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The electron component of large EAS

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Abstract. A large-area neon flash-tube detector has been used to measure the density of electrons occurring in EAS detected at Haverah Park for shower size $0.29 < \rho_{500} < 1.7$. Comparison of the total charged particle lateral density distribution with that of the muon component is made. The response of the flash tubes is also compared with that from neighbouring 1·2 m deep water Čerenkov tanks.

1. Introduction

Model calculations suggest that the electron to muon density in EAS is a sensitive parameter for the study of the primary mass composition of cosmic rays. The Nottingham detector is used to study both components simultaneously on the same piece of equipment. For the electron studies 8 m^2 of the 12 m^2 detector are used.

The detector is a sandwich of iron, lead, flash tubes and scintillator as described in Armitage *et al* (1973, to be referred to as I). The total charged-particle density measurements are carried out using information from the first two layers of neon flash tubes situated beneath 2·5 cm of steel. The associated muon component is revealed by the other elements of the detector as described by Blake *et al* (1971). Comparison of the response of the neon flash-tube trays with and without the presence of the steel gives rise to a correcting factor to obtain the response of unshielded flash tubes.

2. Shower selection and analysis of data

Showers were selected in which the densities at three stations of the Haverah Park 500 m array were greater than 0·45 veμm^{-2}; the core range was restricted to $200 \text{ m} < R < 500 \text{ m}$.

The finite size of each flash tube leads to the possibility of more than one particle ionizing a particular tube. In order to determine the relationship between the number of tubes flashing and the incident charged-particle density a Monte Carlo technique was used. A number (between 1 and 90) was chosen, representing the incident particles, and 5000 to 10 000 simulations were carried out in which these 'particles' were allowed to fall randomly within the area of the detector. The number of flash tubes which would have been traversed by one or more of the 'particles' was computed. Thus the relation between the observed number of flashed tubes and the average number of incident particles was established. A plot of this relationship is shown in figure 1. At more than 40 tubes flashing the number of particles in a particular event becomes increasingly uncertain and this sets the upper limit to the density range that can be usefully used.

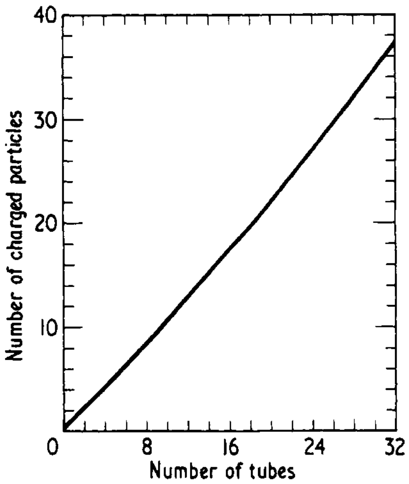

Figure 1. Number of particles incident compared with number of tubes flashing.

3. Lateral distribution of electrons

For six shower size intervals the total charged-particle density (below 2·5 cm of steel) at five mean core distances was determined and corrected for layer efficiency and resolution effects. The distributions are shown in figure 2, and table 1.

Using a simple power law structure function of the form $\rho_{all} = KR^{-n}$ the mean value of n was found to be $2{\cdot}94 \pm 0{\cdot}28$ compared with $2{\cdot}07 \pm 0{\cdot}10$ for the muon structure

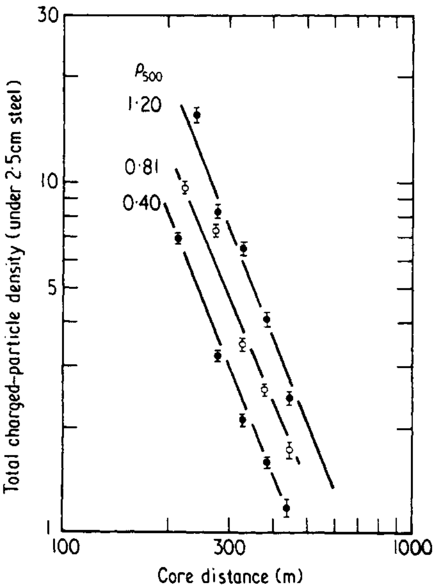

Figure 2. Total charged-particle density as a function of core distance and shower size.

