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Lateral distributions of UHE extensive air showers simulated with CORSIKA (6.03)

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Abstract. Lateral distributions for different type of particles in UHE extensive air showers have been simulated with CORSIKA code, version 6.03. In order to study the influence of the mass of the primary particle in the lateral development of extensive air showers in the atmosphere, different primary masses have been simulated at fixed primary energy, $10^{15}\ eV$.

1 Introduction

The study of the composition of ultra high energy cosmic rays is very interesting in order to obtain information about their origin and the processes involved in their acceleration, since they are generated until entering in the atmosphere. In order to study ultra high energy nuclei, the secondary particles generated by the primary nuclei in the atmosphere are measured at ground level. These secondary particles generate mainly the electromagnetic, muonic and hadronic components.

In the present work the lateral distributions of the three secondary components generated by ultra high energy nuclei are studied in order to obtain some information about the influence of the primary particle mass in the cascade development in the atmosphere for a fixed primary energy. For this reason, lateral distributions at primary energies of 1 PeV from a detailed Monte Carlo calculations are treated and some preliminary results have been obtained.

The lateral distributions of electrons and positrons, muons, photons and hadrons are treated from two points of view. First each component is studied individually for the different primary particles simulated. In a second step, for each primary particle, the four groups of secondary particles are studied to evaluate the influence of the primary mass in these distributions, and in order to look for a method to discriminate between primary particles of very different masses.

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2 Simulation

A good procedure to study the cascade development in the atmosphere is a Monte Carlo code to simulate the EAS development in the atmosphere, taking into account all knowledge of high energy hadronic and electromagnetic interactions involved. In the present work the extensive air showers are generated by CORSIKA (COsmic Ray SImulation for KAscade) (D. Heck et al, 1998) version 6.03. CORSIKA is a detailed Monte Carlo program to study the evolution of EAS in the atmosphere. It was originally developed to perform simulations for the KASCADE experiment at Karlksruhe (K.H. Kampert et al., 1999) (H.O. Klages , 1997) and it has been refined over the past years, the most recent version is from March 2001.

An important task in EAS Monte Carlo simulation is taking into account all knowledge of high energy hadronic and electromagnetic interactions, although the most serious problem of EAS simulation is the extrapolation of hadronic interactions to higher energies, which are not covered by experimental data in accelerators. For these reasons CORSIKA provides different hadronic interaction models at high energies. In this work we have invoked the HDPM (Hadronic Dual Parton Model) subroutine, (D. Heck et al, 1998), to simulate hadronic interactions above 80 GeV. This subroutine is a phenomenological generator inspired by the DPM (Dual Parton Model) (A.Capella and J. Tran Thanh Van, 1980). Below 80 GeV the subroutine GHEISHA (H.Fesefeldt, 1985) is used to simulate hadronic interactions. The electromagnetic interactions have been treated with EGS4 (Electron Gamma Shower) code (W.R.Nelson et al, 1985).

In this work, we have updated our Monte Carlo data library from previous works (M.M. Espinosa et al, 1999) (M.M. Espinosa et al, 2000), where the CORSIKA code, version 5.62, had been used. Extensive air showers initiated by protons, iron nuclei (A = 56) and gamma photons of $10^{15}\ eV$ primary energy have been followed up to sea level ($1030\ gcm^{-2}$). Primary particles with very different masses have been chosen in order to obtain some preliminary results about the in-

