

Studying the Thinning Effect of Longitudinal development in Extensive Air Showers for Primary Proton and Iron Nuclei at Ultra-High Energies

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ABSTRACT

In the present work, extensive air showers (EAS) effects are described by estimating the longitudinal development model of EAS at very high energies of various cosmic ray particles. The longitudinal development was simulated for charged particles such as gamma, charged pions and charged muons at very high energies 10^{17} , 10^{18} and 10^{19} eV. The simulation was performed using an air shower simulator system (AIRES) version 19.04.0. The effect of primary particles, energies, thinning energy and zenith angle (θ) on the number of charged particles (longitudinal development) produced in the EAS was taken into account. The rapprochement of the estimated longitudinal development of the charged particles such as the charged muons and charged pions with the experimental measurements (AUGER experiment) that gave a good agreement for primary proton at the fixed primary energy 10^{19} eV for $\theta = 0^\circ$.

KEYWORDS: AIRES system; Longitudinal Development; extensive air showers; thinning energy.

الخلاصة

في هذا العمل، تم وصف تأثير وإبل الجسيمات المشحونة من خلال تقدير نموذج التطور الطولي لوائل الجسيمات ضمن مدى الطاقات فوق العالية لمختلف جسيمات الأشعة الكونية. وقد تمت محاكاة التطور الطولي للجسيمات المشحونة مثل: اشعة كاما، البايونات المشحونة والميونات المشحونة للطاقات العالية جدا (10^{17} ، 10^{18} و 10^{19} إلكترون فولت). وقد تم تنفيذ المحاكاة باستخدام نظام محاكاة وإبل الجسيمات (AIRES/اصدار 19.04.0). تم اخذ بنظر الاعتبار تأثير الجسيمات الأولية، الطاقات، طاقة التخفيف وزوايا الذروة على عدد الجسيمات المشحونة (التطور الطولي) المتكون في وإبل الجسيمات المتعددة. وقد تمت مقارنة التطور الطولي للجسيمات المشحونة مثل الميونات المشحونة والبايونات المشحونة مع القياسات التجريبية (منظومة اوجر) والتي أعطت توافق جيد للبروتونات الأولية عند الطاقة (10^{19} إلكترون فولت) للزاوية صفر.

INTRODUCTION

Air showers are created penetrating high energy cosmic rays the atmosphere; they intact with nuclei in the top of the atmosphere and produce less secondary particles with high energies [1]. In 1930, Pierre Victor Auger, the French physicist, discovered the EAS by producing more and more particles in the atmosphere [2]. It is important to implement a detailed air shower numerical simulations to infer the primary cosmic ray (PCR) properties which produce them. Because of the number of charged particles in the high energy EAS showers may be massive and may exceed 10^{10} eV, therefore the simulations are a challenge [3]. It is well-known that the longitudinal development in EAS depends on

the type and energy of the primary incident particle [4], therefore, one of its properties is the depth of shower maximum (X_{max}), that is utilized for energy spectrum and mass composition reconstruction of PCRs [5, 6]. (The number of charged particles (N) in EAS as a function of the atmospheric depth is closely related to the elementary particle's type and energy which can be simulated using AIRES simulation code [7]. Since the growth shower is a random process complex and often uses Monte Carlo simulation to design showers atmosphere [8]. Among the many roads to facilitate the problem and to minimize computation time, the thinning approximation is the most common entirety of the importance. Its essential conception is to track only a

represented collection of particles. However, they are highly effective in calculations and provide the right values for observation in medium, this manner offers synthetic vicissitudes because the number of particles trajectory decreases by multiple orders of size. These synthetic vicissitudes are combined with naturalistic fluctuations and thus decreases the accuracy of specifying of physical parameters [9]. The Pierre Auger EAS array studies the very high energy cosmic radiations, which occurs in the field of astrophysics, that is, an important area in physics. Can deduce information on the longitudinal showers, through Pierre Auger Observatory and subsequently on mass composition utilizing both the Surface Detector (SD) and the Fluorescence Detector (FD)[10]

The size of the longitudinal shower of the energy sedimentation in the atmosphere is characterized in specifics [10]. In 2015, Alex Estupiñan studied the achievement of the de-thinning method order to simulate EAS for high-energy cosmic rays[11].

