From a Network to a Networking: The Evolution of the Latin American Giant Observatory (LAGO)

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- Instrumentation
- Simulation framework
- Training in AstroParticle

The LAGO Collaboration

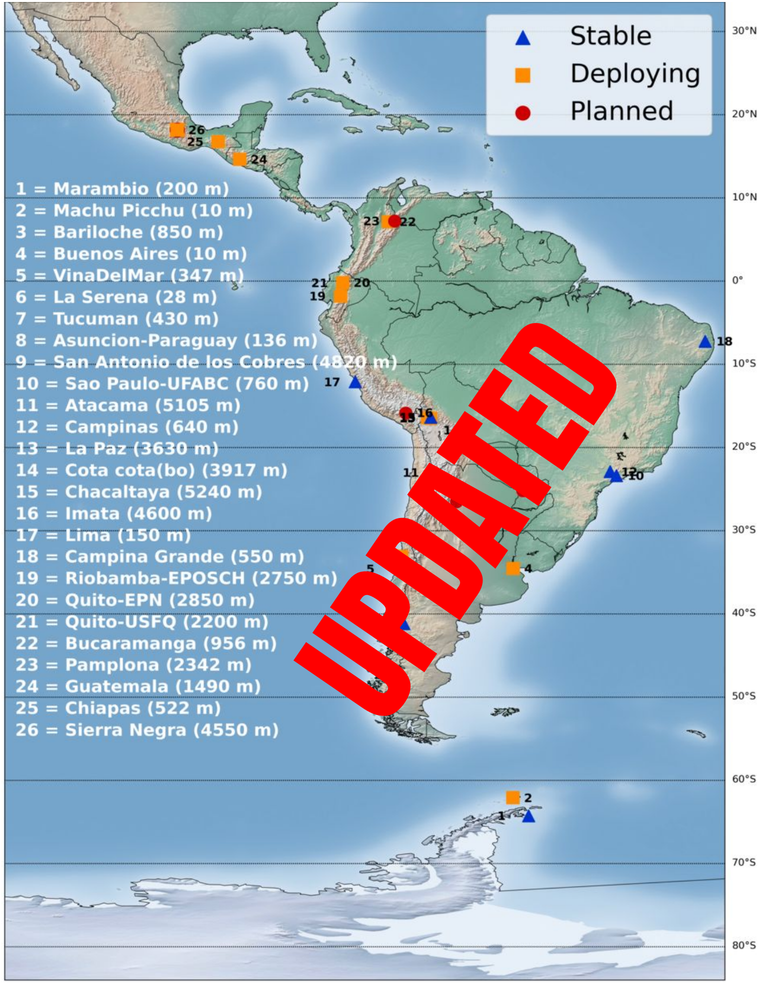
LAGO is an Auger Observatory spinoff collaboration with 83 members from 25 institutions at 10 LA countries & Spain

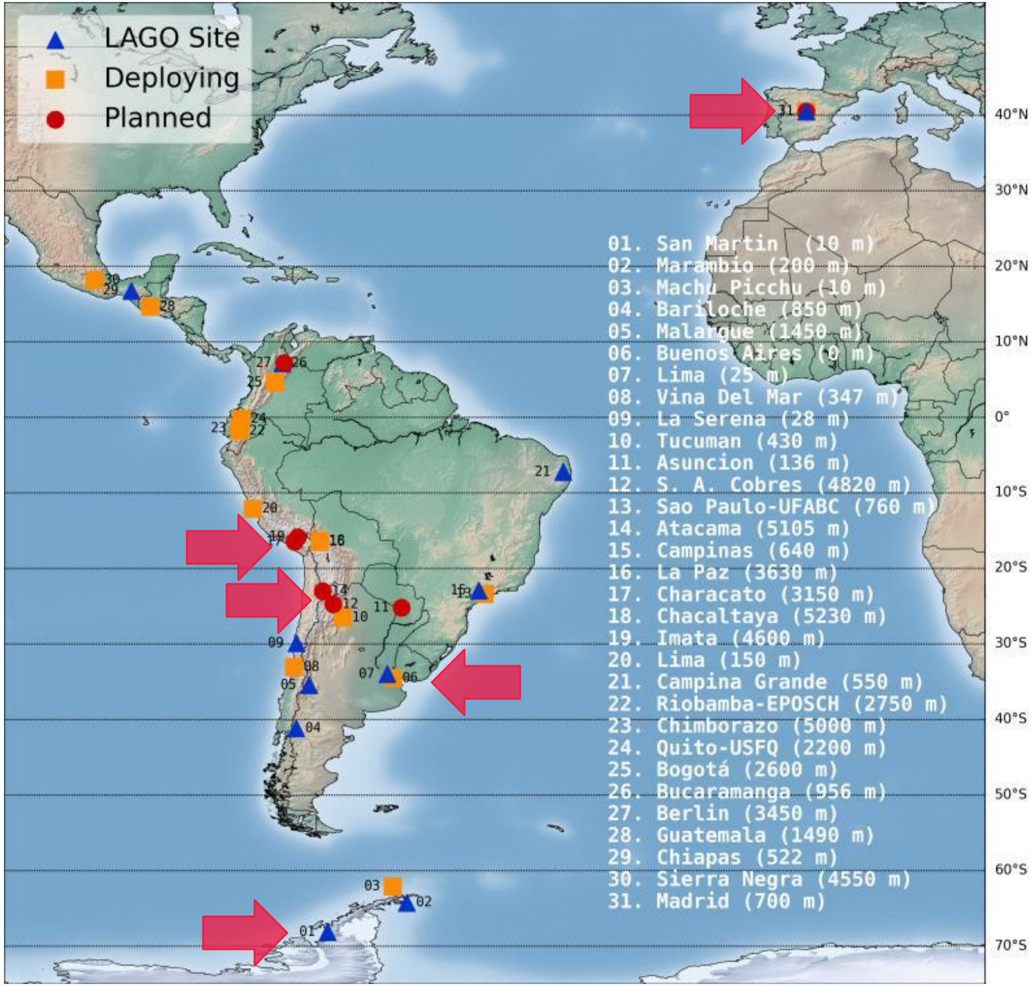
Scientific goals:

- Astroparticles up to the Cosmic Ray knee
- Study transient and long term Space Weather phenomena trough Solar modulation of Cosmic Rays
- Measurements of background radiation at ground level
- Applications of Cosmic Rays (Muography/Moisture)

Academic goals:

- *Train latin-american students in HEP and Astroparticle techniques*
- *Build a Latin-American network of Astroparticle researchers*

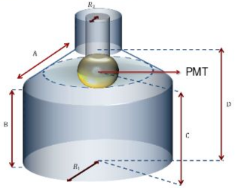




*I. Sidelnik & H. Asorey, NIM A **876** 173, 2017; H. Asorey et al., PoS ICRC2015 247, 2015*

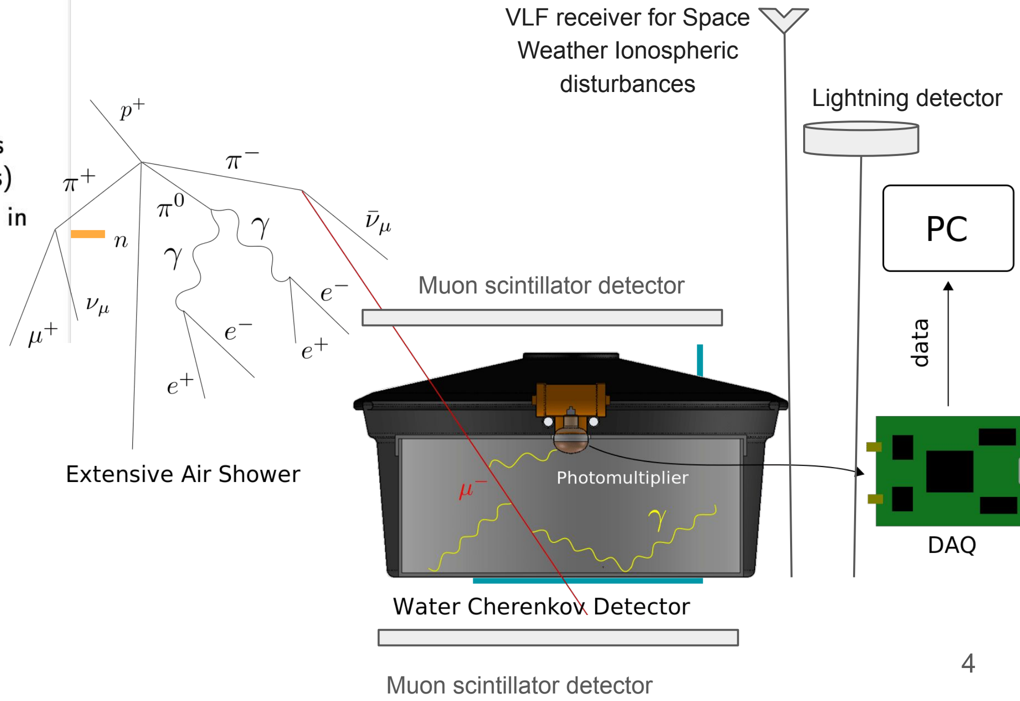
Our detector: sWCD (Water Cherenkov Detector)
s as in *smart*

- Autonomous, reliable, simple and cheap detector
- Commercial tanks with $1{,}5\,\mathrm{m}^2 - 10\,\mathrm{m}^2$ of detection area filled with purified water
- Inner coating of Tyvek (UV diffusive and reflective fabric)
- PMT + Digitizer board (own design)
- FPGA + Raspberry Pi: detector control, telemetry, data acquisition and on board data pre-analysis (including machine learning techniques)



