First Monte Carlo simulation study of Galeras Volcano structure using Muon Tomography

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Abstract

Muon radiography is based on the observation of the absorption of muons in matter, as the ordinary radiography does by using X-rays. The interaction of cosmic rays with the atmosphere produce Extensive Air Showers (EAS), which provide abundant source of muons. These particles can be used for various applications of muon radiography, in particular to study the internal structure of different volcanoes edifice. We will discuss the study the different volcanoes in Colombia focusing on Galeras located 9 km near to the Pasto City.

In this work we present the first study of the muon lateral distribution to the Pasto height (4276 m a.s.l.) and a first order simulation the volcanic cone using GEANT4[1][2]. For the interaction of the cosmic rays with the atmosphere we have used the CORSIKA 74004[3] software with an atmosphere tropical model and QGSJETII-04[4] as hadronic model for the high energies and GHEISHA2002d[5] for low energies. The analysis considers two different primary particle (proton and iron), four zenith angles (0°, 30,° 45° and 60)° with energies in the range of 5, 10 and 100 TeV.

1. Introduction

The Galeras Volcano with a height of 4276 m a.sl., located in San Juan de Pasto city with an estimated age of 4.500 years, is one with the highest activity in Colombia with important records of eruptions in the past. The increasing of population in higher risk areas around the volcano has motivated to develop special techniques of monitoring the volcano activity, especially for its records respecting to pyroplastic flux generated.

The tomography with muons help us to understand the internal volcano structure and its dinamics present during a eruptive process[6].

A simulation using Corsika EAS software has been implemented to obtain lateral distribution of muons (MLD) and their energy spectrum once they arrive at the altitude of San Juan de Pasto city. Furthermore, a preliminary simulation of the interaction of the atmospheric muons with Galeras volcano was made using GEANT4[1][2]. The geometric shape of Galeras volcano was made by SOLiDWORKS and implemented for GDML in FASTRAD.

The MLD consists in obtain the number of muons per square meter in function of the distance from the shower core (see Fig.(1a)[7]).

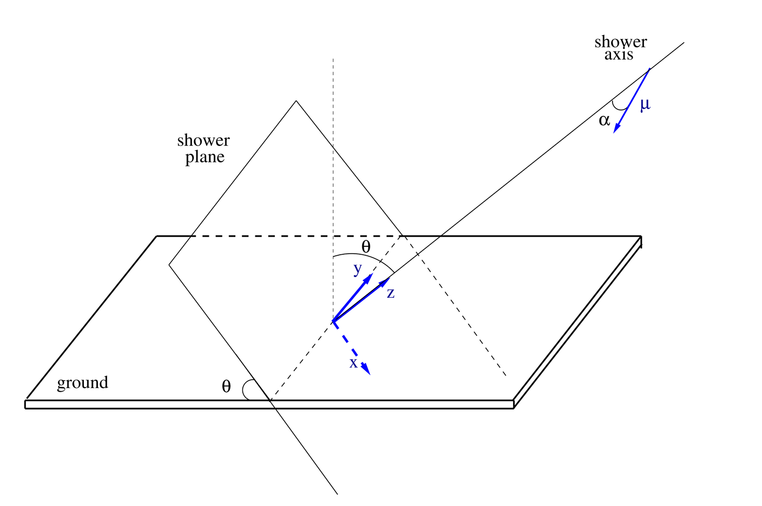
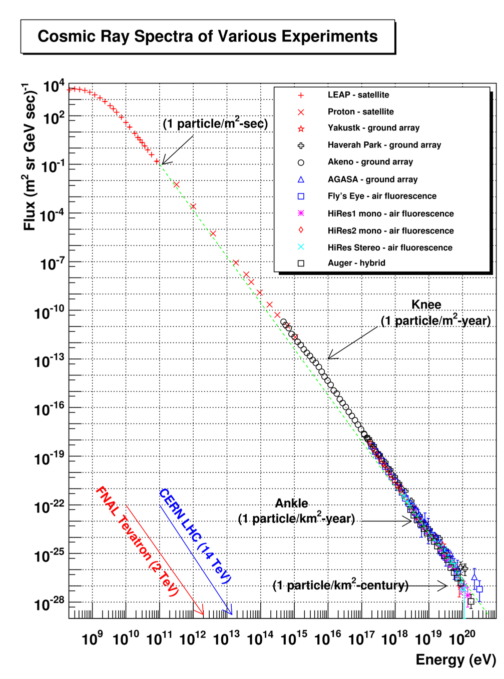


Figure 1. (a) Rain plane (perpendicular to the rain axis), the terrestrial surface and coordinate system.



