LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Potential of Water-Cherenkov Air Shower Arrays for detecting transient sources of high-energy astrophysical neutrinos

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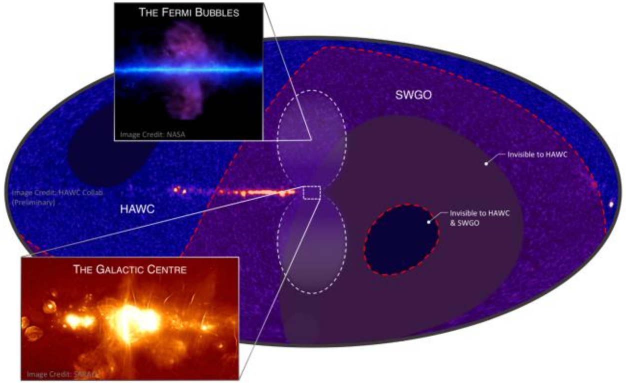
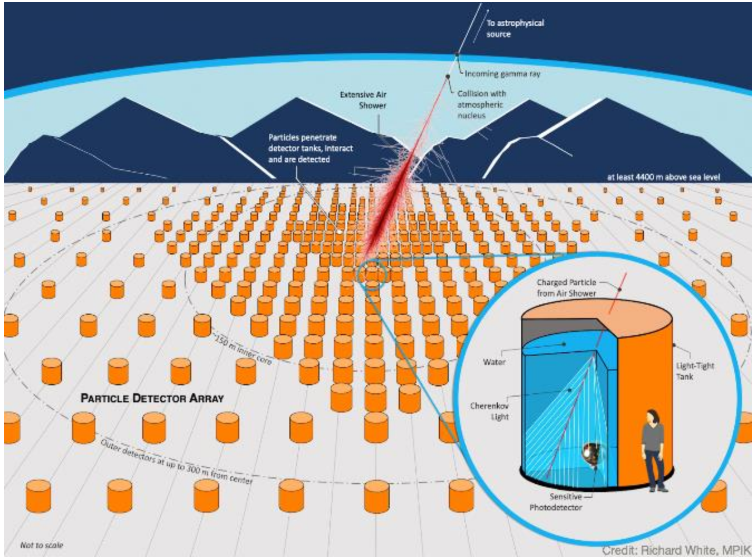
Funding project: PTDC/FIS-PAR/4300/2020
IDPASC PhD grant PRT/BD/151553/2021
https://doi.org/10.54499/PRT/BD/151553/2021

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

R&D Phase of SWGO

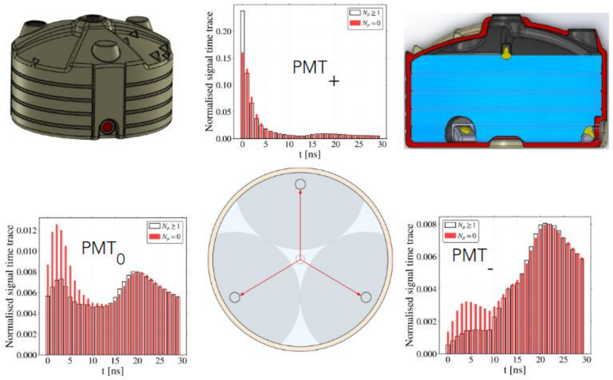
- Wide-field of view **Gamma-ray observatory** in the **Southern Hemisphere**.
- **Ground-based** using water Cherenkov Detectors (**WCDs**).
- To be built at **4770 m** a.s.l. in the Atacama Astronomical Park, **Chile**.
- **Access to the Galactic Center.**
- It was formed in 2019 and it is **about to finish the R&D phase.**





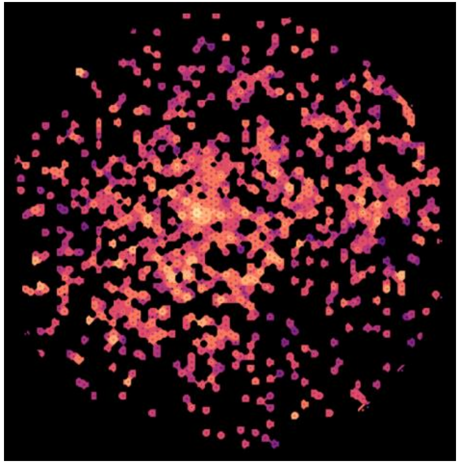
	SWGO R&D Phase Milestones	
✓	**M1**	R&D Phase Plan Established
✓	**M2**	Science Benchmarks Defined
✓	**M3**	Reference Configuration & Options Defined
✓	**M4**	Site Shortlist Complete
✓	**M5**	Candidate Configurations Defined
✓	**M6**	Performance of Candidate Configurations Evaluated
✓	**M7**	Preferred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

Diverse Research Opportunities with WCD Arrays



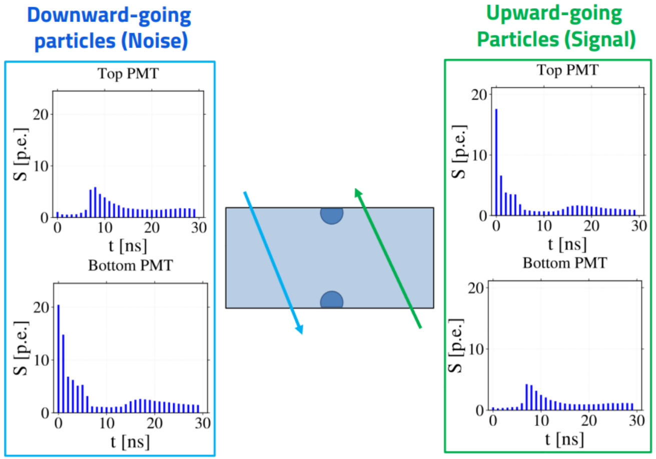
Muon identification in WCDs

- **EPJC 81 (2021) 6, 542.**
- **NCA, 34, 5715–5728 (2022).**
- **Physics Letters B 827, 136969 (2022)**
- **EPCJ 82 (2022) 10, 899.**



