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Study of Lateral distribution Parameters from simulation of HE Cosmic Ray EAS

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Abstract: The measurement of secondary parameters related with lateral or longitudinal development of an Extensive Air Shower (EAS) is important for the estimation of primary mass abundance. These parameters may be studied using Monte Carlo Simulation method. The lateral distribution function (LDF) of secondary particles in an EAS evolves along the cascade propagating in the atmosphere. A detail parametrization of the observable quantities in an EAS is needed for understanding of primary mass composition. Here we have analyzed the characteristics of lateral distribution of simulated EAS using the Monte Carlo programme , CORSIKA 6735 with hadronic interaction model QGSJET01 at the primary energy 10^{17} eV.

Keywords: cosmic rays, CORSIKA code, primary mass composition.

1 Introduction

The nature of cosmic rays at the highest energies is surrounded by uncertainties. The variation of the composition as a function of energy is of extreme importance to the understanding of both the Galactic and the extragalactic components. The measurement of mass composition of high energy cosmic rays above 10^{17} eV can provide important clues about the origin of ultra high energy cosmic rays. However at Ultra High Energies, Cosmic ray mass composition cannot be measured directly. In order to study Ultra High Energy primary, it is necessary to measure the properties of secondary particles generated by the primary nuclei in the atmosphere. The interaction of high energy cosmic ray particle with the atmospheric nuclei creates a cascade of secondary particles, which arrive nearly at the same time but distributed over a large area perpendicular to the direction of propagation of the original particle. The disc of secondary particles may extend over several hundred meters from the shower axis, with maximum density at the center of the disc, which is called the shower core.The measurement of secondary parameters such as lateral density distribution of an extensive air shower(EAS) carries important information about the shower development and nature of shower inducing cosmic ray primary.

In order to study primary abundance, a large number of Monte Carlo events are to be generated with wide range of primary energy and particle type. Shower lateral development depends on high energy interaction characteristics and primary mass composition. The influence of primary mass composition on the secondary cascade development in the atmosphere is studied by analysing the lateral distribution of the electronic component for proton ,Helium ,oxygen and iron primaries at 10^{17} eV for different zenith angles using CORSIKA-6735 code.The simulated lateral distribution of electron(electrons and positrons) is fitted with analytical formula and the best fitted parameters are analysed.

2 Method [Monte Carlo simulation]

A reliable interpretation of the data requires a detailed understanding of the physics of shower development, as well as a detailed knowledge of the detector response. Monte Carlo technique is used to simulate the lateral development of an extensive air shower (EAS) with fixed primary particle type and energy assuming a particular interaction model. CORSIKA (COsmic Ray SImulations for KAscade),an example of Air shower Monte Carlo , is a standard tool in Cosmic Ray Physics, used successfully by many Cosmic Ray experiments at very different energies. It was originally developed to perform simulations for the KASCADE experiment at Karlsruhe and it has been refined over the past years. Here we have simulated air showers using the CORSIKA version 6735 [1], Monte Carlo program with the QGSJET 01 [2] hadronic interaction model. Particles in the shower are followed down to the energy of 0.3 GeV (Muons and Hadrons) and 0.003 GeV (Photons and electrons). Thinning option [3] is used with a factor of 10^{-4} .We have simulated fifty showers for primary energy 10^{17} initiated by each of the primary nuclei. The particle output file from CORSIKA is first decoded with available

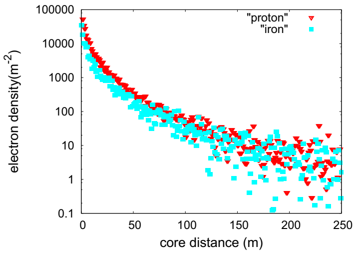

Figure 1: Lateral distribution of electrons at 10^{17} eV for p and Fe initiated showers respectively at 0^0

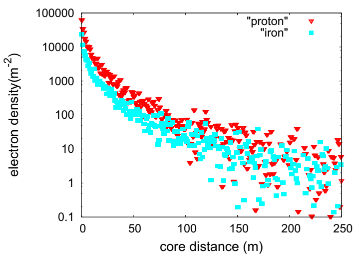

Figure 2: Lateral distribution of electrons at 10^{17} eV for p and Fe initiated showers respectively at 20^0

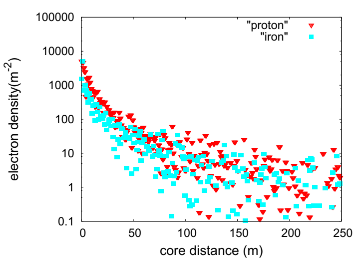

Figure 3: Lateral distribution of electrons at 10^{17} eV for p and Fe initiated showers respectively at 40^0

FORTRAN code and the decoded output is further processed with a FORTRAN program to get number of particles as a function of core distance. Considering annular ring of 1m thickness, density of particles are calculated for different core distance ranges. Thus, lateral distribution for electrons are obtained.

