Considerations about the lateral distribution of electrons in p oton-initiated air showers at energies below 10^{15} eV

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Abstract

We present some parametrization s for the latera l distribution of electrons in proton-initiate d air showers, obtained from simulations performed with the CORSIKA package, at energies below 10^{15} eV. Instead of parametrizin g the latera l distribuition with the traditiona l NKG function, we propose a different expression, which recovers some aspects of the origina l Nishimura-Kamata function, deduced from electromagnetic cascade theory. The parametrizatio n we propose gives better statistica l agreement to the simulated events than NKG function does. We present some results regardin g the behavior of the age paramete r and its relatio n to the latera l distribution of electrons.

1 Introduction

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

Usually, the density of electrons is describe d by the Nishimura-Kamata-Greise n (**NKG**) structur e function. This function was introduce d by K. Greisen in 1956 [3], as an adaptatio n of the analytica l expression obtained by J. Nishimura and K. Kamata [4].

Some author s point out some disagreements between experimental data from hadro n initiated showers and the NKG function.

In this work, we intend to show that a better parametrizatio n 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 reconstructio n of EAS showing a more appropiated expression [1],

An important feature of the NKG expression is the definitio n of the so-called age paramete r , which should account for the shower development, both in longitudinal aspects and in the latera l distribution of electrons. But formulas from electromagneti c cascade theory could fail to reproduc e the continuous energy transfer from hadroni c to electromagneti c component, which occurs in hadron-initiate d EAS.

Hence, a structur e function is proposed, in order to analyse the behaviour of age paramete r and the shap e of the density of electrons in proton-initiate d air shower at energies below 10^{15} **eV**, at different depths of injection.

The propose d function has the form:

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

where $r_\circ = 25.$ **m**, is the radia l scal e factor; A and B, ar e parameter s left to adjust independently, and C is a normalization factor.

The normalization factor is define d by:

$$C = \frac{\Gamma(B)}{2\pi r_\circ^{A-2}\Gamma(A)\Gamma(B-A)} \tag{2}$$

The density of electrons is given by expression:

$$\rho = \frac{N_e}{r_\circ^2} F\left(\frac{r}{r_\circ}\right) \tag{3}$$

where N_e is the number of electrons.

The main difference between the propose d function and the NKG function is relate d to radia l scale factor. The NKG function uses the Molière radius as scale $r_m = 78.$ **m**, expected from electromagnetic interactions, wherea s the propose d function uses

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$r_\circ = 25.$ **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 of 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, 4.69×10^{13} **eV** (90 events each), 1.0, 2.15, 4.69×10^{14} **eV** (90 events each) and 1.0, 2.15×10^{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 $\chi = 1030.$ **g cm**$^{-2}$.

For all energy values, the primary proton was injected at 5., 25., 125., 225., 325. and 425. **g 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 $r_\circ$ parameters varying freely. With this operation, we verify that $r_\circ$ may assume a value fixed in $r_\circ = 25.$ **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 differents $r_\circ$. These different values of $r_\circ$ 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 1.0×10^{14} **eV**, in the case where the primary proton was injected at $X_{inj} = 5.$ **g cm**$^{-2}$.

4 Conclusions

We made atempts 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 $r_\circ = 25.$ **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

[1] - Chinellato, J.A., 1996, Int. Bericht 51.02.03-Z13D, Forschungszentrum, Karlsruhe.
[2] - Fesefeldt, H., 1985, RWTH Aachem Report PITHA 85, 2.

[3] - Greisen, K., 1956, Prog. Cosmic Ray Phys. 3, 1.
[4] - Kamata, K., Nishimura, J., 1998, Suppl. Prog. Theor. Phys. 6, 93.
[5] - Knapp, J., Heck, D., 1997, Forschungszentrum Karlsruhe GmbH.
[6] - Nelson, W.R., et al, 1985, SLAC Report 265.
[7] - Werner, K., 1993, Physics Reports 87, 232.

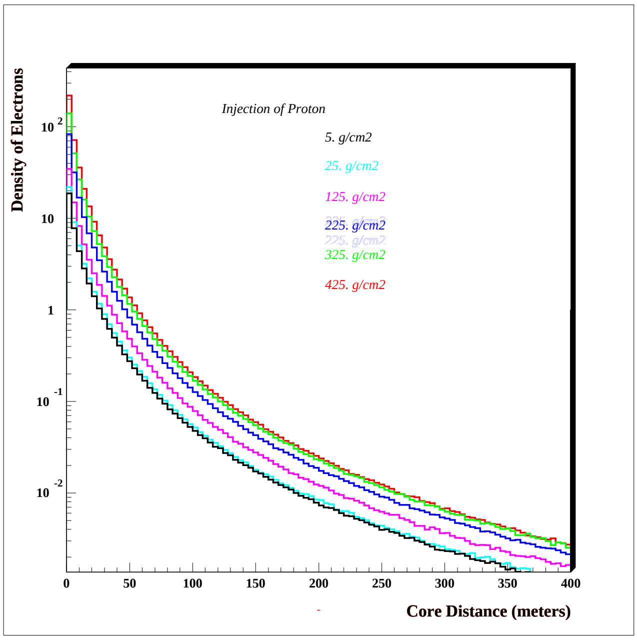

Figure 1: Density of electrons for different depths of injection χ_{inj} of the primary, with energy E=2.15$\times10^{14}$ **eV**.

