Development of Air Showers in the Atmosphere*

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An experiment was carried out at Mt. Evans, Colorado (altitude 4300 m) to study the development of extensive air showers in the atmosphere. Showers with cores striking near a cloud-chamber-hodoscope arrangement were selected, and the differential energy spectrum of the shower particles determined by observing their transition effect in six ½-in. lead plates with a 68-counter hodoscope. Each shower can be assigned an age classification on the basis of this energy spectrum. The lateral structure function between 2 m and 8 m from the core was obtained from measurements of the particle densities at four extension trays containing 50 counters with a total area of 1.34 m². It was found from the hodoscope data that the lateral structure function of the showers of various ages does not agree well with the predictions of the single-particle cascade theory. The observed structure function for showers at and beyond the cascade maximum is less steep than expected near the axis; this is consistent with multiple production of shower-producing particles in the primary collision. It was also found that the lateral distribution of showers past the cascade maximum varies only slowly with age; this tendency is predicted in a general way by the cascade theory, but only at a much later stage of development than observed and with quite a different slope of the distribution curve. The interpretation of this effect as the result of a "rejuvenation" of the shower by the continuous transfer of energy from the nucleonic cascade to the electron cascade is therefore more likely.

I. INTRODUCTION

EXTENSIVE air showers, the display of the highest particle energies known today, have long been a favorite object of study in cosmic-ray physics. But they are an elusive object, and whenever the goal of fair understanding of their essential features seemed within reach, new observations necessitated basic changes in the picture. Thus, the original theory of single-electron or single-photon cascades as summarized in the classical article by Rossi and Greisen,[1] and later developed by, among others, Bhabha and Chakrabarty,[2] Nordheim and his co-workers,[3] Snyder and Scott,[4] Eyges and Fernbach,[5] and Borsellino,[6] seemed to fit all the important experimental data until the presence of penetrating particles in all air showers was demonstrated, particularly in the work of Broadbent and Jánossy,[7] and of Treat and Greisen.[8] Again in a later phase, when the reinterpretation of air showers as mixed cascades of nucleons, mesons, and electrons seemed well enough understood, and new powerful methods for the treatment of both nucleon and electron cascades had been developed in the work of Jánossy, Messel and their collaborators,[9] the discovery of the various new unstable particles made it very doubtful whether so simple a picture for the production of both penetrating particles and electrons, as descendants of charged and neutral π mesons, is adequate.

In a general way, a number of important deviations from the single-electron picture can be considered as established. For instance, since the incident primaries are almost certainly of nucleonic, not electronic, nature, and since, therefore, the shower originates in a nuclear interaction, we can be assured of the multiple character of the electron-producing act, whether or not all electrons derive from the decay of π_0 mesons. As a result, the electron distribution near the shower core should be less peaked than predicted by cascade theory for a "pure" electron cascade, and this feature has been repeatedly verified.[10–13] But a quantitative comparison of these results with the theory is still of dubious value, not only because of the doubts as to the possible over-simplifications used in the theories, but also because in most cases the numerical evaluation of the theoretical results has not yet been completed, and is a long and tedious task. To get numerical data in a simple manner, the best one can do is to calculate the structure of "average" showers by describing the nuclear interactions in, say, terms of the Fermi theory,[14] and by assuming that all interactions or decays take place

