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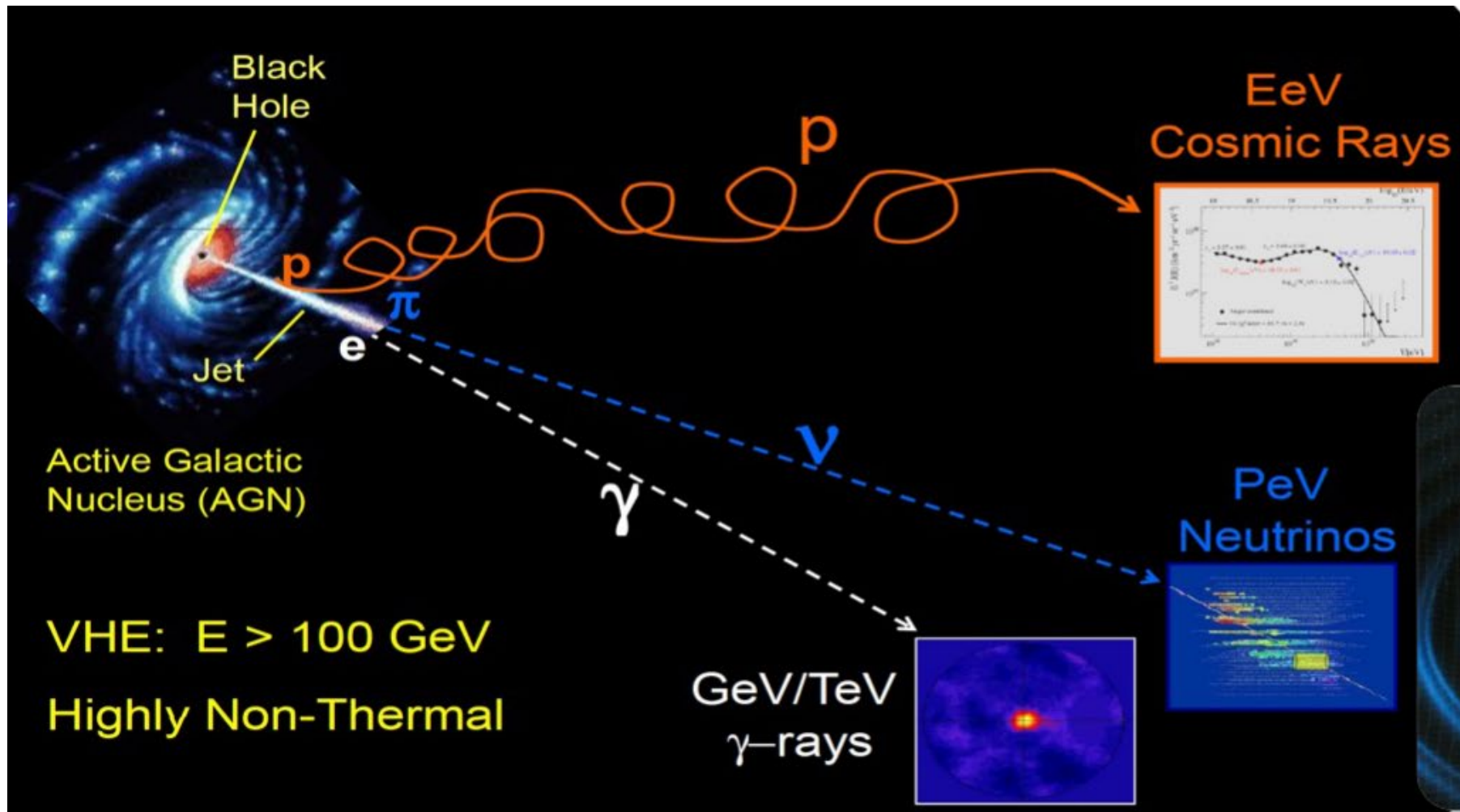
# Design and performance optimization of the Southern Wide-field Gamma-ray Observatory at the PeV scale

Luis Recabarren, 39th Cycle

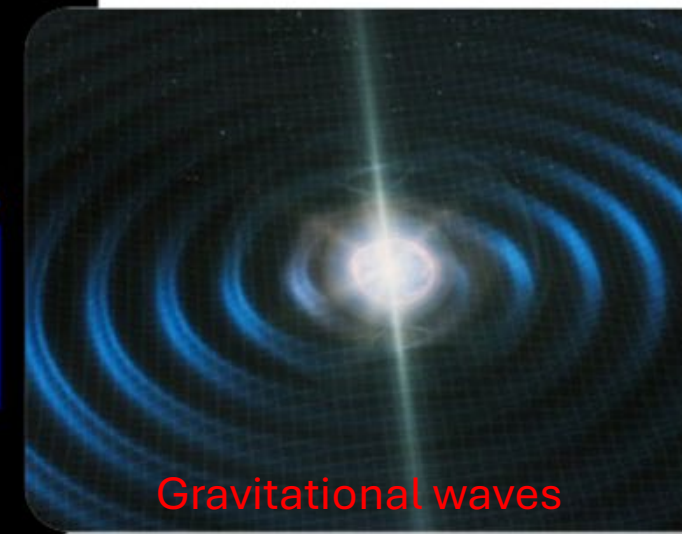
Supervisor: Prof. Michele Doro  
Co-supervisor: Dr. Tommaso Dorigo

2° year admission – 16/09/2024

## A multi-messenger era



Each messenger  
needs its own  
detection technique!

