A next-generation gamma-ray observatory powered by Machine Learning techniques

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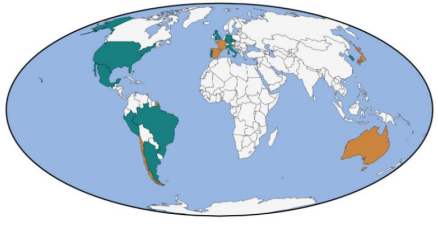
Southern **W**ide-field **G**amma-ray **O**bservatory (SWGO)

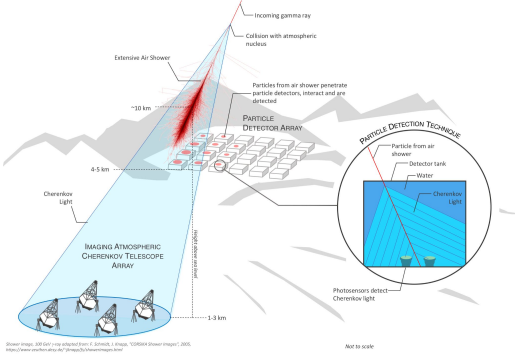
~3-year R&D project to design and plan the next generation wide field-of-view gamma-ray able to survey and monitor the Southern sky

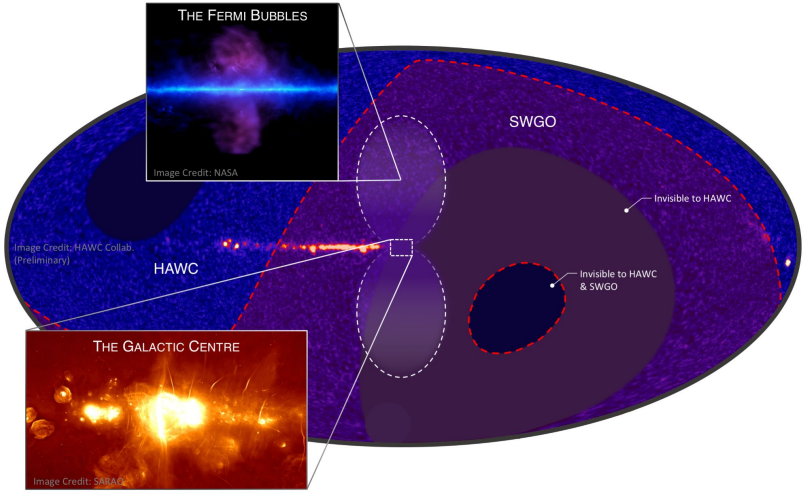
- **S**outhern **W**ide-field **G**amma-ray **O**bservatory (SWGO)
  - Formed at July 1st 2019
  - 12 Countries
  - ~50 institutes
  - More than 100 scientists
  - To be built in South America

The Southern Wide-field Gamma-ray Observatory



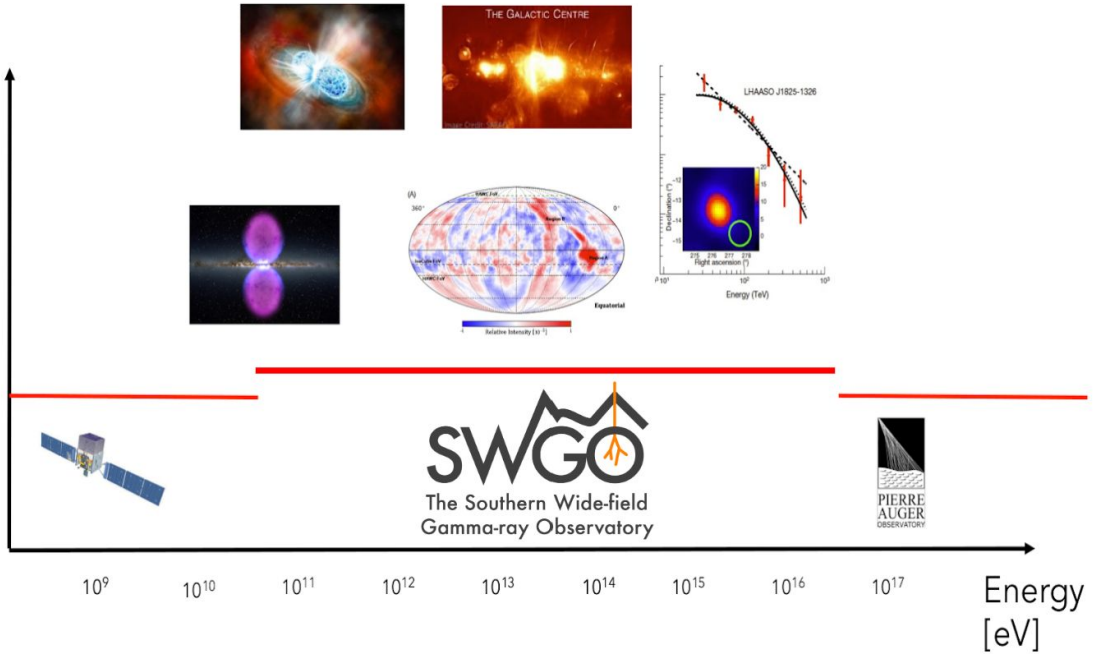
	SWGO R&D Phase Milestones	
✓	M1	R&D Phase Plan Established
✓	M2	Science Benchmarks Defined
✓	M3	Reference Configuration & Options Defined
	M4	Site Shortlist Complete
✓	M5	Candidate Configurations Defined
	M6	Performance of Candidate Configurations Evaluated
	M7	Preferred Site Identified
	M8	Design Finalised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