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[1] B. Rossi and K. I. Greisen, Revs. Modern Phys. **13**, 240 (1941).
[2] H. J. Bhabha and S. K. Chakrabarty, Proc. Indian Acad. Sci. **A15**, 464 (1942); Phys. Rev. **74**, 1352 (1948).
[3] L. W. Nordheim, Phys. Rev. **59**, 929 (1941); J. A. Richards and L. W. Nordheim, Phys. Rev. **74**, 1106 (1948); J. Roberg and L. W. Nordheim, Phys. Rev. **75**, 444 (1949).
[4] H. S. Snyder and W. T. Scott, Phys. Rev. **76**, 220, 1563 (1949).
[5] L. Eyges and S. Fernbach, Phys. Rev. **82**, 23, 287 (1951); S. Fernbach, Phys. Rev. **82**, 88 (1951).
[6] A. Borsellino, Nuovo cimento **6**, 543 (1949); **7**, 638 and 700 (1950).
[7] D. Broadbent and L. Jánossy, Proc. Roy. Soc. (London) **A190**, 497 (1947); **A191**, 517 (1947); **A192**, 364 (1948).
[8] J. E. Treat and K. Greisen, Phys. Rev. **74**, 414 (1948).
[9] E.g., L. Jánossy and H. Messel, Proc. Roy. Irish Acad. **A54**, 245 (1951); H. Messel, Proc. Phys. Soc. (London) **A64**, 726 (1951); H. S. Green and H. Messel, Phys. Rev. **88**, 331 (1952).
[10] R. W. Williams, Phys. Rev. **74**, 1689 (1948).
[11] W. E. Hazen, Phys. Rev. **85**, 455 (1952).
[12] I. D. Campbell and J. R. Prescott, Proc. Phys. Soc. (London) **A65**, 258 (1952).
[13] H. L. Kasnitz and K. Sitte, Phys. Rev. **90**, 361 (1953).
[14] E. Fermi, Progr. Theoret. Phys. (Japan) **5**, 570 (1950); Phys. Rev. **81**, 683 (1951).

after exactly one mean free path has been traversed. But this method can scarcely be trusted to the extent that agreement or disagreement of its results with experimental data may be taken for a crucial test of the underlying hypothesis of a Fermi-type collision with only π-meson production.

For the present experiment, a goal more modest than an attempt of a detailed correlation between the empirical data and the predictions of any particular theory, was set. It was felt that at least general information concerning the nature and the relative importance of the various processes involved in the development of air showers can be obtained if in a single experiment several shower characteristics—such as age, radial distribution, composition—are recorded. The cloud-chamber-hodoscope arrangement used in previous work offers a convenient method, and the first experiment of a planned comprehensive study applied essentially the same equipment as two of the earlier investigations of the Syracuse group.[13,15] We report here the results of a more or less preliminary run in the summer of 1952 at the Mt. Evans station (4300 meters). Unexpected difficulties in technical performance under the trying conditions at this altitude made continuous and satisfactory operation of the cloud chamber impossible, and so principally hodoscope data were obtained. The experiment will be continued, with slight modifications of the arrangement, at various altitudes.

II. THE EXPERIMENTAL ARRANGEMENT

(a) The Triggering System

It is essential for the purpose of this experiment not only to classify the showers at least roughly according to their age, but also to have information on the primary energy so that eventually the stages of development of a shower of a given initial energy can be compared. During this development the total number of particles will vary widely, and the triggering system must therefore be able to accept showers of very different densities while also providing means to discriminate between them. It should likewise be noted that an air shower detection system must require a multiplicity of coincidences greater than the exponent of the differential energy spectrum if the selection is to be sensitive and subject to control.[16] With these criteria in mind the arrangement shown in Fig. 1 was chosen.

A central tray S of ten counters of 1-in.$\times$16-in. active area was flanked by two larger trays A and B of ten counters of dimensions 2 in.$\times$24 in., placed two meters from the center of the chamber, on opposite sides. Standard integration and discrimination circuits permitted an output pulse from the central tray only when at least two of its counters were struck. A master-pulse was then produced by a threefold coincidence of this pulse and pulses from at least one counter in both A and B. Additional discriminators were used to record on the hodoscope whether the number of counters struck in the central tray S was two, three, or four; tray S was not fully "hodoscoped."

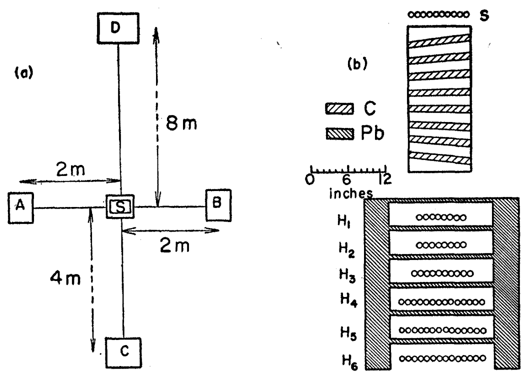

FIG. 1. The experimental arrangement. (a) General layout, top view. (b) Core analyzing system, side view.

