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A Study on the Lateral Structure of Muons in Extensive Air Showers with the GRAPES Array at Ooty

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Abstract

The GRAPES III Experiment has started data taking from the beginning of 1998 with observations on the electron component with 100 out of the 217 detectors placed in 8m hexagonal configuration. The very large area muon detector covering 560m^2 area is spread over 16 modules (E_{mu}>1GeV) located close together. Extensive air showers in the size range 10^4 to 10^6 have been analyzed to study the lateral distribution of muons. Results obtained from this analysis show good agreement with results obtained from earlier observations at Mt. Norikura. Comparison with results reported by other groups are presented.

1 Introduction:

Observations of muon components in EAS have been done for a long time to study some feature of ultra high energy interactions with nuclei and to determine the chemical composition of primary cosmic ray flux. Most of the muon detectors used in earlier times look as point detector compared with the scale of EAS due to the limitations imposed by high cost and difficulties in proper maintenance over long periods. It is essential to scale up the muon detectors in area to understand the physical mechanism underlying the knee region at energy about $3*10^{15}$ eV. In addition , to study the shower phenomena in small size shower, it is preferable to use densely packed detectors. Also, in larger size showers, it is important to determine the lateral distribution of muons in individual showers. The very large area muon detector in the GRAPES III array at Ooty has been installed to achieve these objectives. To determine the lateral distribution of muons at large distances from the core of EAS, classified by size, it is essential to observe large number of muons with good accuracy. Muon detectors used in the present experiment are tracking detectors and satisfied

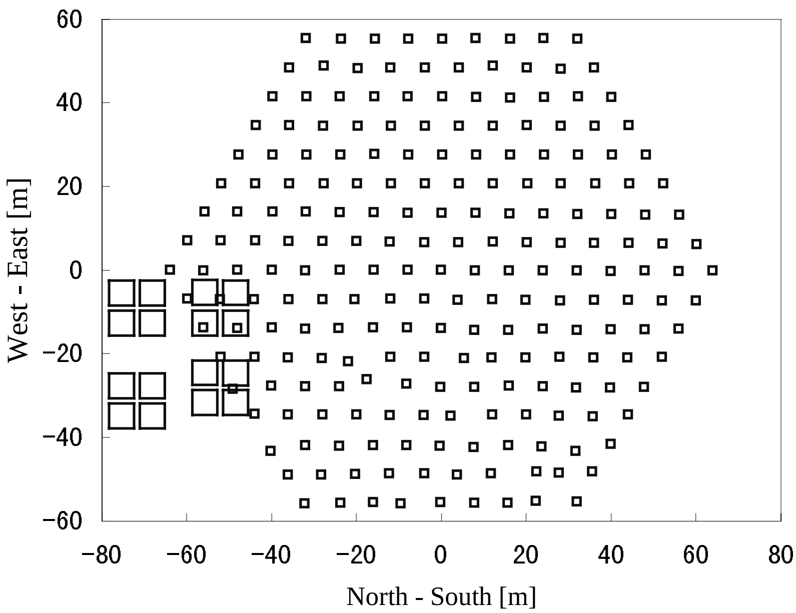

Figure 1: Air Shower Array at Ooty. Small squre shows electeon detectors, large squre showers muon detectors.

the above requirements.

2 Electron and Muon Detectors:

The GRAPES III array has been designed with a separation of 8m between the adjacent detectors. The hexagonal shaped array has given good triggering efficiency over the entire range of interest in energy of $3*10^{13}$ to $3 *10^{16}$ eV. Figure 1 shows the layout of the inner 217 detectors placed around the central laboratory, with muon detectors located towards the northern edge of the array. Each of these electron detectors is a $1m^2$ area, 5cm thick plastic scintillation detector viewed by a fast 5cm diameter photomultipliers placed 65cm above the scintillator. All the electron detectors are instrumented for measurement of particle density for determination of shower size, as well as relative arrival time for determination of the arrival angle, for individual showers. These detectors are monitored in rate at 100msec interval. Trigger rate is 8Hz with selection of any 9 detectors out of 60. The accuracy in the determination of the arrival direction of showers is estimated as 1.5degrees for shower of the size of 10^5. It has been known for a long time that a simultaneous study on the electron and muon components of EAS has good potential of yielding significant results on the composition for primary cosmic rays. We have installed large area muon detectors at Ooty in southern India. The detector element is the 6m long proportional counter with a cross sectional area $10*10\ cm^2$. 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 quite satisfactory tracking of muons. In total 16 modules of muon detectors covering area of 560 m^2 have been fully operational since April 1998. Each module, nearly 36 m^2 in area, detects muons of energy>1.0 GeV (550 g/cm^2, about 20 r.l.). To maintain the detectors in stable, individual channel pulse width, any 3 folds (3900/sec/module) and 4 folds (3300/sec module) rates are being also monitored continuously.

