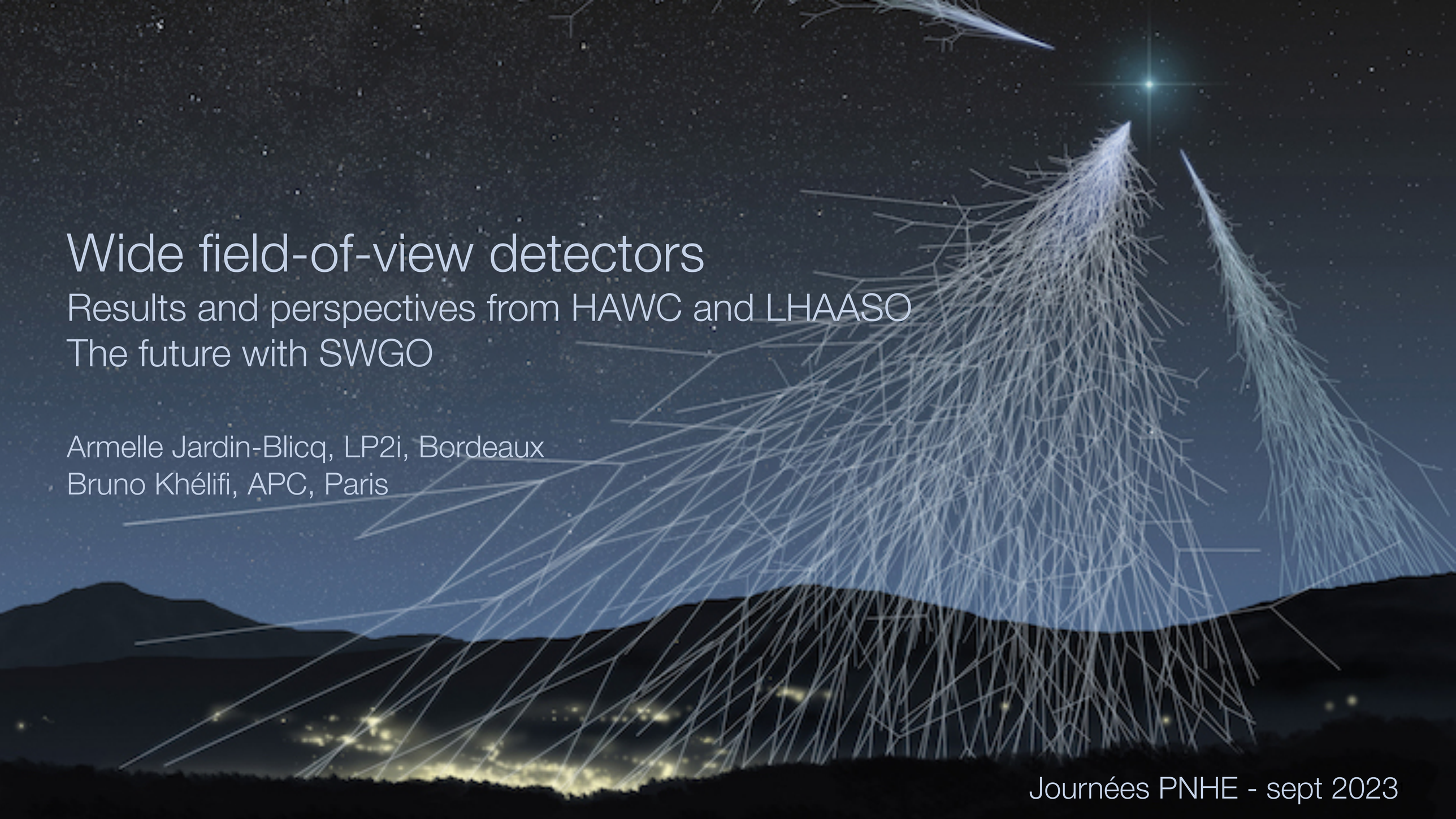
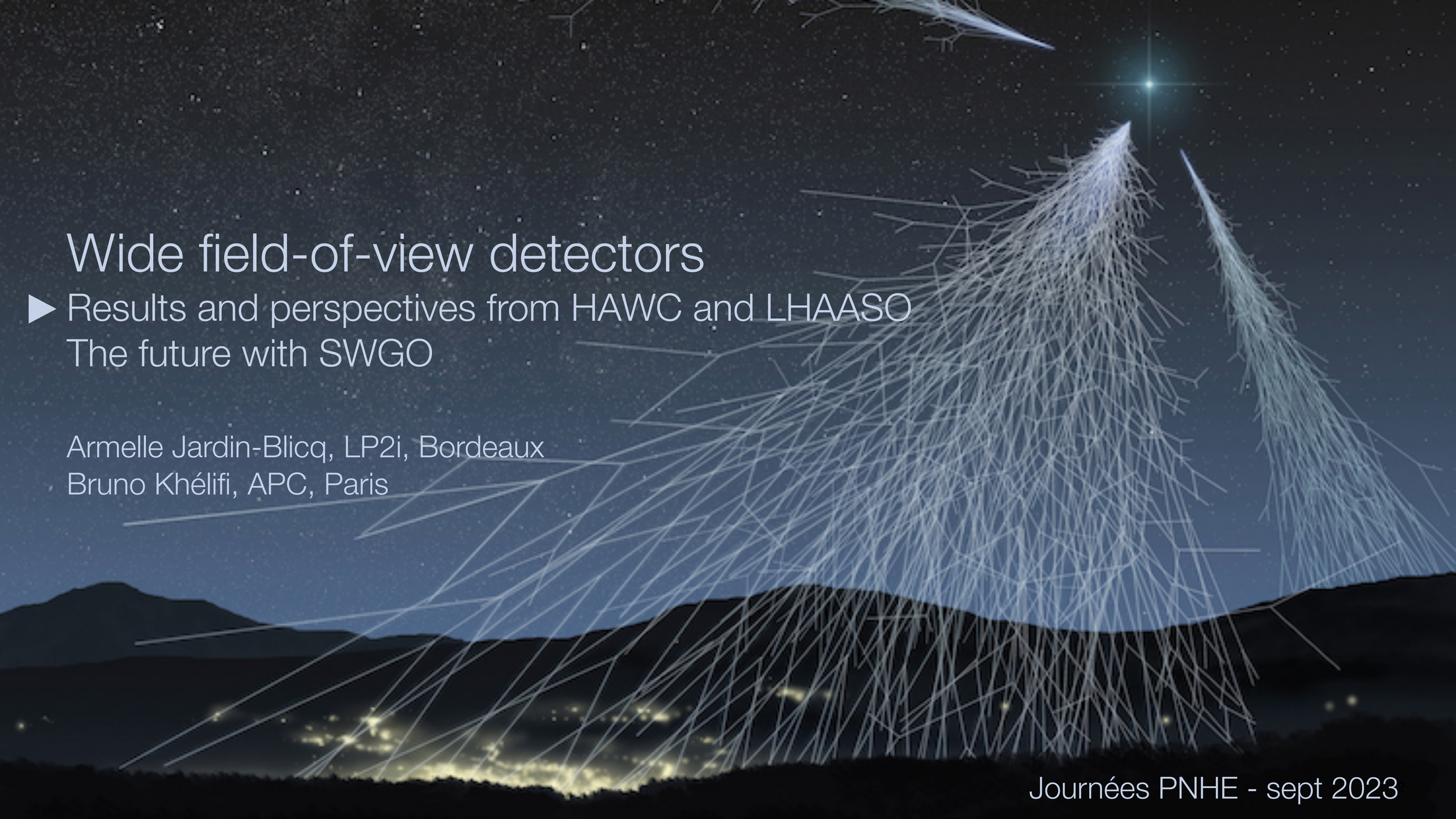


Wide field-of-view detectors

Results and perspectives from HAWC and LHAASO
The future with SWGO

Armelle Jardin-Blicq, LP2i, Bordeaux
Bruno Khélifi, APC, Paris

Journées PNHE - sept 2023



Wide field-of-view detectors

- Results and perspectives from HAWC and LHAASO
  The future with SWGO

Armelle Jardin-Blicq, LP2i, Bordeaux
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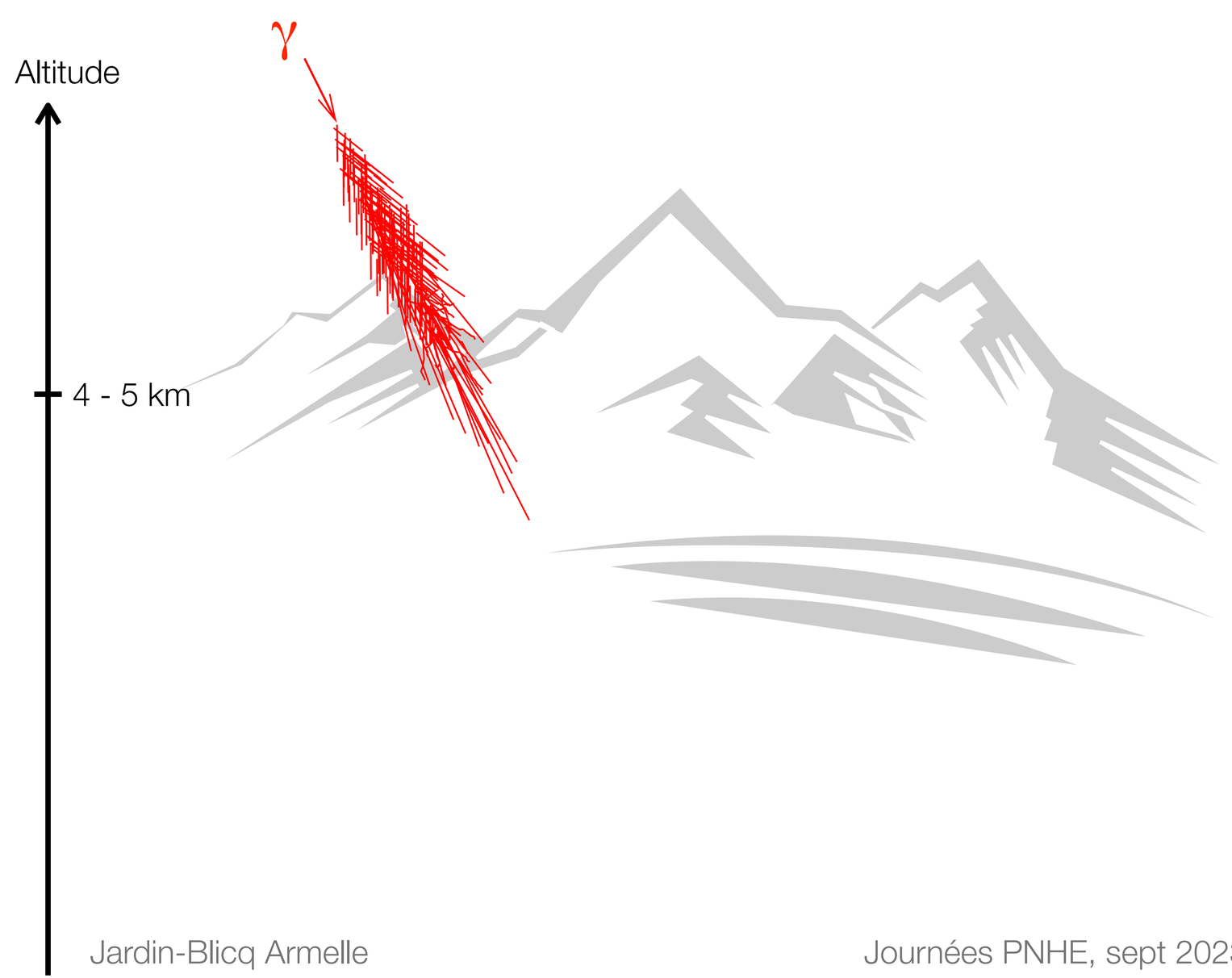
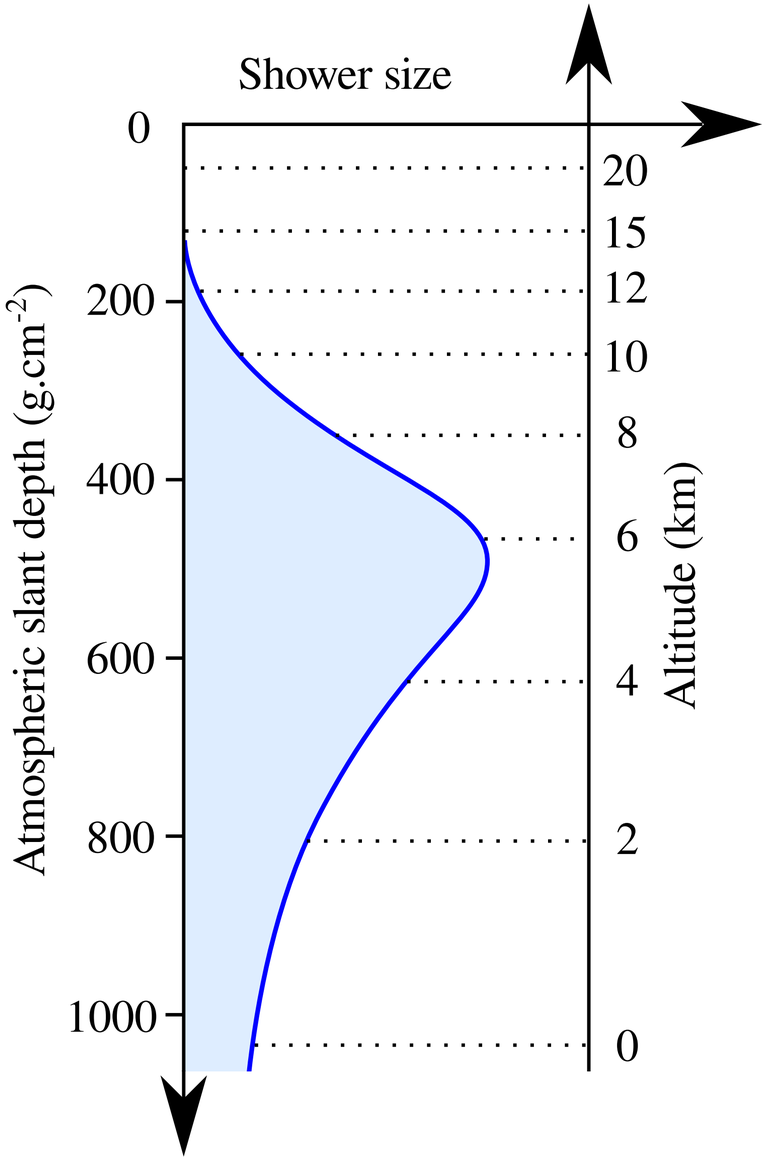
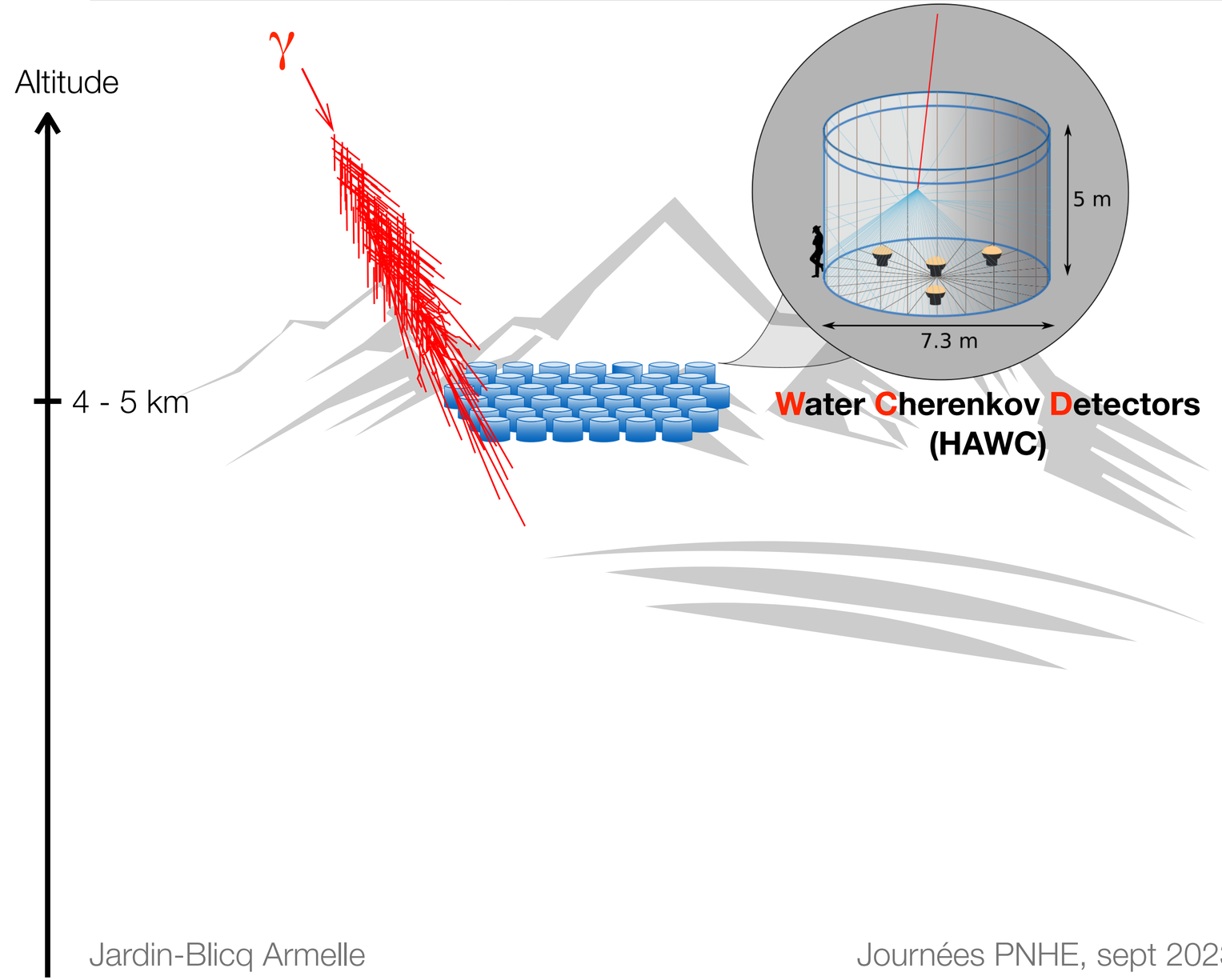
Journées PNHE - sept 2023

Ground based instruments





Ground based instruments



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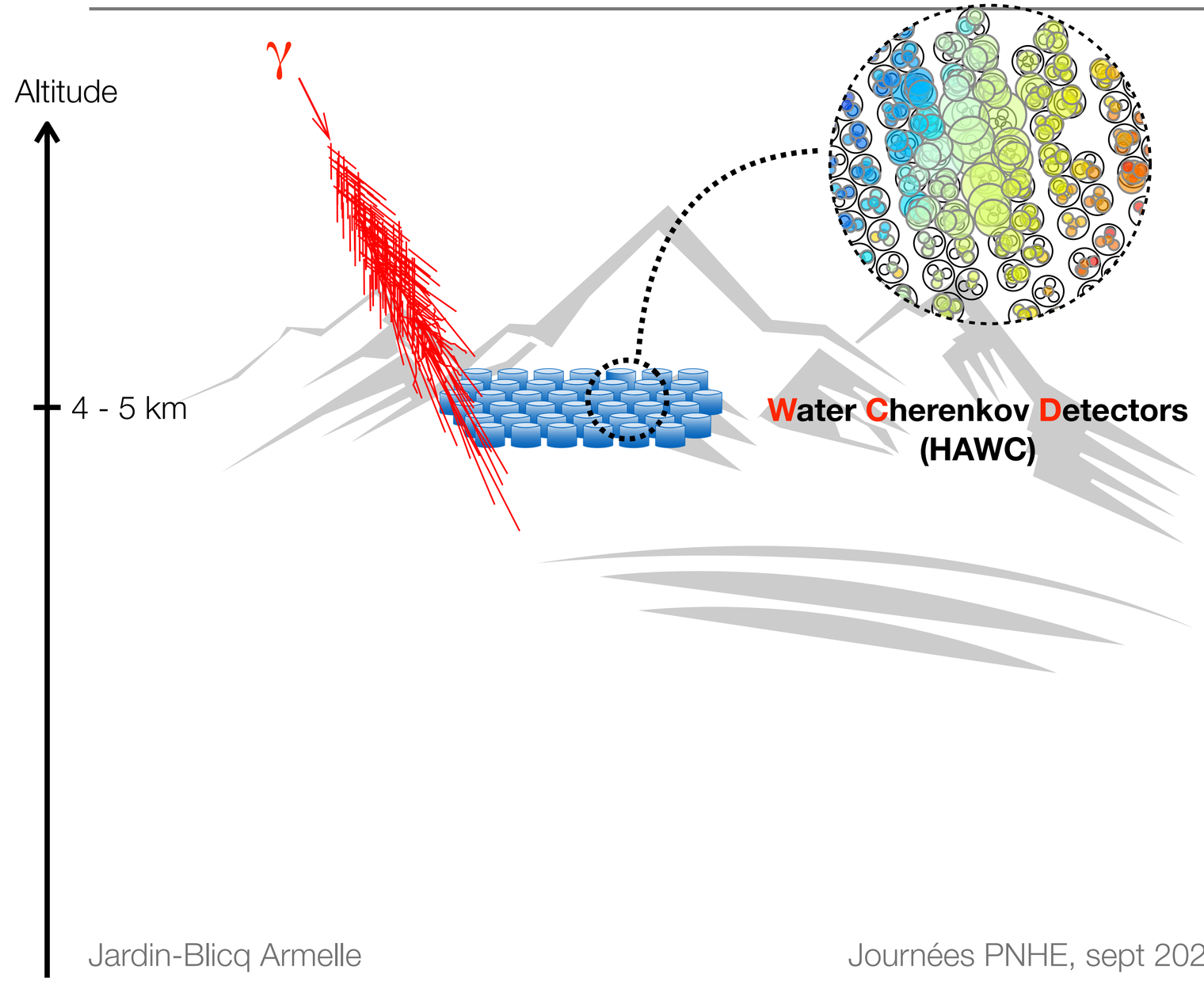
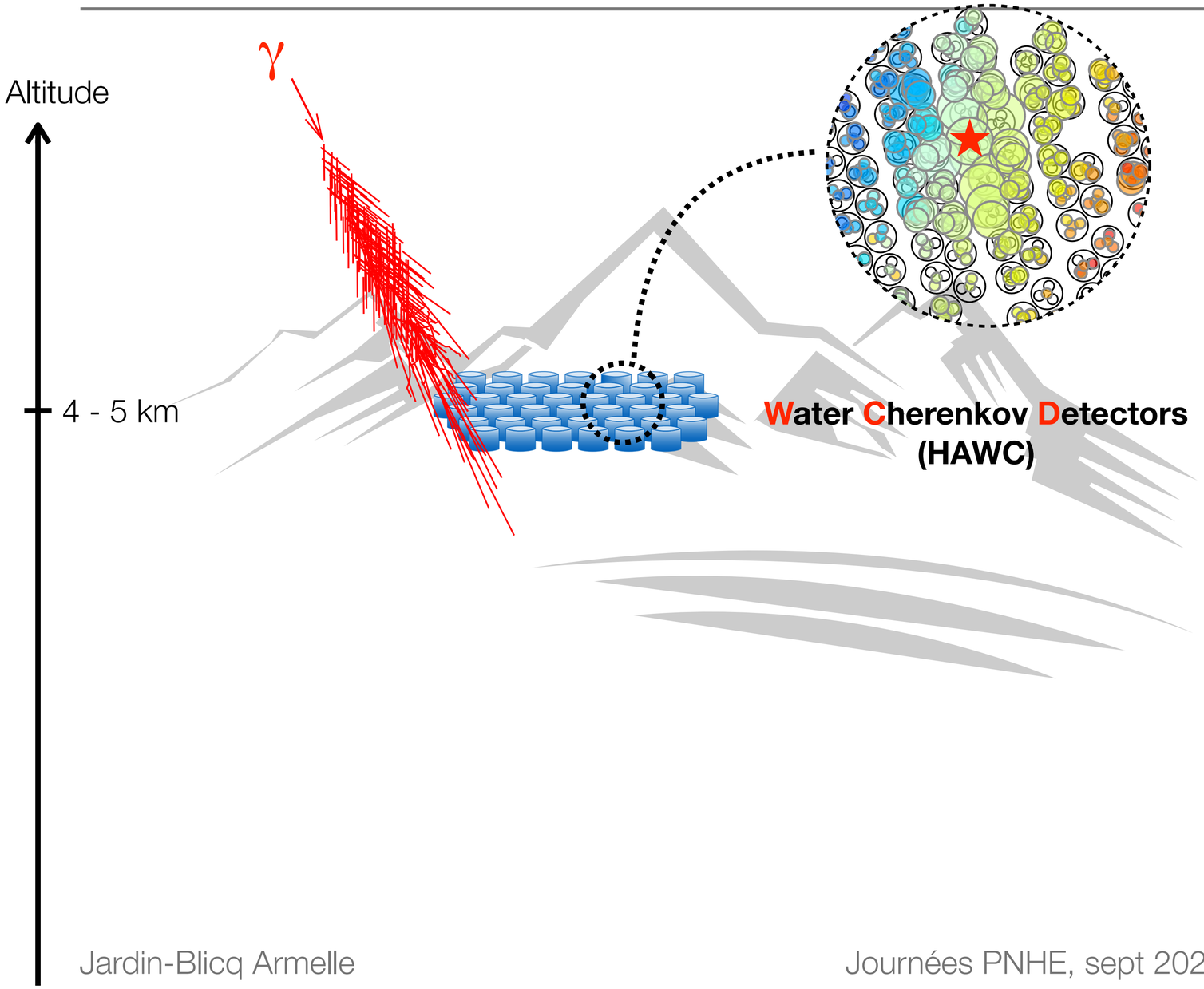


Ground based instruments



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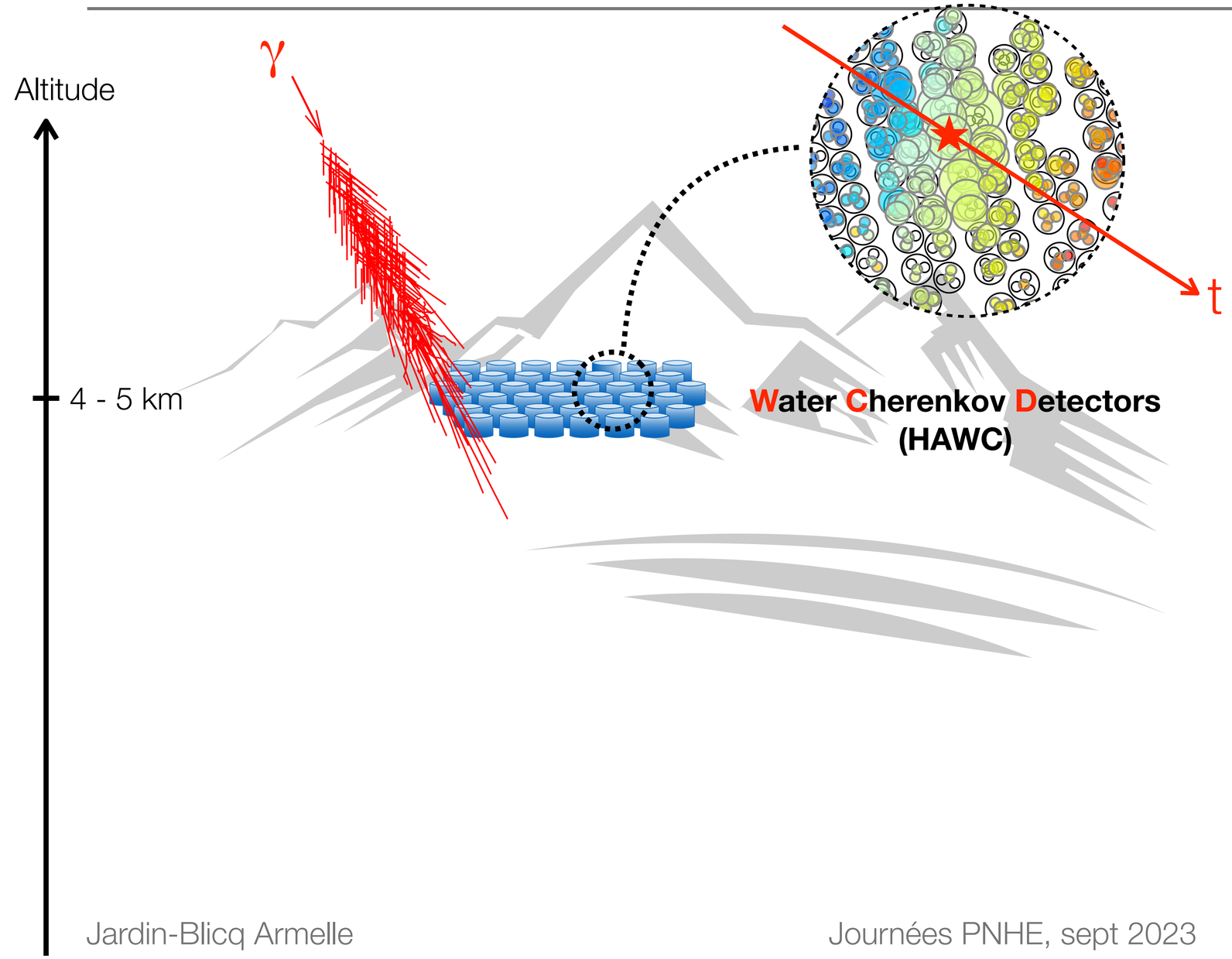
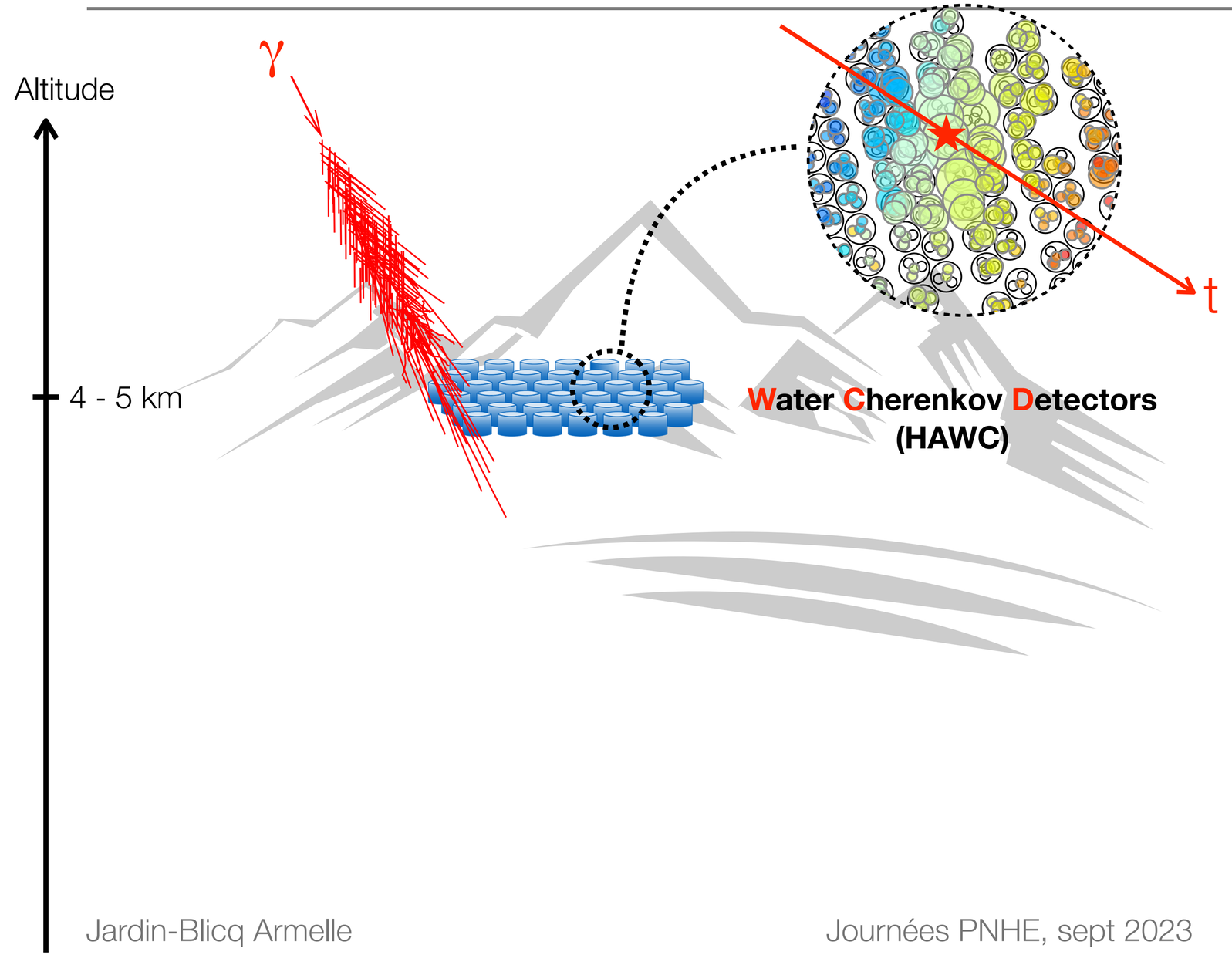
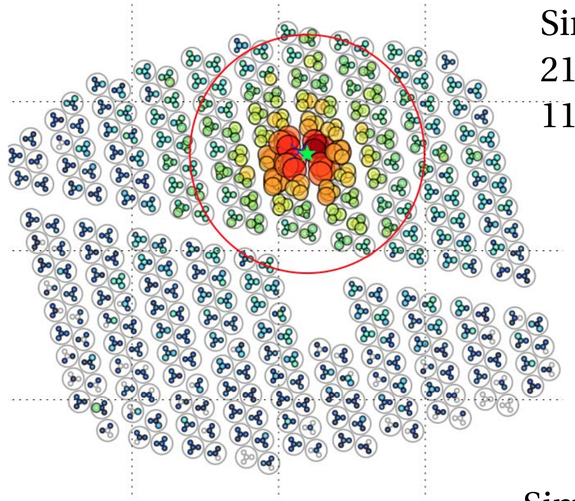
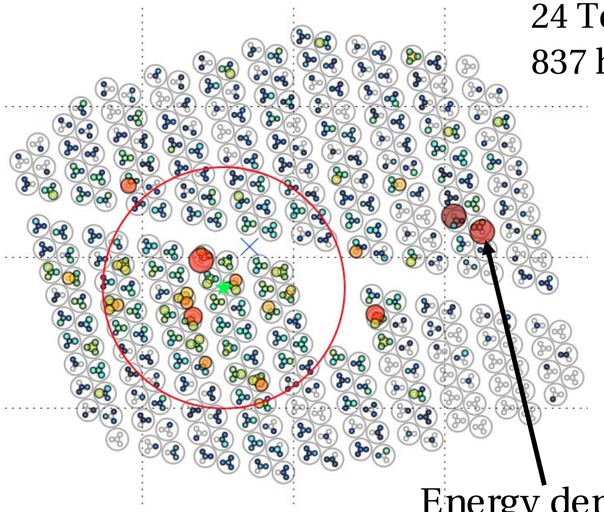