(b) Cosmic ray spectra.

2. Methodology

Were simulated EAS with different zenith angles $\theta = 0°, 30°, 45°$ and $60°$. We have used energies for primary particles (protons and Fe) of 5, 10, 100 TeV (see Fig.(1b)[8]).

For simulation of EAS, were used the hadronic interaction package for high energies QGSJEII-04[4] and for low energies GHEISHA2002d[5]. We used the CORSIKA's tropical atmospheric model and magnetic field components Bx and Bz generated in geomag calculator[9] for Pasto city.

Using GEANT4 we simulate muons interacting within volcano and its crater. The geometry has been constructed using Solidworks (SW) and converted to GDML files. As input in SW contours provided by the volcano observatory "Servicio Geologico Colombiano (SGC)" were used. Materials for volcano structure, crater and their characteristics are shown in tables below:

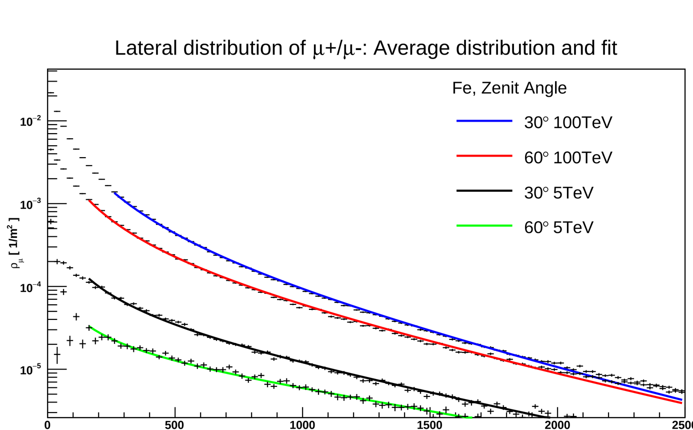
Composition	Percent Weight in Earth's Crust
O	46.6
Si	27,7
Al	8.3
Fe, Ca, Na, K, Mg	17.4

Characteristic of simulated volcano	
Crater Diameter	320 m
Height	1100 m
Crater Depth	250 m

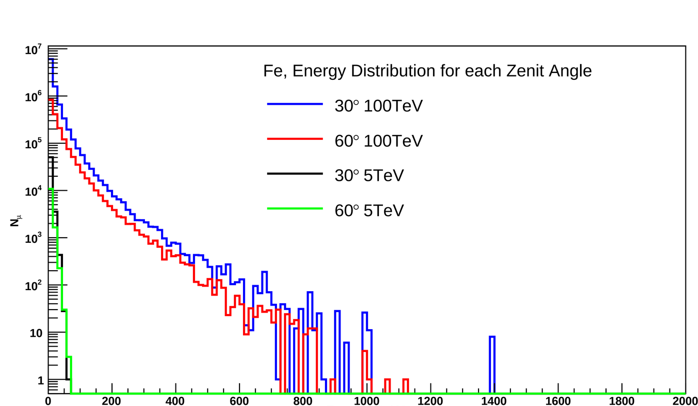
Muons of 2 TeV and $\theta = 80°$ interacting with volcano structure and the crater are show in Fig. 3(a), 3(b).

