FINAL RESULTS ON THE TIFR COSMIC RAY ELECTRON SPECTRUM IN THE REGION 10 TO 800 GeV

K. C. Anand, R.R. Daniel and S. A. Stephens

Tata Institute of Fundamental Research, Bombay, India 4000005

Preliminary results from an experiment carried out to determine the energy spectrum of high energy cosmic ray electrons using a large lead-emulsion sandwich stack, based on 51 electrons of energy greater than 150 GeV were reported at the Hobart Conference. The final data reduction and analysis have now been completed for 86 electrons of energy greater than 50 GeV. Earlier experiments from this group using pure emulsion blocks have yielded results between 10 and 200 GeV; these observations obtained using different scanning and energy determination procedure are in good agreement with one another and those from the present experiment. The results are therefore combined to yield a spectrum from about 10 GeV to 800 GeV using a total of 177 electrons.

1. Introduction. The study of the spectral shape of high energy cosmic ray electrons allows us to understand the propagation of cosmic rays and to deduce the information about the electromagnetic conditions in the region of their traversal. In the past, we have published results on the energy spectrum of cosmic ray electrons in the 10-200 GeV region from experiments carried out using pure emulsion stacks, in which the electrons were unambiguously identified. Thereafter, we reported preliminary results of the spectrum in the energy region 150-800 GeV using a lead-emulsion sandwich stack, specially designed to cover the above mentioned energy region as well as to retain the advantages of a pure emulsion stack capable of unique identification of electrons. In this paper we give the final differential energy spectrum of primary electrons in the region 10 to 800 GeV by combining the results from this experiment with the earlier experimental results.

2. Experimental details.

2.1 Detector assembly. Use is made of a large horizontal lead-emulsion sandwich assembly (Anand et al., 1970a) consisting of an upper block of pure emulsions 1.8 cm thick having 30 Ilford G-5 pellicles and a lead-emulsion sandwich block, having 16 alternate layers of 600 μm thick pellicles and lead sheets; the top lead sheet was 1mm thick followed by 9 of 2mm and 6 of 3mm. The pure emulsion block acted as unique identifier of electrons and the sandwich block permitted the detection and energy estimation of the electrons. The detector had a total depth of 8.3 r.l. and an area of 45 x 30 cm^2.

2.2 Microscope scanning. Each emulsion was cut into 3 equal parts of size 15 cm x 30 cm referred as A, B and C series. Emulsion layers at depths of 3.2 r.l. (Scan I) and 2.4 r.l. (Scan II) were scanned under a total magnification of X225 for $\geqslant$ 5 tracks within an equivalent circle of diameter 100 μm having zenith angles between 15° and 65°. All events obtained in Scan I and additional events found in Scan II, were traced up through successive emulsions and identified uniquely as electrons; in this way a total of 173 electrons were identified.

2.3 Energy estimation. In this experiment, we have estimated the energy of electrons by comparing the number of tracks at the cascade maximum in the detector assembly with that computed from a simulation of electron initiated cascades by Monte Carlo method, for the actual configuration of the present detector assembly. Experimentally, the number of tracks at cascade maximum was obtained from the transition curve constructed by using visual counts of the number of tracks within a circle of radius 68 μm about the cascade axis at various depths in the detector. The criteria adopted in the measurement and their effect on the energy estimation are discussed elsewhere (Anand et al., 1973, Paper I).

2.4 Detection probability, energy and angular acceptance criteria of electron events. The probability of observing an event during the microscope scanning depends upon the detection probability, defined by the minimum number of tracks n_L in the scan layer required by the observer, and his scanning efficiency. However, the final selection of events will also depend upon the angular and energy acceptance criteria employed. All these aspects are discussed in detail in paper I. Therefore here we will briefly summarise the experimental procedure and the criteria adopted in the analysis of the electron events. The number of tracks n_L in each Scan was quantitatively determined by constructing the distribution of events (electrons + gamma rays) as a function of the number of tracks within a circle of radius 28 μm for all the series; knowing the value of n_L, the detection probability of an electron was calculated as a function of [illegible] energy. In order to unambiguously identify electron events, we have accepted only those electrons which have 2 minimum ionising tracks separated by distances $\leq 56\,\mu$m in the lowest emulsion pellicle in the pure emulsion block; the probability of this occurrence for an electron event was also estimated.

In order to eliminate the loss of low energy events at large zenith angles, suitable angular criteria for different energy intervals were determined from a study of the zenith angle dependence of the detected events as a function of energy. Since, we have made two independent scans, we could estimate the scanning efficiency of each observer as a function of energy for both the scans. The results from these selection criteria are given in paper I.

3. Flux and energy spectrum of electrons. All the events satisfying the various selection criteria were then weighted with the appropriate detection probability and scanning efficiency. The geometrical factor at energies $\geqslant 100$ GeV is 4.19×10^3 (m^2.sr.s) and below 100 GeV it was calculated as a function of energy, since the geometrical factor varies with angular selection criteria adopted at these energies. Knowing thus the expected number of events and the corresponding geometrical factor, the differential flux of electrons was estimated for different energy intervals.

