III-4-19. Fluctuations and Correlations in the Fluctuations of Various Components of Extensive Air Showers

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§ 1. Introduction

An extensive air shower array comprising of the following units is in operation at mountain altitude of 800 g/cm^2 (Fig. 1) for the last nine months.

(a) 12 scintillators spread over an area of 80 m$\times$80 m to measure the densities of charged particles at various distances from the core.

(b) 4 additional scintillators placed at the corners of a square of side 16 m, (in the centre of the array) coupled to a 45 channel nano-second chronotron timing equipment, to determine the angle of arrival of showers.

(c) 9 N-particle detectors each of area 0.4 m^2. clustered together at the centre of the array. Each detector is similar to the Simpson type neutron monitor and comprises of 4 BF_3 (enriched) counters surrounded by paraffin and lead. Cadmium sheets introduced in between the detectors prevent slow neutrons from one detector influencing the adjacent detector.

(d) 3 μ-meson detectors each of area of 0.6 m^2: these consist of hodoscoped G-M counter trays. Two of the trays are under 5 ft. brick and 2$''$ of lead ($\approx$ 20 radiation lengths) and the third under 750 g/cm^2 of iron ($\approx$80 radiation lengths). In each tray there are 15 counters and these are connected to 5 hodoscope channels.

(e) One energy flow detector of area 0.36 m^2. located at the centre of the array —this consists of a scintillator placed under 2.5 cm lead.

(f) A total absorption spectrometer (120 cm$\times$120 cm) described in detail in the following paper.

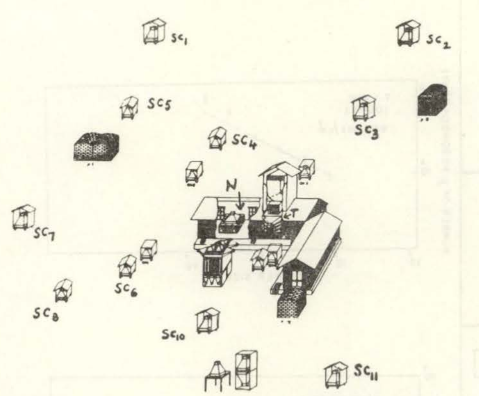

Fig. 1. Extensive Air Shower Array at Ootacamund (800 g/cm^2)
$SC_1 \ldots . SC_{12}$=Scintillation counters.
$CH_1 \ldots . CH_4$=Fast scintillators for timing.
μ_1, μ_2=μ-meson detectors (1.8 m Bricks+5 cm Pb).
T=Total absorption spectrometer.
μ_3 is below the spectrometer (under 150 g/cm^2 Iron).
N=9 N-detectors at the centre of the array.

This array has been designed specifically to study fluctuations and correlations in the fluctuations of N-particles and μ-mesons. 20,000 showers have been recorded and about 5000 showers have been analysed on the electronic computer of the Tata Institute of Fundamental Research (TIFRAC). The main results are presented in the following sections.

2. Lateral Distribution of the Density of Charged Particles

For analysis on the computer the lateral distribution of the density of charged particles is assumed to have the form.

$$\Delta(r)=c(d)\cdot\frac{1}{r^{\alpha}}\cdot e^{-r/r_0}$$

where r is the distance from the core and α is a measure of the steepness of the lateral distribution near the core and r_0 is the

* This paper was combined with III-4-20, III-4-21 and presented by B. V. Sreekantan.

scattering length which has a value of 106 m for an altitude of 800 g/cm². Four values of α, *i.e.* 1.3, 1.5, 1.7, and 1.9 are tried for each shower and the computer prints out the best valve of α, the corresponding core position and shower size. The mean value of α increases with shower size as shown in Fig. 2. The increase was similar for vertical and inclined ($\theta > 40^0$) showers.

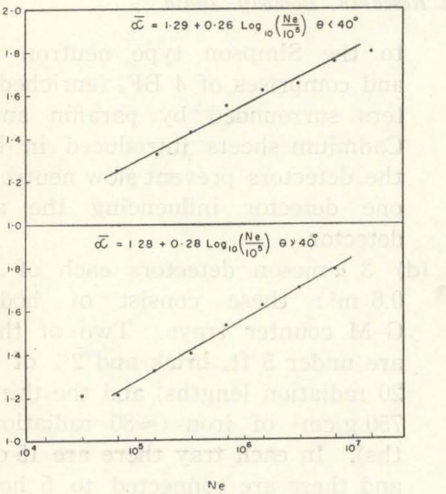

Fig. 2.

