On the Range of the Electrons in Meson Decay

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An experiment has been carried out both at Chicago and on Mt. Evans, Colorado, to determine the absorption of the electrons emitted in the decay of cosmic-ray mesons. Approximately 8000 counts have been obtained, using a hydrocarbon as the absorbing material. These data are used to deduce some features of the energy spectrum of the decay electrons. The resolution of the apparatus is calculated, taking the geometry, scattering, and radiation into account. The results indicate that the spectrum is either continuous, from 0 to about 55 Mev with an average energy ~32 Mev or consists of three or more discrete energies. No variation of the lifetime with the thickness of the absorber is observed. The experiment, therefore, offers some evidence in favor of the hypothesis that the μ-meson disintegrates into 3 light particles.

I. INTRODUCTION

THE nature of the disintegration of the light (μ-) meson is still unknown. It is fairly clear from cloud-chamber measurements, however, that only one of the disintegration products is charged, and that its charge is approximately that of the electron.[1-4] It is probable that this charged decay particle is an electron, since it is then possible to account for the soft component of cosmic radiation near sea level. At low altitudes the soft component cannot be accounted for either as the tail of the showers at higher altitudes, or as the result of knock on and bremsstrahlung processes of the mesons, but must be formed in the decay of mesons. However, photons have never been observed in meson decay.[5,6] So either the observed charged particle is an electron, or one must assume that at least one of the disintegration products is in turn radioactive and is the source for the sea level soft component. It is assumed in the following that the charged decay product is an electron (or positron).

There exist already some data on the energy distribution of these electrons. 13 cloud-chamber photographs permit a determination of the energy. The reported results, in Mev are:**

15 ± 3[4]	40 ± 12[3]	43 ± 9[3]
24[2]	40 ± 8[3]	48 ± 10[3]
20–50[3]	42 ± 8[3]	53 ± 15[3]
20–50[3]	42 ± 12[3]	70 ± 35[1]
		70 with large probable error[3]

In addition, Conversi, Panchini, and Piccioni[7] have measured the average absorption of the decay electrons in iron. They find the average energy to be 45 Mev±20 percent.

We report here an attempt to obtain some features of the energy spectrum by measuring the absorption of the decay electrons of cosmic-ray mesons in polystyrene, a hydrocarbon. The measurements have been made both at Chicago, alt. 600 ft., and on Mt. Evans, alt. 14,200 ft. In all about 8000 counts have been obtained. Early results have been reported in a previous note.[8] A similar experiment has also been performed by Hincks and Pontecorvo.[9]

II. APPARATUS

The arrangement of the counters is shown in Fig. 1. Figure 2 is a block diagram of the experiment. There are eighty brass counters, arranged in four layers of 20 each. All 20 counters of a tray are connected in parallel, so that each tray acts essentially like a square surface, which registers charged particles traversing it. Trays A and B, separated by two inches of lead, detect the incoming mesons. Trays C and D, separated by a variable thickness of polystyrene, register the decay electrons emitted by a meson stopping in absorber 1. Consider a meson that has traversed trays A and B, and has come to rest in absorber 1. If the decay electron is emitted in the proper direction and with sufficient energy to penetrate the remainder of absorber 1, Tray C, absorber 2, and Tray D, then the event is characterized by a coincidence $(A+B)$, followed some time later by a coincidence $(C+D)$. The circuit selects these delayed coincidences, provided the time of delay is between 0.7 and 4.4μ sec.

For the first 0.7μ sec. after a coincidence $(A+B)$, Trays C and D are connected in parallel, and in anti-coincidence with $(A+B)$. This reduces the

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[1] E. J. Wilson and G. E. Roberts, Nature **145**, 102 (1940).
[2] Anderson, Adams, Vogel, and Rau, Phys. Rev. **72**, 724 (1947).
[3] Robert W. Thompson, Phys. Rev. **74**, 490 (1948).
[4] E. G. Fowler, R. L. Cool, and J. C. Street, Phys. Rev. **74**, 101 (1948).
[5] E. P. Hinks and B. Pontecorvo, Phys. Rev. **73**, 257 (1948).
[6] R. D. Sard and E. J. Althaus, Phys. Rev. **74**, 1364 (1948).
** *Note added in proof:* Recently much more extensive cloud-chamber data have been obtained. See R. B. Leighton, C. D. Anderson, and A. J. Seriff, Bull. Am. Phys. Soc. **24** (2), G1 and G2 (1949). The results substantiate and extend those reported here.

[7] M. Conversi, E. Panchini, and O. Piccioni, Phys. Rev. **71**, 209 (1947).
[8] J. Steinberger, Phys. Rev. **74**, 500 (1948).
[9] E. P. Hinks and B. Pontecorvo, Phys. Rev. **74**, 697 (1948).

number of chance events recorded; that is, events in which two different particles, which differ in their time of arrival by 0.7 to 4.4μ sec., traverse the apparatus. We have then for the background counting rate

$$[(A+B)-(A+B+C \text{ or } D)]\times(C+D)\times 3.7\mu \text{ sec.}$$

The time of delay is measured as the separation of two pulses on a linear oscilloscope sweep.

The dimensions of the counters are given in Table I.

