A new CR mass composition sensitive EAS observable

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Introduction

The paper aims to show that the lateral shower age/local age (s) can be estimated employing a newly defined parameter (d_{r_1,r_2}) using the Monte Carlo (MC) simulation. Usually, the lateral density distribution (LDD) of EAS particles is described by the NKG-like distribution function $f(x)$ [1], where $x = r/r_m$, and the local age (LAP) for two neighboring points, i and j, can be expressed as

$$s_{local}(i,j) = \frac{ln(F_{ij} X_{ij}^2 Y_{ij}^{4.5})}{ln(X_{ij} Y_{ij})} \quad (1)$$

where, $F_{ij} = f(r_i)/f(r_j)$, $X_{ij} = r_i/r_j$, $Y_{ij} = (x_i + 1)/(x_j + 1)$ and r_m is the Moliere radius. The local age exhibits some short of scaling feature irrespective of primary particle and energy [1]. It has been observed from the study of s_{local} vs r variation (Fig. 1a) that, s_{local} manifests a local minimum and maximum at radial distances $r_1 \simeq 45$ m and $r_2 \simeq 310$ m from shower core respectively. Considering the generic feature of s_{local} [1], we have taken the ratio of the electron densities at the two radial positions (r_1, r_2) of LDD (Fig. 1b) and defined it as the new parameter

$$d_{r_1,r_2} = \frac{\rho_e(r_1)}{\rho_e(r_2)} \quad (2)$$

From LAP, we can calculate a single s^{lat} by averaging the s_{local} falling between r_1 and r_2 radial distances. An empirical relationship between s^{lat} and d_{r_1,r_2} has been established and the feasibility of direct estimation of mass (A) of primary particles has been investigated.

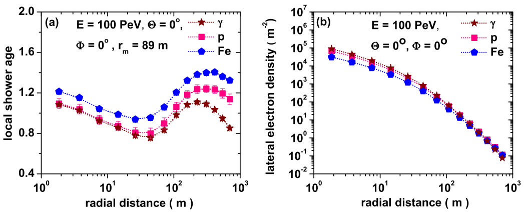

FIG. 1: (a) LAP vs r, (b) LDD vs r

Results and discussion

The MC simulation code *CORSIKA*- 7.7401 with the hadron interaction models EPOS-LHC and UrQMD is used at the KASCADE expt. condition. In Gr-I, about 3060 vertical extensive air showers (EAS) with mean energies 0.5, 1, 2.25, 5, 10, 22.5, 50 and 100 PeV initiated by different primary cosmic rays (PCR) such as p, He, C, O, Mg, S, K, Sc, Fe and γ are simulated. Whereas about 810 EASs with mean energies 2, 8, 32 and 128 PeV initiated by Li, N, Ne, Si, Ar and Cr PCRs are categorised as Gr-II.

An exponential function has been considered to get a suitable relationship between s^{lat} and d_{r_1,r_2}

$$s^{lat}(d_{r_1,r_2}) = a + b \cdot exp(-d_{r_1,r_2}/c) \quad (3)$$

The Eq. (3) is fitted to the s^{lat} vs d_{r_1,r_2} data of Gr-I simulated EASs of different energies and primaries and presented in Fig. 2. The fitted parameters are exploited to the showers of Gr-II to corroborate the Eq. (3) by finding the correlation between calculated s^{cal} from d_{r_1,r_2} and s^{lat} obtained from the LAP of corresponding showers. The average relative difference is $\langle\delta\rangle = \langle\frac{|s^{lat} - s^{cal}|}{s^{lat}}\rangle = 0.0009$. The correlation coefficient between s^{lat} and s^{cal} is obtained as 0.9923, which is also reflected to

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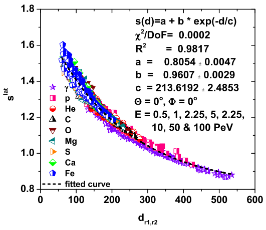

FIG. 2: Variation of s^{lat} with d_{r_1,r_2} for Gr-I showers.

the straight line fitted data in Fig. 3a. The μ and σ of Gaussian fit to the histogram of $s^{lat} - s^{cal}$ give a quite good affirmation to the correlation between s^{lat} and s^{cal} in Fig. 3b.

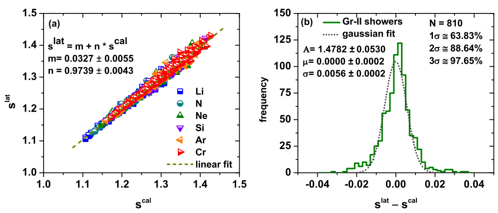

FIG. 3: Correlation between s^{cal} and s^{lat}.

We choose an exponential function to establish the relation between A and d_{r_1,r_2},

$$A = exp(\alpha \cdot \eta + \beta) \tag{4}$$

where shower size (N_e), muon size (N_μ) and d_{r_1,r_2} dependent η is expressed as

$$\eta = \frac{log(N_e \cdot N_\mu)}{[log(d_{r_1,r_2})]^{log(d_{r_1,r_2})}} \tag{5}$$

, and primary energy (E) dependent parameters α and β are represented as

$$\begin{aligned} \alpha &= p + q \cdot log(E) \\ \beta &= r + s \cdot log(E) \end{aligned} \tag{6}$$

Fitting the Eq. (4) to the A vs η data of Gr-I showers, we obtain the value of α and β for eight different primary energies. By fitting the value of α and β to the Eq. (6) we have procured the four parameters ($p, q, r,$ and s) which are presented in Fig. 4.

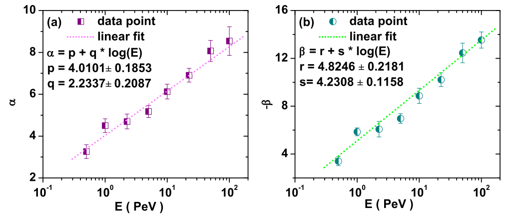

FIG. 4: (a) α vs E, (b) β vs E.

After getting the value of the four parameters of Eq. (6), we can proceed in the reverse order to estimate A from the data of d_{r_1,r_2}, N_e and N_μ for another set of showers (Gr-II) using the Eq. (6), (5) followed by Eq. (4). The σ value of Gaussian fit to the frequency distribution of the deviation of PCR masses implies a statistical error of 13 a.m.u. for a single event mass estimation (Fig. 5a). The mean and variance of the frequency distribution of d_{r_1,r_2} for p, Fe and γ-ray showers reiterated the primary mass sensitive feature of the parameter in Fig. 5b.

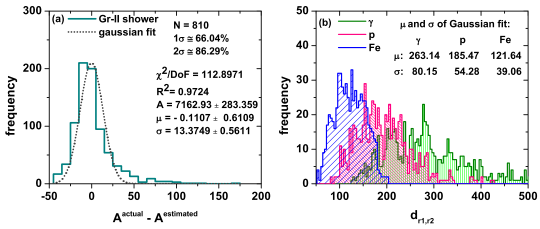

FIG. 5: (a) Distribution of deviation of estimated mass, (b) Distribution of d_{r_1,r_2} for p, Fe and γ.

Conclusion

Considering the generic feature of LAP, d_{r_1,r_2} has been derived from e-LDD of EASs. d_{r_1,r_2} shows a strong correlation with s^{lat}. A novel approach has been adopted to estimate the mass of PCR using the parameter. The primary mass sensitivity of d_{r_1,r_2} is evident.

References

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