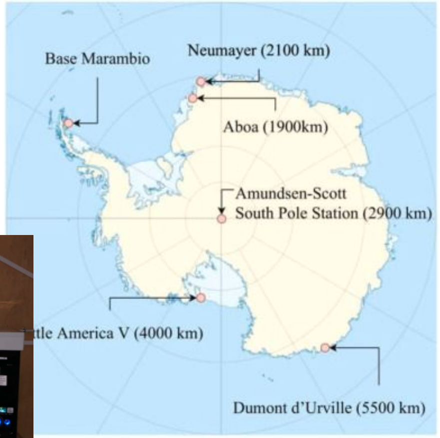
- Digitized signals by a 10-14 bits FADC at 40-100 MHz (10-25 ns)
- Temporal synchronization: GPS in PPS mode
- Station consumption: $\lesssim 8\,\mathrm{W}$

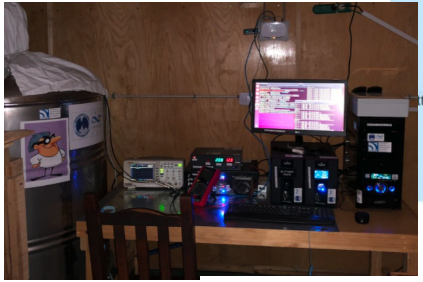
LAGO Space Weather Station

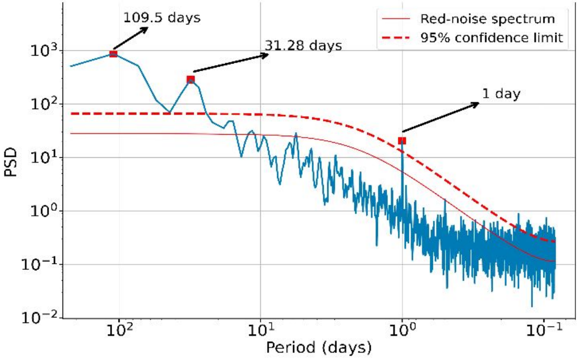


Implementing cost-effective instrumentation in order to have a decentralized and sustainable funding model.

Santos, N. A. & LAGO collaboration. (2023). **First measurements of periodicities and anisotropies of cosmic ray flux observed with a water-Cherenkov detector at the Marambio Antarctic base**. *Advances in Space Research*, *71*(6), 2967-2976.



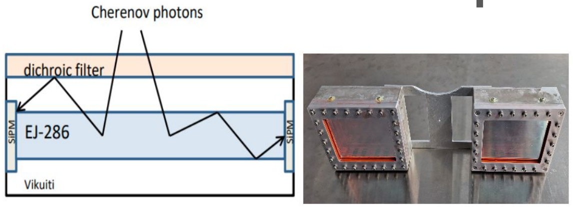




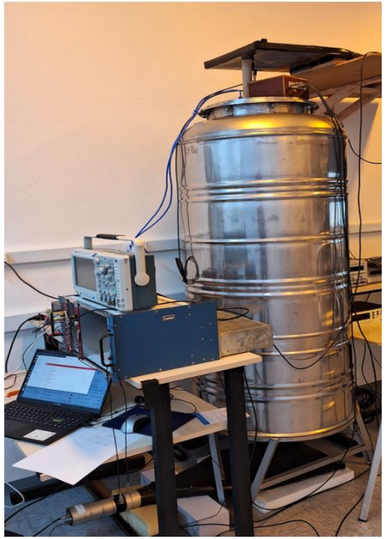
Extreme instrumentation sites

C-Arapuca

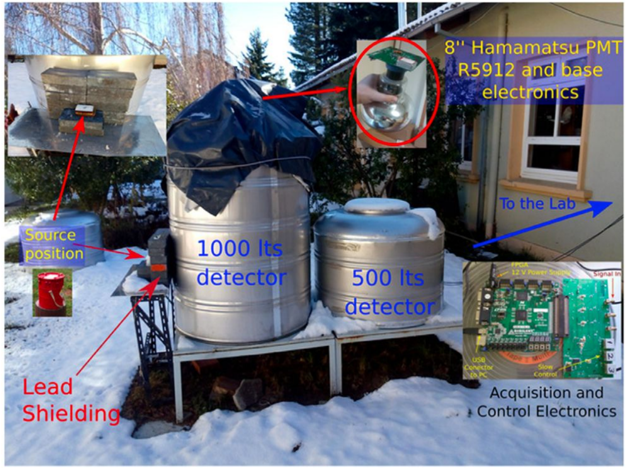
The C-Arapuca



(a) (b)



Fauth, A. C., et al (2023).
C-Arapuca: a new device for Cherenkov radiation detection.
PoS(ICRC2023) 389



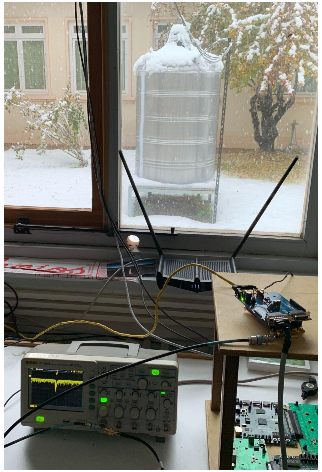
Sidelnik, I., et al (2020). **Neutron detection capabilities of water Cherenkov detectors.** *Nuclear Instruments and Methods in Physics Research*, *952*, 161962.

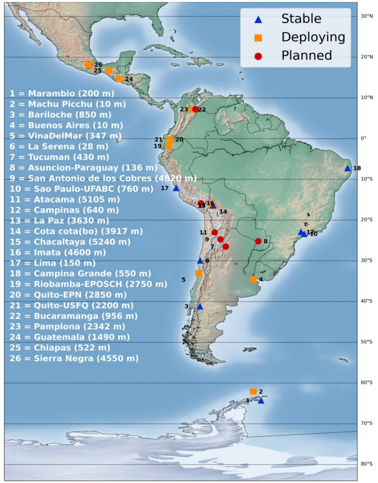
Peña-Rodríguez, et al (2020). **Design and construction of MuTe: a hybrid muon telescope to study colombian volcanoes.** *Journal of Instrumentation*, *15*(09), P09006.

Instrumentation LAGO side project

The Latin American Giant Observatory

Own designed electronics based on RedPitaya SteamLab. Provides services for other experiments



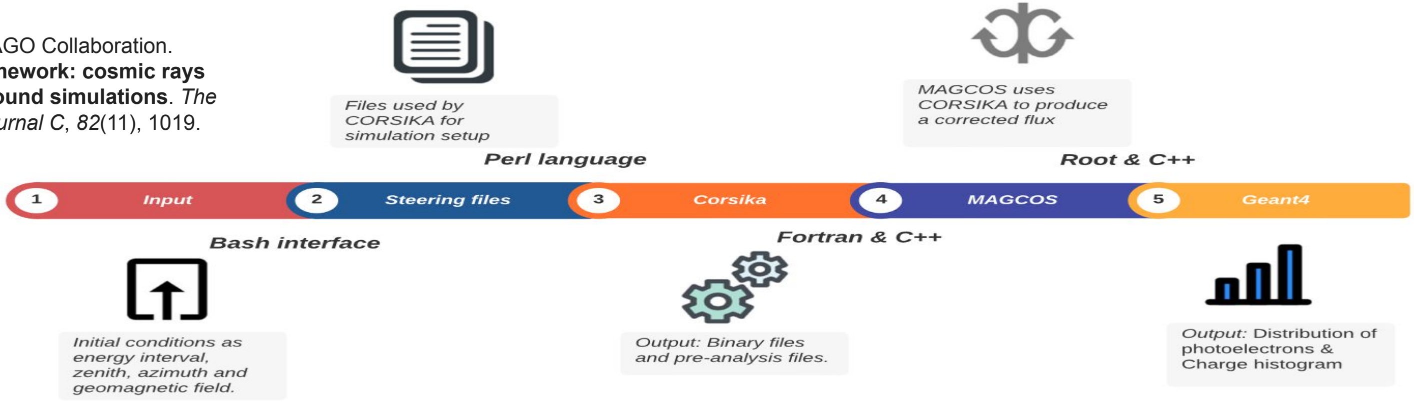


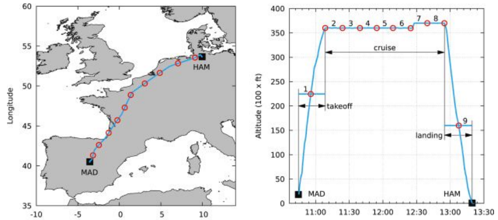
1-10 m^3 WCD deployed at different altitudes and geomagnetic coordinates

LAGO WCDs have a single PMT and are based on SBC and COTS. They are autonomous, reliable, simple, smart, and inexpensive.

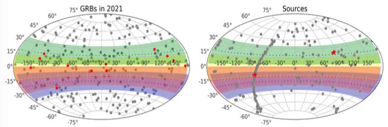
H. Arnaldi et al., IEEE CAE48787, 2020; H. Asorey et al., PoS ICRC2015 247, 2015

Sarmiento-Cano, & LAGO Collaboration. (2022). **The ARTI framework: cosmic rays atmospheric background simulations**. *The European Physical Journal C*, *82*(11), 1019.



