

Energy Spectrum and Arrival Direction of Primary Cosmic Rays of Energy above 10^{18} eV

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Abstract

The observation of ultra high energy cosmic rays with 20km^2 array has started at Akeno. The preliminary results on energy spectrum and arrival direction of energies above 10^{18} eV are presented with data accumulated for four years with the 1km^2 array, for two years with the 4km^2 array and for a half year with the new array. The energy spectrum is consistent with the previous experiments showing the flattening above $10^{18.5}$ eV.

1. Introduction

The detailed study on the energy spectrum and the arrival direction distribution of ultra high energy cosmic rays gives us the information about their origin, acceleration and propagation. There are still discrepancies among experimental results reported, especially in arrival direction distribution at highest energies. In order to clear up these problems, it is essential to increase the statistics. At Akeno the operation of the 20km^2 array has started. In this paper, the preliminary results about energy spectrum and arrival direction of EAS above 10^{18} eV are reported.

2. Experiment

The experiments have been carried out with 3 different arrays, 1km^2 , 4km^2 and 20km^2 . The arrangement of 1km^2 array is described in Hara et al[1]. For 1km^2 array, the data of 4 years are accumulated. The observation with 4km^2 array started at 23rd Dec. 1982[2] and continued until 26th Dec. 1984. The 20km^2 array has been in partial operation from 8th Sep. 1984 and full operation including the 4km^2 array from 27th Dec. 1984. The detector arrangement of 20km^2 array is described in Teshima et al[3].

The trigger requirements of 20km^2 array are 6-fold coincidence of neighbouring detectors of 23 deployed in about 1 km separation with each other. The discrimination level of the signal is 0.5 particle equivalence per detector of 2.25m^2 area.

In this experiment about 250 EAS's of energy above 10^{18} eV and 5 EAS's of above 10^{19} eV are observed.

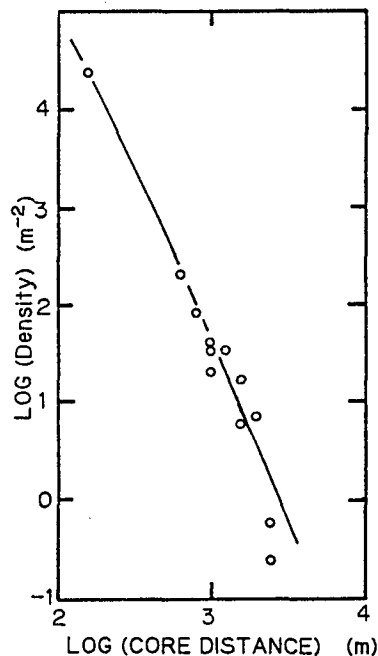


Fig.1(a) The lateral distribution of the largest event.

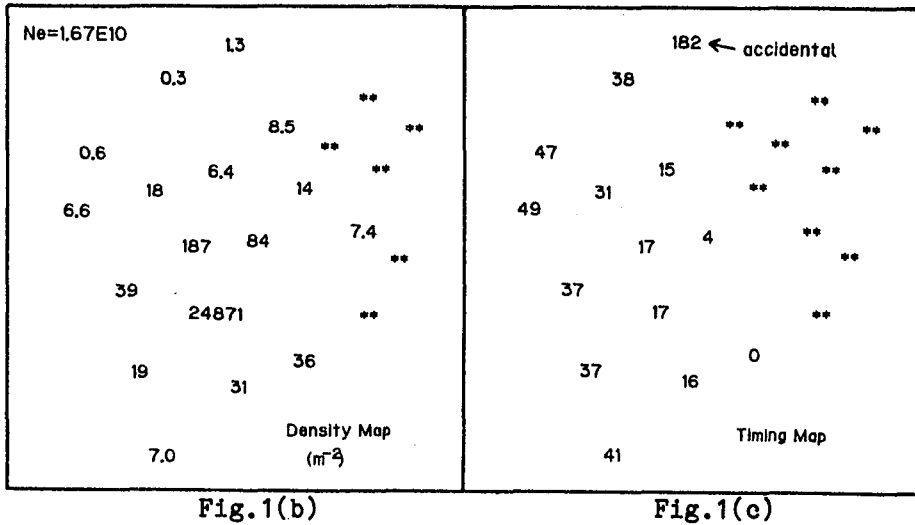


Fig.1(b)

Fig.1(c)

3. The largest event at Akeno

In fig.1 are shown (a) the lateral distribution of electrons, (b) the density map and (c) the arrival time sequence of each detector of the largest event observed so far at Akeno. Numbers of particles per $1 m^2$ are typed on the detector position. In (c) the arrival time differences between each detector and that of the fastest incident particle (indicated by 0) in a unit of 100 ns. This event was recorded in a period under construction of the $20 km^2$ array. The size of total electrons is 1.67×10^{10} and the zenith angle is 30.3 degree. The core hits inside the array. The estimated primary energy is about $3 \times 10^{19} eV$.

