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Status of the construction of a Muon Tomography Detector for the Study of Geophysical Objects

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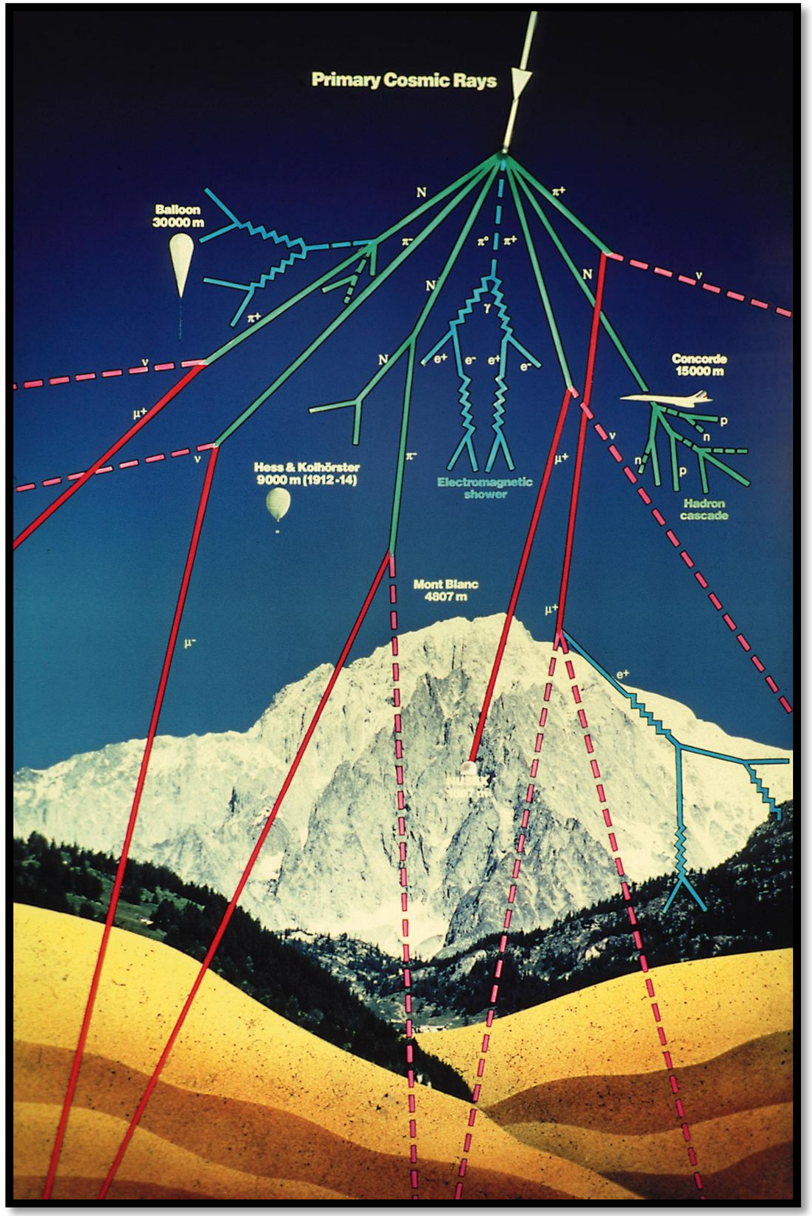
Muography
Motivation

- In the last two decades, muon tomography, or muography, has experienced a great development and has found applications in different fields that requires penetrating probes.
  - ✓ nuclear non-proliferation,
  - ✓ spent nuclear reactor fuel monitoring,
  - ✓ cargo scanning, and
  - ✓ geological structures imaging (volcanoes, mountains, glaciers, etc.).

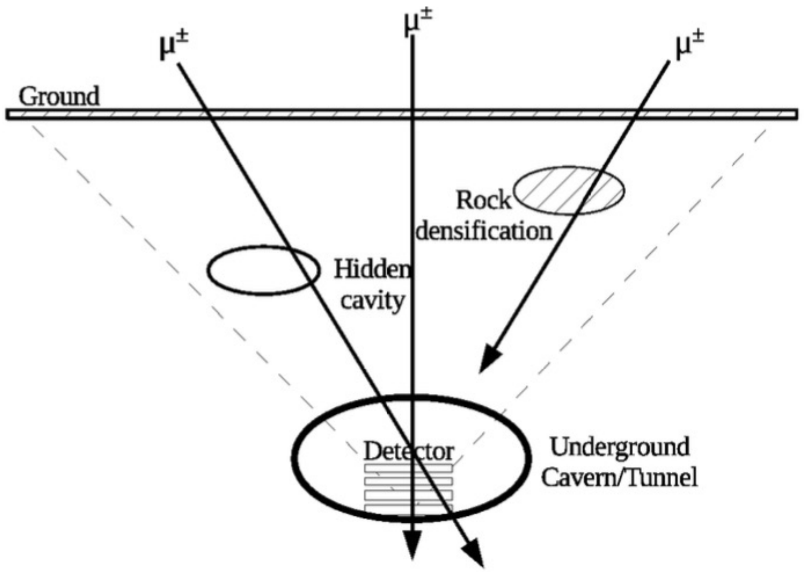
Atmospheric muons

- Cosmic radiation, impacts the upper layers of the atmosphere generating extensive aerial showers (EAS) of secondary particles, including **cosmic muons** that eventually reach the sea level.
- Muons ($\mu^{\pm}$)
  - ✓ charged particles,
  - ✓ ~200 times the mass of the electron (105.7 MeV/c^2).
  - ✓ fall on the earth: ~10000 part./(m^2 x min) at the sea level, with $E_\mu > 2$ GeV.