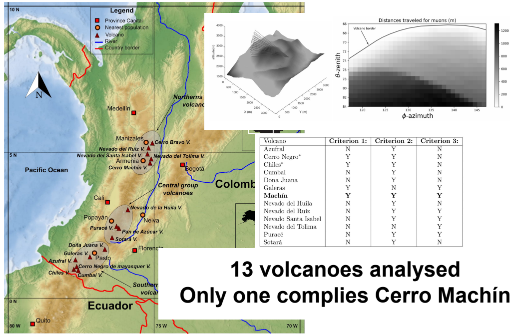


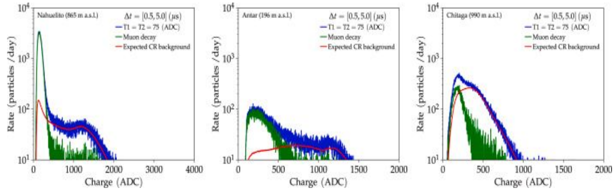
Asorey, H., Suárez-Durán, M., & Mayo-García, R. (2023). **ACORDE: A new application for estimating the dose absorbed by passengers and crews in commercial flights**. *Applied Radiation and Isotopes*, *196*, 110752.



Sidelnik, I.,& LAGO Collaboration. (2023). **The capability of water Cherenkov detectors arrays of the LAGO project to detect Gamma-Ray Burst and high energy astrophysics sources.** *Nuclear Instruments and Methods in Physics Research 1056*, 168576.

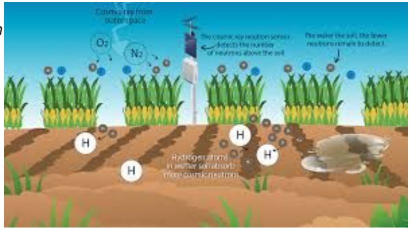
Country	Site	Altitude [m asl]	Latitude [deg]	Longitude [deg]
Sierra Negra	SNG	4,550	18.2 N	97.9 W
Chimborazo	CHI	5,000	1.5 S	78.8 W
Imata	IMA	4,600	15.9 S	71.1 W
Atacama	ATA	5,100	23.0 S	67.8 W
S. A. de los Cobres	SAC	4,500	24.2 S	66.3 W





Otiniano, L.,& LAGO Collaboration. (2023). **Measurement of the muon lifetime and the Michel spectrum in the LAGO water Cherenkov detectors as a tool to enhance the signal-to-noise ratio.** *Nuclear Instruments and Methods in Physics Research 1056*, 168567.

Poster N-03

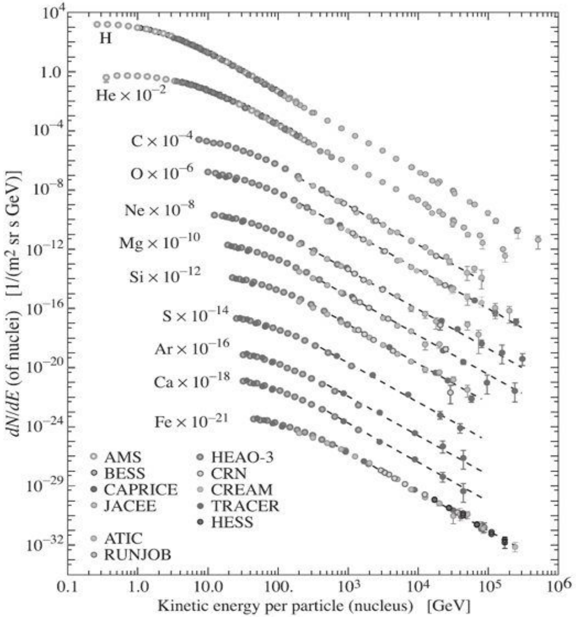


Sarmiento-Cano, & LAGO Collaboration.. (2024). **Cosmogenic neutrons and soil moisture** (in preparation).

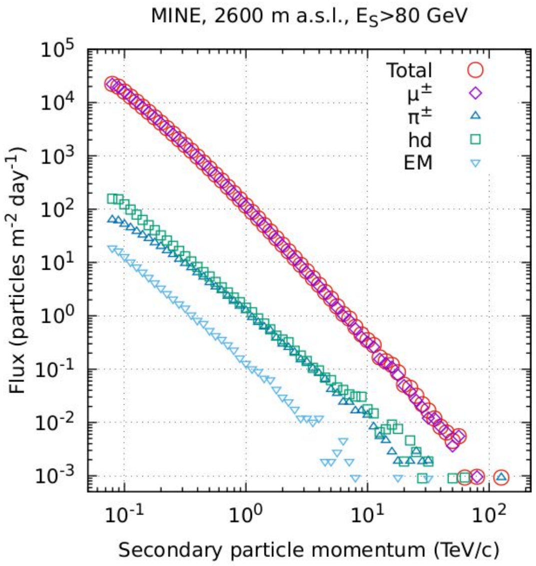
Vesga-Ramírez, A., et al (2020). **Muon Tomography sites for Colombian volcanoes.** *ANNALS OF GEOPHYSICS*, *63*(6).

From Astroparticle to Applications

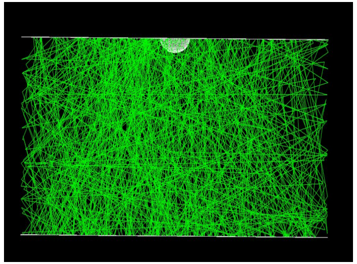
GCR Flux → Heliosphere → **Modulated Flux** → Magnetosphere → **Primaries** → Atmosphere → **Secondaries** → Detector → **Signals or Doses**

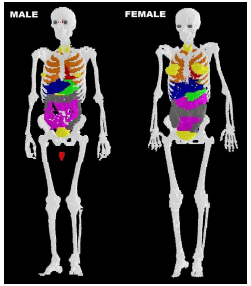


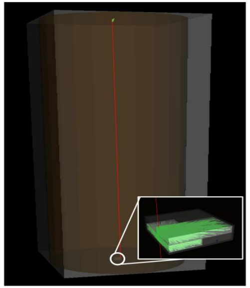
ARTI + CORSIKA



ARTI

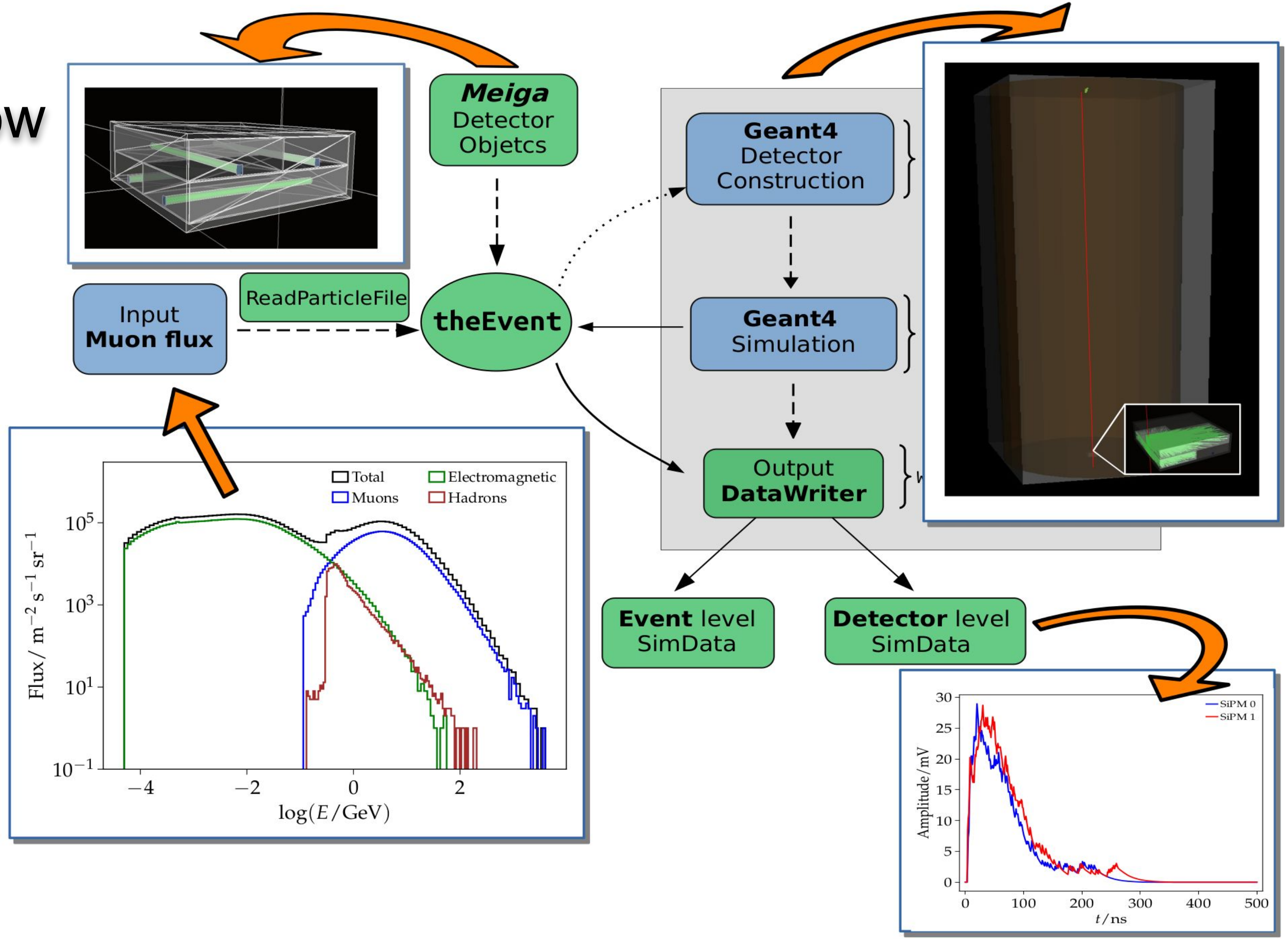






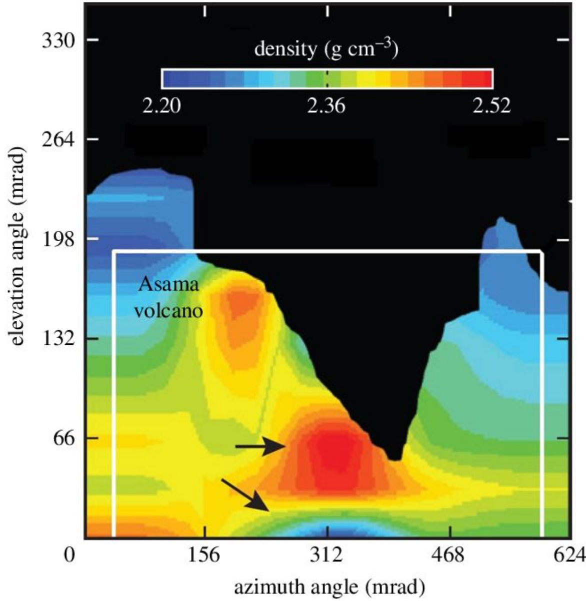
ARTI + MEIGA (Geant4)

