



From 100 GeV to PeV:
Advancing Wide-Field Gamma-Ray Observations
with SWGO

Jonas Glombitza

May 26, 2026



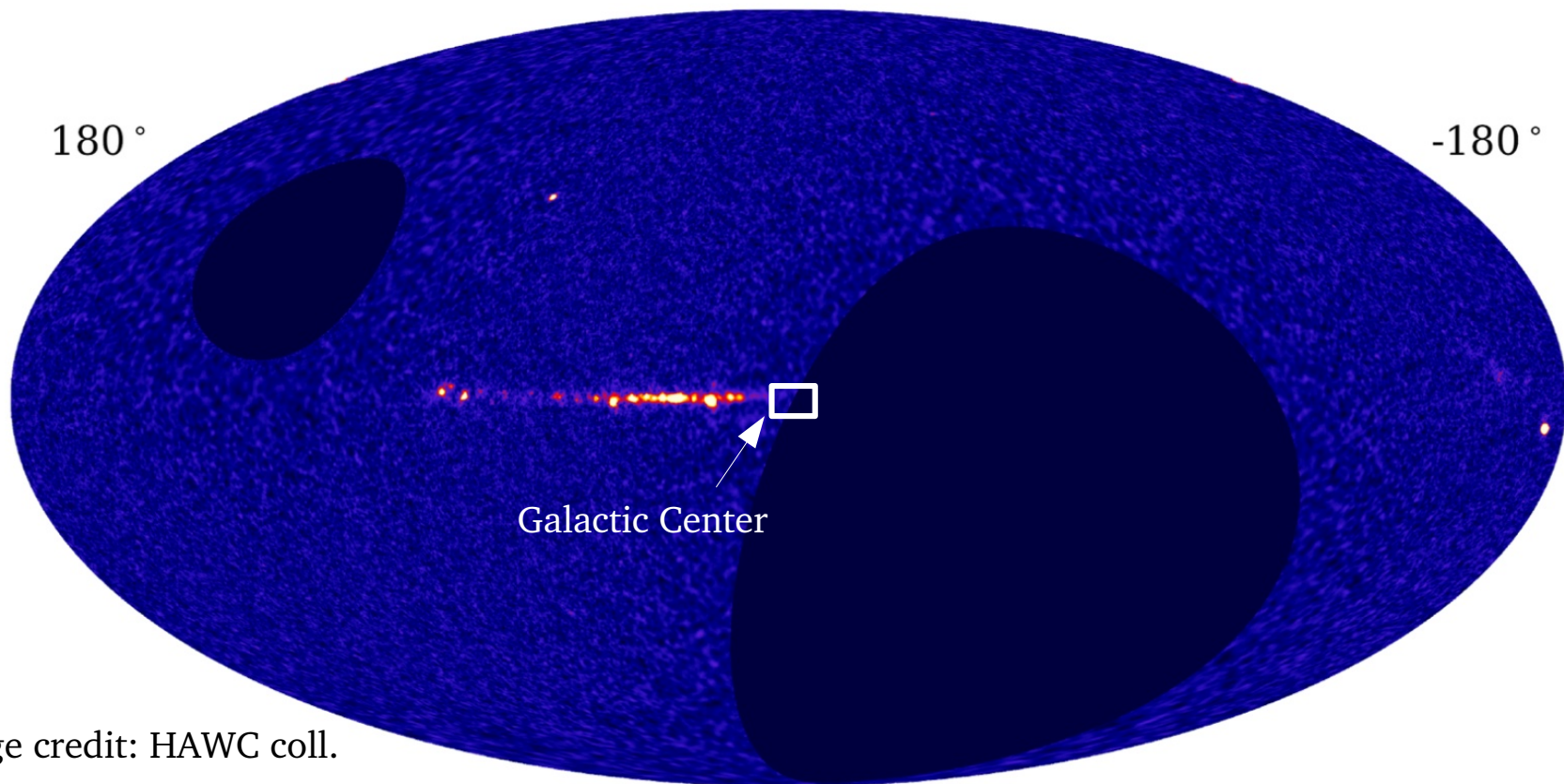
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



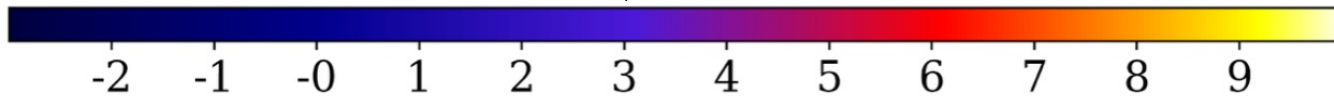
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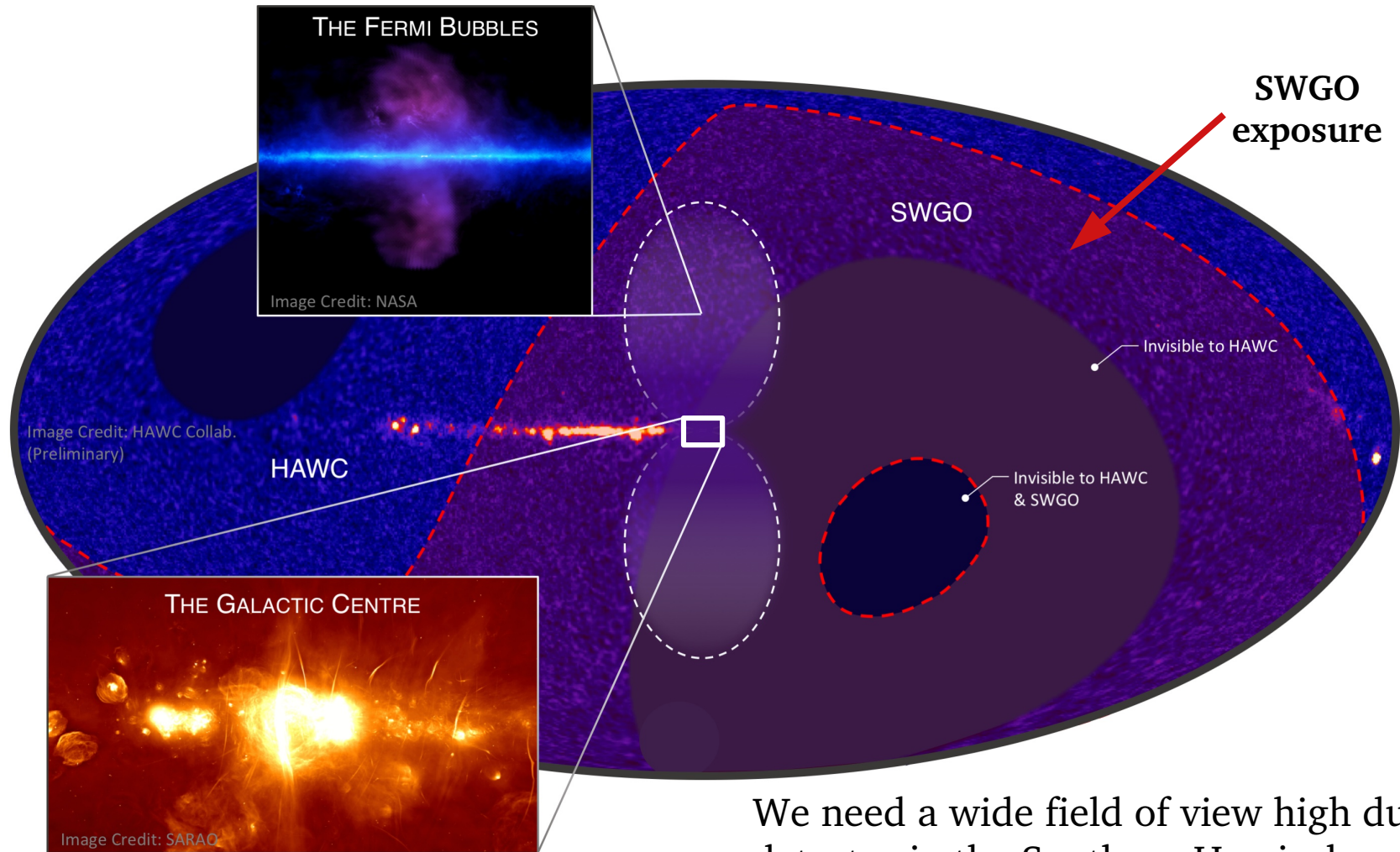
'Holes' in the TeV Gamma-ray sky



\sqrt{TS}

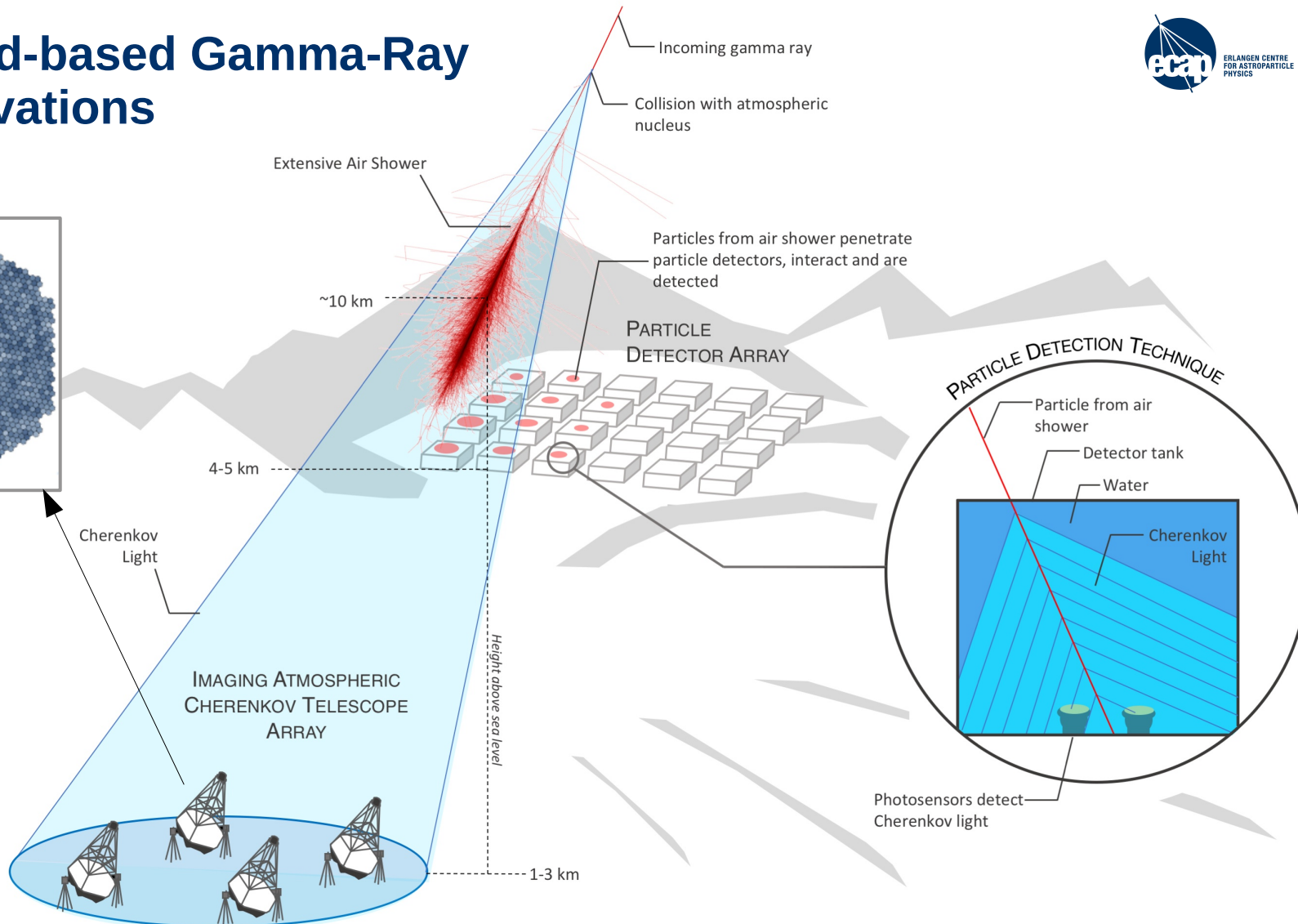
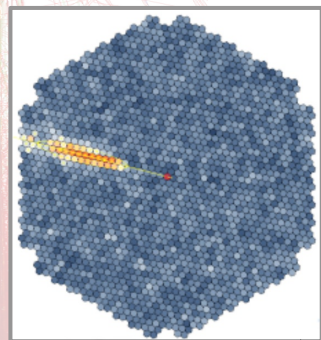


