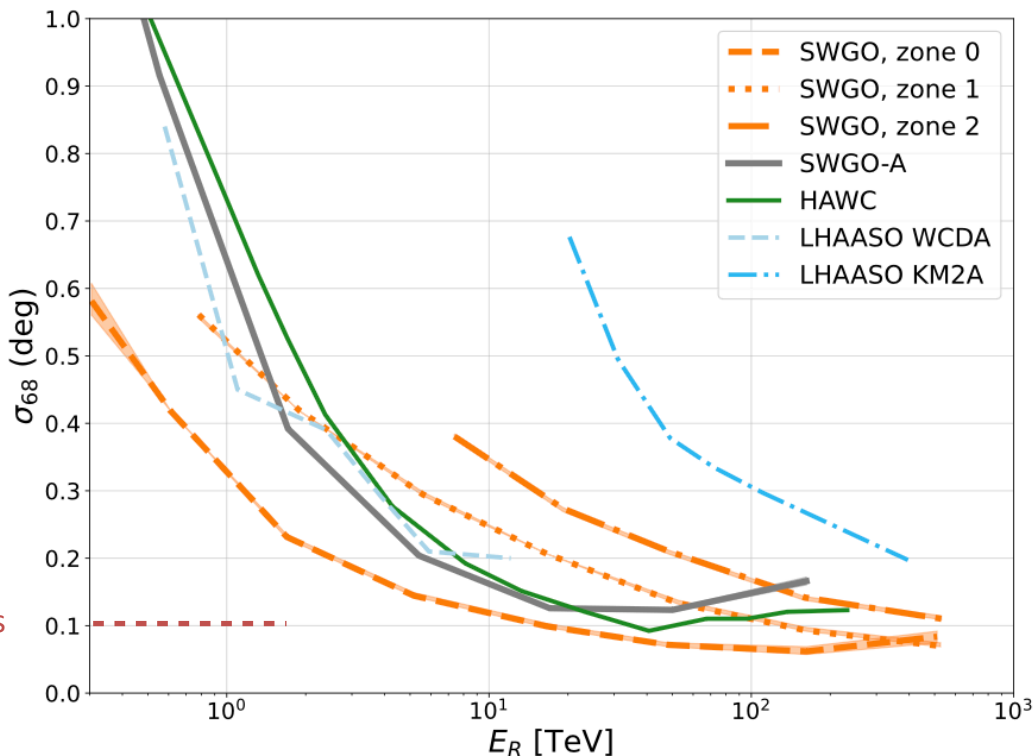
Unprecedented for wide-field instrument

Key for:

- Source morphology for astrophysical modeling above 10 TeV
- Extreme transient alerts, e.g. GRBs and AGN flares
- Reduction of error regions for MM events

