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A NEW STUDY ON THE ENERGY SPECTRUM AND COMPOSITION OF PRIMARY COSMIC RAY FLUX AT ENERGIES $\sim 10^{14} - 10^{16}$ EV USING THE GRAPES-3 ARRAY AT OOTY

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Data collected with the 217-detector air shower array and the 560 m^2 area tracking muon detector, being operated at Ooty in southern India by the India-Japan (Tata Institute-Osaka City University) collaboration, GRAPES, have been analyzed to study the shape of the energy spectrum and the composition around the *knee*. It is shown that the muon multiplicity distribution, observed with the highly modular muon detector, permits a relatively reliable measurement on the composition of primary flux which then helps in a more accurate reconstruction of the energy spectrum from the observed shower size spectrum. The highlights of the GRAPES array, the analysis procedure and the results are presented.

Keywords: Primary Cosmic Rays; Spectrum and Composition; Extensive Air Showers

1. Introduction

A signature of the physical process responsible for the *knee* in the primary cosmic ray energy spectrum is being sought in the change in the composition of primary flux at PeV energies. Due to severe practical constraints on the long duration flights with heavy payloads, studies in cosmic ray astrophysics at energies ≥ 100 TeV have to necessarily rely on indirect measurement on various components of air showers carried out at mountain altitude, sea level or underground locations. It is well-known that the muon component in air showers offers the highest sensitivity[1] for studies on the nuclear composition of primary cosmic ray flux around the *knee*. The GRAPES-3 collaboration is attempting to measure the primary composition from a study on the muon multiplicity distribution for showers over a wide energy range using a very large, 560 m^2 area, muon detector. The GRAPES-3 experiment is located at Ooty (11.4° N latitude, 76.7° E longitude and 2200 m altitude) in southern India.

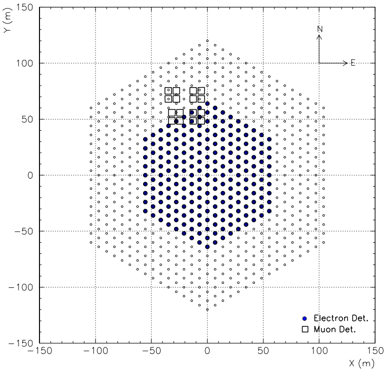

Fig. 1. Schematic layout for the 721 detector (open circles ○) GRAPES-3 shower array of which 217 detectors (filled circles ●) are used for the present analysis. Each of the 16 squares represents a 35 m^2 area muon tracking detector with $E_\mu \geq 1$ GeV.

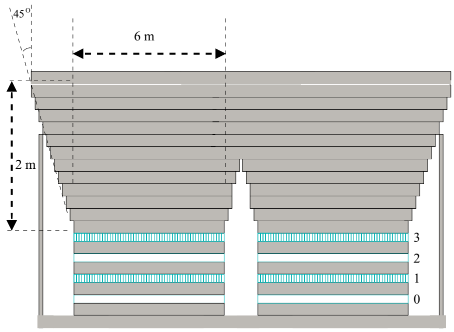

Fig. 2. Schematic of two muon detector modules of a super-module, showing the 4 layers of proportional counters (marked by $0, 1, 2, 3$) embedded within the concrete blocks. Proportions are not preserved.

2. The GRAPES-3 Experiment

Figure 1 shows a schematic layout of the GRAPES-3 array.[2] A total of 721 detectors are planned to be installed over a period of time. Presently only the data from the inner 217 detectors are being used for studies on the energy spectra and the composition of primary cosmic ray flux. Figure 1 also shows 16 squares in the north-west region. Each of these squares represent a 4-layer tracking muon detector module.[3] Each layer consists of 58 proportional counters, each 6 m long with 10×10 cm^2 cross-sectional area. To achieve an energy threshold of 1 GeV for vertical muons, ~ 550 g cm^{-2} thick absorber in the form of concrete blocks has been used. A cross-section of two adjacent muon detector modules is shown schematically in Fig. 2. Four such modules, separated by a horizontal distance of 130 cm at the base, constitute a super-module.

