Muon Production from Proton and Gamma-Ray Initiated Air Showers at UNAB Casona and SWGO Altitudes

Niven Garay Leal

Federico Santa María Technical University

Interships SAPHIR-UNAB and SAPHIR ARM 2025

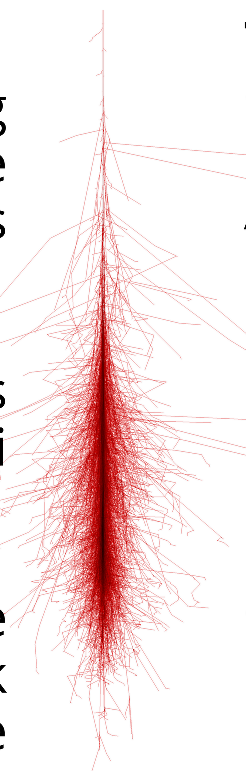
Introduction

Cosmic Ray and Extensive Air Showers

Cosmic rays are high-energy subatomic particles traveling near the speed of light, originating from extreme astrophysical events. They are primarily composed of protons (90%), alpha particles (9%), and heavier nuclei.

When a cosmic ray enters Earth's atmosphere, it generates an **extensive air shower (EAS)**, interacting with air nuclei and producing secondary particles.

The study of cosmic rays is essential for understanding the most extreme phenomena in the universe, such as black holes, supernova explosions, gamma-ray bursts, and active galactic nuclei.



SWGO Proyect

The SWGO (South Wide-field Gamma-ray Observatory) will be located at the Atacama Astronomical Park (PAA), Chile.

Its goal is to detect secondary particles for cosmic ray studies and high-energy phenomena.

It will consist of water Cherenkov detectors, which will measure the light emitted by ultra-relativistic particles to analyze the arrival of cosmic rays.

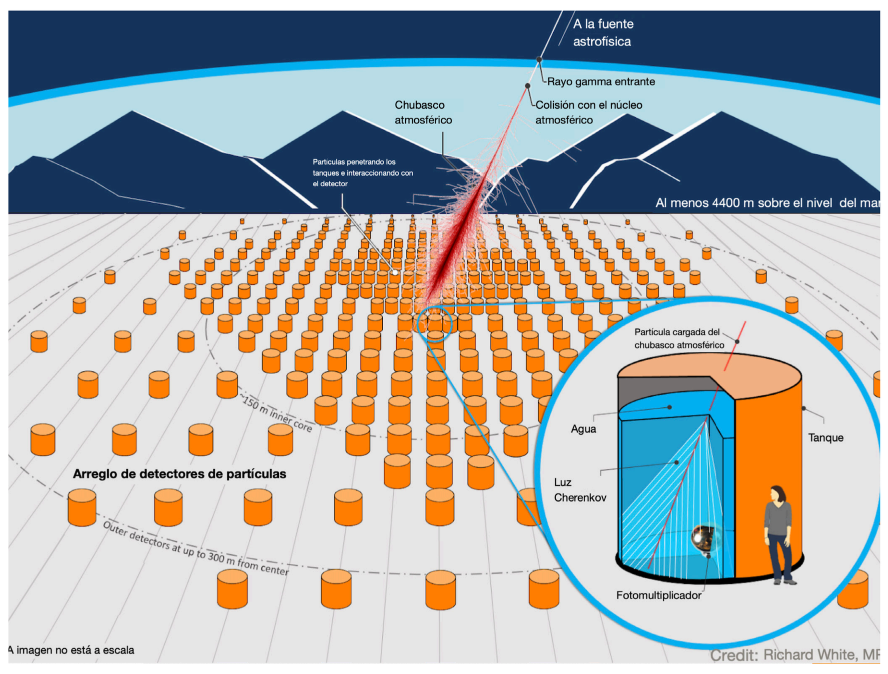


Figure 1: Ilustration of the water Cherenkov detectors [1].

