Muography developments within the MuAR project: advances in simulations and new detectors designs

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Muography developments within the MuAR project: advances in simulations and new detectors designs

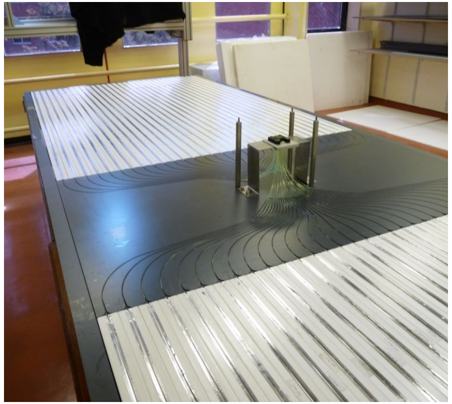
Background

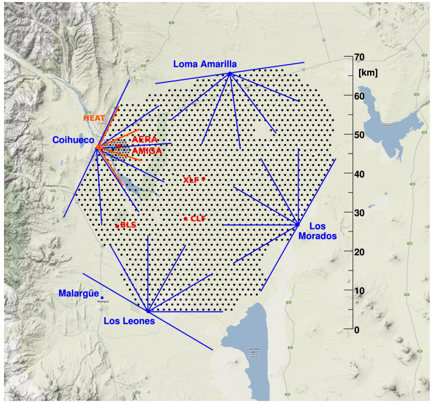
Simulation program

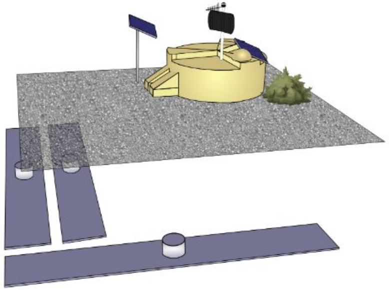
Detectors designs

Background: LAGO, AMIGA and MuTe

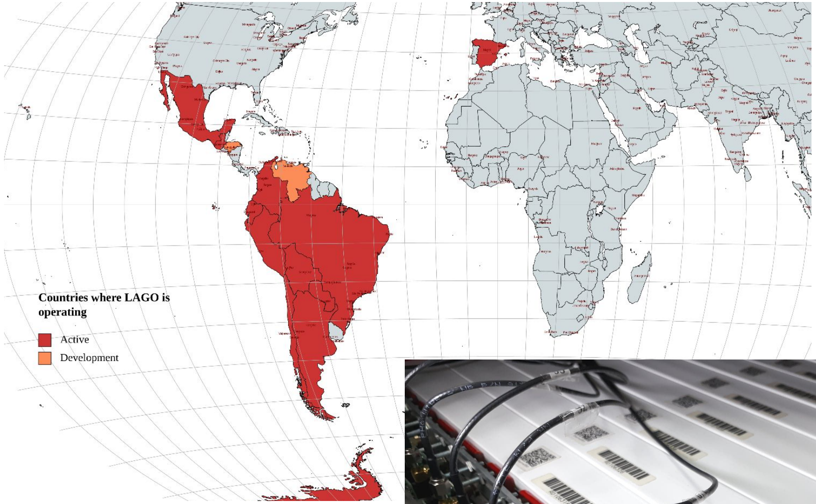
AMIGA is a buried muon counter designed to study the UHECR composition at the Pierre Auger Observatory by measuring the EAS muon distribution density at ground





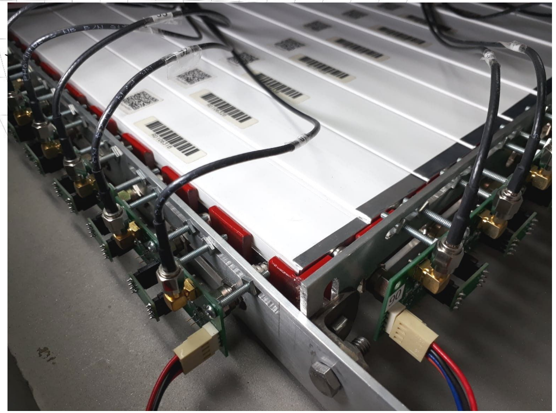


LAGO is a giant network of astroparticle WCD detectors, currently operating in 11 countries. The LAGO network measures the time-evolving flux of secondary particles produced by the modulated flux of GCR



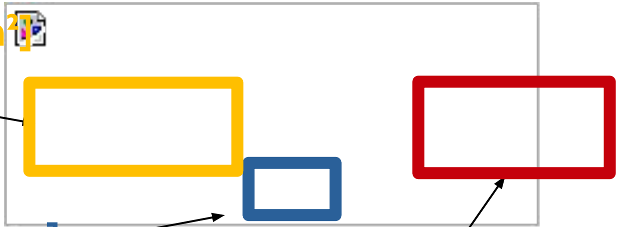
MuTe is a two-panel, 900px and hybrid muographer, scintillators & WCD, designed, funded and built in Latin America

(L. Núñez et al, 2022)

