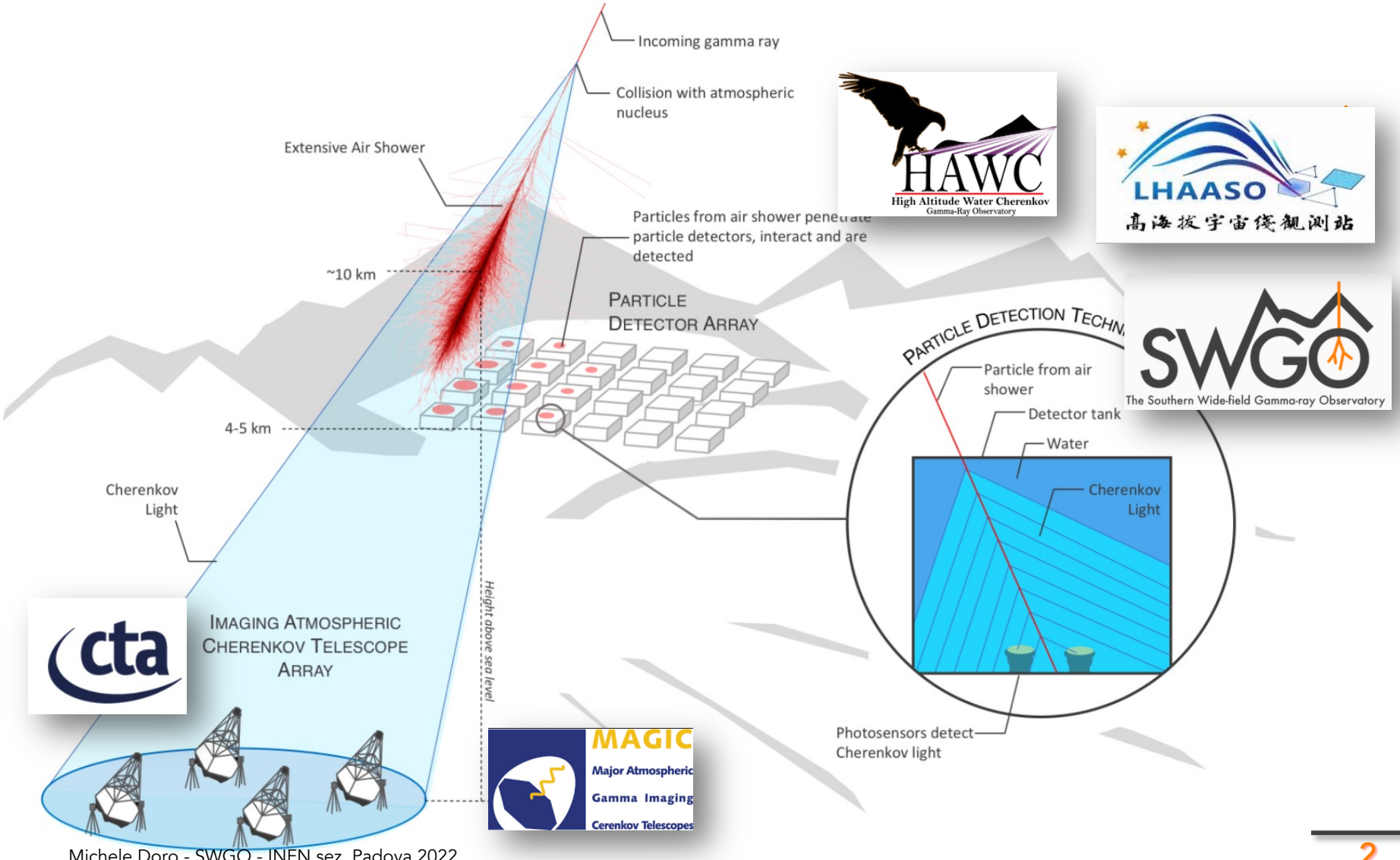
[SWGO] Southern Wide-Field gamma-ray observatory

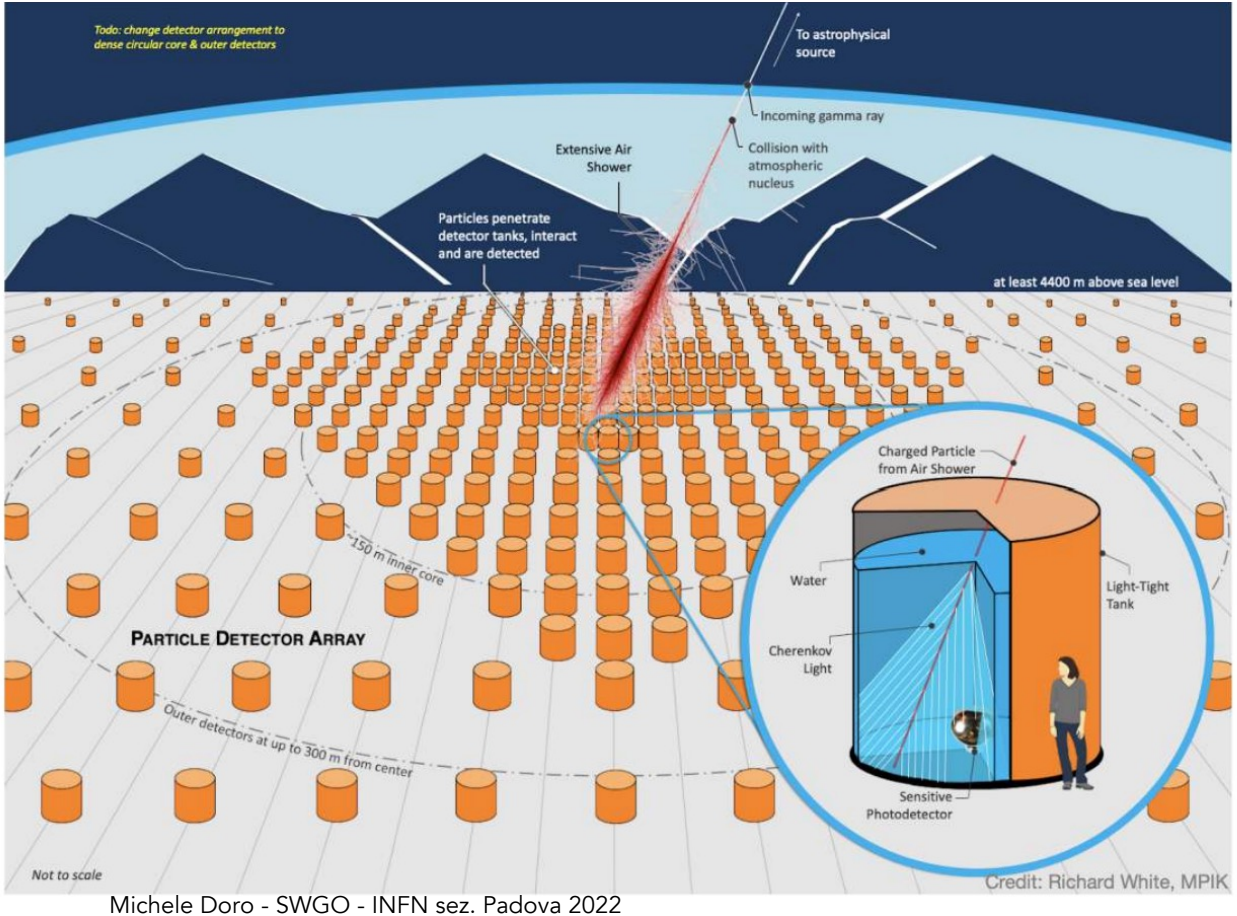
Michele Doro, University & INFN Padova

INFN Padova 01/07/2022



Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

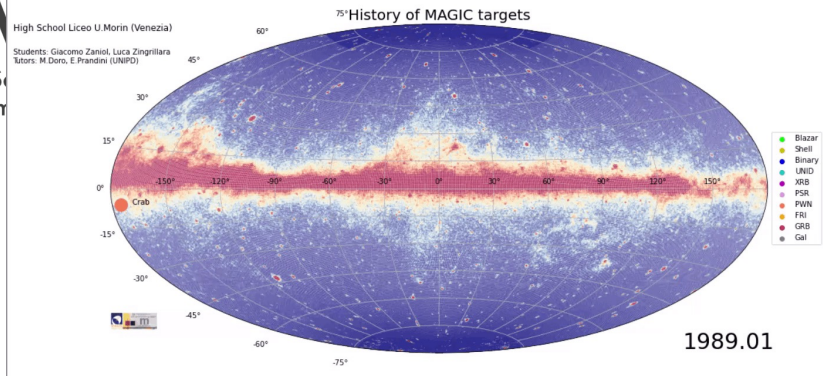
SWGO nutshell



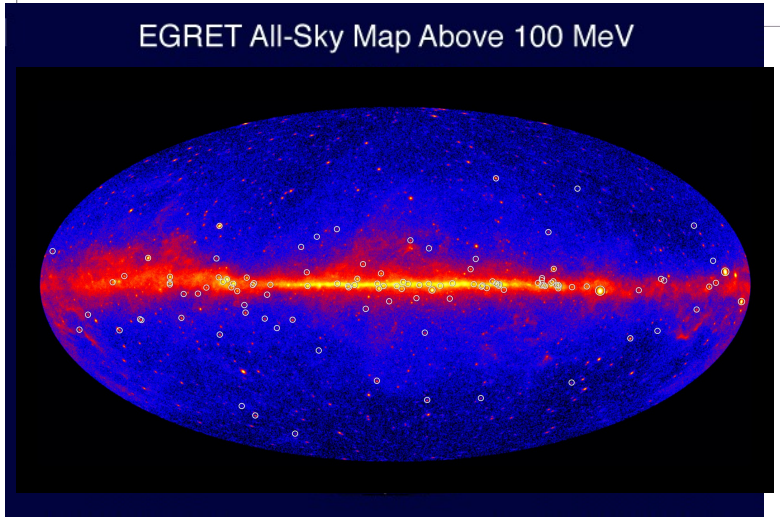
- A shower-front detector of **TeV-PeV gamma rays** to be located in South America
  - → Size km2+
  - → 4400+ asl
  - → Denser core, sparse outer
  - → Water tanks base design

Why?