Workflow



Meiga
Detector
Objetcs
ReadParticleFile
Input
Muon flux
theEvent
Geant4
Detector
Construction
Geant4
Simulation
Output
DataWriter
Event level
SimData
Detector level
SimData
Total
Electromagnetic
Muons
Hadrons
Flux / m^{-2} s^{-1} sr^{-1}
log(E / GeV)
SiPM 0
SiPM 1
Amplitude / mV
t / ns

Muography, how to



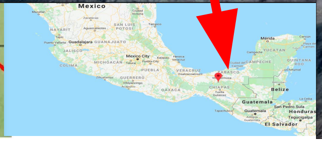
- Start with an object with an unknown density profile
  - … measure the directional muon flux through this object
  - … and compare with the muon reference flux
  - **→ you get the directional opacity of this object [g/cm²]**
- Additionally…
  - … obtain the external geometry of the object
  - **→ and calculate the directional interaction distance [cm]**
- Finally, from…
  - directional opacity
  - directional interaction distances
- **→ get internal density profile along muon propagation direction**

$$\boxed{\varrho(L)} \equiv \int_{\boxed{L}} \boxed{\rho(\xi)}\, \mathrm{d}\xi \,,$$

Colombian Volcanoes

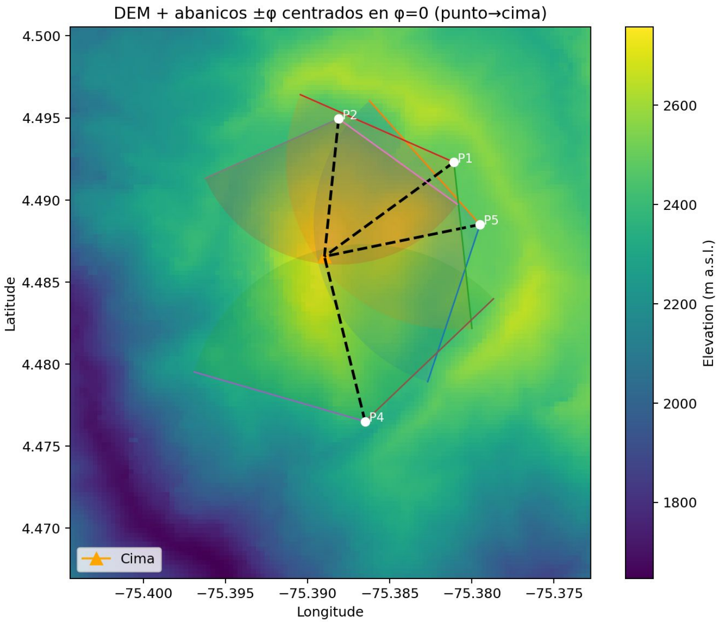
Cerro Machin Volcano

Chichonal or Chichón (Mx) The most deadly eruption of the century (1982)



Vesga-Ramírez, A. et al (2020). ***Muon Tomography sites for Colombian volcanoes.*** *ANNALS OF GEOPHYSICS*, ***63***(6).

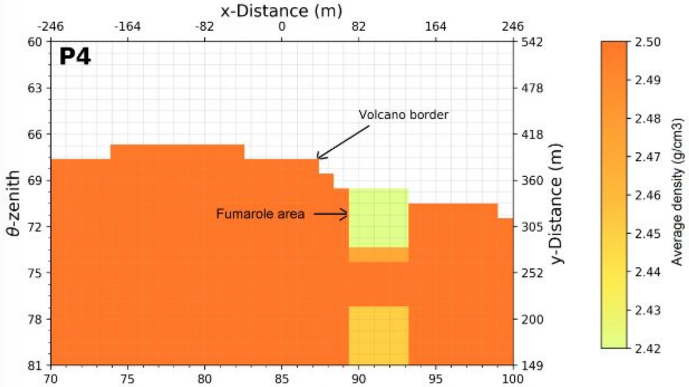
Observation points at Cerro Machín

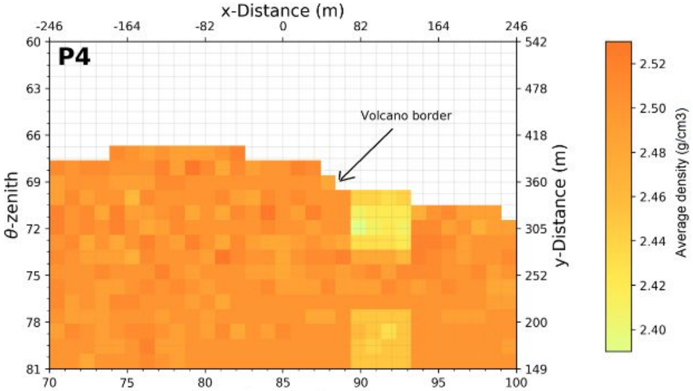


Simulated flux at observation points

Cerro Machín points	P_1	P_2	P_3	P_4
Latitude (°N)	4.492	4.491	4.493	4.494
Longitude (°W)	75.381	75.380	75.392	75.388
Distance to center of the edifice (m)	836	946	762	730
Maximum observed depth (m)	208	228	250	190

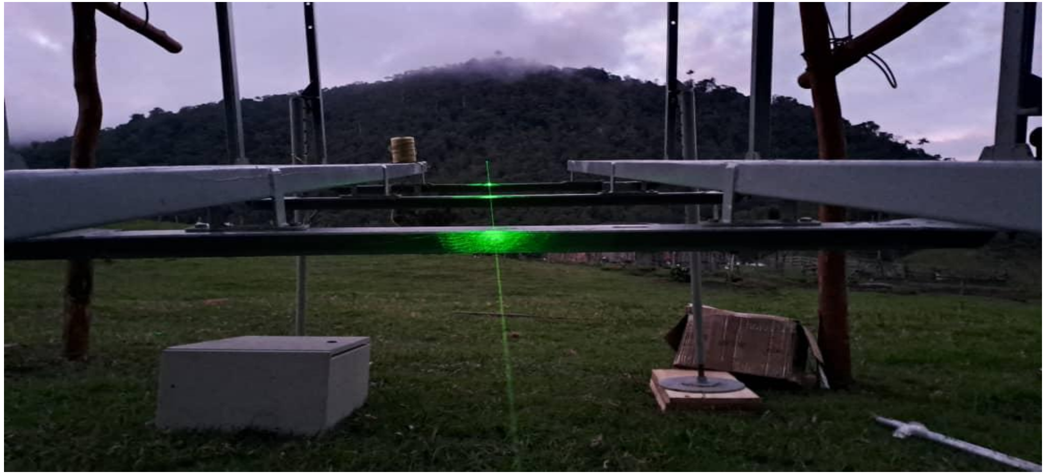
Table 2: Feasible observation points at Cerro Machín volcano (4°29'23.08"N, 75°23'15.39"W)





Vesga-Ramírez, A., et al (2021). ***Simulated annealing for volcano muography.*** *Journal of South American Earth Sciences*, ***109***, 103248.

MuTe



Muon Telescope (MuTe) evolution

Asorey, H., et al (2017). ***Astroparticle Techniques: Colombia active volcano candidates for Muon Telescope observation sites.*** Rev. Mex. Astron. Astrof. Ser. Conf. **49**, 54, arXiv:1704.04967. ***Muon telescope (mute): A first study using geant4.*** In Revista Mexicana de Astronomia y Astrofisica Conference Series **49**, 144

2017 First Simulations Sites & Instrument

Moss, H., et al (2018). ***Muon tomography for the cerro machın volcano.*** Technical report, Department of Physics & Astronomy, University of Sheffield.

2018 HPC MUSIC Site Simulations

Asorey et al (2018). ***miniMuTe: A muon telescope prototype for studying volcanic structures with cosmic ray flux.*** *Scientia et technica*, ***23***(3), 386-391.

2018 First hardware implementation

Asorey, H., et al (2018). **Preliminary results from the latin american giant observatory space weather simulation chain**. *Space Weather*, ***16***(5), 461-475.

2018 First simulation chain implementation

Vásquez-Ramírez, A.et al, (2020). **Simulated response of MuTe, a hybrid Muon Telescope.** *J. Instrumentation*, ***15***(08), P08004.

2020 Full instrument simulation

Peña-Rodríguez, J. et al (2020). ***Design and construction of MuTe: a hybrid muon telescope to study colombian volcanoes***. *J. Instrumentation*, ***15***(09), P09006.

2020 Full Hardware implementation MuTE 1.0

Vesga-Ramírez, A. et al (2020). ***Muon Tomography sites for Colombian volcanoes.*** *ANNALS OF GEOPHYSICS*, ***63***(6).

2020 Full Colombia Muography site simulations

Vesga-Ramírez, A., et al (2021). ***Simulated annealing for volcano muography.*** *Journal of South American Earth Sciences*, ***109***, 103248.