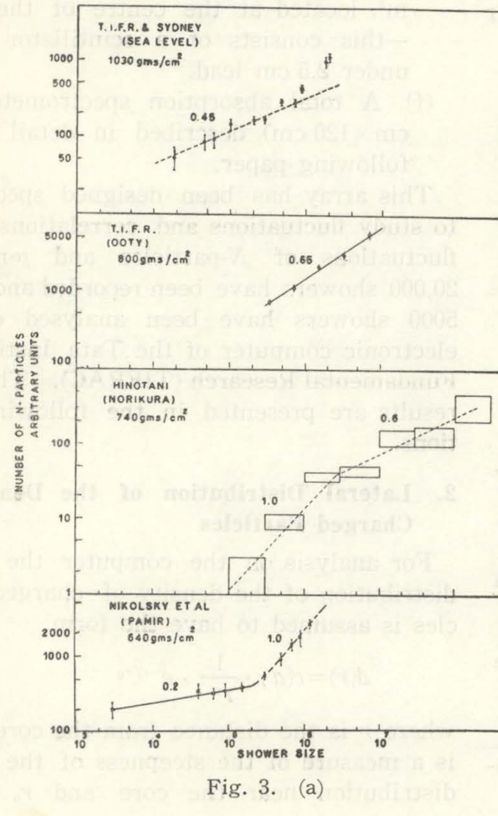

Fig. 3. (a)

3. Variation of the Number of Nuclear Active Particles and μ-mesons with Shower Size

If the assumption is made that there are no large intrinsic fluctuations in the densities of N-particles in showers of the same N_e then the density $\Delta(N_e, r)$ is given by

$$\Delta(N_e, r) = \frac{1}{S\varepsilon m} \ln \frac{T}{T-Q}$$

where S is the area of N-detector, m is total number of detectors and ε is the efficiency of N-detectors, T is the total number of showers of size N_e with cores at distrance r from N-detectors. For our set-up $S=0.4$ m², $\varepsilon=0.25$, $m=9$. Using this procedure, the lateral distribution of the density of N-particles were determined up to a distance of 40 m from the core and by integrating the lateral distribution curves the number of nuclear active particles contained in a radius of 40 m around the core, were determined for various shower sizes. The results are shown in Fig. 3 (a) in which for

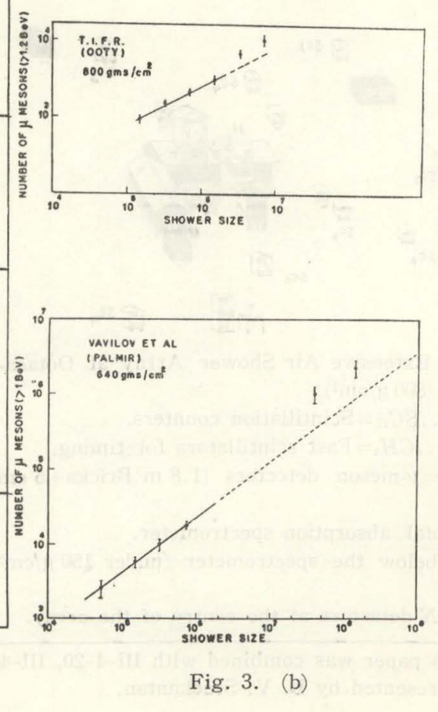

Fig. 3. (b)

comparison purposes similar results of other groups are also presented.

By a similar procedure and considering only the μ-meson detector under 750 g/cm^2 of iron, the variation of the number of μ-mesons within 40 m of the core, as a function of shower size was also determined. The results are shown in Fig. 3b, and compared with the results of others.

4. Fluctuations of *N*-particles and μ-mesons

In all experiments in which the total number of nuclear active particles or μ-mesons have been determined, the statistical procedure outlined in the previous section has been adopted, since it has not been possible to determine the lateral distribution of these components in individual showers. This method will lead to erroneous results if the number of nuclear active particles or μ-mesons fluctuate appreciably in showers of the same size. If the fluctuations are only poissonian, then the number $F(n)$ of showers in which 'n' out of 'm' *N*-detectors are activated is given by

$$F(n) = T \cdot P(n, \Delta) \qquad (2)$$

where $$P(n, \Delta) = {}^{m}C_n [1 - e^{-s\varepsilon\Delta}]^n \, e^{-s\varepsilon\Delta(m-n)} \qquad (3)$$

If the density of *N*-particles has a unique value for all showers of the same size, then

Table I. *N*-Particles

$$F(n) = T \cdot {}^{m}C_n (1 - e^{-s\varepsilon\Delta})^n e^{-s\varepsilon\Delta(m-n)}$$

