Modified lateral density function of muons in EAS

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Introduction

The paper aims to investigate the asymmetry of muon lateral density distribution (LDD) due to attenuation through atmosphere without considering the effect of Earth's geomagnetic field. Usually, NKG type symmetric lateral density function (S-LDF) is used to estimate LDD of EAS particles. These LDFs cannot describe asymmetric LDDs accurately. Based on the Conical shower model, a polar angle (β_g) dependent modified Elliptic-LDF has been derived analytically by considering the geometric correction and the effect of attenuation of EAS muons in the atmosphere [1]. The polar asymmetry of the iso-density contours introduces a significant shift of the EAS core, which is incorporated in the ELDF, is quantitatively expressed as a gap length (GL) parameter [2] between the EAS core and the center of the modified density pattern consisting of several equi-density ellipses.

Conical EAS profile and determination of the GL

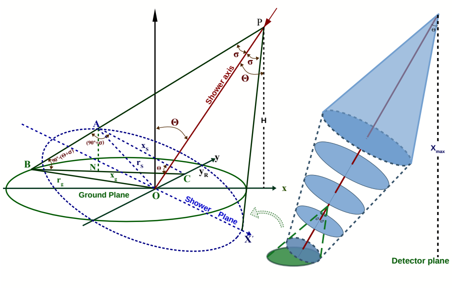

FIG. 1: Conical shower profile

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 the shower plane.

$$\rho_s(r_s) = \rho_g(r_g)/\cos\Theta \tag{1}$$

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

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

Finally the gap length parameter is given by,

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

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

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

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

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

A toy function (TF) for the LDD is proposed as follows,

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

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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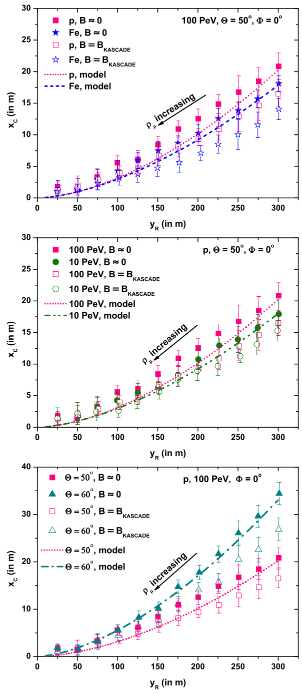

FIG. 2: x_C versus y_R variation. Predicted values for x_C are shown by dotted and dashed lines.

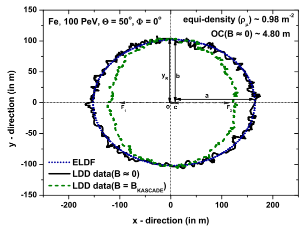

FIG. 3: GL from the equi-density ellipse.

For low-end values of ρ_μ, the GL parameter is more sensitive to p and Fe initiated showers (Fig. 2). The value of x_C is found to increase with CR energy. The higher values of GL with increasing Θ represents the elongation of the major axis of elliptic iso-density curves with Θ. In Fig. 3, the centre of the equi-density ellipse corresponding to $B \approx 0$, experience a translation from O to C ($\overline{OC} \sim 4.80\ m$) solely due to attenuation of EAS muons. On the other hand, the model predicted GL is about 4.29 m, evaluated using the Eq. 3. The inner dashed line of the Fig. 3 shows the equi-density curve with $B = B_{KASCADE}$. The ELDF has been used to fit the simulated μ-LDD data (Fig. 4). Using the value of the fitted parameters, $s_\perp$ and N_μ, the ELDF predicted polar density distribution is in good agreement with the simulated data (unlike the NKG type S-LDF) in Fig. 5.

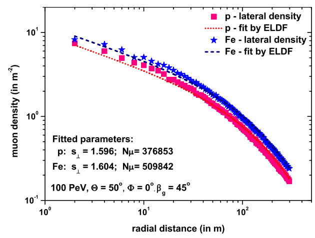

FIG. 4: ELDF fit of muon lateral density.

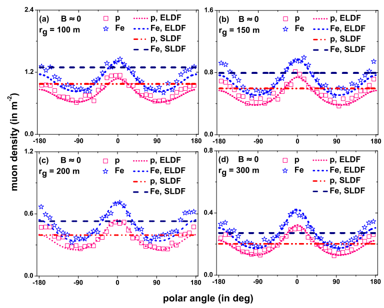

FIG. 5: Polar density distributions for four different radial distances (r_g).

Conclusion

An amended ELDF, based on conical shower model, is employed to describe the asymmetric μ-LDDs. The magnitude of GL determines the attenuation power of muons for non-vertical EASs. The effect of the Earth's geomagnetic field on the motion of the muons is so important that it must be taken into account in proposing an accurate ELDF for it. The work is in progress.

References

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

[2] R. K. Dey *et al. Ind. J. Phys.* **91** (4) (2017).