Source: https://www.swgo.org/

Energy range covered with SWGO

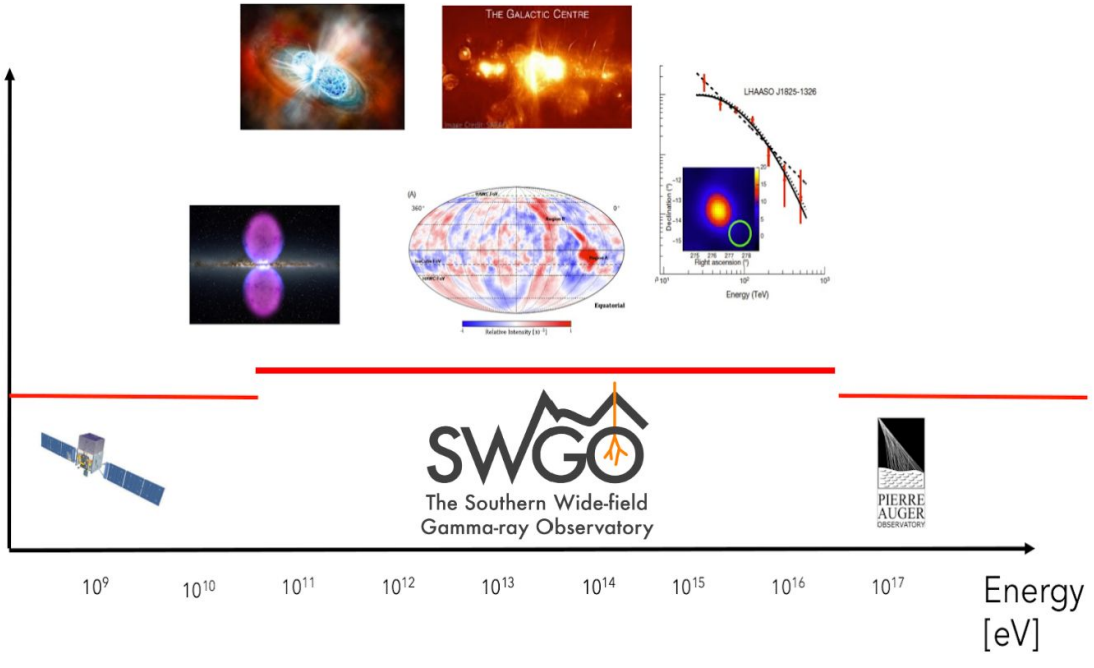


From many tens of GeV to many tens of PeV.

Energy range covered with SWGO

Lowest energies:

- High altitude
- Compact array
- Dedicated ground detector design



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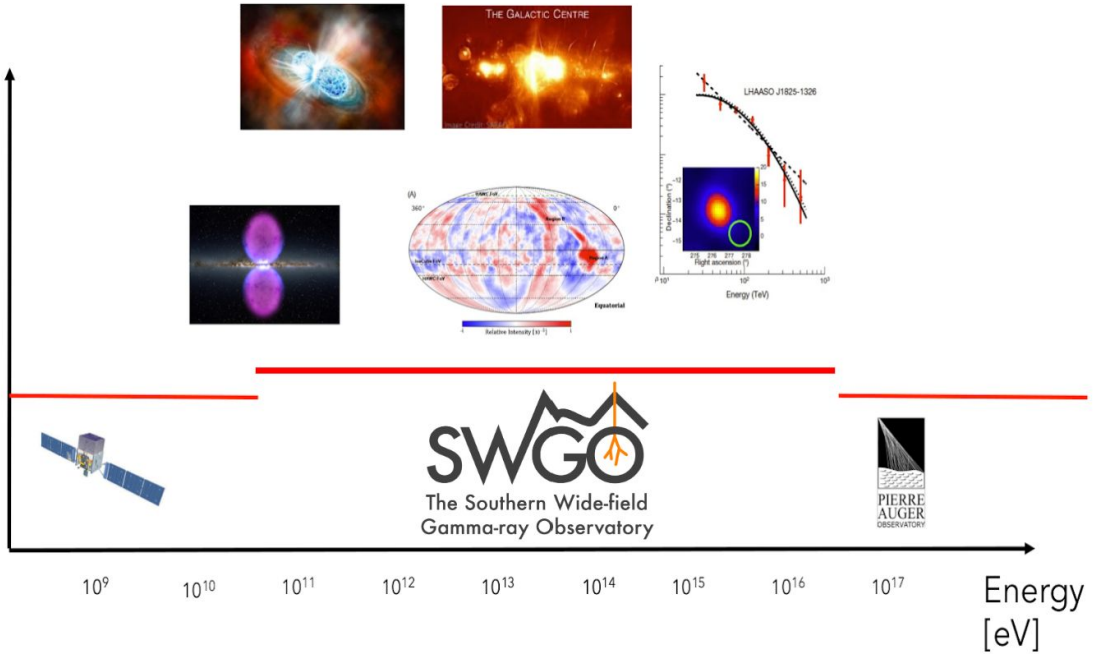


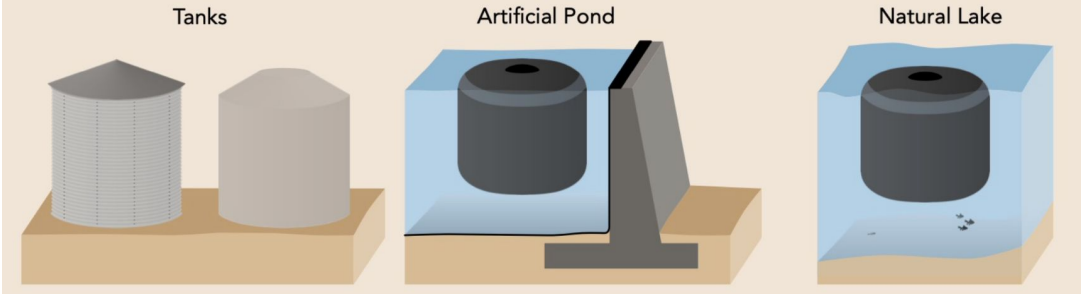
Highest energies:

- Modular
- Sparse array
- Large array area (~1 km² or more)

From many tens of GeV to many tens of PeV.