The triggering system requires, on the average, a higher density at S then at the extension trays A and B, so that showers with cores striking near the center will be favored,[16,17] and actually all others were eliminated by a procedure described in the next section. For the selected showers, however, the average density expected at the distance of the large trays A and B is well above the minimum density required to trigger them so that these extension trays do not impose an appreciable bias against the less dense showers. If, for instance, a shower of a certain primary energy has at its maximum a particle density likely to trigger four S counters, and at a certain earlier stage will on the average strike only two counters at the center, the system will register the event in both cases with about equal probability while allowing us to distinguish between them.

It is useful to remember a few numerical details in considering the age and energy of the showers that will be detected with this apparatus.[18] Since the selection is essentially determined by the central tray S, one verifies easily that showers striking within about two meters from the center are recorded with maximum probability if they contain a total of 12 000 particles in the case that four of the S counters were struck, or 8000 and 5000 particles, respectively, when three or two of the counters in the S tray were discharged. Now consider, for instance, a 12 000-particles shower: if observed at its maximum development (i.e., at a depth of 12 cascade units) its initial energy is about 3×10^{13} ev, and its origin about 2 collision mean free paths below

[15] Froehlich, Harth, and Sitte, Phys. Rev. **87**, 504 (1952).
[16] K. Sitte, Phys. Rev. **87**, 351 (1952).
[17] J. Ise, Jr., and W. B. Fretter, Phys. Rev. **76**, 932 (1949).
[18] For the determination of the total number of shower electrons for a given primary energy, the "Tables of cascade functions" by L. Jánossy and H. Messel, Proc. Roy. Irish Acad. **A54**, 217 (1951), have been used; corrections have been made for the ionization loss and for the extension of the electron spectrum down to the energy necessary to penetrate the counter walls (about one-tenth the critical energy in air).

the top of the atmosphere. On the other hand, showers with three or two electrons at the center, if produced by primaries of the same energy, may have traversed approximately 9 or 7 cascade units; the relative attention of such "young" showers in comparison with the cascade-maximum events is about 2.7 and 5.3 for a primary absorption mean free path of 116 g/cm^2. Similarly a shower which discharged only two S counters could belong to a primary of about 1×10^{13} ev with its cascade at the maximum, or for instance to an "old" shower of about twice that energy produced near the top of the atmosphere. The age difference is then approximately 4 or 5 cascade units and the rates about comparable since the attenuation factor is counterbalanced by the larger number of less energetic primaries. Considerations of this kind give a useful check on the age assignment described below; they also show that the observation will cover a fairly large age range in the energy range above 10^{13} ev with reasonable efficiency.

(b) The Analyzing System

The central, core-analyzing part of the arrangement consisted of a large cloud chamber (dimensions 24 in. $\times$24 in.$\times$10 in.) fitted with eight 1-in. carbon plates. Below it, six hodoscope counter trays H_1-H_6 were placed, with $\frac{1}{2}$-in. lead plates about 3 in. above each tray and with a total vertical distance of $4\frac{1}{2}$ in. between adjacent trays. This geometry permits the transition-effect shower to spread, and thus reduces the errors made in applying random corrections to a non-random distribution of the core particles over the tray area. The first two trays contained eight counters each, the third ten, and H_4-H_6 fourteen counters, all of dimensions 1 in.$\times$16 in. With the 68 counters of H_1-H_6, the transition effect in lead could therefore be followed to a depth of 3 in., or approximately 13 radiation lengths.

