Estimating cosmic-ray shower core using weighted average method: A simulation study

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Introduction

In order to obtain some information on cosmic ray (CR) from the density data of a shower in an extensive air shower (EAS) array, the crucial task is to make an accurate estimation of EAS core. For a precise core measurement a densely packed EAS array with detectors is prerequisite. The GRAPES-3 experiment [1] contains about 395 scintillation detectors in its array with different (x, y, z) coordinates. This work attempts for the estimation of EAS cores using simulated electron density data considering a plane and also an actual array configuration. The detector array here is hexagonally symmetric. A simple weight average method (WAM) using electron densities obtained from a group of 19 highest density detectors has been implemented here.

Estimation of EAS Core

CORSIKA-7.69 simulation code by combining the QGSJet-1c with UrQMD model is used generating simulated showers. In reality EAS cores are randomly distributed over the detector array. To implement the real situation in shower simulation, we use random numbers to distribute the EAS cores within the red hexagon [2] (Fig.1) intentionally, which is analogous to an actual situation. These cores are denoted by (x_r, y_r). Finally, the core position of each shower is estimated (x_e, y_e) by taking the weighted mean of those nineteen detectors having highest count density (ρ_i).

$$(x_e, y_e) = (\frac{\sum x_i \rho_i^2}{\sum \rho_i^2}, \frac{\sum y_i \rho_i^2}{\sum \rho_i^2}); i = 1, ..19 \quad (1)$$

The error in the core estimation is determined as follows

$$\Delta r = \sqrt{(x_r - x_e)^2 + (y_r - y_e)^2} \quad (2)$$

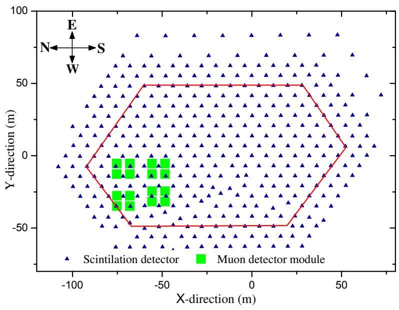

FIG. 1: Grapes detector array

Result and discussion

The main problems in the analysis using the WAM are the density fluctuations at the detectors and their large intermediate separations. The separation is found large for low energy EASs where the number of hit detectors is very few. We noticed that the densities of hit detectors are uniform (Fig.2). Moreover, the EAS cores are not well defined and highest density detectors are scattered in such a way that the EASs form multiple core structures. Hence, the WAM of nineteen highest density detectors cannot estimate the core location fruitfully. To reduce the effect of fluctuations in particle densities at low energies, a cluster approach is found suitable. Here the highest density detectors are chosen from a specified cluster, i.e. for each shower event a maximum density detector is identified, and the rest 18 detectors are chosen within 25 meter radial distance from the maximum density detector. Then the core is estimated from the chosen nineteen highest density detectors by

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applying the WAM method. For low energy proton showers ($4\times10^{12}eV \leq E \leq 1\times10^{13}eV$) the above mentioned approach can estimate 95% of events with uncertainly ±5 m. In the energy range ($3\times10^{14}eV \leq E \leq 7.5\times10^{14}eV$), we have found 95% events within ±4 m for actual detector array.

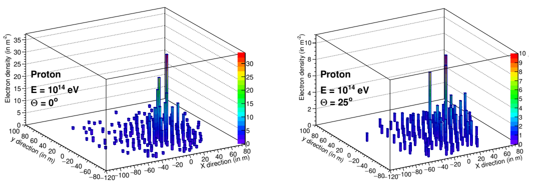

FIG. 2: Density plot for P showers of E = 10^{14} eV having $\Theta = 0^o$ (*left*), and $\Theta = 25^o$(*right*).

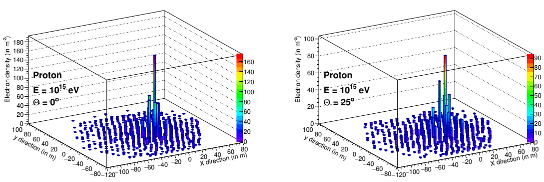

FIG. 3: Density plot for P showers of E = 10^{15} eV having $\Theta = 0^o$ (*left*), and $\Theta = 25^o$(*right*).

For high energy showers, the density fluctuation is found low around the estimated core (Fig.3) and the contrast of density of the highest density detector and other hit detectors is quite clear. In this case the cluster boundary has been increased to select the 19 highest density detectors from entire detector array. The value of Δr (in m) within which 95.5% of events are present for P and Fe initiated showers, both for plane detector array, and also for the actual array introducing a geometric correction for z-coordinate at three different average energies is shown in the Table I.

A population distribution of Δr for P and Fe initiated showers of primary energy $8\times10^{14}eV - 3\times10^{15}eV$, having $\Theta \leq 25^o$ is shown in the Fig.4 and Fig.5.

Conclusion

Measurements of cosmic ray mass composition and energy are very crucial for any ground based EAS experiment in order to understand the origin of primary cosmic rays. Accuracy of these measurements are closely linked with the accurate estimation of EAS shower cores. Different methods are being implemented for obtaining the EAS core. For a densely packed EAS array such as GRAPES-3 experiment the stated WEM using simulation is expected to be a simplified and accurate one for the determination of EAS core. It would be very interesting to implement the method on GRAPES-3 data.

TABLE I: Δr (in m) for different conditions.

PCR		Proton			Iron		
$E(PeV)$		0.8	1	3	0.8	1	3
Plane array (Δr)	$\Theta = 0^o$	1.33	1.23	1.08	2.42	1.93	1.08
	5^o	1.33	1.28	1.18	2.52	1.93	1.13
	15^o	1.58	1.33	1.28	2.72	2.82	1.28
	25^o	1.83	1.48	1.28	3.72	3.77	1.58
Actual array (Δr)	0^o	1.33	1.38	1.18	2.62	2.23	1.28
	5^o	1.43	1.38	1.23	2.57	2.32	1.28
	15^o	2.47	2.32	1.83	3.87	3.02	2.13
	25^o	3.82	3.48	3.32	4.87	4.12	3.57

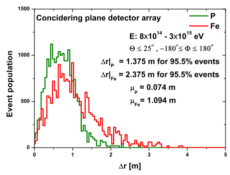

FIG. 4: Plane array.

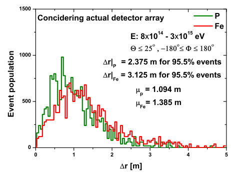

FIG. 5: Actual array.

Acknowledgments

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References

[1] S. K. Gupta *et al.*, *Nuclear Phys. B* 196 (2009)
[2] H. Tanaka *et al.*, *Nuclear Phys. B* 175–176 (2008)