THE FLUX AND ENERGY SPECTRUM OF PRIMARY COSMIC RAY ELECTRONS

Jacques L'Heureux and Peter Meyer

THE FLUX AND ENERGY SPECTRUM OF PRIMARY COSMIC RAY ELECTRONS*

Jacques L'Heureux and Peter Meyer
Enrico Fermi Institute for Nuclear Studies
and Department of Physics
University of Chicago

THE FLUX AND ENERGY SPECTRUM OF PRIMARY COSMIC RAY ELECTRONS*

Jacques L'Heureux and Peter Meyer
Enrico Fermi Institute for Nuclear Studies
and Department of Physics
University of Chicago

Since the discovery of primary electrons in the cosmic radiation[1,2] attempts have been made to measure the flux of these particles at various energies.[3,4,5,6] The low intensity of the electron component causes great difficulties in obtaining enough events for good statistics and energy resolution and has so far prevented the determination of a reliable energy spectrum. Yet, the knowledge of the electron spectrum in the vicinity of the earth is important for several reasons. At the present time, it appears likely that the primary electrons observed near the earth are of galactic origin. A determination of their flux and spectrum makes it possible to investigate in detail their relation to the nonthermal galactic radio emission. Furthermore, the modulation of their intensity and spectrum due to solar controlled mechanisms may be different from the modulation of heavier primary particles. Parker[7] has discussed the possibility of velocity dependent modulation, which can be tested by investigating the primary cosmic ray electrons.

The experiment which we shall discuss here gives an approximate energy spectrum of the primary electron component. It was carried out in the summer of 1964 at a period near solar activity minimum. This period is most advantageous for

---

investigations of low energy galactic particles since the effects of solar modulation

are approaching their minimum. Two balloon flights were made at Ft. Churchill on

July 22 and 29, 1964, both of them floating under about $4g/cm^2$ of residual atmos-

phere, in order to measure the flux and energy spectrum of the electron component.

A schematic cross section of the instrument which was used is shown in Figure 1. Ver-

tically incident particles trigger a counter telescope consisting of the scintillation

counters T and I and a gas-Cerenkov counter C. The geometry factor of the tele-

scope is $1.08 \ cm^2 sr$. The gas counter is filled with 2.4 atm. of SF_6 and has a threshold

of about 8 MeV for electrons and 15 BeV for protons. The energy loss of the particles

in Counter I is measured in order to discriminate between singly and multiply

charged particles. After passing through Counter I, the particles penetrate a layer of

$10.8 \ g/cm^2$ of lead, a plastic scintillation counter S, and enter a lead glass Cerenkov

Counter II (Schott glass No. SF6-FA) with a total depth of 13 radiation lengths. The

amount of Cerenkov light produced in this counter is measured by a pulse height an-

alyzer. Provided the incident particle is an electron and the photon-electron

shower produced by this electron is absorbed in the lead glass, then the light output

is a measure of the energy of the incident electron. The lead glass Cerenkov counter

is completely surrounded by anticoincidence counters in order to discriminate against

events in which one or several particles emerge from the lead glass. All events in

which the anticoincidence counter A3 is fired are also recorded and high energy

protons which penetrate the entire telescope are used for in-flight calibration of

the Counters I and II. In order to further discriminate against high energy protons and

interactions produced by protons in the lead glass, the scintillation counter S is

connected to two independent triggers which respond to singly charged minimum ionizing particles and to particles with 1.6 times minimum ionization or more, respectively. The equipment was calibrated in a monoenergetic beam of electrons* at energies ranging from 700 MeV to 4 BeV. These calibration runs served to determine: a) the pulse height in Counter II as a function of the energy of the incident electrons; b) the resolution of the lead glass Cerenkov counter at various energies; c) the resolution of Counter I; d) the fraction of events in which any of the anti-coincidence counters was triggered as a function of the energy of the incident electrons; e) the probability that an incident electron produces more than one particle in Counter S as a function of energy; and f) the efficiency of the gas Cerenkov counter which was measured to be 95 percent. The resolution of Counter I is 37 percent for relativistic electrons (full width at half maximum) and the lead glass Cerenkov counter has a resolution which varies slightly with energy. We obtained 32 percent at 700 MeV to 21 percent at 1.3 BeV. Using the calibration data it is possible to show that contributions by protons to the measured electron flux are less than 5 percent at any energy. In Fig. 2 we present the electron energy spectrum under 4.1 g/cm^2 of residual atmosphere which we obtained from 20 hours of exposure at ceiling (both flights combined) and which is based on 330 electrons with energies exceeding 180 MeV.