Detector design options

Possible detectors for SWGO



Detector design options

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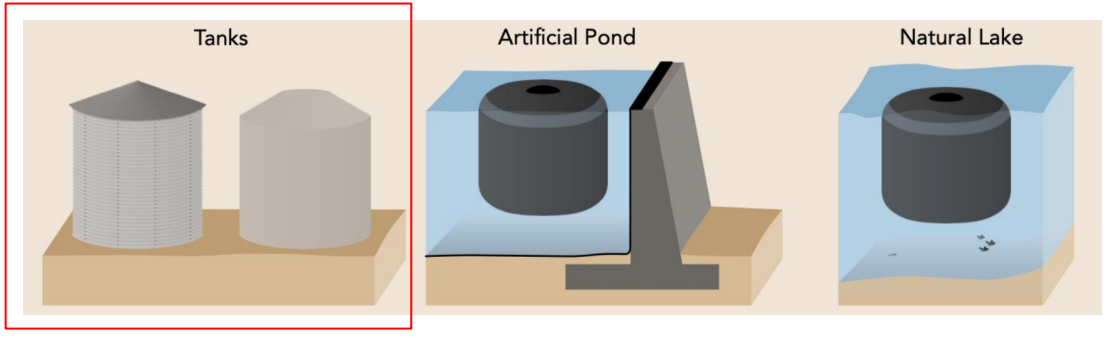


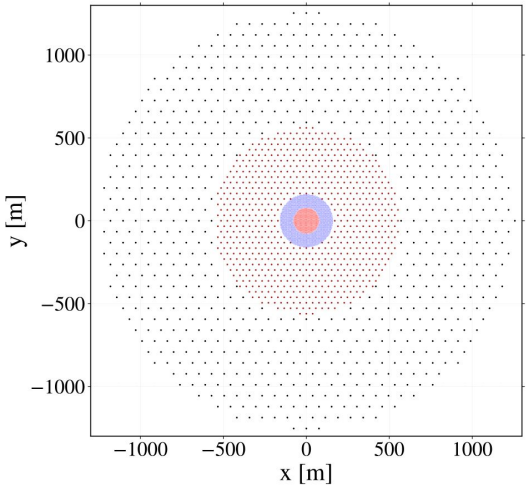
A scalable array

Phase I – very high fill factor;
area up to 20 000 m2

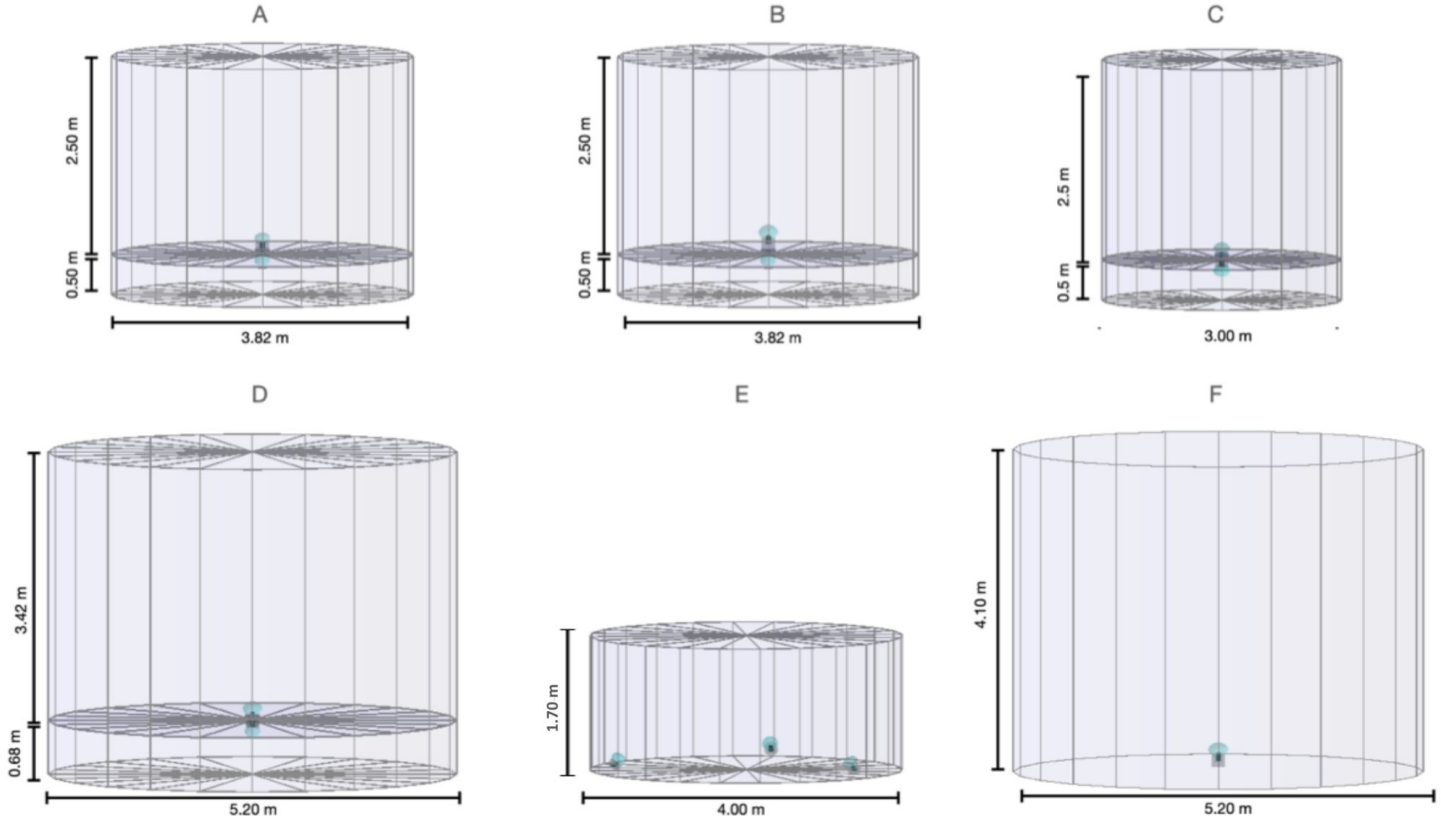
Phase II – low fill factor;
area up to 1km2