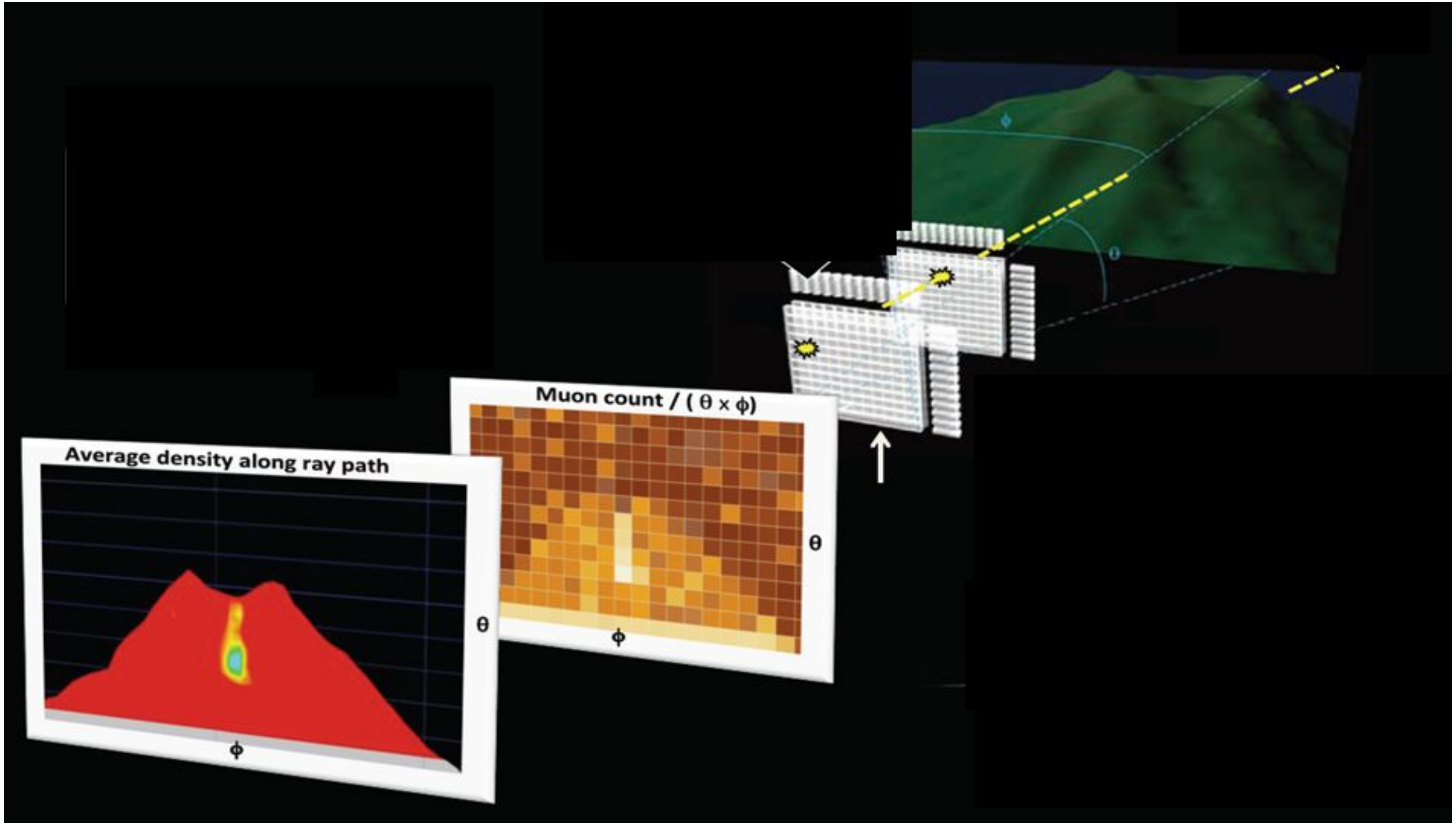


Muography -> the basis

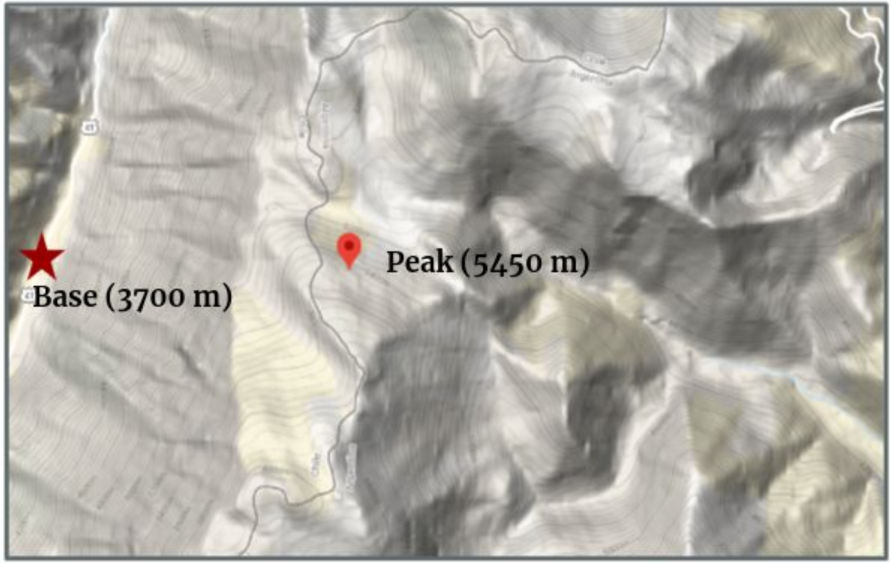
- Suppose you have an object with an unknown density profile, then...
  - ... measure the directional muon flux through this object
  - **... and compare with the muon reference flux**
    - **→ you get the directional opacity of this object [g/cm^2]**
- Additionally...
  - ... obtain the external geometry of the object
    - **→ and calculate the directional interaction distance [cm]**
- Finally, from...
  - directional opacity
  - directional interaction distances
    - **→ you get the internal density profile along muon propagation direction**

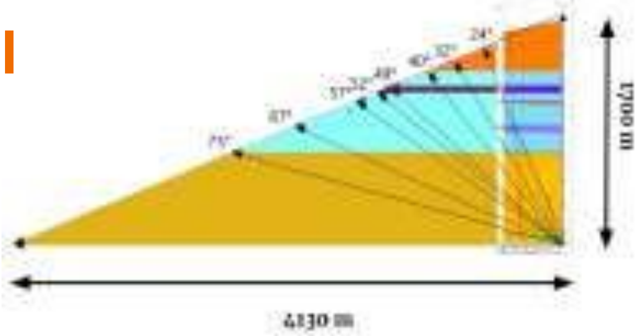


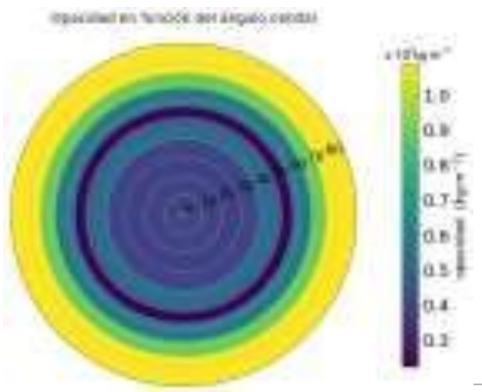
Muography -> the basis



Application: ANDES muon expected flux at 30°24’ S, 69°88’ W, 4000 → 5450 m asl







Integrated muon flux: $\Phi_{\mu} \sim 1{,}3\ m^{-2}\ day^{-1}$

AFA’s Luigi Masperi Award 2020 (C. Perez-Bertolli et al, 2021)

Muography developments within the MuAR project: advances in simulations and new detectors designs

Background

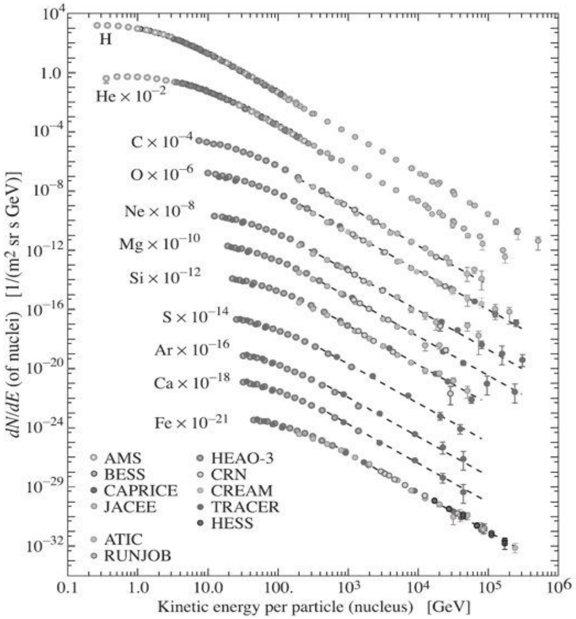
Simulation program

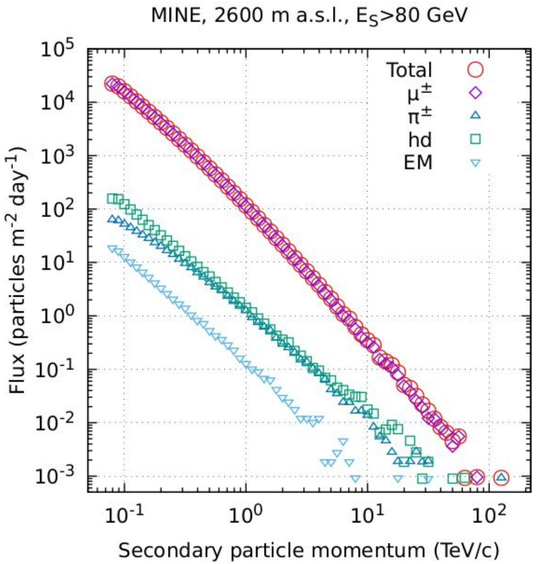
Detectors designs

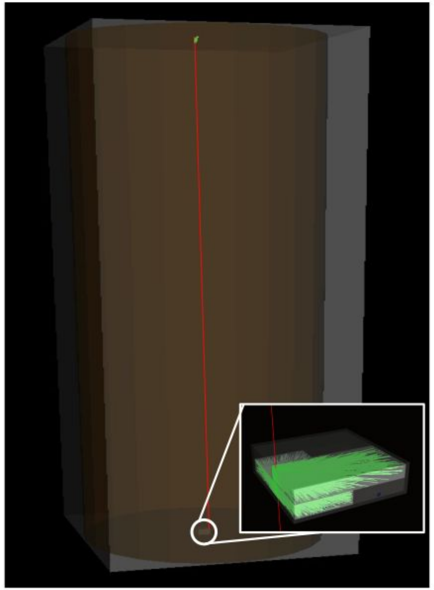
from primary flux to applications

$$\text{GCRFlux} \xrightarrow{\text{Heliosphere}} \text{Modulated Flux} \xrightarrow{\text{Magnetosphere}} \text{Primaries} \rightarrow \cdots$$

$$\cdots \rightarrow \text{Primaries} \xrightarrow{\text{Atmosphere}} \text{Secondaries} \xrightarrow{\text{Detector}} \text{Signals}$$

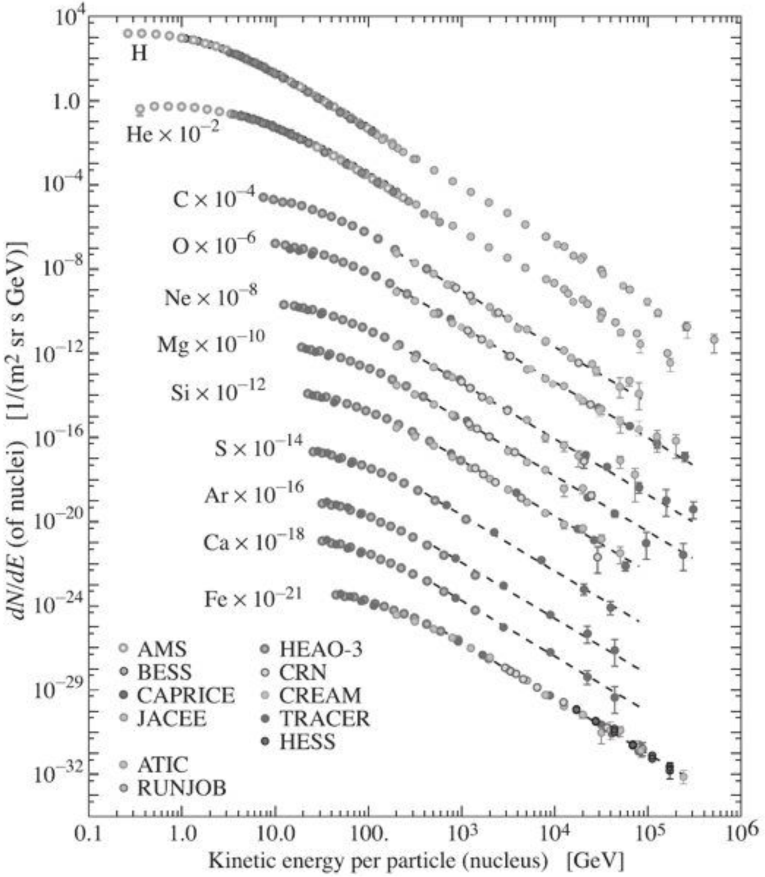






H. Asorey et al., COLAGE2021, Adv. Space Res., in preparation

primary flux integration



For each primary, we need to integrate its spectrum to get the expected (Poissonian) number of primaries at the top of the atmosphere

$$N_{t,S} = \int_t \int_S \int_\Omega \int_{E_p} j_0(E_p, Z_p)^{\alpha(E_p,Z_p)} dt\, dS\, d\Omega\, dE$$