Since the radiation losses in brass are relatively large, the counters have been made with thin walls. This construction is especially necessary for counters in Tray 3, since the electrons traversing it have a high energy and therefore a high radiation probability. Absorber 1 is polystyrene, 4 g/cm^2. The total weight of absorber 1, including counter walls, is 4.8 g/cm^2. For thickness smaller than 17 g/cm^2, absorber 2 is polystyrene. For larger thicknesses it is in part carbon, in part polystyrene.

The experiment consists of measuring the number of delayed coincidences as a function of absorber thickness 2. If the experiment were ideal, one would expect to observe a step function for monoenergetic electrons. That is, the counting rate would be expected to be constant as the thickness of absorber 2 is increased, until a critical point when it would fall to zero. Actually, the resolution is diminished for two reasons:

TABLE I. Dimensions of counters.

	No .of counters	I. D.	Wall thickness	Active length	Material
Tray 1	20	15/16″	0.031″	20″	brass
Tray 2	20	31/32″	0.016″	20″	brass
Tray 3	20	1″	0.008″	22″	brass
Tray 4	20	31/32″	0.016″	20″	brass

(1) Geometry. The apparatus will accept decay electrons which originate in various parts of absorber 1, and traverse the system at different angles and therefore with different path length.

(2) Straggling. Because of radiation and scattering particles of equal energy will be distributed in range.

In order to analyze the experimental results it is necessary to calculate the absorption curves expected for monoenergetic electrons. This will be done in Section IV.

III. RESULTS

The apparatus was in operation for 516 hours in Chicago, where 2181 counts were observed, and for 349 hours on Mt. Evans, where 5771 counts were obtained.

The data on the absorption of decay electrons are given in Tables II and III and Figs. 3 and 4. The lifetime data are given in Table IV.

IV. CORRECTIONS OF THE RESULTS

Analysis of the results necessitates a calculation of the absorption curves expected for monoenergetic

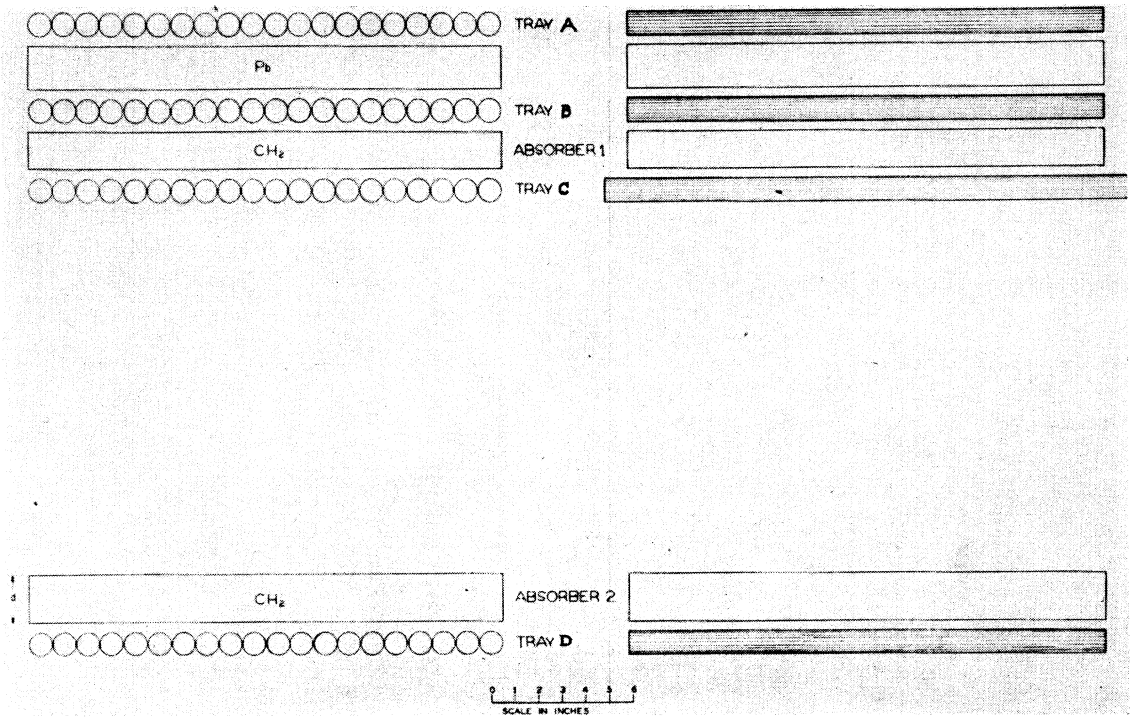

FIG. 1. Arrangement of counters and absorbers.