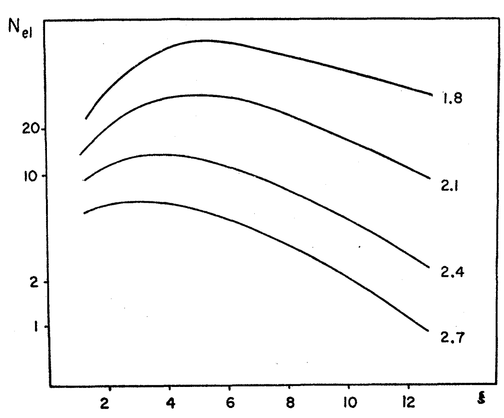

FIG. 2. Transition effect in lead: Number N_{el} of electrons expected under an absorber of thickness ξ (in radiation lengths). The curves are calculated for a differential energy spectrum of the incident particles $\pi(E)dE=dE/(E+E_c)^\gamma$ for various γ, assuming equal numbers of electrons and photons present.

The radial distribution up to a distance of $8m$ from the core was studied with the help of four further hodoscope trays A, B, C, and D, placed in the arrangement shown schematically in Fig. 1 (a). A and B, at 2 m from the center, are the same trays that serve also for the master coincidence; their ten counters feed their pulses individually through the usual cathode followers mounted in the trays, to the hodoscope circuit, but also through isolating diodes to a common lead and to the integrator-discriminator circuits of the masterpulse system. Tray C, at 4-m distance, contained fourteen counters of size 2 in.$\times$24 in., and the sixteen-counter tray D was placed at 8-m distance. The D-counters were of dimension 2 in.$\times$16 in. Thus, a total of fifty counters covering an area of about 1.34 m^2 were available for the analysis of the "outside" density distribution. The tray boxes were made of 25-mil aluminum.

It has been pointed out above that the triggering system favors showers incident near the center. As a further improvement of the selection, only those events were used for the analysis in which the density recorded in the outside trays nowhere exceeded that at the center. In this way, showers with cores striking at distances of more than two meters are in general eliminated,[19] and no great error is made by assuming for a statistical analysis that on the average the shower core is situated at the center of the arrangement.

We rejected 450 events for failing to fulfill the above criterion, and about 300 more because of various uncertainties in their analysis. These latter included large-angle showers, showers striking too near the edges of the core selector trays, and what appeared to be local showers due to penetrating particles. The cloud chamber pictures were used only as a check on the direction of the shower and similar generalities. A total of 2618 useful hodoscope records was obtained.

III. RESULTS

(a) The Shower Age

It is known that for showers not too far from the cascade maximum, the differential energy spectrum of the electrons can be represented in a good approximation by a power law with the exponent $(1+s)$, where s is the "age parameter" of the shower;[1] $s>1$ characterizes a shower past the cascade maximum or an "old" shower, while for "young" showers $s<1$. In the experiment reported here, this variation of the electron energy spectrum offers a convenient way to determine the shower age, since the transition effect in lead is appreciably affected by it. However, an exact calculation of the transition effect is difficult since,

[19] A detailed analysis of the performance of the triggering system has been carried out, using the customary methods described also in previous work. (See references 13 and 15.) The inclusion of these lengthy calculations in the present paper was not deemed worth while, but method and results will be more fully presented in a subsequent publication.

because of the much lower critical energy in lead, the slower electrons which no longer contribute much to radiative effects in air, will go on multiplying in the heavy absorber; furthermore, the shape of the energy spectrum of air shower particles below the critical energy in air is not well known. But fortunately this uncertainty is of significance only for the very beginning of the transition curve, and even there only in a slight degree. Numerical calculations were, therefore, made with a differential energy spectrum of the form $dE/(E+E_c)^{\gamma}$, using for the critical energy E_c in air a value of 86 Mev, and cutting off the spectrum at 20 Mev, the minimum energy required for electrons leaving the lowest cloud chamber plate to reach the first hodoscope tray. For electron energies up to 500 Mev, the results of Wilson's Monte Carlo calculations[20] were used, and for higher energies the tables of Jánossy and Messel.[18] An equal number of incident photons and electrons was assumed.

The results of the computations are shown in Fig. 2 for various exponents γ. To apply them, the sum of the numbers of electrons found under the first, second, and third $\frac{1}{2}$-in. lead plate can be compared with the sum of

TABLE I. The ratio R of the sum of the numbers of electrons found under the first, second, and third lead plate, to the sum of the number of electrons under the fourth, fifth, and sixth plate according to the data of Fig. 1, for various exponents γ of the energy spectrum.