Phase III – high fill factor;
area up to 80 000 m2;

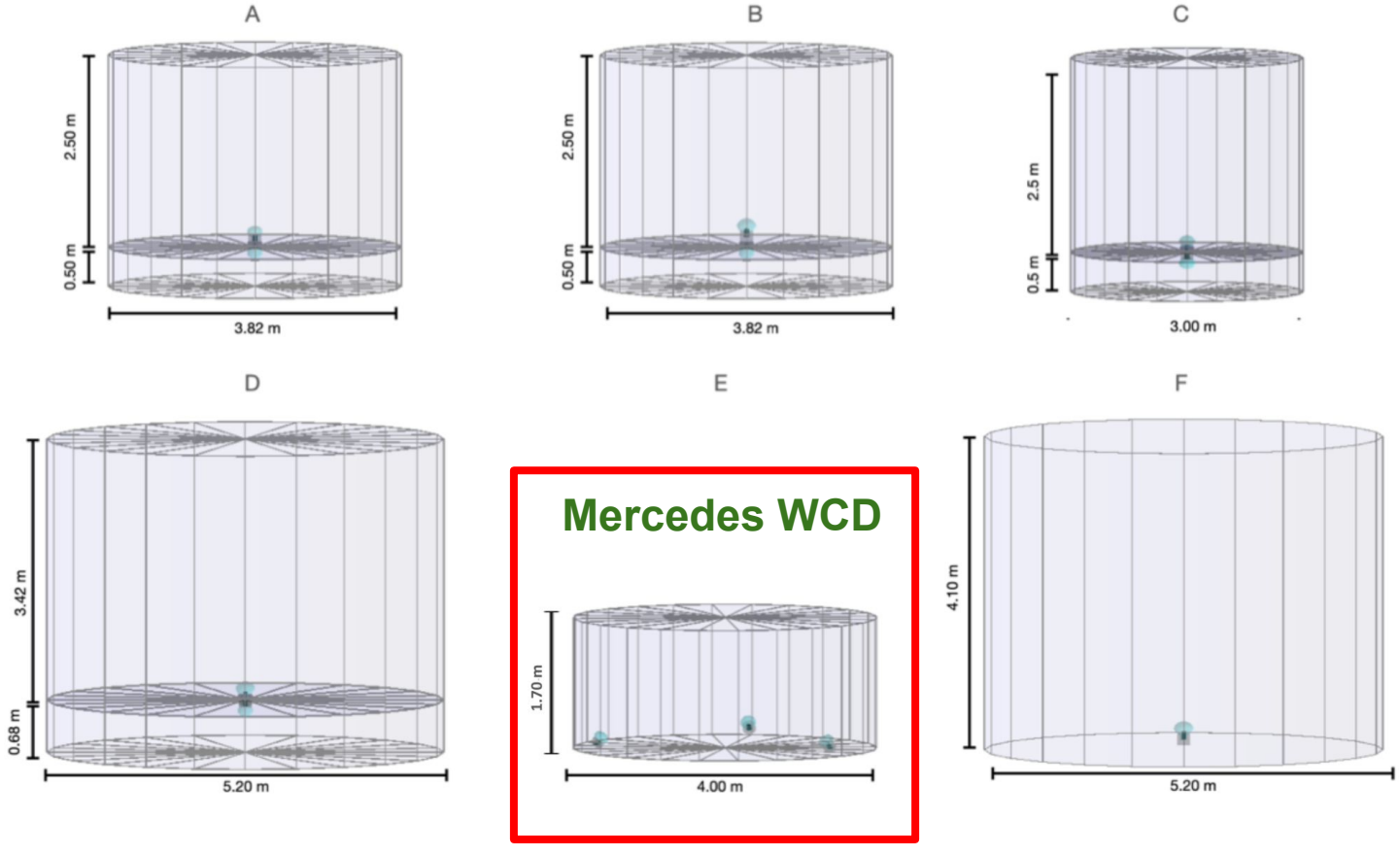
Phase IV – very low fill factor;
area up to 5km2.