Table 1. Density response as function of core distance and shower size

Mean ρ_{500}						
0·28	Mean R (m)	227	260	329	374	
	ρ_{all}	5·12	2·81	2·33	0·71	
	Error	±0·45	±0·30	±0·51	±0·28	
0·40	Mean R (m)	221	279	326	383	437
	ρ_{all}	6·98	3·20	2·11	1·69	1·36
	Error	±0·21	±0·12	±0·10	±0·12	±0·18
0·56	Mean R (m)	223	279	318	376	455
	ρ_{all}	8·87	5·09	3·10	1·79	1·21
	Error	±0·17	±0·16	±0·15	±0·10	±0·08
0·81	Mean R (m)	225	274	329	379	445
	ρ_{all}	9·69	7·38	3·45	2·59	1·73
	Error	±0·38	±0·22	±0·17	±0·12	±0·08
1·20	Mean R (m)	239	273	328	382	457
	ρ_{all}	16·07	8·19	6·50	4·09	2·41
	Error	±0·64	±0·32	±0·30	±0·20	±0·12
1·80	Mean R (m)	275	328	376	441	
	ρ_{all}	15·37	11·99	5·34	3·70	
	Error	±0·71	±0·72	±0·33	±0·28	

function. A much better fit was found however using the function

$$\rho_{all} = K\frac{1}{R}\left(1+\frac{R}{R_0}\right)^{-(\eta-1)}.$$

The value of η was found to be $3{\cdot}79 \pm 0{\cdot}05$ with $R_0 = 160$ m. This value is to be compared with the value of η for the Čerenkov detectors found by the Leeds group which is 3·48, for a mean zenith angle of 17°. This is in agreement with expectations since the Čerenkov detector preferentially detects the muon component.

The experimental lateral density distributions for one interval of shower size ($\rho_{500} = 1$) for the muon, Čerenkov tank and total charged component are shown in figure 3, for comparison.

4. The electron–muon ratio

For each ρ_{500} interval, the total charged particle to muon ratio was determined at various core distances by making cuts across the two lateral density distributions. The mean ratio for each core distance was then determined. The results are shown in table 2.

The only directly comparable recent data are those of the Sydney group (C B A McCusker 1972, private communication) who used shielded and unshielded spark chambers to investigate the electron–muon ratio. These detectors are situated in the EAS array near Narrabri (SUGAR). The primary energy range investigated was similar to that of the present experiment. The results of the Sydney group showed a deficiency

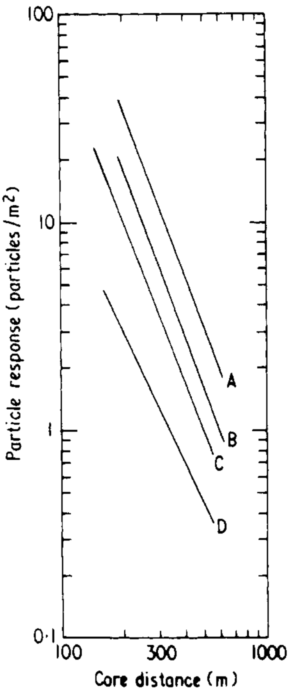

Figure 3. Comparison of measured muon, Čerenkov tank and all charged-particle densities as functions of core distance. Curve A, unshielded flash tubes; curve B, all charged particles (under 2·5 cm steel); curve C, Čerenkov tanks; curve D, muon densities.

Table 2. Comparison of charge-particle density and muon density as functions of core distance

Mean core distance (m)	ρ_{all}/ρ_μ (under 2·5 cm steel)	ρ_{all}/ρ_μ (unshielded flash tubes)	ρ_{all}/ρ_μ (Greisen)	ρ_{all}/ρ_μ (Sydney)
200	6·4 (±0·2)	12·8 (±0·6)		
238	5·9 (±0·2)	11·8 (±0·6)	9·3	$6{\cdot}9^{+1{\cdot}8}_{-1{\cdot}3}$
300	5·0 (±0·2)	10·0 (±0·6)		
360	4·4 (±0·15)	8·8 (±0·5)	5·6	$4{\cdot}9^{+5{\cdot}5}_{-2{\cdot}1}$
475	3·8 (±0·15)	7·6 (±0·5)	4·2	$1{\cdot}9^{+1{\cdot}7}_{-1{\cdot}0}$

in the numbers of electrons detected at distances of 200 m and less from the core compared with that predicted using the Greisen structure functions.