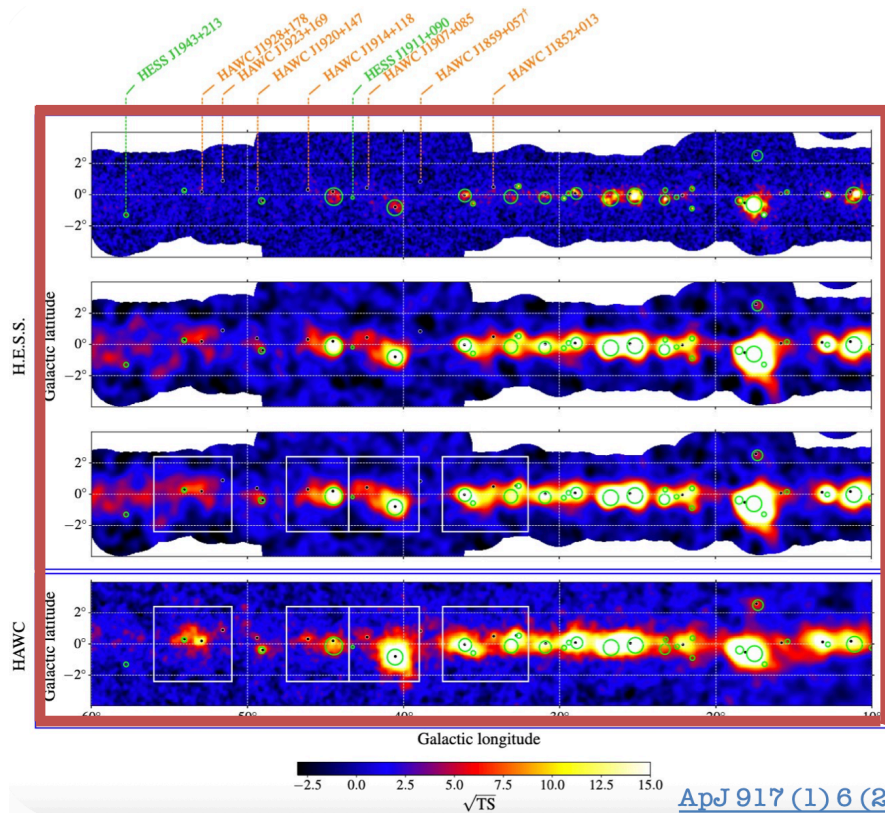
Current IACTs

SYNERGY: A transient alert and MM survey instrument for CTAO.