Methods

The study of muons is crucial for designing the Cherenkov tanks of SWGO, as these penetrating particles represent a significant portion of the expected detector signal.
The CORSIKA 8 Monte Carlo code is used to simulate particle cascades, which will later be used to study the density of secondary particles, particularly the production of muons, generated by protons and gamma rays at two key locations for this work: the Atacama Astronomical Park (PAA) and the Casona Unab campus in Santiago, Chile.
To model their distribution, the SIBYLL 2.3d (high-energy) and UrQMD 1.3.1 (low-energy) models were used in CORSIKA 8, considering protons and gamma rays as primary particles with an initial energy of 1e5 GeV.
Simulations were performed at altitudes of **4770 m a.s.l.** and **840 m a.s.l.**, corresponding to the altitudes of PAA and UNAB Casona Campus, to analyze the density and distribution of secondary particles.

Results and perspectives

Proton

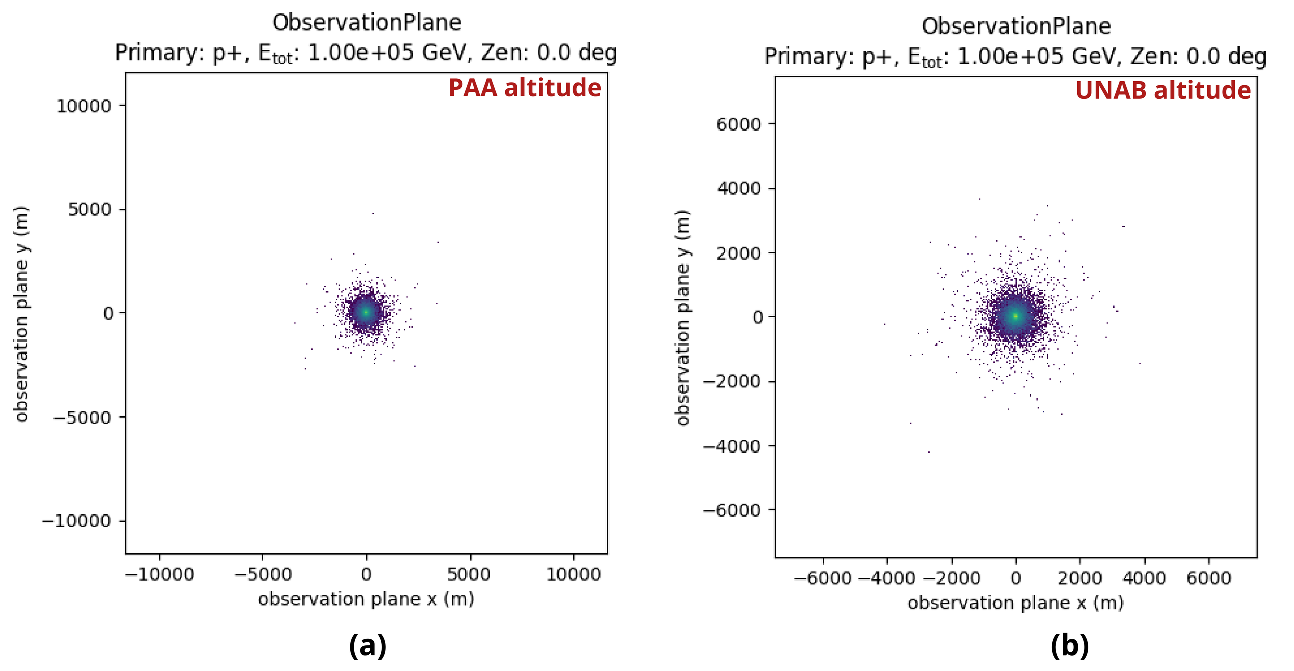


Figure 2: Spatial distribution of secondary particles produced by a proton in the observation plane for the altitudes under study. (a) 4770 m a.s.l. (b) 840 m a.s.l.