Footprint analysis

- **arXiv:2409.11093** (submitted to **PRD**)



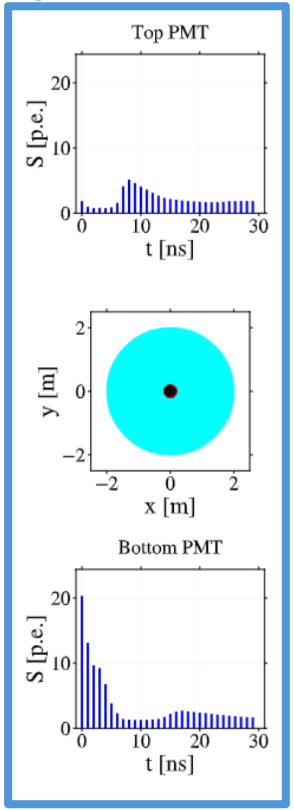
Upward-going neutrino identification

- **PRD 110, (2024), 2, 023032**
- Improvements on angular reconstruction (to be submitted)

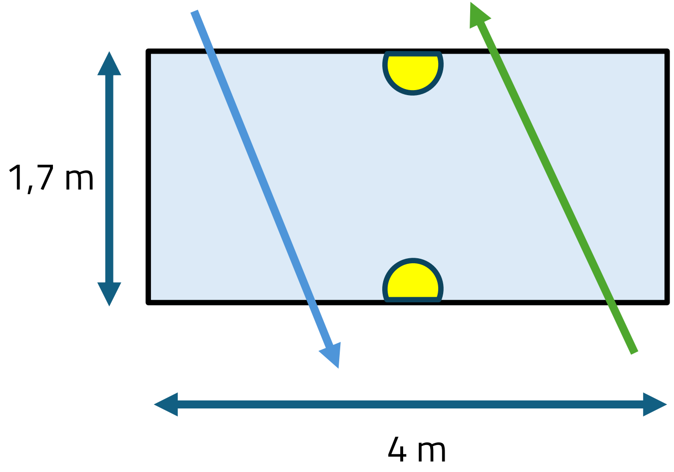
My research in the SWGO Group at LIP

Is it possible to distinguish down- from up-going particles in a single WCD?

Downward-going particles (noise)



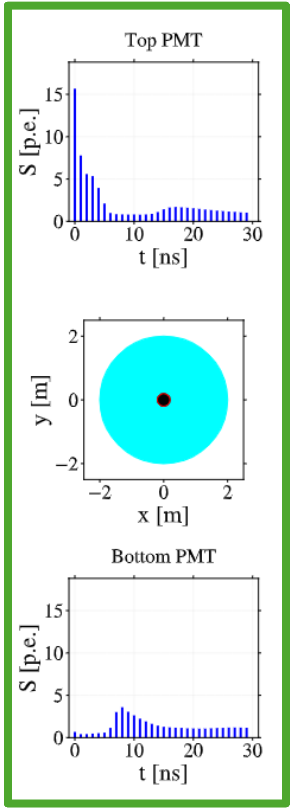
Background – cosmic ray events ($\theta \leq 40°$)



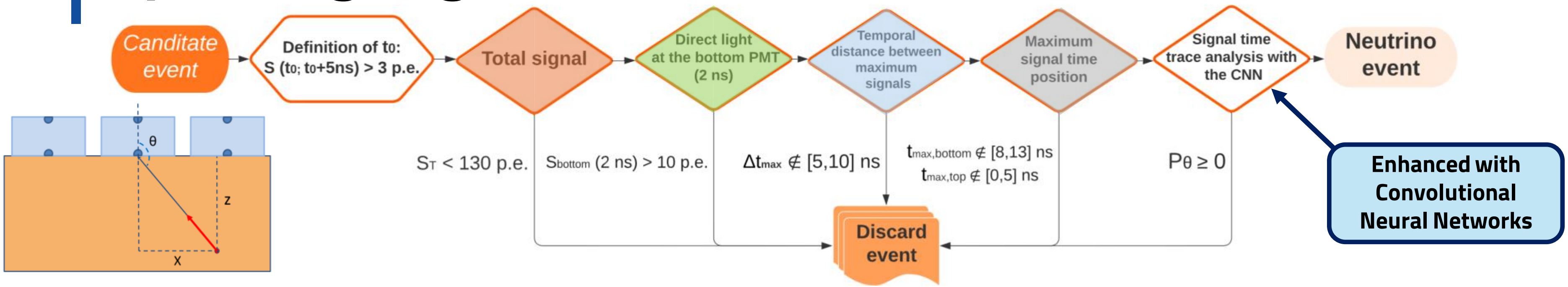
Average signal time traces in PMTs

Signal – neutrino events ($\theta > 140°$)

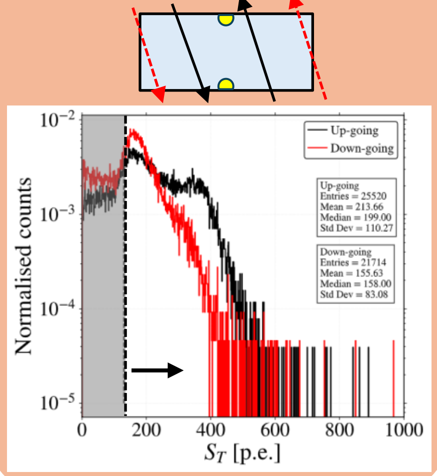
Upward-going particles (signal)