γ	1.8	2.1	2.4	2.7	3.0
R	1.2_5	1.7_5	2.2_5	2.7	3.1

the numbers observed in the three lower trays. In this way, the effect of fluctuations is reduced, and the statistics for a single event improved. Table I shows the expected ratio of the two sums as a function of γ. The procedure applied to determine the energy spectrum of the individual showers was, therefore, the following: First, to obtain the number of electrons at each tray from the number of counters struck, corrections were calculated under the assumption of random distribution over the tray area; next the sums of these corrected particle numbers were formed for the three upper and the three lower trays, and according to the ratio of these sums the shower was classified into one of four age groups (the data corresponding to the last two columns of Table I were combined since the frequency of the oldest showers was too low).

It should be remarked that classification of the showers on the basis of the theoretical $(1+s)$ is not completely valid for two reasons. On the one hand, the data were taken near the shower core where the spectrum is flatter than the over-all expression $dE/(E+E_c)^{1+s}$. A more appropriate spectrum could only be calculated if the lateral distribution were already known. Secondly, if s should be representative of the shower incident from the atmosphere, then it must be noted that the electrons and photons impinging on the top lead plate of the transition-effect hodoscope system have traversed an additional amount of over 8 in. of carbon, 1 in. of glass in the 16 reflector mirrors on the 8 carbon plates, and two $\frac{3}{16}$-in. brass chamber walls, or very nearly two additional cascade units: the shower incident on the central hodoscope is somewhat older than that striking the outside hodoscope arrangement. Even so, it is certainly correct to say that increasing values of the exponent γ will correspond to increasingly older showers and further information on this point can be obtained from the frequency of the various age groups. For instance, as has been pointed out above, events with only two particles at tray S should be composed in about equal frequency of old high-energy showers produced near the top of the atmosphere, and showers near their cascade maximum produced a few mean free paths lower by one of the more abundant lower-energy primaries, with a few very young showers initiated even closer to the apparatus: the latter in a frequency of perhaps one-fifth or less of that of the events in which four electrons strike the top tray. The "four-electron-showers," on the other hand, can be expected to consist predominantly of showers near the cascade maximum, and a few events of greater age. A comparison of the frequency distribution of the various spectral groups among the three triggering groups will, therefore, help to establish more closely the relationship between the absolute shower age and the exponent of the transition-effect spectrum.

TABLE II. Frequency of showers in the four age groups characterized by the exponents of their energy spectrum, as a function of the density of the air shower incident at the top tray S.

Number of electrons at tray S	Exponent of the differential energy spectrum $\gamma<1.8$	$1.8\leqslant\gamma<2.1$	$2.1\leqslant\gamma<2.4$	$\gamma\geqslant2.4$	Total
2	134	517	301	207	1159
3	71	289	128	80	568
4 (or more)	133	476	203	79	891
Total	338	1282	632	366	2618

These data are summarized in Table II which shows, for showers of various incident densities characterized by the number of counters struck in tray S, the number of events recorded in each of the spectral groups. The results were considered as a justification of the tentative identification of the groups, according to which events with $\gamma<1.8$ are "young" showers which have not yet reached the cascade maximum, the second group $(1.8\leqslant\gamma<2.1)$ consists of showers near their maximum development, and the two others are old showers in increasing stages of attenuation.

[20] R. R. Wilson, Phys. Rev. 86, 261 (1952).

(b) The Lateral Distribution

Since the fundamental work of Molière,[21] a number of authors have investigated theoretically the lateral structure function of showers at stages other than the cascade maximum for which Molière's original work was done. In particular, Nishimura and Kamata[22] have obtained solutions for the integral lateral structure function, $\pi_1(E_0, o, r, t)$, the number of electrons of all energies in a distance r from the axis at a depth t, which close to the shower core are essentially of the form $\pi_1(r) \propto r^{s-2}$ for $s<2$, and $\pi_1(r) \approx \text{constant}$ for $s \geqslant 2$. Their definition of the age parameter s leads to somewhat larger values than that otherwise used, but the difference is slight and in particular the variation of s with depth in the neighborhood of the cascade maximum remains very nearly unchanged. The observations here reported which show the lateral distribution in the region from 2 m to 8 m from the shower axis, and for shower ages from about $s=0.6$ to $s=1.8$, can therefore be related to their expressions.