WCD options


A
2.50 m
0.50 m
3.82 m
B
2.50 m
0.50 m
3.82 m
C
2.5 m
0.5 m
3.00 m
D
3.42 m
0.68 m
5.20 m
E
1.70 m
4.00 m
F
4.10 m
5.20 m

WCD options


A
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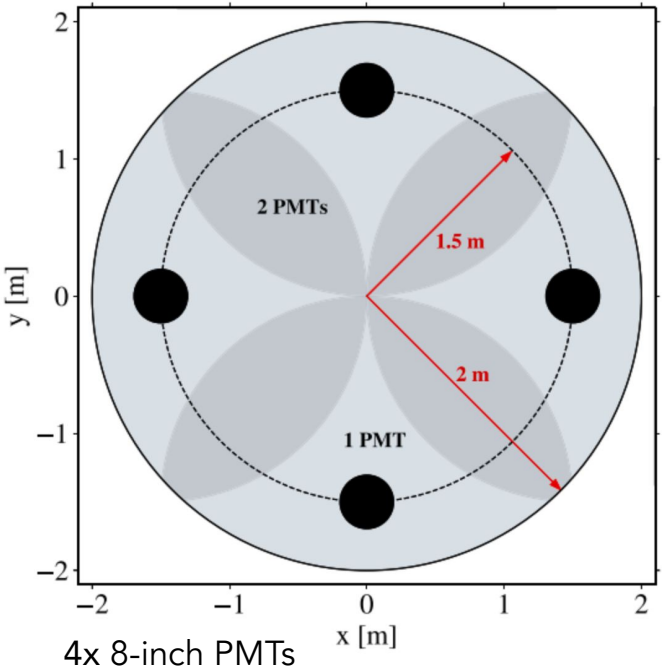
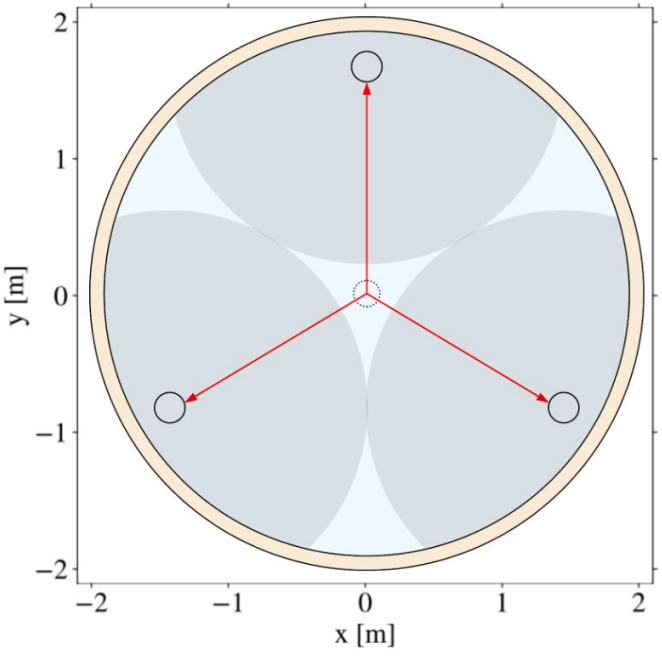
3.00 m
D
3.42 m
0.68 m
5.20 m
E
Mercedes WCD
1.70 m
4.00 m
F
4.10 m
5.20 m

Mercedes WCD: Explore asymmetries to tag muons



4x 8-inch PMTs
Water height 1.7 m
Tyvek walls

Publications:
Eur.Phys.J.C 81 (2021) 6, 542.
Neural Comput & Applic 34, 5715–5728 (2022).
Physics Letters B 827, 136969 (2022)

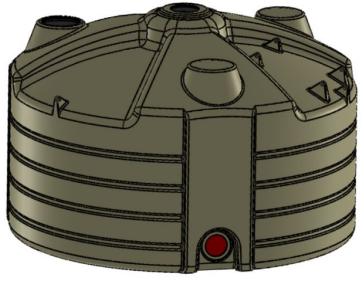


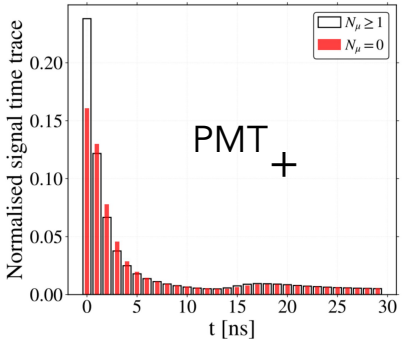
3x 8-inch PMTs
Water height 1.7 m
Tyvek walls

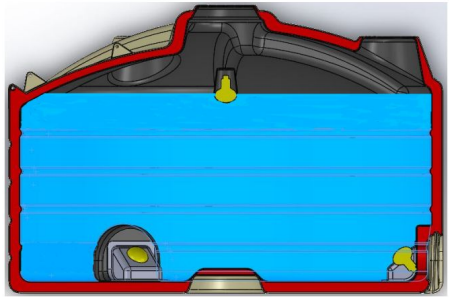
Publications:
arXiv:2203.08782

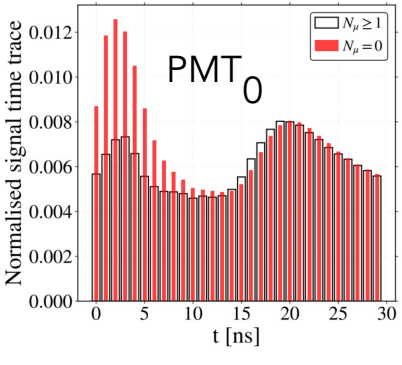
Simulation and ML model

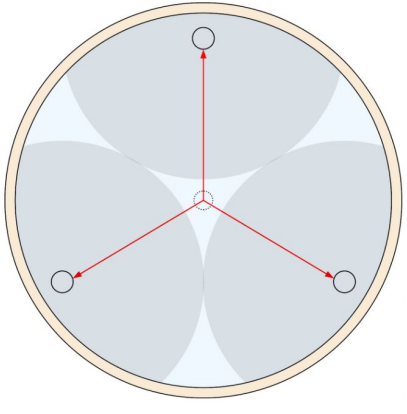
CNN to get the probability that a muon has passed through the WCD.

