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The average mass number of primary cosmic rays around the knee region derived from Grapes III array at Ooty

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ABSTRACT
We analyzed three months data on air showers (total 10^8 showers in 10^4<Ne<10^6) observed with the GRAPES III experiment during 2001. The shower array consists of 257 scintillation detectors (1m^2 each) and 16 muon detectors (35 m^2 each). Very large area (560m^2) of the muon detectors gives good statistics for estimating the number of muons even for small air showers. We present the correlation between muon multiplicity distribution and shower size. This result is compared with simulation (Corsika code with QGS Jet model) for primary energy between 10^{13} eV and 10^{15} eV. We find the average mass number in this energy region follows gradual increase and mixing of proton and heavy nuclei model fits well our observed data.

1 Introduction

Our aim is to establish the chemical composition of primary cosmic rays between 10^{14} to 10^{16} eV. So far quite a few experiments have been conducted in the field of Air shower to investigate the composition. But some results have shown even opposite feature on the chemical composition of primary cosmic rays, one favors for the light element abundance, another favors to the heavy.
Number of muons associated with Air showers are quite sensitive to the primary mass so that we can deduce the type of primary cosmic rays. Though the absolute muon numbers in an Air shower is interaction model dependent, now we can calculate them fairly well with the help of accelerator physics in this energy region.
Chemical composition is important, since it is thought that it reveal the environmental condition from where the cosmic rays are produced and same time it contains the information of propagation in our galaxy. It has been known for a long time that a simultaneous study on the electron and muon components in EAS has good potential of yielding significant results on the composition of the primary cosmic rays.

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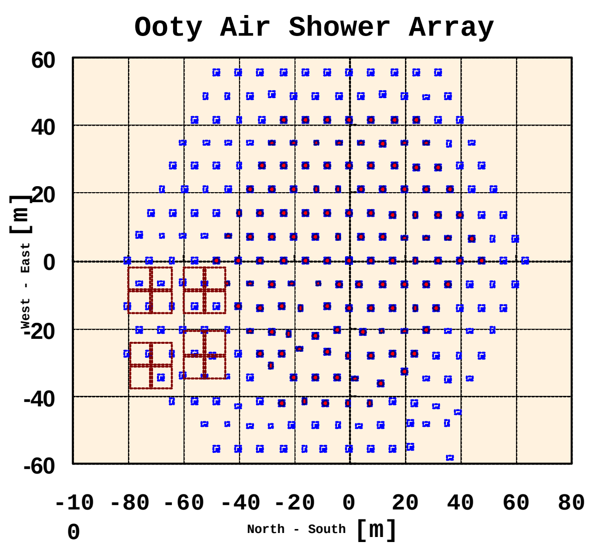

Fig.1 Ooty Air Shower Array

2 Air Shower Array and Muon Detectors

Air shower array of GRAPES III is located at Ooty (latitude 11.4 longitude 76.7). it consists of 257 scintillation detectors and 16 unit of proportional counters. Each of these scintillation detectors (SDs) is 1 m^2 area, 5cm thick plastic scintillation detector viewed by a fast 5cm diameter photomultipliers placed 65cm above the scintillater. SDs are meant to measure the electron and gamma ray component in the Air shower. They are placed in hexagonal shape with a separation of 8m between the adjacent detectors. This arrangement can give good triggering efficiency over the entire range of interest in energy of 10^{13} to 10^{16} eV

We have installed large area muon detectors. The detector element is the 6m long proportional counter with a cross section of 10cm by 10 cm. 58 counters are placed side by side on a concrete platform and covered with 15cm thick concrete slabs. Four layers of counters are arranged in crossed configuration to obtain the track and angle of individual muon. In total 16 modules of muon detectors, area of each module is 35 m^2, covering total area of 560 m^2 have been fully operational since February 1998. Threshold energy of through muons is about 1.0 GeV (550 g/cm^2 of concrete above the top counters, about 20 r.l.).

Trigger rate is 14Hz with selection of any 10 detectors out of 120 SDs.

All the electron detectors are instrumented for measurement of both density and arrival time of particles. We determine the shower size and arrival angle for individual showers. The accuracy in the determination of the arrival direction of showers is estimated as 1.5degrees for shower of the size of around 10^5.

3 Analysis of Data

Detailed analysis has been carried out for showers which satisfy the following conditions

(a) More than 10 SDs firing out of 120 SDs inner array.

(b) In order to select the air showers which core falls inside the SDs array, we adopted the following conditions. Sum of the detected particles of hit SDs out most and one line inside should be less than 35% of total number of detected particle.

(c) Zenith angle of the air shower should be less than 25 degrees.

With these conditions, we selected $3x10^7$ showers in three months.

The followings are the conditions of simulation.

(a) CORSIKA V5.6240 with QGS-Jet model + full EGS is used.

(b) Minimum energy for electron is one MeV and for hadron is one GeV.

(c) Threshold energy for proton is 1 TeV and for iron 5 TeV.

(d) The slope of the primary cosmic rays is –2.7.

Each simulated shower is randomly distributed within an area of 200 m radius from center of the array and we adopted the showers which satisfy the trigger condition exactly same as experiment.

The process and accuracy of the determination of muon number is reported in previous ICRC, Hayashi et. al.(1999) With those results, we are confident of around 15 muons in one module as a maximum number of detectable muons. For the discussion of primary composition of the shower size Ne < 10^6, this will give sufficient accuracy.