Ground based instruments





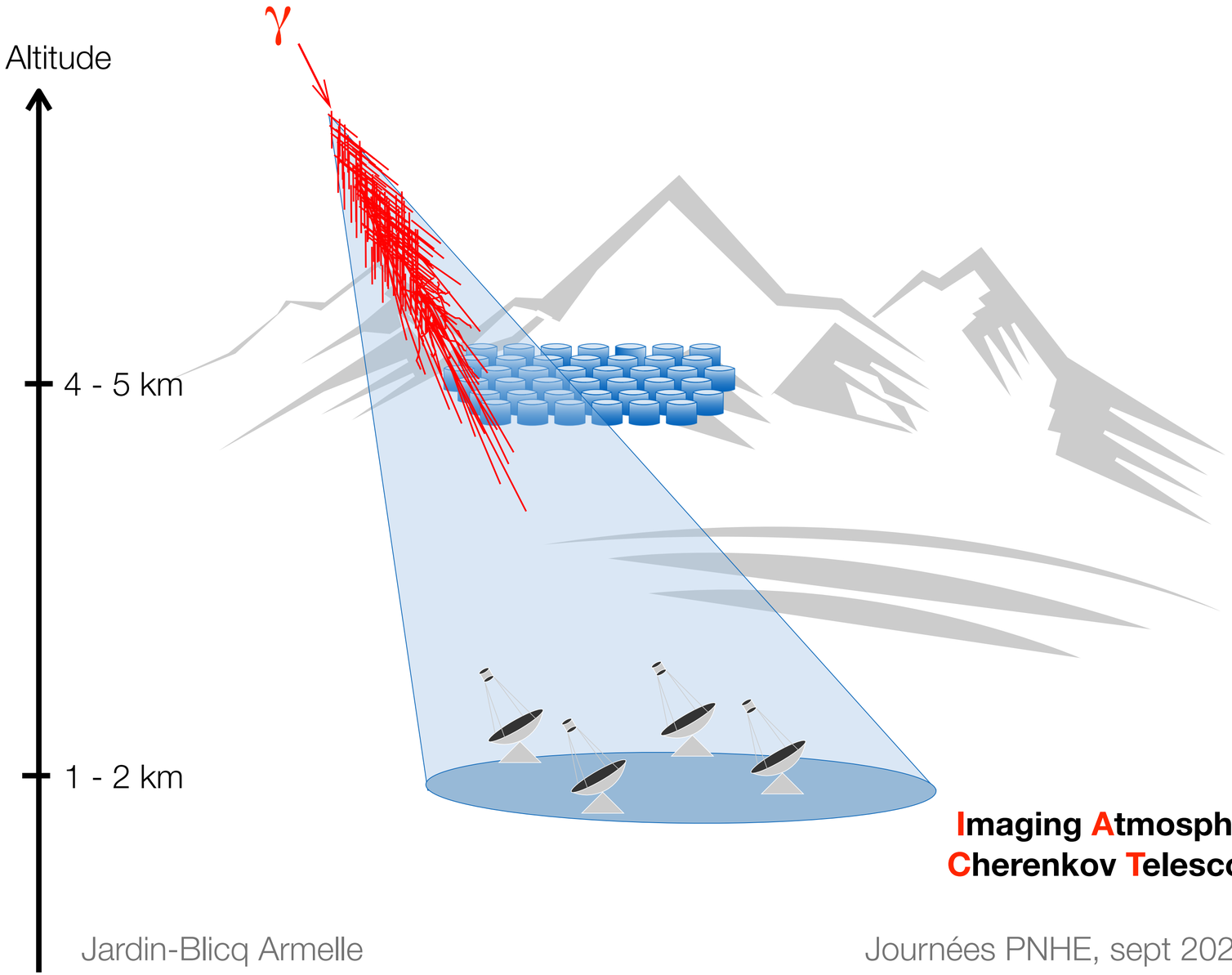
Simulated γ-ray
21 TeV, θ=21°
1131 hit PMTs



Simulated proton
24 TeV, θ=44°
837 hit PMTs

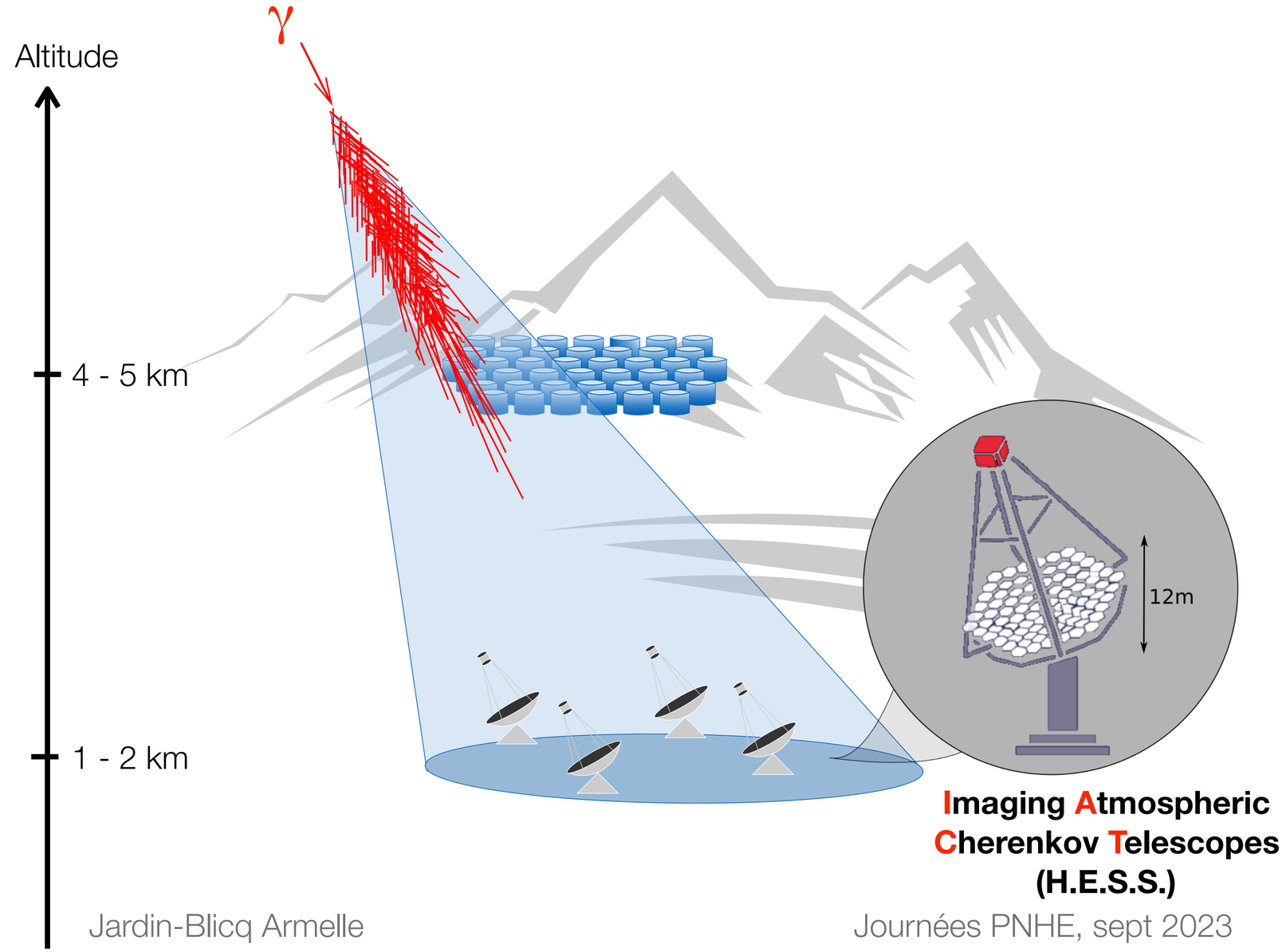
Energy deposited
away from the core

Ground based instruments



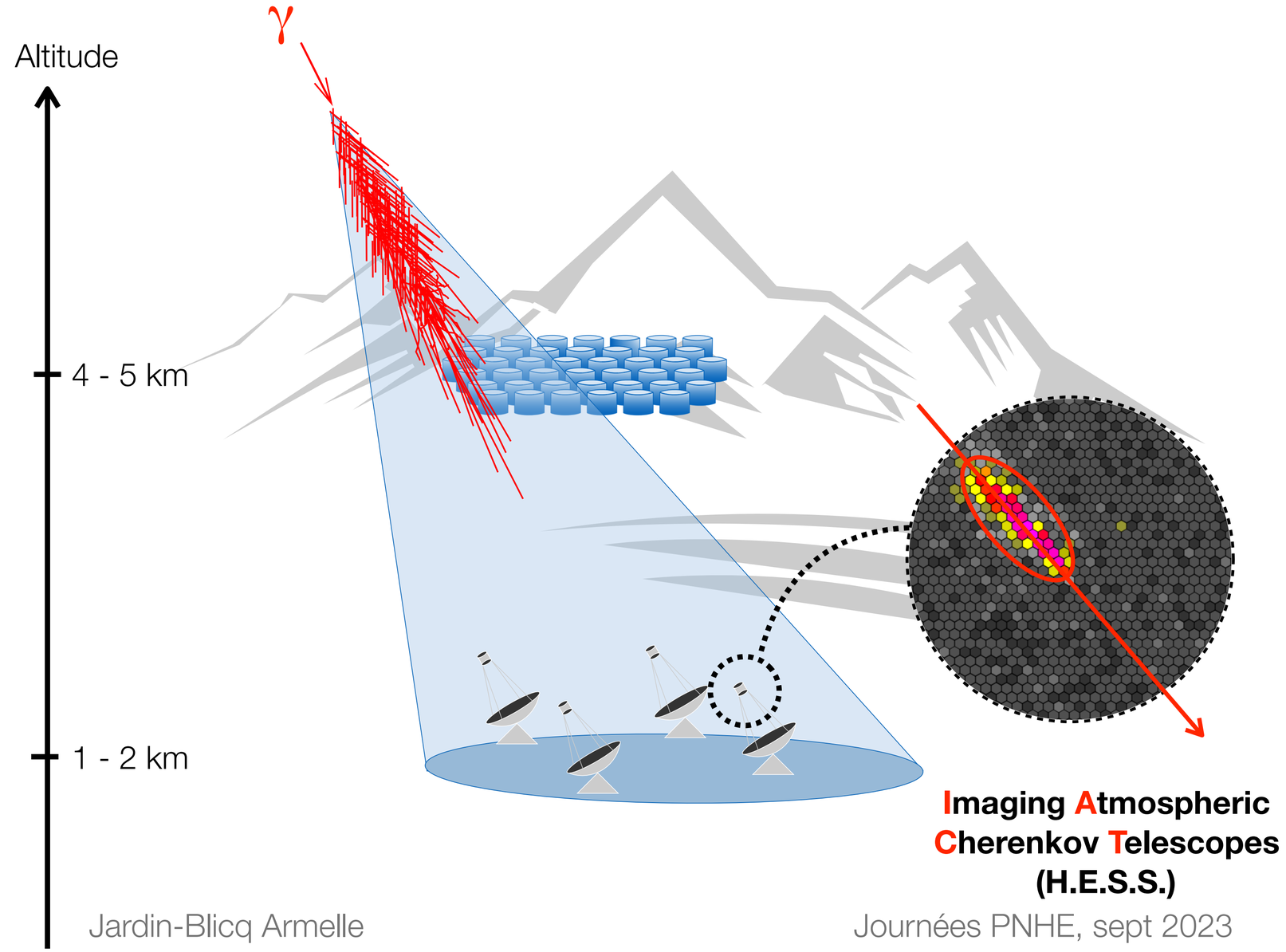
Imaging Atmospheric Cherenkov Telescopes

Ground based instruments



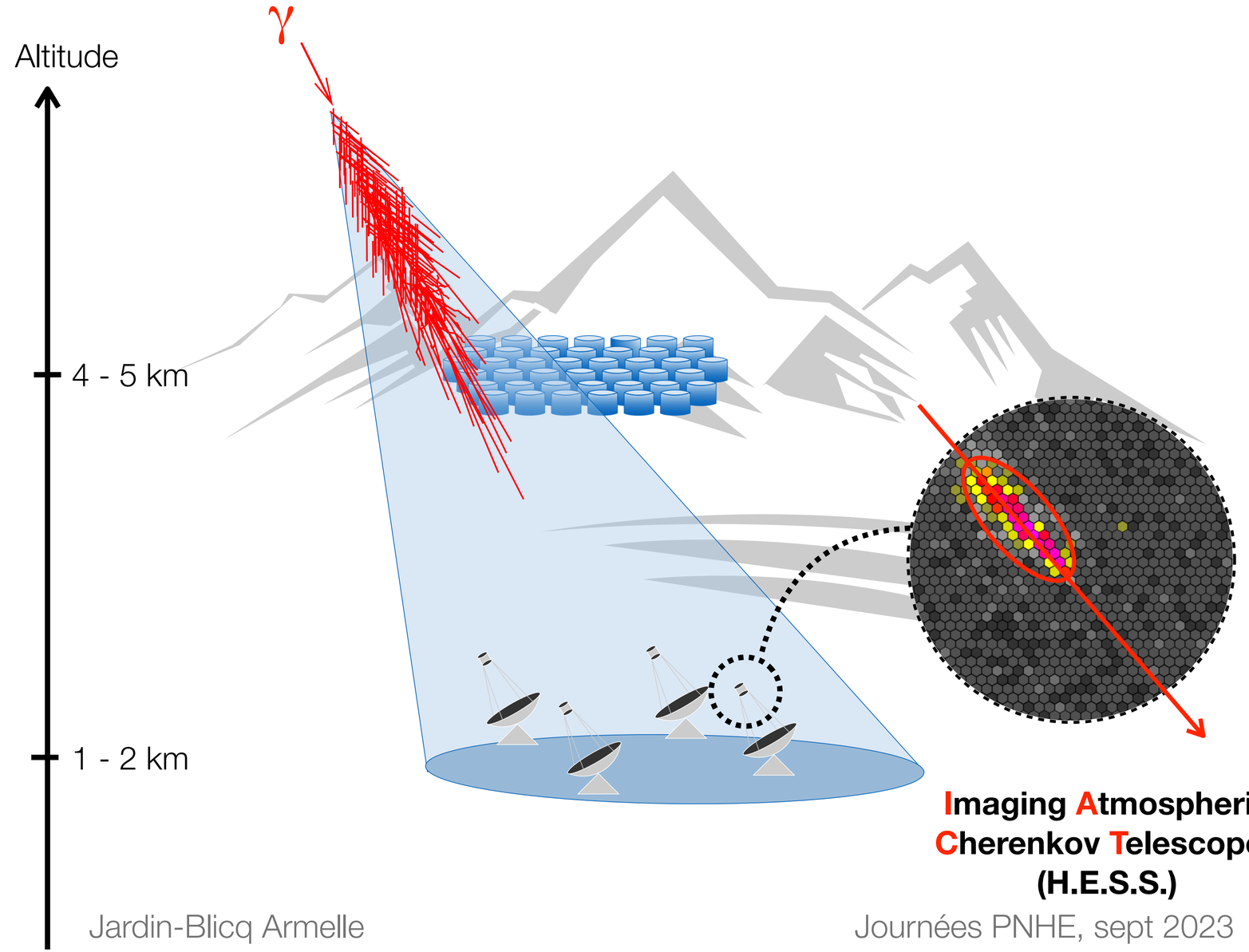
Imaging Atmospheric Cherenkov Telescopes (H.E.S.S.)

Ground based instruments

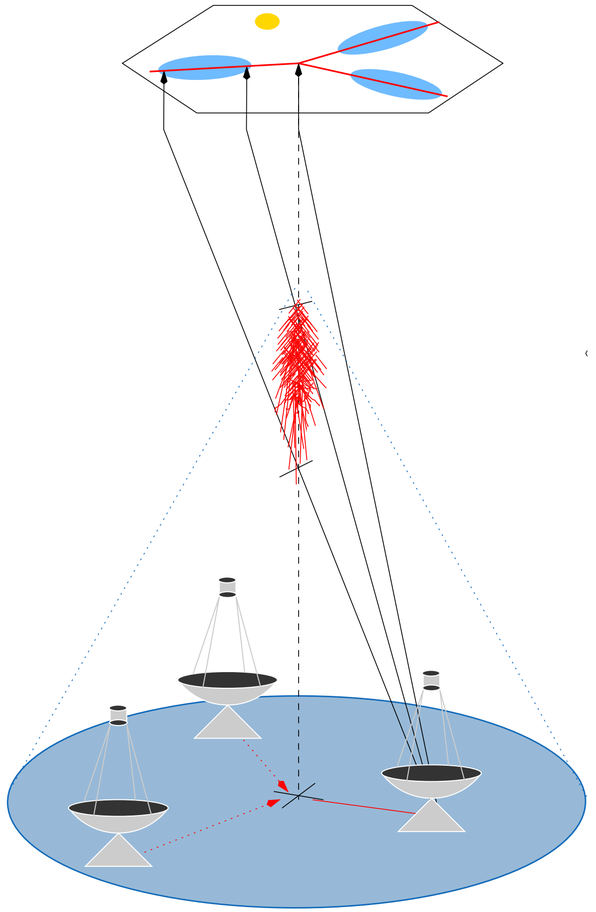


Imaging Atmospheric Cherenkov Telescopes (H.E.S.S.)

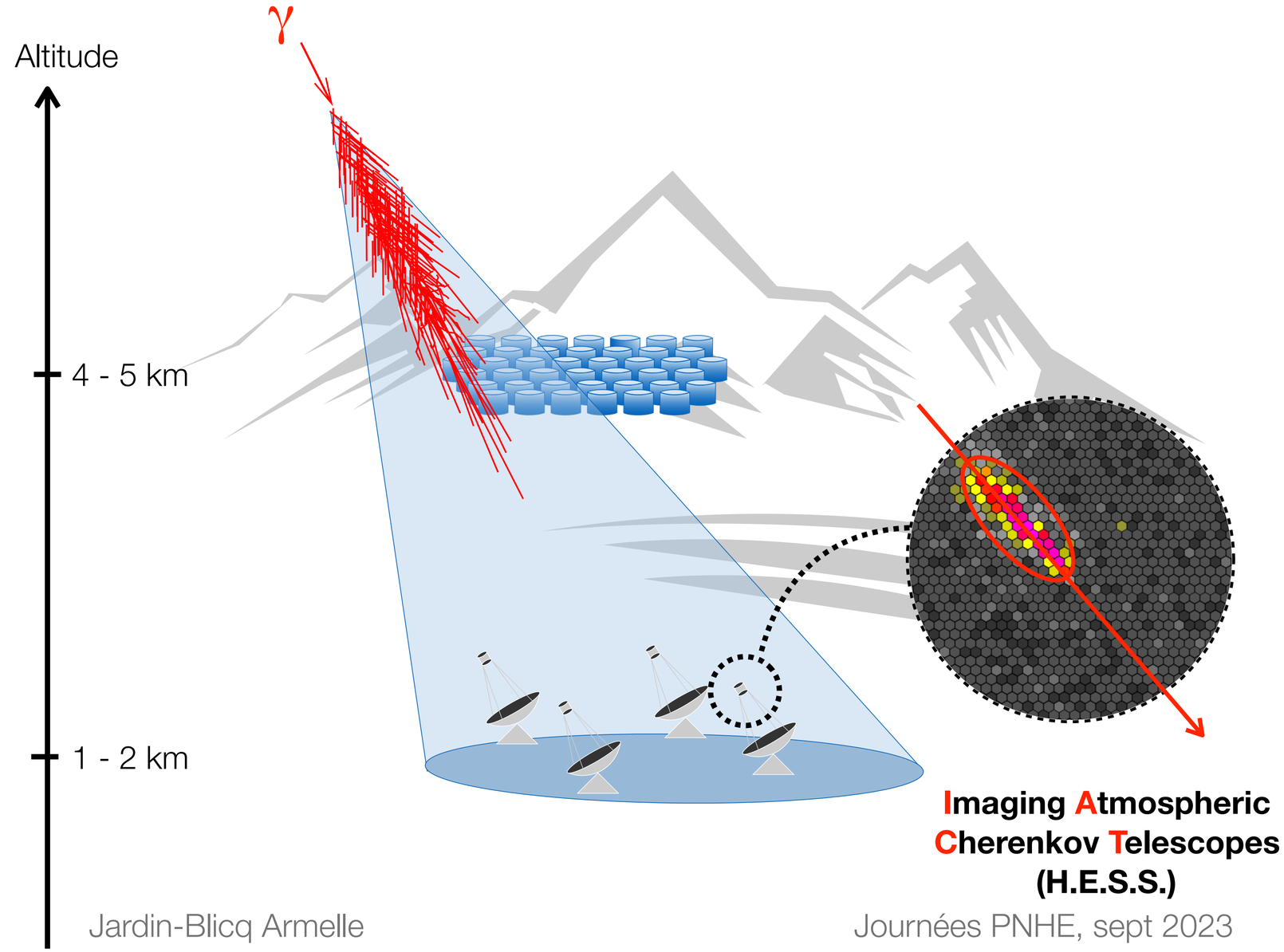
Ground based instruments

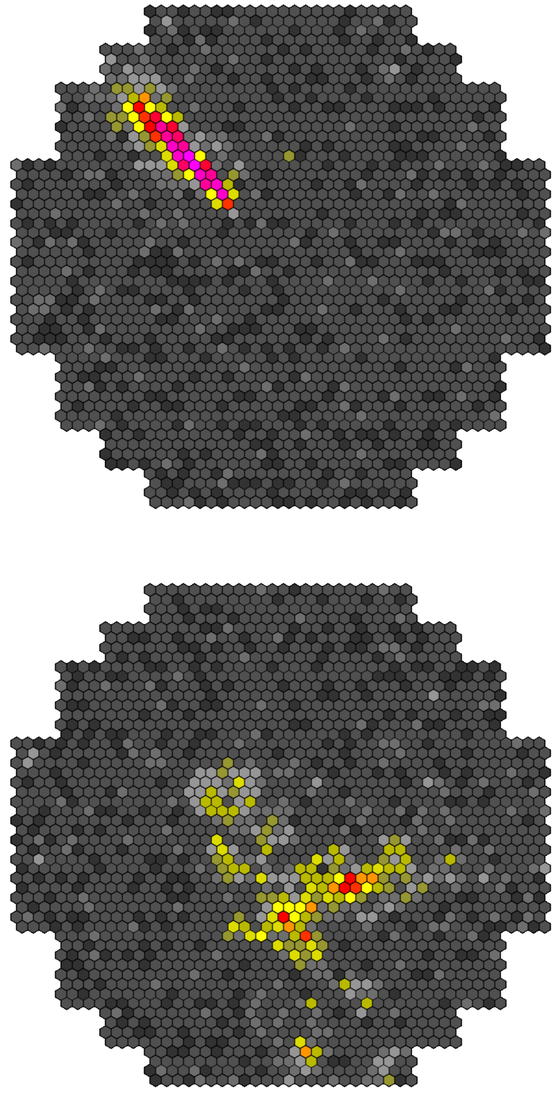


Imaging Atmospheric Cherenkov Telescopes (H.E.S.S.)



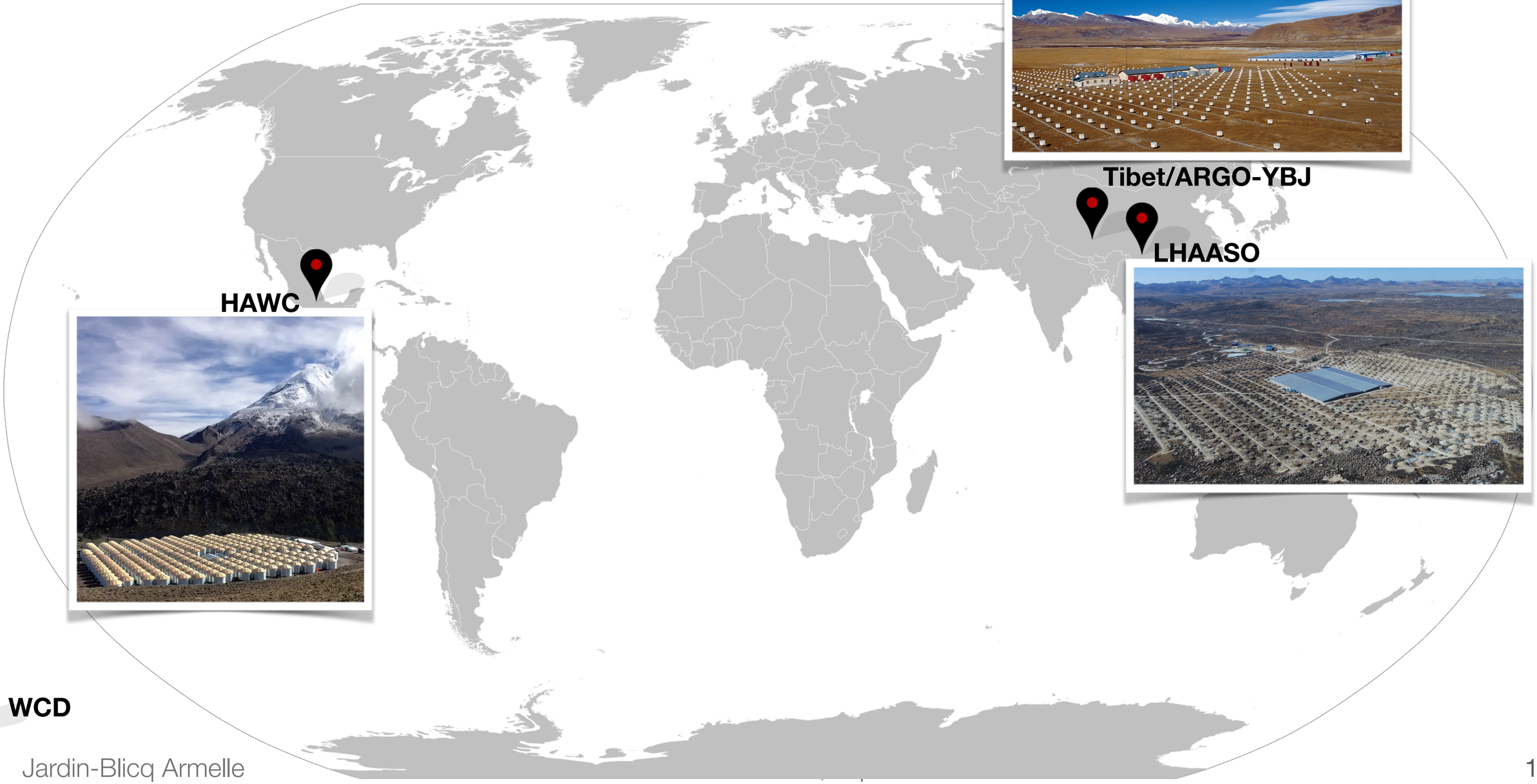
Ground based instruments



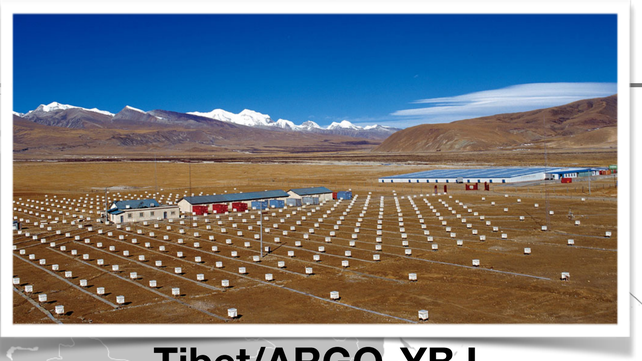


Imaging Atmospheric Cherenkov Telescopes (H.E.S.S.)