First steps

- 1950's: first muon radiographic measurements proposed by E.P. George.
- Aims to determine the rock density above an Australian mine by the measurement of the cosmic muon flux.
- Idea: the rock densifications, cause smaller muon flux than the expected flux, calculated from the soil thickness and the estimated average density.
- In the case of cavities, the measured muon flux is larger than the expected flux due to the missing material.



The discovery of an unknown chamber

- @ Khufu's Pyramid.
- Minimum length: 30 m. Cross section similar to the Grand Gallery.
- Published: 2 November 2017

nature
International journal of science

Letter | Published: 02 November 2017

Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

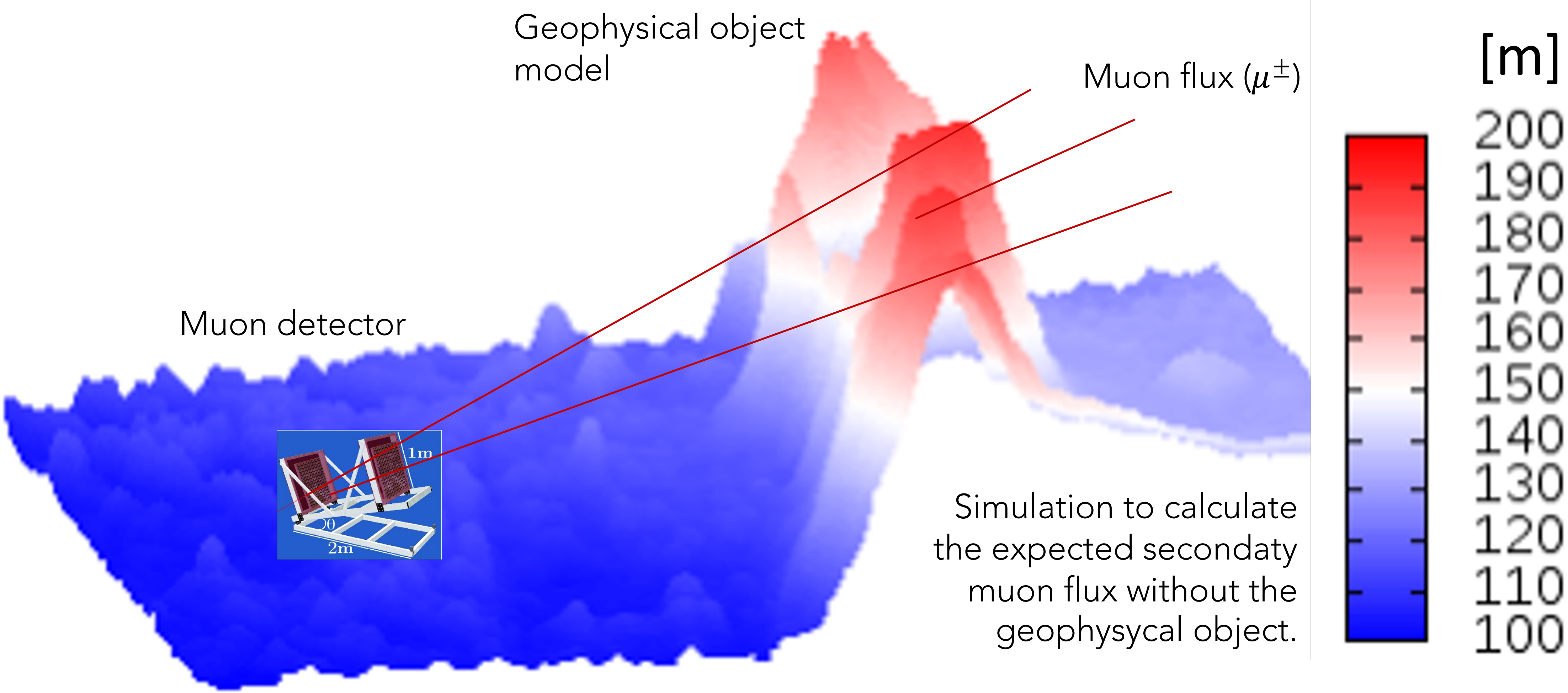
Kunihiro Morishima, Mitsuaki Kuno [...] Mehdi Tayoubi