2021 optimization algorithm applied to Muography

Grisales-Casadiegos, et al. (2022). **Impact of Global Data Assimilation System atmospheric models on astroparticle showers.** *Canadian Journal of Physics*, *100*(3), 152-157.

2022 modelling atmospheric

Sarmiento-Cano, C. et al (2022). ***The ARTI framework: cosmic rays atmospheric background simulations.*** *The European Physical Journal C*, ***82***(11), 1019.

2022 ARTI Full (first principle) simulation framework

Peña-Rodríguez, J. et al (2023). ***Characterization and On-Field Performance of the MuTe Silicon Photomultipliers.*** *Instruments*, 7(1), 7.

2023 Component on field performance

Peña-Rodríguez, J. et al (2024). ***MUYSC: an end-to-end muography simulation toolbox***. *Geophysical J. International*, *237*(1), 540-556..

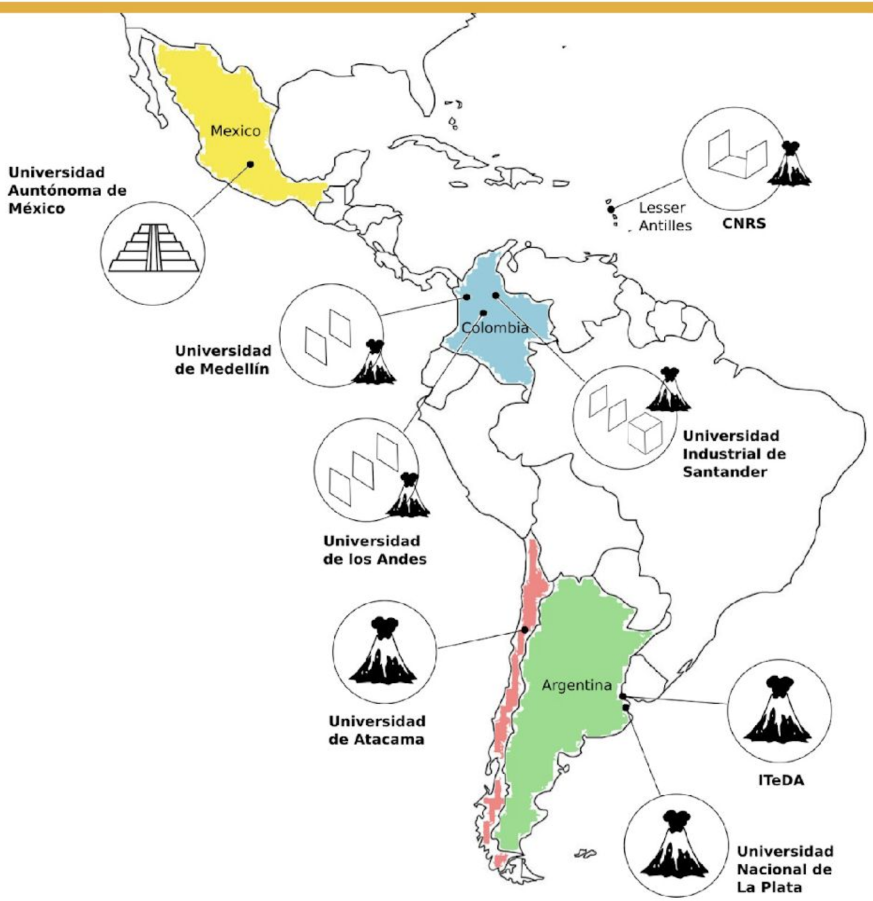
2024 Full phenomenological simulation framework

MuTe

MuTe 2.0

15

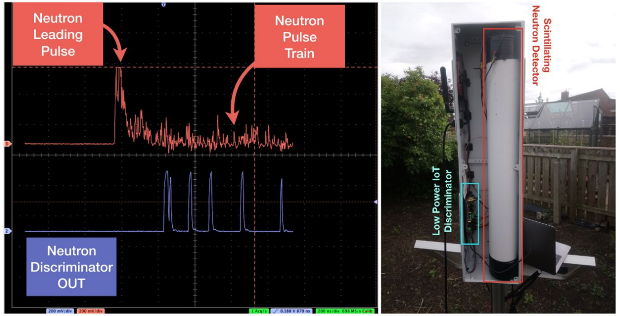
Muography in Latin America

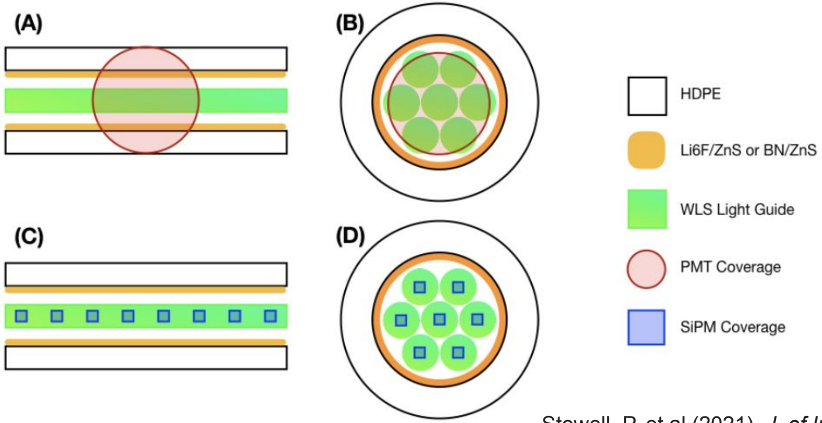


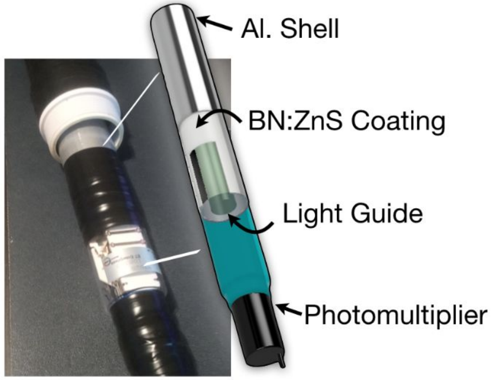
Development of:

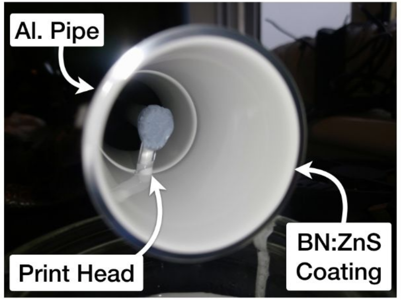
- Simulation tools
- Instrumentation
- New detection techniques
- Hybrid telescopes
- Data analysis
- Experimental Infrastructure
- Collaborative networking

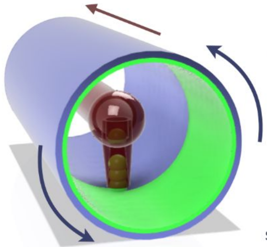
Scintillating thermal neutron detectors for cosmic ray soil moisture monitoring







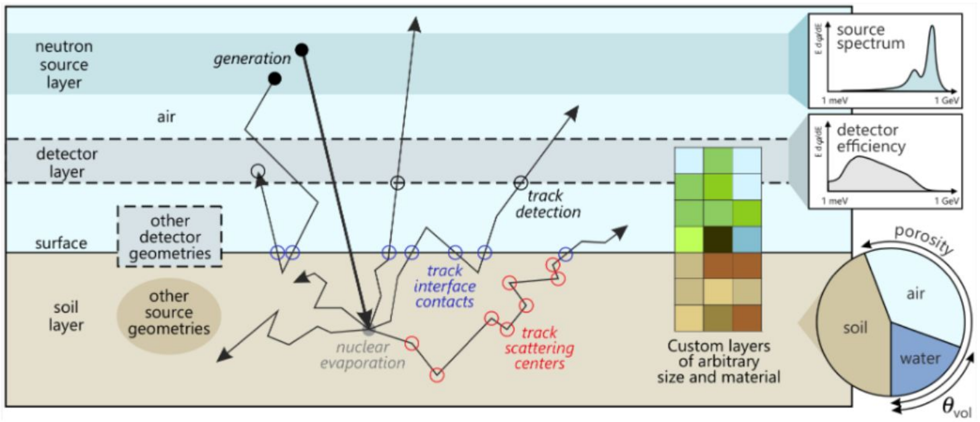




Print head deposits elastomer bead of Boron Nitride mixed with Zinc Sulphide Scintillator.

Centrifugal force spreads coating onto detector inner uniformly.

Stowell, P. et al (2021). *J. of Instrumentation*, ***16***, P11039.