Instruments around the world



Instruments around the world



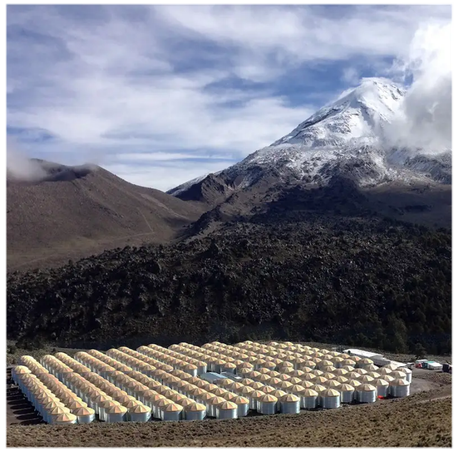
VERITAS

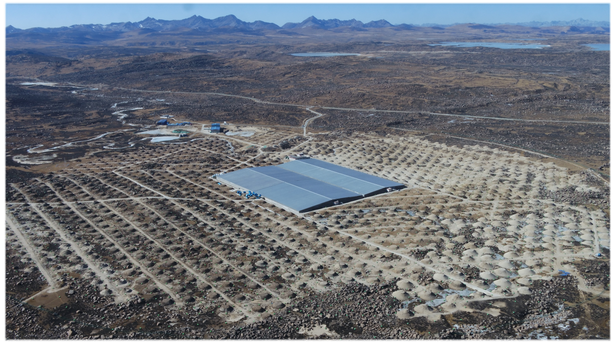
MAGIC

Tibet/ARGO-YBJ

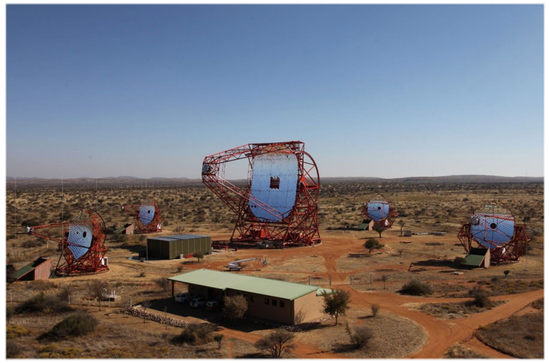
HAWC

LHAASO





H.E.S.S.



WCD IACT

Instruments around the world

Complementary in terms of sky coverage

VERITAS

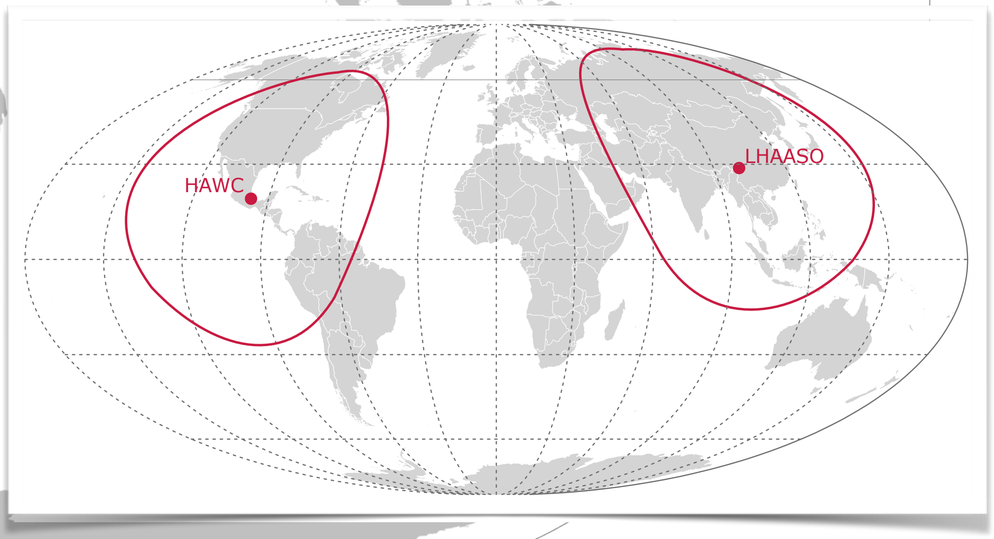
HAWC

MAGIC

H.E.S.S.

Tibet/ARGO-YBJ

LHAASO



WCD IACT

Instruments around the world

Complementary in terms of sky coverage

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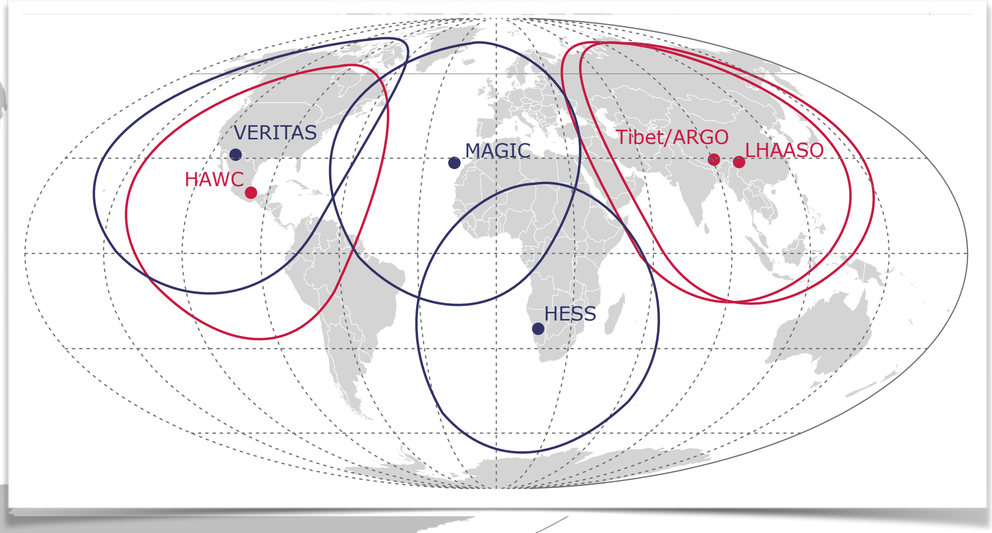

WCD IACT

Instruments around the world

Complementary in terms of sky coverage

VERITAS

HAWC

MAGIC

Tibet/ARGO-YBJ

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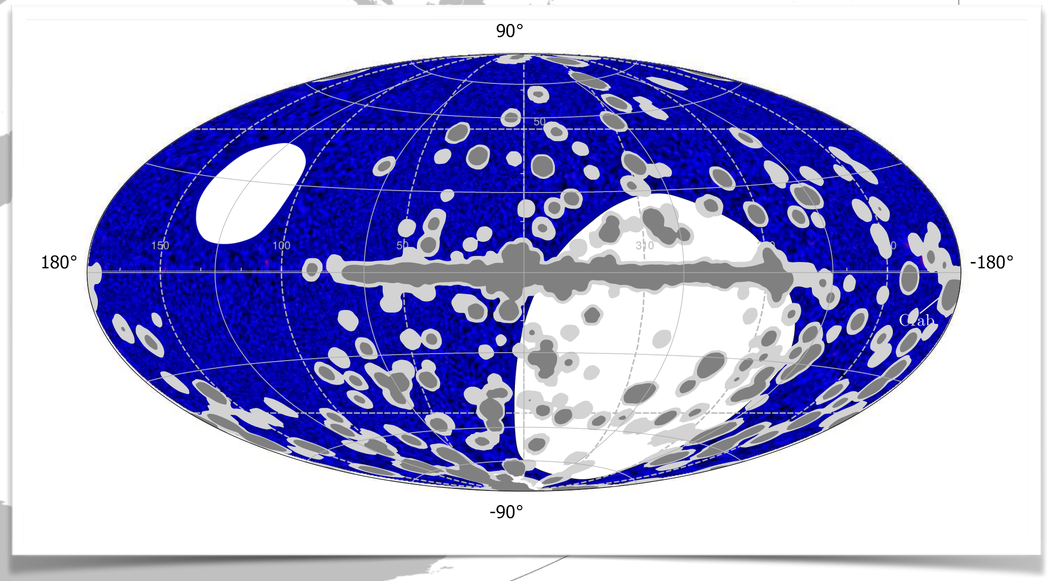
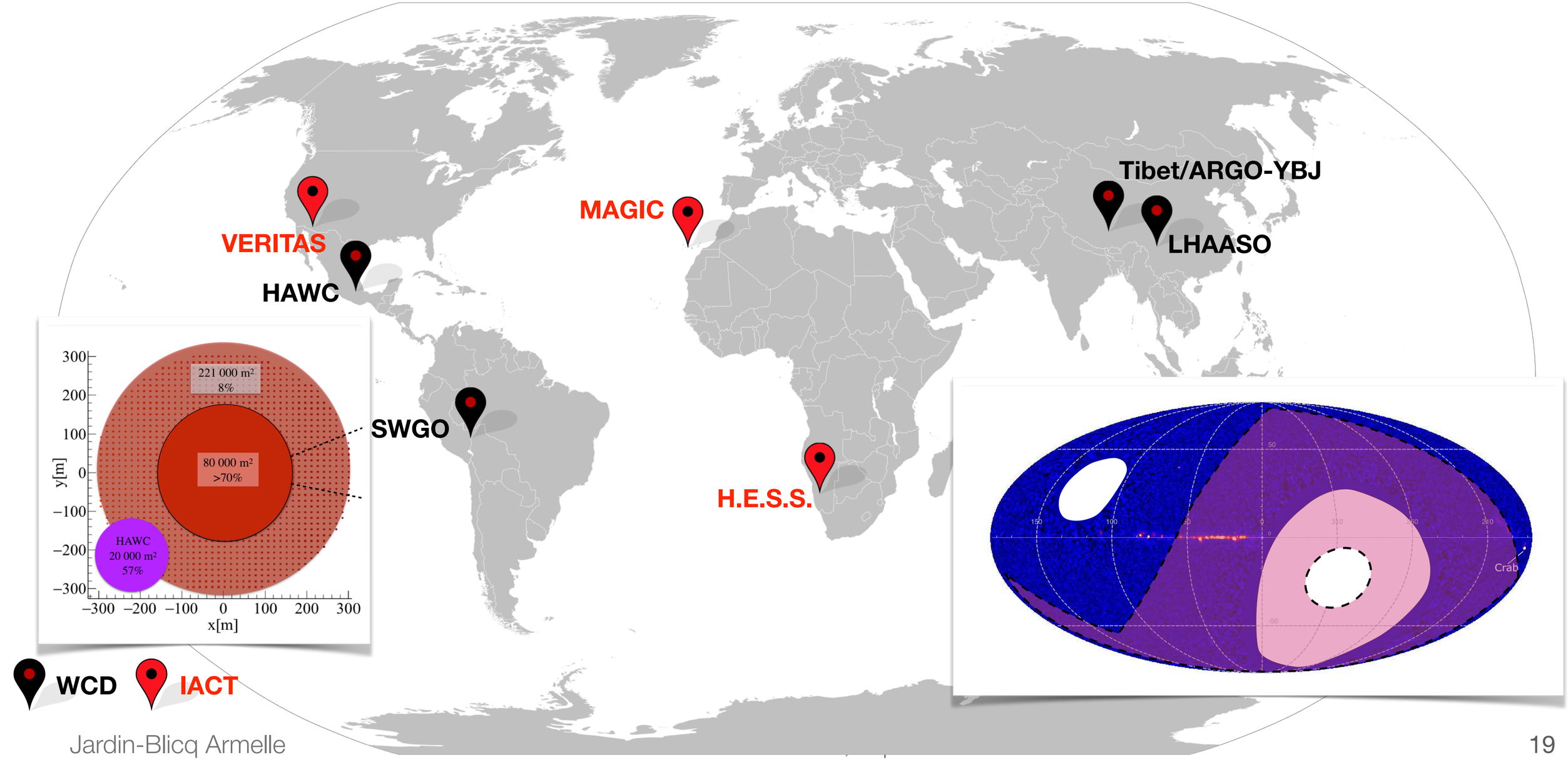
H.E.S.S.



WCD IACT

Instruments around the world



Instruments around the world

VERITAS

HAWC

MAGIC

CTA-N

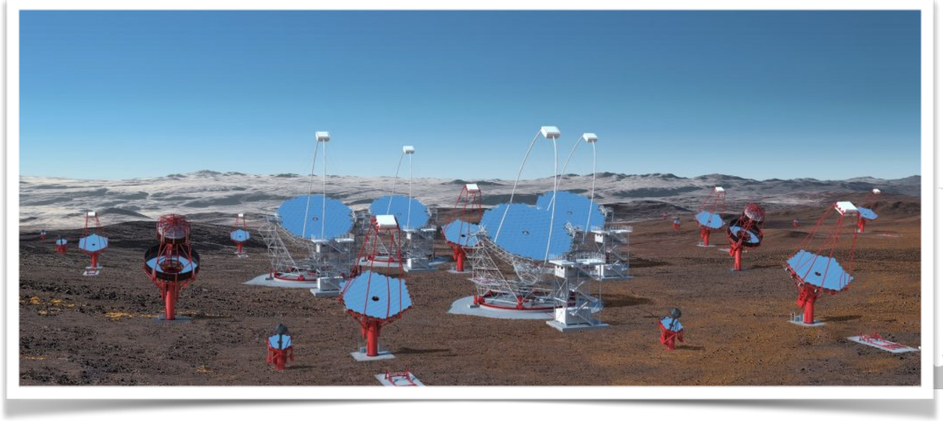
Tibet/ARGO-YBJ

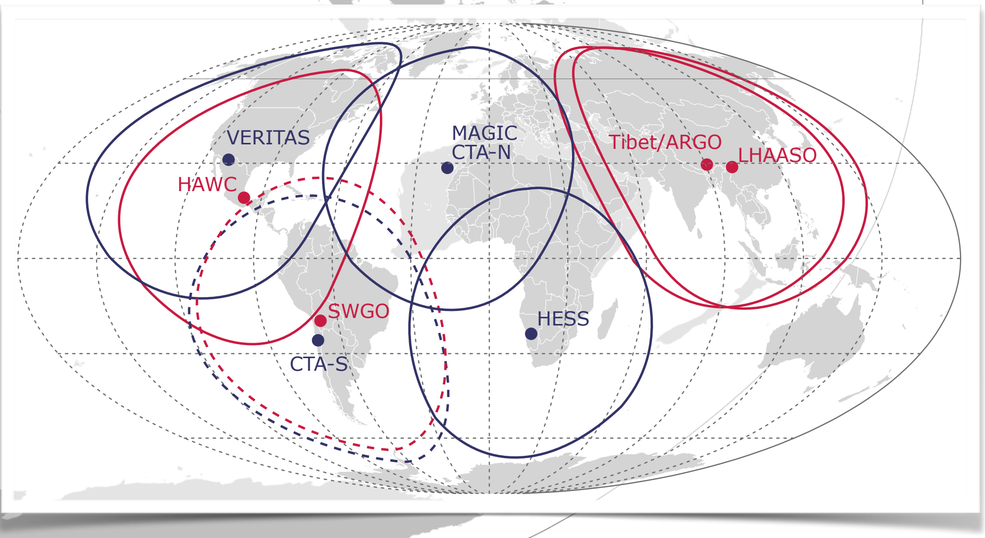
LHAASO

SWGO

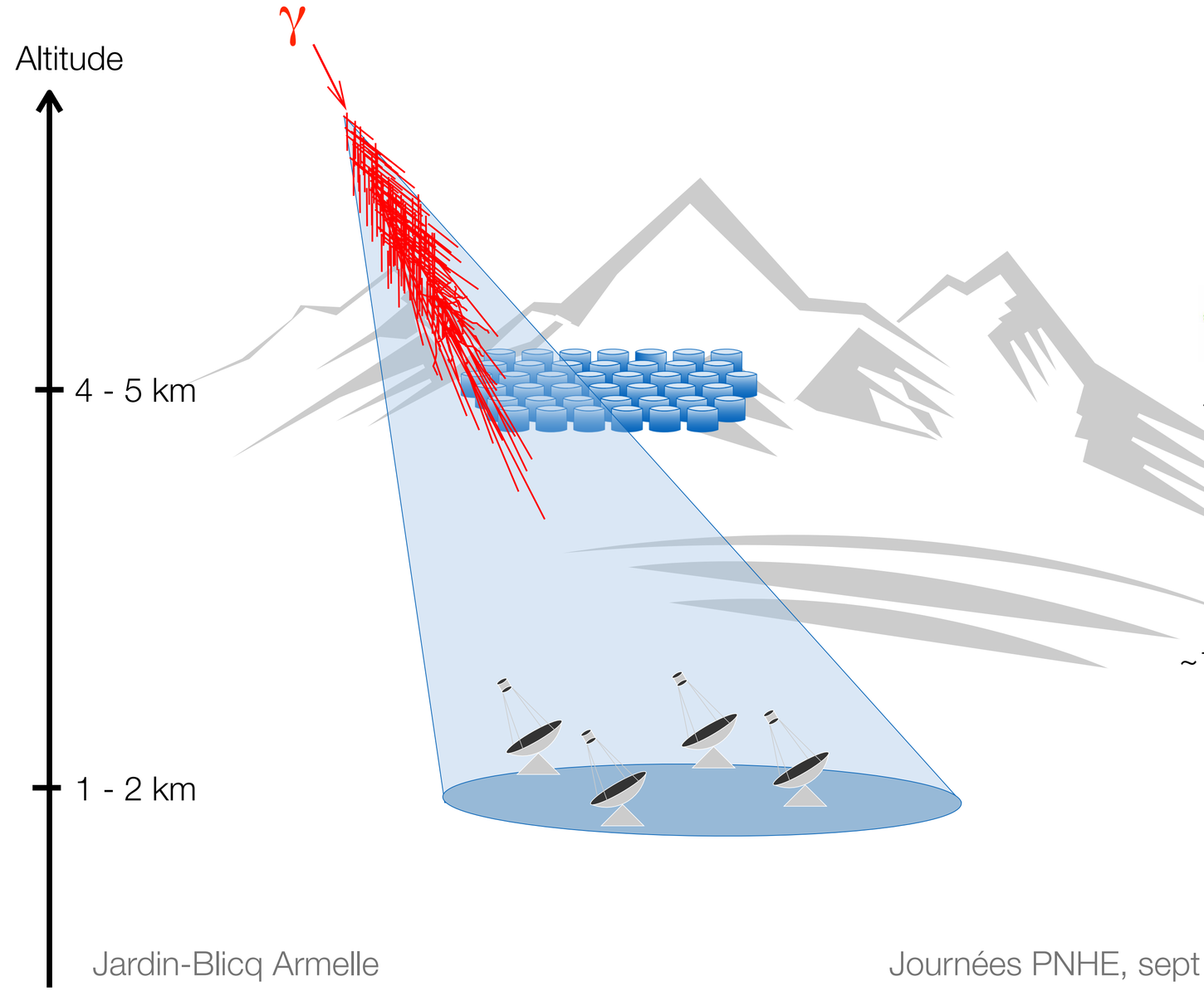
CTA-S

H.E.S.S.



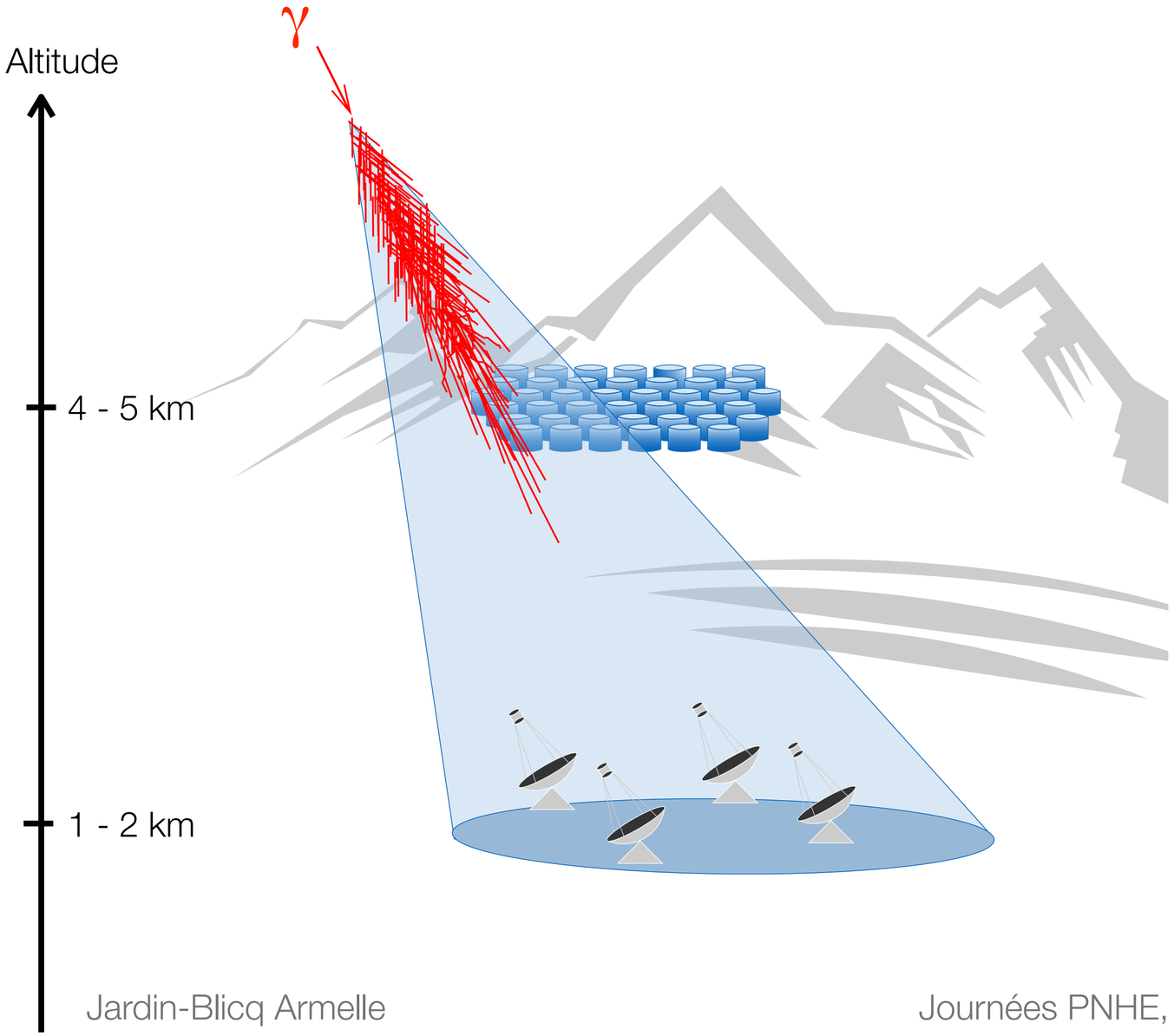


Comparison

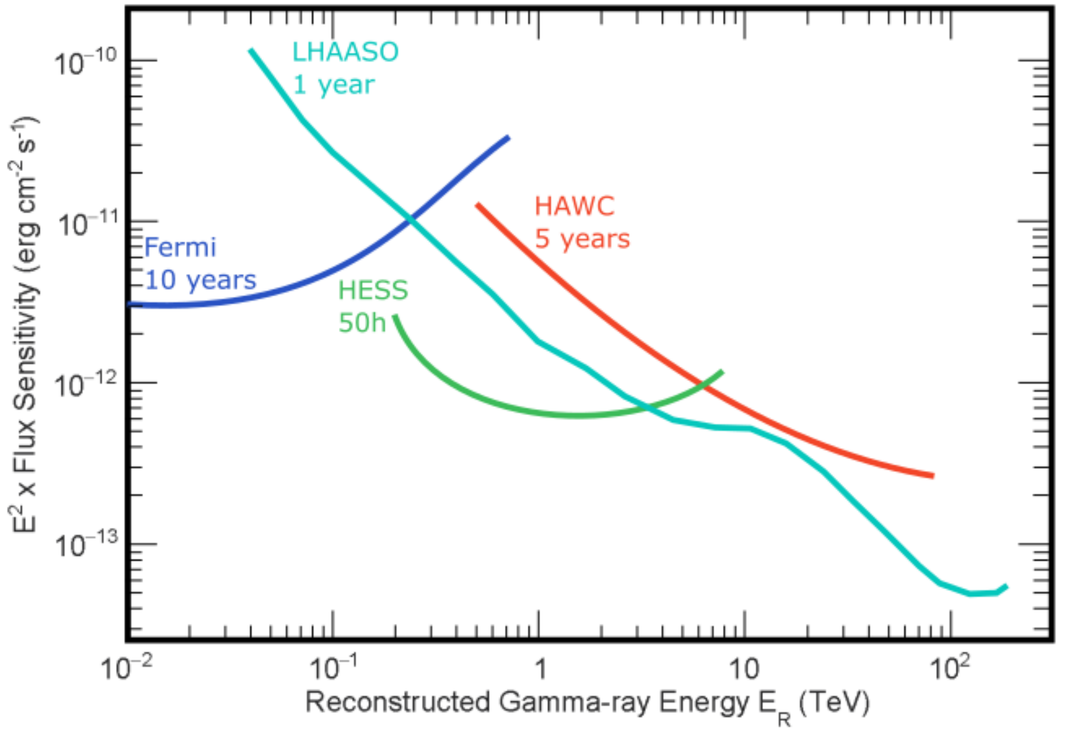


	Duty cycle	Field of view	Energy range	Energy resolution	Angular resolution
IACT	✓ ~95%	✓ 90°	✓ 0.5 - 100 TeV	✗ 20% at 1 TeV 10% at 100 TeV (on-array events)	✗ 0.8 - 0.1°
WCD	✗ ~10% ~1000 h/y	✗ 5°	✓ 0.03 - 100 TeV	✓ < 10% for E > 1 TeV	✓ 0.1 - 0.05°

Sensitivity

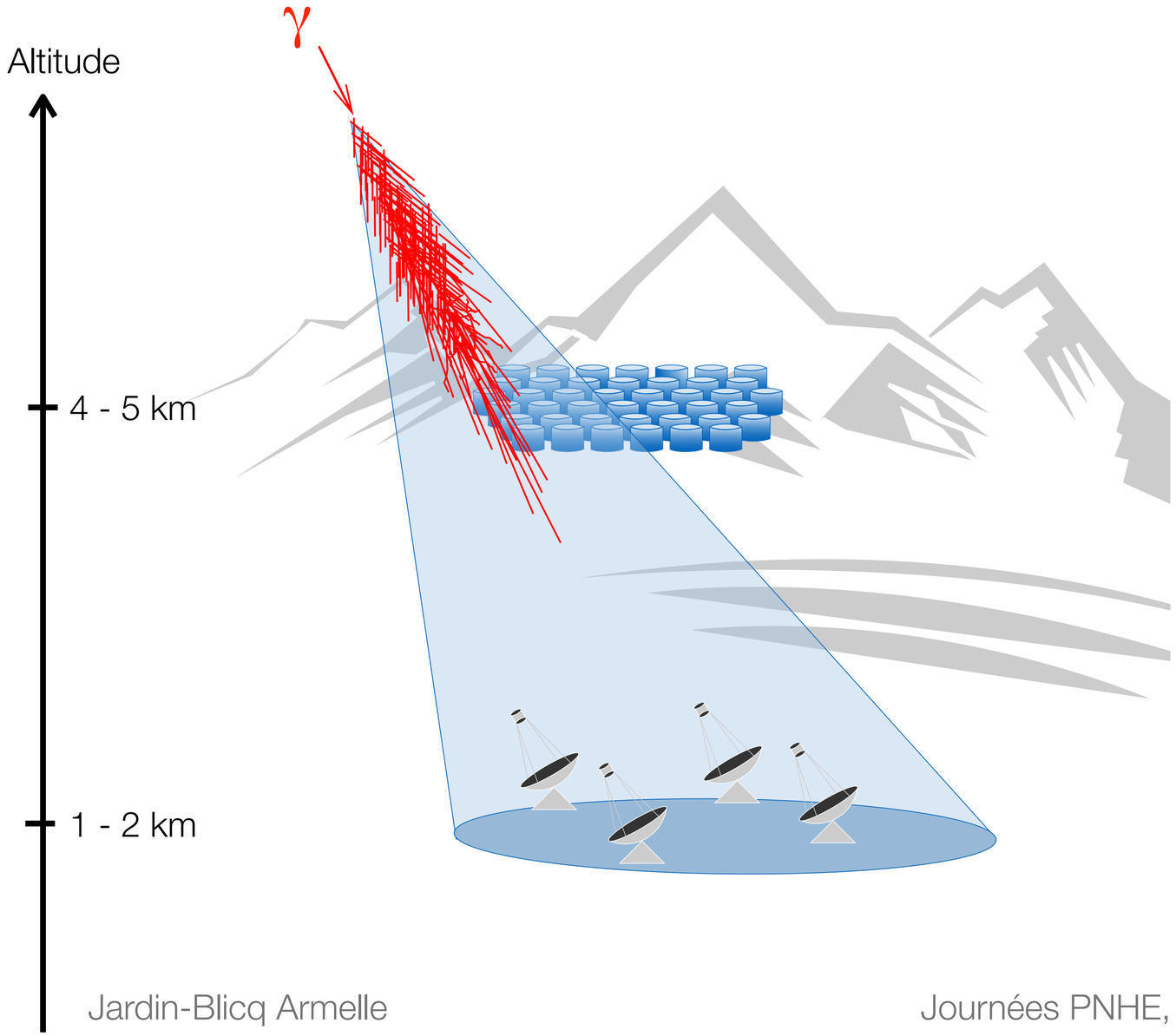


CTAO performance (prod5, v0.1)