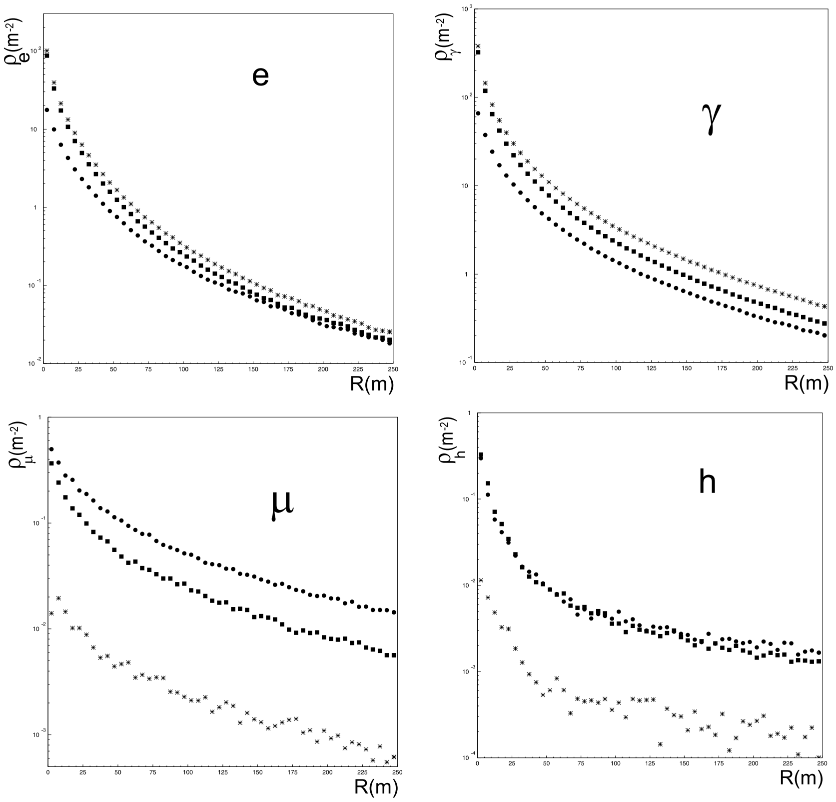

Fig. 1. Lateral distributions for types of primary particles: electrons and positrons, photons, muons and hadrons for primary particles ($*$) gamma photons, (●)iron and (□) protons

fluence of the primary mass at energies around the ”knee”. In order to test the most recent version of the code, we have simulated ten events for each primary particle. The threshold energies are $0.05\ MeV$ for muons and hadrons, and $0.001\ MeV$ for the electromagnetic component.

3 Lateral distribution

The radial evolution of the particle density for four different types of secondary particles, from core distance up to $250\ m$ has been obtained.

At a first step we have studied the lateral distributions for each kind of secondary particles. We have obtained the lateral distributions of the muons, electrons and positrons, photons and hadrons as can be shown in Figure 1. It can be observed that the electromagnetic component of the cascades is very similar for the three primary particles, slightly higher for electromagnetic showers, as may be expected. On the other hand the lateral distributions of muons and hadrons are useful in order to distinguish between electromagnetic and hadronic showers. The number of muons and hadrons is one order of magnitude lower for electromagnetic showers all over the radial distances from the shower core. Moreover, from the muon lateral distributions we can distinguish between showers initiated by protons and iron nuclei, but the difference is lower, increasing when the shower core distance increases.

Both distributions, corresponding to muon and hadronic components could help to distinguish between electromagnetic and hadronic showers in a reliable manner, but the difference in muon component is not important enough to distinguish between showers initiated by protons and iron nuclei and for this reason we have to look for other parameters to help us to distinguish between them.

In second place, we have obtained the four lateral distributions for each primary particle. It has been shown at Figure 2. The results obtained for the electromagnetic component, electrons and positrons and photons, are in agreement in order of magnitude with other results obtained by simulation (L. del Peral and M. D. Rodríiguez-Fríias, 1997), although our results are slightly lower. Comparison with experimental results (T.Antoni et al, 2001) is very difficult for two reasons; primarily we would have to simulate the path of the secondary particles across the detectors, this question could be treated in future works. The second reason is that the determination of the primary energy of each individual cascade is very difficult and therefore the lateral distributions are obtained in function of other experimental parameters, like the shower size or truncated particle numbers integrated only over the experimental covered range of core distances. But in this context we are looking for parameters which can help to discriminate experimentally showers of different masses in this energy range.

The objective of this study is to observe the mass influence of the primary particle in these distributions and find out differences between them that permit us to discriminate between hadronic and electromagnetic cascades. Like in the previous study the differences between the hadronic and elec-

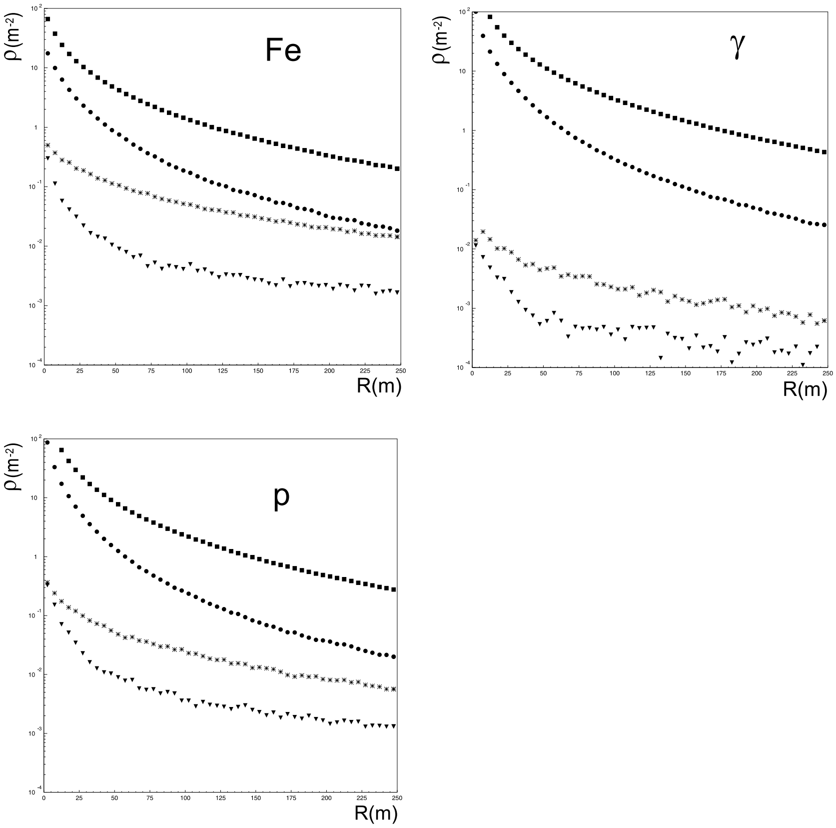

Fig. 2. Lateral distributions of three primary particles proton iron nuclei and gamma photon. In each figure there are four primary particles: ($*$) muons ($\bullet$) electrons and positrons ($\square$) photons and ($\bigtriangledown$) hadrons