Gamma Ray

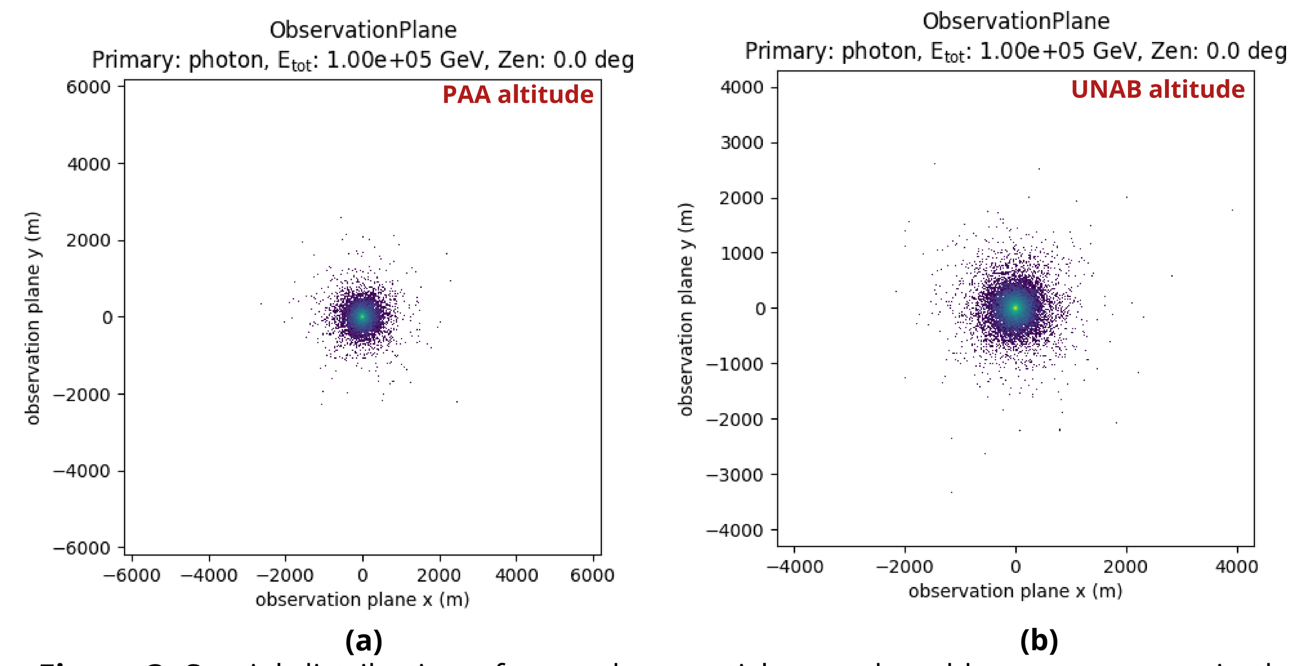


Figure 3: Spatial distribution of secondary particles produced by a gamma ray in the observation plane for the altitudes under study. (a) 4770 m a.s.l. (b) 840 m a.s.l.

In both cases, a greater radial extension of the secondary particles in the observation plane is observed for the PAA altitude. This is because, at higher altitudes, the atmospheric cascade is closer to its maximum interaction, and the secondary particles retain more energy, allowing them to travel greater distances before dissipating.