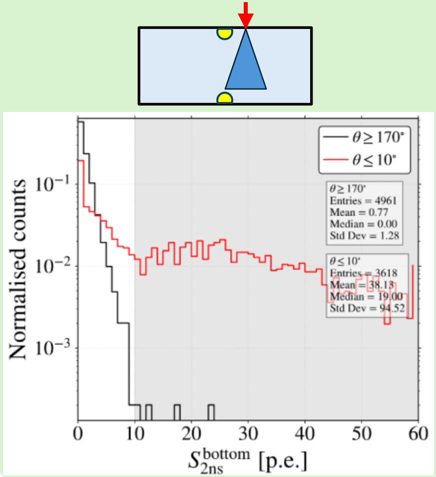
Upward-going neutrino identification chain



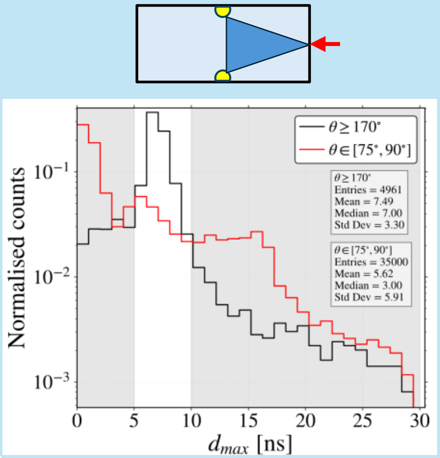
Accept only "good" geometries



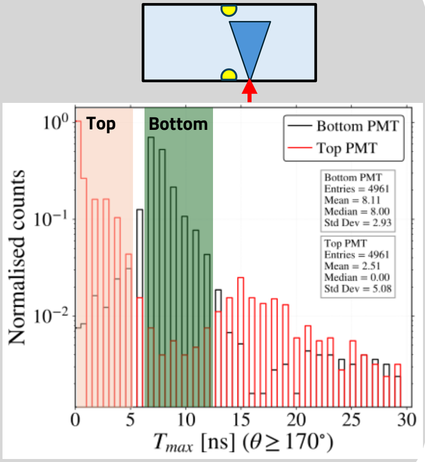
Down-going events



Horizontal events

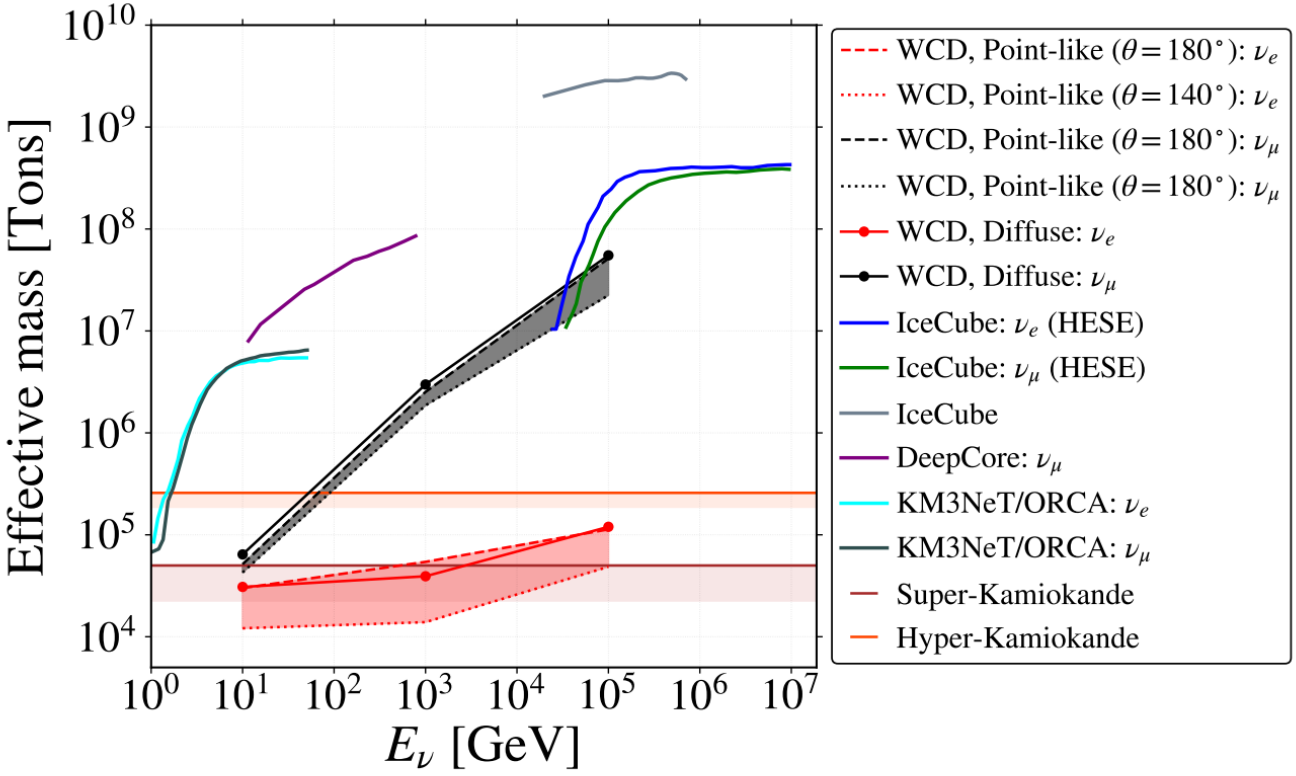


Geometry for up-going events



A **background-free** experiment with **high detection efficiency** achieved through the analysis of **PMT signal time traces.**