tromagnetic showers are very important and these distributions could be used to discriminate between the two types of showers.

Although the differences between lateral distributions of showers initiated by protons and iron nuclei are less evident, there are some differences in the behavior of the electrons and positrons and the muon component. These distributions do not cross in the radial interval considered, but in the case of the iron nuclei they approximate and it is reasonable to think that they cross near the outer edge of the radial interval.

In order to study the relation between these components the ρ_μ/ρ_e relation is analyzed in the next section.

4 The ρ_μ/ρ_e relation

As it can be observed in the last section the electrons and positrons and the muon component studied individually do not help us to discriminate primary nuclei with different ma sses, although it can be observed that the relationships between them are different for each primary particle. For this reason the ρ_μ/ρ_e relation has been obtained for each primary and the results for the three primary nuclei are shown in Figure 3.

In this figure it can be observed that the ρ_μ/ρ_e relation increases when the primary mass increases; it means that increasing the primary mass of the shower the muon number in the radial interval between 0 and $250\ m$ is more important for heavier nuclei than for lighter ones and the electromagnetic component has the opposite behaviour, as it can be observed in Figure 1, so this relation can be useful to discriminate between different masses.

Moreover this kind of relations or other similar can be measured experimentally, for this reason we have involved in a deep study of them.

5 Conclusions

In the present work the Monte Carlo code CORSIKA , version 6.03, has been used to simulate the development of cascades in the atmosphere, initiated by three different primary particles: protons, iron nuclei and gamma photons with an energy of $10^{15}\ eV$. The mean aim of this work is the study of lateral distributions obtained with the new and revised version of the code, in order to obtain some information to distinguish between air showers initiated by different primary particles. Although the results obtained can not be directly compared with experimental data, the information obtained can be applied to discriminate different primary masses experimentally.

Each secondary types of particles of the cascade, muons, electrons and positrons, photons and hadrons have been treated separately (Figure 1). From the muon and hadron lateral developments we can distinguish between hadronic and electromagnetic showers, but they are not useful to achieve any conclusive result concerning mass discrimination.

After we have analyzed the lateral distributions of the four

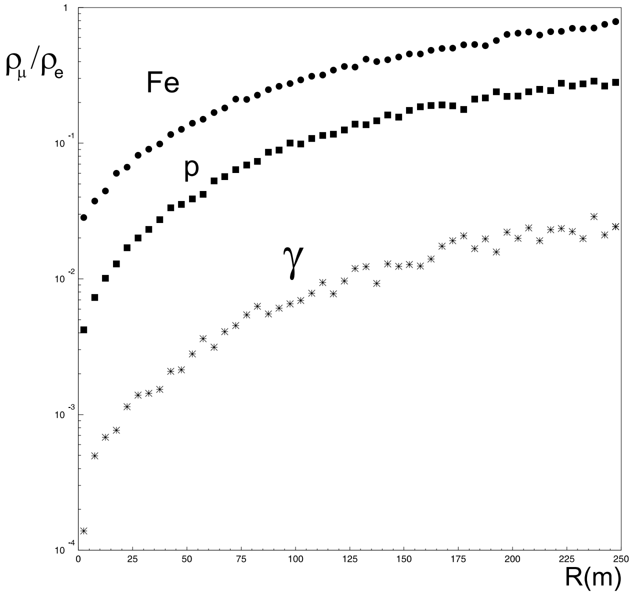

Fig. 3. The relation ρ_μ/ρ_e for three primary particles: ($*$) gamma, (●)iron and (□) proton

secondaries, for each primary particle, in order to know general characteristics of the lateral development of the cascade and observe the mass influence in this development. As it has been found, previously, this method allow us to discriminate between electromagnetic and hadronic extensive air showers. Concerning the behavior of the electron and muon components it has been observed a tendency that should be useful to discriminate between protons and iron nuclei.

In order to analyze this tendency, the ρ_μ/ρ_e relation has been obtained and it is shown in the Figure 3, these types of relations may be used to discriminate between very different primary masses in this energy range.

In future works we will continue studying the lateral distributions at higher energies, using different particle interaction models offered by CORSIKA. Another interesting possibility is to treat these results simulating the pass of the particles across different detectors.

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