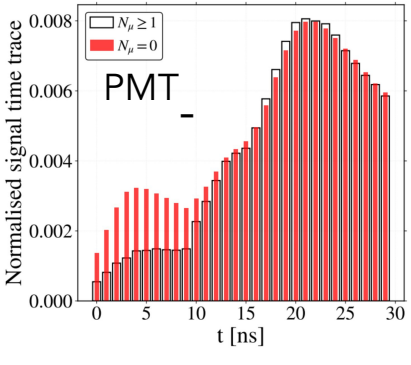












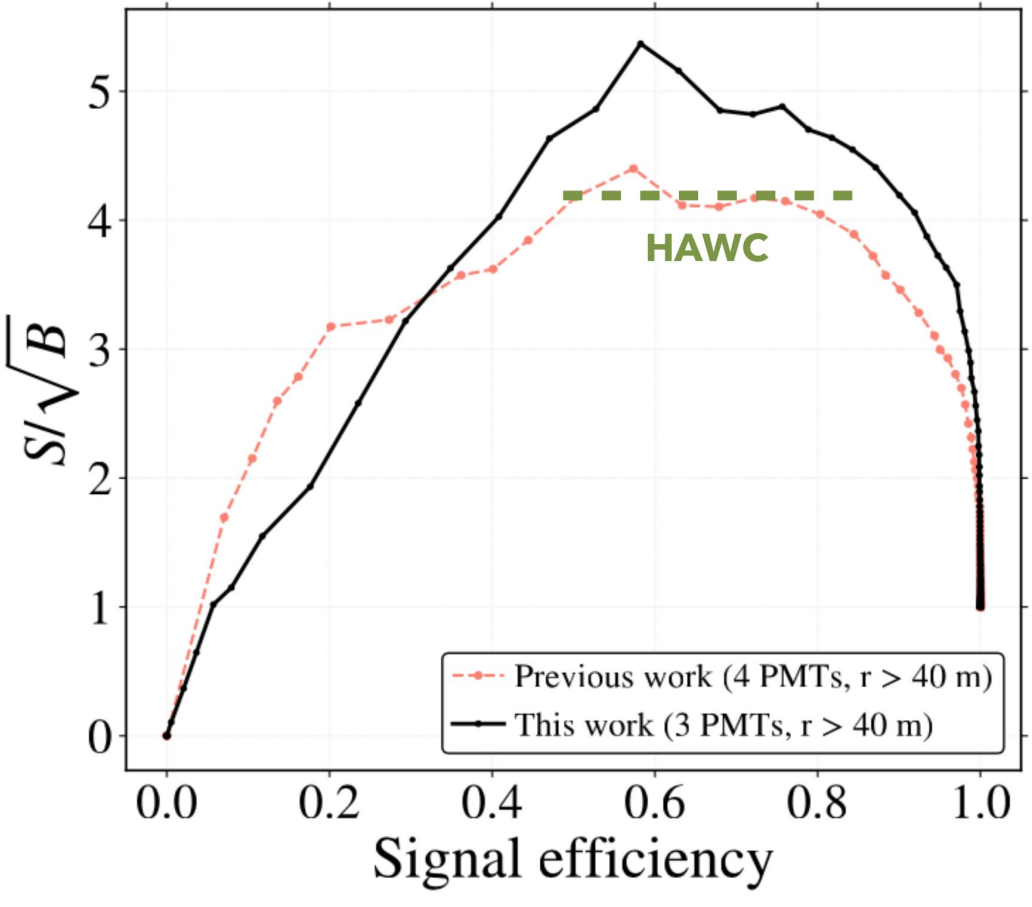
arXiv:2203.08782

Simulation and ML model

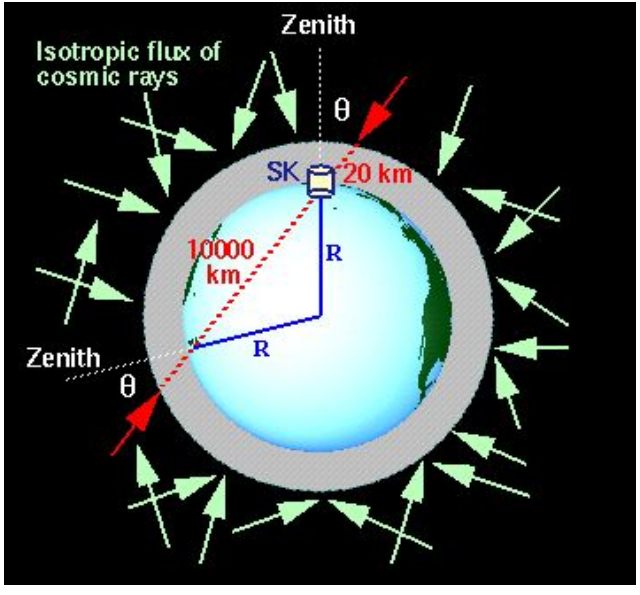
- Variable to evaluate the gamma/hadron discrimination power and the muon quantity in the shower.

