On some aspects of Age Parameter associated with Extensive Air Showers having energy ranging from $\sim 10^{14}$eV to $\sim 10^{20}$eV

Julie Saikia [1], Pranayee Datta [2]
(1) Department of Physics, Pub Kamrup College, Baihata Chariali, Assam, India
(2) Department of Electronics Science, Gauhati University,Guwahati, Assam, India

Abstract

In this paper some important characteristics of age parameter(s) associated with air showers viz. (i) variation of s with primary energy E_p, (ii) variation of s with atmospheric depth beyond shower maximum, (iii) variation of s with zenith angle for different E_p. are studied on the basis of experimental observations of the North Bengal University, India; Gauhati University, Guwahati, India; Yakutsk, Russia etc. The observed characteristics are analysed with the help of the existing theoretical models. Results obtained are expected to throw some light on identification of the primary particle.

1. Introduction

Due to inconsistencies of the experimental results reported by different groups, a comparative study of the existing electron [2] lateral distribution functions (LDFs) of $E_p <\sim 10^{17} eV$ is necessary. It is necessary to study the LD of electron component with $E_p >\sim 10^{19}$ eV also on the basis of s. Such study was first carried out with the Gauhati University Air shower Array (GUASA) and it was concluded that Capdevielle LDF gives the best fit for the LD of electron component of showers having $E_p >\sim 10^{19}$eV [10]. It is also necessary to study important characteristics of s for these two region of E_p.

Hence the present work aims at the following aspects: To make a comparative study of different exiting LDFs on the basis of s for $E_p <\sim 10^{17} eV$, to study the important characteristics of s for giant air showers with $E_p >\sim 10^{19}$ eV. For the above studies, data of different air shower laboratories are used [2, 5, 8].

2. Method

For each of the existing LDFs, [2] by introducing different s, χ^2_{min} is found out. s is determined adopting the method developed by Idenden [6]. The original method is modified by introducing Capdevielle LDF.

The atmospheric depth beyond shower maximum (x_b) can be calculated

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from the experimentally obtained relation [10]. $x_b = \frac{dx}{ds}(s-1) = \frac{x_v}{A}(s-1)$. On the basis of cascade theory, $x_b = 1.5 x_v \sec\theta \left(\frac{s_{theo}-1}{s_{theo}}\right)$. The height of shower maximum H_m for a shower with zenith angle θ is given by

$$H_m = x_b \cos\theta \tag{1}$$

Thus, using particle component density, x_b and hence H_m can be calculated.

Fenyves [4] developed a model to determine the s for different primary particles of vertical shower and hence to identify the primary particle having energy E_p up-to 10^{16}eV. From Fenyves model s for different primary particles and for different E_p are calculated and compared with experimental s from GUASA data (fig 4).

3. Results

(χ^2_{min} - E_p) curves for different LDFs are shown in fig 1. Different characteristics of s are shown in figs 2, 3 & 4.

4. Discussion

The NKG as well as Capdevielle LDF are found to be the most suitable LDF for representing the LD of electrons for $E_p \sim 10^{15}$ eV - $\sim 10^{16}$ eV (fig 1). Capdevielle LDF is found to be the most suitable LDF for representing the LD of electrons for the showers having $E_p >\sim 10^{19}$ eV [10]. This may be explained as follows.

The basic difference between the LDF of NKG and Capdevielle LDF is that s associated with the NKG LDF is distance-dependent whereas that associated with the Capdevielle LDF is distance-independent. Since the maximum lateral spread of the shower particles for $10^{15}eV < E_p < 10^{16}eV$ is narrower ($\sim 100m$) compared to that ($\sim 2km$) with $E_p >\sim 10^{19}eV$, s for the former type of shower may be assumed to be almost constant over the whole shower disk and hence LD for $10^{15}eV < E_p < 10^{16}eV$ can be satisfactorily explained by the NKG LDF adopting a single s. On the other hand the maximum lateral spread is wider ($\sim 2km$) for $E_p >\sim 10^{19}eV$ and hence over this wide shower disk, s cannot be assumed to be constant. As a result the NKG LDF with a single s cannot explain the observed LD for this higher E_p but Capdevielle LDF having a single age parameter can.

s is found to be a decreasing function of E_p also (fig 2). Since for $s > 1$ increase in E_p indicates decrease in height of shower maximum, hence it is quite physical that, at an observation level, for old showers, s will decrease with increase in E_p or with increase in N_e for a small bin of θ. Similarly for $s < 1$ at the observation level physically s must decreases with increase in E_p or with increase in N_e for a small bin of θ [10]. Similar trends are found by other groups [1, 3, 9] for N_e in the range $10^4 - 10^8$.