We integrate:

full spectra, $1 < Z < 26$

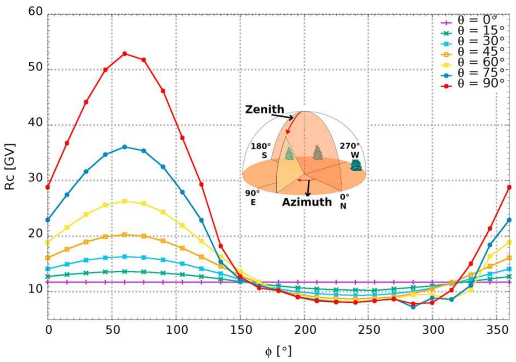
hemisphere, $0 \leq \theta \leq \pi/2, -\pi \leq \phi \leq \pi$

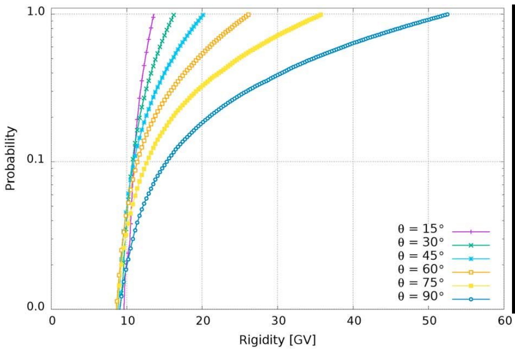
energy range, $(R_C \times Z_p) < E/GeV < E_{\max}$

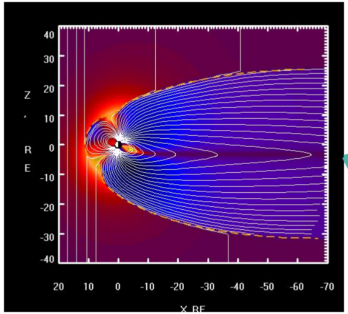
R_C is the local, time-dependent, geomagnetic rigidity cut-off
E_{max} depending on application

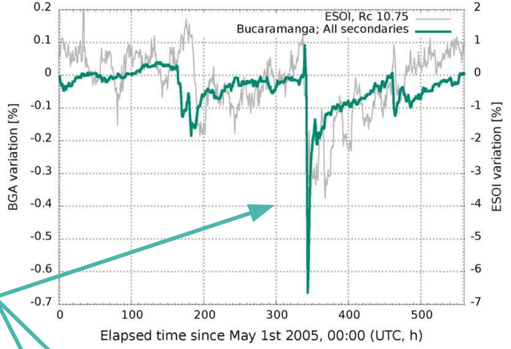
M. Suárez-Durán, H. Asorey and L.A. Núñez, Space Weather, (2018), DOI:10.1002/2017SW001774

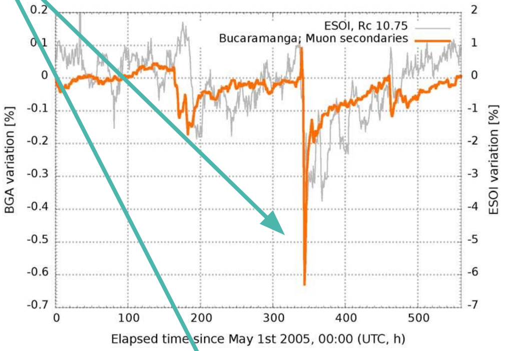
time-dependent local geomagnetic effects