3 Results

3.1 Lateral distribution

The lateral density distributions of electrons at 10^{17} eV for p and Fe initiated showers at three zenith angle 0^0, 20^0 40^0 are shown in Figure 1, 2, 3 respectively.The electron density corresponding to iron induced shower is found to be less compared to same energy proton induced shower as energy per nucleon for iron primary is less . However, the fluctuation is larger at greater core distances. The procedure is repeated for He and O primaries at zenith angles 0^0, 20^0 and 40^0 for the same primary energy. The result of lateral distribution are fitted with modified NKG function, as shown Fig 4. to Fig 9.

particle type	0^0	20^0	40^0
p	4.43521	3.38157	2.19587
He	3.70404	3.97387	2.22547
O	3.04011	3.40831	1.92569
Fe	3.43709	3.24866	1.49476

Table 1: Values of LDF steepness parameter (η) of electrons at three different zenith angles.

3.2 Parameterization of lateral distribution of electrons

Though the Extensive air shower cascade is a superposition of many electromagnetic cascades initiated by gammas of various energies arrising as decay products of π^0 produced in nuclear interactions at various depths in the atmosphere, the NKG (Nishimura-Kamata-Greisen) function is found to be a reasonable approximation for the lateral distribution of charged paticles[4].

Here the lateral distribution of electrons is fitted with modified NKG function [4] with steepness parameter(η)

$$\Delta_e(r) = C(\frac{r}{r_0})^{-1.2}(1+\frac{r}{r_0})^{-(\eta-1.2)}[1+(\frac{r}{1000})^2]^{-0.6}$$

Where C is the normalization constant and r_0 is the Moliere unit for electrons (=80m) in atmosphere.

The fitted values of steepness parameter(η) of the lateral density distribution for various primary masses and zenith angles are shown in Table1. These vales are also plotted as functions of mass number and zenith angle in Fig 10.

3.3 Discussion

From the above analysis it is seen that for higher primary mass number, the steepness parameter changes with mass number[Fig 10.], but it remains almost constant for heavier primaries. On the other hand for different mass compositions, this parameter decreases slightly as zenith angle changes from $0^0$to 20^0. But its value is almost halved as zenith angle is increased to 40^0 . This work is proposed to be further extended for higher primary energies and different azimuthal angles as at larger zenith angles the lateral distribution becomes asymmetric due to variation in azimuthal angles.

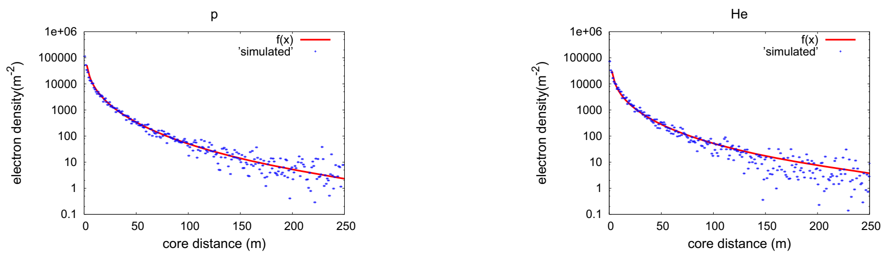

Figure 4: Lateral distribution of electrons at 10^{17} eV for p and He initiated showers respectively at 0^0 . The solid line represents the fitted function.

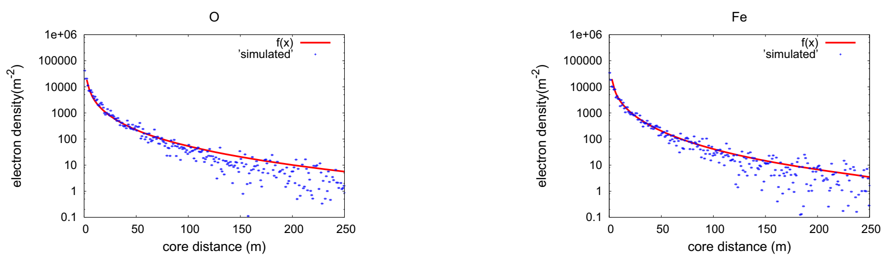

Figure 5: Lateral distribution of electrons at 10^{17} eV for O and Fe initiated showers respectively at 0^0 . The solid line represents the fitted function.