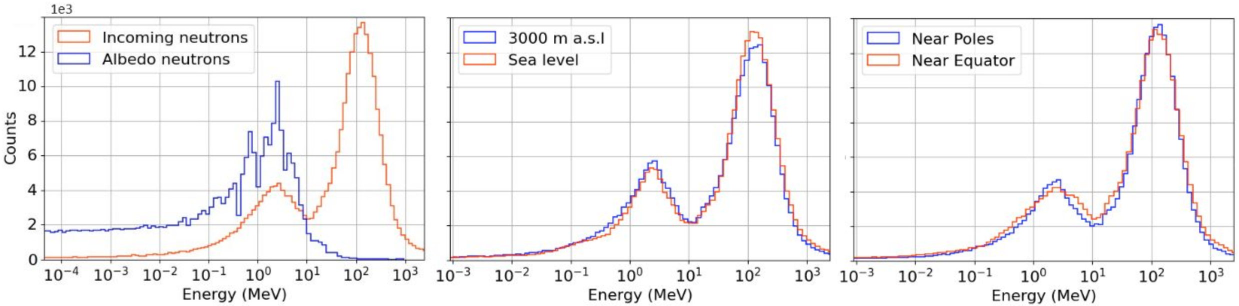


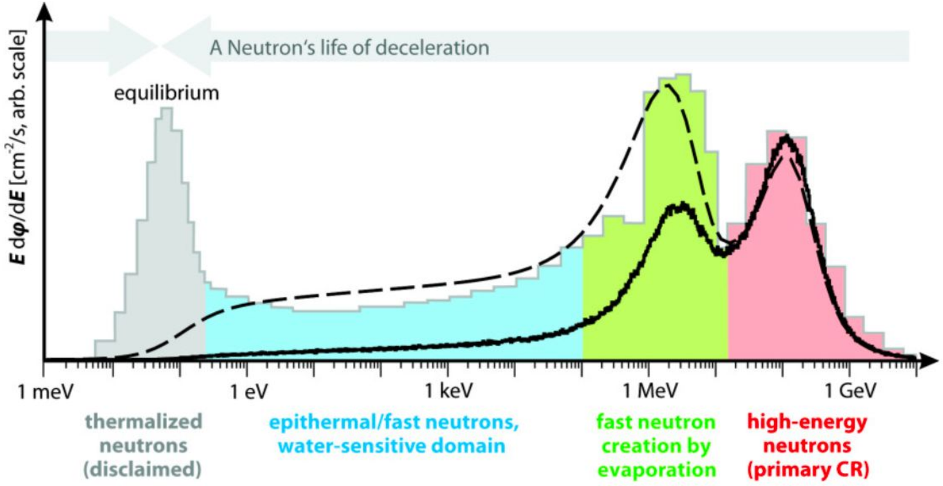
URANOS

Ultra Rapid Adaptable Neutron-Only Simulation
(Köhli, M., et al (2023). *Geoscientific Model Development*, **16**, 449)

- simulates cosmogenic neutron radiation near the Earth's surface
- studies environmental response to soil water content, snow, or biomass.
- uses the analytical cosmic ray neutron spectrum (Sato, T., & Niita, K. (2006). Radiation research, 166, 544)

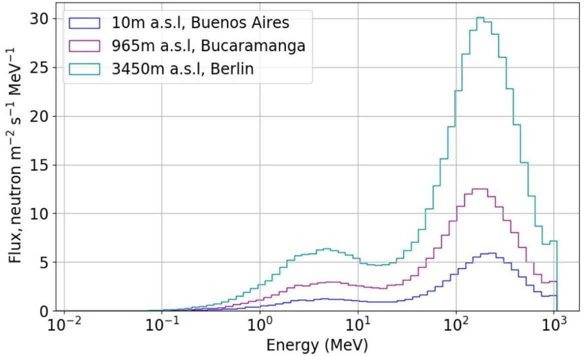
URANUS: Simulations





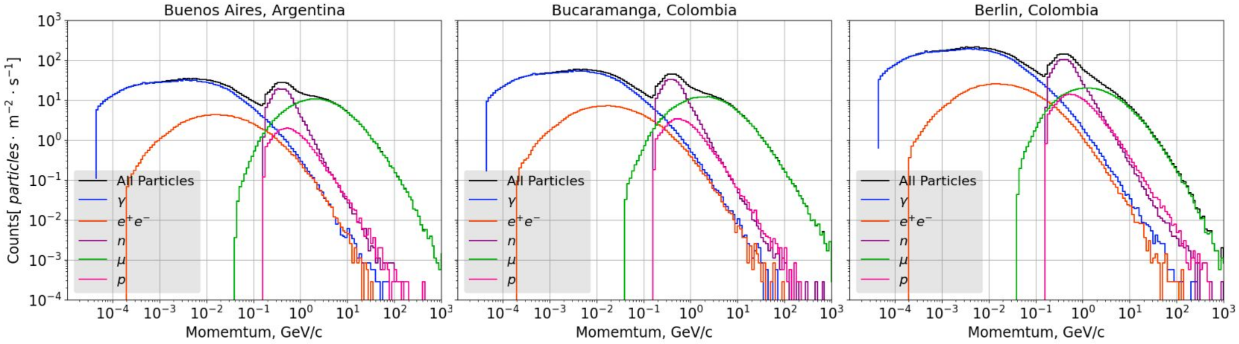
Cosmic neutron energy spectrum.

- Histograms correspond to measurements Goldhagen, P., et al (2002). *Nuclear Instruments and Methods in Physics*, **476**, 42.
- Black line c incoming neutron spectrum Köhli, M., et al. (2015) Water Resources Research, 51, 5772.
- Dashed lines correspond to simulations Sato, T., & Niita, K. (2006). Radiation research, 166, 544).

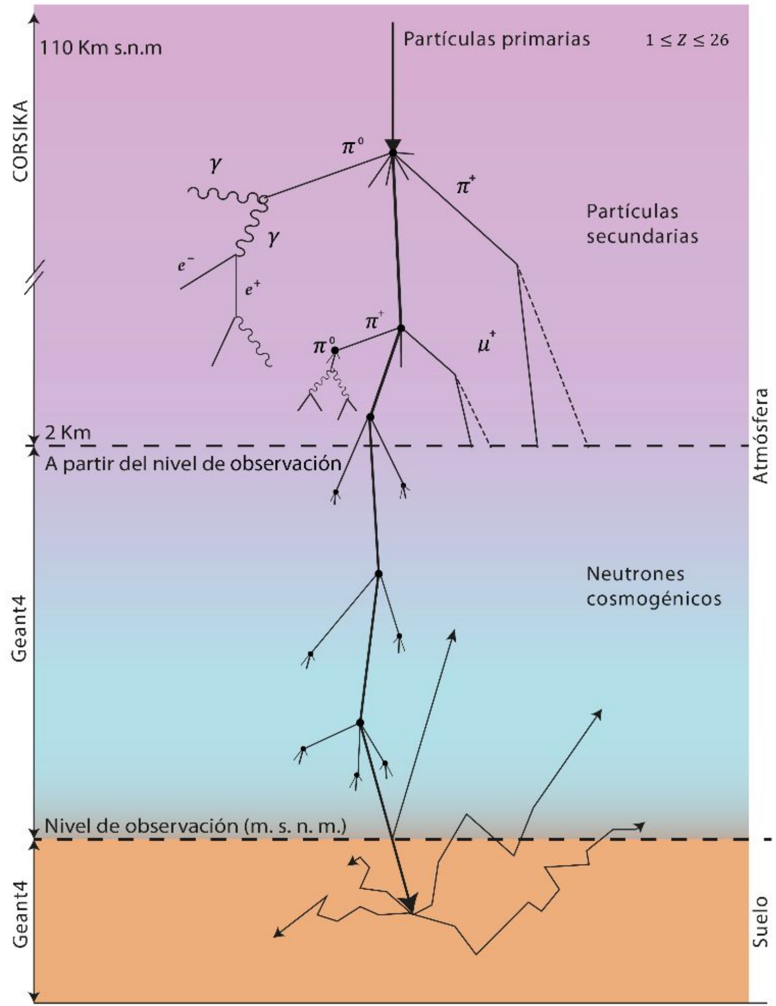


Incoming neutron energy spectra for each location.

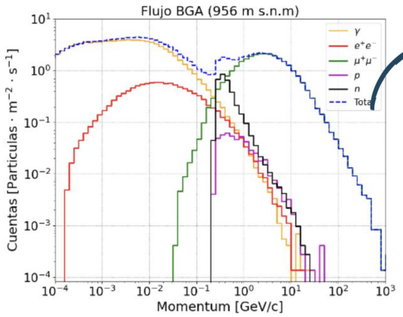
CORSIKA: No way



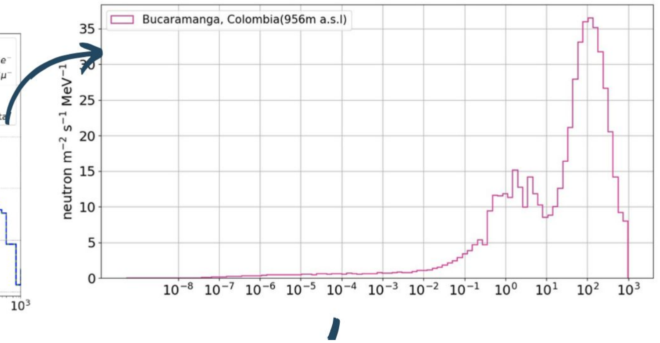
N-ARTI



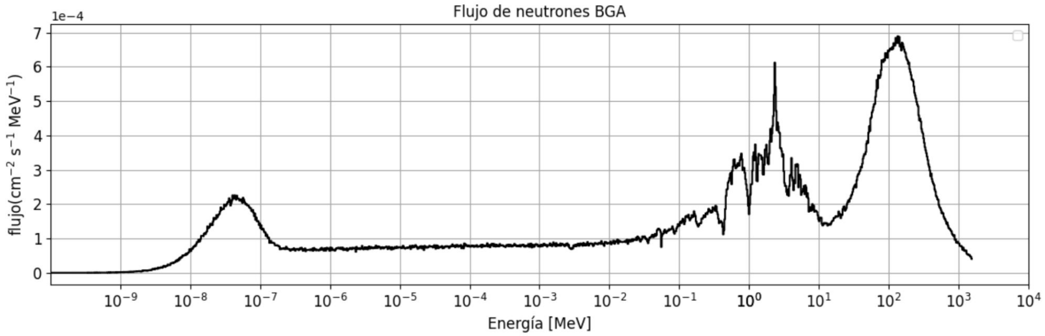
110 Km s.n.m
Partículas primarias
$1 \leq Z \leq 26$
CORSIKA
Partículas secundarias
2 Km
A partir del nivel de observación
Atmósfera
Neutrones cosmogénicos
Geant4
Nivel de observación (m. s. n. m.)
Geant4
Suelo