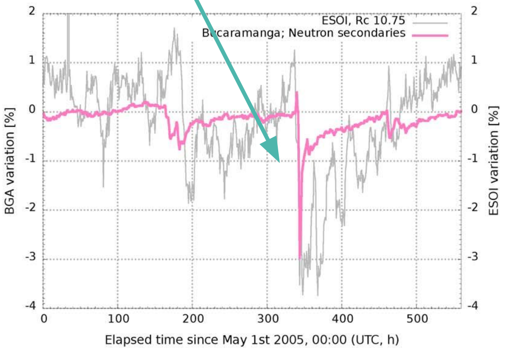


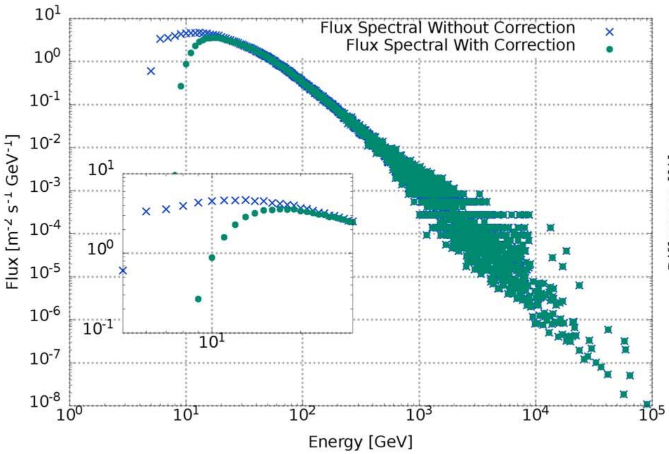


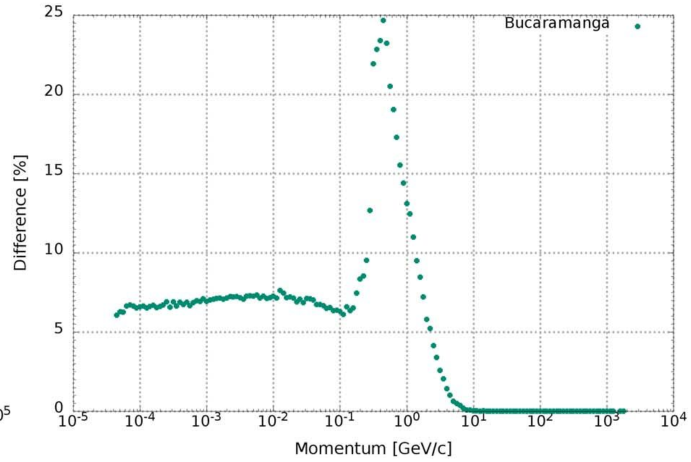








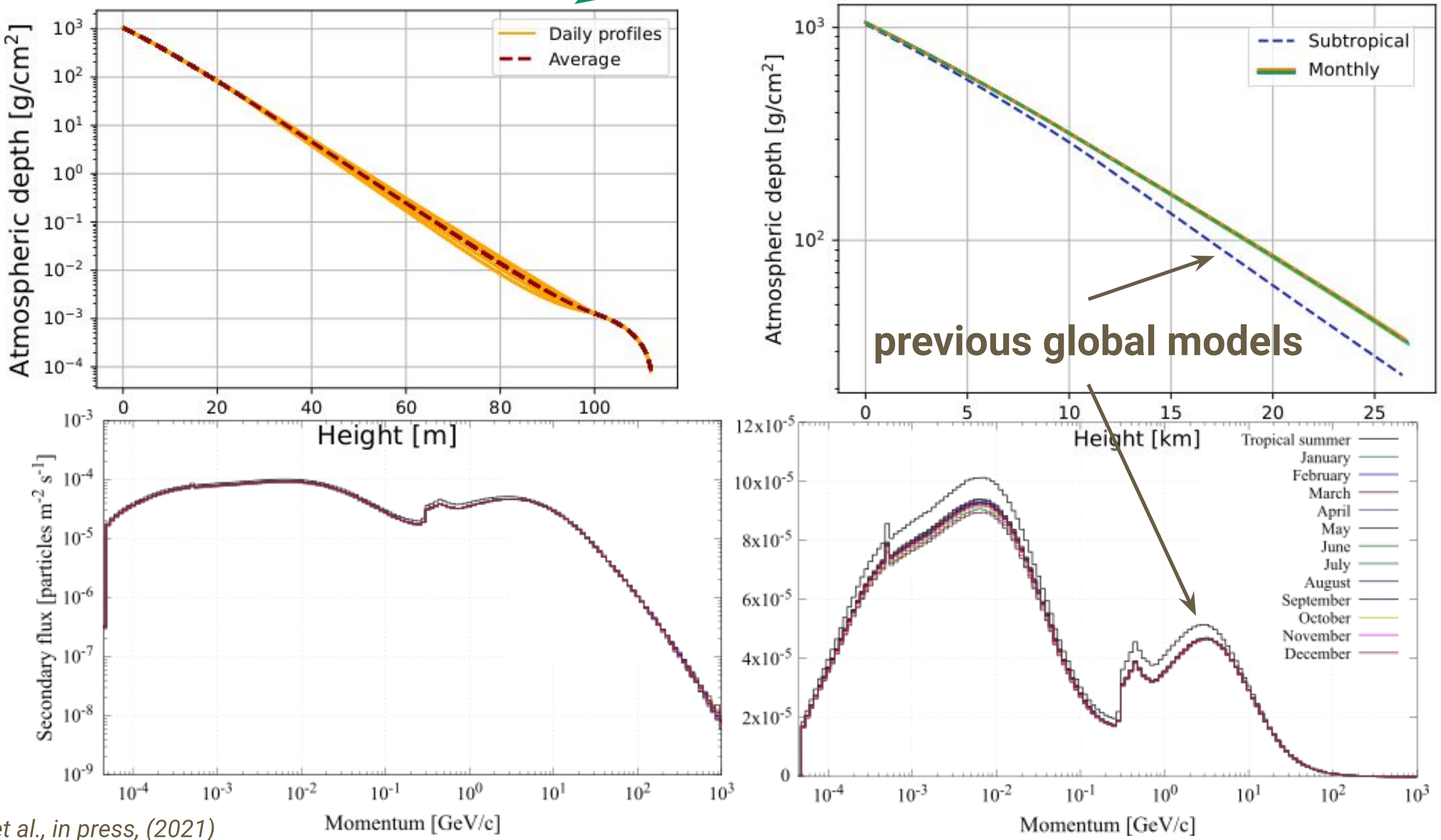




M. Suárez-Durán, H. Asorey and LA Núñez, Space Weather, (2018), [*DOI:10.1002/2017SW001774*]

local atmospheric effects

Monthly-averaged or instantaneous local atmospheric profiles from GDAS



J. Grisales et al., in press, (2021)

Our secondary flux simulation framework

Transient astrophysical phenomena

GRBs, Solar Activity, …

Inputs

Flux of CR

4.5×10^{8} day^{-1} m^{-2}

Primaries

Secondaries

4×10^{8} day^{-1}m^{-2} @4600 m asl

EM : MU : NE : HD= 0.875 : 0.065 : 0.050 : 0.010

Secondary propagation and detector response

type, geometry, materials...

GEANT4 detector models

Signals

Site characteristics

location, altitude, geomagnetic field, atmosphere, …

time-evolving conditions:

MAGNETOCOSMICS (IGRF13&TSY), GDAS and CORSIKA

C. Sarmiento-Cano et al. (2019), DOI:10.22323/1.358.0412; Hernán Asorey et al., Astropart. Phys., in preparation

Cloud-based implementation

Any HPC provider assigns resources to the cloud based implementation: cores, memory and local storage

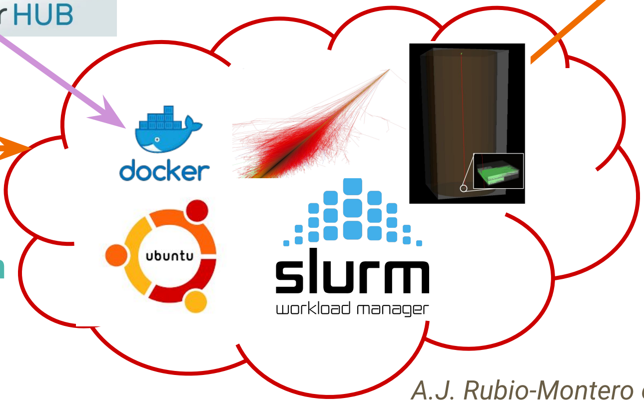
Infrastructure Manager

A web-based service for distributing all the available resources on user-configurable virtual clusters and install the OS (ubuntu 20.04 + slurm manager + docker)

docker HUB

docker containers with our codes are deployed from docker-HUB in the virtual cluster

virtual cluster



aws

Google Cloud

Microsoft Azure

FAIR: produced data catalogs are findable, accessible, interoperable and reusable

B2FIND

ONEDATA

Results are stored at cloud-based storage services. Publicly accessible by requested personal tokens

B2HANDLE

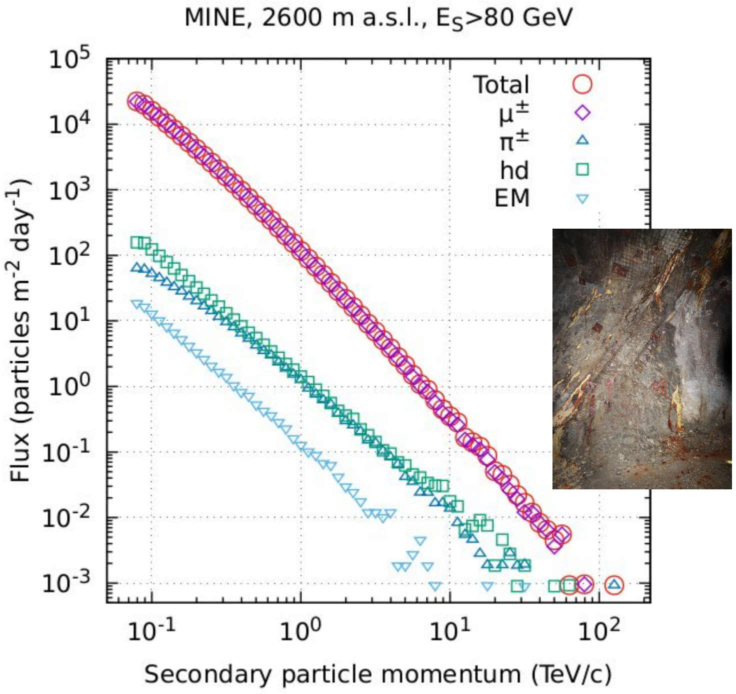
PID (Persistent IDentifiers) are assigned for each data catalog

A.J. Rubio-Montero et al (ICRC 2021) [DOI:10.22323/1.395.0261](DOI:10.22323/1.395.0261)

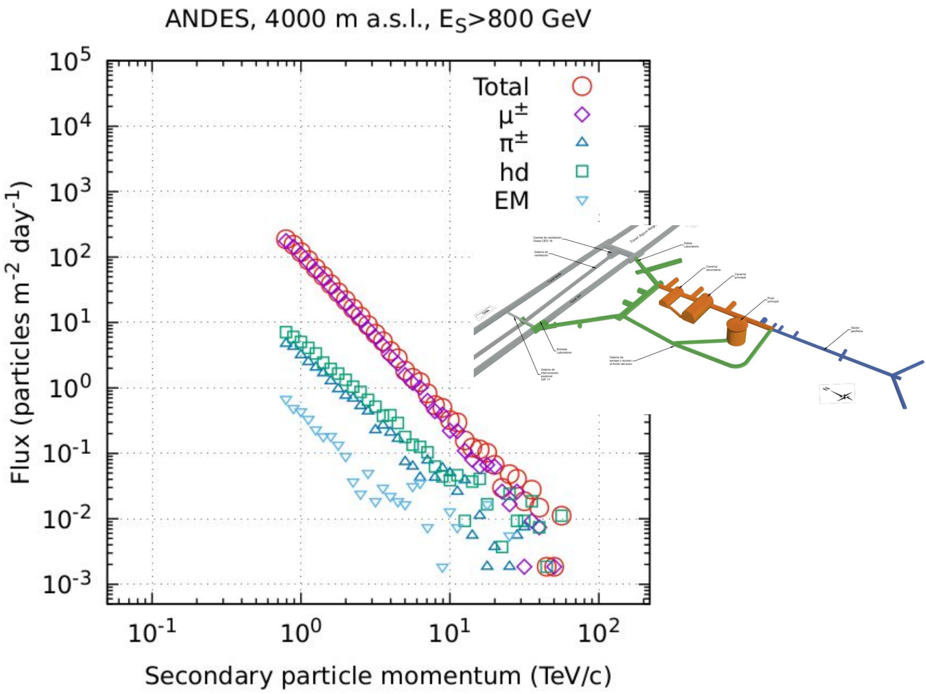
Muography and Underground LABs

One-year simulated flux of secondary particles at ground level (~1.5 kCPU·h/site)

MINE, 900 m.w.e., p_{CUT}=80 GeV/c



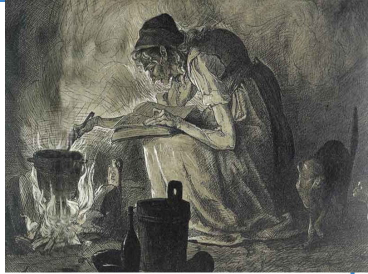
ANDES, 4600 m.w.e., p_{CUT}=800 GeV/c



High-momentum (p_s>p_{CUT}) secondary particle flux at different sites around the World

A.J. Rubio-Montero et al (ICRC 2021) DOI:10.22323/1.395.0261

Meiga, the sorceress (work in progress)



Transient astrophysical phenomena

GRBs, Solar Activity, ...