In order to arrive at the spectrum of the primary electrons, the contribution of secondary electrons which are produced in the residual atmosphere above the equipment has to be estimated. We have, at the present time, based this estimate on

the following data: 1) The measured altitude dependence of the electron flux; 2) Simplified calculations based on the cross section and multiplicity of π-meson production by cosmic ray protons, and 3) Measurements of the μ-meson energy spectrum obtained at aircraft altitude.[8,9] The resulting energy spectrum of secondary electrons under 4.1 g/cm^2 of atmosphere is shown as a dashed line in Figure 2. It should be noted that the estimate of the secondary electron flux is preliminary. We shall investigate it in greater detail in the future.

At energies exceeding about 500 MeV the secondary correction becomes small compared to the measured flux of electrons. In this region our results will be little modified by a more refined analysis. We, therefore, restrict this discussion to primary electrons with energies above 500 MeV. In Figure 3 the energy spectrum of primary electrons in the range from 500 MeV to 3 BeV is shown after applying corrections for secondaries and for energy loss (ionization and bremsstrahlung). We may represent this spectrum as a power law of the form

$$\frac{dJ}{dE} = 11 \times E^{-1.6} \ (m^2 \ sec \ sr \ Bev)^{-1}$$

where E is measured in BeV. The exponent has an error of about ± 0.5. This spectrum falls inside the limits set by earlier determinations[1,2,5] and, if extrapolated beyond 4.5 BeV, is compatible with the results of Agrenier et al[3]. An extrapolation to lower energies falls closely on the data which Cline et al[6] obtained below 10 MeV. Although it is interesting to note this point, it does not lead to any conclusions at this time. In view of the large error limits in the earlier data[1,2], it is not surprising that solar modulation effects, even if present, cannot be noticed in the comparison with the results of this paper.

In the energy interval which we cover in this experiment, the exponent of the power law is appreciably smaller than would be expected on the basis of a collision origin of the electron components in the galaxy[10,11]. It is lower, although not incompatible, with the exponent deduced from observation of the frequency spectrum of the nonthermal galactic radio emission.[12]

References

1. J. A. Earl, P. R. Letters $\underline{6}$, 125 (1961)

2. P. Meyer and R. Vogt, P. R. Letters $\underline{6}$, 193 (1961)

3. Agrenier, Koechlin, Parlier, Boella, Degliantoni, Dilworth, Scarsi, Sironi, P. R. Letters, $\underline{13}$, 377 (1964)

4. J. W. Schmocker and J. A. Earl, P. R. $\underline{138}$, 300 (1965)

5. P. S. Freier and C. J. Waddington (Private communication)

6. T. L. Cline, G. H. Ludwig and F. B. McDonald, P. R. Letters $\underline{13}$, 786 (1964)

7. E. N. Parker, Interplanetary Dynamical Processes, Interscience Publishers (1963)

8. M. Adams, C. D. Anderson, E. W. Cowan, Rev. Mod. Phys. $\underline{21}$, 72 (1949)

9. L. T. Baradzei, M. V. Solovlev, Z. I. Tulinova, L. I. Filatova, JETP $\underline{9}$, 1151 (1959)

10. S. Hayakawa and H. Okuda, Progr. Theoret. Phys. (Kyoto) $\underline{28}$, 517 (1962)

11. V. L. Ginsburg and S. I. Syrovatskii, The Origin of Cosmic Rays, Pergamon Press (1964)

12. See f.e. D. Walsh, F. T. Haddock and H. F. Schulte, Proceed. Fourth International Space Science Symposium, Warsaw 1963, p. 935, John Wiley and Sons, 1964.

Figure Captions

Figure 1.   Schematic Cross-section of the Counter Telescope

Figure 2.   The energy spectrum of electrons as measured under 4.1 g/cm^2 of

residual atmosphere

├─●─┤   Experimental Points

─ ─ ─ ─ ─ ─ Estimated flux and energy spectrum of secondary electrons.