Nature **552**, 386–390 (21 December 2017) | Download Citation

Abstract

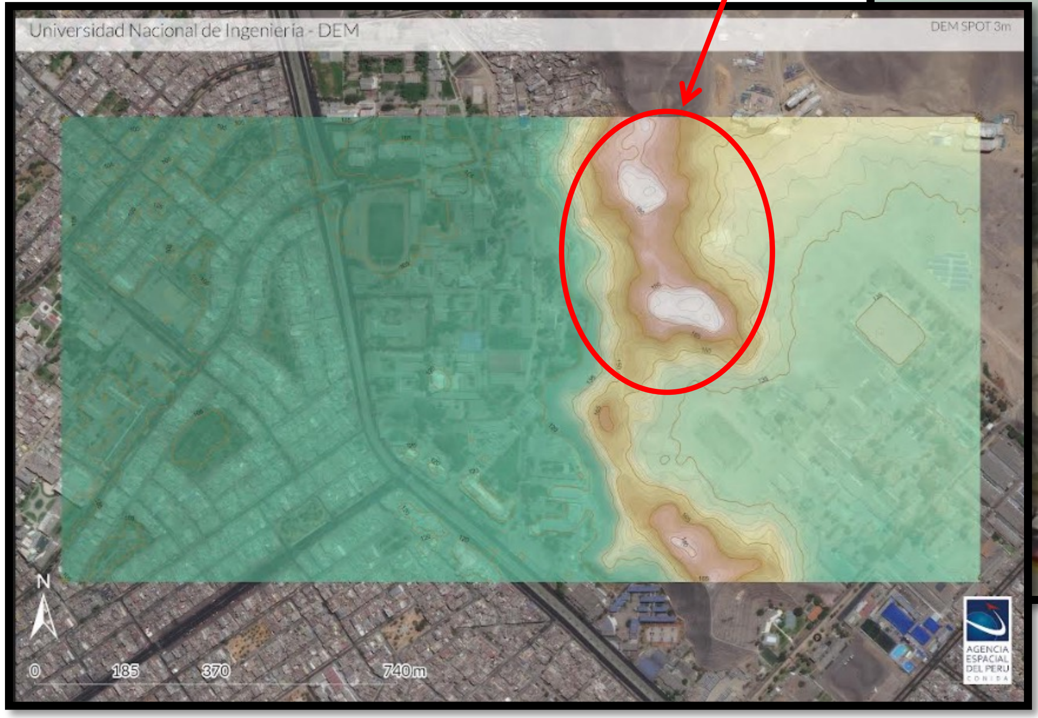
The Great Pyramid, or Khufu's Pyramid, was built on the Giza plateau in Egypt during the fourth dynasty by the pharaoh Khufu (Cheops)[1], who reigned from 2509 BC to 2483 BC. Despite being one of the oldest and largest monuments on Earth, there is no consensus about how it was built[2,3]. To understand its internal structure better, we imaged the pyramid using muons, which are by-products of cosmic rays that are only partially absorbed by stone[4,5,6]. The resulting cosmic-ray muon radiography allows us to visualize the known and any unknown voids in the pyramid in a non-invasive way. Here we report the discovery of a large void (with a cross-section similar to that of the Grand Gallery and a minimum length of 30 metres) situated above the Grand Gallery. This constitutes the first major inner structure found in the Great Pyramid

Muography components



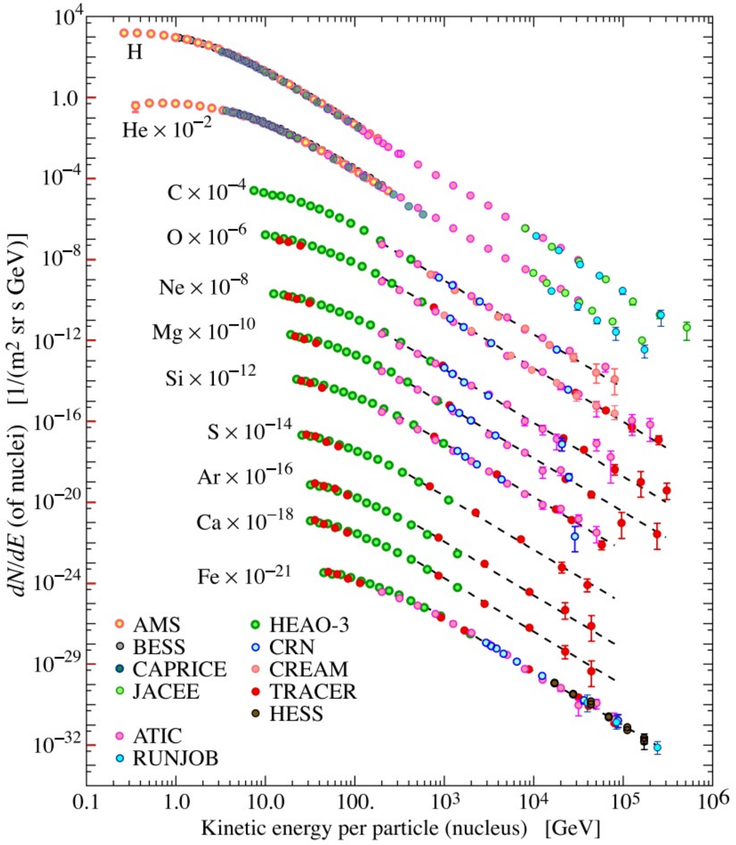
The test site

Geophysical target
(small mountain nearby UNI)