4. The electron size spectrum

The electron size spectrum is derived only from the data of EAS's whose cores hit inside the array, because the error in size determination for those outside the array is so large that the spectrum is possibly deviated as described in Teshima et al[3]. Since the collection efficiency of the new array is not 100% for the showers smaller than 10^9 , the effective area is estimated by analyzing 100,000 artificial showers simulated by the Monte Carlo method, which distribute uniformly over the wide area following the size spectrum with exponent of -3 . The collection factor due to the triggering inefficiency and the error of size determination can be estimated by reconstructing the size spectrum of these artificial showers. The size spectrum thus corrected is shown by open circles in fig.2. The new spectrum obtained by the $1 km^2$

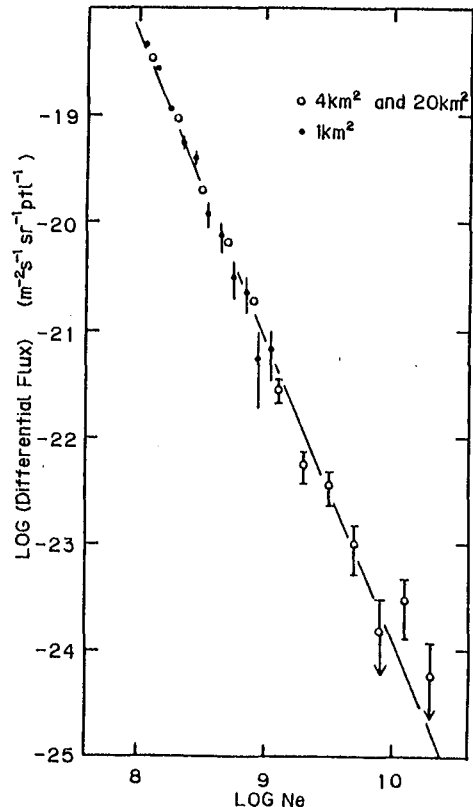


Fig.2 The electron size spectrum.

array with accumulated data are also plotted by solid circles. The effective area times observation time are $2.77 \times 10^8 \text{ km}^2\text{s}$ and $6.08 \times 10^7 \text{ km}^2\text{s}$, respectively. The agreement is satisfactory showing the present correction to be reasonable. The differential size spectrum is expressed by

$$J(N_e)dN_e = (5.65 \sim 6.47) \times 10^{-19} \times (N_e/10^8)^{(-2.72 \sim -2.87)} dN_e m^{-2} s^{-1} sr^{-1},$$

up to 10^{10} , which is consistent with the extrapolation of our previous results[4].

5. The arrival direction

The arrival direction of EAS above 10^{18} eV on the galactic coordinate is shown in fig.3. The area of the open circles are proportional to the primary energies. The smallest circle corresponds to 10^{18} eV and the largest one to 3×10^{19} . These data are the compilation of 1 km^2 , 4 km^2 and 20 km^2 array. The center of the figure is $(l_{II}, b_{II}) = (120, 0)$. The dashed lines indicate the longitude and latitude of equatorial coordinate. The exposure is almost uniform along the longitude lines expressed by the dashed circles, but not along the latitude lines.

