OBSERVATION OF ARRIVAL TIMES OF EAS
WITH ENERGIES $\geqslant 6 \times 10^{14}$ eV

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1. Introduction

The earth's atmosphere is continually being bombarded by primary cosmic ray particles which are generally believed to be high-energy nuclei. The fact that the majority of cosmic ray primaries are charged particles and that space is permeated with random magnetic fields, means that the particles do not travel in straight lines. This makes the identification of distant sources very difficult. Nevertheless, studies of the arrival time and direction distribution of cosmic rays are still used to seek significant information on problems of their origin. From the beginning of the 1950's to the middle of the 1960's about 50 experiments were carried out to study the arrival directions of EAS with energy range from about 10^{14} to 10^{17} eV. Linsley and Watson [1] summarised the results of these experiments and gave a review at 15th Cosmic Ray Conferece.

On the other hand, the arrival time distribution of EAS may also transfer some information about the primary particles. Actually, if the particles come to our earth in a completely random process, the arrival time distribution of pairs of successive particles should fit an exponential law. This is derivable from Poisson's distribution. Several groups [2,3] have reported a non-random component in the arrival times of EAS with $E > 10^{14}$ eV, but others [4] did not find it.

The work reported here was carried out at Sydney University from May 1982 to January 1983. The results are discussed and compared with that of some other experiments.

2. Experiment System

This experiment work was carried out by using the Sydney Small Air Shower Array. This sea level array has been described in detail elsewhere [5]. The array is composed of four fast timing scintillators arranged as a 25m×25m horizontal square with four triggering scintillators in a 4m×4m square in the same plane as the fast timing scintillators. The triggering scintillator square is close

but not at the centre of the fast timing square. Pulses from the scintillators are sent via fast rise time coaxial cables to the recording electronics which is in an air conditioned hut with the triggering scintillators. The recording electronics uses NIM/CAMAC System. A master trigger pulse is produced if three out of four of the triggering scintillators receive shower particles. Showers are analysed in a desk-top compuer which is employed to control the recording system. The shower direction is found by a weighted least-squares fit of a plane shower front to relative arrival time of each detector. Then, using the maximum likelihood method to estimate the shower size and core position. Finally, the celestial coordinates of the incident direction of the event is found out. The rate of analysed showers is 127 per day or one every 11.3 minutes on average. The time needed for the full analysis is about 30 seconds.

3. Analysis and results

The data discussed here were obtained in the period from May 27 in 1982 to January 12 in 1983 at the campus of Sydney University (latitude $33°$ s). During this period more than 23000 showers were recorded. The data are analysed in two different ways as follows.
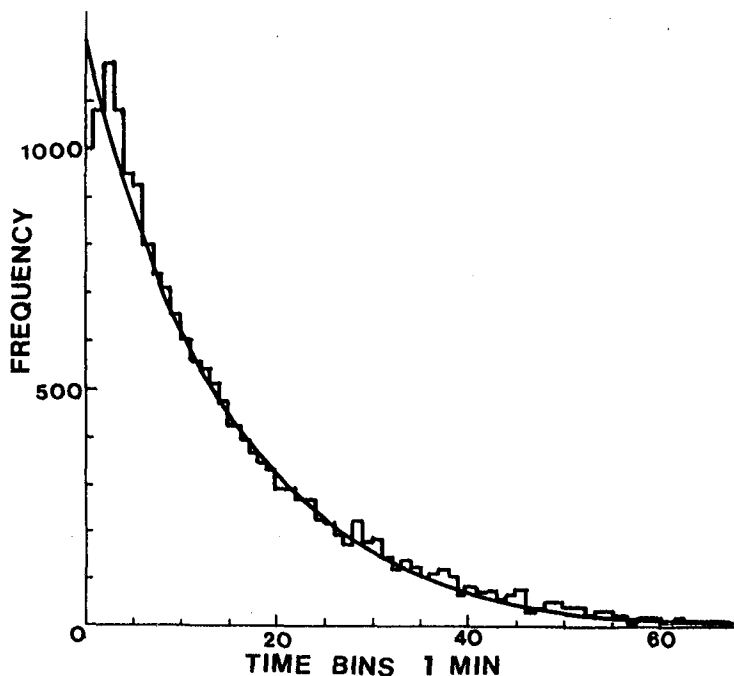

Fig. 1 Cosmic ray arrival time distribution

Firstly, all the data are used to plot the arrival-time distribution of the events, that is, the distribution of time-separation t between consecutive events on a 1 minute bin size (Fig. 1). The smooth curve shows the expected exponential distribution of the arrival times assuming that the time of occurrence of the events is completely random:

$$n = N \bullet (e^{-\lambda t_1} - e^{-\lambda t_2})$$

where λ is the average number of events per unit time. As can be seen

from Fig. 1, the observation data are compatible with random expectation. After adding the estimated losses for the observation data, no deviations are greater than 3σ. So that no experimental evidence for abnormal behaviour in the inter shower arrival time distribution has been found.

Then, the data are analysed with respect to the sidereal time variation. Since the experiment was interrupted occasionally for maintenance and by power failures, some allowances for this interruption must be made before the analysing. After rejecting certain numbers of events from those "over-exposure" time intervals, the run time for every sidereal hour interval is unified. The data are analysed by using the "random walk" harmonic method and the results are:

the fractional amplitude $r = (1.9 \pm 1.1)$ %,
the probability of observing an amplitude $\geq r$ $p = 0.21$,
the phase of maximum $\psi = 74° \pm 33°$.