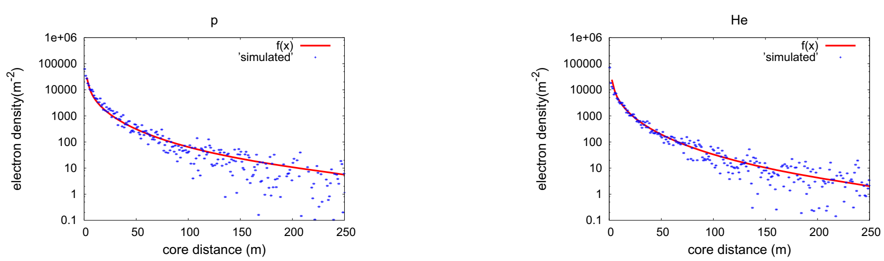

Figure 6: Lateral distribution of electrons at 10^{17} eV for p and He initiated showers respectively at 20^0 . The solid line represents the fitted function.

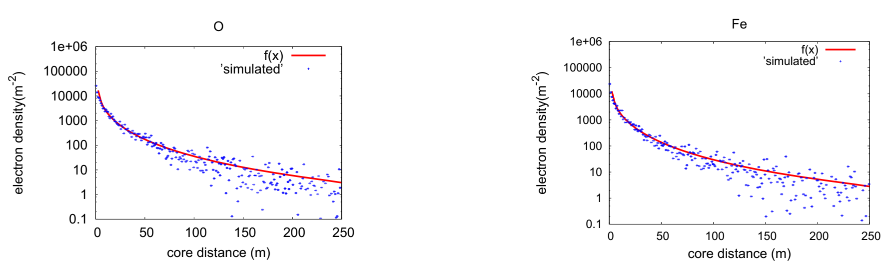

Figure 7: Lateral distribution of electrons at 10^{17} eV for O and Fe initiated showers respectively at 20^0 . The solid line represents the fitted function.

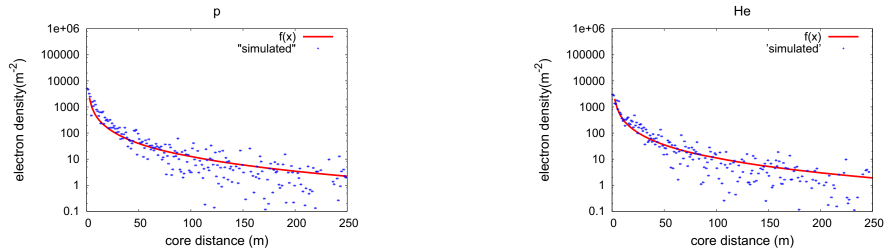

Figure 8: Lateral distribution of electrons at 10^{17} eV for p and He initiated showers respectively at 40^0 . The solid line represents the fitted function.

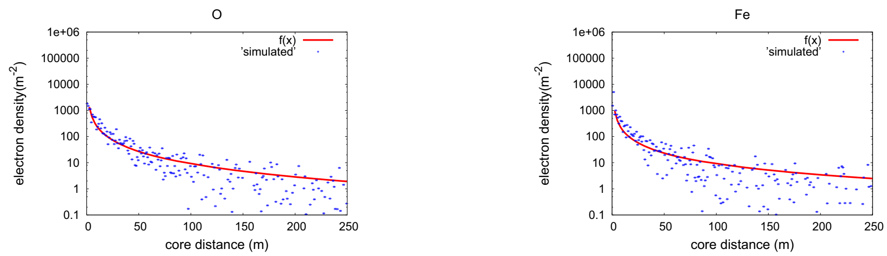

Figure 9: Lateral distribution of electrons at 10^{17} eV for O and Fe initiated showers respectively at 40^0 . The solid line represents the fitted function.

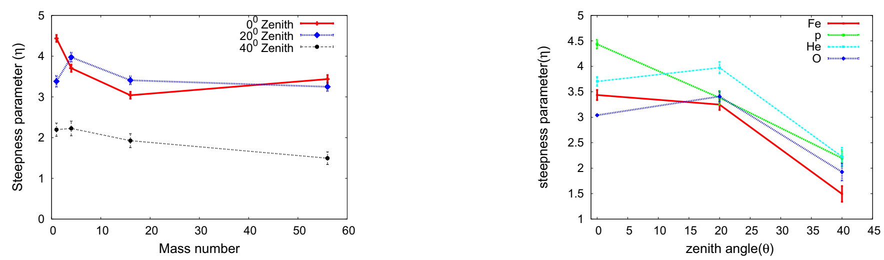

Figure 10: Steepness parameter as a function of mass number and zenith angle at 10^{17} eV.

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