'Holes' in the TeV Gamma-ray sky

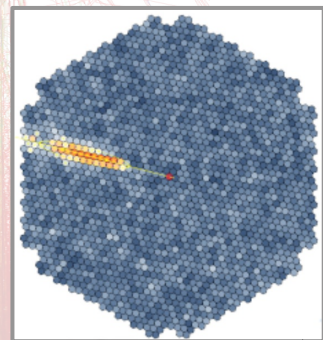


We need a wide field of view high duty cycle detector in the Southern Hemisphere: **SWGO!**

Ground-based Gamma-Ray Observations

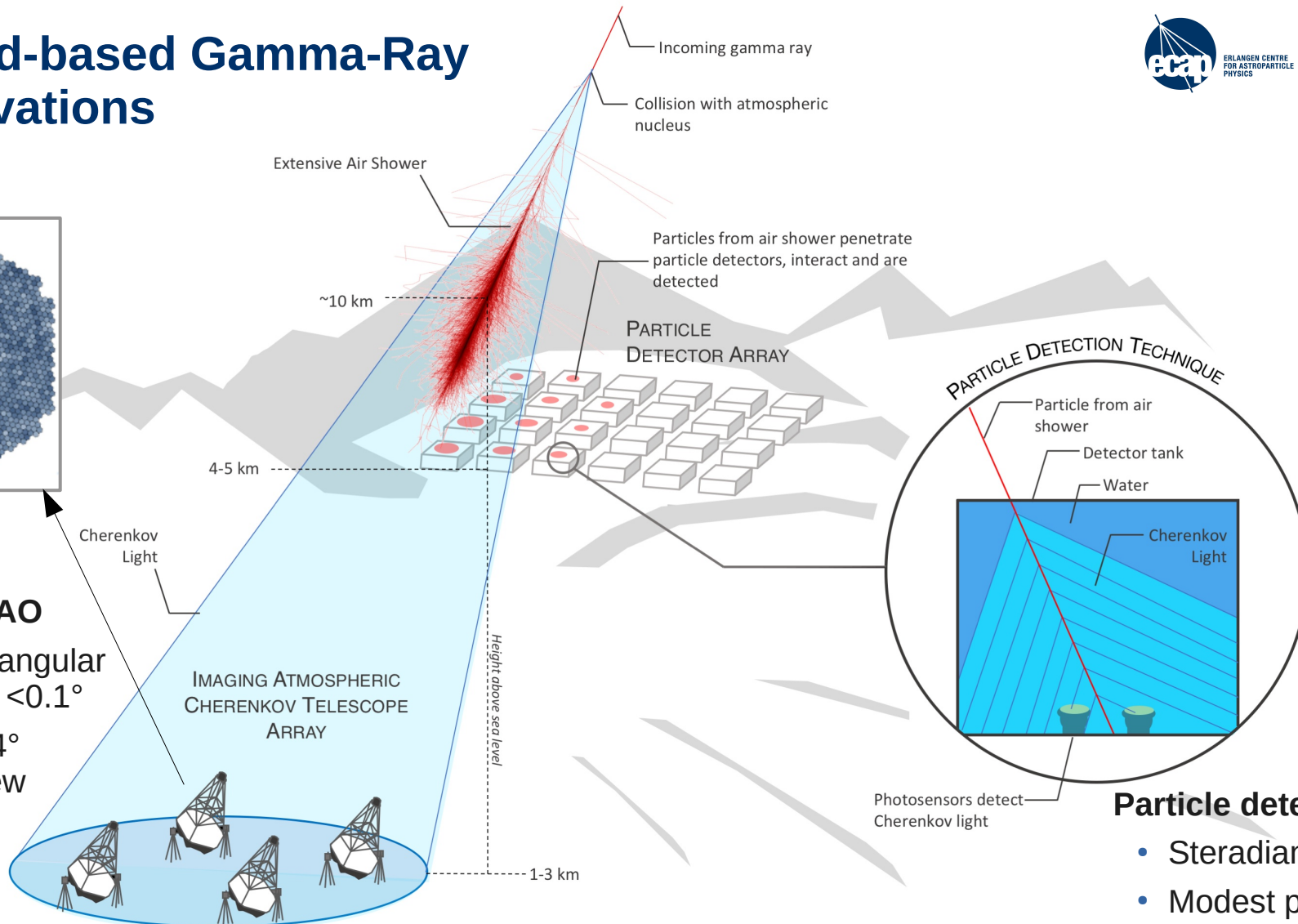


Ground-based Gamma-Ray Observations



IACTs → CTAO

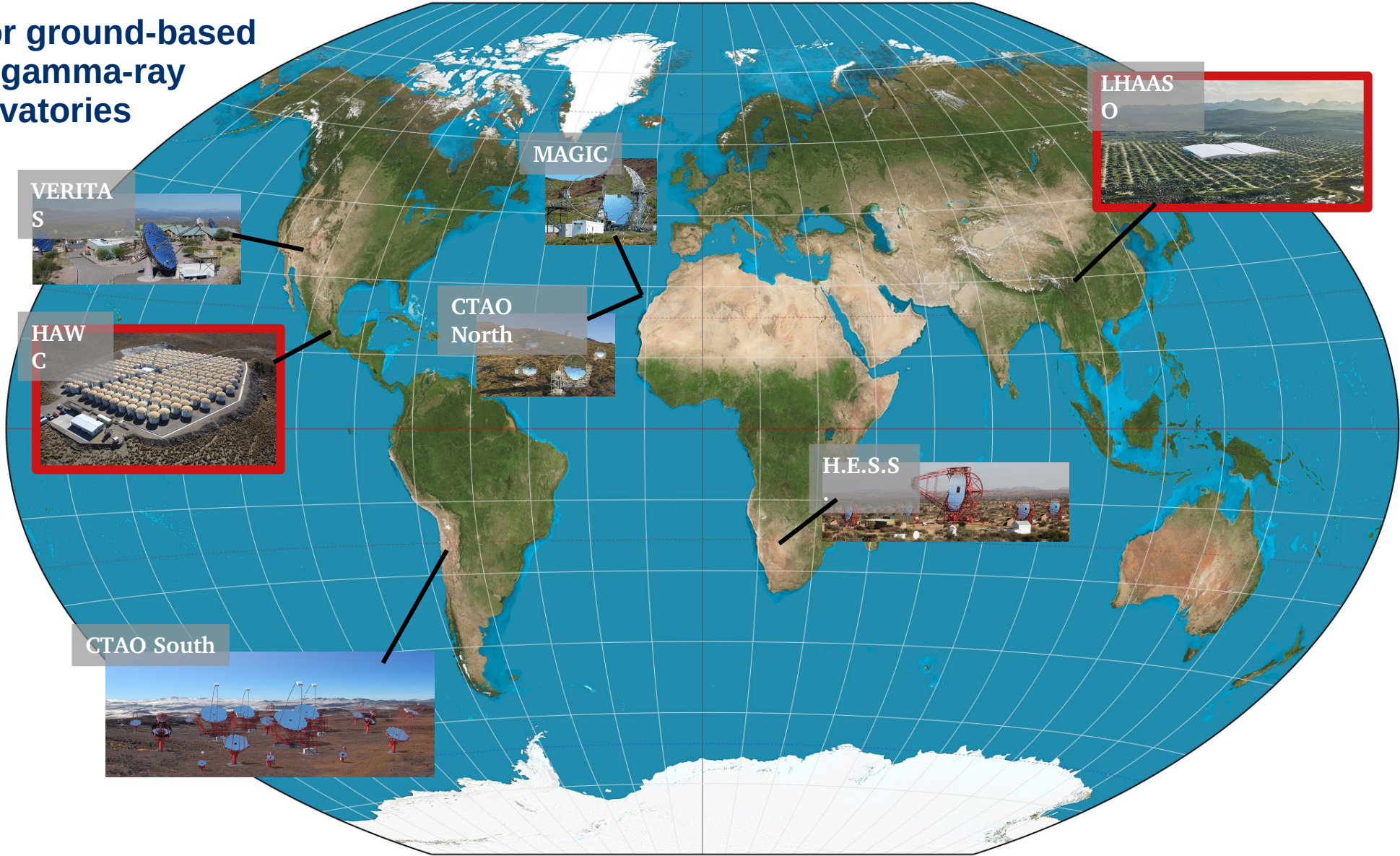
- Excellent angular resolution $< 0.1^\circ$
- Limited $\sim 4^\circ$ field of view
- Low duty cycle



Particle detectors

- Steradian field of view
- Modest precision
- 100% duty cycle

Major ground-based gamma-ray observatories



VERITAS



MAGIC



LHAASO



HAWC



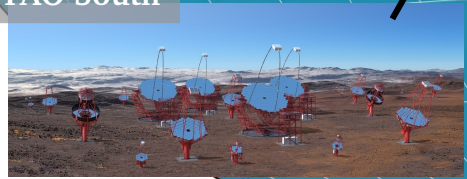
CTAO North



H.E.S.S.