To compare these results with that of the experiments summarised in Ref. (1), they are plotted together in Fig. 2 (after Kiraly et al (6)). the value of p of the present experiment sits at the middle of Fig. 2 (1), and the value of ψ just falls in the gap of the old data in Fig. 2 (2). If anything this confirms the isotropy of arrival directions.

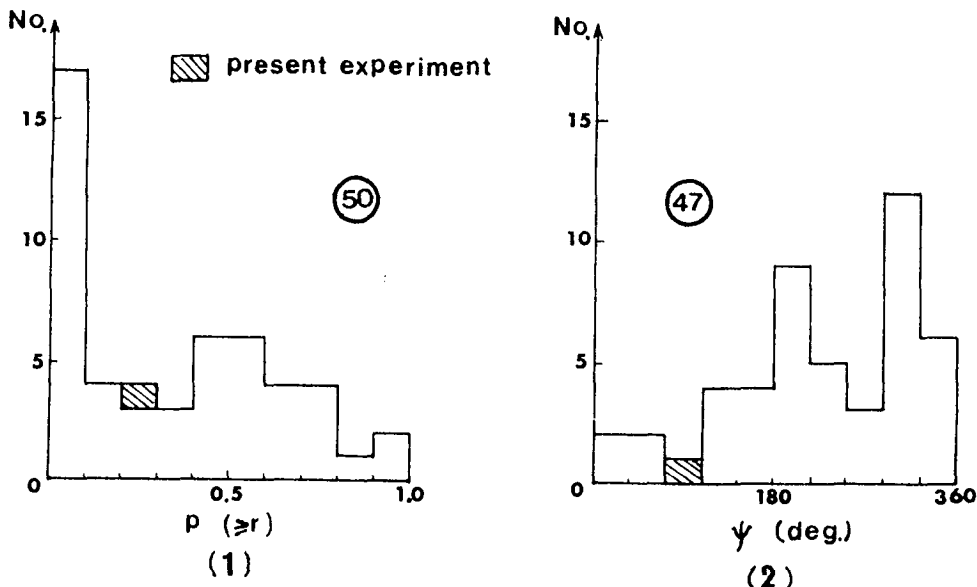(1)   (2)

Fig. 2 Comparison of the present experiment with the data of Ref. (1). The ordinates are the frequencies and the circles contain the numbers of experimental sets contributing to the data (excluding the present experiment).

The data are also tabulated on Mercator Projections and a series of chi-squared tests is applied. The results are shown in Fig. 3. The largest value of X^2 for the tabulation is 57. The probability that X^2 should have exceeded this value for one or more of eight independent

Mercator Projection of Celestial Sphere

Dec \ RA	0	30	60	90	120	150	180	210	240	270	300	330	360	AVE	χ²
50	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0		
40	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0		
30	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 1	0 0 0	0 0 0	0 0 0	0 0 1	0 0 0	0		
20	0 2 0	0 0 1	1 1 0	0 0 1	0 0 0	1 0 1	1 1 1	0 2 1	1 0 0	1 0 1	0 0 0	0 0 1			
10	5 6 6	11 10 0	4 10 5	8 3 6	6 4 9	7 5 4	6 9 4	7 5 8	3 5 6	8 7 6	6 6 8	4 10 4		6	31
0	33 30 36	31 38 30	35 17 30	35 31 40	28 28 34	25 32 31	24 30 34	19 24 35	37 30 39	31 26 29	19 29 31	26 25 36		30	35
−10	61 75 57	71 80 68	83 88 58	74 75 78	77 69 50	78 59 65	65 83 72	63 71 80	58 78 66	84 75 74	75 73 63	78 75 65		71	38
−20	90 98 118	94 100 122	98 104 136	113 101 105	127 101 94	129 109 106	105 103 82	90 92 90	103 128 108	89 115 94	114 107 96	115 118 121		106	57
−30	117 120 107	112 123 122	125 128 100	104 115 110	105 116 121	116 116 124	122 130 110	113 122 118	96 114 128	108 96 123	102 114 113	120 125 123		116	24
−40	84 84 90	90 95 85	89 96 98	86 86 72	89 84 73	92 83 86	70 88 83	78 85 101	88 73 82	83 79 71	83 88 81	73 98		85	25
−50	54 42 40	45 38 41	39 45 42	42 49 57	37 53 46	49 45 45	56 44 54	40 44 50	34 39 49	53 40 42	46 48 47	57 47 41		46	27
−60	11 6 13	14 13 14	9 17 21	20 10 14	13 11 12	9 14 11	18 23 14	18 17 12	20 16 16	17 22 11	12 12 18	11 14 16		14	38
−70	3 2 0	2 4 2	0 3 5	4 1 3	1 2 1	1 1 2	0 4 2	7 1 2	3 2 3	2 4 4	2 0 0	3 3 1			
−80	0 0 0	0 1 1	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0 0 0	0 0 1	0 1 0	0 0 0			

Declination / Right Ascension

Fig. 3 Cellular division of Mercator Projection of celestial sphere for 17164 showers.

bands is 12%. Thus the chi-squared tests show no significant evidence of anisotropy in the tabulated distributions.

4. Acknowlegement

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References

1. Linsley, J. et al, Proc. 15th ICRC, Plovdiv, Vol. 12 (1977), 203.
2. Bhat, C. L. et al, Nature, V288 (1980), 146.
3. Badino, G. et al ,Lett. Al Nuovo Cimento, V28 (1980), 93.
4. Fegan, D. J. et al, Proc. 17th ICRC, Paris, Vol. 6 (1981), 296.
5. Sun, L. et al, Nucl. Instr. & Meth. , 223 (1984), 173.
6. Kiraly, P. et al, Rivista del Nuovo Cimento, 2 (1979), 1.