# Properties of $10^{18}$-$10^{19}$eV EAS at far core distance

M.Teshima*, M.Nagano, T.Hara, Y.Hatano, N.Hayashida, C.X.He**
M.Honda, F.Ishikawa, K.Kamata, Y.Matsubara*, M.Mori*,
H.Ohoka and G.Tanahashi

Institute for Cosmic Ray Research, University of Tokyo, Tokyo, 188 Japan
*Department of Physics, Kyoto University, Kyoto, 606 Japan
**Institute of High Energy Physics, Academia Sinica, Beijing, China.

Abstract
    Properties of $10^{18}$-$10^{19}$eV EAS such as the electron lateral
distribution, the muon lateral distribution (E>1GeV), the ratio of muon
density to electron density, the shower front structure and the transition
effects in scintillator of 5cm thickness are investigated with the Akeno
4km²/20km² array at far core distances between 500m and 3000m. The
fluctuation of densities and arrival time increase rapidly at the core
distances farther than 2km.

## 1. Introduction

The 4km² array has been in
continuous operation for two years[1]
and the expanded array of 20km²[2] from
the end of 1984. Properties of $10^{18}$-
$10^{19}$eV extensive air shower(EAS) at far
core distances are studied with
4km²/20km² array in conjunction with
the data of the dense Akeno 1km²
array[3] which consists of 151
scintillation counters of 1m² area and
9 muon stations of 25 m² area. The
results are important not only for
determining electron size, muon size
and arrival direction of the large
showers and estimating their errors,
but also for designing the future huge
surface array of 100km² area. The
reliability of the Linsley proposal for
the detection of giant air shower with
"mini array"[4] is also discussed using
the data obtained.

The data observed with 4km² array
during a period between Dec. 1982 and
Oct. 1984 and with 20km² between Sep.
1984 and May. 1985 are analyzed.
During this operation time about 250
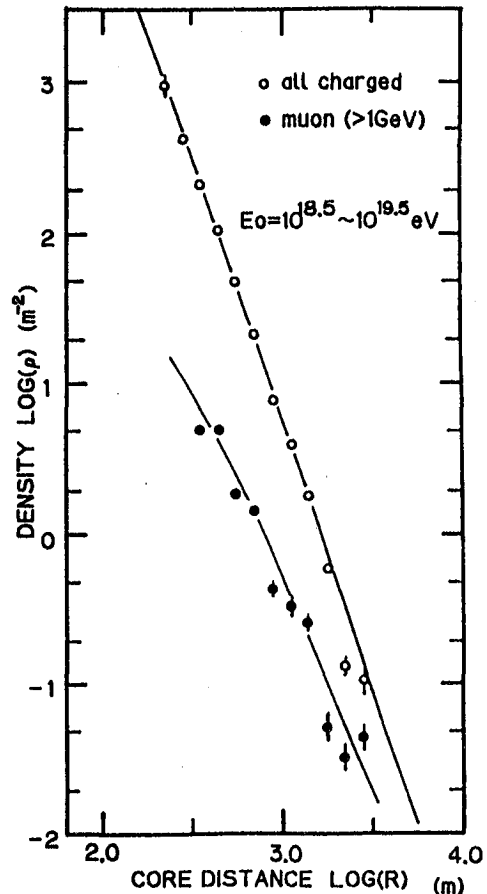EAS of energies above $10^{18}$eV are
observed.



Fig.1 The lateral distribution
of electrons and muons.

## 2. The lateral distribution of electrons(LDE)

The LDE is expressed by the function with two parameters $\alpha$ and $\eta$ [5].

$$\rho_e(R) = C(R/Rm)^{-\alpha}(1+R/Rm)^{-(\eta-\alpha)}. \quad Rm = 91.6m \text{ ; Moliere unit. ---(1)}$$

$\alpha$ is 1.2, to which our experiments is not sensitive. $\eta$ can be measured precisely with many detectors. For the EAS of $3 \times 10^{18}$eV $\eta$ is about 3.8. The LDE becomes steeper as the energy increases and is expressed by

$$\eta = 3.80 \pm 0.05 + (0.10 \pm 0.05) \mathrm{LOG}(E/10^{19}\mathrm{eV}) \qquad \text{------------(2)}$$

between 100m and 1000m. This energy dependence is a little larger than the result reported by Linsley[6].

At core distances above 1km, the LDE becomes steeper than the extraporation of the above formula. In fig.1 the average LDE of $10^{18.5}$eV-$10^{19.5}$eV for vertical EAS is shown.