3. Data Taking and Analysis

Datataking started with the GRAPES-3 array in 2001 and preliminary results are now available from data taken during 2001–02. In an attempt to have the lowest possible energy threshold for the determination of the composition of the primary flux, the processing of data has been kept to a minimum as far as the reconstruction of showers is concerned for estimating shower size and age. Instead, the parameter *Psum* has been used to group showers which represents the sum of the number of particles observed in the inner 127 detectors in a shower. The multiplicity distributions for the muons observed in the 560 m^2 area muon detector have been plotted for showers with various Psum values. Fig. 3 shows the typical distributions observed for 4 broad range of Psum values. These distributions have been compared (Fig. 3) with the expectations from Monte Carlo simulations using the CORSIKA code and the QGS model for hadron interactions. This comparison shows the good sensitivity of the muon distribution to the atomic number of the primary particle.

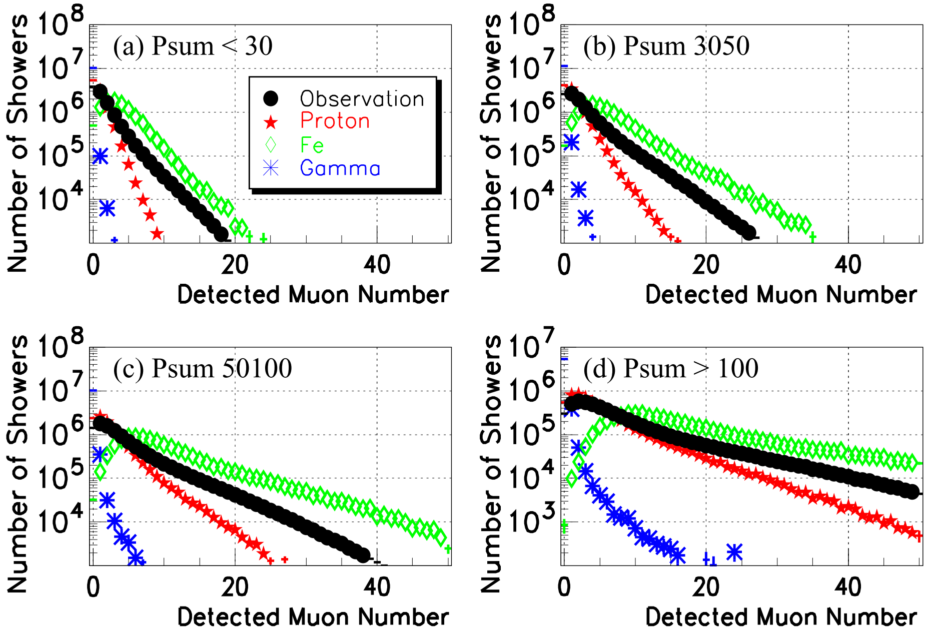

Fig. 3. A comparison of muon multiplicity distributions observed with the 560 m^2 area muon detector with results obtained from Monte Carlo simulations for various primary particles.

4. Results and Conclusion

Based on detailed comparison of observations with the results from simulations and assuming the primary cosmic ray flux to be consisting of 5 nuclear groups (p, He, CNO, Si and Fe), it has been possible to obtain the estimates for the flux of these nuclei in the primary flux. The observed flux values at energies near 10^{14} eV agrees very well with measurements from direct measurements[4] with balloon-borne detectors. Also, the observed steepening in the all-particle energy spectrum at energies around a few PeV confirms the presence of the *knee*, as reported by several other groups.[5] The GRAPES-3 results on the variation of $\ln A$ also agree well with the results presented by the KASCADE group,[6] based on the muon component.

With more statistics available from data collected during 2002–04, these measurements will be extended well beyond the *knee* which may provide some clues to the origin of ultra-high energy cosmic rays.

References

1. S. K. Gupta *et al.*, *Phys. Rev.* **D68**, 052005 (2003).
2. S. K. Gupta *et al.*, to appear in *Nucl. Instrum. Meth. A* (2004).
3. Y. Hayashi *et al.*, submitted to *Nucl. Instrum. Meth. A* (2004).
4. J. P. Wefel *et al.*, *J. Phys. G: Nucl. Part. Phys.* **29**, 821, (2003).
5. J. R. Hörandel, *Astropart. Phys.* **19**, 193 (2003).
6. T. Antoni *et al.*, *Astropart. Phys.* **16**, 245 (2002).