Flujo BGA (956 m s.n.m)
Cuentas [Partículas · m⁻² · s⁻¹]
Momentum [GeV/c]
Total

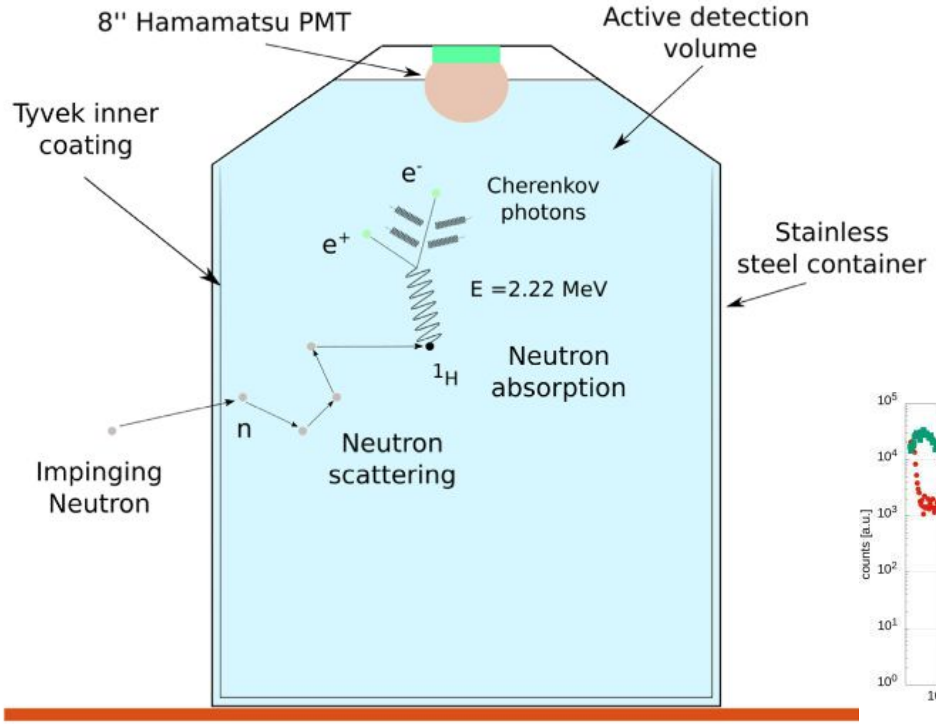


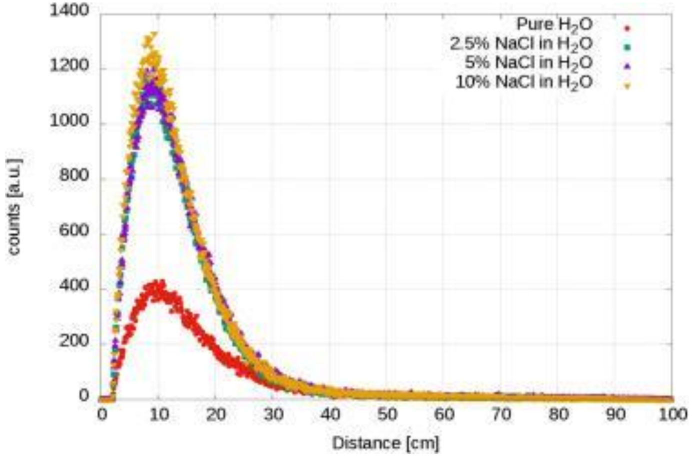
Bucaramanga, Colombia(956m a.s.l)
neutron m⁻² s⁻¹ MeV⁻¹

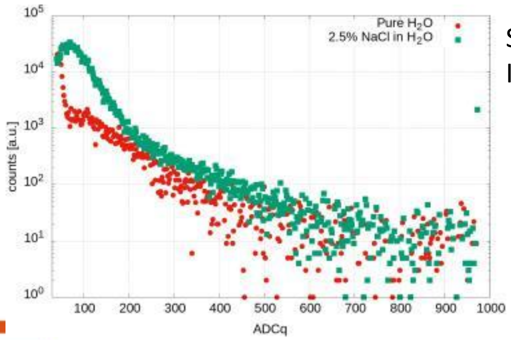


Flujo de neutrones BGA
1e−4
flujo(cm⁻² s⁻¹ MeV⁻¹)
Energía [MeV]

Neutron detection using a WCD & NaCl



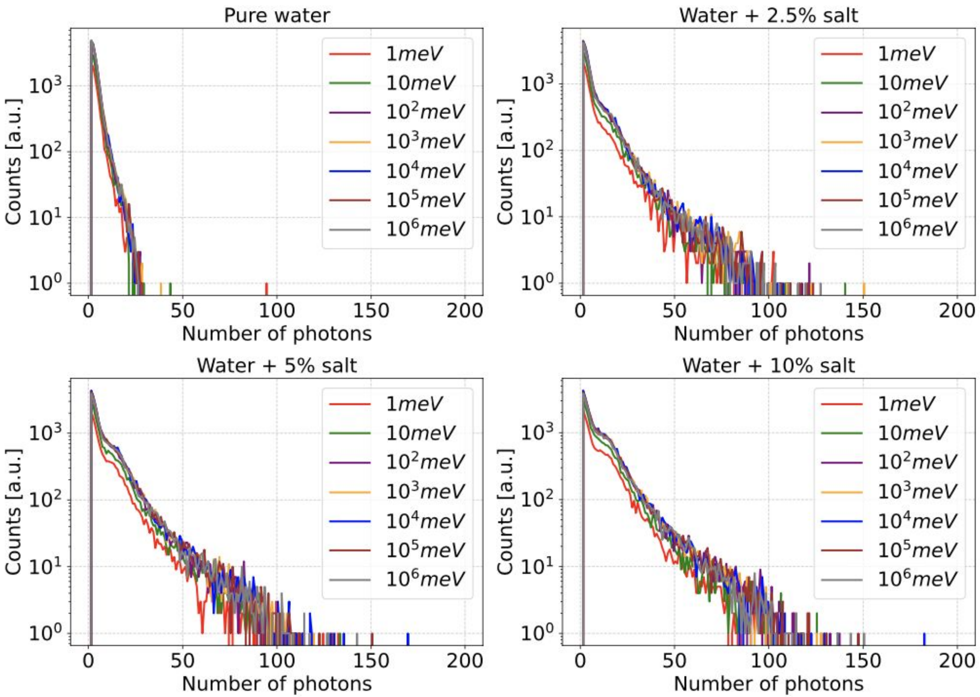


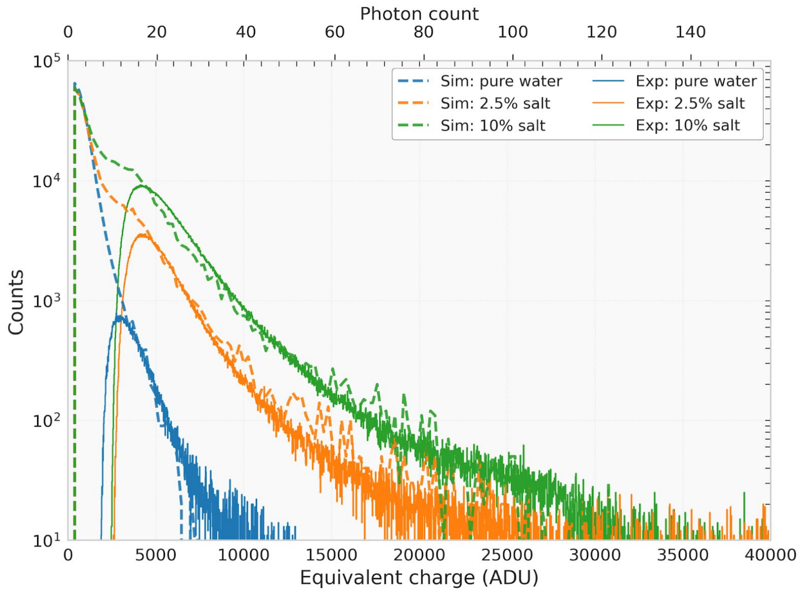


Sidelnik, I., et al (2020). Nuclear Instruments and Methods, **955**, 163172

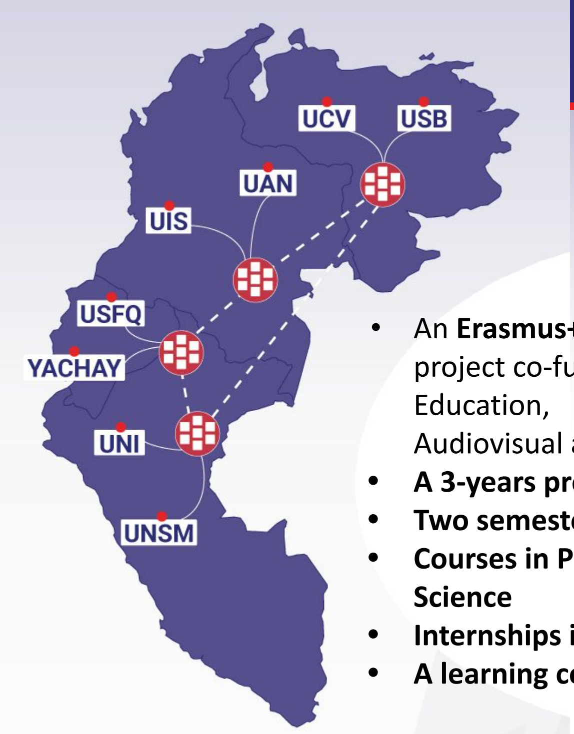
Neutron detection using a WCD & NaCl

Poster T-05





LA-CoNGA physics



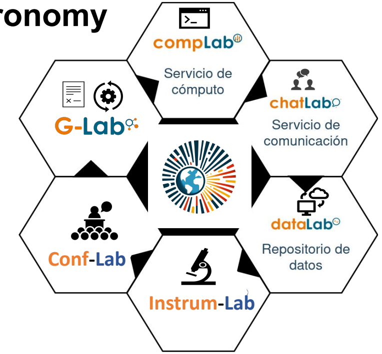
https://laconga.redclara.net/

- An **Erasmus+CBHE (Capacity Building in Higher Education)** project co-funded by the European Commission’s Education,
  Audiovisual and Culture Executive Agency
- **A 3-years project. Officially started in January 2020**
- **Two semesters corresponding to M2 EU Master**
- **Courses in Physics, Scientific Instrumentation and Data Science**
- **Internships in research labs and Industrial partners**
- **A learning community**