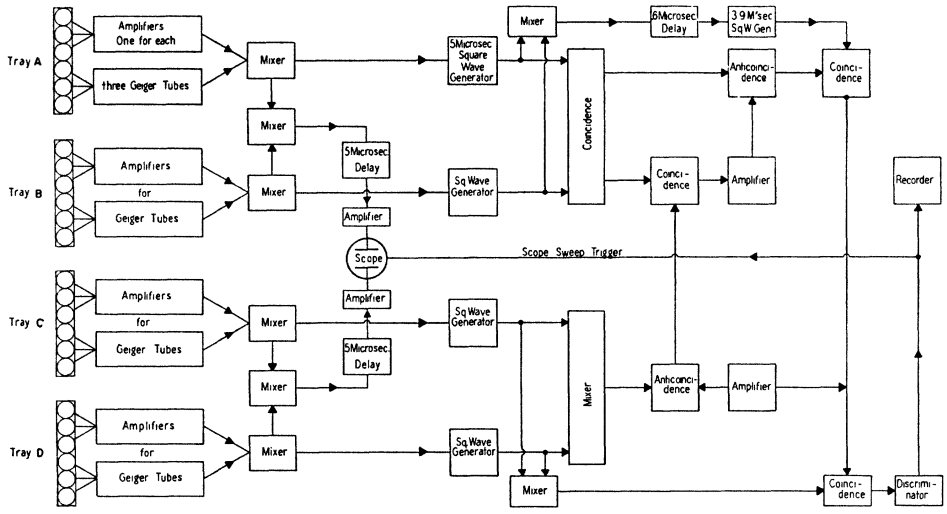

FIG. 2. Block Diagram of electronic circuits.

electrons. To do this, it is necessary to find the range spectrum, $f(E, R)dR$, for electrons of energy E, and the absorption curves, $F(R, D)$, of this geometry for electrons of range R. The absorption curve for electrons of energy E is then

$$G(E, D) = \int dR f(E, R) F(R, D),$$

where $G(E, D)$ is the fraction of electrons of energy E which is able to penetrate a thickness D of absorber 2.

A. Computation of $F(R, D)$

The geometry for the detection of the decay electrons is illustrated in Fig. 5. Two assumptions are made in the calculation of the geometrical absorption curve $F(R, D)$. (1) Mesons disintegrate at an equal rate in all portions of absorber 1. (2) The solid angle subtended at the point of origin of the electron in absorber 1 by Tray 4 is independent of the vertical dimension in absorber 1. Both assumptions are very nearly true; and, for the purposes of this analysis, the geometrical calculation may be considered exact. Then

$$F(R, D) = (wd^2/2\pi) \int_D^{\text{Smaller of } (D+D_1) \text{ and } R} dD' \times \int_1^{\text{Smaller of } [1+(s^2/d^2)]^{\frac{1}{2}} \text{ or } R/D'} (dx/x^2)[(\pi-4)+(2-(d/s)(x^2-1)^{\frac{1}{2}})^2],$$

where w = number of mesons stopped in absorber 1 per unit volume and unit time.

$s = 20.5$ inches, $d = 20$ inches, $D_1 = 1.5$ inches.

In Fig. 6, $f(R, D)$ is plotted for various values of R. For $R > (D+D_1)(1+s^2/d^2)^{\frac{1}{2}}$, $F(R, D)$ assumes a constant and maximum value

$$F(R, D) = wd^2 D_1 \times 0.0519.$$

This means that if the range is sufficiently large, the geometrical detection efficiency is 0.0519.

TABLE II. Absorption of the charged particles in meson decay at Chicago.

Absorber thickness g/cm²	No. of hours	Delayed coin-cidences	Delayed coin-cidences per hour	Coin-cidences $(A+B)$ per minute	Coin-cidences $(A+B+C$ or $D)$ per minute	Coin-cidences $(C+D)$ per minute	Back-ground per hour	Net delayed coin-cidences per hour	Standard division
0.8	57.00	508	8.92	1.36×10^3	1.16×10^3	0.800×10^3	0.66	8.26	0.41
3.45	54.85	418	7.63			0.784	0.65	6.98	0.39
6.10	53.43	369	6.92			0.775	0.64	6.28	0.38
8.75	50.15	238	4.74			0.770	0.63	4.11	0.32
11.4	45.35	199	4.39			0.765	0.63	3.76	0.35
14.05	31.33	83	2.65			0.752	0.62	2.03	0.32
17.27	40.7	94	2.30			0.750	0.62	1.68	0.27
20.49	29.68	52	1.75			0.735	0.61	1.14	0.28
23.14	16.62	31	1.86			0.735	0.61	1.25	0.39
26.36	48.97	84	1.72			0.730	0.60	1.12	0.22
29.58	29.62	51	1.72			0.730	0.60	1.12	0.23
32.23	20.8	22	1.05			0.720	0.595	0.46	0.28
34.88	36.95	32	0.866			0.720	0.595	0.27	0.20

TABLE III. Absorption of the charged particles in meson decay at Mt. Evans, alt. 14200 ft.

Absorber thickness g/cm²	No. of hours	Delayed coincidences	Delayed coincidences per hour	Coincidences $(A+B)$ per minute	Coincidences $(A+B+C$ or $D)$ per minute	Coincidences $(C+D)$ per minute	Background per hour	Net delayed coincidences per hour	Standard deviation
0.8	35.76	1184	33.0	4.17×10^3	3.46×10^3	2.49×10^3	6.54	26.46	1.05
3.45	41.28	1135	27.5			2.32	6.05	21.45	0.90
6.10	42.78	978	22.8			2.18	5.70	17.1	0.81
8.75	39.47	772	19.5			2.05	5.36	14.14	0.71
11.4	44.98	653	14.52			1.92	6.03	9.49	0.66
14.05	30.17	338	11.2			1.92	5.03	6.17	0.73
16.7	28.85	223	7.74			1.87	4.90	2.84	0.60
20.49	24.63	174	7.06			1.85	4.84	2.22	0.70
23.14	22.43	132	5.87			1.84	4.83	1.04	0.69
25.79	21.71	98	4.52			1.82	4.76	−0.24	0.65
34.88	16.79	84	5.00			1.78	4.73	0.27	0.75