The observed flux of electrons at the mean float altitude 13.6 g. cm^{-2} consists of primary electrons and secondary electrons produced in the overlying atmosphere. The flux of secondary electrons for each energy bin was calculated from the observed gamma ray spectrum (Anand et al., 1973). The corrected flux of observed electrons after subtracting the contribution from secondary electrons was then extrapolated to the top of atmosphere using cascade theory. Thus we derive the primary electron spectrum in the region 50 to 800 GeV.

In the past, we have published results in the energy region 10 to 200 GeV using pure emulsion detectors (Daniel and Stephens, 1967; Anand et al., 1968). The energy estimation at high energies, where cascade theory was used, has been now revised using results from a detailed Monte Carlo calculations, which takes care of the experimental criteria. From a comparison of these corrected flux values with the present experimental results, it is found that in the overlapping energy region the flux values are in agreement with each other. In the energy region of 10 to 100 GeV, we have recently completed another experiment (Anand and Stephens, 1973) using a pure emulsion stack (Anand et al., 1970b); the differential fluxes from this experiment are in agreement with the earlier results. Therefore we combined all these results to give a final spectrum in the region of 10 to 800 GeV using a total of 177 electrons. These flux values are given in Table I and are also shown in Fig. 1; the quoted errors, apart from statistical errors, also include the uncertainties in the detection probabilities, scanning efficiency and secondary corrections. The differential energy spectrum in this energy region can be represented by a single power law of the type

$$J_e(E) = 116\, E^{-2.69 \pm 0.1} \text{ electrons}/(m^2 \text{. sr. s. GeV})$$

The slope of this electron spectrum $\beta = 2.69 \pm .1$ in the energy region 10-800 GeV is in agreement with the earlier value of 2.62 ± 0.05 in the energy region 3 to 200 GeV (Anand et al., 1968). Therefore, from our

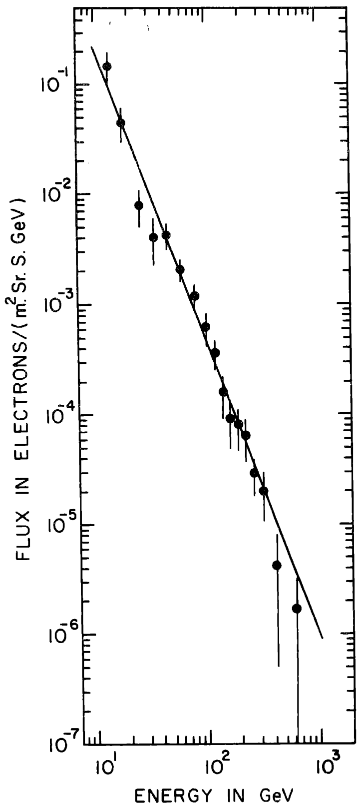

Figure 1. Differential energy spectrum of primary electrons.

experiments the only evidence for a possible steepening of the electron spectrum as earlier suggested by us (Anand et al., 1971) comes from the data points in the region of 300-800 GeV, which have large statistical errors.

Comparing with other experimental results it may be mentioned that the flux values given by Meyer and Muller (1971) and Zatsepin (1971) are consistent with our results. However the flux values given by Matsuo et al., (1971) and Silverberg et al., (1971) are very much lower than our results at energies > 100 GeV.

From the above one may say that the observed electron spectrum does not show a finite steepening in the region of a few GeV to a few hundred GeV. Further a detailed analysis of the existing models of propagation (Anand, 1973) suggest that the apparent steepening of the spectrum around a GeV cannot be also attributed to the first half break expected on the basis of Disk model (Jokipii and Meyer, 1968). Thus it appears that it is rather difficult to understand the observed electron spectrum purely from a steady state concept for the cosmic rays in the galaxy.

At the end we bring to notice that even as early as 1969, we have questioned the existence of submillimeter radiation at 8°K over the galactic

scale on the basis of the then available electron data and recently, the direct measurement (Williamson et al., 1973) on the background radiation suggests its near absence.

Table I. Differential flux of Primary Electrons

Energy Interval in GeV	Number of events	Flux in Particles/(m^2. sr. s. GeV)
12 - 15.5	10	$(1.48 \pm .5) \times 10^{-1}$
15.5 - 21	12	$(4.45 \pm 1.5) \times 10^{-2}$
21 - 30	7	$(7.87 \pm 3.1) \times 10^{-3}$
30 - 40	7	$(4.1 \pm 1.9) \times 10^{-3}$
40 - 50	19	$(4.24 \pm 1.13) \times 10^{-3}$
50 - 70	23	$(2.08 \pm .48) \times 10^{-3}$
70 - 90	17	$(1.15 \pm .32) \times 10^{-3}$
90 - 110	17	$(6.3 \pm 2.1) \times 10^{-4}$
110 - 130	15	$(3.65 \pm 1.12) \times 10^{-4}$
130 - 150	10	$(1.61 \pm .7) \times 10^{-4}$
150 - 175	8	$(9.14 \pm 4.4) \times 10^{-5}$
175 - 210	9	$(8.03 \pm 3.2) \times 10^{-5}$
210 - 240	7	$(6.38 \pm 2.75) \times 10^{-5}$
240 - 290	6	$(2.88 \pm 1.1) \times 10^{-5}$
290 - 350	5	$(2.01 \pm .97) \times 10^{-5}$
350 - 500	3	$(4.25 \pm 3.7) \times 10^{-6}$
500 - 750	2	$(1.645 \pm 1.62) \times 10^{-6}$

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