Mass composition of cosmic rays from slope parameters of lateral density distributions of muons in EAS

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

Introduction

The analytical treatments in obtaining the lateral distribution of Extensive Air Shower (EAS) muons in the cascade theory cannot be applied universally in all situations. Limitations of these analytical treatments result from several simplifications or approximations adopted in their treatment. A Monte Carlo (MC) calculation of the lateral distribution of muons can of course avoid all these limitations, and is in principle more accurate, even if it has normal dependencies upon characteristics of hadronic interaction models adopted in the simulation. A more judicious estimation of slope parameters has been made through local age parameter (LAP) and segmented slope parameter (SSP) in the work. Using KASCADE data freely available from KCDC data shop, we have studied the details of the characteristics of the LAP and SSP in connection with muons.

Slope parameters: LAP and SSP

Several air shower groups have proposed mathematical expressions empirically to describe the lateral distribution of the muons from the EAS core, in analogy to the lateral density functions (LDF) for electrons. These were basically constructed either empirically or borrowed from the electromagnetic cascade theory or from some modified LDFs that were tuned nicely to observed data. Across the *knee*, the NKG type function (eqn. 1), used by several EAS experiments for describing their data, has been chosen here also for the parametrization to the lateral distribution of muons for defining LAP, $s_{local}(r)$ [1].

*Electronic address: rkdey2007phy@rediffmail.com

We have given the following analytical expression for the LAP and SSP, using some suitable LDF between two adjacent points $[\mathrm{x_i}, \mathrm{x_j}]$:

$$a_{\text{local}}(i,j) = \frac{\ln(F_{ij} X_{ij}^{\alpha_1} Y_{ij}^{\alpha_2})}{\ln(X_{ij} Y_{ij})} \quad (1)$$

Where, $F_{ij} = f(r_i)/f(r_j)$, $X_{ij}{=}r_i/r_j$, and $Y_{ij}{=}(x_i{+}1)/(x_j{+}1)$.

For estimating LAP for lateral density distribution (LDD) of muons, the well-known NKG type LDF is exploited. For estimating the SSP from LDDs of muons, the so called Greisen type LDF is being used.

For the NKG-type LDF, we have used $\alpha_1 = 2$ and $\alpha_2 = 4.5$ in the eqn. 1. $\alpha_1 = 0$ and $\alpha_2 = 2.5$ are used while the Greisen function is taken. Here the denominator in the eqn. 1 is also modified by $X_{ji} = X_{ij}^{-1}$ and $Y_{ij} = 1$.

Results and discussions

To compute LAP for showers, the LDF of muons followed from the eqn. 1 is used. The radial variation of LAP follows a curve that is similar to an inverted bell-shape pattern. This pattern is almost independent to EAS initiating primary particle, its energy and level of observation respectively. The inverted bell-shape curve gives a lowest point at around $\approx$ 44 m. This is shown in the top of Fig. 1. Since EAS measurements are subjected to large fluctuations, instead of LAP at a particular radial distance, we consider for each event a mean minimum LAP (s_{min}(mean)); the average of 5 LAP values estimated over several small distance bands (r_i, r_j) across the minimum point. Such average minimum LAPs are shown in the top of Fig. 2. Some of these studies with simulated data are compared to variations obtained from KASCADE density data obtained from the KCDC [2].

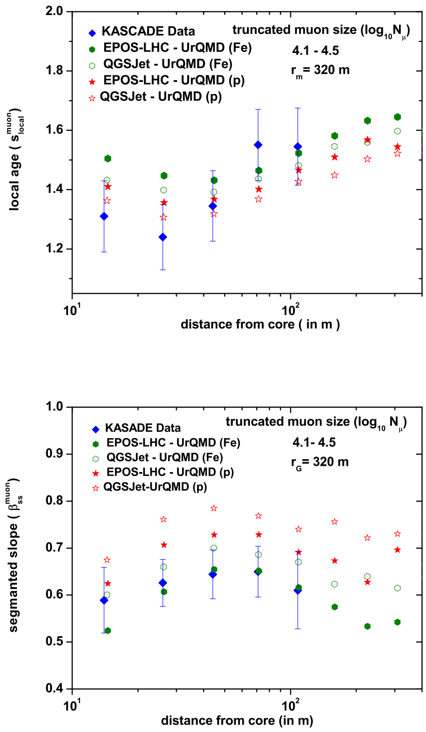

FIG. 1: Top: The radial dependence of the LAP parameter. The NKG type LDF is used; Bottom: Radial dependence of the SSP. Here, the Greisen type LDF is used.

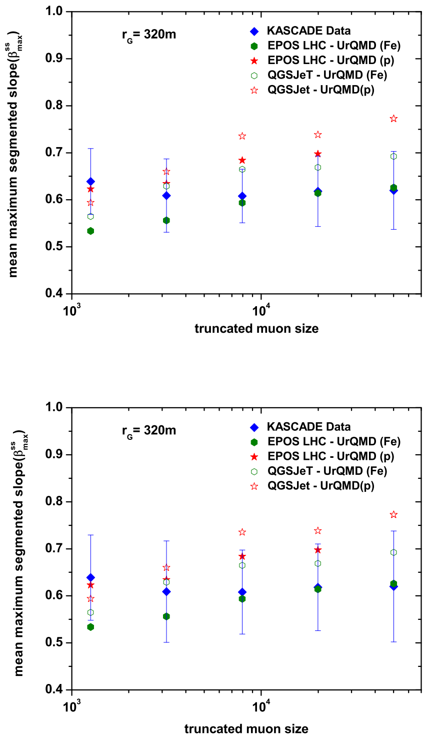

FIG. 2: Top: Variation of mean minimum LAP with truncated muon size. Bottom: Variation of mean maximum SSP with truncated muon size.

For SSPs ($\beta_{local}(r)$) corresponding to LDD of muons, we have used well-known Greisen type function. The radial variation of SSP exhibits a bell-shape pattern with a highest point at around $\approx$ 71 m. Such a variation is shown in the bottom of Fig. 1. Here again, we compute some sort of mean maximum SSP β_{min}(mean) by taking average of about 5 SSP values around the highest point. These mean maximum SSP values are plotted against truncated muon size, and is given in the bottom of Fig. 2.

Conclusions

The behavior of LAP with core distance shows some sort of scaling feature of the lateral distribution of muons. Similar, but some opposite trend of scaling nature is also visible in terms of the SSP. The mean minimum LAP and the maximum SSP clearly show sensitivity to CR mass composition.

Acknowledgments

The author thanks the SERB, DST for financial support under the Grant no. EMR/2015/001390.

References

[1] K Greisen, Progress in Cosmic Ray Physics, Vol.III, Amsterdam, NH Publishing Co 1956; H S Snyder, Phys. Rev. 76, 1563 (1989).

[2] A. Haungs *et al*, *European Phys.J. C*, 78:741 (2018).