3. Results

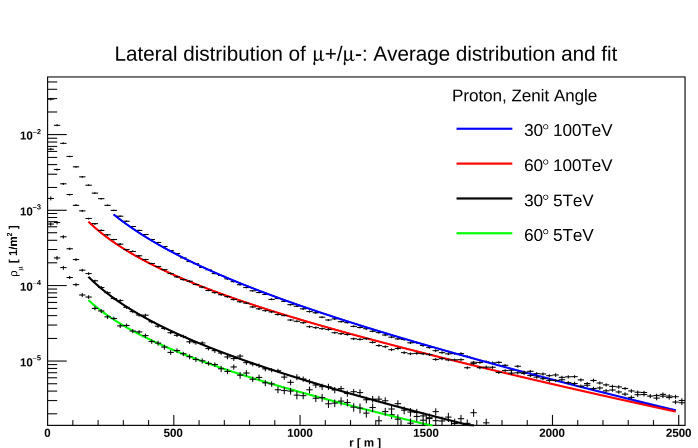
Using CORSIKA were simulated 200 EAS for the angles and energies previously described. In figure 2(a),2(c) and 2(b),2(d) are shown the MLD and the number of muons arriving to the altitude of Pasto city (~ 2600) in function of energy.



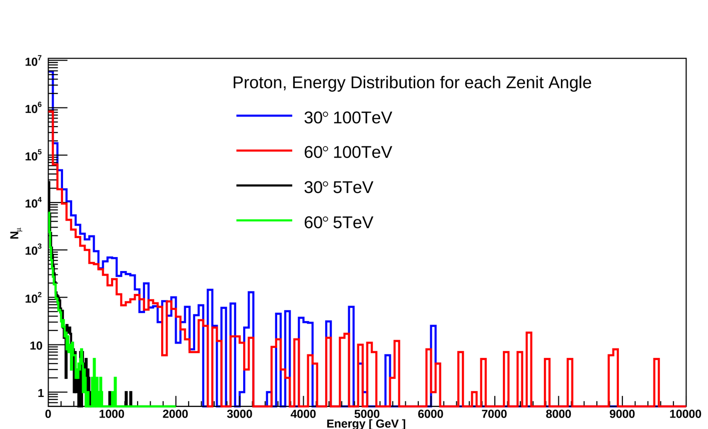
(a)



(b)



(c)



(d)

Number of muons per m^2 from a Fe Nucleus (a) and protons (c).

Energy spectrum for μ expected in surface from a Fe Nucleus (b) and protons (d).

Figure 2

The MLD obtained from simulation behaves according Nishimura-Kamata-Greizen equation[12][13] for the KASCADE-Grande[14] detectors array: $\rho_\mu = N_\mu \left(\frac{r}{r_0}\right)^{-\alpha} \left(1+\frac{r}{r_0}\right)^{-\beta} \left(1+\left(\frac{r}{10r_0}\right)^2\right)^{-\gamma}$. Where N_μ, r_0, α, β, and γ are fit parameters. These parameters r_0, α, and γ were fixed in 320m, 0.75 and 3 respectively[15], and N_μ and β are obtained from the fit. We obtain:

Fe									
		N_μ	β		N_μ	β		N_μ	β
5TeV	0°	0.00016	0.92	10TeV	0.00041	1.3	100TeV	0.0043	1.8
	30°	0.00010	0.71		0.00027	1.0		0.0033	1.7
	45°	0.000060	0.50		0.00015	0.79		0.0022	1.5
	60°	0.000022	0.12		0.000060	0.38		0.0011	1.2

proton									
		N_μ	β		N_μ	β		N_μ	β
5TeV	0°	0.00014	1.5	10TeV	0.00025	1.5	100TeV	0.0029	2.0
	30°	0.00014	1.4		0.00021	1.4		0.0023	1.9
	45°	0.000097	1.3		0.00015	1.3		0.0015	1.6
	60°	0.000063	1.2		0.000010	1.1		0.00074	1.3