The fluctuations of electron densities after subtracting statistical ones(Poisson) are shown by solid lines in fig.2(a) and expressed as a function of core distances as follows.

$$\Delta \rho \, e(R)/\rho \, e(R) = 0.20 \times (1 + R/1500)^{2.0}. \qquad \text{----------------(3)}$$

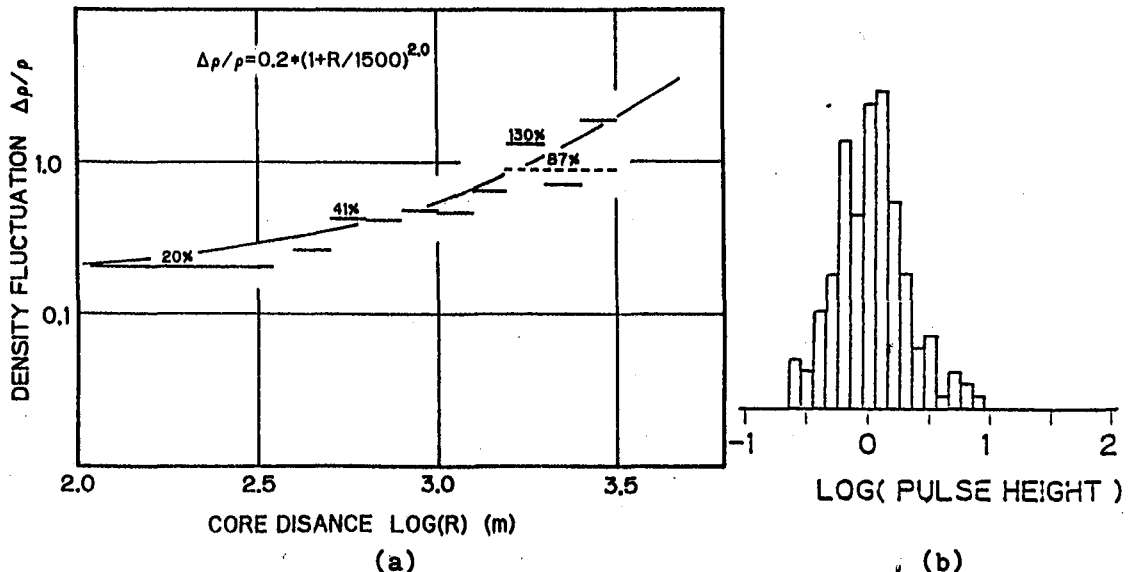At core distances near 2km, the fluctuations become about 100%.



Fig.2 The fluctuation of electron densities(a). The broken line is derived from pulse height distribution of single particles. That is shown in (b).

## 3. Ionization losses in scintillator at far core distances

At far core distances the fluctuations of electron densities become larger. The following causes are possibly related to its increment; the transition effect in scintillator, slow neutrons, large core angle distributions of electrons or broad arrival time distribution of electrons. The last one is important when the densities are measured by one detector of large area.

The transition effect in scintillator is examined by comparing the ionization losses of 16 scintillation detectors of $1\mathrm{m}^2$ area with 5cm thickness and those of 25 detectors of $0.25\mathrm{m}^2$ area with 0.3cm thickness. The ratio of them is $1.05 \pm 0.05$ and the transition effect is negligible.

The slow neutrons may be partly responsible, since the delayed pulses are frequently observed at far from the core[7].

We are measuring the density with the logarithmic amplifier by discriminating the exponential pulse of decay constant 10 μsec. Therefore the successive particle incidence with broad arrival time distribution described in section 5 may contribute to the fluctuation. The fluctuation due to this is estimated to be about 5% at 1km and 60% at 2km, which are less than the observed values. The pulse height distribution of a single particle which traverse the scintillator is measured at core distances around 2km and is shown in fig.2(b). This distribution is obtained with 151 scintillators of 1km$^2$ array when the average density is smaller than 0.2 per detector. Therefore this distribution shows the energy loss distribution of a single particle and is free from the pile up of the exponential pulses. The FWHM is about 100% and is the same with the value of Eq(3). This shows that the large density distribution is not due to the spurious one of the used amplifier.

The large core angle distribution of electrons is expected to be originated from multiple scattering, which is also concerned with time structure of shower front reported in section 5.

4. The lateral distribution of muons(LDM) and the ratio of muon density to electron

The LDM(>1GeV) between 200m and 3km is well expressed by Greisen's formula[6].

$$\rho_\mu(R) = C(R/R0)^{-0.75} (1+R/R0)^{-2.5}. \qquad R0=280m \qquad --------(4)$$

The average LDM for vertical EAS of $10^{18.5}$eV–$10^{19.5}$eV is shown in fig.1.