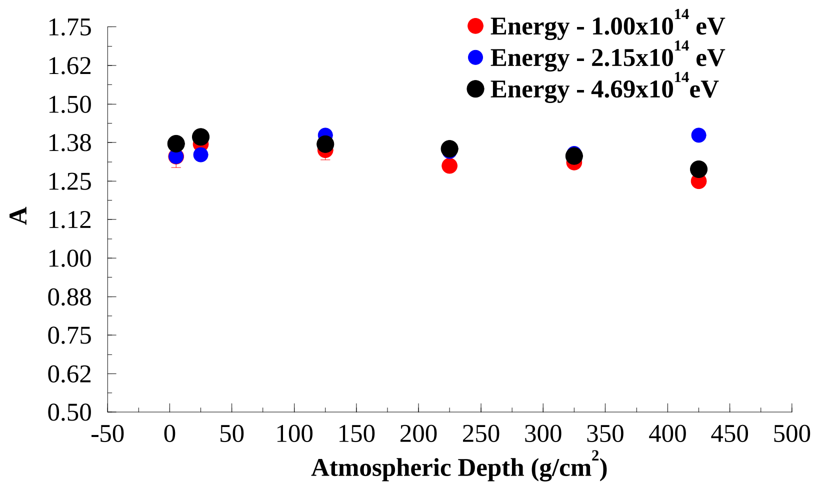

Figure 2: Behaviour of the A parameter in different depths of injection χ_{inj}, for energies near to E=$\times10^{14}$ **eV**.

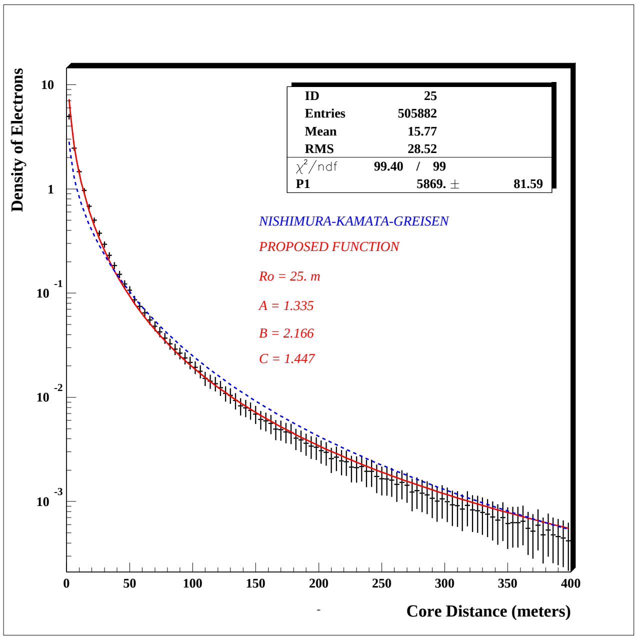

Figure 3: Density of electrons for primary energy E=1.0 $\times\, 10^{14}$ **eV**, with primary proton injected at $\chi_{inj} = 5$. **g cm**$^{-2}$. This figure shows a comparison between the fits of the proposed function and the NKG function to simulated events.

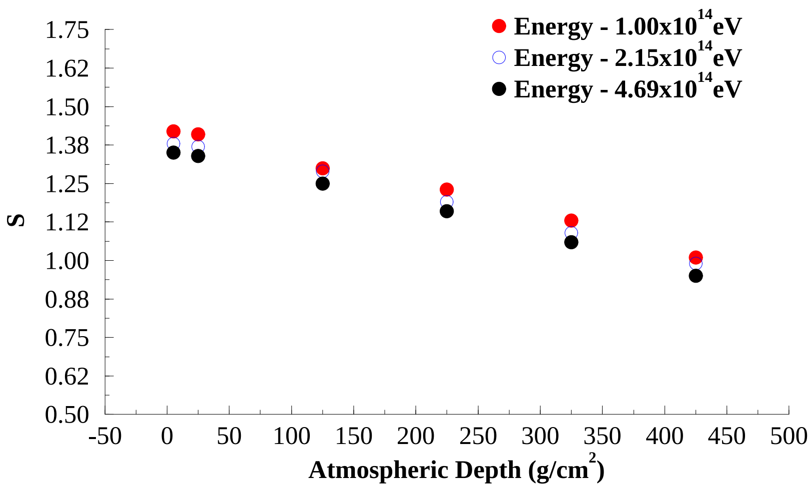

Figure 4: Behaviour of the s parameter in different depths of injection χ_{inj}, for energies near to E=$\times 10^{14}$ **eV**.