The results of the current calculations have shown the thinning energy effect on the fluctuations in the longitudinal development reaching the Earth's surface, such as the pair production of electron and positron, gamma, charged pions and charged muons, by simulating the longitudinal development carried out using the Monte Carlo AIRES system at ultrahigh energies 10^{17} , 10^{18} and 10^{19} eV. Comparison of the estimated longitudinal development model of EAS such as the charged pions and charged muons with experimental results (AUGER experiment) that gave a good agreement at 10^{19} eV with the thinning energy ($\varepsilon_{th} = 10^{-7}$) [12, 13].

THE LONGITUDINAL PROFILE

The profile of the longitudinal cascade is a shower particle number dependence (N) on a specific traversed atmospheric depth, X . The longitudinal cascade parameterization was proposed using Gaisser-Hillas formula for cosmic-ray experiences [14]:

$$N(X) = N_{max} \left(\frac{X}{X_{max}} \right)^{X_{max}/\lambda} \exp(X_{max} - X)/\lambda, \quad (1)$$

where X is the atmospheric depth (in g/cm^2 unit); N_{max} is the number of shower maximum

of charged particles; X_{max} is the depth of shower maximum and λ is a characteristic length parameter (its value is $70 \text{ g}/\text{cm}^2$) [15]. The first interaction point is the location of the first collision of the PCR particle with atmospheric nuclei. A fourth parameter is often introduced into Eq. (1), superficially to permit for a variable initial interaction point [16]:

$$N(X) = N_{max} \left(\frac{X - X_o}{X_{max} - X_o} \right)^{(X_{max} - X_o)/\lambda} \exp(X_{max} - X)/\lambda, \quad (2)$$

Where X_o is the depth of the first interaction point. This value depends on the cross-section of collision and therefore on the mass composition and energy spectrum of the primary particle. While the X_{max} depends on the X_o position, the energy of the shower and the particle composition. But one can illustrate the shower longitudinal development as a function of the cascade "shower" age s that defined as $s = 3X/X_{max} + 2X_o/X_{max}$ by using s instead of the depth X . Translating the depth of shower maximum X_{max} into the shower age s with utilizing the normalized shower size $n = N/N_{max}$ then Eq. (2) will be given as [15]:

$$n(s) = \left(1 - \frac{(1-s)3T_m}{(3-s)(T_m - T_o)} \right)^{T_m - T_o} e^{3T_m(1-s/3-s)} \quad (3)$$

Where $T_m = X_{max}/\lambda$ and $T_o = X_o/\lambda$

THINNING MODEL

The thinning algorithm implementation was used by simulating the EAS cascade on the secondary particles if be satisfied with the condition [11]:

$$E_o \varepsilon_{th} > \sum_{j=1}^n E_j \quad (4)$$

Where E_j is the energy of secondary particles; E_o is the primary particle energy and the thinning level satisfying the relation $\varepsilon_{th} = E_j/E_o$.

Through this state, only secondary particle i can be survived. The survival probability is:

$$P_i = E_i / \sum_{j=1}^n E_j \quad (5)$$

Otherwise, if the total amount of secondary particles n is larger than the threshold thinning energy, i.e.:

$$E_o \varepsilon_{th} < \sum_{j=1}^n E_j \quad (6)$$

less than the threshold thinning energy. Then the probability will be given as:

$$P_i = E_i/E_o \varepsilon_{th} \quad (7)$$

Where, E_j is the energy of secondary particles.

