Considerations about the lateral distribution of electrons in p\textsuperscript{+} proton-initiated air showers at energies below 10\textsuperscript{15} eV

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Abstract

We present some parametrizations for the lateral distribution of electrons in proton-initiated air showers, obtained from simulations performed with the CORSIKA package, at energies below 10\textsuperscript{15} eV. Instead of parametrizing the lateral distribution with the traditional NKG function, we propose a different expression, which recovers some aspects of the original Nishimura-Kamata function, deduced from electromagnetic cascade theory. The parametrization we propose gives better statistical agreement to the simulated events than NKG function does. We present some results regarding the behavior of the age parameter and its relation to the lateral distribution of electrons.

1 Introduction

The lateral distribution of electrons in extensive air showers (EAS) is widely used in event reconstruction, aiming to obtain information about the primary particle.

Usually, the density of electrons is described by the Nishimura-Kamata-Greisen (NKG) structure function. This function was introduced by K. Greisen in 1956 [3], as an adaptation of the analytical expression obtained by J. Nishimura and K. Kamata [4].

Some authors point out some disagreements between experimental data from hadron initiated showers and the NKG function.

In this work, we intend to show that a better parametrization for simulated events can be achieved, if we use a similar formula, which is given below. The objective of this work is the experimental aspect of the reconstruction of EAS showing a more appropriated expression [1].

An important feature of the NKG expression is the definition of the so-called age parameter, which should account for the shower development, both in longitudinal aspects and in the lateral distribution of electrons. But formulas from electromagnetic cascade theory could fail to reproduce the continuous energy transfer from hadronic to electromagnetic component, which occurs in hadron-initiated dEAS.

Hence, a structure function is proposed, in order to analyse the behaviour of age parameter and the shape of the density of electrons in proton-initiated air shower at energies below 10\textsuperscript{15} eV, at different depths of injection.

The proposed function has the form:

\[ F\left(\frac{r}{r_o}\right) = C r^{A-2} \left[1 + \frac{r}{r_o}\right]^{-B} \]  

(1)

where \(r_o = 25\text{m}\), is the radia length scale; \(A\) and \(B\), are parameter sleft to adjust independently, and \(C\) is a normalization factor.

The normalization factor is defined by:

\[ C = \frac{\Gamma(B)}{2\pi r_o^A \Gamma(A) \Gamma(B-A)} \]  

(2)

The density of electrons is given by expression:

\[ \rho = \frac{N_e}{r_o^3} F\left(\frac{r}{r_o}\right) \]  

(3)

where \(N_e\) is the number of electrons.

The main difference between the proposed function and the NKG function is related to radial scale factor. The NKG function uses the Molière radius as scale \(r_m = 78\text{m}\), expected from electromagnetic interactions, whereas the proposed function uses...
$r_0 = 25$, $m$, which seems to be more suitable to describe a mixing of hadronic and electromagnetic scales.

2 Simulations and Parametrizations of EAS

The Monte Carlo simulation has been performed using the CORSIKA (COsmic Ray Simulations for KAscade) code [5] to calculate the lateral distribution in EAS initiated by proton at different depths. The electromagnetic interactions were treated with EGS4 [6] and the hadronic interaction with energy under 80 GeV in lab system, were treated with GHEISHA package [2] and above that limit, with VENUS model [7]. We shall show that the statistical meaning is better that the methods of traditional analysis, thus, we hope to have a good resolution of the primary energy.

The EAS were initiated by vertical primary protons injected into the atmosphere with 1.0, 2.15, 4.69x10^{13} eV (90 events each), 1.0, 2.15, 4.69x10^{14} eV (90 events each) and 1.0, 2.15x10^{15} eV (90 events each) of energy. The threshold energy of hadrons, muons, photons and electrons was 0.3 GeV, 0.3 GeV, 3.0 MeV and 3.0 MeV, respectively. Secondary particles were observed at level $\chi = 1000$, $g \text{ cm}^{-2}$.

For all energy values, the primary proton was injected at 5, 25, 125, 225, 325. and 425. $g \text{ cm}^{-2}$, in order to take showers in different stages of development at detection level. The showers were simulated without any constraint in the depth of the first interaction.

Figure (2) shows the behaviour of electron density in some events simulated in this work, for different depths of injection of the primary. This figure illustrates the likeness between the forms of lateral distributions at different depths, that may result in ambiguities in event reconstruction.

3 Fits

The proposed function (1) was adjusted to the simulated electron density, for each energy and depth value. The steps of this procedure were:

**First** - The proposed function (1) was fitted to the electron density, with $A$, $B$, $C$ and $r_0$ parameters varying freely. With this operation, we verify that $r_0$ may assume a value fixed in $r_0 = 25$, $m$.

**Second** - Once the radial scale factor was fixed, the proposed function was fitted again to the density of electrons. Now $A$, $B$ and $C$ could vary freely.

**Third** - In this step was fixed the mean of the values of $A$ parameter, obtained to different $r_0$. These different values of $r_0$ were defined in the first step. The proposed function was fitted again in order to get the values of $B$ and $C$ parameters.

**Fourth** - Fixed the value of $A$ parameter, we take the value of $B$ parameter (last step) to calculate the $C$ parameter (normalization factor), given by equation (1). Fitting the density of electrons again, with all parameters fixed, we will obtain the number of electrons.

The figure (3) shows a comparison between the proposed function and the NKG function to density of electrons from primary energy $1.0 \times 10^{14}$ eV, in the case where the primary proton was injected at $X_{inv} = 5s$ $g \text{ cm}^{-2}$.

4 Conclusions

We made attempts to adequate a proposed lateral structure function to the radial distribution of electrons in simulated EAS, in the range $10^{13}$ eV to $10^{15}$ eV, instead of the traditional NKG function. Fixing properly the radial scale factor, the proposed function gives a (statistically) better agreement with simulated events than NKG function does.

The best value we find for the radial scale factor is $r_0 = 25$, $m$. The value of parameter $A$, which is equivalent to the age parameter, doesn’t change significantly (figure 2), whereas the $s$ parameter from NKG function would clearly decrease in the cases we studied (figure 4).

References

Figure 1: Density of electrons for different depths of injection $\chi_{\text{inj}}$ of the primary, with energy $E=2.15 \times 10^{14}$ eV.

Figure 2: Behaviour of the A parameter in different depths of injection $\chi_{\text{inj}}$, for energies near to $E=\times 10^{14}$ eV.
Figure 3: Density of electrons for primary energy $E=1.0 \times 10^{14}$ eV, with primary proton injected at $\chi^{\text{proj}} = 5\sigma$ g cm$^{-2}$. This figure shows a comparison between the fits of the proposed function and the NKG function to simulated events.

Figure 4: Behaviour of the $s$ parameter in different depths of injection $\chi^{\text{proj}}$, for energies near to $E=10^{14}$ eV.