B. Computation of $f(E, R)$

The range of the electrons depends on their ionization loss, on the radiative loss, and on the extent to which the effective path length is shortened by scattering.

a. Ionization loss.—Energy is lost by ionization at a rate which is only a slowly varying function of the energy. For the calculations here the ionization loss is taken to be 1.82 Mev/g/cm², independent of the energy. This value is the average of 1.92 as computed for polystyrene by Fermi's[10] formula, and 1.72 as obtained experimentally for 16.5-Mev electrons in water with the Illinois betatron. The data on water were kindly given to me by Professor Skaggs.

b. Radiation.—The spectrum of photons emitted by electrons of energy ~25 Mev may be approximated by the formula[11]

$$\phi(\epsilon)dxd\epsilon=[1-(\epsilon/E)/(\epsilon/E)]dx(d\epsilon/E).$$

Here x is the path length of the electron and ϵ and E, the energies of photon and electron, respectively. It is necessary to integrate $\phi(\epsilon)$ over the total path length of the electron. Since radiation losses are small compared to ionization losses, we may set

$$\phi(\epsilon)d(\epsilon)=Ad\epsilon\int_0^{E_0}\frac{1-\epsilon/E}{E}dE=Ad\epsilon\left[\frac{E_0}{\epsilon}-\frac{\ln E_0}{\epsilon}-1\right],$$

where E_0 is the original energy of the electron and A, a constant, which must be so chosen that the total amount radiated is correct.

$$\int_0^{E_0}\phi(\epsilon)d\epsilon=(AE_0^2/4);$$

$$\therefore A=4\times(\text{average total radiation}/E_0^2).$$

The emission of these photons decreases the range of the electrons. To get an estimate of the resultant range distribution, $M(E_0, r)dr$, the photon distribution is divided into two energy regions; $0-\epsilon'$, $\epsilon'-E_0$. ϵ' is so chosen that

$$\int_{\epsilon'}^{E_0}\phi(\epsilon)d\epsilon=\tfrac{1}{2}.$$

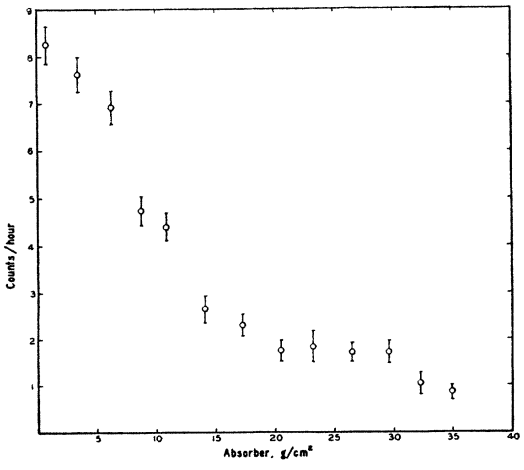

FIG. 3. Absorption of decay electrons in polystyrene in Chicago.

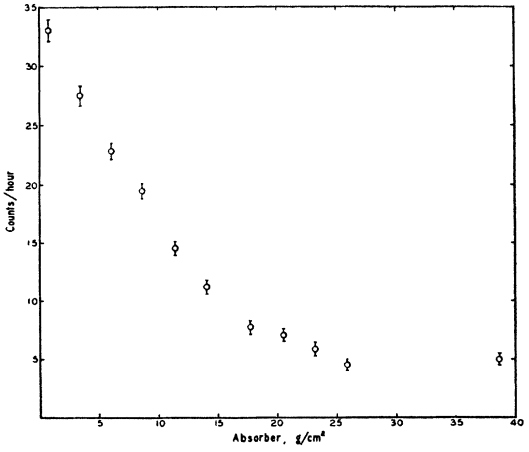

FIG. 4. Absorption of decay electrons in polystyrene on Mt. Evans, Colorado.

[10] Enrico Fermi, Phys. Rev. **57**, 485 (1940).
[11] Bruno Rossi, Rev. Mod. Phys. **13**, 255 (1941).

TABLE IV. Combined data on lifetimes.

Counts in stated time intervals $\times 10^{-6}$ sec.	0.8	3.45	6.1	8.75	11.4	14.05	Total
0.8–1.2	261.8	291.8	246.6	138.8	124.8	47.4	1101.2
1.3–1.7	175.8	249.8	186.6	89.8	91.8	34.4	828.2
1.8–2.2	174.8	204.8	161.6	83.8	81.8	29.4	736.2
2.3–2.7	141.8	141.8	124.6	81.8	64.8	31.4	586.2
2.8–3.2	107.8	135.8	112.6	58.8	68.8	8.4	492.2
3.3–3.7	78.8	102.8	66.6	46.8	38.8	26.4	360.2
3.8–4.2	43.8	40.8	93.6	23.8	20.8	7.4	190.2
Lifetime	2.12	2.10	2.16	2.26	2.24	2.53	2.16
Standard deviation	±0.16	±0.15	±0.18	±0.26	±0.27	±0.56	±0.08

(This means that ϵ' is such that, on the average, an electron radiates one-half of a quantum of energy greater than ϵ'.) In the region, ϵ' to E_0, one may approximate by saying that an electron radiates either 0 or 1 quanta of energy greater than ϵ'. For photon energies lower than ϵ', $\phi(\epsilon)$ increases rapidly. In this latter region the electron loses energy in many small steps, and therefore straggling due to radiation of photons of energy less than ϵ' is neglected. Let E' be the average energy lost by an electron in this region:

$$E'=\int_0^{\epsilon'}\epsilon\phi(\epsilon)d\epsilon.$$

Then the resultant range distribution of the electron is approximated by

$$M(E_0, r)dr=0.5\delta(r-E_0+E')dr+A\left(\frac{r+E'}{E_0-E'-r}-\ln\frac{E_0}{E_0-E'-r}\right)dr,$$

if r is given in units of energy.