Effective mass: $M_{\text{eff}}(E_\nu) = 2\pi \; N_{\text{stations}} \int \sin\theta \; \varepsilon(x, y, D, \theta, E_\nu) \; \mathrm{d}x \; \mathrm{d}y \; \mathrm{d}D \; \mathrm{d}\theta \quad [\mathrm{g}]$

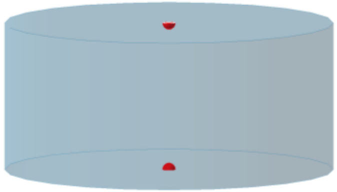


Large **effective mass similar** to **dedicated neutrino experiments** using a 1 km^2 **array**

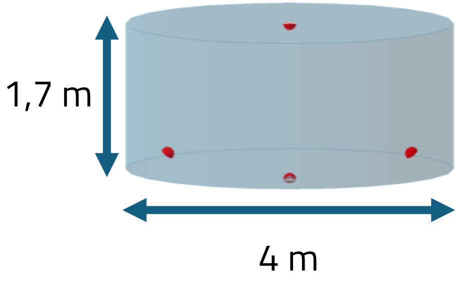
Physical Review D, 2024, vol. 110, no 2, p. 023032.

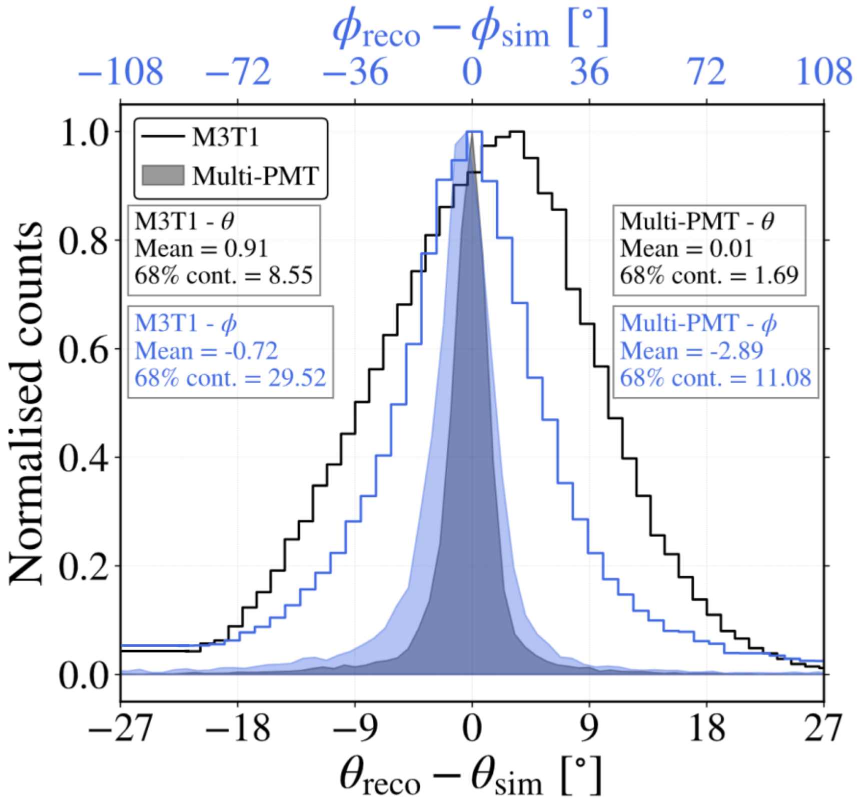
Angular reconstruction

M1T1 **design**

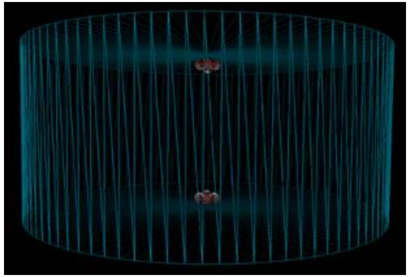


M3T1 **design**

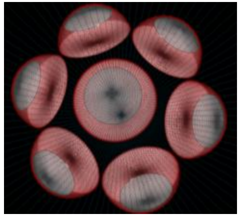




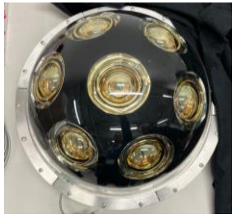
Multi-PMT **design**



Simulation



Prototype



Competitive ML-based angular reconstruction by placing multiple PMTs on the bottom surface or using ***multi-PMTs***.

Conclusions

- Upward-going neutrino identification using **PMT signal time traces:**
  - **PRD 110, (2024), 2, 023032**
- A **background-free** experiment.
- Large **effective mass similar to dedicated neutrino experiments** using a $1\ \mathrm{km}^2$ array.
- ML-based **angular reconstruction with a resolution of a few degrees** by placing **multiple PMTs** on the bottom surface **or** using **multi-PMTs.**

Thanks!

Any questions?