RESULTS AND DISCUSSIONS

Simulating the longitudinal development by using AIRES system

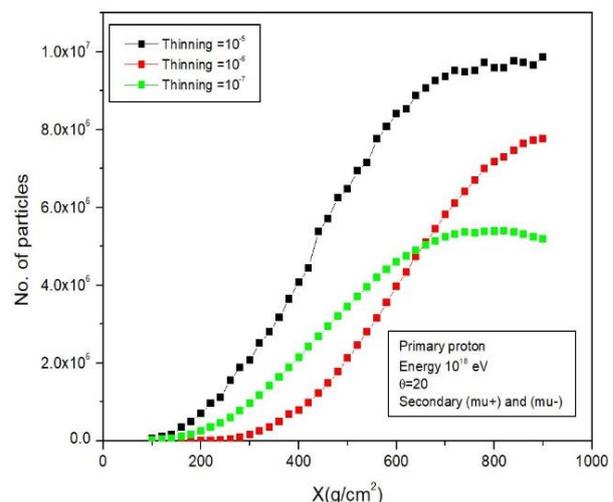
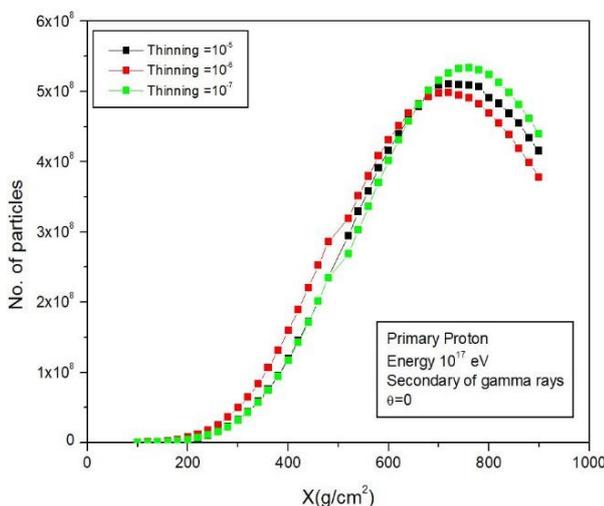
AIRES is an abbreviation for AIR-shower Extended Simulations, which is defined as programs and subroutines set that are used to simulate EAS particle cascades, which initiated after interaction of primary cosmic radiations with high atmospheric energies and the management of all output-associated information. AIRES gives a complete space-time particle diffusion in a real medium, where the features of the atmosphere, the geomagnetic field, and Earth's bend are adequately taken into regard. [7].

The thinning algorithm (statistical sampling step) is used when the number of particles in the showers is very big. The thinning algorithms used in AIRES are localized, i.e. statistical samples never change the average values of the output observables. Many particles are taken into account through simulations using the AIRES system such as: "gammas, charged muons, and charged pions particles". The primary particle of the incident in the EAS may be a primary proton or iron nuclei or other primaries mentioned in the AIRES guidance document with a very high primary energy that may exceed 10^{21} eV [7].

Figure 1 shows the number of charged particles as a function of the atmospheric depth from the shower axis is called longitudinal shower that reaches the Earth's surface by AIRES simulation. The effect of primary particles (protons and iron), energies (10^{17} , 10^{18} and 10^{19} eV), zenith angles ($\theta = 0, 20$ and 30 degrees) and the average of thinning energies ($\varepsilon_{th}=10^{-5}$, 10^{-6} and 10^{-7}) on the number of charged particles produced in the EAS was taken into consideration. As shown in figure 1, the number of charged particles for several secondary particles decreases with increasing atmospheric depth from the shower axis. Finally, the statistical fluctuations of the longitudinal development of several secondary particles decrease while reducing the thinning energy.

Comparison with the experience of Pierre Auger Observatory

Figure 2 demonstrates the comparison between the present results of longitudinal development performed by AIRES simulation (solid lines) with the experimental measurements (AUGER experiment) (symbols)[12]. This figure displayed a good agreement between present results of longitudinal development simulation by the AIRES system of the secondary particles (charged muons and charged pions) initiated by the primary proton at energy 10^{19} eV with the experimental measurements (AUGER experiment) at the thinning energies($\varepsilon_{th}= 10^{-7}$) for vertical EAS showers.



