A new cosmic-ray composition sensitive observable in air shower studies

Rajat K. Dey*
Department of Physics, University of North Bengal, Siliguri, West Bengal, INDIA 734013

Introduction

The lateral density distribution (LDD) of electrons in an average extensive air shower (EAS) is generally assumed to be symmetrical in the shower front plane. For vertically incident showers, the equi-density contours in the LDD are circles in the observed plane. Hence, the lateral density function (LDF) that describes the LDD of EAS particles for vertical showers must be polar symmetric while for inclined EASs some sort of polar averaged densities would be appropriate. For nearly inclined showers with $\Theta \geq 18^0$, the equi-density contours are approximated to ellipses [1]. A linear gap or shift between the center of equi-density ellipses and the EAS core will be developed whose magnitude may determine the attenuation power of different types of EAS particles in the atmosphere for a given incidence and also carries some primary mass signature.

Cylinder shower and determination of the shift

One of the common longitudinal EAS profiles is the cylinder type. In Fig. 1, we have depicted such a profile of an inclined EAS that hits the ground surface. The geometric correction is done through the projection of the horizontal elliptic surface to a circle.

From the Fig. 1, we can write the following:

$$AC^2 = r^2 - y^2, r^2 = x^2cos^2\Theta + y^2, \quad (1)$$

$$AB^2 = x^2sin^2\Theta. \quad (2)$$

From the Fig. 1, it is seen that the observed and shower planes intersect each other at y_R without attenuation. Therefore, we have now,

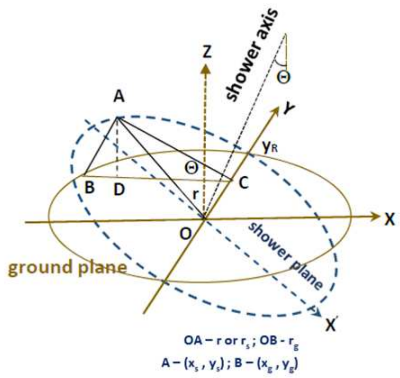

FIG. 1: Cylinder shower.

$$x^2cos^2\Theta + y^2 = y_R^2. \quad (3)$$

If the translation which is experienced by the elliptic center has a magnitude x_C, then eqn. (3) takes the form as under

$$(x - x_C)^2cos^2\Theta + y^2 = b^2, \quad (4)$$

$$x_C^2cos^2\Theta + y_R^2 = b^2. \quad (5)$$

Inserting eqn. (5) in (4), we get as

$$x^2 - 2xx_Ccos^2\Theta + y^2 = y_R^2. \quad (6)$$

We introduce a *characteristic function* (CF) for the LDD as follows,

$$\rho(r) \simeq c.e^{-\alpha(\frac{r}{r_0})^\kappa}. \quad (7)$$

*Electronic address: rkdey2007phy@rediffmail.com

Attenuation effects in the space between A and B reduces the density of EAS particles which is of course very marginal but would follow an exponential fall by a factor $e^{-(X-X_g)/\Lambda}$ [2].

$$\rho_g(r_g) = cos\Theta.\rho_n(r).e^{-\frac{\Delta X}{\Lambda}}. \qquad (8)$$

By simple unit conversion it follows,

$$\rho_g(r_g) = cos\Theta.\rho_n.(r)e^{-\eta.AB}, \qquad (9)$$

$$\rho_g(r_g) = cos\Theta.\rho_n(r).e^{\eta x sin\Theta}. \qquad (10)$$

Putting $x = 0$ in eqn. (3), we get $y = y_R$, then eqn. (10) becomes

$$\rho_g(r_g)_{x=0,y=y_R} = cos\Theta.\rho_n(y_R). \qquad (11)$$

The eqn. (11) will now transform into the following form

$$\rho_g(r_g or(x,y)) = cos\Theta.\rho_n(y_R). \qquad (12)$$

By inserting the eqn. (12) in (10) we obtain one of the important equations dealing attenuation effects on shower particle density which is given by

$$\rho_n(y_R) = e^{\eta x sin\Theta}.\rho_n(r). \qquad (13)$$

We have already introduced the CF for the LDD, the above equation can be written now as

$$e^{-\alpha(\frac{y_R}{r_0})^{\kappa}} = e^{\eta x sin\Theta}.e^{-\alpha(\frac{r}{r_0})^{\kappa}}. \qquad (14)$$

After simplification, and comparing with (4), we have

$$x_C \cong \frac{y_R^2\delta}{cos\Theta}, \qquad (15)$$

$$x_C = y_R^{2-\kappa} r_0^{\kappa}.sin\Theta sec^2\Theta.\eta(\alpha\kappa)^{-1}. \qquad (16)$$

For a given zenith angle and a particular set of values for all remaining quantities in the eqn. (16), the gap distance appears to be positive (i.e. $x_C > 0$).

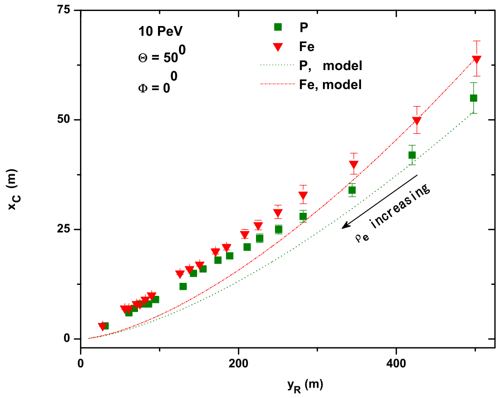

FIG. 2: Variation of the linear gap (x_C) with y_R. Dotted line shows predicted values

Results

In the Fig. 2, these gap distances are shown with their respective y_R values for P and Fe initiated showers.

Conclusion

In the work a modeling of the atmospheric attenuation effect on the LDD of electrons is made. The new parameter x_C obtained from the analysis possesses a clear primary cosmic-ray mass dependence.

Acknowledgments

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References

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