# A Study of Nuclear Composition of Primary Cosmic Rays above 100 TeV

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## Abstract

The GRAPES-3 air shower array is located at Ooty ($800g/cm^2$) in southern India and consists of 256 scintillation detectors ($1m^2$ each) and 16 muon detectors ($35m^2$ each). In order to study the nuclear composition of primary cosmic rays around the knee energy, we investigate the relation between muon multiplicity and shower size using observations from this experiment during the period, 2000–2001 with $\sim 10^6$ showers having $N_e > 10^5$. These results are compared with Monte Carlo simulations (CORSIKA v6.02 with QGSJET model) to obtain the variation of the average mass number with primary energy. We have carried out detailed simulations for five types of primary nucleus (Proton, He, N, Al and Fe) for comparison with observations. We present here the details of the results.

## 1. Introduction

Our main motivation is to understand physical mechanism of steepening of the primary cosmic ray energy spectrum around $10^{15}$ to $10^{16}eV$, what is called *knee*. Though a few observations have been reported about the variation of the nuclear composition in this range recently, there is disagreement among them. Since it contains the information of their origin and acceleration, it is important to establish the nuclear composition of primary cosmic rays.

It is well-known that the number of muons in extensive air showers has a good correlation with mass number of its primary cosmic rays. We have installed very large area ($\sim 560m^2$) muon detectors to observe number of muons with high statistics.

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## 2. Experiment

The GRAPES-3 air shower array is located at Ooty in southern India (N 11.4°, E 76.7°) at an altitude of $2,200m$ above sea level, an atmospheric depth of $800g/cm^2$. It consists of 256 scintillation detectors (SDs) to measure the electron component and 16 units of proportional counters to detect muons in showers.

Each of these SDs contains $1m^2$ area, $5cm$ thick plastic scintillator. They are placed in hexagonal shape with $8m$ separations as shown in fig.1. Each SD can measure both density and arrival time of charged particles. Trigger rate is around $14Hz$ with any 10 fires out of 120 SDs. We determine the shower size and arrival direction for individual showers.

We have large area muon track detectors. Their element is the $6m$ long proportional counter with a cross section of $10cm$ by $10cm$. 58 counters are placed side by side on a concrete platform and covered with $2m$ thick concrete slabs. Four layers of counters are arranged in crossed configuration to identify the track of individual muon. Each unit has $35m^2$ detector area, and total $560m^2$ are covered. Threshold energy of vertical through muons is about $1GeV$. Their data are recorded with trigger from shower array described above.

## 3. Analysis

We carried out analysis of showers between 2000 March and 2001 December, the effective running time is about 560 days. There are $\sim 10^6$ showers having $N_e > 10^5$ whose core locations fall inside a hexagon shown in fig.1.

Detailed analysis has been done for showers that satisfy the following conditions

- More than 10 SDs firing out of 120 SDs inner array.
- Core location should be inside an area as shown in fig.1.
- Zenith angle of the air shower should be less than 25°.

Observed lateral density distribution is fitted with NKG function to estimate shower core location $\mathbf{R}$, size $N_e$ and age parameter $s$. We adopted $103m$ as Molière unit $r_m$.

The followings are the conditions of MC simulation.

- CORSIKA V6.02 with QGSJET model.
- Threshold of primary energy is $10TeV$ for proton and $80TeV$ for iron. These thresholds are kept so small that they should not give any biases for production of $N_e > 10^{4.5}$ showers.

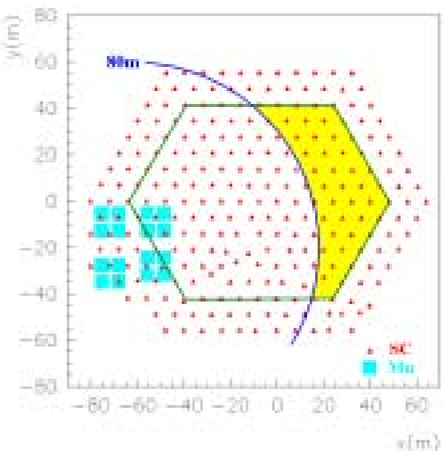


**Fig. 1.** Accepted core location. Triangle marks mean SD arrangement and square ones mean muon detectors. For this analysis, core location should be in yellow (or gray) area, which is inside a hexagon and $80m$ away from muon detectors.