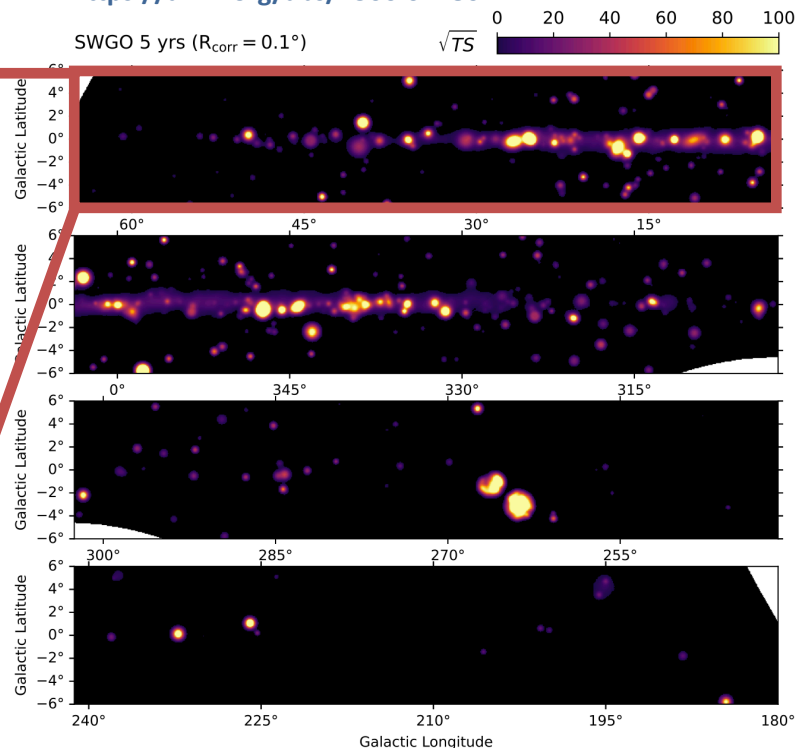


Target Angular Resolution

Unprecedented for wide-field instrument



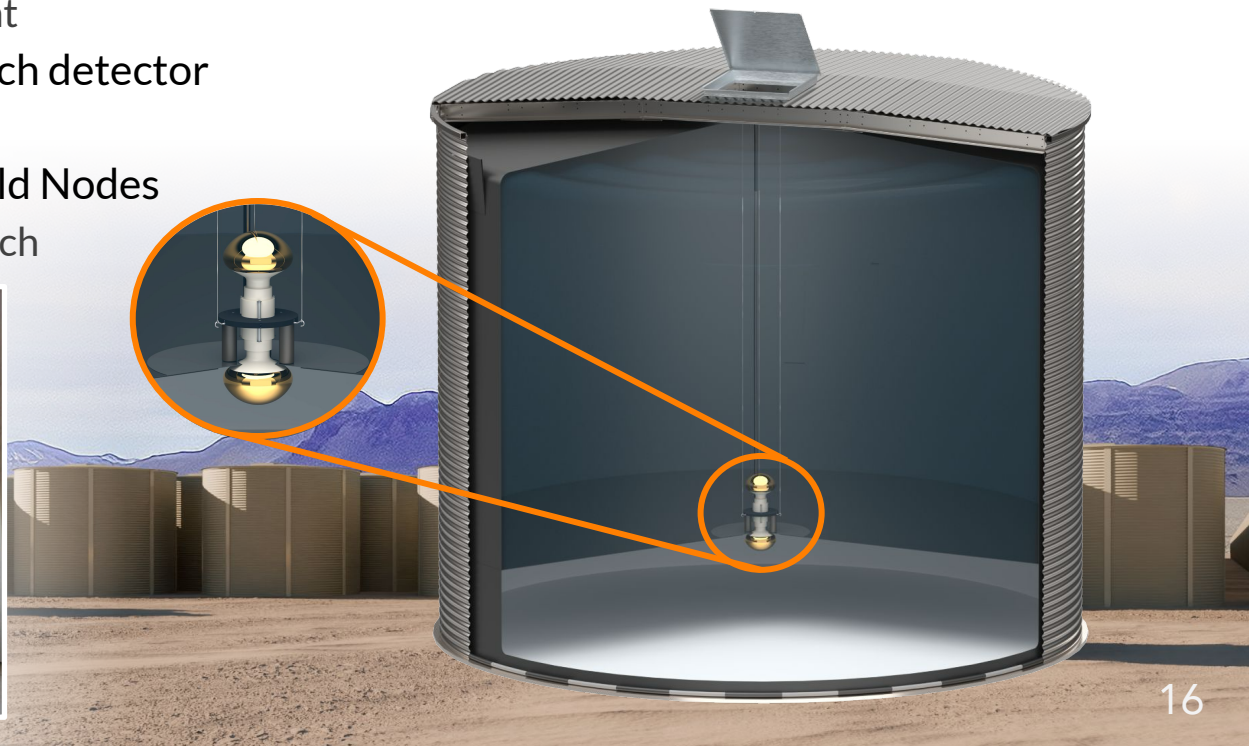
<https://arxiv.org/abs/2506.01786>



[ApJ 917 \(1\) 6 \(2021\)](#)

Design of Inner Array

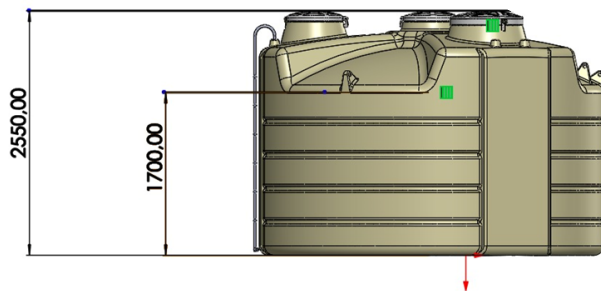
- Steel tanks assembled on site
 - 5.2 m $\varnothing$, 4.1m height
- Double-PMT unit in each detector
 - 10-inch PMTs
- Signals collected at Field Nodes
 - Serve 55 WCDs each



Outer array WCD unit desing

◎ Design principles

- Compact design to minimize water usage
- Simplification of logistics, installation and maintenance
- Robustness and reliability for long-term operations
- Flexibility of unit and array design options
- Inexpensive: \$ 5kUSD/unit



Extensive previous experience with the Pierre Auger Surface Detector Array.