Shower Size (N_e)	Core Distance (in meters)	Δ (particles per m^2)	T	$F(n)$ 0	1	2	3	4	5	6	7	8	9
5.10^6—10^7	10—15	2.11	40	6	8	9	6	4	5	0	0	2	—
				6	12.6	12	6.5	2.3	0.54	0.08	0.008	5×10^{-4}	—
10^6—2.10^6	4—6	2.85	13	1	1	2	1	1	1	3	3	—	—
				1	2.97	4	3	1.5	0.5	0.1	0.015	1.3×10^{-3}	—
10^6—2.10^6	6—10	1.12	129	47	29	22	14	5	4	3	4	1	—
				47	50	24	6.6	1.2	0.14	0.01	6×10^{-4}	1.7×10^{-5}	—
2.10^6—5.10^6	6—10	1.67	54	12	8	9	5	4	7	2	4	3	—
				12	19.6	14.3	6	1.66	0.3	0.04	0.003	1.3×10^{-4}	—
2.10^5—5.10^5	2—4	1.45	39	16	16	9	9	4	2	1	1	1	—
				16	22.4	14	5.1	1.2	0.2	0.02	1.3×10^{-3}	5×10^{-5}	—
5.10^5—10^6	4—6	1.75	63	13	10	11	11	5	6	4	3	—	—
				13	22.4	17.2	7.7	2.2	0.42	0.05	4.4×10^{-3}	—	—

Table II. μ-Mesons

$$F(n) = T \cdot {}^{m}C_n (1 - e^{-s\varepsilon\Delta})^n e^{-s\varepsilon\Delta(m-n)}$$

Shower Size (N_e)	Core Distance (in meters)	Δ (particles per m^2)	T	$F(n)$ 0	1	2	3	4	5
5.10^6—10^7	15—25	1.53	64	26	19	12	5	1	1
				26	25.7	10.1	2	0.197	0.007
2.10^6—5.10^6	15—25	1.2	87	43	21	11	7	3	2
				43	32.5	9.85	1.5	0.13	0.034
10^6—2.10^6	15—25	0.85	125	76	26	13	7	2	1
				76	39.8	8.3	0.87	0.046	0.0009
5.10^6—10^7	15—25	2.14	60	17	20	15	5	2	1
				17	24.5	13.9	4	0.58	0.033

Table III. Correlation in fluctuations of N-particles and μ-mesons.

$$R=\frac{\text{Average No. of detectors activated for showers in which } \mu_1, \mu_2, \mu_3 \geq 1}{\text{Average No. of detectors activated for all showers}}$$

Shower size	Rn	$R\mu_1$	$R\mu_2$	$R\mu_3$
(2–5) 10^5	2.6±0.5	3.6±0.6	4.0±0.8	2.5±0.5
(5–10) 10^5	1.5±0.25	2.44±0.35	2.6±0.4	2.1±0.26
(1–2) 10^6	2.3±0.3	2.2±0.3	2.1±0.3	2.0±0.25
(2–5) 10^6	1.7±0.2	2.9±0.3	2.1±0.2	1.94±0.22
(1–2) 10^7	2.26±0.32	2.20±0.3	1.67±0.23	2.04±0.3
(2–5) 10^7	1.17±0.3	3.0±0.7	1.85±0.3	2.55±0.5
*(1–2) 10^7	4.2±0.9	2.5±0.6	2.7±0.7	2.9±0.7

* The group corresponds to showers in which $\mu_1, \mu_2, \mu_3 \geq 2$

Δ can be calculated from (1) and compared with the experimental distribution. This comparison has been made for N-particles in Table I and for μ-mesons by adopting an identical procedure, in Table II.

It is seen that the observed distribution deviates considerably from that calculated according to (1), (2), and (3). The deviation is more than what can be accounted for in terms of the finite width of size groups and core distances, chosen. It is therefore necessary to exercise a certain amount of caution in the interpretation of the curves presented in Fig. 3. To understand the full implications of those curves one should have all the data on fluctuations and the variation of fluctuations with size.

5. Correlations in the Fluctuations of N-Particles and μ-mesons

In order to see whether there exist correlations between the fluctuations of μ-mesons and N-particles the following procedure was adopted. The average number of μ-mesons that passed through any one of the μ-detectors was determined for the various shower sizes. From each particular size group those cases in which at least one μ-meson passed through each of the three μ-detectors (separated by more than 20 m) were picked up. For these cases the average number of μ-mesons passing through each of the detectors was calculated and compared with the average for all the showers of that size group. These ratios are given in Table III. For these cases in which the total number of μ-mesons had fluctuated, the average number of N-particle detectors that were activated was determined and compared with the average for all the showers. This ratio is also given in the Table III.

It is seen that the μ-mesons and N-particles fluctuate together and the order of fluctuation is of comparable magnitude.

Discussion

Discussion for Papers III-4-19, III-4-20 and III-4-21 is combined and given after the Paper III-4-21.