CTAO South

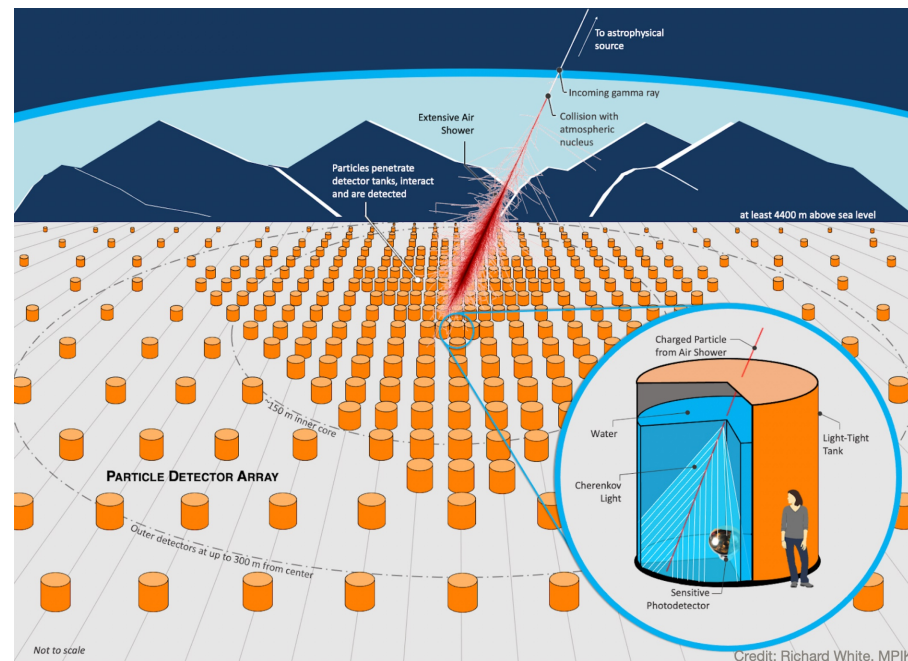




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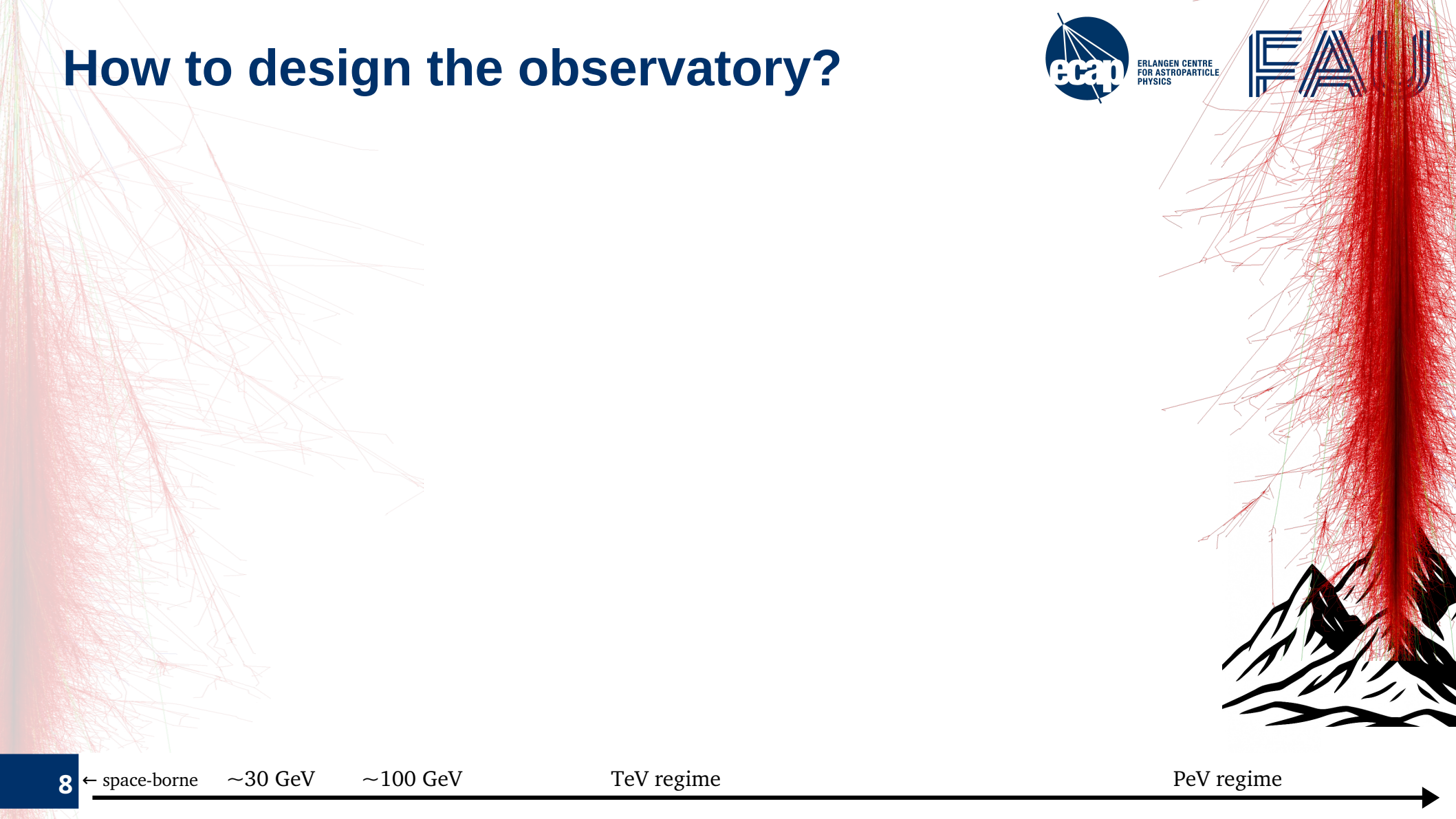
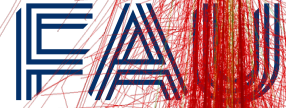
SWGGO! - How to design the observatory?



How to design the observatory?



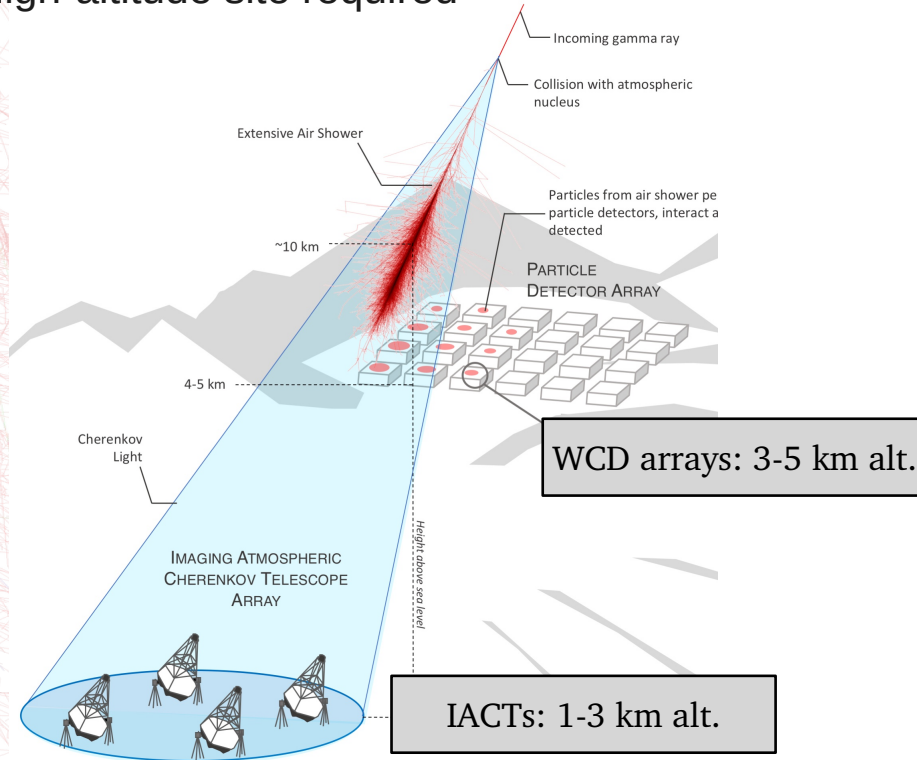
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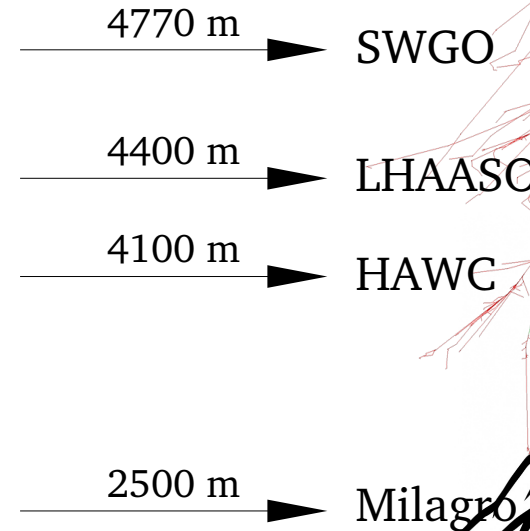
How to design the observatory?

Low energies

- shower maximum high in the atmosphere
- High-altitude site required



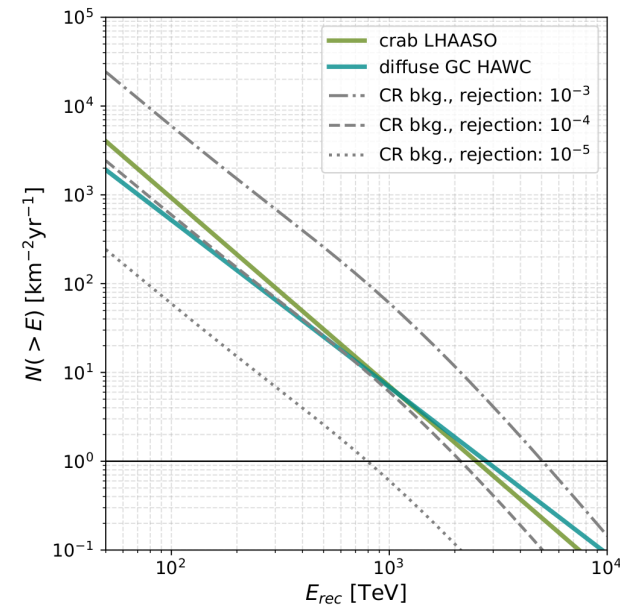
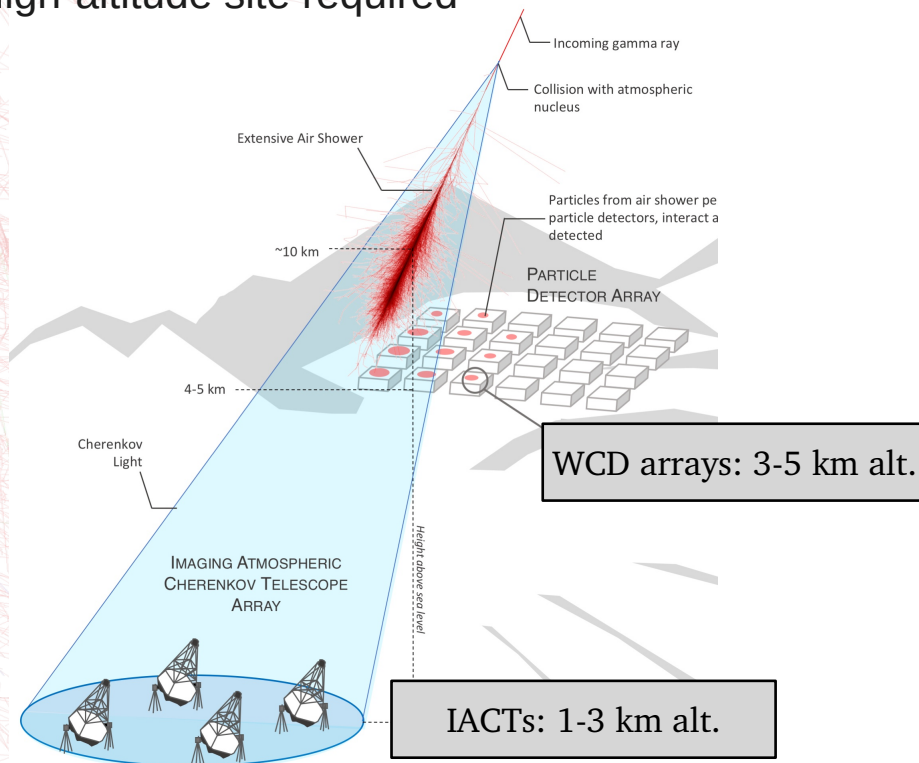
Better low energy sensitivity ↑



How to design the observatory?