Inputs

Flux of CR

Primaries

Secondaries

docker

Site characteristics

location, altitude, geomagnetic field, atmosphere, ...

time-evolving conditions:

MAGNETOCOSMICS (IGRF13&TSY), GDAS and CORSIKA

Secondary propagation and detector response

type, geometry, materials...

GEANT4 detector models

Signals

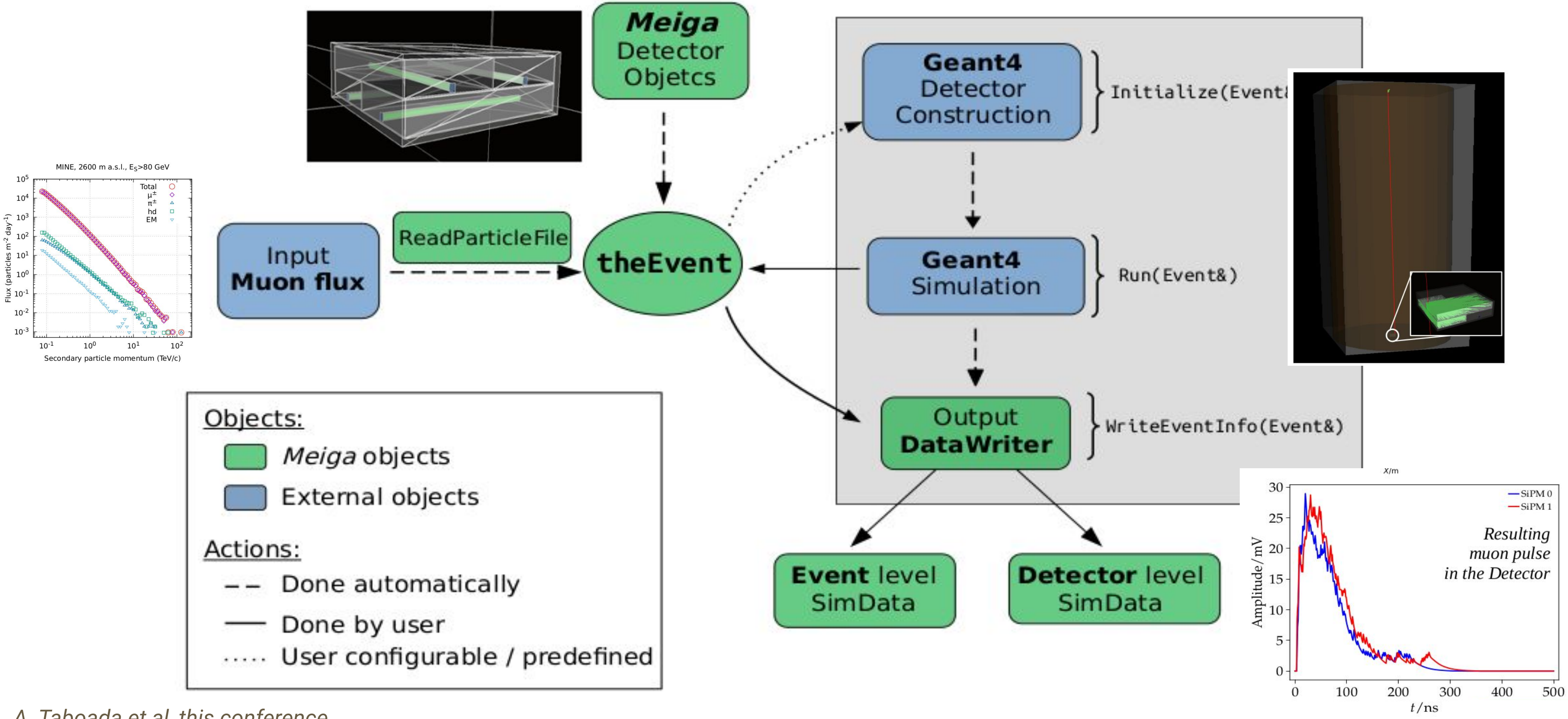
Meiga, a dedicated framework used for muography applications

*A. Taboada and C. Sarmiento for the MuAr group - **Poster #26 - Nov 25, 2021, 15:30 CET - https://indi.to/N4Rqh***

A. Taboada et al, this conference

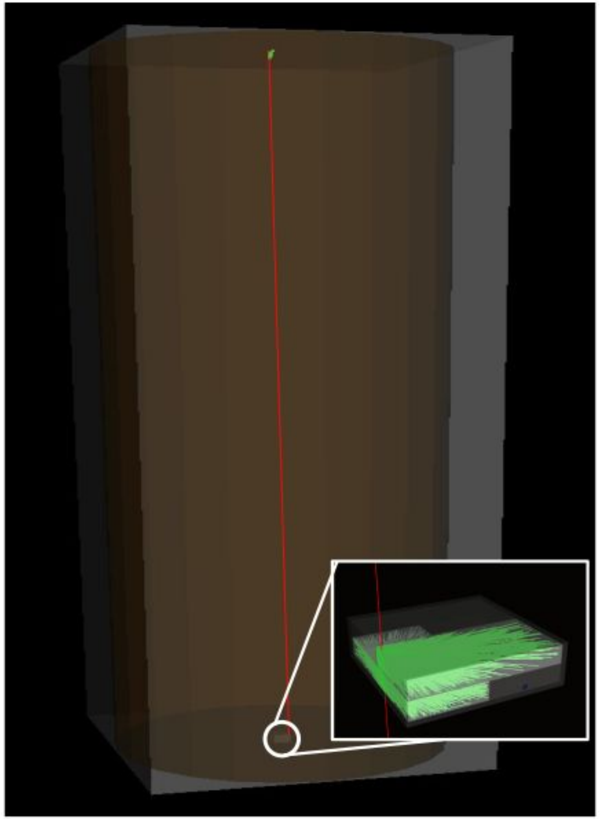
Meiga workflow

Poster #26 - Nov 25, 2021, 15:30 CET

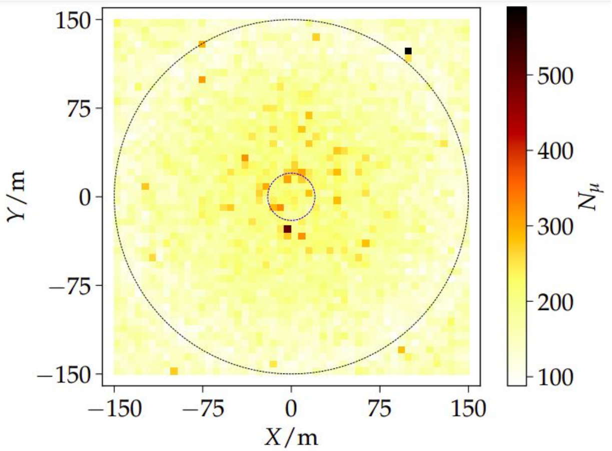


A. Taboada et al, this conference

Meiga example:
muon flux propagation through 500m of rock impinging on a single *Musaic'* tile

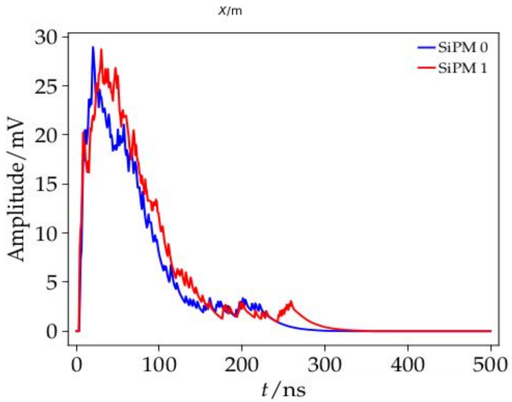


standard rock and
detector models



Muon density footprint after propagation through 500m of standard rock

Expected pulse at each SiPM



A. Taboada et al, this conference

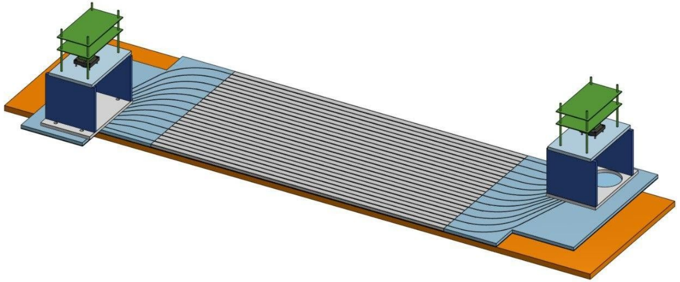
Muography developments within the MuAR project: advances in simulations and new detectors designs

