# Extracting an asymmetry parameter in the lateral distribution of electrons in EAS

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## Introduction

The lateral density distributions (LDD) of inclined cosmic-ray (CR) air showers are asymmetric. The iso-density contours of an EAS are of increasing eccentric ellipses with shower zeniths. These asymmetries introduce a significant shift of the shower core, which is quantitatively expressed by a linear shift (LS) between the shower core and the center of the modified density pattern consisting of several equi-density ellipses [1]. A polar angle ($\beta_g$) dependent modified elliptic lateral density function (E-LDF) of the LDD has been derived analytically by considering the effect of attenuation of EAS electrons in the atmosphere. The LS shows sensitivity to the CR mass composition.

## Conical EAS profile and determination of the shift

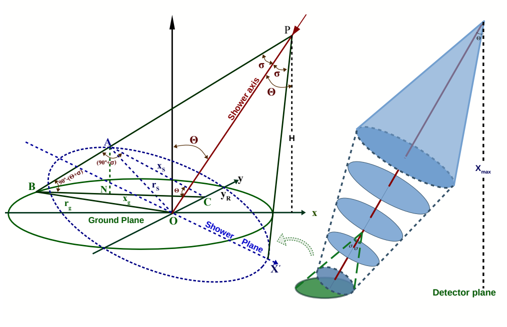


FIG. 1: Conical shower profile

In Fig.1, the evolution of a conical shower profile of an inclined EAS is shown. The geometric correction is done through the projection of the horizontal elliptic surface to a circle.

$$\rho_s(r_s) = \rho_g(r_g)/\cos\Theta \qquad (1)$$

An exponential fall of the density of the shower electrons results from the EAS attenuation with a factor $e^{-\eta \cdot AB}$, where $\eta$ is the attenuation length. Electron density in the ground plane would be

$$\rho_g(r_g) = \cos\Theta \cdot \rho_s(r_s) \cdot e^{-\eta \cdot AB} \qquad (2)$$

Finally the linear shift parameter is given by,

$$x_C = y_R^{2-\kappa} \cdot 6813 r_0^{\kappa} \eta (\alpha\kappa)^{-1} \tan\Theta \cos\sigma \; [\cos(\Theta+\sigma) \cdot (H - r_s \sin\Theta)]^{-1} \qquad (3)$$

The modified length of semi-minor axis of an equi-density ellipse is,

$$y_R = -2A_f r_g \cos\beta_g \tan\Theta \frac{\cos^2(\Theta+\sigma)}{\cos^2\sigma} + r_g\sqrt{1-\cos^2\beta_g \sin^2(\Theta+\sigma)} \qquad (4)$$

The ELDF obtained from the NKG type of LDF after the substitution for $r_s$ by $y_R$,

$$\rho(r_g, \beta_g) = \cos\Theta \cdot C(s_\perp) N_e \; (y_R/r_0)^{s_\perp - 2}(1 + y_R/r_0)^{s_\perp - 4.5} \qquad (5)$$

A characteristic function (CF) for the LDD is proposed as follows,

$$\rho(r_s) \simeq c \cdot e^{-\alpha(\frac{r_s}{r_0})^{\kappa}} \qquad (6)$$

## Results and discussion

The MC simulation code *CORSIKA* of version 7.69 with the hadronic interaction models QGSJet-01 and UrQMD is used.

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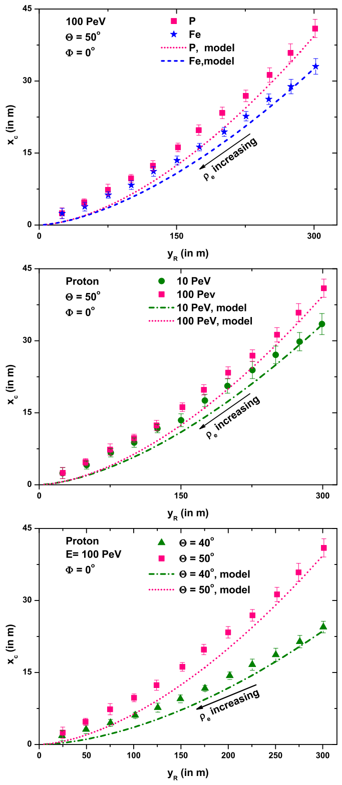


FIG. 2: $x_C$ versus $y_R$ variation. Predicted values for $x_C$ are shown by dotted and dashed lines.

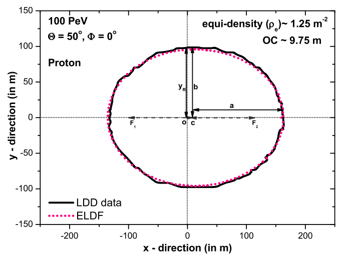


FIG. 3: LS from the equi-density ellipse.

The LS parameter exhibits sensitivity to P- and Fe-initiated showers significantly for low-end values of $\rho_e$. LS is found to increase with energy of CRs. The elongation of the iso-density curve with increasing $\Theta$ is evident from the values of LS for different zenith angles. The model predicted values for LS are shown by the dotted and short dashed lines and are in good agreement with the simulated data. In Fig.3, the centre of the equi-density ellipse experience a translation from $O$ to $C$ ($\overline{OC} \sim 9.75\ m$) solely due to attenuation of EAS electrons. On the other hand, the model predicted LS is about 6.35 m, evaluated using the Eq.3.

Application of ELDF has been incarnated in terms of the Local Age Parameter (LAP). The analytical expression for the LAP [2], using the ELDF between two adjacent radial distances $[r_i, r_j]$ is:

$$s_{ij} = \frac{ln(F_{ij} X_{ij}^2 Y_{ij}^{4.5})}{ln(X_{ij} Y_{ij})} \tag{7}$$

Here, $F_{ij} = \rho(y_R(i))/\rho(y_R(j))$, $X_{ij} = y_R(i)/y_R(j)$, $Y_{ij} = (\frac{y_R(i)}{r_0} + 1)/(\frac{y_R(j)}{r_0} + 1)$ and $r_0$ is the molière radius obtained from the best fit value of LDD by CF.

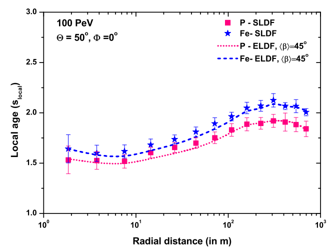


FIG. 4: Variation of the LAP with radial distance.

## Conclusion

In this work a modeling of the atmospheric attenuation effect on the LDD of electrons is made considering the conical shower profile. The magnitude of the LS which determines the attenuation power of shower particles for a non-vertical EAS, possesses a clear primary cosmic ray mass dependence. The ELDF has been used to the simulated electron densities to estimate the LAP, which manifests different radial variation.

## References

[1] J. M. C. Montanus *Exp Astron.* **41** 159-184 (2016)

[2] R. K. Dey *et al.* *J. Phys. G:Nucl. Part. Phys.* **39** 085201 (2012).