The average radiation loss, which is needed to fix A, is calculated according to the formulas in Heitler.[12] For a particle traversing first 0.5 g/cm² of brass, and the remainder of its range in polystyrene, we have:

Average total energy radiated

$$=\left[\frac{E_0(\text{Mev})}{26.6}+\frac{E_0^2(\text{Mev})}{254}\right]\text{Mev}$$

$$=3.21\text{ Mev for }E_0=25\text{ Mev}$$

$$=10.96\text{ Mev for }E_0=50\text{ Mev.}$$

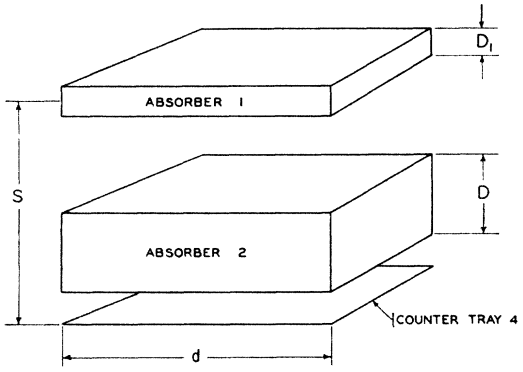

FIG. 5. Geometry of electron detection apparatus. (Note to scale.)

c. Scattering.—The path of the electron is deviated from a straight line by the coulomb field of the nuclei. This results in a shortening of the effective range. The individual scattering process is chiefly through a very small angle. For short path lengths, the distribution in angles is gaussian[13] with

$$\langle\theta^2\rangle_{\text{Av}}=16\pi NZ^2r_0^2(mc^2)\ln(181Z^{-\frac{1}{3}})\int_{x_1}^{x_2}(dx/E^2),\quad(1)$$

provided

$$\langle\theta^2\rangle_{\text{Av}}\ll 1.$$

Here it is assumed that $v/c=1$, and $r_0=2.81\times10^{13}$ cm, N=number of atoms/cm³, Z=nuclear charge, E=energy of electron, x=distance in cm.

Because of the $1/E^2$ factor, scattering is important chiefly near the end of the range. To get an estimate of the shortening of the range, a statistical method is used.[14] One hundred particles are theoretically projected along the z axis, each with energy 50 Mev into a medium in which the energy loss is constant. The total range of each particle is subdivided into intervals of such length that the $\langle\theta^2\rangle_{\text{Av}}$ corresponding to each is $\frac{2}{3}$ according to formula (1). The subdivisions are: 50−6.45; 6.45−3.43; 3.43−2.37; 2.37−1.79; 1.79−1.44; 1.44−1.20; 1.20−1.00. In each interval the particle is scattered through an angle which is selected at random according to the gaussian with $\langle\theta^2\rangle_{\text{Av}}=\frac{2}{3}$. This procedure determines the angle at which the particle leaves the interval. It still leaves the path within the interval undetermined. This path is arbitrarily taken to be a broken line of two segments, the first at the angle of the entering particle, the second at the angle of the leaving particle. The lengths of the segments are such that the total length is that of the interval, and the ratio of the two lengths is fixed so that for each length $\langle\theta^2\rangle_{\text{Av}}=\frac{1}{3}$. The component along z of the total path is then taken as the effective range. A two-dimensional version of the process is illustrated in Fig. 7. Table V gives the results of the calculation. It represents, in tabulated form, a function $n(r, R)$ which gives the distribution in effective range R of particles with total range r.

[12] W. Heitler, *The Quantum Theory of Radiation* (Oxford University Press, London, 1936).

[13] Bruno Rossi, Rev. Mod. Phys. **13**, 263 (1941).

[14] S. Ulam and J. von Neuman, Bull. Am. Math. Soc. **53**, 1120 (1947).