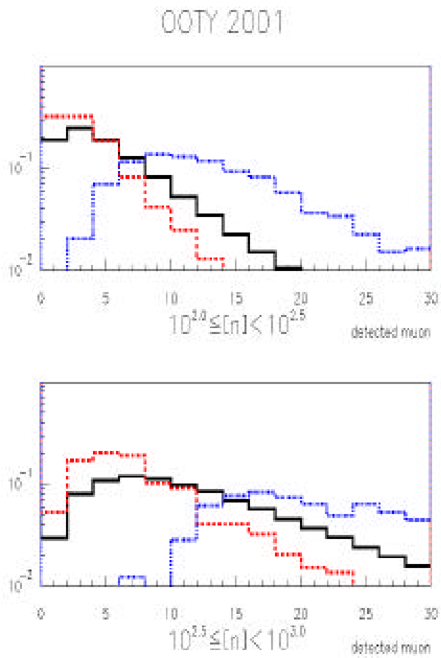

Fig.2 muon multiplicity distribution
With different primary energy
blue:Iron, black:Observed data, red: Proton

4 Experimental Results

There are several possible ways to study for the primary cosmic ray composition through muon components, for example, the multiplicity distribution, the Ne-Nmu relation etc. We adopted here the multiplicity distribution with shower size in order to estimate the primary composition. This method of analysis has an advantage that we need not use the assumed muon's lateral distribution. Fig.2 shows the muon multiplicity distributions obtained by the Ooty experiment for detected number of particles 2.0 < logNe < 3.0. (core positions from the muon detectors are 10m < r < 100m). and the results of the simulations. We can obtain quite high statistics on muon due to the compact but huge array of muon detectors..

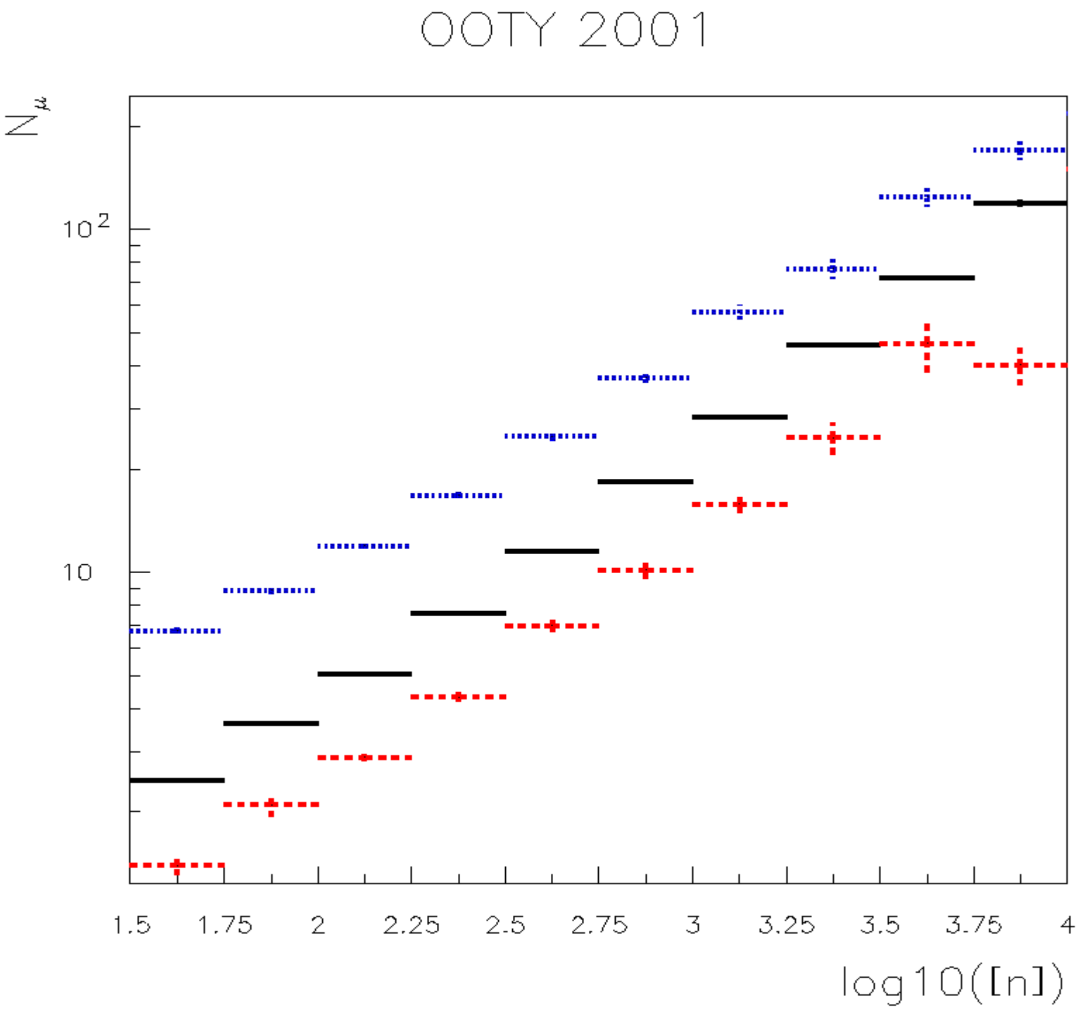


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Fig.3 Muon Multiplicity distribution
      Blue : Iron
      Black: Observation
      Red  : proton
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5 Discussion and Conclusion

. Even though present observations show that the large area muon detectors in the GRAPES III array permit accurate determination of muon numbers with high statistics and these observations are expected to give us reliable information on primary composition of cosmic ray flux.

We could finish only 3moths data so far and another 1.5 years data is still to be analyzed. Though our present results is preliminary, we obtained ratio of proton and iron, around 3 to 1 for the primary cosmic rays in the energy range of 10^{14} to 10^{15} eV from the data shown in Fig.2.

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References

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