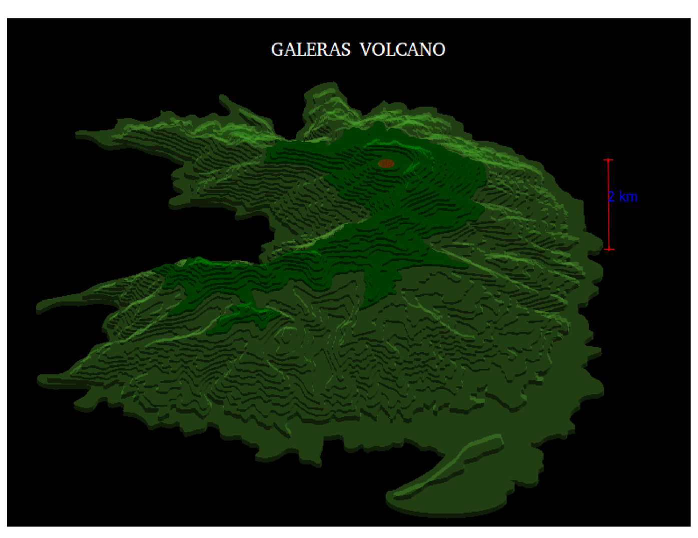
3.1 Preliminar results of volcano simulation in GEANT4

In GEANT4 besides the volcano geometry simulation implementation as shown in figure 3 (b), we have simulated 1000 muons of energy of 1TeV passing trough the volcano crater. We made a study giving to the crater two types of composition:

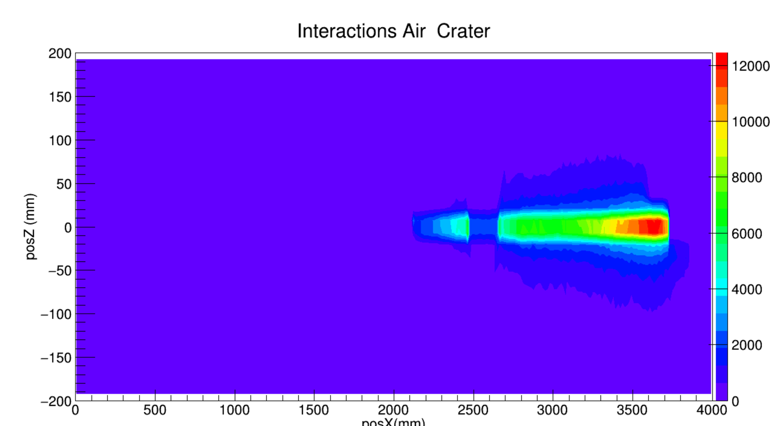
- standard rock
- air

Results from this study are shown in figure 3 (c) and (d).

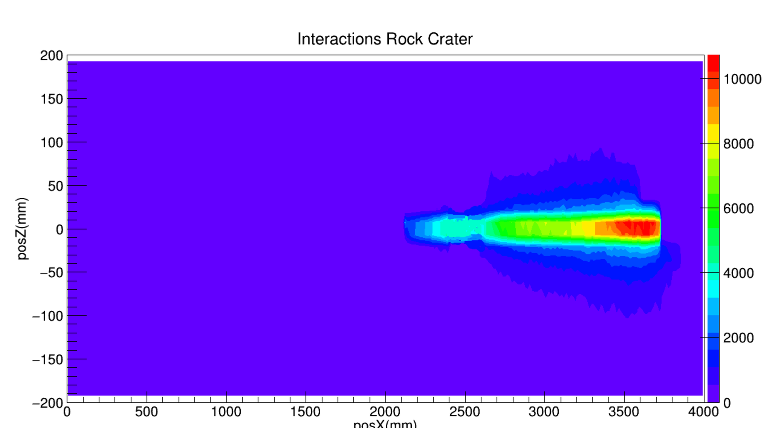
(a)



(b)



(c)



(d)

Figure 3

As a first approach we send the particles through the volcano geometry in an scaled 1:1000. This scaling was done due a simulation at real scale will need an increasing computational power. We are in the process to obtain acces to a cluster and scale the simulation to the real dimensions of the volcano.

4. Conclusions

- We have estimate for the first time the MLD at the Pasto city altitude with different zenith angles and energy of the primary particles of the EAS.
- We have developed the first steps through a complete simulation of the Galeras volcano geometry, and volcano composition using GDML files as input into GEANT4.
- Next step we will calculate the atmospheric profile for Pasto city using stored data in the Global Data Assimilation System (GDAS) platform[16]. Furthermore we are planning to improve the simulation of Galeras volcano composition and increase the number of muons interaction in the volcano using GEANT4. Finally we are in our first steps making simulations of the particle detectors using plastic scintillator bars and SiPM as a future candidate for readout.

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