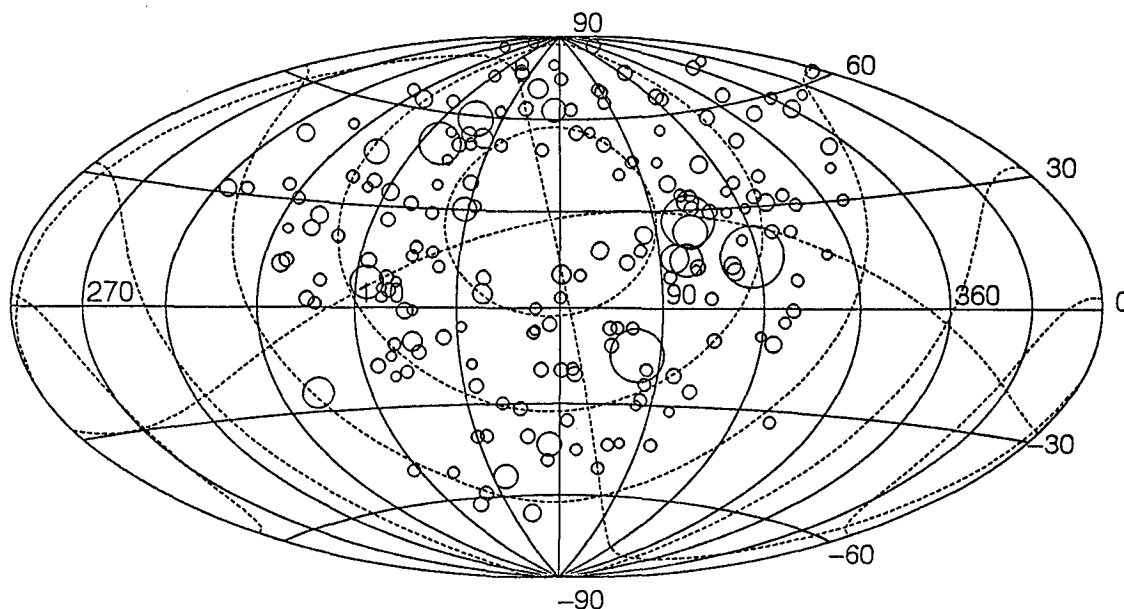


Fig.3 The arrival direction distribution of EAS's above 10^{18} eV on the galactic coordinate.

6. Discussions

The primary energy spectrum is derived from the present size spectrum by multiplying the conversion factor which was derived at smaller size regions as $w \times R = 3.9 \times (N_e/10^6)^{-0.105} \text{ GeV}$ [4]. Where w is the conversion factor from electron size at the maximum development, 1.4 GeV [5] and R is the ratio of the shower size at maximum to the size at 920 gcm^{-2} .

In fig.4 the primary energy spectrum derived from the data of 4 km^2 array and 20 km^2 is shown by the open circles and compared with the previous experiments. The total exposure is about $10 \text{ km}^2 \cdot \text{year}$ for the

showers of 10^{19} eV. This result shows the good agreement with our previous result with the Akeno 1km^2 array[4] at energy region between 10^{17} eV and 10^{18} eV. Above 10^{18} eV the present spectrum is consistent with the results of Haverah Park[4], Yakutsk[5] and Sydney[6] showing the flattening. Here the Sydney results are plotted by applying the conversion factor used in ref[4].

Though the statistics is not enough, some interesting features can be seen around 10^{18} - 10^{19} eV. That is, the largest showers are clustered around the Cygnus direction and the spectrum shape does not follow the simple power law.

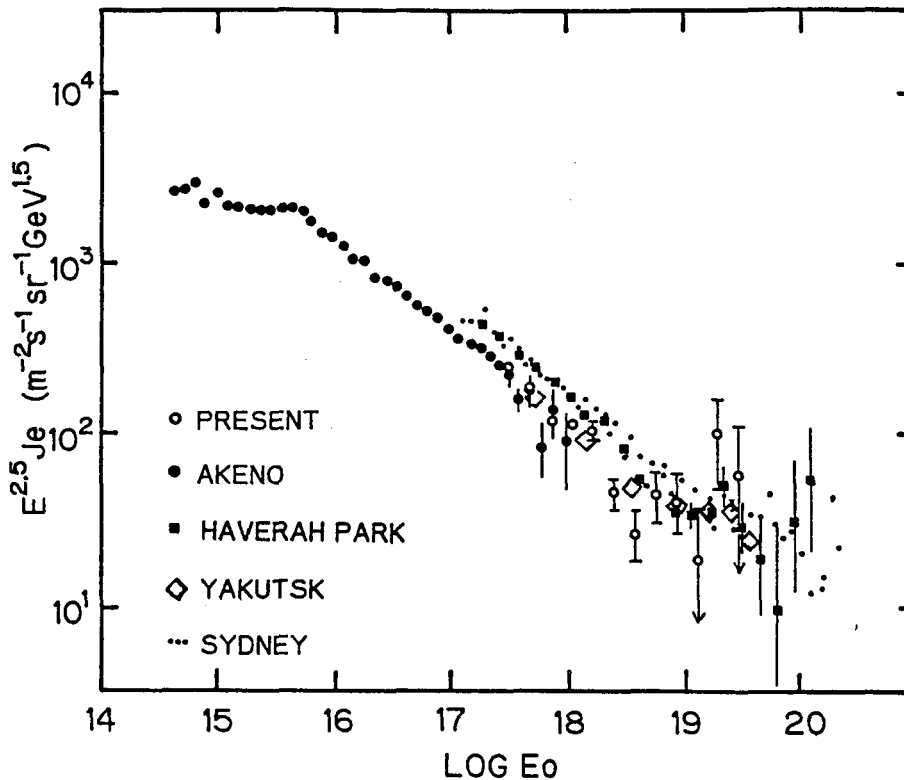


Fig.4 The primary energy spectrum.

Acknowledgements

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