Outer array WCD unit desing

◎ Innovations

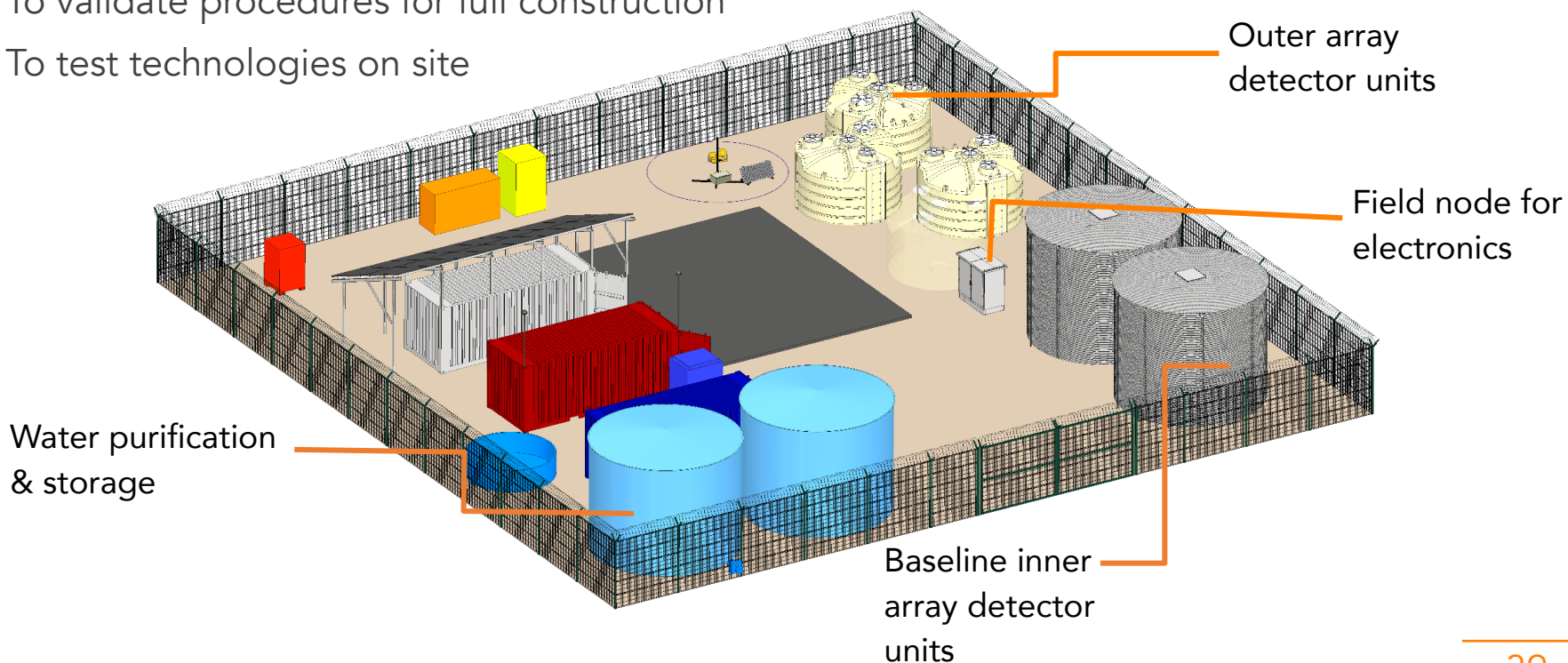
- Higher UV protection resin (UV-30 vs. UV-15 in Auger)
- Thermal insulation for high-altitude operation
- Rotomolding Patent BR1020210266902
- Inner wall resin layer for Cherenkov light reflection
- Substitute of costly and complex Tyvek bags