Low energies

- shower maximum high in the atmosphere
- High-altitude site required



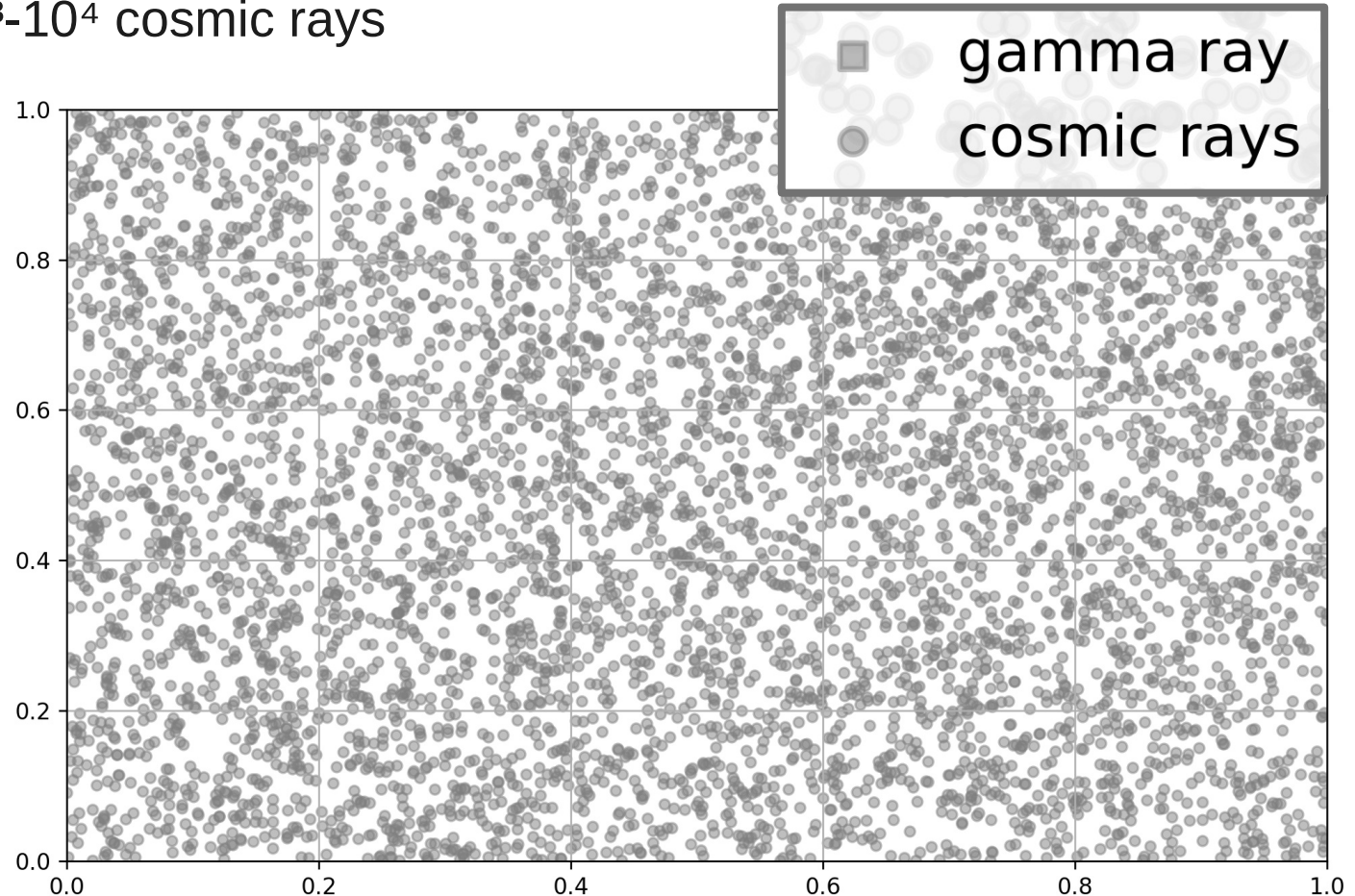
High energies

- Falling gamma-ray spectrum → low flux
- Large array is needed ($\sim 1 \text{ km}^2$)

Rejecting the cosmic-ray background

- Only 1 gamma per 10^3 - 10^4 cosmic rays
challenging background!

- Excellent separation
is essential



Rejecting the cosmic-ray background

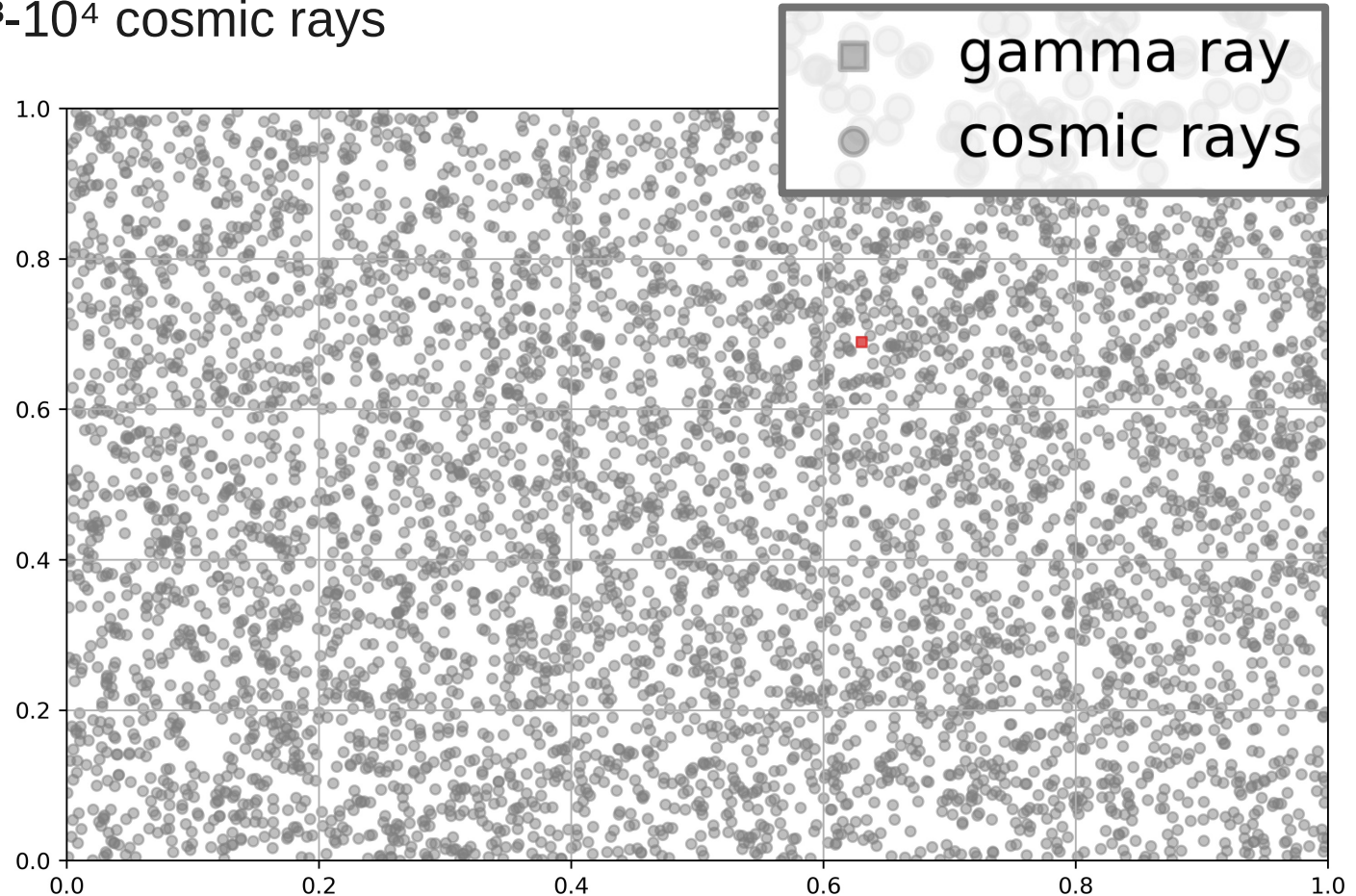


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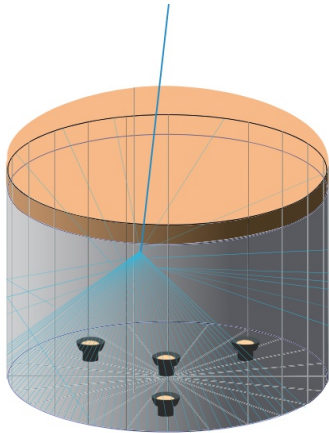


- Only 1 gamma per 10^3 - 10^4 cosmic rays
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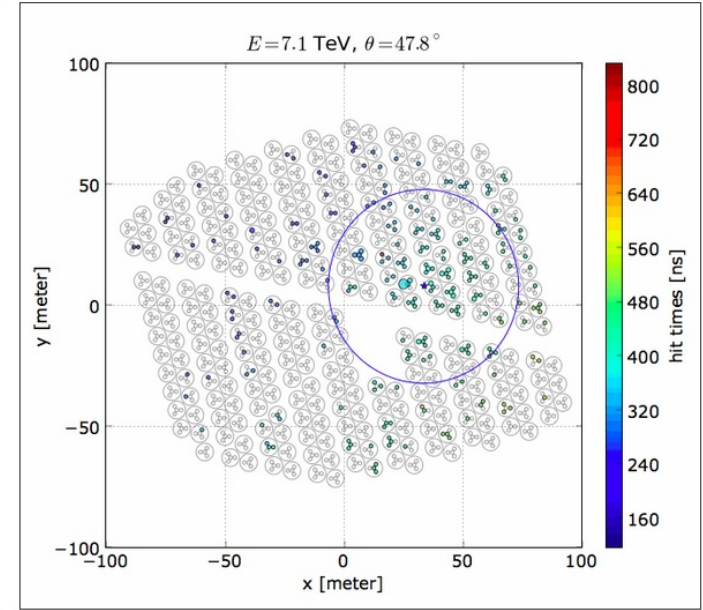
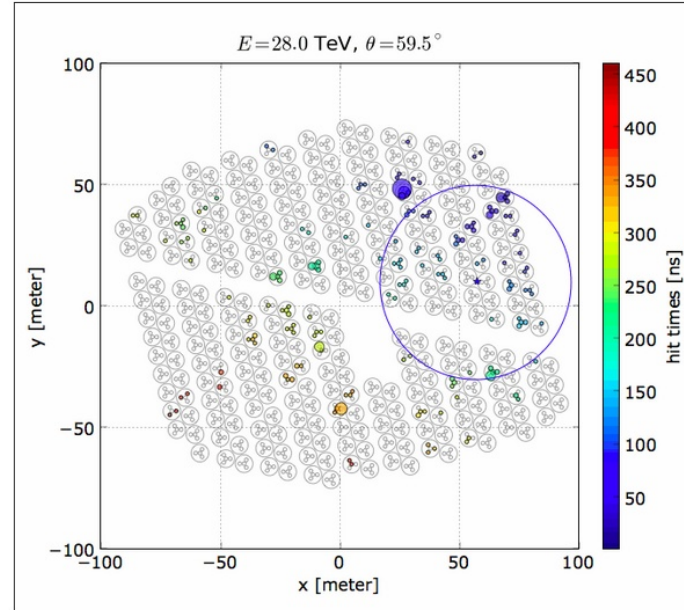
- Excellent separation
is essential



Tag the gamma-ray



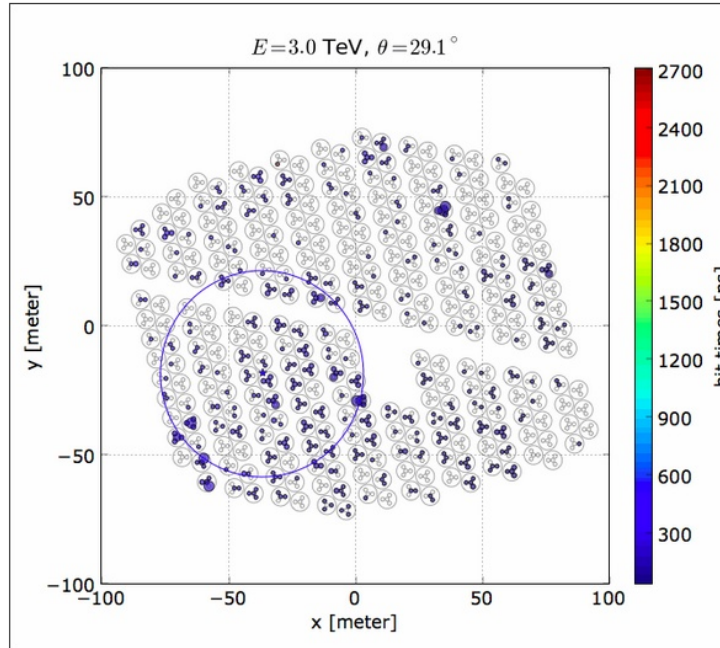
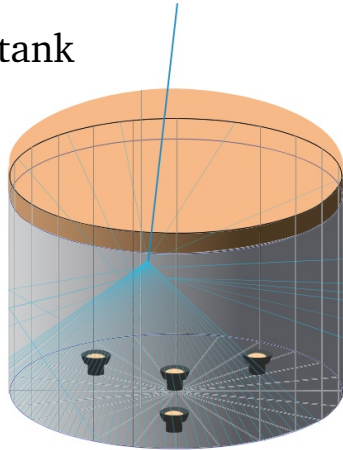
HAWC tank



Which event is a gamma, which event is a proton?