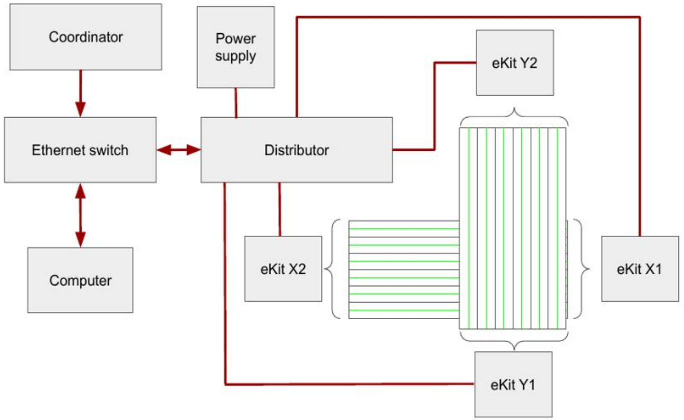
Background

Simulation program

Detectors designs

Modulus, our modular design

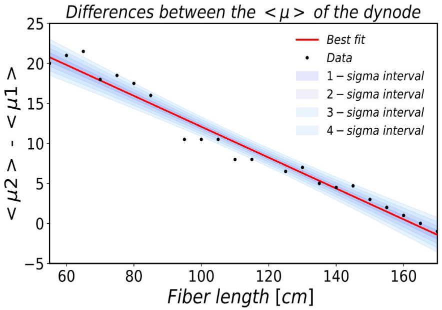


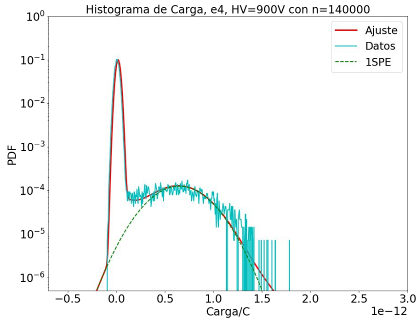


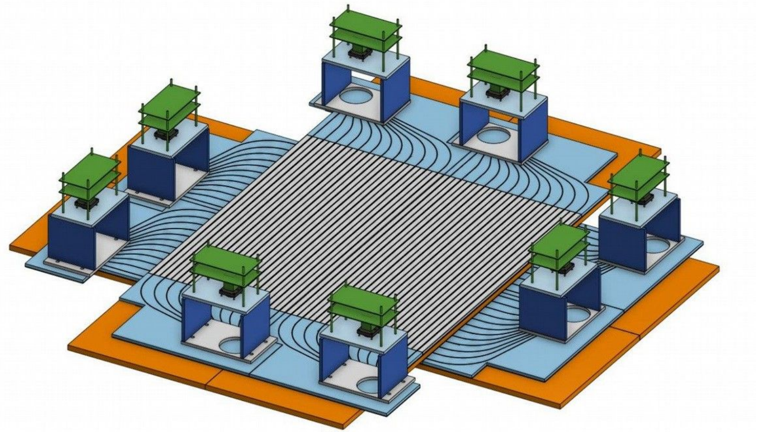
Development of Mudulus, a muography detector based on double-synchronized electronics for geophysical applications

R. Calderón-Ardila et al for the MuAr group

Poster #26 - Nov 25, 2021, 15:30 CET - https://indi.to/HQBZK





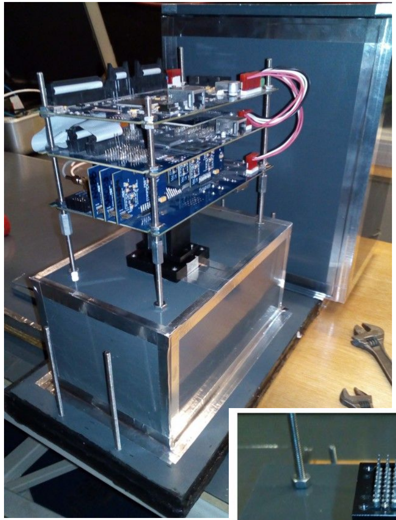


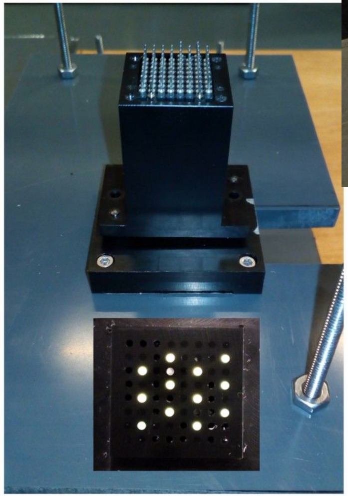
$$S_{real}(x) = S_{ideal}(x) \otimes N(x)$$

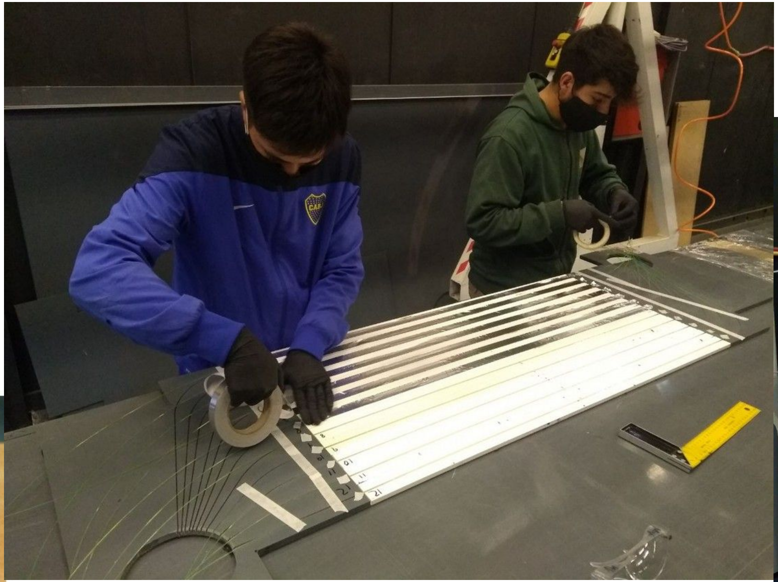
$$S_{ideal}(x) = \sum_{n=0}^{\infty} \frac{u^n \cdot e^{-u}}{n!} \cdot \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(x-n\cdot q)^2}{2n\sigma^2}}$$

R. Calderón-Ardila et al., JINST, submitted, R. Calderón-Ardila et al, this conference

First functional prototype (2021)