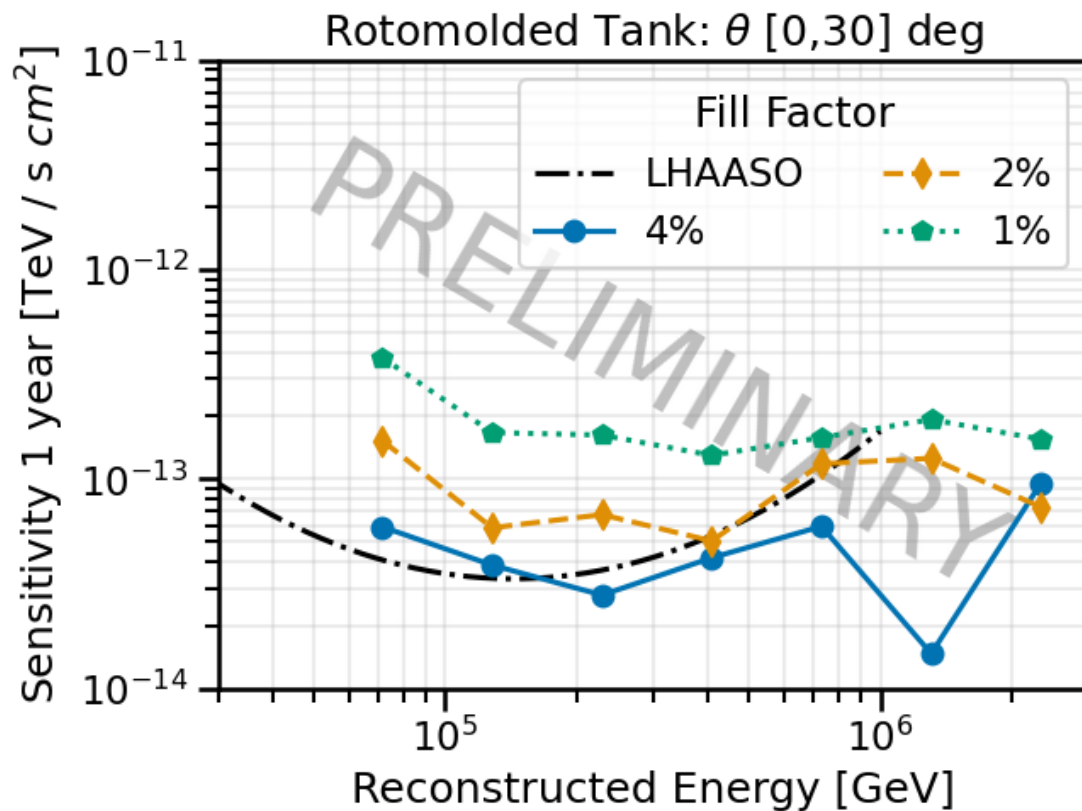
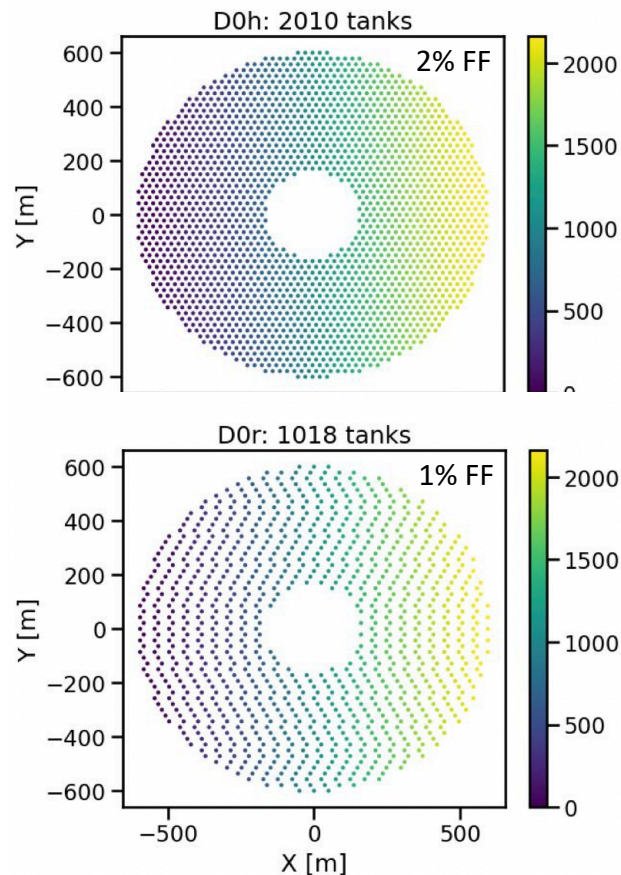
Towards Construction

An SWGO Pathfinder, exp. 2027

- 30 x 30 m fenced area within the future array location
 - To validate procedures for full construction
 - To test technologies on site



An SWGO PeVatron Array



Astroparticle Physics in South America



1. ALPACA* / Chacaltaya
2. CONNIE* / Angra
3. CTAO Observatory
4. HAWC*
5. HERON Observatory
6. Pierre Auger Observatory
7. QUBIC Cosmology Telescope
8. Simons Observatory
9. SWGO Observatory

The goal of the CLAF-CNRS Latin-American Astro-particle Physics Network is to establish a Latin-American Network around the current and next-generation world-leading astro-particle physics and cosmology experiments in the continent with direct CNRS involvement.



www.claffisica.org

Astroparticle Physics in South America



The network is motivated by the vision of bringing together into a single cooperation framework, the institutions developing research in astroparticle physics and cosmology around regional experiments, to explore untapped synergies within the region and with the leading CNRS laboratories.

Summary

- ◉ Ground-based gamma-ray Astronomy will reach its full maturity in the 2030's
- ◉ The context of the field will be dictated by the interplay of large IACTs and Wide-Field Particle Arrays
 - ◉ LHAASO-ASTRI + LSTs in the North
 - ◉ SWGO-CTAO in the South
- ◉ Some aspects I left out of this talk:
 - ◉ TAIGA high-score exploring synergies in particle / Cherenkov-light EAS detection
 - ◉ Auger upgrade to explore the 10^{17} eV photon range
 - ◉ ERC-funded radio extension to SWGO (TURBO)
- ◉ Common tools and the integration between facilities is key to maximize returns

Thank you!

Ulisses Barres de Almeida

CBPF



CBPF

Centro Brasileiro
de Pesquisas Físicas

— 9 to 40 SSTs | 20-24 July | Haus Sixten 2026 —