Muon Tomography for the Cerro Machín Volcano

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Introduction: Muon Tomography for Cerro Machín

Muon tomography is presented as a technique for determining low density regions of the active volcano Cerro Machín situated near the city of Ibagué, Colombia. The identification of such regions can inform volcanologists of the likely direction of ejecta following an eruption. The MuTe detector [1], constructed by staff and students at the Industrial University of Santander, is an adjustable detector composed of scintillating panels and a water Cherenkov detector designed for placement at the foot of the volcanic dome to measure variations in muon flux. A schematic of the detector is shown in figure 1. This poster documents simulations of the muon flux with CORSIKA [3], muon transport through the volcano using the MUSIC software framework [4] to reach the proposed detector location shown in figure 1.

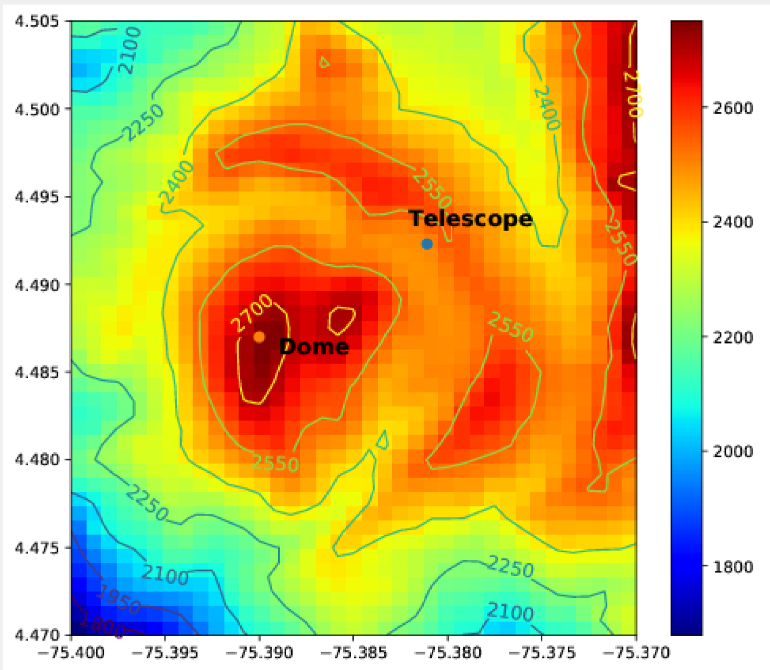

Figure 1: Contour map of the area surrounding Cerro Machín highlighting the positions of the volcanic dome and detector. Elevations are shown in metres. The x and y axes show latitude and longitude, respectively.

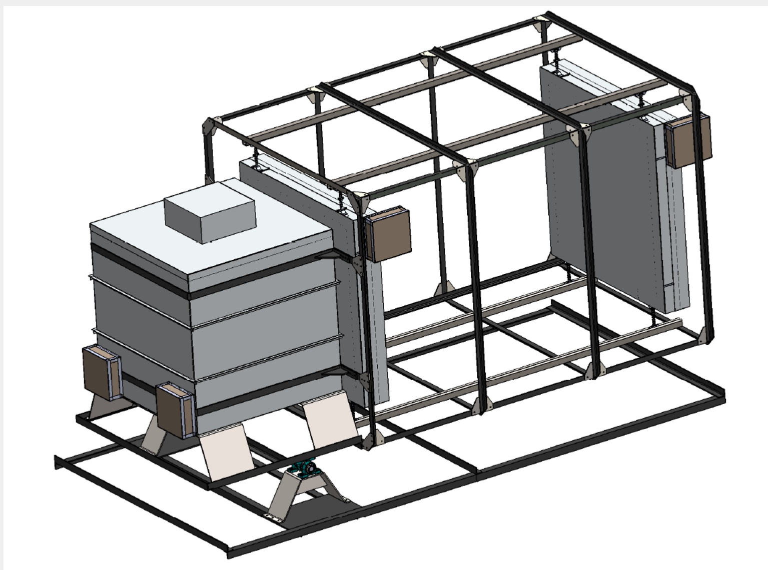

Figure 2: Schematic view of the MuTe detector, with water Cherenkov detector (left) and scintillating tiles (right) shown. Figure from [2].

