Design and Construction of a Muon Detector Prototype for Study the Galeras Volcano Internal Structure

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Abstract. Muon tomography is a technique based on the observation of the absorption of muons in matter, as the ordinary radiography does using X-rays. The interaction of cosmic rays with the atmosphere produce Extensive Air Showers, which provide an abundant source of muons. These particles can be used for multiple applications on muon tomography, in particular, to study the internal structure of different volcanoes edifices. It is necessary in any muon tomography experiment a particle detector that has the capability to be sensitive to muon interactions. Here we report a brief description of the first steps towards a complete design of a prototype particle detector to perform muon tomography in harsh conditions encountered in the surroundings of the Galeras Volcano. The mechanical design and fabrication processes of the supporting structure of the muon detector prototype, and first steps towards a future detector simulations on GEANT4 are described in this work.

1. Introduction

The Galeras volcano (GV) with a height of 4276 m.a.s.l., located in Pasto city (Colombia) with an estimated age of 4,500 years, is a volcano with the highest activity in Colombia with important records of eruptions in the past 30 years [1]. The continuous increasing of population in high risk areas around the volcano has motivated to develop special techniques to monitor the volcano activity, especially, for its past records respecting to pyroplastic flux generated in its previous eruptions [2]. The tomography is a technique used to explore complex and heterogeneous structures under the surface of the Earth by building images. The three-dimensional (3D) models of the terrestrial structure allow us to answer some basic questions of its geodynamics. In volcanic regions, images can provide information on magmatic or hydrothermal systems and other structural features. The reconstruction of the internal structure of a volcano constitutes an input for the geophysical interpretation of the behavior of the eruptive activity and for better
precise determinations of hypocenters of seismovolcanic signals. The tomography with atmospheric muons could help to understand the internal volcano structure, and its magma dynamics during an eruptive process[3].

A preliminary simulation of the interaction of muons with their respective expected energy with the volcano has been done using GEANT4 [4]. The geometric shape of GV was developed using the software SOLIDWORKS (SW) [5], then the files were converted to GDML using the software FASTRAD [6]. The GDML files were used to simulate the volcano structure using GEANT4. Muon tomography experiments are composed mainly by particle detectors that have the capability to be sensitive to muon interactions. Here is presented a brief description of the first steps towards a complete design of a prototype particle detector to perform muon tomography in harsh conditions encountered in the surroundings of GV.

Among the different available detection systems, matrices made with plastic scintillation strips are favored by different teams of scientists around the world doing experiments on volcanoes [7, 8]. The potential choice of the technology for the simulation, design and fabrication of the particle detector presented here was guided by the expertise, knowledge and costs associated with the plastic scintillation detectors (MINERvA [9] and AMIGA [10] experiments).

2. Galeras Volcanic Complex Simulation Using GEANT4

The GEANT4 toolkit was used to simulate the interaction of muons within volcano, its crater and a muon detector prototype. The volcano geometry has been constructed using SW [5] and converted to GDML files using FASTRAD [6]. As input in SW, contours provided by the volcano observatory “Servicio Geológico Colombiano (SGC)” were used[11]. The volcano chemical composition had the following percentage: O (46.6%), Si (27.7%), Al (8.3%) and Fe, Ca, Na, K, Mg (17.4%). The volcano crater geometry was defined using a diameter of 320 m, depth of 250 m and a height of 1100 m.

Figure 1 shows a GEANT4 simulation of GV complex and a simulated muon flux with energy of 1 TeV passing through the volcano crater. A preliminary study of the volcano crater with two different composition using standard rock and air were developed. Results from the study are shown in figures 2 and 3 (see Ref. [12] for more simulations results). When the crater has an air composition, a structure of one of the volcano conduits is observed (see Fig. 2). As a first approach, the muon flux with energy of 1 TeV wassend through a scaled volcano geometry of 1:1000. A real scale simulation will need an increasing computational power.

Figure 1. GEANT4 simulation of the Galeras volcanic complex. Figure 2. Interaction of 1000 muons of 1 TeV with air volcano crater. Figure 3. Interaction of 1000 muons of 1 TeV with standard rock volcano crater.
3. Simulation of the Muon Detector Prototype

The development of scintillators with plastic support in the form of strips has allowed the construction of cosmic ray detectors that are capable of withstanding the difficult environmental conditions that can appear in certain detection sites [13].