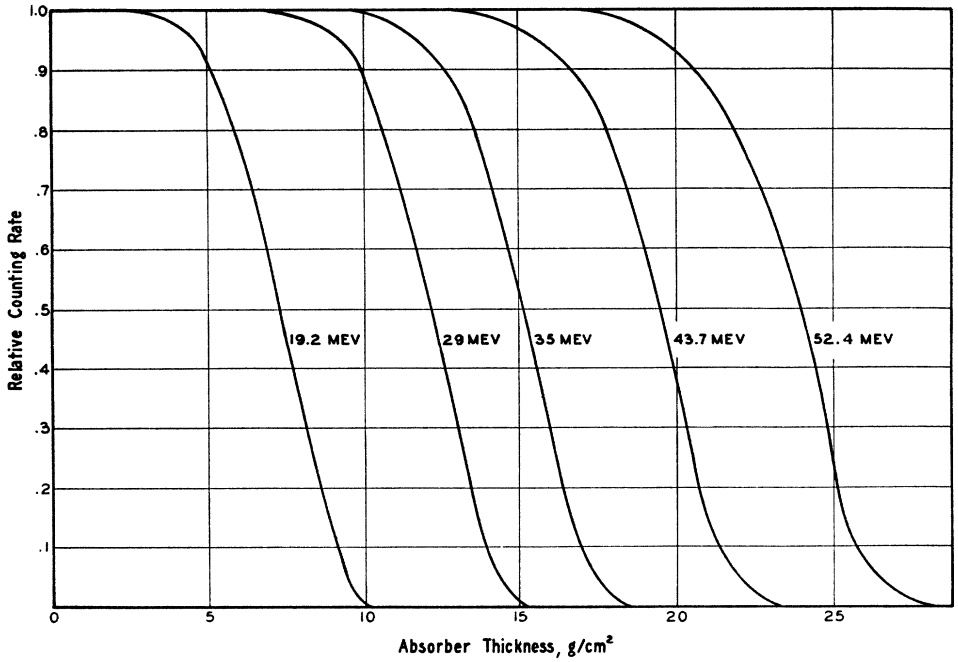

FIG. 6. $F(R, D)$ calculated absorption waves for decay electrons of a unique range.

d. Range distribution of electrons of energy E.—It is now possible to calculate the distribution in range of electrons of energy E. It is given by the integral.

$$f(E, R)dR = dR \int dr M(E, r)n(r, R).$$

Finally, the expected absorption curve for electrons of energy E is given by the integral

$$G(E, D) = \int f(E, R)F(R, D)dR.$$

The curves for $E = 25$ Mev and 50 Mev are shown in Fig. 8.

V. DISCUSSION OF THE RESULTS

The data, with background subtracted, are shown in Fig. 8. Here the Chicago data have been arbitrarily normalized with respect to the Mt. Evans data. In the same figure, curves 1 and 2 are absorption curves for monoenergetic electrons of 50 and 25 Mev, respectively, calculated as described in Section IV. It seems fairly clear from this figure that it would be hard to explain the experimental data on the basis of a single energy. Since such a spectrum is required for a disintegration into two particles, the experiment must be considered as evidence against such a hypothesis. It is not impossible, however, to fit the data by means of several judiciously chosen energies. Theoretically, this would imply that the meson disintegrates by means of several competing processes. In each such process an electron and neutral meson would be emitted, the masses of the neutral particles being determined by the energies of the electron. This requires the invention of several new neutral particles, and is therefore not very palatable. The most reasonable interpretation would then be that the meson disintegrates into three particles. The best fit is obtained if one takes all three particles to have small or zero rest mass, possibly an electron and two neutrinos. The electron then has a continuous spectrum. The main features should be described by a phase space calculation. The

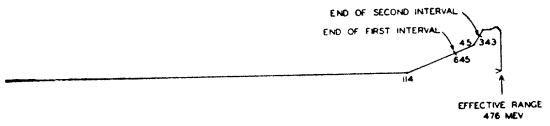

FIG. 7. Two-dimensional example to illustrate the scattering calculation.

TABLE V. This table gives the results of a statistical calculation on the effect of scattering on the range of 50-Mev electrons in polystyrene. Each of the numbers in the table gives the reduction in range in g/cm² for one of the 100 particles for which the computation has been made.

0.71	1.06	1.18	1.38	1.61	1.89	2.05	2.34	2.73	3.27
0.72	1.07	1.18	1.38	1.66	1.89	2.08	2.42	2.79	3.39
0.76	1.07	1.20	1.42	1.66	1.90	2.09	2.48	2.84	3.52
0.83	1.10	1.20	1.43	1.67	1.94	2.09	2.52	2.87	3.53
0.88	1.11	1.25	1.46	1.71	1.97	2.11	2.57	2.92	3.68
0.90	1.11	1.30	1.46	1.80	2.00	2.14	2.58	2.94	3.81
0.99	1.13	1.31	1.50	1.82	2.00	2.14	2.61	2.99	3.82
1.01	1.13	1.31	1.50	1.85	2.03	2.19	2.68	3.03	3.86
1.04	1.13	1.34	1.54	1.85	2.05	2.31	2.69	3.03	3.89
1.04	1.16	1.35	1.55	1.89	2.05	2.33	2.71	3.20	4.05