3 Analysis of data:

Detailed analysis has been carried out for showers which satisfy the following criterion:
(a) More than 15 channels firing out of 80 channels.
(b) Out of the largest 4 signals, less than 1 channel to be on outer most ring.
(c) Sum of the particles in the 4 channels should be > 10 particles.
(d) Out of the largest 6 channels, except the farthest, remaining channels should be exist within 30m in diameter.

With these criteria, the observed shower frequency is 0.24Hz and accuracy in the determination of the core position is less than 3m.

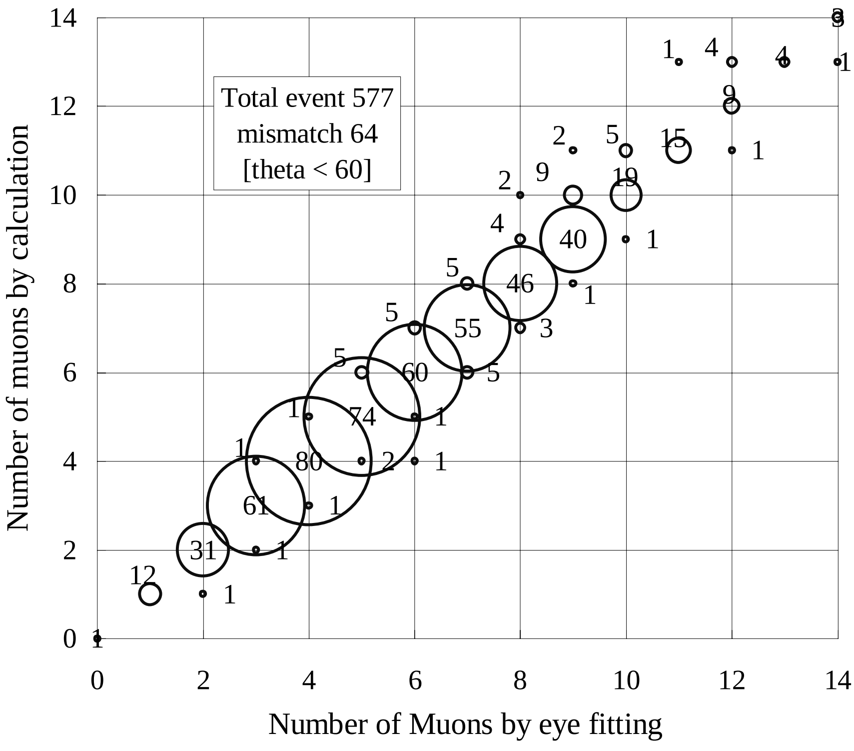

Figure 2: Comparison between eye fitting and automatic calculation for determination of number of Muons[/module]

On the other hand, muon data were analyzed that satisfied the following:

(a) Core position should hit within the array except outer ring area.

(b) Zenith angle theta<25 degrees.

The number of muons were determined by the automatic counting program. Figure 2 shows the correspondence between the number of muons determined by eye fitting and the counting program. Within a miscount of one muon, the correspondence is almost 99%. With this program, up to 15 muons/module can be determined accurately. For larger number of muons, we can determine the number using the ionization information recorded for individual muon counters. For the discussion of primary composition of the shower size $N_e < 10^6$, it is sufficient for the former analysis.

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 N_e-N_{mu} relation etc. Simulation results show that in N_e-N_{mu} relation, the ratio of muon number vs shower size gives a ratio of about 3 between in case of iron and proton primary. In this method, it is important to observe accurately the lateral distribution of muons for showers, which are grouped according to shower size. Figure 3 shows the lateral distribution of muons obtained from the Ooty experiment for shower size of $5.0 > \log N_e > 4.5$