Tag the gamma-ray

HAWC tank



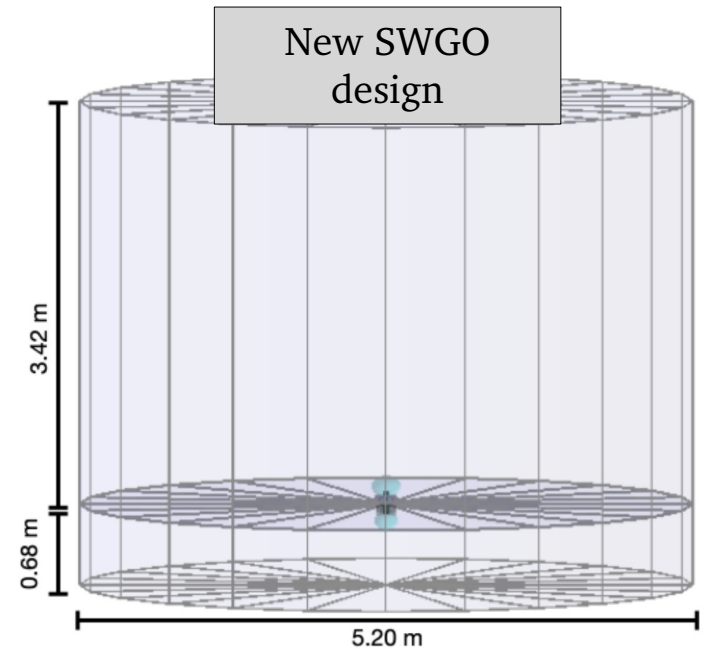
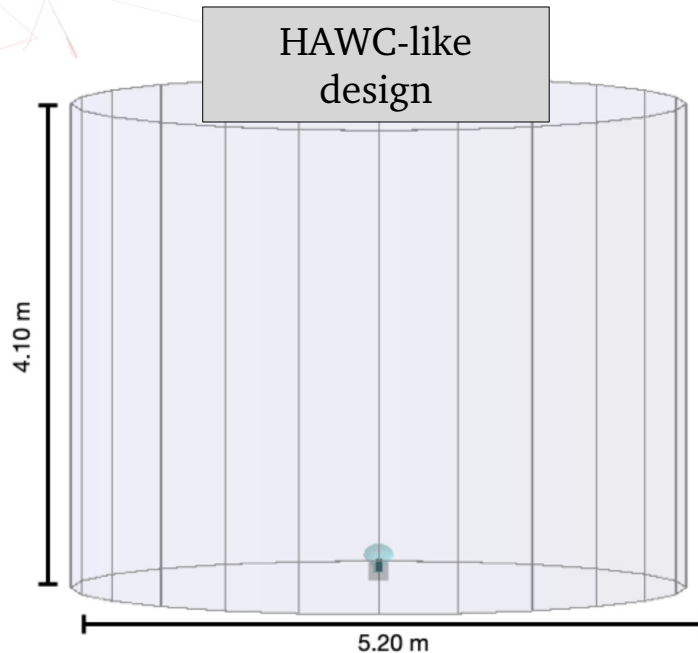
Ability to tag muons!

We need good detectors and dense instrumentation and
(most information as possible & and sophisticated algorithms)

The SWGO baseline design

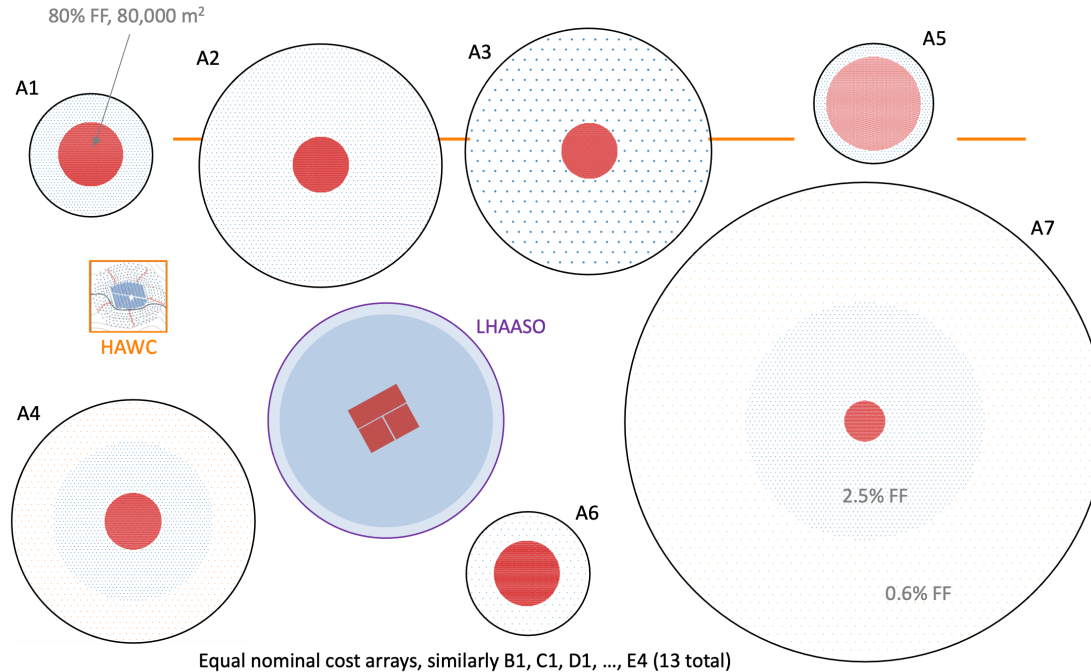


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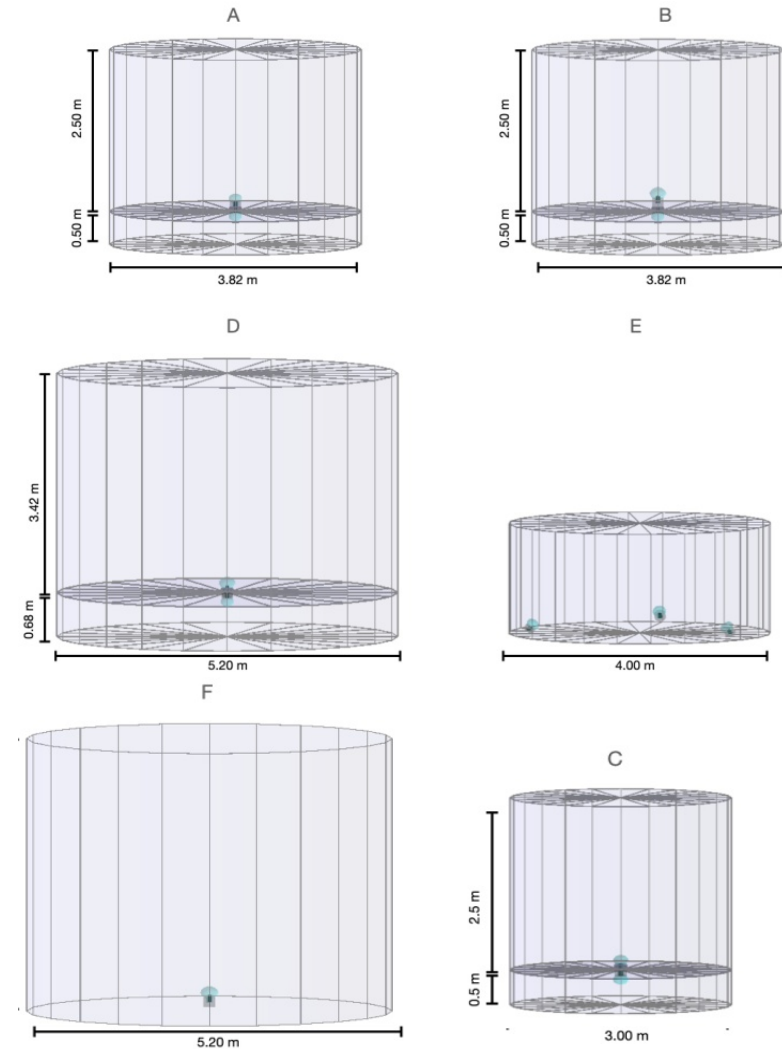


- Upward-facing PMT, tank with black walls: direct Cherenkov light (good timing)
- Double layer (white liner): tagging of muons (shielding of upper chamber)
- Large WCDs: large track lengths (clear depositions)

Benchmarking various designs



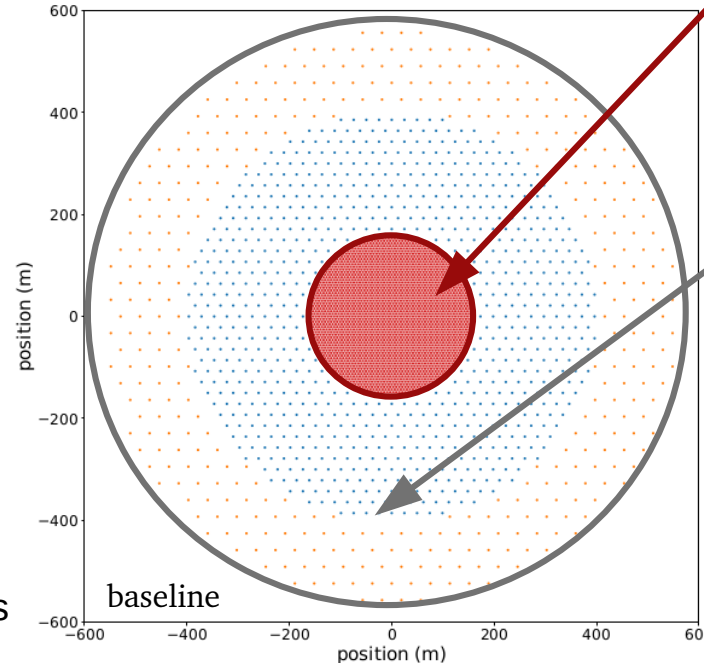
- Extensive simulation study performed
- Design driver: performance over cost
 - ◆ What is the best detector / what is the best layout?



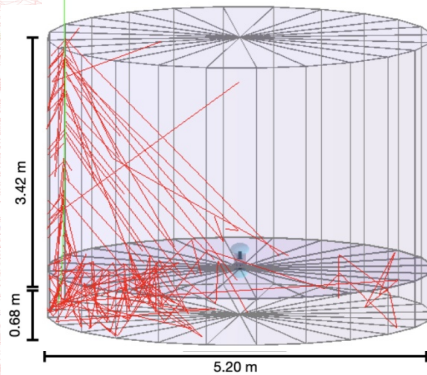


- Pampa La Bola, Chile
 - ♦ 4770 m altitude
 - 1 km² area, 3 zones
 - ♦ sensitive 100 GeV – 1 PeV
 - ♦ ~4000 detector stations

Array Radius = [156m, 400m, 560m], FF = [70.0, 4.0, 1.7, nTank = 3763 [2587, 792, 384]



- Inner array → [see poster Hazel](#)
 - ♦ Metal double liner
 - ♦ High fill factor (65 – 70%)
- Outer array under optimization
 - ♦ New station designs, novel optical modules, station layouts
 - [see poster Laura Valore](#), [Luigis talk](#)