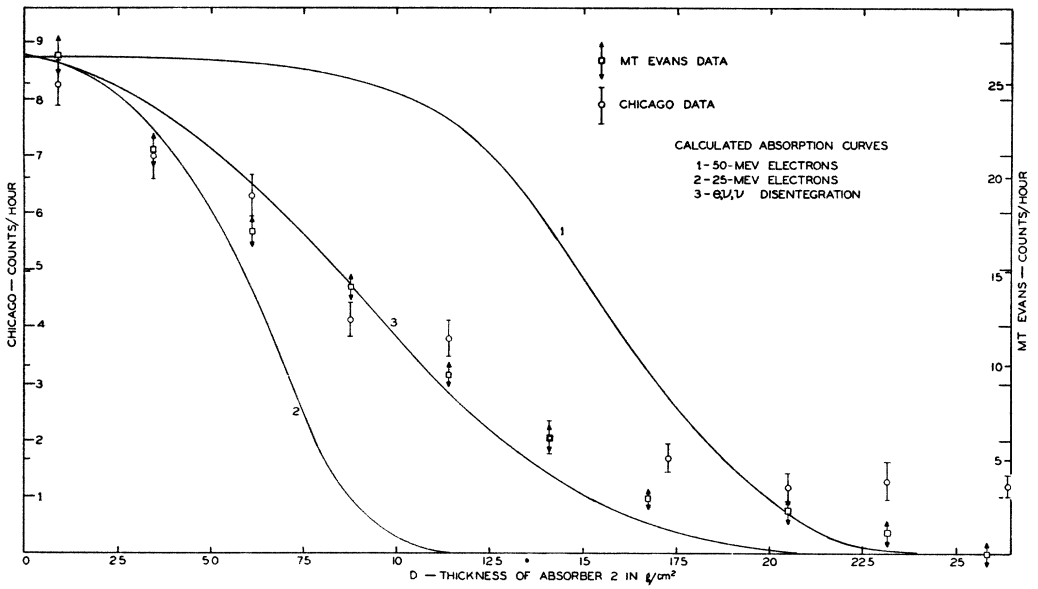

FIG. 8. The experimental points represent the data obtained in Chicago and on Mt. Evans. The indicated error is the standard deviation. The full curves 1 and 2 represent the calculated absorption curves for 50 and 25 Mev, respectively. Curve 3 is the absorption curve calculated for electrons emitted in a continuous spectrum. The spectrum is calculated from Eq. (2), taking $\mu c^2 = 100$ Mev.

result[15] of such a calculation is

$$N(E)dE = E^2[3(\mu c^2)^2 - 6\mu c^2 E + 2E^2 i]dE, \quad (2)$$

where E is the electron energy, μc^2 is the best energy of the meson. The absorption curve of this spectrum has been computed for $\mu c^2 = 100$ Mev and is drawn as curve 3 in Fig. 8. If, as seems more reasonable now,[16] one takes $\mu c^2 = 110$ Mev, slightly better agreement with experiment is obtained. An attempt has also been made to calculate a spectrum which is in good agreement with the experiment. In computing this, it was arbitrarily decided to exclude energies larger than 55 Mev. Such a spectrum is shown in Fig. 9, and its absorption curve compared with experiment in Fig. 10. It must be emphasized that it is difficult to estimate the limits of error of this spectrum. They are certainly very large, but perhaps the main features are correct. The average energy of the spectrum is 32 Mev, and has more claim to correctness than the spectrum itself. The differences between Fig. 9 and the spectrum of (2) are certainly within experimental error if one takes $\mu c^2 = 110$ Mev. The experiment therefore lends some support to the currently popular decay scheme for the meson $\mu \rightarrow e + \nu + \nu_1$ but certainly does not prove it. The results are in agreement with those of Hinks and Pontecorvo[8] and can be reconciled with the cloud-chamber data quoted in Section I. The disagreement with the conclusion of Conversi and Piccioni[6] is, I believe, caused by the difficulty of making the proper calculation for their experiment. In particular, the radiation and scattering in iron result in very great straggling which makes it difficult to calculate the energy accurately.

The average energy of the electrons in meson decay can also be deduced from the energy balance of cosmic radiation. At sea level, the total ionization loss of the soft component per gram of air should be equal to the total energy lost by the hard component as a result of meson decay, multiplied by the fraction of the meson's energy transferred to the

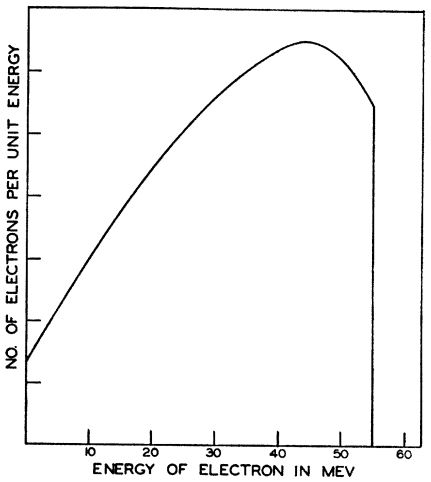

FIG. 9. The decay electron spectrum in this figure has been calculated to give as good a fit as possible with the data, at the same time excluding energies greater than 55 Mev. The limits of error of this spectrum are unknown, but large.

[15] I wish to thank Professor J. A. Wheeler for pointing out an error in the spectrum given in a previous note (see reference 7).

[16] Robert Serber, *The Report of the Solvay Congress* (1948).

electron. The cosmic-ray data have been analyzed by Rossi,[17] who obtains for the average energy of the electron $0.29\mu c^2 \pm 20$ percent. This experiment gives 0.29–$0.32\mu c^2$, depending on whether 110 or 100 Mev is used for the rest energy of the meson.