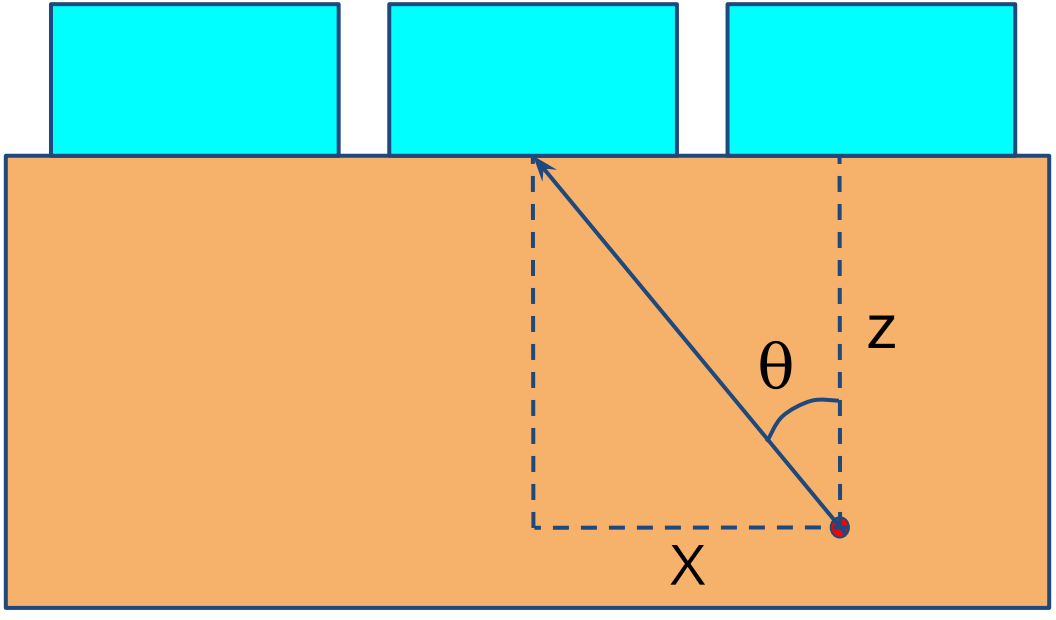
$$P_\mu = \sum_{i=1}^{N_S} P_\mu^{(i)}$$

- Excellent gamma/hadron discrimination at E ~ 1TeV.
  - S/sqrt(B) ~ 5.
  - Submitted to EPJC (arXiv:2203.08782).
  - Previous work with 4 PMTs: Eur.Phys.J.C 81 (2021) 6, 542.