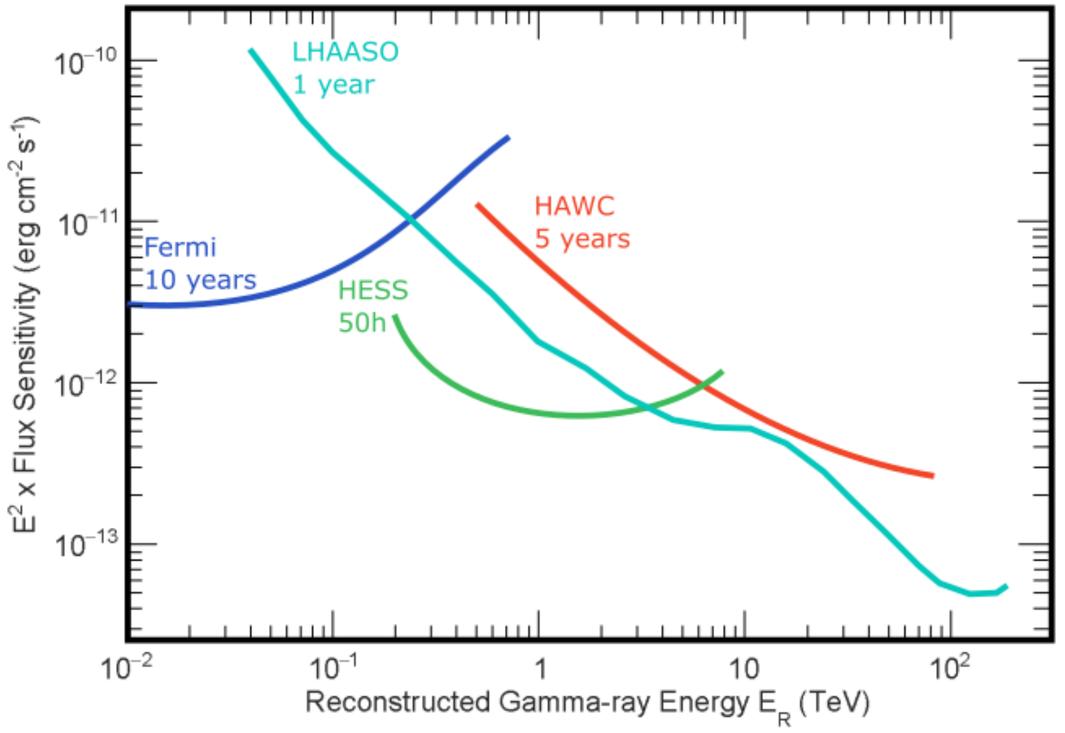


Sensitivity

Complementary in terms of energy range and sensitivity

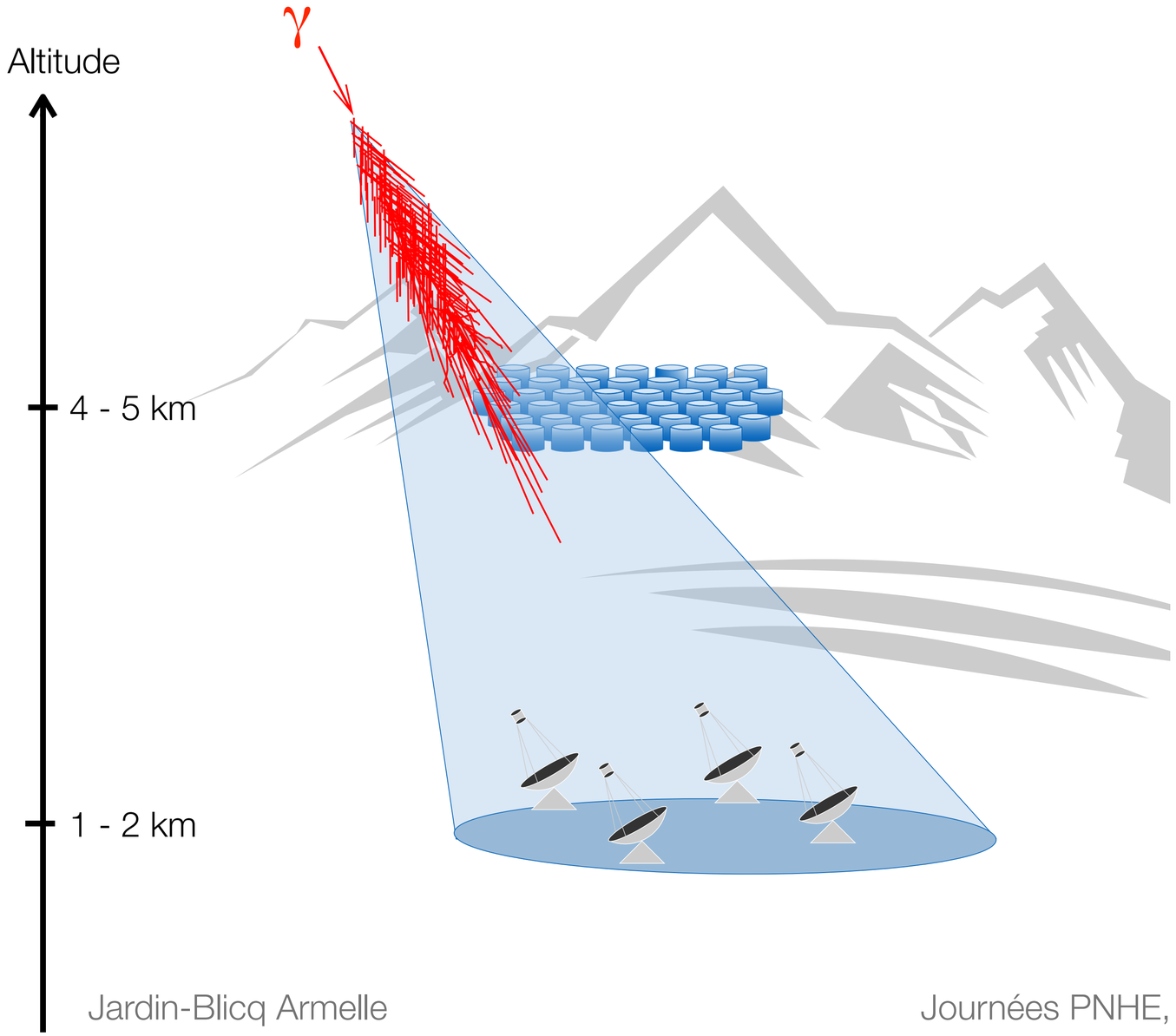


CTAO performance (prod5, v0.1)

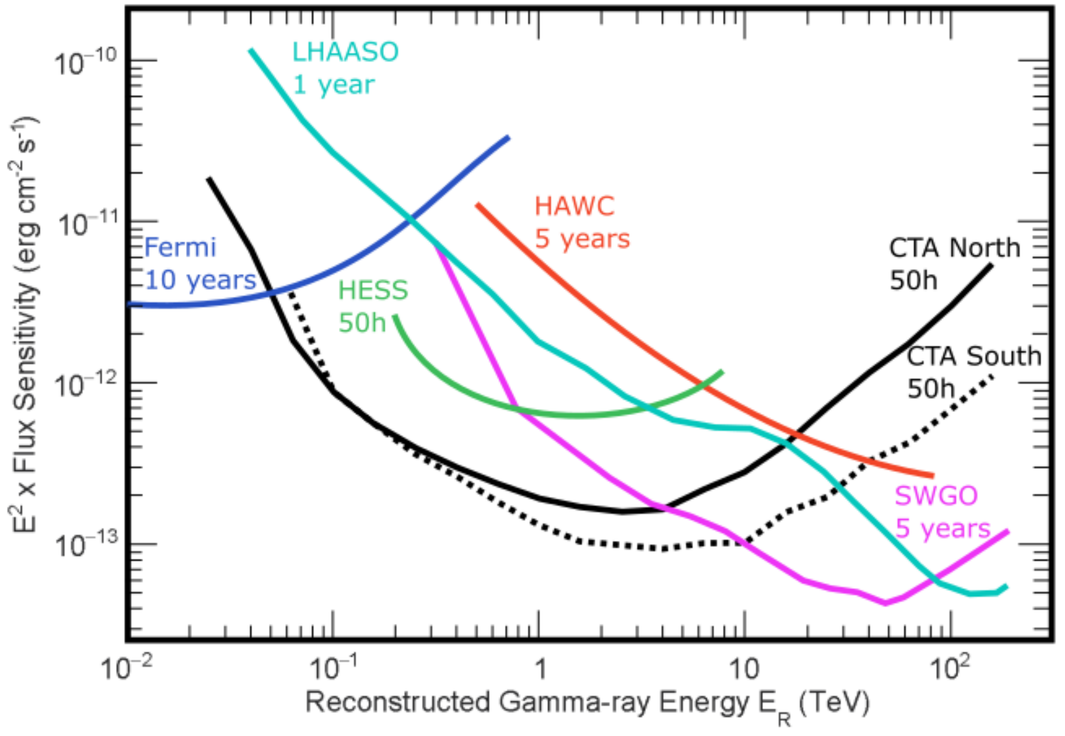


Sensitivity

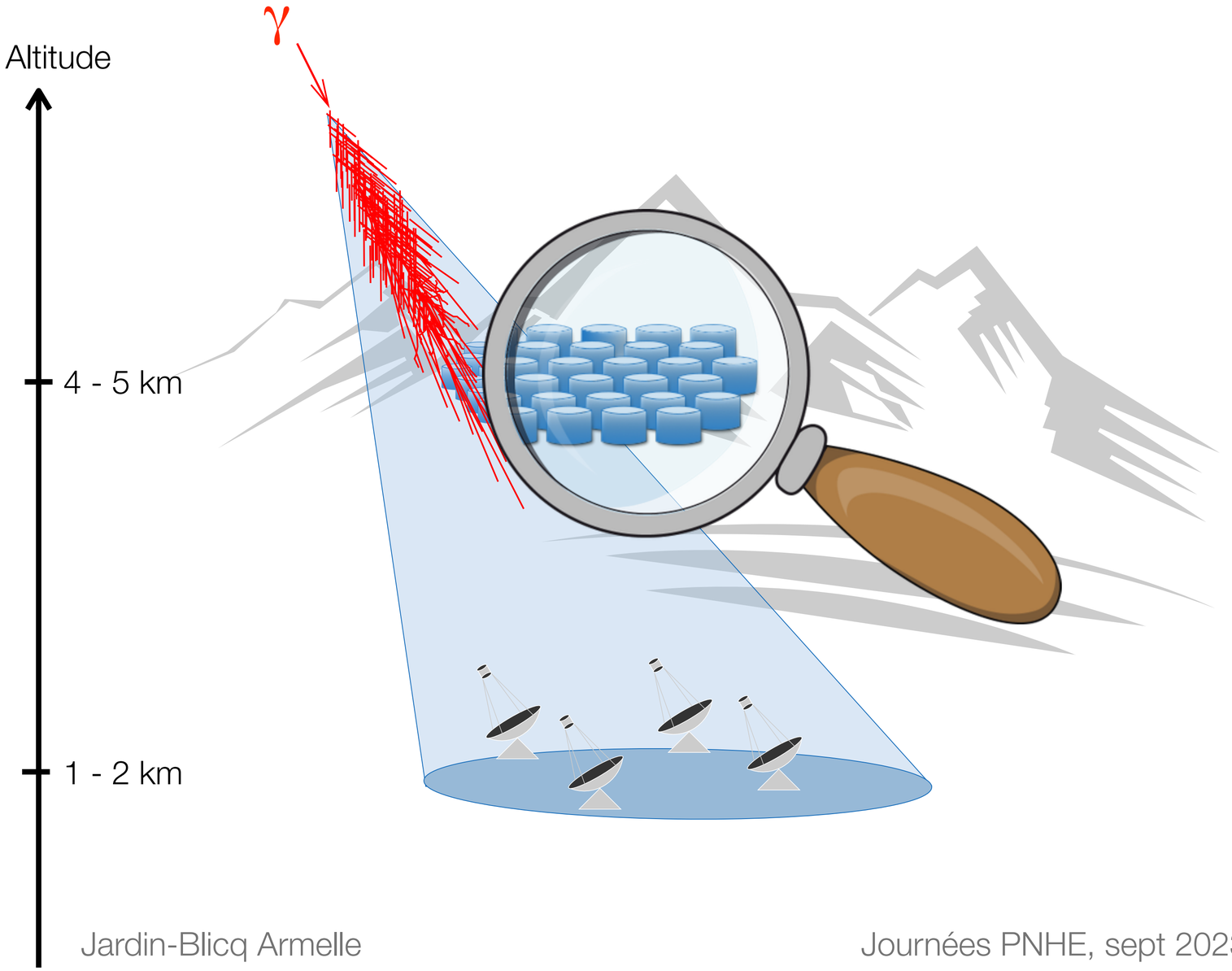
Complementary in terms of energy range and sensitivity



CTAO performance (prod5, v0.1)



Zoom on Water Cherenkov Detectors



The High Altitude Water Cherenkov observatory (HAWC)

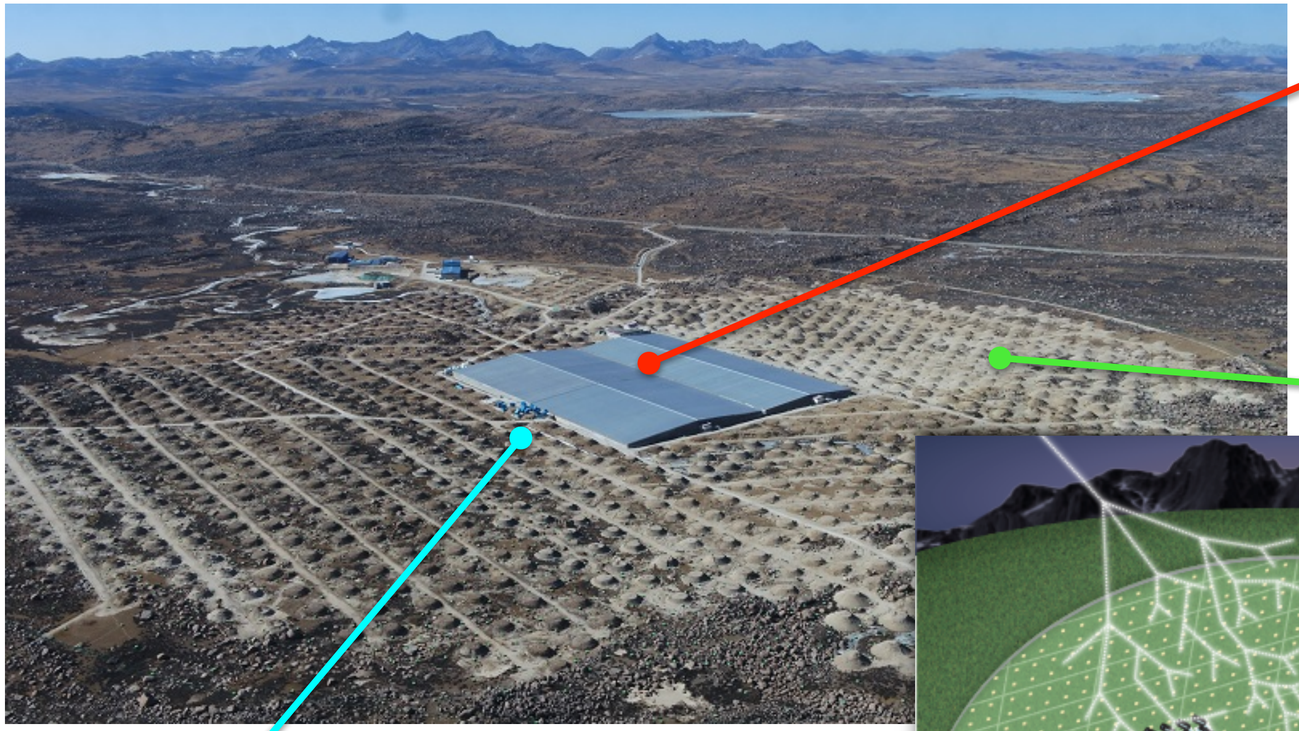
Latitude : 19N
Altitude : 4100 m
Area : 22 000 m^2, 60% coverage
Trigger rate : ~25KHz
Energy range : ~100 GeV - ~100 TeV

Credits: HAWC collaboration

300 light tight tanks
—> 200 kL of purified water
—> 1x10’ PMT and 3x8'PMTs

The Large High Altitude Air Shower Observatory (LHAASO)

The LHAASO collaboration



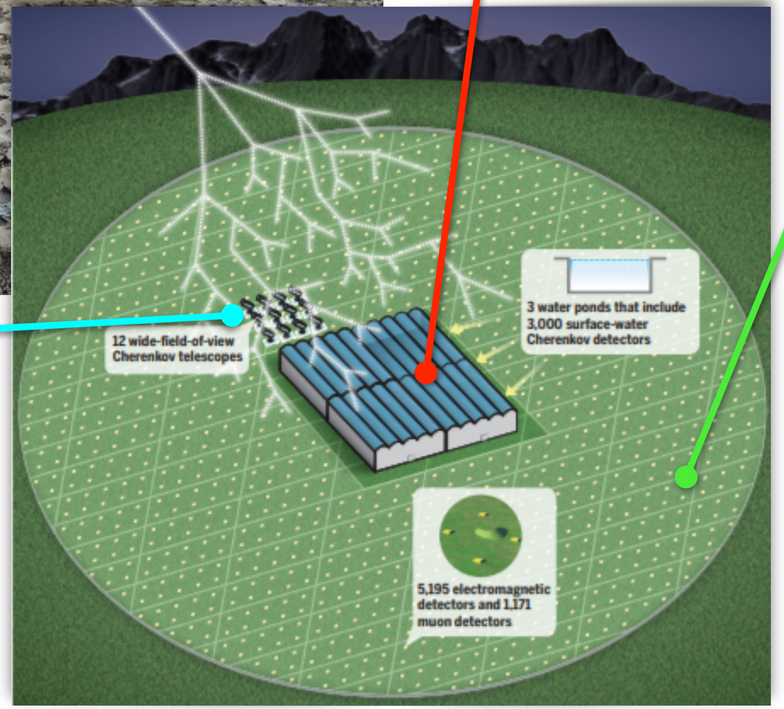
WCDA

(Water Cherenkov Detector Array)

Area : 78 000 m^2, 100% coverage

Water : 4.4m height

Energy range : ~100 GeV - ~20 TeV



IHEP, credits : MUKESH MOHANAN/CHINA DAILY

KM2A

(Kilometre square array)

Area : 1 km^2

5195 electomagnetic detectors

($1m^2$ plastic scintillators)

1171 muon detectors ($36\ m^2$ WCD units under 2.5 m of soil)

Energy range : ~20 TeV - a few PeV

WFCTA

(Wide-Field Cherenkov Telescope Array)

5 m^2 mirrors (vs. 107 m^2 HESS-I)

0.5° pixels (vs. 0.15° HESS-I)

16°×16° field of view (vs 5° HESS-I)

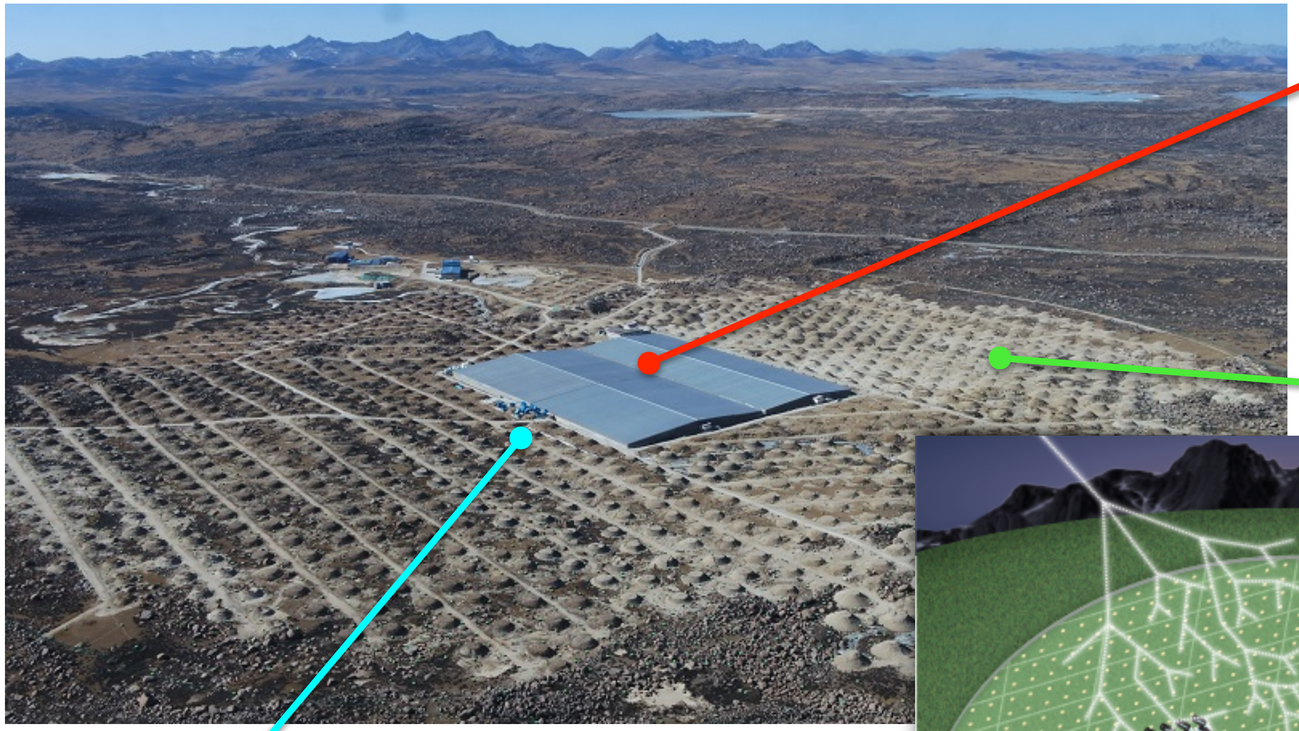
—> performance not similar to IACTs

Latitude : 29N

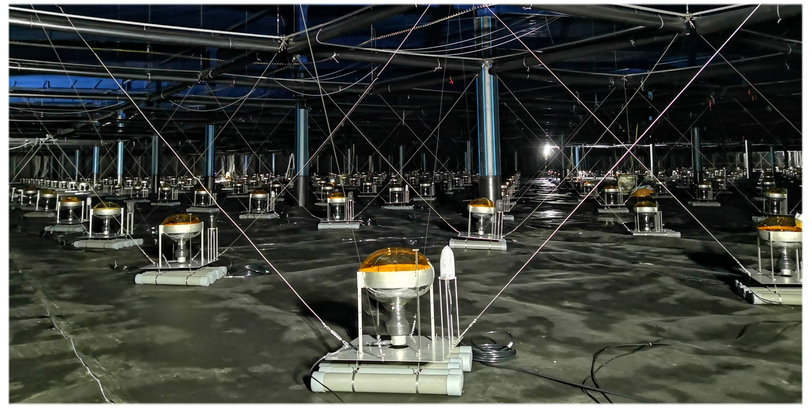
Altitude : 4400 m

The Large High Altitude Air Shower Observatory (LHAASO)

The LHAASO collaboration, Ma et al 2022

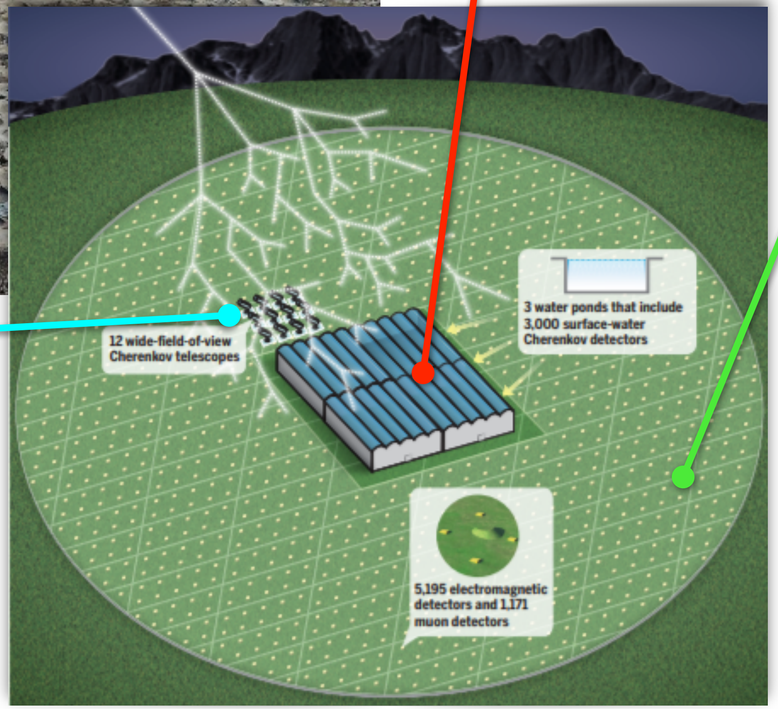


WCDA



KM2A

WFCTA

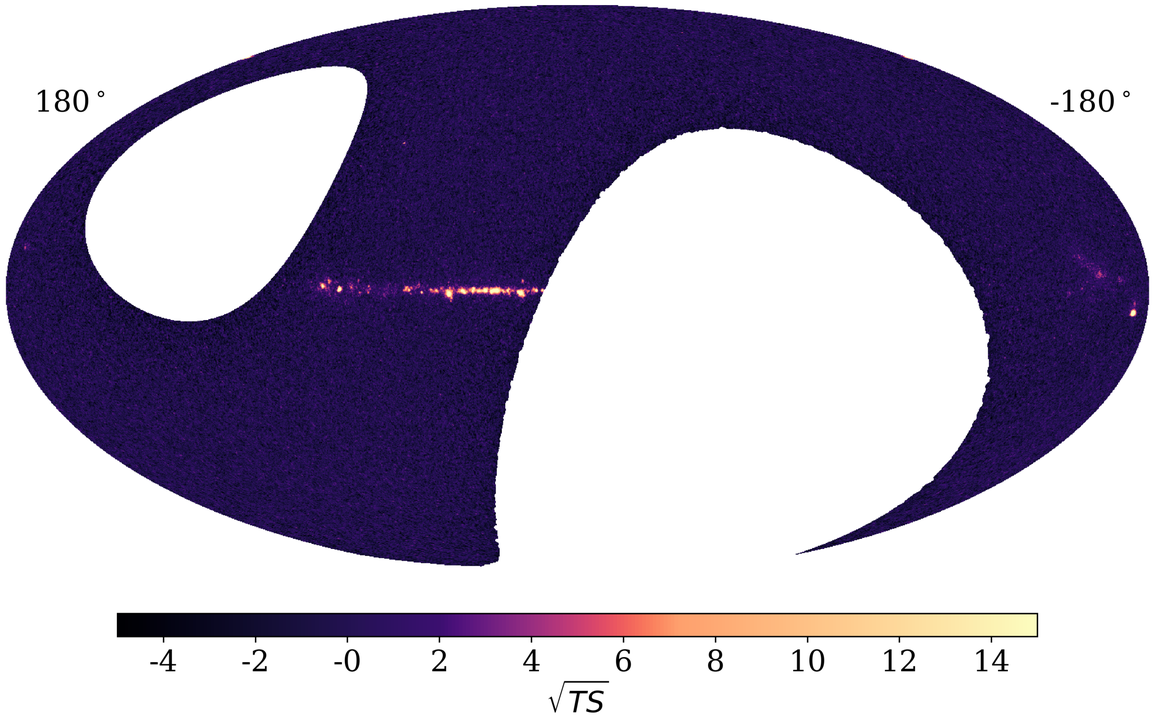


IHEP, credits : MUKESH MOHANAN/CHINA DAILY

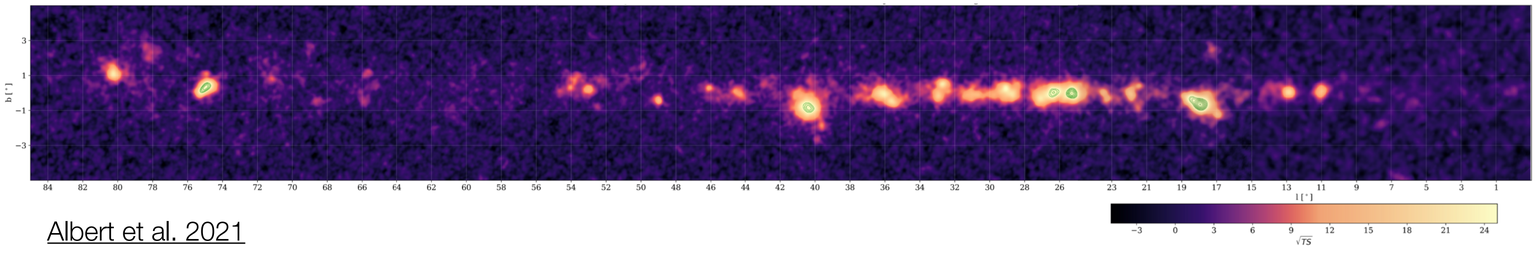
Latitude : 29N
Altitude : 4400 m

Catalogue of VHE and UHE ɣ-ray sources - search for PeVatrons

65 sources reported by HAWC, including
9 sources with E > 56 TeV, 3 sources > 100 TeV