You can also contact me at **borjasg@lip.pt**

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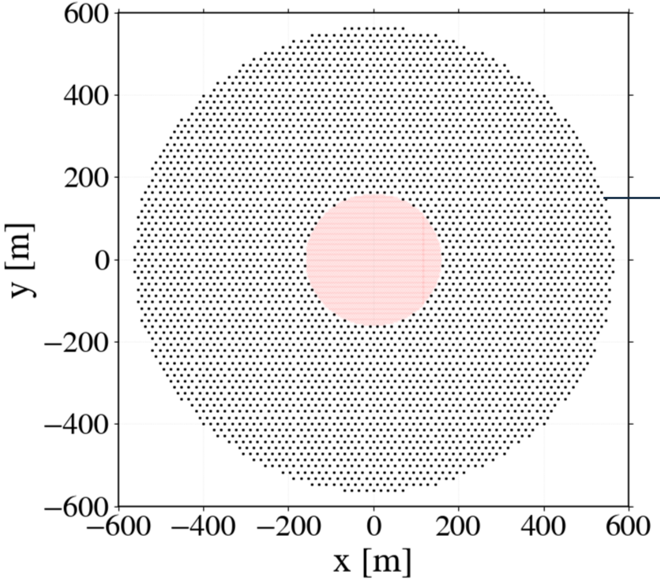
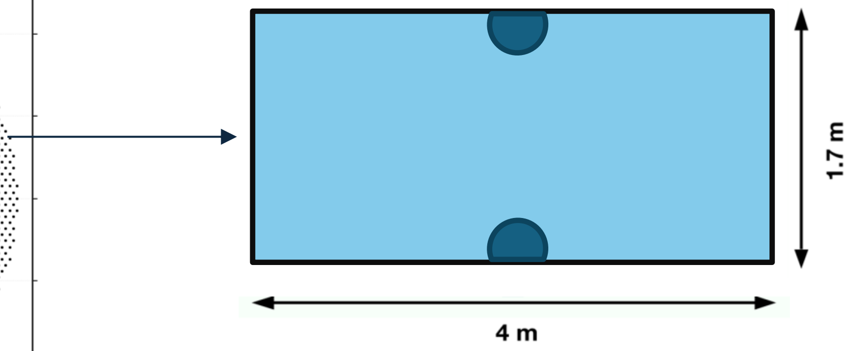
IDPASC
SWGO The Southern Wide-field Gamma-ray Observatory

Backup slides

Detector and Array layout



M1T1 WCD: 2 PMTs of 8’’



$A = 1\ Km^2$

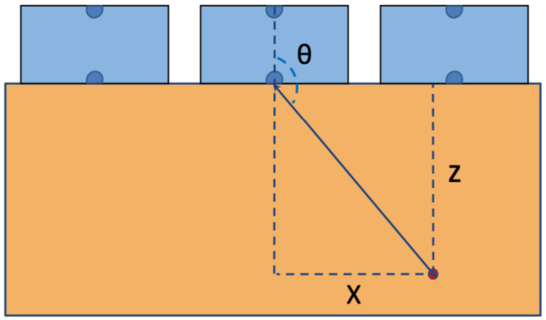
- Inner denser array: 5 720 stations, $r \in [0; 160]$ m, and FF $= 85$ %.
- Outer sparser array: 3 660 stations, $r \in [160, 564]$ m, and FF $= 5\%$.

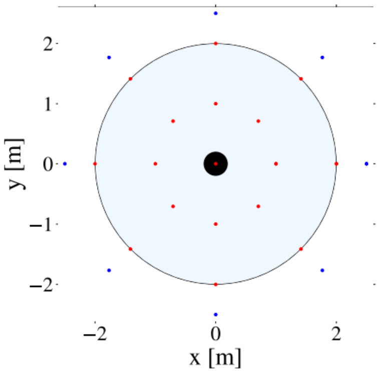
Effective mass calculation

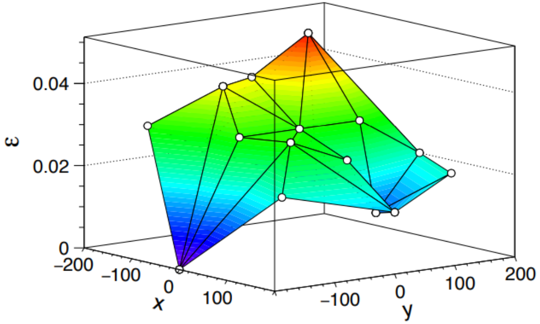
Effective mass for point-like sources

$$M_{\text{eff}}\,(E_\nu, \theta) = \int N_{\text{stations}}\ \varepsilon(x, y, D, \theta, \phi, E_\nu)\ dx\ dy\ dD\ [g]$$

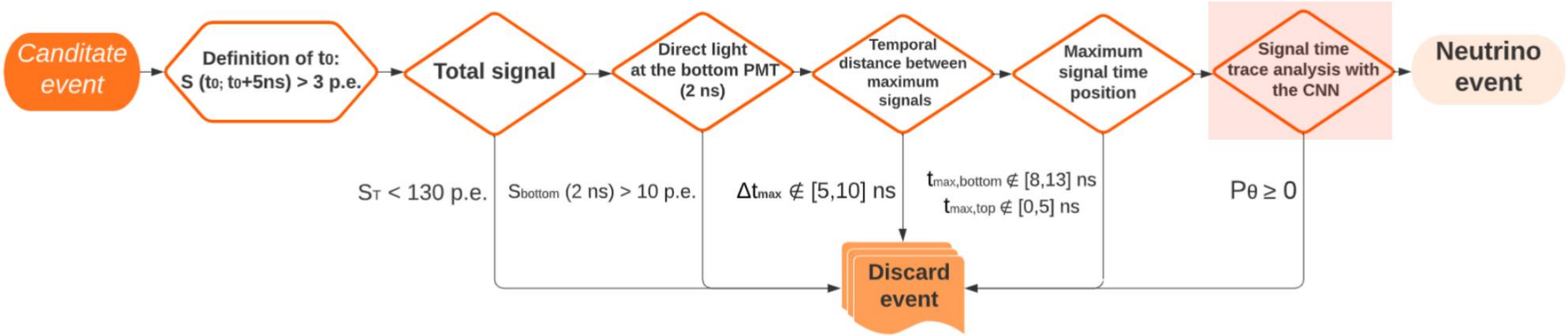
$$\varepsilon(x, y, D, \theta, E_\nu) = \frac{\text{number of events selected as upgoing}}{\text{number of events simulated}} \in [0,1]$$