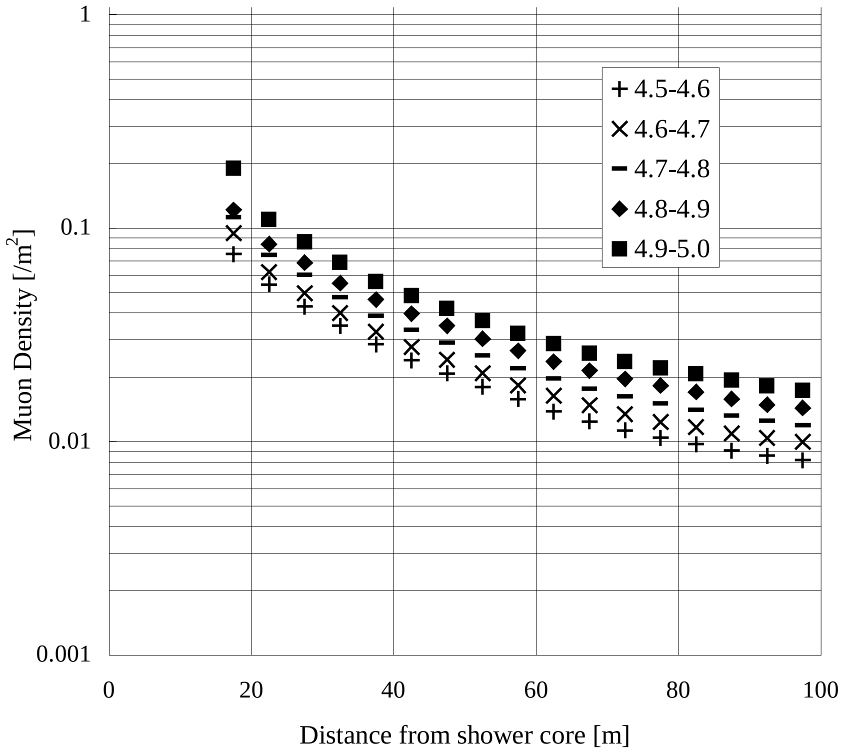

Figure 3: Muon lateral distribution for each shower size groups. (5.0 > logNe > 4.5)

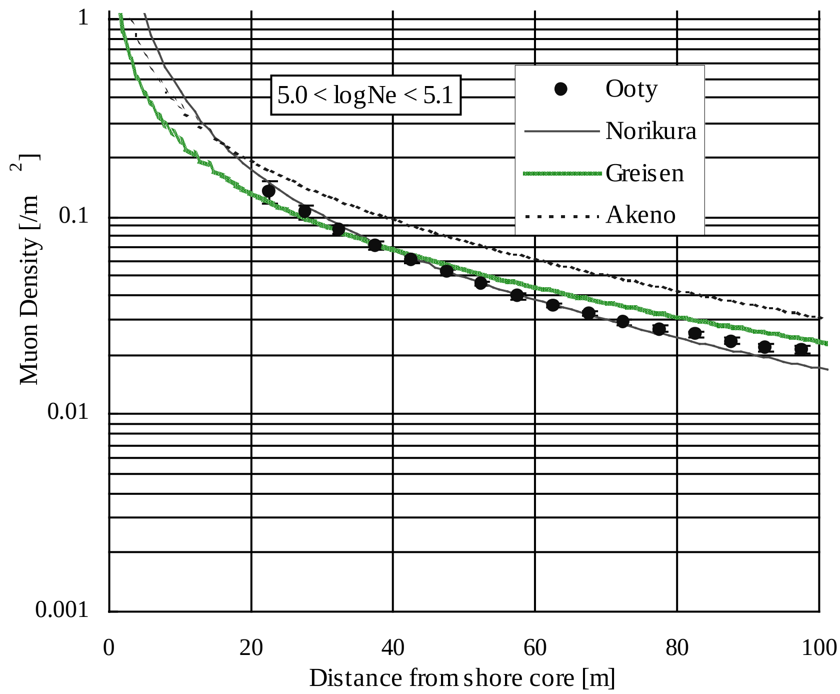

Figure 4: Muon lateral distribution compare with other experimental results.

(at $20m < r < 100m$). Even the number of showers is $1.6*10^6$, we can obtain quite high statistics on muon due to the compact but huge array of muon detectors.

5 Discussion and Conclusions:

To compare the present results with earlier observations by other groups, we show in Figure 4 the lateral distribution of muons for the size range of $5.1 > \log N_e > 5.0$, from Mt. Norikura experiment, and the Akeno experiment. Also shown is the parametrisation given by Greisen. The table below also shows the comparison between experimental data from different experiments.

Table

	a.s.l.(m)	Size Range	Range of distance(m)	Detectors	Eth(GeV)
Greisen	0	5 - 7	10 - 100		1
Akeno	900	7 - 9	10^3 - $3*10^3$	Proportional Counter	1
Norikura	2770	5 - 7	20 - 50	Neon Flash Tube	0.45
KASCADE	110	4.6 - 5.6	20 - 100	Streamer Tube	2
Ooty	2200	4.5 - 5.5	20 - 100	Proportional Counter	1

From the Figure and Table, we can conclude that the Ooty result agree with Mt. Norikura and KASCADE data but Akeno data gives slightly higher in density. This one may come the detector configuration and too much extrapolation are given here in the shower size.

Finally, these observations show that the large area muon detectors in the GRAPES III array permit accurate determination of muon numbers with high statistics. These observations are expected to give us reliable information on primary composition of cosmic ray flux. Also, these observations would help in distinguishing showers due to gamma ray in search carried out for discrete sources of ultra-high energy gamma rays.

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