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Cosmic-ray applications: muon and neutron techniques for volcanology and precision agriculture

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Secondary cosmic-ray muons and neutrons carry information about the matter they traverse, making the natural cosmic-ray flux a free probe of the Earth's surface. We present two applications developed within the Latin American Giant Observatory (LAGO). Both rely on the ARTI–MEIGA framework, which models the chain from the primary flux to the detector response at each site.

The first is volcano muography with MuTe 2.1, a portable hodoscope built at the Universidad Industrial de Santander for imaging the Cerro Machín volcano. It consists of two 60×60 cm² panels of 15×15 scintillator bars read out with WLS fibers and SiPMs. Its calibration validated the detector at three levels. Open-sky muon fluxes agree with ARTI predictions within ~18%. The ~30% attenuation measured with 0.5–3 cm lead absorbers is consistent with MEIGA simulations. Finally, a test muography of a nearby mountain reconstructed its topographic profile under field conditions.

The second is soil moisture estimation with cosmic-ray neutron sensing, which can bridge the gap between point sensors and satellites for plot-scale monitoring in precision agriculture. The N-ARTI chain couples CORSIKA and Geant4 to propagate neutrons into the soil. Continuous boundary conditions remove artificial flux losses of up to 98%, and validation against standalone CORSIKA shows discrepancies below 6%. The simulated epithermal flux follows the expected inverse dependence on soil moisture but lies 7–16% below the standard reference curve. This offset is attributed to soil mineralogy and shows that calibration must include local soil chemistry. In parallel, NaCl-doped water Cherenkov detectors enhance neutron capture, with simulations agreeing with measurements at different salt concentrations.

These results consolidate LAGO's capability to translate cosmic-ray physics into validated tools for volcanology and precision agriculture.

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