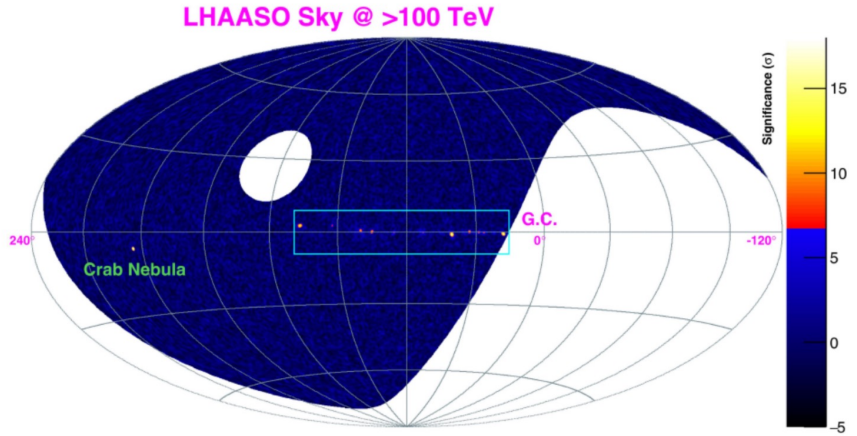
3 revolutions



- TeV revolution (IACT, 2000)



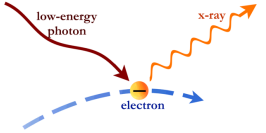
- GeV revolution (AGILE, FERMI, 2010)



Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	−13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	−5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	−3.65	8.5	$0.26-0.10^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	−0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71-0.07^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)

- PeV revolution (LHAASO, 2020)

Pevatrons in our Galaxy?



Felix A. Aharonian

Physicist

Electron PeVatrons - related to the pulsar winds in PWNe with Crab Nebulae as a "special case"

Proton PeVatrons - in young individual SNRs and Stellar Winds with $v > 0.01c$, and provided $B > 0.01$ G

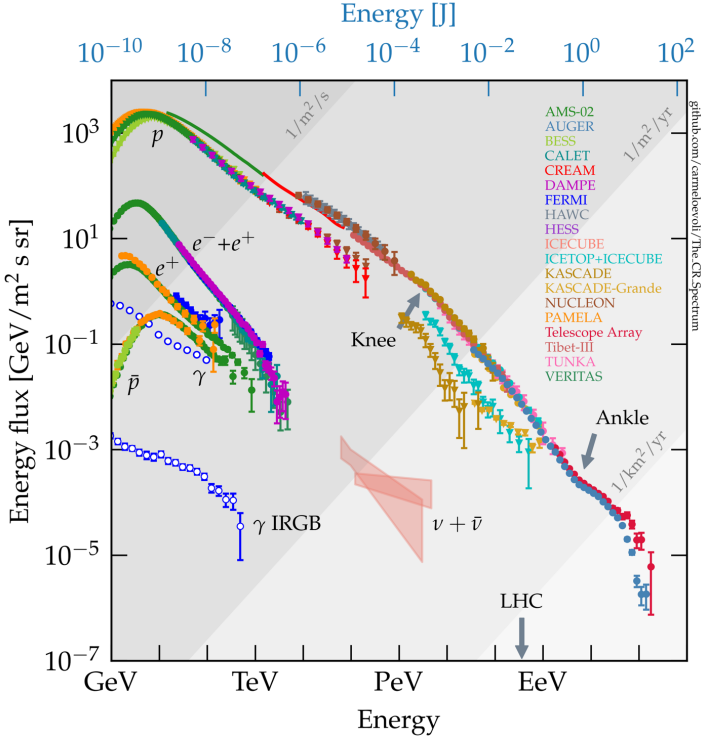
Galactic Center magnetosphere of SMBH (Sgr A*)

$$E_{15} \sim eBR \approx 10^3 (B/10^4\mathrm{G})(\mathrm{M}/3 \times 10^6 \mathrm{M}_\odot)$$

relativistic (barionic) outflows

wind in GC or the jet in SS 433, Cyg X-1, Cyg X-3, GRS 1915

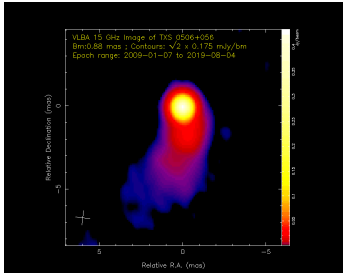
Large Scale structures - Superbubbles, Fermi Bubbles, …