1910 days

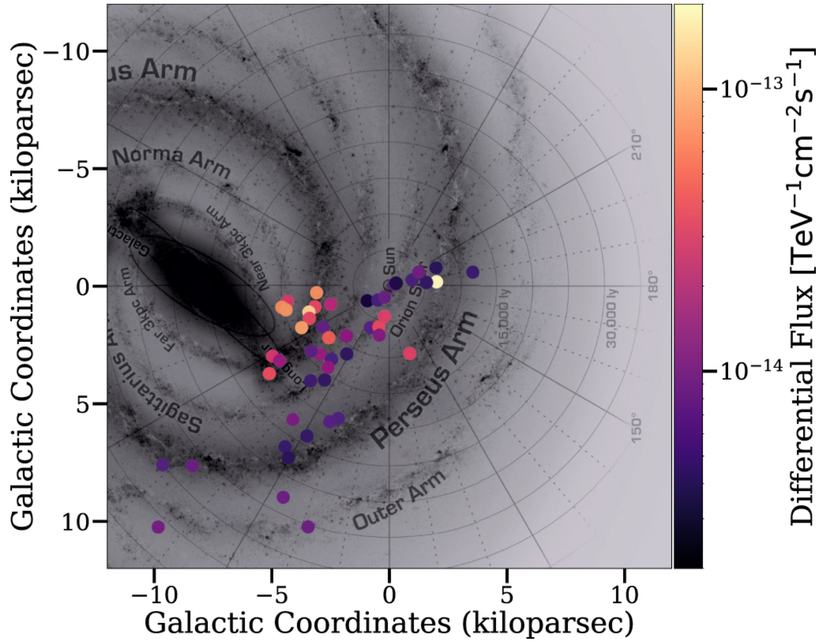


Albert et al. 2021

THE ASTROPHYSICAL JOURNAL

3HWC: The Third HAWC Catalog of Very-high-energy Gamma-Ray Sources

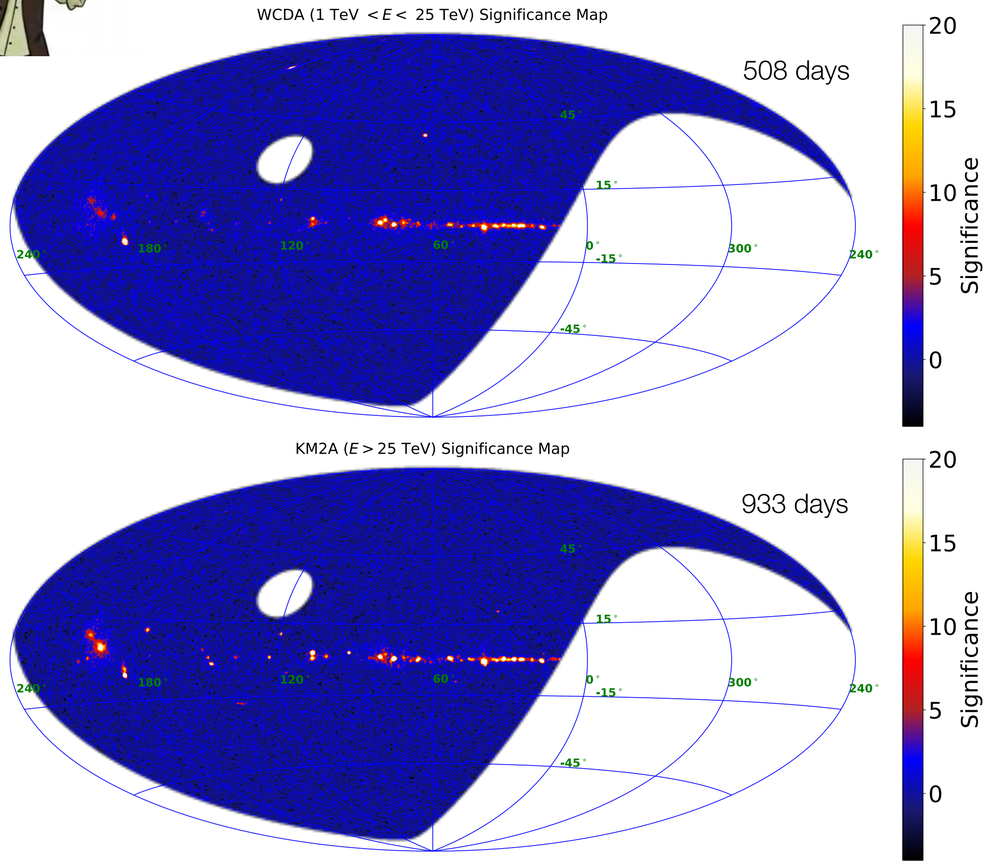
A. Albert[1], R. Alfaro[2], C. Alvarez[3], J. R. Angeles Camacho[2], J. C. Arteaga-Velázquez[4], K. P. Arunbabu[5], D. Avila Rojas[2], H. A. Ayala Solares[6], V. Baghmanyan[7], E. Belmont-Moreno[2]



49 HAWC sources are spatially associated with a pulsar (with available distance)

Catalogue of VHE and UHE ɣ-ray sources - search for PeVatrons

The First LHAASO Catalog of Gamma-Ray Sources



90 sources reported by LHAASO,
43 of them detected at UHE (> 100 TeV)

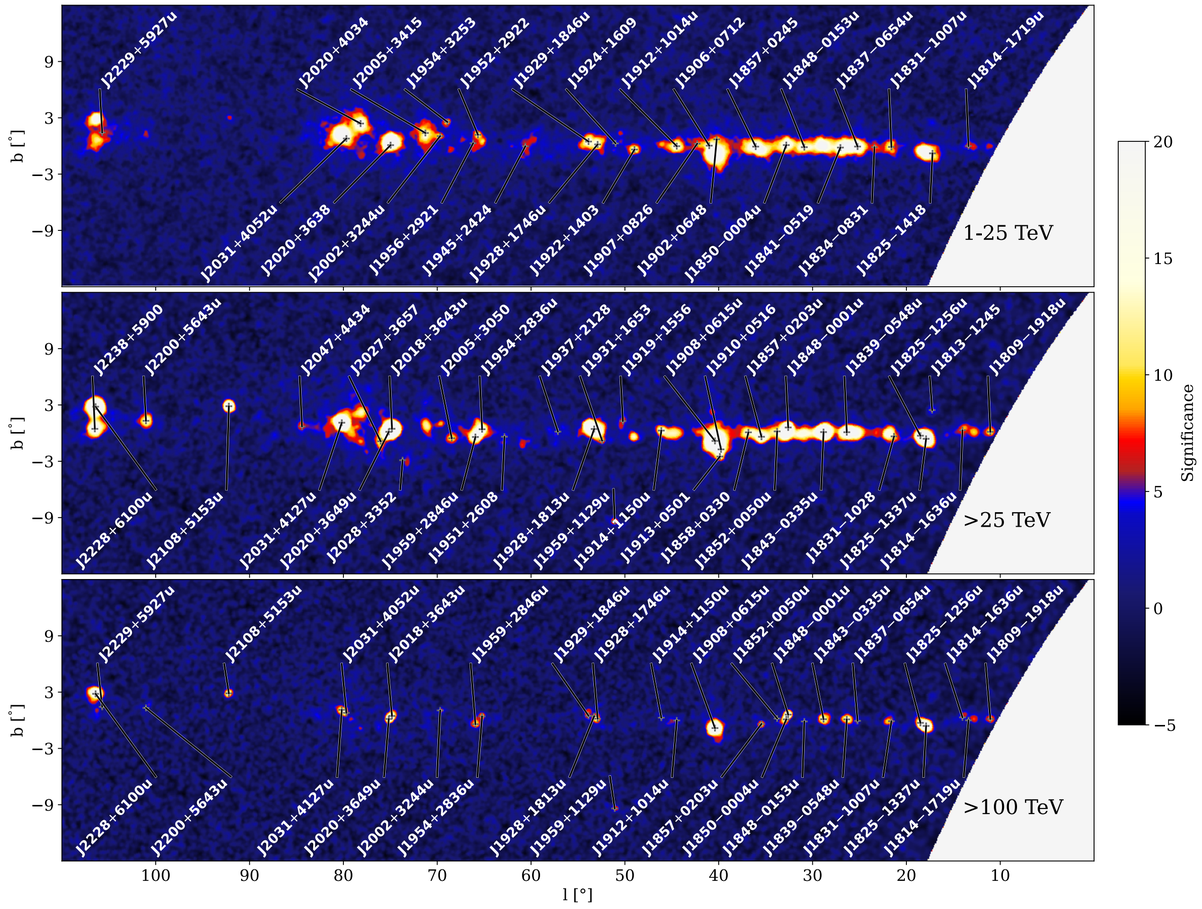
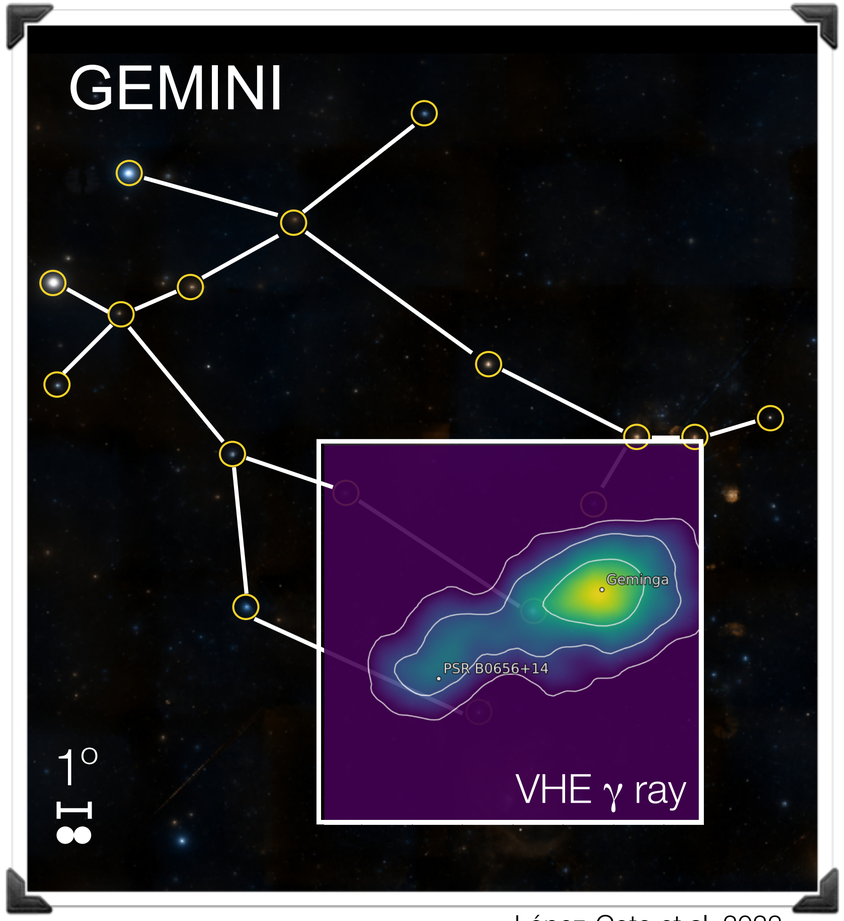


Figure 1. Significance maps of the region monitored by LHAASO. A point test source with a spectral in of 2.6 for WCDA data and 3.0 for KM2A data is used.

Cao et al. 2023

(Very) extended sources

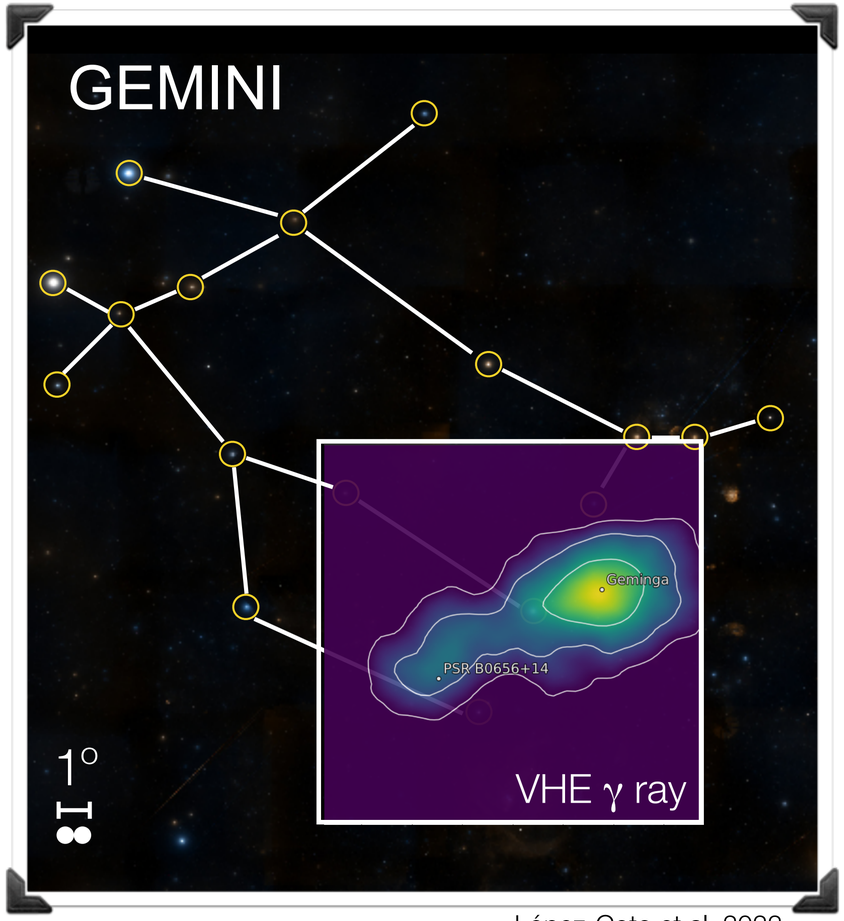
New class of VHE ɣ-ray sources : pulsar halo



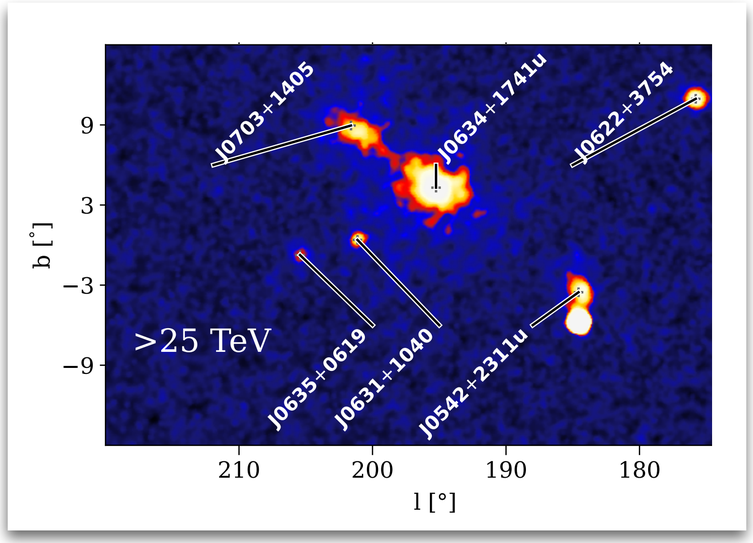
López-Coto et al. 2022

(Very) extended sources

New class of VHE ɣ-ray sources : pulsar halo



López-Coto et al. 2022

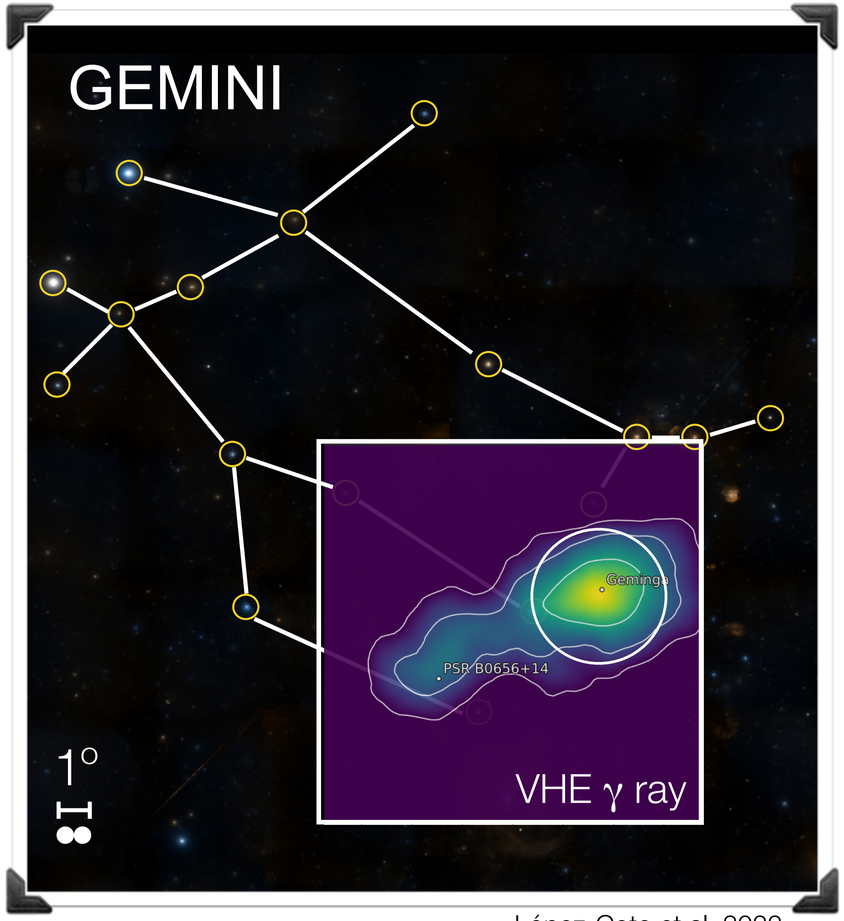


Cao et al. 2023

(Very) extended sources

Complementary to detect and analyse extended sources

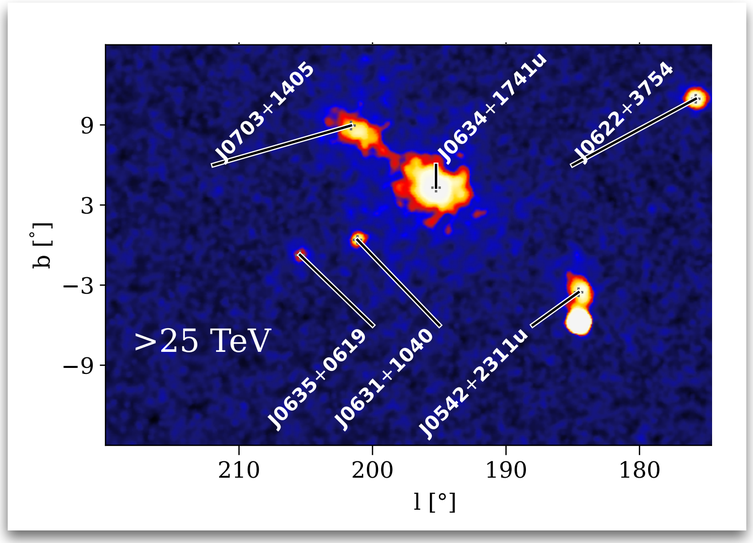
New class of VHE γ-ray sources : pulsar halo



López-Coto et al. 2022

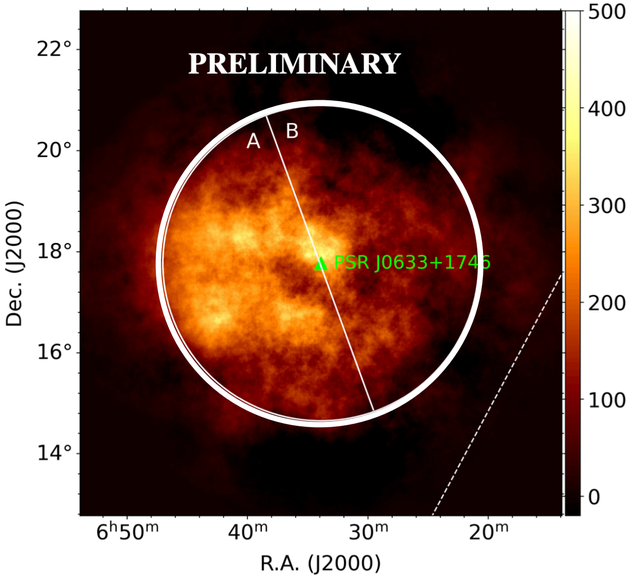
Challenging for Cherenkov telescopes (but not impossible)

-> Detection of Geminga by H.E.S.S. (HESS collaboration, 2023)



Cao et al. 2023

Mitchell et al. 2021



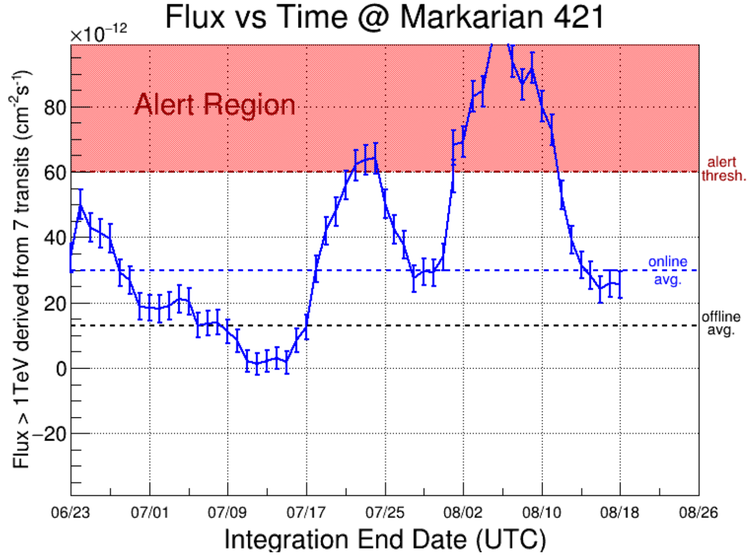
Transient events

[Previous | Next | ADS]

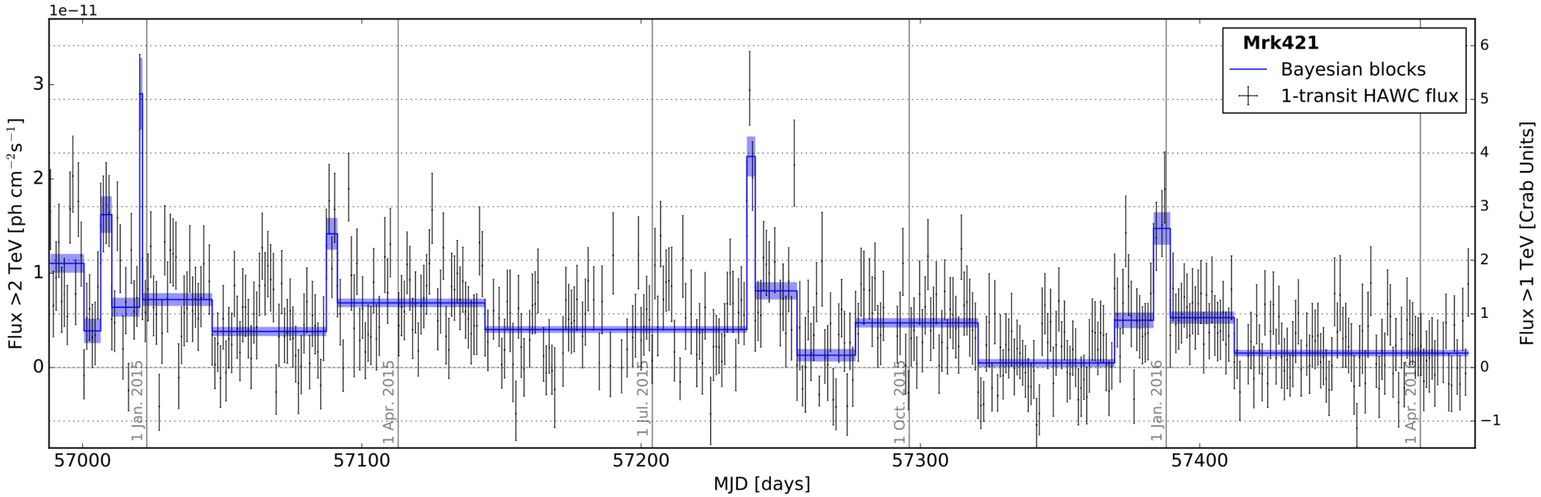
New Enhanced Activity of Mrk 421 measured by HAWC

ATel #13875; *Jose Andres Garcia-Gonzalez (IF-UNAM, jagarcia@fisica.unam.mx, ITESM-EIC, anteus79@tec.mx), Israel Martinez (UMD, imc@umd.edu) on behalf of the HAWC Collaboration*
*on **18 Jul 2020; 03:52 UT***
Credential Certification: JosÃÂ© AndrÃÂ©s GarcÃÂa-GonzÃÂ¡lez (jagarcia@fisica.unam.mx)

Subjects: Gamma Ray, TeV, AGN, Blazar

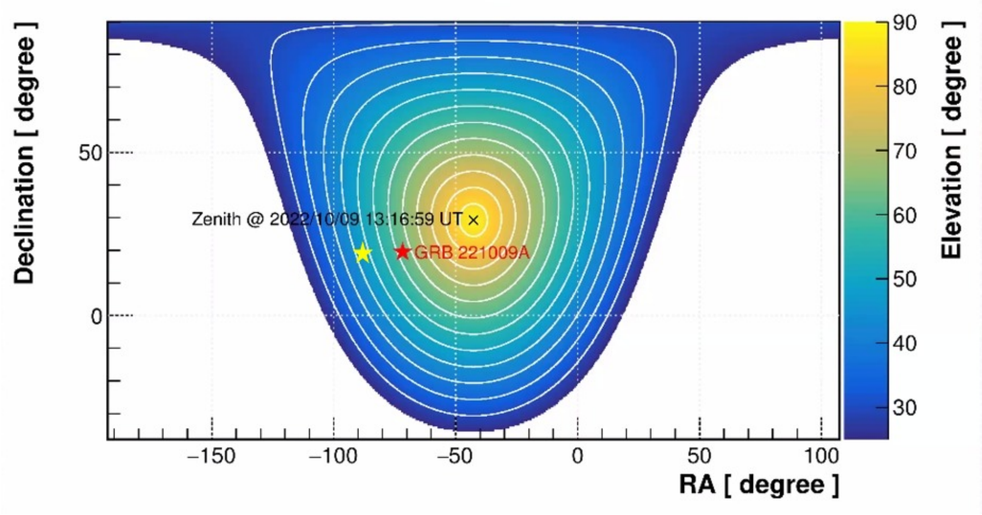


Abeysekara et al, 2017

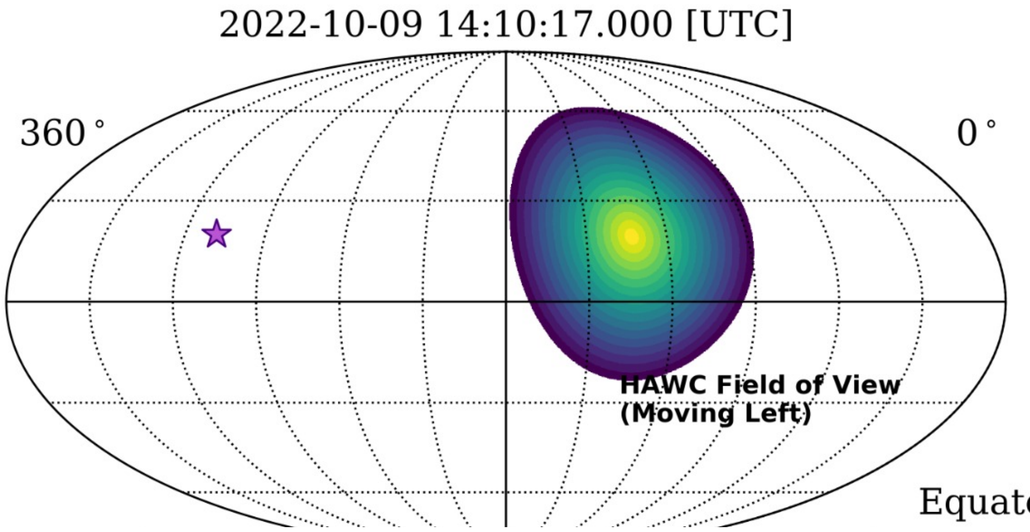


Complementary to detect and follow up transient events

Transient events

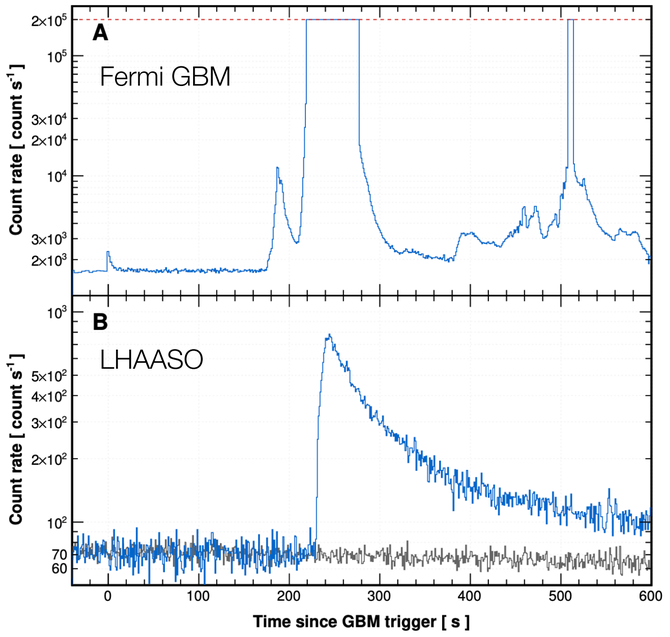


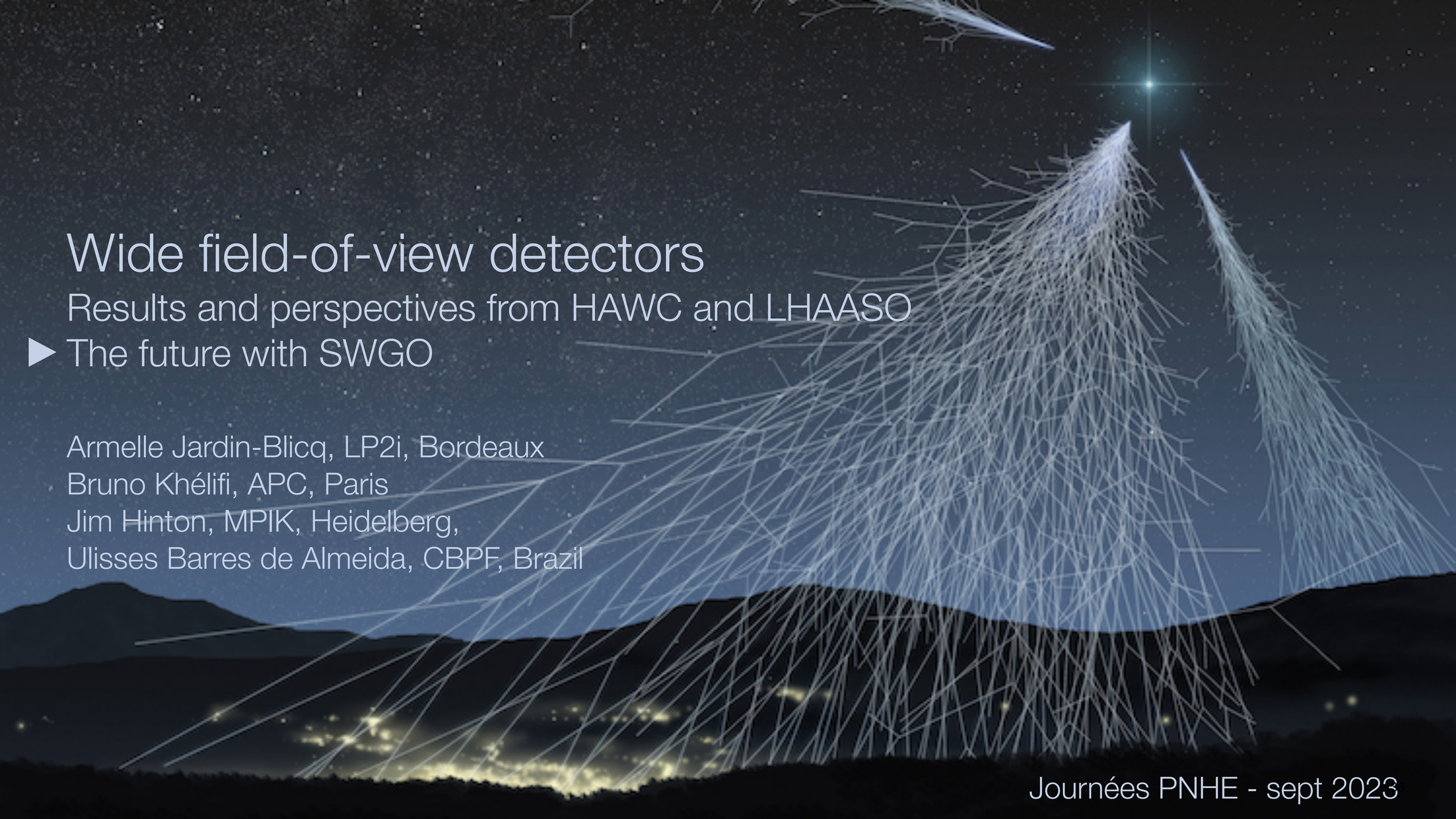

```
TITLE:   GCN CIRCULAR
NUMBER:  32677
SUBJECT: LHAASO observed GRB 221009A with more than 5000 VHE photons up to around 18 TeV
DATE:    22/10/11 09:21:54 GMT
FROM:    Judith Racusin at GSFC  <judith.racusin@nasa.gov>

Yong Huang, Shicong Hu, Songzhan Chen,  Min Zha, Cheng Liu, Zhiguo Yao and
Zhen Cao report on behalf of the LHAASO experiment

We report the observation of GRB 221009A, which was detected by Swift (Kennea
et al. GCN #32635), Fermi-GBM (Veres et al. GCN #32636, Lesage et al. GCN #32642),
Fermi-LAT (Bissaldi et al. GCN #32637), IPN (Svinkin et al. GCN #32641) and so on.
```



More than 64,000 photons (> 0.2 TeV) detected within the first 50 minutes

Complementary to detect and follow up transient events





Wide field-of-view detectors

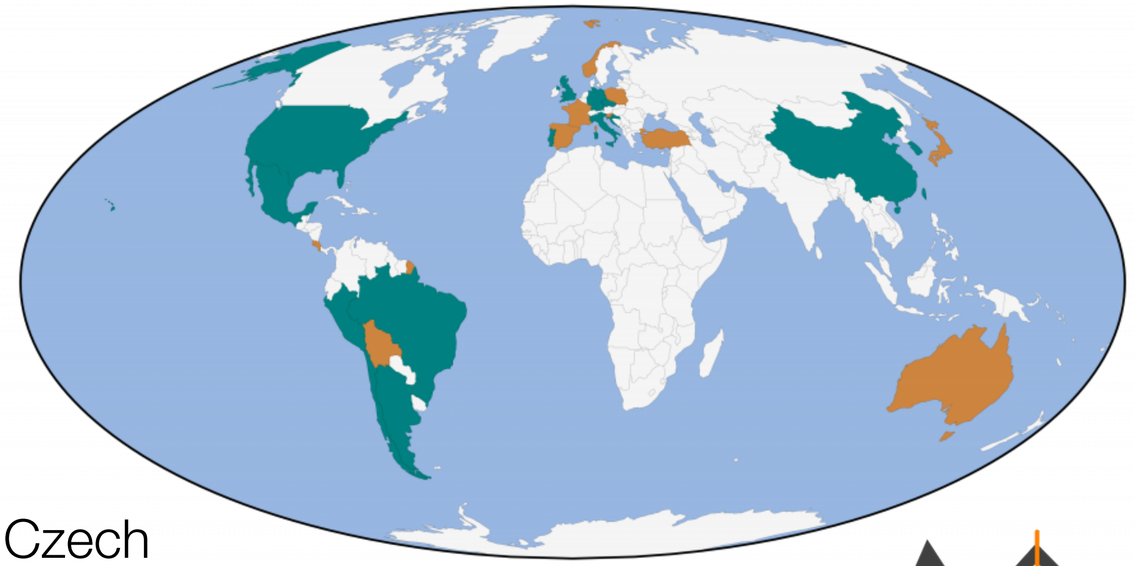
Results and perspectives from HAWC and LHAASO

▶ The future with SWGO

Armelle Jardin-Blicq, LP2i, Bordeaux
Bruno Khélifi, APC, Paris
Jim Hinton, MPIK, Heidelberg,
Ulisses Barres de Almeida, CBPF, Brazil

SWGO : The Southern Wide-field Gamma-ray Observatory

South We GO !