The lifetimes are calculated according to the recipe of Peierls.[18] No variation, greater than statistical error, of the lifetimes with absorber thickness is observed. The mean lifetime agrees with the value of Rossi and Nereson.[19]

The counting rate of delayed coincidences with both absorbers 1 and 2 removed was observed for a short time (5.5 hours) on Mt. Evans. The total number of counts was 42. This is slightly less than the sum of the calculated background and the number of decay particles expected from mesons stopped in the counter walls. One would have expected

$$5.5[6.54+4.3]=59 \text{ counts.}$$

From the counting rate with absorber 2 removed one can calculate the flux of mesons stopped per gram of light absorber.

$$\text{Meson flux}=\frac{\text{counting rate}}{\text{area}\times\text{efficiency for detecting mesons}}\times\frac{1}{\text{fraction of decays observed}}\times\frac{1}{\text{weight of absorber } 1/\text{cm}^2}.$$

At Chicago this is

$$=\frac{8.26/3600}{400\times 6.44\times 0.85}\times\frac{1}{0.0519\times(e-0.65/2.16-e-4.4/2.16)}\times\frac{1}{4.8}$$

$$=6.85\times10^{-6}\ \text{sec.}^{-1}\ \text{g}^{-1}$$

$$=\text{no. of mesons of approximate 100 g/cm}^2 \text{ range per cm}^2\text{, per g/cm}^2 \text{ range.}$$

[17] Bruno Rossi, Rev. Mod. Phys. **20**, 672 (1948).
[18] R. Peierls, Proc. Roy. Soc. **149**, 467 (1935).
[19] B. Rossi and N. Nereson, Phys. Rev. **62**, 417 (1942).

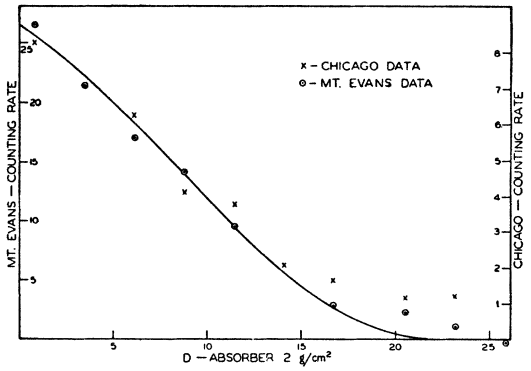

FIG. 10. The absorption curve calculated for the spectrum in Fig. 9.

This can be converted into directional intensity if one assumes a $\cos^3\theta$ distribution for the variation with zenith angle of the intensity of slow mesons. The intensity from the vertical is then

$$6.85\times10^{-6}\div(\pi/2)=4.36\times10^{-6}\ \text{sec.}^{-1}\ \text{g}^{-1}\ \text{sterad.}^{-1}.$$

Previous determinations of this quantity are analyzed by Rossi, who favors the value 5.4×10^{-6} sec.$^{-1}$ g^{-1} sterad.$^{-1}$.[20]

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[20] Bruno Rossi, Rev. Mod. Phys. **20**, 572 (1948).

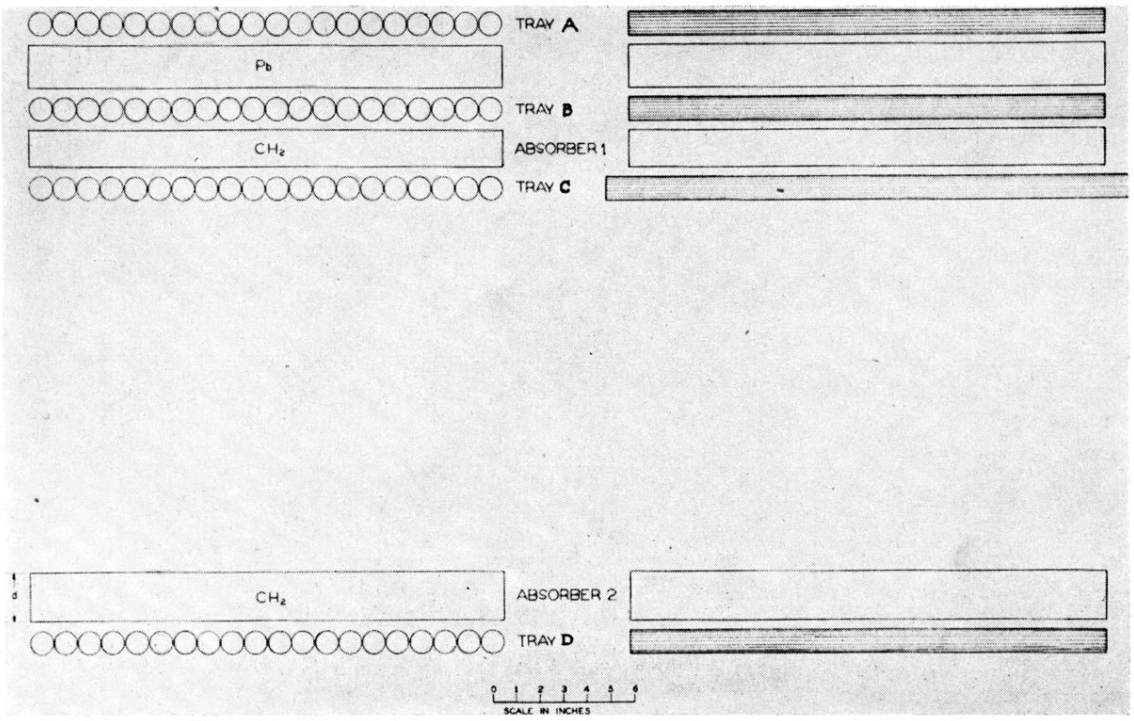

FIG. 1. Arrangement of counters and absorbers.