In order to compare data from the two experiments it is necessary for us to convert our densities, as measured under 2·5 cm of steel plate, to obtain the response equivalent to unshielded flash tubes. Two different methods have been used to determine this conversion factor. An unshielded double layer of flash tubes was operated for six months directly above a double layer of steel-shielded tubes. A comparison of the two responses to EAS in the core distance range 200 m–500 m is shown in figure 4. From this

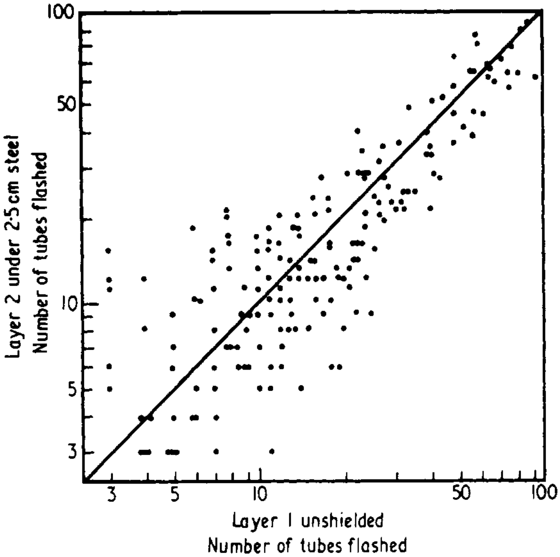

Figure 4. Comparison of response of shielded and unshielded flash tubes.

data, after correcting for resolution, a conversion factor was obtained, that is,

$$\frac{\text{response of unshielded tubes}}{\text{response of steel shielded tubes}} = 1{\cdot}8 \pm 0{\cdot}2.$$

An alternative method of obtaining this conversion factor is to make use of the fact that the Nottingham apparatus contains 3·3 m^2 of unshielded flash tubes as part of the muon direction-measuring array. Comparison of the densities measured by these tubes and those under 2·5 m of steel, shows the top layer of the unshielded detector to have a mean response 2·2 ± 0·2 times higher than that of steel-shielded tubes, a result consistent with the other method.

The conversion factor was found to be independent of core distance. The shape of the lateral distribution thus remains unchanged but the densities shown in figure 2 and table 1 should all be increased by a factor of about 2·0 (±0·2) to yield the response of the unshielded tubes.

The corrected total charged particle to muon ratio is shown in the second column of table 2. The Sydney data along with the predictions of the Greisen (1960) formulae are also shown. It is seen that, over the mutually compatible range, the data obtained from the Nottingham experiments indicate a less steep fall-off with R than that obtained by the Sydney group and are in better agreement with the Greisen figures. Saturation effects in the neon detectors prohibit measurements closer than 150 m to the shower core. It would not seem that the slightly lower muon energy threshold sensitivity of the Sydney detector, that is, about 0·25 sec θ GeV compared with about 0·30 sec θ GeV of the Nottingham detector could explain the difference in absolute values or the form of the variation with R. Since $\rho_\mu = \rho_{500}^{\alpha}$ with $\alpha < 1$ (see I) the electron–muon ratio will be a slowly varying function of shower size. The Nottingham figures represent measurements over the size range $0{\cdot}4 < \rho_{500} < 1{\cdot}80$, that is, approximately 10^{17} eV $< E_p < 5 \times 10^{17}$ eV; the Sydney group data are over the range $1{\cdot}5 \times 10^6 < N_\mu < 7{\cdot}5 \times 10^6$ which is closely the same primary energy (E_p) range.

A possible explanation of the lower electron content of the Sydney data is that they preferentially observe showers low in electrons as they rely on the muon component solely to trigger the SUGAR array. However, this discrepancy between the two sets of data is most likely due to a difference in the performance of the two types of detector and must be further investigated.

Shielded and unshielded liquid scintillators are now being brought into operation on the Nottingham apparatus. It will then be possible to investigate the electron–muon ratio closer into the core and at the same time study the comparative responses of the different types of detector to EAS in more detail.

Acknowledgments

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