Figure 3.   The flux and energy spectrum of primary electrons between 500 MeV and

3.5 BeV.

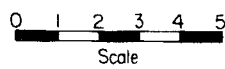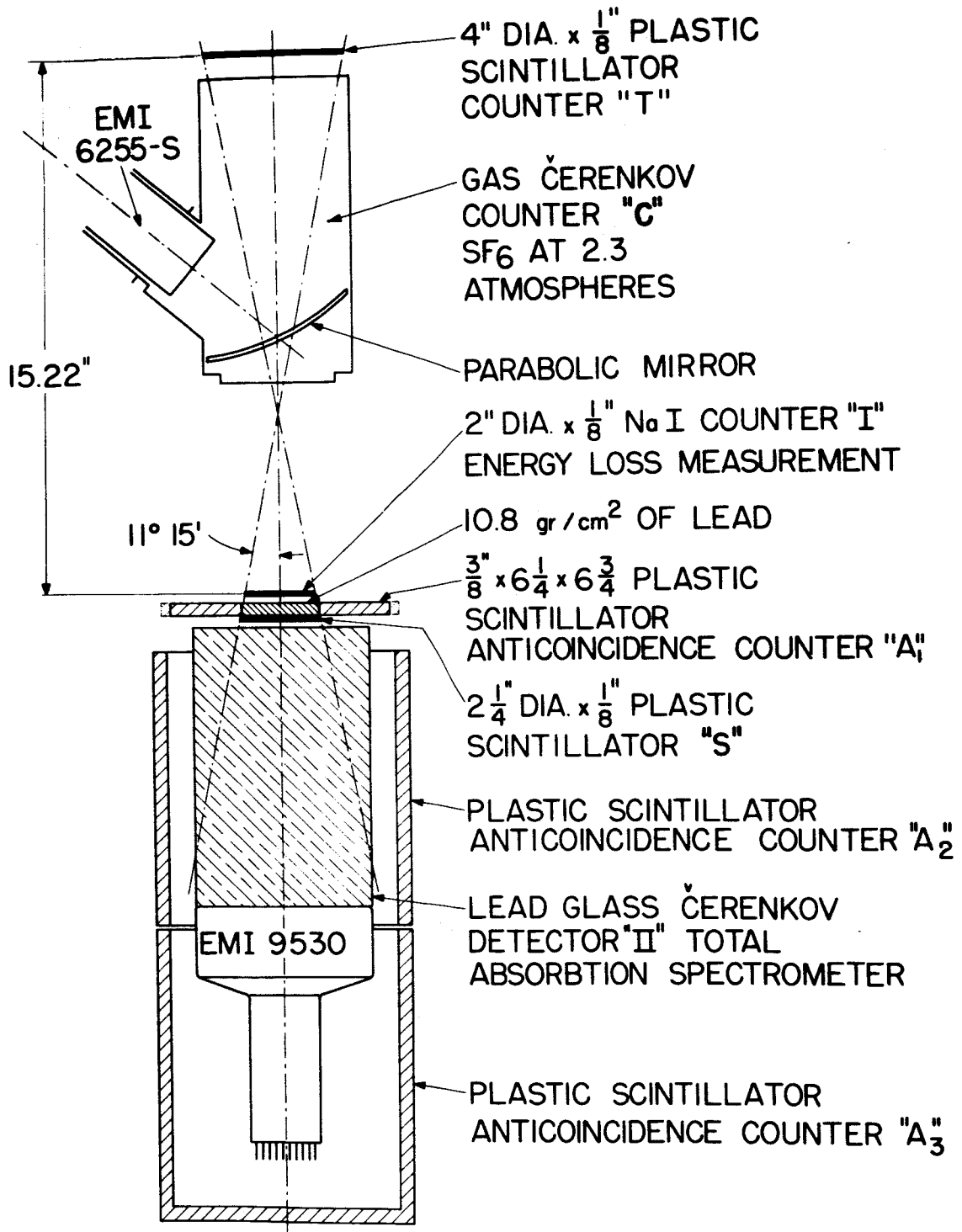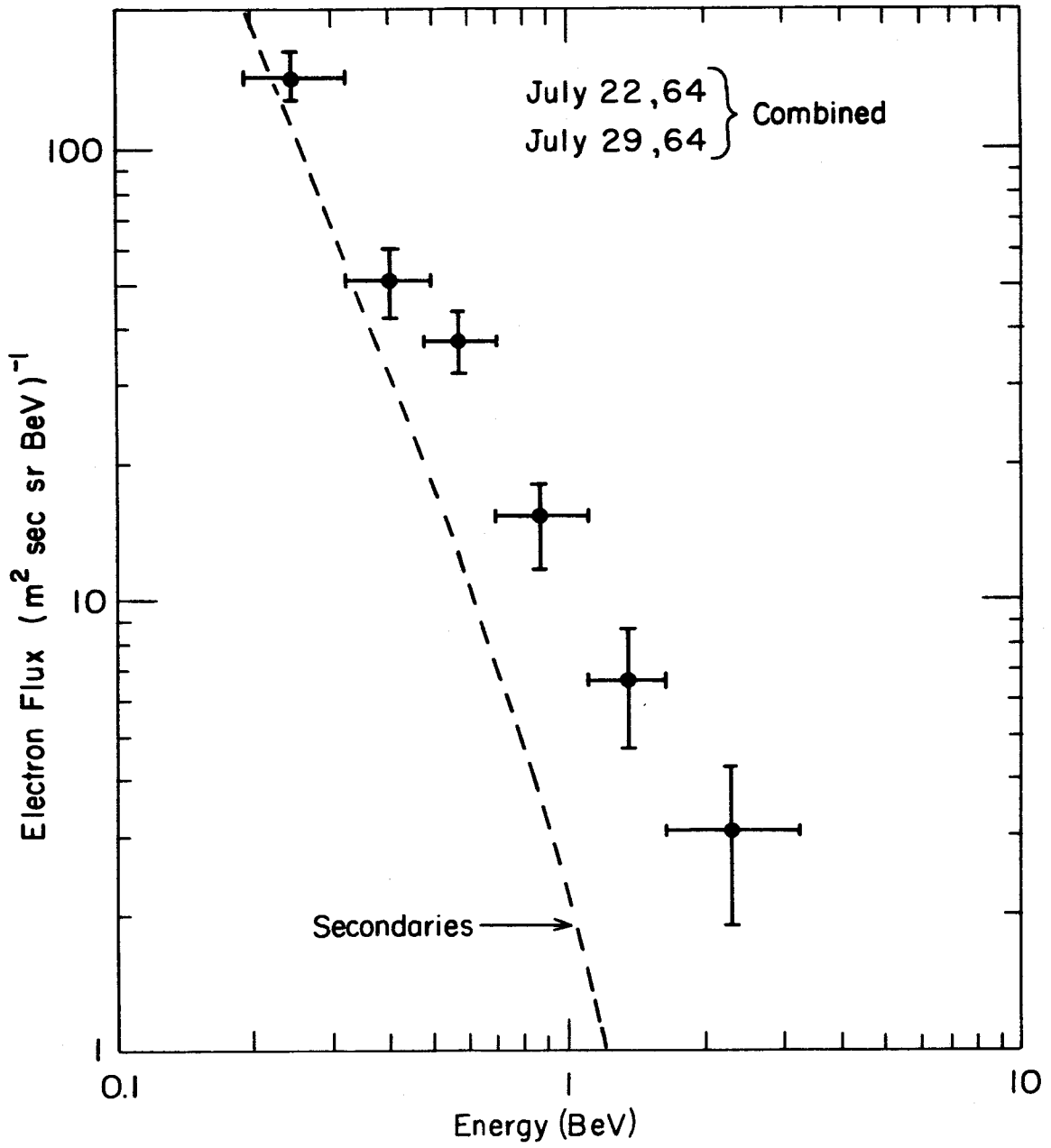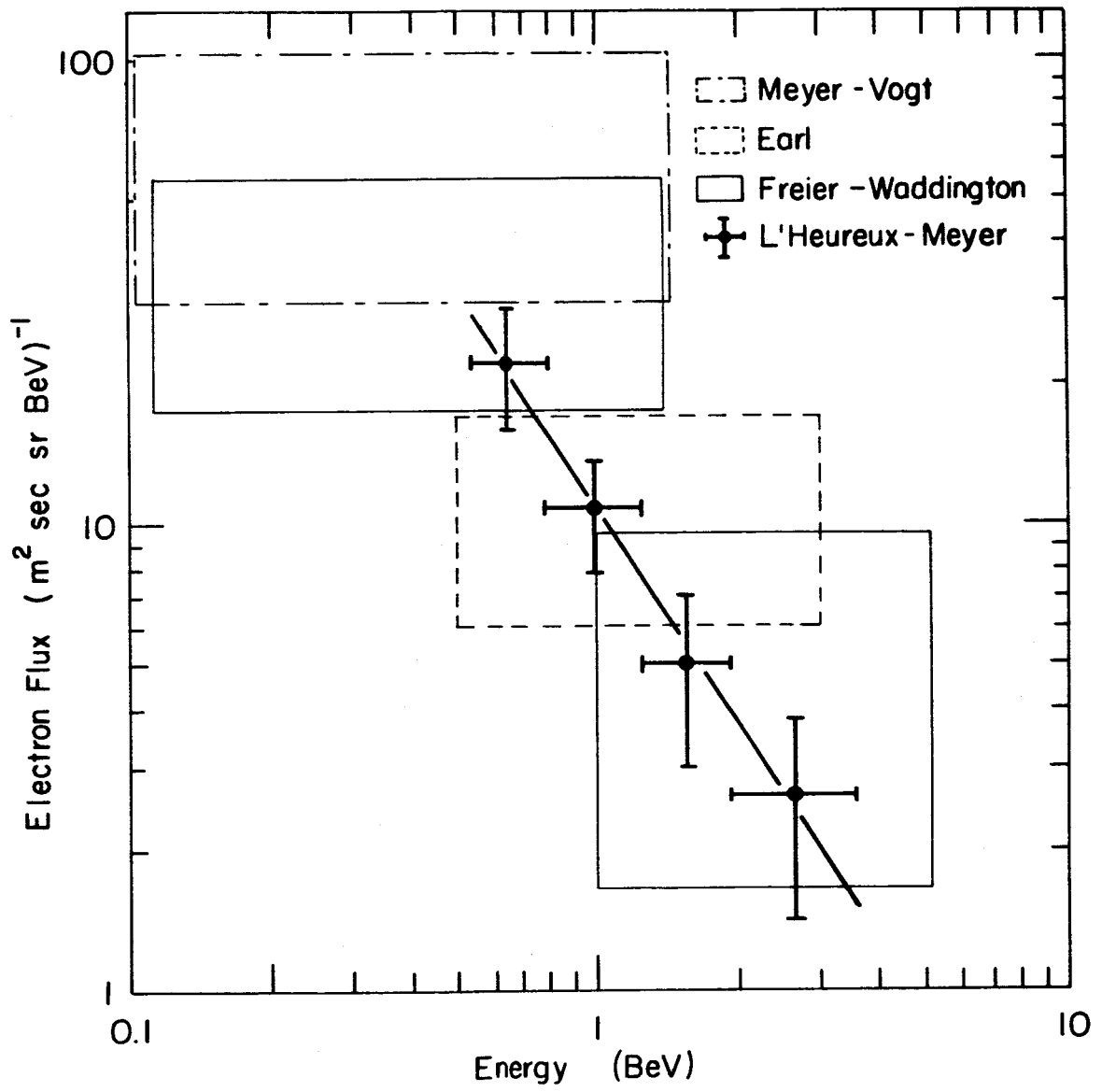(corrected for secondary electrons and energy loss in the atmosphere)

4" DIA. x $\frac{1}{8}$" PLASTIC SCINTILLATOR COUNTER "T"

GAS ČERENKOV COUNTER "C" SF$_6$ AT 2.3 ATMOSPHERES

PARABOLIC MIRROR

2" DIA. x $\frac{1}{8}$" Na I COUNTER "I" ENERGY LOSS MEASUREMENT

10.8 gr/cm^2 OF LEAD

$\frac{3}{8}$" x $6\frac{1}{4}$ x $6\frac{3}{4}$ PLASTIC SCINTILLATOR ANTICOINCIDENCE COUNTER "A$_1$"

$2\frac{1}{4}$" DIA. x $\frac{1}{8}$" PLASTIC SCINTILLATOR "S"

PLASTIC SCINTILLATOR ANTICOINCIDENCE COUNTER "A$_2$"

LEAD GLASS ČERENKOV DETECTOR "II" TOTAL ABSORBTION SPECTROMETER

PLASTIC SCINTILLATOR ANTICOINCIDENCE COUNTER "A$_3$"

EMI 6255-S

15.22"

11° 15'

EMI 9530

0 1 2 3 4 5
Scale

Fig. 1

Fig. 2

Fig. 3