Expected secondary cosmic ray flux

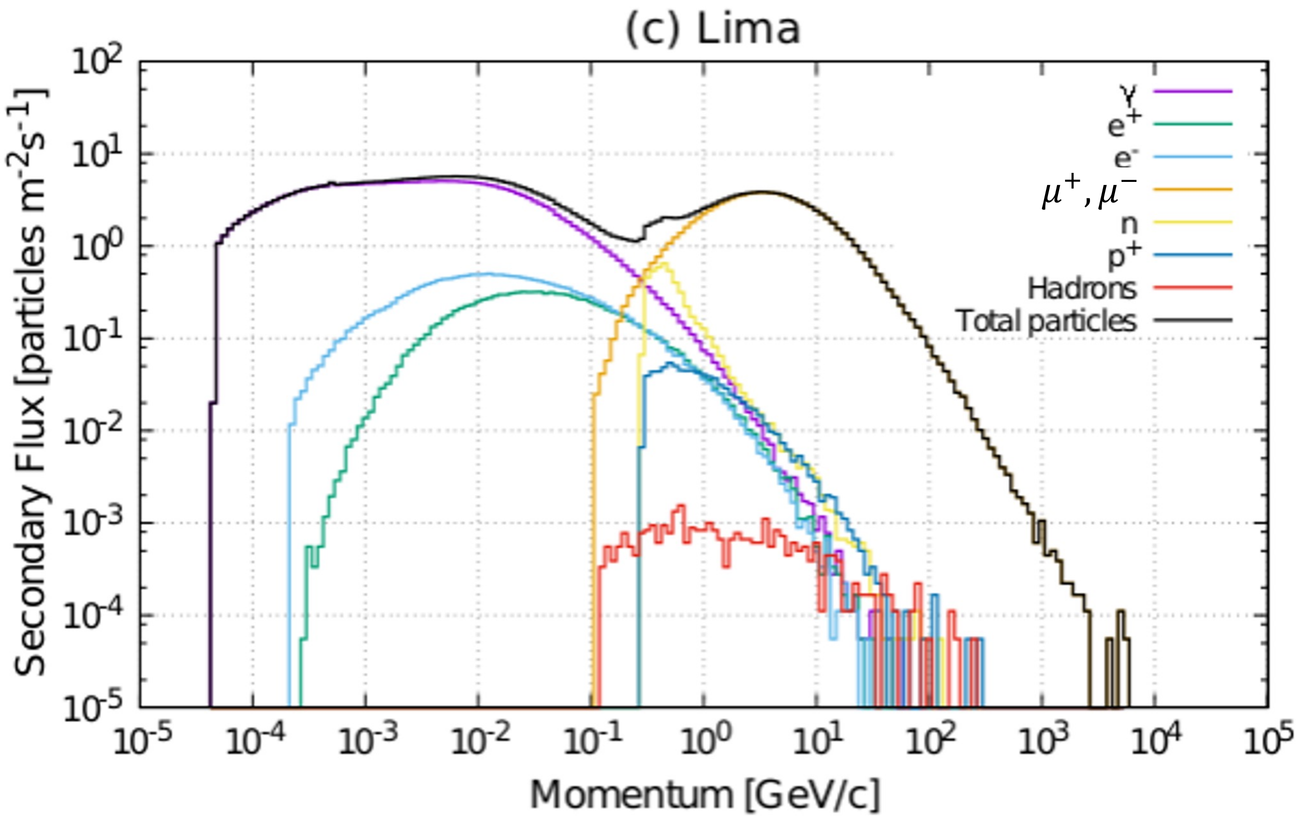
- ARTI: framework developed by the LAGO collaboration
  - ✓ Simulates secondary particles produced from the interaction of the complete flux of primary cosmic rays with the atmosphere.
  - ✓ Particles reach ground at any place on Earth (latitude, longitude and altitude), including the real-time atmospheric (using Global Data Assimilation System, GDAS, atmospheric models) and geomagnetic (using Magnetocosmics) contributions.



Fluxes of nuclei of the primary cosmic radiation in particles per energy-per-nucleus vs energy-per-nucleus.
Credits: P. Boyle and D. Muller

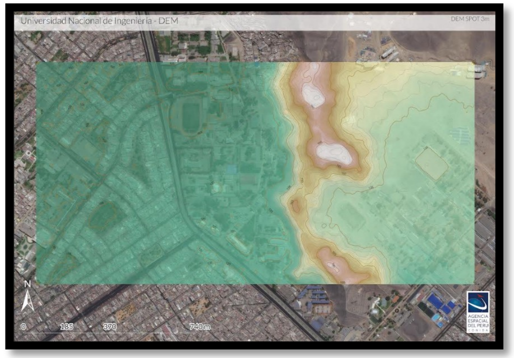
Expected secondary cosmic ray flux

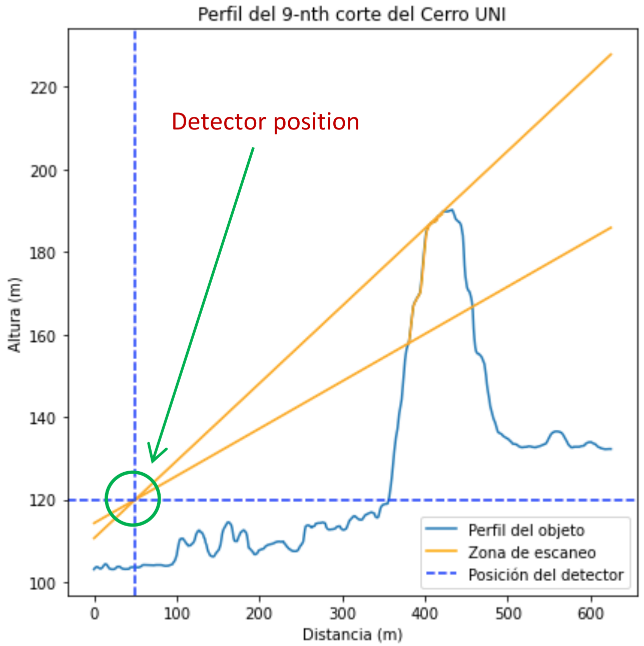
- ARTI allows us to calculate in a very precise way the expected flux of high-energetic muons and other secondaries at the ground level, and to make them pass through geological structures for muon tomography applications.