Detection of Up-going neutrinos





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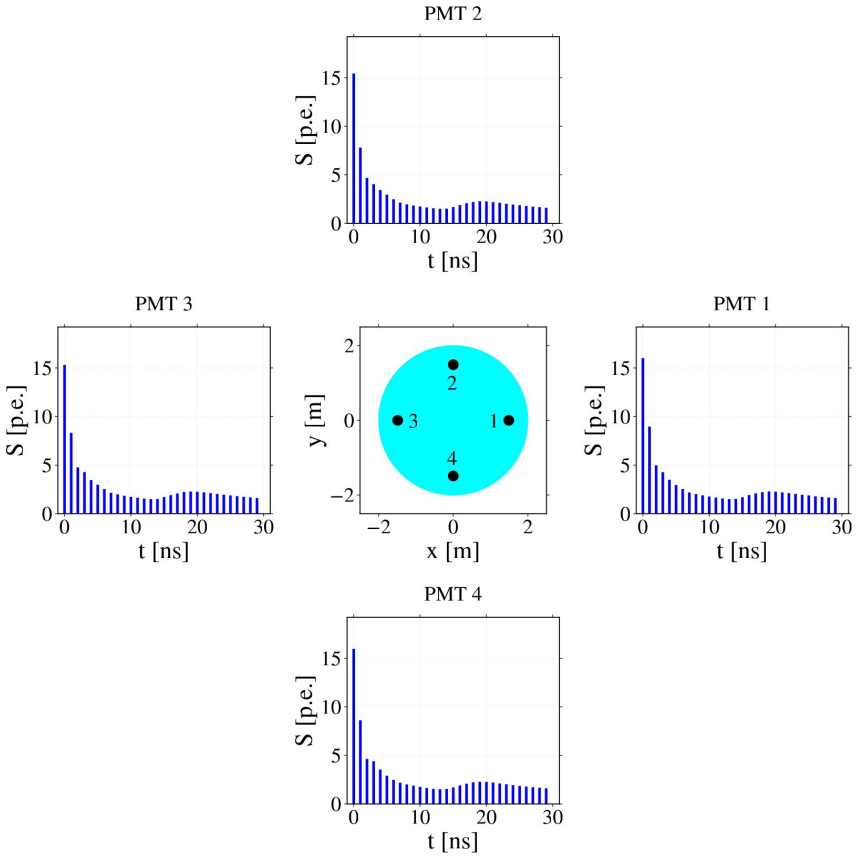
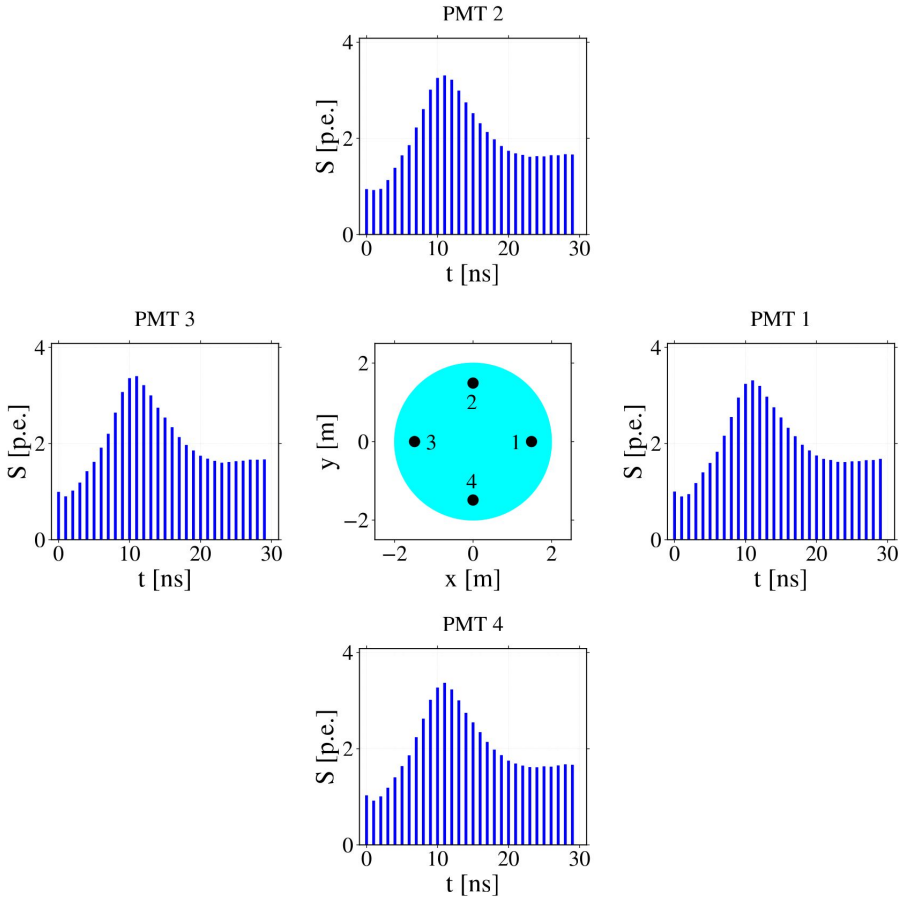
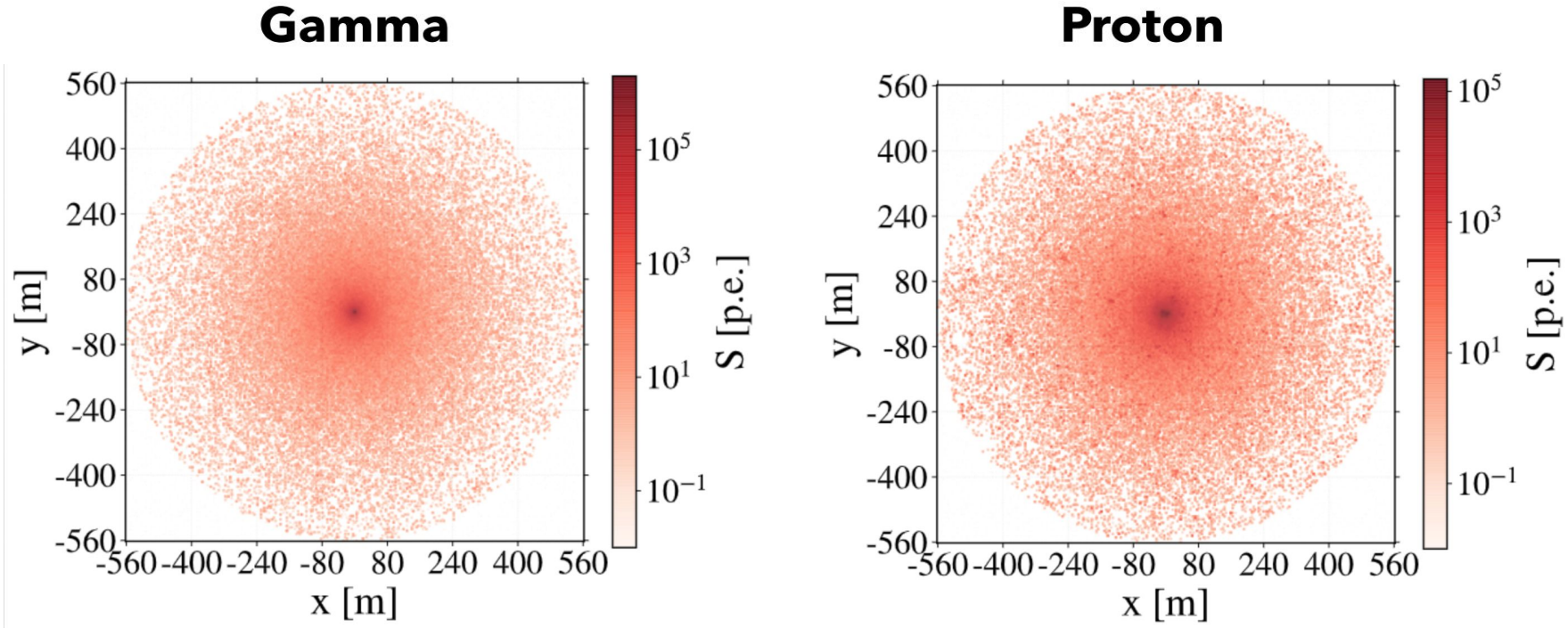


Down-going



Up-going

Future steps: Enhance γ/hadron separation



Combine muon info at WCD with the shower footprint.

Collaboration with the University of Granada (and summer students)

Conclusions

- Studies at few TeV show that it is possible to perform an excellent muon tagging/counting using a small-WCD with multiple PMTs.
  - → Excellent gamma/hadron discrimination.
  - → The method works in vertical/inclined showers and compact/sparse array making it interesting for SWGO.
  - → arXiv:2203.08782 [physics.ins-det]
- Encouraging preliminary results for up-going neutrinos detection (from 10 GeV to 100 TeV).
- On-going work and next steps:
  - → Reconstruction of energy and direction for neutrino events.
  - → γ/h discrimination combining the WCD muon info with shower patterns.
  - → Optimisation studies to be conducted: WCD dimensions, number of PMTs, array fill factor.

Thanks for your attention!

Acknowledgements:
IDPASC PhD grant PRT/BD/151553/2021