SWGO baseline





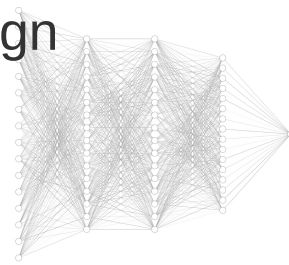
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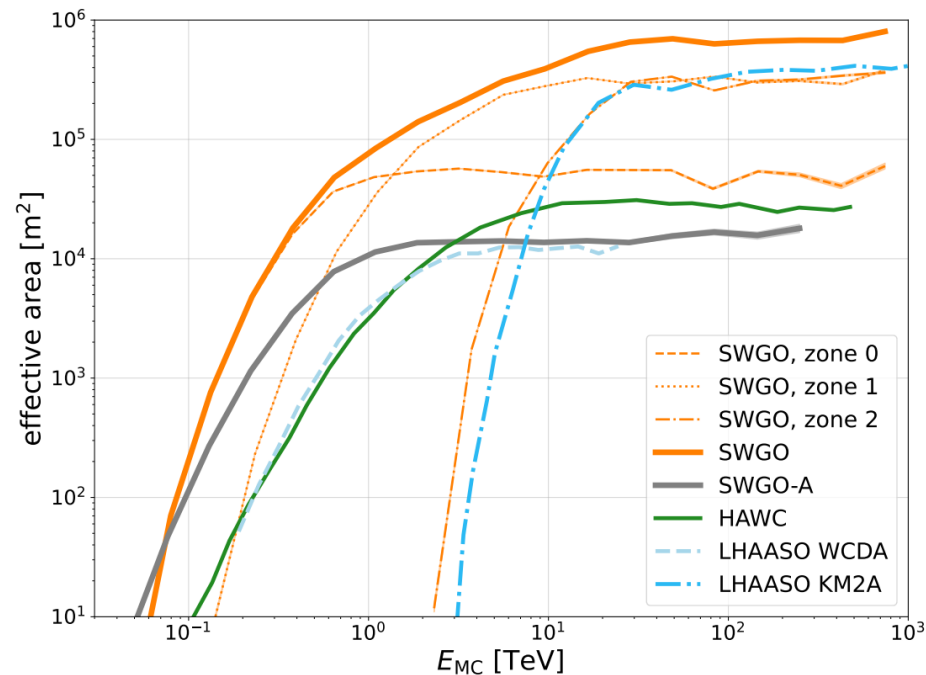
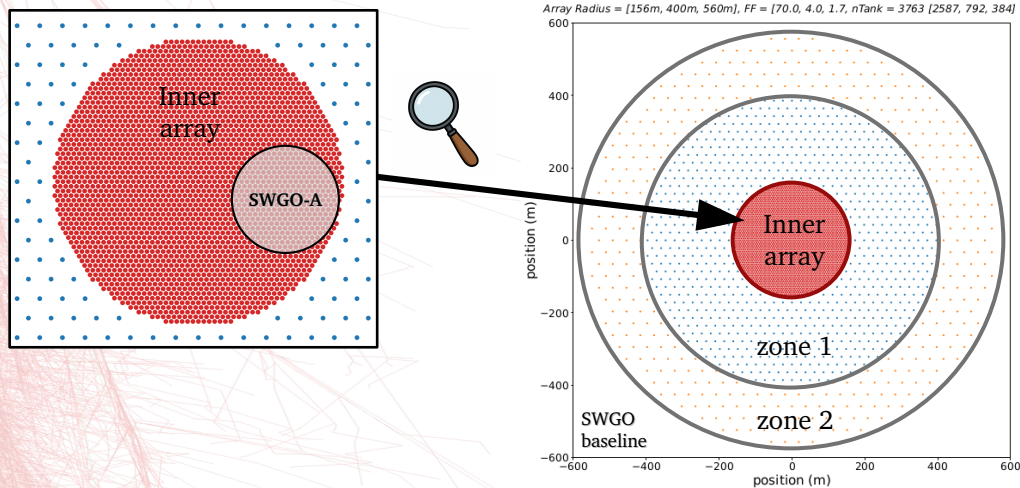
Preliminary

Expected performance of SWGO

Instrument response functions of the SWGO baseline design



Effective area

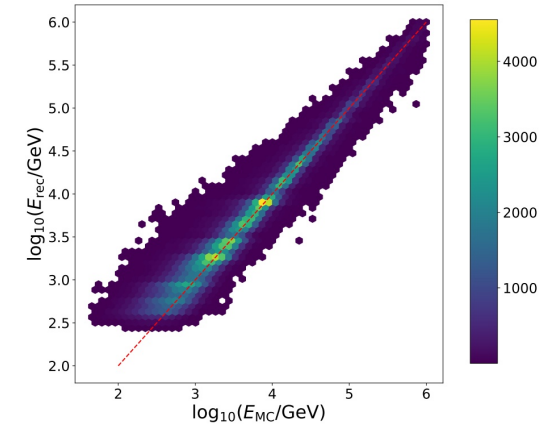
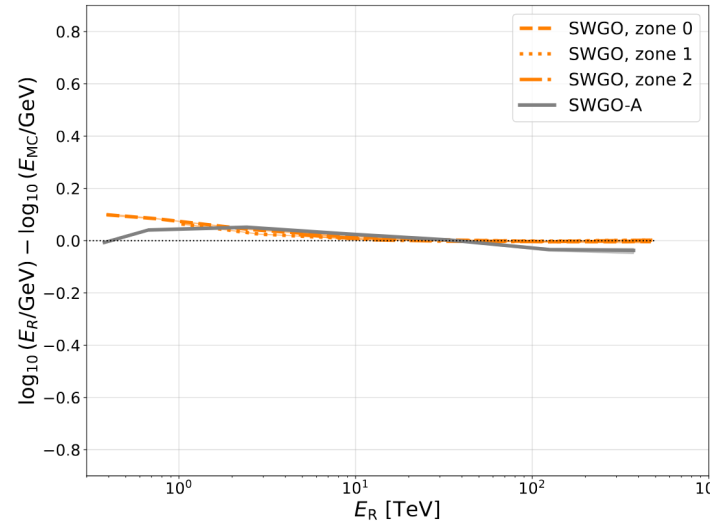
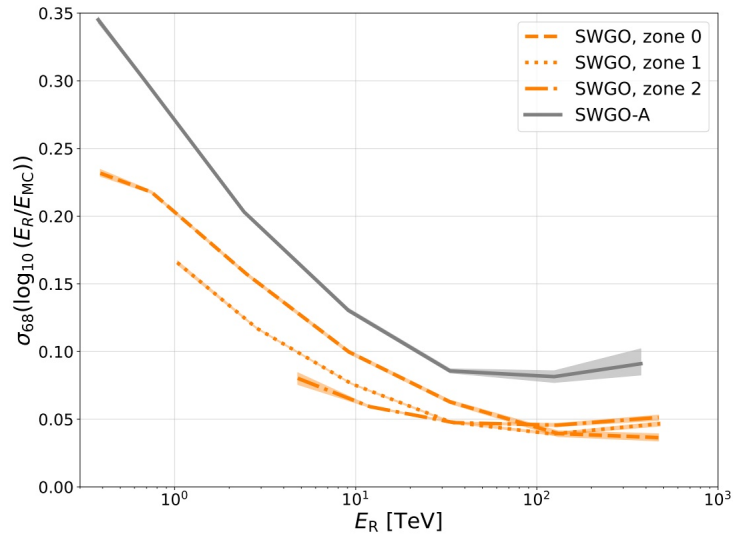


- Inner array / SWGO-A: High-altitude site and high fill factor → threshold below 1 TeV
- Zones 1 & 2: efficient above 10 TeV and 30 TeV, respectively
- Graded design of 1 km² size: sensitivity up to the PeV range
 - ◆ Exact layout shape under optimization

Energy reconstruction

Energy reconstruction based on template methods

- Good energy resolution* of below 20% above 10 TeV
- Bias < 0.1 \rightarrow reliable estimates over whole energy range
- Improvements ongoing for inner array



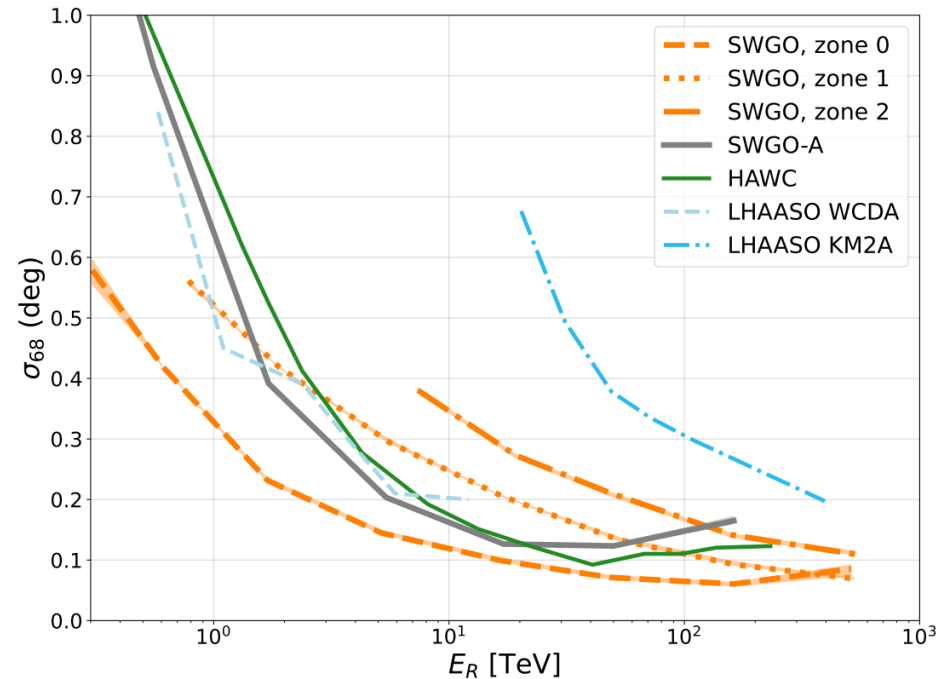
Angular resolution

SWGGO reconstruction based on Gaussian Fitter (as used in HAWC)

SWGGO performance promising

- reaching resolutions* of 0.1° and better
- outperforming HAWC at low and medium energies
- improvements over LHAASO at high energies
- SWGO-A reaches similar performance as HAWC and LHAASO WCDA

*resolutions defined as 68% quantile



Gamma-hadron separation

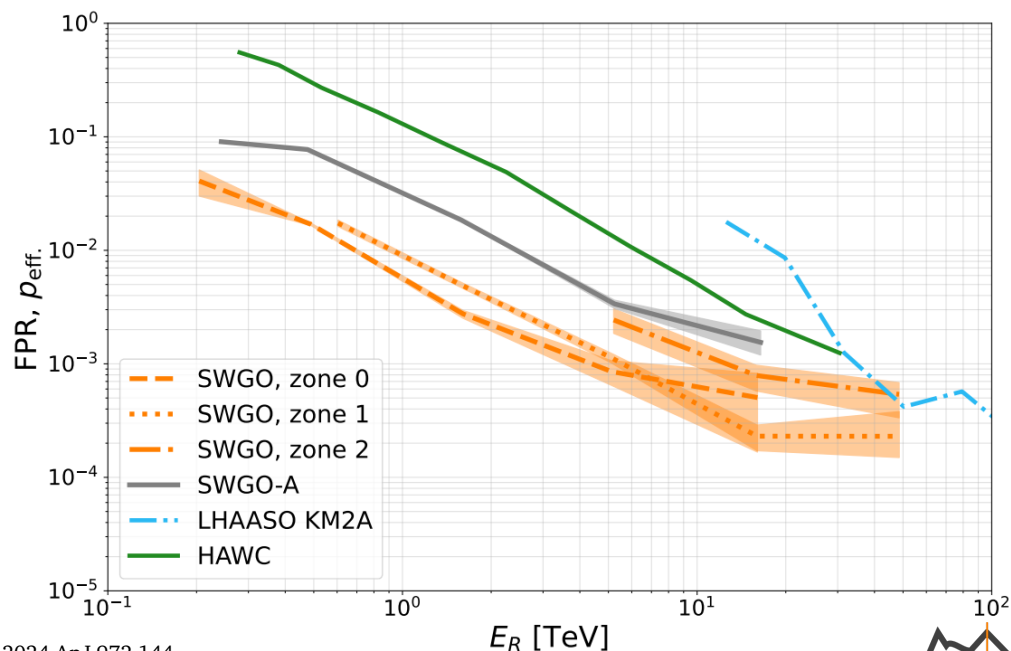
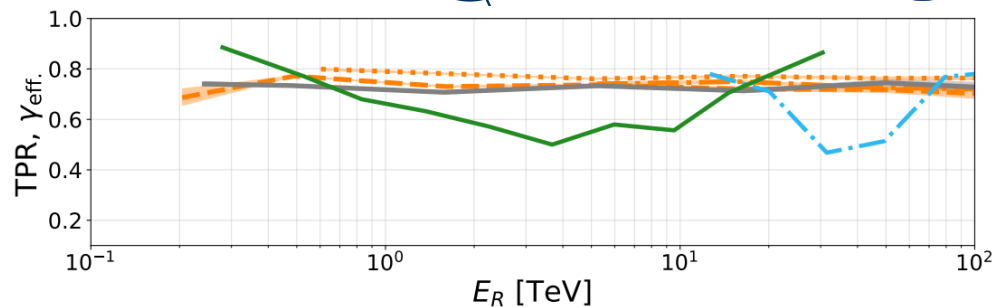
Separation based on high-level observables and deep learning (GNN, deepeaster)