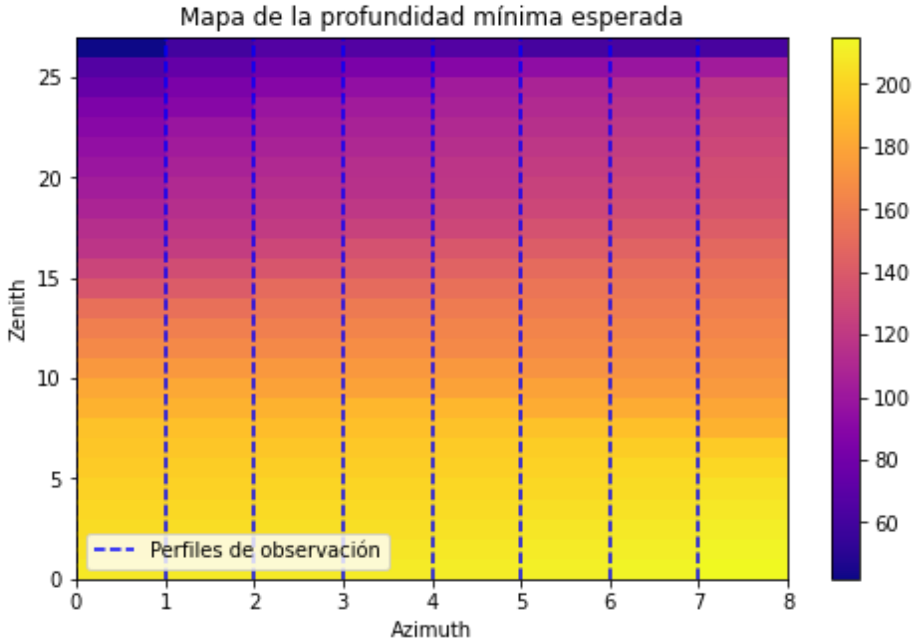


Muon depth distance

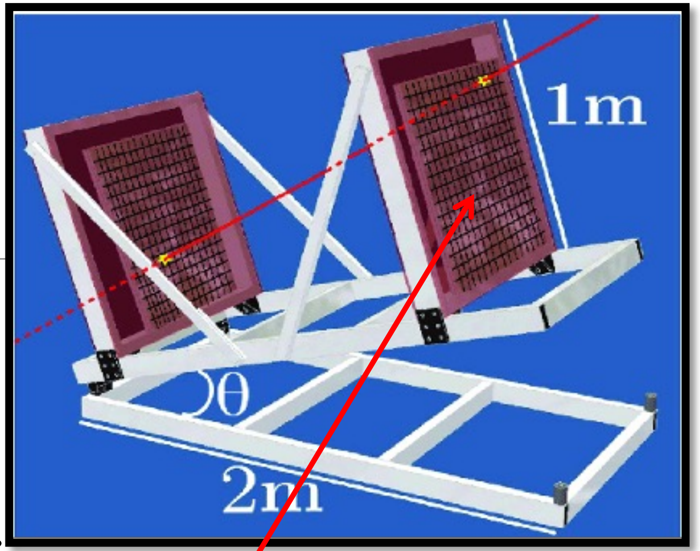
Geographical information of the geophysical object given by the Digital Elevaton Model (DEM), and the Geographic Information System (GIS) software is used to calculate the muon depth distance values for a defined orientation.