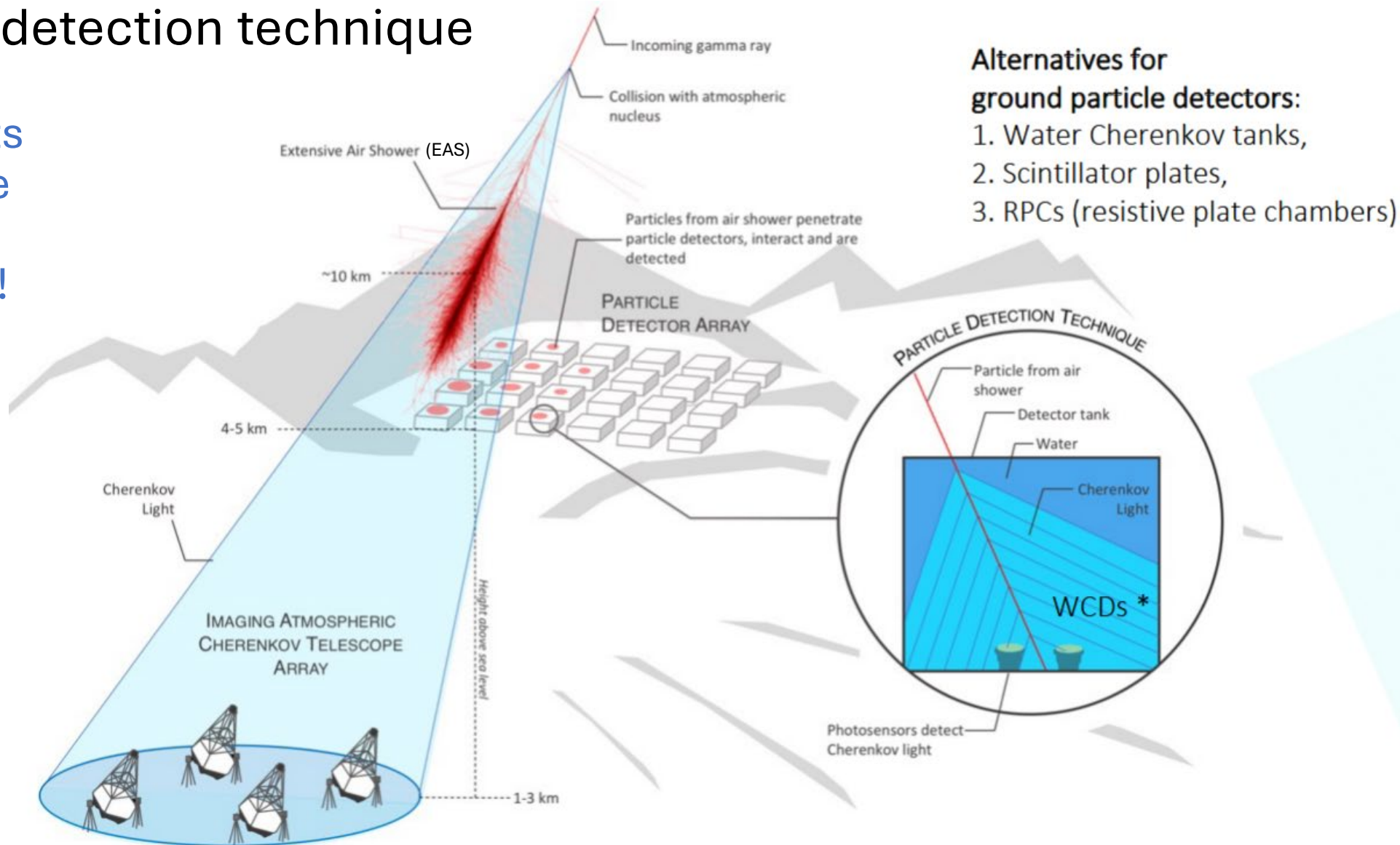


## The ground GR detection technique

These experiments are located at the northern hemisphere only!



Unexplored Southern Hemisphere sky!





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# Introduction: Current instruments



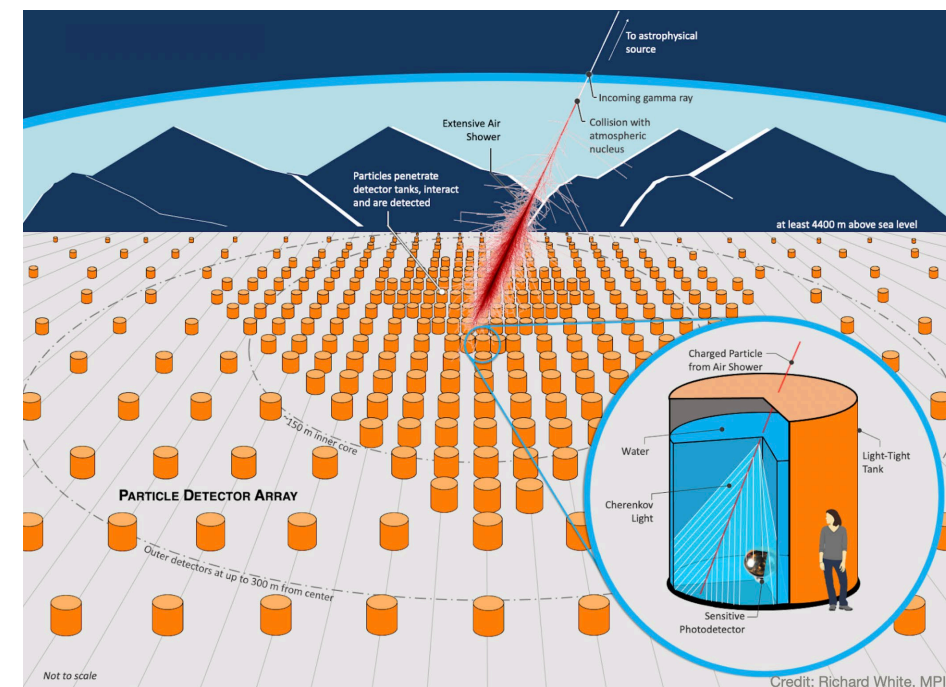


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# Introduction: Current instruments



- International collaboration (15 countries, +90 institutes). UniPd is one of the founders.
- Currently in the R&D phase.
- Location: Andes between  $10^\circ$  -  $30^\circ$  South latitude, at 4700 m.a.s.l. (Also known as altiplano).
- Candidate sites: Chile, Argentina, and Perú.