See posters:

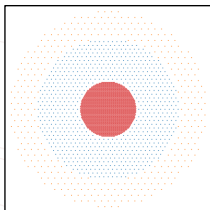
- [GNNs for g/hadron separation, M. Schneider](#)
- [transformers for event reconstruction, I. Watson](#)
- [comparison of state-of-the-art separator., T. Capistran](#)

Excellent performance of SWGO

- Improvements over HAWC
- At the highest energies better or matching LHAASO
- Above 100 TeV, no background left
 - see poster T. Li
- Altitude + double layer unit = effective
 - ♦ significant improvements wrt. HAWC

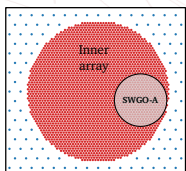


Sensitivity



SWGO baseline

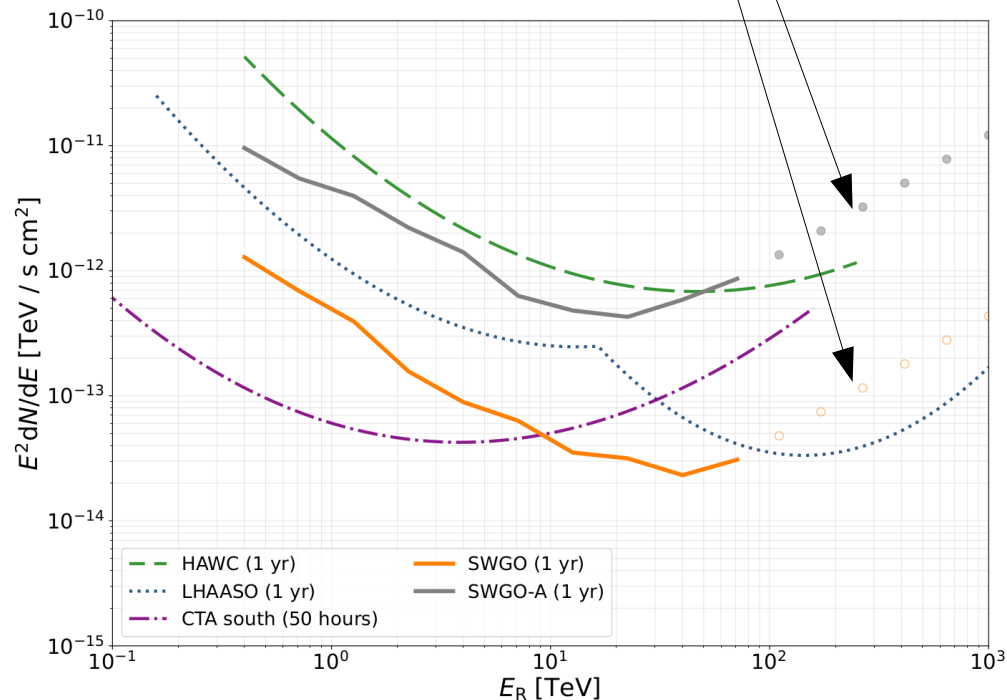
- Improvement over LHAASO at low and mid energies
- competitive at high energies
- Improvements ongoing



SWGO-A

- First science phase, part of inner array
- Improvements over HAWC
 - ◆ driven by improved γ/h separation

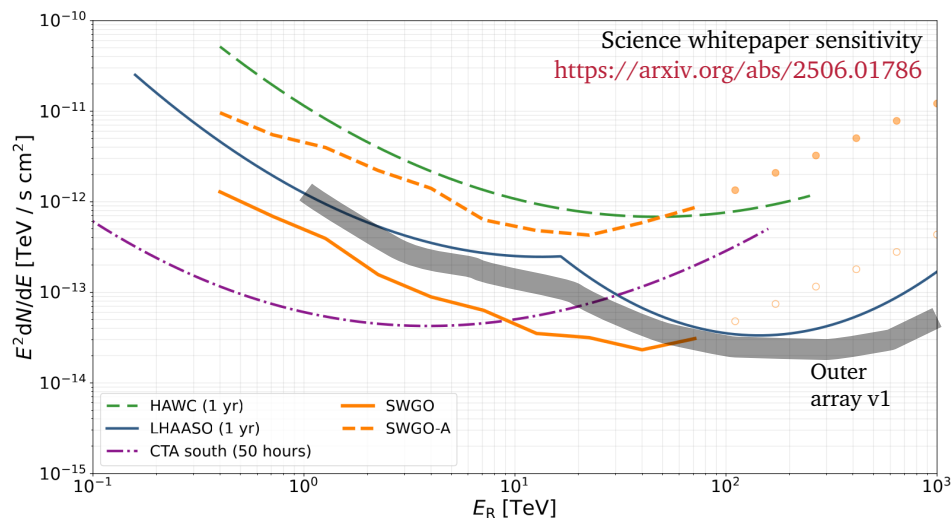
Extrapolations - progress on IRFs using fast simulations, see [talk by Andrea](#)



Outer-array optimization

Benchmark of 4 different candidate designs

- Candidates differ in widths and height (and reflectivity)
- Sensitivity benchmark at fixed costs: Fixed area, cost-adapted FF
- Fixed area of 1 km² (UHE sensitivity scaling ~ A)
 - Results and decision to be expected soon



SWGO: from 100 GeV to PeVs
 Glombitza | ECAP | 05/26/26



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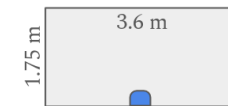
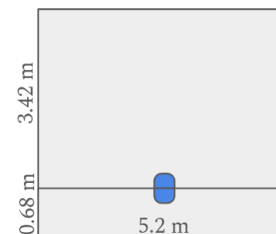


M6 D tank
 Well studied

Shallow single layer
 (updated E-like tank)
 Entirely white

D

H

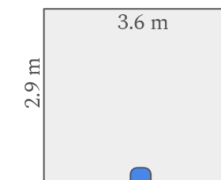
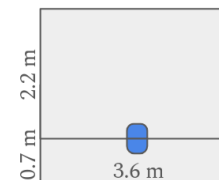


Shallow double layer

Reference station
 (small F-like tank)
 Identify muons
 → larger than UC of J
 → ready soon

J

K



SWGGO Pathfinder

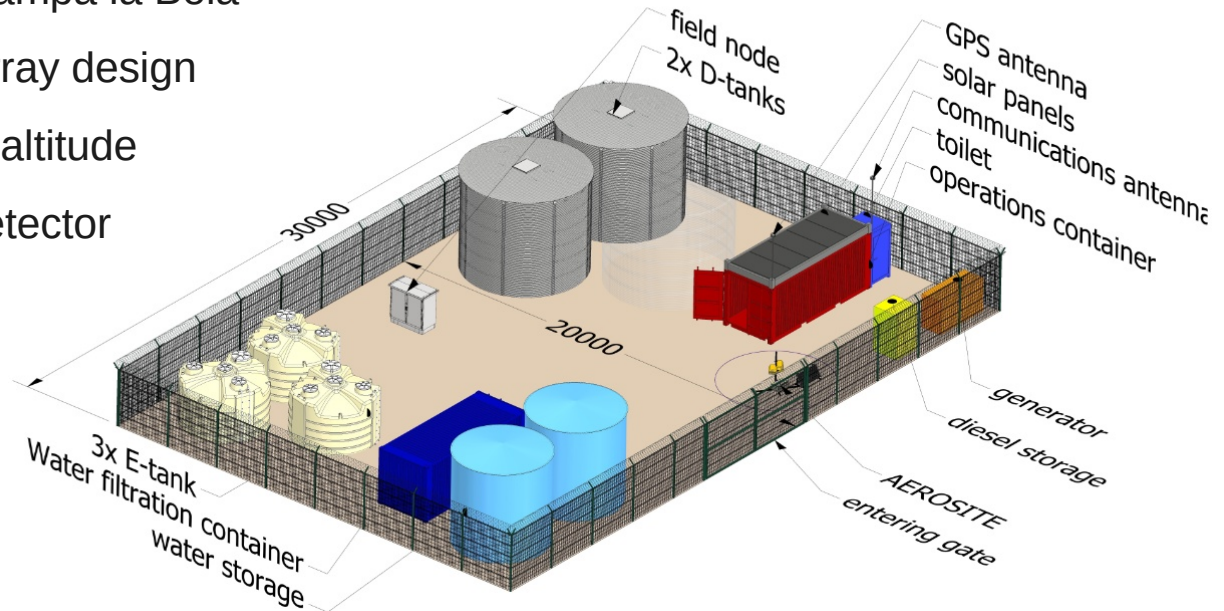


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Detector testing on site!

- Will be deployed within 2026 at Pampa la Bola
- Combination of inner and outer-array design
- Testing of equipment at very high altitude
- Detailed test of electronics and detector
 - Noise rates etc.
- We will have first data soon!



Deep Learning for SWGO

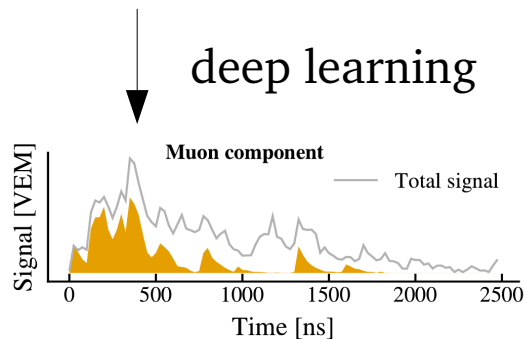
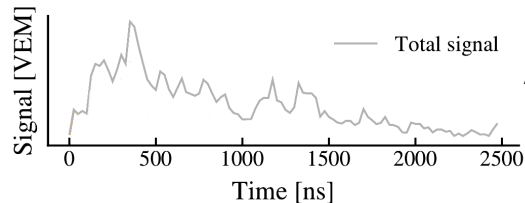
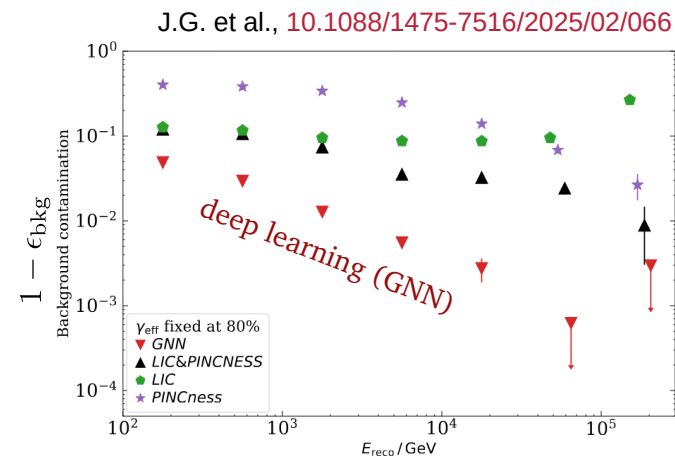
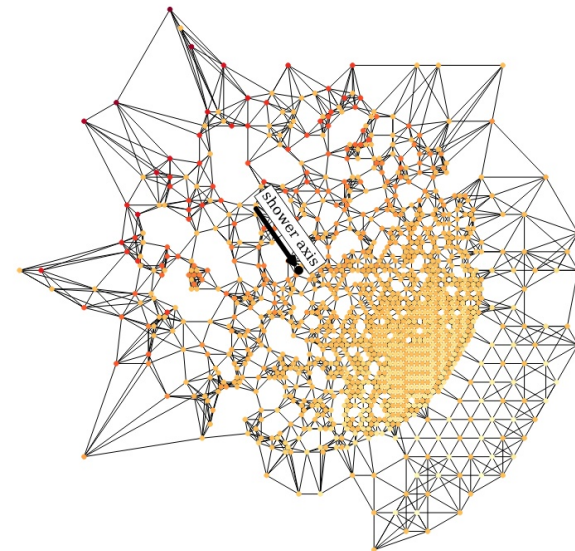
Idea: Improve sensitivity using deep learning
(state-of-the-art machine learning)

Analyze particle footprint with graph networks

- Exploit complex particle footprint
- Outperform classical gamma-hadron separators

Exploit signal traces (in progress)

- Usually thrown away (expensive to store)
- Exploit interesting traces, tag single muons
 - Remove/compress low entropy traces
- perform online, close to sensors
 - Implement on FPGA / on-site computing
- Potential to significantly improve sensitivity



Summary

Exciting phase in gamma-ray astronomy

- LHAASO entered the stage in the Northern Sky
- CTAO will enable precise targeted observations of the Southern Sky
- We need a Southern wide-field-of-view observatory!