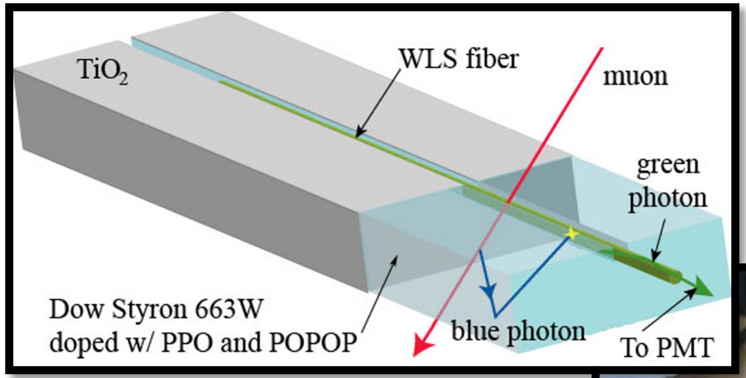




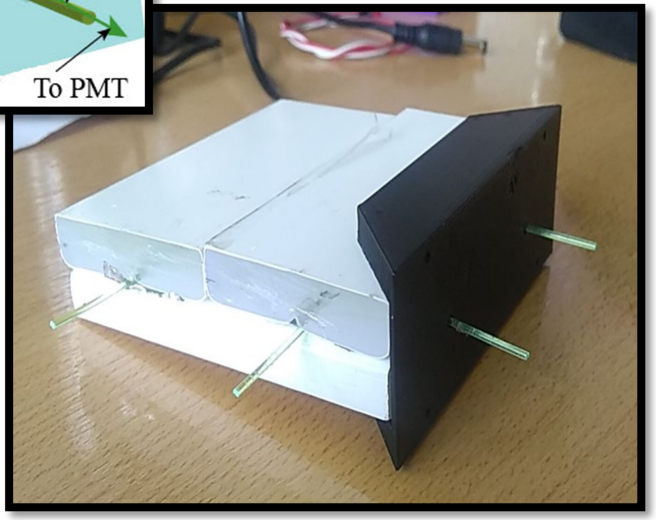
Detector modules development

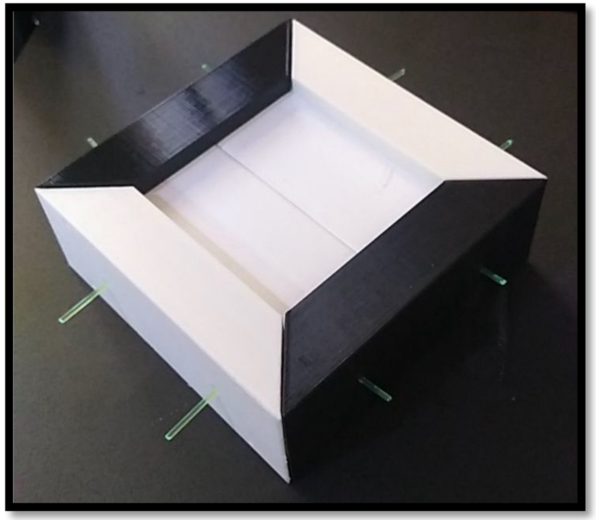


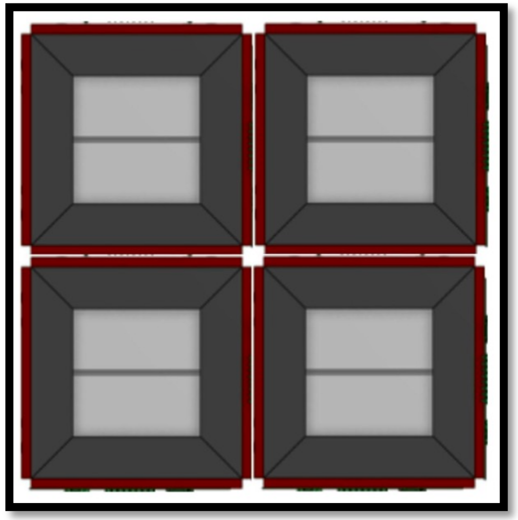
Portable, fully autonomous and interconnectable (2x2) to (6x6) pixel tiles.