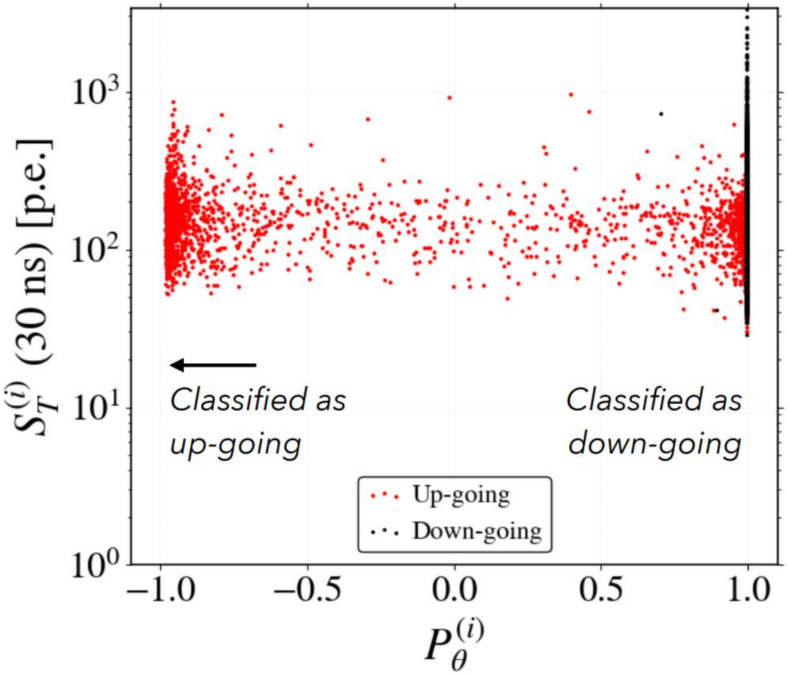
Strategy to discriminate neutrinos with CNNs



- **Input:** Normalised signal time traces + Previous vars for cuts
- **Label:** -1 for up-going and 1 for down-going particles.
- **Output:** Pθ ∈ [-1,1].
- Training particles: μ- (2 GeV), e- (1 GeV), p (10 GeV), ν_e and ν_μ (10 GeV) .
- Testing particles: ν_e and ν_μ (10 GeV, 1 TeV, 100 TeV) .
- Trigger for T_0 so that S(T_0 ; T_0 + 5 ns) > 3 p.e.
- **Analyse the signal time trace $(\mathrm{T_0; T_0 + 30\,ns})$ with a Convolutional Neural Network.**

Results

- Injected more than 10^6 particles with different:
  - Energies
  - Direction
  - Types of particles
- CORSIKA proton showers from 100 GeV to 1 TeV
- **Not a single background event gets misclassified as up-going**



Energy reconstruction

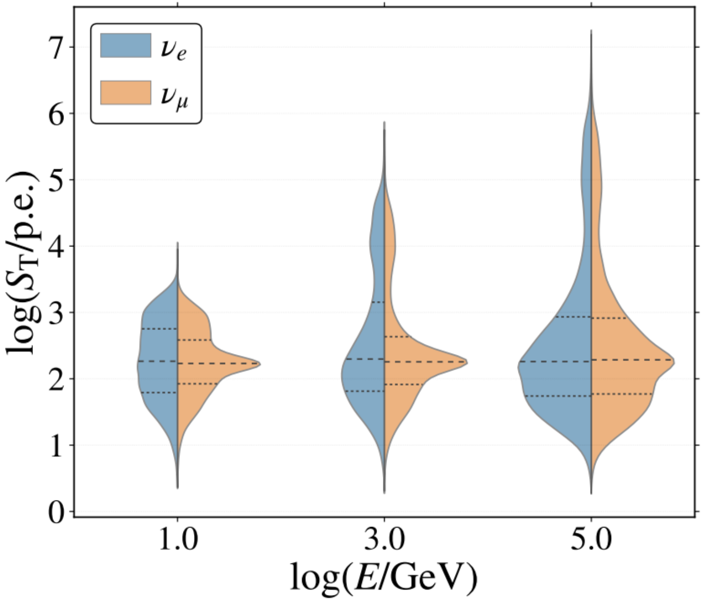
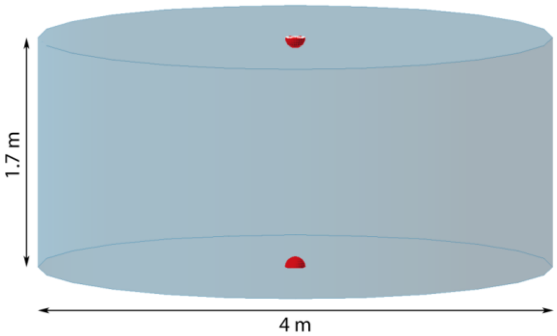


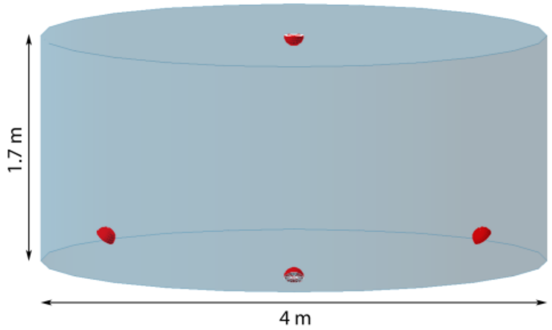
FIG. 9. Distribution of the signal for electron and muon neutrino-induced showers. The shaded areas of the violin plot represent the normalised distribution of the total signal at the WCD for a given neutrino energy. The horizontal lines show the quartiles of the distributions.