The SWGO collaboration

- Founded in 2019
- 80 research institutions from 14 countries
- **Full partner institutes** in Argentina, Brazil, Chile, Czech Republic, Germany, Italy, Mexico, Peru, Portugal, South Korea, Croatia, China, the UK, and the USA
- **Supporting scientists** in 10 additional countries including France

SWGO
The Southern Wide-field Gamma-ray Observatory

Spokesperson : Jim Hinton, MPIK Heidelberg, Germany

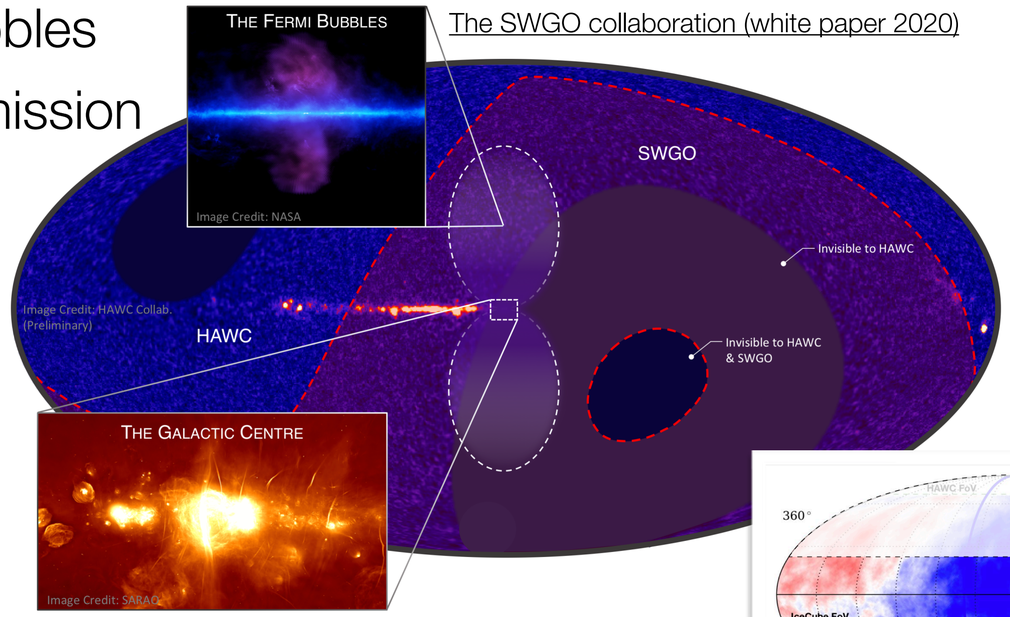
Vice-spokesperson : Petra Hüntemeyer, MTU, Michigan, US
Ulisses Barres de Almeida, CBPF, Brazil

SWGO - Science cases

Transient Sources, GRB
- Prompt phase
- Alert CTA

(very) Extended emission
- Pulsar halos
- Fermi bubbles
- Diffuse emission

The SWGO collaboration (white paper 2020)

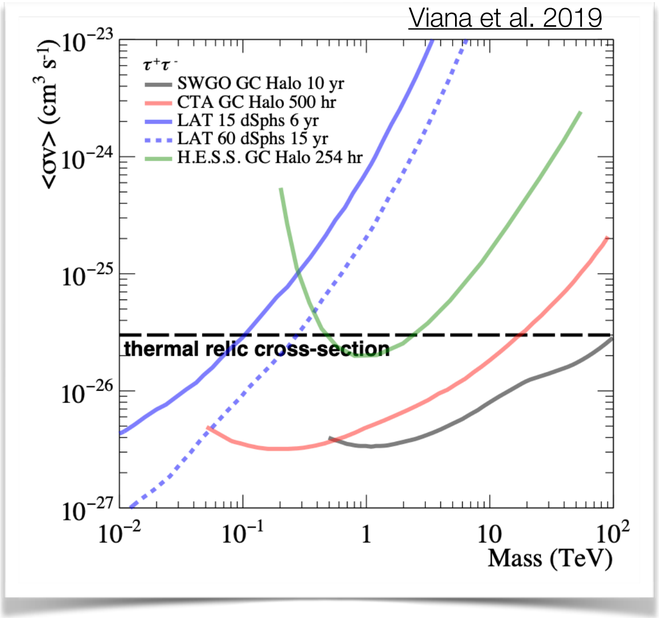


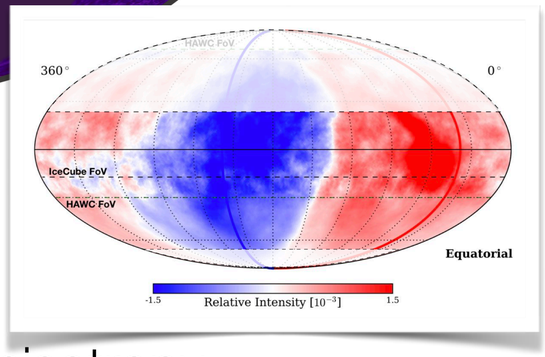
Galactic PeVatrons

The southern sky and the Galactic center region

Dark Matter search in the galactic halo

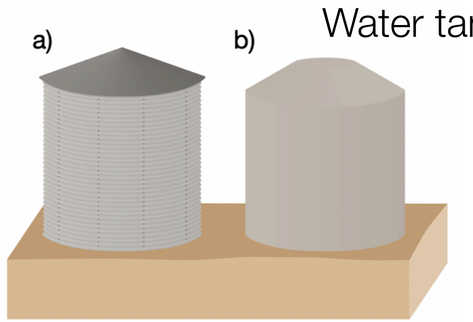
Viana et al. 2019



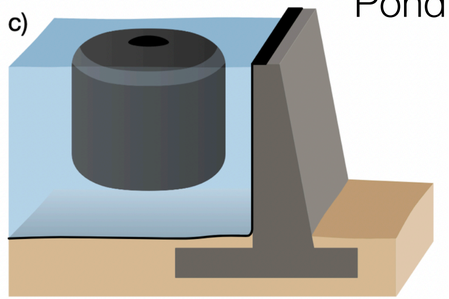


Cosmic ray anisotropy

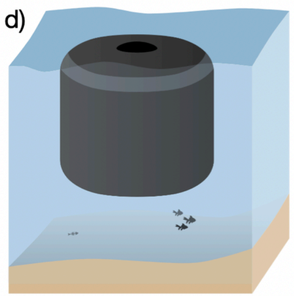
SWGO - Proposed designs



Water tanks



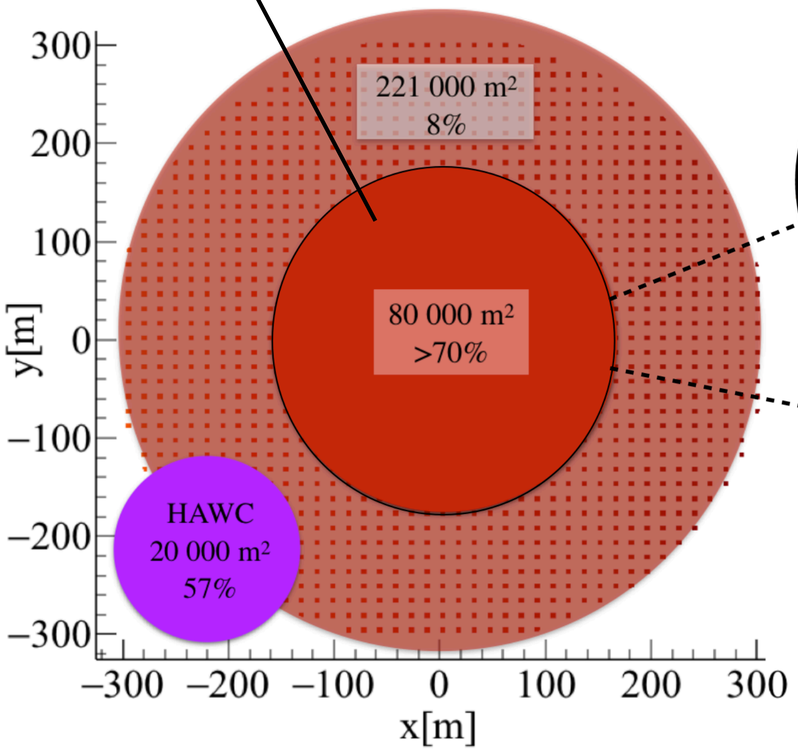
Pond

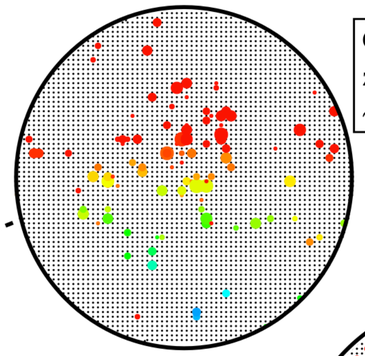


Natural or artificial lake

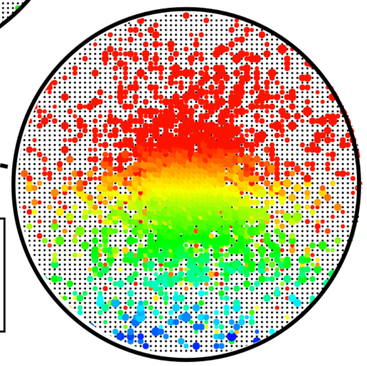
Hinton et al. (ICRC 2021)

Comparable to LHAASO





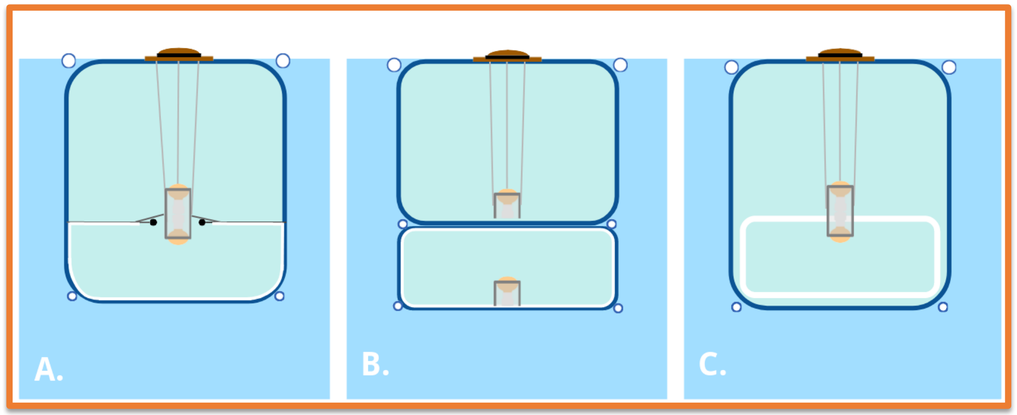
Gamma-ray 0.2 TeV
zenith angle 20°
~100 units hit



Gamma-ray 2.0 TeV
zenith angle 20°
~1000 units hit

The SWGO collaboration (white paper 2020)

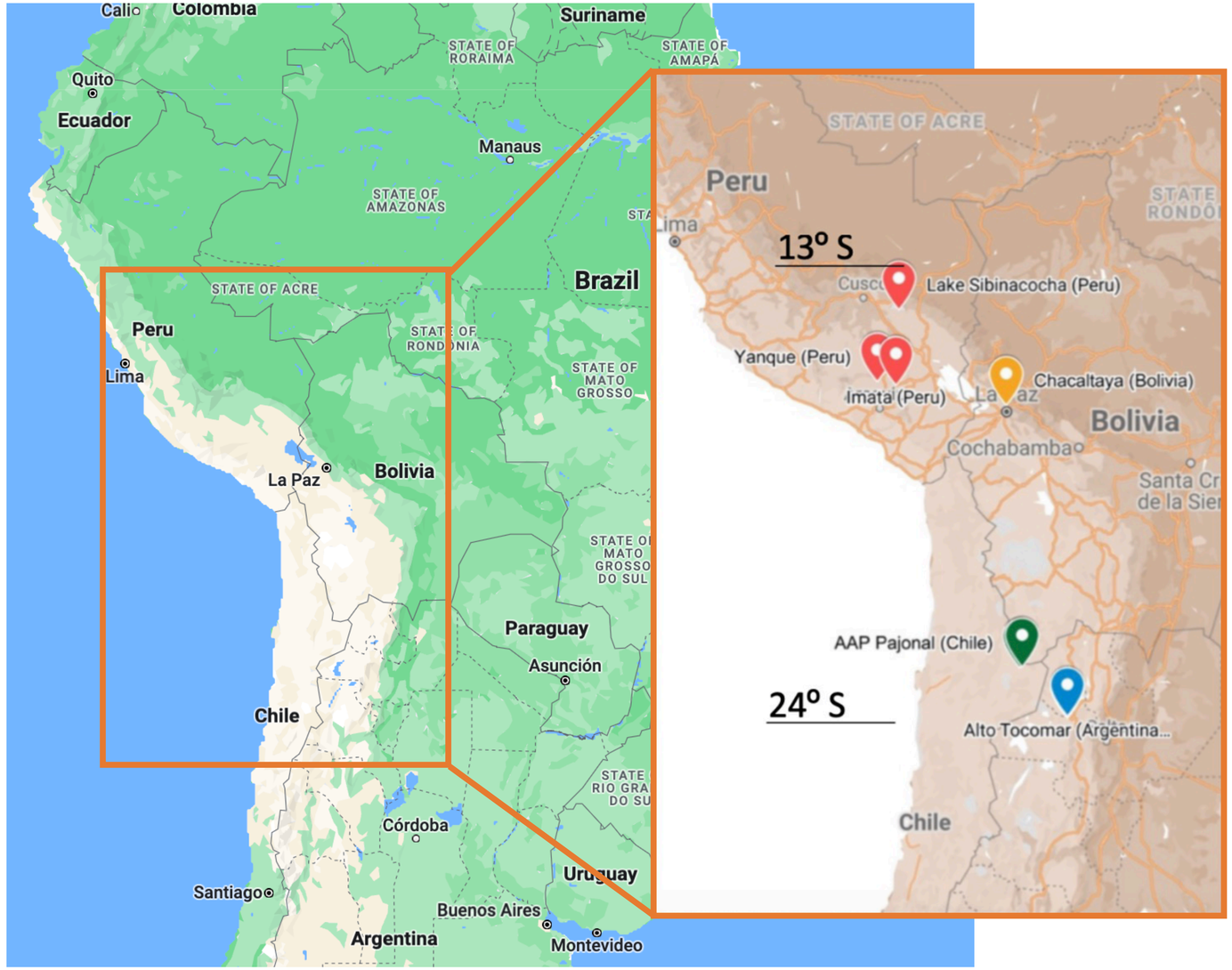
Dual chamber option for muon tagging



Credit : Richard White

SWGO - Site candidates

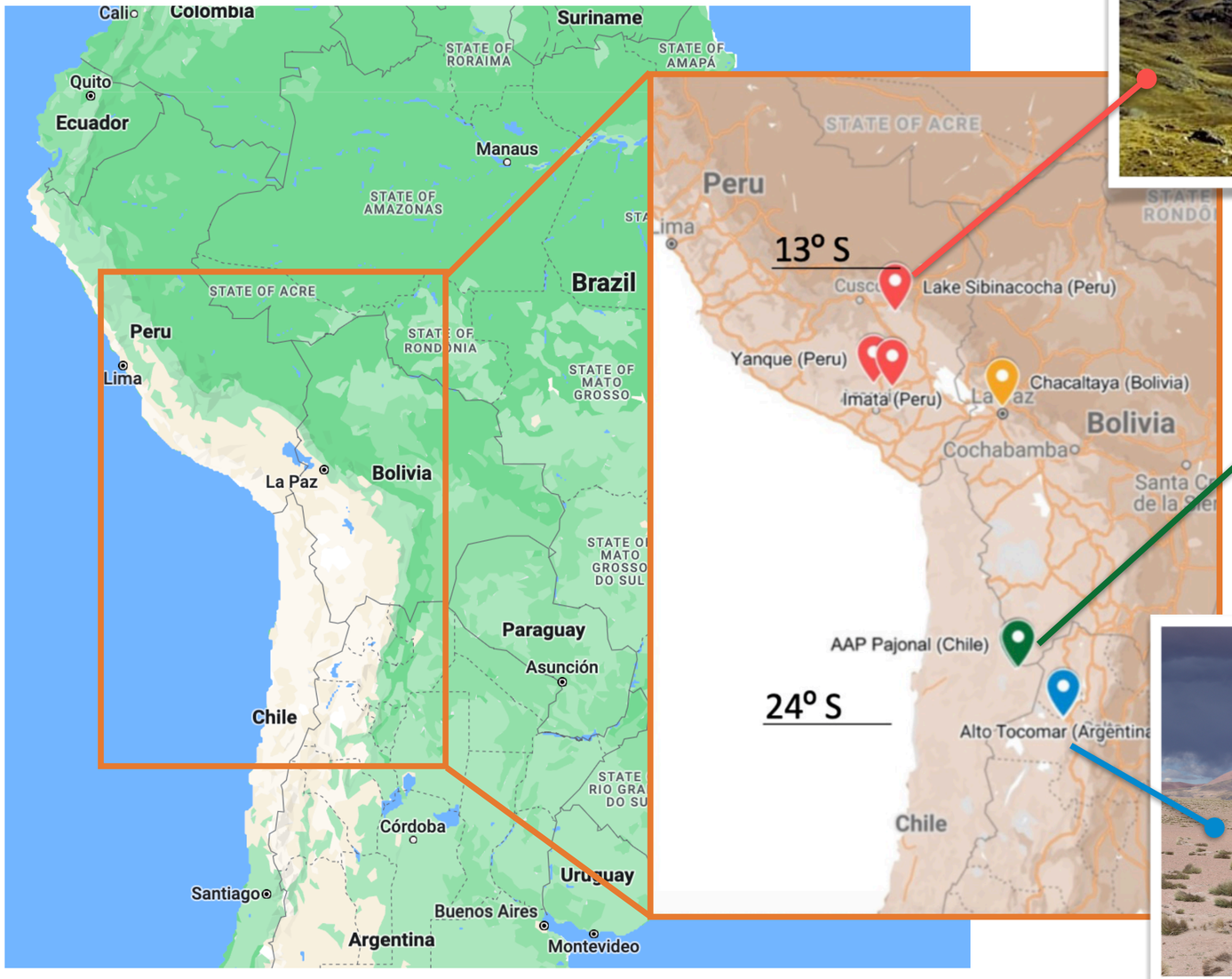
The SWGO collaboration



- 10^{o} > latitude > 30^{o} South
  -> Galactic center region
- altitude > 4400 m
  -> low energy threshold
- available area of ~1 km^2
- Accessibility
- Security/risk concerns
- Cost
- …

SWGO - Site candidates

The SWGO collaboration

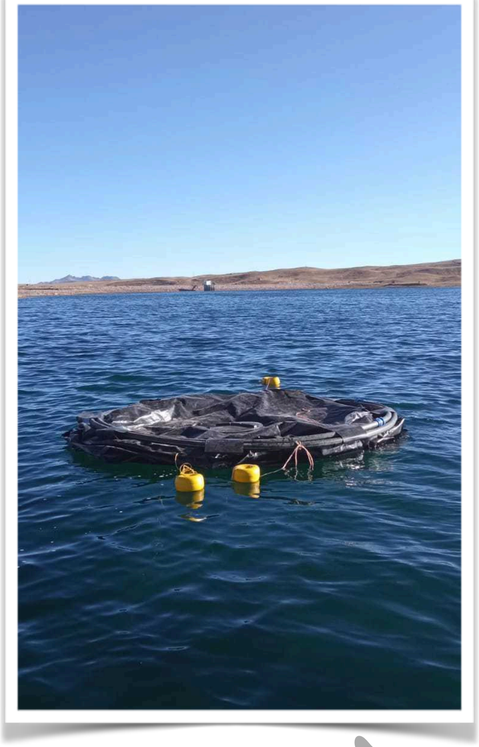


SWGO - Status

Politecnico di Milano, Italy. Grusovin et al, 2022

MPIK Heidelberg, Germany. Credit : Chistian Föhr

Sibinacocha lake, Peru. Credit : Erick Meza



Timeline :

2023 — Design phase

Prototypes

YOU ARE HERE

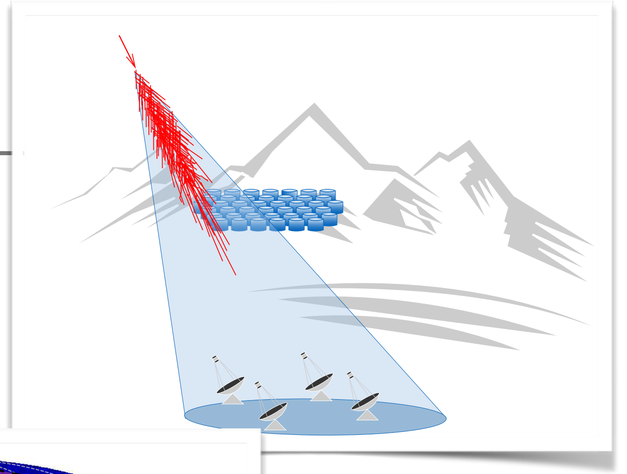
2024 — Concept Design Report document site + baseline decisions

2025 — Obtaining fundings

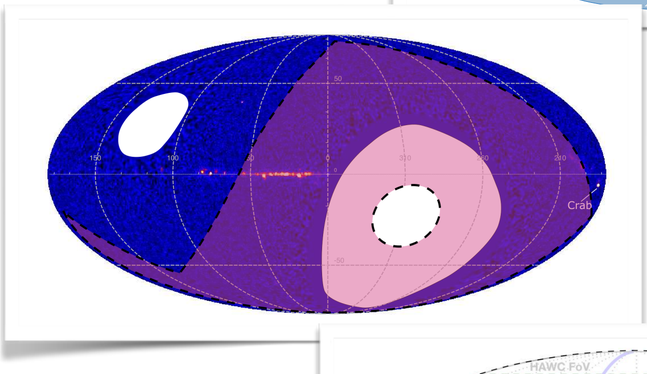
2026 — Building of an engineering array (1-10%)

2028 — Full construction phase

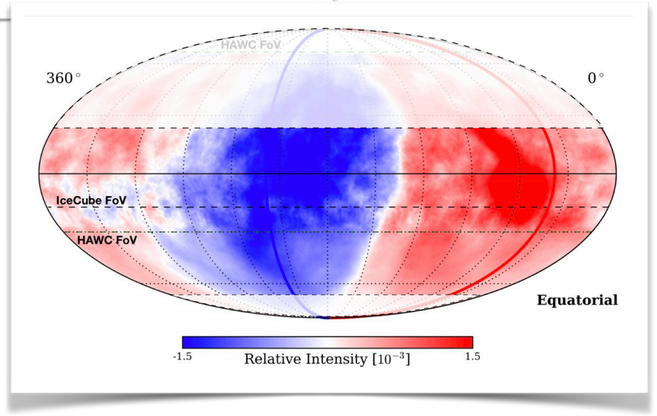
Conclusions



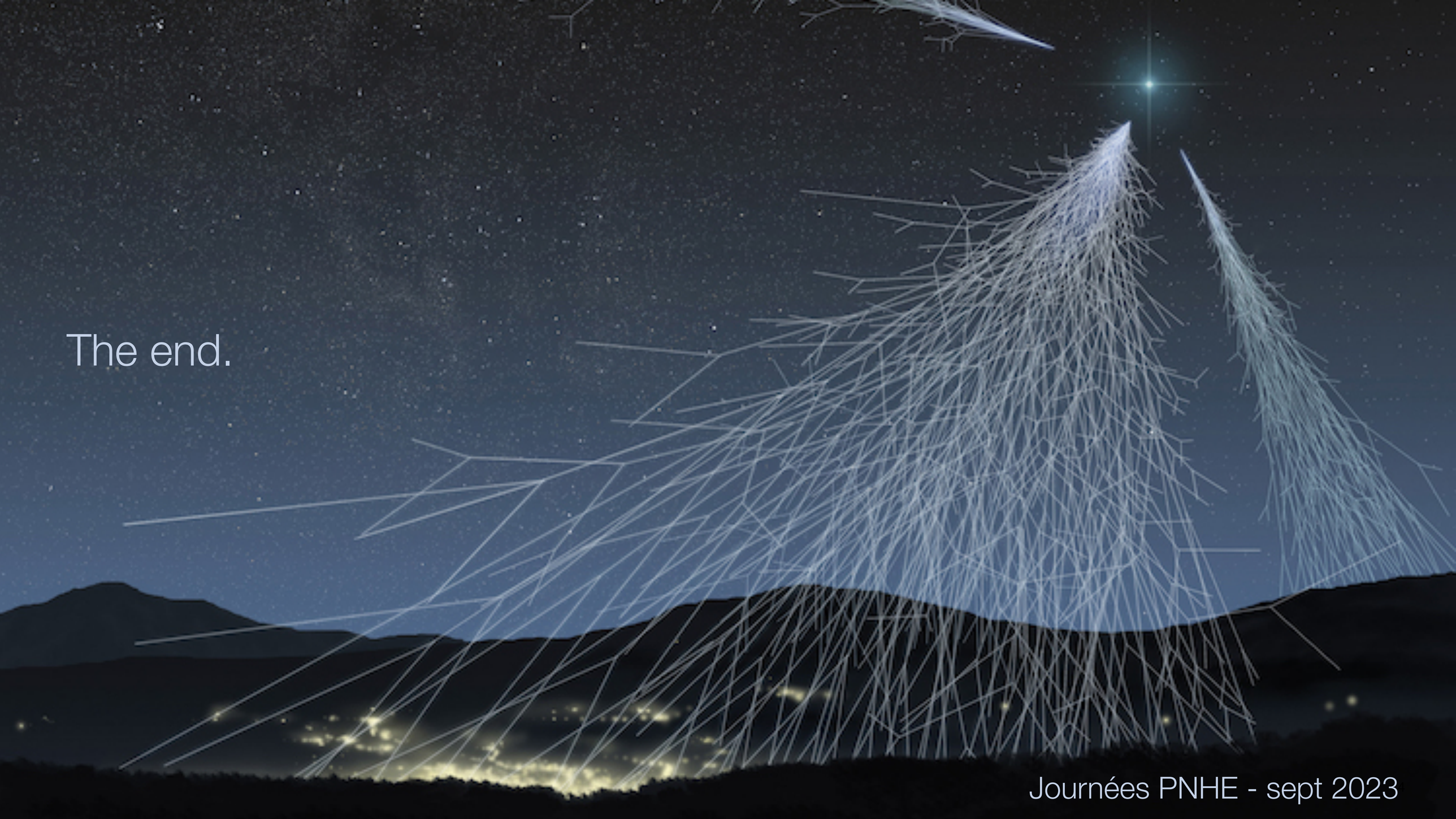
- Two complementary detection techniques to detect ɣ-rays from the ground
- HAWC and LHAASO covering the Northern hemisphere.
  SWGO will join in the Southern hemisphere in a few years.