- ✓ n=2-6, n^2 pixel fully autonomous tiles.
- ✓ 2n SiPM-based tiles

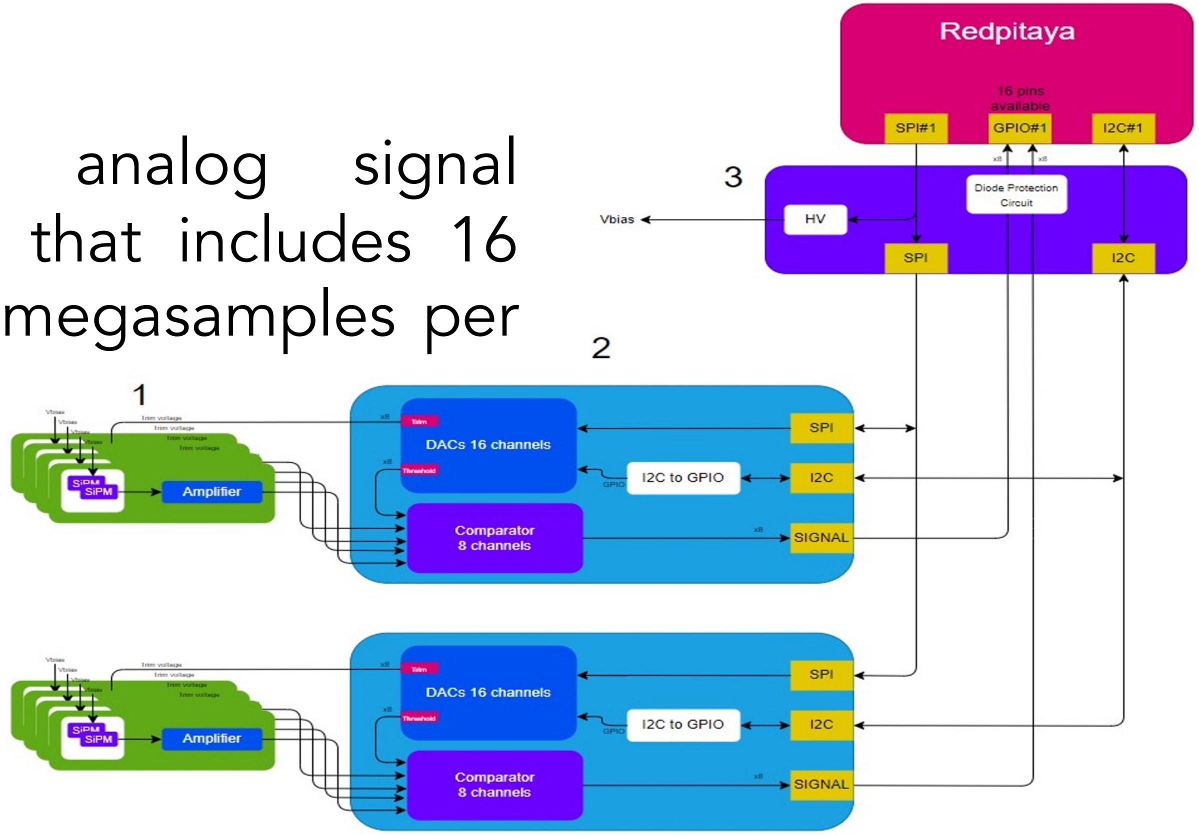




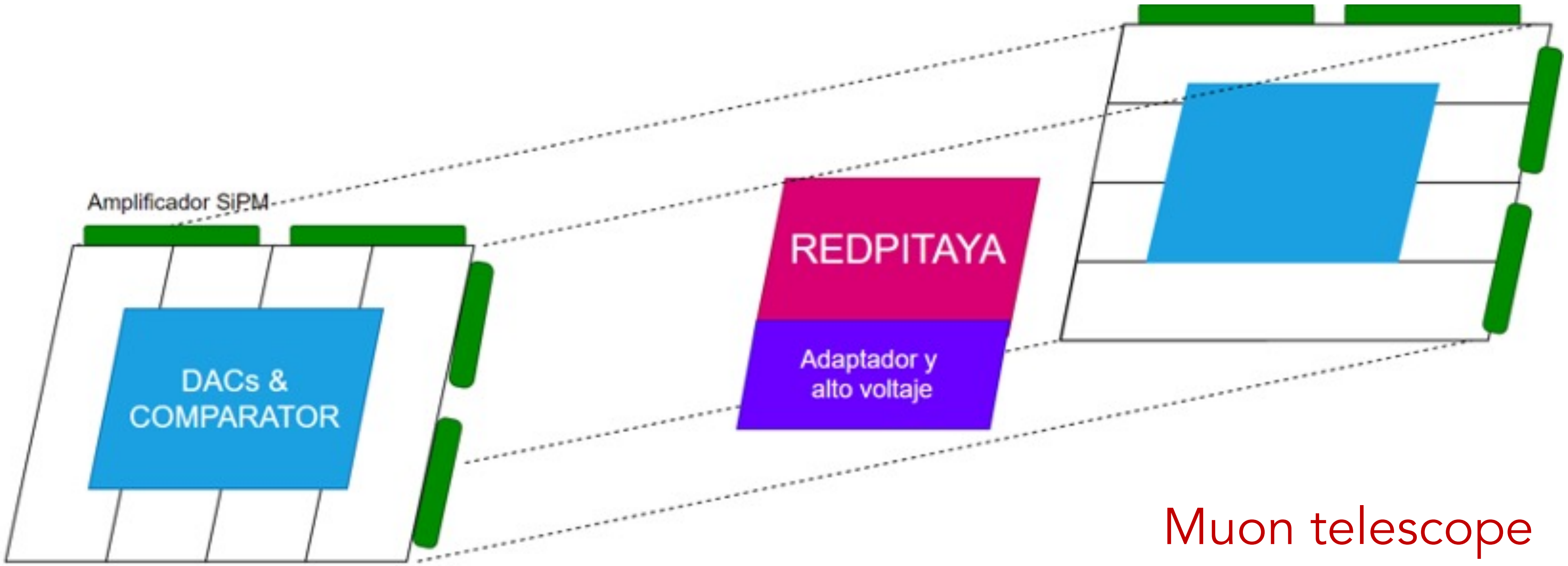


Electronic development

- We use RedPitaya a low-cost analog signal generation/measurement electronics, that includes 16 digital channels and samples at 125 megasamples per second, MSPS.
- The electronics comprises
  1. Front end for SiPm attachment to modules and signal amplification.
  2. Comparators boards that digitize the pulses (DAC).
  3. High voltage control (for SiPm power) and communication coupled with the RedPitaya board.