Topography of Volcano and Detector

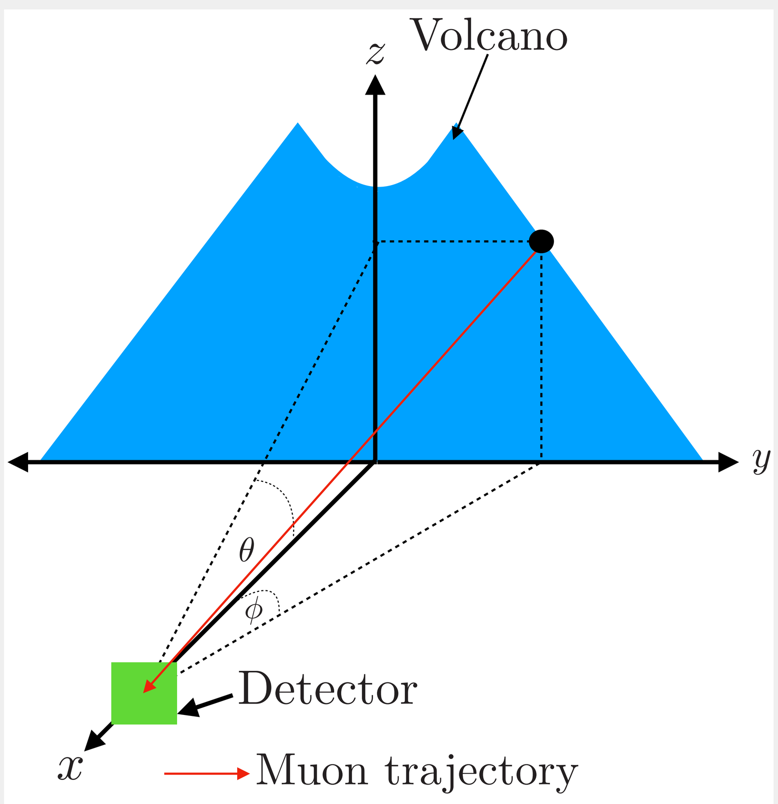

Figure 3: Coordinate system

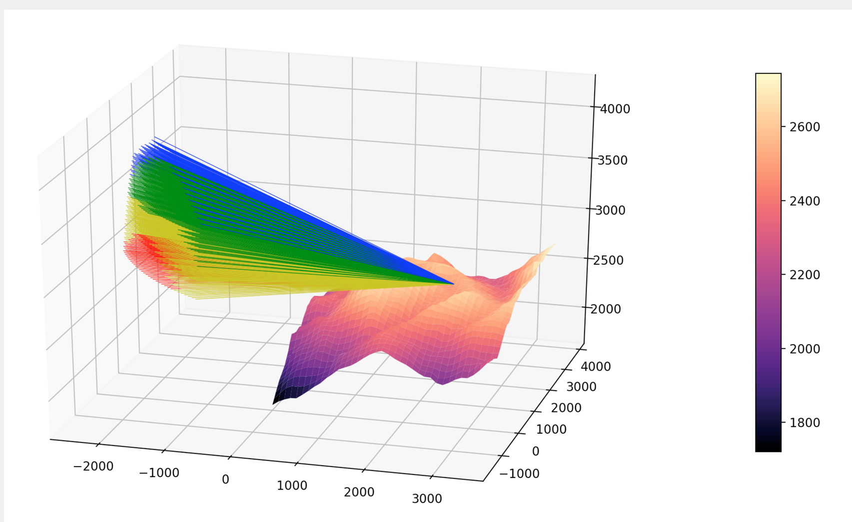

Figure 4: Three-dimensional contour map showing elevation in metres as a function of a locally defined coordinate system. Possible trajectories for muons entering the detector after passing through at least 10 metres of volcanic rock are shown.

Generation of Muon Samples

- Muon samples are generated using CORSIKA [3] – a Monte Carlo code to model cosmic ray showers in the upper atmosphere. The following parameters have been used:
  - Primary particle zenith angle $60 \leq \theta \leq 90$, where $\theta = 0$ when particles are travelling vertically downwards
  - Primary particle energy $\leq 10^6$ GeV
- Particles identified as muons at 2750 m above sea level are considered for transport through the volcano.
- The number of showers performed using CORSIKA is dependent on the live time of the real experiment considered. The results shown in this poster correspond to the live time of 100 days.

Muon Transport

Muons are transported through the volcano using the MUSIC [4] simulation framework. MUSIC considers the properties of the volcanic rock as determined by measurements of samples and accounts for mineral composition, rock density and thickness of rock. In these simulations a uniform density of 2.5 $\mathrm{g\ cm^{-3}}$ has been used.

- Muons identified in the output of the CORSIKA simulation are stored at the maximum height of Cerro Machín
- A MATLAB simulation of the volcano topography [1] provides possible trajectories in x, y, θ and ϕ for detected muons passing through ≥ 10 m of the volcano (figure 1).
- Output muons have x, y, ϕ coordinates randomly selected according to possible trajectories derived from figure 1, assuming an isotropic collection of muons with no ϕ-dependence.
- An artificial low-density region of 2.3 $\mathrm{g\ cm^{-3}}$ in θ and ϕ coordinates is added at the MUSIC transport stage. Outside of this region, rock density is held at 2.5 $\mathrm{g\ cm^{-3}}$.