The average ratio of muon density to electron is shown by horizontal bars as a function of core distances between 100m and 3km in fig.3. The points with error bars are the individual events which are observed by using the detectors of 1km$^2$ array triggered by 20km$^2$ array. The average ratio at core distances between 2km and 3km is 0.20±0.01, but the fluctuation of each event is large.
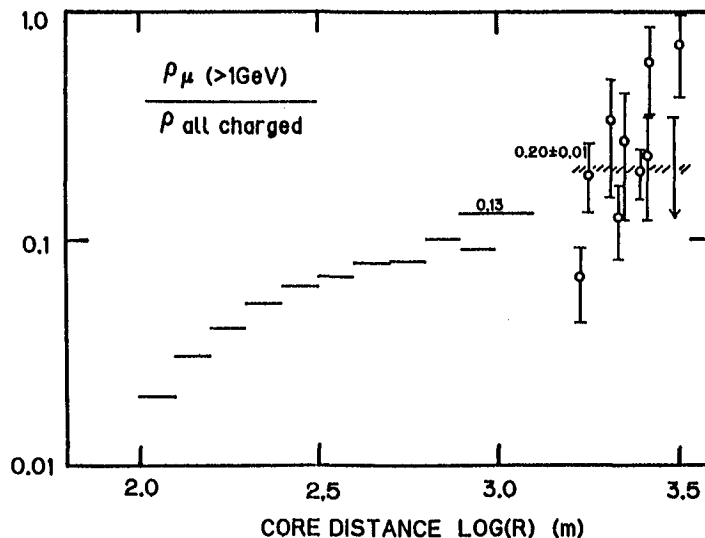


Fig.3 The ratio of muon density to electron.

5. The time structure of shower front

The arrival time of the fastest particle of each detector is measured to determine the arrival direction of EAS. There are 53 fast timing channels with 10nsec resolution in 1km$^2$ array and 23 channels with 20nsec in 20km$^2$. The time structures of shower front are studied by using these 76 channels. Our information is the arrival time of the fastest particle,

but it gives the shower front structure at far from the core where the average density per detector is less than 1.

In fig.4 the dispersion of arrival time is shown. The dispersion increases rapidly at core distances above 2km, and deviates from the extrapolation of the formula given by Linsley[4]. The curvature of shower front shows the similar tendency.
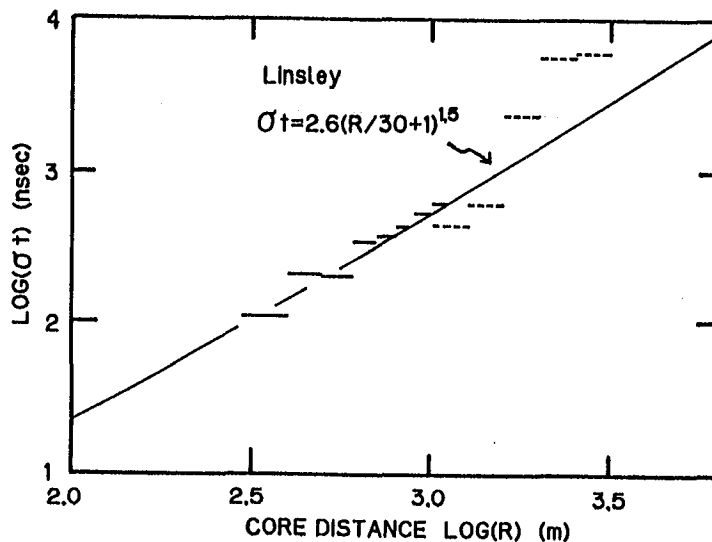
Fig.4 The thickness of shower front.

## 6. Discussion and Conclusion

At core distances above 1km, the LDE becomes steeper than the extraporation of that within 1km. The density fluctuation increases with distances and exceeds 100% above 2km. The causes of the increment of fluctuations are possibly related to the broad arrival time distribution and the large core angle distribution originated from multiple scattering of electrons. The curvature and the thickness of shower front increase more rapidly above 2km. Therefore, it is necessary to arrange the detectors within 1km spacing.

The observation of Giant Air Shower with "mini array" proposed by Linsley[4] has serious limitations, because the lateral distribution of electrons becomes steeper and its fluctuations become large above 1km. Furthermore fraction of low energy muons to total charged particles fluctuate largely in shower to shower. This method requires the detectors of large area.

### Reference

[1] T. Hara et al.,      Proc. 18th ICRC, Bangalore 11 (1983) 276.
[2] M. Teshima et al.,   This conf., La Jolla OG 9.4-8
[3] T. Hara et al.,      Proc. 16th ICRC, Kyoto 8 (1979) 135.
[4] J. Linsley,          Proc. 18th ICRC, Bangalore 12 (1983) 135.
[5] J. Linsley,          Proc. 15th ICRC, Plovdiv 12 (1977) 56.
[6] K. Greisen,          Ann. Rev. Nucl. Sci. 10 (1960) 63.
[7] F. Kakimoto et al.,  This conf., HE4.7-5.