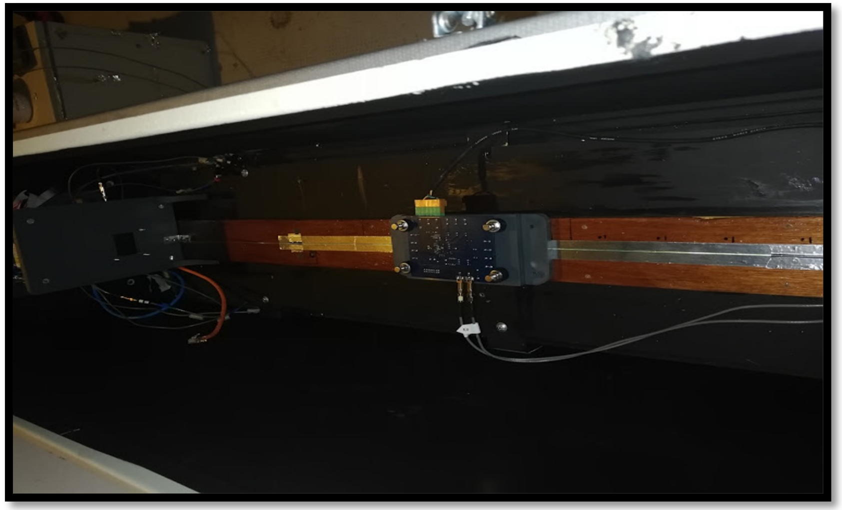
Electronic development

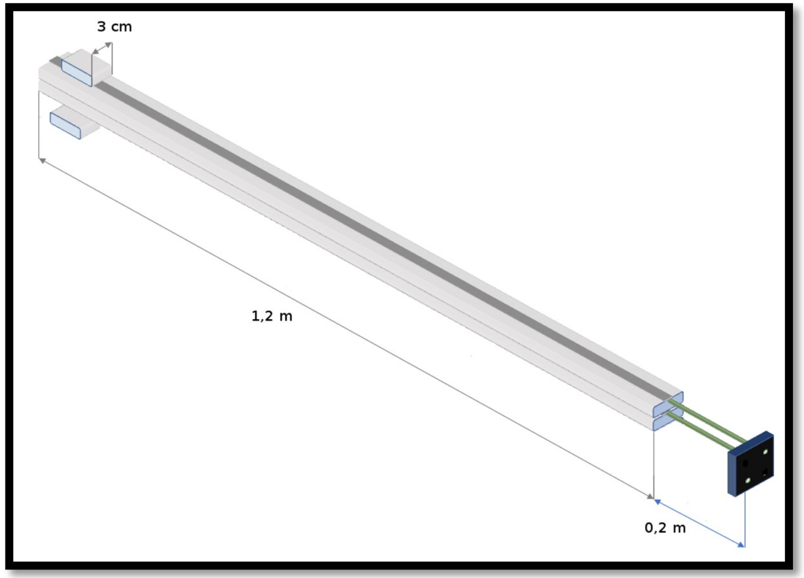


Muon telescope

Detection system response

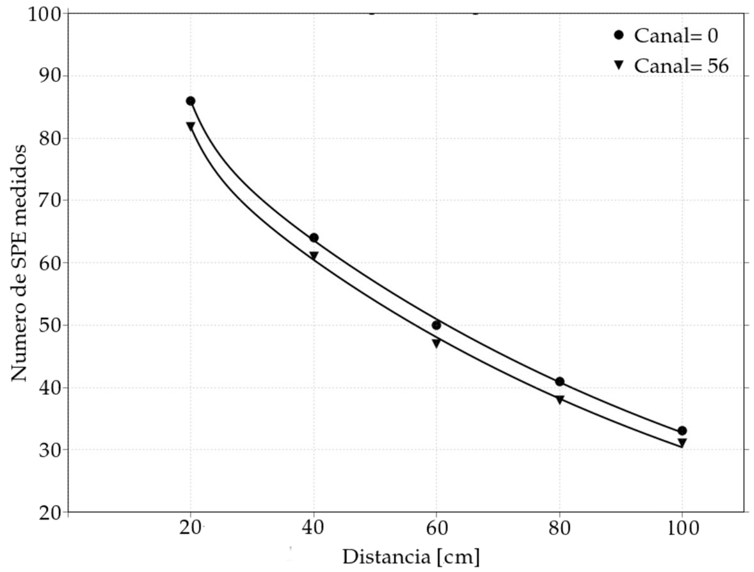
- In order to calibrate our detection system, a single photon generator using a led flasher system and a darkbox was implemented, with the support from the **Institute for Astroparticle and Sensing Technologies** (ITeDA, Argentina).
- We measured the attenuation length of the response of a 1.2 meters bar and an optic fiber array to muons (using a coincidence system) in a underground laboratory at ITeDA.

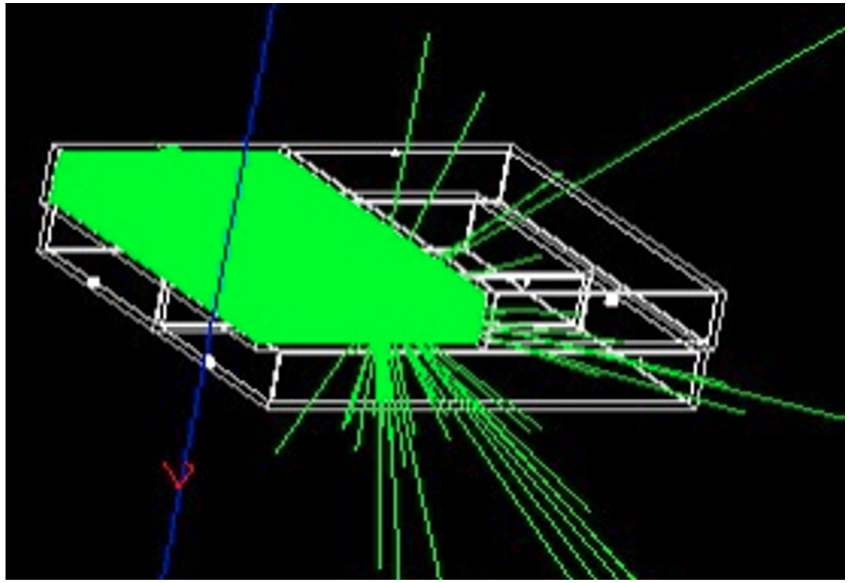




Modeling the detection system

- We model and implement the attenuation length of the bar + optic fiber system.
- Also, we model the response of the SiPM's by using data from the manufacturer in a GEANT4 module simulation.





Conclusions

- UNI and CONIDA has been working in the construction of a muon telescope for non-invasive prospection of geophysical objects.
- What we have so far
  - ✓ The geophysical object to test the muon telescope has been selected.
  - ✓ We model the geophysical object and calculated the flux of cosmic muons at the site.
  - ✓ A detection system and the electronics that controls it have been developed.
  - ✓ We still need to perform some tests with the components.
  - ✓ Next step is to put everything together and start playing with our muon telescope.

Stay tuned!