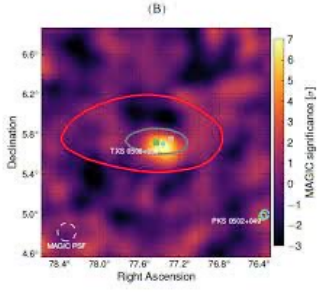


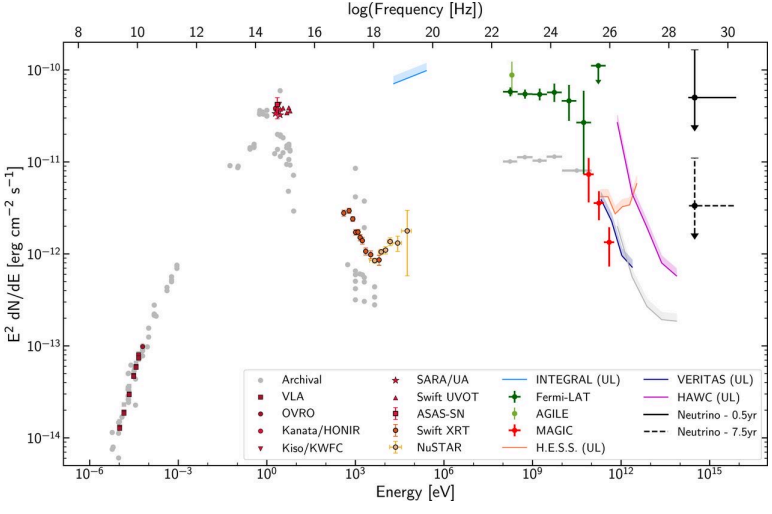
- Very intense theoretical search

Multi-messenger revolutions

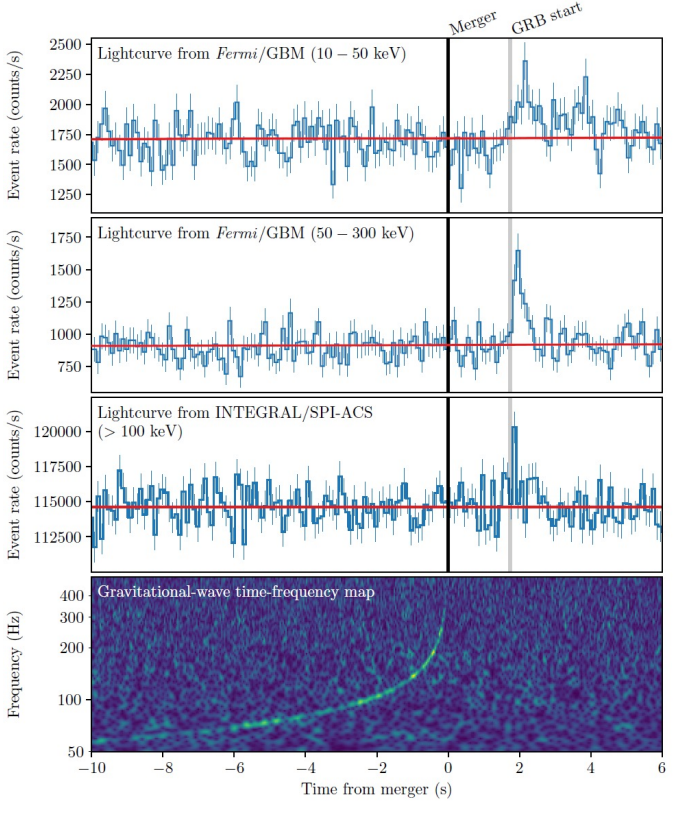
- Neutrino +gamma





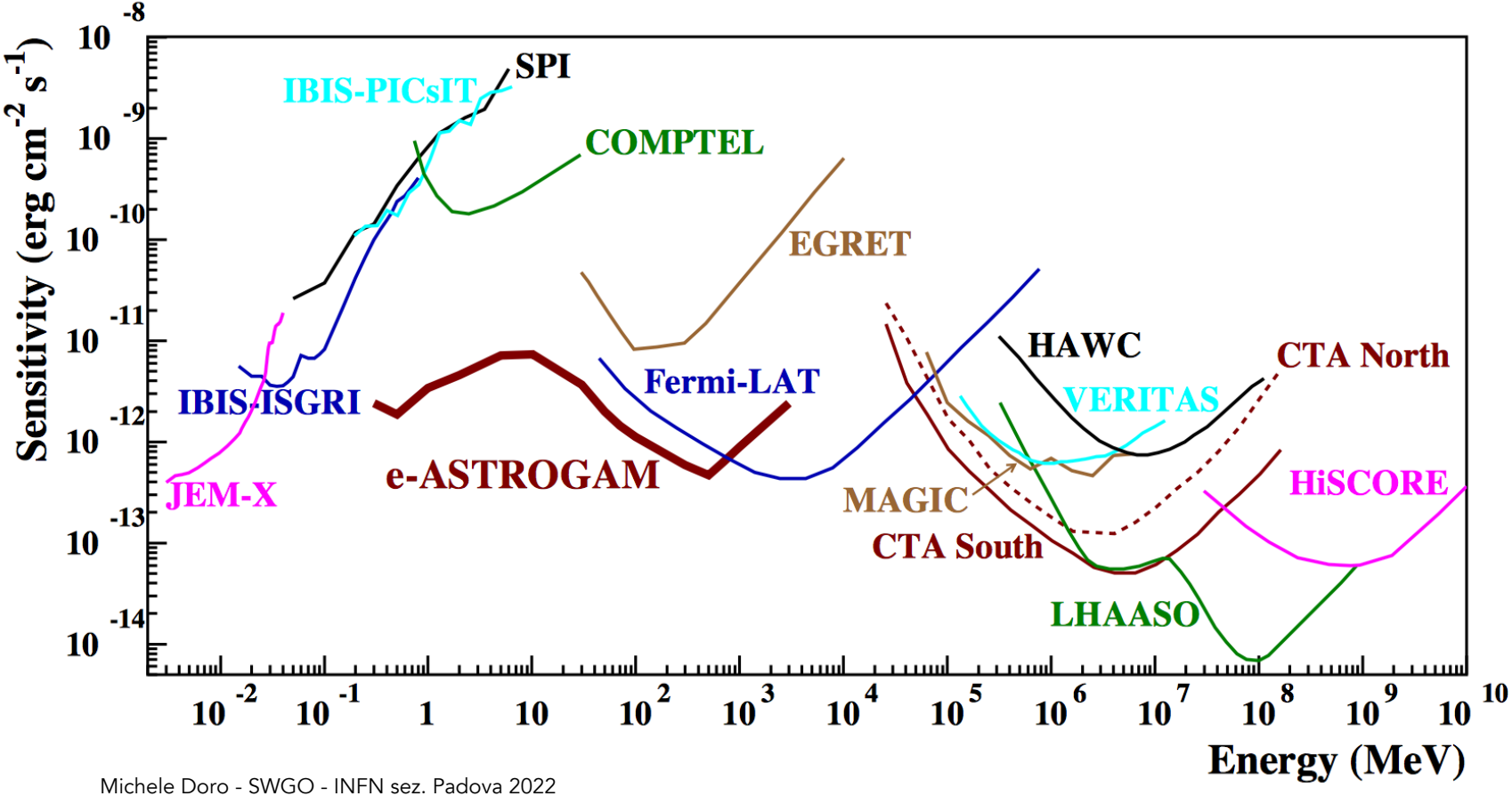


- GW+gamma



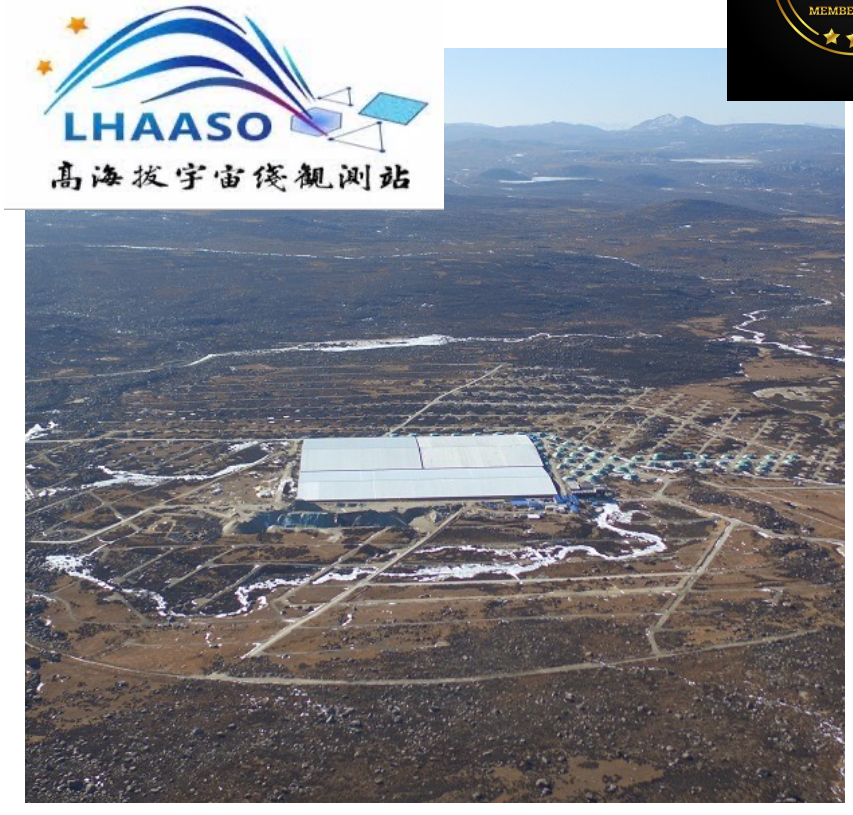
Where are we

Plot from https://arxiv.org/abs/1611.02232

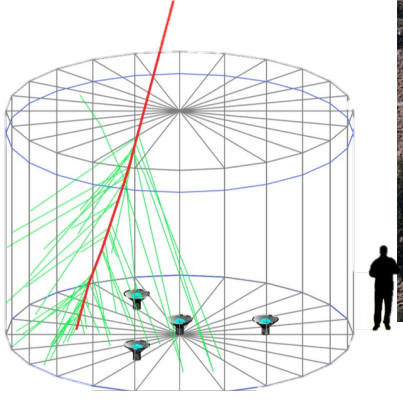


SWGO
The Southern Wide-field Gamma-ray Observatory

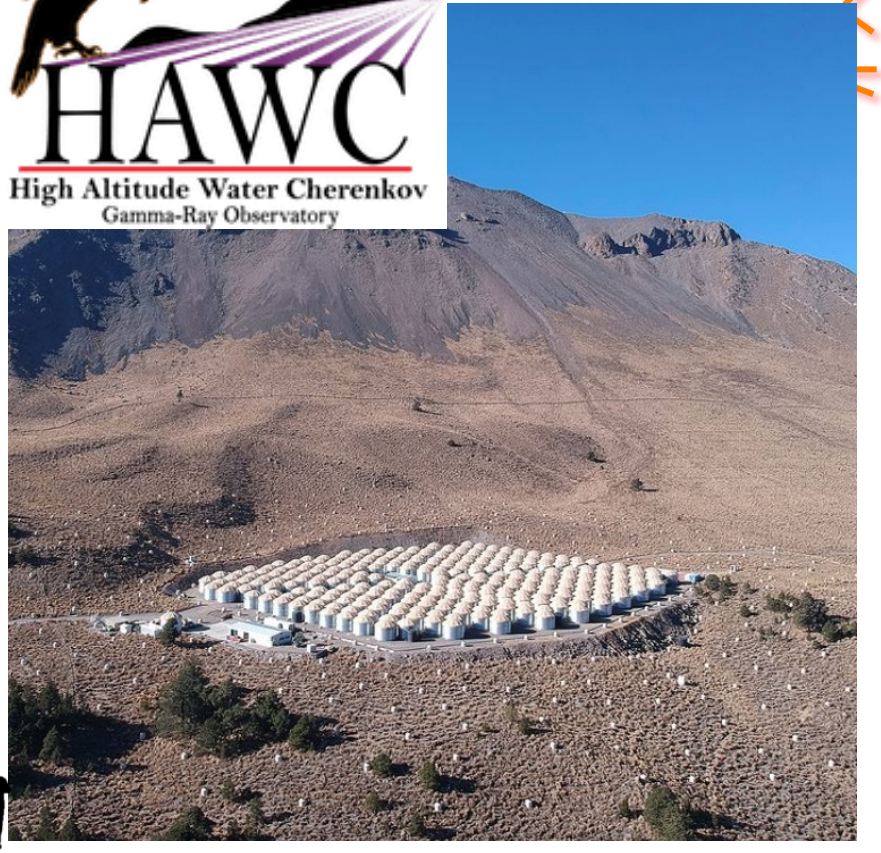
HAWC and LHAASO



- Location: Puebla, Mexico, 4100 m asl
- Collaboration: US+Mexico (mostly), 120 scientists
- Operating: 2016+
- Technique:
  - → Inner 300 water Cherenkov tanks 7m d, 4.5m h
    - ✓ 4 PMTs / tank
  - → Outer sparse 350 tanks 1.65m h
    - ✓ 1 PMT / tank



HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory



REPORT

Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

A. U. Abeysekara[1], A. Albert[2], R. Alfaro[3], C. Alvarez[4], J. D. Álvarez[5], R. Arceo[4], J. C. Arteaga-Velázquez[5], D. Avila Rojas[3], H…

+ See all authors and affiliations

Science 17 Nov 2017:
Vol. 358, Issue 6365, pp. 911-914
DOI: 10.1126/science.aan4880

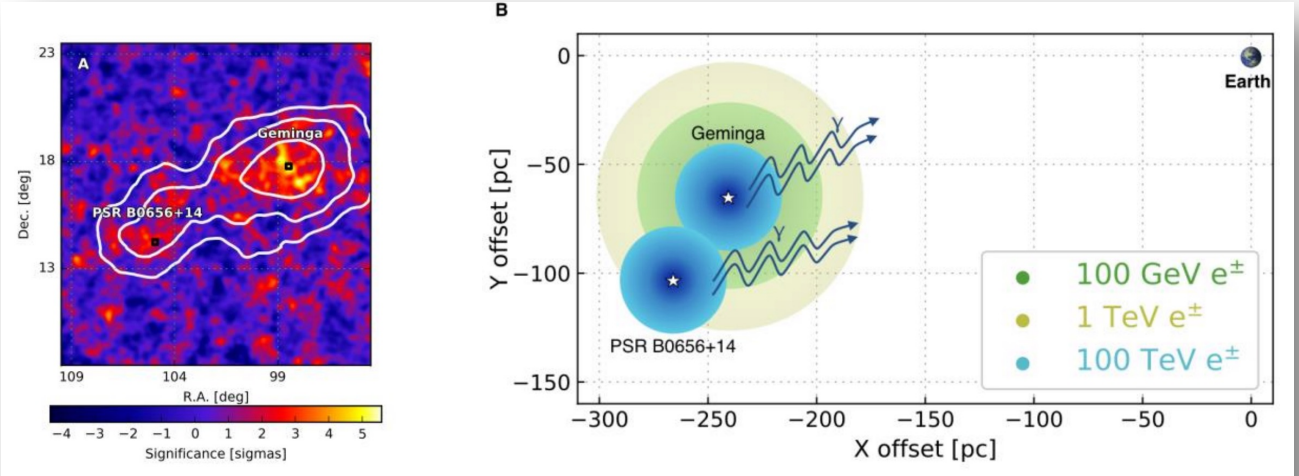


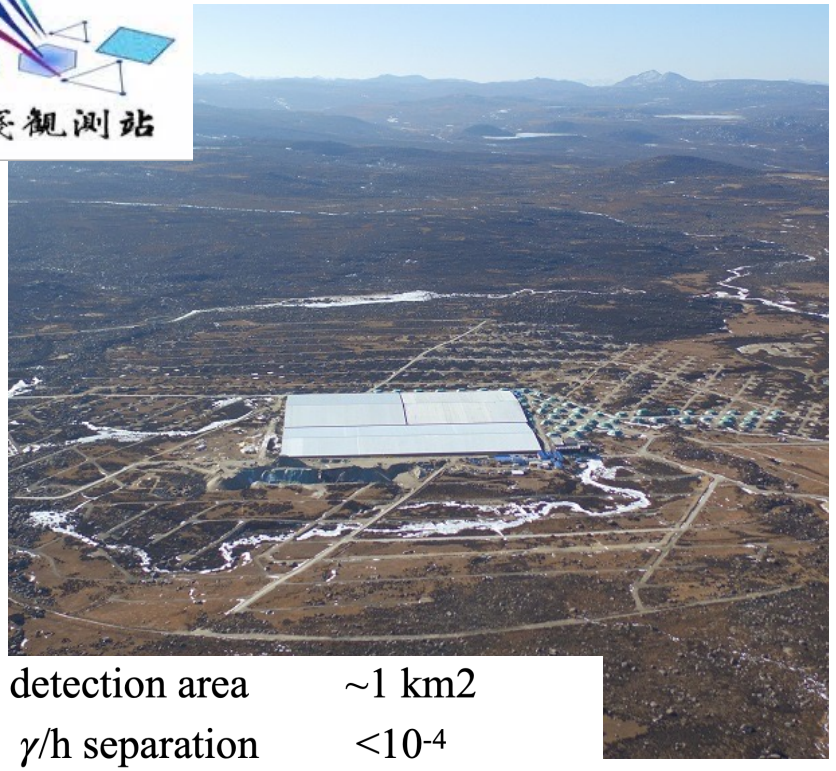
Fig. 1: Spatial Morphology of Geminga and PSR B0656+14. (A) HAWC significance map (between 1 and 50 TeV) for the region around Geminga and PSR B0656+14, convolved with the HAWC point spread function