A detection matrix could be defined as two series of strips, aligned in the $x$ and $y$ directions and forming an array pixels. We simulated a particle detector using 10 matrices, as shown Fig. 4. In the radiation-matter GEANT4 toolkit was designed and simulated a scintillation detector of Polyvinyltoluene bars $C_9H_{10}$ (predetermined material within GEANT4). The chosen shape of the bars is based on the MINERvA experiment [9], which allow to observe how muon interactions occurs within the simulated prototype detector, the different physical processes involved, how their tracks are affected (see Fig. 4) and the energy that the muons deposit in it (see Fig. 5).

![Figure 4. Simulation of muon flux interacting with the scintillation detector prototype.](image)

![Figure 5. Deposited energy by muons on the scintillator detector.](image)

4. Optimal Position of Muon Detector on Galeras Volcano

The two geometries (GV and the detector with its characteristics), were implemented in GEANT4. The location of detector is an aspect of importance when applying muon tomography on geological bodies, mainly because the distance that muons cross through the structure depends on the topography and the location of the place of the structure to be analyzed. Best location points from a previous study performed by SGC are indicated on the Ref. [14].

To implement the location point within the GEANT4, we transformed the geographical coordinates of the volcano and the detector to Cartesians coordinates (X,Y,Z). Then, a translation was made to the origin of the coordinate system in GEANT4.

For practical computing considerations, the GV GEANT4 simulation was scaled to units of “mm”. To observe the location point of the scintillation detector in the GEANT4 graphical interface, a simulation with a considerable size detector was performed. Results of the preliminary simulation are shown in figures 6 and 7. In Fig.6 muons crossing volcanic cone and the scintillation detector in gray color is shown. The muon flux arriving to the prototype detector is shown in Fig. 7.
5. Muon Detector Structural Design

The design of Muon Detector Structure (MDS) was created using the software SW [5]. The figure 8 shows the MDS design with a metallic structure of 5 m in length where two scintillation planes will be mounted, a rotating mechanism and a base. The muon readout electronics will be located inside the box on the detector base.

To measure the muon flux, the MDS allow translational and rotational movements, characterized by horizontal translation of 3 m on its base, 180° of azimuthal rotation, 45° of zenith inclination and a displacement of scintillation planes along upper arm structure. For perform these movements four DC motors were installed in the points A, B, C and D, respectively (see Fig. 8).

Figure 6. Muon crossing volcanic cone and the scintillation detector in gray color.  
Figure 7. Muon flux which arrived to the prototype detector.

Figure 8. Muon detector design and location of each motor in the mechanical structure.
6. Muon Detector Structure Fabrication
The MDS will be deployed on GV surface with a rough topography and harsh weather conditions, therefore the structure was constructed with aluminum due to its characteristics like rigid, light and weather proof material; only its base was constructed with iron for a better support of all the structure but it has a coating with anti-corrosive paint for support weather conditions. In the figure 9 is shown a photo of the constructed MDS in the laboratory. Two scintillation planes are mounted on the metallic structure, each one with a Silicon Photomultiplier (SiPM) sensor to the detection of photons produced by the passage of muons. The figure 10 shows the installation of a SiPM sensor on a scintillation plane.

![Figure 9. Muon detector prototype structure.](image)

![Figure 10. Installation of the SiPM on the scintillation plane.](image)

7. Conclusions
First steps through a complete simulation of the GV density composition and a scaled volcano geometry in GEANT4 were presented. Future steps include calculate the atmospheric profile for Pasto city using stored data in the Global Data Assimilation System (GDAS) platform. The GV density composition within GEANT4 will be constructed using information of geophysics studies. Furthermore, we plan to increase the number of muons interacting with the real dimensions of the volcano structure using a computing cluster. We are in the process to develop mature simulations of particle detectors using plastic scintillator bars as active target and SiPMs as light collection devices.

Using the MDS structure already constructed, we need to perform a calibration of detector to measure the flux of incident cosmic muons in open sky conditions before proceed to do any data analysis with the prototype detector pointing towards the GV volcano location.

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