11 universities from Latin America and Europe join efforts with other scientific (**CERN, CNRS, DESY, ICTP, IRFU, RedCLARA**) and **industrial** partners to contribute to the modernisation, accessibility and **internationalisation of higher education in Colombia, Ecuador, Perú and Venezuela**

EL-BONGO Physics: E-Latin america digital huB for OpeN Growing cOmmunities in physics

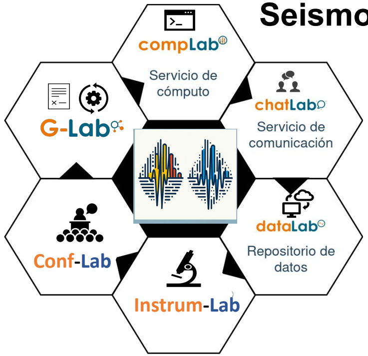
Space Weather Astronomy



- Courses
- Workshops
- Data
- Codes
- Publications
- Chats
- Visualizations

USC(GT), UIS(CO), UCV(VE), UMG(GT), USFQ(EC), UPC(FR), UNMSM (PE)

Seismology



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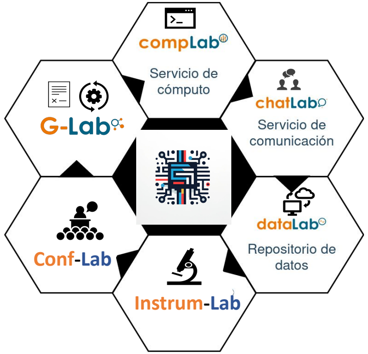
- Visualizations

UES(SV), UIS(CO), USB(VE), USC(GT), UNMSM(PE)

Inter Community Open Science Hub

AI-HPC Tools



USal(ES), UIS, ULyon, UFG(SV), UNMSM(PE), UP(PA)

- Courses
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- Data
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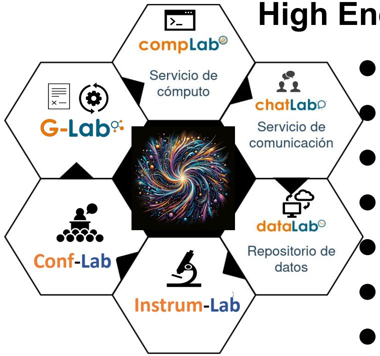
High Energy Physics



- Courses
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- Publications
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- Visualizations

UNAH (HN), USC(GT), UPC(FR), UPS(FR), USFQ(EC), UNI(PE), UAN(CO)

LAGO + LA-CoNGA + EL-BONGO = Continental Astroparticle training

LA-CoNGA EL-BONGO

- Expertise
- Platform
- Remote labs
- Academic links

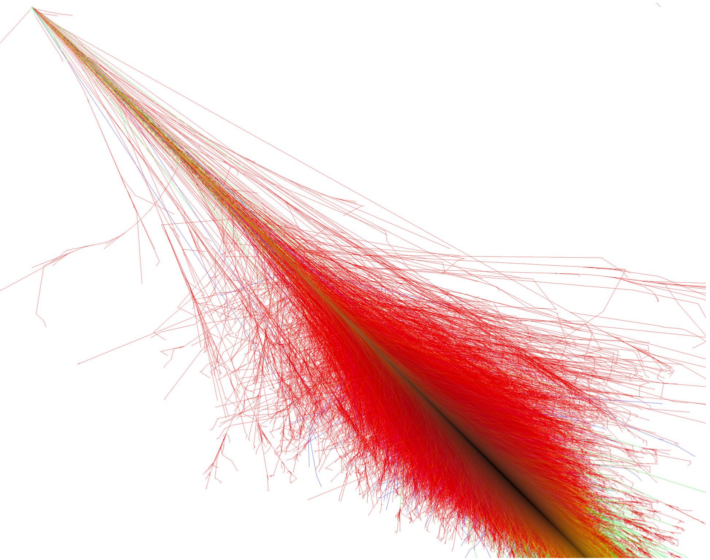
LAGO

- Continental observatory
- Capillarity
- Simulation framework
- Working instrumentation

Space Weather & Astroparticle applications

Gracias por su atención

Current LAGO framework



LAGO@github

LAGO ACQUA

WCD control and data acquisition

- Nexys DAQ v1.0
- RP DAQ v2.0

LAGO ANNA

Automated and integrated data analysis

- Adaptable for DAQ
- C++ analysis tools

LAGO ARTI (+Meiga)

Astroparticle simulations

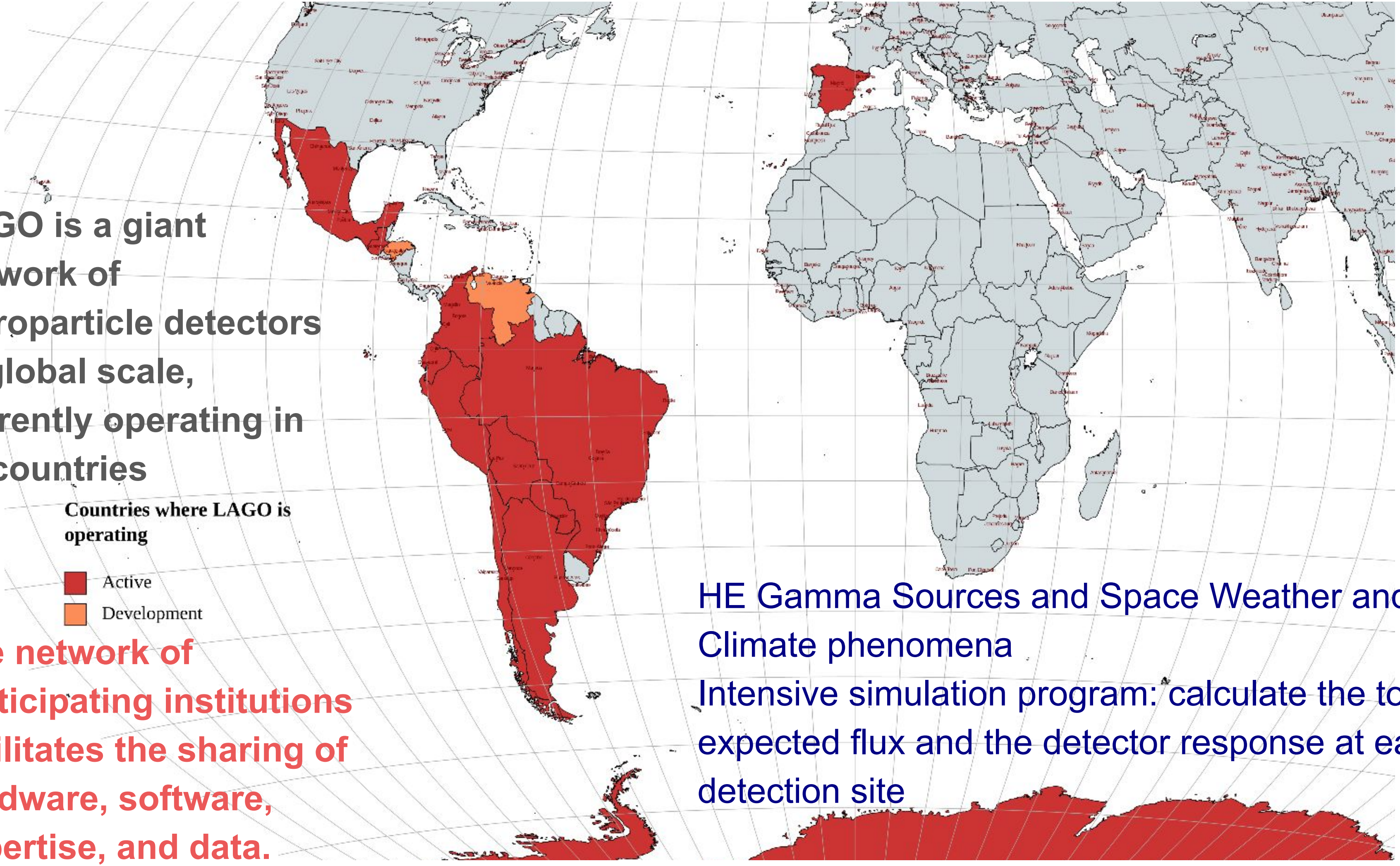
- GCR models
- Atmospheres
- Geomagnetic field
- AP detectors
- + Applications

LAGO onedataSim

LAGO data FAIRificator (currently ARTI data)

- ARTI wrapper
- metadata standardization
- FAIR compliant

LAGO is a giant network of astroparticle detectors at global scale, currently operating in 11 countries



The network of participating institutions facilitates the sharing of hardware, software, expertise, and data.

HE Gamma Sources and Space Weather and Climate phenomena

Intensive simulation program: calculate the total expected flux and the detector response at each detection site

Muogram P1: 12 hours