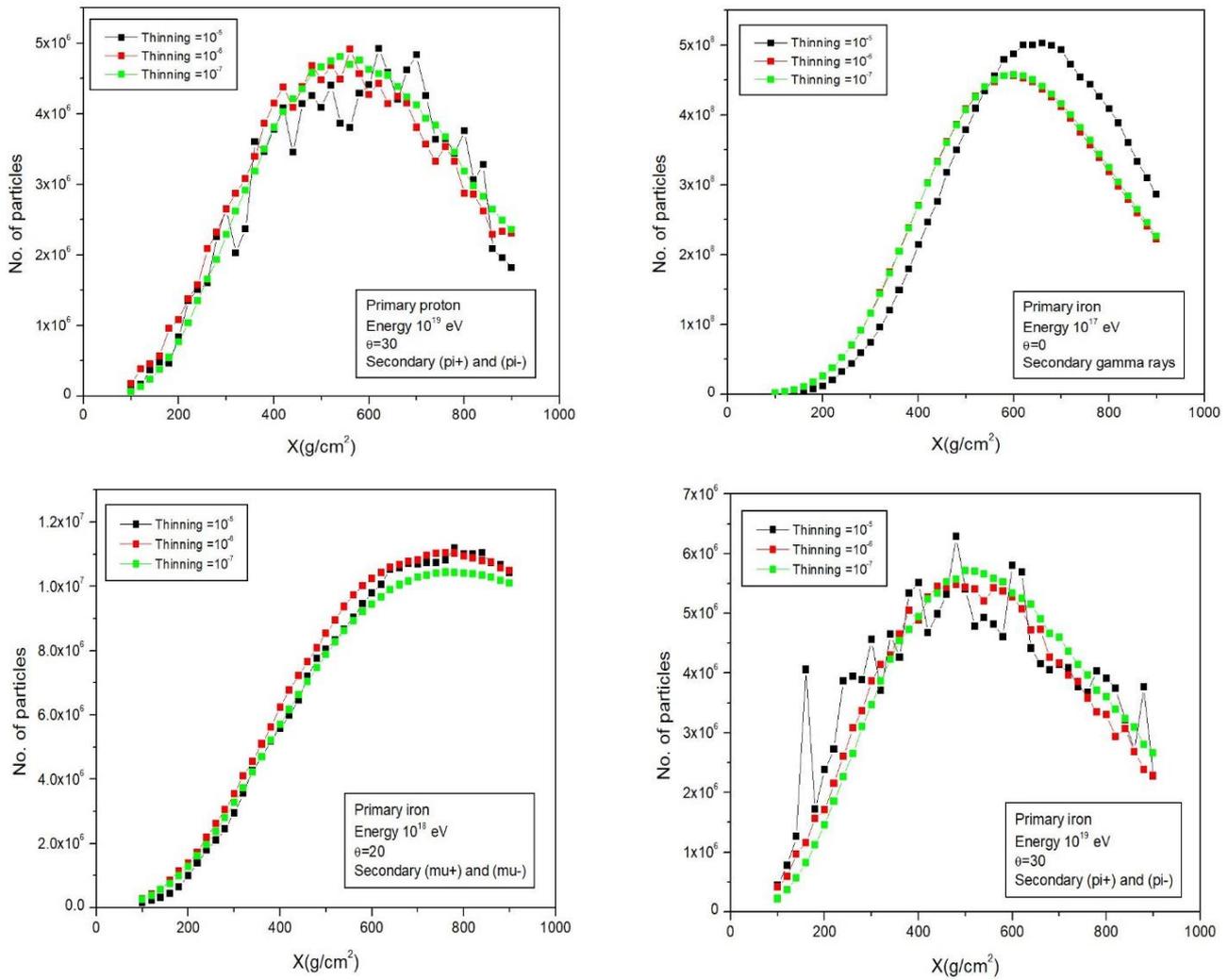


Figure 1. The thinning effect of longitudinal development for primary particles (proton and iron nuclei) at different zenith angles ($\theta = 0^\circ, 20^\circ$ and 30°) and different energies ($10^{17}, 10^{18}$ and 10^{19} eV).

