A Study of High-Energy Cosmic Ray Showers by Extending the Dynamic Range of Scintillator Detectors in GRAPES-3 Experiment

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Introduction

GRAPES-3 (Gamma Ray Astronomy at PeV EnergieS-3), is a ground based air shower experiment, located near to the equator (11.4°N latitude and 76.7°E longitude) at Ooty, in South of India. It is designed to study the primary cosmic rays and gamma rays in 10^{12}eV - 10^{15}eV energy range [1]. The study of cosmic ray energy spectrum and nuclear composition is one of the primary objectives of GRAPES-3. It is equipped with an array of 400 plastic scintillator detectors spread over $\sim 25{,}000\,\mathrm{m}^2$ area and a large area ($560\,\mathrm{m}^2$) tracking muon detector and a snapshot of full array is shown in FIG.1.

FIG. 1: A snapshot of GRAPES-3 air shower array.

GRAPES-3 Air Shower Detector and Data Analysis

Cosmic rays air showers are observed continuously with the 400 plastic scintillator detectors at GRAPES-3 experiment. There are 105 plastic scintillator detectors equipped with the dual photo multiplier tubes (PMTs) and the remaining are operated only with a single PMT. The PMTs are operated ∼(1500–2000)V as per the requirement of the single particle gain ∼40 ADC counts called as high-gain (HG-) PMT and in case of a dual-PMT detector the second PMT is working at relatively lower gain and hence, called as low-gain (LG-) PMT [2].

Estimation of particle densities observed by every plastic scintillator detectors are discussed. In case of HG-PMT, particle densities observed for a high energy shower have limitations due to the non-linearity and saturation of a PMT. These limitations are avoided by using LG-PMT in a same dual-PMT detector. The single particle calibration (gain-ration) of a LG-PMT is estimated indirectly [3], which is the ratio of ADC values of HG-PMT to LG-PMT.

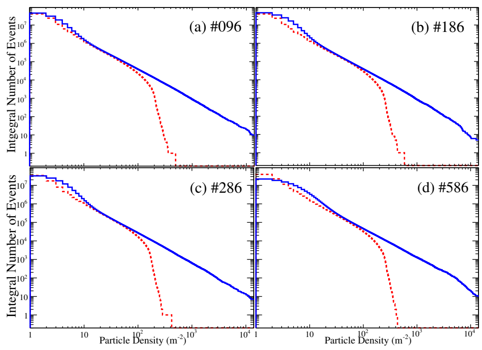

FIG. 2: Integral particle density obtained from the HG- and LG-PMT of 4 dual-PMT detectors.

The integral particle density spectrum is obtained with the total number of events in the range of the particles observed. The effects of a PMT's non-linearity and saturation are clearly visible in the integral particle density spectrum. FIG.2, shows the integral particle density spectrum of HG-PMT attached to four different shower detectors in each panel. The

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non-linearity is observed in the given spectrum from ∼(50–100) particles m^{-2} and afterwards an abrupt fall in the number of events for particle density > 100 particles m^{-2} is observed.

The spectrum obtained from LG-PMTs are drawn with blue lines shown in FIG. 2 and the extended particle densities in the range ∼(5000–10000) m^{-2} are observed in the dynamic range. Therefore, the correct observation of particles present in very high energy air showers are achieved, and henceforth, the energy estimation of primary cosmic rays of energy $> 10^{15}$ eV can be possible.

Non-Linearity Corrections of a PMT

GRAPES-3 air shower array is operated with ∼25% dual-PMT detectors and hence, rest of the PMTs are still measuring the particle density in their non-linear region for a large energy showers, which causes the incorrect estimation of the various air shower parameters such as sower age, shower size, shower core locations. In the present work, an attempt is made to develop a methodology in order to correct at least the non-linearity observed in a PMT. This method takes advantage of the observation of LG-PMT particle density spectrum, which uses the observed spectral slope of -1.58 in the range of 50–5000 particles [4].

The non linearity corrected particle densities

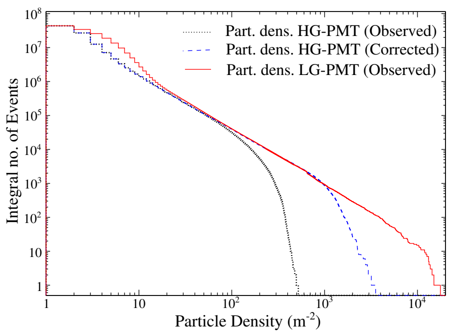

FIG. 3: Integral particle density spectrum for non-linearity correction and observed from HG- and LG-PMT.

are obtained on event-by-event basis. Thereafter, the integral particle density spectrum is obtained from the corrected particle density and is plotted in FIG.3, along with the observed particle densities from HG-PMT and LG-PMT of a dual-PMT detector.

Improvements in Shower Parameters

Inclusion of LG-PMT into particle density observation improves the estimation of various shower parameters obtained from the fitting of the observed lateral particle density distribution with NKG function. One of the shower parameters to be estimated is shower age (s) and, hence, is plotted in FIG.4 for HG-PMT and the LG-PMT used.

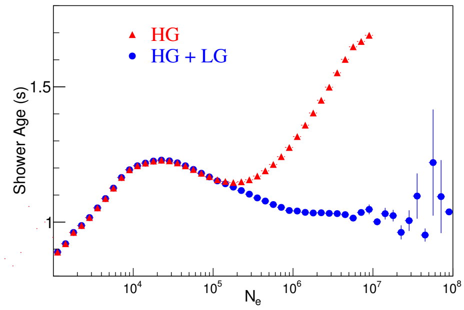

FIG. 4: Variation of shower age (s) for the HG-PMT and LG-PMT against shower size N_e.

The variation of shower age against shower size (N_e) exhibits the increment after the value of $N_e > 10^5$. This increase in the value of N_e is the artifact of non-linear behavior of the PMTs. On the other hand, in case of LG-PMT, the variation of shower age against N_e shows the expected decrements for the values of $N_e > 10^5$. Improvements in the other shower parameters such as shower size, core locations, are also observed and can be presented in the conference in more details.

References

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