- Complementarity with CTA, synergy with neutrinos detectors
- Strength of wide field of view instruments :
  - Extended (pulsar halos) and very extended (diffuse emission, fermi bubbles, CR anisotropy, galactic halo) emission
  - Transient events (prompt phase of GRB), alert other instruments
  - UHE coverage up to > 100TeV : study of PeVatrons

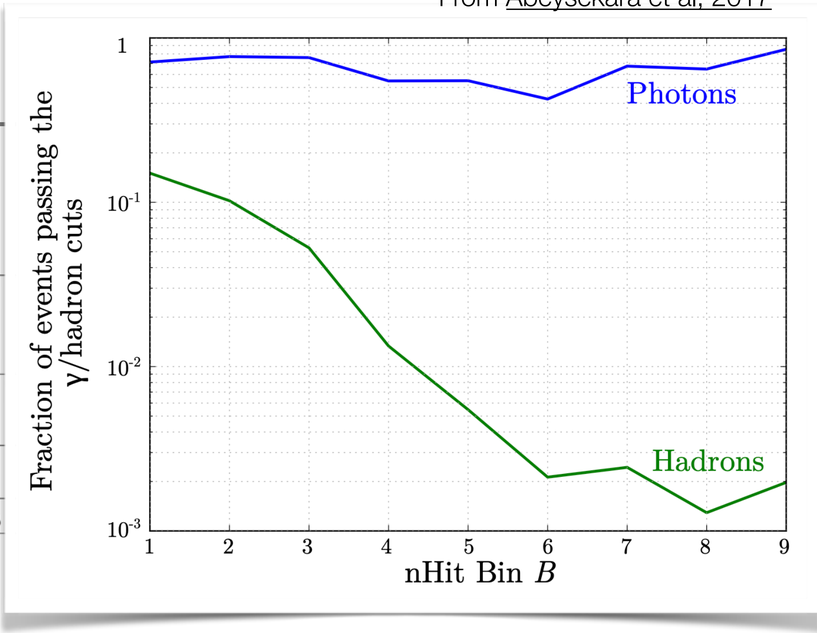


- Data policy : private for HAWC and LHAASO, SWGO's data public after a proprietary period

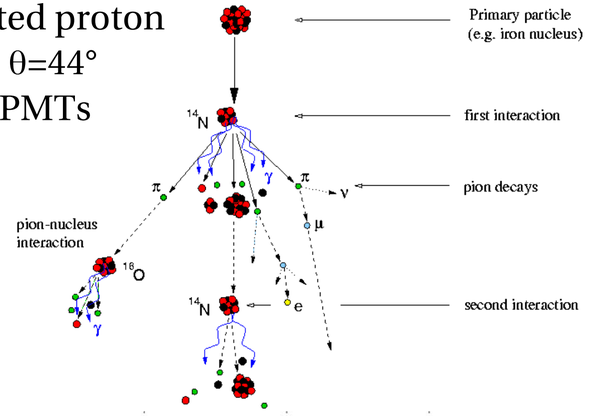

The end.
Journées PNHE - sept 2023

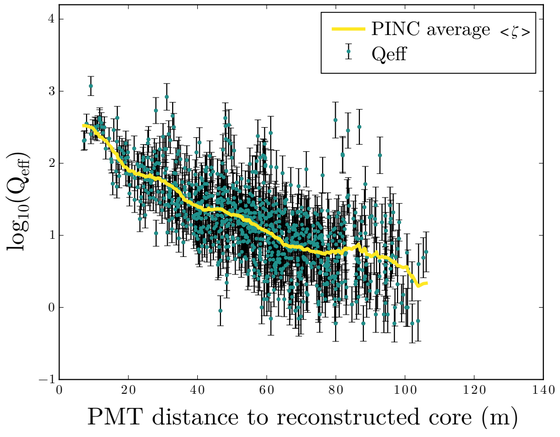
Gamma/hadron separation

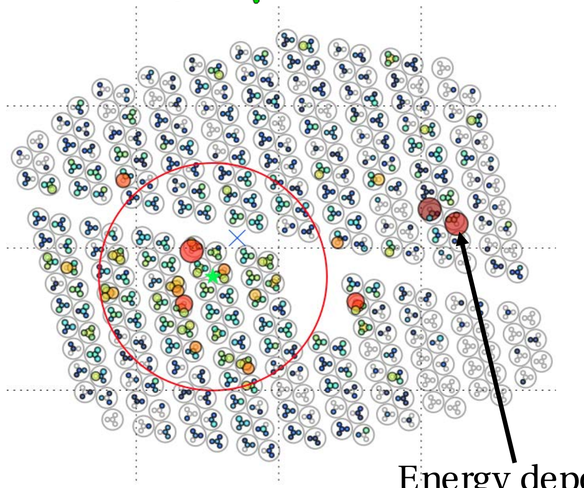
From Abeysekara et al, 2017



Simulated proton
24 TeV, θ=44°
837 hit PMTs

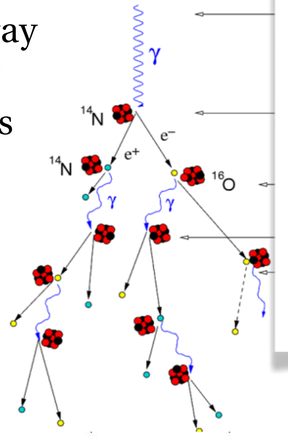


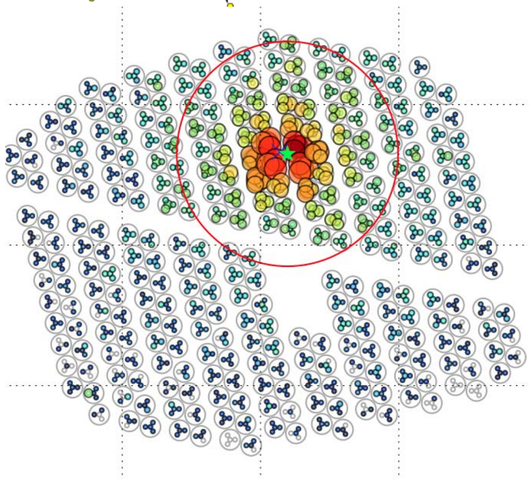


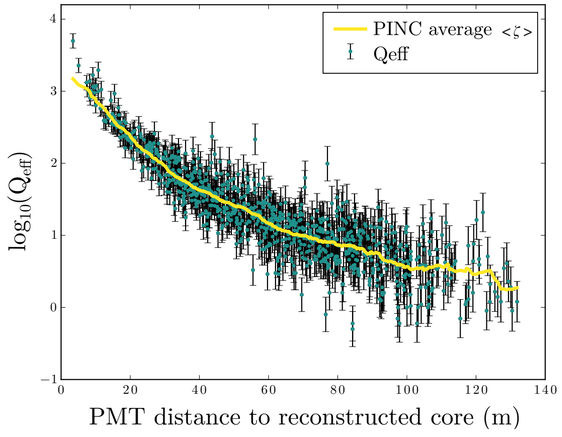


Energy deposited away from the core

Simulated γ-ray
21 TeV, θ=21°
1131 hit PMTs



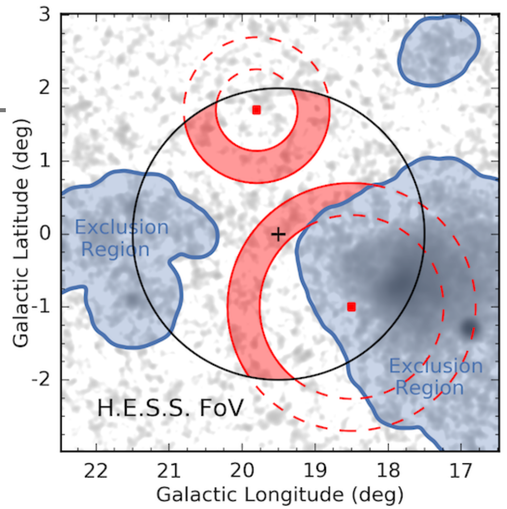




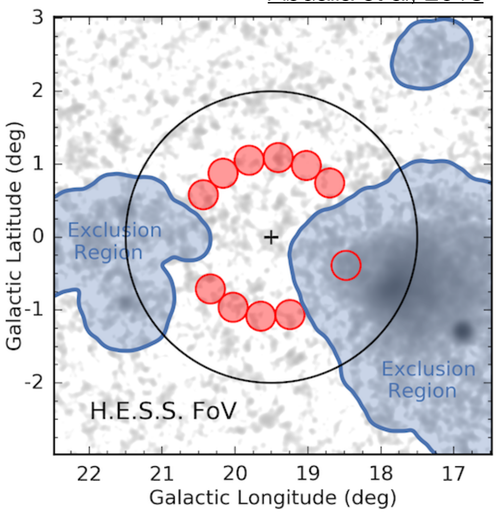
Background estimation

H.E.S.S.

Abdalla et al, 2018

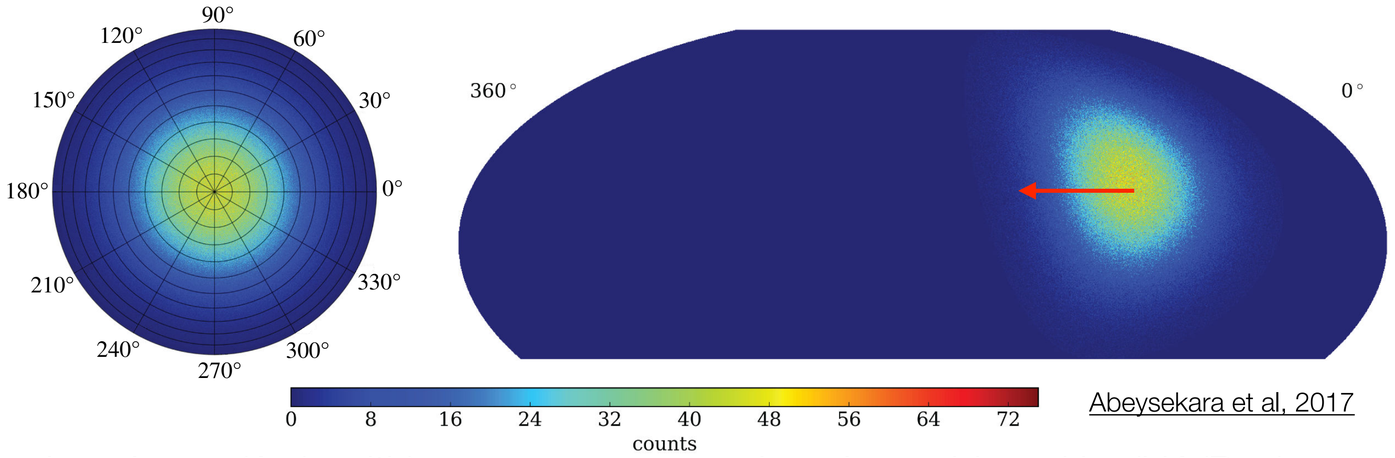


Ring background



Reflected background

Direct integration method



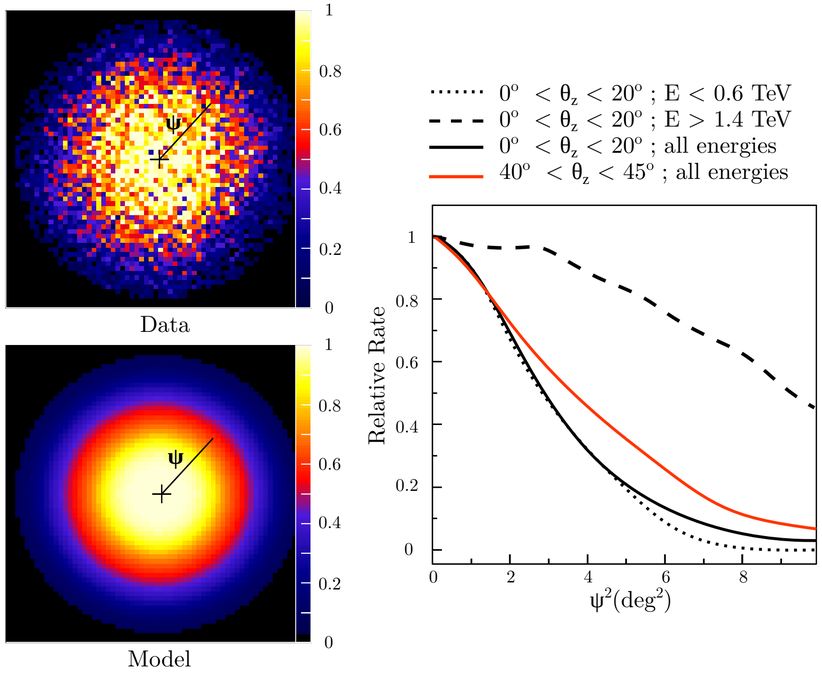
Abeysekara et al, 2017

Local map (Az/zenith)

Local map binned in (HA/Dec)

Detector efficiency times event rate integrated over 2 hours

- ✔ Background estimated on the data themselves and constantly updated
- ✔ Assuming stable detector during 2h
- ✔ Mask the galactic plane and bright known sources

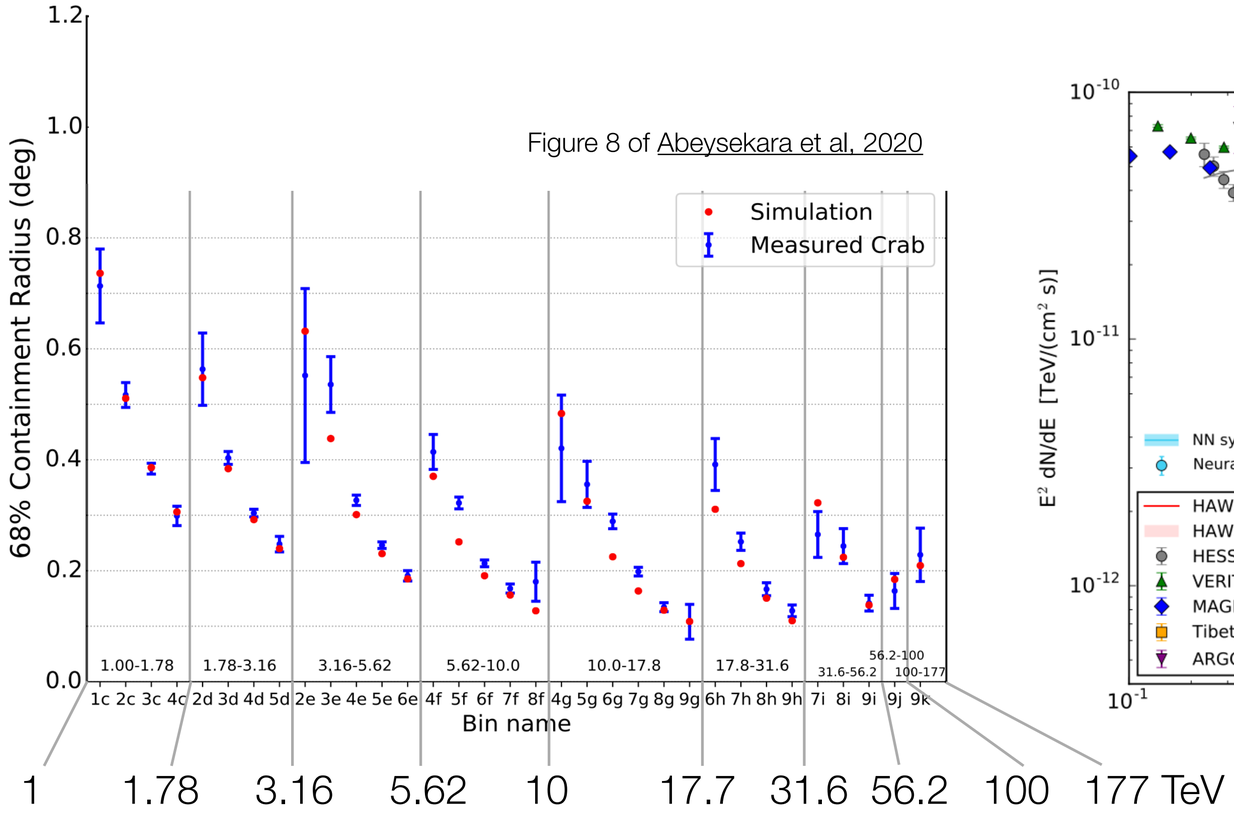


Field-of-view background

Angular and energy resolution improved !

- ✔ Improved PSF modeling
- ✔ Energy estimators using the charge density, developed using MC simulations (corsika + Geant4)
- ✔ Use of shower variables : zenith angle, containment of the shower within the array
- ✔ Cut on showers with core reconstructed on the array

Figure 8 of Abeysekara et al, 2020



20% 15% 10%

Figure 9 of Abeysekara et al, 2020

Figure 14 of Abeysekara et al, 2017

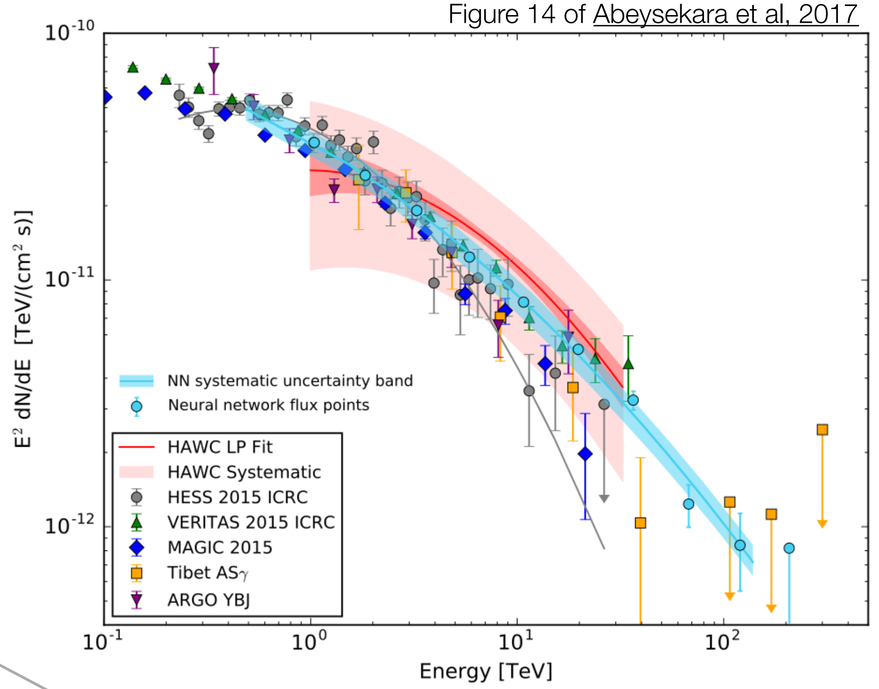


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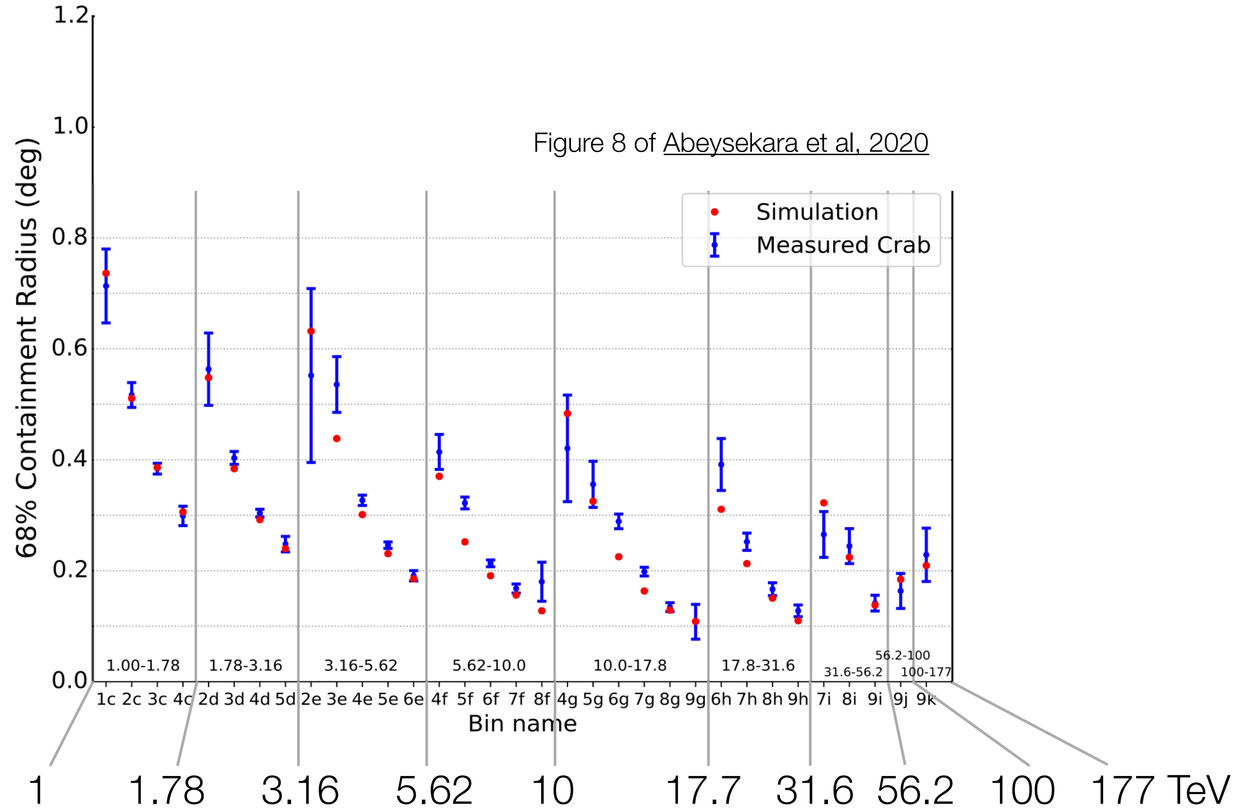
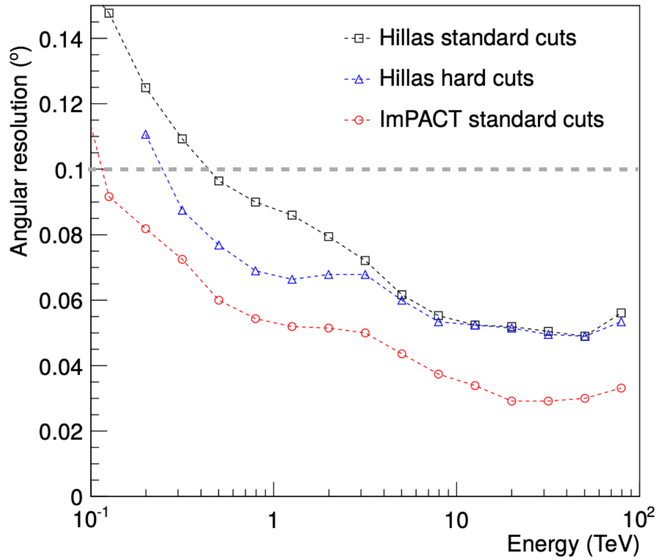
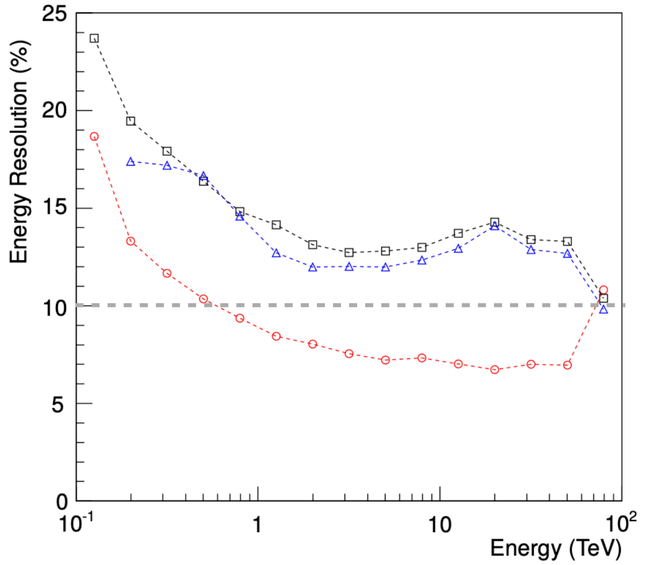
Figure 8 of Abeysekara et al, 2020



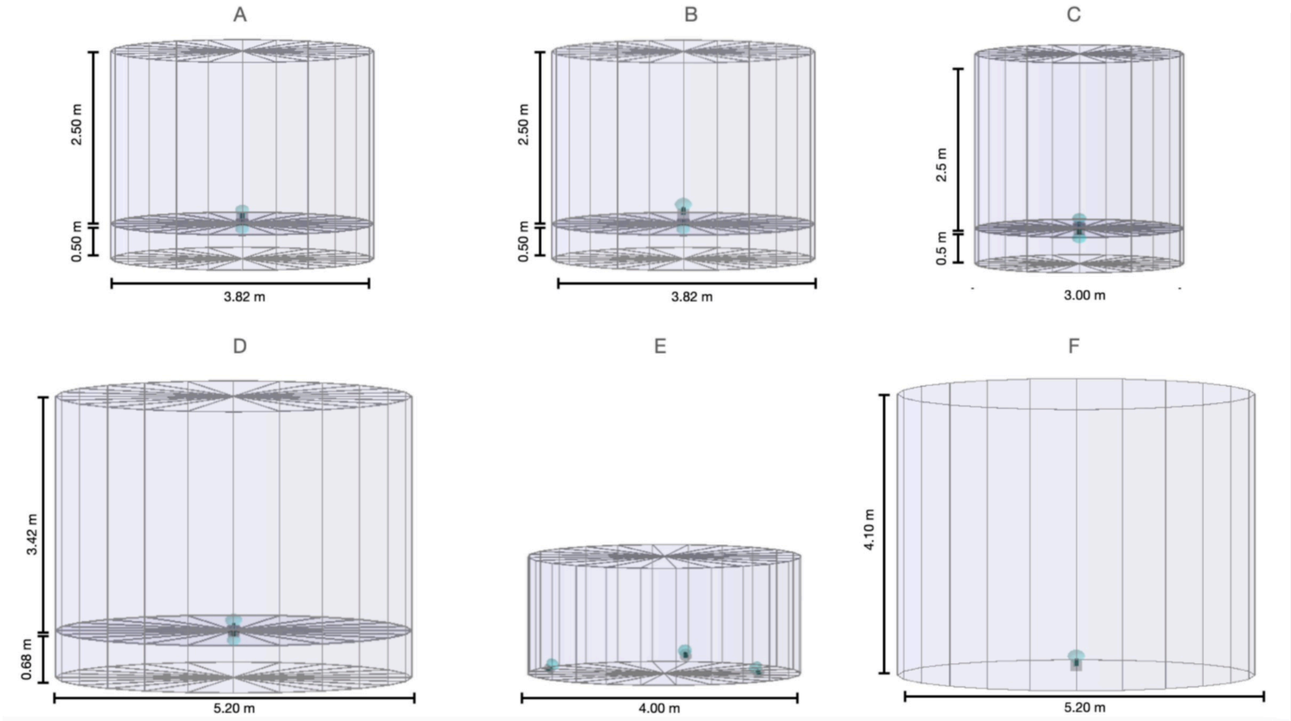
20% 15% 10%

H.E.S.S.

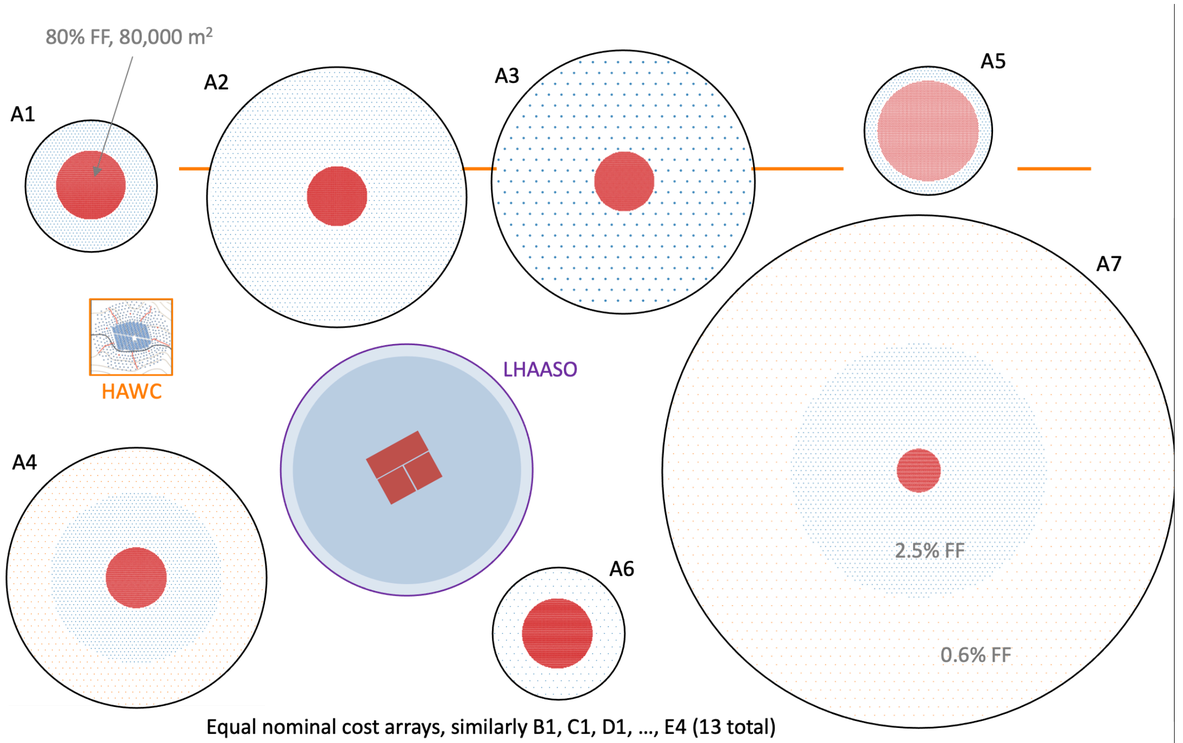




SWGO - R&D



The SWGO collaboration



Equal nominal cost arrays, similarly B1, C1, D1, …, E4 (13 total)

SWGO - Simulations

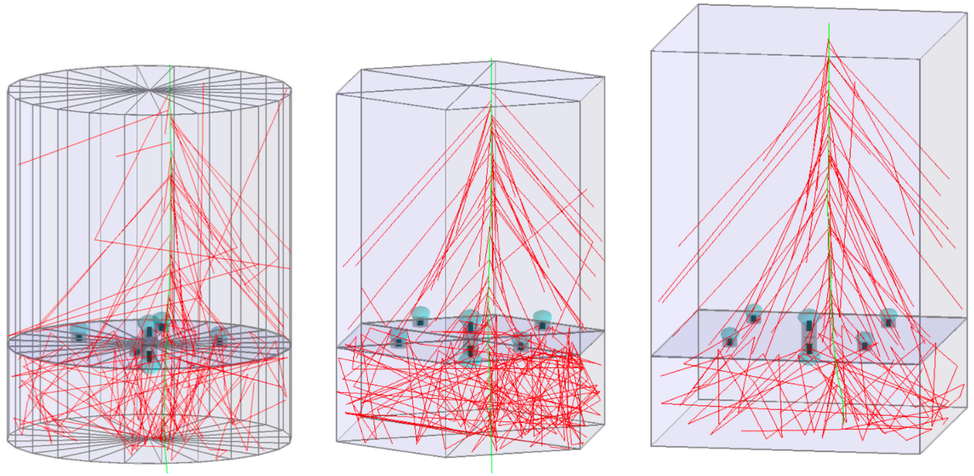


Figure 1: Geant4 visualization of a Circular-DLT, an Hexagonal-DLT and a Square-DLT, crossed by a 1 GeV vertical muon. All tanks have widths of 3 m (diameter for Circular-DLT, two times the side for Hexagonal-DLT, and side for Square-DLT) and lower layers 1 m high. The upper layers were simulated with non-reflective walls, while the lower layer with reflective walls. The green line represents the simulated muon and the red lines a sample of Cherenkov photons.