Ideally, the shower structure should be determined for showers of various sizes in any of the age groups, but for such an analysis to have statistical validity will require a very much larger number of hodoscope records gathered in a correspondingly longer operating time. Long operating times are especially needed to collect information on the rarer very large showers. We have consequently collected into one group all the showers of the same age without regard to their primary energy. In each case the densities observed at trays C and D were normalized to a reference point taken as the average of the densities at the 2-meter

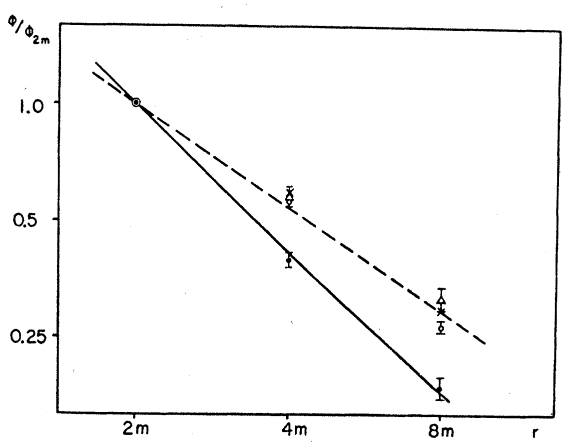

FIG. 3. The lateral distribution. Calculated curves: Bethe approximation (full line) and $\phi(r) \propto r^{-0.85}$ (dashed line). Experimental data for the various age groups: "young" showers ($\gamma<1.8$, full circles), showers near the cascade maximum ($1.8 \leqslant \gamma < 2.1$, empty circles), "old" showers ($2.1 \leqslant \gamma < 2.4$, crosses; and $\gamma \geqslant 2.4$, triangles).

trays A and B. The errors arising from counter inefficiency due to failure to produce an ion pair, chance coincidences with unrelated cosmic-ray particles, circuit inefficiencies, wall-generated secondaries which might spread to the neighboring counter (an effect which has been minimized by separating the counters by $\sim\frac{1}{2}$ in.), and counter deadtime, have been estimated by the standard methods. The most important of these errors appears to be deadtime; on the average one of the 50 "outside" counters is insensitive for each masterpulse.

For comparison with the theoretical structure function, the effect of the finite size of the trays must be considered, as it has been shown, for instance, in the work of Broadbent, Kellermann, and Hakeem.[23] This correction was calculated with the help of the Bethe approximation[24] of the structure function $\phi(r)$:

$$\phi(r) = \frac{0.454}{r}(1+4r)\exp(-4r^{\frac{2}{3}}).$$

In Fig. 3 the experimental data for the four age groups are shown together with the calculated Molière-Bethe distribution. The data for the first age group, the young showers of $\gamma<1.8$, are represented by full circles, those for showers near the cascade maximum ($1.8 \leqslant \gamma < 2.1$) by empty circles, and of the two groups of older showers the first, ($2.1 \leqslant \gamma < 2.4$) is marked by crosses, the second with $\gamma \geqslant 2.4$ by triangles. It is seen that the cascade-maximum group deviates quite appreciably from the Molière curve; in fact, the dashed line calculated for a distribution $\phi(r) \propto r^{-0.85}$ corresponding to an age parameter of $s=1.15$ is a much better approximation. For the youngest showers the Molière function appears to be a good representation, while the two groups of old showers differ only very little in their lateral distribution. For these, the change in the differential energy spectrum is certainly more pronounced than that in the lateral structure function.