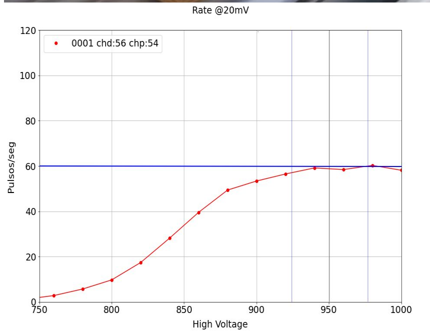


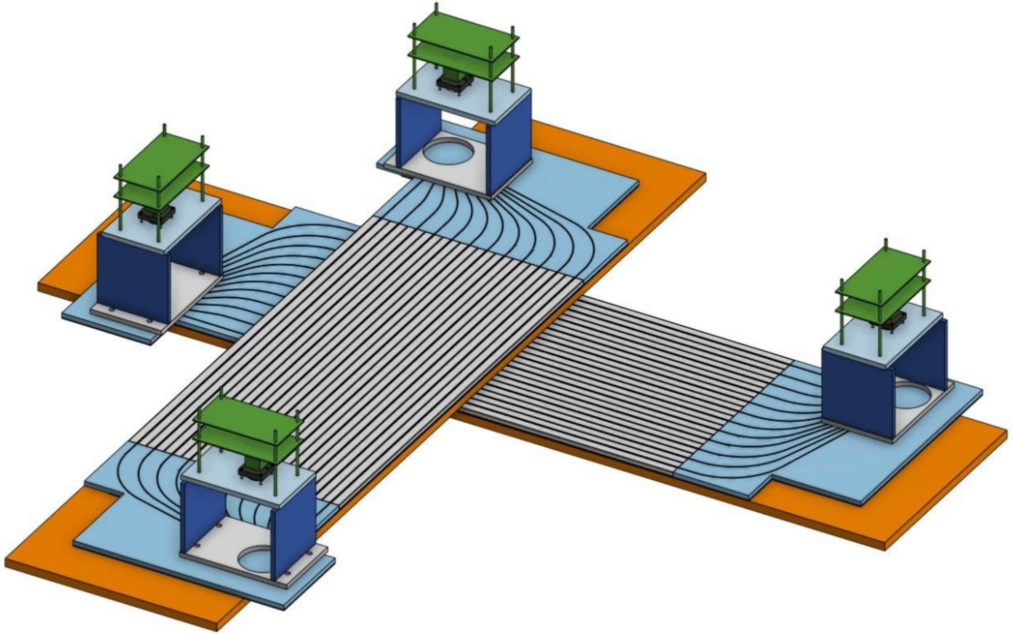




Technology transference from astroparticle detection to muography

Modular assembly, calibration, testing and coincidence detection





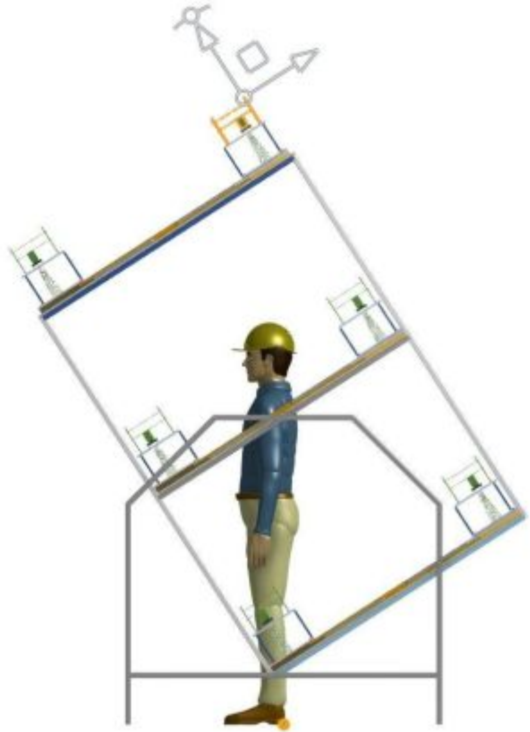
Single or double-head configurable signal acquisition electronics, depending on possible targets characteristics

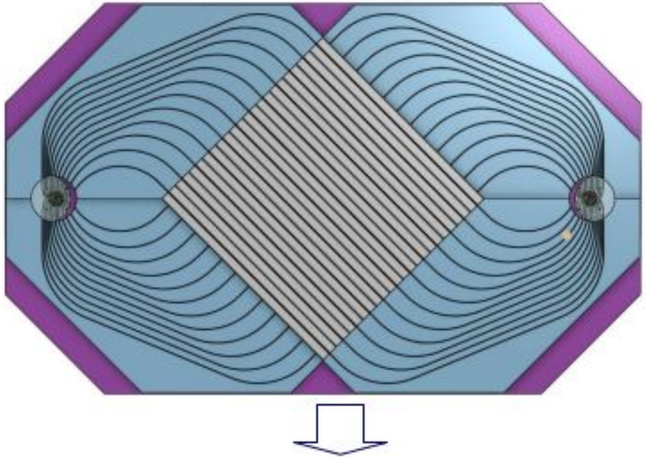
Mining prospecting applications

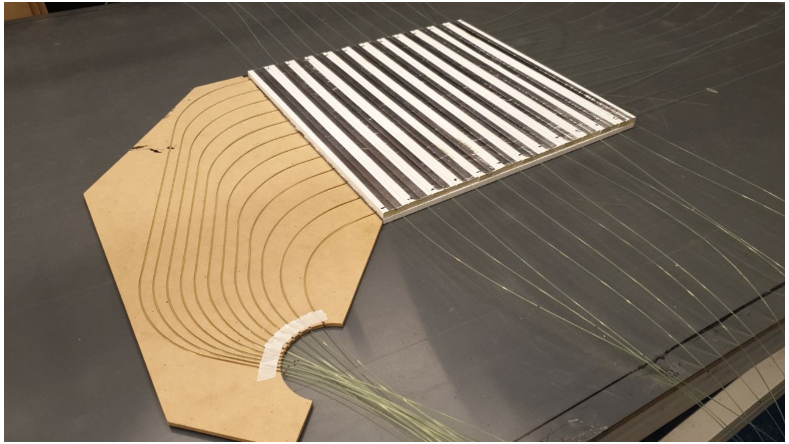
Detector deployment at selected site planned for 2022Q1

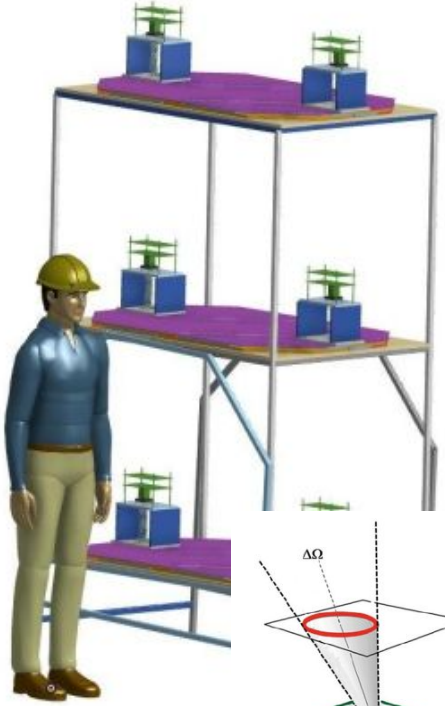
Detector site is selected at 900 mwe deepth

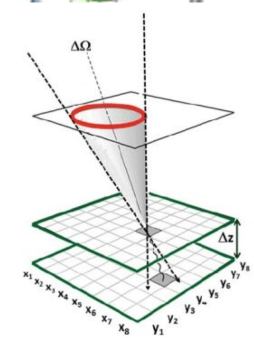
New detector geometry optimized for underground measurement







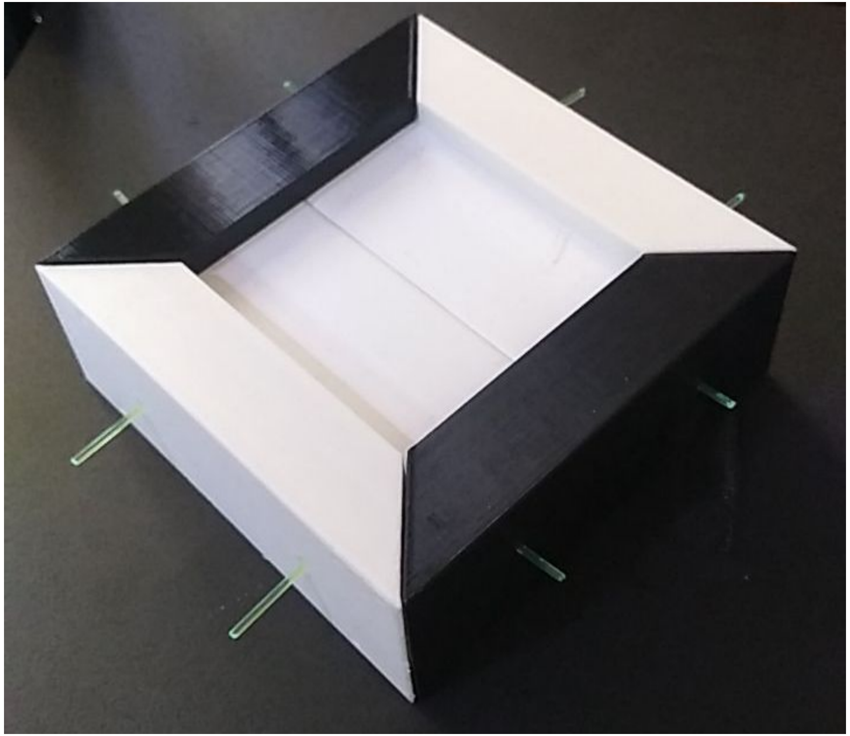




C. Ardila et al, ICES-16 (2021)

Next phase: Musaic

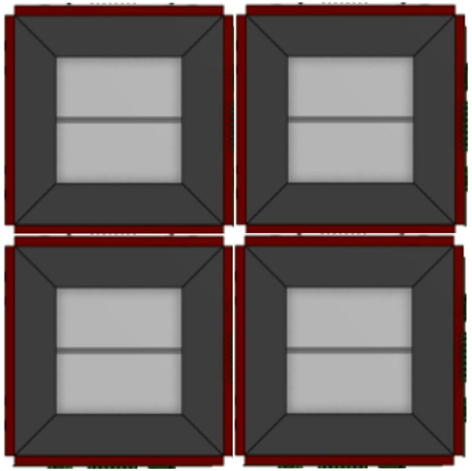
Portable, fully autonomous and interconnectable (2x2) to (6x6) pixel tiles