Bisconti and Chiavassa 2022

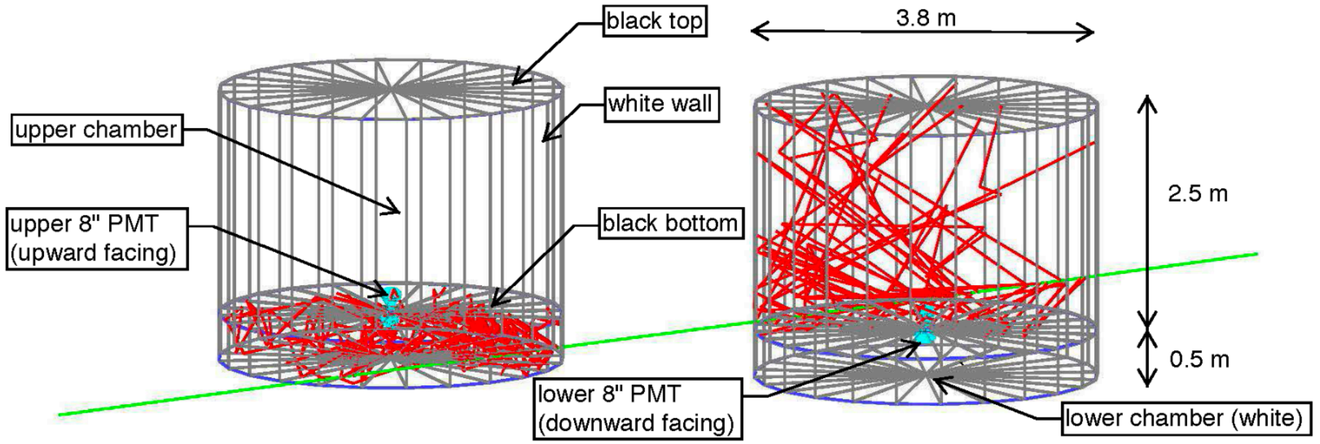
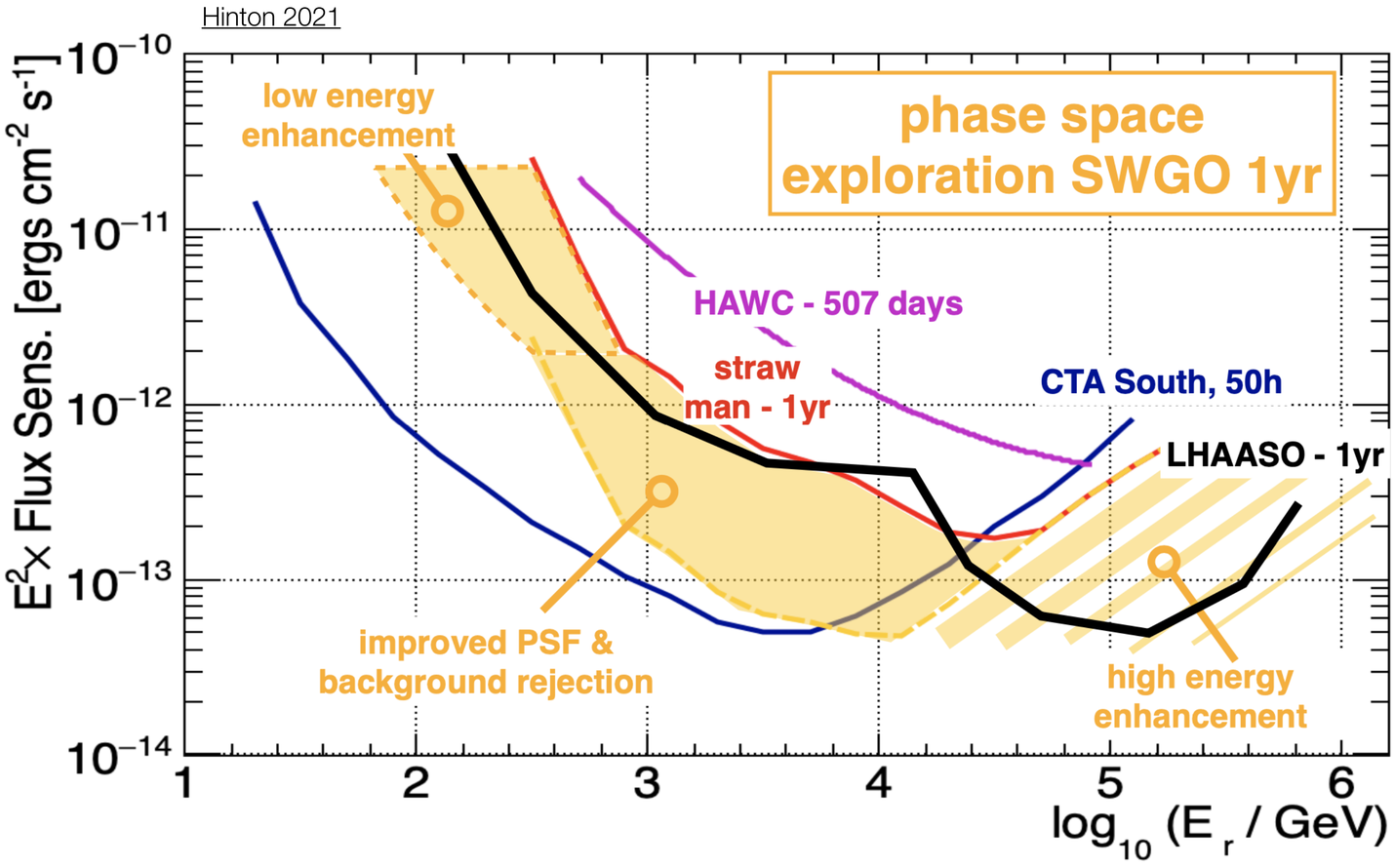
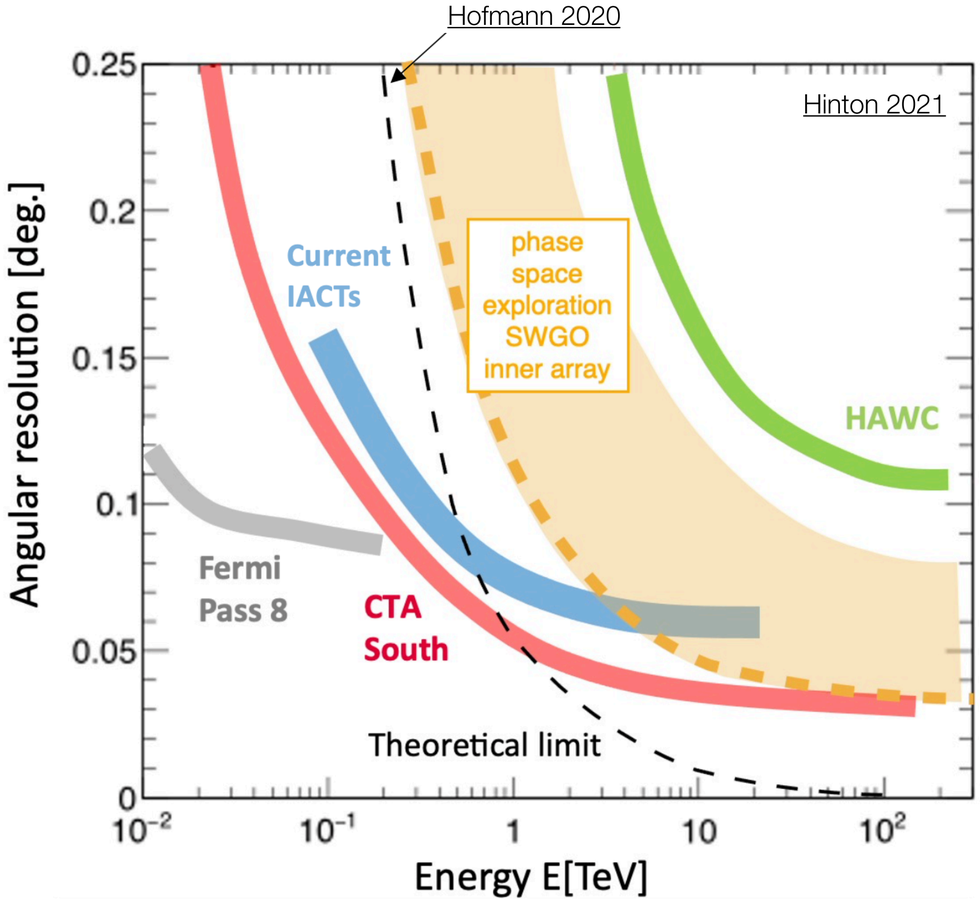


Figure 1: Cylindrical double-layered WCD design comprising an upper chamber of 3.8 m diameter and 2.5 m depth, here with white walls and black bases (top and bottom) and an entirely white lower chamber of 0.5 m depth. The upper chamber contains an 8-inch PMT facing upwards, and the lower chamber has an 8-inch PMT facing downwards. For illustration, a simulated muon (green track) is shown that passes through both units and produces Cherenkov photons (red tracks).

Kunwar et al. 2023

SWGO - Performance





Diffuse VHE ɣ-ray flux from the CMZ

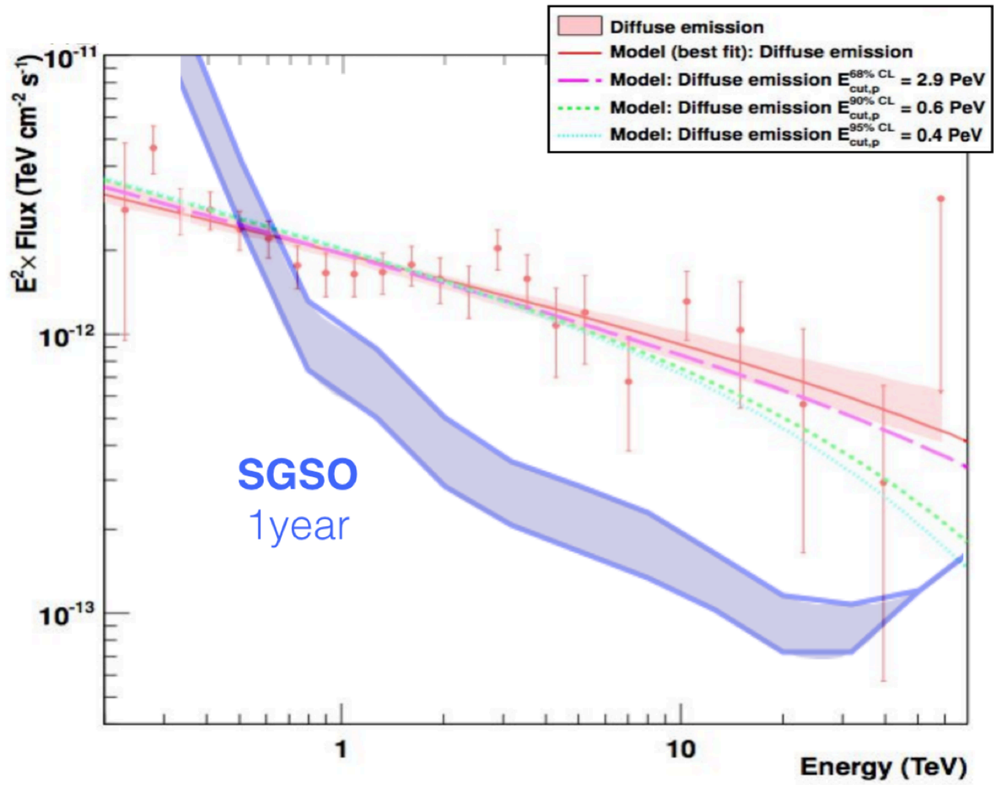


Figure 4.5: Diffuse VHE gamma-ray flux from the central molecular zone in the Galactic center region measured by H.E.S.S. in comparison with the sensitivity after 1 year of SGSO operations. Modified from [48].

The SWGO collaboration (white paper 2019)

Galactic diffuse emission with SWGO

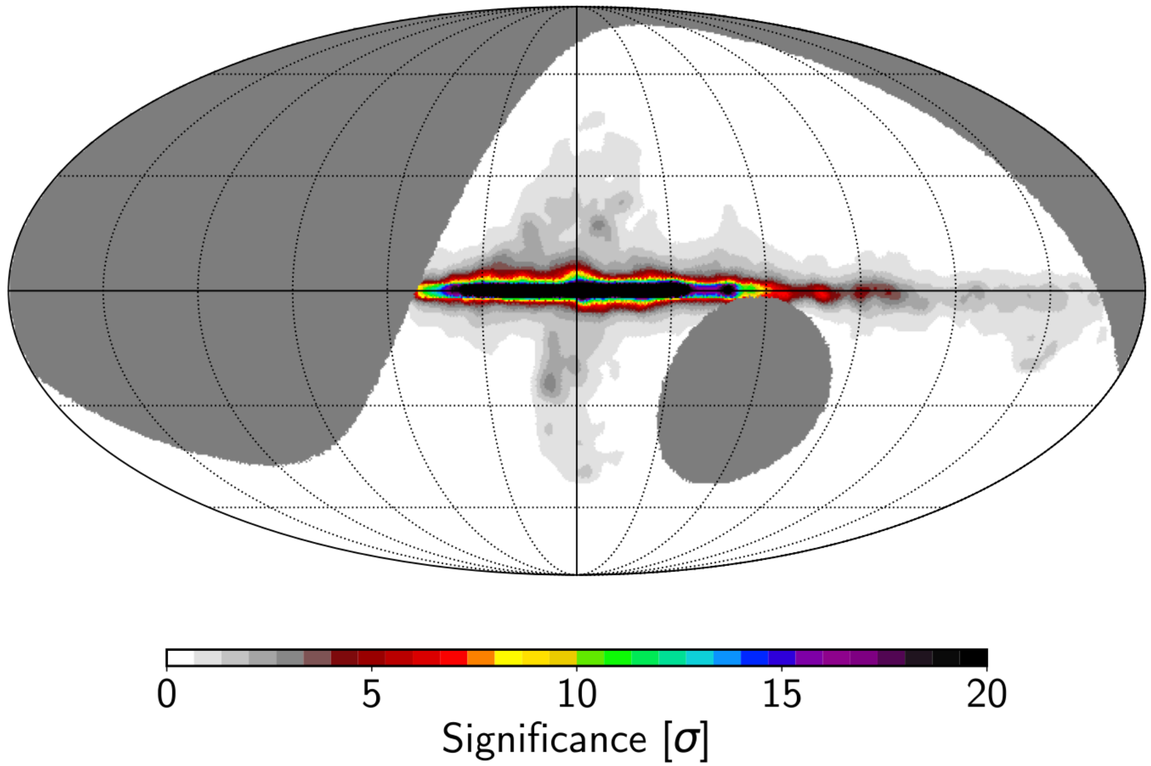


Figure 4.6: Projected significance for the observation of the Galactic diffuse emission with one year of SGSO based on an extrapolation of the *Fermi* diffuse model from [58]. A detector latitude of $-24.2°$ has been assumed, and the sky map is restricted to a zenith angle below $40°$.The skymap has been smoothed with a $2°$ top-hat circular kernel to increase the sensitivity to extended and diffuse emission in the plane.

The SWGO collaboration (white paper 2019)

Fermi bubbles with SWGO

A key challenge for the study of the Fermi Bubbles with SGSO will be the characterization of the background over large angular scales in order to accurately quantify the gamma-ray excess

Three main factors determine the background discrimination at these large scales :

- The first one is the ability to distinguish between hadronic cosmic rays and gamma rays.
- The second is to measure the isotropic cosmic ray and gamma ray fluxes.
- The third is removing effects from the large-scale cosmic ray anisotropy which can still be present due to imperfect gamma-hadron separation

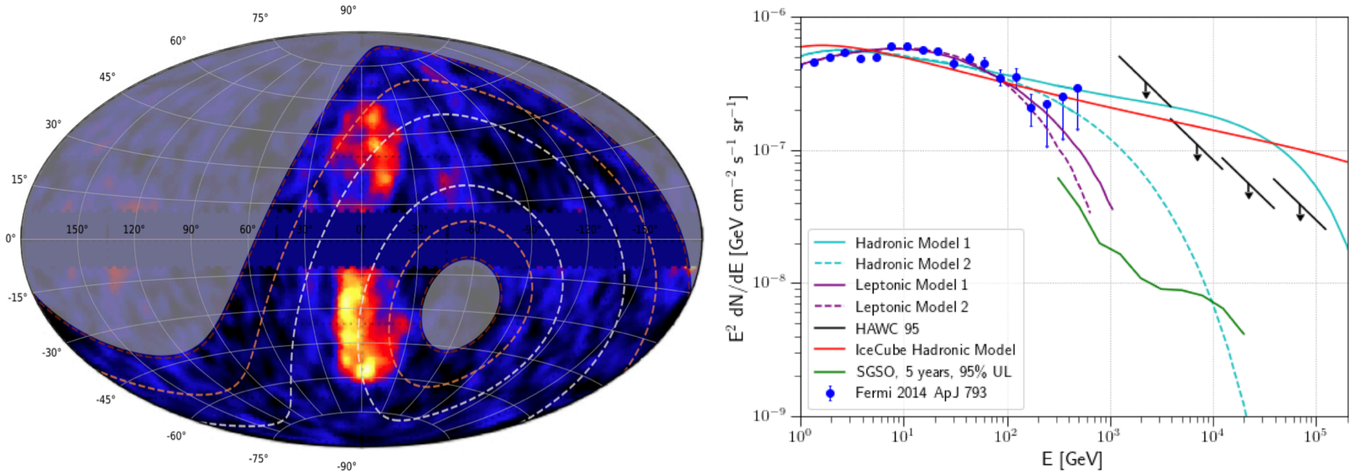


Figure 4.4: *Left:* Field-of-view of SGSO overlaid on the *Fermi* bubbles (Credit:*Fermi*-LAT team, A. Franckowiak, D. Malyshev), the dotted lines indicate steps of 15° from zenith. *Right:* SGSO differential sensitivity from the straw man design to detect the Northern *Fermi* Bubble compared to different emission scenarios [27, 25, 28].

The SWGO collaboration (white paper 2019)

Cosmic ray anisotropy with SWGO

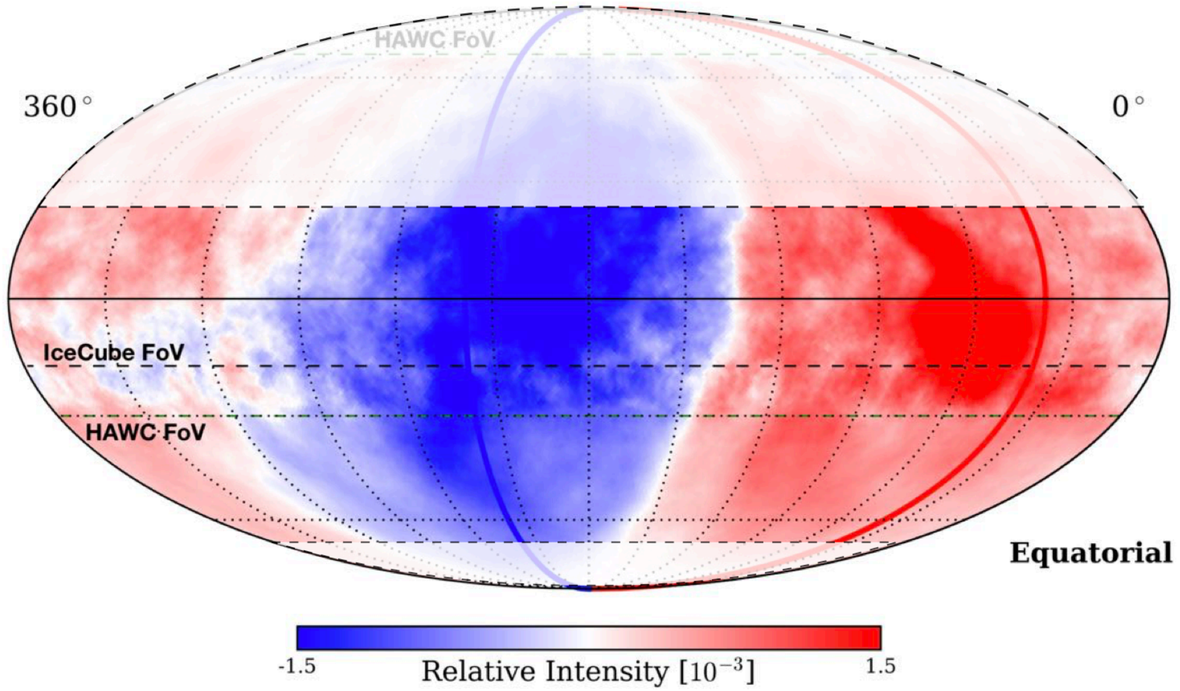


Figure 7.2: Relative intensity of cosmic-ray arrival directions for the combined IC86 and HAWC-300 dataset [293], the unmasked region indicates the declination range of SGSO and illustrates the overlap with both IceCube in the south and HAWC in the north.

The SWGO collaboration (white paper 2019)

LHAASO event on the WCDA

Aharonian et al. 2021

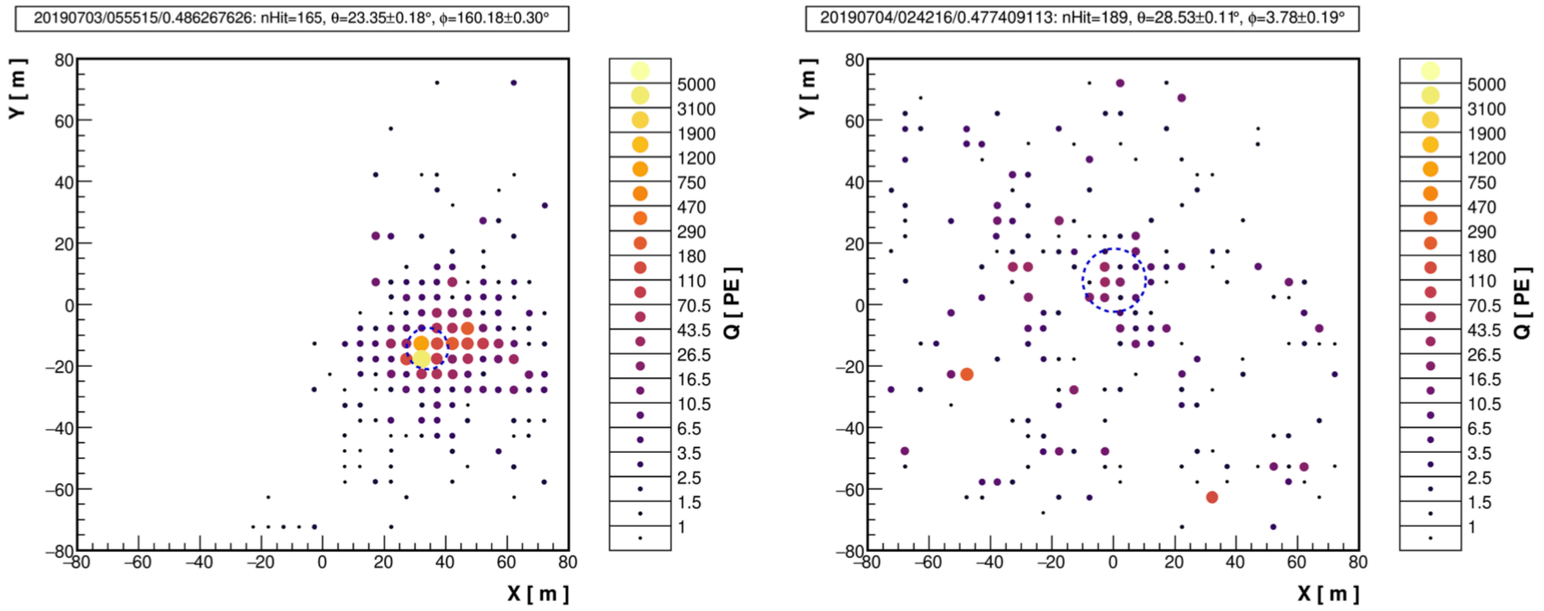


Fig. 10. A high-confidence gamma-ray candidate event from the direction of the Crab Nebula with N_{hit}=165 and a compactness value of $C = 39$ (left panel) and a similar background cosmic-ray event with N_{hit}=189 and $C = 1.0$ (right panel). Dashed circles indicate the reconstruction uncertainties of the shower cores.

Liu et al. 2021

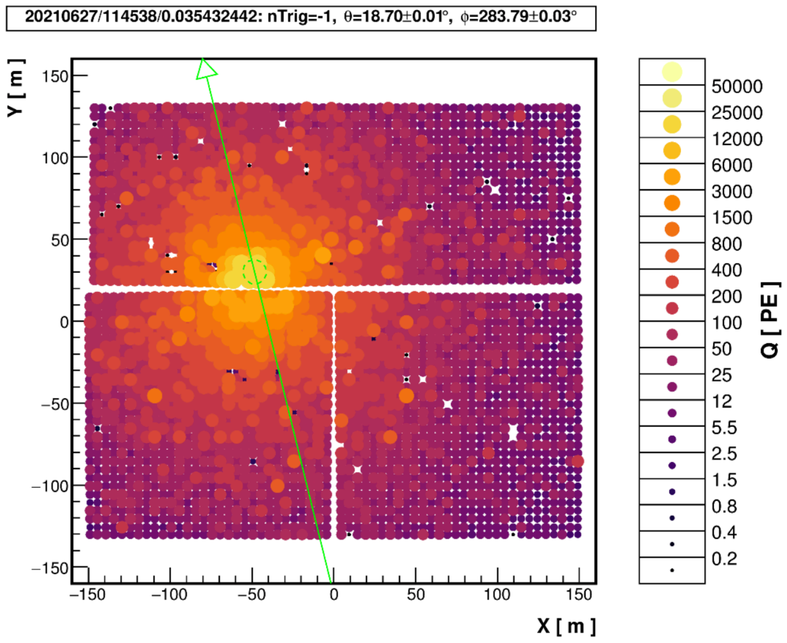
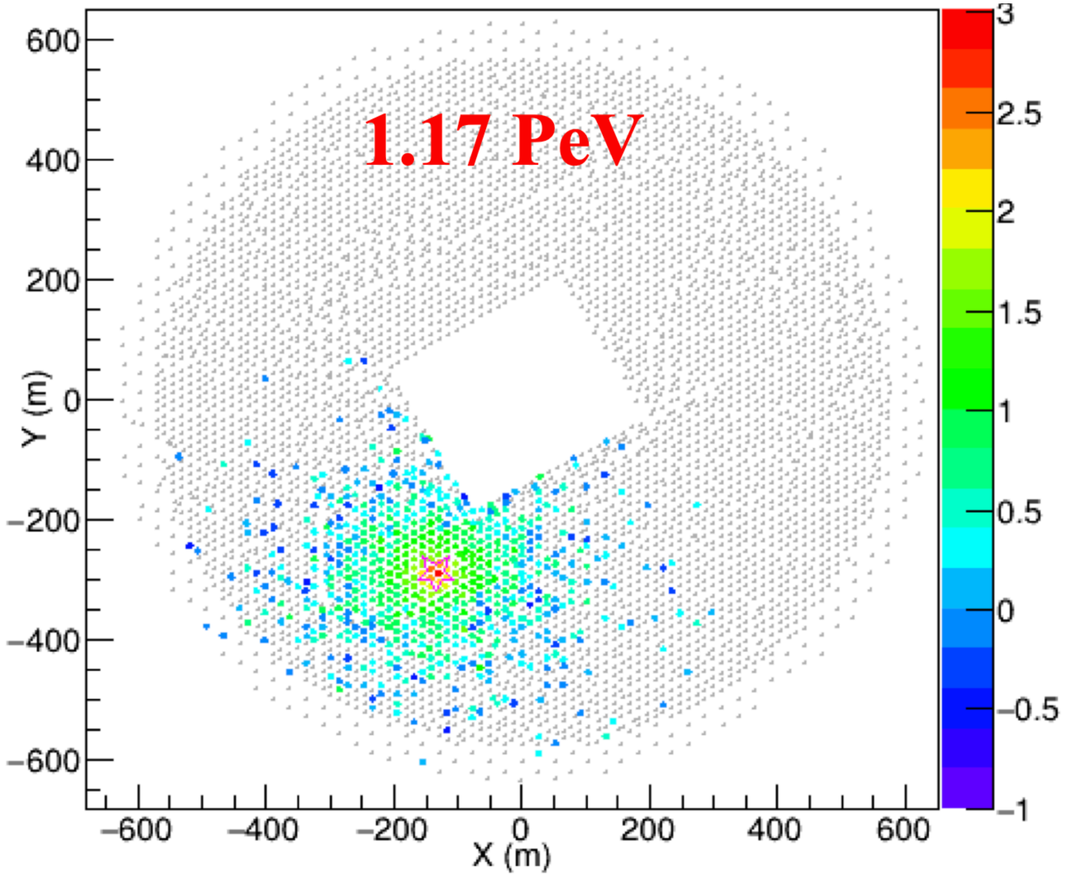


Figure 6: A typical high energy shower event detected by WCDA.

LHAASO event on the KM2A

Electomagnetic detectors



muon detectors