Studied WCD

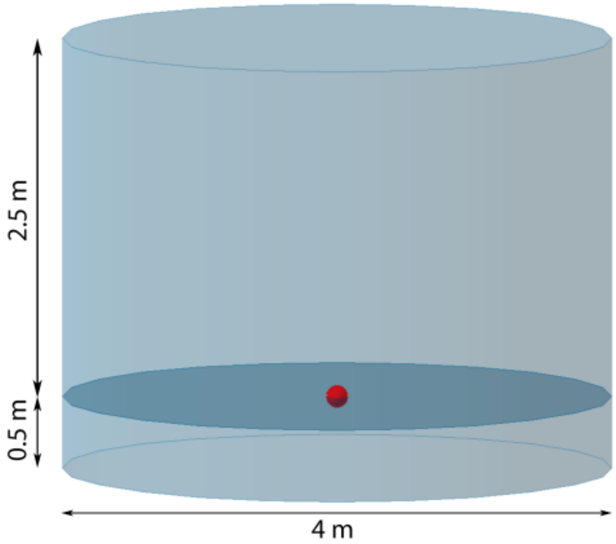
M1T1



M3T1

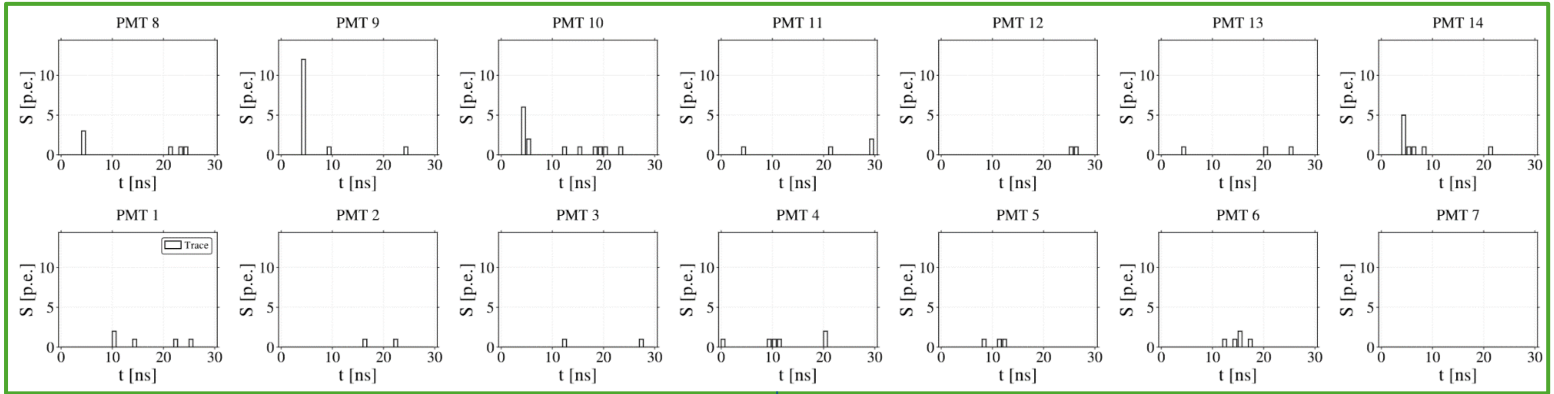


Double-Layer WCD



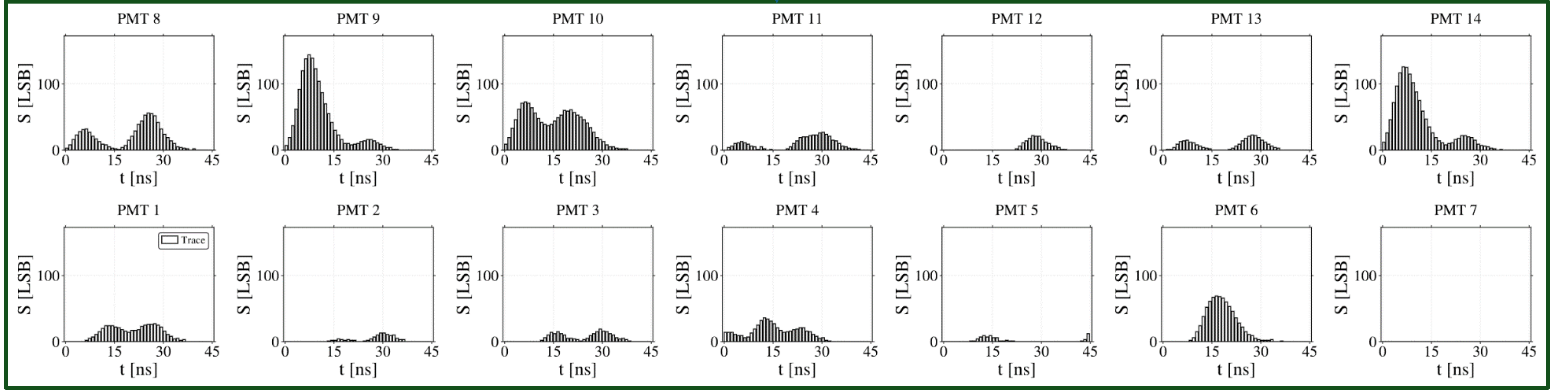
Electronics simulations applied to multi-PMT