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

SWGO
The Southern Wide-field Gamma-ray Observatory

LHAASO
高海拔宇宙线观测站

- Location: Sichuan, China, 4410 m a.s.l.
- Collaboration: China
- Operating: 2020+

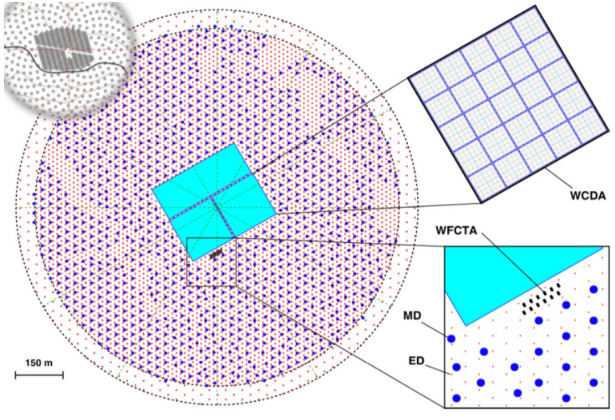


5195 Scintillators
- 1 m² each
- 15 m spacing

1171 Muon Detectors
- 36 m² each
- 30 m spacing

3000 Water Cherenkov Cells
- 25 m² each

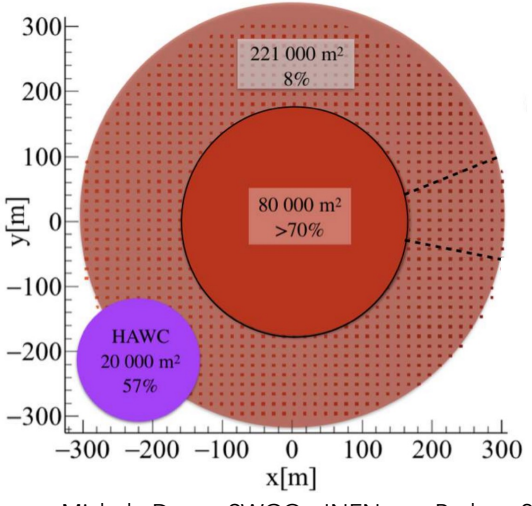
12 Wide Field Cherenkov Telescopes

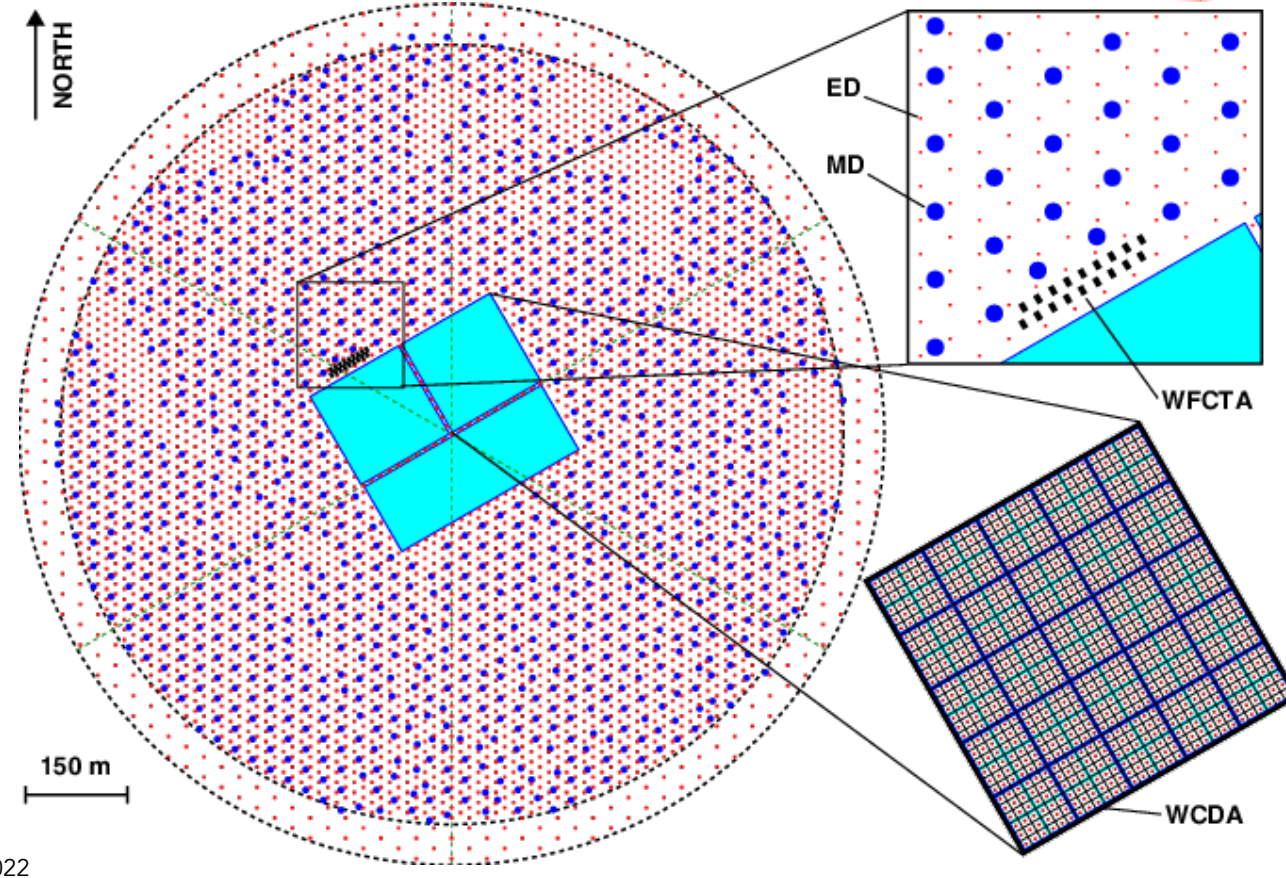


detection area	~1 km2
γ/h separation	$<10^{-4}$
large FoV	~1 ster
exposure time	~2000 h/yr
good PSF	~15 arcmin
energy resolution.	~15%

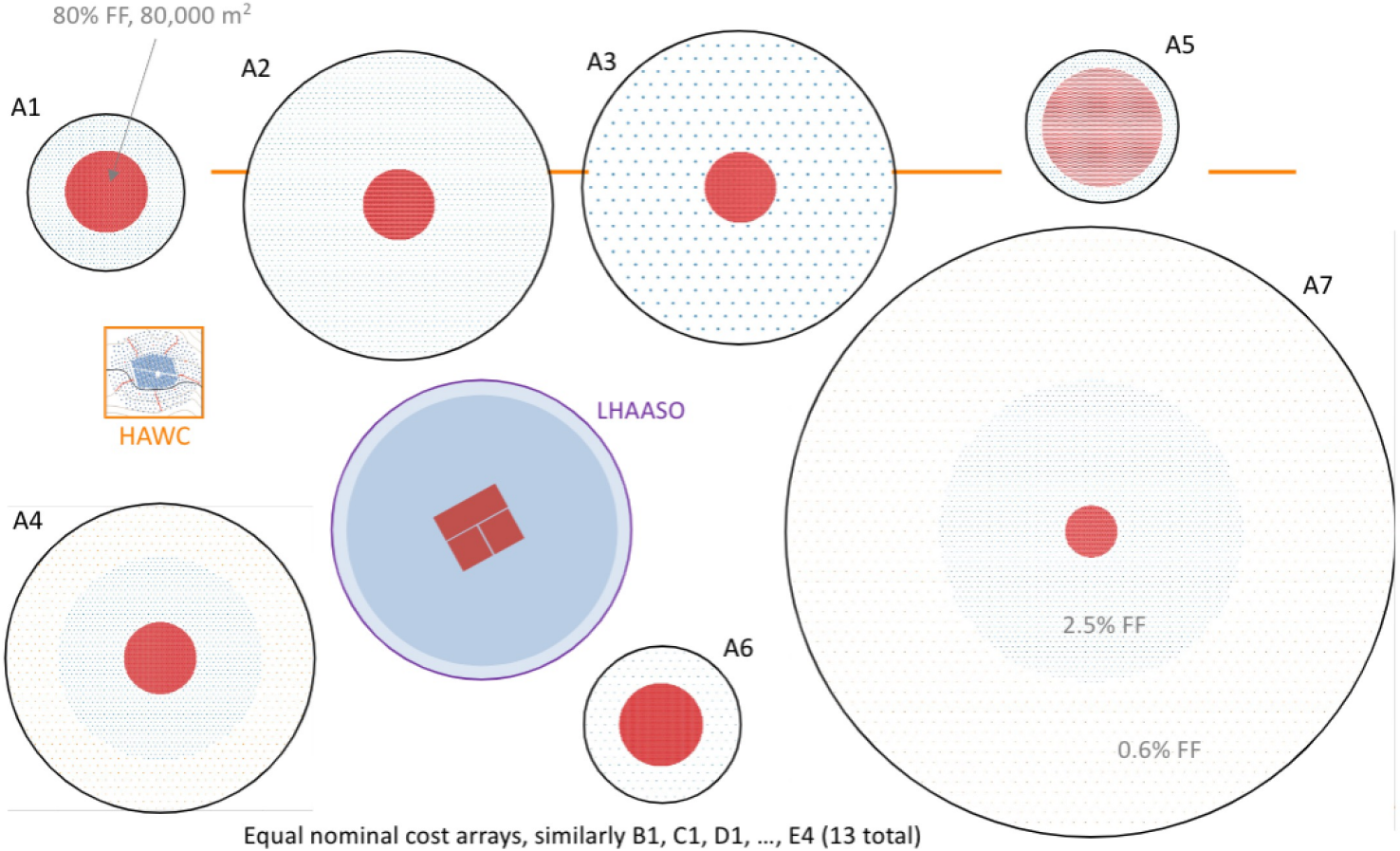
What?