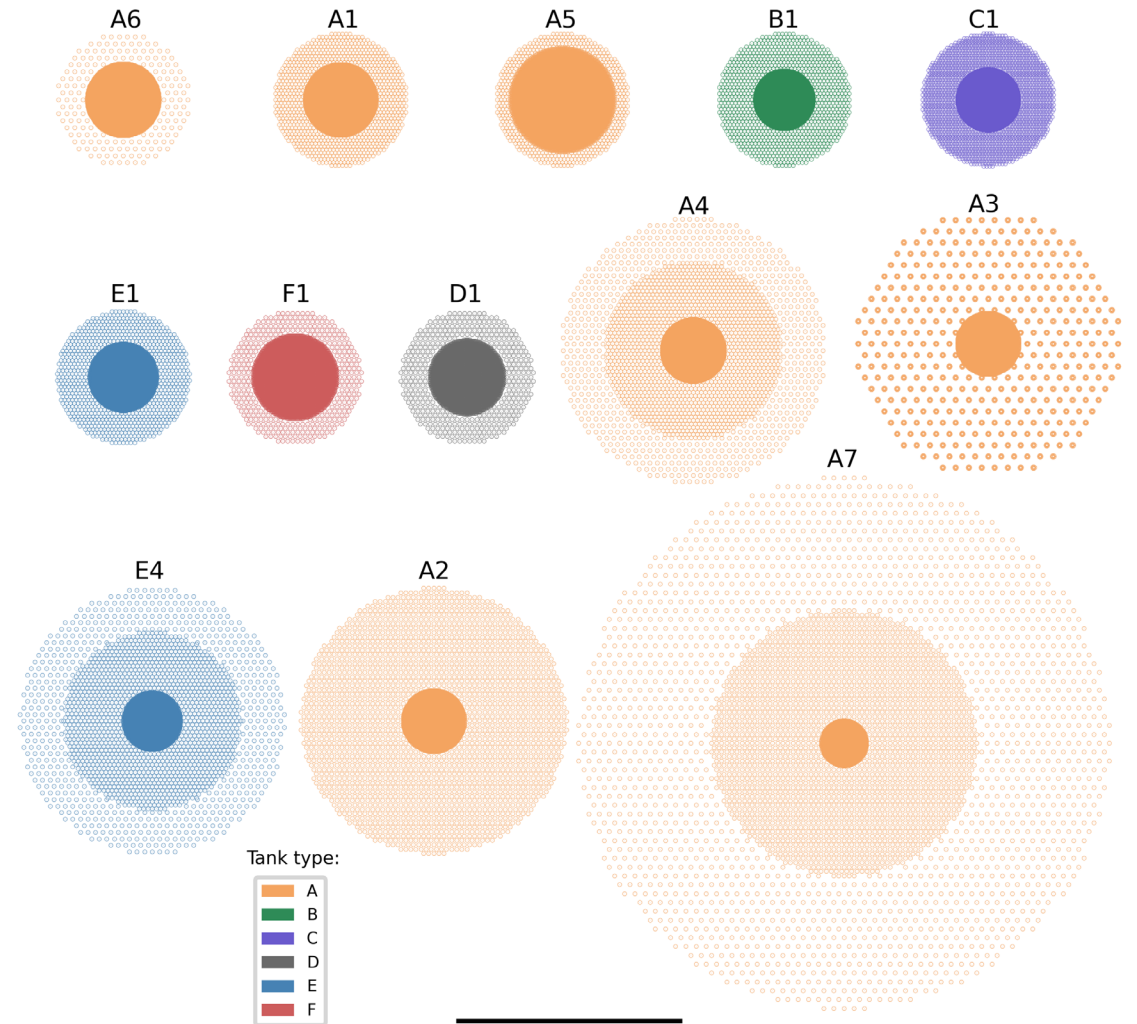
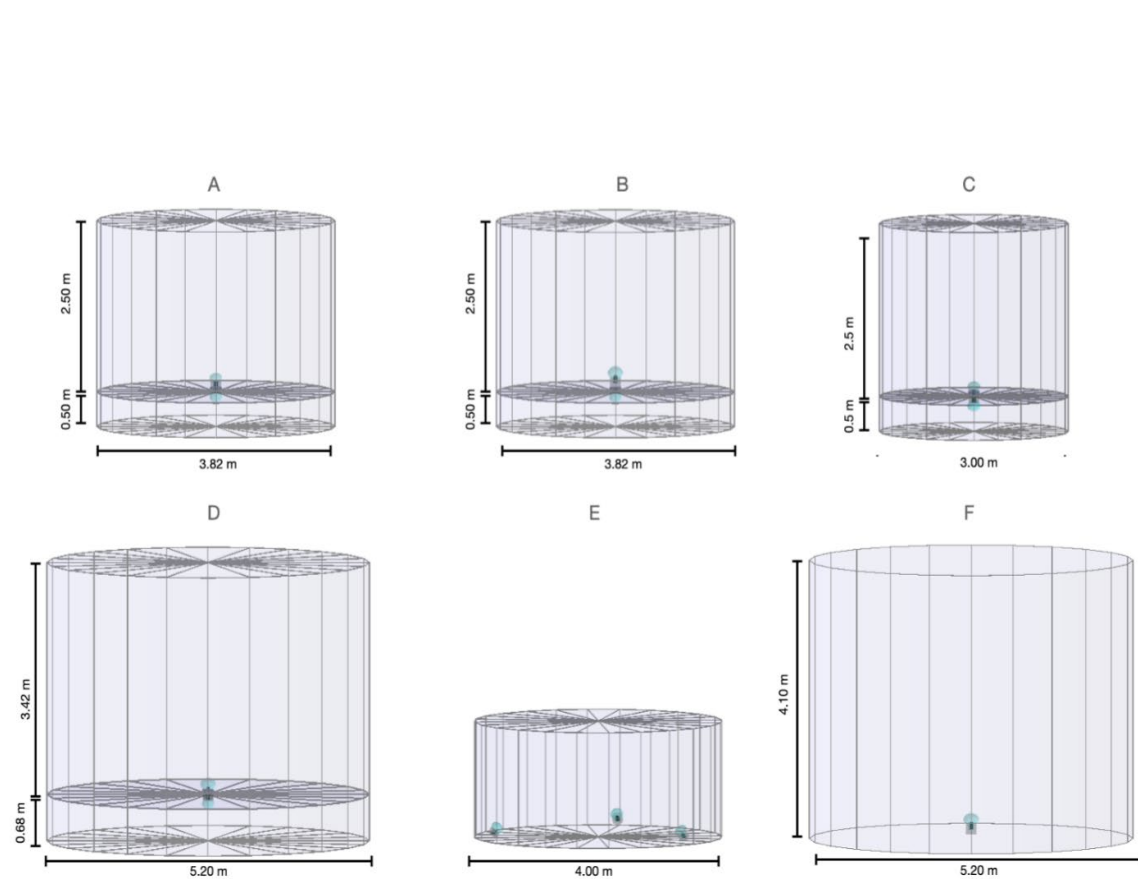
- On July, the collaboration chose the Chilean site (4770 m) as the preferred site for SWGGO, at the “Astronomical Park”, Atacama Desert.
- Cover an area  $\sim 1\text{-}2 \text{ km}^2$ . Water Cherenkov detector units (WCDs).
- Span energies from 100 GeV – 10 PeV.
- SWGGO will be the most advanced GR observatory of its kind.
- Construction expected by the 2028.



*Chilean site for SWGGO,  
“Pampa La Bola”, at the  
Atacama Desert.*



# SWGGO array layouts and tank designs



1 [km]



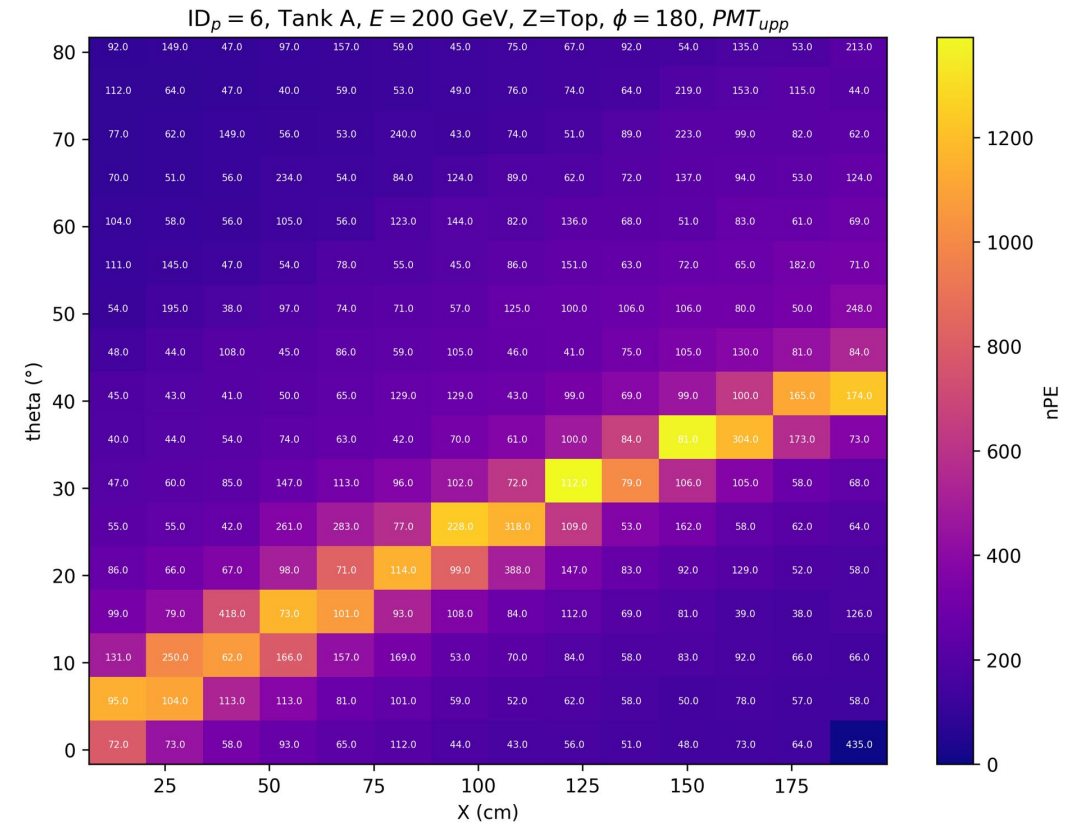
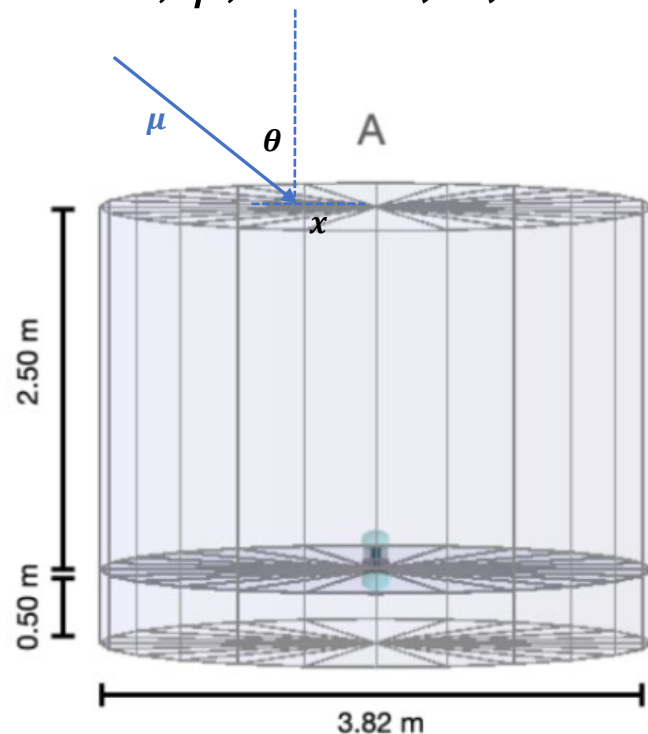
# Progress done on the 1<sup>st</sup> year