Results

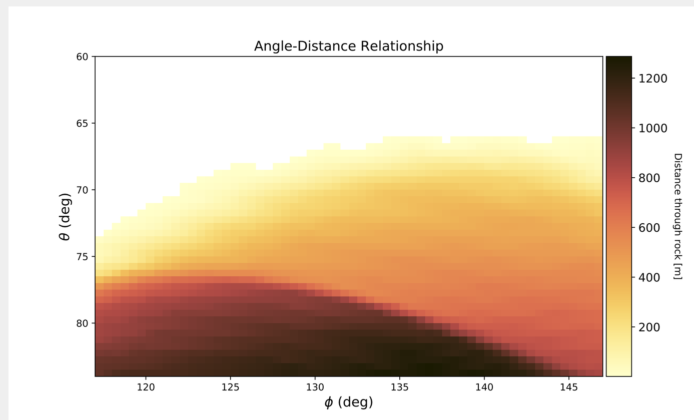

Figure 5: Distance in the rock crossed by muons as a function of angles, for a chosen position of the muon detector.

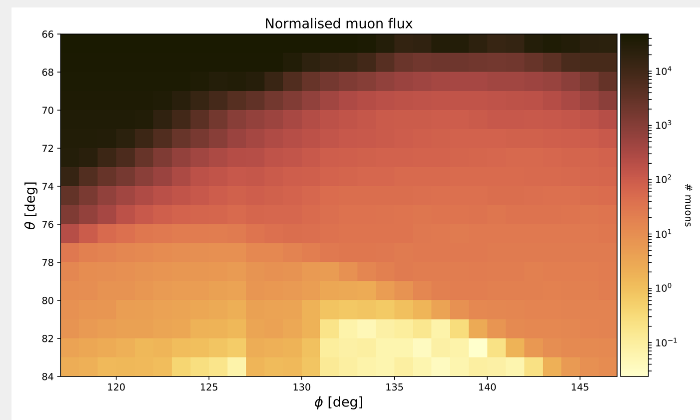

Figure 6: Number of muons expected in each 1×1 degree bin after 100 days of observation. The lower density region is at $\phi = 127 - 131°$.

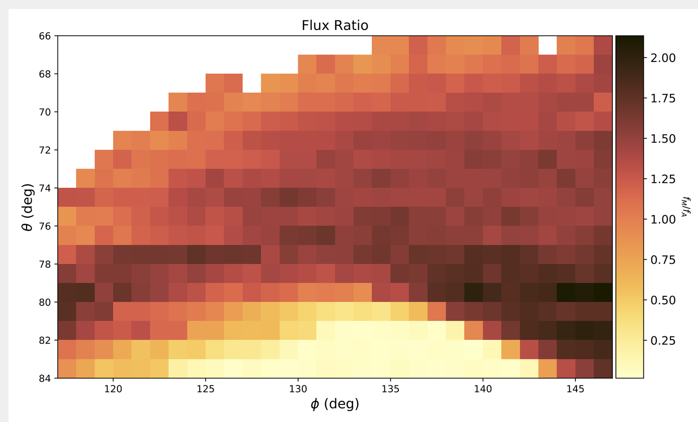

Figure 7: The ratio of muon fluxes from CORSIKA+MUSIC and a previous analytical study by A. Vesga-Ramírez (f_M/f_A) for a detector at 4.492298° N, 75.381092° W.

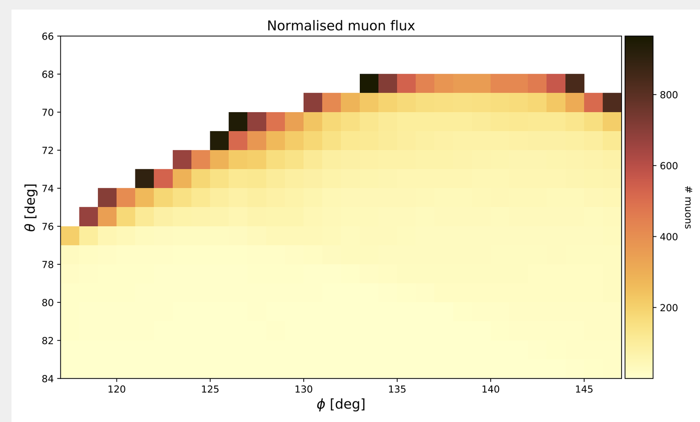

Figure 8: Number of muons expected in each 1×1 degree bin after 100 days of observation. This figure shows a linear scale for ≤ 1000 muons in each bin.

Summary

- Muon fluxes and expected event rates after muon transport through Cerro Machín volcano with the MUSIC code have been studied.
- Simulations accurately replicate mathematical model studied previously by the group at the Industrial University of Santander.
- 10% changes in density due to porous rock (potential route for erupting magma) can be detected with a few hundred muons.

References

[1] H. Asorey et al. Muon tomography sites for Colombian volcanoes. *preprint arXiv:1705.09884*, 2017.

[2] MuTe Collaboration. Mute - el proyecto. URL `https://halley.uis.edu.co/fuego/el-proyecto/`.

[3] D. Heck et al. *CORSIKA: a Monte Carlo code to simulate extensive air showers*. February 1998.

[4] V. A. Kudryavtsev. Muon simulation codes MUSIC and MUSUN for underground physics. *Comput. Phys. Commun.*, 180:339–346, 2009.