Without electronics



Electronics chain simulation + baseline + T0 trigger

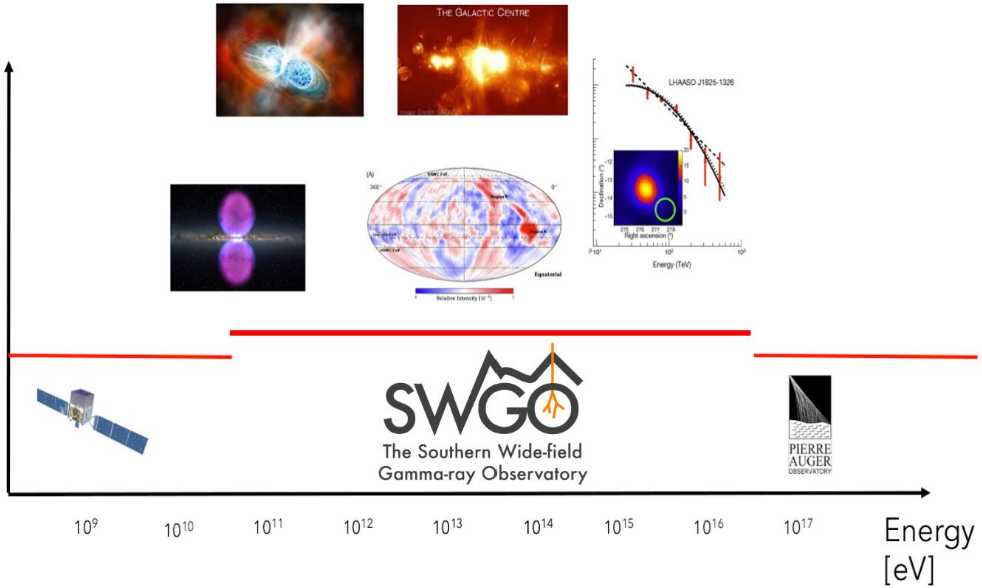
With electronics



Energy range covered with SWGO

Lowest energies:

- High altitude
- Compact array
- Dedicated ground detector design

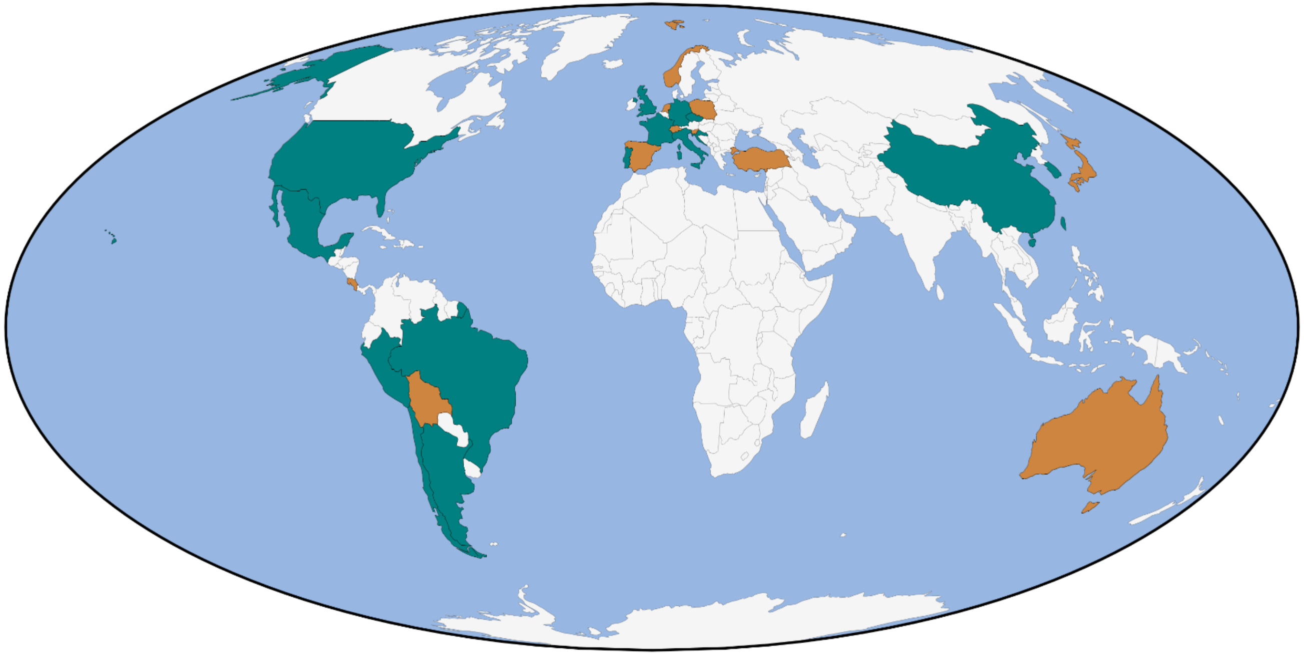


Highest energies:

- Modular
- Sparse array
- Large array area ($\sim$1 km^2 or more)

From tens of GeV to many tens of PeV.

Research institutions and countries in SWGO



Formed in 2019, involving ~90 research institutions from 15 Countries.