TASK TITLE	% OF TASK COMPLETE	T1			T2			T3			T4		
		O	N	D	J	F	M	A	M	J	J	A	S
SWG0 collaboration													
Join SWG0 collaboration (Gitlab, slack, website, working groups, mail lists)	100%	█	█										
Documentation of SWG0	100%	█	█	█									
Acquisition of software (clone repositories)	100%	█	█	█	█	█	█	█	█	█	█	█	█
Account at CNAF (learn to run jobs)	100%	█	█										
Array													
documentation of the 13 designs	100%	█	█	█									
SWG0 layout optimization pipeline	50%	█	█	█	█	█	█	█	█	█	█	█	█
Tank													
documentation of the 6 designs	100%	█	█	█									
Response of tank A in the PeV (use of Fast Simulation)	100%	█	█	█	█	█	█	█	█	█	█	█	█
Shower simulations													
Production and analysis of CORSIKA simulations	100%				█	█	█	█	█	█	█	█	█
Analysis on the muon content of PeV showers	100%						█	█	█	█	█	█	█



# Progress done on the 1<sup>st</sup> year: Tank response

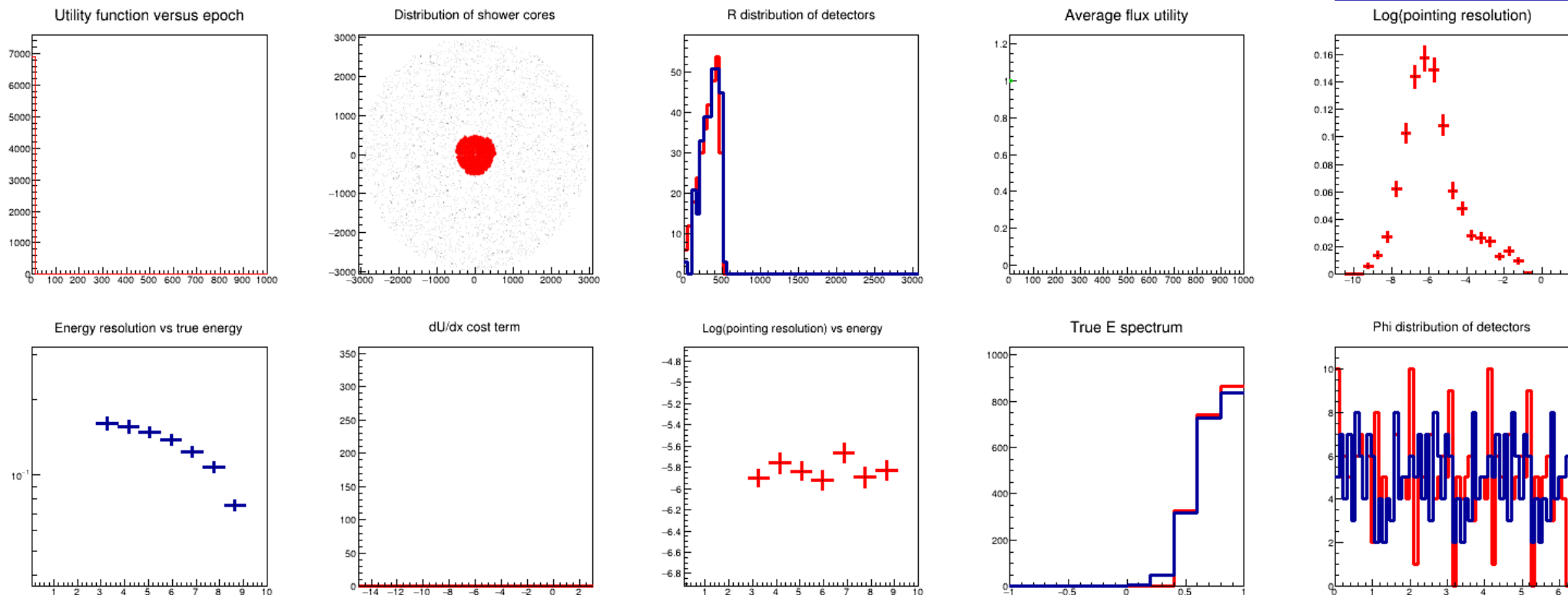
- LUT production for tank A using Fast Simulation (in collab. with Torino group) → Tank A response parametrization for high energy  $e, \mu, \gamma$  injection
  - Binning Energy  $E_e, E_\gamma, E_\mu = 9, 9, 6$
  - Binning tank top:  $\theta, \varphi, R = 16, 6, 15$
  - Binning tank side:  $\theta, \varphi, z = 17, 5, 10$