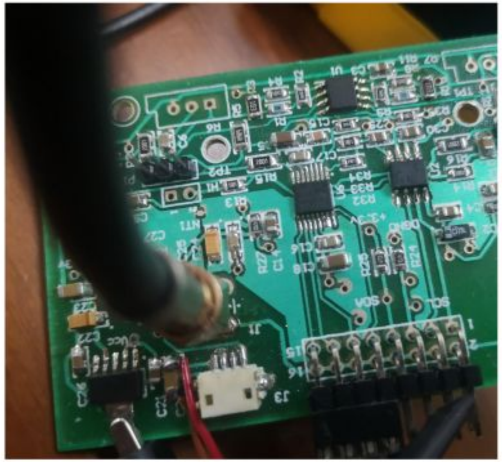


n=2-6, n^2 pixel fully autonomous tiles

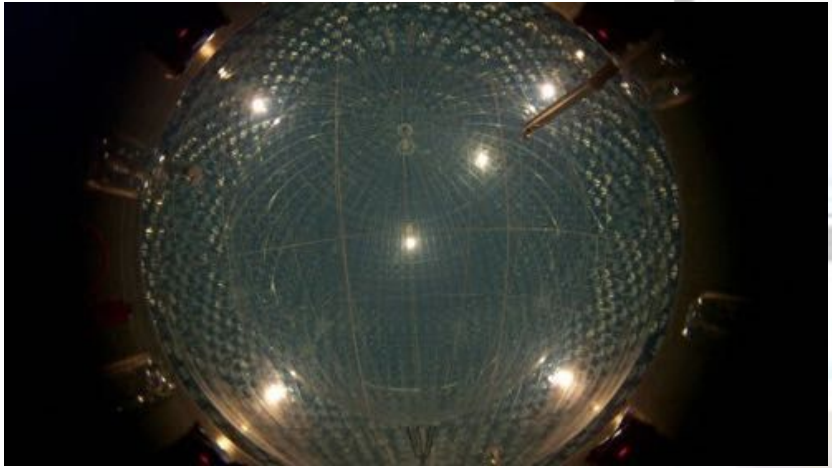
2n SiPM-based tiles

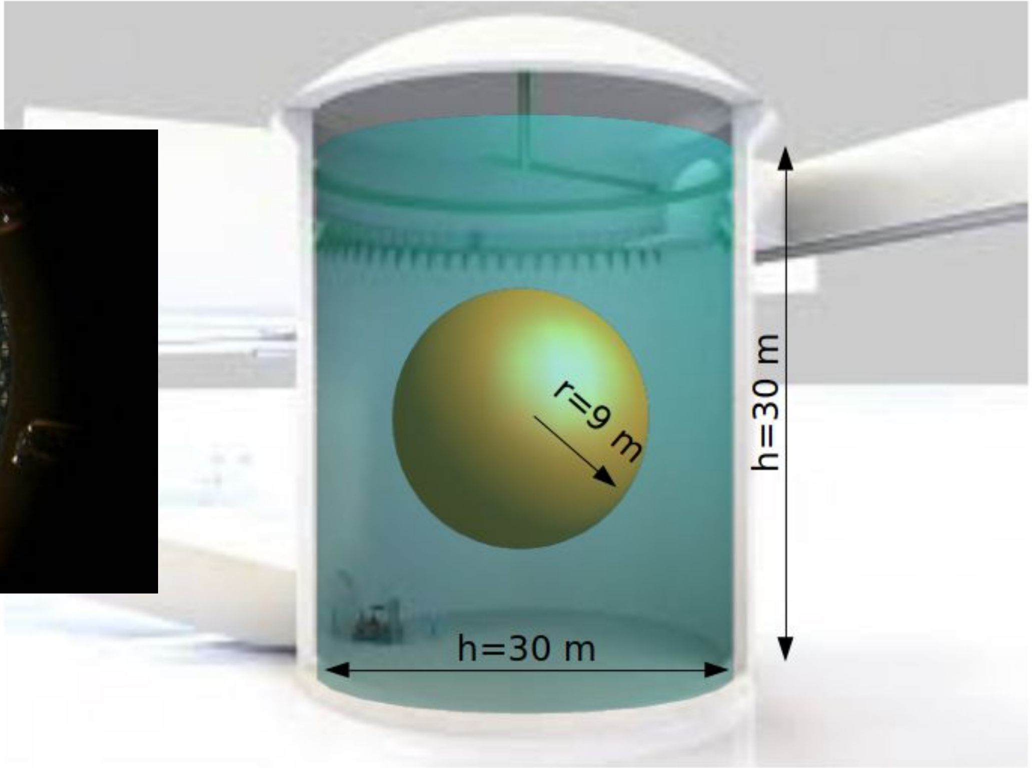
wireless synchronization





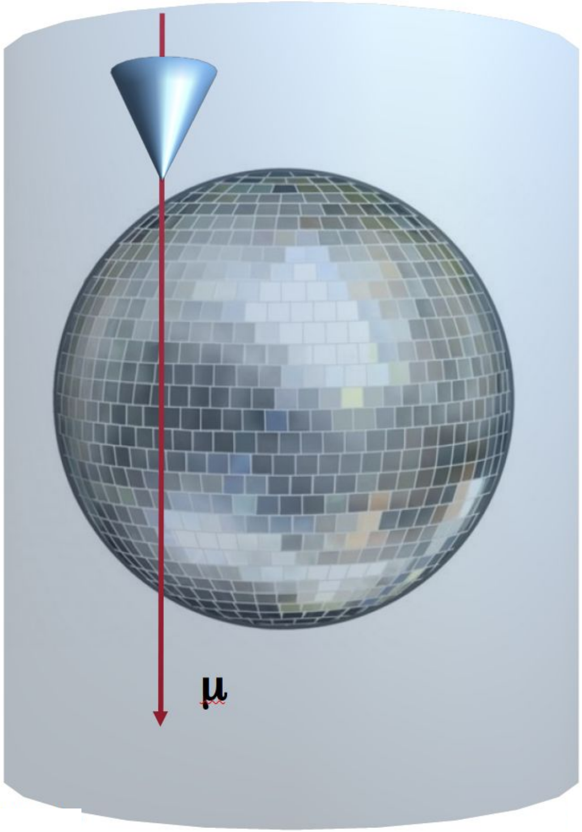
e.g., a neutrino experiment in ANDES





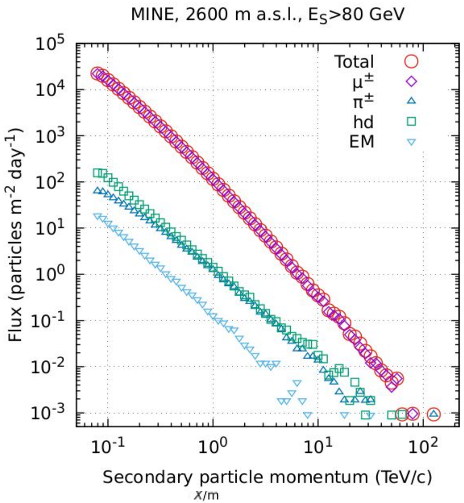
18000 m³ of ultra purified water + r:9 m copper sphere

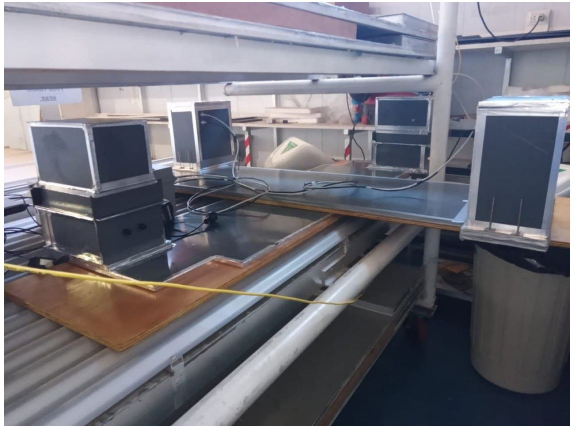
A muography-based muon-veto idea

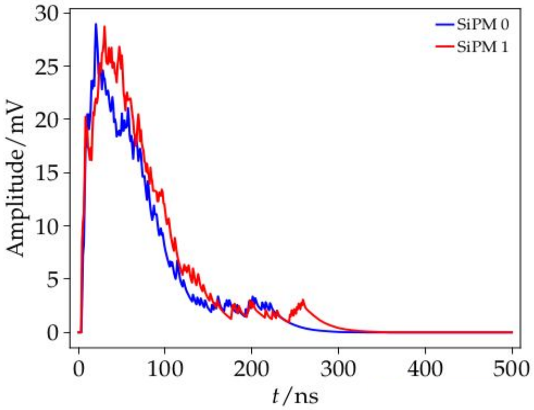


- Cherenkov radiation at water
- Sphere tessellation with
  - Mudulus single panels
  - Musaic mini-panels
- We are starting the R&D phase of the muon veto of several ANDES experiments
- First tests at Sierra Grande and Casposo

Conclusions







Fully integrated simulation sequence

Configurable and autonomous detector designs: portables, modulars and/or teseleables detectors

Starting field acquisition in 2022Q1

Muography developments within the MuAR project: advances in simulations and new detectors designs

Background

Simulation program

Detectors designs

¡Muchas gracias!