Again $(x_b - s)$ curves for N_e in the range $4 \times 10^8 - 4 \times 10^9$ (fig 3) are found to be of similar trend to that for $N_e \sim 10^4 - \sim 10^5$ observed by NBU group [3]

The experimental data do not indicate a single primary composition for $E_p \sim 10^{15}$ eV-$\sim 10^{16}$ eV and also, it is not possible to consider shower age as a distinguishing parameter for identification of primary particles in this energy range (fig 4). Comparison with experimental data for $E_p >\sim 10^{19} eV$ shows that the experimental s values is in complete disagreement with the theory [10]. It is found that the composition is iron dominated [11] above 10^{17} eV and becomes proton dominated around 10^{19}eV. Again for $E_p > 5 \times 10^{19}$ eV, because of GZK cut off, primary cannot be proton. Following discussion indicates that photon is the most probable candidate for primary particle having $E_p >\sim 10^{19}$ eV.

The different observed characteristics of s for $E_p >\sim 10^{19}$ eV are found to be of similar nature to those for $E_p <\sim 10^{15} - \sim 10^{16}$ eV i.e. for $E_p >\sim 10^{19}$ eV showers are observed to have the usual characteristics for s. This may contradict the possibility of the primary particle to be proton or iron nuclei for showers with $E_p >\sim 10^{19}$ eV, because for such showers initiated by proton or iron nuclei there may be some change in the usual characteristics due to LPM effect. But for photon initiated air shower with $E_p >\sim 10^{19}$ eV, due to interaction of the high energy photon in the earth's magnetosphere [7], energy of the particles of the electron photon cascade as they enter the earth's atmosphere will be $\sim 10^{15} - 10^{16}$eV or less and hence LPM effect will not be effective in case of photon-initiated showers having $E_p >\sim 10^{19}$ eV. Thus, for $E_p >\sim 10^{19}$ eV air showers having usual characteristics of s may be photon-initiated. Encouraging results may be expected as enormous data for $E_p >\sim 10^{19}$ eV will be accumulated in the next few years from the Auger observatory.

5. Conclusion

NKG as well as Capdevielle LDF are found to be the most suitable LDF for representing the LD of electrons for $E_p \sim 10^{15} - \sim 10^{16} eV$. Different characteristics of s for $E_p >\sim 10^{19} eV$ are similar to those of non-LPM shower. Height of shower maximum can be estimated from particle (electron) density data. The photon may be the most probable candidate for primary particle for $E_p >\sim 10^{19} eV$.

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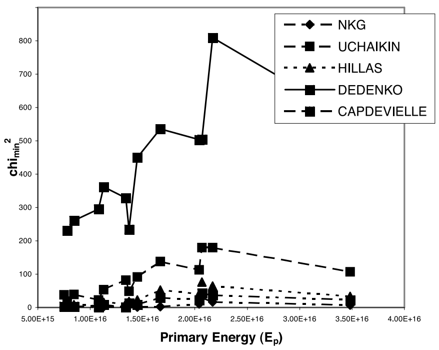

Fig. 1. COMPARISION of DIFFERENT LDFs (For GUASA data)

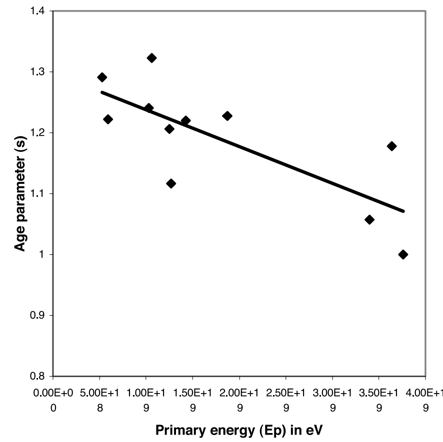

Fig. 2. Theta = 22^6–29^6 (For Volcano Ranch data)

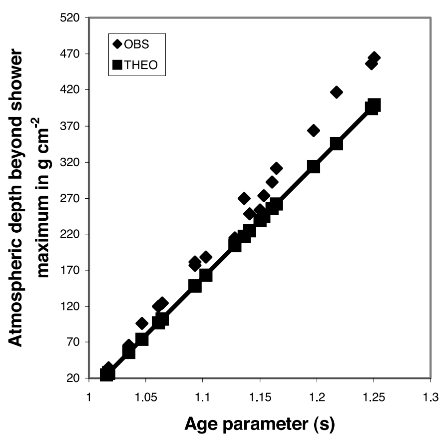

Fig. 3. For $N_e = 4^*10^8 - 4^*10^9$

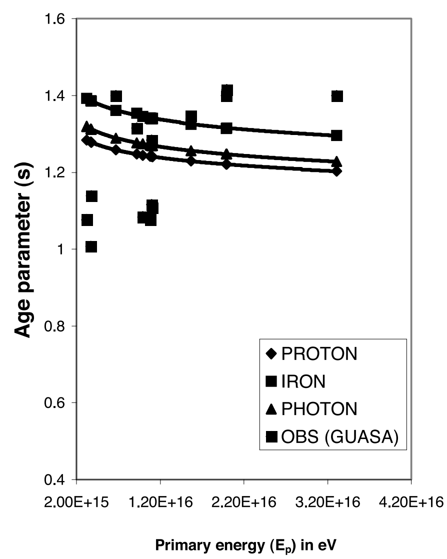

Fig. 4. (s - E_p) curve (For GUASA data)

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