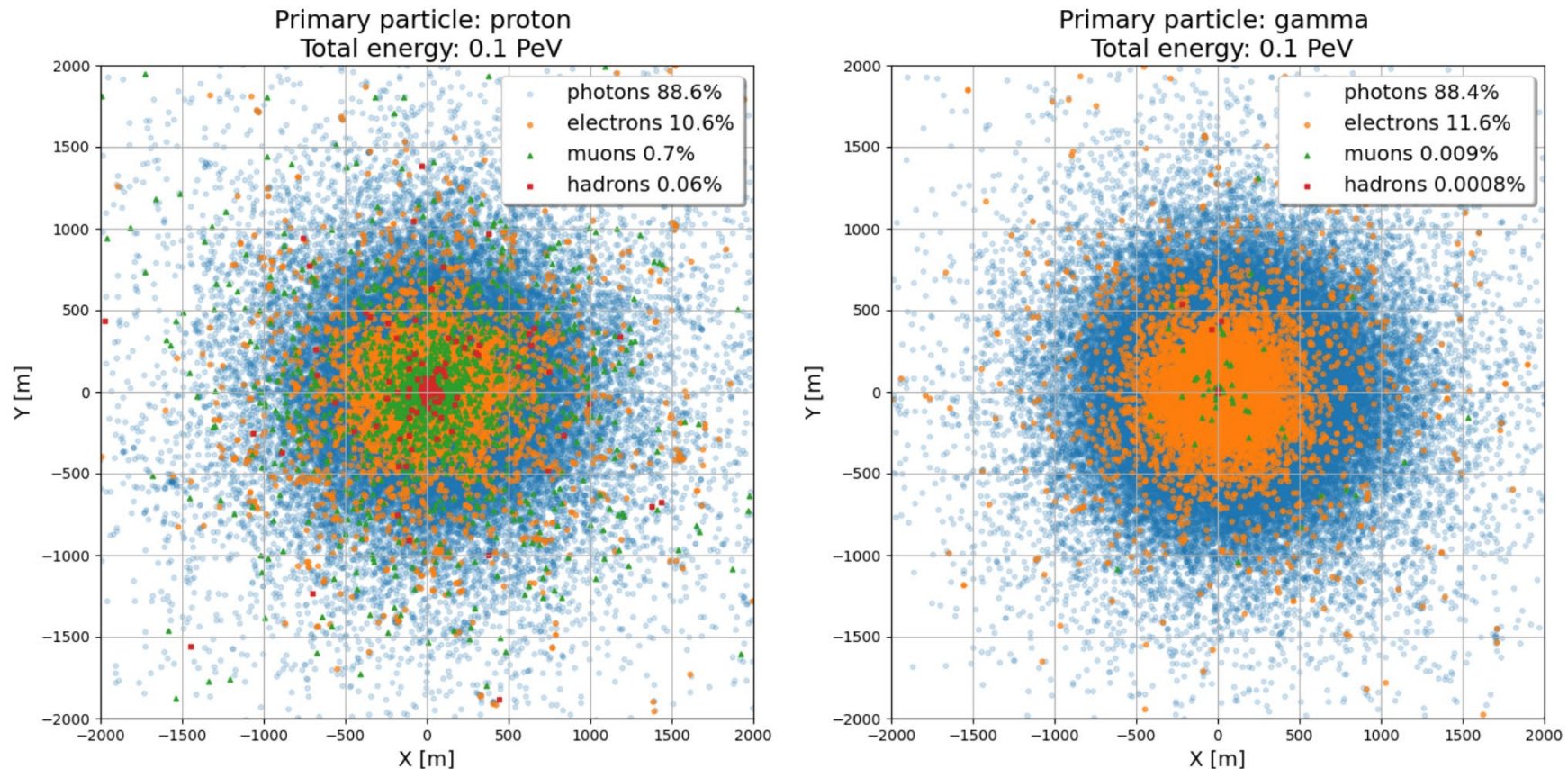
# Progress done on the 1<sup>st</sup> year: SWG0 Layout optimization

- Gradient descent-based algorithm applied on a parametric model of the array layout such that an optimized tanks configuration is found. In collaboration with [MODE experiment](#). This research is led by Tommaso Dorigo (INFN & SWGO member). A publication of this work is ongoing.



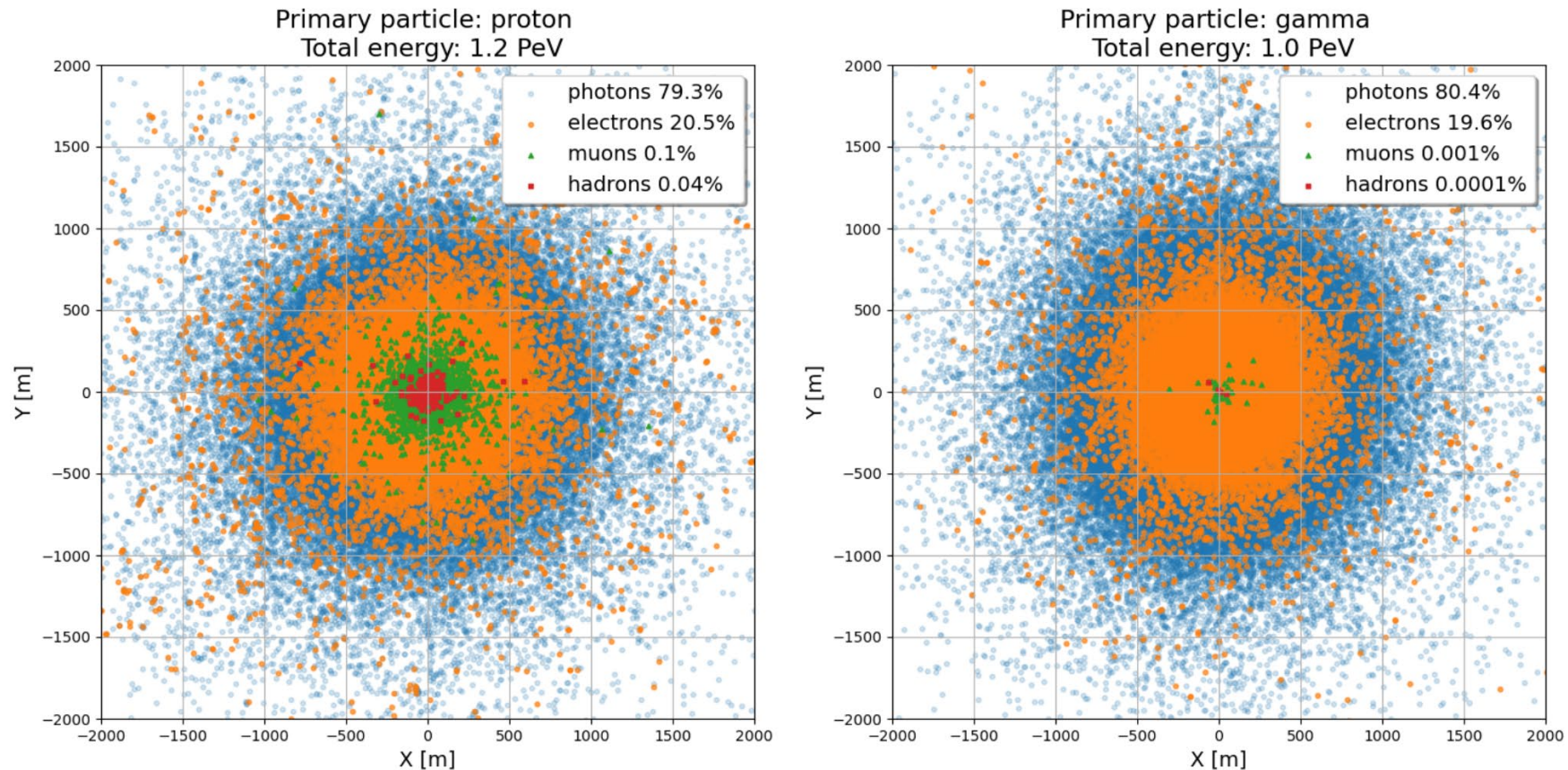
# Progress done on the 1<sup>st</sup> year: Muon content in PeV shower simulations

- Extract the muon content from gamma and proton showers at the ground level and for different array layouts.
- Search for signatures of muon starved protons in CORSIKA showers.