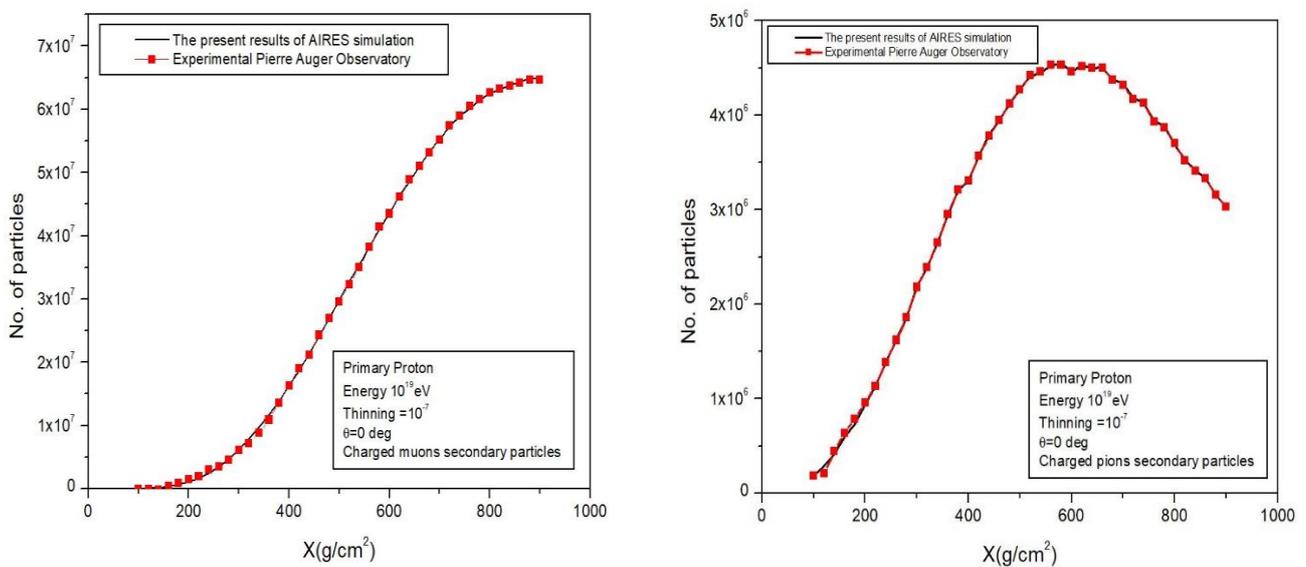


Figure 2. Comparison between the present results of longitudinal development simulation by the AIRES system with the experimental data obtained by Pierre Auger Observatory for primary proton at 10^{19} eV for secondary particles (charged muons and charged pions) for $\theta = 0^\circ$.

CONCLUSIONS

In the present work, the longitudinal development model of charged particles using the AIREs system for two primary particles (proton and iron nuclei) was simulated in different ultrahigh energies 10^{17} , 10^{18} and 10^{19} eV. Simulation longitudinal structure of the charged particle demonstrates the ability for distinguishing the primary cosmic ray particle and its energy. The statistical fluctuations of the longitudinal development of several secondary particles decrease with decreasing the thinning energy. An important feature of the present work is the creation of a library of longitudinal structure samples that can be used to analyze real EAS events that have been detected and registered in EAS arrays.

The introduced results using AIREs system are identified with Auger experimental data, proving that AIREs provides an environment suitable for studying high-energy cosmic rays. Therefore, charged particles reaching the Earth's surface have many effects on weather, human health and other effects.

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