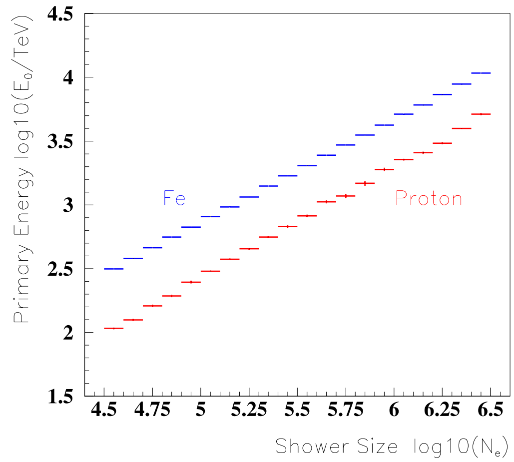


**Fig. 2.** Relations between Shower Size and Primary Energy with MC.

- Energy cut-offs are $1MeV$ for electron and $1GeV$ for muon at the observation height.
- The slope of the primary energy is $-2.7$. ($-3.15$ above $3PeV$ for Proton)

Each simulated shower is randomly distributed within an area of $100m$ radius from the center of the array and we adopted the showers which satisfy the same experimental trigger condition.

In order to reject the accidental muons, we have selected the muon tracks which agree with EAS direction.

## 4. Results and Conclusions

Fig.3. shows variation of number of muons with air shower size and corresponding MC results. This $N_e - N_\mu$ relation features the primary nuclear composition. There is no significant change in their slope within this size range.

Fig.4. shows muon multiplicity distribution in $10^{5.4} \leq N_e < 10^{5.6}$. Each nuclear composition has characteristic multiplicity distribution. As one can see from fig.4., major contribution arises from Proton primary below muon multiplicity of 10. Even multiplicity below 20 we need not to consider the contribution from other nucleus than Proton and Helium. It means we can estimate the abundance of those two nucleus in the primary nuclear composition using this multiplicity distribution (MC's). It will enable us to give some constraint to composition

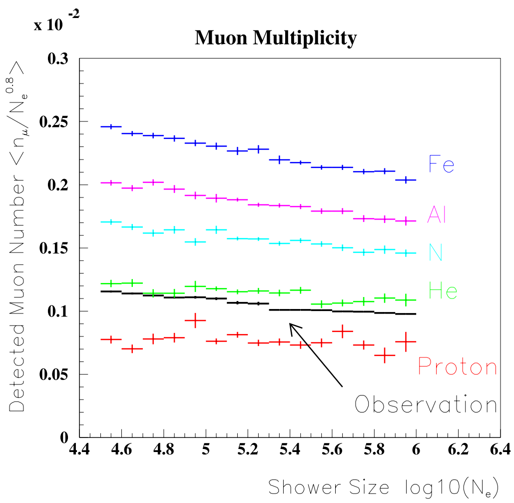


**Fig. 3.** Average number of detected muon with shower size. Observation is shown in black and compared with MC results.

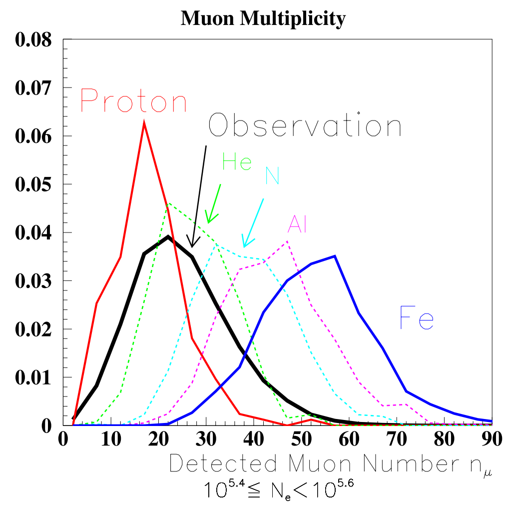


**Fig. 4.** Distribution of detected muon number with size. Observation is shown in black and others are MC results.

model of galactic cosmic rays. Estimation of average mass number for these energy range is still underway and will be given in the conference.

GRAPES-3 has a potential to decide variation of cosmic ray composition with large area muon detectors.

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