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# Progress done on the 1<sup>st</sup> year: Muon content in PeV shower simulations



- CORSIKA production at CNAF (computing center at Bologna):

Particle	# Events	Slope	$E_{min}, E_{max}$	$\theta_{min}, \theta_{max}$	Obs. Level
Proton	1E6	-2	0.1 , 1 PeV	0 , 65	4700 m
Gamma	5E4	-1	0.1 , 10 PeV	0 , 65	4700 m

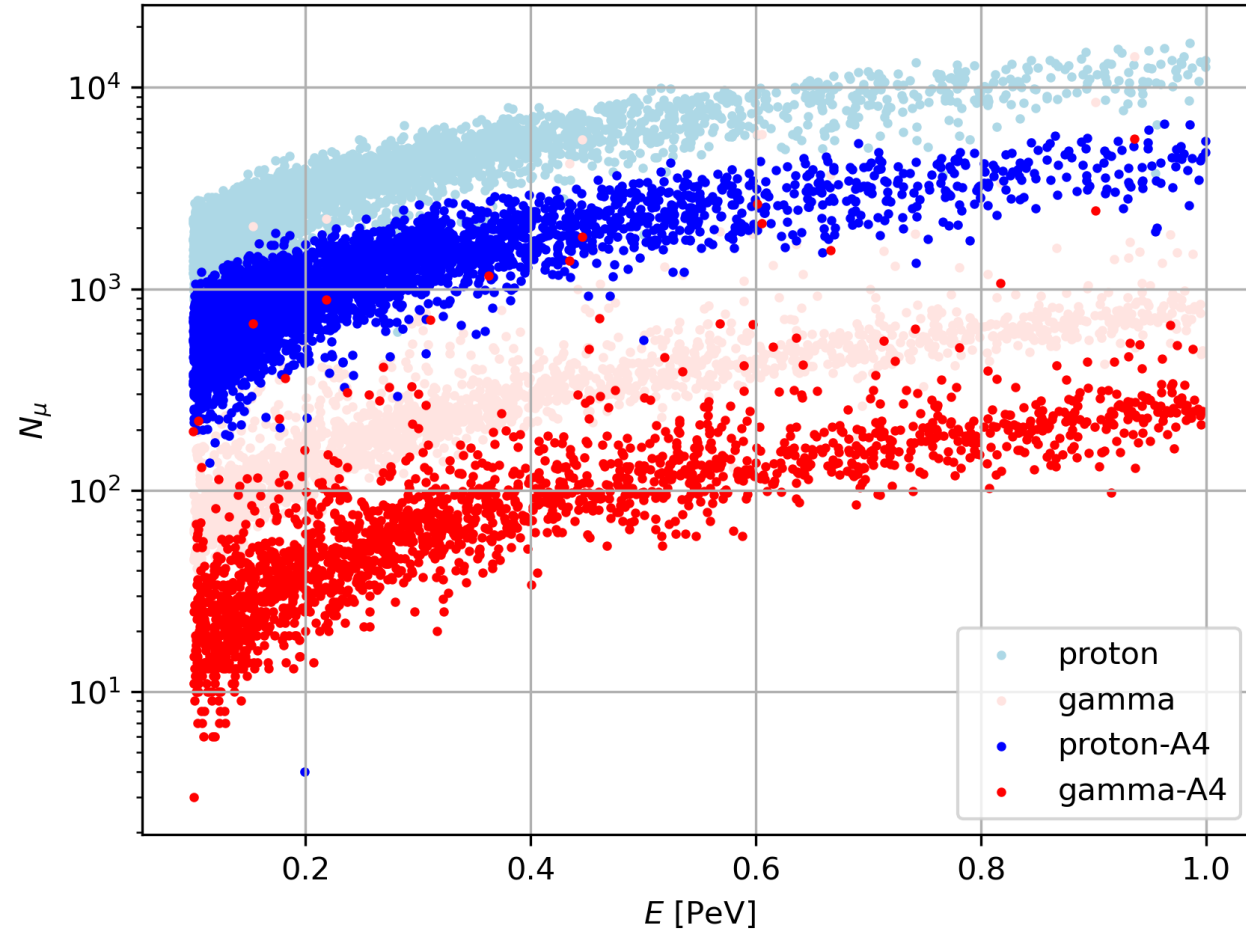
- I selected 10k events for gamma and proton showers each.
- Muon production at observation level for no array, and A4, D8 arrays (i.e. a 100% of muon detection efficiency is assumed).
- I used FastSim tool to count muons on arrays. Basically, a muon injection in the tank is assumed.



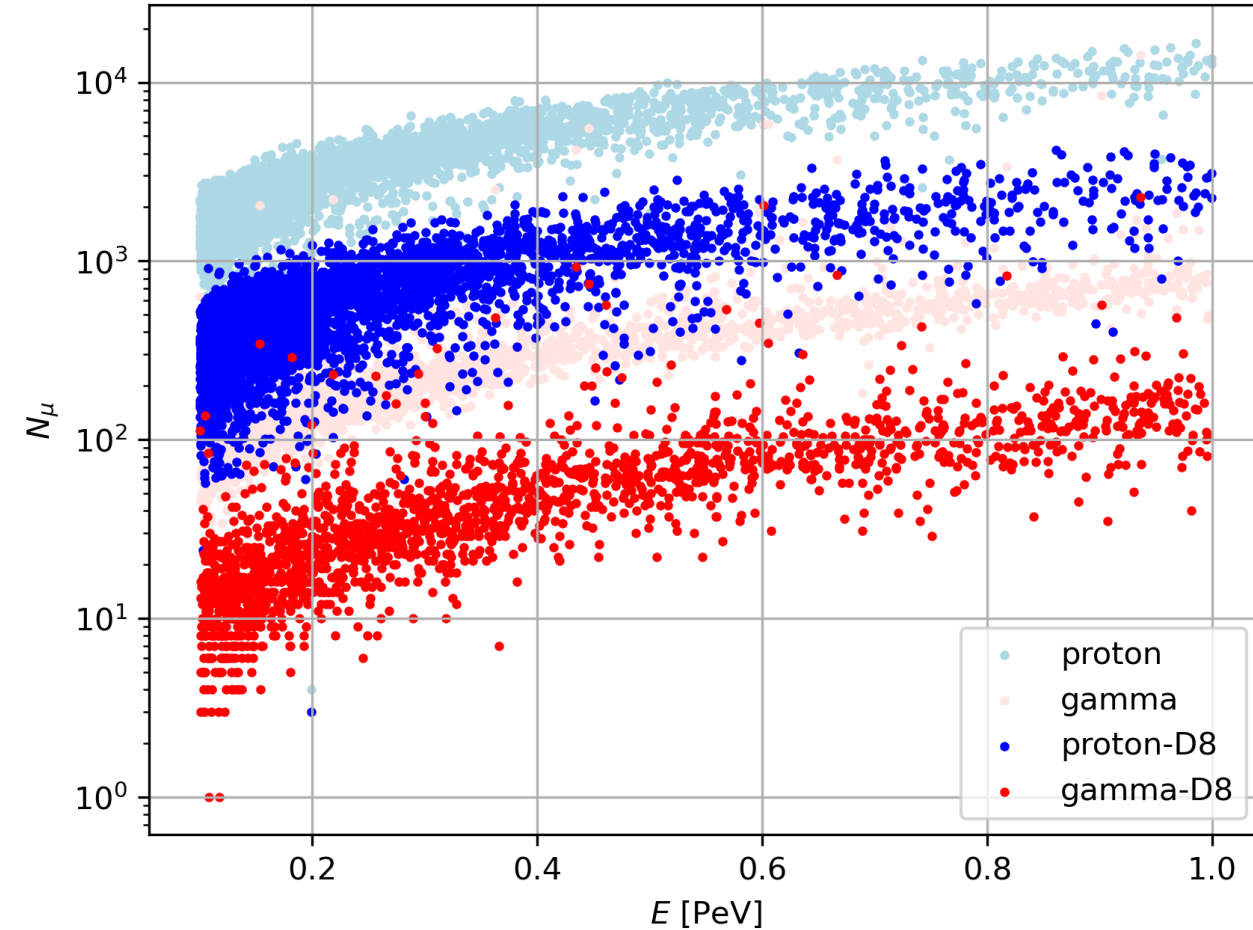
# Progress done on the 1<sup>st</sup> year: Muon content in PeV shower simulations



10k events, zenith=[0,35] deg, 4700 m



10k events, zenith=[0,35] deg, 4700 m

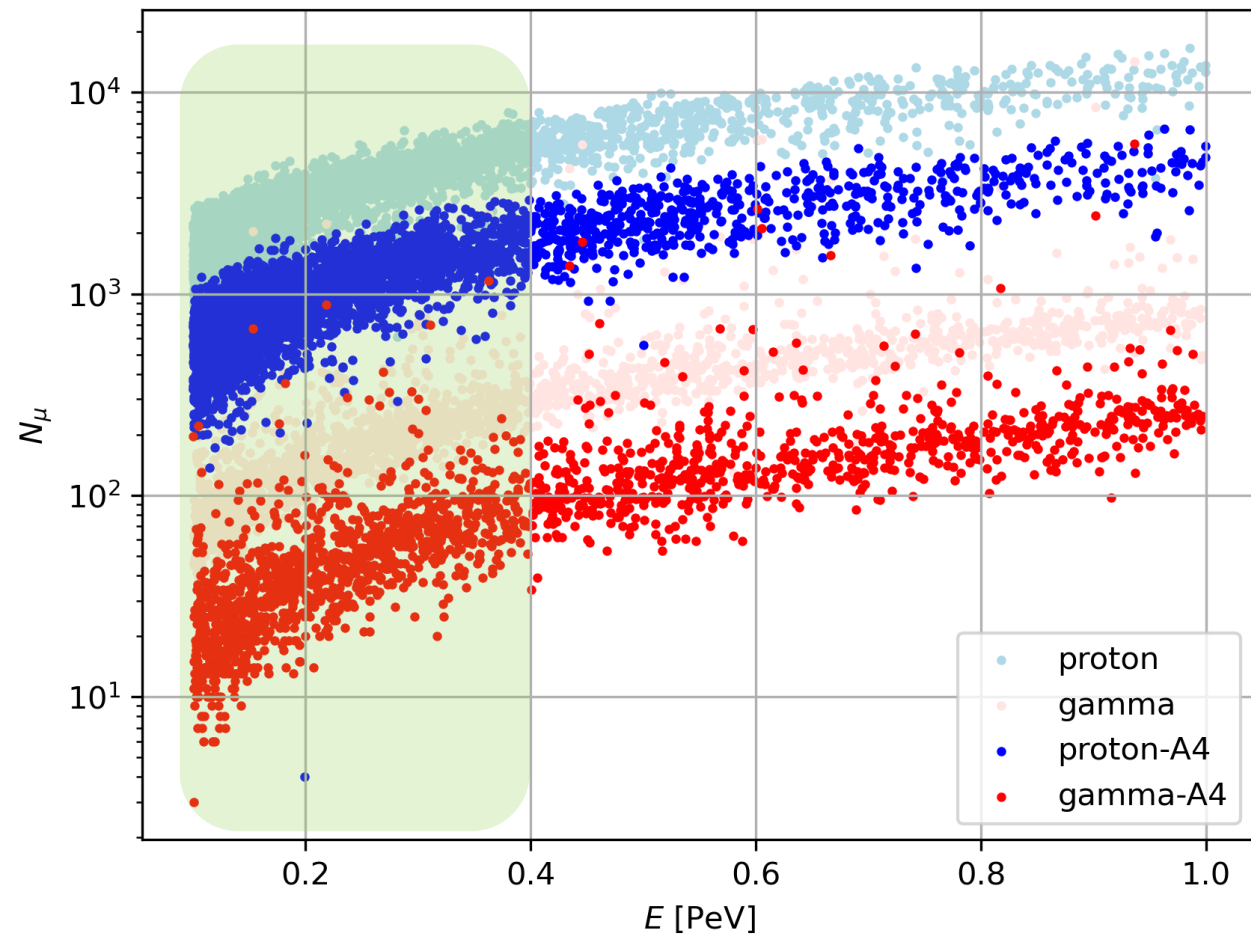




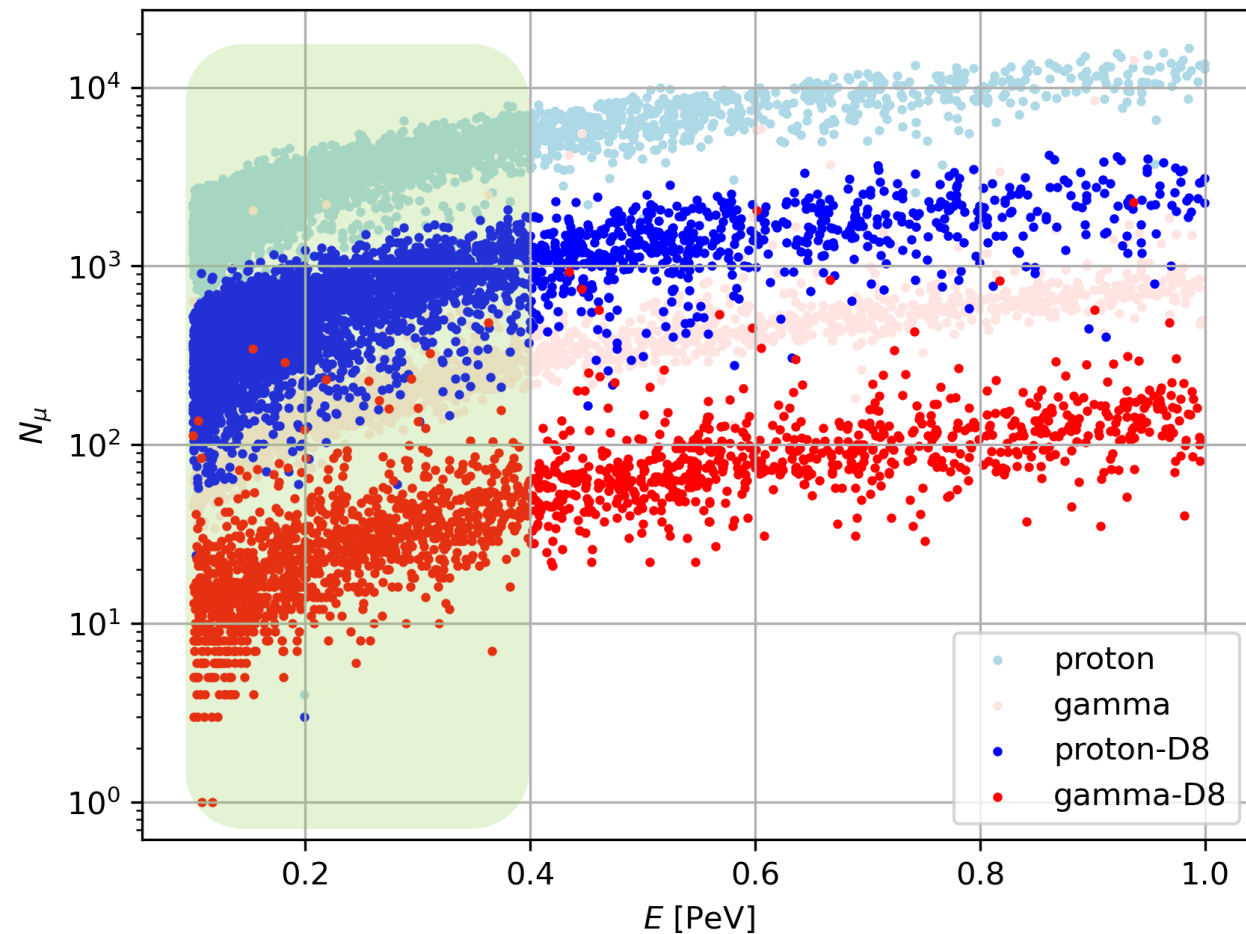
# Progress done on the 1<sup>st</sup> year: Muon content in PeV shower simulations