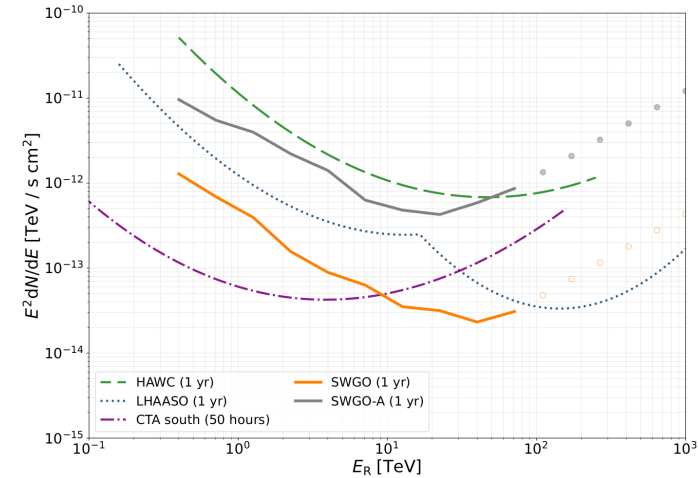
SWGGO, about to finish the development phase

- Preferred site: Pampa la Bola, Chile (4770 m)
- Performance projections are very promising
 - ♦ sensitive from 100s GeV – PeV domain
 - ♦ Improvement of reconstruction in progress
- Optimizations of the outer and minor refinements of the inner array are ongoing
- **First operating pathfinder detectors this year!**

SWGGO: from 100 GeV to PeVs
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SWGGO 2025 whitepaper
<https://arxiv.org/abs/2506.01786>

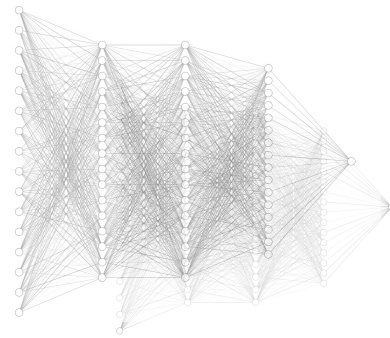
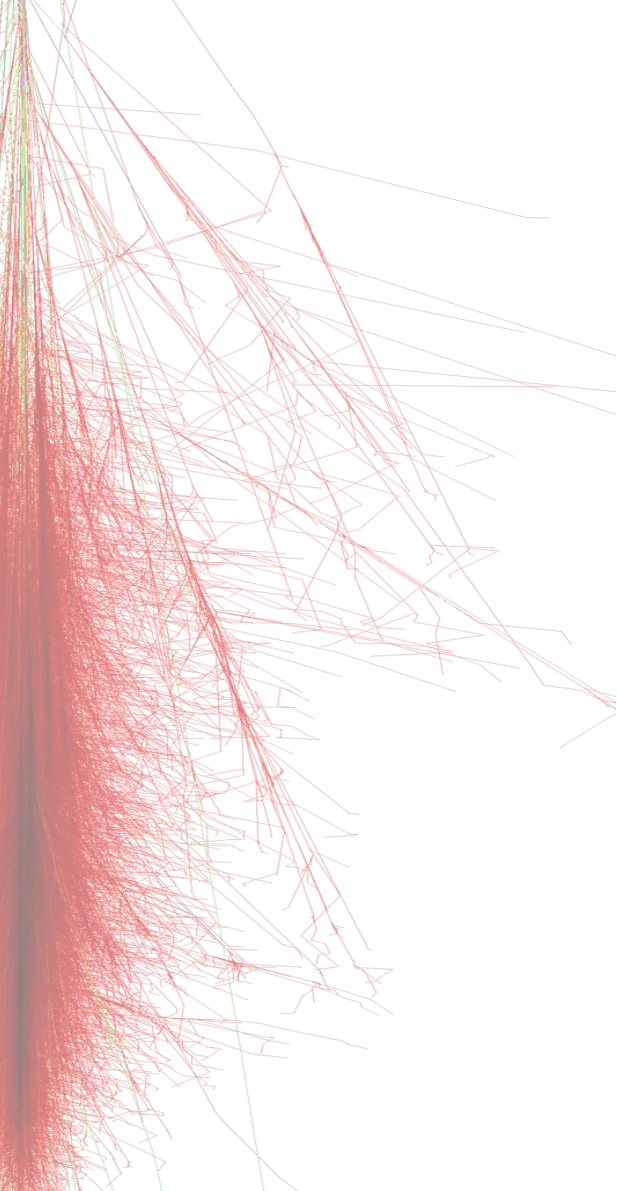




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Backup



Sensitivity, analytical approximation

Point-source flux sensitivity

- Smallest detectable point source flux
- Inverse of the significance level

$$N_\gamma = \overset{\text{Particle flux (source)}}{\Phi} \cdot \underset{\text{Detector size (Effective area)}}{A} \cdot \overset{\text{Selection efficiency}}{\epsilon} \cdot \underset{\text{Observation time}}{\Delta T}$$

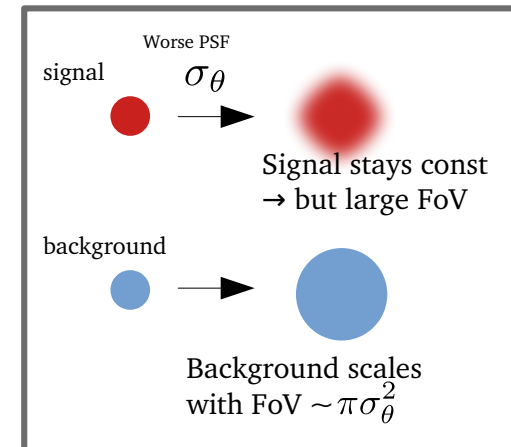
Gaussian regime

$$\sigma_{\text{level}} = \frac{\text{Signal}}{\text{Background}} \rightarrow \approx \frac{N_\gamma}{\sqrt{N_{\text{hadr}}}} = \frac{\epsilon_\gamma A_\gamma}{\sqrt{(1 - \epsilon_p) A_{\text{hadr}}}} \cdot \frac{\Delta T}{\sqrt{\Delta T}} \cdot \frac{1}{\sqrt{\sigma_\theta^2}}$$

$$\rightarrow \left(\frac{\epsilon_\gamma}{\sqrt{\epsilon_{\text{bkg}}}} \right) \cdot \sqrt{A} \cdot \sqrt{\Delta T} \cdot \left(\frac{1}{\sigma_\theta} \right)$$

ϵ_γ → correctly classified gammas (TPR)

ϵ_{bkg} → protons misclassified as gammas (FPR)

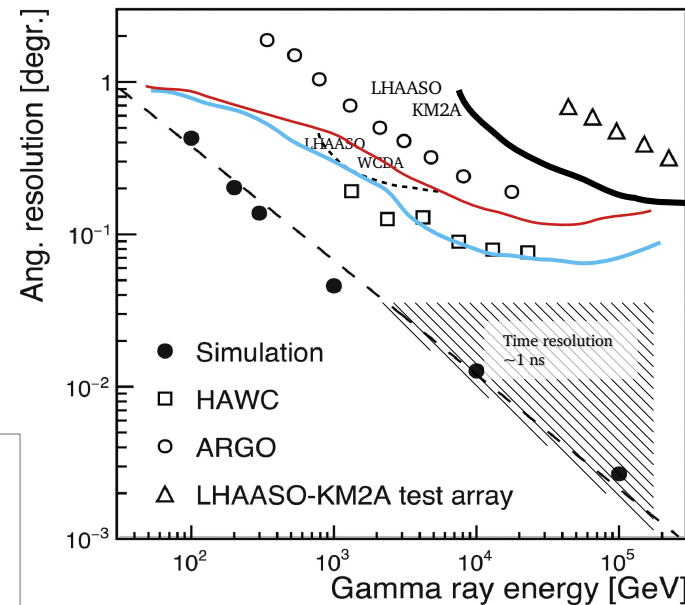
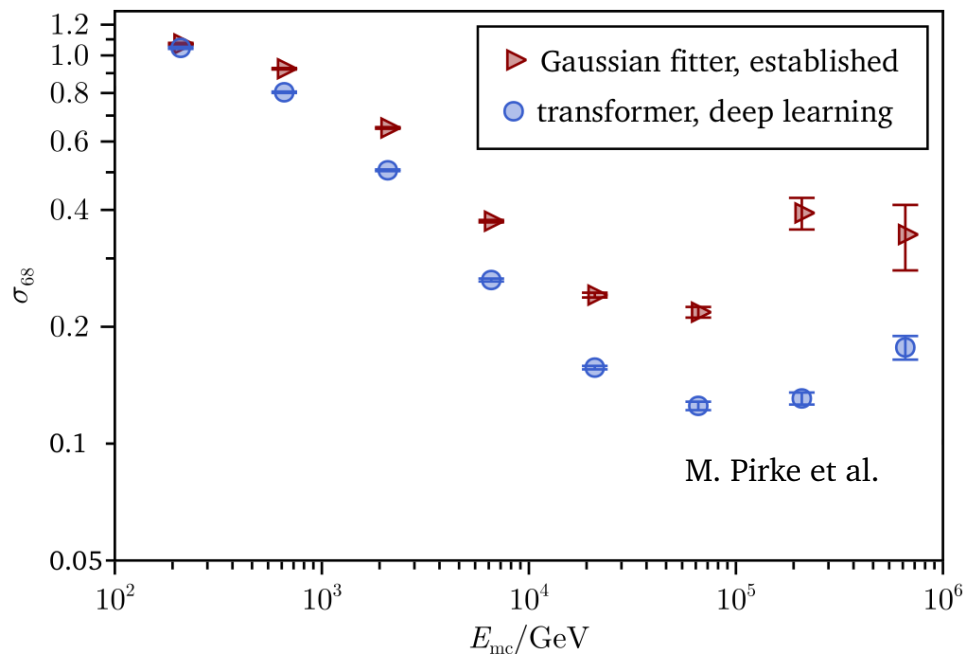


Angular resolution

- Driven by arrival time of particles
 - fill factor and array size
- Deep learning improves resolution 10-40%

Interlude: theoretical limit

- Likelihood fit of position & energy of each particle
- Not reached → improvements possible?



Remember

$$S \sim \frac{1}{\sigma_{\theta}}$$

Energy dispersion

- Mostly relies on footprint and signal depositions
- State-of-the-art: Template method (à la Franzi et al.)
- Application of deep learning (Graph neural network)
 - ♦ signal & timing
- DNN outperforms state-of-the-art
- Improved resolution + bias

(Note the log!)