Proton

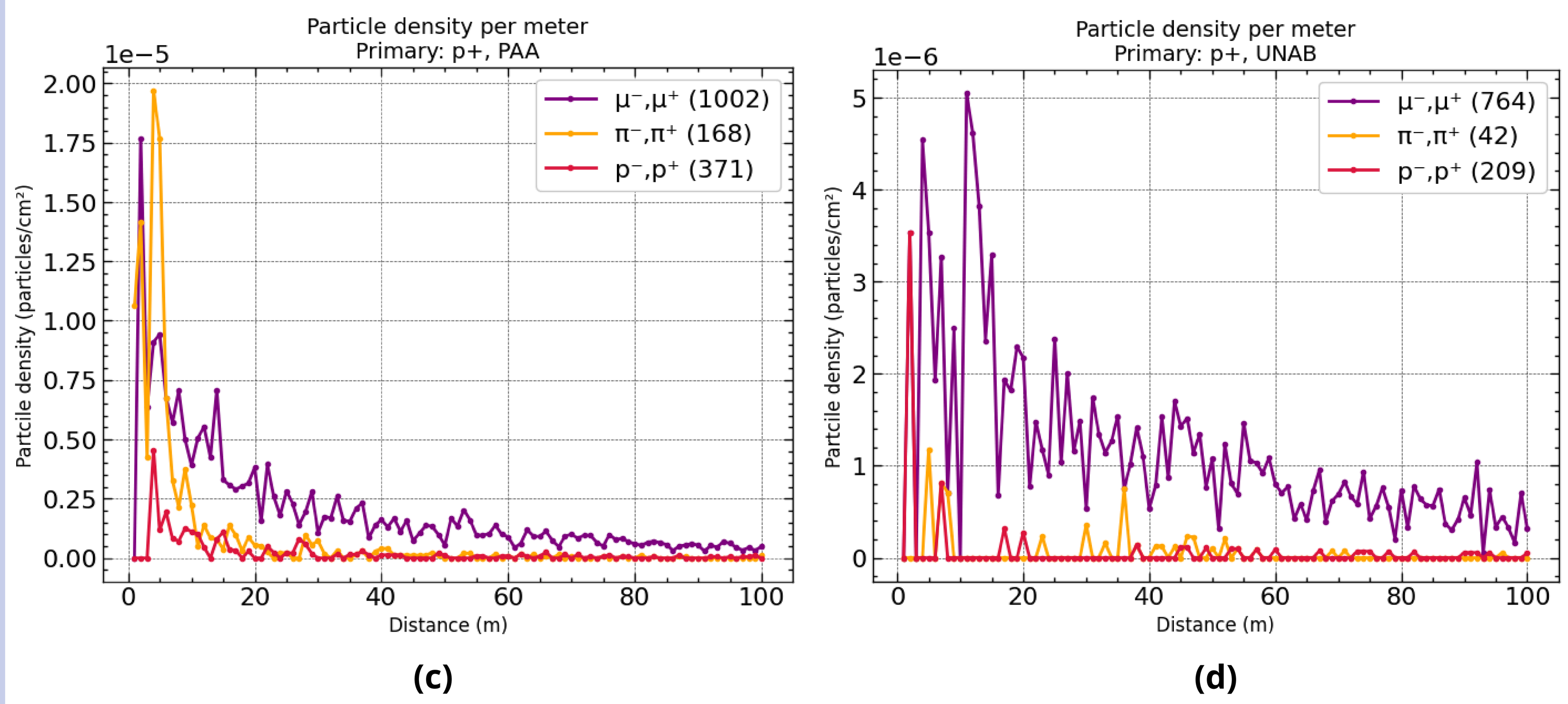


Figure 4: Density of secondary particles per meter for an observation level corresponding to: (c) 4770 m a.s.l. (d) 840 m a.s.l.

In Figure 4(c), the density is higher and extends radially to greater distances, while in Figure 4 (d), the density decreases rapidly with radial distance, indicating greater absorption and dissipation before reaching the observation plane.

The muon density is significantly higher at the altitude of the Atacama Astronomical Park, suggesting that the lower atmospheric matter at higher altitudes reduces particle dissipation, potentially generating more muons in the detector.

Gamma Ray

At the UNAB altitude, particles (particularly muons) are more concentrated in specific regions with sharp peaks, suggesting that the cascades have evolved enough that only a few particles reach the observation plane with significant density.

On the other hand, the particle distribution at the PAA altitude appears more continuous and extended, with more variability in the number of particles detected at different positions.