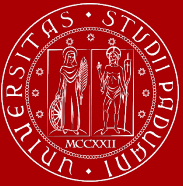


10k events, zenith=[0,35] deg, 4700 m



10k events, zenith=[0,35] deg, 4700 m





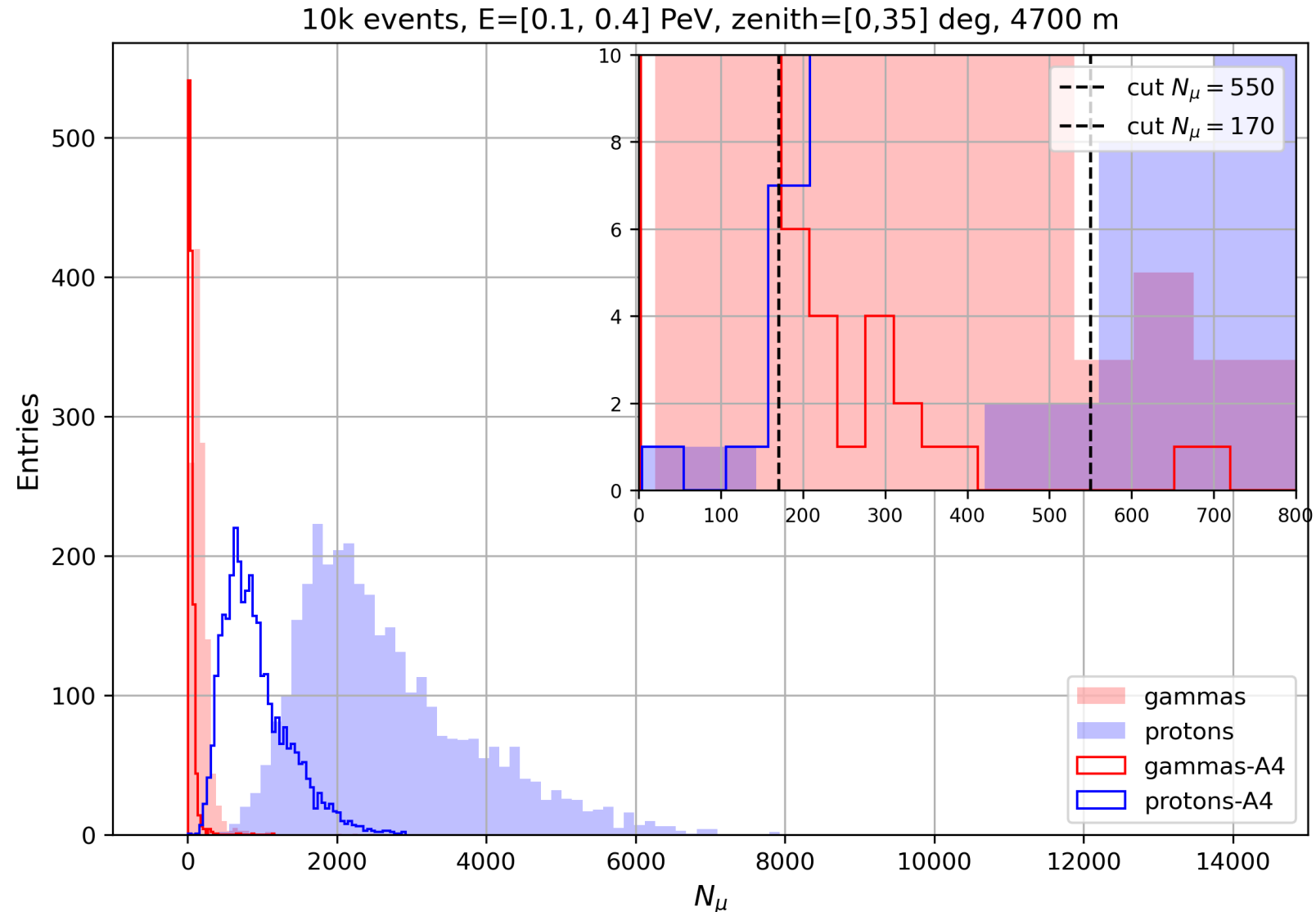
- Using the chosen cuts, the ratio:

$$\frac{\text{misid. } \mu_\gamma}{\text{true } \mu_\gamma} \sim 10^{-3}$$

$$\frac{\text{misid. } \mu_p}{\text{true } \mu_p} \sim 10^{-3}$$

for no array (filled bars) and for A4 array (empty bars).

- The array is not losing information concerning the muon distributions from gamma/proton showers.**







- Congresses:
  - 10<sup>th</sup> SWGO collaboration meeting, México City, Mexico, April 2024.
    - **I presented the last advances of SWGO optimization layout pipeline.**
  - **11<sup>th</sup> SWGO collaboration meeting, Heidelberg, Germany, September 2024. A lot a progress has been done but also there is a lot of work. SWGO is moving faster!**
- PhD school:
  - The first MPIK-CDY School on the Future of Gamma-Ray Astronomy, Max-Planck-Institut für Kernphysik, Heidelberg, Germany, June 25-July 3.
- Collaborations:
  - SWGO Torino group → Simulations for array response at PeV energy scale.



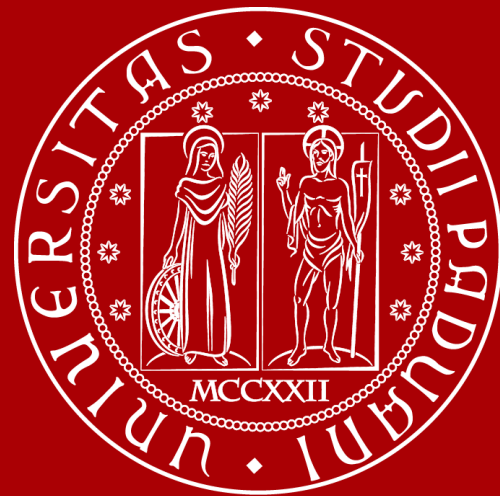
# Research program: Conclusions

- SWGO is a frontier science experiment that certainly will make major advances in Gamma-ray astrophysics.
- SWGO design is not trivial. A lot of techniques/methods and technologies must be developed but also a lot of knowledge can be obtained working on this problem.



*11<sup>th</sup> SWGO collab.  
Meeting, Sept. 2024  
Heidelberg, Germany.*

Thanks for your attention!



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