Initial SWGO idea



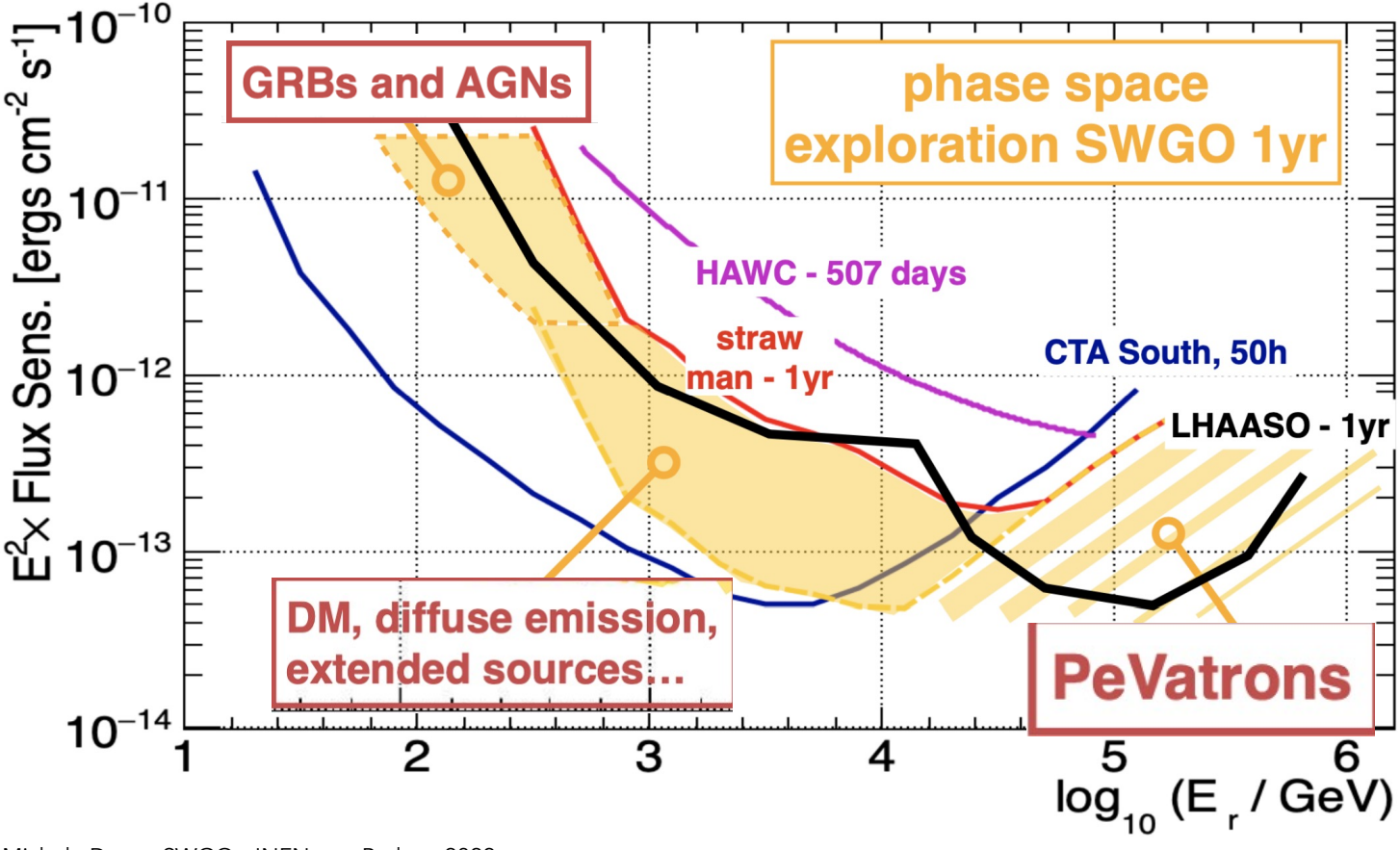


Updates! (muuuuch bigger!)



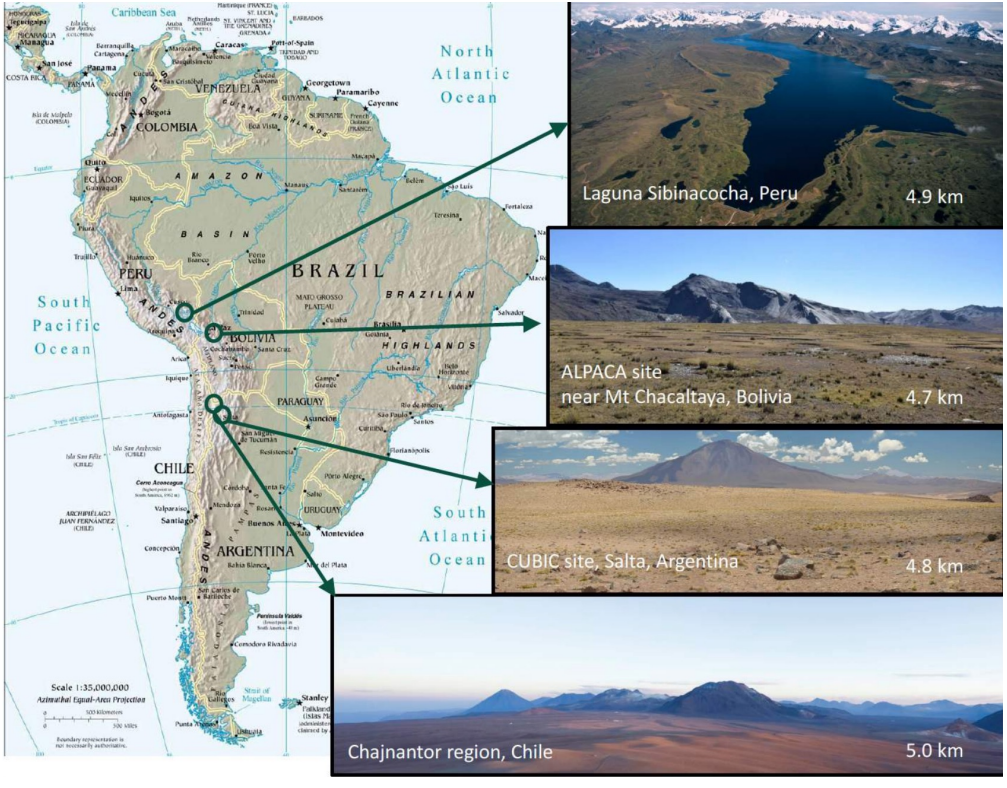
Equal nominal cost arrays, similarly B1, C1, D1, …, E4 (13 total)

Sensitivity

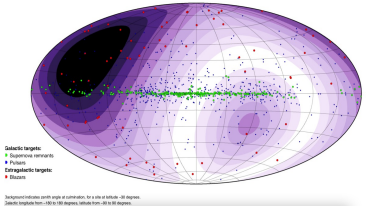


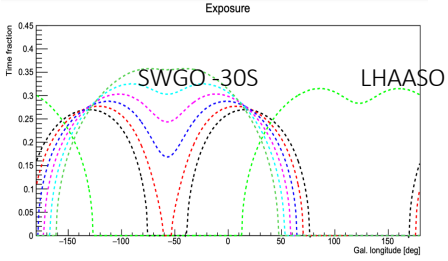
How?

South America, 4400+ m asl



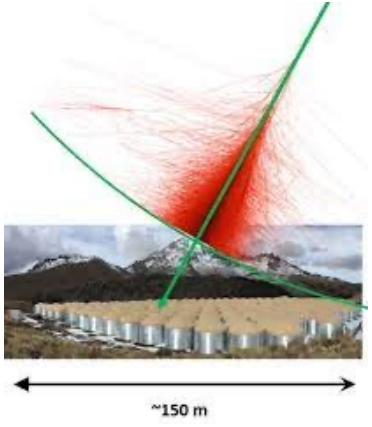
Country	Site Name	Latitude	Altitude [m a.s.l]	Other installations
Argentina	Alto Tocomar	S 24.195; W 66.510	4,430	
	Cerro Vecar	S 24.185; W 66.475	4,800	LLAMA, QUBIC
Bolivia	Chacaltaya	16.23 S	4,740	ALPACA
Chile	Pajonales	22.57 S	4,600	ALMA and others
	Pampa La Bola	22.56 S	4,770	ALMA and others
Peru	Imata	15,50 S	4,450	
	Yanque	15.44 S	4,800	
	Sibinacocha	13.51 S	4,900	

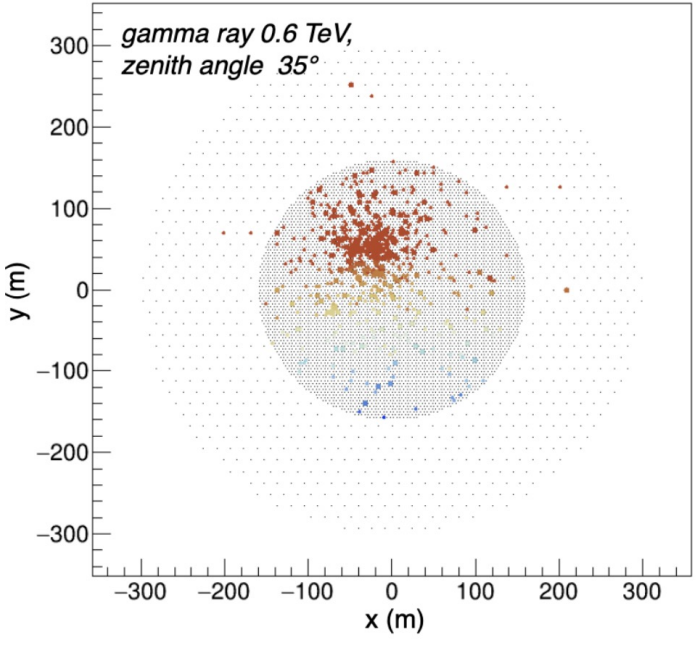


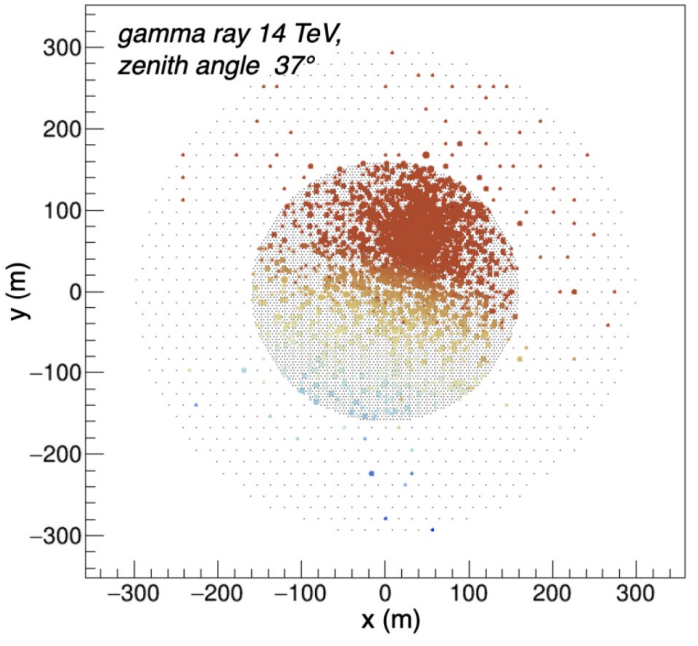


- Site shortlist happening now
- Decision to be taken in 2024

Shower front sampling





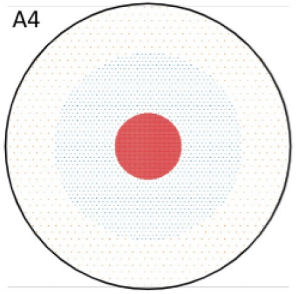


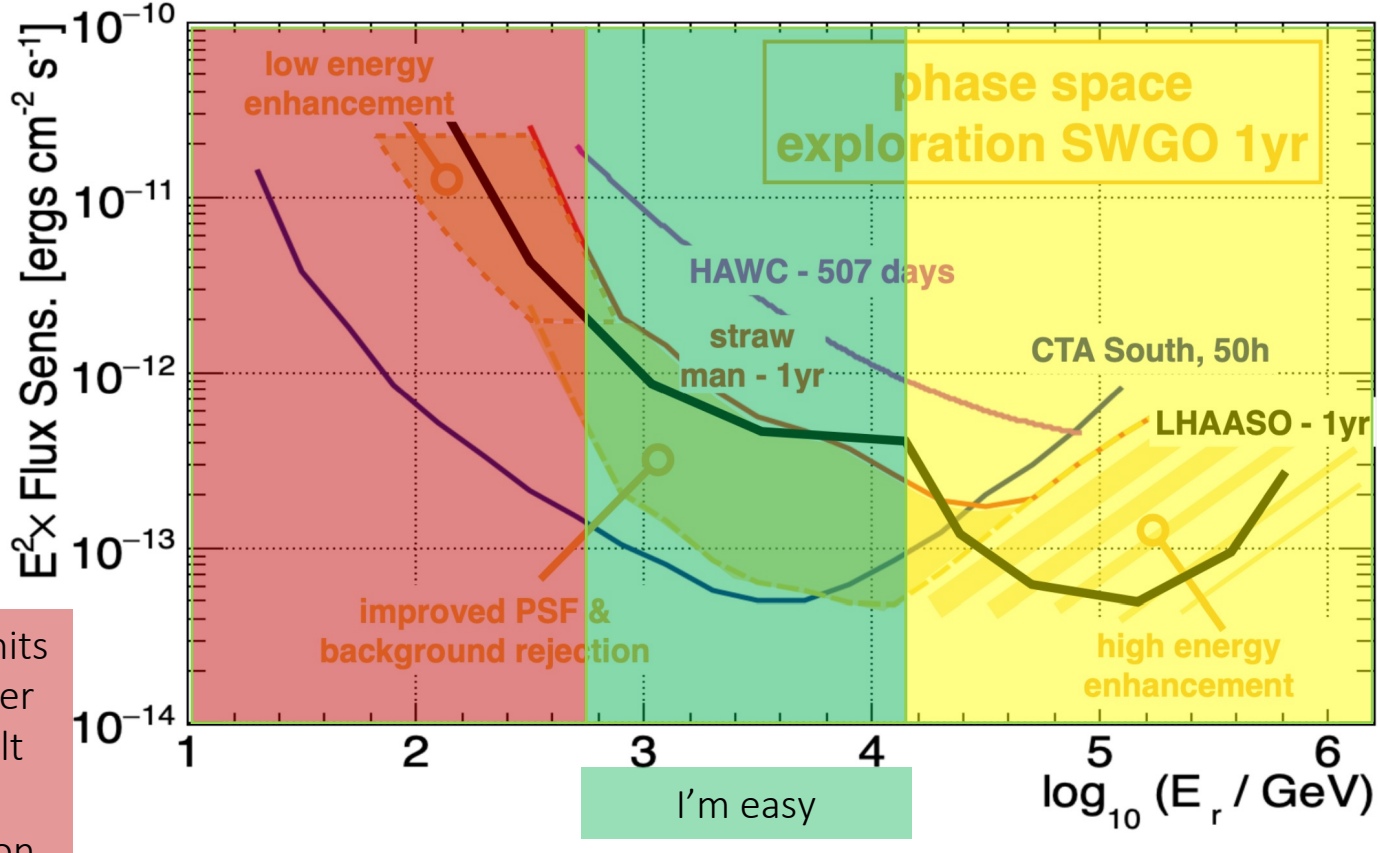
Must have

- ~ns timing resolution of single 'pixel' + shower timing
- Dense sampling in core
- Wide sparse array (PeV)

3 regimes

Maybe not a unique detector unit….

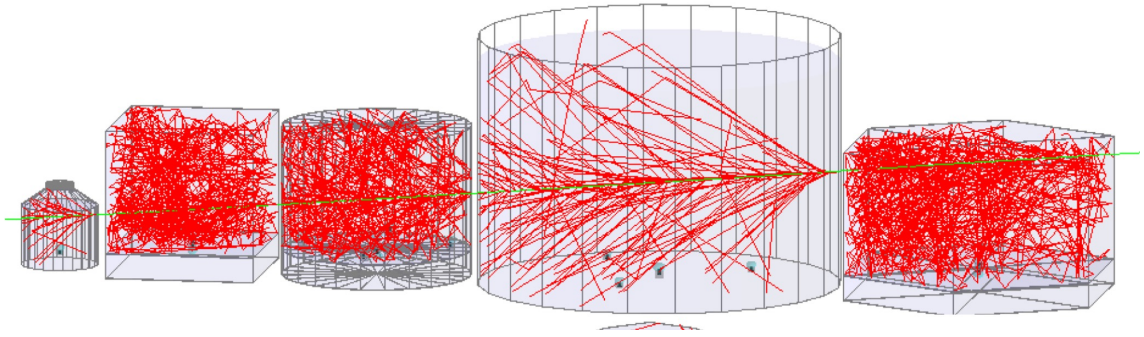




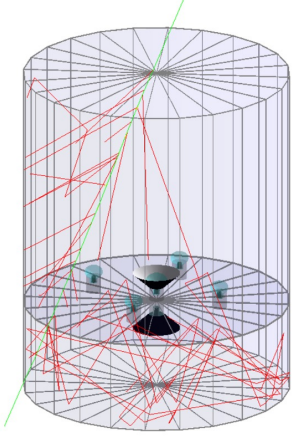
Many more proton than gamma: need to misclassify background very better than 1e-5

A lot of hits everywhere, difficult g/h separation

Tanks

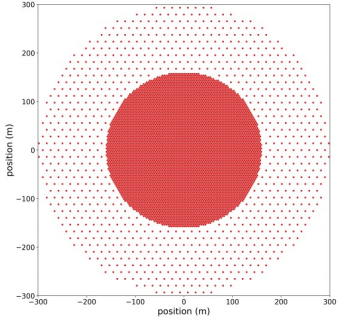


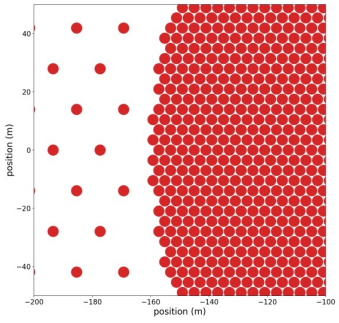
- Tank is basic detector unit
- Optimization on
  - Shape (cilindrical, hexagonal)
  - Height/width
  - One room/two room
  - What photosensors?



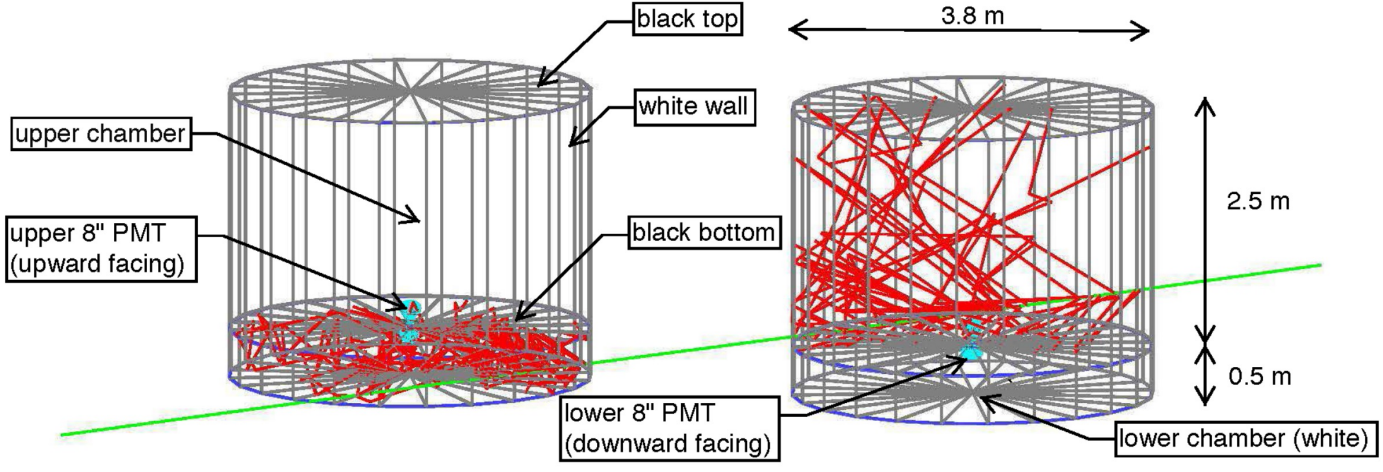
- ← Baseline are 2+ wide cathode PMTs

A Reference Configuration

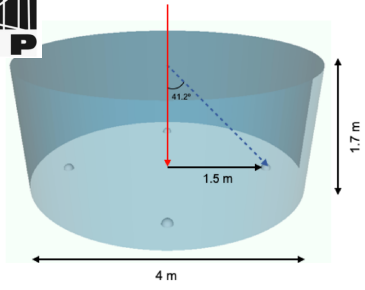


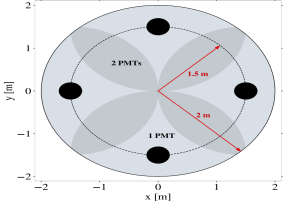


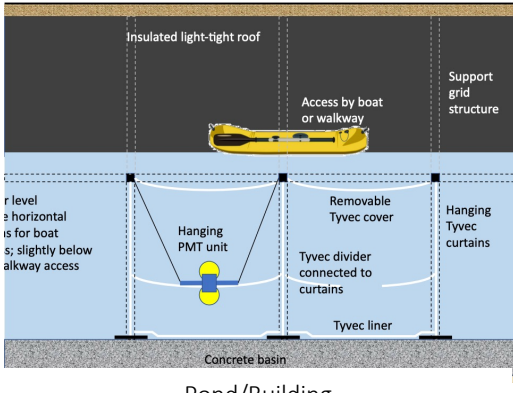
Component	Parameter	Reference design choice
Central array	Geometry	160 m radius circle = 80,400 m^2
	Fill factor	≈80%, 5,700 units
Outrigger array	Geometry	300 m outer radius = 202,200 m^2
	Fill factor	≈5%, 880 units
Simulated site	Altitude	4,700 m above sea level
	Geomagnetic field	B_x: 22.51 μG, B_Z: −5.28 μG†



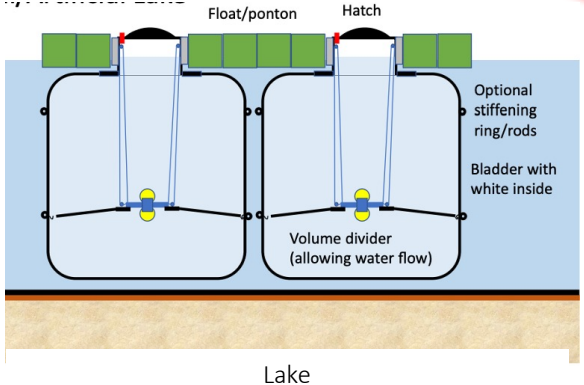
Alternatives







Pond/Building



Lake

← Automatically chosen by powerpoint! :-D

Padova

SWGO INFN Padova

Surname	Name	SWGO	Role
		%	
		300	
Arcaro	Cornelia	20	INFN postdoc
Batkovic	Ivana	50	PhD
Bottacini	Eugenio	10	PA
Busetto	Giovanni	50	PO
De Angelis	Alessandro	40	PO
Dorigo	Tommaso	10	INFN reas.
Doro	Michele	50	PA
Mariotti	Mose'	10	PO
Miceli	Davide	20	UNIPD postdoc
Nardi	Federico	10	PhD
Prandini	Elisa	10	RTDA
Strong	Giles	10	INFN postdoc
Zangrando	Lisa	10	INFN tech.

C. Arcaro

I. Batkovic

E. Bottacini

G. Busetto

A. De Angelis

T. Dorigo

M. Doro

M. Mariotti

D. Miceli

F. Nardi

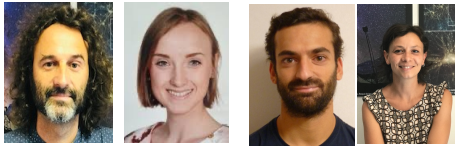
E. Prandini

G. Strong

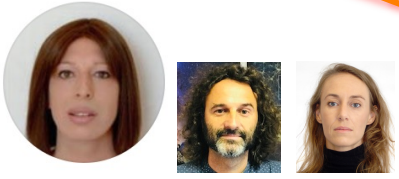
L. Zangrando

Padova Activities

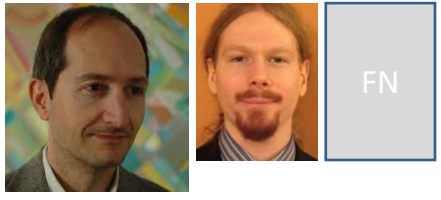
- Technical Development
  - → Novel photosensors: light trap
  - → Read-out electronics
  - → Novel tank design
- Simulations
  - → Array simulation
  - → Performance
- Science
  - → LIV searches
  - → AGN searches



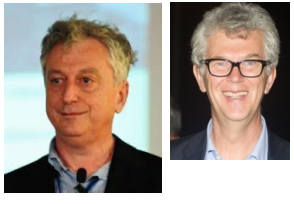
- Software
  - → SWGO pipelines



- Analysis
  - → Differential programming



- Steering



Strong collaboration with
- other INFN units
- Rest of the world

Ongoing works at POLIMI (Bovisa)

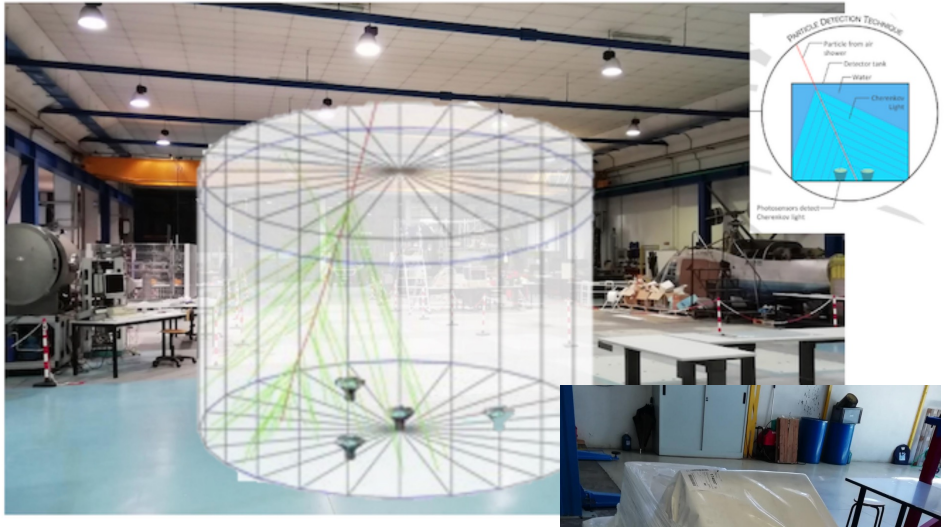
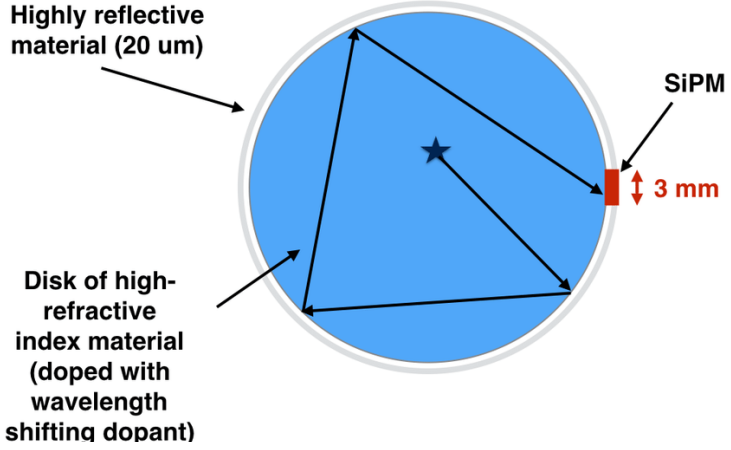


Fig 4. Artistic sketch of the water tank to be installed at the Wo
in the background). Pictures are only 4 PMTs at the location wh
installed. Top right is the detection technique.

- PD+TO+MI construction of a prototype tank at POLIMI
  - → Steel cilinder tank
  - → 1x10" PMT
  - → 4x4" PMT
  - → Water system
- Ongoing construction

Light traps photosensors and SiPMs



- The absorbed photons are reemitted isotropically and,
- If the refractive index of the WLS is larger than the refractive index of the medium, be trapped by total reflection.
- Read by a thin SiPM matrix

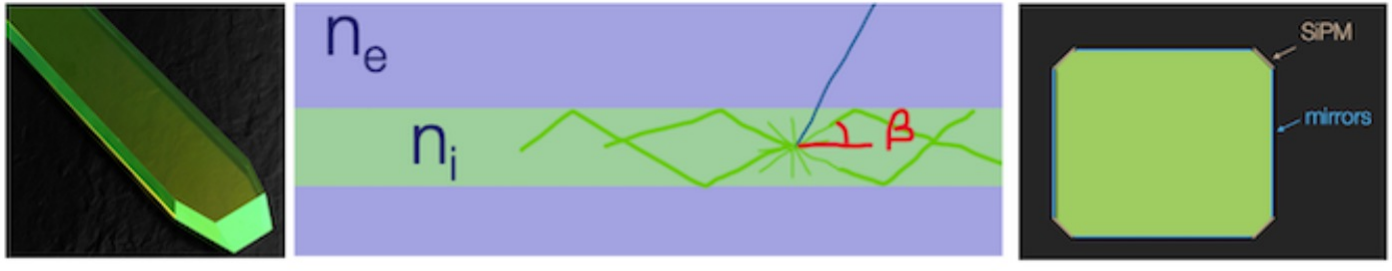
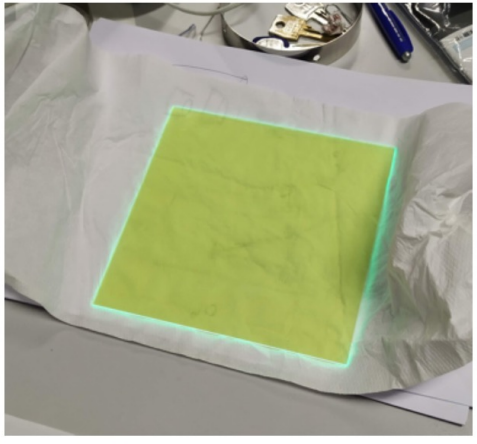


Fig. 5 A WLS (left), the scheme of light trapping in a thin WLS (centre), the tile equipped with a thin SiPM-match

Some pics



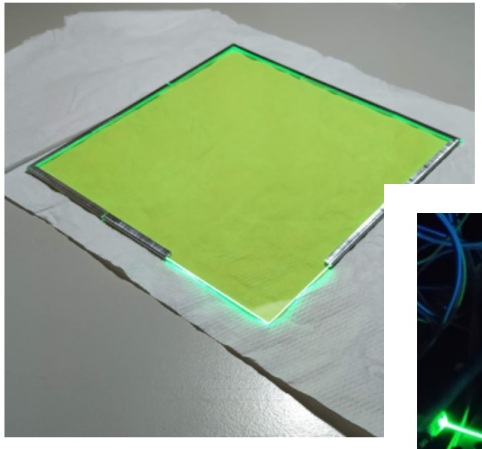


Fig 1) WLS tile 150x150x1 mm of WLS EJ282 from Eljen technology purchased for a light trap right panel several reflector strips are added to recycle (in part) photons that are not going SiPM

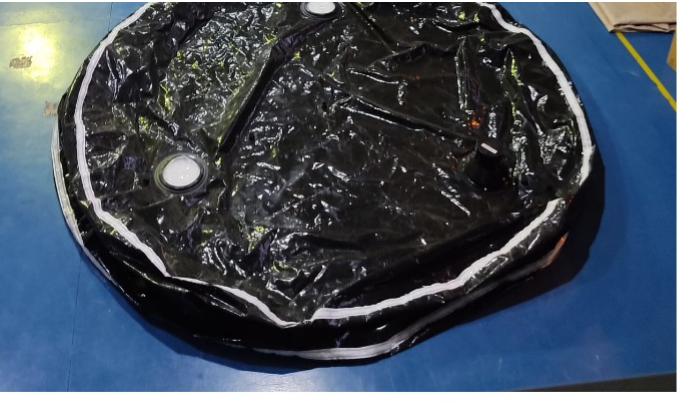
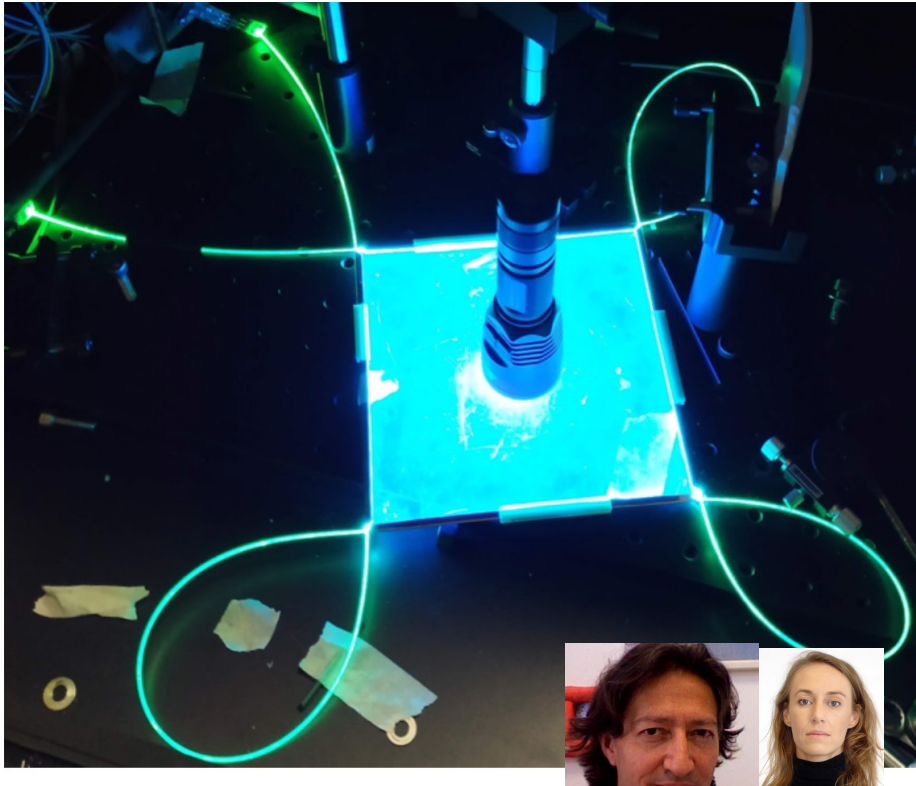


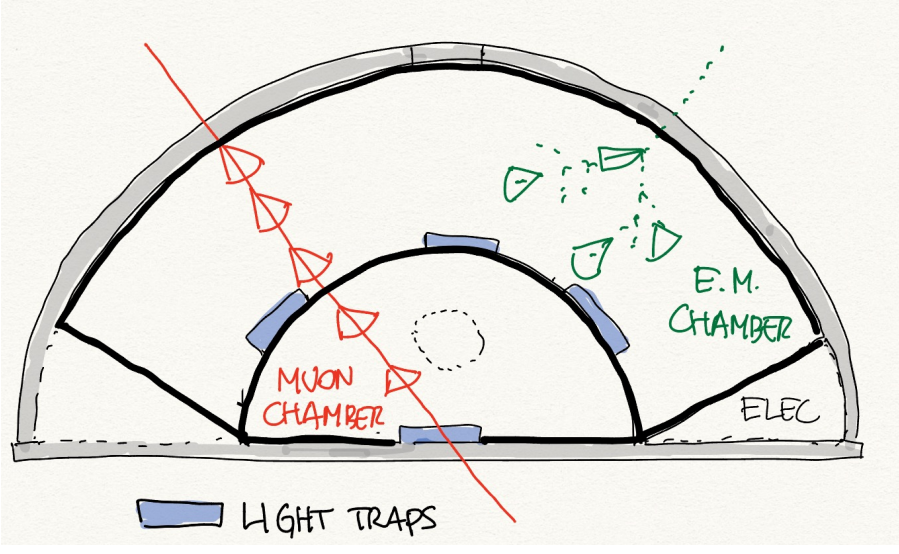
Figure 2.4: A liner from Auger observatory. Left: folded liner. Right: inflated liner for tests.



New tank ideas (Padova/Brasil)

- Photon traps can be 'sewed' in the plastic bladder
- Several photon traps can be 'imaging' withing a tank:
  - → good for g/h separation!

Figure 2.4: A liner from Auger observatory. Left: folded liner. Right: inflated liner for tests.



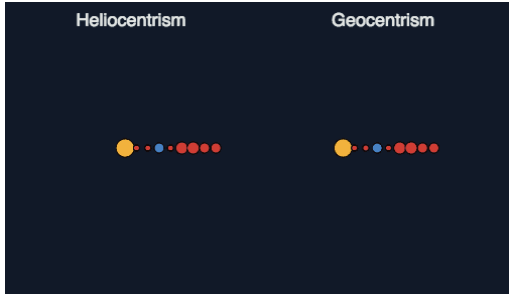
Conclusions

Milestones

Milestone	2019	2020				2021				2022				2023	
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
R&D Phase Plan Established		M1													
Science Benchmarks Defined			M2												
Reference Configuration & Options Defined				→	M3										
Site Shortlist Complete					→			M4							
Candidate Configurations Defined							→	M5							
Perf. of Candidate Configurations Evaluated								→			M6				
Preferred Site Identified									→			M7			
Design Finalised											→			M8	
Construction & Operation Proposal Complete													→		M9

SWGO R&D Phase Milestones	
✅	R&D Phase Plan Established
✅	Science Benchmarks Defined
✅	Reference Configuration & Options Defined
✅	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

Conclusions



- The discovery of Pevatrons strongly ask for an instrument in the S-Hemisphere! May solve the (galactic) cosmic ray puzzle!
- SWGO has now strong momentum toward array design!
  - → Window for relevant contribution strongly closing
- Padova
  - → Ready with strong contribution plans
  - → Need committed persons in Padova

Thanks!

PNRR CTA+

- In this project we plan to install and operate the **engineering array** of the final experiment…
- The Padova group is proposing
  - → alternative and cheap Cherenkov light sensors that can be used together or instead of the PMT,
  - → the development of such sensors is part of this project.
- The main idea is to have segmented light sensors made by an organic material acting as wavelength shifter (WLS), part of the photons emitted are then trapped and transferred to a SiPM. Each elementary cell of the water Cherenkov detector will be equipped with several photodetectors' pads.
- 56K 1y postdoc + 62k equipment + 9k overhead

SWGO Italia 2022

- Still under construction for 2023
- Torino
  - → Tank, array simulations
  - → Prototype
- Milano
  - → Tank construction
  - → Water purification
  - → Electronics
- Napoli
  - → Novel photosensors
  - → Photosensors massive characterization

Ricercatori						
	Nome	Età	Contratto	Qualifica	Aff.	%
1	Bisconti Francesca		Associato	Assegnista	CSN II	70
2	Chiavassa Andrea		Associato	Prof. Associato	CSN II	70
3	Depaoli Davide		Associato	Dottorando	CSN II	20
	Numero Totale Ricercatori			3	FTE: 1.60	

Ricercatori						
	Nome	Età	Contratto	Qualifica	Aff.	%
1	Caccianiga Lorenzo		Dipendente	Ricercatore	CSN II	30
2	Fazzi Alberto		Associato	Prof. Associato	CSN V	10
3	Galelli Claudio		Associato	Dottorando	CSN II	30
	Numero Totale Ricercatori			3	FTE: 0.70	

Ricercatori						
	Nome	Età	Contratto	Qualifica	Aff.	%
1	Calabrese Roberta		Associato	Dottorando		20
2	Chianese Marco		Associato	Ricercatore A Tempo Determinato Tipo A		40
3	Colalillo Roberta		Associato	Ricercatore A Tempo Determinato Tipo A	CSN II	10
4	Guarino Fausto		Associato	Prof. Ordinario	CSN II	20
5	Morisi Stefano		Associato	Ricercatore B Tempo Determinato Tipo B	CSN IV	20
6	Rossi Biagio		Dipendente	Ricercatore	CSN I	15
7	Saviano Ninetta				CSN IV	30
	Numero Totale Ricercatori			7	FTE: 1.55	

Richieste sezione

- Richieste INFN in discussione
- Richieste Padova
  - Meccanica
    - ✓ Non per 2023
  - Elettronica
    - ✓ Non per il 2023
  - Informatica
    - ✓ Lisa Zangrando 0.1 FTE