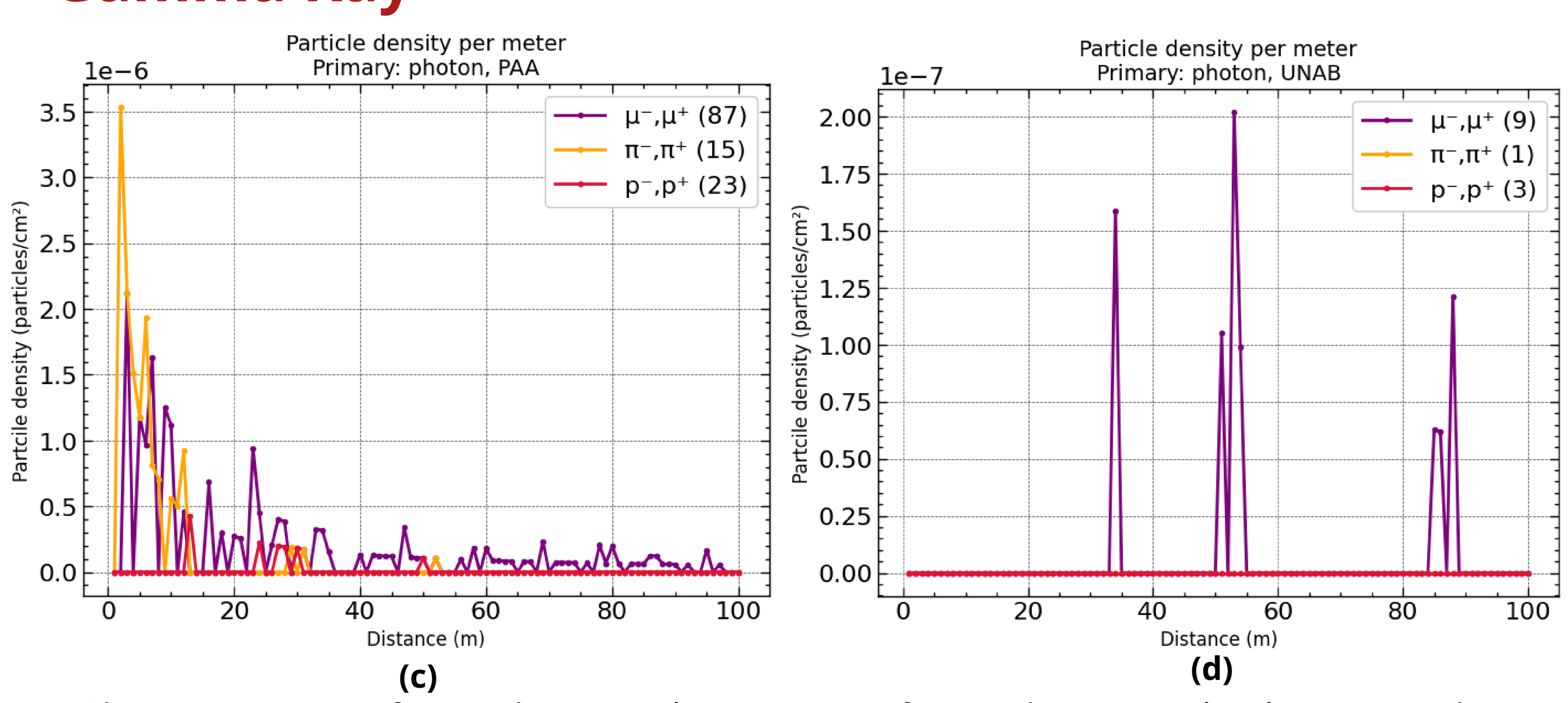


Figure 5: Density of secondary particles per meter for an observation level corresponding to: (c) 4770 m a.s.l. (d) 840 m a.s.l.

In both cases, muons are dominant, but at the PAA altitude, a much larger amount is retained. Muons manage to reach locations with lower altitudes, such as UNAB, due to their high energy and long mean lifetime [2]. The results will be used to study the efficiency of the proposed hodoscopes, which, when combined with the water Cherenkov tanks, are intended to improve muon identification.

Future work

A next step in this work is to refine the simulation setup to define more precise and representative parameters for the SWGO site. Additionally, the impact of cosmic ray primary energy and atmospheric conditions on muon production will be analyzed.

References

[1] SWGO Collaboration. (2024). SWGO Wiki. Retrieved from https://www.swgo.org/SWGOWiki/doku.php

[2] P. D. Group, "Review of particle physics," Physics Reports, 2020, accessible online from the Particle Data Group website. [Online]. Available: https://pdg.lbl.gov

Acknowledgments

The authors thank Yury Ivanov for his help with cluster optimization and software integration. Our thanks to the UNAB team for their support with electronics, mechanics, and administration. Finally, thanks to our mentor, Marco Ayala, for his guidance. This work was supported by ANID Millennium Program ICN2019 044.

Center for Theoretical and Experimental Particle Physics UNIVERSIDAD ANDRÉS BELLO

Agencia Nacional de Investigación y Desarrollo

Fondecyt Fondo Nacional de Desarrollo Científico y Tecnológico

milenio INICIATIVA CIENTÍFICA

MILLENNIUM INSTITUTE FOR SUBATOMIC PHYSICS AT HIGH-ENERGY FRONTIER SAPHIR

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA