Cosmogenic particles at ground level and their correlation with primary particles

Hariom Sogarwal[1,2*] and Prashant Shukla[1,2]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA and*
[2]*Homi Bhabha National Institute, Anushakti Nagar, Mumbai 400094, INDIA*

Introduction

The primary cosmic rays consist of protons (90%), helium nuclei (9%) and other heavy nuclei (1%) which have been accelerated to enormous energies from by 1 GeV to 1 PeV by extra-galactic processes. These particles when enter Earth atmosphere interact with air molecules and produce hadronic and electromagnteic showers [1]. The pions and kaons from the hadronic showers mostly decay to muons and muon neutrinos which reach the ground level. In recent years, the understanding of the showers is improved considerably. Various particle distributions are also understood in simple pictures [2]. The measurement of muons are mostly performed at the ground. Recently, we standardized the measurement technique using a portable setup of four liquid scintillators [3] which can be further used for studying cosmogenic particles.

Analysis

To produce hadronic interactions we use FLUKA model for low energy and SIBYLL model for high energy in the CORSIKA (version 7.7100) [4]. SIBYLL is a program developed to simulate hadronic interactions at extreme high energies based on the QCD minijet model. It also activates the inelastic hadronic interaction cross-sections at higher energies which are based on QCD calculations. FLUKA (FLUctuating KAscade) is a package of routines to follow energetic particles through matter by the monte carlo method. In combination with CORSIKA only low-energy hadronic interactions part is used which calculates the inelastic hadron cross-sections with the constituents of air.

Simulation inputs

In CORSIKA, the primary particles (protons and heliums) energy distribution is chosen as the power law (from 10 GeV to 5×10^5 GeV) of the form

$$I = A\,E^{-2.7}. \qquad (1)$$

with the zenith angle θ distribution ($0^\circ \leq \theta \leq 90^\circ$) generated as per $I(\theta) \sim \sin\theta$ while azimuthal angles are generated uniformly in 2π. These distributions are normalized with the measurements of the primary flux at the top of the atmosphere.

We validated the results of simulations using the muon flux measured at Tsukuba, Japan and then study the flux of other showers particles at ground. We set our observation level as 30 m above sea level, using the atmospheric model for Central European atmosphere for Oct. 14, 1993, which is quite close to Tsukuba, Japan. The horizontal component (towards North) and vertical component (downwards) of the Earths magnetic field are taken as 30.07 μT and 35.32 μT respectively.

Results and discussions

Table I shows the integrated flux I ($\mathrm{m}^{-2}\mathrm{sec}^{-1}$) calculated using zenith angle distribution of cosmogenic particles ν_μ, $\bar{\nu_\mu}$, ν_e, $\bar{\nu_e}$, μ^+, μ^-, n, p, π^+, π^-, $\bar{p}$, $\bar{n}$, K^+, K^-, K°_L and K°_S at ground level which have momentum p >0.5 GeV/c.

Figure 1 shows the muon zenith angle distributions at ground level alongwith the showers produced by primaries at different angles. The zenith angles of secondary particles (muons) reaching at ground keep the memory of initial shower angle.

*Electronic address: sogarwalhariom@gmail.com

TABLE I: Integrated flux I ($\mathrm{m^{-2}sec^{-1}}$) calculated using zenith angle distribution of cosmogenic particles for p >0.5 GeV/c.

Particles	I	Particles	I
ν_μ	2331.16	π^+	0.02412
$\bar{\nu_\mu}$	2255.71	π^-	0.01658
ν_e	1149.74	$\bar{p}$	0.00430
$\bar{\nu_e}$	942.95	$\bar{n}$	0.00324
μ^+	113.76	K^+	0.00013
μ^-	88.24	K^-	0.00011
n	5.70134	K_L°	0.00109
p	2.25121	K_S°	8.1364e-07

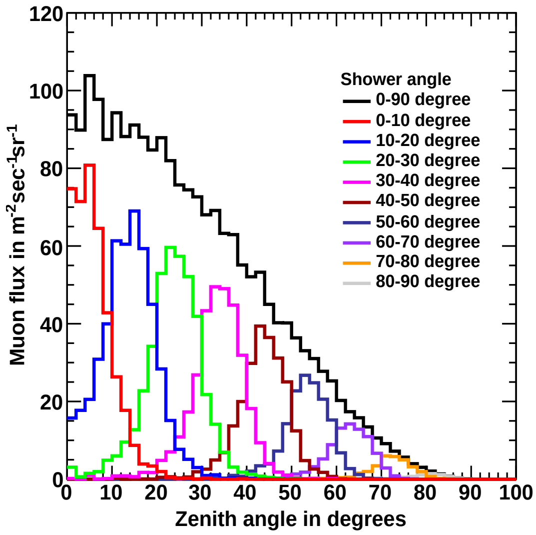

FIG. 1: Muon zenith angle distributions at ground level alongwith the showers produced by primaries at different angels.

Figure 2 shows the flux of the major cosmic ray shower particles reaching at ground level as a function of zenith angle for ν_μ, $\bar{\nu_\mu}$, ν_e, $\bar{\nu_e}$, μ^+, μ^-, n and p. The number of ν_μ and $\bar{\nu_\mu}$ is 2-3 times bigger than ν_e and $\bar{\nu_e}$. The vertical yields of μ^+ and μ^- are $\sim$ 200 times smaller than ν_μ and $\bar{\nu_\mu}$. The number of n and p are $\sim$ 5000 times smaller than ν_μ and $\bar{\nu_\mu}$. The intensity of muons and nucleons decreases at higher angles as they traverse larger path lengths and thus loose energy and have more

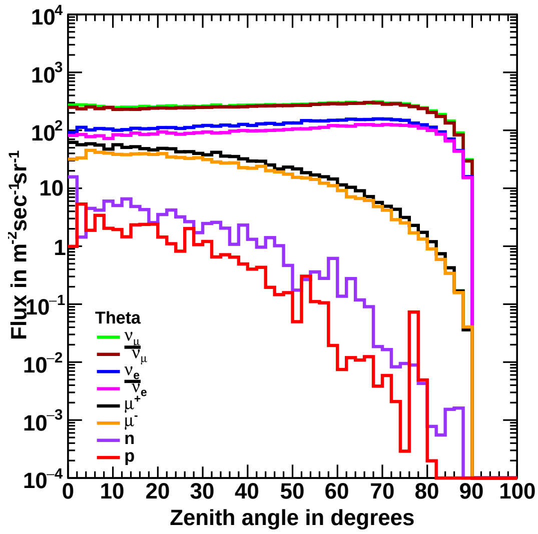

FIG. 2: Flux of the major cosmic ray shower particles reaching at ground level as a function of zenith angle distribution.

chance of decay. For neutrinos, the yields increase at higher angles since they do not interact in the air and their production increase due to the decay of short-lived particles.

Summary

A study of atmospheric shower simulation is performed using SIBYLL and FLUKA models in CORSIKA to obtain the flux of secondary particles at ground level. Relative yields and correlations of various particles with primaries and with each other has been studied quantitatively.

References

[1] P.K.F. Grieder, Cosmic rays at earth: Researcher's reference manual and data book, Elsevier (2001).

[2] P. Shukla and S. Sankrith, Int. J. Mod. Phys. A **33**, 1850175 (2018).

[3] H. Sogarwal and P. Shukla, JCAP **07**, 11 (2022).

[4] D. Heck, and T. Pierog, Extensive air shower simulation with CORSIKA: A users guide (Version 7.7100) (2016).