At a first glance, these results seem to conflict with those of earlier experiments, in particular with those of Williams[10] and of Cocconi *et al.*[25] in which the Molière function was found to be a good approximation for distances above 2 m. However, this discrepancy may not be as serious as at first apparent. While one would hesitate to give too much credit to any attempt at defining the "correct" structure function from the three points of Fig. 3, there are indications that its slope varies rather markedly within the region from 2 m to 8 m, and that beyond about 4 m it quickly approaches that of the Molière curve. A disagreement between these data and the older ones would therefore exist only up to a distance of about 4 m, that is for the closest

[21] G. Molière in *Cosmic Radiation*, edited by W. Heisenberg (Springer, Berlin, 1943, and Dover Publications, New York, 1946).

[22] J. Nishimura and K. Kamata, Progr. Theoret. Phys. (Japan) **5**, 899 (1950); **6**, 262 and 628 (1951).

[23] Broadbent, Kellermann, and Hakeem, Proc. Phys. Soc. (London) **A63**, 864 (1950).

[24] H. A. Bethe, Phys. Rev. **72**, 172 (1947).

[25] Cocconi, Tongiorgi, and Greisen, Phys. Rev. **76**, 1020 (1948).

distances previously reported.[26] On the other hand, the fact that in the neighborhood of the core the variation of the structure function with age is only slow agrees rather well with another recent experiment carried out under widely different conditions.[13]

(c) The Cloud-Chamber Data

As it has been stated above, difficulties in the continuous operation of the cloud chamber at Mt. Evans made it impossible to obtain pictures of good quality for each individual hodoscope record. In general, the cloud chamber data served therefore only as a monitor to exclude events incident at too large an angle, or otherwise unsuitable for hodoscope analysis.

The pictures of better quality were used for a rough analysis of the composition of the shower. Unfortunately, their number was too small to permit a check also on the variation of the multiplicity of nuclear events with the shower age. Even a dependence of the composition of the shower on its age could not be established; the scanty data obtained from the more reliable photographs were for all four age groups consistent with a relative abundance of about 2 percent of penetrating particles, with an about equal frequency of μ mesons and of nucleons.

IV. CONCLUSIONS

From the results discussed above, it can be concluded that the single particle cascade is not a good representation of showers within about 8 m from the core, even in a stage of development not far from the cascade maximum. The age parameter as obtained from the energy spectrum, if applied to calculate the corresponding lateral structure function, does not give the correct curve. This can be stated although an exact determination of the age parameter from the energy spectrum could not be carried out; nevertheless, the relative values of the various exponents γ are significant, and in no plausible way can they be made to fit exactly the observed lateral distribution function.

The fact that for all but the youngest showers the distribution in the neighborhood of the shower axis is considerably flatter than the Molière structure function, is at least qualitatively well understood in terms of the multiplicity of secondary production in the initial shower-producing collision. But the lateral distribution of showers past the cascade maximum was found to be remarkably independent of the shower age. Whether or not this slow variation with s should be quoted as a success of the single-particle cascade theory which demands transition from an integral distribution $\phi(r) \propto r^{s-2}$ to $\phi(r) \approx \text{const}$ in the neighborhood of $s=2$, cannot be stated with certainty. But the trend to independence of shower age appears to occur too early for this explanation, and should then rather be interpreted as a demonstrat ionof a "rejuvenescence" of the shower by the continuous injection into the electron cascade from the nucleonic cascade of electron-producing particles. Other possible explanations have been discussed previously.[13]

The experiment will be continued with a number of improvements and extensions. In particular, the lateral distribution will be followed up to a distance of 16 m, and both the transition effect in lead and the composition of the shower near the core will be studied with greater resolution. It is hoped that thus considerably more information will be obtained.

In preparation and running of the experiment, Mr. J. G. Askowith, Mr. F. E. Froehlich, and Mr. J. E. Rizzo have given valuable assistance. The facilities of the Inter-University High Altitude Laboratories were available for the experiment, and thanks are due Professor Byron E. Cohn and Professor Mario Iona, Jr., for their cooperation. Part of the funds required for operation of the experiment were obtained under a contract with the U. S. Atomic Energy Commission.

[26] A study of the distribution inside of 2 m has recently been reported by R. E. Heinemann and W. E. Hazen, Phys. Rev. **90**, 496 (1953).